# State of the Environment
# Groundwater Quality Report
# 2016-2017

## Technical Report 2017-45

Taranaki Regional Council
Private Bag 713
STRATFORD
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# Executive summary

Regional councils have responsibilities under the Resource Management Act (1991) to monitor the state of the environment within their region. The Taranaki Regional Council (The Council) monitors the state and trends across the region's groundwater resource using a number of measures, including chemical and microbial water quality, groundwater levels and usage. The focus of this report is regional groundwater quality, and incorporates data collected across the regional groundwater quality monitoring network between 1 July 2002 and 30 June 2016. The regional groundwater monitoring network is comprised 35 sites, predominately located across the region's shallow, unconfined groundwater systems, with sites generally located in areas of relatively intensive land use.

The data collected through this programme show that the composition of groundwater across Taranaki is influenced by both natural processes and impacts associated with land use activities. The composition of groundwater varies in response to the occurrence and magnitude of these influences, both spatially and with depth.

The most significant natural influences on groundwater composition observed at monitored locations are those related to reduction and oxidation (redox) processes. These processes have a direct control over the concentration of iron, manganese, ammoniacal nitrogen and nitrate observed in groundwater at monitored locations. Groundwater composition of groundwater is also influenced by water-rock interaction, mineral dissolution and proximity to the coast.

The influence of land use activities on groundwater composition are seen at some monitoring sites, most notably in areas underlying intensive agricultural land use.

Overall, median nitrate concentrations at 94% of monitored sites are below the Maximum Acceptable Value (MAV) for nitrate of 11.3 mg/L (as $NO_3$-N) set out in the Drinking Water Standards for New Zealand (2008) (DWSNZ). Of these sites, 84% have a median nitrate concentration below 50% of the MAV.

A total of 14 shallow groundwater monitoring sites have nitrate datasets suitable for trend analysis (minimum seven year data record). Four of these sites (29%) are displaying improvements (reduction) in nitrate concentrations, while three (21%) show deterioration (increase). Overall, median nitrate concentrations across these sites have increased year on year between 2011 and 2016, after reducing during surveys undertaken between 2002 and 2011. The increase observed in median nitrate concentrations coincides with an increase in dairy production across the Taranaki region from 2011, which peaked in the 2014-2015 season. The median nitrate value recorded across the most recent period (2015-2016) of 3.4 mg/L remains below the historic maximum of 4.1 mg/L recorded during the 2002-2003 monitoring period.

Comparisons of the regional nitrate dataset against those collected by other regional councils are difficult to make, given that most monitoring networks are not specifically designed to focus on shallow groundwater, as is the case in Taranaki. For context however, 13% of sites monitored as part of the National Groundwater Monitoring Programme (NGMP) had nitrate results that exceeded the MAV on more than one occasion between 2012 and 2014, as reported in the '*Our Freshwater 2017 Report*' (MfE, 2017). The NGMP network is comprised of a mixture of shallow and deep monitoring wells located across the Country. In comparison, six sites in the Council's dedicated 32 site shallow groundwater monitoring network (19%) recorded a MAV exceedance between 2002 and 2016. Three of the six sites recorded a single exceedance. Overall, this represents an encouraging result, given the relatively similarity in exceedance numbers when taking into account the dampening effect of results from deeper sites on the NGMP exceedance rate.

Median *E.coli* concentrations have been found to exceed the MAV at 28% of monitored sites. The main factor influencing *E.coli* concentrations measured across the network is well construction, and inadequate wellhead protection or isolation at some monitored locations. Drilled and screened wells installed specifically for monitoring purposes recorded significantly lower numbers of *E.coli* detections and MAV exceedances in comparison to dug and/or unlined wells. These results are indicative of differing *E.coli* transport pathways by well type. It is believed that data from drilled and screened monitoring wells is more representative of *E.coli* concentrations in the region's shallow groundwater, with some dug and/or unlined wells being influenced by surface run off or shallow soil water throughflow.

Overall, raw water sampled from 13 of 35 monitored sites (37%) is potentially unsuitable for potable supply, as a result of both natural and anthropogenic influences. The greatest proportions of sites exceeding a MAV value did so based on their *E.coli* concentration, although it is important to note that the majority of dug and/or unlined wells are not utilised for potable supply. Exceedances of MAV values were also recorded for nitrate and manganese at two sites.

The Council continues to undertake investigations to increase the current understanding of the factors influencing groundwater quality across the region and the potential impact of these on both water users and the wider environment. The Council also actively regulates all activities with potential to have adverse effects on groundwater quality, while promoting land use practices that reduce this risk.

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# 1. Introduction

## 1.1. State of the environment monitoring (SEM)

Regional councils have responsibilities under the Resource Management Act (1991) to monitor the state of the environment within their region. The purpose of state of the environment monitoring (SEM) is to collect sufficient data to produce information on the general health of the environment.

The Taranaki Regional Council (the Council) monitors the state and trends across the region's groundwater resource using a number of measures, including chemical and microbial water quality, groundwater levels and usage. The results of the monitoring undertaken are reported in two separate SEM reports, one covering groundwater quantity and the other dealing specifically with groundwater quality, as reported in this document.

The SEM Groundwater Quality Programme has three primary objectives:

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

This information can then be used to measure how well management practices, policies and rules are working, and whether environmental outcomes are being achieved.

## 1.2. Groundwater quality management

Several policies developed and enforced by the Council are aimed at reducing the land use impacts on groundwater and protecting the quality of the region's groundwater resources. Key policy documents include the Regional Policy Statement for Taranaki (RPS) and the Regional Freshwater Plan for Taranaki (RFWP).

The RPS promotes the sustainable management of groundwater so that adverse effects on groundwater quality from the discharge of contaminants can be avoided, remedied or mitigated.

Likewise, the RFWP sets out a number of policies and rules designed to mitigate potential adverse effects associated with both point source and diffuse discharges. The RFWP also details a number of management practices aimed at maintaining and enhancing water quality by reducing diffuse source contamination. Through the RFWP, and numerous guideline documents, the Council actively encourages good management practices across a range of land use activities that have the potential to adversely affect groundwater.

The Council also undertakes a comprehensive programme of consent compliance monitoring. This includes the monitoring of consents authorising the discharge of contaminants to groundwater, or to land where they may enter groundwater. It also includes inspections of sites where no direct discharges to land or groundwater occur, but where spillages may occur.

The range of monitoring carried out is dependent on the risk associated with the specific activity being monitored, but can include assessment of discharge volumes and application rates, contaminant loading rates, the physicochemical monitoring of local groundwater and any other potentially sensitive receptor.

The Council is actively encouraging the removal of farm dairy effluent discharges from surface water, in favour of discharges to land. While this has clear benefits for surface water quality across the region, it does raise the potential risk of groundwater contamination. The activity will be regulated under the new Land and Water Plan for Taranaki, which is targeted for adoption by 2020. The Council will monitor these discharges and promote the implementation of good management practices to reduce their potential impact on groundwater quality.

# 2. Regional hydrogeology

The Taranaki region hosts an extensive groundwater resource that is widely utilised for potable water supply (predominantly domestic and limited municipal), agricultural (stock water and irrigation) and industrial usage.

The major shallow aquifers within the region are contained within the Taranaki volcanic and marine terrace deposits; while regionally significant confined aquifers exist within the Whenuakura and Matemateaonga Formation's. The distribution of the region's major geological units, including those containing the region's predominant aquifer systems, is illustrated in Figure 1.

The Taranaki volcanic deposits cover a wide area of the Taranaki region, extending from the coastal boundary in the west, to the Tertiary deposits of the Taranaki basin in the east, and bounded to the north and south by the Quaternary marine terrace deposits. The Taranaki volcanic deposits contain both coarse material (sands, breccia and agglomerates) and fine material (clay, tuff and ash), resulting in irregular lithologies and anisotropic hydrogeologic conditions (Taylor and Evans, 1999). These result in a complex system of unconfined, perched and semi confined aquifers within the volcanic deposits. The water table in the ring plain area is typically encountered between 1 to 10 m below ground level. Seasonal variations in water table depth of up to 5 m are common. Groundwater flow generally reflects surface topography and flows radially from Mount Taranaki. Recharge to the Taranaki volcanic aquifers is mainly by rainfall infiltration, with additional contributions from stream and river bed leakage. Tritium dating of shallow groundwater abstracted from wells within the Taranaki volcanic deposits indicated water less than 2 years old (TRC, 2008)

The marine terrace deposits occur in coastal areas south of Hawera and, to a lesser extent, the coastal areas north of New Plymouth. Basal units are typically marine sands often with conglomerate or shell layers, grading upward to terrestrial sediments. The marine terrace sediments range up to about 40 m in thickness and contain multiple unconfined aquifers. The water table within the marine terraces generally lies between 1 to 15 m below ground level. Groundwater flow generally follows a subdued reflection of surface topography. Recharge to the marine terrace aquifers is primarily by rainfall infiltration. The composition and quality of groundwater from the Marine terrace aquifers is variable, as are well yields.

The majority of groundwater abstractions in the Taranaki region are from the shallow Taranaki volcanic deposits and marine terrace aquifers. While significantly fewer wells target the deeper Whenuakura and Matemateaonga Formation aquifers, they generally provide much higher yields than the region's shallow unconfined aquifers, and supply the greatest volume of groundwater used across the region. Recharge to the Whenuakura and Matemateaonga Formation aquifers is not well characterised. Some recharge may occur via the overlying unconfined volcanic and marine terrace deposits and also where the formations are exposed at the surface. The Whenuakura and Matemateaonga Formation aquifers are much less susceptible to contamination from land use activities due to their depth and predominantly confined nature. These aquifer systems generally contain very old water, which is some cases has been found to be tens of thousands of years old (Taylor and Evans, 1999).

Figure 1 Distribution of the main geological units of the Taranaki region (Brown 2013)

# 3. Groundwater quality monitoring programme

The Groundwater Quality Monitoring Programme is an amalgamation of two SEM groundwater monitoring programmes previously run separately by the Council, namely the Groundwater Chemical Quality and Nitrates in Shallow Groundwater monitoring programmes.

Historically, 56 sites were sampled quarterly as part of the Nitrates in Shallow Groundwater Monitoring Programme, at approximately five yearly intervals. A total of three surveys were carried out as part of the original programme. These surveys took place during the 2002-2003, 2006-2007 and 2011-2012 monitoring periods.

The sampling frequency and sites sampled as part of the original Groundwater Chemical Quality programme have remained relatively constant since 1994.

The current programme was initiated during the 2013-2014 monitoring period, following an external review of all groundwater SEM programmes (PDP, 2011).

The review undertaken by PDP recommended that the Council increase the frequency of all shallow groundwater monitoring surveys to include quarterly sampling, on an annual basis as opposed to every five yearly. These proposed changes were adopted by the Council. To facilitate the increased sampling frequency however, a number of monitoring sites were dropped from the programme following a network review. A number of new and replacement sites were also added to the network to provide a more representative distribution of sites across the region. Overall, the changes made to the programme have resulted in a significant increase in the number of samples being obtained in comparison to the original programme.

This is the first report to be published under the revised programme.

## 3.1. Monitoring sites

A total of 35 groundwater sites are monitored as part of the current programme.

Fourteen of the 35 sites were monitored previously as part of Nitrates in Shallow Groundwater monitoring programme. A further 16 sites shallow groundwater monitoring sites were added to the programme following the network review. The remaining five sites included in the programme were established as part of the National Groundwater Monitoring Programme (NGMP) led by GNS Science.

Sampling sites have been classified into two subsets for the purpose of this report. The subset of sites less than 15 m in depth is collectively referred to as the shallow groundwater monitoring (SGWM) network. Sites sampled as part of the National Groundwater Monitoring Programme are referred to as being part of the NGMP network. Two of the shallow groundwater monitoring sites are included in both networks (GND0508 and GND0827).

The wells included in the SGWM network are constructed to varying specifications. The majority of wells in the monitoring network are referred to as dug wells. These wells are excavated by hand, or with machinery. In some instances the wells are lined with precast concrete rings, while some are left unlined. Dug wells, both lined and unlined, are the most common form of well found across Taranaki. Additional construction types include bored or augered wells, both lined and unlined, and drilled and screened wells.

In terms of monitored aquifers, the SGWM network comprises 25 sites which draw water from the unconfined Taranaki volcanics aquifer, and five sites from the marine terrace aquifers. Two deeper sites are monitored in the Whenuakura aquifer and one in the Matemateaonga aquifer. The predominance of sites in the Taranaki volcanics aquifer is a result of its large geographical area and the intensity of agricultural land use occurring across the overlying volcanic ring plain area. The monitoring network is therefore biased toward shallow groundwater monitoring sites, located in areas of the region likely to show the greatest impacts of land use.

Table 1 provides monitoring site information and Figure 2 illustrates their geographical distribution. A montage of photos illustrating some examples of well types is included in Photo 1.

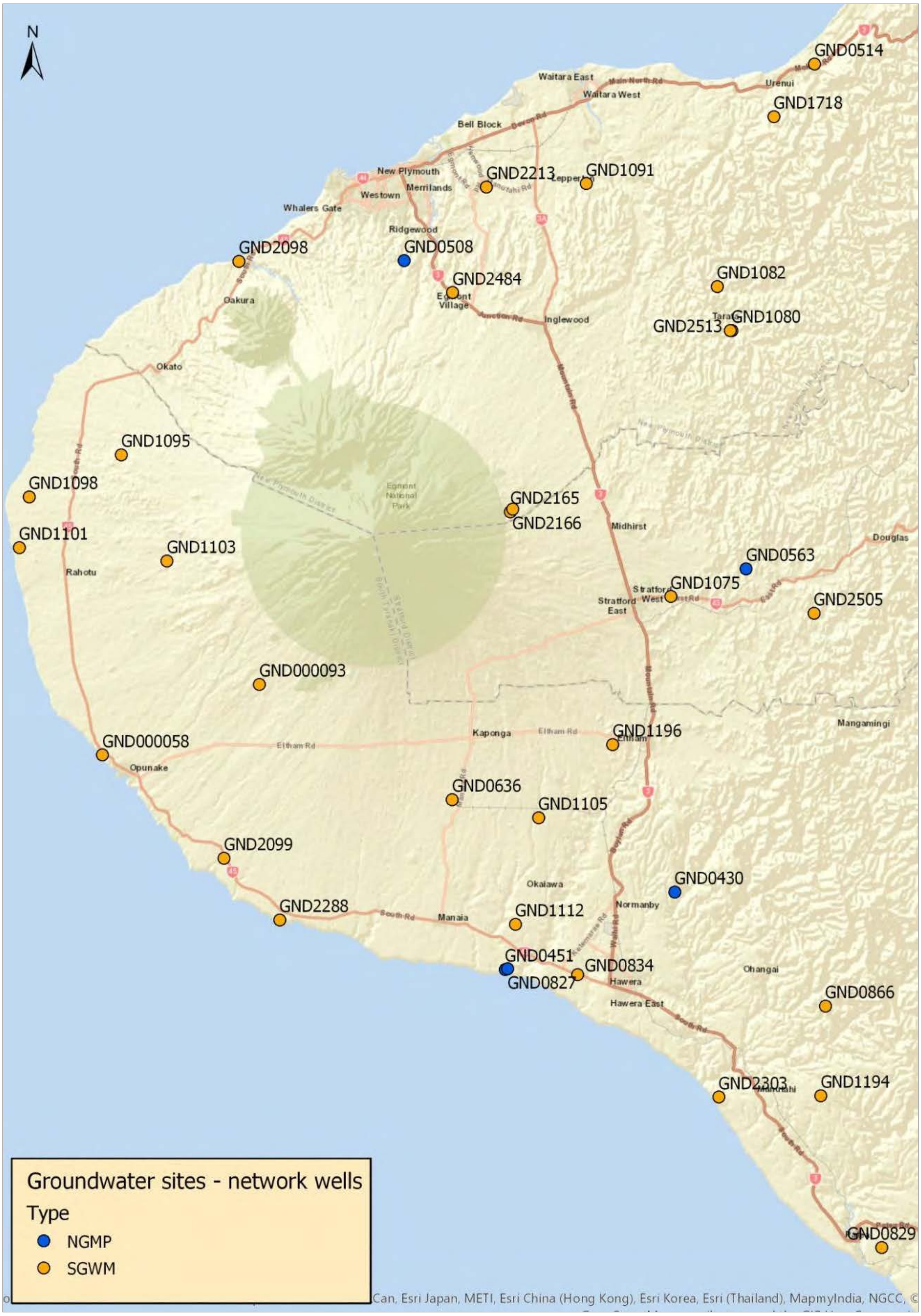

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Figure 2 Monitoring site locations

Table 1 Monitoring site details

| Site code | Monitoring network | Area | Altitude (m AMSL) | Total depth (m) | Diameter (mm) | Screened or open interval depth (m BGL) | Construction | Aquifer | Aquifer type |
|---|---|---|---|---|---|---|---|---|---|
| GND000058 | SGWM | Opunake | 20 | 3.6 | 50 | 4.0 - 4.5 | Driven pipe - open ended | Taranaki volcanics | Unconfined |
| GND000093 | SGWM | Opunake | 240 | 8.0 | - | - | Dug - lined | Taranaki volcanics | Unconfined |
| GND0430 | NGMP | Hawera | 150 | 234.6 | 150 | 54.0 - 234.0 | Drilled - open ended casing | Whenuakura | Confined |
| GND0451 | NGMP | Hawera | 44 | 171.3 | 200 | 64.0 - 171.0 | Drilled - open ended casing | Whenuakura | Confined |
| GND0508 | SGWM & NGMP | New Plymouth | 120 | 14.0 | 50 | 8.0 -14.0 | Drilled - screened | Taranaki volcanics | Unconfined |
| GND0514 | SGWM | Urenui | 30 | 4.2 | - | 0.5 - 4.2 | Dug - lined | Marine terrace (north) | Unconfined |
| GND0563 | NGMP | Toko | 200 | 77.7 | 100 | 72.7 - 77.7 | Drilled - open ended casing | Matemateaonga | Confined |
| GND0636 | SGWM | Kaponga | 181 | 6.5 | 50 | - | Drilled - screened | Taranaki volcanics | Unconfined |
| GND0827 | SGWM & NGMP | Hawera | 35 | 8.0 | 1,500 | - | Dug - unlined | Taranaki volcanics | Unconfined |
| GND0829 | SGWM | Patea | 49 | 5.2 | 1,000 | - | Bored or augered - unlined | Marine terrace (south) | Unconfined |
| GND0834 | SGWM | Hawera | 84 | 7.0 | 1,500 | - | Bored or augered - unlined | Marine terrace (south) | Unconfined |
| GND0866 | SGWM | Manutahi | 240 | 7.0 | 1,000 | - | Bored or augered - lined | Marine terrace (south) | Unconfined |
| GND1075 | SGWM | Stratford | 270 | 7.0 | - | - | Dug - lined | Taranaki volcanics | Unconfined |
| GND1080 | SGWM | Tarata | 100 | 3.5 | 1,200 | - | Dug - lined | Taranaki volcanics | Unconfined |
| GND1082 | SGWM | Tarata | 105 | 3.4 | 1,500 | - | Dug - unlined | Taranaki volcanics | Unconfined |
| GND1091 | SGWM | Lepperton | 95 | 7.5 | 1,500 | - | Dug - lined | Taranaki volcanics | Unconfined |
| GND1095 | SGWM | Okato | 105 | 7.5 | 1,000 | - | Dug - lined | Taranaki volcanics | Unconfined |
| GND1098 | SGWM | Pungarehu | 32 | 5.7 | - | - | Dug - lined | Taranaki volcanics | Unconfined |
| GND1101 | SGWM | Rahotu | 20 | 5.5 |  | - | Dug - lined | Taranaki volcanics | Unconfined |
| GND1103 | SGWM | Rahotu | 195 | 4.7 | 1,900 | - | Dug - unlined | Taranaki volcanics | Unconfined |
| GND1105 | SGWM | Hawera | 190 | 7.2 | 1,200 | - | Dug - lined | Taranaki volcanics | Unconfined |

| Site code | Monitoring network | Area | Altitude (m AMSL) | Total depth (m) | Diameter (mm) | Screened or open interval depth (m BGL) | Construction | Aquifer | Aquifer type |
|---|---|---|---|---|---|---|---|---|---|
| GND1112 | SGWM | Hawera | 95 | 12.2 | - | - | Dug - unlined | Taranaki volcanics | Unconfined |
| GND1194 | SGWM | Manutahi | 145 | - | - | - | Dug - lined | Marine terrace (south) | Unconfined |
| GND1196 | SGWM | Eltham | 213 | 8.5 | 50 | 2.4 - 8.4 | Drilled - screened | Taranaki volcanics | Unconfined |
| GND1718 | SGWM | Urenui | 100 | 11.0 | 1,000 | - | Bored or augered - unlined | Marine terrace (north) | Unconfined |
| GND2098 | SGWM | Oakura | 12 | 13.5 | 50 | 7.5 - 12.0 | Drilled - screened | Taranaki volcanics | Unconfined |
| GND2099 | SGWM | Pihama | 40 | 4.7 |  | - | Dug - unlined | Taranaki volcanics | Unconfined |
| GND2165 | SGWM | Inglewood | - | - | - | - | Drilled - screened | Taranaki volcanics | Unconfined |
| GND2166 | SGWM | Inglewood | 490 | 3.5 | 50 | - | Drilled - screened | Taranaki volcanics | Unconfined |
| GND2213 | SGWM | Lepperton | 80 | 10.7 |  | - | Dug | Taranaki volcanics | Unconfined |
| GND2288 | SGWM | Oeo | 39 | 7.1 | 50 | 3.5 - 6.5 | Drilled - screened | Taranaki volcanics | Unconfined |
| GND2303 | SGWM | Manutahi | 80 | 8.0 | 50 | 5.0 - 8.0 | Drilled - screened | Marine terrace (south) | Unconfined |
| GND2484 | SGWM | New Plymouth | 183 | 8.3 | 50 | 2.3 - 6.3 | Drilled - screened | Taranaki volcanics | Unconfined |
| GND2505 | SGWM | Huinga (Toko) | 180 | 1.7 | 1,000 | - | Dug - unlined | Taranaki volcanics | Unconfined |
| GND2513 | SGWM | Huinga (Toko) | 100 | 5.0 | 50 | 1.0 - 5.0 | Drilled - screened | Taranaki volcanics | Unconfined |

Photo 1 Various examples of well construction types in Taranaki. Top left: Dug and lined well GND1098, Top right: Dug - unlined well GND1082, Bottom left: Example of internal well lining in dug well GND1095, Bottom right: drilled and screened well GND2484 (being sampled with a peristaltic pump).

## 3.2. Sampling procedures

Samples are obtained from all SGWM and NGMP network sites on a quarterly basis, generally during the months of September, December, March and June. The sampling frequency is intended to capture seasonal variations in groundwater composition.

Sampling is undertaken in accordance with the Council's Groundwater Sampling Procedure (TRC, 2015). Where direct access to the bore or well is possible, samples are generally obtained with a peristaltic or pneumatic bladder pump, using low-flow sampling techniques. In both cases, water is purged from the bore or well being sampled and passed through a flow-cell. A multi parameter field chemistry meter is used to monitor changes in temperature, pH, electrical conductivity and dissolved oxygen as the purge proceeds. When these parameters have stabilised within set criteria, the purge is deemed sufficient to enable a sample representative of water within the surrounding aquifer to be obtained (Photo 2). A number of sites sampled are also in regular use, meaning 'fresh' groundwater is continuously drawn into the bore or well from the aquifer being sampled. In these cases, stabilisation of field parameters occurs rapidly.

Where direct access to the bore or well is not available, samples are obtained from the nearest available tap or hose. If the bore or well is in regular use, water will be run for a short period of time and field chemistry measurements taken when obtaining the sample. If not in regular use, a purge will be attempted and field chemistry monitored for stabilisation. When stabilised, the sample is obtained.

Samples obtained from sites in the NGMP network are collected in a range of unfiltered, filtered and acid preserved sample containers provided by GNS Science. Samples from the SGWM network sites are collected in unpreserved sample bottles. All samples are kept chilled to below 4°C during storage and transport to the laboratory for analysis. Samples requiring microbial analysis are delivered to the laboratory within 12 hours of being taken.

Duplicate samples are also obtained from 10% of all sites sampled for quality control purposes.

Photo 2 A staff member monitors field chemistry during purging of GND0508 and obtains a sample using a peristaltic pump

## 3.3. Sample analysis

Samples from the SGWM network wells are analysed for a range of parameters intended to allow an assessment of the potential impacts of land use on groundwater quality. To assist analysis of the data, a number of additional parameters are also analysed to enable an assessment of groundwater redox state (see Section 4.3.3). The analysis of these samples is carried out at the Council's IANZ accredited laboratory.

Samples taken from the sites included in the NGMP are analysed for a more comprehensive range of water quality parameters. These analyses are undertaken by GNS Science at their Wairakei laboratory.

The full range of analyses carried out on samples collected as part of this programme is detailed in Table 2.

For quality assurance purposes, duplicate samples collected as part of this programme are submitted to an accredited external laboratory for comparative analysis.

In addition to the standard testing regime, subsets of shallow wells are also selected for inclusion in the National Pesticides Survey, which the Council elects to participate in. The National Pesticides Survey is led by the Institute of Environmental Science and Research (ESR) and run at four yearly intervals (see Box 1).

The results of all sample analyses carried out are stored in the Council's LAB database.

Table 2 Laboratory testing and sample analysis details

| **Analyte** | **SGWM network** | **NGMP network** |
|---|---|---|
| Temperature (Field) | 💧 | 💧 |
| pH (Field) | 💧 | 💧 |
| Electrical conductivity (Field) | 💧 | 💧 |
| Dissolved oxygen (Field) | 💧 | 💧 |
| pH (Lab) | 💧 | 💧 |
| Electrical conductivity (Lab) | 💧 | 💧 |
| *E.coli* | 💧 | - |
| Bicarbonate (as $HCO_3$) | - | 💧 |
| Carbonate (as $CaCO_3$) | - | 💧 |
| Chloride (Cl) | - | 💧 |
| Sodium (Na) | - | 💧 |
| Total dissolved solids (TDS) | - | 💧 |
| Nitrate (as $NO_3$-N) | 💧 | 💧 |
| Nitrite (as $NO_2$-N | 💧 | 💧 |
| Ammoniacal Nitrogen ($NH_4$) | 💧 | 💧 |
| Dissolved reactive phosphorus (DRP) | - | 💧 |
| Potassium (K) | - | 💧 |
| Calcium (Ca) | - | 💧 |
| Bromide (Br) | - | 💧 |
| Fluoride (F) | - | 💧 |
| Iron (Fe) | 💧 | 💧 |
| Magnesium (Mg) | - | 💧 |
| Manganese (Mn) | 💧 | 💧 |
| Silica ($SiO_2$) | 💧 | 💧 |
| Sulphate ($SO_2$) | 💧 | 💧 |

💧 Indicates test is undertaken

## 3.4. Data analysis

The primary water quality measures of interest at shallow groundwater monitoring sites are those associated with agricultural land use and suitability for domestic consumption. These include nitrogen, in the form of nitrate, and *E.coli*. The analysis of data collected from the SGWM sites focusses on these parameters, and others that may indicate the occurrence of geochemical processes that influence their respective concentrations.

The results of the monitoring undertaken are generally presented in the form of summary statistics. Comparisons of results across monitoring periods, and by season, are also presented in relation to selected analytes. Monitoring results are also compared against any applicable water quality guidelines and standards, as detailed in Section 4.1.

Where suitable datasets are available, an assessment of temporal trends in analyte concentrations has also been undertaken. For sites in the SGWM network, this is limited to the 14 sites included in the current programme that were sampled previously as part of the Nitrates in Shallow Groundwater Monitoring Programme (see Section 3.1). These 14 sites have data records spanning seven years. While ten years of data would be preferable for robust trending purposes, data from these 14 sites has been trended in order to provide indicative trend information. Insufficient data is available across all other SGWM network sites to enable trend analysis to be carried out.

Long term datasets are available for NGMP network sites, with at least 16 years of data available across all sites. Given the sampling regime associated with these sites, the datasets are suitable for long term trend assessment.

The trend analysis for the groundwater quality data was conducted using Time Trends (2017; version 6.1), using a Mann-Kendall trend test.

This analysis is based on two key measures:

- The Mann-Kendall slope estimator (MKSE) which measures the magnitude of the trend; and
- The associated Mann-Kendall trend test which determines whether the trend is significant.

Statistically significant trends were determined using a p-value < 0.05 or <0.01. If a p-value is less than 0.05 or 0.01, then there is a less than 5% or 1% chance of finding a trend when there is not one.

The slope of the trend (MKSE) is expressed in units of change per year, and can also be expressed in terms of relative change (RMKSE) which is the percent of change per year. A positive MKSE or RMKSE indicates a positive (increasing) trend, and a negative MKSE or RMKSE indicates a negative or decreasing trend. The RMKSE allows comparisons in the slope between parameters and sites.

It is recognised that the statistical significance of a trend does not necessarily imply a ‘meaningful’ trend i.e. one that is likely to be relevant in a management sense. Ballantine and Davies-Colley (2009) have determined a ‘meaningful’ trend as one for which the RSKSE is statistically significant and has an absolute magnitude > 1 percent change per year. This approach has also been adopted in this report.

## Box 1: Pesticides in Groundwater

Taranaki contains numerous industries that use pesticides, including those related to agriculture, horticulture and forestry, which have the potential to contaminate groundwater through leaching and spillage. In many regions, including Taranaki, groundwater is an important source of drinking water and is used extensively as a source for irrigation and stock.

The Institute of Environmental Science and Research Limited (ESR) have coordinated a national pesticides survey on a four yearly basis since 1990. The programme is designed to investigate temporal variations in the concentrations of pesticides and to identify any environmental factors linked to the risks of contamination. The Council elects to be involved in the survey and provides the funding for the sample analysis.

The most recent national pesticides survey was undertaken in 2014. During the investigation a total of 165 wells from 13 regions were sampled including five wells in the Taranaki region. Pesticides were detected in six of the 13 regions sampled. Pesticides were not detected in any of the five Taranaki wells. Of the 80 pesticides analysed for in the survey, 21 were detected. The majority of concentrations were extremely low ($<0.1$ mg/$m^3$), with only one well containing a pesticide residue that exceeded the limit set out in the New Zealand Drinking Water Standards (2008).

In addition, the study identified that wells with pesticide detections had higher nitrate concentrations, lower pH, shallower well depth and larger well diameters than those with no pesticides detected (ESR, 2016).

The Council has committed to continued participation in the national pesticides survey as part of its overall SEM programme, and planning is underway for the upcoming 2018 survey.

# 4. Groundwater Quality

## 4.1. Guidelines and standards

The Ministry of Health sets out the requirements for drinking water quality in the Drinking Water Standards for New Zealand (2008) (DWSNZ). The standards apply to water that is designed to be used for human consumption, food preparation, utensil washing, oral or personal hygiene. Given the intended uses and potential for risks to human health from water used for consumptive purposes, the DWSNZ set out the most stringent standards for water quality within New Zealand. Water not meeting these standards can still be utilised for consumptive purposes with adequate treatment, or can be utilised for a range of non-consumptive domestic, industrial and agricultural uses.

The DWSNZ sets Maximum Acceptable Values (MAVs) for a range of chemical and microbial parameters of health significance. MAVs are set at concentrations which, based on current knowledge, constitute no significant risk to the health of a person that consumes two litres of that water per day over their lifetime (assumed as 70 years). Microbial protection is set using MAVs for faecal indicator bacteria (Escherichia coli or *E.coli*), which can indicate the presence of other pathogenic bacteria in water (Table 3).

The DWSNZ also outline a number of Guideline Values (GVs) for a range of chemical parameters. GVs are based on aesthetic impacts only, whereby any exceedance is related to nuisance value as opposed to a health risk (Table 4).

Recognising the connection between groundwater and surface water systems, nitrate concentrations measured in groundwater are also compared against the nitrate toxicity attribute states for surface waters as presented in the National Policy Statement for Freshwater Management (2014) (NPS-FM) (Table 5). While this attribute state is not directly applicable to groundwater, its inclusion as a comparable measure is intended to allow for an assessment of potential risks to ecosystem health posed by elevated groundwater nitrate concentrations, in terms of toxicity. Much lower concentrations of nitrate can, in specific circumstances, also promote the growth and proliferation of instream plants and algae, and the associated impacts on water quality that accompany it. It should be noted that the actual concentrations of nitrate in surface water as a result of groundwater contributions will be significantly influenced by attenuation processes and dilution.

Table 3 MAVs for inorganic determinands of health significance (DWSNZ, 2008)

| Determinand | MAV | Units | Comments |
|---|---|---|---|
| *E.coli* | <1 | CFU/per 100 mL | Faecal indicator bacteria, used to identify the potential presence of pathogenic bacteria of faecal origin |
| Manganese | 0.4 | mg/L | Concentrations of the substance at or below the health-based guideline value that may affect the water's appearance, taste or odour (see Table 4) |
| Nitrate, short term | 50 | mg/L | Expressed in mg/L as $NO_3$ (equivalent of 11.3 mg/L as $NO_3$-N). The sum of the ratio of the concentrations of nitrate and nitrite to each of their respective MAVs should not exceed one. The short-term exposure MAVs for nitrate and nitrite have been established to protect against methaemoglobinaemia in bottle-fed infants |
| Nitrite, long term | 0.2 | mg/L | Expressed in mg/L as $NO_2$ |
| Nitrite, short term | 3 | mg/L | Expressed in mg/L as $NO_2$. The sum of the ratio of the concentrations of nitrate and nitrite to each of their respective MAVs should not exceed one |

Table 4 GVs for aesthetic determinands (DWSNZ, 2008)

| Determinand | GV | Units | Comments |
|---|---|---|---|
| Ammonia | 1.5<br>0.3 | mg/L<br>mg/L | Odour threshold in alkaline conditions<br>For control of chloramine formation in chlorinated water |
| Chloride | 250 | mg/L | Taste, corrosion |
| Iron | 0.2 | mg/L | Staining of laundry and sanitary ware |
| Manganese | 0.04<br>0.10 | mg/L | Staining of laundry<br>Taste threshold (MAV 0.4 mg/L) |
| Total dissolved solids | 1,000 | mg/L | Taste may become unacceptable from 600-1,200 mg/L |
| pH | 7.0 – 8.5 | pH units | Should be between 7.0 and 8.0. Most waters with a low pH have a high plumbosolvency. Waters with a high pH: have a soapy taste and feel. Preferably pH <8 for effective disinfection with chlorine |
| Sodium | 200 | mg/L | Taste threshold |
| Sulphate | 250 | mg/L | Taste threshold |
| Total dissolved solids | 1,000 | mg/L | Taste may become unacceptable from 600–1,200 mg/L |

Table 5 Nitrate toxicity attribute states for surface water (NPS-FM, 2014)

| Attribute state | Annual median | Annual 95th percentile |
|---|---|---|
| A | ≤1.0 | ≤1.5 |
| B | >1.0 and ≤2.4 | >1.5 and ≤3.5 |
| C | >2.4 and ≤6.9 | >3.5 and ≤9.8 |
| National bottom line | 6.9 | 9.8 |
| D | >6.9 | >9.8 |

## 4.2. Anthropogenic influences on groundwater quality

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

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

Diffuse pollution occurs as water moves across the landscape and picks up contaminants which are then available to leach into underlying groundwater. Diffuse pollution is characterised by its occurrence across a large area, as opposed to the plume effect associated with point source discharges. It is often difficult to trace the exact origin or fate of contaminants generated through diffuse processes due to their cumulative nature, and the impact of soil, geology and groundwater flow on contaminant attenuation and distribution. Consequently, the management of diffuse pollution is challenging.

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

### 4.2.1. Land-use effects

The predominance of pastoral land use across Taranaki means that contaminant discharges associated with this land use represents the greatest pressure on groundwater quality across the region.

In terms of animal numbers and the volume of effluent generated, dairy farming is the most intensive agricultural land use in the region. A number of metrics are used to describe the potential pressure of dairy farming activities on water quality. These include total cow numbers in a region, the animal stocking rates and production volumes. Analysis of changes in these metrics can be used to assess changes in the pressure being exerted on water quality as a result of dairying land use.

The New Zealand Dairy Statistics (LIC, 2016) indicate the national dairy cow herd has increased in number by 52% over the 18 year period from 1998 to 2016. In real terms, this represents an additional 1.7 million dairy cows across the country, to a total population of approximately 5 million animals. The average stocking rate has also increased from 2.52 to 2.85 cows per effective hectare (13%). Significantly, milksolids production has increased from 684 to 1,063 kg per effective hectare over the same period (55%). These increases in production are a result of increased stocking rates, additional inputs such as supplementary feeds and developments in production driven farming systems.

The significant expansion in cow numbers and the increases in stocking rates seen nationally have not been replicated in Taranaki. Over the same 18 year period from 1998 to 2016, dairy cow numbers in Taranaki have only increased by 1%, from 481,034 to 486,953 (Figure 3) and average stocking rates have remained at 2.8 cows per effective hectare. Milk solids production has however increased by 42% over the same period, indicating an increase in farming inputs (Figure 4).

Overall, the dairy statistics for Taranaki show that while there has been no expansion in dairy farming land use across Taranaki between 1998 and 2016, the increased production over the same period represents an intensification in farming practices.

Given that the vast majority of intensive dairying land use occurs across the volcanic ring plain and marine terrace areas, any adverse effects of this activity on groundwater quality are likely to manifest in the shallow unconfined groundwater systems underlying these areas. Consequently, these groundwater systems have been the main focus of this monitoring programme.

## 4.3. Natural factors influencing groundwater quality

### 4.3.1. Aquifer recharge

Unconfined aquifer systems in the Taranaki Region are predominantly recharged by infiltration of local rainfall. The volume of water recharging these aquifers will be highly variable as a result of temporal changes in rainfall volumes and evapotranspiration, and spatial variations in land use cover, vegetation, soil and geological factors. Rainfall, and subsequent recharge, is highest in Taranaki through late autumn, winter and early spring. Consequently, recharge rates also peak over these periods. Lower rainfall volumes over summer reduce recharge rates and groundwater levels.

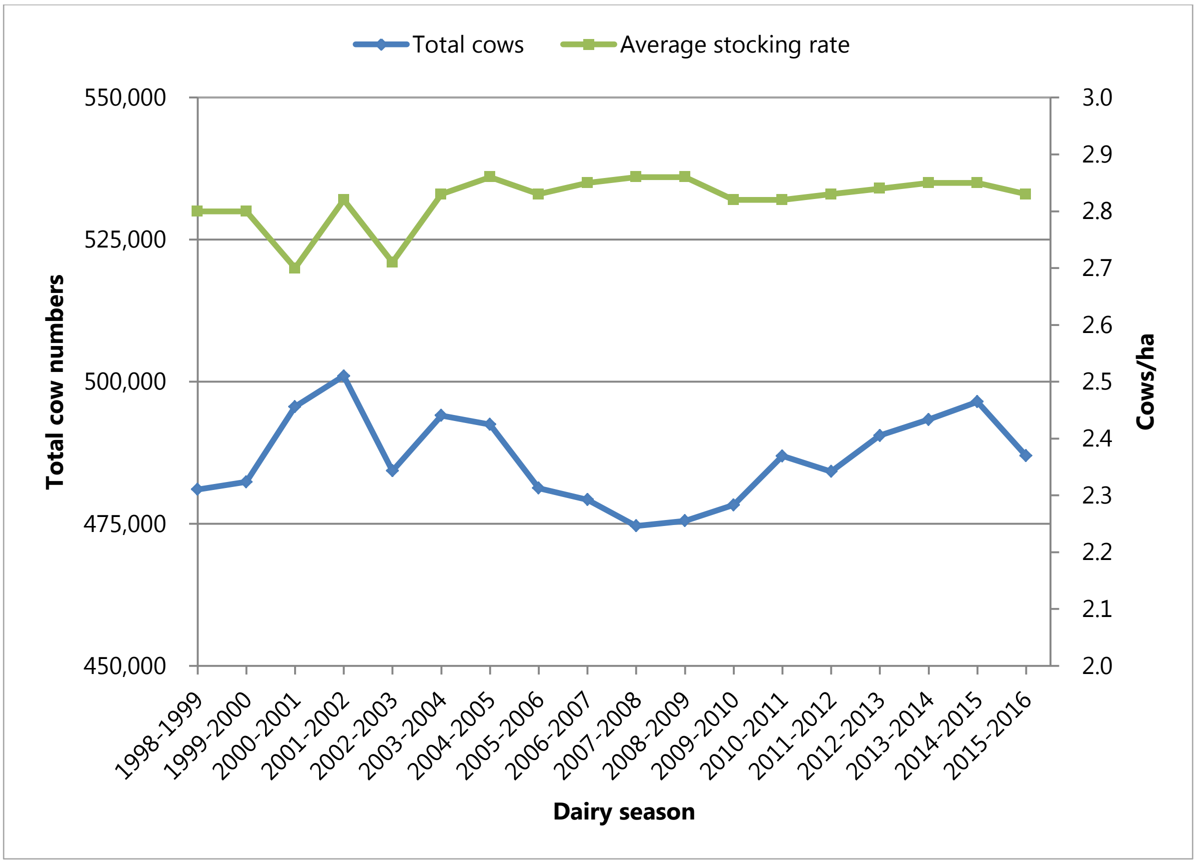

Figure 3 Total cows numbers and stocking rates in Taranaki (1998 to 2016)

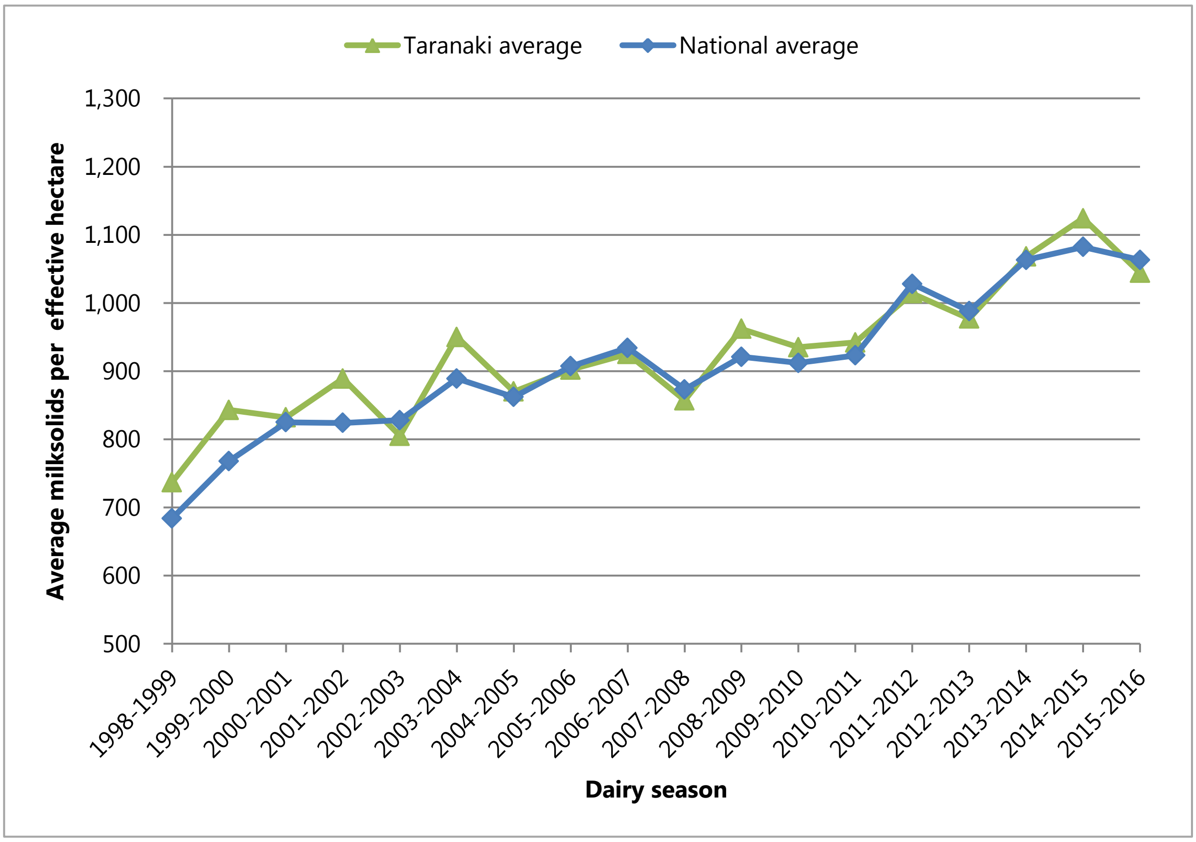

Figure 4 Average dairy cow production in Taranaki and nationally (1998 to 2016)

There is also likely to be some recharge to aquifers through seepage from the numerous rivers and streams that traverse the region. The actual volumes of recharge contributed by surface water systems will be temporally and spatially variable, as a result of changes in river flow and the heterogeneous nature of the region's shallow geology. Investigations undertaken by the Council have found river recharge to be a significant contributor to confined groundwater systems in the South Taranaki area, where the chemical signature of groundwater sampled in the Whenuakura aquifer at Waverly closely resembled that of samples taken from the Whenuakura River (TRC, 1992). Water from the Patea River is also thought to provide significant recharge to Whenuakura Formation aquifers in the Patea area, particularly where the formation is exposed at surface in the eastern hill country (Taylor and Evans, 1999).

While recharge from surface waters typically contains relatively low concentrations of dissolved ions, recharge via soil infiltration (i.e. land surface recharge) is often enriched with respect to parameters such as sodium, potassium, chloride and sulphate and other chemical species which accumulate during passage of water through the soil zone (Daughney, 2004). Depending on land use, recharge infiltrating through the soil zone may also contain elevated concentrations of nitrate as a result of land use activities, in contrast with the relatively low concentrations typically present in recharge from rivers and streams. As a consequence, the sources of aquifer recharge in a particular area, and the proportionate contributions provided by each of them, have a direct impact on the quality of groundwater observed.

### 4.3.2. Water-rock interaction & aquifer residence time

Groundwater resources can be broadly differentiated between shallow unconfined aquifers, and deeper confined or semi-confined aquifers. As discussed above, shallow unconfined aquifers receive the majority of their recharge from localised rainfall and subsequent land surface infiltration. Unconfined aquifers therefore receive relatively rapid recharge during rainfall events and are generally characterised as having 'young' water. As a consequence, groundwater quality in these aquifer systems can be directly influenced by contaminants introduced as a result of overlying land use.

Confined and semi-confined aquifers are so-called as they are physically separated from the overlying land surface by layer(s) of low permeability strata. These confining layers restrict the vertical movement of water into the underlying aquifer. The groundwater flow paths associated with these types of aquifers are generally long, and therefore water found in confined aquifers is generally much older than that found in unconfined aquifers (Figure 5).

The interaction of water with the geological material it interacts with along its flow path has a major bearing on the composition of groundwater observed in an aquifer. Water is a highly effective solvent and dissolves minerals from the geological material it interacts with. This process is closely associated with aquifer residence times and groundwater age, given that the longer water is in contact with geological material, the greater the amount of dissolution that can occur. Some soil and rock types are also more easily dissolved than others, and therefore geological characteristics play a major role in influencing the ionic composition of groundwater. Consequently, the chemical signature of groundwater can be used as an indicator of the geological characteristics and rock types present within an aquifer system.

Surface water and recently recharged groundwater tend to have chemical profiles and ion concentrations similar to that of their recharge sources. As groundwater flow paths lengthen and groundwater residence time increases, groundwater commonly becomes enriched with bicarbonate, calcium and magnesium ions, as a result of dissolution of carbonate rock. The enrichment of calcium and magnesium results in increased water hardness, which is effectively the sum of their mass concentrations. Carbonate dissolution also results in groundwater becoming more alkaline, reflected in higher pH values. Other ions such as sodium, bromine, fluorine and silica can also increase in concentration as groundwater residence time increases.

The influence of water-rock interactions is apparent in groundwater quality data collected by the Council. This is predominantly seen in the variability in the concentrations of carbonate minerals at deeper monitoring locations. In the region's shallower aquifers, the weathering of volcanoclastic material can result in elevated concentrations of iron and manganese. Concentrations of these ions in groundwater can be further increased by biogeochemical reduction, which is further discussed in Section 4.3.3.

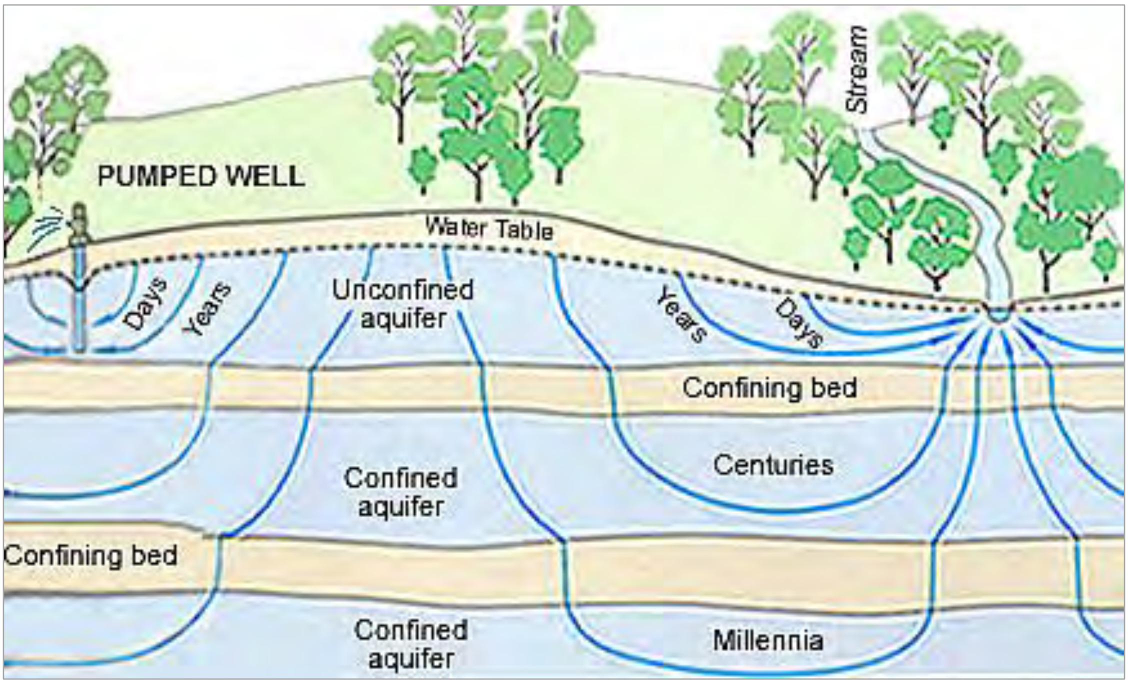

Figure 5 Schematic representation of the length of groundwater flow paths and residence time in an aquifer system (USGS, 1998)

### 4.3.3. Geochemical and biogeochemical processes

Geochemical and biogeochemical processes exert strong control of groundwater composition. These processes can be complex in nature and highly variable in their occurrence and significance, both temporally and spatially.

Geochemical processes begin to influence water composition as soon as recharge waters begin their movement through the soil zone. The interaction of water with atmospheric carbon dioxide, and carbon dioxide produced as organic material is decomposed, results in the production of carbonic acid. The production of carbonic acid acidifies water percolating downward through the unsaturated zone, and ultimately results in reduced pH values at the water table.

Once recharge water reaches the water table, biogeochemical influences begin to exert a degree of control over water composition and the abundance of various ions in solution. The most significant biogeochemical influence on groundwater composition are redox (reduction/oxidation) reactions.

Redox reactions are largely driven by bacteria, which gain energy by facilitating the transfer of electrons from organic matter to an electron acceptor. Bacteria will preferentially utilise electron acceptors that give them greatest energy gain. As illustrated in Figure 6, bacteria will preferentially utilise any dissolved oxygen present as an electron acceptor, given it provides the most energy. Once dissolved oxygen is depleted along the groundwater flow path, microbes will utilise nitrate, manganese, iron, sulphate and carbon dioxide (in that order) as electron acceptors. The order of preferential electron acceptor utilisation is referred to as the ecological succession of electron acceptors.

The reduction of nitrate is termed denitrification, and its occurrence is an important consideration when considering the nitrate attenuation capacity of groundwater and the potential effects of land use activities on groundwater.

Where reduced groundwater predominates, the reduced forms of elements involved in redox processes are commonly found in groundwater, given the reduced forms of some elements are more soluble in water than their oxidised forms (e.g. iron [$Fe^{2+}$] and manganese [$Mn^{2+}$]).

While these redox processes are generally ubiquitous in deeper groundwater systems across Taranaki, redox reactions and associated denitrification can also occur in shallow groundwater systems, under suitable environmental conditions. Initial investigations by the Council into the occurrence of denitrification in shallow groundwater are reported in Box 2.

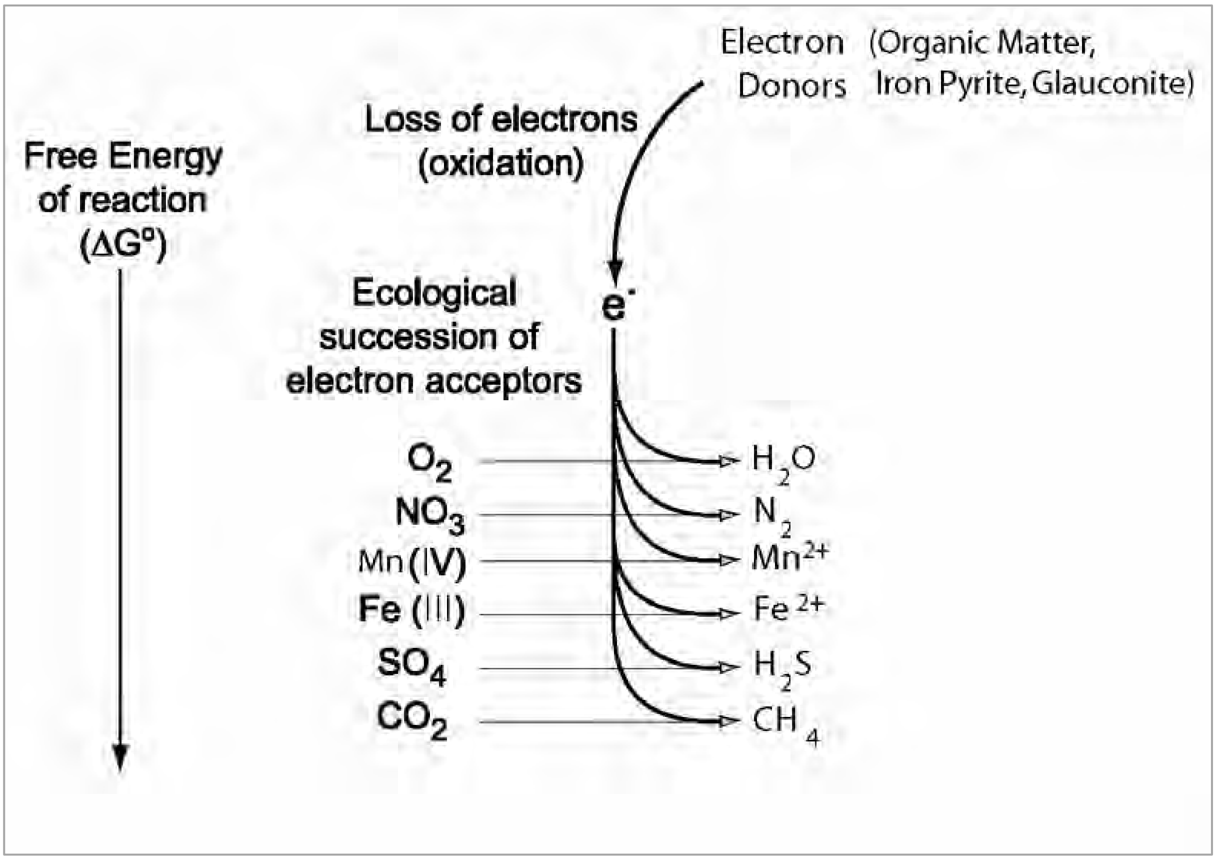

Figure 6 Ecological succession of electron acceptors (modified from McMahon and Chappelle 2008)

Given the significant influence of redox processes on groundwater composition, an understanding of the oxidation state of groundwater at monitored sites provides important context when interpreting results. McMahon and Chapelle (2008) devised a classification scheme that uses concentrations of dissolved oxygen, nitrate, manganese, iron, and sulphate in groundwater to assign a redox category and a dominant redox process. The dominant redox process represents how progressed groundwater is along the ecological succession of electron accepting processes (Figure 6). The concentration thresholds developed by McMahon and Chapelle in their classification scheme have been modified for use in the redox assignment carried out to reflect the thresholds proposed by Stenger & Clauge (2016), which are based on the results of their denitrification studies in New Zealand.

The results of the redox assignment are presented below in Table 6, and show that the monitoring network is dominated by sites drawing oxic groundwater. The dominance of oxic groundwater is particular prevalent across the SGWM network, with only six sites (19%) drawing primarily anoxic groundwater. The weighting of oxic sites in the monitoring network is thought to be reflective of the prevalence of oxic shallow groundwater across the region, based on the current understanding of its distribution. Groundwater monitored in the region's confined aquifers is generally classified as being anoxic. A small number of sites display variability in their redox state, some of which is seasonal.

Table 6 Monitoring site redox assignment

| Site | Monitoring network | Well depth (m) | Primary redox category | Primary redox process | Secondary redox category | Primary redox process |
|---|---|---|---|---|---|---|
| GND000058 | SGWM | 3.6 | Anoxic | Fe/$SO_4$ | - | - |
| GND000093 | SGWM | 8.0 | Oxic | $O_2$ | - | - |
| GND0508 | SGWM & NGMP | 14.0 | Oxic | $O_2$ | - | - |
| GND0514 | SGWM | 4.2 | Oxic | $O_2$ | - | - |
| GND0636 | NGMP | 77.7 | Oxic | $O_2$ | - | - |
| GND0827 | SGWM | 6.5 | Mixed(oxic-anoxic) | $O_2$- Fe/$SO_4$ | - | - |
| GND0829 | SGWM & NGMP | 8.0 | Oxic | $O_2$ | - | - |
| GND0834 | SGWM | 5.2 | Oxic | $O_2$ | - | - |
| GND0866 | SGWM | 7.0 | Oxic | $O_2$ | - | - |
| GND1075 | SGWM | 7.0 | Oxic | $O_2$ | - | - |
| GND1080 | SGWM | 7.0 | Anoxic | Fe/$SO_4$ | - | - |
| GND1082 | SGWM | 3.5 | Oxic | $O_2$ | Anoxic | $NO_3$ |
| GND1091 | SGWM | 3.4 | Oxic | $O_2$ | - | - |
| GND1095 | SGWM | 7.5 | Oxic | $O_2$ | - | - |
| GND1098 | SGWM | 7.5 | Oxic | $O_2$ | - | - |
| GND1101 | SGWM | 5.7 | Oxic | $O_2$ | - | - |
| GND1103 | SGWM | 5.5 | Oxic | $O_2$ | - | - |
| GND1105 | SGWM | 4.7 | Oxic | $O_2$ | - | - |
| GND1112 | SGWM | 7.2 | Oxic | $O_2$ | - | - |
| GND1194 | SGWM | 12.2 | Oxic | $O_2$ | Anoxic | Fe(III)/$SO_4$ |
| GND1196 | SGWM | - | Oxic | $O_2$ | Suboxic | Suboxic |
| GND1718 | SGWM | 8.5 | Oxic | $O_2$ | Anoxic | $NO_3$ |
| GND2098 | SGWM | 11.0 | Anoxic | $NO_3$ | - | - |
| GND2099 | SGWM | 13.5 | Oxic | $O_2$ | - | - |
| GND2165 | SGWM | 4.7 | Oxic | $O_2$ | - | - |
| GND2166 | SGWM | - | Oxic | $O_2$ | - | - |
| GND2213 | SGWM | 3.5 | Oxic | $O_2$ | - | - |
| GND2288 | SGWM | 10.7 | Anoxic | $NO_3$ | - | - |
| GND2303 | SGWM | 7.1 | Oxic | $O_2$ | - | - |
| GND2484 | SGWM | 8.0 | Oxic | $O_2$ | - | - |
| GND2505 | SGWM | 8.3 | Oxic | $O_2$ | - | - |
| GND2513 | SGWM | 1.7 | Anoxic | Fe/$SO_4$ | - | - |
| GND0430 | SGWM | 5.0 | Oxic or suboxic | $O_2$ or suboxic | - | - |
| GND0451 | NGMP | 234.6 | Anoxic or mixed | methane-$O_2$ | - | - |
| ND0563 | NGMP | 171.3 | Anoxic or mixed | methane-$O_2$ | Oxic or suboxic | $O_2$ Or suboxic |

## Box 2: Redox gradient investigation

Due to an increase in agricultural land use intensification in New Zealand and associated increases in nitrogen leaching as a result, understanding the potential nitrate attenuation capacity of groundwater systems has become an important research topic New Zealand wide. Despite some regions showing marked increases in groundwater nitrate concentrations over time, concentrations found in Taranaki are generally low and remain relatively stable. One possible reason for this may be linked to naturally occurring denitrification processes in oxygen depleted (anoxic) groundwater.

The process of denitrification in groundwater can occur when electron donors are available and reducing bacteria are present. Reducing bacteria gain energy from transferring electrons from donors, usually dissolved organic carbon, to electron acceptors. The preferred acceptor is oxygen, however once the oxygen is depleted nitrate can become the preferred acceptor and denitrification occurs.  This process will continue as long as there are electron donors available.

To investigate the possibility that denitrification is contributing to the relatively stable nitrate concentrations in Taranaki, a study was undertaken by the Council in conjunction with Lincoln Agritech. Two sites exhibiting anoxic conditions, one in Opunake and the other in Tarata, were chosen for the study. Two new purpose built groundwater monitoring bores were designed and installed at the sites to ensure that any data collected during the investigation would be robust.

The study aimed to assess the vertical redox profile in each well to determine if water was already reduced at the water table, which would indicate denitrification in the overlying unsaturated (soil) zone, or whether denitrification was occurring within the groundwater system itself, and if so, at what depth. A downhole packer pump was used for the sampling which allowed specific intervals to be isolated for sampling along the well profile. It was hoped that the information collected could be extrapolated more widely to indicate whether these reducing conditions might be prevalent across shallow groundwater in Taranaki.

The results of the study indicated that the groundwater in the Tarata bore was anoxic (<2 mg/L $O_2$). It was evident that strongly reducing conditions were present in all depths sampled within the shallow groundwater profile. Nitrate concentrations were all <0.1 mg/L. In contrast, in the Opunake bore the shallow groundwater was found to be generally oxic (≥2 mg/L $O_2$) with a weak vertical redox gradient and nitrate concentrations >1.0 mg/L, that decreased with depth. During the winter months, when rainfall is greater, the upper zones exhibited oxic conditions and the lower zones exhibited mixed oxic-anoxic conditions, suggesting a gradual progression from fully oxic to anoxic conditions with depth. (Stenger & Clague ,2016).

Overall, the study indicated that the anoxic conditions could be linked to the denitrification processes occurring in the Tarata bore and the deeper zones of the Opunake bore.  Further investigations would be required to determine the prevalence of denitrification across the region and its influence on observed nitrate concentrations.

# 5. State and trends in groundwater quality

## 5.1. Electrical conductivity (EC)

EC is a measure of water's ability to conduct an electrical current. EC values are directly proportional to the concentration of total dissolved solids (TDS) in a sample, which represents its total ion concentration. TDS concentrations (mg/L) can be converted to EC values (mS/m) using an approximated conversion factor.

EC values are useful in providing an indication of spatial and temporal variations in water composition. Monitoring variations in EC values at a particular site can indicate shifts in water quality, which may arise as a result of natural processes, or anthropogenic contamination.

A summary of all EC values recorded across the sampling network is presented in Figure 7.

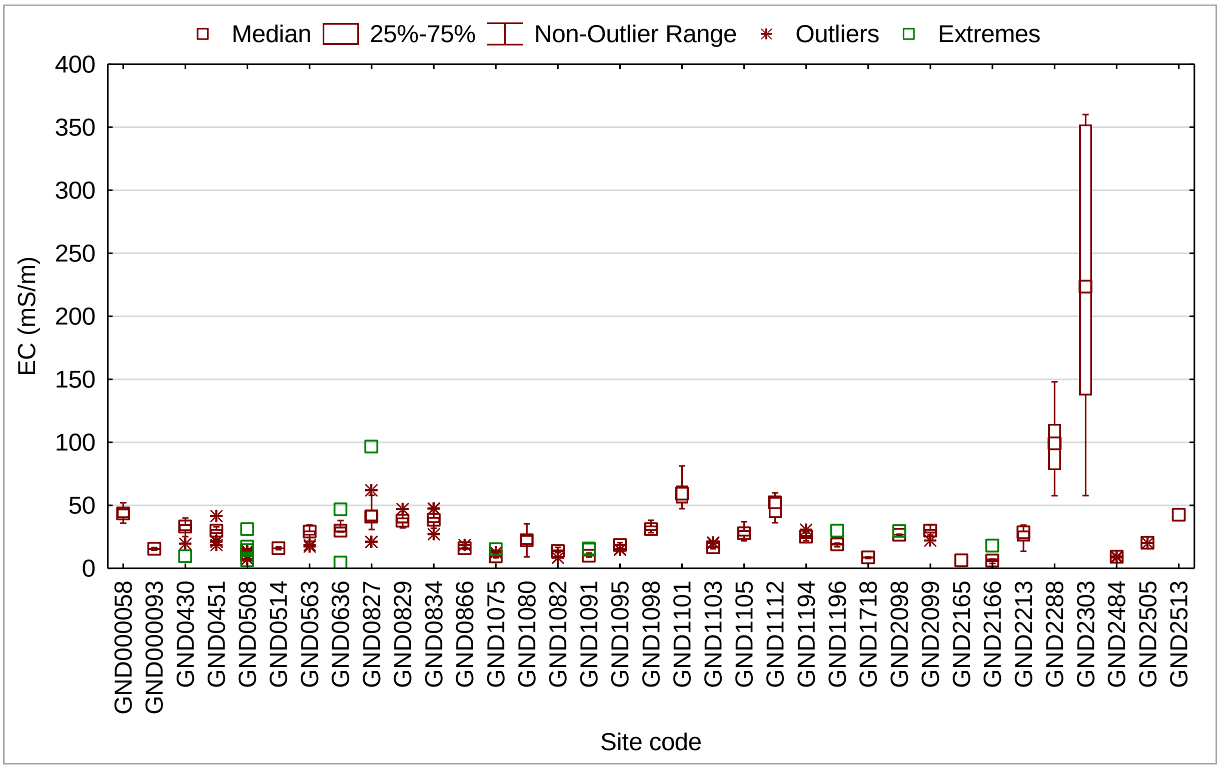

Figure 7 Comparison of measured EC values at all monitored sites

The highest EC values were recorded at sites GND2303 and GND2288, with median EC values of 224 and 99 mS/m, respectively. These two wells are located at coastal sites used for the bioremediation of drilling wastes, and are used for the monitoring of groundwater quality at these locations. The wells selected for inclusion in the programme were assumed to be located upgradient of the spreading areas and therefore likely to be unaffected by the activity. The elevated EC values recorded each site do indicate that water composition in is in fact being influenced by the activity, in combination with a likely input of salts for the from sea spray deposition.

Outside of these sites, the highest median EC values of 59 and 52 mS/m were recorded at sites GND1101 and GND1112, respectively. Both these sites are located in intensively farmed areas, on or near the coast. Both sites have consistently shown the impacts of agricultural land use activities over the course of their respective monitoring records, including elevated nitrate concentrations (see Section 5.6). It is assumed likely that the increased EC values are associated with the leaching of salts contained within animal effluent.

Geographical location appears to be the major driver of EC values across the remainder of the SGWM network sites (Figure 8).

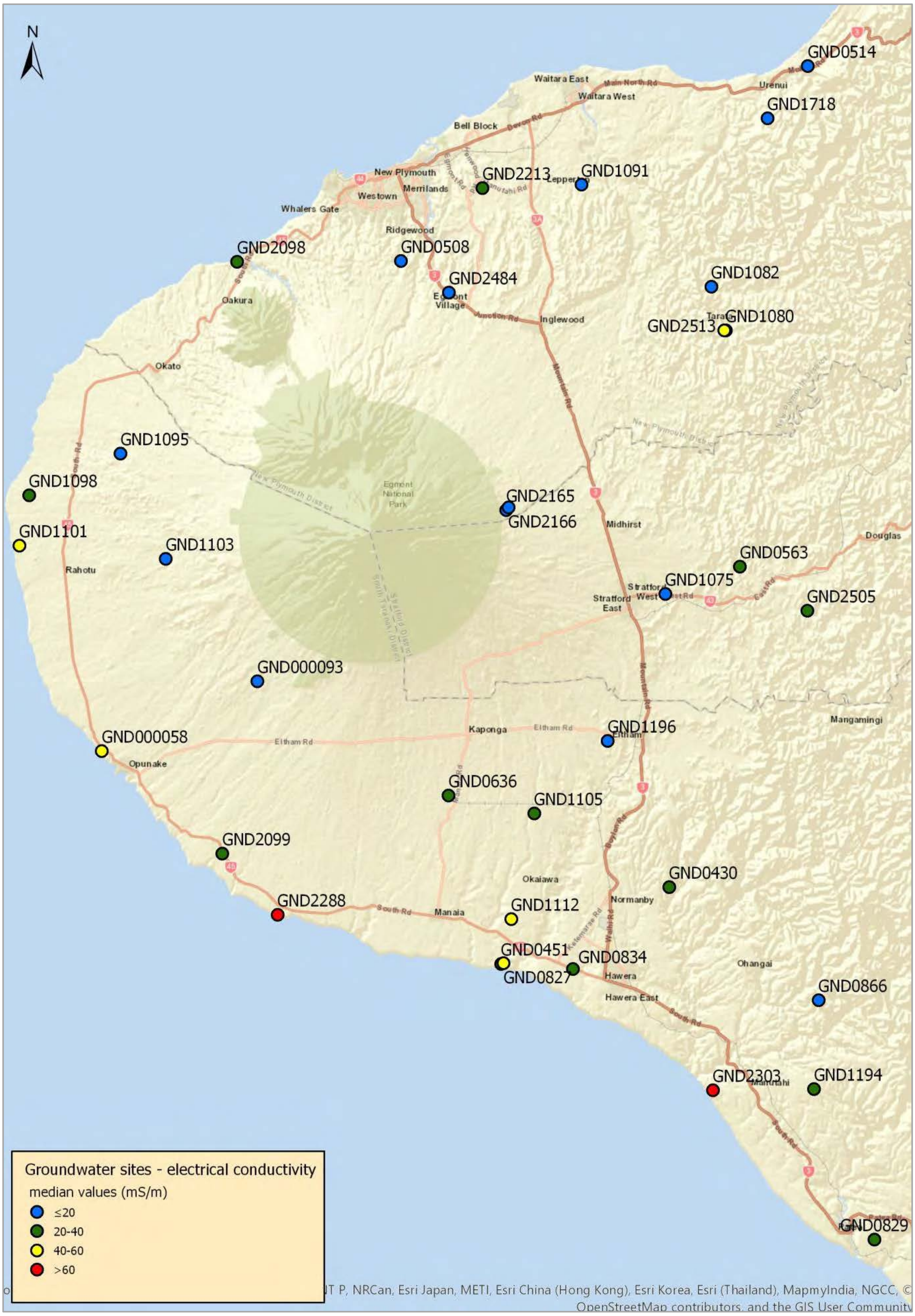

Figure 8 Median EC values across all monitoring sites

Water sampled at shallow coastal sites generally display higher EC values than those located inland, which reflects the greater concentration of salts contained in marine aerosols at the coast (Table 7). The increase in EC apparent across the 15 to 20 km coastal set back distance is skewed by elevated EC concentrations at sites GND1080 and GND2513. These two sites are located in close proximity to each other, with GND2513 being installed as part of the redox gradients investigation project (detailed in Box 2), based on sampling results from GND1080. Analysis undertaken as part of that project indicates that elevated concentrations of sodium in groundwater in this location is responsible for the elevated EC observed. It is noted by Stenger and Clague (2016) that the sodium concentrations observed at this location are naturally present as a result of water-rock interaction within the aquifer.

Table 7 Mean EC values relative to distance from the coast

| Distance from coast (km) | Number of sites | Mean EC (mS/m) |
|---|---|---|
| 0-5 | 10 | 28 |
| 5-10 | 3 | 18 |
| 10-15 | 6 | 19 |
| 15-20 | 3 | 26 |
| >20 | 4 | 11 |

The DWSNZ does not set out a MAV for EC but does include a GV for TDS of 1,000 mg/L (approx. 67 mS/m). It is also noted in the DWSNZ that taste may become unacceptable for potable supply at TDS concentrations of between 600 to 1,200 mg/L (approx. 40 to 80 mS/m). A summary of median EC values recorded across the monitoring network values against the GV for EC is provided in Table 8.

Table 8 Median EC values at all sites in comparison to GV (for TDS)

| Measure | Number of sites | % of all sites |
|---|---|---|
| 0-25% of GV | 12 | 34 |
| 25-50% of GV | 14 | 40 |
| 50-75% of GV | 5 | 14 |
| 75-100% of GV | 2 | 6 |
| Sites exceeding GV | 2 | 6 |

Analysis of data collected at NGMP network sites revealed a statistically significant reducing trend in EC values at site GND0827 (p-value 0.0006). The analysis indicates a PAC in EC values of 1.2% over the length of the data record. No other statistically significant tends in EC values were identified in the dataset.

### 5.1.1. Summary

- EC values in groundwater are generally higher close to the coast, as a result of increased salt concentration in rainfall at these locations and /or the influence of sea spray.
- At some sites, elevated EC values have been found to occur as a result of sodium weathering from geological material.
- There is evidence of land use activities contributing additional salts to groundwater at specific locations, including in the vicinity of waste remediation sites and intensively farmed land.
- 33 sites (94%) have recorded median values that meet the GV for EC (converted from TDS).
- One site is displaying a statistically significant reducing trend in EC. No sites were found to have an increasing trend.

## 5.2. Bicarbonate ($HCO_3$)

Bicarbonate is a major anion species present in groundwater. Its presence and relative concentration in groundwater can be linked to several geochemical processes. These processes include interactions between water and carbon dioxide in the atmosphere and the soil zone, mineral dissolution and redox processes. Bicarbonate has also been suggested as a potential indicator of agricultural land use effects, primarily related to the addition of fertiliser to land (Rosen, 2001).

Bicarbonate concentrations are monitored at NGMP network sites. A graphical comparison of bicarbonate concentrations measured at NGMP network sites is presented in Figure 9.

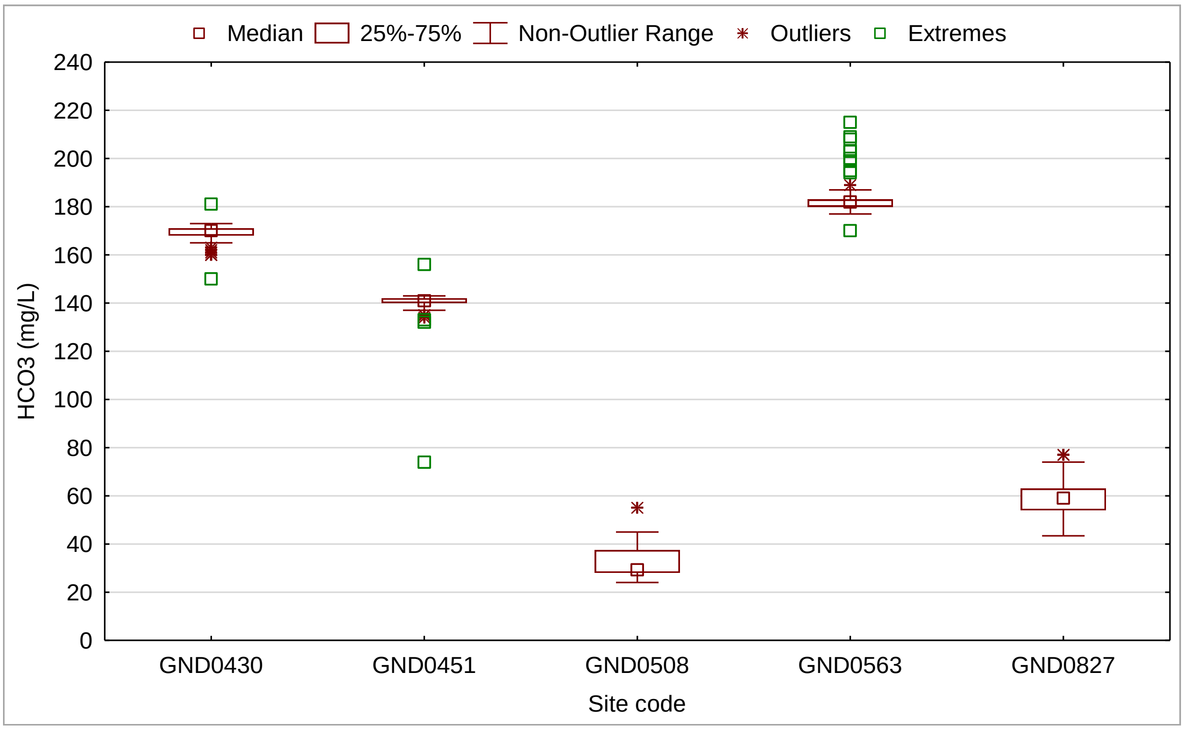

Figure 9 Comparison of bicarbonate concentrations at NGMP network sites

Bicarbonate concentrations at monitored sites appear to be driven by water-rock interaction, with highest concentrations being observed at sites GND0563, GND0430 and GND0451, which draw water from deep, confined aquifers. The residence time is much higher in these aquifers than in shallow unconfined systems, allowing more time for mineral dissolution to occur. In Taranaki, aquifers contained within the Whenuakura and Matemateaonga Formations are generally rich in carbonates.

Statistical analysis of data collected revealed statistically significant reducing trend in bicarbonate concentrations at site GND0508 (p-value 0.003) and an increasing trend at site GND0827 (p-value <0.0001). The analysis indicates a PAC of -2.4 and 1.7% at the respective sites (Figure 10). These two sampling sites represent the shallowest in the NGMP network, and draw water from unconfined aquifers. It is likely that the trends observed in bicarbonate concentrations are linked to changes in land use intensification in the vicinity of both sites.

### 5.2.1. Summary

- Bicarbonate concentrations at monitored sites are driven primarily by natural water-rock interaction.
- Highest bicarbonate concentrations are found at sites drawing 'old' water from deep confined aquifers.

- One site is displaying a statistically significant reducing trend in bicarbonate concentration and one site an increasing trend. Both trends appear at shallow groundwater monitoring sites and would appear to be linked to changes in land use related.

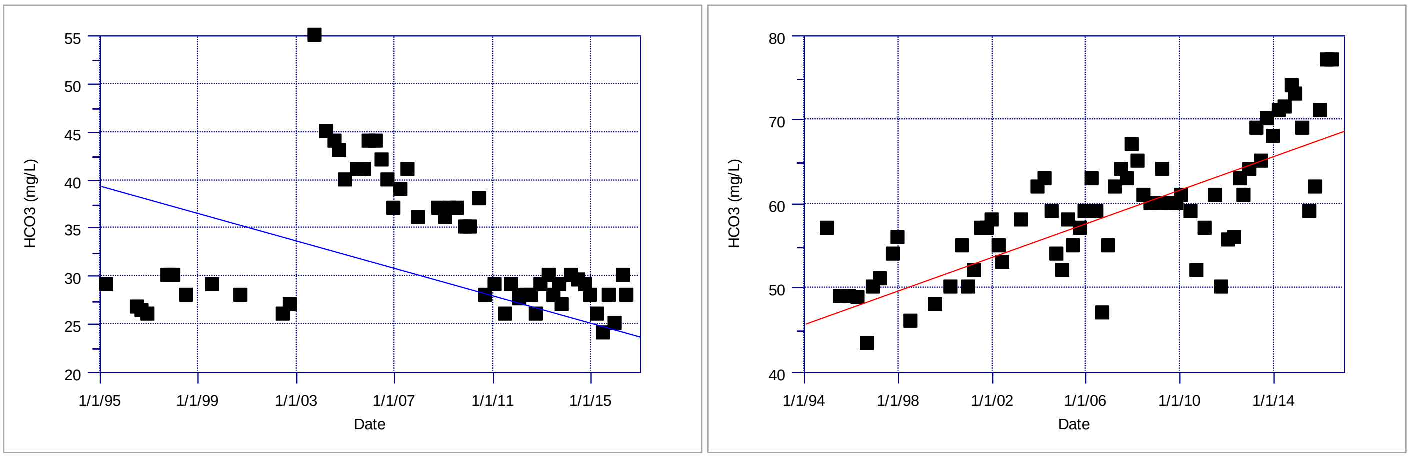

Figure 10 Plot of statistically significant reducing trend in bicarbonate concentration at site GND0508 (L) and increasing trend at site GND0827 (R)

## 5.3. Chloride (Cl) and sodium (Na)

Chloride and sodium concentrations are monitored across the NGMP network. Chloride is generally considered a good indicator of general groundwater quality as its concentration is relatively unaffected by geochemical processes that influence the concentration of other ions in groundwater systems.

The primary source of chloride in groundwater is rainfall deposition. Chloride can also be contributed to groundwater system through land use activities, including wastewater and effluent discharges. While sodium is also deposited through rainfall, it can also accumulate in groundwater systems as a result of geochemical processes, such as ion exchange, and the weathering of sodium bearing rock or sediments within the aquifer itself.

A comparison of measured chloride and sodium concentrations at NGMP network sites is presented in Figure 11. As illustrated, GND0827 has the highest median concentration of chloride of any NGMP network site. Similarly, GND0827 also has the highest median concentration of sodium at any NGMP network site. The higher concentration of chloride and sodium ions at this site is a result of it drawing water from a shallow unconfined aquifer in close proximity to the coast (460 m). There has been no exceedance of the GVs for chloride and sodium set out in the DWSNZ at any site monitored.

The relative ratio of sodium to chloride in a sample can be used to differentiate the source of salinity in groundwater. Seawater has an approximate ratio of sodium to chloride ratio (in mg/L) of 0.55. When plotted, this linear ratio is referred to as the seawater dilution line (SWDL). This ratio is also reflected in rainwater, which is derived from seawater evaporation; however the actual concentrations of each ion in rainwater are orders of magnitude lower than those in seawater. If salinity in groundwater is derived from rainfall recharge, the sodium to chloride ratio will be similar to that found in seawater (0.55), and will plot along the SWDL. Deviations away from this ratio indicate additional inputs of either ion, or the influence of geochemical processes within the groundwater system.

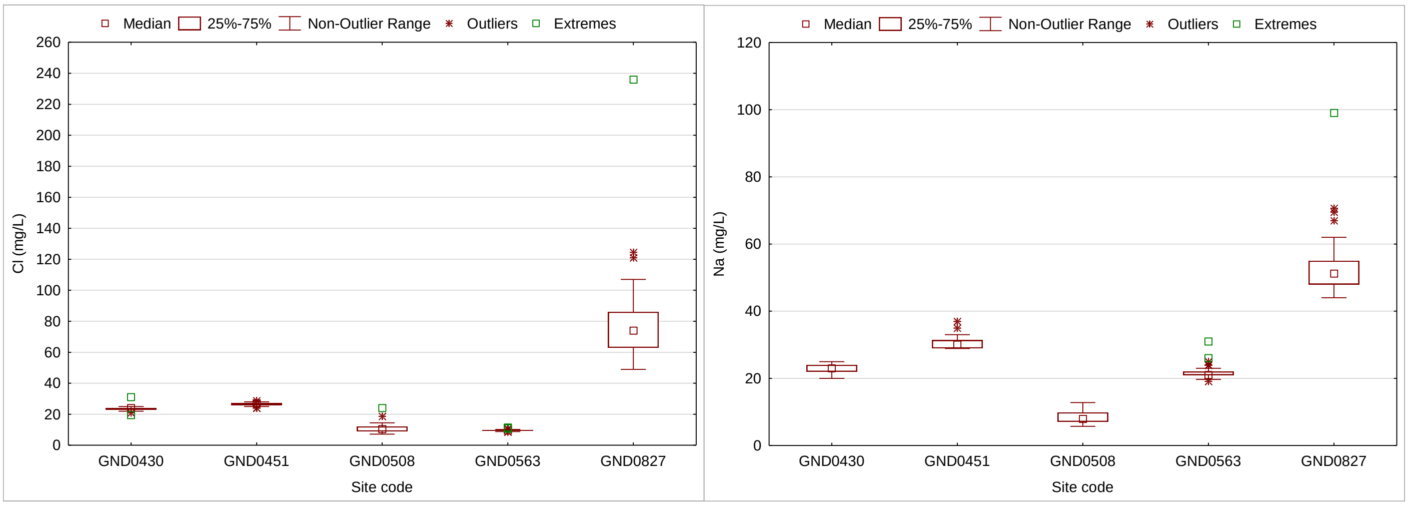

Figure 11 Comparison of measured chloride (L) and sodium (R) concentrations at NGMP network sites

Figure 12 illustrates the relative ratios of sodium to chloride at NGMP network sampled. The plot indicates that samples from GND0430, GND0451 and GND0563 plot well below the SWDL. This indicates that samples from these sites are enriched with sodium. These three sites are the deepest sites monitored in the NGMP network and draw water from confined aquifers. The additional sodium ions found in solution at these sites is a result of dissolution from sodium bearing rock and/or natural ion exchange processes within the aquifer. Samples from GND0508 generally plot near the SWDL, indicating rainfall as the primary source of chloride and sodium ions in samples at this location. Samples taken from site GND0827 display a mixed range of ratios, indicating mixed input sources for each ion. These sources include rainfall recharge, geochemical processes within the aquifer itself and/or land use inputs.

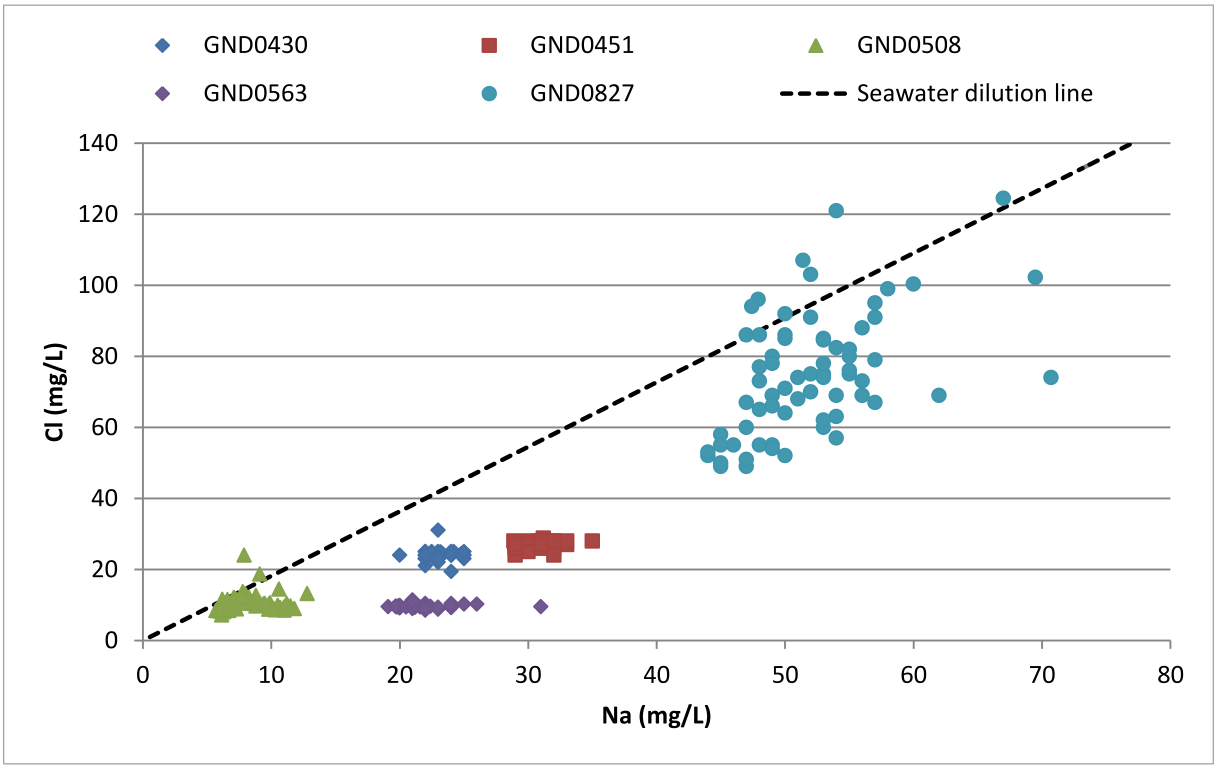

Figure 12 Observed chloride and sodium concentrations compared against the SWDL

Statistical analysis of data collected revealed a statistically significant increasing trend in chloride concentration at site GND0508 (p-value <0.0001) and a reducing trend at site GND0827 (p-value <0.0001). The analysis indicates a PAC of 2.7% and -3.3% at the respective sites (Figure 13). These two sites are the shallowest sites in the NGMP network and draw water from shallow, unconfined aquifers. These sites are therefore the most likely to show changes in concentration of chloride and sodium ions in response to changes in recharge characteristics and land use activities.

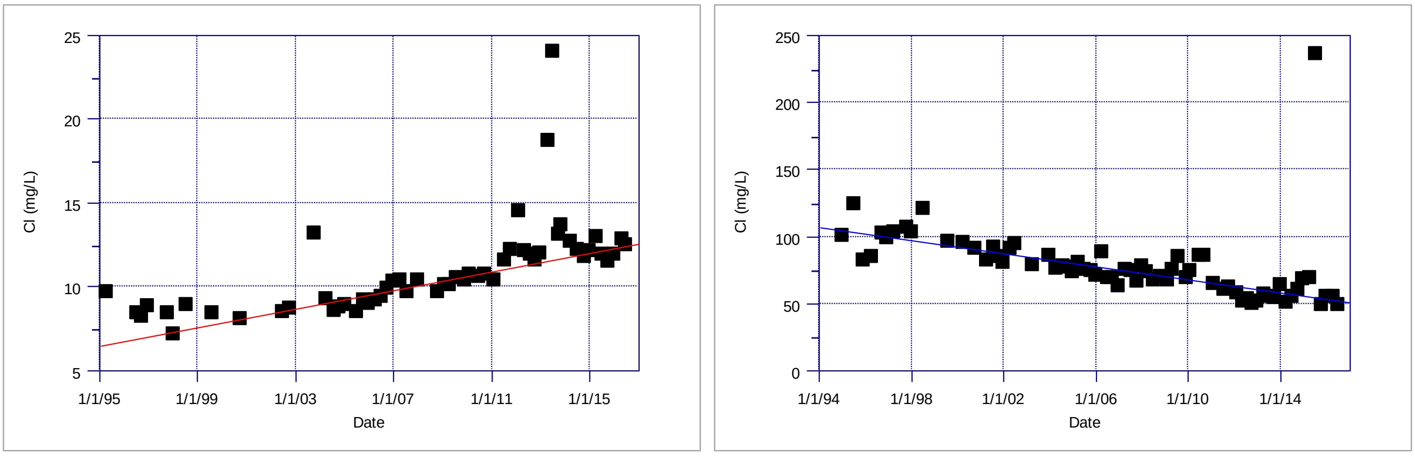

Figure 13 Plot of statistically significant increasing trend in chloride concentration at site GND0508 (L) and reducing trend at site GND0827 (R)

### 5.3.1. Summary

- The highest median sodium and chloride concentrations are found in shallow, unconfined groundwater close to the coast.
- Groundwater in shallow, unconfined aquifers have sodium to chloride ratios that plot on, or close, to the SWDL, indicating rainfall as the primary source of these ions.
- Deeper groundwater is more enriched in sodium as a result of water-rock interaction and the dissolution from sodium bearing minerals within the aquifer.
- One site is displaying a statistically significant reducing trend in chloride concentration and one site an increasing trend. Both trends appear at shallow groundwater monitoring sites and would appear to be linked to changes in either recharge characteristics or land use inputs.

## 5.4. Iron (Fe) and manganese (Mn)

Iron and manganese are metals that occur naturally in soils and rock and are generally found to co-exist. When water is in contact with materials containing iron and manganese, they can be dissolved into solution. Therefore, a major factor in determining the concentrations of iron and manganese found in groundwater, is the concentration of these metals in the soil and rock through which it moves. Material of volcanic origin generally has high concentrations of iron and manganese and therefore both metals are commonly found in Taranaki groundwater, sometimes at concentrations that affect its potential use.

Geochemical processes also influence the concentration of iron and manganese present in groundwater. In low oxygen environments, redox processes result in iron and manganese ions being reduced to their more soluble forms, resulting in a higher concentration of these ions becoming dissolved in groundwater. Given the relatively anoxic characteristics of deeper groundwater aquifers, particularly those that are confined in nature, it is common to find elevated concentrations of iron and manganese in samples from wells drawing water from them. While these redox processes are widespread in deeper aquifers, there is also potential for these to occur in shallow groundwater zones, where environmental conditions are suitable. While less common, a small number of SGWM sites exhibit the effects of redox processes.

A comparison of measured iron and manganese concentrations across all monitored sites is presented in Figure 14 and Figure 15, respectively.

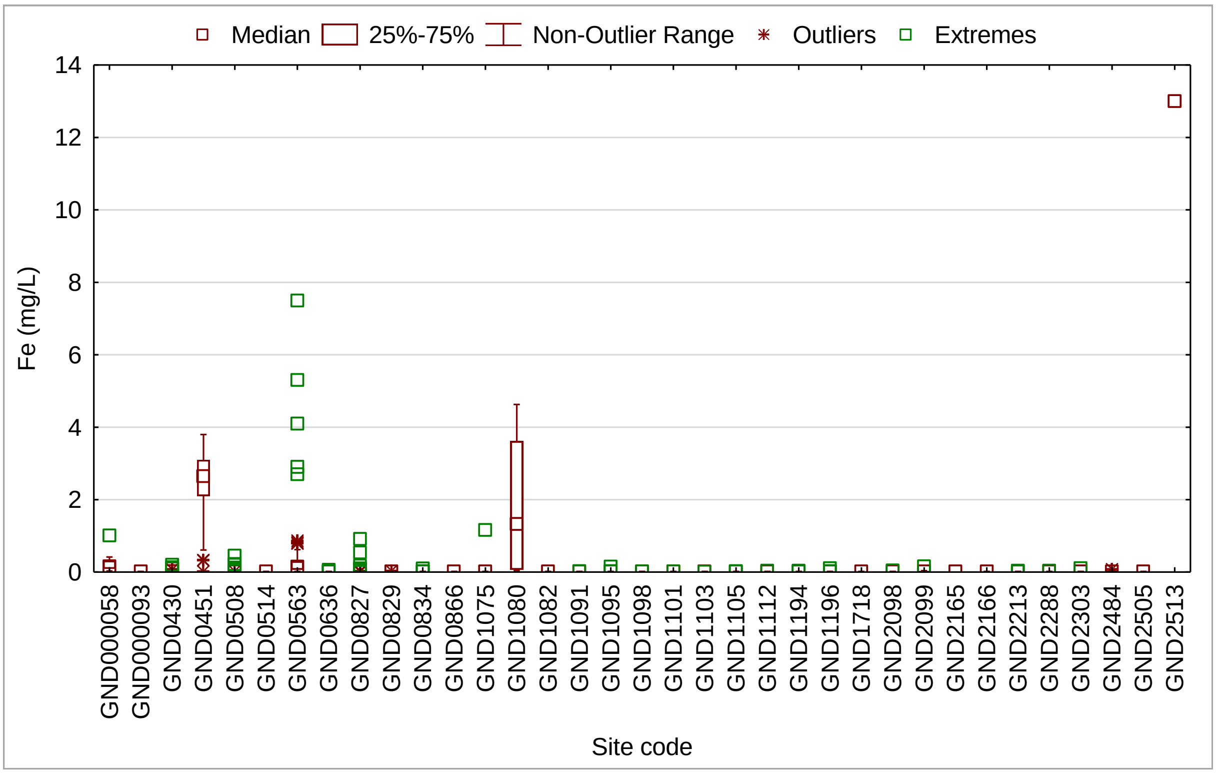

Figure 14 Comparison of measured iron concentrations at all monitored sites

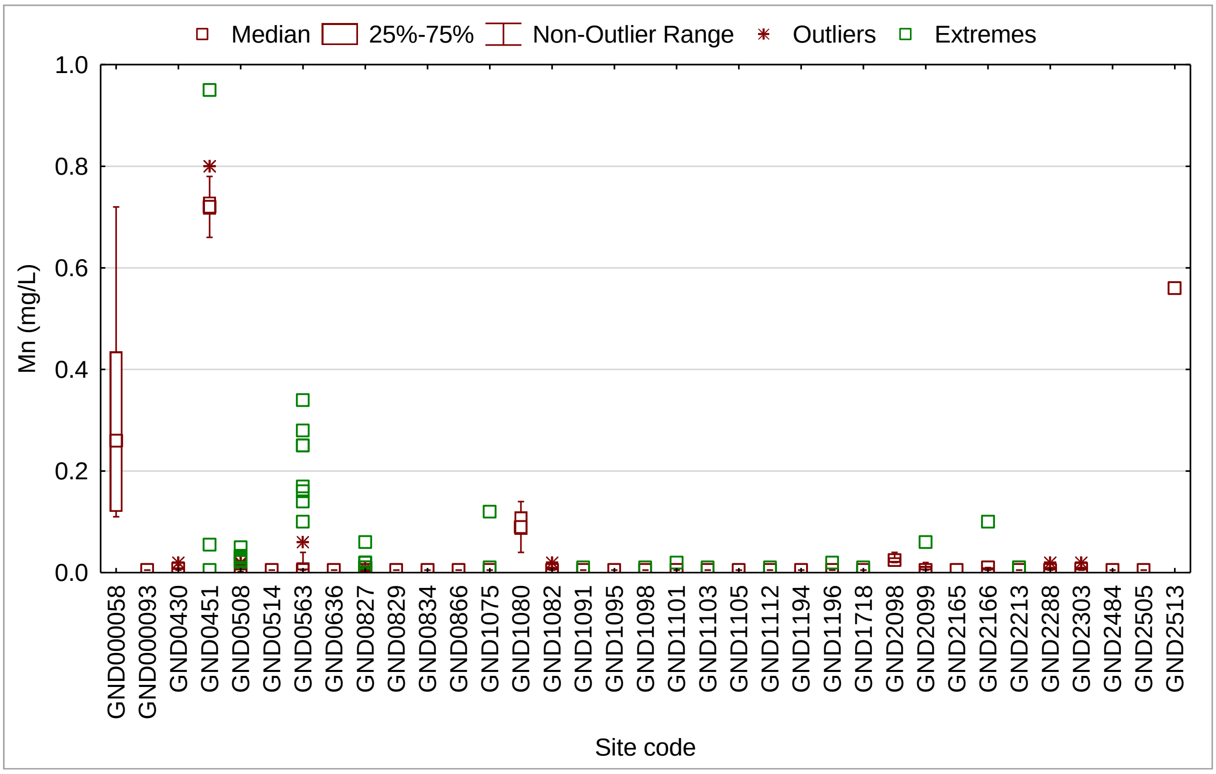

Figure 15 Comparison of measured manganese concentrations at all monitored sites

Figure 15 illustrates iron concentrations above detection limits (0.03 mg/L) at a number of sampling locations. The highest median iron concentrations are found at sites GND2513 and GND1080. These sites are located in close proximity to each other, with site GND2513 drilled as an investigation well for the redox gradient project discussed in Box 2. Both wells draw water from the unconfined Taranaki volcanic aquifer. Water quality results indicate water being drawn from these wells is highly anoxic, and that redox processes are the major influence on observed water composition. Iron concentrations are also elevated at sites GND0451 and GND0563, both of which draw water from highly anoxic confined aquifers. Again, in these highly reduced groundwater environments, redox processes are the main influence on measured iron concentrations.

Figure 16 illustrates that, in most instances, elevated manganese concentrations occur at sites displaying elevated iron concentrations. This is expected given both metals are generally present in the same source rock and that the solubility of both is increased in reduced groundwater environments.

Statistical analysis of data collected revealed statistically significant increasing trends in both iron and manganese concentration at site GND0563, with p-values of 0.02 and<0.0001, respectively. The analysis indicates a PAC of 7% for iron and 4% for manganese (Figure 17). The results from this site indicate that the concentrations of soluble iron and manganese in groundwater water at this site were higher, and more variable from 2011 onward. The results are suggestive of changes in redox status at the site, possibly linked to changes in usage and abstraction demand. The trend analysis carried out also revealed a statistically significant reducing trend in manganese concentration at site GND0508 (p-values <0.0001), with a PAC of -5.5% (Figure 17).

A statistically significant trend in iron concentration was also detected at site GND0508, but the PAC was below the meaningful threshold of 1%. The reduction in manganese concentrations at GND0508 may indicate a groundwater in the immediate vicinity of the well has become slightly more oxidised, meaning manganese (and iron) will exist in less soluble forms, reducing the dissolved concentration in groundwater. The increase in oxidation state may be linked to increased recharge volumes, which may also be indicated by statistically significant increasing trend in chloride concentration at the same site (see section 5.3).

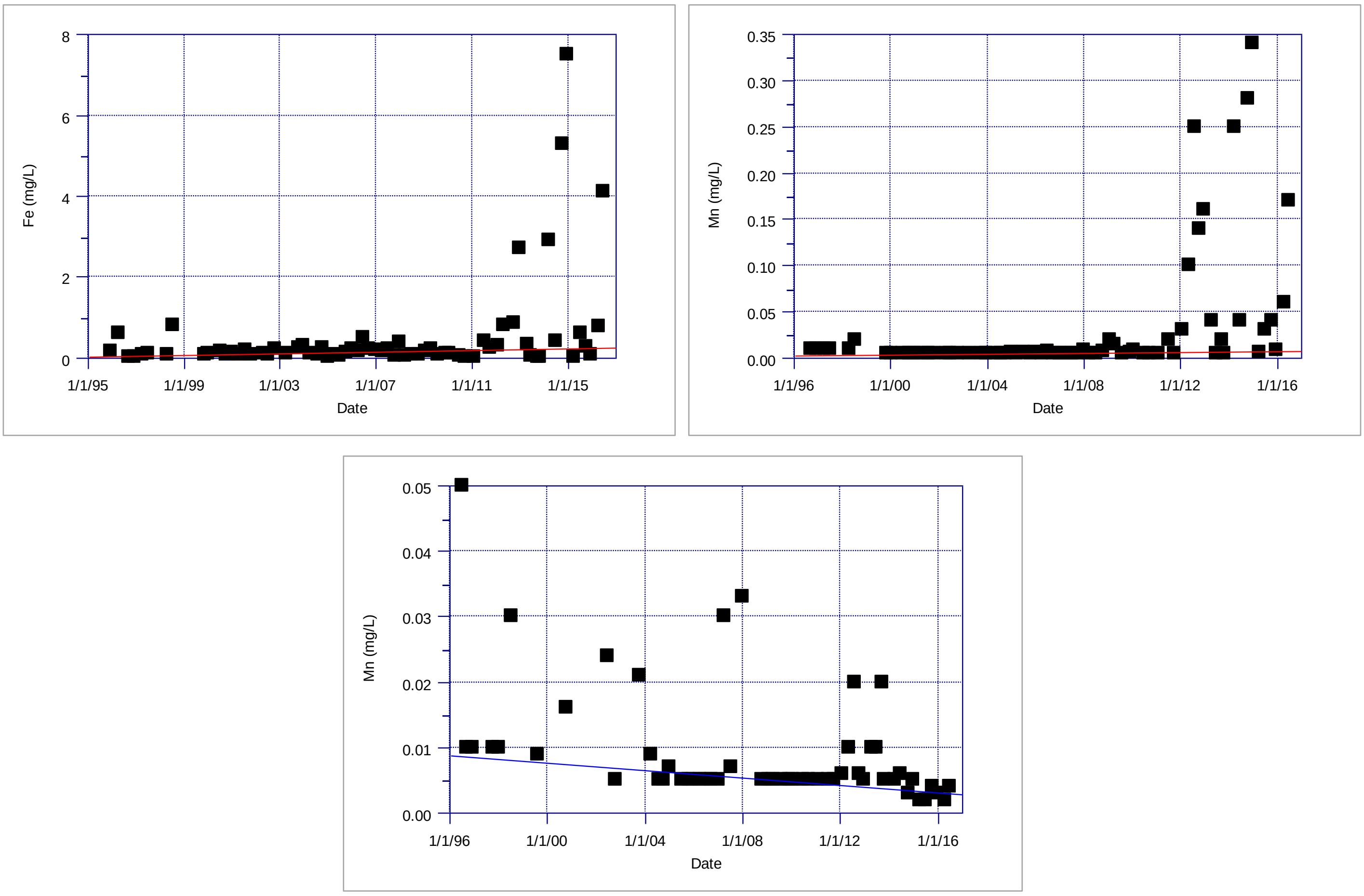

Figure 16 Plot of statistically significant increasing trends in trend in iron and manganese concentrations at site GND0563 (top left and top right) and reducing manganese at site GND0508 (bottom centre)

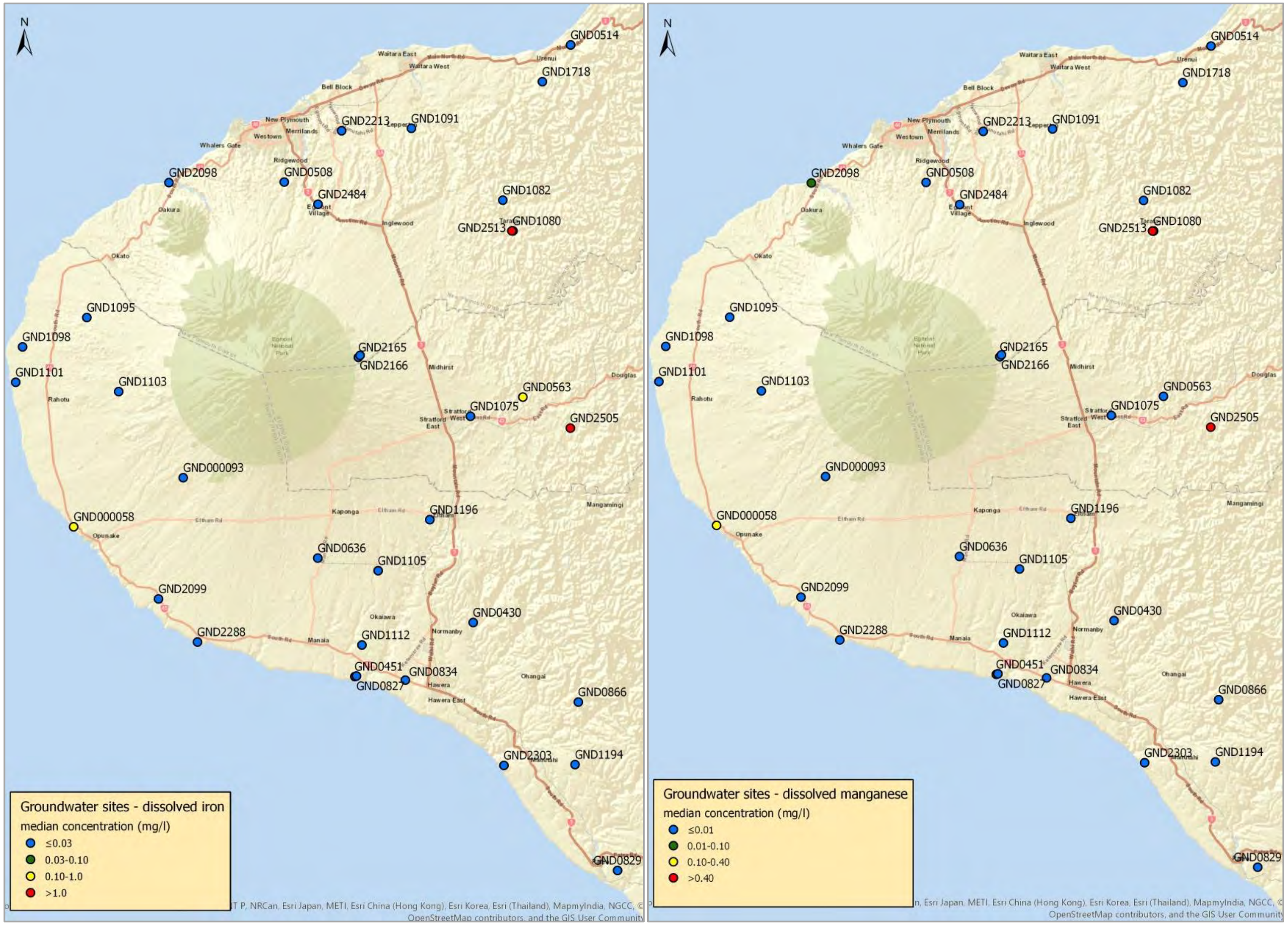

Figure 17 Regional overview of dissolved iron (L) and manganese (R) concentrations at monitored sites

The DWSNZ sets out a GV for manganese of 0.1 mg/L. Concentrations above this value may result in the staining of laundry. A health related MAV for manganese is also set at 0.4 mg/L. There is no MAV set for iron, but a GV of 0.2 mg/L is set, above which staining of laundry and sanitary ware can become an issue. A summary of median iron and manganese concentrations across the monitoring network against the relevant DWSNZ values is provided in Table 9.

Table 9 Median iron and manganese concentrations at all sites in comparison to DWSNZ values

| **Measure** | **GV for iron (0.2 mg/L)** | | **GV for manganese (0.1 mg/L)** | | **MAV for manganese (0.4 mg/L)** | |
|---|---|---|---|---|---|---|
| | Number of sites | % of all sites | Number of sites | % of all sites | Number of sites | % of all sites |
| 0-25% of value | 30 | 86 | 31 | 89 | 32 | 91 |
| 25-50% of value | 0 | 0 | 0 | 0 | 0 | 0 |
| 50-75% of value | 1 | 3 | 0 | 0 | 0 | 0 |
| 75-100% of value | 1 | 3 | 1 | 3 | 1 | 3 |
| Sites exceeding value | 3 | 9 | 3 | 9 | 2 | 6 |

### 5.4.1. Summary

- The volcanic geology of Taranaki is rich in iron and manganese and both are commonly seen in Taranaki groundwater.
- Redox processes in anoxic groundwater systems naturally increase the concentration of both iron and manganese dissolved in groundwater.
- Elevated concentrations of iron and manganese generally occur in tandem.
- One site displays statistically significant increasing trends in both iron and manganese as a result of natural redox processes.
- 91% of sites have median iron and manganese concentrations below the GV for, while 94% have manganese concentrations below the MAV.

## 5.5. Ammoniacal nitrogen ($NH_4$)

Nitrogen can exist in groundwater in numerous forms. The various nitrogen species in groundwater, and their relative proportions, are dictated by a number of factors. Some forms of nitrogen contained in groundwater are found in the same form in which they are released into the environment, while other forms are present as a result of transformation processes. Ammoniacal nitrogen can be present in groundwater as a result of direct discharges of human and animal effluent, but also as a result of the ammonification of organic nitrogen, and/or the reduction of nitrate in a groundwater system.

Ammoniacal nitrogen can accumulate in groundwater where the input of nitrogen into the soil and shallow subsurface exceeds plant uptake capacity and/or the ability of bacteria to convert it to nitrate. This can occur when nitrogen inputs are high, or where environmental conditions are unfavourable for either of the uptake or conversion processes.

In highly anoxic groundwater environments nitrate can also be reduced to ammoniacal nitrogen through a redox process known as dissimilatory nitrate reduction to ammonium (DNRA). As a result, it is common to find elevated levels of ammoniacal nitrogen in deeper aquifers, or in shallow aquifers where reduction processes have removed any available oxygen. Where aquifer residence times predate human settlement, or the intensification of agricultural land use, decomposition of naturally occurring organic matter within the aquifer itself is the likely source of any nitrogen present within the aquifer. Any nitrogen present in these aquifers will be in the form of ammoniacal nitrogen, as the transformation of ammoniacal nitrogen to nitrate only occurs under oxic conditions.

A comparison of measured ammoniacal nitrogen concentrations across all monitored sites is presented in Figure 18. The plot illustrates that median ammoniacal nitrogen concentrations are found above detection limits (0.003 mg/L) at a number of sampling locations.

The highest median ammoniacal nitrogen concentration is found at site GND2513. This well draws water from the unconfined Taranaki volcanic aquifer. Water quality results indicate water being drawn from this well is highly anoxic and that redox processes are the major influence on observed water composition. Ammoniacal nitrogen concentrations are also elevated at sites GND0451, GND0563 and GND0430, which draw water from Whenuakura (GND0451 and GND0430) and Matemateaonga (GND0563) Formation aquifers. The decomposition of organic matter in these highly anoxic groundwater systems is the likely source of ammoniacal nitrogen present in samples obtained at these sites. As expected there is commonality between sites displaying elevated concentrations of ammoniacal nitrogen and other redox sensitive parameters discussed in previous sections (iron, manganese etc.).

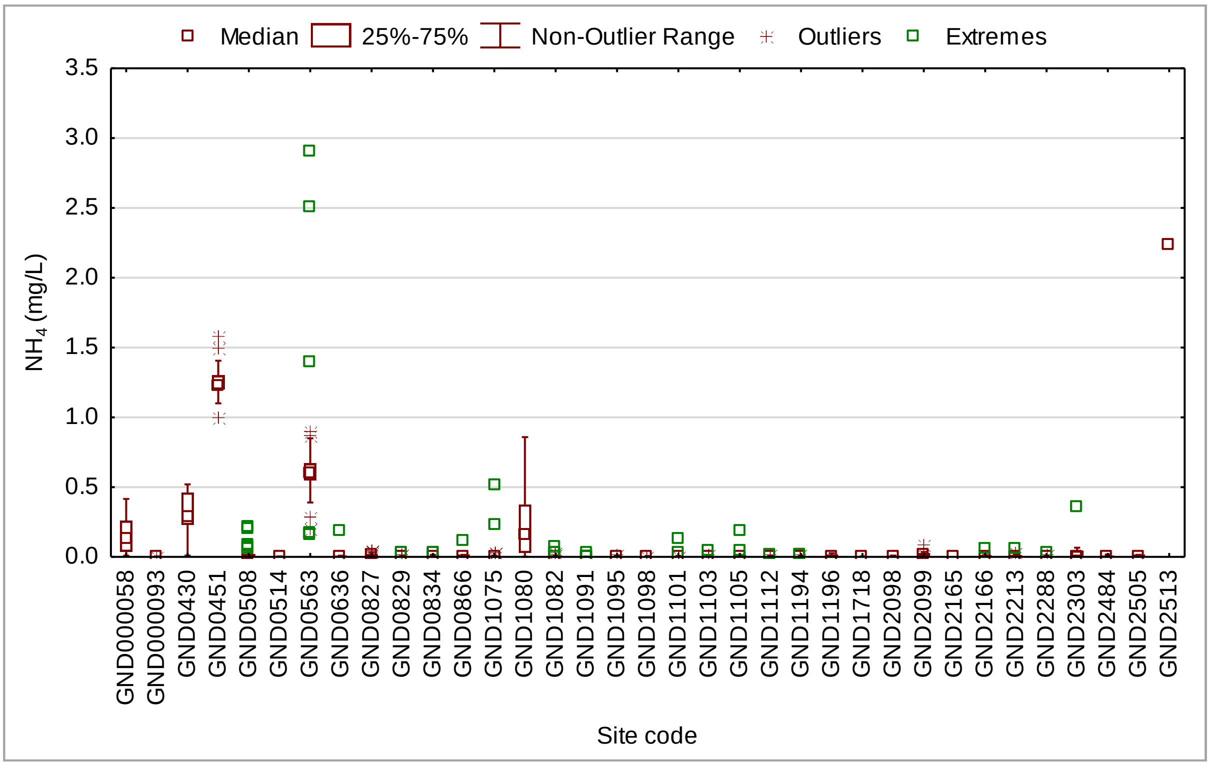

Figure 18 Comparison of measured ammoniacal nitrogen concentrations at all monitored sites

Statistical analysis of data collected revealed statistically significant increasing trend in ammoniacal nitrogen concentration at sites GND0563 (p-value of <0.0001) and GND0430 (p-value of <0.0001). The analysis indicates a PACs of 4% and 5% at each site, respectively (Figure 19). A statistically significant trend was also detected at site GND0451, but the PAC was below the meaningful threshold of 1%.

The trend detected at GND0563, and the corresponding trends in other redox sensitive parameters detected at the site, suggest that water sampled at this location continues to become further reduced, increasing the generation of ammoniacal nitrogen in the aquifer. Similar processes appear to be occurring at site GND0430, resulting in increased ammoniacal nitrogen concentrations.

The geographic distributions of ammoniacal nitrogen concentrations across the region are set out in Figure 20.

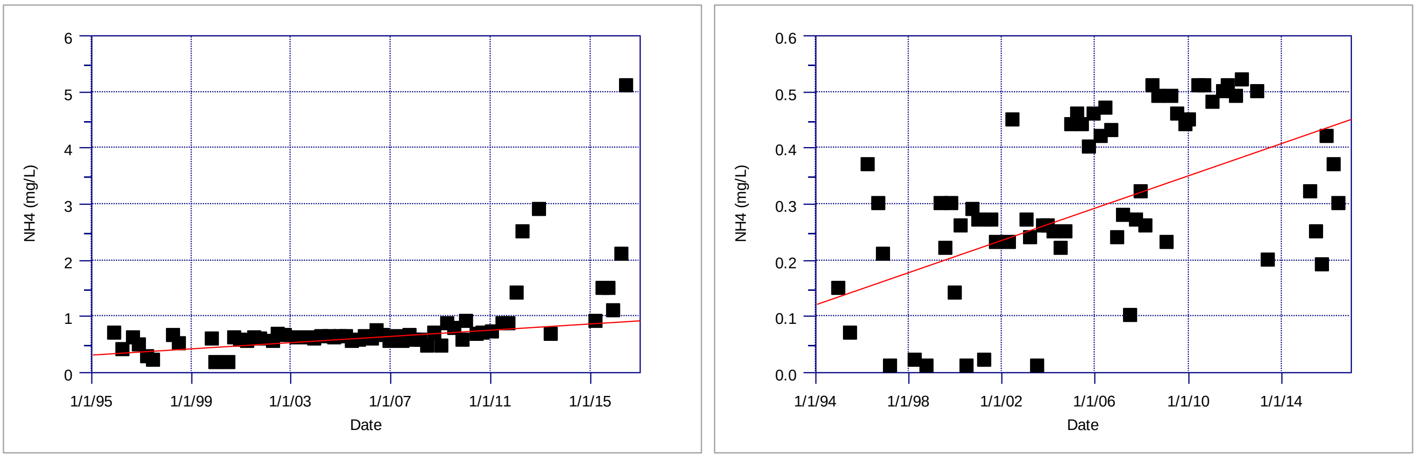

Figure 19 Plot of statistically significant increasing trends in ammoniacal nitrogen concentrations at sites GND0563 (L) and GND0430 (R)

The DWSNZ sets out a GV for ammoniacal nitrogen of 0.3 mg/L for the control of chloramine in treated water. A further GV is set at a threshold of 1.5 mg/L, above which odour generation can become an aesthetic issue. A summary of median ammoniacal nitrogen concentrations across the monitoring network values against these GVs is provided in Table 10.

Table 10 Median ammoniacal nitrogen concentrations at all sites in comparison to DWSNZ values

| **Measure** | **GV for ammoniacal nitrogen (chloramine generation) (0.3 mg/L)** | | **GV for ammoniacal nitrogen (odour) (1.5 mg/L)** | |
|---|---|---|---|---|
| | Number of sites | % of all sites | Number of sites | % of all sites |
| 0-25% of value | 29 | 83 | 32 | 91 |
| 25-50% of value | 1 | 3 | 1 | 3 |
| 50-75% of value | 1 | 3 | 0 | 0 |
| 75-100% of value | 1 | 3 | 1 | 3 |
| Sites exceeding value | 3 | 9 | 1 | 3 |

### 5.5.1. Summary

- Ammoniacal nitrogen can be present in groundwater as a result of land use inputs and/or naturally occurring processes.
- Observed concentrations of ammoniacal nitrogen are generally dictated by the oxidation state of groundwater in which it may be present.
- Higher concentrations of ammoniacal nitrogen are generally found in deeper aquifers across Taranaki, or in areas of the region where shallow groundwater is highly reducing.
- Higher concentrations of ammoniacal nitrogen are also found in shallow oxidised groundwater underlying intensely farmed areas of the region.
- 86% of monitored sites have median concentrations of ammoniacal nitrogen below the GV.
- Two sites display statistically significant and meaningful trends in ammoniacal nitrogen concentrations as a result of natural processes.

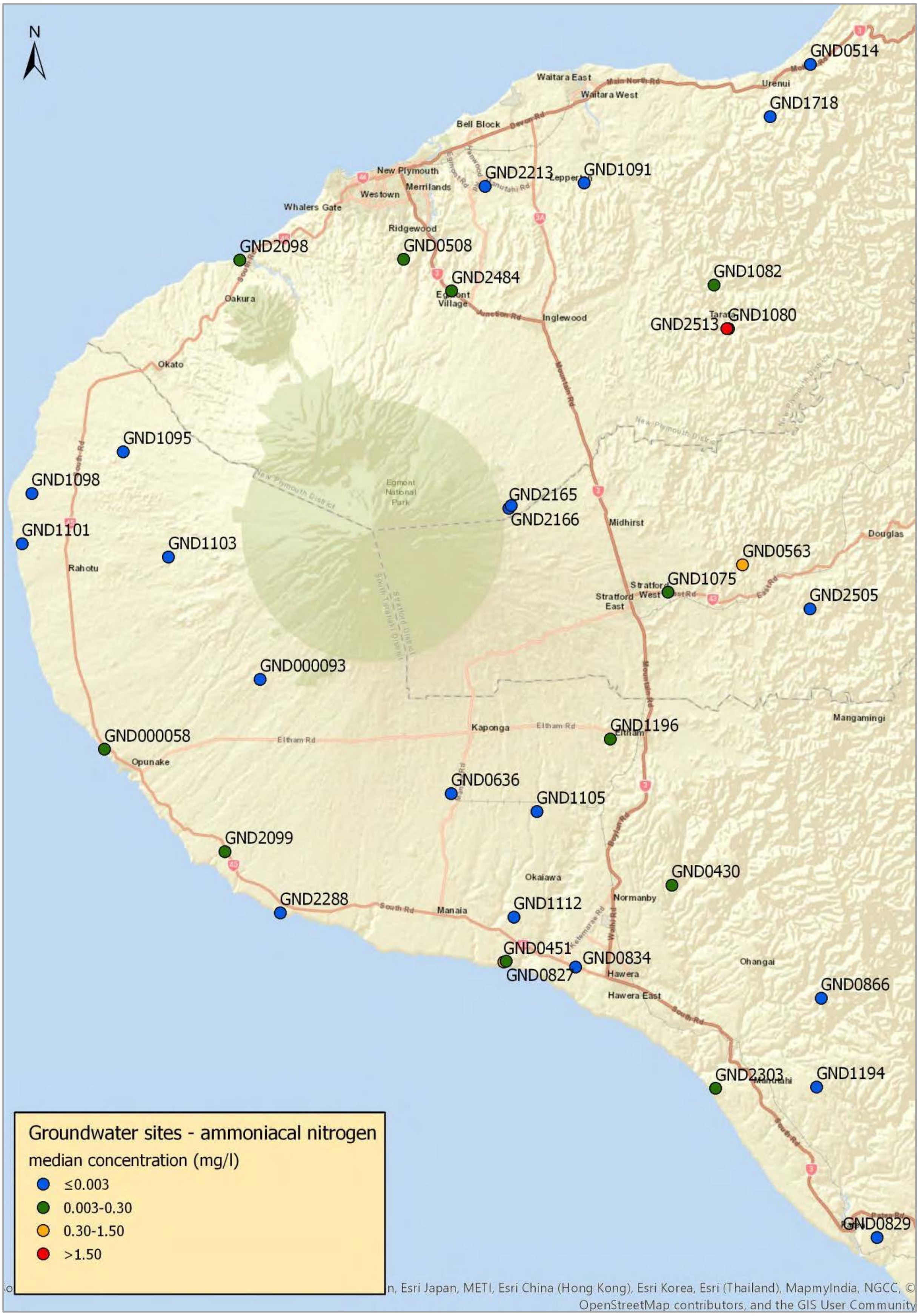

Figure 20 Regional overview of ammoniacal nitrogen concentrations in monitored wells.

## 5.6. Nitrate ($NO_3$)

The SGWM network was set up primarily for the monitoring of nitrate concentrations in shallow groundwater, building on previous state of the environment monitoring programmes specifically designed for this purpose. The focus on nitrate recognised concerns at a national level over the potential for nitrate levels to increase in areas of intensive animal husbandry, fertiliser use, and irrigation.

Shallow unconfined groundwater systems are those most susceptible to inputs from land use activities, and therefore the analysis of nitrate concentrations in groundwater across Taranaki focusses on wells drawing water from these aquifers. A total of 32 sites included in this programme draw groundwater from shallow unconfined aquifers, comprised of 30 sites in the SGWM network and two in the NGMP network. The hydrogeological characteristics of the region's deeper, confined aquifer systems naturally limits the presence of nitrate within them, in addition to the biogeochemical processes which remove nitrate under prevailing anoxic groundwater conditions.

The main sources of nitrate in groundwater are those associated with agricultural land use. The leaching of nitrate to groundwater has the potential to result in subsequent adverse environmental and health effects. The major environmental effect associated with nitrate leaching is the nutrient enrichment of hydraulically connected surface waters, in which nitrate can contribute to the proliferation and abundance of periphyton and undesirable algal growth. This can reduce the amenity value of the water body and adversely affect its ecological health. Nitrate also has the potential to be toxic to sensitive fish species at high concentrations.

High nitrate concentrations also pose a risk to human health. The risk is greatest for bottle fed infants, with consumption of high nitrate water being linked (although rarely) to cases of methaemoglobinaemia (blue baby syndrome), a potentially fatal condition that limits the ability of blood to effectively release oxygen. The MAV for nitrate is set at a threshold designed to protect against this condition.

A summary of the results of nitrate concentration monitoring across all 32 SGWM network sites is presented in Table 11, with sites ordered by their median nitrate concentration. The range in measured concentrations is illustrated in Figure 21.

Table 11 Summary of nitrate monitoring results (2002-2016) (as mg/L $NO_3$-N)

| Site | Sample n. | Min. | Max. | Std. dev. | Median |
|---|---|---|---|---|---|
| GND1112 | 26 | 8.73 | 27.70 | 19.80 | 20.85 |
| GND1101 | 25 | 5.72 | 30.30 | 11.60 | 11.60 |
| GND1105 | 25 | 3.22 | 18.20 | 9.61 | 8.53 |
| GND0636 | 11 | 6.32 | 14.40 | 8.24 | 7.67 |
| GND0829 | 25 | 3.94 | 9.56 | 6.59 | 6.71 |
| GND2288 | 12 | 3.87 | 6.79 | 5.35 | 4.99 |
| GND1082 | 25 | 1.33 | 6.76 | 4.60 | 4.78 |
| GND2303 | 8 | 0.07 | 9.65 | 4.55 | 4.46 |
| GND1196 | 11 | 2.50 | 7.38 | 3.74 | 3.55 |
| GND1103 | 24 | 2.86 | 6.64 | 3.81 | 3.43 |
| GND0514 | 7 | 2.61 | 5.04 | 3.68 | 3.20 |
| GND0834 | 51 | 0.56 | 7.88 | 3.69 | 3.16 |
| GND000093 | 8 | 2.57 | 3.71 | 3.03 | 2.95 |
| GND0827 | 40 | 1.25 | 4.88 | 2.53 | 2.41 |

| Site | Sample n. | Min. | Max. | Std. dev. | Median |
|---|---|---|---|---|---|
| GND1194 | 25 | 1.59 | 14.20 | 2.91 | 2.40 |
| GND0866 | 7 | 2.17 | 4.05 | 2.59 | 2.37 |
| GND1095 | 25 | 1.14 | 3.30 | 2.20 | 2.12 |
| GND2505 | 6 | 1.94 | 2.22 | 2.08 | 2.09 |
| GND2166 | 6 | 1.02 | 13.70 | 3.86 | 2.03 |
| GND2213 | 12 | 1.20 | 2.77 | 2.03 | 1.98 |
| GND2098 | 8 | 1.35 | 2.20 | 1.92 | 1.95 |
| GND1091 | 25 | 1.65 | 2.82 | 2.08 | 1.91 |
| GND1718 | 7 | 0.71 | 2.64 | 1.64 | 1.78 |
| GND1098 | 25 | 0.33 | 6.48 | 2.14 | 1.72 |
| GND1075 | 25 | 0.48 | 4.68 | 1.46 | 1.09 |
| GND2099 | 12 | 0.31 | 4.02 | 1.19 | 0.93 |
| GND0508 | 12 | 0.30 | 0.78 | 0.47 | 0.40 |
| GND000058 | 8 | 0.04 | 5.58 | 1.06 | 0.33 |
| GND2484 | 8 | 0.23 | 0.40 | 0.32 | 0.32 |
| GND1080 | 21 | 0.01 | 0.54 | 0.21 | <0.01 |
| GND2165 | 1 | 0.26 | 0.26 | n/a | n/a |
| GND2513 | 1 | <0.01 | <0.01 | n/a | n/a |

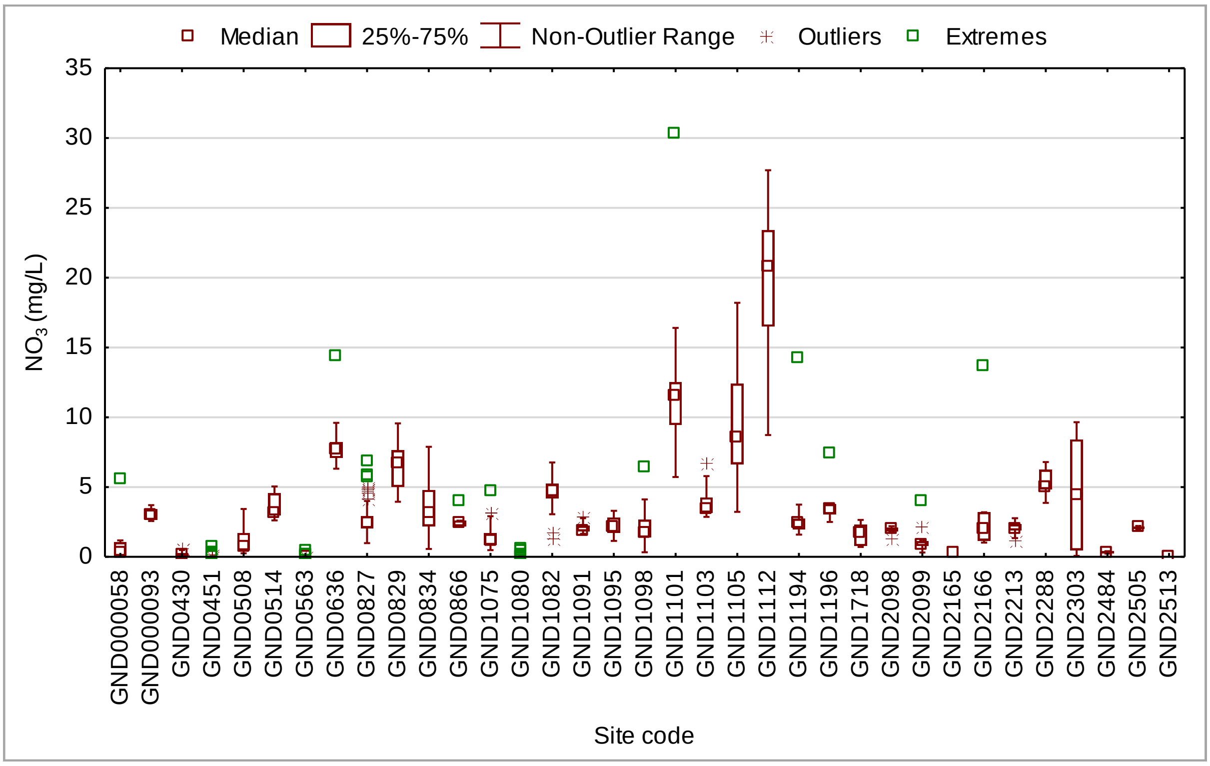

Figure 21 Comparison of measured nitrate concentrations at all monitored sites

The results show that the highest concentration of nitrate is found at sites GND1112 (20.85 mg/L) and GND1101 (11.6 mg/L).

Median nitrate concentrations <1 mg/L were recorded at five sites, GND1080, GND2484, GND000058, GND0508 and GND2099. Of these sites, GND1080 is strongly reducing, resulting in removal of nitrate from groundwater at that location. GND2484 shows indications of being temporarily reduced, and is located in a relatively low intensity land use environment, as are sites GND0508 and GND2099.

Highest nitrate concentrations are generally found in areas of the region where land use intensification is at its highest, including the southern Taranaki ring plain and marine terrace area (Figure 22).

Overall, of the 532 samples analysed and reported on, 50 exceeded the MAV for nitrate (9.4%). A total of six sites recorded at least one exceedance of the MAV over the course of the monitoring record. A summary of the MAV exceedances at these six sites is presented in Table 12.

The data presented shows that 96% of all samples taken at site GND1112 exceeded the MAV for nitrate. Exceedances at this one site account for half of all exceedances recorded across all sites monitored across the region. Site GND1101 accounted for a further 28% of the total number of exceedances across all sites monitored, with 56% of all samples taken at the sites exceeding the MAV. Thirty-two percent of samples taken at site GND1105 also exceeded the MAV for nitrate, accounting for a further 16% of the total number of exceedances recorded across all monitored sites. Exceedances at these three sites accounted for 94% of all exceedances of the MAV recorded across all sites. A single exceedance of the MAV has been recorded at sites GND0636, GND1194 and GND2166.

Table 12 Summary of nitrate MAV exceedances over the course of the monitoring record

| Site | Total no. of samples taken at site | No. of samples exceeding MAV | % of samples taken at site exceeding MAV | % of total MAV exceedances across all sites |
|---|---|---|---|---|
| GND1112 | 26 | 25 | 96 | 50 |
| GND1101 | 25 | 14 | 56 | 28 |
| GND1105 | 25 | 8 | 32 | 16 |
| GND0636 | 11 | 1 | 9 | 2 |
| GND1194 | 25 | 1 | 4 | 2 |
| GND2166 | 6 | 1 | 17 | 2 |

Median nitrate concentrations at the worst two sites, GND1112 and GND1101, exceed the MAV for nitrate set out in the DWSNZ (11.3 mg/L as $NO_3$-N). In comparison, 25 monitored sites (84%) had median nitrate values less than half of the MAV, and a further three sites (10%) recorded median values over half, but not exceeding the MAV (Table 13).

Table 13 Median nitrate values at all sites in comparison to MAV

| Measure | Number of sites | % of all sites |
|---|---|---|
| 0-25% of MAV | 17 | 57 |
| 25-50% of MAV | 8 | 27 |
| 50-75% of MAV | 2 | 7 |
| 75-100% of MAV | 1 | 3 |
| Sites exceeding MAV | 2 | 7 |

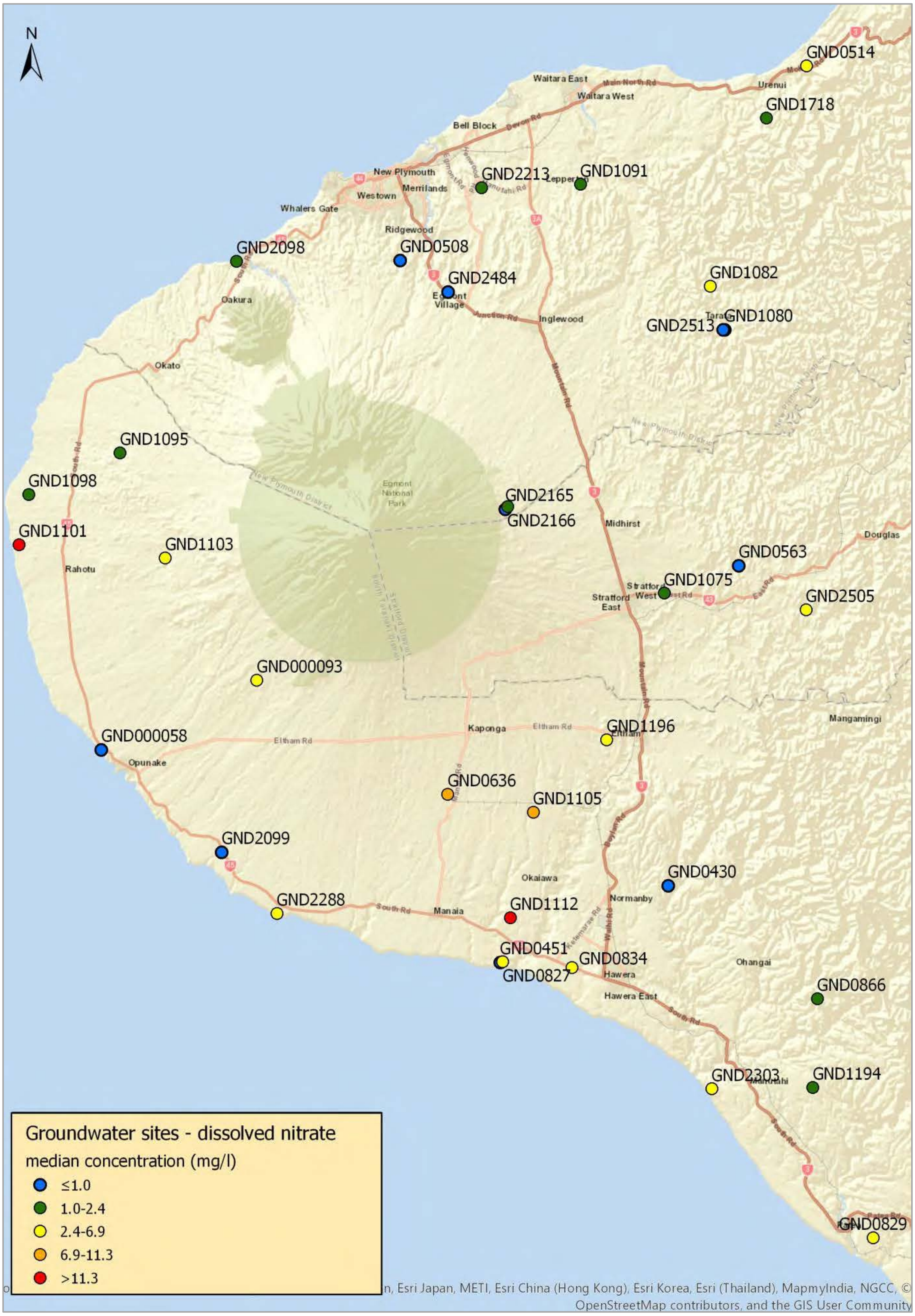

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Figure 22 Regional overview of nitrate concentrations in monitored wells.

Groundwater nitrate concentrations across all sites also show variability by season. A summary of seasonal nitrate concentrations across all sites over the course of the monitoring record is presented in Table 14. The data presented shows that the highest proportion of sites (33%) recorded their highest median concentrations during autumn, with a similar number of sites recording their highest median concentrations in winter. Highest median concentrations are generally linked to seasonal rainfall variations, which dictate the rates of both nutrient leaching and uptake. As a result, the lowest median nitrate concentrations are seen in summer samples. Twelve sites (40%) have also recorded their peak maximum concentrations in autumn. During summer months rainfall volumes are generally low, resulting in limited soil drainage and groundwater recharge. During dry periods, plant uptake of nitrogen also decreases. As a result, nitrate can accumulate in the soil profile and in the unsaturated zone overlying the seasonal water table. As rainfall volumes increase through autumn, soil drainage and groundwater recharge commences, transporting stored nitrate into the groundwater system. As a result, peak nitrate concentrations are often observed during autumn.

Table 14 Summary of seasonal variations in nitrate concentrations at all sites

| Season | No. of sites recording maximum concentration in season | % of all sites | No. of sites recording highest median concentration in season | % of all sites |
|---|---|---|---|---|
| Autumn | 12 | 40 | 10 | 33 |
| Winter | 7 | 23 | 9 | 30 |
| Spring | 8 | 27 | 6 | 20 |
| Summer | 3 | 10 | 5 | 17 |

As discussed earlier, the majority of datasets from SGWM network monitoring sites are unsuitable for trend analysis, given the relatively short length of data records. In total, only 14 of the 32 SGWM sites monitored have data records of suitable length (seven years) to provide an indication of trends in nitrate concentrations at a particular site. The methodology used in the trend analysis was detailed in Section 3.4.

The results of the trend analysis show that significant and meaningful trends in nitrate concentration are apparent at seven of the 14 sites assessed. Of these seven sites, four sites showed improvement (reduction) in nitrate concentration. Nitrate concentrations have deteriorated (increased) at the remaining three sites. The results of the trend analysis for the seven sites where statistically significant and environmentally meaningful trends were identified are presented in Table 15 and illustrated in Figure 23.

Table 15 Summary of seasonal variations in nitrate concentrations at all sites

| Site | P-value | Median Sen slope (annual) | Percent annual change (%) | Trend direction |
|---|---|---|---|---|
| GND0834 | 0.0015 | -0.1716 | -5.4291 | Improving |
| GND1075 | 0.0047 | -0.0896 | -8.2159 | Improving |
| GND1095 | 0.0101 | -0.0969 | -4.5713 | Improving |
| GND1101 | 0.0028 | -0.3406 | -2.936 | Improving |
| GND0827 | 0.0017 | 0.0768 | 3.1884 | Deteriorating |
| GND1091 | 0.0095 | 0.028 | 1.4648 | Deteriorating |
| GND1112 | 0.0009 | 0.6558 | 3.1454 | Deteriorating |

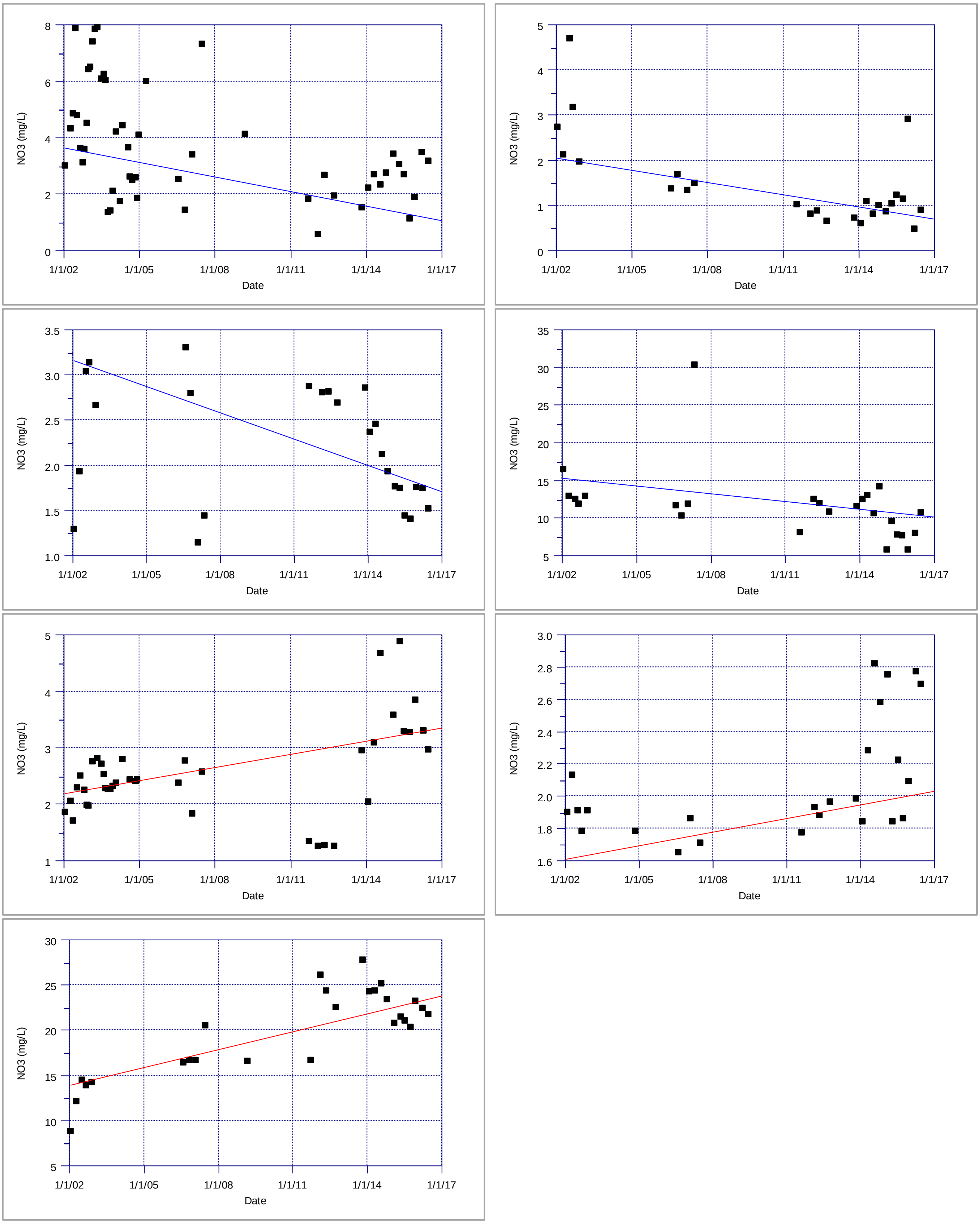

Figure 23 Plots indicating improving trends in nitrate concentration at sites (clockwise from top left) GND0834, GND1075, GND1095 and GND1101; and deteriorating trends at sites GND0827, GND1091 and GND1112

Further analysis of data from the 14 sites shows that the greatest number of these sites recorded both their highest maximum and median nitrate concentrations during the 2002-2003 monitoring year. The number of sites recording peaks in either measure then reduced year on year through to the 2011-2012 period, where no sites recorded either peak median or maximum concentrations. Since 2011-2012, the number of sites recorded either a peak median or maximum value has increased again, with the same number of sites recording their peak maximum nitrate concentrations during the 2014-2015 and 2015-2016 periods, as did in the 2002-2003 period (Table 16 and Figure 24).

Table 16 Historical comparison of measured nitrate concentrations

| Monitoring period | No. of sites recording maximum concentration | % of all sites | No. of sites recording highest median concentration | % of all sites |
|---|---|---|---|---|
| 2001-2002 | 2 | 14 | 4 | 29 |
| 2002-2003 | 3 | 21 | 5 | 36 |
| 2006-2007 | 2 | 14 | 0 | 0 |
| 2011-2012 | 0 | 0 | 0 | 0 |
| 2013-2014 | 1 | 7 | 1 | 7 |
| 2014-2015 | 3 | 21 | 2 | 14 |
| 2015-2016 | 3 | 21 | 2 | 14 |

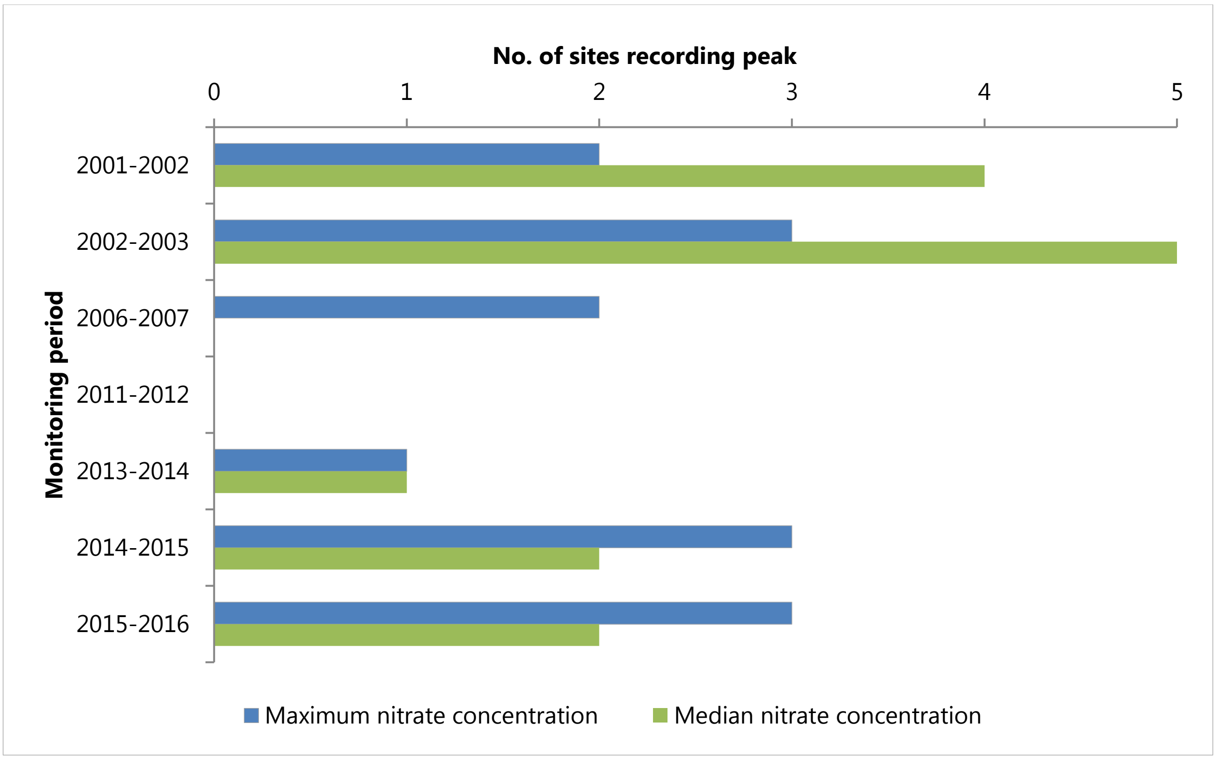

Figure 24 Maximum and median nitrate concentration by monitoring year

Median nitrate concentration across all samples obtained across the 14 sites during each monitoring period is presented in Figure 25. As expected, the data presented shows a similar pattern to that presented in the preceding figure, showing that the highest median nitrate concentration across all 14 sites of 4.11 mg/L was recorded in the 2002-2003 monitoring year. The lowest median nitrate concentration across all sites was recorded in the 2011-2012 monitoring period at 2.67 mg/L. The median nitrate concentration has increased slightly over each of the following three monitoring periods, culminating in a median value of 3.4 mg/L for the 2015-2016 period.

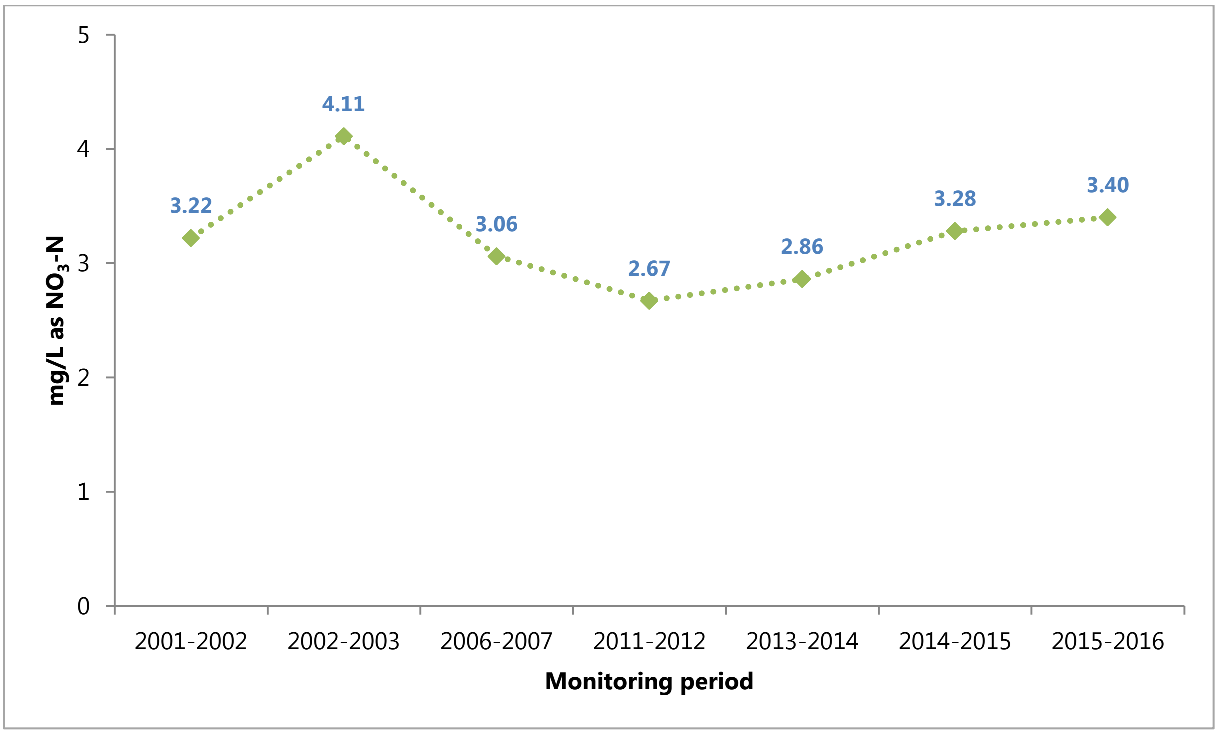

Figure 25 Median nitrate concentrations from the subset of sites sampled over seven monitoring periods

### 5.6.1. Summary

- The leaching of nitrogen from intensive agricultural land use is the main source of nitrate in groundwater systems.
- Median nitrate concentrations exceed the MAV at two sites. In comparison, 25 monitored sites (84%) had median nitrate values less than half of the MAV.
- Highest nitrate concentrations (both maximum and median values) are typically found during autumn and the lowest during summer.
- Of 14 sites assessed for trends in nitrate concentrations, four show significant and meaningful improvement (reduction) and three show deterioration (increase) in nitrate concentrations.
- The highest number of sites recorded either their peak median or maximum nitrate concentration in the 2002-2003 monitoring period, before reducing through to the 2011-2012 period. Since 2011-2012, the number of sites recording peaks in either measure has increased.
- The annual median nitrate concentrations across all the14 sites used in the trend analysis has increased steadily from 2.67 mg/L in 2011 to 3.40 mg/L at the end of 2016, but remains below the peak median of 4.11 mg/L recorded in the 2002-2003 period.

## 5.7. Escherichia coli (*E.coli*)

Bacteriological monitoring is undertaken across all SGWM network sites, with *E. coli* the primary bacterium used to assess the bacteriological state of groundwater. *E.coli* bacteria are commonly found in the lower intestine of warm-blooded organisms and discharged into the environment through faecal matter. *E.coli* is therefore used as an indicator for potential faecal contamination, which may also result in the presence of pathogenic bacteria, protozoa and/or viruses which can cause gastrointestinal illnesses. The DWSNZ sets out a MAV for *E.coli* of <1 CFU/100ml, for health protection purposes. The basis for this MAV being that the detection of any *E.coli* in water indicates some form of faecal contamination, and the potential presence of associated pathogens.

There are numerous potential sources of *E.coli* bacteria, including human, ruminant and avian faecal matter. In terms of potential groundwater contamination, discharges associated with agricultural land use and wastewaters (i.e. septic tanks) are the most likely contributors. In most environmental settings, soils provide effective attenuation of microbes, protecting underlying groundwater from contamination. In some cases however, preferential flow pathways allow microbes to rapidly by-pass the soil zone before entering groundwater. Preferential pathways can form naturally as a result of soil cracking under dry weather conditions, and the development and migration of plant roots and soil fauna. Preferential pathways can also be created by poorly constructed and/or poorly sealed wells and bores, soil drainage measures or other physical modification of the land surface. In addition, hydraulically connected surface waters can also provide a transport pathway for microbes to enter groundwater, particularly when groundwater is pumped for abstraction purposes.

A summary of the results of *E.coli* monitoring across all 32 SGWM network sites is presented in Table 17, with sites ordered by their median *E.coli* concentration. The results show that nine sites (28%) have median *E.coli* counts exceeding the MAV, with the highest median counts recorded at sites GND1082 and GND1103. Of the 419 samples analysed for *E.coli* at the 32 monitored sites being reported on, *E.coli* has been detected in 157 of them (37%).

Table 17 Summary of *E.coli* monitoring results across all sites (2004-2016) (reported as CFU/100 mL)

| Site | Construction | Sample n. | *E.coli* detections | % of sample n. | Min. | Max. | Median |
|---|---|---|---|---|---|---|---|
| GND1082 | Dug - unlined | 20 | 18 | 90 | <1 | 12,000 | 31 |
| GND1103 | Dug - unlined | 19 | 13 | 68 | <1 | 2,200 | 16 |
| GND000058 | Driven pipe - open ended | 8 | 6 | 75 | <1 | 140 | 5 |
| GND2098 | Drilled - screened | 8 | 5 | 63 | <1 | 75 | 4 |
| GND1080 | Dug - lined | 16 | 9 | 56 | <1 | 120 | 2 |
| GND1105 | Dug - lined | 20 | 12 | 60 | <1 | 940 | 2 |
| GND0827 | Dug - unlined | 19 | 10 | 53 | <1 | 52 | 1 |
| GND0829 | Bored or augered - unlined | 20 | 10 | 50 | <1 | 93 | 1 |
| GND2099 | Dug - unlined | 12 | 6 | 50 | <1 | 55 | 1 |
| GND000093 | Dug - lined | 8 | 1 | 13 | <1 | 48 | <1 |
| GND0508 | Drilled - screened | 12 | 3 | 25 | <1 | 33 | <1 |
| GND0514 | Dug - lined | 7 | 2 | 29 | <1 | 240 | <1 |
| GND0636 | Drilled - screened | 11 | 2 | 18 | <1 | 10 | <1 |
| GND0834 | Bored or augered - unlined | 20 | 7 | 35 | <1 | 20 | <1 |

| Site | Construction | Sample n. | *E.coli* detections | % of sample n. | Min. | Max. | Median |
|---|---|---|---|---|---|---|---|
| GND0866 | Bored or augered - lined | 7 | 1 | 14 | <1 | 2 | <1 |
| GND1075 | Dug - lined | 20 | 3 | 15 | <1 | 59 | <1 |
| GND1091 | Dug - lined | 20 | 3 | 15 | <1 | 8 | <1 |
| GND1095 | Dug - lined | 20 | 9 | 45 | <1 | 70 | <1 |
| GND1098 | Dug - lined | 20 | 8 | 40 | <1 | 1,600 | <1 |
| GND1101 | Dug - lined | 20 | 5 | 25 | <1 | 210 | <1 |
| GND1112 | Dug - unlined | 20 | 6 | 30 | <1 | 2 | <1 |
| GND1194 | Dug - lined | 20 | 7 | 35 | <1 | 100 | <1 |
| GND1196 | Drilled - screened | 11 | 2 | 18 | <1 | 1 | <1 |
| GND1718 | Bored or augered - unlined | 7 | 0 | 0 | <1 | <1 | <1 |
| GND2166 | Drilled - screened | 6 | 0 | 0 | <1 | <1 | <1 |
| GND2213 | Dug - lined | 12 | 3 | 25 | <1 | 59 | <1 |
| GND2288 | Drilled - screened | 12 | 1 | 8 | <1 | 44 | <1 |
| GND2303 | Drilled - screened | 8 | 1 | 13 | <1 | 3 | <1 |
| GND2484 | Drilled - screened | 8 | 0 | 0 | <1 | <1 | <1 |
| GND2505 | Dug - unlined | 6 | 2 | 33 | <1 | 120 | <1 |
| GND2513 | Drilled - screened | 1 | 1 | 100 | 20 | 20 | n/a |
| GND2165 | Drilled - screened | 1 | 1 | 100 | 3 | 3 | n/a |

Further analysis of *E.coli* data has been carried out to assess seasonal variations in measured concentrations (Table 18).

Table 18 Summary of seasonal variations in *E.coli* concentrations at all sites

| Season | Total number of detections | No. of sites recording maximum concentration in season | % of all sites | No. of sites recording highest median concentration in season (where median >0) | % of all sites |
|---|---|---|---|---|---|
| Autumn | 49 | 12 | 41 | 11 | 48 |
| Winter | 38 | 10 | 34 | 7 | 30 |
| Spring | 30 | 1 | 3 | 0 | 0 |
| Summer | 40 | 6 | 21 | 5 | 22 |

The analysis shows that *E.coli* concentrations have been detected across all four seasons. The number of detections is greatest in autumn, and this is also the season in which the greatest numbers of sites have recorded their highest maximum and median *E.coli* concentrations. Winter is only the third ranked season in terms of the numbers of *E.coli* detections, but it is the second ranked season in terms of the number of sites recording their highest seasonal maximum and median concentrations. The second greatest number of *E.coli* detections has been recorded during summer, but significantly fewer sites have recorded peak seasonal maximum and median concentrations during these months, indicating that measured concentrations are generally lower during this period. The least number of *E.coli* detections have been made during spring, with only a single site recording its peak *E.coli* concentration during this season. No site has recorded a peak seasonal median *E.coli* concentration during spring.

The SGWM network wells sampled for *E.coli* vary in their respective construction, from purpose built drilled and screened monitoring wells, to unlined dug wells. The wells included in the programme represent the cross section of well types present across the region. An analysis has been undertaken to assess the variation in *E.coli* concentrations by well construction type (Table 19). Two well types represented by only a single site (classified as bored or augered - lined and driven pipe - open ended) have been excluded from the analysis.

The analysis shows that unlined dug wells have the highest proportion of samples exceeding the MAV for *E.coli* (57%). This subgroup of wells also has the highest median *E.coli* concentration. Samples from lined dug wells also have a high MAV exceedance rate at 34%, and the second highest median *E.coli* concentration at 6 CFU/100ml. Cumulatively, 42% of samples obtained from dug wells, be they lined or unlined, have exceeded the MAV for *E.coli*. Samples obtained from unlined bored or augered wells exceed the MAV at a rate at 36%. Samples from drilled and screened wells have recorded the lowest rate of MAV exceedance (21%), and also account for the lowest median *E.coli* construction of any well type monitored.

Dug and unlined bored or augured wells are generally less isolated from the potential ingress of surface runoff and shallow soil water throughflow during rainfall events than drilled and screened wells. Therefore, the likely flow paths for bacteria entering each well type are likely to differ, as is the concentration of *E.coli* observed. When comparing results for each well type, it is evident that the number of *E.coli* detections, and median and maximum concentrations observed in dug and unlined bored or augured wells, exceeds those in drilled and screened wells. This is indicative of bacterial sources derived from localised surface or shallow soil throughflow in dug and unlined bored or augured wells. The six sites that recorded their peak maximum *E.coli* concentrations in summer, when the leaching losses are assumed to be at their lowest, were all dug or unlined wells. This is suggestive of bacteria entering these dug and unlined wells via an overland flow path, as is the number of overall detections recorded during summer months. The results from samples obtained from drilled and screened wells are assumed to be more representative of *E.coli* counts at the water table. Only one drilled and screened well (GND2098) had a median *E.coli* concentration exceeding the MAV. At this site, livestock (horses) are able access the top of the well, and are suspected to be the source of the *E.coli* detected.

Table 19 Summary of *E.coli* concentrations by well construction type

| **Well construction** | **No. of type** | **% of total sites** | **sample n.** | ***E.coli* detections** | **% of sample n.** | **Max.** | **Median** |
|---|---|---|---|---|---|---|---|
| Bored or augered - unlined | 3 | 9 | 47 | 17 | 36 | 93 | 5 |
| Drilled - screened | 10 | 31 | 78 | 16 | 21 | 75 | 4 |
| Dug - lined | 11 | 34 | 183 | 62 | 34 | 1,600 | 6 |
| Dug - unlined | 6 | 19 | 96 | 55 | 57 | 1,200 | 13 |

### 5.7.1. Summary

- *E.coli* is used as an indicator of the faecal contamination of water and can enter groundwater through leaching, or via preferential flow paths created naturally or by physical alteration of the land surface.
- Of the 419 samples analysed for *E.coli* across the monitoring record, *E.coli* detections have been recorded in 157 (37%).
- Nine sites (28%) have median E.coli concentrations that exceed the MAV.

- The well construction type and adequacy of wellhead protection have the greatest influence on *E.coli* concentrations at shallow groundwater monitoring sites.
- Overland flow or shallow soil water throughflow the primary transport pathway for *E.coli* entering monitored wells, as opposed to leaching and natural subsurface percolation.
- The strong relationship between the type of well and measured E.coli concentration suggests that the well itself is the pathway of contamination in the majority of cases, rather than the results being indicative of more widespread aquifer contamination.

# 6. Discussion

## 6.1. General groundwater quality

Groundwater quality across Taranaki is driven by both natural and anthropogenic influences. The observed composition of groundwater varies in response to the occurrence and magnitude of these influences, both spatially and with depth. These influences may be diffuse (widespread) or highly localised in some cases.

Aquifer depth and groundwater residence time (age) are generally closely correlated. Groundwater that remains in an aquifer for longer periods of time has greater interaction with aquifer sediments and dissolves more minerals from them along its flow path. As a result, water contained in deeper, confined aquifers in Taranaki, which includes the Whenuakura and Matemateaonga Formation aquifers, typically have a higher mineral content than water in the region's shallow, unconfined aquifers.

In shallow, unconfined groundwater systems, the salinity of groundwater is generally higher at locations close to the coast. Rainwater in coastal areas generally contains higher concentrations of sodium and chloride than that which falls further inland and, given the recharge of shallow groundwater is generally from localised rainfall, this is reflected in the observed groundwater salinity. Salt deposition from sea spray can also contribute to increased groundwater salinity in coastal areas. Across Taranaki, shallow costal sites located in the Taranaki volcanics and marine terrace aquifers typically display the highest groundwater salinities, which are reflected in their EC values. The concentration of sodium and chloride in groundwater sampled in the region's shallow groundwater systems generally plot along the SWDL, indicating marine derived salinity. Groundwater sampled in the region's deeper aquifers generally plots below the SWDL, indicating the input of additional sodium from geological sources within the aquifer itself.

There is evidence of increased EC values at some shallow groundwater monitoring locations as a result of specific land use activities. This is most prevalent at two monitoring sites located within the operational boundaries of drilling waste bioremediation sites. The increased EC values at these locations are due to the leaching of highly mobile salts from the waste material. This is not unexpected given the nature of the land use activity, which is authorised by resource consents at a small number of sites in the region. Elevated EC values are also found at some shallow groundwater monitoring sites located in intensively farmed areas, likely due to the leaching of salts contained in animal effluent (urine). The dissolution of sodium bearing geological material has also influenced EC values at two shallow groundwater monitoring locations.

Redox related processes represent the most significant natural process influencing groundwater quality in Taranaki. These processes influence the composition of groundwater across the region and are also responsible for a number of the trends detected in analyte concentrations. The redox state of groundwater also influences the effects of land use activities on groundwater quality, most notably the impact of nitrate leaching, which is discussed in further detail below.

In the region's deeper, confined aquifers, low levels of dissolved oxygen promote the removal of nitrate and the reduction of iron and manganese to more soluble forms. Any nitrogen entering, or generated within these aquifer systems is present in the form of ammoniacal nitrogen. As a result, groundwater obtained from wells intersecting these aquifers is likely to contain very little nitrate, but elevated concentrations of iron, manganese and ammoniacal nitrogen.

While less common across Taranaki, anoxic conditions can also exist in shallow groundwater systems. As detailed in the report, the Council has initiated investigations to assess redox gradients and the spatial distribution of reduced shallow groundwater in the region, but to date have been unable to definitively link any physical commonalities across sites where reduced conditions prevail. Investigations to date suggest that the occurrence of reduced shallow groundwater is spatially sporadic. Given the complex and highly heterogeneous nature of the geological setting and associated depositional processes across Taranaki, this is not unexpected. Where reduced conditions do exist in shallow groundwater, extremely low nitrate concentrations are generally encountered, alongside elevated concentrations of iron, manganese and ammoniacal nitrogen.

The impact of reduction processes on groundwater quality and its overall usability are primarily related to aesthetic measures, although the DWSNZ does set out a health related MAV for manganese. Aesthetic effects include odour generated by ammoniacal nitrogen, and the staining of tapware and laundry fixtures by iron and manganese. In addition, elevated iron concentrations can also result in the appearance of coloured flocs in surface water systems, or in areas of groundwater discharge. Up to 97% of monitored sites meet the GVs set out in the DWSNZ for both iron and manganese, while median manganese concentrations exceed the MAV at two sites (6%).

SGWM network sites are more susceptible to adverse effects associated with land use activities. Agricultural land use, or more specifically dairy farming, is the predominant land use across areas monitored as part of this programme. As a result, nitrate concentrations at shallow monitoring sites generally show the impact of nutrient leaching associated with this land use. Median nitrate concentrations at monitored sites range from <1 mg/L to 20.85 mg/L (as $NO_3$-N). In terms of MAV compliance, 25 sites (84%) have median nitrate concentrations below 50% of the MAV. Overall, 94% percent of sites are compliant with the MAV. A total of two sites (6%) have median nitrate concentrations that exceed the MAV. The implications of MAV exceedances relate to potential health risk, and are discussed further in Section 6.2.

The analysis of the nitrates data set indicates that nitrate concentrations found around the region are generally low, but there are indications of land use impacts at some sites, particularly in wells intersecting highly oxidised groundwater. Daughney and Reeves (2005) suggest that concentrations of nitrate >1.6 mg/L indicate probable impacts of anthropogenic effects, while concentrations >3.5 mg/L are almost certainly indicative of human impact. Using these metrics to provide context, median nitrate concentrations at 15 monitored sites (47%) indicate probable human impact, while a further nine sites (28%) display more definitive effects. Given the bias of the monitoring network toward areas of the region where intensive agricultural land use predominates, this is to be expected.

In terms of potential environmental effects, median nitrate concentrations at each site have been compared against the nitrate toxicity attribute set out in the NPS-FM (2014). Median concentrations at 28 monitored sites (87%) are below (better than) the national bottom line for nitrate toxicity. Given that groundwater will generally only contribute a portion of flow to surface waters, and allowing for the attenuation and dilution of nitrate along the groundwater flow path and within the stream itself, it is not expected that the concentrations of nitrate generally seen across the region present a significant toxicity risk to sensitive instream species. It should be noted however that much lower concentrations of nitrate can also promote the growth and proliferation of instream plants and algae, and the associated impacts on water quality that accompany it, under some specific circumstances. The impact of groundwater nitrate contributions to instream nitrate loads is significantly influenced by the amount of attenuation within the groundwater system and instream dilution.

Trend analysis of nitrates data was carried out for 14 of the 32 SGWM sites. The number of sites where trend analysis was possible was limited by the length of available data records. Each of the 14 sites had a minimum of seven years' data available for trending. Of the 14 sites assessed, four showed statistically significant and meaningful improvement (reduction) in nitrate concentrations, while three sites showed deterioration (increases). Trends were indeterminate at the remaining seven sites.

A further temporal analysis of nitrates data was undertaken for the same 14 SGWM sites used in the trend analysis. The results indicate that the highest number of sites recorded their peak maximum and median nitrate concentrations during the 2002-2003 monitoring period. The median nitrate concentration across the entire subgroup of sites included in this analysis peaked during the same period, at 4.11 mg/L. No sites recorded either maximum during the 2011-2012 period, and the median nitrate concentration across all sites during this period of 2.67 mg/L is the lowest on record. Between 2011 and 2016, a total of seven sites recorded their peak maximum nitrate concentration and five their highest median value. Over the same period, the median concentration across all monitored sites has risen slightly year on year to 3.4 mg/L at the conclusion of the most recent monitoring period being reported (2015-2016).

The analysis of trends in the nitrates dataset indicates that more sites are displaying improvements in nitrate concentrations than are showing deterioration. Overall however, median nitrate concentrations across all regularly monitored sites (minimum seven year data record) have increased year on year from 2011 to 2016, after reducing between 2002 and 2011. The increase in median nitrate concentrations coincides with an increase in dairy production across the Taranaki region from 2011, which peaked in the 2014-2015 season (Figure 4).

Comparisons of the regional nitrate dataset against those collected by other regional councils are difficult to make, given that most monitoring networks are not specifically designed to focus on shallow groundwater, as is the case in Taranaki. For context however, 13% of sites monitored as part of the National Groundwater Monitoring Programme (NGMP) had nitrate results exceeding the MAV on more than one occasion between 2012 and 2014, as reported in the '*Our Freshwater Report*' (MfE, 2017). The NGMP network includes both deep and shallow groundwater monitoring wells. In comparison, the Council's dedicated SGWM network had six sites (19%) recording a MAV exceedance between 2002 and 2016. This represents an encouraging result, given the greater susceptibility of shallow groundwater to contamination by land use activities.

Measured concentrations of *E.coli* in shallow groundwater also indicate some impact associated with land use activities. Data collected shows that *E.coli* has been detected in 37% of all samples obtained from the monitoring network. Any detection of *E.coli* constitutes a MAV (drinking water) exceedance. Median *E.coli* concentrations have been found to exceed the MAV at 28% of monitored sites. The implications of MAV exceedances on water potability are discussed further in section 6.2.

The data collected also shows that measured *E.coli* concentrations appear to be correlated with well construction types. The number of *E.coli* detections and maximum and median concentrations found at dug and unlined bore or augured wells, are higher in comparison to those at drilled and screened wells. Total detections in drilled and screened wells only account for 21% of all samples obtained, while the number of detections in dug and unlined well types range from 34% to 57%. Only one drilled and screened well had a median *E.coli* concentration exceeding the MAV, and poor well head protection (livestock exclusion) has been identified as a likely cause at this particular location. As detailed earlier in this report, these results are suggestive of differing bacterial flow paths to respective wells, based on their construction. Overland flow and shallow soil water influences are reflected in higher bacterial concentrations in unlined and dug wells, with the much lower concentrations in drilled and screened wells more representative of bacterial counts at the water table, where bacteria have been filtered and attenuated in the overlying unsaturated zone.

Given the results detailed above, the main factor influencing *E.coli* concentrations measured across the network is well construction, and inadequate wellhead protection or isolation at some monitored locations. The results obtained from drilled and screened monitoring wells indicate much lower rates of detection and concentrations of *E.coli* within the monitored aquifers, with these results deemed a more accurate representation of bacterial concentrations across shallow Taranaki aquifers.

## 6.2. Suitability of groundwater for potable water supply

An assessment of groundwater suitability for potable supply has been made using the MAVs for various analytes of health significance as set out in the DWSNZ. In the majority of cases, the wells used for sampling are not utilised for potable supply, and this is particularly true for SGWM network wells which are generally used for general farm use and/or stock water supply. The assessment also only considers the results of raw water samples, with water still being potentially potable if treated.

MAV exceedances for manganese were recorded at sites GND0451 and GND2513. GND0451 draws highly reduced water from the Whenuakura aquifer, while GND2513 intersects an area of the shallow Taranaki volcanic aquifer, also known to contain highly reduced water. Elevated dissolved manganese concentrations at these locations are a result of natural redox processes within these low oxygen groundwater environments. As a result of these same redox processes, iron and/or ammoniacal nitrogen concentrations at these sites also exceed GVs, making water from these sites potentially unsuitable for potable supply.

A total of two sites have recorded median nitrate concentrations that exceed the MAV. Both sites draw highly oxidised shallow groundwater from the Taranaki volcanics aquifer, in areas of intensive agricultural land use.

A further nine sites drawing highly oxidised water from the shallow Taranaki volcanics and marine terrace aquifers have recorded median *E.coli* concentrations that exceed the MAV. The data indicates that the significantly higher number of *E.coli* detections occur in dug and/or unlined wells. The results suggest that poor well isolation and well head security are the predominant factors influencing bacterial concentrations in monitored wells.

Overall, raw water sampled from 13 of 35 monitored sites (37%) is potentially unsuitable for potable supply, as a result of both natural and anthropogenic influences. The greatest proportions of sites exceeding a MAV value do so based on their *E.coli* concentration. The presence of bacteria in these wells could be reduced by improving the security and isolation of the wellhead from potential ingress of overland and/or shallow soil water throughflow. All well owners are urged to assess their wells for this purpose and upgrade well head protection where required.

Aquifers located within the Whenuakura and Matemateaonga Formation are the most commonly targeted aquifers for potable supply across Taranaki. These aquifers are generally confined, or at least semi-confined, and are therefore more isolated from any impacts associated with overlying land use than shallower, unconfined groundwater systems. Groundwater within these deeper confined aquifers also has a long residence time, meaning it becomes highly reducing as it moves through the aquifer. As a result, there are unlikely to be any potability issues associated with bacteria and nitrate in water abstracted from wells intersecting these aquifers. Given their reducing nature however, issues can arise with regard to manganese and iron concentrations, and these issues are not uncommon in wells targeting the region’s deeper aquifers for potable supply.

# 7. Response

The Council has implemented a number of responses in light of the results obtained through monitoring associated with this programme, and potential water quality issues and/or risks the data has brought to light. These are detailed below.

- The owners of wells monitored through this programme, which are utilised for private supply purposes, are advised of sampling results after each sampling event. This includes advising well owners of any MAV exceedances, noting however that very few of these wells are actually utilised for potable supply.
- A programme of work is underway to address well head security and isolation issues at sites monitored through this programme that consistently exceed the MAV for *E.coli*.
- Investigations are planned to assess *E.coli* transport and survival in vicinity of dug wells to determine the radius of contamination potentially arising from poorly sealed or isolated wells.
- The Council has co-ordinated joint discussions with water supply authorities and the Taranaki District Health Board with regard to public drinking water security, contamination risk and protection. A high level of cooperation between all agencies has been achieved.
- Following on from the above, the Council has undertaken a detailed survey of the Patea groundwater supply catchment to assess the risk posed by poorly constructed and/or abandoned wells, and other activities within the catchment with the potential to result in contamination of the public water supply. The work carried out to date has included identifying the locations of all wells and potential contaminant sources within the catchment, a visual assessments of each site, assessments of well head security, bacteriological and groundwater security assessment sampling and analysis. The results of the survey are being complied, but will conclude that no potential contaminant source within the catchment was identified that currently posed a significant contamination risk to the public supply wells.
- Further surveys of the public groundwater supply catchments in Waverly and Waiinu Beach are planned.
- A programme of catchment surveys are planned for summer 2016-2017, with the objective of identifying all existing wells and bores located within specific catchments. This information will then be used to determine the comprehensiveness of the Council's current groundwater site database and to update details of sites already registered in the database, or enter new records, as required. An assessment of well head security and isolation will be carried out at each site as part of these surveys. Well owners will be provided with results of this work, which will also set out the details of any remedial works required in regard to their well or bore.
- The Council has developed and distributed a document outlining its requirements for good farm management in Taranaki (TRC, 2017). The document outlines a number of Council policies and best practice guidance relating to activities that have the potential to adversely affect groundwater quality.
- The Council continues to develop and implement programmes of compliance monitoring with regard to consents authorising the discharge of contaminants to groundwater, or to land where they may enter groundwater. These programmes also encompass inspections of sites where no direct discharges to land or groundwater occur, but where spillages may occur.

# 8. Recommendations

THAT any of the planned responses outlined in Section 7.0 be implemented as proposed, where not already completed;

THAT dug and/or unlined monitoring sites currently included in the programme be replaced with drilled and screened monitoring wells in similar locations as existing wells (noting recommendation below). Where possible, publically accessible locations should be preferred to private land in order to ensure long-term access to sampling sites;

THAT any replacement of wells at one of the fourteen sites with long term (7 year) data records be made at the same location as existing wells, with the intention of continuing long term data collection at these sites in order to facilitate ongoing trend analysis; and

THAT the range of analyses currently carried out on samples from the SGWM network wells be extended in forthcoming sampling events to include bicarbonate, sodium, chloride and dissolved reactive phosphate.

# Glossary of common terms and abbreviations

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

| | |
|---|---|
| Anisotropic | Different physical properties in all directions. |
| Anoxic | Water that is depleted of dissolved oxygen. |
| Aerobic | Water containing oxygen or a related process requiring oxygen. |
| Aquifer | A permeable water-bearing geological formation through which water moves under natural conditions and which yields water to wells at a sufficient rate to be a practical source of water supply. |
| Bore | Bore means a hole drilled into the ground and completed for the abstraction of water or hydrocarbons to a depth of greater than 20 metres below the ground surface. |
| Confined aquifer | When an impermeable formation, such as clay, overlies an aquifer so that air and water are no longer in contact and the pressure is no longer equal to atmospheric pressure. Water in a well will stand at a different level to the water table. |
| Denitrification | A microbially facilitated process of nitrate reduction. |
| DO | Dissolved oxygen. |
| DWSNZ | Drinking Water Standards for New Zealand 2005 (Revised 2008). |
| *E.coli* | Escherichia coli, an indicator of the possible presence of faecal material and pathological micro-organisms. Usually expressed as colony forming units per 100 millilitre sample. |
| Effluent | Liquid waste including slurries. |
| Electrical conductivity | Conductivity, an indication of the level of dissolved salts in a sample, usually measured at 20°C and expressed in mS/m. |
| GV | Guideline Value (taken from DWSNZ). |
| Heterogeneity | The quality or state being diverse in physical character or content. |
| Heterogeneous | See Heterogeneity. |
| IANZ | International Accreditation New Zealand. |
| Infiltration | The seepage of water into soil or rock. |
| Intervention | Action/s taken by Council to instruct or direct actions be taken to avoid or reduce the likelihood of an incident occurring. |
| Leaching | The loss of mineral and/or organic solutes through percolation. |
| Lithology | The general physical characteristics of a rock or the rocks in a particular area. |
| MAV | Maximum Acceptable Value (taken from DWSNZ). |
| mS/m | Millisiemens per metre. |
| NGMP | National Groundwater Monitoring Programme. |
| $NH_4$ | Ammonium, normally expressed in terms of the mass of nitrogen (N). |
| $NO_3$ | Nitrate, normally expressed in terms of the mass of nitrogen (N). |
| Objective | A statement of a desired and specific environmental outcome. |
| Oxidation state | See Redox. |
| pH | A numerical system for measuring acidity in solutions, with 7 as neutral. Numbers lower than 7 are increasingly acidic and higher than 7 are increasingly alkaline. The scale is logarithmic i.e. a change of 1 represents a ten-fold change in strength. For example, a pH of 4 is ten times more acidic than a pH of 5. |
| Policy | A specific statement that guides or directs decision making. A policy indicates a commitment to a general course of action in working towards the achievement of an objective. |
| Purging | The removal of groundwater from a well or bore prior to obtaining a sample. |
| Recharge | The addition of water from other sources to an aquifer, e.g., seepage from rivers, |

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| | percolation of rainfall. |
| Redox | Redox (reduction-oxidation) reactions include all chemical reactions in which atoms have their oxidation state changed; in general, redox reactions involve the transfer of electrons between species. Oxidation is the loss of electrons or an increase in oxidation state by a molecule, atom, or ion. Reduction is the gain of electrons or a decrease in oxidation state by a molecule, atom, or ion. |
| Reduction processes | See Redox. |
| Residence time | The amount of time water is present within an aquifer between recharge and discharge. |
| Resource consent | Refer Section 87 of the RMA. Resource consents include land use consents (refer Sections 9 and 13 of the RMA), coastal permits (Sections 12, 14 and 15), water permits (Section 14) and discharge permits (Section 15). |
| RFWP | Regional Freshwater Plan for Taranaki (2001). |
| RMA | Resource Management Act 1991 and including all subsequent amendments. |
| SGWM | Shallow groundwater monitoring. |
| Unconfined aquifer | Groundwater which is freely connected to the atmosphere and which is free to rise and fall in the saturated zone, or water of an unconfined aquifer, or water under water table conditions. |
| Water table | The upper level of an underground surface in which the soil or rocks are permanently saturated with water. |
| Well | A hole dug, augured or drilled, tapping the water-table or springs to a depth of 20 metres or less below the ground surface. |
| Yield | The volume of water per unit of time able to be abstracted from a bore or well. |

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