Parkvale groundwater quality investigation 2023-2024

Greater Wellington
Te Pane Matua Taiao

Parkvale groundwater quality investigation 2023-2024

Rob van der Raaij
Knowledge and Insights

We pay respect to iwi, hapū and whānau of the region who have mana over the whenua of Te Upoko o te Ika a Maui, with a particular acknowledgement to:

Rangitāne o Wairarapa, Ngāti Kahungunu ki Wairarapa, Ngāti Toa Rangatira, Taranaki Whānui, Ātiawa ki Whakarongotai and Ngā Hapū o Ōtaki.

Tukua te wairua, kia rere
Tukua te mauri, ka oho
Ruruku ki a Ranginui
Ruruku ki a Papatūānuku
Ko tēnei te rangi ka ū
Ko tēnei re rangi ka mau
Ko tēnei te rangi ka ruruku
Ko ēnei tauira o te whenua ki te rangi
I te Taiao ki te Arorangi, i rukutia noa atu
Tūturu o whiti whakamaua kia tina! Tina!
Haumie! Tāiki e!

Send forth the spiritual essence, so it flows
Send forth the vital life essence, to awaken
Bound together to the sky above
Bound together to the earth below
This is the day, to be sustained
This is the day, to seize hold of
This is the day, to be bound together
These examples are of the land and sky
From the environment to the universal domains
That weave us together, from long ago
Steadfast as a shining light, to behold and be fixed
Affirmed! By gathering here! And it is so!

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Executive summary

Background

The Parkvale catchment is a priority catchment in the Greater Wellington Natural Resources Plan (NRP) and within the Ruamāhanga Whaitua Implementation Programme due to degraded water quality and ecology of the Parkvale stream. State of the Environment (SOE) monitoring by Greater Wellington has reported elevated nitrate-nitrogen concentrations in shallow groundwater and a spring fed stream (Parkvale Stream at Lowes Reserve) for several years. High nitrate in the catchment has been attributed to numerous land uses within the catchment, including waste disposal at the former Affco Freezing Works and other smaller meat works in the Waingawa industrial area, chicken farms, disposal of dairy and piggery effluent, domestic wastewater from septic tanks and fertiliser storage sites (Baker 2018).

Objectives

The study aimed to provide an assessment of the current state of the groundwater quality for the Parkvale catchment. The study was co-designed with the Parkvale Catchment Community steering group to help answer their questions concerning sources and sinks of nitrate-nitrogen in the groundwater and surface water in the catchment. The study objectives were:

1. Collection of groundwater quality data from a selection of springs and groundwater bores within the Parkvale surface and groundwater catchments to provide an assessment of the "state" of the catchment water quality;

2. Use of geochemistry, nitrogen and other isotope tracer tools to identify the likely sources and flows within the surface and groundwater catchments; and

3. Provide Parkvale catchment landowners and the catchment community with base information to enable them to make informed investment decisions for actions to improve water quality and ecology outcomes as required under the NPS-FM and Natural Resources Plan.

Methods

The study used geochemistry, nitrogen and other isotope tracer tools to identify the likely sources and flows of nitrate-nitrogen within Parkvale catchment. Four sampling rounds of groundwater and spring chemistry and nitrate-nitrogen analysis were collected between May 2023 and March 2024 across the Parkvale catchment.

Results

The results of catchment wide survey indicated nitrate contamination of groundwater is widespread in the upper two thirds of the catchment. Nitrate-nitrogen concentrations from all sites ranged from below the detection limit of <0.001 to 43mg/L with a median concentration of 2.6 mg/L. Apart from one nitrate hotspot with localised contamination, most nitrate-nitrogen concentrations were below 7.3 mg/L.

Groundwater-fed springs and drains downgradient from the fault lines in the catchment contribute nitrogen to the surface water network. Nitrate-nitrogen concentrations were found to be above the National Policy Statement for Freshwater Management 2020 bottom line for nitrate toxicity of 2.4 mg/L nitrate-nitrogen (MfE 2023). The elevated nitrate also contributes to the proliferation of algae and macrophytes in surface water impacting the aquatic ecology of the stream network.

Nitrate isotope data has identified that there are multiple sources of nitrate contributing to the aquifer system. This includes upgradient sources above the Waingawa industrial area and from sources within the industrial area itself. Downgradient of the industrial area, isotope data and concentration gradients of nitrate and other contaminants indicate that there are several separate effluent type sources travelling from the industrial area, moving with the natural groundwater flow towards the Lowes Reserve wetland and the Parkvale stream network. In the middle of the catchment high nitrate concentrations have a urea fertiliser isotope signature. At this location there are likely to be multiple sources of nitrogen, and further investigation is recommended to help pinpoint sources.

In the northern two thirds of the study area, shallow groundwater and springs were found to have mean residence times (or groundwater ages) of less than 2 years. Shallow groundwater in the southern part of the catchment has mean residence times of up to 83 years which indicates that groundwater is moving much slower than the northern areas of the catchment. Groundwater in the southern catchment was found to be anoxic which means nitrate is likely to be attenuated by denitrification processes within the aquifer system.

Long term monitoring of groundwater at Lowes Reserve indicates nitrate-nitrogen concentrations are declining in this part of the catchment. Current nitrogen loads sourced from the Waingawa industrial area do not appear to have as large an impact or loading compared to historical levels, and likely to only contribute half or less of the total nitrogen loading to the Lowes Reserve wetland springs and stream network. The current load was found to be mostly coming from sources upgradient of the industrial area.

Legacy sources, such as at monitoring well BP34/0224, still exist within the Waingawa industrial area. However, the evidence shows that the current contribution from these sources to the total nitrogen loading to the Lowes Reserve wetland springs and the downstream stream network is likely to be relatively low overall compared to current land use practices.

Conclusion and recommendations

The top half of the catchment has soils that are naturally highly vulnerable to leaching from most types of land use. This means the risk of nitrate contamination to groundwater and the surface water bodies of the catchment is problematic. However, the lower third of the catchment has heavy soil types that naturally provide a barrier to nitrate leaching and promote for natural nitrate attenuation processes. Therefore, the lower catchment may be better suited to more intensive land uses whereas the upper catchment is likely to be better suited land uses that have lower nitrate leaching risk.

The results of this study indicate there are a wide range of diffuse and point sources of nitrogen in the catchment. Further investigations may help reduce some uncertainty of the sources of specific hot spots if a high level of certainty is needed for catchment management decision making and can be justified. Some options for future investigations are outlined in Section 6 of this report.

Remedial actions targeted towards hot spot legacy sources in the Waingawa industrial area, while they may seem desirable, are likely to have lower benefits than targeting actions towards reducing nitrogen loads that result from current diffuse land use activities across the upper catchment.

Remedial catchment actions could include:

- encouraging landowners to manage treatment of septic tank waste to higher standards;
- investigating options to improve the level of treatment of industrial and agriculture effluent discharges;
- looking for opportunities to reduce fertiliser use and/or application practices that optimise fertilise use and reduce leaching risk;
- optimising stocking rates that align with natural soil leaching risk; and
- exploring opportunities to reduce nitrogen leaching risk from all land use activities in the upper catchment.

Any changes to land use catchment activities in the upper two thirds of the study area are likely to result in a relatively quick response in water quality because the groundwater mean residence time is young (i.e. less than two years).

Contents

1. Introduction

The Parkvale catchment is located between Carterton and Masterton townships on the western lowland plains of the Ruamāhanga Whaitua. The catchment has 200 kilometres of waterways which are hydrologically complex. The streams within the catchment are fed by groundwater springs and from the Taratahi water race network which is diverted from the neighbouring Waingawa River. Wetlands are found along the Carterton fault line which cuts through the middle of the catchment. The catchment contains a mix of agricultural land uses, residential lifestyle blocks, and an industrial park located in the north-eastern area of the catchment.

The Parkvale catchment is a priority catchment in the Greater Wellington Natural Resources Plan (NRP) and within the Ruamāhanga Whaitua Implementation Programme (WIP) due to degraded water quality and ecology of the Parkvale stream. Surface water nitrate-nitrogen levels are monitored at the two State of Environment (SOE) sites in the Parkvale catchment (Figure 1-1). These sites have some of the highest nitrate-nitrogen levels in the region and commonly exceed the National Policy Statement for Freshwater Management 2020 bottom line for nitrate toxicity (MfE 2023).

The Parkvale catchment community would like to understand and pinpoint sources and fluxes of nitrate-nitrogen that are contributing to the Parkvale stream so that appropriate actions can be undertaken to address the sources of nitrate-nitrogen in the catchment.

1.1 Study Objectives

This study has the following objectives based on the co-design process with the catchment community steering group:

1. Collection of groundwater quality data from a selection of springs and groundwater bores within the Parkvale surface and groundwater catchments to provide an assessment of the “state” of the catchment water quality;

2. Use of geochemistry, nitrogen and other isotope tracer tools to identify the likely sources and flows within the surface and groundwater catchments; and

3. Provide Parkvale catchment landowners and the catchment community with base information to enable them to make informed investment decisions for actions to improve water quality and ecology outcomes as required under the NPS-FM and Natural Resources Plan.

1.2 Study area

The Parkvale surface water catchment is located on the lowland plains of the Wairarapa valley and comprises an area of some 8,800 Ha. For the purposes of this study, a wider area beyond the surface water catchment has been used which includes all the Waingawa industrial area (Figure 1-1) due to the natural direction of groundwater flow. The groundwater flow direction at this location is parallel to the northeast of Parkvale catchment and then subsequently flows into the catchment from in and around the industrial area. The wider study area has an area of approximately 12,200 Ha.

The study area also incorporates in part or in whole six groundwater management zones. These are Taratahi (entire zone), Parkvale (most of the zone), Fernhill-Tiffen (about half of the zone) and lesser parts of the Middle Ruamāhanga, Waingawa and Mangatarere groundwater management zones. These zones are primarily used for water quantity management.

Greater Wellington routinely monitor SOE water quality within the study area at four shallow groundwater wells and two surface water sites.

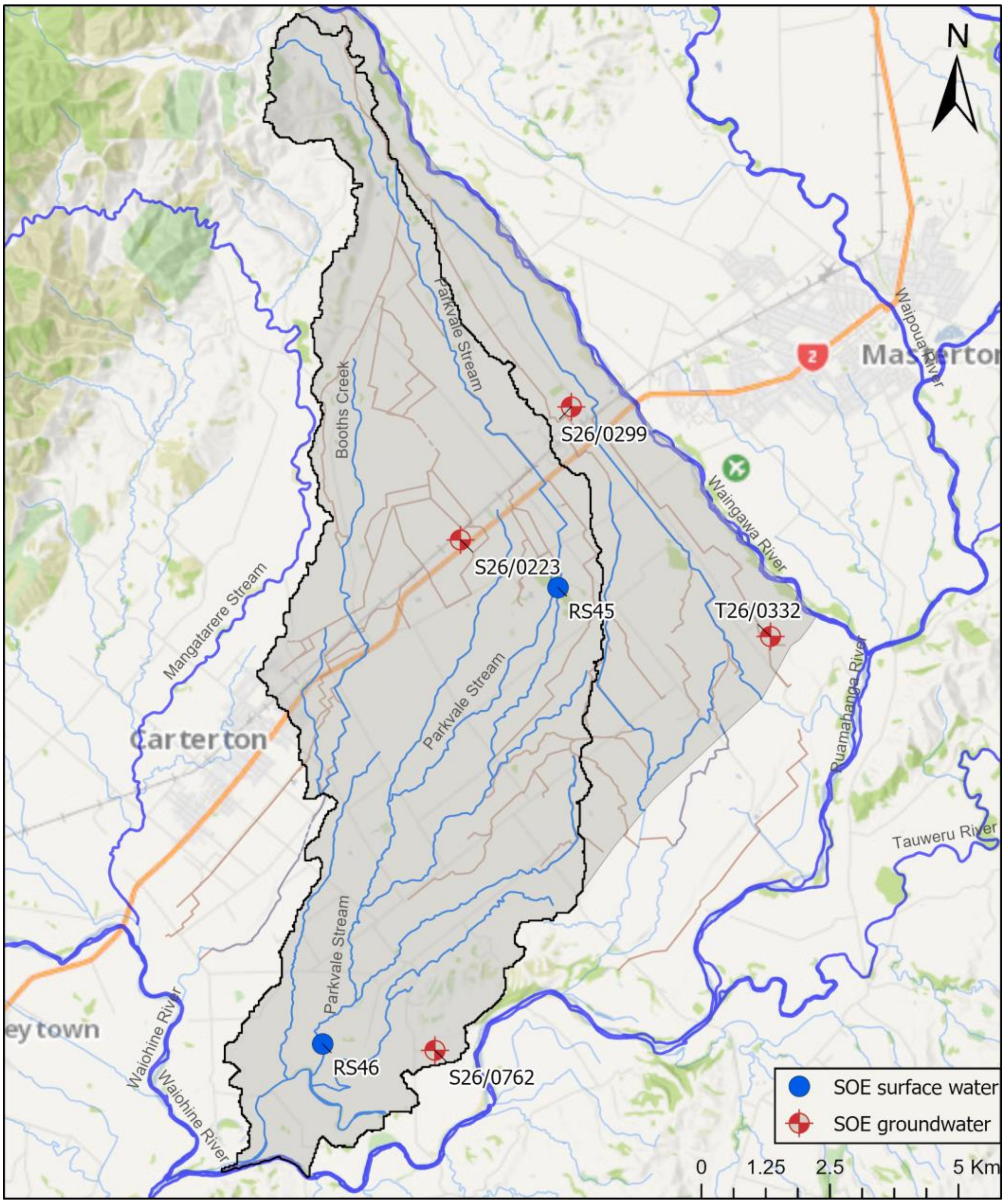

Figure 1-1: Map showing location of the study area (grey shaded area). The thicker black outline shows the Parkvale Freshwater Management Unit (FMU) catchment boundary.

2. Background

2.1 History

Elevated nitrate concentrations have been recorded in the Parkvale catchment and surrounds for the past 40 years (Figure 2-1). Concentrations greater than 100 mg/L have been observed at some groundwater monitoring wells in the area. There are a number of current and historic land uses that may have contributed to the high nitrate in the catchment including; waste disposal at the Affco Freezing Works, smaller meat processing plants, chicken farms, dairy and piggery effluent, domestic septic tanks and fertiliser storage sites. These sources are described in some detail in Baker (2018).

Subsequently, the area has been the focus of targeted studies. Baker (2018) investigated groundwater quality around the Waingawa industrial area seeking to distinguish whether elevated nitrate-nitrogen concentrations in that area and downgradient are a result of historic contamination from the Waingawa Freezing Works waste or a result of more recent or current land use. This investigation concluded that most of the impact was from current practices given that groundwater residence times were short and residual nitrogen in soils from historic discharges was expected to have attenuated by this time. However, a group of Parkvale Catchment Landowners has questioned this conclusion citing the ongoing presence of waste (offal) disposal pits (Parkvale Catchment Landowners 2019).

Baker (2018) also noted high nitrate-nitrogen concentrations of around 40 mg/L downgradient from the effluent disposal area located next to JNL timber mill. These high concentrations were observed in 2014 (The Wastewater Specialists 2017) and have subsequently decreased to where they are currently less than 5 mg/L. This change is due to improvements in effluent treatment lessening the nitrogen load and changes in disposal practices (The Wastewater Specialists 2021).

A newly installed monitoring well (BP34/0224) was found to have very high nitrate-nitrogen concentrations at commencement of monitoring in 2019 (>100 mg/L). The high nitrate-nitrogen concentrations have subsequently decreased and currently fluctuate between 20 and 40 mg/L. Given that the lower and decreasing trend in concentrations observed at the other downgradient wells, it has been suggested that these high nitrate-nitrogen concentrations are not due to the JNL effluent disposal but are likely due to a historic buried offal pit (The Wastewater Specialists 2021).

A surface water quality survey of four sampling rounds was carried out in the Parkvale Catchment in 2020. Elevated concentrations of nitrate-nitrogen up to 13.4 mg/L were observed throughout the mid to lower catchment from this survey. Notably, high nitrate-nitrogen concentrations were observed in streams on the western side of the catchment that are unrelated to land uses in the eastern catchment of the Waingawa industrial area (Figure 2-2).

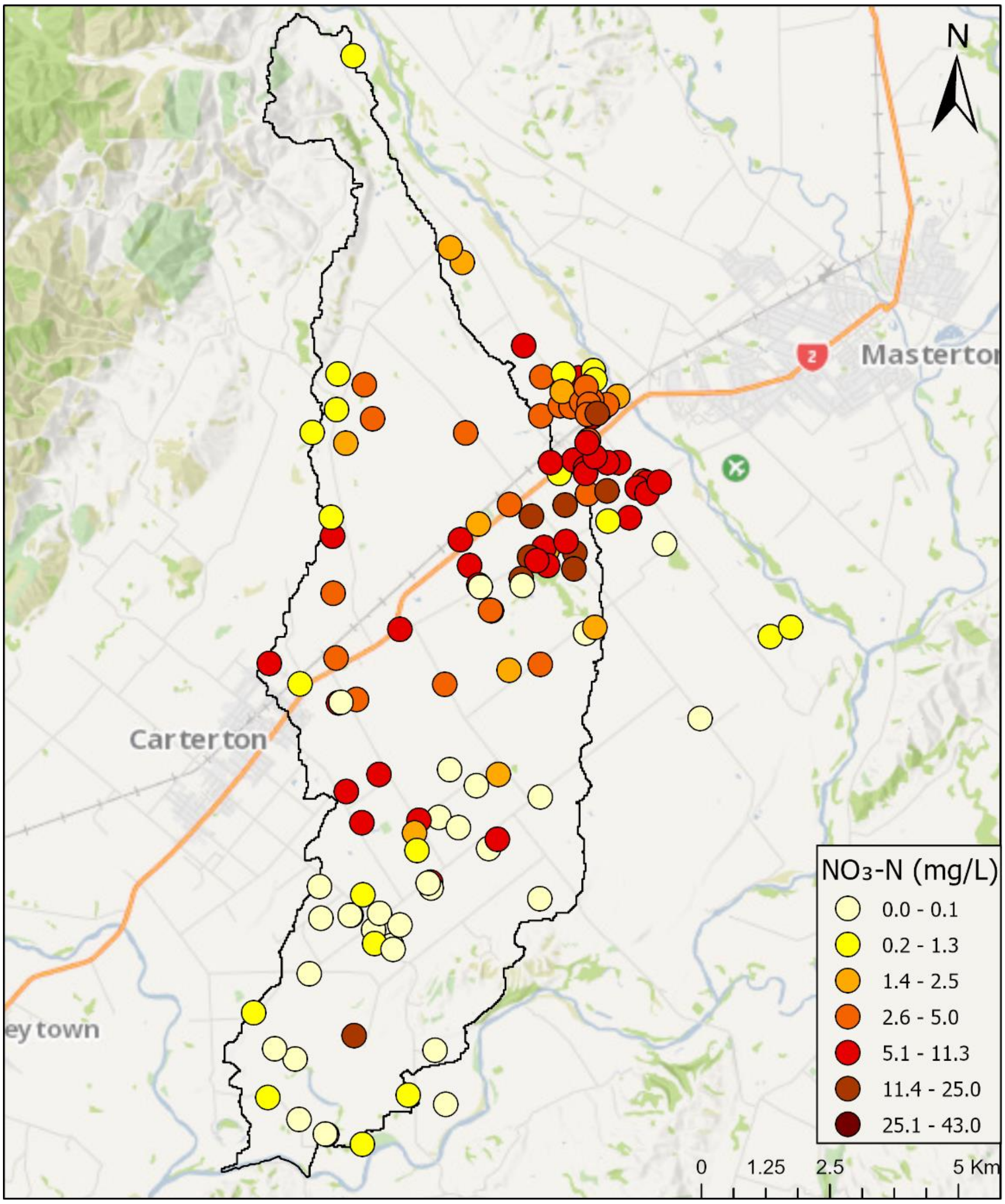

Figure 2-1: Map of historic groundwater nitrate-nitrogen concentrations. The map shows median nitrate-nitrogen concentrations in groundwater wells for the period 1980 – 2022 from data held by Greater Wellington.

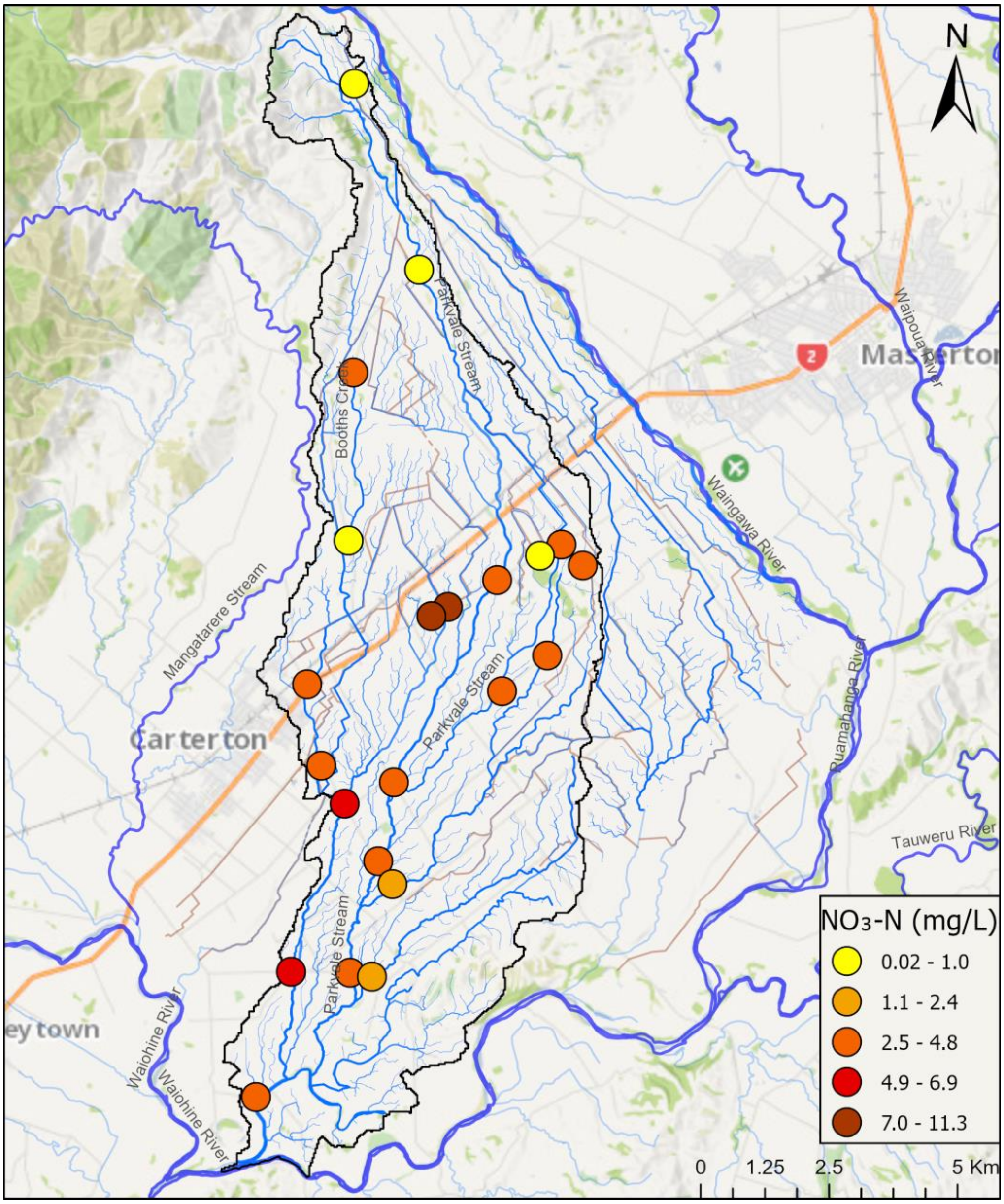

Figure 2-2: Map of surface water nitrate-nitrogen concentrations. The map shows median nitrate-nitrogen concentrations from four sampling rounds taken during 2020.

2.2 Geology and hydrogeology

The geology of the area has been described in some detail previously by Gyopari and McAllister (2010) – a brief overview is provided here.

The study area is dominated by unconsolidated alluvial fan sequences (Q2-Q8), mapped at the surface as last glacial (Q2) deposits (Figure 2-3; Figure 2-4) and becoming progressively older with depth. These fans comprise gravels, sands and silts derived from erosion of the Tararua Range. Two faults cut through the study area, the Masterton Fault and the Carterton Fault. Both faults have formed local partial barriers to groundwater flow because of tilting and deformation (Gyopari and McAllister 2010) resulting in a series of spring-fed wetlands along each fault.

The area to the northwest of the Masterton Fault contains poorly sorted, clay-bound alluvial fan material of low permeability which forms poorly performing aquifers (Figure 2-5; Gyopari and McAllister 2010). Between the Masterton and Carterton faults the fan sequence is dominated by dense, poorly sorted silty-sandy Waingawa fan gravels. Aquifers in these zones range from unconfined to semi-confined with low to moderate transmissivity and hydraulic conductivity, and poor to moderate water yields (Baker 2018).

South of the Carterton Fault the Parkvale sub-basin contains a sequence of productive confined aquifers consisting of thin reworked gravels (Figure 2-6). Swamp and lacustrine deposits (Q5), which outcrop around Tiffen Hill and on the ‘Carterton Surface’ between Parkvale and Carterton (Figure 2-7), form an important aquitard confining the deeper reworked gravel aquifers (Gyopari and McAllister 2010).

In the Fernhill-Tiffen groundwater zone, raised terraces on either side of Tiffen Hill are generally of Q4 age and older and contain inliers of Q5 age interglacial silts and clays. Q4 gravel sequences comprise poorly sorted clay-bound or silty sand gravels with very low transmissivity and hydraulic conductivity resulting in poor water yields (Baker 2018).

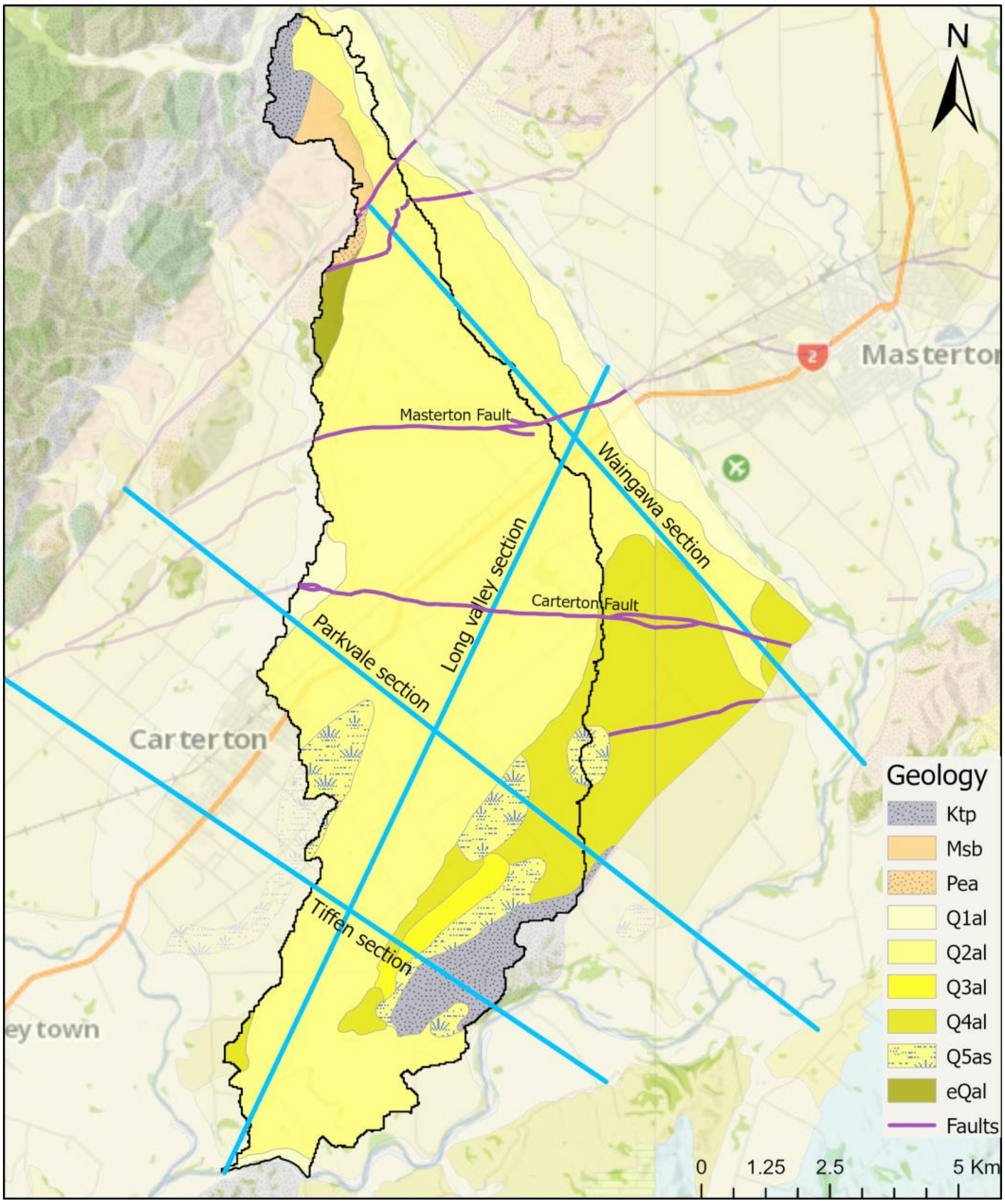

Figure 2-3: Map surface geology within the study area. Geology is from Qmap (Begg and Johnston 2000; Lee and Begg 2002). Cross section lines from Gyopari and McAlister (2010) are shown in blue.

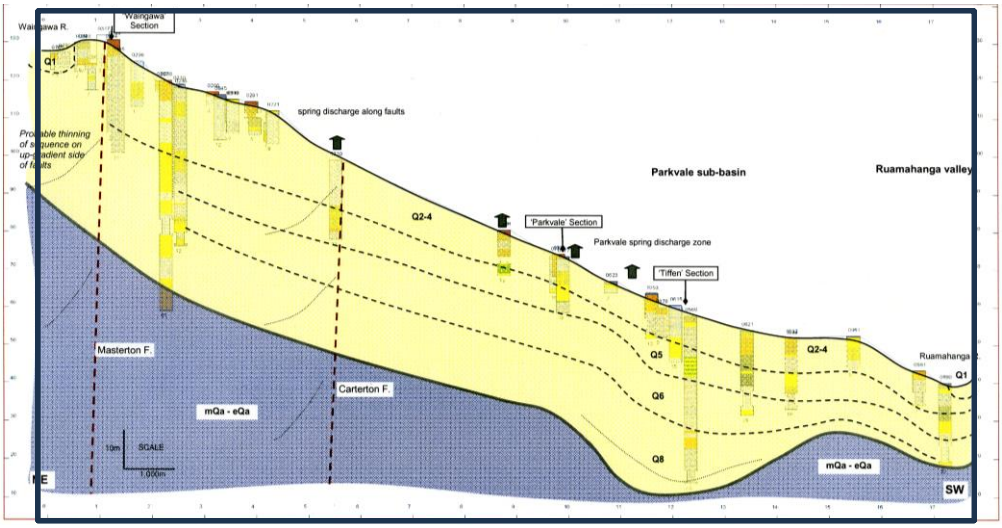

Figure 2-4: 'Long-valley' geological cross-section. The black square shows the approximate section lying within the study area. Reproduced from Gyopari and McAlister 2010.

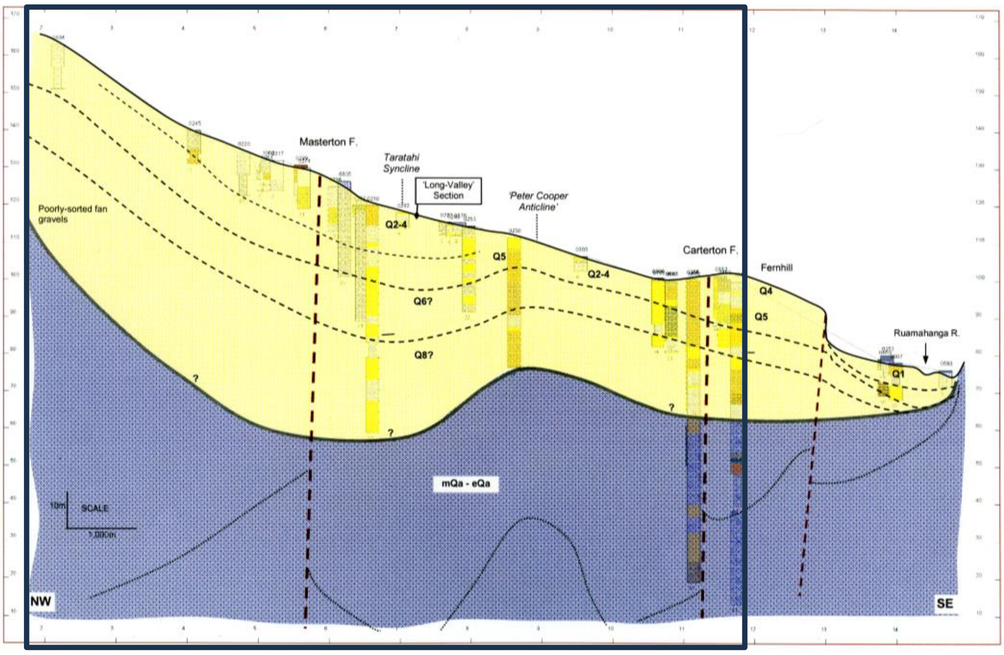

Figure 2-5: 'Waingawa' geological cross-section. The black square shows the approximate section lying within the study area. Reproduced from Gyopari and McAlister 2010.

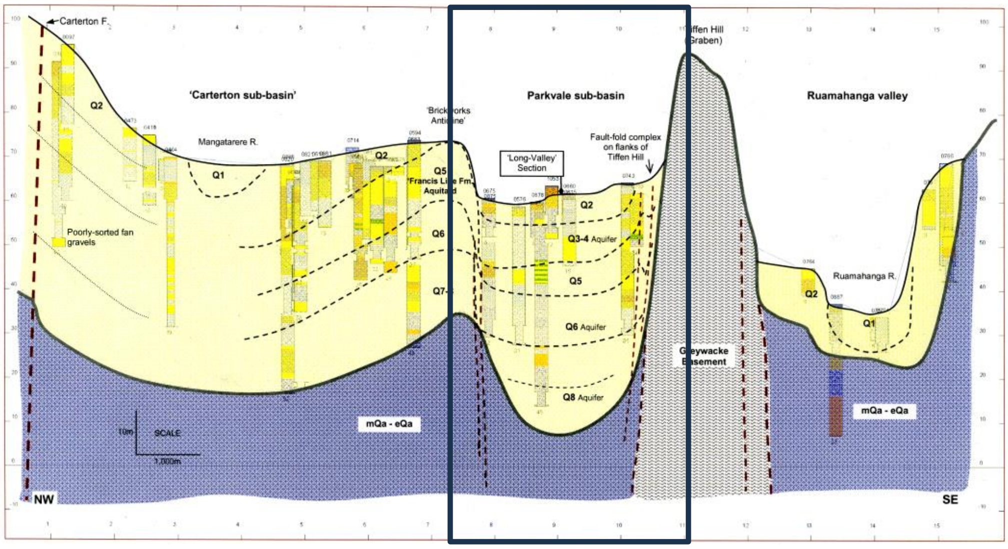

Figure 2-6: ''Tiffen' geological cross-section. The black square shows the approximate section lying within the study area. Reproduced from Gyopari and McAlister 2010.

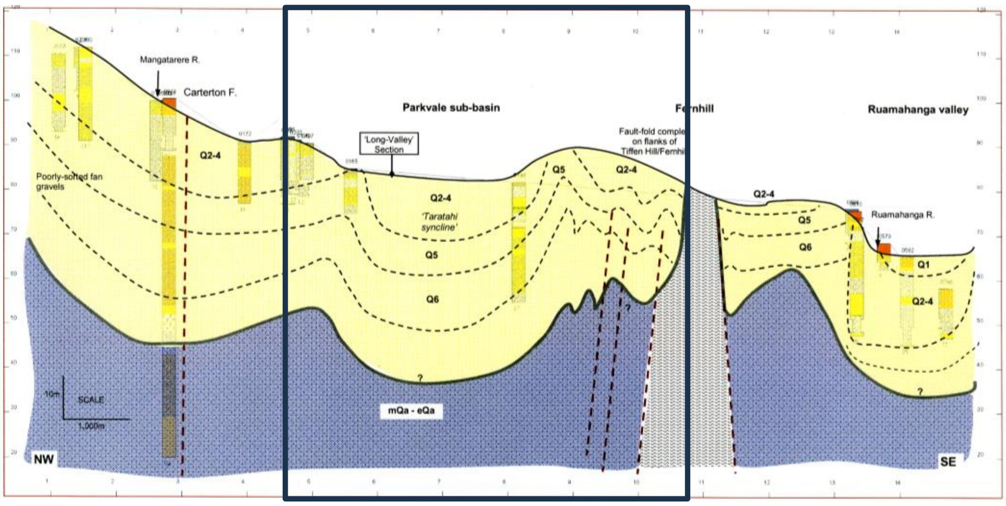

Figure 2-7: 'Parkvale' geological cross-section. The black square shows the approximate section lying within the study area. Reproduced from Gyopari and McAlister 2010.

Groundwater flow direction is from the northern end of the study area southwards – on the western side of the area groundwater flow is in a southwest direction until exiting the study area toward the Mangatarere groundwater zone and Carterton, and the eastern side of the area groundwater flow is parallel to the Waingawa river in a more southeast direction up until near SH2 (Waingawa industrial area) where it begins to flow in more southwest direction into the Parkvale Catchment (Figure 2-8). From there, groundwater flow direction is in a south-westerly direction to the bottom (south) of the Parkvale Catchment.

Shallow groundwater in the Taratahi shallow aquifer is predominantly recharged via losses from the Waingawa River (Baker, 2018). Additional recharge from rainfall has been estimated to be 900 mm/year at the top of the study area beneath the foothills, reducing dramatically to 300 mm/year at SH2 and even lower to less than 200mm/year at the bottom of the Parkvale catchment (Baker 2018; Gyopari and McAlister 2010).

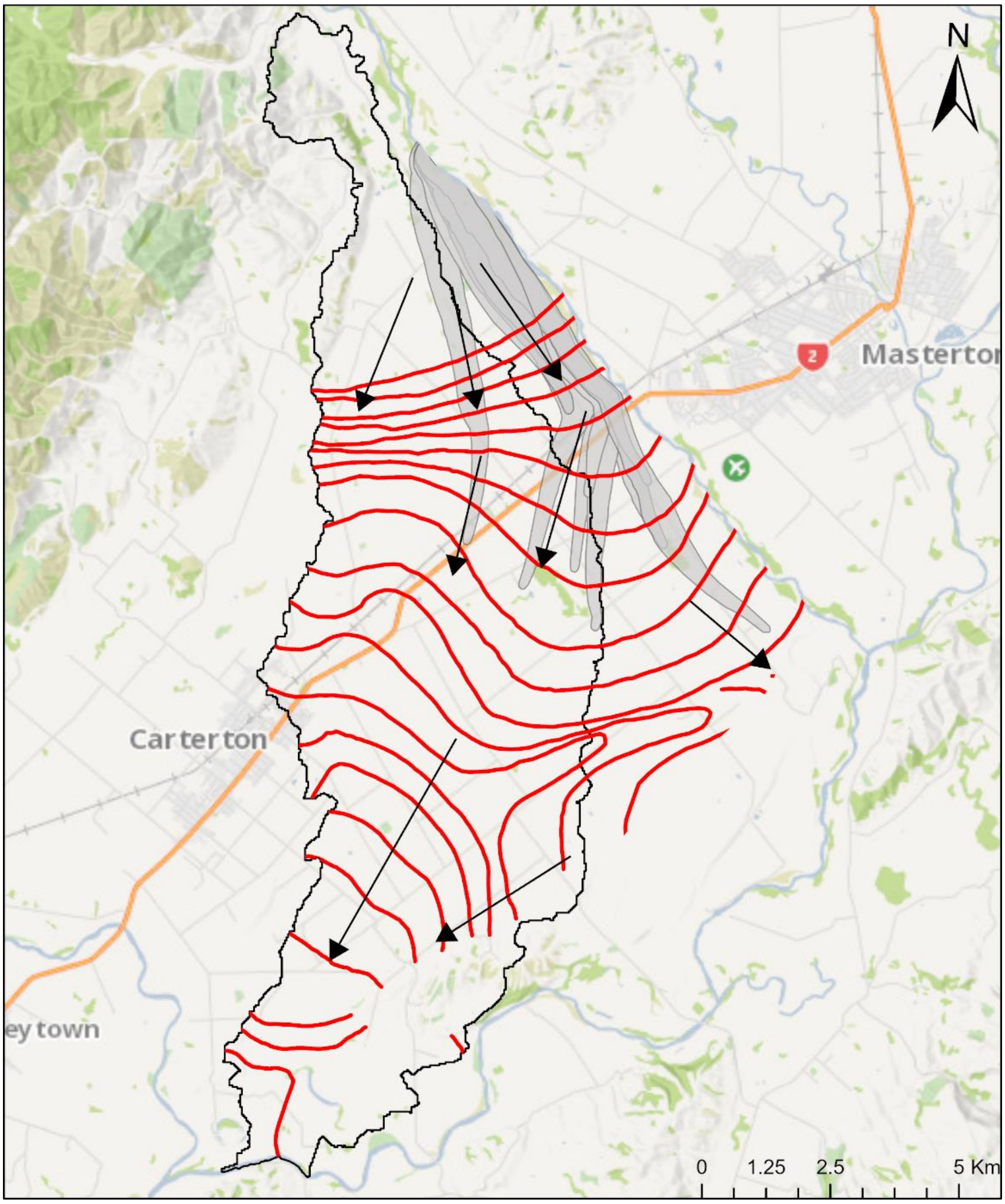

Figure 2-8: Map of shallow groundwater piezometric contours (in red) and generalised groundwater flow direction (black arrows). Shaded areas are modelled capture zones for specific wells (Toews and Donath 2015; Baker 2018). Flow directions are based on the contours shown and other information including additional groundwater piezometric data and flow modelling.

2.3 Surface water

The study area has a complex network of interlinked streams and water races. The area is bounded to the north-east by the Waingawa River, which is the main source of recharge to the aquifer system (Baker 2018). Within the study area flow two main streams; Parkvale Stream and Booths Creek, along with many spring-fed small streams flowing to the southwest. The Taratahi water race is a gravity-fed unlined channel constructed in the early 20th century and is supplied by water diverted from the Waingawa River to supply water for stock, minor irrigation and domestic uses. Carterton District Council (CDC) currently manages flows in the water race and the distribution of water to stakeholders (Gyopari and McAlister 2010). The water race network is distributed into numerous channels which flow in a south to south-easterly direction over the Taratahi, Waingawa and Parkvale areas. Many of the water race channels merge with natural water courses and the Parkvale spring system and eventual discharge to the Ruamāhanga River at various points (Gyopari & McAlister 2010).

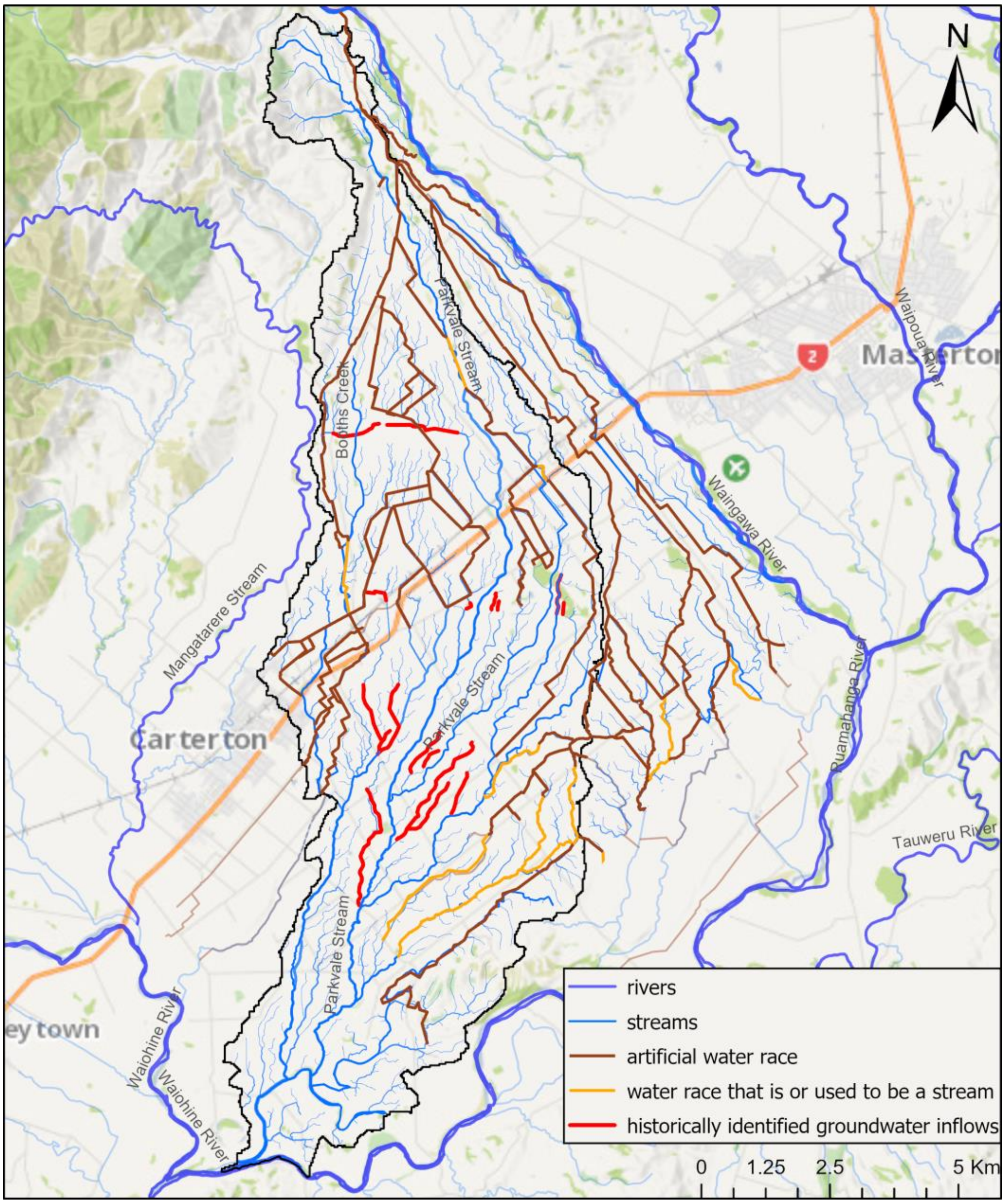

Figure 2-9: Map of surface water features within the study area.

2.4 Soils

S-map is the New Zealand national soils database (Manaaki Whenua 2019) and presents soil property data such as depth, stoniness, and clay content along with modelled properties such as nitrogen leaching susceptibility.

A variety of soil types are found within the study area (Manaaki Whenua 2019; Figure 2-10). Important properties of soil types in the study area which are relevant to the movement of nitrate into groundwater are soil drainage properties, and the susceptibility of the soils to nitrate leaching and bypass flow.

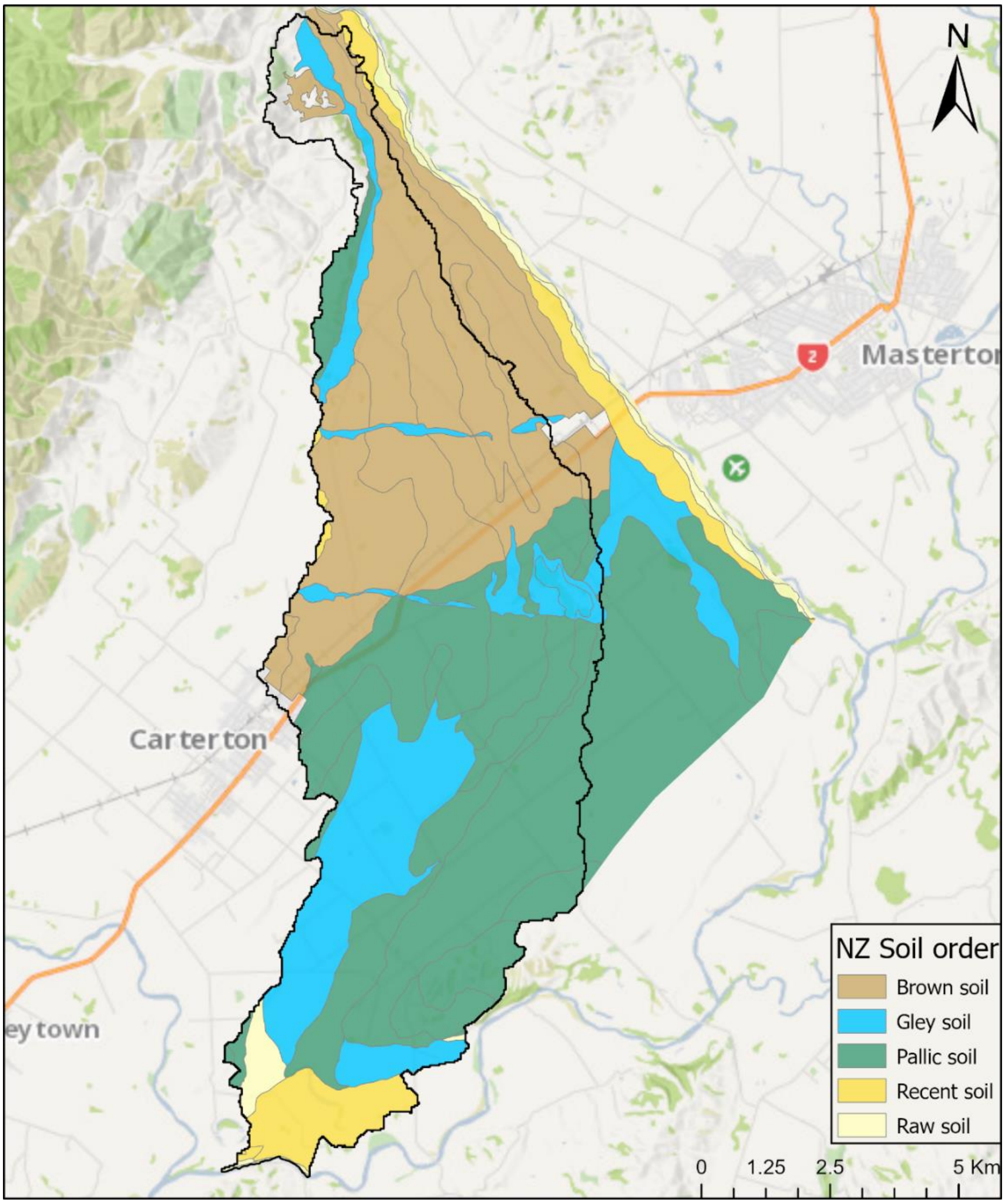

Figure 2-10: Map of NZ soil order types within the study area. Soil data from S-Map (Manaaki Whenua 2019).

There are three predominant soil types within the study area:

- Brown soils dominate the upper (northern) half of the catchment (Figure 2-10). These are mainly yellow-brown shallow silt loams on a gravel substrate (Baker 2018). These soils are generally well drained with a very high vulnerability to nitrogen leaching (Manaaki Whenua 2019).

- Pallic soils dominate the lower half of the study area. These are yellow grey silty loam moderately stony shallow soils that are characteristic of a seasonally dry area (Baker 2018). The soils vary from moderate to poorly drained and generally have a low vulnerability to nitrogen leaching in the study area.

- Gley soils make up the third most common group of soils. These soils are poorly drained organic rich silt loam over clay soils, occurring to a moderate to deep depth (Baker 2018). Poorly drained soils are commonly depleted in oxygen and reducing conditions are therefore likely to be present. The susceptibility to nitrogen leaching is low to very low.

2.4.1 Soil drainage capability

Figure 2-11 shows the dominant soil drainage classes in the study area. In general, soils in the upper half of the catchment are well-drained, those in the middle of the catchment are moderately drained, and in the lower catchment are poorly drained.

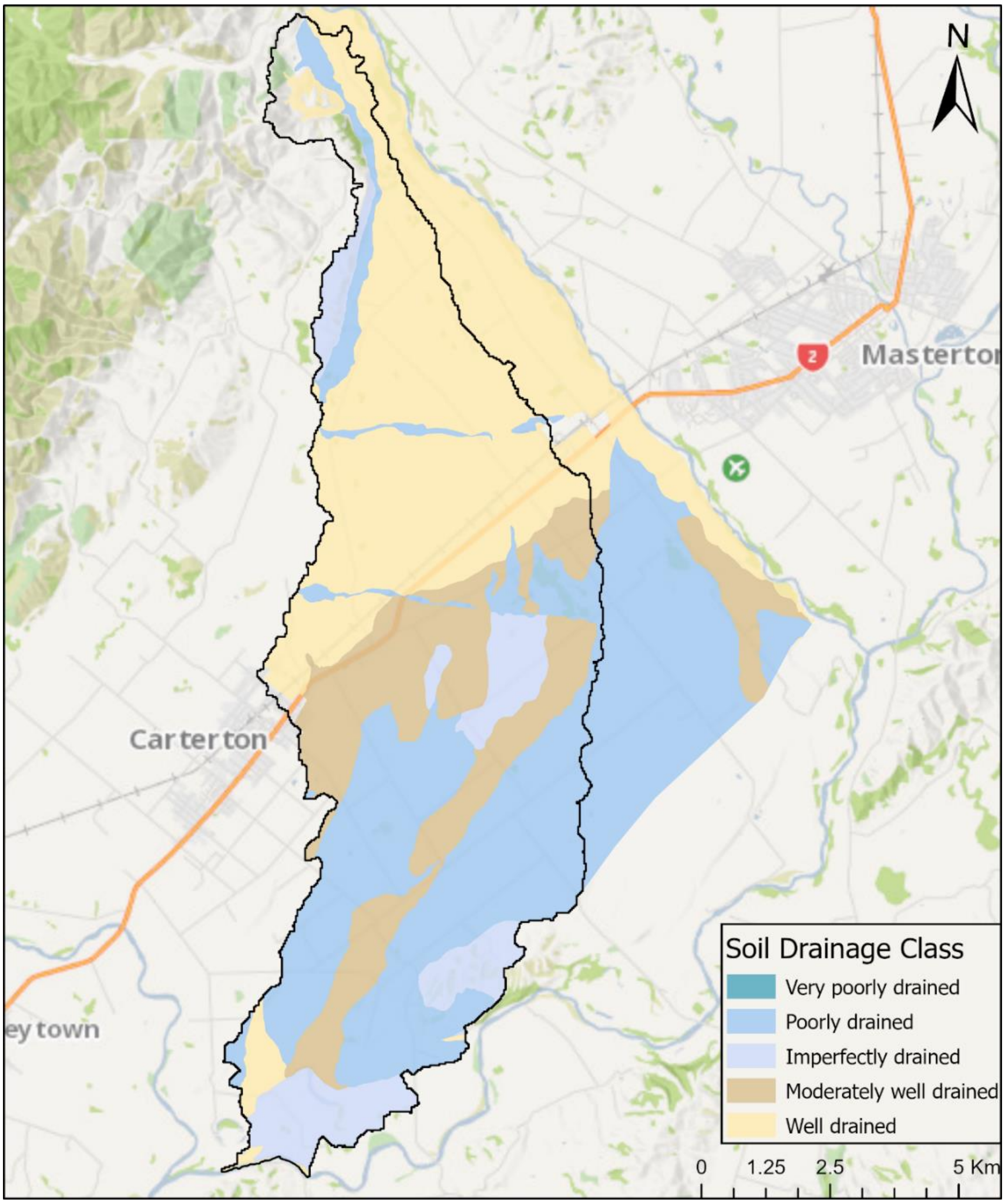

Figure 2-11: Map of S-Map soil drainage class. Where there is more than one dominant class the least draining (worst) drainage class is shown (Manaaki Whenua 2019).

2.4.2 Nitrogen leaching susceptibility

Nitrogen leaching is the process in which nitrogen containing molecules, particularly nitrate, are not retained in the soil matrix and move downwards below the root zone to groundwater. The S-map susceptibility rating is based on the water storage capacity of the soil and nitrogen attenuation associated with anaerobic conditions. It does not account for climate or land use.

Soils with very high to high susceptibility to nitrogen leaching dominate the top half of the catchment where soils are shallow and stony and lie above gravel (e.g., fans, gravel-rich river deposits). These areas are sensitive to land use intensification that increases nitrogen loading to the soil. Soils with low to very low susceptibility to nitrogen leaching dominate the lower half of the catchment, occurring on deep to moderately deep soils with low drainage capability.

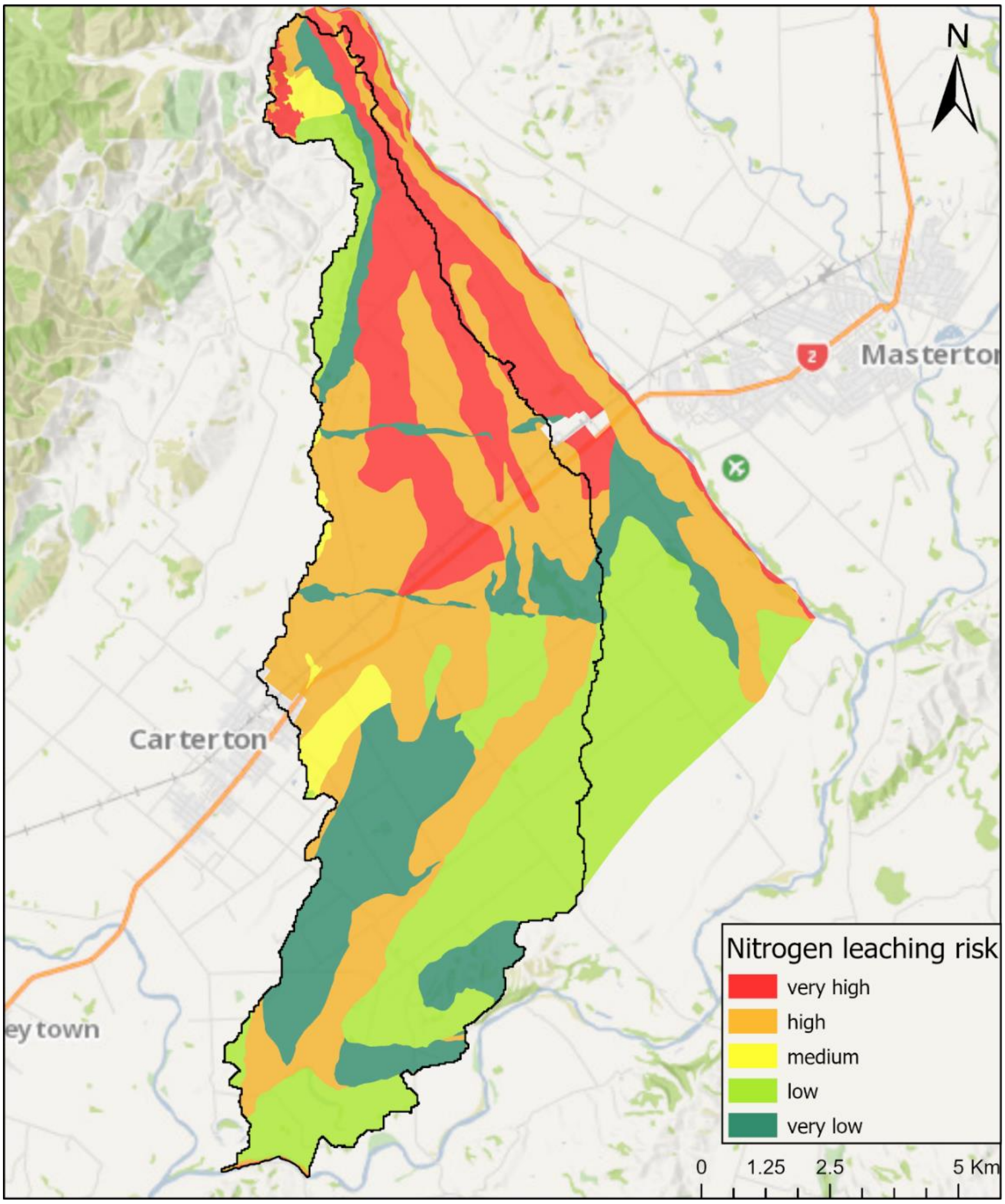

Figure 2-12: Map of S-Map nitrate leaching susceptibility (Manaaki Whenua 2019).

2.4.3 Bypass flow vulnerability

Soils generally have a fine pore network which make them suitable media to filter and 'consume' microbial and chemical contaminants (McDowell et al. 2008, Pang 2009). However, some soils can have preferential pathways such as cracks, fissures, and macropores, which are larger openings in soil that are mainly formed from earthworm burrows and root traces. These pathways create an easier flow path for water so that the natural filtering process provided by soils is bypassed.

Even relatively immobile compounds may be transported through the soil to groundwater by bypass flow. The highest risk occurs soon after the application of chemicals or effluent. Subsurface drains (e.g., tile drains) can increase the bypass flow and promote rapid transport of contaminants to drains and streams (Webb, Lilburne and Eger 2018). S-Map has developed a bypass flow susceptibility rating based on soil classification, soil structure and attributes that promote ponding of water. The S-Map bypass flow rating for the study area is presented in Figure 2-13.

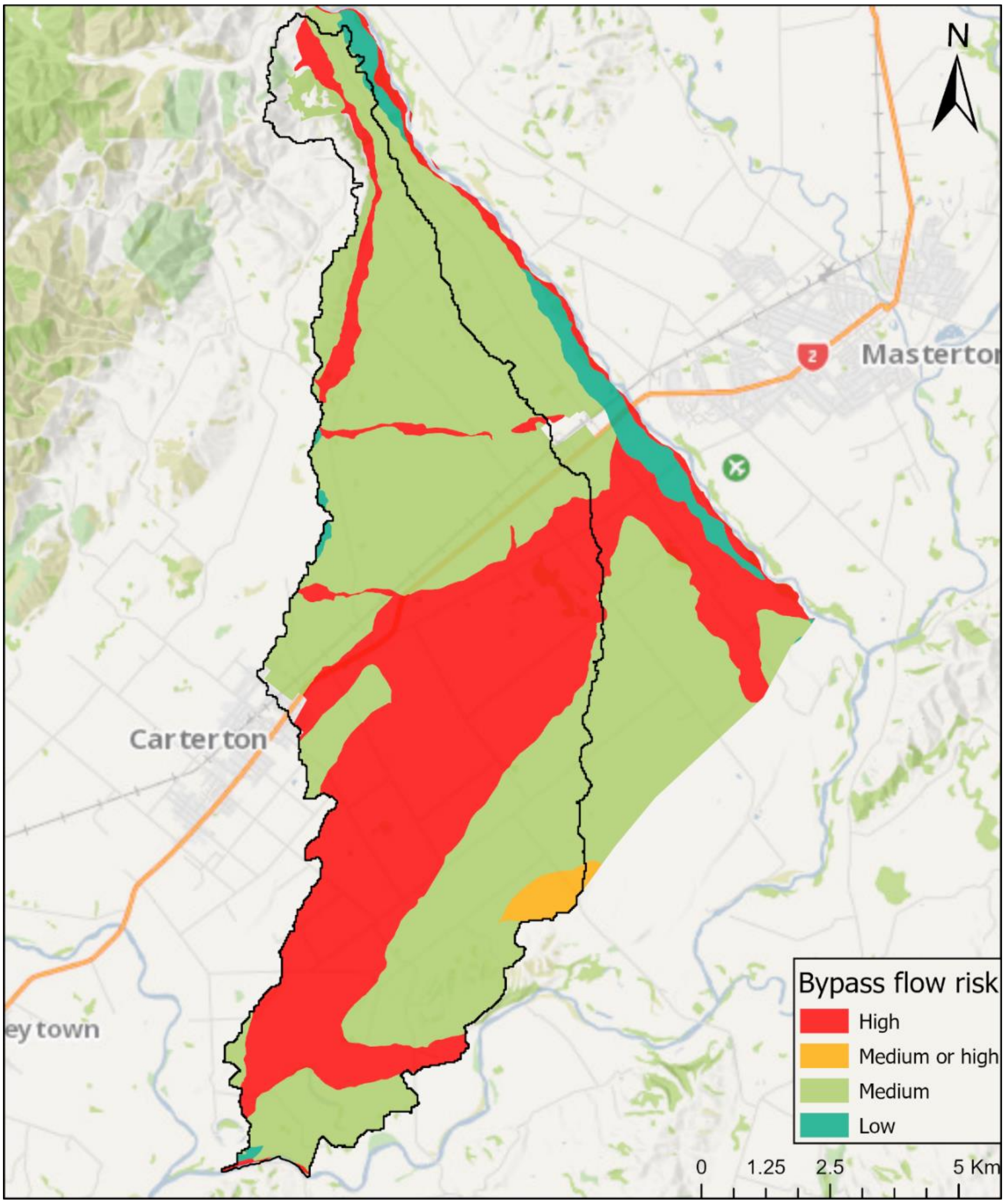

Figure 2-13: Map of S-Map bypass flow (Manaaki Whenua 2019).

2.1 Land use

There are a variety of land uses across the study area (Figure 2-14) (Agribase 2022). Dairying comprises 30% of the catchment area and is prevalent in the southern (lower) end of the catchment. Other livestock (sheep, beef and mixed sheep and beef) comprise 39% of the total area. Lifestyle blocks account for 9%

of the area and are prevalent at the northern (top) end of the catchment. Industrial land uses are centred around the Waingawa industrial area in the east of the study area and to a lesser extent to the west of the study area near Carterton.

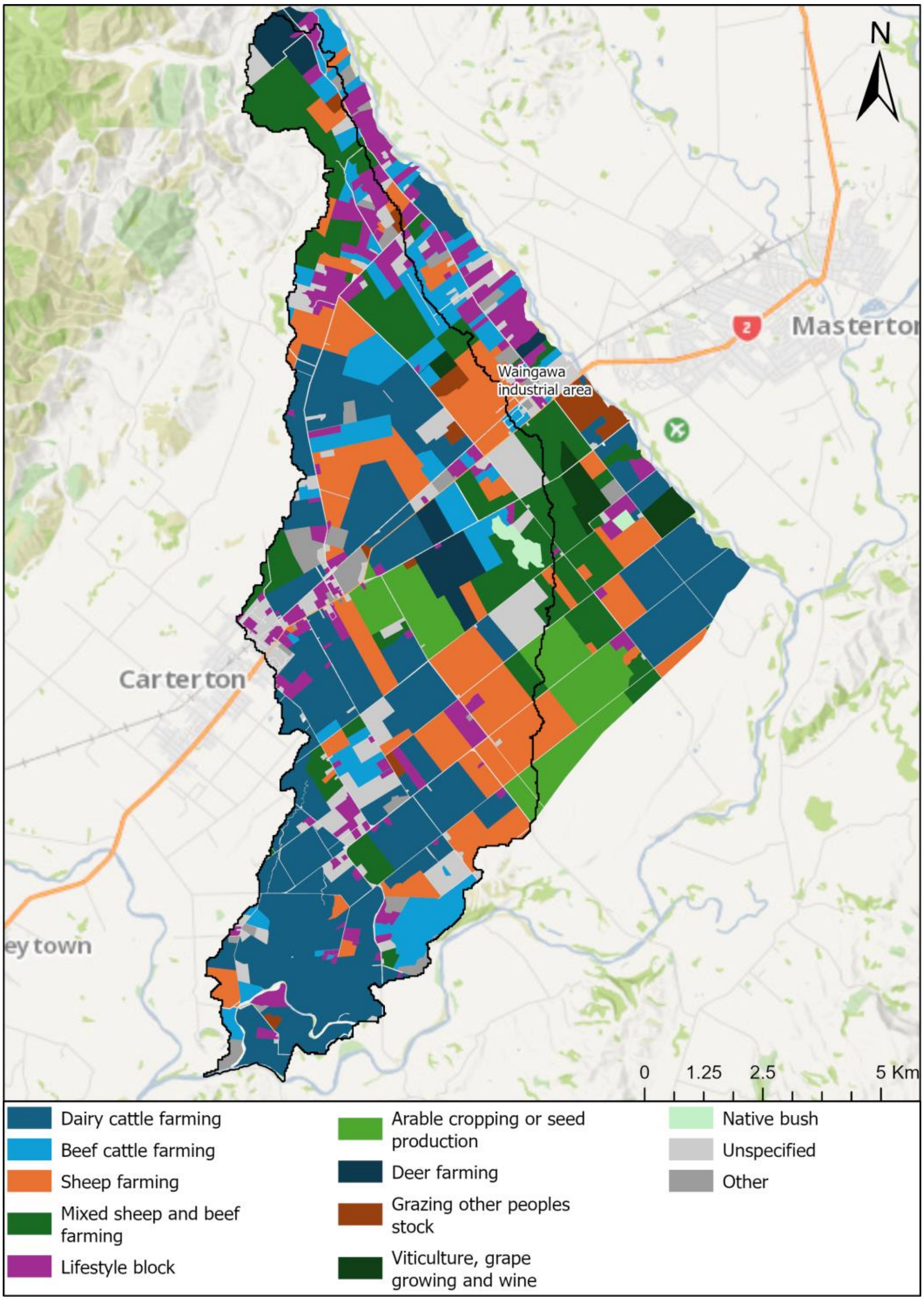

Figure 2-14: Map of land use within the study are. Data from the Agribase database (Agribase 2022).

3. Methods

3.1 Groundwater Sampling Site Selection

The Greater Wellington wells database was used to identify sampling sites from mainly shallow (<12 m) groundwater wells spread spatially across the study area (Figure 3-1). At this depth the wells are generally screened within the shallow unconfined aquifer, which will be most affected by land use and most likely to contribute to surface water flows. Where practical, groundwater wells which had been previously sampled for nitrate-nitrogen were selected. Twenty-six wells were selected in total, although not all wells were sampled during each sampling round. Site details are presented in Appendix 1.

Seven groundwater-fed "springs" were also included in the sampling survey. These springs were selected using previous work carried out by Greater Wellington to identify groundwater inflows to the Parkvale surface water network (Figure 2-9; Gyopari and McAlister 2010). The spring sites included were from outflows from groundwater-fed wetlands located mainly along the fault lines, as well as outflows from tile drains draining shallow groundwater.

Data from four SOE groundwater quality sites (Figure 1-1) were incorporated into the survey.

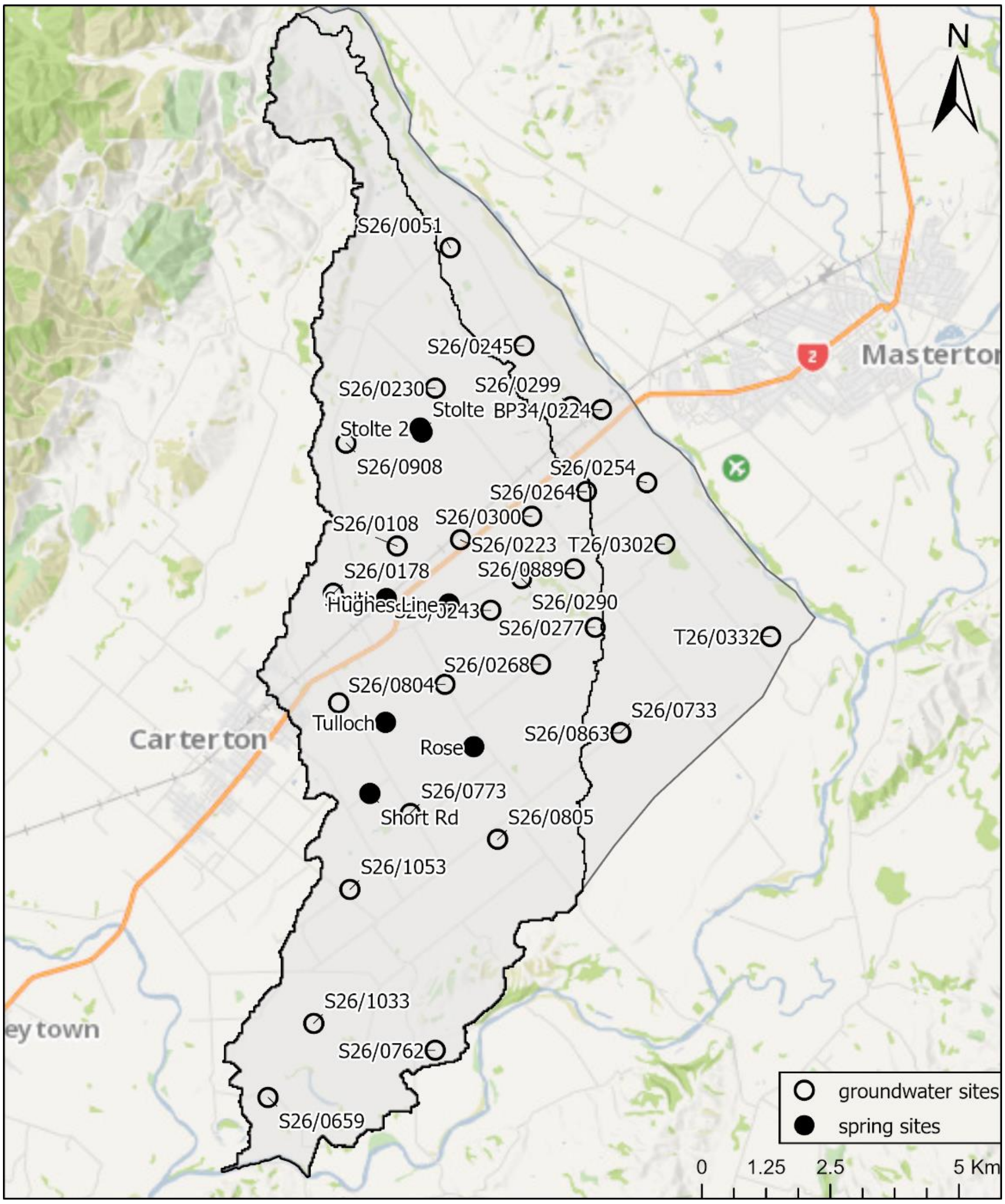

Figure 3-1: Map of site locations

3.2 Water chemistry sampling

A suite of groundwater quality monitoring parameters was selected for the study (Table 3-1). Not all parameters were collected at both groundwater and surface water spring sites, e.g., dissolved iron and manganese were not collected at the spring sites as these, if present, commonly precipitate out on contact with the atmosphere. All parameters (excluding field parameters) were sent to Hill Laboratories for analysis.

Four sampling rounds of groundwater and spring chemistry were collected to provide statistical rigour and account for seasonal variability in results. Sampling periods were May-June 2023, August-September 2023, November-December 2023 and February-March 2024.

Table 3-1: Analytical parameter suite

Parameter		Units	Field/Laboratory	Detection limit
Ammoniacal-nitrogen	NH_4-N	mg/L	Hill Laboratories	0.01 mg/L
Bicarbonate	HCO_3	mg/L	Hill Laboratories	1 mg/L
Conductivity – field	Cond_F	µS/cm	Field	
Conductivity - Lab	Cond_L	mS/m	Hill Laboratories	0.1 mS/m
Dissolved Boron (wells only)	B	mg/L	Hill Laboratories	0.005 mg/L
Dissolved Calcium	Ca	mg/L	Hill Laboratories	0.05 mg/L
Dissolved Chloride	Cl	mg/L	Hill Laboratories	0.5 mg/L
Dissolved iron (wells only)	Fe	mg/L	Hill Laboratories	0.02 mg/L
Dissolved Magnesium	Mg	mg/L	Hill Laboratories	0.02 mg/L
Dissolved manganese (wells	Mn	mg/L	Hill Laboratories	0.0005 mg/L
Dissolved oxygen (mg/L)	DO	mg/L	Field	
Dissolved Potassium	K	mg/L	Hill Laboratories	0.05 mg/L
Dissolved reactive	DRP	mg/L	Hill Laboratories	0.004 mg/L
Dissolved Sodium	Na	mg/L	Hill Laboratories	0.02 mg/L
Escherichia Coli	*E. Coli*	cfu/100mL	Hill Laboratories	1 cfu/100mL
Nitrate-nitrogen	NO_3-N	mg/L	Hill Laboratories	0.001 mg/L
Nitrite-nitrogen	NO_2-N	mg/L	Hill Laboratories	0.002 mg/L
Oxidation-reduction potential	ORP	mV	Field	
pH - field	pH_F	pH units	Field	
pH - Lab	pH_L	pH units	Hill Laboratories	0.1 pH units
Sulphate	SO_4	mg/L	Hill Laboratories	0.5 mg/L
Temperature	T	°C	Field	
Total Kjeldahl nitrogen (TKN)	TKN	mg/L	Hill Laboratories	0.1 mg/L
Total nitrogen (springs only)	TN	mg/L	Hill Laboratories	
Total phosphorus (springs	TP	mg/L	Hill Laboratories	0.002 mg/L

3.3 QA/QC sample collection

Field meters used in the study were calibrated daily by field staff. Samples were collected as close as practicable to NEMS standards (NEMS 2019), due to most sites in the study being privately owned and having well head configurations which do not always allow for strict adherence to NEMs standards.

No QA/QC samples (i.e. field duplicate and field blank) were collected as part of this field campaign given the limited scope and budget available.

3.4 Isotope sampling

Additional samples for nitrate isotopes, radon and tritium were collected at selected springs and wells during the May 2023 sampling round. Dissolved gas data were collected from ten wells during February 2024 sampling round to help characterise nitrogen dynamics. These additional samples were analysed at GNS Science isotope laboratories in Wellington.

Tritium samples were collected from eight wells and three spring sites. Radon samples were collected from the seven spring sites. Tritium was measured by electrolytic enrichment and liquid scintillation counting method (Morgenstern and Taylor 2009). The detection limit is approximately 0.025 tritium units (1 TU is a $^{3}H/^{1}H$ ratio of $1{:}1\times10^{18}$). Radon was measured by liquid scintillation counting (Martindale et al. 2016). The detection limit is 0.1 Bq/L.

Nitrate samples for isotopic analysis were preserved in the field by acidification. $\delta^{18}O$ and $\delta^{15}N$ of dissolved nitrate are measured using a modified method following McIlvin and Altabet (2005). The analytical precision for these measurements is 0.3‰.

Nitrate isotope results are reported as δ values with respect to standards AIR for $\delta^{15}N$ and VSMOW for $\delta^{18}O$; for example, for δ^{15N} (Equation 1):

$$\delta^{15}\mathrm{N}_{\mathrm{AIR}}\,(\text{‰}) = \left[\frac{{}^{15}\mathrm{N}/{}^{14}\mathrm{N}_{\mathrm{sample}}}{{}^{15}\mathrm{N}/{}^{14}\mathrm{N}_{\mathrm{AIR}}} - 1\right] \times 1000 \tag{1}$$

Dissolved gases (Ar, Ne, N_2) were measured at GNS Science by gas chromatography (Coble et al. 2024).

3.5 Hierarchical cluster analysis

An analysis of major ions was undertaken using hierarchical cluster (HCA) analysis to look for relationships between groundwater quality at different sites and to discern changes in composition resulting from hydrochemical processes occurring in the soil and groundwater systems.

Sites have been assigned into groups of similar hydrochemistry by HCA. The HCA analysis used log-transformed and normalised site-specific median concentrations of the major ions calcium, magnesium, sodium, potassium, bicarbonate, chloride and sulphate. Ward's Linkage method and the square of Euclidian distance were used as the measure of similarity. For a full description of the HCA technique and more in-depth analysis of groundwater chemistry in the Wairarapa see Daughney et al. 2009.

3.6 Redox state

The redox state of groundwater influences the attenuation of nitrate. Water high in dissolved oxygen is considered 'oxic' whereas water with no or low levels of dissolved oxygen is 'anoxic'. After entering the aquifer, dissolved oxygen in recharge waters is depleted by the oxidation of organic matter. Typically, anoxic water is higher in dissolved manganese and iron, and low nitrate due to the reduction of nitrate to other forms of nitrogen. The reduction of nitrate in anoxic waters is known as denitrification, which is a microbially mediated natural process in which dissolved nitrate is eventually reduced to nitrogen gas (Equation 2).

$$NO_3^- \rightarrow NO_2^- \rightarrow NO_{(g)} \rightarrow N_2O_{(g)} \rightarrow N_{2(g)} \qquad (2)$$

In groundwater, denitrification is the first redox reaction to occur after oxygen has been depleted (as described below), thus most anoxic waters have little to no nitrate present.

Once oxygen is depleted other redox processes can occur. A series of reactions controlled by the most favourable terminal electron-accepting process (TEAP) takes place. The order of these processes is $O_2 > NO_3^- > Mn(IV) > Fe(III) > SO_4^{2-}$ > methanogenesis. The redox state is a categorisation of where along this series of processes a water sample lies.

In this study the redox state of water at each site was identified using the procedure from McMahon and Chapelle (2008). This procedure uses the measured concentrations of dissolved oxygen, nitrate, dissolved manganese, dissolved iron and sulphate with thresholds for each parameter based on concentrations typically found for redox environments across a range of studies (Wilson et al. 2016). The default criteria were used as localised parameters have not been developed for this catchment.

3.7 Trend analysis

Long term trends and seasonality have been assessed for time series monitoring data for the period 2004 to 2024. Seasonality was assessed using the Kruskal Wallis test (Helsel et al. 2020), which determined the type of test subsequently used for the trend analysis step (Seasonal or Non-Seasonal). Trend direction was calculated using the Mann-Kendall (or seasonal Mann-Kendall) test, which is typically used for the non-parametric nature of environmental data sets (Helsel et al. 2020). Trend analysis statistics and trend magnitudes (Sen slope) are presented in Appendix 3.

Confidence in trend direction follows the guidelines set out in Snelder et al. (2021) (Table 3-2).

Table 3-2: Trend categories following Snelder et al. 2021

Trend categories	Trend direction	Confidence
Highly Likely decreasing	Decreasing	0.95-1.0
Very likely decreasing	Decreasing	0.90-0.95
Likely decreasing	Decreasing	0.67-0.90
As likely as not	Increasing or decreasing	0.50-0.67
Likely increasing	Increasing	0.67-0.90
Very likely increasing	Increasing	0.90-0.95
Highly likely increasing	Increasing	0.95-1.0

3.8 Nitrate isotope interpretation

Nitrate isotope data has been used to discriminate the sources of nitrogen in the catchment. Sources of nitrate in the environment can have a wide range of isotopic ($\delta^{18}O$ and $\delta^{15}N$) compositions, which enables the identification of different sources. However, often there may be overlap of isotopic signals from different nitrate sources and, in these cases, differentiation between sources depends on local knowledge of the range of potential sources, as well as knowledge of the possible flow paths relative to the sample site.

Synthetically produced fertilisers such as urea typically have $\delta^{15}N$ ranging from -4 to +4 ‰ (Kendall 1998). $\delta^{18}O$ values vary depending on the type of fertiliser. Synthetic nitrate fertilisers have $\delta^{18}O$ close to that of the air from which they are derived and are typically around +22‰ ± 3‰ (Kendall 1998; Mayer et al. 2001). Nitrate derived from ammonia and urea-based fertilisers will have less positive $\delta^{18}O$ values, reflective of the reaction pathways leading to the formation of nitrate following fertiliser application.

Both the $\delta^{18}O$ and $\delta^{15}N$ of residual nitrate become more positive as nitrate concentrations decrease due to denitrification, leading to a characteristic geochemical signature. Similarly, wastewater, animal manure and effluent generally have more positive $\delta^{18}O$ and $\delta^{15}N$ values due to volatilisation of ammonia prior to conversion to nitrate. Denitrification can be distinguished from effluent as denitrified samples will have lower nitrate-nitrogen concentrations and higher $\delta^{15}N$ and $\delta^{18}O$ values, while effluent samples have higher nitrate-nitrogen concentrations and less enrichment of ^{15}N and ^{18}O (Rogers et al. 2024).

3.9 Groundwater age

Tritium data have been used to identify the age of groundwater and base flow groundwater sources of the Parkvale stream.

River waters and groundwater outflows such as wells and springs are comprised of a mixture of water with different residence times in the aquifer due to mixing of water from different length underground flow paths. Therefore, the water doesn’t have a discrete age but rather a distribution of ages. The mean residence time (MRTs) can be derived from tritium concentrations using models such as the exponential piston flow model (EPM) (Małoszewski and Zuber 1982).

Groundwater MRTs have been calculated using an EPM matched to the tritium concentrations. The residence time distribution parameter for all sites has been set at 70% exponential mixed flow, a value that experience has shown to be reasonably representative for gravel aquifers.

3.10 Dissolved gas interpretation

All groundwaters contain dissolved gases derived from the atmosphere during recharge, including nitrogen (N_2) and rare noble gases e.g., argon (Ar). These dissolved gas data were collected from wells during the February 2024 sampling round to help characterise nitrogen dynamics in areas of the catchment where high nitrate loadings are being attenuated by denitrification. Gas samples can only be collected from wells as springs sites are exposed to atmosphere.

Anoxic groundwater has geochemical conditions under which denitrification can occur, but redox status alone does not indicate whether significant denitrification has actually occurred (Langmuir 1997). For example, many anoxic groundwater zones can be, in effect, stagnant or very slow moving (Morgenstern et al. 2014), and thus the potential for denitrification may have little effect on reducing nitrogen loads because nitrate-bearing water is not flowing through these zones.

In addition to dissolved atmospheric N_2, groundwaters may contain 'excess' N_2 that has resulted from denitrification of nitrate. The component of dissolved N_2 that originates from the atmosphere can be established by the measurement of two or more atmospherically derived dissolved noble gases, often Ar and Ne. This enables the differentiation of excess N_2 produced via denitrification from atmospherically derived dissolved N_2 and can directly quantify the amount of denitrification that has occurred in an aquifer (Martindale et al. 2019; Stenger et al. 2013; Wilson 1990).

4. Results

4.1 General chemistry

Water chemistry results for all sampling rounds, along with site-specific median values for each parameter are presented in Appendix 2.

HCA analysis reveals five clusters of sites which have waters of similar composition (Figure 4-1). These groupings reflect recharge sources (river vs rain), land use, aquifer geology, location and the length of time the water has been underground. The range of concentrations for each cluster grouping are shown using box and whisker plots in Figure 4-2.

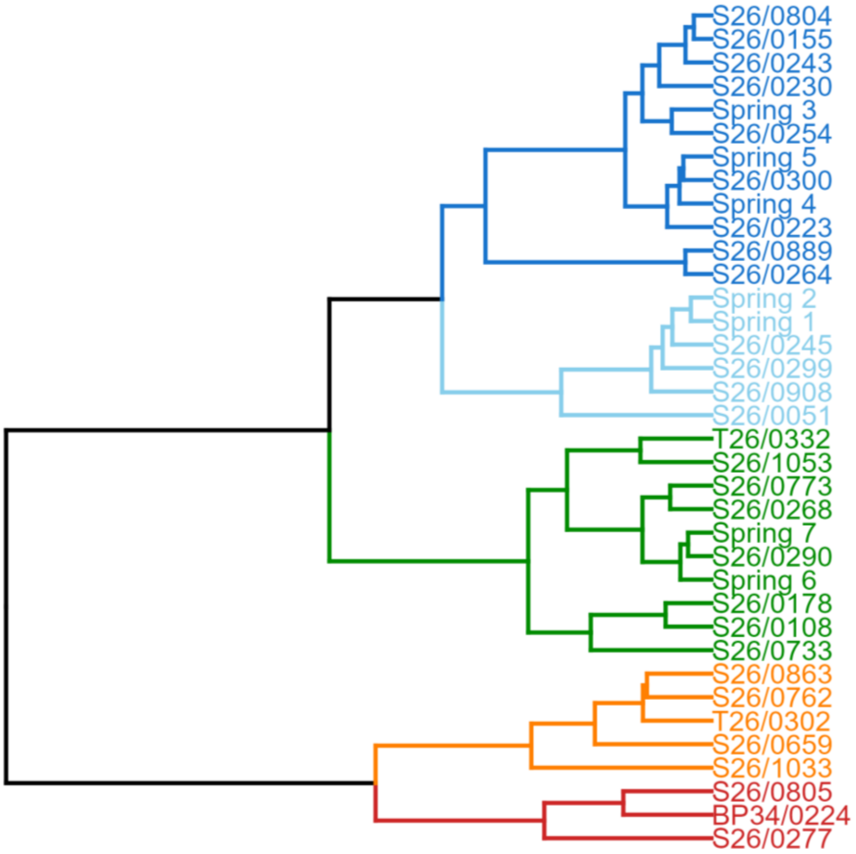

Figure 4-1: Dendrogram produced by hierarchical cluster analysis (HCA). The similarity between sites and groups of sites is indicated by the distance along the x-axis of the connecting lines.

Cluster 4 has the lowest concentrations of ions, similar to what might be expected for river waters, indicating possible surface water recharge to these sites. Sites in this cluster are located in the top (northern) part of the study area (Figure 4-3).

Within the southern area of the study area concentrations of ions increase from those seen in cluster 4 through to cluster 5 and cluster 3 (Figure 4-3), indicating possible higher contributions of rainfall recharge and some hydrochemical evolution (i.e., mineralisation of groundwater). This mineralisation shifts the water type of the clusters from a mixed type towards calcium-magnesium bicarbonate type water (Figure 4-4). Nitrate-nitrogen concentrations are similar in clusters 3 and 4 while nitrate-nitrogen concentrations are highest in cluster 5.

Cluster 2, has sites with even higher concentrations of ions, indicating the influence of anoxic conditions (reduced dissolved oxygen levels) and longer groundwater residence time which has resulted in more advanced hydrochemical evolution. This cluster is characterised as having very low nitrate-nitrogen concentrations that likely reflect the physical aquifer conditions found at this site. Sites in this cluster are also located in the eastern and southern parts of the study area and are associated with moderate to poor draining soils and/or have a well casing placed into older alluvial sediments.

Cluster 1 has three sites which have unusual hydrochemistry. It is likely these sites are affected by site specific contamination e.g., one site may be affected by a buried offal pit, the other sites may be influenced by localised septic tank contamination. Two of these sites have the highest concentrations of ions of sites in this study. One site is screened in unique geology (Q5a) compared to all other wells in the study.

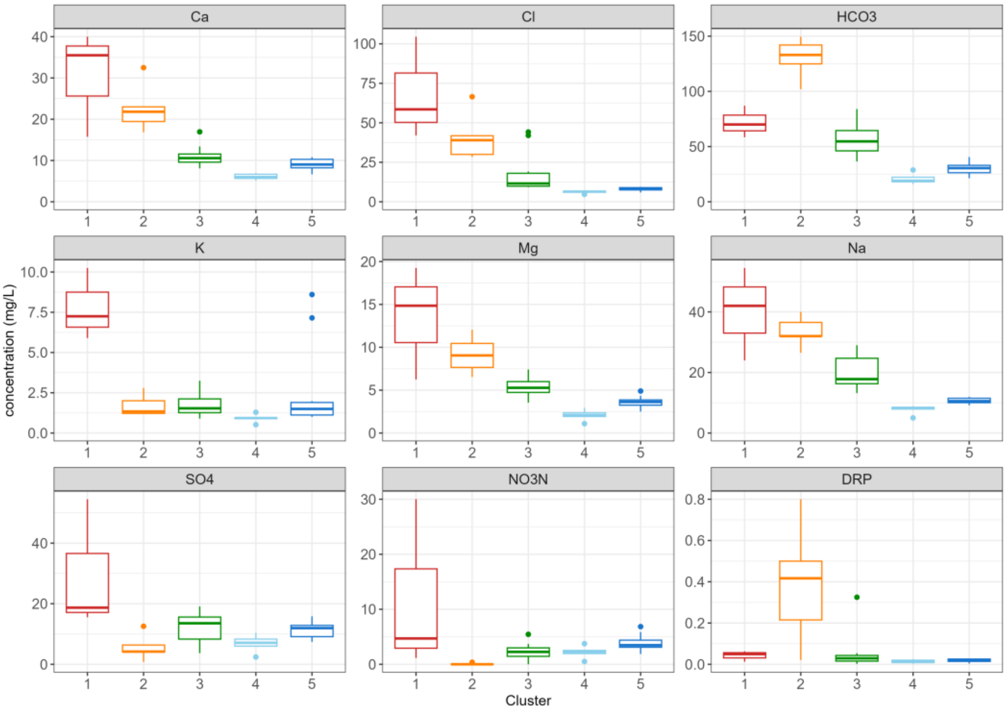

Figure 4-2: Box and whisker plots of the range of site median concentrations (bold line in the box) in each HCA cluster for the major ions Ca, Cl, HCO_3, K, Mg, Na, SO_4 and the nutrients NO_3-N and DRP. Box is the interquartile range (IQR) (25th percentile to 75th percentile) and whiskers extend to the largest and smallest values no further than ±1.5 x IQR.

The spatial distribution of the HCA clusters is shown in Figure 4-3. Chemistry for each site is represented in the form of a Stiff plot, which is a graphical representation of the cation and anion make-up of the water. This allows for quick assessment of similarities in groundwater chemistry across the study area. The shape of the Stiff plots is defined in milliequivalents (meq) per litre, which are a function of the ion concentrations, the molar mass of each component and their respective ionic charges.

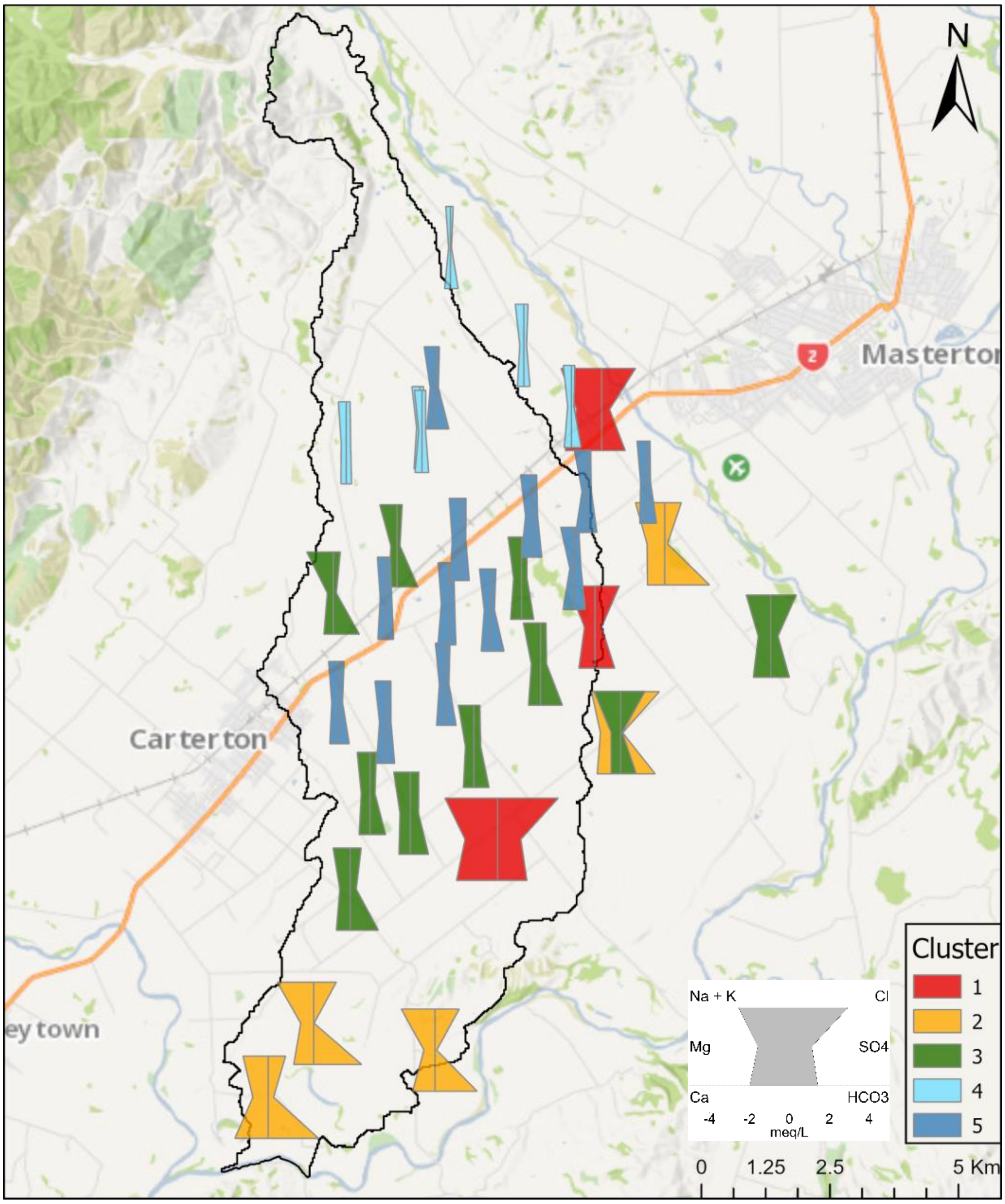

Figure 4-3: Map of groundwater chemistry, represented as Stiff plots of median ion concentrations. Sites are coloured by HCA cluster.

Tri-linear Piper diagrams (Figure 4-4) are used to visualise the hydrochemical signatures and to classify groundwater types. The lower left triangle is the distribution of cations, whilst the right triangle is the distribution of anions. The data from the two triangles are then combined into the quadrilateral field to show the overall hydrochemical characteristics of the samples.

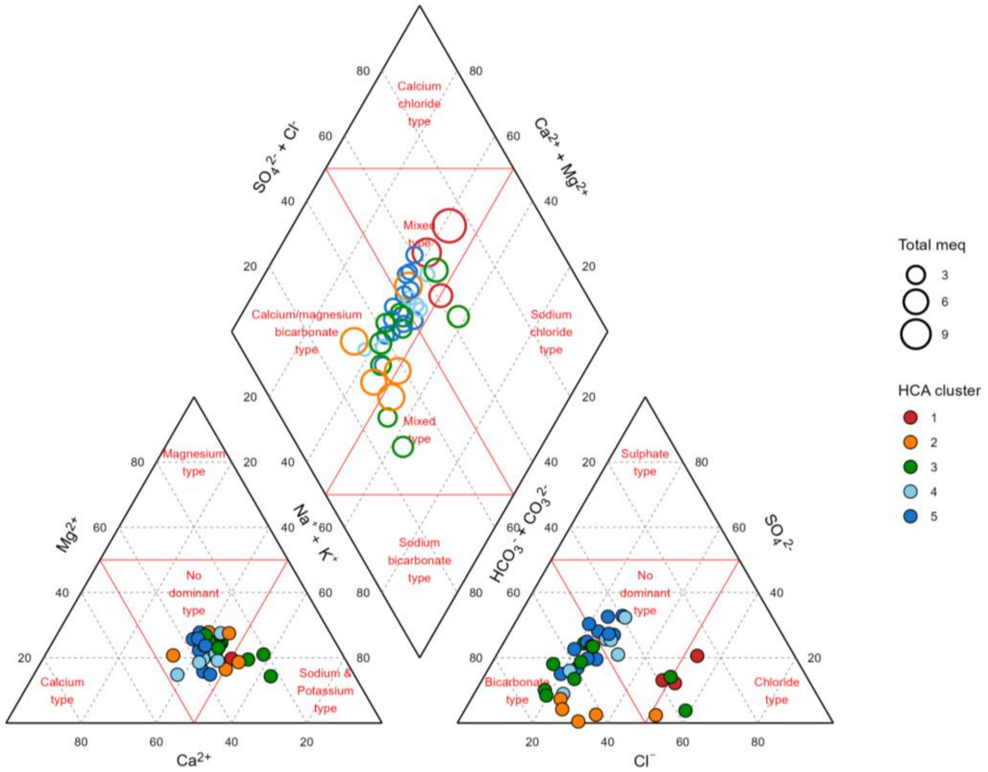

Figure 4-4: Piper diagram of median groundwater chemistry, grouped by HCA cluster. Symbols in the centre quadrilateral are scaled to total ionic load (meq).

Changes in redox state for each site over the four sampling rounds are shown in Figure 4-5. All sites in cluster 2 are anoxic. Sites in cluster 3 to 5 are predominantly oxic, but there are some sites which switch redox state between sampling rounds. These switches may be seasonal and related to the depth of water intercepted by wells screened in unconfined aquifers. Spring sites have an incomplete classification ($O_2 > 0.5$mg/L) as not all required parameters were sampled at these sites. These sites, however, are very likely to be oxic. Median redox categories for each site are presented in Appendix 3.

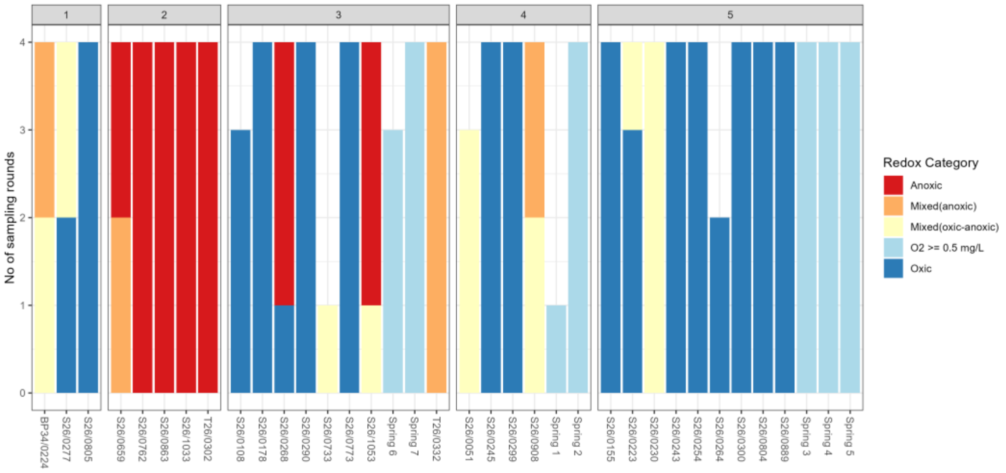

Figure 4-5: Redox category at each site for each sampling round, by HCA cluster

Figure 4-6 shows the geographic distribution of groundwater redox state. Anoxic groundwater is observed at sites in the eastern and southern parts of the study area and is associated with moderate to poor draining soil. Mixed (oxic-anoxic) groundwater observed in shallow wells at the top of the catchment. This mixed (oxic-anoxic) groundwater may be related to wells intercepting zones of the aquifer with different redox states and/or may be related to the poorly sorted sediments in this part of the study area.

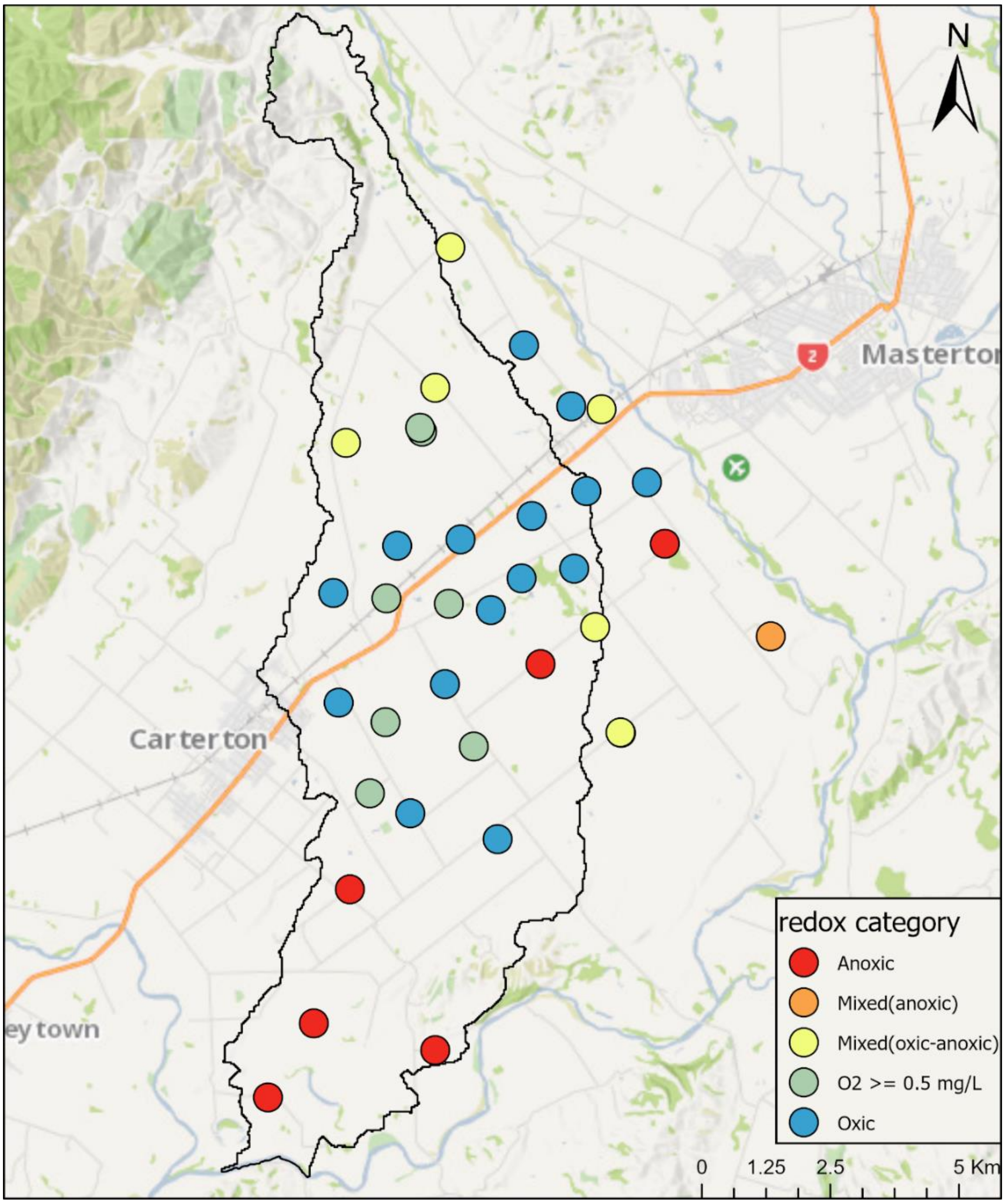

Figure 4-6: Map of median redox state.

4.2 Nitrate

Nitrate-nitrogen concentrations collected for this study ranged from below the detection limit of <0.001 to 43mg/L. The highest concentrations were observed at the monitoring well BP34/0224 which varied between 16 mg/L and 43 mg/L over this study. Excluding this well, the next highest nitrate-nitrogen concentration observed was 10.1 mg/L. All other measurements were below

7.3 mg/L (Figure 4-7). The median of all nitrate-nitrogen measurements over the study period was 2.6 mg/L. Most sites showed little variation between sampling rounds with some exceptions:

- The first two measurements of nitrate-nitrogen at well S26/0300 were around 2.6 mg/L. In the December sampling round a spike of 10.1 mg/L was then observed. The source of this is unknown but corresponding calcium and magnesium increases at that time are indicative of a fertiliser source. The nitrate isotope sample for this site does not have a definitive fertiliser signature (Section 4.8) but the isotope sample was taken prior to the observed increase in nitrate-nitrogen.

- Well S26/0178 also shows some seasonal variation similar to S26/0300 with an increase in nitrate-nitrogen in the November and February sampling rounds. At this well there were also corresponding increases in calcium, magnesium and potassium.

- S26/0659 had a spike in nitrate-nitrogen to 2.8 mg/L in the February sampling round.

- Nitrate-nitrogen at well S26/0051 varied between <0.02 and 2.7 mg/L. Groundwater from this site has a mixed oxic/anoxic redox state and variation between the mix of oxic and anoxic water reaching this bore may be the reason for variation in nitrate-nitrogen.

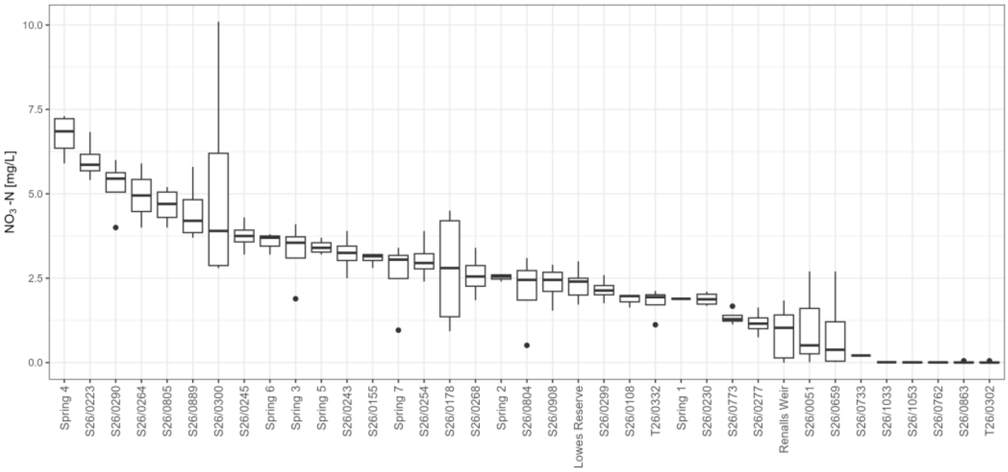

Figure 4-7: Box and whisker plot showing variation in nitrate-nitrogen concentrations per site across the four sampling rounds. Outlier site BP34/0224 is excluded. Box is the interquartile range (IQR) (25th percentile to 75th percentile) and whiskers extend to the largest and smallest values no further than ±1.5 x IQR.

Elevated nitrate-nitrogen concentrations above 2.4 mg/L are prevalent throughout the upper to mid catchment (Figure 4-8) suggesting that there are multiple sources of nitrogen contributing to the aquifer system spread across the upper-mid catchment.

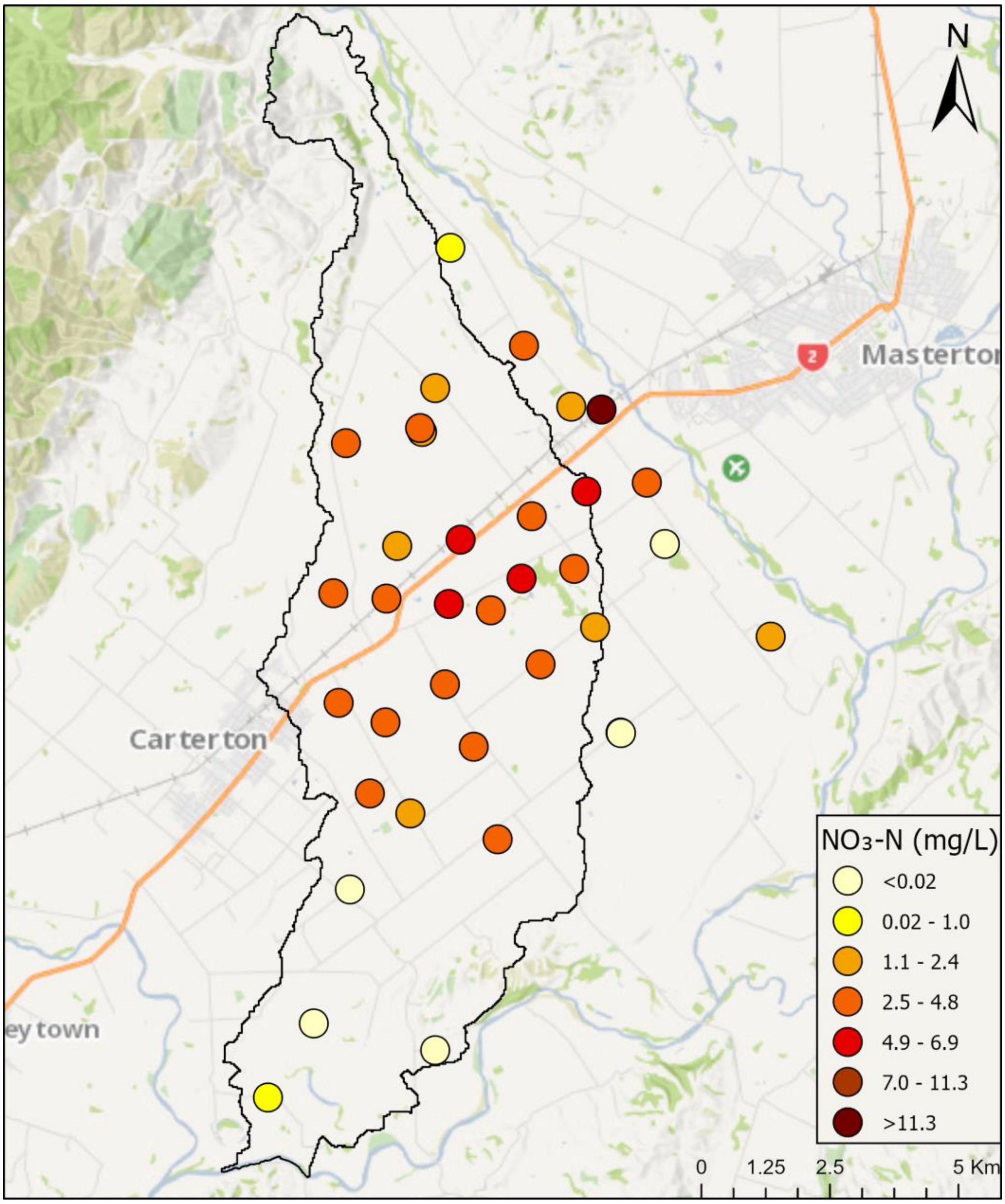

Figure 4-8: Map of median nitrate-nitrogen concentrations from the four sampling rounds May 2023 – March 2024

4.3 Other nitrogen

Aside from well BP34/0224, ammoniacal-nitrogen concentrations showed very little variation between sampling rounds and were generally below the detection limit except for sites with anoxic water. Figure 4-9 shows the geographical distribution of ammoniacal-nitrogen.

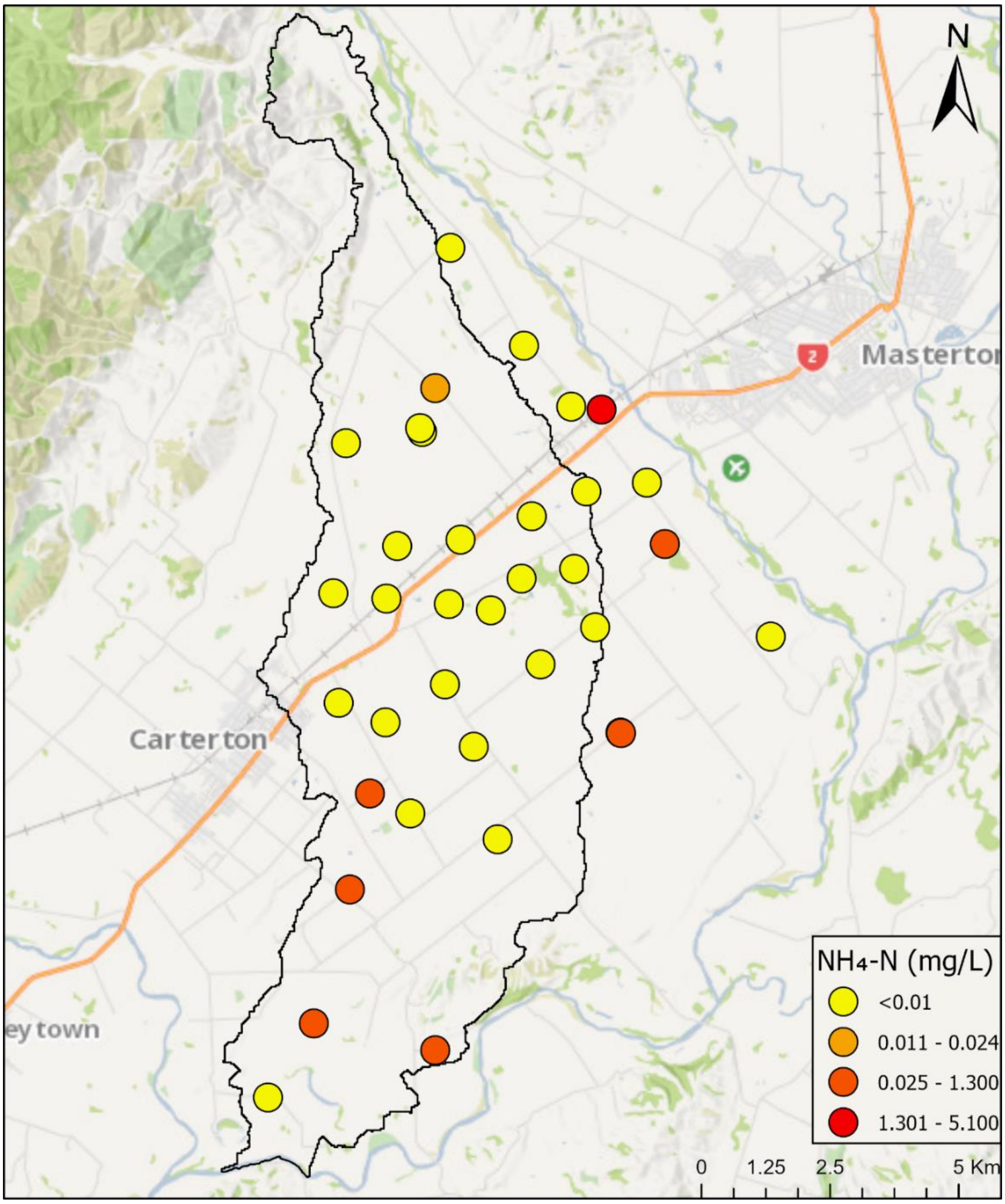

Figure 4-9: Map of median ammoniacal-nitrogen concentrations from the four sampling rounds May 2023 – March 2024

The concentration of organic forms of nitrogen have been calculated as the difference between the two measured parameters Total Kjeldahl Nitrogen (TKN) and ammoniacal-nitrogen. TKN is a measurement of both ammoniacal-nitrogen and all other organic nitrogenous compounds. Organic nitrogen is generally low in groundwater at sites in this study, with most concentrations less than 0.2 mg/L (Figure 4-10). Sites with higher concentrations of organic nitrogen may be affected by site specific sources of contamination e.g., offal pits, septic tank waste or animal effluent.

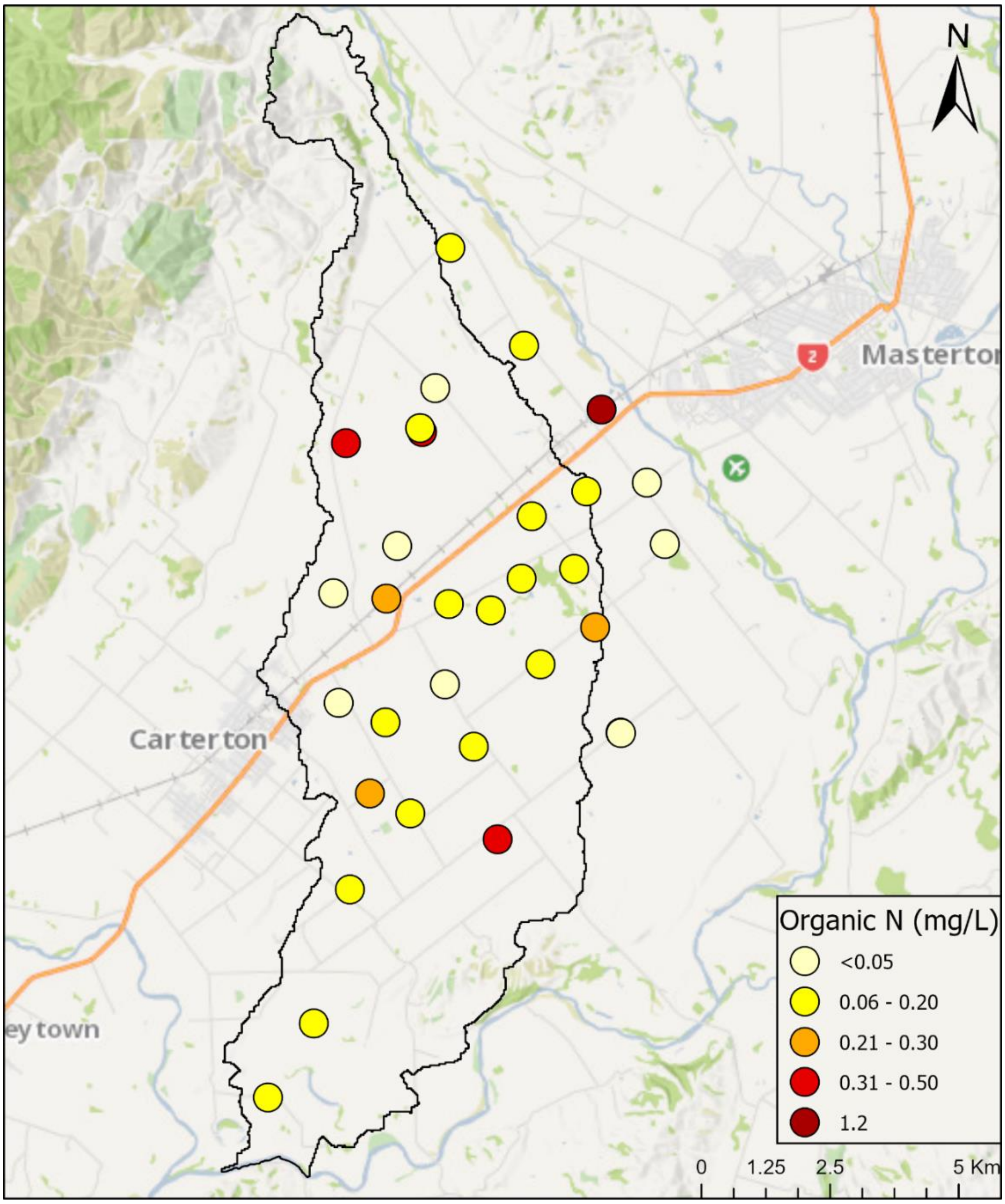

Figure 4-10: Map of median organic nitrogen concentrations from the four sampling rounds May 2023 – March 2024

4.4 Phosphorus

Dissolved reactive phosphorus (DRP) concentrations from all samples over the study period ranged from below the detection limit of <0.004 to 0.89 mg/L (Figure 4-11). Most sites had relatively low DRP concentrations (Figure 4-12), with a median for all sites of 0.022 mg/L. High DRP concentrations greater than 0.1 mg/L only occurred in sites in HCA cluster 2 which had anoxic groundwater (Figure 4-2). High phosphate can be attributed to mineral dissolution of aquifer material or direct waste sources such wastewater disposal.

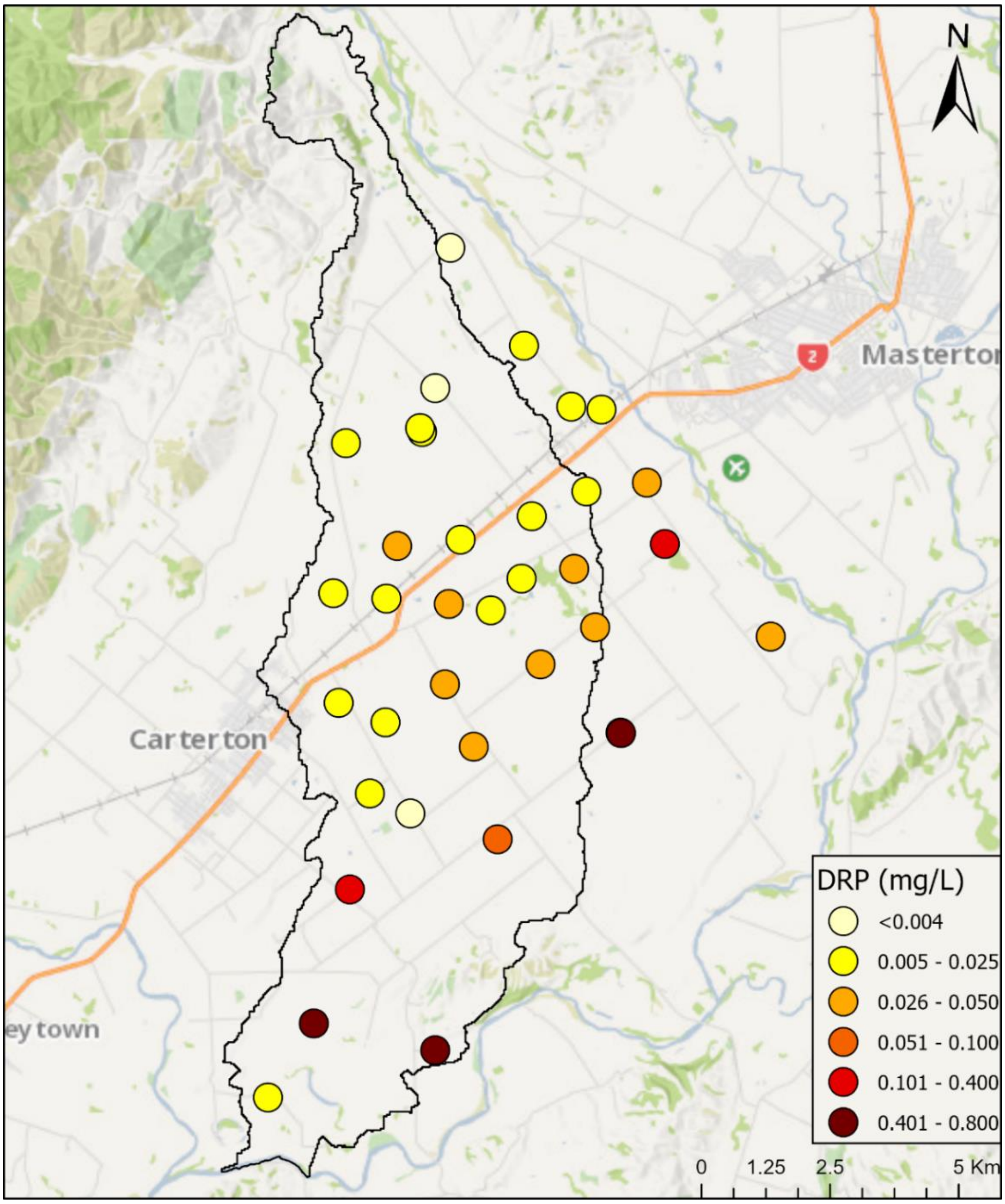

Figure 4-11: Map of median dissolved reactive phosphorus concentrations from the four sampling rounds May 2023 – March 2024

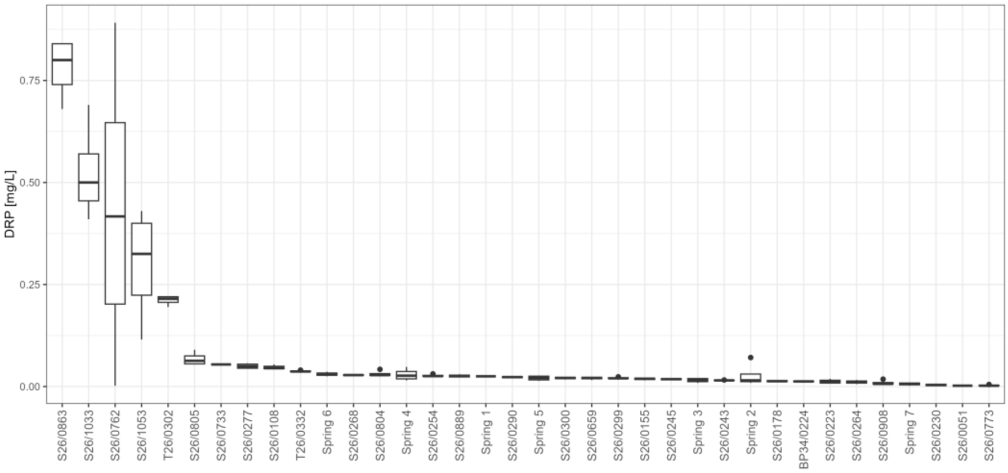

Figure 4-12: Box and whisker plot showing variation in dissolved reactive phosphorus concentrations per site across the four sampling rounds. Box is the interquartile range (IQR) (25th percentile to 75th percentile) and whiskers extend to the largest and smallest values no further than ±1.5 x IQR.

4.5 E. Coli

Counts of *E. Coli* in groundwater are usually low and should be essentially nil for groundwater with residence times in the aquifer of over one year (Lough et al. 2018). The presence of *E. Coli* in groundwater is an indicator of faecal contamination of the water. Sources can be natural (e.g., birds) but are commonly anthropogenic including septic tanks and other waste-water disposal, or from livestock. Insecure well heads are also susceptible to contamination from immediate surface sources.

In this study *E. Coli* counts ranged from the below the detection limit (<1 cfu/100mL) to 1200 cfu/100mL (Figure 4-13). Many of the highest *E. Coli* counts were observed at the spring sites. However, groundwater wells S26/0277, S260/223, S260/804, S26/0908 and S26/0051 all had *E. Coli* counts greater than 80 cfu/100mL in at least one sample. All sites with high *E. Coli* counts showed a large range in counts, with most also having at least one sample of less than 5 cfu/100mL. Figure 4-14 shows the geographic distribution of median *E. Coli* counts observed in this study.

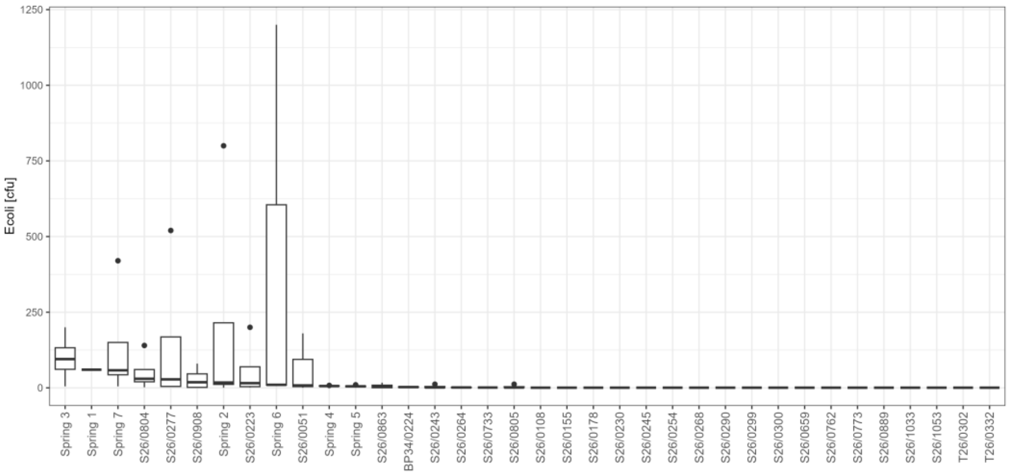

Figure 4-13: Box and whisker plot showing variation in *E. Coli* counts per site across the four sampling rounds May 2023 – March 2024. Box is the interquartile range (IQR) (25th percentile to 75th percentile) and whiskers extend to the largest and smallest values no further than ±1.5 x IQR.

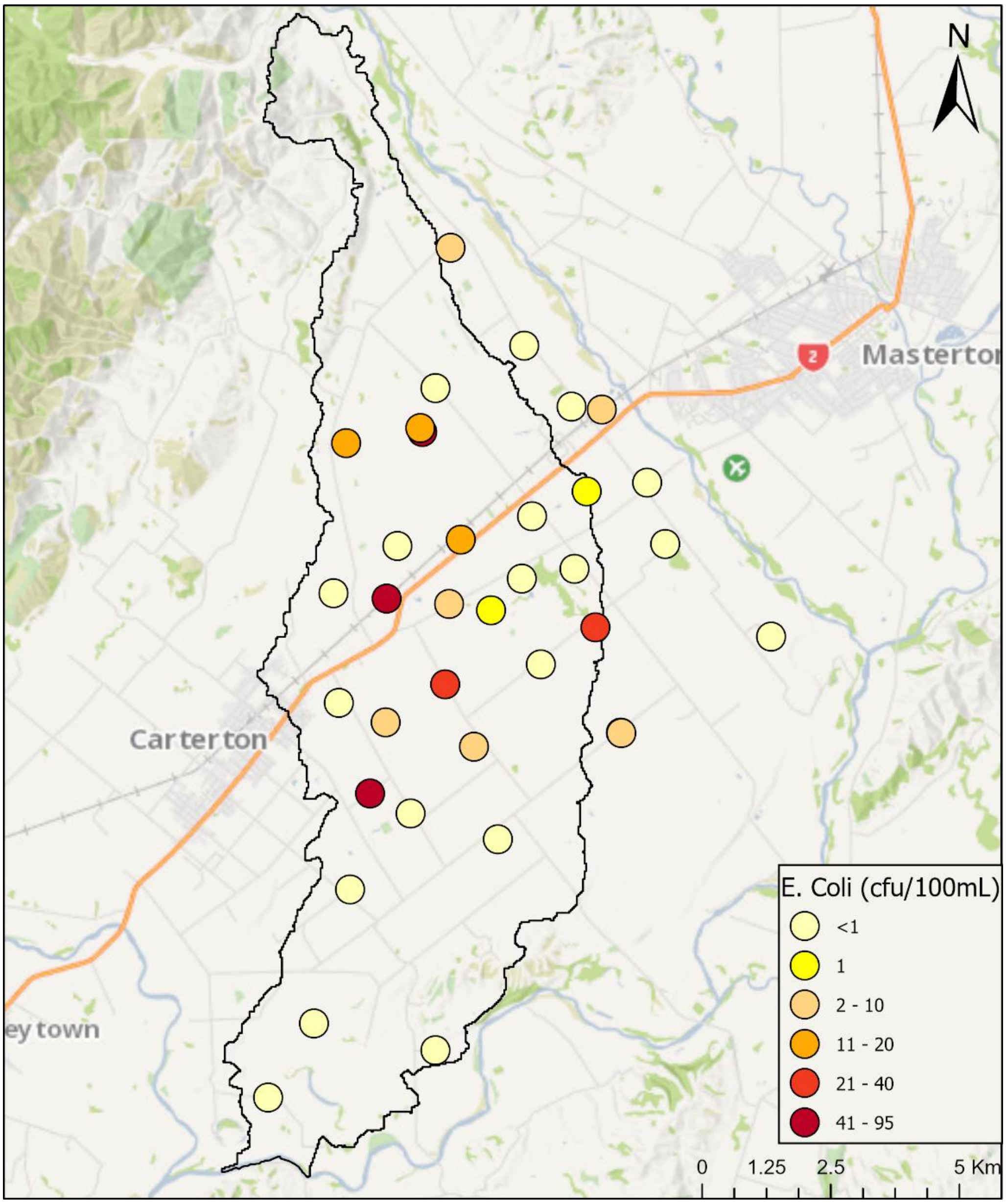

Figure 4-14: Map of median *E. Coli* counts from the four sampling rounds May 2023 – March 2024

4.6 Boron

Boron in groundwater can originate from natural sources such as the breakdown of minerals in basement rocks or in aquifer materials (e.g., gravels) and from leaching of borosilicate minerals in soils. Concentrations of boron from natural sources are usually low. Boron can also originate from anthropogenic sources, in particular domestic wastewater, as boron is found in laundry detergents and other consumer products. Other anthropogenic sources include industrial wastewater and agricultural activities. Under certain circumstances boron in groundwater is a good indicator of human induced contamination over natural processes.

In this study most sites had boron concentrations below 0.1 mg/L (Figure 4-15). Boron concentrations generally increase down the catchment due to hydrochemical evolution (Figure 4-16). Higher boron concentrations in the west of the study area near and downgradient of the Waingawa industrial area suggest possible contamination from industrial activities. Concentration gradients of boron across this area suggest there are multiple sources of boron originating from around the Waingawa industrial site.

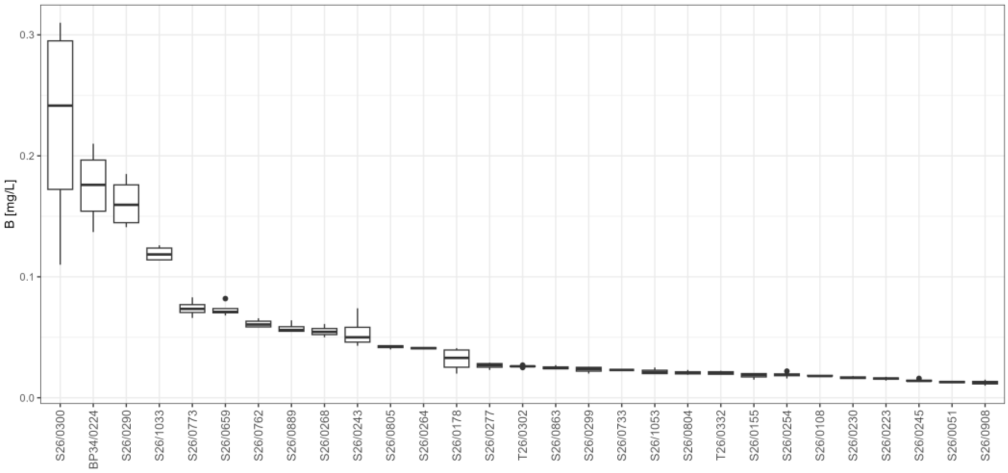

Figure 4-15: Box and whisker plot showing variation in boron concentrations per site across the four sampling rounds May 2023 – March 2024. Box is the interquartile range (IQR) (25th percentile to 75th percentile) and whiskers extend to the largest and smallest values no further than ±1.5 x IQR.

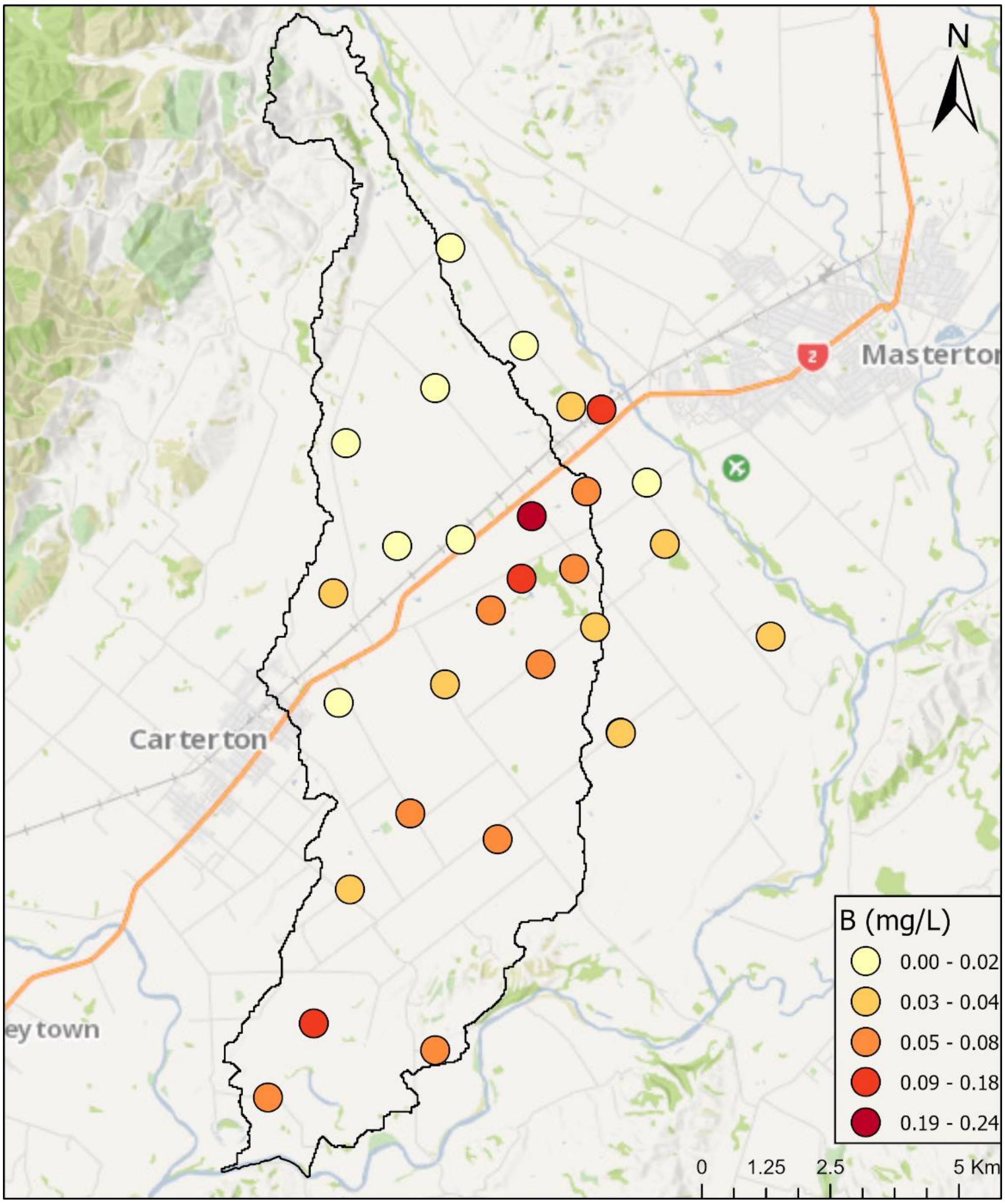

Figure 4-16: Map of median boron concentrations from the four sampling rounds May 2023 – March 2024

4.7 State of the Environment monitoring

Greater Wellington routinely monitor water quality at multiple sites within the study area. Among these there are four shallow groundwater wells and two surface water sites which are relevant to this study (Figure 1-1). These sites have been monitored for many years, with monitoring at the most recent site commencing in 2003.

Long term trends have been assessed for time series monitoring data for the period 2004 to 2024 (Table 4-1). For most parameters, a decreasing trend can be interpreted as an improvement in groundwater quality and an increasing trend is a degradation in groundwater quality.

Table 4-1: Summary of trend analysis for specified parameters at the State of the Environment sites for the period 2004 – 2024. Trend confidence follows Snelder et al. (2021) (Table 3-2). ND = not determined

Site	B	Ca	Cl	Field Conductivity
S26/0223	Highly likely increasing	Likely decreasing	Highly likely decreasing	Likely decreasing
S26/0299	Highly likely increasing	Highly likely decreasing	Highly likely decreasing	Highly likely decreasing
S26/0762	Highly likely increasing	Likely decreasing	Highly likely decreasing	Likely increasing
T26/0332	Very likely increasing	Highly likely increasing	Highly likely increasing	Highly likely increasing
RS45 Parkvale Stream at Renalls Weir	ND	ND	ND	Highly likely decreasing
RS46 Parkvale tributary at Lowes Reserve	ND	ND	ND	Highly likely decreasing
	DRP	**K**	**Mg**	**Na**
S26/0223	Highly likely decreasing	Likely increasing	Likely decreasing	Very likely decreasing
S26/0299	Highly likely decreasing	Highly likely decreasing	Highly likely decreasing	Likely decreasing
S26/0762	As likely as not	Likely decreasing	Highly likely decreasing	Highly likely increasing
T26/0332	Highly likely decreasing	Highly likely increasing	Highly likely increasing	Highly likely increasing
RS45 Parkvale Stream at Renalls Weir	Highly likely decreasing	ND	ND	ND
RS46 Parkvale tributary at Lowes Reserve	Very likely decreasing	ND	ND	ND
	NH_4-N	**NO_3-N**	**SO_4**	**TKN**
S26/0223	ND	As likely as not	As likely as not	ND
S26/0299	ND	Highly likely decreasing	Highly likely decreasing	ND
S26/0762	Highly likely decreasing	Highly likely decreasing	Highly likely increasing	ND
T26/0332	Highly likely decreasing	As likely as not	Highly likely increasing	ND
RS45 Parkvale Stream at Renalls Weir	Highly likely decreasing	Highly likely decreasing	ND	Highly likely decreasing
RS46 Parkvale tributary at Lowes Reserve	Highly likely decreasing	Highly likely decreasing	ND	Highly likely decreasing

4.7.1 Trends in nitrate-nitrogen

No statistically significant ($\alpha = 0.05$) seasonality in nitrate-nitrogen was observed for long term monitoring (State of Environment) wells S26/0223 and S26/0299. However, both Parkvale Stream sites and well T26/0332 had significant seasonal variation in nitrate-nitrogen.

There was no significant trend observed in nitrate-nitrogen at well S26/0223 (Figure 4-17), while there were highly likely decreasing trends observed at well S26/0299 and the two Parkvale Stream sites (Figure 4-18, Figure 4-19).

Decreasing trends in nitrate-nitrogen at these sites are also accompanied by decreasing trends in other parameters e.g., major ions (Table 4-1).

A notable decrease in NO_3-N concentrations occurred after 2022 at the Lowes Reserve stream site and at well S26/0223. When post-2022 data is removed for the Lowes Reserve site then no trend in nitrate-nitrogen is detected but a highly likely increasing trend was detected at well S26/0223. At this time, it is unclear what the underlying reason is for these different trends compared to the other sites.

Well T26/0332 had a likely increasing trend in nitrate-nitrogen driven by a notable increase in nitrate-nitrogen post 2022. With removal of the post-2022 data there is a highly likely decreasing trend in nitrate-nitrogen for the period 2004-2022 at this well. Well T26/0332 also has highly likely increasing trends in most major ions (Table 4-1) indicating declining water quality to this well. Unlike nitrate-nitrogen, increases in major ions have also occurred over a longer term than post-2022 at this monitoring well. This well is located just outside of the catchment and reflects the variability of trends at sites within the catchment.

Overall long-term changes in groundwater quality can be influenced by changes in land use and by changes to natural groundwater flow regimes induced by increased pumping or climatic variability affecting aquifer recharge.

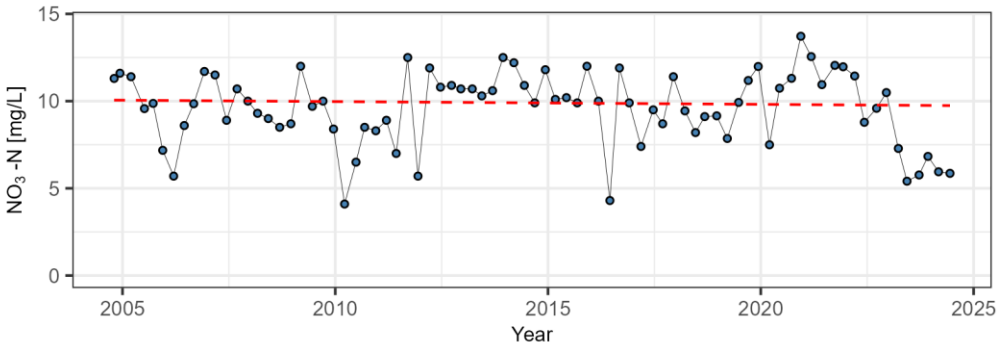

Figure 4-17: NO_3-N data for well S26/0223 for the period 2004 – 2024. The trend is shown by the dashed line.

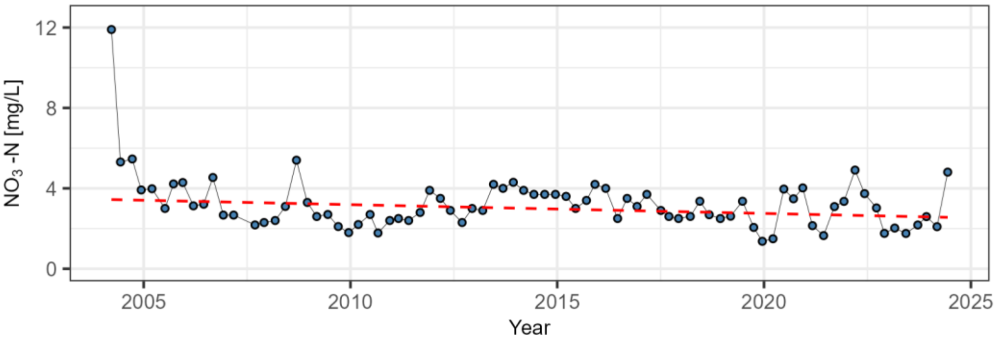

Figure 4-18: NO_3-N data for well S26/0299 for the period 2004 – 2024. The trend is shown by the dashed line.

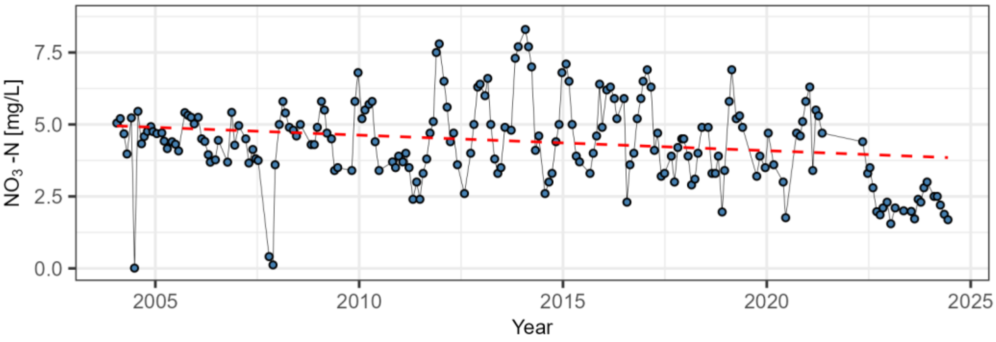

Figure 4-19: NO_3-N data for surface water site at Lowes Reserve (RS45) for the period 2004 – 2024. The trend is shown by the dashed line.

4.8 Nitrate isotopes

Figure 4-20 shows the nitrate isotopes data from this study and historical sampling. Results are presented in Table 4-2. Many samples fall along the Normal-N retention (NNR) zone with δ^{15}N values from +4 to +9 ‰. This zone contains samples affected by low-level diffuse nitrate contaminants as well as mixed urine or urea fertilizer samples distinguishable by their higher nitrate-nitrogen concentrations (Rogers et al. 2024).

The nitrate isotope data show multiple sources of nitrate within the aquifer system, including at least one different source of nitrate upgradient of the Waingawa industrial area to those derived from within the industrial area (Figure 4-21). Isotope and concentration gradients downgradient from the industrial area suggest that there are several separate effluent type sources spreading downgradient from the industrial area towards the Lowes Reserve wetland.

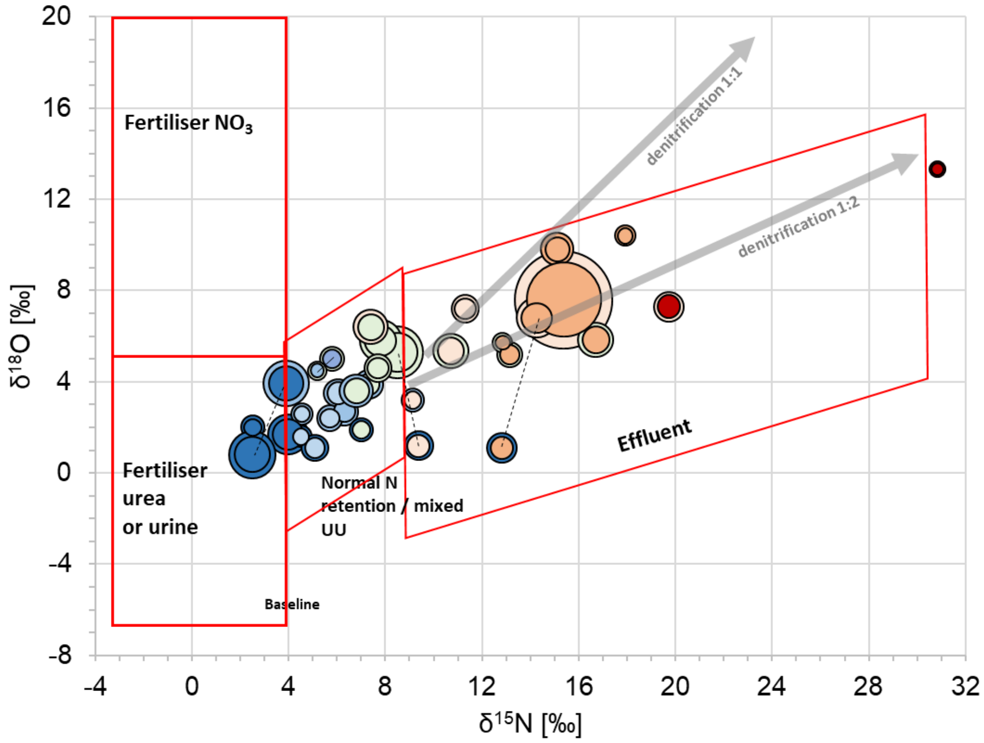

Figure 4-20: Plot of δ^{18}O against δ^{15}N in nitrate samples. Data from 18 sites from this study sampled in May 2023. Historic data shown for additional context from Baker (2018) and van der Raaij (2019). Red boxes showing typical ranges for nitrate sources are from Rogers et al. (2023). Some sites have been measured more than once, data points for these sites are connected by the dotted lines. The size of the symbols is proportional to nitrate-nitrogen concentration (Maximum concentration = 43 mg/L). Symbols colours are coded for comparison to Figure 4-21.

Nitrate hotspot BP34/0224 has a clear effluent or animal waste isotopic signature. Using an end-member mass balance isotopic mixing model (Equation 3) to model mixing between upstream sources and the nitrate at BP34/0224 suggests this hotspot is having some (most likely small) effect on nitrate-nitrogen concentrations downgradient from the industrial area.

$$\delta_{mix} = \frac{(\delta_1 \, m_1 + \delta_2 \, m_2)}{(m_1 + m_2)} \qquad (3)$$

At the centre of the study area there appears to be another distinct source of nitrate with a fertiliser urea or urine isotopic signature.

Some sites with effluent type isotopic signatures located further away from the industrial area may be affected by septic tank waste. Further evidence for this is the unusual chemistry at these sites, particularly the high chloride.

There is no definitive isotopic signature of septic tank waste upstream of the Waingawa industrial area even though this is the area with the highest density of lifestyle blocks and hence domestic wastewater systems.

Table 4-2: Nitrate isotope data for sites measured for this study as well as historic nitrate isotope data

Site	Sampling date	δ^{15}N (‰)	δ^{18}O (‰)	NO_3-N (mg/L)
Spring 4	2/05/2023	4.0	1.7	7.2
Spring 6	2/05/2023	7.3	3.9	3.7
Spring 7	2/05/2023	11.3	7.2	3.4
Spring 3	2/05/2023	6.3	2.7	3.5
Spring 2	2/05/2023	2.5	2.0	2.4
Spring 5	2/05/2023	6.1	3.5	3.7
S26/0230	3/05/2023	4.5	1.6	2.1
S26/0245	3/05/2023	5.1	1.1	3.2
S26/0908	3/05/2023	9.1	3.2	2.3
BP34/0224	9/05/2023	15.4	7.6	43.0
S26/0804	9/05/2023	7.0	1.9	2.3
S26/0805	9/05/2023	19.7	7.3	4.0
S26/0277	18/05/2023	30.8	13.3	1.1
S26/0300	18/05/2023	13.1	5.2	2.9
S26/0889	18/05/2023	9.4	1.2	3.9
S26/0108	31/05/2023	4.6	2.6	2.0
S26/0254	31/05/2023	5.7	2.4	2.9
S26/0264	1/06/2023	12.8	1.1	4.0
S26/0268	8/06/2023	17.9	10.4	1.9
S26/0290	8/06/2023	10.7	5.4	5.5
S26/0235	16/03/2016	12.8	5.7	1.7
Lowes Reserve	16/03/2016	16.7	5.8	5.5
S26/0889	27/09/2016	8.5	5.3	12.0
S26/0286	27/09/2016	7.8	5.8	7.8
S26/0264	8/12/2016	14.3	6.8	7.2
S26/0310	8/12/2016	15.1	9.8	4.6
S26/0299	16/03/2016	4.1	3.9	4.2
S26/0299	14/06/2017	5.8	5.0	2.7
S26/0223	16/03/2016	2.5	0.8	9.9
S26/0223	28/06/2017	3.9	3.9	9.2

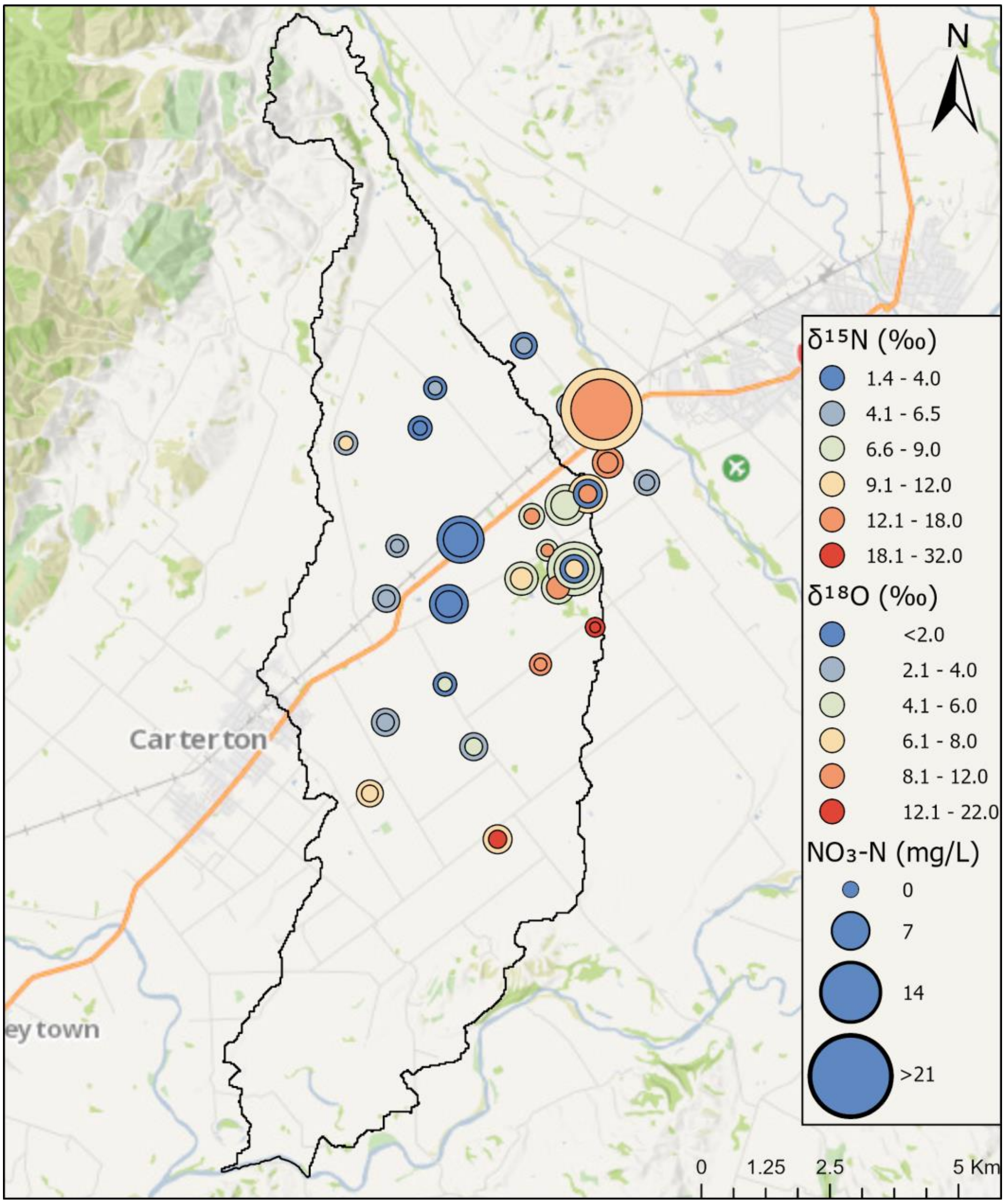

Figure 4-21: Map showing the spatial variation of $\delta^{18}O$ and $\delta^{15}N$ in nitrate. Data from 18 sites from this study. The inner circle of each symbol shows $\delta^{15}N$ and the outer circle $\delta^{18}O$. Historic data shown for additional context from Baker (2018) and van der Raaij (2019).

4.9 Groundwater age

In the northern most two thirds of the study area, groundwater from wells with depths less than 12m and from springs have MRTs of less than 1 year to 2 years (Table 4-3; Figure 4-22). Deeper wells throughout the catchment have much greater MRTs and in some cases exceed the age limit of tritium analyses. This indicates that groundwater moves much slower through the deeper layers of the aquifer system than in the shallow unconfined aquifer system at the top of the catchment. However, at the southern end of the catchment two shallow wells also have relatively old MRTs of 22 years and 83 years, even though they only have depths of 9.5m and 7.7m respectively, indicating that water movement through the unconfined aquifer in this part of the catchment is similarly slow to the deeper layers.

Table 4-3: Tritium concentrations and calculated groundwater MRT

Site	Well depth (m)	Sampling date	Tritium (TU)	±uncertainty (TU)	MRT (years)
Spring 4		02/05/2023	1.884	0.039	<1
Spring 6		02/05/2023	1.904	0.048	<1
Spring 7		02/05/2023	1.647	0.038	<3
S26/0230	18.65	03/05/2023	2.059	0.048	<1
S26/0804	6.75	09/05/2023	1.895	0.046	<1
S26/0805	9.6	09/05/2023	1.634	0.041	3 (<4)
S26/0108	30.5	31/05/2023	0.910	0.028	16
S26/1053	9.5	01/06/2023	0.767	0.025	22
S26/0268	4.2	08/06/2023	1.891	0.036	<1
S26/0773	8.8	08/06/2023	1.686	0.039	2 (<3)
S26/1033	7.68	1/09/2023	0.3	0.02	83

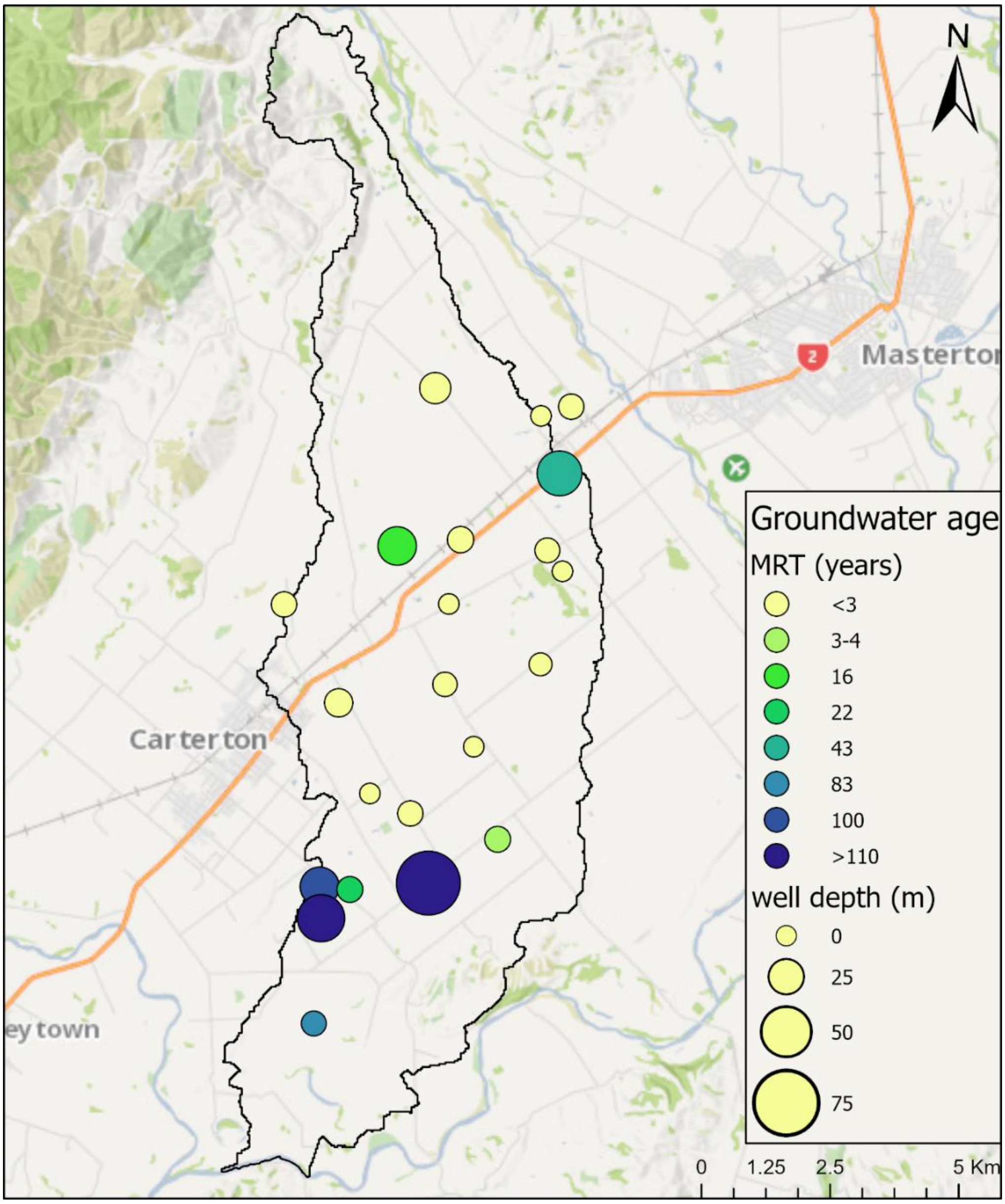

Figure 4-22: Map of groundwater mean residence times (MRT). Eleven sites were sampled for this study (Table 4-3). Additional historic data are shown for context (Morgenstern 2005; van der Raaij 2019). Sites are scaled to well depth, spring sites have been assigned a depth of zero.

4.10 Radon

Radon was measured at all seven spring sites to confirm that these sites are derived from a groundwater source. Concentrations of radon ranged between 8 and 21.4 Bq/L (Table 4-4). Spring numbers 2, 4, 5 and 6 all had high radon concentrations around 19 - 21 Bq/L indicating a strong groundwater influence at the sites. Lower radon concentrations at Spring 1, Spring 3 and Spring 7 are likely at least partially due to losses to atmospheric re-equilibration as these sites were at the outflow of wetlands and, in the case of Short St, outflow from a drain. However, concentrations at these three sites are not close to zero indicating a relatively short residence time in the wetlands for exiting water.

Table 4-4: Radon concentrations

Site	Sampling Date	Rn (Bq/L)	± 1σ uncertainty (Bq/L)
Spring 1	02/05/2023	13.5	0.8
Spring 2	02/05/2023	21.0	1.2
Spring 3	02/05/2023	8.0	0.5
Spring 4	02/05/2023	19.8	1.1
Spring 5	02/05/2023	21.4	1.2
Spring 6	02/05/2023	18.7	1.1
Spring 7	02/05/2023	12.7	0.8

4.11 Dissolved gases

Excess N_2 concentrations derived from dissolved gas measurements ranged from 0.1 mg/L to 4.1 mg/L (Table 4-5). Assuming all dissolved excess N_2 is derived from the denitrification of NO_3 this is equivalent to NO_3-N concentrations of the nitrate removed from the system. The oxic groundwaters found in the top half of the study area were found to have excess N_2 concentrations that are low (Figure 4-23). This indicates there is little to no attenuation of nitrate once it reaches the aquifer in these locations. In anoxic groundwater in the lower part of the catchment up to 4 mg/L of nitrate appears to reach the aquifer before being attenuated. This is the case even for well S26/1033 which has an MRT of 83 years.

Table 4-5: Dissolved gas concentrations. Ar, Ne and N_2 concentrations are expressed in mL of the respective gas at standard temperature and pressure (STP =273.15K, 101.325kPa) per kg of water. Excess N_2 is expressed in mg/L allowing comparison to NO_3-N concentrations.

Site	Sampling Date	Ne mL(STP)/kg	Ar mL(STP)/kg	N_2 mL(STP)/kg	Excess N_2 (mg/L)	± Excess N_2 uncertainty (mg/L)
S26/0155	27/02/2024	0.000218	0.350	14.2	0.2	0.3
S26/0230	27/02/2024	0.000176	0.316	12.4	0.6	0.4
S26/0268	28/02/2024	0.000229	0.365	15.3	0.7	0.5
S26/0290	27/02/2024	0.000207	0.324	13.2	0.2	0.5
S26/0299	8/03/2024	0.000189	0.332	12.8	0.1	0.2
S26/0300	28/02/2024	0.000183	0.323	12.5	0.3	0.3
S26/0773	27/02/2024	0.000208	0.356	15.6	2.1	0.4
S26/0863	27/02/2024	0.000256	0.402	19.6	4.0	0.9
S26/1033	28/02/2024	0.000208	0.369	17.6	4.1	0.8
S26/1053	28/02/2024	0.000221	0.373	17.9	3.9	0.5

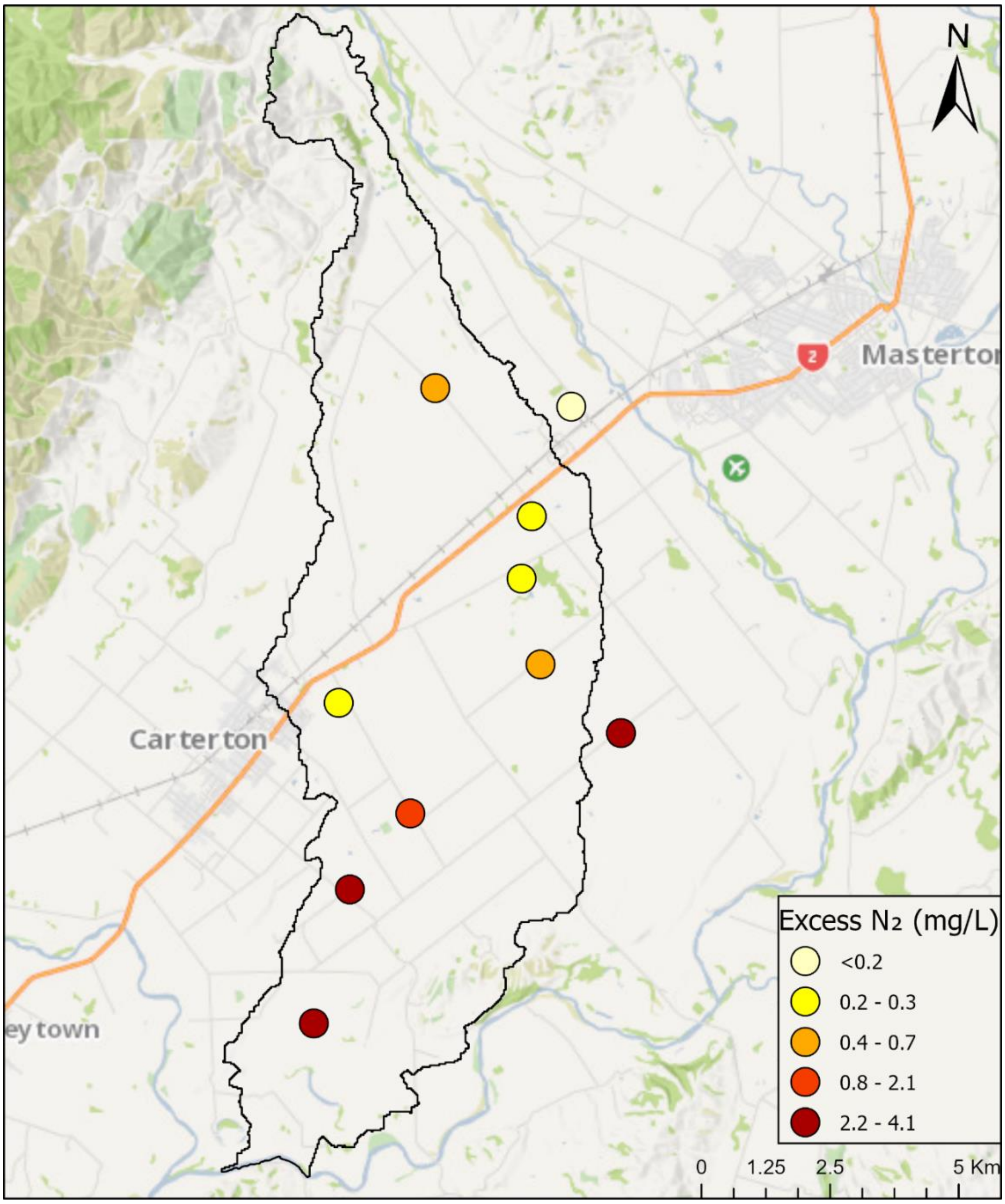

Figure 4-23: Map of excess N_2 concentrations

5. Discussion and Conclusions

Historically a high nitrogen loading from groundwater to the Lowes Reserve wetland has originated from upgradient land uses, including the Waingawa industrial area. Much of this has been attributed to the former Affco meat processing plant, as evidenced by groundwater monitoring prior to the early 2000s (Baker 2018).

In this study an assessment of nitrate-nitrogen concentrations was undertaken from groundwater wells and springs in the Parkvale. Nitrate-nitrogen concentrations were found to range from below the detection limit of <0.001 to 43mg/L with a median value of 2.6 mg/L. Apart from one nitrate hotspot with localised contamination nitrate-nitrogen were found to be below 7.3 mg/L.

Elevated nitrate contamination of groundwater was found to be widespread across the Parkvale catchment with higher levels found in the upper two thirds of the catchment. Groundwater-fed springs and drains downgradient from the fault lines in the catchment were found to contribute nitrogen to the Parkvale stream network.

Nitrate-nitrogen concentrations in the stream network were found to be above the National Policy Statement for Freshwater Management 2020 bottom line for nitrate toxicity (2.4 mg/L nitrate-nitrogen (MfE 2023) for aquatic ecosystem life. The elevated nitrate also contributes to the proliferation of algae and macrophytes in surface water which also impacts on the aquatic ecology of the stream network.

Nitrate isotope data identified that there are multiple sources of nitrate contributing to the aquifer system. This includes upgradient sources above the Waingawa industrial area and from sources within the industrial area itself. Downgradient of the industrial area, isotope data and concentration gradients of nitrate and other contaminants indicate that there are several separate effluent type sources from the industrial area that moving with the natural groundwater flow towards the Lowes Reserve wetland and the Parkvale stream network. In the middle of the catchment high nitrate concentrations at SOE well S26/0223 (located adjacent to SH2) and nearby springs have a urea fertiliser isotope signature. At this location there are likely to be multiple sources of nitrogen including fertiliser storage, lifestyle blocks, dairying and other pastoral activities. Further investigation is needed to help pinpoint specific sources.

In the northern two thirds of the catchment, shallow groundwater and springs were found to have mean residence times (or groundwater ages) of less than 2 years. Shallow groundwater in the southern part of the catchment has mean residence times of up to 83 years which indicates that groundwater is moving much slower than the northern areas of the catchment. Groundwater in the southern catchment was found to be anoxic which means nitrate-nitrogen is likely to be attenuated by denitrification processes before reaching the aquifer system.

Current nitrogen loads sourced from the Waingawa industrial area do not appear to have as large an impact or loading compared to historical levels and are likely to only contribute half or less of the total nitrogen loading to the Lowes Reserve wetland springs and stream network. The current nitrogen load was found to be mostly coming from sources upgradient of the industrial area. However legacy point sources, identified at monitoring well BP34/0224, still occur within the Waingawa industrial area.

Overall, the evidence shows that the current contribution from these point sources to the total nitrogen loading reaching downstream is likely to be relatively low compared to diffuse sources from the wide range of current land use practices. This is based on the following lines of evidence:

- Long term monitoring of groundwater at Lowes Reserve indicates nitrate-nitrogen concentrations are declining in this part of the catchment.
- Upstream of the industrial area, nitrate nitrogen concentrations currently average around 2.1 mg/L as assessed from SOE site S26/0299 and other consent monitoring sites.
- The Lowes Reserve SOE site had a median nitrate-nitrogen concentration of 2.4 mg/L over the study period, suggesting that a significant proportion of nitrate currently reaching the reserve may not have its origin from the industrial area.
- The longer-term (2004-2024) median nitrate-nitrogen concentration for Lowes Reserve is 4.4 mg/L. Additionally, groundwater sites located near the reserve have nitrate-nitrogen concentrations around 4 mg/L in this study. This suggests that over the longer term about half the nitrate load on average reaching the reserve may have originated from the industrial area.
- Except for BP34/0224, downgradient monitoring sites at the JNL effluent disposal field currently show an increase of 1 – 2 mg/L above that of the upgradient sites.
- Mass balance calculations from nitrate isotopes and flow dilution calculations indicate that nitrate from the BP34/0224 hot spot is also likely to be a small contributor to the downstream nitrate-nitrogen load that reach the Lowes Reserve wetlands.
- Isotope, nitrate-nitrogen and boron data indicate that there is more than one source of contamination from the Waingawa industrial area, and the total contribution from this area maybe cumulative.

The top half of the catchment has soils that are naturally highly vulnerable to leaching from most types of land use. This means the risk of nitrate contamination to groundwater and the surface was bodies of the catchment is problematic. However, lower third of the catchment has heavy soil types that naturally provide a barrier to nitrate leaching and promote natural nitrate attenuation processes. To that end the lower catchment may be better suited to more intensive land uses whereas the upper catchment is likely to be better suited for land uses that have lower nitrate leaching risk.

Any changes to land use activities in the upper two thirds of the study are likely to result in a relatively quick response in water quality because the groundwater mean residence time is young (i.e. less than two years).

6. Recommendations

6.1 Optional Science Investigations

The conclusions of this study clearly indicate there are a wide range of diffuse and point sources of nitrogen in the catchment. Further investigations may help reduce some uncertainty of the sources of specific hot spots if a high level of certainty is needed for catchment management decision-making and can be justified. These could include:

1. Installing a temporary monitoring well upgradient of the SOE monitoring well S26/0223 would help pinpoint sources high hot spot nitrate-nitrogen concentrations that occur at this site;
2. Undertaking further nitrate isotope analysis of the discharges from consented waste discharges and possibly other sources to further categorise the source signals; and
3. Undertaking faecal source tracking in groundwater wells with high *E. Coli* counts that also have high nitrate-nitrogen concentrations would help to pinpoint sources of contamination.

6.2 Potential Catchment Actions

Remedial actions targeted toward the legacy sources, such as the presumed offal pits at the monitoring well BP34/0224, may provide further certainty for hot spots but will likely have lower benefits than actions which reduce nitrogen loads from current land use activities in the upper catchment. These actions could include:

1. Supporting landowners to manage treatment of septic tank waste to higher standards;
2. Investigating options to improve the level of treatment of effluent from industrial and agriculture discharges;
3. Looking for opportunities to reduce fertiliser use and/or application practices that optimise fertiliser use and reduce leaching risk;
4. Optimising stocking rates that align with natural soil leaching risk; and
5. Exploring opportunities to reduce nitrogen leaching risk from all land use activities in the upper catchment.

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Appendix 1: Site Details

Table A1-1: Site Details. Well and screen depths are m below ground level (BGL).

Site	Well/Spring	Easting (NZTM)	Northing (NZTM)	Well Depth (m BGL)	Screen depth (m BGL)
BP34/0224	Well	1818943	5461813	10.25	7.25 - 10.25
S26/0051	Well	1816003	5464963	12	10.5 - 12.00
S26/0108	Well	1814964	5459160	30.5	24.9 - 30.50
S26/0155	Well	1813828	5456110	13.4	10.31 - 13.41
S26/0178	Well	1813724	5458240	3.6	Open bottom
S26/0223	Well	1816199	5459283	9.92	
S26/0230	Well	1815706	5462233	18.65	Possibly slotted case
S26/0243	Well	1816785	5457910	1.9	Open bottom
S26/0245	Well	1817430	5463060	7.8	6.3 - 7.8
S26/0254	Well	1819817	5460397	6.15	Likely open bottom
S26/0264	Well	1818645	5460220	3.2	1.7 - 3.2
S26/0268	Well	1817754	5456859	4.2	Assume no screen
S26/0277	Well	1818814	5457579	6.4	Unknown
S26/0290	Well	1817384	5458530	4	Assume no screen
S26/0299	Well	1818355	5461870	8.1	
S26/0300	Well	1817585	5459740	6.35	No screen
S26/0659	Well	1812458	5448432	6	Unknown
S26/0733	Well	1819313	5455530	4.24	
S26/0762	Well	1815702	5449348	9.5	
S26/0773	Well	1815223	5453959	8.8	No screen? (-2.6 m)
S26/0804	Well	1815897	5456467	6.75	Likely open bottom
S26/0805	Well	1816919	5453450	9.6	Likely open bottom
S26/0863	Well	1819316	5455523	13.7	No Screen
S26/0889	Well	1818409	5458720	8	No screen
S26/0908	Well	1813975	5461163	7.5	4.5 - 7.5
S26/1033	Well	1813343	5449871	7.68	4.68 - 7.68
S26/1053	Well	1814051	5452481	9.5	6.5 - 9.5
Spring 1	Spring	1815449	5461386	0	
Spring 2	Spring	1815408	5461459	0	
Spring 3	Spring	1814756	5458140	0	
Spring 4	Spring	1815968	5458033	0	
Spring 5	Spring	1814743	5455728	0	
Spring 6	Spring	1816458	5455258	0	

Site	Well/Spring	Easting (NZTM)	Northing (NZTM)	Well Depth (m BGL)	Screen depth (m BGL)
Spring 7	Spring	1814437	5454341	0	No screen
T26/0302	Well	1820170	5459199	8.98	
T26/0332	Well	1822231	5457402	13.4	

Appendix 2: Water chemistry results

Table A2-1: Median values of measured parameters over the four sampling rounds from May 2023 to March 2024

Site	Ammoniacal-nitrogen (mg/L)	Bicarbonate (mg/L)	Chloride (mg/L)	Conductivity field (us/cm)	Conductivity (Lab)	Dissolved boron (mg/L)	Dissolved calcium (mg/L)	Dissolved iron (mg/L)	Dissolved magnesium (mg/L)	Dissolved manganese (mg/L)	Dissolved Oxygen - field (mg/L)	Dissolved potassium (mg/L)	Dissolved Reactive Phosphorus (mg/L)	Dissolved sodium (mg/L)	*E. Coli*	Nitrate-nitrogen (mg/L)	Nitrite-nitrogen (mg/L)	ORP - Field (mV)	pH field	pH lab	Sulphate (mg/L)	Total Kjeldahl Nitrogen (mg/L)	Total Phosphorus (mg/L)	Water Temperature - field (C)
BP34/0224	5.1	70.0	58.5	604.5	57.8	0.176	35.5	<0.02	14.85	1.44500	0.76	5.90	0.013	42.0	2.5	30.0000	<0.002	115.35	5.33	6	18.7	5.4	NA	15.6
S26/0051	<0.01	23.0	4.7	81.3	7.3	0.013	5.7	0.18	1.09	0.04300	6.88	0.52	<0.004	5.0	8	0.5100	<0.002	242	5.33	6.6	2.4	0.11	NA	14.1
S26/0108	<0.01	63.0	9.3	162.8	16.0	0.018	8.1	<0.02	3.70	0.00160	7.61	0.90	0.045	19.1	<1	1.9700	<0.002	137.6	6.57	7.1	7.0	0.05	NA	17.0
S26/0155	<0.01	31.5	9.4	133.7	12.9	0.019	8.6	<0.02	4.05	0.00110	6.36	1.54	0.019	10.4	<1	3.1500	<0.002	111.15	5.625	6.65	9.1	0.05	NA	13.8
S26/0178	<0.01	77.5	12.2	200.2	19.6	0.033	9.1	<0.02	3.55	<0.0005	7.02	1.19	0.013	28.9	<1	2.8000	<0.002	200.05	6.87	7.6	7.2	0.05	NA	14.8
S26/0223	<0.01	25.8	9.4	159.6	15.3	0.016	10.1	0.07055	4.90	0.00837	7.45	1.12	0.011	11.9	15.5	5.8600	<0.002	271.7	5.485	6.005	12.3	NA	NA	14.0
S26/0230	0.012	40.5	7.3	127.3	12.6	0.017	8.1	1.12	2.95	0.02350	5.18	1.01	0.004	11.8	<1	1.8750	0.0065	114.9	5.73	6.55	7.4	0.05	NA	16.8
S26/0243	<0.01	39.5	9.1	144.7	14.2	0.050	9.1	<0.02	3.80	0.00370	1.39	1.71	0.015	11.6	1.25	3.2500	<0.002	191.75	5.6	6.35	8.8	0.17	NA	14.3
S26/0245	<0.01	18.1	7.3	107.6	10.7	0.014	6.3	<0.02	2.40	0.00365	7.62	1.29	0.018	8.9	<1	3.7500	<0.002	193.85	5.01	5.85	6.4	0.15	NA	14.4
S26/0254	<0.01	29.5	5.9	121.8	11.8	0.019	6.7	<0.02	3.50	0.00105	6.18	1.12	0.026	10.1	<1	2.9500	<0.002	182.4	5.485	6.2	9.1	0.05	NA	16.4
S26/0264	<0.01	31.5	7.6	153.1	15.0	0.041	10.4	0.02	2.50	0.00715	2.24	7.15	0.011	9.2	1.25	4.9500	<0.002	235.5	5.575	6.35	11.6	0.19	NA	14.7
S26/0268	<0.01	65.0	9.5	196.4	18.9	0.055	11.7	<0.02	5.40	0.00910	0.36	3.25	0.028	17.3	<1	2.5500	<0.002	100.85	5.92	6.6	14.2	0.15	NA	14.3
S26/0277	<0.01	58.5	42.0	299.3	29.2	0.027	15.8	0.02	6.25	0.05550	7.51	10.25	0.050	24.0	28	1.1550	<0.002	219.05	6.29	6.95	15.6	0.26	NA	14.3
S26/0290	<0.01	36.5	9.7	171.5	16.7	0.159	10.6	<0.02	4.65	0.00110	4.45	1.71	0.023	14.0	<1	5.4500	<0.002	204.65	5.455	6.35	13.0	0.1	NA	14.8
S26/0299	<0.01	28.8	5.9	101.8	9.6	0.024	7.0	<0.02	2.21	0.00169	7.89	0.93	0.020	8.5	<1	2.1350	<0.002	203	5.335	6.595	5.8	NA	NA	15.3
S26/0300	<0.01	29.5	8.3	155.4	14.8	0.242	10.3	<0.02	3.70	0.00240	6.82	1.98	0.021	11.5	<1	3.9000	<0.002	179.85	5.23	6.05	13.5	0.15	NA	14.4
S26/0659	<0.01	149.5	30.0	362.7	35.9	0.071	32.5	0.09	9.05	1.14500	0.32	2.80	0.021	26.5	<1	0.3805	0.0020	100.85	5.98	6.75	12.6	0.18	NA	14.4
S26/0733	0.036	46.0	42.0	237.8	22.3	0.023	9.4	0.07	5.70	0.24000	0.65	1.29	0.054	29.0	1	0.2100	<0.002	-6.2	5.1	7	3.7	0.05	NA	14.7
S26/0762	0.49	124.9	41.8	373.5	33.7	0.061	21.8	7.29	6.54	0.91750	0.34	2.00	0.417	36.5	<1	0.0055	0.0055	49.35	6.215	6.78	4.1	NA	NA	14.9
S26/0773	<0.01	54.0	14.7	197.1	19.4	0.074	11.2	<0.025	6.15	0.00810	1.88	2.45	<0.002	17.2	<1	1.2850	<0.002	166.5	5.67	6.45	19.1	0.18	NA	13.7
S26/0804	<0.01	33.0	8.6	121.7	11.8	0.021	8.2	<0.02	3.35	0.00075	4.04	1.46	0.028	10.0	30	2.4500	<0.002	198.75	5.79	6.55	9.3	0.05	NA	15.0

Site	Ammoniacal-nitrogen (mg/L)	Bicarbonate (mg/L)	Chloride (mg/L)	Conductivity field (us/cm)	Conductivity (Lab)	Dissolved boron (mg/L)	Dissolved calcium (mg/L)	Dissolved iron (mg/L)	Dissolved magnesium (mg/L)	Dissolved manganese (mg/L)	Dissolved Oxygen - field (mg/L)	Dissolved potassium (mg/L)	Dissolved Reactive Phosphorus (mg/L)	Dissolved sodium (mg/L)	*E. Coli*	Nitrate-nitrogen (mg/L)	Nitrite-nitrogen (mg/L)	ORP - Field (mV)	pH field	pH lab	Sulphate (mg/L)	Total Kjeldahl Nitrogen (mg/L)	Total Phosphorus (mg/L)	Water Temperature - field (C)
S26/0805	<0.01	87.0	104.5	645.0	63.9	0.042	40.0	<0.02	19.25	0.00155	2.32	7.25	0.063	54.5	1	4.7000	<0.002	145.75	6.005	6.55	54.5	0.31	NA	14.3
S26/0863	0.51	102.0	66.5	393.8	38.8	0.025	23.0	2.655	12.05	2.55000	0.28	1.34	0.800	32.0	3.25	0.0025	<0.002	-10.5	6.26	6.8	4.2	0.56	NA	14.5
S26/0889	<0.01	33.0	7.7	164.7	15.9	0.056	10.8	<0.02	2.55	0.00160	6.10	8.60	0.026	10.1	<1	4.2000	<0.002	209.65	5.67	6.2	15.9	0.16	NA	15.6
S26/0908	<0.01	16.0	6.8	101.7	9.9	0.013	5.2	<0.02	2.95	0.08500	3.47	0.89	0.007	8.3	18.5	2.4500	<0.002	221.9	5.11	5.65	10.4	0.48	NA	14.4
S26/1033	1.21	142.0	39.0	367.4	34.1	0.119	19.5	6.2	7.65	0.99000	0.31	1.19	0.500	40.0	<1	<0.02	<0.02	-2.955	6.61	7.2	0.8	1.32	NA	15.0
S26/1053	0.30	84.0	19.2	241.1	22.5	0.021	13.4	8.5	6.10	1.28500	0.33	1.26	0.325	18.3	<1	0.0065	0.0060	-9.15	6.175	6.55	14.4	0.41	NA	12.8
Spring 1	<0.01	20.0	6.5	91.3	8.7	NA	6.8	NA	1.95	NA	4.22	0.94	0.025	7.8	60	1.8900	<0.002	200.9	5.22	7.3	8.5	0.38	0.041	14.5
Spring 2	<0.01	18.1	6.4	87.7	9.1	NA	5.7	NA	1.92	NA	7.45	0.93	0.015	8.4	17.5	2.5500	<0.002	189.5	5.275	6.45	7.8	0.19	0.031	14.2
Spring 3	<0.01	21.5	6.8	123.4	12.1	NA	8.3	NA	3.60	NA	7.03	1.04	0.016	9.4	95	3.5500	<0.002	170.7	5.86	6.55	12.7	0.225	0.0245	13.9
Spring 4	<0.01	21.3	8.6	152.1	15.2	NA	10.5	NA	4.35	NA	7.36	1.87	0.027	10.7	6	6.8500	<0.002	174.2	5.455	6.1	13.9	0.155	0.03	15.1
Spring 5	<0.01	26.5	8.9	132.6	13.4	NA	8.9	NA	3.65	NA	6.41	1.42	0.021	11.2	5	3.4000	<0.002	169.2	5.475	6.3	12.4	0.19	0.024	13.9
Spring 6	<0.01	45.0	10.4	172.8	16.9	NA	10.2	NA	5.00	NA	6.66	2.20	0.030	16.0	10	3.7000	0.0020	159.2	5.77	6.5	16.0	0.17	0.03	13.6
Spring 7	0.06	46.5	11.0	157.9	15.9	NA	10.6	NA	5.15	NA	5.32	1.88	0.007	13.2	58	3.0500	0.0265	123.5	5.865	6.6	11.9	0.34	0.0165	15.0
T26/0302	0.10	133.0	28.5	319.7	30.5	0.026	16.9	0.19	10.45	1.29500	0.28	1.22	0.215	32.0	<1	0.0010	<0.002	28.95	6.525	7.1	6.4	0.1	NA	13.6
T26/0332	<0.01	55.4	44.2	299.7	28.9	0.020	17.0	<0.02	7.41	1.81100	0.36	1.36	0.037	26.6	<1	1.9400	<0.002	-30.4	5.495	6.395	17.0	NA	NA	14.0

Table A2-2: Chemistry results for the May-June 2023 sampling round

Site	Sampling date	Ammoniacal-nitrogen (mg/L)	Bicarbonate (mg/L)	Chloride (mg/L)	Conductivity field (us/cm)	Conductivity (Lab)	Dissolved boron (mg/L)	Dissolved calcium (mg/L)	Dissolved iron (mg/L)	Dissolved magnesium (mg/L)	Dissolved manganese (mg/L)	Dissolved Oxygen - field (mg/L)	Dissolved potassium (mg/L)	Dissolved Reactive Phosphorus (mg/L)	Dissolved sodium (mg/L)	*E. Coli*	Nitrate-nitrogen (mg/L)	Nitrite-nitrogen (mg/L)	ORP - Field (mV)	pH field	pH lab	Sulphate (mg/L)	Total Kjeldahl Nitrogen (mg/L)	Total Nitrogen (mg/L)	Total Phosphorus (mg/L)	Water Temperature - field (C)
BP34/0224	9/05/2023	5.8	60	60	727	69.6	0.192	43	< 0.02	16.2	1.73	0.01	6.3	0.014	47	3	43	< 0.002	163.2	5.24	6	18.5	NA	NA	NA	14.9
S26/0051	3/05/2023	< 0.010	16.1	6.5	82.1	8	0.013	5.7	0.18	1.85	0.043	6.88	0.78	< 0.004	7.7	< 1	2.7	< 0.002	261.4	5.33	5.8	4.3	NA	NA	NA	15.6
S26/0108	31/05/2023	< 0.010	61	9.7	162.8	15.8	0.018	8.1	< 0.02	3.7	0.0016	7.61	0.9	0.042	18.5	< 1	2	< 0.002	262.2	6.58	7	8	NA	NA	NA	13.5
S26/0155	3/05/2023	< 0.010	30	9.3	129.4	12.8	0.02	8.7	< 0.02	3.9	0.0012	5.17	1.57	0.021	10.2	< 1	3.2	< 0.002	262.1	5.52	6.2	9.7	NA	NA	NA	15.8
S26/0178	9/05/2023	< 0.010	29	9.2	105.7	10.2	0.02	6.8	< 0.02	2.6	0.0007	8.04	1.13	0.014	9.3	< 1	0.93	< 0.002	263.1	5.96	6.4	5.7	NA	NA	NA	16.3

Site	Sampling date	Ammoniacal-nitrogen (mg/L)	Bicarbonate (mg/L)	Chloride (mg/L)	Conductivity field (us/cm)	Conductivity (Lab)	Dissolved boron (mg/L)	Dissolved calcium (mg/L)	Dissolved iron (mg/L)	Dissolved magnesium (mg/L)	Dissolved manganese (mg/L)	Dissolved Oxygen - field (mg/L)	Dissolved potassium (mg/L)	Dissolved Reactive Phosphorus (mg/L)	Dissolved sodium (mg/L)	*E. Coli*	Nitrate-nitrogen (mg/L)	Nitrite-nitrogen (mg/L)	ORP - Field (mV)	pH field	pH lab	Sulphate (mg/L)	Total Kjeldahl Nitrogen (mg/L)	Total Nitrogen (mg/L)	Total Phosphorus (mg/L)	Water Temperature - field (C)
S26/0223	9/06/2023	<0.010	23.7	8.02	149.8	14.5	0.016	8.672	0.04	4.4	0.001813	8.02	1.043	9	10.57	26	5.41	<0.002	261.8	5.61	5.99	12.4	NA	NA	NA	14.6
S26/0230	3/05/2023	0.011	35	7.2	117.6	11.6	0.016	7.9	0.85	2.9	0.0186	6.16	1	0.005	10.9	< 1	2.1	0.007	180.7	5.73	6.3	8.6	NA	NA	NA	13.5
S26/0243	9/05/2023	< 0.010	37	9.2	138.9	13.4	0.047	9.1	< 0.02	3.7	0.0034	0.64	1.73	0.015	11.2	12	2.5	< 0.002	262.8	5.72	6.4	8.8	NA	NA	NA	15.3
S26/0245	3/05/2023	< 0.010	16.7	7.5	98.8	9.7	0.016	6.3	< 0.02	2.4	0.0033	7.37	1.27	0.019	8.9	< 1	3.2	< 0.002	260.4	5.33	5.8	7.1	NA	NA	NA	16.1
S26/0254	31/05/2023	< 0.010	29	6	115.3	11.2	0.019	6.2	< 0.02	3.2	< 0.0005	6.39	1.1	0.031	9.9	< 1	2.9	< 0.002	261	5.37	6.2	9.2	NA	NA	NA	15.4
S26/0264	1/06/2023	< 0.010	32	7.7	145.9	14.4	0.042	9.9	0.03	2.3	0.0122	1.75	7.2	0.016	8.8	2	4	< 0.002	261.6	5.55	6	11.6	NA	NA	NA	15.2
S26/0268	8/06/2023	< 0.010	66	9.5	185.8	18.1	0.056	11.4	< 0.02	5.4	0.0133	0.31	3.3	0.03	16.8	< 1	1.85	< 0.002	260.7	5.97	6.8	12.9	NA	NA	NA	15.4
S26/0277	18/05/2023	< 0.010	57	43	297.8	29	0.028	15.9	0.04	6.3	0.131	6.54	11.9	0.057	24	520	1.09	< 0.002	234.9	6.34	6.6	15.5	NA	NA	NA	11.3
S26/0290	8/06/2023	< 0.010	37	9.4	170.1	16.6	0.146	10.6	< 0.02	4.8	0.0011	3.67	1.67	0.024	14.1	< 1	5.5	< 0.002	260.7	5.52	6.2	13.1	NA	NA	NA	14.8
S26/0299	7/06/2023	<0.010	26.4	6.06	93	9.1	0.023	6.07	<0.02	2.0	0.001744	7.74	0.8916	0.024	7.77	<1.00	1.76	<0.002	2624	5.3	6.05	5.8	NA	NA	NA	15
S26/0300	18/05/2023	< 0.010	30	7.4	138.2	13.3	0.193	9.2	< 0.02	3.3	0.0023	6.75	1.86	0.023	10.3	< 1	2.9	< 0.002	262.3	5.24	6.1	12.5	NA	NA	NA	15.4
S26/0659	31/05/2023	< 0.010	151	32	366.1	35.6	0.071	33	0.09	8.9	1.1	0.33	2.8	0.023	25	< 1	0.051	0.003	260.1	6.21	6.8	12.7	NA	NA	NA	14.6
S26/0762	6/06/2023	0.50	124.3	39.26	344.7	33.2	0.059	20.57	6.6	5.608	0.8209	0.32	1.921	0.576	35.48	<1.00	<0.0200	<0.02	263	6.31	6.67	2.4	NA	NA	NA	13.7
S26/0773	8/06/2023	< 0.010	53	14.1	195.6	19	0.083	11.3	< 0.02	6	0.0071	3	2.6	< 0.004	17.2	< 1	1.31	< 0.002	261.2	5.79	6.6	19.6	NA	NA	NA	15.8
S26/0804	9/05/2023	< 0.010	26	8.4	113.9	11.3	0.02	8	< 0.02	2.9	0.0008	5.54	1.47	0.042	9.2	140	2.3	< 0.002	263.5	5.95	6.4	9.5	NA	NA	NA	15.2
S26/0805	9/05/2023	< 0.010	73	90	589	58.3	0.042	34	0.06	17.5	0.0015	3.24	6.8	0.09	47	12	4	< 0.002	262.4	6.09	6.5	54	NA	NA	NA	14.9
S26/0863	1/06/2023	0.52	102	67	394	38.6	0.024	23	1.76	11.5	2.3	0.3	1.29	0.84	29	< 1	< 0.002	< 0.002	261.8	6.39	6.6	4.3	NA	NA	NA	13.9
S26/0889	18/05/2023	< 0.010	32	7.7	158.4	15.5	0.064	10.6	< 0.02	2.5	0.001	5.95	8.8	0.03	10.1	< 1	3.9	< 0.002	262.5	5.89	6.3	17.8	NA	NA	NA	14.8
S26/0908	3/05/2023	< 0.010	13.3	5.6	86.2	8.6	0.012	4.1	< 0.02	2.6	0.08	0.32	0.88	0.007	7.9	35	2.3	< 0.002	273.1	5.24	5.6	11.1	NA	NA	NA	14.9
S26/1033	19/05/2023	1.23	143	41	367.9	34.5	0.114	19.1	6.1	7.6	0.99	0.32	1.21	0.41	40	< 1	< 0.02	< 0.02	263	6.69	6.9	< 0.5	NA	NA	NA	14.5
S26/1053	1/06/2023	0.39	92	20	244.6	23.5	0.02	13.2	8.6	5.6	1.32	3.3	1.27	0.43	18.6	< 1	0.003	0.002	263.1	6.28	6.6	12.8	NA	NA	NA	14.8
Spring 1	2/05/2023	< 0.010	20	6.5	91.3	8.7	NA	6.8	NA	1.95	NA	4.22	0.94	0.025	7.8	60	1.89	< 0.002	200.9	5.22	7.3	8.5	0.38	2.3	0.041	14.7
Spring 2	2/05/2023	< 0.010	14	6.4	86.3	8.1	NA	5.5	NA	1.73	NA	6.78	0.93	0.071	8.3	15	2.4	< 0.002	182.5	5.14	7	7.5	0.25	2.7	0.079	14.3
Spring 3	2/05/2023	< 0.010	22	7.4	124.4	11.8	NA	8.6	NA	3.7	NA	6.44	1.24	0.021	9.7	110	3.5	< 0.002	170.7	5.74	7.3	13.8	0.26	3.7	0.025	15.3

Site	Sampling date	Ammoniacal-nitrogen (mg/L)	Bicarbonate (mg/L)	Chloride (mg/L)	Conductivity field (us/cm)	Conductivity (Lab)	Dissolved boron (mg/L)	Dissolved calcium (mg/L)	Dissolved iron (mg/L)	Dissolved magnesium (mg/L)	Dissolved manganese (mg/L)	Dissolved Oxygen - field (mg/L)	Dissolved potassium (mg/L)	Dissolved Reactive Phosphorus (mg/L)	Dissolved sodium (mg/L)	*E. Coli*	Nitrate-nitrogen (mg/L)	Nitrite-nitrogen (mg/L)	ORP - Field (mV)	pH field	pH lab	Sulphate (mg/L)	Total Kjeldahl Nitrogen (mg/L)	Total Nitrogen (mg/L)	Total Phosphorus (mg/L)	Water Temperature - field (C)
Spring 4	2/05/2023	< 0.010	19.3	9.3	155.7	15.2	NA	11.1	NA	4.6	NA	7.24	1.64	0.02	10.7	6	7.2	< 0.002	174.2	5.42	6.1	14.3	0.18	7.4	0.021	14.7
Spring 5	2/05/2023	< 0.010	26	10.2	139.6	13.8	NA	9.2	NA	3.6	NA	5.45	1.63	0.026	11.5	10	3.7	< 0.002	151.8	5.52	7.4	13	0.19	3.9	0.026	14.8
Spring 6	2/05/2023	< 0.010	41	11	172.8	16.7	NA	10.2	NA	4.8	NA	6.78	2.2	0.03	16	10	3.7	0.002	159.2	5.68	7.5	16.4	0.17	3.9	0.03	15.8
Spring 7	2/05/2023	0.065	48	12.3	176.8	17.3	NA	13.7	NA	5.4	NA	4.64	2.3	0.01	13.3	60	3.4	0.018	187.2	5.69	7.6	12.4	0.48	3.9	0.019	17.3
T26/0302	18/05/2023	0.102	135	29	315.2	30.5	0.026	16.5	0.16	10.5	1.29	0.29	1.25	0.22	31	< 1	< 0.002	< 0.002	262.4	6.64	7.2	6.5	NA	NA	NA	14.6
T26/0332	26/06/2023	<0.010	55.67	42.7	292.3	28.6	0.019	15.92	<0.0200	7.1	1.647	0.36	1.283	0.037	25	<1.00	1.91	<0.002	83.2	5.71	6.82	16.0	NA	NA	NA	14.4

Table A2-3: Chemistry results for the Aug-Sept 2023 sampling round

Site	Sampling date	Ammoniacal-nitrogen (mg/L)	Bicarbonate (mg/L)	Chloride (mg/L)	Conductivity field (us/cm)	Conductivity (Lab)	Dissolved boron (mg/L)	Dissolved calcium (mg/L)	Dissolved iron (mg/L)	Dissolved magnesium (mg/L)	Dissolved manganese (mg/L)	Dissolved Oxygen - field (mg/L)	Dissolved potassium (mg/L)	Dissolved Reactive Phosphorus (mg/L)	Dissolved sodium (mg/L)	*E. Coli*	Nitrate-nitrogen (mg/L)	Nitrite-nitrogen (mg/L)	ORP - Field (mV)	pH field	pH lab	Sulphate (mg/L)	Total Kjeldahl Nitrogen (mg/L)	Total Nitrogen (mg/L)	Total Phosphorus (mg/L)	Water Temperature - field (C)
BP34/0224	25/08/2023	6.2	79	58	672	65.7	0.16	39	< 0.02	15.7	1.76	0.26	6.2	0.012	44	2	38	< 0.002	264.1	5.67	6	17.1	7.8	NA	NA	13.5
S26/0051	22/08/2023	< 0.010	23	4.7	81.3	7.3	0.012	4.8	0.9	1.0	0.26	6.85	0.52	< 0.004	5	8	0.51	< 0.002	242	5.09	6.6	2.4	0.11	NA	NA	13.9
S26/0155	25/08/2023	< 0.010	32	9.4	133.8	13	0.015	8.5	< 0.02	3.9	< 0.0005	6.41	1.46	0.018	9.3	< 1	3.1	< 0.002	126.7	5.73	7.4	9.1	0.2	NA	NA	13.3
S26/0178	25/08/2023	< 0.010	48	11.4	137	13.1	0.027	7.6	< 0.02	2.9	< 0.0005	9.69	0.89	0.012	14.8	< 1	1.5	< 0.002	667.3	6.72	7.4	4.5	< 0.10	NA	NA	9.2
S26/0223	21/09/2023	< 0.010	25.5	9.11	161.2	14.8	0.014	9.481	0.046	4.5	0.008	7.67	1.04	0.014	11.37	5	5.77	< 0.002	316	5.37	6.05	13.33	NA	NA	NA	14.8
S26/0230	21/08/2023	< 0.010	37	6.5	122.4	12.7	0.017	8.1	1.02	2.8	0.024	5.34	1.04	0.007	10.8	< 1	2	0.006	160.7	5.73	6.3	7.8	< 0.10	NA	NA	13.3
S26/0243	23/08/2023	< 0.010	39	8.9	144.7	14	0.043	9.1	< 0.02	3.7	0.0016	1.23	1.49	0.015	11.1	< 1	3.3	< 0.002	211	5.75	6.3	7.9	0.22	NA	NA	10.2
S26/0245	23/08/2023	< 0.010	19.4	7	107.5	10.7	0.014	6.2	< 0.02	2.3	0.004	6.62	1.31	0.019	8.8	< 1	3.7	< 0.002	232	4.91	6	6	0.18	NA	NA	13
S26/0254	24/08/2023	< 0.010	29	5.6	117.9	10.8	0.016	6.3	< 0.02	3.3	0.0007	6.8	1.1	0.025	9.6	< 1	3	< 0.002	189.4	5.57	6.6	8.3	0.11	NA	NA	13.6
S26/0264	25/08/2023	< 0.010	31	7.5	160.3	15.5	0.04	10.8	< 0.02	2.7	0.0021	2.73	7.1	0.006	9.5	< 1	5.9	< 0.002	209.4	5.6	6.7	11.7	0.19	NA	NA	12.4
S26/0268	24/08/2023	< 0.010	63	8.9	194.1	17.9	0.05	11.2	< 0.02	5.2	0.024	0.08	3.1	0.026	16.4	< 1	2.7	< 0.002	199.2	6.07	6.8	13.9	0.2	NA	NA	13.5
S26/0277	24/08/2023	< 0.010	55	46	316.3	29.3	0.023	15	< 0.02	6.8	0.062	7.46	9.3	0.044	26	5	1.63	< 0.002	203.2	6.17	7.2	15.6	0.26	NA	NA	8.1
S26/0290	23/08/2023	< 0.010	40	8.8	172.8	16.7	0.141	10.6	< 0.02	4.5	0.001	3.65	1.54	0.022	13.1	< 1	5.4	< 0.002	234.5	5.58	6.5	12.1	< 0.10	NA	NA	11.6
S26/0299	20/09/2023	< 0.010	28.5	6.4	104.2	9.3	0.020	6.612	< 0.02	2.1	0.002	8.27	0.88	0.020	8.08	<1.00	2.18	< 0.002	278.7	5.65	6.93	5.919	NA	NA	NA	13

Site	Sampling date	Ammoniacal-nitrogen (mg/L)	Bicarbonate (mg/L)	Chloride (mg/L)	Conductivity field (us/cm)	Conductivity (Lab)	Dissolved boron (mg/L)	Dissolved calcium (mg/L)	Dissolved iron (mg/L)	Dissolved magnesium (mg/L)	Dissolved manganese (mg/L)	Dissolved Oxygen - field (mg/L)	Dissolved potassium (mg/L)	Dissolved Reactive Phosphorus (mg/L)	Dissolved sodium (mg/L)	*E. Coli*	Nitrate-nitrogen (mg/L)	Nitrite-nitrogen (mg/L)	ORP - Field (mV)	pH field	pH lab	Sulphate (mg/L)	Total Kjeldahl Nitrogen (mg/L)	Total Nitrogen (mg/L)	Total Phosphorus (mg/L)	Water Temperature - field (C)
S26/0300	24/08/2023	< 0.010	29	7	129.8	11.8	0.11	8.3	< 0.02	3.0	0.002	6.89	1.64	0.02	9.3	< 1	2.8	< 0.002	214.2	5.49	6.6	11.6	0.15	NA	NA	13.1
S26/0568	19/09/2023	0.43	152.1	13.1	299.4	259.3	0.0207	20.84	3.23	9.2	0.78	0.3	1.18	0.96	21.54	NA	< 0.02	<0.0200	110.9	6.83	7.48	<0.5	NA	NA	NA	13.7
S26/0659	22/08/2023	< 0.010	148	30	344.6	35.7	0.071	31	0.12	9.1	1.22	0.13	2.80	0.02	27	< 1	0.71	< 0.002	140.5	6	6.7	12.4	0.18	NA	NA	13.4
S26/0762	19/09/2023	0.51	125.5	43.1	393.6	346.6	0.058	21.58	7.36	6.6	0.9208	0.33	2.00	0.89	36.78	<1.00	<0.0200	< 0.002	130.6	6.25	6.85	5.002	NA	NA	NA	14
S26/0773	22/08/2023	< 0.010	53	14.3	189.9	19.6	0.075	11	< 0.02	6.1	0.0063	1.58	2.5	0.005	17.1	< 1	1.67	< 0.002	202.4	5.7	6.2	21	0.18	NA	NA	14.3
S26/0804	24/08/2023	< 0.010	33	8.7	138.5	12.5	0.019	8.4	< 0.02	3.5	0.0007	3.73	1.44	0.028	10	2	3.1	< 0.002	170.3	5.78	6.8	9.4	0.11	NA	NA	11.7
S26/0805	22/08/2023	< 0.010	82	92	565	58.2	0.04	31	< 0.02	16.9	0.0006	3.83	7.3	0.07	51	1	5.2	< 0.002	184	6.12	6.5	50	0.35	NA	NA	13.6
S26/0863	22/08/2023	0.53	100	68	378.5	38.9	0.024	22	1.81	11.5	2.5	0	1.3	0.84	32	6	< 0.002	< 0.002	-71.9	6.42	6.7	4.4	0.57	NA	NA	13.7
S26/0889	23/08/2023	< 0.010	32	6.7	134	15	0.055	10	< 0.02	2.3	0.0006	6.19	8	0.027	9.3	< 1	3.7	< 0.002	215.3	5.81	6.2	16.2	0.16	NA	NA	12.8
S26/0908	23/08/2023	< 0.010	15.1	5.5	96.8	9.4	0.01	4.6	< 0.02	2.7	0.059	0.35	0.79	0.006	7.5	2	2.6	< 0.002	239.8	4.98	5.6	9.7	0.14	NA	NA	11.6
S26/1033	1/09/2023	1.24	145	37	366.8	33.9	0.123	19.3	6.3	8	0.96	0.06	1.18	0.47	40	< 1	< 0.02		-100.5	6.71	7.8	0.5	1.44	NA	NA	13.9
S26/1053	1/09/2023	0.32	86	19.3	240.9	21	0.022	13.6	8.8	6.4	1.33	0.05	1.24	0.115	18.6	< 1	< 0.02	< 0.02	-32.1	6.26	7.4	14.5	0.45	NA	NA	13.3
Spring 2	31/08/2023	< 0.010	17.8	5.9	89.6	8.9	NA	5.5	NA	1.92	NA	5.19	0.83	0.009	7.7	20	2.6	< 0.002	189.5	5.23	5.8	8.1	0.13	2.7	0.013	11.3
Spring 3	31/08/2023	< 0.010	21	6.5	122.9	12.4	NA	7.9	NA	3.5	NA	8.92	1.04	0.013	9.1	80	4.1	< 0.002	155.9	5.7	6.3	13.9	0.19	4.2	0.024	11.9
Spring 4	31/08/2023	< 0.010	24	7.9	149.6	14.9	NA	10.1	NA	4.3	NA	7.3	1.35	0.015	10.7	8	5.9	< 0.002	173.4	5.37	5.9	16.1	0.13	6	0.017	10.9
Spring 5	31/08/2023	< 0.010	31	8.6	136.8	13.5	NA	8.9	NA	3.7	NA	5.34	1.39	0.017	10.8	< 10	3.5	< 0.002	169.2	5.41	6	12.4	0.32	3.8	0.019	10.7
Spring 6	31/08/2023	< 0.010	49	9.3	172.9	17.8	NA	10.1	NA	5.1	NA	6.66	2.1	0.025	16	1200	3.8	0.002	150.7	5.77	6.2	16	0.17	4	0.024	12.3
Spring 7	31/08/2023	0.02	45	10.9	161.1	16	NA	10.6	NA	5.1	NA	6.01	1.31	< 0.004	11.9	< 10	3.1	0.006	123.5	5.77	6.3	11.5	0.24	3.4	0.006	11.7
T26/0302	24/08/2023	0.095	133	28	324.2	30.1	0.025	16	0.22	10.2	1.26	0.02	1.22	0.21	32	< 1	< 0.002	< 0.002	-23.8	6.67	7.6	6.2	0.1	NA	NA	14.2
T26/0332	28/09/2023	< 0.010	54.9	47.47	317.1	29.2	0.020	16.98	< 0.02	7.5	1.769	0.35	1.35	0.040	26.72	<1.00	2.12	< 0.002	20.3	5.53	6.16	17.81	NA	NA	NA	14.4

Table A2-4: Chemistry results for the Nov-Dec 2023 sampling round

Site	Sampling date	Ammoniacal-nitrogen (mg/L)	Bicarbonate (mg/L)	Chloride (mg/L)	Conductivity field (us/cm)	Conductivity (Lab)	Dissolved boron (mg/L)	Dissolved calcium (mg/L)	Dissolved iron (mg/L)	Dissolved magnesium (mg/L)	Dissolved manganese (mg/L)	Dissolved Oxygen - field (mg/L)	Dissolved potassium (mg/L)	Dissolved Reactive Phosphorus (mg/L)	Dissolved sodium (mg/L)	*E. Coli*	Nitrate-nitrogen (mg/L)	Nitrite-nitrogen (mg/L)	ORP - Field (mV)	pH field	pH lab	Sulphate (mg/L)	Total Kjeldahl Nitrogen (mg/L)	Total Nitrogen (mg/L)	Total Phosphorus (mg/L)	Water Temperature - field (C)
BP34/0224	29/11/2023	4.4	61	59	490.3	48.8	0.21	29	0.03	10.9	1.16	1.26	5.6	0.012	40	< 1	16.3	< 0.002	67.5	5.26	5.9	22	5.4	NA	NA	12.8
S26/0051	28/11/2023	< 0.010	26	4.4	60.3	5.7	0.014	5.9	0.12	1.09	0.0161	10.11	0.4	< 0.004	4.5	180	0.011	< 0.002	160	7.1	7.5	2.3	0.11	NA	NA	16
S26/0108	30/11/2023	< 0.010	63	8.5	162	16	0.018	8.1	< 0.02	3.7	0.008	7.74	0.9	0.045	19.1	< 1	1.97	< 0.002	117.8	6.57	7.1	7	< 0.10	NA	NA	15
S26/0155	28/11/2023	< 0.010	34	8.9	133.5	13.2	0.018	9.4	< 0.02	4.2	0.001	6.46	1.54	0.015	10.5	< 1	3.2	< 0.002	95.6	5.84	6.6	8.7	< 0.10	NA	NA	14
S26/0178	28/11/2023	< 0.010	107	12.9	263.3	26.1	0.041	11.5	< 0.02	4.6	0.0008	6.01	1.3	0.012	43	< 1	4.5	< 0.002	137	7.02	7.8	8.8	< 0.10	NA	NA	17.2
S26/0223	6/12/2023	< 0.010	26.2	9.73	158	15.8	0.016	10.7	0.095	5.281	0.0086	7.22	1.2	0.0085	12.5	1	6.83	< 0.002	281.6	5.6	5.93	11.6	NA	NA	NA	14.8
S26/0230	28/11/2023	0.015	48	7.3	134.3	13	0.018	9.1	1.22	3.1	0.023	4.31	1.01	< 0.004	13.5	< 1	1.75	0.007	69.1	6.12	6.8	7	< 0.10	NA	NA	13.7
S26/0243	1/12/2023	< 0.010	42	8.2	144.7	14.3	0.053	9.2	< 0.02	3.9	0.0057	1.55	1.7	0.015	11.9	< 1	3.2	< 0.002	150.8	5.48	7.4	8.8	0.17	NA	NA	13.4
S26/0245	29/11/2023	< 0.010	19.5	6.8	107.6	10.6	0.014	7.1	< 0.02	2.7	0.0046	7.86	1.32	0.016	9.4	< 1	3.8	< 0.002	155.7	5.11	5.9	5.8	0.15	NA	NA	14.3
S26/0254	1/12/2023	< 0.010	30	5.8	125.7	12.5	0.019	7.8	< 0.02	3.9	0.0014	5.97	1.18	0.026	10.2	< 1	3.9	< 0.002	175.4	5.56	6.1	9.1	< 0.10	NA	NA	14.4
S26/0268	30/11/2023	< 0.010	64	9.5	198.6	19.6	0.053	12	< 0.02	5.4	0.0049	0.41	3.2	0.028	17.8	< 1	3.4	< 0.002	2.5	5.87	6.3	14.4	0.15	NA	NA	13.7
S26/0277	1/12/2023	< 0.010	67	41	300.8	29.4	0.026	19	0.03	6.2	0.031	7.55	11.2	0.045	24	4	0.75	< 0.002	248.3	6.24	6.9	17.5	0.27	NA	NA	14.3
S26/0290	1/12/2023	< 0.010	36	10	177.2	17.7	0.173	11.9	< 0.02	4.9	0.0014	5.22	1.75	0.021	13.9	< 1	6	< 0.002	174.8	5.39	6	12.8	0.14	NA	NA	14
S26/0299	5/12/2023	< 0.010	29.1	4.92	99.4	9.8	0.025	7.4	< 0.02	2.513	0.0016	8.04	1.0	0.0198451	9.1	<1.00	2.59	< 0.002	127.3	5.15	7.22	5.1	NA	NA	NA	13.5
S26/0300	1/12/2023	< 0.010	17.1	9.2	210.8	21.1	0.29	16.2	< 0.02	5.4	0.0115	5.95	2.3	0.017	13.3	< 1	10.1	< 0.002	145.5	5.13	5.7	14.4	0.16	NA	NA	15.4
S26/0659	1/12/2023	< 0.010	146	30	359.3	36.1	0.068	33	0.09	9	1.19	0.35	2.8	0.016	26	< 1	0.015	< 0.002	61.2	5.96	6.8	11.2	0.15	NA	NA	15
S26/0762	4/12/2023	0.47	128.3	40.49	358.4	33.7	0.066	22.1	7.56	6.493	0.9544	0.34	2.1	< 0.004	36.5	<1.00	< 0.002	< 0.002	-31.9	6.18	6.82	3.6	NA	NA	NA	13.6
S26/0773	1/12/2023	< 0.010	55	15	198.7	19.9	0.072	11.6	0.03	6.2	0.0091	2.17	2.4	< 0.004	16.8	< 1	1.26	< 0.002	130.6	5.64	6.3	18.6	0.44	NA	NA	14
S26/0804	28/11/2023	< 0.010	33	7.7	124.8	12.3	0.021	8.5	< 0.02	3.7	0.0005	4.35	1.53	0.025	10.7	34	2.6	< 0.002	59.6	5.8	6.7	9.1	< 0.10	NA	NA	13.3
S26/0805	29/11/2023	< 0.010	92	117	701	69.4	0.043	46	< 0.02	22	0.0016	1.4	7.5	0.056	58	1	5	< 0.002	107.5	5.79	6.6	55	0.31	NA	NA	13.6
S26/0863	29/11/2023	0.49	102	64	393.6	39.1	0.027	25	3.7	12.6	2.6	0.4	1.38	0.68	32	< 1	0.054	< 0.002	50.9	6.13	6.9	3.5	0.56	NA	NA	13.9
S26/0889	1/12/2023	< 0.010	34	7.6	171	17	0.057	12.5	< 0.02	2.8	0.0022	6.01	9	0.022	10.3	< 1	5.8	< 0.002	149.7	5.53	6.2	14.2	0.16	NA	NA	13.1
S26/0908	29/11/2023	< 0.010	16.9	7.9	106.5	10.4	0.013	5.7	< 0.02	3.4	0.09	6.59	0.9	0.006	8.8	< 1	2.9	< 0.002	19.8	4.95	5.7	9.2	0.48	NA	NA	13.3

Site	Sampling date	Ammoniacal-nitrogen (mg/L)	Bicarbonate (mg/L)	Chloride (mg/L)	Conductivity field (us/cm)	Conductivity (Lab)	Dissolved boron (mg/L)	Dissolved calcium (mg/L)	Dissolved iron (mg/L)	Dissolved magnesium (mg/L)	Dissolved manganese (mg/L)	Dissolved Oxygen - field (mg/L)	Dissolved potassium (mg/L)	Dissolved Reactive Phosphorus (mg/L)	Dissolved sodium (mg/L)	*E. Coli*	Nitrate-nitrogen (mg/L)	Nitrite-nitrogen (mg/L)	ORP - Field (mV)	pH field	pH lab	Sulphate (mg/L)	Total Kjeldahl Nitrogen (mg/L)	Total Nitrogen (mg/L)	Total Phosphorus (mg/L)	Water Temperature - field (C)
S26/1033	30/11/2023	1.19	141	36	364	34.2	0.114	19.6	6.5	7.3	1	0.34	1.14	0.69	40	< 1	< 0.02	< 0.02	25.1	6.53	7	1.1	1.32	NA	NA	13.8
S26/1053	30/11/2023	0.28	82	17.8	234.4	22.5	0.02	13.6	8.4	6	1.25	0.34	1.24	0.39	17.8	< 1	< 0.02	< 0.02	13.8	6.09	6.5	14.3	0.41	NA	NA	13.6
Spring 2	6/12/2023	< 0.010	18.3	6.3	89	9.2	NA	5.8	NA	1.93	NA	8.11	0.92	0.013	8.4	< 1	2.5	< 0.002	267.7	5.32	6.3	7.1	< 0.10	2.6	0.013	14.3
Spring 3	6/12/2023	0.02	26	7.1	123.8	12.6	NA	8.9	NA	4	NA	7.62	1.03	0.019	10.5	200	3.6	0.006	244.2	5.98	6.8	11.5	0.29	3.9	0.03	17.5
Spring 4	6/12/2023	< 0.010	23	8.2	149.8	15.1	NA	10.5	NA	4.3	NA	7.42	2.1	0.033	10.2	6	6.5	< 0.002	235.9	5.49	6.5	13.2	0.13	6.6	0.039	15.3
Spring 5	6/12/2023	< 0.010	27	8.8	128.3	13.2	NA	8.9	NA	3.7	NA	7.37	1.45	0.025	11	< 1	3.3	< 0.002	241.4	5.43	6.1	11.7	0.19	3.5	0.023	13.9
Spring 6	6/12/2023	< 0.010	45	10.4	166.8	16.9	NA	11.3	NA	5	NA	2.45	2.2	0.036	15.3	8	3.2	0.008	208.4	5.96	6.5	14.3	0.22	3.5	0.041	15.6
Spring 7	6/12/2023	0.181	52	11.1	154.7	15.7	NA	10.5	NA	5.2	NA	1.43	2.9	0.008	13.4	56	0.96	0.071	113.2	5.96	6.5	11	0.37	1.4	0.014	16.6
T26/0302	30/11/2023	0.098	133	27	312.9	30.4	0.026	17.2	0.19	10.4	1.34	0.29	1.2	0.22	32	< 1	0.052	< 0.002	81.7	6.41	7	6	0.1	NA	NA	14.4
T26/0332	4/12/2023	< 0.010	55.2	45.6	295.9	29.3	0.021	16.9	< 0.02	7.272	1.853	0.3	1.466	0.037	26.4	<1.00	1.97	0.00224	-81.1	5.27	6.16	17.0	NA	NA	NA	14.3

Table A2-5: Chemistry results for the Feb-March 2024 sampling round

Site	Sampling date	Ammoniacal-nitrogen (mg/L)	Bicarbonate (mg/L)	Chloride (mg/L)	Conductivity field (us/cm)	Conductivity (Lab)	Dissolved boron (mg/L)	Dissolved calcium (mg/L)	Dissolved iron (mg/L)	Dissolved magnesium (mg/L)	Dissolved manganese (mg/L)	Dissolved Oxygen - field (mg/L)	Dissolved potassium (mg/L)	Dissolved Reactive Phosphorus (mg/L)	Dissolved sodium (mg/L)	*E. Coli*	Nitrate-nitrogen (mg/L)	Nitrite-nitrogen (mg/L)	ORP - Field (mV)	pH field	pH lab	Sulphate (mg/L)	Total Kjeldahl Nitrogen (mg/L)	Total Nitrogen (mg/L)	Total Phosphorus (mg/L)	Water Temperature - field (C)
BP34/0224	5/03/2024	3.5	93	46	537	49.8	0.137	32	< 0.02	14	1.13	1.52	5.3	0.013	36	5	22	0.006	-370	5.4	6.1	18.9	4.7	NA	NA	14.5
S26/0108	29/02/2024	< 0.010	68	9.3	175.2	16.2	0.019	7.8	< 0.02	3.8	0.0011	7.49	0.88	0.054	19.7	< 1	1.63	< 0.002	137.6	6.55	7.2	6.9	< 0.10	NA	NA	15
S26/0155	27/02/2024	< 0.010	31	9.6	139.1	12.8	0.02	8.2	< 0.02	4.3	0.0017	6.3	1.54	0.02	11	< 1	2.8	< 0.002	58.9	5.12	6.7	9.1	< 0.10	NA	NA	14.6
S26/0178	28/02/2024	< 0.010	112	14.1	290.9	26.9	0.039	10.7	< 0.02	4.2	< 0.0005	5.9	1.25	0.016	43	< 1	4.1	< 0.002	39.7	7.08	7.8	8.6	< 0.10	NA	NA	18.9
S26/0223	6/03/2024	0.053	31.3	11.1	181.4	17.0	0.017	11.4	0.15	5.557	0.02033	5.58	1.2	0.009	13.71	200	5.95	< 0.002	215.2	5.35	6.02	12.1	NA	NA	NA	16.8
S26/0230	27/02/2024	0.013	44	7.8	132.2	12.4	0.016	8.1	1.37	3	0.024	5.01	0.99	< 0.004	12.6	< 1	1.68	0.006	28.5	5.23	6.9	6.3	< 0.10	NA	NA	13.7
S26/0243	26/02/2024	< 0.010	40	9.2	162.5	15	0.074	9.7	< 0.02	4.4	0.004	2.61	1.77	0.016	13	2	3.9	< 0.002	172.5	5.38	6.2	9.7	0.13	NA	NA	16.5
S26/0245	29/02/2024	< 0.010	16.8	8.3	115.1	10.8	0.013	6.2	< 0.02	2.4	0.0029	8.97	1.26	0.017	8.7	< 1	4.3	< 0.002	133.2	4.9	5.8	6.8	< 0.10	NA	NA	15.1
S26/0254	26/02/2024	< 0.010	33	6.9	132.4	12.4	0.022	7	< 0.02	3.7	0.005	4.48	1.14	0.025	11.9	< 1	2.4	< 0.002	175.3	5.41	6.2	11.5	< 0.10	NA	NA	16.3
S26/0268	28/02/2024	< 0.010	68	12.1	216.4	20.2	0.061	12.7	< 0.02	5.7	0.0022	0.75	3.4	0.028	19.3	< 1	2.4	< 0.002	-51.5	5.81	6.4	14.6	0.13	NA	NA	15.3

Site	Sampling date	Ammoniacal-nitrogen (mg/L)	Bicarbonate (mg/L)	Chloride (mg/L)	Conductivity field (us/cm)	Conductivity (Lab)	Dissolved boron (mg/L)	Dissolved calcium (mg/L)	Dissolved iron (mg/L)	Dissolved magnesium (mg/L)	Dissolved manganese (mg/L)	Dissolved Oxygen - field (mg/L)	Dissolved potassium (mg/L)	Dissolved Reactive Phosphorus (mg/L)	Dissolved sodium (mg/L)	*E. Coli*	Nitrate-nitrogen (mg/L)	Nitrite-nitrogen (mg/L)	ORP - Field (mV)	pH field	pH lab	Sulphate (mg/L)	Total Kjeldahl Nitrogen (mg/L)	Total Nitrogen (mg/L)	Total Phosphorus (mg/L)	Water Temperature - field (C)
S26/0277	4/03/2024	< 0.010	60	38	291.9	26.6	0.029	15.6	< 0.02	5.7	0.049	7.74	9.2	0.054	24	51	1.22	< 0.002	84.8	6.38	7	15.4	0.2	NA	NA	18.3
S26/0290	27/02/2024	< 0.010	30	10.7	167.2	15.5	0.185	9.3	< 0.02	4.2	0.0011	7.46	1.75	0.024	14.4	< 1	4	< 0.002	125.8	4.85	6.5	14.5	0.1	NA	NA	18.4
S26/0299	8/03/2024	< 0.010	30.2	5.7	105.9	10	0.026	7.3	< 0.02	2.343	0.004964	6.91	1.019	0.020	8.909	<1.00	2.09	< 0.002	119.4	5.37	6.26	6.1	NA	NA	NA	15
S26/0300	28/02/2024	< 0.010	30	10.5	172.6	16.2	0.31	11.3	< 0.02	4.1	0.0025	7.75	2.1	0.022	12.6	< 1	4.9	< 0.002	110	5.22	6	14.5	0.12	NA	NA	15.1
S26/0659	29/02/2024	< 0.010	158	21	393.6	36.2	0.082	32	< 0.02	9.4	0.99	0.31	4.3	0.022	28	< 1	2.7	0.051	-294.4	5.72	6.5	14	0.26	NA	NA	15.9
S26/0733	27/02/2024	0.036	46	42	237.8	22.3	0.023	9.4	0.07	5.7	0.24	0.65	1.29	0.054	29	1	0.21	< 0.002	-6.2	5.1	7	3.7	< 0.10	NA	NA	15
S26/0762	4/03/2024	0.48	122.8	43.8	388.7	33.8	0.062	22.7	7.22	6.796	0.9142	0.39	2.009	0.269	36.58	<1.00	< 0.02	< 0.02	-248.1	5.98	6.74	4.5	NA	NA	NA	13.6
S26/0773	27/02/2024	< 0.010	56	15.9	207.2	19.1	0.066	11	0.02	6.7	0.023	0.78	2.2	< 0.004	18.6	< 1	1.13	< 0.002	-31.5	5.05	6.8	18	0.13	NA	NA	18.5
S26/0804	26/02/2024	< 0.010	37	8.8	118.6	11	0.023	7	< 0.02	3.2	0.0009	3.39	1.43	0.028	9.9	26	0.51	< 0.002	227.2	5.49	6.3	7.2	< 0.10	NA	NA	16
S26/0805	26/02/2024	< 0.010	98	119	758	70.1	0.043	46	< 0.02	21	0.0166	0.69	7.2	0.054	59	1	4.4	0.009	82	5.92	6.6	57	0.29	NA	NA	14.1
S26/0863	27/02/2024	0.5	102	66	417.4	37.5	0.025	23	3.5	12.6	2.7	0.25	1.38	0.76	34	17	0.004	< 0.002	-246.6	5.51	7.3	4.1	0.53	NA	NA	14.1
S26/0889	29/02/2024	< 0.010	35	8.2	173.9	16.2	0.055	11	< 0.02	2.6	0.008	6.19	8.4	0.024	10.1	< 1	4.5	< 0.002	204	5.21	6.2	15.5	0.12	NA	NA	14.3
S26/0908	29/02/2024	0.038	28	8.1	117	11.2	0.015	6.4	< 0.02	3.2	0.2	7.08	1.02	0.018	8.6	80	1.54	0.003	204	5.42	6.3	11.3	0.6	NA	NA	16
S26/1033	28/02/2024	1.19	141	41	385.7	33.4	0.126	19.7	6	7.7	0.99	0.3	1.22	0.53	40	< 1	< 0.02	< 0.02	-31.01	6.48	7.4	1.4	1.31	NA	NA	14.1
S26/1053	28/02/2024	0.172	71	19	241.3	22.4	0.025	13	6.3	6.2	1.08	0.32	1.41	0.26	18	< 1	< 0.002	< 0.002	-265.7	5.72	6.4	22	0.31	NA	NA	15.3
Spring 2	13/03/2024	0.034	30	8.3	76.5	12.4	NA	8.1	NA	3.7	NA	8.66	1	0.017	10.6	800	2.6	0.006	NA	5.57	6.6	11.4	0.46	3	0.049	15.7
Spring 3	13/03/2024	< 0.010	16.5	6.1	122.4	7.8	NA	4.4	NA	1.53	NA	5.69	0.91	0.009	8.3	< 10	1.89	< 0.002	NA	6.33	6	6.6	< 0.10	1.97	0.017	17.8
Spring 4	13/03/2024	0.013	19.6	9	154.3	15.5	NA	10.4	NA	4.4	NA	6.61	2.7	0.048	11.3	< 10	7.3	0.003	NA	5.52	6.1	13.5	0.24	7.6	0.079	17.7
Spring 5	13/03/2024	< 0.010	25	9	124.2	12.4	NA	7.8	NA	3.5	NA	8.65	1.39	0.014	11.3	< 10	3.2	< 0.002	NA	6.06	6.5	12.4	< 0.10	3.3	0.025	17.2
Spring 7	20/03/2024	0.057	39	10.5	149.3	15	NA	9.4	NA	4.4	NA	14.76	1.45	0.005	13.1	420	3	0.035	NA	6.43	6.7	12.2	0.31	3.3	0.024	19.1
T26/0302	26/02/2024	0.099	133	29	335.8	30.7	0.027	17.2	0.19	11	1.3	0.26	1.22	0.195	32	< 1	< 0.002	< 0.002	-229.2	6.1	7	6.7	0.11	NA	NA	15.8
T26/0332	6/03/2024	< 0.010	59.1	42.5	303.5	27.7	0.022	18.2	< 0.02	8.11	2.045	0.47	1.364	0.036	26.91	<1.00	1.12	0.00243	-303.1	5.46	6.63	17.1	NA	NA	NA	14.2

Appendix 3: Trend analysis

Table A3-1: Trend analysis statistics and trend magnitude (Sen slope)

Site	Parameter	Kruskal Wallis p	Man-Kendall S	Man-Kendall p	Trend confidence	Trend category	Annual Sen Slope (units/year)
S26/0223	B	0.194	1419	0.0000	1.000	Highly likely Increasing	0.0002
S26/0223	Ca	0.178	-137	0.5719	0.714	Likely Decreasing	-0.0160
S26/0223	Cl	0.732	-1290	0.0000	1.000	Highly likely Decreasing	-0.2894
S26/0223	Cond_F	0.285	-171	0.4717	0.764	Likely Decreasing	-0.3084
S26/0223	DRP	0.509	-1167	0.0000	1.000	Highly likely Decreasing	-0.0003
S26/0223	K	0.587	290	0.2297	0.885	Likely Increasing	0.0032
S26/0223	Mg	0.491	-144	0.5523	0.724	Likely Decreasing	-0.0095
S26/0223	NH4N	ND	ND	ND	ND	ND	ND
S26/0223	NO3N	0.122	-82	0.7364	0.632	As likely as not	-0.0159
S26/0223	Na	0.602	-360	0.1356	0.932	Very likely Decreasing	-0.0459
S26/0223	SO4	0.160	-39	0.8745	0.563	As likely as not	-0.0032
S26/0299	B	0.001	206	0.0010	1.000	Highly likely Increasing	0.0002
S26/0299	Ca	0.161	-495	0.0439	0.978	Highly likely Decreasing	-0.0427
S26/0299	Cl	0.064	-697	0.0045	0.998	Highly likely Decreasing	-0.1237
S26/0299	Cond_F	0.609	-530	0.0279	0.986	Highly likely Decreasing	-0.5752
S26/0299	DRP	0.000	-128	0.0423	0.979	Highly likely Decreasing	-0.0001
S26/0299	K	0.830	-493	0.0447	0.978	Highly likely Decreasing	-0.0053
S26/0299	Mg	0.149	-841	0.0006	1.000	Highly likely Decreasing	-0.0274
S26/0299	NH4N	ND	ND	ND	ND	ND	ND
S26/0299	NO3N	0.910	-561	0.0223	0.989	Highly likely Decreasing	-0.0437
S26/0299	Na	0.407	-186	0.4503	0.775	Likely Decreasing	-0.0098
S26/0299	SO4	0.356	-2224	0.0000	1.000	Highly likely Decreasing	-0.2625
S26/0762	B	0.216	799	0.0011	0.999	Highly likely Increasing	0.0002
S26/0762	Ca	0.062	-251	0.3069	0.847	Likely Decreasing	-0.0252
S26/0762	Cl	0.107	-903	0.0002	1.000	Highly likely Decreasing	-0.3169
S26/0762	Cond_F	0.184	144	0.5597	0.720	Likely Increasing	0.2845
S26/0762	DRP	0.354	62	0.8035	0.598	As likely as not	0.0007
S26/0762	K	0.063	-186	0.4497	0.775	Likely Decreasing	-0.0011
S26/0762	Mg	0.064	-415	0.0912	0.954	Highly likely Decreasing	-0.0214
S26/0762	NH4N	0.837	-611	0.0127	0.994	Highly likely Decreasing	-0.0016
S26/0762	NO3N	0.175	-583	0.0135	0.993	Highly likely Decreasing	0.0000
S26/0762	Na	0.478	579	0.0181	0.991	Highly likely Increasing	0.0926

Site	Parameter	Kruskal Wallis p	Man-Kendall S	Man-Kendall p	Trend confidence	Trend category	Annual Sen Slope (units/year)
S26/0762	SO4	0.088	1437	0.0000	1.000	Highly likely Increasing	0.1290
T26/0332	B	0.654	310	0.1634	0.918	Very likely Increasing	0.0000
T26/0332	Ca	0.498	2033	0.0000	1.000	Highly likely Increasing	0.2681
T26/0332	Cl	0.109	1818	0.0000	1.000	Highly likely Increasing	0.5515
T26/0332	Cond_F	0.910	1596	0.0000	1.000	Highly likely Increasing	3.9785
T26/0332	DRP	0.712	-1144	0.0000	1.000	Highly likely Decreasing	-0.0004
T26/0332	K	0.408	1469	0.0000	1.000	Highly likely Increasing	0.0161
T26/0332	Mg	0.931	1925	0.0000	1.000	Highly likely Increasing	0.1173
T26/0332	NH4N	0.660	-462	0.0009	1.000	Highly likely Decreasing	0.0000
T26/0332	NO3N	0.000	23	0.7003	0.650	As likely as not	0.0031
T26/0332	Na	0.837	1571	0.0000	1.000	Highly likely Increasing	0.2849
T26/0332	SO4	0.886	1873	0.0000	1.000	Highly likely Increasing	0.1897
Parkvale Stream at Renalls Weir	Cond_F	0.000	-249	0.0142	0.993	Highly likely Decreasing	-0.4797
Parkvale Stream at Renalls Weir	DRP	0.000	-572	0.0000	1.000	Highly likely Decreasing	-0.0008
Parkvale Stream at Renalls Weir	NH4N	0.000	-269	0.0068	0.997	Highly likely Decreasing	-0.0002
Parkvale Stream at Renalls Weir	NO3N	0.000	-315	0.0020	0.999	Highly likely Decreasing	-0.0186
Parkvale Stream at Renalls Weir	TKN	0.009	-583	0.0000	1.000	Highly likely Decreasing	-0.0118
Parkvale tributary at Lowes Reserve	Cond_F	0.000	-573	0.0000	1.000	Highly likely Decreasing	-1.4200
Parkvale tributary at Lowes Reserve	DRP	0.000	-132	0.1089	0.946	Very likely Decreasing	-0.0001
Parkvale tributary at Lowes Reserve	NH4N	0.860	-1958	0.0180	0.991	Highly likely Decreasing	-0.0001
Parkvale tributary at Lowes Reserve	NO3N	0.000	-236	0.0041	0.998	Highly likely Decreasing	-0.0540
Parkvale tributary at Lowes Reserve	TKN	0.518	-2684	0.0030	0.999	Highly likely Decreasing	-0.0057

Appendix 4: Redox categories

Table A4-1: Redox categories and redox process from median parameter values defined using the procedure of McMahon and Chapelle (2008)

Site	Dissolved oxygen (mg/L)	Nitrate-nitrogen (mg/L)	Dissolved iron (mg/L)	Dissolved Mn (mg/L)	Sulphate (mg/L)	Redox category	Redox process
BP34/0224	0.76	30	0.01	1.445	18.7	Mixed(oxic-anoxic)	O2-Mn(IV)
S26/0051	6.88	0.51	0.18	0.043	2.4	Mixed(oxic-anoxic)	O2-Fe(III)/SO4
S26/0108	7.61	1.97	0.01	0.0016	7	Oxic	O2
S26/0155	6.355	3.15	0.01	0.0011	9.1	Oxic	O2
S26/0178	7.025	2.8	0.01	4.75E-04	7.15	Oxic	O2
S26/0223	7.445	5.86	0.07	0.008	12.26	Oxic	O2
S26/0230	5.175	1.875	1.12	0.0235	7.4	Mixed(oxic-anoxic)	O2-Fe(III)/SO4
S26/0243	1.39	3.25	0.01	0.0037	8.8	Oxic	O2
S26/0245	7.615	3.75	0.01	0.00365	6.4	Oxic	O2
S26/0254	6.18	2.95	0.01	0.00105	9.15	Oxic	O2
S26/0264	2.24	4.95	0.02	0.00715	11.65	Oxic	O2
S26/0268	0.36	2.55	0.01	0.0091	14.15	Anoxic	NO3
S26/0277	7.505	1.155	0.02	0.0555	15.55	Mixed(oxic-anoxic)	O2-Mn(IV)
S26/0290	4.445	5.45	0.01	0.0011	12.95	Oxic	O2
S26/0299	7.89	2.14	0.01	0.0017	5.849	Oxic	O2
S26/0300	6.82	3.9	0.01	0.0024	13.45	Oxic	O2
S26/0659	0.32	0.3805	0.09	1.145	12.55	Anoxic	Mn(IV)
S26/0733	0.65	0.21	0.07	0.24	3.7	Mixed(oxic-anoxic)	O2-Mn(IV)
S26/0762	0.335	0.0055	7.29	0.9175	4.0565	Anoxic	Fe(III)/SO4
S26/0773	1.875	1.285	0.015	0.0081	19.1	Oxic	O2
S26/0804	4.04	2.45	0.01	7.50E-04	9.25	Oxic	O2
S26/0805	2.32	4.7	0.01	0.00155	54.5	Oxic	O2
S26/0863	0.28	0.0025	2.66	2.55	4.2	Anoxic	Fe(III)/SO4
S26/0889	6.1	4.2	0.01	0.0016	15.85	Oxic	O2
S26/0908	3.47	2.45	0.01	0.085	10.4	Mixed(oxic-anoxic)	O2-Mn(IV)
S26/1033	0.31	0.01	6.2	0.99	0.8	Anoxic	Fe(III)/SO4
S26/1053	0.33	0.0065	8.5	1.285	14.4	Anoxic	Fe(III)/SO4
Spring 1	4.22	1.89	NA	NA	8.5	O2 >= 0.5 mg/L	Unknown
Spring 2	7.45	2.55	NA	NA	7.8	O2 >= 0.5 mg/L	Unknown
Spring 3	7.03	3.55	NA	NA	12.65	O2 >= 0.5 mg/L	Unknown
Spring 4	7.36	6.85	NA	NA	13.9	O2 >= 0.5 mg/L	Unknown
Spring 5	6.41	3.4	NA	NA	12.4	O2 >= 0.5 mg/L	Unknown
Spring 6	6.66	3.7	NA	NA	16	O2 >= 0.5 mg/L	Unknown
Spring 7	5.33	3.05	NA	NA	11.85	O2 >= 0.5 mg/L	Unknown
T26/0302	0.275	0.001	0.19	1.295	6.35	Anoxic	Fe(III)/SO4
T26/0332	0.355	1.94	0.01	1.811	17.05	Mixed(anoxic)	NO3-Mn(IV)

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