State of the Environment Monitoring Groundwater Chemical Quality 1994-2013

Technical Report 2012-101

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Executive summary

Section 35 of the Resource Management Act 1991 (the RMA) requires local authorities to carry out environmental monitoring to determine the state of the environment in their region or district. The Taranaki Regional Council (the Council) monitors the state of the environment in the region to the extent that enables it to effectively function under the RMA.

As part of its overall State of the Environment Monitoring Programme, the Council monitors the chemical quality of groundwater through participation in the National Groundwater Monitoring Programme, led by GNS Science. As part of this programme, the Council undertakes quarterly sampling of groundwater at five sites, designed to provide samples representative of groundwater from three of the region's major aquifers (Taranaki volcanics, Matemateaonga and Whenuakura). In addition, the Council also undertakes specific programmes of monitoring targeted at assessing shallow groundwater nitrate concentrations and the presence of herbicide and pesticide residues in groundwater across Taranaki. The results of these programmes are reported separately (see bibliography).

The following report summarises the results and findings of the groundwater chemical quality monitoring programme from July 1994 to June 2013. New Zealand does not have specific standards for groundwater as such. Given abstraction of groundwater for human consumption across much of New Zealand, this tends to be the main concerns for purposes of evaluation of groundwater quality (even though such use in Taranaki is minimal). Therefore, the results of sampling carried out have been compared against drinking water quality standards set out by the Ministry of Health in the Drinking Water Standards for New Zealand (2008) (DWSNZ). The DWSNZ sets out Maximum Acceptable Values (MAVs) for a range of chemical parameters of health significance. The DWSNZ define the maximum concentrations of chemicals of health significance (MAVs) in water, that 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). In addition, the DWSNZ also outline a number of Guideline Values (GVs) for a range of chemical parameters based on aesthetic impacts only, whereby any exceedance is related to nuisance value as opposed to a health risk.

During the period being reported, the only MAV exceedance was in relation to manganese concentrations at site GND0451 (Whenuakura aquifer). The elevated concentrations of manganese at this site are a result of natural biochemical processes within the aquifer. Nitrate concentrations at sites located with in the shallow Taranaki volcanics aquifer displayed variability in response to landuse activities, but remained well below MAV levels at all times. Minimal nitrate was detected in across the region's deeper aquifers as a result of microbial reduction processes (denitrification).

Exceedances of GVs for either pH, ammonia, iron and/or manganese were recorded at all monitored sites at various times during the period being reported. Again, the relative concentrations of these analytes are dictated by natural hydrogeological processes. As the GVs are for aesthetic purposes only, exceedance of these values do not present a risk to human health.

Overall, the data collected as part of the groundwater chemical quality programme does not indicate any major issues with the general quality of groundwater at any of the sites monitored. The data indicates that natural subsurface processes are exerting the greatest influence on water quality at each site and there are some temporal trends in the concentrations of certain parameters at some sites as a result of these processes. There is no evidence of any significant deterioration in water quality as a result of any landuse activities.

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1. Introduction

1.1 Background

Groundwater is an extremely valuable resource for the Taranaki region, providing water supply for numerous agricultural, industrial and domestic needs. In addition, groundwater also sustains flows within rivers and streams and influences the quality of the water found within them. The Taranaki Regional Council (the Council) recognises the importance of groundwater to the region and undertakes a significant amount of monitoring and assessment of groundwater quantity and quality as part of its overall State of the Environment Monitoring (SEM) Programme. The data collected enables the Council to effectively manage the region's groundwater resources.

The Council monitors the chemical quality of groundwater through participation in the National Groundwater Monitoring Programme (NGMP), led by GNS Science. As part of this programme, the Council undertakes quarterly sampling of groundwater at five sites, designed to provide samples representative of groundwater from three of the region's major aquifers (Taranaki volcanics, Matemateaonga and Whenuakura). In addition, the Council also undertakes specific programmes of monitoring targeted at assessing shallow groundwater nitrate concentrations and the presence of herbicide and pesticide residues in groundwater across Taranaki. The results of these programmes are reported separately (see bibliography).

The following report summarises the results and findings of the groundwater chemical quality monitoring programme from July 1994 to June 2013.

1.2 Structure of the report

The following report contains six sections as follows:

- Section 1 is an introductory and background section. It provides general information about groundwater quality monitoring undertaken by the Council.
- Section 2 provides specific details of the groundwater chemical quality monitoring programme, including the objectives of the programme.
- Section 3 presents the data collected as part of the programme.
- Section 4 presents an interpretation of the results.
- Section 5 presents the main conclusions from the report based on the data gathered and the analysis of the data carried out by the Council.
- Section 6 concludes the report with recommendations to be implemented over the forthcoming monitoring period.

A glossary of common abbreviations and scientific terms, and a bibliography, are included at the end of the report.

1.3 Statutory framework

The Resource Management Act 1991 (the RMA) requires the Council to monitor and report on the overall state of the environment within the Taranaki region. To meet this requirement, the Council undertakes a comprehensive programme of monitoring across all areas of the region's natural environment. The groundwater quality programme is part of Council's overall SEM programme.

Environmental monitoring is consistent with the purposes and principles of the RMA, the Regional Policy Statement and the Regional Freshwater Plan for Taranaki (RFWP). The Council manages the quality of the region's groundwater resources through the monitoring of water quality in the major aquifers and by regulating activities that have the potential to result in contaminants entering groundwater.

1.4 Water quality standards and guidelines

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 hygiene 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. It should be noted that this programme is concentrated on assessing the chemical quality of groundwater only and does not take into account microbial quality.

The DWSNZ sets Maximum Acceptable Values (MAVs) for a range of chemical 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). 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.

The applicable MAVs and GVs for parameters analysed for as part of the groundwater chemical quality programme are set out below in Tables 1 and 2, respectively.

Table 1 MAVs for inorganic determinands of health significance (DWSNZ, 2008)

Determinand	MAV	Units	Comments
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 2)
Nitrate, short term[1]	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
Nitrite, long term	0.2	mg/L	Expressed in mg/L as NO_2. PMAV (long term)
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

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[1] Now short term only. The short-term exposure MAVs for nitrate and nitrite have been established to protect against methaemoglobinaemia in bottle-fed infants.

Table 2 GVs for aesthetic determinands (DWSNZ, 2008)

Determinand	GV	Units	Comments
Ammonia	1.5 0.3	mg/L mg/L	Odour threshold in alkaline conditions For control of chloramine formation in chlorinated water
Calcium			See hardness
Chloride	250	mg/L	Taste, corrosion
Hardness (total)	200	mg/L	High hardness causes scale deposition, scum formation. Low hardness (<100 mg/L) may be more corrosive
(Ca + Mg) as $CaCO_3$	100-300	mg/L	Taste threshold
Iron	0.2	mg/L	Staining of laundry and sanitary ware
Magnesium			See hardness
Manganese	0.04 0.10	mg/L	Staining of laundry Taste threshold (MAV 0.4 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

2. Groundwater Chemical Quality Monitoring Programme

2.1 Objectives

The groundwater chemical quality monitoring programme aims to:

- Provide information on the current state of groundwater at a selected number of sites across the region;
- Assess water quality with regard to relevant guidelines and standards;
- Identify natural and non-natural spatial and temporal trends in water quality; and
- Assess the effectiveness of groundwater management objectives and policies for the region.

2.2 Programme overview

The groundwater chemical quality monitoring programme is the primary SEM programme for the monitoring of general groundwater quality in Taranaki. The programme is run in conjunction with the NGMP, which is co-ordinated by GNS Science. The NGMP begun in 1990 and the Council began participating in November 1994. The over-riding objective of the NGMP is to assess the long-term trends in water quality across New Zealand's aquifers, with the participation of all regional councils across the country.

2.3 Monitoring sites

The Council relies on being granted long-term access to privately owned wells or bores for the establishment of monitoring networks and is therefore restricted somewhat as to the location, design and construction of monitoring sites.

The Council entered the NGMP programme in 1994, with a total of six sites, located across three of the region's major aquifers systems, including both shallow (unconfined) and deeper (confined) groundwater. Sampling had to be discontinued at one site from 2002, after the bore collapsed. The remaining five sites have been routinely sampled since the Council joined the programme and, as of June 2013, each site has a data record ranging from 18 to 19 years.

Summary information relating to each of the five sites currently included in the groundwater chemical quality monitoring programme is included in Table 3. The geographical location of each site is illustrated in Figure 1.

Table 3 Monitoring site details

Site code	Site name	Locality	Primary use	Total depth (m BGL)	Screen depth (m BGL)		Aquifer name	Aquifer type	Geology	Local landuse	Data record	
					Top	Bottom					From	To
GND0430	Corrigan	Normanby	Stock	235	54	234	Whenuakura	Confined	Sandstone	Dairy farming, some farm buildings and dwellings	Dec-94	Jun-13
GND0451	McCallum-2	Ohawe	Irrigation	172	64	171	Whenuakura	Confined	Siltstone	Dairy farming with some irrigated land. Some farm buildings and dwellings	Nov-95	Jun-13
GND0508	Carrington Road	New Plymouth	Monitoring	14	8	14	Volcanics	Unconfined	Volcanic sediment	Dairy farming and horticultural. Some farm buildings & private dwellings	Mar-95	Jun-13
GND0563	Bayly	Toko	Stock	78	72	77	Matemateaonga	Flowing artesian	Sandstone and shell deposits	Dry stock and dairy farming. Some farm buildings and dwellings	Nov-95	Jun-13
GND0827	McCallum Well	Ohawe	Domestic	8	Unlined to surface		Volcanics	Unconfined	Volcanic sediment	Dairy farming with some irrigated land. Some farm buildings and dwellings	Dec-94	Jun-13

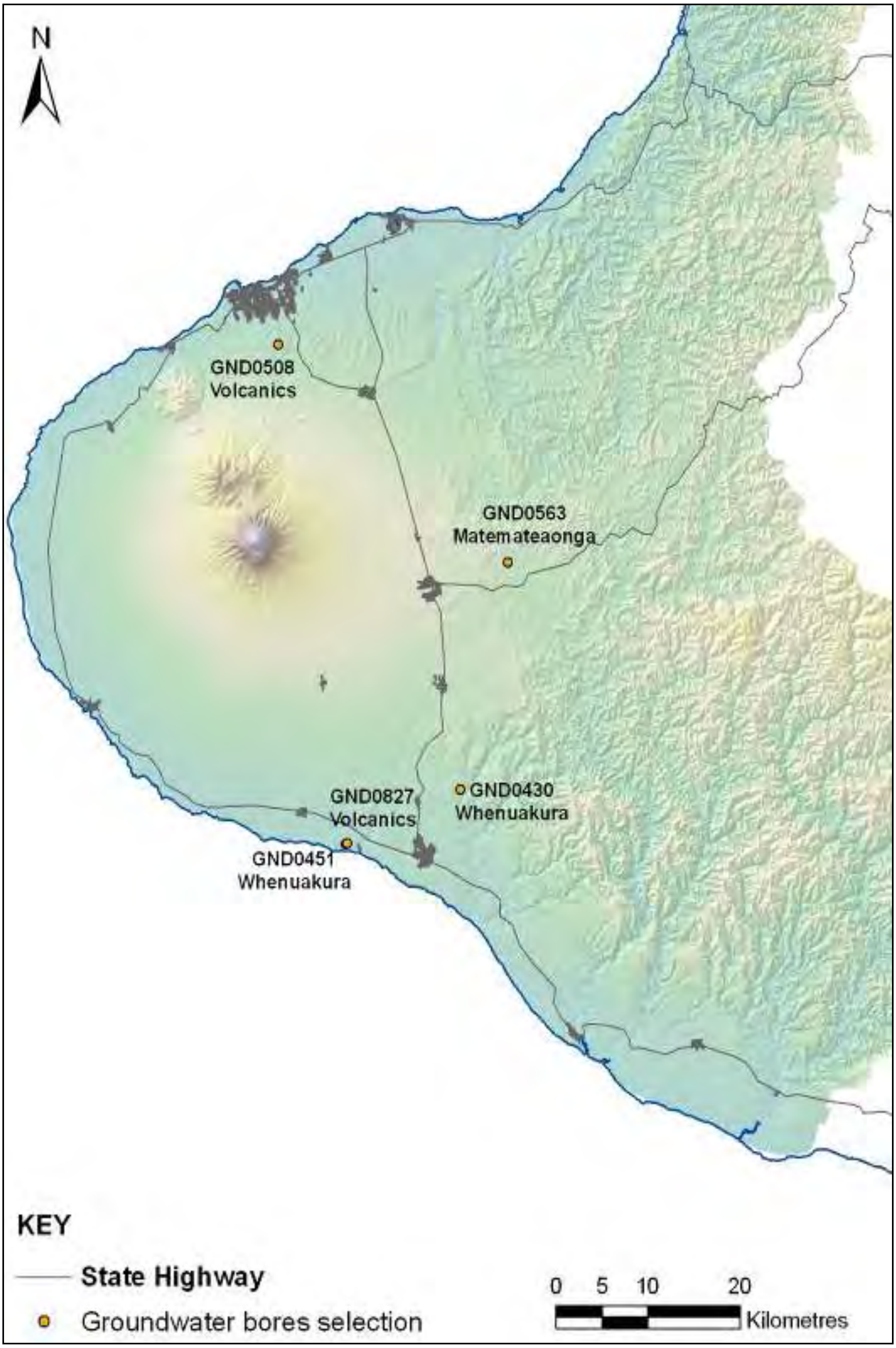

Figure 1 Monitoring site locations and aquifer unit intercepted

2.4 Sample collection and analysis

Each monitoring site is sampled by the Council on a quarterly basis; ensuring one sample is obtained from each site per season of each year.

The procedure for groundwater sampling is generally in accordance with that set out in the National Protocol for State of the Environment Groundwater Sampling in New Zealand (2006). Where access to the bore itself is possible, a water level is obtained on arrival to the site. Sites are then purged prior to sampling and the pH, temperature and conductivity of purge water is monitored throughout this process. Samples are obtained when each field parameter stabilises to within the respective limits specified in the protocol (±0.1 pH units, ±0.2 °C and ± 3% conductivity). Purging is not carried out at site GND0827 as the well is in continual use supplying water for a domestic dwelling. The continual removal of water from the well and replenishment from the aquifer replicates the purging procedure and samples taken from the well are therefore deemed representative of groundwater from the surrounding aquifer.

Where possible, groundwater samples are obtained directly from the well or bore using a bailer or pump. If access to the well or bore itself is not possible, samples are obtained from a sample point at the surface. Samples are collected in a range of unfiltered, filtered and acid preserved sample containers provided by GNS Science.

Photo 1 Monitoring water chemistry during purging

The analysis of samples is also carried out by GNS Science at their Wairakei Laboratory. Samples are analysed for the following range of water quality determinands:

- Acidity (pH units);
- Ammonia (NH_3);

- Bicarbonate as HCO_3
- Bromide (Br)
- Calcium (Ca)
- Chloride (Cl)
- Fluoride (F)
- Iron (Fe)
- Magnesium(Mg)
- Manganese (Mn)
- Nitrate-nitrogen (NO_3-N)
- Nitrite (NO_2)
- Dissolved reactive phosphorus (DRP)
- Potassium (K)
- Silica (SiO_2)
- Sodium (Na)
- Sulphate (SO_4)

In addition, field measurements of pH, temperature and electrical conductivity are recorded at the time of sampling and values of total dissolved solids (TDS) and carbonate (CO_3) are also calculated for each sample.

Results are stored by GNS Science on their internal database system, where they can be accessed by the Council for review and interpretation. Historically GNS Science had provided a report to the Council interpreting the data obtained from the Taranaki region, but this is longer the case, with the last report produced in 2006.

Photo 2 Sampling of groundwater by Council staff at site GND0508

3. Results

3.1 GND0430: Corrigan

3.1.1 Summary data

A summary of all water quality data collected from GND0430 as part of the groundwater chemical quality monitoring programme is presented below in Table 4.

Table 4 GND0430 summary results (1994-2013)

Determinand	Unit	Min	Max	Mean	Median	St. Dev
pH	pH units	7.8	8.5	8.1	8.2	0.2
Ammonia	mg/L	0.01	0.52	0.31	0.29	0.16
Bicarbonate as HCO_3	mg/L	150	181	169	170	4
Bromide	mg/L	0.02	0.15	0.08	0.10	0.03
Calcium	mg/L	28.0	33.0	30.4	30.0	1.2
Carbonate	mg/L	9.0	10.9	10.2	10.2	0.2
Chloride	mg/L	19.4	25.0	23.8	24.0	0.2
Fluoride	mg/L	0.01	0.13	0.07	0.07	0.02
Iron	mg/L	0.02	0.13	0.03	0.02	0.02
Magnesium	mg/L	10.2	12.8	11.9	12.0	0.5
Manganese	mg/L	0.005	0.020	0.008	0.008	0.003
Nitrate-nitrogen	mg/L	0.004	0.621	0.179	0.170	0.174
Nitrite	mg/L	0.01	0.04	0.03	0.03	0.01
Dissolved reactive phosphorus	mg/L	0.03	0.12	0.07	0.07	0.02
Potassium	mg/L	1.9	3.1	2.6	2.6	0.2
Silica	mg/L	23.0	31.0	26.5	26.0	1.5
Sodium	mg/L	20.0	25.0	23.0	23.0	1.0
Sulphate	mg/L	4.5	5.9	5.2	5.2	0.3
Total dissolved solids	mg/L	61	390	250	246	70

3.1.2 Exceedances

There were no exceedances of any MAVs at this site during the period being reported. The lower GV for ammonia was exceeded on several occasions. The lower GV for ammonia (0.3 mg/L) is set for the control of chloramine formation when water is treated with chlorine.

3.1.3 Trends

The data record from site GND0430, spanning the period December 1994 to June 2013, has been analysed using Kendell trend test methods to determine if any statistically significant trends in analyte concentrations exist (p-value <0.05). A trend has been classified as 'meaningful' where the percentage annual change (PAC) in an analyte concentration exceeds 1%.

The trend analysis carried out indicates an increasing trend in ammonia concentrations at a PAC of 8% (Figure 2). The analysis also indicates a decreasing trend in nitrate concentration at a PAC of approximately 10% (Figure 3).

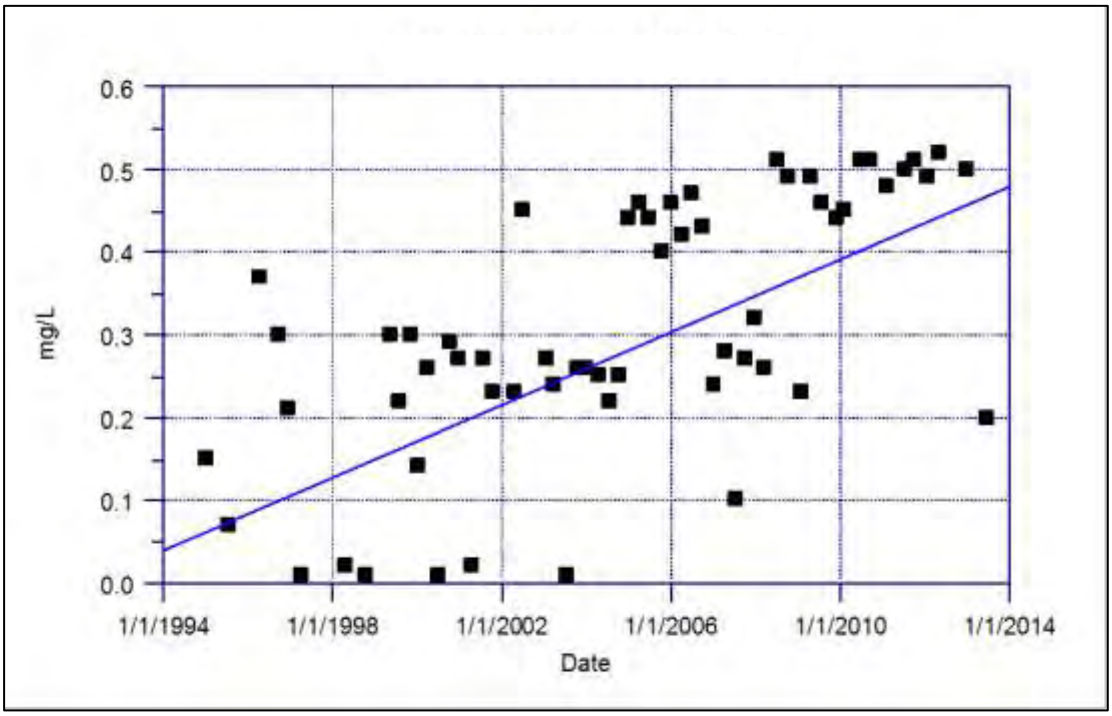

Figure 2 Time-series plot of increasing ammonia concentrations at site GND0430 (1994-2013)

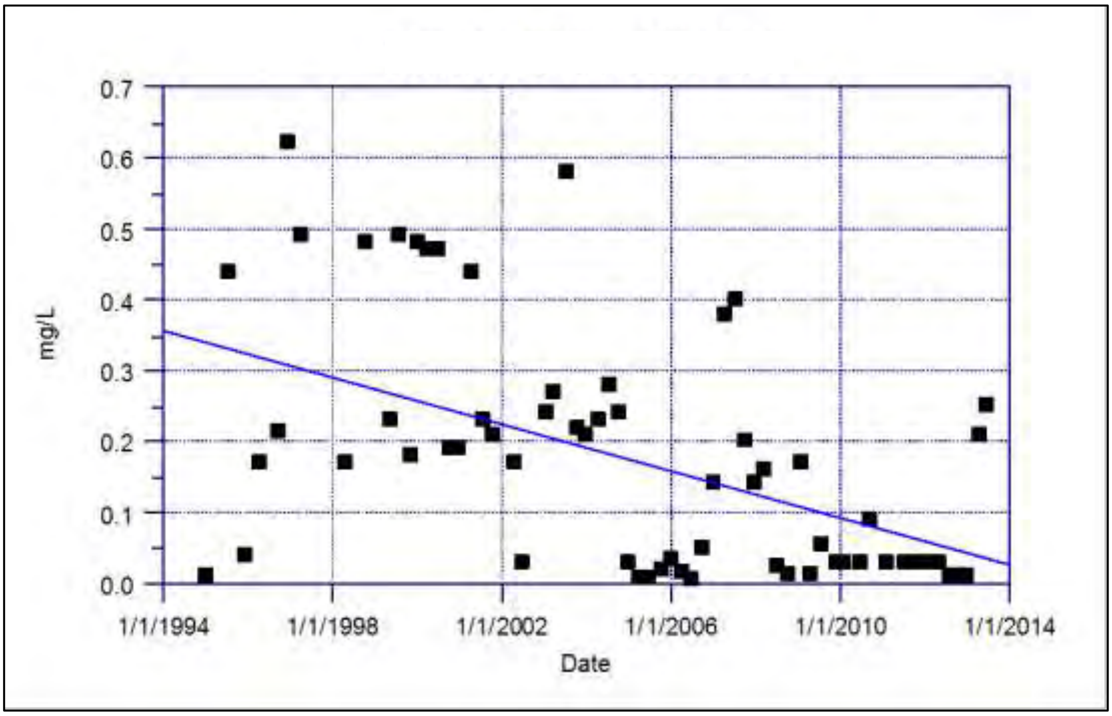

Figure 3 Time-series plot of decreasing nitrate concentrations at site GND0430 (1994-2013)

3.2 GND0451: McCallum-2

3.2.1 Summary data

A summary of all water quality data collected from GND0451 as part of the groundwater chemical quality monitoring programme is presented below in Table 5.

Table 5 GND0451 summary results (1995-2013)

Determinand	Unit	Min	Max	Mean	Median	St. Dev
pH	pH units	7.2	8.2	7.6	7.7	0.2
Ammonia	mg/L	1.0	1.6	1.3	1.2	0.1
Bicarbonate as HCO_3	mg/L	74	156	140	141	10
Bromide	mg/L	0.04	0.22	0.11	0.10	0.03
Calcium	mg/L	8.2	19.4	17.5	17.6	1.6
Carbonate	mg/L	2.60	2.70	2.66	2.66	0.02
Chloride	mg/L	24.0	42.0	27.1	27.0	2.3
Fluoride	mg/L	0.200	0.490	0.314	0.310	0.049
Iron	mg/L	0.32	3.80	2.48	2.60	0.82
Magnesium	mg/L	3.50	8.00	7.27	7.40	0.62
Manganese	mg/L	0.005	0.950	0.697	0.720	0.148
Nitrate-nitrogen	mg/L	0.002	0.761	0.057	0.030	0.118
Nitrite	mg/L	0.002	0.010	0.006	0.005	0.004
Dissolved reactive phosphorus	mg/L	0.080	0.593	0.201	0.150	0.151
Potassium	mg/L	6.2	8.1	7.4	7.6	0.5
Silica	mg/L	22.0	66.0	54.3	55.0	5.6
Sodium	mg/L	28.9	37.0	30.6	30.3	1.5
Sulphate	mg/L	0.02	1.80	0.17	0.10	0.33
Total dissolved solids	mg/L	134	330	220	186	59

3.2.2 Exceedances

Measured iron concentrations at site GND0451 exceeded the GV throughout the monitoring period (Figure 4). The upper GV for ammonia, set at its odour threshold, was also exceeded on a single occasion. Manganese concentrations also exceeded the upper and lower GV, but more significantly, manganese concentrations also exceeded the MAV throughout the monitoring period (Figure 5).

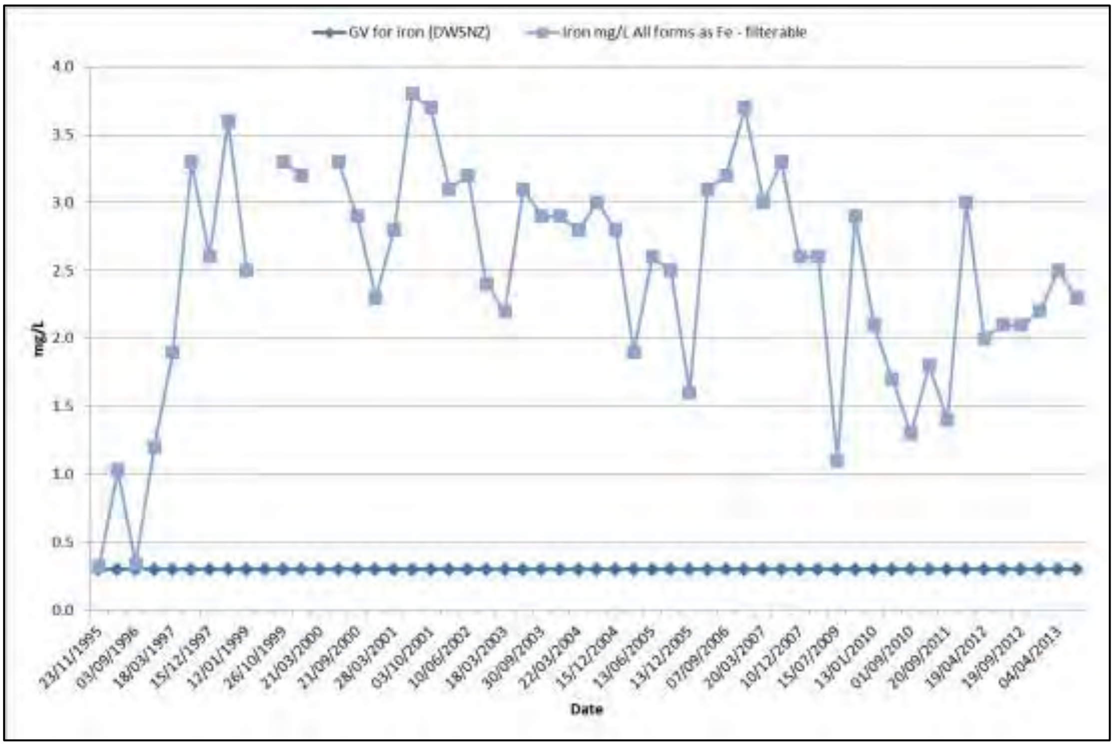

Figure 4 Measured iron concentrations at site GND0451 (1995-2013)

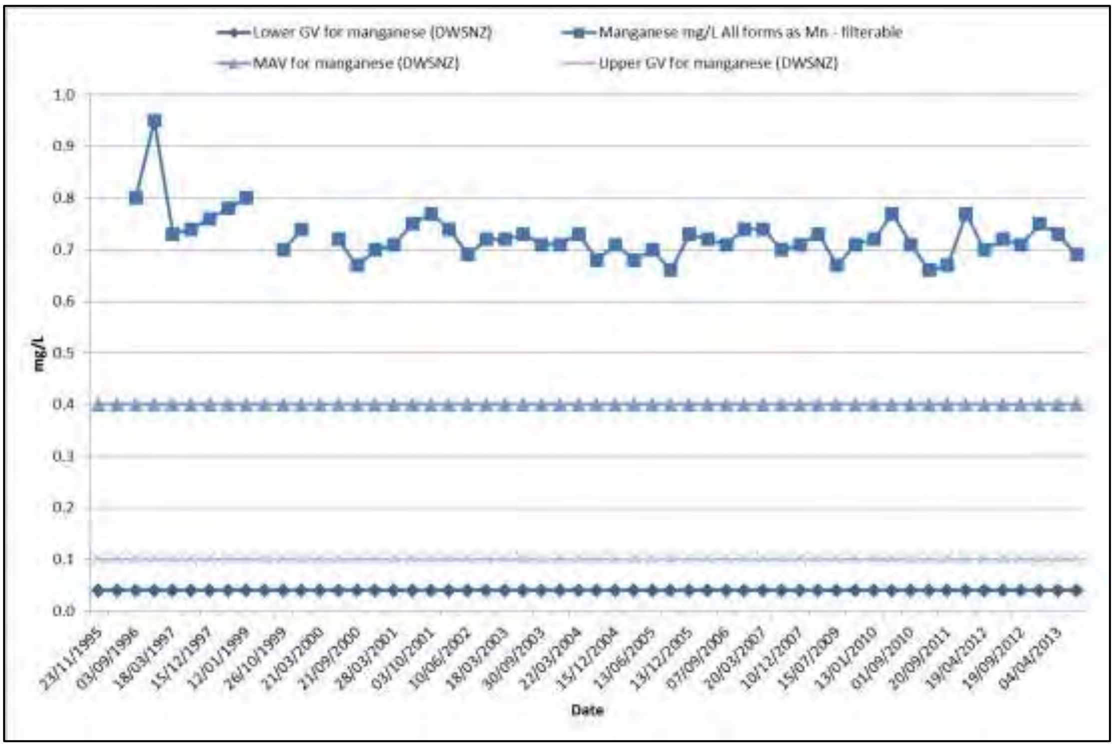

Figure 5 Measured manganese concentrations at site GND0451 (1995-2013)

3.2.3 Trends

The data record from site GND0451, spanning the period November 1995 to June 2013, has been analysed using Kendell trend test methods to determine if any statistically significant trends in analyte concentrations exist (p-value <0.05). A trend has been classified as 'meaningful' where the PAC in an analyte concentration exceeds 1%.

The only meaningful trend identified at the site is a very minor decrease in sulphate concentrations, at a PAC of approximately 2% (Figure 6).

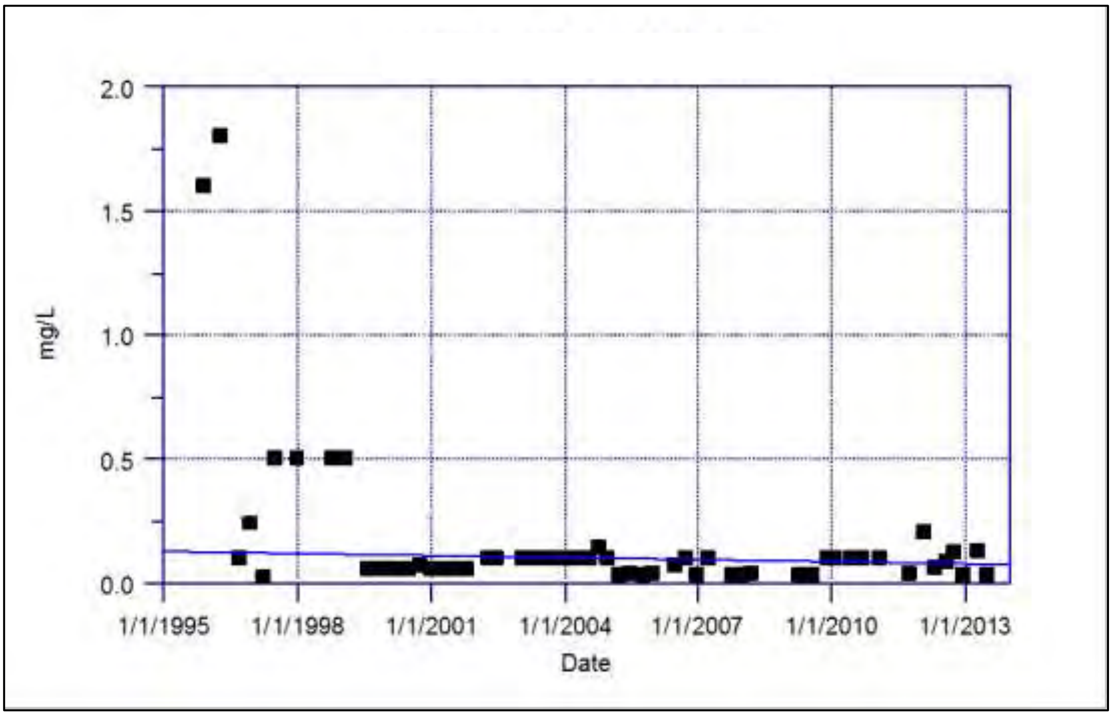

Figure 6 Time-series plot of decreasing sulphate concentrations at site GND0451 (1995-2013)

3.3 GND0508: Carrington Road

3.3.1 Summary

A summary of all water quality data collected from GND0508 as part of the groundwater chemical quality monitoring programme is presented below in Table 6.

Table 6 GND0508 summary results (1995-2013)

Determinand	Unit	Min	Max	Mean	Median	St. Dev
pH	pH units	5.6	7.4	6.3	6.3	0.3
Ammonia	mg/L	0.01	0.22	0.03	0.01	0.05
Bicarbonate as HCO_3	mg/L	26	55	34	33	7
Bromide	mg/L	0.02	0.10	0.07	0.06	0.03
Calcium	mg/L	5.9	12.0	7.5	7.3	1.0
Carbonate	mg/L	7.2	24.0	10.5	9.8	2.9
Chloride	mg/L	0.013	0.028	0.017	0.015	0.003
Fluoride	mg/L	0.005	0.050	0.026	0.030	0.012
Iron	mg/L	0.01	0.45	0.04	0.02	0.07
Magnesium	mg/L	1.9	4.0	2.9	2.7	0.7
Manganese	mg/L	0.005	0.050	0.010	0.005	0.010

Determinand	Unit	Min	Max	Mean	Median	St. Dev
Nitrate-nitrogen	mg/L	0.450	3.430	1.383	1.300	0.674
Nitrite	mg/L	0.005	0.010	0.007	0.005	0.003
Dissolved reactive phosphorus	mg/L	0.010	0.100	0.041	0.029	0.030
Potassium	mg/L	1.2	15.2	3.4	2.9	2.2
Silica	mg/L	14.1	28.0	20.4	20.4	4.2
Sodium	mg/L	5.7	12.8	8.6	8.7	1.9
Sulphate	mg/L	4.5	12.6	6.7	6.7	1.2
Total dissolved solids	mg/L	54	199	85	74.3	28

3.3.2 Exceedances

There were no exceedances of any MAVs at this site during the period being reported. The pH of water sampled at the site did not meet the lower GV for pH throughout the majority of the reporting period (Figure 7). The GV for iron was also exceeded on a single occasion.

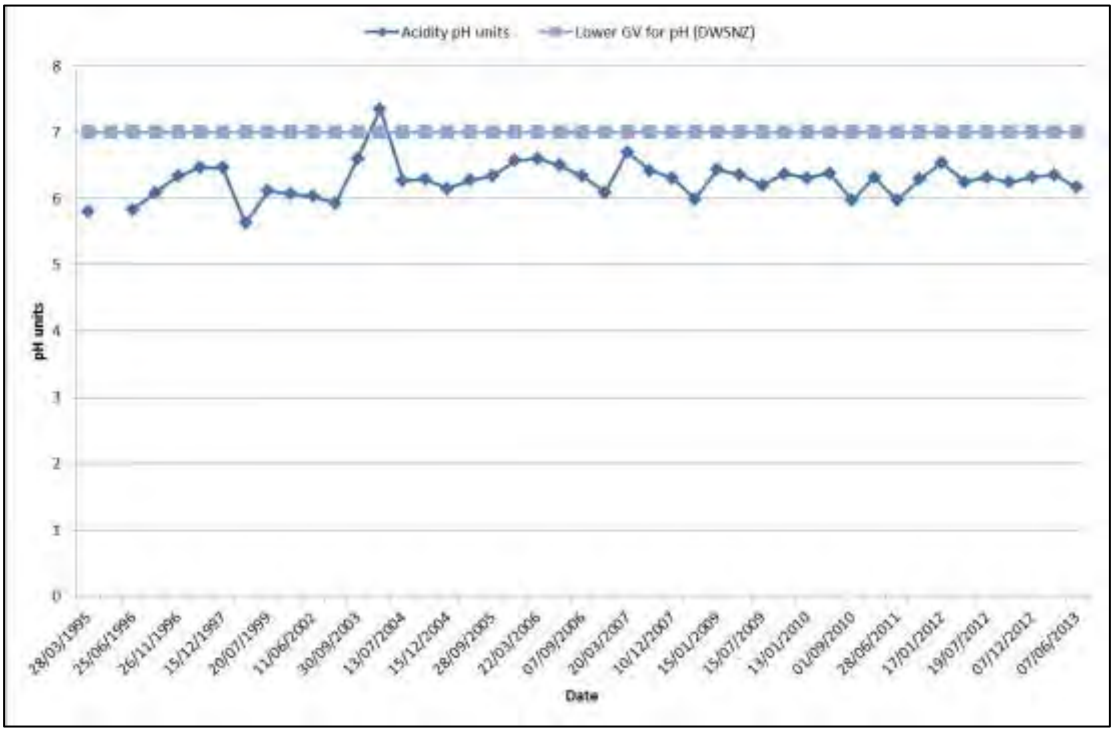

Figure 7 Measured pH values at site GND0508 (1995-2013)

3.3.3 Trends

The data record from site GND0508, spanning the period March 1995 to June 2013, has been analysed using Kendell trend test methods to determine if any statistically significant trends in analyte concentrations exist (p-value <0.05). A trend has been classified as 'meaningful' where the PAC in an analyte concentration exceeds 1%.

The trend analysis carried out indicates an increasing trend in chloride concentrations at a PAC of 3% (Figure 8). The analysis also indicates a decreasing trend in nitrate concentration at a PAC of approximately 10% (Figure 9).

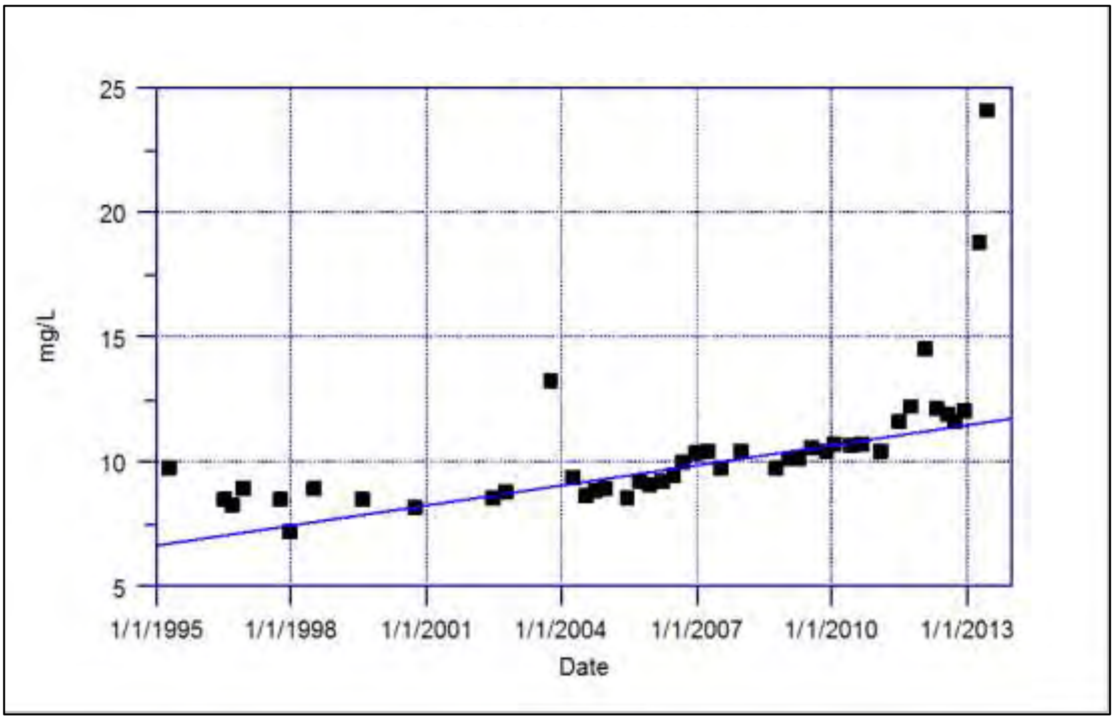

Figure 8 Time-series plot of increasing chloride concentrations at site GND0508 (1995-2013)

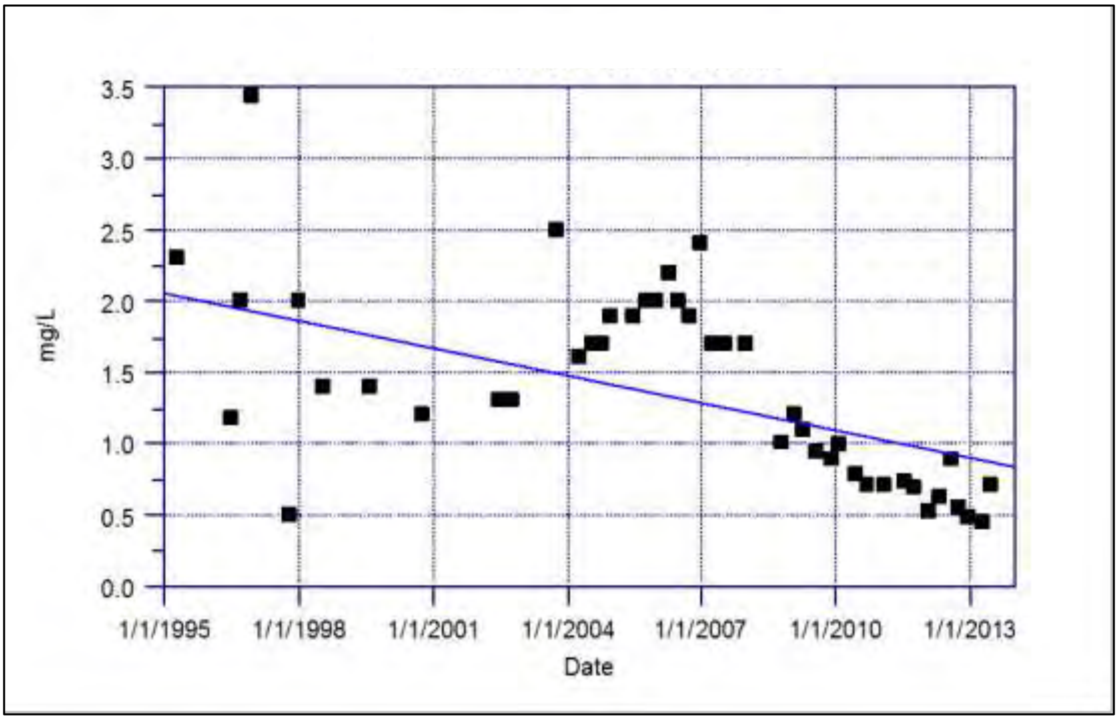

Figure 9 Time-series plot of decreasing nitrate concentrations at site GND0508 (1995-2013)

3.4 GND0563: Bayly

3.4.1 Summary

A summary of all water quality data collected from GND0563 as part of the groundwater chemical quality monitoring programme is presented below in Table 7.

Table 7 GND0563 summary results (1995-2013)

Determinand	Unit	Min	Max	Mean	Median	St. Dev
pH	pH units	7.2	8.3	7.9	8.0	0.2
Ammonia	mg/L	0.16	2.50	0.64	0.60	0.32
Bicarbonate as HCO_3	mg/L	177	208	182	181	5
Bromide	mg/L	0.02	0.10	0.06	0.04	0.03
Calcium	mg/L	26.0	31.0	28.6	29.0	1.2
Carbonate	mg/L	5.3	6.2	5.5	5.4	0.1
Chloride	mg/L	2.2	10.9	9.4	9.5	1.1
Fluoride	mg/L	0.09	0.31	0.15	0.14	0.04
Iron	mg/L	0.03	0.82	0.18	0.11	0.17
Magnesium	mg/L	8.6	10.4	9.4	9.5	0.4
Manganese	mg/L	0.005	0.250	0.014	0.005	0.036
Nitrate-nitrogen	mg/L	0.002	0.435	0.033	0.030	0.060
Nitrite	mg/L	0.002	0.005	0.004	0.005	0.002
Dissolved reactive phosphorus	mg/L	0.004	0.100	0.047	0.040	0.029
Potassium	mg/L	1.2	4.8	1.9	1.7	0.6
Silica	mg/L	17.1	38.0	19.9	19.1	3.0
Sodium	mg/L	19.1	26.0	21.3	21.0	1.2
Sulphate	mg/L	0.02	0.90	0.13	0.10	0.17
Total dissolved solids	mg/L	118	326	206	186	53

3.4.2 Exceedances

There were no exceedances of any MAVs at this site during the period being reported. Measured ammonia concentrations consistently exceeded the lower GV for ammonia throughout the monitoring period. Ammonia concentrations spiked during 2012, where they exceeded the upper GV (Figure 10). Iron concentrations also exceeded the GV on occasions during the period under review, with peak concentration also recorded during the 2012 year (Figure 11). Peak manganese concentrations were also recorded during the 2012 year, where they exceeded GVs (Figure 12).

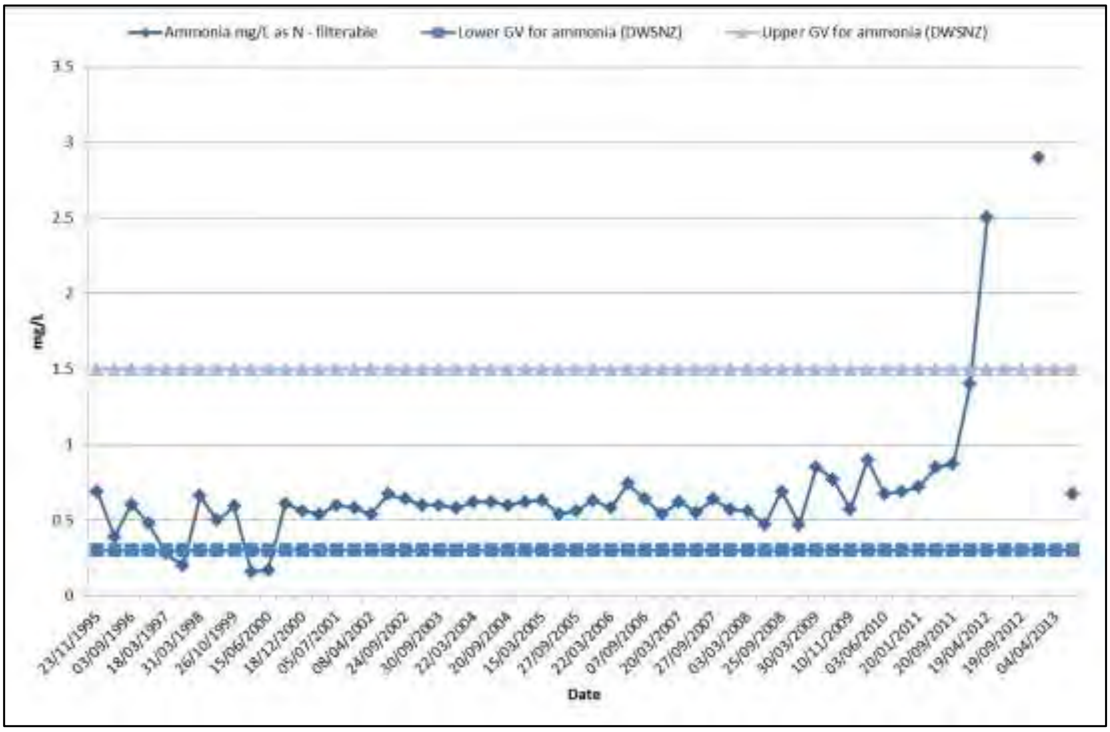

Figure 10 Measured ammonia concentrations at site GND0563 (1995-2013)

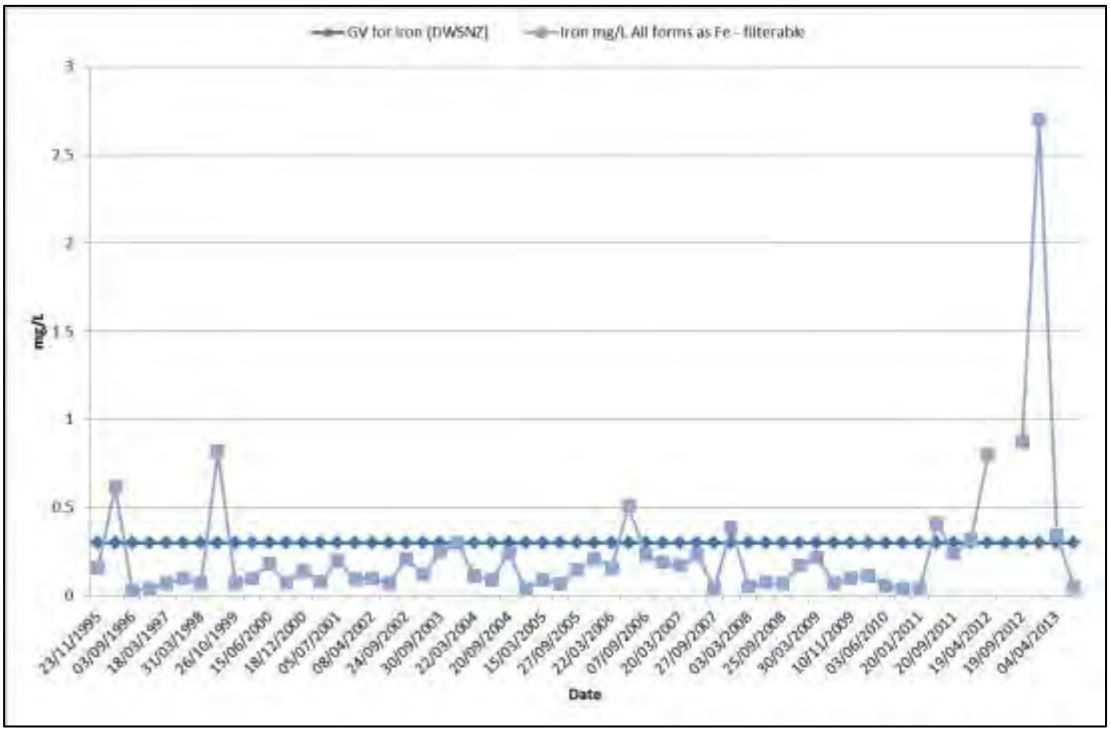

Figure 11 Measured iron concentrations at site GND0563 (1995-2013)

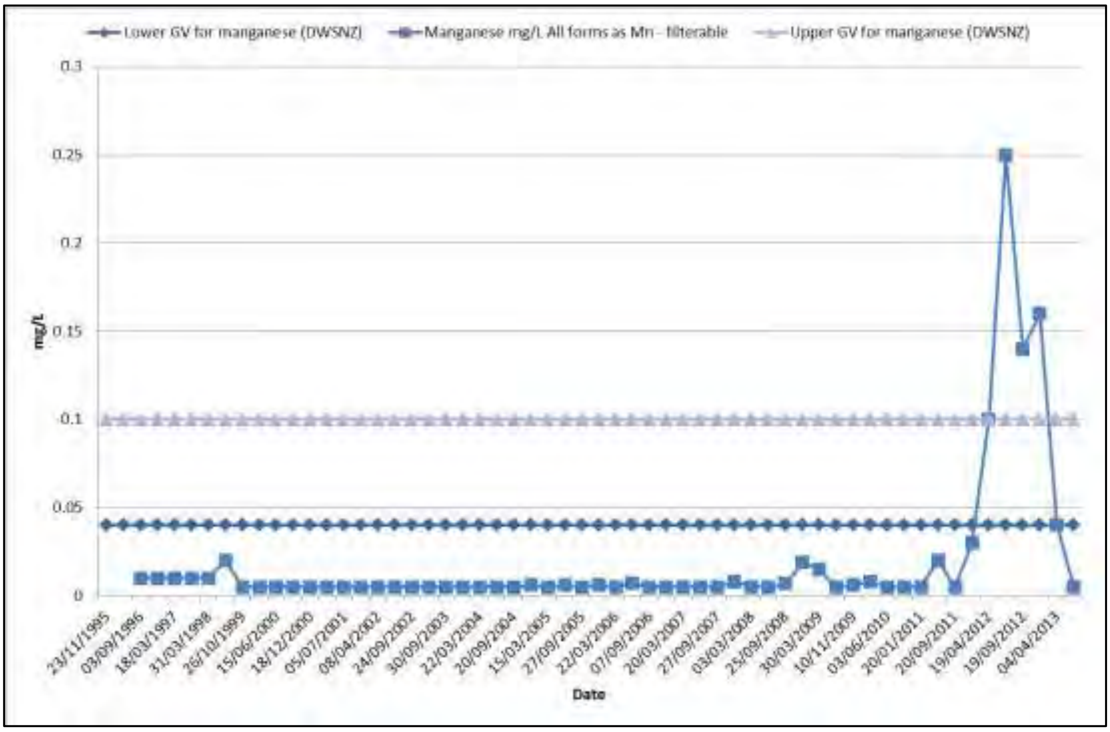

Figure 12 Measured manganese concentrations at site GND0563 (1995-2013)

3.4.3 Trends

The data record from site GND0563, spanning the period November 1995 to June 2013, has been analysed using Kendell trend test methods to determine if any statistically significant trends in analyte concentrations exist (p-value <0.05). A trend has been classified as 'meaningful' where the PAC in an analyte concentration exceeds 1%.

The trend analysis carried out indicates an increasing trend in ammonia (Figure 13) and fluoride concentrations (Figure 14), at PACs of 3% and 2% respectively. The analysis also indicates a reduction in sulphate concentrations at the site at a PAC of 5% (Figure 15).

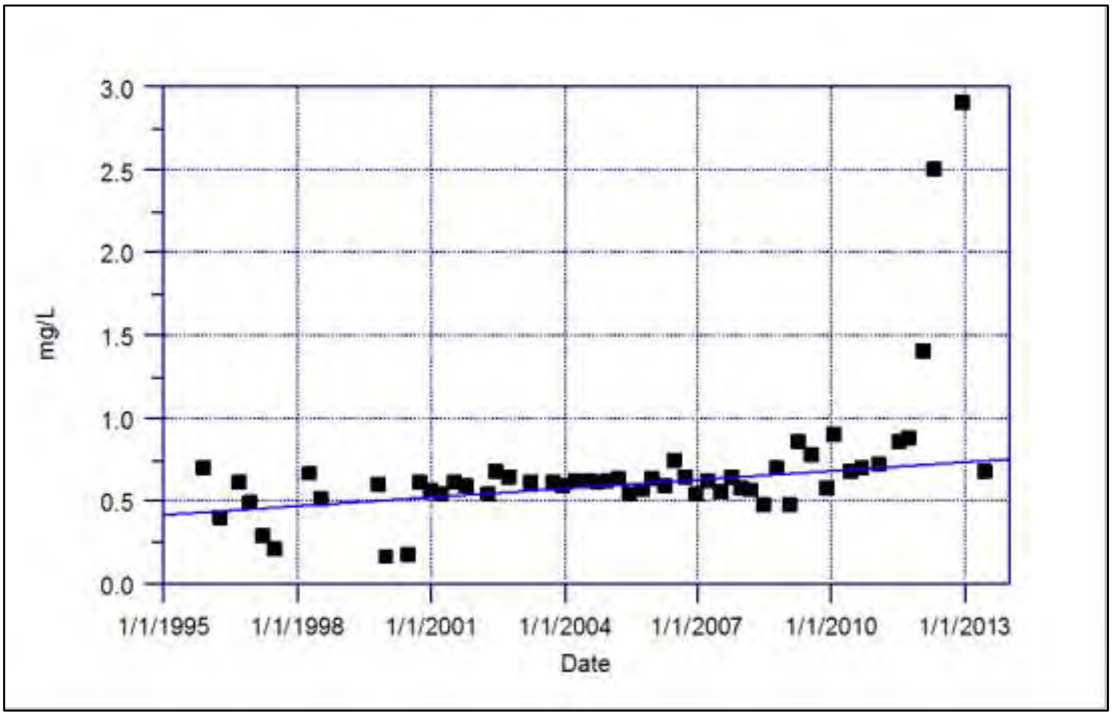

Figure 13 Time-series plot of increasing ammonia concentrations at site GND0563 (1995-2013)

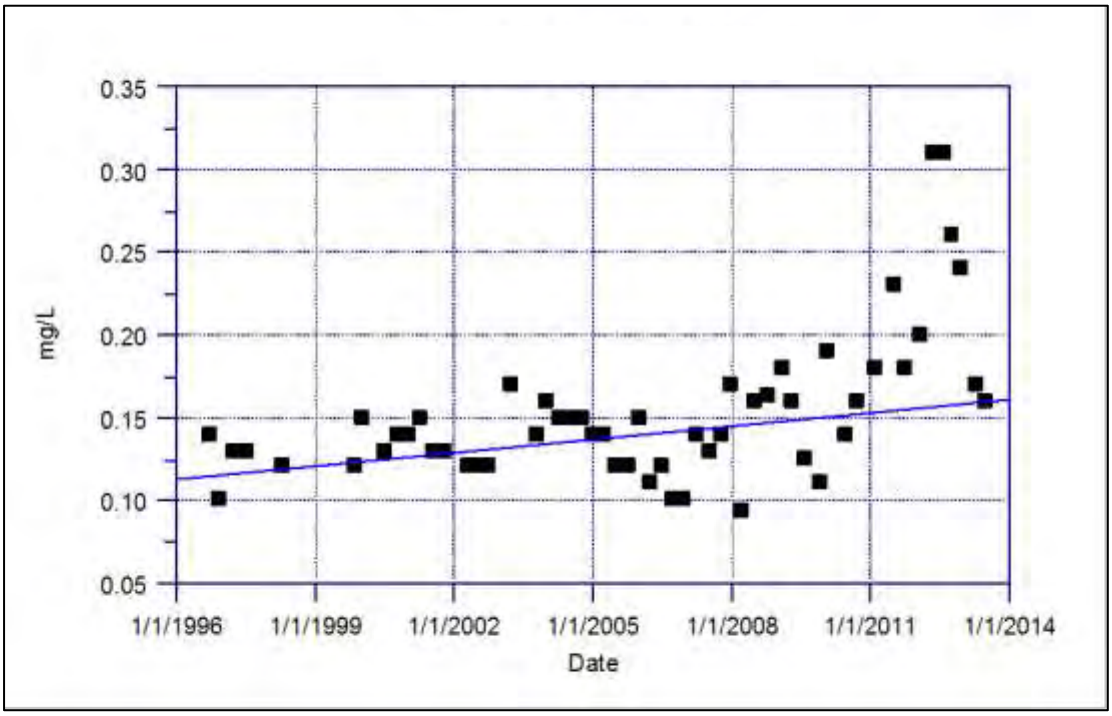

Figure 14 Time-series plot of increasing fluoride concentrations at site GND0563 (1996-2013)

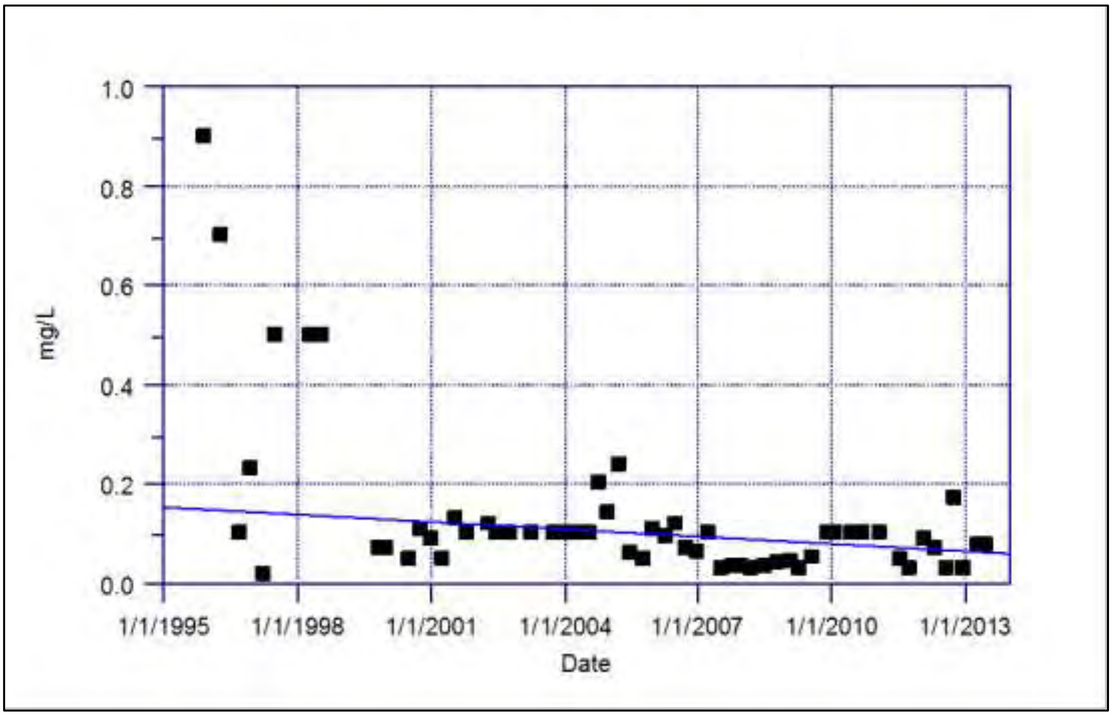

Figure 15 Time-series plot of decreasing sulphate concentrations at site GND0563 (1995-2013)

3.5 GND0827: McCallum Well

3.5.1 Summary

A summary of all water quality data collected from GND0827 as part of the groundwater chemical quality monitoring programme is presented below in Table 8.

Table 8 GND0827 summary results (1994-2013)

Determinand	Unit	Min	Max	Mean	Median	St. Dev
pH	pH units	6.0	8.0	6.8	6.8	0.3
Ammonia	mg/L	0.01	0.040	0.014	0.010	0.008
Bicarbonate as HCO_3	mg/L	43	67	56	57	5
Bromide	mg/L	0.02	0.42	0.26	0.27	0.11
Calcium	mg/L	12.8	26.8	17.4	17.0	2.5
Carbonate	mg/L	0.17	0.27	0.23	0.23	0.02
Chloride	mg/L	52.0	124.5	80.9	78.0	15.6
Fluoride	mg/L	0.01	0.21	0.11	0.11	0.04
Iron	mg/L	0.01	0.10	0.02	0.02	0.02
Magnesium	mg/L	8.6	17.2	11.5	11.3	1.7
Manganese	mg/L	0.005	0.020	0.006	0.005	0.003
Nitrate-nitrogen	mg/L	0.98	6.86	2.53	2.40	1.00
Nitrite	mg/L	0.002	0.008	0.006	0.007	0.002
Dissolved reactive phosphorus	mg/L	0.04	0.10	0.06	0.05	0.02
Potassium	mg/L	4.5	7.4	5.4	5.5	0.6

Determinand	Unit	Min	Max	Mean	Median	St. Dev
Silica	mg/L	46.0	63.0	52.0	51.4	2.8
Sodium	mg/L	45.0	70.7	53.1	52.5	5.4
Sulphate	mg/L	15.2	58.0	42.2	46.0	10.3
Total dissolved solids	mg/L	135	535	327	300	96

3.5.2 Exceedances

There were no exceedances of any MAVs at this site during the period being reported. The pH of water sampled at the site did not meet the lower GV for pH throughout the majority of the reporting period (Figure 16).

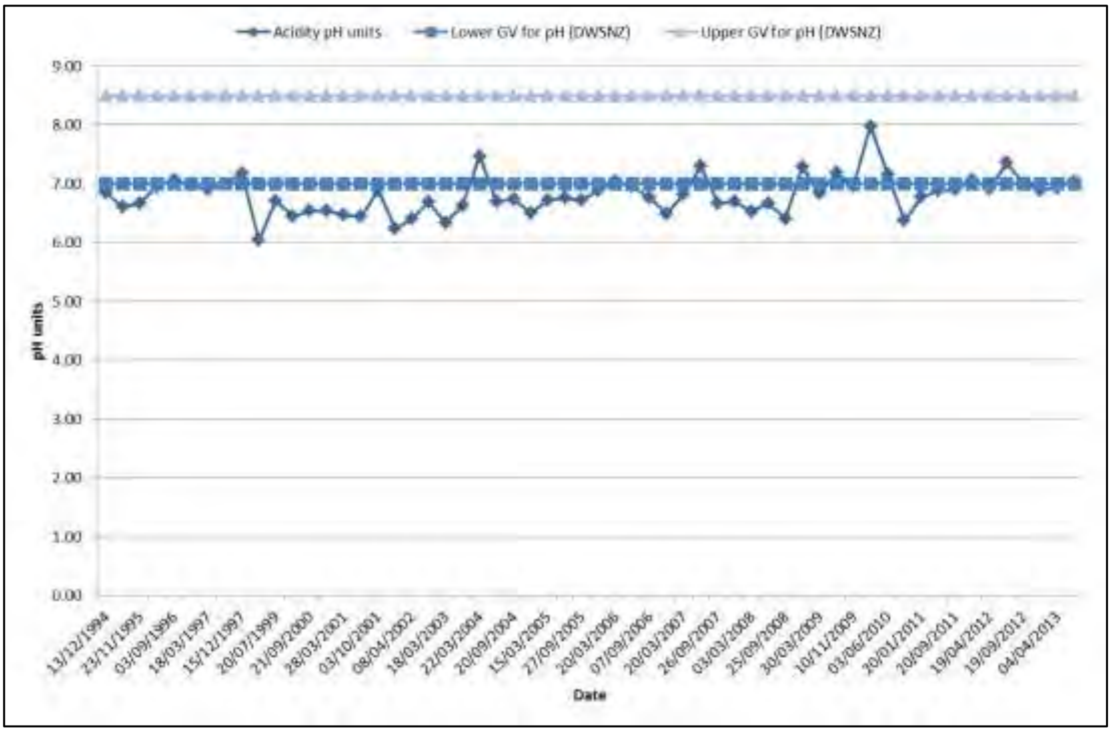

Figure 16 pH values at site GND0827 (1994-2013)

3.5.3 Trends

The data record from site GND0827, spanning the period December 1994 to June 2013, has been analysed using Kendell trend test methods to determine if any statistically significant trends in analyte concentrations exist (p-value <0.05). A trend has been classified as 'meaningful' where the PAC in an analyte concentration exceeds 1%.

The trend analysis carried out indicates an increasing trend in bicarbonate (Figure 17), fluoride (Figure 18) and sulphate concentrations (Figure 19), at PACs of 2%, 5% and 3% respectively. The analysis also indicates decreasing trends in bromide (Figure 20), chloride (Figure 21) and potassium concentrations (Figure 22), at PACs of 4%, 3% and 1% respectively.

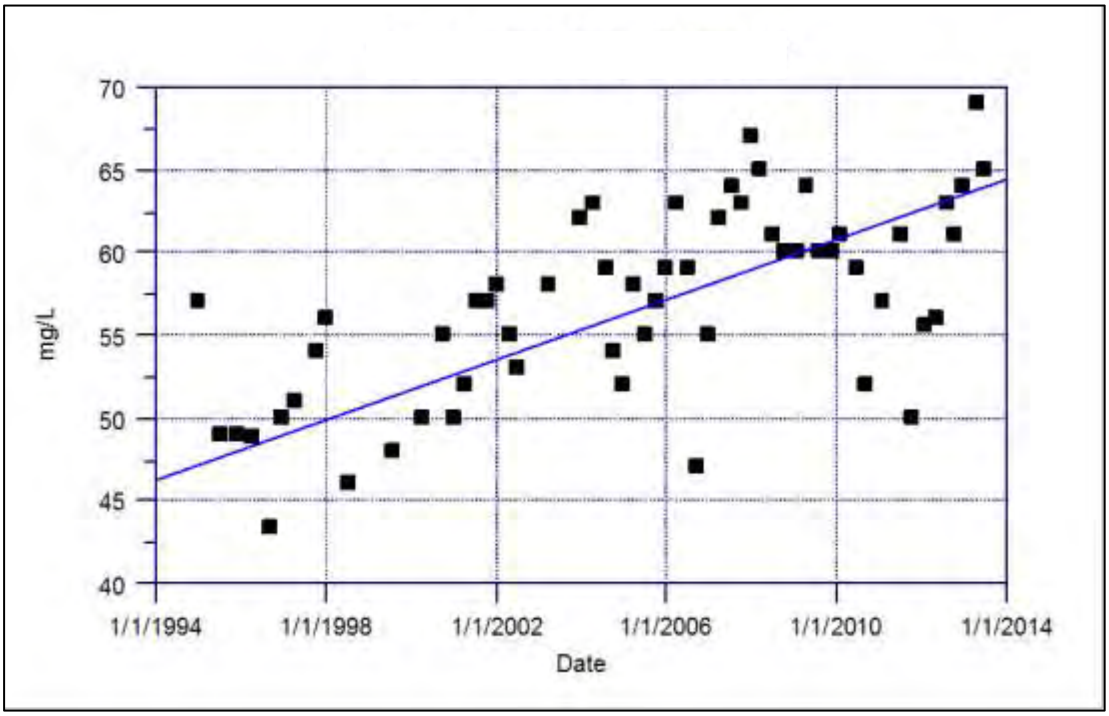

Figure 17 Time-series plot of increasing bicarbonate concentrations at site GND0827 (1994-2013)

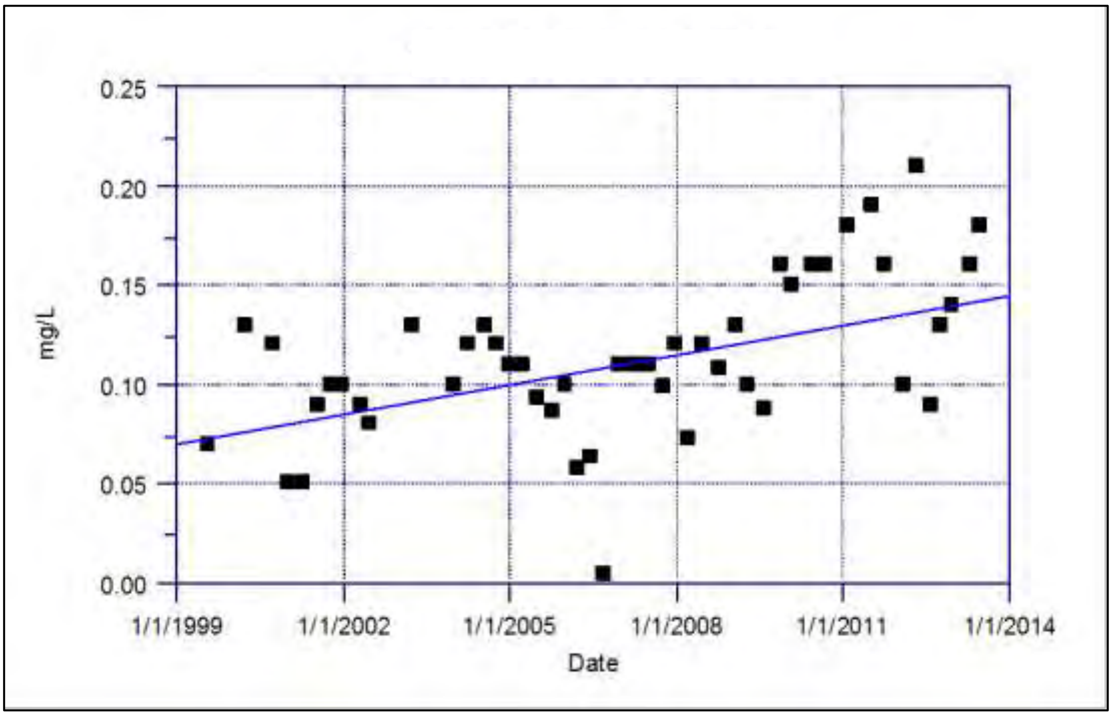

Figure 18 Time-series plot of increasing fluoride concentrations at site GND0827 (1999-2013)

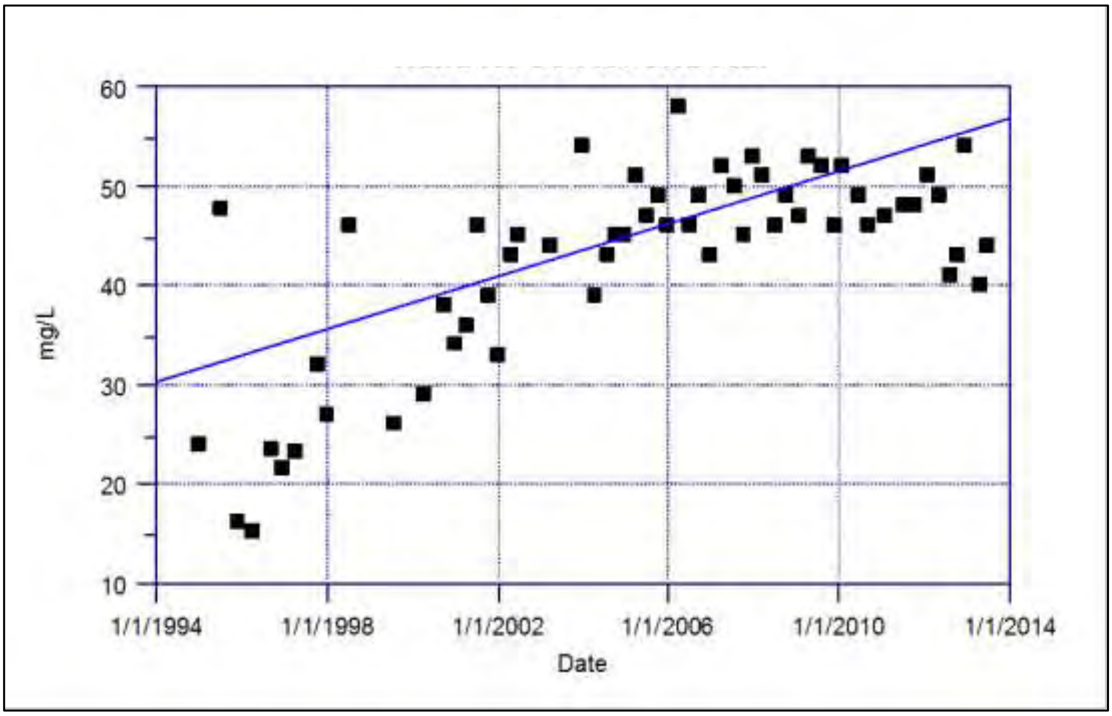

Figure 19 Time-series plot of increasing sulphate concentrations at site GND0827 (1994-2013)

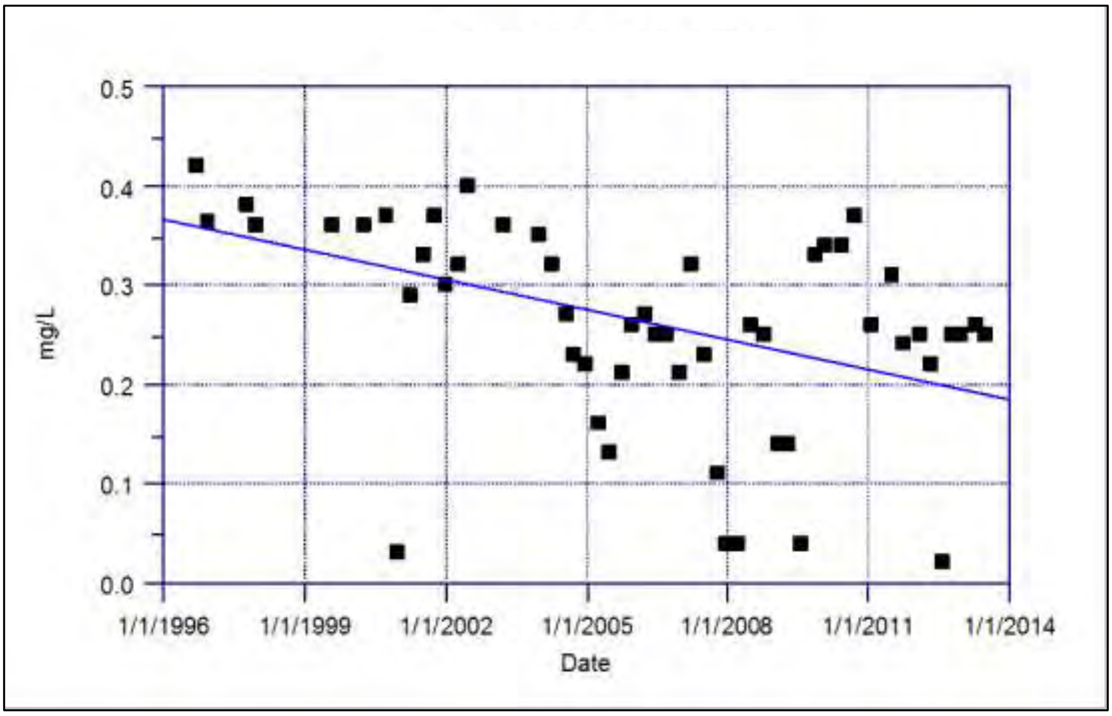

Figure 20 Time-series plot of decreasing bromide concentrations at site GND0827 (1996-2013)

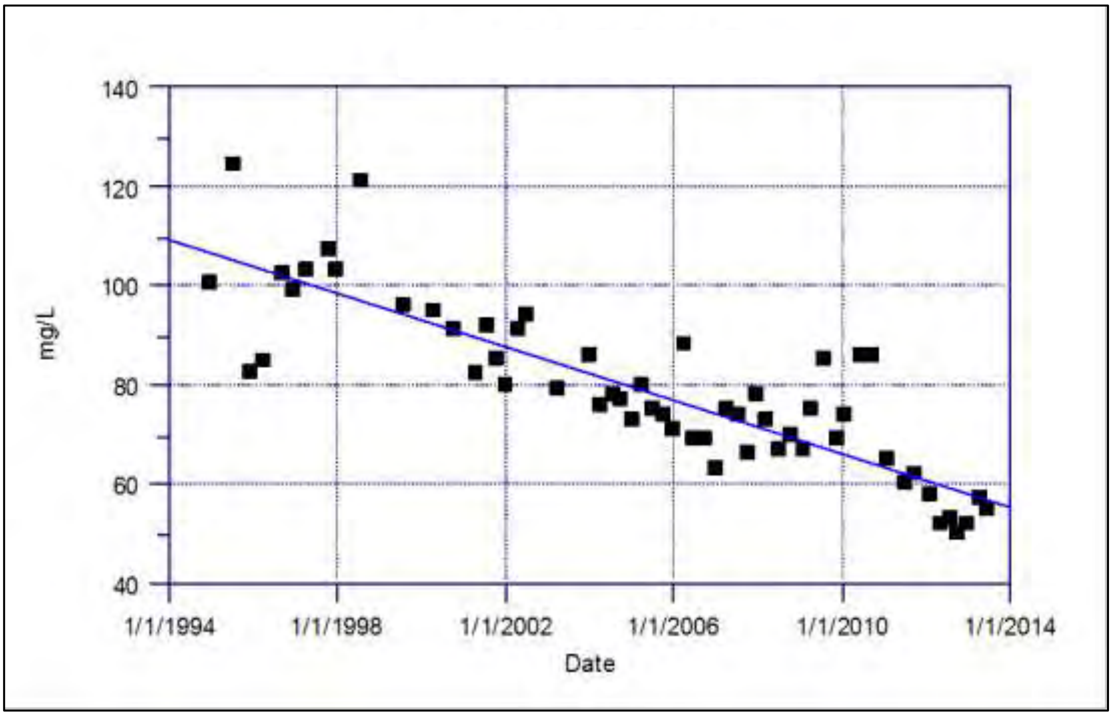

Figure 21 Time-series plot of decreasing chloride concentrations at site GND0827 (1994-2013)

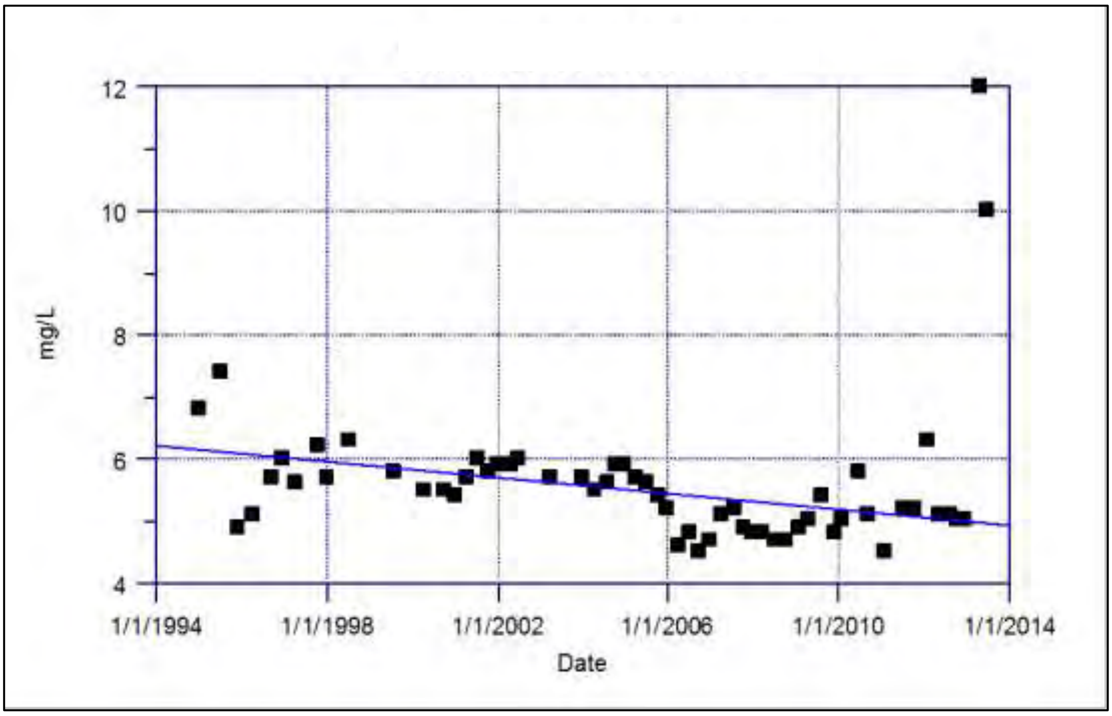

Figure 22 Time-series plot of decreasing potassium concentrations at site GND0827 (1994-2013)

4. Discussion

The chemical composition of groundwater is determined by a number of influences. These include the mineralogy of the soil and rock types forming catchments or aquifers, aquifer structure, the source and volumes of recharge water, aquifer residence times, overlying landuses and biochemical process.

Groundwater aquifers in Taranaki are predominantly recharged by rainfall falling on the land surface, but recharge can also occur via infiltration from surface water systems. Recently recharged groundwater has a chemical composition resembling that of the recharge source, but compositional changes begin to occur as the water percolates downward through underlying soil and rock material. Water is a highly effective solvent and dissolves minerals from the material it interacts with. The longer water is in contact time with this material, the greater the amount of dissolution that will occur. Some soil and rock types are also more easily dissolved than others and therefore geological characteristics play a major role in influencing the presence and relative abundance of various minerals within groundwater.

Once infiltrating recharge water reaches the water table, biochemical influences take effect and exert a degree of control over water composition and the abundance of various ions in solution. The most significant biochemical influence on groundwater composition is redox (reduction/oxidation) reactions. Redox reactions result in a change of the charge of an ion as it gains or loses an electron. These reactions are almost always facilitated by bacteria that are able to gain energy from the reactions. The solubility of some elements in water depends on whether they are oxidized or reduced. The redox potential can be correlated with the amount of dissolved oxygen. As the oxygen content drops, the environment becomes more reducing (the redox potential drops).

Shallow unconfined groundwater is highly oxidised as a result of recharge processes and the interaction of water with atmospheric oxygen. As the depth below the ground surface increases, the amount of oxygen being diffused from the atmosphere decreases and any dissolved oxygen present is consumed by microbes as they breakdown organic material. Typically, deep and/or confined groundwater systems are oxygen deficient given their disconnection to atmospheric oxygen, and the depletion processes outlined above. In the absence of dissolved oxygen, microbes turn to alternative sources of energy to sustain their metabolism, generally utilising nitrate, manganese, iron and sulphate complexes (in that order). These redox processes influence the relative concentrations of ions in solution depending on the extent and completeness of the reduction processes.

Given the range of factors that can influence groundwater composition, it is generally highly variable on a regional scale, both spatially and with depth. This variability can be seen across the five sites sampled as part of the groundwater chemical quality programme. The general composition and relative abundance of major anions and cations in groundwater at each monitoring site is characterised in Figure 23. The variations in chemical signature between the shallow (GND0508 and GND0827) and deeper sites (GND0430, GND0451 and GND0508) is evident in the upper diamond of the diagram. The clustering of the deeper sites within the diagram is a result of their higher mineral content. Mineral concentrations are higher at these sites as a result of water-rock interaction, facilitated by greater contact time between water and aquifer material. There is a clear correlation between the mineral content ($CO_3 + HCO_3$) at each site and the respective groundwater ages presented in Table 9.

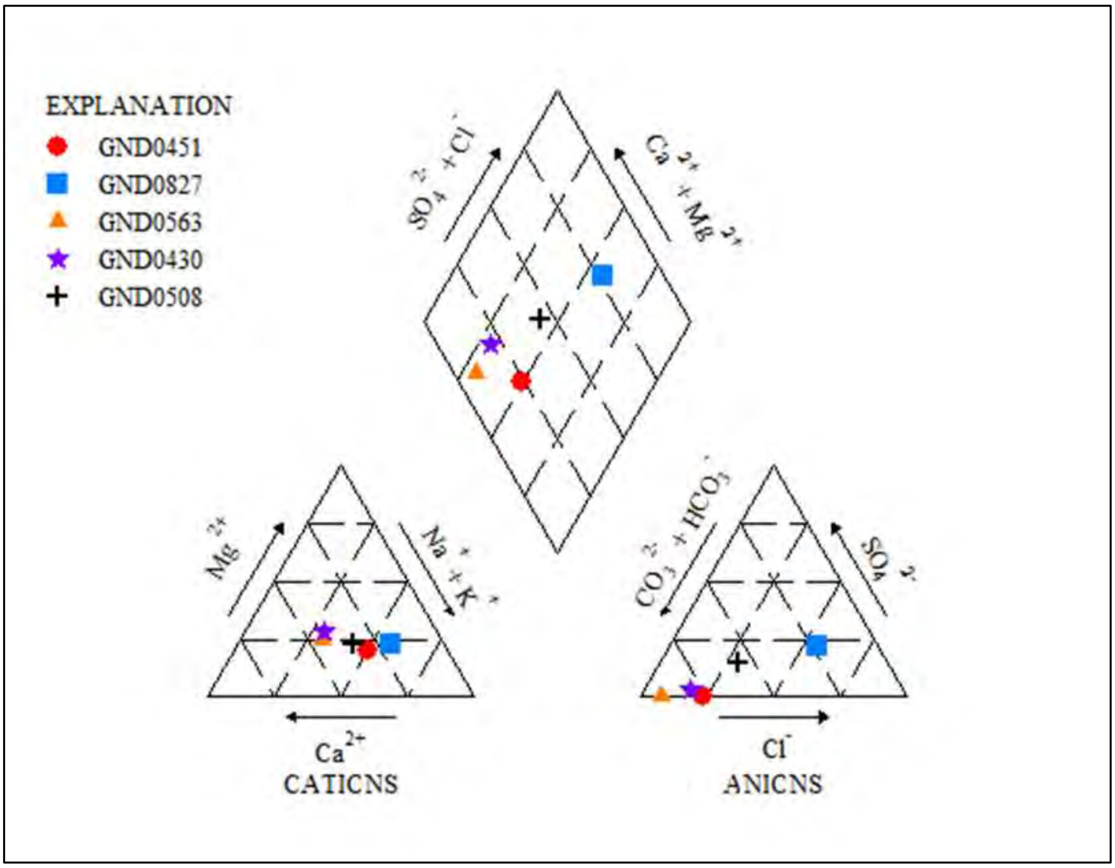

Figure 23 Piper diagram of groundwater composition at each site (based on mean concentrations)

Table 9 Estimated groundwater age at each monitoring site (based on tritium data)

Site	Aquifer	Estimated age (Years)
GND0430	Whenuakura	144
GND0451	Whenuakura	152
GND0508	Volcanics	2
GND0563	Matemateaonga	167
GND0827	Volcanics	2

Given the influence of redox processes on groundwater composition, the redox state of groundwater at each monitoring site has been assessed using the methodology developed by McMahon and Chapelle (2008). This methodology compares measured concentrations of dissolved oxygen, nitrate, manganese, iron and sulphate against threshold values for each parameter to assign a redox classification (Table 10). It should be noted that the length of the screens/open hole sections at sites GND0430 and GND0451 is likely to result in waters of varying oxidation states being drawn into each well. This was particularly evident in the analysis of data from site GND0430, which returned a range of varying redox classifications from oxic to anoxic over the length of the data record. In general however, the redox classifications are comparable with both screen depth and the groundwater ages above, with shallow 'young' groundwater generally more oxidised and deeper 'old' groundwater more reduced.

Table 10 Groundwater redox classifications at each monitoring site

Site	Aquifer	Screen depth		Redox classification
		Top	Bottom	
GND0430	Whenuakura	54	234	Mixed
GND0451	Whenuakura	64	171	Anoxic/mixed
GND0508	Volcanics	8	14	Oxic
GND0563	Matemateaonga	72	77	Anoxic/mixed
GND0827	Volcanics	Unlined to surface		Oxic

As outlined in Section 3 of this report, the only MAV exceedance over the period being reported was for manganese at site GND0451. In addition there were exceedances of GVs for manganese, iron and ammonia at several sites. The redox state of water at each monitoring site is particularly important when assessing the measured exceedances of water quality standards and guidelines presented in the DWSNZ for these parameters.

As discussed previously, elevated iron and manganese concentrations are often indicators of reduced (low oxygen) conditions within an aquifer. In addition, nitrate is typically absent in such environments or exists in extremely low concentrations, with any nitrogen present as ammonia. Microbes present within aquifers require energy to drive their metabolic processes and will preferentially use any dissolved oxygen present within the aquifer, as this is the most efficient energy source. Once all oxygen within an aquifer is depleted, microbes will utilise nitrate, iron (Fe^{3+}) and manganese (Mn^{3+}/Mn^{4+}) as energy sources. The end products of these reduction processes are ammonia, iron (as Fe^{2+}) and manganese (as Mn^{2+}). The reduced forms of iron and manganese are more soluble in water than the oxidised forms, which increase the amount of iron and manganese dissolved in groundwater. The influence of redox processes on observed concentrations of nitrate, ammonia, manganese and iron are illustrated in Figures 24, 25, 26 and 27, which plot their mean concentrations at each site against screen mid point depth. It is clearly evident that groundwater drawn from deeper, less oxidised aquifers display higher concentrations of ammonia, iron and manganese than observed at shallow sites. Similarly, groundwater drawn from shallow sites has higher concentrations of nitrate, indicating reduction is not occurring in these more oxidised groundwater environments. The plotted results from site GND0430 do not correspond with results from other deep sites as a result of the long screened interval and resultant mixing of groundwater from different redox zones.

The only other exceedance of any GV stipulated in the DWSNZ was in relation to low pH (<7) at sites GND0508 and GND0827, indicating groundwater at these sites is slightly acidic in nature. These sites are the two shallowest sites sampled as part of the groundwater chemical quality monitoring programme and therefore represent relatively 'young' groundwater (Table 9). The slightly acidic nature of groundwater at these sites is a result of the acidifying influences of rainwater recharge and biochemical processes. Rainwater falling on land surfaces is slightly acidic in nature and is further acidified as it percolates through the soil profile and interacts with CO_2 generated by the microbial breakdown of organic matter. The interaction of percolating rainfall water with CO_2 results in the formation of carbonic acid, acidifying the water recharging these shallow wells. The pH values observed in shallow groundwater fall only marginally outside the lower GV for pH however and pose no health based risk (although corrosive to plumbing fittings)

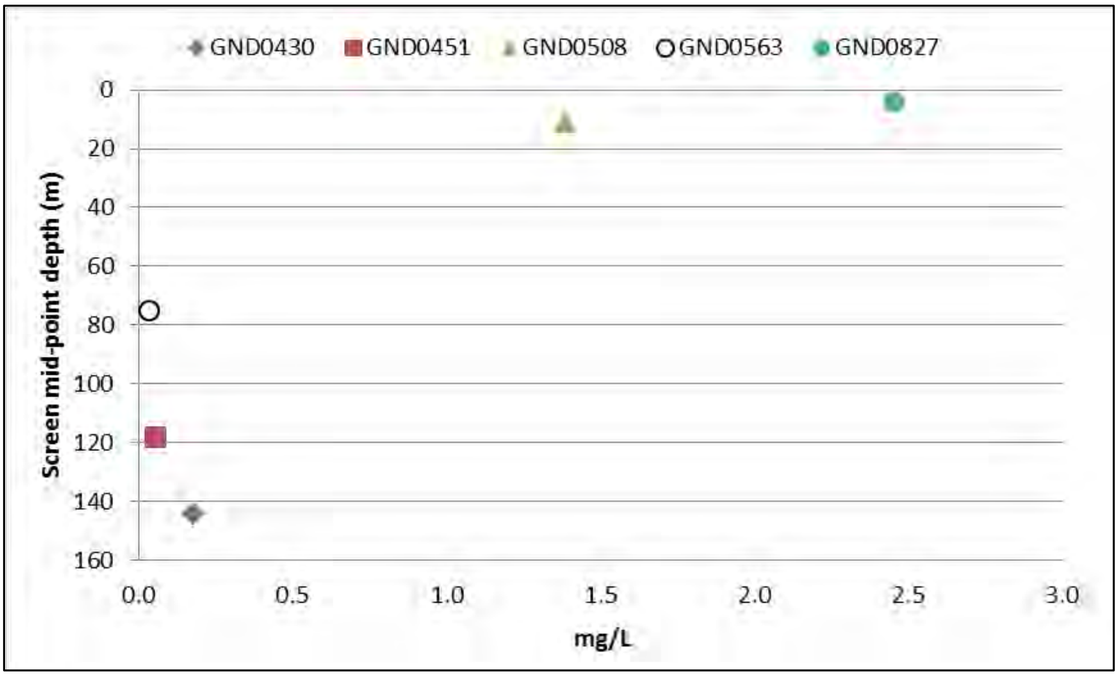

Figure 24 Mean nitrate concentrations by site (1994-2013) vs. screen mid point depth

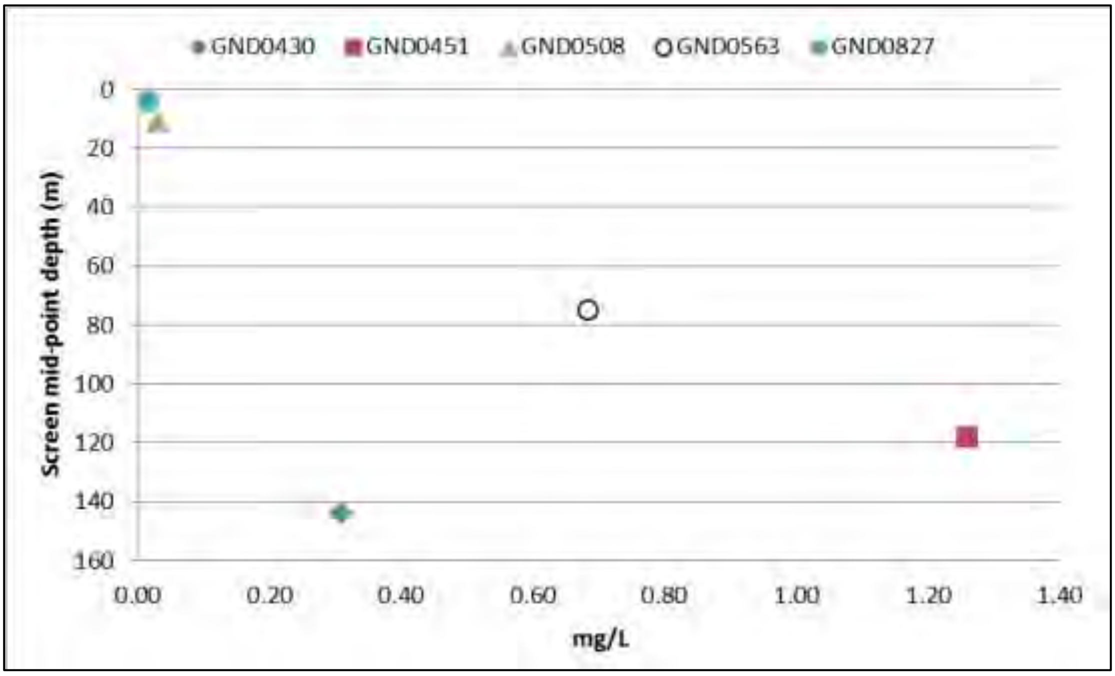

Figure 25 Mean ammonia concentrations by site (1994-2013) vs. screen mid point depth

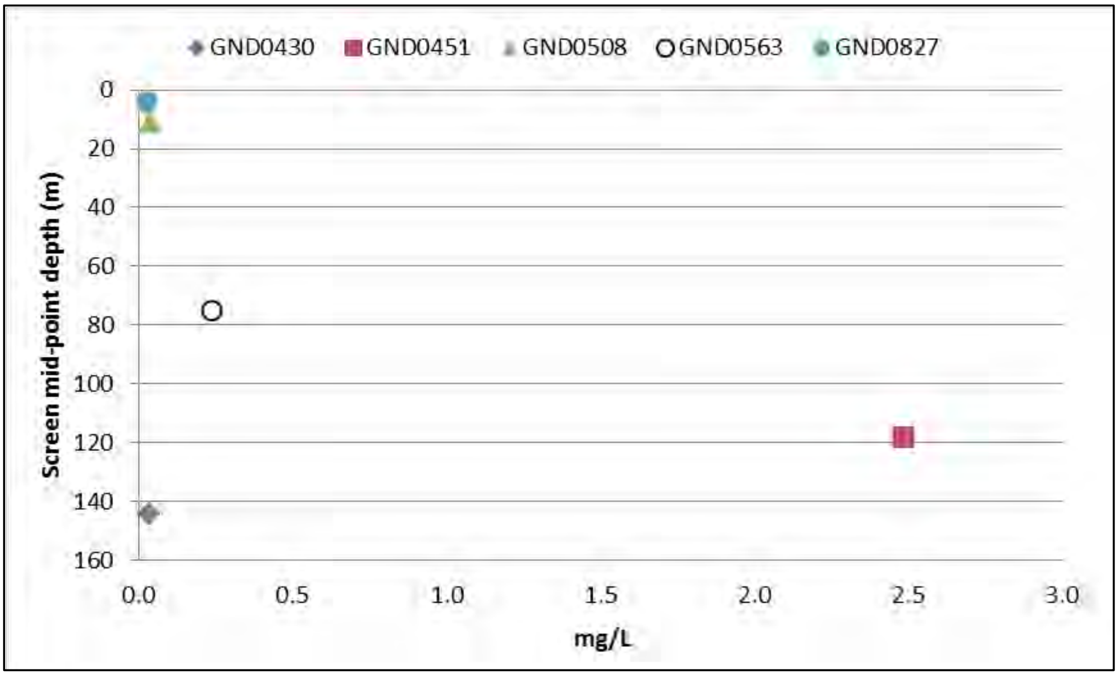

Figure 26 Mean iron concentrations by site (1994-2013) vs. screen mid point depth

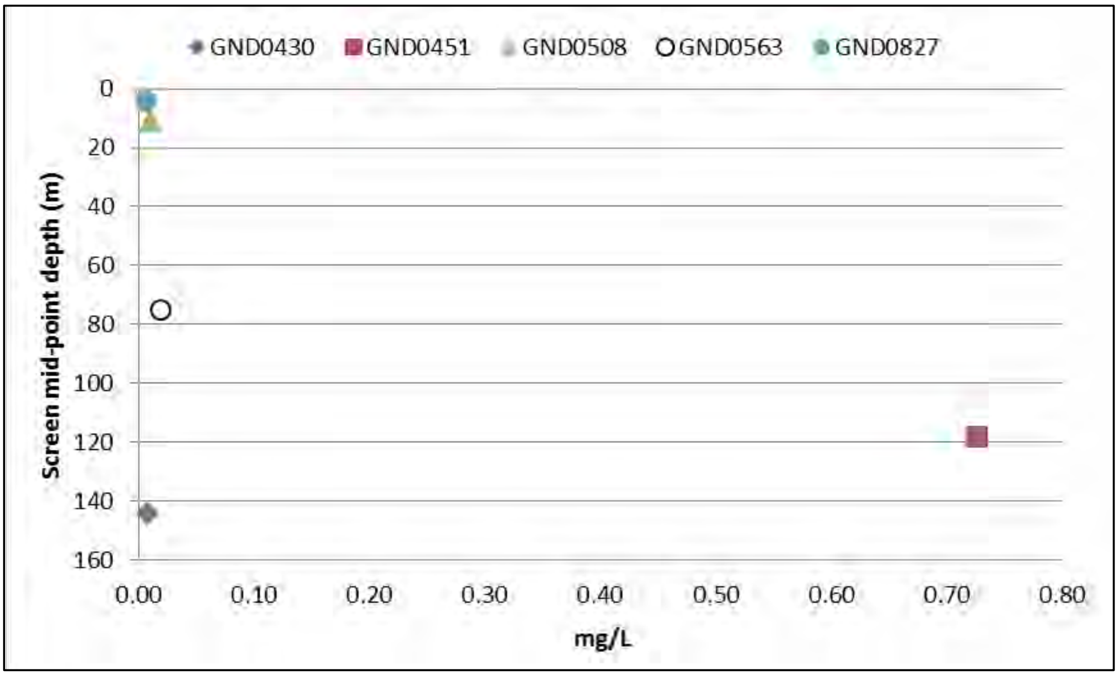

Figure 27 Mean manganese concentrations by site (1994-2013) vs. screen mid point depth

Natural subsurface processes are also responsible for the majority of 'meaningful' trends identified in analyte concentrations. The majority of trends at deeper sampling sites (GND0430, GND0451 and GND0563) relate to analytes impacted by reducing conditions, including nitrate, ammonia, iron, manganese and sulphate. Increasing fluoride concentrations at site GND563 are likely due to increased dissolution of fluoride or fluorite bearing rock within the Matemateaonga aquifer. Were this fluoride coming from human activity (fertilizer use) a strong increase in dissolved phosphorus would be present.

The spikes in some redox related parameters at site GND0563 over the period 2012 to 2013 are noted (Figures 10, 11 and 12). These spikes indicate that a change in redox conditions occurred within the aquifer over this period. While the exact cause of this change remains unclear, it may be related to changes in abstraction rates from the bore over the corresponding period. The concentrations of all analytes had returned to 'typical' values for this site by the end of the monitoring period.

The trends identified at shallow sampling sites appear to be driven by a wider range of processes than those at deeper sites. At site GND0827, the increasing bicarbonate concentrations are likely due to either the dissolution of carbonate minerals from within the shallow aquifer, or by the disassociation of carbonic acid, which produces bicarbonate ions. Another by-product of this reaction is hydrogen ions, which in turn reduce pH levels and it is noted that, outside of some potential outliers in the data set, pH values are relatively low at this site. The increasing fluoride concentrations at the site do however indicate that there is some degree of mineral dissolution occurring within the shallow aquifer. There is also an increasing trend in sulphate concentrations at the site, although actual concentrations remain low. The sulfate/magnesium ratios in groundwater samples from this site do not resemble those associated with rainfall, indicating the source of sulphate lies elsewhere, possibly related to nutrient inputs in the area. Reductions in bromide and chloride concentrations indicate a reduction in rainfall recharge volumes at the site.

At site GND0508, the reduction in nitrate concentrations is a result of reduced nutrient inputs at surface, such as reductions in animal effluent or organic fertiliser loadings. Changes in chloride concentrations are once again likely to be a result of changes in recharge characteristics in the vicinity of the site.

5. Conclusions

The results of the monitoring carried out as part of the groundwater chemical quality programme indicate the chemical composition of groundwater was relatively stable at all sites monitored over the period 1994 to 2013, given that there will always be a degree of minor variation due to the dynamic nature of groundwater systems. The meaningful trends that could be observed in the data from each site relate predominantly to parameters whose concentrations are affected by natural subsurface processes rather than anthropogenic influences.

The results indicate exceedances of the MAV for manganese at a single site and exceedances of aesthetic GVs for some analytes across most sites. The exceedances are as a result of natural subsurface processes, primarily the dissolution of minerals from geological material within the aquifers themselves and biochemical processes. As expected, evidence of mineral dissolution is more pronounced in deeper groundwater systems monitored as part of the programme, including the Whenuakura and Matemateaonga aquifers. Data from these aquifer systems also indicate the occurrence and effects of natural biochemical processes attributed to oxygen deficient environments. These biochemical processes are exerting the greatest control on water quality within the deep aquifer systems being monitored.

The results of the sampling at sites drawing shallow groundwater from the Taranaki volcanics aquifer indicate some minor variability in groundwater composition in response to landuse activities, specifically nitrate concentrations. This is not unexpected given the greater susceptibility of shallow groundwater systems to the impacts associated with landuse activities. Trend analysis of nitrate data indicates a statistically significant reduction in nitrate concentrations at one shallow groundwater site monitored as part of the programme. There was no identifiable trend in nitrate concentrations at the only other shallow groundwater site monitored. The observed concentrations at all sites monitored remain well below the MAV for nitrate.

In summary, the data collected as part of the groundwater chemical quality programme does not indicate any major issues with the general quality of groundwater at any of the sites monitored. The data indicates that natural subsurface processes are exerting the greatest influence on water quality at each site and there are some temporal trends in the concentrations of certain parameters at some sites as a result of these processes. There is no evidence of any significant deterioration in water quality as a result of any landuse activities.

6. Recommendations

It is recommended:

1. THAT the results of the analysis presented in this report be noted for inclusion in the next ‘State of the Environment’ report to be prepared by the Council.

2. THAT the analysis of data gathered during forthcoming monitoring periods follow the same format as the data analysis presented in this report;

3. THAT reports associated with the groundwater chemical quality programme and its results be produced on a two yearly basis;

4. THAT the number of sites being monitored as part of the programme be increased over the forthcoming monitoring period;

5. THAT consideration is given to integrating all groundwater quality related SEM programmes (groundwater chemical quality, nitrates in shallow groundwater and pesticides in groundwater programmes) into a single programme and that the results and interpretation of all data be incorporated into a single biennial report.

Glossary of common terms and abbreviations

The following abbreviations and terms are used within this report:

Anoxic	Water that is depleted of dissolved 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.
DWSNZ	Drinking Water Standards for New Zealand 2008 (revised 2008).
GV	Guideline Value for aesthetic purposes only (taken from DWSNZ).
Impervious	To not allow fluid to pass through.
NGMP	National Groundwater Monitoring Programme.
MAV	Maximum Acceptable Value for determinands of health concern (taken from DWSNZ).
m BGL	Metres below ground level
Objective	A statement of a desired and specific environmental outcome.
Outlier	An outlier is an observation point that is distant from other observations. An outlier may be due to variability in the measurement or it may indicate an error.
Oxic	Water containing dissolved oxygen
Physiochemical	Measurement of both physical properties (e.g. temperature, clarity, density) and chemical determinands (e.g. metals and nutrients) to characterise the state of an environment.
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.
Recharge	The addition of water from other sources to an aquifer, e.g., seepage from rivers, 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.
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.
RPS	Regional Policy Statement.
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.
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.

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