Ground and Surface Water Monitoring Programme

2022 Annual Report

May 2023

Sustainable solutions for our community,
now and into the future

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MHVwater

bci

HEKEAO HINDS
WATER ENHANCEMENT TRUST

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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 2022 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;

ii. extend the spatial footprint of previous survey(s); and,

iii. 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 initial objective was to understand the changes in NO_3-N in groundwater for the Hekeao Hinds Plains.

The 2022 Survey

The 2022 programme monitored some 143 bores on a quarterly basis representing 106,200 hectares(ha) via support from Barrhill Chertsey Irrigation (BCI) and the Hekeao Hinds Water Enhancement Trust (HHWET) – see Figure 1.

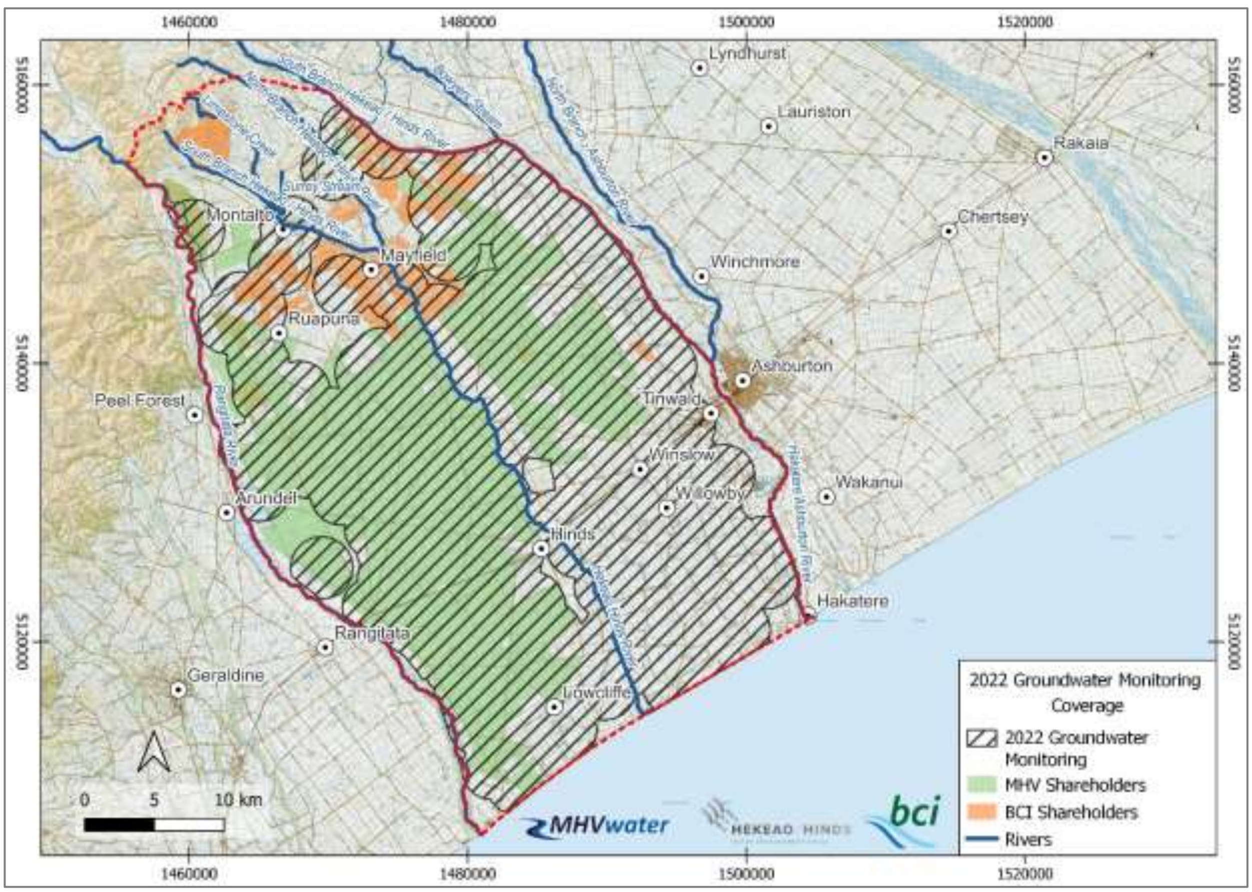


Figure 1 Survey coverage of the 2022 groundwater monitoring programme

Additionally, between 38 and 55 surface water locations were sampled monthly (av. 46) from 64 sample locations - the majority of which were collected from public road culverts or bridges (Figure 2).

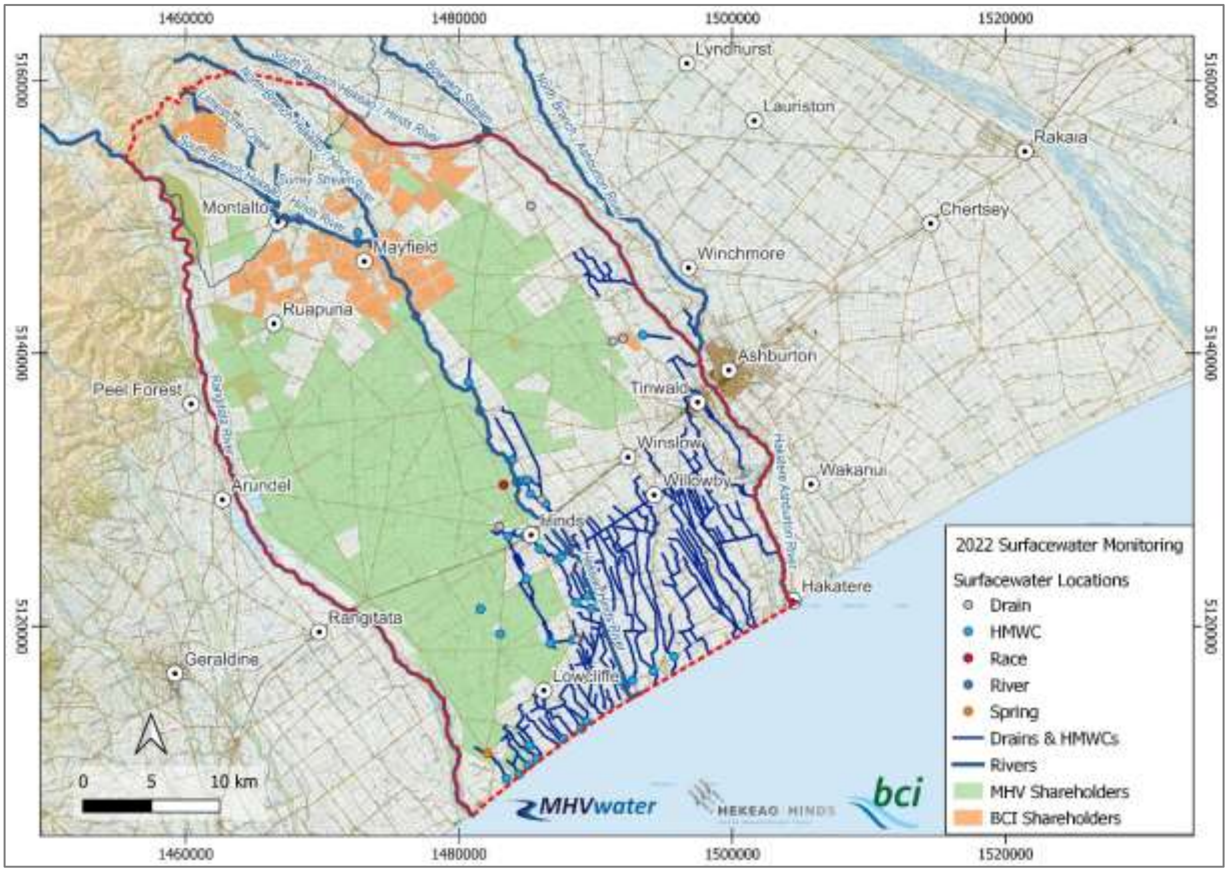


Figure 2 Survey coverage of the 2022 surface water monitoring programme

2022 Groundwater Results

The relative changes in NO_3-N concentration in groundwater were <10% from December 2021 to December 2022. This change in trend from the decrease in NO_3-N concentrations seen in the later part of 2021 (after the rain in May) is largely due to above average rainfall in June and December as shown in Figure 7 and Figure 3.

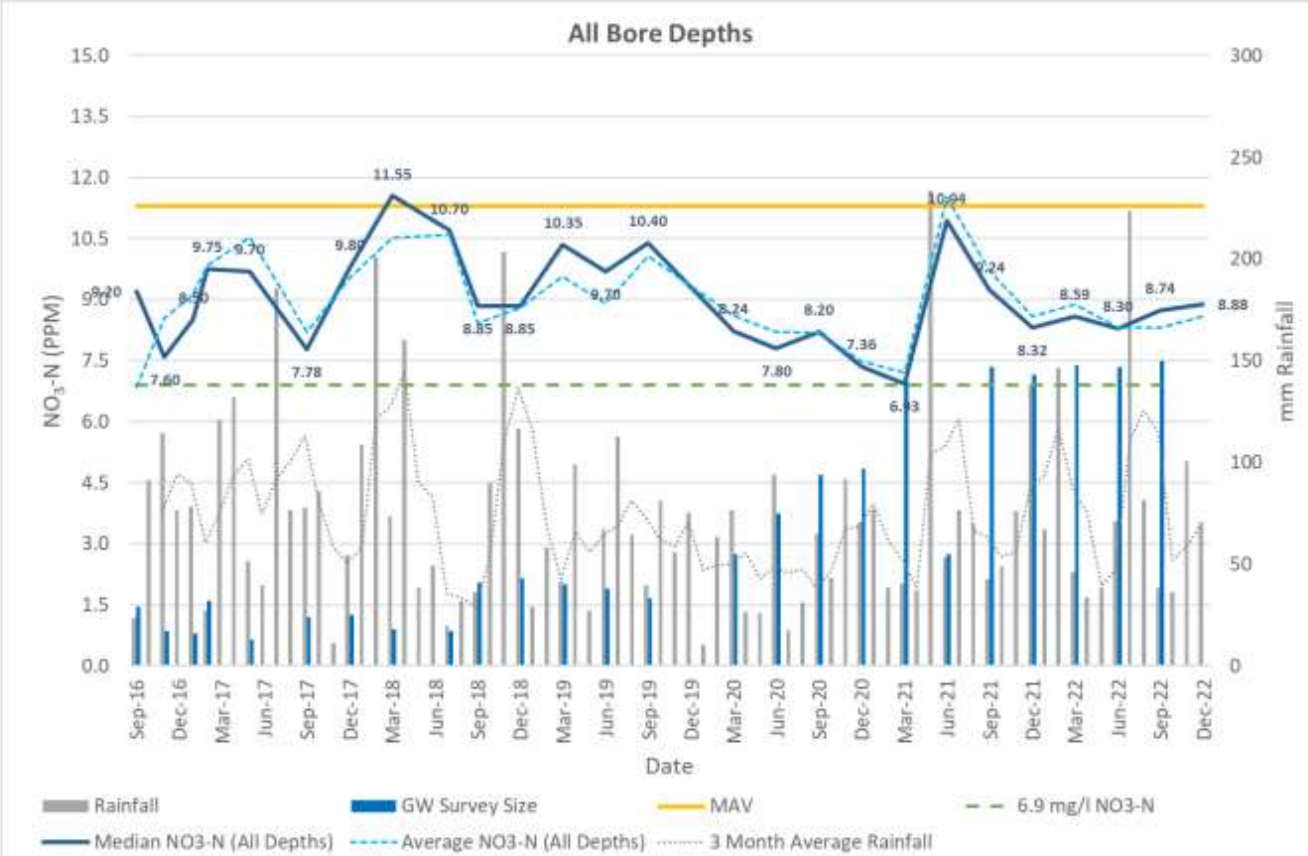


Figure 3 Long term NO_3-N results for the MHV groundwater monitoring programme (All bore depths)

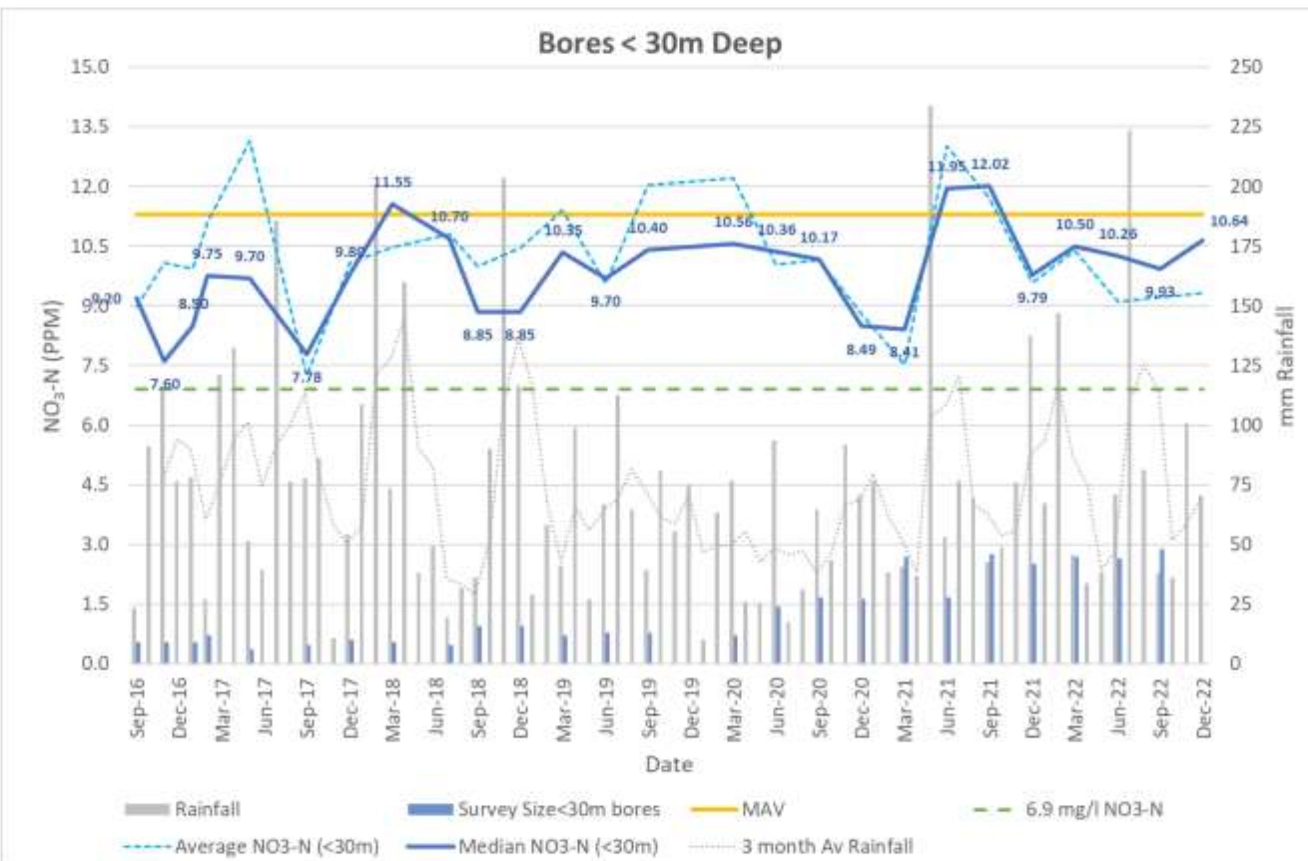


Figure 4 Long term NO_3-N results for the MHV groundwater monitoring programme (Bores <30m deep)

However, this result hides a more complex hydrogeological system. Figure 5 and Figure 6 present the relative changes in NO3-N (from December 2021 and December 2022) spatially for bores <30m and >30m respectively.

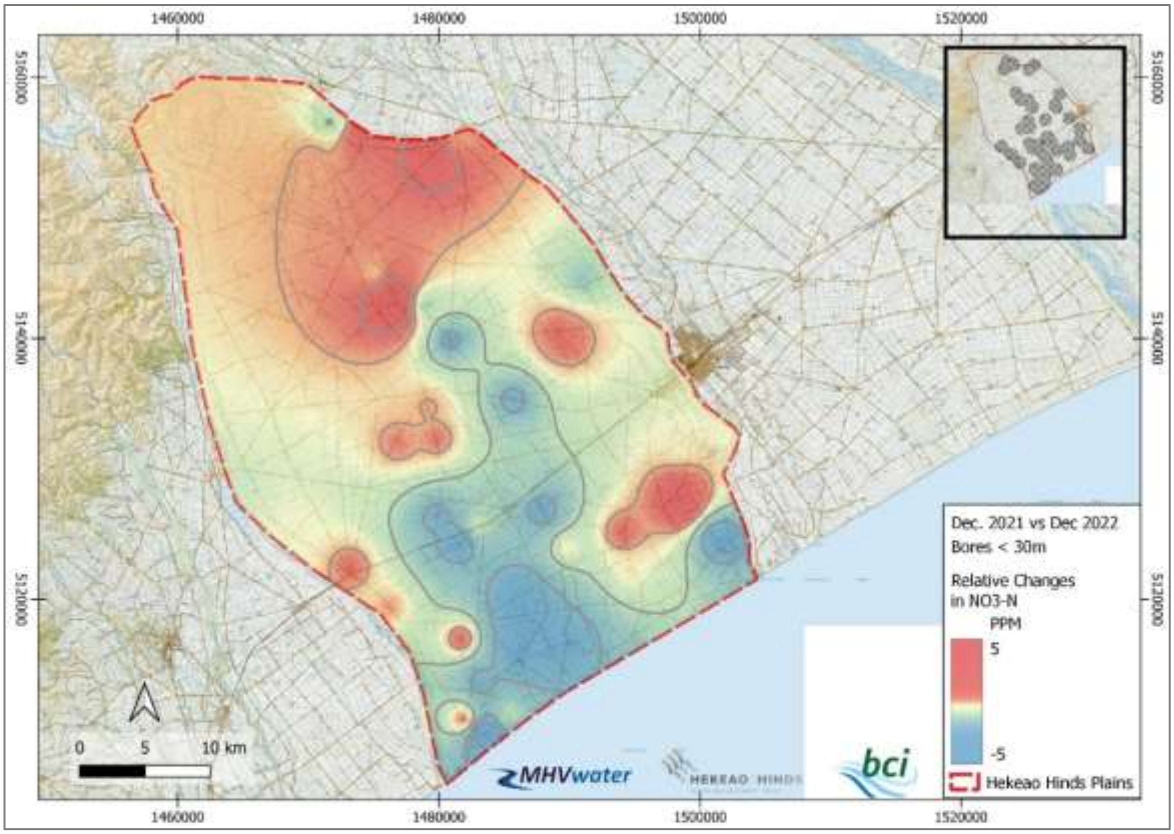


Figure 5 Relative changes in NO_3-N between Dec 2021 & Dec 2022 for bores <30m deep

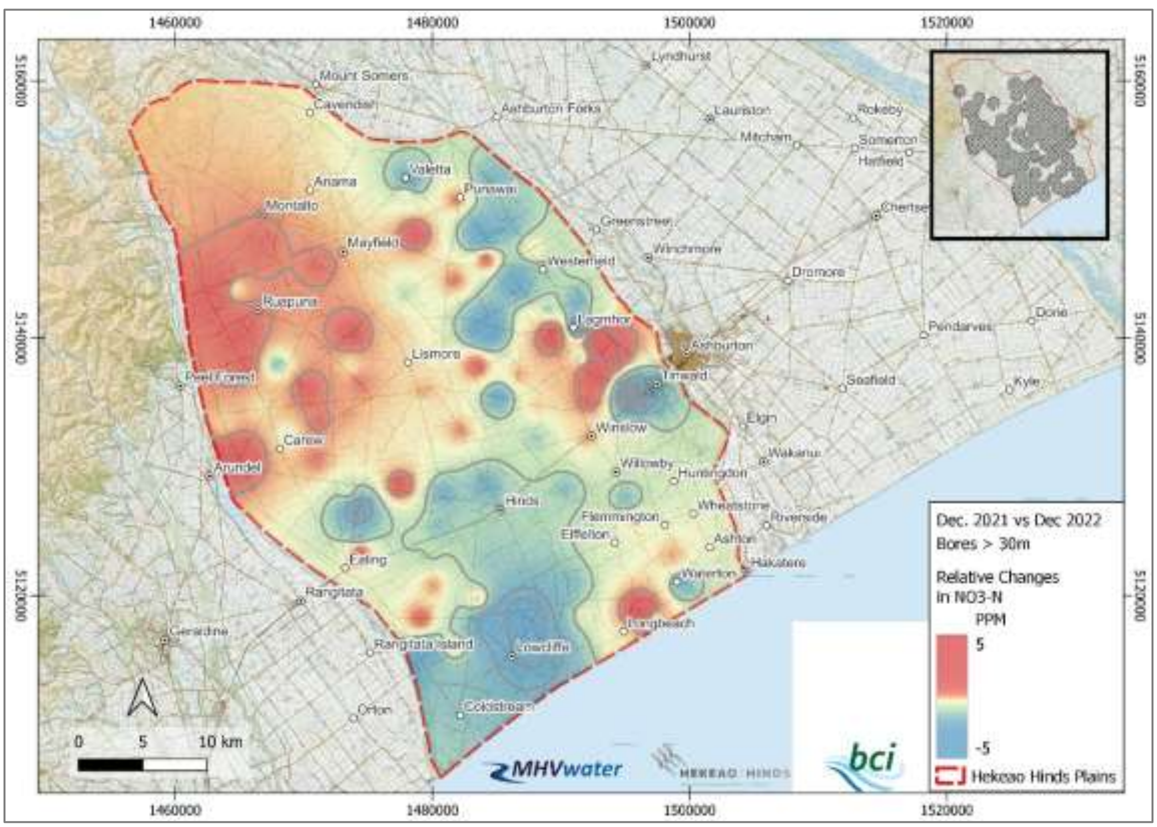


Figure 6 Relative changes in NO_3-N between Dec 2021 & Dec 2022 for bores >30m deep

2022 Surface Water Results

2022 saw a sustained decrease in NO_3-N concentrations in Highly Modified Water Courses despite a wet winter with > 200mm in July (Figure 7).

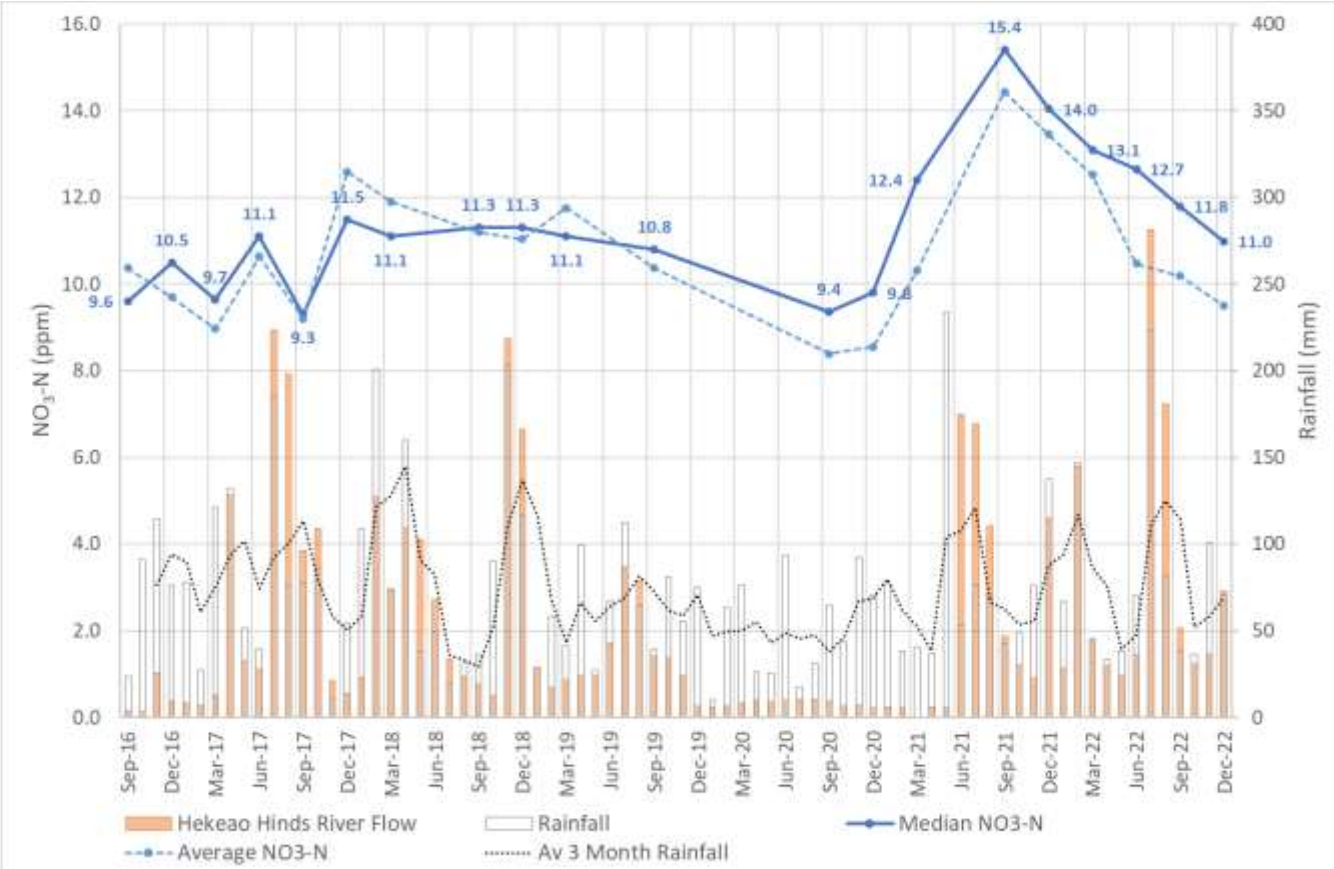


Figure 7 Long-term NO3-N concentrations in Highly Modified Courses (HMWC's)

Conclusion

With each successive year, we are developing a more robust conceptual model of NO3-N migration and retention across the Hekeao Hinds Plains. The data for 2022 suggests that due to extensive rain in June and December, NO3-N concentrations have essentially remained stagnant similar to the above average rainfall 2021 year with variations within ± 10%.

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

- NO_3-N migration is controlled by rainfall and river flow across thew catchment.
- There appears to be a relationship with soil type and NO_3-N response.
- Lateral flow of water via mechanisms such as open framework gravels appear to be the more dominant mechanism for subsurface NO3-N migration than vertical flow associated with rainfall.

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 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 National Policy Statement for Freshwater Management (NPS-FM), 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

AEP	Annual Exceedance Probability
ARI	Annual Recurrence Interval
BCI	Barnhill Cherty Irrigation
°C	Degrees Celsius
CHI	Cultural Health Indicators
CRM	Certified Reference Material
Cumec	Cubic Meter per Second (m^3/s)
CWMS	Canterbury Water Management Strategy
DO	Dissolved Oxygen
DIN	Dissolved organic nitrogen: comprised of nitrate plus nitrite and ammonium
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
FHCG	Foothills Catchment Group
GL	Giga Litre (1,000,000,000 Litres)
GNS	Geological and Nuclear Sciences
ha	10,000 square metres (2.471 acres)
HDWP	Hinds Drains Working Party
HHSCG	Hekeao Hinds Science Collaboration Group
HHWET	Hekeao Hinds Water Enhancement Trust
HMWC	Highly modified water course
ID2	Inverse Distance Squared
IWM	Integrated Water Management
JSEA	Job Safety and Environment Analysis
K	Hydraulic Conductivity i
kL	Kilo Litre (1,000 Litres or $1m^3$)
l	Litre: a metric unit of capacity equal to $1{,}000cm^3$ (0.264 gallons)
LWRP	Land and Water Regional Plan
MAR	Managed Aquifer Recharge
m bgl	Metres below ground level
MAV	Maximum Acceptable Level
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)
NPSFM 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 and Water Regional Plan
pH	a numeric scale used to specify the acidity or alkalinity of an aqueous solution
QAQC	Quality Assurance & Quality Control
RDR	Rangitata Diversion Race
REDOX	Reduction–Oxidation
SOI	Southern Oscillation Index
SOP	Standard Operating Procedures

SPC	Specific conductance
SWL	Standing water level
T	Hydraulic Transmissivity
t/ ha/ yr	Tonnes per hectare per year
TDN	Total dissolved nitrogen. DIN+DON
TN	Total Nitrogen.
	The sum of NO_3-N + NO_2-N + NH_3-N and organically bonded nitrogen
TKN	Total Kjeldahl Nitrogen.
	The sum of NH_3-N + organically bound nitrogen only
SWL	Standing Water Level
QAQC	Quality Assurance & Quality Control

Contents

1. Introduction

1.1.MHV Water Ltd

MHV is a farmer owned water 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 program conducted by MHV Water Ltd (MHV) during the 2022 calendar year.

This work program 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 programs.

1.3.Background of the monitoring program

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 program'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 program 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 140 bores representing an area of over 1000 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 environmental and sustainable water and nutrient management 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 2022 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	BCI

Whilst the Managed Aquifer Recharge (MAR) program 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 8 to 10 ECan shallow[4] (bores screened <30 m below ground level) monitoring bores that are tested on a quarterly basis.

However, in May 2020, the NZ 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).

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

[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

1.8.Background Documents

This report is based on several earlier reports, including:

- Legg, J. 2020. Future Groundwater Monitoring on the Hekeao Hinds Plains: A Green Paper. MHV Water. Internal Report. Ashburton
- Legg, J. 2020. Future Surface-water Monitoring on the Hekeao Hinds Plains: A Green Paper. MHV Water. Internal Report. Ashburton
- Legg, J. 2021. Ground & Surface Water Sampling 2021 – Annual Report MHV Water. Internal Report. Ashburton

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 2022 are presented below.

2.1. Community Engagement

Following the rainfall event on 2021, MHV produced a summary booklet of the 2021 Groundwater monitoring report. This information was made available to shareholders via mail outs, shed talks as well as community meetings.

MHV also attended the Mayfield A & P Show and provided free water quality testing services as well as information about water quality and the work being undertaken by MHV and its shareholders.

2.2. 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 still ongoing.

Figure 8 (left) Members of MCCC, AEC, MHV and Local Farmers discussing proposed wetland sites; (right) MHV staff undertaking field investigations for potential wetland sites

2.3.Hekeao Hinds Science Collaboration

Following the recommendations of the 2021 Ground & Surface Water Report, MHV recognised the need for a holistic integrated research programme at a catchment scale. Subsequently, a series of consultative workshops were held during the year with representatives from:

- Catchment Groups (such as the MCCC and HDWP),
- the research community (University of Otago, University of Waikato, Aqualinc Research),
- Governance agencies such as ECan and HHWET and key stakeholders, and,
- Local farmers and in house experts.

The result was the development of the Hekeao Hinds Science Collaboration Group (HHSCG) that intends to provide governance and guidance around potential research programmes over the next 2-5 years and to ensure:

i. they are relevant to our community (i.e., not science for science's sake – but practical solution focussed science investigations);

ii. they are not duplicating something already completed; and,

iii. increase our knowledge to assist with evidence-based decision making into the future.

HHWET will lead the oversight of the projects and will be responsible for:

- oversight of the workstreams;
- arranging to check back in with the wider community (including scientists) at regular [annual] intervals to ensure we remain focused on the right areas;
- updating the Ashburton Zone Committee and ECan.

Individual projects would have specific community leads who would report progress back to the main entity to be shared with the community.

2.4.University Engagement

Throughout the year MHV initiated and maintained discussions with the universities across the South Island, Te Waipounamu, with the intention of developing a 'pipeline' of research opportunities.

2.4.1. Otago University

During the 4th quarter of 2021, MHV commenced discussions with Louis Martin, a Masters candidate at the University of Otago about a project integrating water quality data and ecological monitoring.

2.4.2. Occasional Guest Lectures

During the first quarter of 2022, MHV was invited to speak as a guest lecturer to postgraduate students undertaking Water Resource Management at the Waterways Centre (University of Canterbury) as well as the University of Otago.

2.5. Callaghan Research

In late 2021 MHV was successful in securing a student grant through the Callaghan Innovation Fund to investigate the changes in NO_3-N concentrations in ground water following the rainfall event in May-June of 2021.

In January 2022 Ms Sidinei Teixeira from Lincoln University was appointed on a fixed term position to analyse MHV data. Sidinei is a Master's candidate in Water Resource Management, with a background in chemistry and teaching.

Sidinei identified 4 broad trends (Figure 9) in the data, namely:

i. Group A: Marginal changes within ± 10%

ii. Group B: Significant short-term increase, with rapid decay

iii. Group C: Moderate but sustained increase

iv. Group D: Initial decrease then increase in later months

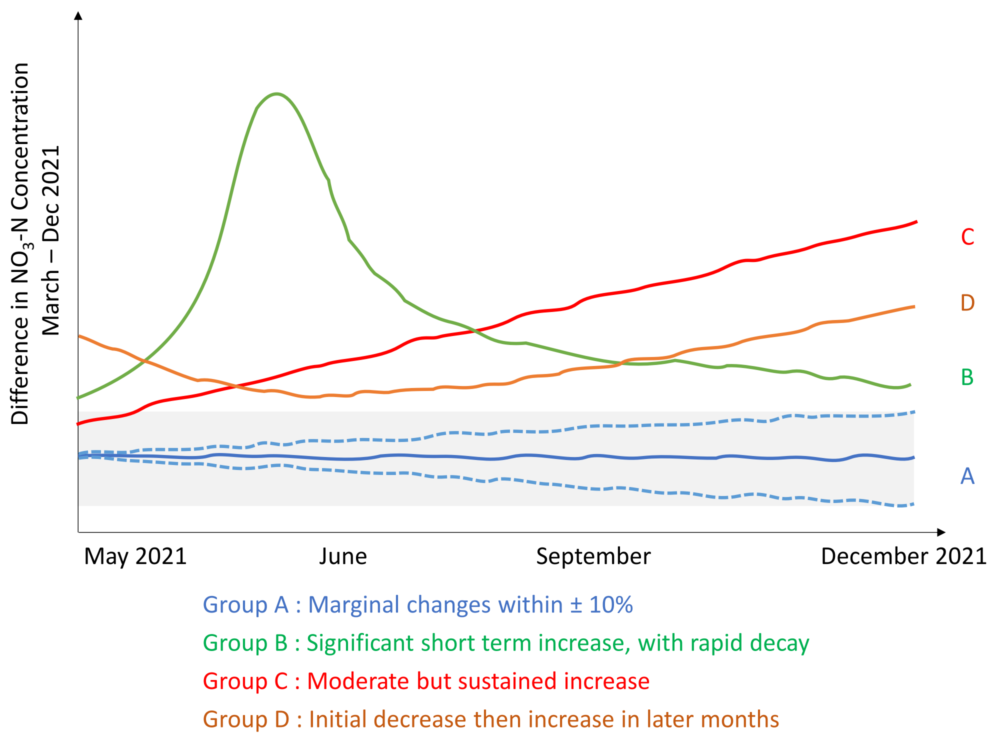


Figure 9 Different NO_3-N Response trends post 2021 rain event

These areas broadly coincided with soil domains as shown in Figure 10 and Figure 11.

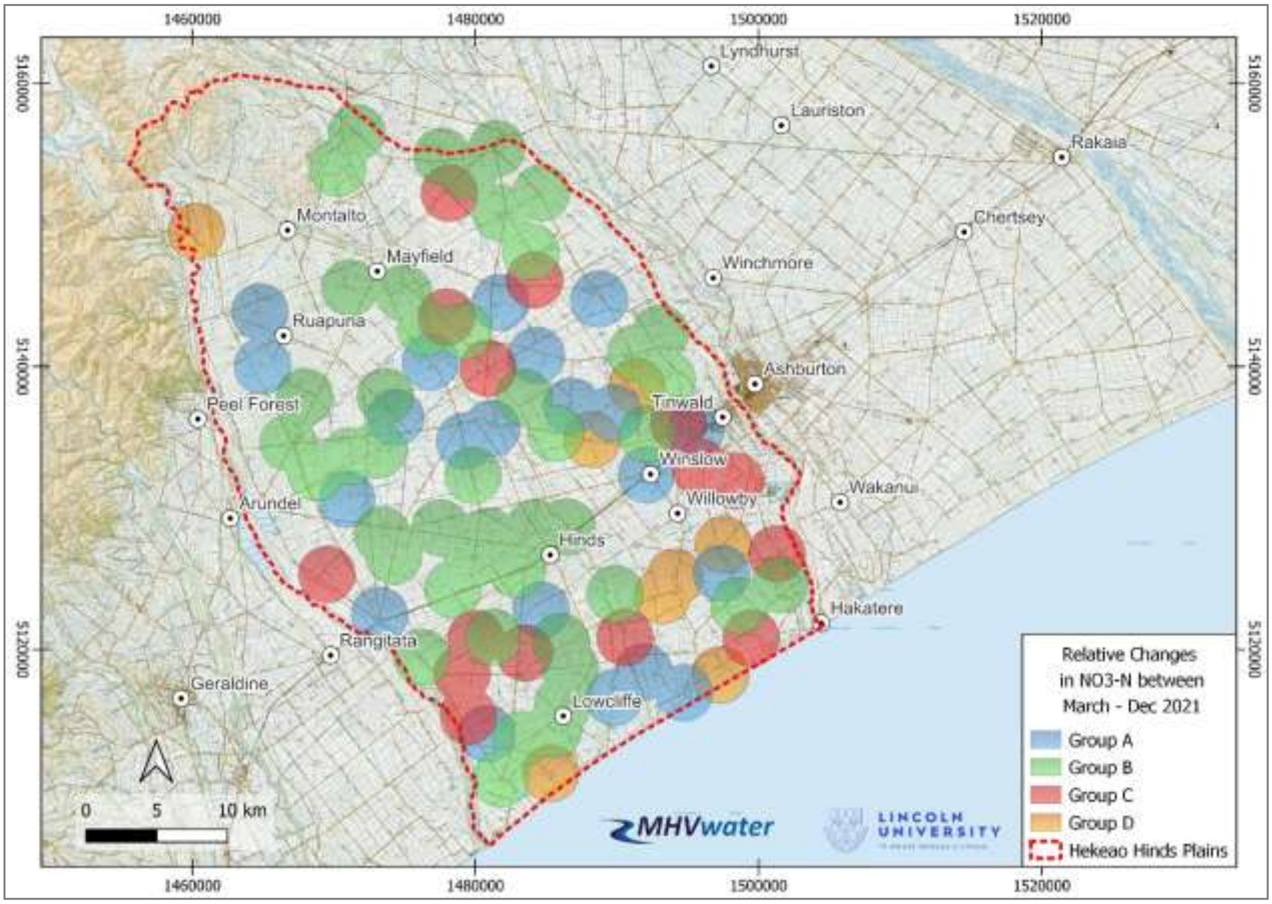


Figure 10 Locations of identified 4 broad NO_3-N response trends following the 2021 rain event

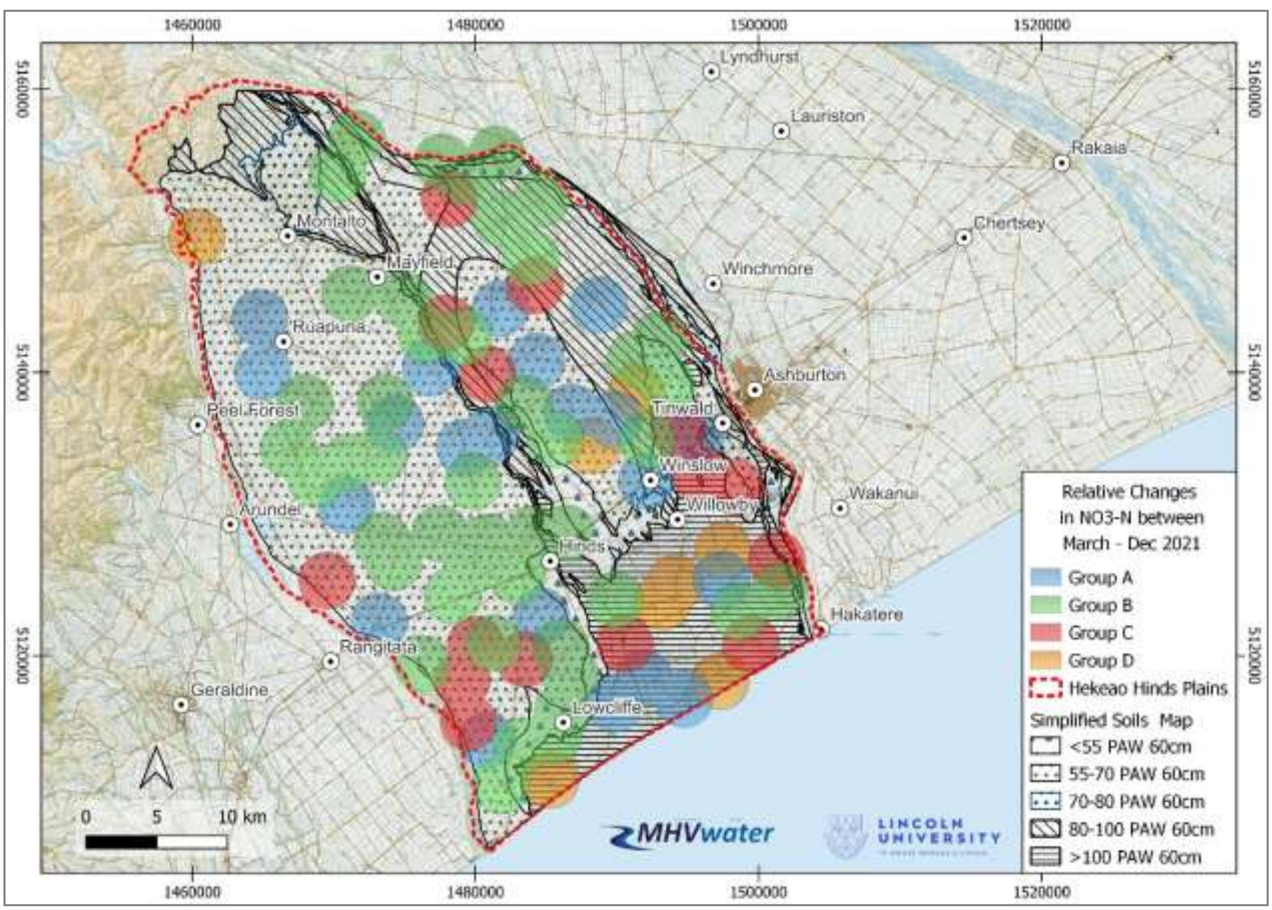


Figure 11 Locations of identified 4 broad NO_3-N response trends following the 2021 rain event, with a simplified soil map

3. Background

3.1. 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.

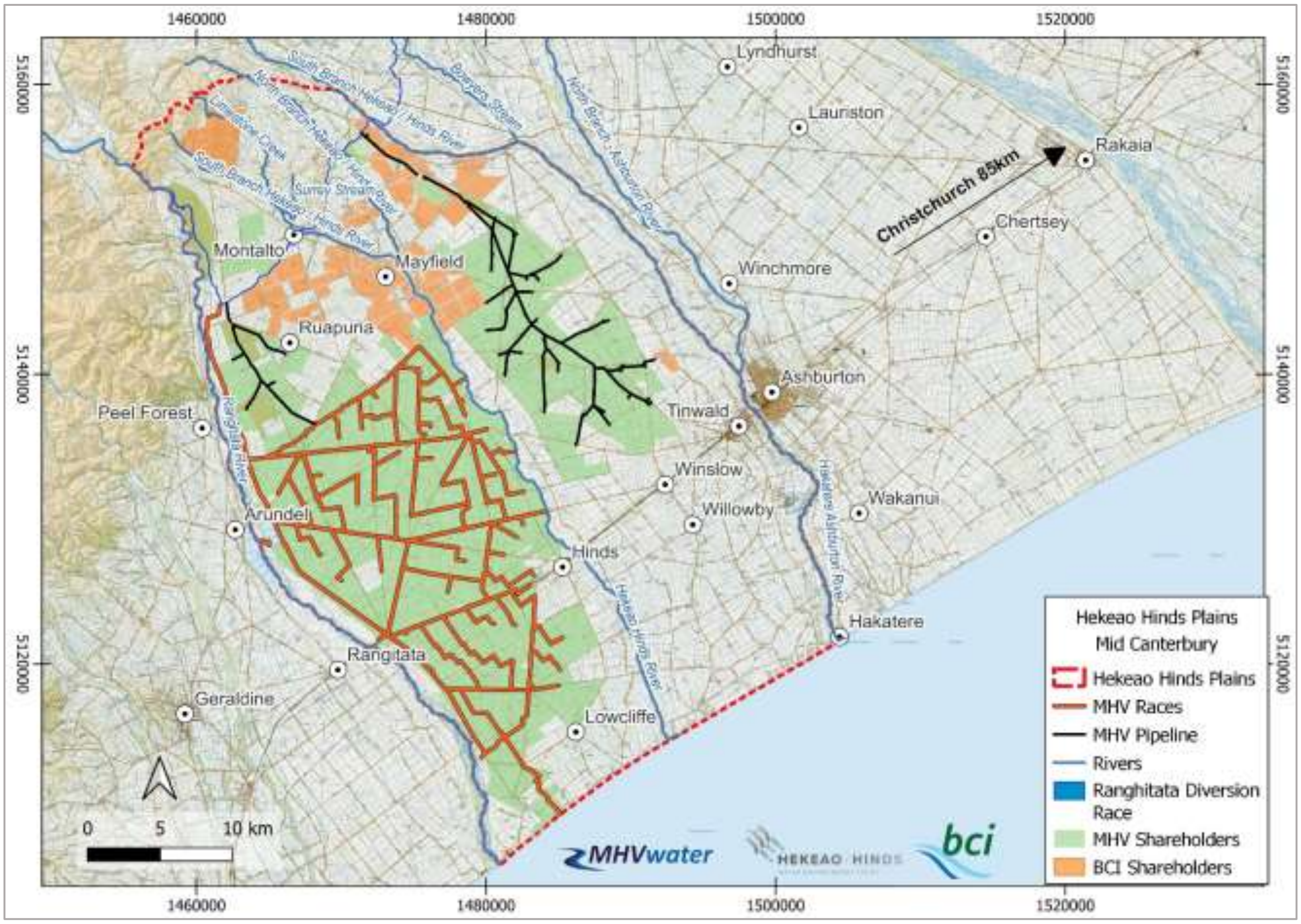


Figure 12 Locality map of the Hekeao Hinds Plains with MHV and BCI irrigation schemes and infrastructure

Following the establishment of the Ashburton District Council in 1876, irrigation was first trailed at the Ashburton Irrigation Farm near Elgin in 1887 [4], [5], although its potential was not fully realized until the construction of the Rangitata Diversion Race (RDR) in the late 1930's. Primary built to irrigate the farmlands of Ashburton County; the 67 km race diverted water from the Rangitata River at Klondyke to the Rakia River near Methven, servicing approximately 66,000 ha, that resulted in a significant increase in farming production as well as diversification from sheep to arable cropping across the Hekeao Hinds Plains [4], [6]–[8].

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 5.8%) [9].

3.2.Climate and Rainfall

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

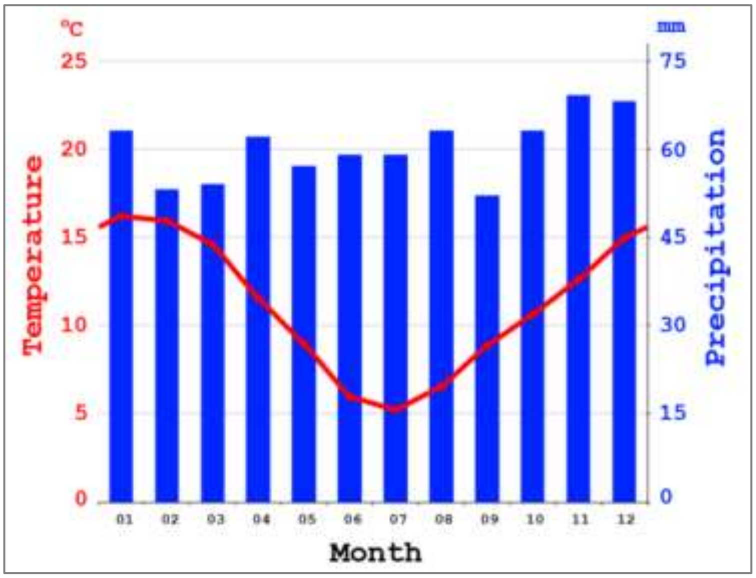


Figure 13 Ashburton Climate[5]

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 [10].

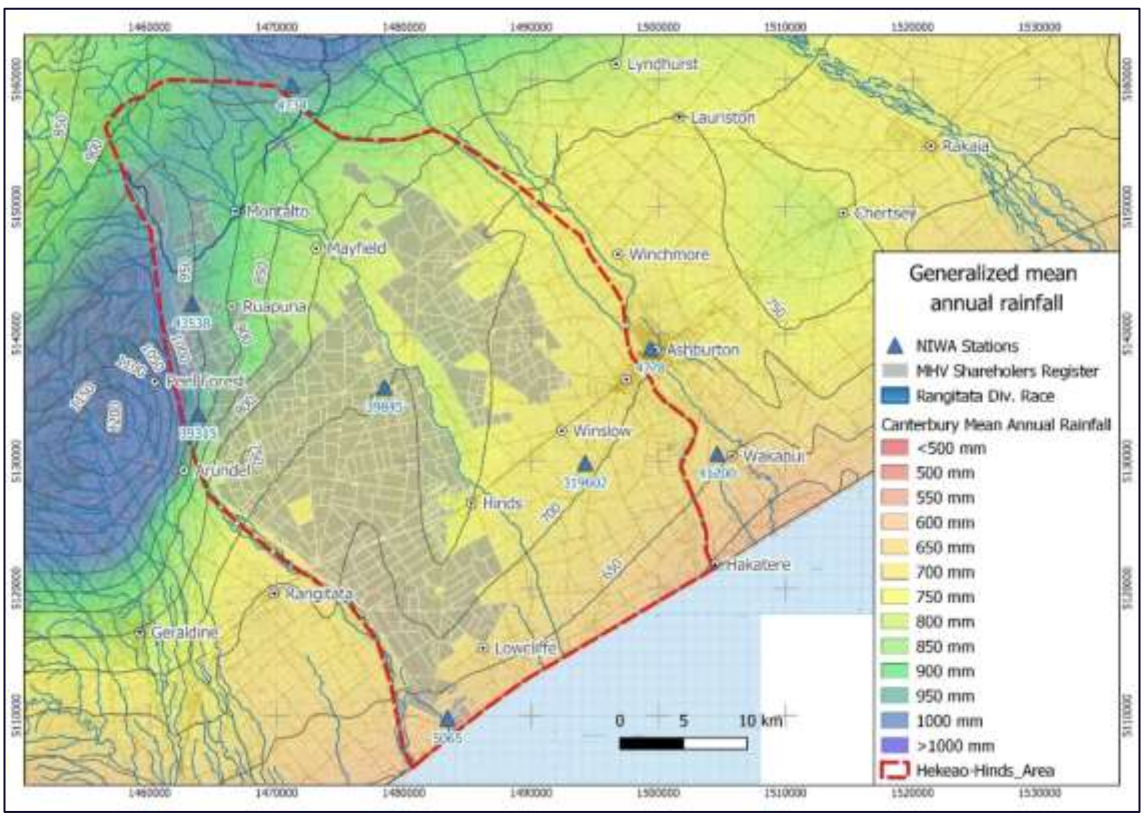


Figure 14 Generalized mean annual rainfall distribution across the Hekeao Hinds Plains

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

3.3. Catchment Characteristics

3.3.1. Soils

The Hekeao Hinds Plains has over twenty 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 [11].

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 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. Theses soils are associated with swamp deposits [11]–[13].

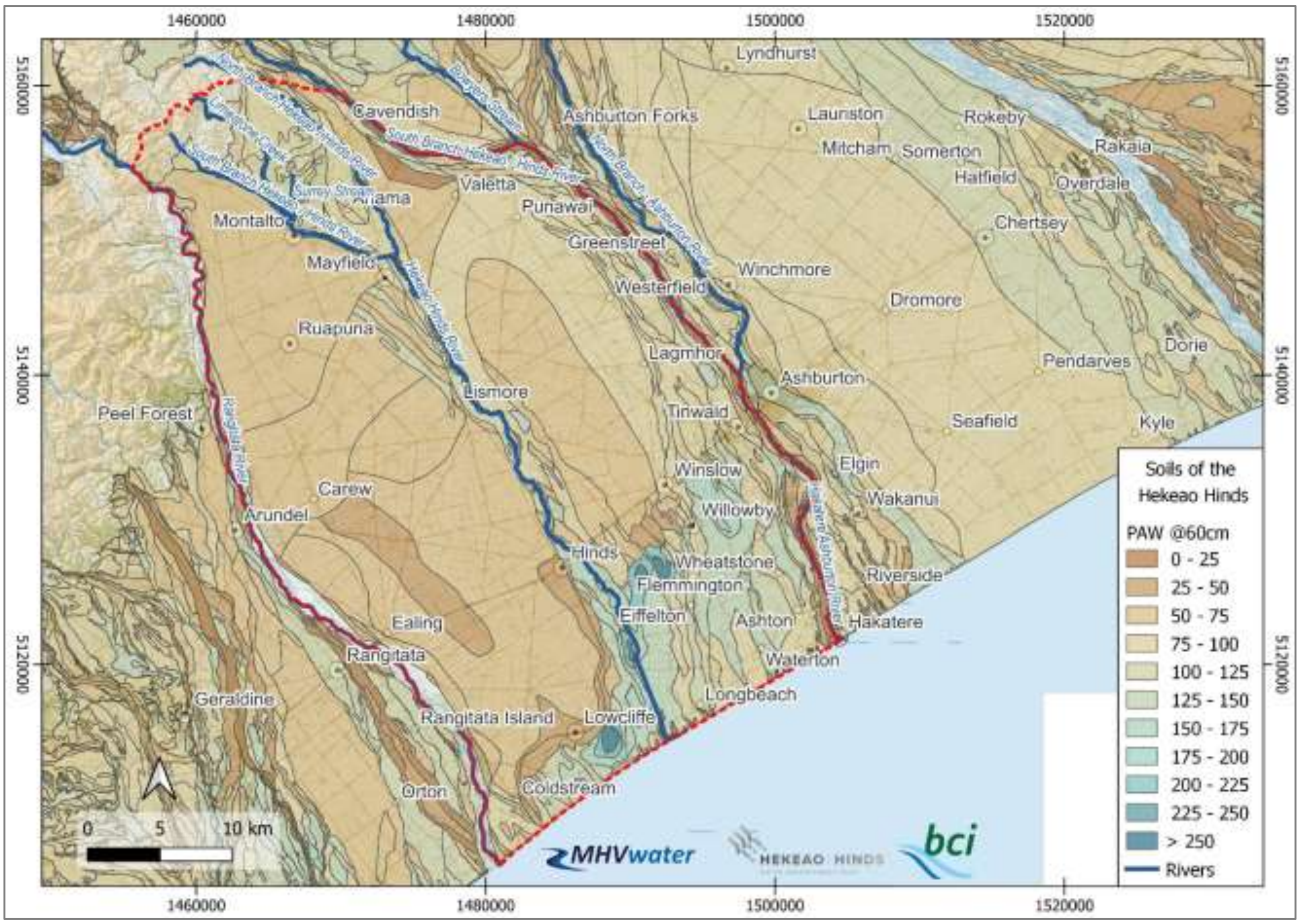


Figure 15 Soils of the Hekeao Hinds Plains

3.3.2. 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 [11], [14]. 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 through high permeability lenses, called open framework gravel- OFG's (refer to section 3.4.3).

These Quaternary sediments are underlain by Tertiary sediments and Cretaceous greywacke basement of the Torlesse Group [13].

3.4.Hydrology

3.4.1. 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 Ashburton, Hekeao Hinds and Rangitata Rivers are shown in Figure 16 and Table 1.

Table 1 Average daily flow rates (m^3/ second) for the rivers in the survey area between 2015 - 2022

	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	36.7	3.19	109.3

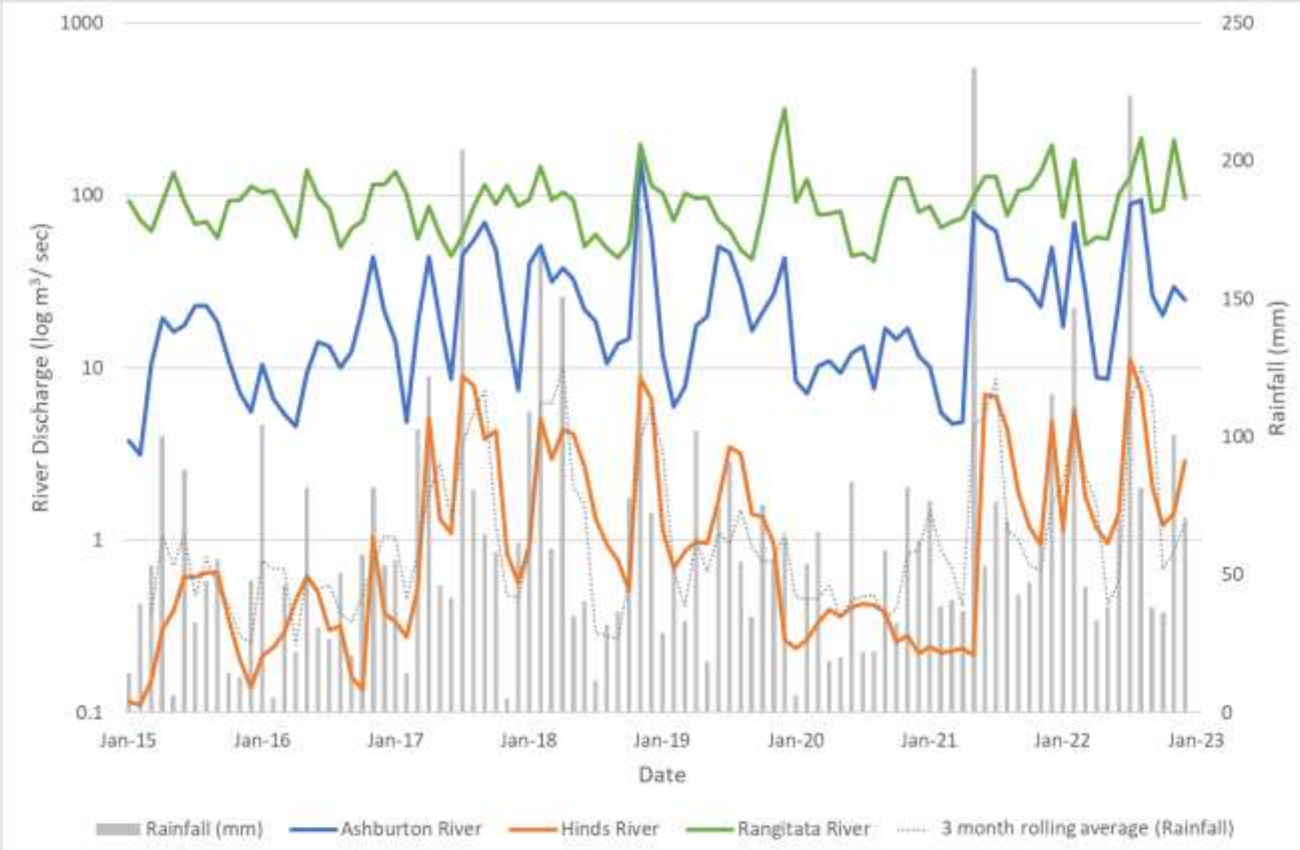


Figure 16 *Rainfall and river flow data for the period 2015 to 2022*

3.4.2. Catchment Scale

The Hekeao Hinds Plains are serviced by three rivers: the Ashburton Hakatere, Rangitata and Hinds Hekeao. As the Ashburton and Hinds Hekeao 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 local 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's 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 3.4.3).

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 [15].

[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

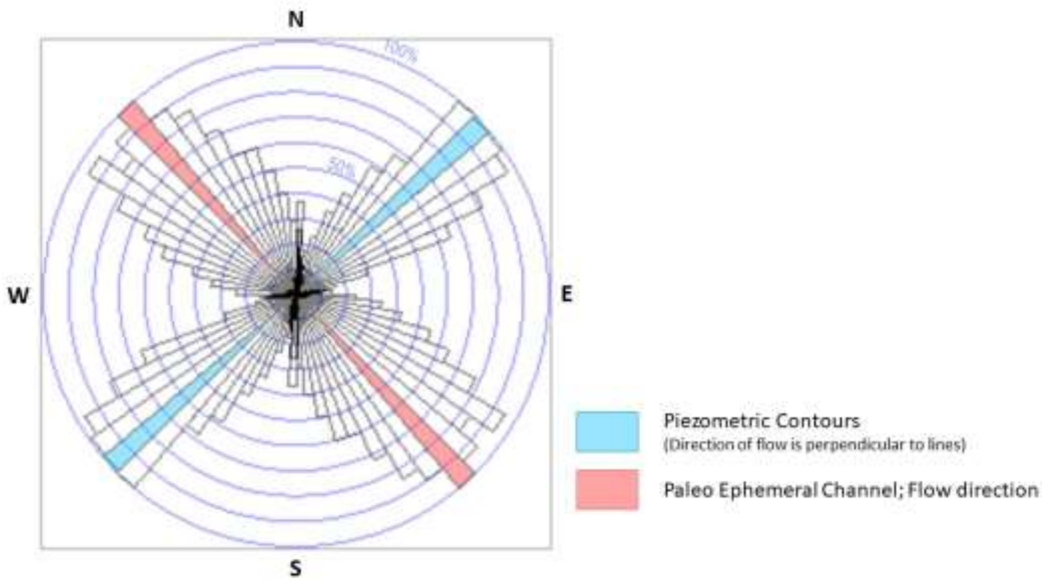


Figure 17 Rose diagram illustrating preferential ephemeral flow direction (red) with 2007 piezometric contours (blue)

These data sets are presented in Figure 18.

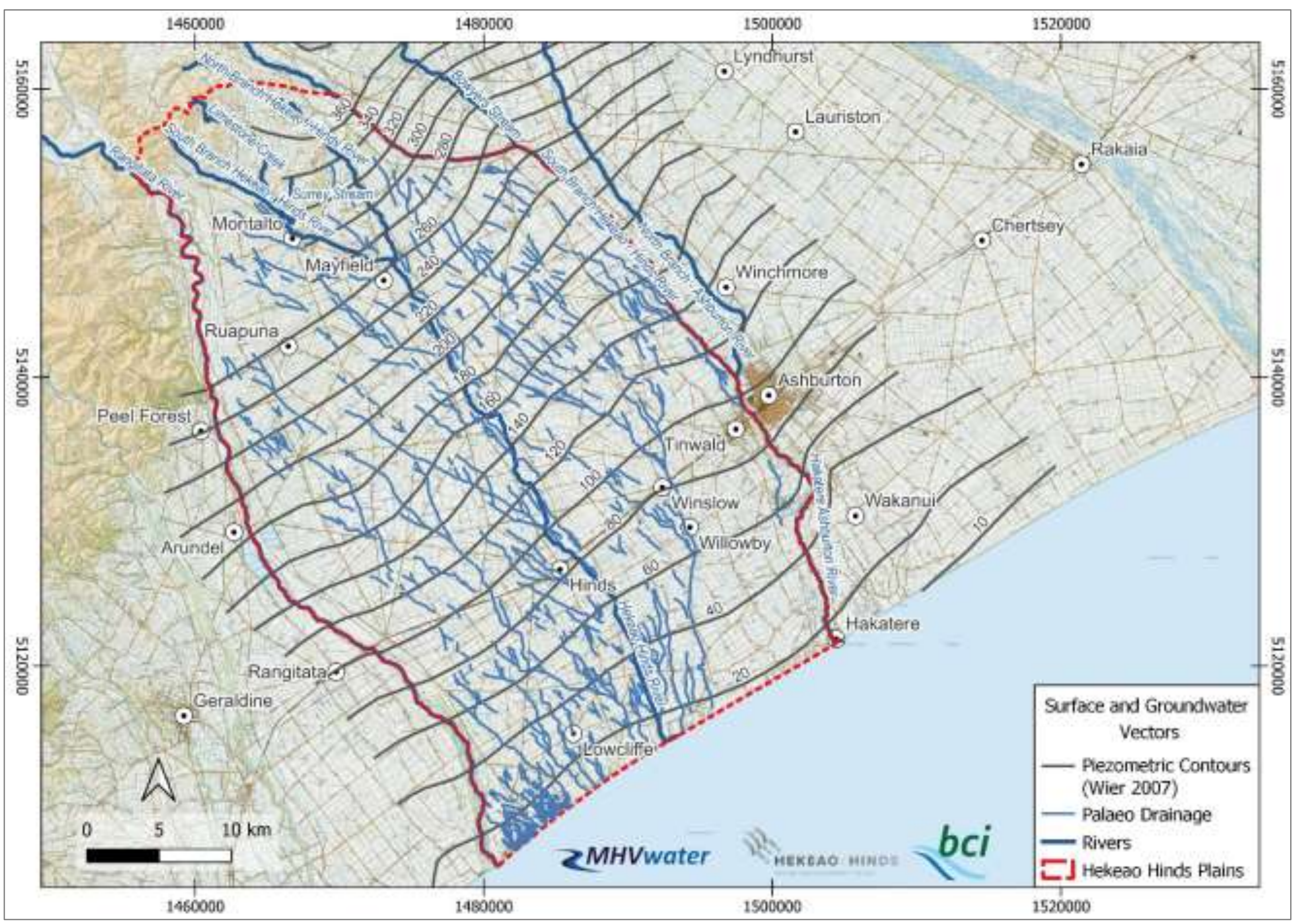


Figure 18 High-level interpretation of the 1m LIDAR digital terrain model (DTM) mapping paleo channels with 2007 Piezometric contours [15]

3.4.3. 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 [14]. 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 [10], [11], [16]. 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 to 7,000 m^2/ day [13].

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 [17]:

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 [13], [16], [18]:

- 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,
- account for approximately 1% of braided river sedimentary systems in the Canterbury Plains.

The gravels within the lenses are characterised as [17], [19]:

- 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)
- 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.

3.5.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 streams / creeks that have been straightened or incorporated into larger extensive drainage and flood protection works [20], [21]. 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 [20], 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.

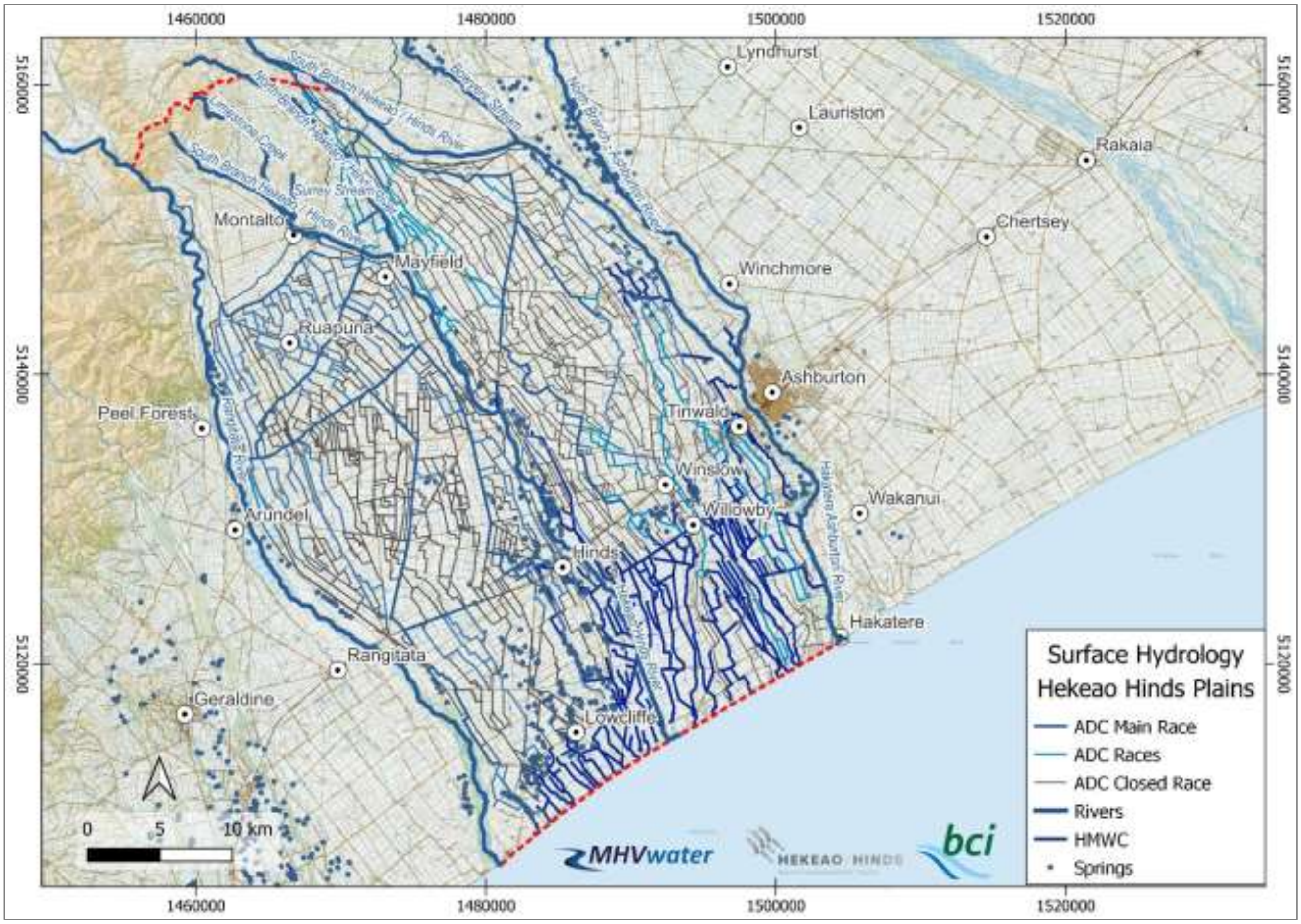


Figure 20 Surface waterways on the Hekeao Hinds Plains

3.6.Nitrate

3.6.1. 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 [12], [13], [22]:

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,
- refuse dumps,
- animal feedlots, and;

Diffuse sources such as:

- Urbanisation and construction,

[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).

- Stormwater runoff and urban drainage,
- Decaying plant debris,
- Agricultural fertilisers, and;
- Land use intensification/change. 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,– either annually or in large pulses at times of land-use change- and/or recharge.

Some of these sources and impacts on groundwater have been quantified in Table 2 [23]

Table 2 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, returned to the atmosphere via *de-nitrification* or is transported as a soluble leachate into the hydrosphere.

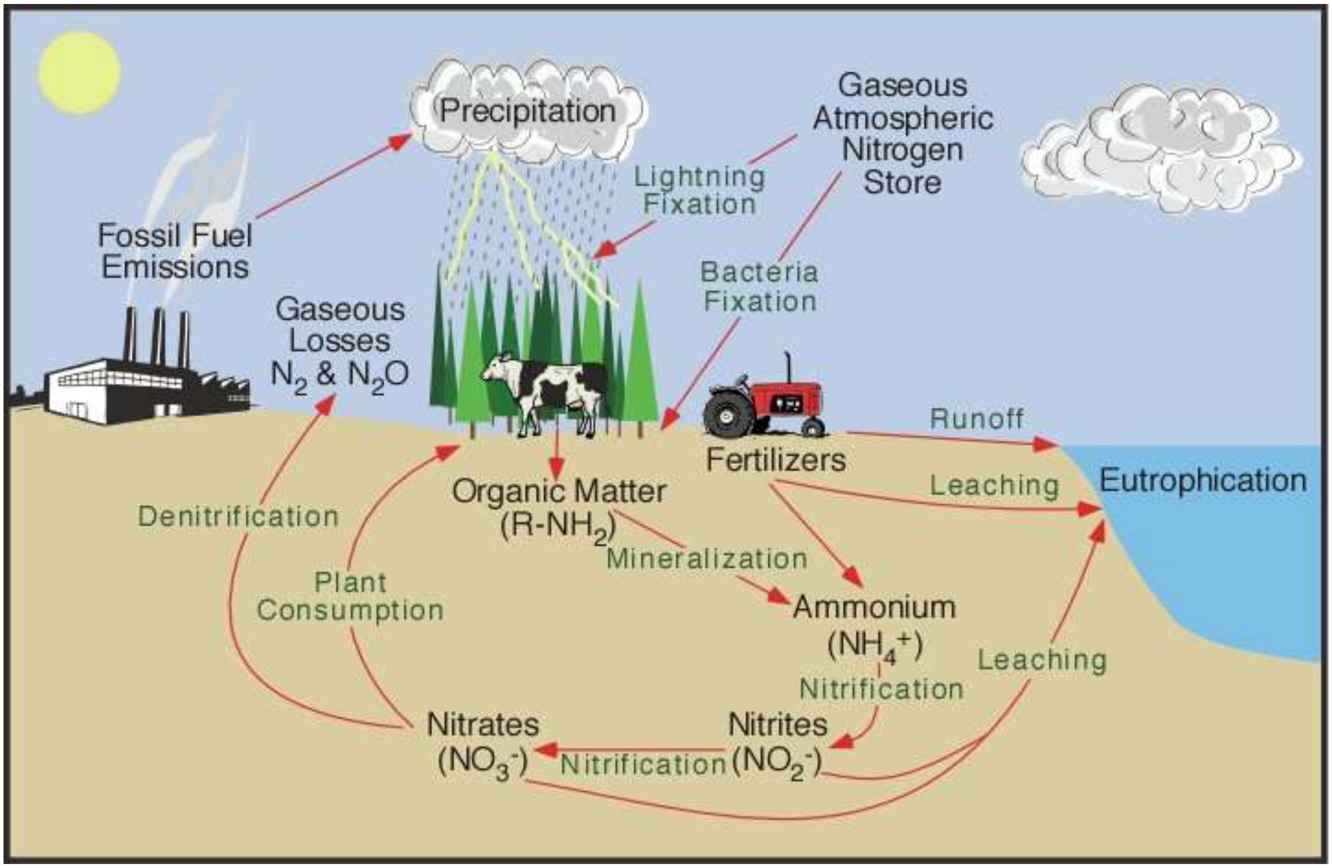


Figure 21 The nitrogen cycle[11]

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.

3.6.2. 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 3.3.1). In summary [12], [13]:

- Higher NO_3-N concentrations were found in the middle and upper parts of the plain 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 over short periods of time.

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

4. Groundwater Sampling Program

4.1.Groundwater Monitoring Program Development

WEQ2016, 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 2022, survey sizes ranged between 141 to 143 bores (Figure 22) representing a spatial footprint of 1070km^2- refer to section 4.3.

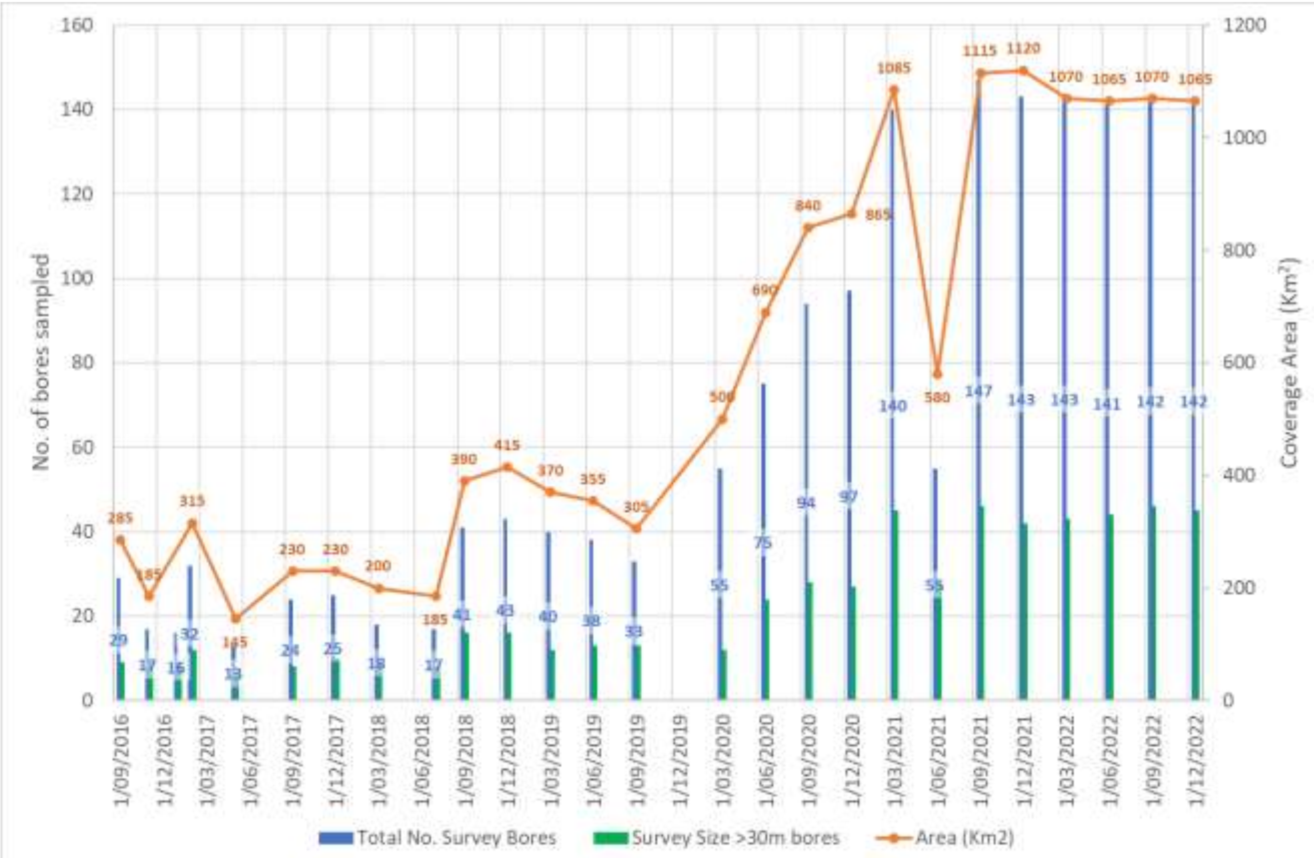


Figure 22 Frequency histogram of survey size changes over time

4.2.Bore Depths and Types

4.2.1. Bore Type

A wide variety of bore types was tested during 2022 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/

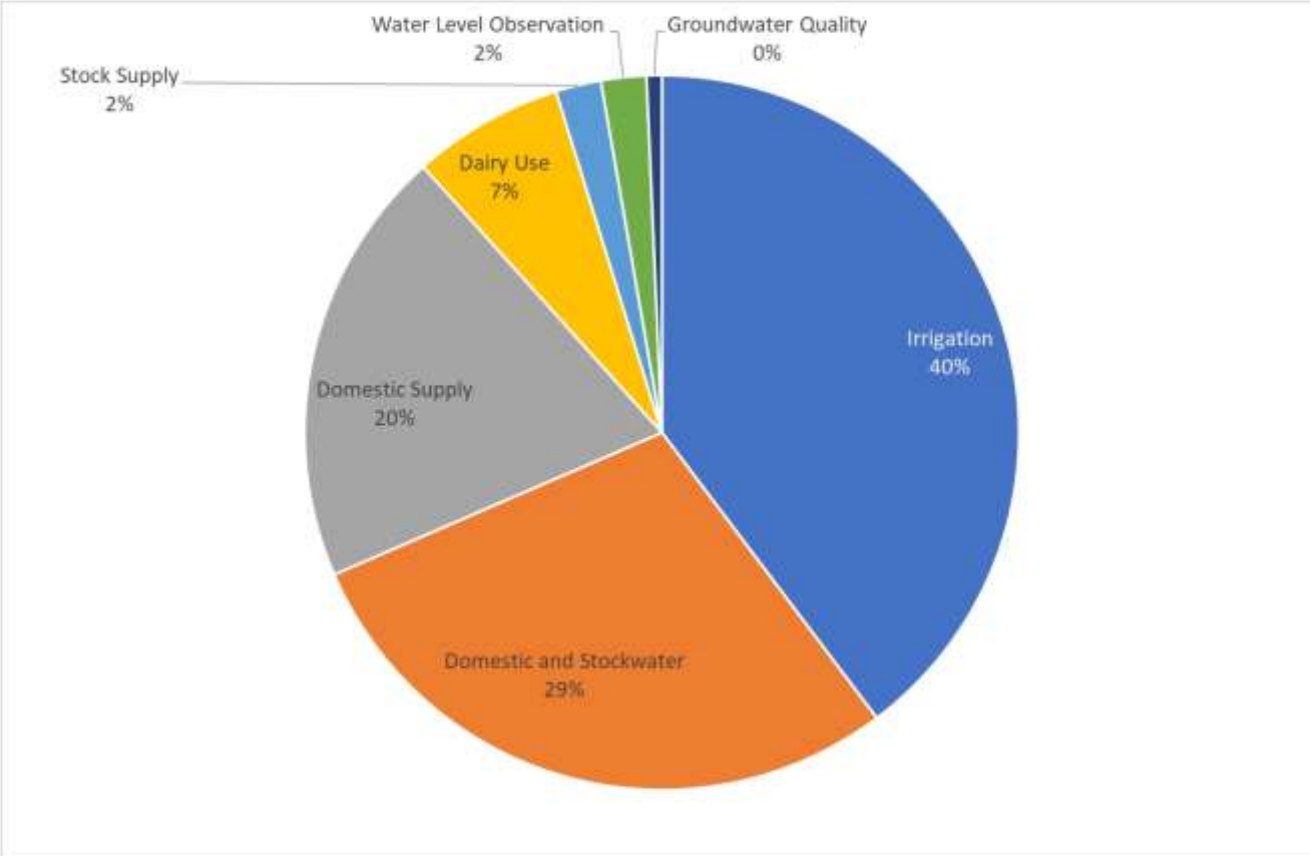


Figure 23 Bore types tested during 2022 as per the ECan database.

4.2.2. 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 2022.

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

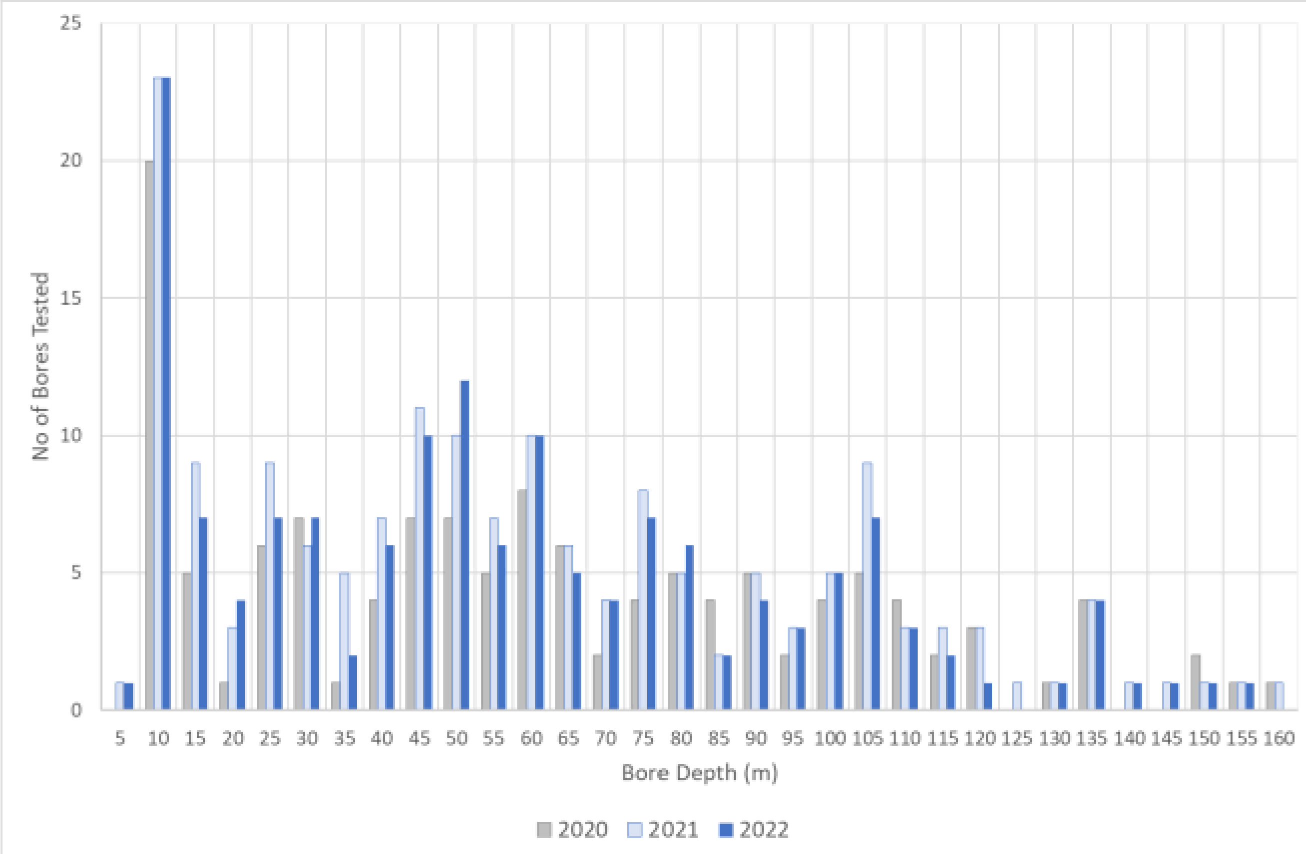


Figure 24 Number of bores tested by bore depth between 2020 and 2022

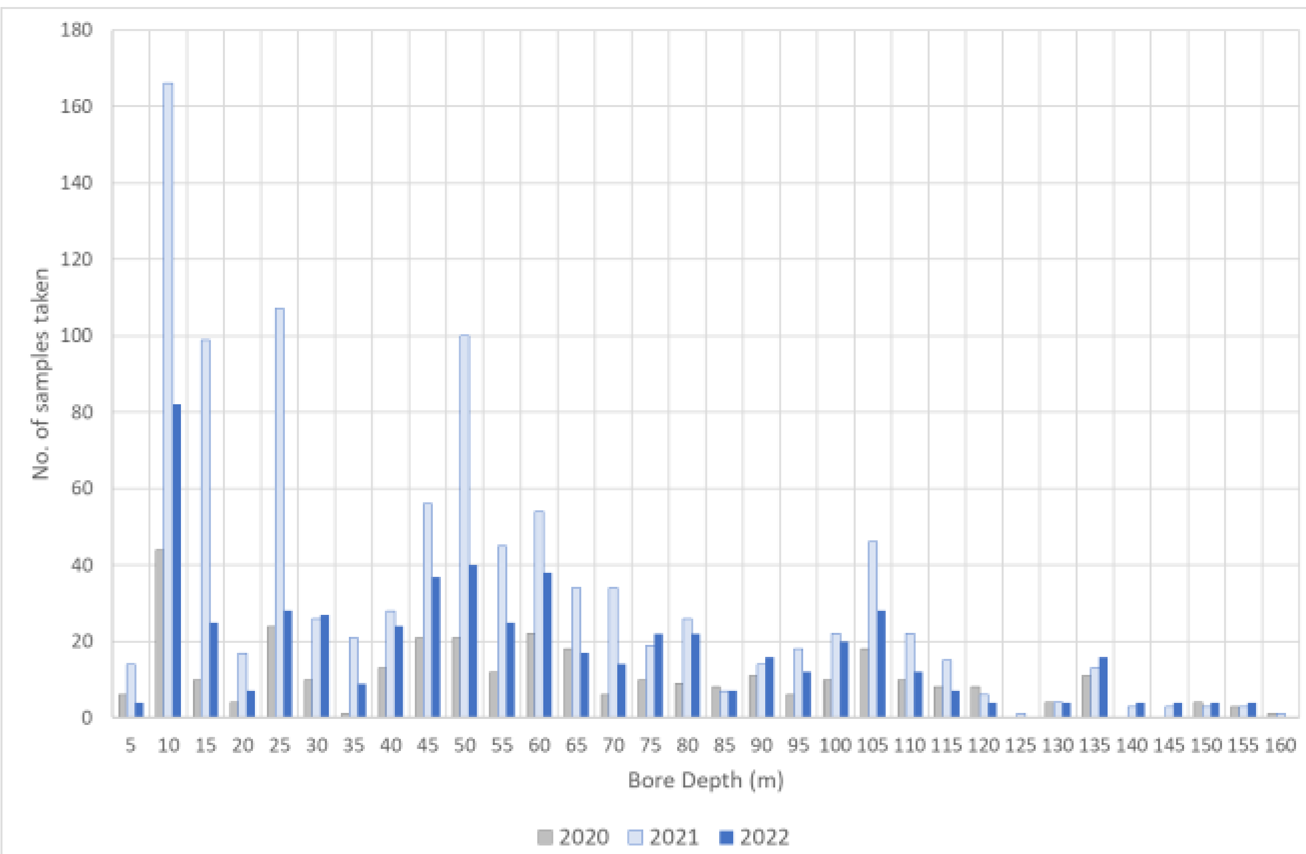


Figure 25 Number of samples collected by bore depth between 2020 and 2022

Table 3 presents a breakdown of bore depth and the number of samples taken during 2022; Figure 26 presents this data as a histogram.

Table 3 Breakdown of bore depth and the number of samples

Month	Bores <30 m	Bores 30 - 80m	Bores > 80m
January	33	22	8
February	25	19	7
March	39	59	35
April	29	21	7
May	32	51	26
June	38	29	15
August	22	28	21
September	20	32	15
November	33	42	30
December	12	20	5
Total	**285**	**326**	**169**

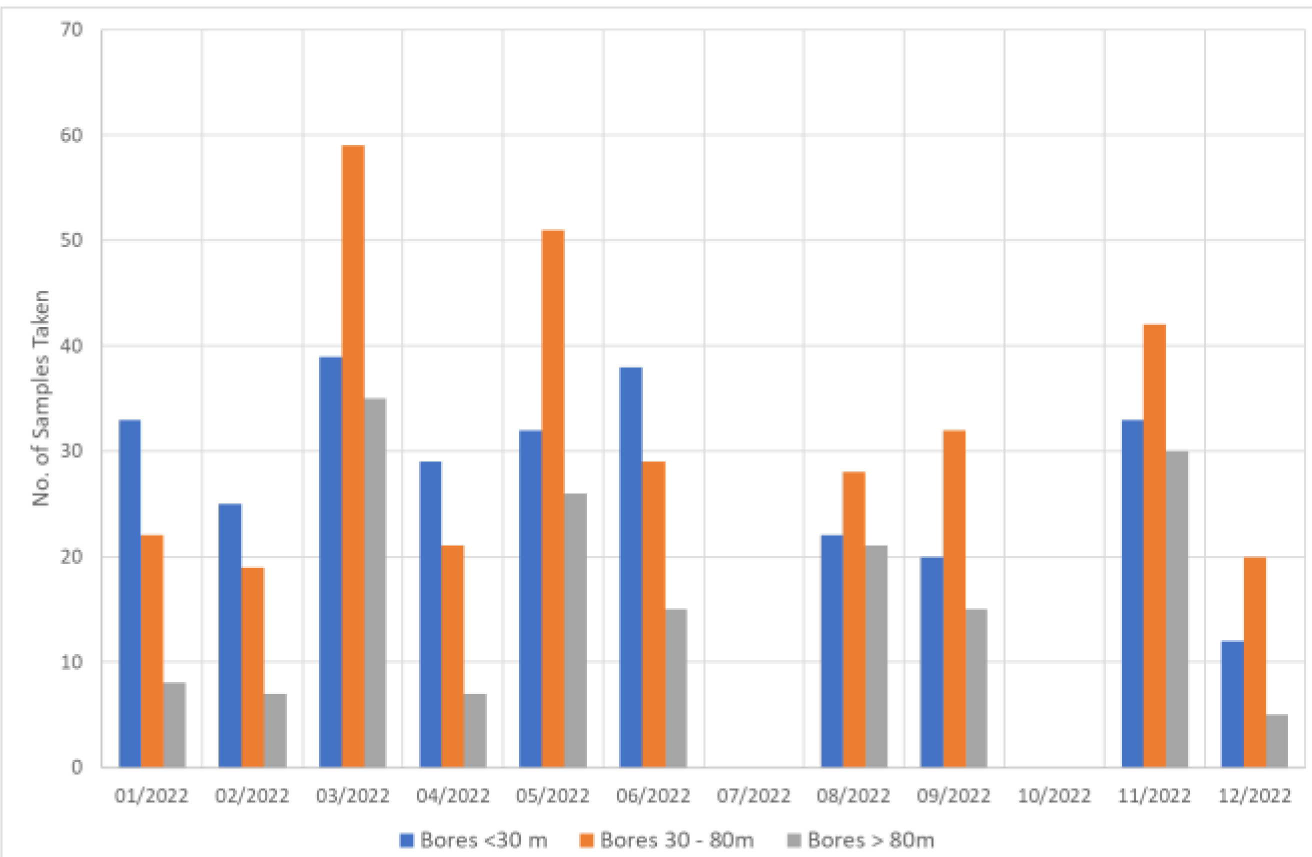


Figure 26 Bore depth and the number of samples taken during 2022

4.3.Survey Spatial Coverage

The current groundwater abstraction guidelines for ECan require a 2 km buffer zone from a bore [24], [25] 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 2022. The average distance between bore sampled in 2022 was 2,225m (range 280m to 6,765m).

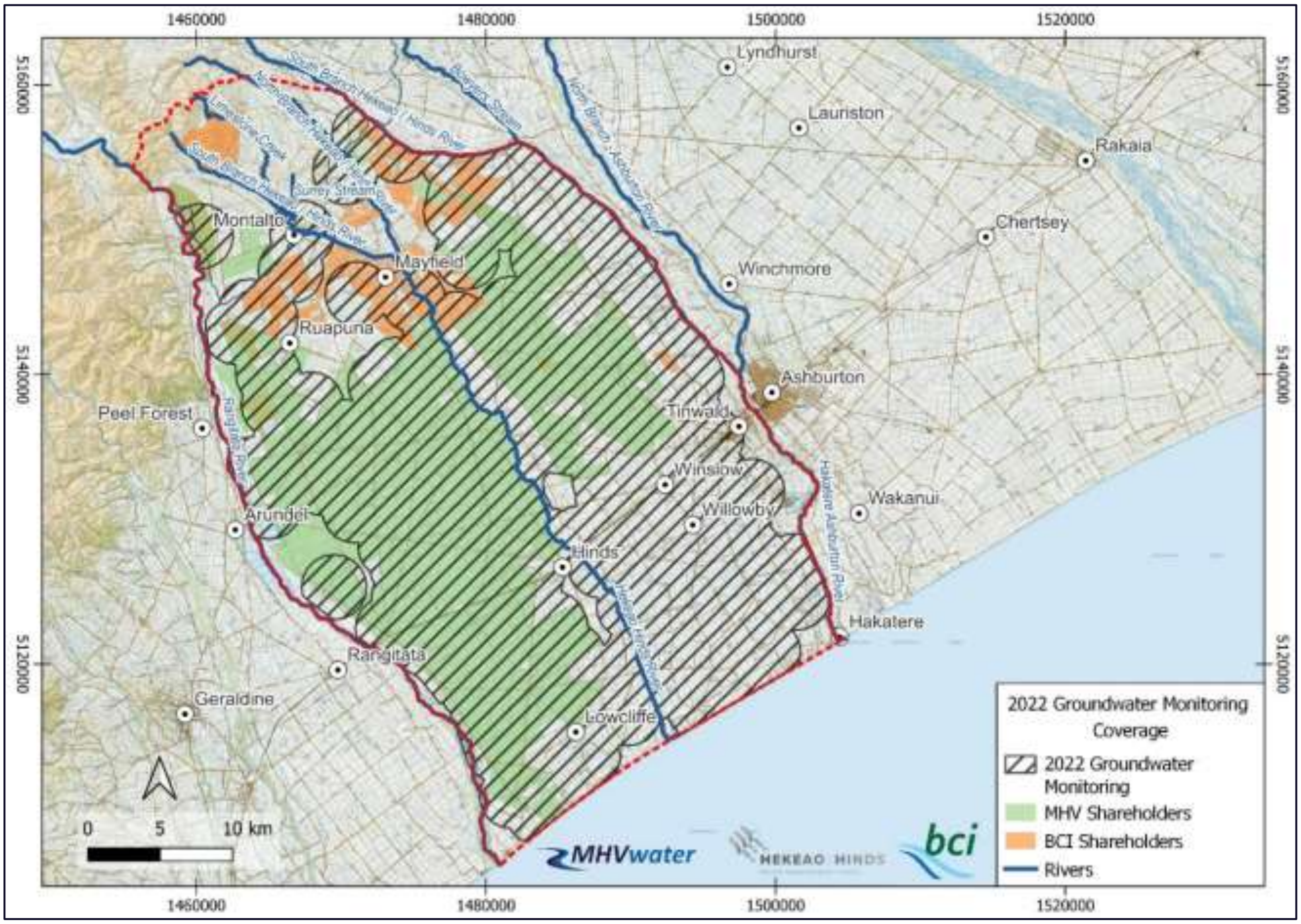


Figure 27 2022 Groundwater survey area

5. Surface Water Sampling Program

5.1.Surface-water Monitoring Program Development

During 2022, MHV sampled between 38 and 55 surface water samples per month (av. 46) from 64 sample locations the majority of which were collected from public road culverts or bridges (Figure 28 & Table 4).

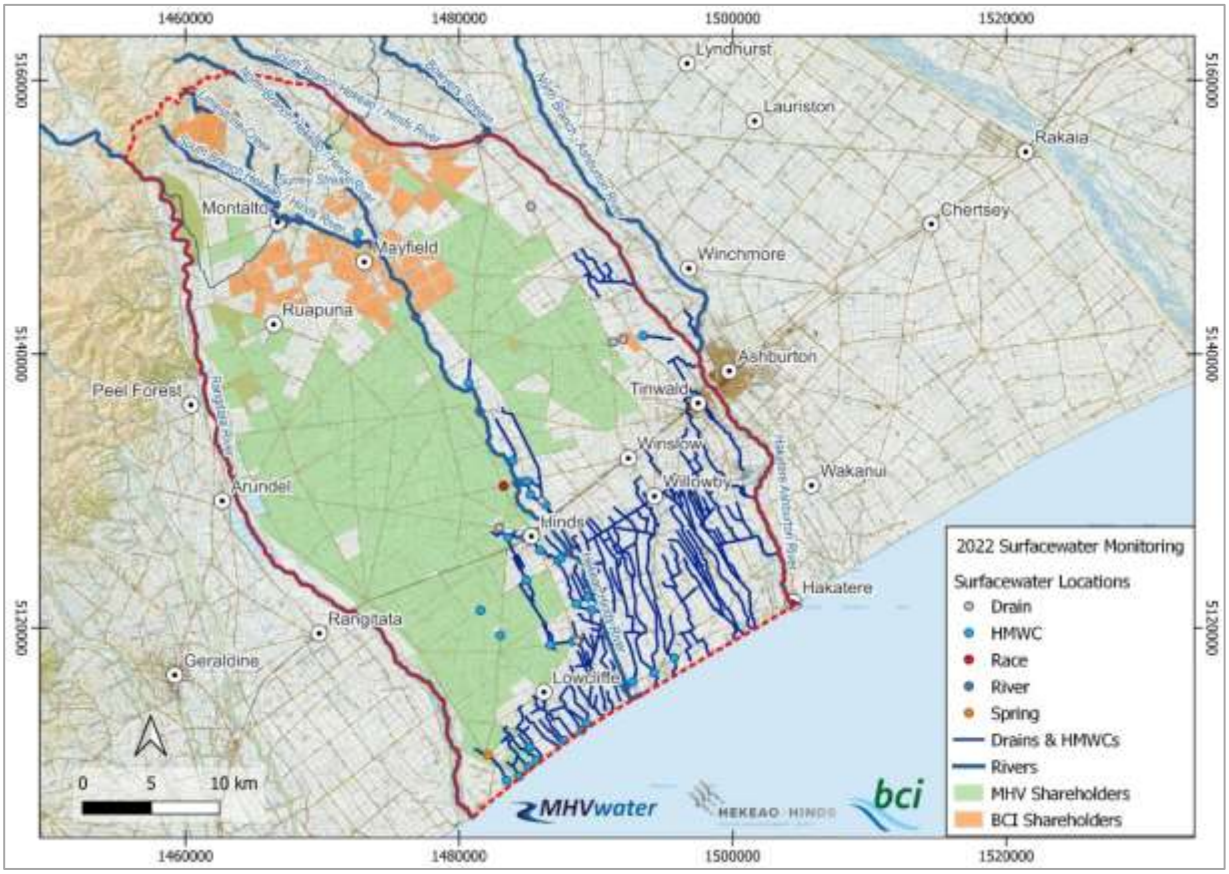


Figure 28 Location of 2022 surface water sampling sites

Table 4 Breakdown of 2022 surface water sampling sites

Location Type	No. of Sites	No of Samples collected
Highly Modified Water Courses (HMWC)	37	292
Drain	7	46
River	15	151
Spring	2	16
Other	3	12
Total	**64**	**517**

Figure 29 presents the evolution of the surface water monitoring program since 2016; Table 5 presents a breakdown of samples collected during 2022.

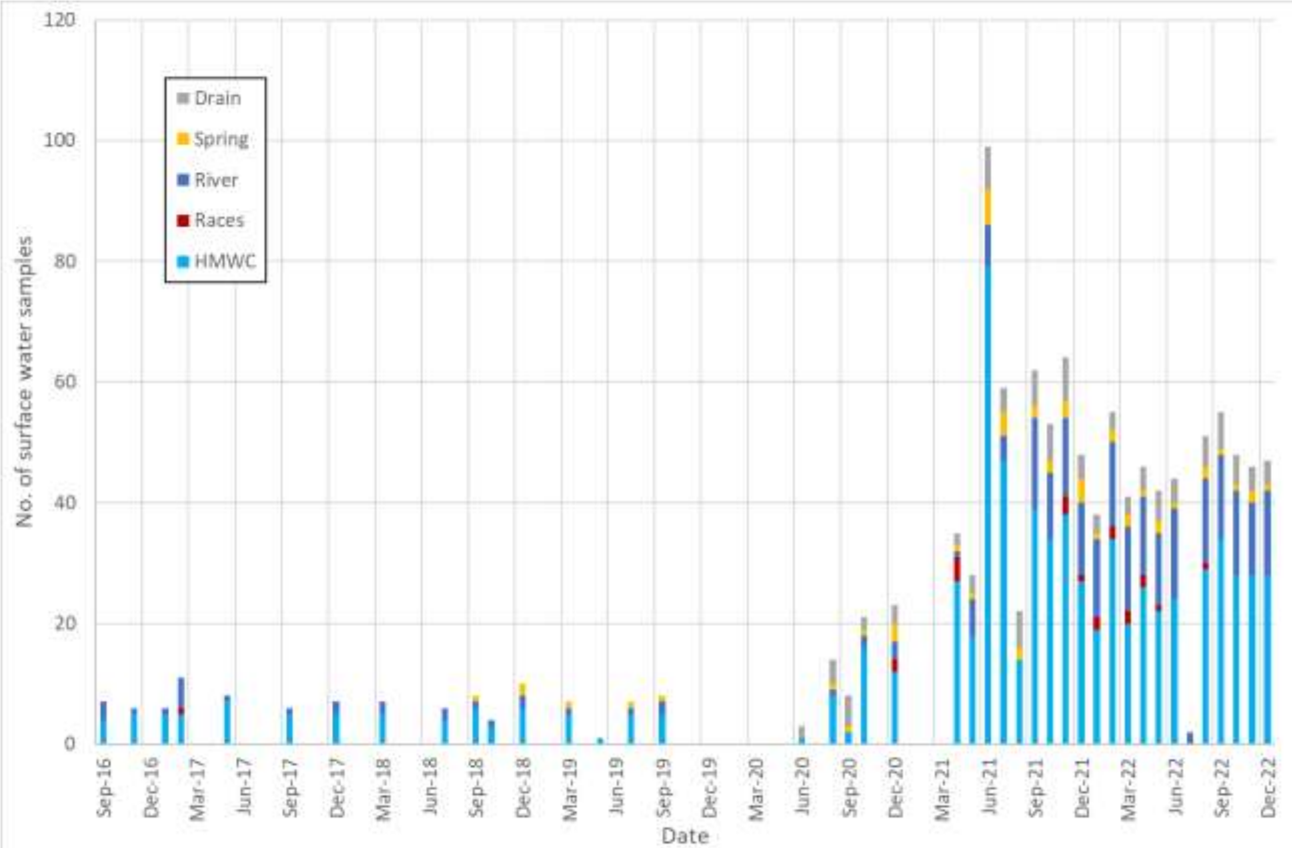


Figure 29 Changes in surface water survey design 2016 - 2021

Table 5 Summary of 2022 surface water sampling program

Month	Drain	HMWC	River	Spring	Other	Grand Total
Jan-22	3	19	13	1	2	**38**
Feb-22	3	34	14	2	2	**55**
Mar-22	3	20	14	2	2	**41**
Apr-22	4	26	13	1	2	**46**
May-22	5	22	12	2	1	**42**
Jun-22	4	24	15	1		**44**
Jul-22			2			**2**
Aug-22	5	29	14	2	1	**51**
Sep-22	6	34	14	1		**55**
Oct-22	5	28	14	1	1	**49**
Nov-22	4	28	12	2	1	**47**
Dec-22	4	28	14	1		**47**
Total	**46**	**292**	**151**	**16**	**10**	**517**

6. 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.

6.1.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 2022 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.

Approximately 10% of the samples were analysed at Hill Laboratories (Hornby) 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) so as to:

i. 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.

ii. The results presented in Figure 32 indicate a correlation co-efficient (R2) of 0.98 for both 2020 and 2021 data (Table 6), with a slight bias of +7% from the Hill Laboratories results (range -8% to +15%): that is, the sensor was slightly under-estimating the NO_3-N concentrations relative to the samples analysed by Hill Laboratories. This provides confidence that the sensor results adequately measures NO_3-N, when compared to accredited laboratory results.

The locations and depths of the cross-checked samples are shown in Figure 30.

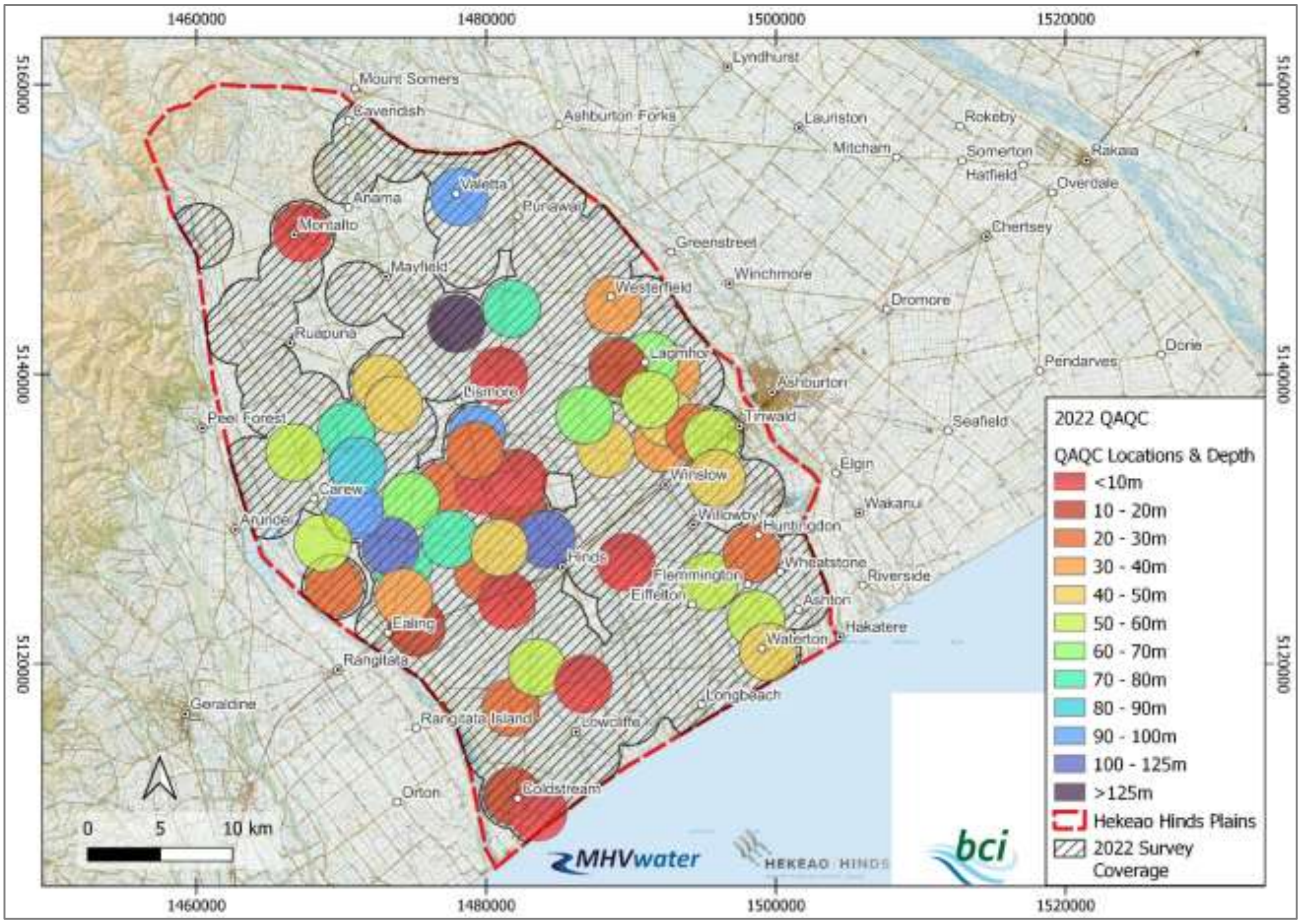


Figure 30 Locations of samples tested for QAQC purposes

The previous 2020 and 2021 reports stated there was a bias of +7% in the results towards the GW50, consistent with these results. This difference is attributed to differences in analytical techniques as Hill Laboratory uses an Automated Azo dye colorimetry[14], whereas the GW50 utilises an optical sensor[15].

Note **It should be noted that this bias is within the ± 12% tolerance that is accepted by Hill Laboratories and is not considered to affect the results or conclusions of this work.**

[14] A technique whereby a specific dye is added to a sample, with the colour change corelating to a NO_3-N concentration.

[15] A pulse of light from a Xenon flash passes through the water sample – the amount of UV light that is absorbed is correlated to a NO_3-N concentration.

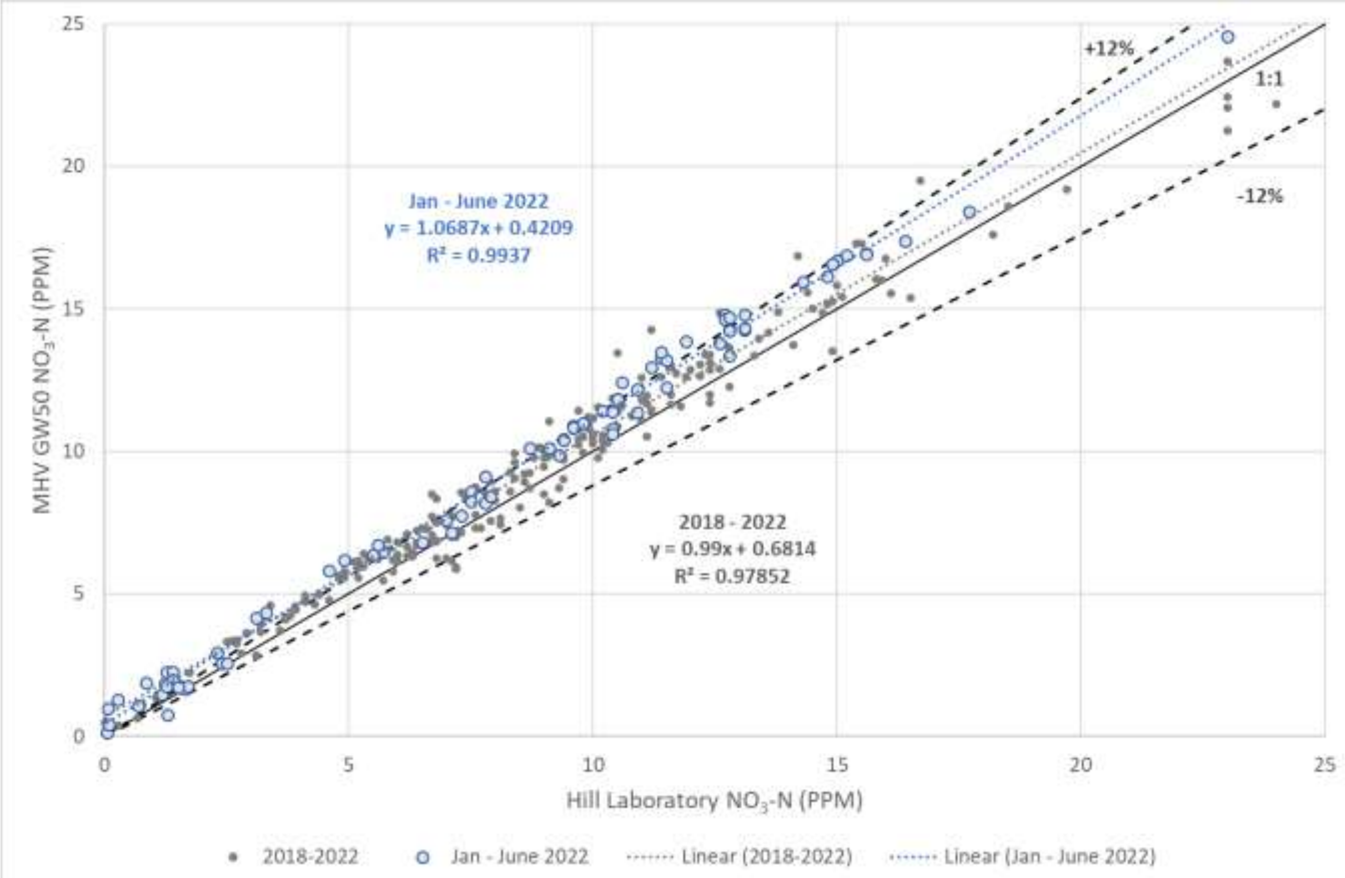


Figure 31 Scatter plot of March – June 2022 with preceding MHV GW50 results to Hill Laboratory Data

In June 2022 MHV's GW50 optical probe was sent to Hydrometrics for routine servicing and calibration. In addition to testing the GW50 against known standard solutions, the analytical software was updated, and the optics re-aligned.

After the calibration, the + 7% bias had become inverted to a - 11% bias, but with improved precision (repeatability). Whilst the post calibration results to date are within the ±12% accepted variance there was a total difference of 18-20% between consecutive readings as shown in Figure 32.

Subsequently, both the pre and post calibration data was normalised against the Hill Laboratories data (a total of 342 samples from March 2018 to Dec 2022) and a regression factor applied (see Appendix 5 for charts).

As shown in Table 6, the regression between the GW50 and the Hill Laboratories results is above R2>0.97 for both the pre and post calibration data, so the normalisation and subsequent regression factor is considered robust Figure 33 illustrates the regression applied.

Table 6 Regression co-efficient between GW50 and Hill Laboratory data between 2020 and 2022

Year	No of samples	Regression	R^2
2020	156	y = 1.0157x - 0.4946	0.983
2021	86	y = 1.001x - 0.615	0.975
Jan – June 2022 (Pre-Calibration data)	80	y = 1.0687x + 0.4209	0.994
August - December 2022 (Post Calibration data)	130	y = 0.9304x - 0.2979	0.992
Adjusted 2022 Data	210	y = 0.9978x	0.998

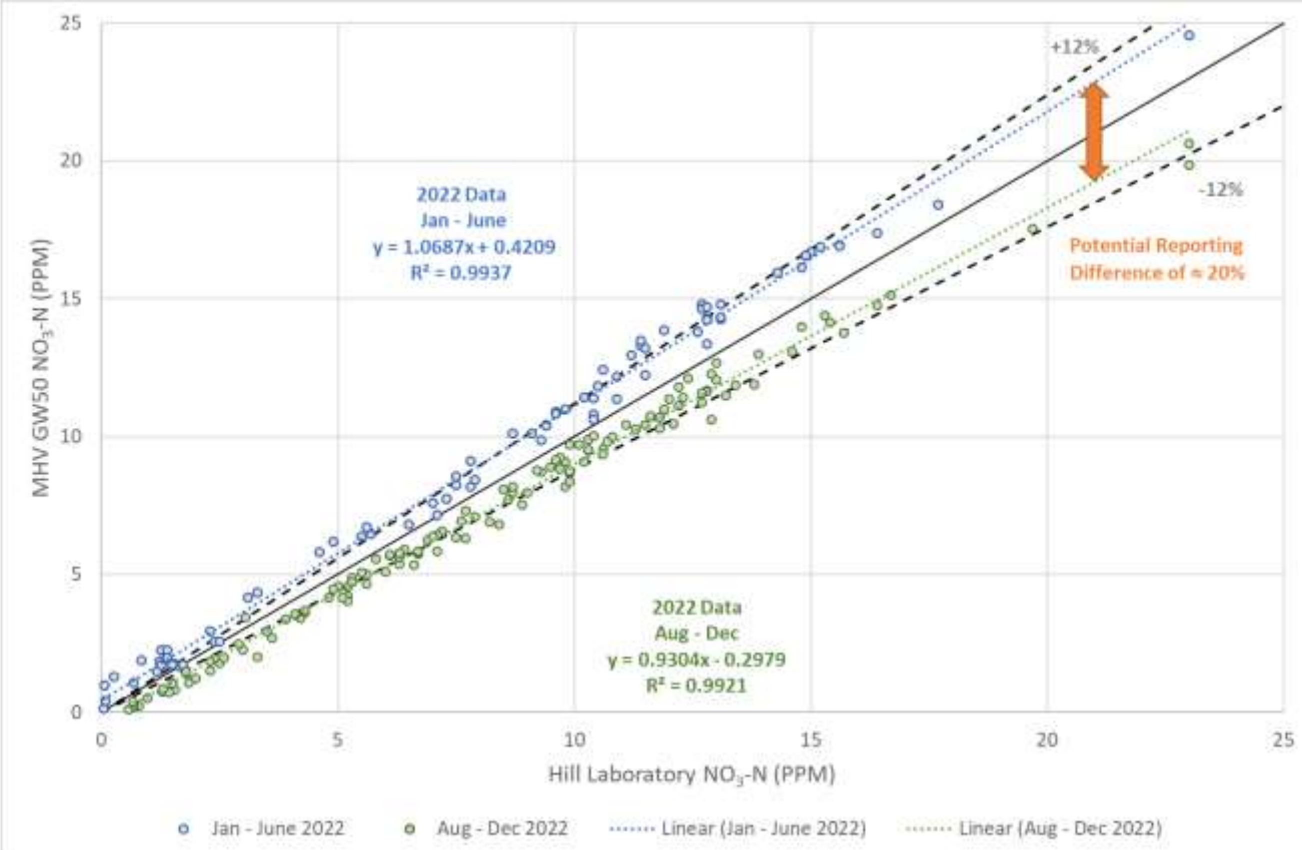


Figure 32 Scatter plot of inhouse NO_3-N results compared to Hill Laboratories results

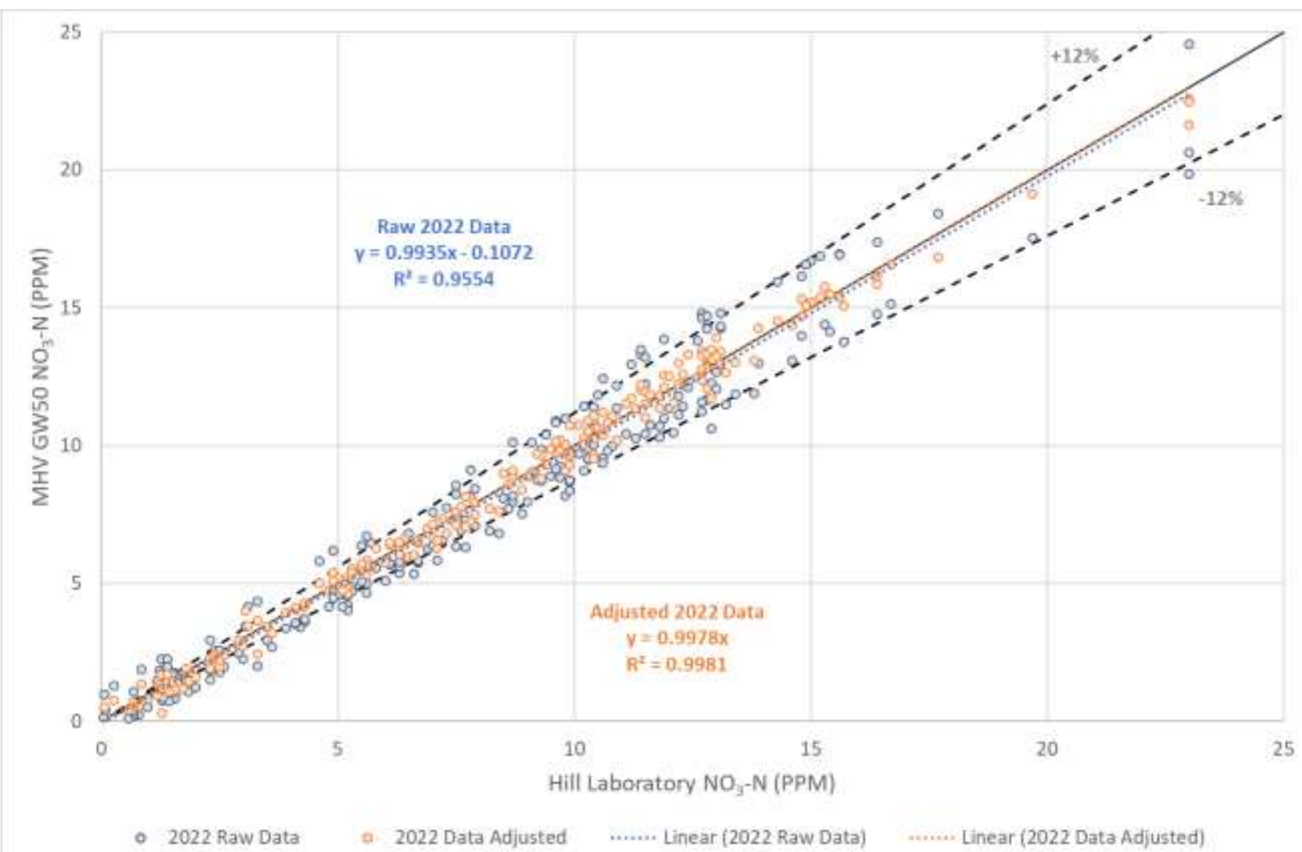


Figure 33 Scatter plot of inhouse NO_3-N results compared to Hill Laboratories Results with regression factor applied

7. Groundwater Monitoring Results

7.1. Annualised groundwater NO_3-N results

A summary of the descriptive statistics for the 2022 results is presented in Table 7 and as a frequency histogram in Figure 34 (refer to Appendix 7 for tabulated results).

Table 7 Descriptive statistics for the 2022 NO_3-N results

Bore Depth	Count	Min	Max	Range	Median	Average	Std. Dev	CV
<30 m	283	0.11	20.45	20.34	9.52	10.21	4.16	0.44
30-80 m	322	0.14	25.30	25.16	9.31	9.53	4.36	0.47
>80 m	169	1.50	14.35	12.85	6.50	6.29	2.86	0.44
All Bores	774	0.11	25.30	25.19	8.77	9.05	4.18	0.48

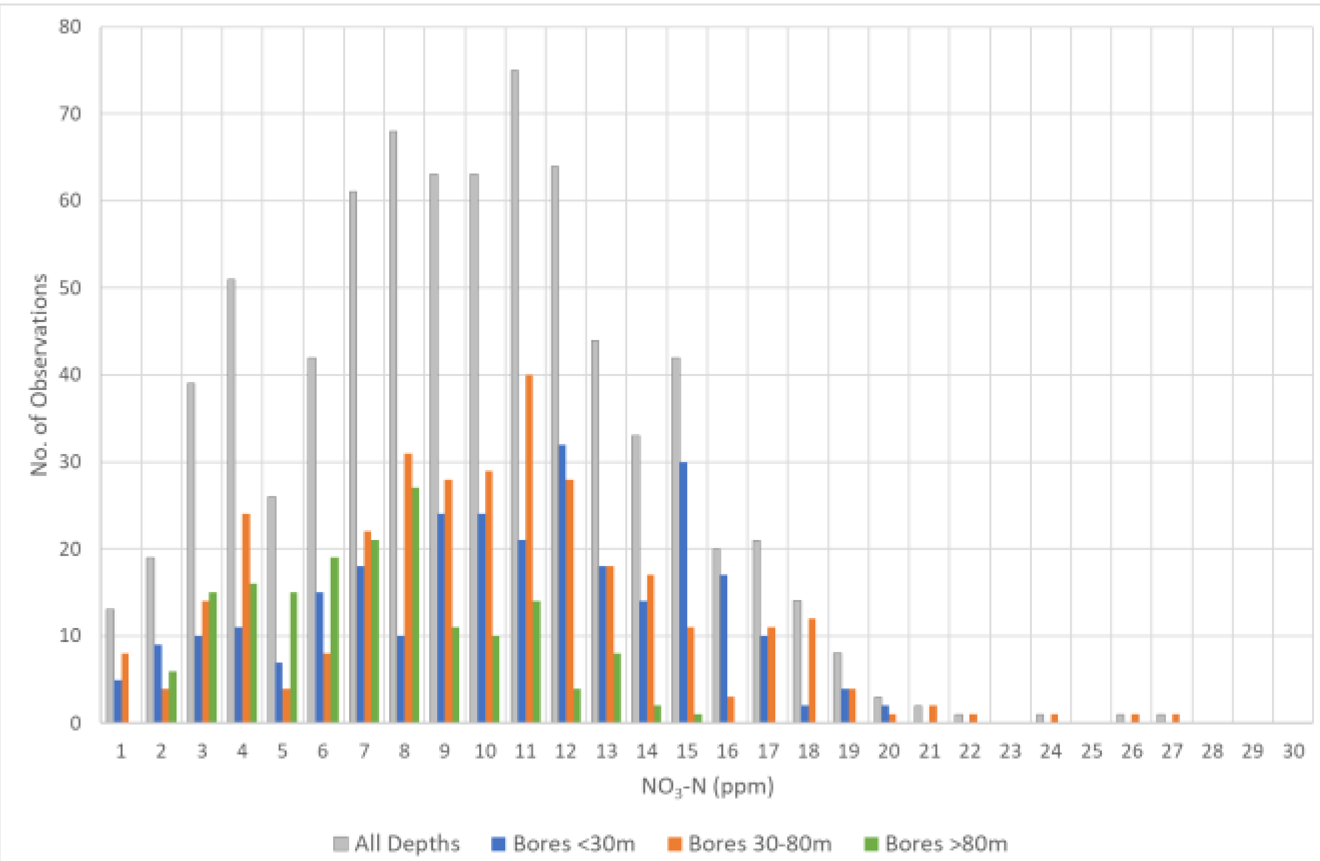


Figure 34 Frequency histogram for the 2022 NO_3-N results

7.2.Post 2021 Rain Event Results

At the end of May 2021, Canterbury experienced a 0.005% Annual Exceedance Probability (AEP)[16] rain event, with an Average Recurrence Interval (ARI) of 1:200 years [27] (see Appendix 6 for rainfall station locations).

Immediately following this event, MHV immediately began a more temporally intensive groundwater monitoring programme consisting of 56 bores (representing an area of 58,230 ha) on a weekly basis between June and July (Figure 35). This was extended to a fortnightly basis until the COVID19 lockdown in August. Following the lockdown, sampling was decreased to monthly, continuing until June 2022 – refer to the 2021 Annual Report for details.

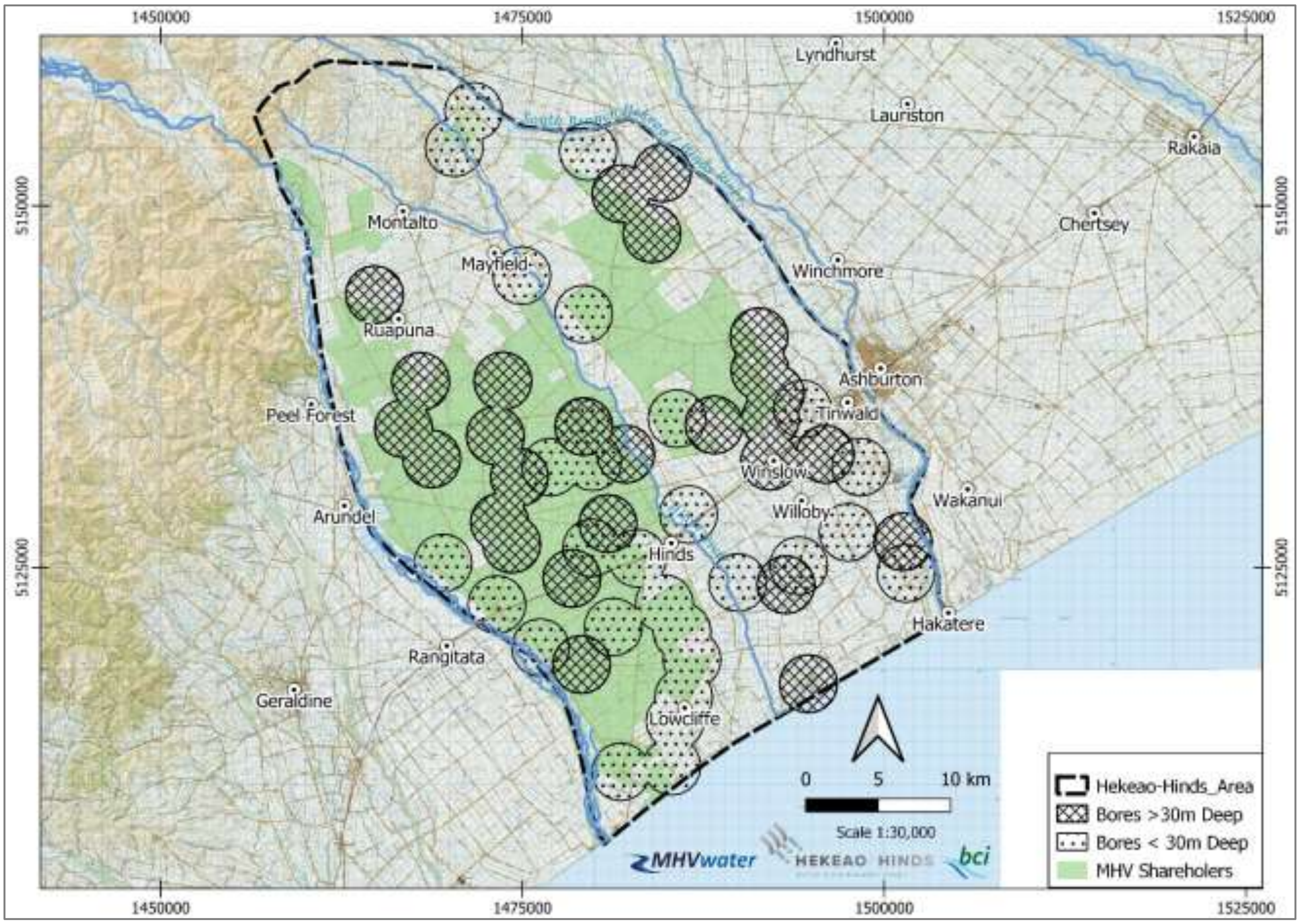


Figure 35 Spatial footprint of post rain event groundwater survey

Figure 36 presents the results to date, indicating that sustained rainfall and river flow in June and December 2022 has arrested the decline of NO_3-N in the selected bores – refer to Appendix 7 for tabulated data.

[16] The terms AEP (Annual Exceedance Probability) and ARI (Average Recurrence Interval) describe the probability of a flow of a certain size occurring in any river or stream. ARI is the average time period between floods of a certain size (i.e., a 100-year ARI flow will occur on average once every 100 years). Alternatively, AEP is the probability of a certain size of flood flow occurring in a single year. A 1% AEP flood flow has a 1%, or 1-in-100 chance of occurring in any one year, and a 10% chance of occurring in any 10-year period. Therefore, the 100-year ARI flow and 1% AEP flow are different terms to describe a flow of the same size in any given river

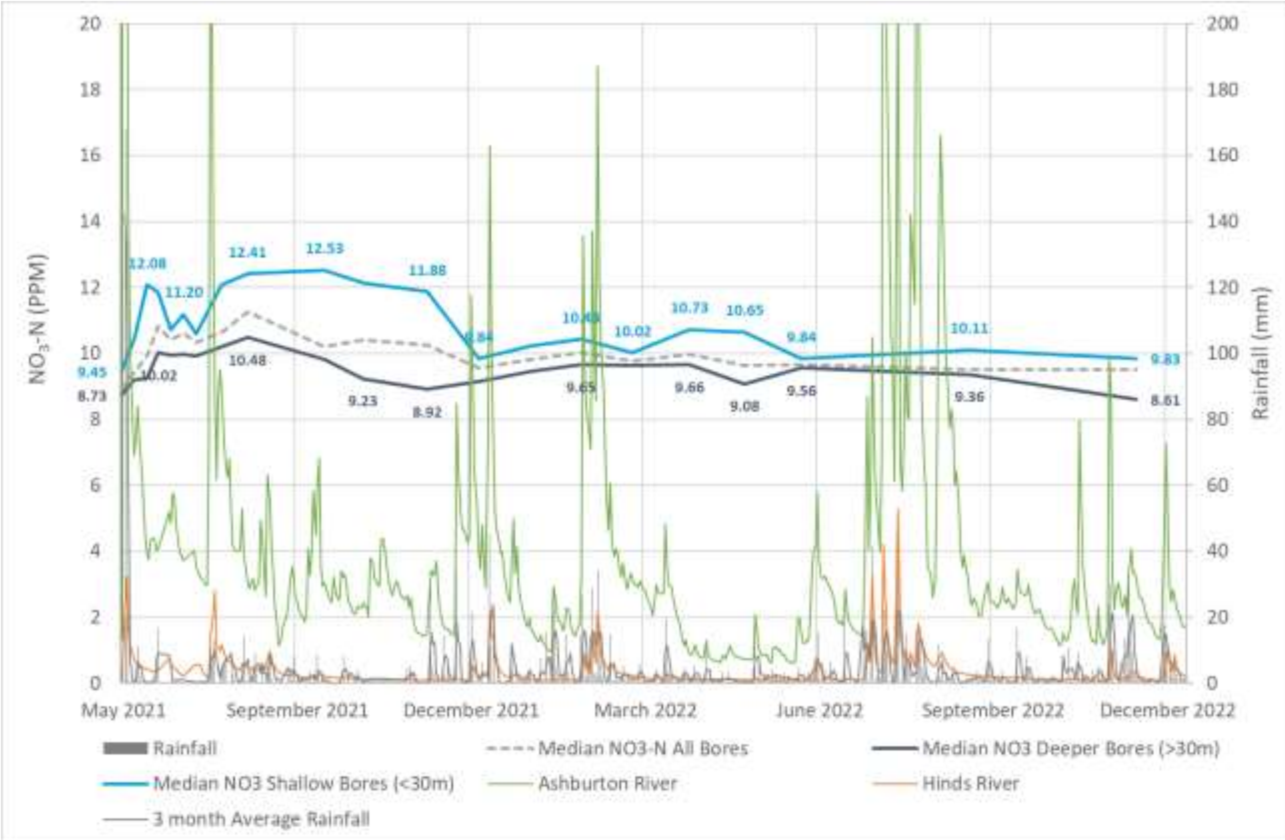


Figure 36 Median NO_3-N results for the 56 bores tested frequently after the May-June Rain event of 2021 with river & Rainfall data

7.3.Groundwater Levels

MHV collected 303 Standing Water Levels[17] readings from 71 bores across the Hekeao Hinds Plains during the year (Figure 37). Table 8 presents a summary of the results.

[17] ***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.

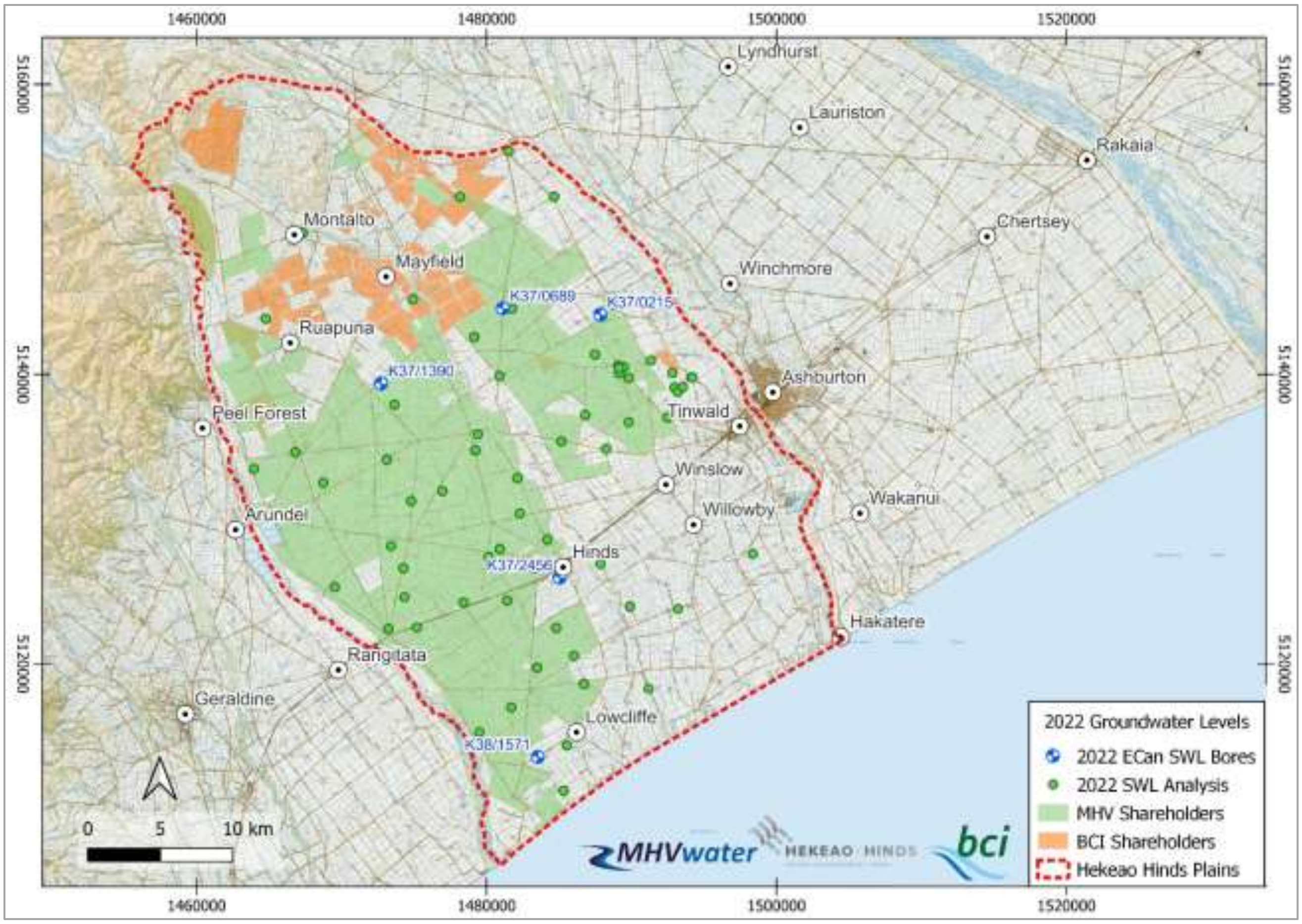


Figure 37 Locations of MHV & ECan groundwater level monitoring bores

Table 8 Summary statistics of groundwater level soundings collected by MHV

Month	No. of readings	Minimum	Maximum	Range	Average	Median
Jan	16	1.500	49.650	48.150	20.378	
Feb	22	1.200	45.050	43.850	18.158	
Mar	43	1.090	64.900	63.810	16.402	**11.975**
Apr	35	1.100	36.750	35.650	12.156	
May	35	1.230	51.900	50.670	17.777	
Jun	39	1.140	62.290	61.150	14.329	**13.485**
Jul	2	2.385	2.620	0.235	2.503	
Aug	8	1.500	69.650	68.150	19.550	
Sep	44	1.040	58.960	57.920	15.650	**11.083**
Oct	2	2.360	2.690	0.330	2.525	
Nov	31	1.290	63.300	62.010	17.058	
Dec	21	2.365	59.900	57.535	15.530	**12.760**

Groundwater levels are generally at their highest in the winter months in response to winter recharge rainfall and the absence of abstraction. Figure 38 presents MHV observations for 2020 – 2022 whilst Figure 39 presents ECan data from 2015 to 2022. 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.

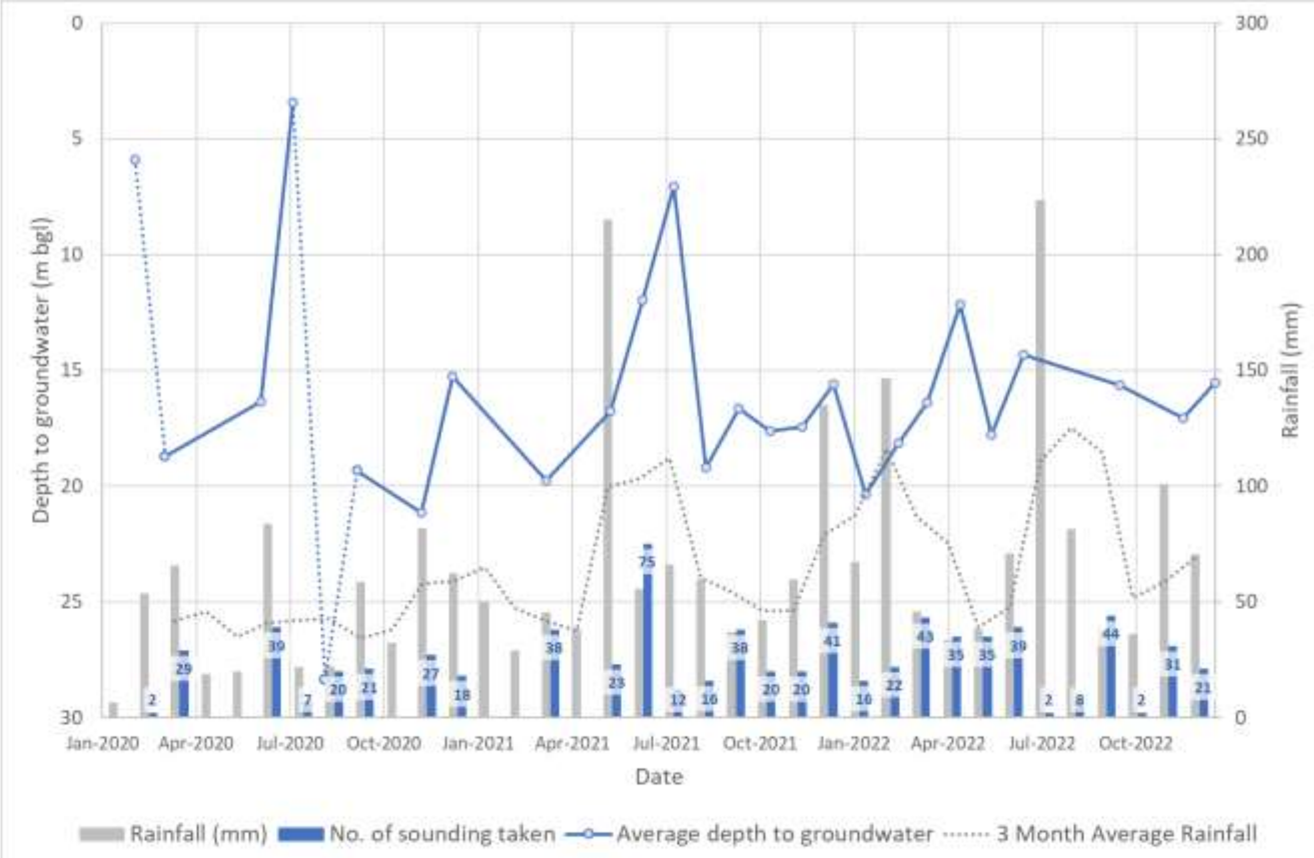


Figure 38 Average groundwater level data for the Hekeao Hinds Plains for 2022 with corresponding rainfall

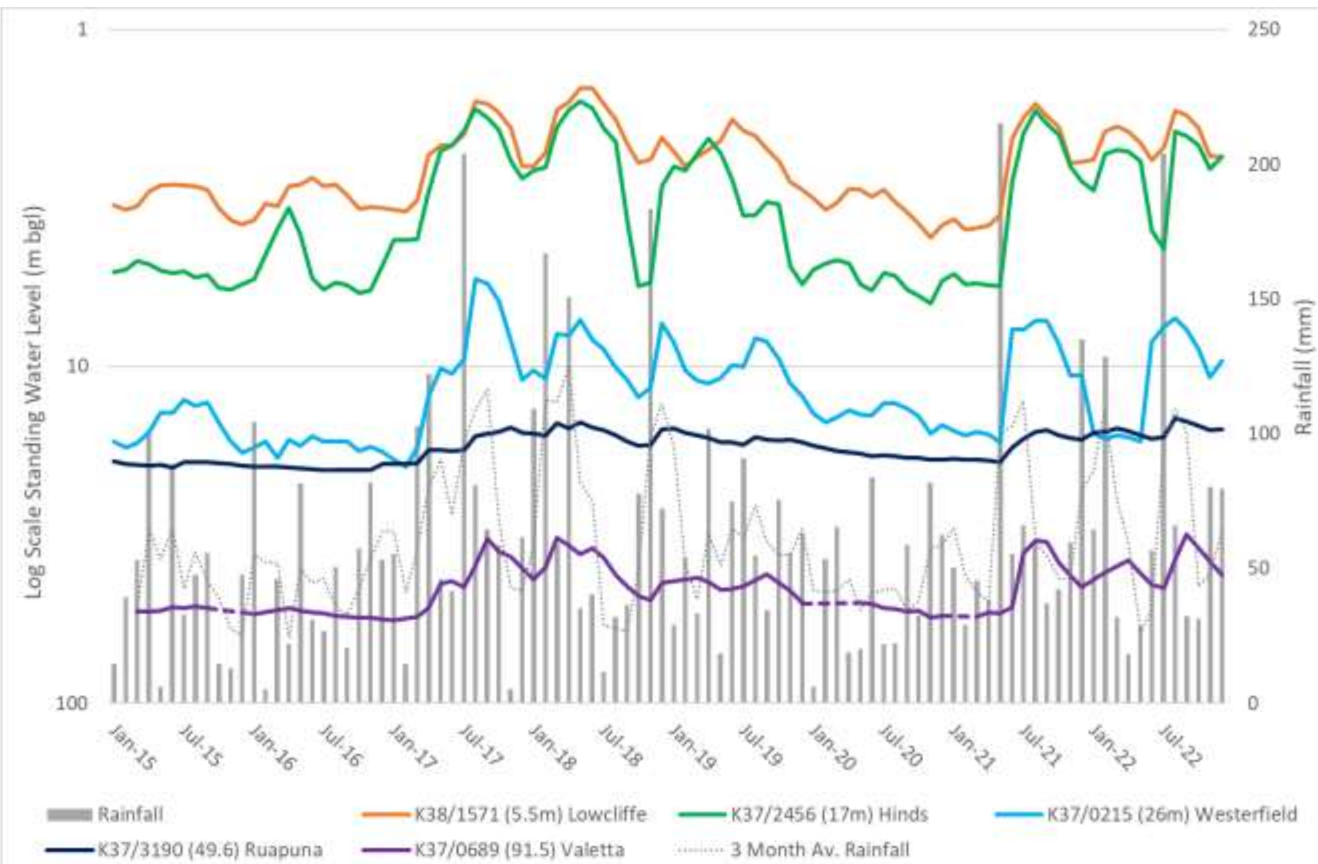


Figure 39 Hydrographs from ECan bores across the Hekeao Hinds Plains with rainfall 2015 to 2022.

SWL data was interpolated in QGIS© software via an Inverse Distance Squared (ID2)[18] method for the September 2020, 2021, and 2022 surveys. The resultant interpolations were then compared to each other to provide an indication of the relative changes in SWL between successive years in a spatial context. The results presented in Figure 40 indicate that SWL's increased dramatically in some areas, specifically the upper catchment, between September 2020 and September 2021, and then progressively decreased from Ruapuna to Winslow. The following years showed a general decrease in levels, though parts of the upper catchment showed still more increase.

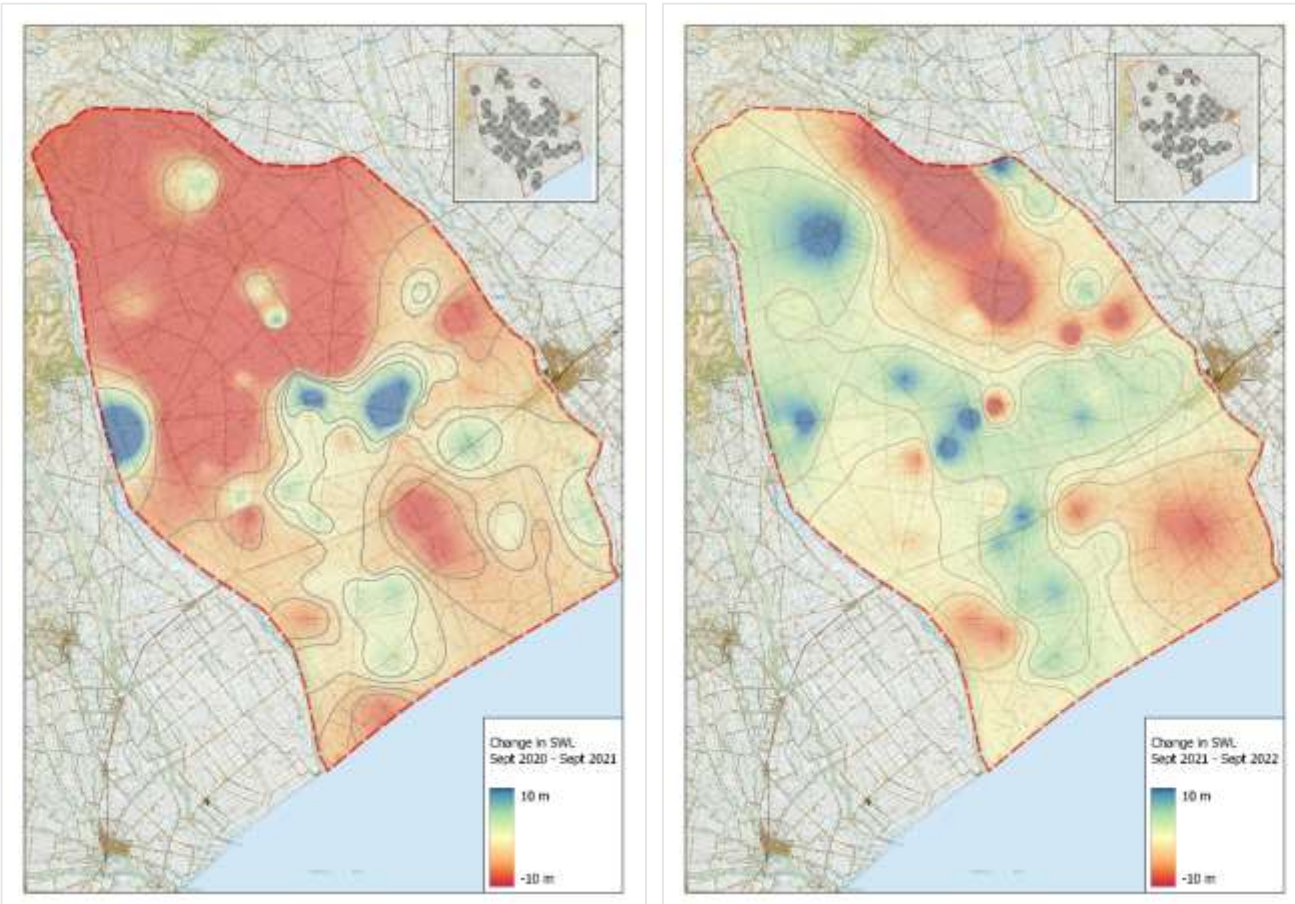


Figure 40 Relative changes in SWL from 2020-2021 (left) & 2021-2022 (right). Warm colours indicate water level was lower in the preceding year – i.e., SWL's increased between the years

[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.

8. Surface Water Results

8.1.Disclaimer

The 2022 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 41.

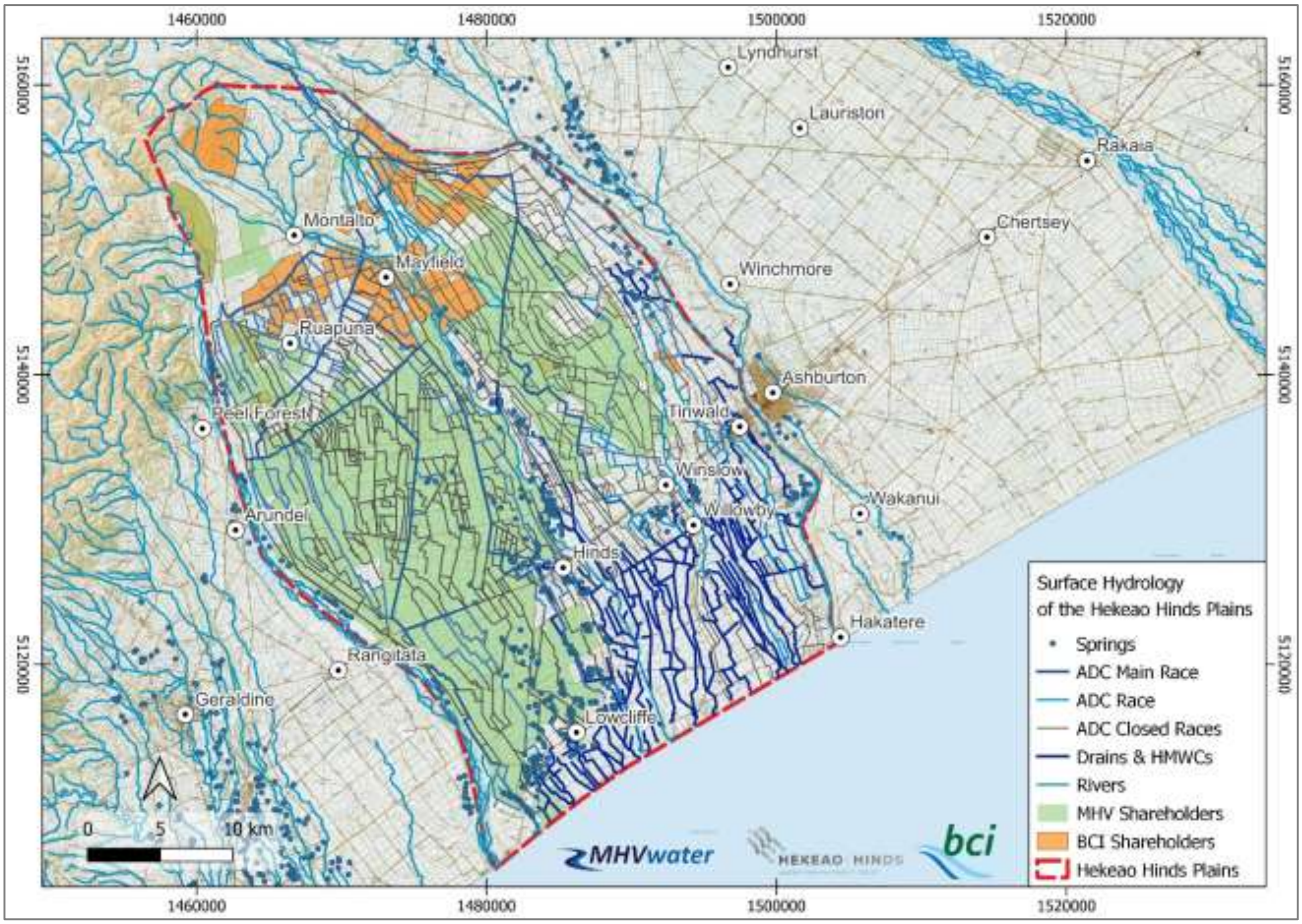


Figure 41 A map of known intersections between farm drains, council stock water races and highly modified waterways

Under normal conditions, water in the HMWC's may be derived from:

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

Additionally, the Hekeao Hinds Plains received significant rainfall (>175 mm) through June 2021 and July 2022, and then high rainfall (>100 mm) through December 2021, February 2022, and November 2022.

The high rainfall and increased groundwater levels are likely to have increase the contribution from sources such as septic tanks and leaky sewers, urban impermeable surfaces, waste pits and landfill, and agricultural land.

Sample locations categorised as springs were, likely as not, flowing streams at the time of sampling, subsequently the results obtained may not accurately reflect the true NO_3-N concentration of the spring water due to inundation from surface water

Therefore, the surface water data collected is considered to be somewhat heterogeneous and need to be considered on a case-by-case basis. An example of this is presented in Figure 42 for two HMWC results.

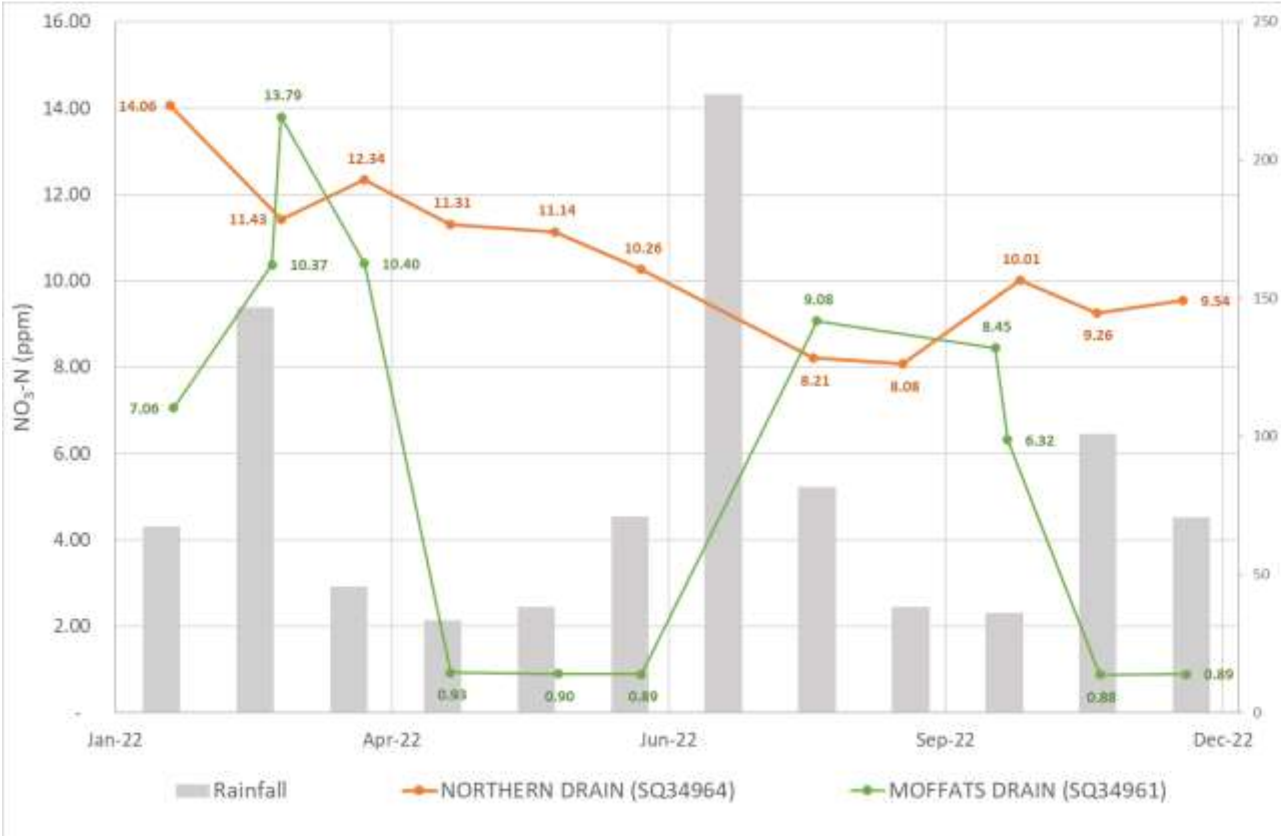


Figure 42 Changes in NO_3-N concentration for the Moffatts and Harris C Drain

Moffatt's Drain is normally sourced from ADC stock water races (which are derived from the Ashburton or Rangitata Rivers), and thus normally has a low NO_3-N concentration. Between January and March, and June and October, there were significant increases due to the aforementioned inputs.

In comparison, the Harris C Drain, is a spring fed drain, is isolated from external inputs. Consequently, its increase in NO_3-N concentrations was not as dramatic as that of the Moffatt's Drain.

A list of HMWC's that are augmented by ADC stock water is in Appendix 8.

8.2.Results

8.2.1. Hekeao Hinds River Results

The NO_3-N results for the Hekeao Hinds River from Mayfield to Lower Beach presented in Figure 43 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 decrease after periods of rainfall and elevated river flows.

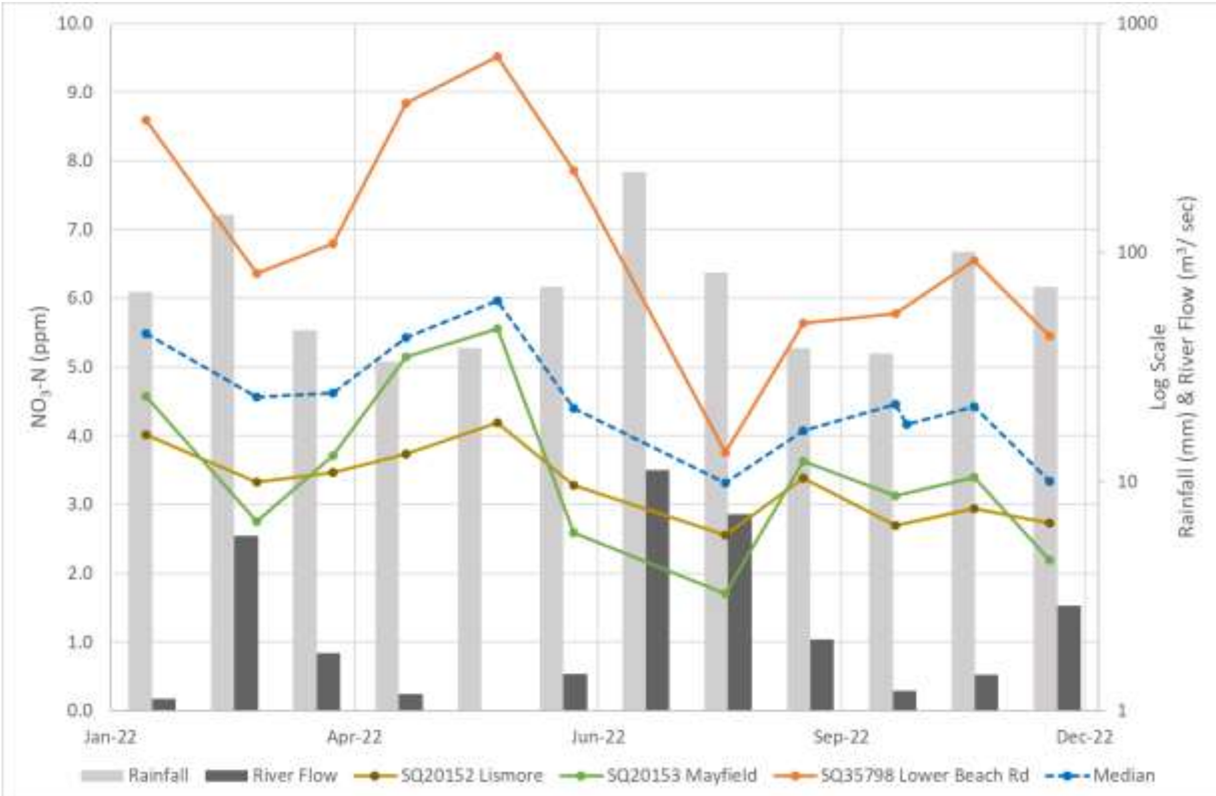


Figure 43 NO_3-N Results for the Hinds River from Mayfield to Lower Beach

8.2.2. Highly Modified Water Course Results

Results from selected Highly Modified Water Courses (HMWC's) throughout the year (that were not influenced by ADC Stock water at the time of sampling) indicates a decrease in NO_3-N throughout the year.

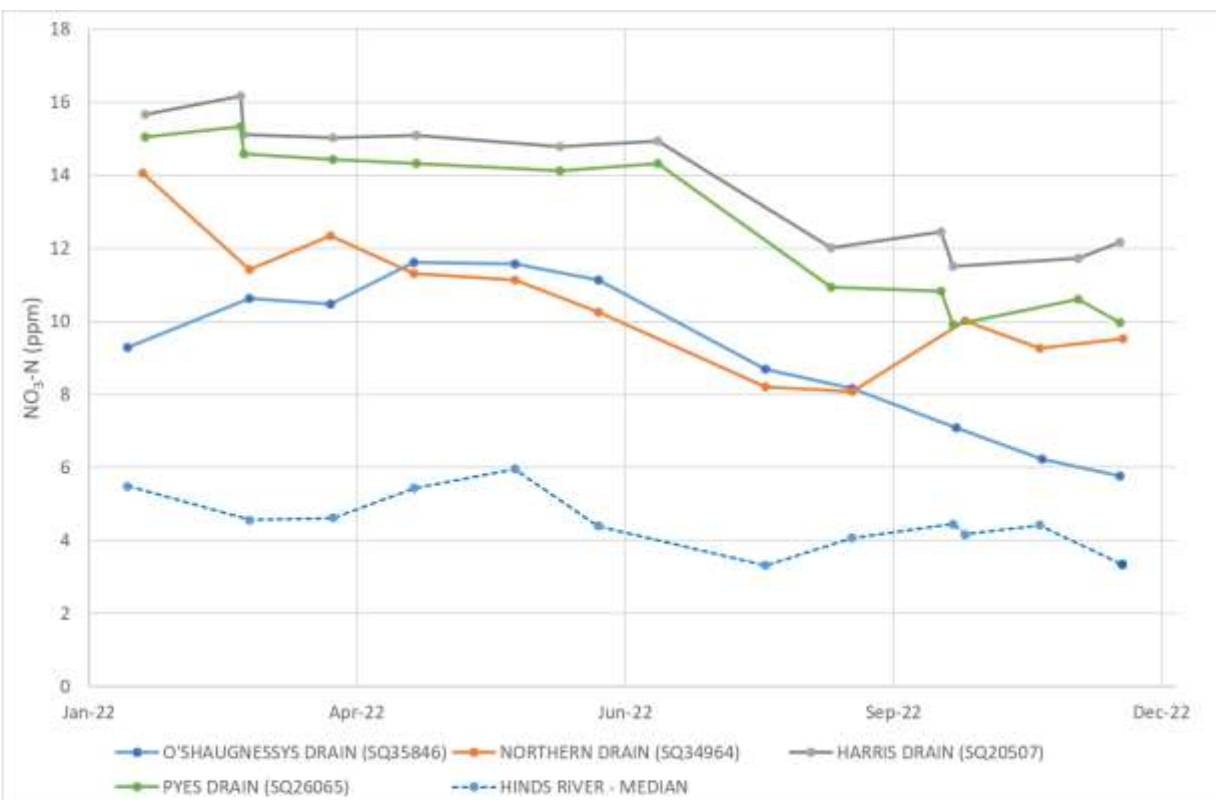


Figure 44 Results from selected HMWC's that were not influenced by ADC Stock water at the time of sampling

9. Transmissivity Analysis

A high-level desktop study of transmissivity (T) data was undertaken to assess whether transmissivity variation could play a role in the observed NO_3-N distribution across the Hekeao Hind Plains.

Hydraulic conductivity (K) (also referred to as permeability) is 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.

Permeability is difficult to measure in the field, and hence we usually measured transmissivity through pumping tests. Transmissivity is hydraulic conductivity of the aquifer multiplied by aquifer thickness. It is measured in m^2/d. Porosity is the proportion of solids to voids in a sedimentary formation (Figure 45)

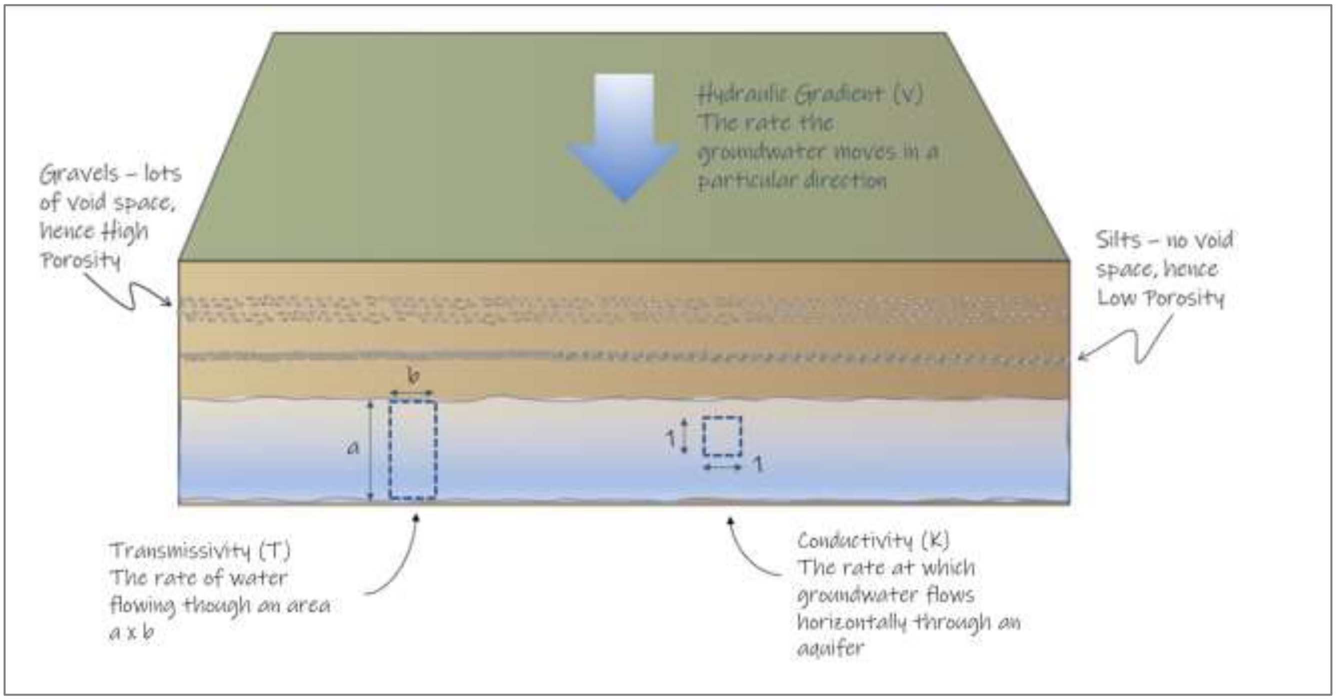


Figure 45 Schematic diagram of Hydrological Transmissivity (T) and Hydraulic conductivity (K)

9.1.Data Analysis

Transmissivity (T) data for 355 bores was obtained from ECan for the Hekeao Hinds Plains. The data was found to be highly variable (CV > 1)[19] with no discernible relationship with depth (Table 9 & Figure 46).

Table 9 Descriptive statistics of transmissivity and Depth data

	Count	Min	Max	Average	Median	Std. Dev^n	CV
Bore Depth	355	5.00	174.00	80.23	80.00	37.32	0.47
T	355	6.00	10380.00	1237.92	647.60	1521.12	1.23

Of the 355 bores with T data, only 24 (< 10%) are monitored by MHV for NO_3-N. Figure 47 presents NO_3-N concentrations vs transmissivity for this limited dataset.

[19] The coefficient of variation (CV) is a measure of relative variability. A population with a CV of < 0.5 is considered to have a low variance low, 0.5 -1.0 moderate and > 1 high.

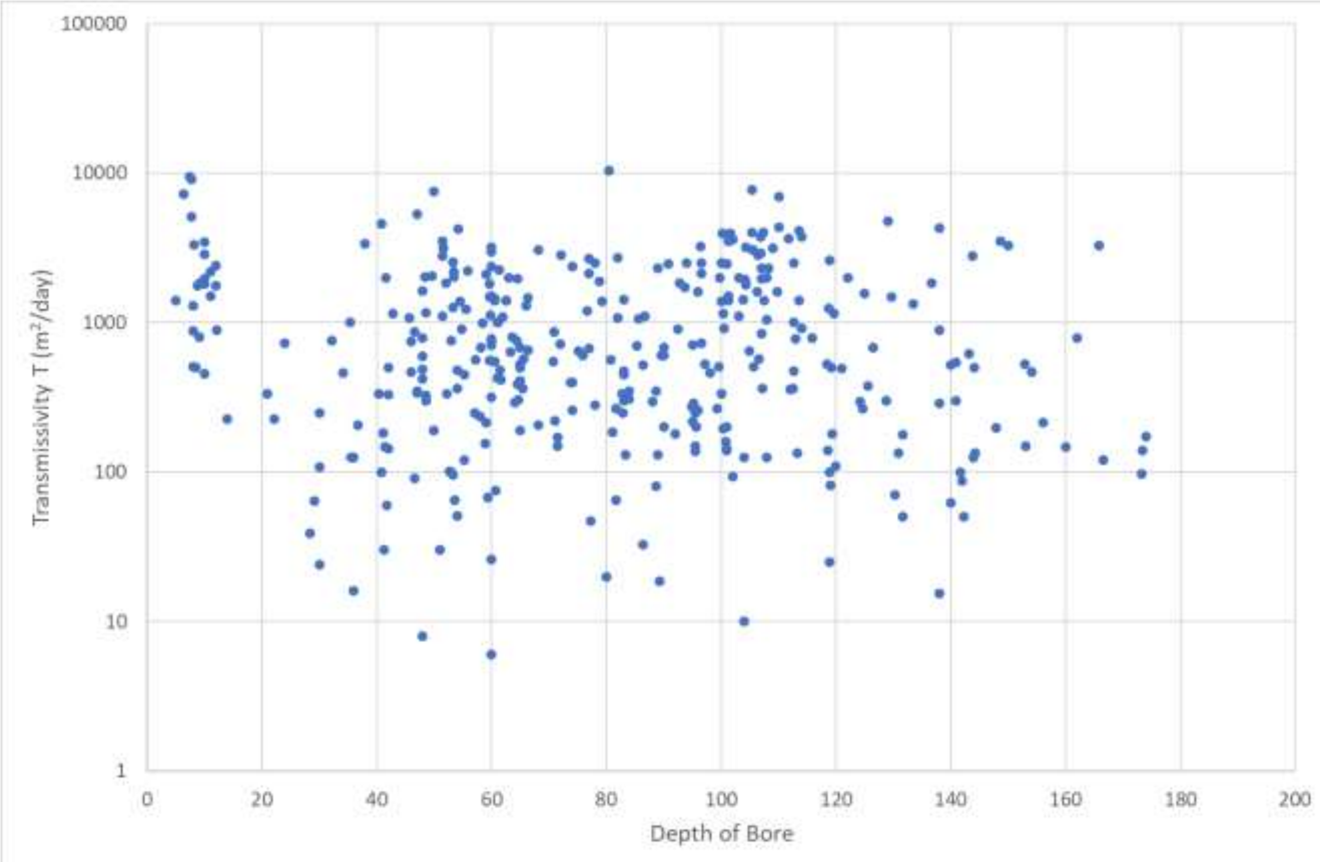


Figure 46 Bore depth to Transmissivity

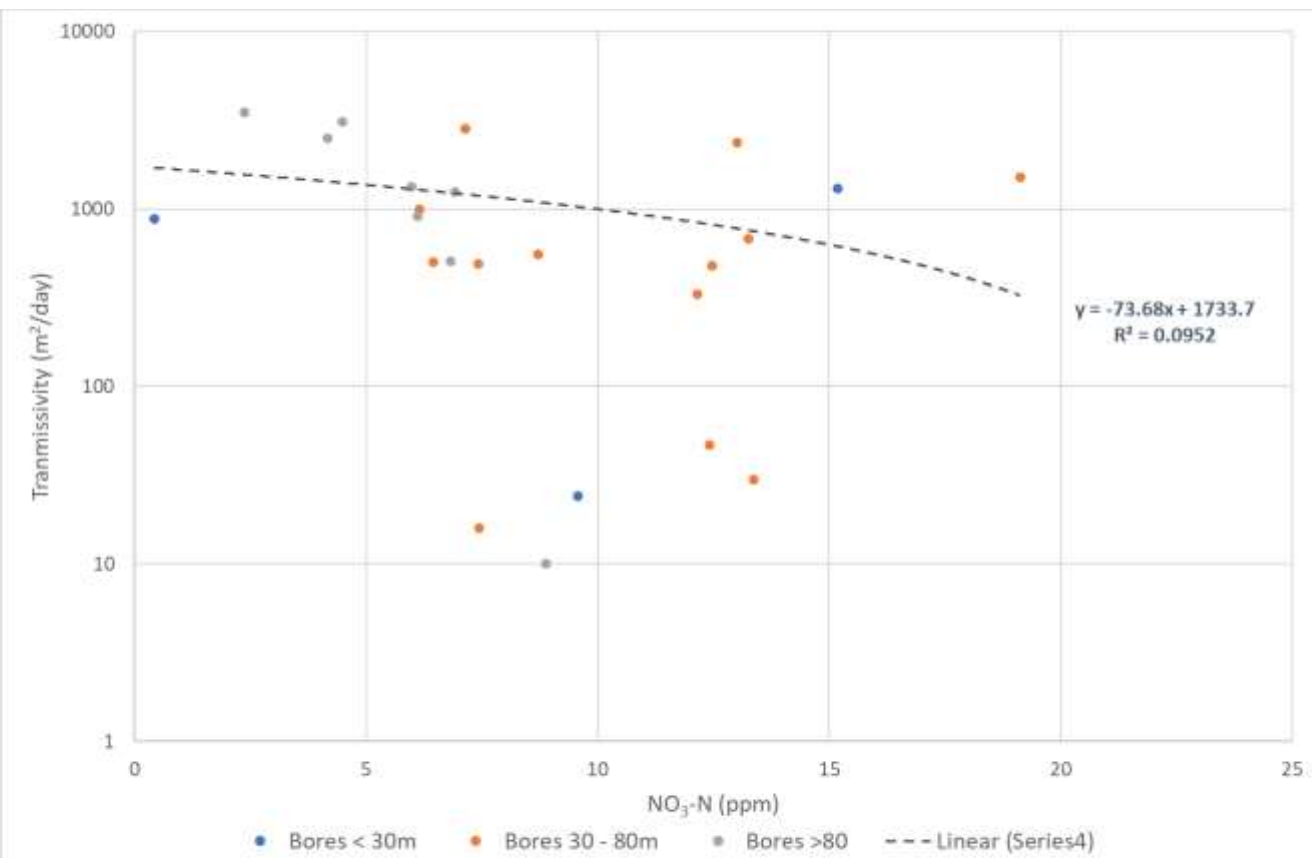


Figure 47 NO_3-N compared to transmissivity (2022 NO_3-N data)

9.2. Spatial Analysis

9.2.1. Coverage

As shown in Figure 48, the transmissivity data points are reasonably well distributed across the Hekeao Hinds Plains.

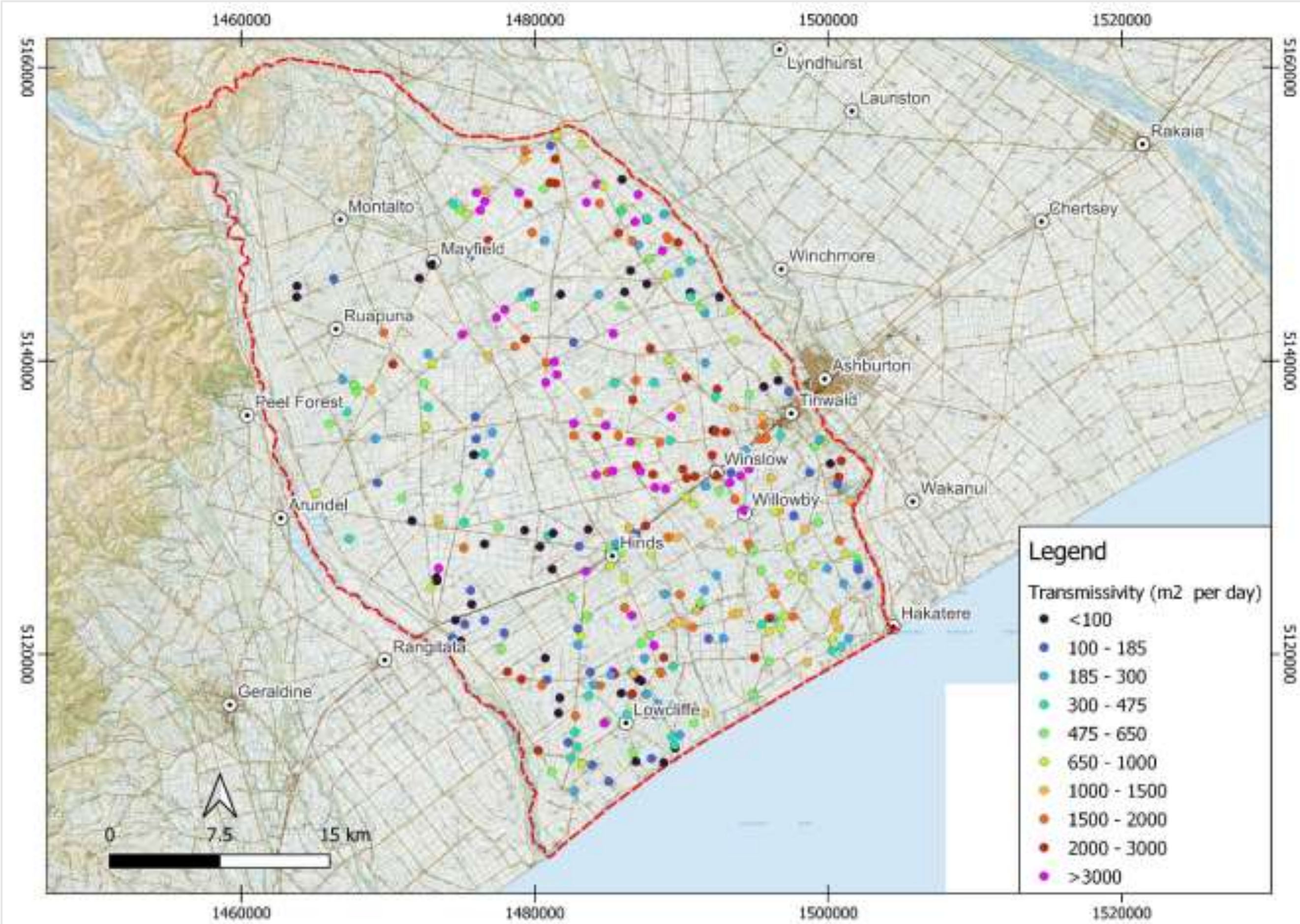


Figure 48 Distribution of bores with Transmissivity data

In general, lower T values were observed south of the Hekeao Hinds River, with the highest values are observed between Winslow and Mayfield on the northern side of the Hekeao Hinds River.

9.2.2. Reconciliation with Soil Types

When the transmissivity data is compared to the S Maps, there does not appear to be a discernible relationship between the major soil types, apart from the Longbeach heavy gley soils, within which areas there appears to be lower T, as shown in Figure 50 and as a box plot in Figure 50.

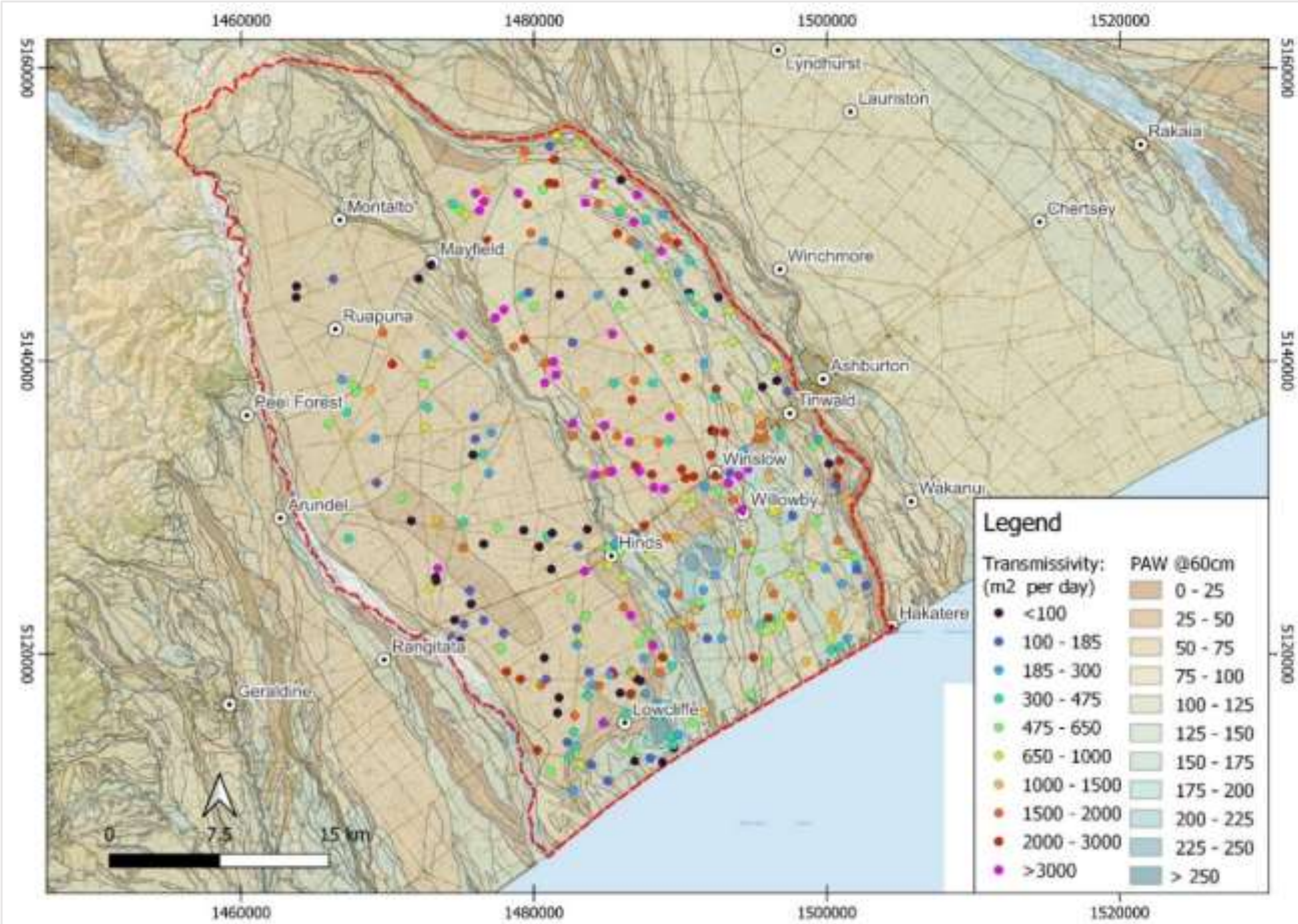


Figure 49 Transmissivity data with Soil Map coloured by PAW

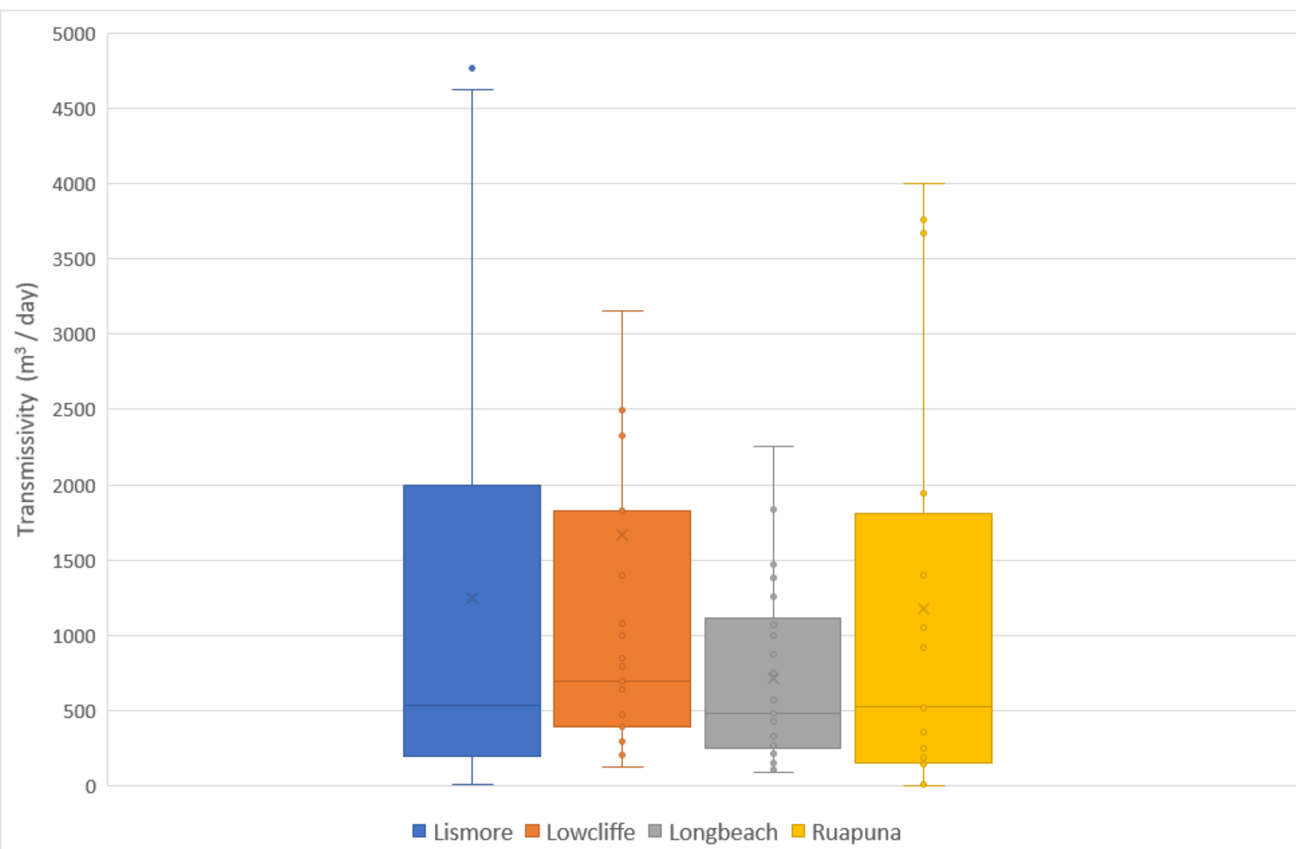


Figure 50 Box and whisker plot of Transmissivity data by major soil type

9.2.3. Paleo / Ephemeral drainage Reconciliation

A high-level reconciliation with Transmissivity observation and proximity to the surface paleo channels failed to identity any discernible relationship.

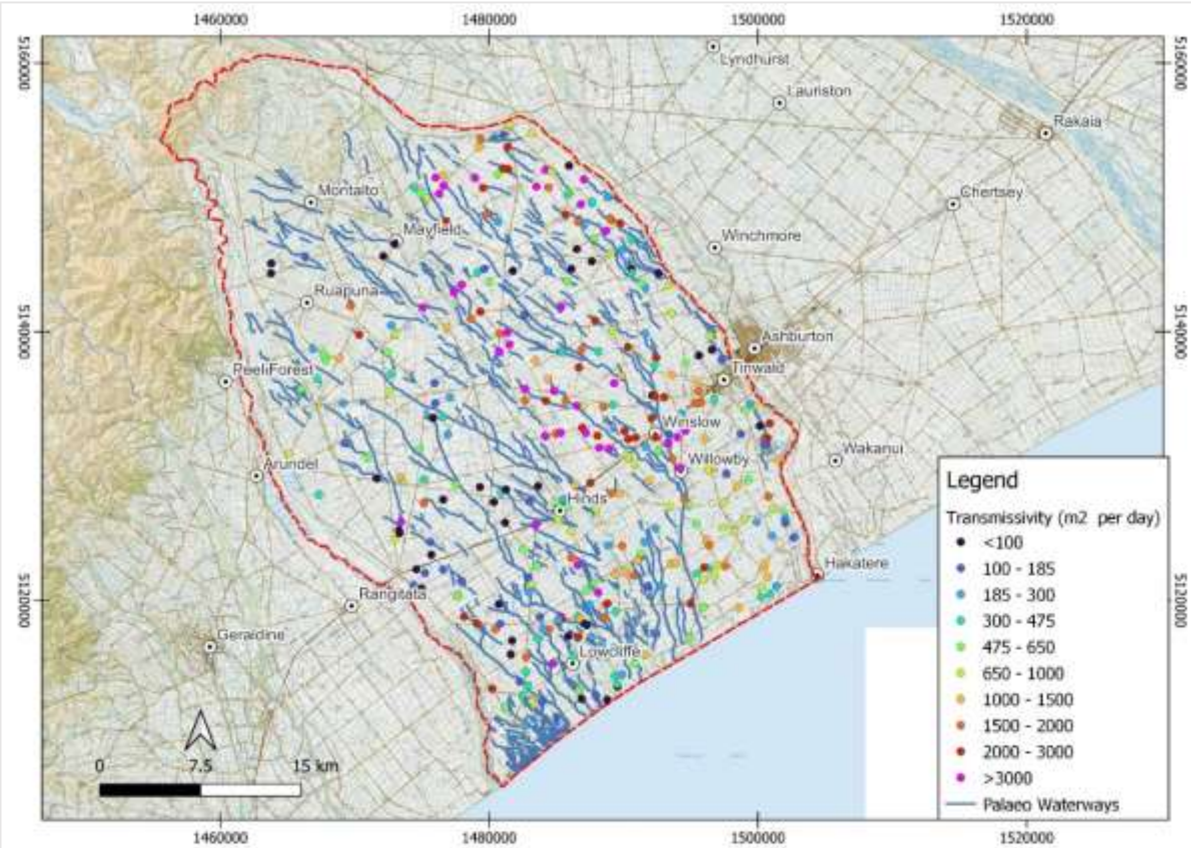


Figure 51 Location of T data points with mapped Paleo / Ephemeral drainage

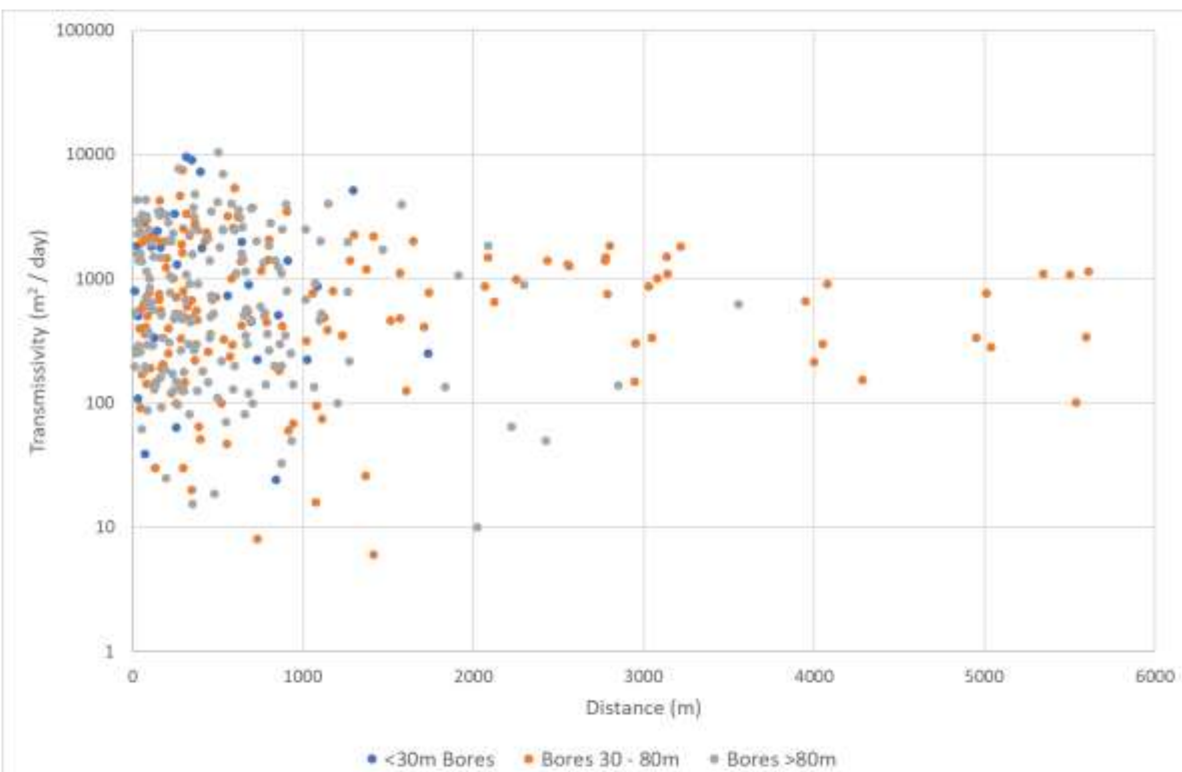


Figure 52 Nearest neighbour analysis of T data points and mapped Paleo / Ephemeral drainage, coloured by bore depth

9.3. Variation of transmissivity with depth

In general, we have been classifying bores into the following categories:

- Shallow <30 m deep
- Intermediate 30 – 80 m deep
- Deep Bores with depths > 80m.

However, when assessing variability of transmissivity with depth, there was insufficient data from bores <30m deep to use this classification system. Based on a cumulative frequency plot of the bore depths (Figure 53), the following classification has been adopted:

- Shallow <65 m deep
- Intermediate 65 – 110 m deep
- Deep > 110m deep.

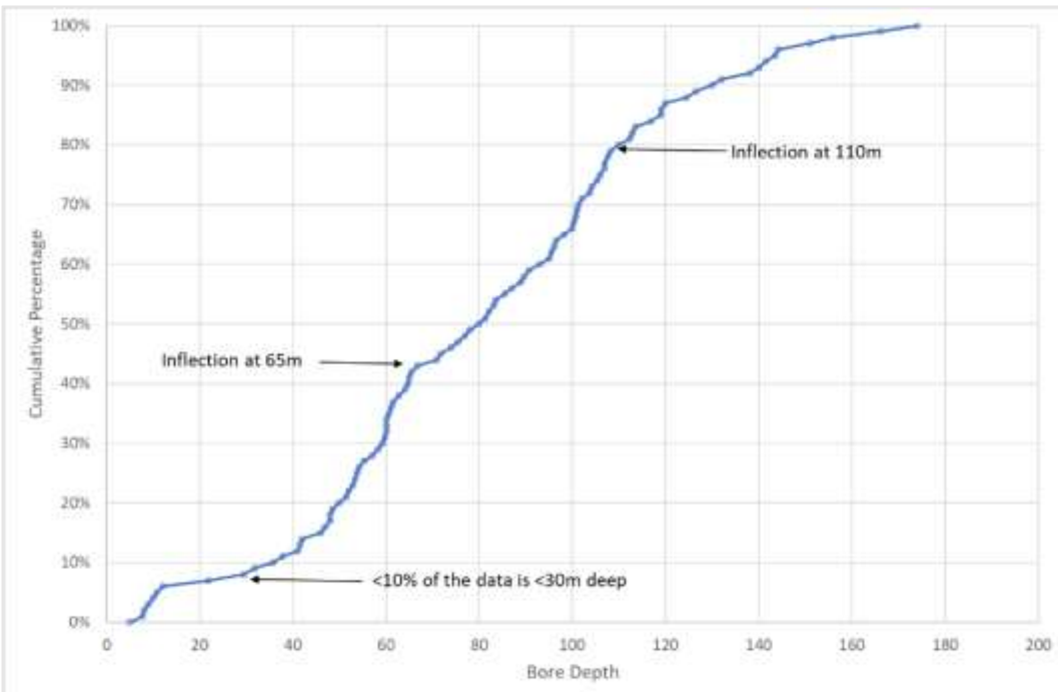


Figure 53 cumulative frequency plot of bore depths

On this basis, a series of ID2 interpolations were generated (see Figure 54 to Figure **57**), Table 10 presents the descriptive statistics for the interpolations.

Table 10 Descriptive statistics for T values classified by bore depth

Bore Depth	Count	Min	Max	Average	Median	Std. Dev^n	CV
<65m	144	6	9515	1279	755	1623	1.27
65 – 110m	139	10	10380	1272	675	1450	1.14
> 110	72	16	7000	1091	483	1455	1.33
All Depth	355	6	10380	1238	648	1521	1.23

***NB** The interpolations are based on the spatial distribution of the data. Hence in areas where there is a scarcity of or absence of data, the confidence in the interpolation is considered low. Equally, where there is a significant difference between proximal observations, or the data point appreciably different from the low confidence interpolation, the interpolation presents as a 'Bull's Eye'.*

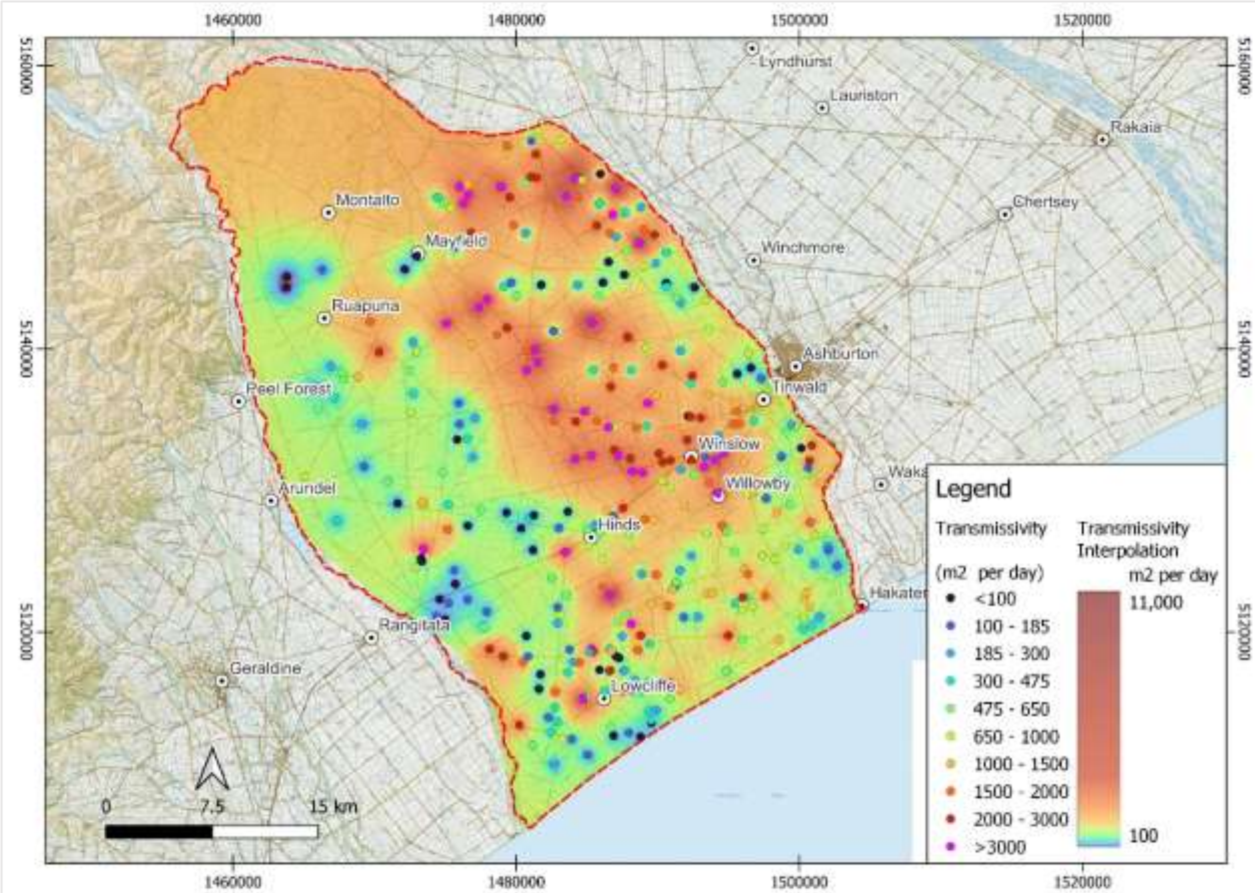


Figure 54 ID2 interpolation of T data for all bore depths

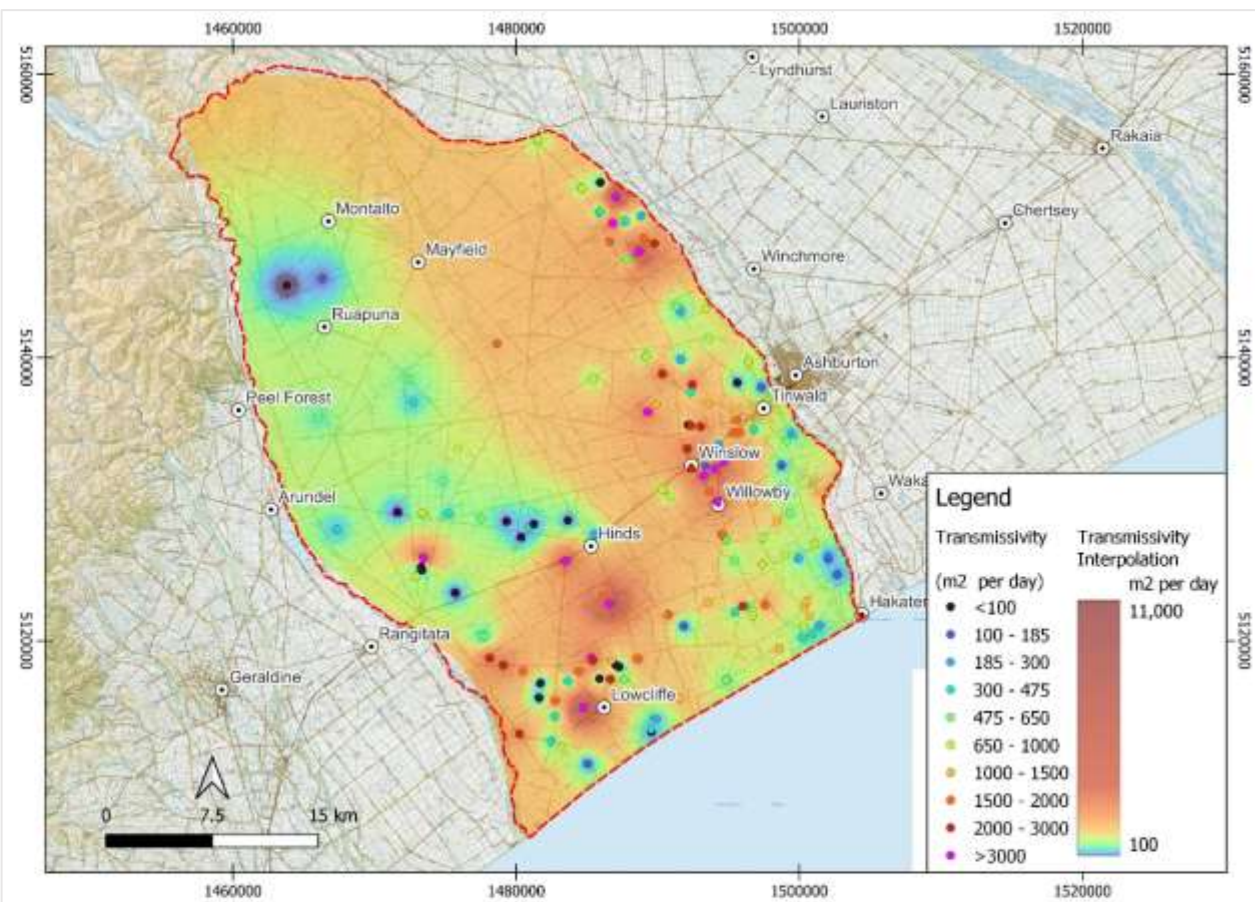


Figure 55 ID2 interpolation of T data for bores <65m deep

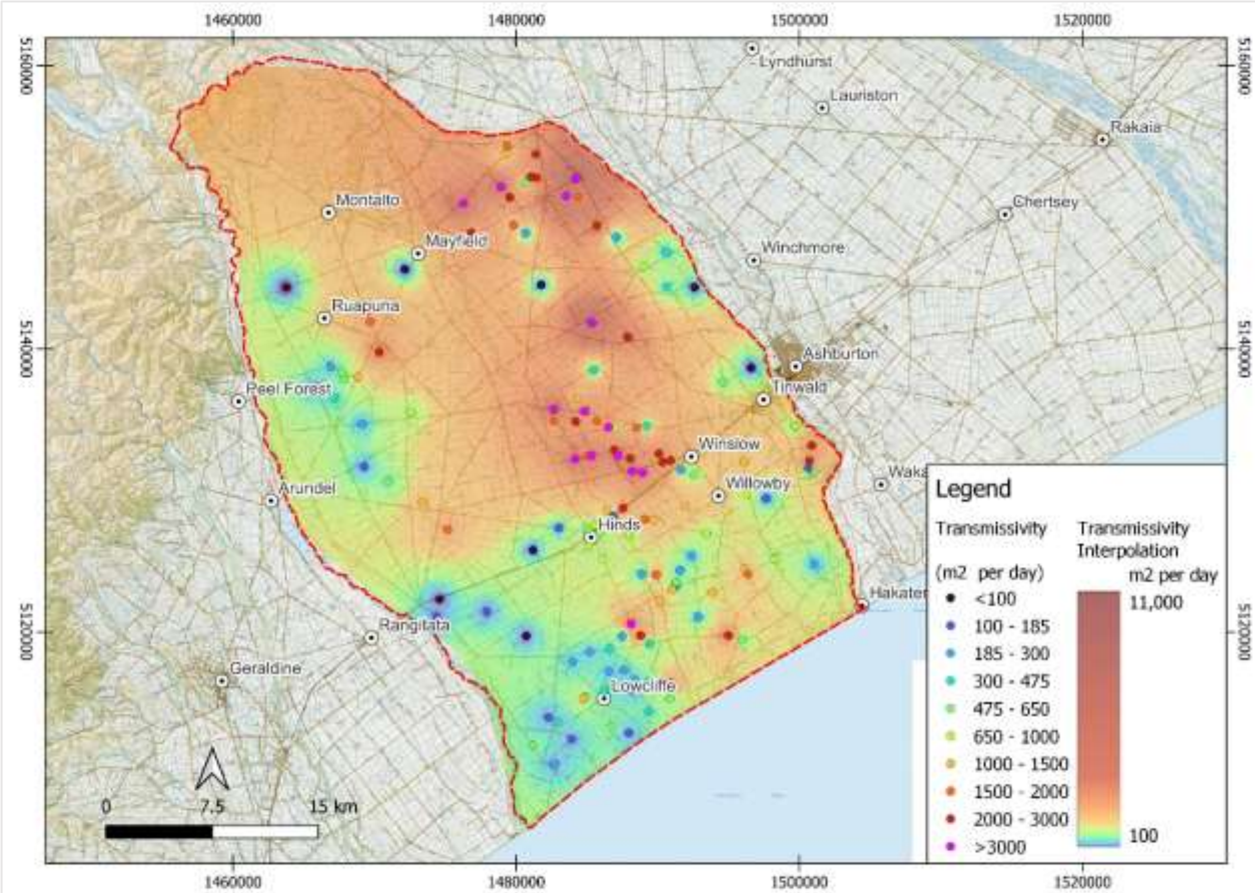


Figure 56 ID2 interpolation of T data for bores 65m – 110m deep

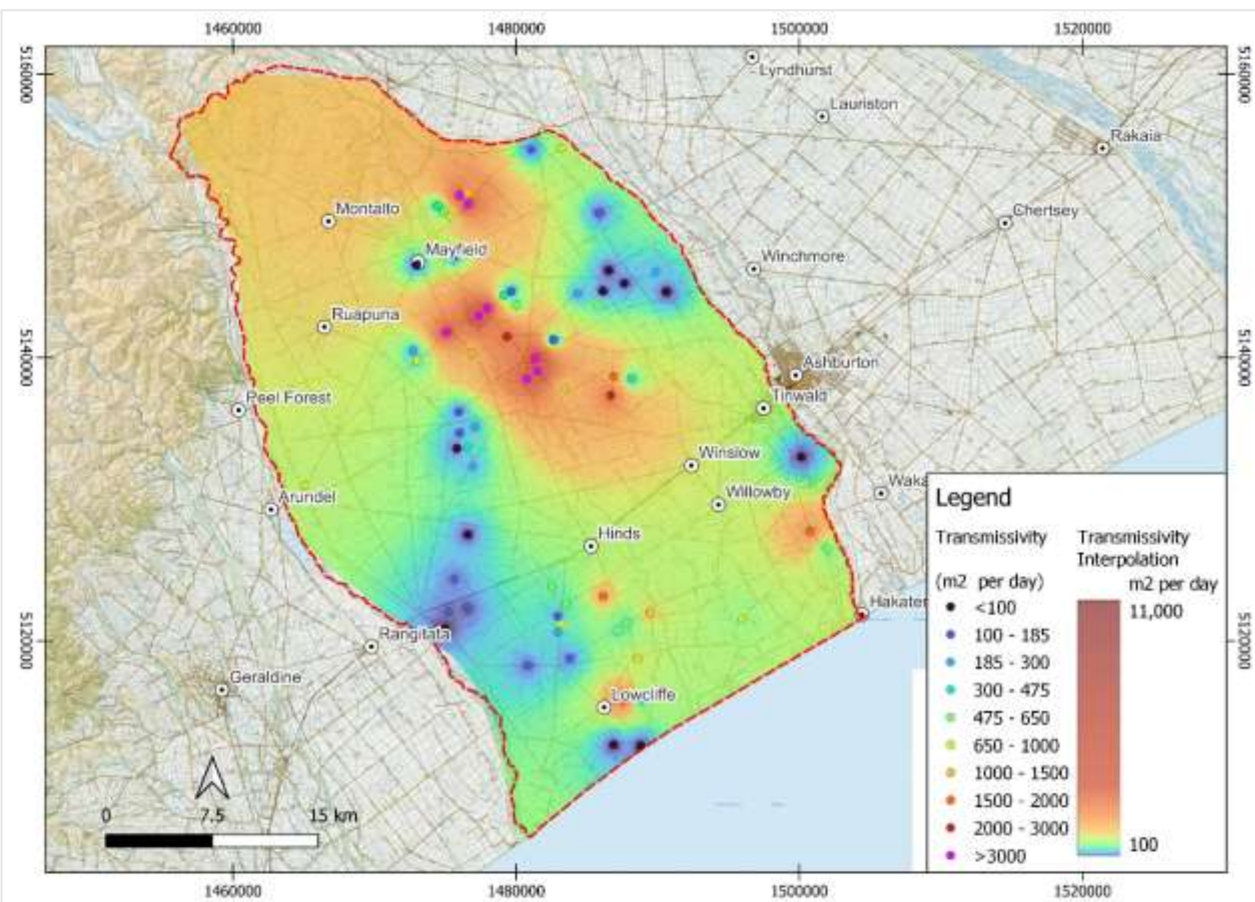


Figure 57 ID2 interpolation of T data for bores >110m deep

9.4. Structural Interpretation

As noted previously (sect 9.2.1), Lower values are noted between Lowcliffe and Rangitata, with higher T values observed between Winslow and Mayfield. Figure 58 presents the ID2 interpolation for bores between 65 – 110m with the current fault interpretation from GNS.

The lower Hekeao Hinds Plains is influenced by the Ealing Fault, a 35 km inactive steeply dipping strike-slip fault that runs from Lowcliffe to Arundel; with subordinate splay shallow dipping faults that strike east-west forming a Horst and Graben system (Figure 59).

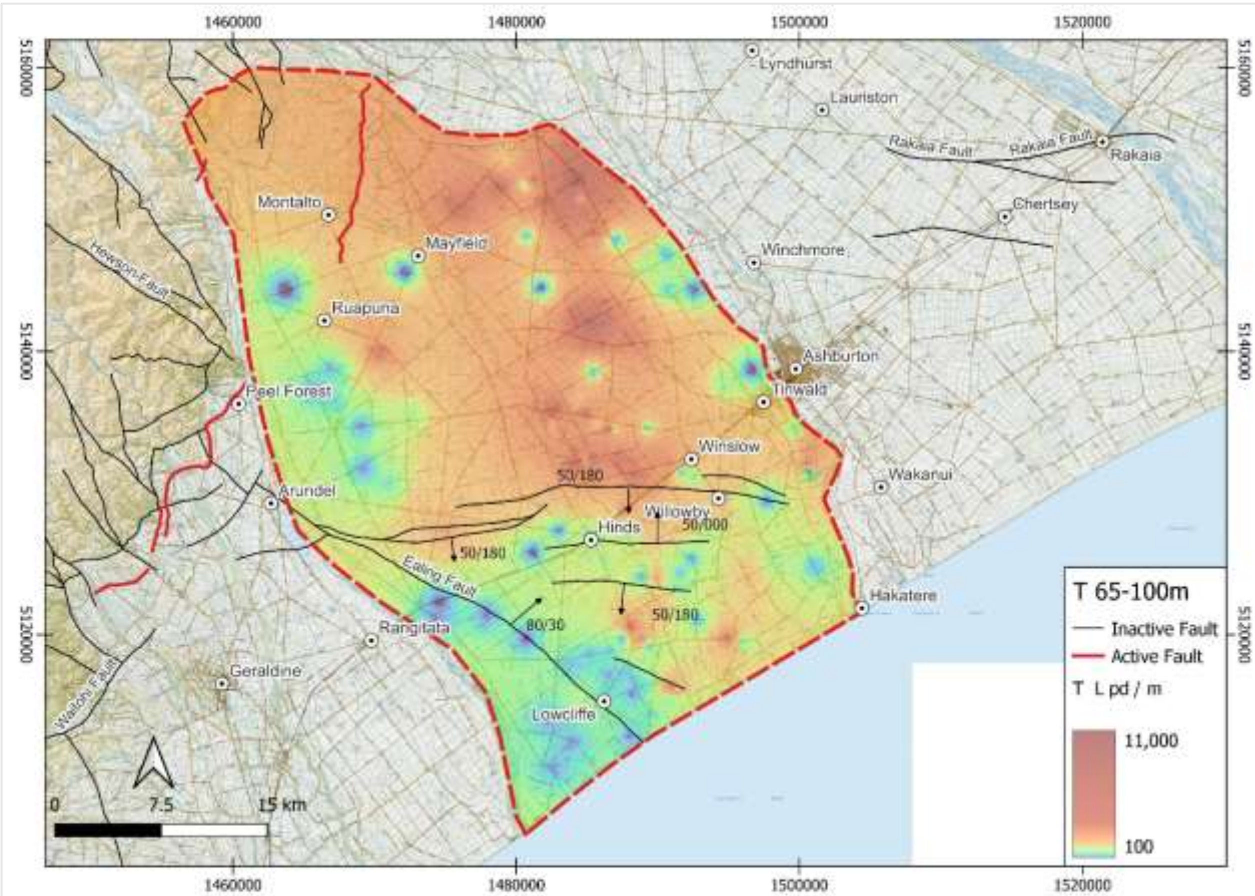


Figure 58 ID2 interpolation of T data for bores 65m – 110m deep with known faults

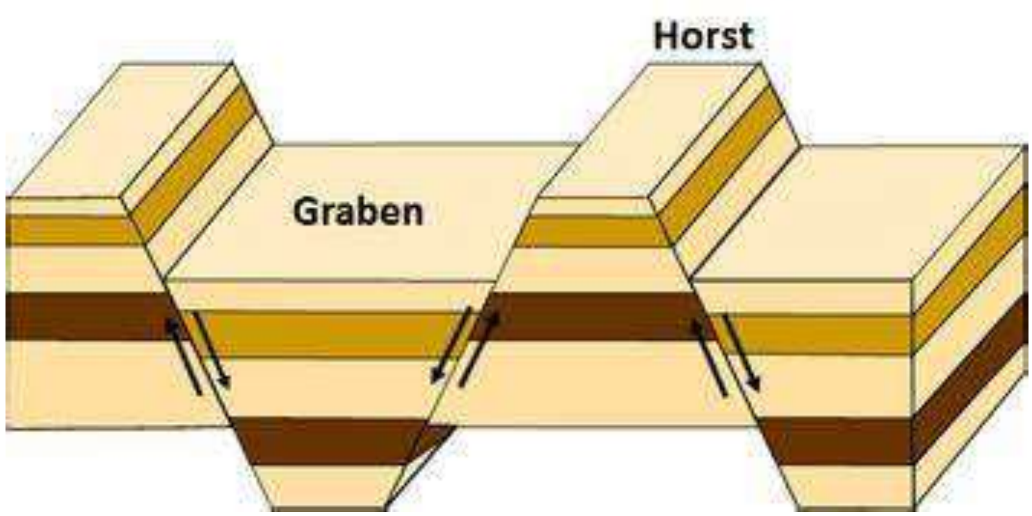


Figure 59 Schematic cartoon of a Horst and Graben System

A real-world example is presented in Figure 60

Figure 60 Extensional horst and graben structures in-Quaternary sedimentary series of the Zanjan Depression, Zanjan-Mianeh-Tabriz highway, northwest Iran

As the faults are interpreted by GNS to have a vertical to sub vertical movement vector, it is inferred that these faults may be applying localised compressional and reciprocal extensional forces that are influencing the transmissivity. Figure 61 presents a schematic orthogonal diagram indicating the potential domains based on the fault system.

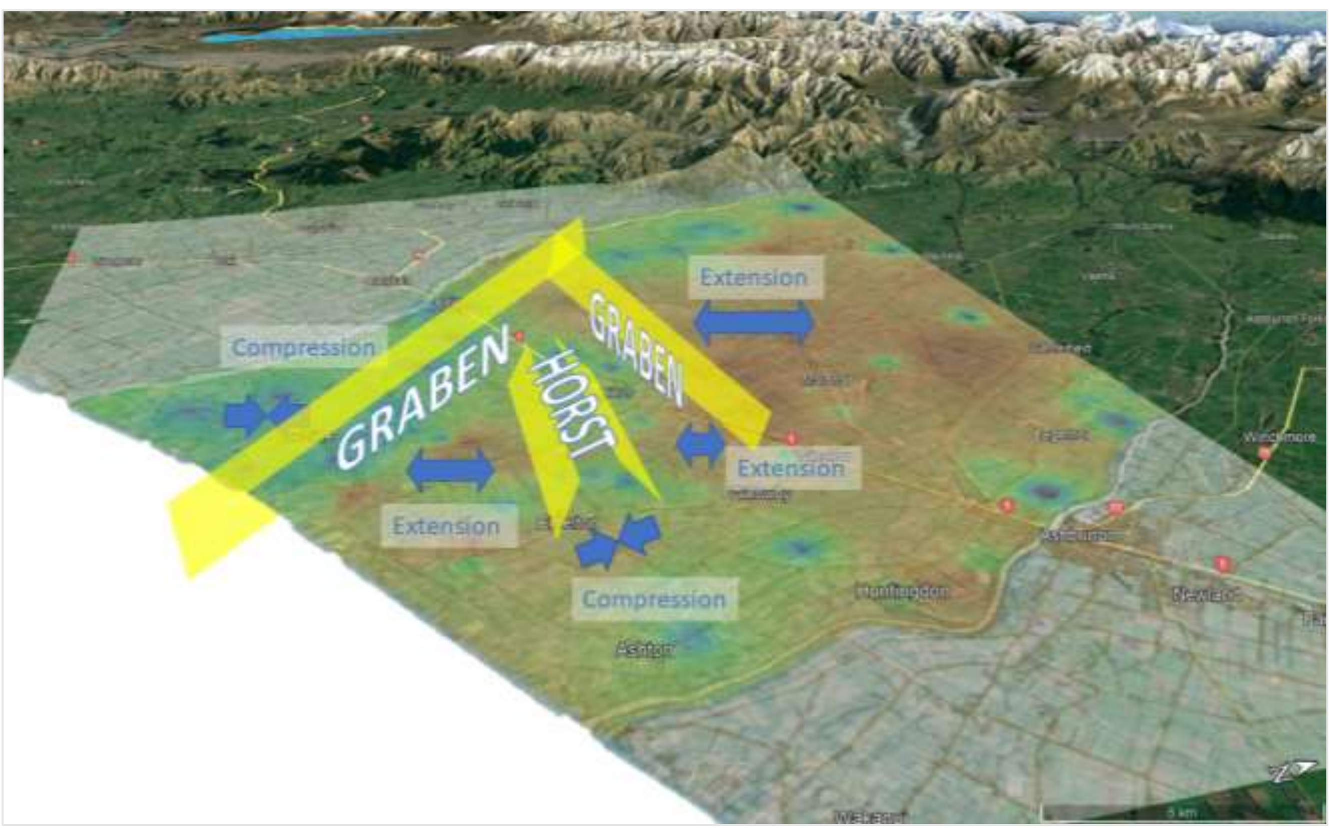


Figure 61 Oblique view of interpreted faults with transmissivity values 65 – 110m

Alternatively, the throw on the fault(s) in the area may be sufficient to provide rapid facies change in the alluvium that will affect both conductivity and transmissivity. Figure 62 is the Mt Hutt Fault at Rakia Gorge showing sufficient throw to alter the geology significantly.

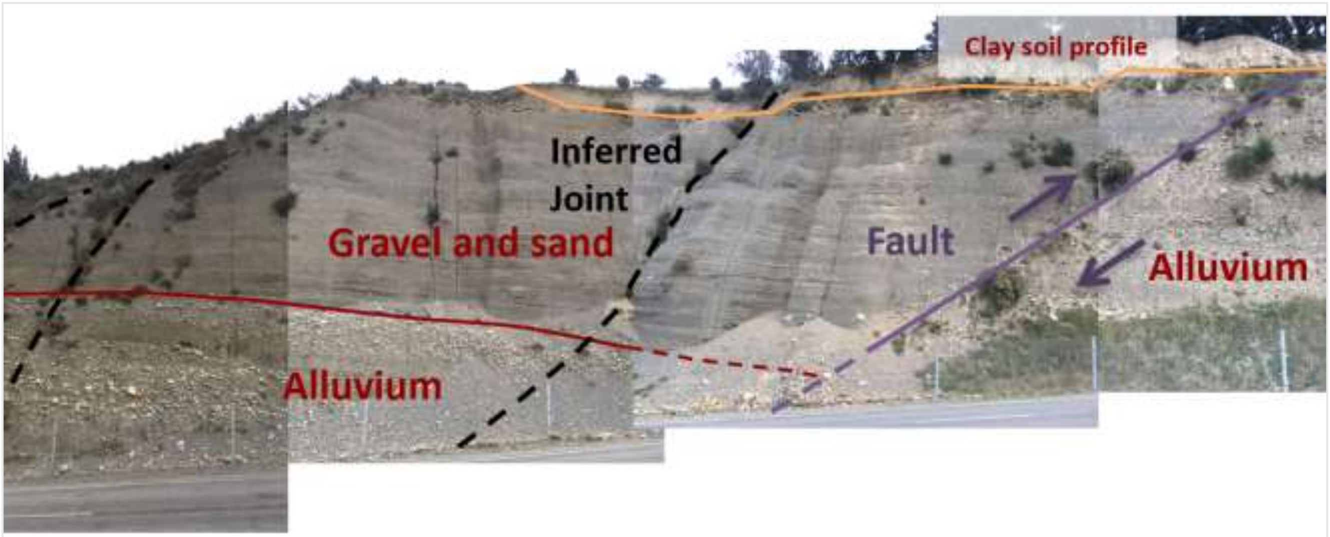


Figure 62 An example of faulting in alluvium – Rakia Gorge

10. Discussion

> *A riddle is a game. The process of solving it essentially boils down to proving the obvious; one knows from the start that the meanings of the two functions given are equal. This transforms the whole process into a sort of intellectual ostensibility.*
>
> *Evgeny Dobrenko*

10.1. Nitrate response to recharge – an overview

NO_3-N concentrations were compared between December 2021 and December 2022 to assess whether there was any change, and the direction and magnitude of the change. Although NO_3-N concentrations in shallow bores overall decreased slightly, concentrations in deeper bores increased over this time frame. The relative changes in NO_3-N from December 2021 to December 2022 appear to be negligible as shown in (Figure 63 and Table 11).

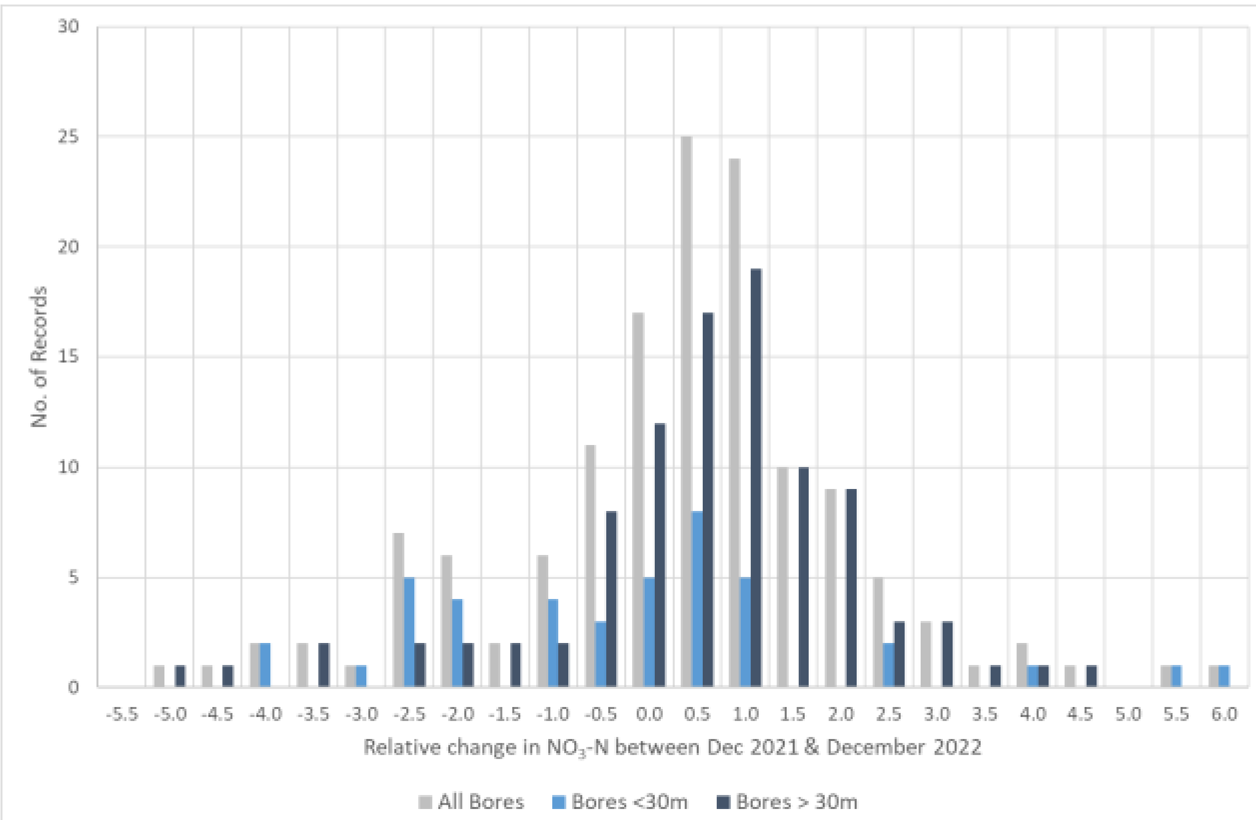


Figure 63 Frequency histogram of the relative changes in NO_3-N concentration from December 2021 to December 2022

Table 11 Summary statistics of the relative changes in NO_3-N concentration from December 2021 to December 2022

Depth	Count	Min	Max	Range	Average	Median	Std Dev	CV
≤ 30m	42	-4.11	5.55	9.66	-0.46	-0.35	2.15	-4.68
>30m	96	-5.20	4.41	9.60	0.33	0.49	1.59	4.85
All	138	-5.20	5.55	10.75	0.09	0.29	1.81	20.41

In a broader context, the longer-term trend indicates that 2022 was a year with little to no material change in NO_3-N concentrations (Figure 64 & Figure 65), as the results varied by ± <10 – i.e. within acceptable reporting tolerances[20].

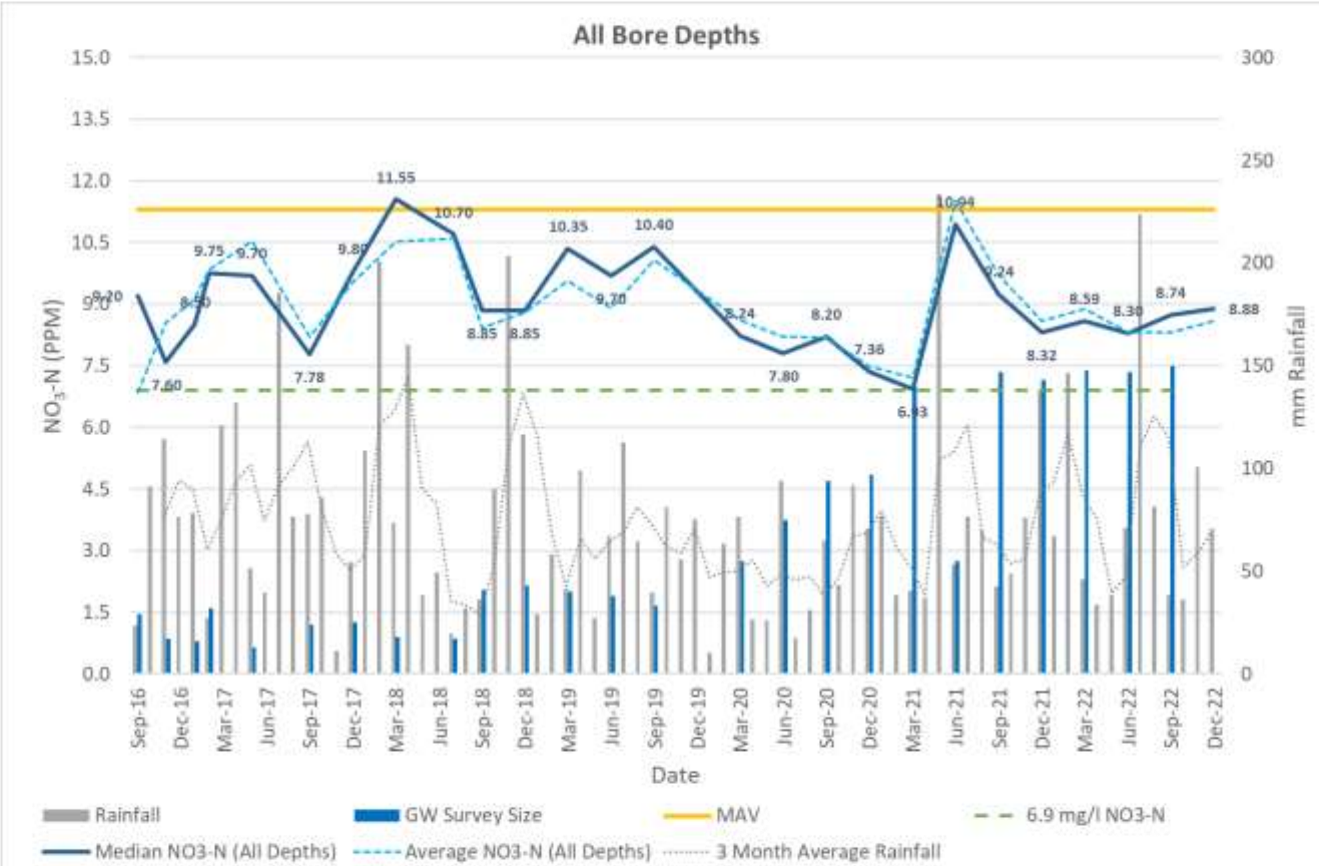


Figure 64 Long term NO_3-N results for the MHV groundwater monitoring programme (All bore depths)

[20] Hill Laboratories report uncertainty to ±12% of a certified result.

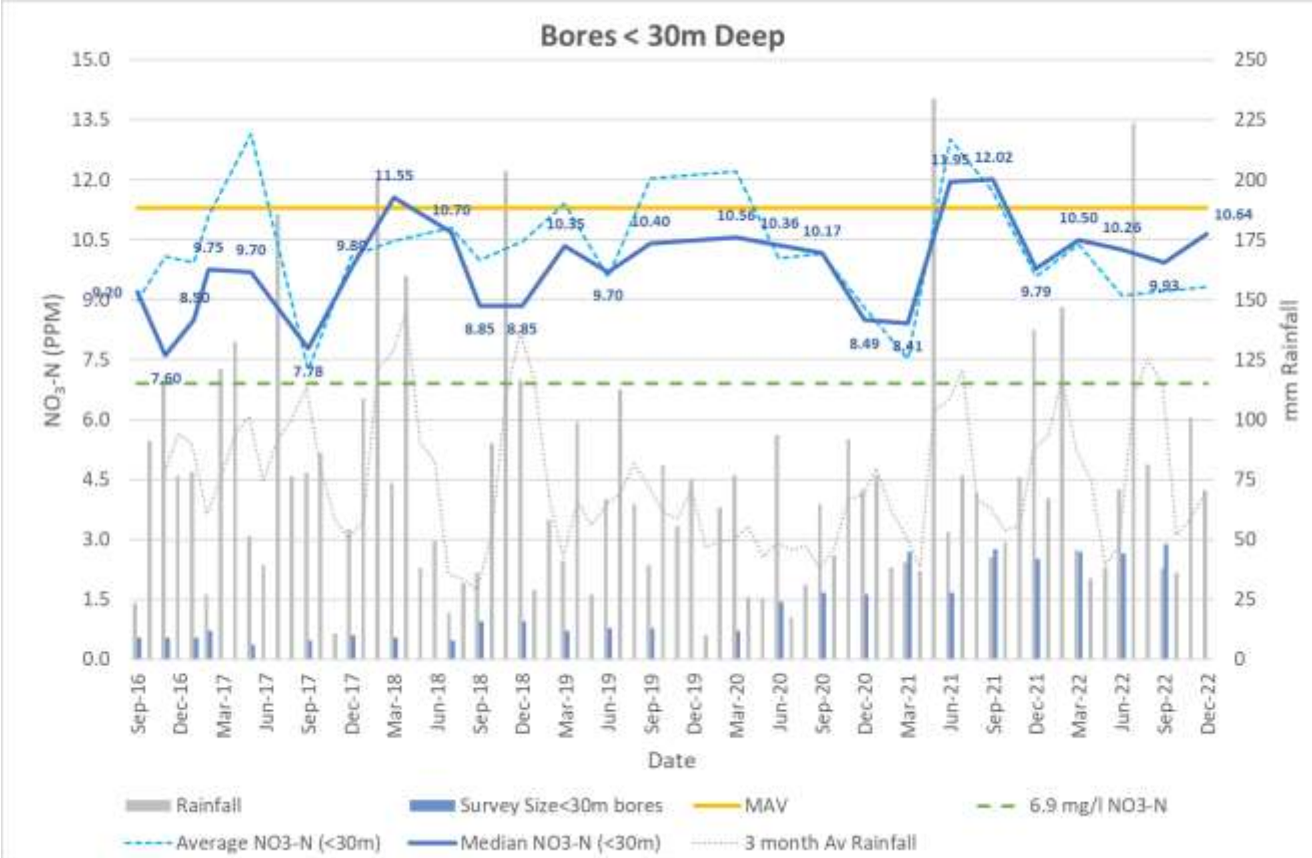


Figure 65 Long term NO_3-N results for the MHV groundwater monitoring programme (bores <30m deep)

The results overall indicate that NO_3-N concentrations respond to major recharge rainfall events, with the decrease in NO_3-N between 2019 and 2021 being attributed to limited rainfall recharge in response to a sustained negative Southern Oscillation Index (SOI) and a short lived El Niño episode in late 2019 thereafter, the SOI progressively increased and initiated a sustained La Niña event from September 2020 to March 2023 [28].

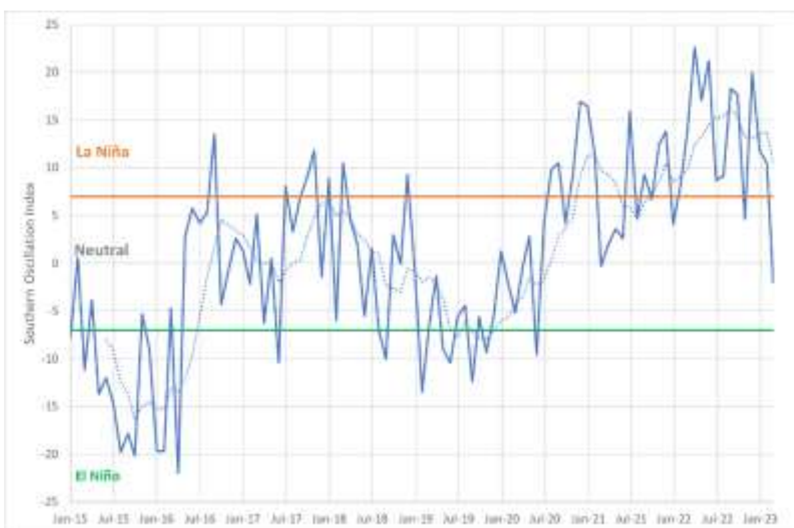


Figure 66 Southern Oscillation Index data 2015 - 2022

However, this doesn't consider the complexity of the hydrogeological system. Figure 67 and Figure 68 present the relative changes in NO_3-N spatially for bores <30m and >30m respectively, which indicates that there is has been a relative increase in NO_3-N in the upper catchment and a decrease in the lower catchment particularly around the Lowcliffe area, with considerable variation in between.

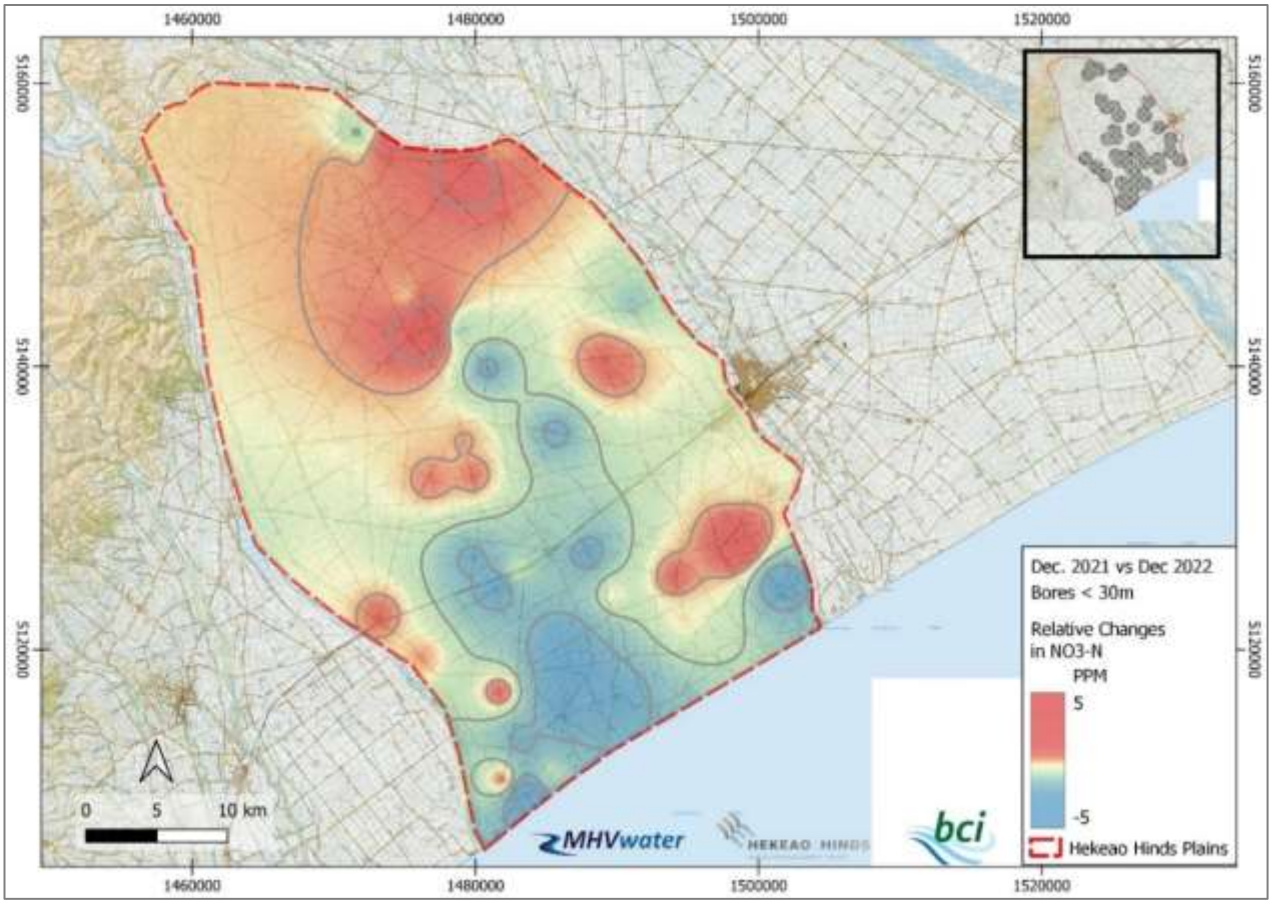


Figure 67 Relative changes in NO_3-N between Dec 2021 & Dec 2022 for bores <30m deep

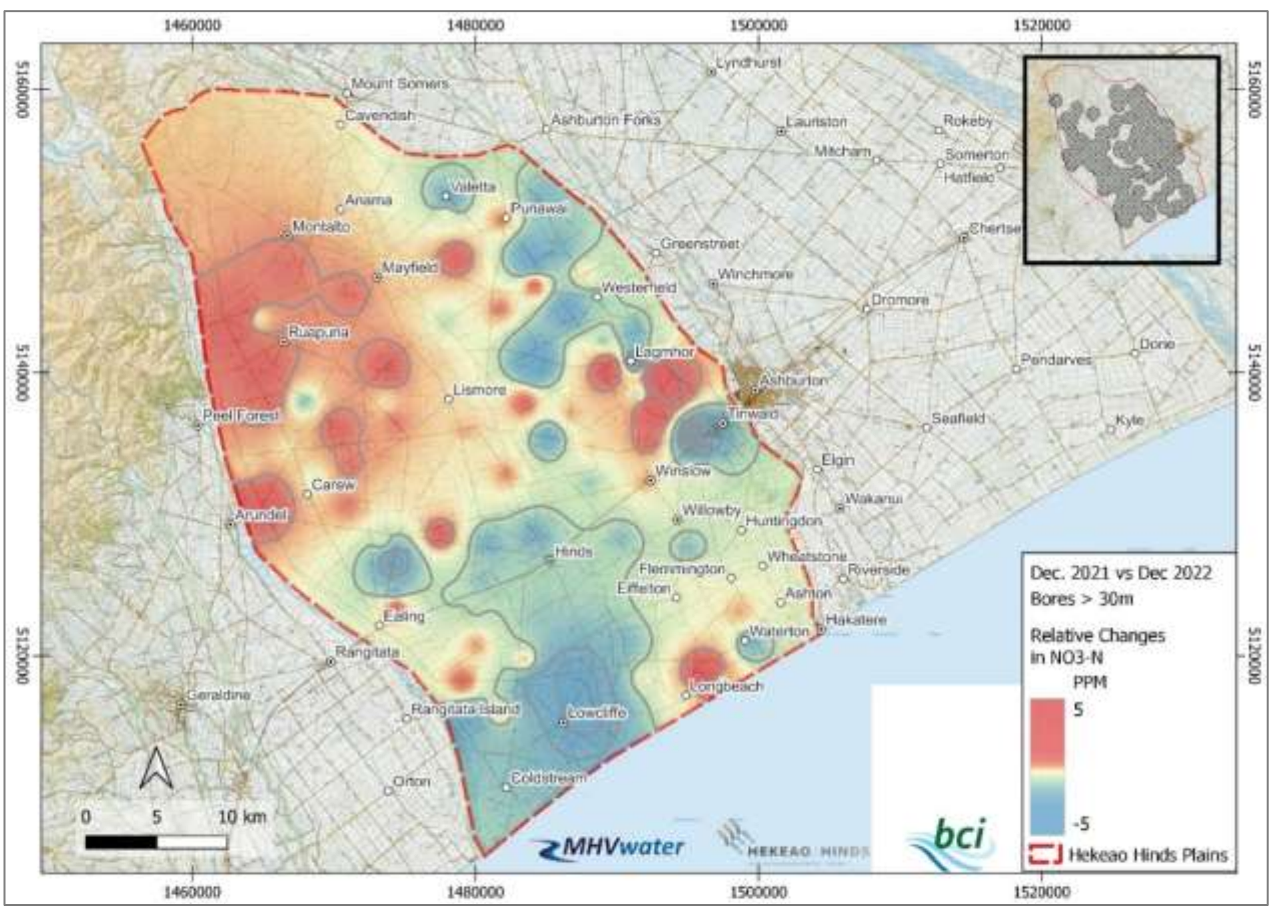


Figure 68 Relative changes in NO_3-N between Dec 2021 & Dec 2022 for bores >30m deep

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 8.1, Figure 42), NO_3-N concentrations in HMWC's have decreased throughout the year. When compared with the longer-term data, HWMC's that have not been augmented by ADC stock water have seen a sustained decrease since the 2021 Rain Event. As shown in Figure 69, 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 8 presents a list of the HWMC's that were excluded as part of this analysis

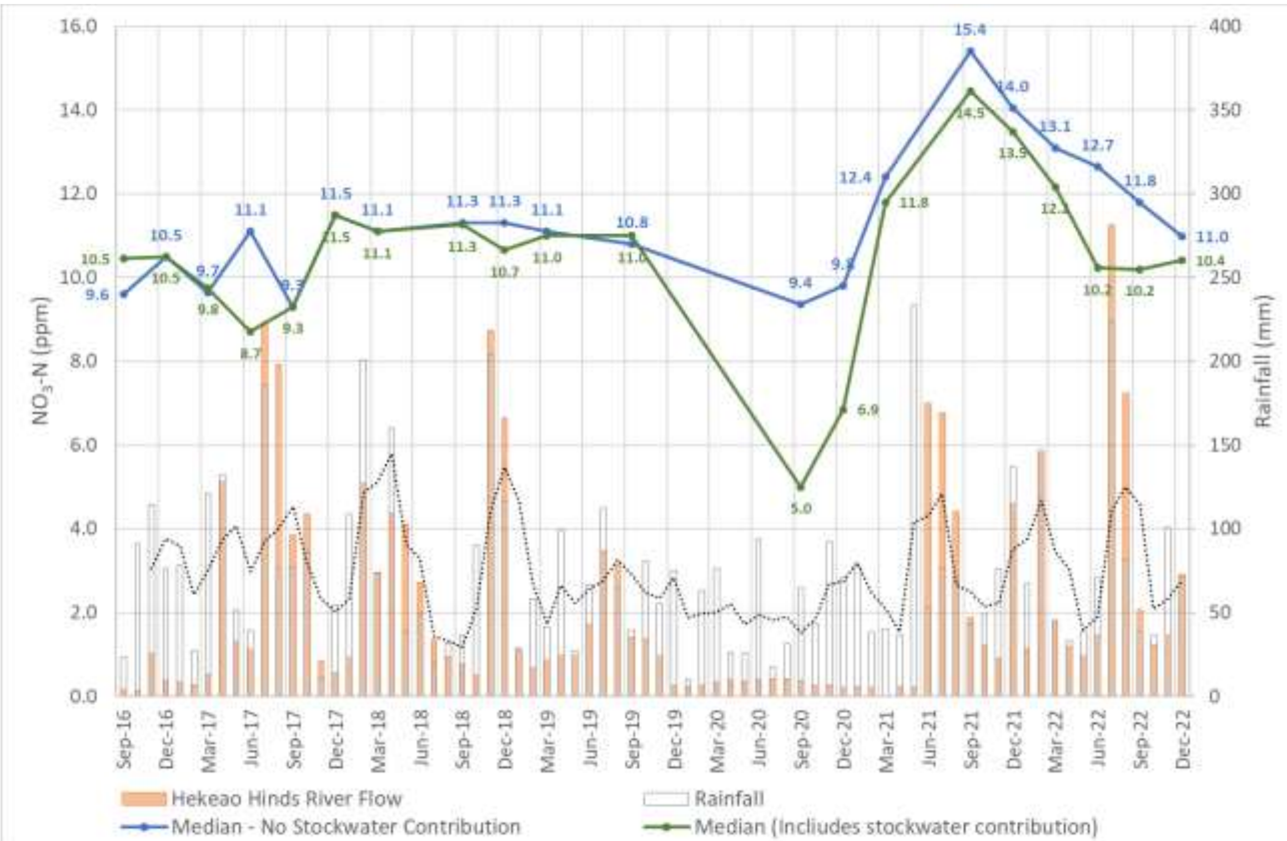


Figure 69 NO3-N concentrations for HMWC's with and without stock water augmentation, compared to rainfall & river flow

10.3. Nitrate response with soils

An apparent general relationship between soil properties (based on PAW)[21] in different soil types and NO_3-N concentrations in groundwater has been reported by MHV since 2020. This relationship is evident again in the 2022 data, where relative increases in NO_3-N were noted in the upper catchment characterised by light Lismore soils and decreases in the lower catchment characterised by heavier Gley soils. These results suggest that areas that had a marked increase in NO_3-N in 2021 are seeing a sustained decrease in NO_3-N, whereas the upper catchment is seeing a renewed increase in NO_3-N – potentially in response to land surface recharge in the upper Hekeao Hinds Plains.

[21] 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 (

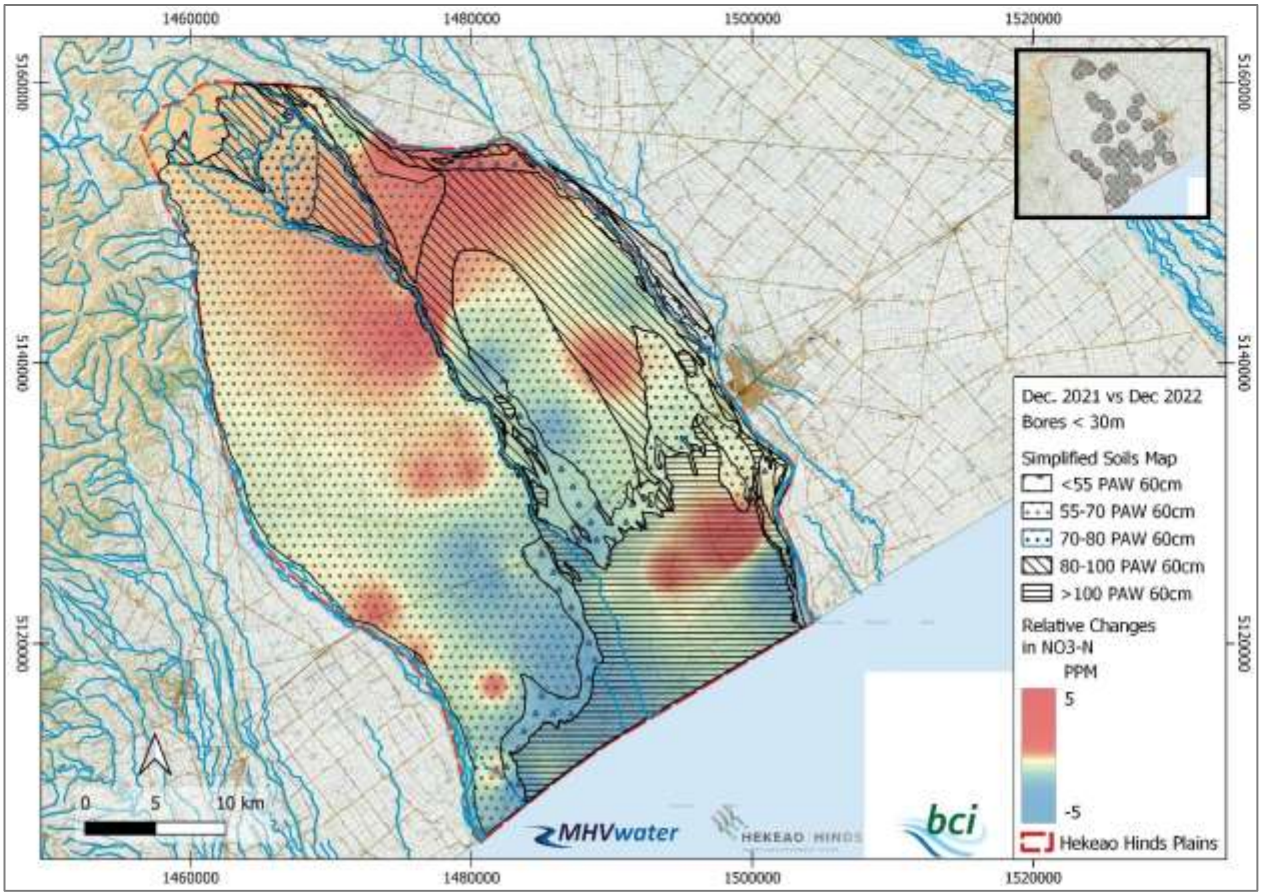


Figure 70 Relative changes in NO_3-N between Dec 2021 & Dec 2022 for bores <30m deep with simplified soil map

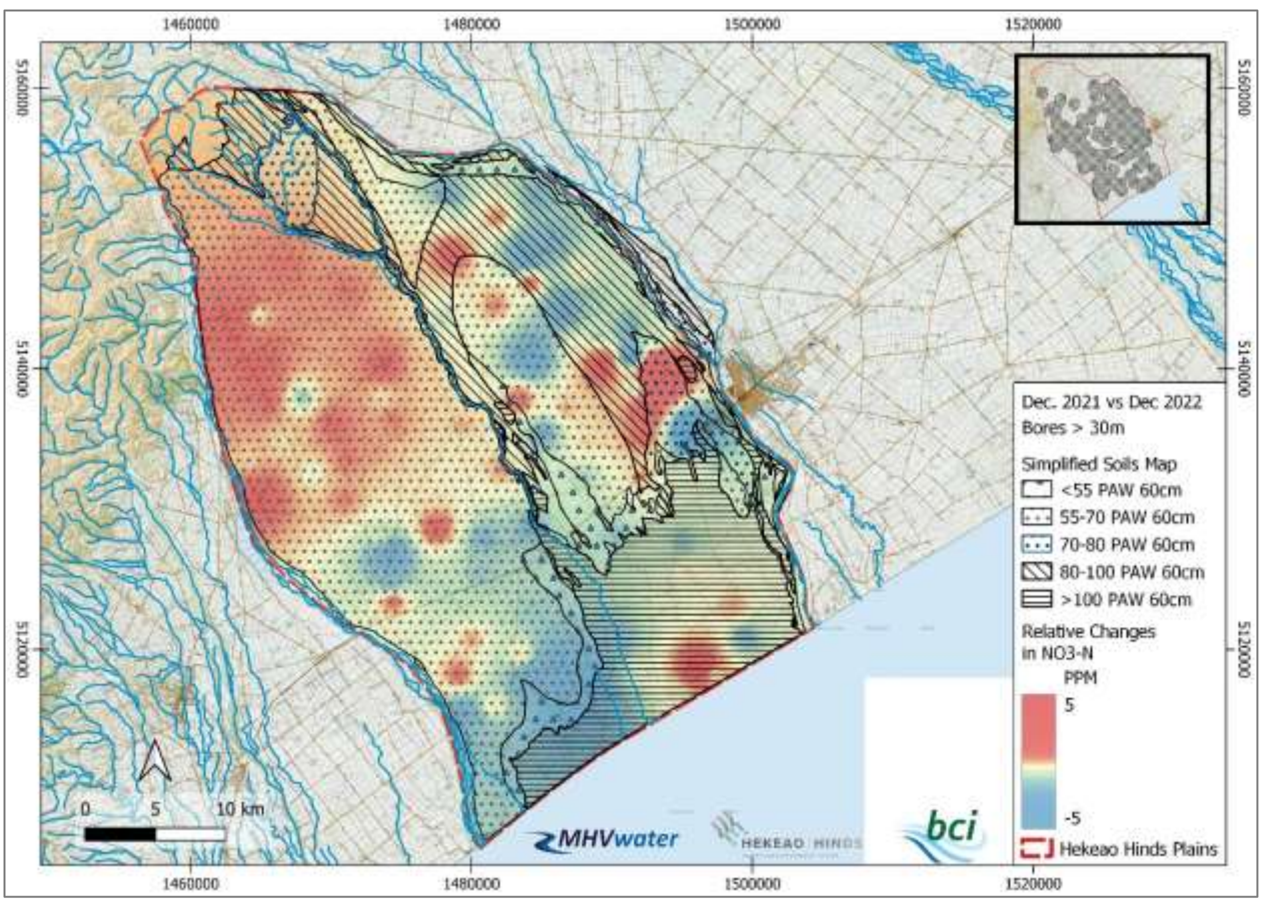


Figure 71 Relative changes in NO_3-N between Dec 2021 & Dec 2022 for bores >30m deep with simplified soil map

10.4. Nitrate response with River Flow

As outlined, in section 3.4 close connectivity between surface waters and shallow groundwater across the Hekeao Hinds plains. Following the rainfall event in 2021, MHV postulated that conventional dispersion flow pathways may become overwhelmed due to high rainfall recharge. Consequently, further rainfall in the upper catchment pressurised the already saturated groundwater system thus enabling migration of NO_3-N s in groundwater despite the absence of rain on the Hekeao Hinds Plains.

Following this observation, MHV installed a GW50 in a shallow bore in Lowcliffe in early 2022 to record real-time variations in NO_3-N and standing water levels at Lowcliffe. Following a period of calibration, MHV started collecting data in May 2022 (Figure 72).

The results from the probe as well as river flow and rainfall data confirm a close temporal relationship between rainfall, river flow, groundwater levels and NO_3-N concentrations. Whilst it is acknowledged that it is usually very difficult to tease apart which individual response as river flow is driven by rainfall, the data supports the idea that river flow (lateral flow) is a primary driver of NO_3-N migration rather than rainfall recharge (vertical flow).

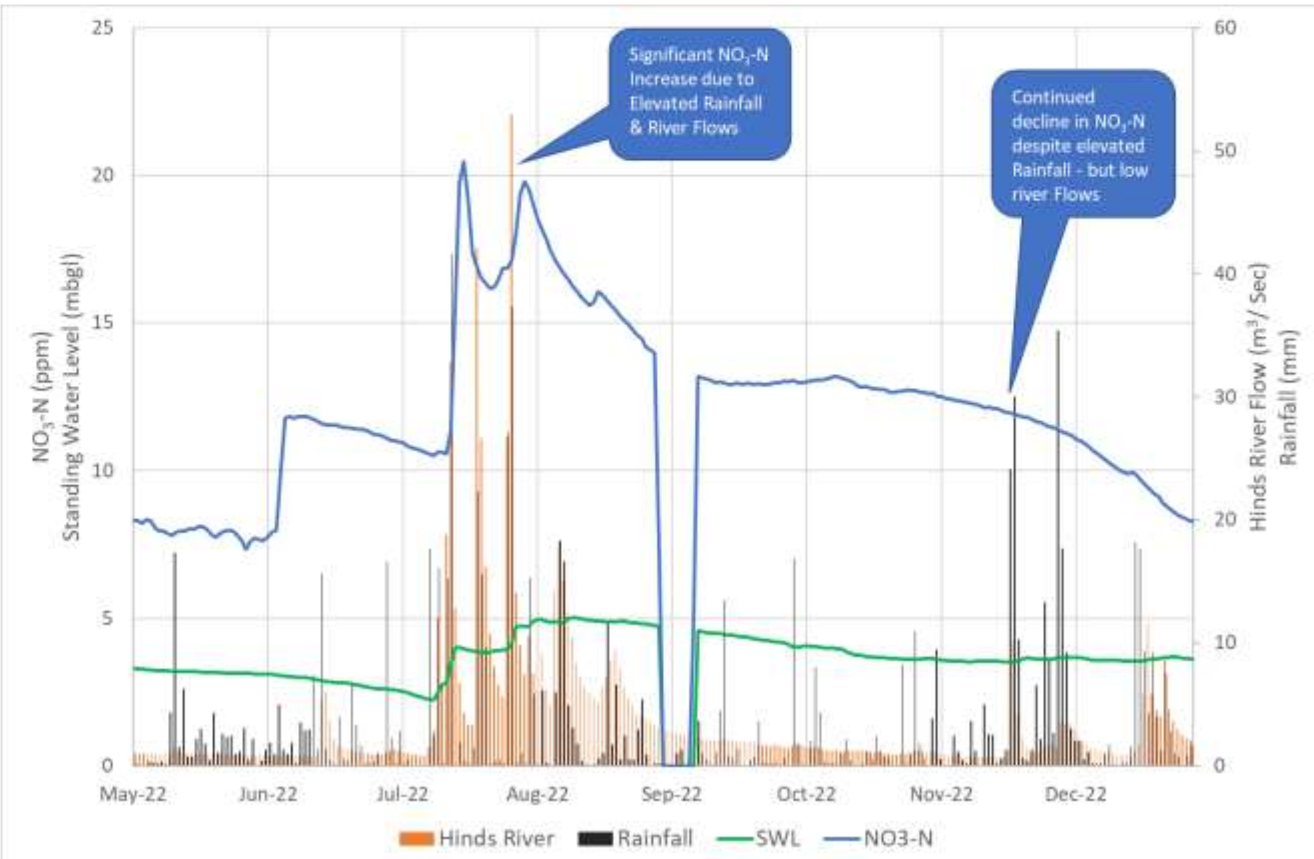


***Figure 72** Daily rainfall and Hekeao Hinds River flow data with real-time NO_3-N and SWL data from Lowcliffe*

10.5. Nitrate Response with Geological Structures

In section 9, it was postulated that faults mapped at 1:250,000 by Institute of Geological and Nuclear Sciences (GNS) could be interpreted as a Horst and Graben set which in turn may affect the transmissivity at depths greater than 65m.

When the relative changes in NO_3-N are compared with the mapped faults, there appears to be a differential in the NO_3-N data that is spatially coincident with the faults in the southwest area of the catchment.

It should be noted that this observation and hypothesis is considered conceptual and further investigation is required to validate this idea.

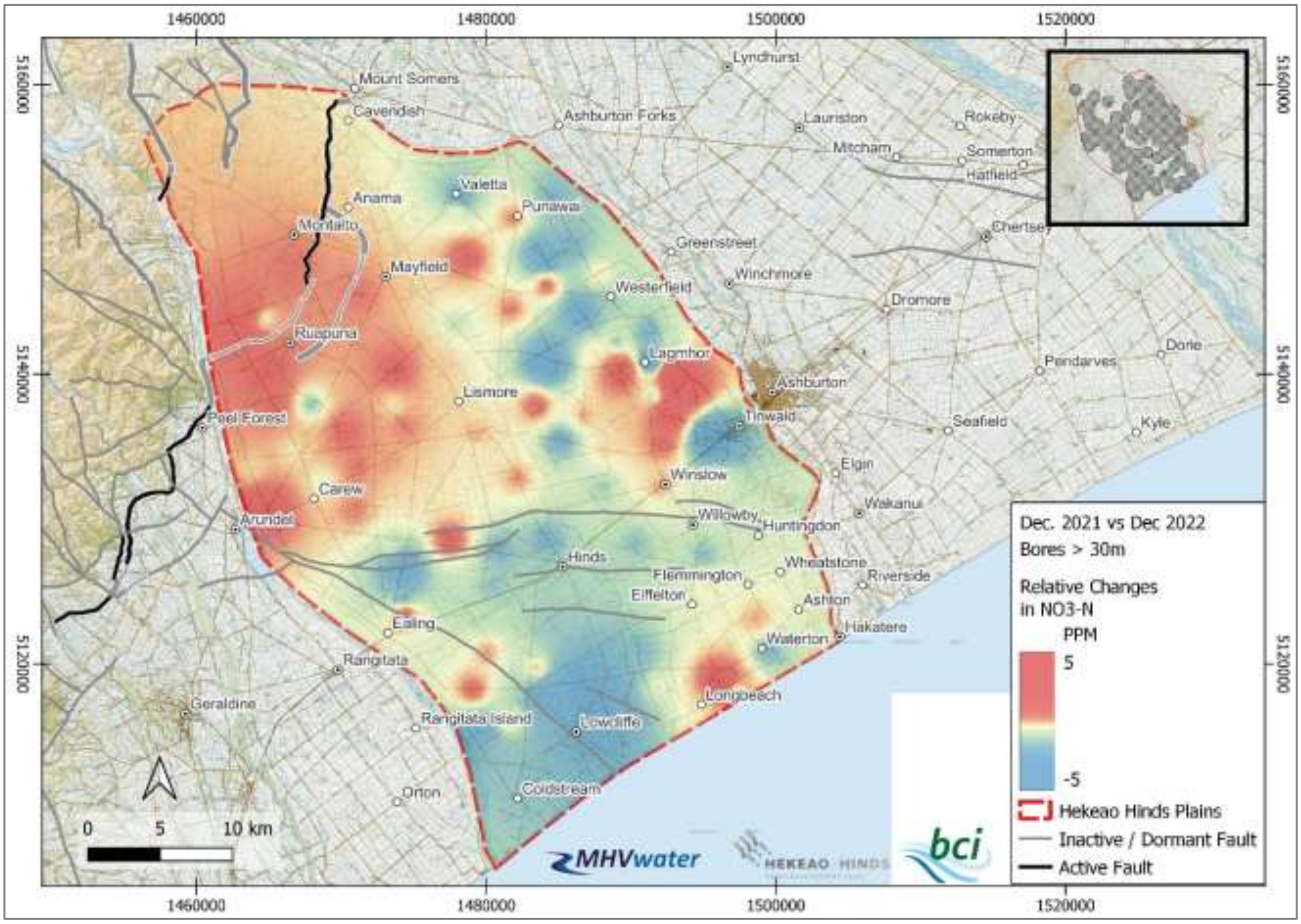


Figure 73 Relative changes in NO_3-N between Dec 2021 & Dec 2022 for bores >30m deep with mapped faults

11. Conclusions

> *It's always the small pieces that make the big picture*
>
> *Unknown*

With each successive year, we are developing a more robust conceptual model of NO_3-N migration and retention across the Hekeao Hinds Plains. The data for 2022 suggests that due to extensive rain in June and December, NO_3-N concentrations have essentially remained stagnant similar to the above average rainfall 2021 year with variations within ± 10%.

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

- NO_3-N migration is controlled by rainfall and river flow across thew catchment.
- There appears to be a relationship with soil type and NO_3-N response.
- Lateral flow of water via mechanisms such as open framework gravels appear to be the more dominant mechanism for subsurface NO_3-N migration than vertical flow associated with rainfall.

It is hoped that further work and research under the auspice of the Hekeao Hinds Science Collaboration Group will help confirm these observations and provide some strategies to resolve them.

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. I am a current member of the following professional initiations:
    a. The Australian Institute of Geoscientists
    b. The Hydrological Society of New Zealand
    c. The New Zealand Freshwater Science Society
5. 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
6. 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.
7. 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'.*
8. 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.
9. 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

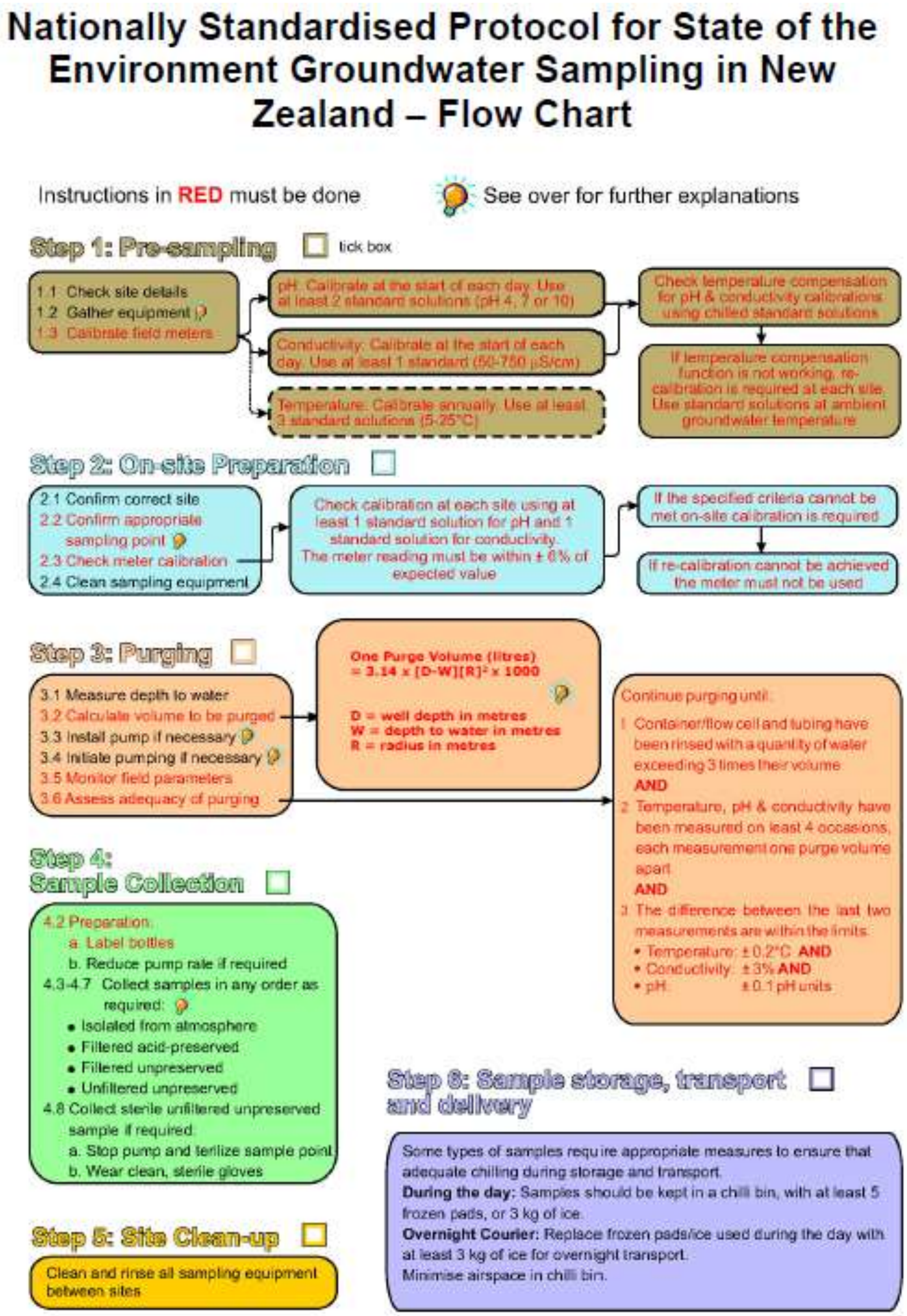
Map Projections

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

Figure 74 Well head with alkathene conduit

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 74.

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.

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 75)	None – but noted as tank sample

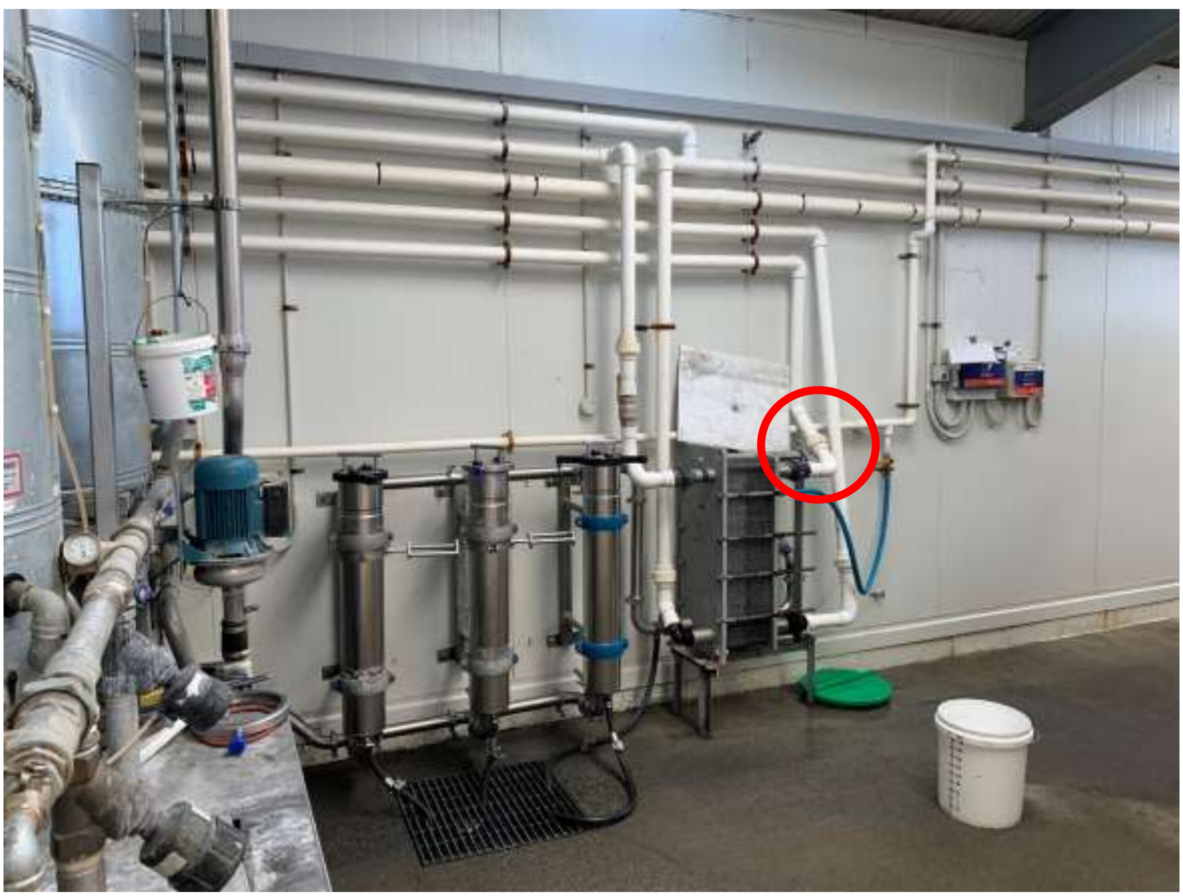


Figure 75 Example of a low flow tap next to milk filter in dairy shed

Appendix 5

Regression Charts for GW50

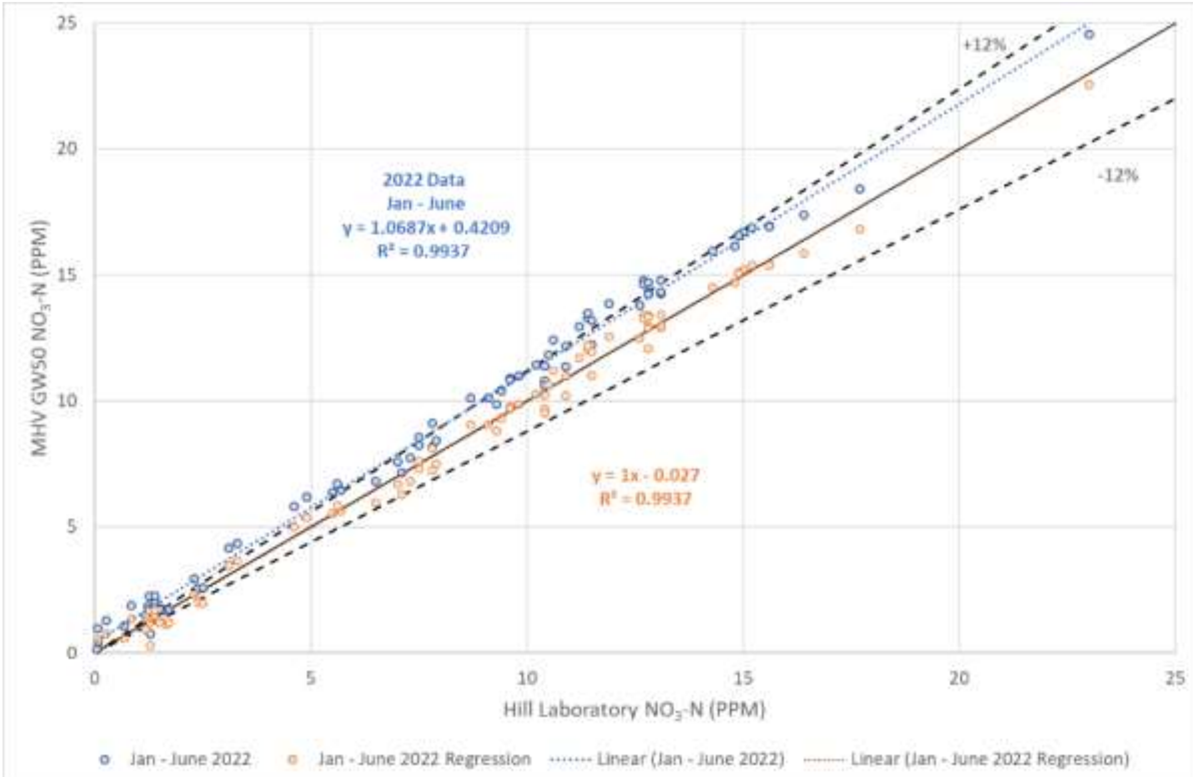


***Figure 76** Data for pre and post regression of MHV NO_3-N data January – June 2022*

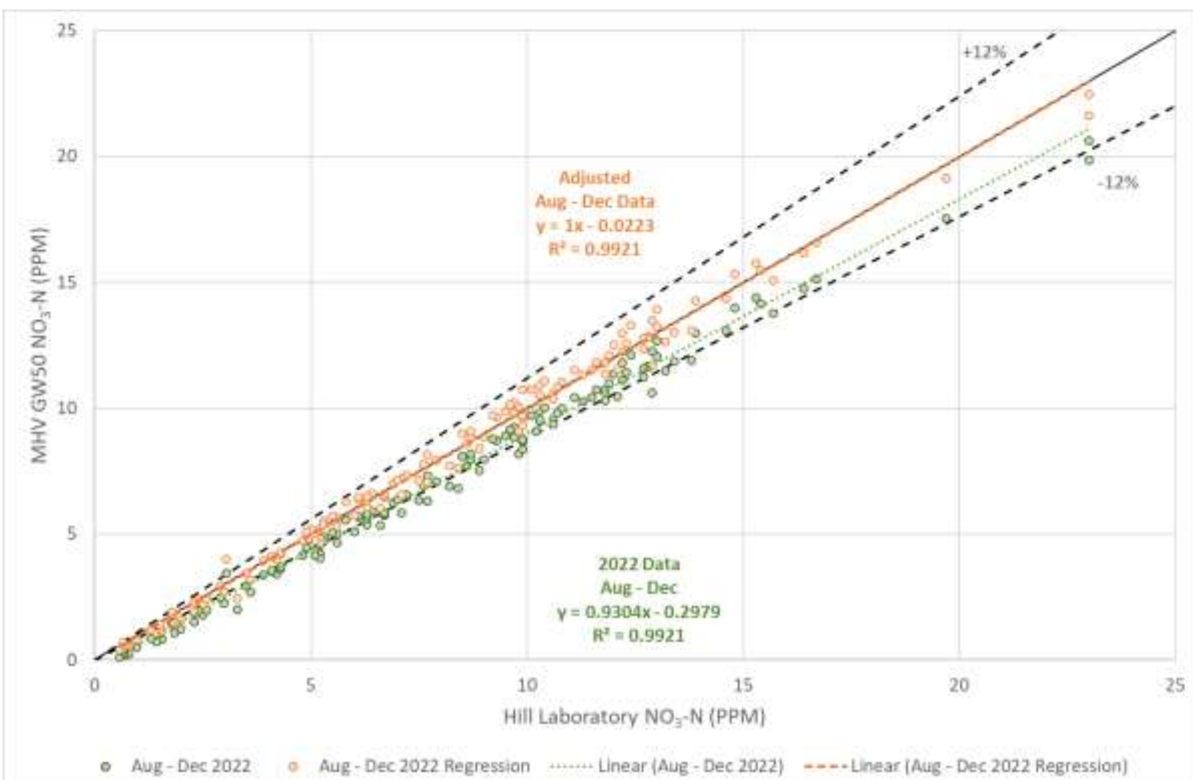


***Figure 77** Data for pre and post regression of MHV NO_3-N data August – December 2022*

Appendix 6

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 7

2022 NO_3-N Results for Surface water

Descriptive Summary Statistics of NO_3-N for Drains

Month	Count	Min	Max	Average	median	Std Dev	CV
Jan	3	3.65	13.43	9.70	12.02	5.28	0.54
Feb	3	5.63	12.93	10.27	12.23	4.03	0.39
Mar	3	3.47	12.54	9.07	11.21	4.90	0.54
Apr	4	1.71	13.35	8.62	9.71	5.34	0.62
May	5	0.56	13.73	6.95	6.41	6.12	0.88
Jun	4	1.20	13.35	8.13	8.98	5.72	0.70
Aug	4	6.47	12.52	9.18	8.86	2.70	0.29
Sep	6	3.81	13.78	10.32	11.97	4.14	0.40
Oct	4	1.08	13.21	8.01	8.87	5.54	0.69
Nov	6	1.21	12.77	7.52	8.80	5.30	0.70
Dec	5	3.68	13.09	9.42	12.10	4.27	0.45

Table 13 Descriptive Summary Statistics of NO_3-N for HMWC's

Month	Count	Min	Max	Average	median	Std Dev	CV
Jan	20	0.32	14.95	9.82	12.05	4.63	0.47
Feb	35	1.69	15.11	11.05	12.29	3.39	0.31
Mar	21	0.00	14.71	10.03	11.81	4.19	0.42
Apr	27	0.45	14.86	8.36	10.16	4.86	0.58
May	23	0.42	13.94	8.48	10.42	5.01	0.59
Jun	25	0.41	13.89	8.04	10.01	4.96	0.62
Aug	31	1.46	15.15	9.66	10.31	3.28	0.34
Sep	34	4.14	14.94	9.65	9.93	3.06	0.32
Oct	30	0.59	13.67	8.59	10.32	3.66	0.43
Nov	36	0.43	15.24	8.60	10.38	4.42	0.51
Dec	33	1.06	14.27	8.34	8.08	4.09	0.49

Table 14 Descriptive Summary Statistics of NO_3-N for River's

Month	Count	Min	Max	Average	median	Std Dev	CV
Jan	12	0.14	8.02	3.24	2.97	2.70	0.83
Feb	13	0.46	5.54	2.55	2.64	1.74	0.68
Mar	13	0.42	5.99	2.65	2.76	1.94	0.73
Apr	12	0.14	7.85	3.29	2.87	2.64	0.80
May	11	0.15	8.48	3.65	3.50	3.00	0.82
Jun	14	0.00	6.94	2.51	2.20	2.14	0.85
Aug	12	0.73	4.83	2.68	2.89	1.40	0.52
Sep	11	0.46	6.40	3.59	4.09	2.17	0.61
Oct	8	2.69	6.59	4.43	4.14	1.51	0.34
Nov	11	0.36	8.04	4.31	4.06	2.60	0.60
Dec	16	0.33	6.23	2.25	1.67	1.95	0.86

2022 NO_3-N Results for Ground water

Table 15 All Bores

Month	No. of Samples	Min NO_3-N	Max NO_3-N	Average NO_3-N	Median NO_3-N	Std Dev NO_3-N	CV NO_3-N
Jan	63	0.41	17.98	9.65	9.91	4.05	0.42
Feb	51	0.14	17.26	9.74	9.62	4.15	0.43
Mar	133	0.11	19.09	8.39	8.25	4.28	0.51
Apr	56	0.33	24.03	10.02	10.26	4.38	0.44
May	109	0.73	17.67	8.62	8.52	3.93	0.46
Jun	82	0.24	23.29	8.40	8.68	4.27	0.51
Aug	71	1.08	19.13	9.02	8.78	4.18	0.46
Sep	67	0.51	23.25	7.73	8.39	4.14	0.54
Nov	105	0.35	25.30	8.96	9.57	3.76	0.42
Dec	37	0.88	20.45	7.54	6.94	4.72	0.63
Total	774	0.11	25.30	8.77	9.05	4.18	0.48

Table 16 Bores < 30m

Month	No. of Samples	Min NO_3-N	Max NO_3-N	Average NO_3-N	Median NO_3-N	Std Dev NO_3-N	CV NO_3-N
Jan	33	1.17	17.98	9.78	10.14	4.34	0.44
Feb	25	0.90	17.26	10.61	10.46	3.95	0.37
Mar	39	0.11	17.87	9.48	10.00	4.49	0.47
Apr	29	2.03	16.11	9.94	10.75	3.94	0.40
May	32	1.25	16.45	9.62	10.65	3.97	0.41
Jun	38	0.24	15.57	8.63	9.81	4.22	0.49
Aug	22	1.15	16.57	10.01	10.91	4.67	0.47
Sep	20	1.48	13.68	8.63	9.49	3.36	0.39
Nov	33	0.35	15.37	9.54	11.02	4.04	0.42
Dec	12	0.88	20.45	8.77	7.76	4.87	0.56
Total	283	0.11	20.45	9.52	10.21	4.16	0.44

Table 17 Bores 30 to 80m deep

Month	No. of Samples	Min NO_3-N	Max NO_3-N	Average NO_3-N	Median NO_3-N	Std Dev NO_3-N	CV NO_3-N
Jan	22	0.41	15.63	10.15	9.98	3.90	0.38
Feb	19	0.14	16.67	9.85	9.53	4.44	0.45
Mar	59	0.56	19.09	8.89	9.27	4.45	0.50
Apr	20	0.33	24.03	11.11	10.85	5.12	0.46
May	51	0.73	17.67	8.84	9.18	4.26	0.48
Jun	29	0.40	23.29	9.50	9.52	4.41	0.46
Aug	28	1.08	19.13	9.60	9.41	4.13	0.43
Sep	32	0.51	23.25	8.40	8.96	4.61	0.55
Nov	42	3.07	25.30	10.07	9.95	3.61	0.36
Dec	20	1.10	19.53	7.63	8.04	4.90	0.64
Total	322	0.14	25.30	9.31	9.53	4.36	0.47

Table 18 Bores >80m deep

Month	No. of Samples	Min NO_3-N	Max NO_3-N	Average NO_3-N	Median NO_3-N	Std Dev NO_3-N	CV NO_3-N
Jan	8	2.54	11.07	7.75	7.89	2.98	0.38
Feb	7	2.65	9.69	6.33	6.01	2.30	0.36
Mar	35	1.99	13.21	6.35	6.34	2.96	0.47
Apr	7	2.96	10.90	7.27	6.68	2.72	0.37
May	26	2.97	11.68	6.95	6.51	2.57	0.37
Jun	15	1.97	11.24	5.71	4.84	3.04	0.53
Aug	21	1.97	14.35	7.21	6.57	3.18	0.44
Sep	15	1.50	11.19	5.11	4.87	2.96	0.58
Nov	30	1.98	12.65	6.77	6.56	2.67	0.40
Dec	5	2.67	6.94	4.27	3.21	1.88	0.44
Total	169	1.50	14.35	6.50	6.29	2.86	0.44

56 Rain Bores data

Table 19 All Bore Depths

Week Ending	Count	Raw Min	Raw Max	Raw Average	Raw Median	R^2 Average	R^2 Median
Results for corresponding bores in March 2021	56	0.43	21.25	9.11	9.97	8.10	8.91
5/06/2021	55	0.00	36.22	11.67	10.53	10.50	9.43
12/06/2021	56	0.06	36.81	12.11	11.05	10.91	9.92
18/06/2021	56	0.15	35.11	12.32	12.03	11.11	10.84
25/06/2021	55	0.36	29.40	12.27	11.59	11.06	10.42
2/07/2021	57	0.53	29.09	12.32	11.79	11.11	10.61
9/07/2021	53	0.36	23.53	11.78	11.51	10.60	10.34
23/07/2021	56	0.48	24.59	12.38	11.82	11.16	10.64
6/08/2021	55	0.61	24.65	12.52	12.49	11.29	11.27
15/09/2021	55	0.57	24.62	11.99	11.36	10.80	10.21
8/10/2021	55	0.78	25.15	11.90	11.58	10.72	10.41
12/11/2021	55	0.92	25.00	11.56	11.42	10.39	10.26
10/12/2021	55	0.60	25.03	10.32	10.67	9.24	9.56
8/01/2022	55	0.89	24.74	11.14	10.94	10.00	9.82
4/02/2022	57	0.60	24.70	11.13	11.16	9.99	10.02
4/03/2022	56	1.04	24.91	10.85	10.89	9.73	9.77
4/04/2022	55	0.002	18.42	10.57	11.10	9.47	9.96
4/05/2022	53	1.23	17.37	10.31	10.75	9.23	9.64
4/06/2022	52	0.87	17.62	9.69	10.79	8.64	9.67
4/09/2022	57	0.20	15.14	7.95	8.57	8.84	9.51
4/12/2022	57	0.54	14.34	7.71	8.58	8.58	9.52

Table 20 Bores <30m deep

Week Ending	Count	Raw Min	Raw Max	Raw Average	Raw Median	R^2 Average	R^2 Median
Results for corresponding bores in March 2021	29	0.54	21.25	9.46	10.55	8.43	9.45
5/06/2021	28	1.80	36.22	13.01	11.62	11.75	10.45
12/06/2021	28	0.64	36.81	13.87	13.36	12.55	12.08
18/06/2021	29	1.07	35.11	14.04	13.11	12.72	11.85
25/06/2021	28	2.49	29.40	13.90	11.90	12.58	10.71
2/07/2021	30	3.20	29.09	13.91	12.42	12.59	11.20
9/07/2021	27	2.95	23.53	13.09	11.77	11.83	10.60
23/07/2021	29	3.75	24.59	13.70	13.37	12.39	12.09
6/08/2021	30	4.98	24.65	13.77	13.72	12.46	12.41
17/09/2021	29	4.02	24.62	13.36	13.84	12.08	12.53
8/10/2021	31	2.24	25.15	13.40	13.41	12.12	12.13
12/11/2021	31	2.02	25.00	12.78	13.14	11.54	11.88
10/12/2021	29	2.02	25.03	10.60	10.97	9.50	9.84
8/01/2022	28	3.00	24.74	11.79	11.39	10.61	10.24
4/02/2022	29	1.41	24.70	11.48	11.59	10.32	10.43
4/03/2022	30	1.92	24.91	11.17	11.16	10.03	10.02
4/04/2022	28	2.62	16.37	10.84	11.92	9.72	10.73
4/05/2022	26	1.78	16.43	10.43	11.83	9.34	10.65
4/06/2022	27	1.61	15.85	9.31	10.97	8.29	9.84
4/09/2022	29	0.79	15.14	8.01	9.13	8.90	10.11
4/12/2022	28	0.54	11.95	7.50	8.87	8.36	9.83

Table 21 Bores >30m deep

Week Ending	Count	Raw Min	Raw Max	Raw Average	Raw Median	R^2 Average	R^2 Median
Results for corresponding bores in March 2021	27	0.43	16.27	8.73	9.77	7.75	8.73
5/06/2021	27	0.00	17.17	10.28	10.29	9.20	9.21
12/06/2021	28	0.06	16.64	10.20	10.33	9.13	9.25
18/06/2021	27	0.15	16.26	10.48	11.16	9.38	10.02
25/06/2021	27	0.36	16.68	10.58	11.07	9.48	9.94
2/07/2021	27	0.53	15.59	10.57	11.11	9.46	9.97
9/07/2021	26	0.36	16.72	10.42	11.05	9.33	9.92
23/07/2021	27	0.48	17.50	10.97	11.35	9.84	10.19
6/08/2021	25	0.61	17.88	11.02	11.65	9.89	10.48
15/09/2021	26	0.57	18.29	10.47	10.95	9.37	9.83
8/10/2021	24	0.78	18.17	9.96	10.32	8.90	9.23
12/11/2021	24	0.92	20.25	9.98	9.98	8.92	8.92
10/12/2021	27	0.60	17.16	9.94	10.22	8.88	9.14
8/01/2022	27	0.89	17.06	10.47	10.55	9.38	9.46
4/02/2022	28	0.60	18.26	10.77	10.77	9.66	9.65
4/03/2022	26	1.04	17.24	10.48	10.74	9.38	9.63
4/04/2022	27	0.00	18.42	10.29	10.78	9.21	9.66
4/05/2022	27	1.23	17.37	10.20	10.16	9.13	9.08
4/06/2022	25	0.87	17.62	10.09	10.67	9.02	9.56
4/09/2022	28	0.20	14.10	7.89	8.44	8.78	9.36
4/12/2022	29	2.20	14.34	7.91	7.73	8.80	8.61

Appendix 8

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

Aquifer An aquifer is a body of saturated rock through which water can easily move. Aquifers must be both permeable and porous and include such rock types as sandstone, conglomerate, fractured limestone and unconsolidated sand and gravel

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 Figure 78 (Brikowski 2013).

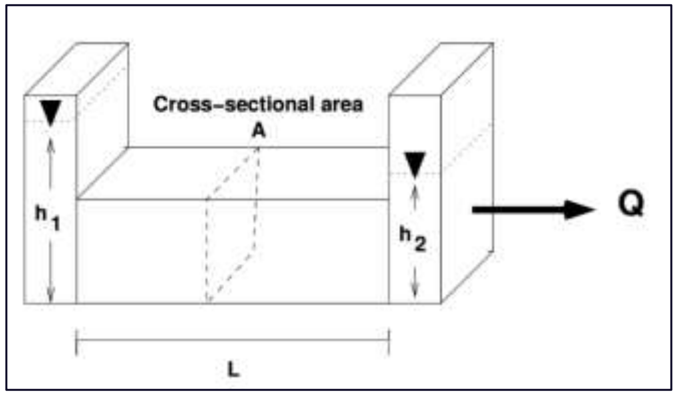


Figure 78 Schematic representation of Darcy's Law

The *Permeability* (**K**) of the material is derived from the *'Kozeny–Carman Equation'* $K = Cd^2$ 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:

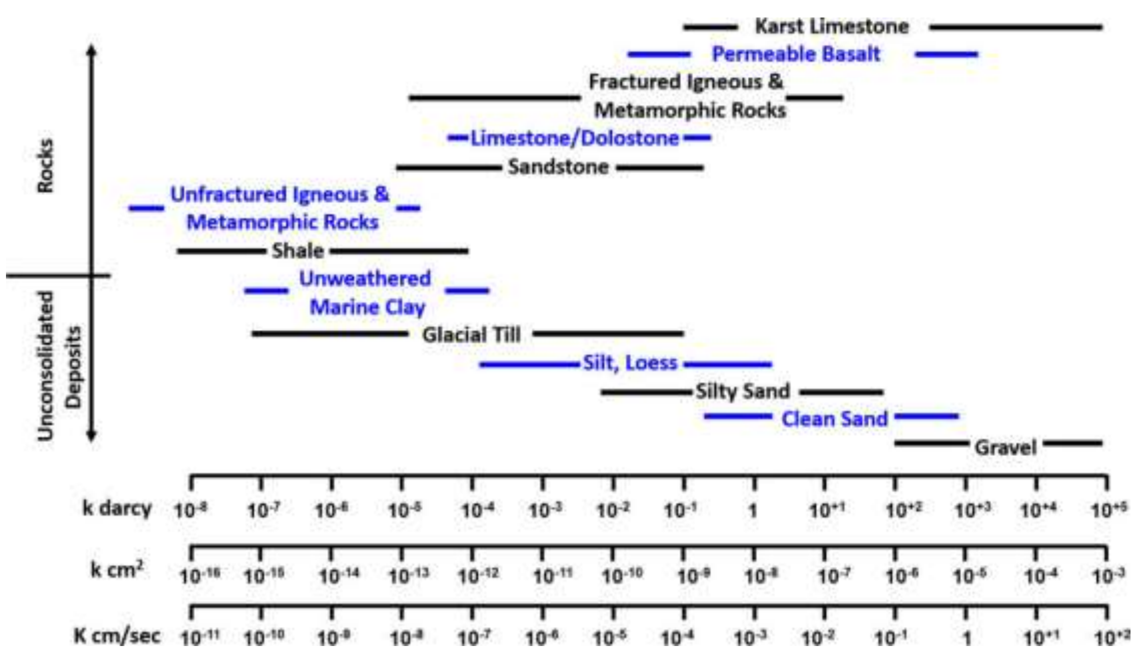
$$Q = -KA\,(h_1 - h_2)/L$$

Dissolved Oxygen a relative measure of the amount of oxygen (O_2) dissolved in water.

Freshwater Water of salinity less than 1,000 mg/L

Hydraulic conductivity (K) aka 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 [30].



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.

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.

Porosity The proportion of solids to voids in a sedimentary formation.

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.

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.

Transmissivity is the rate of flow under a unit hydraulic gradient through a unit width of aquifer of given saturated thickness. It is measured in m^2 per-day

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