Groundwater Quality State of the Environment monitoring programme

Annual data report, 2016/17

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Contents

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 2016 to 30 June 2017 inclusive. The GQSoE programme incorporates quarterly monitoring of water quality in 71 wells 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). A trend report has been produced recently for nitrate levels (see Baker 2017).

2. Overview of programme SoE 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 wells (Figure 2.1 and Appendix 1). During the 2016/17 monitoring period, four wells could not be sampled at all, and others listed were only sampled two or three times. Brief explanations as to why wells could not be sampled are included below:

- S26/0756 was modified by the owner after the September 2014 monitoring round and no longer has a sampling tap on the headworks.
- S25/5256 is on land purchased by NZTA for the Peka Peka to Otaki Expressway. Power was turned off to the well pump in March 2012 and groundwater was no longer able to be abstracted from this well.
- R25/5164 was disconnected by the owner in December 2015. This well is a bore spear (steel tube driven into the sand), and is unlikely to be able to be used in the future.
- T26/0489 collapsed in June 2016. A new well was drilled in place of T26/0489. However, it is located in a shallower aquifer than the old monitoring well and is not suitable as a replacement monitoring site in this location.

- S26/0846 was sampled once in September 2016. After this date, the well owner retracted permission to collect SoE samples from this well for the foreseeable future.

- BQ33/0032 was drilled in September 2015 to replace S27/0614 which had collapsed. Sampling commenced at this well in December 2015.

- T26/0087 was unable to be sampled in March and June 2017 due to irrigation pump requiring repairs.

Faecal indicator bacteria are only tested for in the wells used for potable water supplies or in shallow groundwater wells, which total 44 of the 71 GQSoE sites. During the 2016/17 monitoring period samples for *Escherichia coli (E.coli)* could only be collected from 43 well as R25/5164 could not be sampled (see reason above).

Samples from four wells (R27/1137, R27/1171, R27/1182 and R27/1265) in the Hutt Valley, not usually tested for faecal indicator bacteria, were tested in response to the detection of bacteria in the public water supply wells at the Waterloo Production Wellfield.

The GQSoE monitoring wells are spread across four of the five Whaitua catchments (GWRC identified water management areas). The distribution of sites is primarily based on historical groundwater use and resource availability so they are not evenly distributed. The number of wells located in each Whaitua are:

- Ruamahanga – 48 (only 46 wells sampled in 2016/17)

- Kapiti Coast – 13 (only 11 wells sampled in 2016/17)

- Wellington and Hutt Valley – 9

- Wairarapa Coast - 1

- Porirua - 0

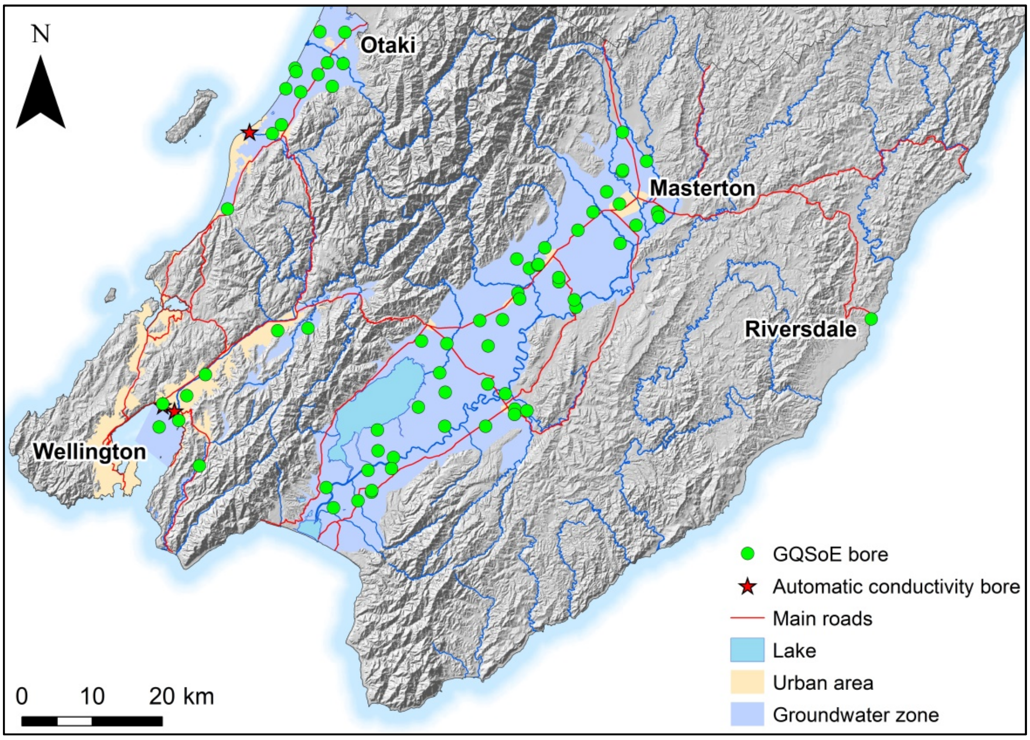

Figure 2.1: Location of groundwater quality monitoring sites in the Wellington Region. Automated saline intrusion (conductivity) groundwater monitoring sites are also shown (red stars).

2.3 Monitoring variables

The GQSoE network is sampled quarterly for a wide range of physio-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 report presents the results of the four rounds of sampling that were conducted during the 2016/17 monitoring year. Results are discussed by whaitua.

For the 2016/17 sampling year, two key indicators of groundwater contamination (typically arising from land use intensification and/or on-site wastewater disposal systems) have been evaluated: nitrate-nitrogen (nitrate) and *E. coli* bacteria.

Details of the analytical methods used by the laboratory are provided in Appendix 2. Summary statistics were calculated using NIWA Time Trends Version 6.2 (2011). 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. Raw data is provided in Appendix 4.

3.2 Results

3.2.1 Nitrate

(a) 2016/17 Summary

Median nitrate concentrations across the region were low (<3 mg/L[1]) in most of the 67 wells monitored during 2016/17 (Figure 3.1). When assessed by whaitua, the following is noted:

- In the Ruamahanga Whaitua, seven of the 46 wells (15.2%) had elevated (3-7 mg/L) concentrations of nitrate, while a further three wells of 46 monitored (6.5%) had median nitrate concentrations in the highly elevated range (7-11.3 mg/L);
- In the Kapiti Whaitua, two of the 11 wells (18.2%) had elevated (3-7 mg/L) concentrations of nitrate while a further individual well of 11 monitored (9.1%) had median nitrate concentrations in the highly elevated range (7-11.3 mg/L);
- In the Hutt Valley Whaitua, all nine sites had median nitrate concentrations below 3 mg/L (low), and
- The single well in the Wairarapa Coast Whaitua (at Riversdale) had a median nitrate concentration of 1.27 mg/L.

[1] Groundwater nitrate nitrogen (nitrate) concentrations are evaluated in terms of likely human influence. Although, groundwater in New Zealand rarely has nitrate concentration above 1 mg/L naturally, a threshold of 3 mg/L has been adopted as a means of defining nitrate contamination from anthropogenic sources (Close et al. 2001). This threshold has been used by Greater Wellington in precious reporting (Tidswell et al 2012) and follows the findings of a US study of nitrates (Madison & Brunett 1985) that concluded concentrations of nitrate in groundwater above 3 mg/L were due to human influence. Reference to "elevated" nitrate concentrations indicates the concentrations are above 3 mg/L; an additional 'highly elevated' threshold was arbitrarily set at >7 mg/L, approximately mid-way between the elevated threshold and DWSNZ MAV of 11.3 mg/L.

No wells had maximum nitrate concentrations above the Ministry of Health Drinking-water Standards (DWSNZ) 2008 maximum acceptable value (MAV) concentration of 11.3 mg/L.

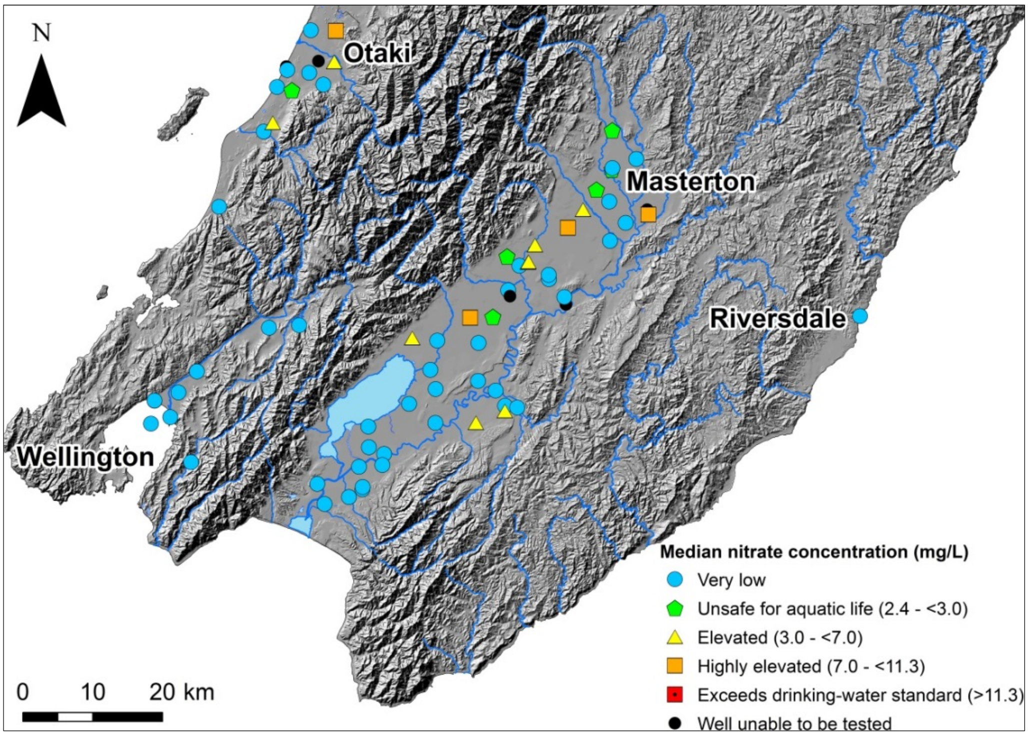

Figure 3.1: Median nitrate-nitrogen (nitrate) concentrations in GQSoE wells monitored quarterly during 2016/17

Overall, elevated nitrate was found in wells where previous GQSoE sampling has historically detected elevated nitrate concentrations. The land use in these areas is typically agricultural (Wairarapa) and (often historically) horticulture (Kapiti Coast).

Elevated nitrate concentrations across the region are typically associated with unconfined, shallow and oxygen rich groundwater. All 13 wells which recorded elevated concentrations of nitrate were from wells shallower than 35 meters.

(b) Effect on surface water

Groundwater discharges from aquifers into a number of surface water bodies throughout the region and there is the potential that groundwater high in nitrate could contribute to the decline of surface water quality. The 2000 Australia New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC 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 35 of the 67 (52.2%) wells (see Figure 3.2). These wells were distributed across the Whaitua as follows:

- 23 (of 46) were in the Ruamahanga;

- 6 (of 11) were in Kapiti;
- 5 (of 9) were in the Hutt, and
- 1 was at Riversdale

In addition to exceeding the ANZECC (2000) trigger value, median nitrate concentrations in 19 of the 35 wells (28.4 %) were also above the Hickey (2013) threshold for aquatic toxicity (≤ 2.4 mg/L)[2].

Of the 19 sites exceeding the threshold for aquatic toxicity in 2016/17 (≤ 2.4 mg/L), two were Category A aquifers (direct connection to surface water), 13 Category B aquifers (moderate degree of connectivity to surface water) and four were Category C aquifers (not directly connected to surface water) (see Figure 3.2).

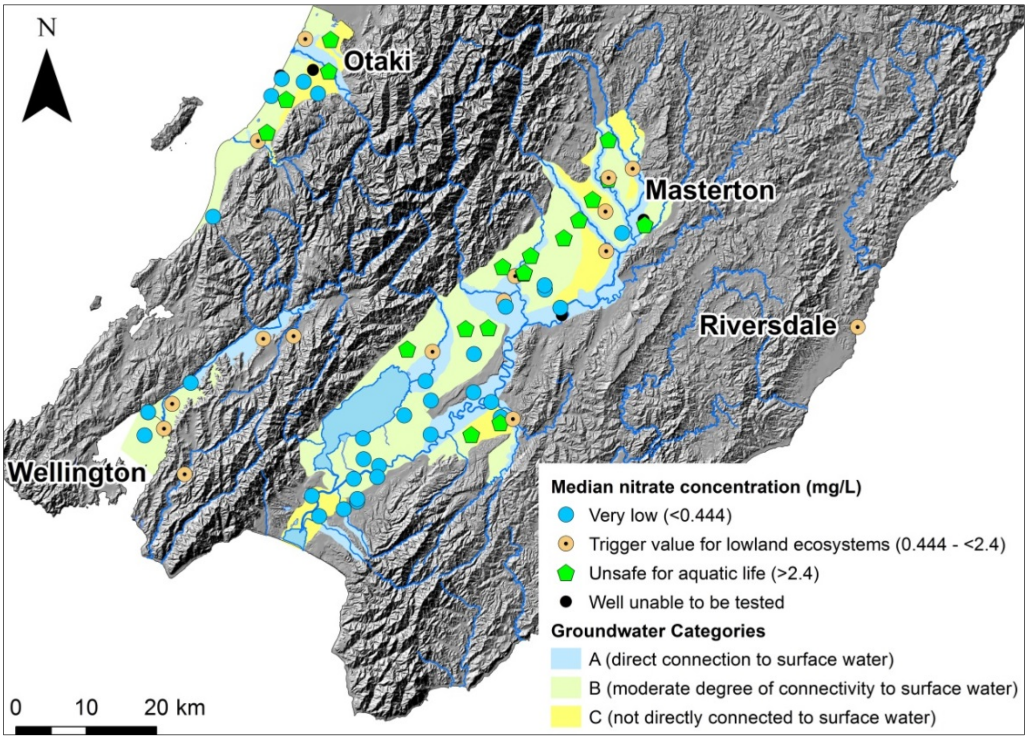

Figure 3.2: Median nitrate-nitrogen (nitrate) concentrations in GQSoE wells monitored quarterly during 2016/17 and groundwater categories showing degree of groundwater connectivity to surface water

The wells located in Category A aquifers were S26/0117 in the Mangatarere groundwater management zone near Carterton, and S25/5125 located in the Otaki groundwater management zone alongside the Otaki River. S26/0117 is in a rural lifestyle area, but also downgradient of dairying land. S25/5125 is located in the middle of a horticultural (pip/stone fruit) area.

2 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.

3.2.2 *E. coli*

The DWSNZ (2008) uses *E. coli* as an indicator[3] of faecal contamination in drinking water. For drinking water supplies, *E. coli* counts should be the MAV of <1 cfu/100mL.

- *E. coli* was not detected (i.e. < 1 cfu/100mL) in 30 of the 43 (69.8%) wells monitored.

- *E. coli* was detected (ie, ≥ 1 cfu/100mL) on one or more occasions in 13 of the 43 (30.2%) wells tested (Figure 3.3):

The highest *E. coli* count (24 cfu/100mL) was recorded in well T26/0063 at Riversdale Beach Settlement. The settlement is located above an unconfined sand aquifer on the Wairarapa Coast. Historical groundwater quality investigations have indicated the local sand aquifer is susceptible to rapid nutrient and bacteriological contamination. Historical investigations demonstrated contamination was caused by the large number and dense concentration of onsite wastewater treatment systems (OWWTS) used for effluent disposal at Riversdale Beach Settlement (Beca 1997, Hurndell & Sevicke-Jones 2002, Tidswell 2008).

In 2012, Masterton District Council installed a reticulated wastewater scheme for residents to connect to. Although, contamination from OWWTS discharges groundwater quality has significantly reduced, the unconfined sand aquifer is at Rivesrdale still at risk from other sources of contamination given surface water can rapidly infiltrate into the sand aquifer. It is likely the *E. coli* count recorded at well T26/0063 was due to localised contamination around the sampling well possibly after heavy rainfall. This well is not now used for potable supply and historically residents in the Riversdale Beach Settlement were advised not to use groundwater in the area for as a source of drinking-water.

The second highest *E. coli* count (17 cfu/100mL) was recorded in well R26/6587, located in Waikanae. This well is uncovered, shallow in depth and has a large diameter. Historically, this well has periodically shown *E. coli* counts above the DWSNZ (2008) MAV and is most likely contaminated directly through the uncovered well head. This well is not now used for potable supply.

The remaining 11 wells had *E. coli* counts ranging from 1 to 12 cfu/100mL. All wells that had positive *E. coli* counts during the 2016/17 monitoring period had tested positive for bacteriological contamination historically and are located in unconfined aquifers in either Category A (direct connection to surface water) and Category B (moderate degree of connectivity to surface water) groundwater.

[3] 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.

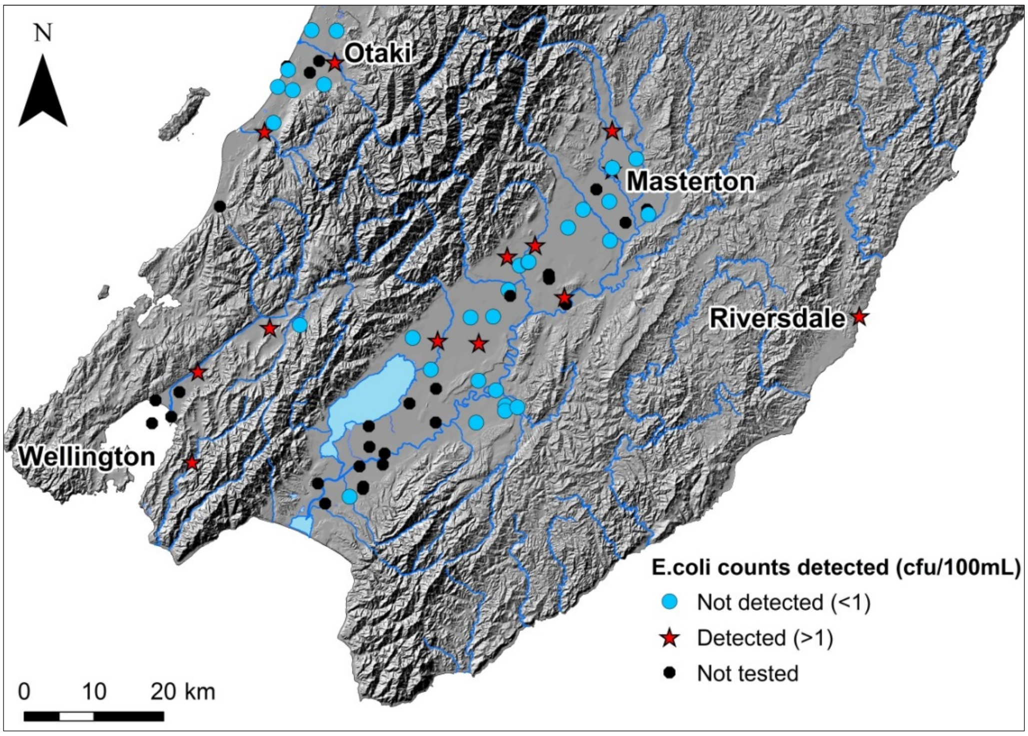

Figure 3.3: Detection of *E. coli* bacteria in GQSoE wells monitored quarterly over 2016/17

Samples from four wells (R27/1137, R27/1171, R27/1182 and R27/1265) in the Hutt Valley, not usually tested for faecal indicator bacteria, were tested in response to the detection of bacteria in the public water supply wells at the Waterloo Production Wellfield (December 2016 – April 2017). No positive counts of *E.coli* were detected in any of these four wells on the single sampling occasion in June 2017. Positive counts of *E.coli* were detected in three wells regularly monitored for faecal indicator bacteria as part of the GQSoE monitoring programme.

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- Emily Martin for providing data quality assurance.

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	Schaef	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
BQ33/0032	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	Huangarua	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					
R26/6956	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 well for a predetermined amount of time to remove any standing water and monitoring the pumped water continuously until field measurements (e.g. conductivity) stabilise. Field measurements (temperature, conductivity, pH, dissolved oxygen and ORP) 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 *E. coli*	Faecal coliforms *and E. coli* can indicate pollution due to faecal matter and the presence of potentially harmful pathogens in groundwater. Ministry for the Environment uses *E. coli* 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 effect 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 Dissolved manganese Dissolved lead Dissolved zinc	Trace metals are usually present in groundwater at low concentrations. Elevated concentrations of trace metals can suggest contamination of groundwater. Elevated concentrations of dissolved of lead and manganese can have an adverse effect on human health.
Trace elements	Bromide Fluoride Dissolved boron	Bromide naturally occurs in water but can suggest contamination from wastewater and agricultural run-off. Elevated concentrations of dissolved of boron can have an adverse effect on human health and the DWSNZ (2005) MAV for fluoride is set to protect against potential dental fluorosis.
Other	pH	Water with a low pH can have a high plumbosolvency. Measured in the field to identify when the well 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 well 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 well 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_2CO_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 –YSI Professional Plus Meters	0.01 ˚C
Dissolved oxygen	Field meter –YSI Professional Plus Meters	0.01 mg/L
Electrical conductivity	Field meter –YSI Professional Plus Meters	0.1 µS/cm
pH	Field meter –YSI Professional Plus Meters	0.01 units
ORP	Field meter –YSI Professional Plus Meters	
pH (lab)	pH meter APHA 4500-H+ B 22st ed. 2012.	0.1 pH units
Total alkalinity	Titration to pH 4.5 (M-alkalinity), Radiometer autotitrator. APHA 2320 B (Modified for alk <20) 22st ed. 2012.	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 22st ed. 2012.	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 22st ed. 2012.	1.0 mg/L at 25°C
Total hardness	Calculation from calcium and magnesium. APHA 2340 B 22st ed. 2012.	1.0 mg/L $CaCO_3$
Electrical conductivity (lab)	Conductivity meter, 25°C APHA 2510 B 22st ed. 2012.	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) 22st ed. 2012.	10 mg/L
Dissolved boron	Filtered sample, ICP-MS, trace level. APHA 3125 B 22st ed. 2012.	0.005 mg/L
Dissolved calcium	Filtered sample, ICP-MS, trace level. APHA 3125 B 22st ed. 2012.	0.05 mg/L
Dissolved Iron	Filtered sample, ICP-MS, trace level. APHA 3125 B 22st ed. 2012.	0.02 mg/L
Dissolved Lead	Filtered sample, ICP-MS, trace level. APHA 3125 B 22st ed. 2012.	0.0001 mg/L
Dissolved magnesium	Filtered sample, ICP-MS, trace level. APHA 3125 B 22st ed. 2012.	0.02 mg/L
Dissolved manganese	Filtered sample, ICP-MS, trace level. APHA 3125 B 22st ed. 2012.	0.0005 mg/L
Dissolved potassium	Filtered sample, ICP-MS, trace level. APHA 3125 B 22st ed. 2012.	0.05 mg/L
Dissolved sodium	Filtered sample, ICP-MS, trace level. APHA 3125 B 22st ed. 2012.	0.02 mg/L
Dissolved zinc	Filtered sample, ICP-MS, trace level. APHA 3125 B 22st ed. 2012.	0.001 mg/L
Bromide	Filtered sample. Ion Chromatography. APHA 4110 B 22st ed. 2012.	0.05 mg/L
Chloride	Filtered sample. Ferric thiocyanate colorimetry. Discrete Analyser. APHA 4500-Cl- E (modified from continuous-flow analysis) 22st ed. 2012.	0.5 mg/L
Fluoride	Ion selective electrode APHA 4500-F- C 22st ed. 2012.	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) 22st ed. 2012.	0.01 mg/L
Nitrite-N	Automated Azo dye colorimetry, Flow injection analyser. APHA 4500-NO_3 - I (modified) 22st ed. 2012.	0.002 mg/L
Nitrate-N	Calculation: (Nitrate-N + Nitrite-N) - Nitrite-N. In-House.	0.001 mg/L
Nitrate-N + Nitrite-N (NNN)	Total oxidised nitrogen. Automated cadmium reduction, Flow injection analyser. APHA 4500-NO_3 - I (modified) 22st ed. 2012.	0.002 mg/L
Dissolved reactive phosphorus	Filtered sample. Molybdenum blue colorimetry. Discrete Analyser. APHA 4500-P E (modified from manual analysis) 22st ed. 2012.	0.004 mg/L
Reactive silica	Filtered sample. Heteropoly blue colorimetry. Discrete Analyser. APHA 4500-SiO2 F (modified from flow injection analysis) 22st ed. 2012.	0.1 mg/L as SiO_2
Sulphate	Filtered sample. Ion Chromatography. APHA 4110 B 22st ed. 2012.	0.5 mg/L
Total organic carbon (TOC)	Supercritical persulphate oxidation, IR detection, for Total C. Acidification, purging for Total Inorganic C. TOC = TC -TIC. APHA 5310 C (modified) 22st ed. 2012.	0.05 mg/L
Total anions	Calculation: sum of anions as mEquiv/L [Includes Alk, Cl, NO_xN, F, DRP & SO_4]. APHA 1030 E 22nd ed. 2012.	0.07 mEquiv/L
Total cations	Calculation: sum of cations as mEquiv/L [Includes pH (H^+), Ca, Mg, Na, K, Fe, Mn, Zn & NH_4N]. APHA 1030 E 22nd ed. 2012.	0.06 mEquiv/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	0.1 %

Variable	Method Used	Detection Limit
	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 APHA 1030 E 22nd ed. 2012.	
Faecal coliforms	Membrane filtration, count on mFC agar. Incubated at 44.5°C for 22 hours, confirmation. Analysed at Hill laboratories – Microbiology: 1 Clow Place, Hamilton. Method 9222 D 22st ed. 2012.	1 cfu/100 mL
E. coli	Membrane filtration, count on mFC agar. Incubated at 44.5°C for 22 hours, MUG confirmation. Analysed at Hill laboratories – Microbiology: 1 Clow Place, Hamilton. Method 9222 G 22st ed. 2012.	1 cfu/100 mL

Appendix 3: Tabulated Statistical Data

Site	Easting	Northing	E.coli detected	No. of E.coli samples	Median NO3-N	No. of NO3-N samples
BQ33/0032	1786750	5421805	Not tested		0.005	4
R25/5100	1774552	5479451	N	4	0.001	4
R25/5135	1779152	5481483	Not tested		0.01	4
R25/5164	1775873	5482367	Well could not be sampled.			
R25/5165	1776019	5481886	N	4	0.002	4
R25/5190	1776678	5478988	N	4	2.7	4
R25/5233	1779398	5487565	N	4	1.73	4
R26/6503	1766253	5462295	Not tested		0.023	3
R26/6587	1772634	5473057	Y	3	1.04	3
R26/6624	1773933	5474297	N	3	3	3
R27/0320	1756996	5434508	Not tested*	1	0.001	4
R27/1137	1773406	5444956	Y	4	1.93	4
R27/1171	1756493	5431227	Not tested*	1	0.001	4
R27/1180	1760435	5435698	Not tested		0.88	3
R27/1182	1759274	5432161	Not tested*	1	0.7	3
R27/1183	1763084	5438691	Y	4	0.33	4
R27/1265	1756998	5434516	Not tested*	1	0.123	4
R27/6418	1762218	5425695	Y	4	1.41	4
R27/6833	1777716	5445324	N	4	0.815	4
S25/5125	1782734	5483013	Y	4	3.45	4
S25/5200	1781183	5479785	N	4	0.001	4
S25/5256	1780490	5483153	Well could not be sampled.			
S25/5322	1782983	5487486	N	4	9.2	4
S26/0117	1811483	5456780	Y	3	3.45	4
S26/0223	1816203	5459285	N	4	9.7	4
S26/0299	1818355	5461870	N	3	3.5	3
S26/0439	1807492	5455180	Y	4	2.65	4
S26/0457	1807657	5450331	N	3	0.65	3
S26/0467	1809272	5453850	N	4	2.35	4
S26/0568	1813487	5451921	Not tested		0.01	3
S26/0576	1813462	5452534	Not tested		0.001	3
S26/0705	1810472	5454279	N	3	4.4	3
S26/0756	1815919	5448296	Well could not be sampled			
S26/0762	1815702	5449348	Y	4	0.004	4

S26/0824	1810547	5454381	N	3	4.9	3
S26/0846	1807902	5449492	Not tested		<0.010	1
S27/0009	1793895	5443481	N	4	3.8	4
S27/0070	1797508	5443111	Y	4	0.73	4
S27/0136	1802217	5446389	N	4	8.85	4
S27/0156	1803403	5442776	Y	4	0.015	4
S27/0202	1805461	5446520	N	4	2.8	4
S27/0268	1793453	5434055	Not tested		0.005	4
S27/0283	1797276	5436168	Not tested		0.01	3
S27/0299	1796504	5438936	N	3	0.31	3
S27/0344	1803348	5437340	N	4	0.001	4
S27/0389	1807205	5433792	N	2	0.004	2
S27/0396	1805859	5435962	N	3	0.29	3
S27/0433	1787692	5427839	Not tested		0.01	3
S27/0435	1787608	5430805	Not tested		0.001	4
S27/0442	1789891	5426884	Not tested		0.001	4
S27/0495	1797227	5431330	Not tested		0.009	4
S27/0522	1803032	5431324	N	3	3.5	3
S27/0571	1807158	5433014	N	3	5.6	3
S27/0585	1780321	5422598	Not tested		0.001	4
S27/0588	1784844	5420713	N	4	0.001	4
S27/0594	1781351	5419721	Not tested		0.01	4
S27/0602	1789626	5425302	Not tested		0.001	4
S27/0607	1786289	5425037	Not tested		0.01	4
S27/0615	1786805	5422158	Not tested		0.01	3
S27/0681	1808952	5433542	N	3	0.6	3
T26/0003	1822559	5473237	Y	4	2.85	4
T26/0087	1820296	5464750	Not tested		2.45	2
T26/0099	1822518	5467619	Y	4	2.45	4
T26/0206	1822582	5467829	N	4	1.935	4
T26/0259	1825997	5469120	N	4	1.105	4
T26/0332	1822231	5457402	N	3	0.53	3
T26/0413	1824486	5459979	Not tested		0.001	4
T26/0430	1822131	5463028	N	4	1.94	4
T26/0489	1827571	5461855	Well could not be sampled.			
T26/0538	1827738	5461169	N	3	8.45	4
T27/0063	1858025	5446630	Y	4	1.27	4

Appendix 4: Raw Data

Site Name	Date	E-Coli (cfu/100ml)	Nitrate Nitrogen (g/m3-N)
BQ33/0032	06-Sep-2016		<0.002
BQ33/0032	06-Dec-2016		<0.002
BQ33/0032	06-Mar-2017		<0.02
BQ33/0032	23-Jun-2017		<0.02
R25/5100	30-Aug-2016	<1.00	<0.002
R25/5100	21-Nov-2016	<1.00	<0.002
R25/5100	21-Feb-2017	<1.00	<0.002
R25/5100	13-Jun-2017	<1.00	<0.002
R25/5135	29-Aug-2016		<0.02
R25/5135	21-Nov-2016		<0.02
R25/5135	21-Feb-2017		<0.02
R25/5135	14-Jun-2017		<0.002
R25/5165	29-Aug-2016	<1.00	<0.002
R25/5165	21-Nov-2016	<1.00	0.003
R25/5165	21-Feb-2017	<1.00	<0.002
R25/5165	13-Jun-2017	<1.00	0.082
R25/5190	30-Aug-2016	<1.00	2.8
R25/5190	21-Nov-2016	<1.00	1.85
R25/5190	21-Feb-2017	<1.00	2.6
R25/5190	13-Jun-2017	<1.00	5
R25/5233	29-Aug-2016	<1.00	1.45
R25/5233	21-Nov-2016	<1.00	1.46
R25/5233	22-Feb-2017	<1.00	2
R25/5233	13-Jun-2017	<1.00	2
R26/6503	29-Aug-2016		0.044
R26/6503	22-Nov-2016		0.021
R26/6503	22-Feb-2017		0.023
R26/6587	30-Aug-2016	<1.00	1.04
R26/6587	21-Nov-2016	1	1.47
R26/6587	13-Jun-2017	17	0.9
R26/6624	30-Aug-2016	<1.00	3
R26/6624	15-Mar-2017	<1.00	3
R26/6624	14-Jun-2017	<1.00	3
R27/0320	31-Aug-2016		<0.002
R27/0320	23-Nov-2016		<0.002

R27/0320	23-Feb-2017		<0.002
R27/0320	15-Jun-2017	<1.00	<0.002
R27/1137	01-Sep-2016	<1.00	1.88
R27/1137	24-Nov-2016	12	2.2
R27/1137	24-Feb-2017	<1.00	1.98
R27/1137	16-Jun-2017	<1.00	1.75
R27/1171	01-Sep-2016		<0.002
R27/1171	20-Dec-2016		<0.002
R27/1171	24-Feb-2017		0.038
R27/1171	27-Jun-2017	<1.00	<0.002
R27/1180	31-Aug-2016		0.88
R27/1180	23-Nov-2016		0.76
R27/1180	23-Feb-2017		0.88
R27/1182	31-Aug-2016		0.68
R27/1182	23-Feb-2017		0.72
R27/1182	15-Jun-2017	<1.00	0.7
R27/1183	31-Aug-2016	<1.00	0.39
R27/1183	23-Nov-2016	1	0.42
R27/1183	23-Feb-2017	<1.00	0.26
R27/1183	15-Jun-2017	<1.00	0.27
R27/1265	31-Aug-2016		0.115
R27/1265	23-Nov-2016		0.121
R27/1265	23-Feb-2017		0.126
R27/1265	15-Jun-2017	<1.00	0.128
R27/6418	31-Aug-2016	<1.00	1.83
R27/6418	23-Nov-2016	8	1.55
R27/6418	23-Feb-2017	<1.00	1.06
R27/6418	15-Jun-2017	<1.00	1.27
R27/6833	31-Aug-2016	<1.00	0.86
R27/6833	23-Nov-2016	<1.00	0.77
R27/6833	22-Feb-2017	<1.00	1.04
R27/6833	15-Jun-2017	<1.00	0.56
S25/5125	29-Aug-2016	<1.00	4.4
S25/5125	22-Nov-2016	2	3.4
S25/5125	22-Feb-2017	<1.00	3.5
S25/5125	14-Jun-2017	<1.00	2.9
S25/5200	29-Aug-2016	<1.00	<0.002
S25/5200	22-Nov-2016	<1.00	0.004

S25/5200	21-Feb-2017	<1.00	<0.002
S25/5200	13-Jun-2017	<1.00	<0.002
S25/5322	29-Aug-2016	<1.00	9.4
S25/5322	22-Nov-2016	<1.00	9
S25/5322	22-Feb-2017	<1.00	9.5
S25/5322	14-Jun-2017	<1.00	9
S26/0117	07-Sep-2016	<1.00	3.5
S26/0117	01-Dec-2016	<1.00	4.3
S26/0117	27-Feb-2017	3	3.4
S26/0117	20-Jun-2017		2.8
S26/0223	05-Sep-2016	<1.00	11.9
S26/0223	28-Nov-2016	<1.00	9.9
S26/0223	09-Mar-2017	<1.00	7.4
S26/0223	22-Jun-2017	<1.00	9.5
S26/0299	09-Sep-2016	<1.00	3.5
S26/0299	06-Dec-2016	<1.00	3.1
S26/0299	02-Mar-2017	<1.00	3.7
S26/0439	07-Sep-2016	<1.00	2.8
S26/0439	01-Dec-2016	<1.00	2.4
S26/0439	27-Feb-2017	6	2.8
S26/0439	20-Jun-2017	<1.00	2.5
S26/0457	12-Sep-2016	<1.00	1.67
S26/0457	05-Dec-2016	<1.00	0.65
S26/0457	28-Feb-2017	<1.00	0.36
S26/0467	12-Sep-2016	<1.00	2.4
S26/0467	01-Dec-2016	<1.00	3.1
S26/0467	27-Feb-2017	<1.00	2
S26/0467	20-Jun-2017	<1.00	2.3
S26/0568	07-Sep-2016		<0.02
S26/0568	01-Dec-2016		<0.02
S26/0568	27-Feb-2017		0.003
S26/0576	07-Sep-2016		<0.002
S26/0576	27-Feb-2017		<0.002
S26/0576	20-Jun-2017		<0.002
S26/0705	13-Sep-2016	<1.00	4.4
S26/0705	29-Nov-2016	<1.00	4.4
S26/0705	07-Mar-2017	<1.00	4.7
S26/0762	07-Sep-2016	<1.00	<0.002

S26/0762	01-Dec-2016	<1.00	0.006
S26/0762	27-Feb-2017	1	<0.02
S26/0762	20-Jun-2017	<1.00	<0.002
S26/0824	13-Sep-2016	<1.00	4.8
S26/0824	29-Nov-2016	<1.00	4.9
S26/0824	07-Mar-2017	<1.00	5.3
S26/0846	05-Sep-2016		<0.02
S27/0009	12-Sep-2016	<1.00	3.2
S27/0009	05-Dec-2016	<1.00	4
S27/0009	28-Feb-2017	<1.00	4
S27/0009	26-Jun-2017	<1.00	3.6
S27/0070	12-Sep-2016	<1.00	0.95
S27/0070	05-Dec-2016	<1.00	1.49
S27/0070	28-Feb-2017	<1.00	0.42
S27/0070	26-Jun-2017	2	0.51
S27/0136	05-Sep-2016	<1.00	11.3
S27/0136	05-Dec-2016	<1.00	9
S27/0136	10-Mar-2017	<1.00	8.7
S27/0136	26-Jun-2017	<1.00	4.6
S27/0156	12-Sep-2016	<1.00	0.014
S27/0156	05-Dec-2016	<1.00	0.017
S27/0156	28-Feb-2017	1	0.114
S27/0156	26-Jun-2017	<1.00	0.014
S27/0202	05-Sep-2016	<1.00	3.5
S27/0202	28-Nov-2016	<1.00	2.5
S27/0202	09-Mar-2017	<1.00	2.8
S27/0202	22-Jun-2017	<1.00	2.8
S27/0268	06-Sep-2016		<0.002
S27/0268	06-Dec-2016		<0.02
S27/0268	06-Mar-2017		<0.002
S27/0268	23-Jun-2017		0.2
S27/0283	14-Sep-2016		<0.02
S27/0283	07-Dec-2016		<0.02
S27/0283	01-Mar-2017		<0.02
S27/0299	13-Sep-2016	<1.00	0.31
S27/0299	07-Mar-2017	<1.00	0.31
S27/0299	28-Jun-2017	<1.00	0.27
S27/0344	13-Sep-2016	<1.00	<0.002

S27/0344	29-Nov-2016	<1.00	<0.002
S27/0344	07-Mar-2017	<1.00	<0.002
S27/0344	28-Jun-2017	<1.00	<0.002
S27/0389	14-Sep-2016	<1.00	<0.002
S27/0389	08-Dec-2016	<1.00	0.007
S27/0396	14-Sep-2016	<1.00	0.33
S27/0396	07-Dec-2016	<1.00	0.29
S27/0396	01-Mar-2017	<1.00	0.198
S27/0433	14-Sep-2016		<0.02
S27/0433	06-Dec-2016		0.03
S27/0433	06-Mar-2017		<0.02
S27/0435	06-Sep-2016		<0.002
S27/0435	06-Dec-2016		0.004
S27/0435	06-Mar-2017		<0.002
S27/0435	23-Jun-2017		<0.002
S27/0442	06-Sep-2016		<0.002
S27/0442	08-Dec-2016		<0.002
S27/0442	10-Mar-2017		<0.002
S27/0442	23-Jun-2017		<0.002
S27/0495	06-Sep-2016		<0.002
S27/0495	06-Dec-2016		<0.02
S27/0495	06-Mar-2017		0.007
S27/0495	23-Jun-2017		<0.02
S27/0522	14-Sep-2016	<1.00	3.5
S27/0522	07-Dec-2016	<1.00	3.4
S27/0522	01-Mar-2017	<1.00	3.5
S27/0571	09-Sep-2016	<1.00	5.6
S27/0571	07-Dec-2016	<1.00	5.6
S27/0571	01-Mar-2017	<1.00	5.5
S27/0585	12-Sep-2016		<0.002
S27/0585	05-Dec-2016		<0.002
S27/0585	28-Feb-2017		<0.002
S27/0585	26-Jun-2017		<0.002
S27/0588	13-Sep-2016	<1.00	<0.002
S27/0588	29-Nov-2016	<1.00	<0.002
S27/0588	07-Mar-2017	<1.00	<0.002
S27/0588	28-Jun-2017	<1.00	<0.02
S27/0594	13-Sep-2016		<0.02

S27/0594	29-Nov-2016		<0.02
S27/0594	07-Mar-2017		<0.002
S27/0594	28-Jun-2017		<0.02
S27/0602	06-Sep-2016		<0.002
S27/0602	06-Dec-2016		<0.002
S27/0602	06-Mar-2017		<0.002
S27/0602	23-Jun-2017		<0.002
S27/0607	13-Sep-2016		<0.02
S27/0607	29-Nov-2016		<0.02
S27/0607	07-Mar-2017		<0.02
S27/0607	28-Jun-2017		<0.20
S27/0615	06-Sep-2016		0.003
S27/0615	06-Dec-2016		<0.02
S27/0615	06-Mar-2017		<0.02
S27/0681	09-Sep-2016	<1.00	0.66
S27/0681	07-Dec-2016	<1.00	0.6
S27/0681	01-Mar-2017	<1.00	0.33
T26/0003	08-Sep-2016	<1.00	7.1
T26/0003	02-Dec-2016	1	3
T26/0003	02-Mar-2017	<1.00	0.69
T26/0003	21-Jun-2017	<1.00	2.7
T26/0087	09-Sep-2016		2.7
T26/0087	02-Dec-2016		2.2
T26/0099	08-Sep-2016	<1.00	2
T26/0099	02-Dec-2016	1	2.5
T26/0099	02-Mar-2017	2	2.4
T26/0099	21-Jun-2017	<1.00	2.7
T26/0206	08-Sep-2016	<1.00	1.74
T26/0206	02-Dec-2016	<1.00	1.97
T26/0206	02-Mar-2017	<1.00	1.9
T26/0206	21-Jun-2017	<1.00	2.2
T26/0259	08-Sep-2016	<1.00	1.45
T26/0259	08-Dec-2016	<1.00	0.92
T26/0259	02-Mar-2017	<1.00	0.58
T26/0259	21-Jun-2017	<1.00	1.29
T26/0332	05-Sep-2016	<1.00	0.48
T26/0332	28-Nov-2016	<1.00	0.67
T26/0332	09-Mar-2017	<1.00	0.53

T26/0413	08-Sep-2016		0.004
T26/0413	02-Dec-2016		<0.002
T26/0413	02-Mar-2017		<0.002
T26/0413	21-Jun-2017		<0.002
T26/0430	05-Sep-2016	<1.00	2.2
T26/0430	28-Nov-2016	<1.00	1.68
T26/0430	06-Mar-2017	<1.00	0.89
T26/0430	28-Jun-2017	<1.00	2.5
T26/0538	13-Sep-2016	<1.00	8.6
T26/0538	28-Nov-2016	<1.00	8.3
T26/0538	07-Mar-2017		8.1
T26/0538	22-Jun-2017	<1.00	10.5
T27/0063	15-Sep-2016	<1.00	1.12
T27/0063	29-Nov-2016	<1.00	1.42
T27/0063	28-Feb-2017	24	1.86
T27/0063	22-Jun-2017	<1.00	0.51