Hekeao / Hinds Managed Aquifer Recharge Trial

Year 5 Annual Report

(June 2020 – May 2021)

Dr Brett Painter (HHWET Project Manager)

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Wetland beside the Hekeao / South Hinds River supported by MAR, before the May 29-31, 2021, flooding (Source: B. Painter)

Same wetland after the May 29-31, 2021, flooding (Source: B. Painter)

Chairman's Foreword

It gives me great pleasure to present this Chairman's Foreword on behalf of Hekeao Hinds Water Enhancement Trust.

Total year 5 MAR recharge volume of 13.5 M m^3 shows significant progress from the previous year's recharge volume of 7.7 M m^3. This has been delivered through 18 operational sites, including 4 new sites commissioned during the year.

A notable highlight this year has been the positive response in the lower Hekeao Hinds River attributable to MAR operations at two sites targeting the river, resulting in water quality at or below the 2035 ECan Plan Change 2 targets for a period of months.

Community consultation in the form of public meetings at Mayfield and Hinds were held to gain local support for Canterbury Regional Council targeted rate funding to provide capital and running expenses to progress the MAR trial. This funding is intended to expand the trial to a scale that will provide the Hekeao Hinds catchment with the water quality results that, in tandem with on farm nutrient reductions, will meet Canterbury Regional Council Plan Change 2 (PC2) targets.

The Crown's Essential Freshwater Package 2020 was released during the year; the full implications and effects are yet to be seen for our district. Canterbury Regional Council have until December 2024 to develop regulations and regional plan changes to give effect to NPSFW2020, including how the attribute national bottom line of Nitrate toxicity is to be achieved.

HHWET have contracted and are partnering with MHV Water to carry out significant groundwater and surface water monitoring in the Hekeao Hinds Plains Catchment. This work is caried out by the MAR Scheme Operations team of Murray Neutze and Justin Legg. Results from this monitoring are showing a reduction in Nitrate levels from a high in 2019.

The Crown's Provincial Growth Fund funding has enabled progress during Year 5 to continue in the Hekeao Hinds catchment toward meeting community and PC2 water quality targets. I acknowledge the Crown for the PGF funding coming into this district.

On behalf of HHWET I also acknowledge Canterbury Regional Council's contributions to this project, one being a share of project manager Dr Brett Painter's time. Brett has been invaluable to this project. Anne Marret has resigned as a Trustee to be replaced by Marcus Murdoch. I would like to thank Anne for her contribution to HHWET. Central South Island Fish and Game Council requested their nominee Mark Webb resign as a HHWET Trustee; he has since been appointed as an advisor to HHWET.

As chairperson I would like to take the opportunity to thank HHWET Trustees for their valuable contribution of expertise and time, and our project manager Dr Brett Painter, MAR Scheme operational staff, consultants and contractors for their valued contributions to this project.

Peter Lowe
Chairperson
Hekeao Hinds Water Enhancement Trust

Acknowledgements

The author wishes to thank the Hekeao / Hinds Water Enhancement Trust (HHWET) for project oversight, Mark Webb (Central South Island Fish and Game) for the fish survey monitoring and analysis, Kimberley Dynes (Canterbury Regional Council) for Hekeao / Hinds River monitoring and analysis, Pattle Delamore Partners for computer modelling analysis, MHV Water, RDRML, Lincoln Agritech and Environment Canterbury field staff for monitoring information, and all report reviewers.

Executive summary

Background:

Aquifer / groundwater recharge happens both naturally and artificially every minute of every day and is the reason groundwater systems and spring-fed waterways exist at all. Recharge from rainfall, rivers, leaky water races and canals, and irrigation activities all act to recharge groundwater. These recharge sources replenish groundwater, leading to increased groundwater levels and improved groundwater quality as well as the quality and flow rate of connected spring-fed waterways. Managed Aquifer Recharge (MAR) is the purposeful recharge of specifically high-quality water into a groundwater system to complement natural recharge. This can assist with the rehabilitation of the groundwater system and its connected spring-fed waterways.

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 changes to future water quality and quantity 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 Hekeao / Hinds MAR Trial utilises three different variants of MAR:

- MAR basins and races, which recharge groundwater across the plains (i.e., away from the Hakatere / Ashburton, Hekeao / Hinds and Rangitata Rivers);
- Near River Recharge (NRR), which recharges groundwater in the flood plain of the Hekeao / Hinds River; and
- Targeted Stream Augmentation (TSA), which directly augments a spring-fed waterway using nearby groundwater.

The reporting of progress towards these objectives focusses on the MAR contribution to groundwater level rise, reduction in groundwater nitrate-nitrogen (nitrate-N) concentrations and improvements to Hekeao / Hinds River ecosystem health.

Our objectives:

In February 2020, the Hekeao Hinds Water Enhancement Trust (HHWET) signed a funding agreement with the Provincial Growth Fund through to June 2022. Financial 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 (2020-21):

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.

What we did:

Progress to address these priorities during Year 5 (2020-21) is summarised as follows:

a. Governance

- Ashburton District Council (ADC) stated ongoing support for Managed Aquifer Recharge via resolutions from Council at their meeting of 24 September 2020. Discussions regarding long term access to water, land and water race distribution continued through Year 5.
- A MAR supply strategy and MAR Scheme development next steps were approved by HHWET in February 2021.
- MAR water supply discussions with Rangitata Diversion Race Management Ltd (RDRML) continued through Year 5, with the expectation of finalising Conveyance and Water Supply Agreements in Year 6 (2021-22).
- HHWET, Canterbury Regional Council (CRC) and MHV Water reached agreement on the distribution of long-term MAR monitoring tasks and began the transition from current providers.
- MHV Water continued to provide MAR operational and distribution services under contract to HHWET. During Year 5 these services were expanded to include water storage for managing high suspended sediment water and implementation of the Hekeao / Hinds Monitoring Plan.
- A proposal to include targeted funding over the Hekeao / Hinds Plains for the MAR Trial was included in Canterbury Regional Council's 2021-31 Long Term Plan (LTP) consultation. The positive response to this proposal resulted in CRC Council confirming this funding early in Year 6 (June 17, 2021).

b. Business Case

- The Business Case completed in December 2020 was a key supporting document for the Long-Term Plan consultation.

c. Communications

- An HHWET website (www.hhwet.org.nz) and Facebook profile (@HekeaoHindsWET) were created during Year 5 (2020-21), with links to additional media articles on the HHWET website.

d. Access to water

- Ashburton District Council (ADC) have provided a further 8 years supplementary access to 500 l/s of their consented stockwater as part of the HHWET re-consenting process for the HHWET Ltd MAR Take and Use consent.
- An Agreement was confirmed with RDRML in August 2020 that enabled the development of a Water Supply Agreement and a MAR use consent application, supplementary to the RDRML Rangitata River Take Consent. Both are expected to conclude during Year 6 (2021-22).

e. Proof of concept

- Following a review of suspended solids management challenges and opportunities for Hekeao / Hinds MAR sites during Year 4 a trial was initiated to increase the use of irrigation ponds to allow the heavier sediment to drop out before distribution to MAR sites. This trial proved successful and has resulted in operational changes during Year 5 for this purpose.
- During Year 4 HHWET trialled and then purchased a laser bird scarer which was deployed to MAR supply ponds with high bird numbers. This contributed to a reduction in site shutdowns for high *E. coli* from 41 in Year 3 to 16 in Year 4. Due to this success, HHWET purchased a second laser bird scarer during Year 5. There were 20 site shutdowns for *E. coli* in Year 5.
- MAR sites in Year 5 have been able to recharge at a total rate of up to 915 l/s, plus race losses of 270 l/s outside of the irrigation season (as race losses during the irrigation seasons are counted as irrigation distribution losses). Three test sites have shown the potential to recharge more than their current limit of 100 l/s. Higher recharge limits will be sought through a consenting process in Year 6.

- 13.85 million m^3 of MAR water was delivered to the end of Year 5 (31 May 2021) compared to 8.32 million m^3 the previous year (a 66.5% increase). This is out of a possible 15.77 million m^3 available (87.8% utilisation of maximum consented volume).
- The MHV Water groundwater monitoring programme (a programme supported by HHWET to provide water quality monitoring information at an increasingly fine resolution) collected water quality measurements from approximately 50 different bores during Year 4. This increased to approximately 150 bores by the end of Year 5, with 44 surface water locations also sampled.
- During Year 5 HHWET contracted the creation of a three-dimensional computer model of the Hekeao / Hinds Plains surface and groundwater systems. This provided more detailed water quantity and quality analysis than previous computer models. Initial model assessments focussed on calibrating the model with historical monitoring information. These were followed by an assessment of relative water quantity and quality changes resulting from a theoretical MAR volume of 125 M m^3 per year distributed evenly across the 18 currently consented MAR sites.
- The MAR project has supported an MPI-funded project (through the Sustainable Food and Fibres Future Fund) to add a grid-tied solar voltaic panel system to an existing irrigation / Targeted Stream Augmentation (TSA) bore which is part of the Eiffelton Community Group Irrigation Scheme. TSA is a key component of the Hekeao / Hinds MAR Trial as it provides supply reliability to lowland waterways during dry periods. Solar panel construction and connection to the electricity grid was completed during Year 5, with on-going assessment and optimisation resulting in an initial business case for future implementation of similar systems. TSA will be further addressed in the Year 6 report.

f. Enabling Regulatory Environment

- As part of HHWET's increasing responsibilities for the Hekeao / Hinds MAR Trial, all Hekeao / Hinds MAR Trial consents were transferred from CRC to HHWET Ltd (a company owned by HHWET) during Year 5.
- Applications to replace the trial discharge consents at the Pilot Site (MAR 01) plus the primary take and use consent with long term consents were lodged during Year 5. This consenting process is expected to conclude early in Year 6.
- Documentation to support a new MAR consent process has begun. This includes a new MAR use consent application (supplementary to RDRML's divert, take and use consent CRC182542), new discharge, and upgraded discharge consents. Following consultation, this application is intended to be lodged during Year 6.

What we found:

Key learnings from Year 5 include:

- The primary constraint on recharge rates at MAR sites away from river systems has been found to be the hydraulic conductivity of the down-gradient hydrogeology. This is known as hydraulic clogging and is caused by the groundwater system becoming saturated. We assessed this effect by monitoring the change over time in recharge rates alongside other potential factors affecting recharge rates (in particular, physical clogging from accumulated sediment).
- Hydraulic clogging has been found to be much less constraining at Near River Recharge sites (where hydraulic conductivities are generally higher than under the plains), except when high river conditions saturate the groundwater system. At these times, Near River Recharge sites can be turned off as nature is already providing this service. The extent of these high recharge connections depends on the way the river system has moved around over time, thus depositing gravel over a wider area (and depth) than the visible current channel.
- The addition of a second Hekeao / Hinds River Project (HHRP) Near River Recharge site during Year 5 contributed to an increased flowing length of the Hekeao / Hinds River during late 2020, when surrounding groundwater levels were considered too low to provide this level of river

baseflow. An increased flowing river length during dry periods improves the survival rates of both fish and aquatic plants in these areas, as well as improving water quality and quantity down the river system.

- The increased use of irrigation ponds to allow the heavier sediment to drop out for longer periods of time before distribution to MAR sites has resulted in less sediment accumulation at MAR sites. This is particularly important for the small test sites, which are not easily cleaned.
- The addition of two lateral race MAR sites (at right angles to groundwater flow direction) during Year 5 have provided opportunities to trial more distributed (and potentially less constrained) recharge than a recharge basin. The bed of the race is scraped to encourage recharge and boulder beds are inserted in sections of the race that may connect to higher groundwater flow pathways. These races are comparatively easy to maintain and allow the MAR water to influence the down-gradient groundwater over a much wider area than a MAR basin site.
- The significantly increased Hekeao / Hinds Plains monitoring coverage in combination with groundwater system assessment and modelling workstreams has enabled the refinement of MAR site placement and MAR Scheme design. This is expected to improve the efficiency and effectiveness of MAR in the Hekeao / Hinds Plains through more targeted siting and design.
- The combination of a solar powered laser bird scarer on key storage ponds, increased duration in storage ponds for high sediment source water and increased understanding of bacterial die-off in groundwater has further reduced the risk of bacterial contamination of groundwater due to MAR operations.
- Initial results from the solar powered grid-tied TSA trial suggest that positive economic returns can be expected over a variety of array sizes and uses (e.g., environmental-only as well as combined environmental / irrigation).

What does it mean?

The Year 4 report posed four significant questions to be addressed during Year 5:

- 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?

Potential MAR water sources have been evaluated and are constrained to only seeking supplementary access to existing Rangitata River water take consents, making broad-scale MAR challenging. However, Year 5 results provide confidence that the current adaptive and targeted approach to Hekeao / Hinds Plains MAR Scheme development can meet the MAR aspects of the Ashburton Zone Committee’s Zone Implementation Programme (ZIP) and Addendum (ZIPA). Confirmed Targeted Rate funding through CRC’s 2021-31 Long Term Plan provides a level of planning and financial certainty for the Trial. A full review of scheme cost, design and performance is proposed in 2024 to inform any proposals for adjustments to the current Targeted Funding rates and differentials.

The New Zealand Government’s “Essential Freshwater” package introduced during Year 5 consists of three interlinked objectives that are aligned with PC2 implementation in the Hekeao / Hinds Plains:

- <u>Stopping further degradation and loss</u> – this is being addressed through PC2 requirements to significantly reduce nutrient leaching from landuse activities.
- <u>Reversing past damage</u> – this is being addressed through the Hekeao / Hinds Plains MAR Trial alongside complementary environmental infrastructure projects such as Targeted Stream Augmentation, constructed wetlands and bioreactors.
- <u>Addressing water allocation issues</u> – this is being addressed through irrigated area constraints, nutrient discharge consent renewals and the Ashburton Water Consents Review process.

Additional MAR sites have been identified to accelerate the development of the Hekeao / Hinds Plains MAR Trial and its contribution to the above Zone Committee, local and central government objectives. However, only 500 l/s of MAR water supply had been secured to the end of Year 5. The ZIPA timeline to achieve PC2 objectives by 2035 assumed that 2000 l/s of MAR supply would be confirmed by 2020. It is acknowledged that supplementary MAR access to an existing water take for a different purpose requires careful assessment of effects and discussions with interested / affected parties, and that these processes are often complex and challenging. However, as a viable alternative to the role of MAR has not been identified for reversing past damage to the Hekeao / Hinds Plains groundwater / spring-fed systems, it is important to accelerate progress in securing additional MAR supply during Year 6.

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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-N to a target of <6.9 mg/l by 2035. The PC2 2035 target for the lower Hekeao / Hinds River is 3.8 mg/l nitrate-nitrite-N. It is possible that LWRP changes in response to the New Zealand Government's "Essential Freshwater" package may result in further changes to targets and/or monitoring from 2025, but PC2 remains active in the meantime. The nitrate-N PC2 update to 30 June 2021 (which is different from the MAR project reporting period to 31 May) in Figure 1-1 shows median nitrate-N concentrations in PC2-specified "shallow" wells across the Hekeao / Hinds Plains. The values in Figure 1-1 and their presentation are slightly different from previous Annual Reports due to a clarification by Environment Canterbury in the method for reporting PC2 nitrate-N groundwater concentrations. This clarification confirms that the 13 wells screened <30 m below the water table that were part of PC2 technical analyses (and their subsequent replacements) are to be monitored quarterly, with the median of each monitored bore's median used as the annual value. Previously, only wells within 30 m of the ground surface were included in this assessment.

Figure 1-1 shows that the 2020-21 nitrate-N median concentration of 9.4 mg/l was the second year in a row with a concentration decrease and the lowest concentration since 2010. Figure 1-1 also shows that 2020-21 was drier than average (over the presented timescale), in particular the year until 29 May 2021 (when 185 mm of rain fell over the following 3 days). The PC2 groundwater nitrate-N monitoring for 2020-21 had been completed by this time so does not include any changes in groundwater nitrate-N concentrations as a result of this heavy rainfall event. It is likely that the below average rainfall during the 2020-21 PC2 reporting period contributed to the decrease in annual median PC2 groundwater concentration. However, MAR along with continued changes to landuse, water distribution infrastructure, irrigation methods and nutrient leaching management are also likely to be influencing groundwater concentrations during this time. The complex interactions between these influences, and (often) long lag times, makes detailed analysis of individual influences very challenging.

Analyses 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 NNN in the lower Hekeao / Hinds River (for 90% aquatic species protection). Table 1-1 (below) shows that the total recharged MAR volume in Year 5 was approximately 13.85 million m^3. This was a 66.5% increase on the previous year and an 88% utilisation of consented MAR supply water. The key reason for this improvement was the increased use of irrigation scheme storage, which allowed for higher turbidity water to be taken for use once the sediment had dropped out. Consistent with previous annual recharge assessments, the Year 5 MAR monitoring 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 5 Hekeao / Hinds MAR recharge

	MAR Volume (cubic metres)
Delivered to South Hinds NRR1 Site	3,416,805
Delivered to Pilot Site #1	1,659,867
Delivered to Test Sites #2-18	7,332,553
Distribution system recharge (race "losses" when MAR water-only delivered)	1,473,398
Total Year 5 recharged flow	**13,844,589**

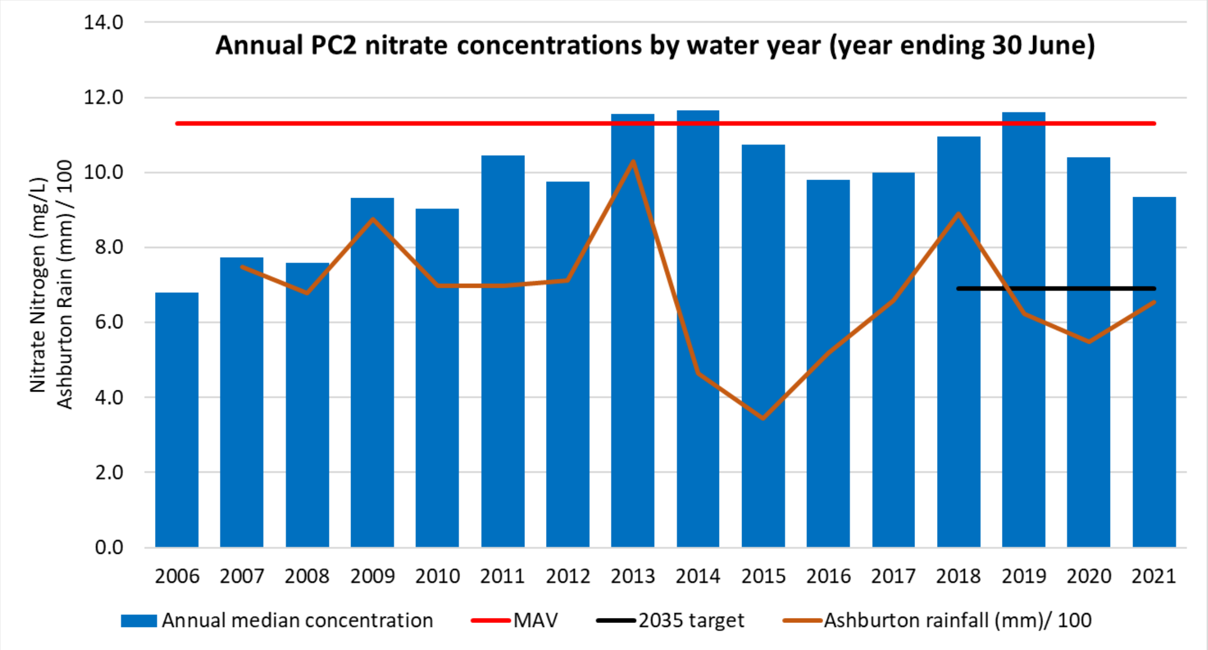


Figure 1-1: Plan Change 2 to Canterbury's Land and Water Regional Plan – Hekeao / Hinds Plains median annual nitrate-nitrogen concentrations plus Ashburton annual rainfall (Source: CRC)

This report focusses on MAR operational updates, key monitoring information and analysis. Consent compliance monitoring results are presented in the Annual Compliance Report (HHWET, 2021). Figure 1-2 presents the MAR sites operational during Year 5 and Table 1-2 presents their key performance indicators.

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 5 monitoring, though turbidity continued to vary 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 1-3) on key storage ponds (with a second bird scarer purchased during Year 5) 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 and 20 site shutdowns in Year 5.

Table 1-2: MAR site performance information for Year 5 (June 2020 – May 2021 inclusive)

June 2020-May 2021	Maximum recharge rate (l/s)	Total recharge volume (m^3)	Weeks in operation	*E. coli* shutdowns	Notes
1 – Lagmhor Pilot	130	1,659,867	36	1	
2 – Timaru Track	75	659,019	34	1	
3 - Walls	18	25,823	4		Supply limited to ~30 l/s. Low priority when limited supply.
4 - NZSF	21	38,177	6		Low priority when limited supply.

5 – Pond 2	20	148,636	20		
6 – BCI/Howden	15	387,010	48		Supply limited to ~25 l/s
7 - Lobblin	100	1,003,076	25		
8 - Lacmor	17	49,211	7		Low priority when limited supply.
9 – Riverbank	25	453,270	49	2	
10 - Foster	51	472,338	38	7	
12 - Slee	51	693,669	42	1	
13 – Hills view	36	637,583	43		
15 - Oakstone	26	149,154	19	3	Low priority when limited supply.
16 - Broadfields	17	380,897	44		
17b – Jones (NRR site)	100	1,573,385	41	1	
18 - McDougall	50	661,276	41	4	
NRR1 - South Hinds	150	3,416,805	49		
MH race losses	268	1,473,398	13		

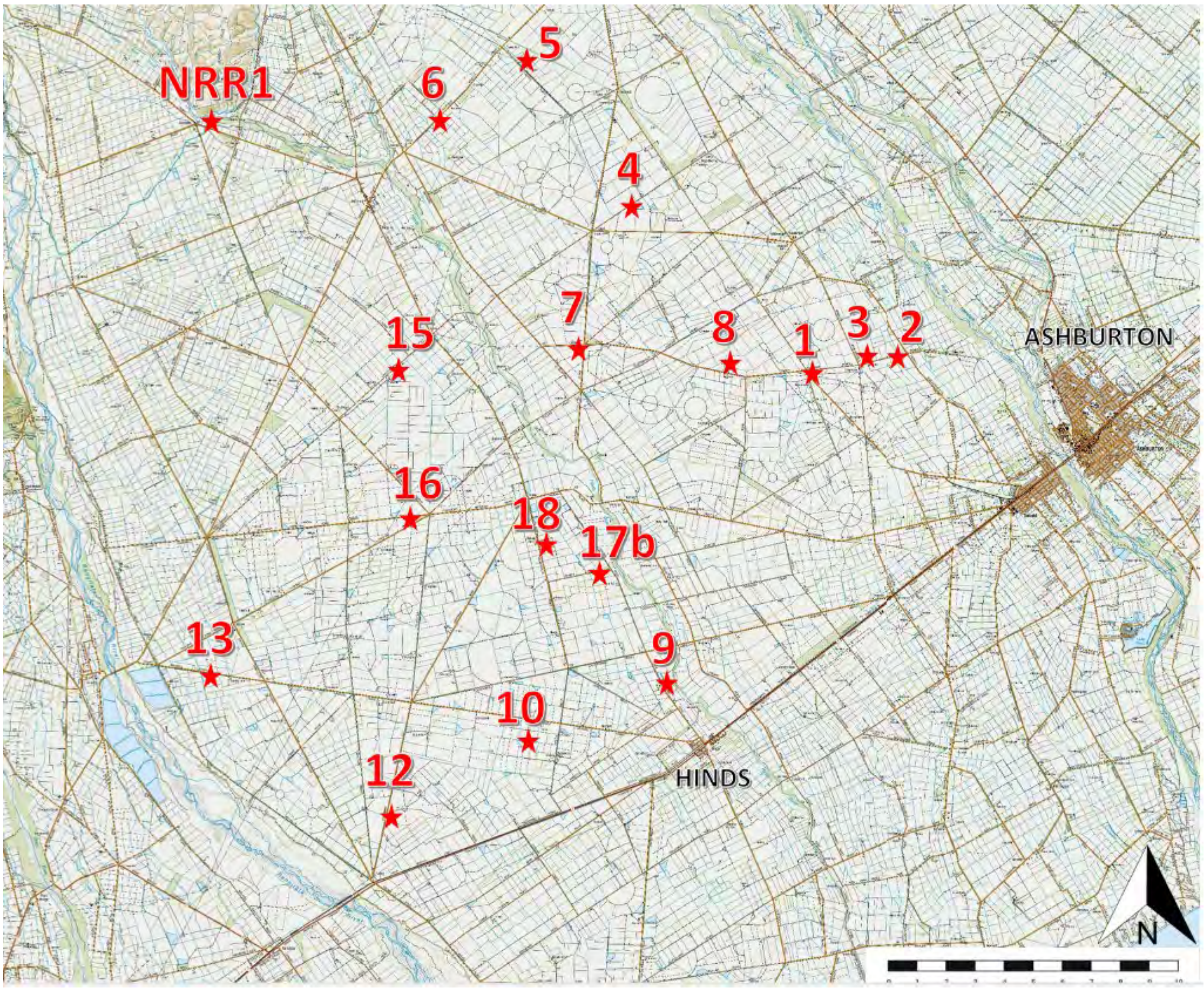


Figure 1-2: Hekeao / Hinds MAR sites operational during 2020-21

Table 1-3: RDR Intake turbidity distribution for Year 5

Percentile	RDR Intake Turbidity (NTU)
10	30
20	32
30	35
40	39
50	45
60	54
70	75
80	117
90	289
100	2838

Figure 1-3: Hekeao / Hinds MAR laser bird scarer (Source: M. Neutze)

Most Hekeao / Hinds MAR sites showed signs of physical clogging by suspended solids during Years 1-5. Sites with a functioning forebay for dropping out heavy sediment (e.g., MAR 01 and NRR1) and lateral race sites 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 (open) 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 almost all the time in Year 5.

In response, MAR operations staff increased the use of MHV Water scheme storage and connected distribution storage via a water swap. This involved diverting MAR supply with high turbidity to storage ponds and then taking this water from storage at a later date when the heavier sediment had dropped out. This practice has enabled a significant increase in MAR volume supplied to sites while also reducing sediment supply to MAR sites.

2 Hekeao / Hinds River Project

The majority of the strata under the Hekeao / Hinds Plains were formed during the Late Quaternary period, from approximately 400,000 years ago until the present time. During this period outwash from the Rangitata and Ashburton Glaciers, and the rivers during the interglacial periods, transported gravel, sands and silts across the plains, with the larger Rangitata Glacier dominating the majority of the area (Barrell et al. 1996). We can still see surface river channels from previous time period using digital terrain model mapping (e.g., Figure 2-1). In between glacial periods, the Hekeao / Hinds River created a pathway to the lower catchment swamp and sea by reworking sediments laid down by outwash from the Rangitata and Ashburton Glaciers (Mitchell,1980; Dommisse, 2006). Lower catchment springs outline a historic swamp area, which can also be identified through soil mapping (Figure 2-2).

Following high rainfall events and during periods of high groundwater levels, the Hekeao / Hinds River can be expected to flow for its full length. At other times, the upper and lower Hekeao / Hinds Rivers are separated, with flow in the upper reaches primarily dependent on springs and seeps around the Surrey Hills and the lower reach dependent on lower catchment spring and drain flows. Dommisse (2006) describes the role of the Mayfield-Hinds Irrigation Scheme (now part of MHV Water) in supporting Hekeao / Hinds River flows, particularly from scheme discharge points into the riverbed and from border-dyke irrigation recharge. In recent decades, a lower-than-average rainfall, in combination with more efficient irrigation distribution and use, have reduced these contributions to the lower Hekeao / Hinds River system (e.g., Dench and Morgan, 2021). Lower river flows combined with increasing nutrient concentrations have resulted in decreased eco-system health.

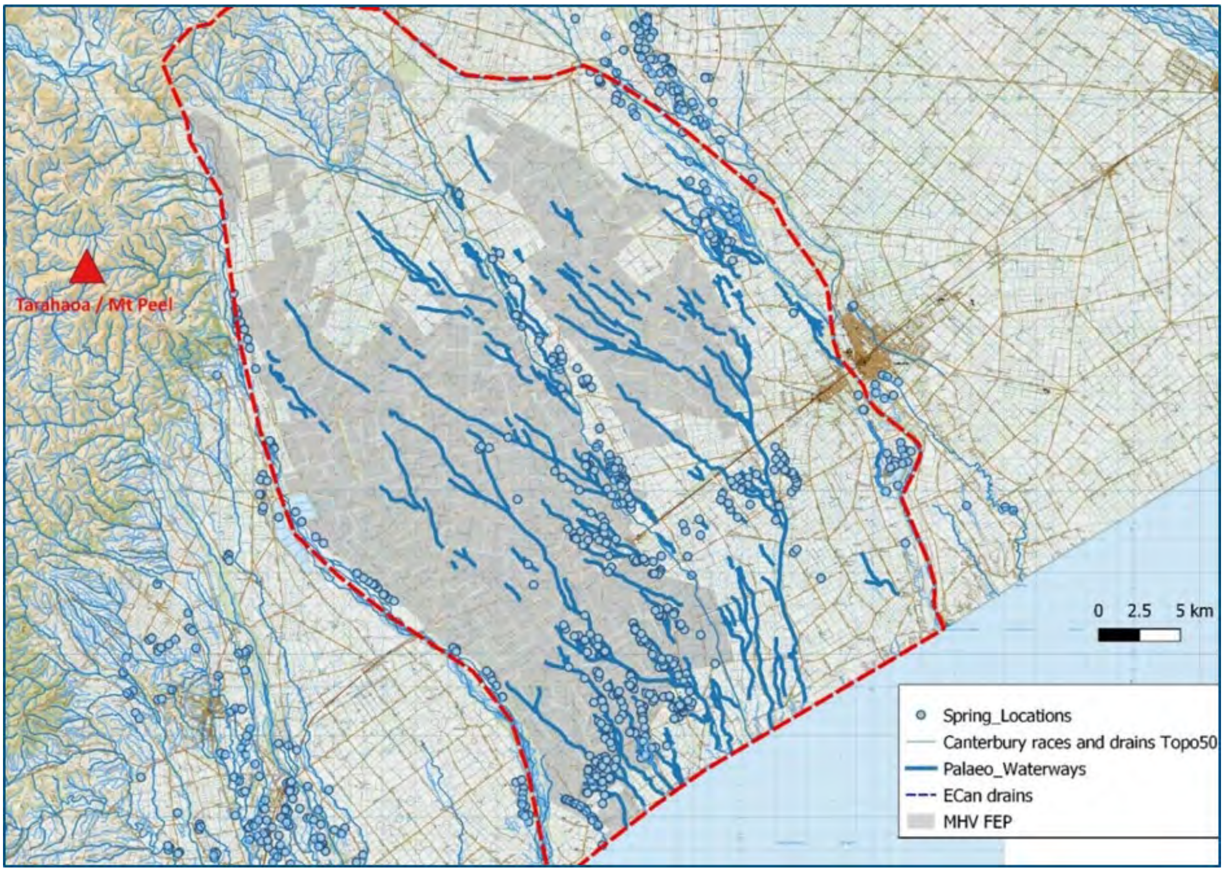


Figure 2-1: High-level interpretation of the 1m LIDAR digital terrain model (DTM) mapping paleo channels (Source: MHV Water)

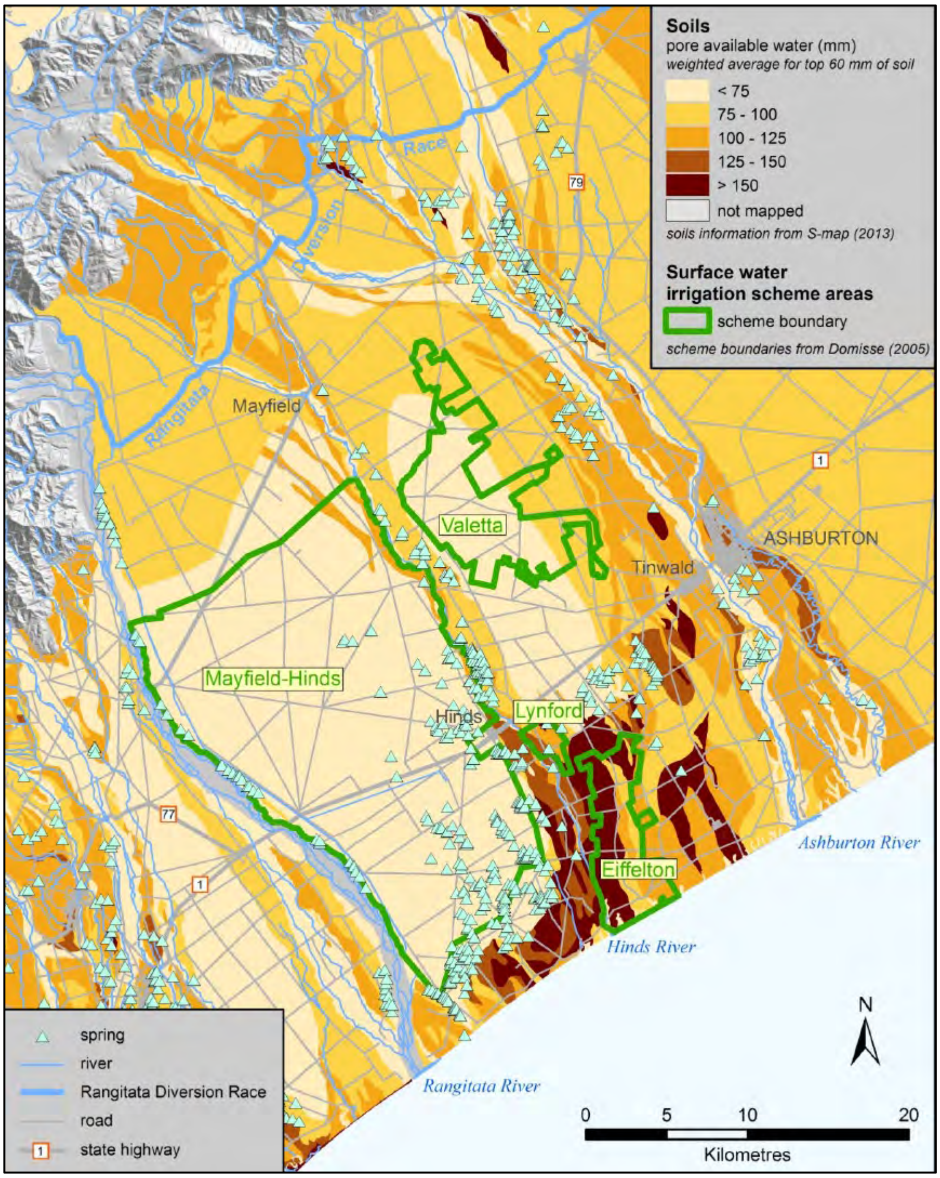


Figure 2-2: Soils of the Hekeao / Hinds Plains (Source: Hanson and Abraham, 2013)

The purpose of the Hekeao / Hinds River Project (HHRP) is to assist in improving the eco-system health of the whole Hekeao / Hinds River system (in combination with relevant land management practices and other concepts such as constructed wetlands and bioreactors). One of its specific goals is to contribute positively to Canterbury's Land and Water Regional Plan (Plan Change 2) 2035 annual median target of 3.8 mg/l nitrate-nitrite-N (NNN) in the lower Hekeao / Hinds River for 90% aquatic species protection. The key contribution of the Hekeao / Hinds MAR project is the addition of clean water to the river system via the concept of Near River Recharge (NRR). NRR is like MAR in that it involves recharging groundwater via leaky basins, wetlands and / or races. However, NRR sites are close enough to contribute directly (via shallow groundwater) to the river reach immediately adjacent and down-gradient of the discharge site.

NRR sites are designed to ensure that water is always filtered through alluvial material before mixing with natural river system water. This filtering process modifies the temperature and potentially the chemistry of NRR water through mixing with groundwater and ensures that there is no direct mixing of NRR water with river water. The shallow groundwater table around NRR sites is raised, which supports the establishment of native plants. The aquatic life of supported wetlands and river reaches is enhanced. Other biodiversity initiatives, such as protection of valued terrestrial plants and / or wildlife, can be progressed at NRR sites as added value.

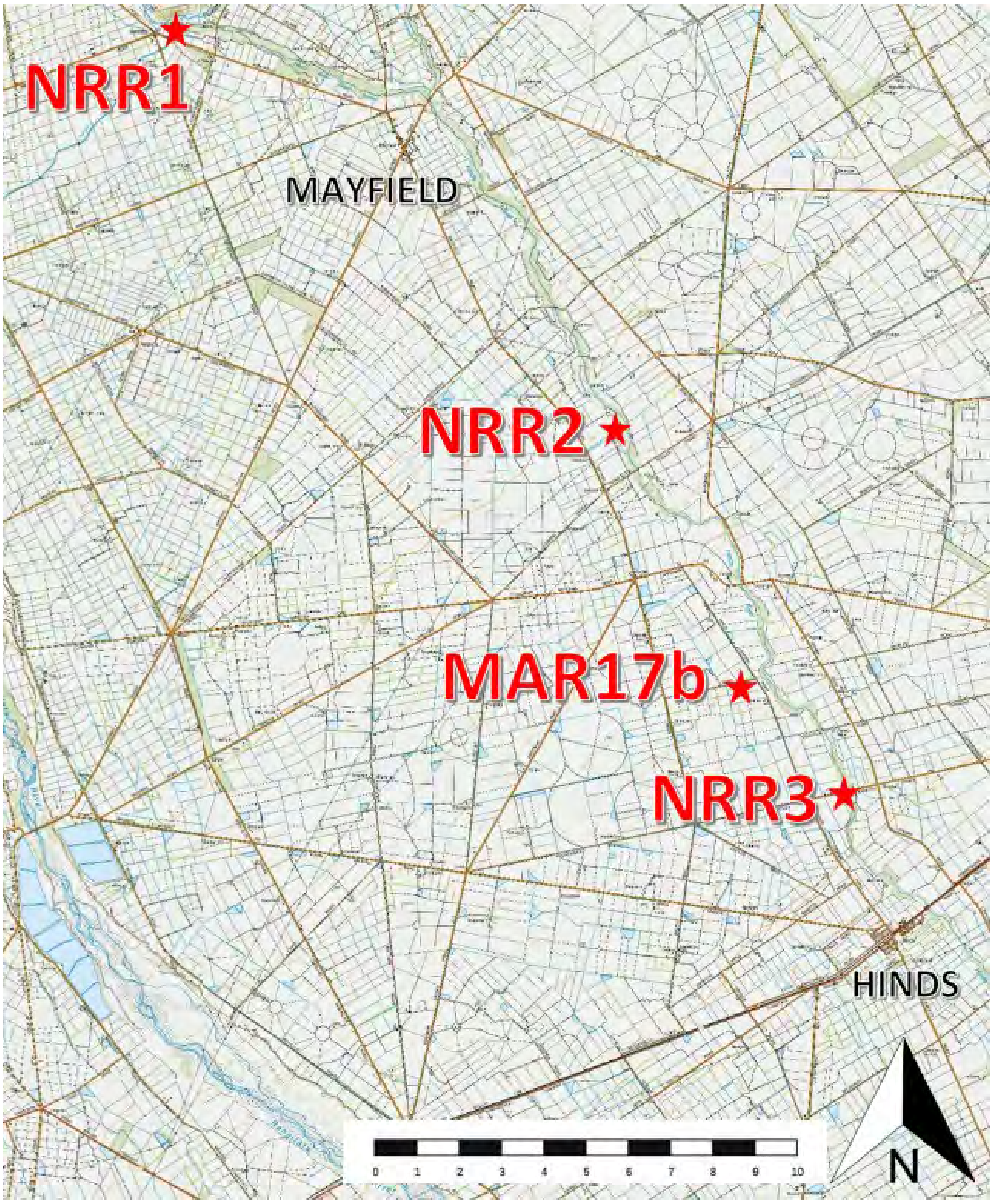


Figure 2-3: HHRP sites

Figure 2-3 shows the location of four current and potential NRR sites. The first HHRP site (NRR1) has been operational since September 2018 (Figure 2-4). MAR17b (classified as a MAR test site but close enough to the Hekeao / Hinds River to also provide Near River Recharge) began operation in June 2020. NRR2 and NRR3 began their initial planning phases during Year 5.

2.1 NRR1 – South Branch Hekeao / Hinds River

This site receives Rangitata River water, via siphon, directly from the Rangitata Diversion Race (RDR). Although the consented supply flow is 210 l/s, a flow rate of 170 l/s is the maximum rate that has been introduced to date in order to keep basin levels well below their maximum. In addition to the recharge channels and basins, lizard habitat (under DOC Covenant) has been created away from the flood plain, an oxbow wetland (with potential to establish Kōwaro / Canterbury mudfish habitat) has been rehabilitated and is supported by the raised local groundwater, and native plants (wetland and dryland) have been reintroduced (Figures 2-4 to 2-6). A flood event from May 29-31, 2021, with flows in the Hekeao / Hinds River of ~200 m^3/s, caused significant damage to this site (Figures 2-7 and 2-8). It will be repaired, protected and enhanced during Year 6.

Figure 2-4: NRR1 site overview (Source: MAR Year 2 report)

Table 2-1 and Figure 2-6 present the monitoring requirements for NRR1 consent CRC210704, with key compliance monitoring results 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 (Table 2-2). 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 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 Hekeao / Hinds River (>4000 l/s), which, to date, have occurred 2% of the time.

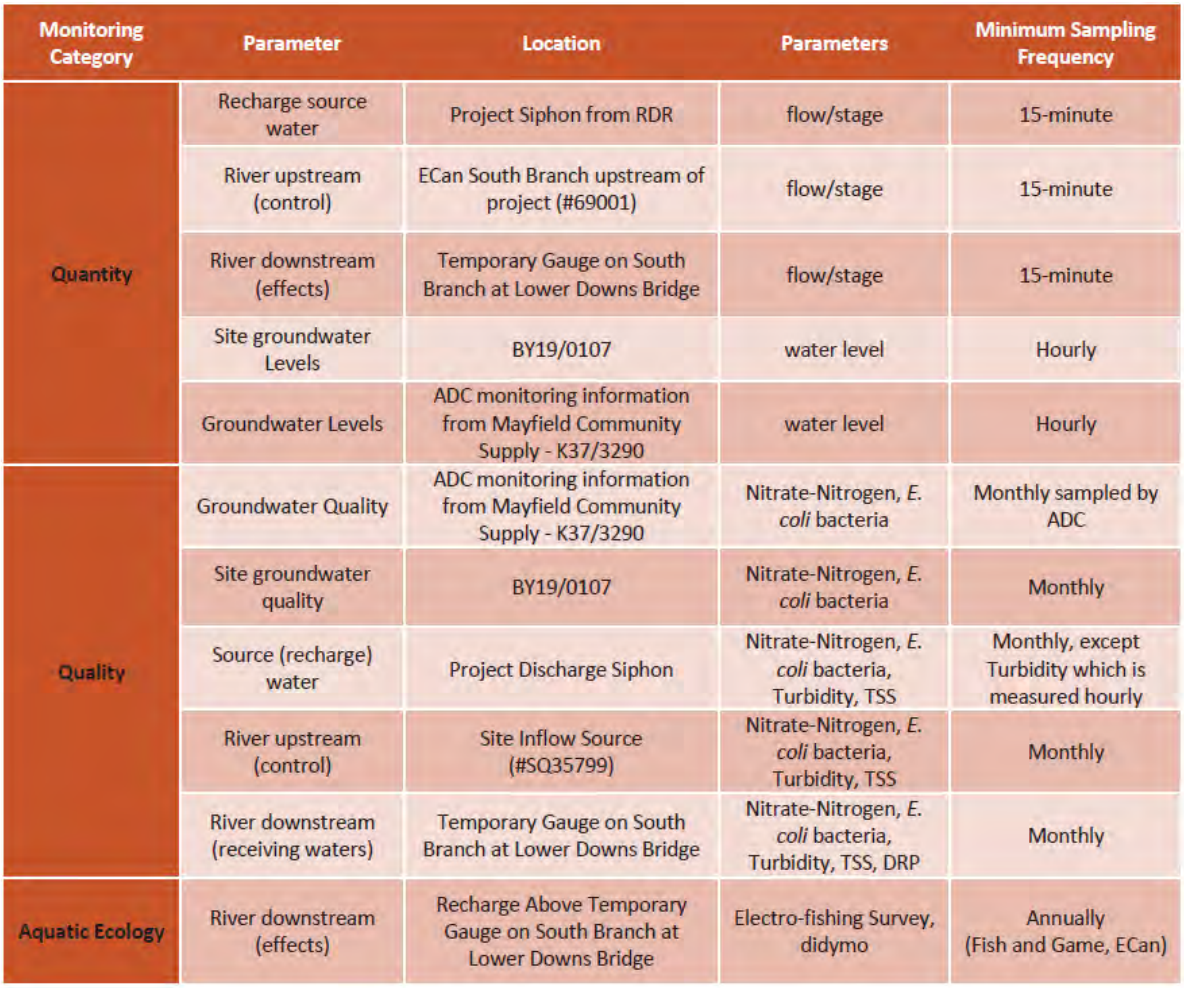
Figure 2-5: View across wetland to Hekeao / South Hinds River prior to rehabilitation (2018) (Source B. Painter)

Figure 2-6: Wetland after rehabilitation (2020), supported by NRR1 and under preparation as Kōwaro / Canterbury mudfish habitat (Source: B. Painter)

Figure 2-7: Wetland following May 29-31, 2021, flooding (Source: B. Painter)

Figure 2-8: NRR1 site following May 29-31, 2021, flooding (Source: RDRML)

Table 2-1: NRR1 Monitoring (CRC210704)



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 2-2: NRR1 source water turbidity distribution

Percentile	Turbidity, 1/3/2019-17/2/2021 (NTU)
10	8
20	12
30	19
40	24
50	32
60	42
70	58
80	107
90	271
100	1,304

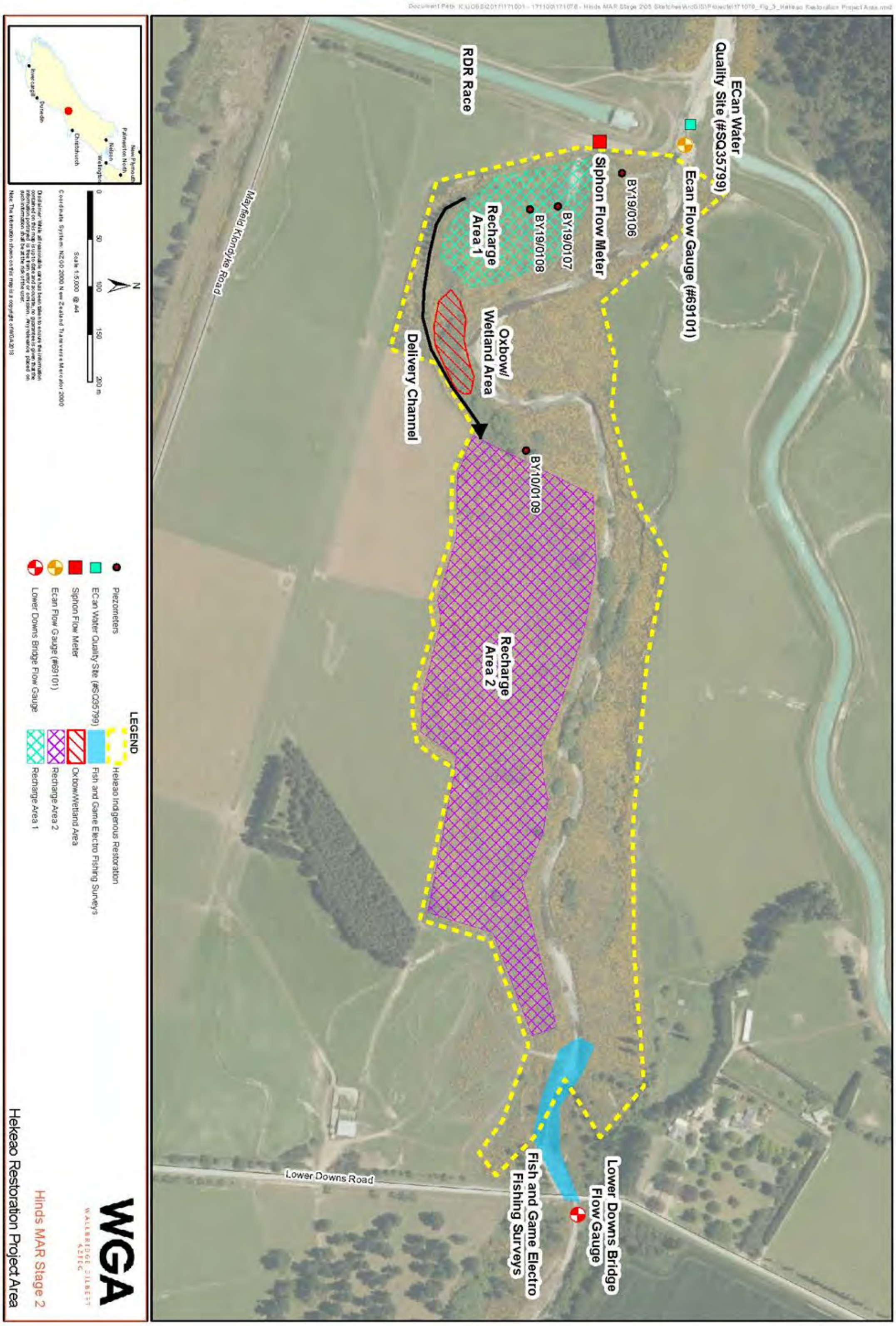


Figure 2-9: NRR1 monitoring points (Source: MAR Year 2 report)

2.1.1 Water quantity monitoring

Figure 2-10 compares up-gradient Hekeao / Hinds River flow (RDR Siphon #69101) with NRR1 flow and down-gradient river flow (Lower Downs #69106). When the NRR1 site is turned on site #69106 responds within a day, showing a flow increase less than the supplied NRR1 flow. This suggests that NRR1 flow is recharging local groundwater as well as the river. Sites #69101 and #69106 produce similar flows when the NRR1 site is turned off, thus flow differences can be attributed to NRR1 recharge. The flow differences vary with river flow, but the low river flow periods in February 2020 and April 2021 suggest that up to 60 l/s may be recharging groundwater at the site (i.e., not reaching the local river reach). The median Year 3-5 flows of 100 l/s at Site #69101 and 168 l/s at Site #69106 suggest a 68% increase in median flow due to NRR1 recharge. The proportion of time the reach is flowing at less than 50 l/s also reduces from 33% to 6%, which is a significant improvement for fish in this reach.

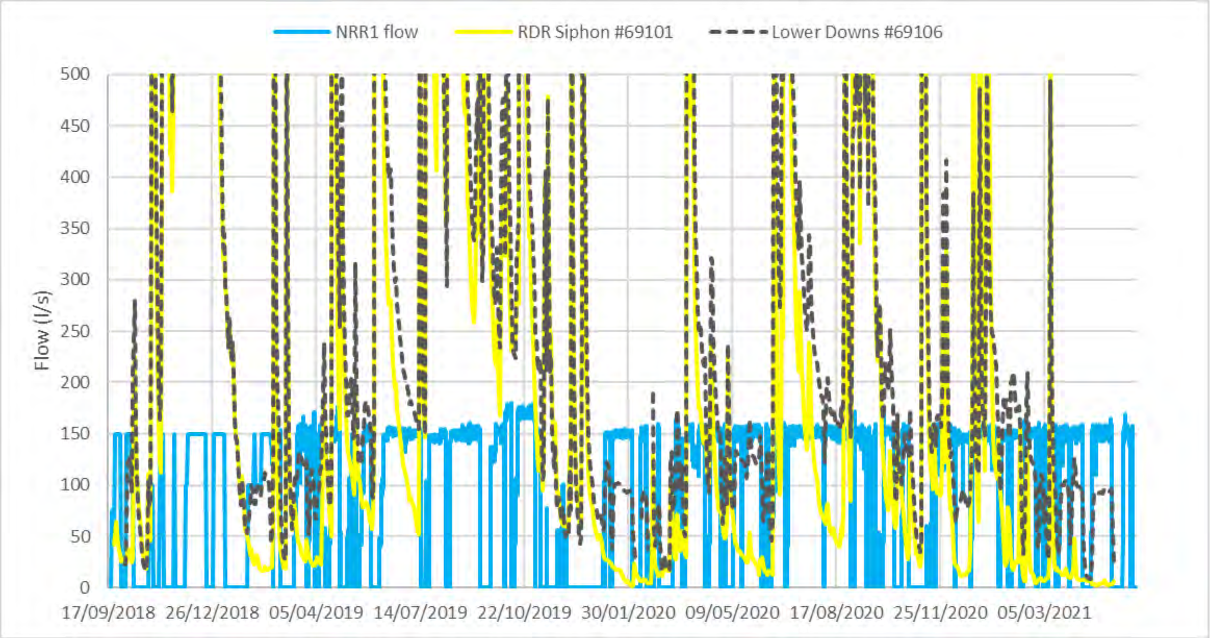


Figure 2-10: NRR1 and Hekeao / Hinds River flow (Source: HHWET, CRC)

NRR1 effects on down-gradient surface flow and nearby groundwater are presented in the MAR Year 4 Annual Report (HHWET, 2020). Figure 2-11 presents the location of groundwater bores and flow site 69106, plus minimum depth to groundwater contours in green (increasing with increasing distance from the river). Barrell et al. (1996) suggested that the Montalto Fault line, along Lower Downs Rd (site 69106), may cause localised effects to groundwater flow, though there is not sufficient data collected for this project to show any effects from this. The MAR Year 4 study showed that, for river flows of up to 500 l/s at the Lower Downs Road Bridge (site 69106 - 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, and some flow is retained within the river.

Groundwater levels in the shallow (2.3 m deep) bore (BY20/0222) respond quickly to increases in flows at 69106, with subsequent increases in flows in Silverstream, just north of the Hekeao / Hinds South branch. Silverstream also receives recharge flow from the Hekeao / Hinds North Branch when this is flowing. The stream provides the only surface flow to the confluence of the Hekeao / Hinds South and North Branches during low flow conditions, and during these periods, NRR1 flow can therefore be expected to measurably increase Silverstream flows as well as the Hekeao / Hinds South Branch immediately below the NRR1 site. To improve habitat, key reaches of Silverstream have had their banks planted recently, which will decrease water temperature via shading and improve riparian habitat for birds and insects.

The MAR Year 4 study also considered NRR1 recharge effects to the true right of the Hekeao / Hinds South Branch via analysis of the four bores presented in Figure 2-11. Of these bores, K37/0278 is shallow (depth 16 m) while the other three are deep (84 to 145 m). K37/0278 was found to respond quickly (within days) to freshes of greater than 1000 l/s (Figure 2-12); that is when the Hekeao / Hinds South Branch is flowing down to its confluence with the North Branch. When only Silverstream is flowing, K37/0278 still shows small fluctuations, suggesting that the two are connected near the confluence of the three Hekeao / Hinds River tributaries as well as the South Branch above the confluence. We can therefore conclude that K37/0278 groundwater levels are influenced by NRR1 recharge.

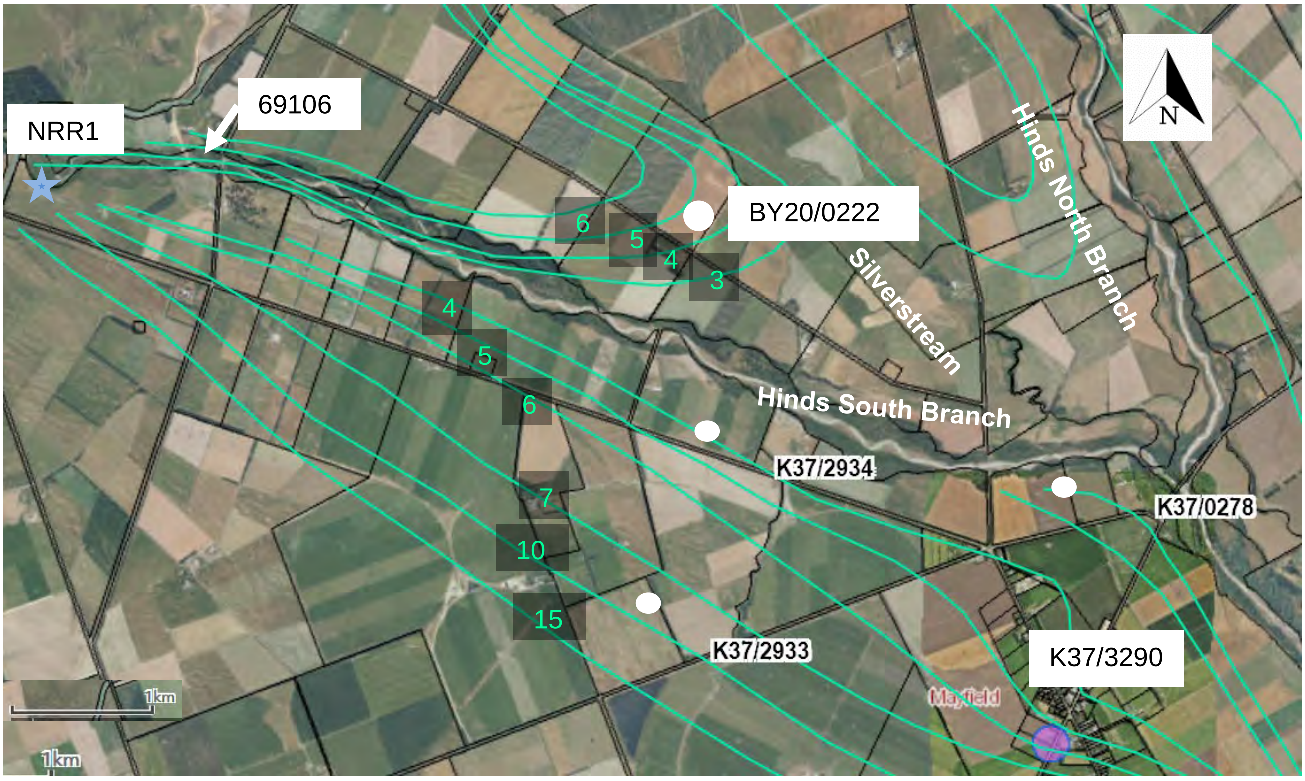


Figure 2-11: NRR1 down-gradient monitoring wells and minimum depth to groundwater contours (in m) (Source: Canterbury Maps)

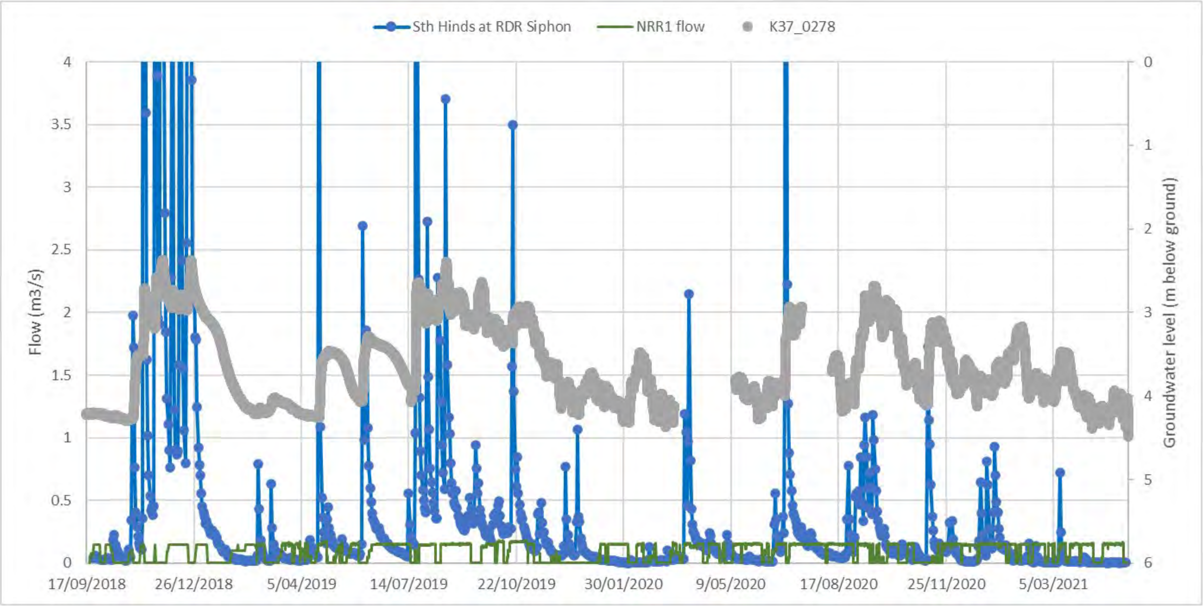


Figure 2-12: NRR1 flow, Hinds River flow and K37/0278 groundwater level (Source: HHWET, CRC)

Figures 2-13 and 2-14 compare Hekeao / Hinds River flows (up to 4 m^3/s) at the RDR Siphon, NRR1 flow and depth to groundwater in bore K37/2934 and the Mayfield community supply bore (K37/3290). These deep (145 m and 119 m respectively) bores possibly show a delayed (approximately 50 days), damped response to major rainfall events and river freshes (greater than approximately 3.5 m^3/s) and declining levels at other times. In addition, K37/3290 shows significant daily variation in response to pumping. During the 2015/16 drought the groundwater levels in this bore dropped approximately 25 m (from a high in 2014 to more than 119 m below ground level). This evidence suggests the bores are in an aquifer with good capacity potential and groundwater levels primarily determined by significant weather events and patterns. The MAR Year 4 South Branch recharge study (HHWET, 2020) shows river losses between the Lower Downs Bridge (site 69106) and the confluence with the North Branch Hekeao / Hinds River. Cumulatively, this evidence suggests that increased NRR1 flowrates / flow volume will be beneficial for shallow groundwater levels on both sides of the South Branch when groundwater levels are low.

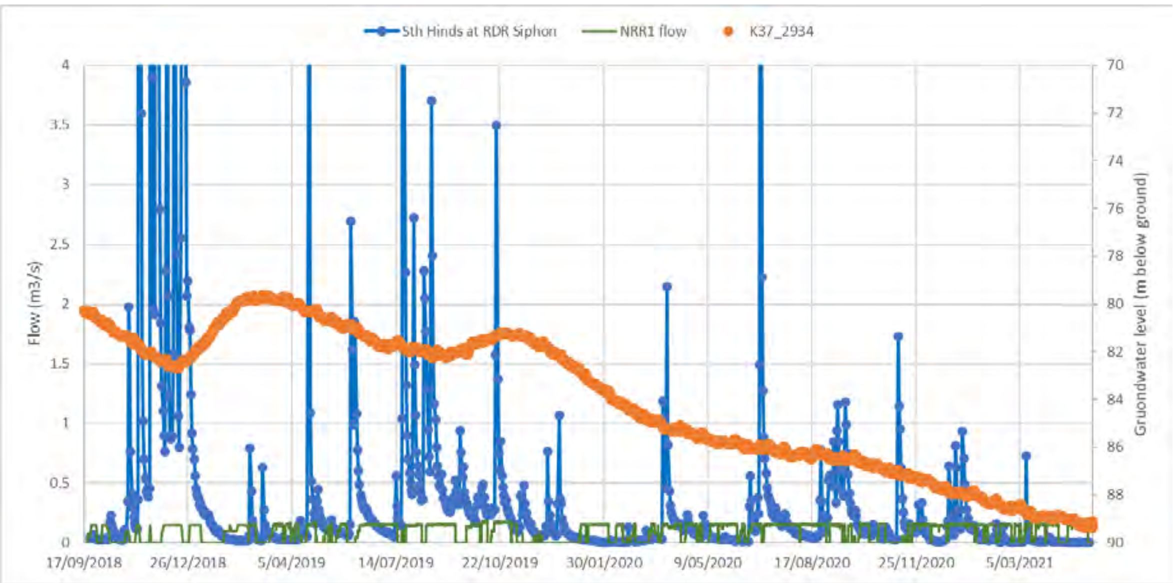


Figure 2-13: NRR1 flow, Hekeao / Hinds River flow and K37/2934 groundwater level (Source: HHWET, CRC)

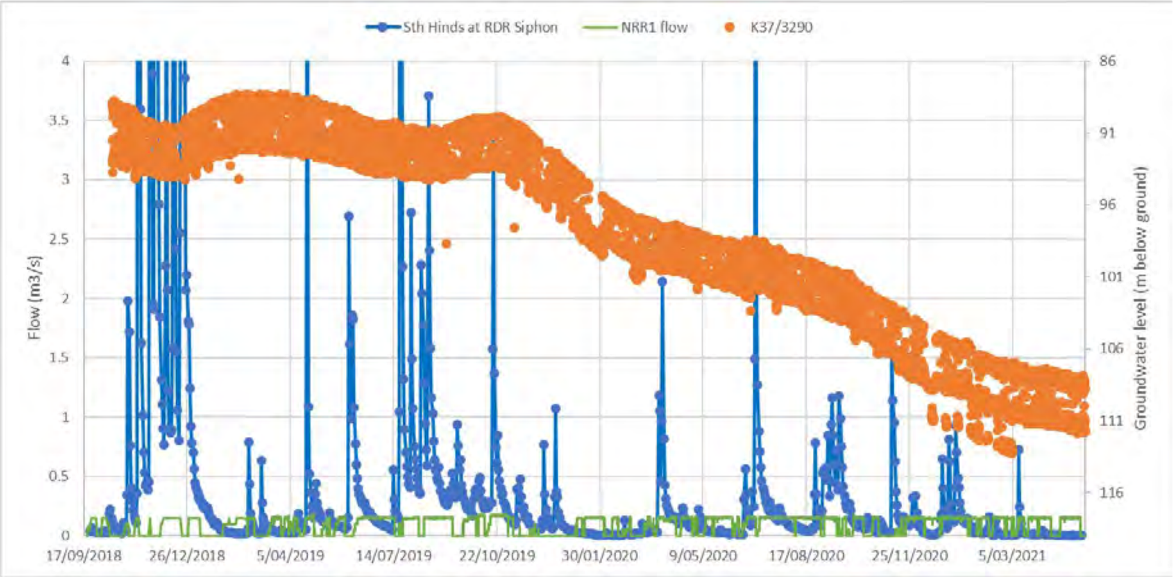


Figure 2-14: NRR1 flow, Hekeao / Hinds River flow and K37/3290 groundwater level (Source: HHWET, CRC)

2.1.2 Water quality monitoring

The advice note for discharge consent CRC210704 requires consideration of an *E. coli* and a nitrate trigger level for site shutdown following its first year of operation, to ensure protection of the receiving environment. MAR Year 4 report analyses (HHWET, 2020) showed that high quality water is being recharged and therefore, in the longer term, *E. coli* or nitrate trigger levels for site shutdown were not required. Figure 2-15 presents the NRR1 site *E. coli* monitoring results to date. BY19/0107 (6 m deep, see Fig. 2-9 for location) is included as per the consent conditions, but as it is up-gradient from recharge basins it is expected to represent river recharged groundwater more than NRR1 recharged groundwater. For future consents, groundwater monitoring is proposed to be moved to BY19/0108, which is situated down-gradient from recharge basins. All *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 could be significantly higher.

Figure 2-15 shows that *E. coli* counts in the source water were consistently less than 200 MPN/100 ml. 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 dilution with the addition of the NRR1 recharge water. 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. However, *E. coli* counts in the source water were less than 100 MPN/100ml, so the additional *E. coli* can be assumed to have originated from another source between the monitoring points.

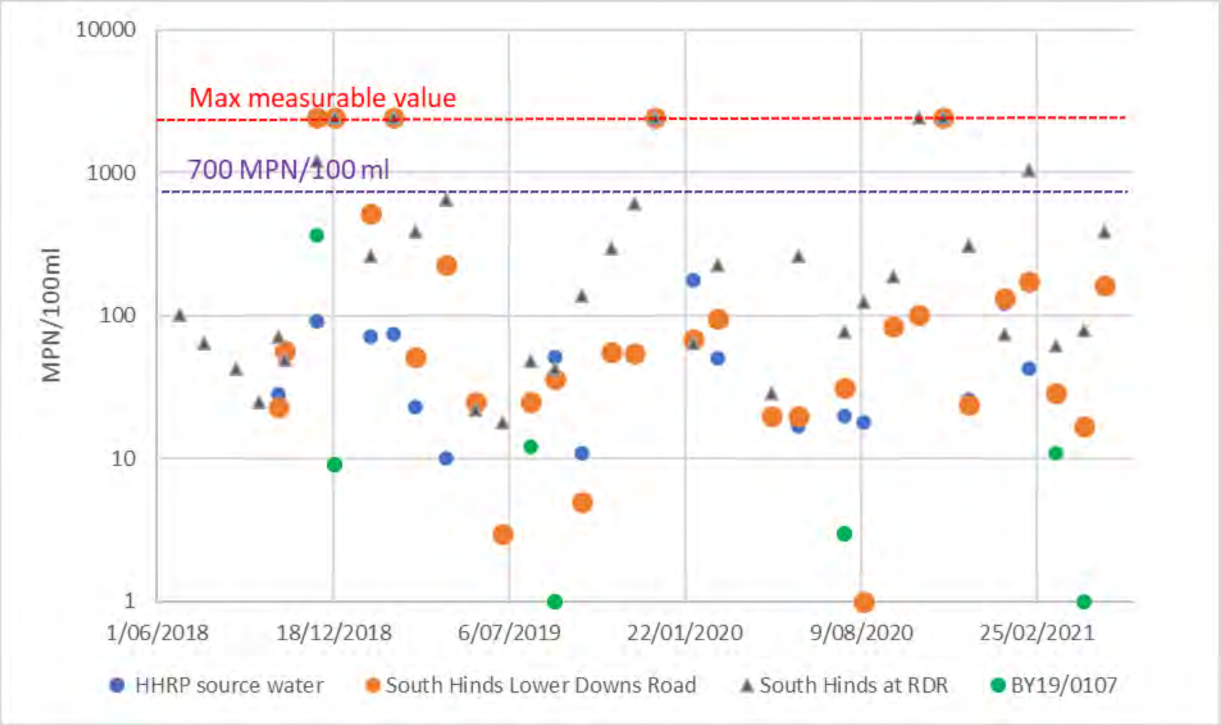


Figure 2-15: NRR1 *E. coli* monitoring (Source: HHWET, CRC)

Figure 2-16 presents the NRR1 site nitrate-N monitoring information to date. Source water Nitrate-N concentrations have remained very low (generally below 1 mg/l) and less than up-gradient groundwater concentrations represented by BY19/0107. Nitrate-N concentrations in the south Branch Hekeao / Hinds are also low, with the Lower Downs Rd (downstream) concentrations almost always less than or similar to the South Hinds at the RDR Siphon (upstream) concentrations.

Water quality monitoring of the Mayfield community supply bore K37/3290 is also included in Table 2-1, to provide background information to assist with understanding groundwater quality (particularly drinking water risk) in groundwater influenced by the Hekeao / South Branch Hinds River and NRR1. Figure 2-17 shows Nitrate-N concentrations in K37/3290. While the entire record from 2016 indicates a slightly increasing trend in Nitrate-N concentrations, over the last 3 years the concentrations have remained steady with reported concentrations between approximately 2.6-2.7 mg/l. These concentrations are well below the current New Zealand Maximum Acceptable Value (MAV) of 11.3 mg/l for drinking water. With no K37/3290 groundwater level response due to NRR1 operation identified to date (Fig. 2-14), we do not expect to see a water quality response at K37/3290 either.

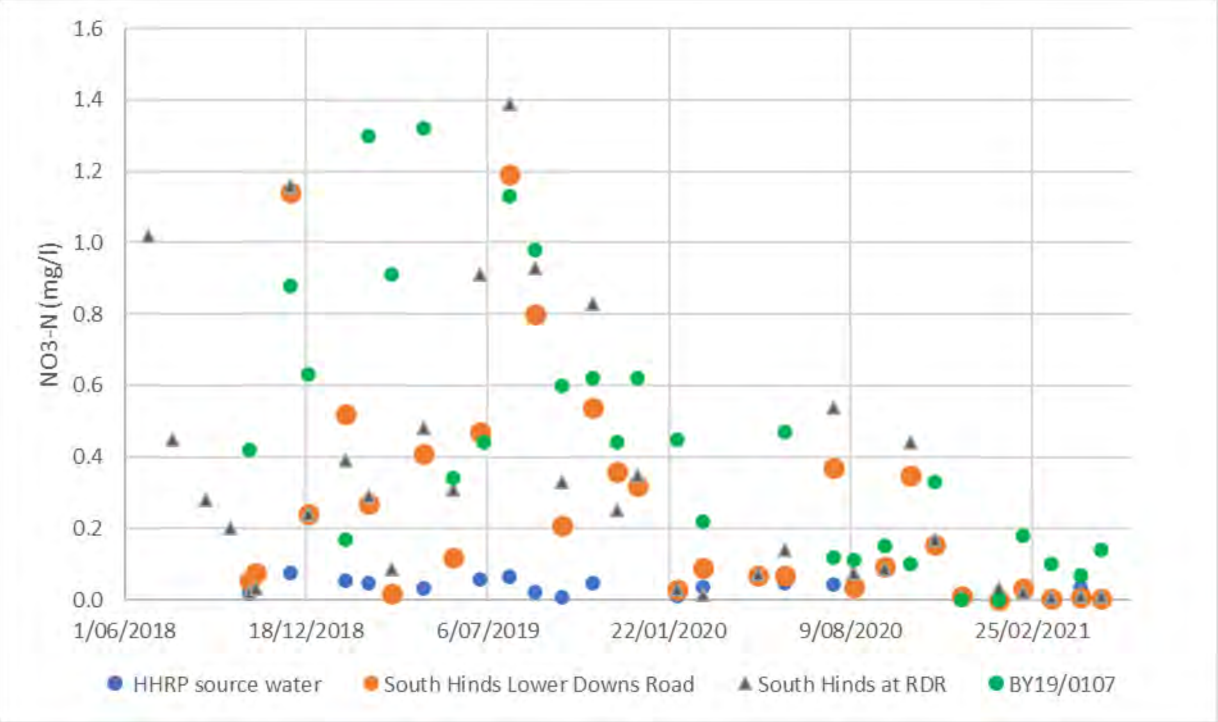


Figure 2-16: NRR1 Nitrate-N monitoring (Source: HHWET, CRC)

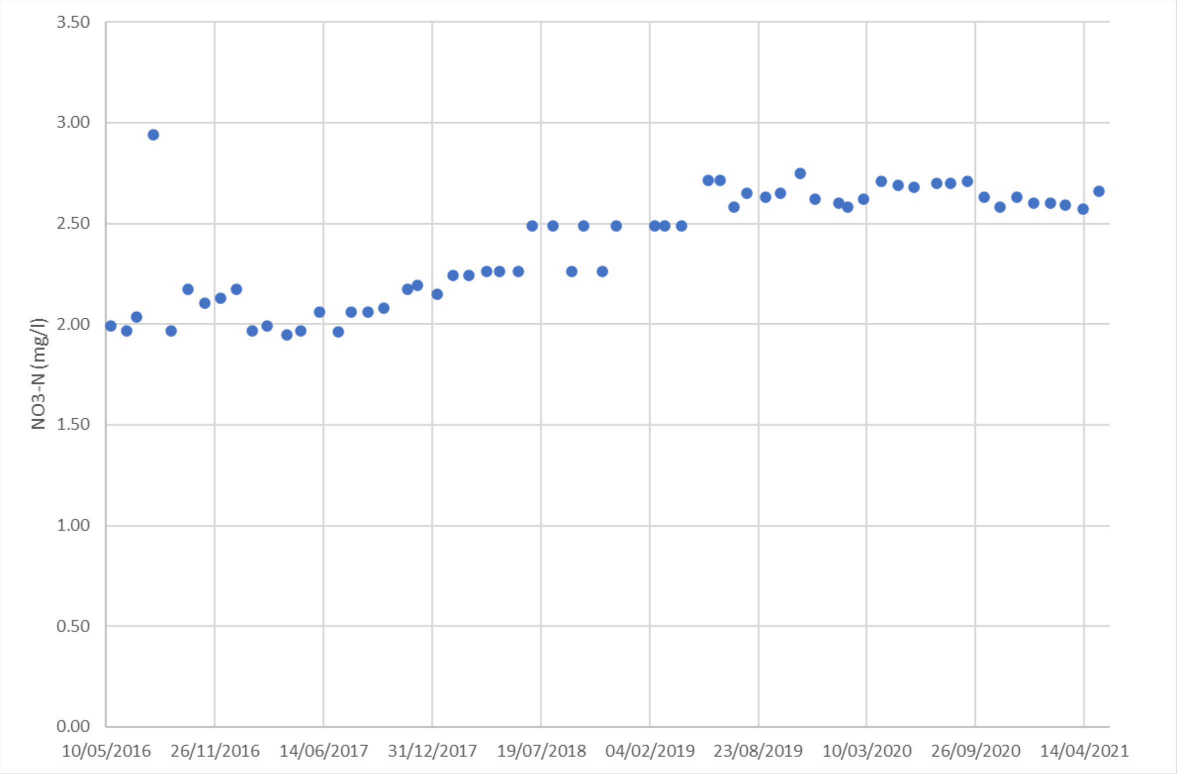


Figure 2-17: Mayfield drinking water bore K37/3290 Nitrate-N monitoring (Source: ADC)

2.1.3 Turbidity “Trigger Level”

Turbidity relates to the level of suspended sediment in water. This sediment can clog up recharge facilities. NRR1 discharge consent CRC210704 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 NRR1 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 CRC via the Compliance Monitoring Report dated 10 May 2019. Figure 2-18 shows that NNR1 discharge has ceased on several occasions in accordance with the trigger level. In late January 2021, the siphon turbidity sensor failed and couldn't be fixed. A new sensor was ordered and will be installed as soon as possible. In the meantime, the turbidity sensor at the RDR intake has been used. This is in general expected to be more conservative (show higher turbidity levels than the siphon sensor) as it is up-gradient from the RDR sand trap where heavier sediment is known to drop out of suspension.

Figure 2-18: NRR1 turbidity monitoring (Source: HHWET)

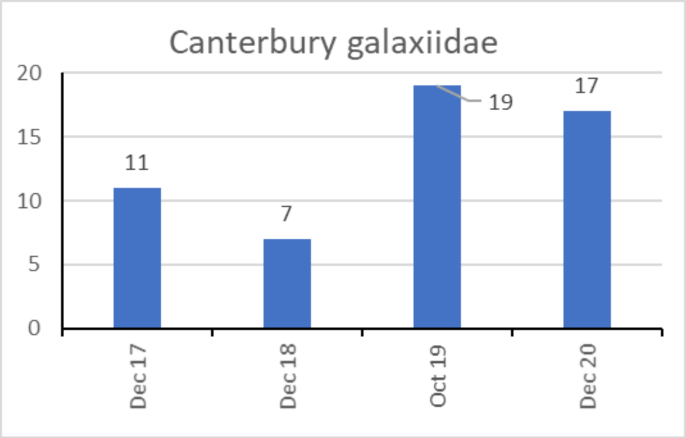
2.1.4 Aquatic Ecology monitoring

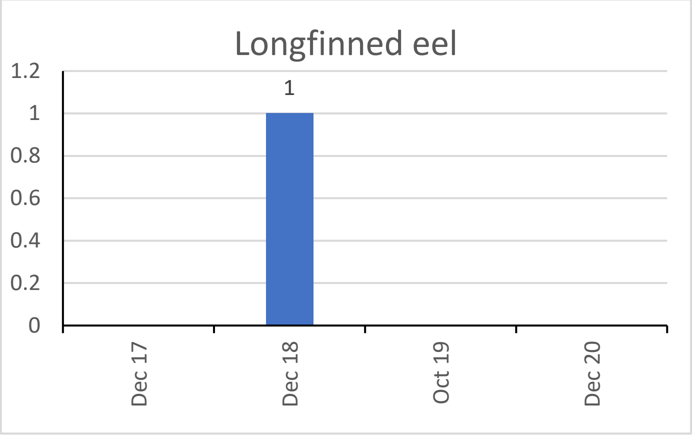
The Hekeao / Hinds River is a priority for restoration of ecosystem health and recreation amenity, as part of the MAR trial for the Hekeao / Hinds Plains. To monitor long term changes in fish diversity and population sizes and any potential MAR influence, Central South Island Fish and Game, along with CRC, 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 NRR1 site as detailed in Table 2-1 (aquatic ecology monitoring). All sites are 30 m long with upstream and downstream nets used to enable diminishing-return population estimates to be calculated.

At the Hekeao / South Branch Hinds site only three fish species were found during the October-December surveys. In total 227 fish were caught, comprising 74.5% upland bully, 24% Canterbury galaxias, and 0.5%

longfinned eel. In an additional electric fishing survey in May 2019, two brown trout at 180mm and 187mm, were caught at this site. Total fish population estimates for the Hekeao / South Branch Hinds site for combined species were 32, 21, 97, and 113 for 2017, 2018, 2019, and 2020 respectively. Upland bully may be increasing in population size while Canterbury galaxias populations have been stable if not increasing (Figure 2-19).

A review of the length distribution for upland bully caught at the Hekeao / South Branch Hinds site each year suggests that in 2017 only adult upland bully were present and these spawned successfully to produce a juvenile cohort in 2018. In 2019 and 2020 both juvenile and adult components contributed to the age distribution of a larger population. The Canterbury galaxias length distribution suggests a low population of only adult fish in 2017 and a low population dominated by juvenile fish in 2018. In 2019 and 2020 adult fish were more abundant than previous years and juvenile numbers were low. Only one longfinned eel has been caught since 2017 – a 900 mm long adult. The open boulder and gravel habitat at this site and absence of instream debris cover is unlikely to support a high eel population. The May 2021 floods are likely to have further reduced eel (and trout) potential for this reach. The lack of eels and trout combined with the improved flows due to NRR1 are likely to be key contributors to increased population levels for Canterbury Galaxiidae and Upland Bully.





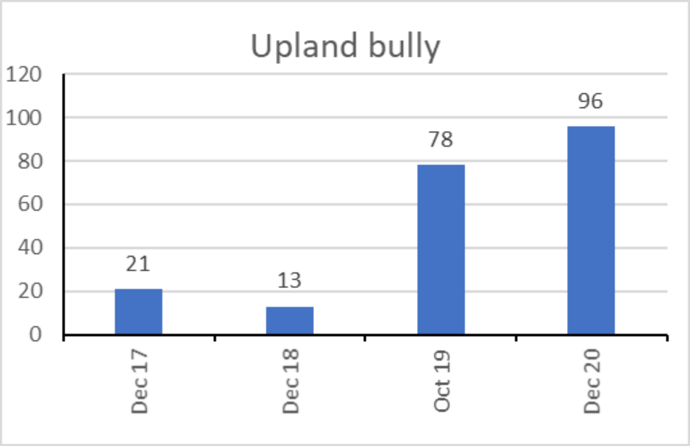


Figure 2-19: Hekeao / South Branch Hinds River at Lower Downs Rd Bridge, annual fish population estimates per 30 lineal metres, 2016 – 2020 (Source: Central South Island Fish and Game)

Additional aquatic ecological monitoring was initiated above (RDR Siphon) and below (Lower Downs Bridge) the NRR1 site for the first 18 months 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. The results of this study showed higher populations of Canterbury Galaxiidae and bully species at the Lower Downs Bridge site compared to the RDR Siphon site, plus invertebrate communities at both sites that are reflective of good water quality and habitat under relatively stable flow conditions (see Dynes, 2020 and HHWET, 2020).

In Year 4, additional analysis was undertaken at the NRR1 wetland (Figures 2-5 to 2-7), which was enhanced by the removal of willow trees during site construction (see HHWET, 2020). This analysis resulted in a wetland Management Plan (McMurtrie 2020a), Kōwaro Transfer Plan (McMurtrie 2020b) and DOC Kōwaro Transfer Permit (Authorisation number 82103-OTH). Prior to progressing these plans, the flooding from May 29-31, 2021, destroyed the lower portion of the wetland and highlighted a significant risk for re-establishing the wetland in the same position. A risk assessment followed by re-design of the true right riverbank and wetland is planned for 2021/22.

2.2 MAR17b – Lennies Road

A second NRR site (MAR17b) is close to Lennies Road. Discharge at MAR17b (Figure 2-20) is covered by MAR Test Site discharge consent CRC 210702. However, its proximity to the Hekeao / Hinds River means that under no or low flow river conditions, we can expect this site to contribute to groundwater connected to the river and therefore surface river flow when local groundwater levels are high enough. Minimum depth to groundwater contours, plus MAR17b and the proposed NRR3 site (see Section 2.3) are presented in Figure 2-21. Figures 2-1 and 2-2 show a significant number of spring locations between MAR17b and NRR3. Some of these springs supply Hekeao / Hinds River tributaries, while others supply the Swamp Rd Drain / Taylors Drain, a portion of which is managed for mahinga kai purposes. Discharge flowrates for MAR17b are presented on Figure 2-22, with discharge beginning at the site on 2 June 2020. Two visits to the Hekeao / Hinds River were undertaken on 22 November and 3 December 2020. On both occasions there was no surface flow up-gradient from MAR17b (Figure 2-23), but surface flow was evident below MAR17b for at least 6 km (Figures 2-24 and 2-25). A personal communication with the local landowner confirmed that this situation was unusual given the nearby groundwater conditions and MAR17b was therefore likely to be a significant contributor (*pers. comm*. I. Jones).

Figure 2-20: MAR17b, with Hekeao / Hinds River margins in the background (Source: M. Neutze)

Figure 2-21: Location of MAR17b and proposed NRR3, plus minimum depth to groundwater contours (in m) (Source: Canterbury Maps)

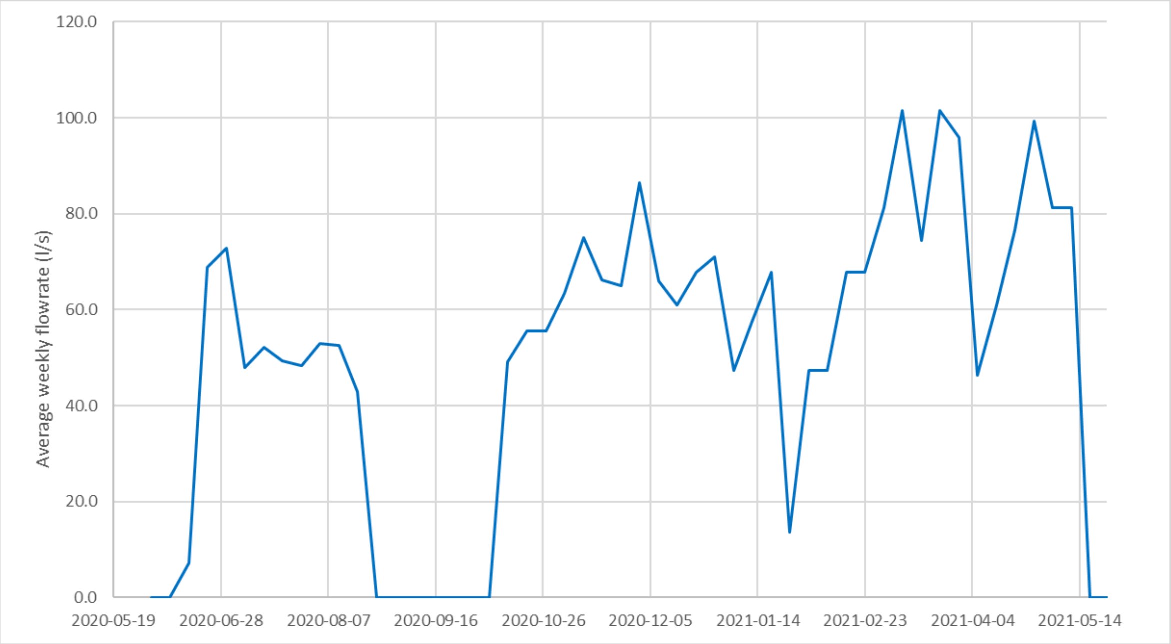


Figure 2-22: MAR17b discharge average weekly flowrate (Source: HHWET)

Figure 2-23: Maronan Rd, 22/11/2020 above Lennies Rd (Source: P. Lowe)

Figure 2-24: Between Lennies Rd and Winslow Rd, 22/11/2020 (Source: P. Lowe)

Figure 2-25: Immediately up-gradient from Winslow Rd, 22/11/2020 (Source: P. Lowe)

2.3 NRR2 and NRR3 – Middle Reaches of the Hekeao / Hinds River

As noted at the beginning of this chapter, the purpose of the Hekeao / Hinds River Project (HHRP) is to assist in improving the eco-system health of the whole Hekeao / Hinds River system. With two NRR sites producing measurable benefits to date, two further sites have been identified with the aim of providing similar benefits in other reaches of the river. Key to the position of these sites is the presence of an existing MHV Water discharge race and available land for recharge basins with relatively low flooding risk.

Figure 2-26: NRR sites and spring locations (Source: Canterbury Maps)

Figure 2-26 shows that NRR3 (at the Winslow / Fountaines Rd crossing) is located down-river from MAR17b and in the vicinity of a significant number of groundwater springs. Together with the anticipated upriver flow support provided by MAR17b, the additional near river recharge at site NRR3 could enable a significant increase in the length of the flowing reach of the river when, without NRR, it would otherwise be dry to the SH1 bridge. A discharge race from the MHV Water irrigation scheme provides good supply reliability to site NRR3. During Year 5, initial river engineering, ecological and cultural assessments were completed, and a flood modelling assessment was started. A draft design concept was also prepared (Figure 2-27), which includes a constructed wetland for the purpose of providing a nursery for threatened native aquatic species. The floods of May 29-31, 2021 provided additional information to the flood modelling and design processes, which will be considered in Year 6.

Site NRR2 is also beside a discharge race from the MHV Water irrigation scheme. However, it is located in a reach of the Hekeao / Hinds River that is often dry (between Hackthorne and Pooles Rd), so the potential eco-system benefits will be assessed further during Year 6 before significant investment in this site.

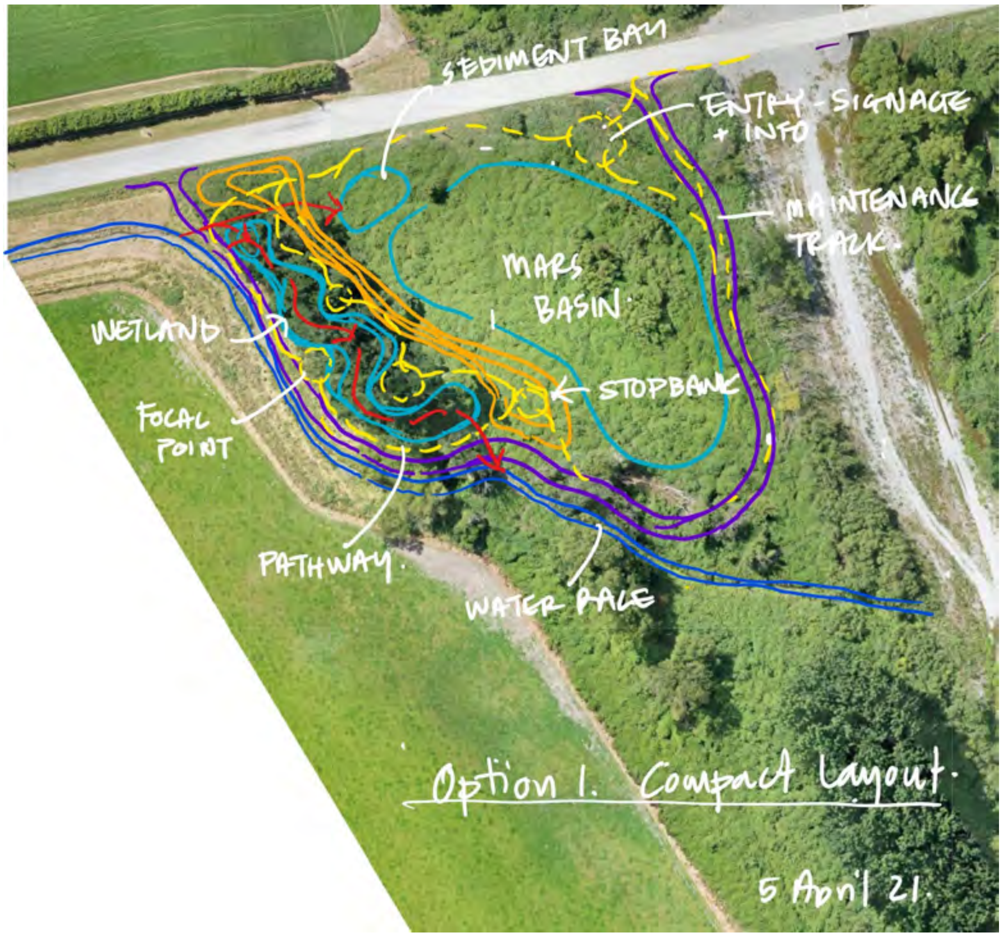


Figure 2-27: Draft concept for NRR3 site (Source: Boffa- Miskell)

2.4 Lower Hekeao / Hinds River monitoring

Surface water quality and aquatic ecosystem health monitoring along the Hekeao / Hinds River and some of its lower catchment contributing drains (Northern and Taylors) are carried out by CRC and Fish and Game staff. For the last 5 years this information has been provided as an annual update to the Hinds Drains Working Party – HWDP (via Dynes, 2021). Additional surface water quality monitoring was initiated by MHV Water in 2020/21, with O'Shaughnessy's Drain also of relevance to lower Hekeao / Hinds River water quality. Key surface water monitoring points in the lower catchment are noted on Figure 2-28, with Hekeao / Hinds River flow data presented on Figure 2-29 and water quality monitoring presented on Figures 2-30 to 2-33.

The Year 5 monitoring shows that for around 5 months from late October 2020 until late February 2021 (within red circle on Figure 2-30), the measured wate quality was close to the 2035 PC2 annual target. This is a similar water quality and flow result to the 2015/16 summer, with the 2016/17 summer starting similarly until an 8 m^3/s fresh in April 2017 raised NNN concentrations. In the same way, the period of low NNN concentrations was followed by a rapid rise due to the 29-31 May 2021 rainfall recharge event. Figure 2-31 shows that Taylors Drain (influenced by Hekeao / Hinds River recharge via Swamp Road Drain and then Taylors Drain) NNN averages 2.5 mg/l in the 2020/21 period which is 34% lower than the 2015/16 period. Figure 2-32 shows that Northern Drain (influenced by catchment groundwater) NNN at <=6.9 mg/l is similar for the early 2015/16 and 2020/21 summers but increases 2 months earlier in 2020/21. The single O'Shaughnessy's NNN monitoring point during the 2020/21 summer of 4.9 mg/l NNN suggests that its water quality was slightly lower than the mainstem lower Hekeao / Hinds River. MHV Water also measured an NNN concentration of 6.2 mg/l at the Montgomery's Drain on 25 May 2021. From this information we can infer that the Hekeao / Hinds River recharge returning via Taylors Drain in addition to mainstem flows in the Hekeao / Hinds River (above and below ground) were likely to positively contribute to the low NNN concentrations during 2020/21. Section 2.2 shows the Near River Recharge flow support during this time period.

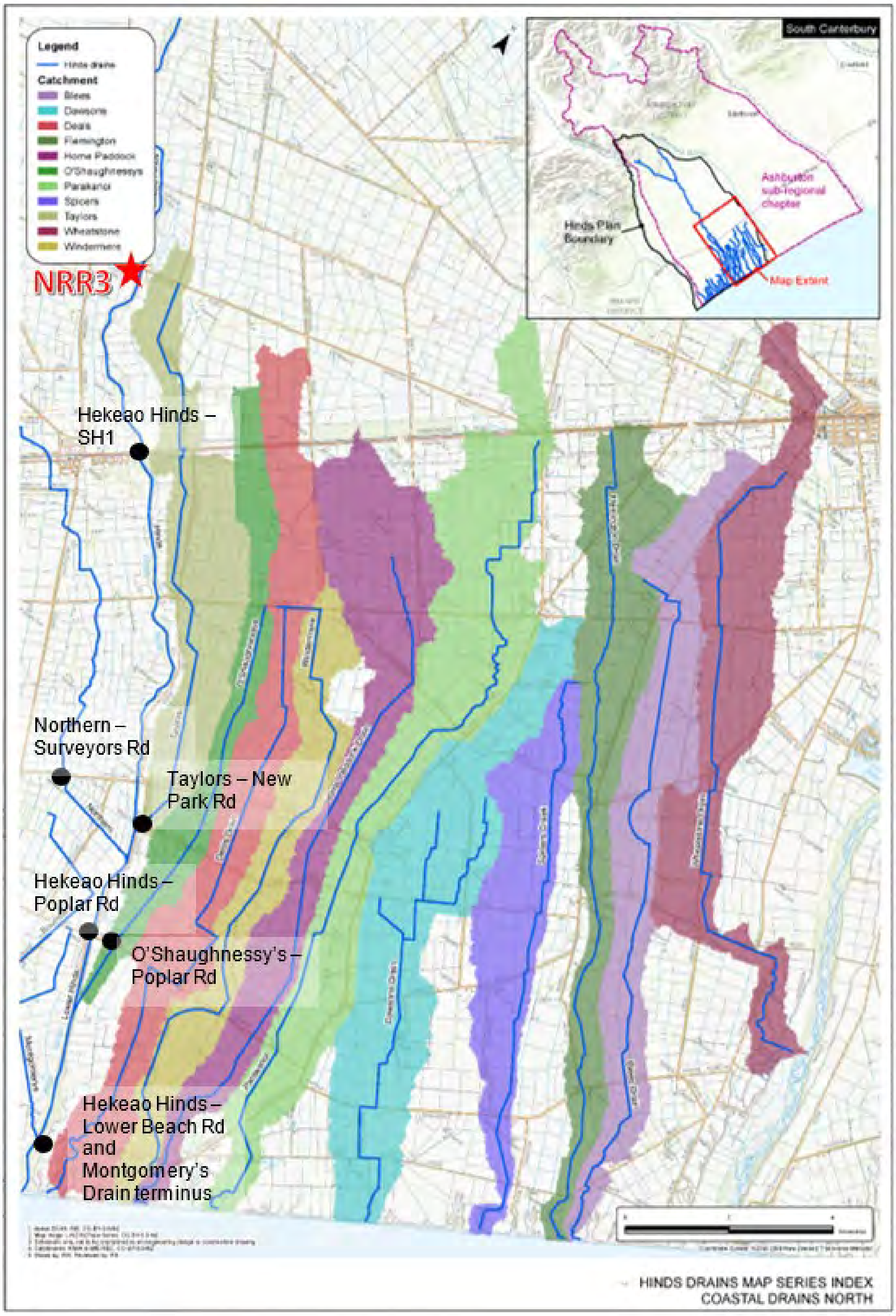


Figure 2-28: Hekeao / Hinds River monitoring sites (Source: HDWP)

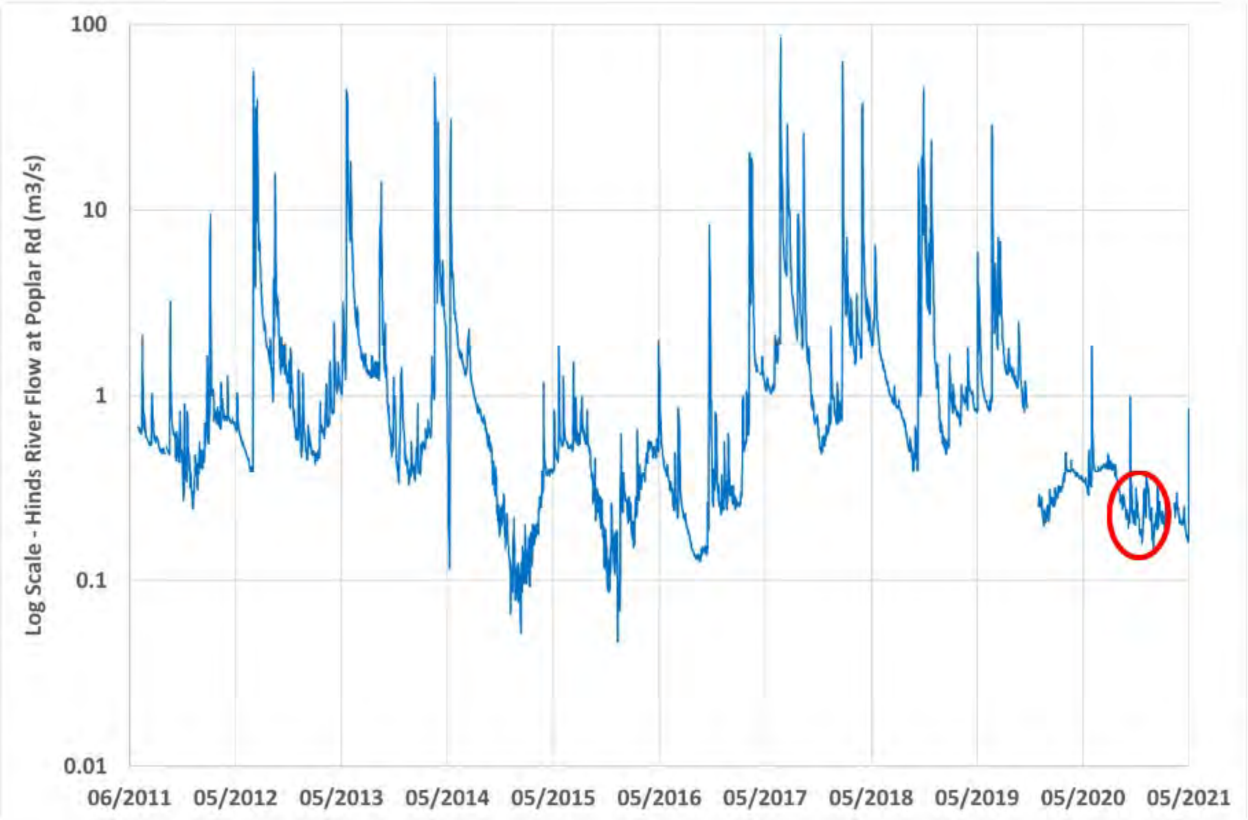


Figure 2-29: Hekeao / Hinds River flow at Poplar Rd (Source: CRC)

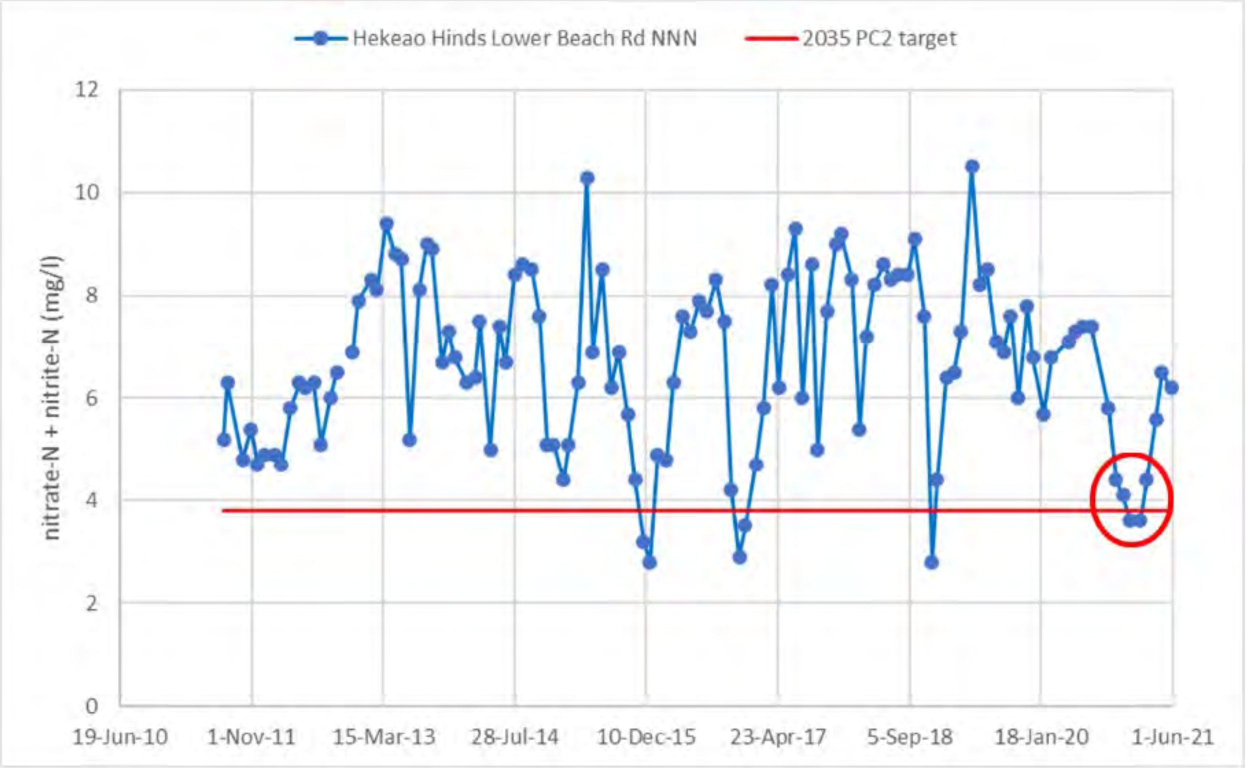


Figure 2-30: Hekeao / Hinds River Nitrate-Nitrite-Nitrogen concentrations at Lower Beach Rd (Source: CRC)

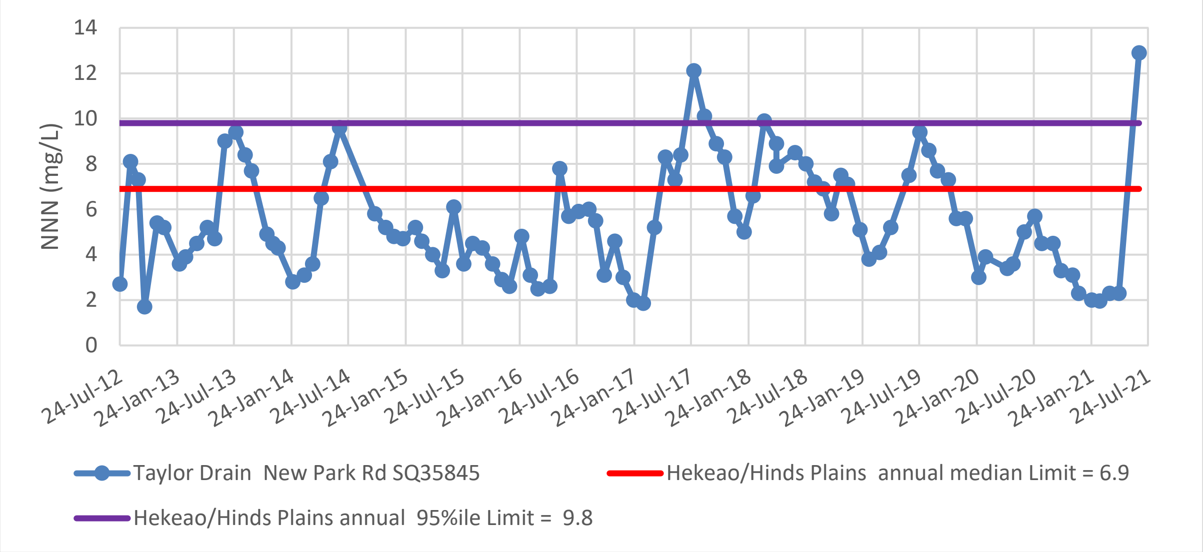


Figure 2-31: Taylors Drain NNN concentrations at New Park Rd (Source: CRC)

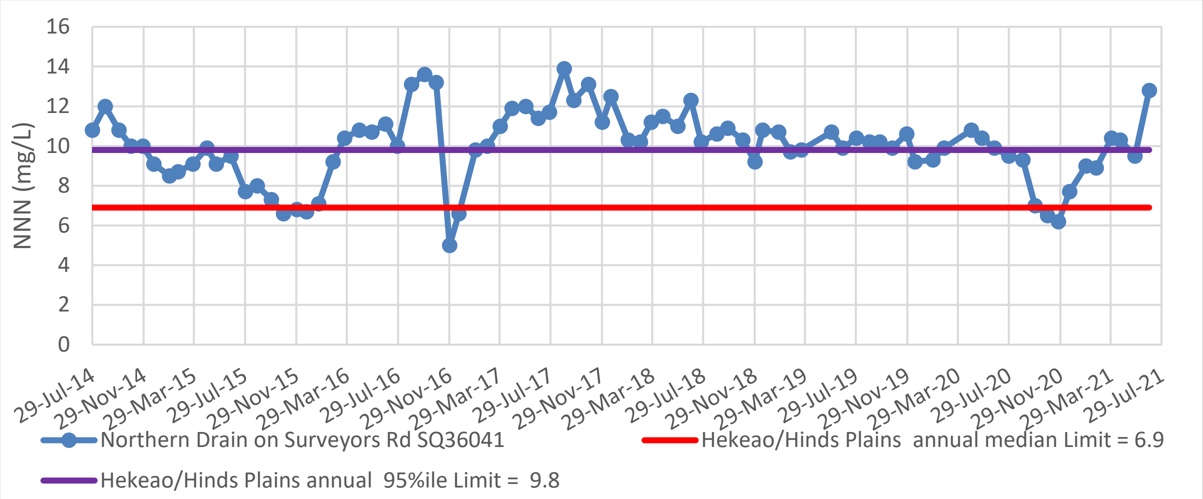


Figure 2-32: Northern Drain NNN concentrations at Surveyors Rd (Source: CRC)

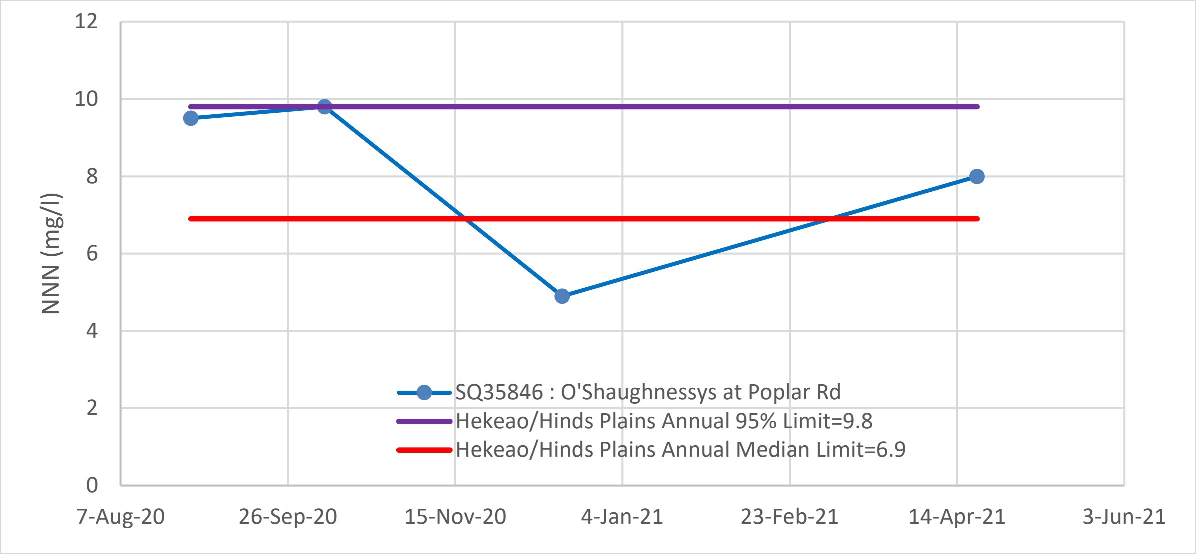


Figure 2-33: O'Shaughnessy's Drain NNN concentrations at Poplar Rd (Source: MHV Water)

The QMCI (Quantitative Macroinvertebrate Community Index) is based on the tolerance or sensitivity of species (taxa) to organic pollution and nutrient enrichment. Figure 2-34 presents the QMCI scores derived from monitoring at SH1, Poplar Rd and Lower Beach Rd sites, indicating aquatic ecosystem health is variable and responds to annual climatic and flow conditions in the Hekeao / Hinds River. In the past 3 years, the QMCI has shown an improvement to meet / be close to meeting the minimum PC2 QMCI objective. In the past, these reaches generally did not meet this objective.

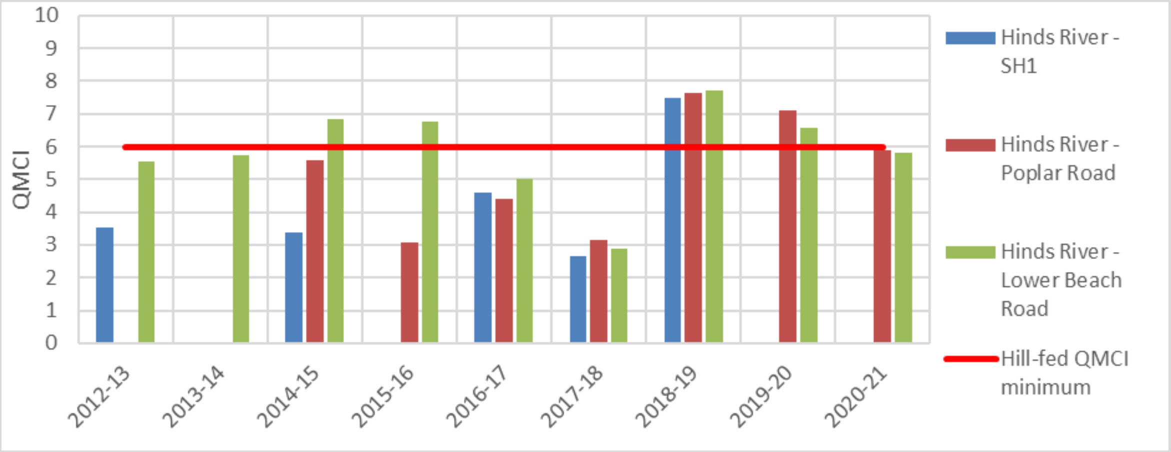


Figure 2-34: QMCI Scores for three lower Hekeao / Hinds River sites (Source: CRC)

Lower Hekeao / Hinds fish surveys comprise annual assessment of fish diversity and abundance by electric fishing at two sites in the lower river – one about 0.4 km above the coastal lagoon and the other just above Poplar Rd (about 6km above the lagoon). Total surveyed population size is presented in Figure 2-35, with breakdown by species and site in Figures 2-36 and 2-37 (N.B., the Above Poplar Rd site was not surveyed in 2018). The 2020 Above Lagoon population dominated by bluegilled bully. Seven of the nine fish species caught in the lower river were migrant species requiring passage to and from the sea to complete their life cycles. Webb (2021) notes that their presence suggests the Hinds River mouth is open frequently enough to enable fish migration. Population sizes for most lower river species have been variable over the five years of October-December monitoring. The three bully species may have an antagonistic relationship with bluegilled bully abundance impacting on common and upland bully abundance. Eel populations are low, thus the chance of catching any in a 30 m reach of river fished is also low. However, there appears to be abundant eel habitat in the lower river. While the NRR contribution of flow support with high quality water can be assumed to be positive for fish populations and macroinvertebrates, direct links between NRR volume and fish populations / QMCI are unlikely to be measurable, given the more significant influence provided by natural flow extremes.

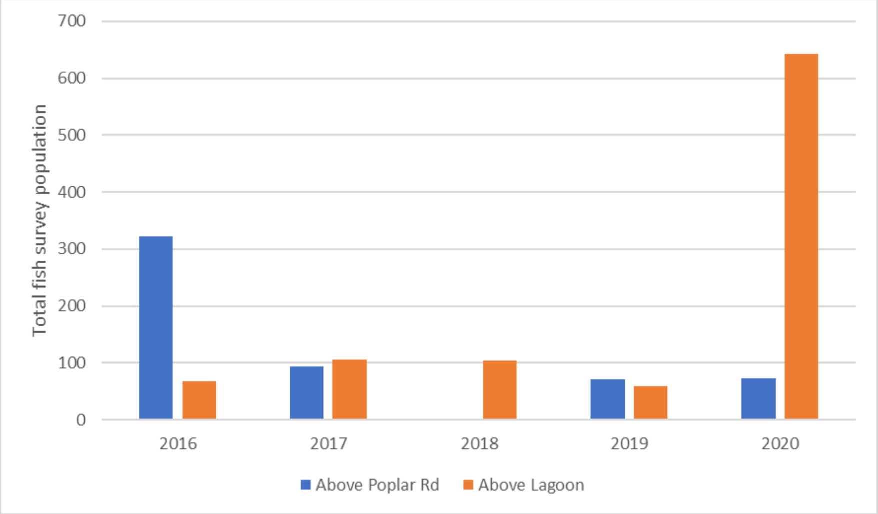


Figure 2-35: Total fish survey populations for two lower Hekeao / Hinds River sites (Source: M. Webb, Central South Island Fish and Game)

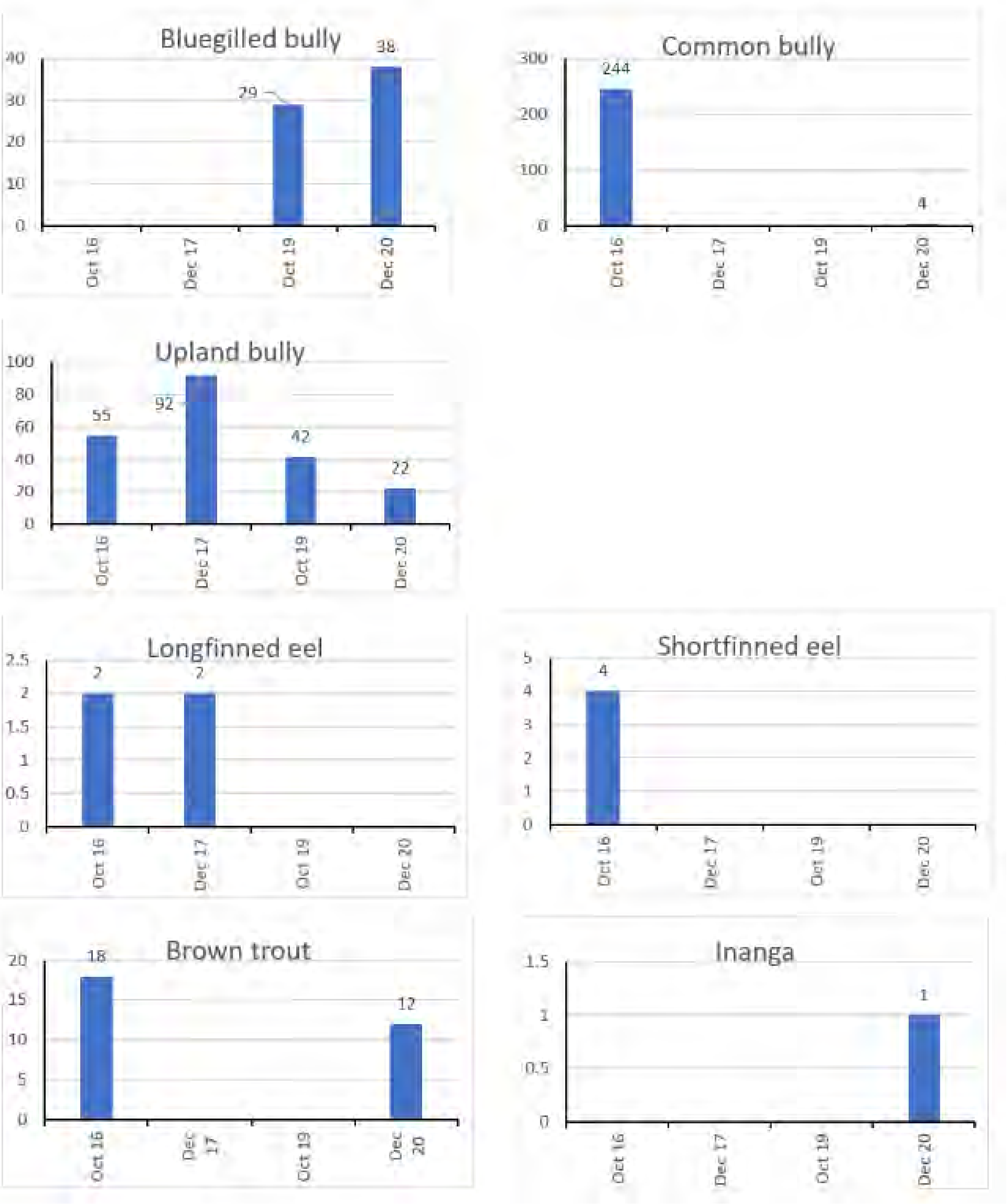


Figure 2-36: Hinds River, Poplar Rd site approx. annual fish population estimates per 30 lineal metres, 2016/17/19/20. Record of one unidentified galaxiidae caught in December 2017 has not been included. (Source: M. Webb, Central South Island Fish and Game)

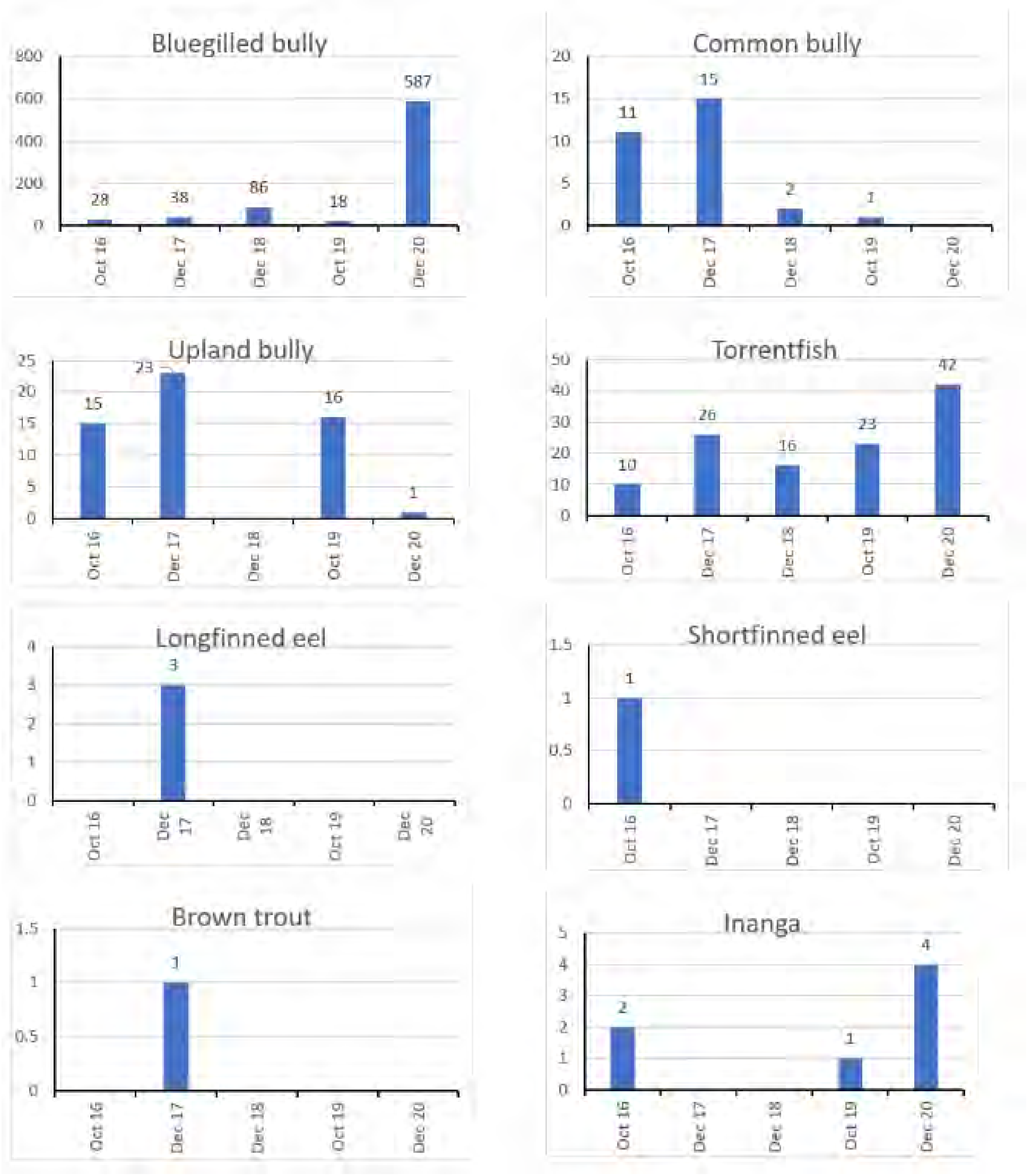


Figure 2-37: Hekeao / Hinds River, above lagoon site approx. annual fish population estimates per 30 lineal metres, 2016 – 2020. (Source: M. Webb, Central South Island Fish and Game)

3 Hekeao / Hinds MAR Sites

The locations of MAR Plains sites operational during Year 5 are presented in Figure 3-1 with their key performance indicators presented in Table 3-1. In combination with the two NRR sites, the total recharged MAR volume in Year 5 was approximately 13.85 million m^3, with around 8.98 million m^3 being via the MAR sites. This was a 66.5% increase on the previous year and an 88% utilisation of consented MAR supply water. The key reason for this improvement was the increased use of irrigation scheme storage, which allowed for higher turbidity water to be taken and used at a later date once the sediment had dropped out.

Testing of MAR source water ensures that it is of high quality. Nitrate-N, 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 5 monitoring, though turbidity continued to vary 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 (with a second bird scarer purchased during Year 5) 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 and 20 site shutdowns in Year 5.

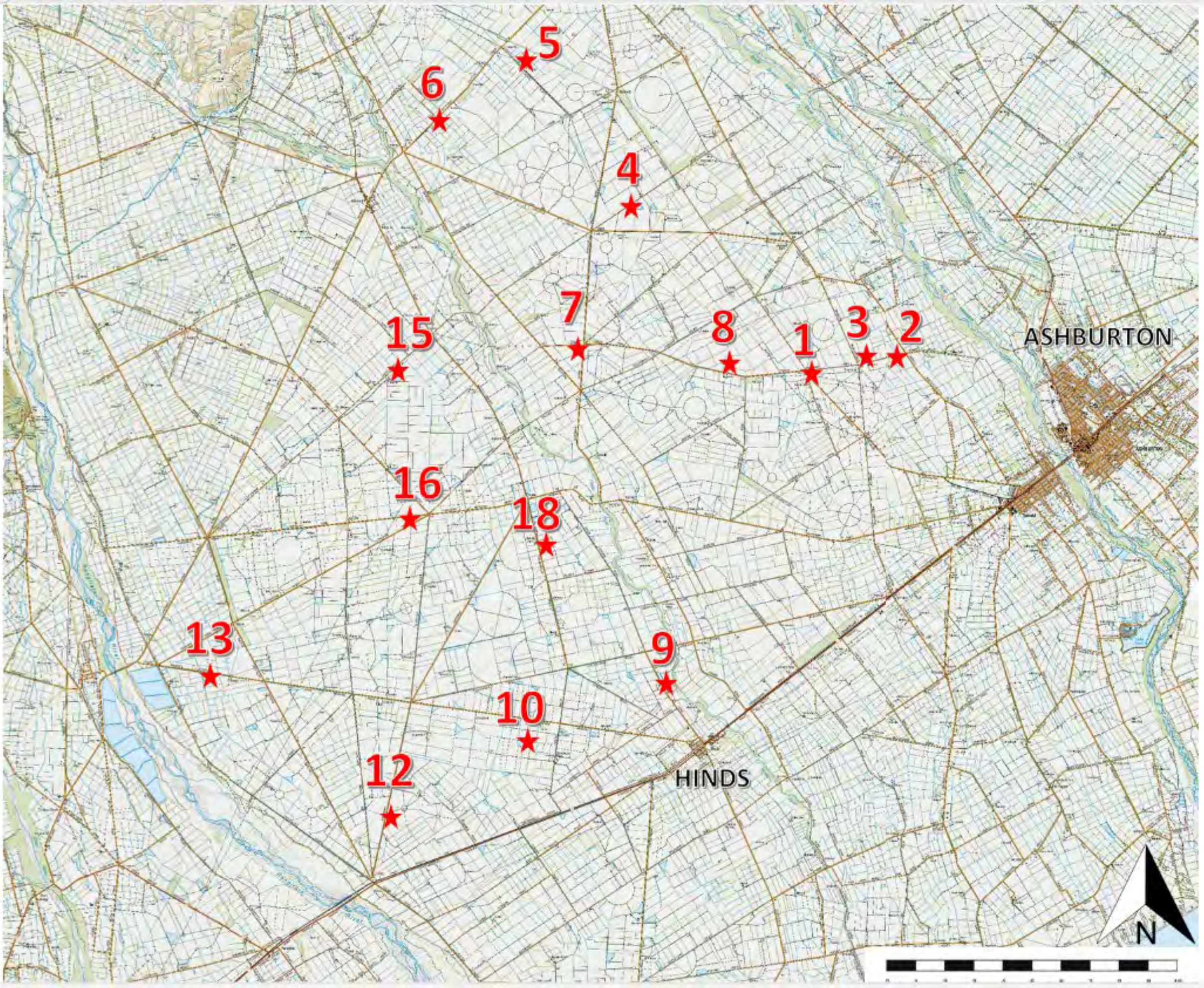


Figure 3-1: Hekeao / Hinds MAR Plains sites operational during 2020/21

Table 3-1: MAR Plains site performance information for Year 5

June 2020-May 2021	Maximum weekly recharge rate (l/s)	Total recharge volume (m^3)	Weeks in operation	*E. coli* shutdowns	Notes
1 – Lagmhor Pilot	130	1,659,867	36	1	
2 – Timaru Track	75	659,019	34	1	
3 - Walls	18	25,823	4		Supply limited to ~30 l/s. Low priority when limited supply.
4 - NZSF	21	38,177	6		Low priority when limited supply.
5 – Pond 2	20	148,636	20		
6 – BCI/Howden	15	387,010	48		Supply limited to ~25 l/s
7 - Lobblin	100	1,003,076	25		
8 - Lacmor	17	49,211	7		Low priority when limited supply.
9 – Riverbank	25	453,270	49	2	
10 - Foster	51	472,338	38	7	
12 - Slee	51	693,669	42	1	
13 – Hills view	36	637,583	43		
15 - Oakstone	26	149,154	19	3	Low priority when limited supply.
16 - Broadfields	17	380,897	44		
18 - McDougall	50	661,276	41	4	
MH race losses	268	1,473,398	13		

Examples of the type of operational MAR test site designs during Year 5 are presented in Figures 3-2 to 3-6. Of these designs, the original test site design (Figure 3-2) is the most sensitive to sediment clogging as the recharge basin (backfilled with cobbles) is comparatively small. For this reason, these sites are directly connected to an irrigation pond where possible. Using this configuration, MAR supply water can be pumped into the pond before it is used to recharge at the test sites, allowing time for sediment suspended in the water to drop out. Sites 3-6, 8, 9, 15 and 16 currently use this design. Table 3-1 shows that their maximum recharge rate is less than 30 l/s, with basin size and local geology expected to be the primary constraints on maximum recharge rate. The enlarged test site in Figure 3-3 (Site 13) has the same sediment clogging potential but a lower risk due to doubling of the recharge basin volume. The initial test site at this location recharged less than 20 l/s. Table 3-1 shows that doubling the volume has increased the recharge rate to approximately 36 l/s.

In Figure 3-4, MAR 12 has 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 3-5), with an open channel sediment forebay trench, connected to a soak hole and down-gradient buried perforated pipe. The perforated pipe extension is a recharge design used for treated wastewater recharge that has the advantage that it doesn’t take land out of production. Another potential advantage of the perforated pipe extension is that the recharge water can be spread over a wider area, thus increasing the chance of intercepting open framework gravels with higher recharge flow potential. This enhancement has increased recharge rates at the site from <15 l/s to >50 l/s.

Figure 3-5 (MAR 07) shows an example of a large MAR basin. The other large basin site (MAR 01) uses a forebay for dropping out sediment. MAR 07 instead uses parallel bunds to slow the flow of water and progressively drop sediment. Higher turbidity water has been recharged at this site, as it is comparatively easy to clean. Recharge rates are currently limited (by consent conditions) to 100 l/s, but a higher recharge rate will be applied for under a replacement consent. MAR 02 (similar to MAR 17b) is a lateral race site, where an unused water race is scraped then multiple boulder beds inserted along with bunds. These are also easy to clean, and due to their length increase the chance of connecting to higher permeability groundwater flow pathways (open framework gravels).

Figure 3-2: MAR 08: Timaru Track Rd. MAR test site (Source: M. Neutze)

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Figure 3-3: MAR 13, Hinds Arundel Road. Enlarged MAR test site (Source: M. Neutze)

Figure 3-4: MAR 12, Maronan Ealing Road, up gradient (left) and down gradient (right). MAR test site enhanced with buried slotted pipe (Source: M. Neutze)

Figure 3-5: MAR 07, Corner Timaru Track and Maronan Valetta Roads. MAR basin (Source: B. Painter)

Figure 3-6: MAR 02, Timaru Track Rd. MAR lateral race (Source: B. Painter)

4 Hekeao / Hinds MAR Case Studies

All MAR sites are designed and operated to maximise their positive potential (improved groundwater quality and levels) while avoiding potential negative effects (localised flooding or transmission of pathogenic bacteria - indicated by *E. coli*) through the groundwater system. Consent conditions focus particularly on avoidance of potential negative effects. A portion of MAR sites were also chosen as case study sites for specific monitoring and analysis of positive impacts.

For this status report, assessment of two of the MAR test sites are presented in more detail. MAR 01 (the Lagmhor Pilot Site) was the initial case study site to prove the single site MAR concept for the Hekeao / Hinds Plains. This required investment in new monitoring bores as well as the monitoring of groundwater levels and quality in existing bores in the area potentially impacted by the site. The second case study site is MAR 12. Additional sites on the 'watch list' will be presented in future reports if preliminary assessments are supported by further monitoring.

4.1 MAR 01 - Lagmhor Pilot Site

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 4-1). Relevant discharge consents are CRC210700 and CRC210696. Pre-construction modelling and infiltration testing suggested potential infiltration / recharge rates of 300-500 l/s, with significant lateral as well as down-gradient influence. The actual infiltration rate achieved during the first two years was approximately 80-100 l/s, with the water quality influence initially following a path under identified surface paleo-channels before increased mixing in the area feeding lowland springs. During Year 3, potential improvements were trialled: a deep soakage system, removal of accumulated sediment from the recharge basins and up-gradient delivery channel, and a higher basin depth. Maximum recharge rates (including the recharge race) increased to 120-140 l/s following these enhancements. The most recent addition to this site has been the installation of an automated flow measurement and control gate.

Figure 4-2 presents recharge flows and local monitoring for Years 1-5. Recharge flows (in hundreds of litres per second) are shown in yellow, with a maximum instantaneous recharge of approximately 180 l/s (though as a weekly average the maximum was approximately 130 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 (at a 29 m deep bore 1 km down-gradient from MAR 01) 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 1.2-3.5 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 rapid 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. Discharge was not required to cease due to consent conditions on Hinds Plains Rainfall & Parakanoi Drain flow exceedance but was required to cease once for *E. coli* exceedance during Year 5.

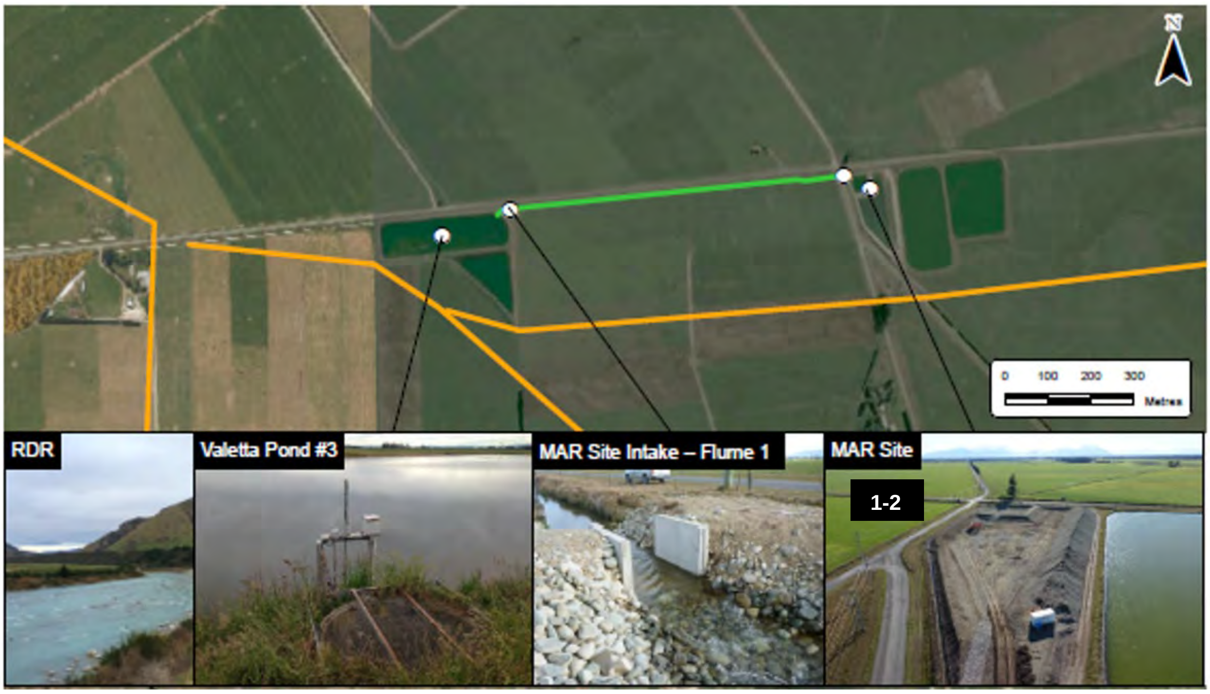

Figure 4-1: MAR 01 (Lagmhor Pilot Site) infrastructure (Source: MAR Year 1 report)

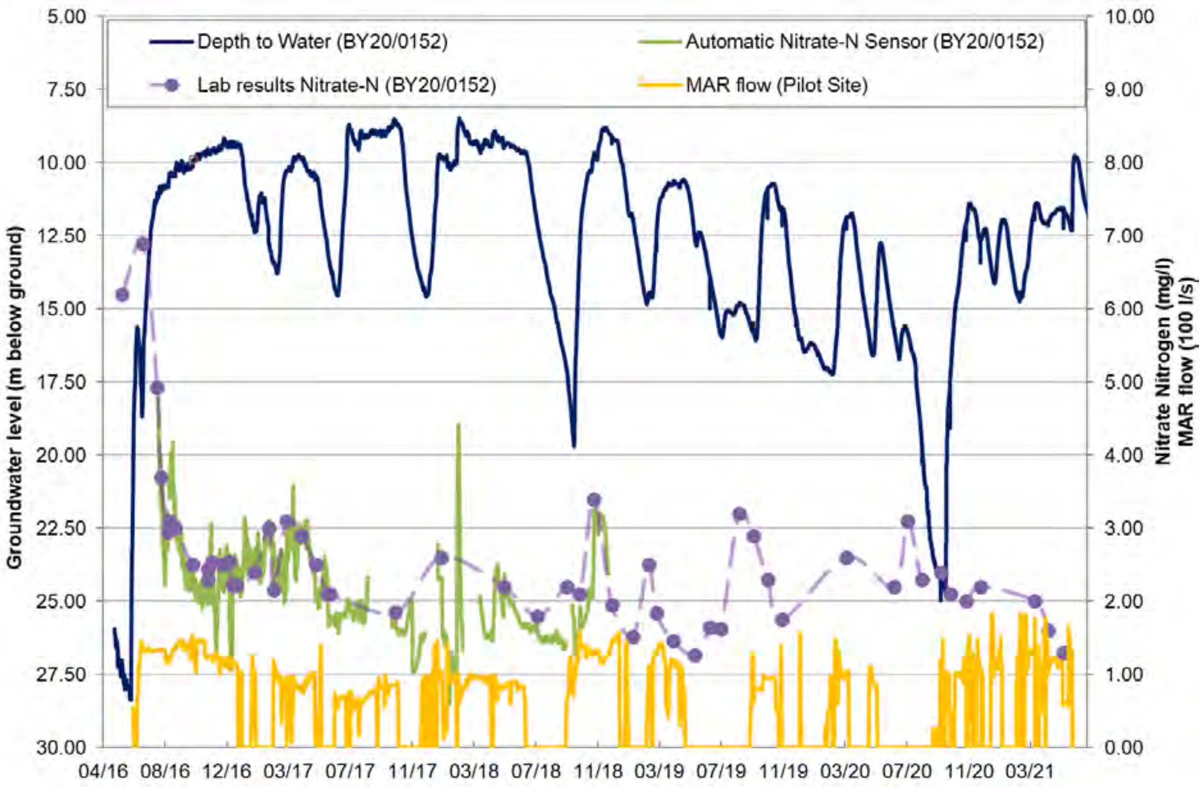

Figure 4-2: MAR 01 (Lagmhor Pilot Site) operational and key down-gradient monitoring

In the Year 4 (2019/20) Annual Report, groundwater level and water quality monitoring down-gradient from MAR 01 was compared to the 2019 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" by former Environment Canterbury scientist Patrick Durney. The relevant conclusion from this thesis was:

> *"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)

A comparison of modelled and actual results to the end of Year 4 concurred with this conclusion, albeit with caveats regarding the challenge of distinguishing recharge effects from abstractive effects on groundwater levels, particularly with increasing distance away from MAR 01. Results to the end of Year 5 further support this Year 4 analysis. Figure 4-4 presents modelled groundwater level changes with a continuous recharge flow rate of 110 l/s, from greater than 3 m (dark red) near the Pilot Site to less than 20 cm (blue) at distances greater than 10 km from the site. Groundwater level monitoring sites have been added to the figure, colour coded to the groundwater level graphs in Figure 4-5. 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 4-6 to assist with understanding groundwater level response to rainfall events. As noted above, 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 Durney (2019) modelling suggests that the area immediately surrounding the Lagmhor Pilot Site (MAR 01) would experience groundwater level changes due to MAR of at least 3.3 m at high recharge rates. Measured water levels in Bores 1, 2 and 3 on Figure 4-5 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. The longer-term impacts of the MAR operation on groundwater levels are evident when the full record from Bore 1 (K37/1748) is assessed, with a marked change in groundwater level from 2016 onwards (Figure 4-3).

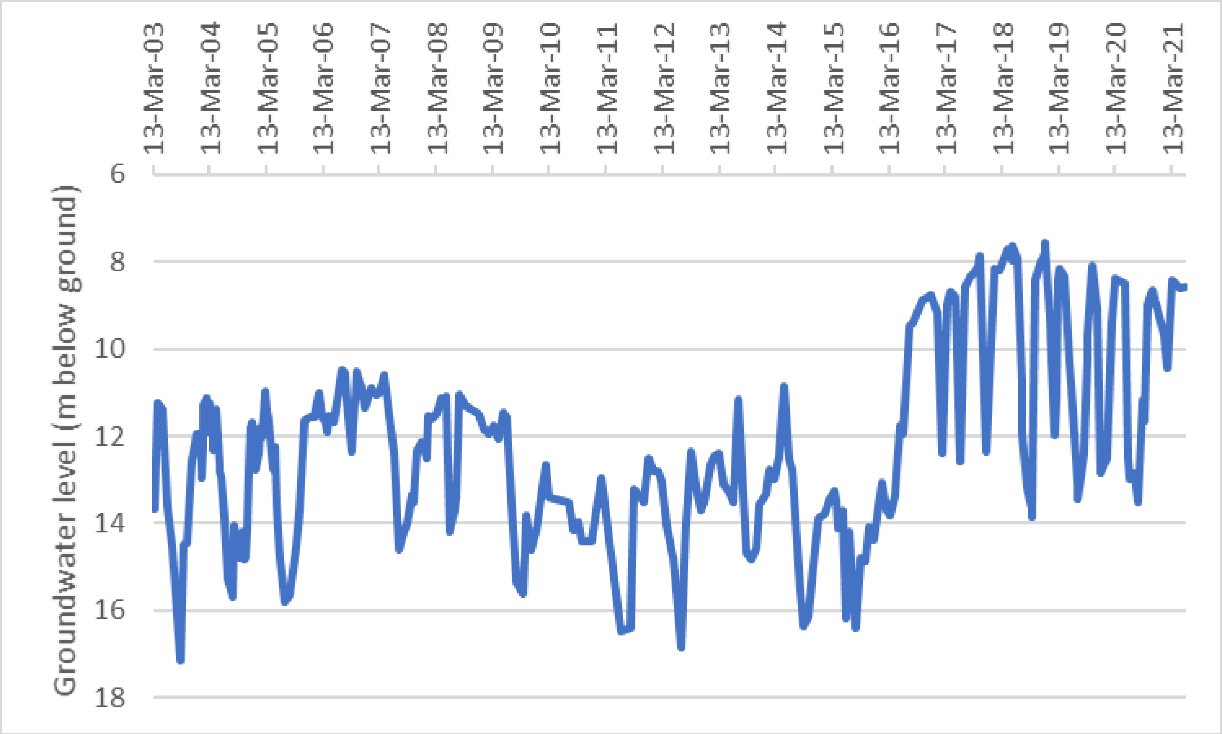

Figure 4-3: K37/1748 groundwater levels

In Figure 4-5, groundwater levels in Bore 5 (blue) respond to MAR 01 operations in a similar manner to Bores 1-3, though with more extreme decreases in groundwater level when MAR 01 is not operational for an extended period. As noted in the Year 1 MAR report (Hinds MAR Governance Group, 2017) and Durney (2019), these extreme changes are likely to be due to water leaking down the outside of the bore casing from a perched overlying layer, thus over-representing actual groundwater level changes.

Bores 4, 6, 7 and 8 show groundwater level changes that are difficult to distinguish from their typical seasonal and inter-annual rainfall and pumping responses. For Bores 6-8, this aligns with the results from Durney (2019), but Durney's (2019) prediction that Bore 4 would show a similar magnitude of groundwater level change to Bore 5 is not observed. Importantly, during the extended MAR 01 shutdown periods in winter 2019 and winter 2020, Bore 4 groundwater levels recovered in response to winter recharge at a similar rate to Bores 6-8. These bores appear to be responding in a similar manner and do not show the effects of the MAR operation. This suggests that the alluvial deposition down-gradient from MAR 01 may be constraining lateral groundwater level increases more than predicted by Durney (2019).

Of particular interest is the relatively sharp rise in BY21/0183 (Bore 7) groundwater levels from 20 April 2021. Figure 4-7 zooms in on this period (first half of 2021). Alongside MAR 01 flow, Hinds rainfall and Bore 7 (BY21/0183), K37/2456 and BY21/0184 (see Figure 4-9) are also presented to enable comparison with shallow groundwater levels south and east (respectively) of the influenced area. From mid-January 2021, groundwater levels in BY21/0183 and BY21/0184 decline more sharply than K37/2456, presumably due to the higher proportion of groundwater abstraction north of the Hekeao / Hinds River compared with south. Rainfall events are also followed by larger groundwater level responses in BY21/0183 and BY21/0184 compared with K37/2456. Local groundwater pumping records suggest that most groundwater irrigation abstraction ended for the season within a week following the 12.5 mm rainfall event on 16 April (*pers. comm P Lowe*). Between this rainfall event and the 100 mm rainfall event on 30 May, groundwater levels measurably increased in BY21/0183, slightly increased in BY21/0184 and did not measurably increase in K37/2456. In the absence of groundwater abstraction information, we can be confident that rainfall recharge from April 2020 contributed to the start of the winter recovery in groundwater levels in BY21/0183 and BY21/0184. However, Willowby locals with many years living near BY21/0183 have also expressed the opinion that the groundwater levels increased faster than they expected given the rainfall during this period, and the on-going high MAR 01 recharge flows could therefore have also contributed to this groundwater level rise (*pers. comm I Mackenzie*).

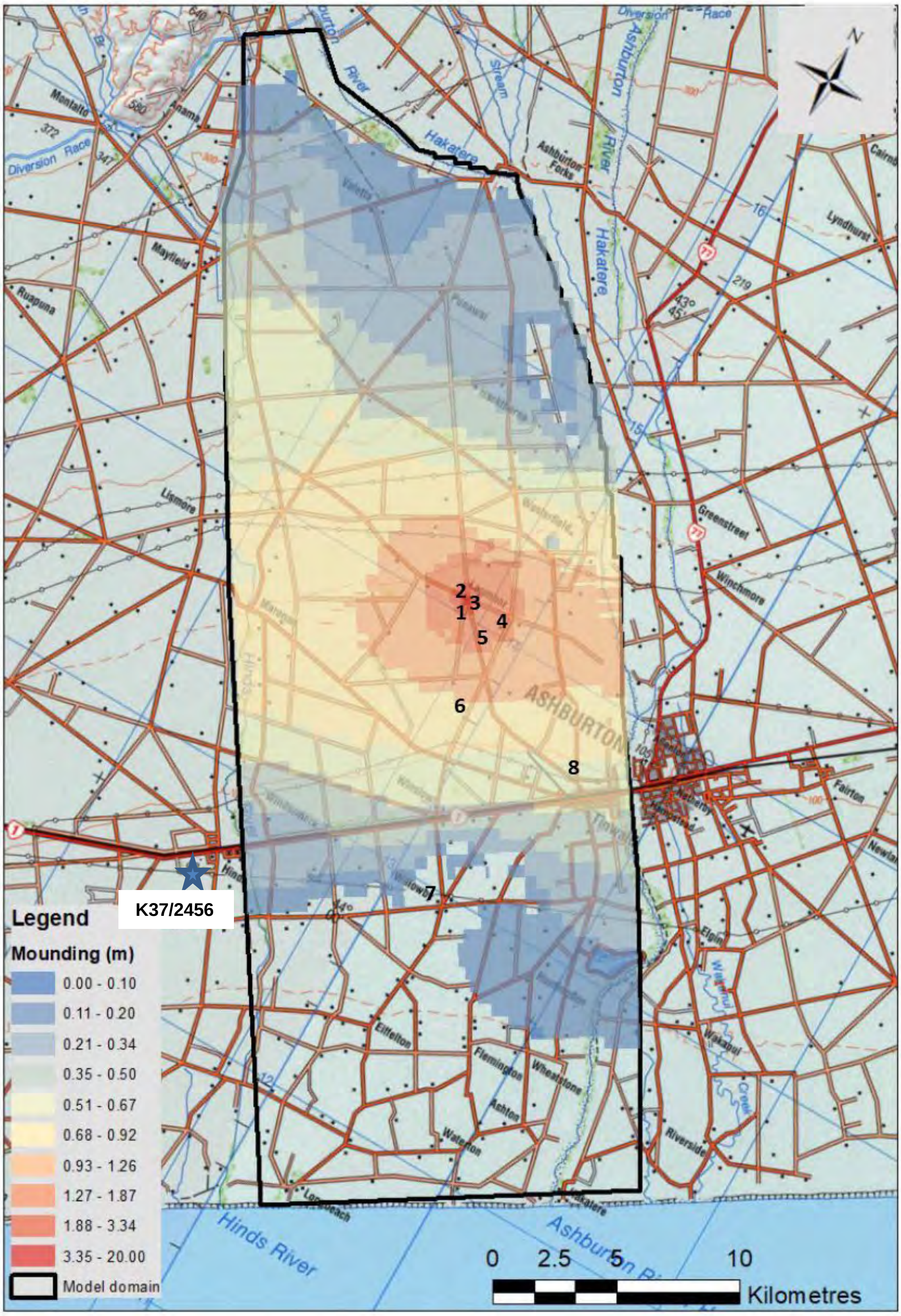

Figure 4-4: **Durney, 2019 (Figure 5-16 Modelled groundwater level change in response to the MAR trial) plus numbered monitoring bore locations and K37/2456**

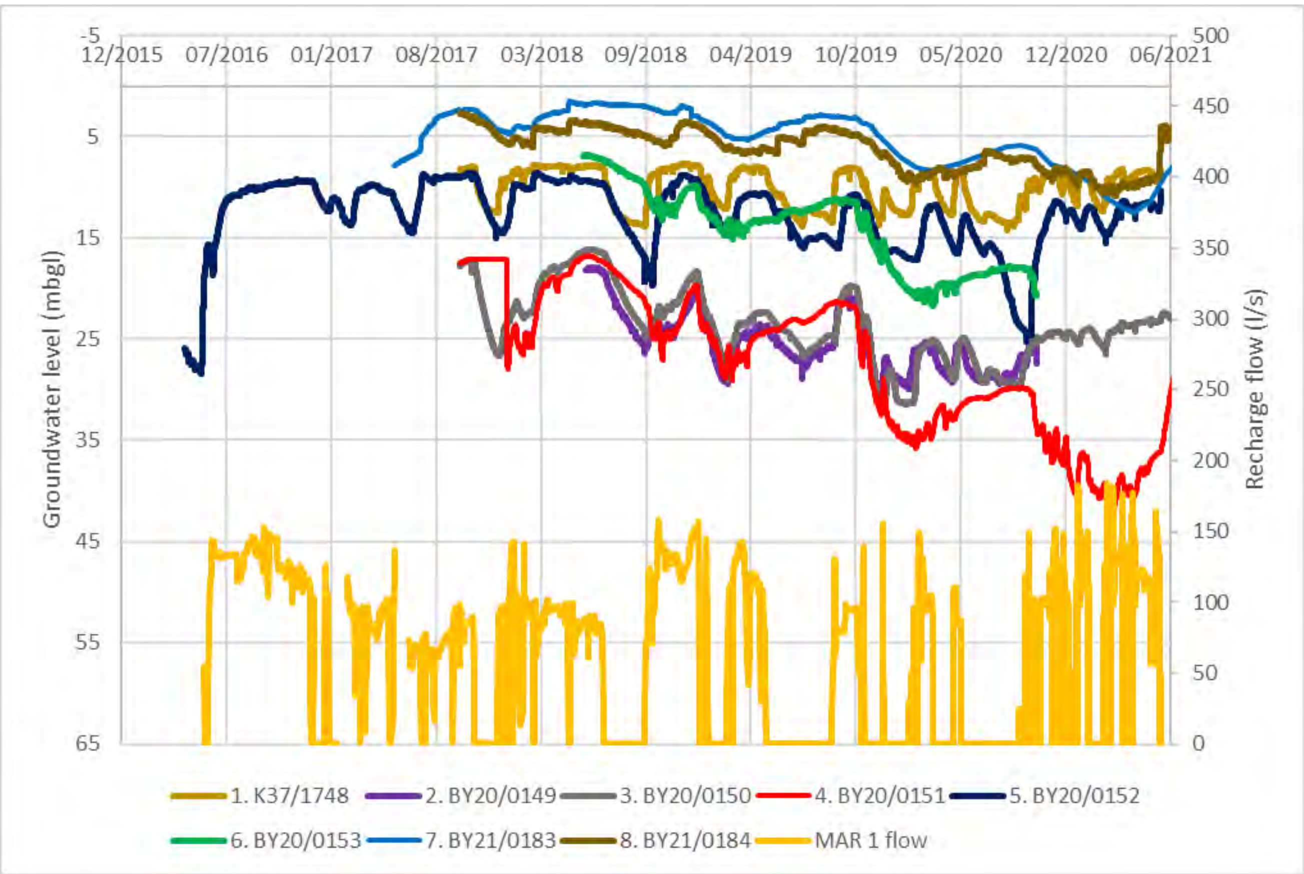

Figure 4-5: **Monitoring bore records, colour coded to locations in Figure 4-3**

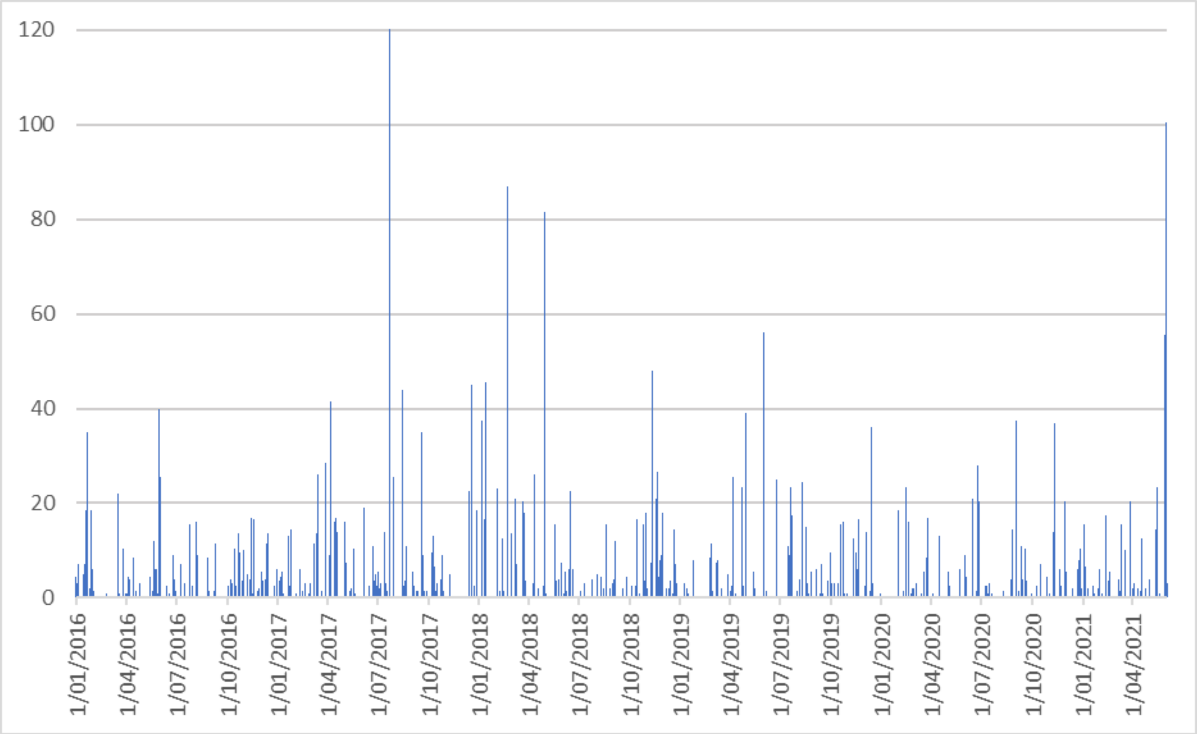

Figure 4-6: **Hinds Plains daily rainfall (Source: CRC)**

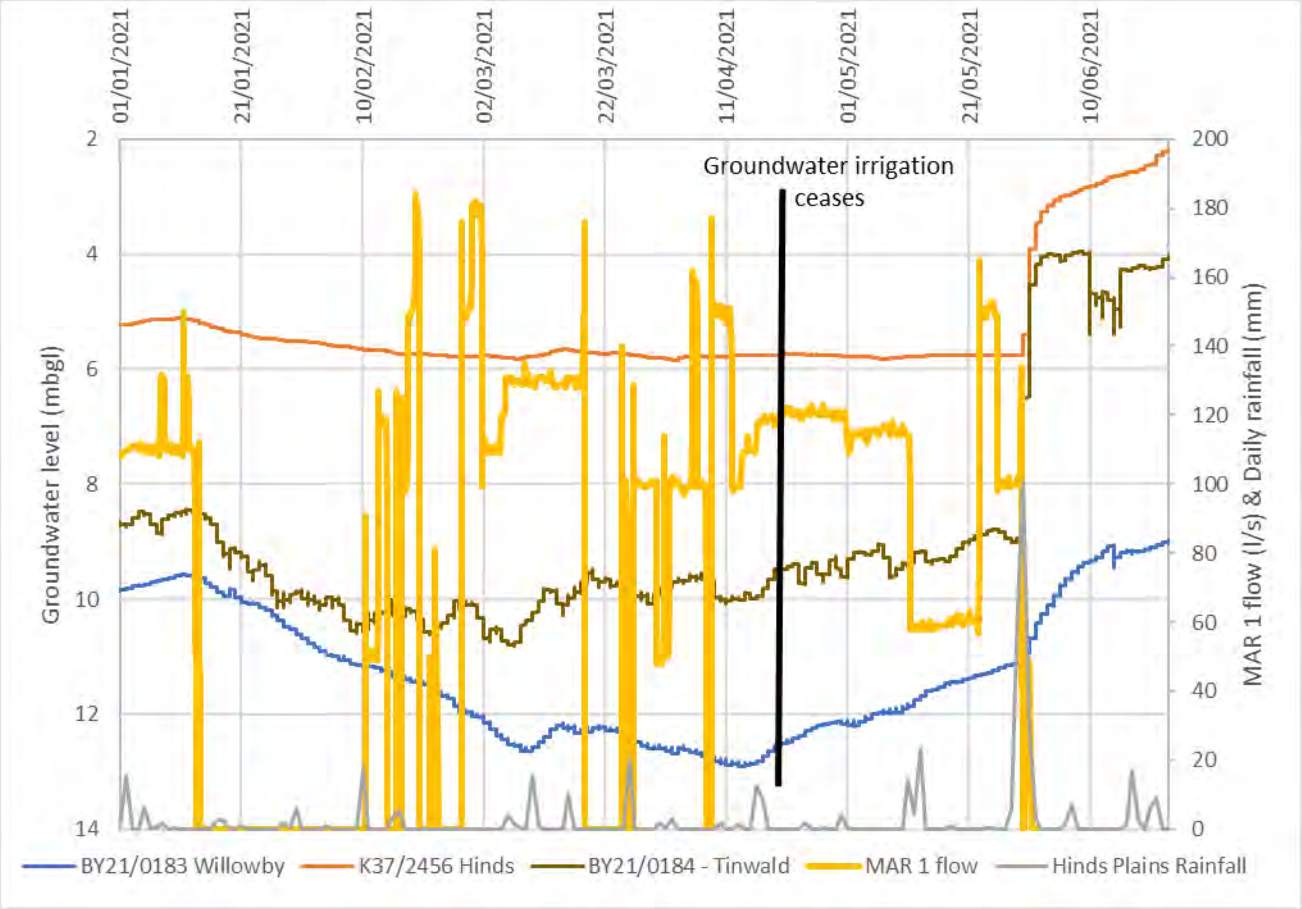

Figure 4-7: Lower catchment groundwater levels, rainfall and MAR 1 flow (Source: CRC, HHWET)

Figure 4-8 presents Durney's (2019) modelled groundwater quality changes after 5 years. Model results indicated that groundwater (in the identified depth range approximately 20-45 m below ground level) is comprised of approximately 80-100% MAR water immediately down-gradient from the Pilot Site (red), reducing to a 10-20% MAR groundwater component at the margins of MAR 01-influenced area (dark green). Numbers 1-13 have been added to Figure 4-8, at the location of bores with water quality monitoring information relevant to the MAR 01 analysis (N.B., this numbering is not the same as in Figure 4-5). These bores are also shown in Figure 4-8 in the MAR Year 2 report, with colour coding on the bores to show assessed MAR water quality influence as likely (green), possible (yellow) and unlikely (red).

The nitrate-N concentrations measured at these numbered bores are presented alongside MAR 01 inflow data in Figures 4-10 to 4-12 in this report. Bores with green dotted lines show evidence for changes in nitrate-N concentration (along with other water chemistry changes such as electrical conductivity, chloride, and hardness) and an initial lag time consistent with water particle travel time estimates in the Year 1&2 MAR reports. It was therefore concluded in the MAR Year 2 report that these wells are in the MAR 01 zone of water quality influence. Results to Year 5 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 MAR 01 zone of water quality influence. Bores with yellow dotted lines remain inconclusive.

Bores close to MAR 01 (Fig. 4-10) show nitrate-N reductions of at least 50%, consistent with the influence of low nitrate MAR water, as indicated by Figure 4-8. In the bores further down-gradient from MAR 01 (Figs 4-11 and 4-12), Bore 6 on Figure 4-8 does not appear to show the modelled influence of MAR operations, while Bores 7-9 plus Bore 12 do show a potential water quality influence. This suggests that the MAR water is following preferential flow paths along the locally varying hydraulic gradient presented in Figure 4-9 (blue arrows, at right angles to the blue piezometric contours), rather than a south easterly direction, at right angles to the land contours. 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 4-8. 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 five years of operations at MAR 01 is 50 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, due to the higher nitrate water also feeding this area from catchments to the northeast and southwest of MAR 01-influenced groundwater. Monitoring will continue to be carried out, to understand both the individual and cumulative influences of MAR sites, as more become operational in this area.

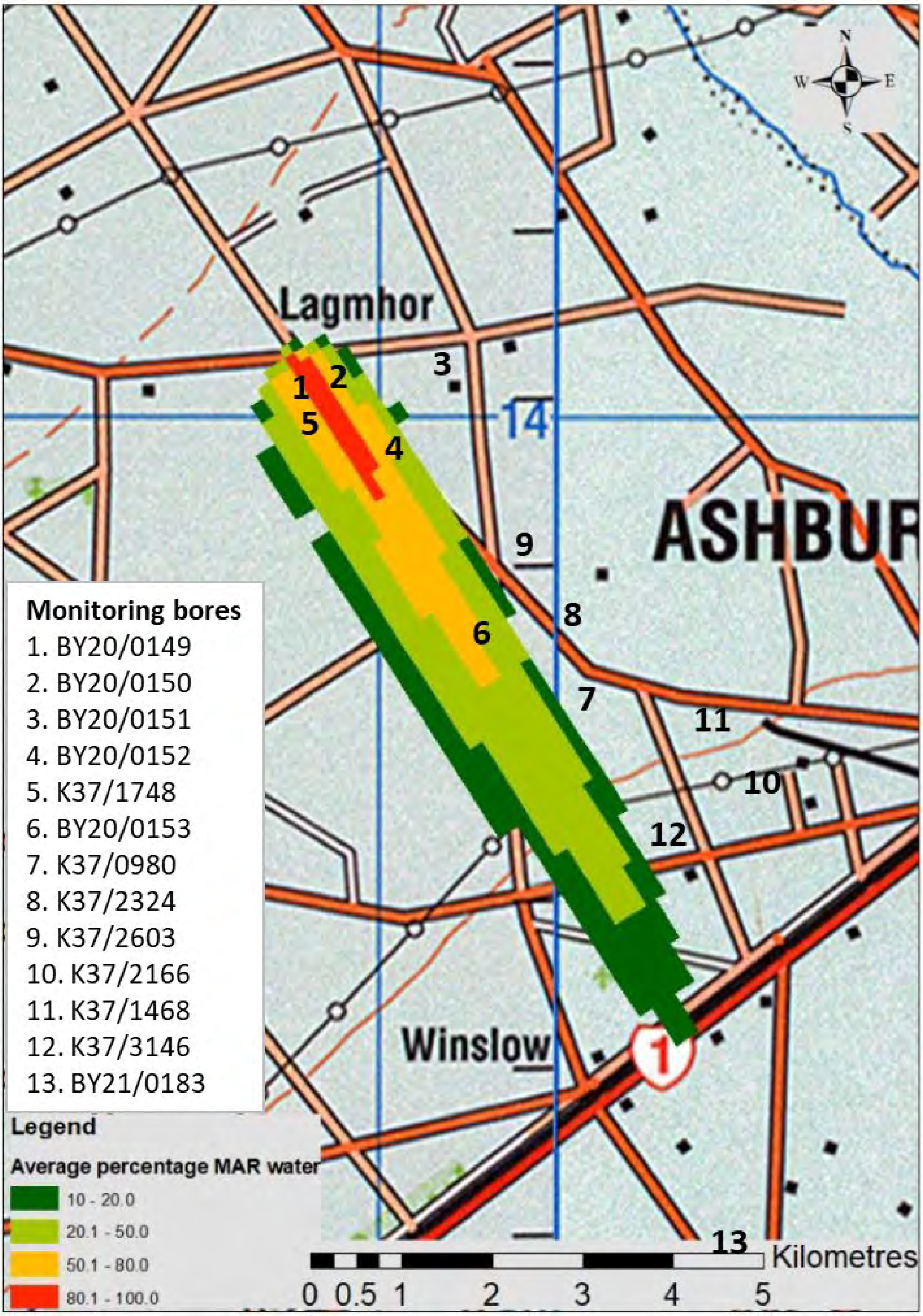

Figure 4-8: Modelled groundwater quality change after 5 years in response to the MAR trial (from Durney, 2019, Figure 5-23 MAR plume Layer 3)

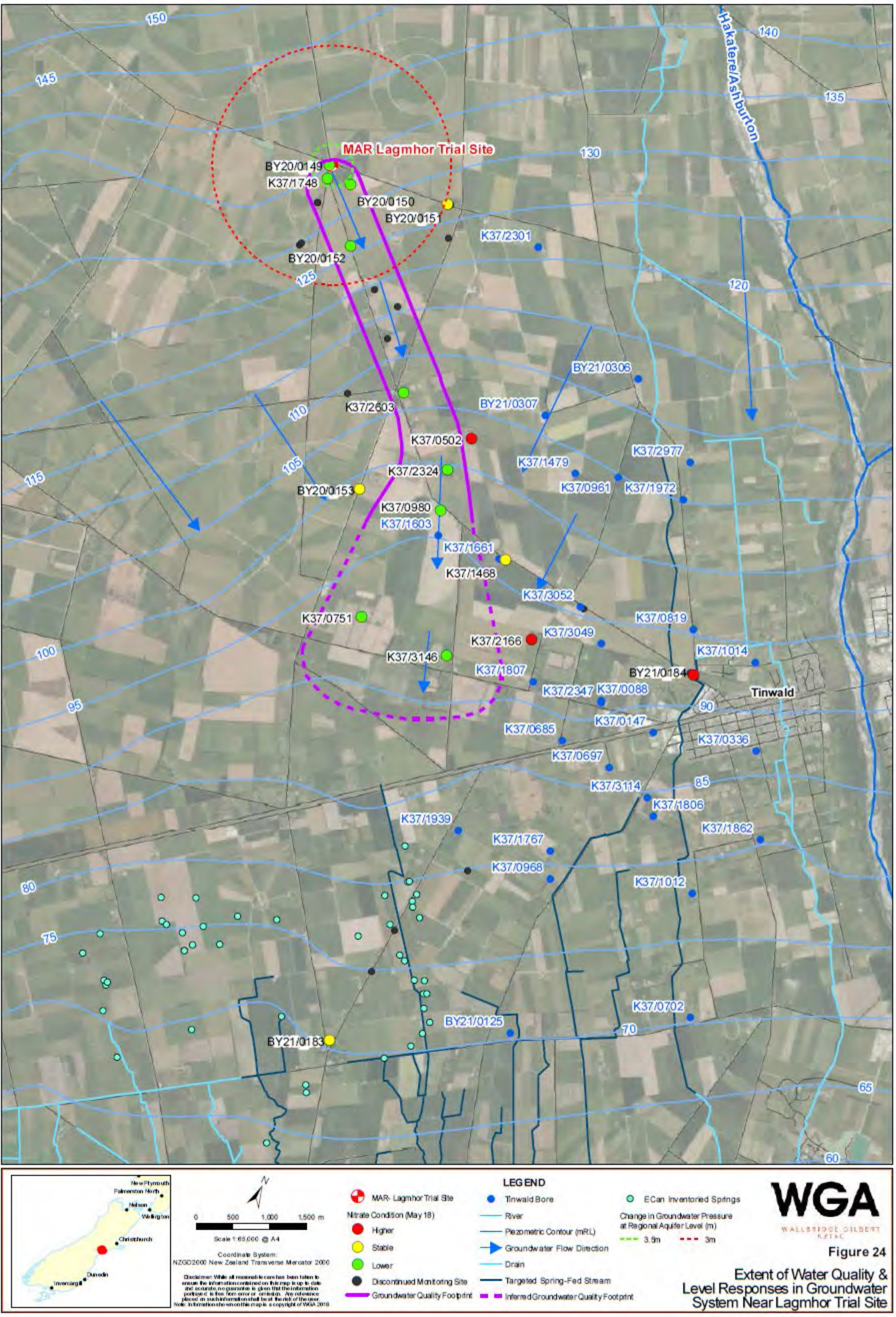

Figure 4-9: **Figure 24 from Year 2 report (with updated bore names) showing assessed groundwater level and quality responses to MAR 01 operations**

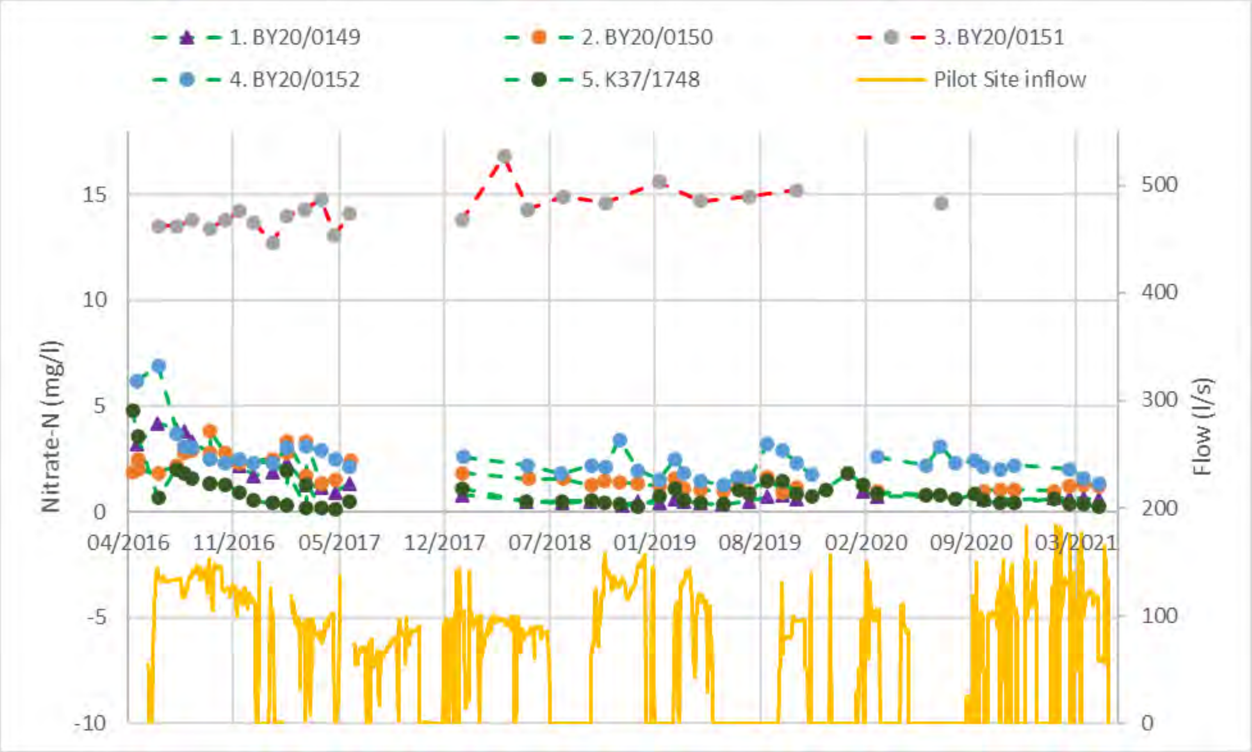

Figure 4-10: Nitrate-N measured concentrations for wells close to MAR 01

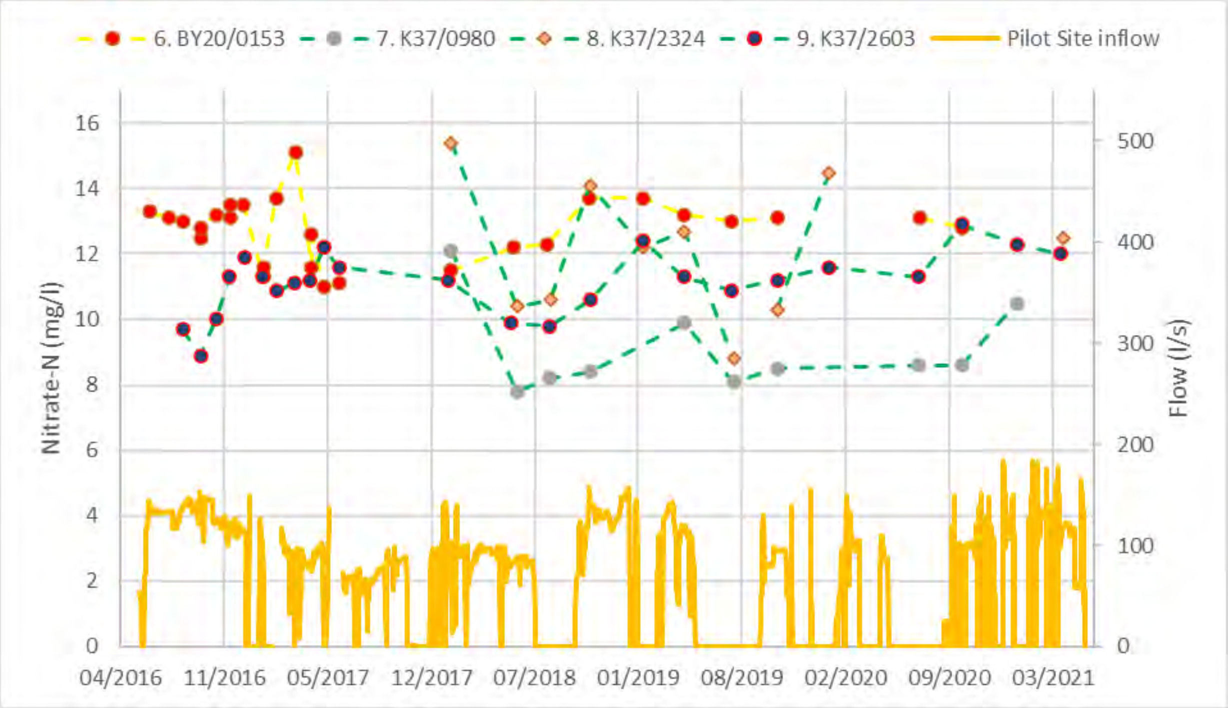

Figure 4-11: Nitrate-N measured concentrations for wells 3-5 km from MAR 01

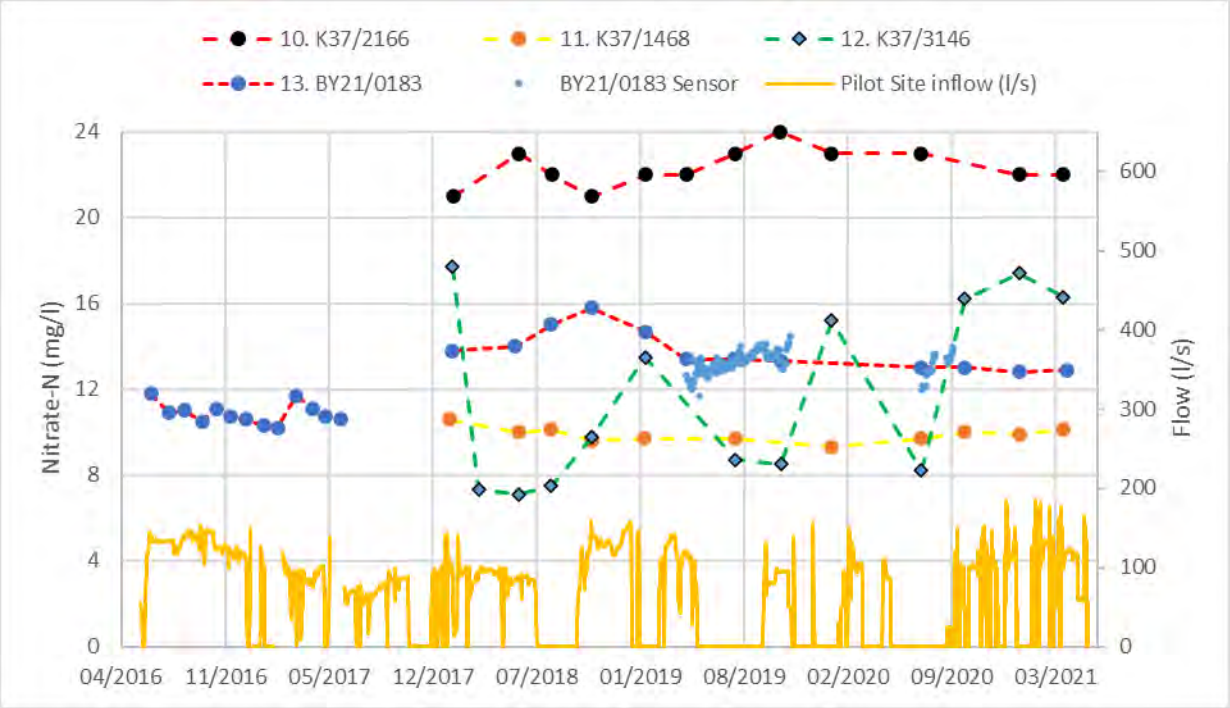

Figure 4-12: Nitrate-N measured concentrations for wells 6-12 km from MAR 01

4.2 MAR 12 - Maronan Ealing Road

As discussed in Chapter 3 and presented in Figure 3-4, MAR 12 has replaced a test site (at the same location on Maronan Ealing Rd) which did not perform well due to sediment and *E. coli* management challenges. The new site (which began operation in June 2020) is fed by the same water race as the previous test site, with the addition of an open channel sediment forebay trench, connected to a soak hole and down-gradient buried perforated pipe. This enhancement has increased recharge rates at the site from <15 l/s to >50 l/s. Figure 4-13 shows the location of MAR 12, two bores of interest with water quality monitoring and the anticipated groundwater flow direction at right angles to the regional piezometric contours.

Figure 4-14 presents the MAR 12 recharge flow since construction plus nitrate-N concentrations at the two nearby bores (BY20/0148 and K37/0234). Both sites are monitored quarterly by CRC. BY20/0148 also has a groundwater nitrate sensor installed (See MAR Year 4 report). Figure 4-14 shows nitrate-N concentrations following a similar, downward trend until the first monitoring round following the site upgrade in June 2020. From this point through to March 2021, nitrate-N concentrations continued to decrease at K37/0234 but increased at BY20/0148. After the end of MAR 12 operations for the year nitrate-N concentrations increased slightly at K37/0234. These changes in water quality are consistent with the piezometric contours on Figure 4-13 that suggest BY20/0148 water quality is unlikely to be influenced by MAR 12 operations while K37/0234 water quality could be influenced by MAR 12 operations if groundwater flow pathways provide a physical groundwater connection.

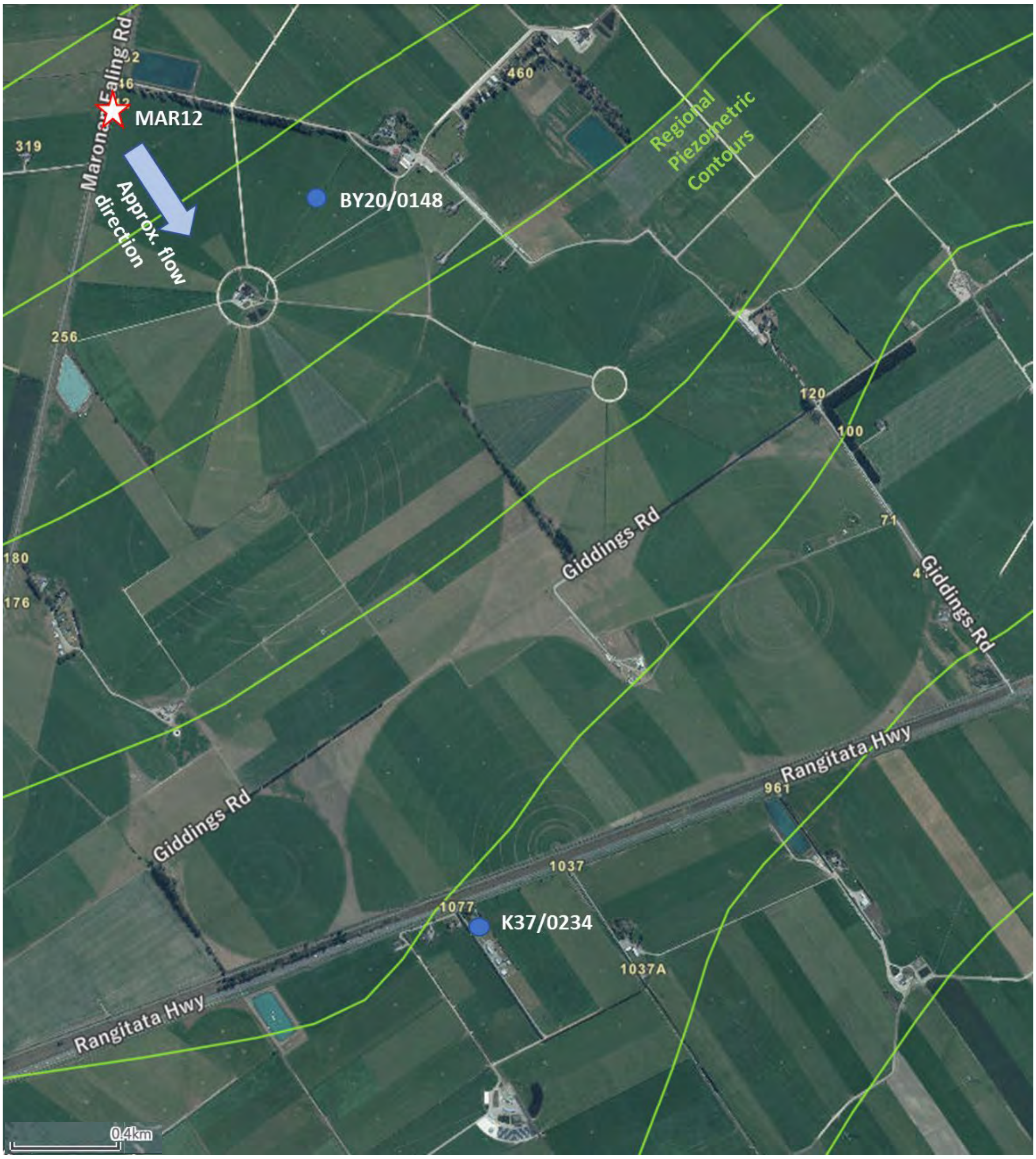

Figure 4-13: Location of MAR 12, regional piezometric contours and two bores of interest (Source: Canterbury Maps)

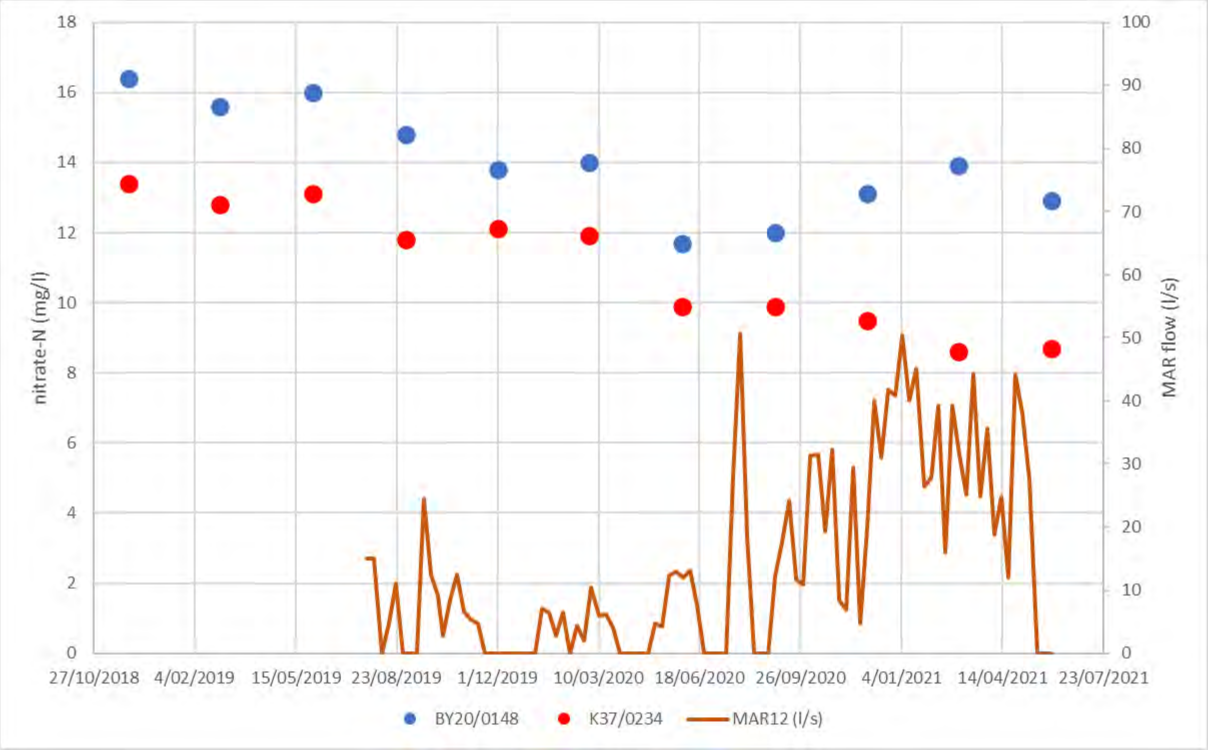

Figure 4-14: MAR 12 recharge flow, plus nitrate-N concentrations at two nearby bores (Source: CRC)

5 Hekeao / Hinds Northern Drains and Plains Water Quality

5.1 Hekeao / Hinds Northern Drains Water Quality

Consent conditions for MAR 01 (Lagmhor Pilot Site) discharge consents require water quality, quantity (flow) and ecology to be monitored in key Hekeao / Hinds northern drains. A comparison of Figures 2-1, 3-1, 4-9 and 5-1 suggest that MAR 01, MAR 07 and MAR 08 may contribute to the groundwater that provides spring-fed supply to the Flemington and Parakanoi Drains. However, the water quality assessment in Section 4-1 of this report concurs with Durney (2019), which 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, due to the higher nitrate water also feeding this area from catchments to the northeast and southwest of MAR-influenced groundwater. The MAR volume delivered in Year 5 through these sites was 2.7 million cubic metres, equivalent to 86 l/s continuous recharge. The Hekeao / Hinds Northern Drains monitoring will therefore continue to be regarded as baseline monitoring until MAR volumes in this vicinity increase significantly.

Dynes (2021) presents the ecological monitoring to date in the northern Hekeao / Hinds Drains in a report for the Hinds Drains Working Party. Relevant monitoring is presented on Figure 5-1 and summarised in Tables 5-1, 5-2 and 5-3. Some sites on these drains were dry during Year 5, which meant that the 95th percentile (at least) couldn't be calculated. For each drain, the NNN concentration was generally lower closer to the coast than in its upper reach. For each year the Flemington and Parakanoi NNN concentrations were similar, with the Windermere NNN higher. Broader conclusions from Dynes (2021) are:

Nitrate-Nitrite-Nitrogen (NNN) results for most drains in the Hekeao/Hinds Plains area do not meet the LWRP annual median and 95th percentile limits. Patterns in NNN concentrations reflect climatic conditions prior to monitoring such as seasonally low NNN concentrations during dry periods when nitrates are held in the soil profile. Spikes in NNN were observed following region-wide floods such as those in 2017 and the recent May 2021 flood events, when the nitrates stored in the soil profile are flushed into groundwater and subsequently feed into the spring-fed streams.

Long-term NNN trends were calculated for 9 sites with a minimum of 9 years of data. Two sites showed a significant increasing trend over 20+ years of continuous monitoring. An additional site showed a significant increasing trend over 9 years of continuous monitoring. All other sites that had 9 or 10 years of monitoring did not show any "probable/certain" or statistically significant trends.

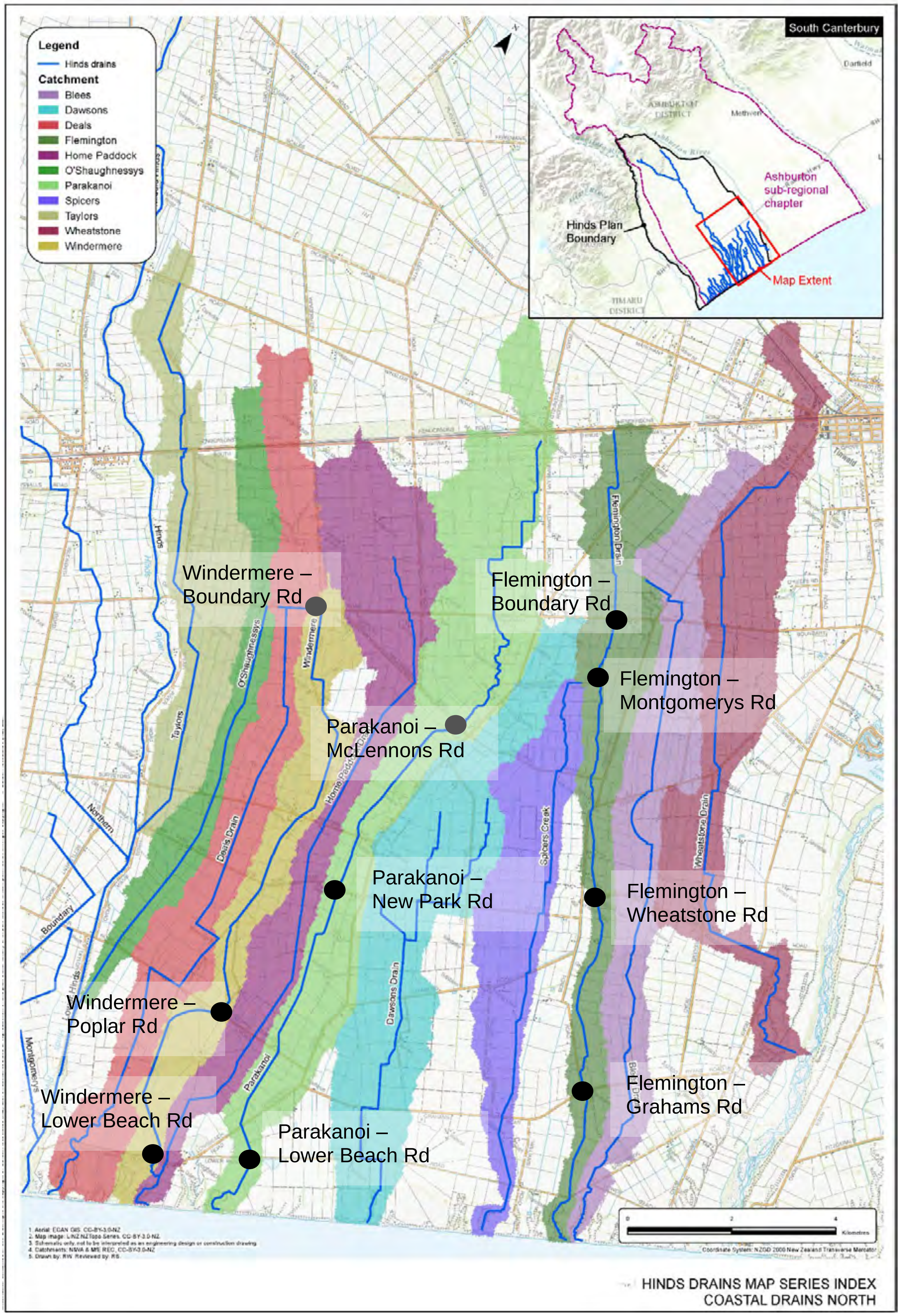

Figure 5-1: Hekeao / Hinds Northern Drains monitoring sites

Table 5-1: Windermere Drain - Annual median and 95th percentile NNN concentrations compared to the LWRP Nitrate limits (median 6.9 mg/L and 95th %ile 9.8 mg/L). (Source: Dynes, 2021)

Year (June-July)	Windermere/Boundary cnr SQ36071		below Boundary Rd SQ36070		Poplar Rd SQ36073		Lower Beach Rd SQ26245	
	Median	95th %ile	Median	95th %ile	Median	95th %ile	Median	95th %ile
2016-17	21	23.8	16.2	22	13.1	20.8	14	-
2017-18	14.8	19.1	11	17	11.5	17.9	12	15.8
2018-19	13.6	6	11.3	14.5	10.5	14.7	10.7	13.3
2019-20	15.6	17	13.5	15.2	9.9	14.5	10.3	-
2020-21	15.6	18.4	13	-	4.3	17. 6	9.3	-

Table 5-2: Parakanoi Drain - Annual median and 95th percentile NNN concentrations compared to the LWRP Nitrate limits (median 6.9 mg/L and 95th %ile 9.8 mg/L). (Source: Dynes, 2021)

Year (July-June)	New Park Rd SQ36154		McLennons Rd SQ36153		Lower Beach Road SQ26242	
	Median	95th %ile	Median	95th %ile	Median	95th %ile
2016-17	6	-	8.4	-	0.6	-
2017-18	13.8	19.6	13.6	19.4	13.2	18.2
2018-19	11.6	13.3	12.6	13.9	11.3	12.8
2019-20	11.7	-	13.5	14.8	11.9	-
2020-21	Not sampled		13.6	-	Dry	

Table 5-3: Flemington Drain - Annual median and 95th percentile NNN concentrations compared to the LWRP Nitrate limits (median 6.9 mg/L and 95th %ile 9.8 mg/L). (Source: Dynes, 2021)

Year (July-June)	Boundary Rd SQ36064		Montgomerys Rd SQ36151		Wheatstone Rd SQ00681		Grahams Rd Fords cnr SQ36067	
	Median	Median	Median	Median	Median	95th %ile	Median	95th %ile
2016-17	-	-	Not Sampled		Not Sampled		-	-
2017-18	10.2	9.7	10.7	13.7	10.2	15.3	9.7	-
2018-19	12	9.7	11.1	12.8	10	11. 5	9.7	-
2019-20	12	11.2	13.1	-	11.3	-	11.2	-
2020-21	Dry		13.8	-	Not Sampled		8.5	-

5.2 Hekeao / Hinds Plains Groundwater Quality

The groundwater nitrate-N PC2 monitoring update to 30 June 2021 (which is different from the MAR project reporting period to 31 May) in Figure 5-2 shows median nitrate-N concentrations in PC2-specified "shallow" wells across the Hekeao / Hinds Plains. The values in Figure 5-2 are slightly different from previous annual PC2 reporting due to a clarification by CRC in the method for reporting PC2 nitrate-N groundwater concentrations. This clarification confirms that the 13 wells screened <30 m below the water table that were part of PC2 technical analyses (and their subsequent replacements) are to be monitored quarterly, with the median of each monitored bore's median used as the annual value. Previously, only wells within 30 m of the ground surface were included in this assessment.

Figure 5-2 shows that the 2020-21 nitrate-N median concentration of 9.4 mg/l was the second year in a row with a concentration decrease and the lowest concentration since 2010. Figure 5-2 also shows that 2020-21 was drier than average (for the presented timescale), in particular the year until 29 May 2021, when 185 mm of rain fell over the following 3 days. The PC2 groundwater nitrate-N monitoring for 2020-21 had been completed by this time so does not include any changes in groundwater nitrate-N concentrations as a result of this heavy rainfall event. We can be confident that the below average rainfall during the 2020-21 PC2 reporting period contributed to the decrease in annual median PC2 groundwater concentration. However, MAR plus continued changes to landuse, water distribution infrastructure, irrigation methods and nutrient leaching management are also likely to be influencing losses from the soil, and potentially groundwater concentrations, during this time. The complex interactions between these influences, and (often) long lag times, makes detailed analysis of individual influences very challenging.

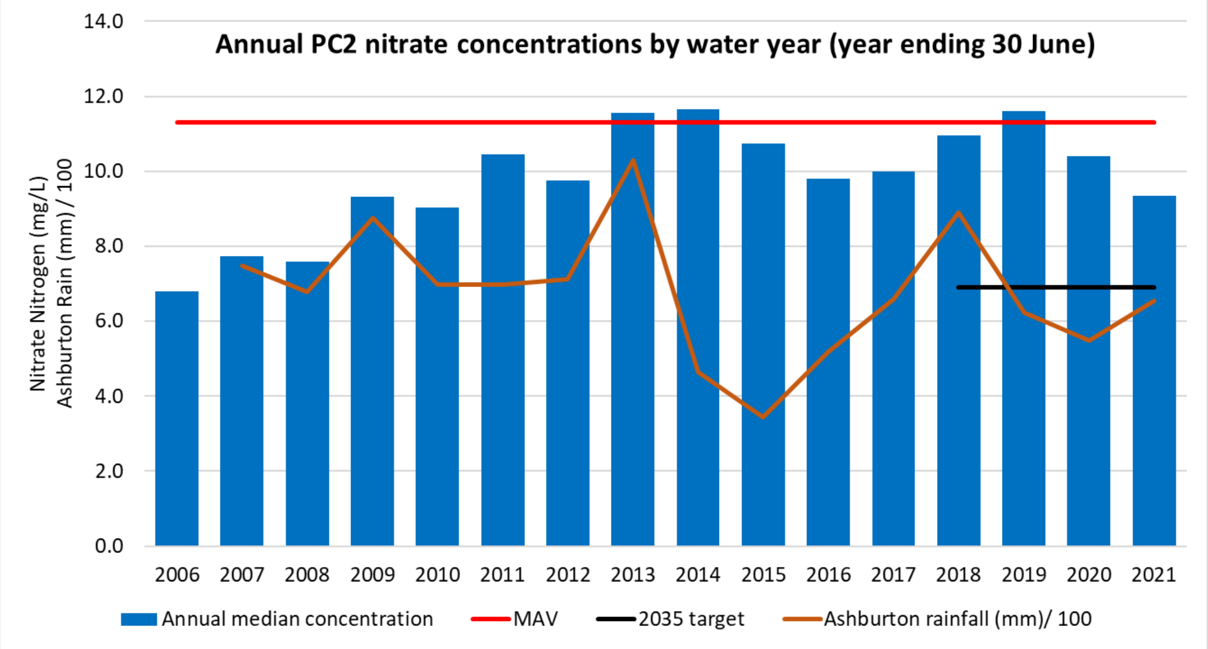

Figure 5-2: PC2 nitrate-N concentrations and Ashburton rainfall by year (Source: CRC)

In order to assist with improved understanding of the catchment water quality along with improved targeting of concepts such as MAR to improve eco-system health, MHV Water's Hekeao / Hinds Plains groundwater monitoring (on behalf of MHV Water and HHWET) has been underway since 2017. Results to 2020 are presented in the MAR Year 4 report. MHV Water monitoring coverage has increased significantly during Year 5. The vertical bars in Figure 5-3 show the number of MHV Water shallow (light blue), MHV Water deep (dark blue) and PC2 bores for each quarterly sampling round on the right axis. The number of PC2 bores stays the same throughout the year, but the total number of MHV Water bores increases through the year. The ~150 bores in total monitored by MHV Water by the end of Year 5 cover the whole Hekeao / Hinds Plains, which will greatly assist analyses once a few years monitoring at this level of coverage is completed. The joined dots show the median nitrate-N concentration (on the left axis) for each set of bores and sampling round. Figure 5-3 shows that the Year 5 shallow MHV Water and PC2 bores produced similar median nitrate-N concentrations, except for the September 2020 sampling round when the median PC2 result was significantly lower than the MHV Water result. For each quarter, as expected, the deep MHV Water bores show lower median nitrate-N concentrations than the shallow bore sets. More detailed analyses will be appropriate once a longer MHV Water dataset at the current coverage is available.

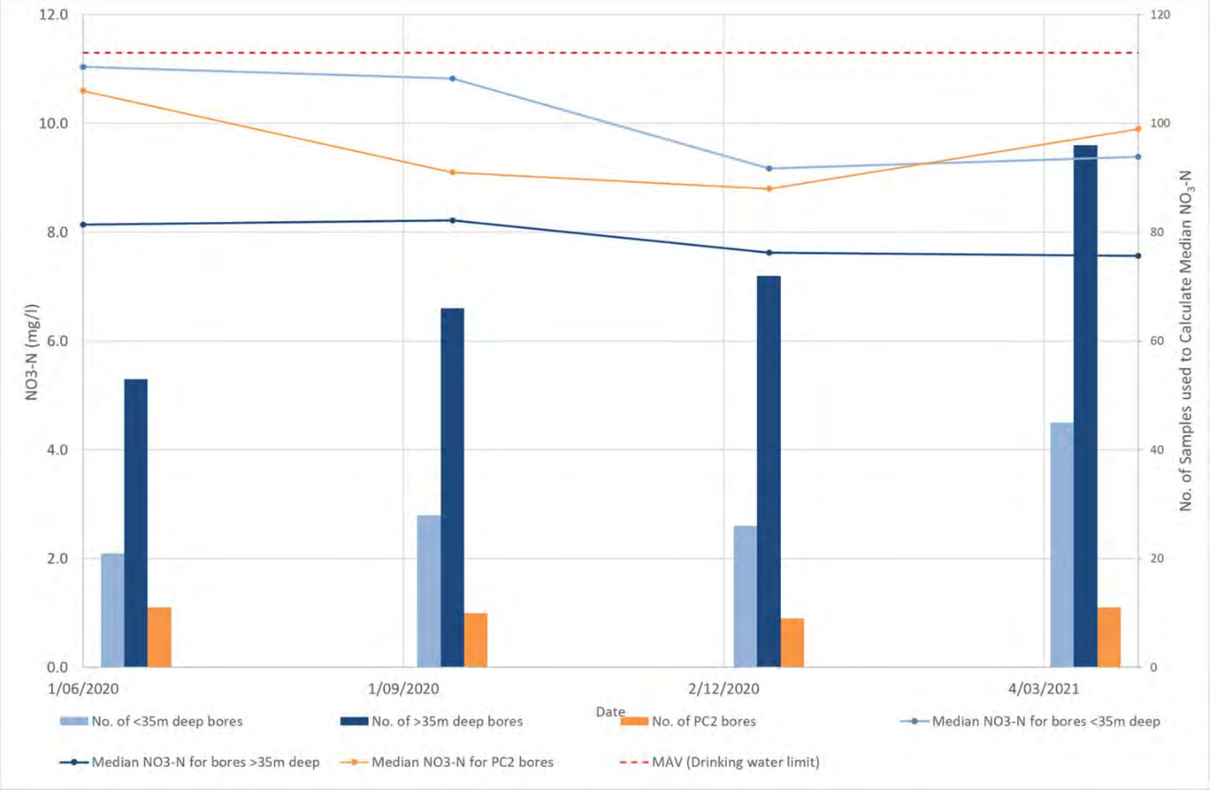

Figure 5-3: Year 5 Hekeao / Hinds groundwater nitrate-N monitoring (Source: MHV Water, CRC)

6 Hekeao / Hinds Plains Computer Modelling

Analysis of operations and monitoring results for Hekeao / Hinds MAR case study sites since 2016 suggests that these sites are achieving their performance objectives on a site-by-site basis. However, total Year 5 recharge of 13.8 million m^3 is well short of the ~125 million m^3/year assessed as the annual required MAR volume to assist with meeting relevant PC2 objectives. Tracking progress towards catchment-scale objectives can be greatly assisted by computer modelling. HHWET contracted Pattle Delamore Partners (PDP) to develop a numerical groundwater model of the Hekeao / Hinds Plains and surrounding areas for this purpose (Figure 6-1). The model boundaries extend past the area of interest so that “boundary effects” are minimised. The remainder of this chapter summarises the initial computer modelling report (PDP, 2021).

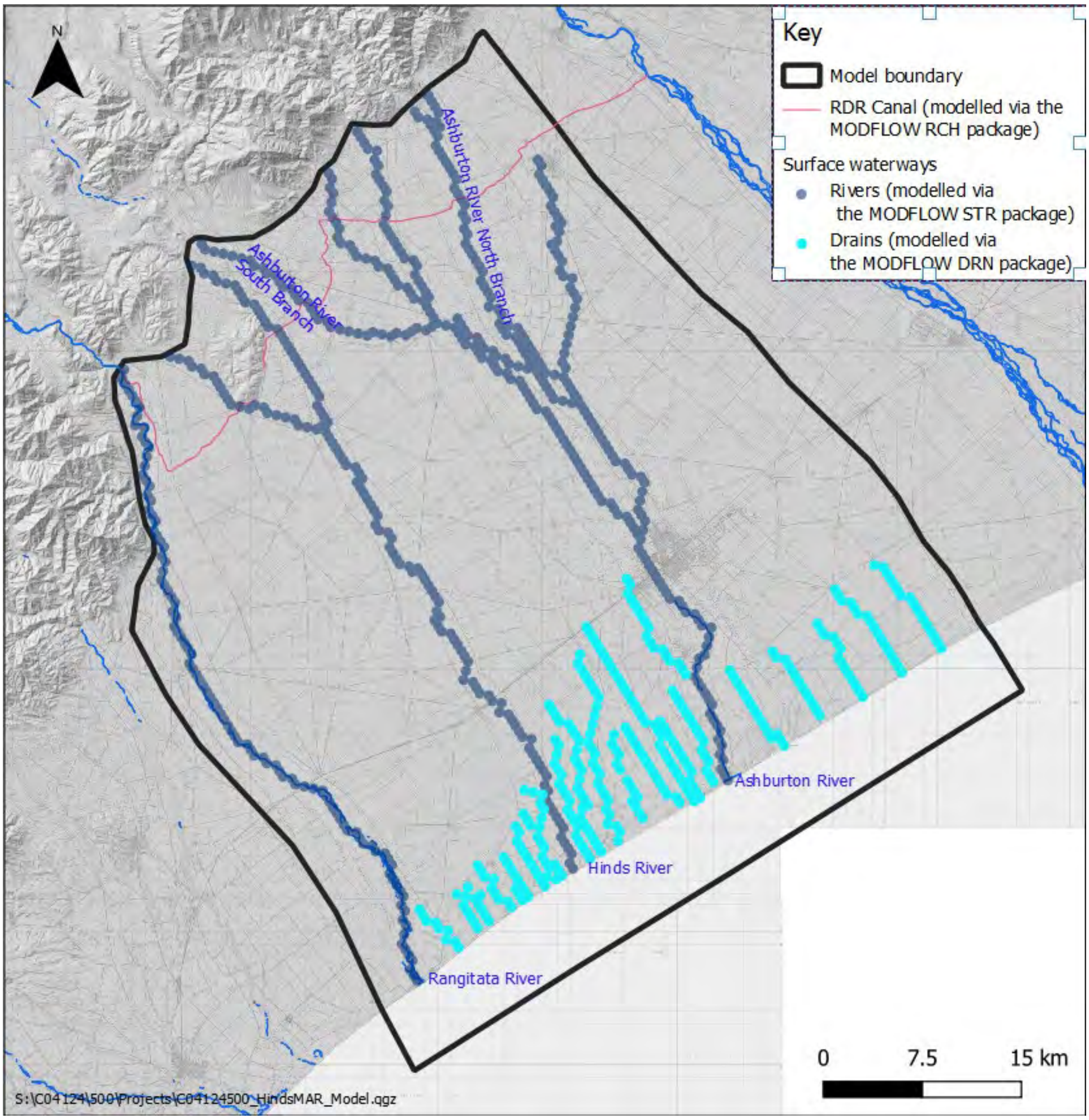

Figure 6-1: Computer model boundaries and surface waterways (Source: PDP, 2021)

Numerical groundwater models include a large number of parameters to describe groundwater flow and its interaction with surface waterways across the model area. The level of confidence in a computer model is related to how well calibrated the model parameters are to observed groundwater levels and surface water flows. Modelling confidence is growing with the increasing monitoring underway in the modelled area, but there are still areas with reasonably sparse information.

For different MAR Schemes, such a computer model can assist with answering the following questions:

- How can the MAR Scheme most efficiently and effectively assist with achievement of the PC2 targets for spring-fed water bodies and shallow groundwater (annual median of 6.9 Nitrate-N mg/l by 2035 and improved flows with drainage capacity maintained)?
- How can the MAR Scheme most efficiently and effectively assist with achievement of the PC2 targets for the Hekeao / Hinds River (annual median 3.8 NNN mg/l by 2035)?
- How can the MAR Scheme most efficiently and effectively assist with drinking water supply bores meeting the drinking water standards for nitrate?
- What are the expected changes in groundwater storage and groundwater discharge from the MAR Scheme to surface waterways?

The initial model purpose is to assess the broadly expected relative changes in groundwater quality and quantity as a result of MAR at the currently consented sites, in combination with land use changes anticipated in response to PC2. The intent has not been to create a fully calibrated model at a fine detail for assessing changes in groundwater levels, surface water flows and concentrations. However, the model provides a platform that can be refined over time to achieve improved calibration at a finer scale, for example to allow for more localised assessments of MAR effects or further informing groundwater monitoring plans.

Land surface recharge to the model is based on drainage rates from OverseerFM models representing farms within the Hekeao / Hinds Plains. Drainage rates from OverseerFM were used in place of separately generated recharge time series, as this approach was consistent with previous assessment work undertaken by CRC to inform PC2 and also enables consistency with the use of nitrogen outputs from OverseerFM to assess groundwater quality changes in the model scenarios.[1] The OverseerFM files are based on Everest (2013) and represent drainage from a number of different landuse and soil combinations, between 2011 and 2012. All these landuses are assumed to be irrigated, which is true for the majority of the model area.

Additional recharge was added to the model to represent losses from the irrigation races in the Mayfield Hinds Scheme area (excluding the Valletta area which is piped) and the Ashburton Lyndhurst Scheme area (given areas to the north of the Ashburton River are included in the model). Additional recharge was added to cells underlying the Rangitata Diversion Race, which is reported to lose around 720 l/s along its 53 km length (based on information supplied by RDRML).

The major rivers were simulated using a separate stream package, with modelled flows added to the most upstream reach based on observed flows at respective recorder locations. Stream flows were then calibrated to observed losses (flow losses and absolute flows) from gauging runs (from Durney et al., 2014).

The first modelling objective was to calibrate the model by varying the hydraulic conductivity of the strata to match observed groundwater levels and flows. The mass balance for the modelled area (greater than the Hekeao / Hinds Plains) is summarised in Table 6-1.

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[1] Overseer was under review by the NZ Government at the time of reporting. The outcomes of this review will inform future use of Overseer results in computer modelling for this project.

Table 6-1: Mass balance summary (Steady state model)

Component	Inflow (m^3/s)	Inflow ($m^3/year$)	Outflow (m^3/s)	Outflow ($m^3/year$)
Stream leakage (including race losses)	17.13	540,154,375	4.42	139,525,630
Land surface recharge	49.37	1,556,819,170[1]		
Discharge to drains			3.75	118,391,765
Groundwater Abstraction			7.94[2]	250,540,745
Discharge across general head boundary			50.37	1,588,513,945
Total	66.49	2,096,973,545	66.49	2,096,972,085

Notes: 1. The total active model area is 2,944 km². Average modelled land surface recharge (including race losses) is ~528 mm/year.
2. based on 50% of the consented rate, as per Durney (2019).

The next step was to check modelled groundwater levels in each of the model layers with observed levels. Figure 6-2 indicates that modelled groundwater flow is predominantly from the north-west to south-east with limited inputs from the major rivers. The contours also show the effect of the high hydraulic conductivity inferred through model calibration in deeper strata in the area to the north-east of the Hakatere / Ashburton River, where the contours for layers 7, 8 and 9 are shifted to show a more easterly flow direction, although it is acknowledged that there is significant uncertainty in the inferred hydraulic conductivity values. The pattern of groundwater levels in the model is generally consistent with observed piezometric contours for the area.

A steady state groundwater transport model was then set up to simulate nitrate movement through groundwater and initial concentrations of nitrate provided to the model based on concentration estimates from OverseerFM, applied to the model via recharge. The concentrations represent leaching from farms across the model area based on landuse information from 2010. 2010 was used as the baseline, because under CRC's Land and Water Regional Plan, baseline leaching from farms is set as the average between 2009 and 2013.

The groundwater transport model was run for 25 years (from 2010 to 2035), with constant input concentrations through that time (assuming no land use change or recharge changes) and with the groundwater flow field based on the groundwater flow model described above. The results of this scenario indicate that modelled concentrations of nitrate in groundwater begin to approach steady state after 10 years. Therefore, concentrations at the end of this simulation provide a modelled baseline against which the effects of good management practice and MAR can be modelled.

A map showing the initial distribution of nitrate concentrations applied to the model is provided in Figure 6-3. It is important to note that the initial concentrations do not include legacy nitrate concentrations, as this information is not currently available at sufficient level of detail. Legacy concentrations are expected to be higher than modelled recharge concentrations in some areas and lower in others.

The lack of legacy nitrate concentrations seems to have the greatest impact on modelled concentrations inland from Tinwald, where the modelled concentrations are significantly less than observed concentrations. This issue is being addressed through further development of the model in this area, where the calculated OverseerFM recharge for affected properties are updated by replacing the default irrigation water nitrate concentration with a nitrate concentration based on available local monitoring. It is relevant to note that Stewart and Aitchison-Earl (2020) identifies groundwater irrigation return flow as a key cause of the high nitrate groundwater inland from Tinwald. In response to this study, HHWET have initiated a workstream to assist groundwater irrigators to incorporate irrigation water nutrients into their fertiliser budgets. This workstream will continue into Year 6.

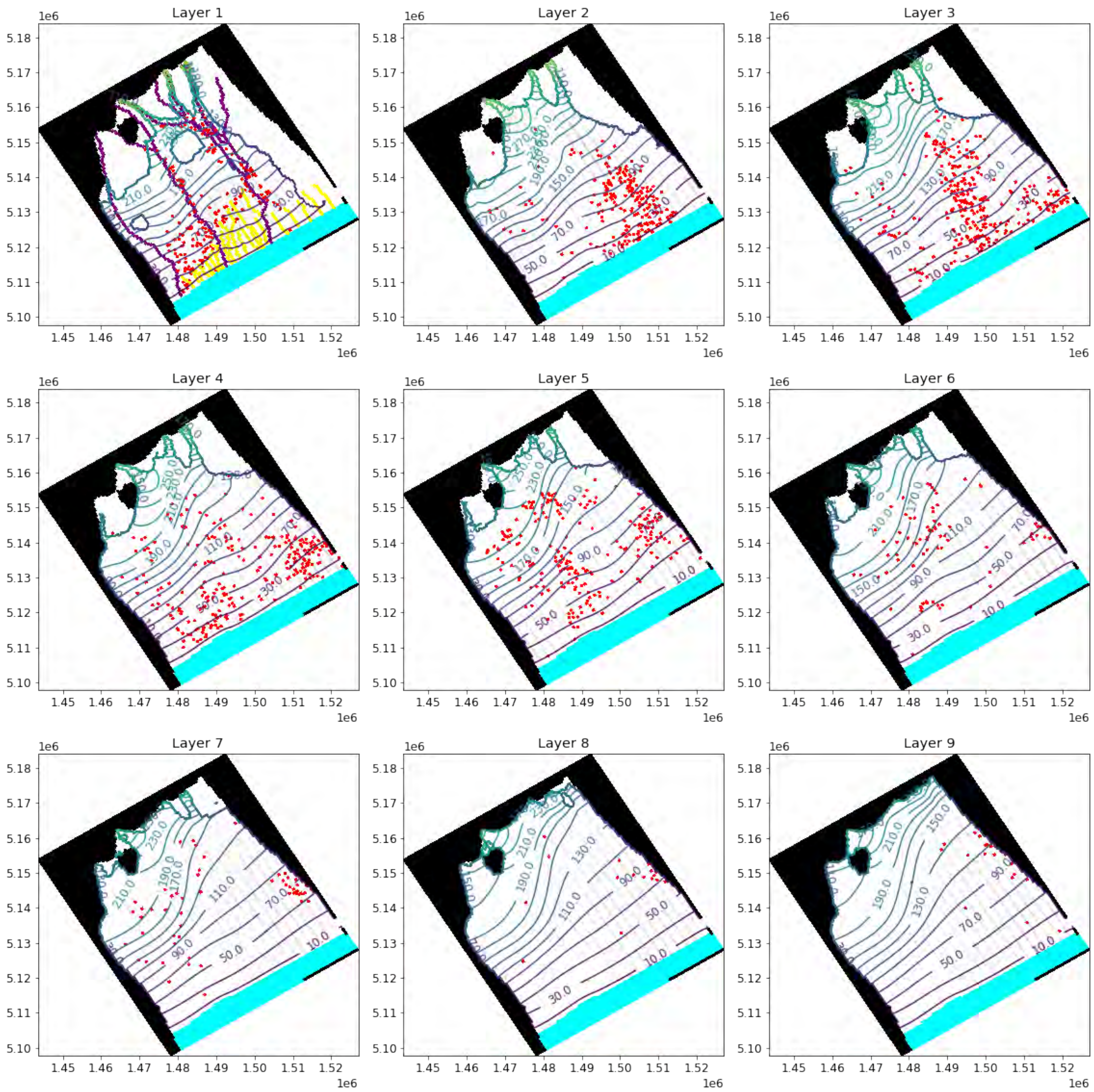

Figure 6-2: Modelled groundwater level contours (m above mean sea level) - red dots indicate the location of groundwater abstractions. (Source: PDP, 2021)

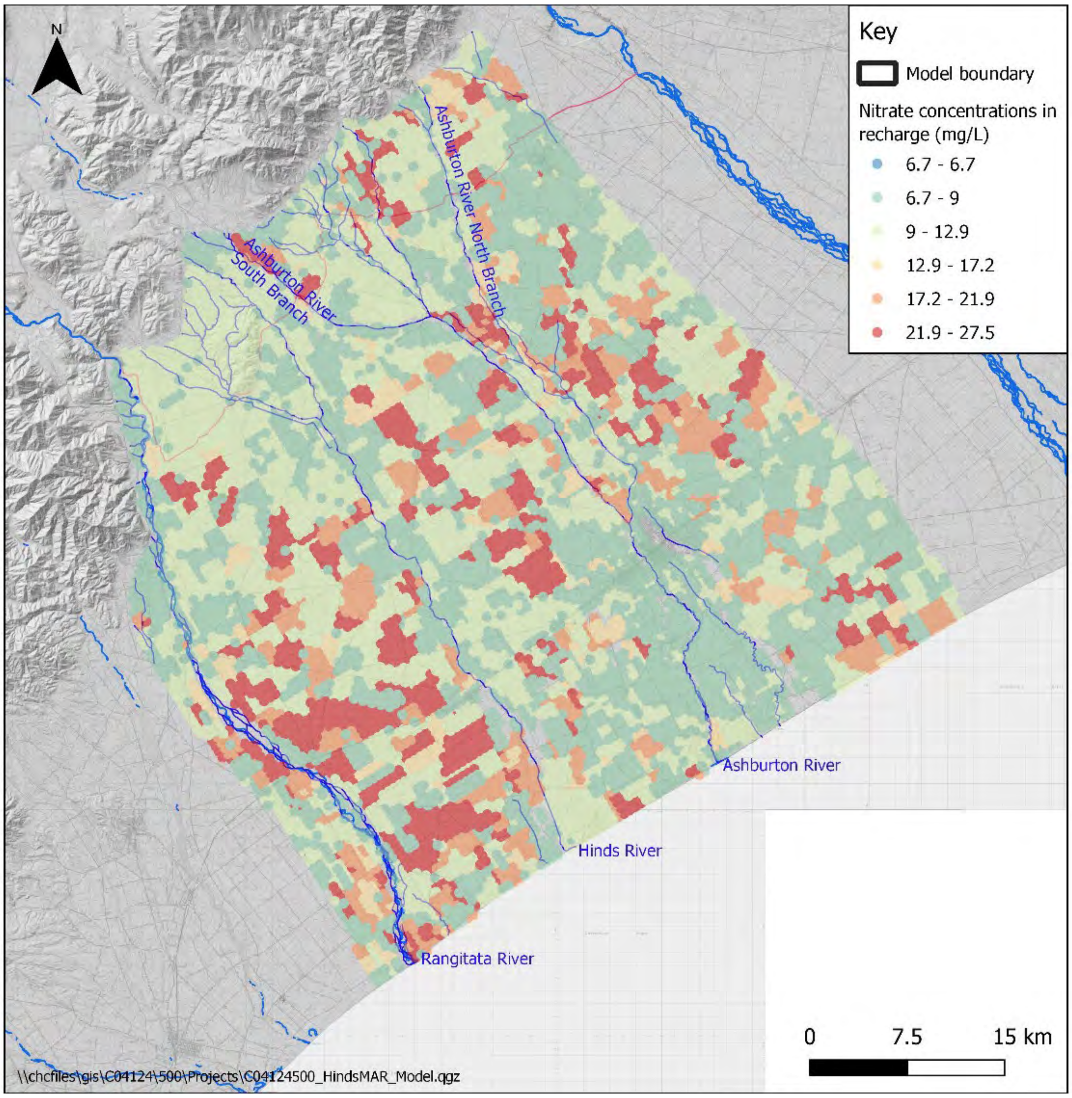

Figure 6-3: Initial modelled nitrate concentration distribution from Overseer records (Source: PDP, 2021)

In parallel with on-going model development, four model scenarios were developed:

- A **base model**, with inputs as described above, which represents the modelled 'existing' situation. This scenario runs for a total of 25 years, from 2010 to 2035.
- **Scenario 1**: A scenario allowing for managed aquifer recharge at the consented rates (125 million m³/year split evenly across 18 currently consented sites, or an average of 222 l/s per site). This scenario runs for a total of 15 years, from 2020 to 2035, and uses the final concentrations from the base model as starting concentrations.
- **Scenario 2**: A scenario assuming that nitrate leaching is reduced by 30%. This scenario runs for a total of 15 years, from 2020 to 2035, and uses the final concentrations from the base model as starting concentrations.
- **Scenario 3**: A scenario representing the combined effects of 30% reduced nitrate leaching and MAR. This scenario runs for of 15 years, from 2020 to 2035, and uses the final concentrations from the base model as starting concentrations.

The addition of MAR to the model has significant effects on modelled local groundwater levels around each MAR site, which translated ultimately into modelled downstream effects of varying magnitude on surface water flows. A summary of the effects of MAR on the overall model water balance is presented in Table 6-2. The key changes were increases in stream discharges, increases in drain discharges and some effects on discharge across the coastal boundary.

Table 6-2: Mass balance summary and comparison to baseline model (Scenario 1)

Component	**Inflow (calibrated model) (m³/year and (m³/s))**	**Inflow (including MAR) (m³/year and (m³/s))**	**Outflow (calibrated model) (m³/year and (m³/s))**	**Outflow (including MAR) (m³/year and (m³/s))**
Stream leakage	540,154,375 (17.1)	500,971,990 (15.9)	139,525,630 (4.4)	189,690,135 (6)
Land surface recharge	1,556,819,170 (49.4)	1,681,818,895 (53.3)		
Discharge to drains			118,391,765 (3.8)	129,654,205 (4.1)
Groundwater Abstraction			250,540,745 (7.9)	250,587,100 (7.9)
Discharge across coastal boundary			1,588,513,945 (50.4)	1,612,857,255 (51.1)
Total	2,096,973,545 (66.5)	2,182,791,250 (69.2)	2,096,972,085 (66.5)	2,182,789,425 (69.2)

Figure 6-4 shows the simulated effects of MAR on stream flows in the model. The greatest modelled effects were on the lower Hakatere / Ashburton River, close to the confluence of the north and south branch and downstream of the confluence, where increases in streamflow were estimated to be in the order of 1,500 l/s. Likewise, increases in flows in the Hekeao / Hinds River around and downstream of State Highway 1 were also simulated, with increases of over 1,500 l/s. Some modest increases in drain flows were also simulated, totalling approximately 500 l/s across the drains.

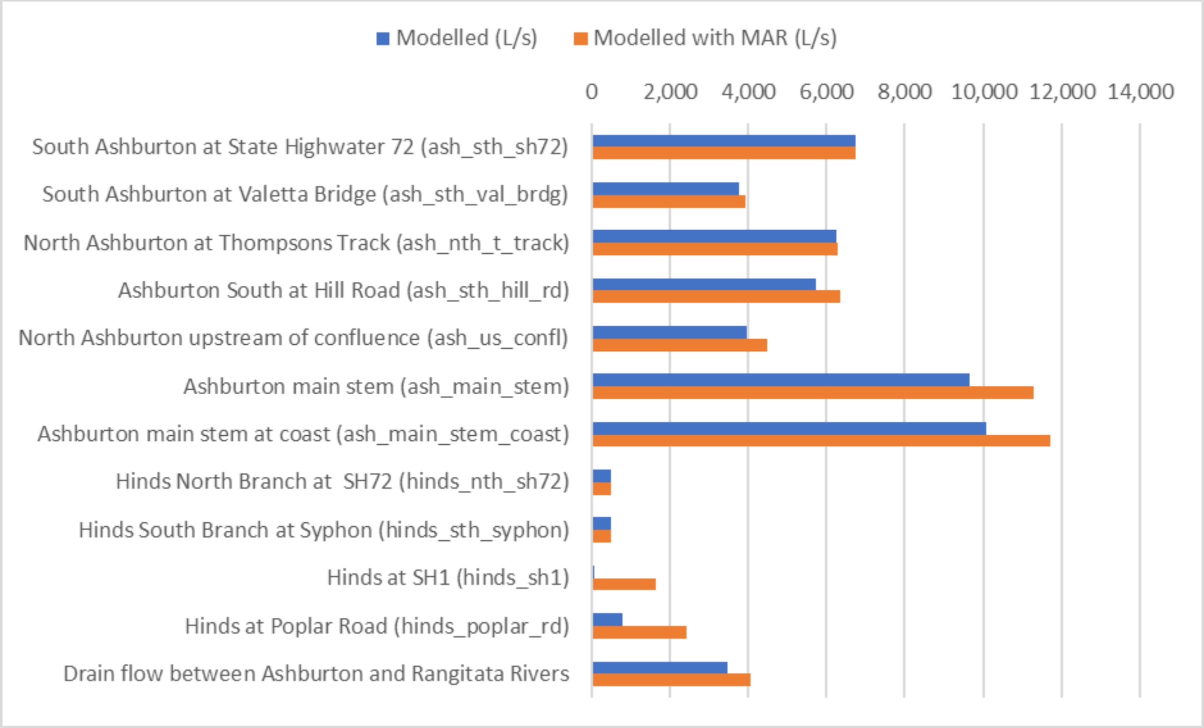

Figure 6-4: Effects of MAR on stream flows (Source: PDP, 2021)

Figure 6-5 provides plots of the modelled impacts of MAR on groundwater nitrate-N concentrations. These impacts are clearly visible in the lower right-hand plot, which shows the difference in concentration between the baseline scenario and the MAR scenario in 2035 (i.e., after 25 years of simulated discharge to the groundwater system). The MAR system is simulated as 'turning on' in 2020 and the impacts represent the effect of 15 years of MAR.

In the local area around each MAR site, significant water quality impacts of MAR are observed. However, the effect of different horizontal hydraulic conductivities in the model are apparent. In particular, higher interpreted horizontal hydraulic conductivities between the Hekeao / Hinds and Hakatere / Ashburton River than south of the Hekeao / Hinds River means that the water quality benefits of MAR water are apparently more widespread in that area in this particular model, with the 'plume' of lower concentrations extending some distance downgradient. In contrast, the modelled lower hydraulic conductivities in the area between the Hekeao / Hinds and Rangitata Rivers (i.e., the Mayfield Hinds area) result in more localised effects, although in time, these effects will become more widespread. However, as noted above, the 'baseline' concentrations are different to those being observed, including the patterns of concentrations across the study area. This means the patterns of predicted changes in effects should also be viewed with caution. There is also significant uncertainty in the true hydraulic conductivity distribution and a number of other model limitations, so these plots should be viewed as providing only an indication of the changes in effects that may occur.

Despite these limitations, at a broad scale, the modelling indicates that there is the potential for significant MAR effects on water quality to be quite localised, even in the model scenarios where MAR was modelled to occur at each site over a large 1 km^2 area (much larger than reality). After 15 years of recharge, the model indicates that a significant proportion of down-gradient areas will experience only minimal improvements with MAR. This is consistent with the conclusions of Durney (2019) where model areas overlap.

Figure 6-6 provides plots of the modelled impacts on groundwater nitrate-N concentrations of a 30% reduction in nitrate leaching across the whole model area (Scenario 2). In general, the results of the simulation indicate that modelled concentrations in 2035 would be similar to, or slightly lower than, the concentrations modelled in 2020. This indicates that a 30% reduction in nitrate leaching across the whole model area is expected to have an observable impact on concentrations across the wider area, although the expected magnitude of change varies with location and is modest in many areas.

The final model scenario combines the effects of MAR and a 30% reduction in nitrate leaching into a single run to evaluate the effects of both mitigation approaches simultaneously. Plots of the results from Scenario 3, showing the differences in modelled concentrations of nitrate in groundwater, are shown in Figure 6-7 for the uppermost active model layer. Significant modelled impacts (i.e., reductions in modelled concentrations) are apparent in the plains area between the Hekeao / Hinds River and the Hakatere / Ashburton River, where nitrate concentrations are modelled to reduce by a reasonable degree compared to the baseline scenario. Significant modelled impacts also occur in the plains area between the Hekeao / Hinds and Rangitata Rivers, although elevated concentrations remain in some areas.

At a broad scale, Figure 6-7 indicates that the combination of MAR and 30% nitrate leaching reduction is expected to result in measurable improvements in shallow groundwater, although the improvements specifically due to MAR may be more localised. It is important to reiterate that these plots are for comparative purposes rather than forecasted actual nitrate-N concentrations. This is because legacy nitrate concentrations are not included (as suitable data does not currently exist) and there is also uncertainty over other model parameters, such as the distribution of hydraulic conductivity across the modelled area.

To conclude the current stage of modelling, the issue of OverseerFM's treatment of nitrate in irrigation water (for pasture with clover) is being further investigated. The model is also being run with four different discharge rates at the Lagmhor site (MAR 01) to see the modelled effects of MAR sites discharging less than 200 l/s. Once additional monitoring and MAR site (location and recharge) information is available, further cumulative effects model scenarios will be run.

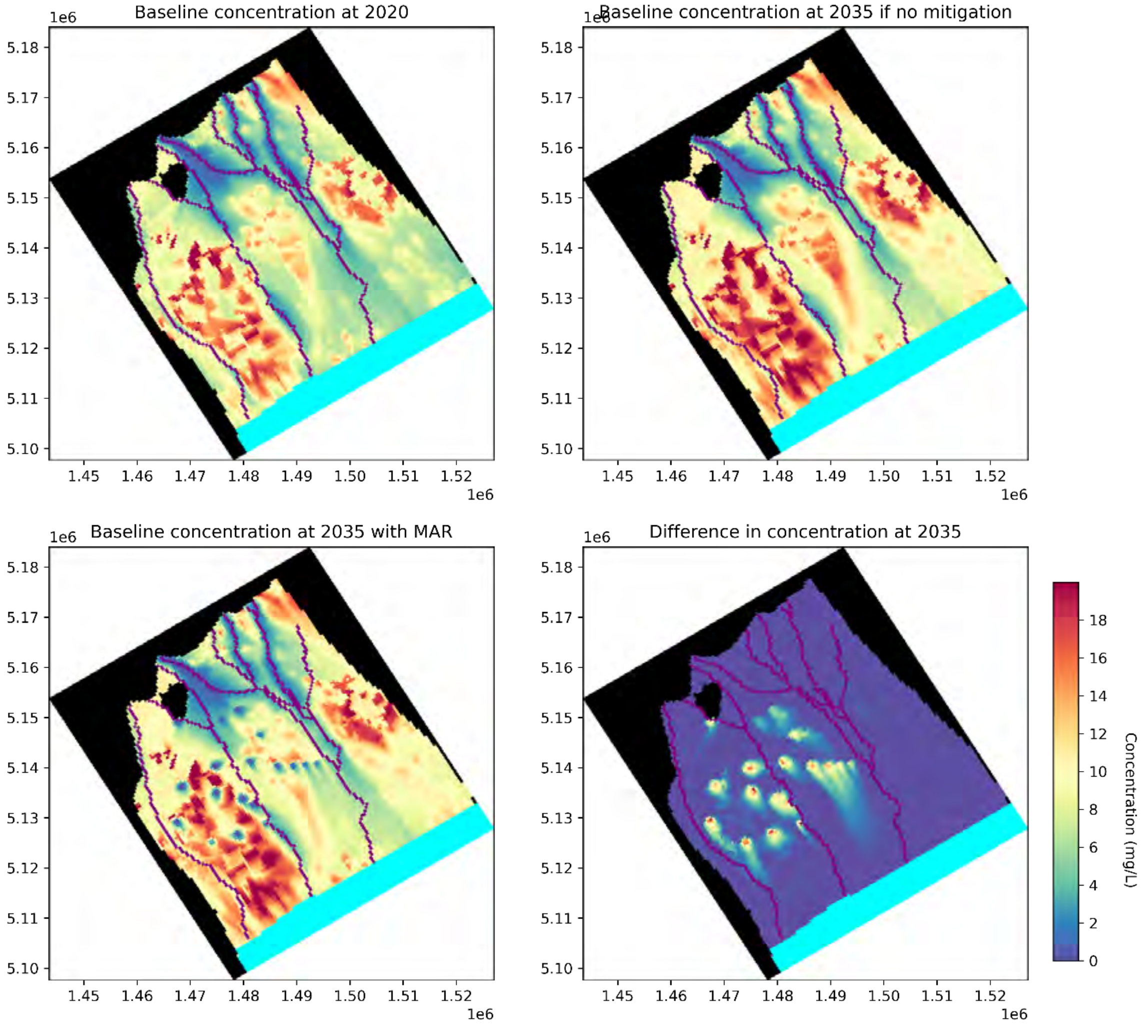

Figure 6-5: Effects of MAR on concentrations (mg/L). Concentration shown represents uppermost active model layer (Source: PDP, 2021)

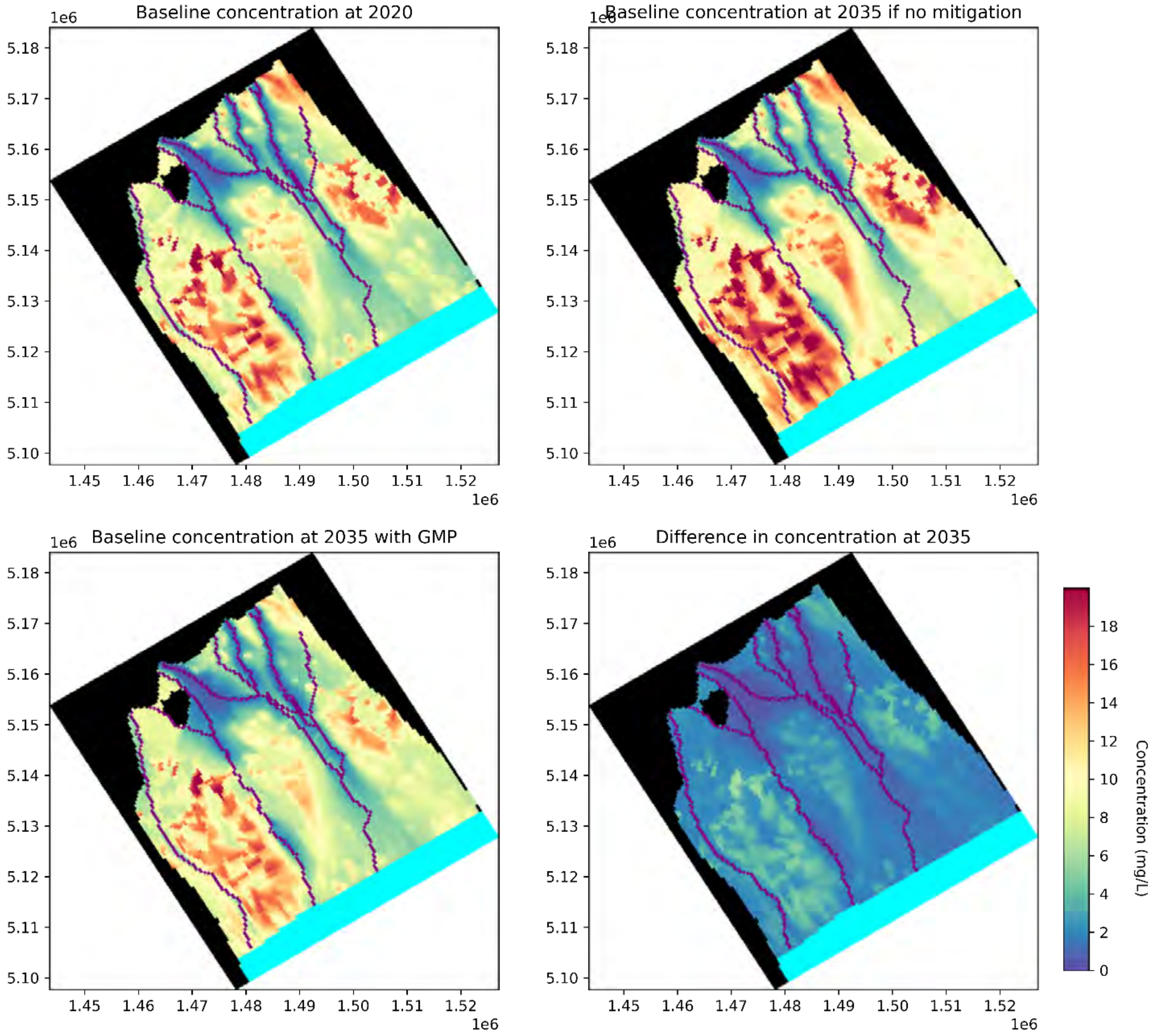

Figure 6-6: Modelled concentrations of nitrate in groundwater in uppermost active model layer under the 30% nitrate leaching reduction scenario (Scenario 2). (Source: PDP, 2021)

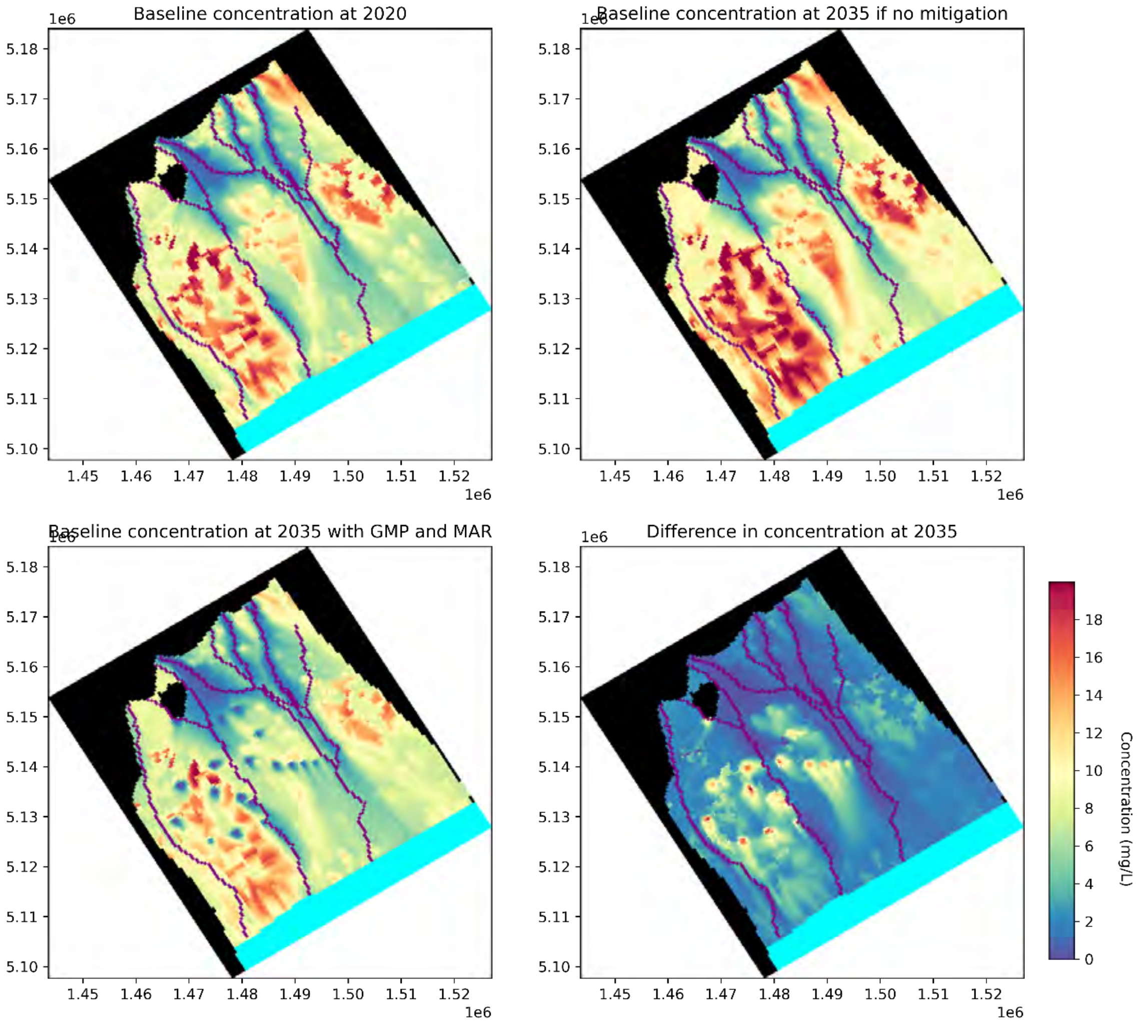

Figure 6-7: Modelled concentrations of nitrate in groundwater in uppermost active model layer under the MAR plus 30% nitrate leaching reduction scenario (Scenario 3). (Source: PDP, 2021)

7 Next Steps

Year 5 highlights include a significantly increased total MAR volume, promising monitoring results, the trialling of new MAR concepts and enhancements, improved monitoring coverage, and a new computer model for catchments scale analyses. However, current MAR supply flow of less than 500 l/s is well short of the 2020 Ashburton ZIP / ZIPA target of 2000 l/s. This makes the 2035 PC2 groundwater nitrate-N targets harder to reach, given reported groundwater lag times (e.g., Aitchison-Earl, 2019) across the catchment. The last few days of Year 5 also delivered high rainfall and significant flooding across the catchment, which will affect Year 6 priorities and monitoring results. Next steps therefore include:

- Remedial repairs, resilience improvements and Kōwaro (Canterbury mudfish) habitat enhancements at the South Hinds NRR1 site.
- Monitoring and assessment of ground and surface water responses to the May 2021 high rainfall event.
- Continuation of high monitoring coverage.
- Further development of the computer model to improve its accuracy.
- Computer model scenarios of the cumulative effects of current and proposed MAR sites.
- Advancement of MAR use and discharge consent processes.
- New site construction and testing, following the granting of relevant consents (including a new Mahinga Kai / NRR site at Winslow / Fountaines Rd).
- Advancement of water supply and conveyance agreements.
- Advancement of MAR site access agreements.
- Completion of the TSA trial / business case and consideration of further sites.
- Continuing the workstream to assist groundwater irrigators to incorporate irrigation water nutrients into their fertiliser budgets.

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