Ground & Surface Water Sampling 2020

Annual Report

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Executive Summary

Background

This report outlines and documents the ground and surface water monitoring program conducted by MHV Water Ltd (MHV) during the 2020 calendar year. This work program 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);

iii. complete a catchment scale survey of Dissolved Reactive Phosphorus (DRP) and Dissolved Inorganic Nitrogen (DIN) survey of groundwater; and

iv. provide input data and observations for future work and research programs.

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

In early 2020 the program was reviewed, and the following changes made:

- Sample sites were to be tested on consecutive surveys where possible;
- Based on a WQN 10 assessment a nominal 2 km radius around each bore was used as a measure of spatial coverage;
- The number of both ground and water monitoring sites was increased to provide increased spatial representation.

Survey Spatial Coverage

The Canterbury's Land and Water Regional Plan (LWRP) uses annualised statistics of water quality to track progress towards Plan Change 2 target of 6.9 ppm NO_3-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.

During 2020, the groundwater monitoring program increased from 75 bores (from which 56 samples were obtained) to 114 bores with 97 providing samples. (Non-sampled bores were not able to be accessed at the time of the survey). Based on a 2 km radius of influence, this represents an increase from 62,000 ha to 92,300 ha (Figure 1).

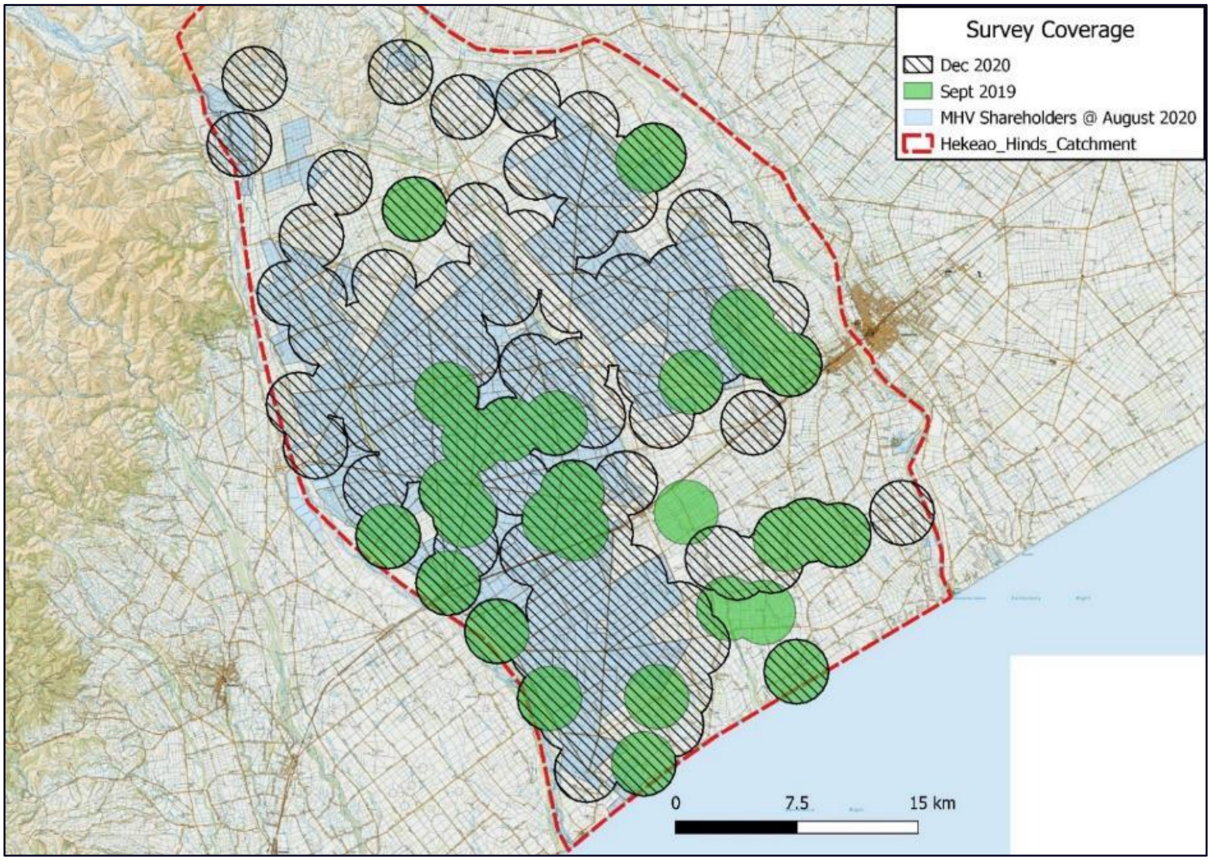


Figure 1 Comparison of September 2019 and December 2020 groundwater monitoring survey.

Groundwater Results

In total, 336 NO_3-N samples were obtained from 126 bores during 2020. The annualised average results for shallow (<30 m bores) and all bore depths are presented in Table 1; with highly elevated NO_3-N results related to a known historic concentration in the Tinwald area (refer to Aitchison-Earl, 2019; Hanson and Abraham, 2013, and Hanson and Abraham, 2010).

The median annual shallow (<30 m screen depth) will be the key statistic to track through to the 2035 LWRP groundwater NO_3-N target. This statistic is not currently graphed as a few years of consistent monitoring is required before defensible comparisons can be made.

Table 1 Descriptive summary statistics for annualised NO_3-N results from bores sampled in 2020

	No. of Holes	No. of Samples	Min	Max	Range	Average	Median	Std Dev	CV[1]
All Bores	126	336	0.09	26.43	26.34	9.06	8.70	3.98	0.44
Bores < 30m	40	99	0.74	26.43	25.69	11.19	11.04	4.87	0.44

The highly elevated maximum NO_3-N results presented in Table 1 are related to a known historic concentration in the Tinwald area (refer to Aitchison-Earl, 2019; Hanson and Abraham, 2013, and Hanson and Abraham, 2010).

[1] 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.

The results of the 2020 surveys indicate that NO_3-N concentrations in groundwater across the Hekeao Hinds catchment varied by over 10% between March and December (Table 2). The longer-term quarterly monitoring results are presented in Figure 2 to Figure 4. No attempts were made to remove seasonal effects or derive statistically significant trends.

Table 2 Changes in groundwater NO_3-N concentrations for the Hekeao Hinds Plains

	March 2020	December 2020	No. of congruent Samples	Change
Average NO_3-N - All Depths	9.28	8.17	47	12%
Average NO_3-N – Bores < 30m deep	12.90	9.49	10	26%
Median NO_3-N – Bores < 30m deep	11.24	9.17	37	18%

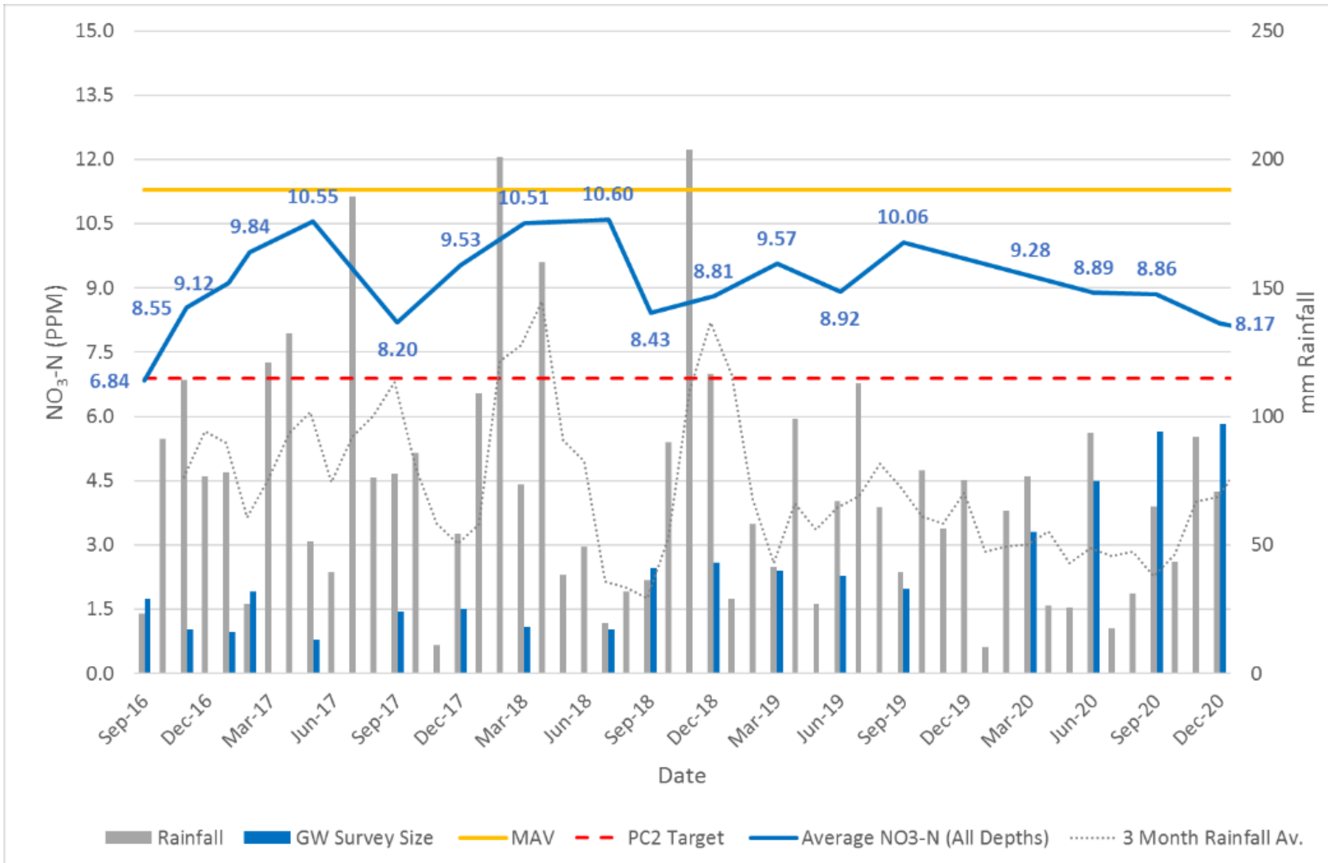


Figure 2 Arithmetic mean NO_3-N results over time irrespective of bore depth

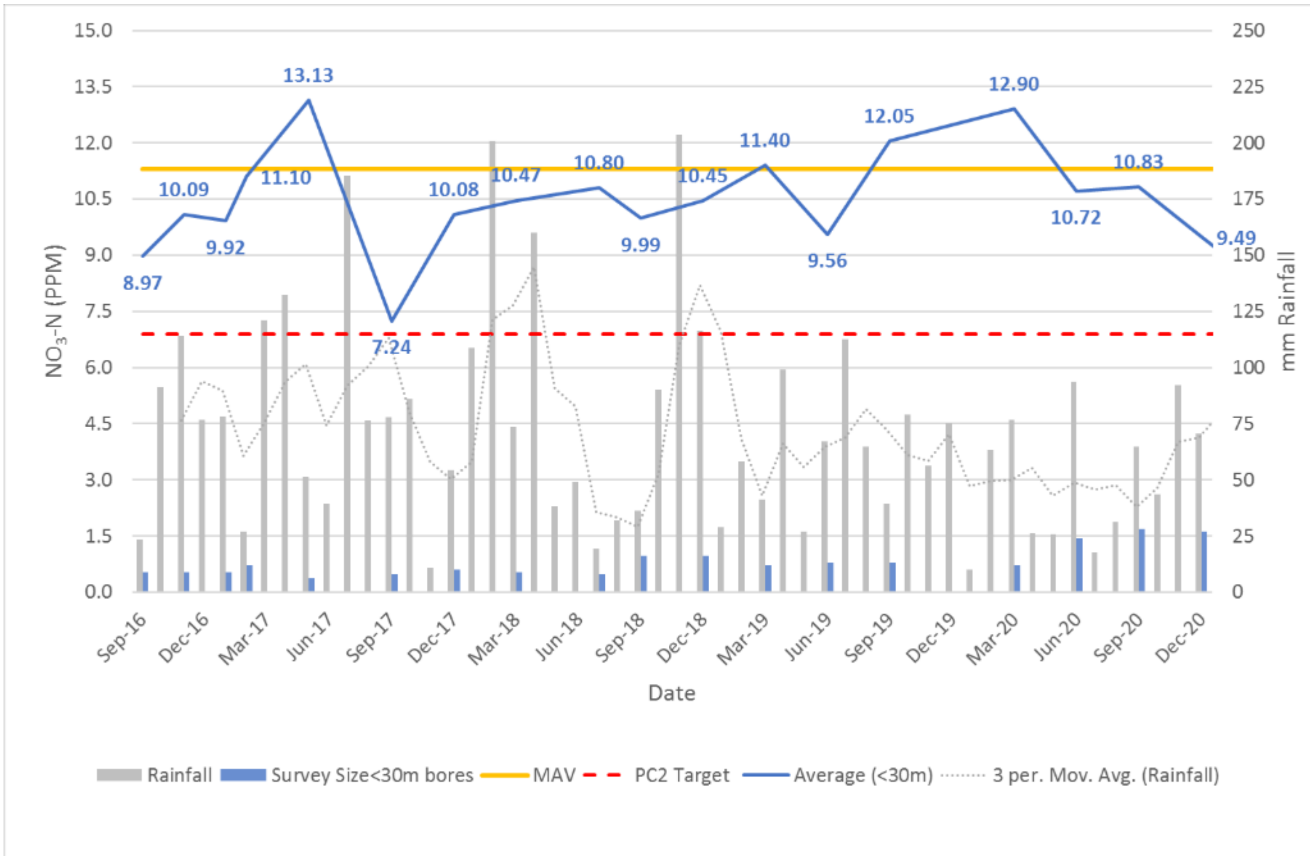


Figure 3 Arithmetic mean NO_3-N results over time for bores <30 m deep

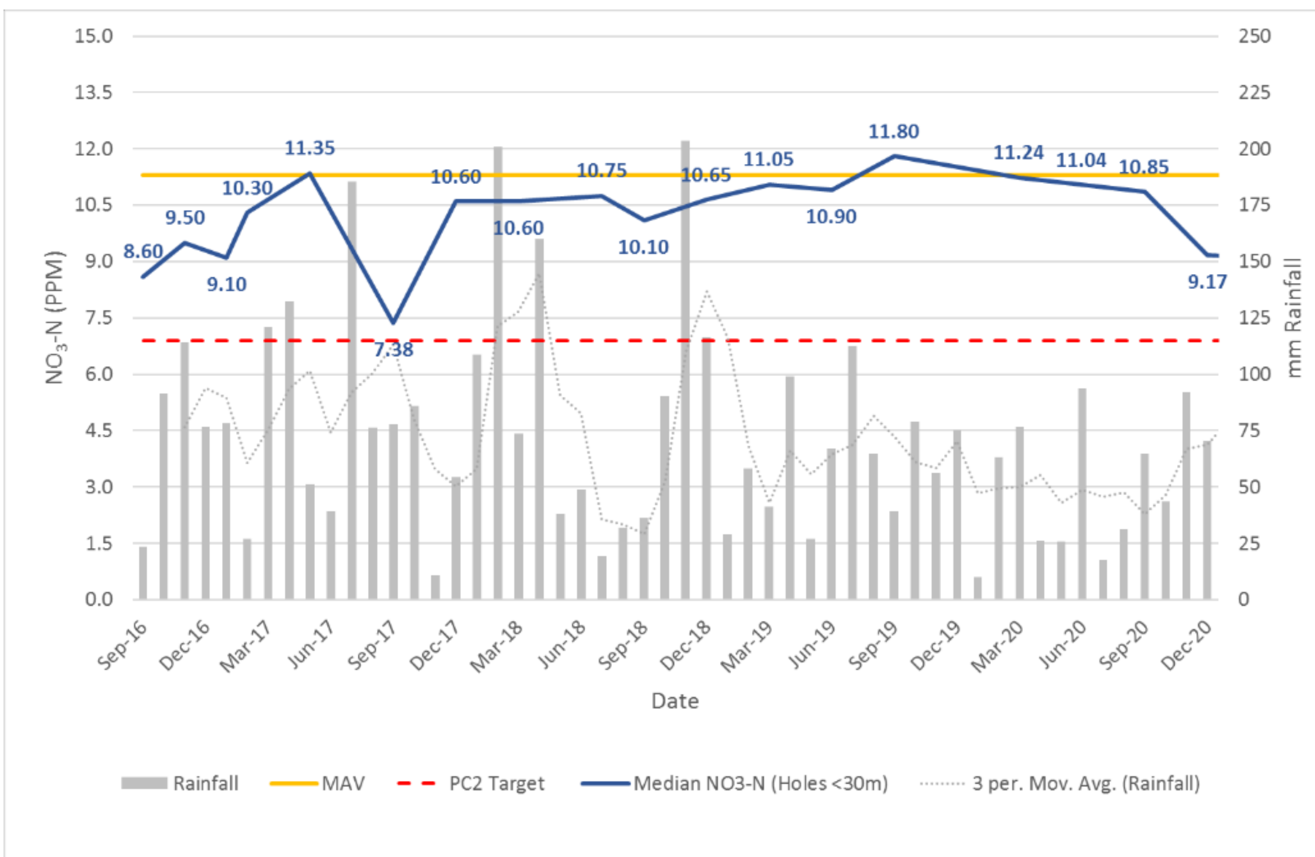


Figure 4 Median NO_3-N results over time for bores <30 m deep

Surface Water Results

Between June and December, 69 surface water samples were collected from 44 water locations on public roads (Figure 5). Samples were taken from springs, rivers, ephemeral drains, water races and Highly Modified Water Courses (HMWC) – referred to as 'Hill-fed Lower' and 'Spring-fed Plains' surface waters in the Canterbury Land and Water Regional Plan.

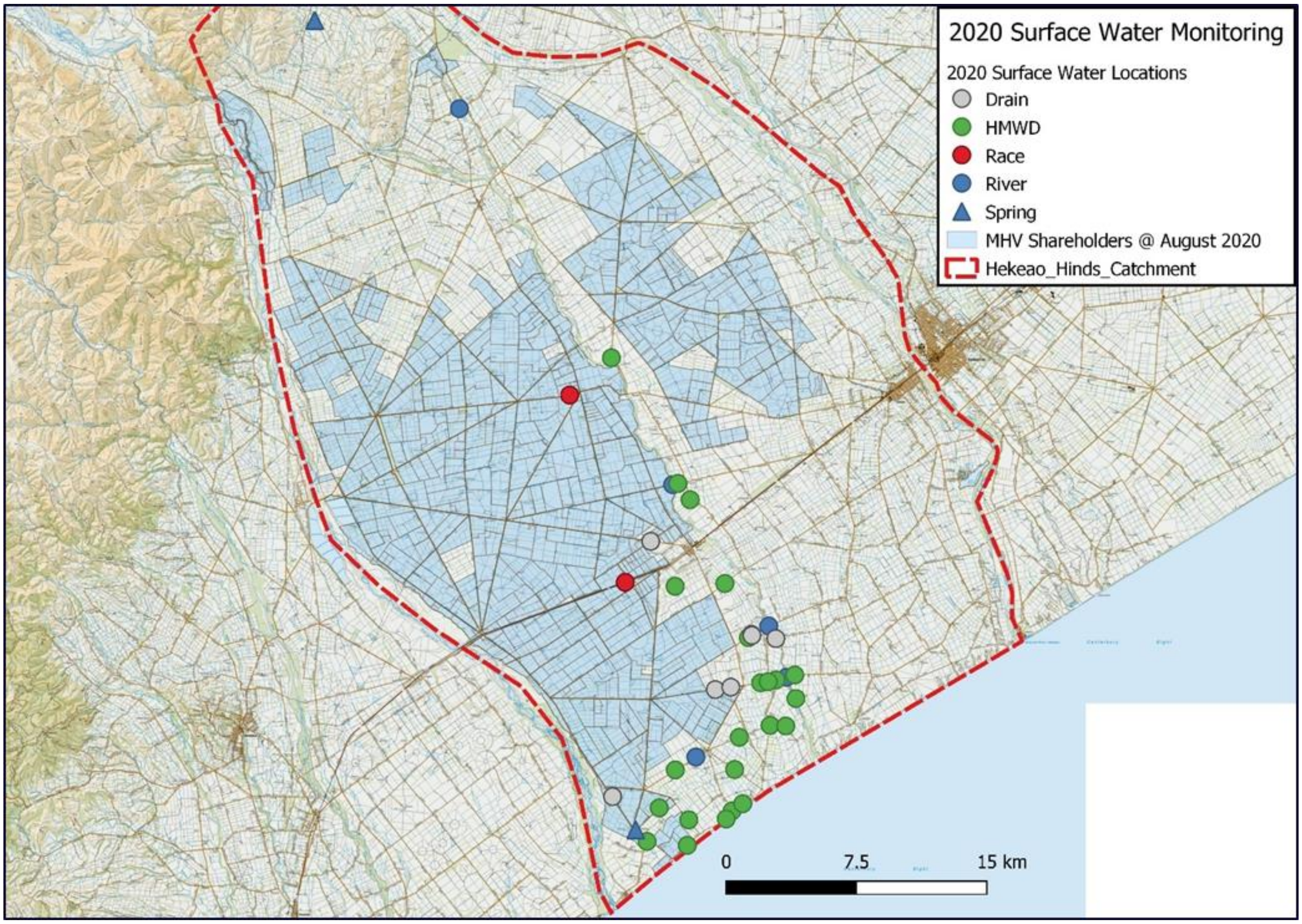


Figure 5 Locations of surface water samples taken from public roads

The NO_3-N results for the HMWC's dropped by 30% in the period between June and December 2020 (Table 3) – possibly due to seasonal variation.

Table 3 Variations in HMWC's NO_3-N concentrations for the Hekeao Hinds Plains

	June 2020	December 2020	Change
Average NO_3-N	10.30	7.14	31%
Median NO_3-N	12.35	8.30	33%

The longer-term trends are presented in Figure 6 and Figure 7.

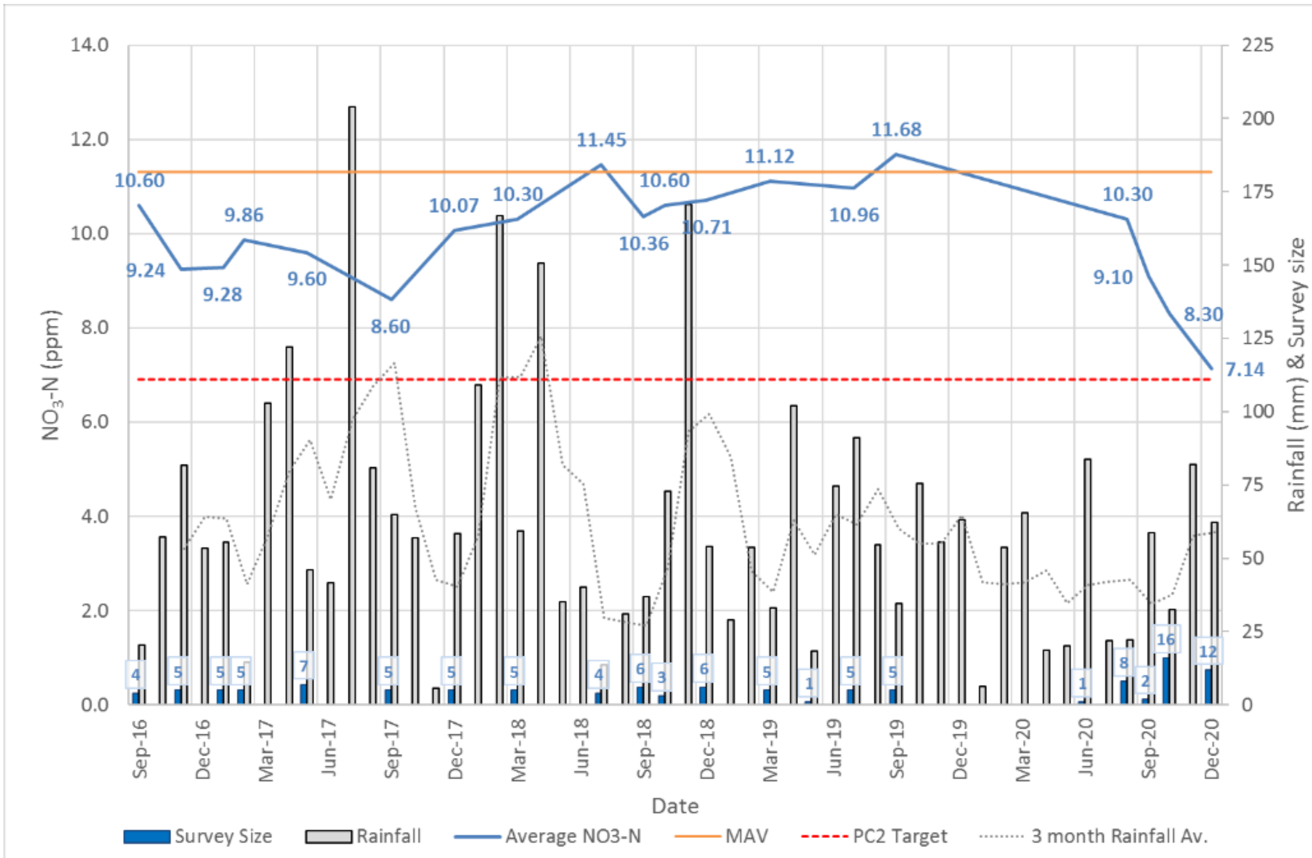


Figure 6 Arithmetic Mean of NO_3-N for HMWC's

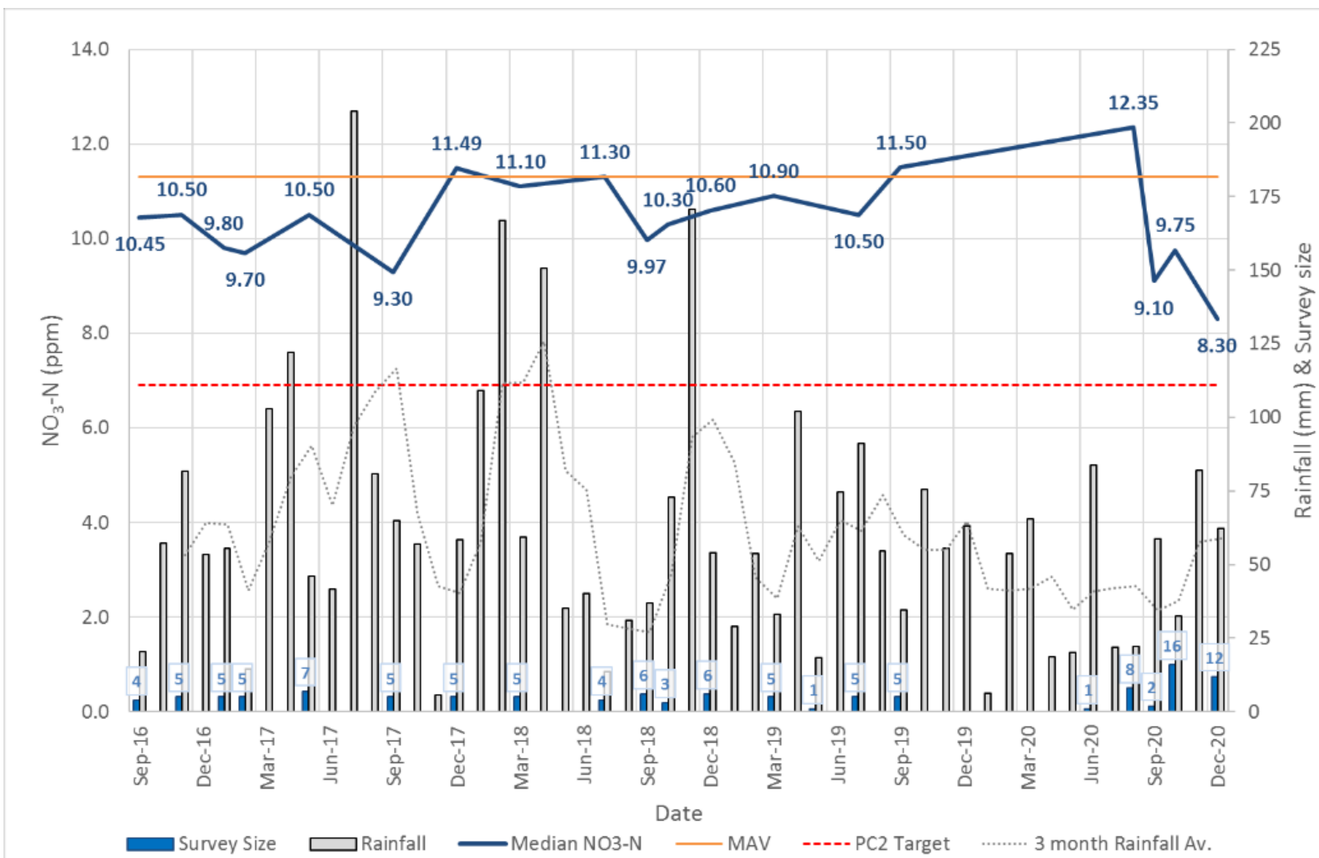


Figure 7 Median of NO_3-N for HMWC's

Groundwater Level Results

Groundwater levels[2] are generally at their highest in the winter months in response to Autumn rainfall (April – May) and the irrigation season hiatus between May and September.

119 groundwater level observations were obtained from 76 bores during the year. These were obtained at times when there was no pumping and represent a standing water level. The limited number of levels collected were due to one of three main reasons:

- The bore not possessing an alkathene conduit for water measurements;
- Bore not possessing an observation bung; and/or,
- The observation bung rusted or welded shut.

There was an appreciable drop between the June and September results (i.e. the non-irrigation period) of approximately 25% indicating that there has been a reduction in groundwater levels across the catchment. This was confirmed with ECan data that also indicates a gradual decline in groundwater levels since mid-2018.

Groundwater DRP Orientation Survey Results

In September 2020, 68 bores were sampled for Dissolved Reactive Phosphorus (DRP) on a nominal 5km spacing utilising bores that were already being tested.

The results (Figure 8) indicate that the groundwater of the Hekeao-Hinds has a median value of 0.006 ppm (for both greater and less than 30 m bores) that would classify as Band A (no impact) and Band B (slightly impacted) as per the National Policy Statement for Freshwater Management 2020; with localised examples of Band C (moderate impact).

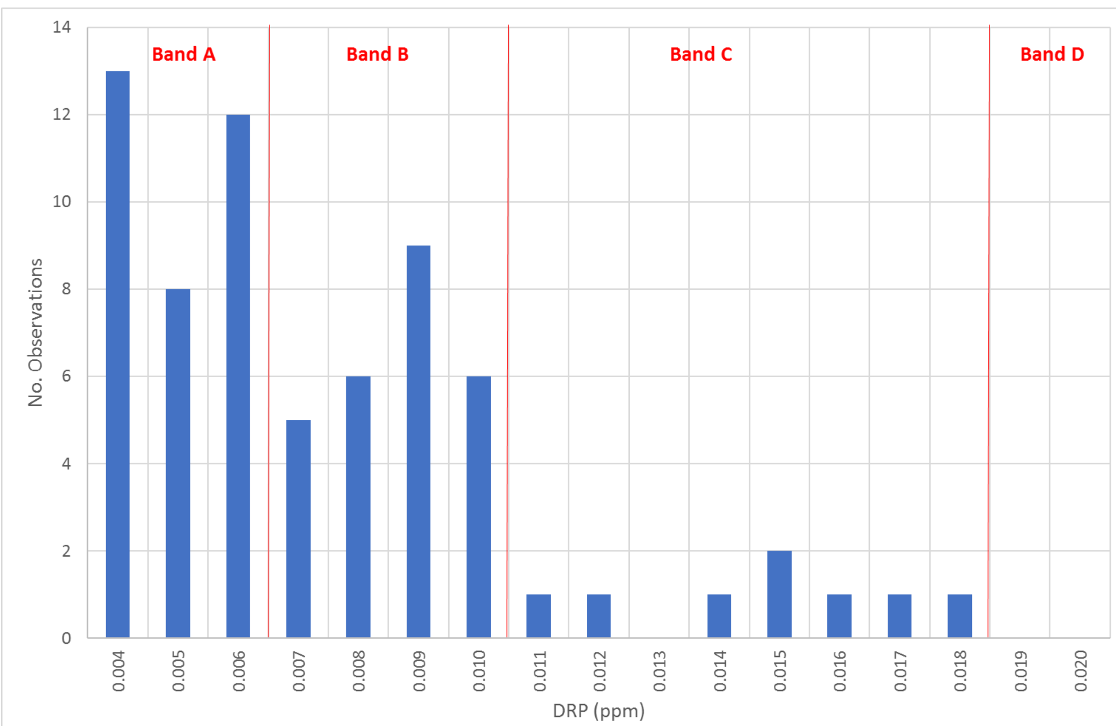


Figure 8   Frequency histogram of the DRP results with NP-FWM toxicity bands

[2] 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.

Summary

As outlined in Section 1.2, The groundwater programme is a tangible expression of MHV's mission to provide *"Sustainable Solutions for our Shareholders and the Community*". MHV encourages continuous improvement of on farm practices as well as supporting other environmental mitigations both on farm and as part of the wider community to achieve the objectives of Plan Change 2 of the Land and Water Regional Plan and also the Essential Freshwater Package.

The intention of the groundwater and surface water 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. By monitoring groundwater and surface water across the scheme area, MHV intends to provide data and complementary information that will enable evidence-based decision making, that leads to environmentally and sustainable water and nutrient management practices.

In doing so, MHV intends to develop sustainable strategies to assist farmers manage land use and mitigate the migration of NO_3-N in both surface and groundwaters.

Recommendations

1. The current monitoring program to be maintained and extended so that the spatial footprint extends to cover the Hekeao Hinds Plains in its entirety. This will inform a consistent, comprehensive analysis of annual NO_3-N concentration tracking toward catchment targets.
2. Kaupapa māori methodologies – also known as cultural health indicators (CHI) be incorporated into future surveys.
3. Ecological surveys should be carried out to compliment the water quality data as well as identify any ecological constraints. These might include:
    - Assessing the ecological status of waterways, using, for example, the Stream Health Monitoring and Assessment Kit (SHMAK)[3];
    - Multi-pass electrofishing surveys to estimate the abundance or density of freshwater fish in the HMWC's.
4. A reconciliation (aka mass balance) of rainfall, river flows, MAR inflows, water levels, irrigation schedules to ascertain if there is a temporal element to nitrate migration.
5. Further investigation into the potential drivers of NO_3-N distribution be undertaken, e.g., the correlation with soil and NO_3-N concentration as outlined in section 7.3.
6. A 3-D conceptual be developed in house to collate all the spatial data as well as provide a platform for visualisation, conceptualisation and communication of the results (Figure 47).

[3] https://niwa.co.nz/freshwater/management-tools/water-quality-tools/stream-health-monitoring-and-assessment-kit

Nitrogen naming & unit convention

Nitrate-Nitrogen (NO_3-N)

When a laboratory reports directly 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 (Ministry of Health, 2018).

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 0.0226

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})" (Ministry of Health, 2018, 2017)

Abbreviations

CHI	Cultural Health Indicators
Cumec	Cubic Meter per Second (m^3/s) = 1,000 litres per second
DO	Dissolved Oxygen
DIN	Dissolved organic nitrogen: comprised of nitrate plus nitrite and ammonium
DRP	Dissolved Reactive Phosphorus
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
GL	Giga Litre (1,000,000,000 Litres)
ha	10,000 square metres (2.471 acres)
HMWQC	Highly modified water course
ID2	Inverse Distance Squared
IWM	Integrated Water Management
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	(Canterbury) 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
N	Nitrogen
NO_2-N	Nitrite-Nitrogen. The concentration of nitrogen (N) present in the form of the nitrite (NO_2)
NO_3-N	Nitrate – Nitrogen. The concentration of nitrogen (N) present in the form of the nitrate (NO_3)
NPS-FM	National Policy Statement for Freshwater Management
OFG	Open Framework Gravels
p.a.	per annum (for each year)
PAW	Profile Available Water
pH	a numeric scale used to specify the acidity or alkalinity of an aqueous solution
SWL	Standing Water Level
QAQC	Quality Assurance & Quality Control

Contents

1. Introduction

1.1. Purpose

This report documents the groundwater sampling program conducted by MHV Water Ltd (MHV) during the 2020 calendar year.

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

a) complete routine groundwater monitoring of Nitrate-Nitrogen (NO_3-N)[4] levels within the MHV irrigation area[5];

b) complete a catchment scale survey of Dissolved Reactive Phosphorus (DRP) and Dissolved Inorganic Nitrogen (DIN) survey of groundwater;

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

d) provide input data and observations for future work and research programs.

1.2. Background of the monitoring program

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 Shareholders and the Community*". By monitoring groundwater behaviour and character across the scheme, MHV intends to provide data and complementary information that will 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

[4] 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^-.
[5] The MHV irrigation area is constrained within the Rangitata, Coldstream, Hinds and Westerfield Plains catchment areas

1.3.Scope

This report represents the work program, and subsequent results of selected boreholes within the MHV scheme and surrounding areas undertaken by MHV Senior Hydrogeologist- Justin Legg. Refer to Appendix 1 for statement of qualifications.

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

Environment Canterbury (ECan)	Fish and Game
Hinds Drains Working Party (HDWP)	Independent farmers
Hekeao Hinds Water Enhancement Trust (HHWET)	

This report only pertains to data collected by MHV during 2020. It is envisaged that in future reports, the data from these agencies may be incorporated where appropriate.

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

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

- current and/ or historical land use practices;
- localised geology, geomorphology and/ or soil types;
- 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 (Environment Canterbury, 2019). This target will be determined by the results from the Canterbury Regional council's monthly surface waterbodies monitoring sites[6].

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[7] (bores screened <30 m below ground level) 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, up from 80% under the former NPS-FM 2017. This effectively reduces the NO_3-N limit from 6.9 to 2.4 ppm.

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

As the implementation of the new policy is yet to be confirmed, this report will refer both the PC2 and NPS-FM 2020 NO_3-N limits of 6.9 ppm and 2.4 ppm respectively (see Appendix 3 for details).

1.5. Background Documents

This report is based on several earlier reports, including:

Legg, J. 2020. MHV Groundwater Report March 2020. MHV Water. Internal Report. Ashburton

Legg, J. 2020. MHV Groundwater Report June 2020. MHV Water. Internal Report. Ashburton

Legg, J. 2020. MHV Groundwater Report September 2020. MHV Water. Internal Report. Ashburton

Legg, J. 2020. MHV Groundwater Report December 2020. MHV Water. Internal Report. Ashburton

Legg, J. 2020. Future Groundwater Monitoring on the Hekeao Hinds Plains: A Green Paper. MHV Water. Internal Report. Ashburton

Legg, J. 2020. Future Surface-water Monitoring on the Hekeao Hinds Plains: A Green Paper. MHV Water. Internal Report. Ashburton

2. Study Area

2.1. Climate and Rainfall

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

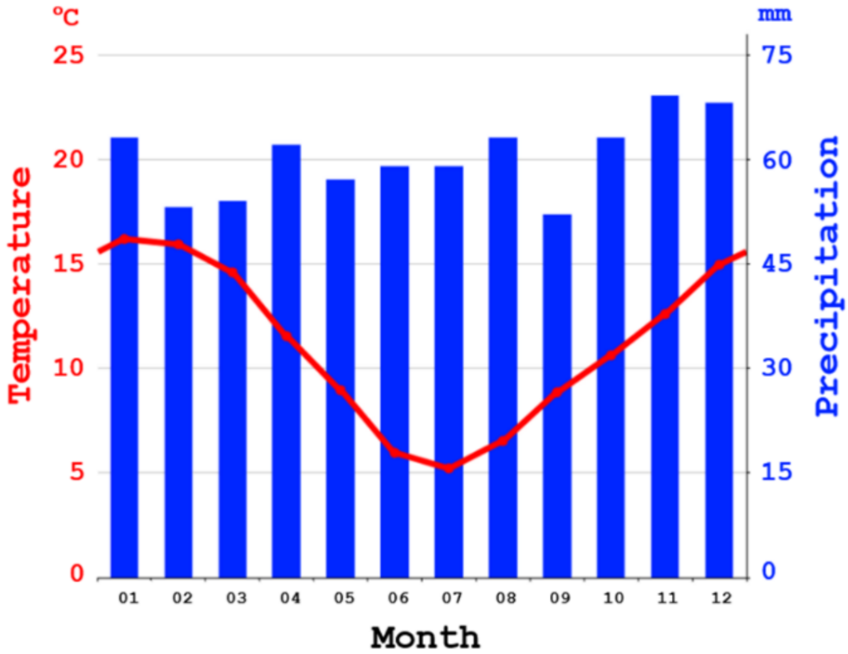


Figure 9 Ashburton Climate[8]

Mean annual rainfall of 680 mm p.a., which varies from 614 mm at the coast to approximately 950 mm at the foothills near the top of the plains (Figure 10). 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 (Durney et al., 2014).

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

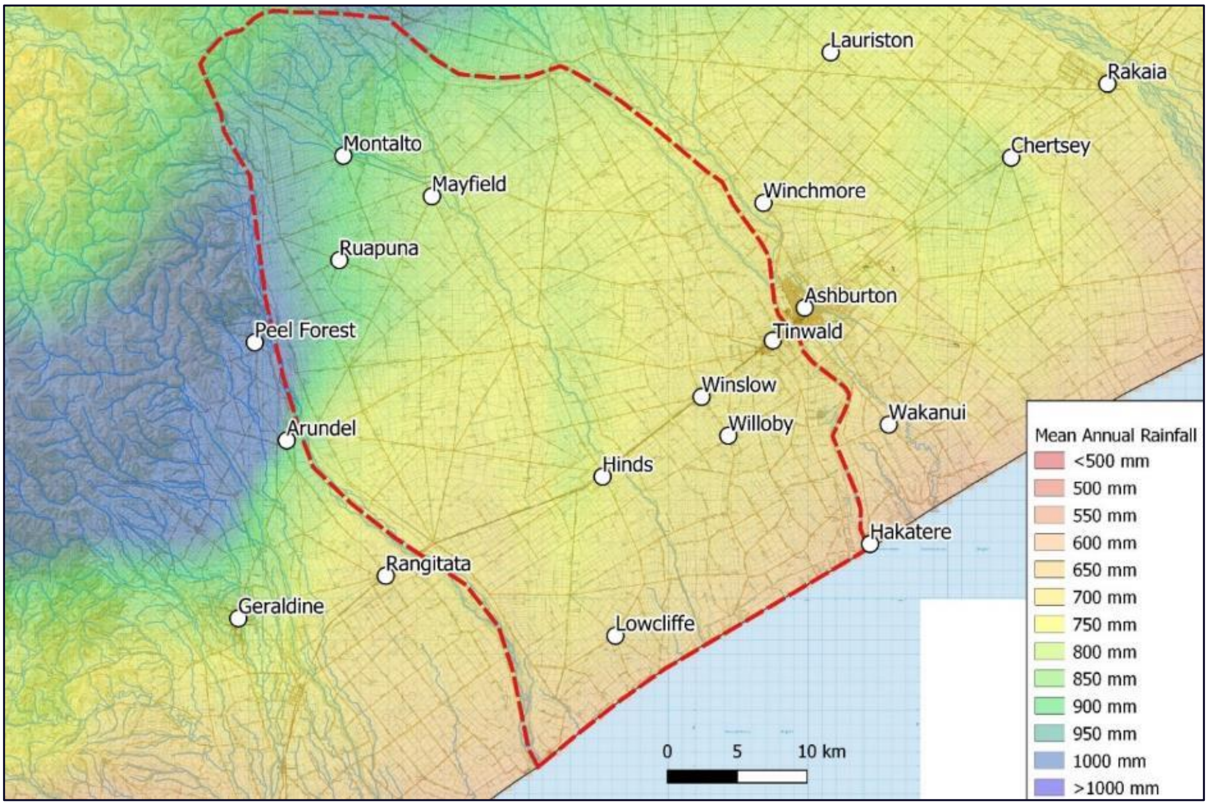


Figure 10 Generalised mean annual rainfall distribution across the Hekeao Hinds Plains

Approximately 533 mm of rainfall was recorded across the Hekeao/ Hinds catchment during 2020, based on an average of 6 NIWA weather stations (Figure 11). The data are presented in Appendix 2.

2020 was a relatively dry year, with particularly low rainfall in late autumn/early winter (on average only 40mm in April and May). Apart from June, there was little winter rainfall, and the current low groundwater levels reflect this. Based in the NIWA data, 2020 had around 22% less rain than the long term average of 680mm/ pa for Ashburton (Macara, 2016).

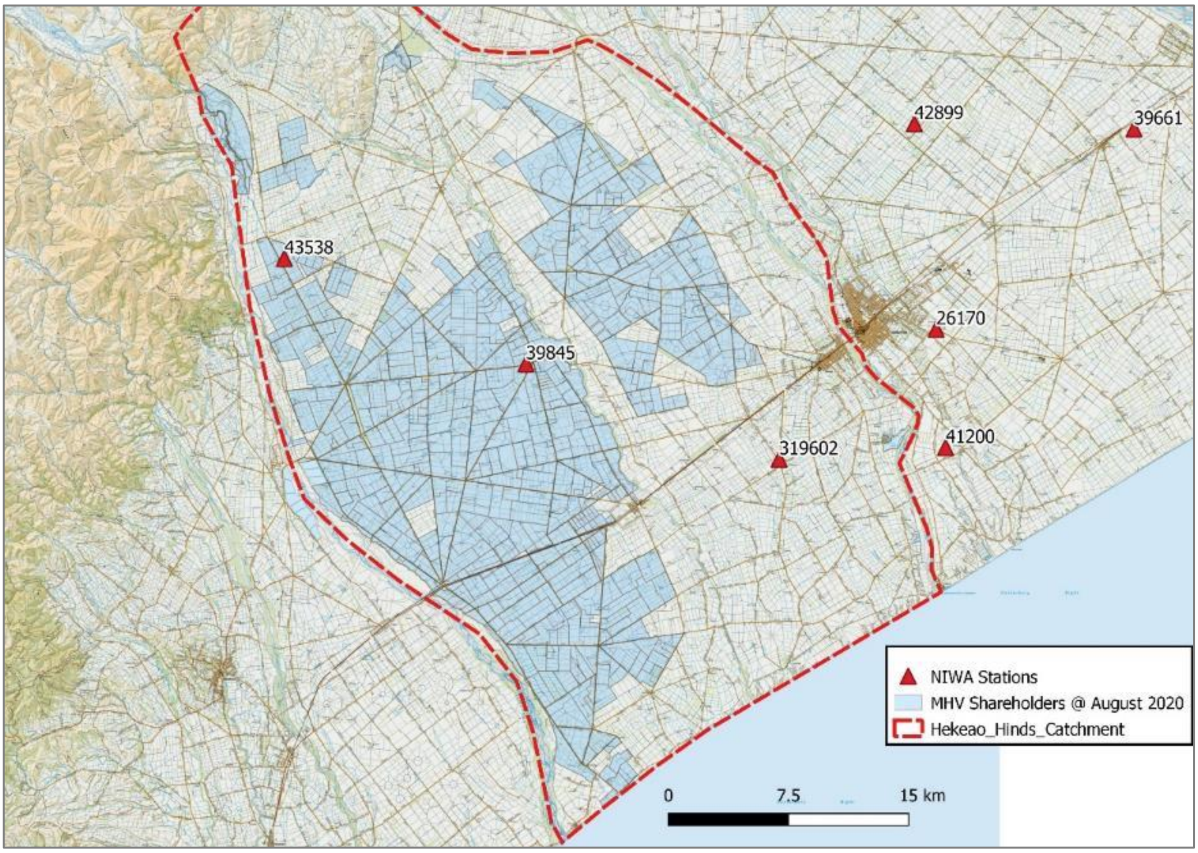


Figure 11 Locations of NIWA weather observation stations

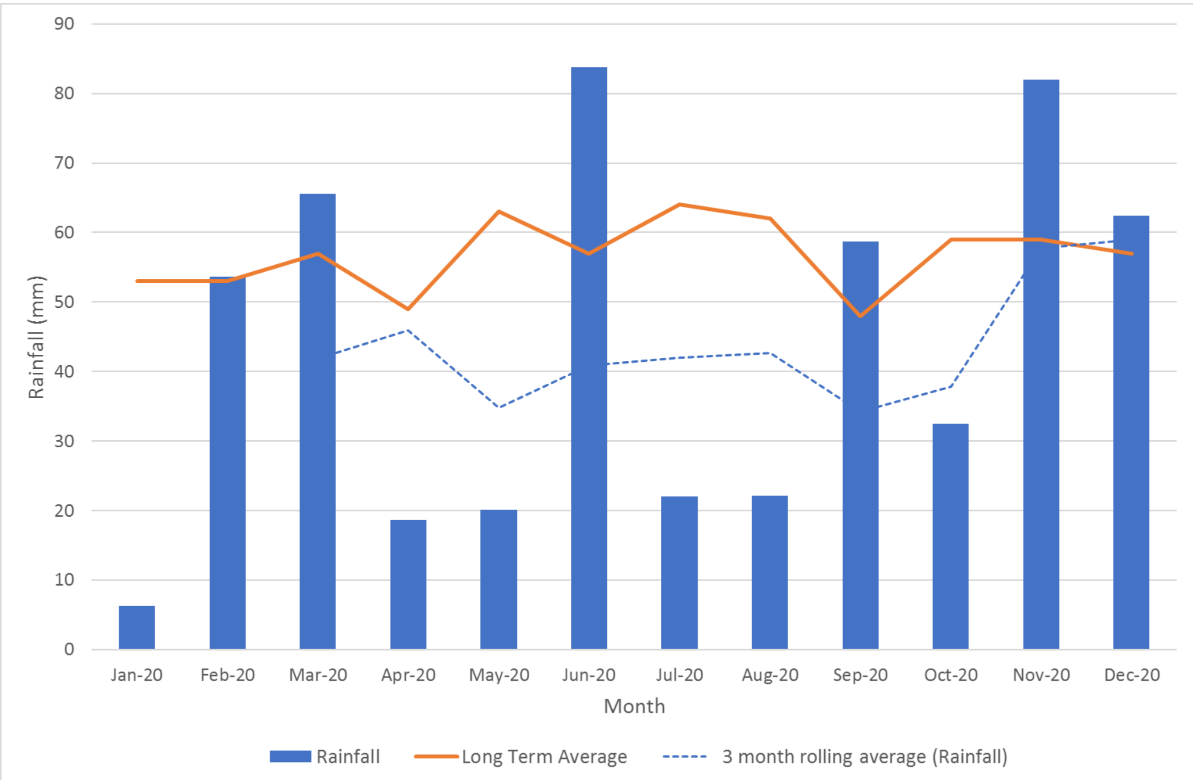


Figure 12 Average rainfall on the Hekeao Hinds Plains 2020

2.1.1. River Flows

River flows across the Hekeao / Hinds almost mirror the seasonal rainfall average as shown in Figure 13, with river flows in all three rivers having reduced flows from 2019 (Table 4).

Table 4 Average daily flow rates (m^3/ second) for the rivers in the survey area between 2015 - 2020

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

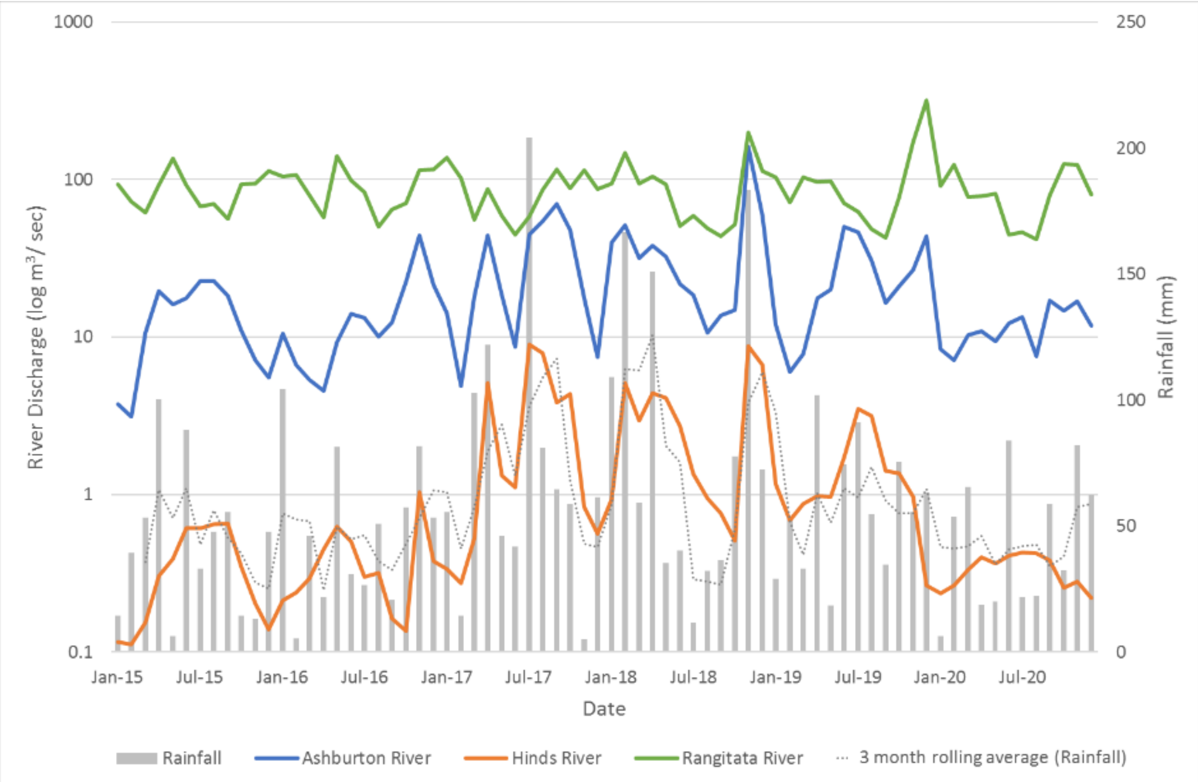


Figure 13 Rainfall and river flow data for the period 2015 to 2020

2.2. Catchment Characteristics

The area is generally characterised as having a 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 (Figure 14) (Hanson and Abraham, 2013).

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 (Dommisse, 2006; Hanson and Abraham, 2013). 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.

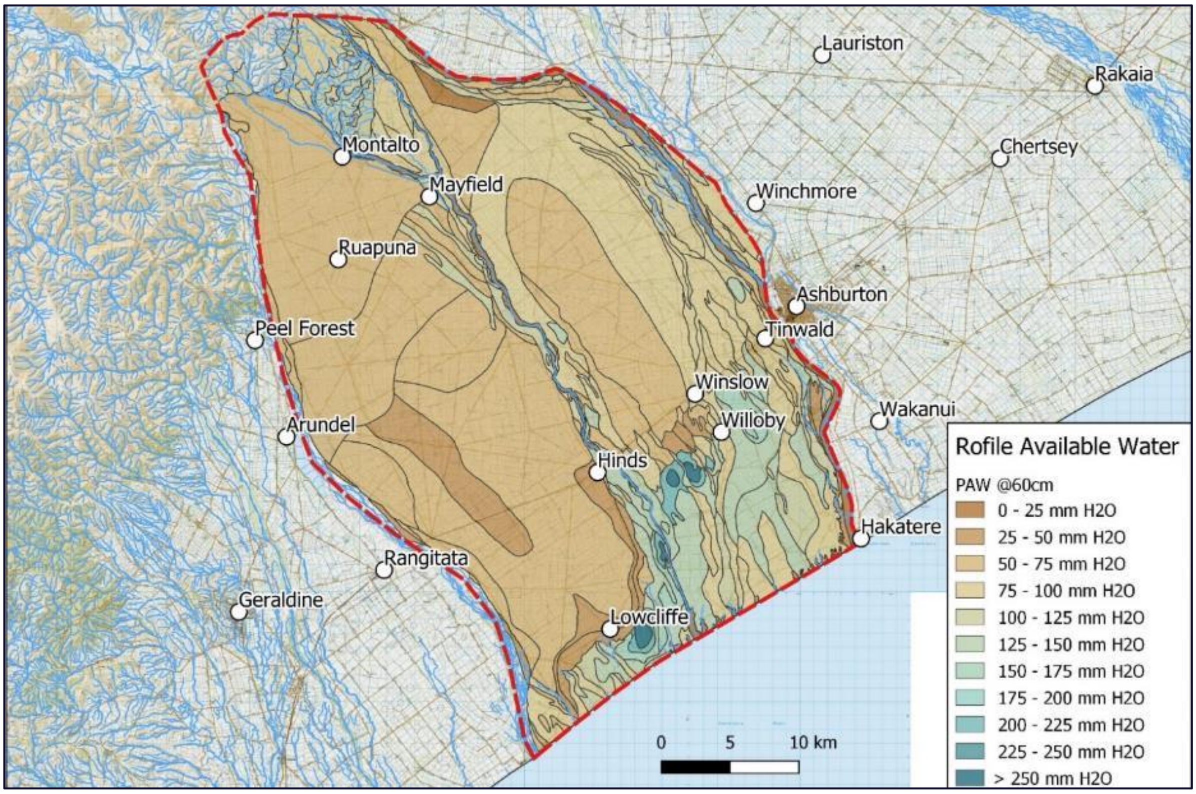


Figure 14 Soils of the Hekeao/Hinds Plains

2.3. Hydrology

2.3.1. Surface waters

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. As 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.

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. Additionally, the area between from Lagmhor to Waterton

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

(often referred to as the 'Old Hinds Swamp') was/ is considered 'heavy' and prone to becoming waterlogged (Aitchison-Earl, 2019).

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 15). 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 2.3.2).

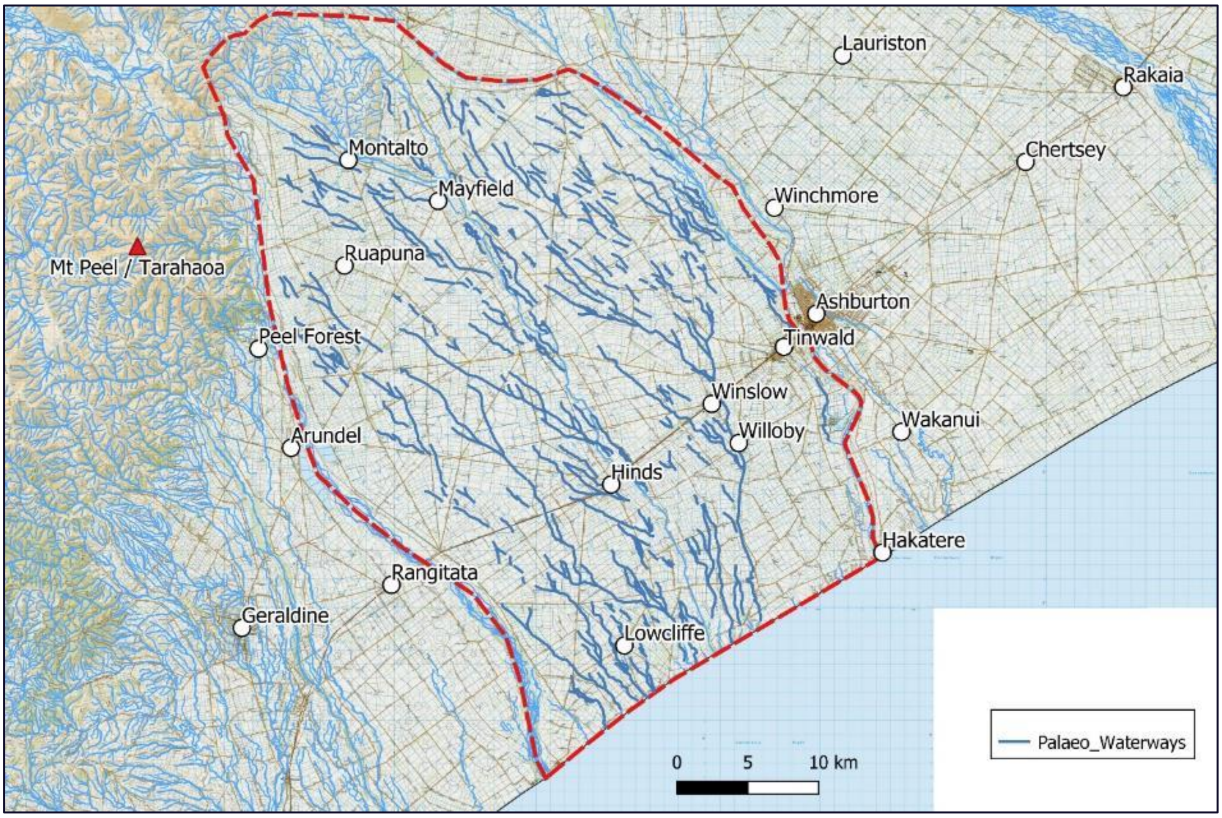


Figure 15 High-level interpretation of the 1m LIDAR digital terrain model (DTM) mapping paleo channels

2.3.2. 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 (Dommisse, 2006). 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. At a local scale, semi-confined (leaky) conditions are likely to be encountered, with confinement generally increasing with depth (Burbery et al., 2018; Durney et al., 2014; Hanson and Abraham, 2013).

The majority of flow and transport is to be through open framework gravels (OFG's). Notably, based on work in the Burnham area, it has been suggested that up to **98%** of groundwater flow occurs through OFG's gravels. These gravels lenses can:

[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

- be planar-stratified or cross-stratified,
- vary in thickness from centimetres to decimetres,
- can extend from metres to tens of metres (Burbery et al., 2018; Rutter et al., 2016),
- account for approximately 1% of braided river sedimentary systems in the Canterbury Plains

The gravels within the lenses are characterised as (Jussel, 1989; Lunt and Bridge, 2007):

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

Figure 16 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. Groundwater sampling program

3.1. Groundwater Monitoring Program 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 program's initial objective was to understand the changes in NO_3-N in the groundwater of the Hekeao/Hinds Plains, as a result of ongoing and/or changing land use activities within the area.

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

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

The 2020 program extended to 114 bores by December with samples being obtained from 97 – the discrepancy being due factors such as bores being offline, the bore being dry, or the well head undergoing maintenance etc. (Figure 17). The aim of the program is to have a catchment scale data set that provides a more holistic understanding of water quality across the Hekeao/ Hinds plains.

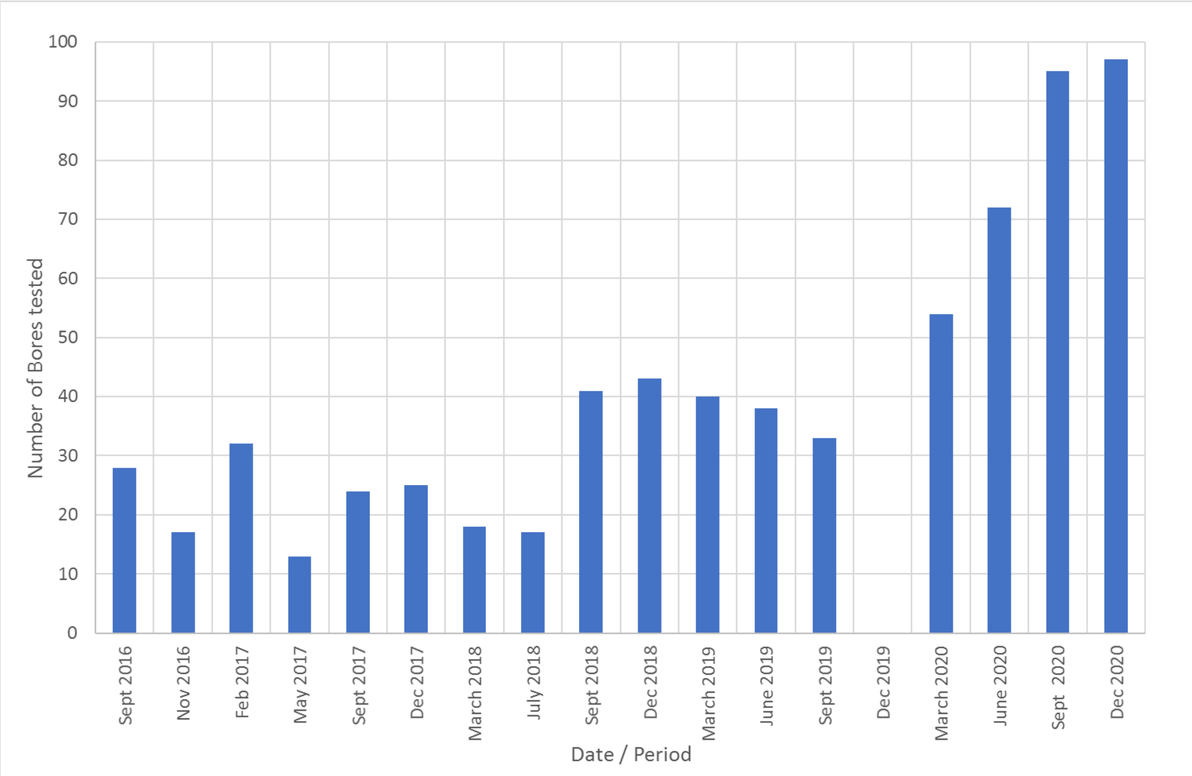


Figure 17 Frequency histogram of survey size changes over time

The variation in survey size affects the frequency in which an individual bore is tested. Figure 18 presents a frequency histogram of the number of times a bore has been sampled since September 2016 (i.e., 18 quarterly surveys); revealing that only 2 bores have been tested consistently since September 2016. An example of the variation in survey design is presented in Figure 19; subsequently, trends can be difficult to analyse.

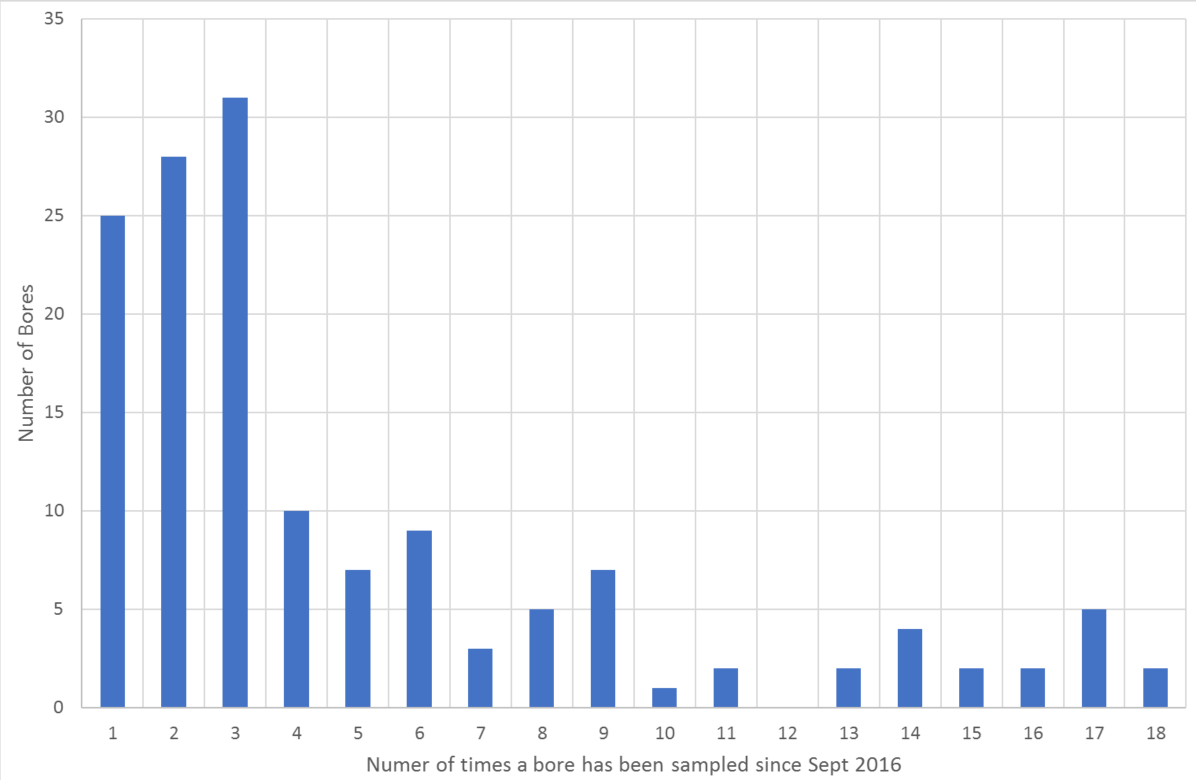
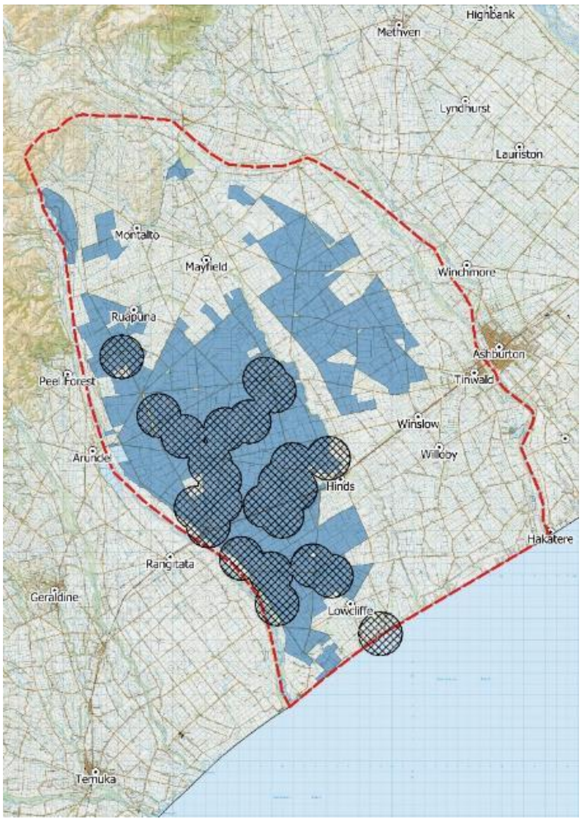
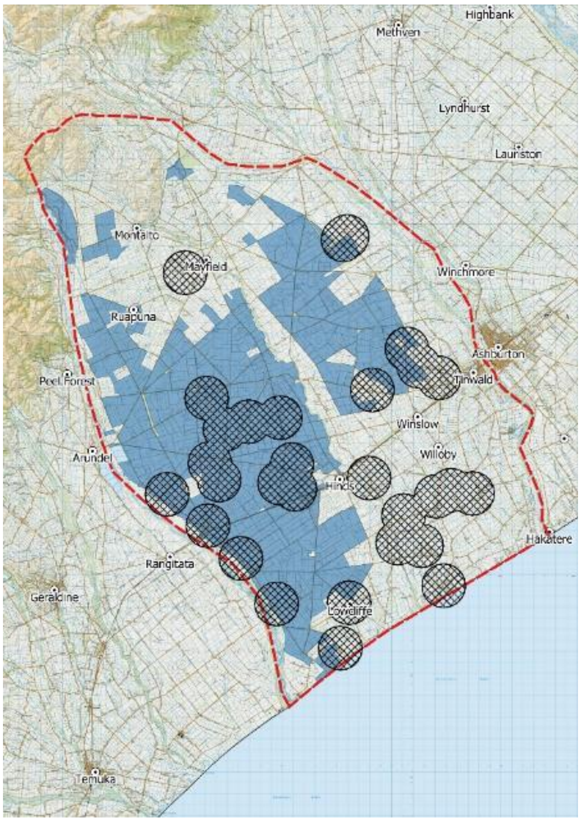


Figure 18 ***Histogram indicating the number of times a bore has been sampled during the 18 groundwater surveys (09/2016 to 12/20)***





September 2017 September 2019

Figure 19 ***Examples of different survey design***

3.2. Bore Depths and Types

Bore depths for the 2020 monitoring program have ranged from 5 m to 155 as shown in Figure 20, with 30% of the bores surveyed throughout the year being < 30 m deep.

Bore depths are categorised in keeping with the LWRP[12] (Environment Canterbury, 2019), 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

A breakdown of bore types sampled is presented in Figure 21.

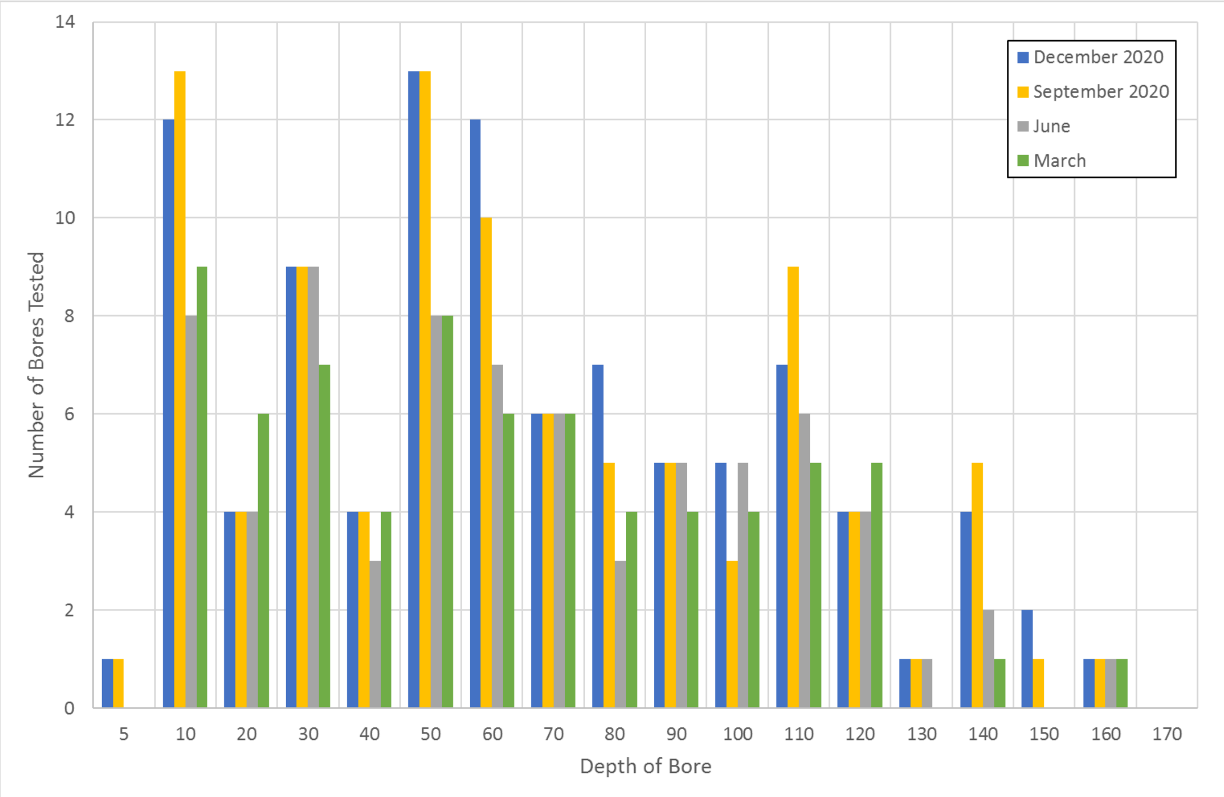


Figure 20 Bore depths tested during 2020

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

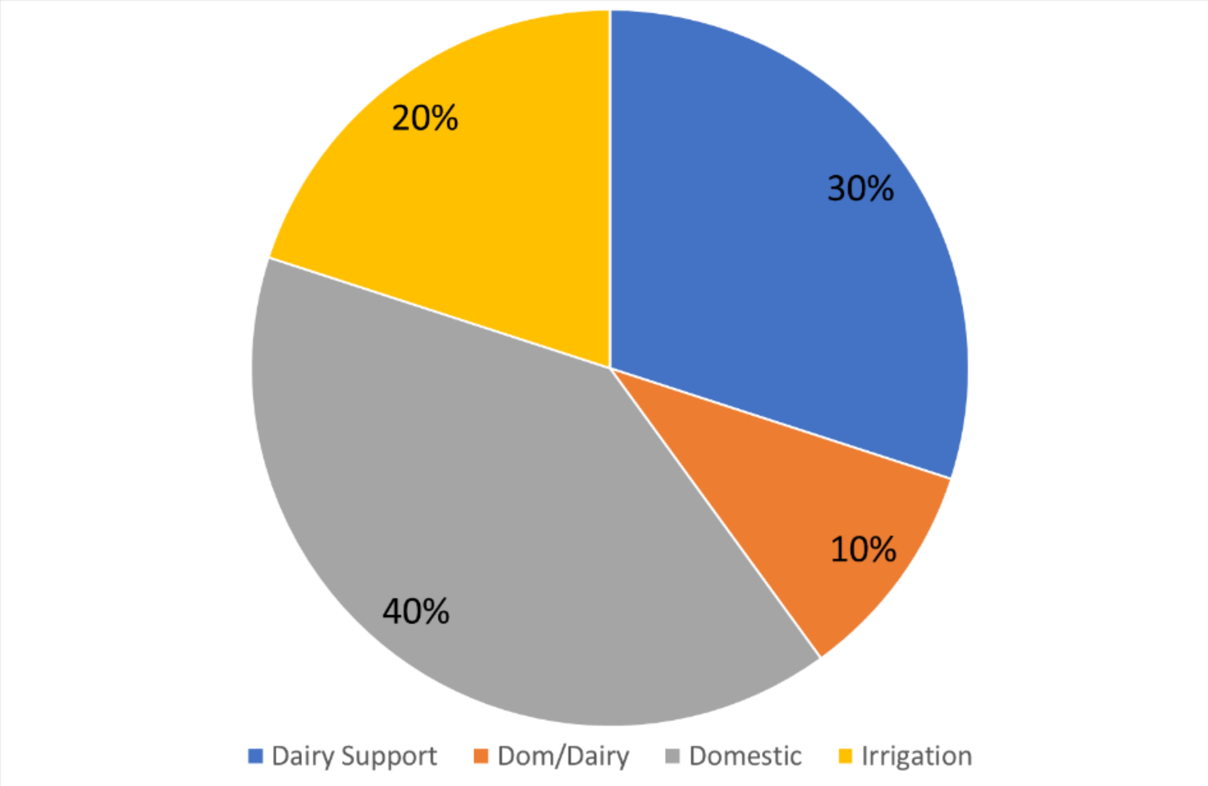


Figure 21 Breakdown of bore types sampled

3.3. 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 program, visual inspections of well head security were completed based on the following criteria[13] (Environment Canterbury, 2019):

Collared	Does the bore have a portion of the gallery pipe extending above the surface that is >200m in height that 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?

[13] The criterial was based on s5.103 to s5.110 of the Canterbury Land and Water Regional Plan

NB: It should be noted that this inspection did not consider section 8 *"Meaning of drinking water supplier"* of the Water Services Bill that is before 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 22).

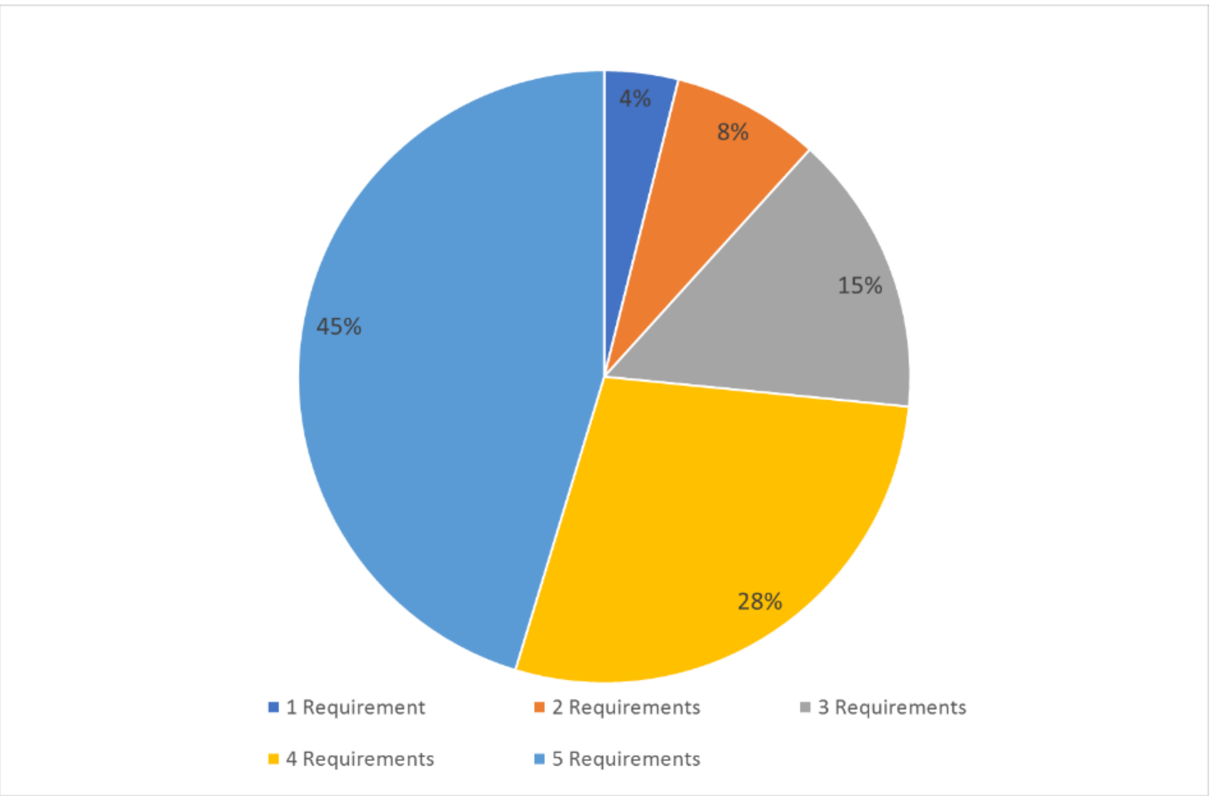


Figure 22 Cumulative pie chart indicating the percentage of bores that meet all of the LWRP well head security requirements.

Figure 23 presents a breakdown of well head security requirements, indicating that

- 87% of the bores have a collar > 200mm to mitigate surface run off;
- 91% of the bores inspected are capped;
- 70% have a concrete pad;
- 77% are spudded in a secure location (e.g. have a fence around them); and,
- 20% of the bores are <20 m from a potential contaminant source such as a dairy track. As these bores may have adequate collars, concrete pads and secure caps or well heads, this is not considered an issue.

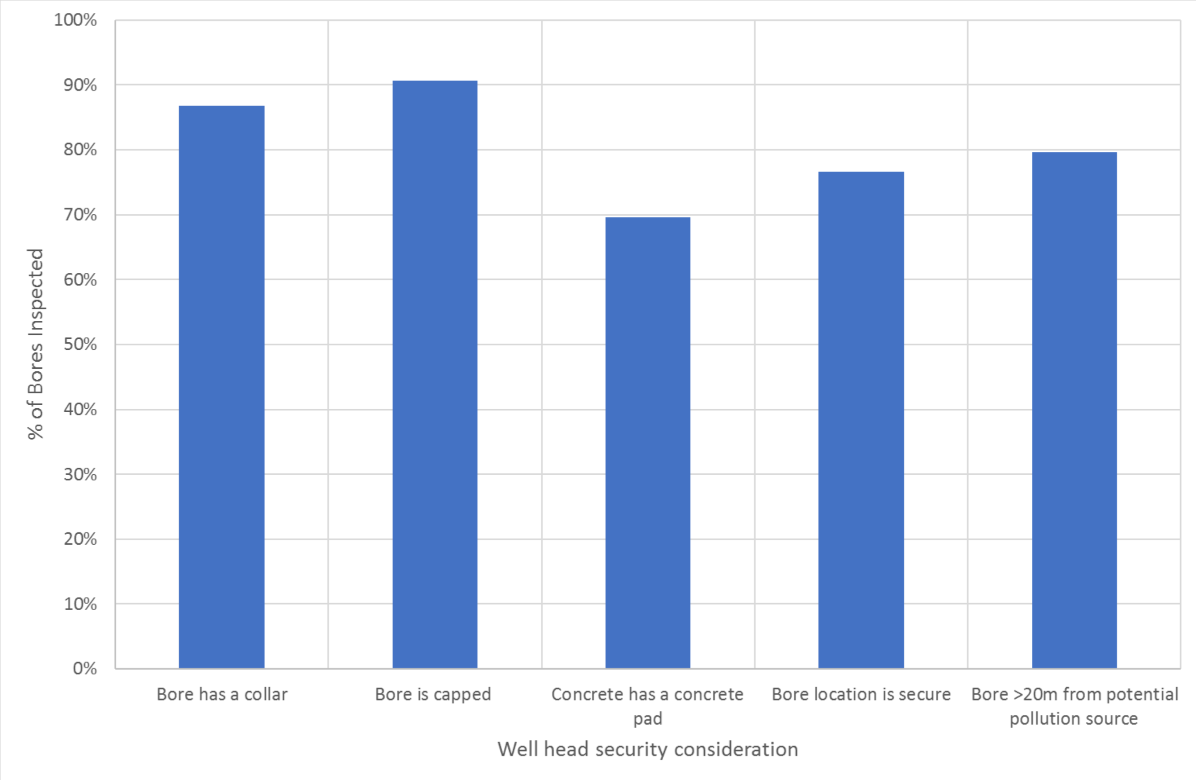


Figure 23 Breakdown of well head security audit

3.4.Survey Spatial Coverage

The current groundwater abstraction guidelines for ECan require a 2 km buffer zone from a bore (Aitchison-Earl and Smith, 2008; Kaelin, 2015) for a WQN 10 assessment to assess interference effects from abstraction[14]. 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 24 presents the survey coverage from 2019 to 2020.

As no survey was conducted in December 2019, Figure 25 presents a spatial comparison of September 2019 with December 2020. At the time of writing it is envisaged that the footprint of the program will be extended to fill in the gaps of the current survey.

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

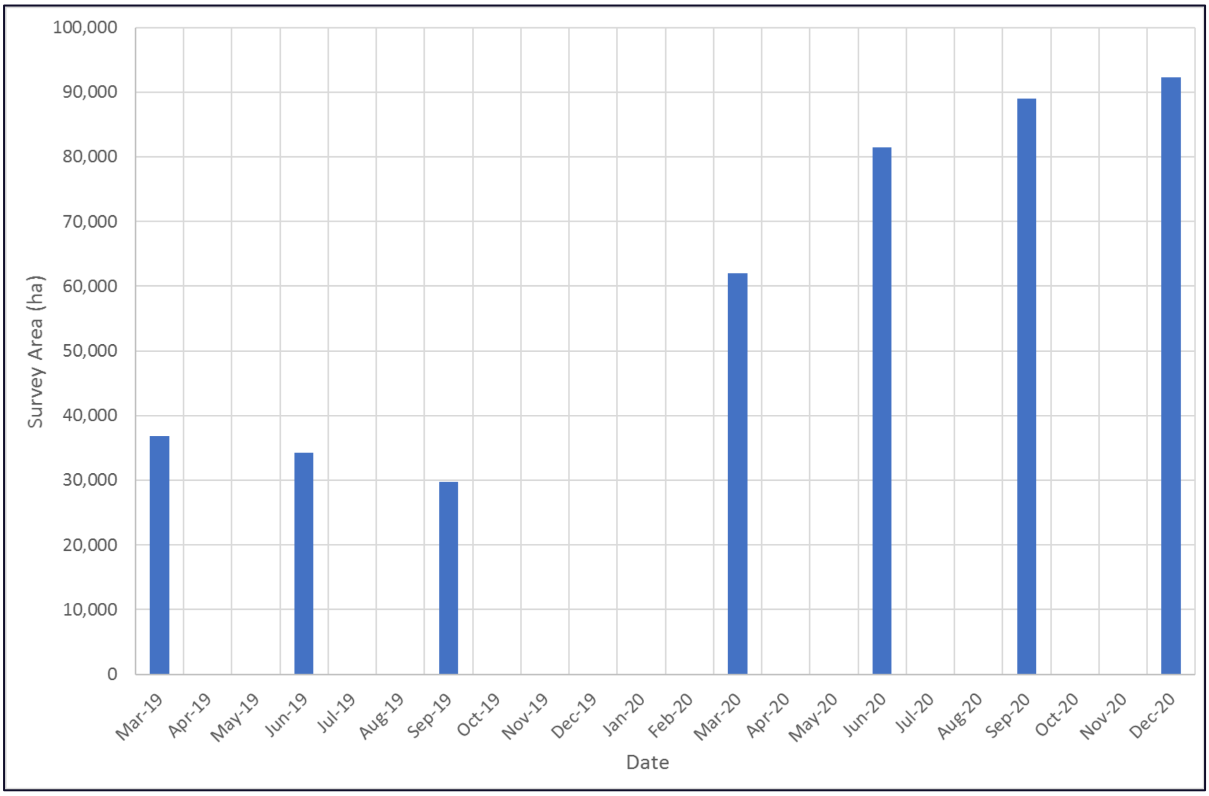


Figure 24 Survey coverage (ha) 2019 - 2020

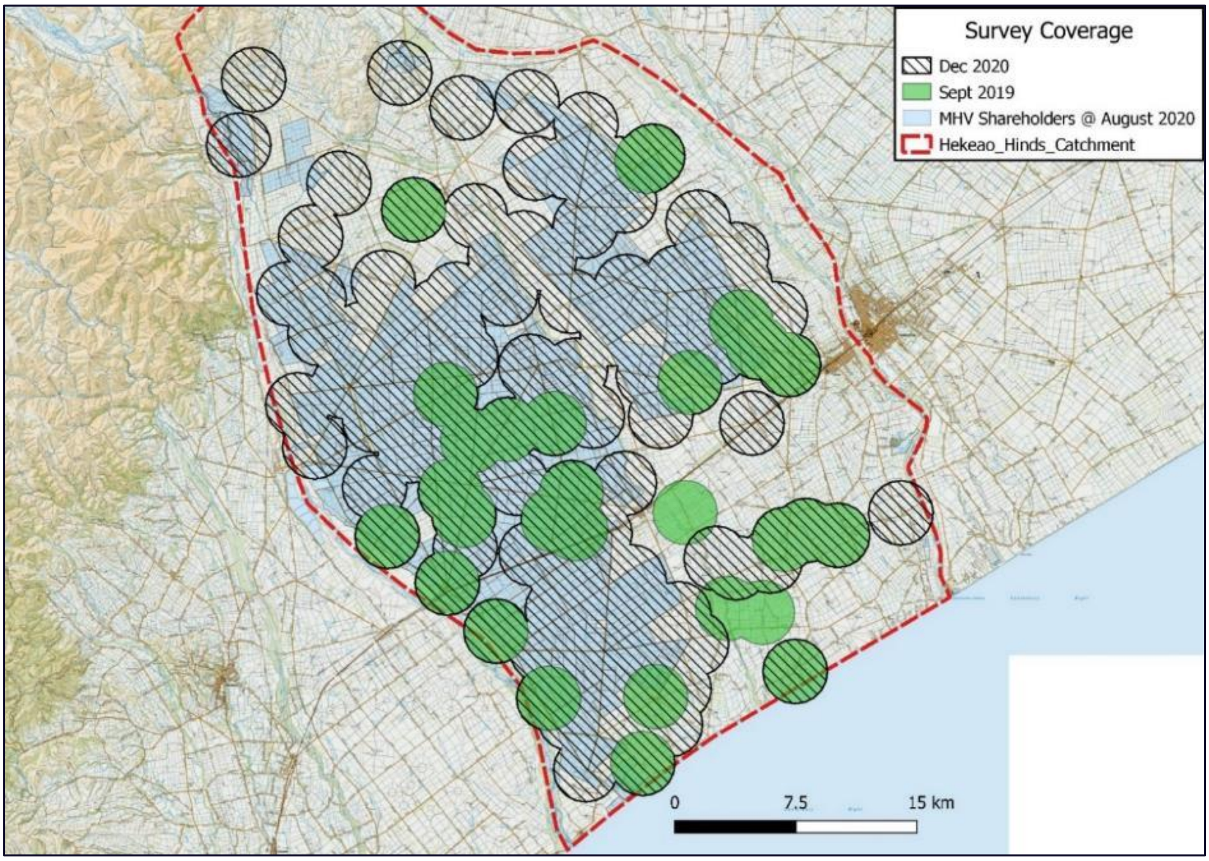


Figure 25 September 2019 compared to December 2020

3.5. Methodology

Samples were obtained using standard sampling protocols, described in the following sections.

3.5.1. Standing Water Level measurements

Standing Water Levels[15] (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 26.

Figure 26 Well head with alkathene conduit

3.5.2. 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 5.

.

[15] ***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 5 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 27)	None – but noted as tank sample

Figure 27 Example of a low flow tap next to milk filter in dairy shed

Based on these assumptions, as well as considerations such as ease of access, safety, practicality, and limiting disruption to on farm activities, Figure 28 presents a breakdown of the sample types collected.

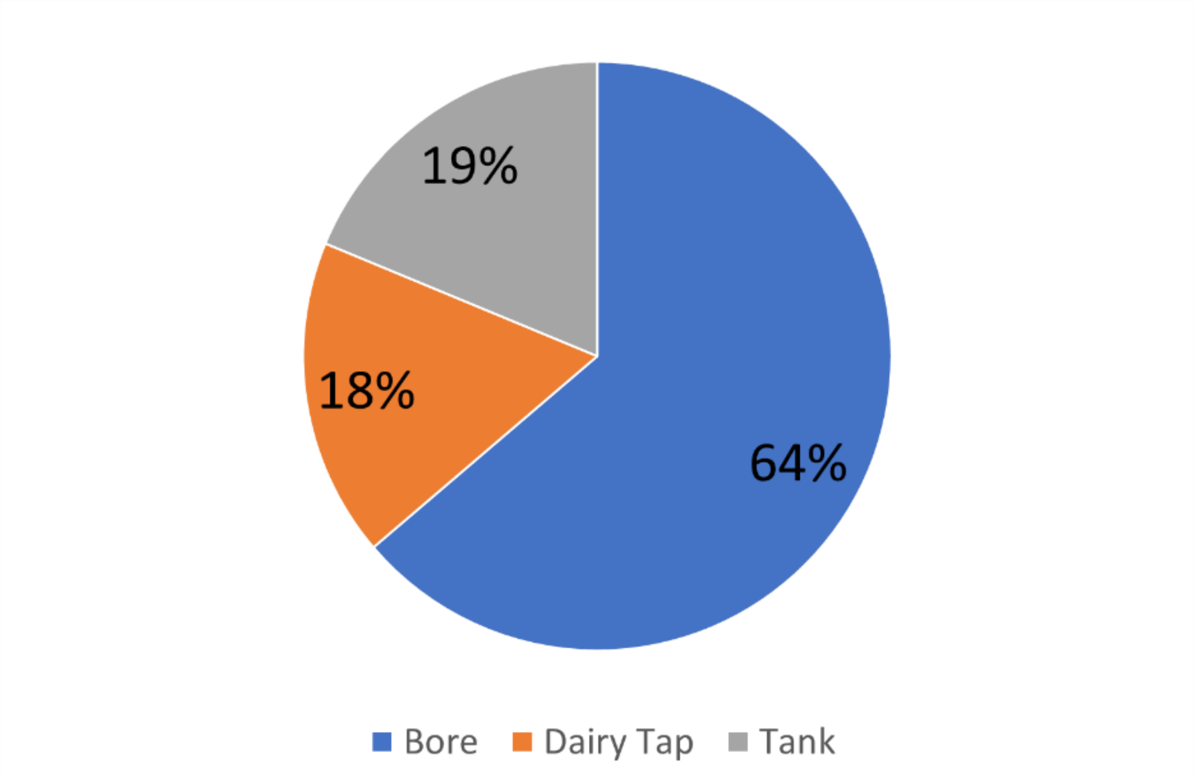


Figure 28 A breakdown of sample types collected during 2020

3.5.3. Water Quality and NO_3-N Measurements

Water quality measurements were obtained via a Hach HQ40d Multi/2 Channel portable water quality meter to measure Dissolved Oxygen (DO), pH, conductivity and water temperature. Unfortunately, the Hach unit was inoperable in December, so a YSI Plus ProPlus portable water quality meter was rented from Van Walt Ltd. No pH data was collected in December due to the pH probe failing in the YSI unit, with no immediate replacement available before Christmas.

All samples collected in 2020 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 40% 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:

confirm the validity of the HydroMetrics Nitrate GW50 Groundwater Optical Nitrate Sensor and quantify and characterise the difference in reported results from both analytical methods. It also enabled a simple cross-check of the results.

The results presented in Figure 29 indicate a correlation co-efficient (R^2) of 0.98, with a slight bias of +5% from the Hill Laboratory results. This provides confidence that the sensor results adequately measure NO_3-N, when compared to accredited laboratory results.

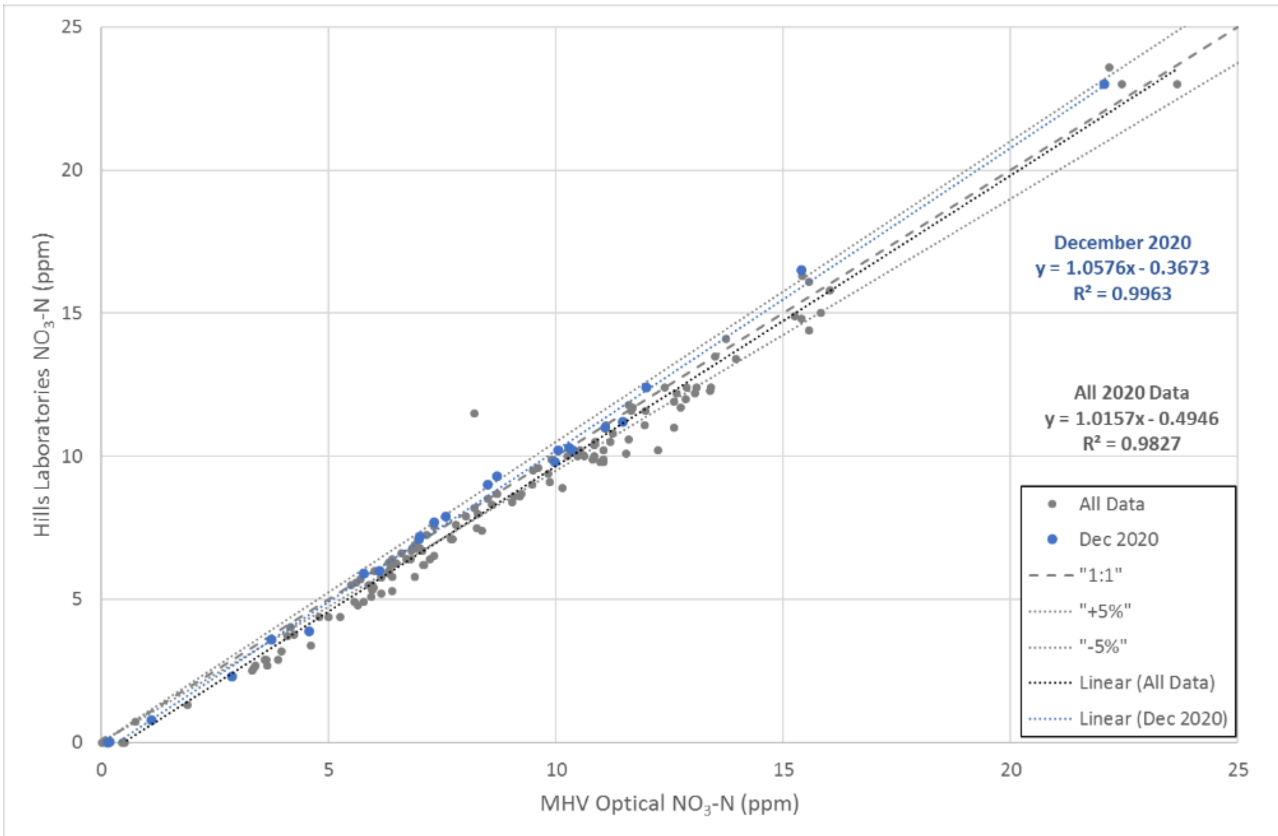


Figure 29 Scatter plot of inhouse NO_3-N results compared to Hills Laboratory Results

4. Surface water sampling program

4.1. Description of surface hydrology

The Hekeao/Hinds plains are characterised by a number of different watercourse types (Figure 30). These include:

- **Highly modified water courses (HMWC)** - often lowland streams / creeks that have been straighten or incorporated into larger extensive drainage and flood protection works (ECan, 2013; Meredith and Lessard, 2014);
- **Drains** - extensive drainage and flood protection works including channelization and man-made drains (ECan, 2013);
- **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; and,
- **Rivers** – i.e. the Hakatere/ Ashburton, Hekeao/ Hinds and Rangitata Rivers.

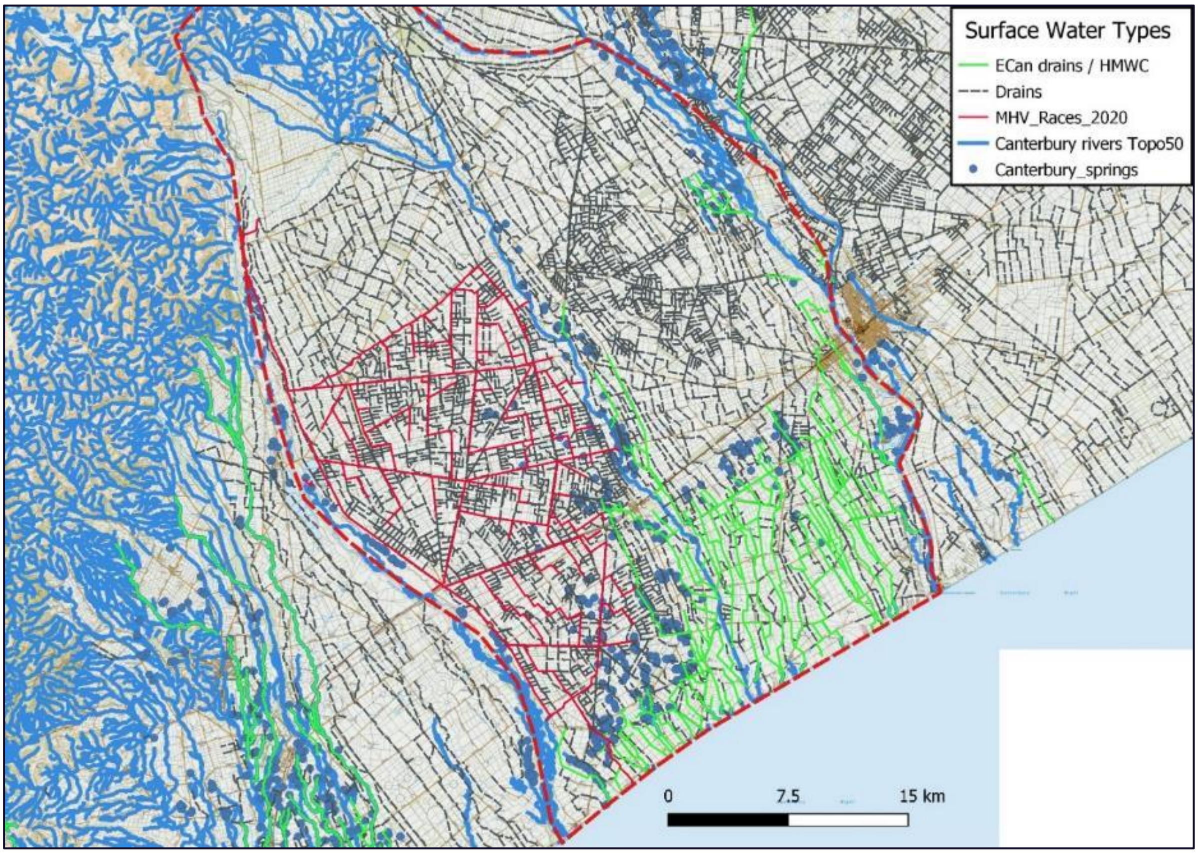


Figure 30 Map of differing surficial hydrological regimes

4.2. Surface-water Monitoring Program Development

Similar to the groundwater monitoring program, surface water monitoring has evolved over time with monitoring rounds ranging in size from less than 5 sites, to over 25, as shown in Figure 31.

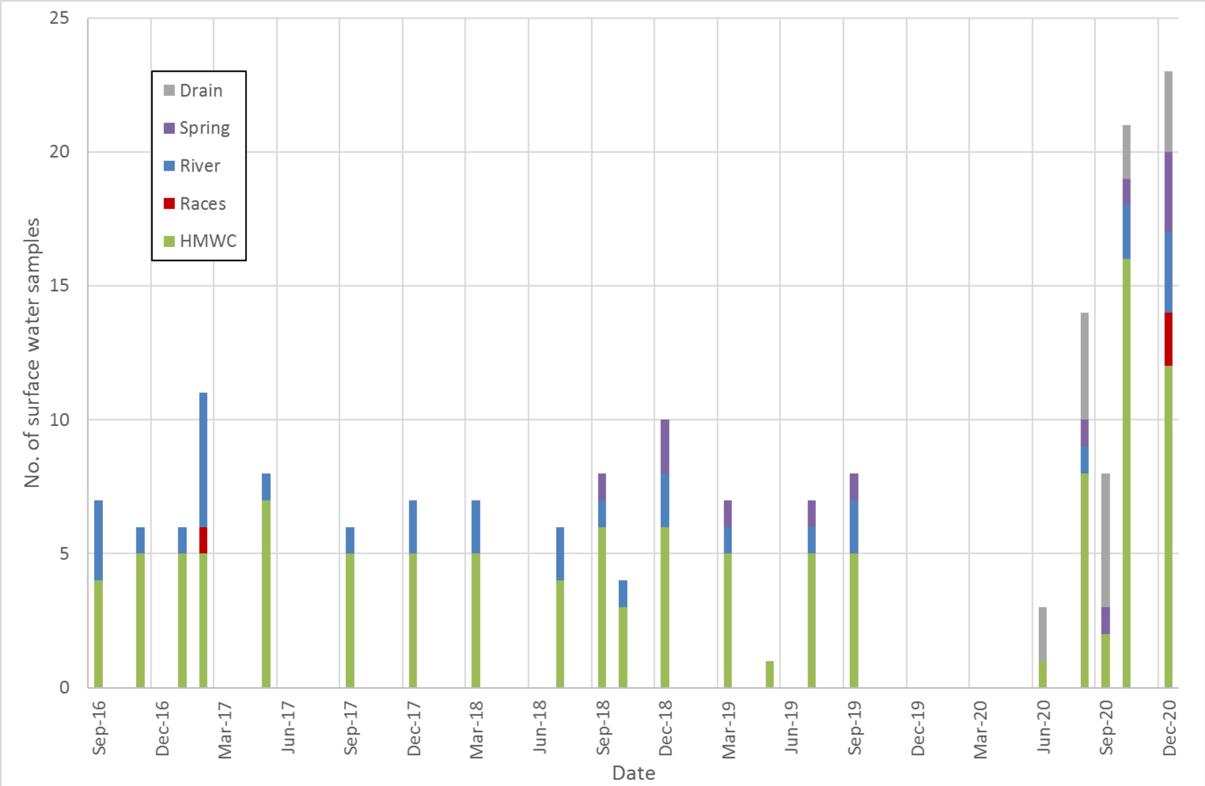


Figure 31 Frequency histogram characterising the development of the surface water monitoring program

During the year, 69 surface water samples were collected from 44 water locations (Table 6, Figure 32), the majority (90%) of which were collected from public road culverts or bridges.

Table 6 Breakdown of 2020 surface water samples

	Drain	HMWC	Race	River	Spring	Grand Total
Jun-20	2	1				3
Aug-20	4	8		1	1	14
Sep-20	5	2			1	8
Oct-20	2	16		2	1	21
Dec-20	3	12	2	3	3	23

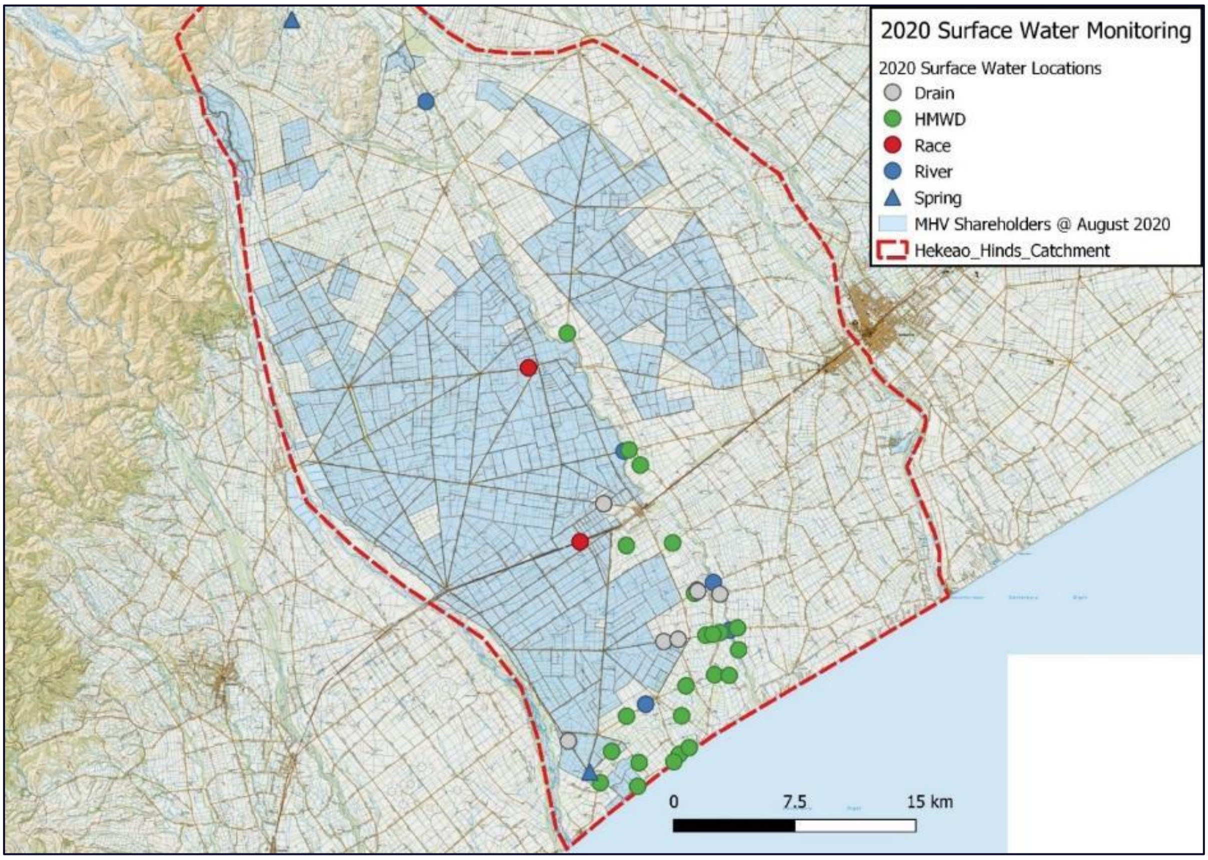


Figure 32 Sample locations accessed via public roads

5. Groundwater Results

5.1. Groundwater NO_3-N Results

336 NO_3-N samples were obtained from 126 bores during 2020. The results are summarised in Table 7 (see Appendix 5 for individual survey results). Overall, there is little difference between surveys, with the exception of the March survey. This is due to:

i. the lower number of samples collected in March; and,

ii. bores with potentially lower nitrates were not sampled due to the reduced sample size.

Table 7 Descriptive summary statistics for NO_3-N results from the 2020 surveys for all depths

Survey	No of Samples	Min	Max	Range	Mode	Median	Average	Std Dev	CV
Mar	56	3.39†	22.17	18.78	10.50	8.75	9.28	3.36	0.39
June	72	0.45	23.67	23.22	6.15	8.14	8.89	4.02	0.45
Sept	94	0.09	22.44	22.35	8.70	8.88	8.86	3.73	0.42
Dec	97	0.13	22.06	21.93	#N/A	8.04	8.17	3.49	0.43

† *The March survey omitted a <1 ppm result as it was assumed at the time to be a failed test. Subsequent readings have proven this not to be the case*

The average results for shallow (<30 m bores) and all bores (for the 2020 period) is presented in Table 8, with Figure 33 and Figure 34 presenting the 2020 results graphically. The data show that, whilst peak nitrate concentrations are present at shallower depths, elevated nitrates (of up to close to the drinking water standard of 11.3 mg/l) are present at all depths.

Table 8 Descriptive summary statistics for annualised NO_3-N results from bores sampled in 2020

	No. of Holes	No. of Samples	Min	Max	Range	Average	Median	Std Dev	CV[16]
All Bores	126	336	0.09	26.43	26.34	9.06	8.70	3.98	0.44
Bores < 30m	40	99	0.74	26.43	25.69	11.19	11.04	4.87	0.44

NB The highly elevated NO_3-N results presented in Table 8 are related to a known historic concentration in the Tinwald area (refer to Aitchison-Earl, 2019; Hanson and Abraham, 2013, and Hanson and Abraham, 2010).

[16] 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.

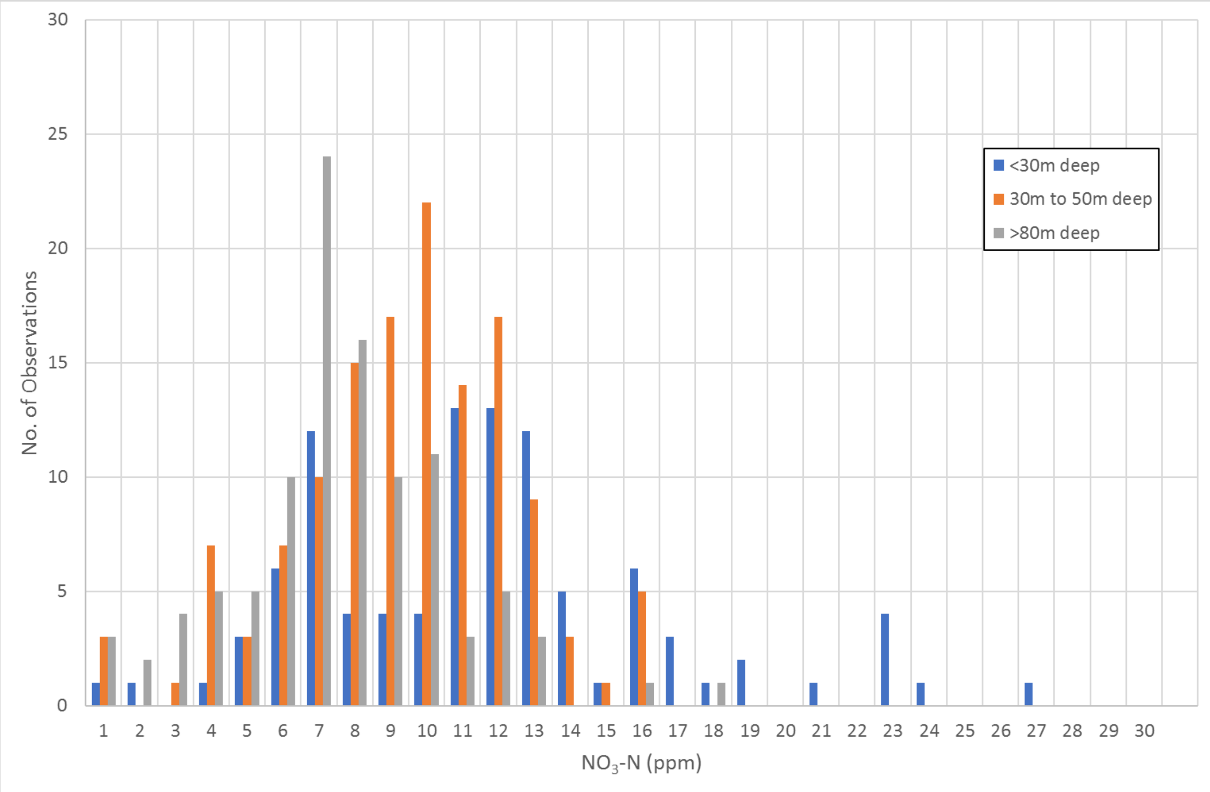


Figure 33 Frequency histogram of the average NO_3-N 2020 results by depth of bore tested

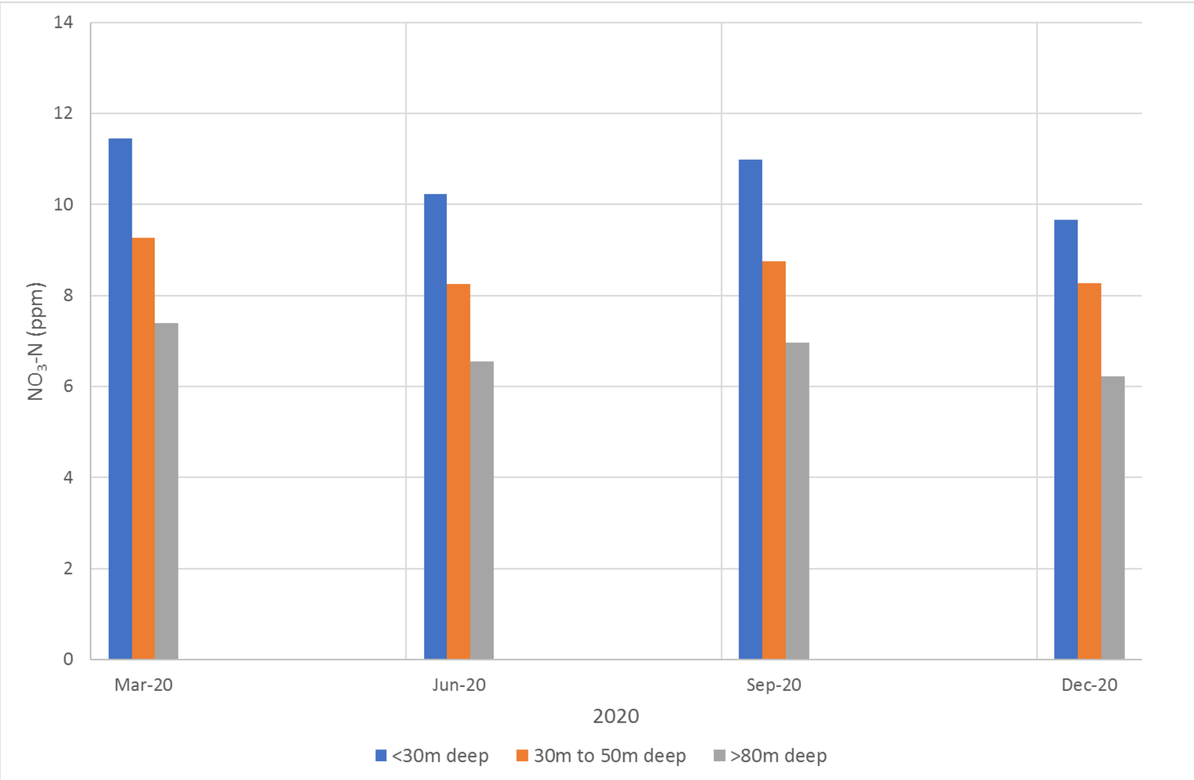


Figure 34 NO_3-N histogram of the average NO_3-N 2020 results by depth for each survey

Figure 35 indicates that no meaningful relationship between NO_3-N concentrations and depth can be discerned., although it is apparent that

- NO_3-N values above the MAV are observed to a depth of >100m; and,
- elevated NO_3-N (i.e. > 15 PPM) values are present to a depth of up 40m deep.

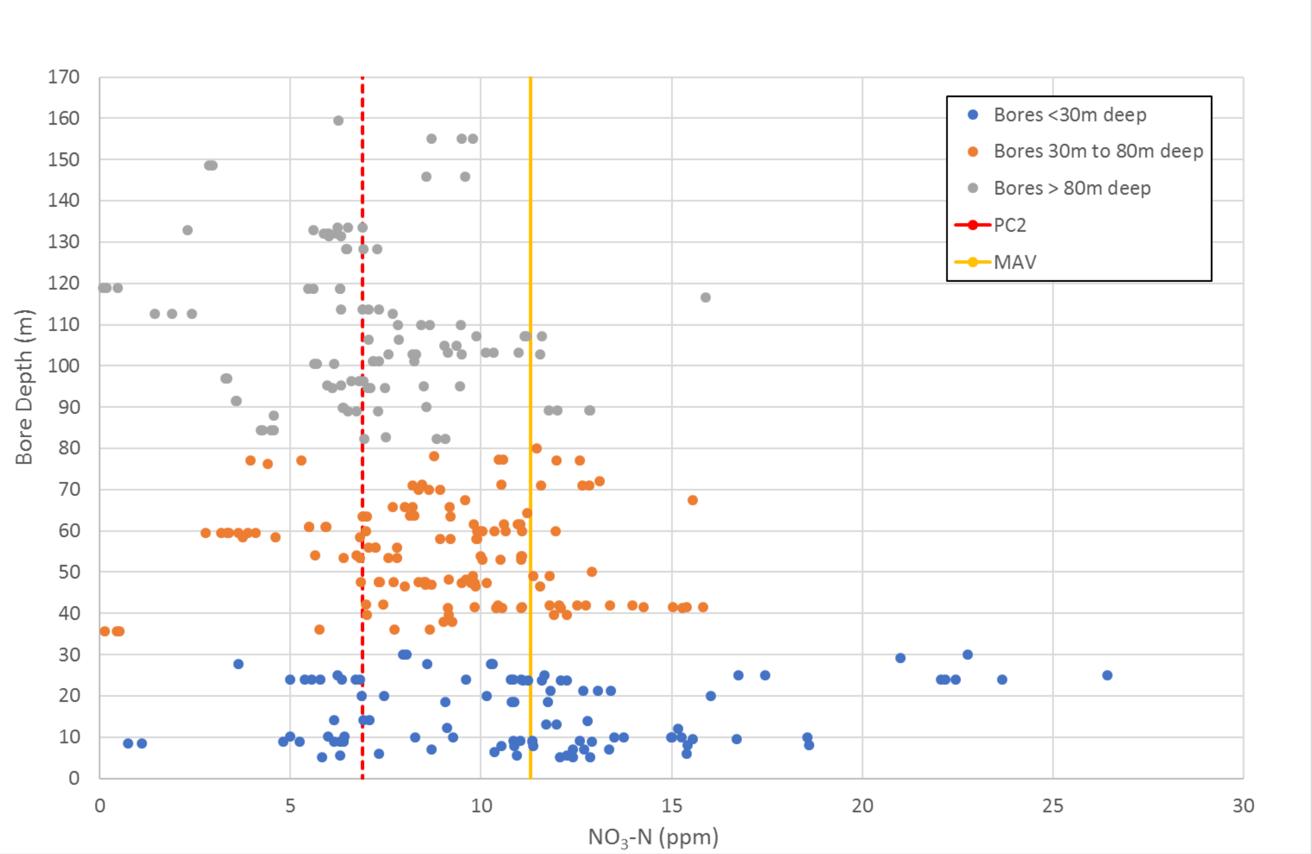


Figure 35 Scatter plot of NO_3-N and depths of bores tested

5.2.Groundwater DRP & DIN Orientation Survey Results

In September 2020, 72 bores were sampled for dissolved inorganic nitrogen (DIN) and dissolved reactive phosphorus (DRP), on a nominal 5km spacing, utilising bores that were already being tested as part of the NO_3-N monitoring program. This was done as an orientation survey in response to the 'Action for Healthy Waterways Package' that was being proposed by the Central Government.

The results are presented in Table 9, and graphically in Figure 36 to Figure 37 with the National Policy Statement for Freshwater Management 2020 (NPS-FM) DRP bands plotted for context. There are no groundwater standards for phosphorus, so we have classed the data by surface water quality thresholds. The NPS-FM bands indicate the levels, at which, ecological communities in surface waters may be affected by DRP (see Table 10), though it should be noted that other factors (including nitrate, light and temperature) affect such communities.

The results (Figure 8) indicate that the groundwater of the Hekeao-Hinds has a median value of 0.006 ppm (for both greater and less than 30 m bores) that would classify as Band A (no impact) and Band B (slightly impacted) as per the National Policy Statement for Freshwater Management 2020; with localised examples of Band C (moderate impact) (Table 10).

Phosphorous can occur naturally or can be leached from the land surface. Soil characteristics will influence the fate of phosphorus applied to the land, and stony and sandy soils with a low content of clay, carbonate or aluminium- and iron oxide minerals (material that helps to bind phosphorus), are prone to leaching. It has also been found that phosphorous mobility is increased in oxic conditions.

The fact that groundwater can contain concentrations of phosphorous that would be considered to be enriched, even at depths greater than 100m, challenges some previously-held views that phosphorus concentrations are too low to be an issue in groundwater: in some circumstances, there is obviously the potential for phosphorous to be transported to depth, and likely laterally through the groundwater system as well.

Table 9 September DRP and DIN Results for all bores tested

Variable	Min	Max	Range	Mode	Median	Average	Std Dev	CV
NH_3-N	0.01	0.08	0.07	0.01	0.01	0.01	0.01	0.72
DRP	0.004	0.018	0.014	0.004	0.006	0.007	0.003	0.459
DIN	0.02	23.00	22.98	12.40	8.70	8.72	4.10	0.47

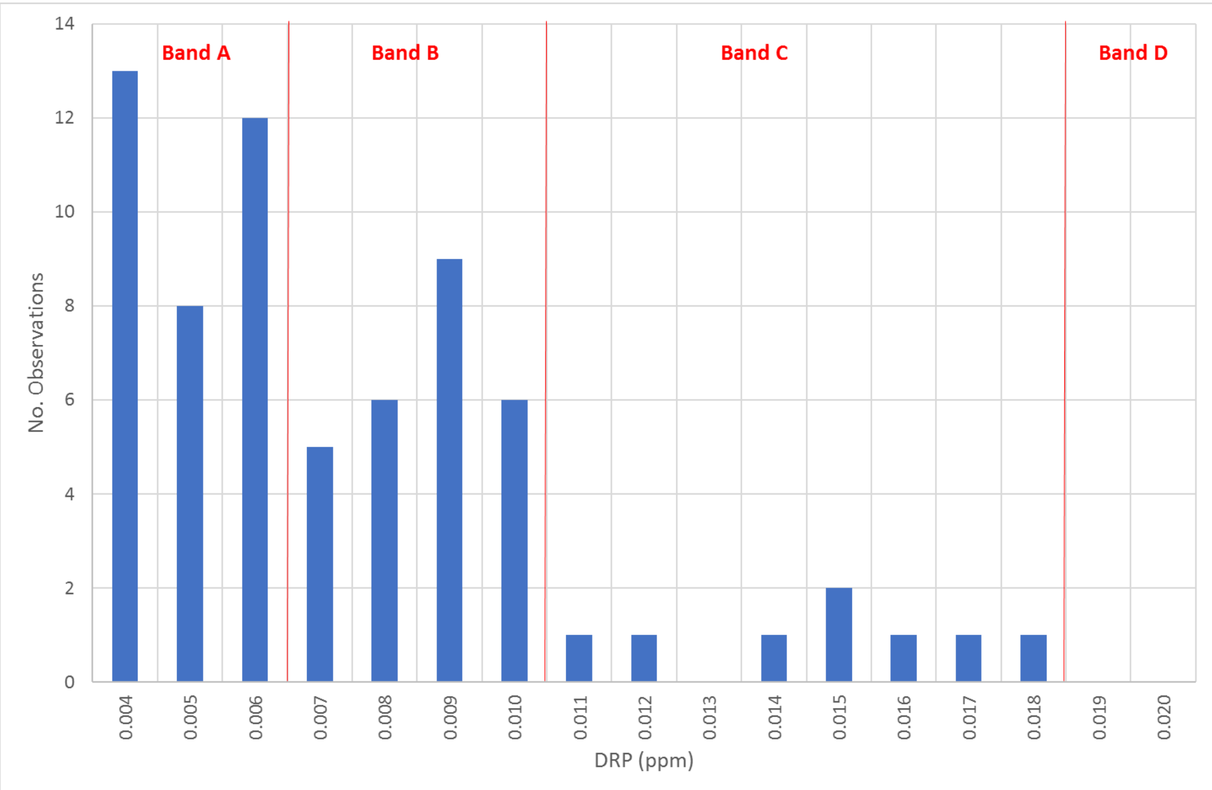


Figure 36 Frequency histogram of the DRP results with DRP Bands as per the NPS-FM 2020

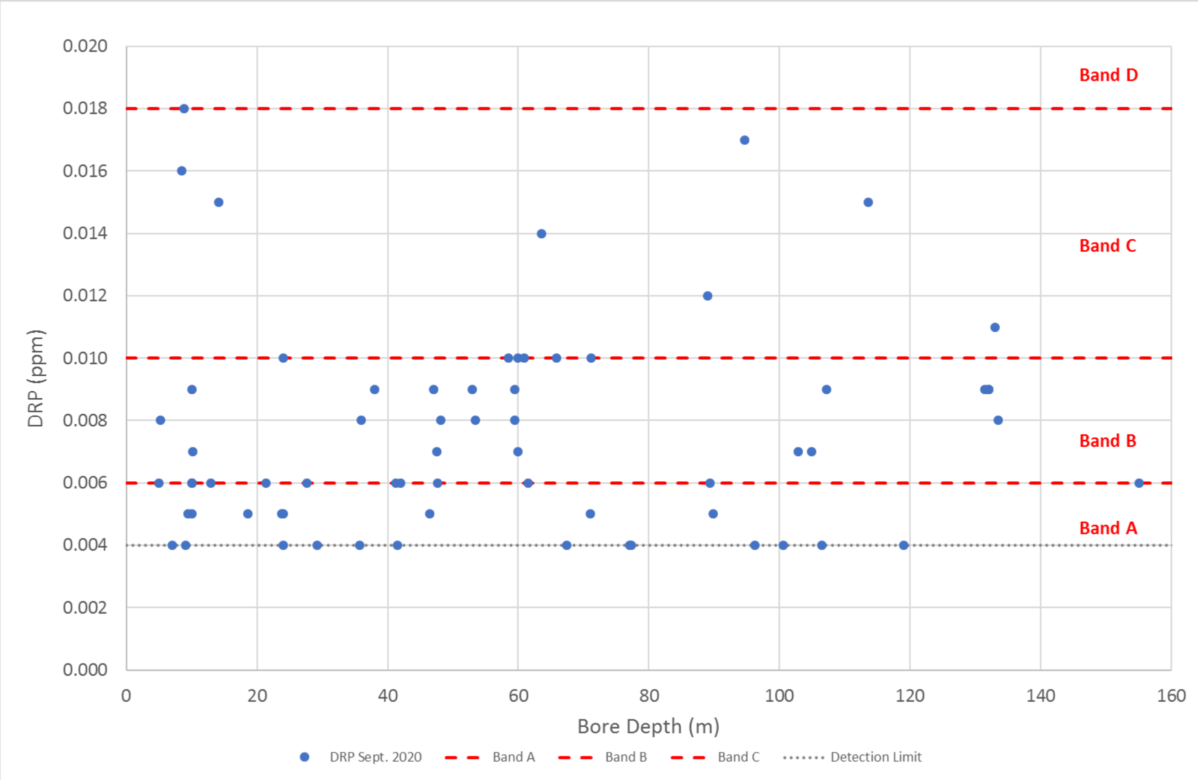


Figure 37 DRP with respect to depth with DRP Bands as per the NPS-FM 2020

Table 10 DRP Bands as per the NPS-FM 2020 – (Table 20)

Value (and component)	Ecosystem health (Water quality)	
Freshwater body type	Rivers	
Attribute unit	DRP mg/L (milligrams per litre)	
Attribute band and description	**Numeric attribute state**	
	Median	95th percentile
A Ecological communities and ecosystem processes are similar to those of natural reference conditions. No adverse effects attributable to dissolved reactive phosphorus (DRP) enrichment are expected.	≤ 0.006	≤ 0.021
B Ecological communities are slightly impacted by minor DRP elevation above natural reference conditions. If other conditions also favour eutrophication, sensitive ecosystems may experience additional algal and plant growth, loss of sensitive macroinvertebrate taxa, and higher respiration and decay rates.	> 0.006 and ≤0.010	> 0.021 and ≤0.030
C Ecological communities are impacted by moderate DRP elevation above natural reference conditions. If other conditions also favour eutrophication, DRP enrichment may cause increased algal and plant growth, loss of sensitive macro-invertebrate and fish taxa, and high rates of respiration and decay.	> 0.010 and ≤ 0.018	> 0.030 and ≤ 0.054
D Ecological communities impacted by substantial DRP elevation above natural reference conditions. In combination with other conditions favouring eutrophication, DRP enrichment drives excessive primary production and significant changes in macroinvertebrate and fish communities, as taxa sensitive to hypoxia are lost.	>0.018	>0.054
Numeric attribute state must be derived from the median of monthly monitoring over 5 years.		

5.3.Groundwater Levels

Groundwater levels[17] are generally at their highest in the winter months in response to Autumn rainfall (April – May) and the irrigation season hiatus between May and September.

Whilst groundwater levels respond to rainfall almost immediately (i.e. < 1 month), the degree of the response is a function of location within the catchment and corresponding hydrological gradient. Figure 38 presents groundwater data from three shallow ECan monitoring bores across the Hekeao/ Hinds plains with average monthly rainfall:

K37/0215 – located near Westerfield has the most pronounced response;

K37/24556 – located near Hinds, has a medium response; whilst,

K37/1571 – located between Coldstream and Lowcliffe has the lowest response

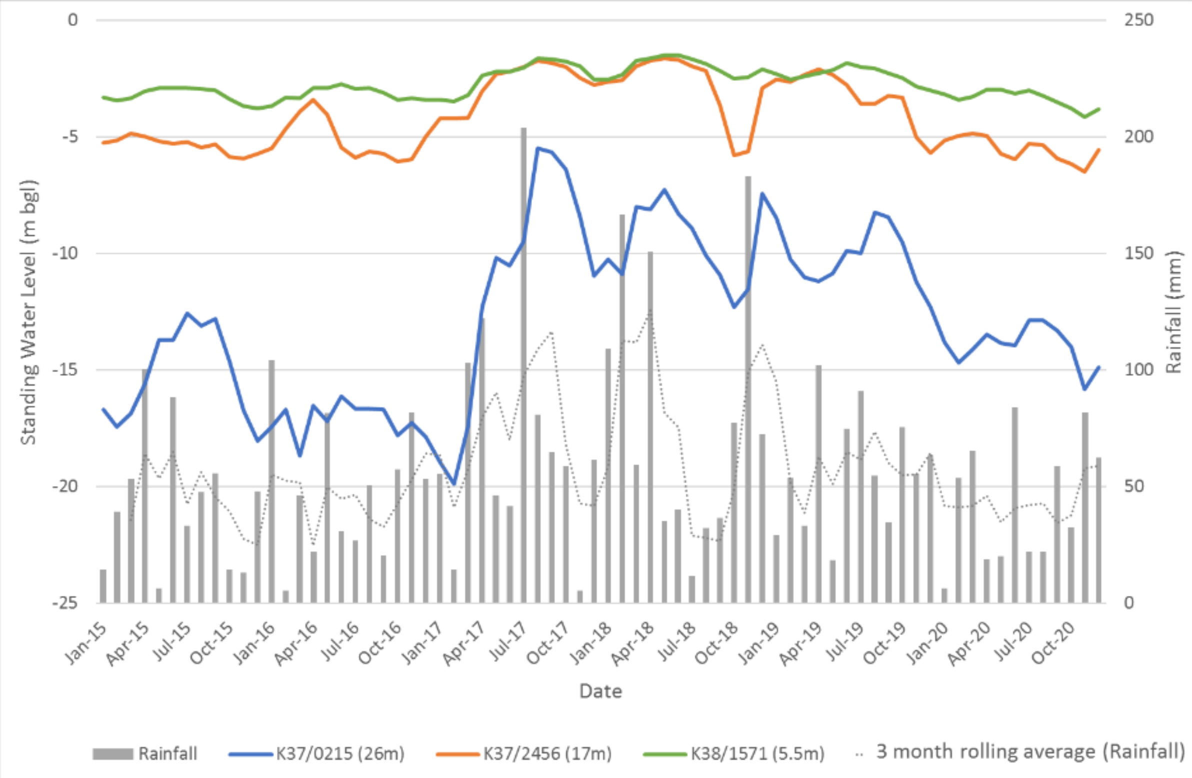


Figure 38 Hydrographs from 3 ECan bores across the Hekeao Hinds Plains with rainfall 2015 to 2020.

The ECan data also indicates a gradual decline in groundwater levels since mid-2018.

119 groundwater level observations were obtained from 76 bores during the year. These were obtained at times when there was no pumping and represent a standing water level. The reasons for taking groundwater levels is to understand groundwater conditions at the time of water quality sampling as well as to provide additional data regarding groundwater level conditions across Hekeao/ Hinds.

The limited number of levels collected were due to one of three main reasons:

[17] Standing water level is the ambient water level of an active bore that is not being pumped at the time of the observation.
Static water level is the ambient water level of an abandoned bore that has not been pumped for a considerable period of time.

- The bore not possessing an alkathene conduit for water measurements;
- Bore not possessing an observation bung; and/or,
- The observation bung rusted or welded shut.

Table 11 Summary descriptive statistics of groundwater levels for 2020

SWL (m bgl)	Min	Max	Range	Arithmetic Mean	Standard Deviation	CV
March 2020	1.41	65.78	64.37	12.38	3.36	1.30
June 2020	1.09	61.09	60.00	16.29	13.29	0.82
Sept 2020	2.68	75.00	72.32	23.15	19.85	0.82
Dec 2020	1.9	59.24	57.34	18.46	15.58	0.84
Average 2020	1.09	75.00	73.91	18.18	16.46	0.91

There was an appreciable drop between the June and September results (i.e. the non-irrigation period) that indicated that there has been a reduction in groundwater levels across the catchment.

An alternative comparison methodology via a Q-Q plot[18] was also undertaken which indicated that water levels dropped by > 25% (Figure 39) between the two surveys.

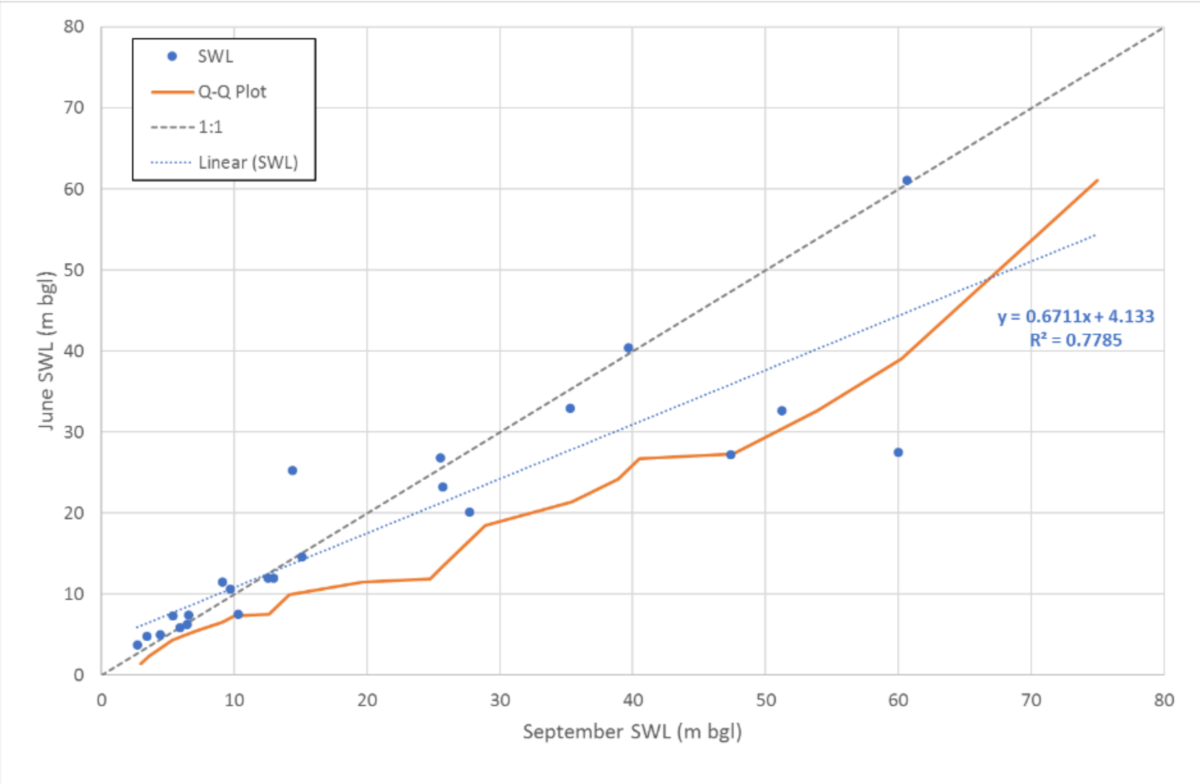


Figure 39 Direct comparison and Q-Q plot for SWL for June and September

[18] A graph of the percentiles from each dataset are plotted against each other, whereby if this plot forms a straight 1:1 line, then the datasets have the same distribution

6. Surface water results

6.1. Surface Water Survey

During the year, 69 surface water samples were collected from 44 water locations (Table 6) – a majority (90%) of which were collected from public road culverts or bridges (Figure 32).

Table 12 to Table 14 present the water quality results for all results, HMWC's and drains.

Table 12 Descriptive statistics for all surface water results 2020

	Total Suspended Solids	Total Ammoniacal Nitrogen	NO_2-N	NO_3-N	NO_2 + NO_3	Dissolved Reactive Phosphorus	Dissolved Inorganic Nitrogen	E.coli
Min	3	0.010	0.001	0.001	0.001	0.004	0.001	1
Max	62	0.087	0.06	15.10	15.10	0.035	15.10	2420
Range	59	0.077	0.06	15.10	15.10	0.031	15.10	2419
Average	7	0.013	0.01	6.22	6.18	0.007	6.32	488
Median	3	0.010	0.00	6.80	6.60	0.004	6.85	178
Std Dev	11	0.011	0.01	4.76	4.82	0.006	4.77	750
CV	1.48	0.858	1.48	0.76	0.78	0.891	0.75	2

Table 13 Annualised descriptive statistics for Highly Modified Water Courses for 2020

	Total Suspended Solids	Total Ammoniacal Nitrogen	NO_2-N	NO_3-N	NO_2 + NO_3	Dissolved Reactive Phosphorus	Dissolved Inorganic Nitrogen	E. coli
Min	3	0.01	0.001	0.001	0.001	0.004	1	0.01
Max	62	0.09	0.06	15.10	15.10	0.025	2420	15.10
Range	59	0.08	0.06	15.10	15.10	0.021	2419	15.09
Average	7	0.01	0.01	8.36	8.36	0.006	570	8.40
Median	3.0	0.01	0.01	9.70	9.70	0.004	278	9.80
Std Dev	11.8	0.01	0.01	4.07	4.13	0.004	801	4.08
CV	3.9	1.32	1.80	0.42	0.43	1.004	2.9	0.42

Table 14 Annualised descriptive statistics for drains for 2020

	Total Suspended Solids	Total Ammoniacal Nitrogen	NO_2-N	NO_3-N	NO_2 + NO_3	Dissolved Reactive Phosphorus	Dissolved Inorganic Nitrogen	E. coli
Min	3	0.01	0.002	0.002	0.002	0.004	1	0.01
Max	35	0.06	0.02	12.70	12.70	0.019	2420	13.00
Range	32	0.05	0.01	12.70	12.70	0.015	2419	12.99
Average	11	0.01	0.00	3.25	3.00	0.007	556	3.46
Median	6.0	0.01	0.00	0.04	0.03	0.004	166.0	0.05
Std Dev	11.7	0.01	0.00	4.58	4.63	0.005	842.1	4.67
CV	1.9	1.13	1.78	125.43	165.21	1.138	5.1	95.30

7. Discussion

> *"…graphs are not always what they seem. There may be more in them than meets the eye, and there may be a good deal less."*
>
> *(Huff, 1954)*

The results of the 2020 ground and surface water monitoring suggest a > 10% reduction in NO_3-N in both surface and groundwaters across the Hekeao Hinds Plains.

This result is likely to be the confluence of several factors such:

a) Increased awareness of Good Management Practices (GMPs) that include adoption of improved on farm practices such as:
   - integrated soil moisture monitoring irrigation schedules and scheduling;
   - changes to the timing and rate of fertiliser and water application.

b) Regular FEP audits and ongoing education initiatives such as 'shed talks';

c) Reduced rainfall and river flows (refer to section 2.1) during 2020; as well as,

d) The influence of the Managed Aquifer Recharge program

Whilst this is undoubtably a positive outcome, the results presented here should be treated with caution for the following reasons:

1. The information and data presented here is a compilation and amalgamation of results collected throughout 2020. Hence, this report presents a snapshot in time of a larger system that is dynamic and responsive to drivers such as recharge.
2. The Canterbury's Land and Water Regional Plan (LWRP) uses *annualised statistics* of water quality to track progress towards Plan Change 2 target of 6.9 ppm NO_3-N in 'Spring-fed Plains' surface waterbodies of the Lower Hekeao Hinds Plains by 2035. Hence seasonal variations may not be accurately represented under this requirement.
3. Land surface recharge (rainfall / irrigation) is the primary driver of seasonal NO_3-N concentration changes, with land use change also showing up in the longer term. Whilst land use practices, irrigation rates, stocking rates etc. also contribute to the narrative, they have not been considered as part of this survey.
4. As noted in section 3.1, and section 4.2, both the ground and surface water monitoring surveys have developed over time, with the ground water sample population increasing from 56 to 97 during 2020 alone. Whilst the CV of the NO_3-N data from each survey has remained reasonably consistent throughout (0.39 – 0.45), there is the potential for bias to be introduced into the results due to different bores being sampled each survey.
5. NO_3-N mobility is governed by two factors interconnected drivers depending on the hydrological conditions:
   i. In the vadose zone, NO_3 migration is dominated by electrostatic interactions between negatively charged NO_3 anions and charged soil particle surfaces in the lower parts of the soil profile, whereby NO_3 ions are attracted to positively charged soil surface particles (Allred et al., 2007; Kadyampakeni et al., 2018; Wang et al., 2015).

ii. If the soil profile becomes saturated, the polarity of both NO_3-N and NO_2-N makes it water soluble thus enabling it to leach out of the soil profile and migrate to the saturated zone (Padilla et al., 2018, 1999).

These processes are further influenced at a local scale by factors such as soil and regolith composition, pH, REDOX State, and hydrological conductivity – none of which have been examined in detail.

In this case, the observed reduction in NO_3-N could be ascribed to a relatively dry year, with particularly low rainfall in late autumn/early winter (on average only 40mm in April and May), when nutrient losses tend to be worst. The low winter rainfall has resulted in a lack of both

i. groundwater recharge resulting in lower water tables (as discussed in section 5.3); and,

ii. an increased the potential for NO_3-N to be bound in the soil profile due to electrostatic interactions described previously – thus reducing the likelihood of NO_3-N migration into groundwater via leeching.

6. Land use practices, irrigation rates, stocking rates etc. also contribute to the narrative, but have not been considered at this time.
7. Hydrological factors such as variations in soils, sedimentary facies, aquifer properties (including hydraulic conductivity) and recharge were acknowledged, but not incorporated in understanding the temporal and spatial distribution of the results of sampling. This also includes the.

   Preferential drainage - via paleo-channels (refer to section 2.3.2)

   sedimentary facies – the physical, chemical, and biological aspects of a sedimentary bed and the lateral change within sequences of beds of the same geologic age;

   conductivity - measure of how easily water can pass through a material;

   transmissivity – measure of how easily water can pass through cross-sectional area based on its conductivity;

   recharge - the primary method through which water enters an aquifer, usually via rainfall or 'leaky' rivers - were acknowledged, but not actively as part of the analysis.

7.1.Groundwater Results

The results of the 2020 surveys indicate that NO_3-N concentrations in groundwater across the Hekeao/ Hinds catchment varied by over 10% (Table 15).

Table 15 Variations in groundwater NO_3-N concentrations for the Hekeao Hinds Plains

	March 2020	December 2020	Change
Average NO_3-N - All Depths	9.28	8.17	12%
Average NO_3-N – Bores < 30m deep	12.90	9.49	26%
Median NO_3-N – Bores < 30m deep	11.24	9.17	18%

The longer-term quarterly monitoring data are presented in Figure 40 to Figure 42.

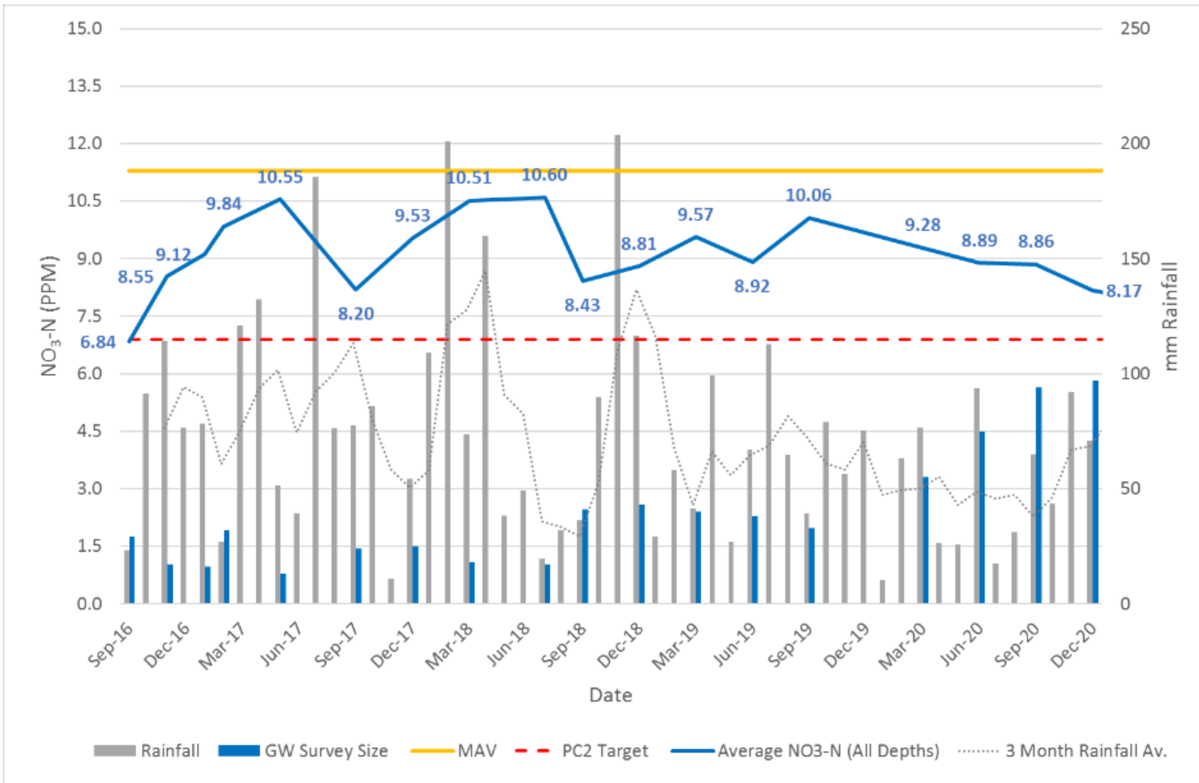


Figure 40 Arithmetic mean NO_3-N results over time irrespective of bore depth

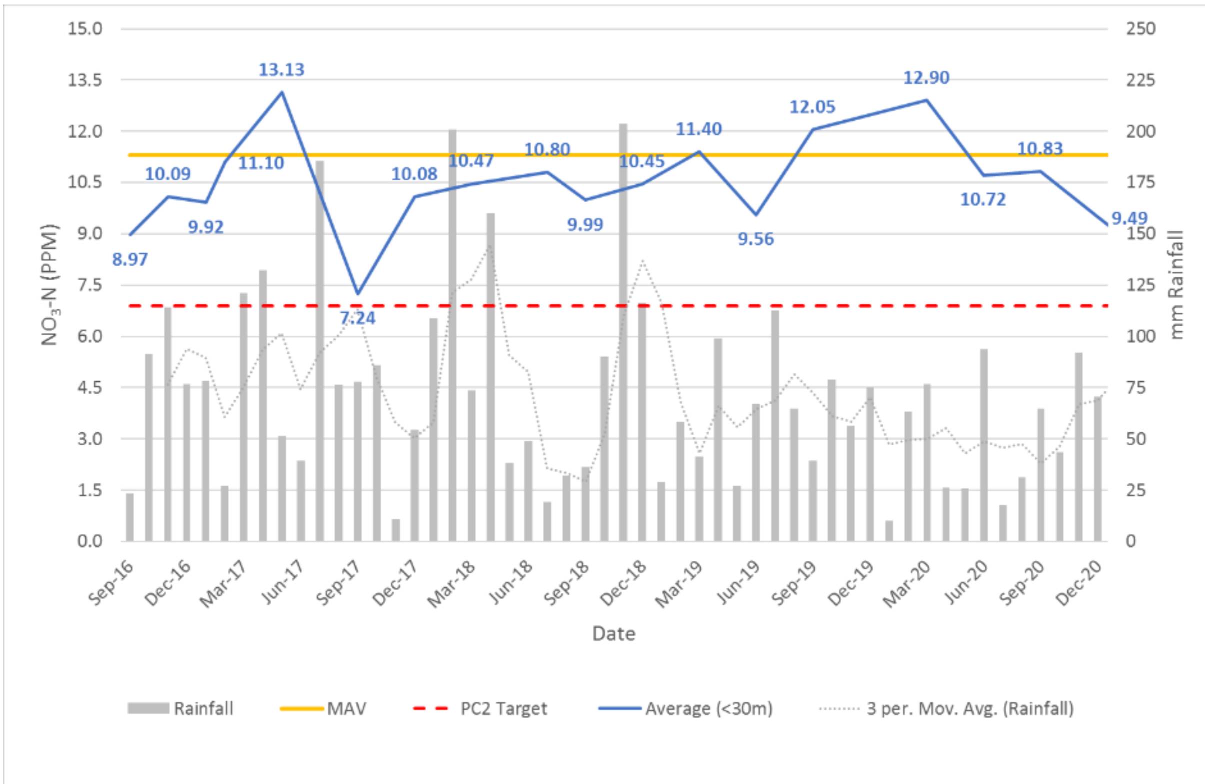


Figure 41 Arithmetic mean NO_3-N results over time for bores <30 m deep

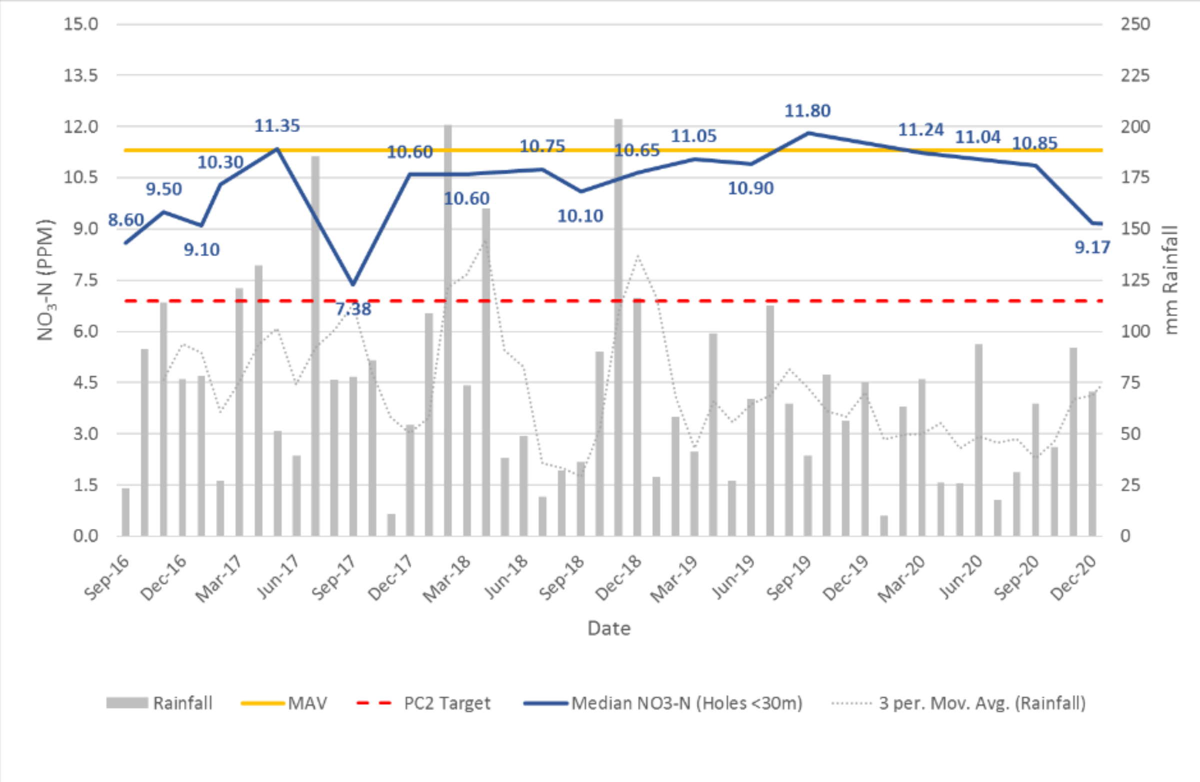


Figure 42 Median NO_3-N results over time for bores <30 m deep

7.2.Surface Water Results

The NO_3-N results for the highly modified water courses (aka Hill-fed and Spring-fed Plain's surface waters) dropped by 30% in the period between June and December 2020 (Table 15), again possibly being driven by the low rainfall in 2020.

The longer-term trends quarterly monitoring data is presented in Figure 43 and Figure 44.

Table 16 Changes in HMWC's NO_3-N concentrations for the Hekeao Hinds Plains

	June 2020	December 2020	Change
Average NO_3-N	10.30	7.14	31%
Median NO_3-N	12.35	8.30	33%

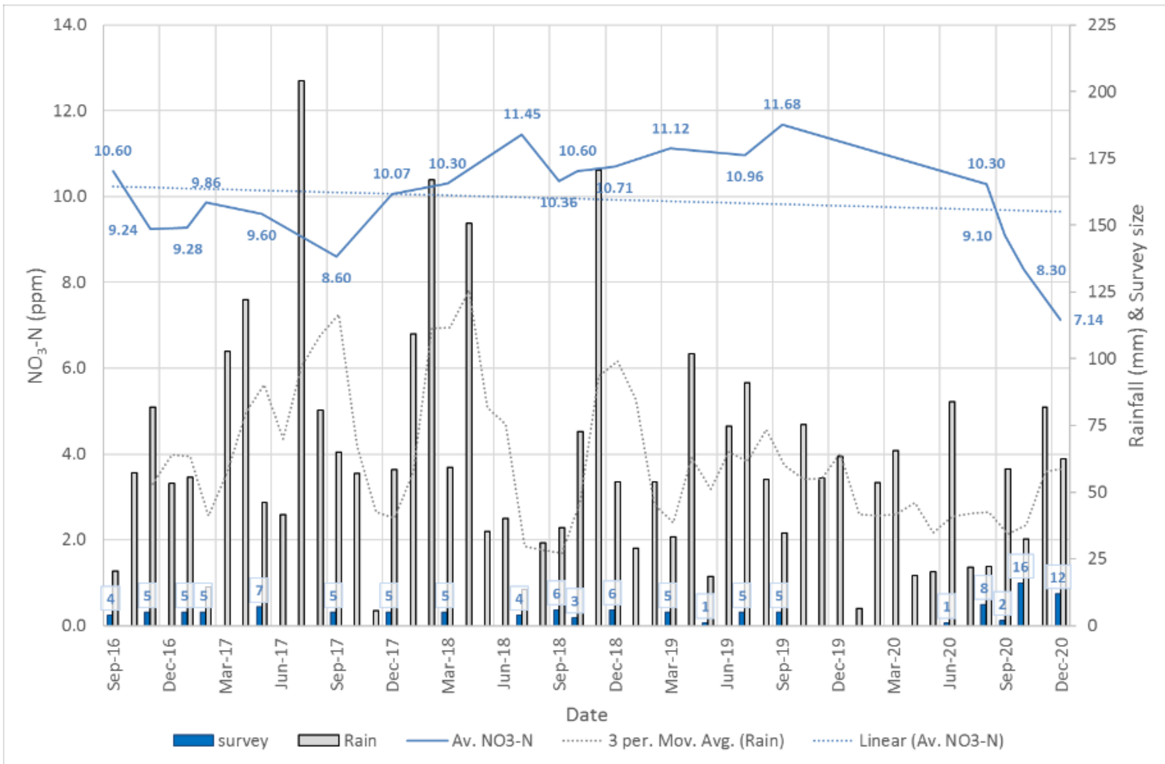


Figure 43 Arithmetic Average of NO_3-N for HMWC's

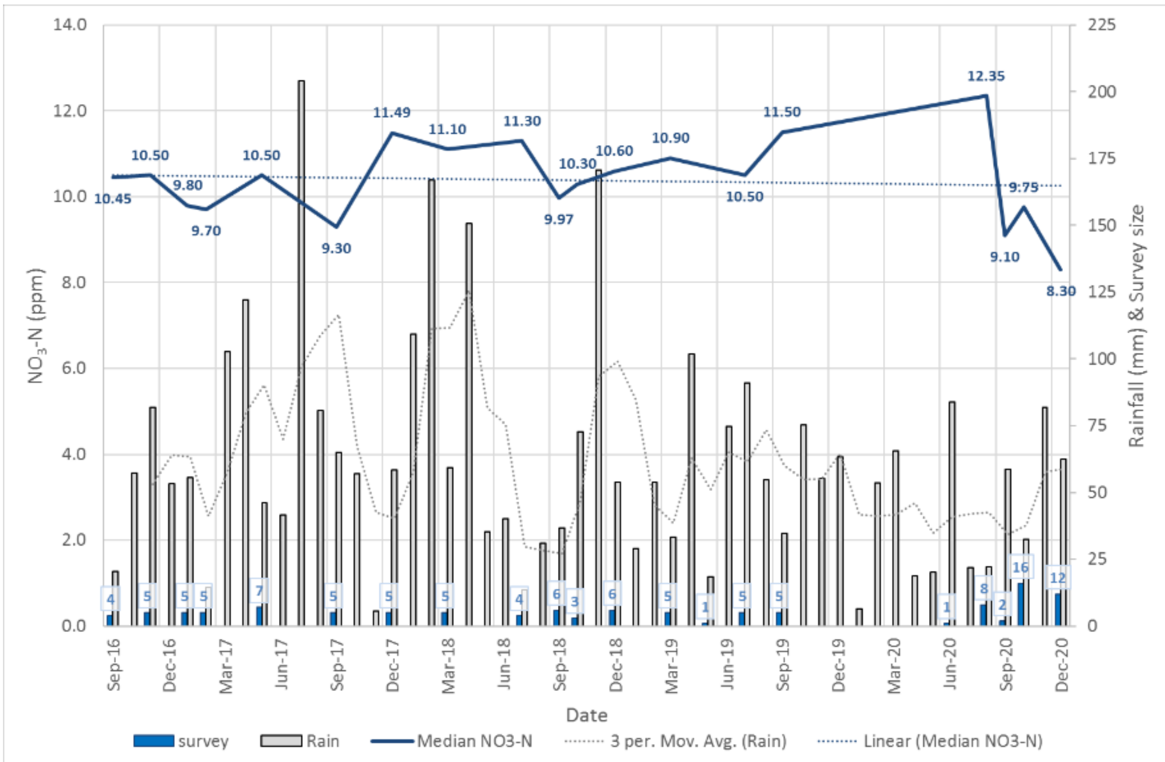


Figure 44 Median of NO_3-N for HMWC's

7.3.Soil type relationship to NO_3-N

As noted previously, the NO_3-N migration is dominated by;

i. electrostatic interactions between negatively charged NO_3 anions and charged soil particle surfaces the soil profiles; and,

ii. the migration of leachate that can transport NO_3-N to the groundwater.

It is prudent to consider the Profile available water (PAW) of the soils in the Hekeao/ Hinds in analysis.

PAW is defined as

> *"The amount of water potentially available to plant growth that can be stored in the soil to 100 cm depth. PAW takes into account variations in soil horizons and is expressed in units of millimetres of water, i.e., in the same way as rainfall.*
>
> *A PAW of 100 mm implies that 10% of the soil volume is water available to plants. Low PAW is <60 mm, moderate is between 60 and 150 mm, and high is ≥150 mm."* (Landcare Research, 2020).

There are 66 different soil types mapped in the Hekeao/ Hinds plains with PAW values ranging between 0 and 268 (Appendix 6). Of the 66 possible soil types that may have a water bore on the Hekeao Hinds plains, 16 possessed bores that were tested for NO_3-N. (Figure 45)

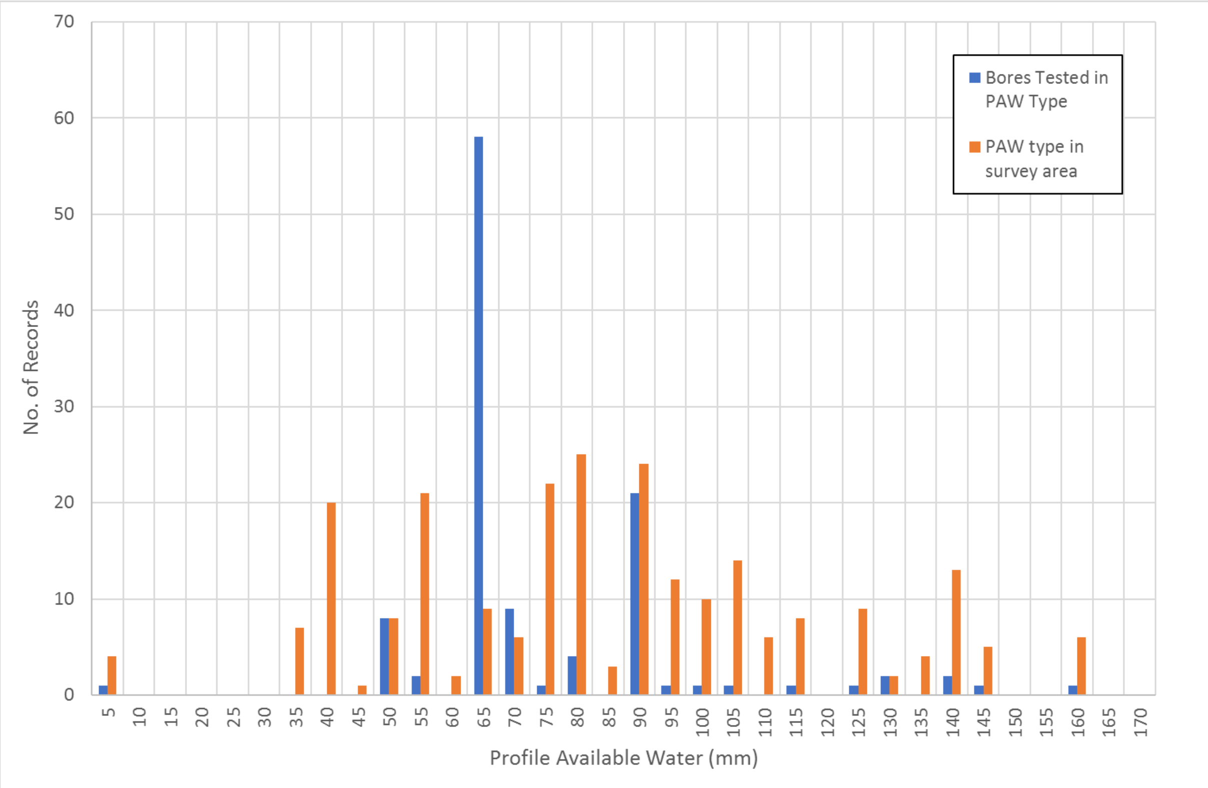


Figure 45 Frequency histogram of soil types by PAW in the Hekeao / Hinds Plains†

† Figure 45 excludes 4 classes with PAW >200 mm

From the frequency distribution, a majority of water samples were obtained from soils with a PAW of around 65 mm, that is, in the low to moderate range, and would be expected to be relatively free draining.

It is important to realise that the soil maps generated by Maanaaki Whenua - Landcare Research are based on 1:50,000 topographic data sets: hence inaccuracies and variations at farm scale are expected.

Subsequently Maanaaki Whenua - Landcare Research have provided the following limitation statement:

"Accuracy of information within a map unit is dependent on the amount of site data available for any map unit. While all reasonable skill and care have been exercised in the collection and preparation of this data, the Data Providers can give no warranty that the data supplied are free from errors, omissions or other inaccuracies."[19]

As part of the June survey, a reconciliation of nitrate-N and DRP concentrations with soil types was undertaken. The following is an extract from the June survey report:

A scatter plot of the NO_3-N and DRP results compared to the PAW (Figure 46) values suggests:

- *NO_3-N > 11.3 ppm are associated with PAW Soils < 88; and*
- *There does not appear to be a discernible relationship between DRP and soil PAW.*

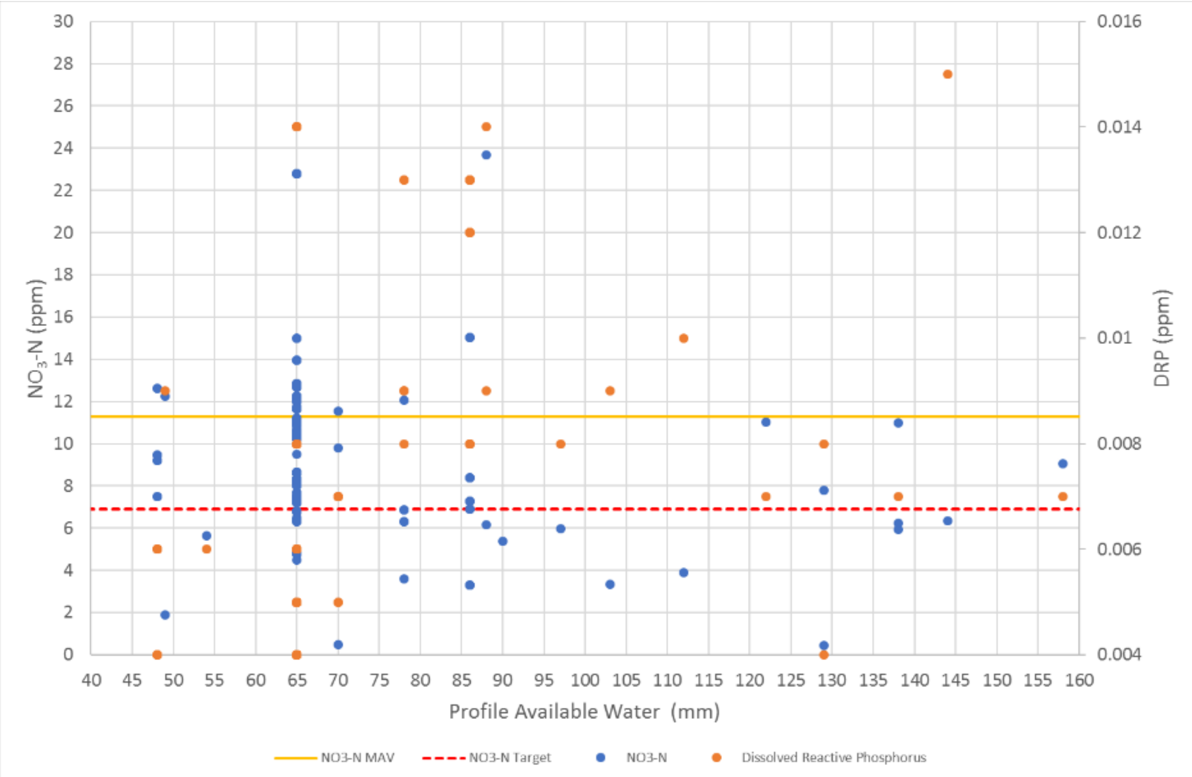


Figure 46 Scatter plot of NO_3-N and DRP against Soil PAW

The results of this analysis suggested that, while there may potentially be a relationship between NO_3-N and PAW values, a clear picture is not apparent. Further soil mapping could reduce the uncertainties in the soils data, and a clearer distribution might emerge as a result. However, there are many other factors driving NO_3-N concentrations at a location, including land use, groundwater flow paths, depth at which the sample was taken, etc. and there may still not be a clear relationship. In addition, whilst the soils at the surface may be related to the sediments immediately underlying them, given the sedimentary environment that deposited the material, there will be considerable heterogeneity, both laterally and vertically, and hence attempting to predict nitrate migration pathways based on soil properties, on anything but a broad scale, may not be successful.

[19] https://smap.landcareresearch.co.nz/data-provenance/

8. Recommendations

> *Scientific data are not taken for museum purposes; they are taken as a basis for doing something. If nothing is to be done with the data, then there is no use in collecting any.*
>
> *The ultimate purpose of taking data is to provide a basis for action or a recommendation for action.*
>
> *(Deming, 1942)*

As outlined in Section 1.2, The groundwater programme is a tangible expression of MHV's mission to provide *"Sustainable Solutions for our Shareholders and the Community*". MHV wish to fulfil their social license to operate through encouraging BFMP's, environmental impacts are minimised, and the objectives of PC2, and ultimately the higher standards outlined in the *Essential Freshwater Package*, are achieved.

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. By monitoring groundwater across the scheme area, MHV intends to provide data and complementary information that will enable evidence-based decision making, that leads to environmentally and sustainable water and nutrient management practices.

In doing so, MHV intends to develop sustainable strategies to assist farmers manage land use and mitigate the migration of NO_3-N in both surface and groundwaters

1. The current monitoring program to be maintained and extended so that the spatial footprint extends to cover the Hekeao Hinds Plains in its entirety. This will inform a consistent, comprehensive analysis of annual NO_3-N concentration tracking toward catchment targets.
2. Kaupapa māori methodologies – also known as cultural health indicators (CHI) be incorporated into future surveys.

   Kaupapa māori methodologies is a tool that tangāta whenua can use to assess cultural and biological health of a stream or catchment. These observations complement, support and ultimately enhance the water quality observations.

   Having been utilised for over a decade in New Zealand, CHI's are an established and legitimate Integrated Water Management (IWM) strategy with several types / configurations available (Awatere et al., 2017; Rainforth, 2020; Tipa, 2013; Tipa and Teirney, 2006)
3. Ecological surveys should be carried out to compliment the water quality data as well as identify any ecological constraints. These might include:
   - Assessing the ecological status of waterways, using, for example, the Stream Health Monitoring and Assessment Kit (SHMAK)[20];

[20] https://niwa.co.nz/freshwater/management-tools/water-quality-tools/stream-health-monitoring-and-assessment-kit

- Multi-pass electrofishing surveys to estimate the abundance or density of freshwater fish in the HMWC's.

4. A reconciliation (aka mass balance) of rainfall, river flows, MAR inflows, water levels, irrigation schedules to ascertain if there is a temporal element to nitrate migration.
5. Further investigation into the potential drivers of NO_3-N distribution be undertaken, e.g., the possible correlation with soil and NO_3-N concentration as outlined in section 7.3.
6. A 3-D conceptual be developed in house to collate all the spatial data as well as provide a platform for visualisation, conceptualisation and communication of the results (Figure 47).

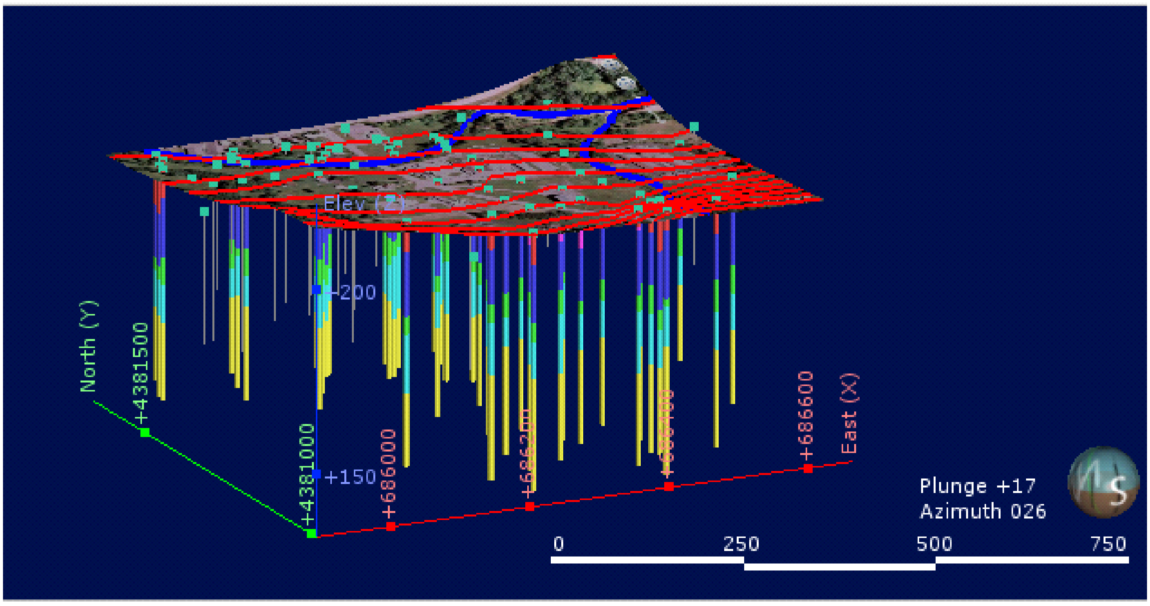


Figure 47 An example of a 3-D integrated model developed in LeapFrog

9. Conclusions

> *"Reports that say that something hasn't happened are always interesting to me, because as we know, there are known knowns; there are things we know we know.*
>
> *We also know there are known unknowns; that is to say we know there are some things we do not know.*
>
> *But there are also unknown unknowns—the ones we don't know we don't know.*
>
> *And if one looks throughout the history of our country and other free countries, it is the latter category that tend to be the difficult ones."*
>
> Donald Rumsfeld
>
> United States Secretary of Defence

The issue of water management has now entered the public zeitgeist with pundits stating that it is difficult to make any comprehensive commentary about the "actual levels of nitrate" in New Zealand because (Cowie, 2020):

"…no one organisation is collecting the data"

In the Hekeao Hinds catchment MHV is involved in a monitoring collaborative initiative with:

- Local Farmers
- Hekeao Hinds Water Enhancement Trust (HHWET)
- Hinds Drains Working Party (HDWP)
- Aoraki Environmental Consultants acting on behalf of te Arowhenua Rūnanga
- Environment Canterbury (ECan)
- Fish and Game

that could become this "one organisation".

The data collected thus far from all the parties has confirmed the complexity of the hydrogeological system and in fact pose more questions than answers.

The results presented here add to existing data, highlighting:

The results presented here have highlighted:

- The variability of NO_3-N concentrations across the Hekeao Hinds Plains spatially, with depth, and over time;
- The degree that groundwater levels respond to rainfall depends on the hydrological gradient and location in the catchment.
- There are some areas of elevated DRP albeit on a localised scale. As stated by Scott and Wong, (2016)

  "We may need to rethink some previously-held views that phosphorous concentrations are too low to be an issue in groundwater"
- There may be potential controlling factors for NO_3-N migration and pathways such as paleo channels and changes in soil type;
- Well head security is generally good, but there is a significant proportion of wells that are non-compliant and potentially a point source for contamination.

Appendix 1

Statement of Qualifications

1. My name is Justin Legg
2. I am a fulltime salaried employee of MHV Water Limited where I hold the position of Senior Hydrogeologist.
3. I hold the following qualifications:
    a. Bachelor of Science (Geology) from the Australian National University, Canberra (1997);
    b. Bachelor of Science with honours majoring in exploration geology and geochemistry from the University of Tasmania (2001);
    c. Master of Integrated Water Management majoring in Catchment Management from the University of Queensland (2017).
4. I am a current member of the following professional initiations:
    a. The Australian Institute of Geoscientists
    b. The Hydrological Society of New Zealand
    c. The New Zealand Freshwater Science Society
5. I have worked exclusively as a geologist on a full-time basis since 1997 and a hydrogeologist on an exclusive full-time basis since 2017
6. I am a Registered Geologist (R.P. Geo No. 10076) in the fields of Exploration (2008) and Mining (2015) 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

2020 Rainfall

Location	Stn	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Ashburton Aero	26170	6.8	51.4	55.0	18.8	21.2	85.2	30.0	23.4	59.6	29.4	43.6	72.2
Chertsey	39661	1.6	46.8	38.4	14.0	19.4	80.2	36.0	16.6	37.2	19.2	76.0	67.8
Lismore	39845	3.6	49.4	71.8	20.8	21.8	43.0		17.8	58.4	38.8	81.8	45.4
Wakanui	41200	5.6	32.6	42.6	10.8	10.4	92.0	21.8	12.4	42.6	27.8	78.6	57.0
Winchmore	42899	3.0	55.0	60.4	14.2	20.4	92.0	14.2	12.6	55.8	30.6	87.8	45.6
Mayfield	43538	21.2	75.6	145.0	35.4	32.8	99.4	16.0	51.0	88.2	58.2	113.8	109.2
Average		**7.0**	**51.8**	**68.9**	**19.0**	**21.0**	**82.0**	**23.6**	**22.3**	**57.0**	**34.0**	**80.3**	**66.2**

Appendix 3

Summary of Nitrogen Limits for the National Objectives Framework

Appendix 3

Summary of Nitrogen Limits for the National Objectives Framework

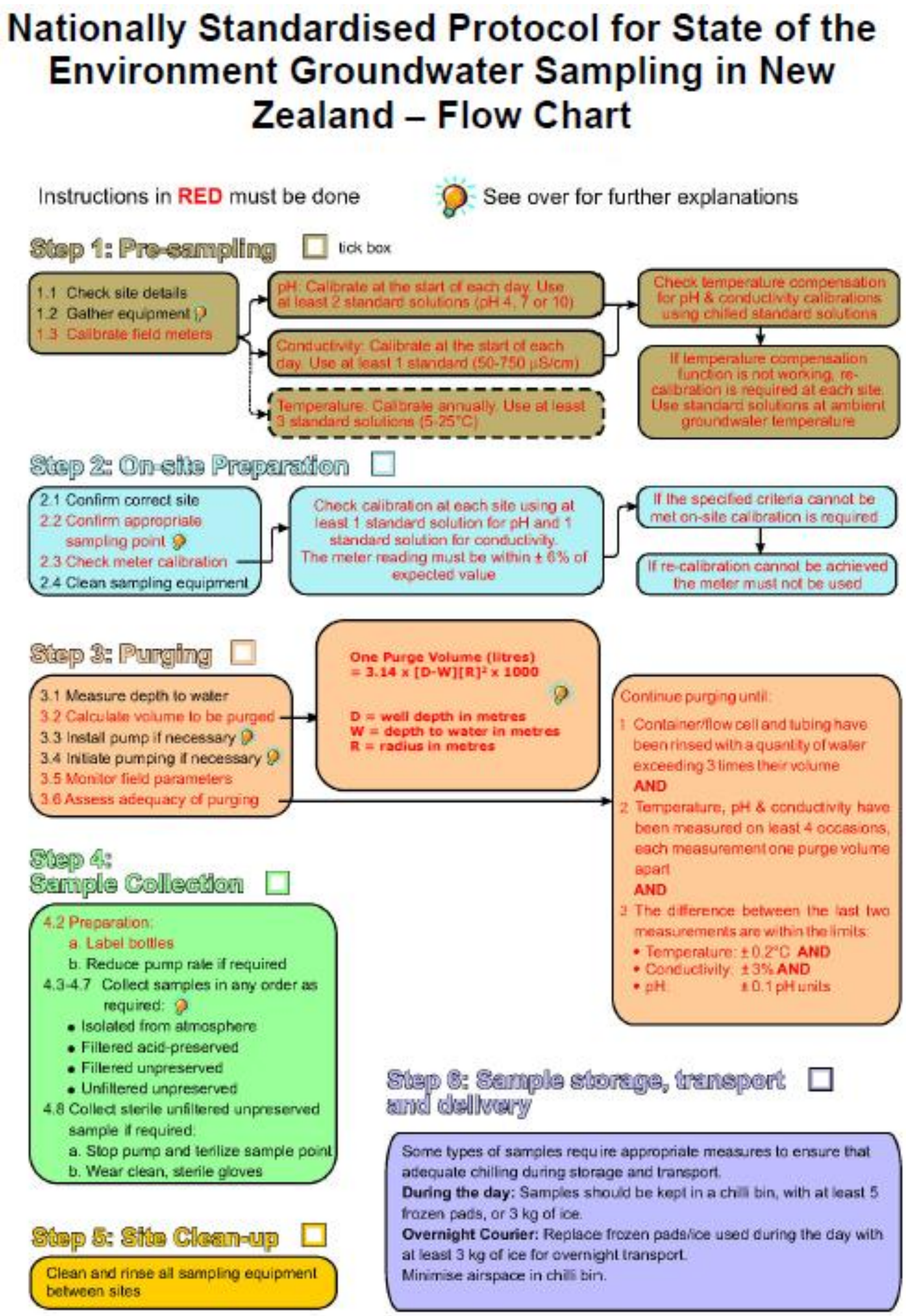
Table 17 Summary of Nitrogen Limits for the National Objectives Framework

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

† Values presented here are from Ecosystem health – Lakes from the 2014 NPS-FM (updated 2017)

Appendix 4

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



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

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

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

3.2 For calculation of purge volume:

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

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

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

3.6 For assessment of adequacy of purging, note that:

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

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

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

Refer to Groundwater Sampling Protocol for further detailed explanations when required

Appendix 5

Individual Survey Results 2020

Summary descriptive statistics of the December 2020 results (n=97)

Variable	Min	Max	Range	Mode	Median	Average	Std Dev	CV[21]
NO_3-N (ppm)	0.13	22.06	21.93	#N/A	8.04	8.17	3.49	0.43
NO_3-N (ppm) <30 m bores	1.10	22.06	20.96	#N/A	9.43	9.59	4.48	0.46
pH	-	-	-	-	-	-	-	-
Dissolved Oxygen (mg/l)	3.60	11.95	8.35	9.06	8.89	8.50	1.54	0.18
Conductivity (µS/cm)	1.00	411.00	410.00	194.00	201.50	202.97	62.68	0.31
ORP	-18.00	773.00	791.00	135.00	135.00	147.55	88.64	0.60

Summary descriptive statistics of the September 2020 results (n=94)

Variable	Min	Max	Range	Mode	Median	Average	Std Dev	CV
NO_3-N (ppm)	0.09	22.44	22.35	8.70	8.88	8.86	3.73	0.42
pH	6.10	8.18	2.08	7.46	7.43	7.29	0.57	0.08
Dissolved Oxygen (mg/l)	2.10	12.39	10.29	9.37	9.43	9.05	1.81	0.20
Conductivity (µS/cm)	76.10	538.00	461.90	280.00	258.50	264.51	73.22	0.28
Temp. °C	8.97	18.00	9.03	12.03	12.52	12.62	1.62	0.13

[21] 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.

Table 18 Summary descriptive statistics of the June 2020 results (n=72)

Variable	Min	Max	Range	Mode	Median	Average	Std Dev	CV[22]
NO_3-N (ppm)	0.45	23.67	23.22	6.15	8.14	8.89	4.02	0.45
pH	6.05	8.25	2.20	7.56	7.35	7.25	0.59	0.08
Dissolved Oxygen (mg/l)	0.70	14.71	14.01	11.12	9.04	9.05	2.28	0.25
Conductivity (µS/cm)	67.10	556.00	488.90	258.00	256.00	274.34	80.06	0.29
Temp. °C	5.67	16.53	10.86	11.83	11.80	11.28	2.06	0.18

Table 19 Summary descriptive statistics of the March 2020 56 results

Variable	Min	Max	Range	Mode	Median	Average	Std Dev	CV
NO_3-N (ppm)	3.39	22.17	18.78	10.50	8.75	9.28	3.36	0.39
pH	6.10	8.40	2.30	7.40	7.25	7.21	0.65	0.09
Dissolved Oxygen (mg/l)	0.31	10.80	10.49	8.05	8.57	7.01	2.55	0.36
Conductivity (µS/cm)	165.80	512.00	346.20	321.00	282.00	280.43	71.20	0.25
Temp. °C	11.80	17.50	5.70	13.27	13.00	13.45	1.23	0.09

[22] 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.

Appendix 6

Soils identified and mapped on the Hekeao Hinds Plains

S Map Code	Soil Description	PAW 0 - 60cm
Ayre_3a.1	moderately deep, poorly drained, clay	112
Balm_10a.1	very shallow, well drained, silty loam	48
Barr_6a.1	moderately deep, well drained, loam	108
Chas_2a.1	moderately deep, moderately well drained, silty loam	113
Clar_1a.1	moderately deep, poorly drained, silty loam	90
Clar_1a.2	moderately deep, poorly drained, silty loam	90
Darn_1a.1	shallow, moderately well drained, silty loam	80
Darn_7a.1	shallow, moderately well drained, silty loam	54
Eyre_1a.1	shallow, well drained, silty loam	113
Eyre_2a.1	shallow, well drained, loam	104
Eyre_3a.1	shallow, well drained, silty loam	71
Eyre_4a.1	shallow, well drained, loam	59
Fere_3a.1	deep, well drained, sandy loam	78
Flax_1a.1	deep, poorly drained, silty loam	158
Flax_2a.1	moderately deep, poorly drained, silty loam	158
Fris_1a.1	deep, moderately well drained, silty loam	88
Hind_2a.1	moderately deep, imperfectly drained, loam	135
Kaia_1a.1	deep, imperfectly drained, silty loam	144
Kaia_2a.1	moderately deep, imperfectly drained, silty loam	145
Kaka_2a.1	moderately deep, well drained, silty loam	113
Lism_1a.1	shallow, well drained, silty loam	86
Lism_2a.1	shallow, well drained, silty loam	65
Long_2a.1	moderately deep, poorly drained, silty loam	138
Long_4a.1	moderately deep, poorly drained, silty loam over clay	129
Lowc_1a.1	shallow, imperfectly drained, silty loam	49
Lowc_2a.1	shallow, imperfectly drained, silty loam	72
Lowc_3a.1	very shallow, imperfectly drained, silty loam	41
Mayf_2a.1	moderately deep, moderately well drained, silty loam	88
Paha_31a.1	moderately deep, imperfectly drained, silty loam over clay	79
Paha_5a.1	deep, imperfectly drained, silty loam	87
Raka_1a.1	shallow, well drained, loam	79
Raka_2a.1	shallow, well drained, loam	55
Raka_4a.1	shallow, well drained, silty loam	84
Rang_18b.1	very shallow, well drained, sandy loam	31
Rang_19a.1	very shallow, well drained, sandy loam	38
Rang_21a.1	shallow, well drained, sandy loam	67
Rang_32a.1	shallow, well drained, sandy loam	52

Rang_32a.2	shallow, well drained, sandy loam	52
Rang_6a.1	shallow, well drained, sandy loam	46
River_1a.1	very shallow, well drained, sandy loam	0
Ruap_1a.1	shallow, well drained, silty loam	94
Ruap_2a.1	shallow, well drained, silty loam	70
Salix_4a.1	deep, imperfectly drained, silty loam over clay	73
Selw_25a.1	moderately deep, well drained, loam over sandy loam	115
Sock_3a.1	shallow, imperfectly drained, loam	97
Temp_1a.1	deep, moderately well drained, silty loam	97
Temp_2a.1	moderately deep, moderately well drained, silty loam	104
Temp_2a.2	moderately deep, moderately well drained, silty loam	108
Temp_3a.1	deep, moderately well drained, silty loam	103
Temp_3a.2	deep, moderately well drained, silty loam	109
Temp_4a.1	moderately deep, moderately well drained, silty loam	103
Temp_9a.1	moderately deep, well drained, silty loam	107
Temu_49a.1	deep, poorly drained, silty loam over clay	135
Timu_1a.2	moderately deep, imperfectly drained, silty loam	92
Utuh_8a.1	moderately deep, very poorly drained, peat over skeletal	268
Waim_42a.1	deep, well drained, loam over sandy loam	135
Waka_1a.1	deep, imperfectly drained, silty loam	94
Waka_2a.1	moderately deep, imperfectly drained, silty loam	94
Waka_3a.1	deep, imperfectly drained, silty loam over sandy loam	103
Waka_5a.1	deep, imperfectly drained, silty loam over clay	78
Waka_6a.1	deep, imperfectly drained, silty loam	90
Wate_2a.1	shallow, poorly drained, silty loam	78
Wate_3a.1	shallow, poorly drained, silty loam	123
Wilb_7a.1	shallow, poorly drained, silty loam	122
Ymai_18a.2	moderately deep, very poorly drained, peat over silty loam	205
Ytoh_1a.1	deep, poorly drained, silty loam over clay	85

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