Darfield / Kirwee Groundwater Monitoring

2021 Update

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Executive Summary

The Darfield and Kirwee townships currently utilise on-site treatment and disposal of domestic wastewater via septic tanks and soak holes. Identification of potential impacts on down gradient groundwater quality is central to consideration of potential options for future wastewater disposal for these communities.

This report provides an overview of groundwater quality sampling undertaken by the Selwyn District Council in the Darfield and Kirwee areas since 2006 and includes a detailed assessment of available groundwater quality data including results of a repeat survey undertaken in February 2021..

Sample results indicate groundwater quality in the Darfield and Kirwee areas is high, with little indication of contamination potentially associated with on-site wastewater disposal in the Darfield and Kirwee townships. While elevated concentrations of indicator parameters (including Nitrate-Nitrogen) are observed in the area east of Darfield, spatial variations in groundwater quality appear to be largely associated with general land use activities across the contributing recharge area rather than any specific or concentrated contaminant source. Temporal variability in groundwater quality is observed on an inter-annual basis across the study area, possibly reflecting changes in groundwater recharge flux occurring through the thick unsaturated zone in response to climatic variability (such as that observed during winter 2017).

The ability to draw definitive conclusions with respect to likely effects of onsite wastewater disposal in the Darfield and Kirwee townships is however constrained by the spatial distribution and screen depths of existing wells in the area.

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1. Introduction

The Darfield and Kirwee townships currently utilise on-site treatment and disposal of domestic wastewater via septic tanks and soak holes. Annual sampling of groundwater quality from existing wells in the vicinity of the Darfield and Kirwee townships was initiated by SDC in early 2006. The overall objective of this sampling programme is to characterise spatial and temporal variations in groundwater quality to determine if existing wastewater disposal practices in the Darfield and Kirwee townships are resulting in adverse effects on groundwater quality down-gradient of both settlements. Since the initial survey in March 2006, sampling has been repeated on a semi-annual annual basis on a further fifteen occasions.

This report provides a summary of the results of groundwater quality sampling undertaken in the Darfield/Kirwee area during mid-February 2021. These results are utilised to provide an updated analysis of the available groundwater quality data set.

1.1. Hydrogeological Setting

The extensive alluvial gravel deposits underlying the Central Plains area accumulated as a result of the deposition and subsequent reworking of gravel materials by the Waimakariri River in response to successive cycles of climate variation during the late Quaternary period. The cyclical nature of these depositional processes resulted in significant lateral and vertical variation in material properties, with layers of cleaner, high permeability gravels interspersed with more clay-bound, lower permeability alluvium. This gravel sequence hosts an extensive groundwater resource in a series of discrete water-bearing layers and is extensively utilised for domestic, municipal and irrigation water supply across the Central Plains area.

The two main water-bearing gravel layers in the Darfield area (based on well screen placement) occur at depths of approximately 100 to 130 metres and 220 to 250 metres below ground respectively. The shallower water-bearing layer present at Darfield also extends at a similar depth across the Kirwee area[1]. East of Kirwee, a further shallower water-bearing layer between 65 to 80 metres below ground is accessed by wells to the east of Highfield Road. Elsewhere in the area, particularly along the margins of the Waimakariri and Hawkins Rivers, groundwater occurs at variable depths of between 25 to 80 metres below ground.

Recharge to the aquifer system in the vicinity of Darfield and Kirwee is primarily derived from the infiltration of local rainfall, with some localised contribution from surface water. While seepage from the Hawkins River provides a portion of recharge to the area west of Darfield, flow gaugings indicate limited flow loss from the Waimakariri River over the reach between the Gorge and Halkett.

As shown on **Figure 1**, groundwater flow in the Darfield/Kirwee area is interpreted to occur in a south-easterly direction generally following the topographic gradient.

[1] An insufficient number of deeper bores are present in the Kirwee area to identify the lateral continuity of the deeper (220 to 250 metre) water-bearing layer observed near Darfield

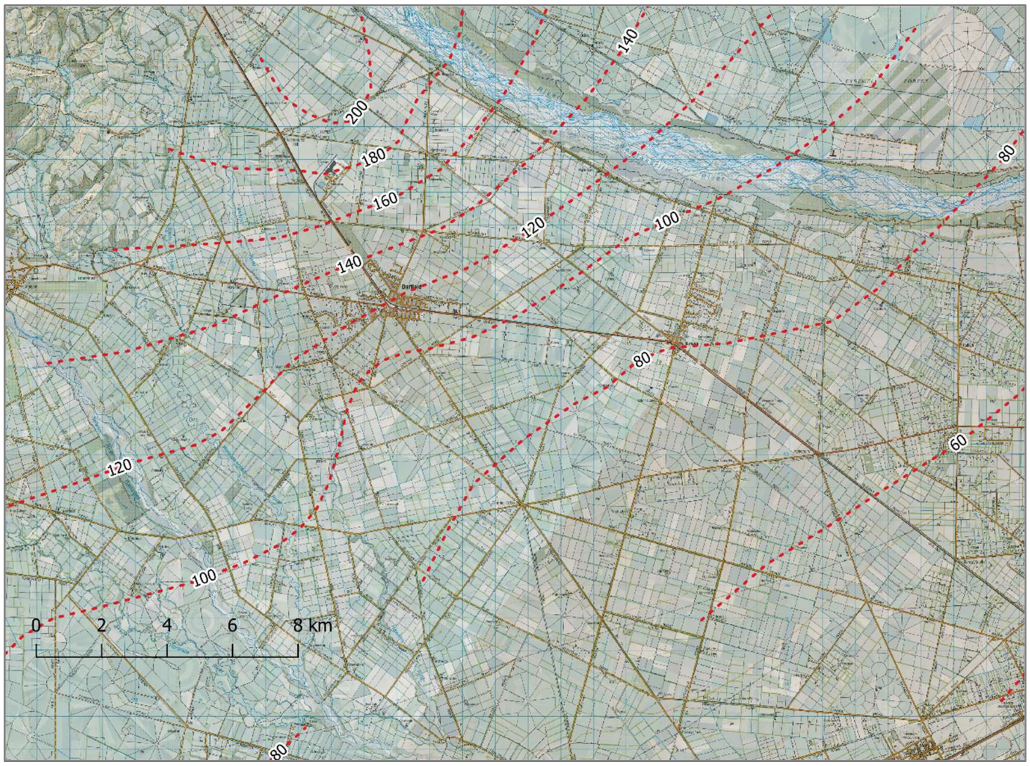

Figure 1. *Piezometric contours (m asl) in the Darfield/Kirwee area estimated from the ECan September 2003 piezometric survey. Note: groundwater flow is interpreted to occur perpendicular to the piezometric contour lines (Source: Canterbury Maps).*

It is noted that the interpreted groundwater flow directions shown in Figure 1 are likely to be influenced by the relatively sparse well coverage (particularly in the Darfield area), as well as the shallow groundwater depths recorded adjacent to the Waimakariri River. Due to these factors the actual piezometric contours in any given water-bearing interval may vary from that shown. It is therefore considered likely that the direction of groundwater flow in the 100 to 130 metre water-bearing layer in the Darfield/Kirwee area will generally follow the overall east south-easterly topographic gradient of the land surface.

2. Overview of Historical Groundwater Quality Monitoring

Sampling of groundwater quality in the Darfield and Kirwee areas has been undertaken by SDC on a semi-annual basis since early 2006. The following section provides a brief history of sampling and provides an outline of results from investigations undertaken between 2006 and 2020. Prior to the 2021 survey, previous sampling rounds include:

- March 2006 (17 wells)
- December 2006 (28 wells)
- May 2007 - (28 wells)
- December 2008 - (24 wells)
- December 2009 - (24 wells)
- January 2011 - (26 wells)
- January 2012 - (26 wells)
- January 2013 - (26 wells)
- January 2014 - (24 wells)
- May 2015 - (23 wells)
- March 2016 - (25 wells)
- February 2017 - (28 wells)
- February 2018 - (28 wells)
- February 2019 - (27 wells)
- January 2020 - (28 wells)

Since the monitoring programme commenced in 2006, a total of 382 samples have been collected from 47 wells in the vicinity of the Darfield and Kirwee. Figure 2 shows the location of wells sampled over this period. Of the sites shown, a total of 15 wells have been sampled twelve or more times, with a further seven wells sampled between eight and ten times.

Figure 2. Wells included in the Darfield/Kirwee groundwater quality sampling programme, 2006-21

Table 1 provides a listing of wells sampled during individual sample rounds. Based on well construction details recorded on the ECan Wells database, wells sampled range in depth from 24 to 270 metres. In general, a majority of sites sampled in the immediate vicinity of both Darfield and Kirwee are screened in the 100 to 130 metre water-bearing interval.

Since the sampling programme commenced, eight deeper wells screened more than 150 metres below ground have been sampled in the southern portion of the survey area (i.e., south of SH73) due to the limited number of shallower wells in this area. Four wells of a similar depth have been sampled to the west of Darfield to provide an indication of background groundwater quality given there are few, if any, wells screened in the 100 to 130 metre water-bearing interval in this area. Wells screened at depths of less than 80 metres are generally restricted to areas of shallower groundwater along the margin of the Waimakariri River and in the east of the study area near Station Road where, as previously noted, a shallower water bearing layer (~70-90 metres bgl) is accessed by several wells.

In recent years, the availability of wells able to be sampled has been limited by the reticulation of the Central Plains Water (CPW) irrigation scheme and the expansion of SDC reticulated supplies around both the Darfield and Kirwee townships.

Table 1. *Wells sampled for the Darfield/Kirwee groundwater monitoring programme, 2006 to 2021*

Well No	Depth (m)	Feb-2021	Jan-2020	Feb-2019	Jan-2018	Feb-2017	Mar-2016	May-2015	Jan-2014	Jan-2013	Jan-2012	Jan-2011	Dec-2009	Dec-2008	May-2007	Nov-2006	Mar-2006	Total Samples
BX22/002	139	x	x	x	x	x	x											6
BX22/005	113	x	x	x	x	x	x											6
BX22/007	100			x														1
BX22/016	251	x	x	x														3
BX22/016	114	x	x	x														3
BX23/000	245	x	x	x	x	x	x		x									7
BX23/073	106.	x	x	x	x													4
L35/0009	125									x	x	x	x	x	x	x	x	8
L35/0187	113.	x	x	x						x	x	x	x	x	x	x	x	11
L35/0190	120.	x	x	x	x	x	x		x	x	x	x	x	x	x	x	x	15
L35/0191	115.	x	x	x	x	x	x	x	x	x	x	x	x	x			x	14
L35/0210	120.	x	x			x		x	x	x	x	x	x	x	x		x	12
L35/0213	122.	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x	15
L35/0248	120	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	16
L35/0523	118.						x	x	x	x	x	x						6
L35/0527	101	x	x	x	x		x	x										6
L35/0561	121.	x	x	x	x	x	x	x										7
L35/0562	114											x	x	x	x	x		5
L35/0568	113.					x		x	x	x	x	x	x	x	x	x	x	11
L35/0575	128.														x	x		2
L35/0685	131	x		x	x	x	x			x			x	x	x	x	x	11
L35/0687	211.				x													1
L35/0688	214				x	x												2
L35/0714	123.	x	x	x	x	x	x		x	x	x	x	x	x	x	x	x	15
L35/0729	125	x	x	x				x	x	x	x	x	x					9

Well No	Depth (m)	Feb-2021	Jan-2020	Feb-2019	Jan-2018	Feb-2017	Mar-2016	May-2015	Jan-2014	Jan-2013	Jan-2012	Jan-2011	Dec-2009	Dec-2008	May-2007	Nov-2006	Mar-2006	Total Samples
L35/0767	125.	x	x	x	x	x	x	x	x	x	x	x	x	x				13
L35/0778	221.														x	x		2
L35/0781	223				x	x	x		x	x	x	x	x	x	x	x	x	12
L35/0806	270.											x			x	x		3
L35/0832	117.	x	x	x	x	x	x											6
L35/0843	221.	x	x	x		x		x	x	x	x	x	x	x	x	x	x	14
L35/0870	114	x	x	x	x	x	x	x	x	x	x							10
L35/0876	130	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x	15
L35/0883	245			x	x	x	x	x										5
L35/0884	251.	x	x		x	x	x		x	x	x							8
L35/0910	209				x	x			x	x	x	x	x	x	x		x	10
L35/0956	120	x	x	x	x	x	x	x	x	x	x	x	x	x				13
L35/0980	246.	x	x	x	x				x	x	x							7
L35/1079	126		x	x														2
L35/1163	125.				x													1
L35/1164	125.				x	x	x											3
L35/1173	250.										x							1
M35/0921	65.5		x	x	x	x	x	x		x	x	x	x	x	x	x	x	14
M35/7010	88		x		x	x	x	x	x	x	x	x	x	x	x	x	x	14
M35/7555	107	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x	15
M35/8049	117	x																1
M35/9293	72					x	x	x	x	x	x	x	x	x	x	x	x	12
M35/9628	120.							x	x	x	x	x						5

x = sample collected

2.1. Summary of groundwater quality results

Overall observations from the available groundwater quality data set include:

- Groundwater down-gradient of the Darfield and Kirwee townships generally contains low concentrations of dissolved ions which fall within Maximum Acceptable Values (MAV) specified in the New Zealand Drinking Water Standards (DWSNZ). Observed groundwater quality in these areas is consistent with that observed across the wider Canterbury Plains area.

- Of the range of water quality parameters analysed, only indicator bacteria (*E.Coli*) have been detected at levels exceeding the MAV for potable supply. The intermittent detection of low levels of indicator bacteria in (seemingly) random wells is largely attributed to localised sample contamination, rather than reflecting any widespread issues related to microbial of groundwater (particularly given the >60-metre thick unsaturated zone across the study area).

- pH and iron concentrations have, on occasion, transgressed DWSNZ aesthetic guideline values of the at some sites. Most of the iron transgressions are attributed to inconsistencies in sample collection procedures (i.e., well purging and field filtering, particularly when wells have not been utilised for an extended period). Transgressions related to pH are interpreted to reflect the natural geochemical evolution of groundwater infiltrating through an extensive unsaturated zone.

- The presence of elevated nitrate nitrogen concentrations (>50% MAV) suggest land use activities are impacting on groundwater quality. Nitrogen isotope data analysed in the 2008 survey indicated that the major nitrogen inputs into groundwater in the area result from agricultural sources (fertiliser or soil mineralisation) rather than animal sources (e.g., wastewater discharge).

- Laboratory analysis for fluorescent whitening agents (originating from washing powders and detergents) in samples collected during the May 2007 sample round did not identify the presence of these compounds above method detection limits in the wells sampled. However, the absence of these compounds does not necessarily rule out onsite wastewater disposal as impacting on groundwater quality.

- Analysis of temporal trends in groundwater quality show several sites with statistically significant trends in individual parameters. Many of the temporal trends observed appear to reflect inter-annual variations in aquifer recharge which are lagged to varying degrees according to well location and depth. The somewhat random spatial distribution of sites exhibiting groundwater quality trends tend to suggest the importance of localised controls on groundwater quality, rather than input from a spatially defined source (such as the Darfield or Kirwee townships).

Overall, sample results indicate groundwater quality in the Darfield/Kirwee area is generally high and consistent with that reported across the wider Canterbury Plains area. Results do not provide any clear indication of contamination potentially resulting from on-site wastewater disposal in the Darfield and Kirwee townships. Rather, both spatial and temporal variations in groundwater quality appear to be largely associated with general land use activities across the contributing recharge area.

3. 2021 Sampling Round

Sampling for the 2021 Darfield/Kirwee annual groundwater survey was undertaken in late-February 2021. Samples were collected from a total of 27 wells distributed across the study area[2]. Twenty-five of the wells included in the 2021 survey were also sampled during the 2020 sampling round. Of the remaining wells, one (L35/0685) had previously been sampled but was not included in the 2020 survey, while the remaining well (M35/8049) was sampled for the first time.

It is noted that operation of the Central Plains Water Limited (CPW) irrigation scheme which commenced October 2018 resulted in several changes to the historical sampling network due either to wells no longer being operational or having undergone changes to headworks that make it impossible to collect samples. In addition, several former irrigation wells are now only utilised for domestic or stock supply (often via larger storage tanks) potentially reducing their utility as 'representative' sampling sites.

3.1. Methodology

3.1.1. Sampling locations

Wells included in the February 2021 sampling round are shown on Figure 3 below. The figure indicates the monitoring sites are distributed across a broad east-west alignment centred on the Kirwee and Darfield townships. It is noted that the location of sampling sites is largely dictated by the availability of existing domestic and irrigation wells in the local area which, in part, reflects the extent of existing CPW and SDC reticulated water supplies. The timing of sample collection (February) was intended to coincide with the period of maximum water use to increase the likelihood that the wells sampled were being used on a regular basis.

Figure 3 shows most sample sites are screened in the 90 to 130 water-bearing layer which appears to be semi-continuous across most of the study area, with only a single bore (L35/0853) located down-gradient of Darfield screened in the deeper water-bearing interval. Due to a lack of wells screened in the 100 to 130 metre water-bearing layer to the west of Darfield, background (i.e., up-gradient) samples were collected in four deeper bores in this area (BX22/0006, BX22/0162, L35/0884 and L35/0980).

For the 2021 survey, groundwater quality monitoring data was also provided by Central Plains Water (CPW) for a monitoring bore located adjacent to Telegraph Road approximately 2 kilometres south-east of the Darfield township, an area where there are few existing wells able to be sampled. As further discussed in Section 3.5 below, while both well construction and sampling method for this site differ from other bores included in the Darfield/Kirwee sampling programme, results provide a useful indication of temporal groundwater quality variation at shallower depths than those typically accessed by existing irrigation, stock or domestic bores in the area.

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[2] Twenty-eight samples were collected during the 2021 survey. However, a review of water quality results indicates a sample point previously supplied by L35/1164 is now connected to CPW reticulation. Sample results from this site were therefore excluded from reporting.

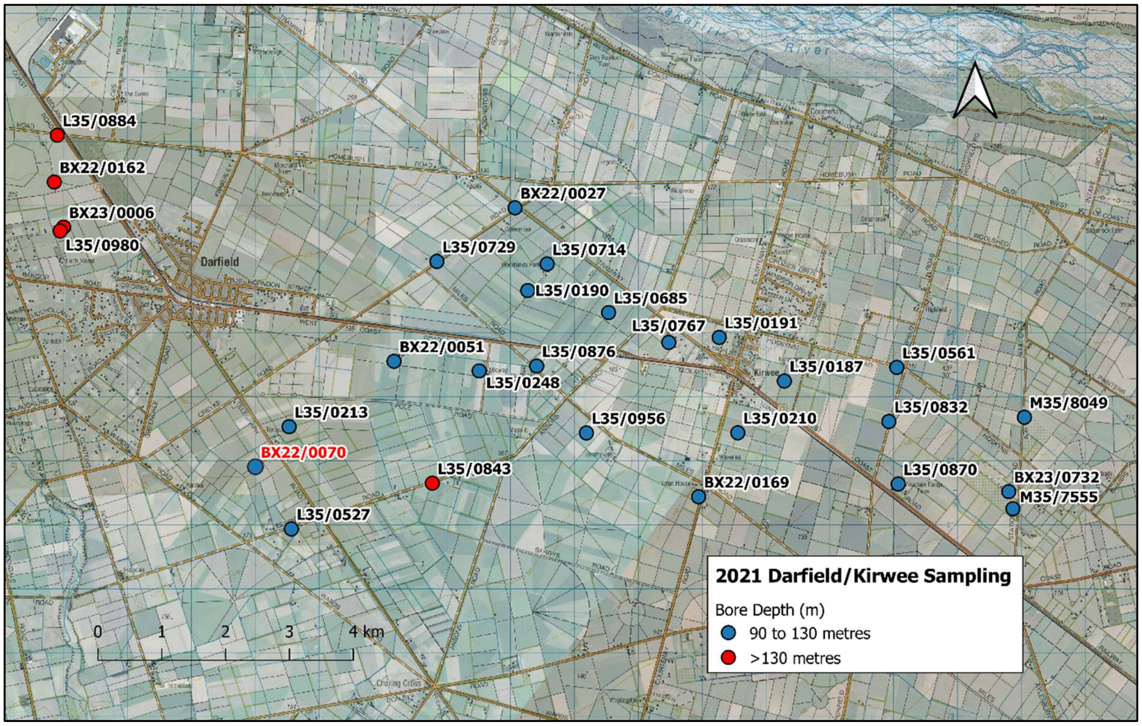

***Figure 3**. Location and depth of wells included in the January 2021 Darfield/Kirwee sampling round (Note: CPW monitoring site identified by red label).*

3.1.2. Sample collection and analysis

Samples were collected between 23rd to 26th February 2021, in accordance with standard groundwater quality sampling protocols (e.g. MfE, 2006). Where possible, sites were selected to enable samples to be collected directly from the wellhead. However, due to the limited number of wells located in suitable areas, a number of sites required samples to be collected from points located within the reticulation system, in some cases after pressure or storage tanks or from irrigation infrastructure (e.g., K-line irrigators).

Water quality analysis was undertaken by Hill Laboratories for a range of parameters including:

- Total Arsenic
- Turbidity
- Total Chromium
- Total Lead
- Total Alkalinity
- pH
- Free CO2
- Electrical Conductivity
- Total Hardness
- Total Nickel
- Total Boron
- Total Calcium
- Total Copper
- Total Iron
- Total Magnesium
- Total Manganese
- Total Potassium
- Total Sodium
- Total Zinc
- Chloride
- Nitrate-Nitrogen
- Sulphate
- Approximate Total Dissolved Salts
- *E.coli*

Sample analysis results are listed in **Appendix A**.

Following receipt of sample results, a standard charge balance error (CBE)[3] calculation was undertaken to identify any inconsistencies in sample results. Results of this calculation listed in **Appendix A** indicate a CBE of ranging between -1.4 and +3.8% (median = +1.0%) in the samples analysed. As illustrated in **Figure 4** below, the CBE calculation shows all samples were well within the +/-5% figure typically considered acceptable for a range of analytical purposes.

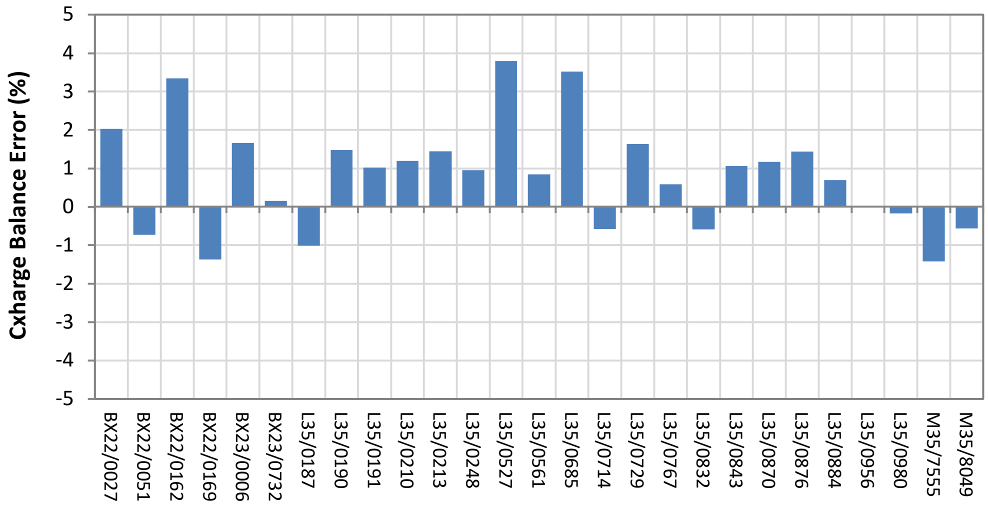

Figure 4. *Charge balance errors (CBE) for the 2021 survey.*

3.1.3. Groundwater Levels

Figure 5 shows a plot of groundwater levels recorded by Environment Canterbury (ECan) in three wells the wider Darfield area between 1950 and 2021. The data indicate significant temporal variability which is interpreted to reflect inter-annual fluctuations in land surface recharge (generally reflecting rainfall departure from the median over the late-autumn to early-spring period). In the context of the historical record, groundwater levels at the time of the February 2021 survey were low, particularly toward the east of the study. In this area, 2021 groundwater levels were similar to historical minimums observed in the early 1970s and mid-2000s. The low levels observed during 2021 are interpreted to reflect significantly below normal recharge over the 2020 winter.

[3] The CBE calculation compares the reported concentrations of major cation and anion species present in a water sample (theoretically cation and anion concentrations should balance so the sample is electrically neutral). Typically, a CBE error greater than +/- 5% indicates an error in analysis results or the presence of appreciable quantities of an ionic species not included in the CBE calculation.

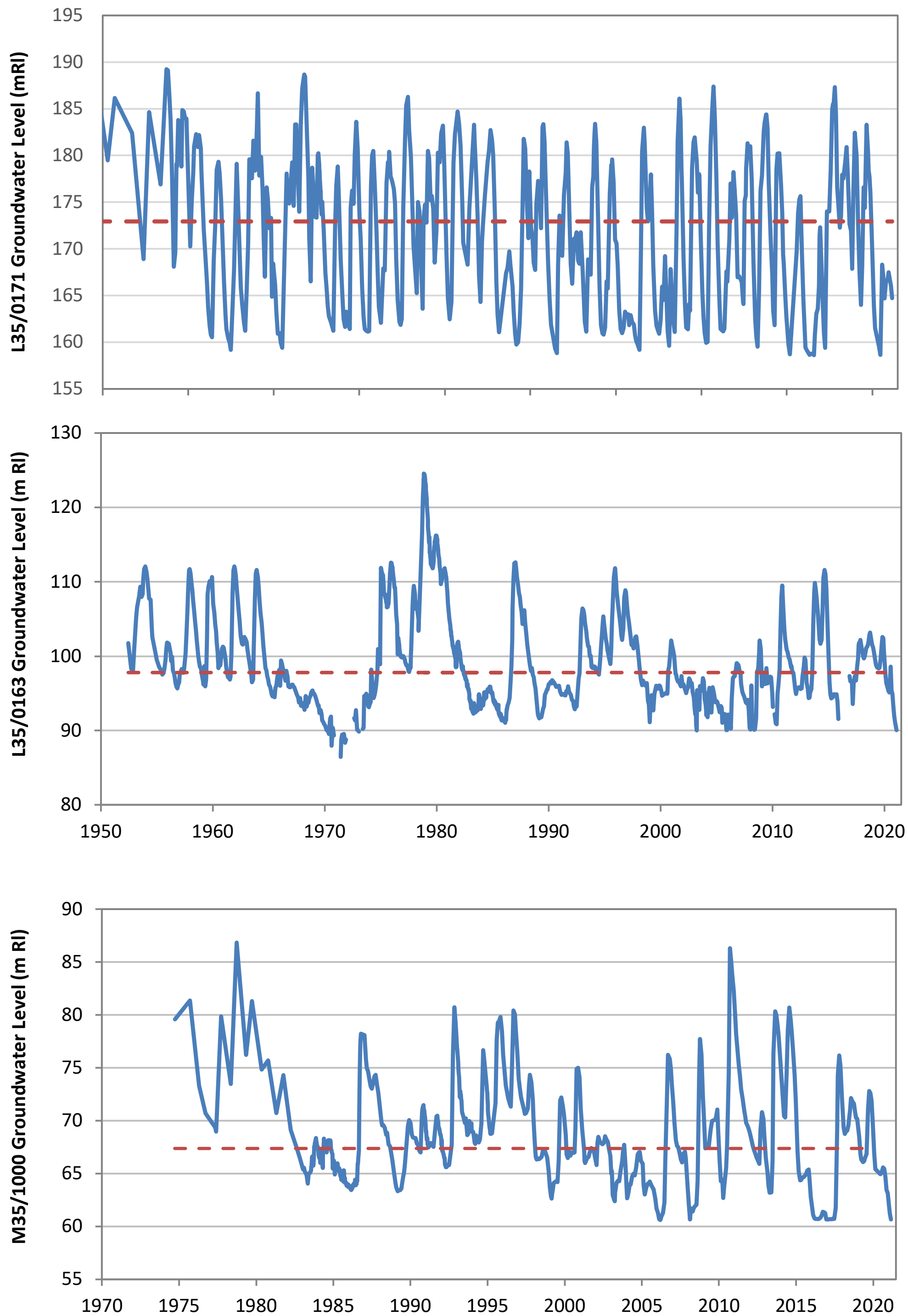

Figure 5. *Groundwater levels recorded across the mid to upper Central Plains area to January 2021 (upper plot L35/0171 Hawkins, middle plot L35/0163 Courtenay, lower plot M35/1000 West Melton). Dotted line indicates long-term median level.*

The potential influence of seasonal variations in land surface recharge flux on groundwater quality are further discussed in Section 3.6 below. However, it is noted that the large magnitude of temporal groundwater level variation (>20 metres) occurring across the Central Plains area means that individual wells will draw water from different depths below the water table in different seasons. Given potential vertical differences in groundwater age and quality with depth (e.g., Stewart *et al*., 2002), such fluctuations in recharge flux may contribute to observed temporal variations in groundwater quality.

3.2. General water chemistry

Table 2 below provides summary statistics for the January 2021 sampling round. Results show groundwater in the Darfield and Kirwee areas is characterised by low concentrations of dissolved ions (approximate dissolved solids ranging between 82 and 163 g/m^3), with calcium and bicarbonate the dominant cation and anion species respectively. One well (L35/0248) recorded presence of low levels of indicator bacteria (*E.coli*). Nitrate concentrations at all monitoring sites were below the Maximum Acceptable Values (MAV) specified in the Drinking Water Standards for New Zealand (DWSNZ). The concentration of iron recorded in L35/0729 exceeded the NZDWS aesthetic guideline (a result consistent with previous sample rounds).

***Table 2.** Summary groundwater quality statistics from the January 2021 sampling round.*

Parameter	**Units**	**Minimum**	**Maximum**	**Median**	**NZDWS MAV**	**NZDWS guideline**
Total Alkalinity	g/m^3 as $CaCO_3$	36	50	43		
Approx TDS	g/m^3	86	157	116		
Arsenic	g/m^3		<0.0011		0.01	
Boron	g/m^3	0.0172	0.025	0.021	1.4	
Calcium	g/m^3	15.8	26	19.8		
Chloride	g/m^3	3.9	11.6	9.0		>250
Chromium	g/m^3		<0.00053		0.05	
Conductivity	µS/m	128	234	172.5		>1,500
Copper	g/m^3	<0.00053	0.0028		2	
E coli	MPN/100mL	<1	**3**		<1	
Free CO_2	g/m^3	1.0	2.2	1.4		
Iron	g/m^3	<0.021	**0.85**			0.2
Lead	g/m^3	<0.00011	0.003		0.01	
Magnesium	g/m^3	1.14	4.8	2.55		
Manganese	g/m^3	<0.00053	0.015		0.5	
Nickel	g/m^3		<0.00053		0.08	
Nitrate-Nitrogen	g/m^3 as N	2.0	10.6	5.8	11.3	
pH	pH units	7.6	8.2	7.8		7.0 - 8.5
Potassium	g/m^3	0.91	1.56	1.2		
Sodium	g/m^3	5.9	12.7	10.3		>200
Sulphate	g/m^3	0.8	5.8	2.9		250
Turbidity	NTU	0.03	22	0.25		
Total Hardness	g/m^3 as $CaCO_3$	49	84	60		200
Zinc	g/m^3	<0.0011	0.80			3

Table 3 provides a comparison of median parameter concentrations from the 2020 and 2021 Darfield/Kirwee surveys with those derived from the 2019 Environment Canterbury annual groundwater quality survey[4] which included samples from a total of 328 wells distributed across the entire Canterbury Region (ECan, 2020). The data indicate groundwater quality in the Darfield/Kirwee area is within the range observed in the regional data set.

The most significant departures from regional values in the Darfield/Kirwee data are for median Total Alkalinity, Sulphate, and Magnesium concentrations which are over 40% lower than equivalent values from the regional survey. In contrast, Nitrate-Nitrogen concentrations were approximately 40% higher than the regional median. These differences are likely to reflect a combination of aquifer recharge source (i.e., river vs rainfall recharge), overlying land use and the local physical characteristics (particularly geology and hydraulic properties) of the primary water-bearing units in the Darfield and Kirwee areas.

Table 3. *Comparison of median major ion concentrations between the 2021 Darfield/Kirwee sample results and regional median values from the 2018 and 2019 ECan groundwater quality surveys.*

Parameter	**Units**	**Darfield/Kirwee 2021**		**ECan Regional Survey 2019**		**ECan Regional Survey 2018**	
		Median	**Range**	**Median**	**Range**	**Median**	**Range**
Total Alkalinity	g/m^3 as $CaCO_3$	43	36 - 52	63	12.6 - 320	63	14.2 - 280
Chloride	g/m^3	9.0	3.9 - 11.6	8.6	<0.5 - 210	8.6	<0.5 - 220
Sulphate	g/m^3	2.9	0.8 - 5.8	8.1	<0.5 - 135	8.5	<0.5 - 85
Nitrate Nitrogen	g/m^3 as N	5.8	2.0 - 10.6	3.4	<0.05 - 23	3.3	<0.05 - 25
Calcium	g/m^3	19.8	15.8 - 26	19.6	1.19 - 95	19	1.13 - 90
Magnesium	g/m^3	2.6	1.14 - 4.8	4.8	0.33 - 27	4.7	0.31 - 27
Sodium	g/m^3	10.3	5.9 - 12.7	10.6	1.29 - 117	10.8	1.35 - 122
Potassium	g/m^3	1.2	0.9 - 1.6	1.26	0.19 - 10.5	1.24	0.23 - 21
Conductivity	mS/m	17.3	12.8 - 23.4	20.4	2.6 - 103.8	19.9	2.6 - 108.7
Total Hardness	g/m^3 as $CaCO_3$	60	49 - 84	71	9.3 - 310	66	9.1 - 280
pH	pH units	7.8	7.6 - 8.2	7.3	5.9 - 8.3	6.6	6.0 - 8.9

Table 4 below compares median parameter concentrations from the 2013 to 2021 Darfield/Kirwee sample rounds. Despite slight differences in the number and location of wells sampled between individual years, median concentrations are relatively consistent between the nine sample rounds listed. It is noted that the 2021 results were within the historical range for all parameters.

[4] The most recent results available at the time of writing.

Table 4. *Comparison of median concentrations from the 2013 to 2021 Darfield/Kirwee groundwater quality surveys*

Parameter	Units	2021	2020	2019	2018	2017	2016	2015	2014	2013
Total Alkalinity	g/m^3 as $CaCO_3$	43	42	43	43	42	44	43	44	48
Chloride	g/m^3	9.0	9.1	8.9	8.4	8.8	9.2	9.8	8.8	9.4
Sulphate	g/m^3	2.9	3.4	3.1	3.5	2.9	3.2	3.3	3.5	3.0
Nitrate Nitrogen	g/m^3 as N	5.8	6.6	6.3	5.4	5.2	6.2	6.6	6.3	6.0
Calcium	g/m^3	19.8	19.1	20	18.3	18.4	19.9	19.5	19.1	19.3
Magnesium	g/m^3	2.6	2.1	2.5	2.3	2.5	2.9	2.3	2.8	2.5
Sodium	g/m^3	10.3	9.6	10.3	9.6	9.4	9.6	10.0	10.2	9.8
Potassium	g/m^3	1.2	1.12	1.17	1.01	1.04	1.2	1.1	1.1	1.1
Conductivity	µS/m	17.3	17.4	17.1	16.5	16.0	17.4	17.6	17.3	17.3
Total Hardness	g/m^3 as $CaCO_3$	60	58	61	55	55	58	58	58	58
pH	pH units	7.8	7.8	7.7	7.7	7.7	7.7	7.7	7.5	7.4

Figure 5 shows a piper plot of water quality analyses from the January 2021 sample round. Overall, the data exhibit relatively consistent major ion composition (dilute calcium-bicarbonate type waters). The relatively tight grouping of sample results is also inferred to reflect limited geochemical evolution of groundwater within the aquifer system either spatially or with screen depth. This limited geochemical change is likely to reflect the relatively inert and highly permeable nature of the aquifer materials (predominantly greywacke gravels) which result in (largely) oxic conditions and moderately rapid throughflow through the various water-bearing layers. The relatively constant pattern of major ion chemistry also suggests water quality is influenced by a consistent range of factors across the study area with no obvious evidence of significant anomalies in relative major ion concentrations as could be expected in response to specific or localised contaminant discharges.

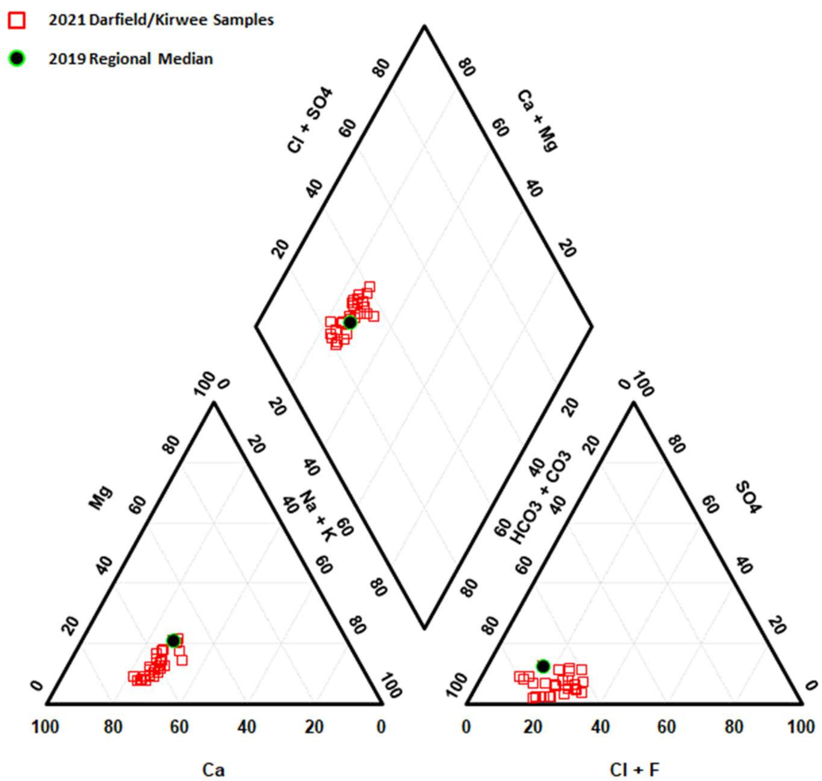

Figure 6. *Piper plot of major ion chemistry from the February 2021 sampling round, compared to the 2019 regional median.*

Based on the available data set, subsequent section of this report provide an overview of major ion chemistry in the Darfield/Kirwee area, along with analysis of spatial and temporal variations in observed groundwater quality. This analysis considers general water quality with an emphasis on three key indicator parameters (electrical conductivity (EC), chloride and Nitrate-Nitrogen) which are considered as being most likely to be affected by localised groundwater contamination, such as that resulting from on-site wastewater disposal.

3.3. Spatial variations in groundwater quality

3.3.1. Electrical conductivity (EC)

Electrical Conductivity (EC) is a useful measure of the overall concentration of dissolved ions in a water sample and has broad utility as an indicator of the relative concentration of dissolved ions between individual samples. EC is also a useful indicator of areas where groundwater quality may be locally impacted by land use or discharge activities.

Figure 7 shows the spatial distribution of EC values across the survey area observed in the February 2021 sample round. The map shows EC values ranged from 128 to 234 µS/cm in wells sampled, with the highest values (>200 µS/cm) generally observed in wells located north of West Coast Road to the west of Ansons Road and lowest values in shallow bores to the east of Kirwee[5].

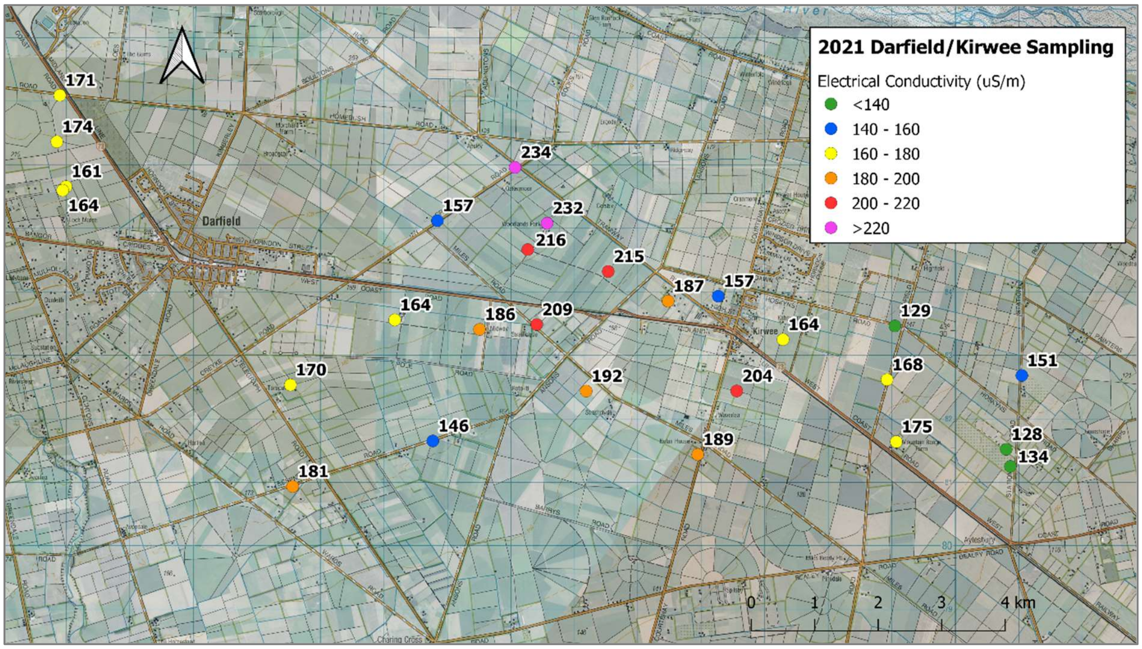

Figure 7. *Electrical Conductivity values observed in the February 2021 survey.*

Overall, EC values of the magnitude recorded in the Darfield/Kirwee area indicate relatively low concentrations of dissolved ions and are in the typical range for groundwater across much of the Canterbury Plains. The spatial distribution of EC values does not indicate any specific anomalies but does show a group of wells screened in the 90 to 130 m water-bearing layer east of Darfield along a north-west to south-east alignment that exhibit higher values than those observed across the remainder of the survey area.

3.3.2. Chloride

Chloride has wide utility in groundwater quality investigations given it is a conservative ion that is not greatly impacted by geochemical processes occurring in the relatively inert gravel media of the Canterbury Plains. The main chloride inputs to groundwater are via atmospheric concentrations in local rainfall and river recharge. However, many wastewater discharges (e.g., on-site wastewater and dairy shed effluent) contain elevated chloride concentrations which have the potential to result in a corresponding increase in concentrations in down-gradient receiving environments.

Figure 8 shows a plot of chloride concentrations recorded in the February 2021 survey. The data show chloride concentrations vary across the study area with observed concentrations exhibiting a broadly

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[5] The value of 230 µS/cm recorded in M35/0921 being a notable anomaly

similar spatial distribution to EC values. Generally, EC in wells east of Kirwee is similar to, or lower than, lower than background values (6 to 9 mg/L), while slightly higher values (>11 mg/L) are observed along a north-west to south-east alignment east of Darfield where elevated EC values area also observed. However, there are no clearly discernible spatial groupings of elevated Chloride concentrations that would indicate elevated concentrations specifically associated with either Darfield or Kirwee townships.

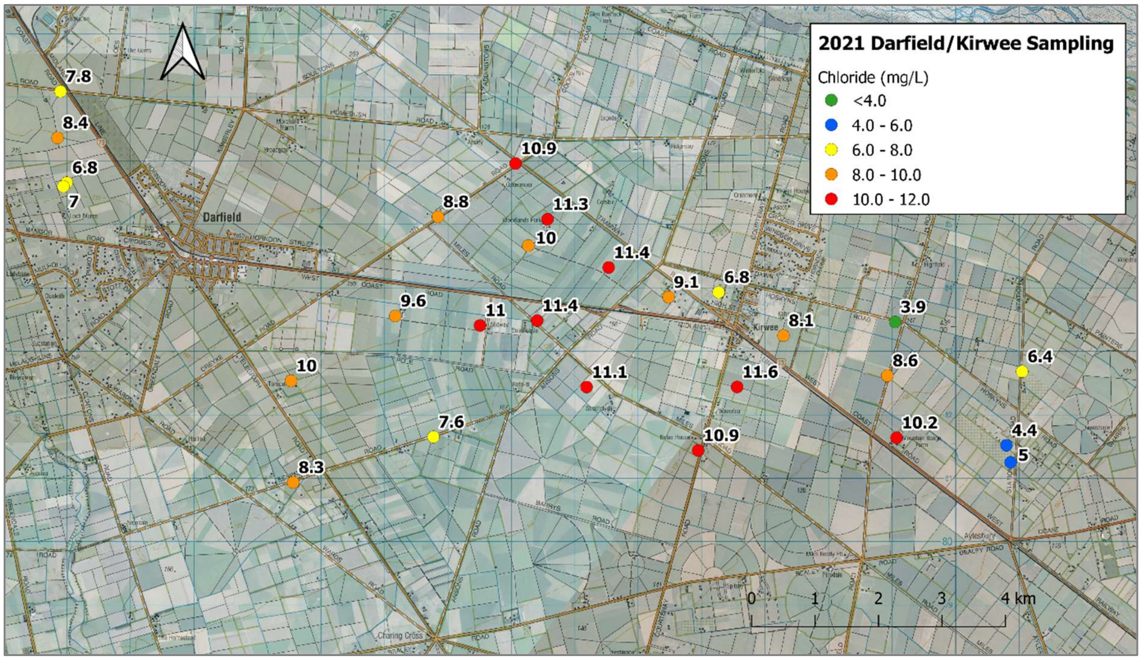

Figure 8. *Chloride concentrations from the February 2021 survey.*

Figure 9 shows a histogram of chloride concentrations from the 2021 survey. The data show a relatively normal distribution with most samples exhibiting concentrations between 6 and 12 g/m^3, with the low concentrations from three wells east of Kirwee (BX23/0732, L35/0561, M35/7555) evident. Given the relatively extensive spatial and depth distribution of sites sampled, the data do not suggest any significant localised chloride inputs to the system (such as would be typically associated with wastewater discharge) in the wells sampled, other than those occurring via seasonal variations in land surface recharge and general agricultural land use effects.

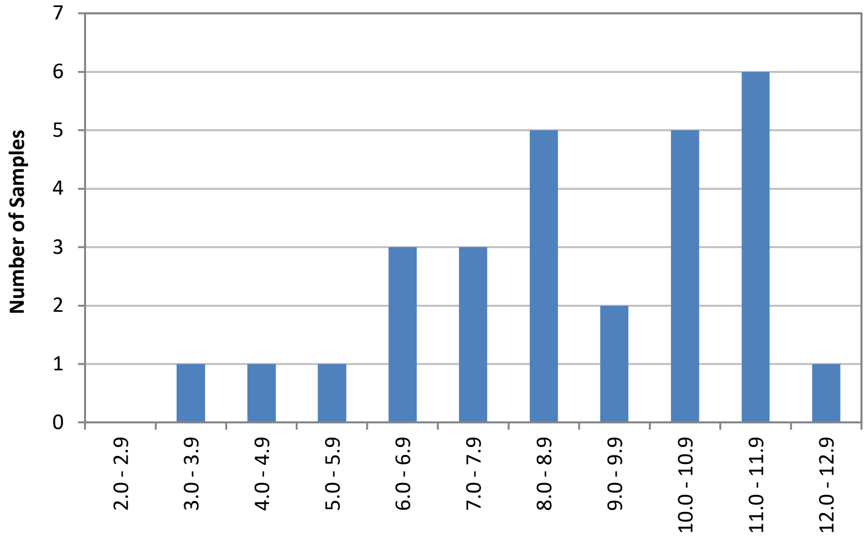

Figure 9. *Histogram of Chloride concentrations from the February 2021 survey.*

3.3.3. Nitrate

Nitrate inputs to groundwater can be derived from a wide range of land use activities including soil cultivation and pastoral farming as well as the application of fertiliser or effluent to land. Nitrate is highly soluble in water so in situations where soluble nitrate concentrations in soil exceed those able to be absorbed by plants and microbial activity, nitrate can be readily transported through the soil zone into underlying groundwater. Once below the root zone, denitrification is typically the only process which will reduce the mass load of nitrate within an aquifer system. In the Canterbury region, nitrate-nitrogen concentrations in groundwater in excess of 1 mg/L are generally considered to reflect input from land use activities (Hanson, 2002).

Figure 10 shows the spatial distribution of nitrate-nitrogen concentrations from the 2021 survey. These data show observed nitrate-nitrogen concentrations range from 2.0 mg/L to 10.6 mg/L with a median value of 5.7 mg/L. A total of 15 wells (56% of those sampled) exhibited nitrate concentrations exceeding 50% of the MAV, with six wells (BX22/0027, L35/0190, L35/0210, L35/0685, L35/0714 and L35/0876) exhibiting concentrations in excess of 75% of MAV. These wells are situated along the same north-west to south-east alignment between the Darfield and Kirwee townships where elevated EC and Chloride concentrations are observed, while the lowest concentrations are observed east of Kirwee. Nitrate concentrations up-gradient (west) of Darfield are similar to those recorded across much of the area to the south-east (i.e., the area most likely to down-gradient based on the piezometric contours shown in Figure 1 above).

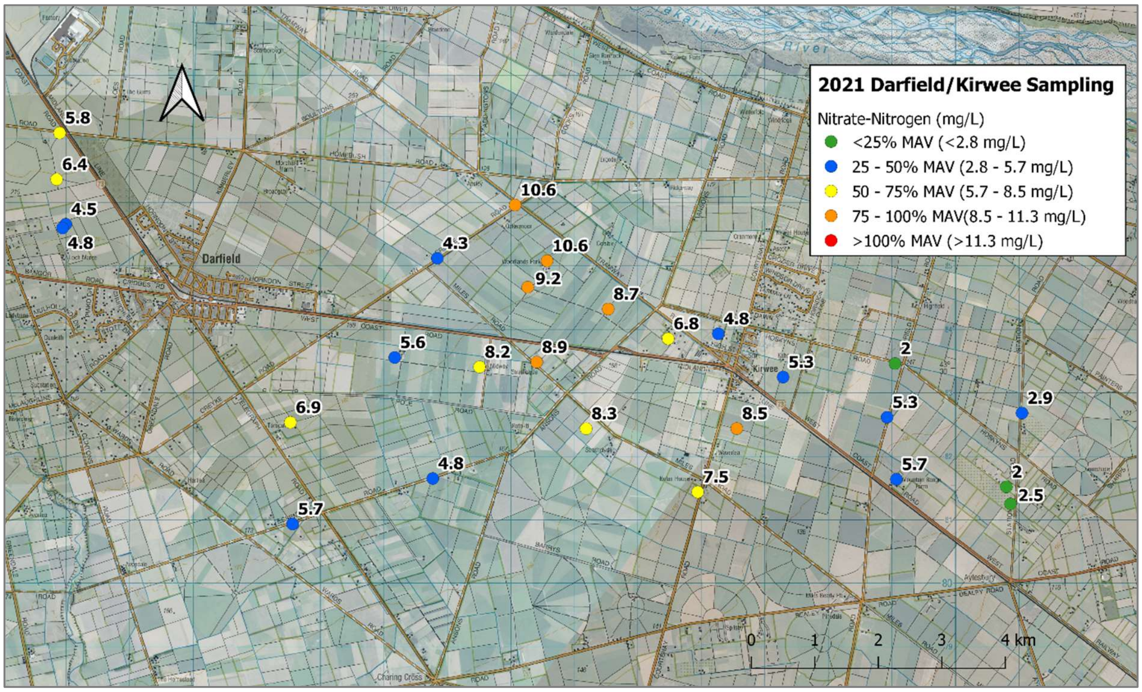

Figure 10. *Nitrate-nitrogen concentrations from the February 2021 survey.*

Overall, nitrate results from the 2021 survey exhibit a spatial distribution which is consistent with previous sampling rounds. Highest nitrate concentrations are generally observed in a cluster of wells to the east of Darfield, while bores to the south-east (i.e., the area assumed as most likely down-gradient) are similar to those observed to the up-gradient (west) of the township. It is noted that the cluster of elevated nitrate concentrations east of Darfield also coincides with an area of relatively intensive agricultural land use (arable and dairying). Similarly, at Kirwee, nitrate concentrations observed in wells to the west (i.e., up-gradient) are similar to or slightly higher than those measured to the east.

Figure 11. *Distribution of nitrate-nitrogen concentrations with respect to MAV for the 2017 to 2021 sample rounds*

Figure 11 shows a plot of nitrate-nitrogen results from the last five sample rounds (2017 to 2021) expressed in terms of percentage of MAV. Historically, while there have been changes to the number and location of individual wells sampled over this period, the results indicate a relatively consistent distribution of nitrate concentrations across the study area.

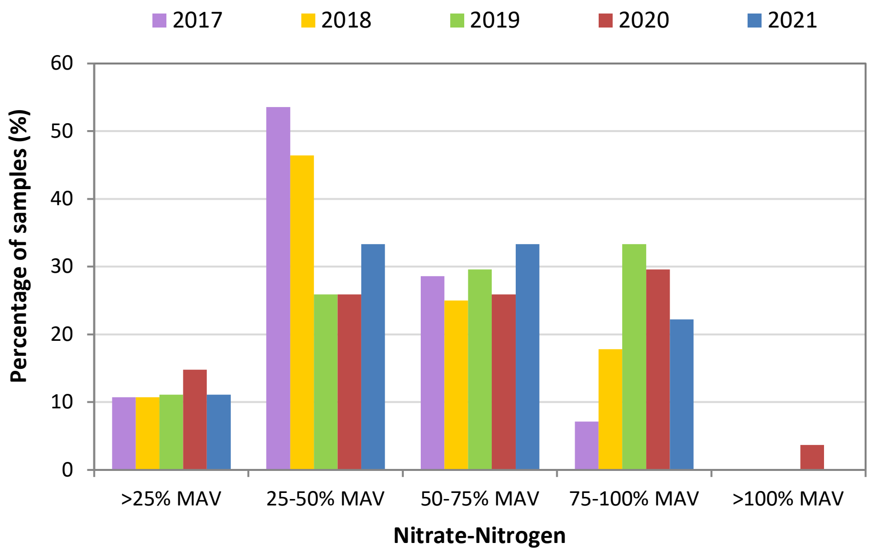

Figure 11. *Distribution of nitrate-nitrogen concentrations with respect to MAV for the 2017 to 2021 sample rounds*

Figure 12 shows a map of the observed differences between nitrate concentrations observed in the 2020 and 2021 surveys. While the average change in nitrate concentrations between wells sampled was small (-0.3 mg/L), significant changes in nitrate concentrations were observed in some individual wells. Large increases in nitrate concentrations were observed in BX22/0169 and L35/0876 (2.0 and 3.0 mg/L respectively), while appreciable decreases were observed in L35/0213, L35/0248, L35/0527 and L35/0729 (-1.6, -1.2, -1.5 and -4.6 mg/L respectively). Significant decreases in nitrate concentrations were also observed in up-gradient monitoring wells L35/0884 and L35/0980 (--3.0 and -1.9 mg/L respectively). The spatial distribution of observed inter-annual variations in nitrate concentrations does not exhibit any consistent pattern and may therefore be related to localised factors particular to each bore (i.e., a complex interaction between historical variations climate in up-gradient land use and, groundwater residence time, screen depth and pumping rate).

It is noted that nitrate concentration of in BX22/0027 (which exceeded the NZDWS MAV in the 2020 survey) reduced from 12.0 mg/L to 10.6 mg/L in the 2021 survey. Further analysis of temporal changes in nitrate concentrations is provided in Sections 3.4 and 3.5 below.

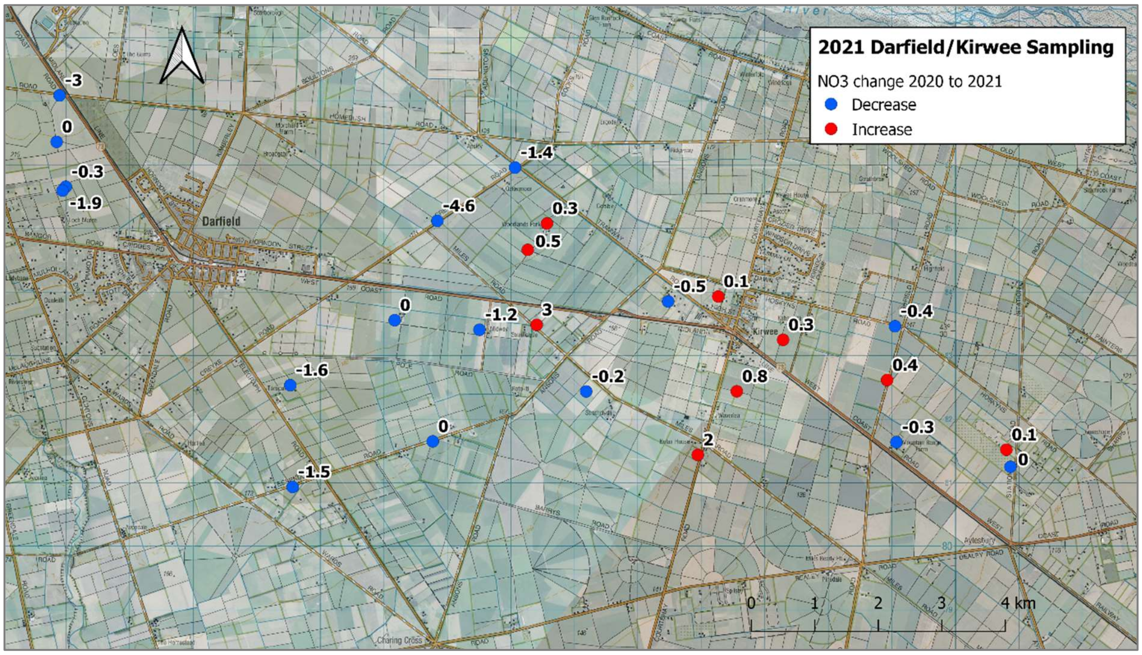

Figure 12. *Variation in nitrate concentrations (mg/L) between the 2020 and 2021 surveys.*

Overall, nitrate results from the 2021 survey exhibit a spatial distribution which is consistent with previous sampling rounds. The data indicate a cluster of wells showing elevated nitrate concentrations to the east of Darfield. However, this area (particularly toward the intersection of Creyke Road and Tramway Road) is considered as unlikely to be directly down-gradient of the Darfield township (based on piezometric contours shown in Figure 1 above). Similarly, inter-annual variability in nitrate concentrations dues do not exhibit any consistent pattern suggesting the influence of localised or site-specific factors rather than a spatially consistent source as would be expected if wastewater discharge was significantly influencing groundwater quality.

3.3.4. Microbial quality

Results from one well (L35/0248) sampled during the 2021 survey showed the presence of indicator bacteria (*E.coli*) at a concentration slightly above detection (3 MPN).

This site has been sampled on 15 previous occasions (sampled annually 2006 to 2020), with a single (low level) E.coli detection in 2019. It is however noted that while L35/0248 was historically used as an irrigation well, following commissioning of the CPW scheme, it is now primarily used for farm and domestic supply. As a result of this change, samples now have to be sourced from a sample point located some distance after a large storage tank rather than directly from the wellhead. This increases the potential for inadvertent sample contamination.

Consequently, as with similar detections of low-level microbial contamination in previous sampling rounds, it is inferred that the indicator bacteria detected at L35/0248 is likely to represent localised contamination, rather than the widespread occurrence of microbial contamination within the groundwater system.

3.3.5. Other major ions

Other major ions including calcium, potassium and sulphate show a spatial variable distribution broadly similar to that observed for EC, Chloride and Nitrate-Nitrogen, with an overall increase in parameter concentrations in the area to the east of Darfield. For example, **Figure 13** shows the spatial distribution of calcium concentrations in the 2021 survey which are broadly similar to those observed for the primary indicator species (e.g. **Figure 7**, **Figure 8** and **Figure 10**).

Other major ions (including alkalinity and magnesium) exhibit less obvious spatial and depth distributions across the study area, aside from a generalised increase in concentrations with depth and decrease in shallower bores east of Kirwee.

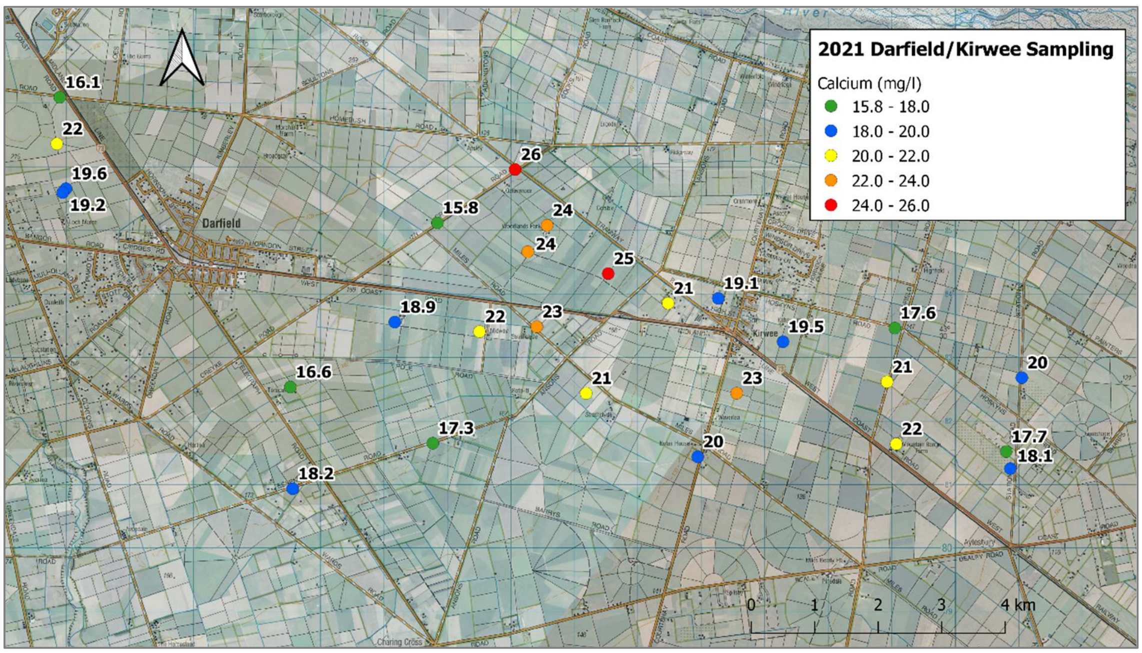

Figure 13. *Calcium concentrations from the January 2021 survey.*

3.4. Temporal variations in groundwater quality

3.4.1. SDC Kirwee Supply

L35/0191, a 115 metre deep public supply bore operated by SDC at Kirwee, has the longest record of groundwater quality for any site in the Darfield/Kirwee area. As shown in **Figure 14**, data from this well shows low concentrations of major ions which have remained relatively consistent since regular measurements commenced in 1980.

While limited variability is observed in parameter concentrations between individual (~annual/bi-annual) samples, short-term trends in groundwater quality are evident over timescales of 5 to 10 years. For example, the data show a general decline in concentrations of calcium, chloride, nitrate (and associated EC values) between the late 1990's and 2006 followed by a gradual increase until 2015 with a subsequent decline through to mid-2017 (which has seemingly reversed through to 2021). Over the same period concentrations of Sulphate and Magnesium have remained relatively stable.

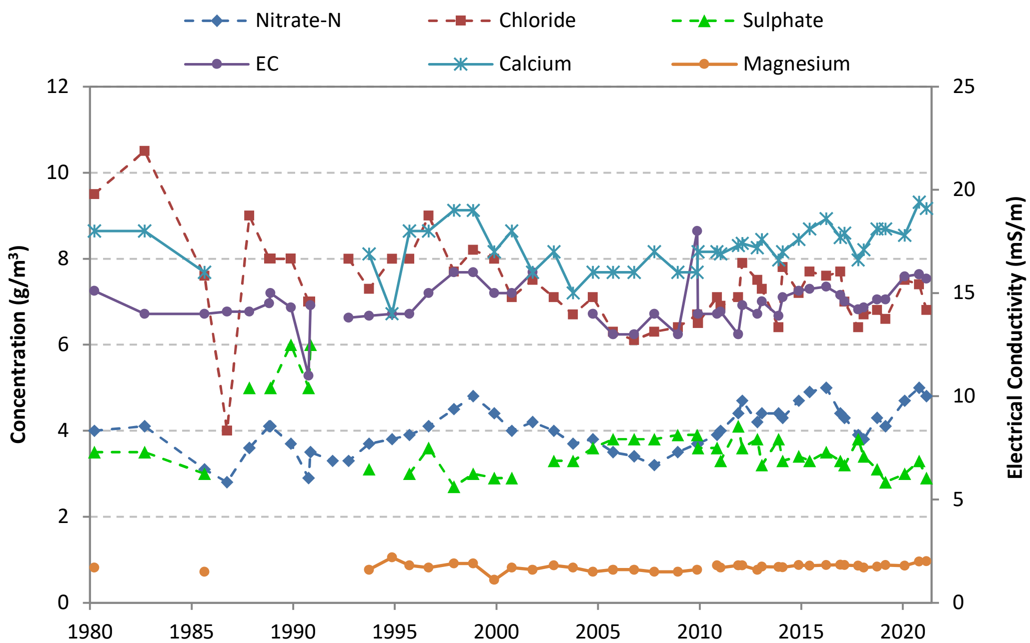

***Figure 14**. Long-term variations in groundwater quality recorded in the SDC Kirwee supply bore (L35/0191), 1980-2021.*

Overall, data from L35/0191 indicates groundwater quality at this site has remained relatively stable over the past 40 years. While some variability in parameter concentrations is observed on an inter-annual scale, such changes are possibly related to lagged effects climate variability (i.e., the volume and timing of aquifer recharge) rather than reflective of any significant long-term temporal trends. The relative stability of major ion concentrations at this site does not indicate groundwater quality at this location has impacted to any major extent by temporal variations in contaminant inputs to the up-gradient groundwater system.

3.4.2. SDC Darfield/Kirwee monitoring data

In order to identify any statistically significant trends in groundwater quality in the Darfield/Kirwee area, the available data set was analysed using Sen's slope estimator to quantify temporal trends detectable with the Mann-Kendall test at the 95% confidence interval. Wells selected for analysis include those with five or more samples prior to 2021 with no more than a 1-year gap in the sampling record.

Results of this analysis are presented in Table 5 below and show statistically significant trends in individual water quality parameters were identified in nine of the seventeen wells with sufficient for analysis. Of the parameters utilised in the assessment, Potassium exhibited statistically significant increasing trends in 6 wells (35%), with increases in EC and Calcium observed in 5 (29%) and 4 (24%) wells respectively. Increasing trends were also observed in Magnesium (3 wells), Sodium (3) and Nitrate (2) and Chloride (1). The magnitude of the calculated annual trends ranged from +0.10 to +0.32 mg/L/year for Calcium, +0.04 to +0.23 µS/m/year for EC and 0.03 to 0.10 mg/L/year for nitrate.

Table 5. *Statistically significant trends in groundwater quality in the Darfield/Kirwee area, 2006-2021*

Site	Parameter	Trend (increase/decrease)	Trend Magnitude (g/m^3 or μS/year)
BX22/0051	EC	Incr	+0.51
L35/0190	Sulphate	Decr	-0.06
L35/0191	Potassium	Incr	+0.02
	EC	Incr	+0.17
	Calcium	Incr	+0.19
L35/0248	Chloride	Incr	+0.11
	Potassium	Incr	+0.02
L35/0714	Potassium	Incr	+0.03
	Sodium	Incr	+0.13
	EC	Incr	+0.23
	Calcium	Incr	+0.25
L35/0870	Potassium	Incr	+0.03
L35/0843	EC	Incr	+0.04
	Nitrate-N	Incr	+0.03
L35/0876	Sodium	Incr	+0.14
	Potassium	Incr	+0.03
	Magnesium	Incr	+0.07
	EC	Incr	+0.20
	Calcium	Incr	+0.32
	Nitrate	Incr	+0.10
L35/0956	Sodium	Incr	+0.10
	Potassium	Incr	+0.01
	Magnesium	Incr	+0.02
M35/7555	Magnesium	Incr	+0.03
	Calcium	Incr	+0.10

Figure 15 shows the temporal variation in chloride concentrations in 7 representative wells distributed across the study area. The data show a range of temporal trends ranging from relatively steady increasing trends (e.g., L35/0190) to sites where significant short-term variability is observed over inter-annual timescales (e.g., L35/0248 and L35/0767). Some sites (e.g., L35/0213) also appear to show the effects of short-term variability overlain on an increasing trend.

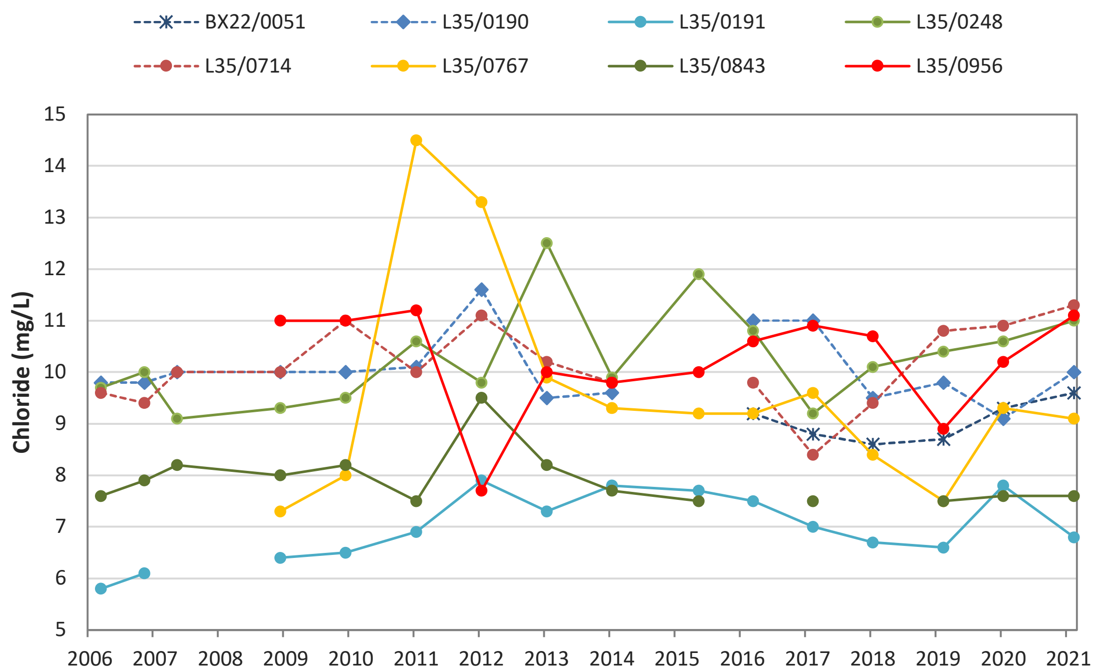

Figure 15. *Temporal variation in Chloride concentrations in representative wells in the Darfield/Kirwee area, 2006 to 2021.*

It is noted that while temporal variations in the concentrations of water quality parameters in individual wells may be relatively well correlated (e.g., as discussed for L35/0191 in the previous section), consistent temporal trends are less evident across the wider group of wells sampled. This suggests that much of the temporal variability in groundwater quality observed across the full dataset may reflect localised factors specific to individual bores, rather than a consistent pattern associated with a specific, geographically constrained and relatively constant source of contaminant input to the aquifer system (such as on-site wastewater disposal in Darfield and Kirwee townships).

Figure 16 below shows a plot of Nitrate-Nitrogen concentrations in the group of wells immediately east of Darfield exhibiting elevated concentrations of indicator parameters (Chloride and nitrate). While only a sub-set of the wells have a continuous sampling record, the data again show significant differences between individual wells with relatively stable concentrations at some sites (e.g., L35/0191) contrasting with significant temporal variability at others (e.g., L35/0767).

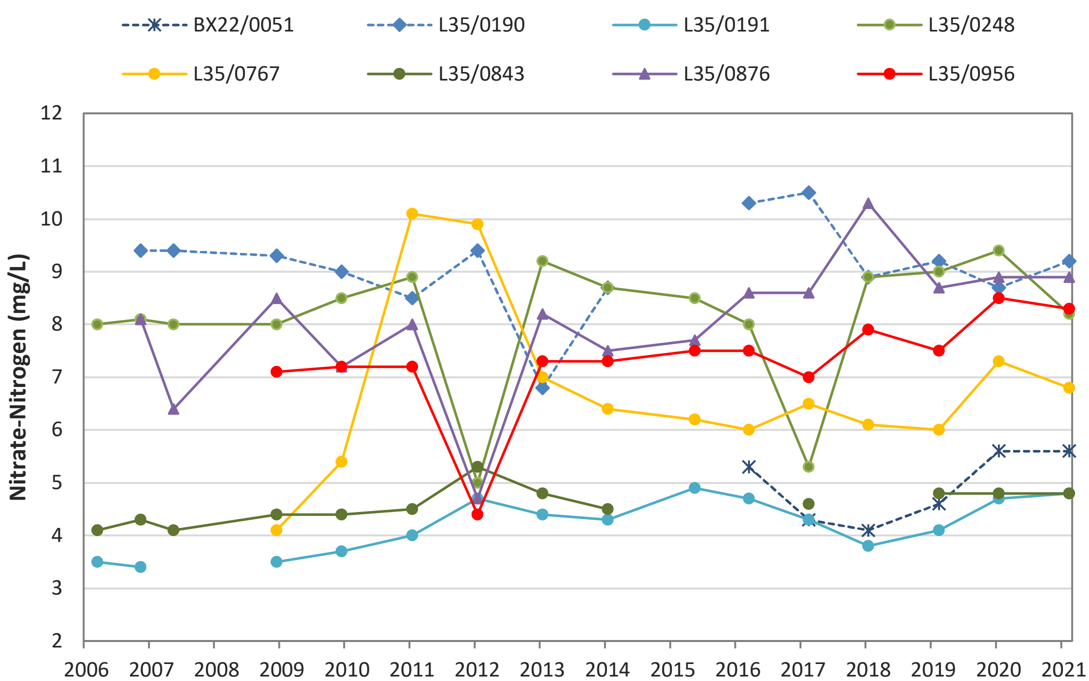

Figure 16. *Temporal variation in Nitrate-Nitrogen concentrations in representative wells in the Darfield/Kirwee area, 2006 to 2021.*

3.5. CPW compliance monitoring

As part of its resource consent compliance monitoring requirements, CPW collect groundwater samples on a quarterly basis from a monitoring well (BX22/0070) located in the area potentially down-gradient of Darfield township (at the location shown on Figure 2 above). This well is one of a network of sites monitored across the CPW Scheme command area.

BX22/0070 is both constructed and sampled in a manner that differs from that utilised for bores included in the SDC Darfield/Kirwee monitoring programme. The CPW bore is constructed with a long screened interval which extends across the entire range of expected water table variation. Samples are collected via a low-flow sampling method from the upper 1 metre of the saturated zone. In contrast, wells included in the Darfield/Kirwee sampling programme are typically screened <15 metres below the lowest recorded water level (~90 to 100 metres in the Darfield area, 50 to 60 metres in the Kirwee area), and in some cases may draw water several 10s of metres below the water table surface.

Consequently, samples obtained from the CPW monitoring bore are expected to represent 'worst case' water quality given they are derived from the surface of the water table where recharge infiltrating through the unsaturated zone is concentrated, rather than from groundwater at greater depths below the water table which likely represents a 'mix' of recharge sourced from a spatially extensive up-gradient recharge area, and which may have been resident in the aquifer for a considerable time period (depending on the depth of sampling and local hydrogeological conditions)[6].

Figure 16 below shows a plot of depth to groundwater, Nitrate-Nitrogen and Chloride concentrations observed in BX22/0070 between June 2015 and March 2021.

Prior to June 2017 the data indicate relatively stable Chloride and Nitrate concentrations of 9.8 to 10.2 and 7.5 to 7.7 mg/L respectively, accompanied by a gradual decline in groundwater levels (with a small seasonal variation of ~2-3 metres). In comparison, nearby wells (L35/0213 and L35/1164) sampled for the 2017 Darfield/Kirwee survey showed nitrate concentrations of between 5.5 and 5.6 g/m^3 and Chloride concentrations between 7.5 and 8.0 g/m^3. This comparison suggests a difference of around 2 g/m^3 in both nitrate and Chloride concentrations between upper surface of the water table (represented by BX22/0070) and the two adjacent irrigation bores both screened between 15 to 20 metres below the water table (at the time).

After a series of dry winters, significant recharge occurred during the 2017 year. This recharge is reflected in an almost 20 metre increase in the water table during spring 2017. This groundwater level recovery was accompanied by a large ‘spike’ in both Nitrate and Chloride concentrations (to levels approximately twice those observed prior to September 2017). This spike in concentrations is interpreted to reflect the flushing of contaminants through the thick unsaturated zone to the underlying water table in response to significant recharge during winter/spring 2017. Subsequent to the observed peak in concentrations in the September 2017 sample, concentrations of both nitrate and Chloride initially declined rapidly before exhibiting a gradual reduction to reach pre-September 2017 concentrations by late 2020.

Chloride and Nitrate concentrations recorded in BX22/0070 in March 2021 were marginally higher (0 to 1.3 mg/L) higher than those observed in nearby bores (L35/0213 and L35/0527) screened in the 100 to 130 m water-bearing layer.

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[6] For example, as described in Stewart *et al*., 2002.

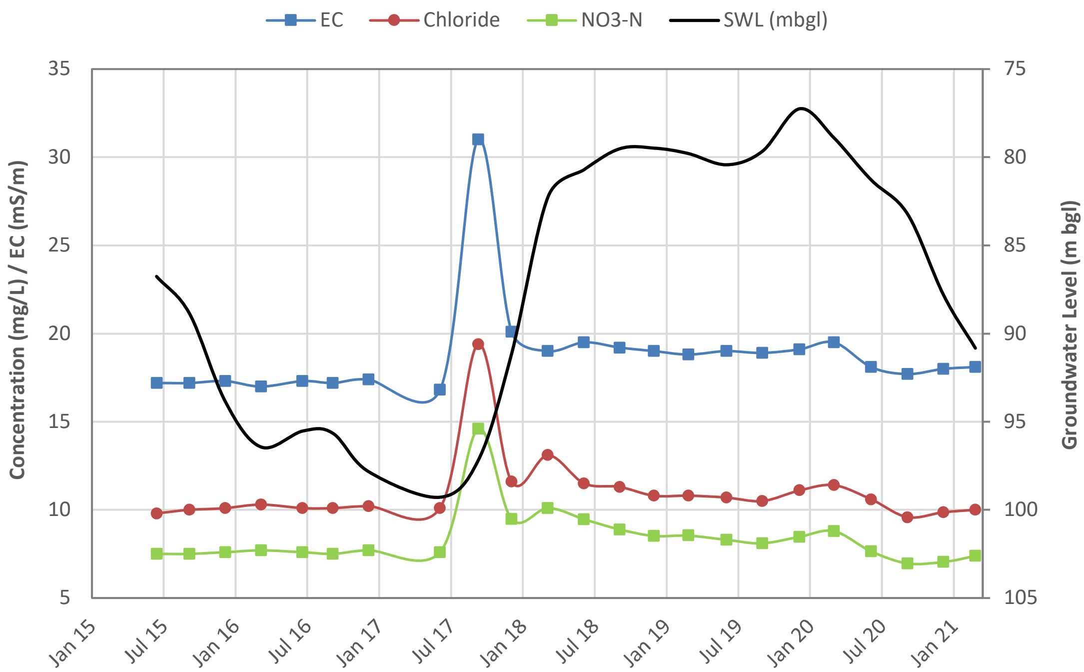

Figure 16. *Temporal variation in groundwater level, Chloride and Nitrate-Nitrogen concentrations in BX22/0070, 2015-19 (data provided by CPW).*

It is noted that the temporal variability in groundwater quality observed in BX22/0070 between 2017 and 2021 is not unique to this location, as similar variations are observed in the CPW monitoring wells located in other parts of the Central Plains area.

In the context of the Darfield/Kirwee monitoring programme, results of the CPW monitoring suggest:

- In inland areas of the Canterbury Plains where the water table is relatively deep (i.e., >30 to 40 metres bgl), contaminant inputs associated with overlying land use may be highly episodic, with significant contaminant loads associated with large recharge events.
- Nitrate concentrations in an area likely to be down-gradient of the Darfield township are typically lower (even at the water table) than those observed in 'conventionally' (i.e., those screened >15 metres below minimum groundwater levels) screened bores in nearby areas where land use is predominantly agricultural.
- There may be significant vertical differences in groundwater quality within a single water-bearing layer, with water quality in the upper part of the saturated zone representing a 'worst-case' that reflects episodic recharge through the unsaturated zone.
- The magnitude of temporal variations in groundwater quality observed in 'conventionally' screened bores are significantly less than those occurring at the top of the saturated zone. This may reflect mixing of local recharge with older groundwater derived from more distant recharge sources.

- Observed variations in groundwater quality in 'conventionally' screened bores may lag changes in groundwater quality at the water table due to the slow rate of vertical mixing within the aquifer (even in the vicinity of high yielding bores).

- Observed temporal variations in groundwater quality are likely to vary between individual bores reflecting screen depth (below the water table), pumping rate and other localised factors that influence the rate of vertical mixing within the aquifer. It is therefore reasonable to observe that the magnitude and timing of temporal trends are unlikely to be consistent between individual bores.

In addition, it is noted that positive detections of indicator bacteria in BX22/0070 were recorded in 3 out of 23 samples (13%) collected between June 2013 and March 2021. These detections are inferred to correspond with recharge events during winter 2017 and winter 2019 respectively (reflected in increased groundwater levels) when similar E.coli detections were also recorded in other CPW monitoring bores located across the Central Plains area. Given the location of this bore and the method of sampling (i.e., from the upper 1 m of the saturated zone) the episodic nature of the observed microbial contamination does not indicate a continuous source of microbial contamination, such as could be associated with extensive on-site wastewater discharge across the up-gradient area.

3.6. Discussion

In total, twenty-eight[7] samples were collected from wells in the Darfield/Kirwee area for the 2021 groundwater quality survey. Twenty-five of the wells sampled were also sampled for the 2020 survey providing a relatively consistent sample network.

Sample results indicate groundwater in the Darfield and Kirwee areas is typical of that seen across much of the Canterbury Plains. Concentrations of dissolved ions are relatively low reflecting both the short to moderate residence time of the water and the relatively inert nature of the aquifer materials. Results from all samples collected in the February 2021 survey show relatively consistent water chemistry, with limited evidence of obvious outliers that could be associated with localised contamination. This observation is consistent with results of previous groundwater quality surveys undertaken from 2006 to 2020.

Data collected for the 2021 survey indicate the concentrations of key water quality determinands were within Maximum Acceptable Values (MAV) specified in the Drinking Water Standards for New Zealand (2005) in a majority of wells sampled. Single well recorded a positive detection of low levels of indicator bacteria (*E.coli*). Such low-level microbial contamination has been observed in previous sample rounds and is potentially attributable to localised contamination of sample points (possibly due to the location of sample points within reticulation systems downstream of wellheads). No sites exceeded the NZDWS Nitrate-Nitrogen MAV while one exceedance of the aesthetic guidelines for iron was recorded.

A total of 15 wells (56% of those sampled) exhibited nitrate concentrations exceeding 50% of the MAV, with nine wells (BX22/0027, L35/0190, L35/0210, L35/0685, L35/0714 and L35/0876) exhibiting concentrations in excess of 75% of MAV. These wells are largely situated along a north-west to south-

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[7] One sample was derived from CPW reticulation and was excluded from analysis.

east alignment between the Darfield and Kirwee townships. Given interpolated groundwater flow direction, this area is unlikely to be directly down-gradient of either township.

The spatial distribution of individual water quality parameters in the 2021 survey similar to those observed in previous investigations. The two most notable aspects of the spatial distribution of groundwater quality are an area to the east of Darfield where slightly elevated concentrations of indicator species (EC, Chloride, Nitrate-Nitrogen) are observed, and a group of wells east of Kirwee that exhibit major ion concentrations appreciably lower those to the west.

Statistically significant temporal trends in groundwater quality were observed in nine of the seventeen wells with sufficient data. The most common parameters exhibiting increasing trends were Potassium, Electrical Conductivity (EC), Magnesium and Nitrate. It is noted that in many cases inter-annual variability in parameter concentrations (interpreted to, at least in part, reflect climatic variability and associated effects on groundwater recharge flux) is significantly larger than underlying temporal trends.

Overall, analysis of spatial and temporal variation in groundwater quality in the Darfield/Kirwee area provides limited evidence to indicate groundwater quality in the local area is influenced by factors other than general land use and climate variability across the contributing recharge area. Certainly, the available data does not indicate existing wastewater disposal practices in the Darfield and Kirwee townships are having any significant adverse impact on groundwater quality over and above that occurring due to agricultural land use.

The ability to draw definitive conclusions with respect to likely effects of onsite wastewater disposal in these townships is however constrained by the spatial distribution and screen depths of existing wells (particularly in areas immediately down-gradient of the Darfield and Kirwee townships), and the limited data available to characterise groundwater quality across a wider area.

4. Summary

In mid-February 2021, groundwater quality samples were collected from 28 wells in the vicinity of the Darfield and Kirwee townships. Results of this survey are consistent with previous groundwater quality investigations in the area and indicate:

- Groundwater quality down gradient of the Darfield and Kirwee townships generally contains low concentrations of dissolved ions which are within Maximum Acceptable Values (MAV) specified in the New Zealand Drinking Water Standards.
- Groundwater quality in the Darfield/Kirwee area is consistent with that observed across the wider Canterbury Plains area (ECan, 2020). The most significant departures in the 2021 Darfield/Kirwee data were for sulphate, magnesium and Total Alkalinity which were at least 40% lower than regional median values, while nitrate concentrations were approximately 40% higher than regional median values.
- Sample results show no obvious indications of widespread contamination from existing on-site wastewater discharge activities in Darfield or Kirwee.
- An area of elevated concentrations of indicator species (e.g., EC, Nitrate-Nitrogen and Chloride) is observed to the east of Darfield. Groundwater quality in this area is inferred to reflect agricultural land use across the contributing recharge area, rather than effects associated with on-site wastewater discharge.
- Low levels of indicator bacteria were detected at one site (L35/0248). Such low-level microbial contamination has been observed in previous sample rounds and is potentially attributable to localised contamination of sample points (particularly where samples are derived from sites with non-ideal sample points such as centre pivot/lateral irrigators and, in some instances, after pressure and/or storage tanks).
- Inter-annual variations in parameter concentrations are observed in a majority of wells sampled. Such inter-annual variation and associated medium-term trends (5 to 10 years) are observed in data from L35/0191 which has a monitoring record extending back to 1980. Such variations appear (at least in part) to reflect changes in winter rainfall and resulting recharge flux.

Overall, analysis of available data area shows groundwater quality in the Darfield/Kirwee area is high, with no obvious indication of contamination likely to be associated with on-site wastewater disposal in the Darfield and Kirwee townships.

However, the ability to draw definitive conclusions with respect likely effects of onsite wastewater disposal in the Darfield and Kirwee townships is limited by the spatial distribution and screen depths of existing wells in the area, the relatively short monitoring record, and the limited data available to characterise groundwater quality across a wider area.

5. References

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Appendix A. February 2021 sample results

Well No		**BX22/0027**	**BX22/0051**	**BX22/0162**	**BX22/0169**	**BX23/0006**	**BX23/0732**	**L35/0187**	**L35/0190**	**L35/0191**	**L35/0210**
Lab No		2536486.1	2536485.1	2540544.1	2536481.1	2540547.1	2537670.1	2536489.1	2536487.1	2540546.1	2536482.1
Arsenic	g/m^3	<0.0011	<0.0011	<0.0011	<0.0011	<0.0011	<0.0011	<0.0011	<0.0011	<0.0011	<0.0011
Chromium	g/m^3	<0.00053	<0.00053	<0.00053	<0.00053	<0.00053	<0.00053	<0.00053	<0.00053	<0.00053	<0.00053
Lead	g/m^3	<0.00011	<0.00011	<0.00011	0.00071	0.003	0.00026	<0.00011	<0.00011	<0.00011	<0.00011
Nickel	g/m^3	<0.00053	<0.00053	<0.00053	<0.00053	<0.00053	<0.00053	<0.00053	<0.00053	<0.00053	<0.00053
E Coli	MPN/100 mL	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
pH	pH units	7.7	7.8	7.8	7.8	7.8	7.9	7.9	7.7	7.8	7.8
Tot Alkalinity	g/m^3 as $CaCO_3$	50	41	44	41	48	45	42	43	42	43
Free CO2	g/m^3	2.2	1.4	1.3	1.2	1.4	1	1.1	1.8	1.2	1.4
Tot Hardness	g/m^3 as $CaCO_3$	84	55	65	61	58	49	56	74	56	72
Electrical Conductivity	mS/m	23.4	16.4	17.4	18.9	16.1	12.8	16.4	21.6	15.7	20.4
Electrical Conductivity	uS/cm	234	164	174	189	161	128	164	216	157	204
Approx Dissolved Solids	g/m^3	157	110	116	127	108	86	110	145	105	136
Boron	g/m^3	0.0230	0.0210	0.0220	0.0197	0.0210	0.022	0.0199	0.0185	0.0220	0.0220
Calcium	g/m^3	26	18.9	22	20	19.6	17.7	19.5	24	19.1	23
Copper	g/m^3	<0.00053	<0.00053	<0.00053	0.0023	0.0025	0.00084	<0.00053	<0.00053	<0.00053	<0.00053
Iron	g/m^3	<0.021	<0.021	<0.021	0.086	0.186	<0.021	<0.021	<0.021	<0.021	<0.021
Magnesium	g/m^3	4.8	1.89	2.5	2.6	2.1	1.15	1.73	3.6	2	3.4
Manganese	g/m^3	<0.00053	<0.00053	0.00059	0.00970	0.00770	0.00174	<0.00053	<0.00053	<0.00053	<0.00053
Potassium	g/m^3	1.56	1.08	0.96	1.22	0.98	1.02	1.16	1.34	1.15	1.32
Sodium	g/m^3	12.7	9.3	9.5	10.8	9.3	6.4	8.4	11.0	8.1	10.7
Zinc	g/m^3	0.029	0.0065	0.0071	0.3500	0.8	0.099	<0.0011	<0.0011	0.0017	<0.0011
Chloride	g/m^3	10.9	9.6	8.4	10.9	6.8	4.4	8.1	10.0	6.8	11.6
Nitrate-N	g/m^3	10.6	5.6	6.4	7.5	4.5	2	5.3	9.2	4.8	8.5
Sulphate	g/m^3	4.4	1.5	1.0	3.1	0.8	3.6	2.9	5.5	2.9	2.5
Charge Balance Error	%	2.0	-0.7	3.3	-1.4	1.7	0.2	-1.0	1.5	1.0	1.2

Well No		**L35/0213**	**L35/0248**	**L35/0527**	**L35/0561**	**L35/0685**	**L35/0714**	**L35/0729**	**L35/0767**	**L35/0832**	**L35/0843**
Lab No		2537667.1	2536493.1	2537672.1	2536484.4	2536490.1	2536488.1	2536328.1	2537668.1	2536491.1	2537666.1
Arsenic	g/m^3	<0.0011	<0.0011	<0.0011	<0.0011	<0.0011	<0.0011	<0.0011	<0.0011	<0.0011	<0.0011
Chromium	g/m^3	<0.00053	<0.00053	<0.00053	<0.00053	<0.00053	<0.00053	<0.00053	<0.00053	<0.00053	<0.00053
Lead	g/m^3	<0.00011	<0.00011	0.00038	<0.00011	<0.00011	<0.00011	0.00011	0.00046	<0.00011	<0.00011
Nickel	g/m^3	<0.00053	<0.00053	<0.00053	<0.00053	<0.00053	<0.00053	<0.00053	<0.00053	<0.00053	<0.00053
E Coli	MPN/100 mL	<1	3	<1	<1	<1	<1	<1	<1	<1	<1
pH	pH units	7.6	7.8	7.7	7.9	7.7	7.7	7.6	7.8	7.9	7.7
Tot Alkalinity	g/m^3 as $CaCO_3$	36	37	43	45	47	48	38	46	44	40
Free CO2	g/m^3	1.9	1.1	1.8	1	1.8	1.9	1.7	1.3	1.1	1.5
Tot Hardness	g/m^3 as $CaCO_3$	56	63	63	49	80	79	50	66	59	51
Electrical Conductivity	mS/m	17.0	18.6	18.1	12.9	21.5	23.2	15.7	18.7	16.8	14.6
Electrical Conductivity	uS/cm	170	186	181	129	215	232	157	187	168	146
Approx Dissolved Solids	g/m^3	114	125	121	86	144	155	105	125	112	98
Boron	g/m^3	0.0200	0.0172	0.0188	0.0220	0.0250	0.0220	0.0175	0.0230	0.0200	0.0220
Calcium	g/m^3	16.6	22	18.2	17.6	25	24	15.8	21	21	17.3
Copper	g/m^3	0.00056	0.00063	0.002	<0.00053	<0.00053	0.00074	0.0028	<0.00053	<0.00053	0.00115
Iron	g/m^3	0.053	0.062	0.042	<0.021	<0.021	<0.021	0.85	<0.021	<0.021	0.022
Magnesium	g/m^3	3.4	1.81	4.3	1.14	4.3	4.6	2.6	3	1.4	2.0
Manganese	g/m^3	0.00122	0.00192	<0.00053	<0.00053	<0.00053	<0.00053	0.015	<0.00053	<0.00053	<0.00053
Potassium	g/m^3	1.23	1.28	1.32	1.01	1.38	1.43	1.19	1.31	1.16	1.11
Sodium	g/m^3	10.8	10.4	11.2	6.7	11.4	12.1	10.9	10.4	8.8	8.8
Zinc	g/m^3	0.0122	0.0129	0.0350	0.0043	0.0017	0.0025	0.0082	0.0050	0.0018	0.0062
Chloride	g/m^3	10.0	11.0	8.3	3.9	11.4	11.3	8.8	9.1	8.6	7.6
Nitrate-N	g/m^3	6.9	8.2	5.7	2.0	8.7	10.6	4.3	6.8	5.3	4.8
Sulphate	g/m^3	1.9	1.6	5.6	3.9	3.2	4.3	5.4	2.9	2.8	0.8
Charge Balance Error	%	1.4	1.0	3.8	0.8	3.5	-0.6	1.6	0.6	-0.6	1.1

Well No		**L35/0870**	**L35/0876**	**L35/0884**	**L35/0956**	**L35/0980**	**M35/7555**	**M35/0849**
Lab No		2536483.1	2536480.1	2540545.1	2536492.1	2540360.1	2537663.1	2537671.1
Arsenic	g/m^3	<0.0011	<0.0011	<0.0011	<0.0011	<0.0011	<0.0011	<0.0011
Chromium	g/m^3	<0.00053	<0.00053	<0.00053	<0.00053	<0.00053	<0.00053	<0.00053
Lead	g/m^3	<0.00011	<0.00011	<0.00011	<0.00011	<0.00011	0.00037	0.00037
Nickel	g/m^3	<0.00053	<0.00053	<0.00053	<0.00053	<0.00053	<0.00053	<0.00053
E Coli	MPN/100 mL	<1	<1	<1	<1	<1	<1	<1
pH	pH units	7.9	7.7	7.8	7.7	7.8	7.9	8.2
Tot Alkalinity	g/m^3 as	42	40	45	37	47	45	50
Free CO2	g/m^3	1.1	1.7	1.4	1.3	1.4	1.1	<1
Tot Hardness	g/m^3 as	63	72	57	63	56	51	56
Electrical Conductivity	mS/co	17.5	20.9	17.1	19.2	16.4	13.4	15.1
Electrical Conductivity	uS/cm	175	209	171	192	164	134	151
Approx Dissolved Solids	g/m^3	117	140	115	129	110	90	101
Boron	g/m^3	0.0200	0.0189	0.0196	0.0185	0.0210	0.0230	0.0240
Calcium	g/m^3	22	23	16.1	21	19.2	18.1	20
Copper	g/m^3	<0.00053	<0.00053	<0.00053	0.00092	<0.00053	<0.00053	<0.00053
Iron	g/m^3	<0.021	<0.021	<0.021	<0.021	<0.021	0.12	0.053
Magnesium	g/m^3	1.74	3.4	4.2	2.6	1.93	1.4	1.44
Manganese	g/m^3	<0.00053	<0.00053	<0.00053	<0.00053	<0.00053	<0.00053	0.00071
Potassium	g/m^3	1.22	1.32	0.91	1.21	0.92	1.05	1.21

Sodium	g/m³	8.8	11.6	10.1	10.4	9.0	5.9	7.7
Zinc	g/m³	0.0420	0.0320	<0.0011	0.137	0.0018	0.0166	0.075
Chloride	g/m³	10.2	11.4	7.8	11.1	7.0	5.0	6.4
Nitrate-N	g/m³	5.7	8.9	5.8	8.3	4.8	2.5	2.9
Sulphate	g/m³	2.3	5.8	0.9	3.3	0.9	4.0	3.4
Charge Balance Error	%	1.2	1.4	0.7	0.0	-0.2	-1.4	-0.6