Ground and Surface Water Monitoring Programme

2021 Annual Report

May 2022

Sustainable solutions for our community,
now and into the future

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HEKEAO / HINDS
WATER ENHANCEMENT TRUST

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MHVwater

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Mid Canterbury Catchment Collective	Duncan Barr	Chair

Executive Summary

Background

This report outlines and documents the ground and surface water monitoring programme conducted by MHV Water Ltd (MHV) during the 2021 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 the groundwater for the Hekeao Hinds Plains.

The 2021 Survey

The Canterbury Land and Water Regional Plan (LWRP) uses annualised statistics of water quality to track progress towards Plan Change 2 target of 6.9 ppm NO3-N in 'Spring-fed Plains' surface waterbodies of the Lower Hekeao Hinds Plains by 2035. By increasing the survey coverage will provide confidence that monitoring data is representative of the catchment.

In 2021 the programme was extended from 97 bores representing 92,300 hectares(ha) to 147 bores representing 106,200 ha via support from Barrhill Chertsey Irrigation (BCI)and the Hekeao Hinds Water Enhancement Trust (HHWET) – see Figure 1.

Between the 29th and 31st of May 2021, Canterbury experienced a 0.005% Annual Exceedance Probability (AEP) rain event, with an Average Recurrence Interval (ARI) of 1:200 years. Consequently, the catchment received three times the average May rainfall falling in a period of 7 days.

In response to this event, MHV immediately began a concurrent programme to monitor 56 bores on a weekly basis for a six-week period between 2nd June and 9th July. This was extended to a fortnightly basis until the COVID19 lockdown between 18th August and 8th September when monthly sampling was initiated. The survey area represented an area of 58,230 ha with 50% of the bores being <30 m deep (refer to Figure 2).

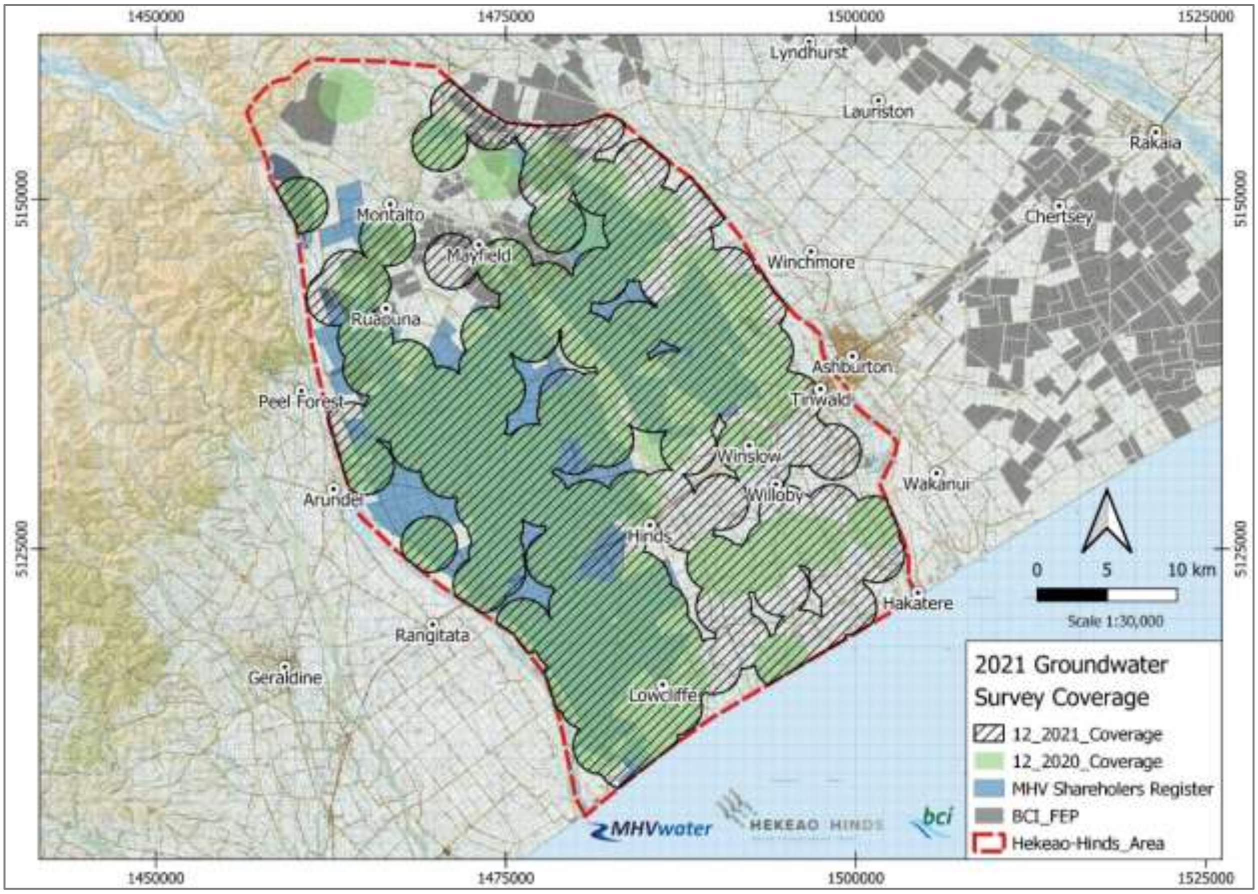

Figure 1 Comparison of 2020 and 2021 groundwater survey spatial footprint

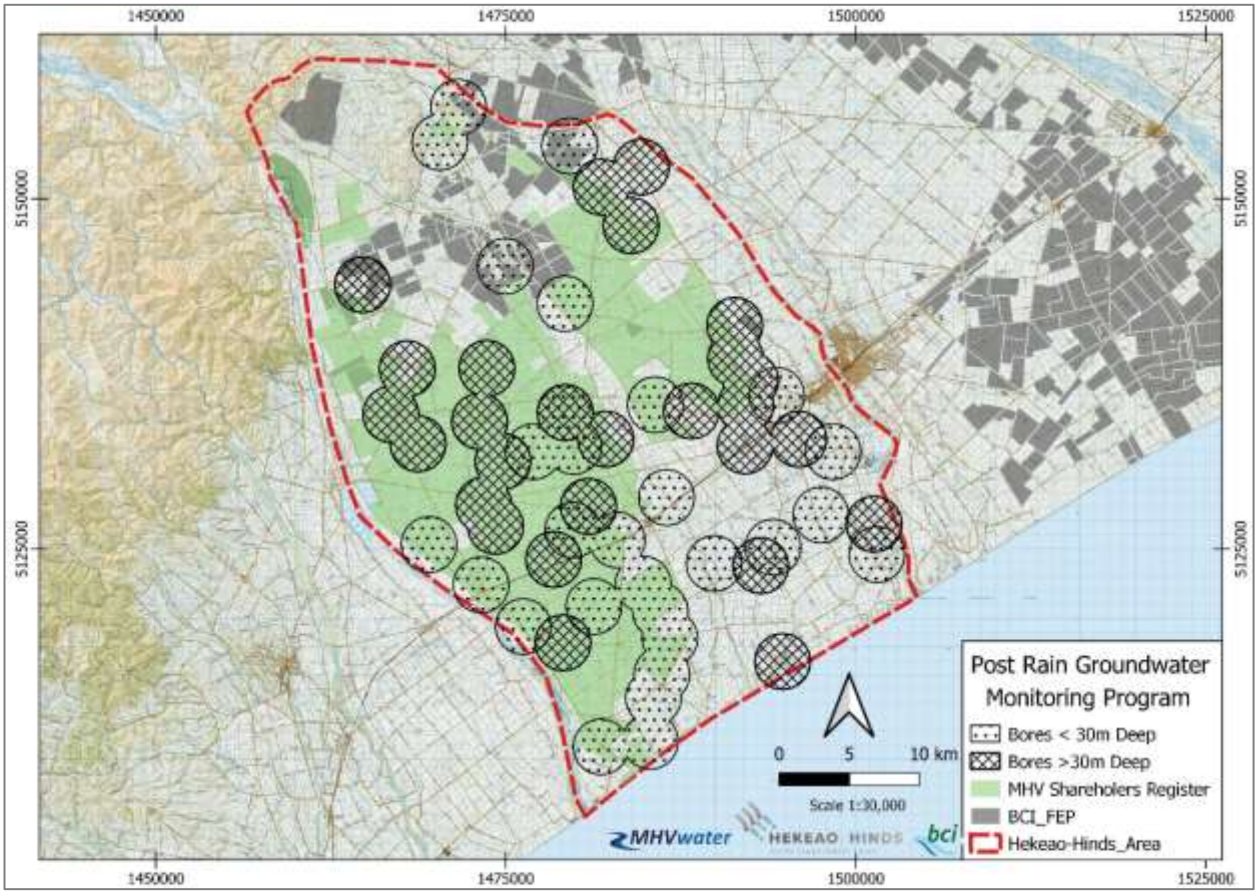

Figure 2 Spatial footprint of post rain event groundwater survey

Groundwater Results

Following the May-June rain, NO_3-N levels rose across the Hekeao Hinds catchment by an average of 30%, and then stared to decrease (Figure 3). However, further rain and subsequent increased river flows in July and August arrested the reduction in groundwater NO_3-N. By December 2021, NO_3-N concentrations had reduced to within 15% of March 2021 values (Figure 3).

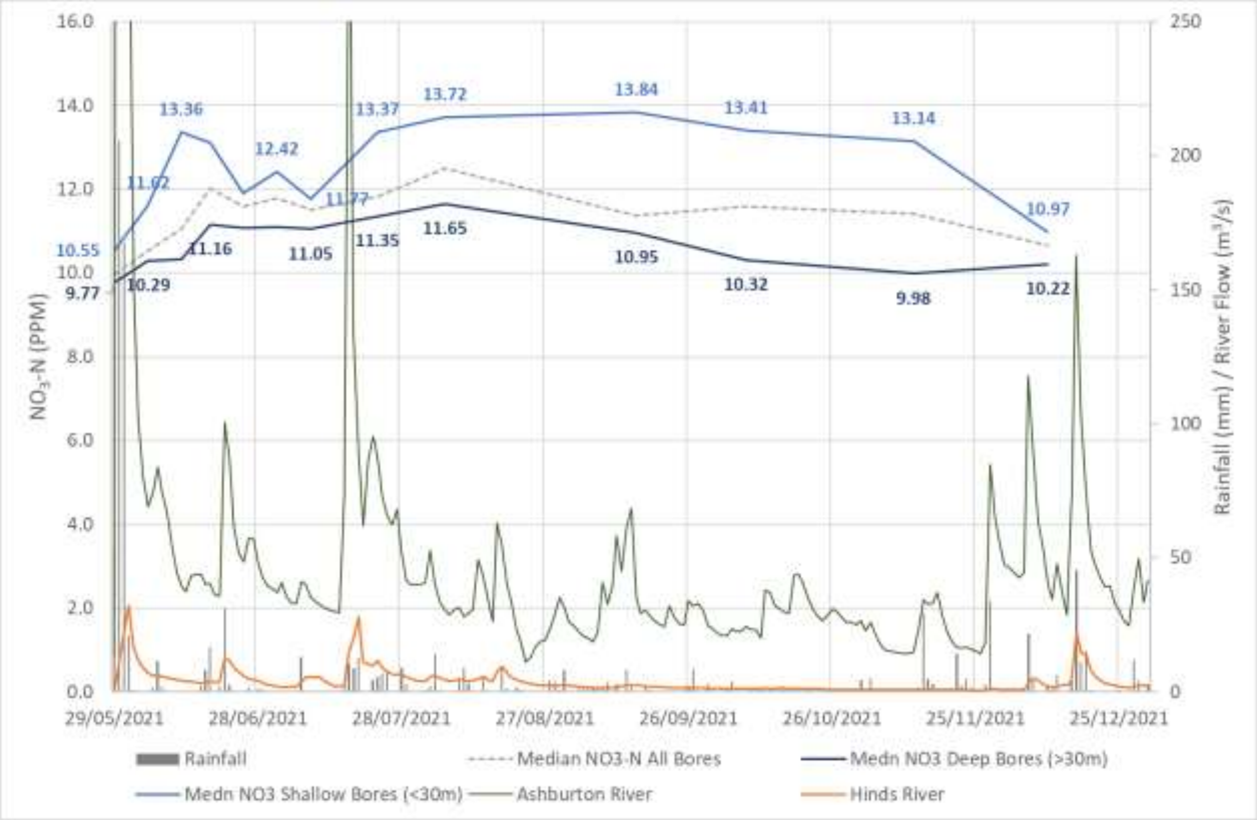

Figure 3 Average and median NO_3-N results for the 56 bores monitored immediately after the May-June 2021 rain event

By the conclusion of 2021, MHV had undertaken over 1000 groundwater samples across the Hekeao Hinds plains. Table 1 presents a summary of the results from bores sampled in 2021.

Table 1 Descriptive summary statistics for annualised NO_3-N results from bores sampled in 2021

Bore Depth	No. of Samples	Average	Median	Std. Dev	CV
<30 m	425	12.40	11.63	6.58	0.53
30-80 m	417	10.25	10.40	4.34	0.42
>80 m	181	8.10	7.05	3.79	0.47
All Depths	1023	10.77	10.53	5.54	0.51

The results for 2021 indicate a sustained decrease in NO_3-N concentrations in both shallow and deeper bores from the elevated values reported during June, with elevated NO_3-N concentrations restricted to the Lowcliffe and Coldstream areas; which is interpreted to be related to lag times and soils.

Figures 4 to 6 present the quarterly NO_3-N concentrations for MHV monitoring surveys since 2016. It is important to note that the survey size has changed over this time period, with the increasing survey size expected to produce an increasingly accurate representation of catchment-scale NO_3-N concentrations. Shallow and deep bore NO_3-N concentrations changes are shown to correlate with changing rainfall patterns. On-farm nutrient management improvements and groundwater enhancement projects such as Managed Aquifer Recharge / Near River Recharge have also accelerated during the presented time period.

On-going analysis is focussed on understanding how these improvements also contribute to the changing NO_3-N concentrations.

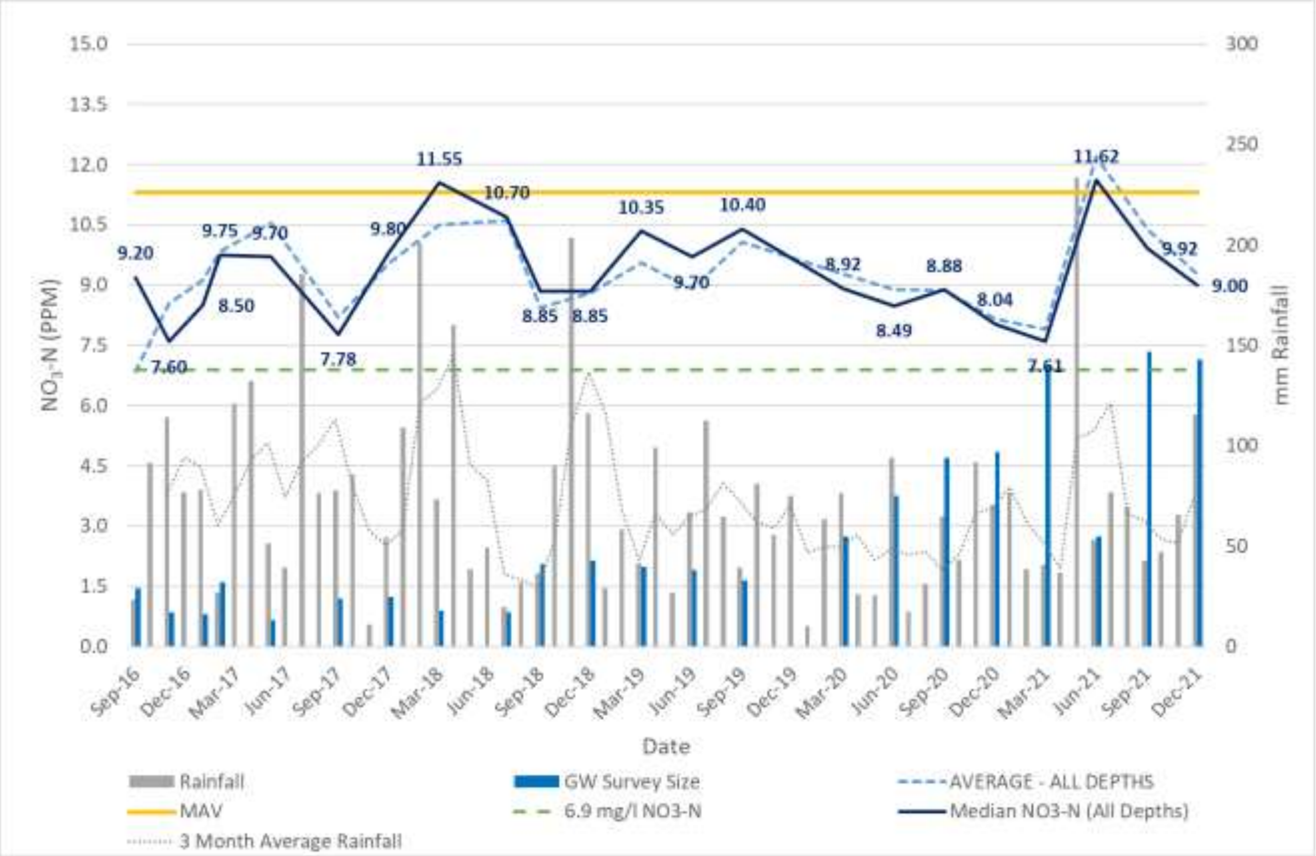

Figure 4 Average and median NO_3-N results for the MHV monitoring programmes for all bores between 2016 and 2021

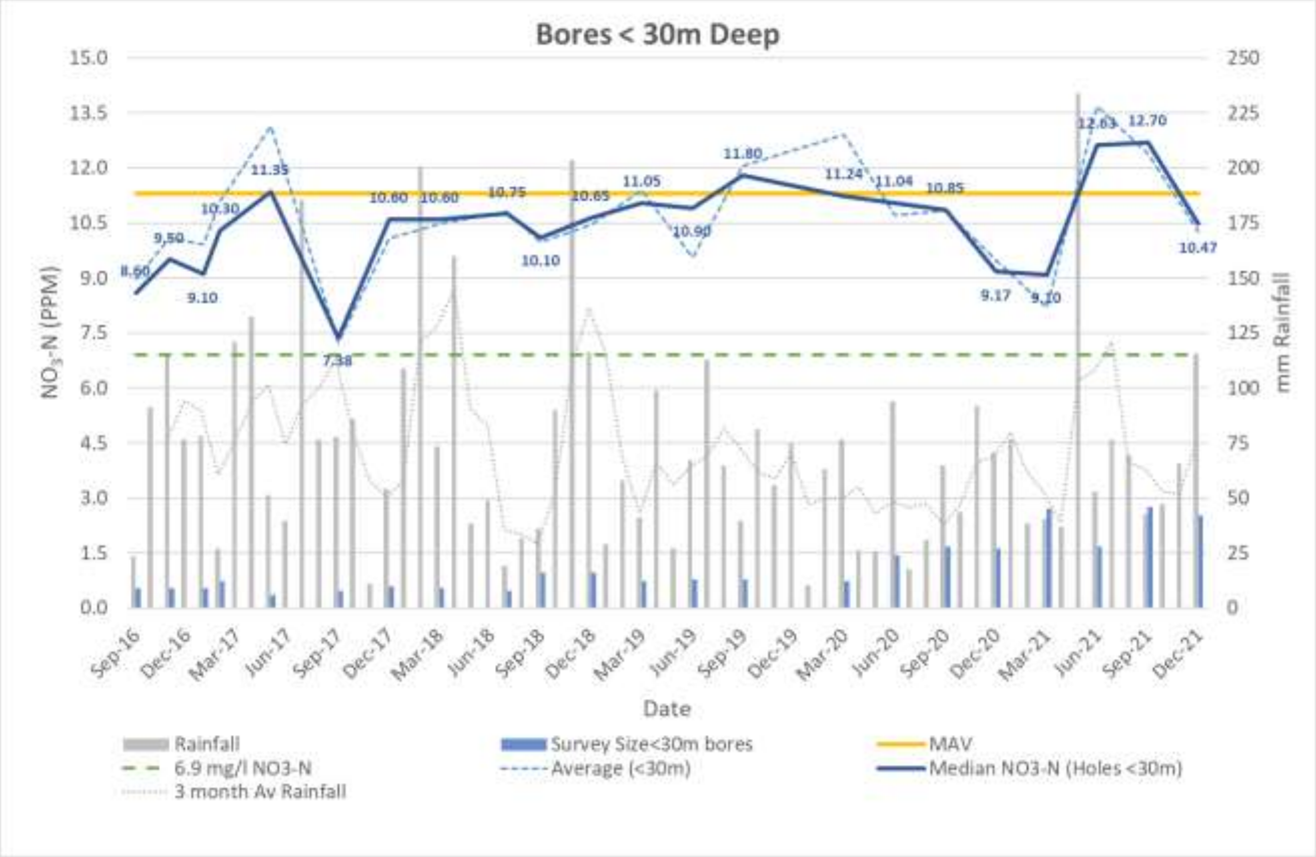

Figure 5 Average and median NO_3-N results for the MHV monitoring programme for bores <30m deep between 2016 and 2021

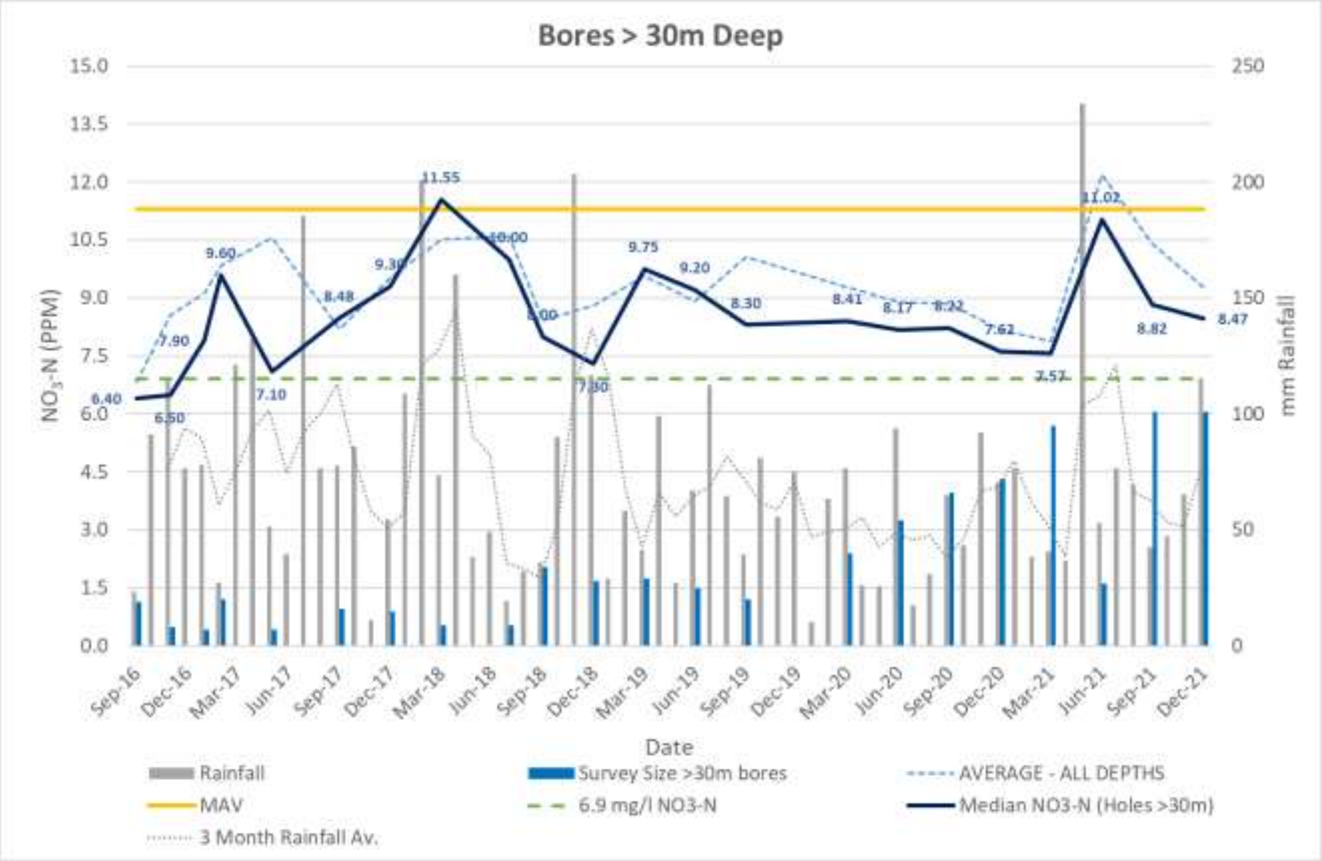

Figure 6   Average and median NO$_3$-N results for the MHV monitoring programme for bores >30m deep between 2016 and 2021

Surface Water Results

During 2021 MHV increased its surface water sampling programme significantly from an average of 10 samples per quarter to over 40 per month as shown in Figure 7†.

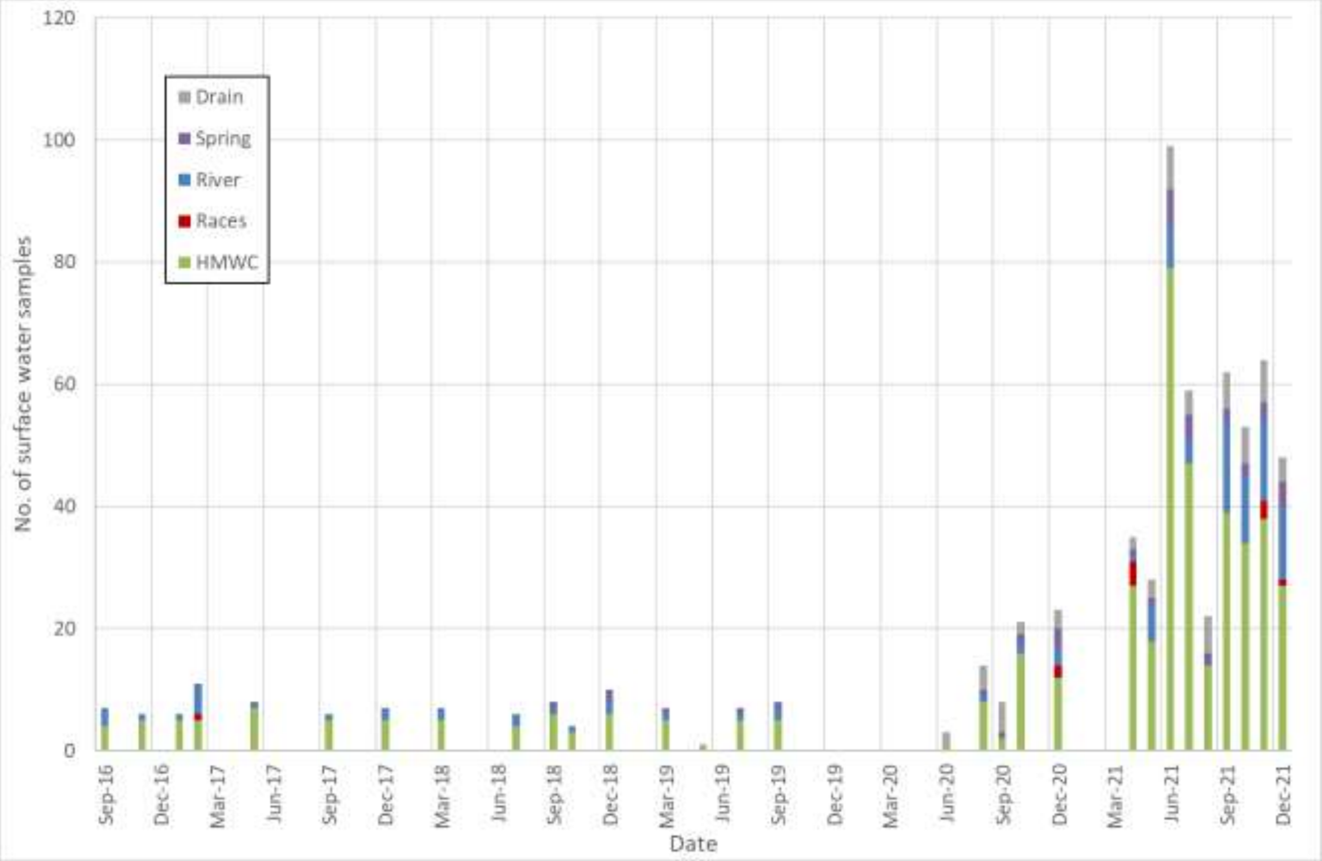

Figure 7 Changes in surface water monitoring programme 2016 to 2021

† HMWC – Highly Modified Water Course

NO_3-N concentrations in all the major waterways increased markedly after the May-June rain and peaked in late-July to early August (Figure 8).

It should be noted that there was extensive flooding across the Hekeao Hinds catchment in May-June. Subsequently, diffuse and point source nutrient leaching from sources such as:

a) septic tanks and leaky sewers;

b) urban runoff;

c) waste pits and landfill; and

d) soil and agricultural material

are likely to have contributed to the changes in NO_3-N concentrations [1].

Figure 8 Surface water NO$_3$-N 2021 results by different waterways

Groundwater Level Results

During the year, MHV collected 446 groundwater level soundings from 89 bores across the Hekeao Hinds Plains. Groundwater levels are generally at their highest in the winter months in response to Autumn - Winter recharge rainfall and the absence of abstraction. This year, there was a significant response in groundwater levels across the Hekeao Hinds Plains as result of the rainfall in June (Figure 9).

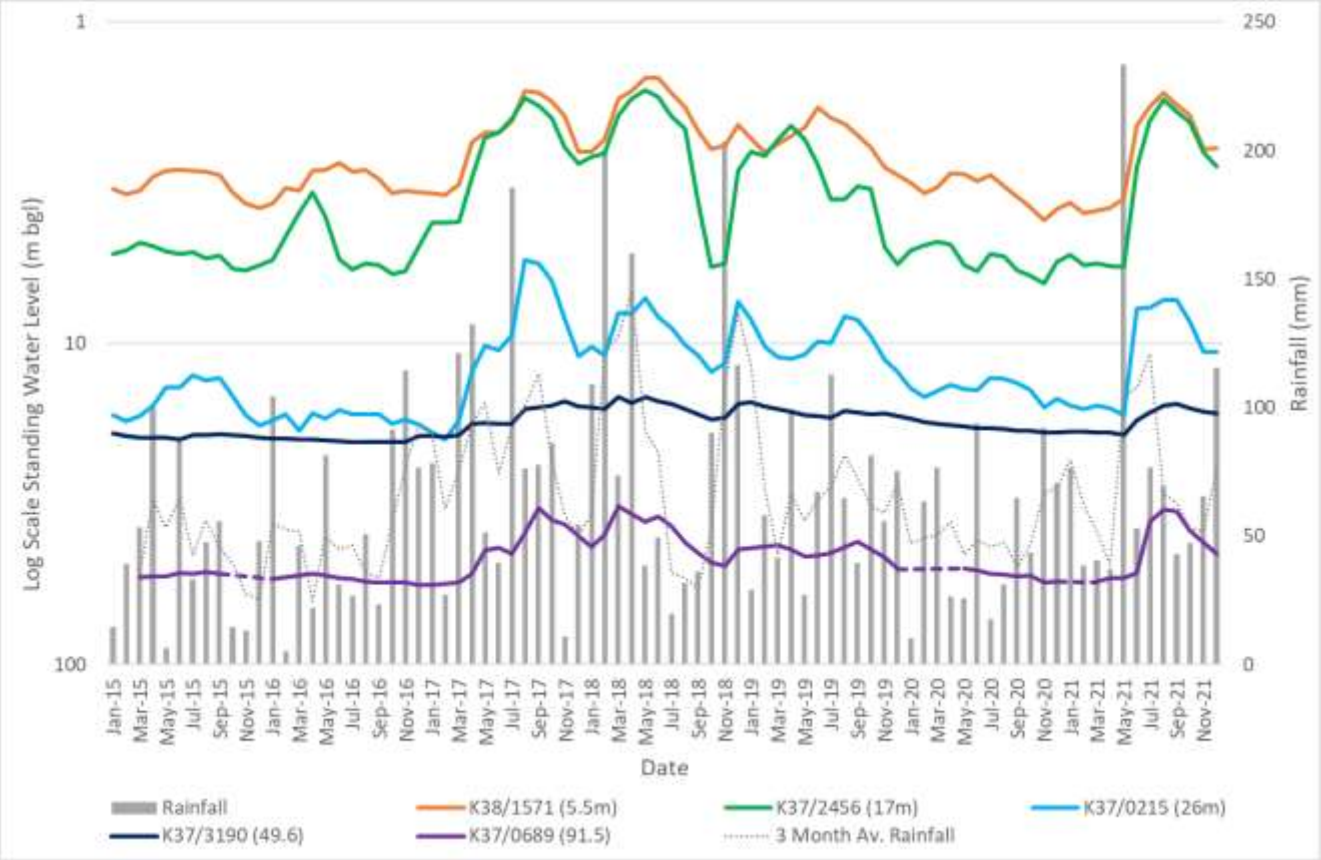

Figure 9 Hydrographs from ECan bores across the Hekeao Hinds Plains with rainfall 2015 to 2021.

The key drivers

3 key drivers have been identified as being influential on NO_3-N migration and concentration.

I. The heterogeneous nature **of geology and soils across** the plains resulted in differing NO_3-N responses across the Hekeao Hinds Plains (Figure 10). Notably, where significant increases were observed in the lower catchment, they were short lived with NO_3-N concentrations decreasing by 35% in <3 months.

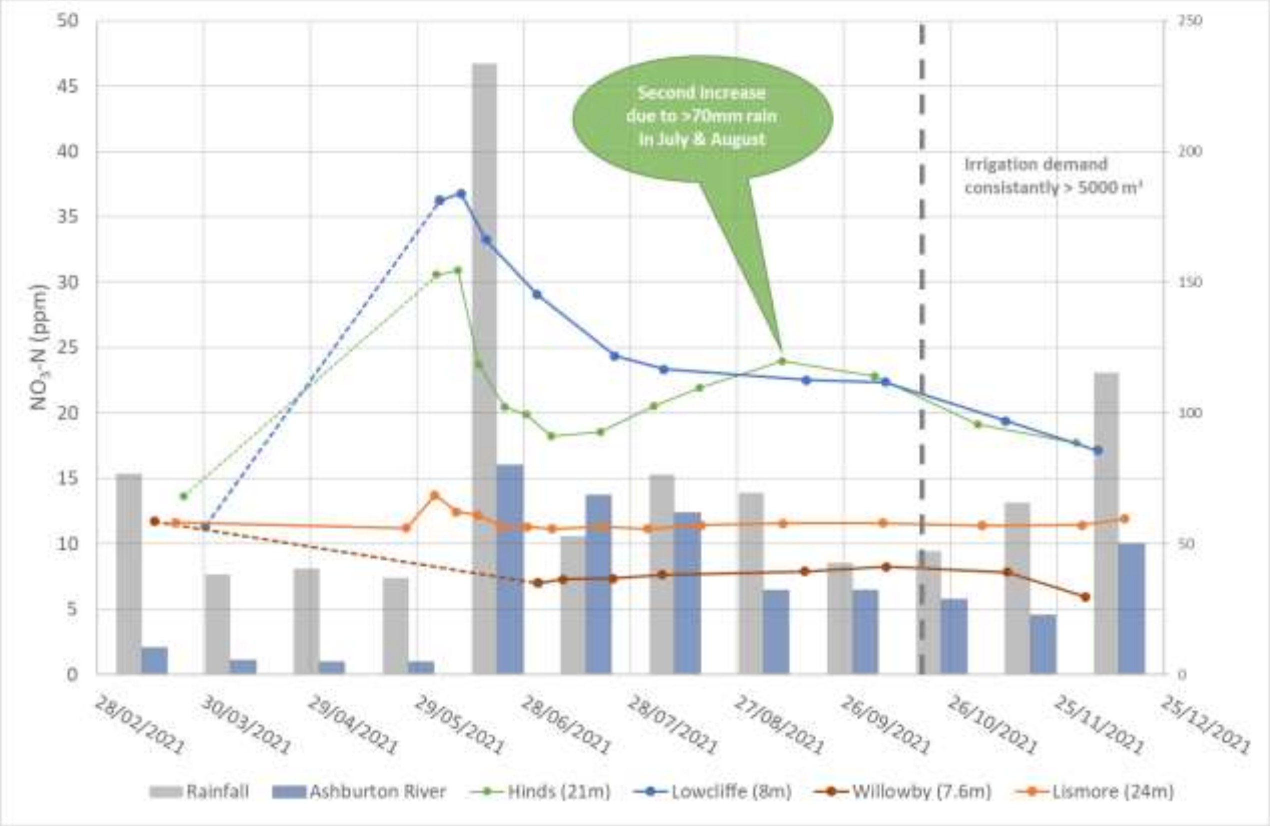

Figure 10 Heterogeneous response to NO_3-N concentrations in groundwater 2021

II. As shown in Figure 3, NO_3-N levels increased as expected following the May/ June rain and were further influenced by subsequent **rainfall events** and high **river flows** that mobilised NO_3-N in already saturated soils due to the 'hydraulic piston' effect.

III. The increase in **groundwater levels** in the lower catchment correlated with a reduction of NO_3-N in groundwater within Gley soils and an increase in NO_3-N in lighter Lismore Soils.

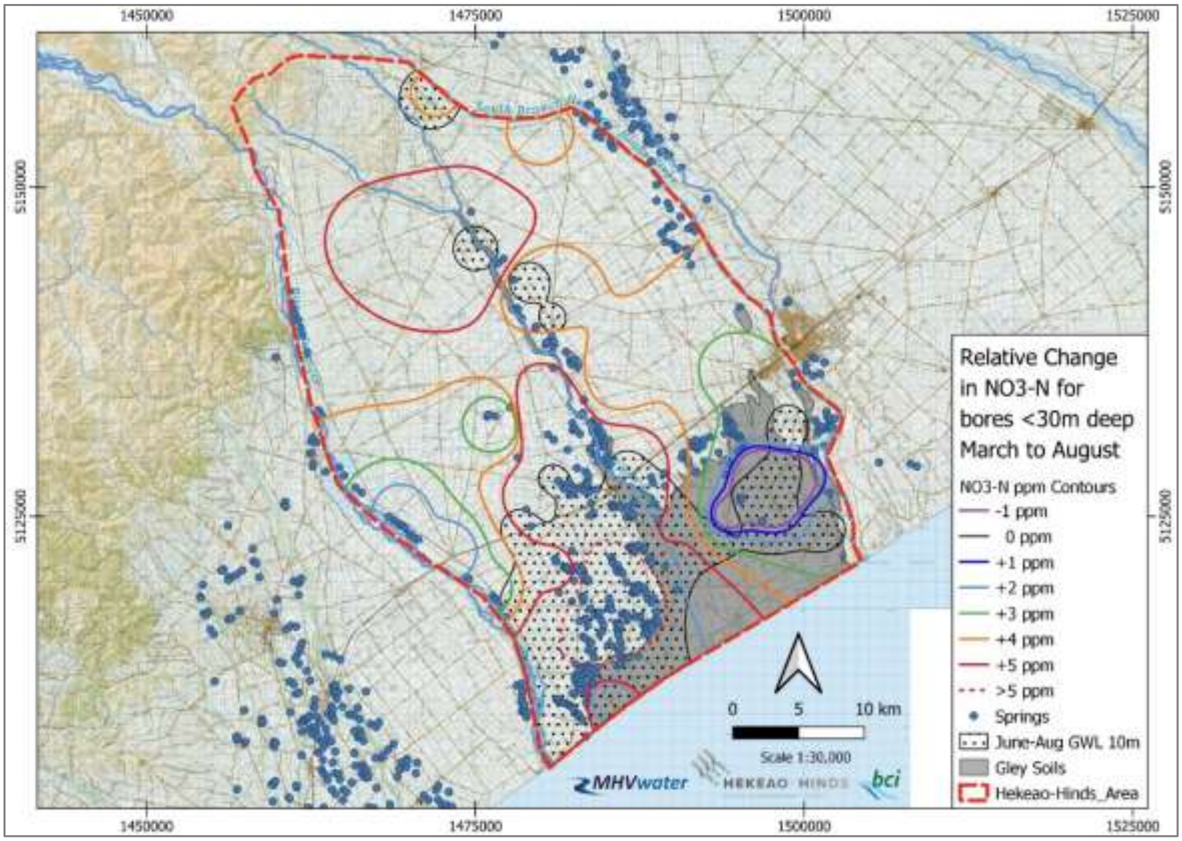

Figure 11 Relative changes in NO_3-N between March and August 2021.

By December, there had been considerable reductions in groundwater nitrate concentrations. Figure 12 presents a frequency histogram of the results taken immediately after the rain event and the December results.

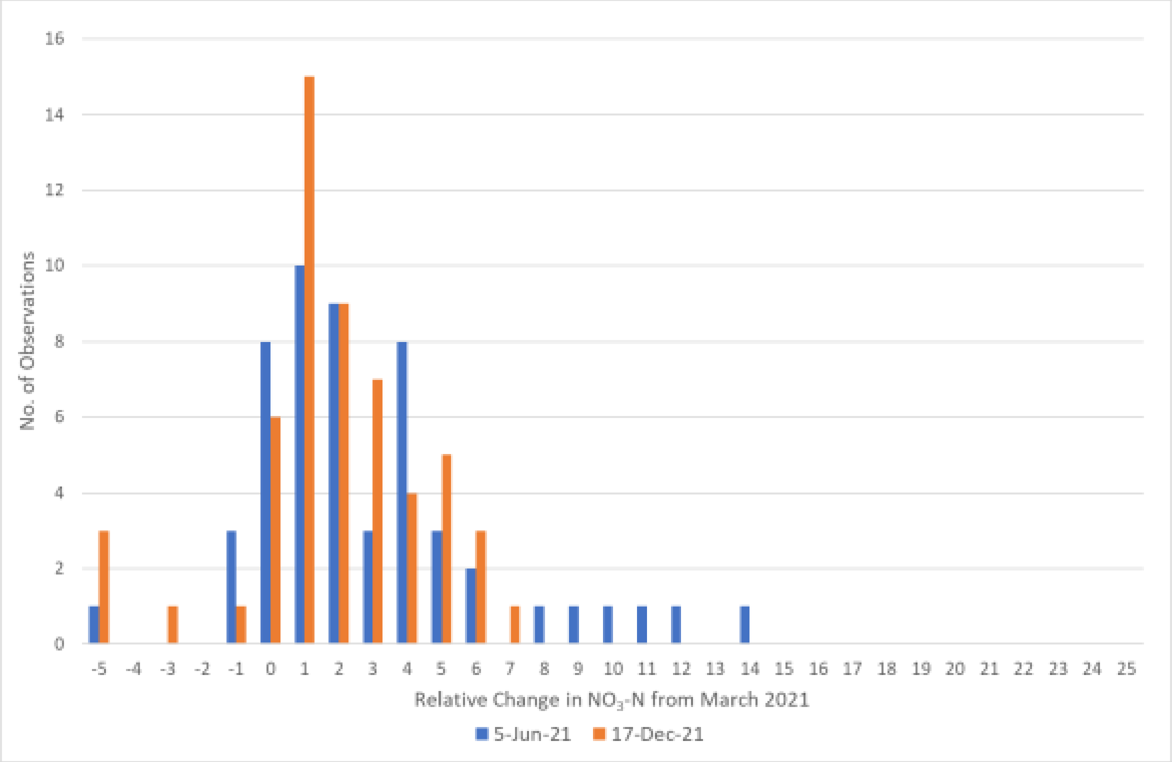

Figure 12 Frequency histogram of the relative changes in NO3-N concentrations between June and December 2021

Where to from here?

I. MHV is committed to ongoing ground and surface water monitoring and will continue to do so into the future.

II. In late 2021, MHV received funding from Callaghan Innovation to support a student to examine the post heavy rainfall data in detail.

III. MHV is working closely with The Universities of Otago, Lincoln, and Canterbury to engage future postgraduate students to continue research into this area.

IV. MHV is working collaboratively with our community stakeholders to establish a community wetland in the Hekeao Hinds catchment. The intention is to utilise Dairy NZ's Guidance on performance estimates and design of constructed farm wetlands framework as a test case for NO_3-N mitigation.

Nitrogen naming & unit convention

Nitrate-Nitrogen (NO_3-N)

When a laboratory directly reports the concentration of nitrate, it is referring specifically to the nitrate compound, which is designated chemically as NO_3. The drinking-water standards for New Zealand 2005 (Revised 2018) currently define the Maximum Acceptable Level (MAV) for NO_3-N in potable water as 50 mg/L [2].

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 determinand is the concentration of that determinand 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 determinand in question at the MAV for 70 years (i.e. an assessed risk of 10^{-5})" [2], [3]

Abbreviations

AEP	Annual Exceedance Probability
ARI	Annual Recurrence Interval
BCI	Barnhill Cherty Irrigation
°C	Degrees Celsius
CSF	Cumulative Distribution Function
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)
ha	10,000 square metres (2.471 acres)
HDWP	Hinds Drains Working Party
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
SOP	Standard Operating Procedures
SPC	Specific conductance
SWL	Standing water level
T	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. Purpose

This report documents the groundwater sampling programme conducted by MHV Water Ltd (MHV) during the 2021 calendar year.

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

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

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

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

1.2. Background of the monitoring programme

1.2.1. Why are we doing it?

The groundwater programme is a tangible expression of MHV's mission to provide "*Sustainable Solutions for our community, now and in the future*". By monitoring groundwater behaviour and character across the scheme, MHV intends to provide data and complementary information that will meet our statutory reporting requirements, enable evidence-based decision making, that leads to environmentally and sustainable water and nutrient management practices.

1.2.2. What are we doing it?

MHV recognises that the water governance space is dynamic at both local catchment and national levels. As a result, our ground and surface water programme has developed over time, such that MHV now seeks to understand the interconnected nature of current and historical land use practices with changes in groundwater and lowland stream health and then upscale this understanding to across the whole catchment.

1.2.3. How will this help MHV - What will it provide / do?

The intention of the groundwater programme is to provide impetus (via data and information) that will facilitate robust scientific investigations and will increase our understanding and awareness of the interconnectivity of groundwater, surface water and land use practices.

In doing so, MHV intends to develop sustainable strategies that will assist shareholders as well as the broader farming community manage and mitigate the migration of NO_3-N in both surface and groundwaters.

1.3. Scope

This report represents the work programme, and subsequent results of selected boreholes within the MHV scheme and surrounding areas undertaken by MHV – see Appendix 1 for statement of qualifications.

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

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[1] Nitrate-nitrogen 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, Hinds and Westerfield Plains catchment areas

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) programme is recognised in this report, it is not considered the focus of this study.

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

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

1.4.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 [4]. This target will be determined by the results from the Canterbury Regional council's monthly surface waterbodies monitoring sites[3].

The plan also requires that shallow groundwater Nitrate-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 the water table) monitoring bores that are tested on a quarterly basis.

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 nitrate and ammonia toxicity, to provide protection from nitrogen toxicity for 95% of freshwater species to 2.4 ppm, up from 80% under the former NPS-FM 2017. ECan are required to address how they will achieve the objectives of the NPS-FM 20 by 2024.

As the implementation of the new policy is yet to be confirmed, this report will refer to the PC2 NO_3-N limit of 6.9 ppm as a reference.

1.5.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 2.

1.6.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

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[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

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 highlights of 2021 are presented below.

2.1.Community Information

MHV continued its commitment to community engagement by sharing information via mail outs (Figure 13), social media posts as well as by direct engagement. An example of a post card highlighting well head security that was both mailed out to shareholders and posted on social media is shown in Figure 13.

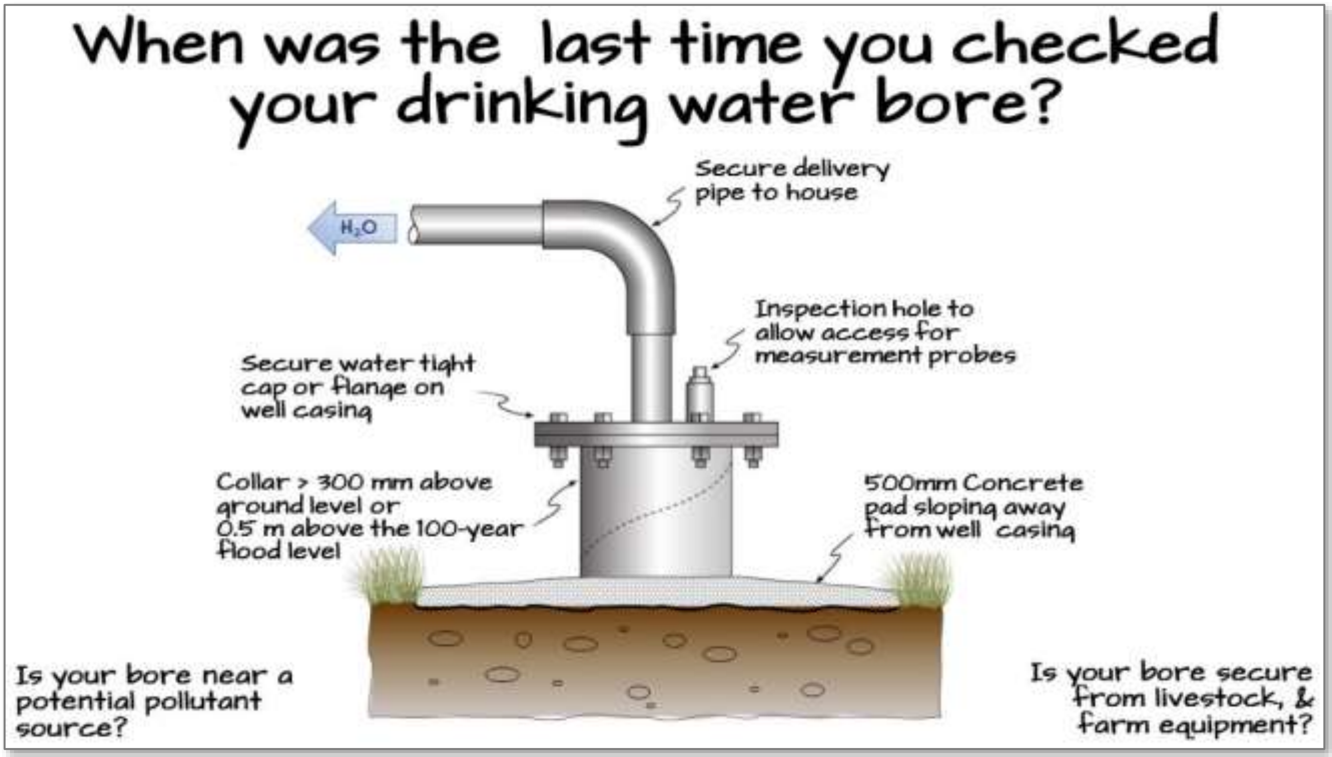

Figure 13 An example of a mailout post card sent to landowners

2.2.Mayfield A & P Show

In early March 2021, MHV attended the Mayfield A & P Show, where free nitrate water testing was available to the public. During the day, some 200 public water samples were tested for free (MHV did not keep a record of results) and provided laboratory sample kits to those who wished to have further analysis undertaken (Figure 14).

Figure 14 MHV stall and water testing

2.3. Ngāi Tahu Intern

During the summer of 2020-2021, MHV supported Ngāi Tahu Iwi Capability Scholarship winner Evelyn Murray (Ngāi Tahu, Ngāti Porou) who had completed a Bachelor of Environment and Society at Lincoln University.

Evelyn was involved in water monitoring, bucket testing, and FEP audits (Figure 15).

Figure 15 Evelyn Murray (Ngāi Tahu, Ngāti Porou)

2.4. 60th Hydrological Society Annual Conference

The New Zealand Hydrological Society held its 60th Annual Conference[5] in Wellington in late 2021. As part of the theme of *He kimihanga waiwaiā o te wai māori / An Essential Freshwater Odyssey* MHV presented two papers:

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[5] NZHS 2021 | 60th Annual Conference | Wellington (nzhsconference.co.nz)

i. Mel Brooks and Justin Legg presented:

The mouse that roared: How a farmer led co-operative is spearheading water monitoring on the Hekeao Hinds Plains.

That outlined the development of MHV's monitoring programme and the results to date (Figure 16).

ii. Justin Legg and Dr Helen Rutter (Aqualinc Research) presented

Nitrates: The Conundrum of Rapid Response and Time Lag.

That outlined the monitoring programme immediately after the May-June rain event and the subsequent results.

Figure 16 MHV CEO Mel Brooks presenting at the New Zealand Hydrological Society Annual Conference

2.5.Catchment Groups

2.5.1. Hinds Drain Working Party

Following discussions within the Hinds Drains Working Party (HDWP) in October, MHV assisted Donna Lill and Ryan Dynes at the Ashburton ECan Office with the conceptual design of a freshwater habitat in Bowyers Stream near Mt Sommers (Figure 17).

Figure 17 Freshwater Habitat developed at Bowyers Stream Rocks

2.5.2. Foothills Catchment Group

The Foothills Catchment Group (FHCG) is a recently formed catchment management group that is seeking to manage water quality in an area extending from Te Kiekie/ Mt Somers to the of Mt Hutt ski field to the Rangitata Diversion Race (RDR) at Methven – an area of approximately 510 km^2 (Figure 18).

In late 2021, the FHCG approached MHV to assist with the conceptual development of a water quality monitoring programme. MHV delivered to the FHCG a high-level technical note that outlined a monitoring programme consisting of 27 bores and 29 surface water locations.

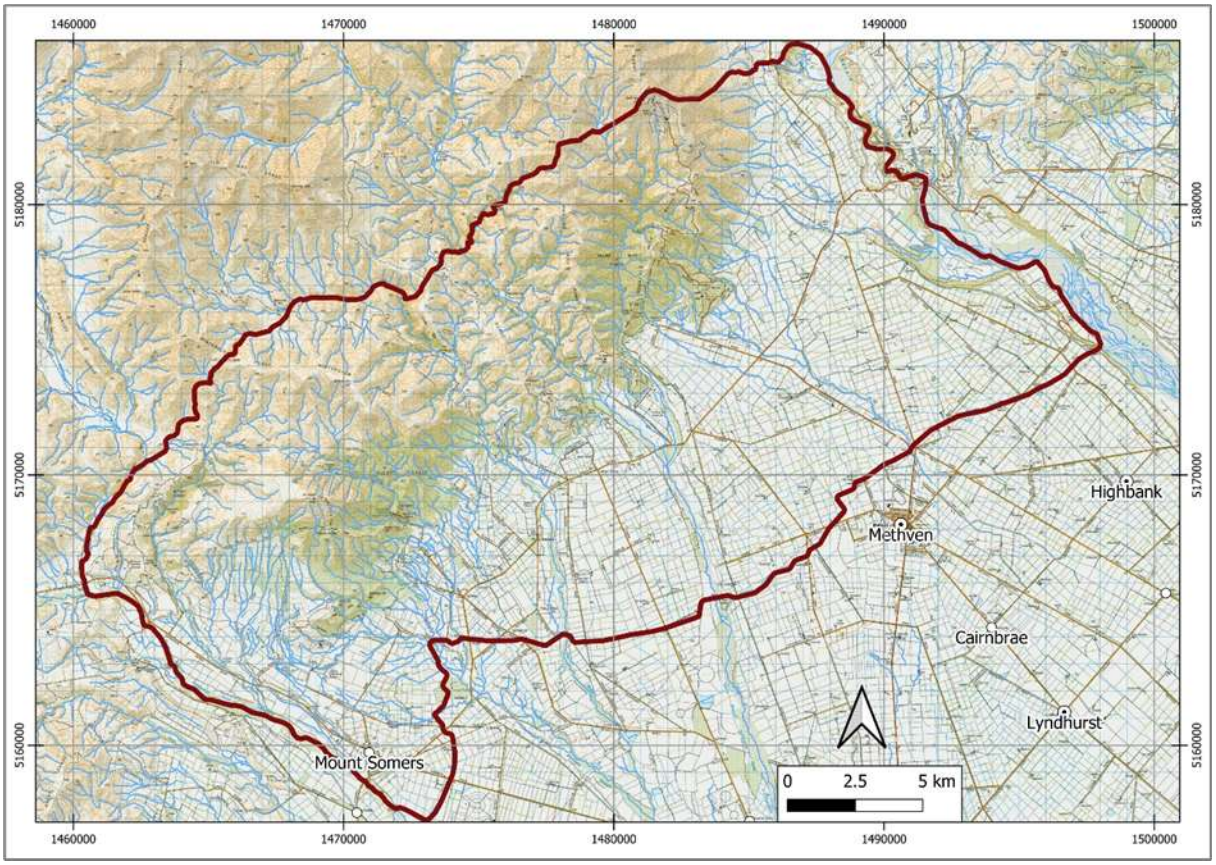

Figure 18 Catchment area of the Foothill Catchment Group (FHCG)

2.6.Hekeao Hinds Community Wetland

In late 2021, MHV started working collaboratively with

Hekeao Hinds Water Enhancement Trust (HHWET)	Te Rūnanga o Arowhenua
Hinds Drains Working Party (HDWP)	Environment Canterbury (ECan)
Mid Canterbury Catchment Collective	DairyNZ

to establish a community constructed wetland. The intention is to utilise Dairy NZ's *Guidance on performance estimates and design of constructed farm wetlands* framework [5], [6] as a test case to promote to the Hekeao Hinds Community.

Work is ongoing at the time of writing.

2.7.University Engagement

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

2.7.1. Otago University

Dr Sarah Mager visited the scheme in October, and provided the following preliminary research questions for future post grad projects:

- Assessment of the Efficacy of MAR for nitrate dilution in the Rangitata-Hinds aquifer (MSc);
- Preferential flow pathways for groundwater flow during the 'Big Wet' (MAppSci);
- Groundwater-Surface Water Interactions in the Rangitata Irrigation Race (MSc); and,

- Efficacy of riparian offsets on stream water quality and habitat near Hinds (MAppSci).

2.7.2. University of Lincoln

MHV is assisting Dr Naomi Wells at Lincoln University to undertake research into greenhouse gas emissions from the farm drains and ditches, which will feed into a global assessment, under the project 'Land Use Effects on Aquatic Fluxes of Greenhouse Gases from Ponds and Ditches (LEAF-PAD)', led by the Swedish University of Agricultural Sciences[6].

2.7.3. University of Canterbury

In March, MHV was invited to speak as a guest lecturer to postgraduate students reading Advanced Water Resources (WATR 401/601) at the Waterways Centre at the University of Canterbury.

2.8.Callaghan Research

In September 2021 MHV received funding via a Callaghan Innovation[7] Grant to analyse the NO_3-N data generated from the May 2021 Flood event. This funding is intended to support an internship programme with MHV Water to:

a) consider the data from a data analysis/ statistical perspective and to reconcile any trends with the spatial data;

b) provide a foundation for further research opportunities, and,

c) enable MHV to develop fit for purpose strategies to facilitate and enable on farm mitigation solutions.

To that end Sidinei Teixeira, a Water Resource Management Masters candidate at Lincoln University was engaged to review the data.

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[6] Land Use Effects on Aquatic Fluxes of Greenhouse Gases from Ponds and Ditches (LEAF-PAD) | Externwebben (slu.se)
[7] https://www.callaghaninnovation.govt.nz/

3. Background

3.1.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 and manages the environmental compliance for those farmers over an area of ~58,000 ha.

3.2.Climate and Rainfall

The Hekeao Hinds plains are prone to drought, with a cool temperate climate, (Köppen climate classification Cfb) – see Figure 19.

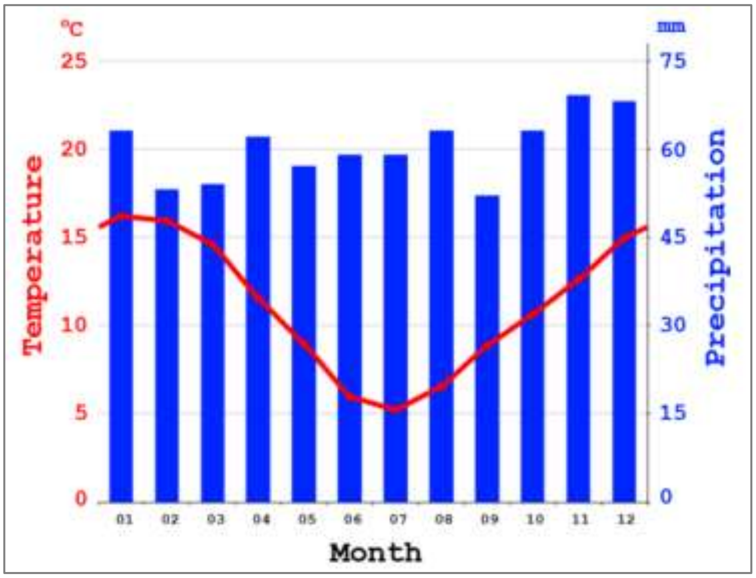

Figure 19 Ashburton Climate[8]

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 (Figure 20). 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 [7].

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

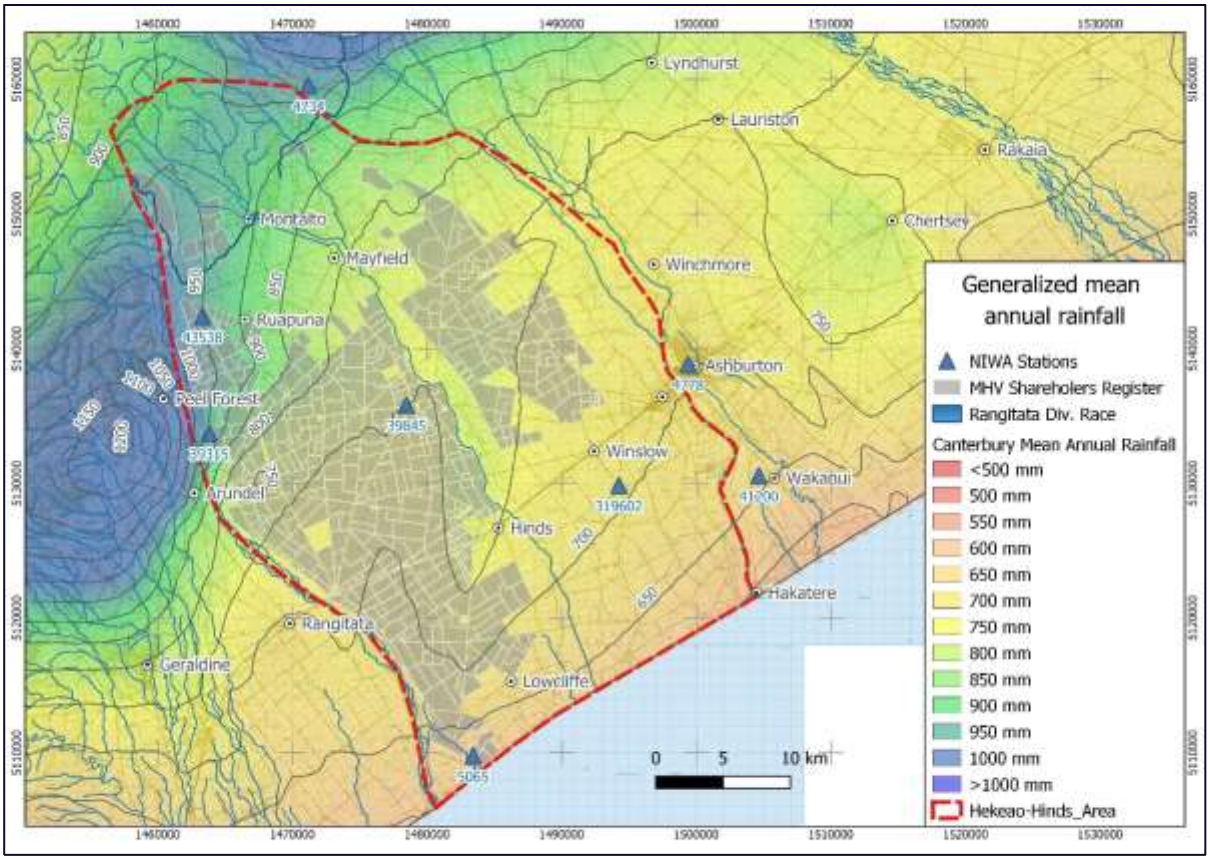

Figure 20 Generalised mean annual rainfall distribution across the Hekeao Hinds Plains

3.2.1. River Flows

River flows across the Hekeao Hinds almost mirror the seasonal rainfall average as shown in Figure 21, with river flows varying in orders of magnitude. (Table 2).

Table 2 Average daily flow rates (m³/ second) for the rivers in the survey area between 2015 - 2021

	Rangitata River at Klondyke	Ashburton River at SH1	Hinds River at Poplar Rd
2015	86.9	13.3	0.36
2016	90.6	14.5	0.39
2017	86.1	29.4	2.99
2018	91.2	40.8	3.24
2019	105.7	25.0	1.54
2020	82.6	11.6	0.33
2021	106.7	33.4	2.35

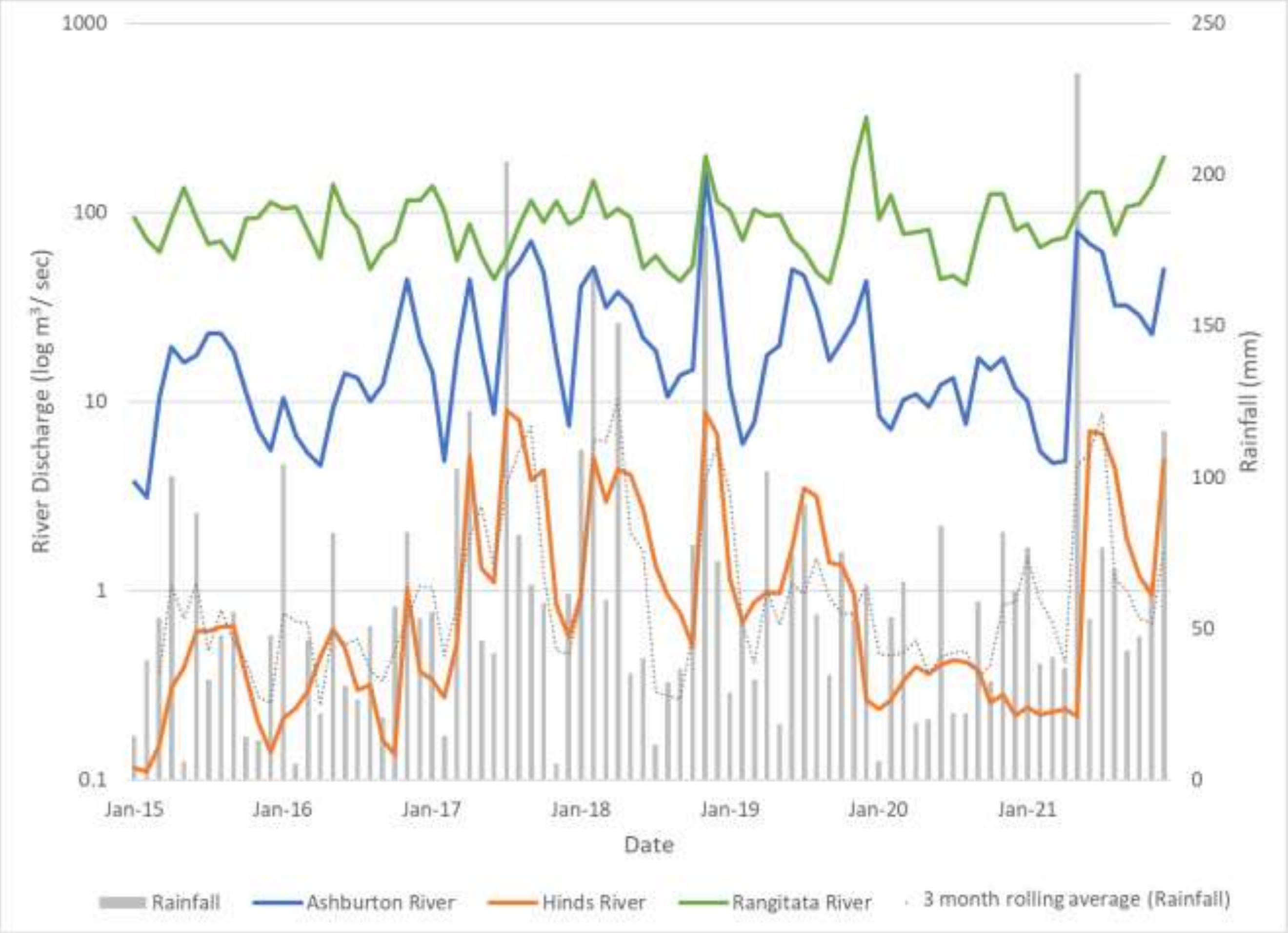

Figure 21 Rainfall and river flow data for the period 2015 to 2021

3.3.Catchment Characteristics

3.3.1. Soils

The Hekeao Hinds Plains has over twenty main soil types (Figure 22), 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 [8].

Closer to river margins, soils tend to be deeper and more varied in type, depth and quality. Notably, the area between from Lagmhor to Waterton, as well as the coastal margin of the plain, the area is dominated by Waterton gley soils and Wakanui deep silt loam soils with higher water holding capacities up to more than 150 mm associated with swamp deposits [8]–[10].

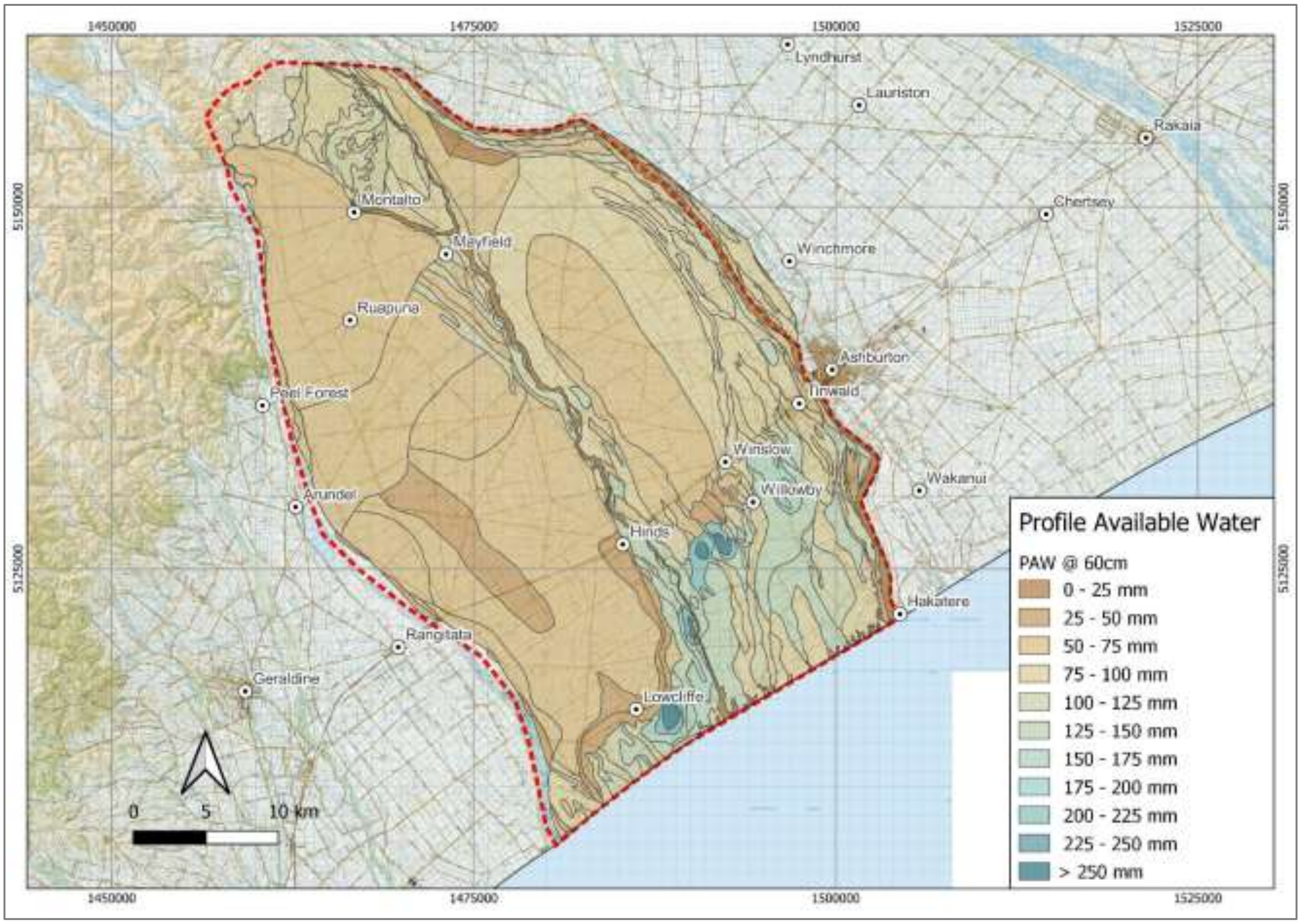

Figure 22 Soils of the Hekeao Hinds Plains

3.3.2. Geology

Deep (>600 m) Quaternary[9] aged anisotropic and heterogeneous glacial outwash alluvial gravel fans underlie these soils; these were deposited as part of the uplift and erosion of the Southern Alps [8], [11]. These gravels are predominantly composed of greywacke gravel clasts, in a matrix of sandy fine gravel and minor silt with minimal clay (colloquially known as clay-bound gravels), resulting in sediments that are variable and heterogeneous in structure.

Due to their fluvio-tectonic origins, the alluvial gravel fans are up to 600 m thick, within highly permeable lenses of coarse, matrix-free gravel, surrounded by less permeable gravel with sandy or silty matrix - often referred to as Open Framework Gravels - OFG's (refer to section 3.4.2).

These Quaternary sediments are underlain by Tertiary sediments and Cretaceous greywacke basement of the Torlesse Group [10].

3.4.Hydrology

3.4.1. Catchment Scale

The Hekeao Hinds plains are serviced by three rivers: the Ashburton Hakatere, Rangitata and Hinds-Hekeao, with a combined catchment of some 148,000 ha. The Ashburton/ Hakatere and Hinds/ Hekeao rivers are considered foothill rivers and the Rangitata an Alpine River. These rivers have variable flow rates and are confined to terraced alluvial fans.

---

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

Both mātauranga māori and local farm knowledge attest that the local hydraulic gradient runs obliquely across the Hekeao Hinds from Tarahaoa/ Mt Peel towards the mouth of the Hakatere/ Ashburton River. This assertion is also supported by geological mapping and geochronology studies that indicate that relatively thick ice occupied valley reaches of the Rangitata Gorge during the last ice age until 21,000 years ago, and that its subsequent outwash would also influence surface hydrology morphology [12], [13]

A high-level interpretation of the 1 m LiDAR[10] digital terrain model (DTM) supports this assertion, whereby observable lineation's (i.e., trends that were immediately observable in the data[11]) were digitised Figure 23. 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 flow paths and/ or indicators of open framework gravels (see section 3.4.2).

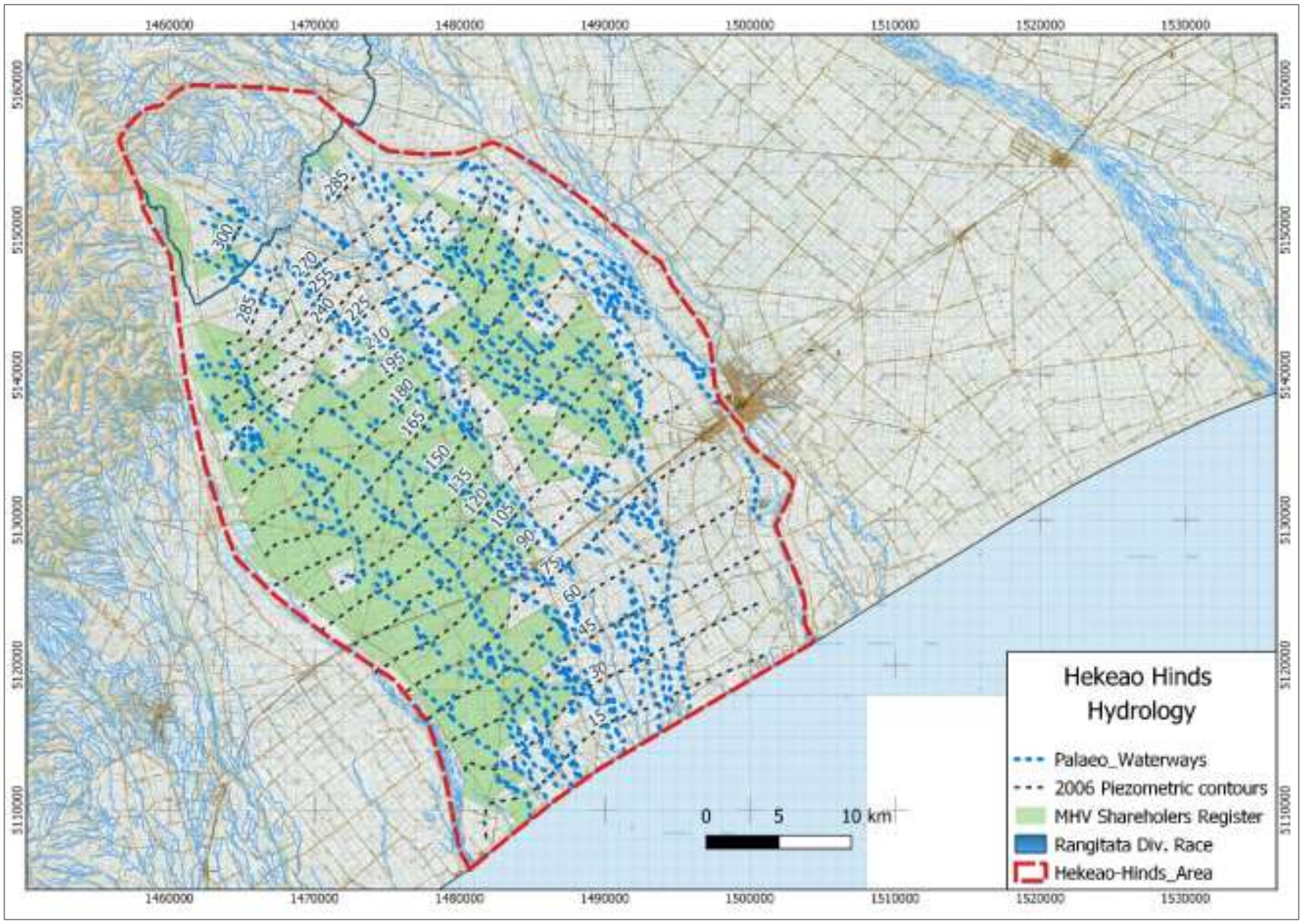

Figure 23 ***High-level interpretation of the 1m LIDAR digital terrain model (DTM) mapping paleo channels***

3.4.2. Aquifers

Historically, the groundwater has been conceptualised as three poorly connected, and laterally discontinuous, aquifers at near surface, ~50 m and ~100 m depths respectively [11]. The current interpretation (at a regional scale) considers the aquifers of the Hekeao Hinds plains to be a gravitationally driven flow 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 confinement generally increasing with depth [7], [8], [14].

---

[10] Light detection and ranging

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

Due to the inherent variability of the sedimentary facies, there is a corresponding variability in hydrological transmissivity[12] with calculated flows ranging from 150 to 7,000 m^2/ day [10] with aquifer recharge being derived from rainfall, irrigation losses, and seepage from the Hekeao Hinds, Hakatere-Ashburton, and Rangitata Rivers.

Most of the flow and transport is thought to be through open framework gravels (OFG's), which are formed by unidirectional river surface water flows. The origins of OFG's is still contested with three dominant theories, namely [15]:

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 is not well understood.

These gravel lenses can [10], [14], [16]:

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

The gravels within the lenses are characterised as [15], [17]:

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

An example is presented in Figure 24.

---

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

Figure 24 Example of an 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 nitrate transport, is not yet fully understood.

3.5.Localized surface hydrology

The Hekeao Hinds plains possess several different types of watercourse (Figure 25). 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 [18], [19]. 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 channelisation and man-made drains [18], 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.

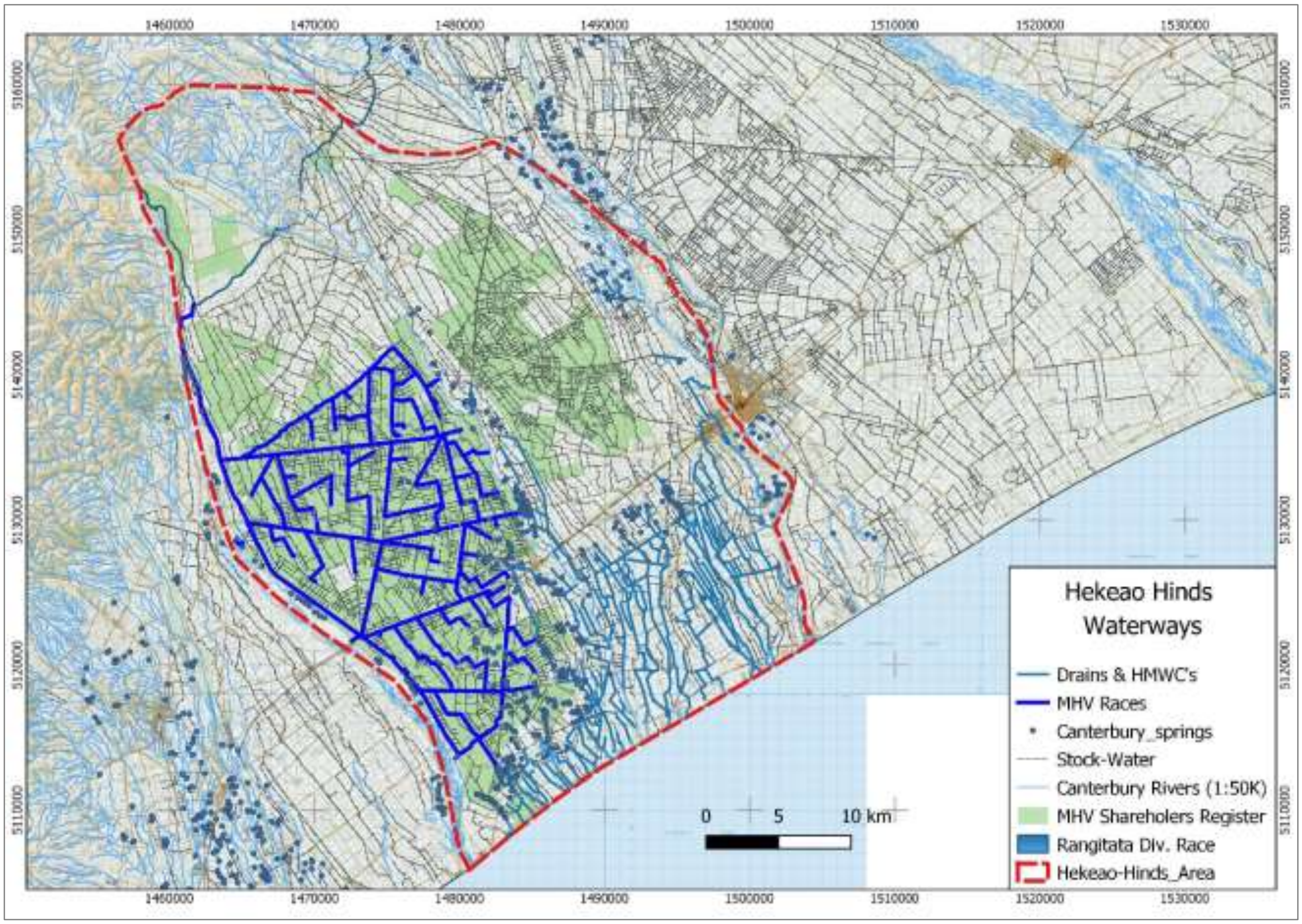

Figure 25 Surface waterways on the Hekeao Hinds Plains

3.6.Nitrate

3.6.1. Sources

Nitrate is a stable, plant available form of oxygenated nitrogen formed through various chemical and biological processes. In the Hekeao Hinds catchment, nitrate is mostly derived from several sources including [9], [10], [20]:

Point sources such as

- septic tanks (human effluent)[13];
- stormwater and contaminated water;
- Industrial water such as factory washdown water and gravel processing;
- refuse dumps; and,
- animal feedlots.

Diffuse sources such as

- dairy and other animal effluent (including urine patches);
- Urbanisation and construction;
- Stormwater runoff and urban drainage;
- Decaying plant debris;
- Agricultural land management practices including application of fertilisers and irrigated effluent; and,
- Acceleration of soil organic N mineralization and oxidation caused by land clearing ploughing, drainage, and other agricultural practices, which provide large amounts of leachable NO_3 – either annually or in large pulses at times of land-use change.

Some of these sources and impacts on groundwater have been quantified in Table 3 [1].

---

[13] 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).

Table 3 Quantification of non-agricultural sources of Nitrate 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	

† Without quantitative data such as flow rates, the values presented here are indicative.

Nitrate is one component of a broader natural cycle known as the Nitrogen Cycle (Figure 26). In simple terms:

i. Nitrogen enters the soil via fertilisers, animal effluent (dung and urine), fixated from the atmosphere or soil organic matter.

ii. It is then first converted into ammonium (NH_4^+) via a process known as *mineralisation*.

iii. The ammonium then undergoes *nitrification* that oxidises it to form nitrite (NO_2^-) and the more stable nitrate (NO_3).

iv. 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.

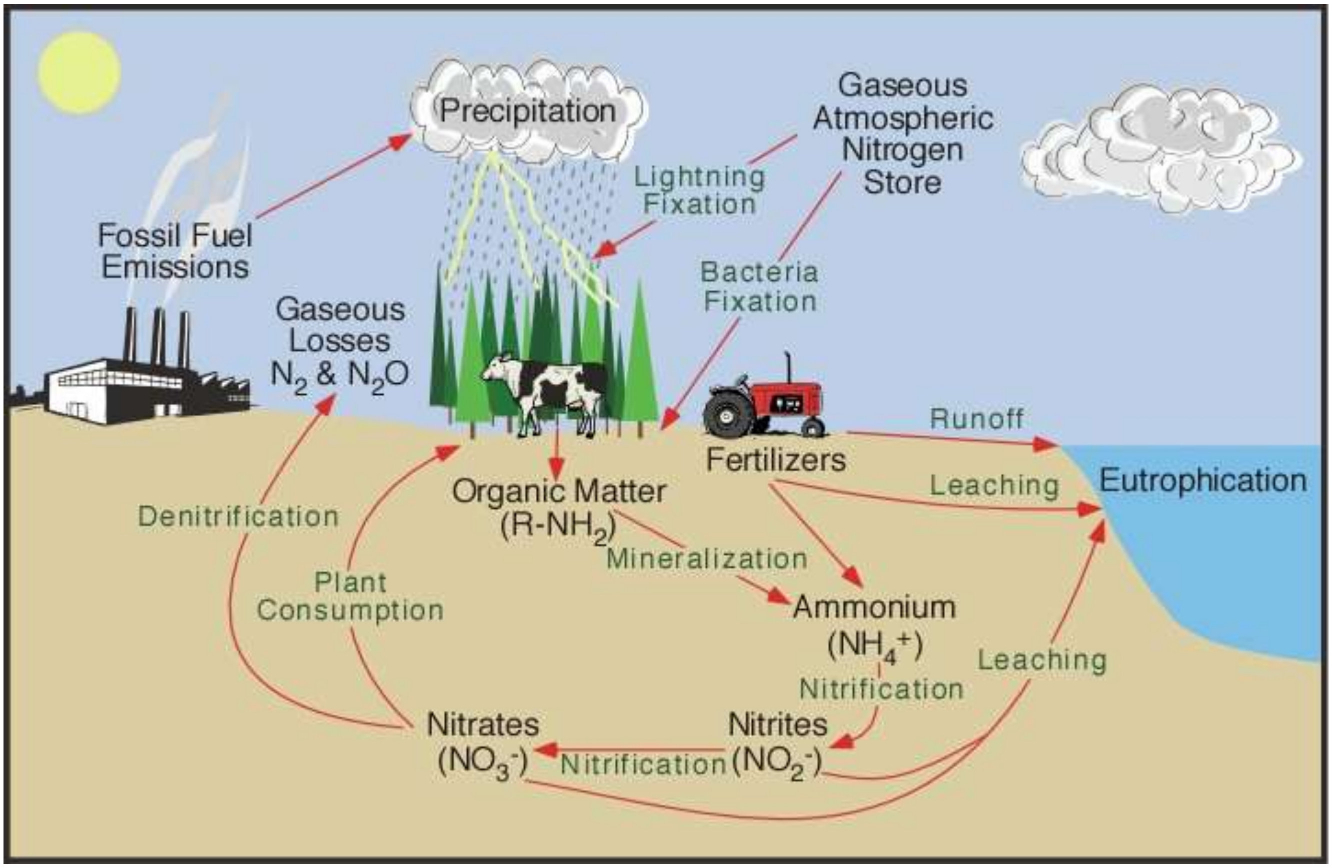

Figure 26 The nitrogen cycle[14]

It is important to note that depending on hydrological conditions, it may take years (and potentially decades) for nitrate to move from the original source and through the groundwater system, so current and historical sources for nitrate must be considered.

3.6.2. Nitrate Distribution

Work undertaken by ECan has revealed variable nitrate distribution across the Hekeao Hinds plains (Figure 27) in response to different soil types (refer to section 3.3.1). In summary [9], [10], [21]:

- Higher nitrate 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 nitrate 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; and,
- The highest nitrate nitrogen concentrations, including those in the Tinwald area, were found near the transition zone between high-permeability sediments beneath the upper plains 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 nitrate sources, it is important to recognise that NO_3-N levels in shallow bores in the Hekeao Hinds Plains can fluctuate significantly both spatially and temporally over a short period. [8], [9], [19]

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

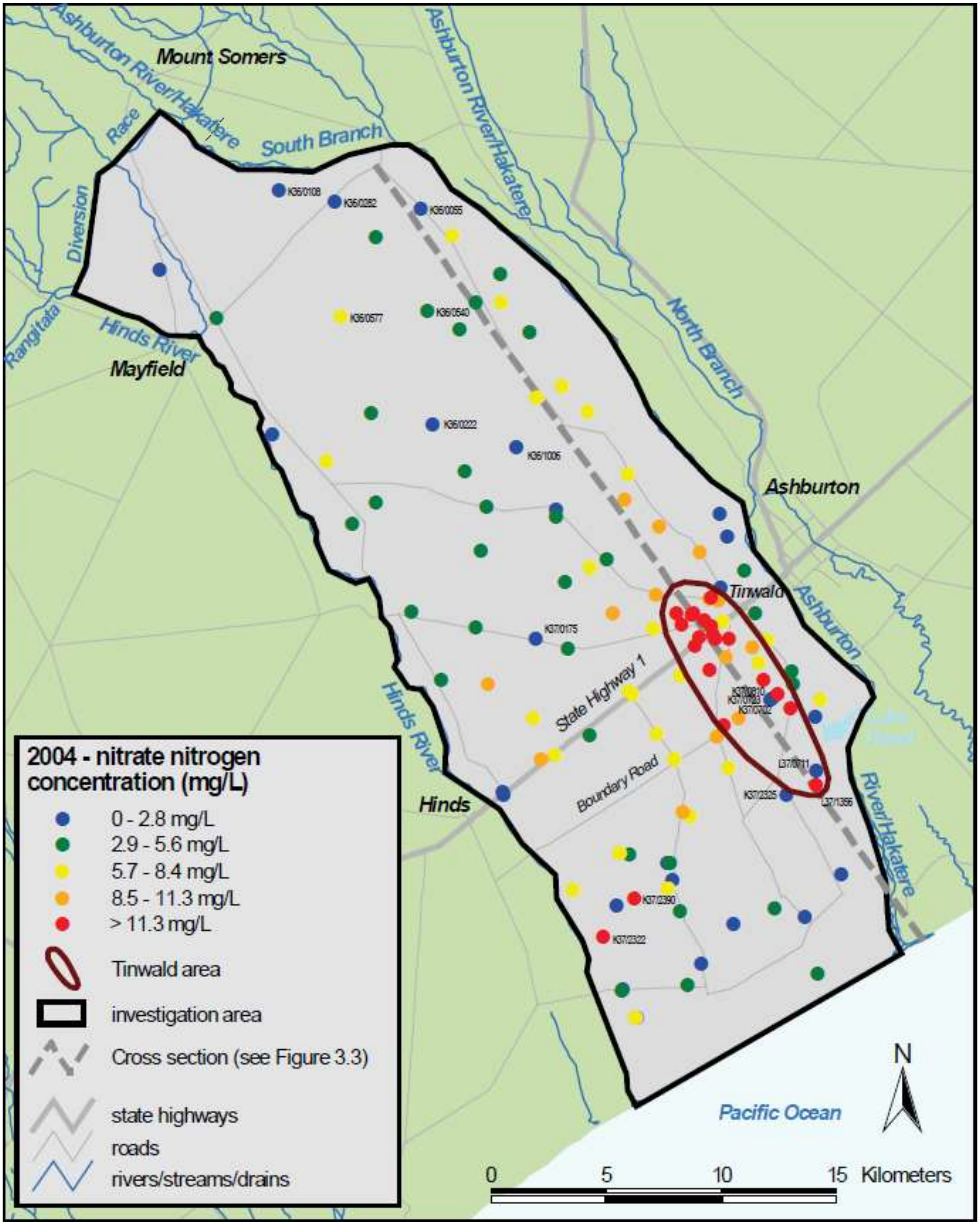


Figure 27 Nitrate nitrogen concentrations in groundwater, [10]

4. Groundwater Sampling Programme

4.1.Groundwater Monitoring Programme Development

MHV commenced routine groundwater monitoring of NO_3-N within the MHV scheme area in September 2016, with an initial survey of 29 bores. The programme's initial objective was to understand the changes in NO_3-N in the groundwater of the Hekeao Hinds Plains, because 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 (Figure 28). In early 2020 the programme was reviewed and extended in consultation with:

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

The outcome was a collaboration between MHV, HHWET, and BCI to expand the survey to cover the entirety of the Hekeao Hinds Plains such that the average catchment scale survey was 150 bores. At the time of writing, MHV has over 2000 records obtained from 200 bores across the Hekeao Hinds catchment.

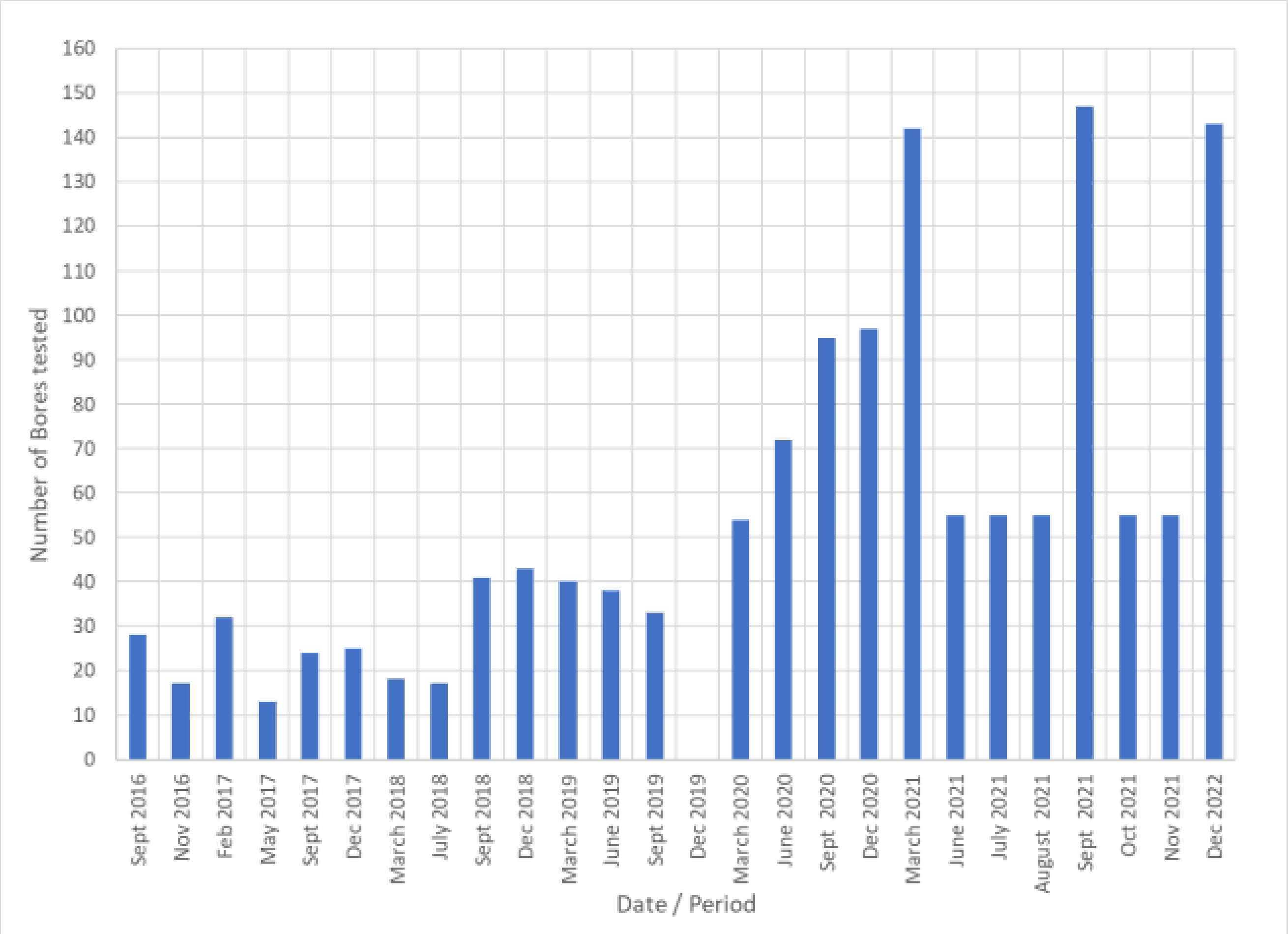
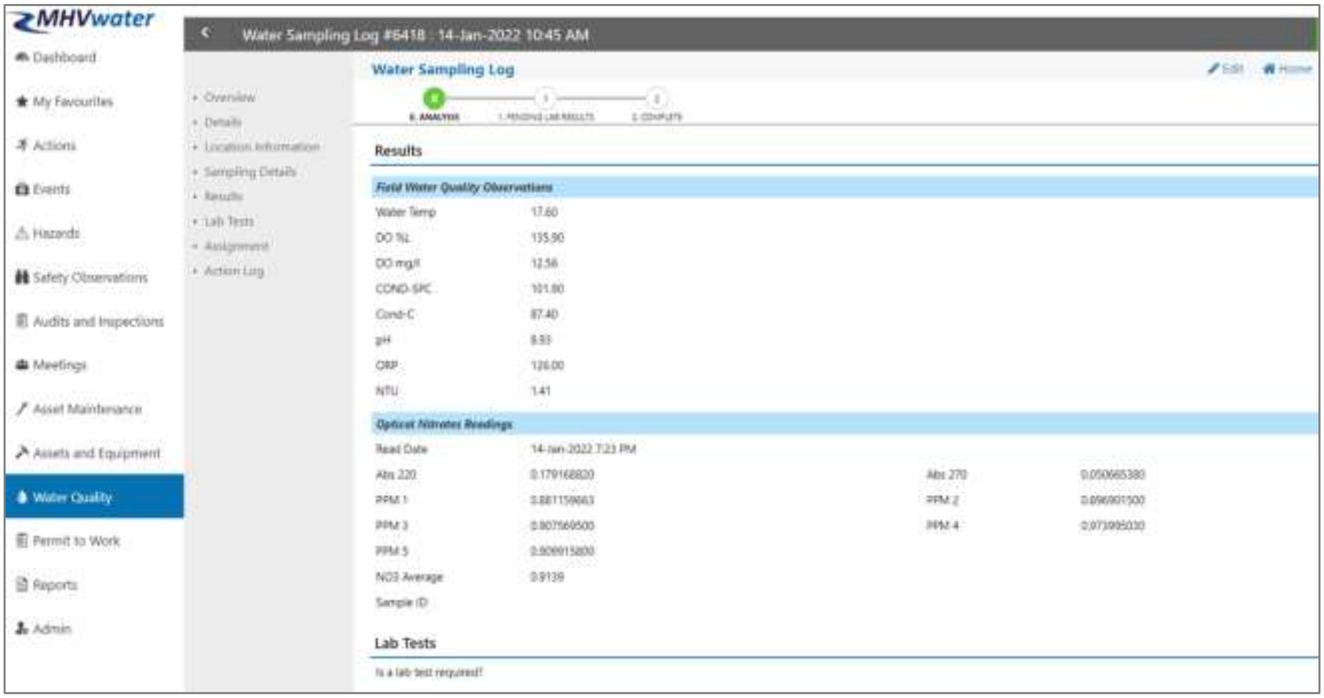


Figure 28 Frequency histogram of survey size changes over time

4.2.Data Management

In addition to the increase in the survey size from 2020, MHV introduced the use of a digital logging system that replaced the existing field notebooks and subsequent need for data entry (Figure 29). The cloud-based logging system was developed by Assura Software and MHV.



Water Sampling Log #6418 : 14-Jan-2022 10:45 AM

Water Sampling Log

Results

Field Water Quality Observations

Water Temp	17.60
DO %L	135.90
DO mg/l	12.56
COND-SPC	101.80
Cond-C	87.40
pH	8.93
ORP	126.00
NTU	1.41

Optical Nitrates Readings

Read Date	14-Jan-2022 7:23 PM		
Abs 220	0.179168820	Abs 270	0.050665380
PPM 1	0.881159063	PPM 2	0.896901500
PPM 3	0.807569500	PPM 4	0.973995030
PPM 5	0.909915800		
NO3 Average	0.9139		
Sample ID			

Lab Tests

Is a lab test required?

Figure 29 Interface of Assura Water Quality Logging System

4.3.Bore Depths and Types

4.3.1. Bore Type

A wide variety of bore types was tested during 2021 to avoid sampling bias (i.e., sampling only type X bore or depth Y wells) as well as for logistical / practical considerations. Figure 30 presents a breakdown of the types of bores tested based on their designation in the ECan database[15].

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

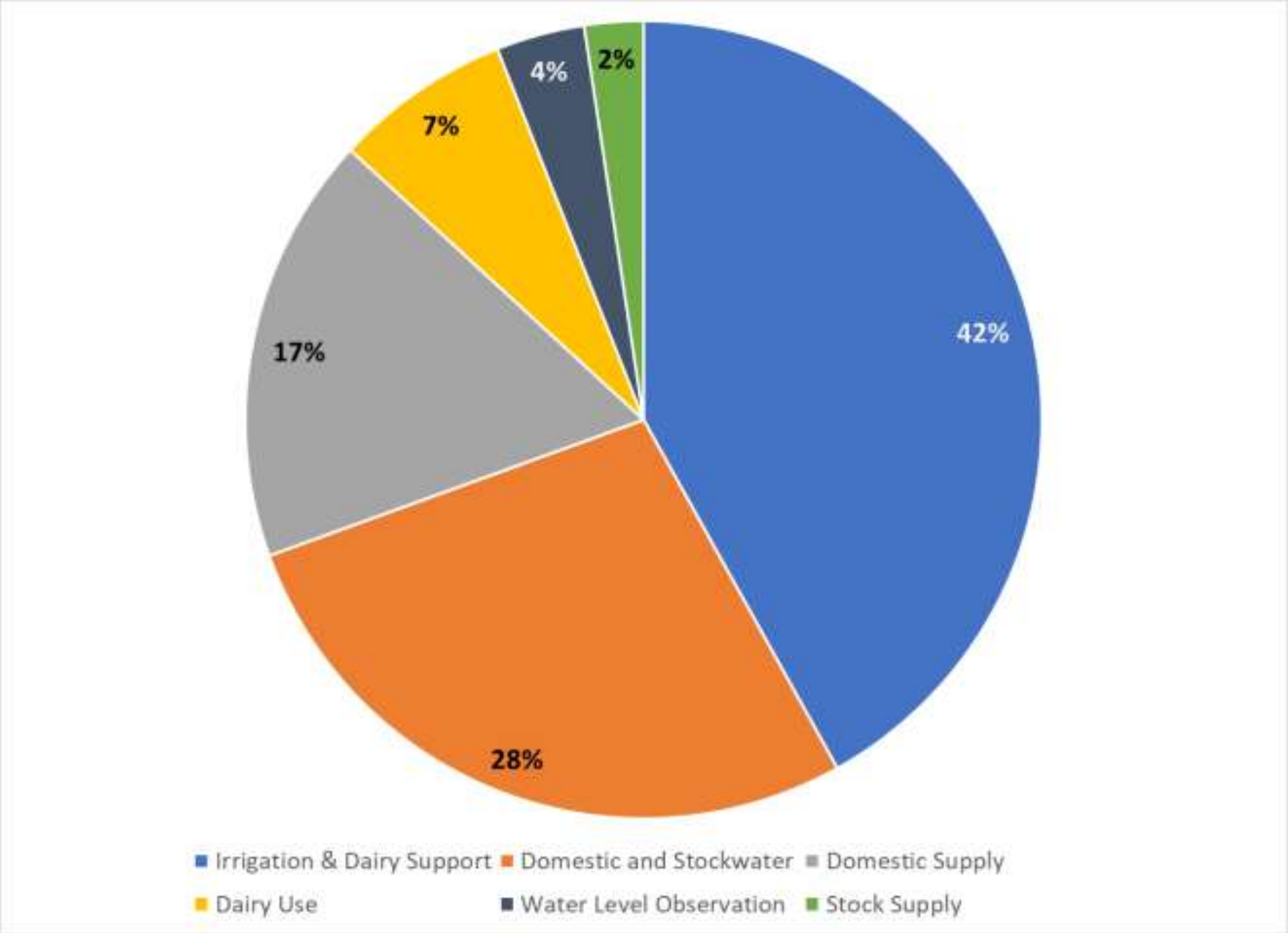

Figure 30 Bore types tested during 2021 as per the ECan database.

4.3.2. Bore Depths

Bore depths are categorised in keeping with the LWRP[16] [4], and are split into:

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

Figure 31 and Figure 32 presents a frequency histogram of the depths of bores and number of samples collected in 2021.

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

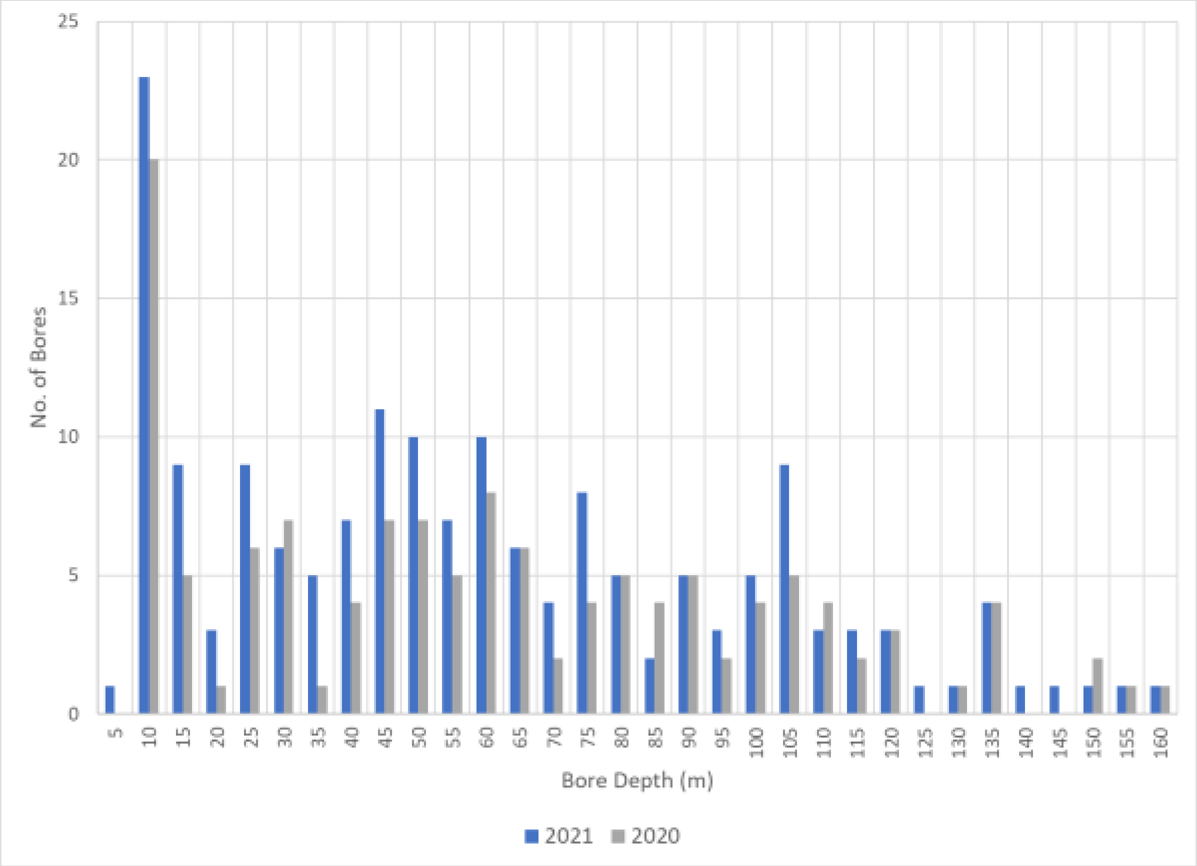

Figure 31 Groundwater monitoring programme by bore depth for 2020 and 2021

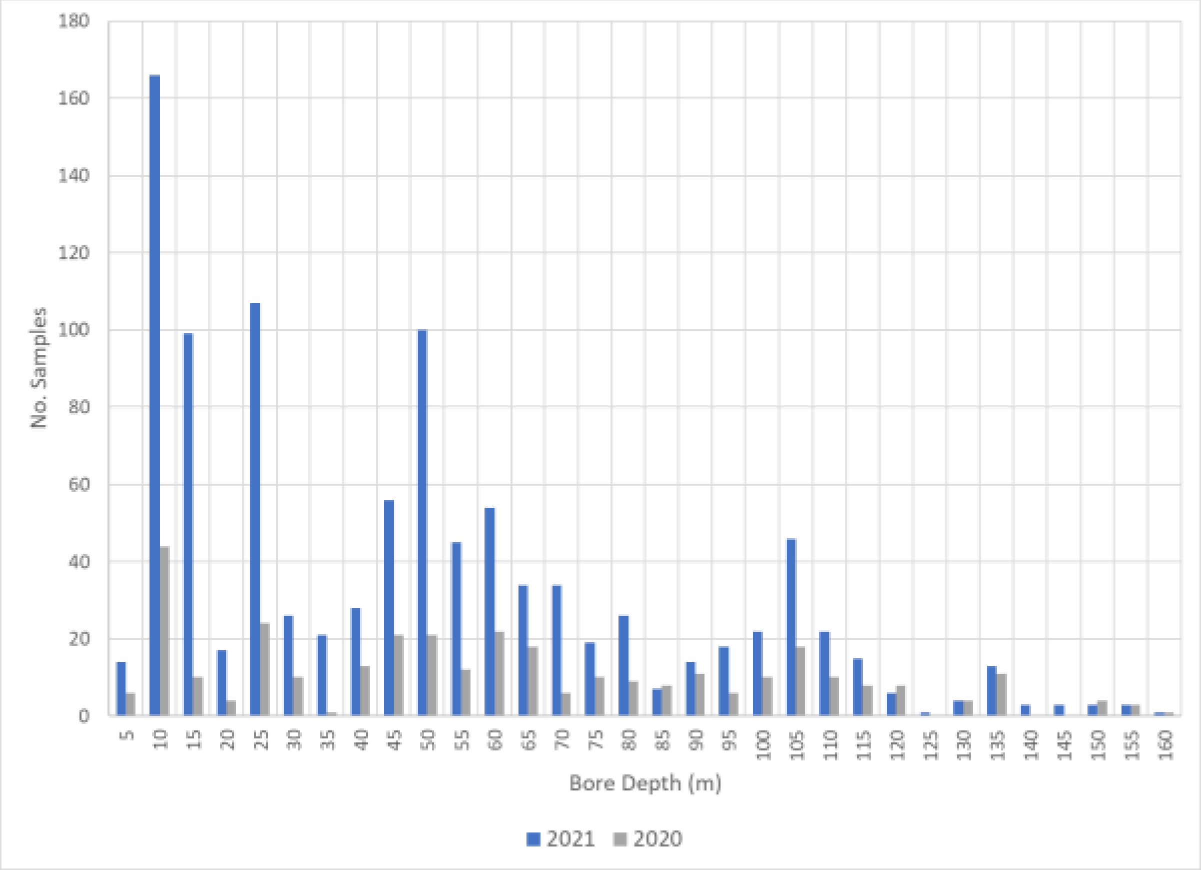

Figure 32 Groundwater monitoring programme sampling regime by bore depth for 2020 and 2021

4.4.Well head security

Section 5.103 of the LWRP requires that all wellheads are secure, such that the construction prevents contaminants or surface water from entering the top of the bore or gallery or underlying groundwater. Whilst not necessarily relevant to nutrient sampling, non-secure well heads could present an opportunity for localised, point source contamination to occur. Therefore, as part of the monitoring programme, visual inspections of well head security were completed based on the following criteria **[22]**:

Collared	Does the bore have a portion of the gallery pipe extending above the surface that is >200m in height and is in reasonable condition?
Capped	Does the bore have a robust, permanent, and weatherproof cap on the collar?
Pad:	Is the collar of the bore encased in a single concrete pad of at least 0.3 m radius and 0.1 m thickness which is contoured to slope away from the bore or pipe?
Proximity	Is the bore <20 m from a potential pollution source? e.g., a dairy track to the milking shed.
Secure	Is the bore in a secure location – is the bore confined to a shed or a small-fenced area?

NB: **It should be noted that this inspection did not consider section 8 *“Meaning of drinking water supplier”* of the Water Services Bill which has passed its third reading in parliament at the time of writing.**

Based on these criteria, 70% of the bores inspected meet four or more of the requirements, a large number of the 4’s being due to the bore not being in a secure location as there was not considered to be a need to do so (Figure 33). Figure 34 presents a breakdown of the 2021 well head audit and opportunities to reduce the potential for point source contamination.

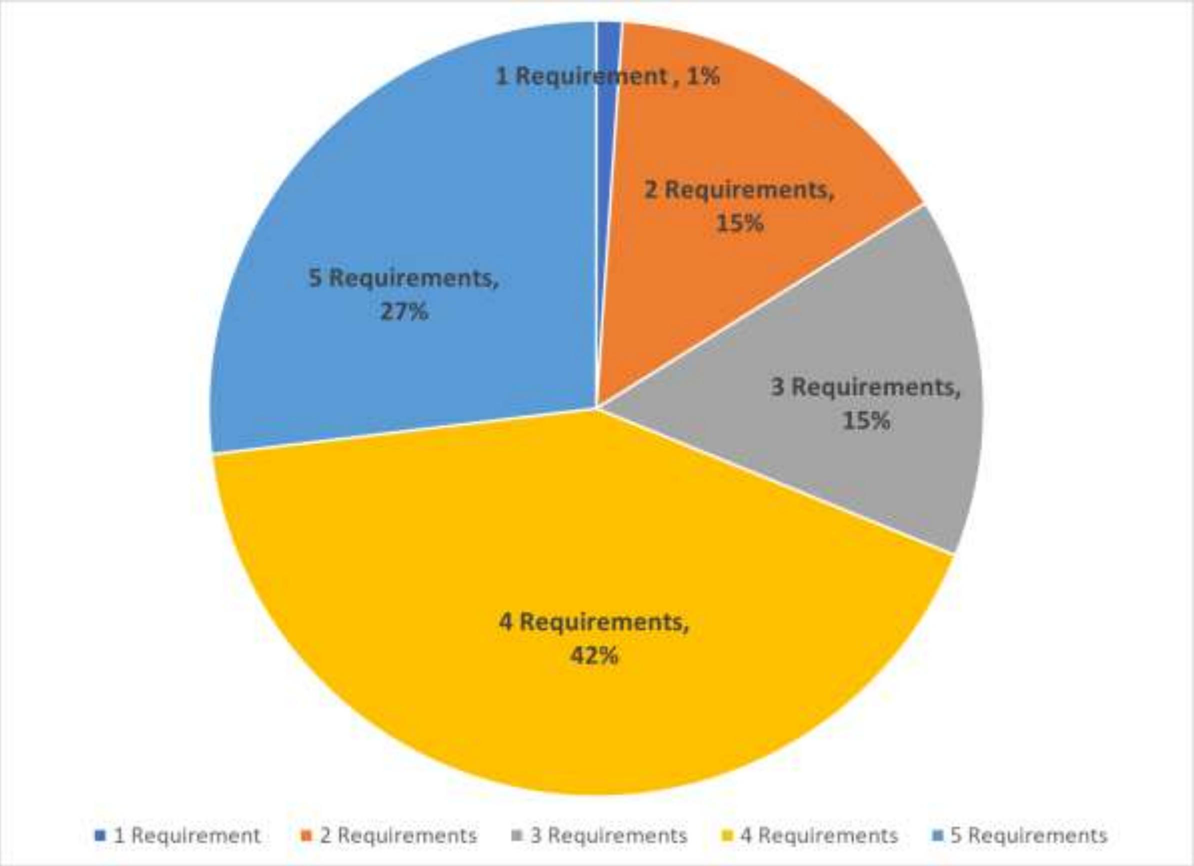

Figure 33 ***Cumulative pie chart indicating the percentage of bores that meet all of the LWRP well head security requirements***

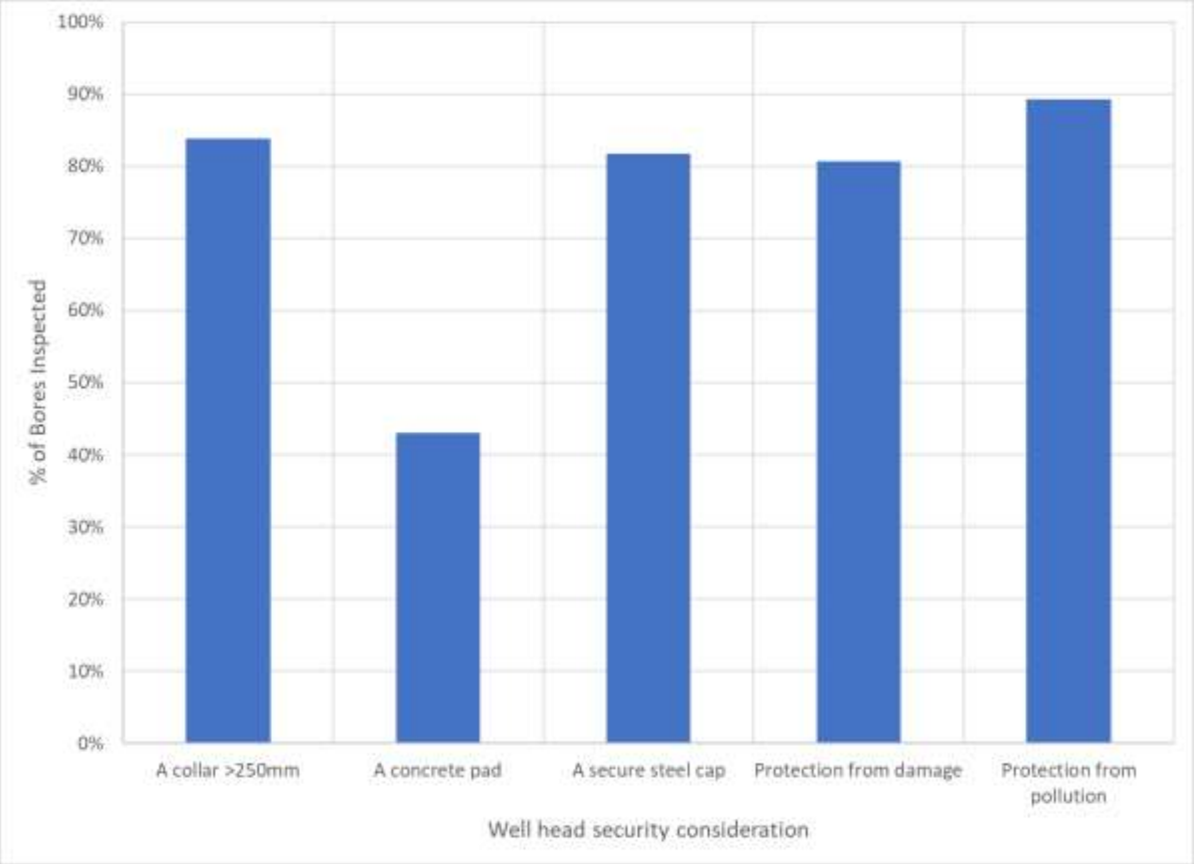

Figure 34 ***Breakdown of well head security audit***

4.5.Survey Spatial Coverage

The current groundwater abstraction guidelines for ECan require a 2 km buffer zone from a bore [23], [24] for a WQN 10 assessment to assess interference effects from abstraction[17]. 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 35 presents the survey coverage from 2016 to 2021.

Figure 36 presents a spatial comparison of December 2020 with December 2021.

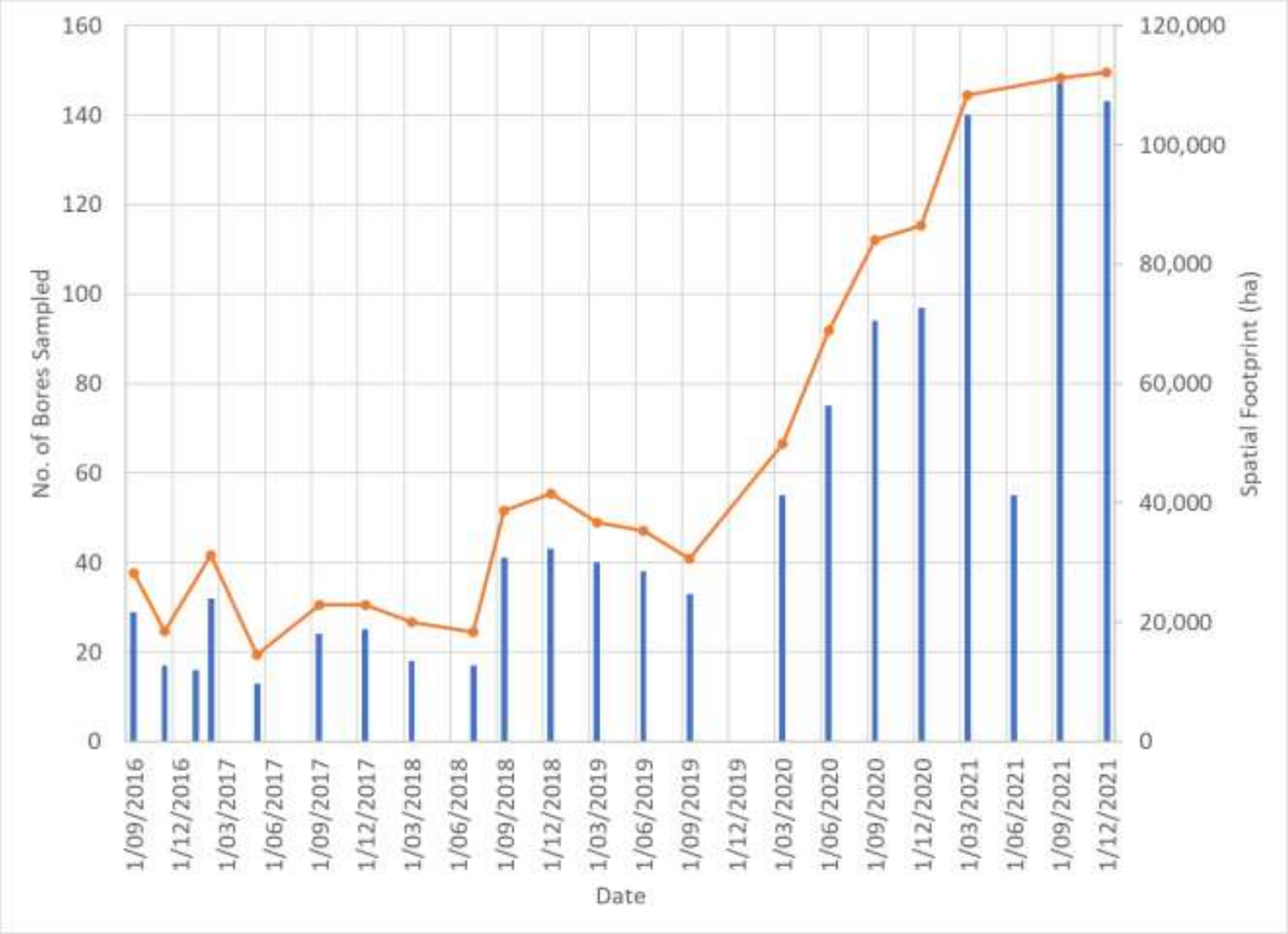

Figure 35 Survey coverage (ha) 2019 - 2020

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[17] https://wqn10.ecan.govt.nz/

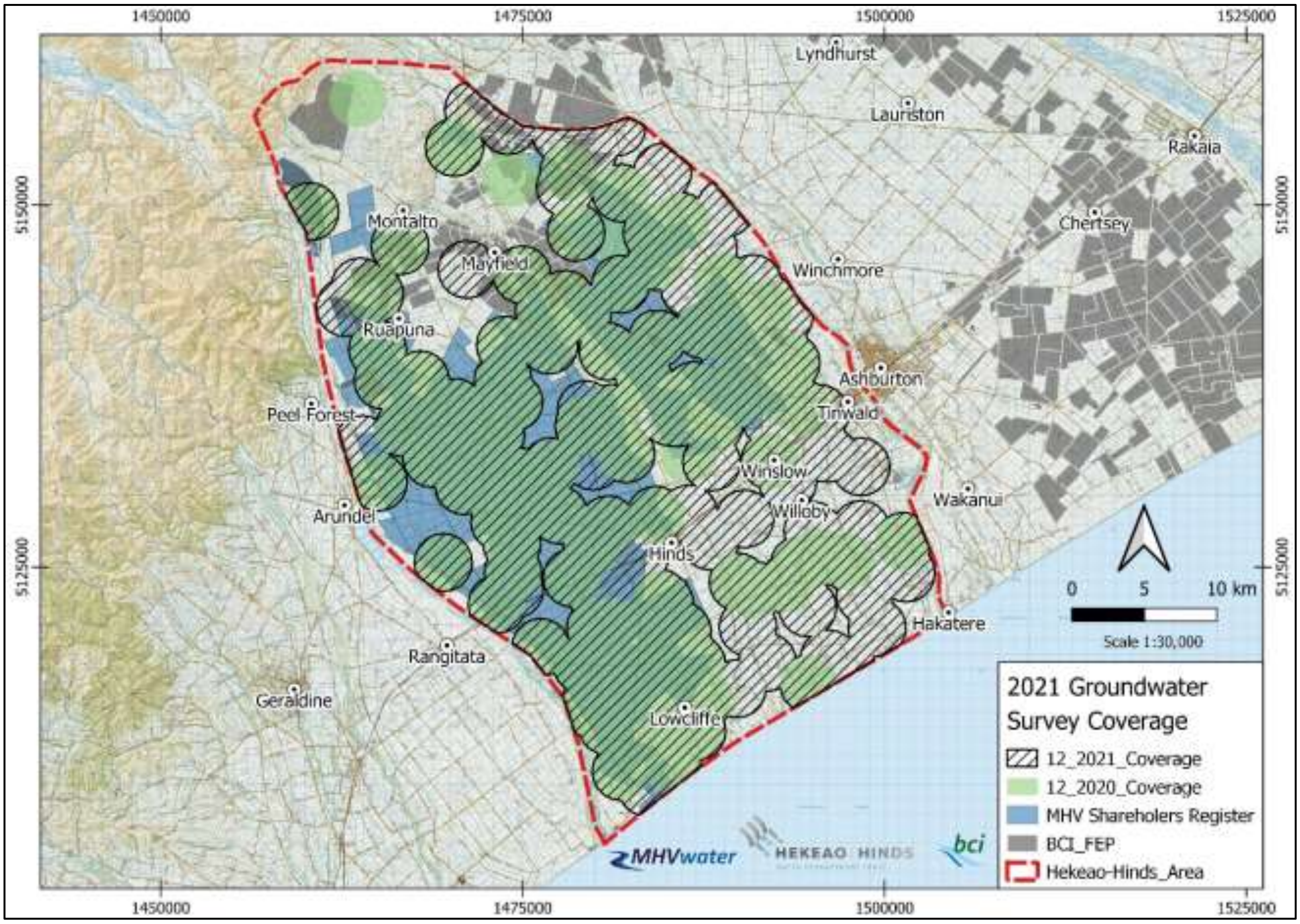

Figure 36 December 2020 compared to December 2021

4.6.Methodology

Samples were obtained using standard sampling protocols (see Appendix 3 for details), based on the National Environmental Monitoring Standards [25] (see Appendix 4 for details).

Based on these assumptions, as well as considerations such as ease of access, safety, practicality, and limiting disruption to on farm activities, Figure 37 presents a breakdown of the sample types collected.

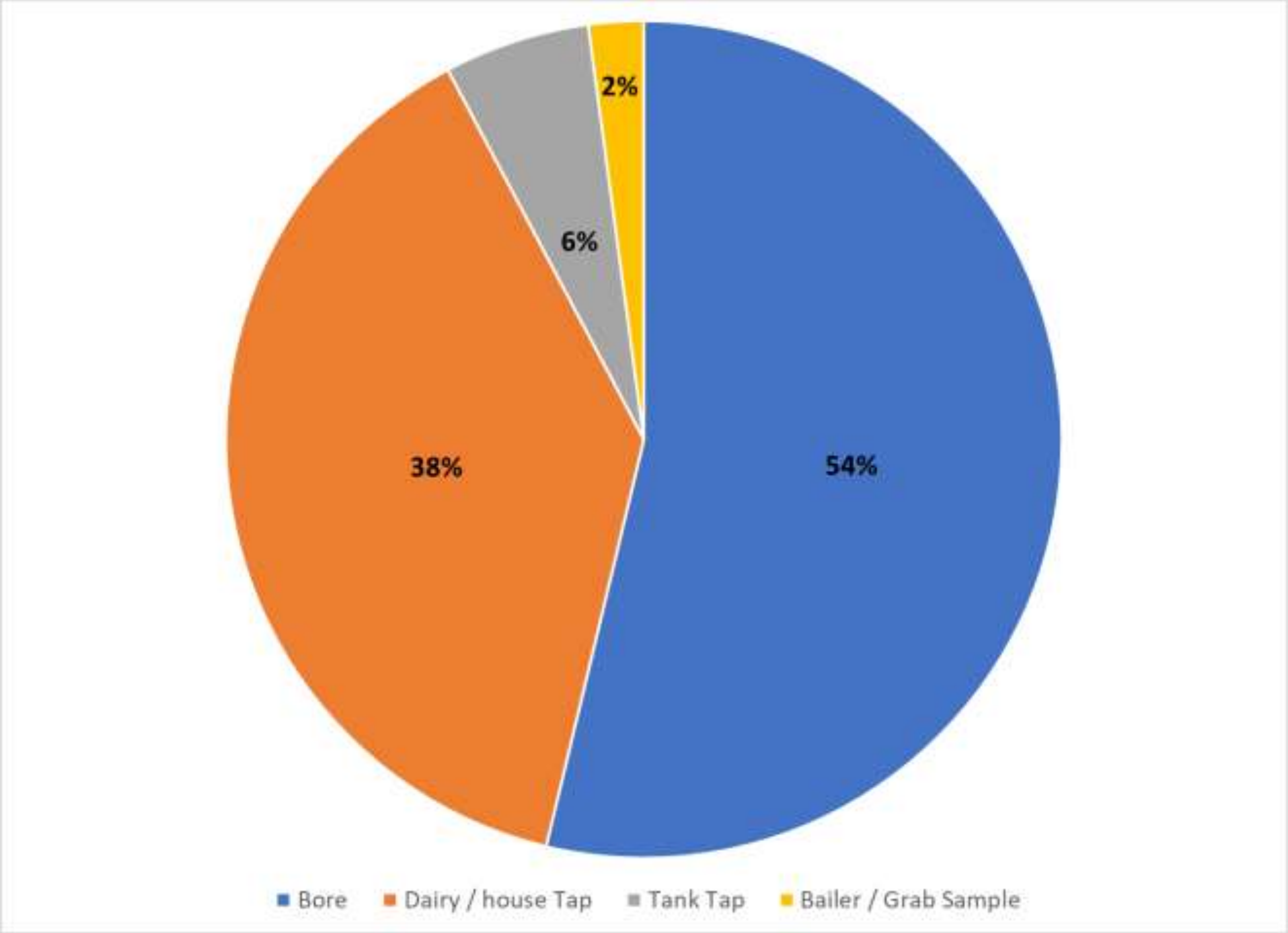

Figure 37 A breakdown of sample types collected during 2021

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

All samples collected in 2021 were determined in house via a HydroMetrics Nitrate GW50 Groundwater Optical Nitrate 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 parent site sample). An arithmetic mean was then calculated from the readings and used for reporting purposes.

Approximately 10% of the samples were analysed at Hills Laboratories (Hornby) throughout the year for Nitrite (NO_2) and Nitrate (NO_3) 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; and,

ii. provide confidence that the sensor results adequately measure NO_3-N, when compared to accredited laboratory results. The results presented in Figure 39 indicate a correlation co-efficient (R^2) of 0.98 for both 2020 and 2021 data (Table 4), with a slight bias of +7% from the Hill Laboratory results (range -8% to +15%).

The locations and depths of the cross-checked samples are shown in Figure 38.

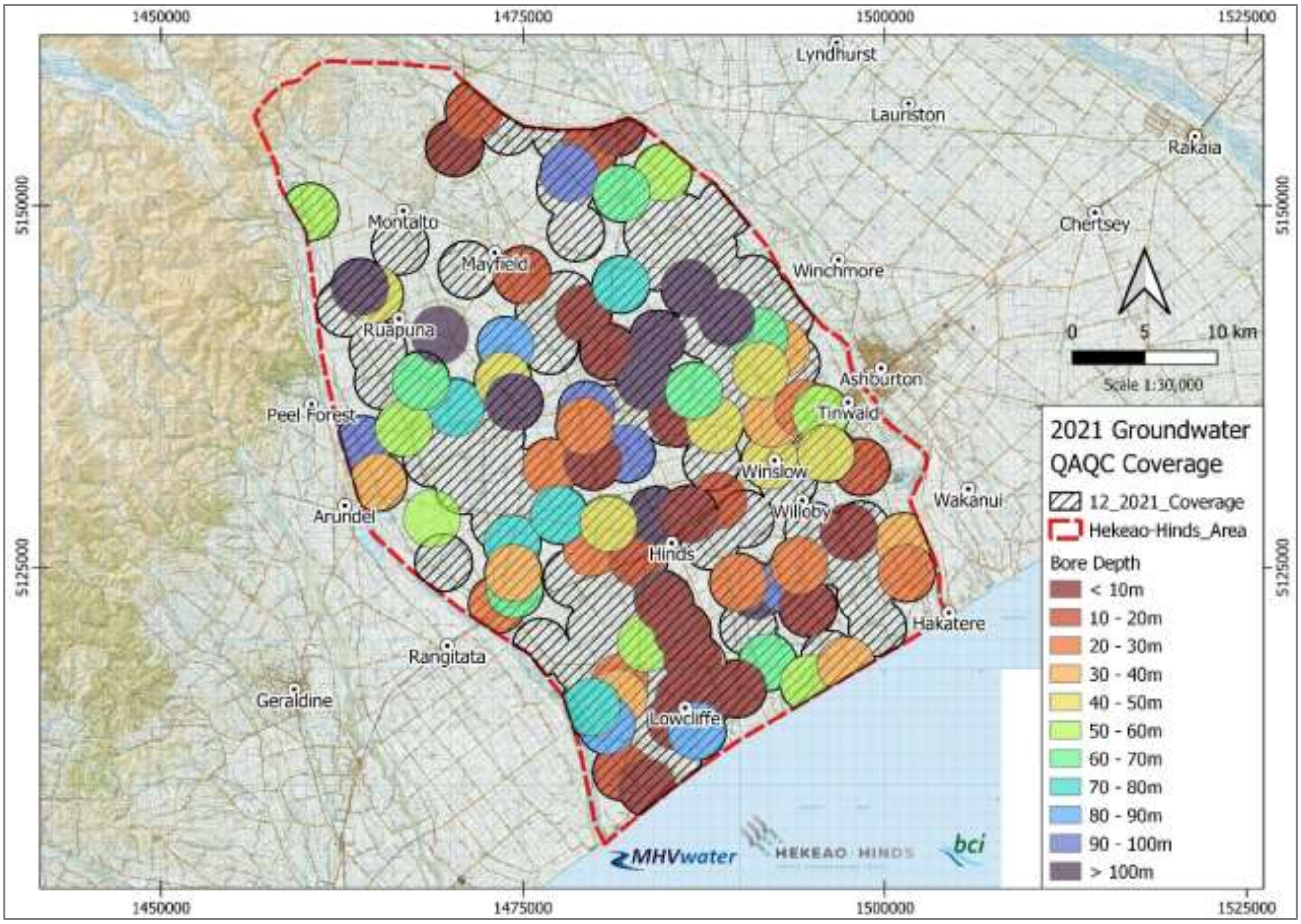

Figure 38 Locations of samples tested for QAQC purposes

As shown in Table 4, the regression between the GW50 and the Hill Laboratory results is above $R^2>0.95$ – see Figure 39.

Table 4 Regression co-efficient between GW50 and Hill Laboratory data for 2020 and 2021

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
2020 + 2021	240	y = 1.0092x - 0.5059	0.983

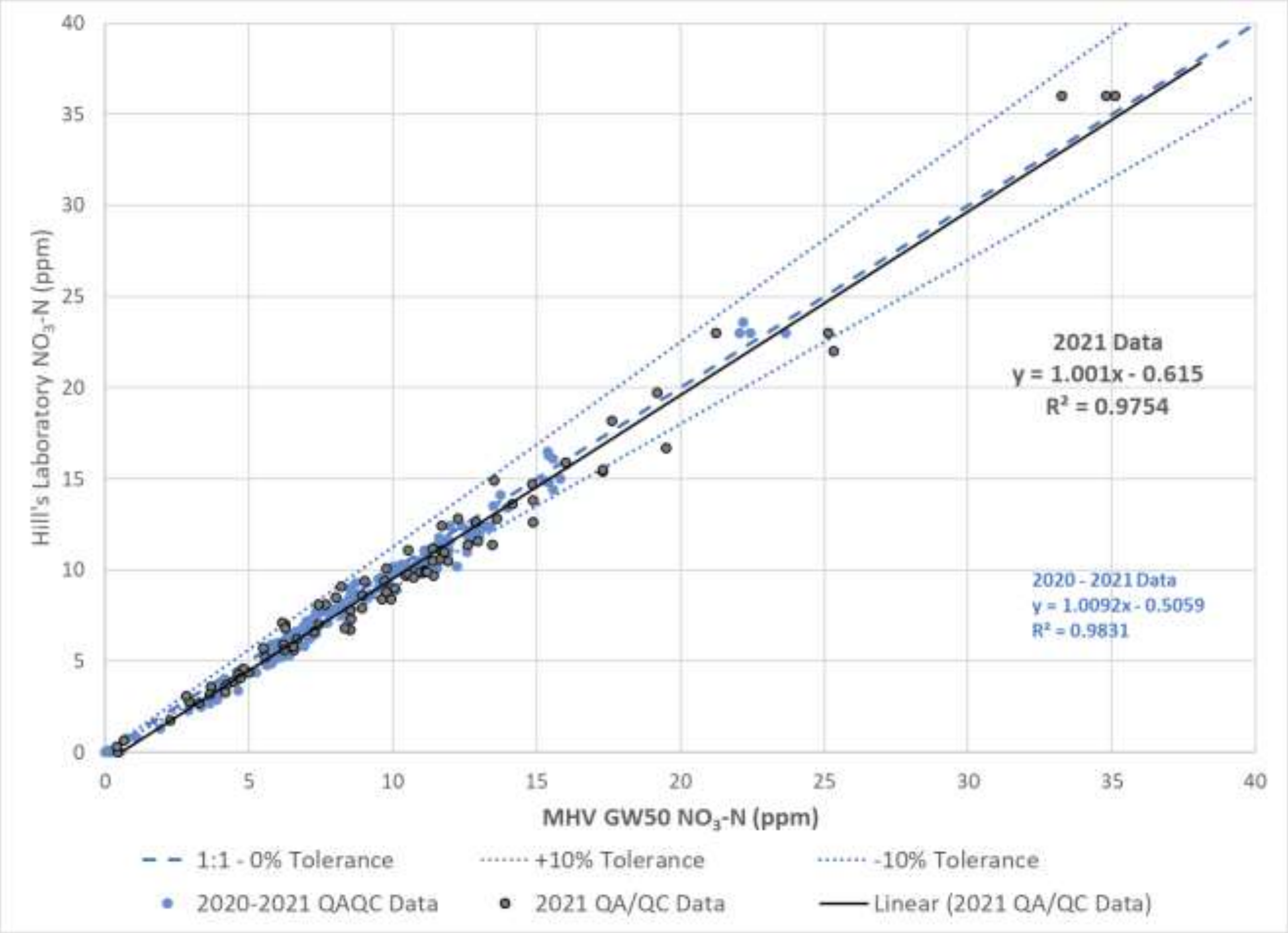

Figure 39 Scatter plot of inhouse NO_3-N results compared to Hills Laboratory Results

5. Surface water sampling programme

5.1.Surface-water Monitoring Programme Development

During 2021 MHV increased its surface water sampling programme significantly from an average of 10 samples per quarter to over 40 per month as shown in Figure 40.

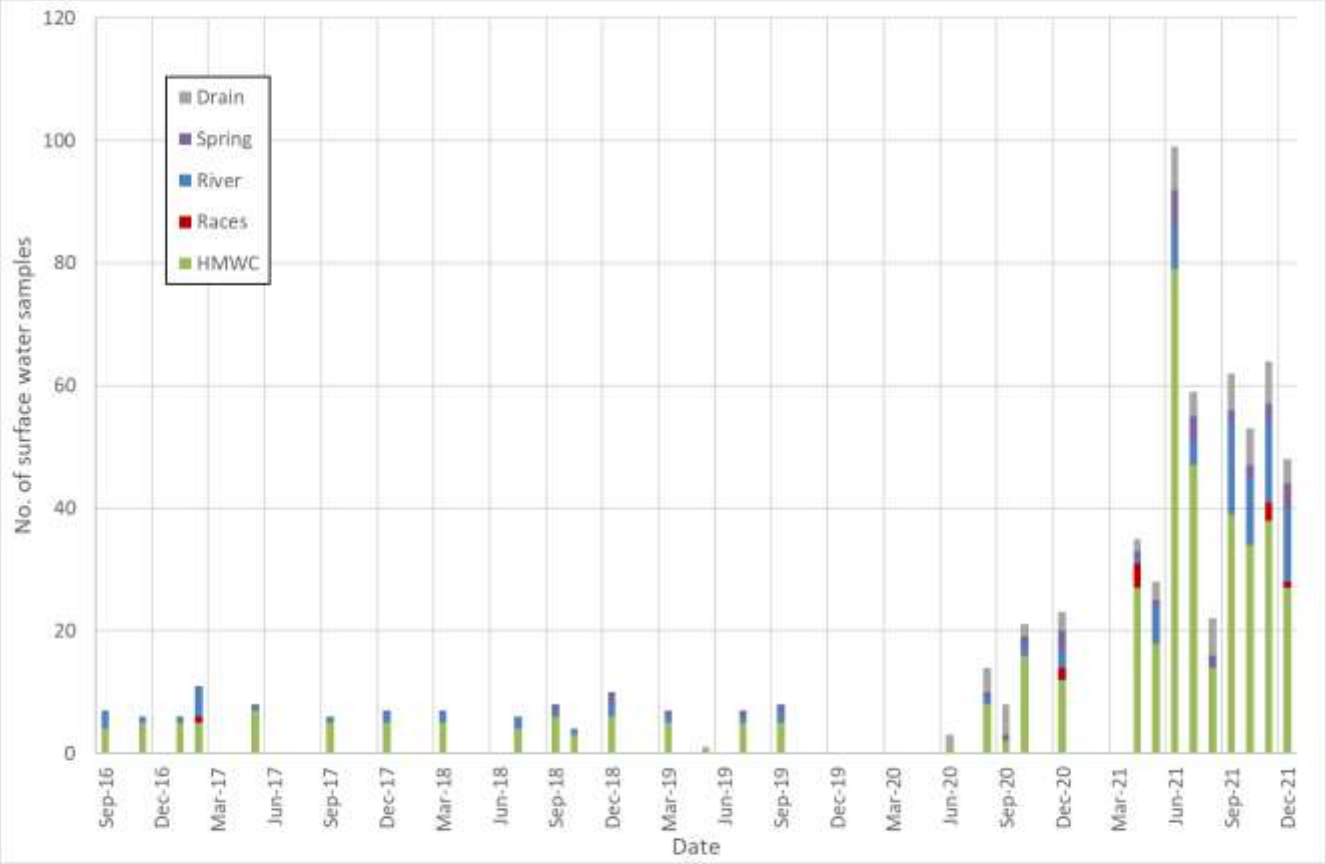

Figure 40 Changes in surface water survey design 2016 - 2021

During the year, some 470 surface water samples were collected from 83 water locations (Table 5) the majority of which were collected from public road culverts or bridges (Figure 41).

Table 5 Summary of 2021 surface water sampling programme

	Drain	HMWC	Race	River	Spring	Monthly Total
April	2	27	4	1	1	**35**
May	3	18		6	1	**28**
June	7	79		7	6	**99**
July	4	47		4	4	**59**
August	6	14			2	**22**
September	6	39		15	2	**62**
October	6	34		11	2	**53**
November	7	38	3	13	3	**64**
December	4	27	1	12	4	**48**
Annual Total	**45**	**323**	**8**	**69**	**25**	**470**

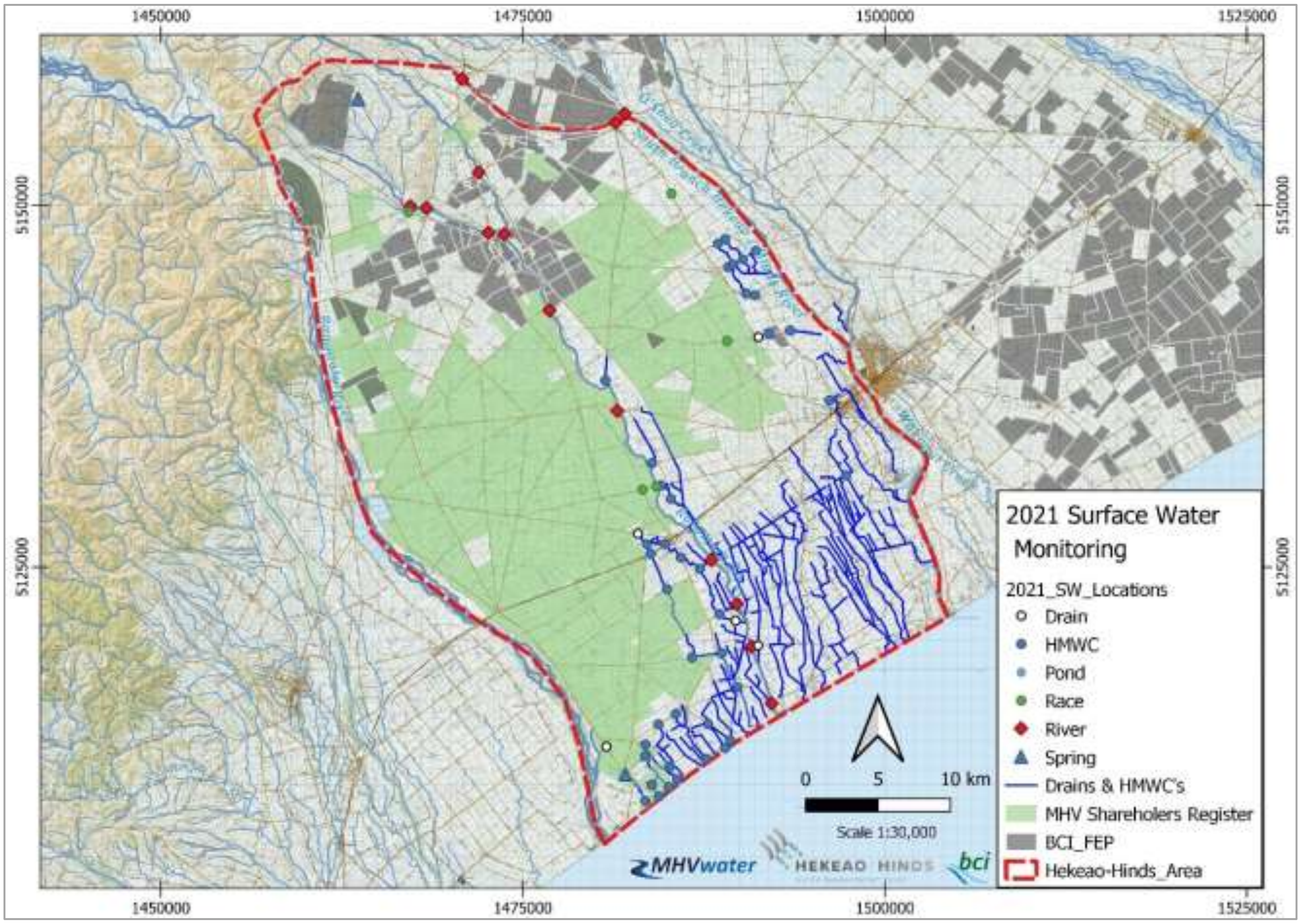

Figure 41 2021 Surface water sample locations

6. 2021 Rain Event

At the end of May, Canterbury experienced a 0.005% Annual Exceedance Probability (AEP)[18] rain event, with an Average Recurrence Interval (ARI) of 1:200 years (Figure 42 [28]).

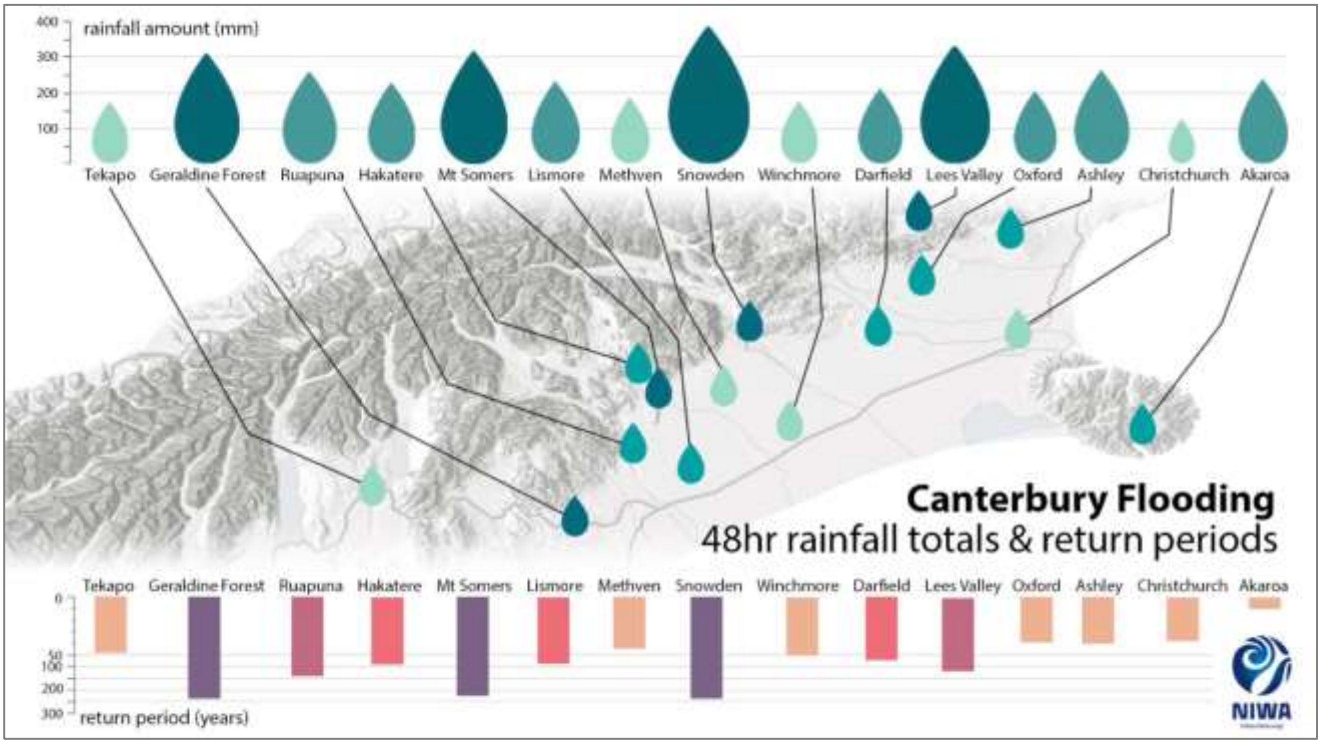

Figure 42 An infographic illustrating the rainfall and Average Recurrence Interval across Canterbury [28]

Within the Ashburton District, 540 mm of rainfall was recorded at the ECan Mount Somers weather station (approx. 800m above msl) with 185mm of rainfall being recorded at the ECan Hinds Plains weather station (approx. 90m above msl) over the course of the three day event between 29th and 31st May 2021.[29]. This resulted in excessive rain across the Hekeao Hinds catchment with three times the average May rainfall falling in a period of 7 days (Table 6), with higher rain recorded in the foothills (Figure 43).

Table 6 NIWA Rainfall data for the period 28th May – 5th June 2021

Location	May Monthly Av. Rainfall(mm)	28th May – 5th June 2021 Rainfall (mm)
Mayfield	77	264
Lismore	60	238
Winchmore	66	158
Methven	75	191
Coldstream	30	169
Willowby	45	188

---

[18] 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 [27].

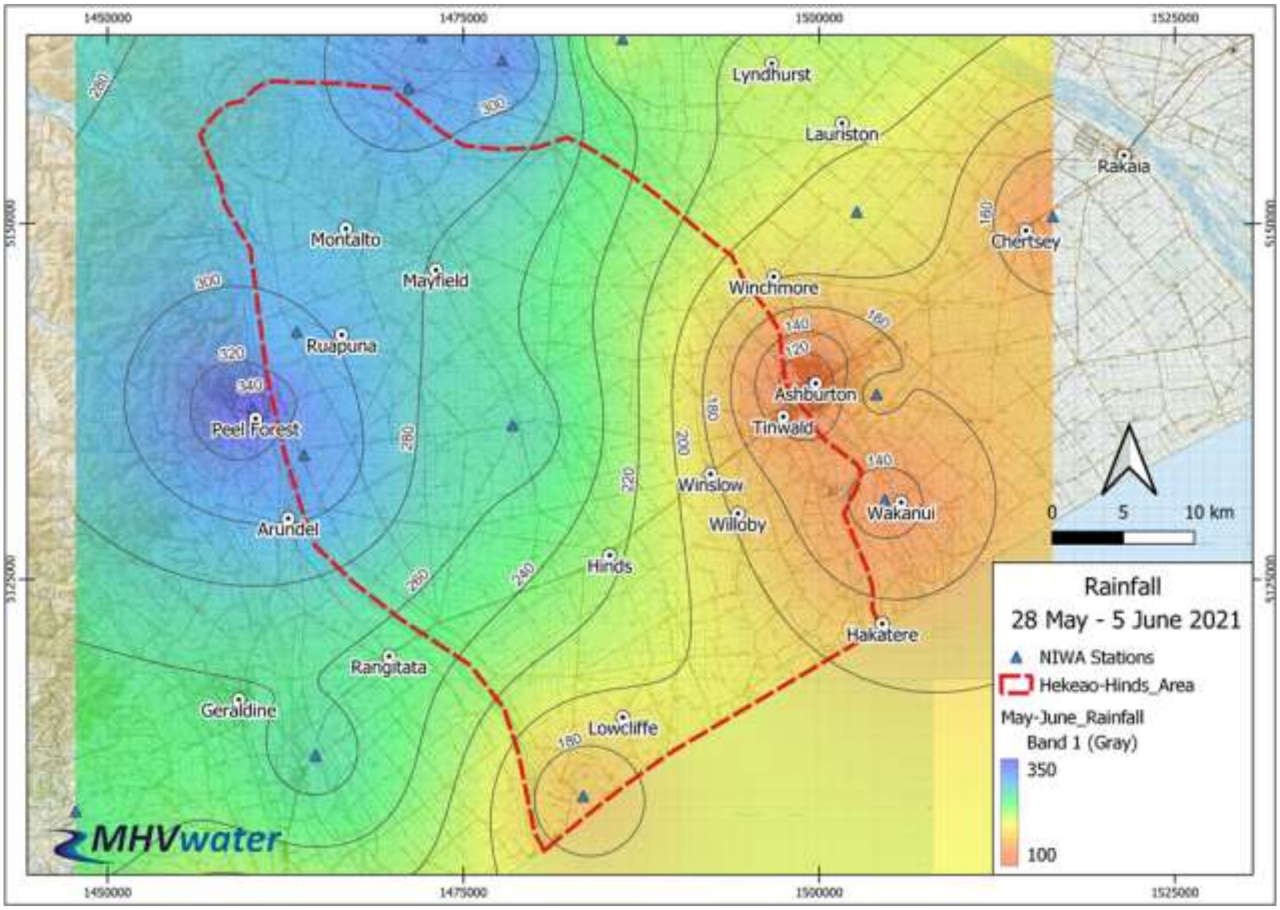

Figure 43 Rainfall distribution across the Hekeao Hinds catchment based on NIWA Data

Subsequently there was extensive flooding and damage across the catchment (Figure 44) with an estimated recovery cost of $19.7 Million (Tarboton and McCracken, 2021).

Figure 44 Example of flooded paddocks [31]

In response to this event, MHV immediately began a parallel groundwater monitoring programme, detailed below in section 7.

7. Groundwater Monitoring Results

MHV immediately began a parallel groundwater monitoring programme following the rainfall event and commenced monitoring 56 bores on a weekly basis for a six-week period between 2nd June and 9th July. This was extended to a fortnightly basis until the COVID19 lockdown between 18th August and 8th September when monthly sampling was initiated. The survey area represented an area of 58,230 ha with 50% of the bores being <30 m deep (refer to Figure 45 and Figure 46). Between 2nd June and 6th December 2021, some 660 observations were made from 56 bores (Figure 47).

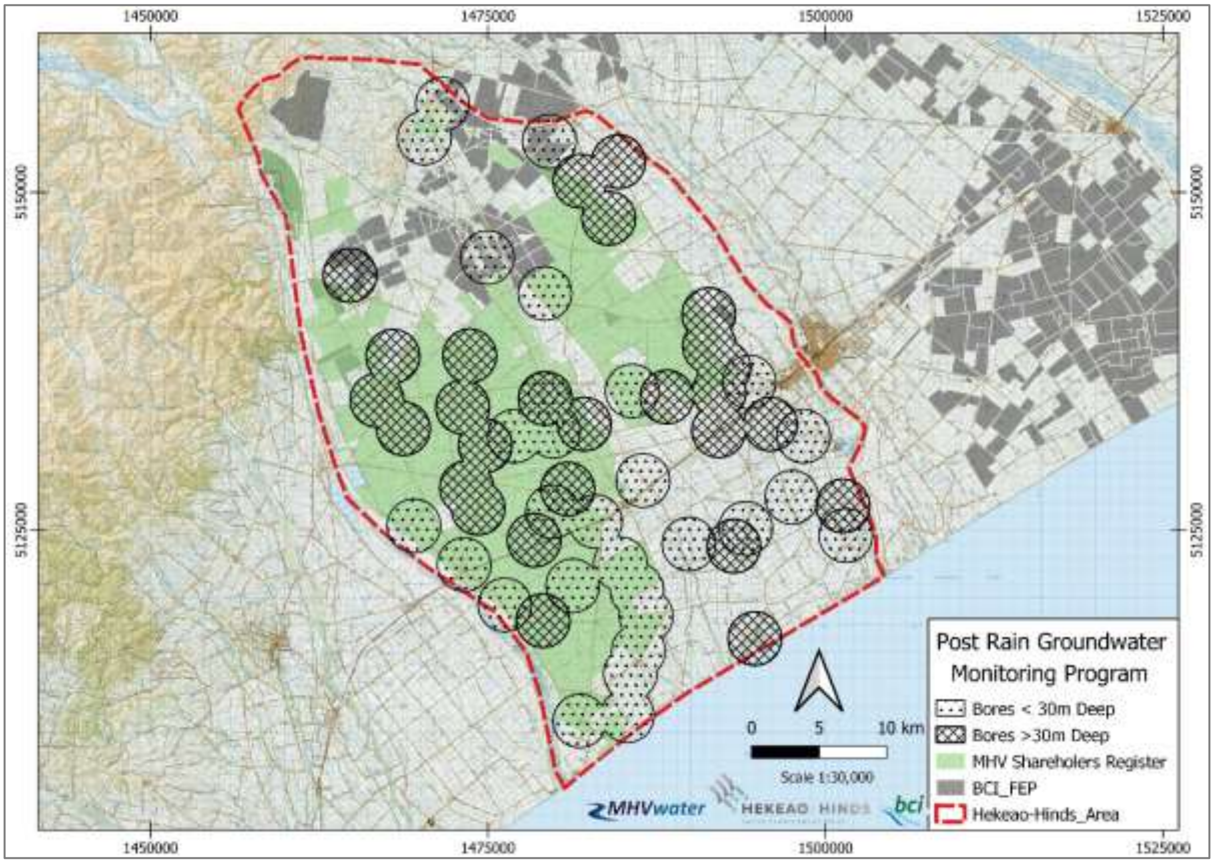

Figure 45 Spatial footprint of post rain event groundwater survey

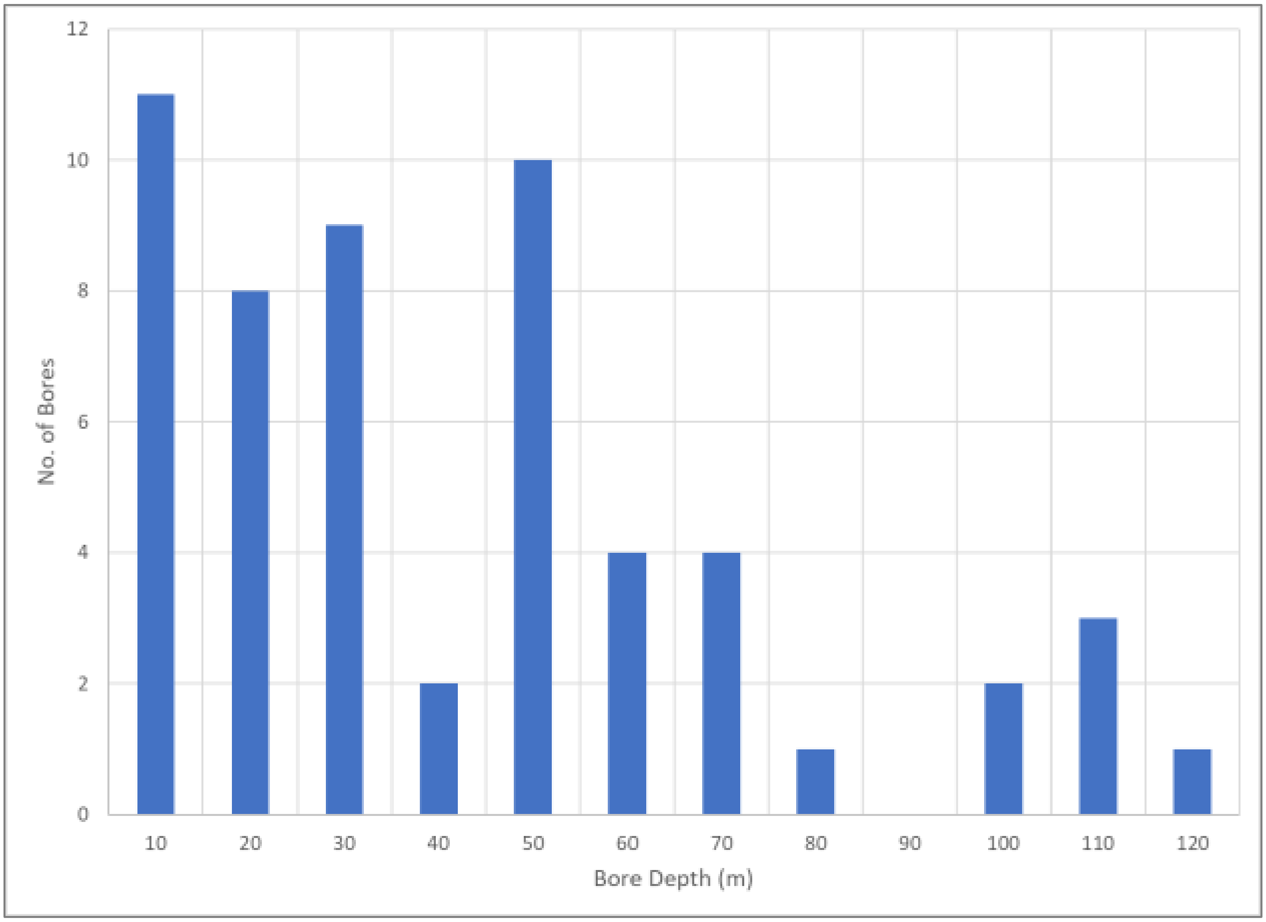

Figure 46 Depth histogram of bores incorporated into the post rain event groundwater survey

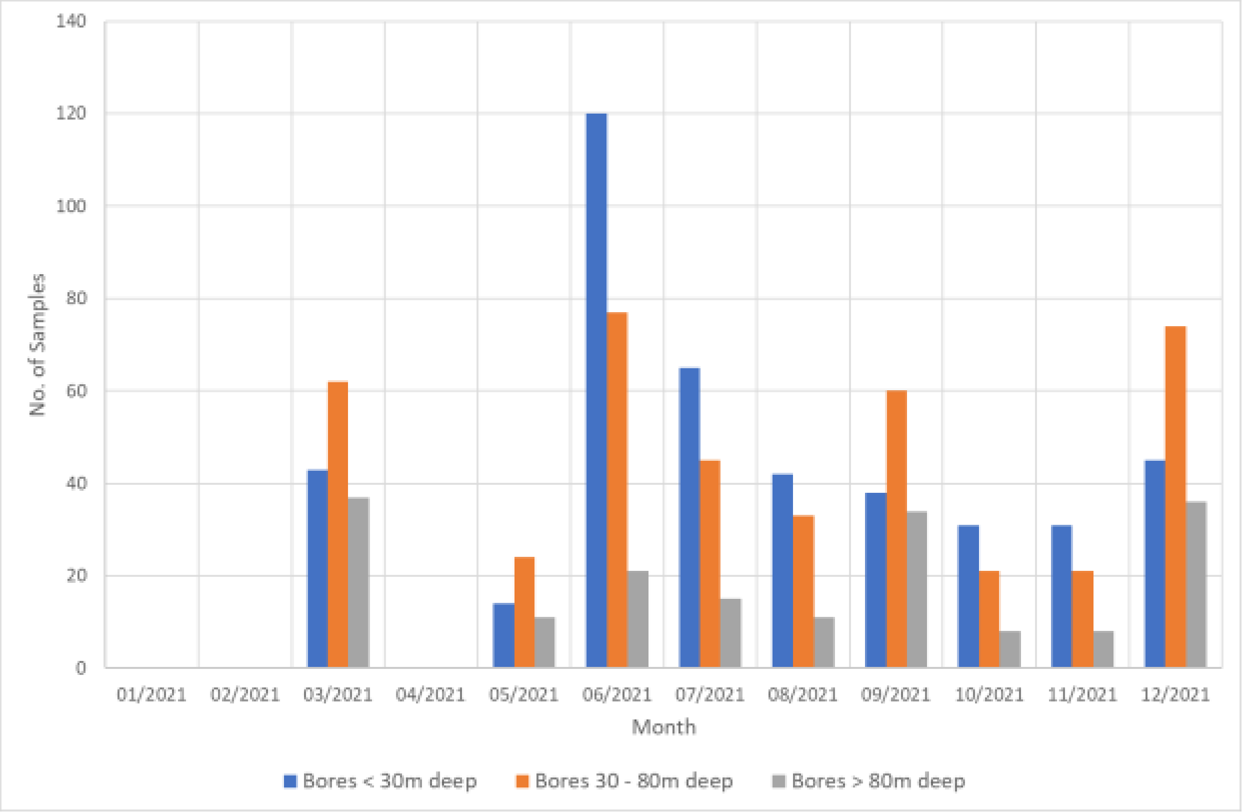

Figure 47 Groundwater sampling frequency 2021

7.1.Post Rain Groundwater NO_3-N Results

When considering the results collected during 2021, it is important to recognise the following:

i. The annualised results will be skewed due to the rainfall event of May - June 2021; and,

ii. The rainfall event was a short temporal event with variable responses across the catchment – refer to section 9.

The results of the

- 56 bores between programme between 2nd June and 6th December 2021 (Table 7); and,
- The 2021 programme as a whole (Table 8);

entire indicate that the shallow bores (<30 mbgl) had a significant range in NO_3-N compared to the deep bores (>80 mbgl). This is also evident in the coefficient of variation (CV) being higher for the shallow bores compared to the deeper ones.

Table 7 Raw descriptive statistics of the NO_3-N results of the post rain monitoring programme between 02/7/2021 – 6/12/2021

Bore Depth	No. of Samples	Min	Max	Range	Average	Median	Std. Dev	CV[19]
<30 m	349	0.71	36.81	36.10	13.20	11.92	6.39	0.48
30-80 m	269	0.36	20.25	19.89	10.94	10.92	3.87	0.35
>80 m	83	2.60	17.17	14.57	9.01	7.97	3.99	0.44
All Depths	701	0.36	36.81	36.44	11.84	11.32	5.48	0.46

Table 8 Raw descriptive statistics of the NO_3-N results for 2021

Bore Depth	No. of Samples	Min	Max	Range	Average	Median	Std. Dev	CV
<30 m	425	0.39	36.81	36.41	12.40	11.63	6.58	0.53
30-80 m	417	0.36	26.31	25.95	10.25	10.40	4.34	0.42
>80 m	181	0.13	18.46	18.33	8.10	7.05	3.79	0.47
All Depths	1023	0.13	36.81	36.68	10.77	10.53	5.54	0.51

When the 2021 data is presented as a frequency histogram with a Cumulative Distribution Function[20] (CDF) (Figure 48), is it apparent that there is a long tail above the 98th percentile that that is not representative of the data population. This tail is driven by four shallow bores that saw an increase immediately after the rain, but then immediately started to decrease (a 35% reduction from the initial response was noted after 8 weeks). Extreme values are common in natural systems monitoring. This is a key reason for using the median rather than the average as the primary reporting statistic.

---

[19] The coefficient of variation (CV) is a measure of relative variability. The CV is particularly useful when you want to compare results from two different surveys or tests that have different measures or values. A population with a CV of < 0.5 is considered to have a low variance low, 0.5 -1.0 moderate and > 1 high.

[20] A cumulative distribution function (CDF) is an accumulated histogram where the proportion of samples below each value threshold (cumulative probability) is plotted against that value.

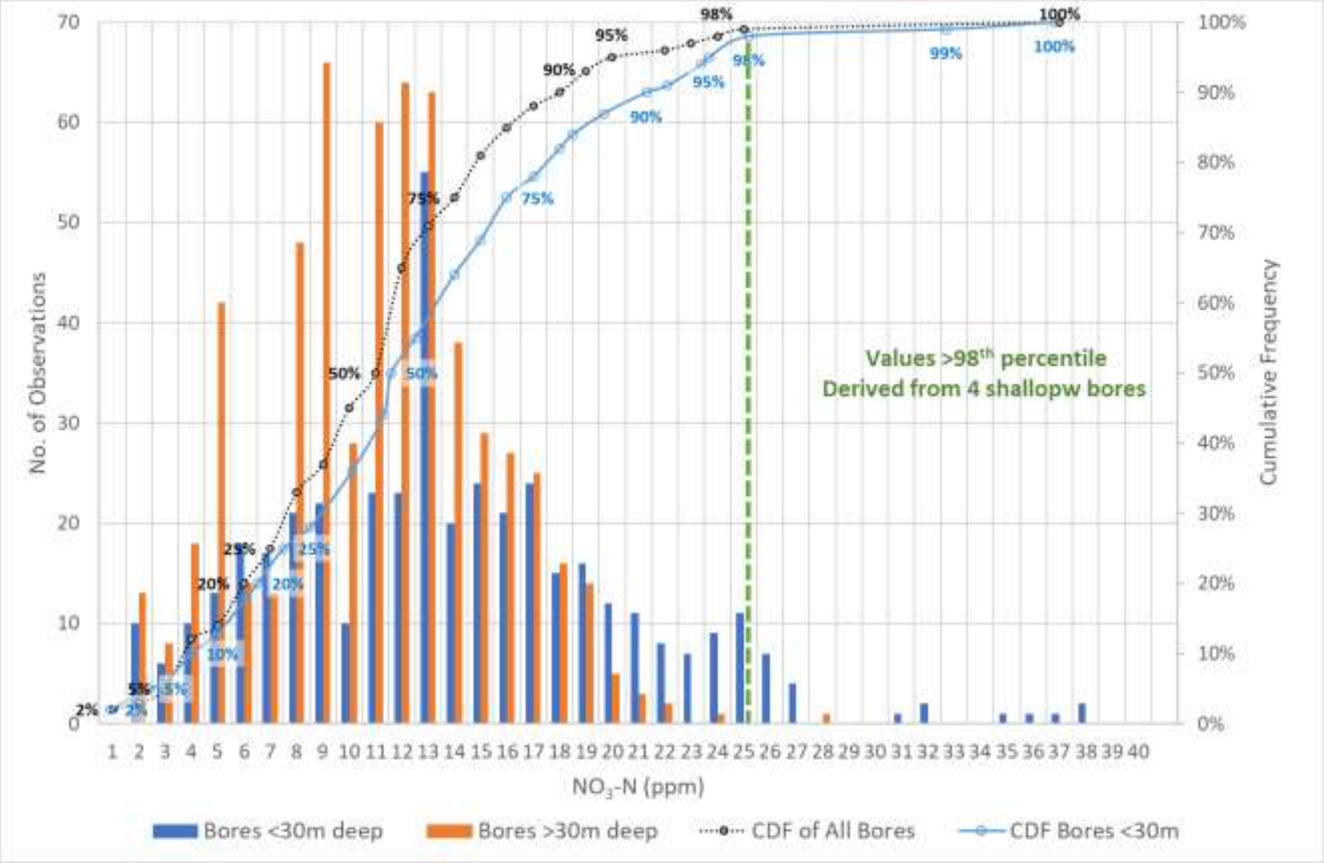

Figure 48 Frequency histogram with a cumulative distribution function of the 56 bores between 02/7 – 6/12/2021

7.2.Relative changes Post Rain Groundwater NO_3-N Results

When the results of the 56 monitoring bores between June and December were compared with their corresponding March 2021 results (Table 9 and Figure 49), the following generalised observations can be made:

- 6% of the NO_3-N results decreased;
- 45% of the NO_3-N results increased by 0 - 2 ppm;
- 27% of the NO_3-N results increased by 2 - 5 ppm;

  hence 72% of data increased by 0 - 5ppm;
- 17% of the NO_3-N results increased by 5 - 10 ppm; and,
- 5% of the NO_3-N results increased by 10ppm or more – these results were restricted to 8 shallow bores (<30m deep).

Table 9 Descriptive statistics of the changes in NO_3-N between June and December relative to the corresponding bores in March 2021

Bore Depth	Count	Min	Max	Range	Median	Average	Std. Dev	CV
<30 m	347	-7.66	25.41	33.07	3.26	3.75	4.44	1.18
30-80 m	241	-3.80	10.16	13.97	1.02	1.68	2.41	1.43
>80 m	72	-3.38	9.55	12.94	0.94	1.89	2.57	1.36
All	660	-7.66	25.41	33.07	1.87	2.79	3.77	1.35

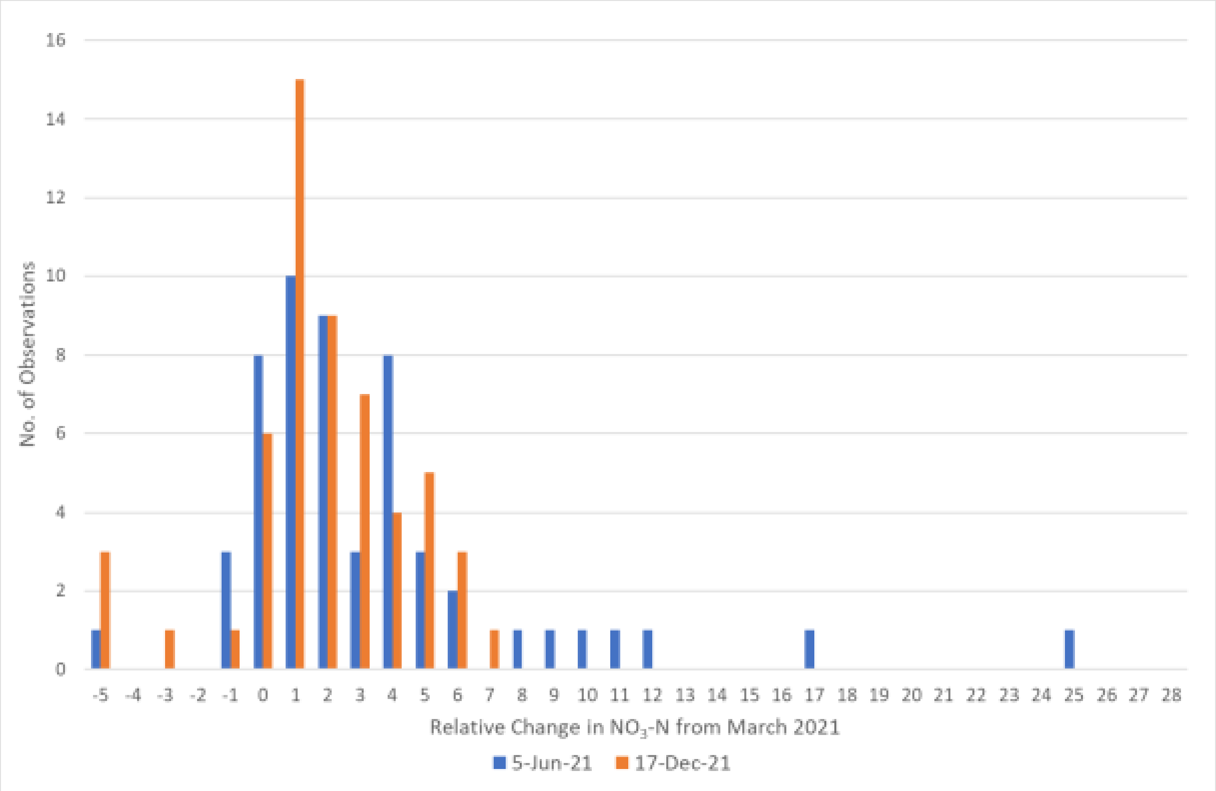

Figure 49 Frequency histogram of relative changes in NO_3-N to the corresponding bores in March 2021

From a catchment perspective, the NO_3-N results went up markedly immediately after the rain (by some 30%). Subsequent rains in mid-July arrested the decline in concentration. The data presented in Figure 50 has not been cut to illustrate the changes in NO_3-N concentrations in response to rainfall and changes in river flow over time.

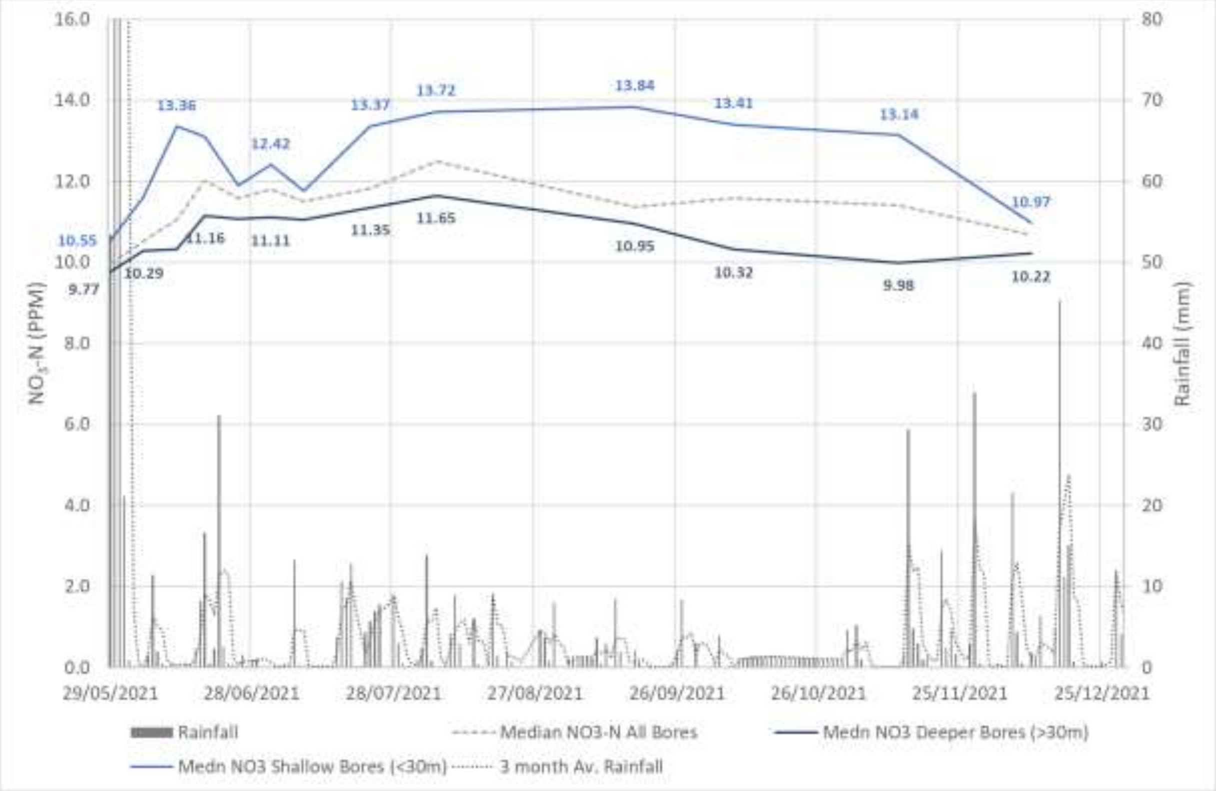

Figure 50 Median NO_3-N results for the 56 bores tested frequently after the May-June Rain

However, this level of statistical analysis of the relative changes in NO_3-N belies a more complex system that is variable both spatially and statistically - as indicated by CV values >1 in Table 9. This observation will be discussed in more detail in section 9.

7.3.Quarterly Catchment Scale Groundwater NO_3-N Results

As described in section 6, the quarterly catchment scale groundwater monitoring survey was disrupted in June due to the rain event. Table 10 present the results from the March, September, and December catchment surveys. Table 10 presents a summary of the results for each survey with the results presented graphically in Figure 51 and Figure 52. The long-term quarterly catchment scale groundwater monitoring results are discussed in section 9.4.

Table 10 Descriptive summary statistics for NO_3-N results from the 2021 surveys for all depths

Survey	Depth of bore	No of Bores	Min	Max	Range	Median	Average	Std Dev	CV
March	All	142	0.13	21.25	21.12	7.61	7.89	4.34	0.55
	<30m	46	0.40	21.25	20.86	9.10	8.19	5.29	0.65
	>30m	96	0.13	19.93	19.80	7.57	7.75	3.83	0.49
June - August	All	56	0.36	36.81	36.44	11.32	11.84	5.48	0.46
	<30	29	0.71	36.81	36.10	11.92	13.20	6.39	0.48
	>30	27	0.36	20.25	19.89	10.68	10.49	3.97	0.38
Sept	All	146	0.57	26.31	25.74	9.80	10.33	5.38	0.52
	<30m	45	1.10	24.62	23.52	12.62	12.24	6.40	0.52
	>30m	101	0.60	26.30	25.70	8.80	9.49	4.65	0.49
Dec	All	147	0.60	25.03	24.44	8.83	9.13	4.82	0.53
	<30m	43	0.62	25.03	24.41	10.24	10.06	5.75	0.57
	>30m	104	0.60	22.77	22.18	8.39	8.74	4.35	0.50

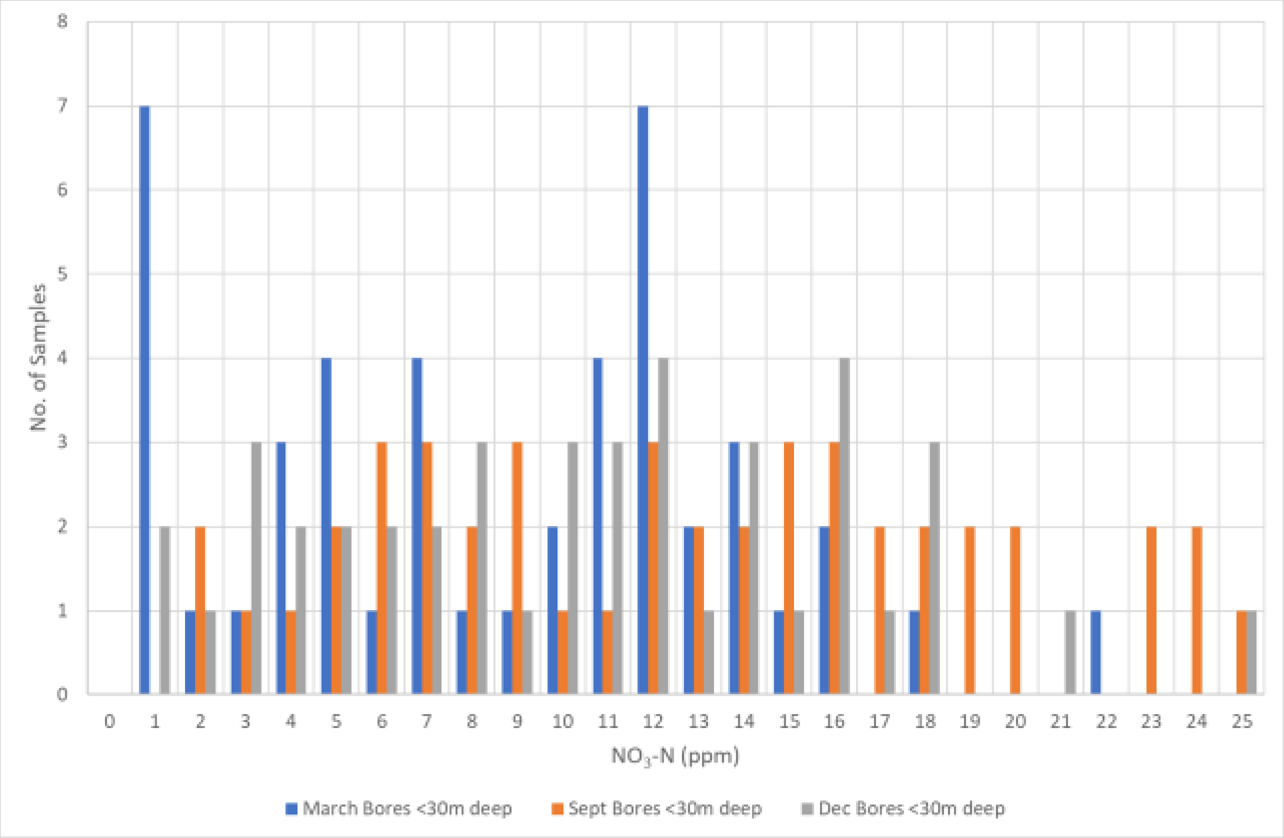

Figure 51 Frequency histogram of NO_3-N results for bores < 30m by quarterly survey

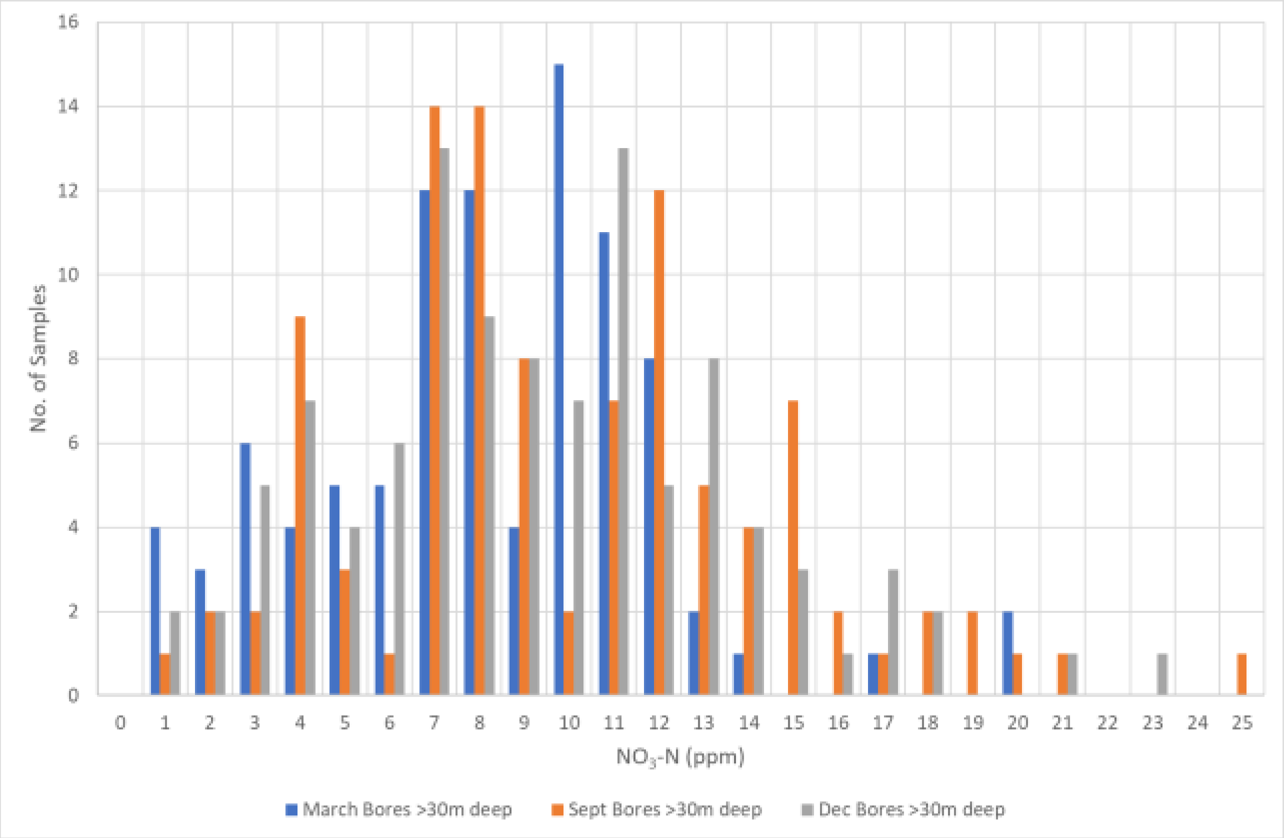

Figure 52 Frequency histogram of NO_3-N results for bores > 30 mbgl by quarterly survey

7.4.Groundwater Levels

MHV collected 446 groundwater level[21] soundings from 89 bores across Hekeao Hinds Plains during the year (Figure 53). Table 11 presents a summary of the results.

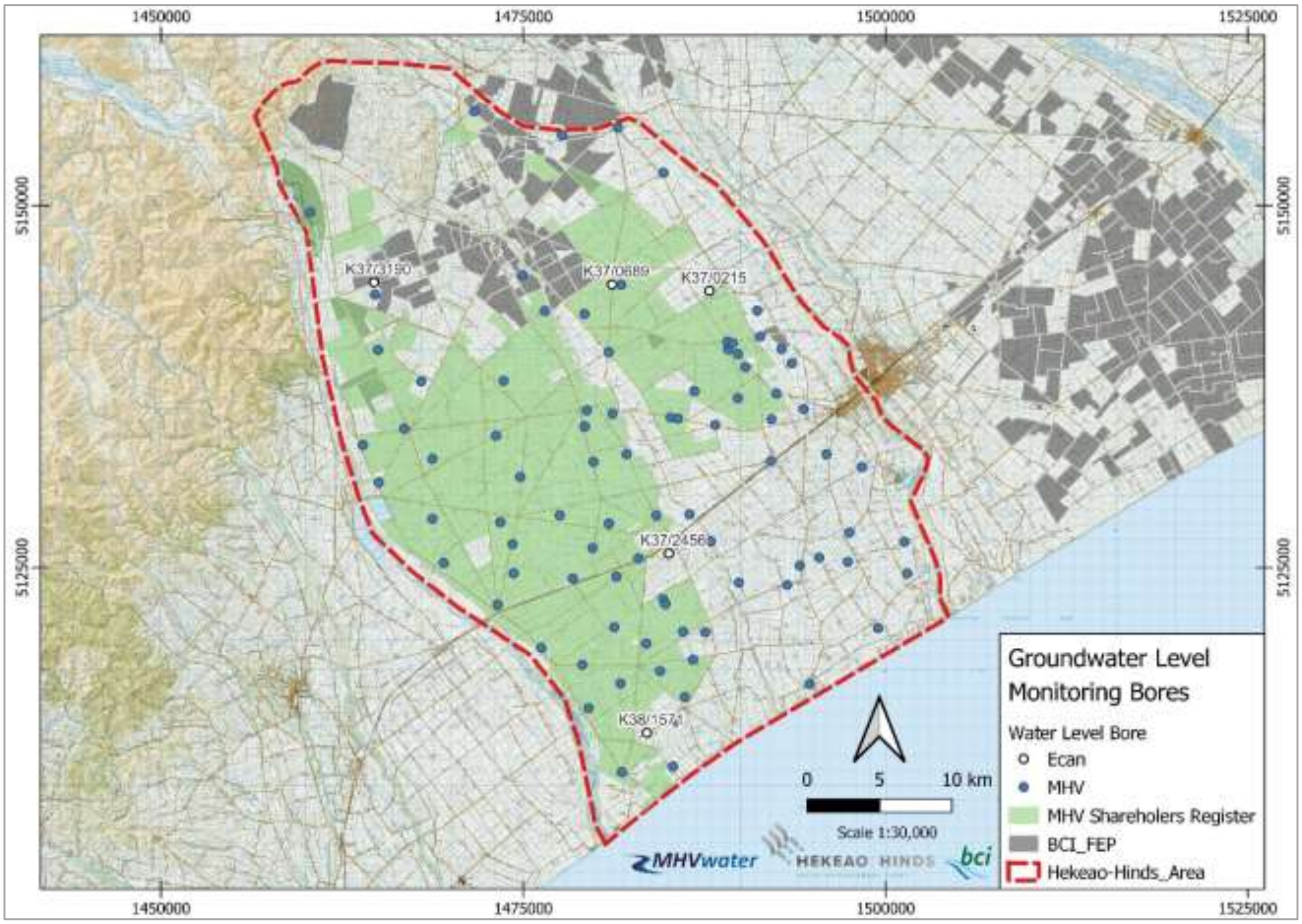

Figure 53 Locations MHV & ECan groundwater level monitoring bores

Table 11 summary statistics of groundwater level soundings

Month	No. of soundings	Minimum	Maximum	Range	Average
March	38	2.55	47.89	45.34	19.76
May	23	1.00	60.00	59.00	16.75
June	75	0.50	75.00	74.50	11.96
Jul	12	1.20	20.00	18.80	7.07
August	16	3.70	58.70	55.00	19.19
September	38	1.00	62.00	61.00	16.65
October	20	1.40	57.63	56.23	17.64
November	20	1.40	42.10	40.70	17.46
December	41	1.00	50.00	49.00	15.60

Groundwater levels are generally at their highest in the winter months in response to winter recharge rainfall and the absence of abstraction. This year, there was a significant response to groundwater levels

---

[21] ***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.

across the Hekeao Hinds Plains as result of the rainfall in June (Figure 54 presents MHV observations for 2020 – 21 whilst Figure 55 presents ECan data since 2015).

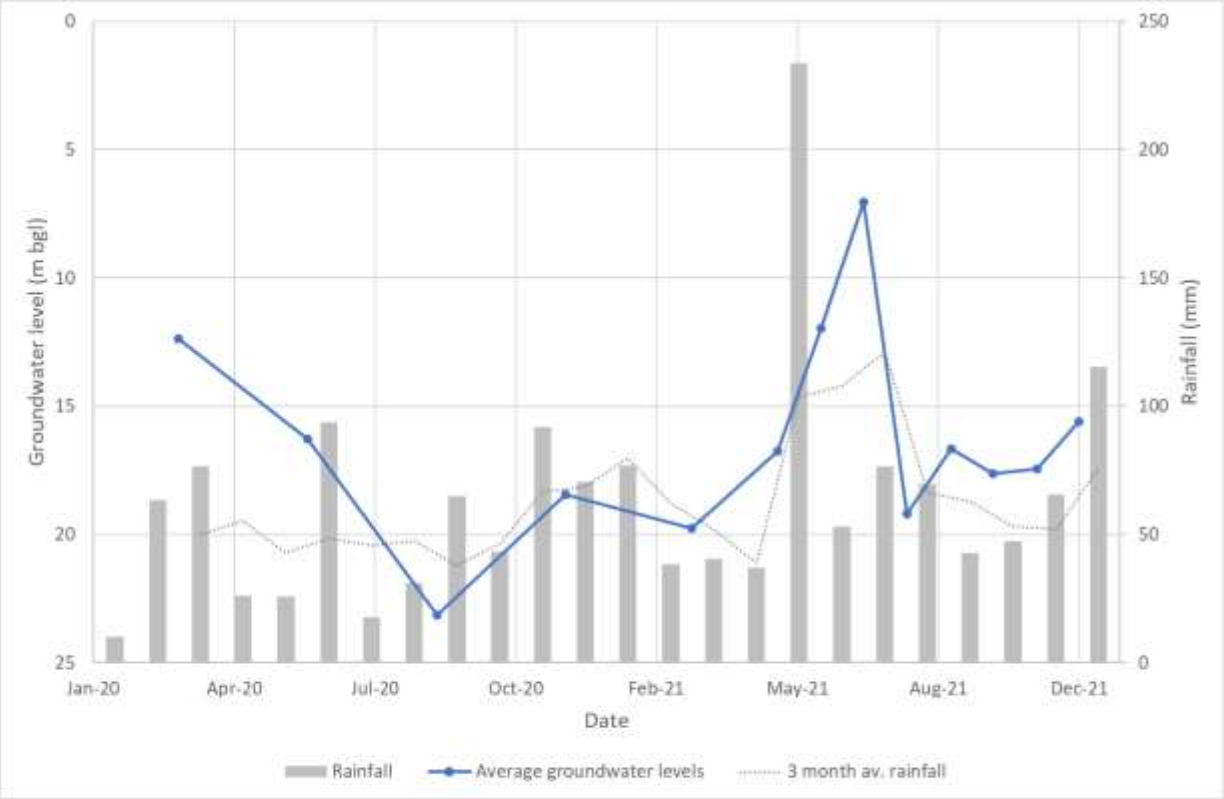

Figure 54 Average groundwater level data for the Hekeao Hinds Plains for 2021 with corresponding rainfall

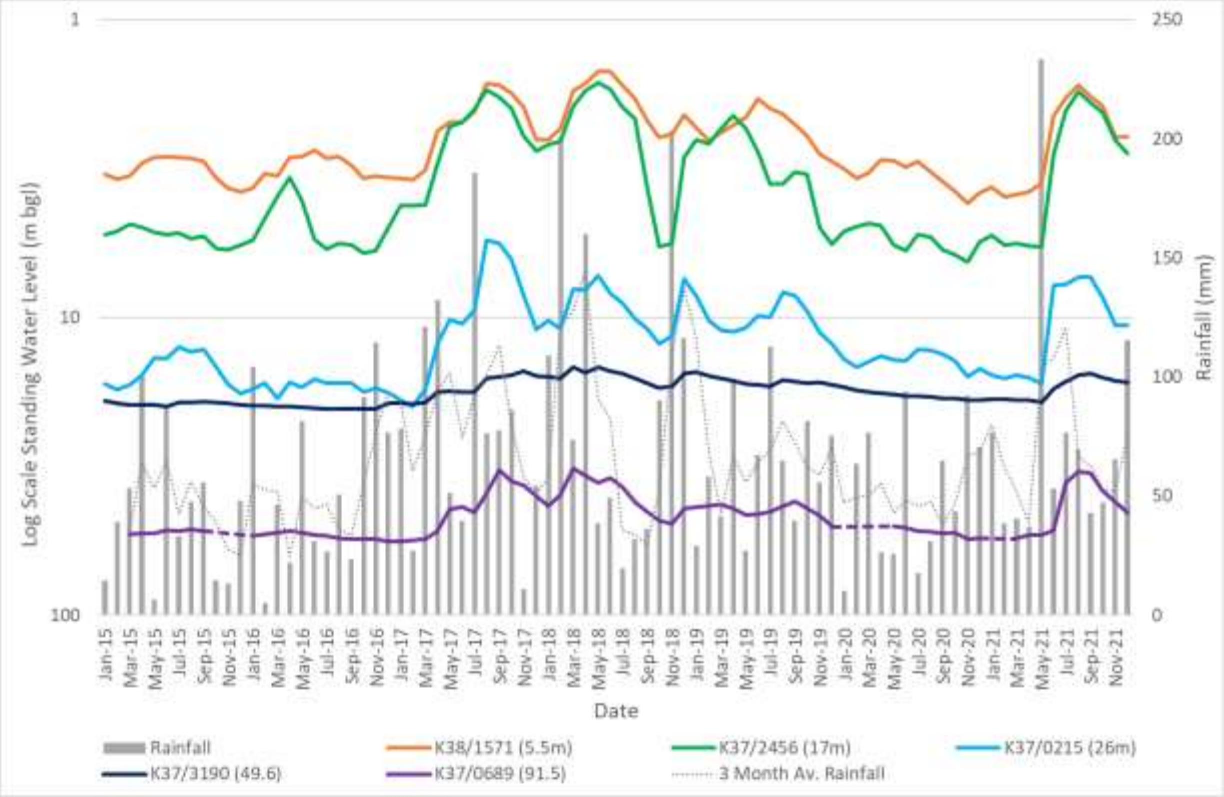

Figure 55 Hydrographs from ECan bores across the Hekeao Hinds Plains with rainfall 2015 to 2021.

8. Surface water Results

8.1. Disclaimer

The 2021 surface water results presented here need to be considered in the following context.

I. There are innumerable intersections between farm drains, council stock water races irrigation races and highly modified water courses (HMWC) as shown in Figure 56.

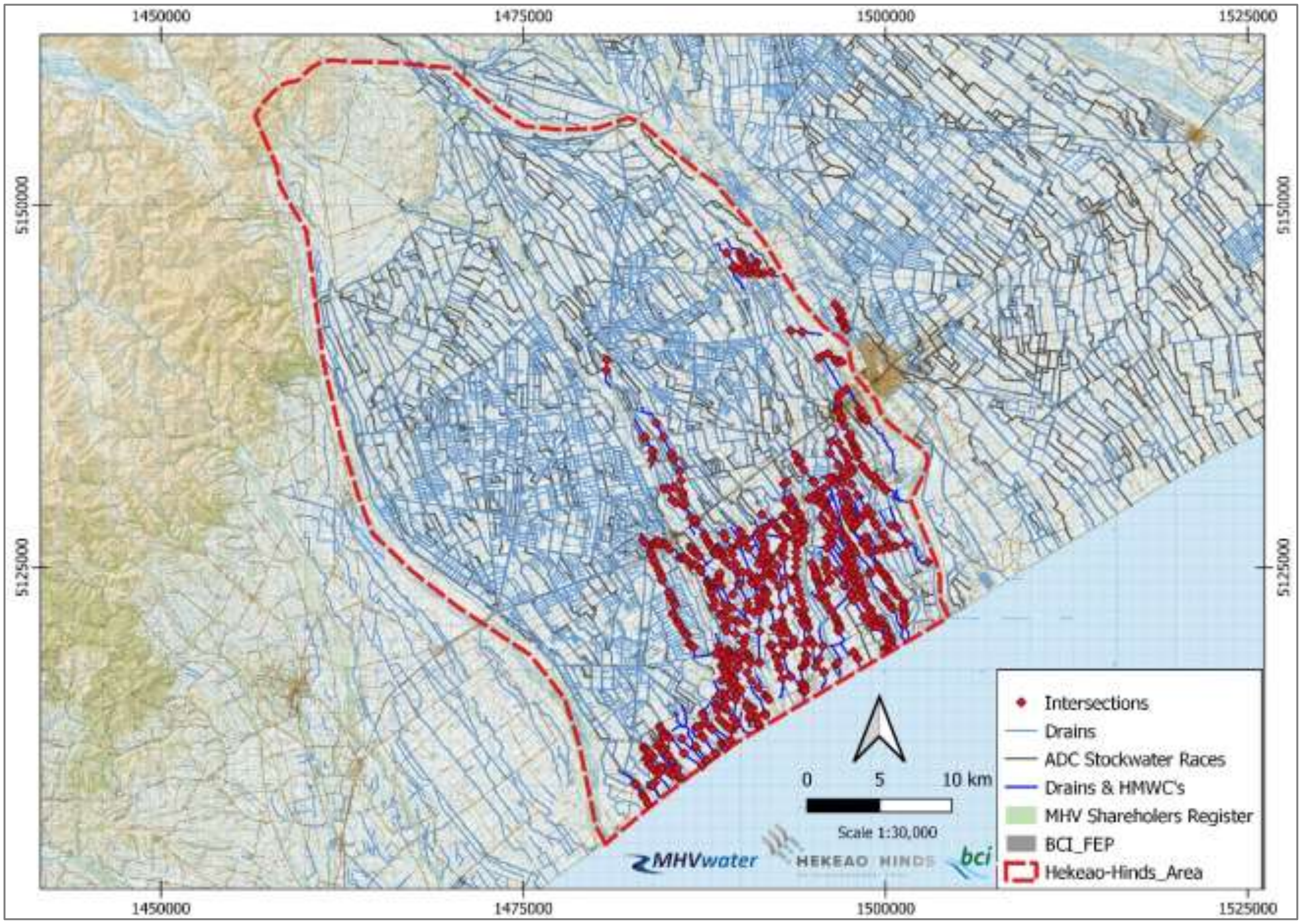

Figure 56 A map of known intersections between farm drains, council stock water races and highly modified waterways

Subsequently, 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 Hinds, Ashburton or Rangitata Rivers;
- farm drains; and/or,
- irrigation races which are sourced from the Rangitata River via the RDR.

II. As noted in section 6, there was extensive flooding across the Hekeao Hinds catchment in May-June (Figure 58). Subsequently, diffuse and point source leaching of nutrient may have occurred from [1], [32]:

   a. septic tanks and leaky sewers;
   b. urban runoff;
   c. waste pits and landfill; and/or,

d. soil and agricultural material.

This has contributed to the results.

Figure 57 Canterbury Maps imagery of Hinds January 2020[22]

Figure 58 Canterbury Maps imagery of Hinds June 2021

III. Sample locations categorised as 'springs' were generally 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.

---

[22] https://mapviewer.canterburymaps.govt.nz/?webmap=1ee2780295704d80ab37b61cdd768a76

Subsequently, the surface water data collected is somewhat heterogeneous - an example of this is presented in Figure 59 for two HMWC results.

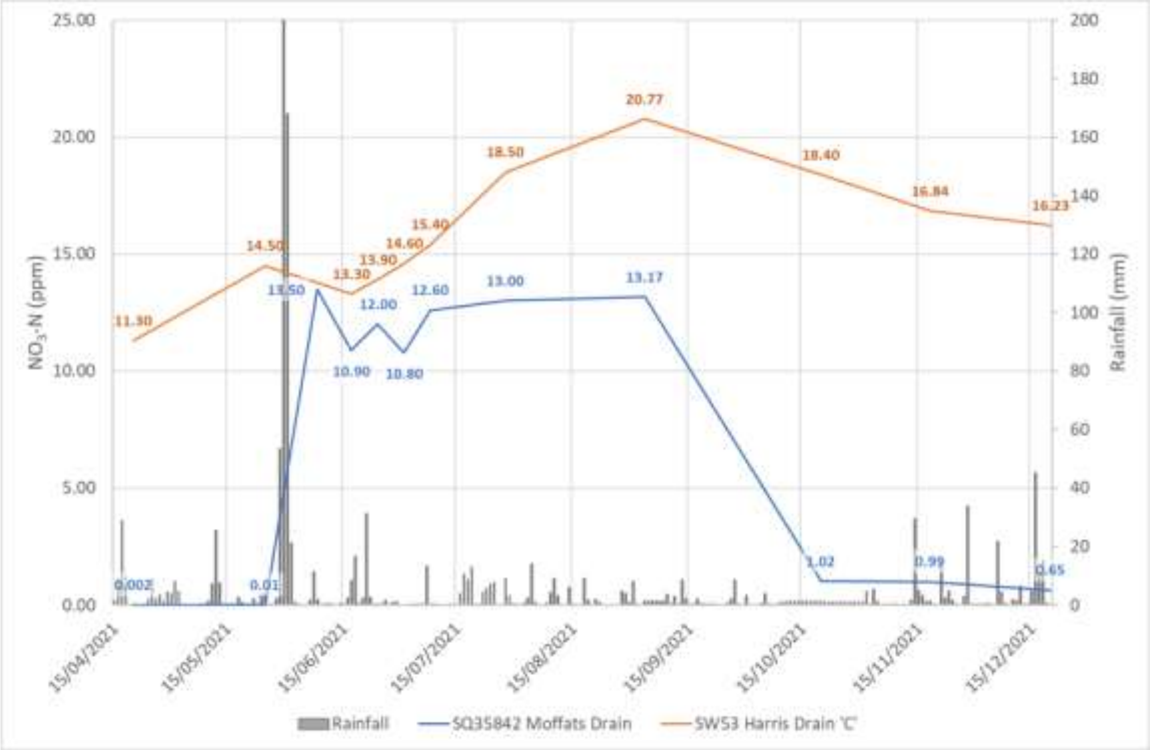

Figure 59 Changes in NO_3-N concentration for the Moffatts and Harris C Drain

Moffats Drain is normally sourced from ADC stock water races (which is derived from the Ashburton or Rangitata Rivers), and thus normally has a low NO_3-N concentration. However, between June and October, there was a significant increase due to the aforementioned inputs.

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

8.2. Results

As noted in section 5.1, some 470 surface water samples were collected during 2021 across the catchment (see Figure 41). The NO_3-N results are presented in Table 12, with Figure 60 presenting the average NO_3-N results for the respective surface water category for 2021 (refer to Appendix 5 for details). The long-term average NO_3-N for HMWC's is presented in Figure 61.

NB: *It should be noted that the data presented here may be influenced by the increased sampling regime after the rain event as shown in Figure 61.*

Table 12 Summary statistics for NO_3-N concentrations in different waterways

All	Min	Max	Range	Average	Median	Std Dev	CV
All Surface Water	0.002	26.00	26.00	10.79	12.95	5.78	0.54
HMWC	0.002	26.00	26.00	12.78	13.65	4.49	0.35
Drains	0.002	16.90	16.90	6.61	1.66	7.12	1.08
Rivers	0.04	13.78	13.73	4.39	4.15	3.11	0.71
Spring	0.98	21.95	20.96	10.75	9.35	6.36	0.59

Figure 60 Average NO_3-N concentrations for different surface waterways during 2021

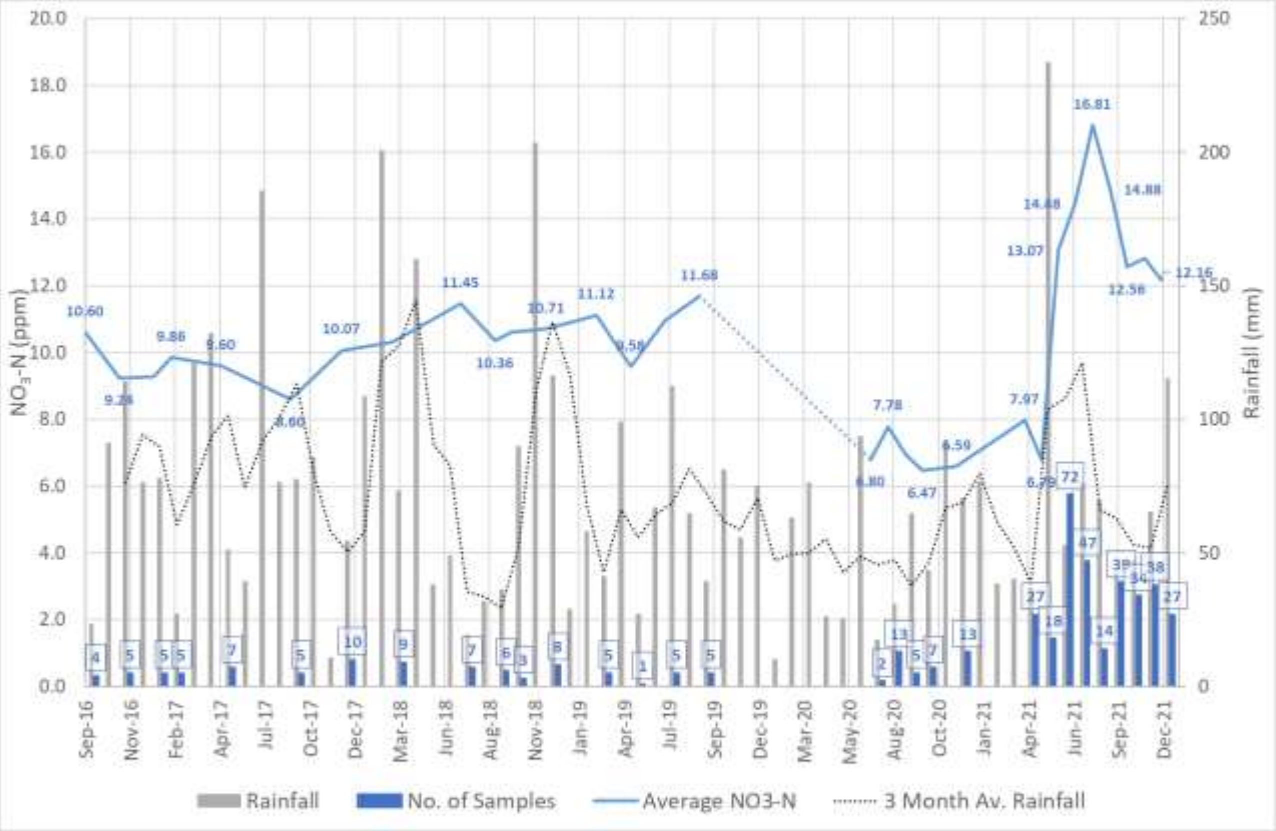

Figure 61 Changes in NO_3-N for HMWC's from 2016 to 2021

9. Discussion

> *"There are no hard and fast facts. Every scientific statement is provisional. Politicians hate this. How can anyone trust scientists? If new evidence comes along, they change their minds.*
>
> *Of course, some parts of science are less provisional than others."*
>
> *Terry Pratchett* [29]

9.1. Nitrate response to recharge – an overview

It is well established that NO_3 is highly soluble in water with < 100 ml of water required to dissolve 1-gram NO_3. Hence both of the following statements could be made:

> *"Higher average precipitation dilutes nitrates in the soil, further reducing groundwater nitrate concentration"* [33]
>
> *"… nitrate concentrations increased during the summer monsoon rains because of the infiltration of nitrate previously concentrated in the soil zone,"* [34].

Historical data for K37/0216[23] (9.5m deep) in Westerfield indicates a temporal correlation between:

- rainfall (recharge),
- groundwater level,
- Irrigation season, and,
- NO_3-N concentrations.

In Figure 62, NO_3-N concentrations (and groundwater levels) increase in response to rainfall recharge, whilst Figure 63 illustrates a corresponding decrease in NO_3-N concentrations (and groundwater levels) due to the absence of rainfall and subsequent abstraction.

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[23] **NOTE**: The bores and data specified here is public domain data and available from the ECan website.

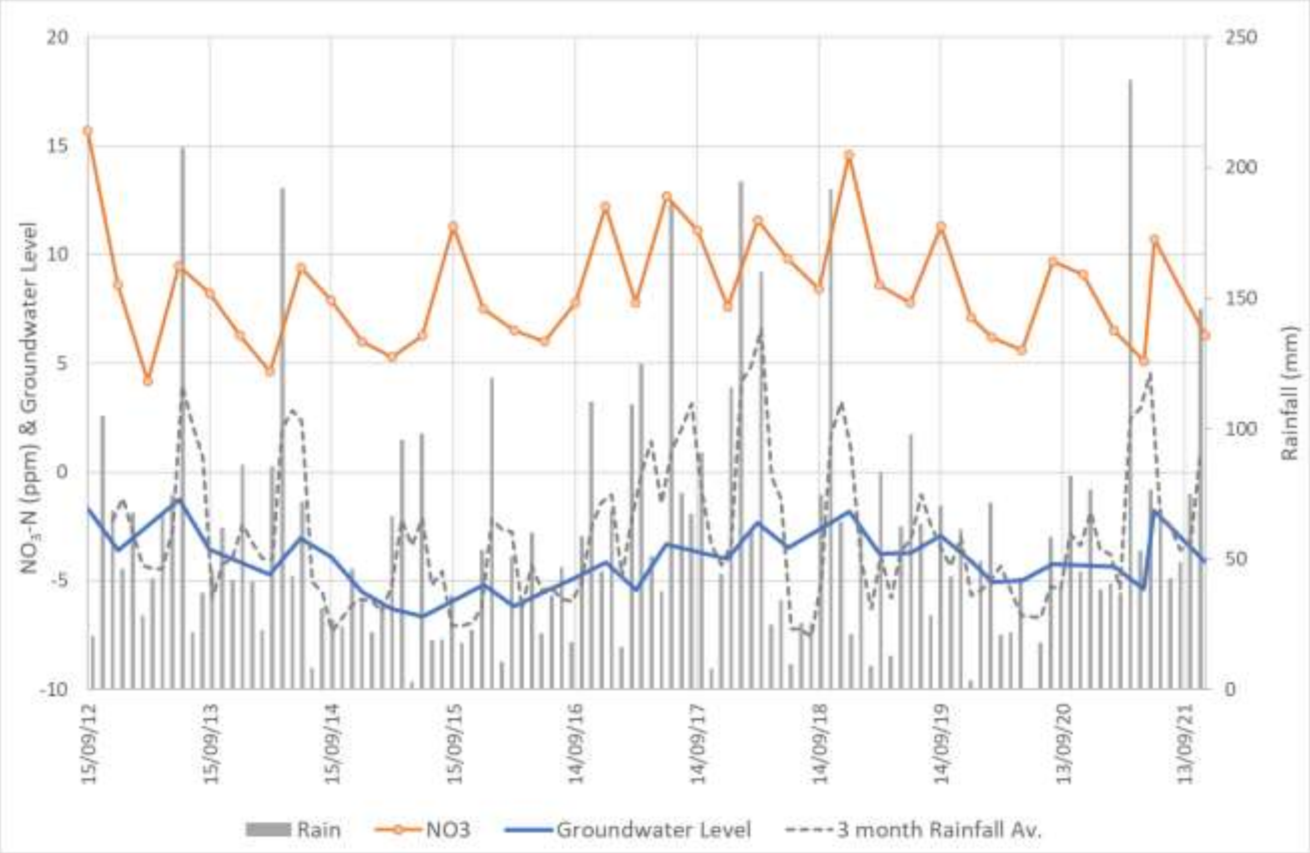

Figure 62 Relationship between NO_3-N and recharge / groundwater levels for K37/0216

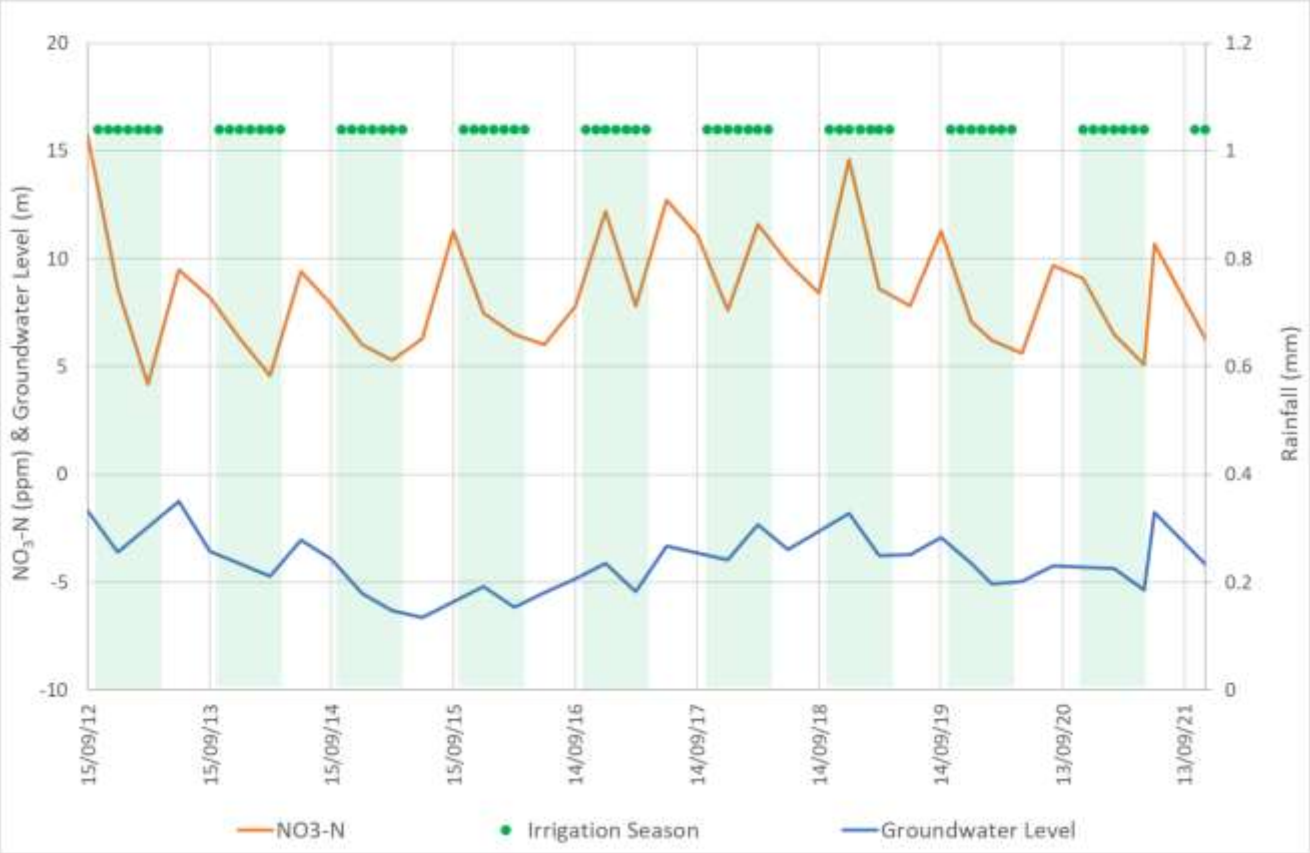

Figure 63 Relationship between NO_3-N irrigation season for K37/0216

In addition to the relationship between recharge and NO_3-N concentration, there is a corresponding relationship with depth and NO_3-N response. Figure 64 presents a similar NO_3-N response to recharge as shown in Figure 62; this time for three proximal bores of increasing depth in the immediate Ashburton area.

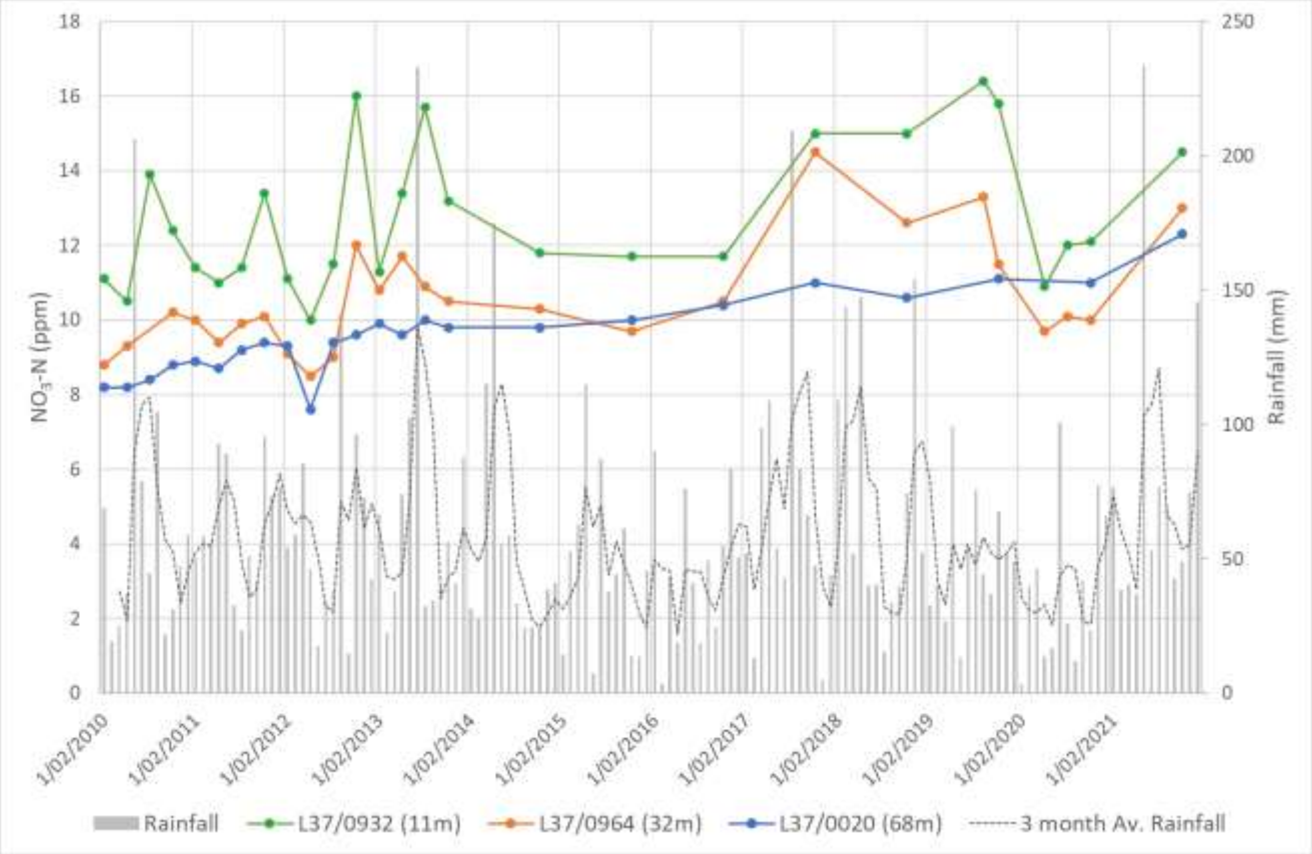

Figure 64 Variable NO_3-N response with increasing depth from 3 bores in the Ashburton Area.

Whilst this relationship makes intuitive sense, the results from the survey are more complex. Figure 66 presents the results of 4 bores that were monitored throughout the year, revealing:

- Greater changes in NO_3-N were observed in shallow bores, but ***this was short*** lived with values decreasing by 35% in 3 months. Notably their respective decay curves had regression co-efficients of R^2 >0.98 indicating that their decrease in NO_3-N over time is predictable.
- In some areas, NO_3-N concentrations increased, whilst in others it decreased.

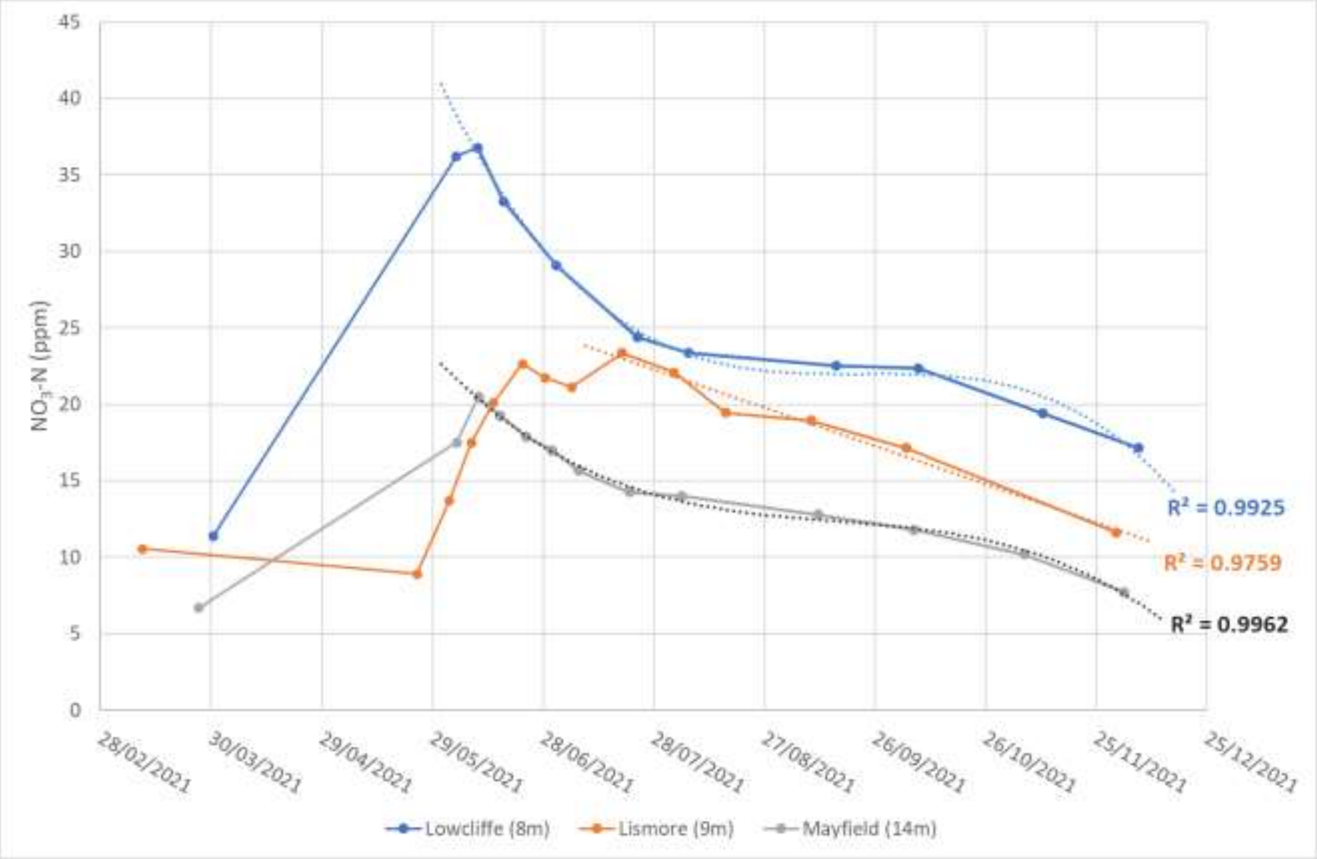

Figure 65 Examples of NO$_3$-N response in shallow bores

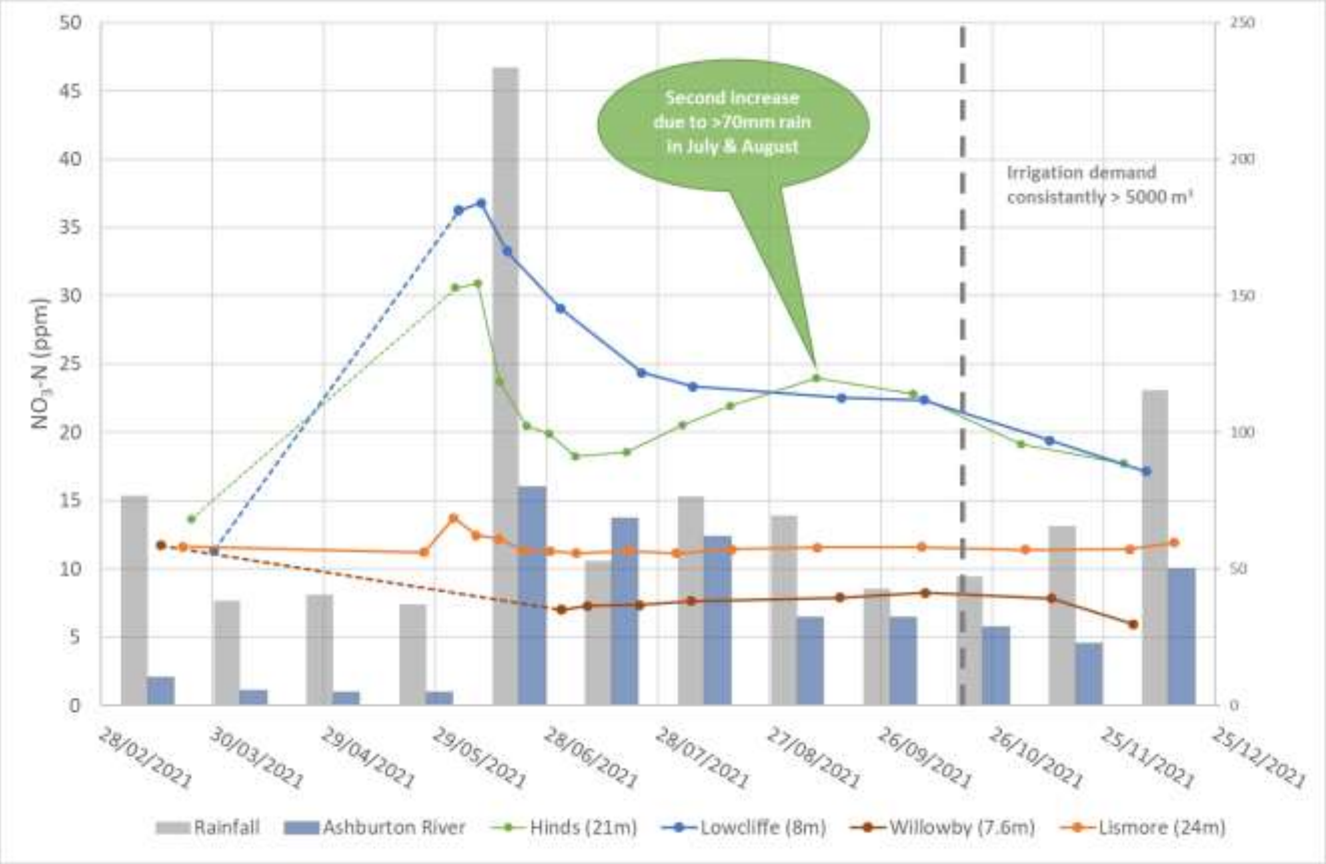

Figure 66 Variable NO$_3$-N responses in groundwater bores across the Hekeao Hinds Plains

9.2.Catchment scale response to recharge

The Hekeao Hinds catchment is a heterogeneous system with:

i. flow rates between the Rangitata, Ashburton and Hinds River varying by orders of magnitude (refer to section 3.2.1).

ii. differing soil types (refer to section 3.3.1) with hydrological properties varying from [35], [36]:

  - well drained Pallic Brown Soils with a Profile available water (PAW) of 65 (K=3.1 x 10^{-3} to 5.2 x 10^{-3} m/ day) to
  - Poorly drained Argillic Orthic Gley Soils with PAW of > 135 (K=3.7 x 10^{-5} to 7.3 x 10^{-6} m/ day).

Subsequently the changes in NO_3-N in response to the rain event of 29–31 May are equally temporally and spatially heterogeneous. Figure 67 and Figure 68 present the median change in NO_3-N between June and August calculated from an Inverse Distance Squared[24] (ID2) interpolation in QGIS© software.

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

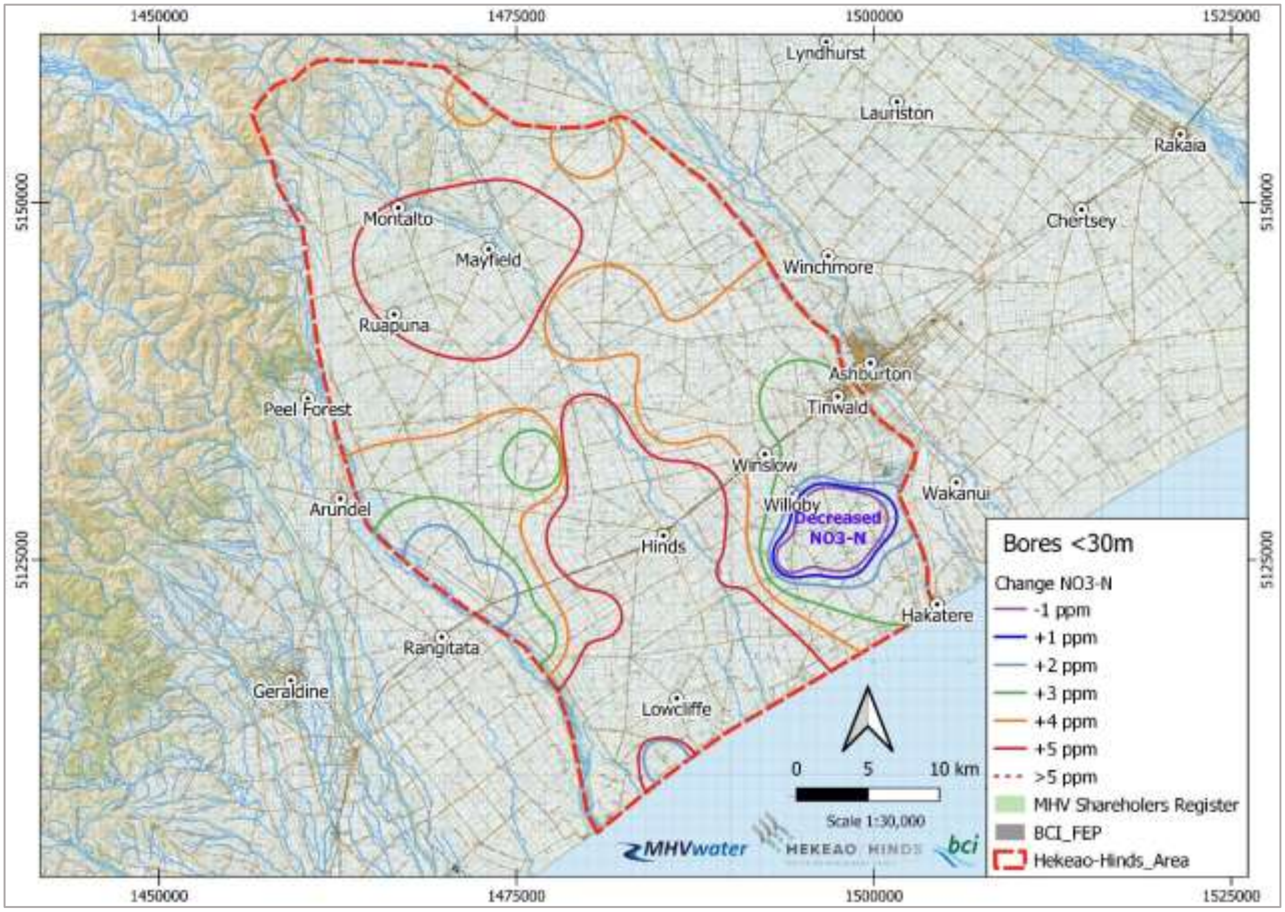

Figure 67 ID2 contour interpolation of changes in NO_3-N for bores <30 mbgl from the survey of 56 bores between June and August 2021

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

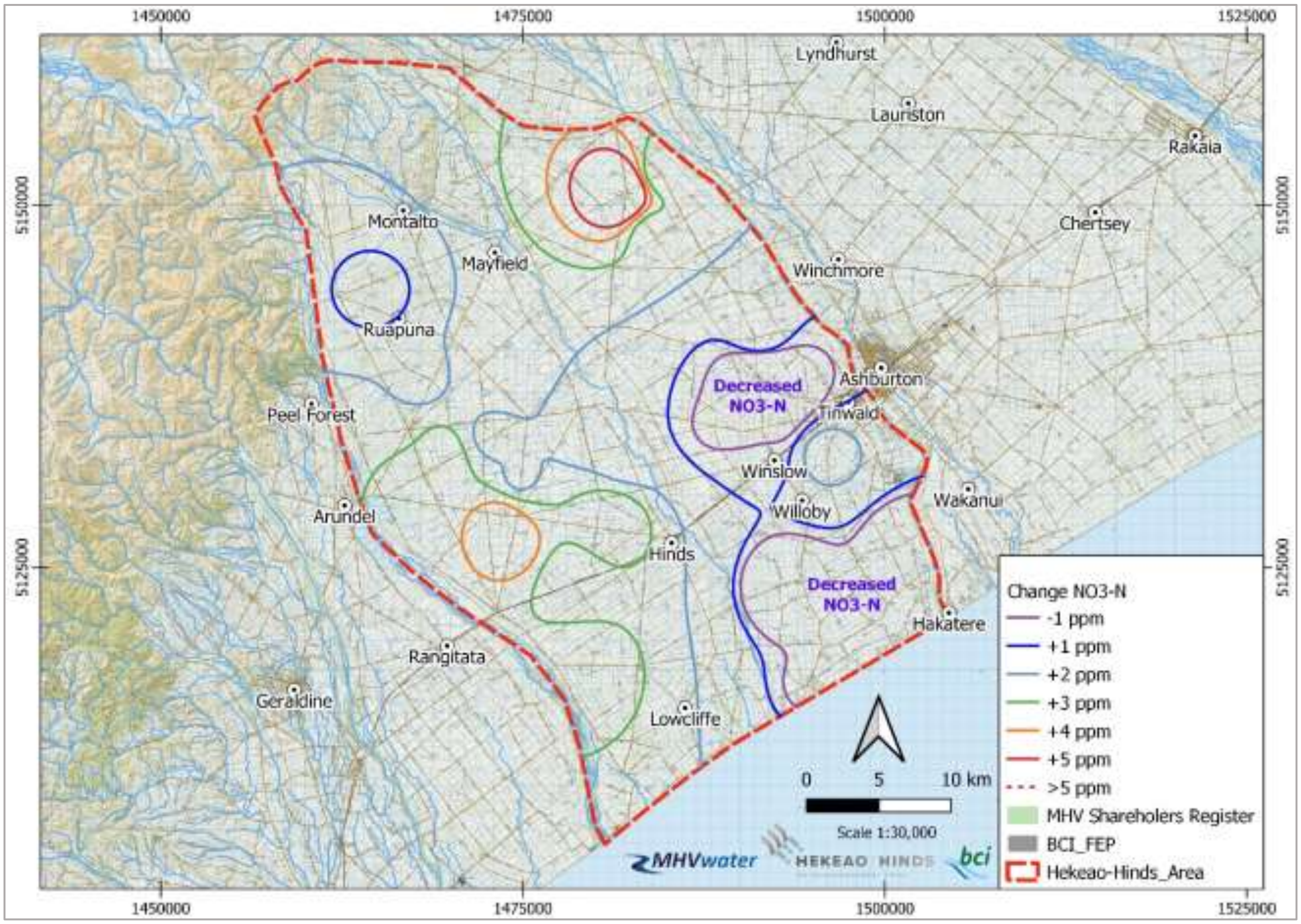

Figure 68 ID2 contour interpolation of changes in NO_3-N for bores >30 mbgl from the survey of 56 bores between June and August 2021

When the ID2 interpolation for all off the data (regardless of depth) and compared to the March 2021 survey the following correlations are noted:

- NO_3-N values lowered between Lagmhor and Winslow, as well as between Eiffelton – Huntington, and south of Willowby
- Negligible changes were noted at Longbeach
- There was a considerable spatial change in NO_3-N values (i.e., a gradient) at Coldstream
- There was a gradual increase in NO_3-N from Ruapuna to Lowcliffe
- Increases were noted at Mayfield and Punawai

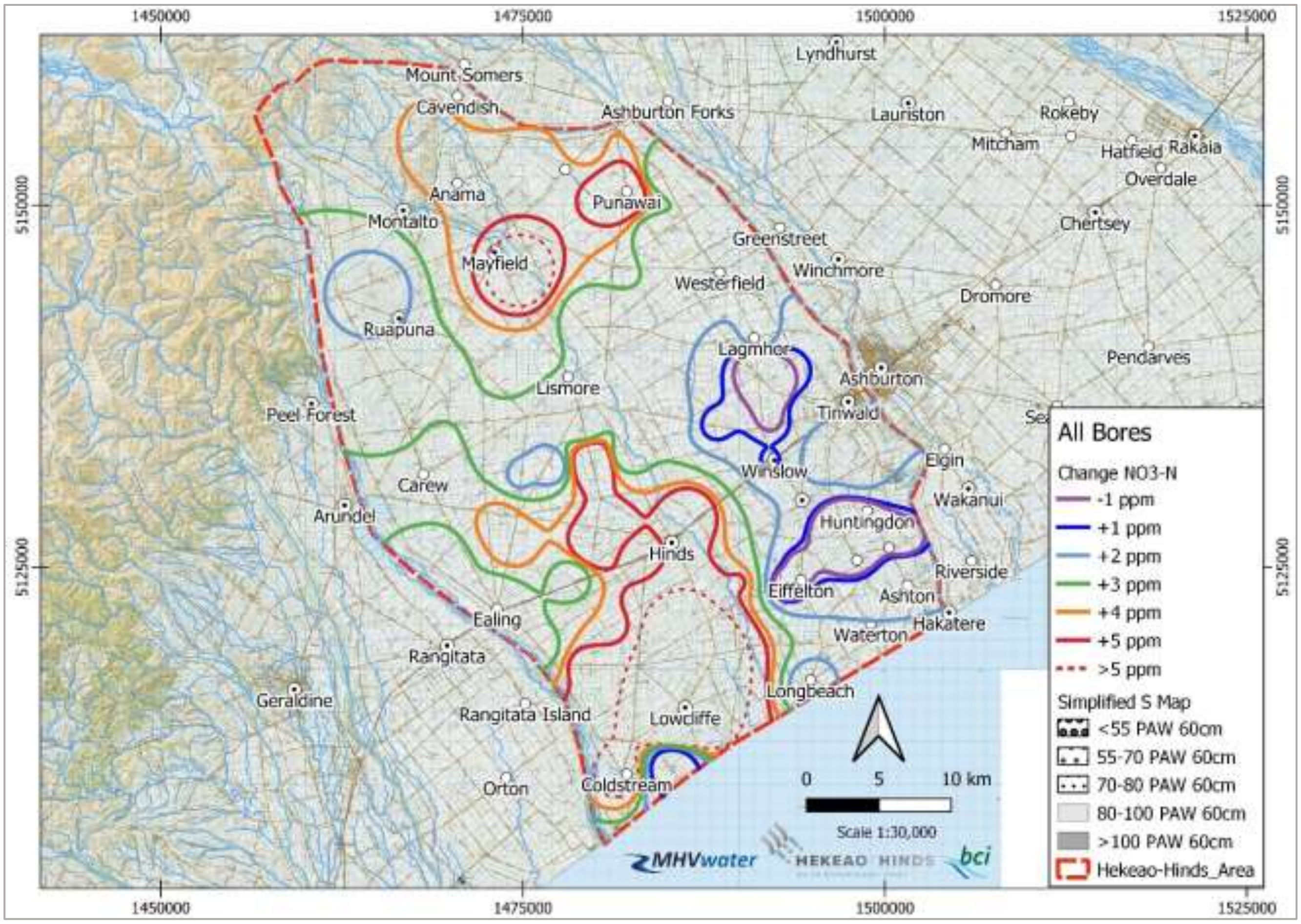

Figure 69 ID2 contour interpolation of changes in NO_3-N for all bores from the survey of 56 bores between June and August 2021

9.3. Drivers of NO_3-N response to recharge

9.3.1. Soils

As noted in section 3.3.1, the soils of the Hekeao Hinds plains vary, and differing soil types have different hydrological properties.

This variability is further compounded by the variability within and between different soil horizons, the dominant hydrological vector (i.e., horizontal ground water flow and/ or vertical rainfall) and slope of the surface [37].

When the relative changes in NO_3-N between March and the June 2021 (for the 56 bores monitored) are compared by soil type, there is a significant range and increase in NO_3-N results for the moderately well drained Lismore Soils (PAW ≈65) compared to the more poorly drained Longbeach and Flaxton soils that are more constrained with their results (Figure 70).

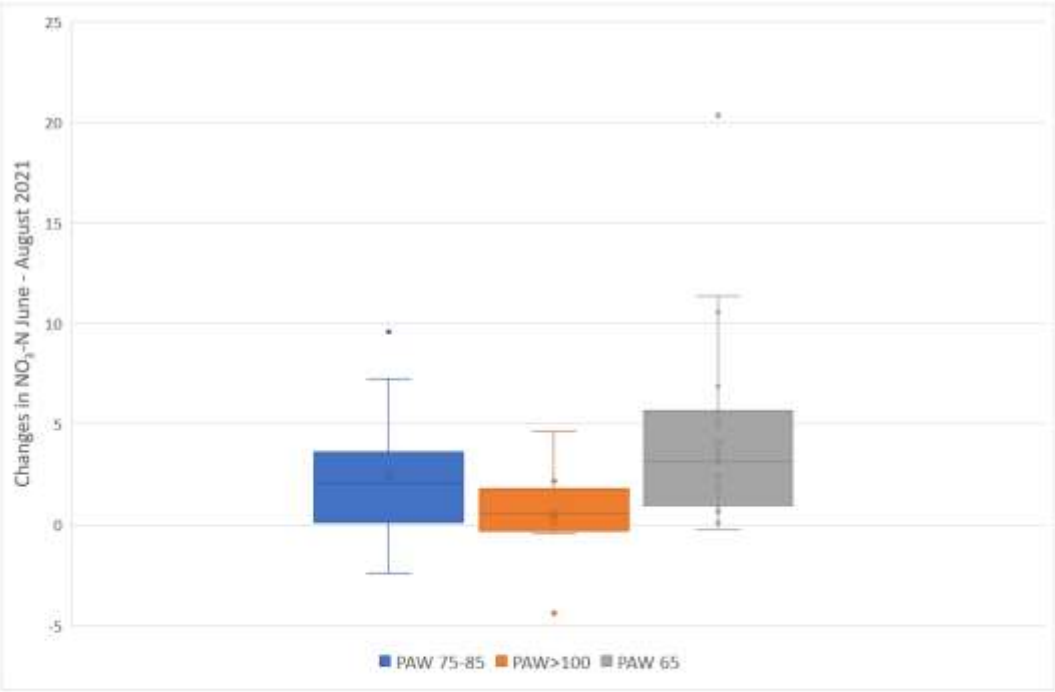

Figure 70 Box and whisker plot of changes in NO_3-N for 56 bores between June and August by soil type

When the ID2 interpolation for all off the data is reconciled with a simplified Soils map, the following inferences can be made:

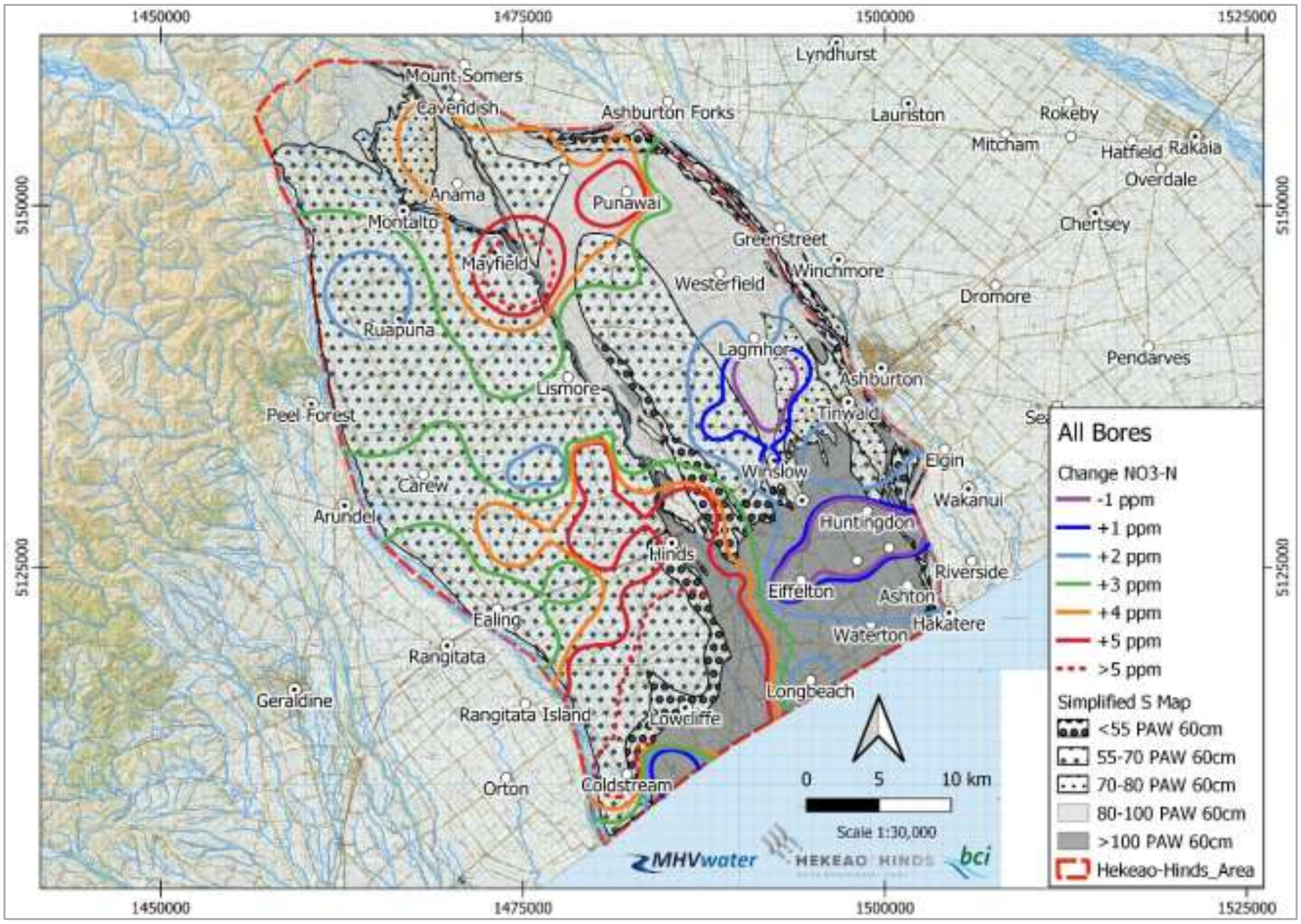

Figure 71 ID2 contour interpolation of changes in NO_3-N for all off the data with a simplified Soils map between June and August 2021*

** Recall that the ID2 interpolation is completely independent of the soil map.*

1. The Eiffelton – Huntington area is dominated by Argillic Orthic Gley Soils with low hydraulic conductivities (K=3.7 x 10^{-5} to 7.3 x 10^{-6} m/ day) and reduced oxidation states [36], [38]. In anaerobic or waterlogged environments, denitrification and dissimilatory nitrate reduction to ammonium (DNRA) are the two major pathways by which the NO_2^- and NO_3^- formed by nitrification can be subsequently reduced by anaerobic bacteria and/or fungi, especially during alternating wet and dry conditions [39], [40].

2. According to Manaaki Whenua, the area between Lagmhor and Winslow is bisected longitudinally by two different soil types:

    i. Typic Argillic Pallic Soils (Darnley[25] and Mayfield[26]) that are moderately well drained with low iron contents that tends to be dry in summer and wet in winter.
    ii. Pallic Firm Brown Soils (Lismore)[27] that are moderately well drained with a high iron content creating the brown colour.

    The interface between the ferrous Lismore and pallid Argillic Pallic soils may represent a REDOX boundary that may facilitate either biological and/ or chemical denitrification [41]–[43] that is enhanced during periods of re-wetting [40].

3. The increase in NO_3-N observed near Lowcliffe is inferred to be the results of a rapid change in soil properties from:

    - a Lismore Pallic Firm Brown Soils with a PAW of 65mm,
    - to a Lowcliffe Mottled Argillic Pallic Soils with a PAW of 49mm,
    - to a mixture of soils with PAW's varying between 100mm and 205mm

    in a space of <2km; resulting in retardation of subsurface water flow and causing potential upwelling.

9.3.2. Groundwater

An ID2 interpolation was conducted on the groundwater level data collected between June and September. Figure 72 presents the areas where groundwater was ≥ 10m below ground level and changes in NO_3-N indicating that there is a spatial correlation with areas that increased and/ or decreased significantly.

Additionally, MHV identified areas of persistent surface water (i.e., springs) and correlated these observations with known springs, ephemeral paleo pathways, and areas of elevated nitrate. Figure 73 illustrates that there is a strong spatial correlation between springs and elevated NO_3-N in some of the southern areas of the catchment.

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[25] SMap Ref Darn_1a.1
[26] SMap Ref Mayf_2a.1
[27] SMap Ref Lismore_1a.1

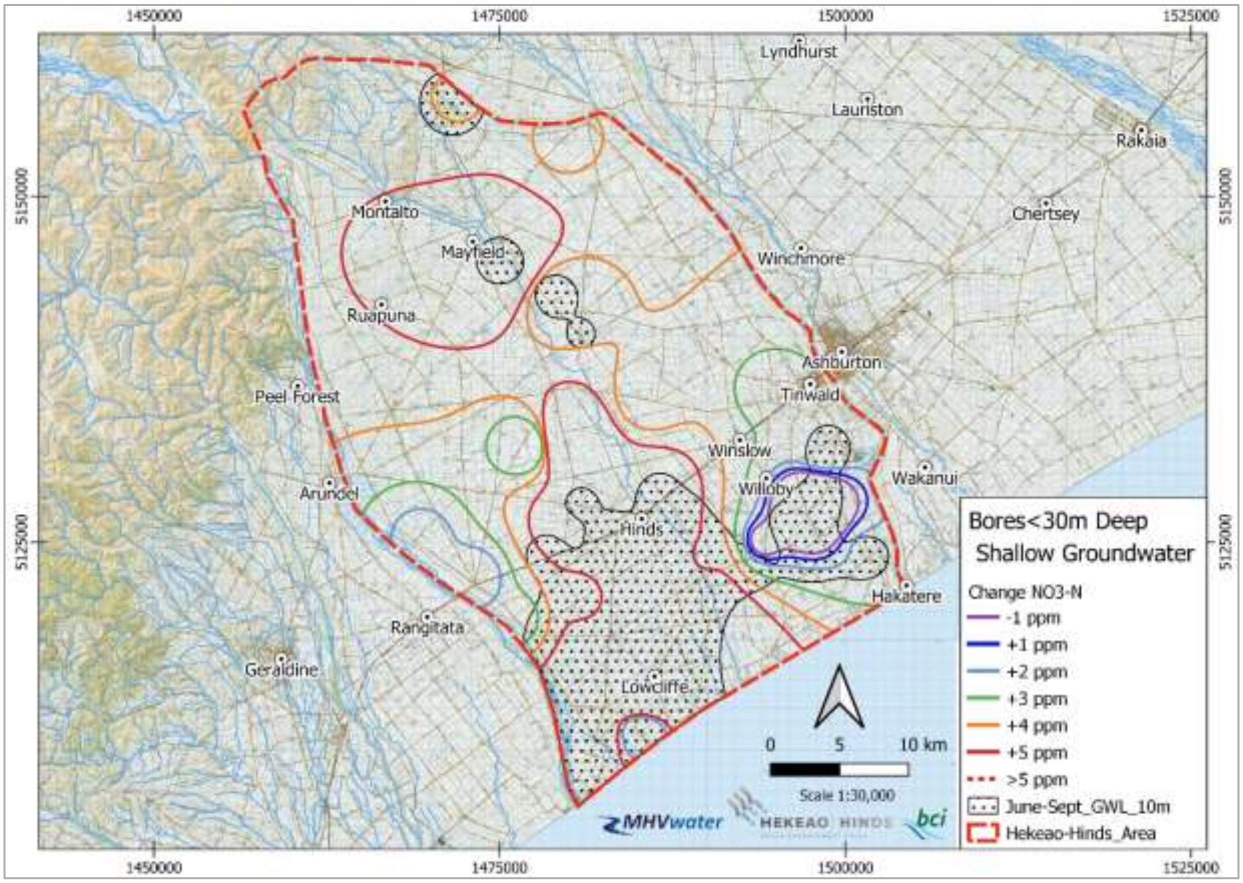

Figure 72 ID2 contour of changes in NO_3-N for bores <30 mbgl from the sub survey of 56 bores, with groundwater <10m deep between June and August 2021

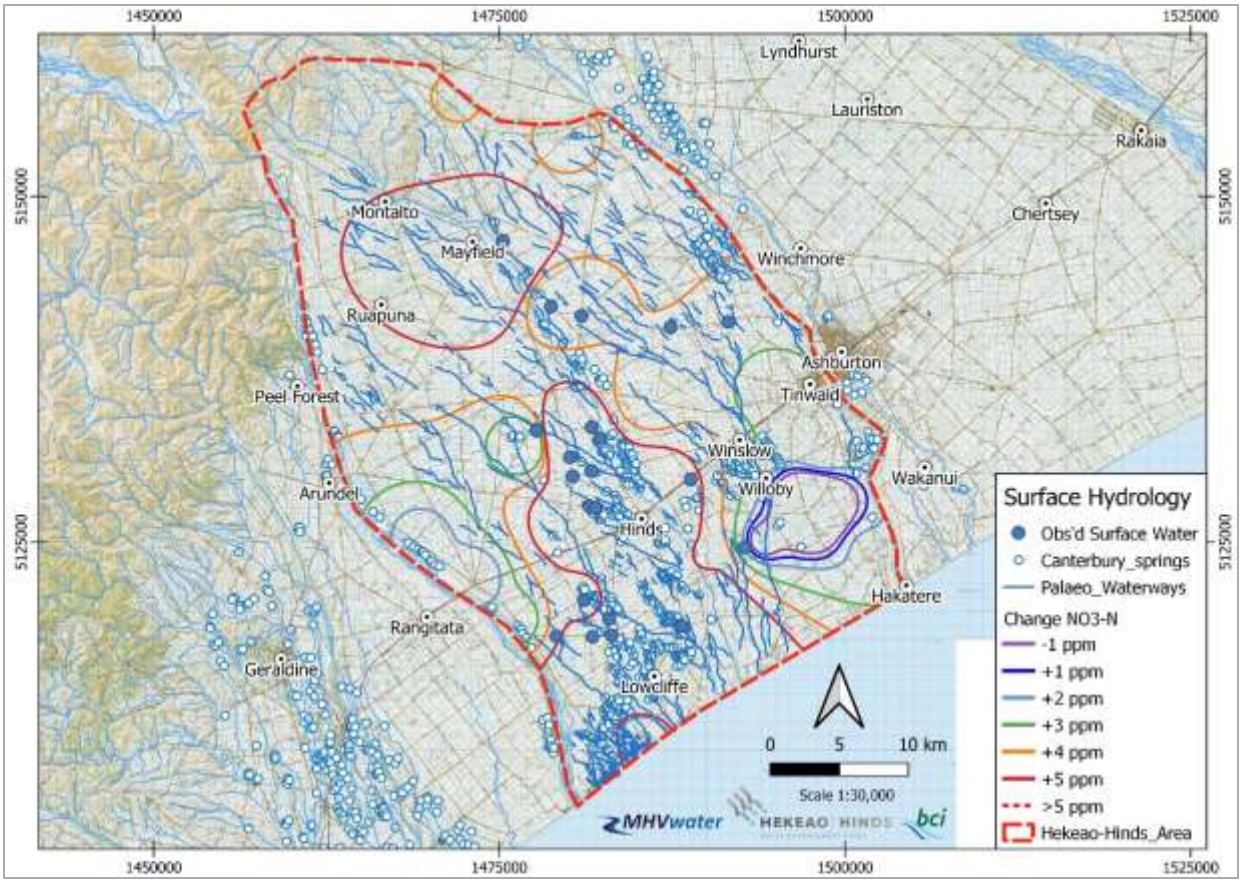

Figure 73 Changes in NO_3-N in bores <30 m deep with springs and mapped areas of persistent flooding between June and August 2021

Research undertaken at the Environmental Research Observatory of the Kervidy-Naizin catchment in French Brittany has shown that in catchments dominated by subsurface flows - shallow groundwater was a key driver of NO_3-N variability following storm events (Fovet et al., 2018). Additionally, studies by Min et al., (2018) and Kawagoshi et al., (2019) have shown that NO_3-N concentrations will be higher in areas with shallow groundwater and highly permeable soils, indicating that hydraulic conductivity is a the key driver of NO_3-N migration and concentration.

9.3.3. River

Figure 74 presents median NO_3-N levels in both shallow (depth <30 mbgl) and deeper bores (depth >30 mbgl) of the 55 bores tested immediately after the initial rain event of 29–31 May 2021.

NO_3-N concentrations rose significantly after the initial rain event of 29–31 May. NO_3-N concentrations also rose in mid-July after rain that was restricted to the Main Divide and lower ranges above the Hekeao Hinds Plains, which resulted in an increased flow in the Ashburton and Hinds rivers, despite <10 mm of rain falling in the Hekeao Hinds Plains.

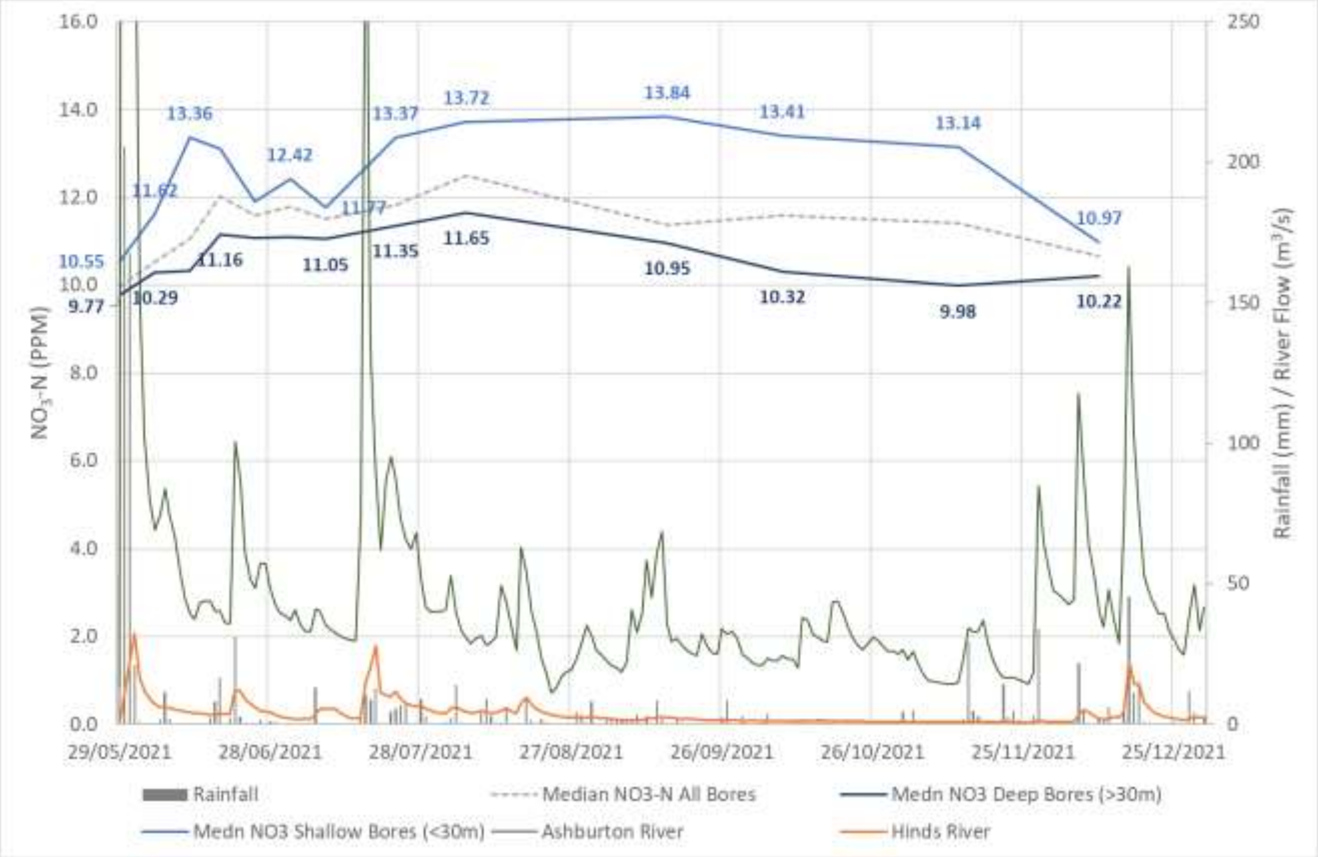

Figure 74 Changes in NO_3-N for the 56 bores monitored with rainfall and river flows

As stated in section 3.4.2 there is close connectivity between surface waters and shallow groundwater across the Hekeao Hinds plains. Subsequently, the river flow data could be used as a proxy indicator for groundwater flow whereby rainfall in the upper catchment would have further pressurised the groundwater system from the upper catchment, moving more nitrate from the near surface through the shallow groundwater system and also increasing connection with deeper groundwater.

This would have acted as a piston flow geo-hydraulic system whereby the conventional dispersion flow pathways are overwhelmed due to high recharge (**Error! Reference source not found.**). In this instance, it is inferred that as the area was already saturated, from the previous rain, groundwater vector pathways would already be established, hence enabling migration of nitrates in groundwater despite the absence of rain in the Hekeao Hinds Plains. Examples of this phenomenon have been noted in the Waimea Plains near Nelson [45] and Drava alluvial aquifer system, located in northern Croatia [46].

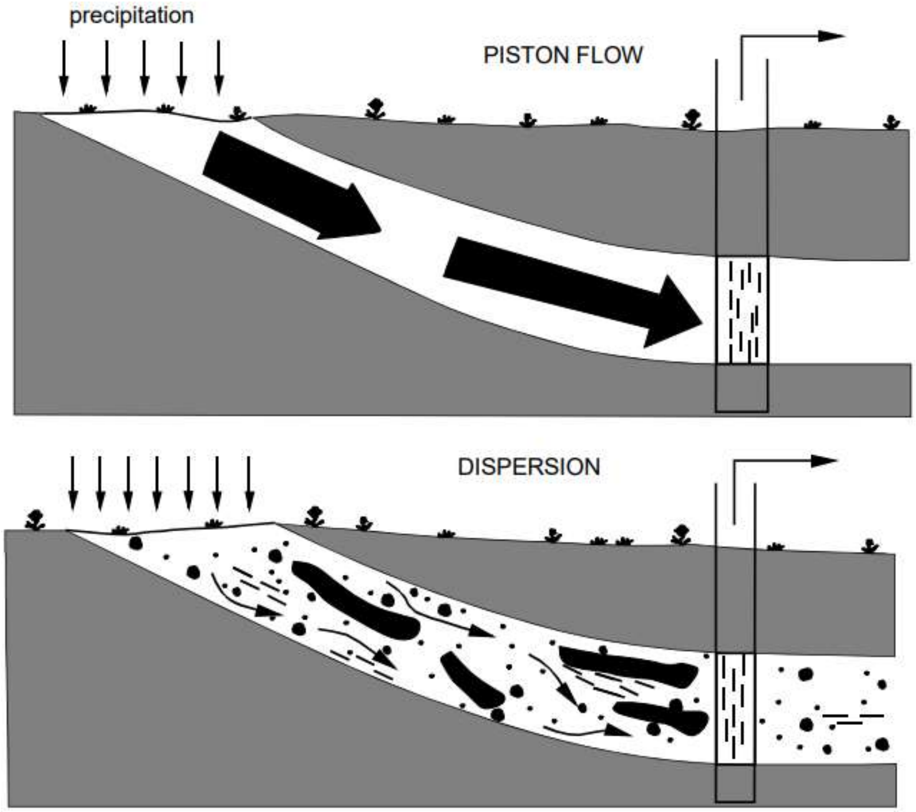

Figure 75 A simplified example of groundwater movement via piston-flow and dispersion [47].

Consequently, it is inferred that the following were the key drivers to the short-term changes in NO_3-N [40]:

- mobilisation of nutrient material is derived from distal in addition to proximal sources, as local sources would become depleted after a short time; and/ or,
- highly connected areas enabled cross contamination.

This concept is supported by Kawagoshi et al., (2019), who found that nitrate concentrations increased as groundwater levels increased. Additionally, there was an increase in the Valetta to Punawai area in bores >30m deep (Figure 68). Flood modelling undertaken by ECan in 2015 indicates that the area would be prone to flooding in the absence of the constructed stop banks located along the North Branch, South Branch, and Main Stem of the Ashburton River [48].

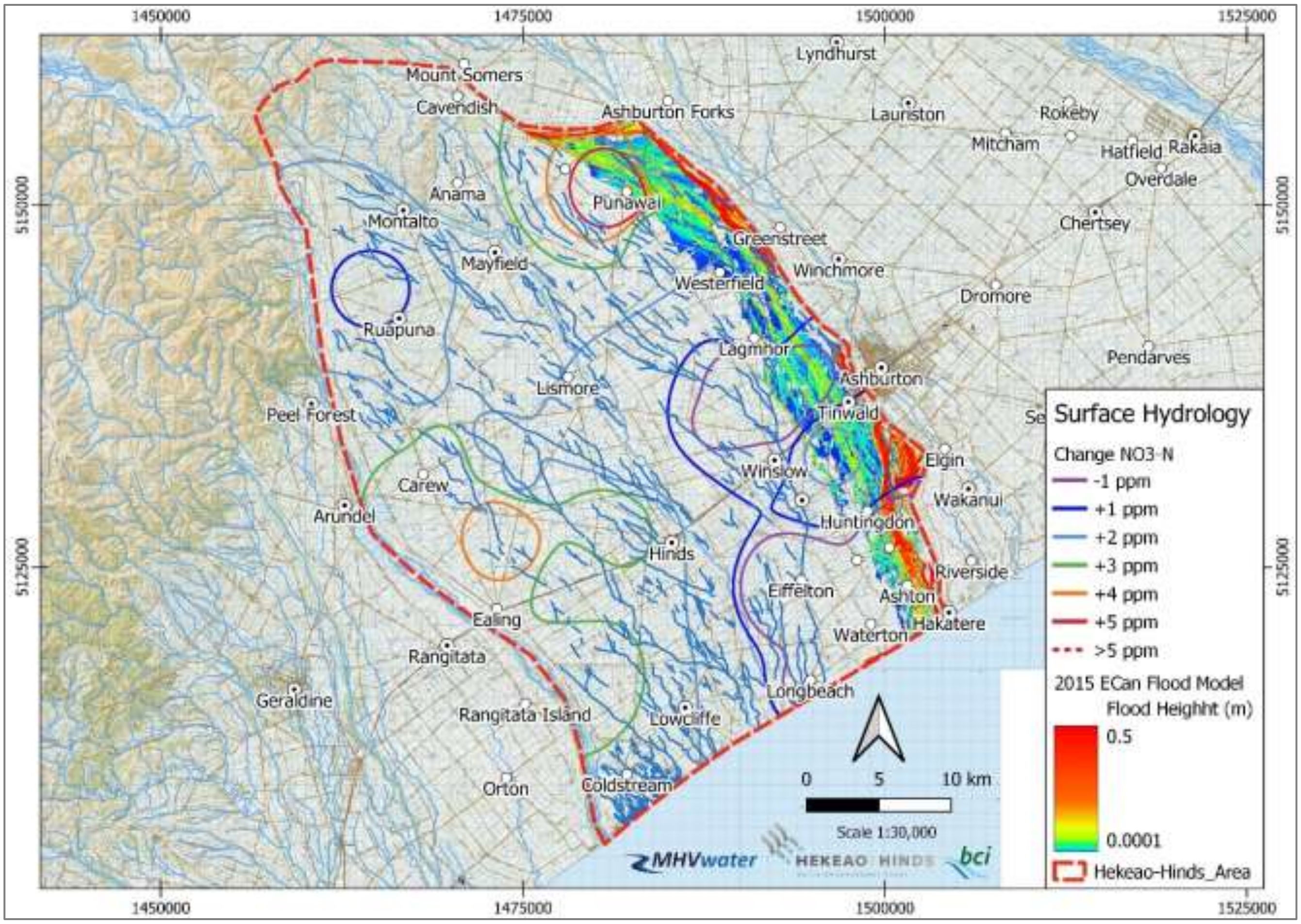

Figure 76 Changes in NO_3-N for bores >30 mbgl between June and August 2021 with ECan 2015 Flood Model and Paleo pathways

If said stop banks were inefficient in reducing the groundwater flow, it is inferred that the elevated NO_3-N levels in Punawai are due to the combination of:

- a steep hydrological gradient in the upper catchment and
- semi porous soils[28],
- oxidised gravels suggesting the presence of open framework gravels between 60m and 75m[29] (refer to section 3.4.2), and,
- surface recharge from flooding.

9.4. Post Flood Results Combined Effects

The results for the September and December 2021 catchment groundwater surveys (147 and 143 bores respectively) indicate a sustained decrease in NO_3-N concentrations in both shallow and deeper bores from the elevated values reported during June (based on 56 bores) – refer to Figure 77 to Figure 79.

Elevated NO_3-N concentrations were restricted to the Lowcliffe and Coldstream areas, which is interpreted to be related lag times and soils.

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[28] The Lismore soils have almost 75% stone content at depths greater than 100cm

[29] Refer to bore logs K36/0778 and K36/1011

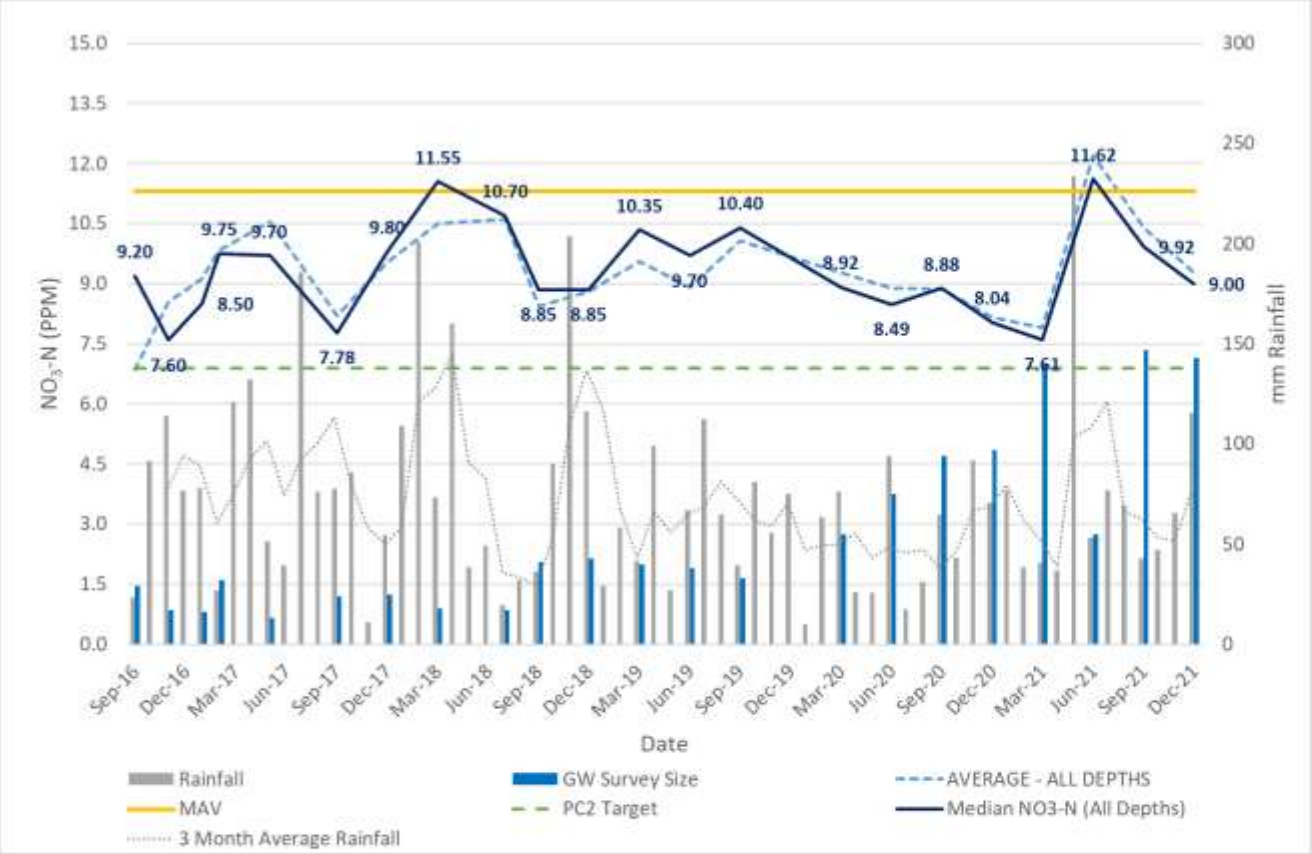

Figure 77 Changes in NO$_3$-N for all bores 2016 - 2021

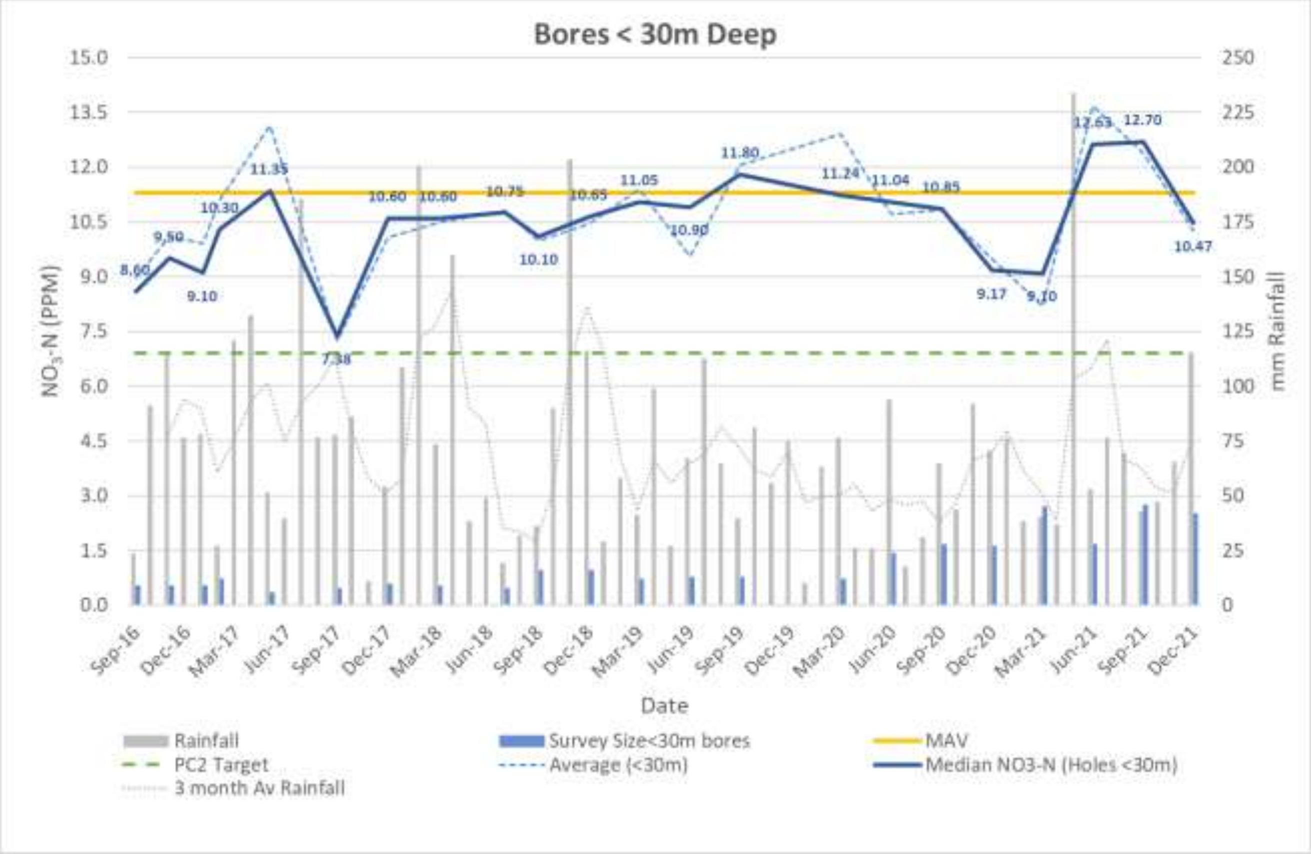

Figure 78 Changes in NO$_3$-N for bores < 30m deep 2016 - 2021

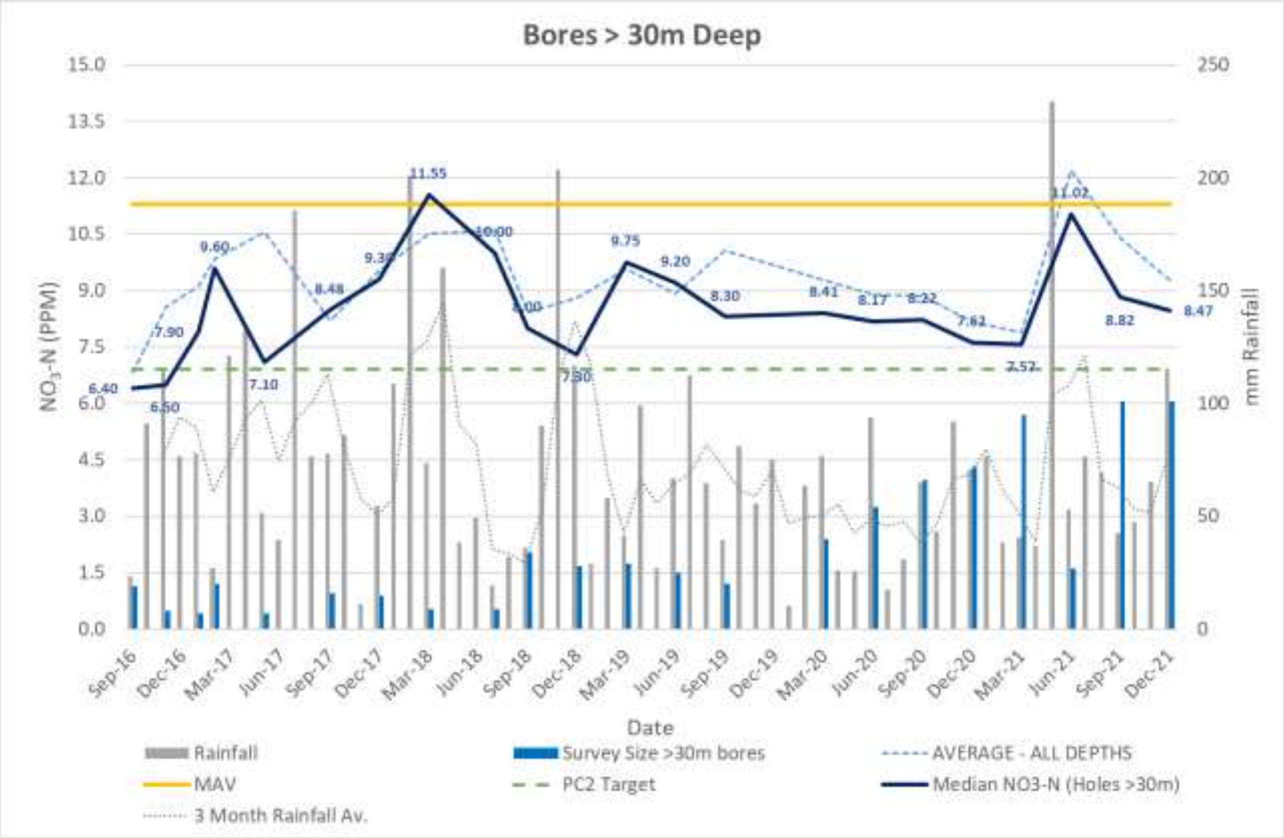

Figure 79 Changes in NO_3-N for bores > 30m deep 2016 - 2021

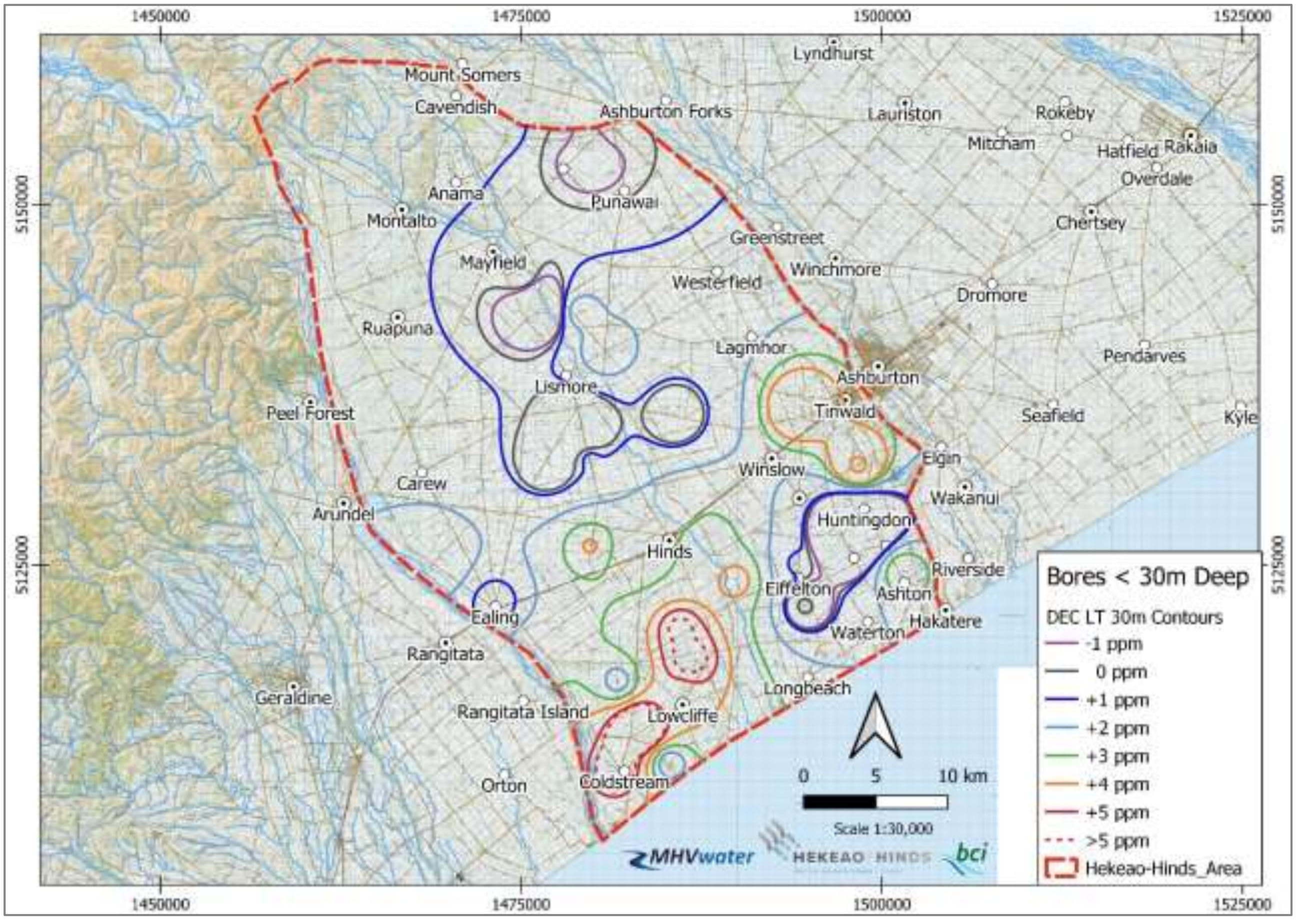

Figure 80 Changes in NO_3-N from March to December 2021 Bores < 30m deep

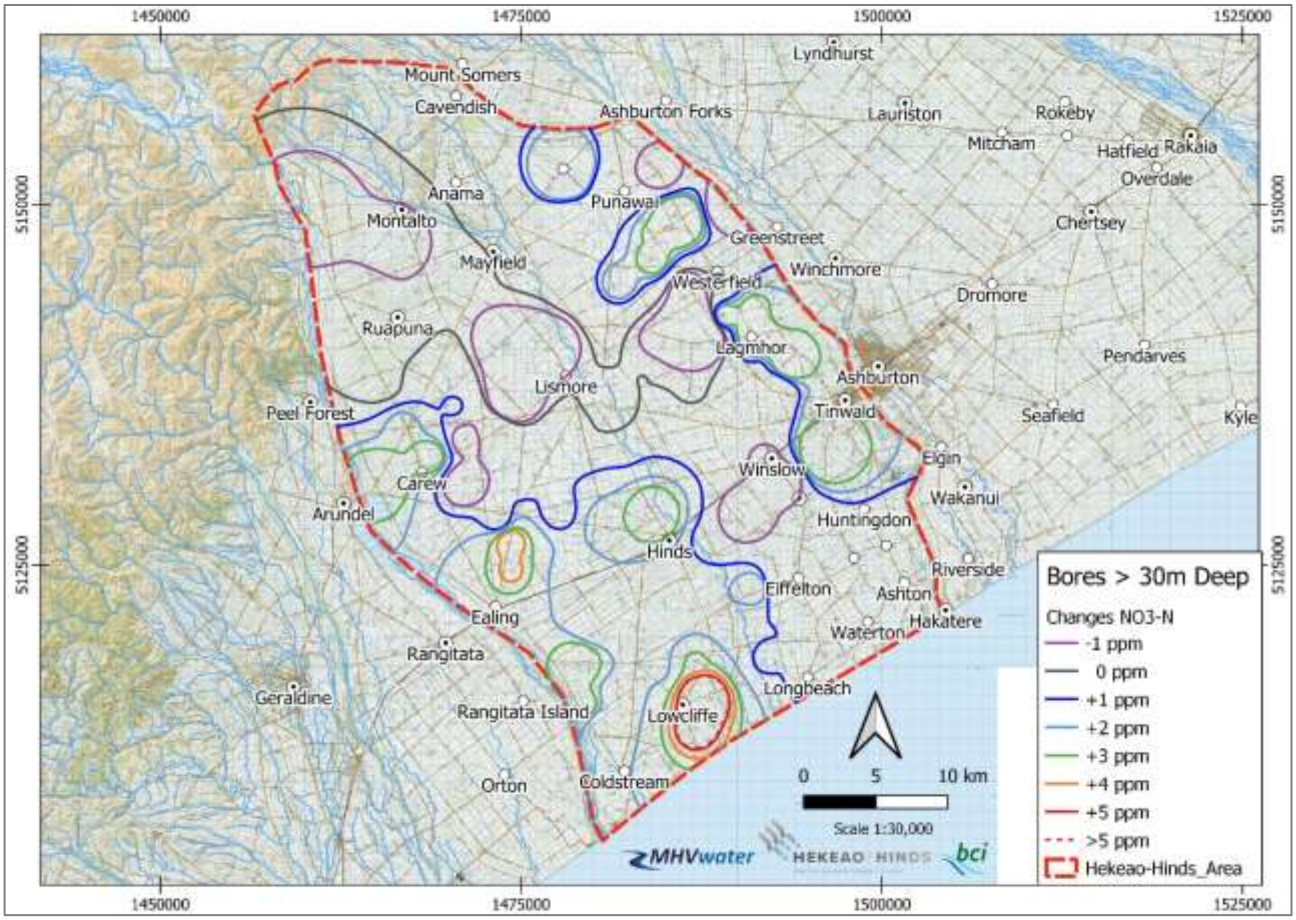

Figure 81 Changes in NO_3-N from March to December 2021 Bores > 30m deep

As noted previously, changes in NO_3-N concentrations are driven by rainfall which increases land surface recharge and river recharge. The March to December 2021 NO_3-N concentration changes indicate that NO_3-N material is sourced from distal and proximal sources, with local sources becoming depleted after initial flushes.

When all the hydrological inputs (river flows + rainfall) from the available monitoring record are compared to NO_3-N in shallow (<30 mbgl) bores (Figure 82), it is evident that the lack of rainfall has contributed to consecutive decreases in median NO_3-N concentrations on a quarterly basis from early to mid-2019 until June 2021. On-farm nutrient management improvements and groundwater enhancement projects such as Managed Aquifer Recharge / Near River Recharge have also occurred during this time period. On-going analysis is focussed on understanding how these improvements contribute to the changing NO_3-N concentrations.

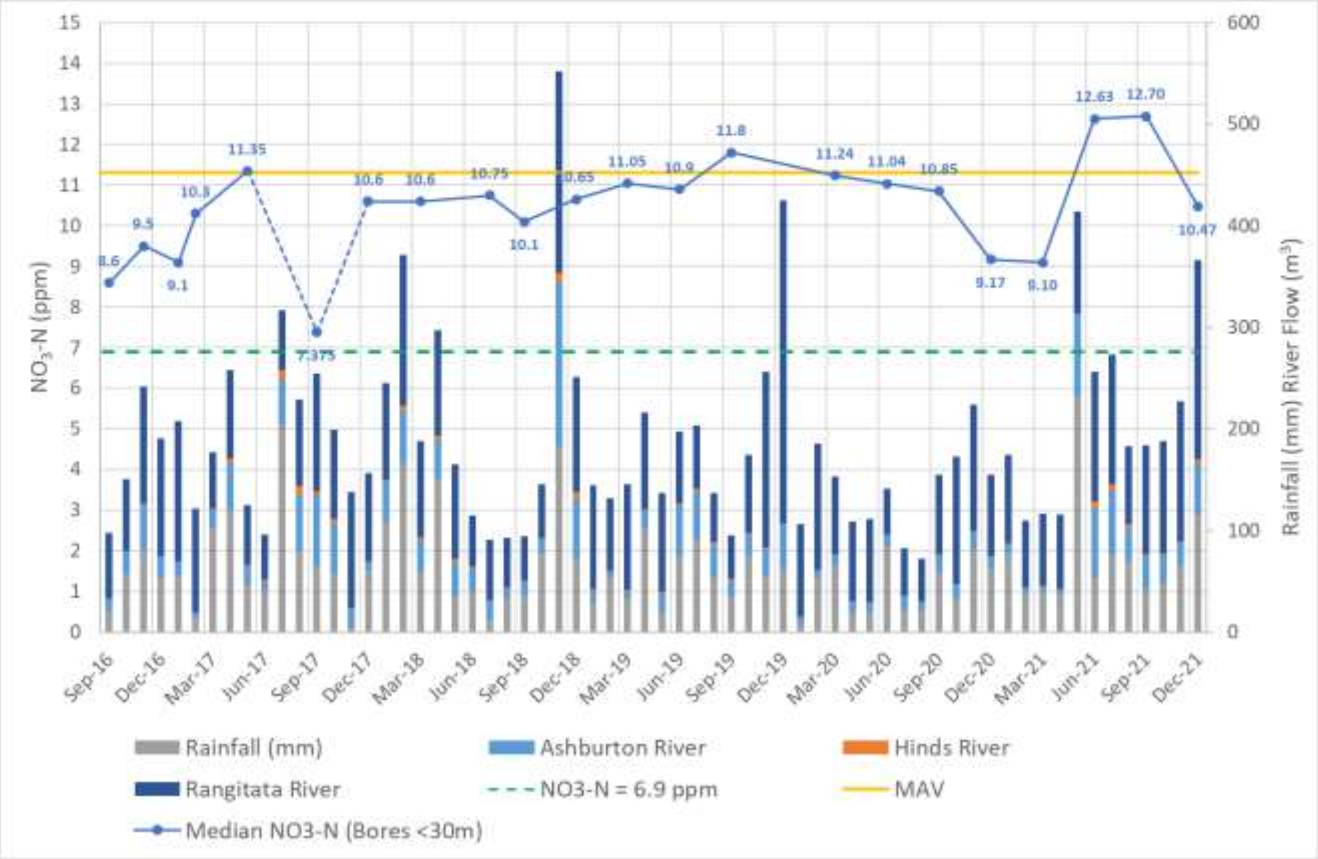

***Figure 82** Hydrological inputs (river flows + rainfall) are compared to NO_3-N in shallow (<30 mbgl) bores*

10. Where to from here?

> *A thought that does not result in action is nothing much, and an action that does not proceed from a thought is nothing at all.*
>
> *Georges Bernanos*

The intention of this programme is to provide data and complementary information that will enable evidence-based decision making, that leads to environmentally and sustainable water and nutrient management practices.

From this position, the following opportunities are presented.

10.1. Ongoing Research

The results presented in this report present a comprehensive review of NO_3-N migration and concentration across the Hekeao Hinds Plains. This information could be used as inputs to industry collaborative research such as

1. Ongoing opportunities to support research be pursued via government funding agencies such as:
    - Environment and natural resources: funding and programmes
    - Sustainable Food and Fibre Futures: Sustainable Farming Fund projects
    - Callaghan Innovation Fund
    - Agricultural and Marketing Research and Development Trust.
2. MHV, BCI, and HHWET support postgraduate study programmes from the University of Otago, Lincoln University and the University of Canterbury to engage future postgraduate students to continue research into this area.

10.2. Reducing Point Source and Diffuse Nitrate Leaching

Utilising the data to integrate with and support on farm decision making to drive improved environmental outcomes.

10.3. Community Collaboration

This data set is also valuable to help understand the impacts of potential MAR/NRR sites at different locations, i.e., areas with more significant and faster changes after heavy rain events are also likely to respond to MAR/NRR.

11. Conclusions

> *Context is to data what water is to a dolphin*
>
> *Dan Simmons*

The rain event of 31 May – 2 June 2021 had a significant impact on Mid Canterbury and the Hekeao Hinds Community, with an estimated repair bill of $19.7 million [49]. Whilst these costs and disruptions are not insignificant, the rain provided an invaluable opportunity to observe NO_3-N migration across the Hekeao Hinds Plains in almost 'real time' fashion.

Unsurprisingly, immediately following the rain, most of the catchment saw an increase in NO_3-N concentrations. These increases were spatially and temporarily heterogeneous, highlighting the complexity of the hydrology of the Hekeao Hinds plains. Consequently, these observations should be placed in a clear context of:

a) a 0.005% AEP rain event, with an ARI of 1:200 years;
b) surface hydrology that varies in flow by orders of magnitude;
c) different farming platforms; and,
d) complex soil and regolith landform associations.

From these observations, the following inferences can be made:

I. There was no one point source of NO_3-N; rather increases in NO_3-N were cumulative as both surface and groundwater migrated down the catchment.

II. Flow rates in the rivers respond almost immediately to rainfall. Using river flow as a proxy indicator for groundwater migration - there is a strong relationship between rainfall in the upper catchment and groundwater migration (under saturated conditions) and NO_3-N concentrations.

III. Areas of elevated nitrates were associated with:

   - known springs or areas that had persistent flooding;
   - shallow groundwater (<10 mbgl);
   - well drained Pallic Brown Soils such as the Lismore Type (PAW 60 – 80) abutting against Argillic Orthic Gley Soils with PAW values >100; and
   - where changes in NO_3-N were greater than 10 ppm, these were confined to shallow bores, and NO_3-N levels dropped quickly, reducing by 35% in 3 months.

IV. Areas where NO_3-N concentrations decreased were associated with:

   - poorly drained Argillic Orthic Gley Soils with PAW values >100. As these soils are reduced, there is potential for denitrification and dissimilatory nitrate reduction via anaerobic bacteria and/ or fungi;
   - Due to the low transmissivities of poorly drained Argillic Orthic Gley Soils, there is an increased propensity for surface water flow directly into nearby drains; and,
   - The interface between Typic Argillic Pallic Soils (Darnley and Mayfield) and Pallic Firm Brown Soils (Lismore) that may represent a REDOX boundary.

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); and,
    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 Hydrogeology (2022), Exploration (2008) and Mining (2015) 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

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 3

Water Sampling Procedure

Standing Water Level measurements

Standing Water Levels[30] (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 83.

Figure 83 Well head with alkathene conduit

Water Column Purging and Sampling

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

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

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

Where possible, samples were collected in accordance with New Zealand standard protocols (Daughney et al., 2006, refer to Appendix 4) with purge times amended for practicality as shown in Table 13.

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[30] 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.

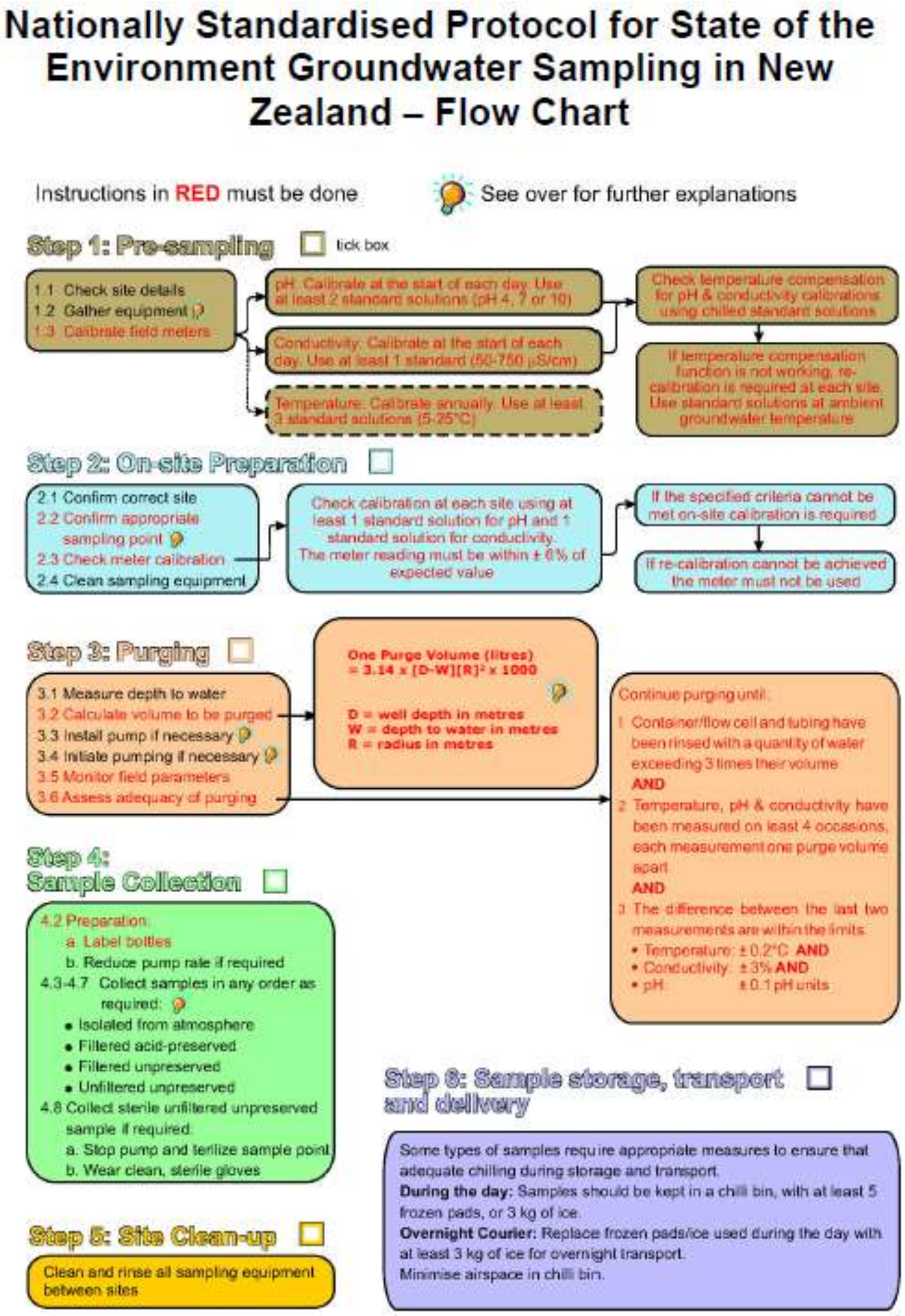
Table 13 Water bore purging protocols for sampling

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 84).	None – but noted as tank sample.

Figure 84 Example of a low flow tap next to milk filter in dairy shed

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 – Flow Chart

Instructions in **RED** must be done

See over for further explanations

Step 1: Pre-sampling ☐ tick box

1.1 Check site details
1.2 Gather equipment
1.3 Calibrate field meters

pH: Calibrate at the start of each day. Use at least 2 standard solutions (pH 4, 7 or 10)

Conductivity: Calibrate at the start of each day. Use at least 1 standard (50-750 µS/cm)

Temperature: Calibrate annually. Use at least 3 standard solutions (5-25°C)

Check temperature compensation for pH & conductivity calibrations using chilled standard solutions

If temperature compensation function is not working, re-calibration is required at each site. Use standard solutions at ambient groundwater temperature

Step 2: On-site Preparation ☐

2.1 Confirm correct site
2.2 Confirm appropriate sampling point
2.3 Check meter calibration
2.4 Clean sampling equipment

Check calibration at each site using at least 1 standard solution for pH and 1 standard solution for conductivity. The meter reading must be within ± 6% of expected value

If the specified criteria cannot be met on-site calibration is required

If re-calibration cannot be achieved the meter must not be used

Step 3: Purging ☐

3.1 Measure depth to water
3.2 Calculate volume to be purged
3.3 Install pump if necessary
3.4 Initiate pumping if necessary
3.5 Monitor field parameters
3.6 Assess adequacy of purging

One Purge Volume (litres)
$= 3.14 \times [D-W][R]^2 \times 1000$

D = well depth in metres
W = depth to water in metres
R = radius in metres

Continue purging until:

1. Container/flow cell and tubing have been rinsed with a quantity of water exceeding 3 times their volume
   AND
2. Temperature, pH & conductivity have been measured on least 4 occasions, each measurement one purge volume apart
   AND
3. The difference between the last two measurements are within the limits:
   - Temperature: ± 0.2°C **AND**
   - Conductivity: ± 3% **AND**
   - pH: ± 0.1 pH units

Step 4: Sample Collection ☐

4.2 Preparation:
  a. Label bottles
  b. Reduce pump rate if required
4.3-4.7 Collect samples in any order as required:
  - Isolated from atmosphere
  - Filtered acid-preserved
  - Filtered unpreserved
  - Unfiltered unpreserved
4.8 Collect sterile unfiltered unpreserved sample if required:
  a. Stop pump and terilize sample point
  b. Wear clean, sterile gloves

Step 5: Site Clean-up ☐

Clean and rinse all sampling equipment between sites

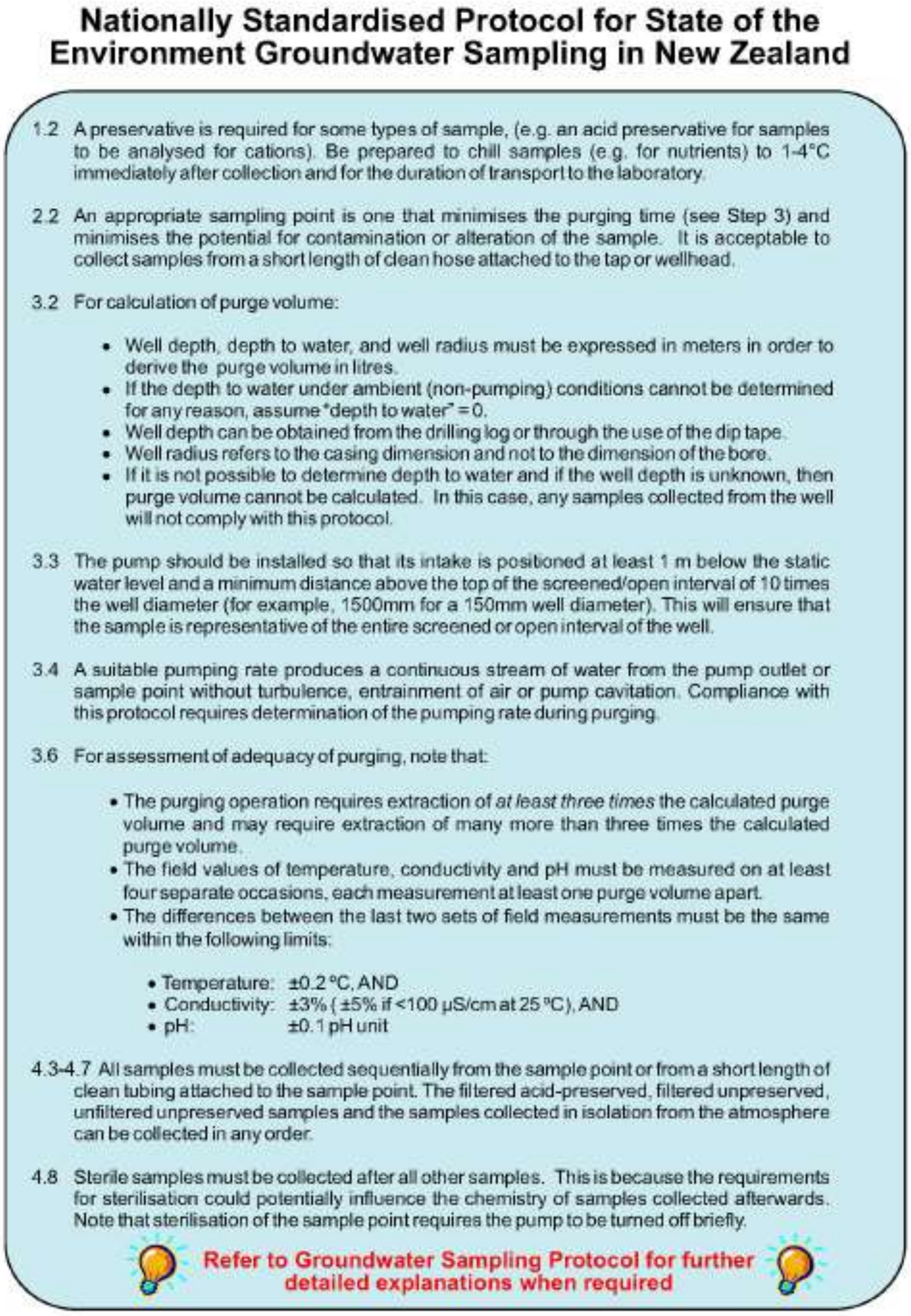
Step 6: Sample storage, transport and delivery ☐

Some types of samples require appropriate measures to ensure that adequate chilling during storage and transport.

During the day: Samples should be kept in a chilli bin, with at least 5 frozen pads, or 3 kg of ice.

Overnight Courier: Replace frozen pads/ice used during the day with at least 3 kg of ice for overnight transport.

Minimise airspace in chilli bin.



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

Appendix 5

Water quality results for different surface water bodies

Table 14 to Table 16 to present the water quality results for all results, HMWC's and drains.

Table 14 Descriptive statistics for all surface water results 2021

All	Min	Max	Range	Average	Median	Std Dev	CV
Cond-C	27.80	347.30	319.50	188.50	225.00	88.38	0.47
COND-SPC	38.90	493.60	454.70	248.59	300.90	116.58	0.47
DO %L	56.90	139.80	82.90	107.08	107.20	11.37	0.11
DO mg/l	5.80	15.30	9.50	11.37	11.53	1.44	0.13
NO_3-N Average	0.00	26.00	26.00	10.79	12.95	5.78	0.54
NTU	0.03	101.47	101.44	4.46	1.19	10.27	2.30
ORP	54.60	258.60	204.00	134.43	134.10	25.70	0.19
pH	6.13	9.09	2.96	7.50	7.50	0.61	0.08

Table 15 Annualised descriptive statistics for Drains 2021

All	Min	Max	Range	Average	Median	Std Dev	CV
Cond-C	27.80	282.20	254.40	153.82	130.80	104.19	0.68
COND-SPC	38.90	358.80	319.90	213.96	248.45	139.26	0.65
DO %L	101.20	128.00	26.80	110.20	108.05	6.64	0.06
DO mg/l	9.63	13.77	4.14	11.89	12.16	1.00	0.08
NO_3-N Average	0.002	16.90	16.90	6.61	1.66	7.12	1.08
NTU	0.72	56.95	56.23	6.49	2.75	12.09	1.86
ORP	96.30	158.20	61.90	129.30	127.05	21.20	0.16
pH	6.71	9.09	2.38	7.50	7.50	0.61	0.08

Table 16 Annualised descriptive statistics for HMWC's 2021

All	Min	Max	Range	Average	Median	Std Dev	CV
Cond-C	40.80	347.30	306.50	227.43	249.80	70.16	0.31
COND-SPC	50.50	493.60	443.10	299.75	328.10	92.17	0.31
DO %L	56.90	139.80	82.90	106.60	107.70	12.81	0.12
DO mg/l	5.80	15.30	9.50	11.34	11.48	1.49	0.13
NO_3-N Average	0.008	26.00	25.99	13.22	13.90	3.91	0.30
NTU	0.13	25.88	25.75	2.59	1.06	4.09	1.58
ORP	81.20	258.60	177.40	137.90	137.70	22.80	0.17
pH	6.13	9.09	2.96	7.30	7.25	0.59	0.08

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