



greater WELLINGTON
REGIONAL COUNCIL
Te Pane Matua Taiao

Groundwater Quality State of the Environment monitoring programme

Annual data report, 2012/13

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1. Introduction

This report summarises the results from Greater Wellington Regional Council's (GWRC) Groundwater Quality State of the Environment (GQSoE) monitoring programme for the period 1 July 2012 to 30 June 2013 inclusive. The GQSoE programme incorporates quarterly monitoring of water quality in 71 bores across the Wellington region.

Reports containing detailed analyses of long-term trends are produced approximately every five years (see Jones & Baker 2005, Tidswell et al 2012).

2. Overview of GQSoE monitoring programme

Groundwater quality has been routinely monitored in the western half of the Wellington region (Kapiti Coast and Hutt Valley) since 1994 and in the Wairarapa since 1997. Up until 2003, this monitoring was effectively conducted under two separate programmes, with some differences in the suite of water quality variables and analytical methods. From late 2003, management practices were aligned to provide consistency in sampling methods, sampling frequency (increased from six-monthly to quarterly), analysis and reporting. At this time, a number of changes were also made to the location of monitoring sites, the range of variables monitored and the methods of analysis to improve the representativeness and quality of the information collected (see Jones & Baker 2005 and Tidswell et al 2012) for more details.

2.1 Monitoring objectives

The aims of GWRC's GQSoE monitoring programme are to:

1. Provide information on the baseline quality of groundwater;
2. Describe the current state of the region's groundwater resources at a regional scale;
3. Assist in the detection of spatial and temporal changes in groundwater quality;
4. Recommend the suitability of groundwater for designated uses; and
5. Provide a mechanism to determine the effectiveness of regional policies and plans.

2.2 Monitoring network

The existing GQSoE monitoring network consists of 71 bores (Figure 2.1, Appendix 1). During the 2012/2013 year, only 68 bores were sampled. Three bores could not be used for the reasons shown below:

- Bore S25/5256 was purchased by Transit for the Peka Peka to Otaki Expressway (note that GWRC are currently trying to gain access to the bore to continue sampling).
- Bore R27/1180 has not been able to be sampled due to prolific growth of iron bacteria. However, it is hoped this bore will be online again by early next year.
- Bore R27/1137 has been decommissioned by its owner and pumping equipment removed.

Faecal indicator bacteria¹ are only tested for in 44 of the 71 bores. As sampling could not be conducted at bore R27/1137, only 43 bores were tested for the presence of faecal indicator bacteria during 2012/13.

¹ *Escherichia coli* and faecal coliforms are only tested for in GQSoE bores that are used for potable water supply.

With the exception of a single bore at Riversdale on the eastern Wairarapa Coast, all bores are located in one of the three principal groundwater management areas in the Wellington region; the Kapiti Coast, Lower Hutt Valley or the Wairarapa Valley (see Jones & Baker 2005 and Hughes & Gyopari 2011 for a description of groundwater management areas in the Wellington region).

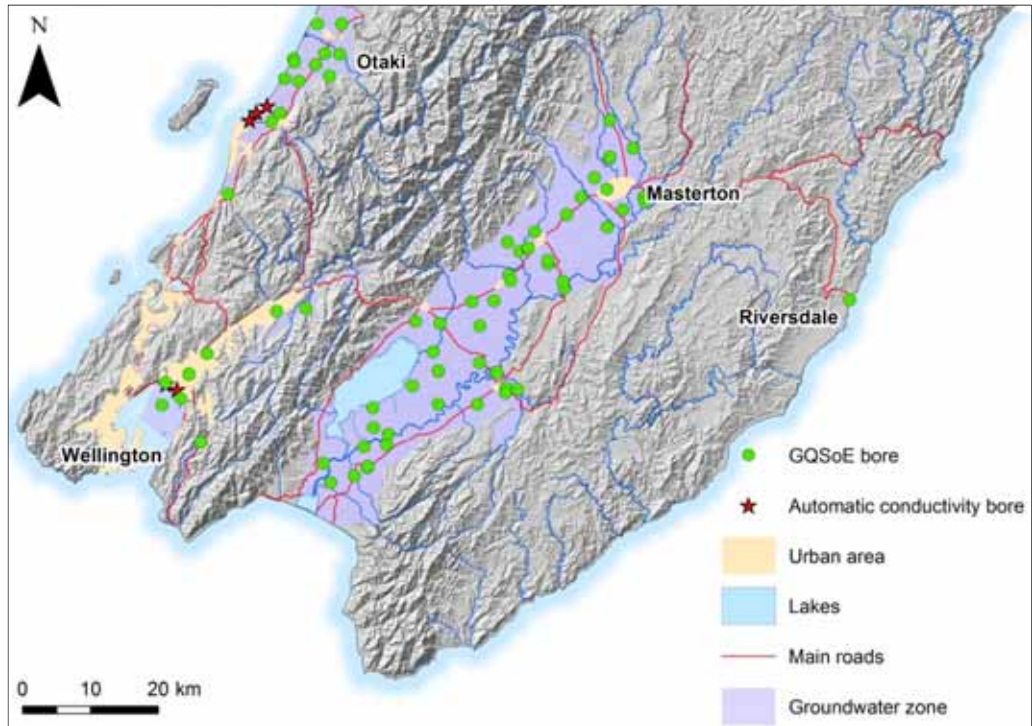


Figure 2.1: Location of groundwater quality monitoring sites in the Wellington region. Automated saline intrusion (conductivity) groundwater monitoring sites are also shown (red stars).

2.3 Monitoring variables

The GQSoE network is sampled quarterly for a wide range of physico-chemical and microbiological variables. Groundwater samples are collected by trained GWRC staff using nationally accepted protocols (Ministry for the Environment 2006).

Groundwater quality is assessed by measuring 31 different variables including pH, conductivity, turbidity, faecal indicator bacteria, total organic carbon, dissolved nutrients and major ions. A full list of the variables measured and the analytical methods used are provided in Appendix 2.

3. Physico-chemical and microbiological water quality

3.1 Approach to analysis

This section provides a brief overview of groundwater quality in the 2012/13 year. As the sampling regime only provides four sets of results per bore per year, a comprehensive evaluation of all the different variables is not undertaken on an annual basis. Instead, the analysis in this report focuses on two key indicators of groundwater contamination arising from landuse intensification and/or on-site wastewater disposal systems; nitrate-nitrogen (nitrate) and *Escherichia coli* (*E. coli*) bacteria.

Details of the analytical methods used are provided in Appendix 2 (Table A2.2). Summary statistics were calculated using Hilltop Hydro (Version 6.37) and full data summaries are provided in Appendix 3. Data with values less than the laboratory's analytical detection limit were assigned a value of half their respective detection limit.

3.2 Results

3.2.1 Nitrate

Median nitrate concentrations were low (<3 mg/L) in most of the 68 bores monitored during 2012/13. Six of 68 (8.8%) bores had elevated (3-7 mg/L)² concentrations of nitrate (Figure 3.1). A further four bores in Kapiti and the upper Wairarapa Valley had median nitrate concentrations in the relatively high range (7-11.3 mg/L).

No bores had median nitrate concentrations above the Ministry of Health Drinking Water Standards (DWSNZ) 2008 maximum acceptable value (MAV) of 11.3 mg/L. However bore T26/0489 had a median nitrate concentration of 11.2 mg/L and on one sampling occasion had a nitrate concentration of 11.4 mg/L, which is above the DWSNZ MAV. This bore is located in the upper Wairarapa Valley and is 54 metres deep. No maximum nitrate concentrations were above the DWSNZ MAV in any other bore.

² While most groundwater in New Zealand rarely has background nitrate-nitrogen concentrations exceeding 1 mg/L (Close et al. 2001), in this report 3 mg/L nitrate nitrogen is used as an indicator of anthropogenic influence in order to increase certainty caused by variability. A threshold concentration of 3 mg/L was also used by Madison & Brunett (1985) and Close et al. (2001). See Tidswell et al. (2012) for further discussion.

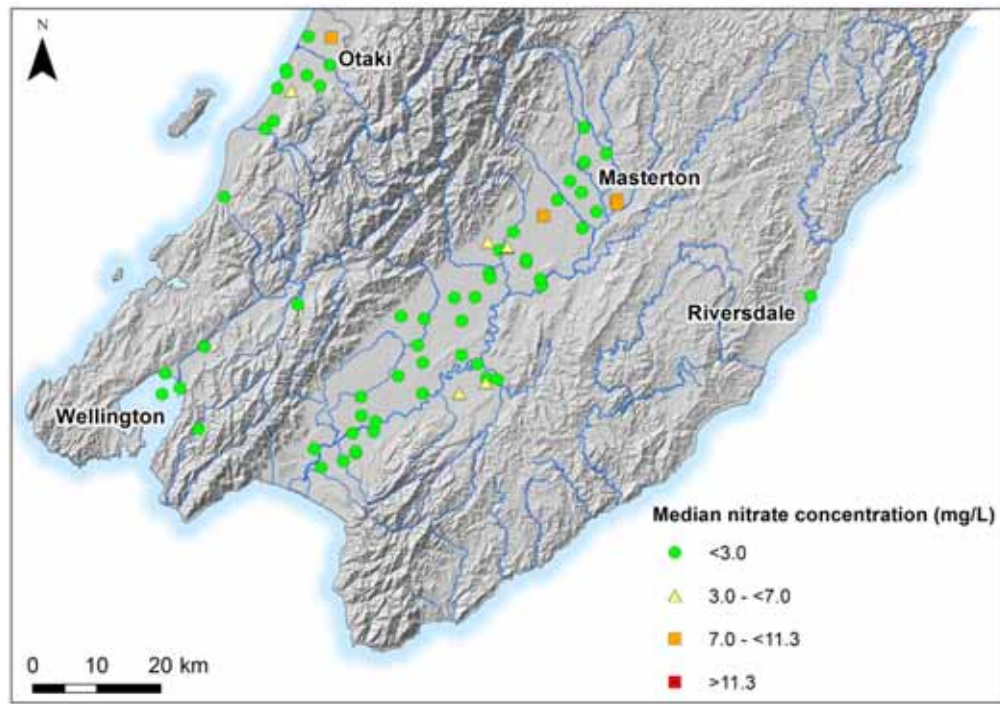


Figure 3.1: 2012/13 median nitrate concentrations in GQSoE monitoring bores

Overall, nitrate contamination was found in bores where previous sampling has detected elevated nitrate concentrations, in areas of intensive agriculture (Wairarapa) and horticulture (Kapiti Coast). The wide-ranging depth of bores with elevated nitrate concentrations (<5 m to 54 m) suggests that nitrate contamination is not limited to shallow unconfined aquifers but is able to migrate into deeper aquifer systems³.

Groundwater discharges to a number of surface water bodies throughout the region and there is the potential that groundwater discharge high in nitrate could contribute to the decline of surface water quality. The ANZECC (2000) guidelines are commonly used to assess physico-chemical aspects of surface water quality in rivers and streams. Median nitrate concentrations were above the ANZECC (2000) trigger value for lowland ecosystems (0.444 mg/L) in 34 of the 68 (50%) bores. Of these, 16 (24%) recorded median concentrations above the Hickey (2013) threshold for aquatic toxicity (2.4 mg/L)⁴.

3.2.2 *E. coli*

The DWSNZ uses *E. coli* as an indicator⁵ of faecal contamination in drinking water. For drinking water supplies, *E. coli* counts should be <1 cfu/100mL.

E. coli was not detected (ie, <1 cfu/100mL) in 26 of the 43 (60%) bores monitored.

³ This is particularly evident in recharge areas, with elevated nitrate concentrations not commonly found in deeper confined aquifers.

⁴ This (median) value replaces the former threshold of 1.7 mg/L (Hickey & Martin 2009) and is a recommended replacement value for the ANZECC (2000) toxicity threshold value of 7.2 mg/L.

⁵ It is impracticable to monitor water supplies for all potential human pathogens, so surrogates are used to indicate possible contamination from such things as human and animal excrement, these being the most frequent causes of health-significant microbial contamination in drinking water supplies.

E. coli was detected (ie, ≥ 1 cfu/100mL) on one or more occasions in 17 of the 43 (40%) bores tested (Figure 3.2). The highest *E. coli* count was 1600 cfu/100mL in bore R25/5164 at Te Horo Beach. Te Horo Beach is a small settlement reliant on onsite wastewater treatment systems for effluent disposal. Previous studies involving dye tracer tests have confirmed that groundwater at Te Horo Beach is able to move from wastewater treatment systems into nearby bores relatively quickly (Hughes 1998). It is possible that the microbial contamination in bore R25/5164 is due to the bore's proximity to a nearby wastewater treatment system. This bore is not used as a potable drinking water supply.

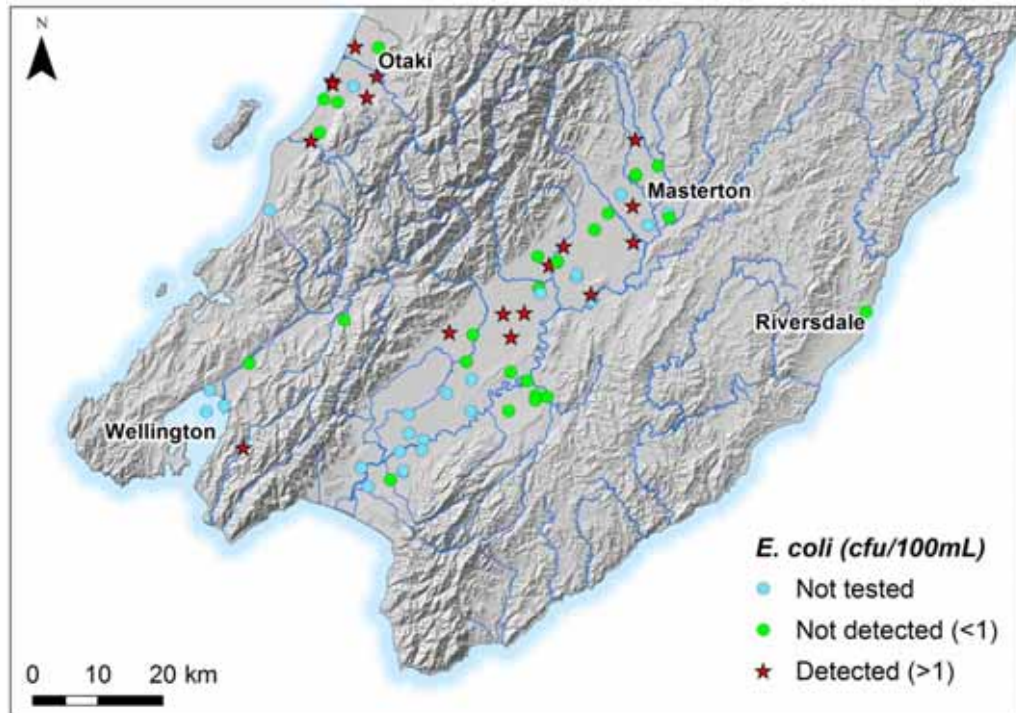


Figure 3.2: Detection of *E. coli* bacteria in GQSoE monitoring bores in 2012/13

References

ANZECC 2000. *Australian and New Zealand Guidelines for Fresh and Marine Water Quality, Volume 1, The Guidelines*. Australian and New Zealand Environment and Conservation Council. Agriculture and Resource Management Councils of Australia and New Zealand, Canberra.

Close ME, Rosen MR and Smith VR. 2001. *Fate and transport of nitrates and pesticides in New Zealand's aquifers*. In Rosen MR, and White PA, (Eds), *Groundwaters of New Zealand*. New Zealand Hydrological Society, Wellington.

Hickey C and Martin M. 2009. *A review of nitrate toxicity to freshwater aquatic species*. Christchurch, Environment Canterbury.

Hilltop Hydro (Version 6.37). Hilltop Software Ltd 1998-2013.

Hughes B. 1998. *Te Horo Beach groundwater quality investigation*. Wellington Regional Council, Publication No. WRC/RINV-T-98/10.

Hughes B and Gyopari M. 2011. *Wairarapa Valley groundwater resource investigation: Proposed framework for conjunctive water management*. Greater Wellington Regional Council, Publication No. GW/EMI-T-11/53, Wellington.

Jones A and Baker T. 2005. *Groundwater monitoring technical report*. Greater Wellington Regional Council, Publication No. GW/RINV-T-05/86.

Madison RJ and Brunett JO. 1985. *Overview of the occurrence of nitrate in groundwater of the United States*. In *National water summary, 1984 – Hydrologic events, selected water quality trends, and groundwater resources*. U.S. Geological Survey – Supply Paper 2275, pp. 93–105.

Ministry of Health. 2008. *Drinking Water Standards for New Zealand 2005*. Ministry of Health, Wellington.

Ministry for the Environment. 2006. *A national protocol for state of the environment groundwater sampling in New Zealand*. Ministry for the Environment, Wellington.

Tidswell S, Conwell C and Milne JR. 2012. *Groundwater quality in the Wellington region, state and trends*. Greater Wellington Regional Council, Publication No. GW/EMI-T-12/140.

WRC 1999. *Regional Freshwater Plan for the Wellington Region*. Wellington Regional Council, Publication No. WRC/RP-G-99/31.

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Appendix 1: GQSoE monitoring sites

Site number	Site name	X coordinates	Y coordinates	Groundwater zone	Category
Kapiti Coast					
R25/5100	O'Malley	1774552.15	5479451.35	Te Horo	Category B
R25/5135	Windsor Park	1779152.45	5481483.39	Te Horo	Category C
R25/5164	Card	1775873.28	5482367.50	Te Horo	Category B
R25/5165	Salter	1776019.28	5481886.47	Te Horo	Category B
R25/5190	Williams	1776678.23	5478988.27	Te Horo	Category B
R25/5233	Otaki Porirua Trust	1779397.56	5487564.84	Otaki	Category A
R26/6503	Queen Elizabeth Park	1766253.09	5462295.15	Raumati	Category B
R26/6587	Liddle	1772633.83	5473057.09	Waikanae	Category A
R26/6624	Boffa	1773932.93	5474297.10	Waikanae	Category B
S25/5125	Betty Partnership	1782733.73	5483013.44	Otaki	Category A
S25/5200	Common Property	1781182.52	5479785.21	Te Horo	Category C
S25/5256	Penray	1780490.58	5483153.49	Te Horo	Category C
S25/5322	Edhouse	1782982.85	5487485.83	Otaki	Category C
Hutt, Mangaroa and Wainuiomata Valley					
R27/0320	IBM 1	1756996.50	5434507.51	Hutt Valley	Category B
R27/1137	South Pacific Tyres	1773406.32	5444956.34	Hutt Valley	Category A
R27/1171	Somes Island	1756493.07	5431226.71	Hutt Valley	Category B
R27/1180	Mahoe/Willoughby St	1760435.48	5435698.05	Hutt Valley	Category B
R27/1182	Seaview Wools	1759274.04	5432161.32	Hutt Valley	Category B
R27/1183	Television New Zealand	1763083.77	5438690.64	Hutt Valley	Category A
R27/1265	IBM 2	1756997.50	5434515.51	Hutt Valley	Category B
R27/6418	Wainuiomata Golf Club	1762217.86	5425695.18	Wainuiomata	Unknown
R27/6833	Mangaroa School	1777716.35	5445323.81	Mangaroa	Unknown
Wairarapa Valley					
S26/0117	Butcher, G	1811483.15	5456780.11	Mangatarere	Category A
S26/0223	Nicholson	1816203.19	5459284.79	Taratahi	Category B
S26/0299	Graham	1818354.91	5461869.91	Taratahi	Category B
S26/0439	Rogers	1807492.42	5455180.48	Mangatarere	Category B
S26/0457	Palmer Berry Fruits	1807656.62	5450330.89	Waiohine	Category A
S26/0467	Fitzgerald	1809272.40	5453850.06	Mangatarere	Category A
S26/0568	Denbee	1813486.57	5451921.15	Parkvale	Category B
S26/0576	Mcnamara	1813461.67	5452534.23	Parkvale	Category B
S26/0705	Carterton District Council South	1810471.61	5454278.93	Mangatarere	Category B
S26/0756	Stevenson	1815919.19	5448296.24	Middle Ruamahanga	Category A
S26/0762	Schaefer	1815702.37	5449348.42	Middle Ruamahanga	Category A
S26/0824	Carterton District Council North	1810546.63	5454380.93	Mangatarere	Category B
S26/0846	Druzianic	1807902.50	5449491.76	Waiohine	Category A
S27/0009	Dondertman	1793895.42	5443481.45	Tauherenikau	Category B
S27/0070	South Featherston School	1797507.54	5443110.86	Tauherenikau	Category B
S27/0136	Sugrue	1802217.44	5446389.36	Tauherenikau	Category B
S27/0156	O'Neale	1803402.88	5442775.85	Tauherenikau	Category B
S27/0202	Croad	1805460.73	5446519.85	Tauherenikau	Category B
S27/0268	Barton	1793452.70	5434055.07	Lake	Category B
S27/0283	Osborne	1797276.24	5436168.48	Tauherenikau	Category B
S27/0299	Johnson	1796503.73	5438935.77	Tauherenikau	Category A
S27/0344	George	1803347.81	5437340.43	Lower Ruamahanga	Category A
S27/0389	Dimattina	1807205.35	5433792.40	Martinborough	Category C
S27/0396	SWDC Martinborough	1805858.70	5435961.84	Lower Ruamahanga	Category A
S27/0433	Mapuna Atea	1787692.45	5427838.97	Lake	Category B
S27/0435	Wairio	1787608.01	5430805.03	Lake	Category B
S27/0442	Robinson Transport	1789891.27	5426883.54	Lake	Category B
S27/0495	Bosch	1797227.31	5431330.26	Lower Ruamahanga	Category A
S27/0522	Duggan	1803031.58	5431324.10	Martinborough	Category C
S27/0571	Martinborough Golf Club	1807158.18	5433014.36	Martinborough	Category C
S27/0585	McCreary	1780320.53	5422598.32	Onoke	Category C
S27/0588	SWDC Piriona	1784844.06	5420713.48	Onoke	Category A
S27/0594	Warren	1781350.93	5419721.16	Onoke	Category C
S27/0602	Weatherstone	1789625.95	5425301.57	Lake	Category B

Site number	Site name	X coordinates	Y coordinates	Groundwater zone	Category
S27/0607	Finlayson	1786288.91	5425037.20	Lake	Category B
S27/0614	Sorenson South	1786778.28	5421924.10	Unknown	Unknown
S27/0615	Sorenson North	1786805.33	5422158.09	Unknown	Unknown
S27/0681	Te Kairanga Wines	1808952.42	5433542.02	Huangaaru	Category A
T26/0003	Lenton	1822559.22	5473236.52	Upper Ruamahanga	Category B
T26/0087	Biss	1820295.66	5464750.15	Waingawa	Category C
T26/0099	Butcher, M	1822518.46	5467619.40	Upper Ruamahanga	Category B
T26/0206	Thornton	1822581.50	5467829.43	Upper Ruamahanga	Category B
T26/0259	Opaki Water Supply Association	1825997.33	5469120.23	Upper Ruamahanga	Category A
T26/0332	Taratahi Agricultural Training Centre	1822230.80	5457401.54	Fernhill-Tiffen	Category C
T26/0413	Seymour	1824485.62	5459978.64	Waingawa	Category B
T26/0430	Trout Hatchery	1822130.71	5463027.57	Waingawa	Category B
T26/0489	Duffy	1827571.49	5461854.50	Te Ore Ore	Category B
T26/0538	Percy	1827738.41	5461169.34	Te Ore Ore	Category B
Riversdale					
T27/0063	Acacia Ave	1858025.04	5446630.37	Riversdale	Unknown
Saline intrusion monitoring					
R26/6378	Rutherford Drive	1771994.91	5475389.21	Waikanae	Category B
R26/6566	Waikanae Estuary Shallow	1769406.76	5473310.22	Waikanae	Category A
R26/6673	Taiata Shallow	1770438.83	5474422.22	Waikanae	Category B
R26/6955	Taiata Deep	1770438.83	5474422.22	Waikanae	Category B
R26/6956	Waikanae Estuary Deep	1769406.76	5473310.22	Waikanae	Category A
R27/0122	McEwan Park Shallow	1758681.27	5433523.34	Hutt Valley	Category B
R27/7153	McEwan Park Deep	1758681.27	5433523.34	Hutt Valley	Category B
R27/7154	Tamatoa Deep	1757019.47	5434294.51	Hutt Valley	Category B
R27/7215	Tamatoa Shallow	1757021.47	5434298.51	Hutt Valley	Category B

Appendix 2: Monitoring variables and analytical methods

Groundwater samples are collected quarterly by trained GWRC staff using nationally accepted protocols (Ministry for the Environment 2006). This involves purging the bore for a predetermined amount of time to remove any standing water and monitoring the pumped water continuously until field measurements (eg conductivity) stabilise. Field measurements (temperature, conductivity, pH and dissolved oxygen) are taken using field meters which are calibrated on the day of sampling.

Water samples are stored on ice upon collection and transported to an external laboratory within 24 hours of sampling. RJ Hill Laboratories in Hamilton analysed the samples for the variables listed in Table A2.1

The rationale for variables monitored is detailed in Table A2.1 and analytical methods are summarised in Table A2.2.

Table A2.1. Rationale for inclusion in GQSoE sampling regime

Test type	Variable	Rationale for inclusion
Bacteria	Faecal coliforms <i>E. coli</i>	Faecal coliforms and <i>E. coli</i> can indicate pollution due to faecal matter and the presence of potentially harmful pathogens in groundwater. Ministry for the Environment uses <i>E. coli</i> as an indicator of ground water quality.
Major ions	Dissolved sodium Dissolved potassium Dissolved calcium Dissolved magnesium Chloride Sulphate Total alkalinity	Concentrations of major ions can give an indication of the chemical composition of the water, the origins of groundwater, water residence time in the aquifer and extent of rock/water interaction. Concentrations of major ions can also be indicative of groundwater contamination from industrial, agricultural and domestic sources.
Nutrients	Total ammoniacal nitrogen Nitrite-nitrate nitrogen (NNN) Nitrate nitrogen Nitrite nitrogen Dissolved reactive phosphorus	Dissolved concentrations of nutrients can indicate impact from anthropogenic activity such as intensive land use. Nitrate nitrogen represents the oxidised form of nitrogen. Elevated concentrations of nitrate nitrogen can have an adverse affect on human health and can be harmful to biota. Total ammoniacal nitrogen usually exists under oxygen-poor conditions and represents the reduced form of nitrogen. Therefore, can be used as an indicator of contamination in the absence of nitrate nitrogen. The ANZECC guidelines (2000) state trigger values for the direct toxicity to biota.

Table A2.1 cont. Rationale for inclusion in GQSoE sampling regime

Chemical tests	Variable	Rationale for inclusion in sampling regime
Metals	Dissolved iron	Trace metals are usually present in groundwater at low concentrations. Elevated concentrations of trace metals can suggest contamination of groundwater. Elevated concentrations of dissolved lead and manganese can have an adverse affect on human health.
	Dissolved manganese	
	Dissolved lead	
	Dissolved zinc	
Trace elements	Bromide	Bromide naturally occurs in water but can suggest contamination from wastewater and agricultural run off. Elevated concentrations of dissolved boron can have an adverse affect on human health and the DWSNZ (2005) MAV for fluoride is set to protect against potential dental fluorosis.
	Fluoride	
	Dissolved boron	
Other	pH	Water with a low pH can have a high plumbosolvency. Measured in the field to identify when the bore is purged and sample can be collected.
	Electrical conductivity	Electrical conductivity can provide a measure of total dissolved solids. Measured in the field to identify when the bore is purged and sample can be collected.
	Dissolved oxygen	Dissolved oxygen can indicate whether groundwater is under reduced or oxidised conditions. Measured in the field to identify when the bore is purged and sample can be collected.
	Dissolved reactive silica	Can help interpret the extent of rock/water interaction
	Total organic carbon (TOC)	Can indicate the presence of organic matter (either from wastewater or natural sources) in groundwater.
Calculations	Total dissolved solids (TDS)	Can indicate the extent of rock/water interaction.
	Free carbon dioxide (CO ₂)	Can indicate the extent of rock/water interaction.
	Bicarbonate (H ₂ CO ₃)	Can indicate the extent of rock/water interaction.
	Total hardness	Can indicate the extent of rock/water interaction.
	Total anions	Sum of all anions
	Total cations	Sum of all cations
	% Difference in ion balance	Difference between the sum of all anions and the sum of all cations. Can be used as a measure of analytical accuracy of water quality data. Value should be 0% but generally a difference of <5% is considered acceptable.

NB: Groundwater samples are also tested for arsenic, chromium, cadmium, nickel and copper but on a not routine basis. Conductivity and pH are tested both in the field and by Hills Laboratory. Dissolved oxygen is only tested for in the field.

Table A2.2. Analytical methods

Variable	Method Used	Detection Limit
Temperature	Field meter – Hach HQ40d, YSI 556 , WTW P4 Multiline and WTW350i Meters	0.01 °C
Dissolved oxygen	Field meter – Hach HQ40d, YSI 556 , WTW P4 Multiline and WTW350i Meters	0.01 mg/L
Electrical conductivity	Field meter – Hach HQ40d, YSI 556 , WTW P4 Multiline and WTW350i Meters	0.1 µS/cm
pH	Field meter – Hach HQ40d, YSI 556 , WTW P4 Multiline and WTW350i Meters	0.01 units
pH (lab)	pH meter APHA 4500-H+ B 21 st ed. 2005.	0.1 pH units
Total alkalinity	Titration to pH 4.5 (M-alkalinity), Radiometer autotitrator. APHA 2320 B (Modified for alk <20) 21 st ed. 2005.	1 mg/L as CaCO ₃
Bicarbonate	Calculation: from alkalinity and pH, valid where TDS is not >500 mg/L and alkalinity is almost entirely due to hydroxides, carbonates or bicarbonates. APHA 4500-CO ₂ D 21 st ed. 2005.	1 mg/L at 25°C
Free carbon dioxide	Calculation: from alkalinity and pH, valid where TDS is not >500 mg/L and alkalinity is almost entirely due to hydroxides, carbonates or bicarbonates. APHA 4500-CO ₂ D 21 st ed. 2005.	1.0 mg/L at 25°C
Total hardness	Calculation from calcium and magnesium	1.0 mg/L CaCO ₃
Electrical conductivity (lab)	Conductivity meter, 25°C APHA 2510 B 21 st ed. 2005.	0.1 mS/m, 1 µS/cm
Total dissolved solids (TDS)	Filtration through GF/C (1.2 µm), gravimetric. APHA 2540 C (modified; drying temperature of 103 – 105°C used rather than 180 ± 2°C) 21 st ed. 2005.	10 mg/L
Dissolved boron	Filtered sample, ICP-MS, trace level. APHA 3125 B 21 st ed. 2005.	0.005 mg/L
Dissolved calcium	Filtered sample, ICP-MS APHA 3125 B 21 st ed. 2005.	0.05 mg/L
Dissolved Iron	Filtered sample. ICP-MS APHA 3125 B 21 st ed. 2005.	0.02 mg/L
Dissolved Lead	Filtered sample. ICP-MS APHA 3125 B 21 st ed. 2005.	0.0001 mg/L
Dissolved magnesium	Filtered sample, ICP-MS APHA 3125 B 21 st ed. 2005.	0.02 mg/L
Dissolved manganese	Filtered sample. ICP-MS APHA 3125 B 21 st ed. 2005.	0.0005 mg/L
Dissolved potassium	Filtered sample, ICP-MS APHA 3125 B 21 st ed. 2005.	0.05 mg/L
Dissolved sodium	Filtered sample, ICP-MS APHA 3125 B 21 st ed. 2005.	0.02 mg/L
Dissolved zinc	Filtered sample. ICP-MS APHA 3125 B 21 st ed. 2005.	0.001 mg/L
Bromide	Filtered sample. Ion Chromatography. APHA 4110 B 21 st ed. 2005.	0.05 mg/L
Chloride	Filtered sample. Ferric thiocyanate colorimetry. Discrete Analyser. APHA 4500-Cl- E (modified from continuous-flow analysis) 21 st ed. 2005.	0.5 mg/L
Fluoride	Ion selective electrode APHA 4500-F- C 21 st ed. 2005.	0.05 mg/L
Total ammoniacal nitrogen	Filtered sample. Phenol/hypochlorite colorimetry. Discrete Analyser. (NH ₄ -N = NH ₄ ⁺ -N + NH ₃ -N) APHA 4500-NH ₃ F (modified from manual analysis) 21 st ed. 2005.	0.01 mg/L
Nitrite-N	Automated Azo dye colorimetry, Flow injection analyser. APHA 4500-NO ₂ - I (modified) 21 st ed. 2005.	0.002 mg/L
Nitrate-N	Calculation: (Nitrate-N + Nitrite-N) - Nitrite-N.	0.002 mg/L
Nitrate-N + Nitrite-N (NNN)	Total oxidised nitrogen. Automated cadmium reduction, Flow injection analyser. APHA 4500-NO ₃ - I (modified) 21 st ed. 2005.	0.002 mg/L
Dissolved reactive phosphorus	Filtered sample. Molybdenum blue colorimetry. Discrete Analyser. APHA 4500-P E (modified from manual analysis) 21 st ed. 2005.	0.004 mg/L
Reactive silica	Filtered sample. Heteropoly blue colorimetry. Discrete Analyser. APHA 4500-SiO ₂ F (modified from flow injection analysis) 21 st ed. 2005.	0.1 mg/L as SiO ₂
Sulphate	Filtered sample. Ion Chromatography. APHA 4110 B 21 st ed. 2005.	0.5 mg/L
Total organic carbon (TOC)	Catalytic oxidation, IR detection, for Total C. Acidification, purging for Total Inorganic C. TOC = TC -TIC. APHA 5310 B (modified) 21 st ed. 2005.	0.05 mg/L
Total anions	Calculation: sum of anions as mEq/L [Includes Alk, Cl, NO _x N & SO ₄]	0.07 mEq/L
Total cations	Calculation: sum of cations as mEq/L [Includes Ca, Mg, Na, K, Fe, Mn, Zn & NH ₄ N].	0.06 mEq/L
% Difference in Ion Balance	Calculation from Sum of Anions and Cations. Please note: The result reported for the '% Difference in Ion Balance' is an absolute difference between the 'Sum of Anions' and 'Sum of Cations' based on the formula taken from APHA. This does not indicate whether the 'Sum of Anions' or the 'Sum of Cations' produced a higher value. APHA 1030 E 21 st ed. 2005.	0.1 %
Faecal coliforms	APHA 21 st Ed. Method 9222 D.	1 cfu/100 mL
<i>E. coli</i>	APHA 21 st Ed. Method 9222 G.	1 cfu/100 mL

Appendix 3: Tabulated monitoring results

Bore	Easting	Northing	<i>E. coli</i> detected	No. of <i>E. coli</i> samples	Median nitrate	No. of nitrate samples
R25/5100	1774552	5479451	NO	4	0.001	4
R25/5135	1779152	5481483	NA		0.003	4
R25/5164	1775873	5482368	YES	4	0.265	4
R25/5165	1776019	5481886	YES	4	0.042	4
R25/5190	1776678	5478988	NO	4	4.30	4
R25/5233	1779398	5487565	YES	4	1.43	4
R26/6503	1766253	5462295	NA		0.033	4
R26/6587	1772634	5473057	YES	4	0.670	4
R26/6624	1773933	5474297	NO	4	2.80	4
R27/0320	1756996	5434508	NA		0.001	4
R27/1171	1756493	5431227	NA		0.003	4
R27/1182	1759274	5432161	NA		0.680	4
R27/1183	1763084	5438691	NO	4	0.295	4
R27/1265	1756998	5434516	NA		0.009	4
R27/6418	1762218	5425695	YES	4	1.61	4
R27/6833	1777716	5445324	NO	4	1.95	4
S25/5125	1782734	5483013	YES	4	2.21	4
S25/5200	1781182	5479785	YES	4	0.001	4
S25/5322	1783001	5487382	NO	4	9.50	4
S26/0117	1811483	5456780	YES	4	2.85	4
S26/0223	1816203	5459285	NO	4	10.70	4
S26/0299	1818355	5461870	NO	4	2.95	4
S26/0439	1807492	5455180	NO	4	3.15	4
S26/0457	1807657	5450331	NO	4	0.355	4
S26/0467	1809272	5453850	YES	4	2.55	4
S26/0568	1813487	5451921	NA		0.002	4
S26/0576	1813462	5452534	NA		0.014	4
S26/0705	1810472	5454279	NO	4	4.55	4
S26/0756	1815919	5448296	NA	1	0.001	4
S26/0762	1815702	5449348	YES	4	0.004	4
S26/0824	1810547	5454381	NO	4	4.35	4
S26/0846	1807902	5449492	NA		0.700	4
S27/0009	1793895	5443482	YES	4	2.650	4
S27/0070	1797508	5443111	NO	4	0.490	4
S27/0136	1802217	5446389	YES	4	1.52	4
S27/0156	1803403	5442776	YES	4	0.007	4
S27/0202	1805461	5446520	YES	4	2.30	4
S27/0268	1793453	5434055	NA		0.002	4
S27/0283	1797276	5436168	NA		0.010	3
S27/0299	1796504	5438936	NO	4	0.330	4
S27/0344	1803348	5437340	NO	3	0.001	3
S27/0389	1807205	5433792	NO	4	0.116	4
S27/0396	1805859	5435962	NO	4	0.495	4
S27/0433	1787692	5427839	NA		0.008	4
S27/0435	1787608	5430805	NA		0.001	4
S27/0442	1789891	5426884	NA		0.002	4
S27/0495	1797227	5431330	NA		0.002	4
S27/0522	1803032	5431324	NO	4	3.30	4
S27/0571	1807158	5433014	NO	4	6.60	4
S27/0585	1780320	5422598	NA		0.004	4
S27/0588	1784844	5420714	NO	4	0.019	4
S27/0594	1781351	5419721	NA		0.001	4
S27/0602	1789626	5425302	NA		0.001	4

Bore	Easting	Northing	<i>E. coli</i> detected	No. of <i>E. coli</i> samples	Median nitrate	No. of nitrate samples
S27/0607	1786289	5425037	NA		0.002	4
S27/0614	1786778	5421924	NA		0.007	4
S27/0615	1786805	5422158	NA		0.004	4
S27/0681	1808952	5433542	NO	4	0.325	4
T26/0003	1822559	5473236	YES	4	0.595	4
T26/0087	1820296	5464750	NA		0.765	4
T26/0099	1822518	5467619	NO	4	2.85	4
T26/0206	1822582	5467829	NO	4	1.48	4
T26/0259	1825997	5469120	NO	4	0.865	4
T26/0332	1822231	5457402	YES	4	0.615	4
T26/0413	1824486	5459979	NA		0.001	4
T26/0430	1822131	5463028	YES	4	1.34	4
T26/0489	1827572	5461854	NA		11.20	4
T26/0538	1827738	5461169	NO	4	7.65	4
T27/0063	1858025	5446630	NO	3	1.48	3