CatchmentCARE
Community Actions for Resilient Ecosystems

Sampling and Analysis of Groundwater at selected locations on the island of Ireland

Hillsborough Catchment Hydrochemistry Report

UK Research and Innovation/British Geological Survey
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Section 1 Introduction

1.1 Background

The British Geological Survey (BGS) appointed CDM Smith Ireland Ltd (CDM Smith) to undertake a programme of groundwater monitoring at locations at Hillsborough, Co. Armagh, Northern Ireland. This work was completed as part of the CatchmentCARE project.

Four monitoring events, which were part of a wider project of six monitoring events, were carried out between November 2021 and August 2022:

- November 2021 (monitoring event 3)
- March 2022 (monitoring event 4)
- June 2022 (monitoring event 5)
- August 2022 (monitoring event 6)

Five monitoring wells were sampled during each monitoring event. In total, 20 samples were collected over the monitoring period.

This report presents the fundamental hydrochemical characteristics of the associated groundwater body based on the four monitoring events. The hydrochemistry is summarised, an initial assessment of the water type is provided and potential anthropogenic pressures are discussed.

1.2 Site Background

The Hillsborough lies in Armagh in Northern Ireland (Figure 1). From the Corine 2018 Landcover dataset, land use in the area around Hillsborough is predominantly agricultural pastures, with some patches of coniferous forests and mixed forests (Corine Landcover 2018).

Subsoils comprise of till largely derived from sandstones and shales with drumlins scattering the surface (GSNI GeoIndex). Soils are largely Stagnosols (periodically wet and mottled) with some cambisols in the area around the wells to the north (UK Soil Observatory). The bedrock comprises of shales, mudstone, greywacke and conglomerates (GSNI GeoIndex). Bedrock geology and associated mineralogy are presented in Table 1.

The aquifer is largely classified as Bl (f) (limited potential productivity fracture flow), where moderate yields are unusual and low yields more common (GSNI GeoIndex). Regional flow is limited, mainly shallow, local flow. The vulnerability of the aquifer in the area of the wells ranges from level “two” (low) in the west to “five” (high) in the north east (GSNI GeoIndex).

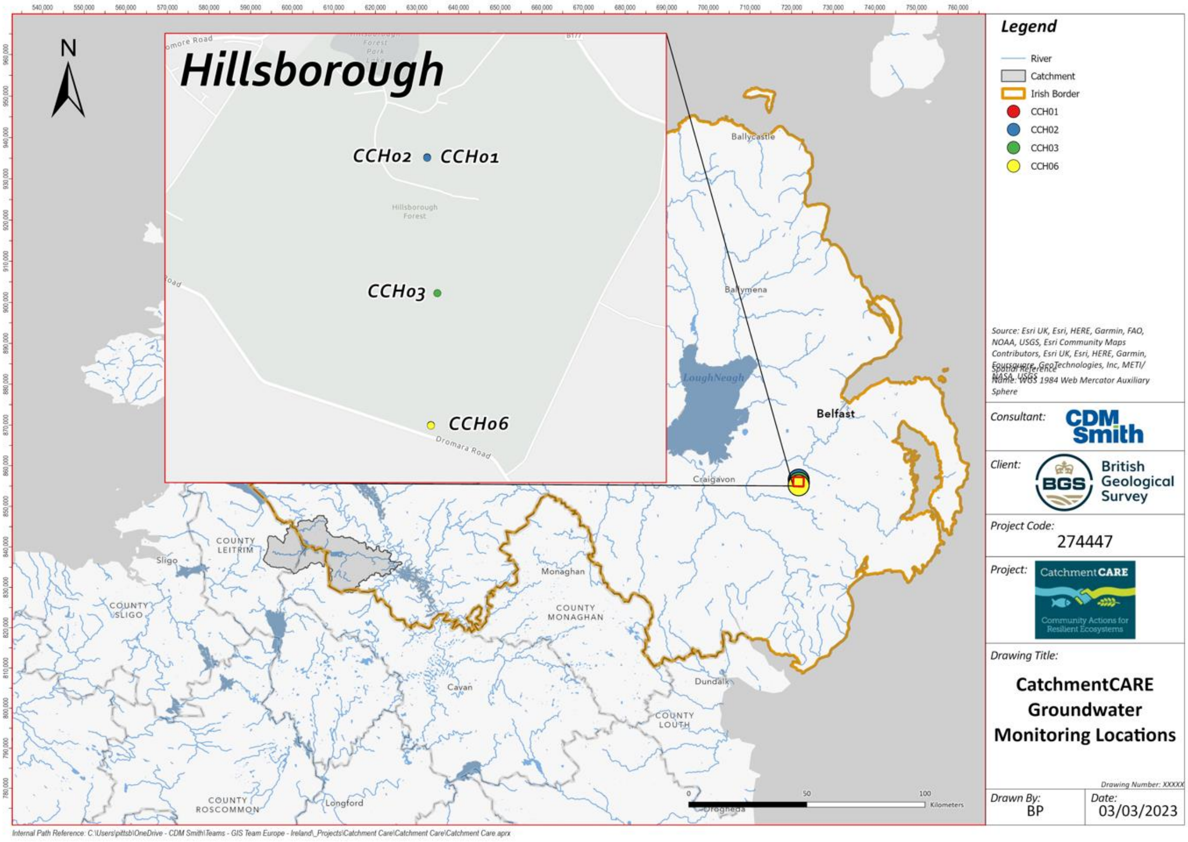

Figure 1: Hillsborough Location Map

Table 1 Bedrock Geology and Associated General Mineralogy

Bedrock Geology (GSNI 1:10,000 & 1:250,000)	General mineral composition
Sandstone (gala group) & silurian mudstone (moffat shale group).	Quartz: iron, silica, calcium carbonate, iron. Feldspar: aluminium, sodium, calcium, potassium, barium. Mudstone: manganese & iron.

Section 2 Methodology

2.1 Field Sampling Method

Groundwater samples were collected using either the low-flow technique or fixed volume technique. Ground water purging and sampling was carried out using pumps as follows:

- Bladder pump (low flow purge and sample method);
- Peristaltic pump (low flow purge and sample method); or
- Suction pump (fixed volume purge).

Groundwater levels were measured at all wells prior to pumping using a portable electronic water level meter and the initial static water level was recorded.

Field water quality parameters (temperature, pH, oxidation-reduction potential (ORP), conductivity and dissolved oxygen (DO)) were measured at all wells.

For low flow monitoring, the field water quality parameters were monitored in the field during low-flow purging using a flow-through cell to minimise oxidation by the atmosphere. Purging continued until the water quality indicator parameters stabilised (pH $< \pm 0.1$; specific electrical conductivity $< 3\%$; temperature $< \pm 0.1$ ° C). The water level was measured throughout the purging process to monitor drawdown. The field data were recorded in a Survey123 Groundwater Purging and Sampling Survey digital form using a handheld portable electronic device every approximately three-five minutes during the purging process. After the well was purged and stable parameters measured, the flow was reduced for low-flow sample collection (500 ml / minute).

Fixed volume purging was carried out by purging three times volume of the complete water column in the well. The well was then allowed to recharge before sampling using either the peristaltic pump or suction pump.

All samples for trace metal analyses were filtered in the field using a 0.45-micron membrane filter before filling bottles containing nitric acid preservative. New bottles supplied by the laboratories were used for sample collection.

2.2 Laboratory Analysis

Analysis of water samples was undertaken by McQuillan Environmental, Antrim, Northern Ireland, United Kingdom and Element Materials Technology (Element), Deeside, United Kingdom. Both laboratories are accredited by the United Kingdom Accreditation Service (UKAS) in accordance with ISO/IEC 17025:2005.

Water samples were either collected by a courier on the day of sampling (McQuillan Environmental) or dispatch by DHL to Element in UK.

The laboratory monitored parameters fall into three groups:

1. Inorganic parameters: 52 parameters, including metals, major anions and cations, macronutrients (nitrogen and phosphorus species), physico-chemical parameters (analysed by McQuillan Environmental);

2. Organic parameters: up to 218 parameters, including pesticides, and herbicides (analysed by Element); and

3. Microbial parameters: *E. coli*, total coliforms and *Clostridium Perfringens* (analysed by McQuillan Environmental).

Section 3 Data Quality and Usability Evaluation

3.1 Introduction

Laboratory data quality and usability were assessed using data quality indicators (DQIs). Data "usability" means that the data are acceptable to use for their intended purpose and associated evaluations. The DQIs for assessing data are expressed in terms of precision and accuracy. These DQIs provide a mechanism to evaluate and measure laboratory data quality throughout the project. The definitions and methods of measurement of precision and accuracy are discussed below.

3.2 Precision

Precision is the measurement of the ability to obtain the same value on re-analysis of a sample (i.e., the reproducibility of the data). The closer the results of the measurements are together, the greater is the precision. Precision is not related to accuracy or the true values in the sample; instead, precision is focused upon the random errors inherent in the analysis that result from the measurement process and are compounded by the sample vagaries. Precision is measured by analysing two portions of the sample (sample and duplicate) and then comparing the results. This comparison can be expressed in terms of relative percent difference (RPD). RPD is calculated as the difference between the two measurements divided by the average of the two measurements, as follows:

$$RPD = \frac{D_1 - D_2}{(D_1 + D_2) \times 0.5} \times 100$$

where:

RPD = Relative percent difference

D_1 = First sample value

D_2 = Second sample value (duplicate)

Acceptable RPD values for field duplicates are usually 50 % to 150 %. Field duplicates were generated for this project. One field duplicate was collected each round, totalling six for the project.

3.2.1 Field QA/QC Samples

The results are used to evaluate the combined reproducibility of both the laboratory analyses and field sampling.

Note, six monitoring events were carried out for the complete project. The Hillsborough wells were monitored during four events only (the final four monitoring events).

One duplicate sample per monitoring event was generated in the field (by filling two sets of bottles from the sampling tube alternating between bottles) and sent blind to McQuillan Environmental for analysis. Table 2 presents the results of 52 parameters and the calculated RPD between each pair of samples. Note, where both the original and duplicate result are less than the limit of detection (LOD), the RPD is zero. Where only one value is less than the LOD, half of the LOD value is used to permit calculation of the RPD; in such cases the "0.5 X <LOD"

value is indicated by grey fill. Table cells with a blue fill indicates an RPD greater than 50% but less than 150%. Yellow filled cells indicates an RPD greater than 150%.

Table 2 Duplicate data and associated RPD (%), monitoring events 3, 4, 5 & 6

		Round 3		Round 3	Round 4			Round 5			Round 6		
Sample Description		CCF07 (F-STC-DEEP)	% RPD	CCF07 (F-STC-DEEP)	CCD08 (D-DIW-TRANS)		% RPD	FPBH02		% RPD	RW-BH-03		% RPD
Lab ref (MCQ)		086071	086073	086071	101359	101365		105794	105796		108346	108349	
Date Sampled	Units	13/10/2021		13/10/2021	10/03/2021			16/06/2022			25/08/2022		
Alkalinity, Bicarbonate as CaCO3	mg/l	140	135	140	70.6	90	24.2	250	295	16.5	133	84.7	-44
Alkalinity, Total	mg/l	148	138	148	70.3	89.6	24.1	280	274	-2.2	119	105	-13
Aluminium (diss.filt)	ug/l	19.1	18	19.1	<10	<10	0	11.3	5	-77.3	17.1	21.9	25
Ammonia as N	mg/l	0.34	0.055	0.34	0.055	0.14	87.2	<0.11	<0.11	0	<0.11	<0.11	0
Anions	ueq/l	4,600	4,340	4,600	2820	3890	31.9	6720	6580	-2.1	3050	2850	-7
Arsenic (diss.filt)	ug/l	<0.5	<0.5	<0.5	<0.5	<0.5	0	0.674	0.882	26.7	1.77	1.8	2
Barium (diss.filt)	ug/l	27.2	27.1	27.2	79.9	77.8	-2.7	163	163	0	25	24.3	-3
Boron (diss.filt)	ug/l	<10	<10	<10	18.9	11.5	-48.7	11.6	10.5	-10.0	<10	<10	0
Bromide	mg/l	0.0873	0.0994	0.0873	0.0866	0.102	16.3	0.114	0.116	1.7	0.071	0.104	38
Cadmium (diss.filt)	ug/l	<0.08	<0.08	<0.08	0.125	0.04	-103	<0.08	<0.08	0	<0.08	<0.08	0
Caesium, Dissolved	ug/l	< 1.0	< 1.0	< 1.0	<1.0	<1.0	0	<1.0	<1.0	0	1	1	0
Calcium (diss.filt)	mg/l	13.058	13.788	13.058	31.7	41	25.6	54	55	1.8	27.3	26.4	-3
Cations	ueq/l	4,190	4,300	4,190	2480	3240	26.6	6350	6500	2.3	2540	2490	-2
Cerium, Dissolved*	ug/l	-	-	-	-	-	-	-	-	-	-	-	-
Chloride as Cl	mg/l	27.7	25.0	27.7	15.2	33.3	74.6	25.8	25.3	-2.0	19.1	20.4	7
Chromium (diss.filt)	ug/l	<1	<1	<1	<1	<1	0	1.05	1.13	7.3	<1	<1	0
Cobalt (diss.filt)	ug/l	<0.5	<0.5	<0.5	<0.5	<0.5	0	<0.5	<0.5	0	3.81	3.83	1
Copper (diss.filt)	ug/l	<0.3	<0.3	<0.3	0.388	1.93	133	1.93	2.04	5.5	<0.3	<0.3	0
DOC	mg/l	< 2.0	< 2.0	< 2.0	10	3.1	-105	3.4	3.4	0	4.7	3.5	-29
Electrical Conductivity	uS/cm	442	439	442	298	410	31.6	643	642	-0.2	285	260	-9

		Round 3		Round 3	Round 4			Round 5			Round 6		
Sample Description		CCF07 (F-STC-DEEP)	% RPD	CCF07 (F-STC-DEEP)	CCD08 (D-DIW-TRANS)		% RPD	FPBH02		% RPD	RW-BH-03		% RPD
Lab ref (MCQ)		086071	086073	086071	101359	101365		105794	105796		108346	108349	
Date Sampled	Units	13/10/2021		13/10/2021	10/03/2021			16/06/2022			25/08/2022		
Fluoride as F	mg/l	1.67	1.65	1.67	0.0614	0.022	-94.5	0.304	0.286	-6.1	0.0698	0.764	167
Iodide*	mg/l	-	-	-	-	-	-	-	-	-	-	-	-
Ionic Balance	%	-4.7	-0.5	-4.7	-6.5	-9.1	33.3	-2.8	-0.6	-129	-9.3	-6.6	-34
Iron (diss.filt)	mg/l	<0.019	<0.019	<0.019	<0.019	<0.019	0	<0.019	<0.019	0	10.9	11.2	3
Lead (diss.filt)	ug/l	<0.2	<0.2	<0.2	0.1	0.208	70.1	0.343	0.325	-5.4	<0.2	<0.2	0
Lithium (diss.filt)	ug/l	12.4	12.7	12.4	<1	<1	0	26.1	26.1	0	1.65	1.78	8
Magnesium (diss.filt)	mg/l	4.17	4.31	4.17	5.45	5.91	8.1	20	20.5	2.5	1.82	1.74	-4
Manganese (diss.filt)	ug/l	8.73	8.05	8.73	3.23	241	195	23.8	23.1	-3.0	1320	1290	-2
Mercury (diss.filt)	ug/l	<0.01	<0.01	<0.01	<0.01	<0.01	0	<0.01	<0.01	0	<0.01	<0.01	0
Nickel (diss.filt)	ug/l	<0.4	<0.4	<0.4	0.585	0.481	-19.5	1.03	1.29	22.4	3.15	3.16	0
Nitrate as N	mg/l	0.13	0.09	0.13	9.46	13	31.5	0.1	0.1	0	<0.08	<0.08	0
Nitrite as N	mg/l	< 0.05	< 0.05	< 0.05	<0.05	<0.05	0	<0.05	<0.05	0	<0.05	<0.05	0
Nitrogen, Total	mg/l	<1	<1	<1	9.22	12.5	30.2	<1	<1	0	<1	<1	0
pH	Units	8.47	8.53	8.47	6.22	6.18	-0.6	7.87	7.87	0	6.56	6.47	-1
Phosphate, Ortho as P	mg/l	<0.02	<0.02	<0.02	<0.02	<0.02	0	<0.02	<0.02	0	<0.02	<0.02	0
Phosphorus (diss.filt)	ug/l	10	20	10	10	23.6	81.0	<20	<20	0	77.9	75.7	-3
Potassium (diss.filt)	mg/l	7.05	7.47	7.05	0.833	4.8	141	23.3	23.8	2.1	<0.87	<0.87	0
Selenium (diss.filt)	ug/l	<1	<1	<1	<1	<1	0	<1	<1	0	<1	<1	0
Sodium (diss.filt)	mg/l	68.80	70.50	68.80	9.65	12.9	28.8	32.5	33.4	2.7	8.82	8.74	-1
Strontium (diss. filt)	ug/l	236	234	236	140	166	17.0	1240	1250	0.8	68.4	67.7	-1
Sulphate as SO4	mg/l	41.00	41.80	41.00	14.8	11.1	-28.6	18.3	18.1	-1.1	6.46	8.3	25
TDS	mg/l	245	229	245	152	263	53.5	367	374	1.9	167	163	-2
TOC	mg/l	1	0.09	1	2.8	15	137	3.3	3.2	-3.1	5	3.7	-30

		Round 3		Round 3	Round 4			Round 5			Round 6		
Sample Description		CCF07 (F-STC-DEEP)	% RPD	CCF07 (F-STC-DEEP)	CCD08 (D-DIW-TRANS)		% RPD	FPBH02		% RPD	RW-BH-03		% RPD
Lab ref (MCQ)		086071	086073	086071	101359	101365		105794	105796		108346	108349	
Date Sampled	Units	13/10/2021		13/10/2021	10/03/2021			16/06/2022			25/08/2022		
TON as N	mg/l	0.13	1	0.13	9.46	13	31.5	0.1	0.1	0	<0.08	<0.08	0
True Colour	mg/l Pt/Co	<1	<1	<1	0.5	2.1	123	4.48	4.47	-0.2	12.2	45	115
Turbidity	ntu	0.93	1.03	0.93	0.616	0.427	-36.2	0.452	0.359	-22.9	64.4	81.8	24
Uranium (diss.filt)	ug/l	10.9	10.7	10.9	<0.5	<0.5	0	46.8	46.7	-0.2	1.03	1.06	3
Zinc (diss.filt)	ug/l	6.53	3.14	6.53	9.91	8.4	-16.5	3.44	3.49	1.4	16.5	10.3	-46

* Removed following absence of detections in any well

The majority of RPD values were below 50%. Of 141 RPDs, 17 were > 50% but less than 150%. There were two instances of RPD > 150%. With one exception, these exceedances/high RPDs were generally associated with low concentrations and often with one value being at the LOD (and thus 0.5 x LOD used for the calculation). For manganese in the monitoring event four duplicate, the recorded concentration were 3.23 ug/L and 241 ug/L. All other parameters for these two duplicates are in line with expected values for a duplicate pair. The manganese concentrations were checked with the laboratory who confirmed their accuracy and suggested the deviation was due to a contamination issue at some point.

Overall, the duplicate %RPD data are considered satisfactory.

3.3 Ionic Balance/Charge Balance

Within a water sample, the amount of positive charges and negative charges should be equal, resulting in a charge balance or ionic balance of close to zero. Determining the ionic balance of a sample is a useful means of checking the laboratory analysis of ions have been carried out correctly. Values of ± 10% are satisfactory for this QA/QC test.

Of the 20 values, 18 were within ± 10%, with median value of -3.2 %. The remaining two values were close to ±10%, as below:

- -11.1% (CCH06 Lab ref: MCQ086851, monitored on 15/11/2021), and
- -11.3 % (CCH06 Lab ref: MCQ101169, monitored on 07/03/2022).

The laboratory checked the results for samples with elevated ionic balances and confirmed analysis were correct and data accurate.

The ionic balances are acceptable indicating good and complete analysis, with all major anions and cations analysed.

Section 4 Data Summary & Interpretation

4.1 Summary Statistics

This section provides a statistical summary of the analytical results and a comparison of the analytical results against selected assessment criteria. Where the reported values were below the detection limit (<LOD), the values were substituted with a value of half the limit of detection (0.5 x <LOD). The summary statistics apply to all 20 samples collected during the four monitoring events across all wells.

The summary statistics presented are briefly described below:

- WQS: water quality standard value/threshold (IGV or GTV, as below) to which the results are compared
- IGV: EPA Interim Guide Value (Towards Setting Guideline Values for The Protection of Groundwater In Ireland – Interim Report http://www.epa.ie/pubs/advice/water/ground/towardssettingguidelinevaluesfortheprotectionofgroundwaterinireland.html)
- GTV: Groundwater Regulations Threshold Value (S.I. No. 9 of 2010)
- Source: WQS source
- LOD: laboratory analytical limit of detection
- Min: minimum detected value above the LOD
- Mean: mean of dataset
- Maximum: maximum value detected
- Median: median value of dataset
- 97.7th percentile: 97.7th percentile of dataset
- No. of Samples: number of samples analysed for this parameter
- No. of WQS Exceedances: number of exceedances of the WQS threshold
- % of WQS Exceedances: percentage of values above the WQS threshold
- No. of Detections: number of values above the detection limit
- % of WQS Detections: percentage of values above the limit of detection

Summary statistics of the field physico-chemical water quality parameters along with major and minor elements are contained in Table 3. Table 4 contains the summary statistics of the trace metals (trace elements). Exceedances of the respective WQS are indicated by orange highlight of the number and percentage WQS exceedance.

There were exceedances of the respective threshold/WQS for the following field parameters, and major elements:

- Specific electrical conductivity (SEC) (exceedance no. 7, or 35 %);
- Sulphate (SO_4) (exceedance no. 4, or 20 %);
- Ammonia (N) (exceedance no. 4, or 20%);
- Potassium (K) (exceedance no. 3, or 15 %); and,
- Total Dissolved Solids (TDS) (exceedance no. 1, or 5 %).

There were exceedances of the respective threshold/WQS for the metals (trace elements):

- Manganese (Mn) (exceedance no. 13 or 65 %);
- Barium (Ba) (exceedance no. 12 or 60 %);
- Iron (Fe) (exceedance no. 5 or 25 %);
- Magnesium (Mg) (exceedance no. 4, or 20 %); and,
- Uranium (U) (exceedance no. 1 or 5 %).

Table 3 Summary statistics of field parameters, and major and minor elements

Test	Units	LOD	WQS	Source	Min*	Mean	Max	Median	97.7th percentile	No. Samples	No. Detections	% Detections	No. WQS Exceedances	% WQS Exceedances
Specific Electrical Conductivity (lab)	µS/cm	<1	800	GTV 2016	437	725	1440	593	1,370	20	20	100	7	35
Sulphate as SO_4	mg/l	<5	188	GTV 2016	7.96	117	627	27.2	586	20	20	100	4	20
Ammonia (as N)	mg/l	<0.11	0.065	GTV 2016	0.110	0.088	0.480	0.055	0.336	20	4	20	4	20
Potassium (Dissolved)	mg/l	<0.174	5.00	IGV 2003	0.435	4.21	29.3	2.31	22.8	20	20	100	3	15
Total Dissolved Solids (TDS)	mg/l	<3	1000	IGV 2003	250	437	1080	328	1,017	20	20	100	1	5
pH	su	-	<6.5, >9.5	IGV 2003	6.68	7.40	9.07	7.29	8.61	20	20	100	0	0
Fluoride as F	mg/l	<0.02	1.00	2003	0.073	0.137	0.402	0.101	0.379	20	20	100	0	0
Oxidation reduction potential (ORP) (field)	mV	-	-	-	-444	-244	30.0	-308	19.6	20	-	-	-	-
Dissolved oxygen (field)	mg/l	-	-	-	0.210	1.90	6.00	1.04	5.70	20	-	-	-	-
Sodium (Dissolved)	mg/l	<0.145	150	GTV 2010	6.61	25.8	74.1	15.2	71.7	20	20	100	0	0
Calcium (Dissolved)	mg/l	<0.2	200	IGV 2003	13.5	73.7	136	70.3	128	20	20	100	0	0
Chloride as Cl	mg/l	<0.35	188	GTV 2016	19.2	37.8	97.0	31.1	90.4	20	18	90	0	0
Nitrate (as N)	mg/l	<0.08	37.5	GTV 2016	0.090	0.191	1.38	0.095	0.965	20	12	60	0	0

Test	Units	LOD	WQS	Source	Min*	Mean	Max	Median	97.7th percentile	No. Samples	No. Detections	% Detections	No. WQS Exceedances	% WQS Exceedances
Alkalinity Total as $CaCO_3$	mg/l	<5	NO WQS	-	126	209	296	199	294	20	20	100	-	-
Alkalinity (Bicarbonate $CaCO_3$)	mg/l	<5	NO WQS	-	120	205	295	195	293	20	20	100	-	-
Total phosphorus	ug/l	<20	No WQS	-	21.1	30.3	176	15.6	136	20	10	50	-	-
Total organic carbon	mg/l	<2	No WQS	-	2.80	26.2	80.0	21.7	74.3	20	20	100	-	-
Dissolved organic carbon	mg/l	<2	No WQS	-	2.20	26.8	83.0	22.6	76.0	20	16	80	-	-
Anions	ueq/l	ueq/l	No WQS	-	4,500	7,797	16,100	6,195	15,488	20	20	100	-	-
Cations	ueq/l	-	No WQS	-	3,590	7,284	15,400	6,090	14,745	20	20	100	-	-
Ionic Balance	%	< -50%	No WQS	-	-11.3	-4.03	3.20	-3.15	2.11	20	20	100	-	-
True colour	mg/l Pt/Co	<1	No WQS	-	1.02	11.0	66.0	2.36	58.5	20	15	75	-	-
Turbidity	ntu	<0.1	No WQS	-	0.151	15.7	89.8	3.31	88.5	20	20	100	-	-
TON as N	mg/l	<0.08	No WQS	-	0.428	0.197	4.17	0.095	0.965	20	12	60	-	-
Ortho-phosphate as P	mg/l	<0.02	0.035	GTV 2016	-	-	-	-	-	20	0	-	-	-

*Minimum result above detection limit

Table 4 Summary statistics of metals (trace elements)

Test	Units	LOD	WQS	Source	Min*	Mean	Max	Median	97.7th percentile	No. Samples	No. Detections	% WQS Detections	No. WQS Exceedances	% WQS Exceedances
Manganese	ug/l	<3	50.0	IGV 2003	11.6	708	2780	617	2,575	20	19	95	13	65
Magnesium	mg/l	<0.101	50.0	IGV 2003	9.68	28.0	60.0	23.2	59.8	20	20	100	4	20
Barium	ug/l	<0.20	100	IGV 2003	4.54	140	457	122	442	20	20	100	12	60
Iron	mg/l	<0.019	0.20	IGV 2003	0.023	0.936	7.43	0.002	7.19	20	11	55	5	25
Uranium	ug/l	<0.50	9.00	IGV 2003	0.528	41.3	815	0.555	460	20	12	60	1	5
Aluminium	ug/l	<10	150	GTV 2016	11.80	5.99	18.0	5.00	15.3	20	2	10	0	0
Zinc	ug/l	<1	75.0	GTV 2016	1.04	2.71	7.18	2.01	6.90	20	17	85	0	0
Arsenic	ug/l	<0.50	7.50	GTV 2016	0.534	1.43	4.97	0.891	4.56	20	17	85	0	0
Boron	ug/l	<10	750	GTV 2010	10.6	25.3	120	12.1	112	20	12	60	0	0
Bromide	mg/l	<0.02	No WQS	-	0.025	0.110	0.219	0.105	0.201	20	20	100	0	0
Cadmium	ug/l	<0.08	3.75	GTV 2010	0.121	0.048	0.122	0.040	0.122	20	2	10	0	0
Chromium	ug/l	<1.00	37.5	GTV 2016	1.54	0.607	1.59	0.500	1.57	20	2	10	0	0
Caesium	ug/l	<1.00	No WQS	-	-	-	-	-	-	20	0	0	-	-
**Cerium	ug/l	<1.00	No WQS	-	-	-	-	-	-	5	0	0	-	-
Copper	ug/l	<0.30	1500	GTV 2010	0.337	1.14	5.70	0.557	5.02	20	12	60	0	0

Test	Units	LOD	WQS	Source	Min*	Mean	Max	Median	97.7th percentile	No. Samples	No. Detections	% WQS Detections	No. WQS Exceedances	% WQS Exceedances
Cobalt	ug/l	<0.50 or <0.096	No WQS	-	0.048	0.514	1.62	0.437	1.49	20	12	60	-	-
Lithium	ug/l	<1.00	No WQS	-	1.41	15.8	79.0	8.41	63.4	20	20	100	-	-
Mercury	ug/l	<0.01	0.75	GTV 2016	0.025	0.006	0.025	0.005	0.016	20	1	5	0	0
Nickel	ug/l	<0.40	15.0	GTV 2010	0.428	1.44	4.17	1.23	3.85	20	20	100	0	0
Lead	ug/l	<0.20	7.50	GTV 2016	1.64	0.872	7.34	0.100	6.34	20	4	20	0	0
Selenium	ug/l	<1.00	No WQS	-	-	-	-	-	-	20	0	0	-	-
Strontium	ug/l	<1.00	No WQS	-	142	618	2600	316	2,412	20	20	100	-	-

*Minimum result above detection limit

**Analysis discontinued due to non-detects across all monitoring locations in project

Section 5 Water Physiochemical Characteristics and Water Type

This section provides analysis and interpretation of water physicochemical characteristics and the water type. Samples were collected at three depths/aquifer waterbodies – deep, shallow and transition. All samples from any one depth are grouped together for analysis and interpretation purposes in this report. The groupings, wells, sampling depth and total number of samples per group are given below and locations are presented in Figure 1:

- Group 1: Hillsborough Deep (*n* = 8)
  - CCH01(sampling depth 63 m) and
  - CCH03 (sampling depth 46 m);
- Group 2: Hillsborough Shallow (*n* = 4)
  - CCH05 (sampling depth 14 m); and
- Group 3: Hillsborough Transition (*n* = 8)
  - CCH02 (sampling depth 6 m); and
  - CCH06 (sampling depth 8 m).

The following are assessed in this section:

- Water chemistry:
  - Major cations and anions, with box plots and interpretation in Section 5.1, and
  - Major and minor (/trace) constituents, with box plots and interpretation in Section 5.2.
- Water physiochemistry, via assessment of alkalinity, redox and pH with box plots and interpretation in Section 5.3.1; and
- Water type, by piper diagram assessment of major ions in Section 5.3.2.

5.1 Major Cations and Anions

A summary of the concentration pattern of each of the major cations and anions is provided below.

5.1.1 Calcium

- Calcium (Ca) concentrations range from 13.5 mg/L to 136 mg/L, both at Group 1: Hillsborough Deep (Figure 2).
- The widest interquartile range of calcium concentrations occurs at Group 1: Hillsborough Deep while Group 2: Hillsborough Shallow shows the narrowest range.

- The interquartile range of data overlap across all three groups.
- Generally, lower calcium concentrations occur at Group 2: Hillsborough Shallow and higher concentrations at Group 3: Hillsborough Transition, with intermediate concentrations at Group 1: Hillsborough Deep.

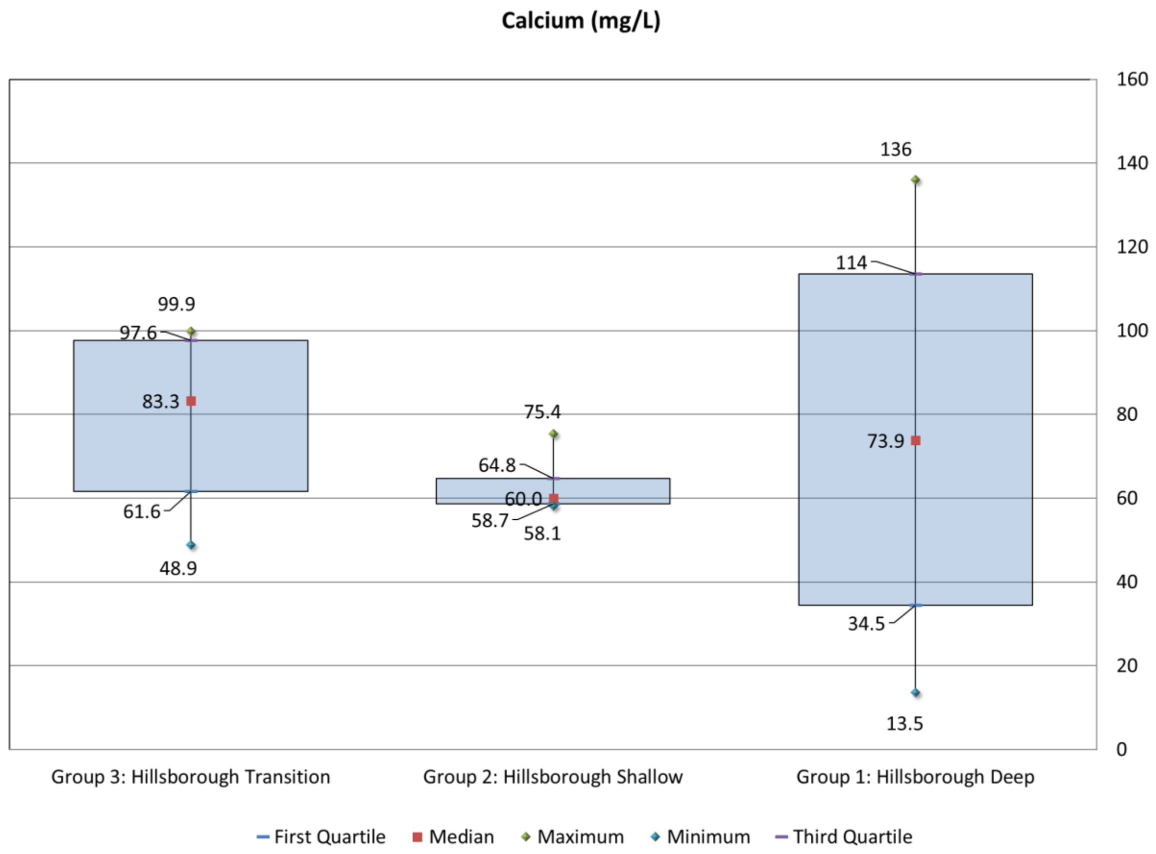

Figure 2: Calcium (Ca) boxplot, where x-axis is the well group

5.1.2 Magnesium

- Magnesium (Mg) concentrations range from 9.68 mg/L at Group 3: Hillsborough Transition to 60.0 mg/L at Group 1: Hillsborough Deep (Figure 3).
- The interquartile range of Group 1: Hillsborough Deep is distinct from (i.e., not overlapping) to the other two depths. The interquartile range of Group 2: Hillsborough Shallow and Group 3: Hillsborough Transition overlap.
- Generally, higher magnesium concentrations occur at Group 1: Hillsborough Deep and lower and similar concentrations occur in Group 2: Hillsborough Shallow and Group 3: Hillsborough Transition.

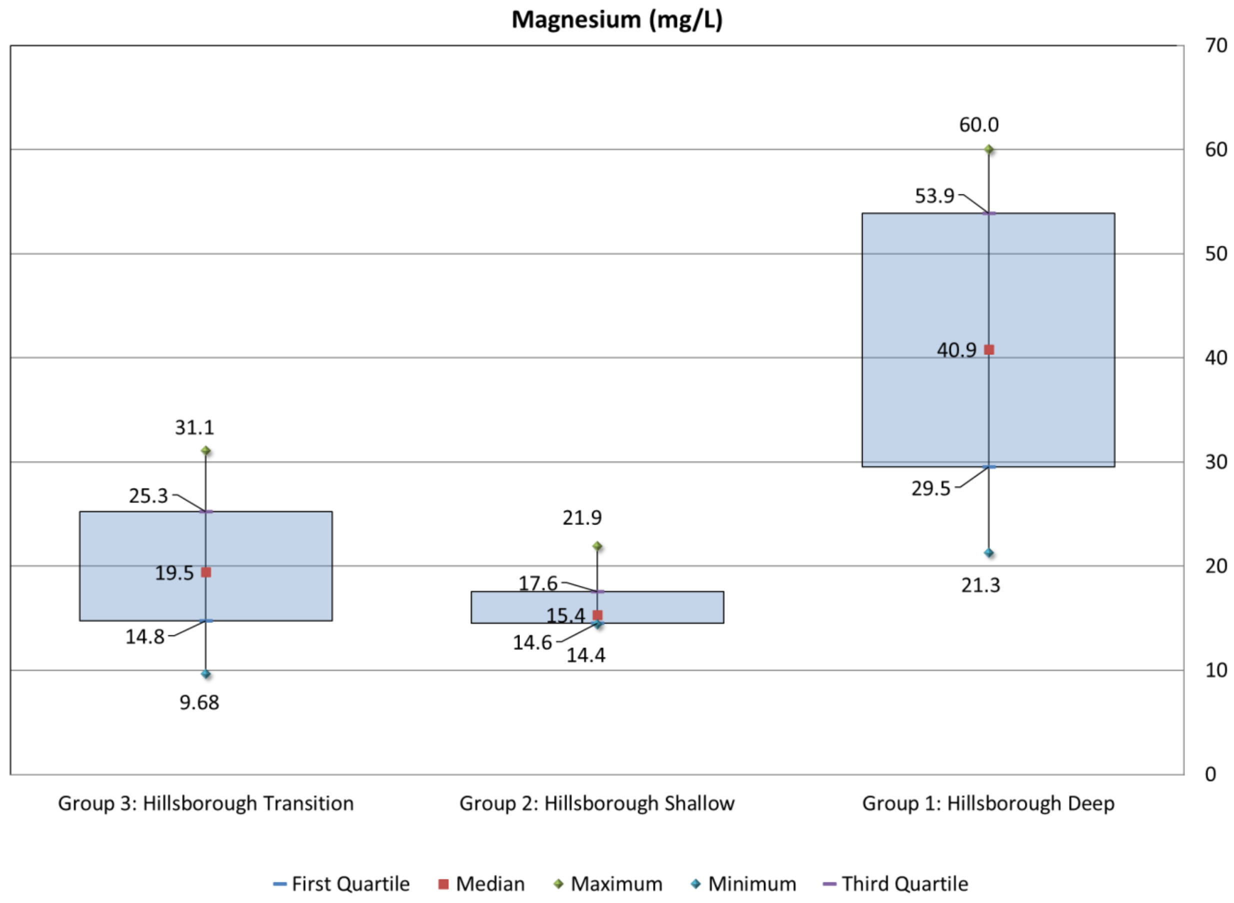

Figure 3: Magnesium (Mg) boxplot, where x-axis is the well group

5.1.3 Sodium

- Sodium (Na) concentrations range from 6.61 mg/L at Group 3: Hillsborough Transition to 74.1 mg/L at Group 1: Hillsborough Deep (Figure 4).
- Group 1: Hillsborough Deep has the widest interquartile range of concentrations, with relatively more narrow interquartile ranges at the other two locations.
- The interquartile range of sodium concentration at Group 1: Hillsborough Deep is distinct from (i.e., not overlapping) to the other two depths. The interquartile range of sodium concentration at Group 2: Hillsborough Shallow and Group 3: Hillsborough Transition overlap.
- Generally, higher sodium concentrations occur at Group 1: Hillsborough Deep, and lower and similar concentrations occur at Group 2: Hillsborough Shallow and Group 3: Hillsborough Transition.

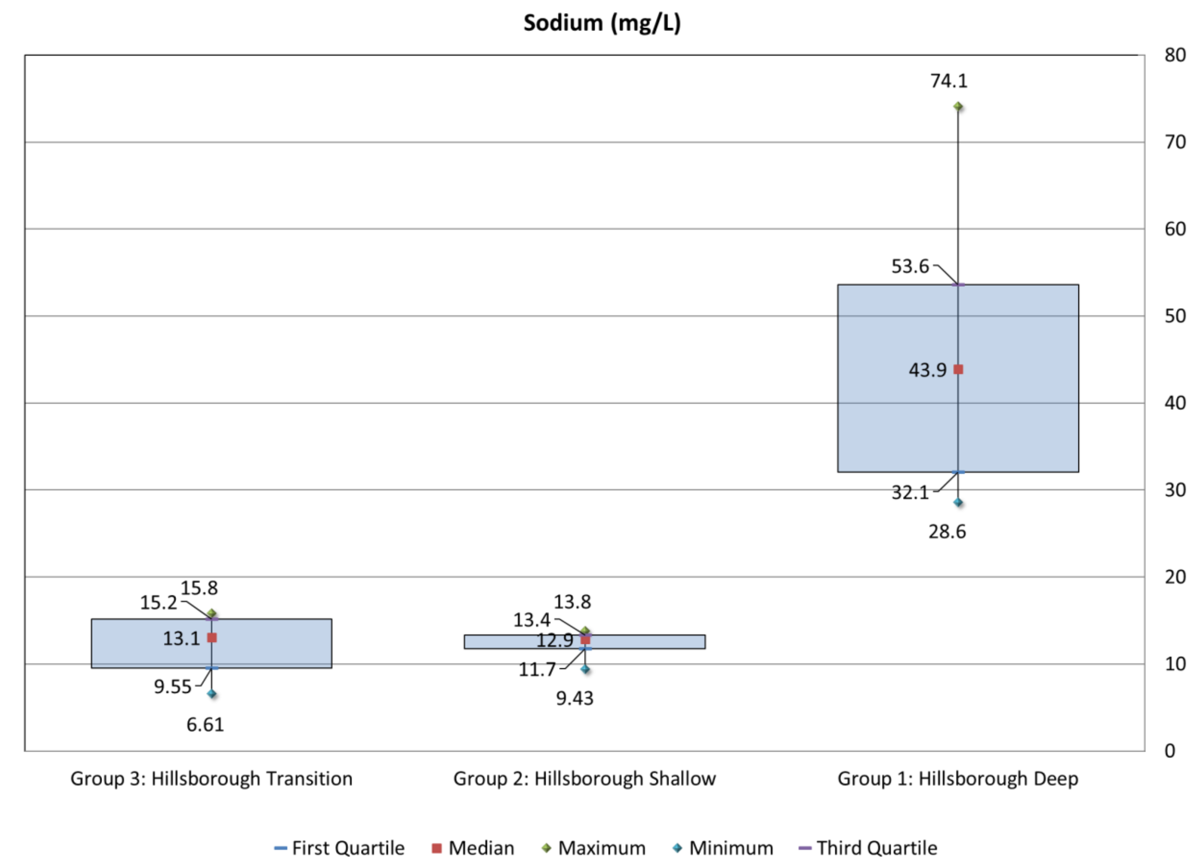

Figure 4: Sodium (Na) boxplot, where x-axis is the well group

5.1.4 Chloride

- Chloride (Cl) concentrations range from <LOD (0.20 mg/L, included in the graph as 0.10 mg/L) at Group 1: Hillsborough Deep and Group 2: Hillsborough Shallow to 97 mg/L at Group 3: Hillsborough Transition (Figure 5).
- The interquartile range of chloride concentrations overlap across all three depths.
- Generally, higher concentrations of chloride are recorded at Group 3: Hillsborough Transition, and lower concentrations at the other two depths.
- The widest interquartile range of chloride concentration is found at Group 3: Hillsborough Transition and the narrowest interquartile range found at Group 2: Hillsborough Shallow, with intermediate width of interquartile range at Group 1: Hillsborough Deep.

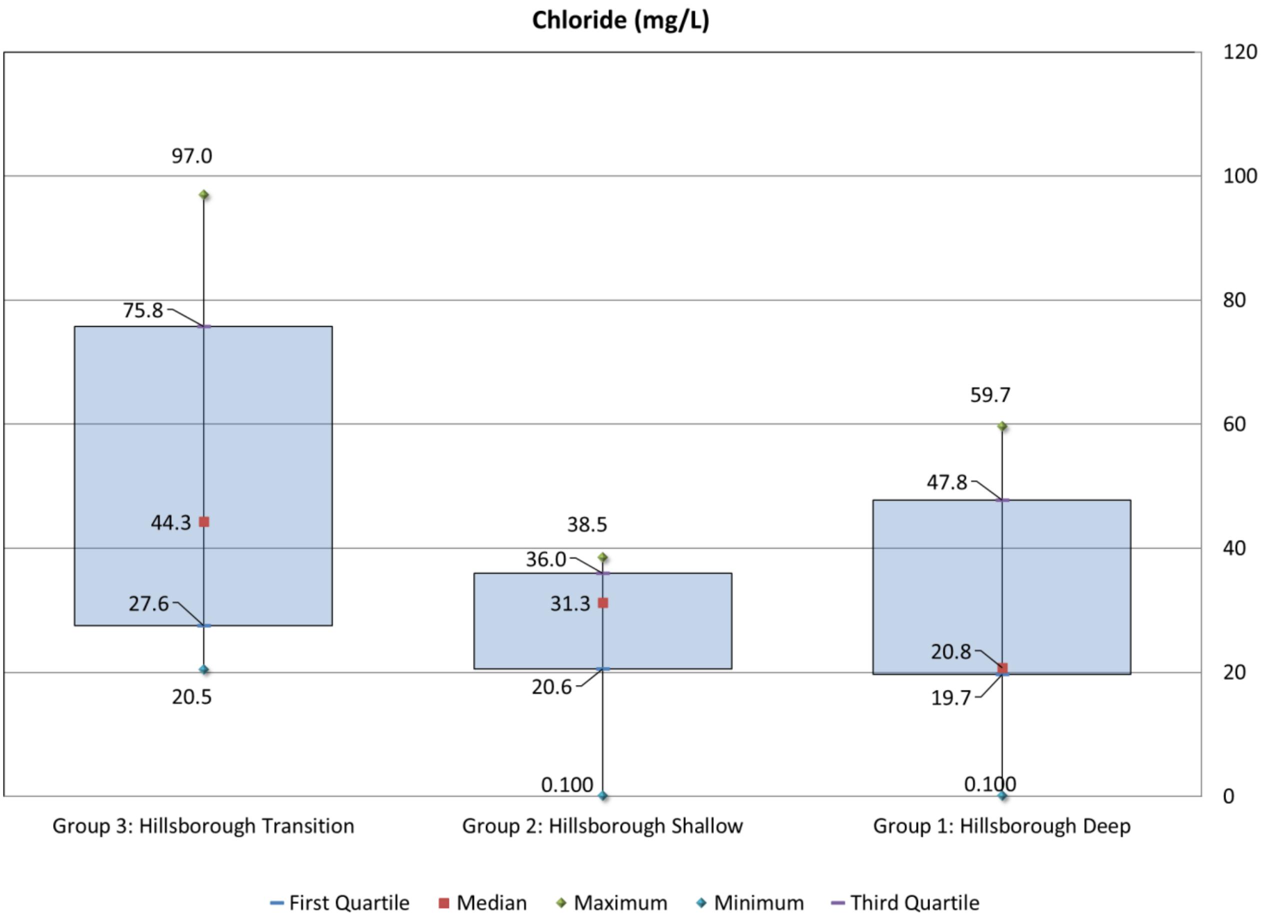

Figure 5: Chloride (Cl) boxplot, where x-axis is the well group

5.1.5 Fluoride

- Fluoride (F) concentration range from 0.073 mg/L at Group 3: Hillsborough Transition to 0.402 mg/L also at Group 1: Hillsborough Deep (Figure 6).
- Higher concentrations of dissolved fluoride are generally recorded in samples from Group 1: Hillsborough Deep with lower concentrations generally recorded at the other two depths.
- The interquartile range of fluoride concentrations of all three groups/well depths overlap.
- Group 1: Hillsborough Deep shows the widest interquartile range of fluoride concentrations, with the interquartile ranges at the other two depths relatively more narrow and also similar in concentrations.

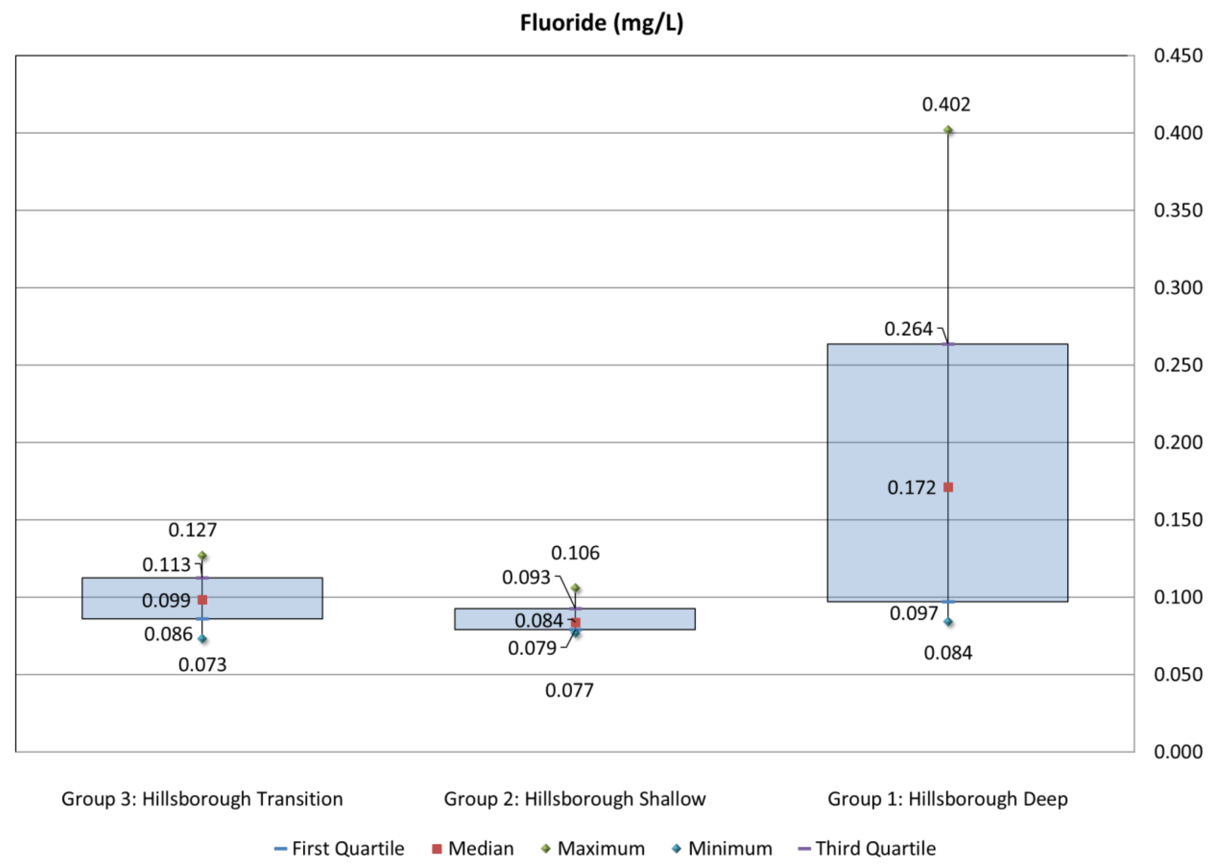

Figure 6: Fluoride (F) boxplot, where x-axis is the well group

5.1.6 Potassium

- Potassium (K) concentrations range from 0.44 mg/L at Group 2: Hillsborough Shallow to 29.3 mg/L at Group 1: Hillsborough Deep (Figure 7).
- The interquartile range of potassium concentrations are distinct (i.e., not overlapping) for all three depths.
- Generally, higher concentrations of potassium are recorded at Group 1: Hillsborough Deep, followed by Group 2: Hillsborough Shallow, with lower chloride concentrations generally occurring at Group 3: Hillsborough Transition.

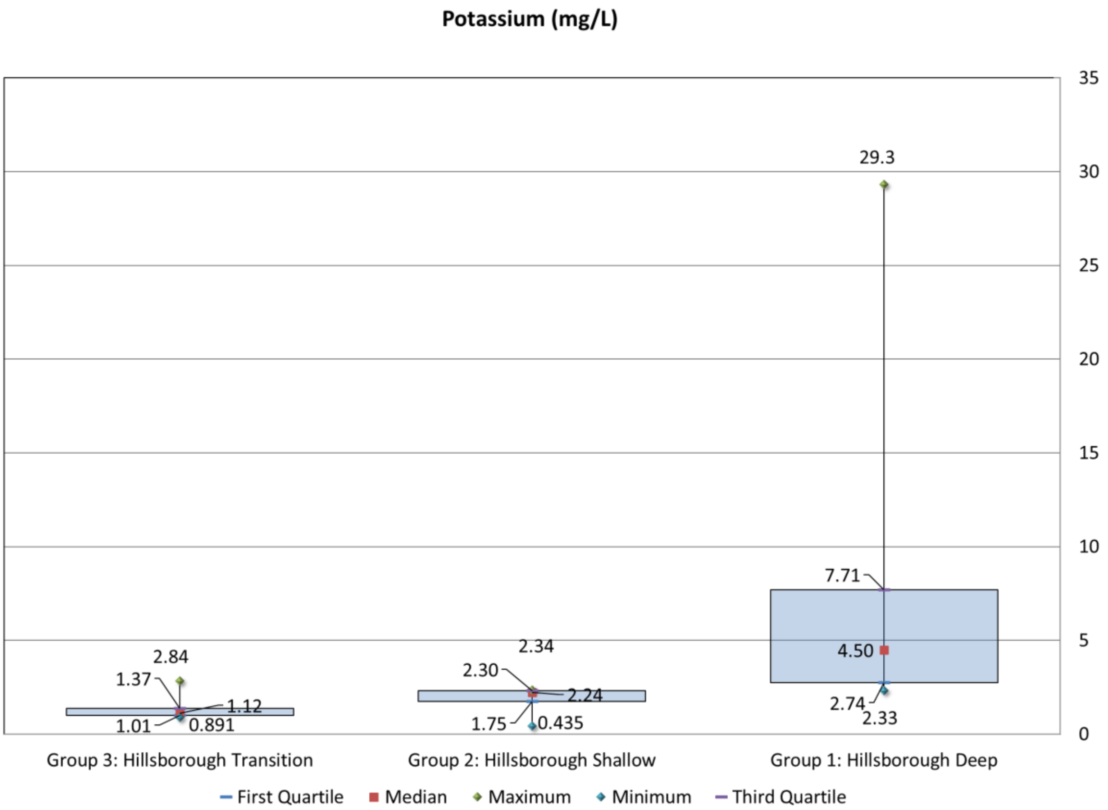

Figure 7: Potassium (K) boxplot, where x-axis is the well group and log scale y-axis

5.1.7 Sulphate

- Sulphate (SO_4) concentrations range from 2.5 mg/L at Group 1: Hillsborough Deep to 627 mg/L also at Group 1 (Figure 8).
- The interquartile range of sulphate concentrations overlap across all three depths.
- Group 1: Hillsborough Deep has the widest interquartile range of sulphate concentrations, with the interquartile ranges at the other two depths are relatively more narrow and similar.
- Generally, higher sulphate concentrations occur at Group 1: Hillsborough Deep and lower sulphate concentrations occur at Group 2: Hillsborough Shallow and Group 3: Hillsborough Transition.

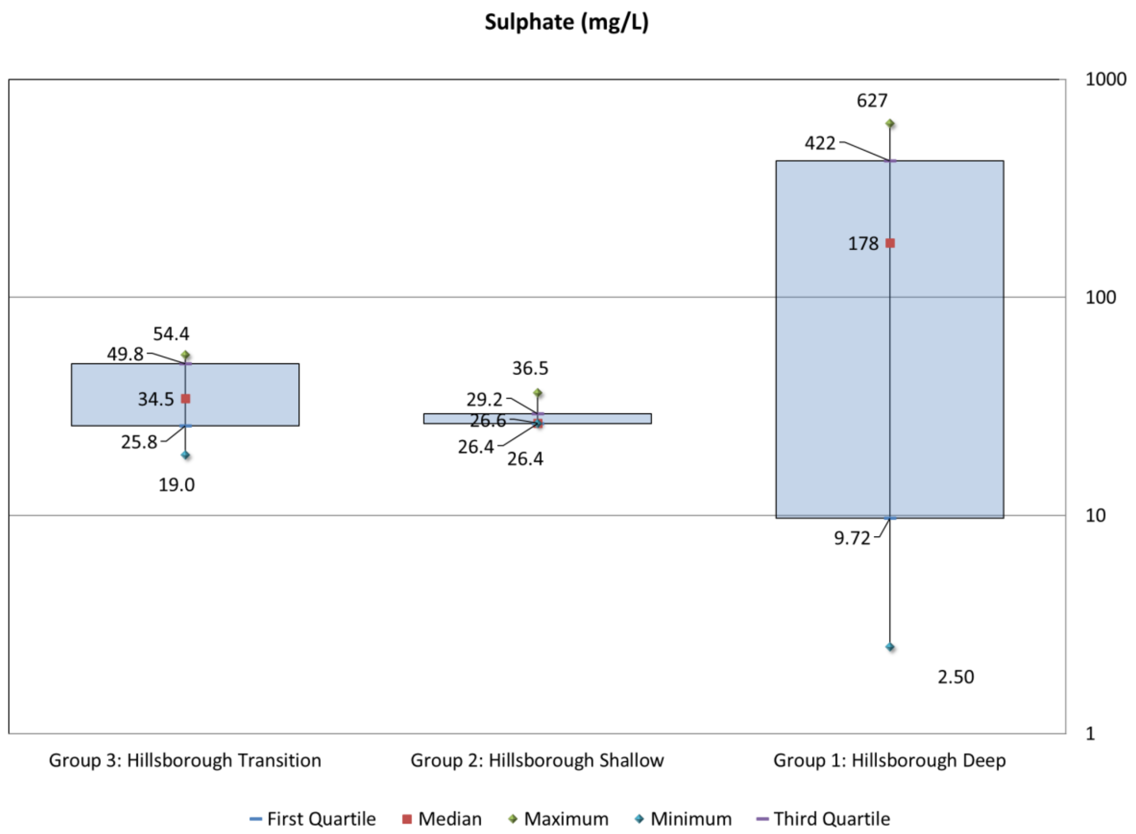

Figure 8: Sulphate (SO_4) boxplot, where x-axis is the well group and log scale y-axis

5.1.8 Nitrate (NO_3 as N)

- Nitrate (NO_3) concentrations range from <LOD (0.08 mg/L, included in the graph as 0.04 mg/L) at Group 3: Hillsborough Transition and Group 1: Hillsborough Deep to 1.38 mg/L at Group 3: Hillsborough Transition (Figure 9).
- Generally, higher nitrate concentrations occur at Group 2: Hillsborough Shallow. Generally, lower nitrate concentrations occur at Group 3: Hillsborough Transition, with the lowest nitrate concentrations occurring at Group 1: Hillsborough Deep.
- The interquartile range of nitrate concentrations overlap for Group 1: Hillsborough Deep and Group 3: Hillsborough Transition (due to values <LOD at both locations).
- The interquartile ranges of nitrate concentrations at Group 1: Hillsborough Deep and Group 2: Hillsborough Shallow do not overlap. The interquartile ranges of nitrate concentration at Group 2: Hillsborough Shallow and Group 3: Hillsborough Transition also do no overlap.

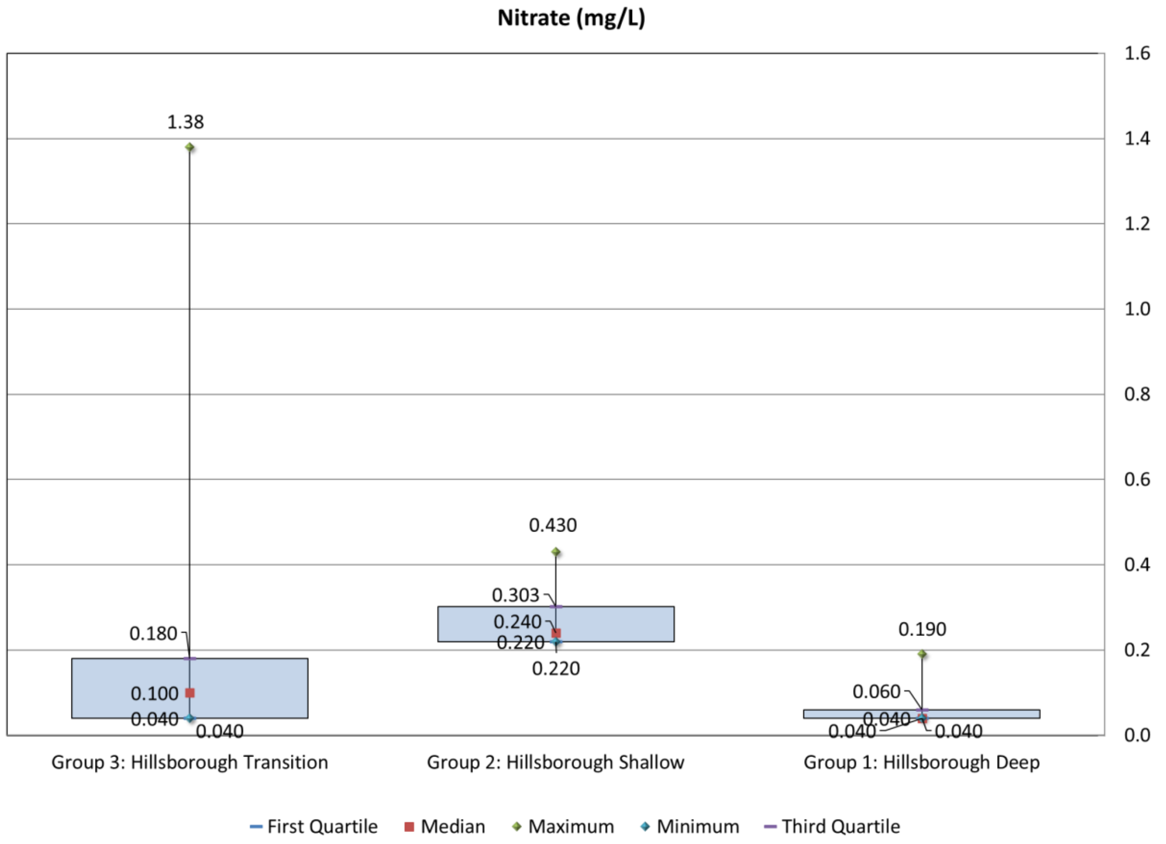

Figure 9: Nitrate (NO_3 as N) boxplot, where x-axis is the well group

5.2 Major and Minor (Trace) Elements

A summary of the concentration patterns of major and minor (trace) elements, for which there is at least one detection at each site, is provided below. The data are grouped based on well depth as previously discussed.

5.2.1 Dissolved Iron

- Dissolved iron (Fe) concentrations range from <LOD (0.02 mg/L, included in the graph as 0.01 mg/L) at all groups to 7.43 mg/L at Group 3: Hillsborough Transition (Figure 10).
- The interquartile range of iron concentrations at all three depths overlap, with higher concentrations generally occurring at Group 3: Hillsborough Transition relative to the other two depths.

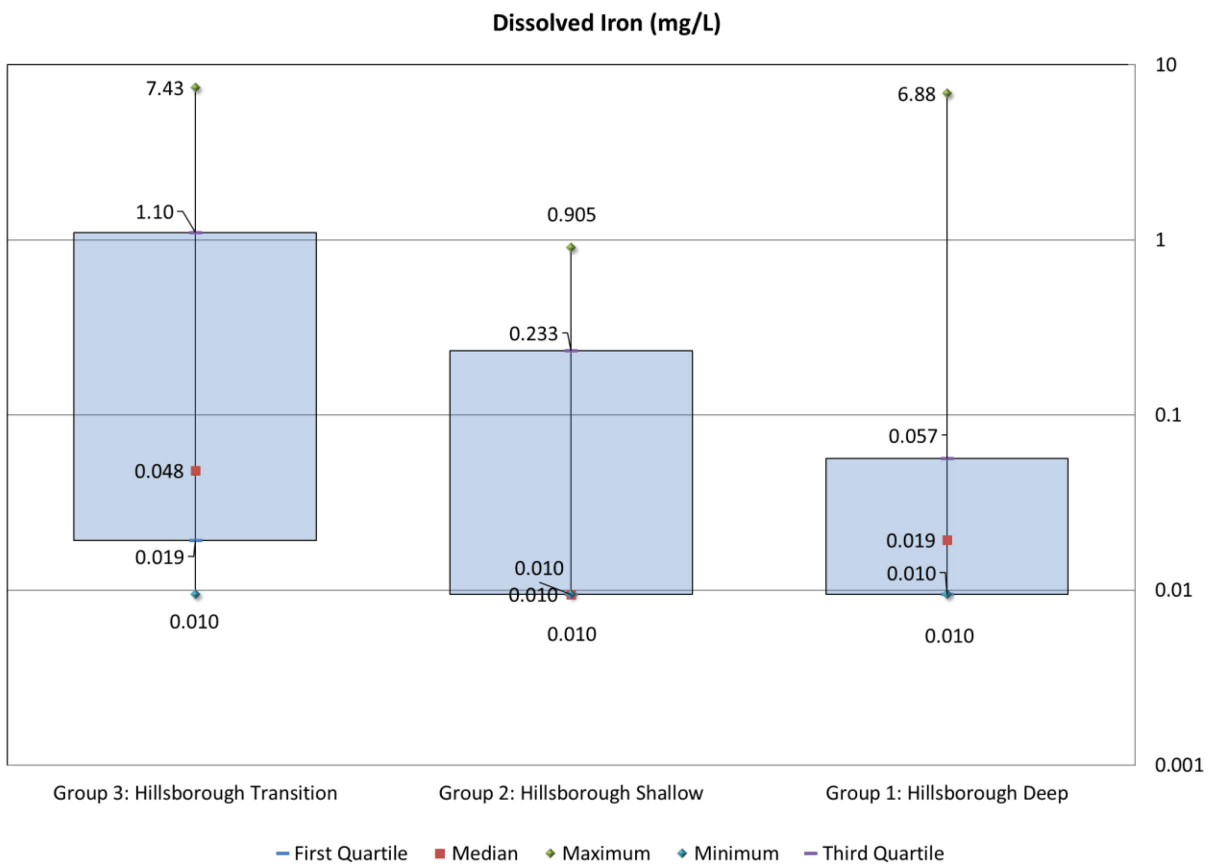

Figure 10: Dissolved Iron (Fe) boxplot, where x-axis is the well group and log scale y-axis

5.2.2 Dissolved Barium

- Dissolved barium (Ba) concentrations range from 4.54 ug/L at Group 2: Hillsborough Shallow to 457 ug/L at Group 3: Hillsborough Transition (Figure 11).
- Group 3: Hillsborough Transition generally has higher barium concentrations, with lower barium concentrations generally occurring at Group 2: Hillsborough Shallow, and intermediate concentrations occurring at Group 1: Hillsborough Deep.
- The interquartile range of barium concentrations at Group 3: Hillsborough Transition and Group 2: Hillsborough Shallow do not overlap.

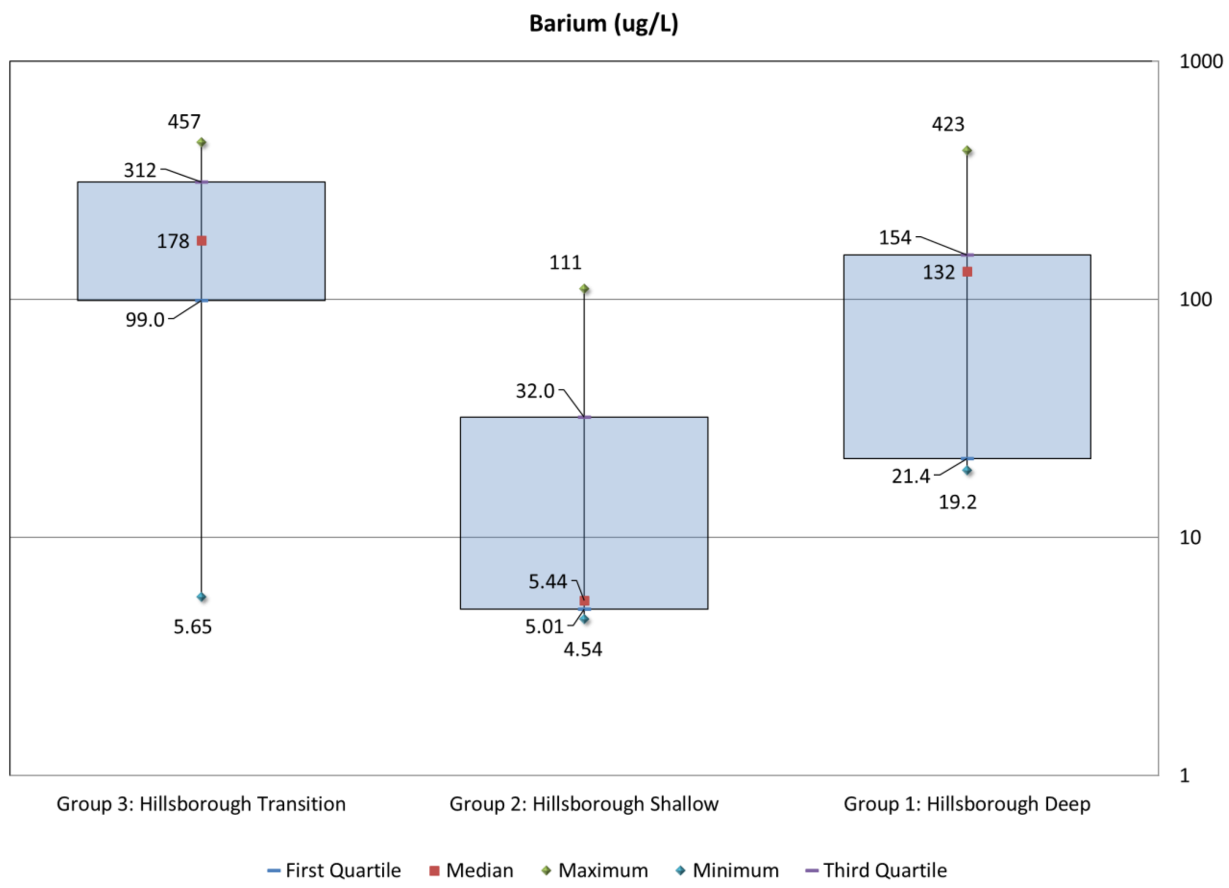

Figure 11: Barium (Ba) boxplot, where x-axis is the well group and log scale y-axis

5.2.3 Dissolved Nickel

- Dissolved nickel (Ni) concentrations range from 0.43 ug/L at Group 1: Hillsborough Deep to 4.17 ug/L at Group 2: Hillsborough Shallow (Figure 12).
- Group 2: Hillsborough Shallow has the widest interquartile range of nickel concentrations, while Group 1: Hillsborough Deep has the narrowest interquartile range of nickel concentrations.
- Generally, similar and relatively higher concentrations of dissolved nickel are recorded at Group 2: Hillsborough Shallow and Group 2: Hillsborough Shallow, with generally lower nickel concentrations occurring Group 1: Hillsborough Deep.

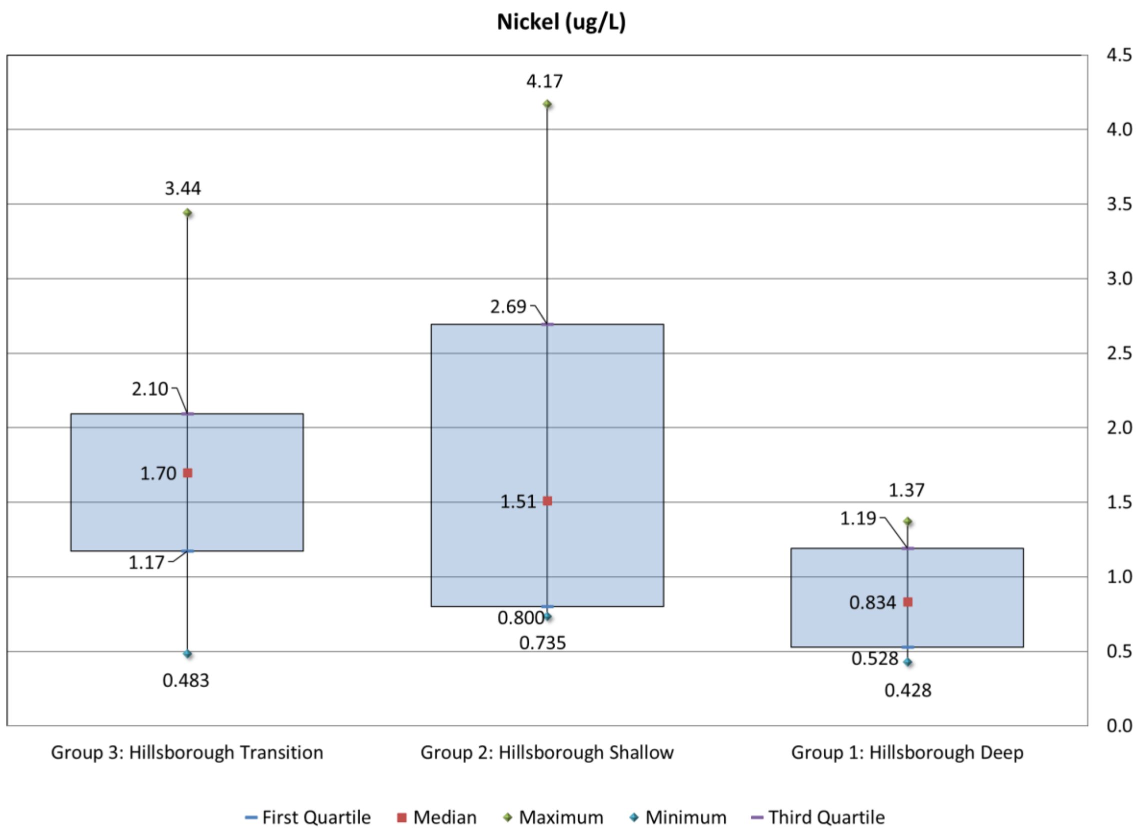

Figure 12: Nickel (Ni) boxplot, where x-axis is the well group

5.2.4 Dissolved Zinc

- Dissolved zinc (Zn) concentrations range from <LOD (1 ug/L, included in the graph as 0.5 ug/L) at Group 2: Hillsborough Shallow and Group 1: Hillsborough Deep to 7.18 µg/L at Group 2: Hillsborough Shallow (Figure 13).
- Generally, higher concentrations of zinc occur at Group 2: Hillsborough Shallow, with lower concentrations generally occurring at Group 1: Hillsborough Deep and intermediate concentrations occurring at Group 3: Hillsborough Transitions.
- The interquartile range of zinc concentrations of Group 1: Hillsborough Deep and Group 2: Hillsborough Shallow are distinct, while the interquartile ranges of all other combinations overlap.

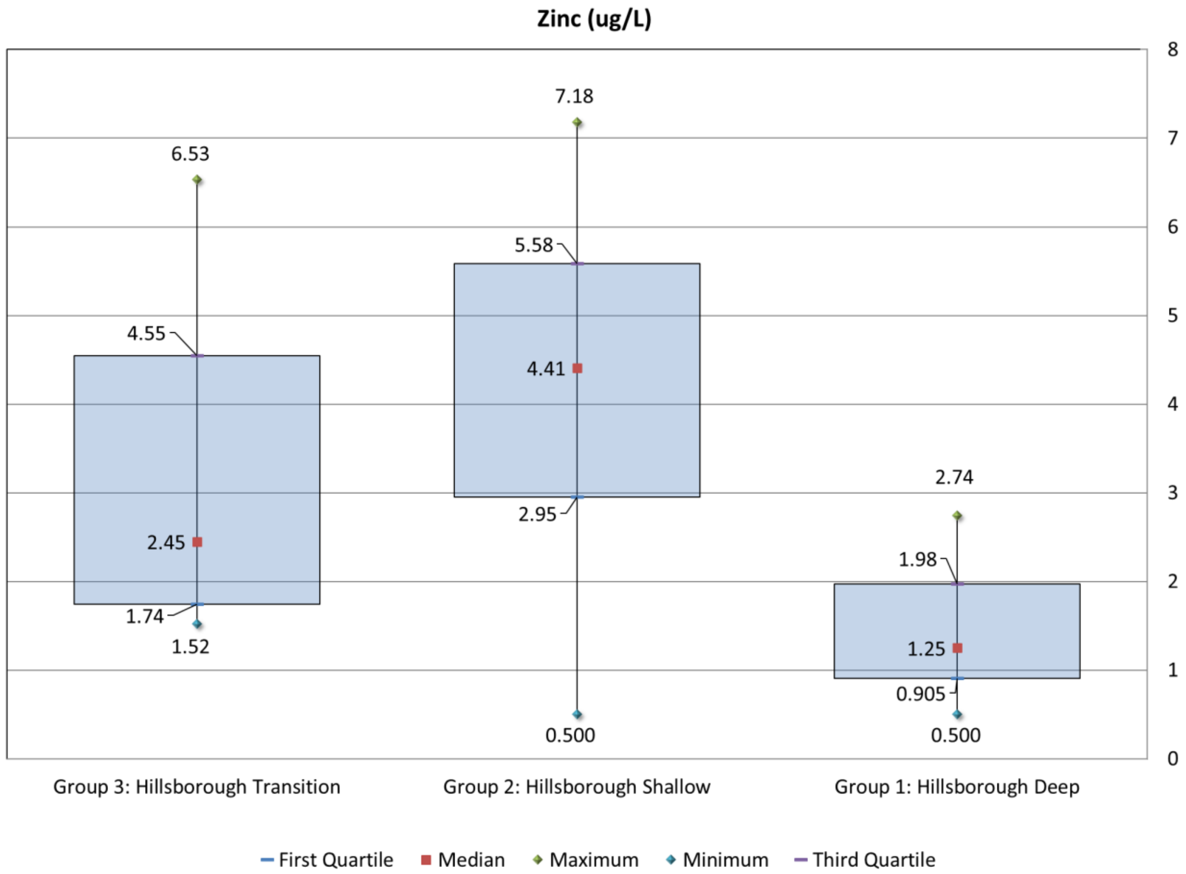

Figure 13: Zinc (Zn) boxplot, where x-axis is the well group

5.2.5 Dissolved Strontium

- Strontium (Sr) concentrations range from 142 ug/L at Group 3: Hillsborough Transition to 2,600 ug/L also at Group 3 (Figure 14).
- Generally, higher concentrations of dissolved strontium are recorded in samples from wells in Group 1: Hillsborough Deep, and lower strontium concentrations are recorded in samples across the other depths.
- Group 1: Hillsborough Deep has the widest interquartile range of strontium concentrations whereas the interquartile range of the other two groups are relatively narrower.
- The interquartile range of strontium concentrations of Group 2: Hillsborough Shallow and Group 3: Hillsborough Transition overlap with each other and not with Group 1: Hillsborough Deep (i.e., are distinct from Group 1: Hillsborough Deep).

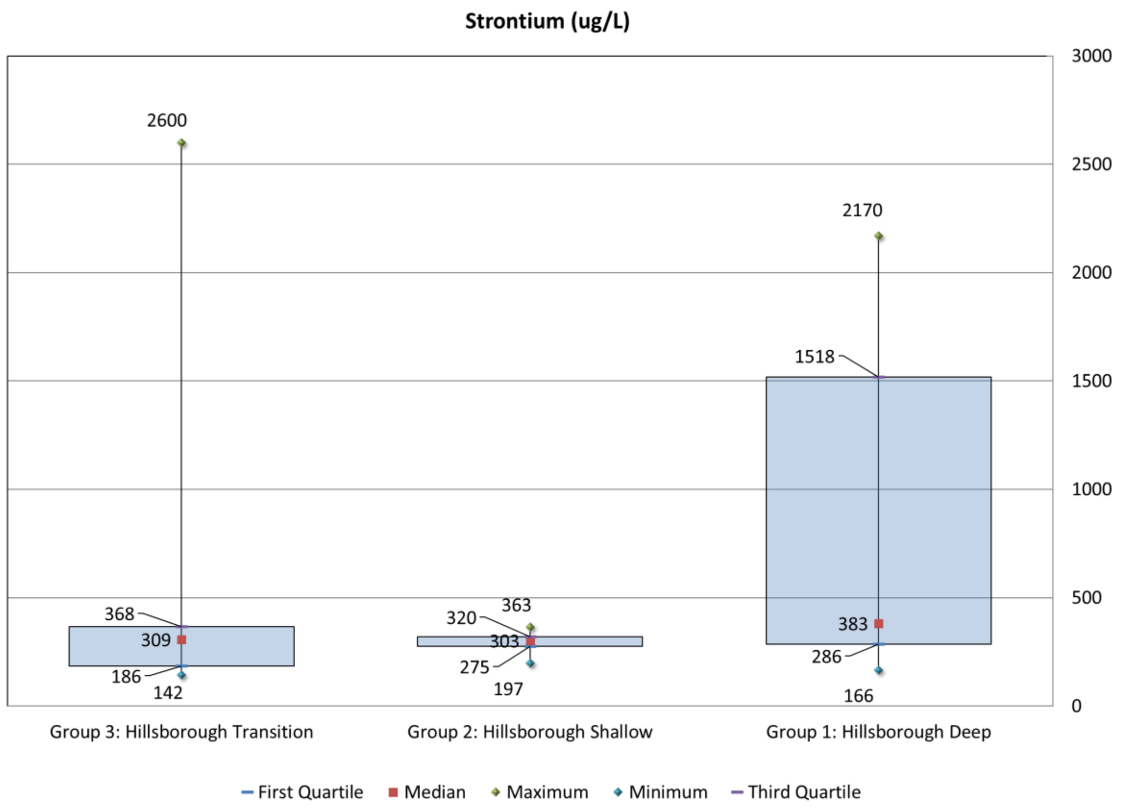

Figure 14: Strontium (Sr) boxplot, where x-axis is the well group

5.2.6 Dissolved Manganese

- Manganese (Mn) concentrations range from <LOD (3 ug/L, included in the graph as 1.5 ug/L) at Group 1: Hillsborough Deep to 2,780 ug/L at Group 2: Hillsborough Shallow (Figure 15).
- The interquartile range of manganese concentrations of Group 2: Hillsborough Shallow and Group 3: Hillsborough Transition overlap and are similar and relatively narrow.
- The interquartile range of manganese concentrations of Group 1: Hillsborough Deep is distinct from, and wider than, the other two depths. Generally, lower manganese concentrations occur at Group 1: Hillsborough Deep and higher manganese concentrations occur at the other two depths.
- Higher concentrations of dissolved manganese are recorded in samples from Group 2: Hillsborough Shallow and Group 3: Hillsborough Transition, and lower concentrations were recorded in samples from wells in Group 1: Hillsborough Deep.

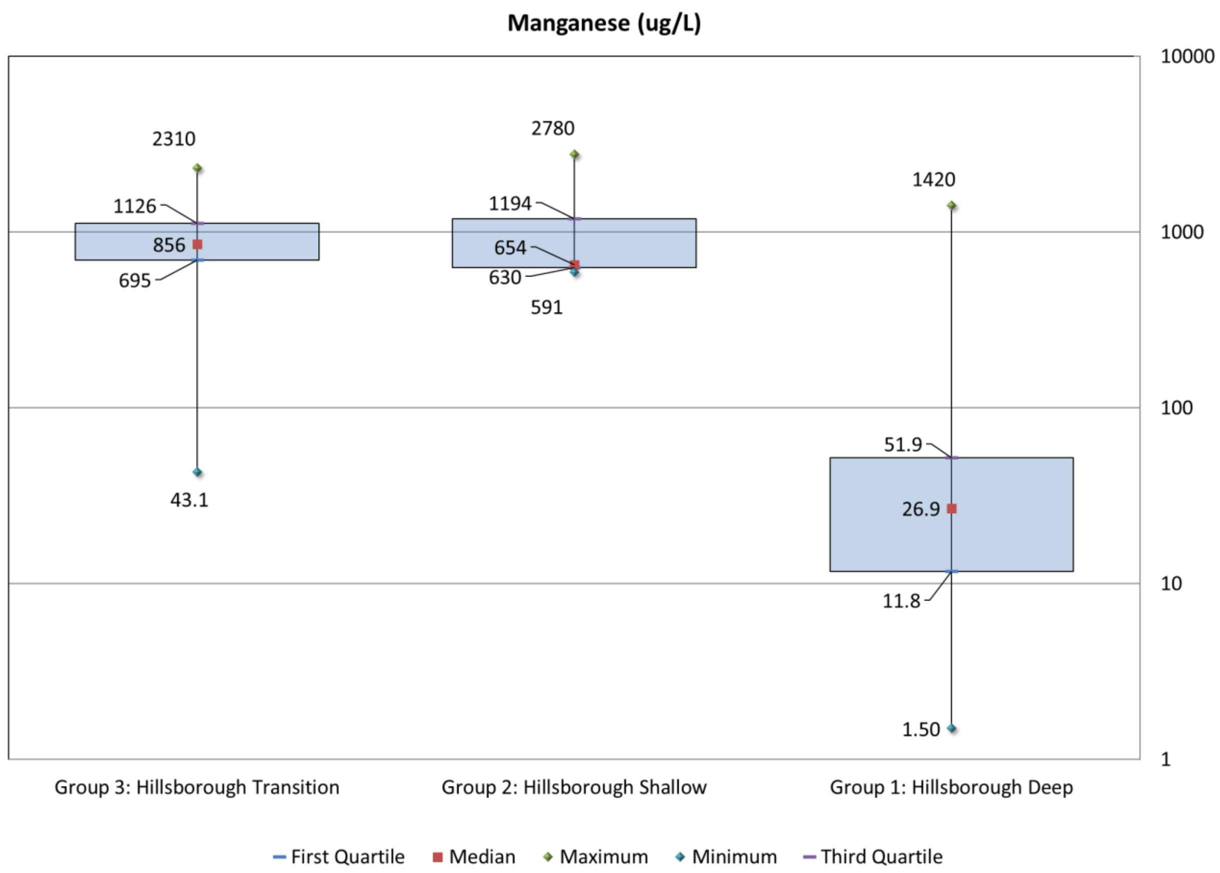

Figure 15: Manganese (Mn) boxplot, where x-axis is the well group and log scale y-axis

5.2.7 Dissolved Lithium

- Dissolved lithium (Li) concentrations range from 1.41 ug/L at Group 3: Hillsborough Transition, to 79.0 ug/L at Group 1: Hillsborough Deep (Figure 16).
- Group 3: Hillsborough Transition displays the widest interquartile range of concentrations, while the narrowest interquartile range of concentrations is observed at Group 2: Hillsborough Shallow.
- Higher concentrations of dissolved lithium are recorded at Group 1: Hillsborough Deep, with lower concentrations at the other two groups.
- The interquartile lithium concentration range of Group 3: Hillsborough Transition and Group 2: Hillsborough Shallow overlap, whereas the interquartile range of Group 1: Hillsborough Deep is distinct from the other two locations.
- Generally, relatively higher lithium concentrations occur at Group 1: Hillsborough Deep and lower concentrations at Group 3: Hillsborough Transition, with intermediate concentrations at Group 2: Hillsborough Shallow.

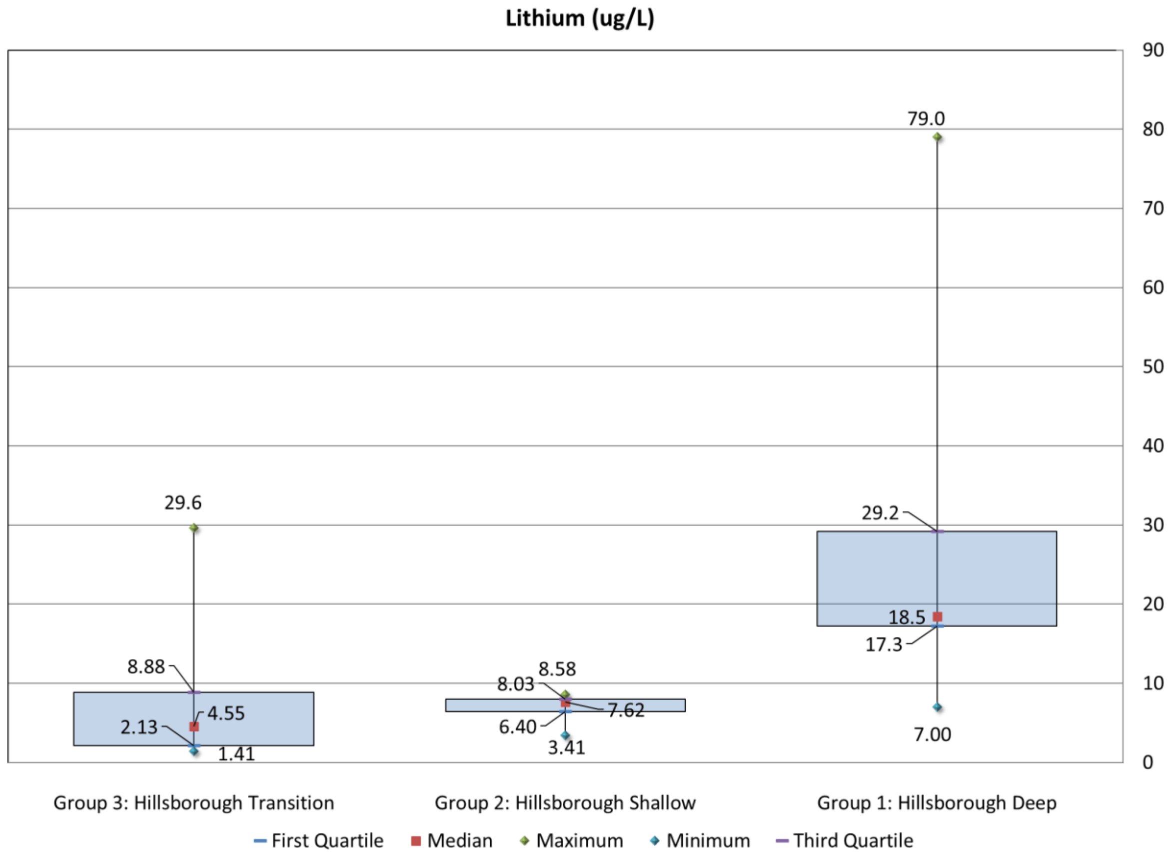

Figure 16: Lithium (Li) boxplot, where x-axis is the well group

5.2.8 Dissolved Uranium

- Dissolved uranium (U) concentrations range from <LOD (0.5 ug/L, included in the graph as 0.25 ug/L) at all groups to 815 ug/L at Group 2: Hillsborough Shallow (Figure 16).
- The interquartile range of uranium concentrations overlap at all three depths.
- The widest interquartile range of uranium concentrations occurs at Group 2: Hillsborough Shallow. The interquartile range of uranium at the other two locations are similar and comparatively lower relative to Group 2: Hillsborough Shallow.
- Generally, higher concentrations of dissolved uranium are present at Group 2: Hillsborough Shallow relative to the other two depths.

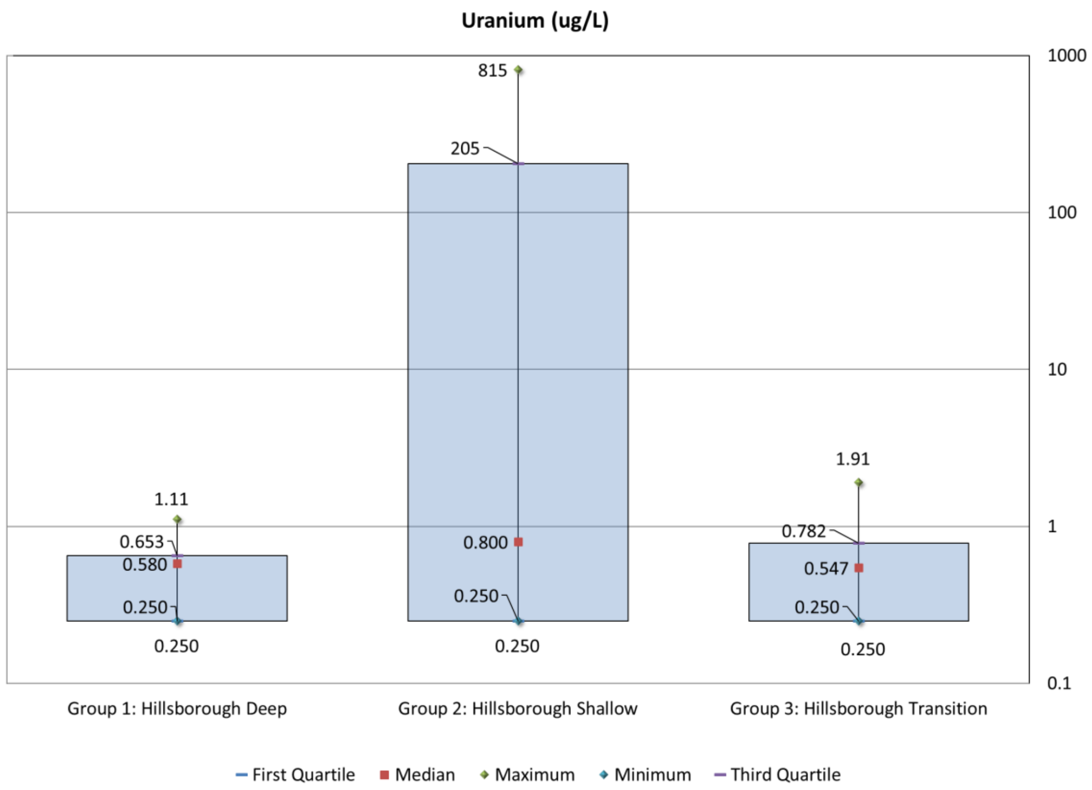

Figure 17: Uranium (U) boxplot, where x-axis is the well group and log scale y-axis

5.2.9 Dissolved Copper

- Dissolved copper (Cu) concentrations range from <LOD (0.30 ug/L, included in the graph as 0.150 ug/L) at all groups to 5.70 ug/L at Group 3: Hillsborough Transition (Figure 18).

- The interquartile range of copper concentrations overlap for Group 3: Hillsborough Transition and Group 2: Hillsborough shallow. The interquartile range for Group 1: Hillsborough Deep does not overlap with the other two depths.

- The widest interquartile range of copper concentrations occurs at Group 3: Hillsborough Transition. The interquartile range of copper at Group 2: Hillsborough Shallow is narrow relative to Group 3: Hillsborough Transition. The narrowest interquartile range of copper concentrations occurs at Group 1: Hillsborough Deep.

- Generally, higher concentrations of dissolved copper occur at Group 3: Hillsborough Transition and lower concentrations at Group 1: Hillsborough Deep.

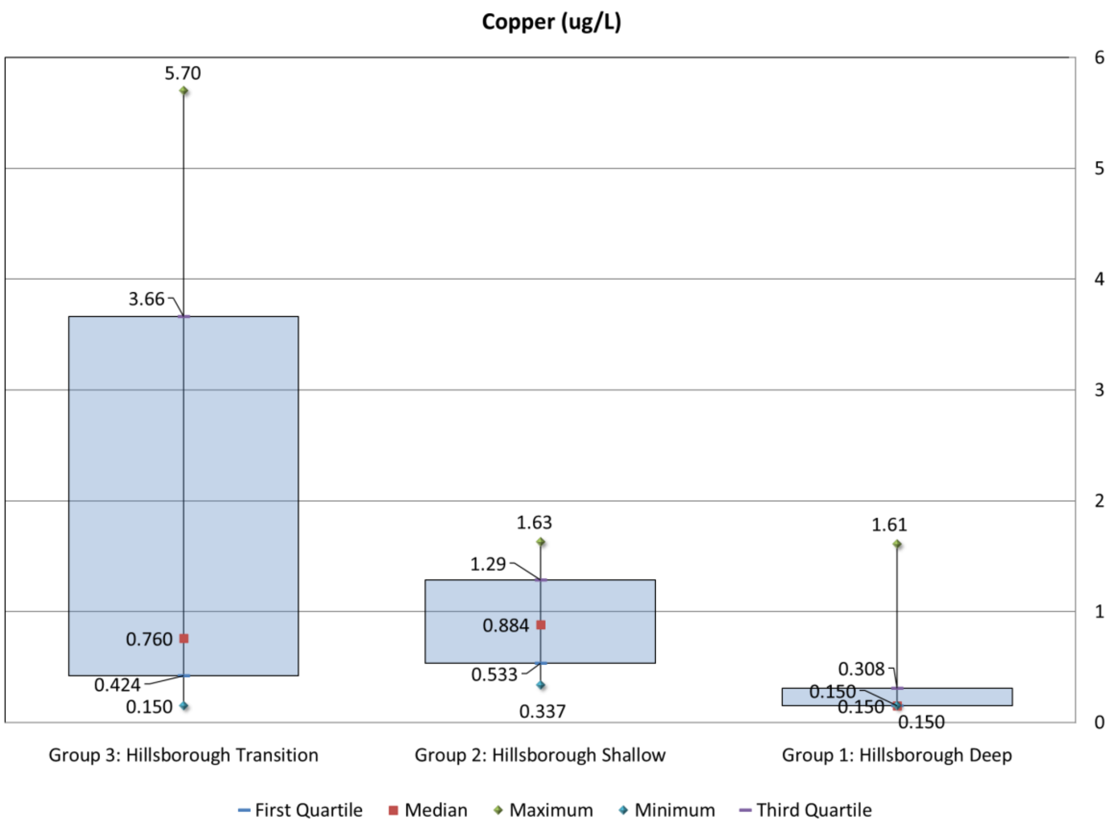

Figure 18 Copper (Cu) boxplot, where x-axis is the well group

5.3 Physicochemical Characteristics and Water Types

5.3.1 Water physiochemistry: Alkalinity, Oxidation-Reduction Potential (ORP) & pH

A summary of water chemistry parameters alkalinity, pH and oxidation-reduction potential (ORP) are presented below.

Alkalinity (Bicarbonate a $CaCO_3$)

- The alkalinity ranges from 120 mg/L in Group 1: Hillsborough Deep to 295 mg/L in Group 3: Hillsborough Transition (Figure 19).
- The alkalinity interquartile concentration ranges overlap for all three locations.
- Generally, relatively higher alkalinities occur at Group 3: Hillsborough Transition, relatively lower alkalinities occur at Group 1: Hillsborough Deep, and relatively intermediate alkalinities occur at Group 2: Hillsborough Shallow.

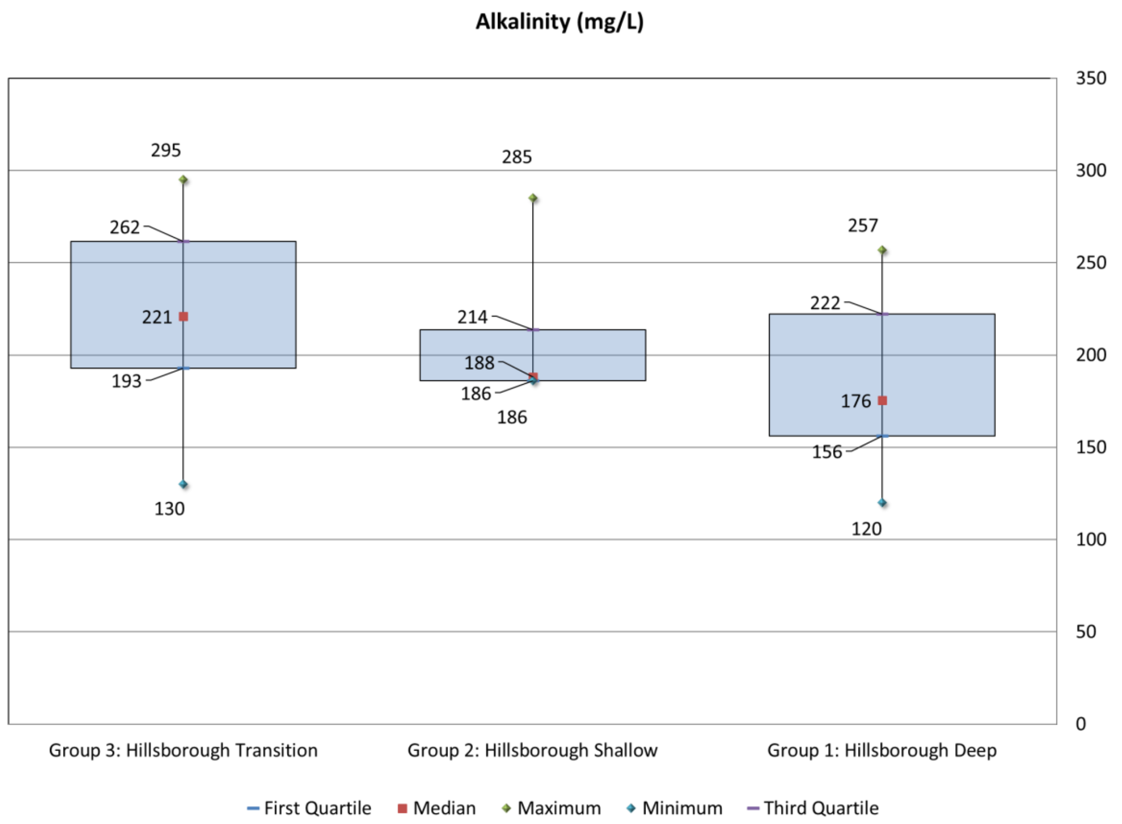

Figure 19: Alkalinity (Bicarbonate as $CaCO_3$) boxplot, where x-axis is the well group

Oxidation-Reduction Potential (ORP)

- The ORP ranges from -444 mV at Group 3: Hillsborough Transition to 30 mV at Group 1: Hillsborough Deep (Figure 20).
- The ORP data interquartile ranges for the three groups overlap and all groups have similar median ORP values (-308 to -327 mV).
- At all three depths, the interquartile range of ORP values are negative, indicating predominantly more reducing groundwater conditions at all depths (and particularly for Group 3: Hillsborough Transition, where all ORP values are negative).

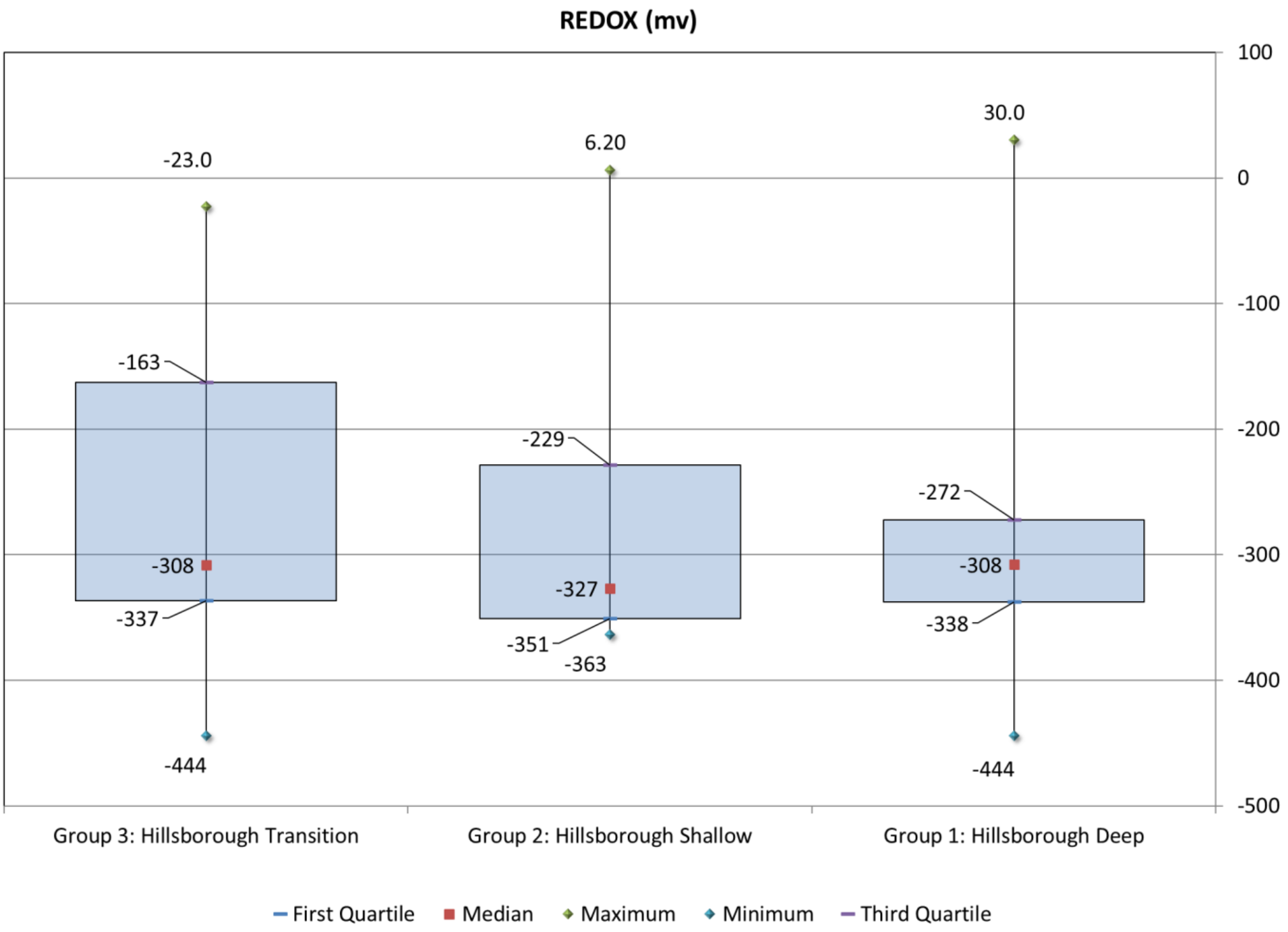

Figure 20: Redox boxplot, where x-axis is the well group

pH

- The pH values range from 6.68 at Group 3: Hillsborough Transition to 9.07 at Group 1: Hillsborough Deep (Figure 21).
- The interquartile range of pH values at all three depths are distinct (i.e., not overlapping).
- Generally, relatively higher pH values occur at Group 1: Hillsborough Deep, relatively lower pH values occur at Group 3: Hillsborough Transition and relatively intermediate pH values occur at Group 2: Hillsborough Shallow.

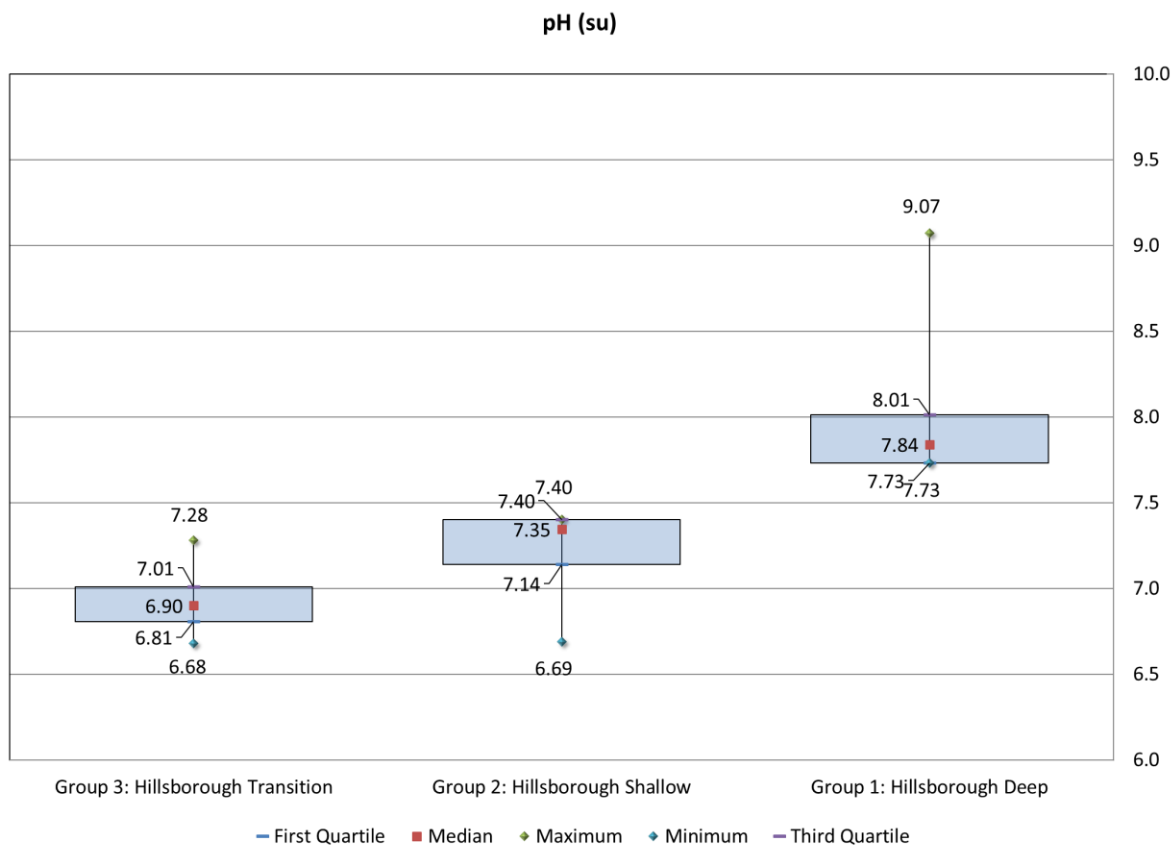

Figure 21: pH boxplot, where x-axis is the well group

5.3.2 Water Type

Piper diagrams are used to determine the general water type and also of transition, shallow and deep aquifers specifically. An illustration of the interpretation of piper diagrams is presented in Figure 22.

Overall, the groundwater is predominantly Ca-Mg-HCO_3 type, with a small number of samples plotting as a mixed type, no dominant type, Ca-Cl type or SO_4 type (

Figure 23).

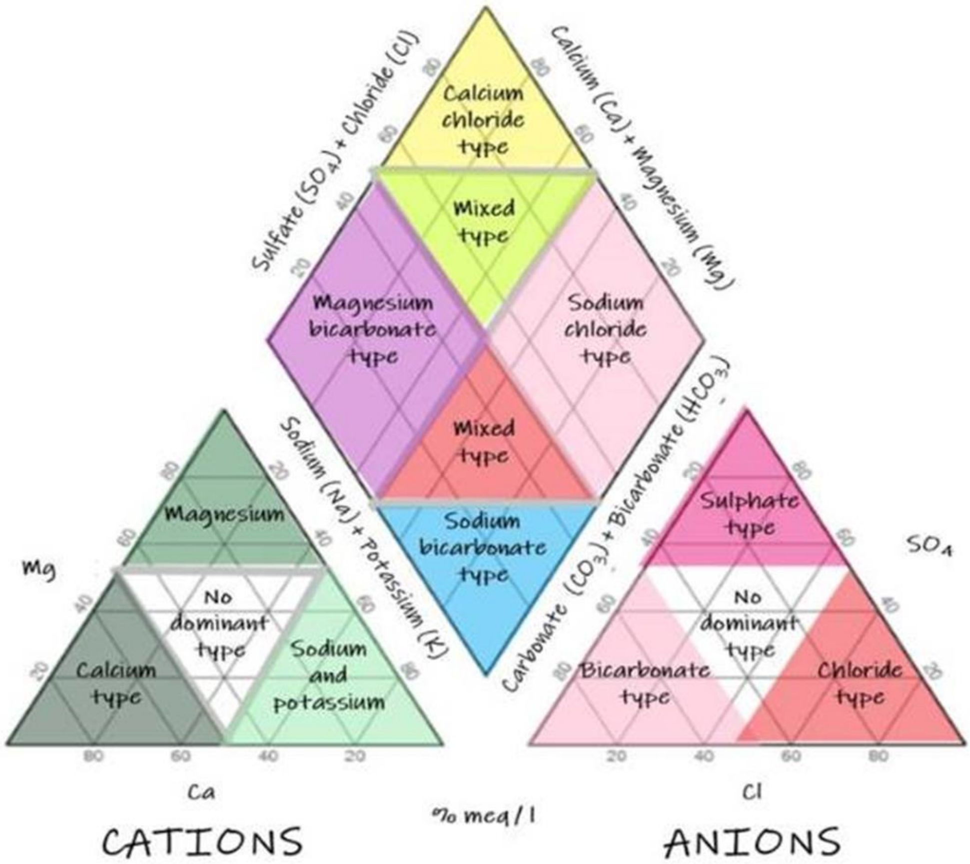

Figure 22 Piper Diagram Interpretation

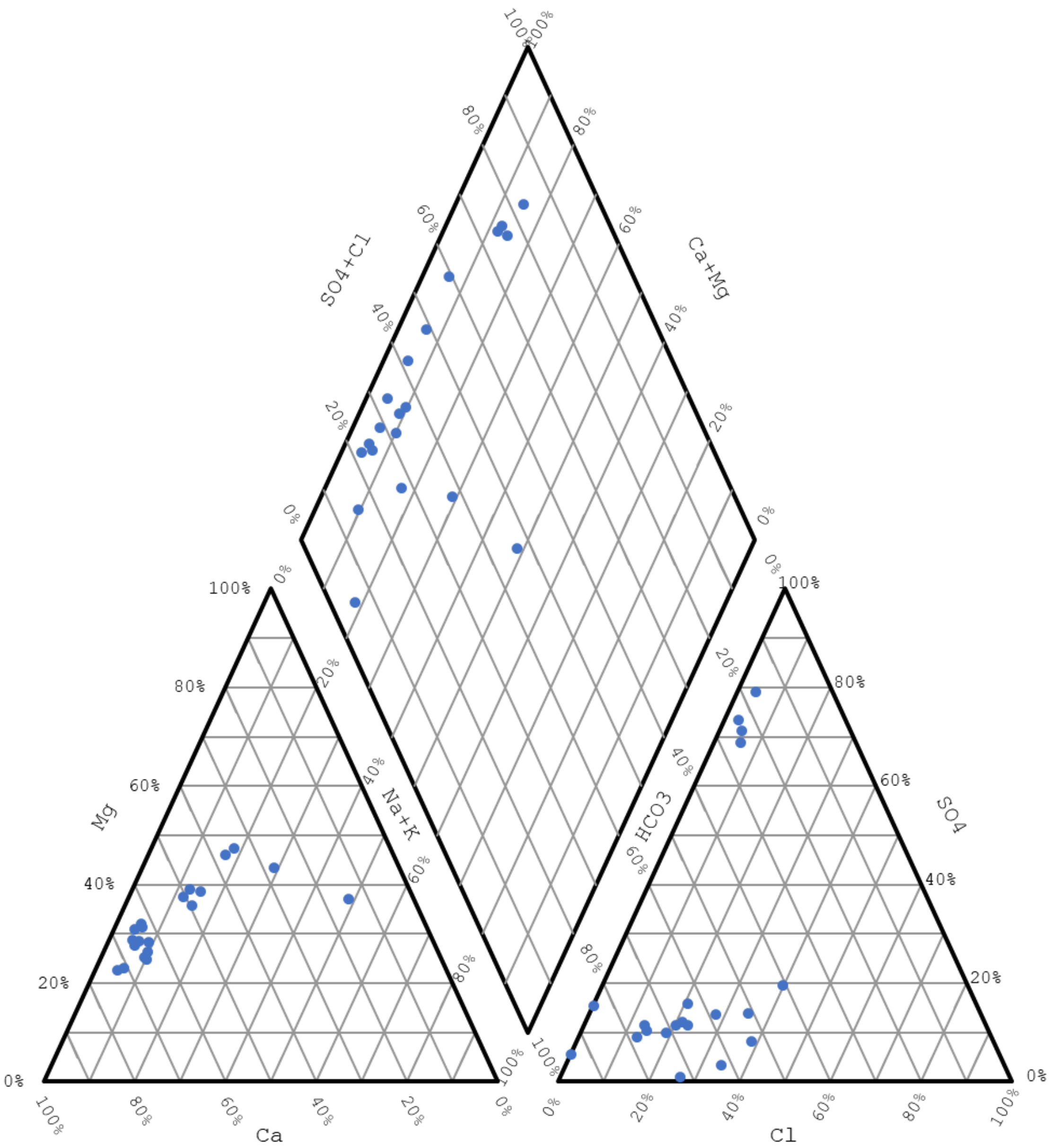

Figure 23: Piper Diagram of all Samples

● Group 1 ● Group 2 ● Group 3

Figure 24 illustrates the different groundwater types for each depth. Groundwater at Group 1: Hillsborough Deep plots as two different types: Ca-Cl and Mg-SO_4-HCO_3; the data plotting as two different water types may be an artifact of monitoring close to the time of well contruction and monitoring at temporal remove from well monitoring. Groundwater at Group 2: Hillsborough Deep is Ca-Mg-HCO_3 type and groundwater at Group 3: Hillsborough Transition is Ca-Mg-HCO_3 type.

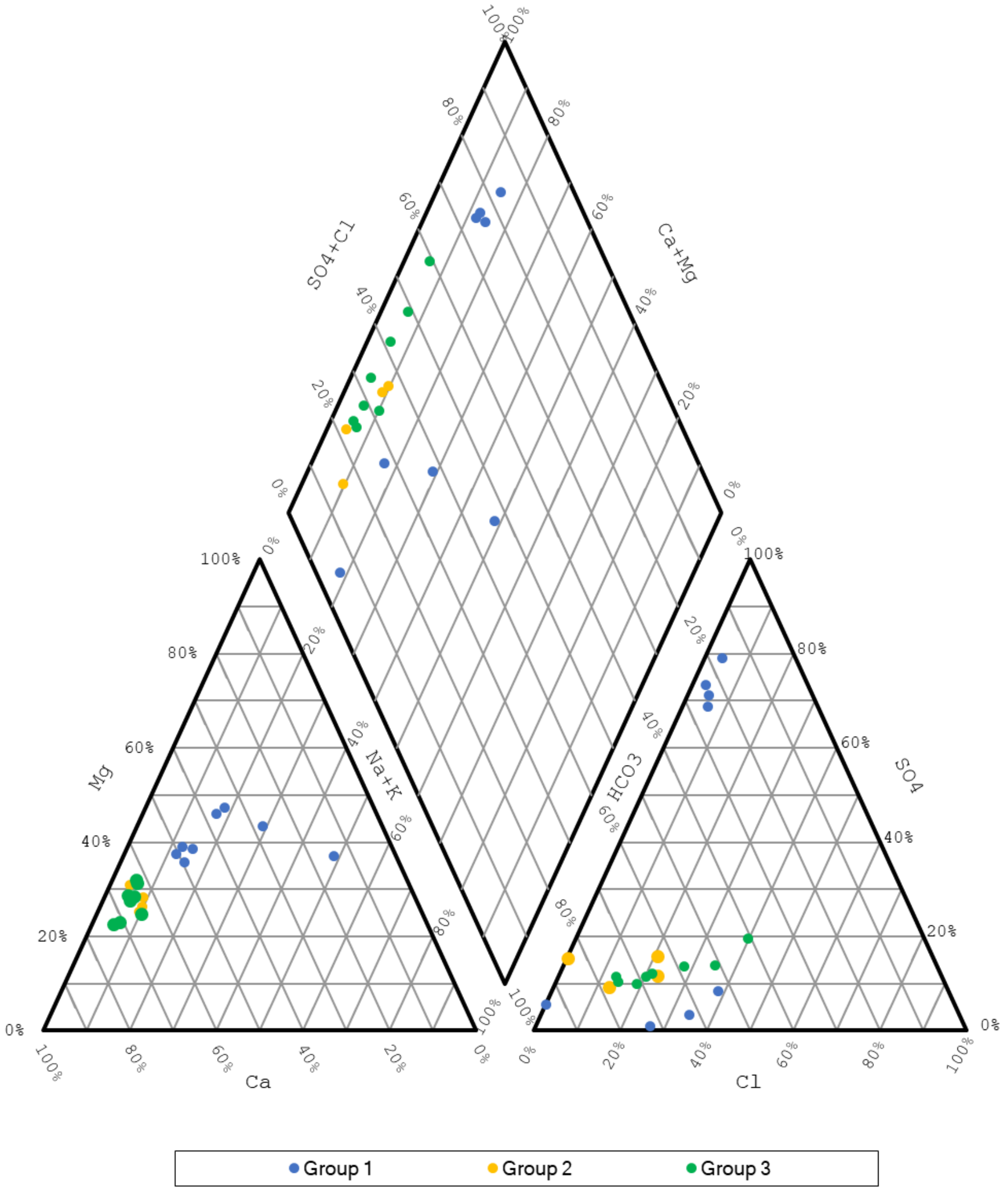

Figure 24: Piper Diagram of Wells Grouped by Depth

5.4 Organic and Microbial Parameters

A number of organic parameters and microbial parameters were monitored as pollution indicator parameters. These included pesticides and herbicides.

5.4.1 Organic parameters

Organic parameters were monitored in the two transition wells (CCH02 and CCH06) in monitoring event 6 (August 2022). A range of organic parameters, pesticides and herbicides were analysed, including MCPA (< 0.01 µg/l), cypermethrin (<100 µg/l) and glyphosate (<0.2 µg/l). There were no detections of any of the 218 parameters at either well.

5.4.2 Microbial parameters

Microbial parameters were monitored in the two transition wells (CCH02 and CCH06) in monitoring event 6 (August 2022).

Total coliforms were detected in both wells. Total coliforms were detected at 13 cfu/100 ml in CCH06 and at 2 cfu/100ml in CCH02. Total coliforms can be contributed from soil and are in themselves not an indicator of pollution.

Clostridium Perfringens was detected at a low level (1 cfu/100 ml) in one well (CCH02).

Section 6 Summary and Recommendations

6.1 Water Type

The data indicate that overall, the groundwater is predominantly Ca-Mg-HCO_3 type, with a small number of samples plotting as a mixed type, no dominant type, Ca-Cl type or SO_4 type.

Groundwater at Group 1: Hillsborough Deep appears to be of two different types: Ca-Cl and Mg-SO4-HCO_3; the data plotting as two different water types may be an artifact of monitoring close to the time of well contruction and monitoring at temporal remove from well monitoring. Groundwater at Group 2: Hillsborough Deep are Ca-Mg-HCO_3 type and groundwater at Group 3: Hillsborough Transition are Ca-Mg-HCO_3 type.

6.2 Exceedances, Pressures & Pollution Indicators

Land use across is predominantly agricultural pastures, with some patches of coniferous forests and mixed forests (Corine Landcover 2018).

There were exceedances of the respective WQS threshold for the physicochemical parameters, and major and minor elements:

- Specific electrical conductivity (SEC) (exceedance no. 7, or 35 %);
- Sulphate (SO_4) (exceedance no. 4, or 20 %);
- Ammonia (N) (exceedance no. 4, or 20%);
- Potassium (K) (exceedance no. 3, or 15 %); and,
- Total dissolved solids (TDS) (exceedance no. 1, or 5 %).

There were exceedances of the respective threshold/WQS for the metals (trace elements):

- Manganese (Mn) (exceedance no. 13 or 65 %);
- Barium (Ba) (exceedance no. 12 or 60 %);
- Iron (Fe) (exceedance no. 5 or 25 %);
- Magnesium (Mg) (exceedance no. 4, or 20 %); and,
- Uranium (U) (exceedance no. 1 or 5 %).

Some of these elevated concentrations may reflect aquifer hydrochemistry (e.g., potentially barium) and others may relate to land use practices/anthropogenic pressures (e.g., possibly ammonia).

The locations of the exceedances of WQS thresholds are outlined in (Table 5) with yellow fill indicating relatively few exceedances of the relative threshold (one exceedance only) and orange fill indicating higher numbers of exceedances (>1 exceedance).

Table 5 Exceedances of WQS parameters relative to well group/well location

Parameter	Manganese	Barium	Iron	Specific Electrical Conductivity (SEC)	Ammonia	Potassium	Magnesium	Sulphate	Total Dissolved Solids (TDS)	Uranium
Group 1: Hillsborough Deep										
Group 2: Hillsborough Shallow										
Group 3: Hillsborough Transition										

Minerals bearing barium and iron, also though to a lesser extent manganese, are found in the bedrock geology (Table 2).

Manganese is mobilized from minerals under reducing conditions. The oxidation-reduction potential indicates generally reducing conditions at all locations.

The elevated uranium at Group 2: Hillsborough Shallow may be due to the presence of sedimentary rock and graphitic minerals (Table 5).

Elevated ammonia (a nutrient pollution parameter) occurred at Group 1: Hillsborough Deep and Group 3: Hillsborough Transition. Given the predominantly agricultural landuse, this may be derived from agricultural practices. Elevated specific electrical conductivity (SEC) was occurred at both of these depths. The elevated SEC may be associated with well construction or an anthropogenic pressure (possibly also agriculture, as for ammonia).

Elevated concentrations of potassium, magnesium, sulphate and total dissolved solids also occurred at Group 1: Hillsborough Deep. These exceedances are unlikely the result of geology and may indicate that anthropogenic pressure(s) impact the deep groundwater body. Potassium, magnesium and sulphate can occur in both synthetic and natural fertilizer (i.e., manure), as well as other anthropogenic sources.

There were no detections of any of the 218 organic parameters monitored in two transitions wells in monitoring event 6 (August 2022).

The two wells in Group 3: Hillsborough Transition were monitored for microbial parameters during monitoring event 6 (August 2022). Total coliforms was detected at 13 cfu/100 ml in CCH06 and at 2 cfu/100ml in CCH02. Total coliforms can be contributed from soil and are in themselves not an indicator of pollution. *Clostridium Perfringens* was detected at a very low level (1 cfu/100ml) in one well (CCH02).

The data indicate that anthropogenic pressure(s) may be impacting the deep groundwater body (Group 1: Hillsborough Deep) and also potentially the transition groundwater body (Group 3: Hillsborough Transition). Given the landuse and the data, agricultural practices may be (among) potential pressures (and possibly also domestic wastewater sources in the case of Group 3: Hillsborough Transition).

It should be noted that these conclusions are based on a relatively small dataset. Additional monitoring should take place to carry out further assessments and determine/confirm any pressures on the groundwater bodies.

6.3 Recommendations

It is recommended that monitoring is continued to develop a robust baseline dataset and to assess and characterize the pressures on the groundwater bodies, where they exist, particularly for the deep and transition groundwater bodies (Group 1: Hillsborough Deep and Group 3: Hillsborough Transition). This programme should be guided by the results of this project and include at a minimum the parameters that indicate anthropogenic pressures for which there were exceedances/detections.

It is recommended that analysis of microbial parameters be continued and extended to determine the extent, source and pattern of microbial inputs.

It is recommended that further assessments be carried out to provide insight on the potential sources of anthropogenic contamination (i.e., pressures). This might include assessments of phosphorus and nitrogen species (ammonia, nitrate, nitrite) concentrations relative to background values to assess the impact of agricultural practices. Other assessments might consider further analysis of total organic carbon and total dissolved solids, as well as the ratios of chloride to bicarbonate, sodium to calcium and sulfate to bicarbonate.

Further work might include probability plots or other statistical methods to develop background values when a larger dataset is available.

Section 7 References

Corine Landcover 2018. Available at: https://land.copernicus.eu/pan-european/corine-land-cover/clc2018 (Accessed: February 7, 2023).

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