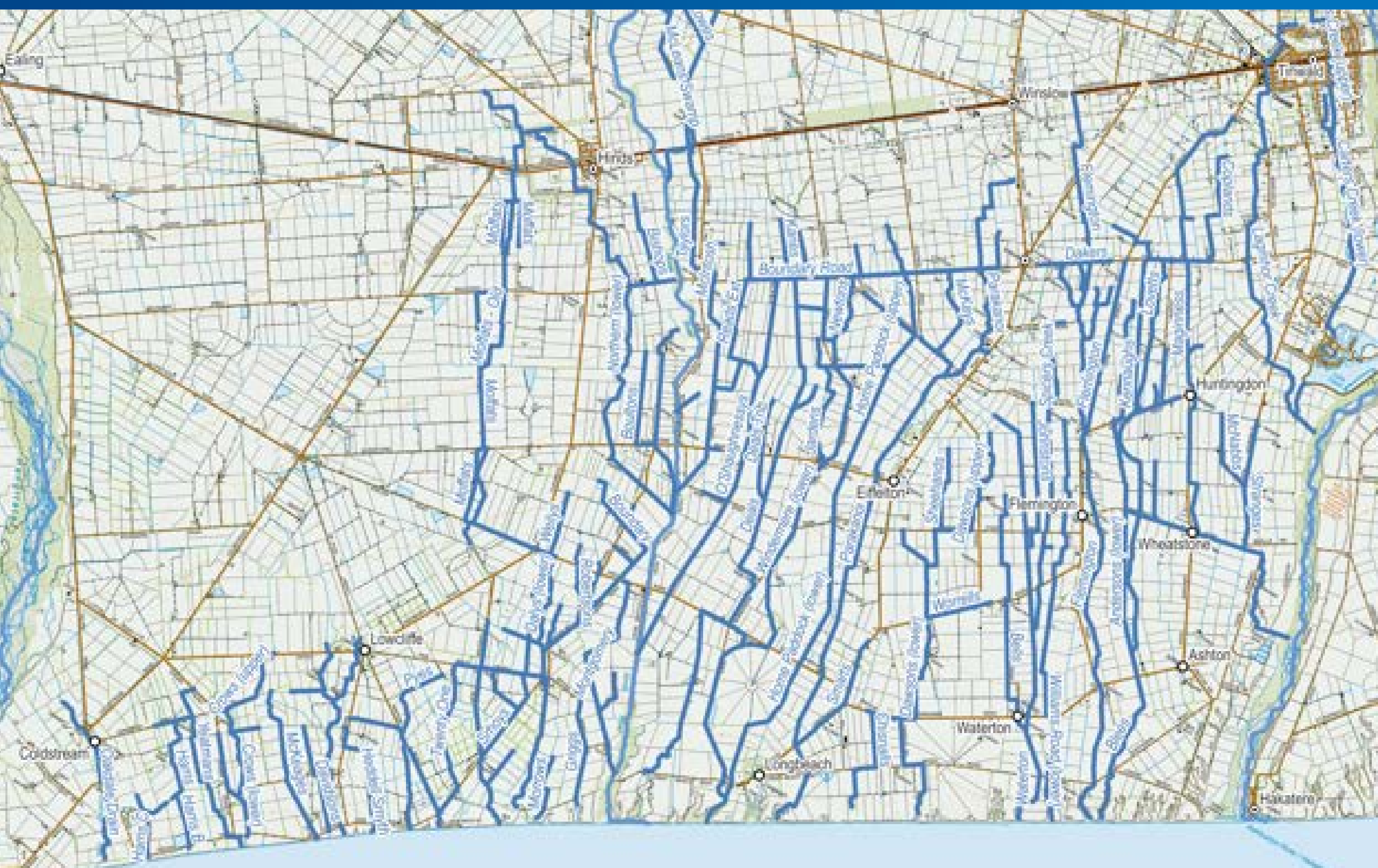
Ground and Surface Water Monitoring Programme

2023 Annual Report

August 2024

Sustainable solutions for our community,
now and into the future



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bci

HEKEAO / HINDS
WATER ENHANCEMENT TRUST

MHVwater

Document Control

Document Title	Ground & Surface Water Sampling 2023: Annual Report		
Document Number			
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Date Issued	August 2024		
Document Status	Final		
File Name	2023_Groundwater_Report_R1		
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Executive Summary

Background

This report outlines and documents the ground and surface water monitoring programme conducted by MHV Water Ltd (MHV) during the 2023 calendar year. This work programme was undertaken to meet the following objectives for both ground and surface waters:

i. complete routine ground and surface water monitoring of Nitrate-Nitrogen (NO_3-N) levels within the MHV irrigation area; as well as,

ii. provide input data and observations for future work and research programmes.

MHV commenced routine ground and surface water monitoring of NO_3-N levels within the MHV scheme area in September 2016. The programme's objective is to understand the changes in NO_3-N in groundwater for the Hekeao Hinds Plains.

The 2023 Survey

In 2023, groundwater survey sizes ranged between 156 to 164 bores representing a spatial footprint of ≈111,000 ha (Figure 1).

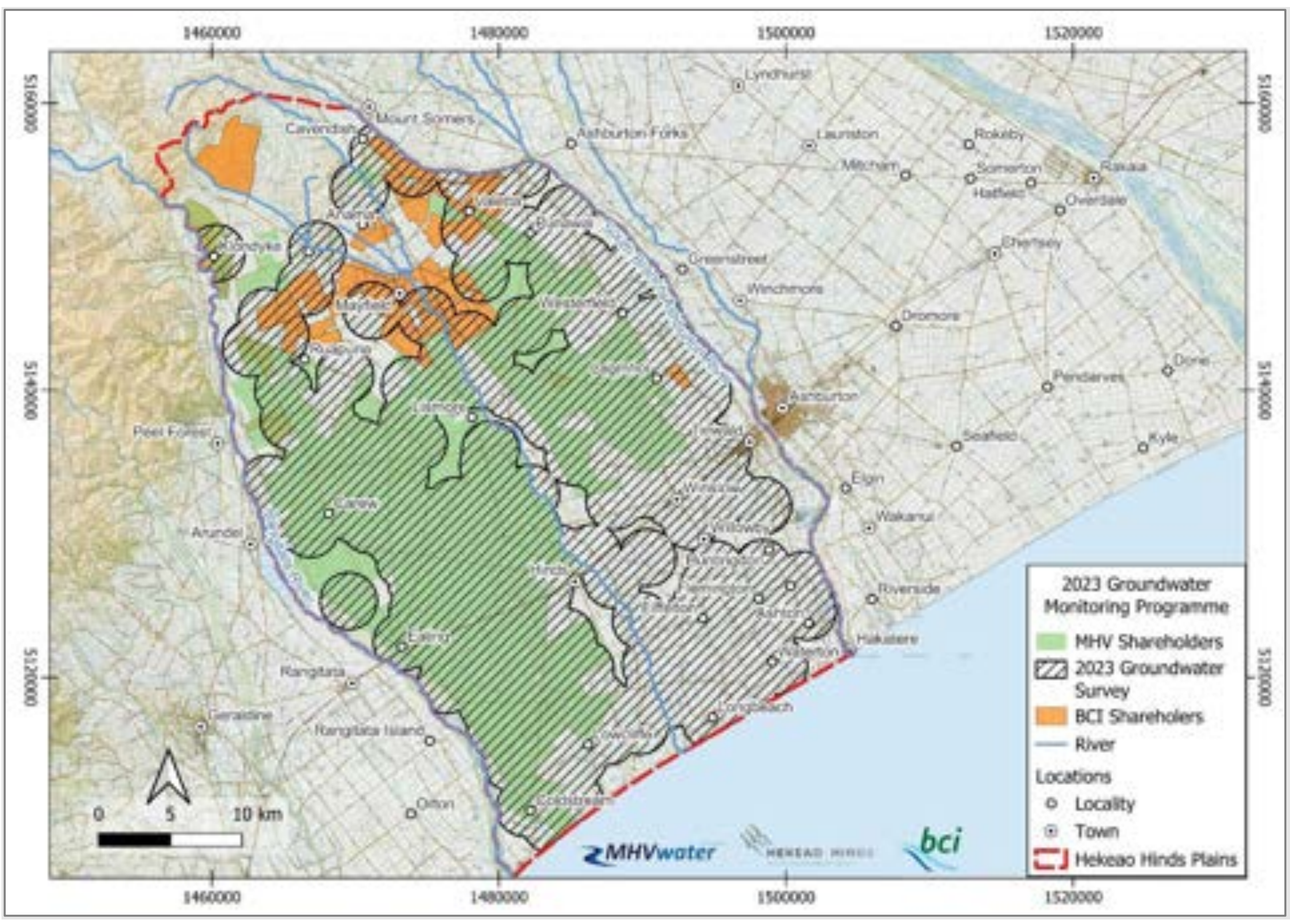


Figure 1 Survey coverage of the 2023 groundwater monitoring programme

Additionally, MHV increased its surface water sampling from 64 locations to 98, with a corresponding increase in sampling from an average of 46 per month to 65 - the majority of which were collected from public road culverts or bridges (Figure 2).

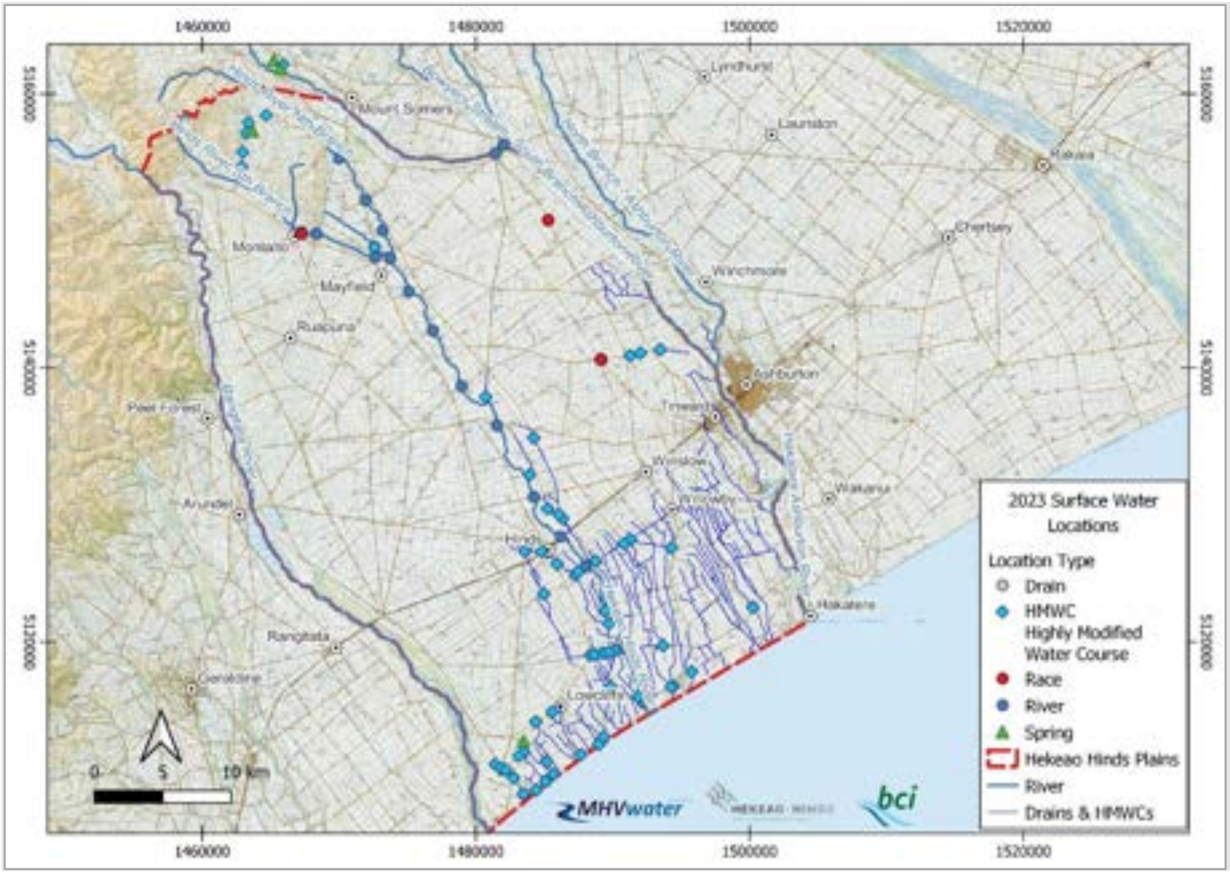


Figure 2 Location of 2023 surface water sampling sites

2023 Groundwater Results

During 2023, the Hekeao Hinds Plains received 833mm of rainfall, down from 953mm and 930mm for the preceding two years respectively. Whilst NO_3-N concentrations varied in response to rainfall events such as the 154mm rains of July 2023, overall results are within 5% of the 2022 results (Figure 3 and Figure 4). This may be due to a variety of factors such as:

- the lag effect of the 2021 rain event; and/ or,
- ongoing rainfall wetting an already saturated catchment.

An Inverse Distance (ID2) interpolation of the relative median changes in groundwater year on year are presented in Figure 5 and Figure **6**.

NOTE The ID2 interpolation utilised the **annual median** NO_3-N data only and did not consider factors such as (but not limited to) the influence of rivers, streams, soil type, preferential flow pathways etc. Hence by interpolating bores of that are close to each other, but vary significantly in depth, the results may appear 'blotchy'.

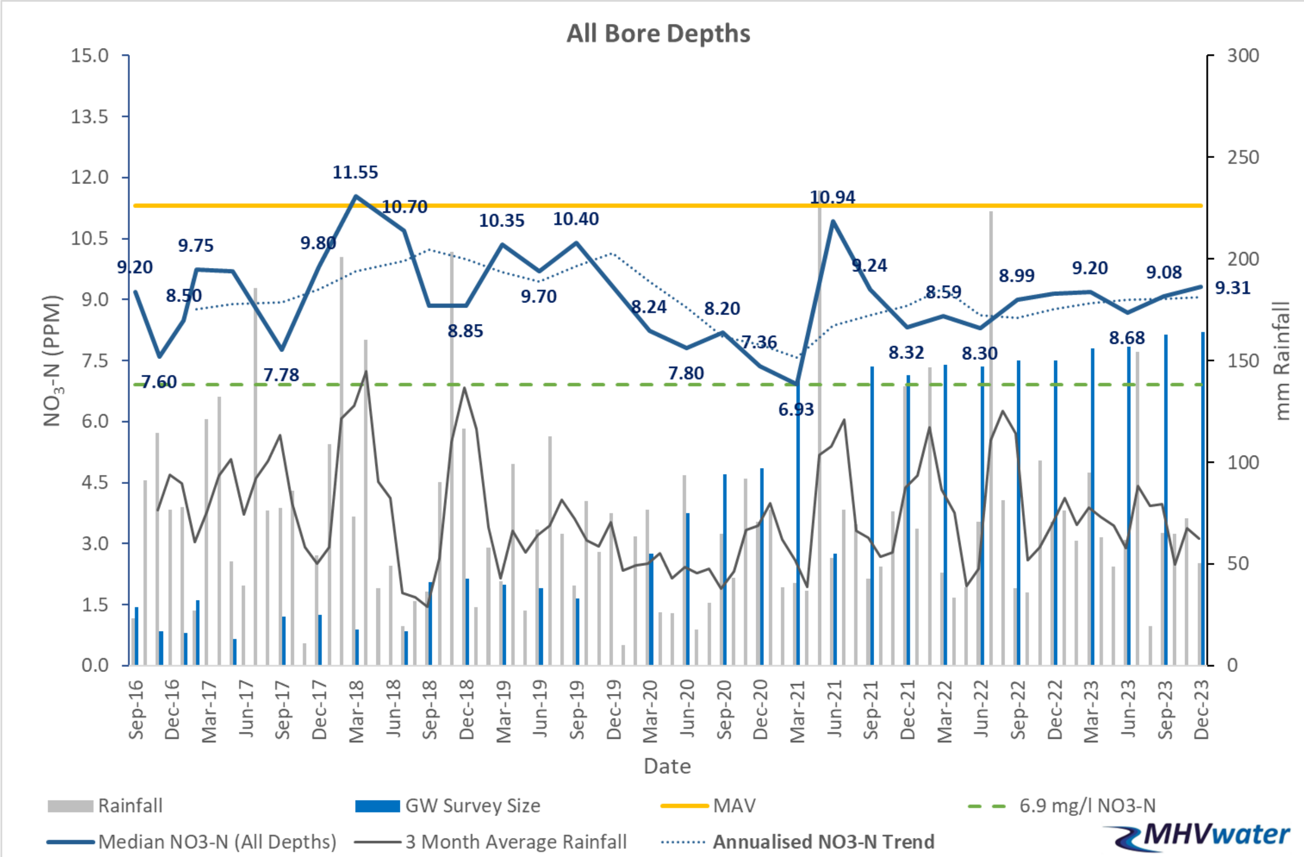


Figure 3 Long term NO_3-N results for the MHV groundwater monitoring programme (All bore depths)

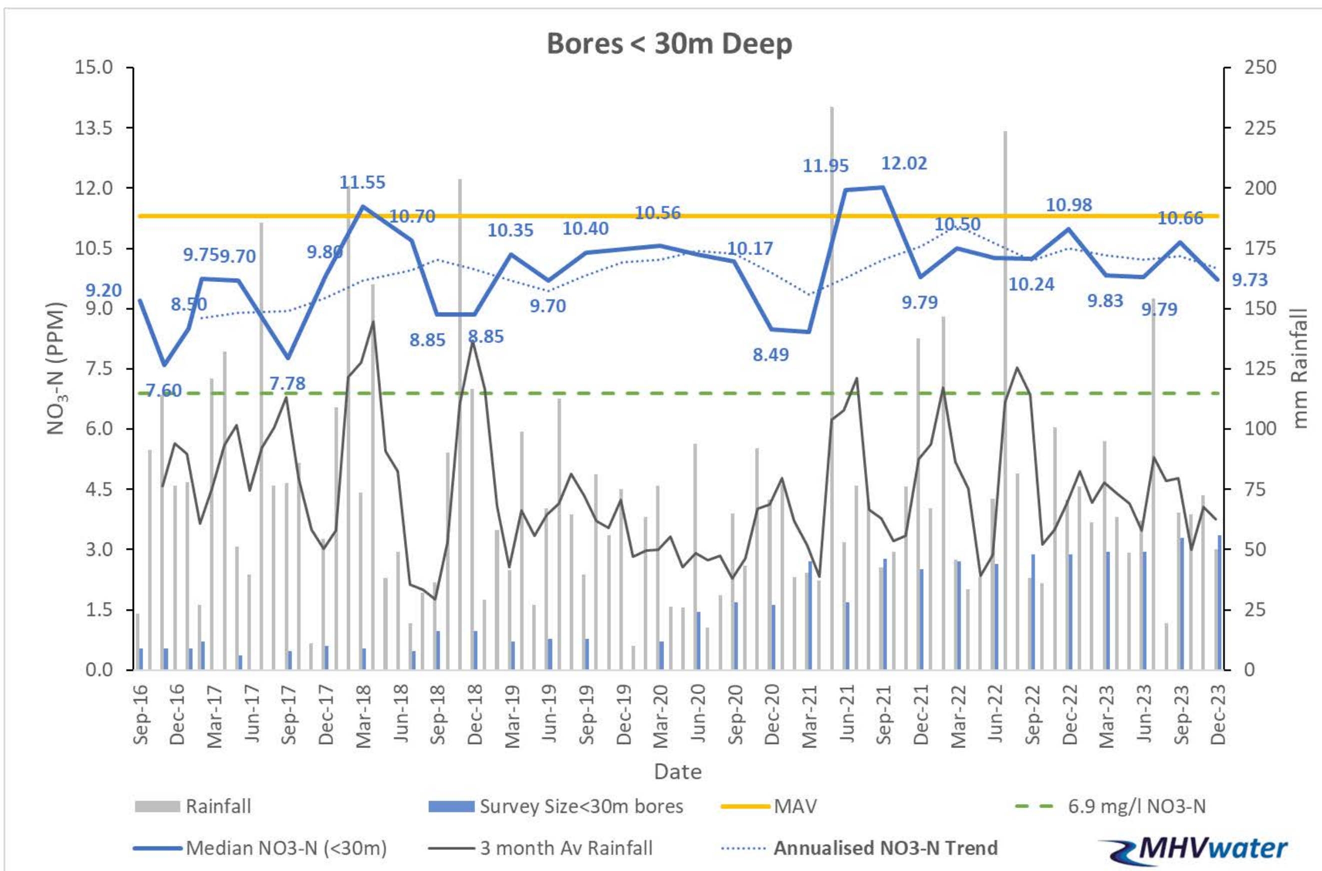


Figure 4 Long term NO_3-N results for the MHV groundwater monitoring programme (Bores <30m deep)

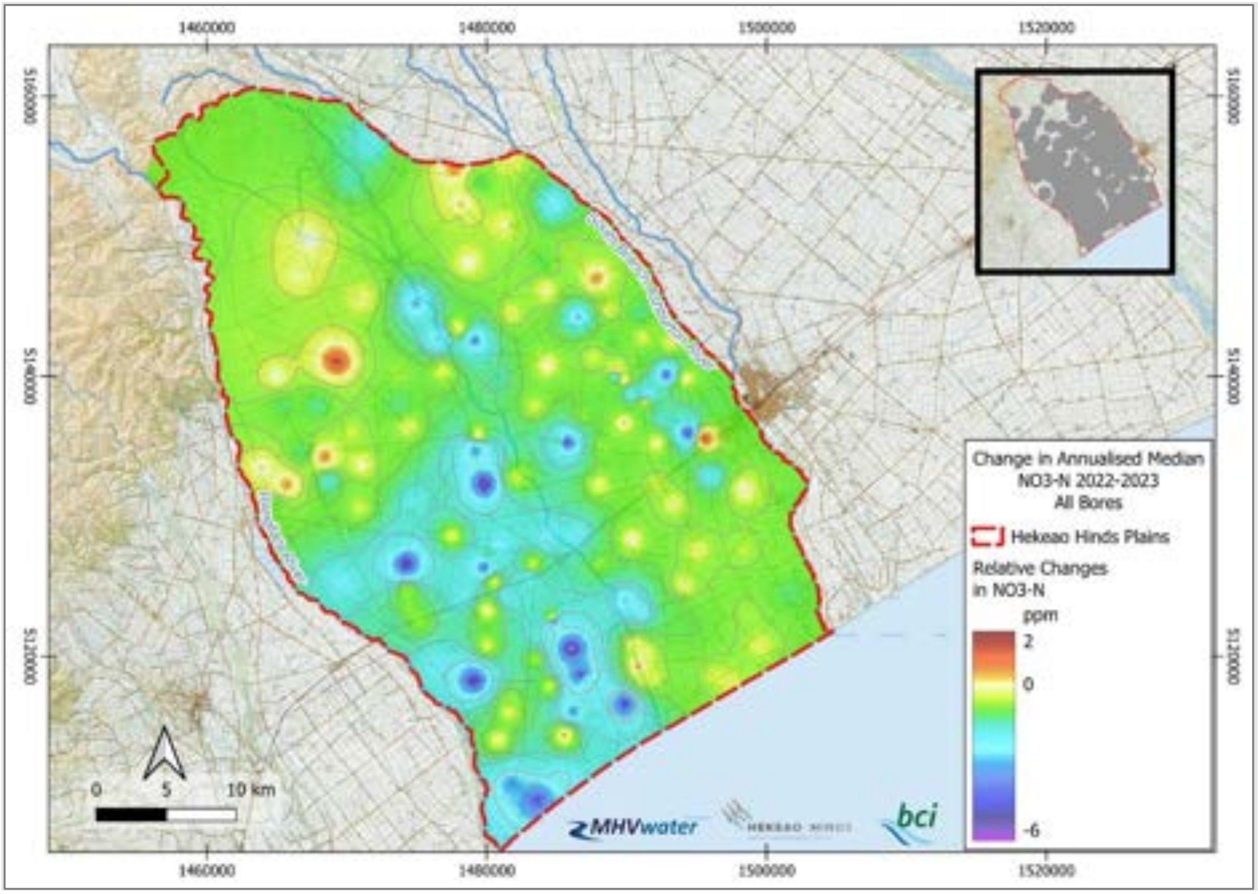


Figure 5 ID2 interpolation the difference between the annualised median for all bores between 2022 and 2023

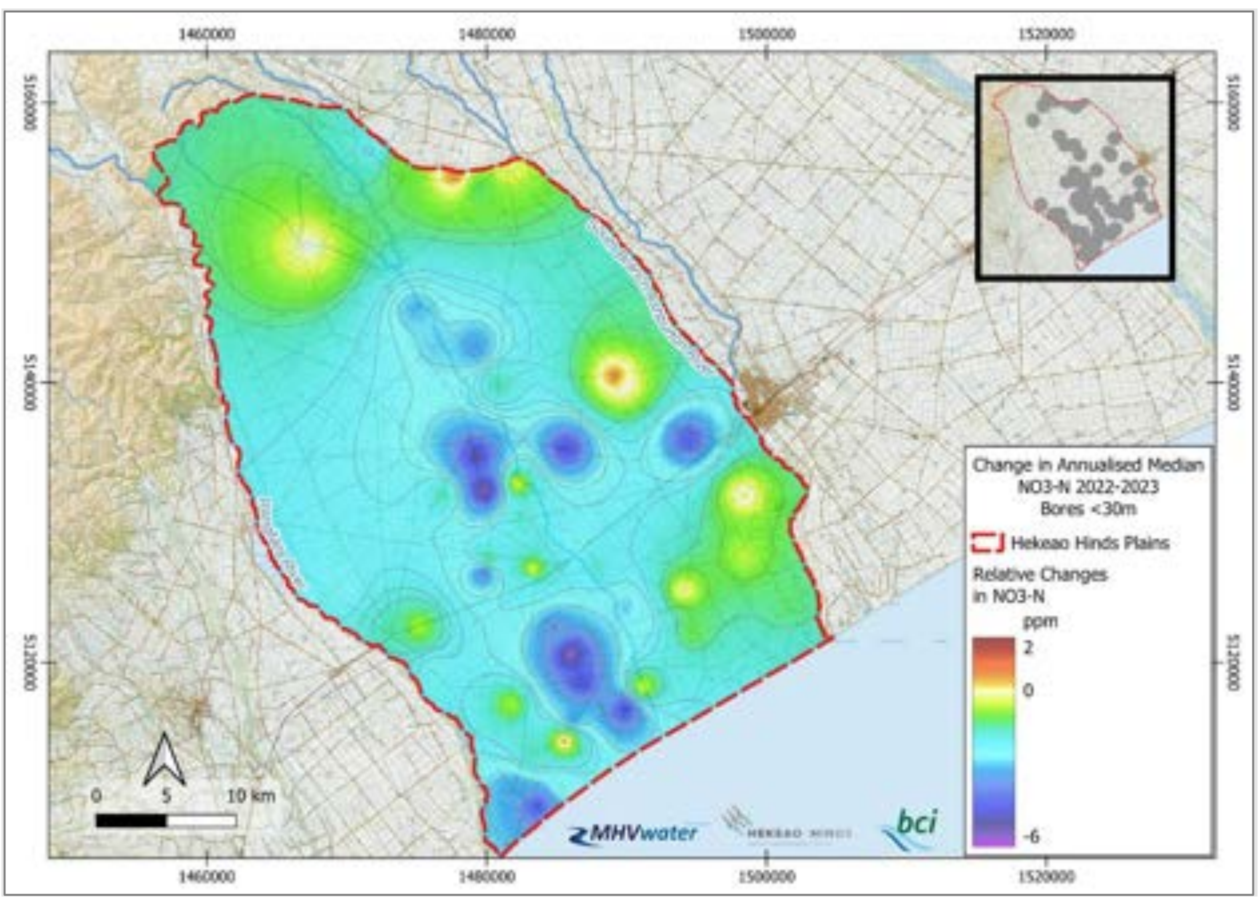


Figure 6 ID2 interpolation the difference between the annualised median for bores <30m deep between 2022 and 2023

2023 Surface Water Results

2023 saw a plateauing of NO_3-N concentrations in Highly Modified Water Courses despite a wet winter with > 150mm in July (Figure 7).

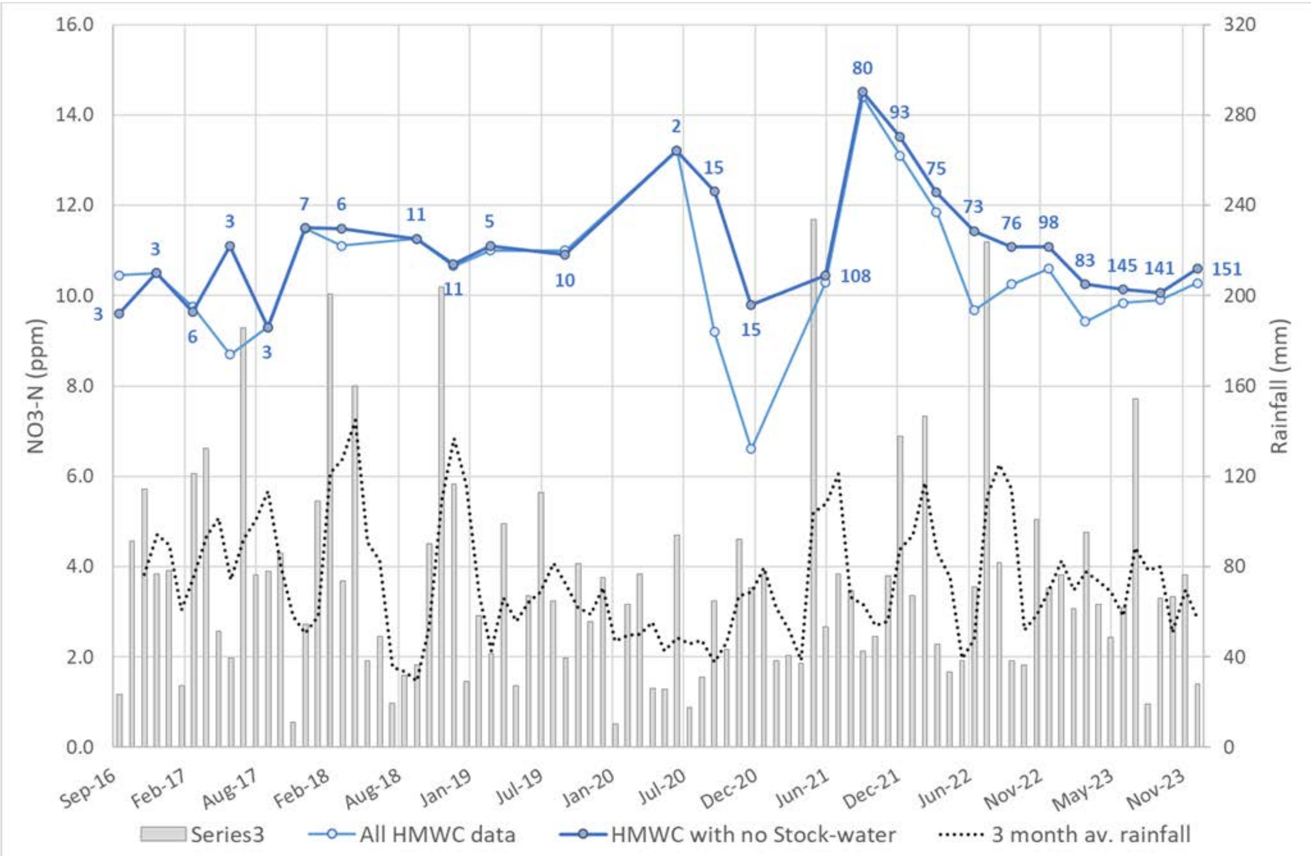


Figure 7 Long-term NO_3-N concentrations in Highly Modified Courses (HMWC's)

Nitrogen naming & unit convention

Nitrate-Nitrogen (NO_3-N)

When a laboratory directly reports the concentration of nitrate, it is referring specifically to the nitrate compound, which is designated chemically as NO_3. The drinking-water Standards for New Zealand 2005 (Revised 2018) currently define the Maximum Acceptable Level (MAV) for NO_3-N in potable water as 50 mg/L [1].

However, nitrate (NO_3) is one-part Nitrogen (N) plus three parts oxygen (O), so, nitrogen only makes up about 22.6% of the nitrate compound by weight (nitrogen weighs 14u, oxygen weighs 16u). Hence it can also be reported as the concentration of nitrogen (N) in the form of NO_3 (denoted as NO_3-N), as opposed to the amount of nitrogen in the form of NO_2, NH_4, NH_3, N_2 etc. which may also be present in a water sample.

Hence the following conversion is often applied:

Nitrate-Nitrogen (NO_3-N) = Nitrate (NO_3) x 0.226

Or conversely

Nitrate (NO_3) = Nitrate-Nitrogen (NO_3-N) x 4.43

So, **50 mg/L NO_3 = 11.3 mg/L NO_3-N**

As the 2020 National Policy Statement for Freshwater Management (NPS-FM 2020), the Ashburton Zone Committee and others refer to nitrate concentrations in terms of NO_3-N, all references to nitrates in this report will be with respect to NO_3-N.

Additionally, concentrations of NO_3-N can be reported as:

- milligrams per litre (mg/L),
- parts per million (ppm) and/ or
- grams per metre cubed (g/m^3).

All of which are different volumetric expressions of 1 g solute per 1,000,000 g solution (i.e. they are the same).

To avoid all ambiguity, NO_3-N will be reported in this document in terms of ppm (e.g. NO_3-N MAV = 11.3 ppm).

Maximum Acceptable Level (MAV) for NO_3-N

The Ministry of Health defines Maximum Acceptable Level (MAV) for NO_3-N as follows.

"The MAV of a chemical determinant is the concentration of that determinant which does not result in any significant risk to the health of a 70 kg consumer over a lifetime of consumption of two litres of the water a day.

For genotoxic carcinogens the MAV represents an excess lifetime cancer risk, usually amounting to one extra incidence of cancer per 100,000 people drinking water containing the determinant in question at the MAV for 70 years (i.e. an assessed risk of 10^{-5})" [1], [2]

Abbreviations

ADC	Ashburton District Council
ADZC	Ashburton District Zone Committee
AEC	Aoraki Environmental Consultancy Ltd
AEP	Annual Exceedance Probability
ARI	Annual Recurrence Interval
BCI	Barrhill Chertsey Irrigation
°C	Degrees Celsius
CHI	Cultural Health Indicators
CRM	Certified Reference Material
Cumec	Cubic Meters per Second (m^3/s)
CV	Coefficient of Variation
CWMS	Canterbury Water Management Strategy
CLWRP	Canterbury Land & Water Regional Plan
DIN	Dissolved organic nitrogen:
	comprised of nitrate plus nitrite and ammonium
DO	Dissolved Oxygen
DOC	Dissolved Organic Carbon
DON	Dissolved Organic Nitrogen
DRP	Dissolved Reactive Phosphorus
DTM	Digital Terrain Model
ECan	Canterbury Regional Council. It uses the promotional name Environment Canterbury, frequently abbreviated to ECan.
E. coli	*Escherichia coli*, a microbe used to indicate the potential for faecal contamination.
FEP	Farm Environment Plan
FHCG	Foothills Catchment Group
GL	Giga Litre (1,000,000,000 Litres)
GNS	Geological and Nuclear Sciences
GMP	Good Management Practices
GWL	Groundwater Level
ha	10,000 square metres (2.471 acres)
HAB	Harmful Algal Bloom
HDWP	Hinds Drains Working Party
HHP	Hekeao Hinds Plains
HHSCG	Hekeao Hinds Science Collaboration Group
HHWET	Hekeao Hinds Water Enhancement Trust
HMWC	Highly modified water course
ID2	Inverse Distance Squared
IEEE	Institute for Electrical & Electronics Engineers
IWM	Integrated Water Management
JSEA	Job Safety & Environment Analysis
K	Hydraulic Conductivity
kL	Kilo Litre (1,000 Litres or $1m^3$)
l	Litre: a metric unit of capacity equal to $1{,}000cm^3$ (0.264 gallons)
LSR	Land Surface Recharge
LWRP	Land and Water Regional Plan
MAR	Managed Aquifer Recharge
MAV	Maximum Acceptable Level
m bgl	Met res below ground level
MCCC Collective	Mid Canterbury Catchment
mg/ L/ p.a.	milligrams per litre per annum
ML	Mega Litre (1,000,000 litres)
mm	Millimetres
ml	millilitres
N	Nitrogen
NEMS	National Environmental Monitoring Standards
NH_3	Ammonia
NH_4^+	Ammonium
NO_2-N	Nitrite-Nitrogen. The concentration of nitrogen (N) present in the form of the nitrite (NO_2)

NO_3-N	Nitrate – Nitrogen. The concentration of nitrogen (N) present in the form of the nitrate (NO_3)
NPS-FM 2020	National Policy Statement for Freshwater Management 2020
OFG	Open Framework Gravels
p.a.	per annum (for each year)
PAW	Profile available water
PC2	Plan Change 2 of the Canterbury Land & Water Regional Plan
PCE	Parliamentary Commissioner for the Environment
pH	a numeric scale used to specify the acidity or alkalinity of an aqueous solution.
QAQC	Quality Assurance & Quality Control
QCMI	Quantitative Macroinvertebrate Community Index
RDR	Rangitata Diversion Race
REDOX	Reduction–Oxidation
SOP	Standard Operating Procedures
SPC	Specific Conductance
T	Hydraulic Transmissivity
TDN	Total dissolved nitrogen. DIN+DON
TDR	Time Domain Reflectometry
t/ ha/ yr	Tonnes per hectare per year
TKN	Total Kjeldahl Nitrogen. The sum of NH_3-N + organically bound nitrogen only
TN	Total Nitrogen. The sum of NO_3-N + NO_2-N + NH_3-N and organically bonded nitrogen
QAQC	Quality Assurance & Quality Control
VMS	Vadose Monitoring System
ZIP	Zone Implementation Programme

Contents

1. Introduction

1.1. MHV Water Ltd

MHV is a farmer owned co-operative that has been delivering water for irrigation to the Hekeao Hinds Plains since 1947. On 1 June 2017 Mayfield Hinds Irrigation Limited merged with Valetta Irrigation Limited to form MHV Water Limited. MHV now stores and delivers water for the purpose of irrigation to over 200 shareholders via ~320km of open race and ~100km of piped infrastructure over an area of ~58,000 ha. As part of this delivery, MHV manages the environmental compliance for its shareholders.

1.2. Purpose

This report documents the groundwater sampling programme conducted by MHV Water Ltd (MHV) during the 2023 calendar year.

This work programme was undertaken to meet the following objectives for both ground and surface waters:

a) complete routine groundwater monitoring of Nitrate-Nitrogen (NO_3-N)[1] levels within the MHV irrigation area[2];

b) provide input data and observations for future work and research programmes.

It also informs ongoing research as part of a PhD Research programme being undertaken by the author at the University of Otago.

1.3. Background of the monitoring programme

MHV commenced routine groundwater monitoring of NO_3-N within the MHV scheme area in September 2016, with an initial survey of 29 bores. The programme's initial objective was to understand the changes in NO_3-N in the groundwater of the Hekeao Hinds Plains, as a result of ongoing and/or changing land use activities within the area.

As the focus of the monitoring programme has evolved over time, so too has the design of the programme. This evolutionary progression has resulted in survey sizes ranging from 13 to 41 boreholes. In early 2020 the programme was reviewed and extended in consultation with:

Te Arowhenua Rūnanga	Hekeao Hinds Water Enhancement Trust (HHWET)
Hinds Drains Working Party (HDWP)	Fish and Game
Environment Canterbury (ECan)	Aqualinc Research Ltd

The outcome was a collaboration between MHV, HHWET, and BCI to expand the survey to cover the entirety of the Hekeao Hinds Plains such that the average catchment scale survey was 150 bores representing an area of over 111,000 ha.

1.4. Why are we doing it?

The ground and surface water monitoring programme are a tangible expression of MHV's mission statement *"To Provide Sustainable Solutions for our community, now and in the future"*. By monitoring NO_3-N in groundwater and surface waters across the scheme, MHV intends to provide data and complementary information that will enable evidence-based decision making, that leads to continuous improvement of sustainable water, nutrient management, and overarching environmental practices.

[1] Nitrate-nitrogen (NO_3-N) is the concentration of nitrogen present in the form of the nitrate ion. Nitrate is a water-soluble molecule made up of nitrogen and oxygen with the chemical formula NO_3^-.
[2] The MHV irrigation area is constrained within the Rangitata, Coldstream, Hekeao Hinds and Westerfield Plains catchment areas

1.5. Scope

This report is intended to be a transparent account of MHV's ground and surface water monitoring programme for the 2023 calendar year. It presents the results of sampling selected boreholes as well as surface water sites within the MHV scheme and surrounding areas by MHV staff – see Appendix 1 for statement of qualifications.

MHV is collaborating with other stakeholders who are also monitoring water quality in the Hekeao Hinds Plains, such as:

Environment Canterbury (ECan)	Fish and Game
Hinds Drains Working Party (HDWP)	Hekeao Hinds Water Enhancement Trust (HHWET)
Independent farmers	Barrhill Chertsey Irrigation Limited (BCI)
Mid Canterbury Catchment Collective (MCCC)	

Whilst the Managed Aquifer Recharge (MAR) programme is recognised in this report, it is not considered the focus of this study.

This report does not seek nor intend to quantitively reconcile the results with:

- current and/ or historical land use practices or nutrient allocation budgets;
- boreholes and/ or well logs; or
- numerical models.

1.6. National Policy Statement for Freshwater Management 2020

MHV has operated under Plan Change 2 (PC2) of the (Canterbury) Land and Water Regional Plan (LWRP) since 2018.

The plan requires that 'Hill-fed Lower' and 'Spring-fed Plains' surface waterbodies of the Lower Hekeao Hinds Plains have an annual median NO_3-N concentration of 3.8 and 6.9 ppm, respectively, by 2035 [3]. This target is to be determined by the results from the Canterbury Regional Council's monthly surface waterbodies monitoring sites[3].

The plan also requires that shallow groundwater NO_3-N concentrations have an annual median concentration less than 6.9 ppm. This target will be determined by the results from up to 16 ECan nominated shallow[4] (bores screened <30 m below ground level) monitoring bores that are tested on a quarterly basis.

NB *depending on operating conditions, not all 16 bores may be sampled at any one time.*

In May 2020, the New Zealand Central Government released the *Action for Healthy Waterways* Package, including the National Policy Statement for Freshwater Management 2020 (NPS-FM 2020) which came into force in September 2020. This package includes the strengthening of the bottom lines for NO_3-N and ammonia toxicity, to provide protection from nitrogen toxicity for 95% of freshwater species, up from 80% under the former NPS-FM 2017. This effectively reduces the NO_3-N limit from 6.9 to 2.4 ppm.

As the implementation of the new policy is yet to be confirmed, this report will refer to both the PC2 and NPS-FM 2020 NO_3-N limits of 6.9 ppm and 2.4 ppm respectively (see for Appendix 2 for details).

[3] Refer to 13.7.3, Table 13(g) of the LWRP
[4] Refer to s13.4.14 and s13.7.3, Table 13(i) of the LWRP

1.7.Map Projections

All maps are presented in New Zealand Transverse Mercator 2000 (NZTM2000) projection based on the NZGD2000 datum using the GRS80 reference ellipsoid – see Appendix 3.

1.8.Referencing and citations

For ease of reading, this document uses the Institute for Electrical and Electronics Engineers (IEEE) referencing system, a numeric style, where citations are numbered [1] in the order of appearance. Once a source has been cited, the same number is re-used for all subsequent citations to the same source.

Foot notes will be specified by a superscript numerical annotation such as [1].

2. Engagement

Throughout the year MHV engaged with several stakeholders within the community as part of its value commitments, namely:

Intergenerational Focus	Responsible Stewards	Community Minded
Co-operative Spirit	Enable Innovation	

The following highlights of 2023 are presented below.

2.1. Catchment Groups

During the year, MHV worked closely with:

Mid-Canterbury Catchment Collective (MCCC)	Hekeao Hinds Water Enhancement Trust (HHWET)
Hinds Drains working Party (HDWP)	Dairy NZ
Te Rūnanga o Arowhenua, via AEC Limited	

investigating potential sites for a farm wetland utilizing DairyNZ's '*Wetland Practitioner Guide – Wetland Design and Performance Estimates*'. Work is ongoing. with an anticipated completion date of mid 2024

2.2. University Engagement

Throughout the year, MHV supported a number of research projects.

2.2.1. Louis Martin Masters Student

Louis Martin, a master's candidate from the University of Otago investigated spatial and temporal variations in water quality along the Oakdale and Harris Drains. Louis will submit his thesis in the first quarter of 2024.

2.2.2. Sidinei Teixeira Masters Student

Sidinei Teixeira a master's candidate from Lincoln University, investigated changes in nitrate-nitrogen (NO_3-N) concentrations in groundwater in response to land surface recharge (LSR), specifically:

- Managed Aquifer Recharge (MAR),
- irrigation with low and high NO_3-N levels; and,
- rainfall.

Sidinei will submit her thesis in the first quarter of 2024.

2.2.3. Madeline Inglis Masters Student

In late 2023, Madeline Inglis from the University of Canterbury commenced her master's that aims to assess transport mechanisms of microbial pathogens in groundwater from the MAR scheme.

3. Collaboration & Research

3.1. Hekeao Hinds Science Collaboration Group - Deep Pit Programme

Leaching rates of NO_3-N to groundwater systems can vary between <10 to over 80 kg N/ ha/ p.a depending on the commodity, farming platform, soil type, and climate [4], [5], [6]. This leaching rate is further exacerbated by variable lag times (i.e. the period between land use change and a resulting change in nitrate concentrations at a monitoring location such as a well or river, wetland or lake) that can vary from months to years to decades depending on the characteristics of the catchment [7], [8].

It is important to note that these leaching rates are derived from numeric models (such as Overseer®) or from lysimeters that are installed at shallow depths of 0.25 to 1.2m [3] with very little data being derived from the deeper variably saturated vadose zone, which lies between the unsaturated phreatic zone and saturated (permanent groundwater) zone.

To better understand these processes on the Hekeao Hinds Plains (HHP), the Hekeao Hinds Science Collaboration Group (HHSCG) excavated 14 pits across 13 locations between December 2022 and January 2023 (Figure 8).

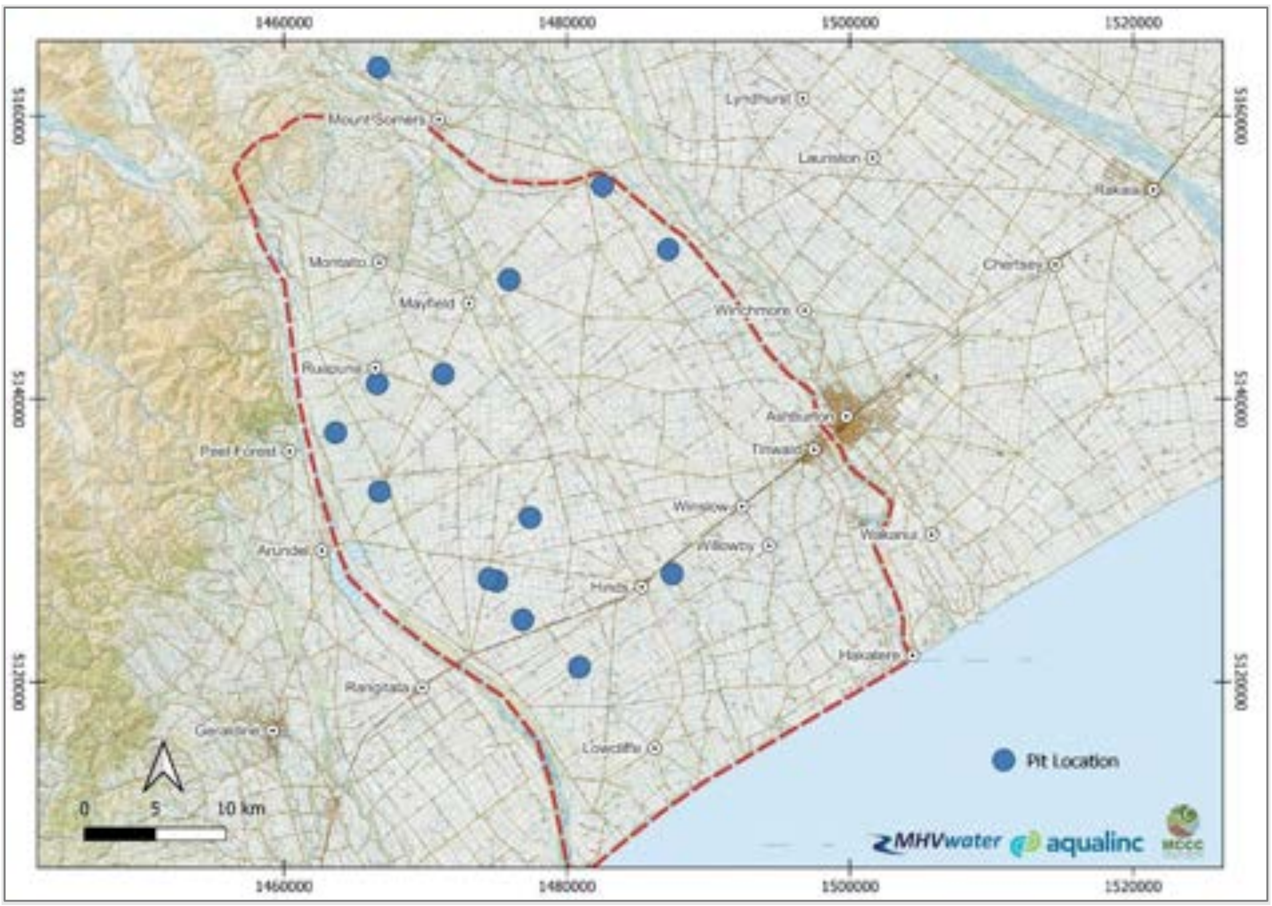


Figure 8 Locations of excavation pits

42 samples were collected below the soil profile (minimum depth 0.35m) to a maximum depth of 2.2m which underwent Horticultural Soil Analysis (S9) at Hill Laboratories. Most of the sites reported no significant nitrogen in the three main nitrogen indicators in soils, namely:

i. **Total Nitrogen (tN)** - the total amount of nitrogen, regardless of form/ species and therefore includes nitrogen that is unavailable to the plant e.g. nitrogen bound up in rocks and minerals.

ii. **Mineral N** or *Deep Soil Mineral N* – the amount of NH_4^+-N and NO_3-N that is available to plants in the soil at the time of sampling but may be in an organic form.

iii. **Potentially Available Nitrogen** or *Anaerobic Mineralisable Nitrogen* the amount of nitrogen that has been released (mineralised) from soil organic matter during the growing season based on temperature, moisture, aeration, and time.

Root depths were observed at depths of 1.2m – possibly due to moderate to low organic matter content across the sites with an average of 0.5% (0.1% to 4.1%), resulting in an average C:N ratio of 9.2 - which indicates that nitrogen will be released (mineralised) quickly for plant uptake.

4 sites reported the following results (Table 1)

Table 1 Summary Nitrogen results for the 4 sites

Nitrogen Species	Minimum	Maximum	Average
Potentially Available Nitrogen	10 kg/ha	40 kg/ha	19 kg/ha
Anaerobically Mineralisable Nitrogen	9 µg/g	19 µg/g	9.4 µg/g
Anaerobically Mineralisable N/Total N Ratio	9.0%	16.3%	3.8%
C/N Ratio	0.5	20.9	6.5

These sites were found to have elevated pH 5.9 – 6.7 (Av. 6.4) with elevated calcium, magnesium, and sodium with depleted aluminium.

Of note, lenses of well sorted gravels with minimal fine material, referred to as Open Framework Gravels (OFG's) were found to be more prevalent than expected. These lenses have high hydraulic conductivities (K) that are up to two orders of magnitude greater than for sandy gravel, and up to four orders of magnitude greater than for sand (Figure 9). This suggests that leaching in the vadose zone may have a significant horizontal vector through the vadose zone as it migrates to the saturated zone (Figure 9).

OFG's are described in more detail in section 4.4.3.

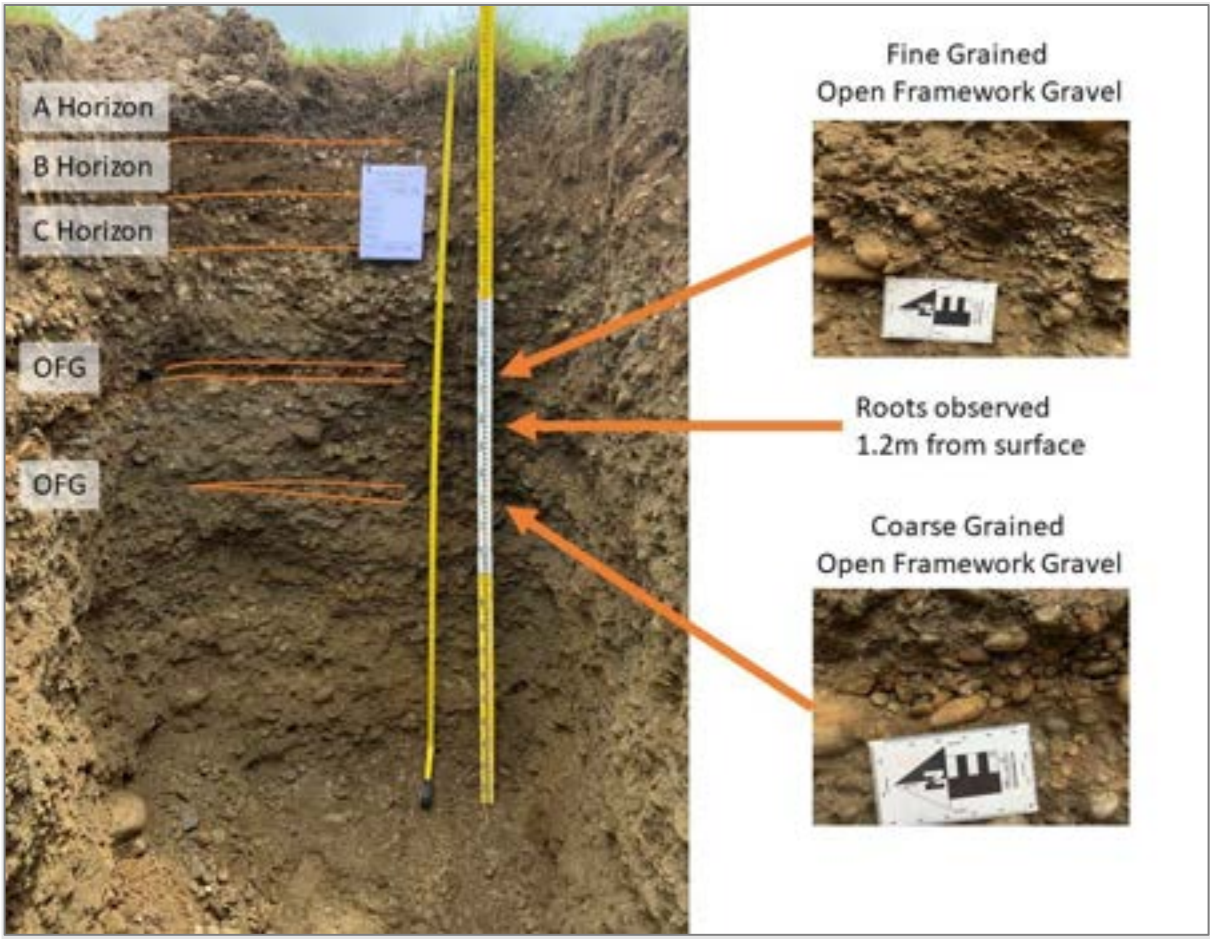


Figure 9   Example of one of the 'Deep Pits' showing Open Framework Gravels

Based on the results of the Deep Pit Programme, MHV along with the Hekeao Hinds Science Collaboration Group (HHSCG) is exploring funding opportunities for a Vadose Monitoring System (VMS).

3.2.MHV PhD Programme

As noted in section 1.3, MHV has been monitoring water quality across the HHP since late 2016. From a business and community perspective, after 6 years of monitoring and a major rain event, the question now is: **"Where to from here?"**

To address this question, MHV agreed to sponsor a “PhD thesis by publication” project at the University of Otago to be undertaken by Justin Legg (MHV Senior Hydrogeologist); who will change his primary work focus from managing the monitoring programme to one of solution-based research to meet cultural, shareholder, community, and statutory expectations.

The scope of the research is to ***characterise, quantify and define*** the key drivers of Nitrate-Nitrogen (NO_3-N) sources, migration, and retention across the Hekeao Hinds Plains with the intention of defining solutions for the co-existence of improving water quality practices and farming communities.

By better understanding and quantifying the interconnections between the land (soil and geology), water (ground and surface water, infiltration rates etc) and people (farm practices), it is envisaged that MHV, and the Hekeao Hinds community could identify environmental values and set parameters that prioritise protecting the health and wellbeing of the water.

The basis of the research programme is to:

A. characterise and quantify hydrological processes and with it NO_3-N migration,

B. provide linkages between point and diffuse sources, morphology and processes, farming practices and irrigation, as well as

C. enable the farming community to enact changes to manage, mitigate and potentially reduce NO_3-N leaching to groundwater by providing strategies based on the findings of A and B.

These linkages are presented thematically as ‘Land’, ‘Water’ and ‘People’ in Figure 10.

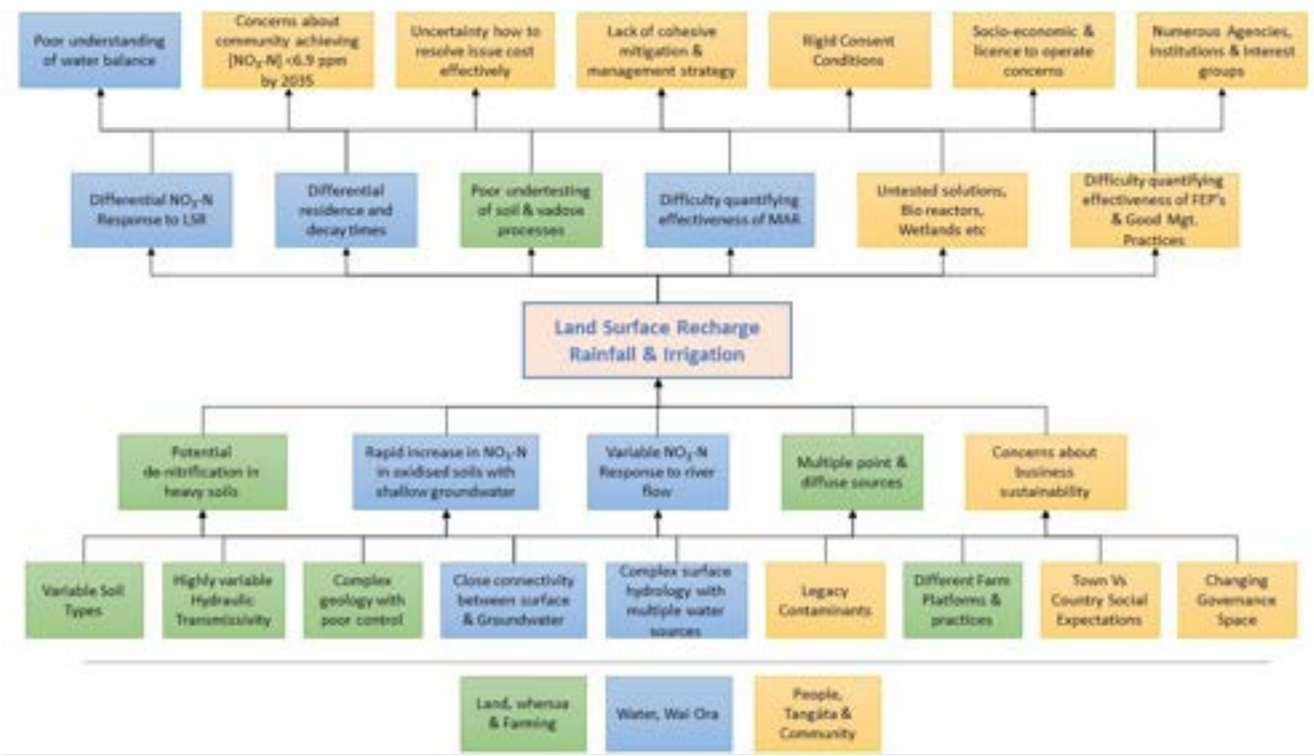


Figure 10 Problem tree of the NO_3-N situation on the Hekeao Hinds Plains

The deliverable of the research programme is to develop a framework (with a series of guidelines), that would enable farmers to implement on farm solutions that are sustainable, practical, and affordable and that will lead to improved freshwater outcomes.

These on farm solutions would be the primary driver of effecting change in groundwater and surface water quality, with community-based solutions such as Managed Aquifer Recharge (MAR), constructed wetlands etc. to be seen as a complimentary and supporting infrastructure initiatives.

It is envisaged that by having contiguous properties practising similar on-farm techniques to improve water quality, a catchment scale mosaic approach will be developed to complement the MAR/wetland etc locations across the catchment - Figure 11 presents this concept (based on soil types) as well as the locations of the current MAR sites.

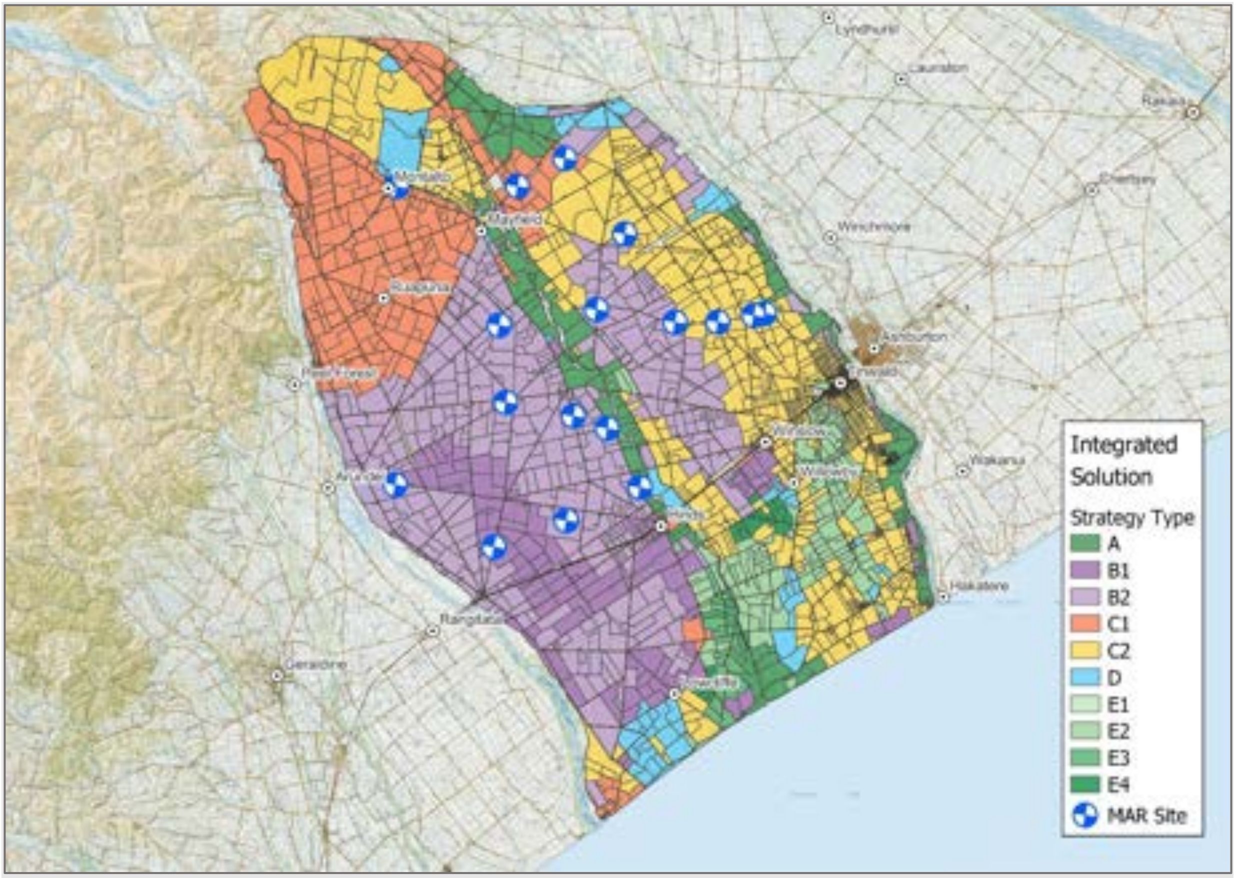


Figure 11 Conceptual example of contiguous properties using similar water quality management solutions

The research proposal was accepted by the university in July and Justin officially started on 1 September 2023.

4. Background

4.1.Location

The Hekeao Hinds Plains is an area of some 1,465 km^2 (146,500 ha) located within the larger Ashburton District of Canterbury in the South Island of New Zealand, approximately 85km northeast from Ōtautahi Christchurch. The plains are bounded by the Hakatere Ashburton and Rangitata Rivers and stretches from the Moorhouse Range to the coast.

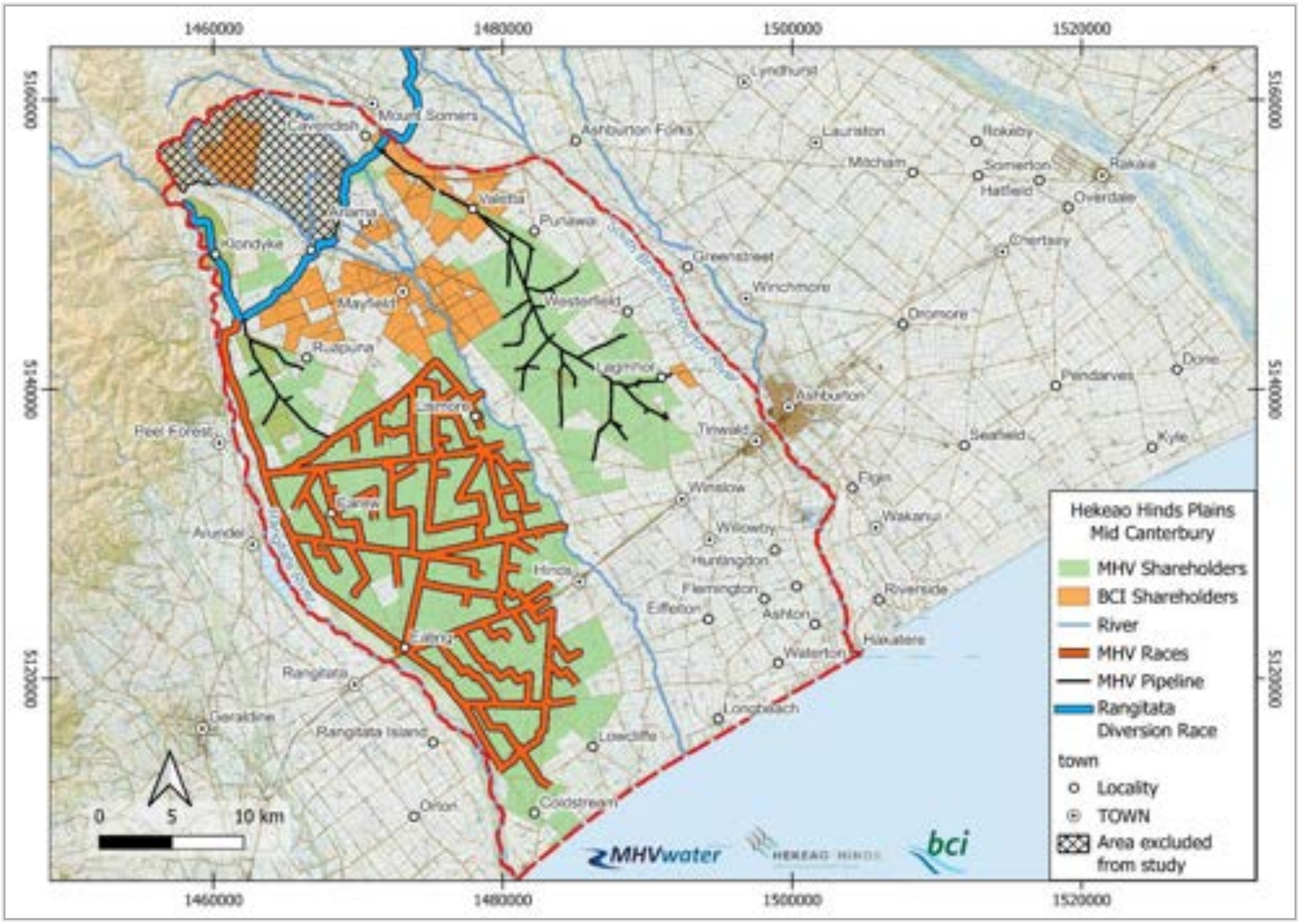


Figure 12 Locality map of the Hekeao Hinds Plains with MHV and BCI irrigation schemes and infrastructure

Following the establishment of the Ashburton District Council in 1876, irrigation was first trailled at the Ashburton Irrigation Farm near Elgin in 1887 [9], [10], although its potential was not fully realised until the construction of the Rangitata Diversion Race (RDR) in the late 1930's. The RDR was primarily built to provide irrigation water to the farmlands of Ashburton County; the 67 km race diverted water from the Rangitata River at Klondyke to the Rakaia River near Methven, servicing approximately 66,000 ha. It resulted in a significant increase in farming production as well as diversification from sheep to arable cropping across the Hekeao Hinds Plains [9], [11], [12], [13].

In 2022 the Ashburton District alone contributed to almost 1% to Aotearoa New Zealand's GDP, driven largely by its agriculture industry which makes up 28% of the local economy (the national average is 5.8%) [14].

4.2. Climate and Rainfall

The Hekeao Hinds Plains are prone to drought, with a cool temperate climate, (Köppen climate classification Cfb).

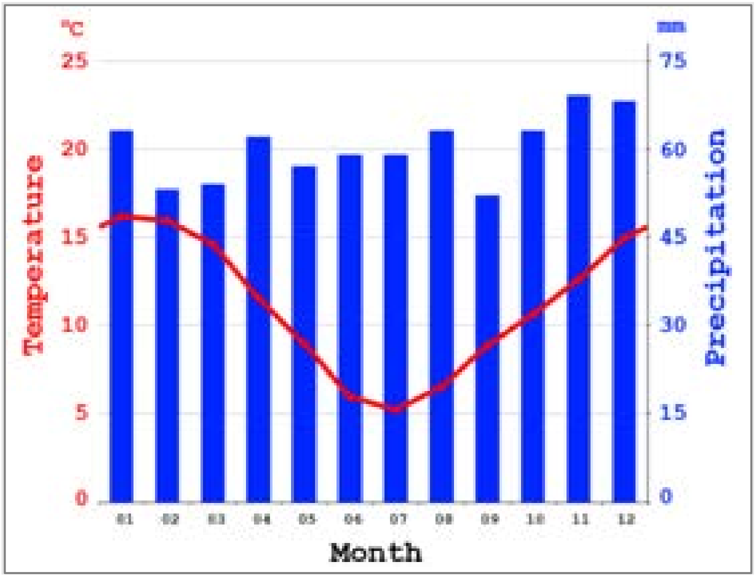


Figure 13 Ashburton Climate[5]

The mean annual rainfall of 680 mm p.a. varies from 614 mm at the coast to approximately 950 mm at the foothills near the top of the plains (2). Regular snow does not make up a large proportion of the total precipitation in the catchment since only a small area of the catchment lies above 500 m [15].

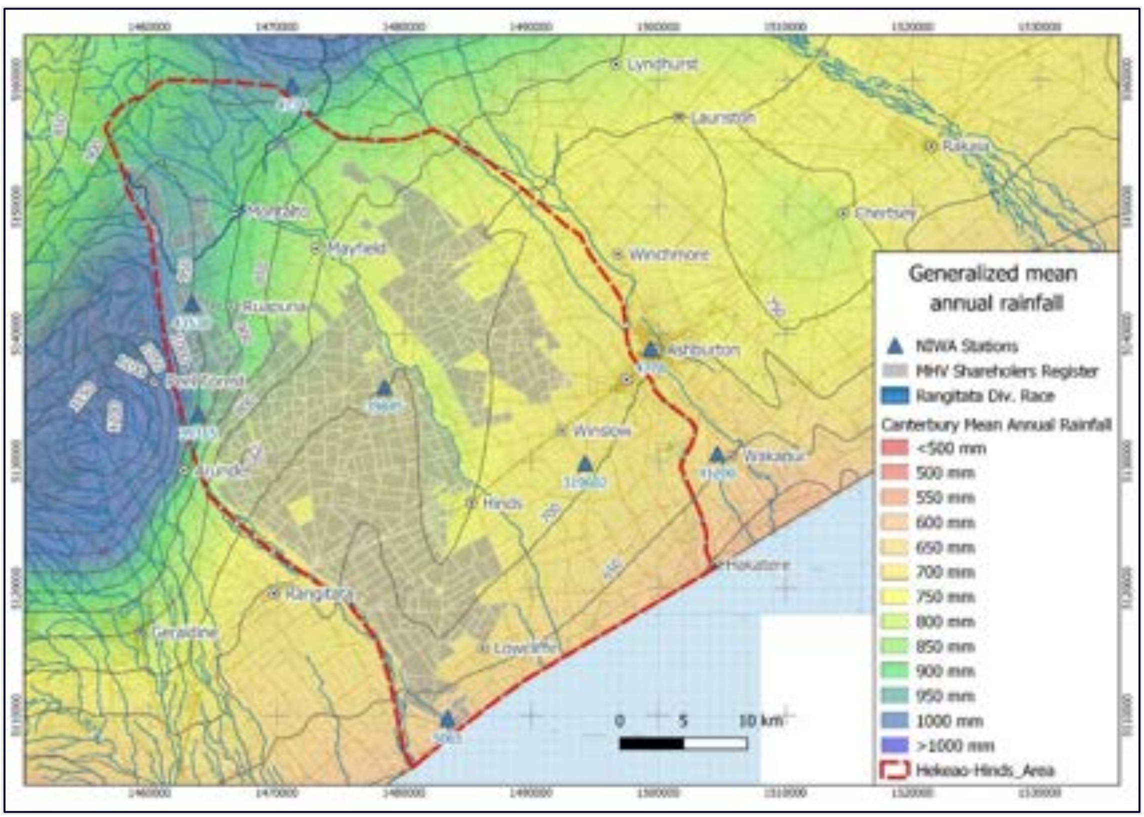


Figure 14 Generalised mean annual rainfall distribution across the Hekeao Hinds Plains

[5] https://en.climate-data.org/oceania/new-zealand/canterbury/ashburton-26549/

4.3. Catchment Characteristics

4.3.1. Soils

The Hekeao Hinds Plains has over 20 main soil types, the most common being thin (<0.5 m) sequence of stony, free-draining loess and Lismore-type soils, with a low water holding capacity of less than 75 mm [16].

Closer to river margins, soils tend to be deeper and more varied in type, depth and quality. Notably, between Lagmhor and Waterton (on the southern side of the Hakatere Ashburton River), as well as the coastal margin of the plain, the area is dominated by gley soils and wakanui deep silt loam soils with higher water holding capacities up to more than 150 mm. These soils are associated with swamp deposits [16], [17], [18].

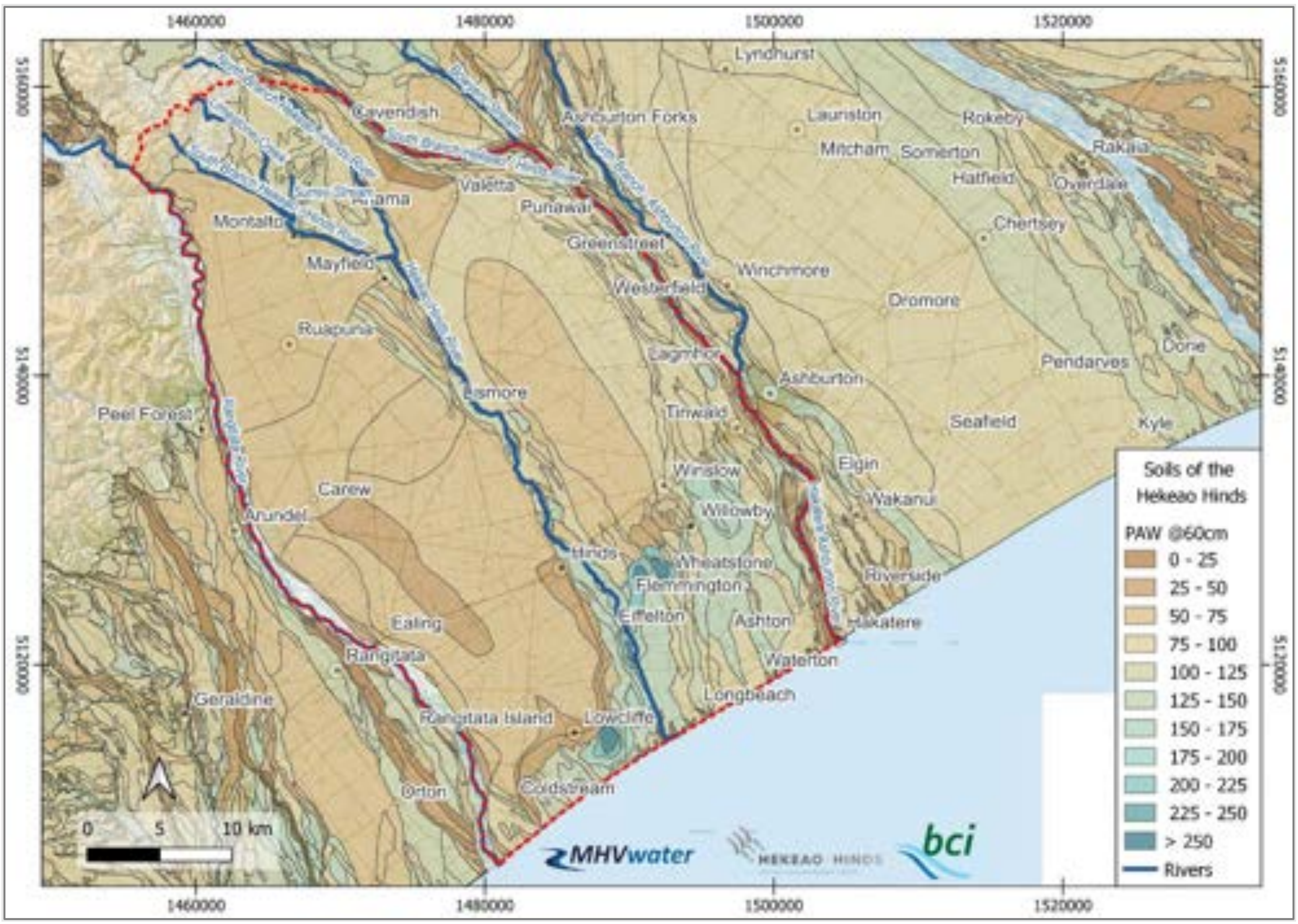


Figure 15 Soils of the Hekeao Hinds Plains

4.3.2. Geology

Deep (>600 m) Quaternary[6] aged anisotropic and heterogeneous glacial outwash alluvial gravel fans immediately underlie the previously described soils; these were deposited as part of the uplift and erosion of the Southern Alps [16], [19]. These gravels are predominantly composed of greywacke gravel clasts, in a matrix of sandy fine gravel and minor silt with minimal clay, resulting in sediments that are variable and heterogeneous in structure. The sequence is generally dominated by poorly sorted silty/sandy gravels (colloquially known as clay-bound gravels), but groundwater flow and

[6] Late Quaternary (0.4 Ma) to Holocene (0.014 Ma).

transport has been found to predominantly occur through high permeability lenses, called open framework gravel or OFG's (refer to section 4.4.3).

These Quaternary sediments are underlain by Tertiary sediments and Cretaceous greywacke basement of the Torlesse Group [18].

4.4. Hydrology

4.4.1. River Flows

River flows in the Hekeao Hinds Plains almost mirror the seasonal rainfall, with river flows in all three rivers having lower flows over periods of lower rainfall (such as between 2019 and 2020) and responding to the much higher rainfall accumulations since mid-2021.

Monthly rainfall and river flows for the Hakatere Ashburton, Hekeao Hinds and Rangitata Rivers are shown in Figure 16 and Table 2.

Table 2 Average daily flow rates (m^3/ second) for the rivers in the survey area between 2015 - 2023

	Hakatere Ashburton River at SH1	Hekeao Hinds River at Poplar Rd	Rangitata River at Klondyke
2015	13.3	0.36	86.9
2016	14.5	0.39	90.6
2017	29.4	2.99	86.1
2018	40.8	3.24	91.2
2019	25.0	1.54	105.7
2020	11.6	0.33	82.6
2021	34.3	2.35	106.7
2022	37.4	3.34	109.3
2023	25.3	1.89	92.7

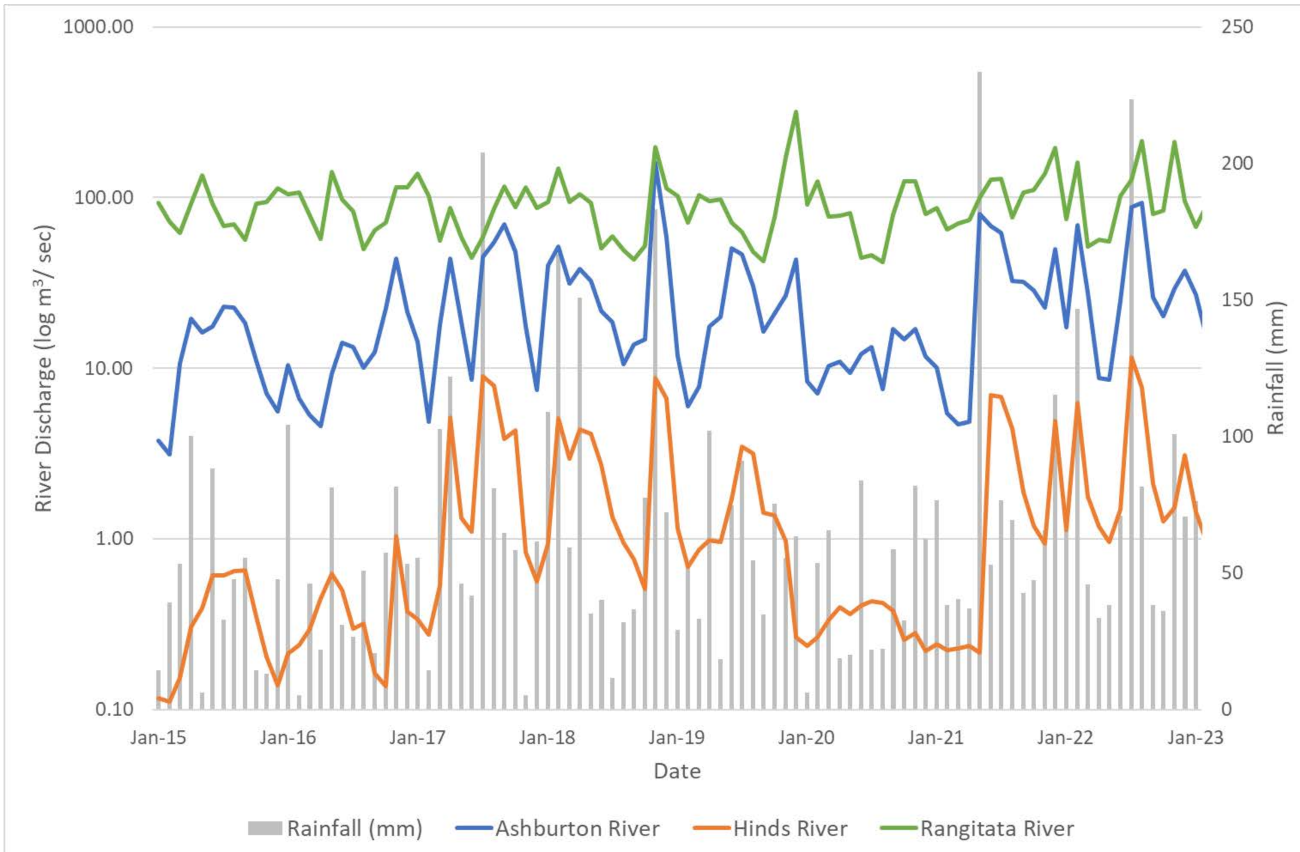


Figure 16 Rainfall and river flow data for the period 2015 to 2023

4.4.2. Catchment Scale

The Hekeao Hinds Plains are serviced by three rivers: the Hakatere Ashburton, Rangitata, and Hekeao Hinds. The Hakatere Ashburton and Hekeao Hinds Rivers are considered foothill rivers whereas the Rangitata is an Alpine River. All these rivers have variable flow rates and are confined to terraced alluvial fans.

Both mātauranga māori and local farm knowledge attest that the regional shallow hydraulic gradient runs obliquely across the Hekeao Hinds from Tarahaoa Mt Peel towards the mouth of the Hakatere Ashburton River. A high-level interpretation of the 1 m LiDAR[7] digital terrain model (DTM) supports this assertion, whereby observable lineation of the data[8] were digitised (Figure 18). These lineation's are interpreted to be 'paleo drainage channels', associated with the migration of Hekeao Hinds Plains rivers over time; and may represent near-surface preferential ephemeral flow paths and/or indicators of open framework gravels (see section 4.4.3).

These near-surface preferential ephemeral flow paths (or paleo channels) are variable in size and direction with a mean direction of 135° (Figure 17) which is concordant with existing piezometric contours [20].

[7]Light detection and ranging

[8] The LIDAR data was not manipulated via differential methods such as a 1st vertical derivative (1VD) as part of this process

NB: Note that flow direction is perpendicular to piezometric contours

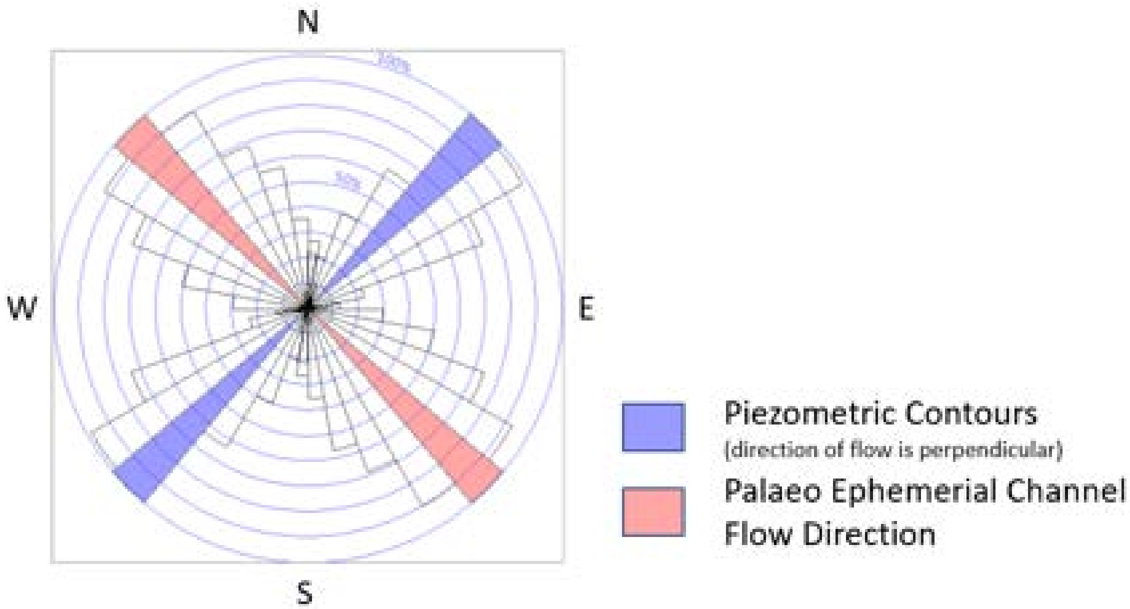


Figure 17 Rose diagram illustrating preferential ephemeral flow direction (red) with 2007 piezometric contours (blue)

These data sets are presented in Figure 18.

Figure 18 High-level interpretation of the 1m LIDAR digital terrain model (DTM) mapping paleo channels with 2007 Piezometric contours [20]

4.4.3. Aquifer system

Historically, the groundwater system has been conceptualised as three poorly connected, and laterally discontinuous, aquifers at near surface, ~50 m and ~100 m depths respectively [19]. The current interpretation (at a regional scale) considers the aquifers of the Hekeao Hinds Plains to be a gravitationally driven system with the Quaternary gravels behaving as a *single hydrological system with close connectivity to surface waters* (i.e., rivers and drains). At a local scale, semi-confined (leaky) conditions are likely to be encountered, with the degree of confinement generally increasing with depth [15], [16], [21]. Aquifer recharge is derived from rainfall, irrigation losses, and seepage from the Hekeao Hinds, Hakatere Ashburton, and Rangitata Rivers.

Due to the inherent variability of the sedimentary facies, there is a corresponding variability in hydrogeological properties. Transmissivity[9] has been estimated to vary between 150 and 7,000 m^2/ day [18].

Most of groundwater flow and solute transport has been shown by other studies to be through open framework gravels (OFG's), which are lenses of well sorted gravels with minimal fine material. The origin of OFG's is still contested with three dominant theories namely [22]:

i. They are formed under high flow conditions when finer materials are suspended in the water column and separated from the bedload gravel; with later lower flow regimes depositing finer-grained, matrix-filled strata above them.

ii. They are formed under variable flow rates (e.g. glacial melt-water streams) resulting in a bi-modal gravel with the finer sediment being winnowed from the gravelly bed at low flow stage to leave an open-framework deposit.

iii. They are formed via migration of 'minor bedforms' in the river resulting in differential deposition of materials.

Notably, based on work in the Burnham area, it has been suggested that >95% of groundwater flow occurs through OFG's gravels; however, their lengths and interconnectedness at a broader scale is not well understood.

These gravel lenses can [18], [21], [23]:

- be planar-stratified or cross-stratified,
- vary in thickness from centimetres to decimetres,
- be variable in their spacing between lenses,
- can extend from metres to tens of metres, and,
- account for approximately 1% of braided river sedimentary systems in the Canterbury Plains.

The gravels within the lenses are characterised as [22], [24]:

- well sorted (possessing a unimodal grain size distribution) with a mean grain size $\geq$ 2 mm,
- negligible sand and/ or clay matrix,
- having hydraulic conductivities (K) of up to 5×10^{-1} m/ sec (i.e., up to two orders of magnitude greater than for sandy gravel, and up to four orders of magnitude greater than for sand), and,
- having Mn or Fe staining of the clasts

An example is presented in Figure 19.

[9] Transmissivity is a measure of the rate at which groundwater flows through a unit width of an aquifer under a unit hydraulic gradient

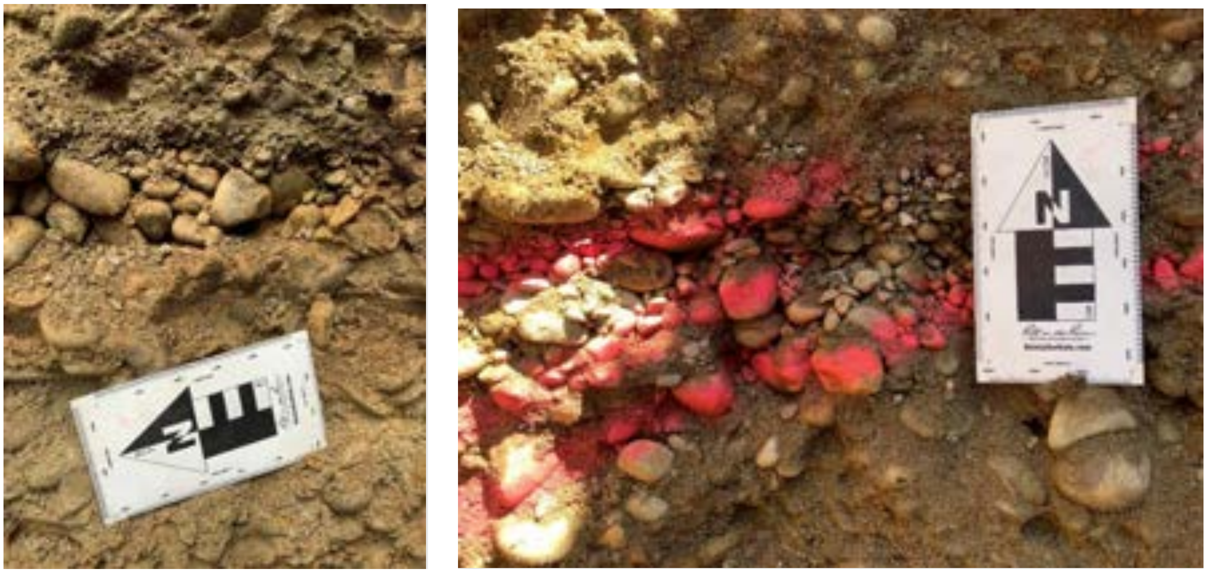


Figure 19 ***Examples of open framework gravel lens***

OFGs are important as they contribute significantly to flow within, and transport of solutes through, the Canterbury gravel aquifer system. Their exact role, in terms of NO_3-N transport, is not yet fully understood.

4.5.Localised surface hydrology

The Hekeao Hinds Plains possess several different types of water courses (Figure 20). These include:

- **Highly modified water courses (HMWC)** - often lowland surface water bodies that have been straightened or incorporated into larger extensive drainage and flood protection works [25], [26]. There are over 150 HMWC's within the catchment representing ≈430 km of waterways. Of these, < 10% (35.3 km) are within the MHV shareholding area.
- **Drains** - extensive drainage and flood protection works including channelization and man-made drains [25], it is estimated that there are ≈2,300km of council stock water races in the catchment.
- **Races** – Primary water delivery canals.
- **Springs**- a natural discharge point of subterranean water at the surface of the ground or directly into the bed of a stream.
- **Rivers** – i.e., the Hakatere Ashburton, Hekeao Hinds and Rangitata Rivers.

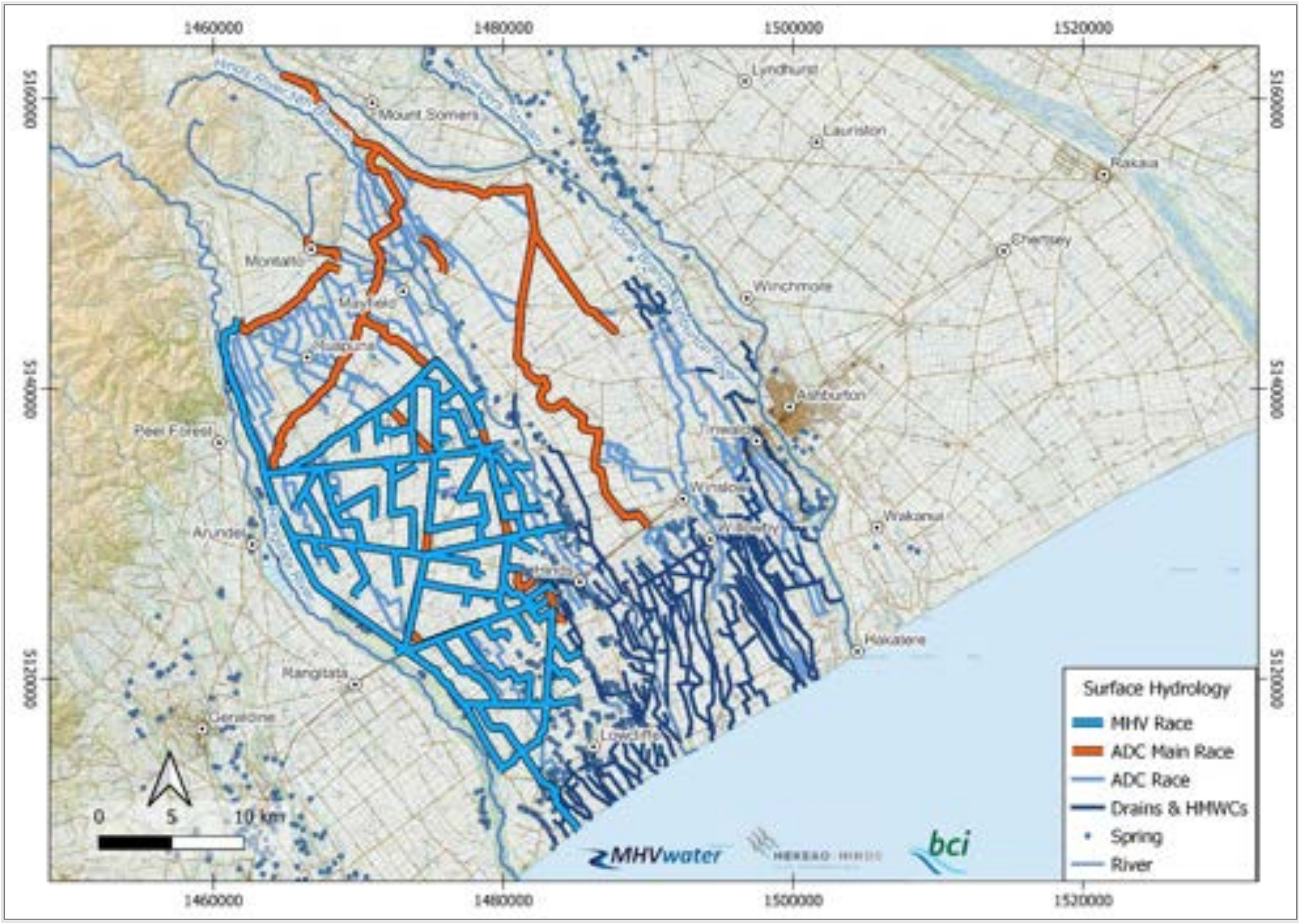


Figure 20 Surface waterways on the Hekeao Hinds Plains

4.6. Nitrate

4.6.1. Sources

Nitrate (reported as Nitrate -Nitrogen or NO_3-N) is a stable, plant available form of oxygenated nitrogen formed through various chemical and biological processes. In the Hekeao Hinds catchment, NO_3-N is mostly derived from several sources including [17], [18], [27]:

Point sources such as

- septic tanks (human effluent)[10],
- dairy and other animal effluent discharges,
- stormwater and contaminated water,
- industrial water such as factory washdown water and gravel processing,
- Offal pits
- Soak holes
- Silage pits
- refuse dumps,

[10] In Canterbury, septic tanks are estimated to contribute a load of 9 kg of nitrogen (a concentration of 55 mg/L) per dwelling per year for those installed pre-2006, and 3 kg (a concentration of 20 mg/L) post-2006 (Aitchison-Earl, 2019).

- animal feedlots, and;

Diffuse sources such as:

- Urbanisation and construction,
- stormwater runoff and urban drainage,
- Decaying plant debris,
- Agricultural fertilisers, and;
- Land use practices, ploughing, drainage, land clearing and other agricultural practices can cause acceleration of soil organic N mineralisation and oxidation and result in large amounts of leachable NO_3–N,– primarily pulses following recharge events but also potentially as baseflow recharge.

Some of these sources and impacts on groundwater have been quantified in Table 3 [28]

Table 3 Quantification of non-agricultural sources of NO_3-N

Source	Loading	Effluent concentration	Contribution to nearby groundwater
	kg N/ ha/ yr	ppm	ppm
Leaky Sewers	123	2	4 - 10
Leaky Mains	19		5 - 10
Septic tanks	100	25 - 68	10 – 30
Landfill	300 - 5700	2.0 – 2.5	6 - 70
River–aquifer interaction			1.8 to 5 in < 1 week
Highways and roads	3.2 – 8.7	0.4 – 3.3	1 – 3
Construction sites	59	48 – 303	
Urban Environ		0.0 – 2.70	

Nitrate is one component of a broader natural cycle known as the Nitrogen Cycle (Figure 21). In simple terms:

- Nitrogen enters the soil via fertilisers, animal effluent (dung and urine), fixated from the atmosphere or soil organic matter.
- It is then first converted into ammonium (NH_4^+) via a process known as *mineralisation*.
- The ammonium then undergoes *nitrification* that oxidises it to form nitrite (NO_2^-) and the more stable nitrate (NO_3^-)
- The nitrate is then consumed by plants and bacteria in the soil profile, what is remaining is returned to the atmosphere via *de-nitrification* or is transported as a soluble leachate into the hydrosphere.

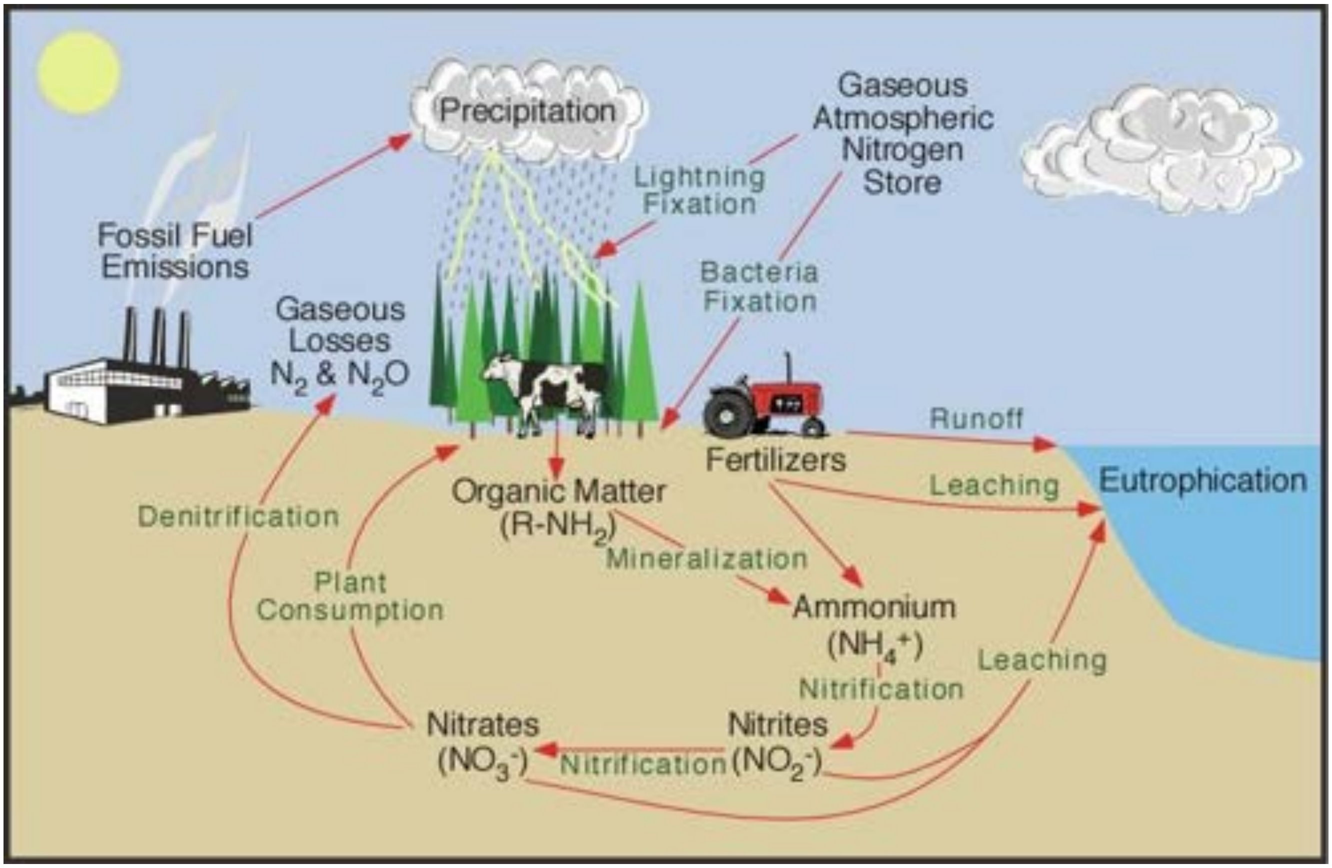


Figure 21 The nitrogen cycle[11]

It is important to note that depending on hydrological conditions, it may take years (and potentially decades) for NO_3-N to move from the original source and through the groundwater system, so current and historical sources for NO_3-N must be considered when trying to account for NO_3-N concentrations in groundwater and surface water.

4.6.2. Nitrate Distribution

Work undertaken by ECan has revealed variable nitrate distribution across the Hekeao Hinds Plains in response to different soil types (refer to section 4.3.1). In summary [17], [18]:

- higher NO_3-N concentrations were found in the middle and upper parts of the Hekeao Hinds Plains (Hinds to Ruapuna) with free-draining loess and Lismore-type soils and well oxygenated groundwater,
- lower NO_3-N concentrations were found in groundwater near the coast. This area was formerly covered by swamp and is characterised by heavy Waterton gley soils and low-permeability Wakanui loam silts,
- the highest NO_3-N concentrations, including those in the Tinwald area, were found near the transition zone between high-permeability sediments beneath the upper plain and the lower-permeability sediments near the coast.

Due to the confluence of the soil type(s), the interconnectivity of surface and groundwater as well as numerous NO_3-N sources, it is important to recognise that NO_3-N levels in shallow bores in the Hekeao Hinds Plains can fluctuate significantly with rainfall and over short periods of time.

[11] http://www.physicalgeography.net/fundamentals/9s.html

5. Groundwater Sampling Program

5.1.Groundwater Monitoring Program Development

The groundwater monitoring programme was initiated in late 2016, with an initial survey of 29 bores. As the focus of the monitoring programme has evolved over time, so too has the design of the programme. In 2023, survey sizes ranged between 156 and 164 bores (Figure 22) representing a spatial footprint of ≈111,00 ha- refer to section 5.3.

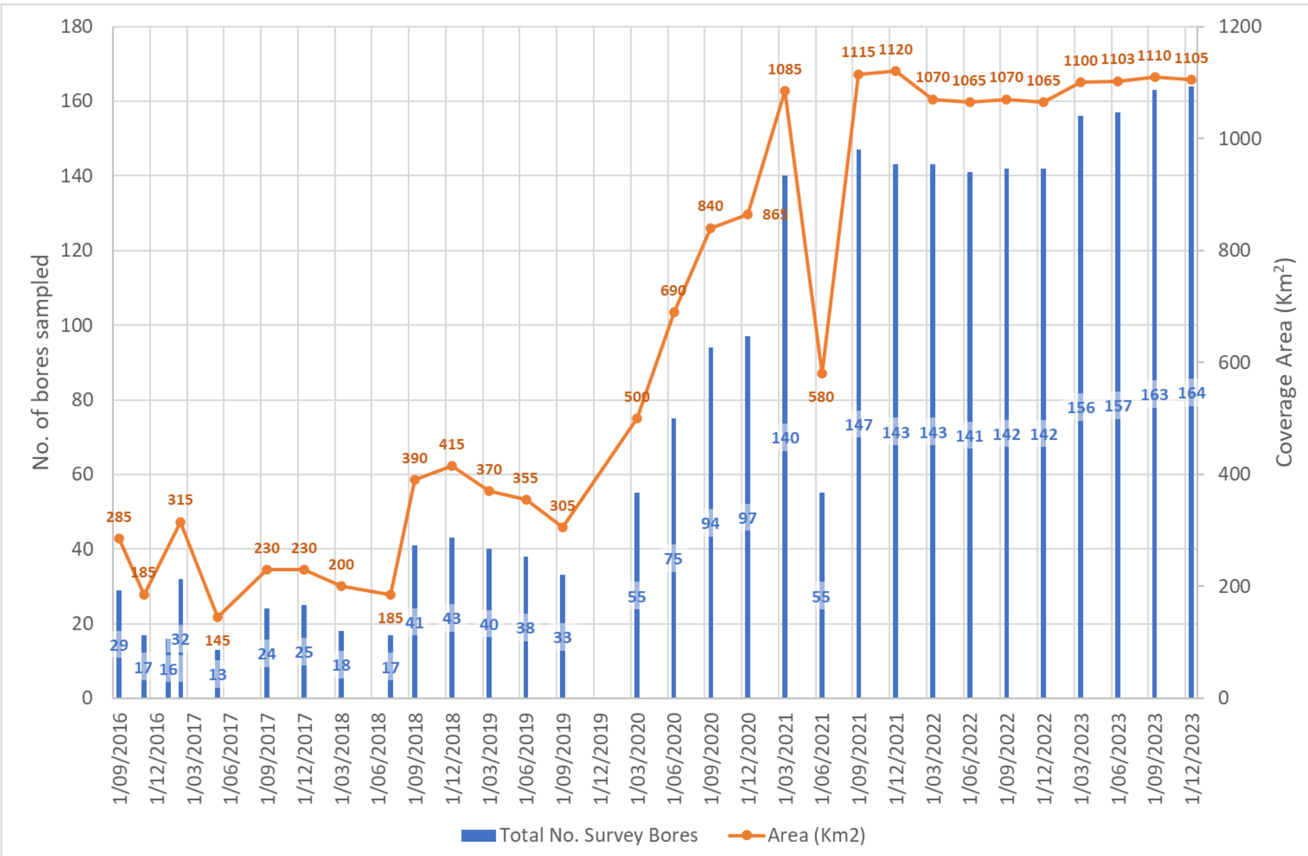


Figure 22 Frequency histogram of survey size changes over time

5.2.Bore Depths and Types

5.2.1. Bore Type

A wide variety of bore types was tested during 2023 to avoid sampling bias (i.e., sampling only type X bore or depth Y bore) as well as for logistical/ practical considerations. Figure 23 presents a breakdown of the types of bores tested based on their designation in the ECan database[12].

[12] https://www.ecan.govt.nz/data/well-search/

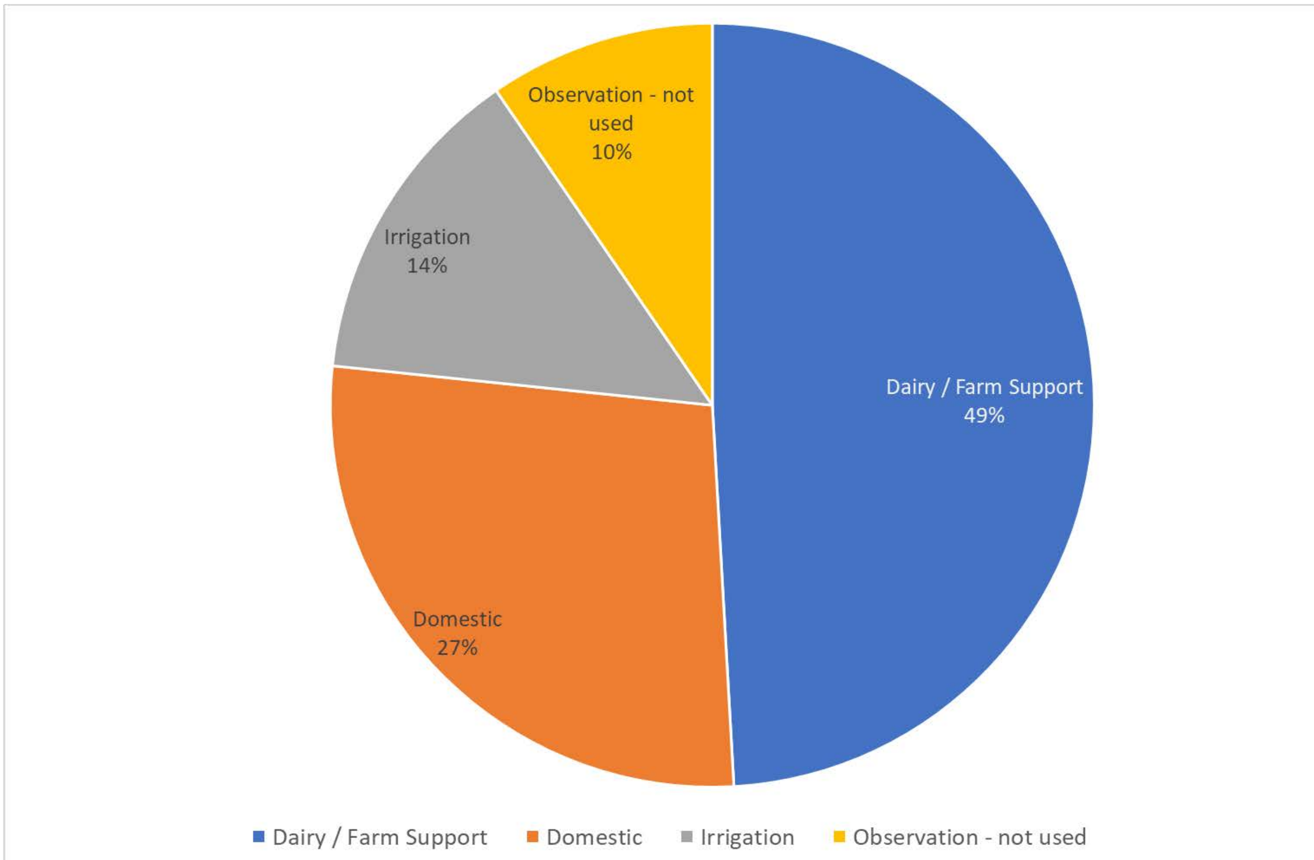


Figure 23 Bore types tested during 2023 as per the ECan database.

5.2.2. Bore Depths

Bore depths are categorised in keeping with the LWRP[13] [3], and are split into:

- **Shallow bores:** Groundwater bores screened **<30 m** below ground level (m bgl)
- **Intermediate bores:** Groundwater bores screened **between 30 and 80 m bgl.**
- **Deep bores:** Groundwater bores that abstract from depths **≥ 80 m bgl**

Figure 24 and Figure 25 presents a frequency histogram of the depths of bores tested and number of samples collected by their respective depth in 2023.

[13] Refer to s13.7.3 Water Quality Limits and Targets - Canterbury Land and Water Regional Plan (Environment Canterbury, 2019)

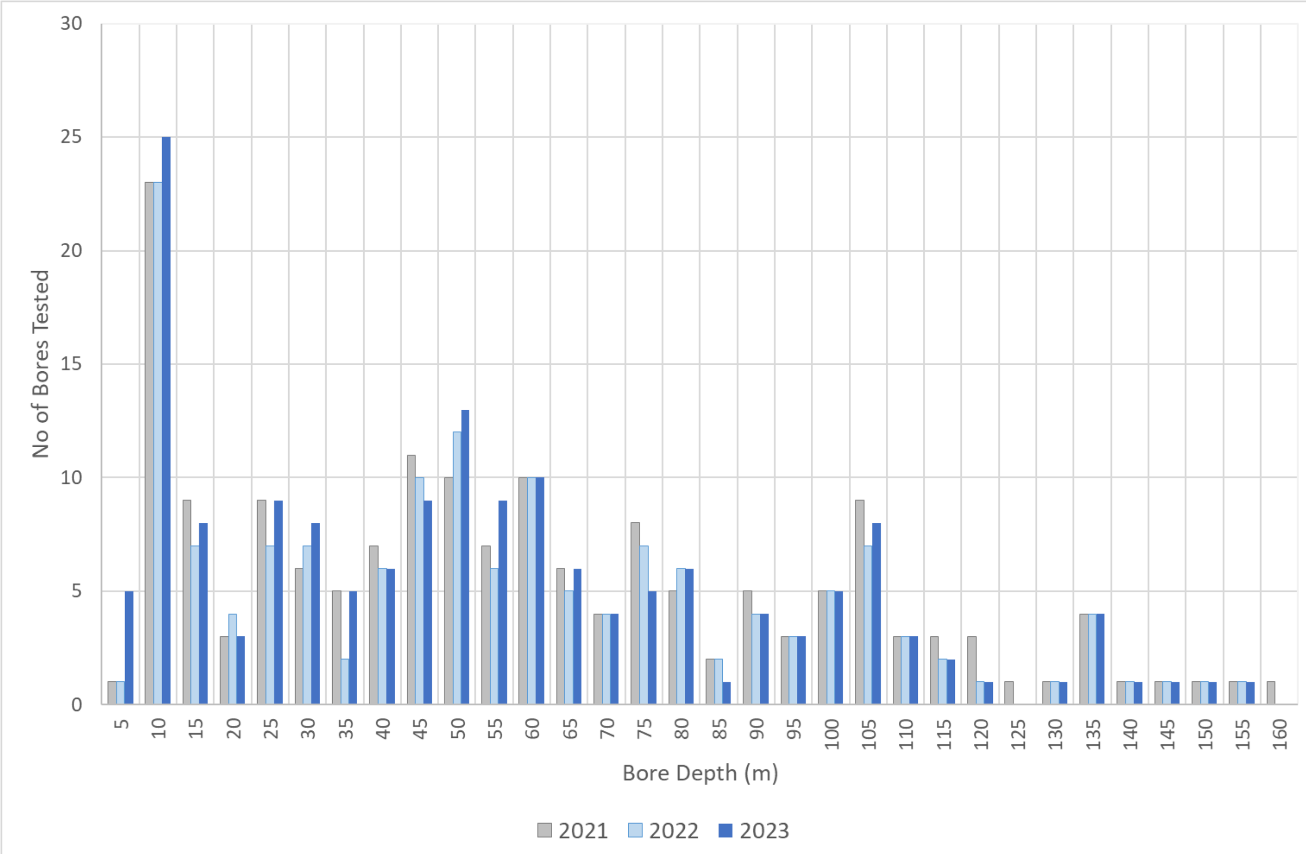


Figure 24 Number of bores tested by bore depth between 2021 and 2023

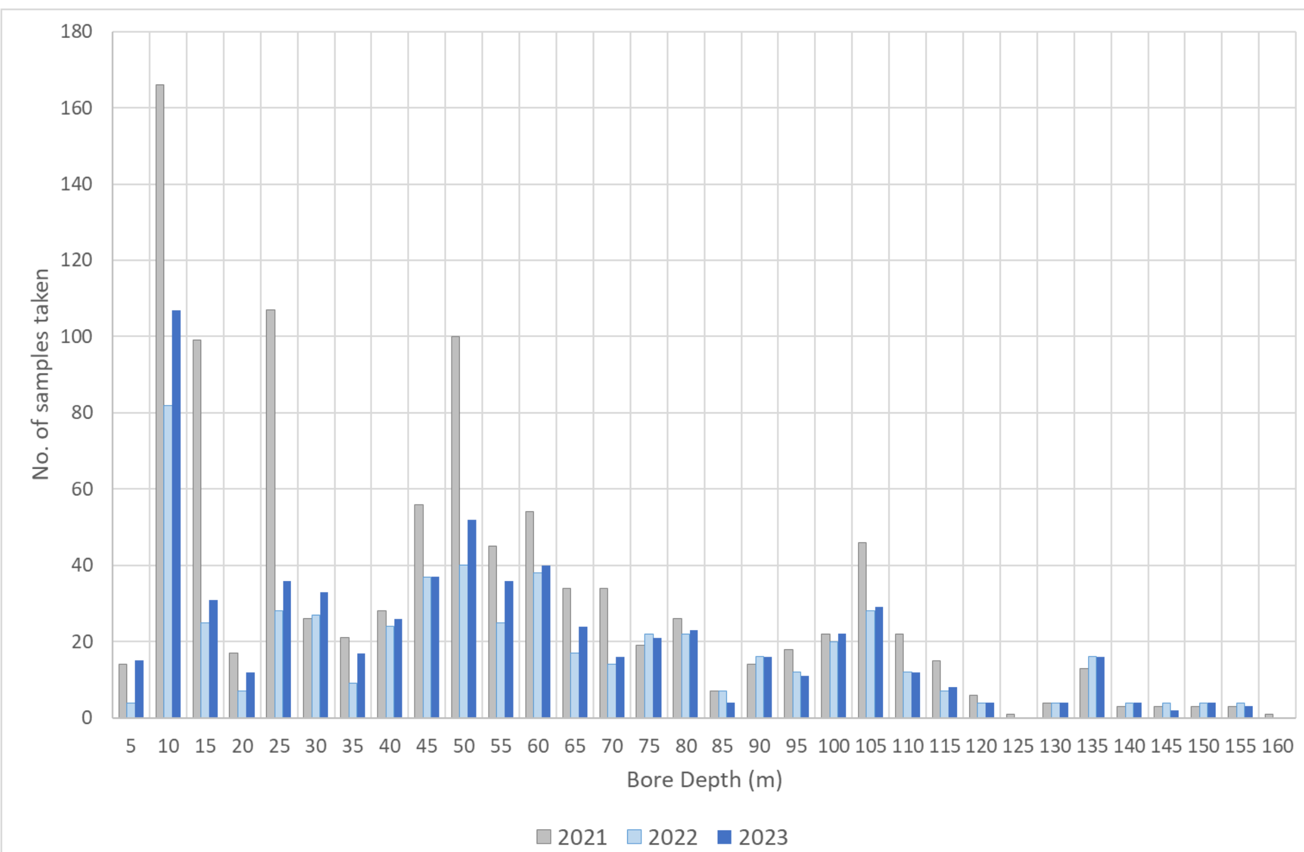


Figure 25 Number of samples collected by bore depth between 2021 and 2023.

A breakdown of bore depth and the number of samples taken during 2023 is presented in Table 4 and Figure 26.

Table 4 Breakdown of bore depth and the number of samples for 2023.

Month	Bores <30 m	Bores 30 - 80m	Bores > 80m
January			
February	36	54	30
March	18	18	4
April	2		
May	27	59	30
June	27	14	4
July	2		
August	27	46	24
September	28	28	10
October	2		
November	30	38	28
December	28	35	9
Total	**227**	**292**	**139**

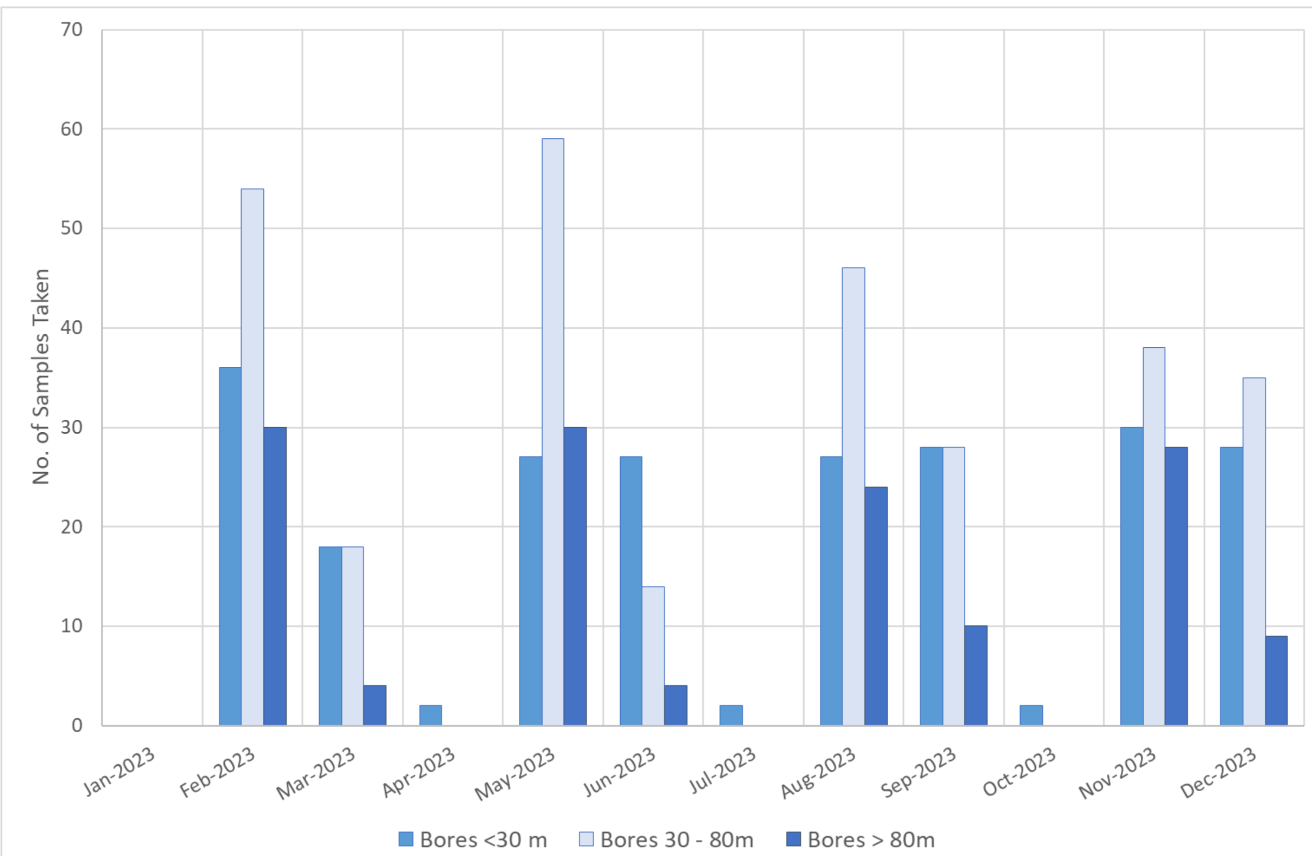


Figure 26 Sample frequency during 2023.

5.3.Survey Spatial Coverage

The current groundwater abstraction guidelines for ECan require a 2 km buffer zone from a bore [29], [30] for a WQN 10 assessment to assess interference effects from abstraction. On this basis, as well as the nominal spacing of the bores tested in pre 2020 surveys – a 2 km buffer around each bore was used as a measure of spatial coverage. Figure 27 presents the groundwater survey area for 2023. The average distance between bore sampled in 2023 was 2.15km (range 8.1m to 6.7km).

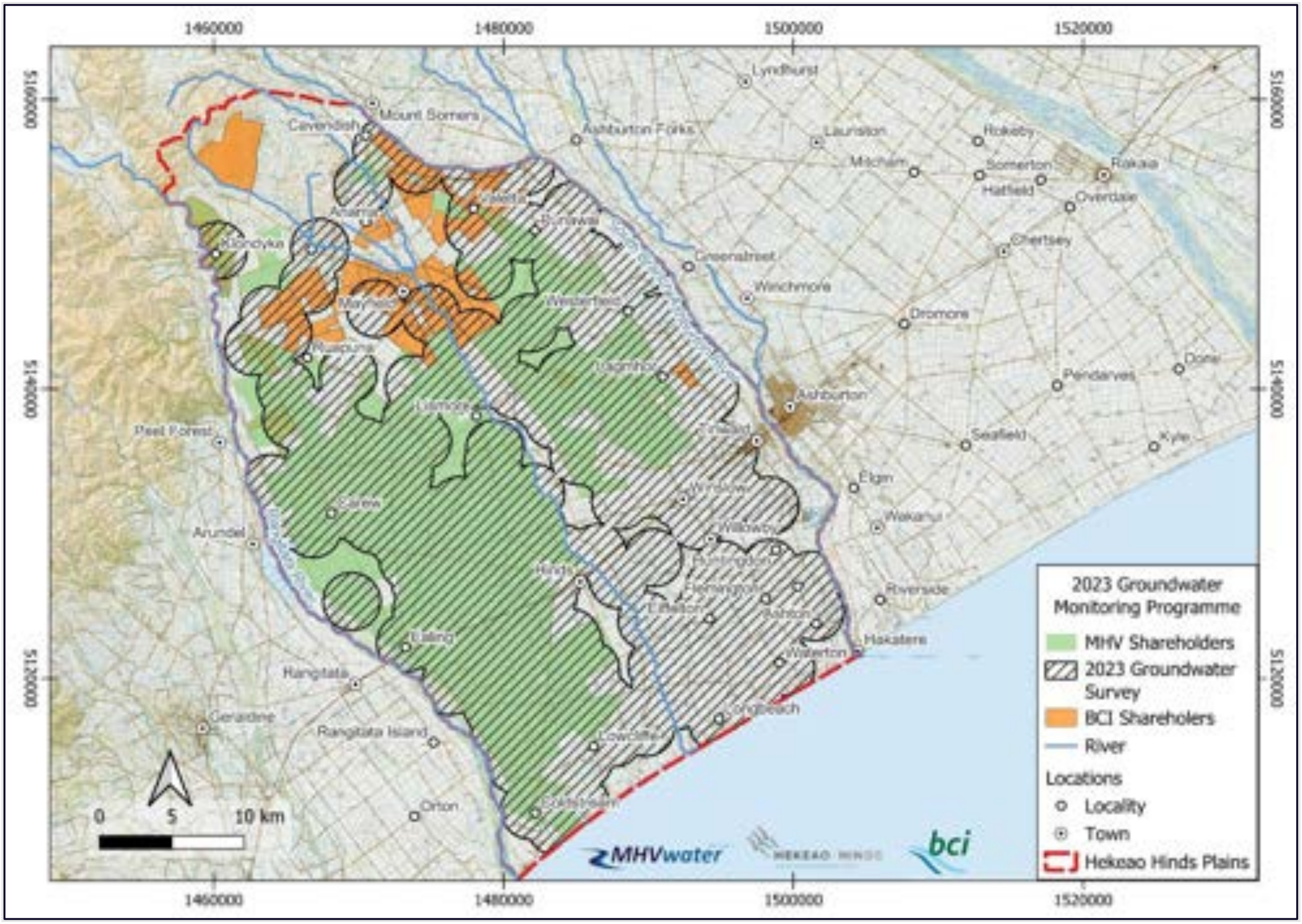


Figure 27 2023 Groundwater survey area

6. Surface Water Sampling Program

6.1.Surface-water Monitoring Program Development

During 2023, MHV increased its quarterly surface water sampling programme from 64 locations to 98 with a corresponding increase in sampling from an average of 46 per month to 65 - the majority of which were collected from public road culverts or bridges (Figure 28 & Table 5).

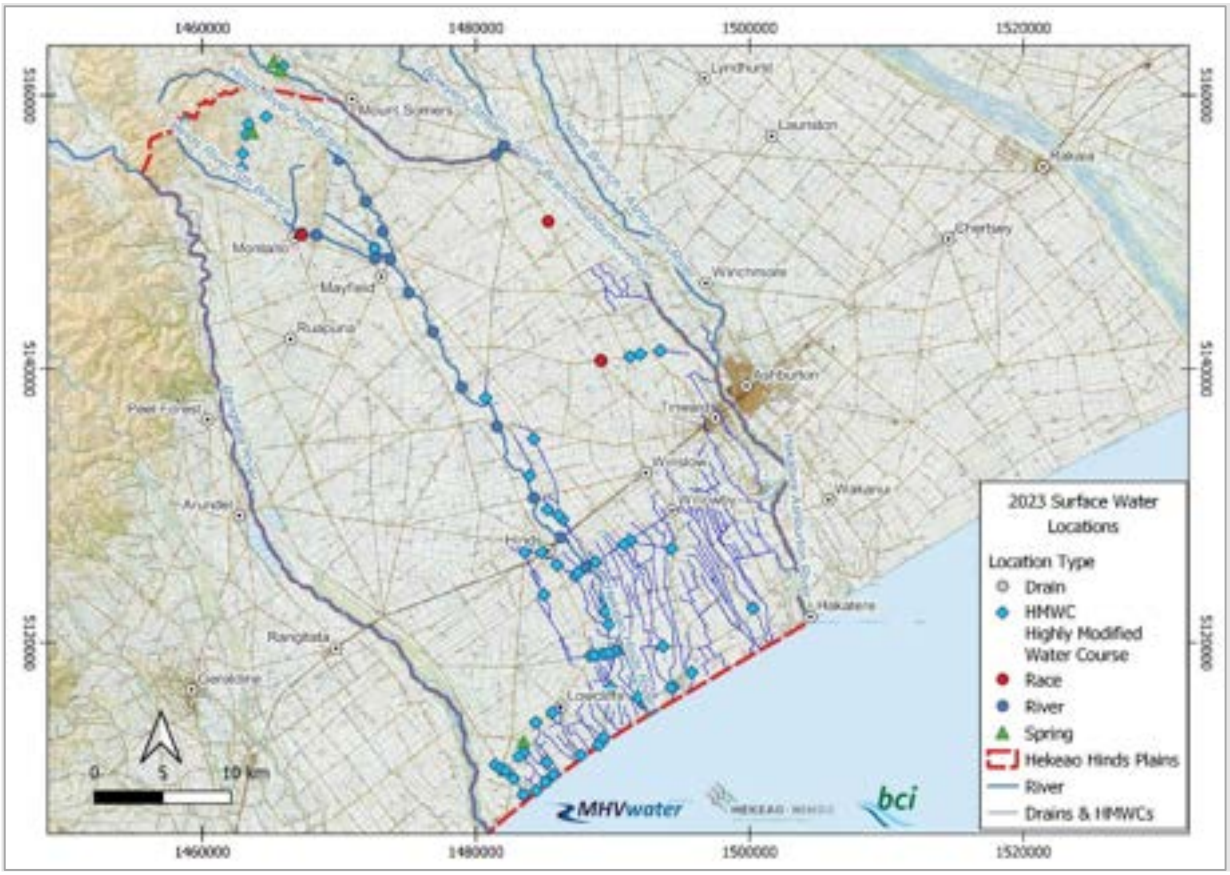


Figure 28 Location of 2023 surface water sampling sites

Table 5 Breakdown of 2023 surface water sampling sites

Location Type	No. of Sites	No of Samples collected
HMWC - Highly modified water course	66	511
Race	4	28
River	20	158
Spring	8	22
Total	**98**	**719**

Figure 29 presents the evolution of the surface water monitoring program since 2016; Table 6 presents a breakdown of samples collected during 2023.

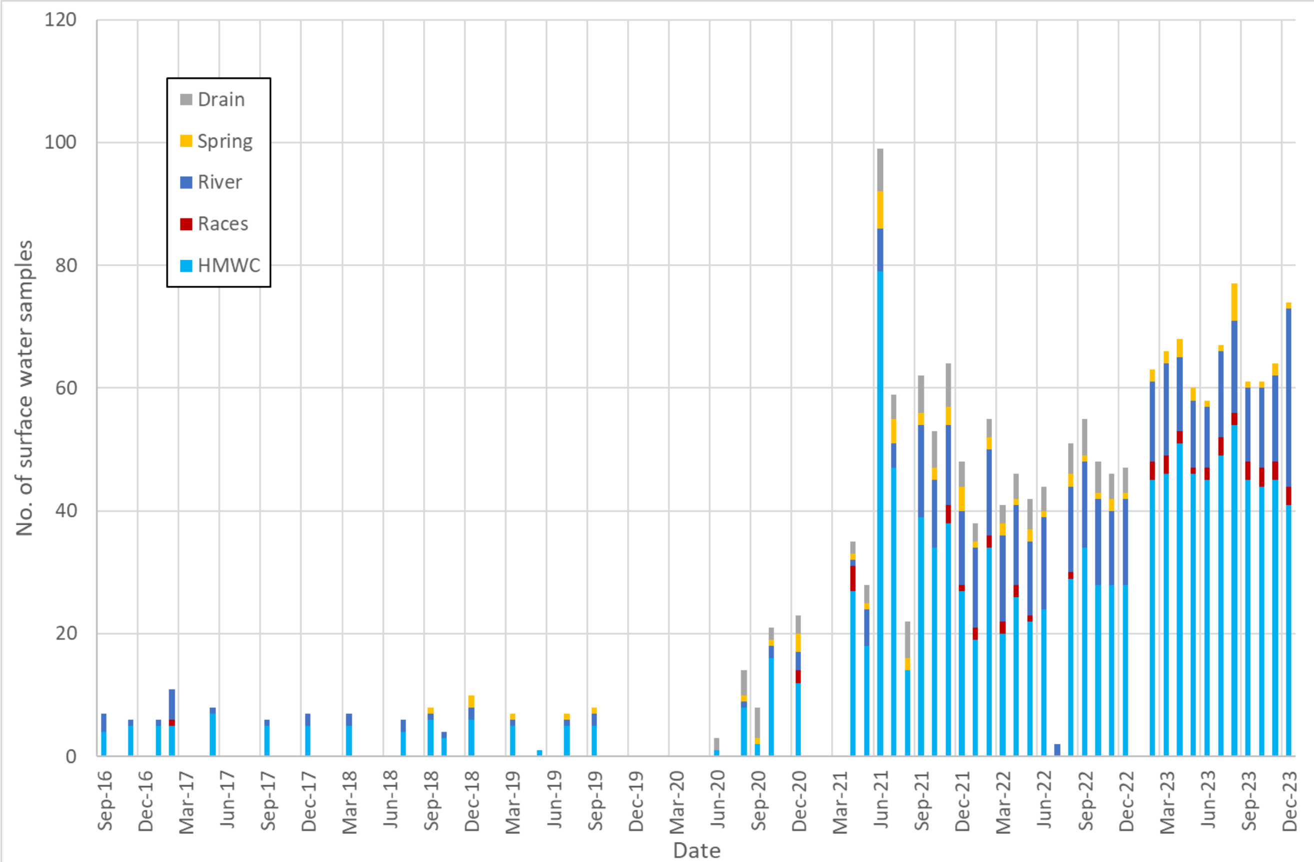


Figure 29 Changes in surface water survey design 2016 - 2023

Table 6 Summary of 2023 surface water sampling program

Month	Drain	HMWC	River	Spring	Race	Total
Jan-23						
Feb-23		45	13	2	3	**63**
Mar-23		46	15	2	3	**66**
Apr-23		51	12	3	2	**68**
May-23		46	11	2	1	**60**
Jun-23		45	10	1	2	**58**
Jul-23		49	14	1	3	**67**
Aug-23		54	15	6	2	**77**
Sep-23		45	12	1	3	**61**
Oct-23		44	13	1	3	**61**
Nov-23		45	14	2	3	**64**
Dec-23		41	29	1	3	**74**
Total	**46**	**511**	**158**	**22**	**28**	**719**

7. QAQC

Samples were obtained using Standard Operating Procedures (SOP's) that are based on, and, in keeping with the National Environmental Monitoring Standards (NEMS) for Water Quality – Parts 1 & 2. A summary is presented in Appendix 4.

7.1.Water Quality and NO_3-N Measurements

Water quality data was obtained via a YSI Plus ProPlus portable water quality meter to measure:

- Dissolved Oxygen (% and mg/l),
- pH,
- Conductivity,
- Specific Conductance (SPC),
- Oxidation Reduction Potential (ORP),
- Turbidity (Nephelometric Turbidity Units – NTU), and;
- Water temperature (degrees Celsius).

NO_3-N concentrations for all samples collected in 2023 were measured in house via a HydroMetrics Nitrate GW50 Groundwater Optical NO_3-N Sensor. These in-house samples were analysed a minimum of 5 times with at least two sub-samples (i.e., 2 x 10ml samples from the site sample). An arithmetic mean was then calculated from the readings and used for reporting purposes.

7.2.Water Quality QAQC

Approximately 10% of the samples were analysed at Hill Laboratories (Middleton) throughout the year for Nitrite-N (NO_2-N) and Nitrate-N (NO_3-N) via Automated Azo dye colorimetry, with a flow injection analyser (refer to Rice et al., 2017) to confirm the validity of the HydroMetrics Nitrate GW50 Groundwater Optical Nitrate Sensor and quantify and characterise the difference in reported results from both analytical methods. It also enabled a simple cross-check of the results. The approximate locations and depths of the 2023 QAQC samples are shown in Figure 30.

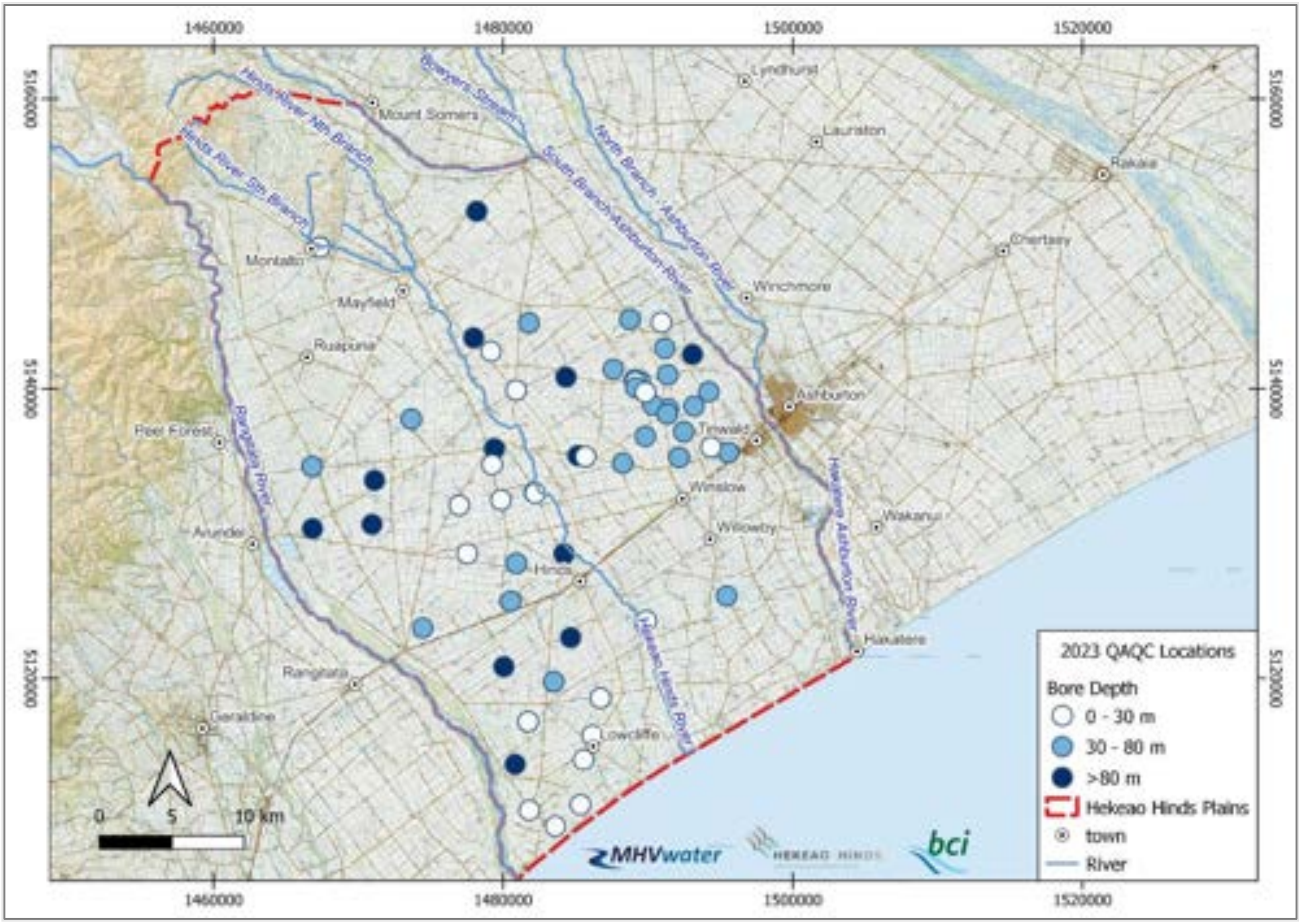


Figure 30 Location of and depth of QAQC samples sent to Hill Laboratories

As reported in 2022, routine calibration and maintenance of the GW50 affected the acceptable bias between the laboratory and instrument results from +7% to -8%. Whilst this bias is within the acceptable precision tolerance of ± 12% as noted by Hill Laboratories, it does create a step change in the results. Subsequently, the data is now normalised[14] with respect to the Hill Laboratory data via linear regression.

Figure 31 presents the raw and normalised data from the calibration period (August 2022 to June 2023). In both cases, the R^2 is >0.95, indicating a strong correlation. To date, the results for the 2023 – 2024 calibration appear to be well within acceptable limits as shown in Figure 32.

[14] Normalisation means adjusting values measured on different scales to a notionally common scale. In this case the raw data is shifted via a linear regression equation so that the normalized values are directly comparable to the corresponding Hill Laboratory values, thus eliminating the effects of gross influences – such as calibration.

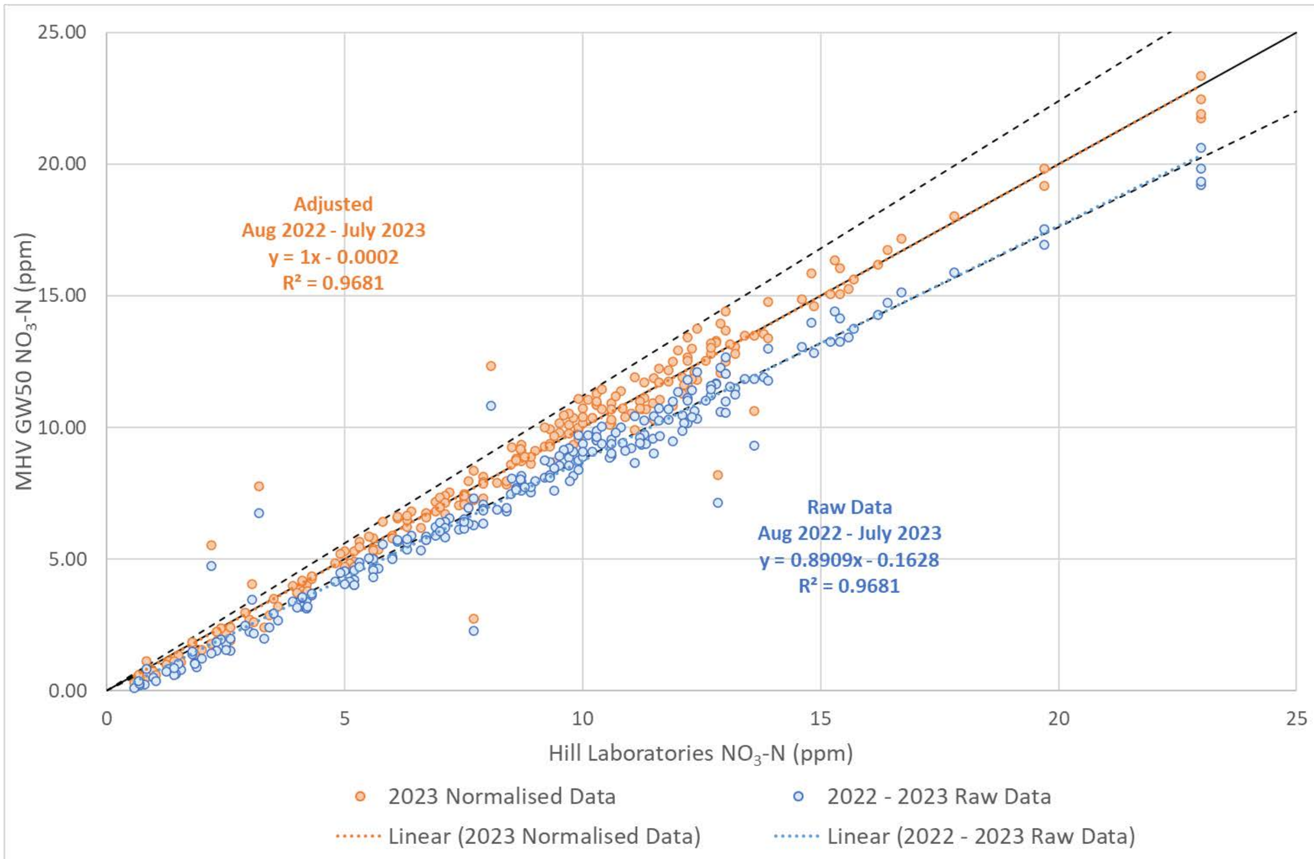


Figure 31 Regression analysis and normalisation factor for samples collected between August 2022 and July 2023

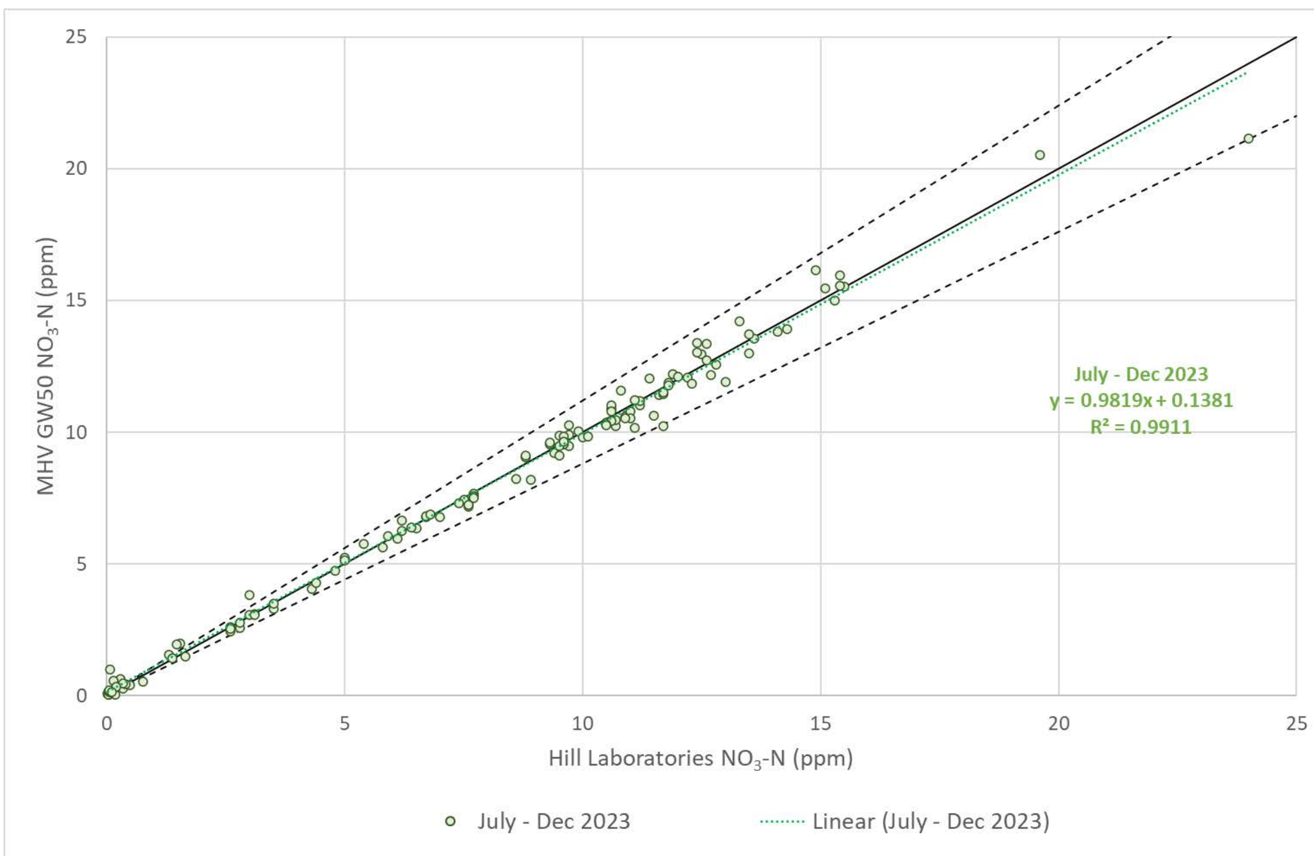


Figure 32 Regression analysis and normalisation factor for samples collected between August and December 2023

8. Groundwater Monitoring Results

8.1.Annualised groundwater NO_3-N results

A summary of the descriptive statistics for the 2023 results is presented in Table 7 and as a frequency histogram in Figure 33 (refer to Appendix for tabulated results).

Table 7 Descriptive statistics for the 2023 NO_3-N results

Bore Depth	Count	Min	Max	Median	Average	95th Percentile	Std. Dev	CV[15]
<30 m	214	0.009	21.65	9.05	8.46	15.05	4.63	0.51
30-80 m	287	0.043	23.25	9.03	8.64	15.13	4.04	0.45
>80 m	143	1.478	12.58	6.03	6.05	10.28	2.67	0.44
All Bores	644	0.009	23.25	8.22	8.01	14.53	4.13	0.50

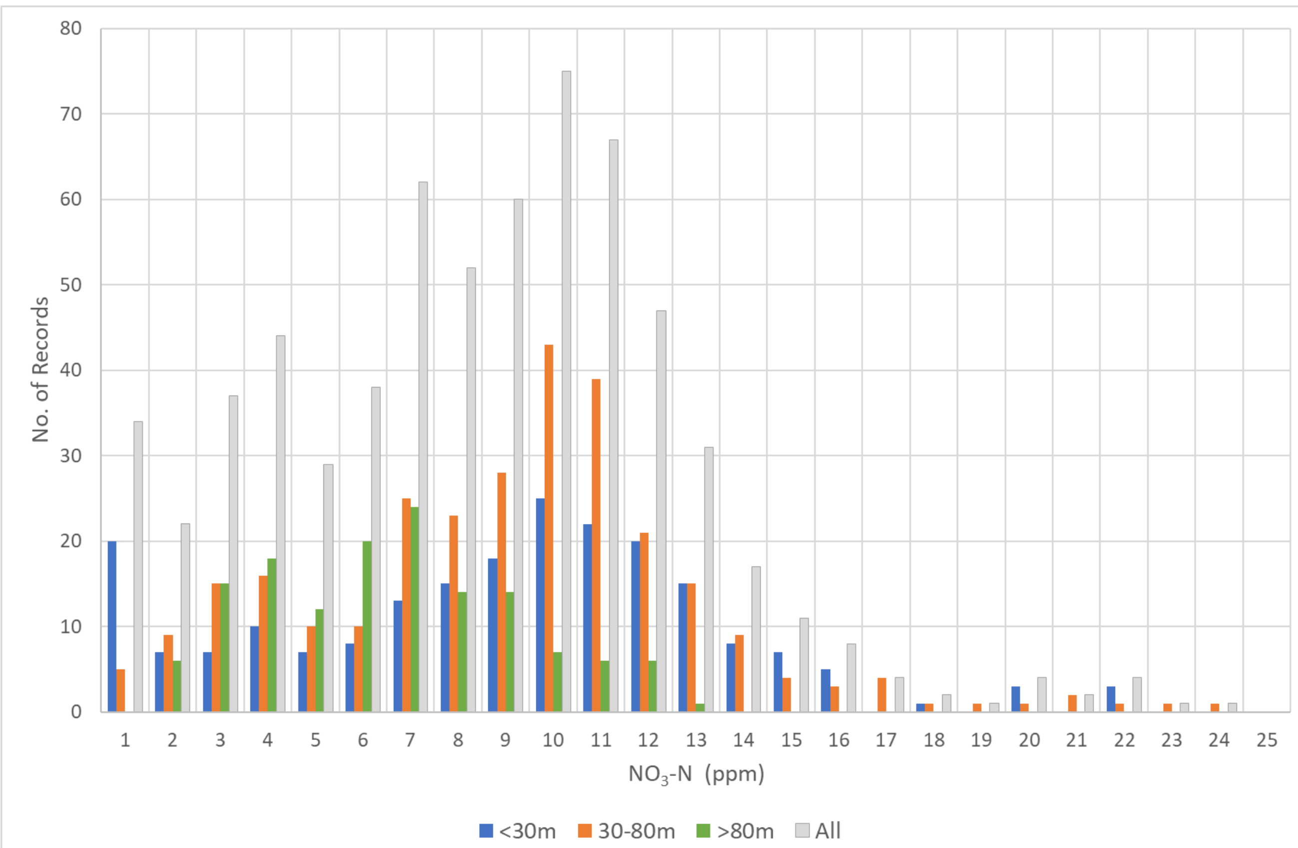


Figure 33 Frequency histogram for the 2023 NO_3-N results

[15] The coefficient of variation (CV) is the ratio of the standard deviation to the mean. The higher the coefficient of variation, the greater the level of dispersion around the mean.

8.2.Groundwater Levels

MHV collected 303 Ground Water Levels (GWL) readings from 71 bores across the Hekeao Hinds Plains during the year (Figure 34). Table 8 presents a summary of the results.

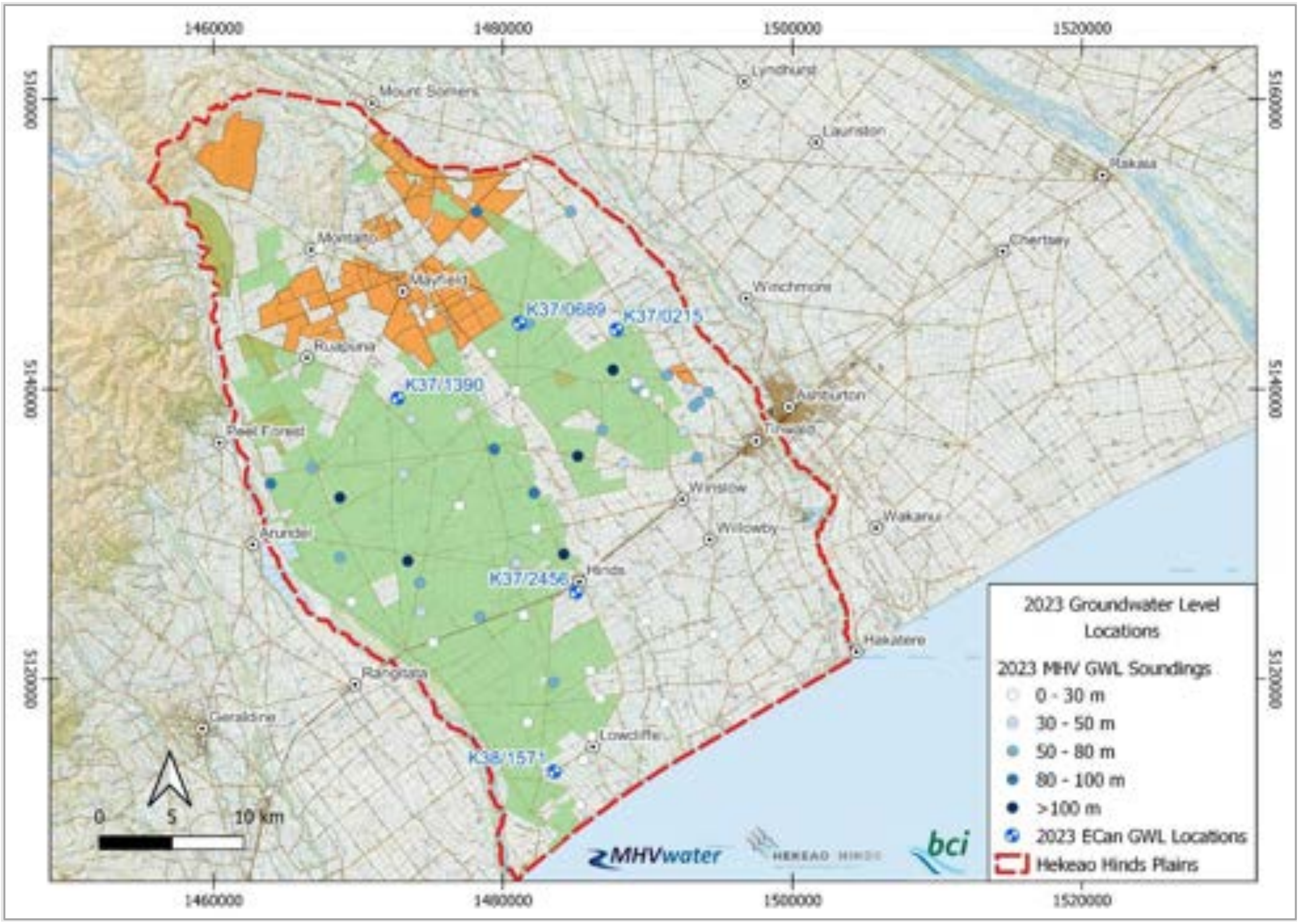


Figure 34 Locations of MHV & ECan groundwater level monitoring bores

Month	Count	Minimum (m bgl)	Maximum (m bgl)	Median (m bgl)
Feb	18	1.8	52.71	6.74
Mar	18	0.89	59.94	7.635
Apr	2	2.26	2.44	2.35
May	30	2.93	50.2	14.48
Jun	17	0.86	60.1	4.61
Jul	2	2.42	2.57	2.495
Aug	22	1.04	50.02	11.78
Sep	26	1.03	59.15	4.74
Oct	2	1.82	2.05	1.935
Nov	24	1.06	55.52	6.635
Dec	22	1.88	61.49	8.26
Grand Total	183	0.86	61.49	7.88

Table 8 Summary statistics of groundwater level soundings collected by MHV during 2024

A hydrograph of the different bore depths (see section 5.2.2) indicates that GWL's remained constant throughout the year, with the deeper bore data being disproportionately affected by 1 bore - this bore is presented as single line in Figure 35.

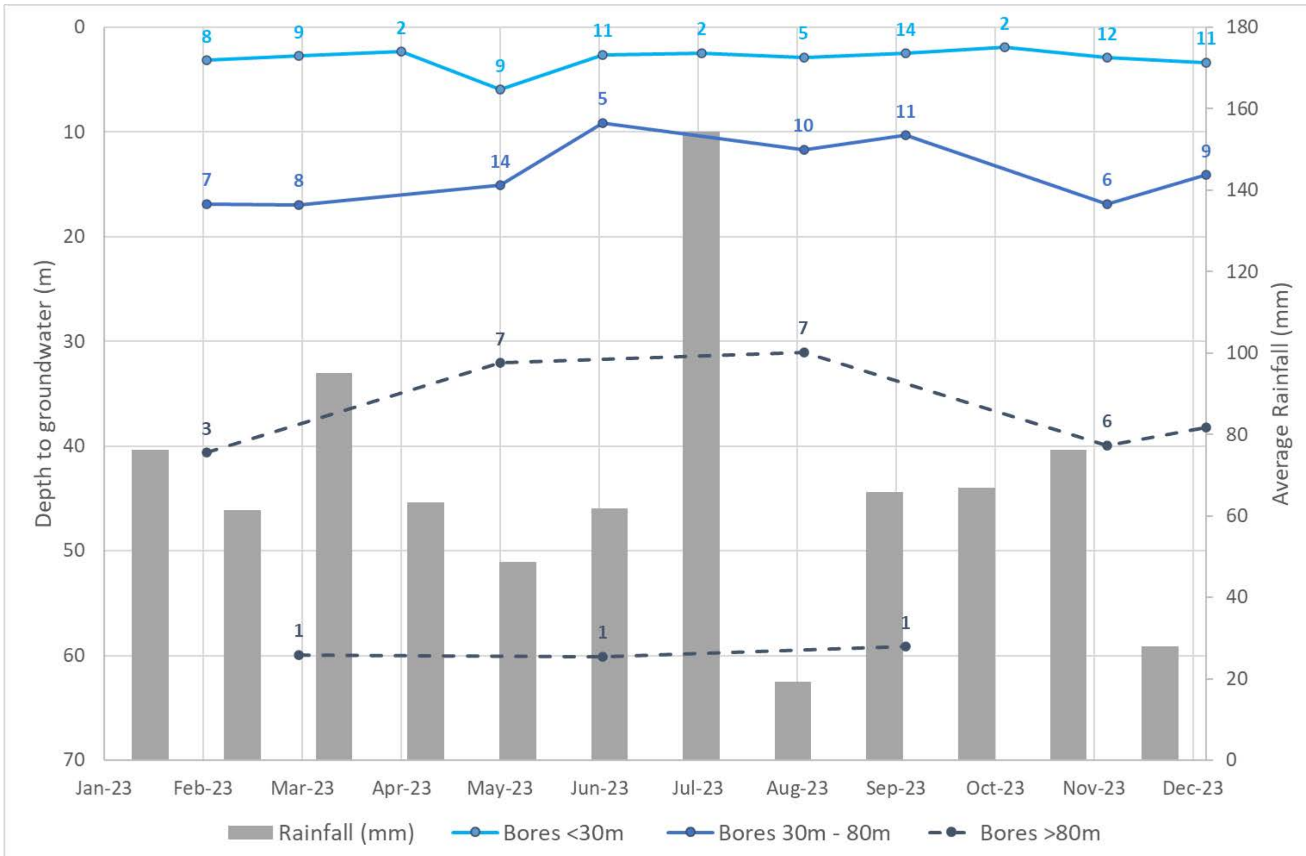


Figure 35 ***Median GWL for the 2023 year by depth. Numerical annotation indicates the number of readings.***

GWL's are generally at their highest in the winter months in response to winter recharge rainfall and the absence of abstraction. Figure 36 presents MHV observations for 2020 – 2023 whilst Figure 37 presents ECan data for the same period. The ECan data clearly show that shallow groundwater levels respond more rapidly and with greater magnitude to recharge events than do deeper levels. This may reflect both a pressure and a transport effect.

GWL data for 2022 and 2023 was data was interpolated via an Inverse Distance Squares (ID2)[16] estimation technique in QGIS© software. The resultant interpolations were then compared to each other to provide an indication of the relative changes in GWL between successive years in a spatial context. The results presented in Figure 38 indicate that GWL's increased dramatically in some areas, specifically the upper catchment, and then progressively decreased from Ruapuna to Winslow.

[16] Inverse Distance Weighting (IDW) interpolation assumes closer values are more related than those values further away. Interpolated points are estimated based on their distance from known cell values. Points that are closer to known values will be more influenced than points that are farther away. Increasing the exponent of the interpolation (i.e. from 1 to 2 – designated ID2) increases the influence of a known value.

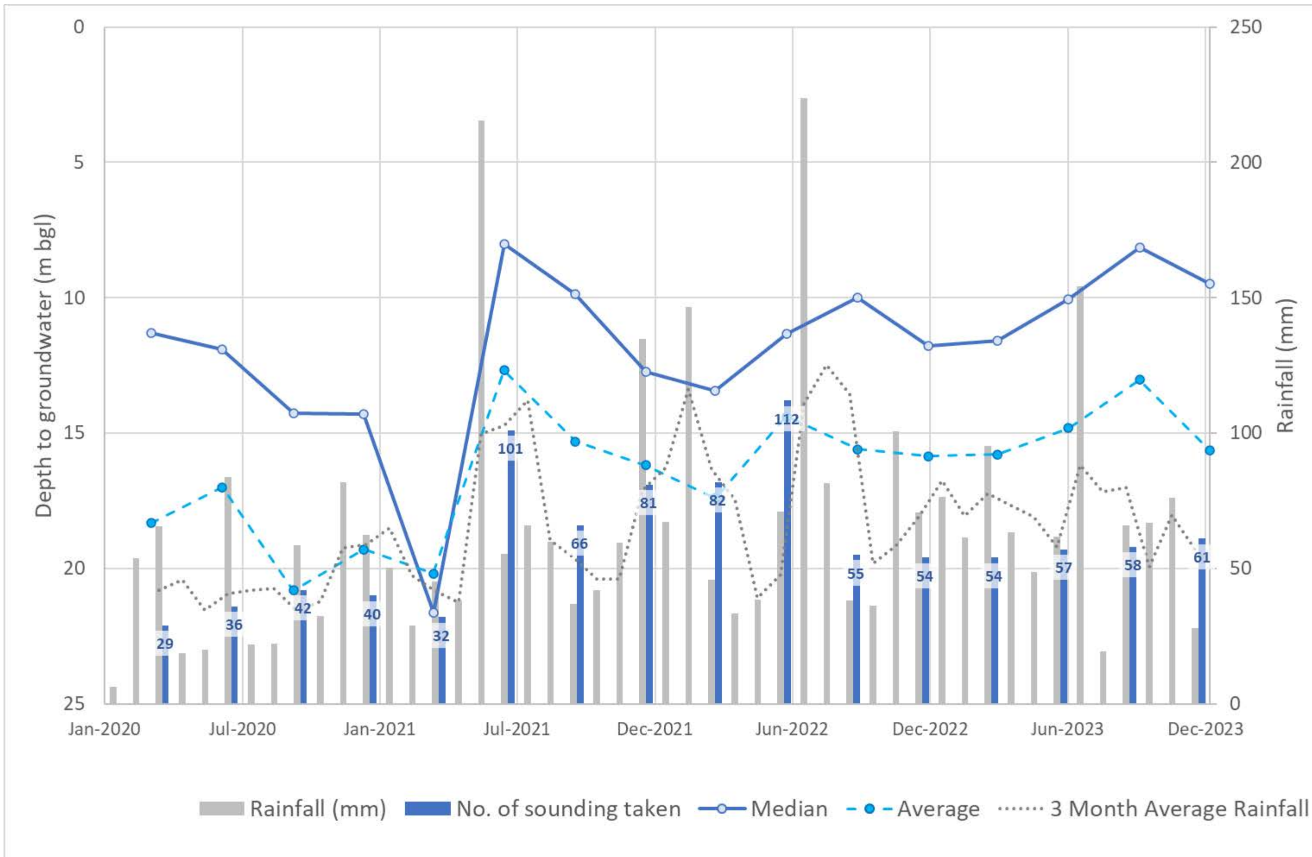


Figure 36 Average & Median groundwater levels for all data for the Hekeao Hinds Plains between January 2020 & December 2023 with corresponding rainfall

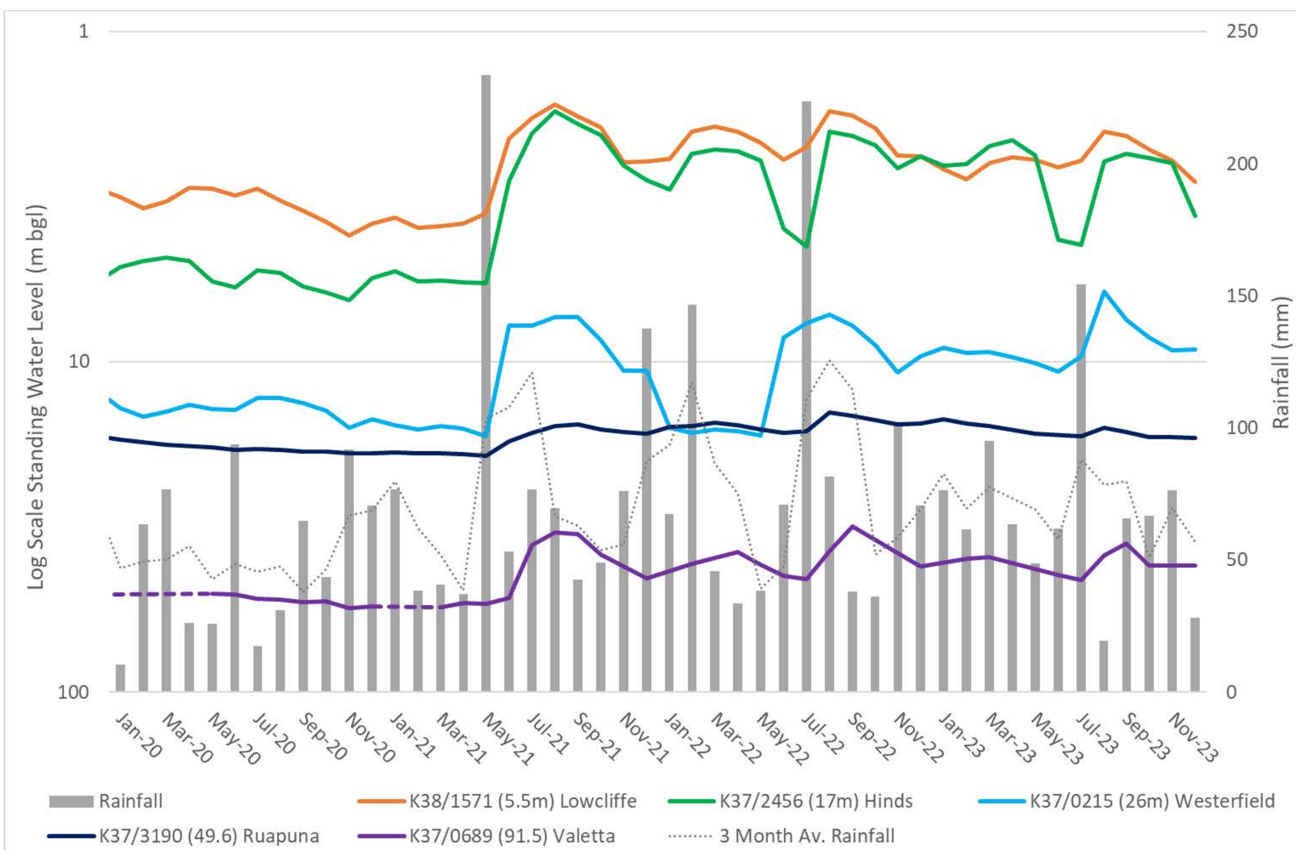


Figure 37 Groundwater levels from ECan bores across the Hekeao Hinds Plains with rainfall between January 2020 & December 2023

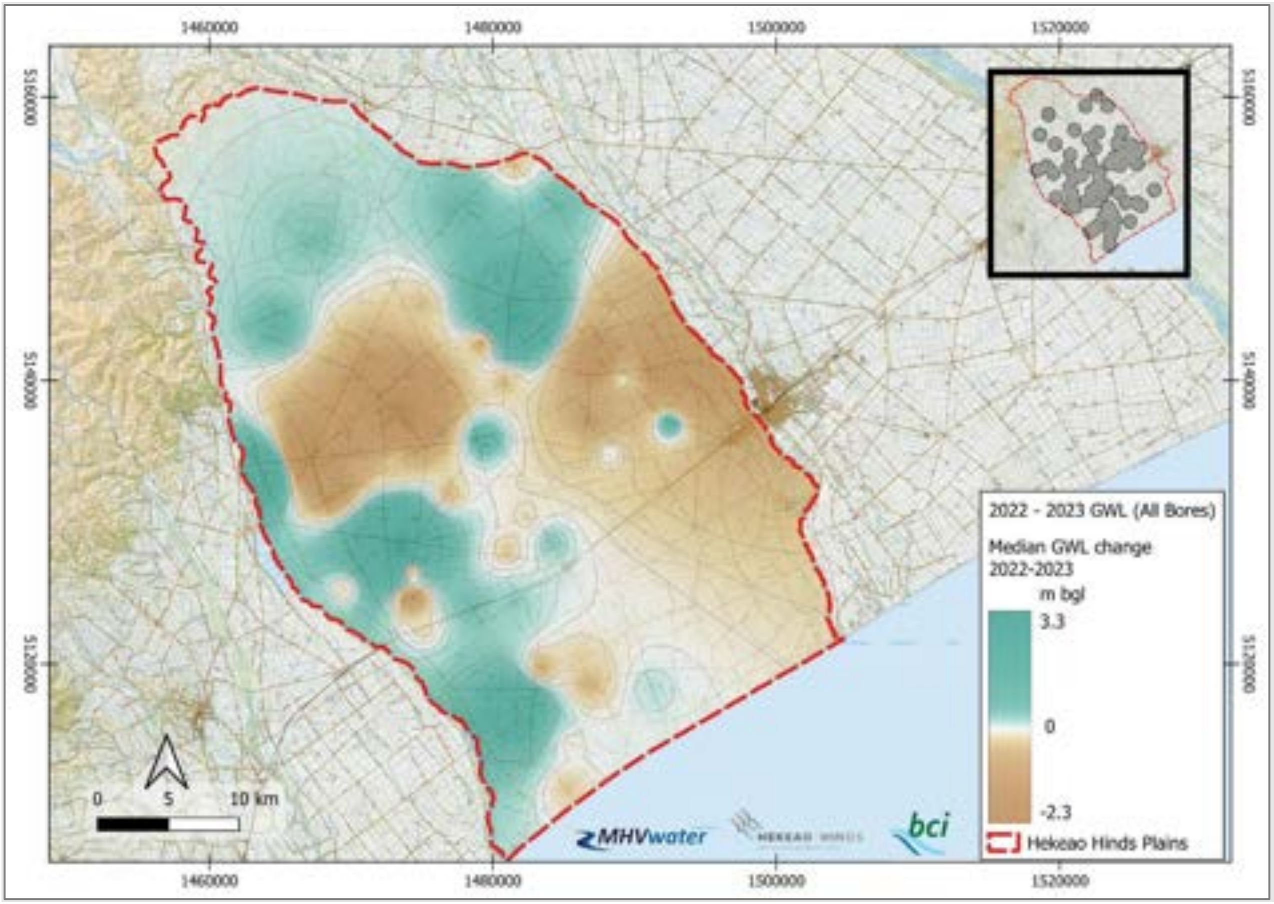


Figure 38 Relative changes in annual median GWL from 2022 to 2023 for all bores

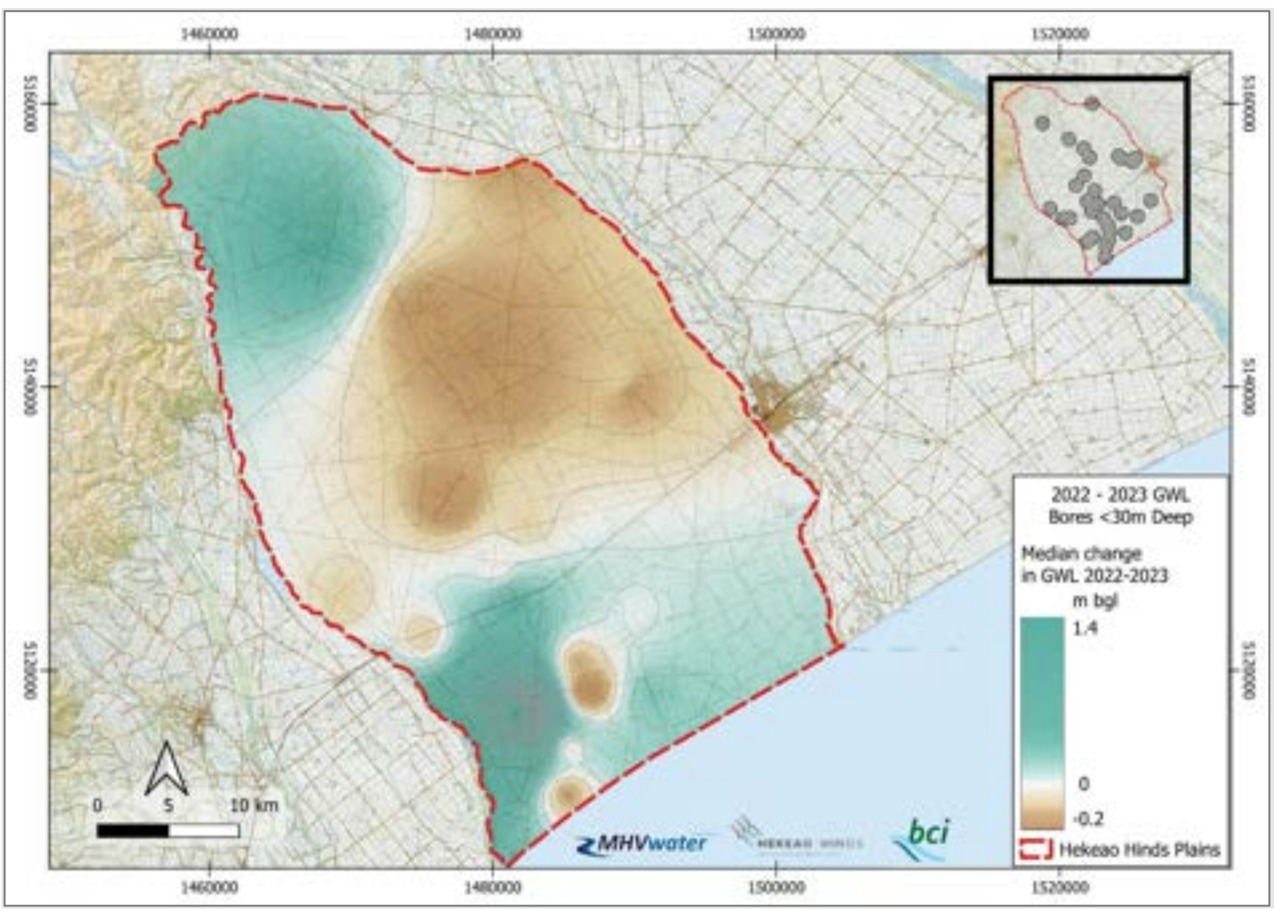


Figure 39 Relative changes in annual median GWL from 2022 to 2023 for bores <30m deep.

9. Surface Water Results

9.1.Disclaimer

The 2023 surface water results presented here need to be considered in the context that there are innumerable intersections between farm drains, council stock water races, irrigation races and highly modified water courses (HMWC) as shown in Figure 40.

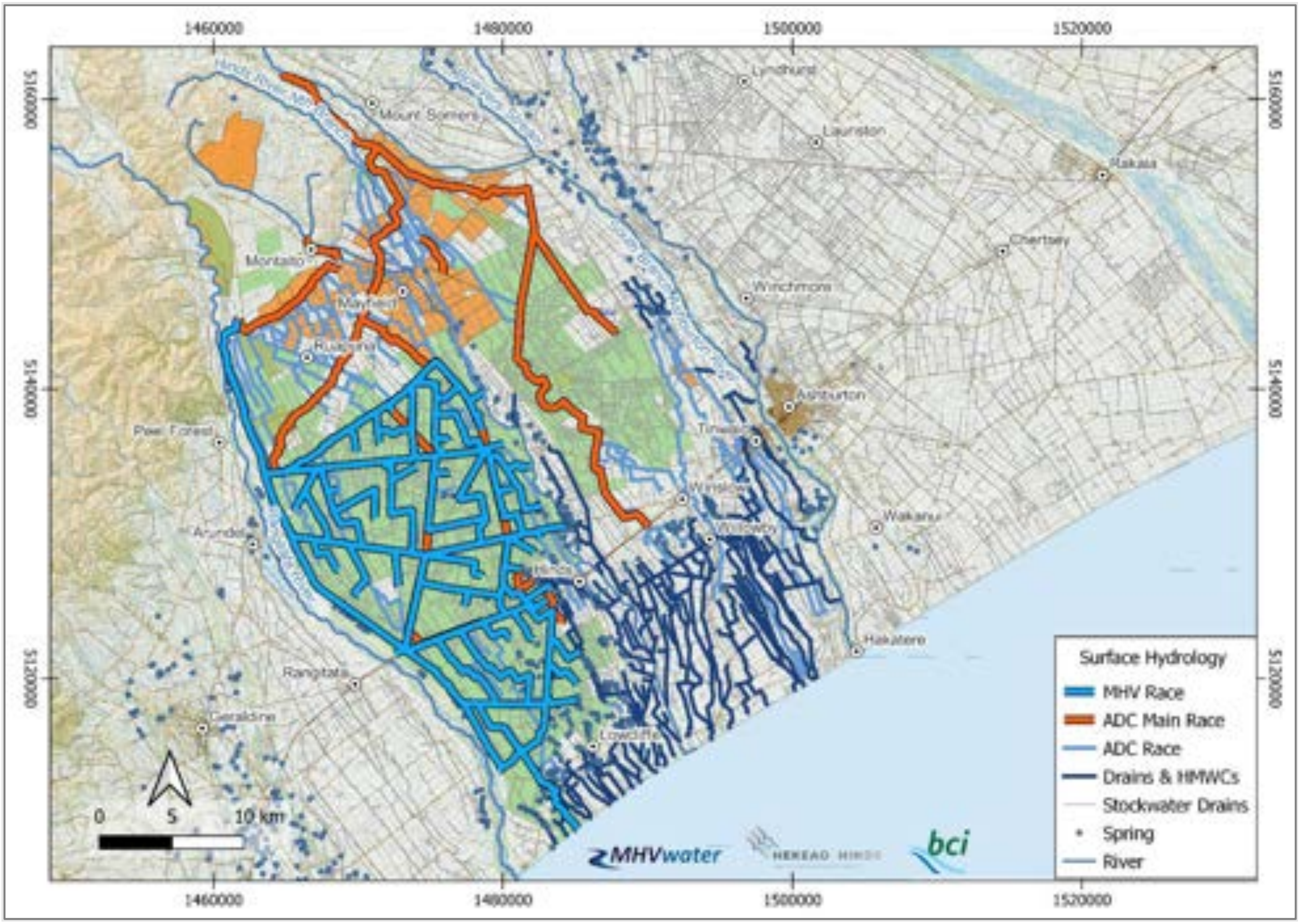


Figure 40 A map of known intersections between farm drains, council stock water races and highly modified waterways

Under normal conditions, water in the HMWC's may be derived from one or more of the following sources:

- Springs,
- Ashburton District Council (ADC) stock water races – which is in turn is sourced from the Hakatere Ashburton or Rangitata Rivers,
- Farm drains,
- Surface run off;
- Tile drains and/ or,
- Irrigation races which are sourced from the Rangitata River via the RDR.

Additionally, factors such as proximal groundwater and/ or surface water abstraction, prevailing weather conditions and soil / geology can have a significant influence on flow rates.

Additionally, the Hekeao Hinds Plains has received unusually high[17] (>175mm) rainfall since 2021 due to persistent La Niña conditions (see section 10) which has maintained groundwater levels that are likely to increase the contribution from sources such as septic tanks and leaky sewers, urban impermeable surfaces, waste pits and landfill, and agricultural land.

Therefore, the surface water data collected is considered to be somewhat heterogeneous and needs to be considered on a case-by-case basis.

For example, Moffatt's Drain is a spring fed HMWC that is augmented with ADC stock water races (which are derived from the Hakatere Ashburton or Rangitata Rivers) resulting in significant decreases in NO_3-N concentrations in the short term (Figure 41). In comparison, the Parakanoi Drain, is a spring fed drain, which is not augmented with additional water and therefore has more consistent NO_3-N results.

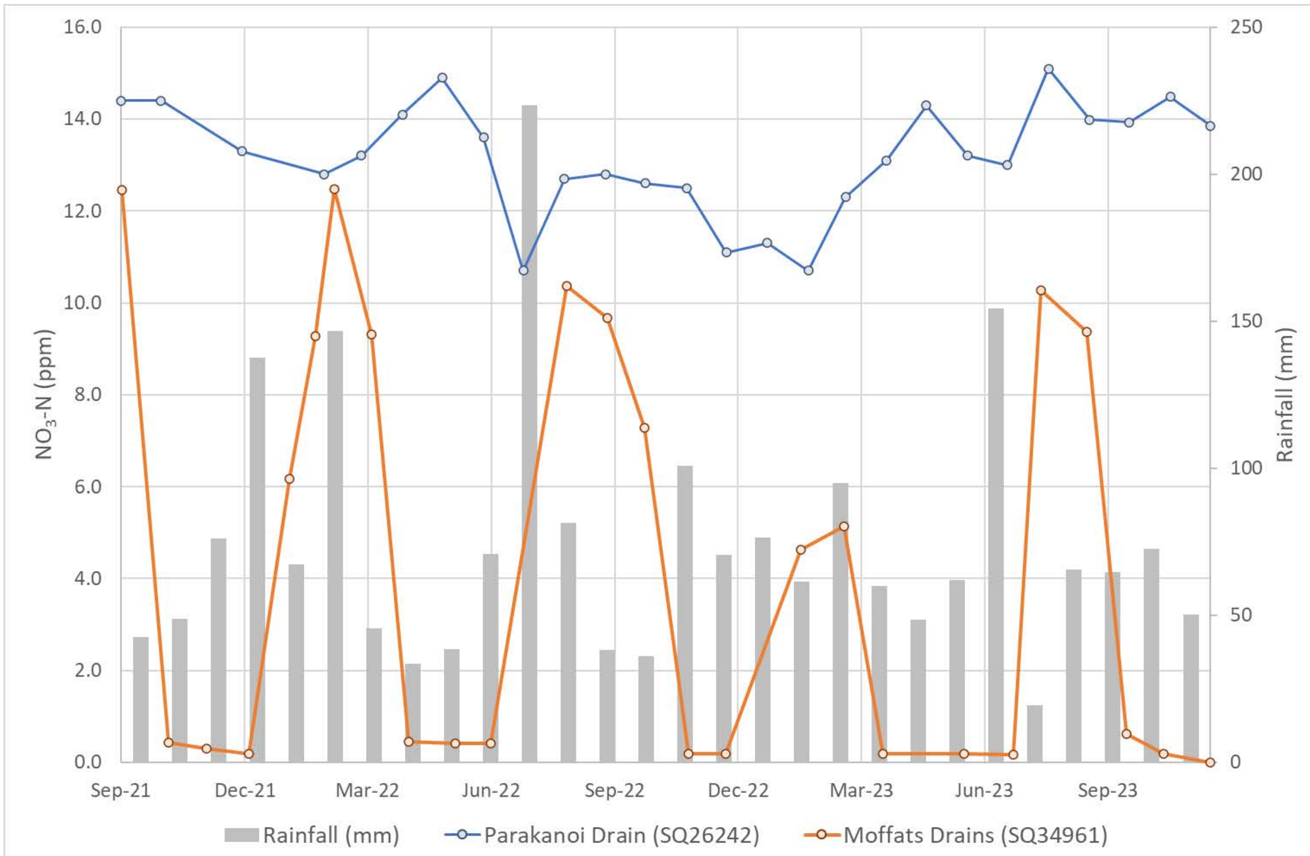


Figure 41 Changes in NO_3-N concentration for the Moffatts and Parakanoi Drains

A list of HMWC's that are augmented by ADC stock water is in Appendix 7.

[17] Greater than the long term 95th percentile or 175mm a month

9.2. Results

9.2.1. Hekeao Hinds River Results

The flow rates for the Hekeao Hinds River at Poplar Road (ECan station 69102) demonstrates that the Hekeao Hinds River is very responsive to rainfall (Table 9 and Figure 42).

Table 9 Descriptive statistics of daily flow rates (m^3/ sec) for the Hekeao Hinds River at Poplar Road

Count	Daily Minimum (m^3/s)	Daily Maximum (m^3/s)	Daily Average (m^3/s)	Daily Median (m^3/s)	95th Percentile (m^3/s)
345	0.00	71.93†	1.89	1.19	3.11

† Elevated flows between 23/072023 and 6/8/2023.

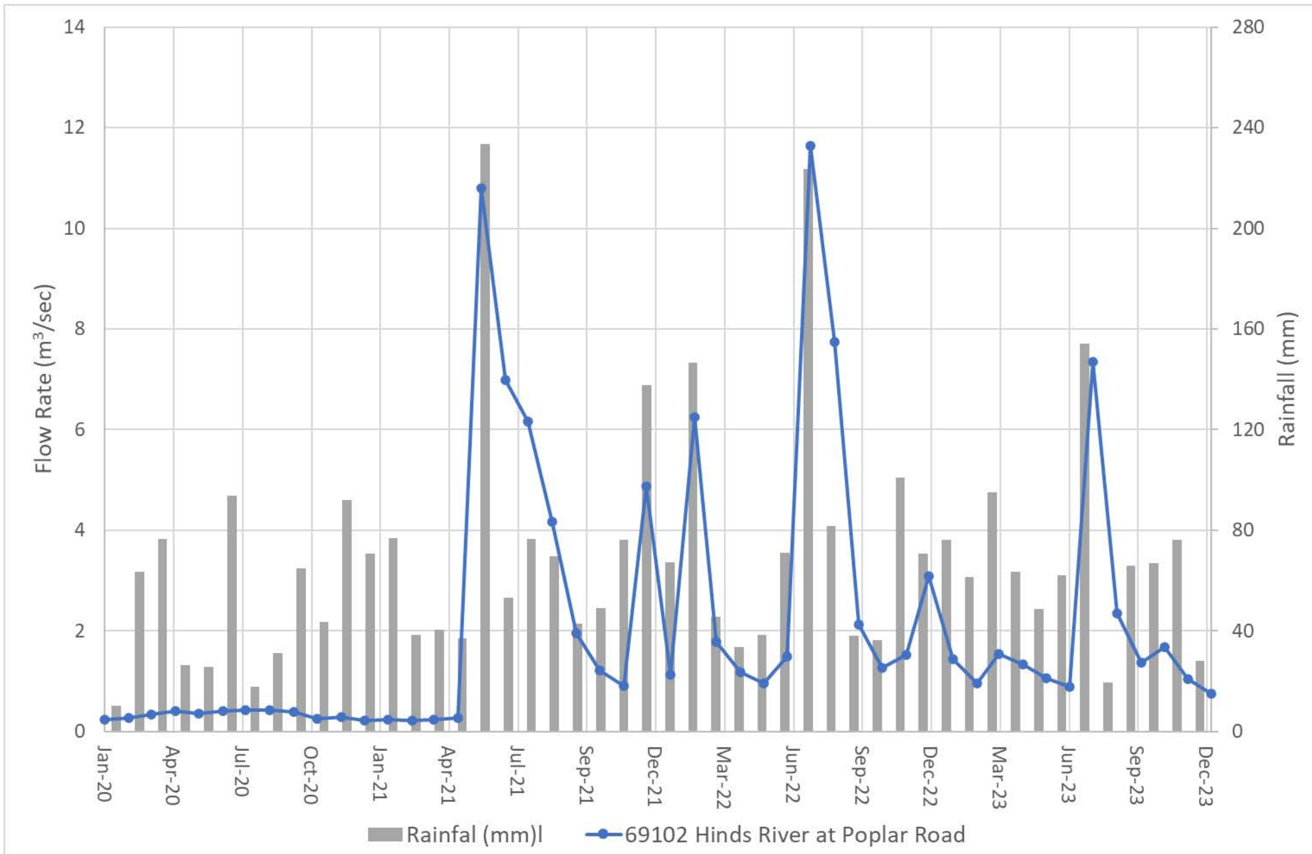


Figure 42 Monthly flow and rainfall for the Hekeao Hinds River

In late 2023, the number of samples along the length of the Hekeao Hinds River was increased as part of a longitudinal study (see section **Error! Reference source not found.**). The 2023 sample locations (including those as part of the longitudinal study) are shown in Figure 43.

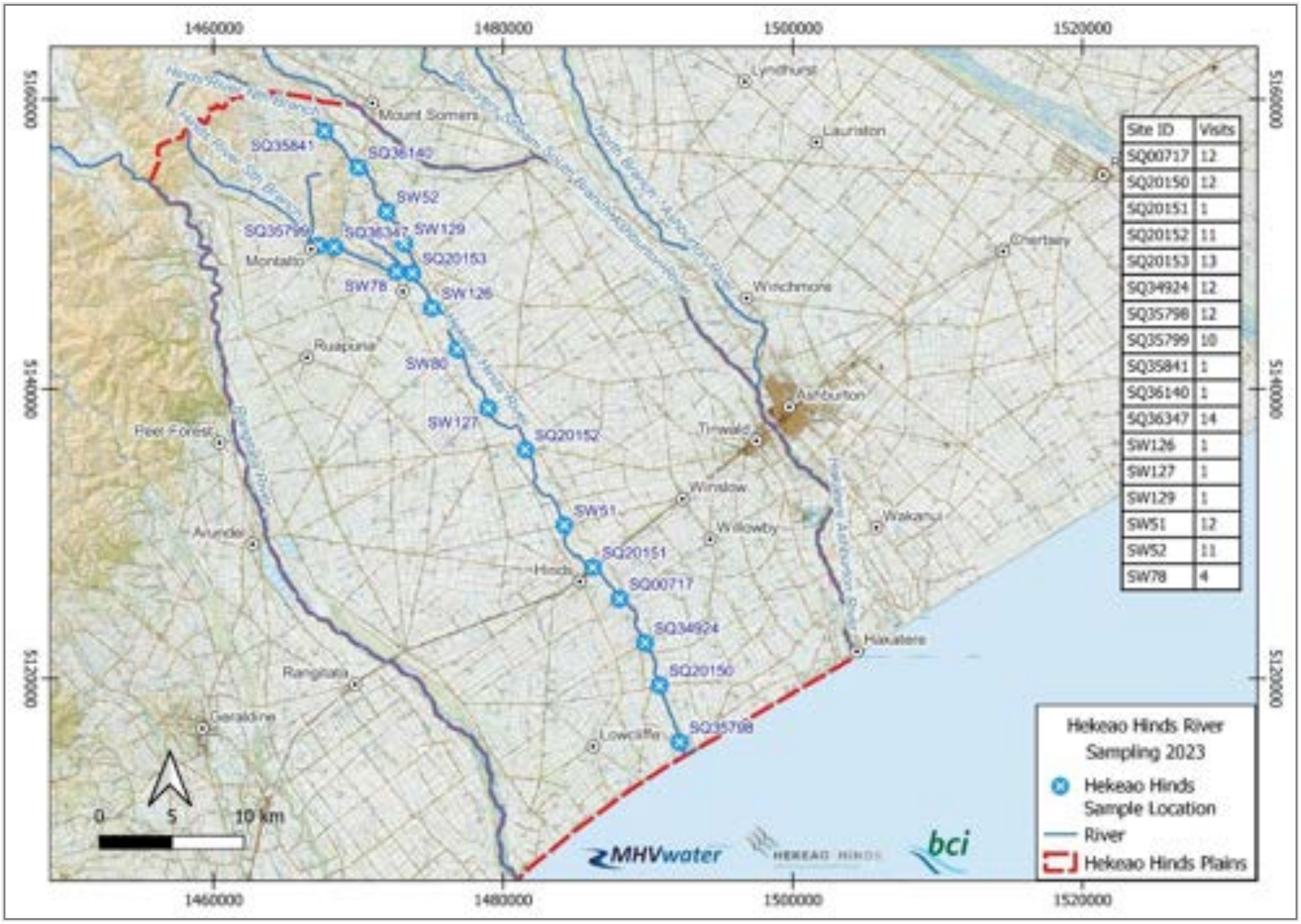


Figure 43 2023 Sample locations along the Hekeao Hinds River

The NO_3-N results for the Hekeao Hinds River from Mayfield to Lower Beach presented in Figure 44 indicate:

- that there is an increase in NO_3-N as the river progresses down the catchment, and
- that NO_3-N concentrations appear to increase some 3 months after periods of rainfall and elevated river flows (Figure 44 and Figure 45).

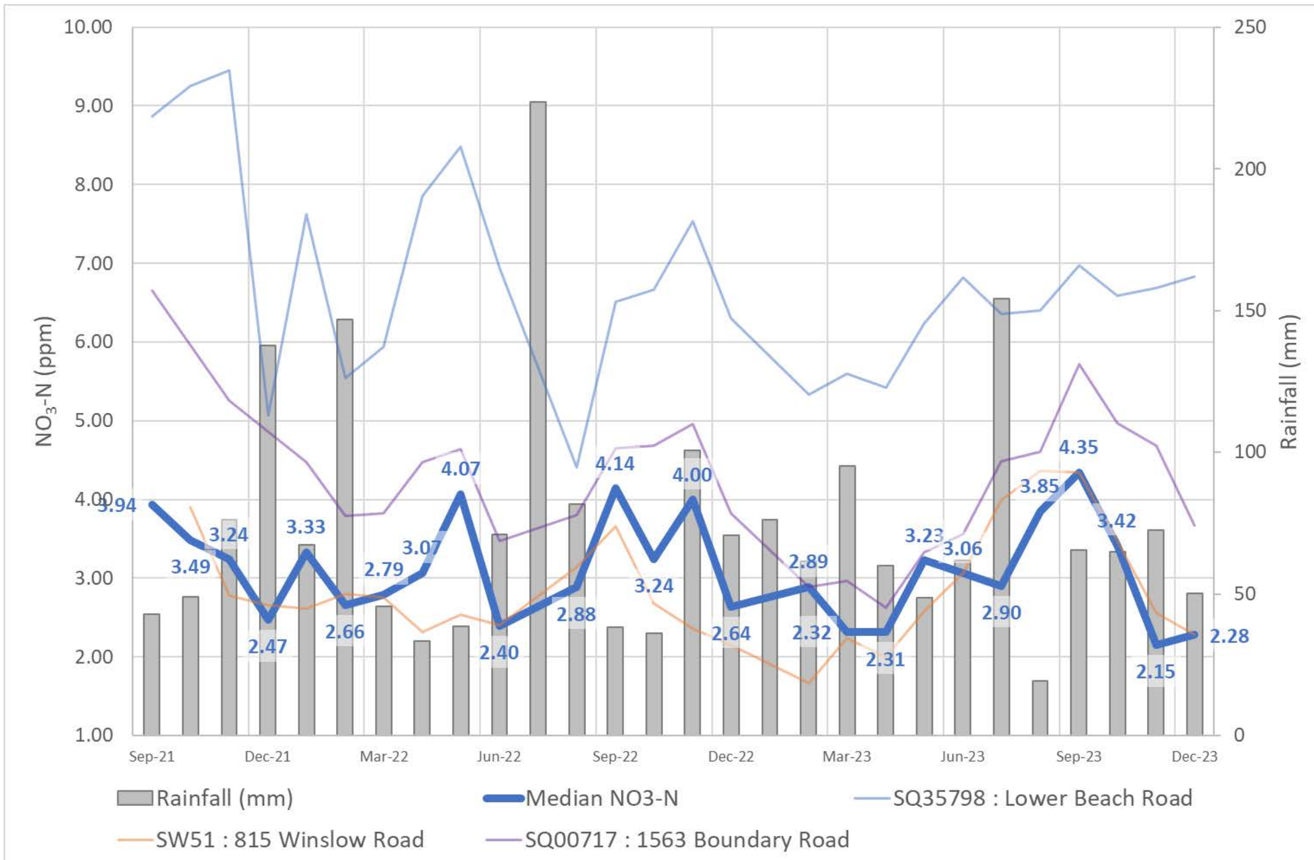


Figure 44 NO_3-N Results for the Hinds River from Mayfield to Lower Beach with rainfall

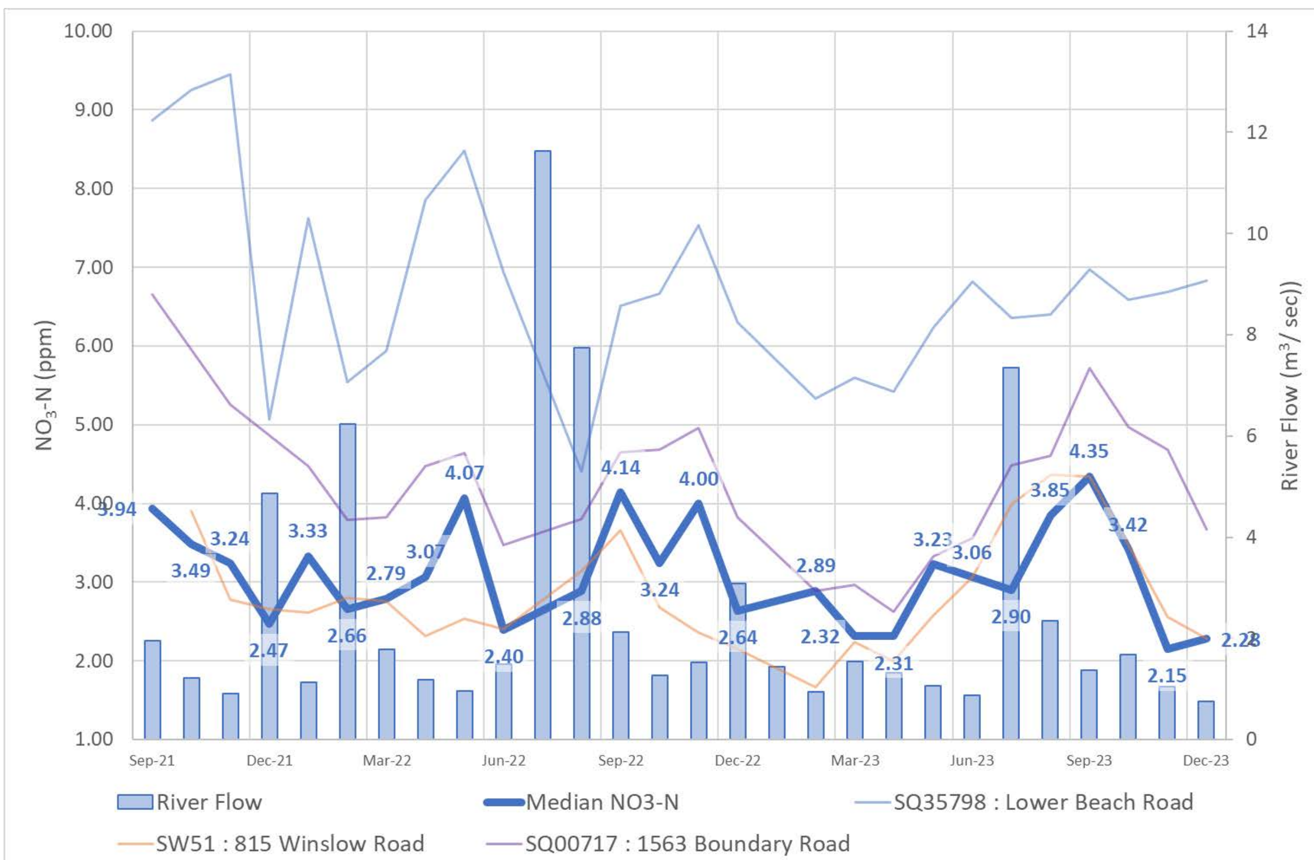


Figure 45 NO_3-N Results for the Hinds River from Mayfield to Lower Beach with river flow

9.2.2. Highly Modified Water Course Results

During 2023, MHV absorbed the surface water sampling programme of the Hinds Drains Working Party (HDWP). Subsequently the revised Highly Modified Water Course (HMWC) monitoring was increased to 68 sites along 47 HMWC's with some 524 samples analysed (Figure 46). Summary statistics for all locations is in Appendix 6.

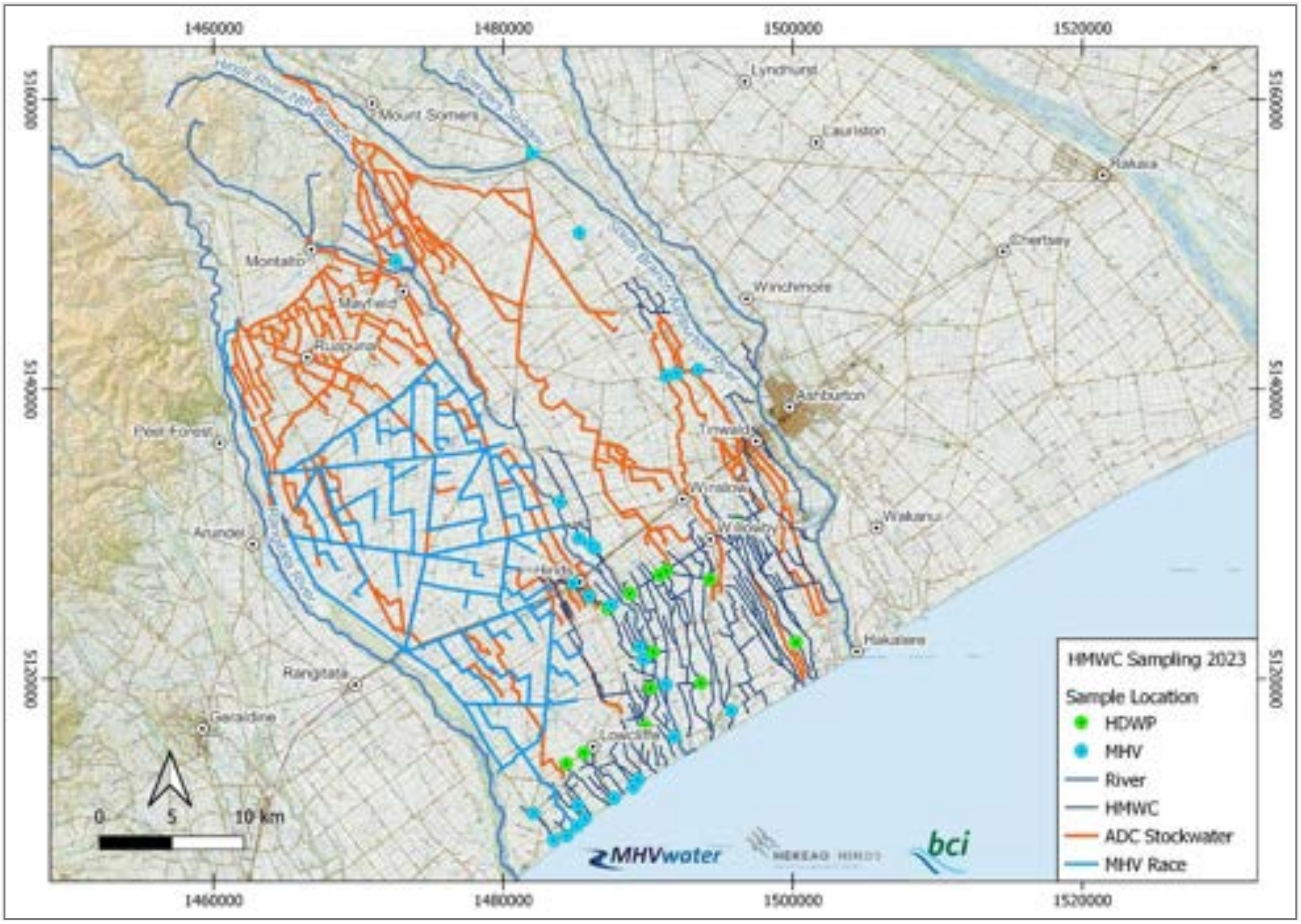


Figure 46 Sample locations for HMWC Monitoring

As noted in section 9.1, some of the HMWC's are augmented with water from other sources such as the Ashburton District Council (ADC) stock water network. These were identified via:

- their proximity to the ADC Network; and/ or
- a CV >0.6 for the results throughout the year.

On this basis, the results of samples from 55 locations (Figure 47) are presented in Table 10 and graphically in Figure 48.

Figure 47 Sample locations for reporting NO_3-N results for HMWC's†

† *Samples on the Moffat's and Northern Drains that are augmented by ADC stock water are presented in red and only included for reference purposes.*

Table 10 Descriptive statistics of NO_3-N data in HMWC's not augmented with stock water.

Month	Count	Min	Max	Average	Median	95th Percentile	Std Dev	CV
Jan	-	-	-	-	-	-	-	-
Feb	33	1.66	14.22	8.02	9.46	13.19	3.95	0.49
Mar	36	2.12	15.31	8.96	10.07	13.74	3.39	0.38
Apr	42	1.68	15.08	8.55	9.41	14.10	3.68	0.43
May	36	2.21	15.25	9.00	9.94	14.99	3.64	0.40
Jun	34	2.35	15.39	9.05	10.23	15.33	3.69	0.41
Jul	39	1.42	15.75	9.21	9.93	14.99	3.32	0.36
Aug	43	0.07	15.55	8.92	10.24	15.12	4.10	0.46
Sep	34	4.34	15.08	9.66	10.18	14.26	3.10	0.32
Oct	34	4.06	15.54	9.39	10.10	15.49	3.26	0.35
Nov	35	4.11	16.14	10.03	11.04	16.00	3.45	0.34
Dec	32	1.85	13.91	8.74	10.37	13.87	3.67	0.42

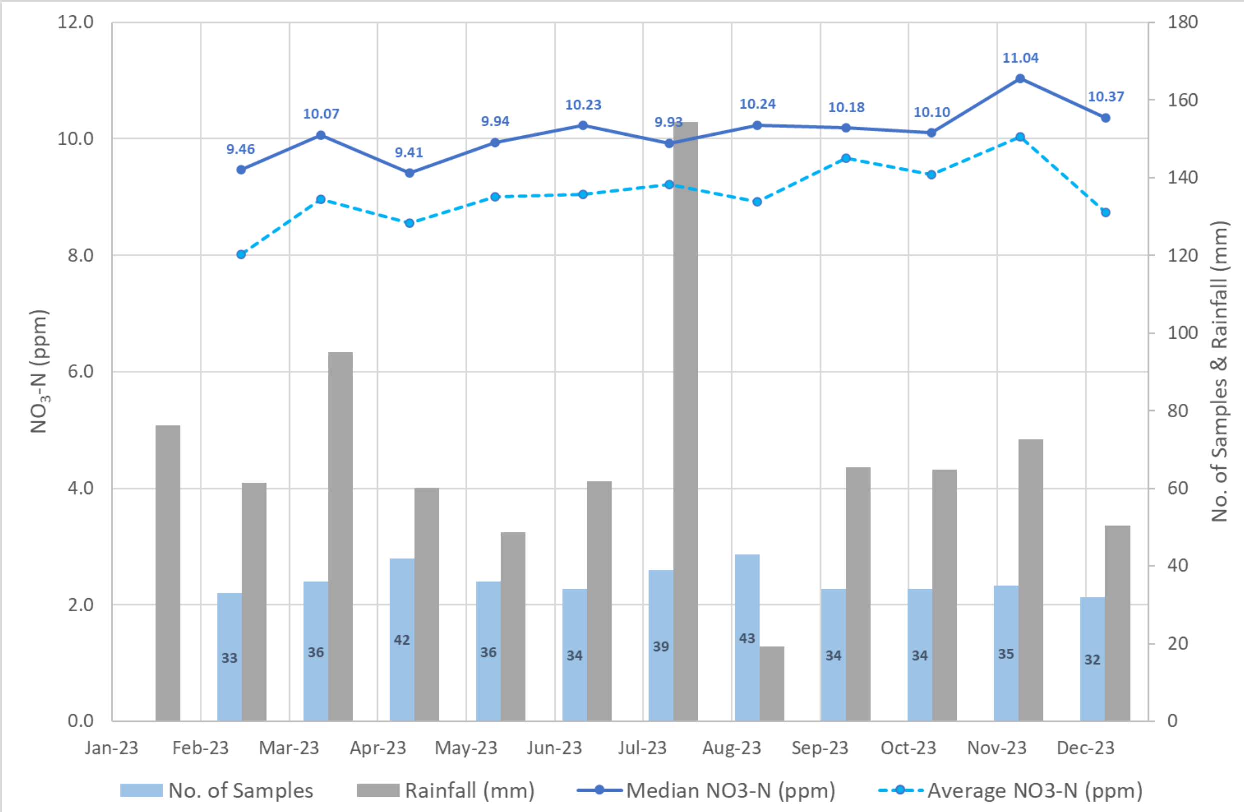


Figure 48 Average and median results of NO_3-N data in HMWC's not augmented with stock water, with rainfall.

The month-on-month results throughout the year varied by ±<10% (i.e. within acceptable ranges of precision) with a slight increase of <10% in median NO_3-N from 9.46 ppm to 10.37 ppm over the course of the year. When compared to the longer-term data (Figure 49), the results indicate a sustained reduction of NO_3-N from September 2021 to June 2023, with a results thereafter plateauing due to high rainfall in July 2022, and July 2023.

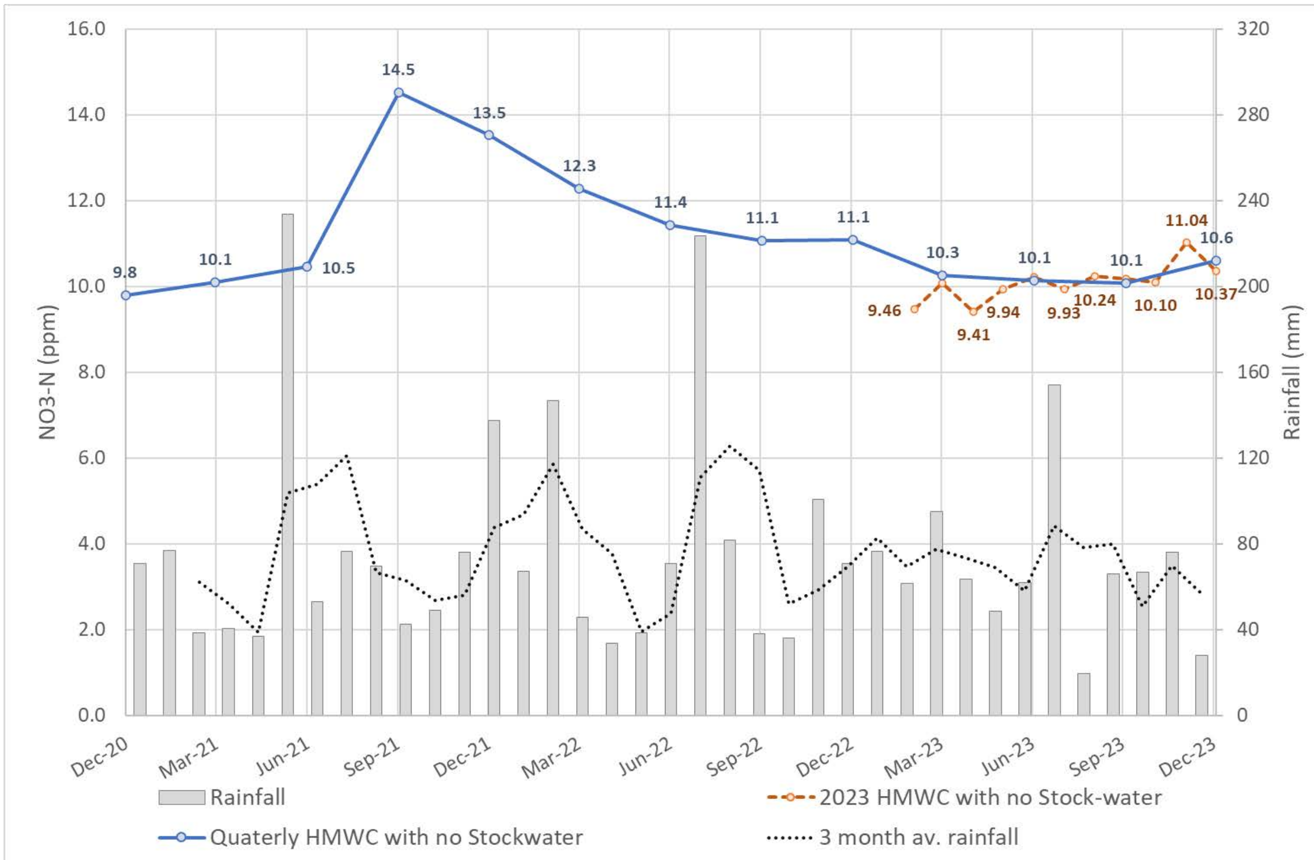


Figure 49 Long term median results of NO_3-N in HMWC's not augmented with stock water, with rainfall and 2023 monthly data.

10. Discussion

> *Organisms are not billiard balls, propelled by simple and measurable external forces to predictable new positions on life's pool table. Sufficiently complex systems have greater richness. Organisms have a history that constrains their future in myriad, subtle ways.*
>
> *Stephen Jay Gould*

During 2023, the Hekeao received 833mm of rainfall, down from 953mm and 930mm for the preceding two years respectively. Whilst NO_3-N concentrations varied in response to rainfall events such as the 154mm rains of July, overall results are within 5% of the 2022 results. This may be due to a variety of factors such as:

- the lag effect of the 2021 and subsequent rainfall to NO_3-N migration; or,
- ongoing rainfall wetting an already saturated system (recalling that there was no appreciable change in groundwater levels).

Additionally, following rapid change in the SOI from La Niña to El Niño in December 2022, the SOI has fluctuated within the neutral range (Figure 50), suggesting normal to lower rainfall for 2024 [32], [33], which may affect NO_3-N concentrations.

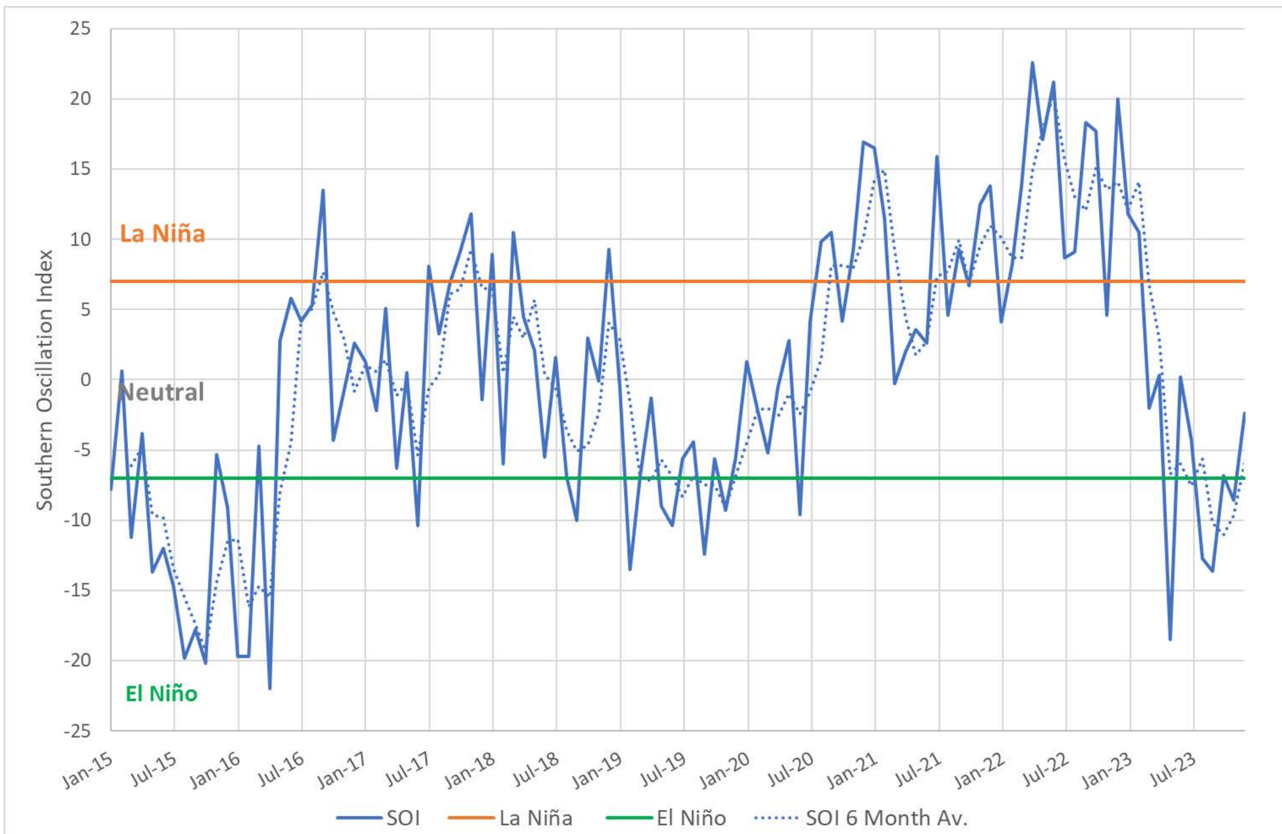


Figure 50 Southern Oscillation Index data 2015 - 2023

10.1. Nitrate response to recharge – an overview

A median for the NO_3-N data at each bore was calculated for the calendar years 2022 and 2023 – hence an annualised median. A comparison of the annualised median NO_3-N concentrations indicates a slight decrease in shallow bores and a negligible decrease across the catchment (Figure 51 and Table 11).

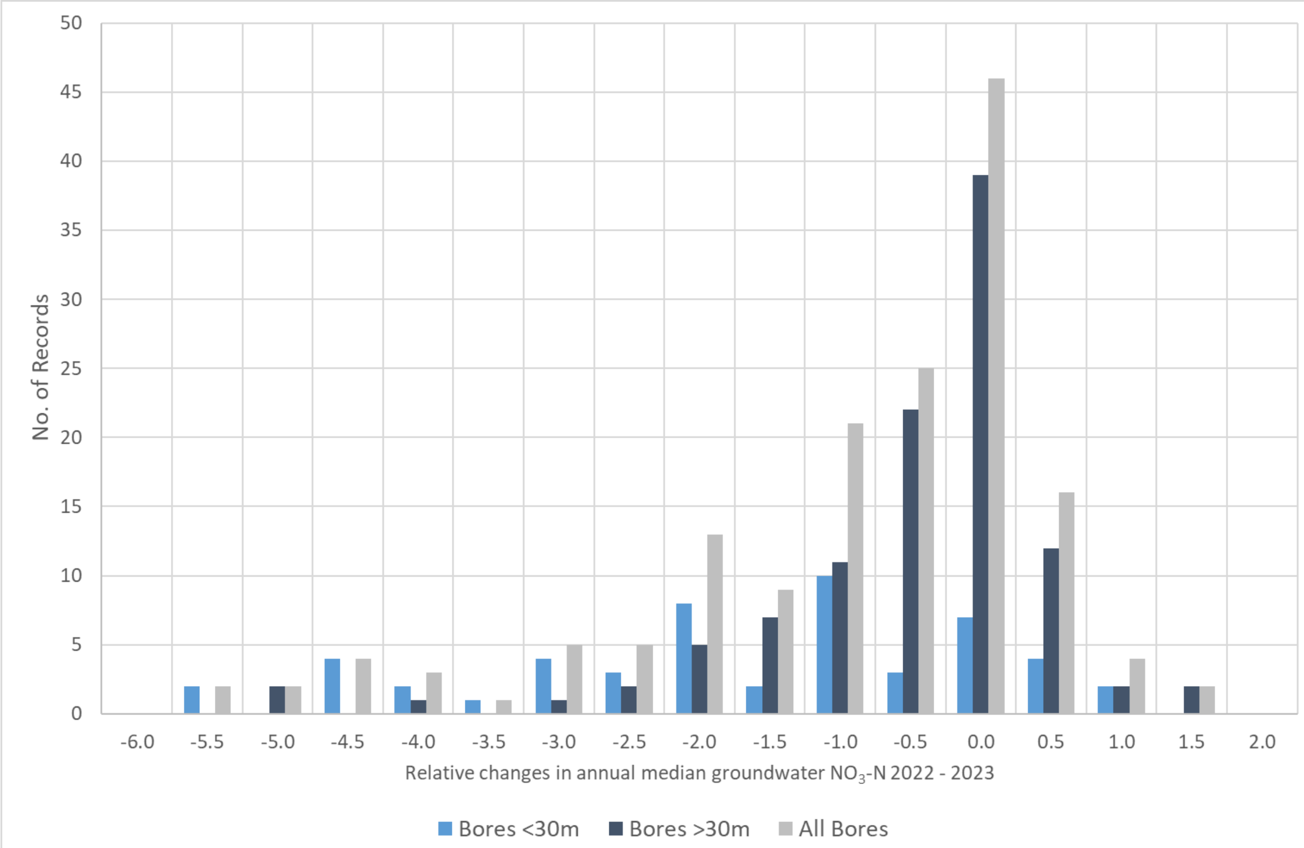


Figure 51 Frequency histogram of the relative annual median changes in NO_3-N concentration from 2022 to 2023

Table 11 Summary statistics of the relative annual median changes in NO_3-N concentration from 2022 to 2023

Depth	Count	Min	Max	Average	Median	95th Percentile	Std Dev	CV
≤ 30m	52	-5.66	0.60	-1.93	-1.50	0.21	1.67	-1.11
>30m	106	-5.21	1.48	-0.74	-0.39	0.38	1.07	-2.72
30-80m	70	-5.21	1.19	-0.86	-0.60	0.47	1.16	-1.94
80 – 150m	36	-2.87	1.48	-0.50	-0.23	0.14	0.82	-3.56
All	158	-5.66	1.48	-1.13	-0.68	0.37	1.07	-1.58

The difference between the annualised median results for 2022-23 was interpolated via an Inverse Distance Squared (ID2)[18] estimation technique using QGIS© software.

[18] Inverse Distance Weighting (IDW) interpolation assumes closer values are more related than those values further away. Interpolated points are estimated based on their distance from known cell values. Points that are closer to known values will be more influenced than points that are farther away. Increasing the exponent of the interpolation (i.e., from 1 to 2 – designated ID2) increases the influence of a known value.

NOTE The ID2 interpolation utilised the NO_3-N data only and did not consider factors such as (but not limited to) the influence of rivers, streams, soil type, preferential surface channels etc.

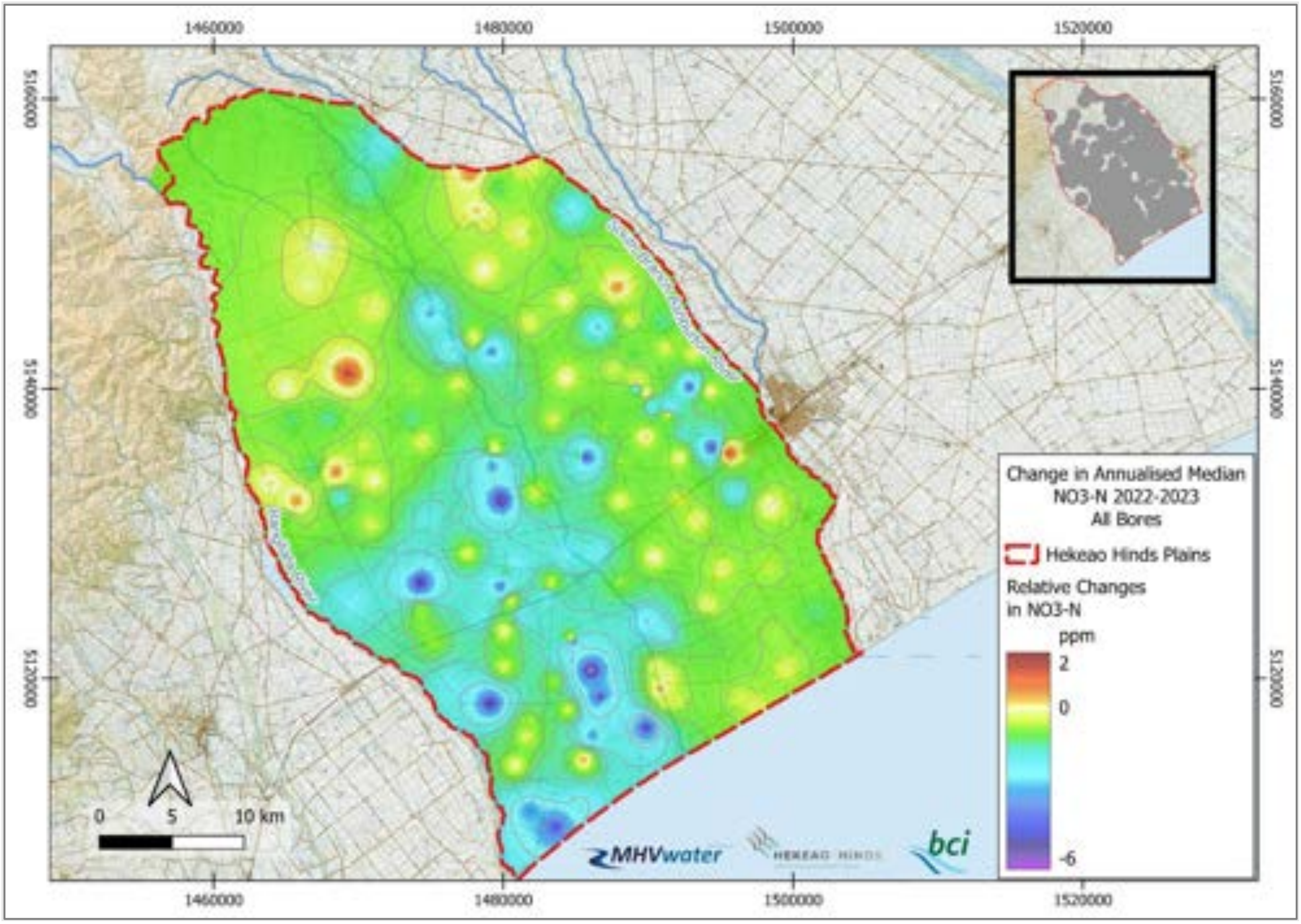


Figure 52 ID2 interpolation of the difference between the annualised median for all bores between 2022 and 2023

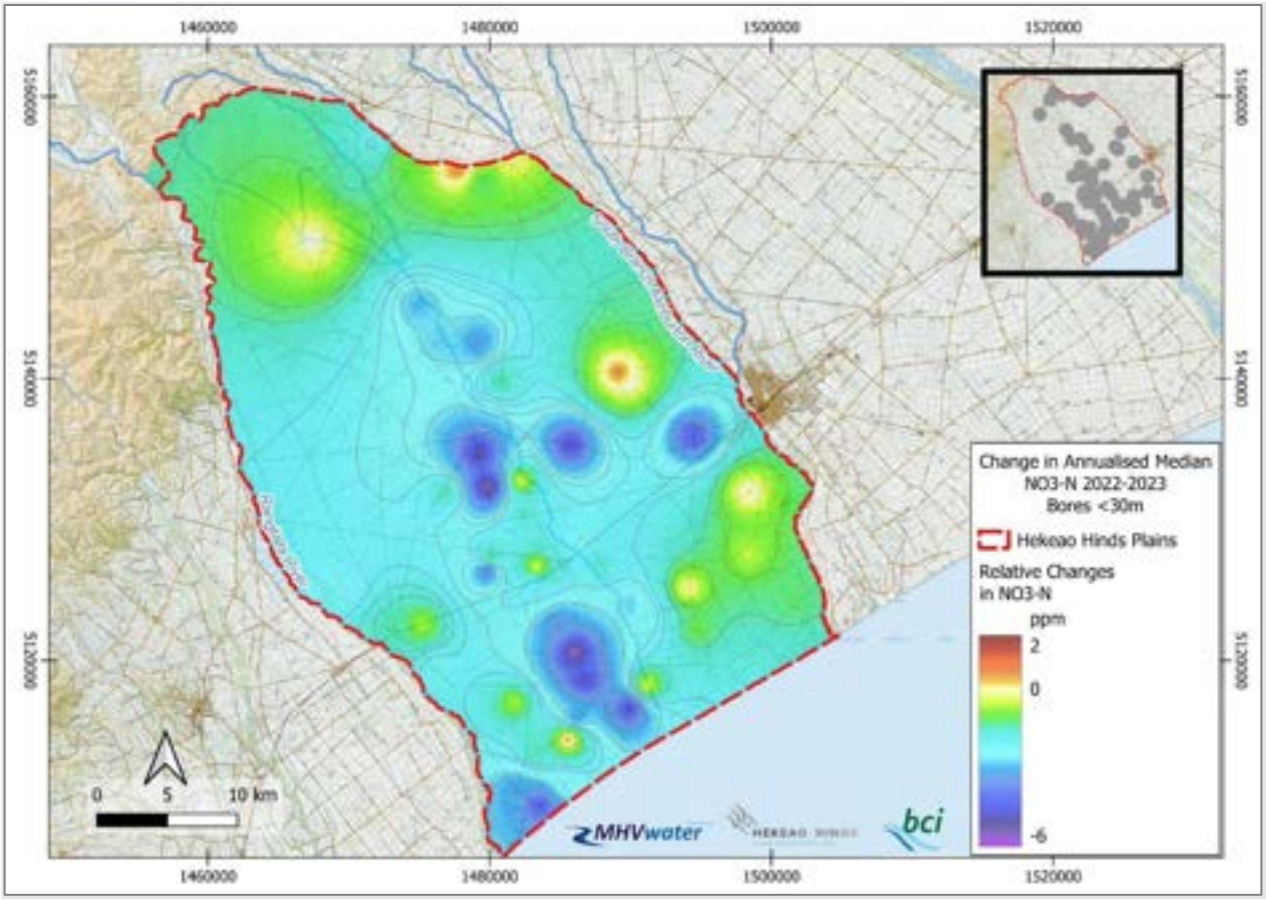


Figure 53 ID2 interpolation the difference between the annualised median for bores <30m deep between 2022 and 2023

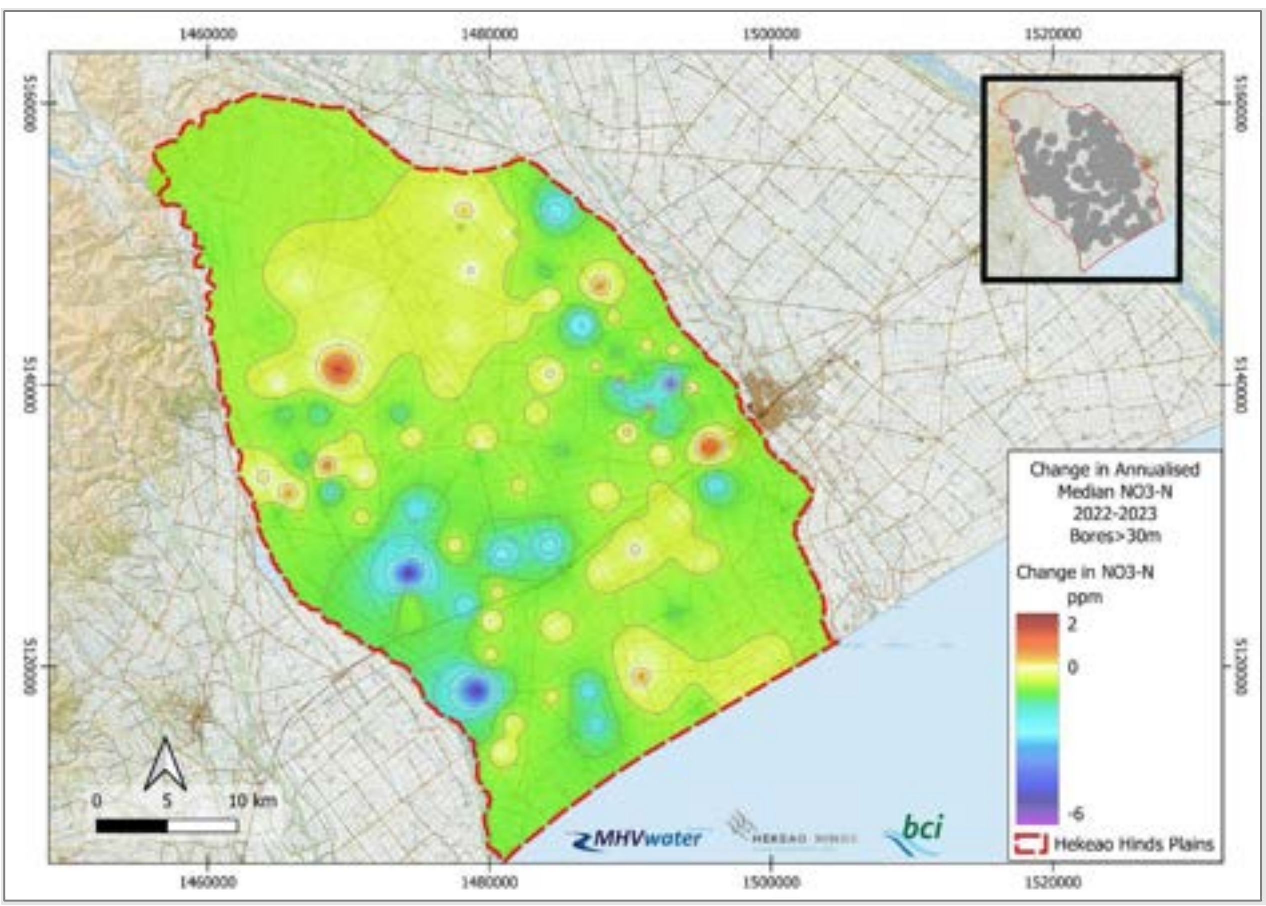


Figure 54 ID2 interpolation the difference between the annualised median for bores >30m deep between 2022 and 2023

Whilst the annualised median data suggests no significant changes in NO_3-N concentrations for 2023; it assumes a single temporal value (i.e. a single value in time). When compared to the quarterly survey data, despite minor fluctuations in response to rainfall, NO_3-N has gradually increased from 8.32 ppm in December 2021 to 9.31 ppm in December2023 (Figure 55). – which is hydrologically driven rather than land use related due to the interconnectivity between river flows, GWL and rainfall across the HHP. Following the 2021 rainfall event, the newly saturated ground would act as a hydraulic piston in response to follow up rainfall. This would affect the NO_3-N migration slowly as groundwater moves through the system, accumulating recently mobilised NO_3-N (from follow up rain in 2022) *en route*, resulting in a delayed increase in NO_3-N that is likely to subside as the groundwater reaches the coast. This interpretation is consistent with previous investigations in Canterbury that have used exponential-piston flow mixing models to calculate mean resident times [34], [35]., as well as isotope studies that have demonstrated multiple water sources within groundwater (i.e. mixing) from Land surface recharge [36], [36], [37] [36], [37].

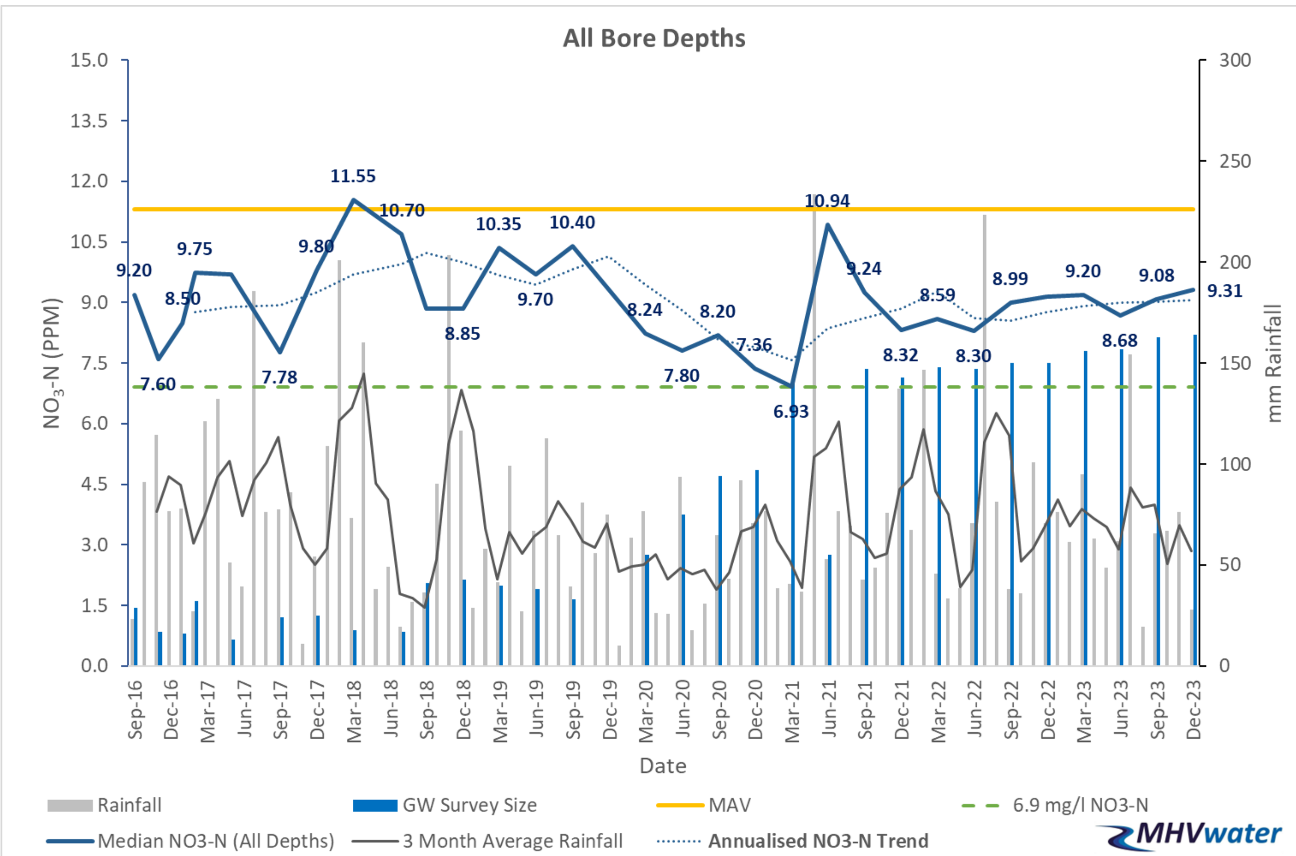


Figure 55 Long term NO_3-N results for the MHV groundwater monitoring programme (All bore depths)

Closer inspection of the results reveal that this is being driven by:

a) Short term spikes in shallow groundwater (<30m deep) from rainfall events – for example, June 2023 had 154mm of rainfall (Figure 56); and,

b) Lag time of deeper groundwater migration, for example following the 2021 rain event (Figure 57).

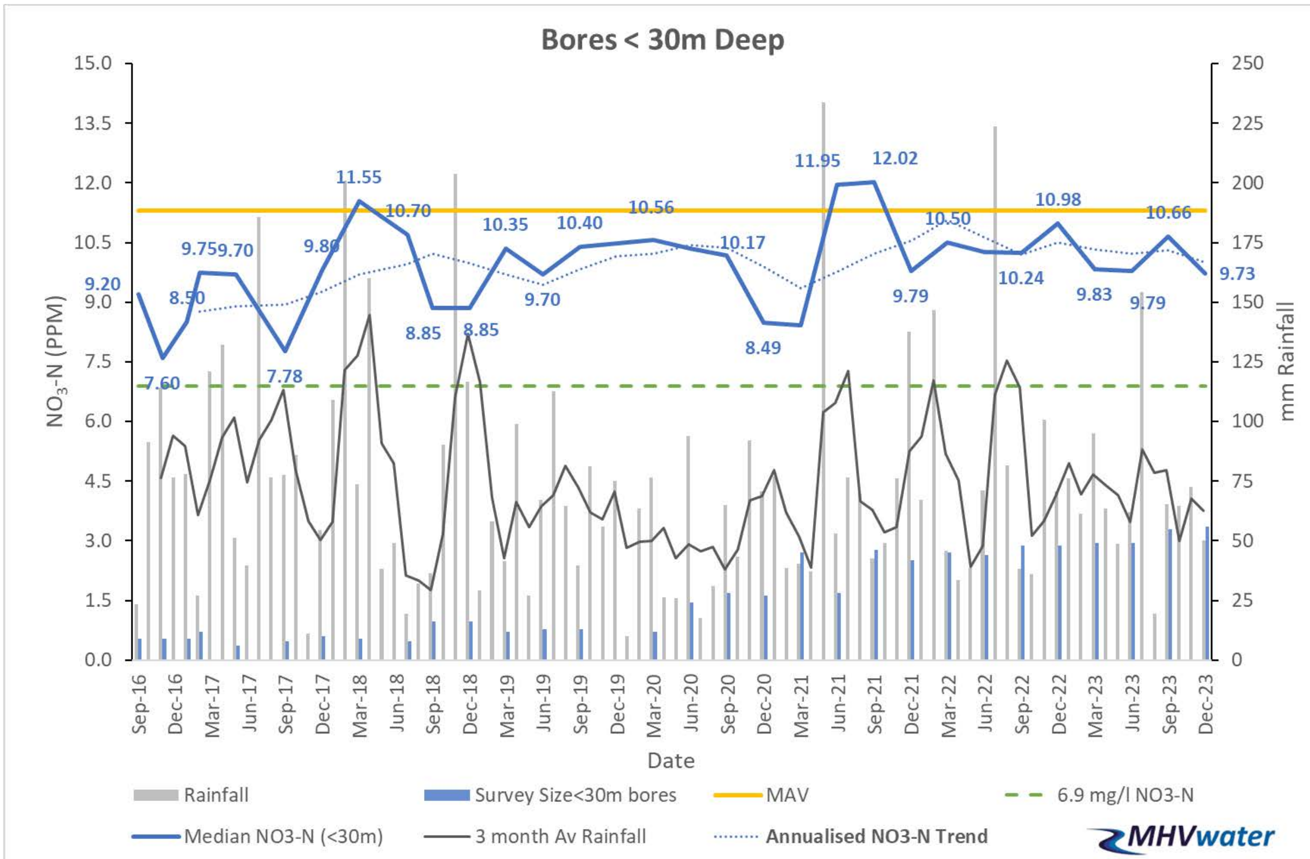


Figure 56 Long term NO_3-N results for the MHV groundwater monitoring programme (bores <30m deep)

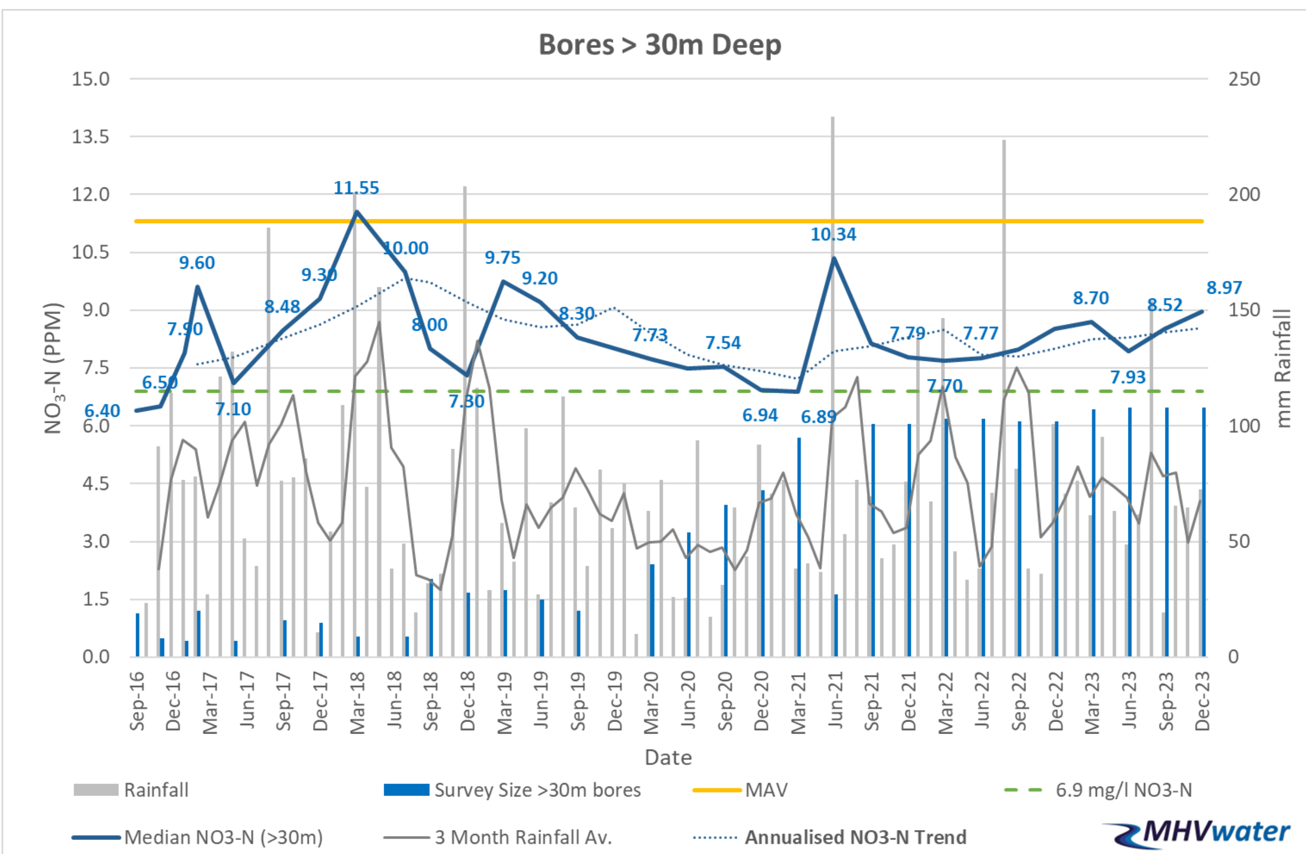


Figure 57 Long term NO_3-N results for the MHV groundwater monitoring programme (bores >30m deep)

10.2. Nitrate response in Highly Modified Water Courses (HMWC)

Notwithstanding the variability in the NO_3-N results for HMWC's due to augmentation from ADC stock water (as shown in section 9.1, Figure 41), NO_3-N concentrations in HMWC's have decreased throughout the year. When compared with the longer-term data, HMWC's that have not been augmented by ADC stock water have seen a sustained decrease since the 2021 Rain Event. As shown in Figure 58, whilst the inclusion of the augmented data can significantly reduce the results during dry periods (e.g., September 2020), the trends are broadly similar. Appendix 7 presents a list of the HMWC's that were excluded as part of this analysis.

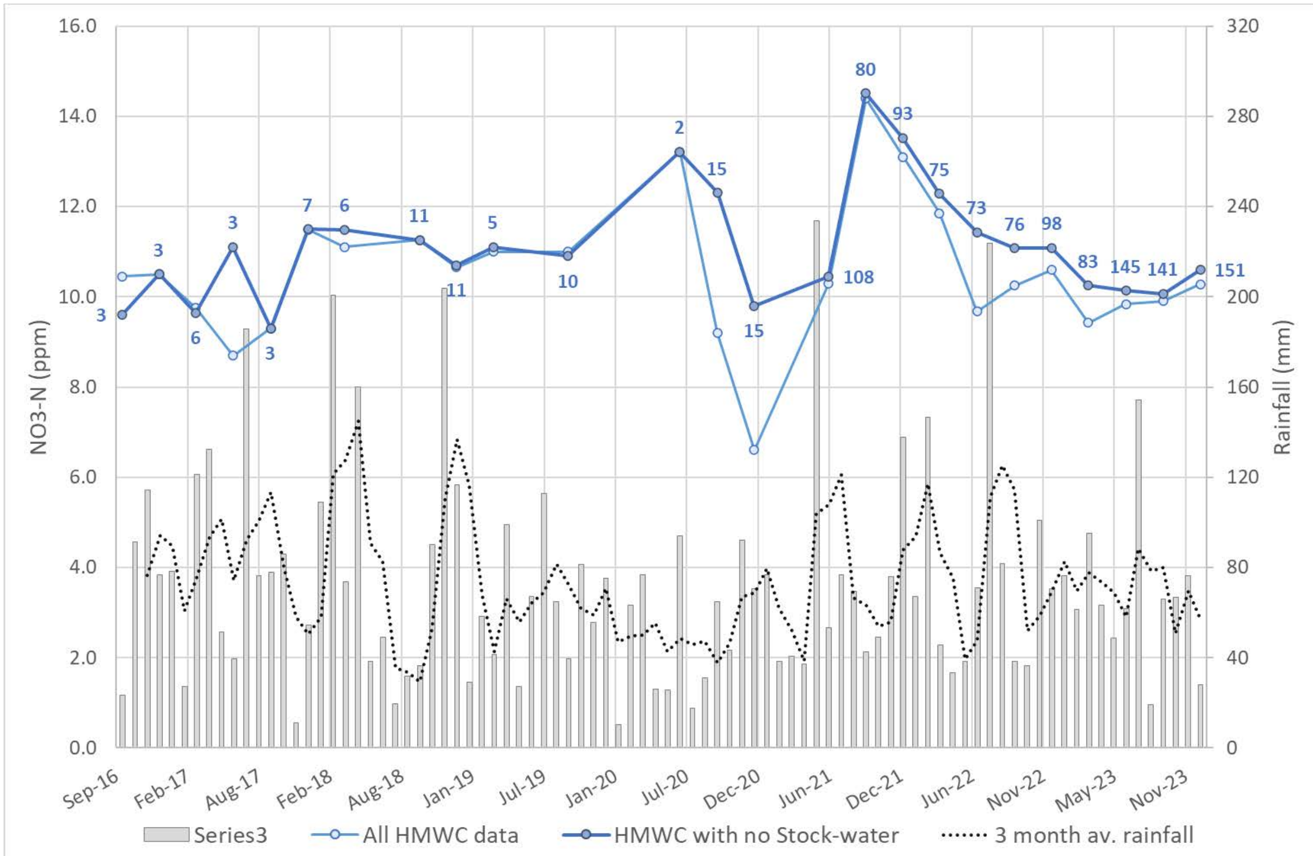


Figure 58 NO_3-N concentrations for HMWC's with and without stock water augmentation, compared to rainfall & river flow

11. Conclusions

At first glance, the 2023 results suggest no discernible change in groundwater NO_3-N concentrations despite a rapid change La Niña to El Niño in December 2022, and subsequent fluctuations within the neutral range (Figure 50). This however beguiles a more complex system that is inherently complex and functions at variable time scales, which can be affected by external factors such as weather. The interconnectivity between river flows, GWL and rainfall across the HHP invokes a hydraulic piston in response to rainfall, resulting in a temporally displaced response or lag between rainfall and NO_3-N concentrations, which is consistent with previous investigations in Canterbury, hence it is inferred that if rainfall returns to long term averages, then there should be a continued decline in NO_3-N concentrations.

That being said, the development of the HHSCG, and the ongoing research programme, MHV is developing a more robust conceptual model of NO_3-N migration and retention across the Hekeao Hinds Plains year on year.

The results presented here also support previously identified observations such as:

- NO_3-N migration is controlled by rainfall and river flow across the catchment.
- There appears to be a relationship with soil type and NO_3-N response to recharge events.
- Lateral flow of water via mechanisms such as open framework gravels appear to be the more dominant mechanism for subsurface NO_3-N migration. This contributes to significant variation across the catchment in nutrient concentration responses to recharge events.

Appendix 1

Statement of Qualifications

1. My name is Justin Legg.
2. I have been a fulltime salaried employee of MHV Water Limited where I hold the position of Senior Hydrogeologist since January 2020.
3. I hold the following qualifications:
    a. Bachelor of Science (Geology) from the Australian National University, Canberra (1997);
    b. Bachelor of Science with honours majoring in exploration geology and geochemistry from the University of Tasmania (2001);
    c. Master of Integrated Water Management majoring in Catchment Management from the University of Queensland (2017).
4. MHV is sponsoring my PhD research at the University of Otago which directly relates to my role at MHV.
5. I am a current member of the following professional initiations:
    a. The Australian Institute of Geoscientists
    b. The Hydrological Society of New Zealand.
6. I have worked exclusively as a geologist on a full-time basis since 1997 and a hydrogeologist on an exclusive full-time basis since 2017.
7. I am a Registered Geologist (R.P. Geo No. 10076) in the fields of Exploration (2008) and Mining (2015) and Hydrogeology (2022) in accordance Australian Institute of Geoscientists 1996 guidelines.
8. I am considered a *Competent Person* for Public Reporting of Exploration Targets, Exploration Results, and Mineral Resources as defined in the 2012 Edition of the *'Australasian Code for Reporting of Exploration Results, Mineral Resources and Ore Reserves'.*
9. I declare that to the best of my knowledge, the information contained herein is accurate, and all third-party information sources have been cited where practically possible.
10. I declare that I have no external financial relationships, social or political affiliations and/ or cultural or religious proclivities that may constitute a conflict of interest.

Appendix 2

Summary of Nitrogen Limits for the National Objectives Framework

Guideline Type	NO_3-N mg/l	NH_4-N mg/l	Total Phosphorus mg / m^3	Description of Management Class
A – Excellent High conservation value systems (99% protection)	1.0	<0.03	<10	Pristine environment with high biodiversity and conservation values. Lake ecological communities are healthy and resilient, similar to natural reference conditions
B – Good Slightly to moderately disturbed systems (95% protection)	2.4	0.03-0.24	50 - 120	Environments which are subject to a range of disturbances from human activities, but with minor effects. Lake ecological communities are slightly impacted by additional algal and plant growth arising from nutrient levels that are elevated above natural reference conditions
Highly disturbed systems (90% protection)	3.8			Environments which have naturally seasonally elevated concentrations for significant periods of the year (1-3 months).
C - Fair Highly disturbed systems (80% protection)	6.9	0.24-0.54	20 - 50	Environment which are measurably degraded, and which have seasonally elevated concentrations for significant periods of the year (1-3 months). Elevated concentrations from point source discharges or diffuse organic inputs noted. Potential for marked diurnal temperature and pH variability associated with excessive macrophyte, river periphyton and lake phytoplankton growths. Lake ecological communities are moderately impacted by additional algal and plant growth arising from nutrient levels that are elevated well above natural reference conditions
D Acute	20	3.9	>50	Environments which are significantly degraded. Probable chronic effects on multiple species. Lake ecological communities have undergone or are at high risk of a regime shift to a persistent, degraded state (without native macrophyte/seagrass cover), due to impacts of elevated nutrients leading to excessive algal and/or plant growth, as well as from losing oxygen in bottom waters of deep lakes
Method of comparison	Annual median	Annual median		

Appendix 3

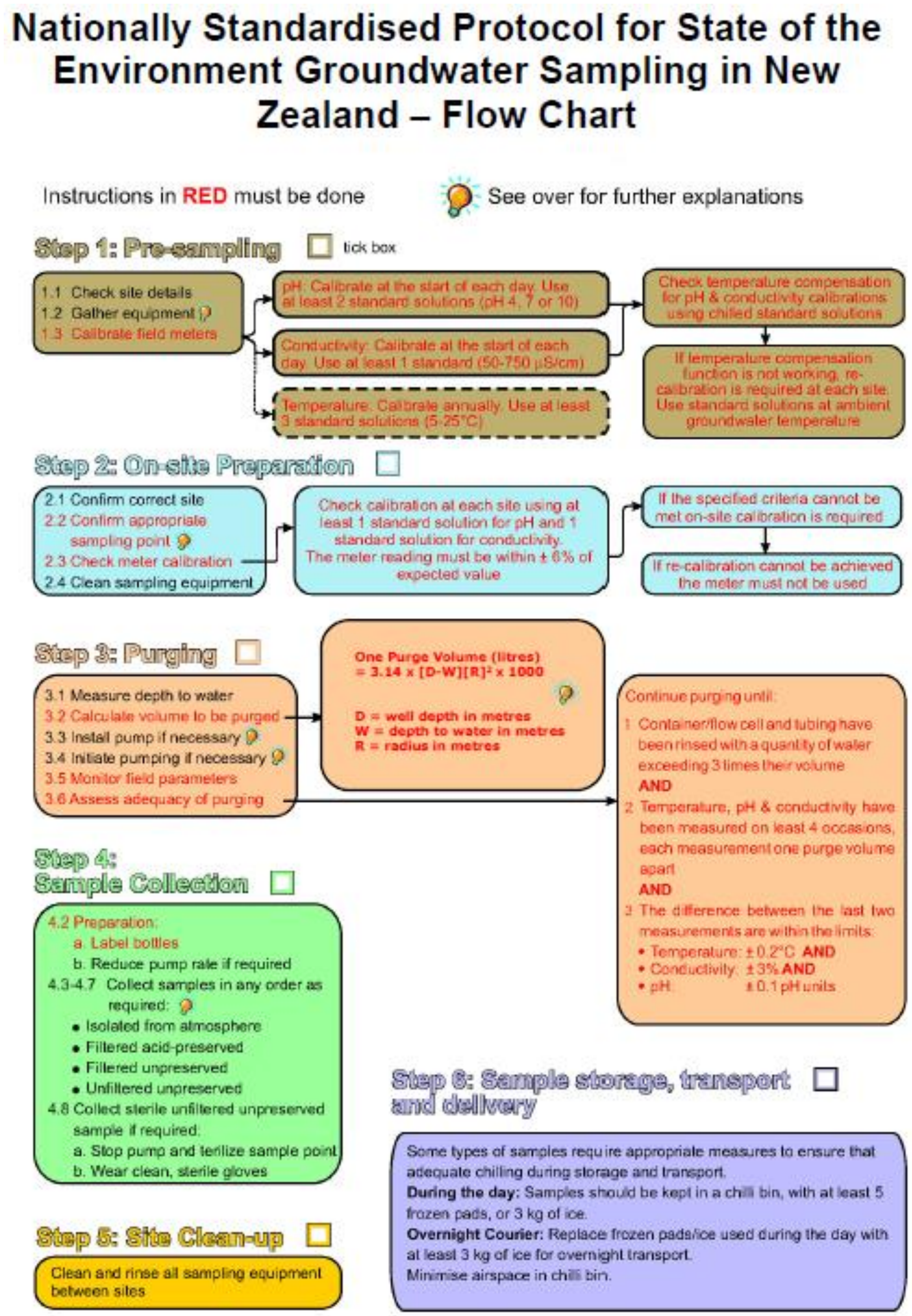
Map Projections

NZTM2000 is formally defined in the LINZ standard LINZS25002 (Standard for New Zealand Geodetic Datum 2000 Projections). The key parameters from this standard are summarised below:

Name:	New Zealand Transverse Mercator 2000
Abbreviation:	NZTM2000
Projection type:	Transverse Mercator
Reference ellipsoid:	GRS80
Datum:	NZGD2000
Origin latitude:	0° 00' 00" South
Origin longitude / central meridian:	173° 00' 00" East
False Northing:	10,000,000 metres North
False Easting:	1,600,000 metres East
Central meridian scale factor:	0.9996

Appendix 4

Nationally Standardised Protocol for State of the Environment Groundwater Sampling in New Zealand



Nationally Standardised Protocol for State of the Environment Groundwater Sampling in New Zealand

1.2 A preservative is required for some types of sample, (e.g. an acid preservative for samples to be analysed for cations). Be prepared to chill samples (e.g. for nutrients) to 1-4°C immediately after collection and for the duration of transport to the laboratory.

2.2 An appropriate sampling point is one that minimises the purging time (see Step 3) and minimises the potential for contamination or alteration of the sample. It is acceptable to collect samples from a short length of clean hose attached to the tap or wellhead.

3.2 For calculation of purge volume:

- Well depth, depth to water, and well radius must be expressed in meters in order to derive the purge volume in litres.
- If the depth to water under ambient (non-pumping) conditions cannot be determined for any reason, assume "depth to water" = 0.
- Well depth can be obtained from the drilling log or through the use of the dip tape.
- Well radius refers to the casing dimension and not to the dimension of the bore.
- If it is not possible to determine depth to water and if the well depth is unknown, then purge volume cannot be calculated. In this case, any samples collected from the well will not comply with this protocol.

3.3 The pump should be installed so that its intake is positioned at least 1 m below the static water level and a minimum distance above the top of the screened/open interval of 10 times the well diameter (for example, 1500mm for a 150mm well diameter). This will ensure that the sample is representative of the entire screened or open interval of the well.

3.4 A suitable pumping rate produces a continuous stream of water from the pump outlet or sample point without turbulence, entrainment of air or pump cavitation. Compliance with this protocol requires determination of the pumping rate during purging.

3.6 For assessment of adequacy of purging, note that:

- The purging operation requires extraction of *at least three times* the calculated purge volume and may require extraction of many more than three times the calculated purge volume.
- The field values of temperature, conductivity and pH must be measured on at least four separate occasions, each measurement at least one purge volume apart.
- The differences between the last two sets of field measurements must be the same within the following limits:
  - Temperature: ±0.2 °C, AND
  - Conductivity: ±3% (±5% if <100 µS/cm at 25 °C), AND
  - pH: ±0.1 pH unit

4.3-4.7 All samples must be collected sequentially from the sample point or from a short length of clean tubing attached to the sample point. The filtered acid-preserved, filtered unpreserved, unfiltered unpreserved samples and the samples collected in isolation from the atmosphere can be collected in any order.

4.8 Sterile samples must be collected after all other samples. This is because the requirements for sterilisation could potentially influence the chemistry of samples collected afterwards. Note that sterilisation of the sample point requires the pump to be turned off briefly.

Refer to Groundwater Sampling Protocol for further detailed explanations when required

Standing Water Level measurements

Standing Water Levels (SWL) were obtained for background information, as well as to estimate the purge volumes required. Due to the potential for water monitoring equipment to become jammed and subsequently damaged (and/ or lost completely) within the within the wellhead infrastructure, or fouled amongst pump service cables, measurement of water levels was restricted to bores with an alkathene conduit down the bore, as shown in Figure 59.

Standing Water Level is the ambient water level of an active bore that is not being pumped at the time of the observation.

Static Water Level is the ambient water level of an abandoned bore that has not been pumped for a considerable period of time.

Figure 59 Well head with alkathene conduit

Water Column Purging and Sampling

Sampling was restricted to domestic and irrigation bores with pumps installed.

Locations of bores were confirmed via a Garmin eTrex 10 Handheld GPS. All sampled bores had a field sheet written up, indicating:

- Physical address
- Location on farm
- Pump and bore configuration
- On farm contacts

Where possible, samples were collected in accordance with New Zealand standard protocols (Daughney et al., 2006, refer to Appendix 2with purge times amended for practicality as shown in Table 12.

Table 12 Water bore purging protocols for sampling

Bore Type	Assumption	MHV purge time
Domestic	Bore will be regularly purged	Minimum of 1x water column volume purged If occupants not home, then 3x water column purged
Farm Support	i. If used for domestic purposes, bore will be regularly purged. ii. If bore is running, then the bore has been purged. iii. If the farm has been / is milking, then the bore has been purged.	Purge time 15 minutes if (i) to (iii) else bore purged 3x water column
Irrigation	Bore will be purged already if running. If not – purge required	Purge time 10 minutes if the pump running, else bore purged 3x water column volume. If the bore is offline (i.e. off season) – no sample taken
Domestic Tank	Purge unavailable, sample taken from the domestic tank	None – but noted as tank sample
Dairy Tank	Purge unavailable, sample taken from the low flow tap next to milk filter in dairy shed (Figure 60)	None – but noted as tank sample

Figure 60 Example of a low flow tap next to milk filter in dairy shed

Appendix 5

NIWA Stations

Name	Agent No.	Network No.	Latitude	Longitude	NZTM (mE)	NZTM (mN)	Height (m)	Observing Authority
Mt Somers, Somer Downs	18394	H31641	-43.674	171.413	1472069	5163110	372	N/A
Ashburton Aero AWS	26170	H31983	-43.903	171.804	1503965	5138172	88	Metservice
Orari Estate EWS	35704	H41132	-44.125	171.311	1464854	5112878	81	NIWA
Methven CWS	36645	H31665	-43.640	171.652	1491282	5167249	313	NIWA
Methven, Three Springs CWS	37920	H31656	-43.678	171.588	1486216	5162955	305	NIWA
Dorie CWS Riverstone	38866	H32805	-43.832	172.094	1527182	5146376	55	N/A
Arundel Simla	39315	H31824	-43.937	171.303	1463801	5133724	237	N/A
Chertsey CWS	39661	H31793	-43.794	171.961	1516388	5150492	108	NIWA
Lismore Racemans House CWS	39845	H31944	-43.921	171.486	1478423	5135819	168	NIWA
Wakanui 2 CWS	41200	H31986	-43.972	171.811	1504628	5130583	53	NIWA
Winchmore 2 EWS	42899	H31772	-43.789	171.790	1502671	5150806	164	NIWA
Mayfield At Ruapuna Forecast	43538	H31827	-43.859	171.299	1463333	5142392	325	NIWA
Springburn	4711	H31643	-43.690	171.483	1477776	5161461	312	N/A
Rakaia, Greenfields	4720	H31671	-43.609	171.733	1497722	5170817	305	N/A
Mt Somers	4734	H31736	-43.706	171.401	1471170	5159537	383	N/A
Lyndhurst Limewood Farm	4740	H31771	-43.703	171.717	1496625	5160313	243	N/A
Orari Gorge	4771	H31926	-43.976	171.196	1455307	5129210	259	N/A
Peel Forest	4772	H31927	-43.907	171.259	1460198	5137027	286	N/A
Ashburton Council	4778	H31971	-43.897	171.747	1499384	5138848	101	N/A
Kakahu Bush	5053	H41111	-44.159	171.096	1447757	5108704	122	N/A
Orari Estate	5061	H41131	-44.127	171.308	1464635	5112629	81	N/A
Coldstream No 3	5065	H41153	-44.156	171.542	1483413	5109766	12	N/A
Timaru Aero Aws	5086	H41325	-44.305	171.221	1458135	5092689	27	Metservice

Appendix 6

2023 NO_3-N Results for Highly Modified Water Courses

Location	No. of Samples	Min NO_3-N (ppm)	Max NO_3-N (ppm)	Average NO_3-N (ppm)	Median NO_3-N (ppm)	Std Dev	CV
Anama Settlement Creek							
SW128	1	1.85	1.85	1.85	1.85		
BARFORD DRAIN							
SW84	9	4.81	6.86	5.93	5.87	0.72	0.12
SW94	11	4.78	7.02	5.64	5.63	0.63	0.11
BISHOPS/HERRIDGES DRAIN							
SW23	11	2.30	5.20	3.96	4.45	1.12	0.28
BOUNDARY DRAIN							
SQ20509	12	10.03	12.04	11.11	10.96	0.64	0.06
SQ36075	1	10.33	10.33	10.33	10.33		
SQ36076	5	6.05	10.96	8.59	8.93	2.14	0.25
BOUNDARY DRAIN TRIB							
SQ35844	11	8.22	10.26	9.18	9.11	0.53	0.06
Bowyers & Taylors Stream							
SW75	11	0.18	1.44	0.77	0.79	0.42	0.55
CROWES DRAIN							
SQ36083	11	11.52	13.51	12.31	12.12	0.64	0.05
DEALS DRAIN							
SQ26246	10	2.57	10.69	8.73	9.59	2.27	0.26
Dicksons Cut-off							
SW83	11	2.39	5.76	4.71	4.82	0.86	0.18
Dowdings Drain							
SW08	1	11.60	11.60	11.60	11.60		
SW99	1	11.70	11.70	11.70	11.70		
FIFTY LINK DRAIN							
SW24	11	3.97	5.73	4.82	4.74	0.66	0.14
FLEMINGTON DRAIN							
SQ36064	11	8.37	15.97	13.28	14.60	2.75	0.21
SQ36067	11	6.73	13.38	11.23	11.85	2.16	0.19
Gawler Stream							
SW115	1	0.58	0.58	0.58	0.58		
Harris							
SW42	1	12.30	12.30	12.30	12.30		
Harris C							
SQ26072	12	11.17	13.05	12.06	12.11	0.64	0.05

HARRIS DRAIN							
SQ20507	13	9.40	12.96	11.57	11.77	0.85	0.07
Kingston							
SW38	11	9.93	11.04	10.52	10.63	0.37	0.04
Lagmohr Creek							
SW68	11	4.63	6.35	5.43	5.23	0.66	0.12
Langdons Creek (South)							
SW114	1	1.42	1.42	1.42	1.42		
Limestone Creek							
SW117	1	0.26	0.26	0.26	0.26		
Lower Limestone Creek							
SW119	1	1.48	1.48	1.48	1.48		
Lower Taylor Drain							
SW58	1	3.33	3.33	3.33	3.33		
McLeans Swamp							
SW40	11	1.66	4.82	3.06	3.06	1.14	0.37
Mid Limestone Creek							
SW118	1	0.07	0.07	0.07	0.07		
MOFFATS DRAIN							
SQ34961	10	0.18	10.27	3.09	0.40	4.03	1.30
SQ35842	10	0.02	9.65	2.80	0.35	3.73	1.33
Montgomery							
SW96	11	9.81	10.70	10.28	10.25	0.31	0.03
MOORE DRAIN							
SW57	8	3.93	5.64	4.84	4.98	0.73	0.15
Mulligans Cut-off							
SW12	2	6.65	7.93	7.29	7.29	0.91	0.12
Murdochs							
SW37	6	9.62	11.19	10.16	9.93	0.59	0.06
Northern							
SW85	11	7.93	11.43	9.98	9.96	1.15	0.11
SQ34910	11	8.45	9.81	9.17	9.21	0.38	0.04
SQ34963	11	0.04	13.20	5.15	5.62	4.63	0.90
SQ34964	12	7.14	15.33	9.05	8.50	2.15	0.24
Oakdale							
SW104	1	2.10	2.10	2.10	2.10		
SW105	1	1.92	1.92	1.92	1.92		
SW106	1	8.70	8.70	8.70	8.70		
SQ26073	1	9.88	9.88	9.88	9.88		
SQ34958	1	12.30	12.30	12.30	12.30		
SW41	13	9.42	13.58	11.05	11.11	1.10	0.10
O'SHAUGNESSYS DRAIN							
SQ35846	11	4.73	8.02	7.30	7.59	0.95	0.13

PARAKANOI DRAIN							
SQ26242	11	12.74	14.99	14.17	14.39	0.66	0.05
SQ36153	11	13.91	16.14	15.19	15.31	0.64	0.04
PYES DRAIN							
SQ26065	11	10.34	12.22	11.19	11.06	0.60	0.05
Remington Drain							
SW67	11	11.19	12.60	11.92	11.97	0.43	0.04
Robertsons							
SW03	3	9.55	10.14	9.89	9.97	0.30	0.03
Shepherds Brook							
SW66	11	10.35	12.94	11.33	11.14	0.99	0.09
Silverstream Drain							
SW92	11	1.63	5.08	2.56	2.10	1.15	0.45
STORMY DRAIN							
SQ26068	11	8.91	11.01	9.96	9.85	0.64	0.06
SQ36078	11	7.94	11.23	9.36	9.27	1.05	0.11
TAYLOR DRAIN							
SQ35845	11	3.51	7.18	5.11	4.58	1.32	0.26
SQ36082	11	2.06	6.33	4.09	3.45	1.48	0.36
SW93	11	2.54	5.96	3.88	3.38	1.11	0.29
TWENTY-ONE DRAIN							
SQ26064	11	8.89	12.96	10.79	10.72	1.31	0.12
Upper Limestone Creek							
SW116	1	0.39	0.39	0.39	0.39		
WEILYS DRAIN							
SW04	3	9.84	11.41	10.53	10.34	0.81	0.08
WINDERMERE							
SQ36070	11	9.18	11.69	10.46	10.46	0.66	0.06
SQ36071	11	11.05	14.20	12.70	12.55	0.87	0.07
SQ36073	11	7.31	12.46	10.67	10.73	1.34	0.13
SQ26245	10	5.25	12.06	10.22	10.62	1.85	0.18
Yeatmans Drain							
SW88	11	10.07	12.55	11.17	11.11	0.79	0.07

Appendix 7

HMWC's that are augmented with ADC Stock water

The following Highly Modified Water Courses were noted as having inconsistent low NO_3-N results that was attributed to water augmentation by the ADC

Bowyers & Taylors Stream

Crowes Drain

Dalys

Dicksons Cut-Off

Farrells

Harris Drain

Heddell Smyth

Lagmohr Creek

Mcleans Swamp

Moffats Drain

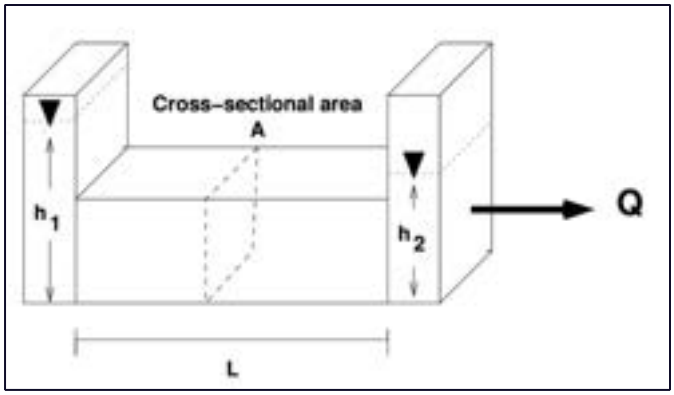
Northern Drain

Okawa Spring

Glossary

Taken from *Water quality in New Zealand: Understanding the science* [39] *and other sources where cited*

Aerobic	A condition of water where the oxygen level is high enough to support oxygen using bacteria.
Algae	A class of simple aquatic plants, including microscopic species known as periphyton and phytoplankton. Larger algae like seaweeds and charophytes are known as macrophytes. Almost all algae can use photosynthesis but are dependent on nutrients including nitrogen and phosphorus.
Algal bloom	Dense growths of microscopic algae or cyanobacteria in response to high nutrient levels and warm temperatures. Often makes water discolored and turbid, sometimes including scum on the surface of the water.
Ammonia	A highly soluble nitrogen compound, chemical formula NH_3, characteristically found in manure, sewage and anaerobic conditions.
Anaerobic	A condition of water where the oxygen level is too low to support any kind of oxygen-breathing life.
Anoxic	Without any oxygen.
Aquifer	A geological layer of sand, gravel, or fractured rock that contains groundwater. Confined aquifers are underneath impermeable layers of silt or clay (aquitards) so they do not receive water and dissolved pollutants from land directly overlying them. Unconfined aquifers lack aquitards, so pollutants can leach directly into them.
Benthic	Living on the bottom of a water body.
Biochemical oxygen demand (BOD)	The amount of dissolved oxygen needed by micro-organisms to break down organic matter in the water. It is a measure of organic pollution, usually from wastewater.
Blue-green algae	See Cyanobacteria
Campylobacter	A type of bacteria living in the guts of humans and animals, which may cause gastroenteritis.
Catchment	A catchment is the area of land feeding a river system. All the precipitation within the catchment combines and flows down to form a single interconnected network of water bodies, including streams, rivers, lakes, wetlands, and aquifers.
Chlorophyll	A pigment used by plants, algae, and cyanobacteria to harvest energy from light as part of photosynthesis.
Cryptosporidium	A type of protozoan pathogen, living in the guts of humans and animals.
Cyanobacteria	A group of bacteria that can use photosynthesis, like true algae. Some species are periphyton and others are phytoplankton. Unlike freshwater algae, some species of cyanobacteria produce toxins and some are able to extract nitrogen directly from the air.
Darcy's Law	Developed by Henry Darcy in 1856, the law describes the flow of a fluid through a porous medium such as an aquifer.

	Darcy's Law states that *Total Flow* (**Q**) is proportional to the change in *Head Pressure* (**h**) (or hydraulic gradient) due to friction relative to the *Cross Sectional Area of Flow* (**A**), which is proportional to the flow distance or *Length* (**L**) (Hiscock & Bense 2014). This is presented schematically in **Error! Reference source not found.** (Brikowski 2013). The *Permeability* (**K**) of the material is derived from the *'Kozeny–Carman Equation'* $\mathbf{K = Cd^2}$ where C is the tortuosity (grain size distribution) of the medium and d is the mean grain diameter (a proxy for the mean pore diameter) (Brikowski 2013).  Hence Darcy's Law is expressed as: $\mathbf{Q = -KA\ (h_1\text{-}h_2)/L}$
Denitrification	A bacterial process removing nitrate from soil, air, or water, requiring anaerobic conditions and usually forming nitrogen gas.
Deposited sediment	Layers of fine sand, silt, and clay that have settled on the bottom of a waterway.
Diffuse source pollutants	Pollutants that do not come from a single end-of-pipe source, but from many small sources or from a wide area of leaching, runoff, erosion, etc.
Dissolved Oxygen	A relative measure of the amount of oxygen (O2) dissolved in water.
Escherichia coli	(abbr. E. coli) A type of bacteria that live in the guts of humans and other animals. Although usually harmless themselves, high levels of E. coli indicate that other pathogens are present.
Flow regime	Typical behavior of a stream or river, including how much water it carries, how fast it flows, how often it floods, and how big its flood peaks are.
Freshwater	Water of salinity less than 1,000 mg/L
Gastroenteritis	General term for gut disease involving inflammation of the stomach and intestines.
Giardia	A type of protozoan pathogen, living in the guts of humans and animals. Notoriously associated with trampers and possums, occasionally found in poorly treated drinking water supplies.
Hydraulic conductivity (K) (coefficient of permeability)	A measure of how easily water can pass through soil or rock. High values indicate a permeable material through which water can pass easily; low values indicate that the material is less permeable. Ranges of intrinsic permeability, k, and hydraulic conductivity, K, values. The alternating colours are used to make the chart easier to read [40].
Hypoxic	Of water with low levels of oxygen, low enough to kill fish.
Invertebrates	Types of animals without a backbone, such as insects, worms, and snails.
Leaching	Process by which pollutants in and on soil are dissolved by rain or irrigation water and carried down into groundwater.

Leptospirosis	An infectious bacterial disease of rats, dogs, pigs, and other animals, which can be transmitted to humans.
Macrophytes	Large water plants and algae that are visible to the naked eye, as opposed to the microscopic periphyton and phytoplankton.
Meteoric water	Water derived from rain, snow, streams, and other bodies of surface water that percolates in rocks and displaces interstitial water that may have been connate, meteoric, or of any other origin.
Mole-and-tile drainage	Drainage systems to remove excess water from heavy clay soils, formed by tunnelling through the soil (mole drains) or by laying down pipework (tile drains).
Nitrate	A highly soluble compound of nitrogen and oxygen with the chemical formula NO_3
Nitrification	A process, usually bacterial, forming nitrate from other forms of nitrogen.
Nitrogen	A chemical element, symbol N. Common forms of nitrogen in water include ammonia and nitrate. 'Nitrogen gas' N2, also makes up about 78 percent of the Earth's atmosphere. All life needs nitrogen for molecules such as proteins and DNA.
Non-point source pollution	Diffuse source pollution.
NTU	'Nephelometric turbidity units'; arbitrary units in which turbidity is measured.
Nutrient	A substance, element, or compound that organisms need to live and grow.
Nutrient budget	A calculation comparing nutrients brought onto a farm in fertilizer, feed, and new stock, with nutrients lost in produce, leaching, runoff, and into the atmosphere as gas.
Nutrient management plan	A written plan that documents how the major plant nutrients on a farm will be managed to maximize production or productivity while minimizing any adverse effects.
Organic matter	Any solid, liquid, or gaseous substance that contains carbon. It is generally taken to mean substances that have been produced by a plant or animal.
Pathogens	Disease-causing micro-organisms, including many bacteria, protozoa, and viruses.
Periphyton	Microscopic algae, cyanobacteria, and bacteria living in fresh water but attached to objects such as submerged rocks, wood, or macrophytes.
Phosphorus	A chemical element, symbol P. The most common form of phosphorus is (ortho)phosphate PO43- which is only slightly soluble in water. Phosphates are constituents of bone and of molecules like DNA.
Photosynthesis	A biochemical process by which green plants and some other organisms use sunlight to help them make organic matter from carbon dioxide gas. Photosynthesis generally involves the green pigment chlorophyll. Oxygen is generated as a by-product.
Phytoplankton	Microscopic algae and cyanobacteria drifting or floating in water.
Plankton	Organisms drifting or floating in water, including some algae, some cyanobacteria, waterborne pathogens, and microscopic invertebrates.

Point sources	Pollutants from local, stationary sources such as factories or mines, which discharge wastewater through pipes or channels.
Porosity	The proportion of solids to voids in a sedimentary formation.
Precipitation	Water deposited on the ground; dew, rain, snow, etc.
Profile available water (PAW)	The amount of water potentially available to plant growth that can be stored in the soil to 100 cm depth. PAW takes into account variations in soil horizons and is expressed in units of millimetres of water, i.e. in the same way as rainfall. A PAW of 100 mm implies that 10% of the soil volume is water available to plants. Low PAW is <60 mm, moderate is between 60 and150 mm, and high is ≥ 150 mm.
Protozoa	A class of simple, one-celled micro-organisms that do not photosynthesize, instead preying on bacteria, algae and other microscopic organisms. They include pathogens like Giardia and Cryptosporidium.
REDOX Reduction / Oxidation.	A chemical reaction that takes place between an oxidizing substance and a reducing substance. The oxidizing substance loses electrons in the reaction, and the reducing substance gains electrons.
Respiration	The process whereby animals, plants, algae, and some bacteria use oxygen to break down carbohydrates to generate energy. Respiration reduces dissolved oxygen.
Riparian	Relating to the banks of a river or wetland; a riparian strip is a buffer zone covered with plants and trees between surrounding land and a waterway.
Run-off	Water moving overland, carrying fine sediment and dissolved pollutants.
Salmonella	A family of bacterial pathogens that live in the guts of humans and other animals. In humans they can cause diarrhoea and vomiting; in cattle and sheep the symptoms are similar but often fatal.
Sediment	Material transported by the water. Sediment is generally inorganic material, but can include organic material such as plant fragments, and dead algae.
Sedimentation	Settling or depositing of sediment within waterways.
Sewage fungus	A form of periphyton made up of masses of bacteria, growing in water polluted by organic matter.
Stratification	Formation of two distinct layers within a lake over summer; a bright, warm upper layer or ‘epilimnion’ and a denser, cooler lower layer or ‘hypolimnion’.
Suspended sediment	Particles of silt, clay, or organic matter floating in water.
Transmissivity	The rate of flow under a unit hydraulic gradient through a unit width of aquifer of given saturated thickness. It is measured in m2 per-day
Turbidity	Murkiness or cloudiness of water due to suspended sediment and/or other material, including phytoplankton.
Typhoid	A disease affecting people only, caused by the bacteria Salmonella enterica Typhi, transmitted in food or water. Typhoid causes fever, gastroenteritis, and potentially death.
Wash load	Suspended sediment carried by a stream or river.
Watershed	The boundary dividing one catchment from its neighbours.

Bibliography

[1] Ministry of Health, *Drinking-water Standards for New Zealand 2005 (Revised 2018)*. 2018, p. 128.

[2] Ministry of Health, ‘Chapter 10: Chemical compliance’, in *Guidelines for Drinking-water Quality Management for New Zealand*, 3rd ed., Wellington, New Zealand: Ministry of Health, 2017. [Online]. Available: https://www.health.govt.nz/publication/guidelines-drinking-water-quality-management-new-zealand

[3] Environment Canterbury, *Canterbury Land and Water Regional Plan*. 2019. [Online]. Available: https://eplan.ecan.govt.nz/eplan/#Rules/0/55/1/25081

[4] S. Baram *et al.*, ‘Estimating Nitrate Leaching to Groundwater from Orchards: Comparing Crop Nitrogen Excess, Deep Vadose Zone Data-Driven Estimates, and HYDRUS Modeling’, *Vadose Zone J.*, vol. 15, no. 11, p. vzj2016.07.0061, Nov. 2016, doi: 10.2136/vzj2016.07.0061.

[5] J. Dai *et al.*, ‘Winter wheat grain yield and summer nitrate leaching: Long-term effects of nitrogen and phosphorus rates on the Loess Plateau of China’, *Field Crops Res.*, vol. 196, pp. 180–190, Sep. 2016, doi: 10.1016/j.fcr.2016.06.020.

[6] L. Lilburne, T. Webb, M. Robson, and N. Watkins, ‘Estimating nitrate-nitrogen leaching rates under rural land uses in Canterbury (updated)’, Environment Canterbury (ECan), Christchurch, New Zealand, R14/19 (PU1C/7817-1), 2013.

[7] L. Scott, M. Scott, A. Pearson, B. Wilkins, J. Tregurtha, and A. Kreleger, ‘“How long will it take?” A summary of information about nitrate time lags in Canterbury’, Environment Canterbury (ECan), Christchurch, New Zealand, R23/02, 2023. [Online]. Available: https://www.ecan.govt.nz/document/download?uri=4825996

[8] R. W. McDowell, Z. P. Simpson, A. G. Ausseil, Z. Etheridge, and R. Law, ‘The implications of lag times between nitrate leaching losses and riverine loads for water quality policy’, *Sci. Rep.*, vol. 11, no. 1, p. 16450, Aug. 2021, doi: 10.1038/s41598-021-95302-1.

[9] A. Body and A. Cushnie, *Water, Farming and Families - The Mayfield Hinds Irrigation Scheme*. Mayfield Hinds Irrigation Ltd, 2015.

[10] A. H. McLintock, ‘Ashburton’, in *An Encyclopaedia of New Zealand*, Wellington, New Zealand: R.E. Owen, 1966. [Online]. Available: https://teara.govt.nz/en/1966/ashburton

[11] C. Knight, *New Zealand’s Rivers - An environmental History*. Christchurch, New Zealand: Canterbury University Press, 2016.

[12] IPENZ, ‘Rangitata Diversion Race’, Engineering New Zealand Te ao ranhahau. [Online]. Available: https://www.engineeringnz.org/programmes/heritage/heritage-records/rangitata-diversion-race/

[13] R. Dynes, V. Burggraaf, C. Goulter, and D. Dalley, ‘Canterbury farming: production, processing and farming systems’, *Proc. N. Z. Grassl. Assoc.*, vol. 72, pp. 1–8, 2010.

[14] Infometrics, ‘ASHBURTON DISTRICT OVERVIEW’, Infometrics. [Online]. Available: https://rep.infometrics.co.nz/ashburton-district

[15] P. Durney, J. Ritson, A. Druzynski, F. Alkhaier, D. Tutulic, and M. Sharma, ‘Integrated catchment modelling of the Hinds Plains’, Environment Canterbury (ECan), Christchurch, New Zealand, R14/64 (PU1C/7864-1), 2014.

[16] C. Hanson and P. Abraham, ‘Cross sections of groundwater chemistry through the Ashburton Rangitata plain’, Environment Canterbury (ECan), Christchurch, New Zealand, R13/30 (PU1C/7705-1), 2013.

[17] P. Aitchison-Earl, ‘Sources of nitrate in groundwater in the Tinwald, Ashburton area’, Environment Canterbury (ECan), Christchurch, New Zealand, R19/85 (PU1C/8628), 2019.

[18] C. Hanson and P. Abraham, ‘Nitrate contamination and groundwater chemistry – Ashburton-Hinds plain’, Environment Canterbury (ECan), Christchurch, New Zealand, R10/143, 2010.

[19] J. Dommisse, ‘Hydrogeology of the Hinds Rangitata Plain, and the Impacts of the Mayfield-Hinds Irrigation Scheme’, Masters Thesis, University of Canterbury, Christchurch, 2006. [Online]. Available: https://ir.canterbury.ac.nz/handle/10092/1400

[20] J. Weir, ‘Central Plains Water - Canterbury Groundwater Model 2’, Aqualinc Research Ltd, Christchurch, New Zealand, L07021/4, 2007.

[21] L. F. Burbery, C. R. Moore, M. A. Jones, P. M. Abraham, B. L. Humphries, and M. E. Close, ‘Study of connectivity of open framework gravel facies in the Canterbury Plains aquifer using smoke as a tracer’, *Geol. Soc. Spec. Publ.*, vol. 440, no. 1, pp. 327–344, 2018, doi: 10.1144/SP440.10.

[22] I. A. Lunt and J. S. Bridge, ‘Formation and preservation of open-framework gravel strata in unidirectional flows’, *Sedimentology*, vol. 54, no. 1, pp. 71–87, 2007, doi: 10.1111/j.1365-3091.2006.00829.x.

[23] H. Rutter, S. Cox, N. Dudley Ward, and J. Weir, ‘Aquifer permeability change caused by a near-field earthquake, Canterbury, New Zealand’, *Water Resour. Res.*, vol. 52, pp. 8861–8878, 2016, doi: 10.1002/2015WR018524.

[24] P. Jussel, ‘Stochastic description of typical inhomogeneities of hydraulic conductivity in fluvial gravel deposits’, in *Contaminant Transport in Groundwater*, Stuttgart: A.A. Balkema, Apr. 1989, pp. 221–228.

[25] ECan, ‘Living Stream: A Guide To Managing Waterways on Canterbury Farms’, Environment Canterbury (ECan), Christchurch, New Zealand, PU8C/5604, 2013.

[26] A. Meredith and J. Lessard, ‘Ecological assessment of scenarios and mitigations for Hinds Catchment streams and waterways’, Environment Canterbury (ECan), Christchurch, New Zealand, R14/72, PU1C/7872-1, Mar. 2014.

[27] J. F. Bohlke, ‘Groundwater recharge and agricultural contamination’, *Hydrogeol. J.*, vol. 10, no. 1, pp. 153–179, 2002, doi: 10.1007/s10040-001-0183-3.

[28] F. T. Wakida and D. N. Lerner, ‘Non-agricultural sources of groundwater nitrate: a review and case study’, *Water Res. Oxf.*, vol. 39, no. 1, Art. no. 1, 2005, doi: 10.1016/j.watres.2004.07.026.

[29] P. Aitchison-Earl and M. Smith, ‘Aquifer Test Guidelines’, Environment Canterbury (ECan), Christchurch, New Zealand, R08/25 (PU1C/6940), 2008.

[30] N. Kaelin, ‘Guidelines for analysing and reviewing aquifer tests that support consent applications and/or comply with consent conditions’, Environment Canterbury (ECan), Christchurch, New Zealand, 4921 CONGuidelinesforreviewingaquifiertestsJuly2015.PDF, 2015. [Online]. Available: https://www.ecan.govt.nz/document/download?uri=2996965

[31] E. W. Rice, R. B. Baird, and A. D. Eaton, *Standard Methods For the Examination of Water and Wastewater*, 23rd ed. American Public Health Association, 2017. [Online]. Available: https://www.standardmethods.org/doi/10.2105/SMWW.2882.089

[32] NIWA, ‘Seasonal Climate Outlook January 2024 - March 2024’, NIWA. [Online]. Available: https://niwa.co.nz/climate/seasonal-climate-outlook/seasonal-climate-outlook-january-2024-march-2024

[33] Bureau of Meteorology, ‘Southern Oscillation Index (SOI) since 1876’, Bureau of Meteorology. [Online]. Available: http://www.bom.gov.au/climate/enso/soi/

[34] M. Stewart and R. van der Raaij, ‘Age and source of Canterbury plains groundwater’, Environment Canterbury (ECan), NIWA, Christchurch, New Zealand, PU1C/6133 (U02/30), 2002. [Online]. Available: https://docs.niwa.co.nz/library/public/ECtrU02-30.pdf

[35] R. W. van der Raaij, ‘Age-tracer and stable isotope interpretation for nine wells on the Ashburton-Rangitata Plain’, GNS Science, Lower Hutt, New Zealand, 2019/157, 2019.

[36] M. K. Stewart and P. L. Aitchison-Earl, ‘Irrigation return flow causing a nitrate hotspot and denitrification imprints in groundwater at Tinwald, New Zealand’, *Hydrol. Earth Syst. Sci.*, vol. 24, no. 7, pp. 3583–3601, 2020, doi: 10.5194/hess-24-3583-2020.

[37] S. Teixeira, ‘Impact of managed aquifer recharge on nitrate concentration changes in an alluvial aquifer’, Masters Thesis, Lincoln University, Lincoln, Canterbury, 2024.

[38] C. J. Daughney *et al.*, ‘A National Protocol for State of the Environment Groundwater Sampling in New Zealand’, Ministry for the Environment, Wellington, New Zealand, GW/EMI-T-06/249 (ME number: 781), 2006.

[39] Parliamentary Commissioner for the Environment, ‘Water quality in New Zealand - Understanding the science’, The Parliamentary Commissioner for the Environment, Wellington, New Zealand, 2012. [Online]. Available: https://www.pce.parliament.nz/media/1278/pce-water-quality-in-new-zealand.pdf

[40] W. Woessner and E. Poeter, *Hydrogeologic properties of earth materials and principles of groundwater flow*. Guelph, Ontario, Canada: Groundwater Project, 2020. [Online]. Available: https://books.gw-project.org/hydrogeologic-properties-of-earth-materials-and-principles-of-groundwater-flow/front-matter/copyright/