Hekeao/Hinds Managed Aquifer Recharge Trial

Year 4 Annual Report

(June 2019 – May 2020)

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Wetland beside the Hekeao / South Hinds River supported by MAR

Chairman's Foreword

It gives me great pleasure to present this Chairman's Foreword, again in a year of significant progress for New Zealand's largest groundwater rehabilitation project.

Central Government has shown confidence in the Hekeao/Hinds Managed Aquifer Recharge project by granting significant funds to the project. The Funding Agreement between HHWET and MBIE's Provincial Growth Fund began on 11 February 2020.

The MAR trial has also continued to have support from the wider Ashburton community and businesses, Ashburton District Council and Environment Canterbury. On behalf of the Hekeao/Hinds Water Enhancement Trust I wish to thank all those involved, including of course the Provincial Growth Fund for their ongoing support.

This funding has allowed ECan on behalf of HHWET to secure and contract various technical, consenting, construction and communication experts to work on and add value to our project.

Work streams undertaken during Year 4 include the start of drafting a detailed MAR business case to be completed early in Year 5. A dedicated HHWET website has been developed and is available at www.hhwet.org.nz. The original MAR consents expire in February 2021 and the consent renewal process is well advanced.

During Year 4 of the Trial, 15 test sites were, or became, operational, to join the near river recharge site and the Lagmhor Pilot Site. The new sites, and site upgrades, increased the maximum flow able to be recharged through all MAR sites, from 485 l/s to 900 l/s plus Mayfield Hinds irrigation race losses of up to 300 l/s available outside of the irrigation season.

Highlights for the year are a total recharged volume increase of 44% from 5.5 million cubic metres in Year 3 to approximately 7.9 million cubic metres in Year 4. This total was achieved despite 13 weeks of scheme shutdowns for Rangitata River floods, and scheme shutdowns during the COVID-19 lockdown period. In addition, there were 10 weeks of winter (2019) maintenance shutdown for the Valetta sites (Sites 1-7). The Hekeao Hinds River Project site has been the project's top performer for water recharge volume. DOC approval has been sought to introduce Kōwaro / Canterbury Mudfish to the wetland developed as part of this site.

The challenges faced by the Hekeao/Hinds Managed Aquifer Recharge pilot trial have not changed, namely access to sufficient water to make this project a success and how the community will fund that water supply and delivery.

Brett Painter in the role of Project Manager and Murray Neutze as MAR operational manager are both working extremely effectively for HHWET; on behalf of HHWET Trustees I sincerely thank them for their expertise and dedication to our project.

Finally, I am pleased to report the non-profit trust that is HHWET works effectively for the benefit of our community and is working towards achieving the goals the trust has set for itself, so from the chair I sincerely thank all trustees for the time and expertise given to this project.

Peter Lowe
Chair
HHWET

Acknowledgements

The authors wish to thank the Hekeao Hinds Water Enhancement Trust (HHWET) for project oversight, Mark Webb (Central South Island Fish and Game) for the fish survey and drains enhancement sections, MHV Water, RDRML, Lincoln Agritech and Environment Canterbury field staff for monitoring information, and Dr Helen Rutter (Aqualinc Research) for external report review.

Executive summary

Background:

Aquifer recharge happens both naturally and artificially every minute of every day and is the reason aquifers and spring-fed waterways exist at all. Recharge from rainfall, rivers, unlined water races and canals, and irrigation activities all act to continually recharge groundwater. These kinds of recharge lead to increased water levels and influence the quality of water in the aquifer. Managed Aquifer Recharge (MAR) is the purposeful recharge of specifically clean water into an aquifer to complement natural recharge in the rehabilitation of groundwater systems.

The problem:

The Hekeao Hinds MAR Trial is a response to recommendations from the Hinds Drains Working Party and Ashburton Zone Committee through Plan Change 2 to Canterbury's Land and Water Regional Plan (PC2). These recommendations were based on analysis of historical monitoring information that showed declining water quality and groundwater levels, as well as potential future water quality and quantity levels from a variety of landuse and water management scenarios. The proposed "Solutions Package" is a combination of improved on-farm nutrient management, irrigated area constraints and MAR.

The Hekeao Hinds MAR Trial was designed to provide the evidence for assessing the potential of MAR to assist with the achievement of four key objectives:

- Target and protect drinking water supplies.
- Enhance groundwater quality.
- Improve baseflows to spring-fed streams and rivers for ecological, cultural and social values; and
- Improve and sustainably manage groundwater storage (levels).

The reporting of progress towards these objectives focusses on the MAR contribution to groundwater level rise and reduction in groundwater nitrate-nitrogen concentrations.

What we did:

The 2018-18 Annual report states the 2019-20 priority actions as follows:

- Increased MAR supply by arrangement with relevant water take consent holders.
- MAR site optimisation to increase recharge rates, in particular for the MAR sites situated up-gradient from the community water supplies of Tinwald, Hinds and Mayfield.
- Assessment of priorities for new MAR sites. This assessment includes:
    - Identification of potential new MAR sites (including gravel pits), stockwater and, currently redundant, Mayfield Hinds Scheme races that could be connected to RDRML/MHV Water/BCI distribution. In particular:
    - Supply rate potential (in collaboration with RDRML/MHV Water/BCI);

  - Learnings to date from test sites including soil profile, depth to water and recharge potential.
  - Potential to influence drinking water supplies (community and individual).
  - Catchment spread of MAR sites and current nitrate concentration monitoring.
- Assessment to support the development of a catchment-wide MAR monitoring network, starting with current public and private bores.
- Assessment of long term consenting requirements, collection of relevant technical information and drafting of consent application documentation.

Progress to address these priorities is summarised as follows:

- The relevant water take consent holders were identified as Ashburton District Council (ADC) and Rangitata Diversion Race (RDR) Management Ltd. During Year 4, discussions progressed with both parties regarding supplementary / subservient access to their Rangitata River water take consents. These discussions are expected to result in consent applications by HHWET in Year 5. No new Rangitata River takes, and no Ashburton River takes for MAR are proposed.
- During Year 4 of the Trial, 15 test sites were or became operational to join the near river recharge site and the Lagmhor Pilot Site. The new sites and site upgrades increased the maximum flow able to be recharged through all MAR sites, from 485 l/s to 900 l/s (plus Mayfield Hinds race losses of ~300 l/s when irrigation water is not being delivered).
- Total recharged volume increased by 44% from 5.5 million cubic metres in Year 3 to approximately 7.9 million cubic metres in Year 4. This total was achieved despite 13 weeks of Scheme shutdowns for Rangitata River floods (late November to early January), and the COVID-19 lockdown (late March to late April – except for the Hekeao Hinds River Project site which has automatic monitoring so could keep running). In addition, there were 10 weeks of winter (2019) maintenance shutdown for the Valetta sites (Sites 1-7). PC2 analysis estimated that an annual MAR requirement of approximately 125 million cubic metres would be required to fulfil its role (alongside on-farm nutrient leaching reduction and irrigated area constraints), in reaching PC2 water quantity and quality goals.
- New site assessments included consideration of the use of ADC land and stockwater races, MHV Water distribution and storage, spatial variation of nitrate concentrations, recharge potential based on local hydrogeology, management of suspended sediment to reduce basin clogging, and the potential for deep recharge bores as part of the MAR Scheme. Decisions on which new sites to progress will be made in Year 5.
- A catchment-wide monitoring plan was progressed in collaboration with Te Rūnanga o Arowhenua, MHV Water and Environment Canterbury. This monitoring plan significantly increases the number of bores monitored quarterly for water quality as well as co-ordinating the placement of additional monitoring bores containing automatic nitrate-nitrogen monitoring at 15 minute intervals.
- An application was made to Environment Canterbury regarding the transfer of all Hekeao Hinds MAR Trial consents from Environment Canterbury to HHWET Ltd (a company owned by HHWET). A consent review was undertaken to support the subsequent renewal of these consents.

What we found:

Key learnings from Year 4 include:

- None of the Lagmhor Pilot Site enhancements constructed to date have provided significant long-term recharge rate increases. In Year 4, the site achieved 120-130 l/s on a couple of occasions, but generally operated in the 90-100 l/s range. Total recharged volume decreased from approximately 2.2 million m^3 in Year 3 to 882,000 m^3 in Year 4, mostly due to lack of water from the Scheme shutdowns, as well as the prioritisation of the limited (500 l/s maximum) supply to other sites.
- The Hekeao Hinds River Project (HHRP) near river recharge site, performed above expectations, with 3.3 million m^3 (42 % of the Year 4 total) recharged, up from 1.7 million m^3 in Year 3. Assessments of river losses and nearby groundwater bore levels suggests that the river recharges groundwater to both the true right and left, with groundwater to the true left feeding Silverstream (which then flows back into the Hekeao Hinds River at the North/South branch confluence).
- The original test site design enabled recharge comparisons in different parts of the catchment but was not expected to be the optimal long-term design at each location. Amendments to the test site discharge consent (in particular to enable higher recharge rates) enabled the construction of 4 new sites and 3 site upgrades. Another site was replaced with a new standard test site design after clogging up during Year 3/4. This enabled recharge volume at the test sites to increase by 37% from 1.68 M m^3 in Year 3 to 2.30 M m^3 in Year 4.
- The implementation of a solar powered laser bird scarer on key storage ponds contributed to a significant reduction in site shutdowns for *E. coli* exceedance, from 41 site shutdowns in Year 3 to 16 site shutdowns in Year 4. Therefore, reduction in the numbers of birds on the ponds can have a significant impact on the ability to keep the sites operating.
- A review of suspended solids management challenges and opportunities for Hekeao Hinds MAR sites, identified the Rangitata River supply as the primary source of suspended solids, with MAR distribution race bank erosion a secondary source. The recommended maximum turbidity in MAR source water of 10 NTU was exceeded at the RDR Intake ~75% of the time in Year 4. A trial to increase the use of irrigation ponds to allow the heavier sediment to drop out before distribution to MAR sites began in Year 4, to be continued in Year 5.
- The cost to benefit ratio of deep recharge bores, as a contribution to a Hekeao Hinds Plains MAR Scheme, was considered too high to be progressed at this time.

What does it mean?

Year 4 results provide confidence that the technical development of a Hekeao Hinds Plains MAR Scheme is progressing in accordance with the MAR aspects of the Ashburton Zone Committee’s Zone Implementation Programme (ZIP) and Addendum (ZIPA). However, four significant questions remain:

- What size MAR Scheme is required to meet the MAR contribution to the Ashburton Zone Committee’s ZIP / ZIPA and Plan Change 2 to Canterbury’s Land and Water Regional Plan (PC2)?
- Where will the required supply water come from?
- How much will it cost?
- Who will pay?

Significant progress on these three questions is anticipated during Year 5.

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1 Introduction

Plan Change 2 to Canterbury's Land and Water Regional Plan (PC2) includes requirements to reduce on-farm nitrogen leaching by up to 36% by 2035 and reduce median annual shallow groundwater concentrations of nitrate-nitrogen to a target of <6.9 mg/l by 2035. The nitrate-nitrogen PC2 update to June 2020 (Figure 1-1) shows median nitrate-N concentrations in PC2-specified "shallow" (<30 m) and "deep" (>30 m) wells across the Ashburton district. This suggests there has been a decrease in shallow groundwater concentrations during Year 4 but a corresponding increase in deeper groundwater concentrations. Figure 1-2 shows that 2019-20 was drier than average (for the presented timescale) and a simple comparison of these figures suggests that the rise and fall in shallow groundwater nitrate-nitrogen concentrations since 2012 corresponds primarily with the rise and fall of annual rainfall. Changes to landuse, water distribution infrastructure, irrigation methods and nutrient leaching management are also likely to be influencing groundwater concentrations during this time. However, the complex interactions between these influences, and (often) long lag times, can make detailed analysis of all influences very challenging.

Analysis carried out for PC2 estimated that an annual MAR requirement of approximately 125 million cubic metres would be required to fulfil its role (alongside on-farm leaching reduction and irrigated area constraints) in reaching PC2 goals, in particular a median of 6.9 mg/l nitrate-N in shallow groundwater for 80% aquatic species protection and 3.8 mg/l in the lower Hekeao Hinds River for 90% aquatic species protection. Table 1-1 (below) shows that the total recharged MAR volume in Year 4 was approximately 7.9 million cubic metres. Consistent with previous annual recharge assessments, the Year 4 MAR Trial has shown positive localised effects for water quantity and quality. However, because of the relatively limited amount of water available for MAR (compared to what is estimated to be needed for regional impact), the effects are localised, and not yet discernible from other effects on a catchment scale.

Table 1-1: Year 4 Hekeao/Hinds MAR recharge

	MAR Volume (cubic metres)
Delivered to HHRP Site	3,299,011
Delivered to Pilot Site #1	881,971
Delivered to Test Sites #2-18	2,304,934
Distribution system recharge (race "losses" when MAR water-only delivered)	1,400,077
Total Year 4 recharged flow	**7,885,993**

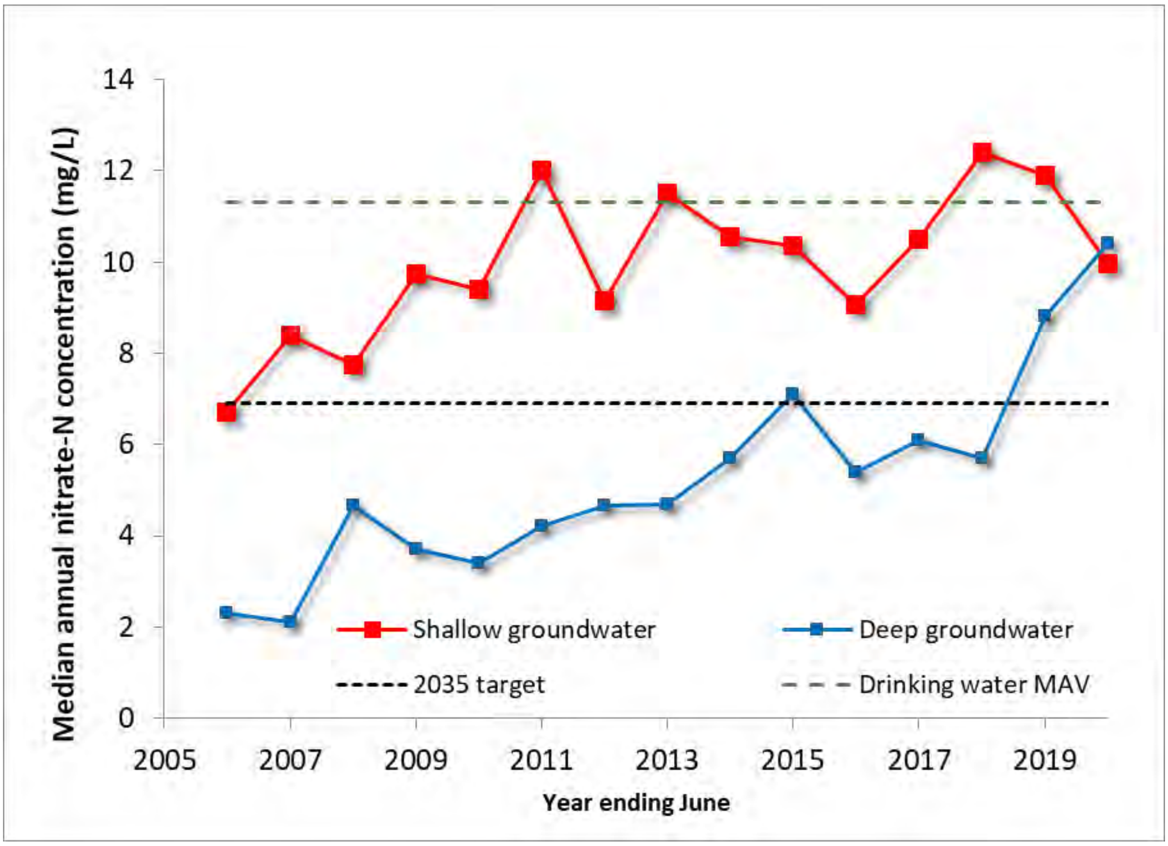


Figure 1-1: **Plan Change 2 to Canterbury's Land and Water Regional Plan – Hekeao / Hinds Plains median annual nitrate-nitrogen concentrations**

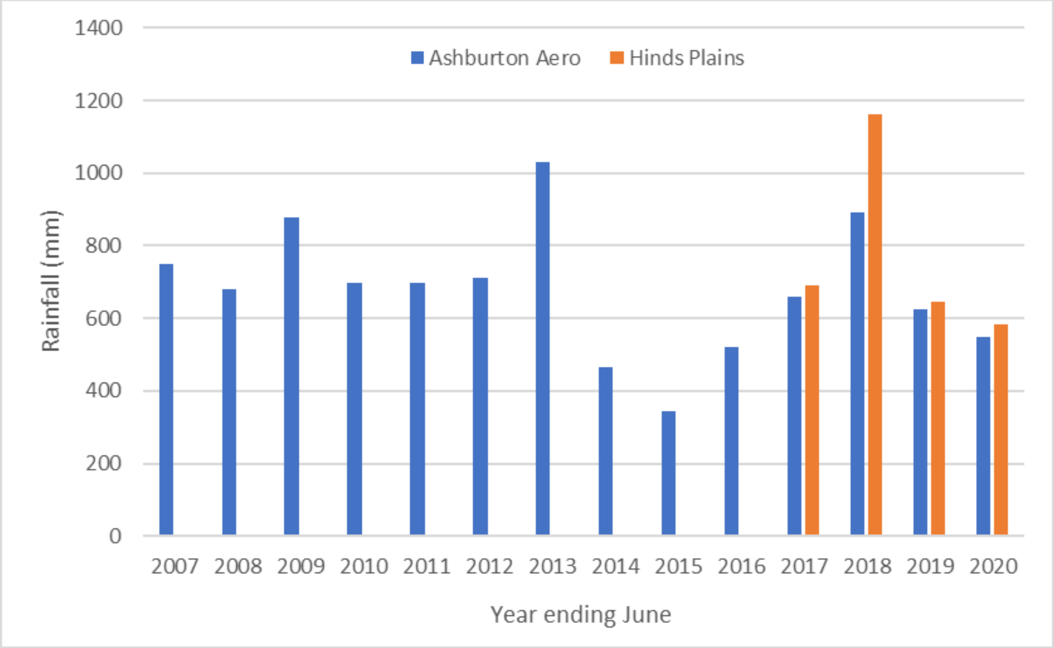


Figure 1-2: **Total annual (July – June) rainfall (in mm) for two nearby rainfall sites**

This report focusses on design and operational updates for MAR sites, as well as key monitoring information and analysis. Compliance monitoring results are presented in the Annual Compliance Report 2019-20. Figure 1-3 presents the MAR sites operational during Year 4 and Table 1-2 presents their key performance indicators. Sites 1, 3-6, 8, 9, 15 and 16 retained the same design as in Year 3 (though MAR 16 was rebuilt). Sites 7, 12 and 13 received a design and capacity upgrade. Sites 2, 10, 17 and 18 were new site constructions, with initial construction and testing completed during Year 4.

Testing of MAR source water ensures that it is of high quality. Nitrate-nitrogen, suspended sediment and *E. coli* are the key source quality parameters (as indicators of water quality, MAR clogging risk and down-gradient drinking water risk respectively). Source water from the Rangitata River remained very low in nitrate-nitrogen (<0.2 mg/l) throughout Year 4 monitoring, though turbidity varied significantly (Table 1-3). Rangitata River source water also remained low in *E. coli (*~30 MPN/100 ml), except for brief spikes during flood events. An *E. coli* source tracking study during Year 3 identified birds on irrigation storage ponds as the most significant *E. coli* management challenge for the MAR sites. The implementation of a solar powered, laser bird scarer (Figure 1-4) on key storage ponds has contributed to a significant reduction in site shutdowns for *E. coli* exceedance (>=700 MPN/100 ml), from 41 site shutdowns in Year 3 to 16 site shutdowns in Year 4.

Table 1-2: MAR site performance information for Year 4 (June 2019 – May 2020 inclusive)

June 2019-May 2020	Maximum recharge rate (l/s)	Total recharge volume (m³)	Weeks in operation	*E. coli* shutdowns	Notes
1 – Lagmhor Pilot	130	881,971	17		
2 – Timaru Track	100	21,240	<1		Testing during construction
3 - Walls	20	163,672	20	3	Supply limited to ~30 l/s
4 - NZSF	24	150,230	16	1	
5 – Pond 2	28	206,832	5	2	
6 – BCI/Howden	18	217,181	28		Supply limited to ~25 l/s
7 - Lobblin	65	31,085	<1		Testing during construction
8 - Lacmor	33	190,536	23		
9 – Riverbank	23	286,080	29	2	
10 - Foster	50	117,279	4		Testing and commissioning
12 - Slee	40	141,621	28	1	Replacement site May 2020
13 – Hills view	38	309,536	33	1	Replacement site May 2020
15 - Oakstone	23	113,473	13	4	
16 - Broadfields	27	354,859	37	2	Replacement site July 2019
17 - Jones	75				Brief test during construction
18 - McDougall	40	860	<1		Testing during construction
HHRP	170	3,299,011	41		
MH race losses	303	1,400,077	12		

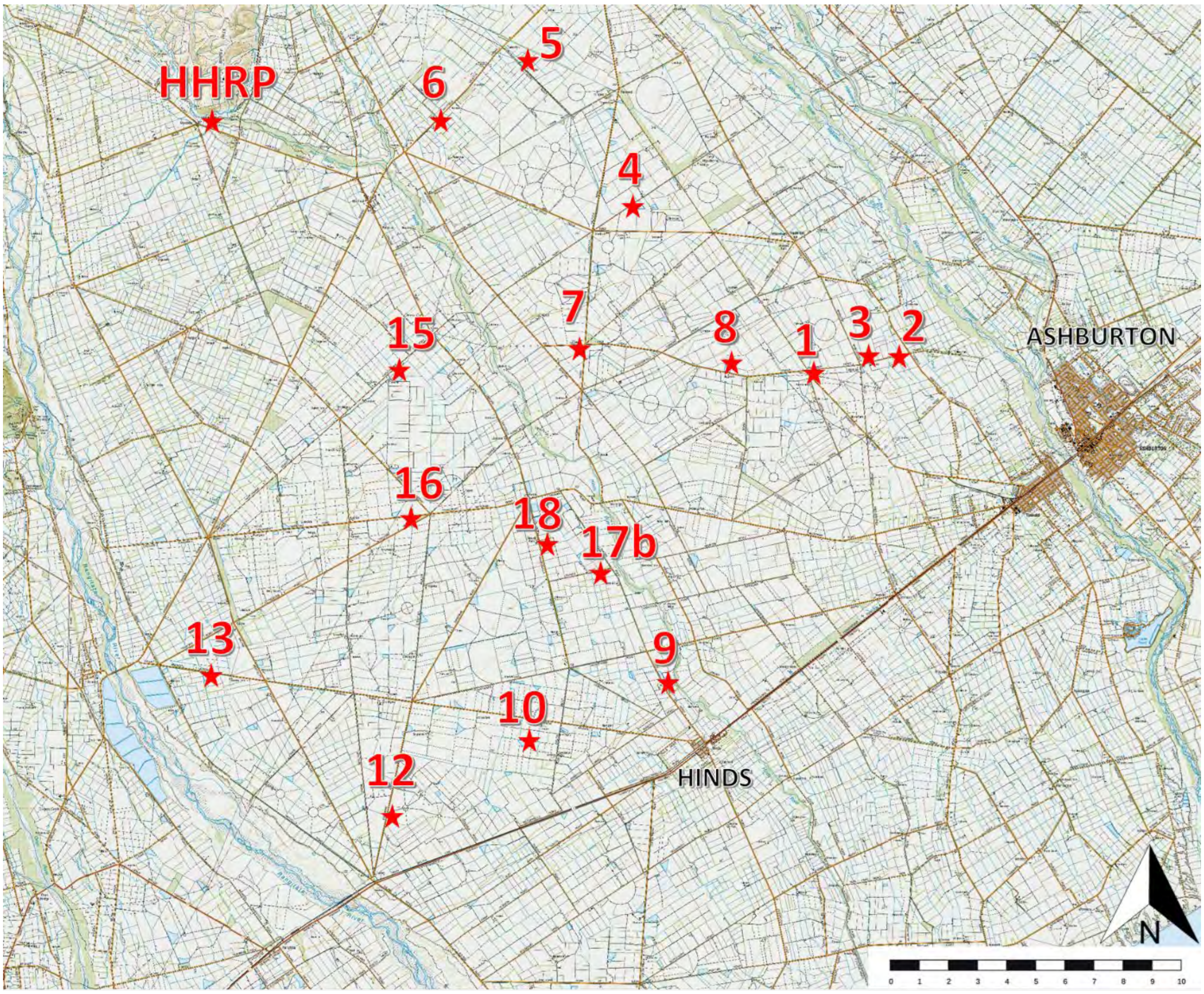


Figure 1-3: Hekeao Hinds MAR sites operational during 2019-20

Table 1-3: RDR Intake turbidity distribution for Year 4

Percentile	RDR Intake Turbidity (NTU)
10	0
20	8
30	13
40	20
50	26
60	39
70	55
80	106
90	247
100	1,304

Figure 1-4: Hekeao Hinds MAR laser bird scarer

Most Hekeao Hinds MAR sites showed signs of physical clogging by suspended solids during Years 1-3. Sites with a functioning forebay for dropping out heavy sediment (e.g., Lagmhor and HHRP) are relatively easy to clean, while sites that just consist of a soakage basin and/or infiltration gallery (including buried perforated pipe) require significant effort to clean. Golder Associates (2020) conducted a review of suspended solids management challenges and opportunities for Hekeao Hinds MAR sites. The primary source of suspended solids was identified as the Rangitata River source water, with MAR distribution race bank erosion a secondary source. Golder Associates (2020) quote the Australian MAR guideline (NRMMC, 2009) recommendation of keeping turbidity in MAR source water less than 10 NTU. Table 1-3 shows that this guideline was exceeded at the RDR Intake ~75% of the time in Year 4.

Golder Associates (2020) recommended a combination of source water pre-treatment (storage time in irrigation ponds and sediment traps / forebays up-gradient from MAR sites), plus minimisation of distribution race bank erosion (stepped flowrates and riparian planting) as the key sediment management techniques. For MAR basins, a combination of tillage (so the sediment accumulates in the base of furrows) and periodic drying was also recommended. In response to these recommendations, the proportion of MAR water supplied from irrigation storage (as a water swap) was increased in order to provide additional pre-treatment during Year 4. In addition, periodic drying and stepped flowrates are already utilised in MAR operations. Tillage and riparian planting will be considered further in Year 5.

2 MAR Site 1 - Lagmhor Pilot Site

2.1 Lagmhor site operations and monitoring

The Lagmhor Pilot Site (MAR 01) is a 0.9 ha recharge basin, inland from Tinwald. The site is supplied by an open channel race, connected to Valetta Pond 3, owned by MHV Water (Figure 2-1). Relevant discharge consents are CRC183882 and CRC184617 (changed to CRC210700 and CRC210696 early in Year 5). Pre-construction modelling and infiltration testing suggested a potential infiltration/recharge rate of 300-500 l/s, with significant lateral as well as down-gradient influence. The actual achievable infiltration rate during the first two years was approximately 80-100 l/s, with the zone of influence initially constrained by down-gradient geology before increased mixing in the area feeding lowland springs. During Year 3, several improvements were put in place: a deep soakage system was installed, accumulated sediment was removed from the recharge basins and up-gradient delivery channel, and a higher basin depth was trialled. Maximum recharge rate (including the recharge race) initially increased to 120-140 l/s following these enhancements.

Figure 2-2 presents recharge flows and local monitoring for Years 1-4. Recharge flows (in hundreds of litres per second) are shown in yellow, with maximum recharge of approximately 140 l/s, and significant periods in recent years of no recharge (due to supply constraints or prioritisation of available flow to other sites). Measured nitrate-N concentrations are shown in purple, with an in-situ continuous nitrate-N sensor (in green) providing detailed monitoring until late 2019. This record shows nitrate-N at 6-7 mg/l immediately pre-MAR, reducing to 1.3-3.5 mg/l with MAR. Concentrations exceed 3 mg/l after a period of no MAR, but quickly drop back to below 3 mg/l once MAR resumes. Groundwater levels are presented in dark blue, with reasonably quick level changes when MAR begins or stops. The three significant Year 4 shutdown periods (Valetta maintenance, Rangitata floods and COVID-19 shutdown) significantly limited operations, with resulting decreases in groundwater levels and increases in nitrate-N concentration starting to show. Discharge was not required to cease as required by consent conditions on Hinds Plains Rainfall & Parakanoi Drain flow exceedance or *E. coli* exceedance during Year 4.

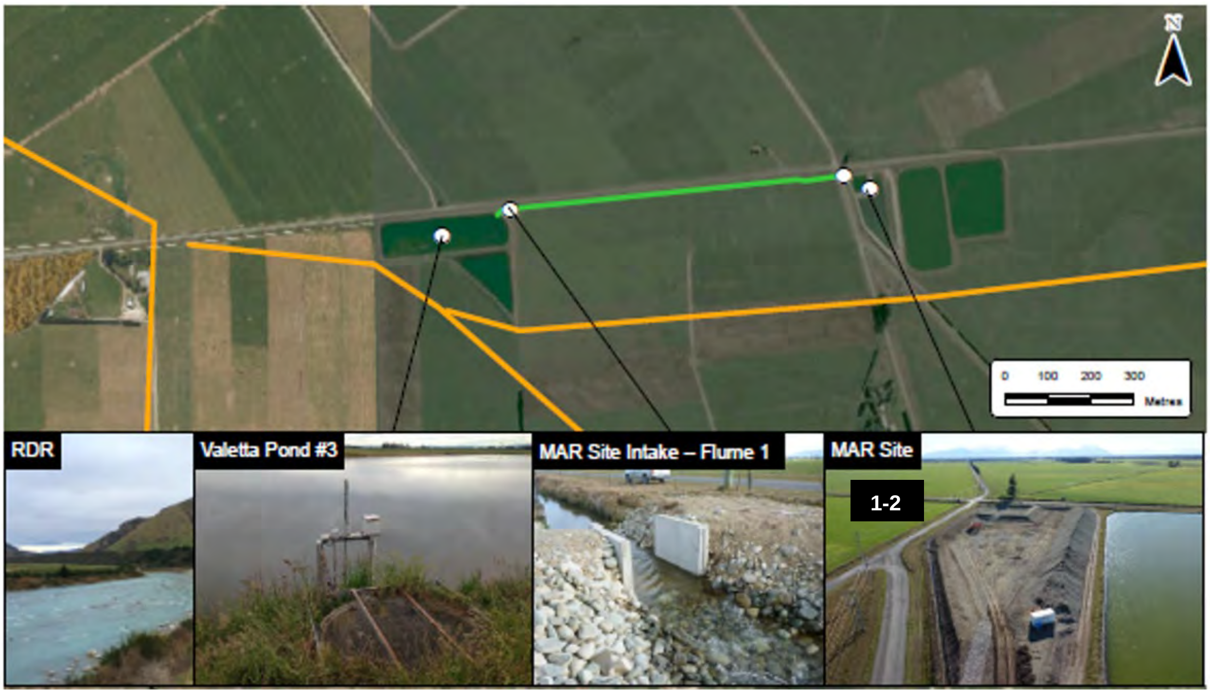


Figure 2-1: Lagmhor Pilot Site (MAR 01) infrastructure

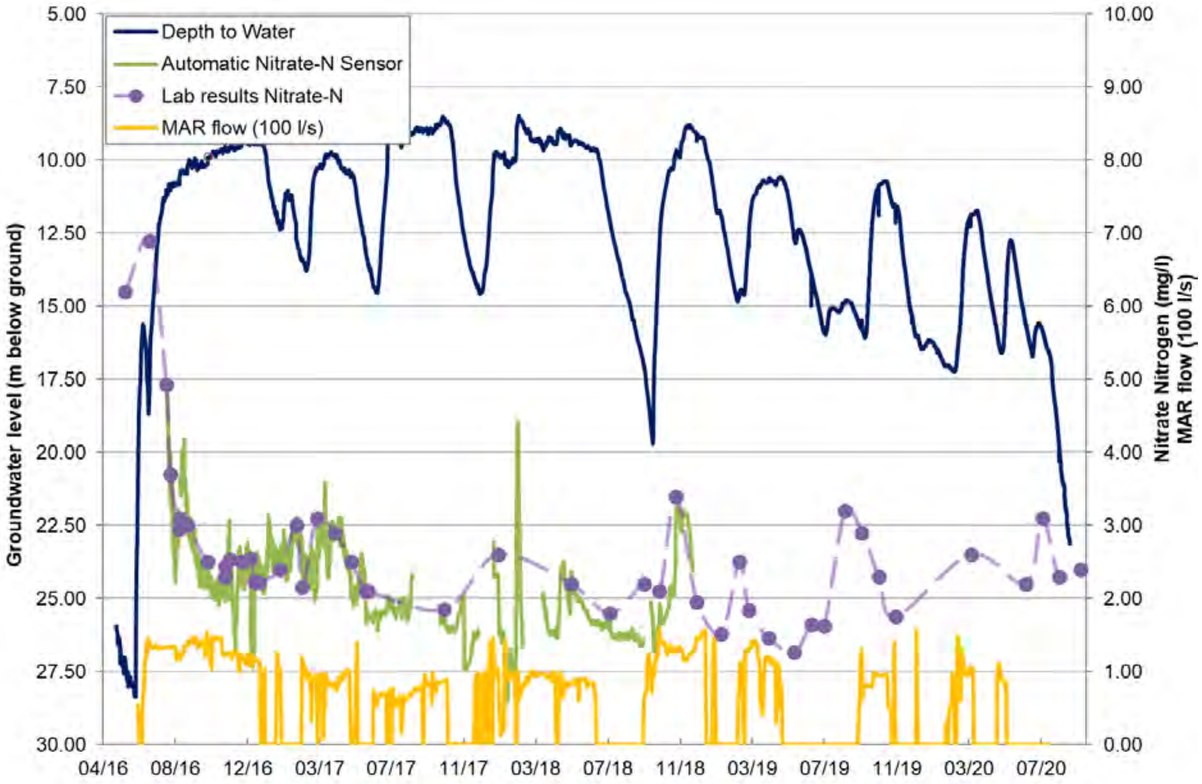


Figure 2-2: Lagmhor Pilot Site (MAR 01) operational and key down-gradient monitoring

2.2 Comparison of Lagmhor Pilot site (MAR 01) monitoring with the computer modelling of Durney (2019)

In late 2019, former Environment Canterbury scientist Patrick Durney submitted a Master of Water Resource Management Thesis titled “Quantification of the Probable Environmental Effects of the Hinds Managed Aquifer Recharge Trial using Mathematical Modelling and Advanced Uncertainty Techniques”. In this thesis, different computer modelling approaches are trialled to see which best explain observed groundwater level and groundwater quality responses to Year 1&2 Lagmhor Pilot site operations. The preferred modelling approaches are then used to forecast potential groundwater level and groundwater quality responses to the Lagmhor Pilot site operations after 5 years at an average recharge rate of 110 l/s. This analysis concluded:

> *“the Hinds MAR trial will successfully raise groundwater levels across a large area and increase stream flows. Further, the trial will improve water quality in groundwater, though it will probably not influence surface water quality. Transport modelling suggests water quality improvements can be expected for several kilometres down-gradient of the trial site, though they are unlikely to propagate as far as the lowland streams.”* (Durney, 2019)

With four years of groundwater level and quality monitoring information now available, it is timely to compare modelled and actual results. Figure 2-3 presents modelled groundwater level changes, from greater than 3 m (dark red) near the Pilot Site down to less than 20 cm (blue) at distances greater than 10 km from the Pilot Site. Groundwater level monitoring sites have been added to the figure, colour coded to the groundwater level graphs on Figure 2-4. MAR operational flow (in l/s on the right axis) is added to show operational periods. Daily rainfall from the nearby Hinds Plains recording site follows as Figure 2-5 to assist with understanding groundwater level response to rainfall events. Groundwater pumping (primarily for irrigation) is the other significant influence on groundwater levels, particularly in the summer months. Relevant groundwater pumping information is not currently available.

The modelling suggests that the area immediately surrounding the Lagmhor Pilot site would experience groundwater level changes due to MAR of at least 3.3 m. Bores 1, 2 and 3 on Figure 2-4 concur with this, with groundwater levels generally increasing by ~5 m immediately following the beginning of each MAR operational period and similar reduction in groundwater level once MAR ceases. Groundwater levels in the blue and red bores seem to have changed more due to MAR than the 1.9-3.3 m suggested by the modelling. The blue bore is assumed to be in a paleo channel immediately down-gradient from the Lagmhor Pilot site (see Fig. 0-3), so groundwater level changes due to MAR of ~5 m are not surprising. The blue line also shows an initial, apparent, groundwater level response to MAR operations in June 2016 of 18 m, but the Year 1 MAR report and Durney (2019) propose that this is likely to be due to water leaking down the outside of the bore casing from a perched overlying layer. The red line shows potential groundwater level changes of up to 5 m from MAR, but also changes that correlate with regular rainfall (e.g., winter/spring 2019) or pumping plus low rainfall (e.g., early 2020). This also aligns with Durney (2019), as the red bore is across gradient from the Lagmhor Pilot Site, so is expected to be more influenced by up-gradient groundwater (with rainfall and pumping influences) than the bores close to the Pilot Site.

As suggested by the modelling, the bore 6, 7 and 8 hydrographs show groundwater level changes that are difficult to distinguish from their primary correlation with rainfall and pumping periods. This means that spring fed drains below SH1 are unlikely to be measurably increased as a result of Pilot Site operations, though this may change with other nearby MAR sites also operational. The waterways more likely to receive increased flows from higher groundwater levels are those to the north east of the Lagmhor Pilot Site.

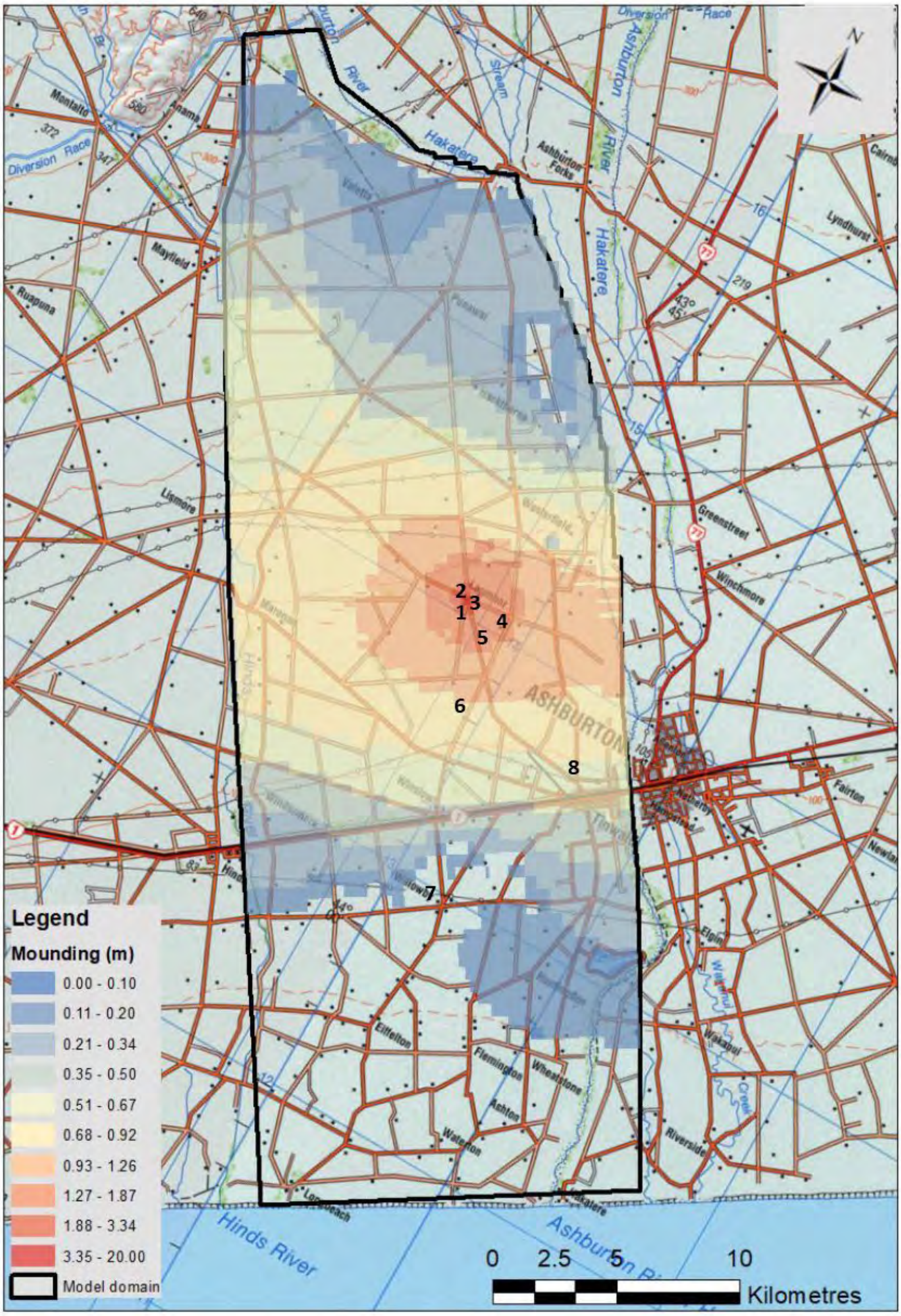


Figure 2-3: Durney, 2019 (Figure 5-16 Modelled groundwater level change in response to the MAR trial) plus numbered monitoring bore locations

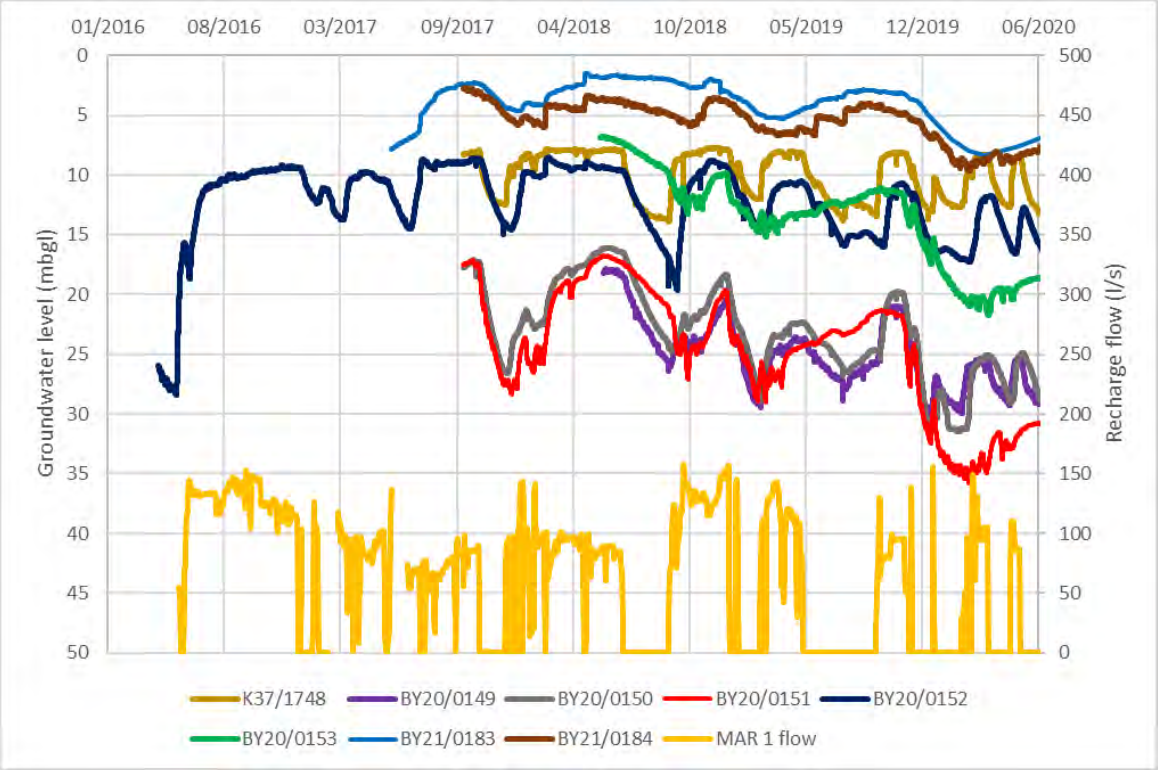


Figure 2-4: Monitoring bore records, colour coded to locations in Figure 2-3

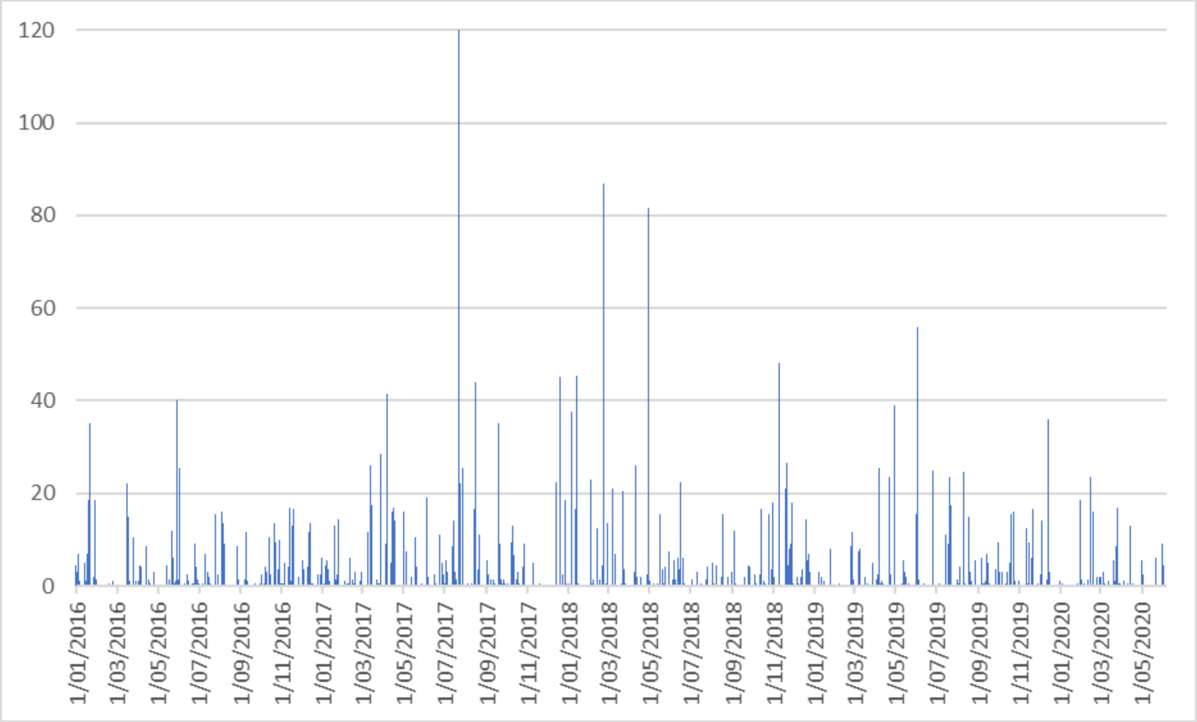


Figure 2-5: Hinds Plains daily rainfall

Figure 2-6 presents modelled average percentage MAR water, representing groundwater quality changes after 5 years. For groundwater in the identified depth range (approximately 20-45 m below ground level), it comprised 80-100% MAR water immediately down-gradient from the Pilot Site (red), reducing to a 10-20% MAR groundwater component at the margins of the Pilot Site-influenced area (dark green). Numbers 1-13 have been added to Figure 2-6, at the location of bores with water quality monitoring information relevant to the Pilot Site analysis. The nitrate-N concentrations measured at these numbered bores are presented alongside Pilot Site inflow data in Figures 2-8 to 2-10. Bores with green dotted lines show evidence for a decrease in nitrate-N concentration (along with other water chemistry changes) and a lag time consistent with water particle travel time estimates in the Year 1&2 MAR reports. It is therefore concluded in the Year 2 report that these wells are in the Lagmhor Pilot Site zone of water quality influence. Results to Year 4 do not change these conclusions. Bores with red coloured dotted lines do not show nitrate-N concentration changes consistent with expected water particle travel time, and it is concluded that these wells remain outside the Lagmhor Pilot Site zone of water quality influence.

Bores close to the Lagmhor Pilot site (Fig. 2-8) show nitrate-N reductions of at least 50%, consistent with the influence of low nitrate MAR water, as indicated by Figure 2-6. In the bores further down-gradient from the Lagmhor Pilot Site (Figs 2-9 and 2-10), bore 6 on Figure 2-6 does not show the influence of the MAR input, while bores 7-9 plus bore 12 do show a potential water quality influence. This suggests that the MAR water is following the locally-varying hydraulic gradient presented in Figure 2-7 (blue arrows, at right angles to the blue piezometric contours), rather than south easterly, at right angles to the land contour in Figure 2-6 (brown wavy line just inland from SH1). The maximum nitrate-N changes in bores 7-9 and 12 are reasonably consistent with the influence of MAR proposed by the modelling in Figure 2-6. The monitoring to date for bore 13 (BY21/0183), including a groundwater nitrate sensor installed for part of 2019, suggests that no measurable effect on water quality has occurred, to date, in an area of shallow groundwater feeding the lowland waterways and springs. The average flow rate from the first four years of operations at the Lagmhor site is 47 l/s. Durney (2019) concludes that no measurable water quality effect on potentially connected lowland waterways is likely even if an average of 110 l/s from contributing MAR sites is achieved, and this result confirms this conclusion. Monitoring will continue to understand both the individual and cumulative influences of MAR sites, as more become operational in this area.

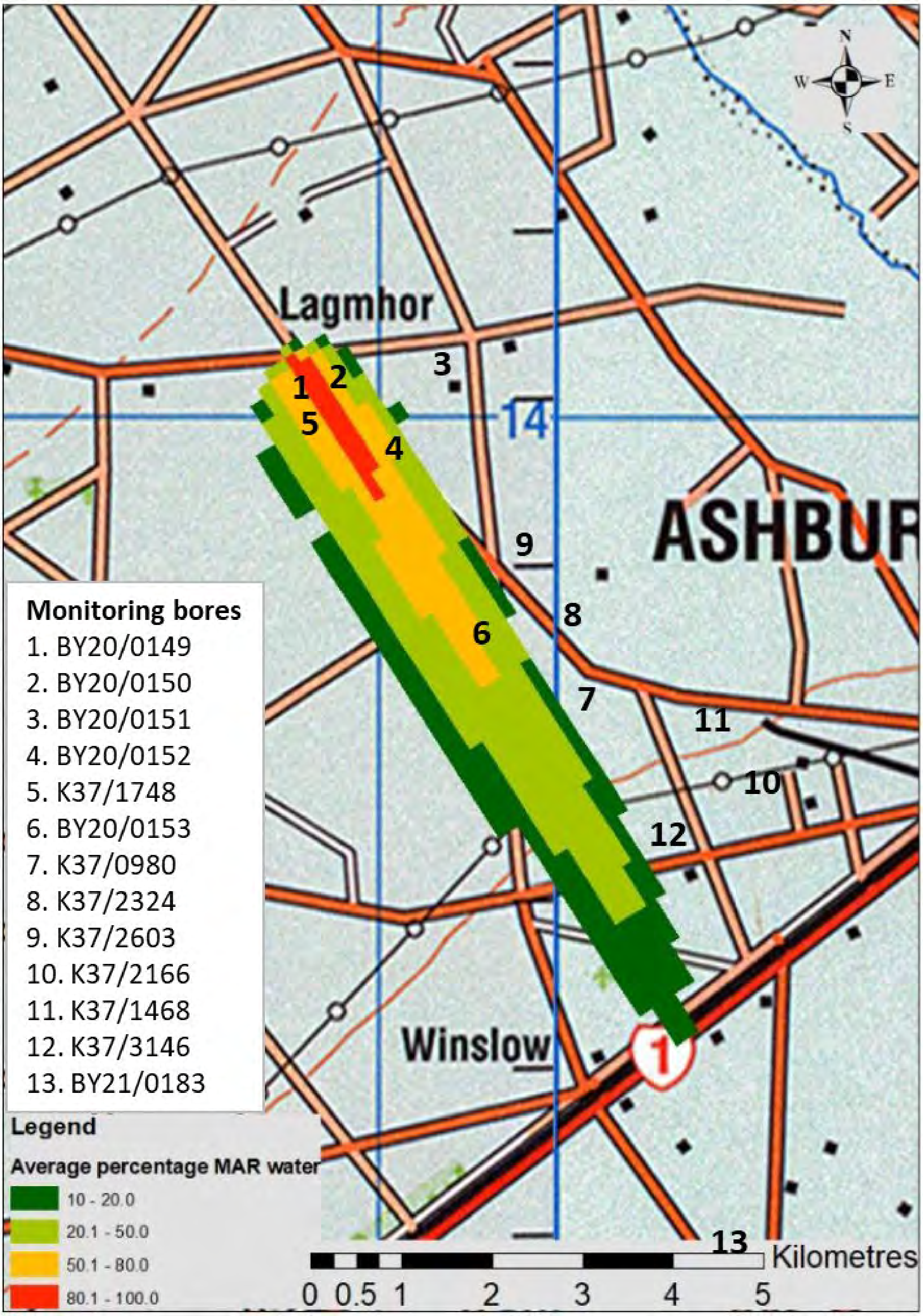


Figure 2-6: **Modelled groundwater quality change after 5 years in response to the MAR trial (from Durney, 2019, Figure 5-23 MAR plume Layer 3)**

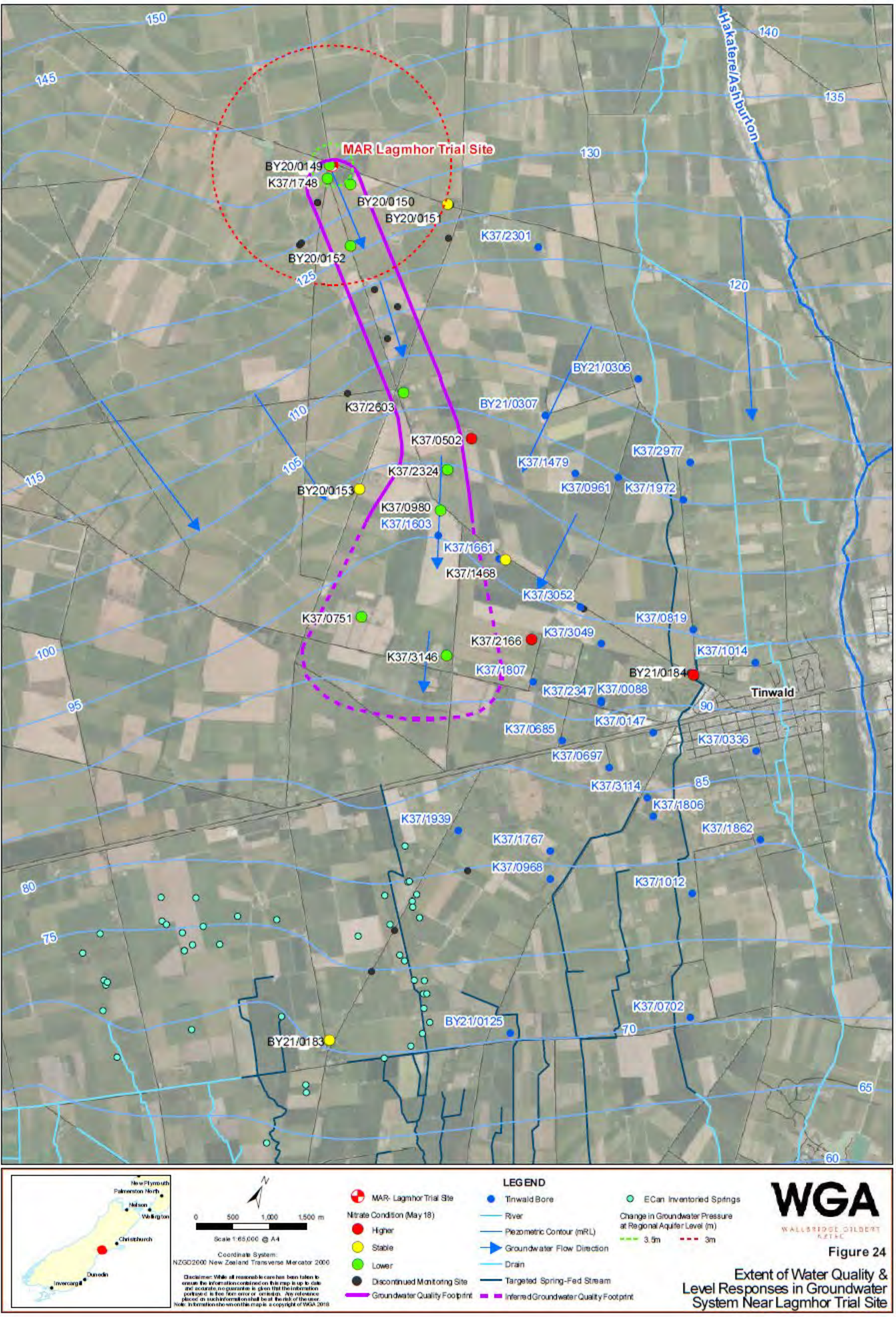


Figure 2-7: Figure 24 from Year 2 report (with updated bore names) showing assessed groundwater level and quality responses to Pilot Site operations

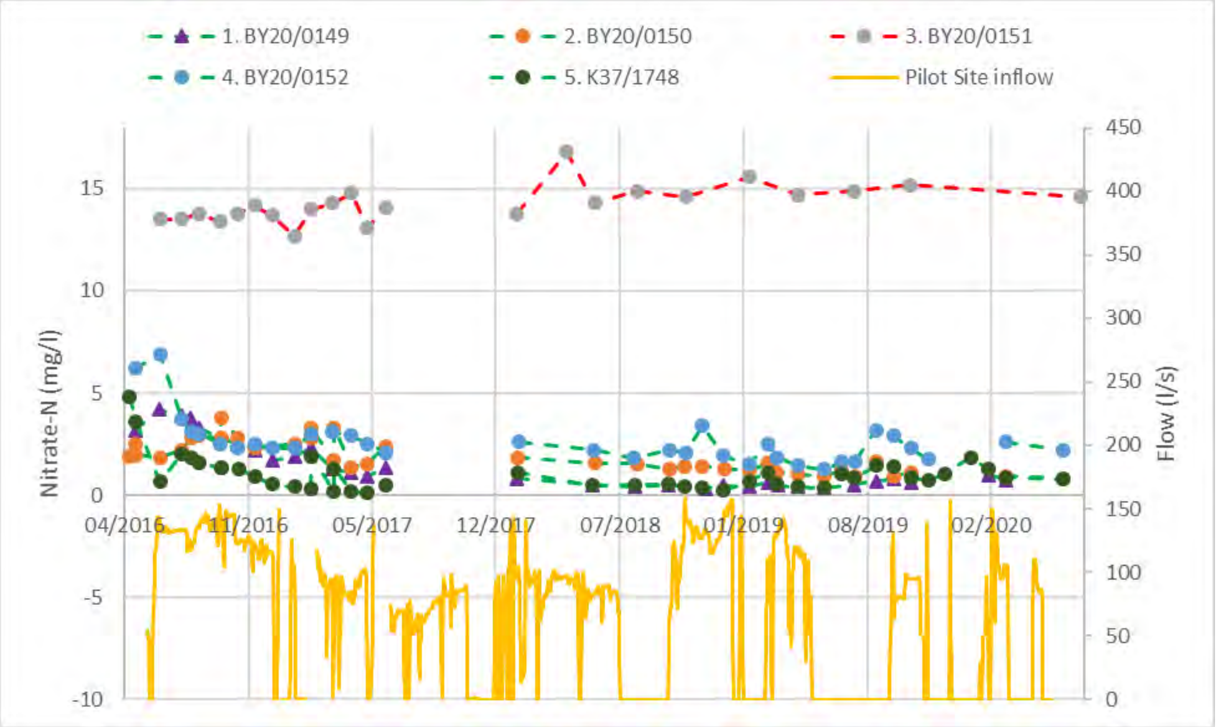


Figure 2-8: Nitrate-N measured concentrations for wells close to the Lagmhor Pilot Site

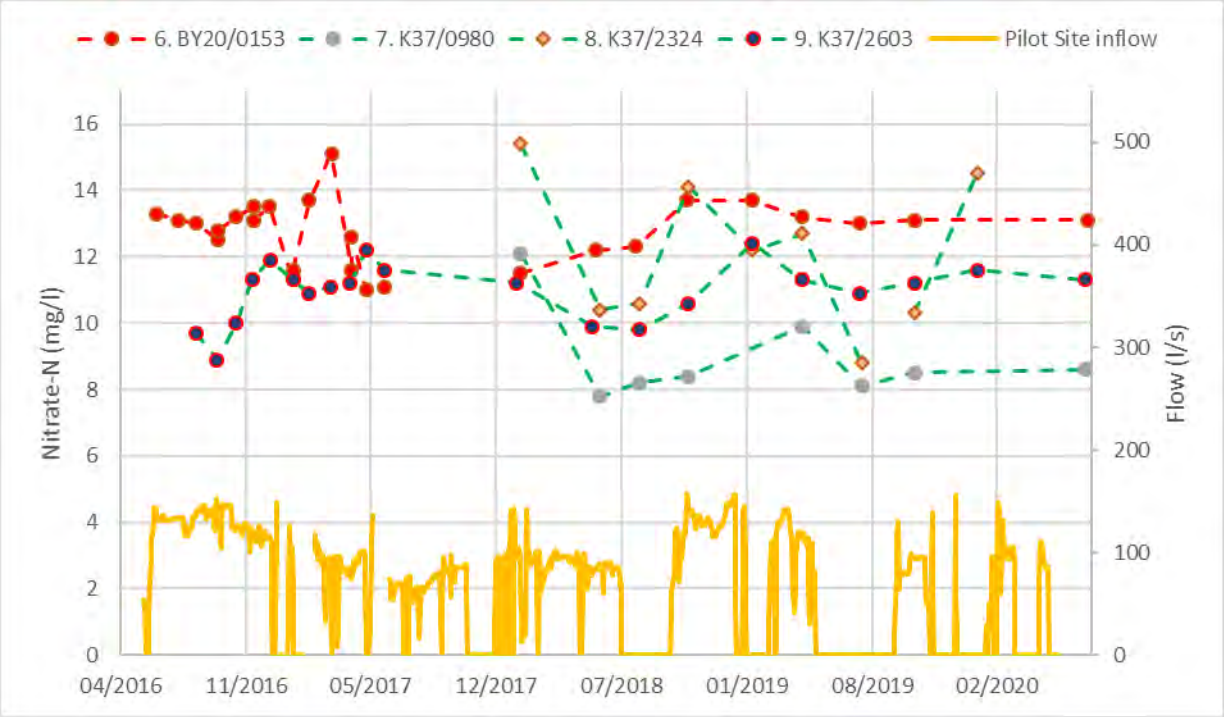


Figure 2-9: Nitrate-N measured concentrations for wells 3-5 km from the Lagmhor Pilot Site

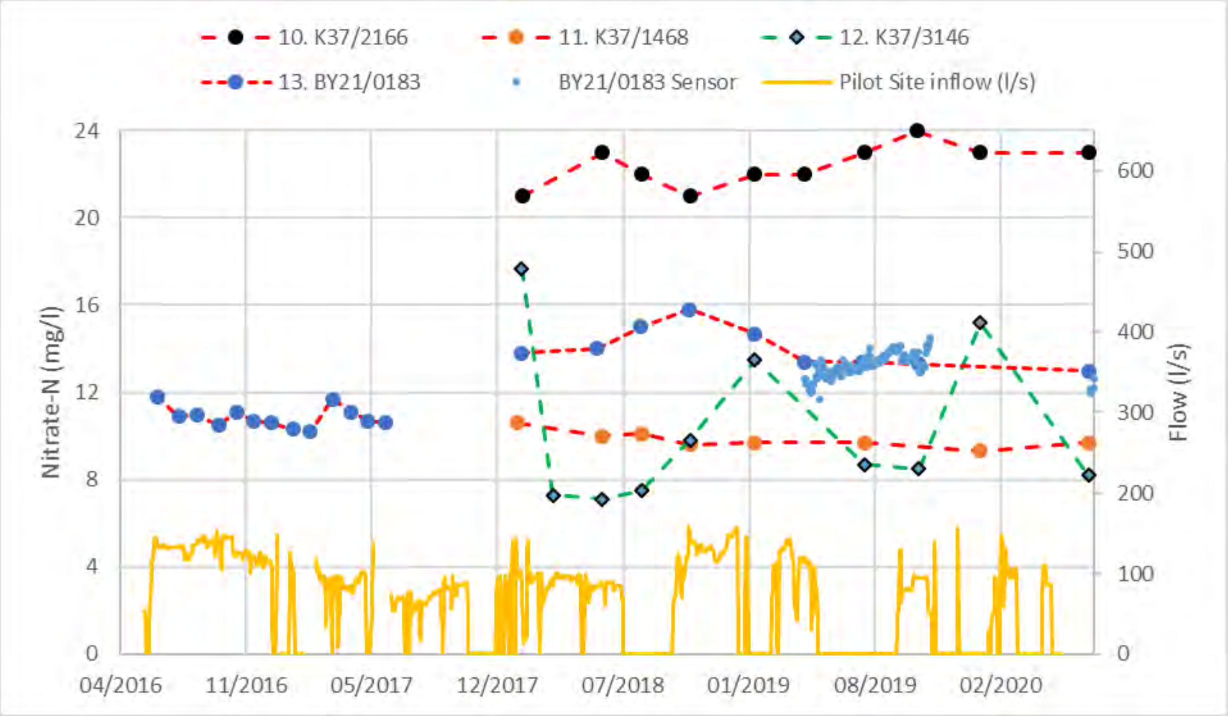


Figure 2-10: Nitrate-N measured concentrations for wells 6-12 km from the Lagmhor Pilot Site

3 Hekeao Hinds River Project

The Hekeao Hinds River Project (HHRP) has been operational since September 2018 (Figure 3-1). This site receives Rangitata River water, via siphon, directly from the Rangitata Diversion Race (RDR). Consented supply flow is 210 l/s, but a maximum flow rate of only 170 l/s has been introduced to date. In addition to the recharge channels and basins, lizard habitat (under DOC Covenant) has been created away from the flood plain, an oxbow wetland (containing potential Canterbury mudfish habitat) has been rehabilitated and is supported by the raised local groundwater, and native plants (wetland and dryland) have been reintroduced (Figures 3-2 and 3-3).

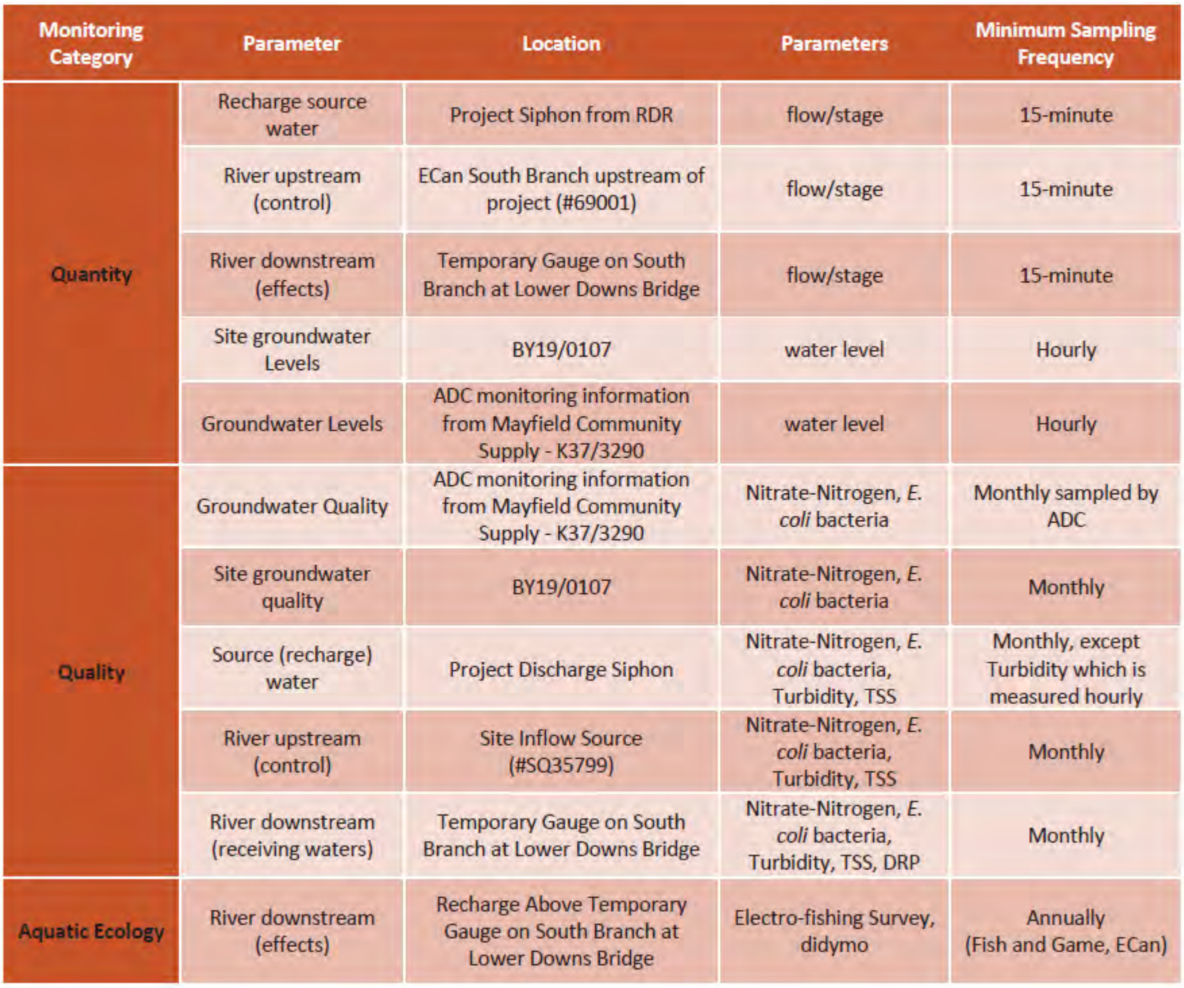
Figure 3-1: HHRP site overview

Table 3-1 and Figure 3-4 present the monitoring requirements for HHRP consent CRC186228 (now CRC210704), with key compliance monitoring presented in the annual compliance monitoring report. Recharge source water has remained low in nitrate-N and *E. coli* since 2018, but turbidity varies significantly with Rangitata River flow changes (Table 3-2). The turbidity trigger for ceasing MAR operations at this site has been set at 100 NTU, with operations resuming when turbidity is below 60 NTU. This is a higher trigger than at other MAR sites as the heavy sediment is relatively easy to clean from the recharge basins. Site shutdowns to date for high turbidity occur approximately 20% of the time. The site is also shut down when there are high flows in the adjacent south Hinds River (>4000 l/s), which, to date, have occurred 1.3% of the time.

Figure 3-2: View across wetland to Hekeao / South Hinds River prior to rehabilitation (2018)

Figure 3-3: Wetland after rehabilitation (2020), supported by the HHRP and under preparation as Kōwaro / Canterbury mudfish habitat

Table 3-1: HHRP Monitoring (CRC186228)



Monitoring Category	Parameter	Location	Parameters	Minimum Sampling Frequency
Quantity	Recharge source water	Project Siphon from RDR	flow/stage	15-minute
	River upstream (control)	ECan South Branch upstream of project (#69001)	flow/stage	15-minute
	River downstream (effects)	Temporary Gauge on South Branch at Lower Downs Bridge	flow/stage	15-minute
	Site groundwater Levels	BY19/0107	water level	Hourly
	Groundwater Levels	ADC monitoring information from Mayfield Community Supply - K37/3290	water level	Hourly
Quality	Groundwater Quality	ADC monitoring information from Mayfield Community Supply - K37/3290	Nitrate-Nitrogen, *E. coli* bacteria	Monthly sampled by ADC
	Site groundwater quality	BY19/0107	Nitrate-Nitrogen, *E. coli* bacteria	Monthly
	Source (recharge) water	Project Discharge Siphon	Nitrate-Nitrogen, *E. coli* bacteria, Turbidity, TSS	Monthly, except Turbidity which is measured hourly
	River upstream (control)	Site Inflow Source (#SQ35799)	Nitrate-Nitrogen, *E. coli* bacteria, Turbidity, TSS	Monthly
	River downstream (receiving waters)	Temporary Gauge on South Branch at Lower Downs Bridge	Nitrate-Nitrogen, *E. coli* bacteria, Turbidity, TSS, DRP	Monthly
Aquatic Ecology	River downstream (effects)	Recharge Above Temporary Gauge on South Branch at Lower Downs Bridge	Electro-fishing Survey, didymo	Annually (Fish and Game, ECan)

Table 3-2: HHRP source water turbidity distribution

Percentile	RDR Turbidity, 2018-20 (NTU)
10	0
20	8
30	13
40	20
50	26
60	39
70	55
80	106
90	247
100	1,304

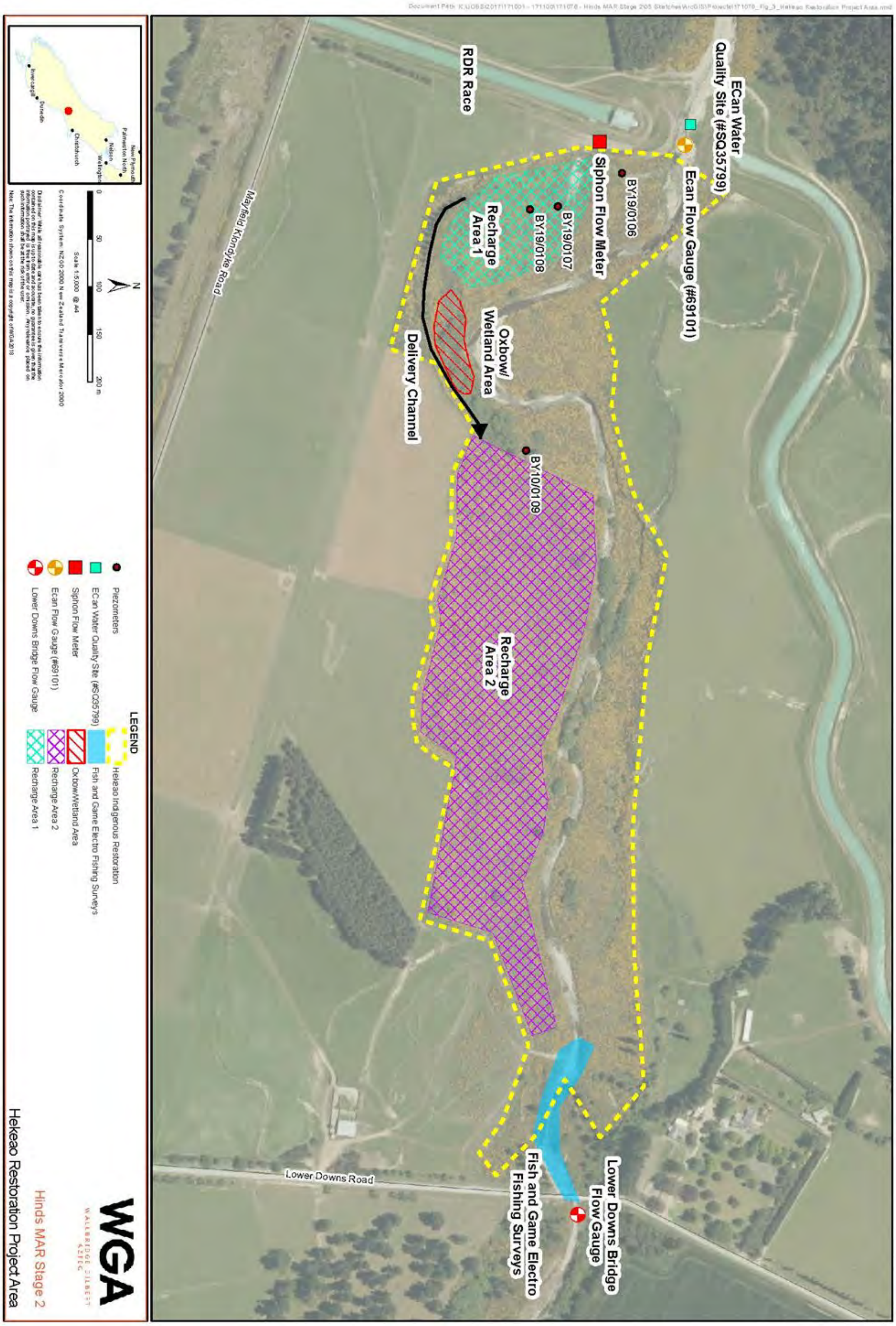


Figure 3-4: Hekeao Hinds River Project (HHRP) site and monitoring points (Source: MAR Year 2 report)

3.1 Water quantity monitoring

Figure 3-5 compares up-gradient Hinds River flow (RDR Siphon #69101) with HHRP flow and down-gradient flow (Lower Downs #69106). When the HHRP site is turned on site #69106 responds within a day, showing a flow increase less than the supplied HHRP flow. This suggests that HHRP flow is recharging local groundwater as well as the river. Sites #69101 and #69106 produce similar flows when the HHRP recharge site is turned off, thus flow differences can be attributed to HHRP recharge. The flow differences vary with river flow, but the low river flow period in February 2020 suggests that up to 60 l/s may be recharging groundwater at the site. The median Year 3 and 4 flows of 131 l/s at Site #69101 and 181 l/s at Site #69106 suggest a 39% increase in median flow due to HHRP recharge. The proportion of time the reach is flowing at less than 50 l/s also reduces from 28% to 5% (see February 2019 and January 2020 in particular).

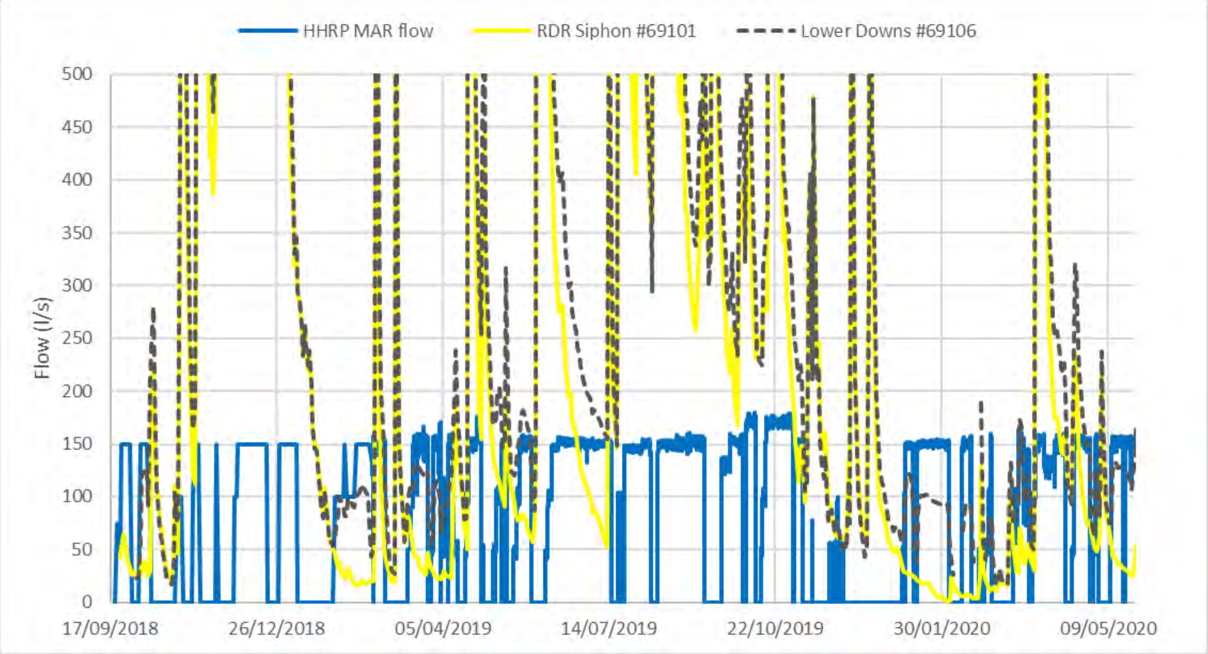


Figure 3-5: HHRP and Hekeao Hinds River flow

Figure 3-6 shows minimum depth to groundwater lines in green (increasing with increasing distance from the river) and four local groundwater level monitoring bores. K37/0278 (16 mbgl) and K37/2934 (145 mbgl) log levels every 15 minutes, while K37/3290 (119 mbgl) logs groundwater level every 60 minutes. K37/2933 (84 mbgl) is manually measured monthly. Two shallow (2.3 and 2.5 m respectively) piezometers (BY20/0222 and BY20/0223) were installed, due to local landowner concerns on the north side (true left) of the south Hinds River, early in Year 4, to assist with understanding the relationship between river flows and groundwater between the south and north branches of the Hekeao / Hinds River.

Figure 3-7 presents the results of a Hekeao South Branch Hinds River gauging survey undertaken by Environment Canterbury Hydrologists during Year 4. It shows that for river flows of up to 500 l/s at the Lower Downs Road (Ballantynes) Bridge, 6 km upstream from the confluence with the North Branch, all flow is recharged to groundwater by approximately 3 km upstream from the confluence. For higher flows, groundwater recharge in this reach is approximately 350-450 l/s.

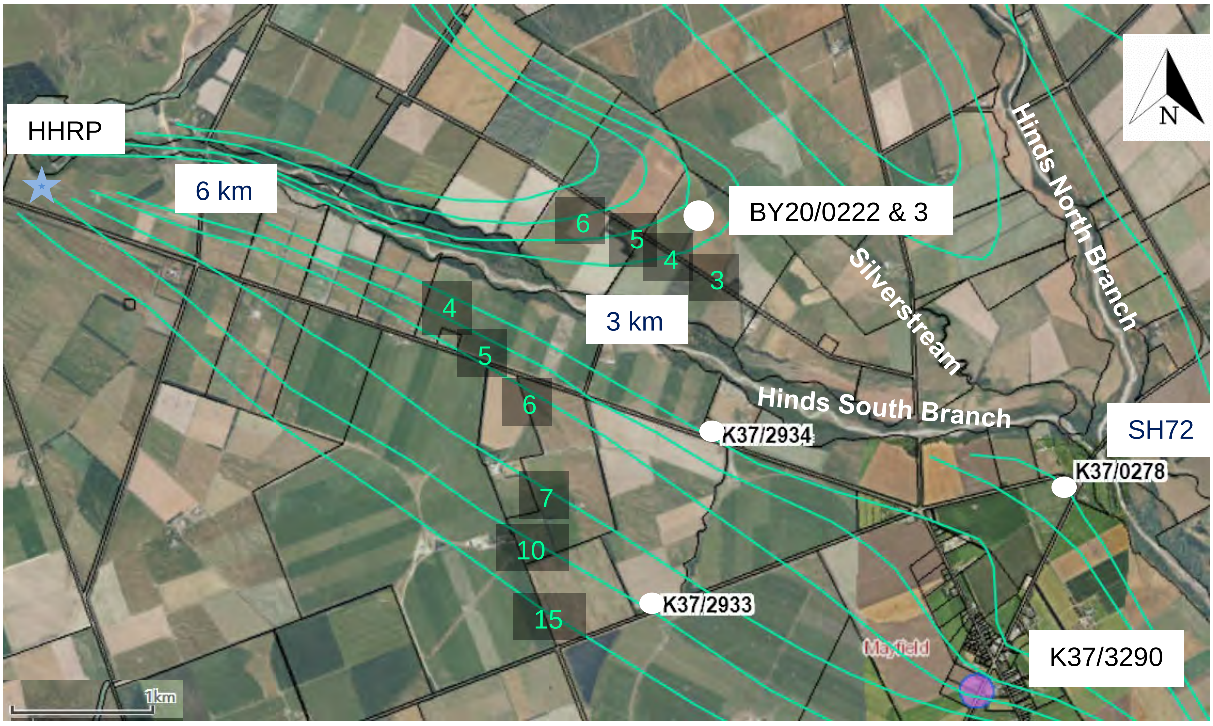


Figure 3-6: **HHRP down-gradient monitoring wells and minimum depth to groundwater contours (in m)**

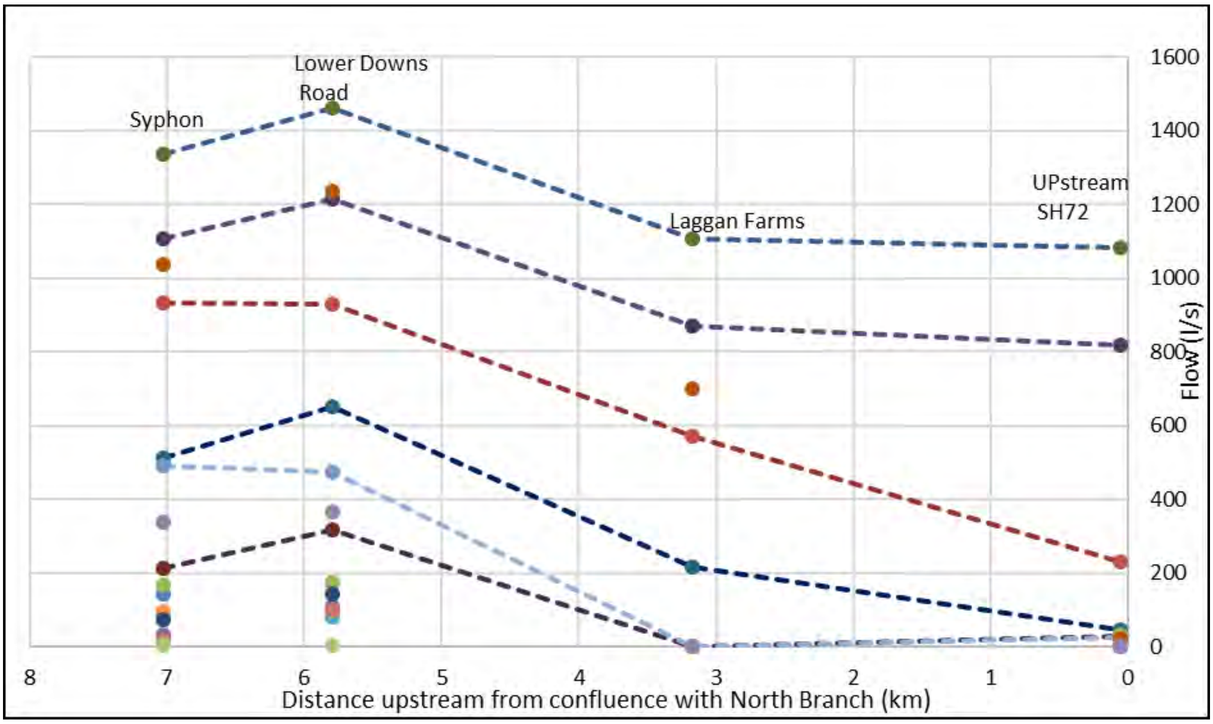


Figure 3-7: **Hekeao South Branch Hinds flows from Siphon to the confluence with the North Branch, with key points on Fig. 3-6 (Source: Gabites, 2020)**

Figure 3-8 suggests that a portion of Hekeao South Branch Hinds River recharge moves to the true left of the river and influences groundwater levels in bore BY20/0222, located approximately 3km downstream, and to the north of the river (see Figure 3-6). River flows greater than 500 l/s correspond with a brief rise in groundwater level at BY20/0222, while sustained higher river flows correspond with sustained higher groundwater levels. Groundwater level increases generally start within a day of river flow increases, although this is not shown in April 2020 due to the groundwater level being very low (below the base of the bore at times). Nearby groundwater pumping records were not available, so their influence could not be considered. Rainfall events of at least 15 mm/ day (Figure 3-9) correspond well with freshes down the river. The rainfall will also contribute to increased groundwater levels through land surface recharge from the contributing catchment (which includes the Surrey Hills). This groundwater feeds the Silverstream tributary which supplies the main branch of the Hekeao Hinds River at the confluence of the North and South Branches. The local hydraulic gradient between the South and North branches of the Hekeao Hinds suggests that recharged groundwater will also follow the direction of the main branch of the Hekeao Hinds River, thus supporting the river ecosystem and its flowing extent.

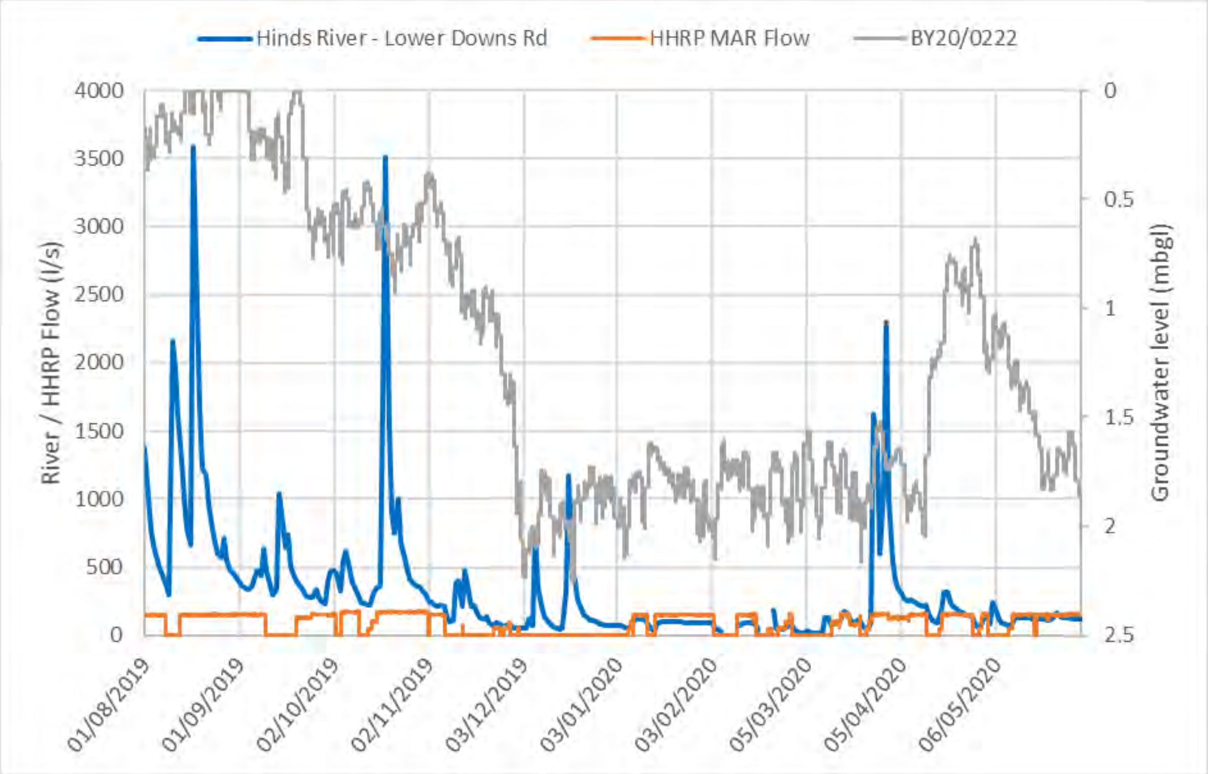


Figure 3-8: Relationship between Hekeao South Branch Hinds River at Lower Downs Rd and groundwater levels in BY20/0222.

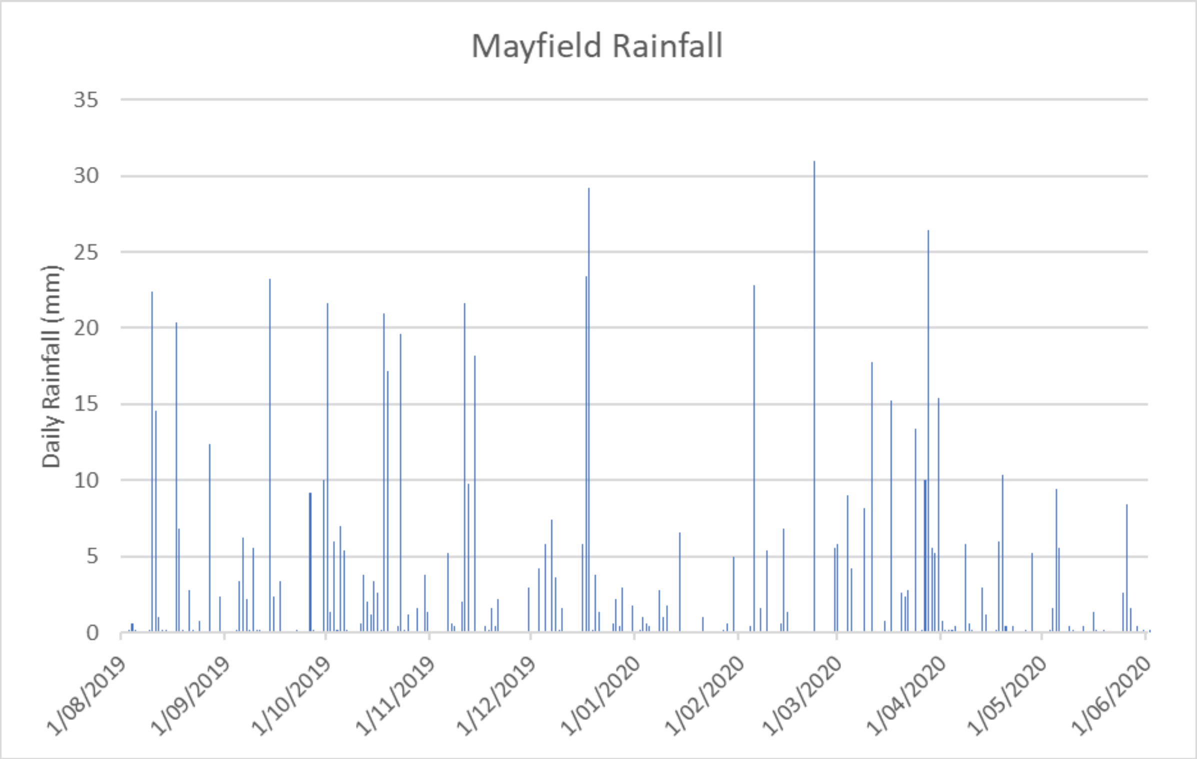


Figure 3-9: Daily rainfall at Mayfield for Years 3 and 4

With regard to concerns about HHRP recharge flow influencing BY20/0222 groundwater levels, we can conclude that current recharge flows, of approximately 170 l/s, do not in themselves cause BY20/0222 groundwater level increases, and recharge would need to increase to approximately 1000 l/s before this occurred. However, the sustained groundwater level increases from river freshes suggests that HHRP recharge rates after a river fresh could be held at ~50 l/s (for local wetland enhancement) longer than current sustained HHRP flow, thus minimising recharge contribution to BY20/0222 groundwater levels. This will be considered further in Year 5.

Figure 3-10 compares Hekeao Hinds River flow (up to 4 m^3/s) at the RDR Siphon, HHRP flow and depth to groundwater in K37/0278. This shallow (15 m) bore beside the river, responds quickly (within days) to freshes greater than 1000 l/s. The effect of HHRP flows is therefore expected to be most measurable during sustained periods of naturally low river flow, as in early 2020. Here we can see groundwater levels remaining relatively stable when we would otherwise expect them to decline. Visual observations of surface water flow in the Hekeao / Hinds River during Spring 2020, at the Maronan and Winslow Road ridges, was considered unusual following the low natural river flows since late 2019. Further monitoring will be required before the influence of recharge flow on the extent of flowing surface water in the Hekeao / Hinds River, during dry periods, can be assessed.

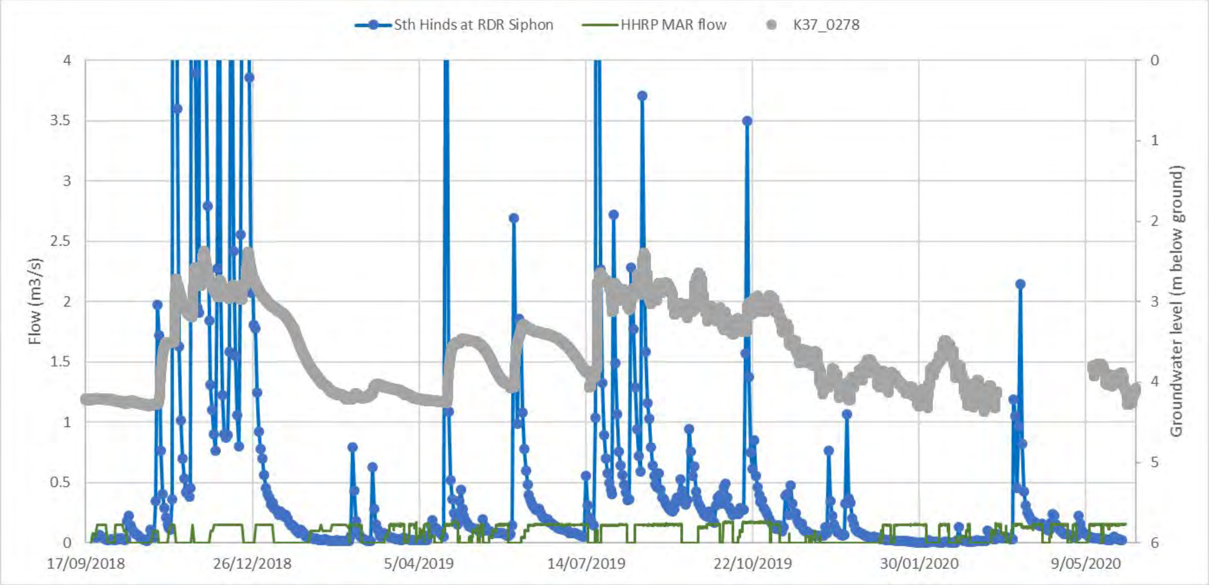


Figure 3-10: HHRP flow, Hinds River flow and K37/0278 groundwater level

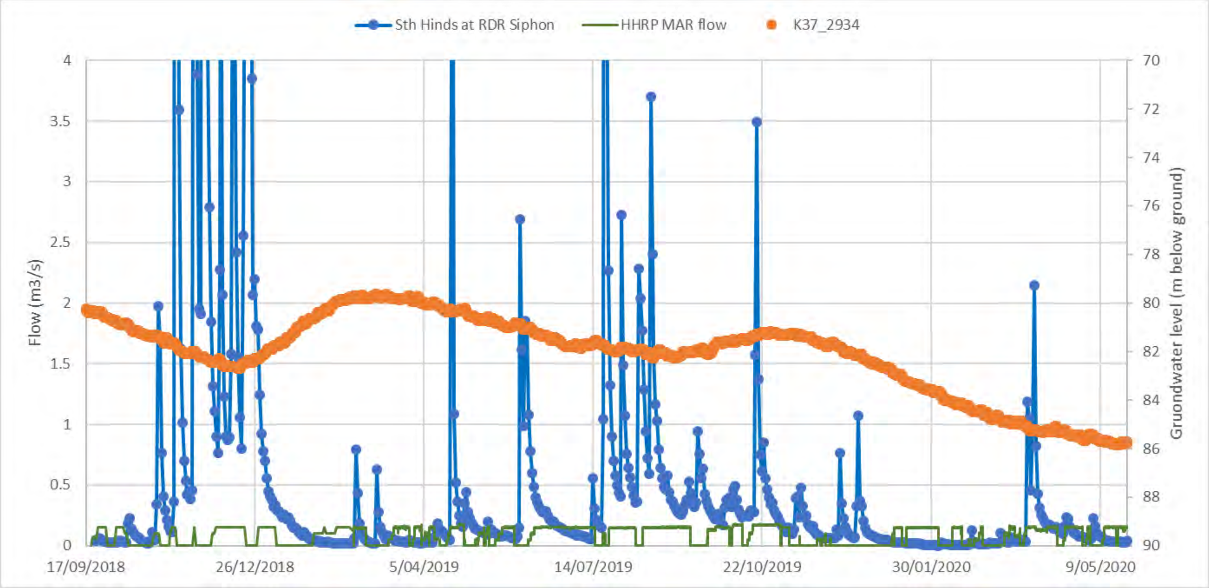


Figure 3-11: HHRP flow, Hekeao Hinds River flow and K37/2934 groundwater level

Figure 3-12 compares Hekeao Hinds River flow (up to 4 m^3/s) at the RDR Siphon, HHRP flow and depth to groundwater in the Mayfield community supply bore (K37/3290). This deep (119 m) bore, further away from the river (see Figure 3-6) shows significant daily variation in response to pumping. It also shows a slow (approximately 50 days) damped response to large river freshes. Given the dominating factors of bore pumping and large river freshes, the effects of HHRP flow are not likely to be measurable. It will continue to be monitored, however, and assessed in more detail, particularly in case a long period of low flows / groundwater eventuates (e.g., conditions similar to the 2015/16 drought that resulted in this bore dropping approximately 25 m to more than 119 m below ground level).

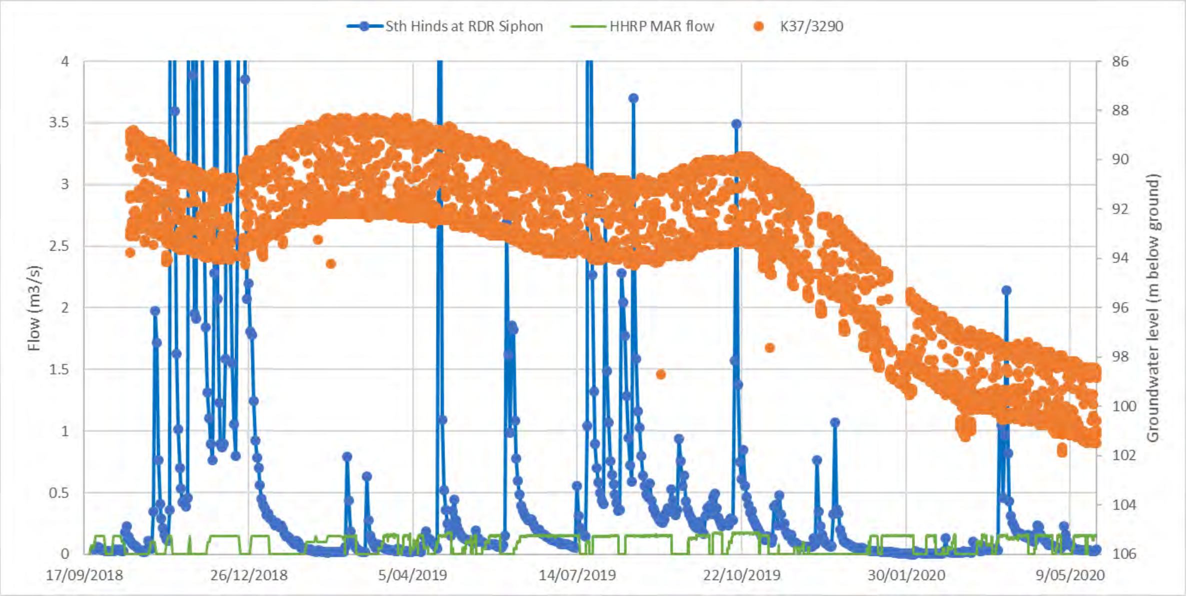


Figure 3-12: HHRP flow, Hekeao Hinds River flow and K37/3290 groundwater level

3.2 Water quality monitoring

The advice note for discharge consent CRC186228 requires consideration of an *E. coli* and a nitrate trigger level for site shutdown following its first year of operation in order to ensure protection of the receiving environment. Figure 3-13 presents the HHRP site *E. coli* monitoring results for the first 21 months of operation of the HHRP site. *E. coli* counts are graphed on a log scale due to the significant variation in results. The 700 MPN/100 ml level is included to enable comparison with the consented MAR Test Site shutdown trigger level. The maximum measurable count using existing methods is 2420 MPN/100 ml, so results assigned this value can be significantly greater than this in reality.

The key point of interest in Figure 3-13 is whether HHRP source water contributes to increased *E. coli* counts between the up-gradient (South Hinds at RDR) and down-gradient (South Hinds Lower Downs Road) river monitoring points. If this were to occur, then a source water shutoff trigger level would be determined, as exists for the MAR Test Sites (currently at 700 MPN/100 ml). With all Year 3 and 4 source water with *E. coli* counts of less than 200 MPN/100 ml, there is no evidence for this requirement. On one occasion (30/11/2018) the *E. coli* counts between South Hinds at RDR and South Hinds Lower Downs Road increased from 1,200 to at least 2,420 MPN/100ml, but *E. coli* counts in the source water were less than 100 MPN/100ml, so the additional *E. coli* was more likely to have originated from a another source between the monitoring points. The three BY19/0107 (6 m deep, see Fig. 3-4 for location) monitoring results where *E. coli* counts were greater than 1 occurred during high river flow events when the river had high *E. coli* counts, which appears to have impacted on connected groundwater. For the majority of monitoring data points the *E. coli* counts decrease between South Hinds at RDR and South Hinds Lower Downs Road, most likely due to the addition of the HHRP recharge water.

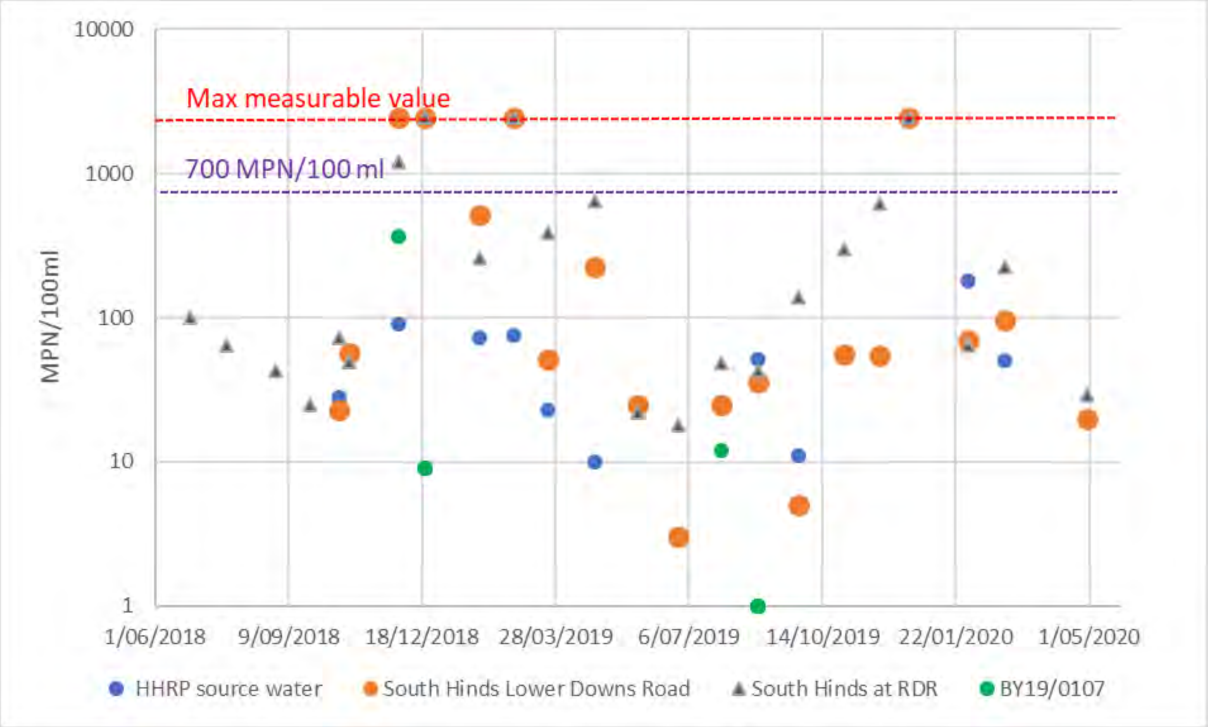


Figure 3-13: HHRP *E. coli* monitoring

Figure 3-14 presents the HHRP site nitrate-N monitoring information for Years 3 and 4. Source water Nitrate-N concentrations are very low (generally below 1 mg/l), though groundwater concentrations (in BY19/0107) tend to be slightly higher, as the recharge water mixes with recharged river water and land surface recharge. In the first six months of operation, river nitrate-N concentrations were similar up-gradient and down-gradient from the recharge site. Between late March 2019 and November/December 2019, concentrations were consistently lower at the down-gradient site, though from this time to May 2020, the concentrations were similar again. The reduction in nitrate-N concentrations was not unexpected, given that the HHRP flow contributed a significant proportion of the Hekeao Hinds River flow at Lower Downs Road during low flow periods, though the reason for the change back in the latter months of monitoring is not clear (see Figure 3-5). The primary occasion (26/11/2019) when nitrate-N concentration increased between South Hinds at RDR and South Hinds Lower Downs Road, coincided with a brief site shutdown due to high turbidity. From the monitoring information available to date, we can conclude that there is no evidence to support the requirements to put in place a nitrate-N trigger level to trigger a site shutdown.

Water quality monitoring of the Mayfield community supply bore K37/3290 is also included in Table 3-1, to provide background information to check whether a water quality influence from the HHRP site on the bore can be identified. During Years 3 and 4 no influence was detected, with monitored *E. coli* counts remaining below detection and nitrate-N concentrations increasing slightly from 2.5 to 2.7 mg/l (Fig. 3-15).

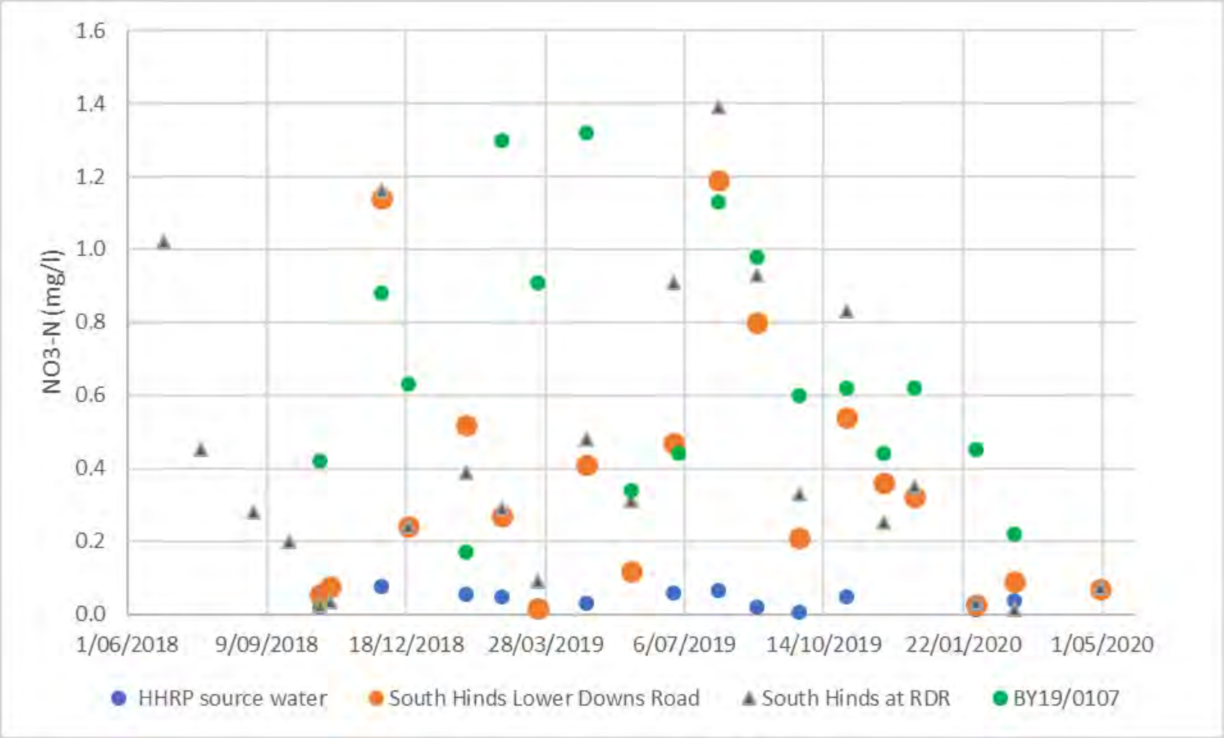


Figure 3-14: HHRP Nitrate-N monitoring

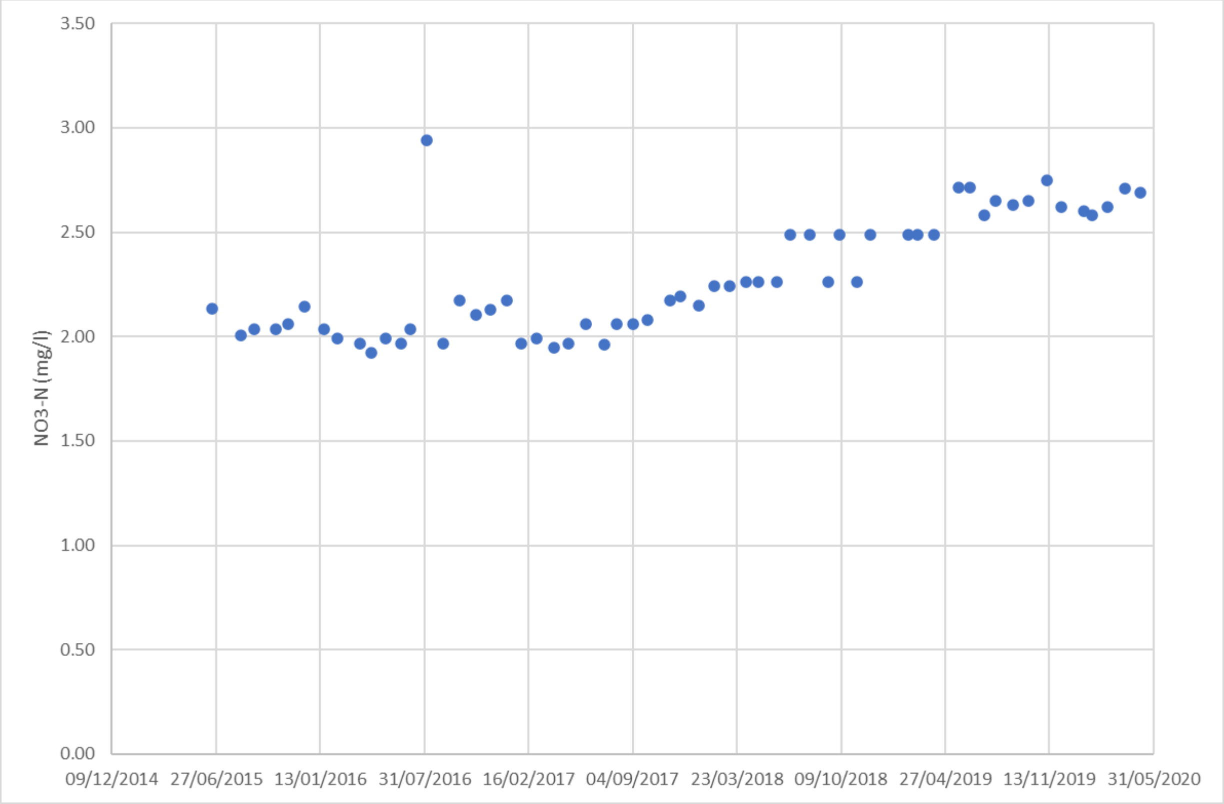


Figure 3-15: Mayfield drinking water bore K37/3290 Nitrate-N monitoring

3.3 Turbidity “Trigger Level”

Turbidity relates to the level of suspended sediment in water. This sediment can clog up recharge facilities. HHRP discharge consent CRC186228 contains the following advice note:
“The "trigger level" NTU is calculated over the first 12 months of active recharge operation using the turbidity and Total Suspended Solids (TSS) data from the siphon (Plan CRC186228, Site A), ECan Water Quality Site SQ35799 (Plan CRC186228, Site B), and at the Lower Downs Bridge flow gauge (Plan CRC186228, Site C) to generate a ‘real time’ trigger for turbidity management for project operations.”

Monitoring and analysis conducted during the first 12 months resulted in a “trigger level” proposal to cease discharge at 100 NTU (at the HHRP intake automatic sensor), with up to 12 hours to cease discharge, such that short turbidity spikes could be ignored. The proposed consented recommencement trigger was also 100 NTU, though an operational recommencement of 60 NTU has been utilised for additional safety. This “trigger level” was approved by Environment Canterbury via the Compliance Monitoring Report dated 10 May 2019. Figure 3-16 shows that HHRP MAR discharge has ceased in accordance with the trigger level, in particular for an extended period in December 2019, due to the Rangitata River floods.

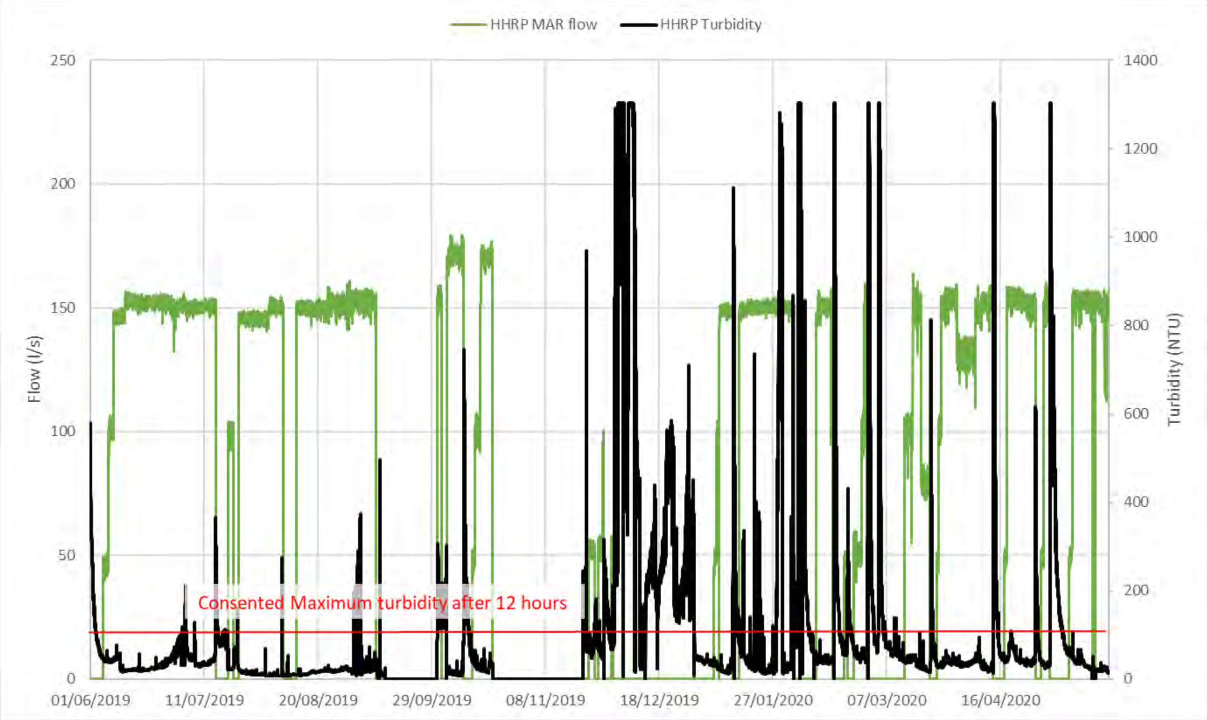


Figure 3-16: HHRP turbidity monitoring

3.4 Aquatic Ecology monitoring

The Hekeao Hinds River is a priority for restoration of ecosystem health and recreation amenity, under the Managed Aquifer Recharge (MAR) trial for the Hekeao Hinds Plains. To monitor long term changes in fish diversity and population sizes and any potential MAR influence, Fish and Game, along with Environment Canterbury, implemented monitoring surveys in 2017. Surveys comprise annual assessment of fish diversity and abundance, by electric fishing at two sites in the lower river, below SH1, and one upper river site downstream from the HHRP site as detailed in Table 3-1 (aquatic ecology monitoring). All sites are 30 m long with upstream and downstream nets used to enable diminishingreturn population estimates to be calculated. The most recent South Hinds River survey that was able to be undertaken, was in Year 3 (2019/20) at the Lower Downs Bridge site (Figure 3-4). Only three fish species were found – upland bully (66% to 99%), Canterbury galaxiid (34%) and brown trout (1%).

Additional aquatic ecological monitoring was initiated above (RDR Siphon) and below (Lower Downs Bridge) the HHRP site, following commissioning in September 2018,. This consisted of monthly invertebrate monitoring, carried out using the Stream Health Monitoring and Assessment Kit (SHMAK) method, and quarterly fish monitoring, using a single pass electric fishing machine method (EFM), over a 50m reach, to provide a semi-quantitative estimate of fish abundance and species present.

Figure 3-17 presents the SCHMAK scores and flow to date for the above (RDR Siphon), and below (Lower Downs Bridge), sites. Both SCHMAK scores decreased after the November 2018 floods, and then took a few months to improve. Following this period, the SCHMAK at both sites increased to a score that consistently sat between 8 and 9. This indicates invertebrate communities at both sites are reflective of good water quality and habitat under relatively stable flow conditions (Biggs et al. 2002), including extended low flow periods such as early 2020.

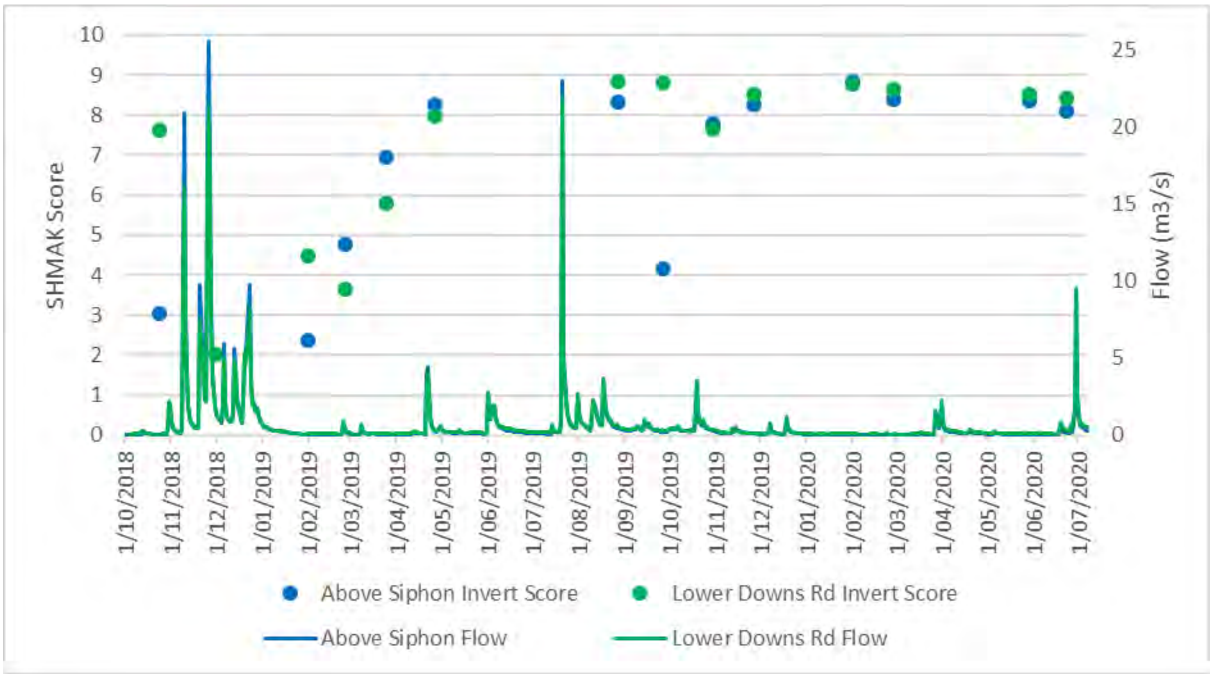


Figure 3-17: Macroinvertebrate communities and flow regime of the Hinds River South Branch (from Dynes, 2020)

Figures 3-18 and 3-19 present fish abundance monitoring at the RDR siphon and Lower Downs Road flow HHRP sites. Canterbury Galaxias and bullies (Upland and an unidentified species) were observed at both the sites. While populations of both the Canterbury Galaxias and bully species were comparable between sites, there were often more individuals observed at the Lower Downs Road site, particularly in terms of Upland Bully numbers. Under low flow conditions (<200 l/s), the Lower Downs Rd site has more flow than the RDR Siphon site upstream, when HHRP is operational. This may have provided increased habitat area, allowing the site to support greater densities of fish. Further information is available in Dynes (2020).

Surveys to identify brown trout spawning have also been undertaken sporadically since 2011, in up to six river reaches, from the RDR siphon on the South Branch down to the river mouth, and on two reaches on the North Branch. Total counts are generally low, with less than 10 spawning sites over the whole length of the river, and a range of 0 to 2 spawning sites per river reach. The main variable contributing to the distribution and intensity of spawning, appears to be flow related (Dynes, 2020). It is expected that the Hekeao Hinds River Project will contribute to improving base flows of the South Branch and provide improved conditions for consistent trout spawning.

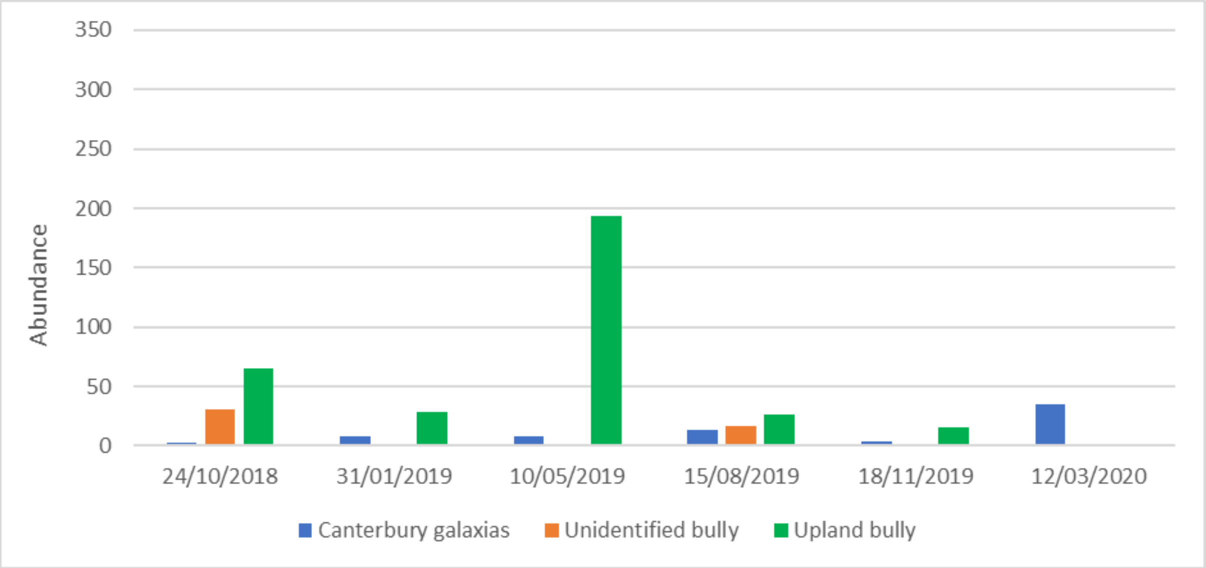


Figure 3-18: Fish Abundance for the Hekeao Hinds River South Branch above the RDR Siphon (from Dynes, 2020)

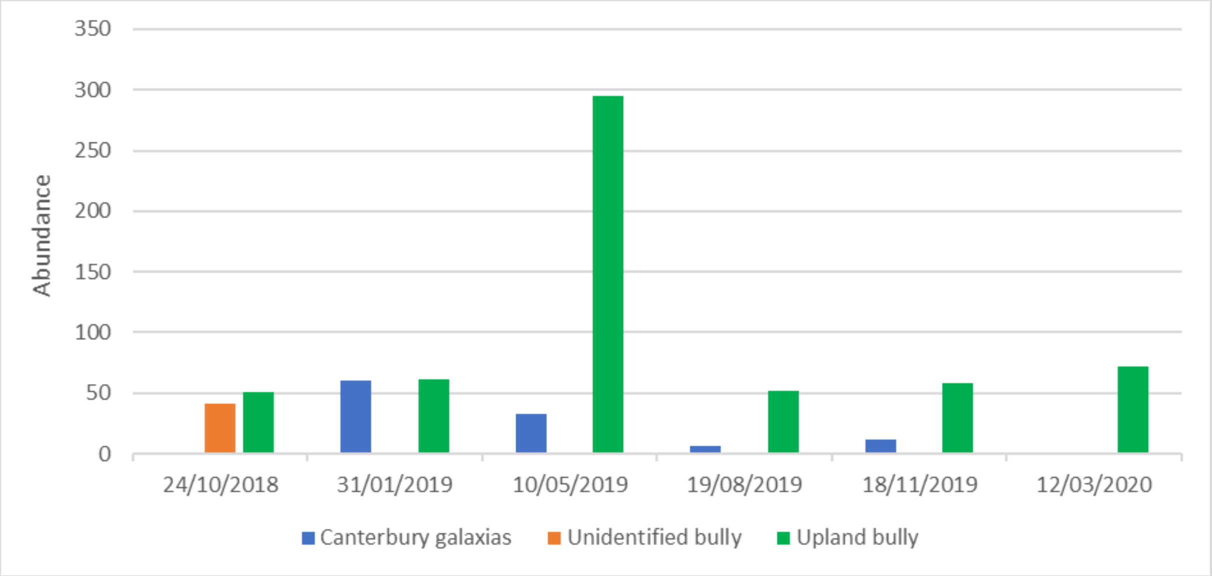
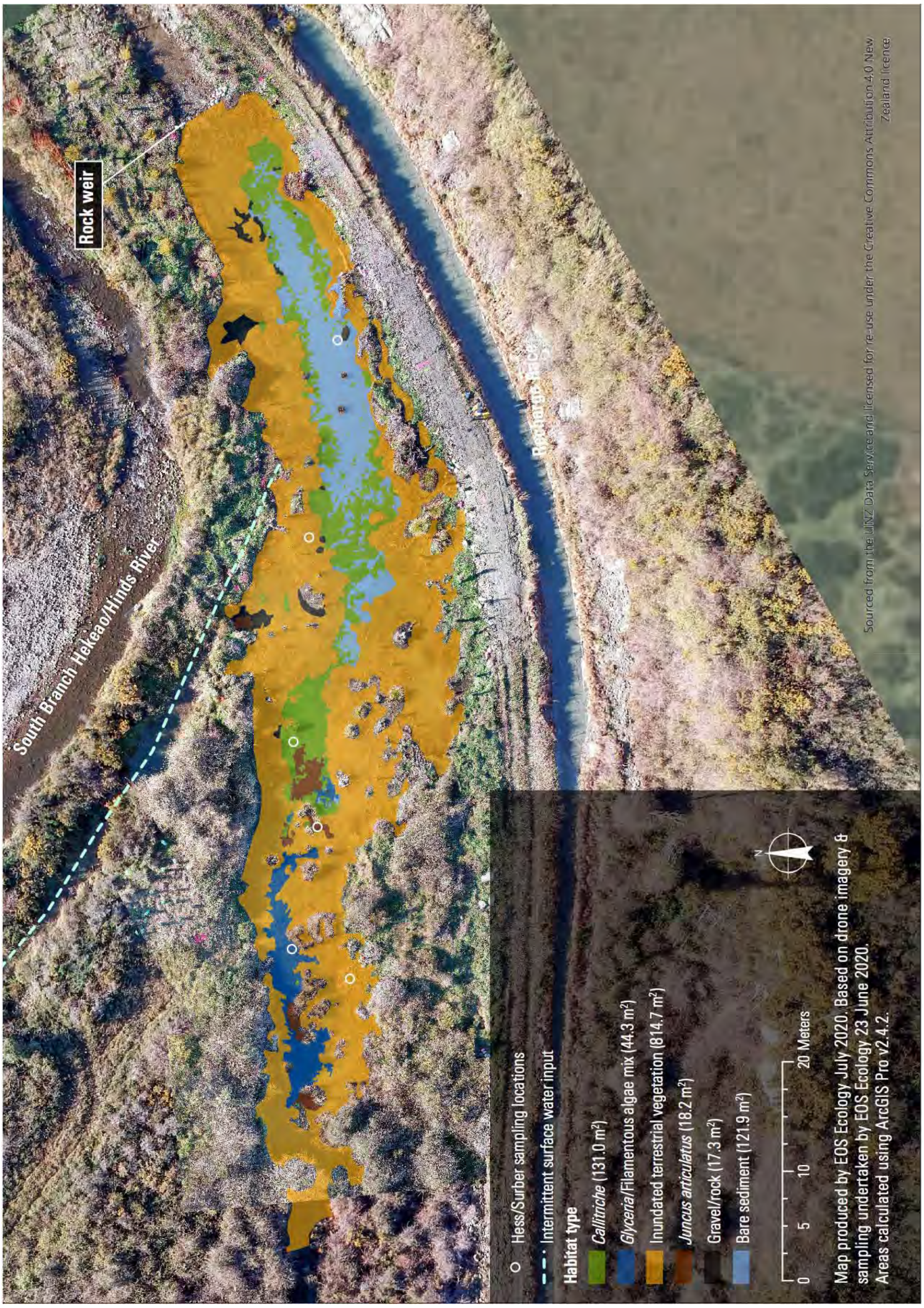


Figure 3-19: Fish Abundance for the Hekeao Hinds River South Branch at Lower Downs Rd (from Dynes, 2020)

In Year 4, additional analysis was undertaken at the HHRP wetland (Fig. 3-3), which was enhanced by the removal of willow trees during site construction. The work included habitat mapping (Fig. 3-20), invertebrate, and water quality sampling. This analysis concluded that the site is expected be suitable for Kōwaro / Canterbury mudfish release, after the addition of aquatic plants and habitat (tree stumps).

A wetland Management Plan (McMurtrie 2020a) and Kōwaro Transfer Plan (McMurtrie 2020b) have been completed and provided to DOC in support of a Kōwaro Transfer Permit application.



Map produced by EOS Ecology July 2020. Based on drone imagery & sampling undertaken by EOS Ecology 23 June 2020. Areas calculated using ArcGIS Pro v2.4.2.

Sourced from the LINZ Data Service and licensed for re-use under the Creative Commons Attribution 4.0 New Zealand licence

Figure 3-20: Habitat mapping of the South Hinds Canterbury mudfish/kōwaro release site, based on georeferenced aerial imagery and ground surveys undertaken by EOS Ecology (Source: McMurtrie, 2020a)

4 Test sites

4.1 Introduction

During Year 2, the Hinds MAR Governance Group approved an initial testing programme for up to 16 new test sites. A consent (CRC182576 – now CRC210702) to operate these sites was approved by Environment Canterbury, with testing beginning in February 2018. The overall testing programme comprised of two phases:

1. Initial testing programme. This was a short, technically-focused phase where the hydraulic behaviour of each site was tested and recorded.
2. On-going testing operations. Following initial testing, a ‘tested’ site then became operational. Each site was then operated to maximise the amount of recharge, collect on-going basic water quality and groundwater level data, and observe any longer-term changes in flow rates or general conditions.

4.2 Initial Testing and Operations

Twelve of the sixteen consented test sites were initially constructed, and hydraulic testing conducted, between February 2018 and February 2019. Each site utilised the same design (1.5 m diameter and 6 m deep pit backfilled with clean cobbles, plus two piezometers to monitor groundwater levels), as described in the Year 2 report. The results of initial testing are presented in the Year 2 and 3 reports. Learnings from this testing included:

- Shallow depth to groundwater on the plains may restrict site performance, due to groundwater mounding limiting infiltration rates. However, shallow depth to groundwater near the Hekeao Hinds River may increase infiltration performance when river flows are low, due to low natural groundwater levels in the shallow open framework gravels.
- The pit design is difficult to clean once clogged with sediment from turbid source water, or bank erosion from a supply race. Direct connection to a water storage pond reduces the clogging risk, but may increase the risk of *E. coli* contamination, due to birds on the pond.
- Infrastructure (e.g., turnout or pipe sizing) can restrict supply flow rate.
- Supply reliability reduces with distance down the irrigation distribution system during peak irrigation season (particularly on the piped Valetta Scheme). However, MAR sites near the end of the irrigation distribution system are important for mitigation of nitrates in the groundwater, before it reaches the lower catchment springs.
- The locations of lower catchment sites are likely to be more critical than upper catchment sites, if the aim is that their operation can most effectively target priority groundwater quality areas, such as community drinking water supplies.

Eight of the initial test sites remained as operational test sites through Year 4 (including Site 16, which was replaced at the beginning of Year 4 due to clogging, by a new site 20 m away), with one of the four remaining test sites shut down and three others upgraded (by increased capacity or addition of a buried perforated pipe). In Figure 4-1, the Year 4 test sites are coloured red, while the new or upgraded sites are coloured purple. Figure 4-2 shows an example of a test site setup. Table 4-1 presents site performance for Years 3 and 4 combined. For these sites minimum depth to water was not found to be a key factor for maximising total consented recharge volume, with the site with the shallowest depth to water (#9), producing the second highest total recharge volume, and the site with greatest depth to water (#15) producing the lowest total recharge volume. This is despite both sites producing a similar maximum recharge rate. The differences in performance were found to be related to supply reliability and *E. coli* risk: these were shown to be more significant factors in maximising recharge volume than minimum depth to water, though sites where the water table is regularly less than 3 m are avoided due to potential groundwater mounding effects. Prioritisation of MAR sites that are up-gradient from areas where high groundwater nitrate concentrations exist, should also be a factor, in terms of siting further trials, particularly when water supply is limited.

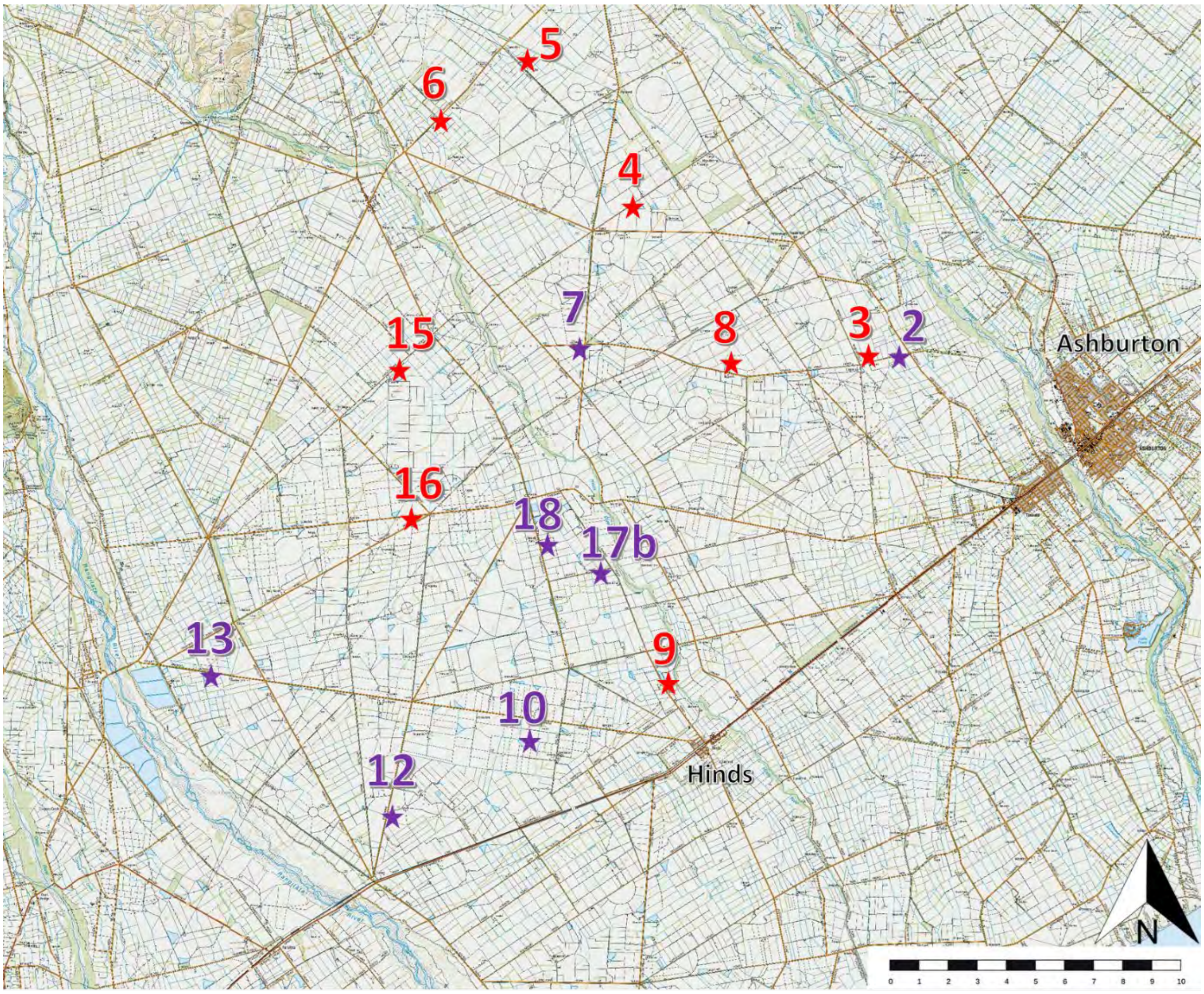


Figure 4-1: Year 4 MAR Test (red) and New (purple) Sites.

Figure 4-2: MAR 08: Lacmor test site set up

Table 4-1: MAR test site performance for Years 3 and 4

June 2018-May 2020	Minimum depth to water (m)	Maximum recharge rate (l/s)	Total recharge volume (m^3)	Weeks in operation	*E. coli* shutdowns	Notes
3 - Walls	10	20	188,237	22	6	Supply limited to ~30 l/s
4 - NZSF	>10	24	345,850	36	6	
5 – Pond 2	>10	28	424,560	23	12	
6 – BCI/Howden	6	18	368,958	48	4	Supply limited to ~25 l/s
8 - Lacmor	>10	33	387,926	49	2	
9 – Riverbank	3	25	500,119	45	2	
15 - Oakstone	>15	26	170,891	20	9	
16 - Broadfields	10-15	27	510,992	70	4	Replaced July 2019

Dedicated down-gradient bores to monitoring the water quality influence of the MAR test sites have not been drilled, due to the relatively small recharge volumes per site to date. No regular Environment Canterbury water quality monitoring sites are nearby either. However, two potential bores of interest have been identified in the MHV Water groundwater monitoring program (see Section 6.3). These bores are less than 35 m deep and within 2500 m of a MAR site (not necessarily directly down-gradient), but their locations are not identified at this time for privacy reasons.

Figure 4-3 presents the recharge flows at MAR 05 and two recent nitrate-N samples from the nearby bore. Figure 4-4 presents the recharge flows at MAR 09 and four nitrate-N samples over the last 2 years from the nearby bore. It is not currently possible to conclude anything about the effects of the MAR sites at these locations. The nitrate-N at these bores will continue to be monitored and compared with nearby bores to determine if MAR influence is realised.

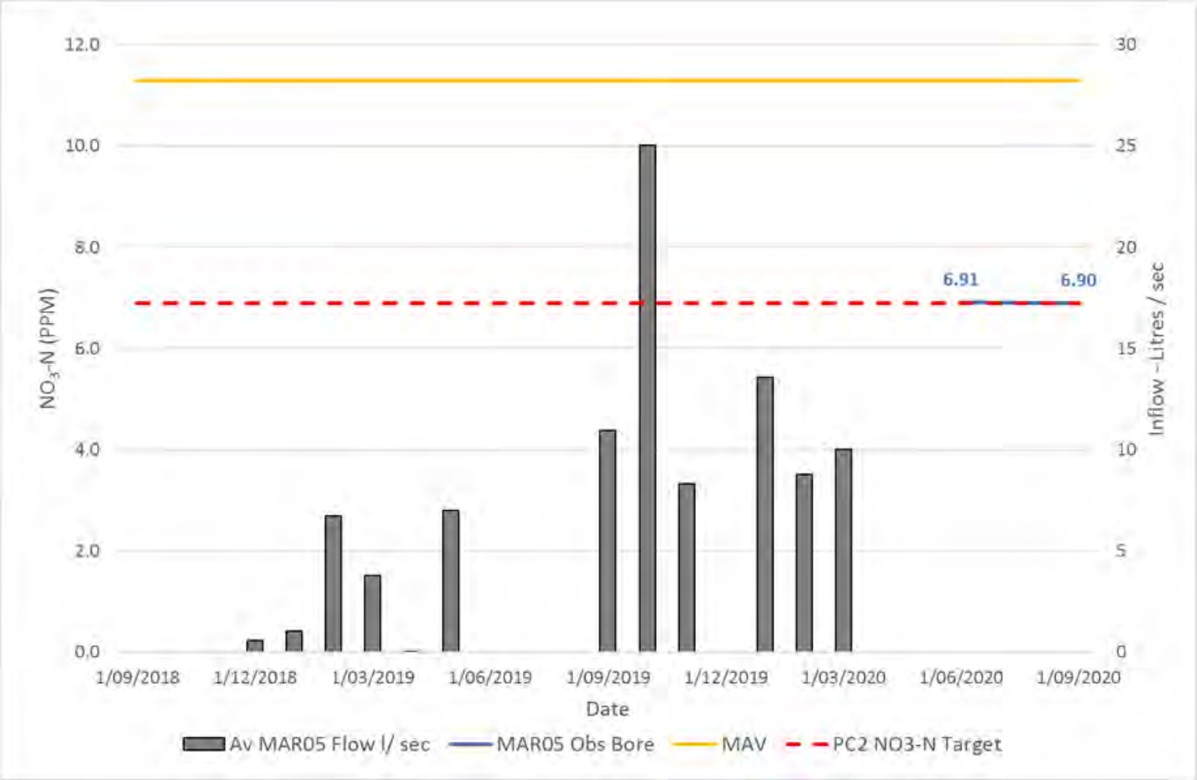


Figure 4-3: NO$_3$-N results for a bore down gradient from MAR 05 (Source: MHV Water)

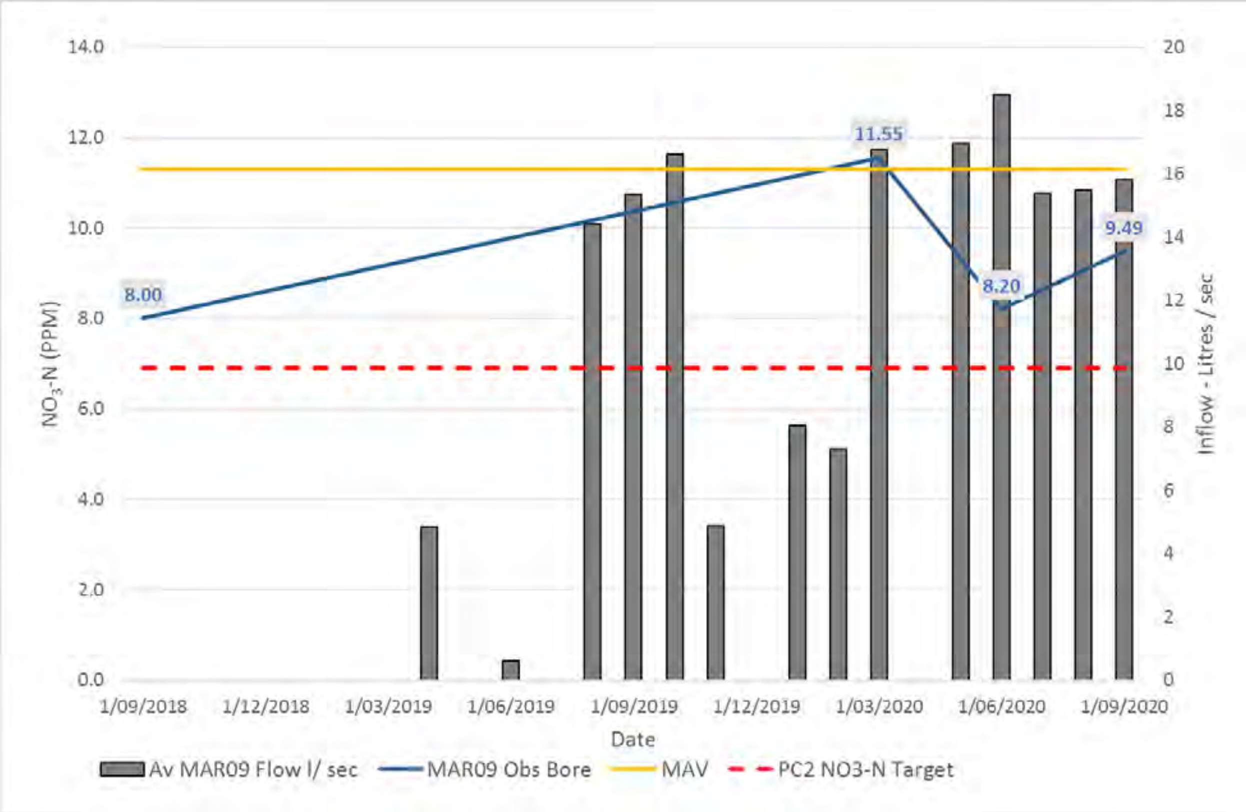


Figure 4-4: NO$_3$-N results for a bore cross gradient from MAR 09 (Source: MHV Water)

5 New sites and site upgrades

During Year 4, MAR test site discharge consent CRC182576 was amended (with new number CRC202205) to increase maximum MAR flow rate from 50 to 100 l/s and replace unrequired test site locations with new site locations. Later in Year 4, this consent was transferred from Canterbury Regional Council to HHWET Ltd and given the consent number CRC210702. Construction of the new sites and site upgrades (Figure 4-1 in purple) is described in the following sections, with additional technical detail available in WGA (2020). The objective of these new sites was to infiltrate at least 50 l/s per site in areas up-gradient from elevated groundwater nitrate concentrations.

5.1 MAR 02

MAR 02 (Figure 5-1) has three soakage pits, dug into the bed of 840 m of a bywash race from the Valetta irrigation distribution scheme, now unused following piping of the Valetta scheme. The race runs beside Timaru Track Road and is up-gradient from a high groundwater nitrate area that persists through to Tinwald. Construction of this site was funded by an Ashburton District Council grant, in recognition of the benefits for Tinwald residents, as well as for the groundwater ecosystem and connected lower catchment waterways. The site is connected to the end of the MHV Water Valetta piped distribution system. As MAR water supply will be limited at times of high irrigation demand, nearby stockwater races are also being considered for their supply potential. Initial testing at the site has indicated that a recharge rate at least 100 l/s is achievable. A higher recharge flow consent will be considered if this proves to be the case over an extended period. A new 33 m deep monitoring bore (BY21/0398) was drilled 1100 m down-gradient from the site and the groundwater nitrate sensor moved to this bore from BY21/0183 (see Fig. 2-10). Site operations began in Year 5, and results in terms of operation, recharge rates, nitrate concentrations and water levels, will be provided in the Year 5 report.

Figure 5-1: MAR 02, Timaru Track Road

5.2 MAR 07

MAR 07 (Figure 5-2) was originally constructed as an irrigation storage pond, but the pond leaked significantly and is no longer used for this purpose. A MAR test site was constructed in the base of the pond but was only operational for 9 weeks during Year 3, as the site was connected to the farm irrigation supply and could only be operated when no irrigation was required. The new site includes a dedicated offtake and the whole of the 0.5 ha basin. Lateral bunds have been added to slow the incoming water flowrate, and thus drop out suspended sediment in the initial bays. Basin sediment is easily cleaned compared with other MAR sites, so this site will be trialled with higher turbidity water than is safe to deliver to other MAR sites, that are more susceptible to sediment clogging.

Site operations for the new site began in Year 5. A potential bore of interest for this site (Figure 5-3) has been identified in the MHV Water groundwater monitoring program (see Section 6.3). Although this bore is not considered directly down-gradient of the site, it will be monitored and assessed for potential MAR influence over the next few years.

Figure 5-2: MAR 07, Corner Timaru Track and Maronan Valetta Roads

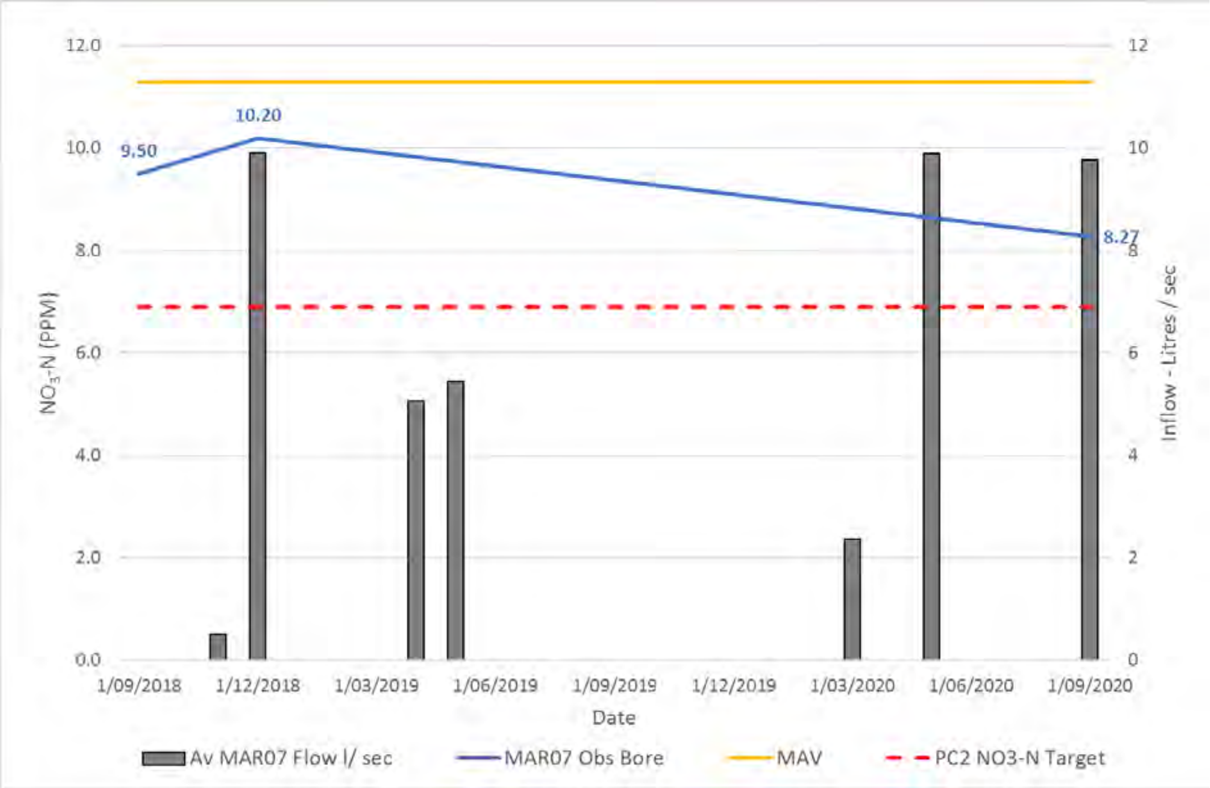


Figure 5-3: **NO_3-N results for a bore indirectly down gradient from MAR 07 (Source: MHV Water)**

5.3 MAR 10

MAR 10 (Figure 5-4) utilises a gate-controlled supply off an irrigation pond, followed by a supply race with multiple weirs to settle sediment, and then a cobble-filled soakage pit with perforated pipe extension. The perforated pipe extension is a recharge design used for treated wastewater recharge that doesn't take land out of production. Site operations for the new site began in Year 5. A potential bore of interest for this site (Figure 5-5) has been identified in the MHV Water groundwater monitoring program (see Section 6.3). This bore shows historical nitrate-N concentrations above the NZ Drinking Water MAV (MoH, 2018) so will be monitored and assessed for potential MAR influence over the next few years.

Figure 5-4: MAR 10, off Fields Road

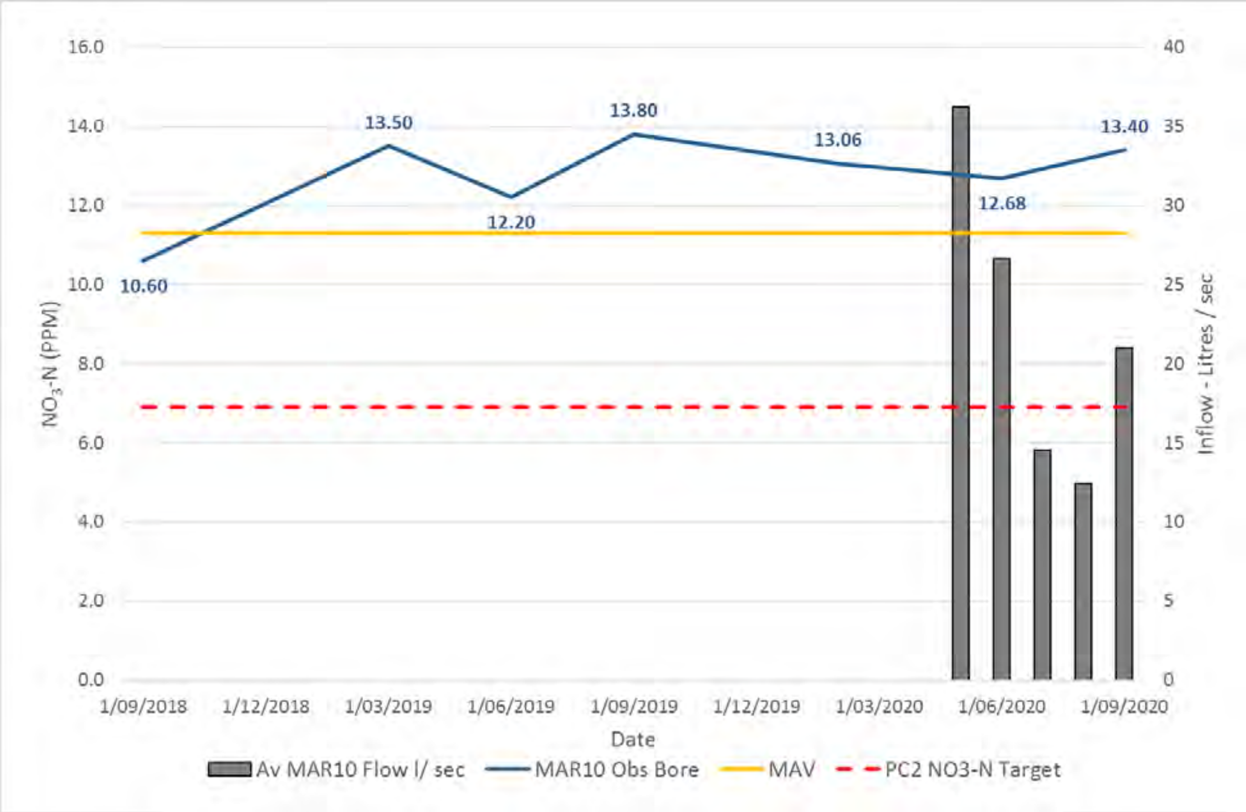


Figure 5-5: NO_3-N results for a bore down gradient from MAR 10 (Source: MHV Water)

5.4 MAR 12

MAR 12 replaced a test site at the same location which did not perform well, due to sediment and *E. coli* management challenges. The new site is fed by the same water race as the test site (left of Figure 5-6), with an open channel sediment forebay trench, connected to a soak hole and down-gradient buried perforated pipe. Initial testing early in Year 5 suggested recharge rates of 30-50 l/s were possible (up from a maximum of 13 l/s at the original site). Operation of the new site began in Year 5. A potential bore of interest for this site (Figure 5-7) has been identified in the MHV Water groundwater monitoring program (see Section 6.3). This bore shows a nitrate-N concentration decrease following the start of new site operations, but a longer monitoring time period is required before MAR influence can be assessed. A groundwater nitrate sensor has also been installed in nearby bore BY20/0148 (in which, water quality exceeds the NZ Drinking Water MAV for nitrate-N), but this has not showed improved water quality (which is consistent with expectations that it is sited cross-gradient from MAR 12).

Figure 5-6: MAR 12, Maronan Ealing Road, up gradient (left) and down gradient (right)

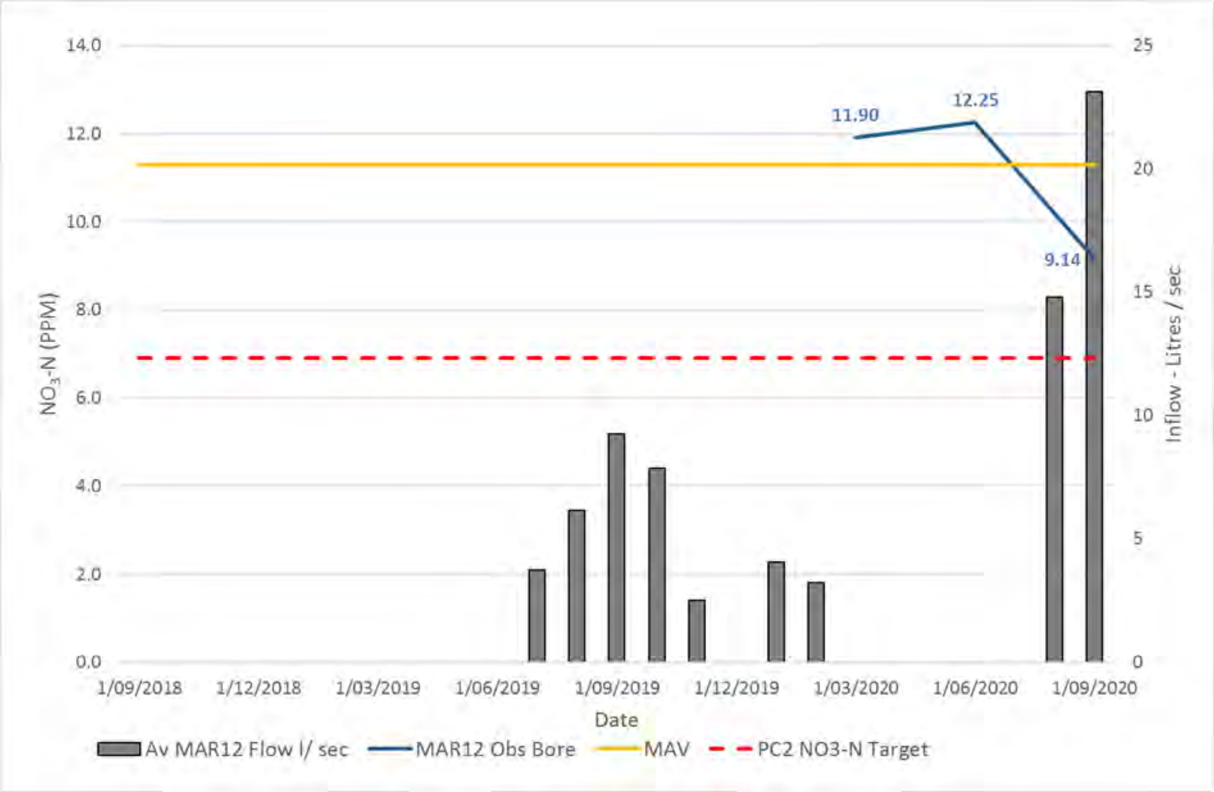


Figure 5-7: NO_3-N results for a bore down gradient from MAR 12 (Source: MHV Water)

5.5 MAR 13

MAR 13 (Figure 5-8) was originally a standard test site connected to an irrigation pond. After recharge rates declined (most likely due to sediment clogging), an identical site was built immediately adjacent to, and connected to, the test site. This has increased recharge rates from 15-20 l/s up to 20-40 l/s. A potential bore of interest for this site (Figure 5-9) has been identified in the MHV Water groundwater monitoring program (see Section 6.3). This bore shows nitrate-N concentrations close to the NZ Drinking Water MAV (MoH, 2018) and will be monitored and assessed for potential MAR influence over the next few years.

Figure 5-8: MAR 13, Hinds Arundel Road

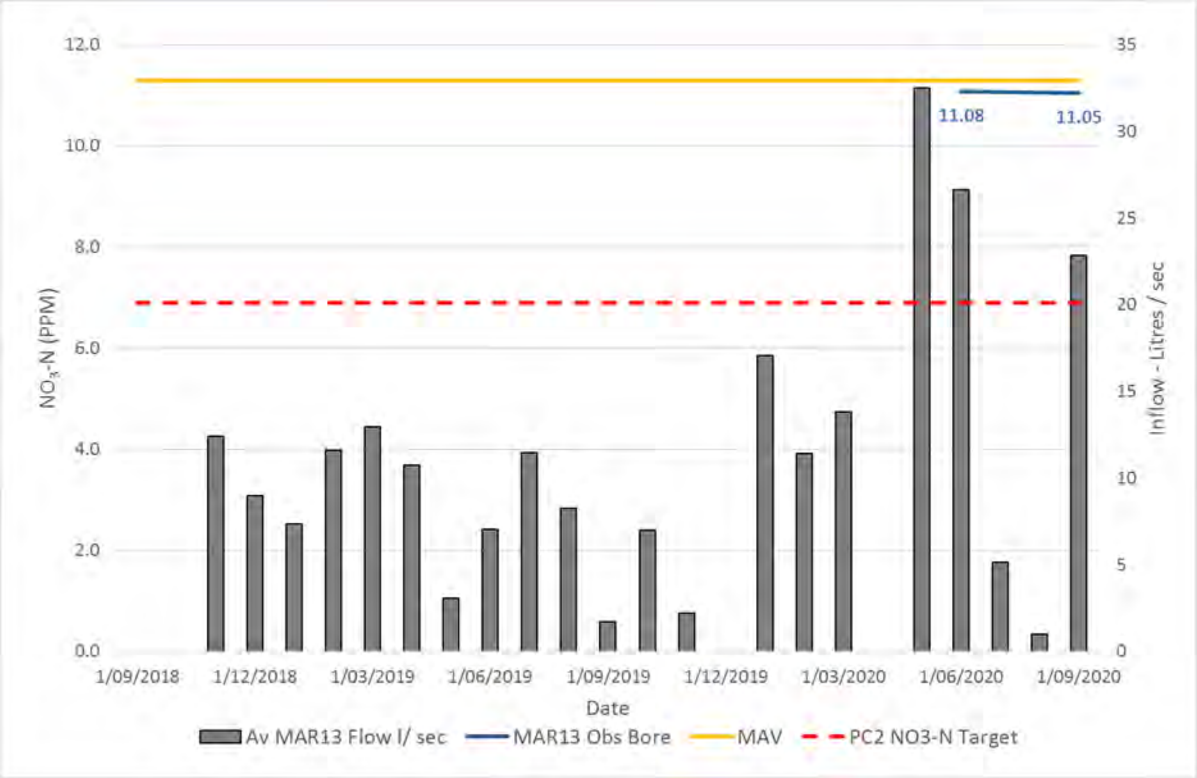


Figure 5-9: **NO_3-N results for a bore down gradient from MAR 13 (Source: MHV Water)**

5.6 MAR 17b

MAR 17b (Figure 5-10) is supplied from an irrigation pond, ~700 m from the Hekeao Hinds River and heads towards the river (at ~45º to the hydraulic gradient), along a recharge race with multiple weirs and soak holes. An alternative consented site (17a), situated slightly up-gradient, is not expected to be constructed following benefit / cost comparisons between 17a and 17b. The site became operational early in Year 5 with recharge rates of 45-75 l/s. The current lateral race has the capacity for additional expansion if the site maintains this level of performance. Two potential bores of interest for both MAR 17b and MAR 18 (Figure 5-11) have been identified in the MHV Water groundwater monitoring program (see Section 6.3). Bore 2 showed a temporary decrease in nitrate-N concentrations immediately following the onset of MAR site operations, nearly matching the concentrations at Bore 1 (which only has recent monitoring results). However, concentrations then returned to level more similar to pre-MAR concentrations. Both bores will be monitored and assessed for potential MAR influence over the next few years. The banks of MAR 17b have also been prioritised for native planting, in consultation with mana whenua and the landowner.

Figure 5-10: MAR Site 17b, Lennies Road

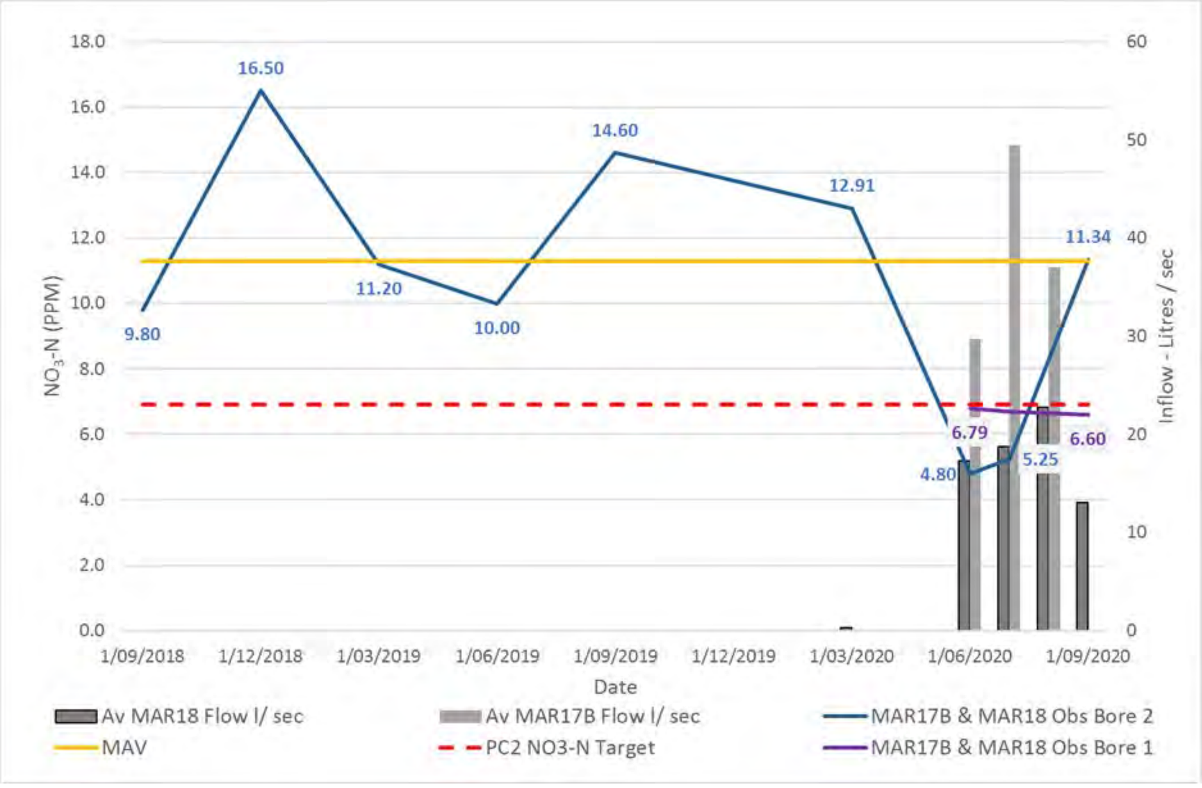


Figure 5-11: NO_3-N results for a bore down gradient (Bore 1) and from a bore cross gradient (Bore 2) from MAR 17B & MAR 18 (Source: MHV Water)

5.7 MAR 18

MAR 18 (Figure 5-12) utilises an existing pit, backfilled with cobbles, located beside an irrigation distribution race. The site became operational early in Year 5 with recharge rates of 20-50 l/s. The potential monitoring bores identified for MAR 17, presented in Figure 5-11 will be monitored and assessed, to determine potential MAR influence over the next few years.

Figure 5-12: MAR Site 18, McDougalls Road (infiltration testing prior to backfilling)

6 Hekeao Hinds Plains Monitoring

Consent conditions for the Lagmhor Pilot Site discharge consents require water quality, quantity (flow) and ecology to be monitored in key Northern Hinds Drains (see Figure 6-1). However, there is little monitoring required for groundwater. Targeting high groundwater nitrate areas with MAR sites, requires comprehensive monitoring coverage throughout the Hekeao Hinds Plains at a variety of bore depths. Failure to do this would mean that it would not be possible to determine the success of the MAR trials, in terms of groundwater quality or quantity. As a result, baseline monitoring in the lower Hekeao Hinds River and Southern Hinds Drains was initiated, in preparation for any potentially measurable influences from MAR operations across the plains. Existing Environment Canterbury monitoring was increased, and new Fish and Game monitoring, plus MHV Water-led monitoring, was added. A subset of this monitoring, that is directly related to MAR consents and / or operations, will be presented in this chapter.

6.1 Hekeao Hinds Drains and lower Hekeao Hinds River monitoring

Gabites (2020) presents the MAR hydrology monitoring to date in the northern Hinds Drains, and a Year 4 site review, while Dynes (2020) presents the MAR ecology monitoring to date in the northern Hinds Drains. Hinds Drains Working Party reports (e.g., HDWP, 2020) also present aquatic ecology monitoring analysis as well as water quality monitoring for the Hekeao Hinds Drains and River. While we assume that MAR water is contributing to spring flows that feed some northern Hinds Drains, no measurable MAR water quantity or quality influence has yet been identified, and this monitoring is therefore currently regarded as baseline monitoring. The clean MAR water from the Hekeao Hinds River Project (Chapter 3) is expected to benefit the lower Hekeao Hinds River over time, with MAR sites (e.g., MAR 09, 17b and 18) near the middle reaches of the Hekeao Hinds River also potentially benefitting the quantity, quality and ecology of the lower Hekeao Hinds River.

6.1.1 Parakanoi and Flemington Drain Hydrology

Key current northern Hinds Drains monitoring sites are presented in Figure 6-1. A combination of flow gauging and stage recorders have been used, to build an understanding of flow gains and losses in the Parakanoi and Flemington Drains under different flow conditions (Gabites, 2020). The results of these analyses are presented in Figures 6-2 and 6-3, with concurrent gaugings represented by the linked monitoring points. Both drains show their highest flows in the middle reaches, with losses toward the coast. This intensive gauging ceased at the end of Year 4, with monitoring reducing to the key sites (most with automatic recorders).

6.1.2 Parakanoi and Flemington Drain Water Quality

Water quality (in particular NNN – nitrate plus nitrite as nitrogen) is measured at three sites along the Parakanoi Drain (McLennons Rd, New Park Rd and Lower Beach Rd), and four sites along the Flemington Drain (Boundary Rd, Montgomerys Rd, Wheatstone Rd and Grahams Rd). The uppermost site (if flowing), is of most interest regarding potential MAR water quality impacts, so the available data for Parakanoi Drain at McLennons Rd is presented in Figure 6-4 and for Flemington Drain at Boundary Rd in Figure 6-5. Both sites were dry through most of the 2014-16 drought but have had monitored NNN concentrations in the 10-15 mg/l range since this time, consistent with nearby shallow groundwater concentrations. The monitoring record for Flemington Drain at Boundary Rd also shows a few low NNN concentrations. The lowest two of these were a few days after a rainfall event, suggesting that rainfall dilutes the NNN concentration in the drains.

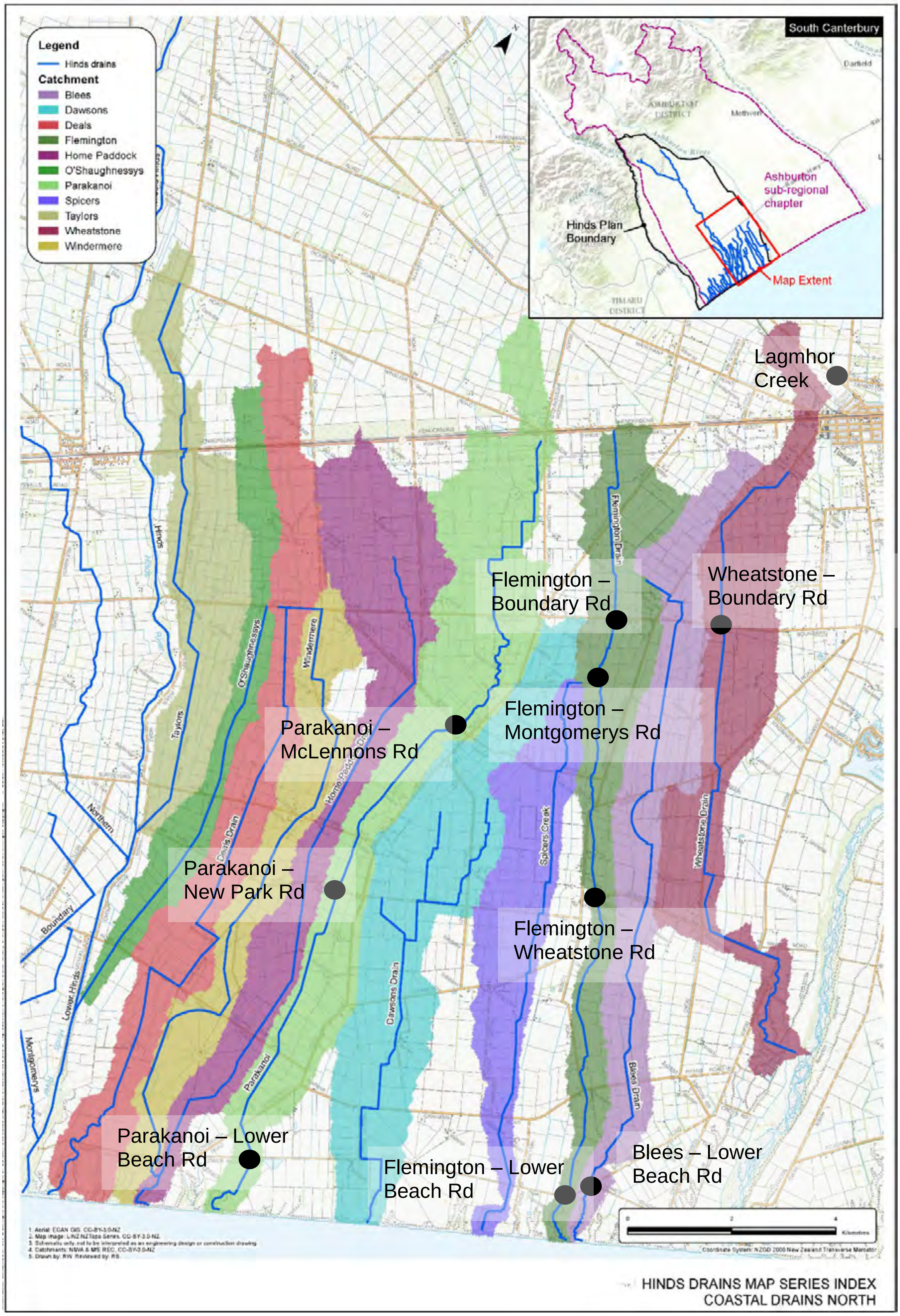


Figure 6-1: Northern Hinds Drains monitoring sites

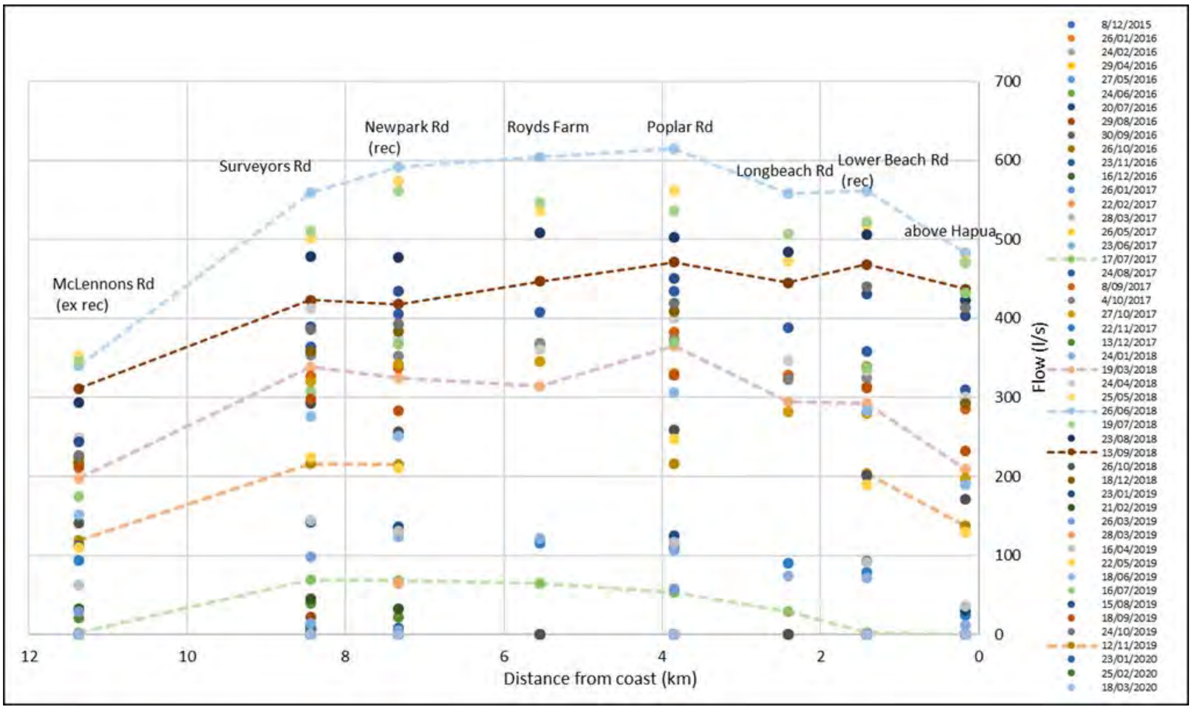


Figure 6-2: Parakanoi Drain from McLennons Road to Hāpua (Source: Gabites, 2020)

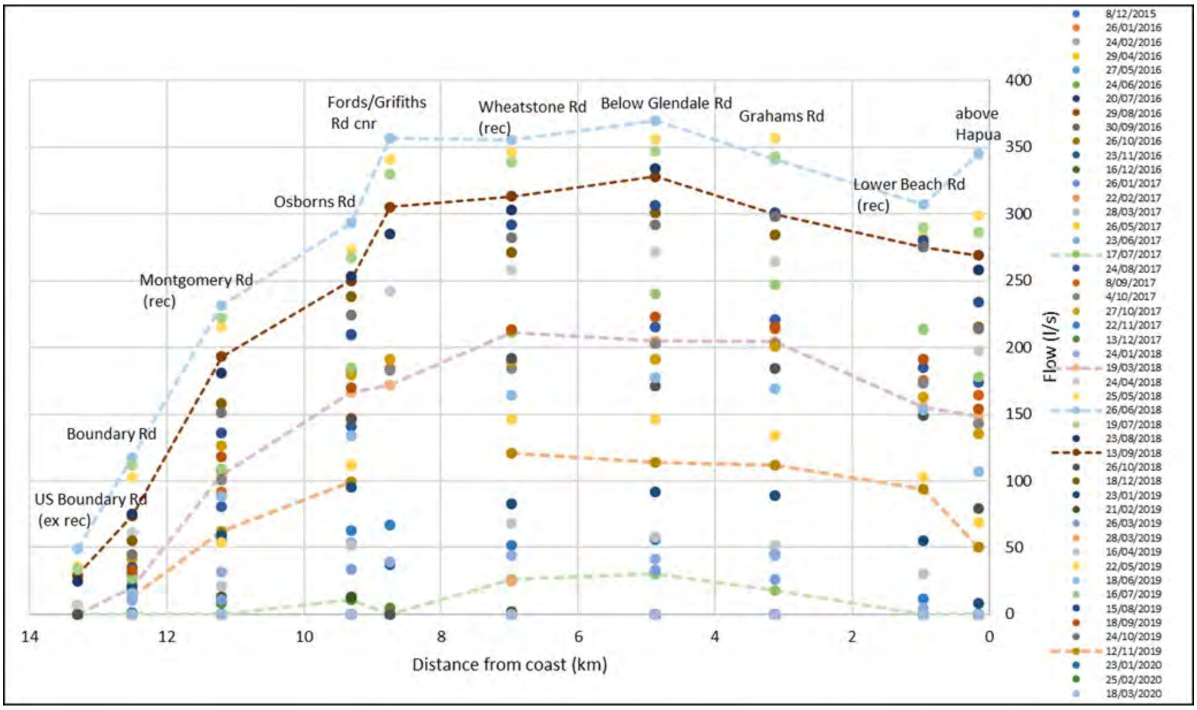


Figure 6-3: Flemington Drain from US Boundary Road to above Hāpua (Source: Gabites, 2020)

Figure 6-4: NNN concentrations at Parakanoi Drain (McLennons Rd) – Source: HDWP (2020)

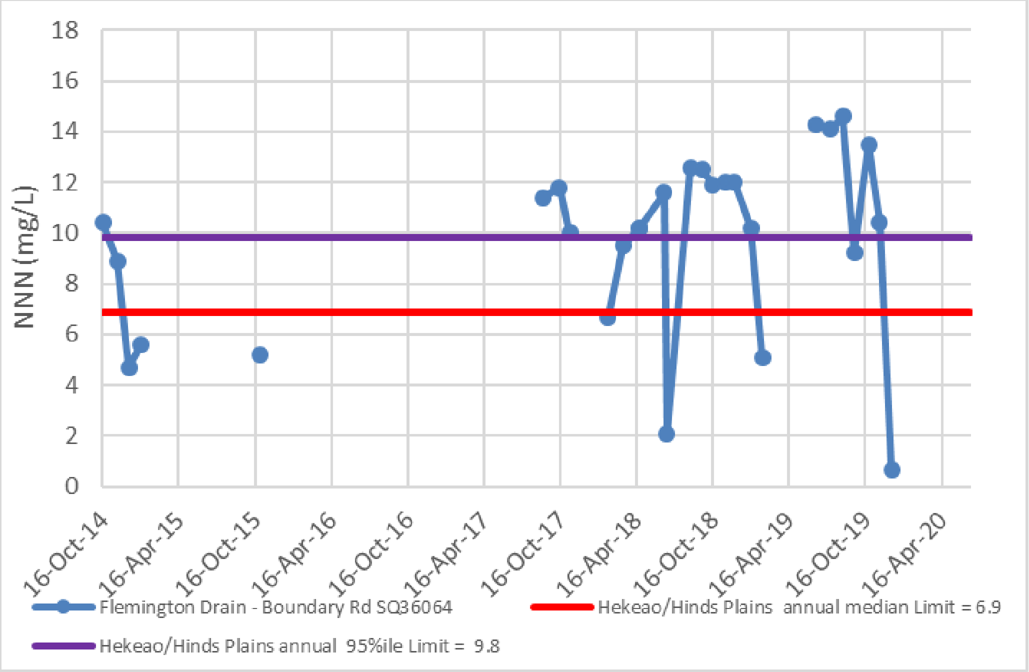


Figure 6-5: NNN concentrations at Flemington Drain (Boundary Rd) – Source: HDWP (2020)

6.1.3 Parakanoi and Flemington Drain Invertebrate and fish communities

Monitoring for invertebrate and fish communities has been carried out in the Parakanoi Drain and Flemington Drain, to assess how these communities respond to any potential changes in flow regime as a result of MAR (Dynes, 2020). Monitoring commenced in June 2017, 1 year after the discharge began at the Lagmhor Pilot site. Monthly invertebrate monitoring has also been carried out using the Stream Health Monitoring and Assessment Kit (SHMAK) developed by the National Institute of Water and Atmospheric Research (NIWA). Quarterly fish monitoring is carried out using a single pass electric fishing machine method (EFM) over a 50m reach to provide a semi-quantitative estimate of fish abundance and species present. As no measurable flow or water quality influence from MAR operations have been determined to date, this monitoring information is currently regarded as baseline monitoring.

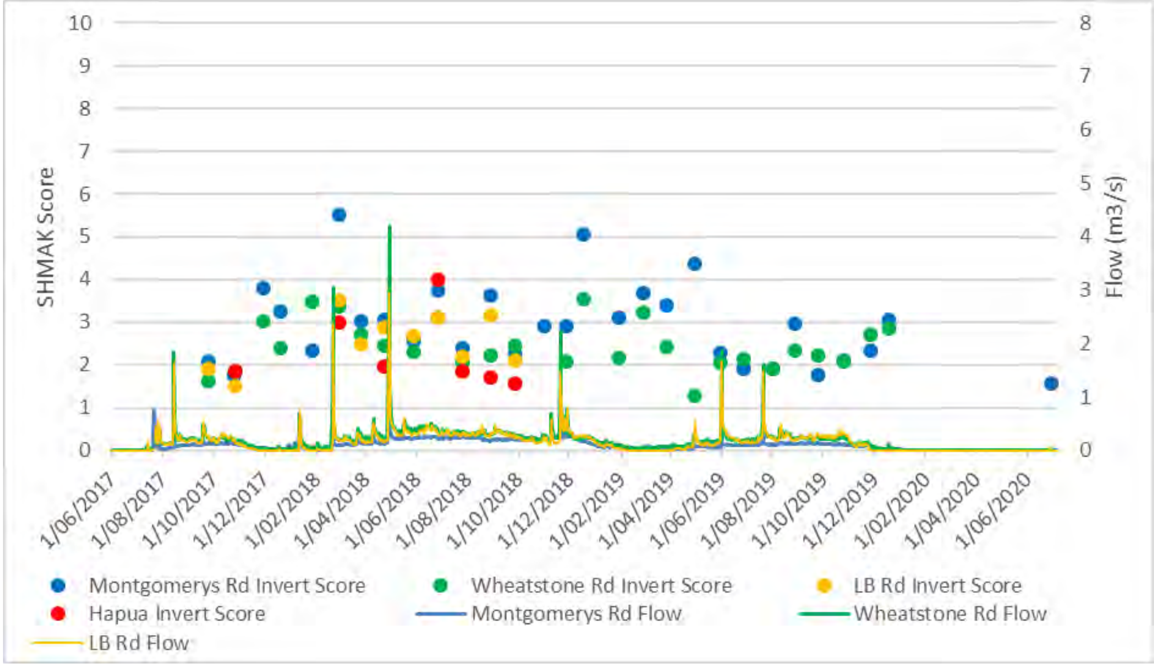


Figure 6-6: Macroinvertebrate communities and flow regime of Flemington Drain (Source: Dynes, 2020)

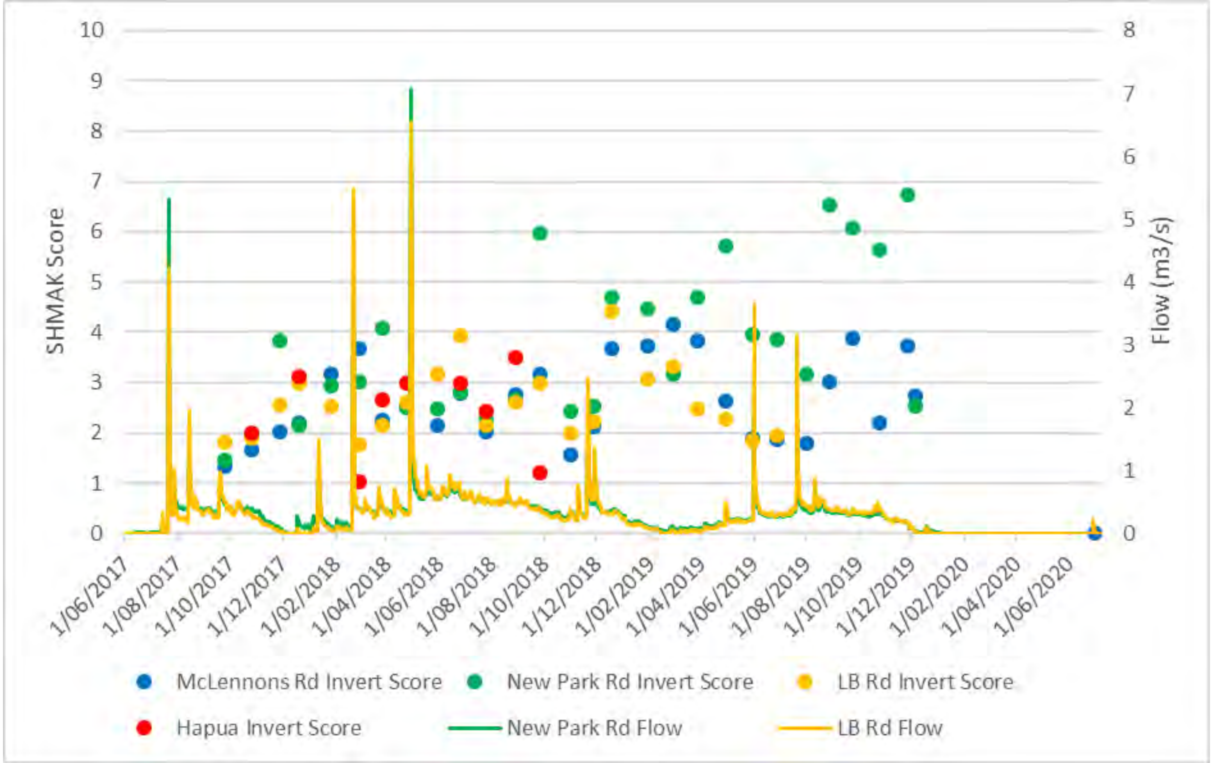


Figure 6-7: Macroinvertebrate communities and flow regime of Parakanoi Drain (Source: Dynes, 2020)

SHMAK scores for Flemington Drain indicate invertebrate communities have been fairly consistent for the duration of monitoring (Figure 6-6). SHMAK scores were generally higher for the upstream site at Montgomerys Rd, despite flow being marginally lower for this site. All four sites monitored for invertebrate communities in Flemington Drain have SHMAK scores below 6. This indicates communities are composed of species that are generally tolerant to degraded water quality and habitat (Biggs et al. 2002). During the summers of 2018-19 and 2019-20, flows in Flemington Drain were lower (Figure 6-6). The SHMAK score did not appear to decrease in response to these lower flows, with the exception of when the sites were dry.

SHMAK scores for Parakanoi Drain were similar to those in Flemington Drain (Figure 6-6 and 6-7). Scores were generally below a SHMAK of 6, and indicative of species tolerant to water quality and habitat degradation (Biggs, et al. 2002). SHMAK scores for the New Park Rd site showed an improvement in 2019 to reflect a moderately healthy site, however this improvement was not observed for other sites.

A low number of fish species and low abundance were observed in both Flemington and Parakanoi Drains (Table 6-1). A single Upland Bully (*Gobiomorphus breviceps*) was observed for Flemington Drain at Wheatstone Rd, on one sampling occasion out of 8. While Parakanoi Drain had a few more species observed, the majority of these were confined to the hāpua environment with Īnanga (*Galaxias maculatus*), common smelt (*Retropinna retropinna*) and Torrentfish (*Cheimarrichthys fosteri*) observed on one or two occasions. A single Kōwaro / Canterbury mudfish was observed on two occasions for Parakanoi Drain at McLennons Rd, while a single shortfin eel (*Anguilla australis*) was observed once at New Park Rd.

Table 6-1: Fish species observed in Flemington and Parakanoi Drains

Site Name	Common name	Count
Flemington at Wheatstone Road	Upland bully	1
Parakanoi at McLennons Road	Canterbury mudfish	2 (1 on 2 occasions)
Parakanoi at New Park Road	Shortfin eel	1
Parakanoi above hāpua	Īnanga	2 (2 on 1 occasion)
Parakanoi above hāpua	Common smelt	1
Parakanoi above hāpua	Torrentfish	1

6.1.4 Lower Hekeao Hinds River

Figure 6-8 presents the locations of current Hekeao Hinds River monitoring sites. Figure 6-9 presents the mean daily flows for the Hekeao Hinds River at Poplar Rd. The drought from mid-2014 to mid-2017 provided an extended period of low flows (primarily due to low groundwater) and no significant freshes. Figures 6-10 and 6-11 present the water quality (nitrate and nitrite as nitrogen) and ecology (Quantitative Macroinvertebrate Community Index - QMCI) results, to date, for the lower river sites. Baseflows in the mid/lower river are heavily influenced by spring-fed stream inflows. The Lower Beach Rd site is generally in excess of the LWRP limits for nitrate for the Hekeao Hinds River. A comparison of Figures 6-9 and 6-10 shows that low NNN concentrations can occur after a large fresh (due to dilution with low nutrient rainwater) and after periods of low flows (due to reduced land surface recharge). Aquatic ecosystem health monitoring at SH1, Poplar Rd and Lower Beach Rd sites indicates the QMCI for the upper two sites (SH1 and Poplar Rd) generally do not meet the minimum QMCI objective of 6. QMCI seems to improve further downstream at the Lower Beach Rd site where stream flow is more consistent. The past two seasons have shown an improved QMCI, likely influenced by a return to higher baseflows and more regular freshes following the mid-2014 to mid-2017 drought. As MAR capacity is increased near the middle reaches of the Hekeao Hinds River, it is possible that the water quality and ecology of the River, from SH1 downstream, (particularly during low flow periods) will improve. Monitoring and analysis will continue to assess the impacts of ongoing MAR.

Figure 6-8: Hekeao Hinds River monitoring sites (Source: HDWP, 2020)

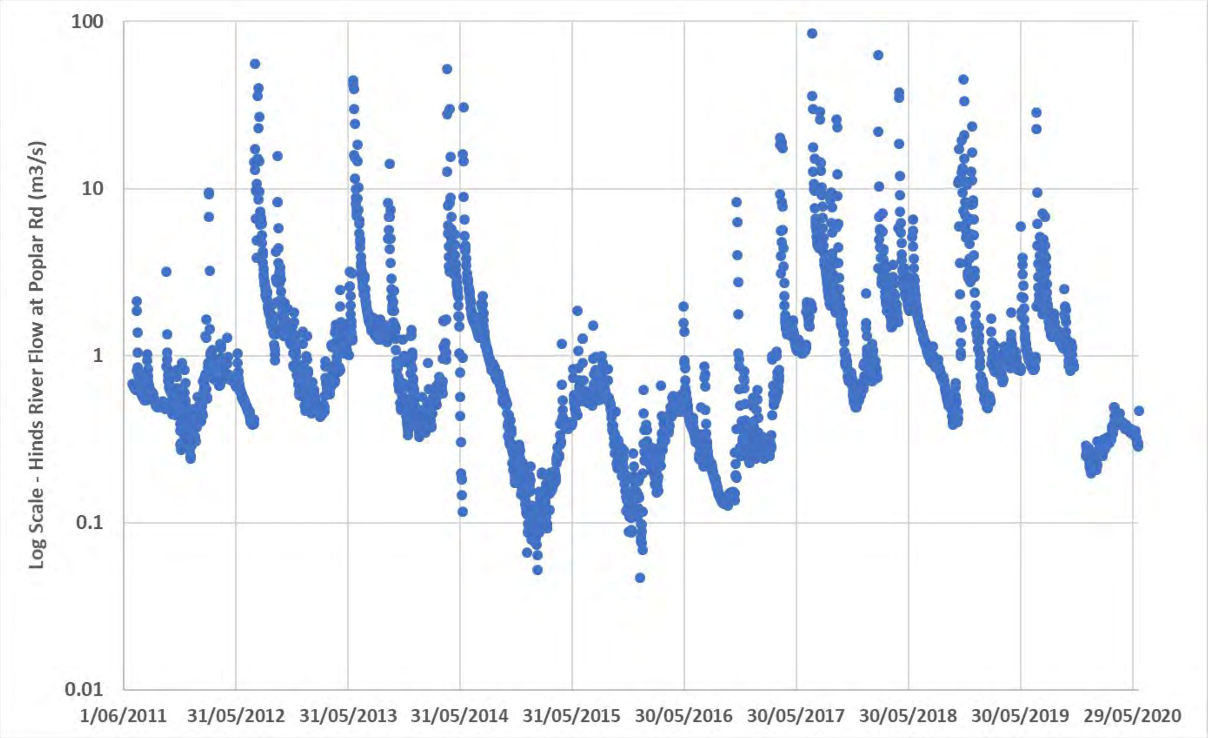


Figure 6-9: Hekeao Hinds River at Poplar Rd flow monitoring (Source: CRC)

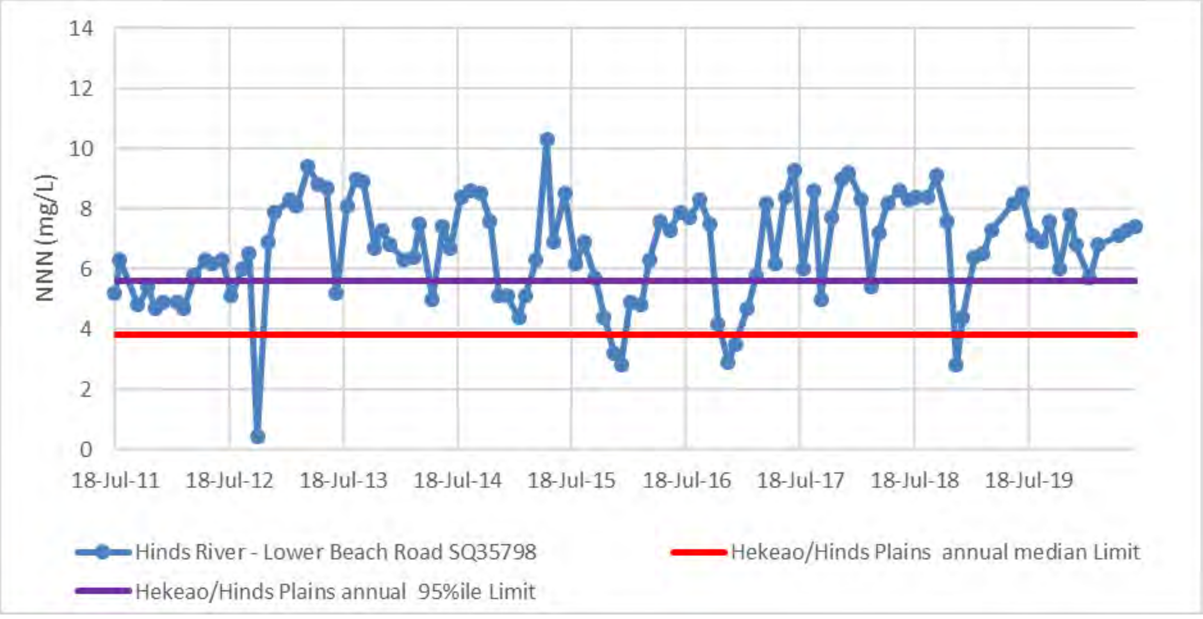


Figure 6-10: Lower Hekeao Hinds River water quality monitoring (Source: HDWP, 2020)

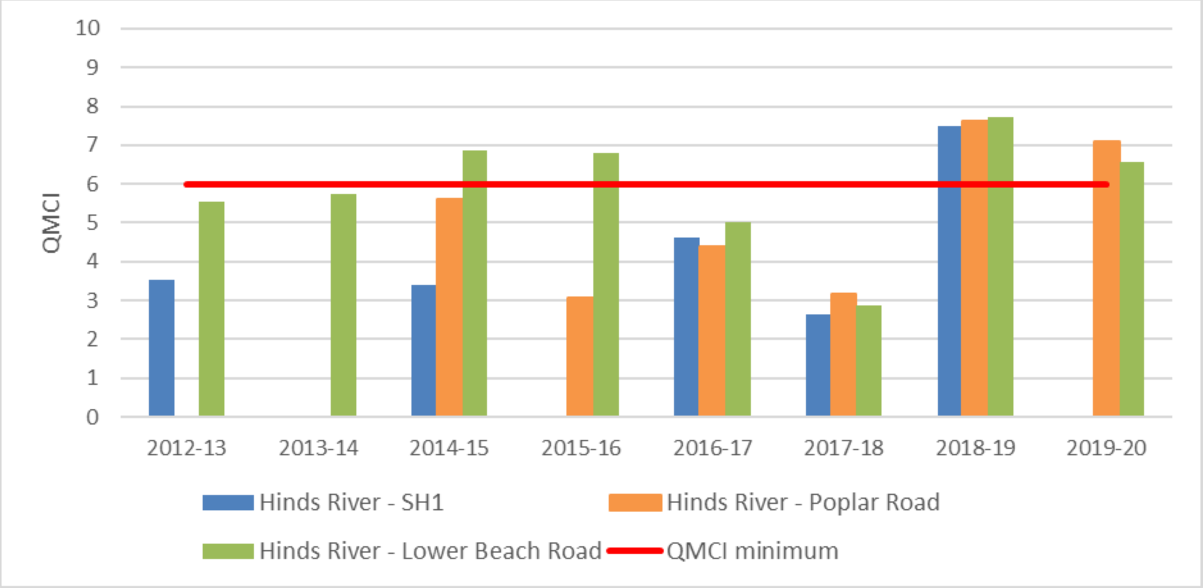


Figure 6-11: Hekeao Hinds River ecology monitoring (Source: HDWP, 2020)

6.2 Tinwald Catchment Groundwater Analysis

Aitchison-Earl (2019) and Stewart and Aitchison-Earl (2020) presented monitoring and analysis regarding potential causes of elevated nitrate concentrations in groundwater, up-gradient from Tinwald, that has been known to be present since at least the mid-1980s. Figure 6-12 shows a large cluster of maximum nitrate-N concentrations (1990-2017) above the NZ Drinking Water MAV of 11.3 mg/l (MoH, 2018) near Tinwald, with further high nitrate bores south of the Hekeao Hinds River near SH1. Figure 6-13 shows the additional sites monitored during the 2018 study in the Tinwald area, with a “plume” of very high nitrate-N groundwater sandwiched between lower concentrations near the Ashburton River (likely influenced by clean river recharge) and the area of Lagmhor MAR site influence. In the coastal zone pockets of denitrifying conditions may also be contributing to low nitrate-N groundwater (Stewart and Aitchison-Earl, 2020). By analysing the stable isotopes of nitrogen and oxygen (^{15}N and ^{18}O) in groundwater samples, the primary causes of high nitrate-N in the Tinwald area were found to be historical fertiliser use, with the effects amplified by irrigation return flow (where the combination of irrigation water nitrate concentration and fertiliser results in an increased nitrate concentration leaching to groundwater). In addition to Environment Canterbury targeting awareness regarding irrigation return flow, this area of elevated nitrate concentrations is now down gradient from MAR 02 and 03 as well as the Lagmhor Pilot Site (MAR 01).

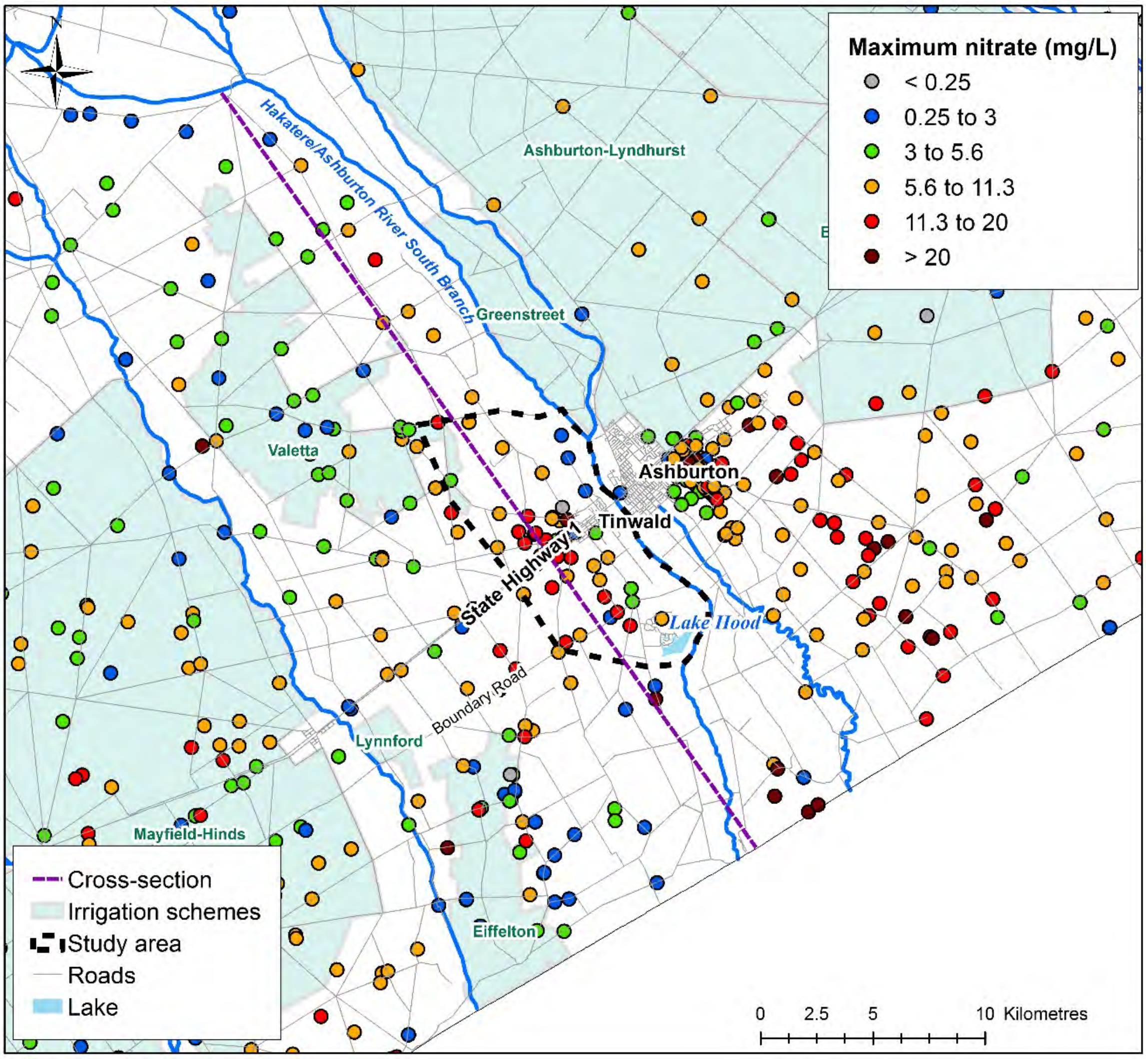


Figure 6-12: Maximum nitrate concentrations in the greater Ashburton area 1990 to 2017 (Source: Aitcheson-Earl, 2019)

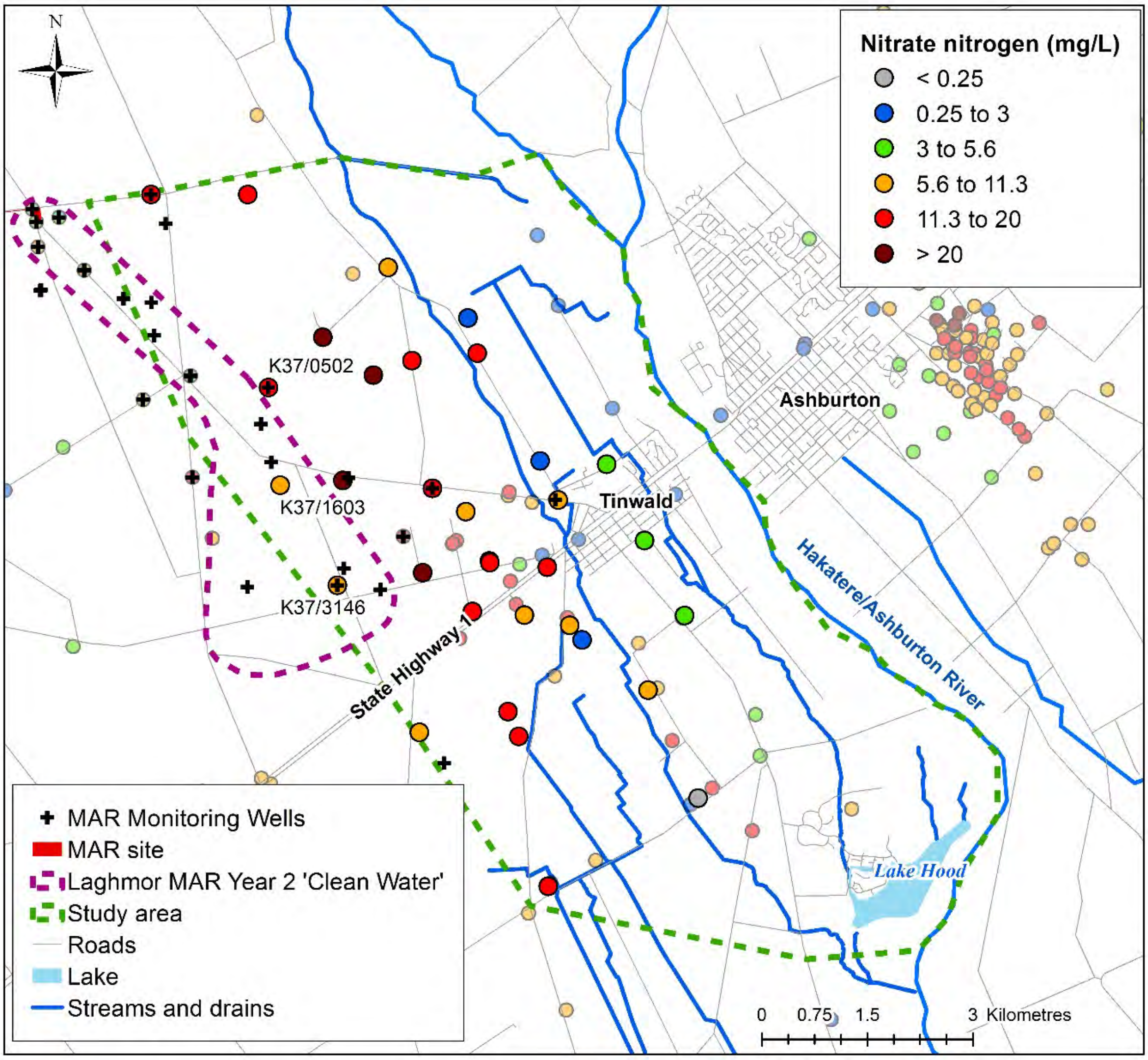


Figure 6-13: Nitrate in the Tinwald study area (lighter shade dots indicate maximum nitrate measured prior to the 2018 investigation) (Source: Aitcheson-Earl, 2019)

Aitchison-Earl (2019) and Stewart and Aitchison-Earl (2020) also present groundwater age analysis (from prior GNS studies), as part of their investigation into the Tinwald high nitrate-N "plume" (Figure 6-14). Groundwater age, along with flow direction, helps to determine potential flow paths for nutrients, identifying where and when they may be sourced from. Groundwater sampled from a well is, in reality, a mixture of ages (potentially including recent land surface recharge), and the modelling of age dating tracers produces an age distribution (which also comes with uncertainties) so the mean ages reported should be viewed with this in mind. Figure 6-14 shows mean groundwater ages from 0 to 112 years across the Hekeao Hinds Plains, with the two wells in the Tinwald study area dated at approximately 12 and 63 years. This is key information for the rehabilitation of the Hekeao Hinds groundwater system, as it suggests the presence of a significant mass of legacy nutrients from past decades, and therefore long lag times for the nutrients leaching from the land surface to reach monitoring bores. The benefits of the nutrient leaching reduction requirements of Plan Change 2 to Canterbury's LWRP (and any future requirements), may also take similar time frames to be measurable. MAR is showing the capacity to greatly speed up influenced parts of the Hekeao Hinds groundwater system, and the groundwater age analysis combined with nitrate-N monitoring, assists with prioritisation of areas to target.

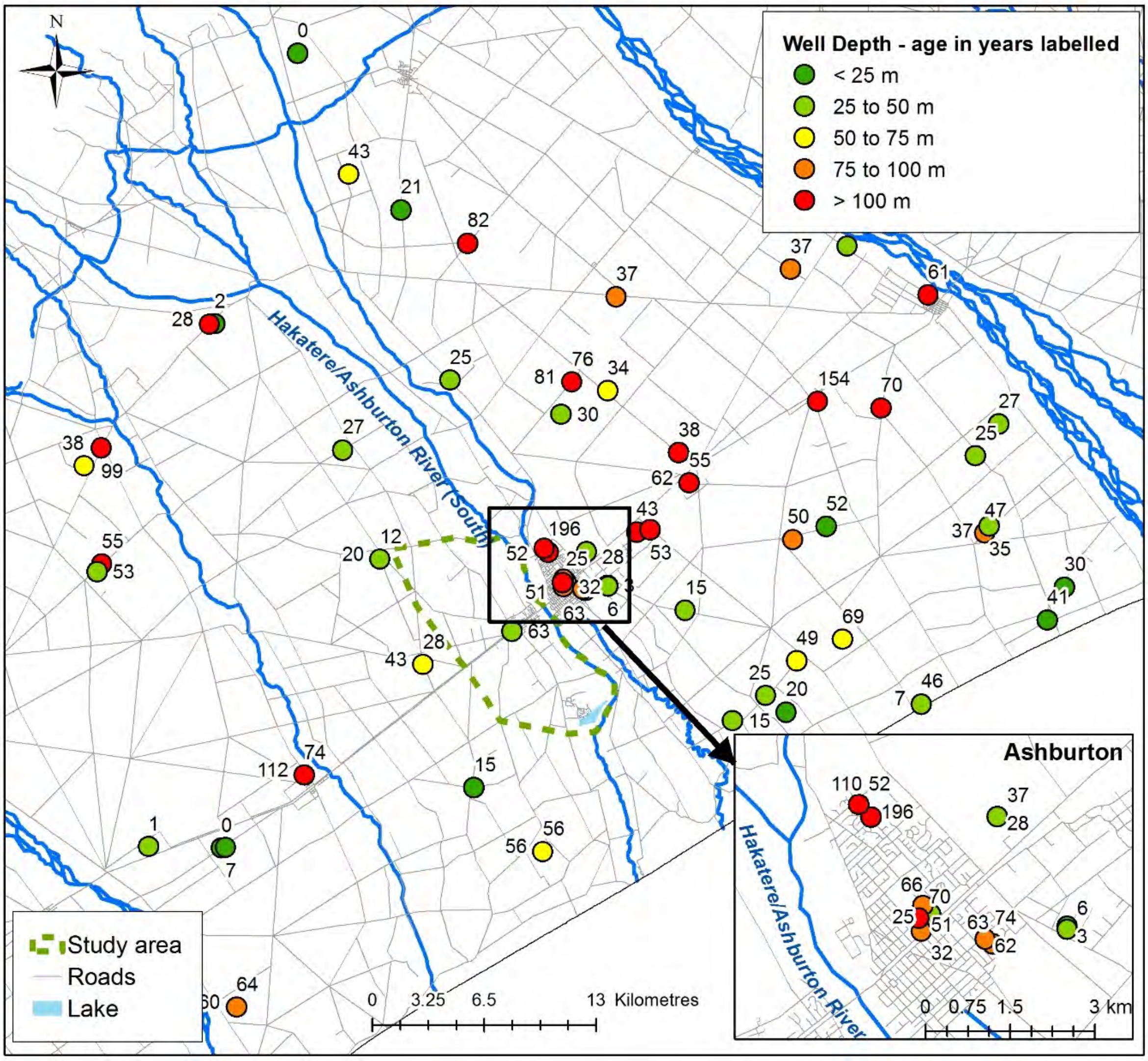


Figure 6-14: Approximate mean groundwater ages (labels) and well depths (colour) in Ashburton Plains groundwater (Source: Aitcheson-Earl, 2019)

6.3 Hekeao Hinds Plains Groundwater Quality

Plan Change 2 (PC2) to Canterbury's Land and Water Regional Plan, Table 13 (i), stipulates that the monitoring of groundwater quality that is to be used to track progress towards the 2035 target of 6.9 mg/l, comprises the Canterbury Regional Council (CRC) monitoring bores, screened at less than 30 m below ground level, and monitored on a quarterly basis. These bores were chosen as they have a historical baseline record and are expected to have comparatively short lag times, and therefore would be expected to show improved nitrate-N concentrations, due to reduced nutrient leaching, by 2035. In addition, CRC monitor a set of deeper bores annually in Spring / Summer (Figure 6-15). In the last 4-5 years, MHV Water have also been monitoring groundwater quality across the Hekeao Hinds Plains, with between 3 and 5 monitoring rounds per year (Figure 6-16). CRC and MHV Water use similar sampling protocols, but MHV Water use an optical nitrate sensor for a higher proportion of samples. Whilst using a nitrate sensor may not have the accuracy of lab determination, it has been tested and found to be highly correlated with lab results. For 2017 and 2018 the total number of CRC and MHV Water bores were similar, but MHV Water have significantly expanded the total number of bores sampled since 2019 and are continuing to expand bore numbers through 2020/21. Using one bore per 2 km radius, the MHV

Water coverage is approximately 90,000 ha, compared with 33,000 for the CRC bores (Figure 6-17). The two monitoring programme data sets currently have six bores in common (two shallow and four deep).

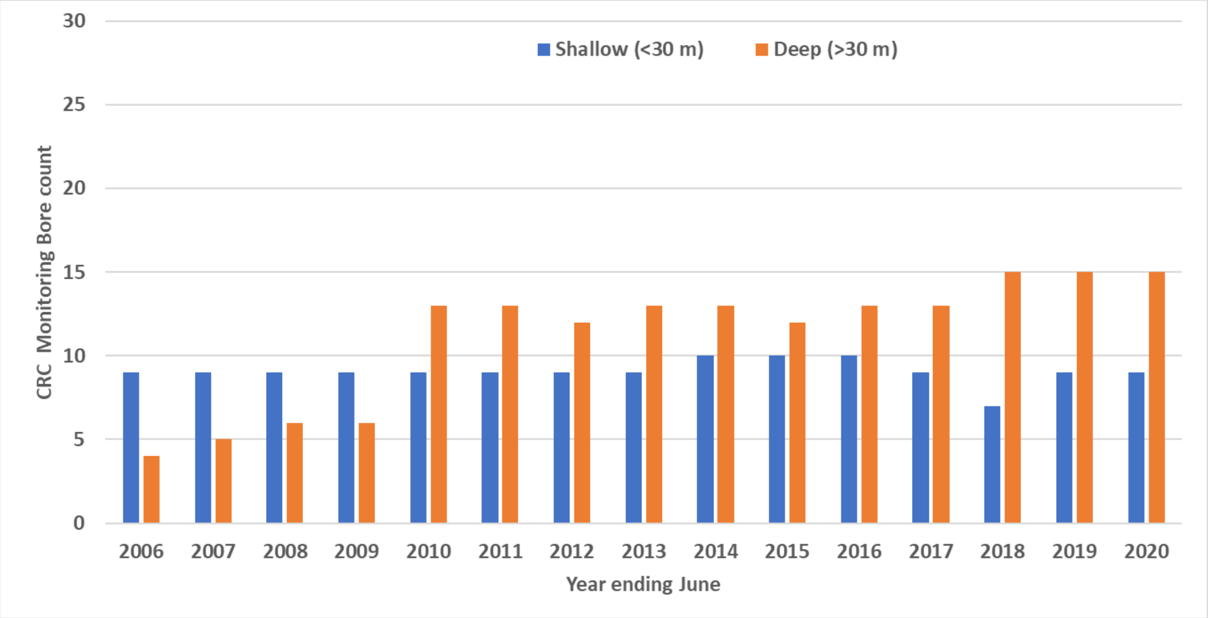


Figure 6-15: Number of Hekeao Hinds Plains shallow (<30 m) and deep (>30 m) bores by year monitored by CRC

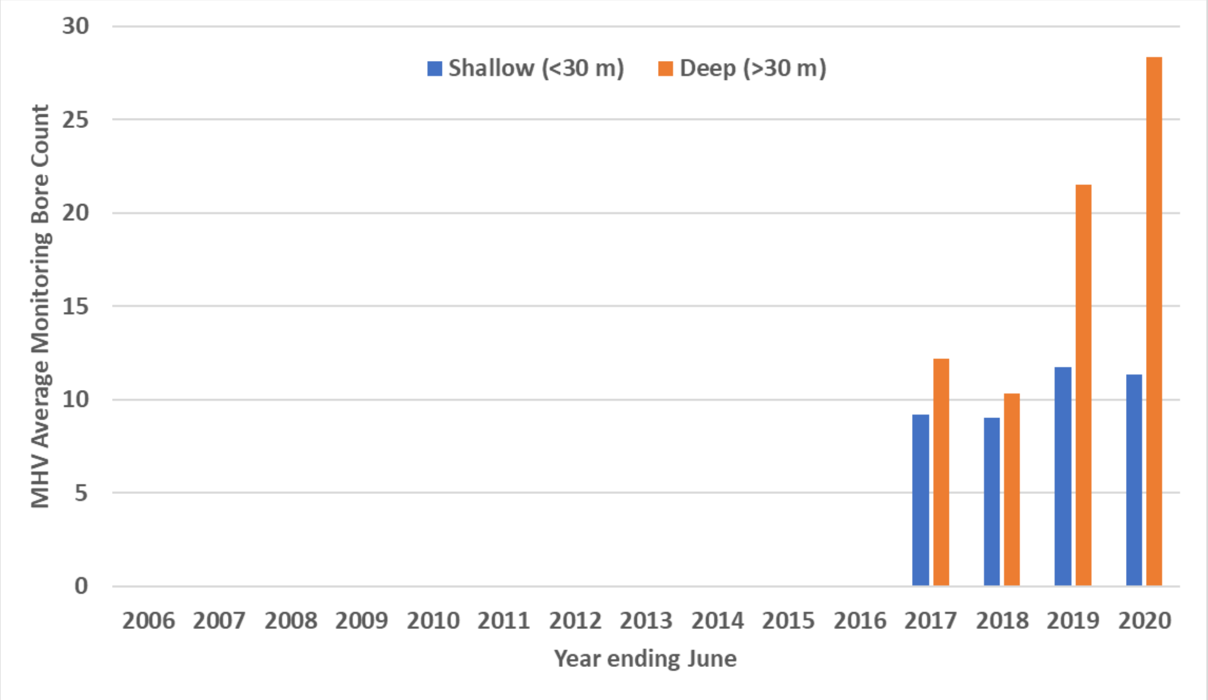


Figure 6-16: Number of Hekeao Hinds Plains shallow (<30 m) and deep (>30 m) bores by year monitored by MHV Water

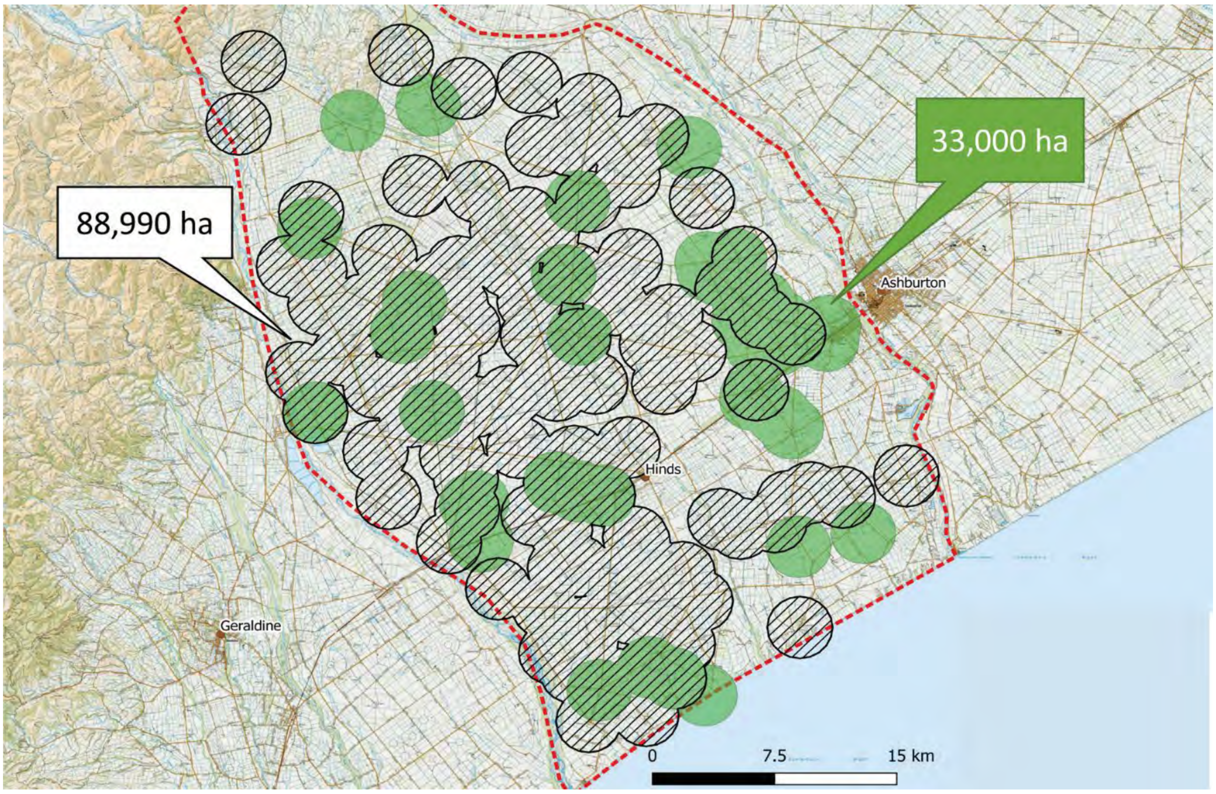


Figure 6-17: Current Hekeao Hinds Plains groundwater quality monitoring coverage using 2 km radius per bore (MHV Water in black and CRC in green)

Figures 6-19 and 6-20 present, respectively, the median and average annual nitrate-N concentrations for the CRC (PC2) and MHV Water shallow and deep bores. In Figure 6-21, the shallow and deep bores are combined for the CRC and MHV Water datasets. The 2014-16 drought (see Figure 6-18), appears to have had a significant effect (decreased nitrate-N) in the CRC monitoring bores, due to the reduction in land surface recharge in dry years. The 2018 above average rainfall year corresponds with peak nitrate-N concentrations in shallow CRC bores, with deeper bores being delayed by one to two years. Median values show greater variation between years than average values, especially for the shallow PC2 bores. The relative influences of rainfall, nutrient leaching reductions, and MAR, on these PC2 bores will need to be carefully evaluated through to 2035, in order to inform PC2 reviews.

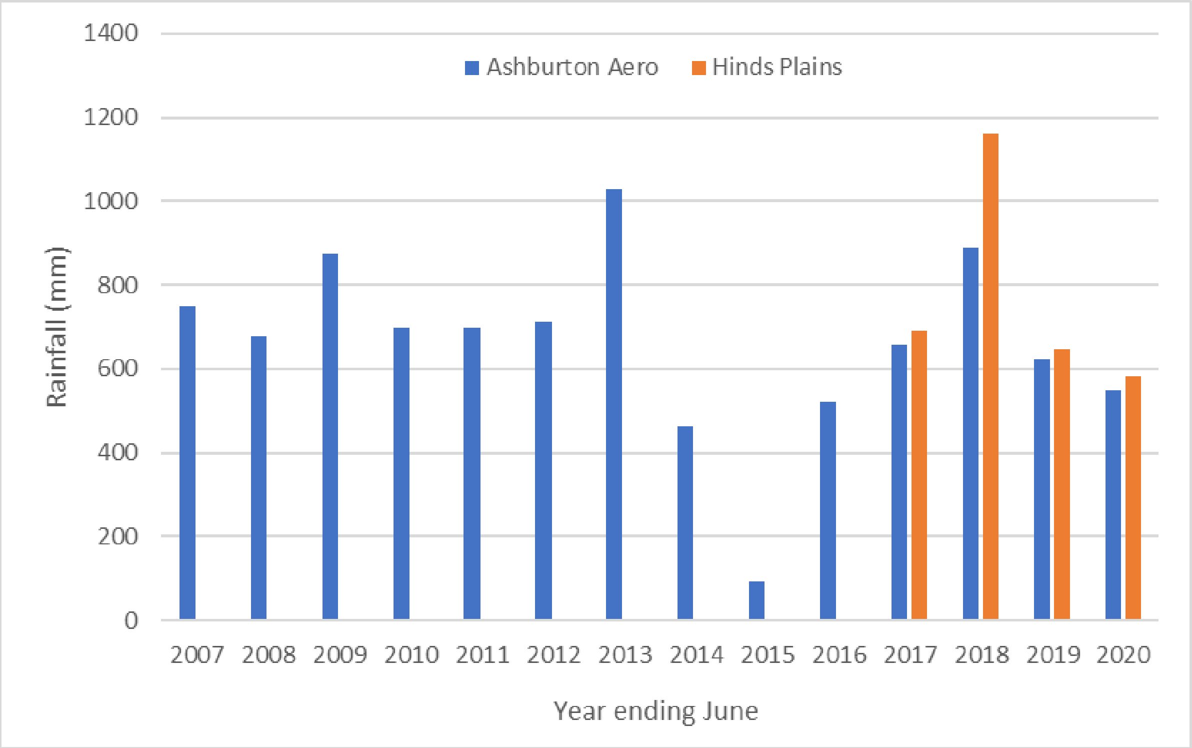


Figure 6-18: Annual Hekeao Hinds Plains rainfall (July to June) for two rainfall sites

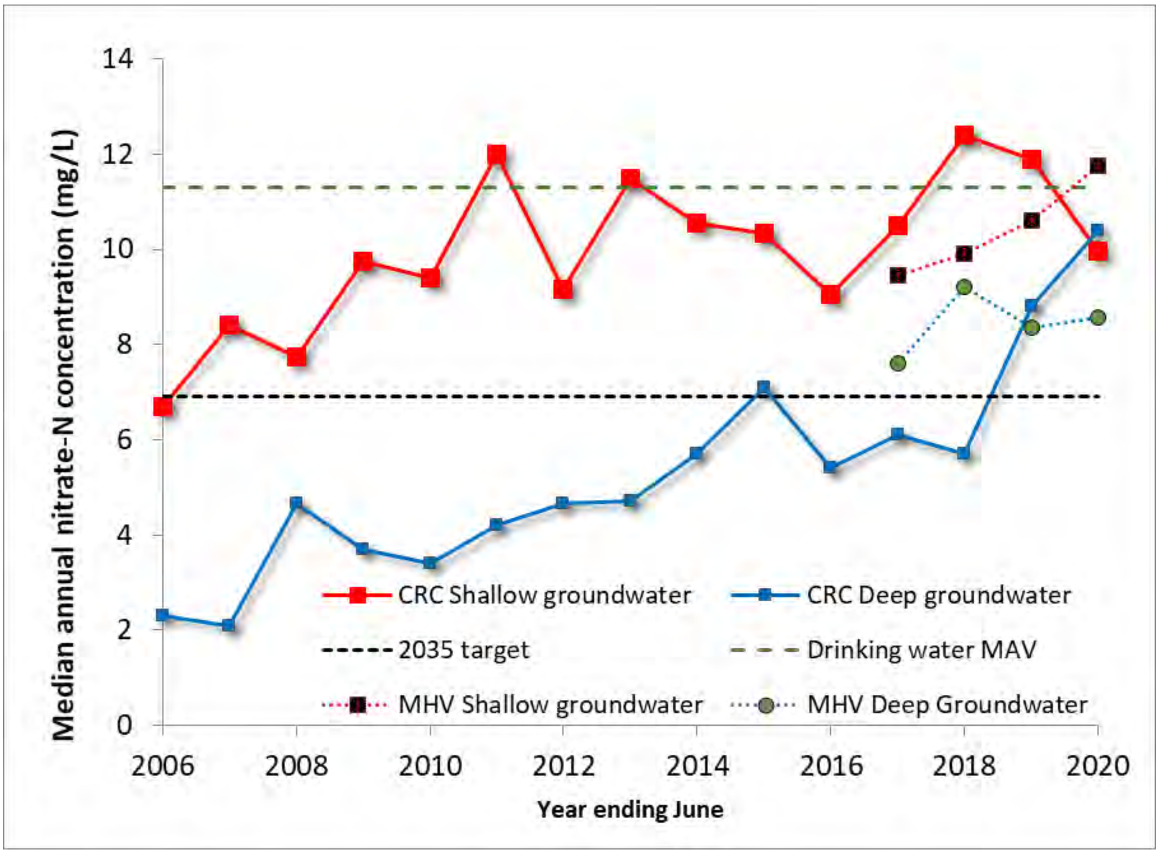


Figure 6-19: Median annual Hekeao Hinds Plains nitrate-N for four monitoring bore sets

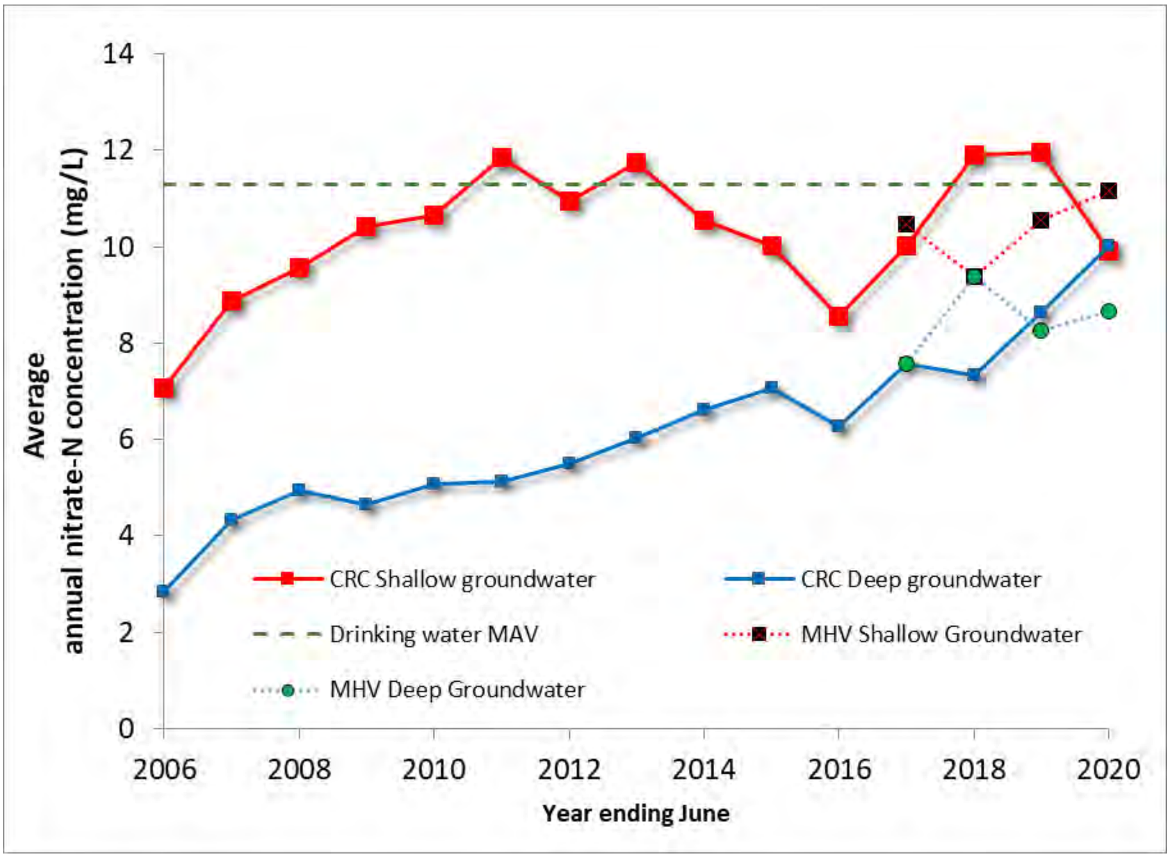


Figure 6-20: Average annual Hekeao Hinds Plains nitrate-N for four monitoring bore sets

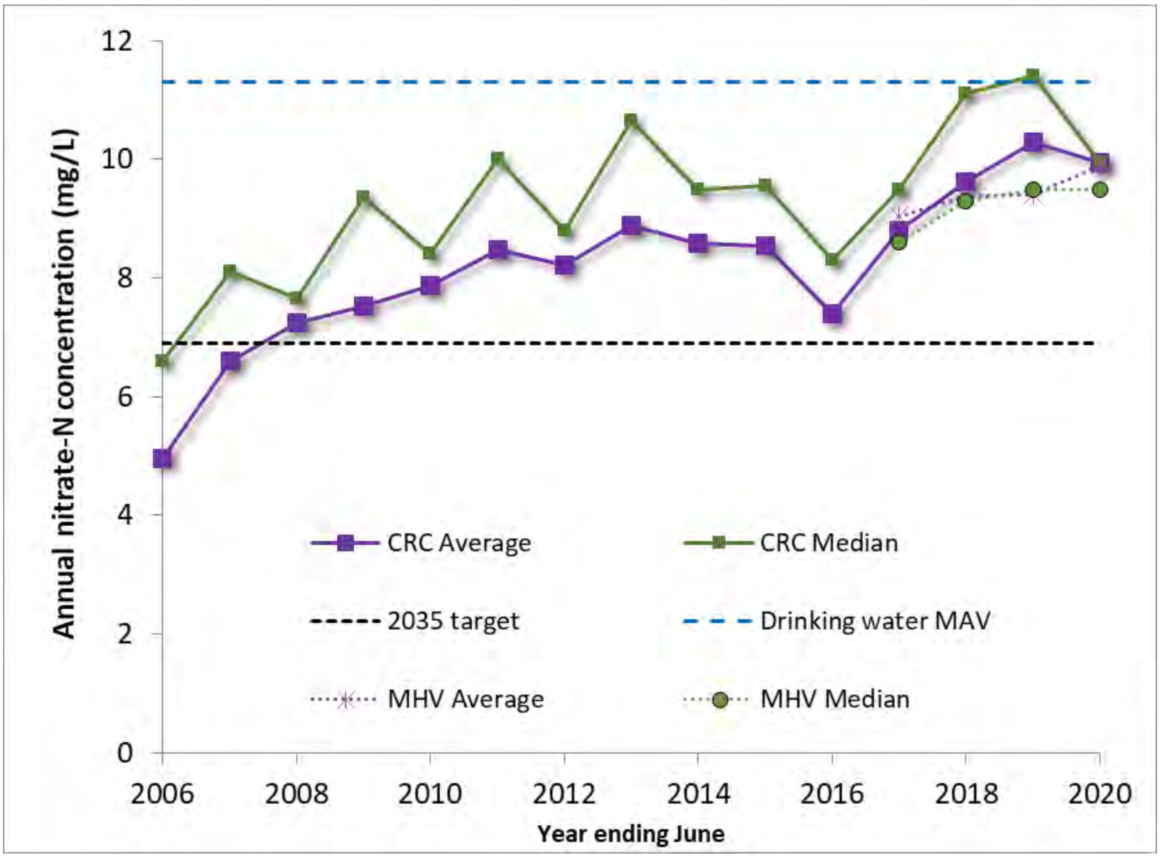


Figure 6-21: Comparison of median and average annual Hekeao Hinds Plains nitrate-N for combined (shallow and deep) CRC and MHV Water monitoring bore sets

It is important to note that the MHV Water dataset has changed each year to date, as the number of bores has increased, so between-year comparisons are less valid than for the CRC bores. As the MHV Water dataset settles (i.e., becomes more consistent year to year) over the next few years, the significant coverage it provides will enable an important comparison with CRC bore monitoring, with which to assess the relative contributions of rainfall, reduced nutrient leaching and MAR to groundwater nitrate-N concentrations. Although CRC monitor deep bores, only on an annual basis, quarterly deep bores monitored by MHV Water show reasonable variation within calendar years. This will be relevant when comparing with the CRC deep bores that are only monitored once per year.

7 Next Steps

In February 2020, the Hekeao Hinds Water Enhancement Trust (HHWET) signed a funding agreement with the Provincial Growth Fund through to June 2022. Cash and in-kind support were also confirmed with Canterbury Regional Council, Ashburton District Council, Rangitata Diversion Race Management Ltd, Central South Island Fish and Game and MHV Water. In accordance with the funding agreement and the Ashburton Zone Committee ZIPA proposed timeframe of full-scale MAR by 2025, the following objectives were determined by HHWET through to March 2022, with significant progress anticipated on all areas during Year 5:

a. Governance
   - i. Long term agreements in place with MAR Scheme operators (monitoring and supply), partners and landowners.
   - ii. Long term funding arrangements with stakeholders at an advanced stage of development.
   - iii. HHWET structure reviewed and amended as required for subsequent MAR Scheme phase/s.

b. Business Case
   - i. MAR Scheme Business Case scoped, drafted, discussed with stakeholders and updated as required.

c. Communications
   - i. MAR Scheme Communications Plan developed, implemented and updated as required.

d. Access to water
   - i. Long term agreements in place for MAR supply flowrate of at least 1500 l/s (approximately 47 million m^3/year), toward the long term target of 4000 l/s (approximately 125 million m^3/year).

e. Proof of concept
   - i. Improved methods of managing bacterial contamination and suspended sediment to reduce MAR supply shutdowns for these reasons.
   - ii. MAR Scheme infrastructure in place that provides compliant, safe, efficient and reliable operation.
   - iii. All recharge concepts identified in preliminary Business Case assessed further for inclusion in MAR Scheme Business Case.
   - iv. Operational MAR sites with demonstrated potential to recharge a combined flow greater than 2000 l/s (approximately 63 million m^3/year), toward the long term target of 125 million m^3/year with scheme over-build capacity of 55 million m^3/year.
   - v. MAR Scheme Monitoring Plan developed and updated as required.

f. Enabling Regulatory Environment
   - i. Long term HHWET (or parallel entity) take, use and discharge consents confirmed for a MAR Scheme of at least 2000 l/s flowrate (equivalent to approximately 63 million m^3/year).
   - ii. Additional short term (e.g., construction) consents secured as required.
   - iii. Additional permissions (e.g., DOC) secured as required.

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Appendix – Hekeao Hinds Plains Description

The Hekeao Hinds Plains are prone to drought, with a cool temperate climate including mean annual rainfall of 695 mm p.a, that varies from 614 mm at the coast to approximately 950 mm at the foothills near the top of the plains. 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). The surface geology is generally characterised having a thin (<0.5 m) sequence of stony, free-draining loess and Lismore type soils with a low water holding capacity of <75 mm (Figure 0-1) (Hanson and Abraham, 2013). Deep (>600 m), Quaternary aged, anisotropic and heterogeneous glacial outwash alluvial gravel fans underlie these soils and 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 a sedimentary formation that is variable and heterogeneous in structure.

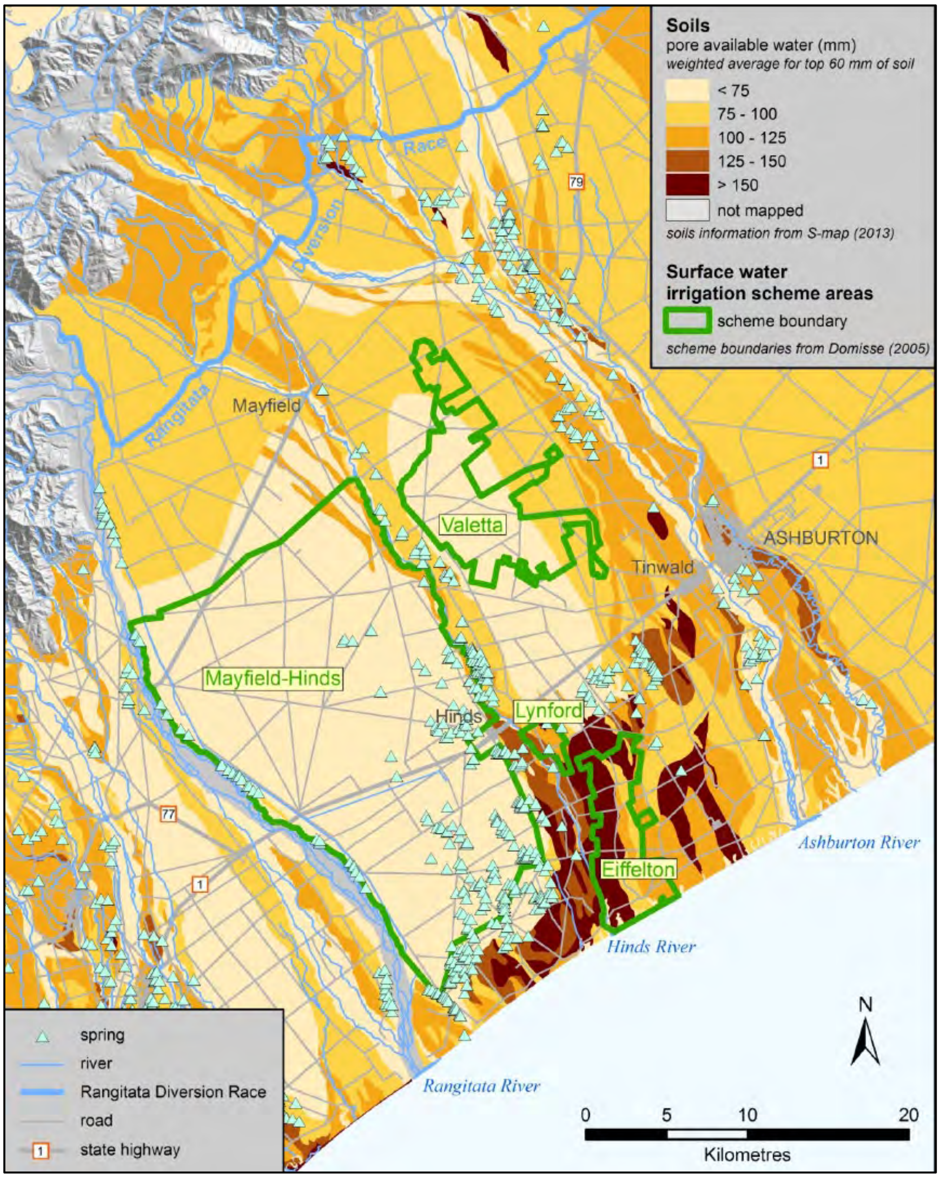

Figure 0-1: Soils of the Hekeao Hinds Plains (Source: Hanson and Abraham, 2013)

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. Sourced from the Southern Alps (*Kā Tiritiri o te Moana)*, these rivers are confined to terraced alluvial fans with variable flow rates. Historically, the groundwater system was conceptualised as three poorly connected and laterally discontinuous unconfined aquifers, split between the 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 hydrogeological system. General groundwater direction through the Hekeao Hinds Plains is assumed to be at right angles to regional groundwater level contours (Figure 0-2). These show some groundwater movement (known as river recharge) away from the upper and mid reaches of the Hekeao / Hinds and Hakatere / Ashburton Rivers.

Figure 0-2: Regional groundwater level contours – Hekeao Hinds Plains (Source: Canterbury Maps)

At a local scale, groundwater can flow preferentially depending on the presence of lenses of low permeability material (e.g. clay/silt), vertical hydraulic gradients (e.g. upwards toward a spring head) and through high permeability deposits. Notably, it has been suggested that up to 98% of groundwater flow occurs through open framework gravels (OFG's) (Dann et al., 2009). Such OFGs may be more prevalent in old buried river channels (known as paleo channels), where the sediments have been reworked by fluvial processes. Figure 0-3 presents mapping of paleo channels, based on air photo interpretation (Burbery et al., 2018; Durney et al., 2014; Hanson and Abraham, 2013). OFG's gravels:

- can 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).

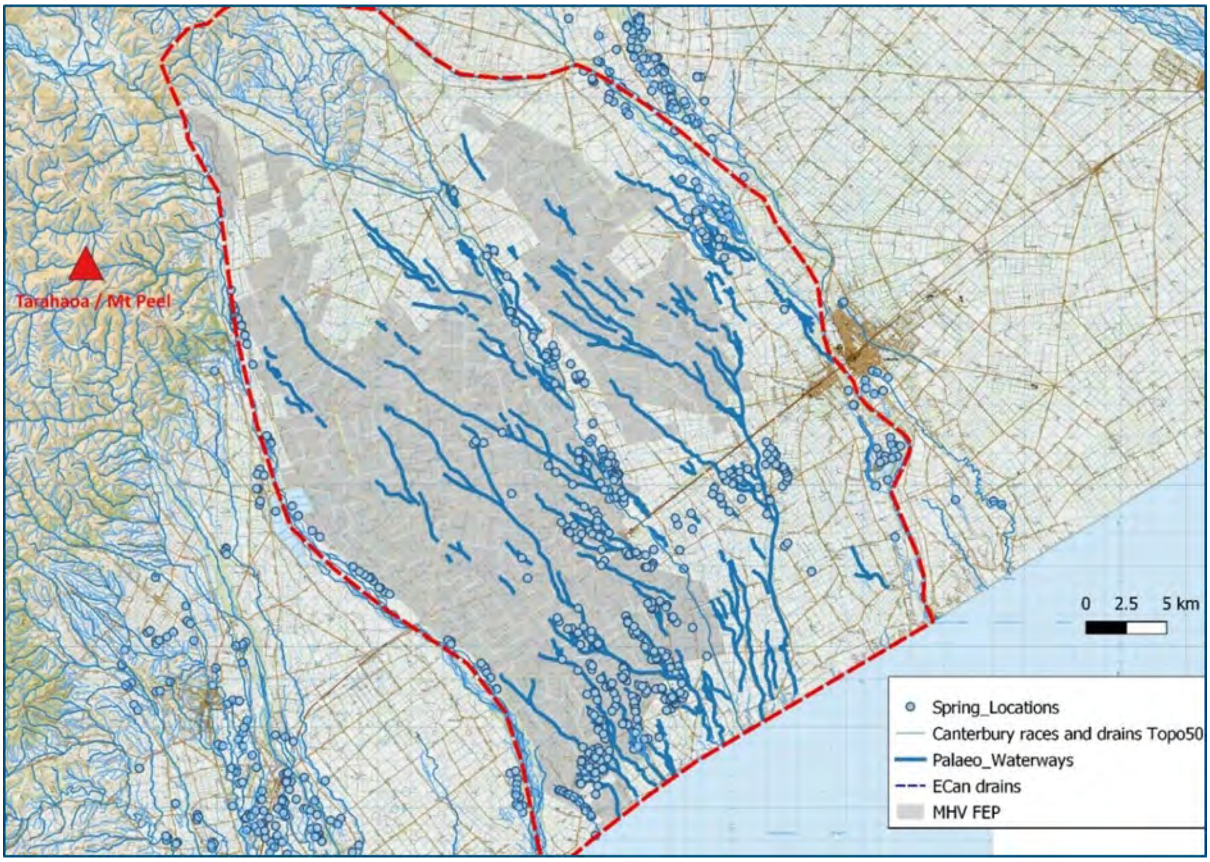

Figure 0-3: High-level interpretation of the 1m LIDAR digital terrain model (DTM) mapping paleo channels (Source: MHV Water)