WGA

WALLBRIDGE GILBERT AZTEC

Hinds/Hekeao MAR Governance Group

Hinds/Hekeao Managed Aquifer Recharge Trial - Year 2 Final Report

RESULTS REPORT

Job No. 171076 / Rev D
30 August 2018

Revision History

Rev	Date	Issue	Originator	Checker	Approver
A	13/7/2018	Tech Lead review	Houlbrooke / Sinclair	Bower	Bower
B	10/8/2018	Full Year 2 report draft	Houlbrooke/ Dench	Bower/ Sinclair	Bower
C	17/08/2018	Draft to MAR GG	Houlbrooke	Sinclair	Bower
D	30/08/2018	Final	Houlbrooke	Bower	Bower

CONTENTS

Figures

Tables

Appendices

Appendices are provided in a separate compendium.

EXECUTIVE SUMMARY

Year 2 of the Hinds/Hekeao Managed Aquifer Recharge Trial involved several sub-projects including:

- Continuation of the Lagmhor Trial
- Investigation and consenting of an upgrade to the Lagmhor Trial site
- Consenting and testing of sixteen new soakage sites
- Consenting and construction of a river recharge project (Hekeao/Hinds River Project),
- Plans for enhancing the Hekeao/Hinds Plains baseline water quality understanding.

During Year 2, approximately 1,854,000 m^3 was recharged through the Lagmhor Trial site (10 June 2017 to 31 May 2018). This volume compares to 2,442,000 m^3 recharged during Year 1. Operations were disrupted more by rainfall and irrigation requirements during Year 2 than during Year 1. Flow rates to the site varied during Year 2, peaking at about 95 L/s. Of this total flow, approximately 22 L/s was infiltrated to groundwater through the base of the delivery race.

Total infiltration rates at the Lagmhor Trial site varied significantly during Year 2. Forebay infiltration has decreased substantially due to clogging by accumulated sediment. An assessment of water level responses following site shutdowns suggests that infiltration rates in the main basin may be influenced by depth of water in the basin, antecedent rainfall and depth to underlying groundwater.

The clean water plume generated by the Lagmhor Trial continued to propagate toward the south east, advancing at a rate of approximately 11 m/day. The plume is considered to have migrated a total distance of seven kilometres from the trial site and appears to be spreading out at the southern end. Water quality in the receiving groundwater beneath the trial site continues to be good. *E. coli* was not detected in the clean water plume during Year 2. Nitrate concentrations in the clean water plume remained low, even with the increased leaching of nitrates from the topsoil during the very wet periods of Year 2. Water quality responses in shallow groundwater and springs within the upper catchment of Flemington Drain may start to appear during Year 3 of the trial.

Geophysical information was used to support the design of a site upgrade at the Lagmhor Trial site to direct source water past interpreted restricting layers and increase the overall site recharge efficiency. The upgrade to the site will progress in August 2018 and the effectiveness of the upgrade will be assessed in Year 3.

To date (August 2018) six new MAR sites have been tested with a total of 352,388 m^3 of groundwater recharged. The combined Year 2 recharge volume for the Hinds/Hekeao Plains is approximately 2,206,000 m^3, including the Lagmhor Trial. The results show that the new MAR test sites can typically receive long-term flow rates between 15 L/s and 30 L/s. High groundwater levels due to rainfall events in the recharge period restricted flow rates at some sites during the initial test periods.

Through community consultation, the Hekeao/Hinds River Project has developed a range of beneficial outcomes for stakeholders whilst working toward achieving the targets for environmental restoration, reversing declining trends in groundwater levels, and improving groundwater quality in the catchment. A resource consent application was lodged in June 2018 and the consent process is still underway. The project will continue with construction and monitoring in Year 3.

To improve the understanding of baseline water quality, a community-based water quality snapshot is planned. An updated map of baseline water quality is recommended to support a Groundwater Replenishment Scheme.

1 INTRODUCTION

1.1 BACKGROUND

Zone committees have been set up under the Canterbury Water Management Strategy (CWMS) to find solutions to community water issues within the Canterbury Region through collaboration and consultation processes. The Ashburton Zone Committee (AZC, 2011) has released a Zone Implementation Plan (ZIP) and a Zone Implementation Plan Addendum (ZIPA) (AZC, 2014), which include water management objectives agreed by the community.

Managed Aquifer Recharge (MAR) implemented at the catchment-scale was incorporated into a Solutions Package (Bower, 2014) as a tool to help the community achieve the agreed objectives. The Solutions Package provided for groundwater augmentation as one of the catchment management measures proposed (Table 1).

Table 1: Primary changes required to achieve AZC water quantity and quality outcomes for the Hinds/Hekeao Plains (Golder 2017).

Quantity	Quality
Cap all groundwater allocations.	Reduce on-farm nitrogen losses by up to 36% by 2035.
Review all existing consents with actual usage information (National Metering Rules).	Reduce average annual groundwater concentrations of nitrate-nitrogen to a target of <6.9 g/m^3 by 2035.
Allow surface water users to transfer to groundwater, to help protect restored baseflows in spring-fed waterbodies (drains).	Individual Farm Environment Plans (FEPs) required.
Implement a MAR pilot trial project for proof of concept testing – increasing storage and baseflows.	Implement a MAR pilot trial project for proof of concept testing – clean water addition.

A five-year MAR trial was designed and initiated at a site near Lagmhor, within the Valetta Groundwater Allocation Zone. The location for the Lagmhor MAR Trial (Lagmhor Trial) was chosen, among other reasons, because groundwater conditions in this area are characterised by:

- Degraded quality relative to environmental and drinking water values.
- Over-allocation of groundwater for abstraction.
- Declining incidental recharge due to improving irrigation efficiency, piping of irrigation water delivery systems and decommissioning of the district stockwater race systems.

- Declining groundwater levels (storage), leading to reductions in baseflows in spring-fed waterbodies, formerly perennial stream flows becoming transient and consequent negative effects on habitat and cultural values.

Year 1 operations of the Lagmhor Trial started on 10 June 2016 and continued through until 9 June 2017 (Golder 2017). The results from the Year 1 operations were deemed to have successfully demonstrated the validity of the concept of using MAR to help the local community achieve the agreed outcomes.

The first year of the trial was guided by the Hinds MAR Pilot Working Group. After the successful completion of Year 1 operations a new steering committee, the Hinds/Hekeao MAR Governance Group (MAR GG), was formed.

Membership of the MAR GG was expanded to include stakeholder representation from business and community interests from the town of Ashburton and the Mātaitai Committee at Te Rūnanga o Arowhenua.

Year 2 of the trial built upon the results from Year 1 and sought to explore the application of MAR techniques across the catchment, and the formation of a catchment wide Groundwater Replenishment Scheme (GRS). Primary activities in Year 2 of the trial were:

- Ongoing operations at the Lagmhor Trial site, including the design of site upgrades to improve recharge performance and quantifying the extent of the clean water plume resulting from the recharge.
- Identification and testing of additional MAR sites and techniques across the Hinds/Hekeao Plains.
- Sourcing of water, land and resources to support on-going trial operations.
- Development of a business case to support the development of a catchment wide GRS.
- Continuation of the public and stakeholder outreach and education campaign.

Figure 1 provides a map of the Hinds/Hekeao area identifying the location of the above sites and work stream areas.

1.2 DOCUMENT STRUCTURE

This report documents the Hinds/Hekeao MAR field programme and analysis of the results from several associated technical work streams. These work streams are:

- Lagmhor Trial – Year 2 (Chapter 1 - Report Sections 3 and 4)
  - This chapter relates to tasks 1.2, 2.1, 2.2, 2.6, and 2.7 as per Ministry for Primary Industries (MPI) funding agreement.
- Lagmhor Trial Site Upgrade (including Geophysics) (Chapter 2 - Report Section 5)
  - This chapter relates to task 2.5 as per MPI funding agreement.
- New MAR Test Sites (Chapter 3 - Report Section 6)
  - This chapter relates to tasks 4.1 and 4.3 as per MPI funding agreement.
- Hekeao/Hinds River Project (Near River Recharge) (Chapter 4 - Report Section 7)
  - This chapter relates to tasks 5.2, 5.3 and 5.4 as per MPI funding agreement.
- Hekeao/Hinds Plains Baseline Water Quality
  - This chapter relates to task 4.1 as per MPI funding agreement (Chapter 5 – Report Section 8)

The document meets the reporting requirements set out under the Irrigation Acceleration Funding (IAF) agreement provided by MPI and supporting contributions from Environment Canterbury (ECan).

Summary sections covering discussion material and conclusions for these work streams are presented in Sections 8 and 9 of this report.

The various work streams for the Year 2 programme are staggered relative to their timing of development and implementation. This document provides a summary of results from all programmes up to the end of the Year 2 testing (31 May 2018).

1.3 APPENDIX COMPENDIUM

To keep this document short and focused on reporting results, additional data and analyses are documented in a separate Hinds/Hekeao MAR Year 2 Appendix Compendium. Guidance on the information contained in each of the appendices in the compendium is provided below.

- Appendix A presents the conditions attached to the consents authorising the Lagmhor Trial and documents compliance with the conditions during Year 2.
- Appendix B presents plots of groundwater level data from the Lagmhor Trial and analysis of the response to rainfall recharge.
- Appendix C presents plots of groundwater quality within the Lagmhor Trial command area.
- Appendix D presents basin clogging calculations.
- Appendix E presents WGA memos regarding the Lagmhor Trial upgrade.
- Appendix F presents the consent for the new MAR test sites and a compliance report. In addition plots and photographs of the new MAR test sites are provided.

Document Path: K:\JOBS\2017\171001 - 171100\171076 - Hinds MAR Stage 2\05 Sketches\ArcGIS\Projects\Lagmhor\171076_Fig_1_Location Map.mxd

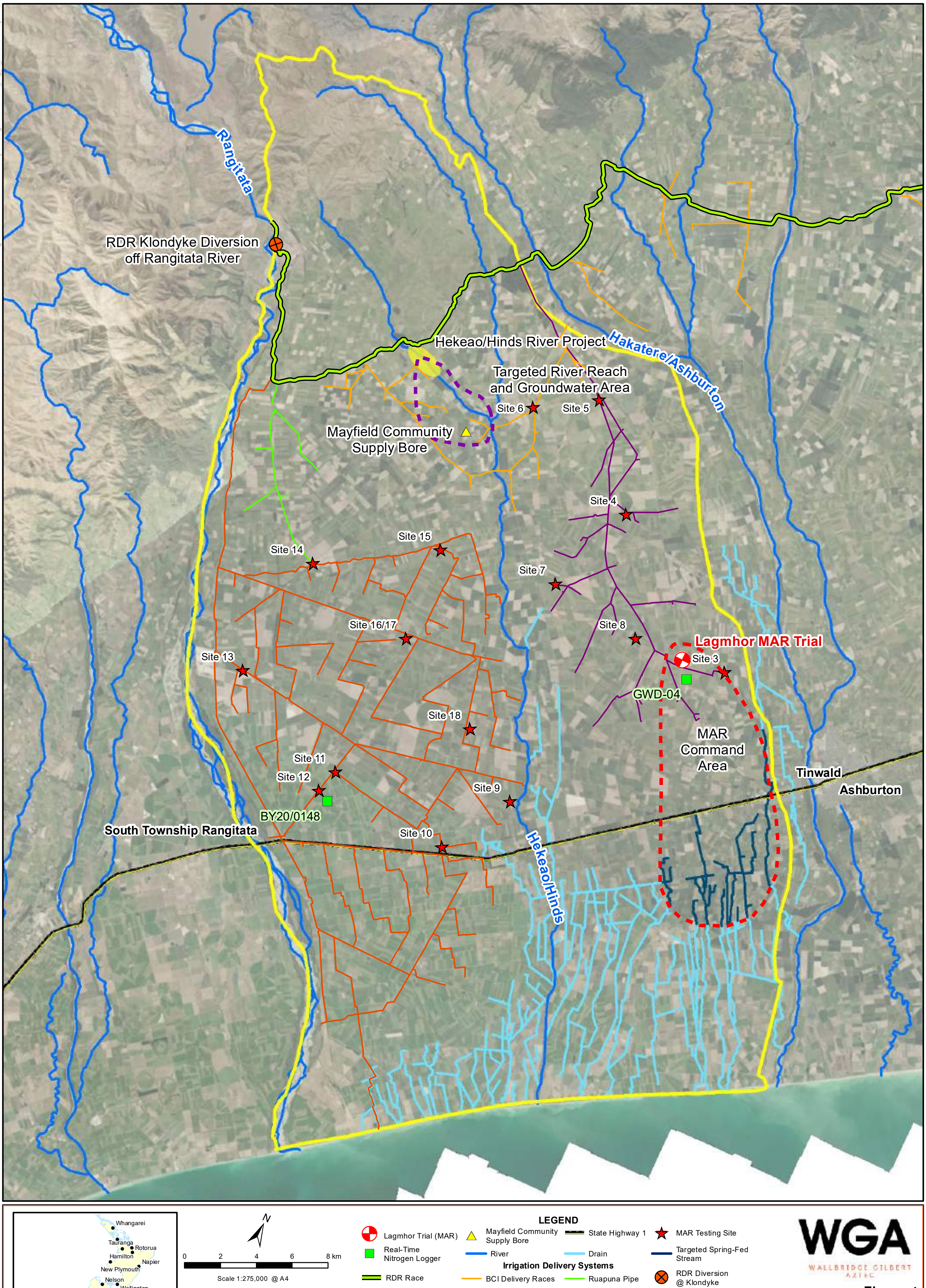


Figure 1
Hinds/Hekeao MAR Trial
Year 2 Catchment-scale
project map

2 LAGMHOR TRIAL SITE MONITORING PROGRAMME

2.1 INTRODUCTION

The following monitoring programme was designed to comply with regulatory monitoring requirements set out in the consents and to meet foreseeable operational and environmental monitoring requirements at the Lagmhor Trial site. The operational and environmental monitoring programme encompasses surface water, groundwater and rainfall monitoring sites designed to cover the area surrounding and down-gradient from the trial site. Monitoring covers:

- *MAR Site* – providing specific information for source and receiving water quality and quantity and to help manage project operations in real time with automation, internet and mobile communications (**Figure 1**).
- *MAR Footprint* – the specific area where MAR operations directly influence water levels and/or quality. This area continues to expand over time provided operations at the site remain ongoing.
- *MAR Command Area* – the area of the Hinds/Hekeao Plains which encompasses the key targets of the Lagmhor Trial site, including the Tinwald-area nitrate-N hotspot, coastal spring-fed waterbodies and the depleted groundwater resources of the Valetta Groundwater Allocation Zone. It was not expected that the MAR project would show results in this entire area, and this term is used here to simply describe the sub-catchment of the Hinds/Hekeao directly relevant to the trial and the background water quality and quantity conditions (**Figure 1**).

2.2 LAGMHOR TRIAL OBJECTIVES

2.2.1 Overall Objectives

The key outcome sought for the five-year Lagmhor Trial is to demonstrate the ‘proof of concept’ of MAR to help achieve the overall catchment outcomes for quantity and quality (Golder 2015). To achieve this outcome, three primary objectives have been defined for the five-year period of the Lagmhor Trial:

- Increase groundwater levels and overall groundwater storage near the Lagmhor Trial site.
- Decrease concentrations of nitrate-N in groundwater near the site.
- Increase baseflows and improve water quality in the down-gradient coastal spring-fed waterbodies (drains).

The Lagmhor Trial site has been operational for more than two years, with the outcomes from the trial to date being evaluated based on data derived from an extensive monitoring site network. The initial network design was based on desktop assessment of the effects of the trial on the surrounding groundwater system.

At the end of Year 1, analysis of data derived from the monitoring programme provided more certainty regarding the extent and magnitude of the effects of the Lagmhor Trial (Golder 2017). The Lagmhor

Trial monitoring programme for Year 2 was optimised based on an understanding of the effects detected during Year 1.

2.2.2 Year 2 Objectives

Based on discussions between the MAR GG, Environment Canterbury and Wallbridge Gilbert Aztec (WGA), the following monitoring objectives have been taken into account in the Lagmhor Trial Year 2 programme:

- On-site monitoring of water levels, flows and quality for operational site management and consent compliance purposes.
- Monitoring of groundwater levels and quality for consent compliance purposes, to enable assessment of the effectiveness of the trial and to support the design of site upgrades to improve overall system performance.
- Monitoring of surface water flows, quality and ecology in the coastal drains for consent compliance purposes and to enable identification and evaluation of the effects of the trial on these drainage systems.
- Monitoring of catchment rainfall and other hydrologic influences for operational site management and consent compliance purposes and to enable the effects of the Lagmhor Trial to be differentiated from natural changes in the groundwater and surface water systems.

2.2.3 Consents and Consent Conditions

The construction and operations of the Lagmhor Trial have been authorised under consents issued by Environment Canterbury and ADC (**Table 2**). The Lagmhor Trial operated throughout Year 2 in compliance with the conditions attached to these consents. Note that the consent to discharge water to land (CRC162191) was superseded near the end of Year 2 operations (May 2018) by CRC164192, with some minor changes to the rainfall/flow trigger condition and supporting monitoring programme schedules. The conditions relevant to each of the consents listed in **Table 2** are documented in Appendix A. A summary of the record of compliance with the key consent conditions is also provided in Appendix A.

Table 2: Resource consents for components of the Hinds/Hekeao MAR Trial Programme.

Consent number	Consenting authority	Activity	Commencement date	Expiry date
CRC162191 (1)	ECan	To discharge water into land	25 Feb 2016	25 Feb 2021
CRC162192	ECan	To excavate land	25 Feb 2016	25 Feb 2021
CRC164281	ECan	To take and use surface water	25 Feb 2016	25 Feb 2021
CRC183882 (2)	ECan	To discharge water to water	17 Apr 2018	25 Feb 2021
LUC15/0110 (3)	ADC	To excavate land	2 Feb 2016	2 Feb 2021
CRC184617 (4)	ECan	To discharge water into land	18 May 2018	25 Feb 2021

Notes: 1) Lagmhor Trial consent superseded by changed conditions attached to CRC184617.
2) Lagmhor Trial upgrade consent has been granted; construction will commence in August 2018.
3) Consented activity completed at the start of Lagmhor Trial Year 1.
4) Lagmhor Trial consent with changed conditions superseding CRC162191.

2.3 LAGMHOR TRIAL SET-UP

The Lagmhor Trial is consented to recharge up to 500 L/s of unutilised ADC stockwater, sourced from the Rangitata River and delivered (through the Rangitata Diversion Race (RDR) and Valetta portion of the Mayfield Hinds Valetta (MHV) Scheme) to the corner of Frasers Road and Timaru Track (**Figure**

2). One of the Lagmhor Trial consents authorises water for recharge (source water) to be diverted by Rangitata Diversion Race Management Ltd (RDRML) at their Klondyke diversion. This take is managed in conjunction with ADC's existing stockwater take consent for the Cracroft diversion on the Rangitata River. A memorandum of understanding (MOU) on the project between ADC, RDRML and Valetta (now Mayfield-Hinds Valetta Water Ltd – MHV Water) was set up to ensure that the source water could be delivered for the trial. Due to delivery capacity (pipeline) limitations during the peak irrigation season, source water is delivered to the Lagmhor trial site only when all consented (and requested) irrigation water has already been supplied. The Valetta side of the MHV Water scheme has three in-line ponds where water is often stored for interim delivery periods.

Source water leaves the Valetta system from Valetta Pond #3 and enters the Lagmhor Trial site at Flume 1 (**Figure 2**). Flow rates, stages and water quality information is collected at Flume 1 as the water flows past and down a 900 m long open race to Flume 2 (**Figure 2** and **Figure 3**). A bypass gate allows water to be diverted (if required) to two adjacent farm storage ponds during trial start-up periods if initial sediment loads would present a clogging risk to the infiltration basin (**Figure 3**). Flow rates are collected at Flume 2 as water enters the Lagmhor Trial forebay. The forebay is designed primarily to facilitate the settling of suspended sediments in the source water prior to the source water spilling into the main infiltration basin (**Figure 3**). Some infiltration also occurs through the base of the forebay.

In the context of quantifying the water quality relationship between surface water recharged at the trial site and the groundwater directly affected by this recharged water, the terms *source water* and *receiving water* are used respectively. *Source water* quality samples are obtained from the RDR and from water entering the site at Flume 1.

Monitoring Well GWD-01, located adjacent to the forebay (**Figure 3**), is used to monitor receiving groundwater level and quality changes at the regional aquifer level beneath the site. Monitoring Well GWE-01, located approximately 45 m southwest from the main infiltration basin, is used to monitor groundwater level and quality changes at the level of a perched aquifer beneath the site.

2.4 CLIMATE MONITORING

Resource consent conditions require operations at the site to shut down under specified rainfall conditions. Climate monitoring is therefore an integral component of site operations. Data from three climate monitoring stations (**Table 3**) are utilised to support trial outcomes.

1. The Hinds Plains climate station at Willowby was installed specifically for the purposes of the MAR trial and therefore only provides a rainfall record for the past two years.
2. A longer-term rainfall record is obtained for comparison purposes from the Ashburton Council climate station operated by the National Institute for Water and Atmospheric Research (NIWA) (Table 3).
3. Potential evapotranspiration (PET) data is obtained from the Ashburton Aero climate station also operated by NIWA.

Figure 2
Hinds MAR Stage 2
Lagmhor MAR Trial Source Water Diversion & Delivery System

Figure 3: Lagmhor Trial site overview (from Golder 2017).

Table 3. Climate monitoring site summary.

Climate station ID	Status	Parameters measured
Ashburton District Council (NIWA #4778)	Pre-existing. Data available up to May 2018.	Rainfall, temperature
Ashburton Aero AWS (NIWA #26170)	Pre-existing.	Rainfall, temperature, potential evapotranspiration (PET)
Hinds Plains (Willowby) (ECan #319610)	Installed for Lagmhor Trial monitoring. Record length limited to two years.	Rainfall, temperature

2.5 SOURCE WATER MONITORING

Water diverted from the Rangitata River for the purposes of the Lagmhor Trial is measured by RDRML at their Klondyke Diversion and at the Valetta irrigation scheme offtake. Automated water level data from RDRML and ADC are used to ensure that the Lagmhor Trial operations are within the 500 L/s allotted for project operations.

Automated water level and flow monitoring has been undertaken throughout Years 1 and 2 of the Lagmhor Trial at two sites in the delivery race (Flume 1 and Flume 2) from the Valetta #3 pond (**Figure 2**, **Figure 3**). Water flows and cumulative volumes delivered to the Lagmhor Trial site are assessed on data from the above monitoring points and compared against water delivery records provided by MHV Water Ltd.

In addition to flow monitoring, water levels and temperature are monitored automatically in the main Lagmhor infiltration basin. This data is utilised to evaluate infiltration efficiency and infiltration rates. Each monitoring site is linked to a telemetry system and the real-time data is continuously available for download via the Lagmhor Trial web site operated by Scottech.

Source water quality has been monitored monthly during Year 2 of the trial. Samples have been obtained from Flume 1, for laboratory analysis. Additionally, data on water quality has been collected from several RDR locations along the delivery line and off-takes. The samples collected from Flume 1 have been analysed for *E. coli,* and samples along the delivery line have been tested for ammonia, dissolved reactive phosphorus, nitrate-N, nitrite-N, total coliforms, total kjeldahl nitrogen and total nitrogen.

2.6 GROUNDWATER MONITORING

Based on the results from the Year 1 trials the groundwater monitoring programme was optimised with some sites being removed and new sites added. Monitoring wells hydraulically down-gradient from the site were added to the programme to help capture the clean water plume effects during Year 2 operations. Monitoring at other wells was discontinued or the suite of monitoring parameters reduced to match the available budget and focus on capturing the clean water plume interface. The number of wells monitored specifically during Year 2 of the trial was reduced from 24 wells to 16 wells.

2.6.1 Groundwater Levels

Automated groundwater level and temperature monitoring for Year 2 of the Lagmhor Trial (**Table 5**, **Figure 4**) has been undertaken at seven dedicated monitoring wells (GWD-01 to GWD-07) and one long-term environmental monitoring well (GWE-01).

Groundwater levels are recorded automatically at 15-minute intervals. Data downloads of levels and manual measurements at the monitoring wells have been undertaken quarterly, except for GWD-01. The data from GWD-01 is accessible on-line through the Lagmhor Trial web site, supported by quarterly manual groundwater level measurements. The data is presented in Appendix B in the Appendix Compendium.

Automated groundwater level monitoring systems (previously installed in selected surrounding private wells during Year 1 to track groundwater level changes) were removed shortly after the completion of the Year 1 Trial. Environment Canterbury continues to undertake long-term groundwater level monitoring in GWE-04 for regional environmental monitoring purposes. This data has been included to assist in quantifying the effects of the Lagmhor Trial on groundwater levels at this location.

2.6.2 Groundwater Quality

Water quality monitoring has been continued from Year 1 through Year 2 at the seven dedicated monitoring wells (GWD-01 to GWD-07) and at one long-term environmental monitoring well (GWE-01). The sampling frequency was amended from the monthly monitoring carried out during Year 1 to quarterly for Year 2 due to funding limitations. The parameter list for quarterly sampling is provided in **Table 4**.

Data from two of these monitoring wells (GWE-01 and GWD-01) are used to evaluate the effect of the source water on the receiving groundwater directly beneath the trial site. The water quality data reported for the remaining monitoring wells are used to evaluate the degree and extent of improvement in groundwater quality resulting from the trial (**Table 5**, **Figure 4**).

Analysis of the accumulated groundwater quality data at the end of Year 1 (Golder 2017) indicated that a “clean water” plume extended southeast from the trial site beyond the furthest well monitored for groundwater quality along this flow line. Additional monitoring wells to the south and southeast of the site were initiated for Year 2 to identify the orientation, extent and rate of movement of the downstream end of this “clean water” plume.

Table 4. Water quality monitoring programme for groundwater and surface water in Year 2.

Source water (monthly)	Groundwater (Quarterly)		Surface water in coastal drains (monthly)
Ammonia Nitrogen	Turbidity	Ammoniacal Nitrogen	Nitrate-N + Nitrite-N
Dissolved Reactive Phosphorus	Alkalinity	Nitrate Nitrogen	Electrical Conductivity
Nitrite - Nitrogen	Bicarbonate	Nitrate-N + Nitrite-N	
Nitrate - Nitrogen	Hardness	Nitrite Nitrogen	
Total Coliforms	pH	Dissolved Reactive Phosphorus	
E. coli	Electrical Conductivity	Total Phosphorus	
Total Kjeldahl Nitrogen	Total Suspended Solids	Bromide	
Total Nitrogen	Boron, Dissolved	Chloride	
Total Phosphorus	Calcium, Dissolved	Silica, Reactive	
	Iron, Dissolved	Total Organic Carbon	
	Magnesium, Dissolved	Water Temperature (Field)	
	Manganese, Dissolved	Dissolved Oxygen	
	Potassium, Dissolved	Total Coliforms	
	Sodium, Dissolved	E. coli	
	Sulphate		

In addition to the Lagmhor Trial monitoring sites, Environment Canterbury analysed samples from a number of bores in the Tinwald area as part of the Tinwald Nitrate Investigation project. Nitrate-N concentration results from the sampling in March 2018 have been included in Section 3.5.2 where relevant.

As part of Environment Canterbury's ongoing State of the Environment (SOE) and Land and Water Regional Plan (LWRP) monitoring programmes, extended records and ongoing collection of water levels and water quality at four bores located within the Lagmhor Trial command area are maintained. Long-term groundwater level records have been plotted and presented in Appendix B.

2.7 SURFACE WATER MONITORING

2.7.1 Flows

As per Lagmhor Trial consent conditions (CRC184617), operations are to be shut down (minimum of 48 hours) if either coastal waterbodies (drains) flows (ECan Gauge# 69001[1], Parakanoi @ Lower Beach Road) **and** rainfall (ECan #39610[2], Hinds Plains at Willowby) exceed their trigger levels. The trigger levels for rainfall is >30 mm in a 24-hour period, as measured at the Hinds Plains climate site. For the Environment Canterbury gauge at Parakanoi Drain, the trigger level is high flows over 2,200 L/s.

[1] https://www.ecan.govt.nz/data/riverflow/sitedetails/69001
[2] https://www.ecan.govt.nz/data/rainfall-data/sitedetails/319610

2.7.2 Quality and Ecology

Monitoring in the coastal spring-fed streams/drains area of the Hinds Plains has provided valuable information to support the Year 2 monitoring programme at the Lagmhor Trial site. The coastal spring-fed streams/drains monitoring programmes focus on water quality, ecology and climate and include partnerships between Environment Canterbury, Fish and Game and the Hinds rural community (Hinds Drains Working Party).

These complementary efforts are summarised as follows:

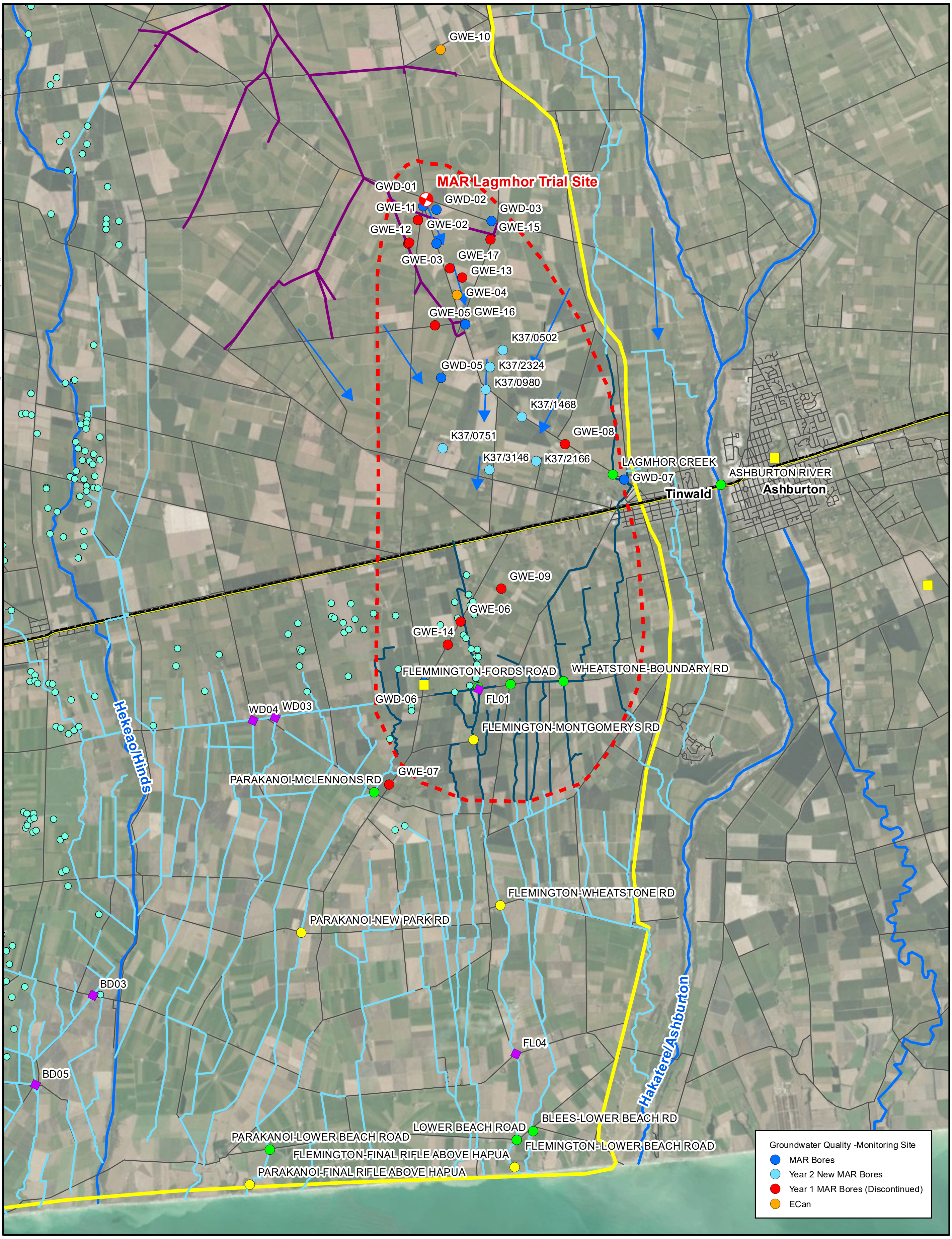
- Hinds Drains Working Party (HDWP)
  - On behalf of the HDWP, Fish and Game (Mark Webb/Jayne Couper) continued to collect surface water samples for nitrate analysis from several drain sites identified in 2014 by the coastal Hinds community. These sites represent a baseline for nitrogen levels in the groundwater fed waterways. A selection of the results is provided in the results Section 3.6.
- Environment Canterbury ecology and water quality monitoring:
  - This monitoring was continued as proposed for Year 1, when the streams were flowing at eight sites in Flemington Drain and Parakanoi Drain. This was undertaken by Environment Canterbury with water quality measurements (quarterly) combined with an ecological rapid habitat assessment at each site.
  - Duncan Gray (Environment Canterbury) carried out electro-fishing of these sites once annually (Year 2).
- Coastal streams/drains water quality and flow monitoring
  - Environment Canterbury collects water quality data quarterly at the State of the Environment (SOE) monitoring sites.
  - Environment Canterbury maintains both permanent and temporary flow gauging sites in several of the drains down-gradient from the Lagmhor Trial, including a permanent site on the Parakanoi at Lower Beach Road, which is used for consent condition compliance monitoring.

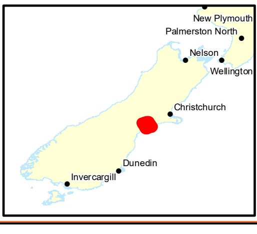
It is anticipated that if sufficient volumes are infiltrated at the Lagmhor Trial site the on-going monitoring programmes will assist to identify discharges from the clean water plume into the coastal spring-fed streams/drains.

Table 5. Lagmhor Trial groundwater level and quality monitoring sites – Year 2.

Lagmhor Trial ID	ECan Station ID	Groundwater level objective [1]	Groundwater quality objective
GWD-01 [2]	BY20/0149	Monitor responses to infiltration at regional aquifer level beneath the trial site.	Monitor responses to infiltration at regional aquifer level beneath trial site.
GWD-02	BY20/0150	Monitor responses to infiltration at regional aquifer level close to the trial site.	Monitor responses to infiltration at regional aquifer level close to trial site.
GWD-03	BY20/0151	Monitor responses to infiltration at regional aquifer level to the east of site to validate groundwater modelling.	Monitor background groundwater quality.
GWD-04	BY20/0152	Monitor responses to infiltration at perched aquifer level to south of trial site.	MAR “clean water” plume tracking.
GWD-05	BY20/0153	Monitor responses to infiltration at regional aquifer level to the south east of the site, to validate groundwater modelling.	MAR “clean water” plume delineation.
GWD-06	BY21/0183	Process management monitoring well with trigger groundwater levels.	MAR “clean water” plume tracking.
GWD-07	BY20/0184	Monitor shallow groundwater near Tinwald. Distinguish MAR trial effects from other influences.	Monitor shallow groundwater near Tinwald.
GWE-01	K37/1748	Monitor responses to infiltration at perched aquifer level beneath trial site.	Monitor responses to infiltration at perched aquifer level beneath MAR Trial site.
GWE-04	K37/0200	Monitoring undertaken by ECan for long-term environmental monitoring purposes. Data used to evaluate response to infiltration down-gradient from trial site.	N/A
GWD-16	K37/2603	N/A	MAR “clean water” plume tracking
NA	K37/0502	N/A	MAR “clean water” plume tracking
NA	K37/2324	N/A	MAR “clean water” plume tracking
NA	K37/0980	N/A	MAR “clean water” plume tracking
NA	K37/1468	N/A	MAR “clean water” plume tracking
NA	K37/2166	N/A	MAR “clean water” plume tracking
NA	K37/3146	N/A	MAR “clean water” plume tracking
NA	K37/0751	N/A	MAR “clean water” plume tracking

Notes: 1) All sites are monitored automatically except GWE-04, which is monitored manually.
2) The data from site GWD-01 is telemetered. All other sites require manual downloads.
N/A - Not applicable.





N

0 1,000 2,000 3,000 m

Scale 1:125,000 @ A4

Coordinate System:
NZGD2000 New Zealand Transverse Mercator 2000

Disclaimer: While all reasonable care has been taken to ensure the information contained on this map is up to date and accurate, no guarantee is given that the information portrayed is free from error or omission. Any relevance placed on such information shall be at the risk of the user.

LEGEND

- MAR- Lagmhor Trial Site
- Surface Water Monitoring Site
- Ecology Monitoring Site
- ECan Inventoried Springs
- Drain
- Targeted Spring -Fed Stream
- Lagmhor Trial Groundwater Command Area
- Hinds/Hekeao Groundwater Replenishment Scheme Area
- Weather Station
- Drain Site
- Groundwater Flow Direction
- Valetta Irrigation Network
- State Highway 1
- Roads
- River

WGA
WALLBRIDGE GILBERT AZTEC

Figure 4

Hinds MAR Stage 2
Monitoring Map & Project Area Overview

3 LAGMHOR TRIAL SITE RESULTS

3.1 CLIMATIC CONDITIONS

The average annual rainfall recorded at the Ashburton Council climate monitoring station (NIWA station #4778) between 1990 and 2016 was 717 mm (Golder 2017a, Appendix B). During the two years prior to the start of the Lagmhor Trial, rainfall had been substantially less than the long-term average (Table 6). Land Surface Recharge (LSR) of groundwater in the command area had therefore been significantly less than average during this period leading up to the trial.

Rainfall during Year 1 of the Lagmhor Trial (June 2016 to May 2017) was approximately average for the Hinds Plains. Rainfall recorded during Year 2 (June 2017 to May 2018) was, however, substantially greater than the 1990 to 2016 average (Table 6).

Table 6: Annual rainfall in the Hinds/Hekeao Plains.

Year (June to Following May)	Hinds Plains (Willowby) (1) Annual Rainfall (mm)	Ashburton (2) Annual Rainfall (mm)	Ashburton (2) Average Annual Rainfall 1990 – 2016 (mm)
2014 – 2015	NA (3)	535	717
2015 – 2016	NA (3)	513	
Year 1 2016 – 2017	663	721	
Year 2 2017 – 2018	1,142	N/A (4)	

Note: 1) Environment Canterbury climate monitoring station #319610.
2) NIWA climate monitoring station #4778.
3) NA means Not Available (N/A). Rainfall monitoring station was not installed at this time.
4) Data for complete year not available.

During Year 1, rainfall was less than half the monthly average for four of the twelve months and was more than double the monthly average only once (Figure 5). In contrast, rainfall during three of the Year 2 months was at least double the average for these months. The July monthly rainfall recorded in Ashburton during Year 2 of the trial was the third highest reading since records commenced in 1909 (NIWA 2017). In addition, rainfall during the months December 2017 through to April 2018 was consistently above average. The effect of the significant difference in rainfall between Year 1 and Year 2 is explored in the results analysis for Year 2 (Section 3).

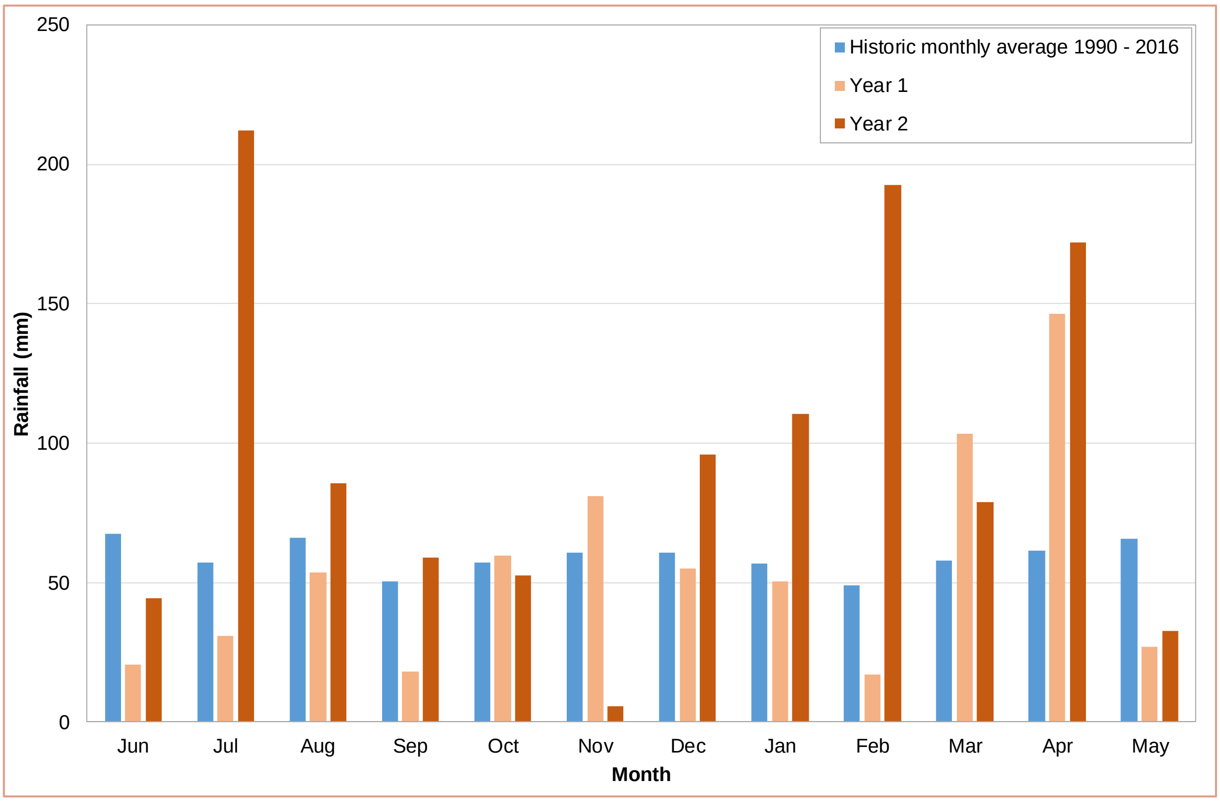


Figure 5: Monthly rainfall in the Hinds/Hekeao Plains – Year 1 and Year 2.

Three daily rainfall events exceeding 80 mm were recorded at the Willowby monitoring station during the first two years of the Lagmhor Trial (Figure 6), each of these occurring during Year 2.

- 22 July 2017 121 mm
- 21 February 2018 87 mm
- 29 April 2018 81.5 mm

The event of 22 July 2017 contributed to the near record July rainfall total and resulted in extensive regional flooding.

The operational shut-down rainfall trigger of 30 mm during a single 24-hour period was exceeded:

- Three times during Year 1
- Five times during Year 2, with two of these events extending over more than one day.

In each case recharge operations at the Lagmhor Trial ceased when the rainfall trigger was exceeded, in compliance with the consent requirements (refer Section 3.2.1).

Monthly potential evapotranspiration (PET) exceeded monthly rainfall from September 2017 to January 2018, with PET reaching a seasonal maximum in December 2017 (Figure 7). During Year 2 monthly rainfall only exceeded PET for three months (July 2017, February 2018 and April 2018). During these three months the difference between rainfall and PET was due to the major rainfall events listed above.

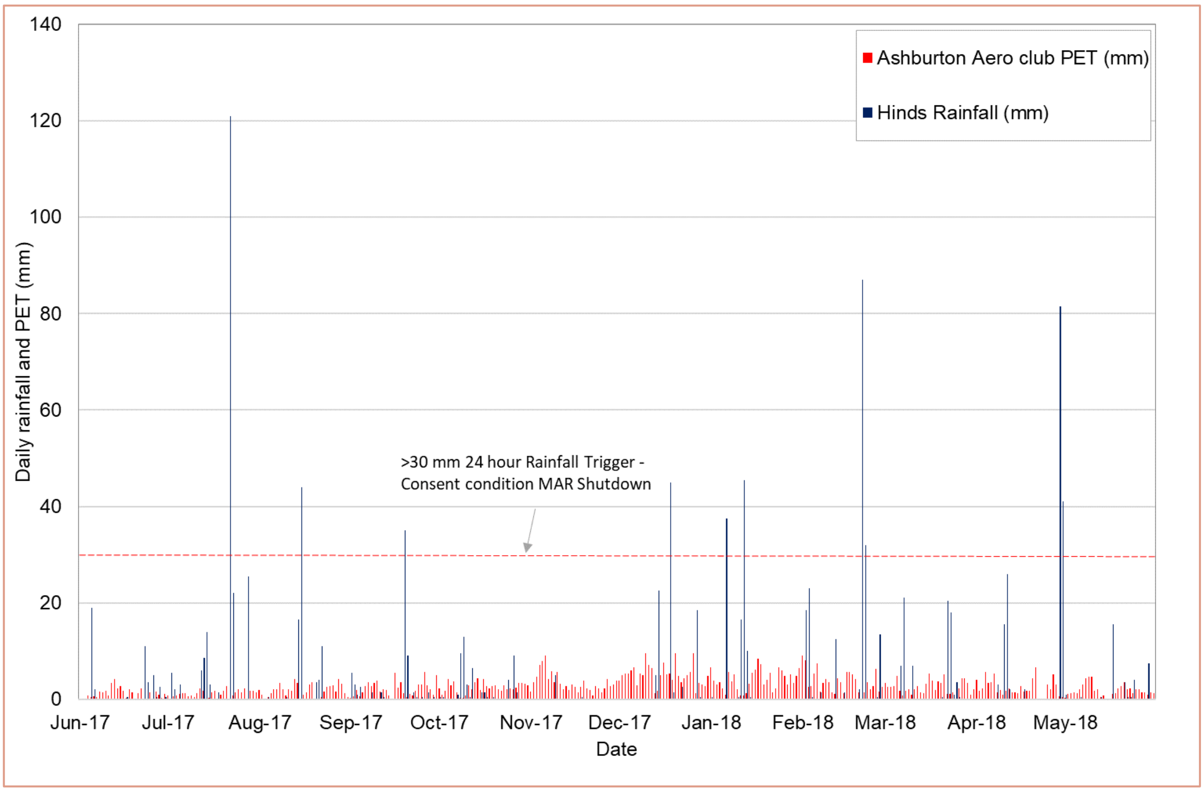


Figure 6: Daily rainfall in the Hinds/Hekeao Plains – Year 2.

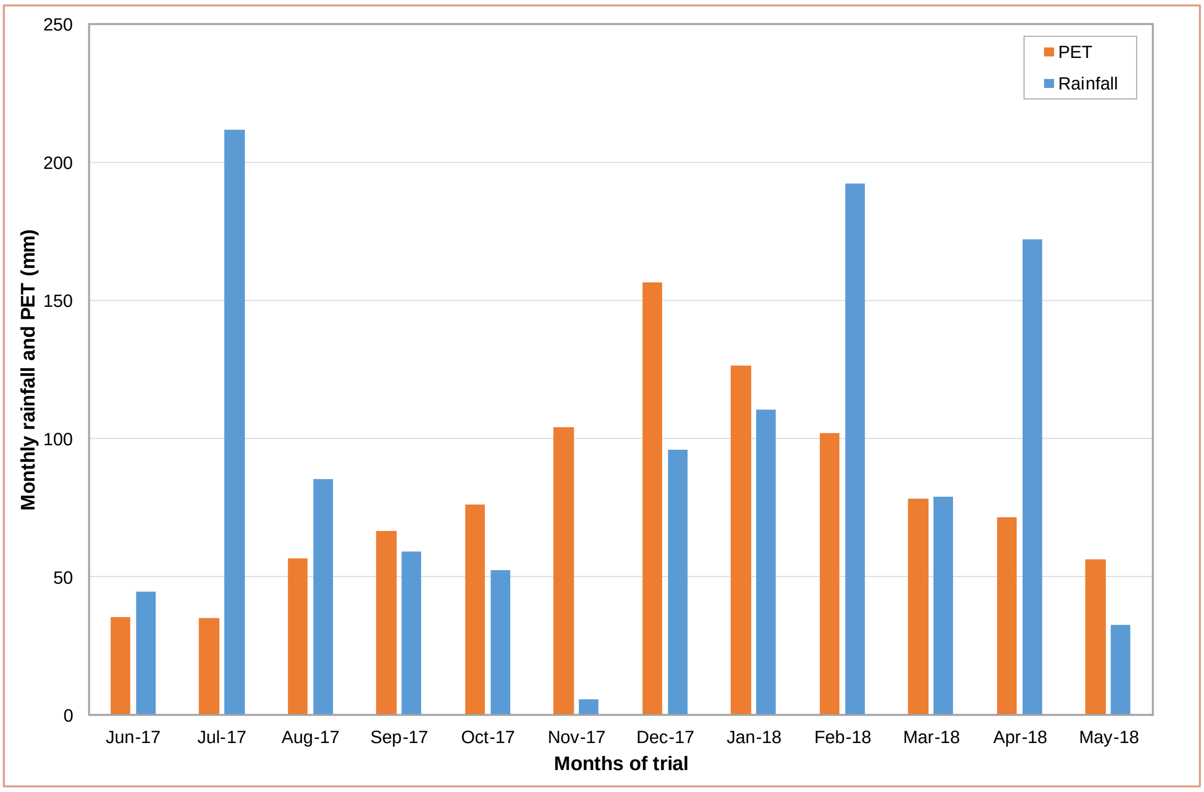


Figure 7: Rainfall and potential evapotranspiration (PET) in the Hinds/Hekeao Plains – Year 2.

3.2 SOURCE WATER

3.2.1 Source Water Flows, Infiltration Basin Levels and Infiltration Rates

During Year 2 the infiltration basin water level was operated generally at depths of between 0.65 m and 0.80 m (**Figure 8**). Interruptions to operations included supply restrictions during the irrigation peak demand periods between November to December 2017 and in January 2018. In addition, rainfall events that triggered the consent criteria halted recharge operations in July 2017, January 2018 and April 2018 (**Figure 9**).

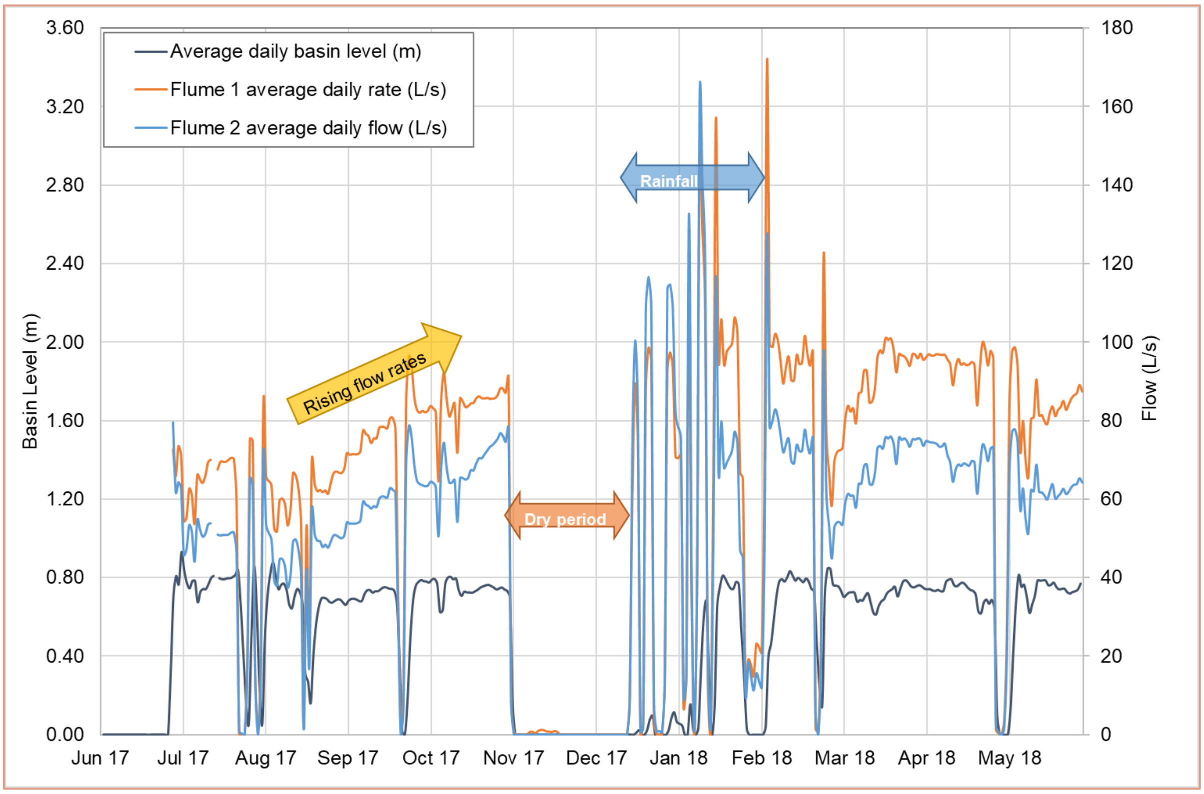


Figure 8: Basin levels and flow rates into the Lagmhor Trial site – Year 2.

During late 2017 the water level in the main infiltration basin was relatively stable. Over the same period the flow rates increased (**Figure 8**). The average flow rate at Flume 1 from July to October 2017 was 66 L/s and Flume 2 was 53 L/s. Following the summer 2017-2018 site shut down, and a period of highly variable inflows during early 2018, the flow rate stabilised at a higher average daily rate during March and April 2018 of approximately 95 L/s through Flume 1 and 72 L/s through Flume 2. As the basin was operated at similar water levels during these two periods, the capability of the basin to receive water at an increased flow rate and still operate at similar water levels is attributed to an increase in infiltration rate in the basin. An analysis of the relationship between basin infiltration rates and potential clogging is discussed in Section 3.4 and Appendix D.

The Year 2 flow rates are comparable to the range of flow rates observed during Year 1 (**Figure 10**). The initial flow rates when the site was started in 2016 (September to December 2016) were approximately 90 L/s at Flume 2. The rates during March and April 2018 are approximately 80% of these initial flow rates.

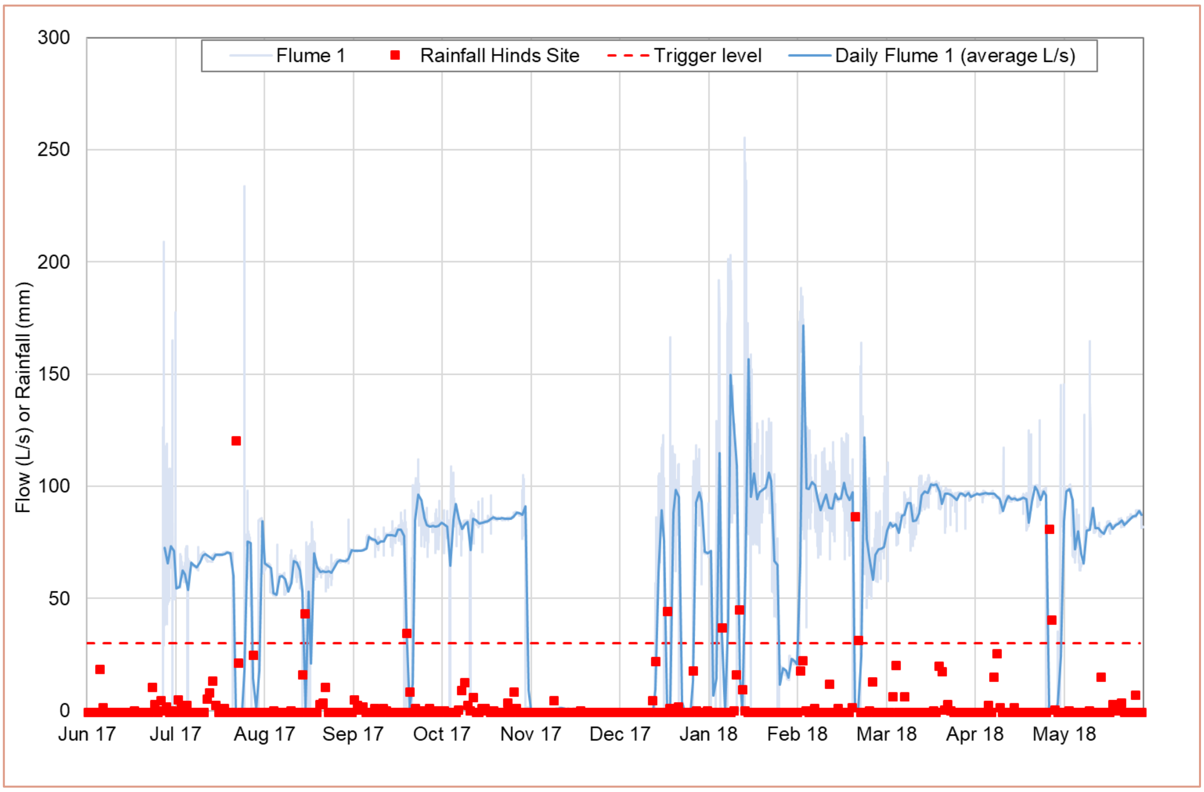


Figure 9: Flume 1 flow rates (15 min data and average daily) compared to daily rainfall events.

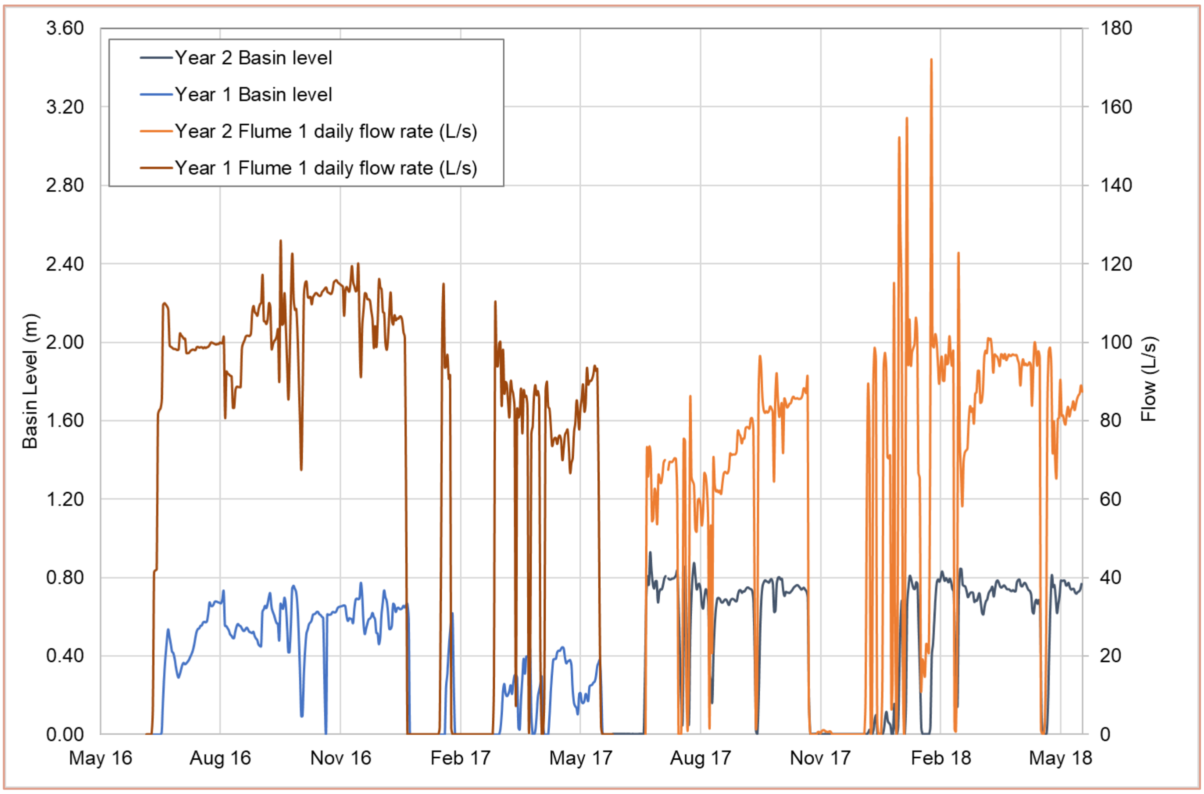


Figure 10: Year 2 Lagmhor Trial flow rates compared to Year 1.

The difference in flow between Flume 1 and Flume 2 indicates infiltration rates through the base of the supply race (**Figure 11**). The average difference in flow rates (**Figure 11**) was:

- 17 L/s between August and October 2017
- 22 L/s between February and May 2018.

During Year 2 flow losses from the supply race to infiltration were similar to the average infiltration rate of 17 L/s observed during Year 1 (Golder 2017).

Records kept by the Lagmhor Trial site manager (Pers. comms. Giles Pinfold) noted that after one of the large rainfall events triggered a site shutdown, basin infiltration rates were subsequently reduced by approximately 20 L/s. He also noted that flow rates then recovered over a few weeks to the flow rates recorded prior to this event. He hypothesised that the reduced flow rate resulted from a combination of increased rainfall on the surface of the basin and more saturated sub-surface soil conditions (hydraulic clogging). Further consideration of hydraulic clogging can be found in Section 3.4.

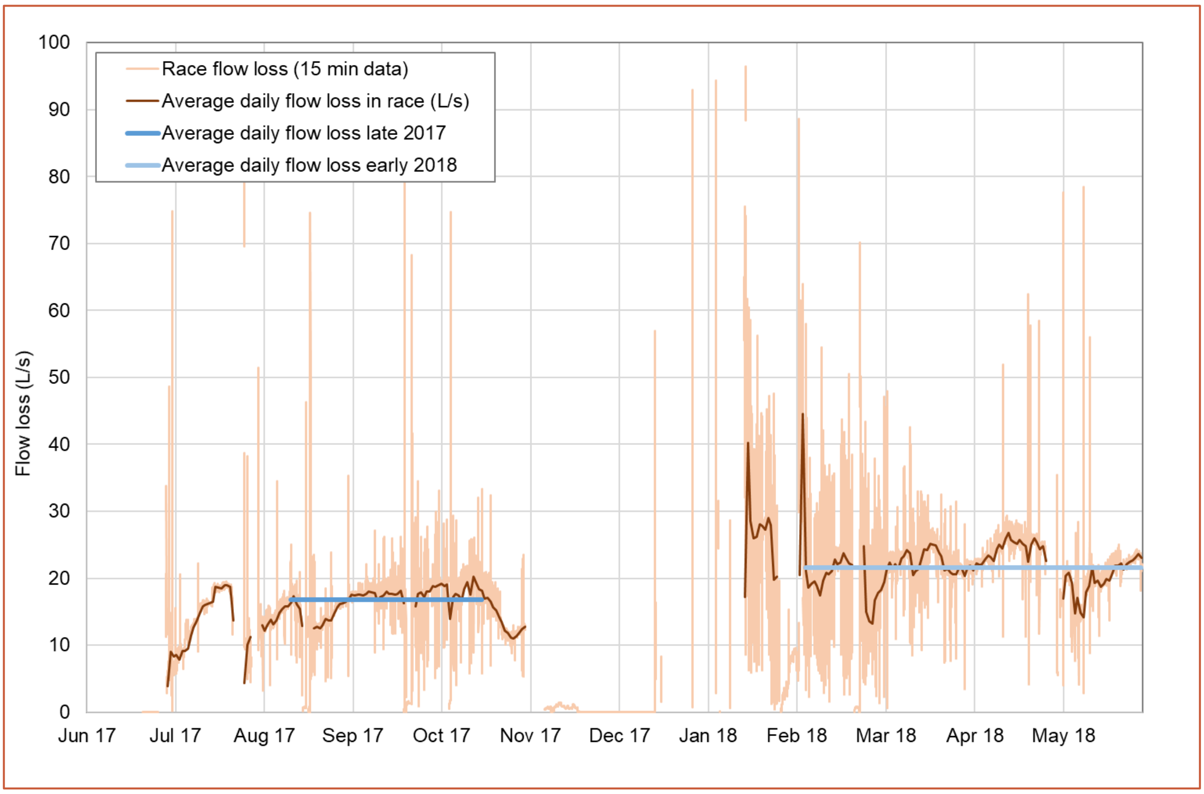


Figure 11: Flow loss (infiltration) in race between Flume 1 and Flume 2 – Year 2.

3.2.2 Quantity of Water Recharged

In Year 2 approximately **1,854,000 m^3** was recharged through the Lagmhor Trial site. Daily flows measured at Flume 1 correspond well to the delivered flows measured by RDRML (**Figure 12**).

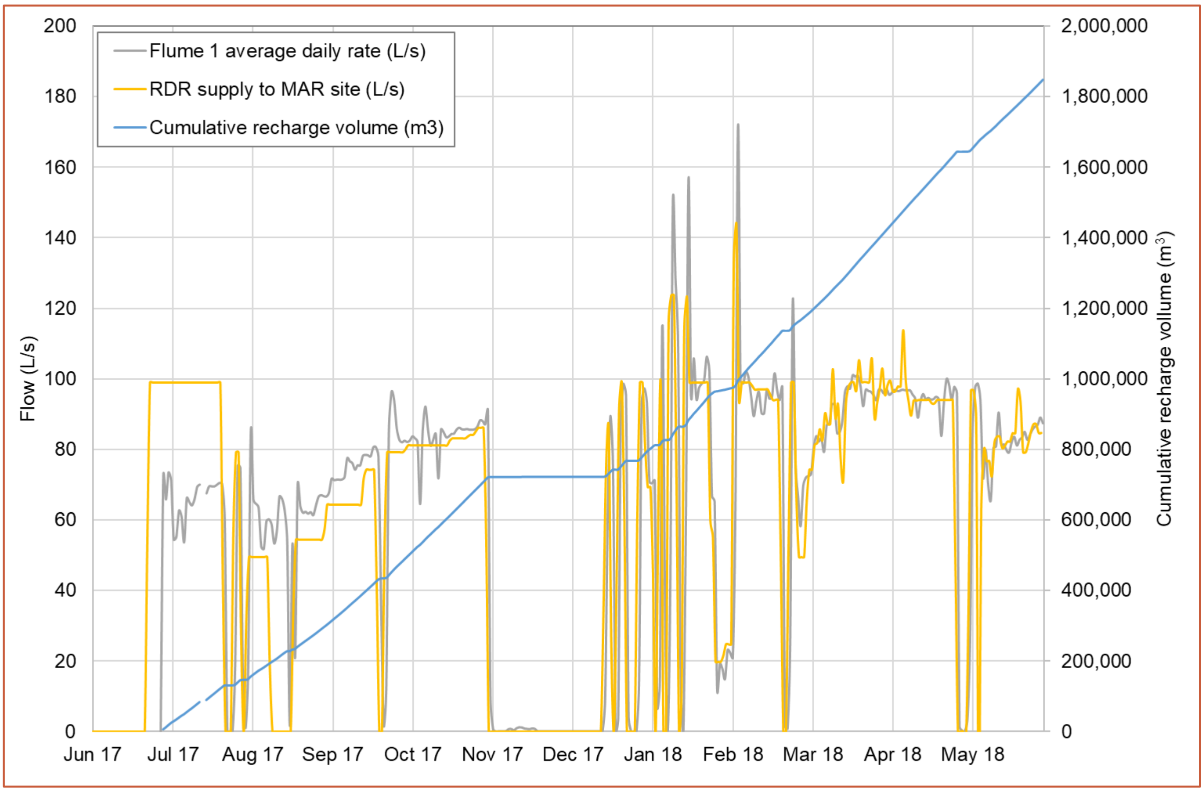


Figure 12: Comparison of water flow measurements to Lagmhor Trial site – Year 2.

The water delivered to the Valetta pond site by RDRML was generally balanced by flow into the Lagmhor MAR site (Flume 1) from September 2017 onwards (**Figure 12**, **Table 7**). Flows delivered to the site (MAR Valetta flows) supplied both the Lagmhor Trial site and one new testing site (Site 8, refer to report Section 5).

The Lagmhor MAR site water balance is presented in **Table 7**. The flow provided to the site, in combination with the Ashburton District Council take (9,050,600 m^3 up to 31 May 2018), is below the annual compliance limit of 15,780,000 m^3 (Appendix A). Approximately half of the 153,000 m^3 of water allocated to the Lagmhor Trial and stored in the Valetta ponds at the end of Year 1 was utilised in Year 2. At the end of Year 2 operations there remained approximately 73,000 m^3 of allocated water in the Valetta ponds (**Table 7**).

3.2.3 Quality of Water Recharged

Results from source water quality monitoring show nutrient concentrations to be low throughout the delivery system. Average nitrate-N concentrations in samples collected through the delivery line during Year 2 were below 0.05 g/m^3. Reported concentrations for ammoniacal-N, nitrite-N, and dissolved reactive phosphorus were all generally below laboratory detection limits. Reported total nitrogen averaged less than 1 g/m^3 in the collected samples. The data from the sampling programme is presented in Appendix C.

E. coli were detected in the delivery line and at the Lagmhor Trial site at Flume 1. The highest count at Flume 1 was 150 MPN/100 ml during May 2018. The average *E. coli* result for the delivery line was approximately 60 MPN/100 ml for the Year 2 period. These results are similar to the results from Year 1.

Table 7: Year 2 delivery from RDR to Lagmhor Trial site – water budget.

Point of Measurement	Year 2: Total Volumes (m^3) (1)
Total available under ADC consented take	15,780,000
Diversion and Delivery:	
RDRML annual volume at MAR Valetta site	1,956,000
Diverted to MAR new site testing sites (Site 8)	84,000
Measurement accuracy (2) and conveyance system losses (~5 %)	98,000
Total delivered to Lagmhor Trial site	**1,774,000**
Recharge Operations:	
Total recharged Lagmhor Trial site operations 10 June 2017 – 31 May 2018	**1,854,000**
Storage:	
From Year 1 Storage	153,000
Remaining MAR water held (5) in Valetta Ponds for Year 3 operations	73,000
Water Balance: diverted minus delivered	~0
Water remaining available under ADC consented take	13,926,000

Notes: 1) Values rounded to +/- 1,000 m^3.
2) MAR recharge rates (~100 L/s) fall within the margin of anticipated accuracy (error) for both RDRML's (+/- 8 % of ~30,000 L/s equal to error of +/- 2,400 L/s) and Valetta's (+/- 8 % of 3,500 L/s equal to accuracy of +/- 280 L/s).

3.3 GROUNDWATER LEVEL RESPONSES

3.3.1 Introduction

Groundwater level trends recorded in monitoring wells in Year 2 of the trial responded to a range of factors including:

- Recharge induced by seasonal rainfall patterns and high-intensity rainfall events.
- Recharge from the Lagmhor Trial operations.
- Abstraction for irrigation purposes.
- Aquifer/aquifer layer intersected by the monitoring well screen.
- Distance from monitoring wells to Lagmhor Trial site, streams, and/or drainage channels.

The Year 1 report (Golder, 2017) provides an in-depth assessment of the lithology and hydrogeology beneath, and surrounding, the Lagmhor Trial site. The lithological sequence beneath the site and the interpreted aquifer layers are summarised in **Table 8**. Examples of the groundwater level responses to each of the above factors in the perched (AQ2) and regional (AQ3) aquifers are presented in Appendix B and the following sections.

Table 8: Interpreted lithological sequence beneath Lagmhor Trial site.

Depth below ground level (m)	Description [1]	Hydrogeological interpretation	Depth to Groundwater (m)		
			Before Trial	Close Year 1 [2]	Close Year 2 [3]
0 – 6	Silty sandy GRAVELS	Unsaturated or perched groundwater layer (AQ1)	Dry	0 [4]	0 [4]
6 – 9	Sandy gravelly SILTS	Aquitard (AQT1)			
9 – 18	Cobbles and GRAVELS, probably constituting a buried river paleochannel	Perched highly permeable aquifer (AQ2)	13.5	8.4	7.5
18 – 26	Gravelly SILT	Aquitard (AQT2)			
26 – >30	GRAVEL	Highly permeable aquifer connected to the regional groundwater system (AQ3)	29.5	26.5	18

Notes 1) Based on geological log from Monitoring Well GWD-01.
2) Approximated from Year 1 monitoring data (Golder, 2017).
3) Approximated from Year 2 monitoring data (refer Appendix B).
4) Assumed complete saturation of uppermost gravels beneath basin.

3.3.2 Groundwater Responses to Rainfall

Groundwater level responses in Year 2 to rainfall are detailed in Appendix B.

3.3.3 Groundwater Responses to the Lagmhor Trial – Year 2

The regional groundwater level responses to the Lagmhor Trial differed between Year 1 and Year 2. During Year 1, which was an average rainfall year following two dry years, the groundwater response to Lagmhor Trial recharge operations was well defined (Golder 2017). This response was characterised by:

1. Elevated but stable groundwater levels in the immediate vicinity of the Lagmhor site (GWD-01 and GWD-02), which were not drawn down by irrigation pumping during Year 1.

2. Groundwater levels at GWD-03, approximately 975 m east from the Lagmhor site, were above background levels represented by GWD-05. GWD-03 also showed a delayed response to irrigation pumping (Golder, 2017).

During Year 2 the MAR responses at the regional aquifer level have been visually subsumed in the larger scale groundwater responses to increased seasonal rainfall (**Figure 13**). Following the rainfall event of 22 July 2017 groundwater levels have not stabilised sufficiently to enable a direct assessment of the water level increases resulting from the Lagmhor Trial. However, an assessment has been undertaken based on groundwater levels recorded immediately prior to the July 2017 rainfall event.

The calculated extent and magnitude of groundwater mounding at the regional level are similar although slightly less than those calculated for Year 1 (**Figure 14**).

The extent of observed groundwater mounding in the regional aquifer resulting from the Lagmhor Trial to date is relatively small compared to the size of the entire catchment. There is no indication that the mounding generated by the trial would extend as far as the coastal drains.

Groundwater levels in the perched aquifer (AQ2) were predominantly influenced by infiltration from the Lagmhor Trial during both Year 1 and Year 2 (**Figure 15**). Groundwater levels in the perched aquifer have generally continued to increase since the start of the trial in 2016. It is not clear however whether this rise is due solely to ongoing MAR operations or also reflects increased rainfall recharge during Year 2.

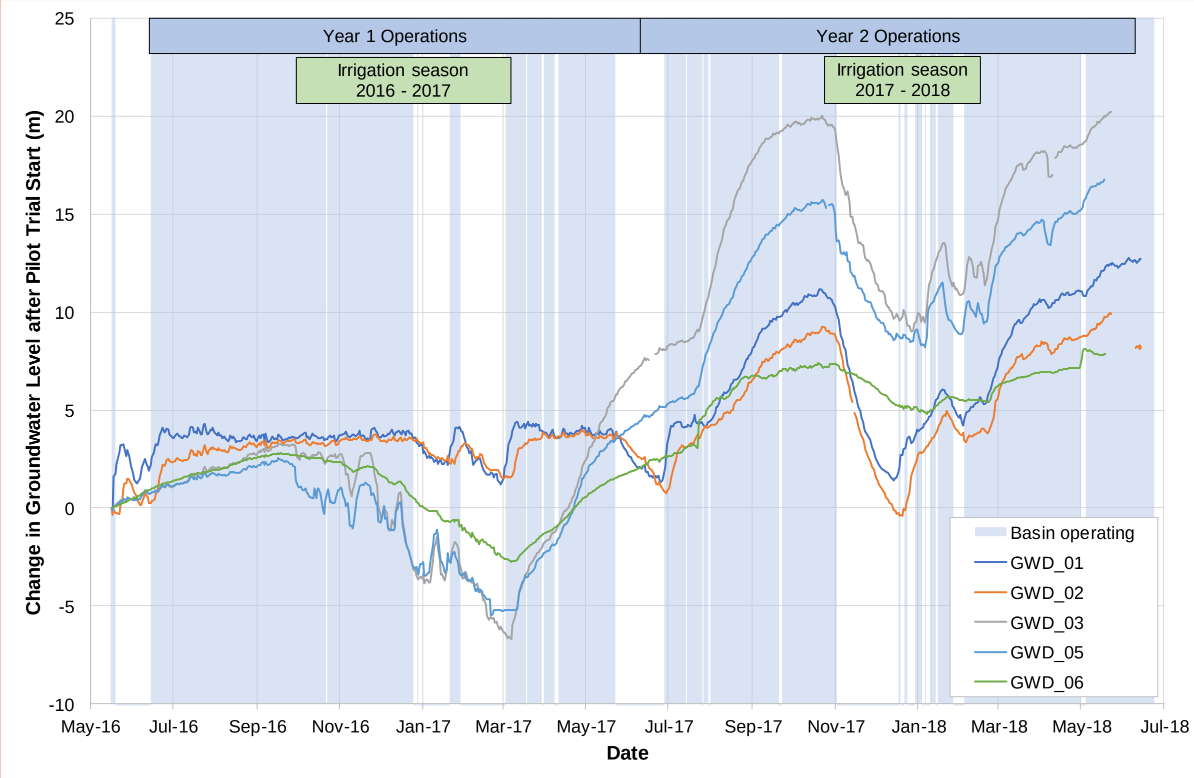


Figure 13: Groundwater level responses to MAR at regional aquifer level.

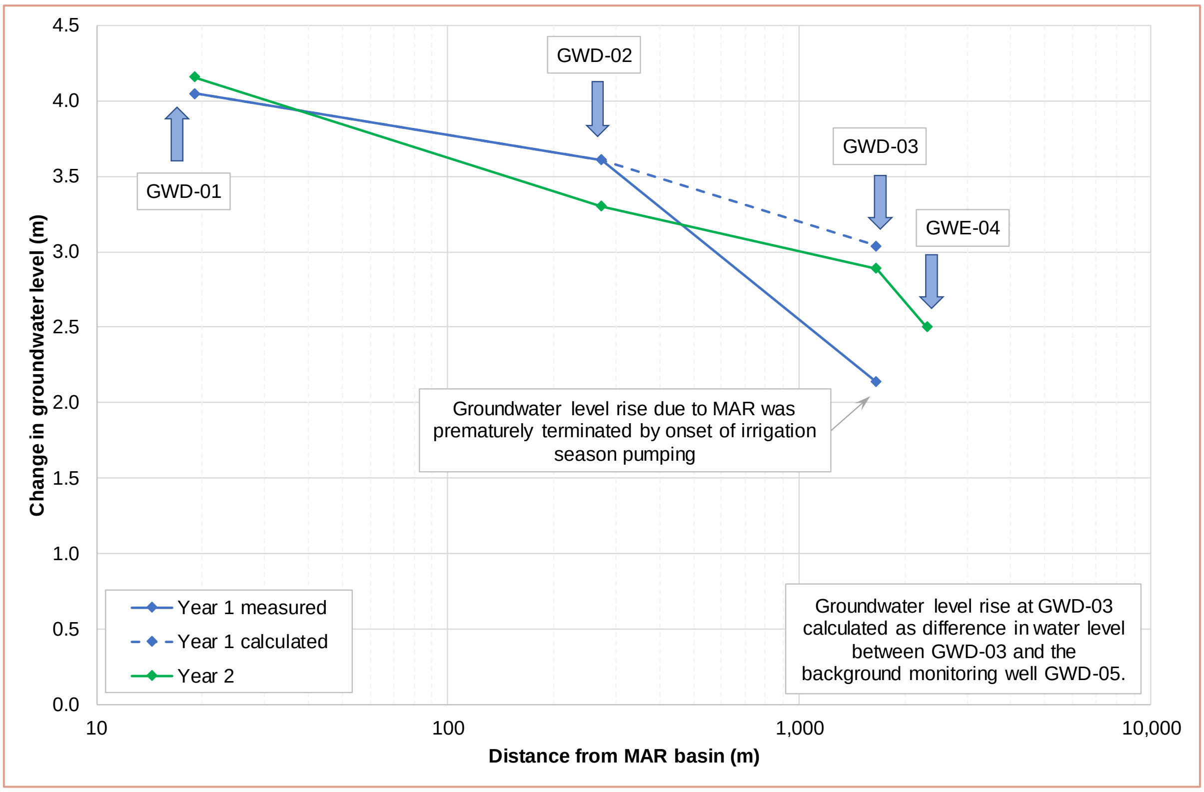


Figure 14: Regional groundwater level responses with distance from Lagmhor Trial site.

Groundwater levels in the perched aquifer declined rapidly almost immediately following the close of operations at the Lagmhor Trial. During the 2017-2018 summer close of MAR operations, the groundwater level in GWE-01 stabilised at a level approximately 1.4 m higher than it had been at the start of the trial.

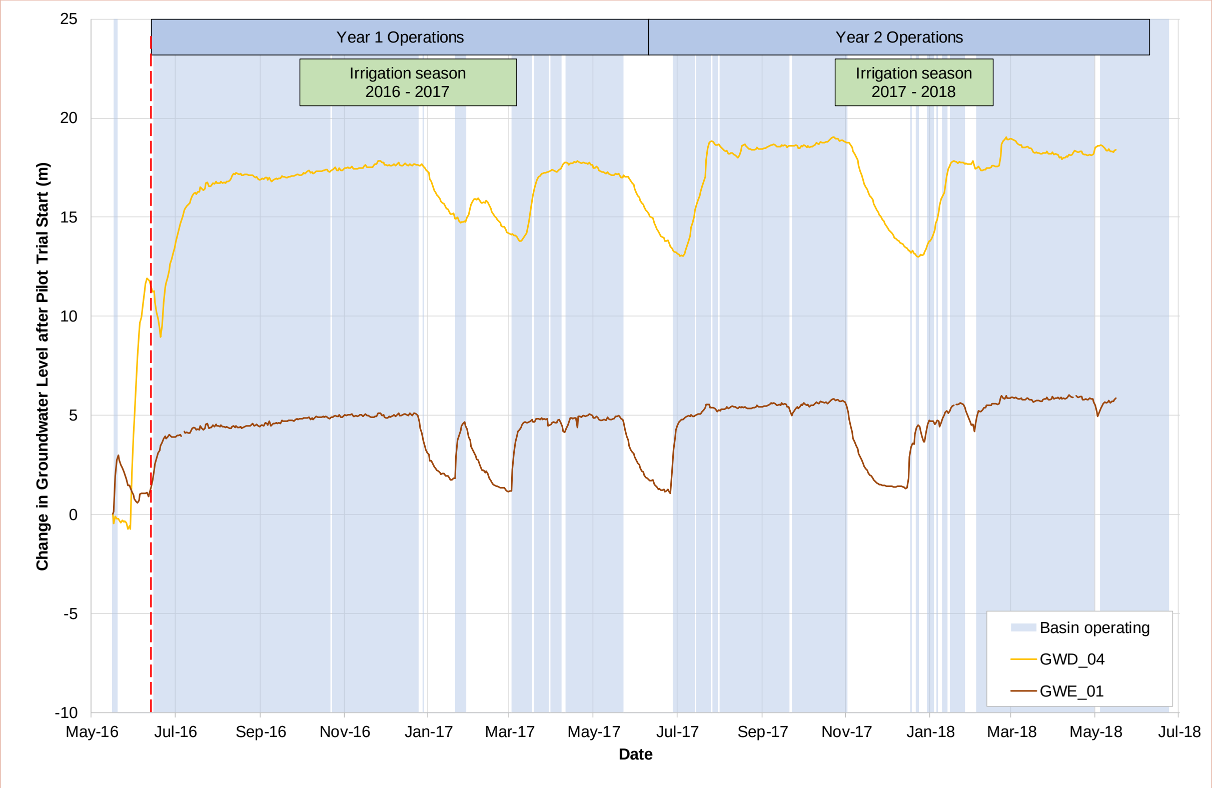


Figure 15: Groundwater level responses to MAR at perched aquifer level.

3.3.4 Groundwater Response Comparison Between Perched and Regional Aquifers

Work undertaken during the geophysical assessment of ground conditions beneath the Lagmhor Trial site (Section 4) identified two aquitard layers above the regional aquifer level (refer **Table 8**). These aquitards slow downward seepage and enable the development of perched groundwater in the intervening aquifer layers (AQ1 and AQ2; **Table 8**).

Groundwater at the regional aquifer level beneath the Lagmhor Trial site was approximately 18 m bgl at the close of Year 2 operations. This compares to a level of approximately 31 m bgl at the start of the trial. Based on the interpreted aquitard levels there was an unsaturated zone between the lower aquitard and the regional aquifer at the start of the trial in 2016. At the end of Year 2 groundwater had filled this unsaturated zone between the regional aquifer and the perched aquifer beneath the Lagmhor Trial site. The implications of this rise in groundwater level regarding the planned site upgrade are considered in the discussion section of this report (refer Section 8.2).

The large groundwater responses recorded in GWD-01 and GWD-02 (**Figure 16**) to seasonal and individual rainfall events may reflect semi-confinement of the regional aquifer occurring as groundwater levels rise. Once the regional aquifer beneath the site became completely saturated, additional rainfall pushing groundwater through from further up-gradient acts to rapidly increase the pressure in the regional aquifer. These increases in regional groundwater pressures are not evident in the perched aquifer layer.

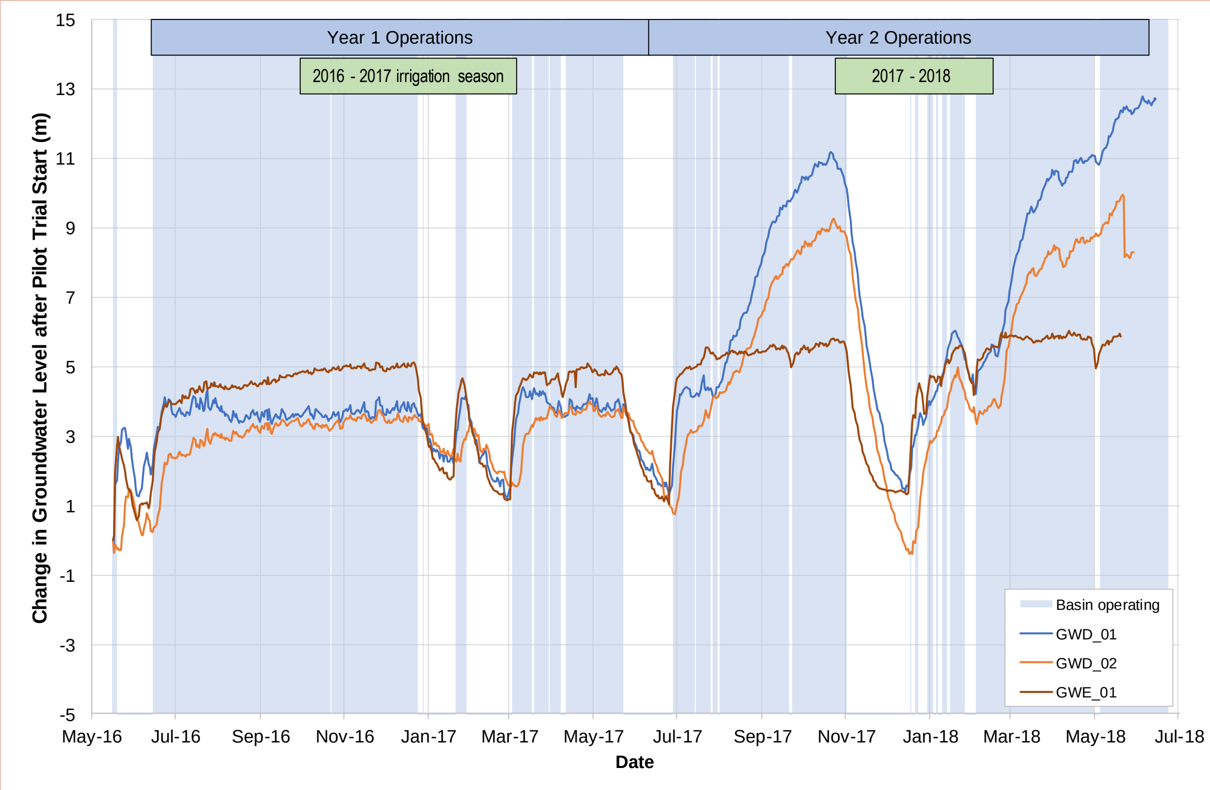


Figure 16: Groundwater level responses to MAR in perched and regional aquifers.

3.3.5 Groundwater Responses to Irrigation Pumping

Groundwater drawdown due to irrigation pumping typically starts in October, with seasonal shut-down of the Lagmhor Trial during the peak demand period generally occurring over December to January. This was what occurred in Year 1 of the Lagmhor Trial (**Figure 13**). The drawdown due to groundwater pumping exceeded the mounding due to infiltration during Year 1, except close to the trial site.

During Year 2 there was very little rainfall in November 2017. This resulted in groundwater abstraction starting and infiltration operations being shut down at the same time. Consequently, the drawdown in groundwater levels during November and December 2017 was much greater and occurred more rapidly than during the corresponding period in 2016.

In effect, recharge from the Lagmhor Trial can help to delay the drawdown effects of groundwater use for irrigation. The recharge from a single MAR infiltration site is, however, insufficient to counteract the regional drawdown in groundwater levels associated with multiple pumping centres.

3.4 BASIN CLOGGING

Basin infiltration rates are affected by a range of factors including:

- Depth of water in the basin
- Clogging of the basin floor and underlying soils
- Degree and form of soil saturation underlying and surrounding the basin

An assessment of infiltration basin clogging has been undertaken and documented in Appendix D. Direct observations of the basins and delivery race at the end of Year 1 identified a small amount of sediment in the forebay, but only a light covering in the main basin. Observations at the end of Year 2 identified increased sediment in the forebay (**Figure 17**) and sections of the delivery race, but only a light covering again in the main basin. Following Year 2 shutdown, it required over two weeks to infiltrate all water stored in the forebay, compared with only a few hours for water in the main basin to be infiltrated.

The reduced overall flow rates into the Lagmhor Trial site during Year 2 is considered to be due to clogging in the settling basin. The significant reduction in forebay infiltration rate will have affected overall site performance. However progressive sediment accumulation information over time is not available for a more detailed assessment. No mechanical cleaning of the forebay or main basin has been conducted since the site construction in April 2016.

Other factors potentially influencing infiltration rates from the main infiltration basin were assessed using water level recovery curves for six basin shutdown events recorded during the first two years of site operations. The small number of recovery curves evaluated provide insufficient data for a full statistical analysis, however the initial assessment undertaken suggests infiltration rates may be correlated with:

- water depth in the basin;
- antecedent rainfall;
- groundwater depths to groundwater beneath the basin.

At the close of Year 2 operations the calculated infiltration rates at the Lagmhor Trial site were:

- 119 mm/day from the forebay
- 894 mm/day from the main infiltration basin.

Figure 17: Sediment clogging in settling basin (forebay) following Year 2 scheme shutdown (July 2018).

3.5 GROUNDWATER QUALITY RESPONSES

3.5.1 Bacterial Concentrations

Groundwater samples collected from monitoring wells in October 2017, January 2018 and May 2018 were tested for *E. coli*. No detections were observed in any bore influenced by the Lagmhor Trial clean water plume. Even monitoring wells located close to the Lagmhor Trial site that show receiving water quality similar to the source water (GWD-01 within 30 m) did not detect *E. coli.* The reduction in *E. coli* counts between source and receiving water is due to continued Soil Aquifer Treatment (SAT) mechanisms which have shown to rapidly reduce any bacterial concentrations. The effectiveness of SAT with respect to the Lagmhor Trial was documented extensively in the Year 1 report (Golder, 2017).

3.5.2 Nitrate-N and Electrical Conductivity

In Year 2 the freshwater MAR plume continued along a similar path as observed in Year 1. Monitoring wells previously considered to be influenced by the Lagmhor Trial continued to maintain lower concentrations of nitrate-N than those wells not influenced by the trial (**Figure 18**).

One of the monitoring sites considered to be outside the influence of the Year 1 clean water plume (GWE-16) showed a slight decline in nitrate-N in 2018. This decline may be attributed to the movement of water from the upper perched layer down into the regional groundwater system (**Figure 19**). This well is screened over the interval 53 m to 54 m bgl and is therefore considered to be in the regional aquifer. Further monitoring at this site will indicate if the observed decline is due to the influence of the MAR plume.

Four of the new 2018 monitoring bores (K37/0751, K37/0980, K373146, K37/2324) show a change in water chemistry (nitrate-N, electrical conductivity, chloride, and hardness) between sampling events in January 2018 and May 2018 (**Figure 18**, **Figure 19**, **Figure 20**). One of these bores (K37/3146) showed a significant reduction in nitrate-N concentration between 23 January 2018 when the reported concentration was 17.7 g/m^3 and 14 March 2018 when the reported concentration was 7.3 g/m^3 (Environment Canterbury's Tinwald Nitrate Investigation). The bore is screened between 51 and 54 m bgl and is completed in the regional groundwater aquifer. As of February 2018, the plume interface is considered to have passed this location, which is seven kilometres down-gradient from the site. This bore does not have long-term historical water quality data so prior fluctuations in nitrate-N concentration are not known.

Monitoring wells outside of the clean water plume generally showed stable to increasing nitrate-N concentrations over Year 2 (**Figure 20**). One shallow monitoring well (GWD-07), screened from 4.5 to 10.5 m bgl and located outside of the clean water plume near Tinwald, shows sudden changes in water quality from low nitrate-N concentrations (approximately 5 g/m^3) to relatively high nitrate-N concentration (approximately 22 g/m^3) in a short timeframe (1 month). These rapid changes are associated with localised changes in the dominant groundwater source (influence from rainfall recharge and local drain sources). Water quality results from this monitoring well are treated with caution and are not considered to be associated with influences from the Lagmhor Trial.

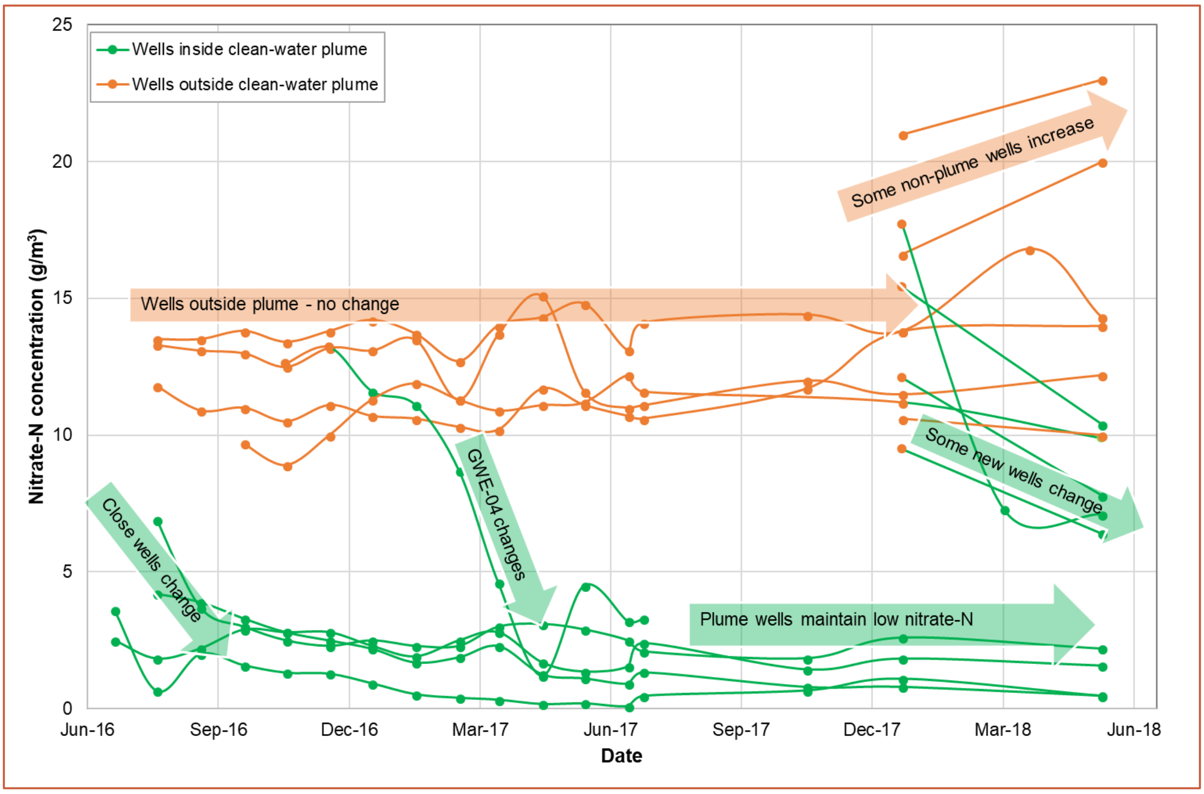


Figure 18: Nitrate-N trends over time in Lagmhor Trial monitoring wells.

Electrical conductivity was observed to decrease in the monitoring wells influenced by the trial (Appendix C, **Figure 21**). Electrical conductivity of the source water is lower than the receiving groundwater and is considered to be a relatively good indicator of the clean water plume extent from the Lagmhor Trial. Electrical conductivity can also decrease in some shallow monitoring wells due to local variations in recharge sources (e.g., GWD-07). The depth of monitoring wells is taken into consideration when assessing reliability of observed groundwater quality changes. The new monitoring wells generally have only two samples over Year 2, so the results need to be treated with some restraint. Continued monitoring will allow a more confident assessment.

The reduction in the nitrate-N concentration and electrical conductivity in samples from four of the new monitoring sites suggests the Lagmhor Trial clean water plume has reached these down-gradient wells (**Figure 19**, **Figure 21**, **Figure 22**). These monitoring wells are domestic water supply bores.

Other bores monitored as part of the Environment Canterbury's Tinwald Investigation showed relatively low nitrate concentrations and electric conductivity on the edge of the MAR plume (**Figure 23**). Due to the lack of historical data on some of these sites the concentrations cannot be solely attributed to the MAR trial. However, ongoing monitoring in the area may show the expansion of the MAR plume through time.

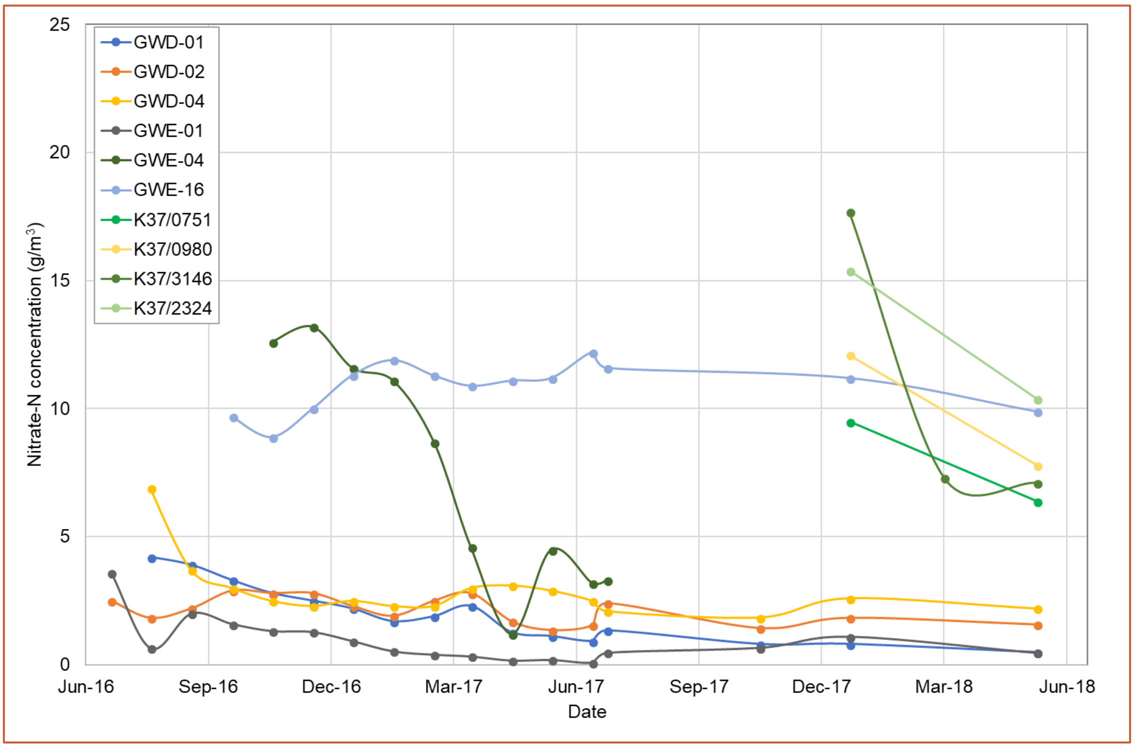


Figure 19: Nitrate-N trends over time in monitoring wells influenced by the Lagmhor Trial clean water plume (well locations shown in Figure 22).

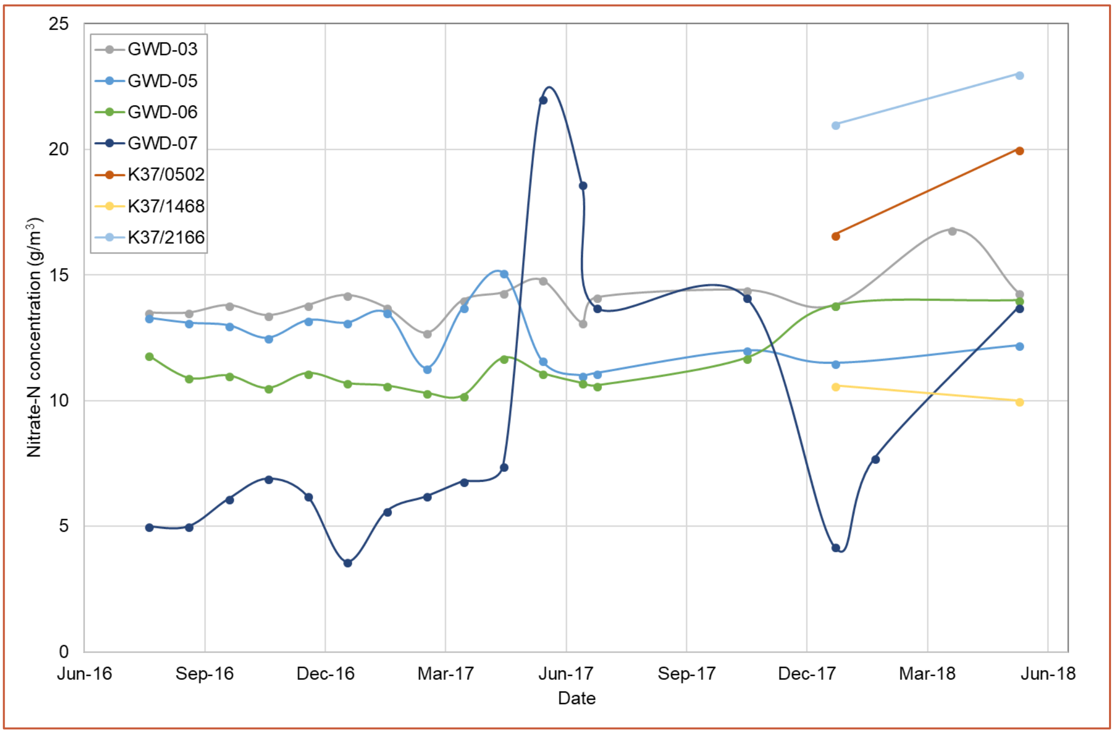


Figure 20: Nitrate-N trends over time in monitoring wells not influenced by the Lagmhor Trial plume (well locations shown in Figure 22).

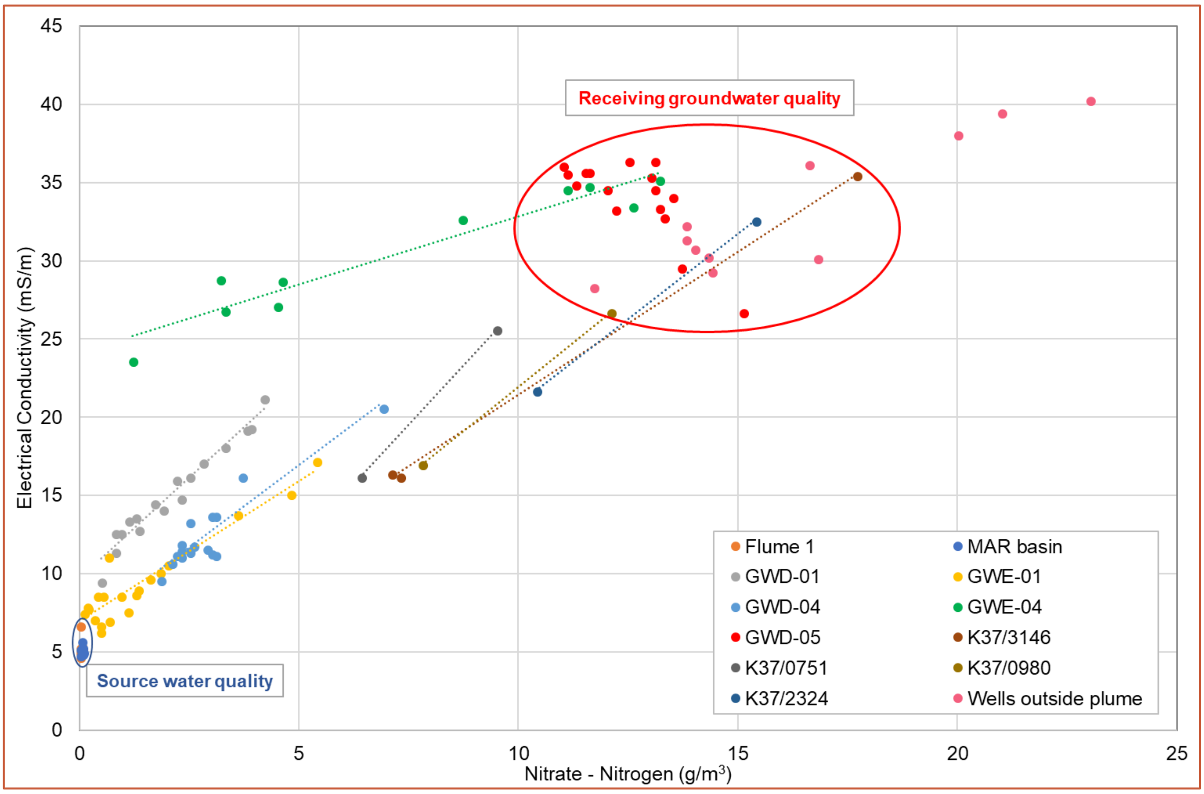
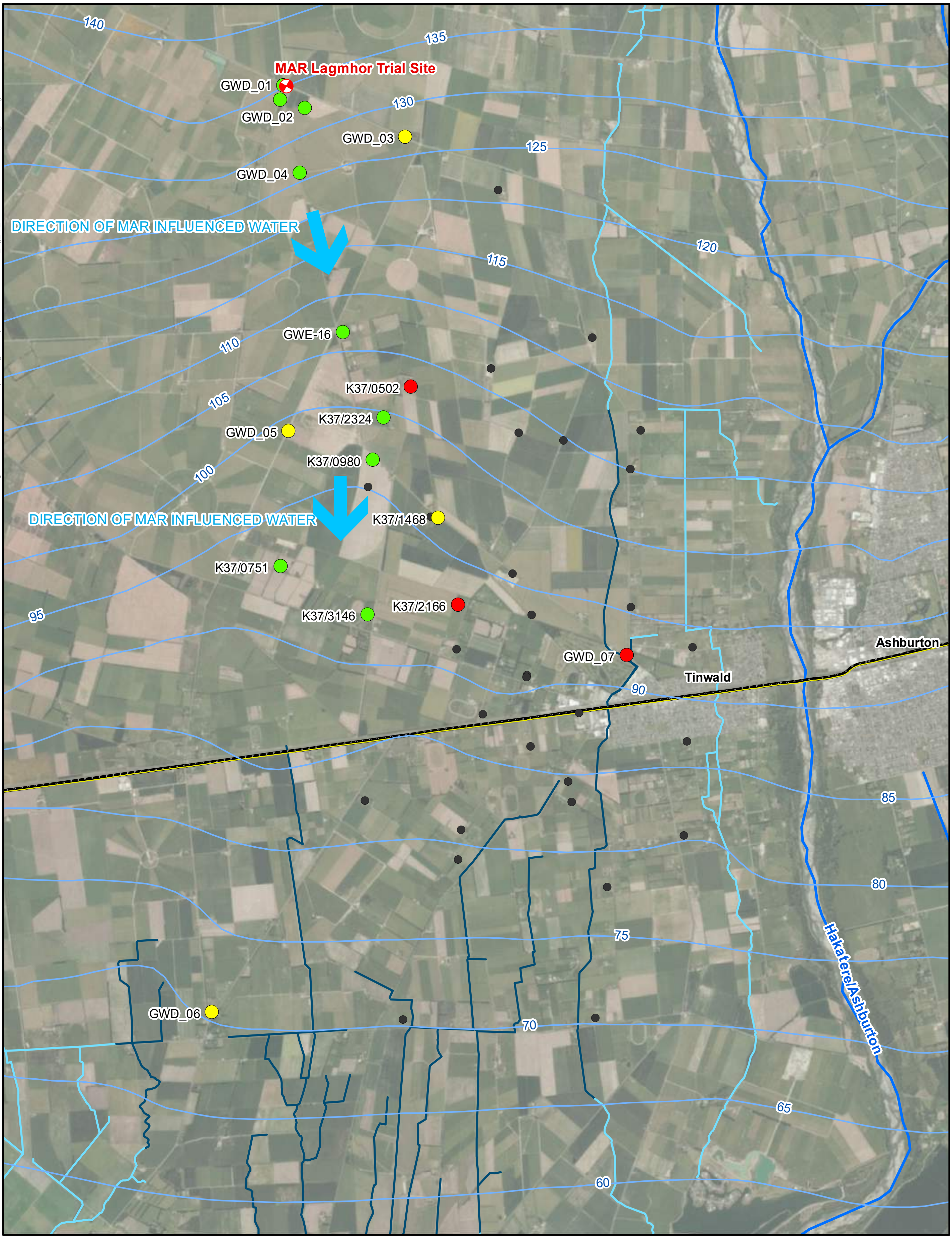
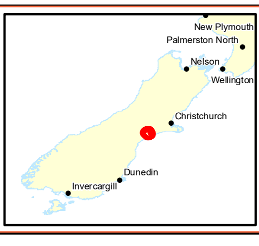


Figure 21: Nitrate-N versus electrical conductivity in monitoring wells.

The spatial distribution of the clean water plume presented in **Figure 24** is based on the observed water quality changes in four of the deep monitoring wells within the plume, while at the same time monitoring wells outside of the plume showed either stable or increasing nitrate-N concentrations. The direction of plume advance has changed slightly from that observed during Year 1, due to the piezometric surface and underlying lithology (Golder 2017a).

As the plume moves further from the infiltration site the water quality in the plume is expected to equilibrate with the surrounding groundwater. Based on a plume length of seven kilometres from the Lagmhor Trial site and a travel time of approximately 650 days, the plume is advancing at a rate of approximately 11 m/day. This rate is similar to the rate of advance calculated for the plume during Year 1, based on data from monitoring wells GWE-04 (9 m/day) and GWE-17 (7 m/day). The velocity may decline as the plume moves into areas of potentially increased permeability and it is expected to spread laterally in areas less restrained by the paleochannel geological feature. The rate and direction of plume advance may also be influenced by localised hydraulic gradients created by seasonal pumping and discharges to springs in the upper catchment of Flemington Drain.





N

0 500 1,000 1,500 m

Scale 1:65,000 @ A4

Coordinate System:
NZGD2000 New Zealand Transverse Mercator 2000

LEGEND

- MAR- Lagmhor Trial Site
- Tinwald Nitrate Bore (ECan)

Monitoring Bore Site

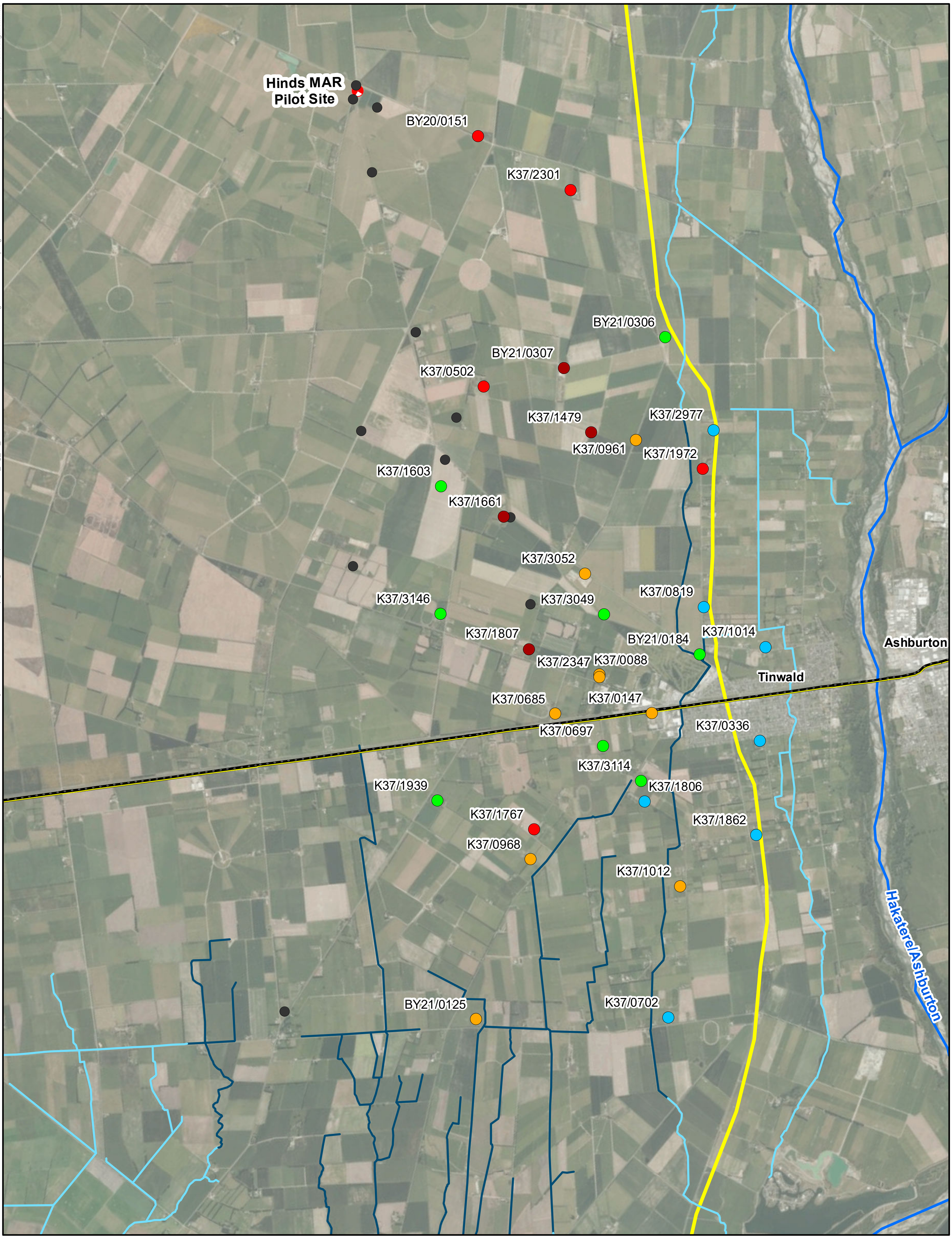
Nitrate Condition (May 18)

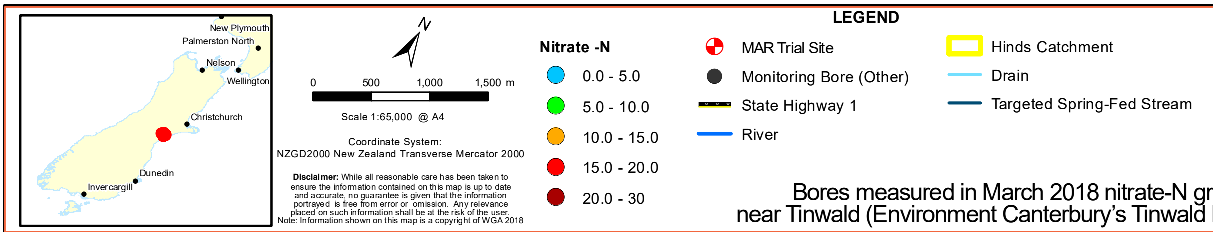
- Higher
- Stable
- Lower

- Direction of MAR influenced water
- Piezometric Contour (mRL)
- State Highway 1
- Drain
- Targeted Spring-Fed Stream
- River

WGA
WALLBRIDGE GILBERT AZTEC

Figure 22
Results of Nitrate-N Monitoring Showing Trends in Concentrations in the Direction of MAR Influenced Water





Disclaimer: While all reasonable care has been taken to ensure the information contained on this map is up to date and accurate, no guarantee is given that the information portrayed is free from error or omission. Any relevance placed on such information shall be at the risk of the user. Note: Information shown on this map is a copyright of WGA 2018

WGA
WALLBRIDGE GILBERT AZTEC

Figure 23
Hinds MAR Stage 2
Bores measured in March 2018 nitrate-N groundwater sampling near Tinwald (Environment Canterbury's Tinwald Nitrate Investigation)

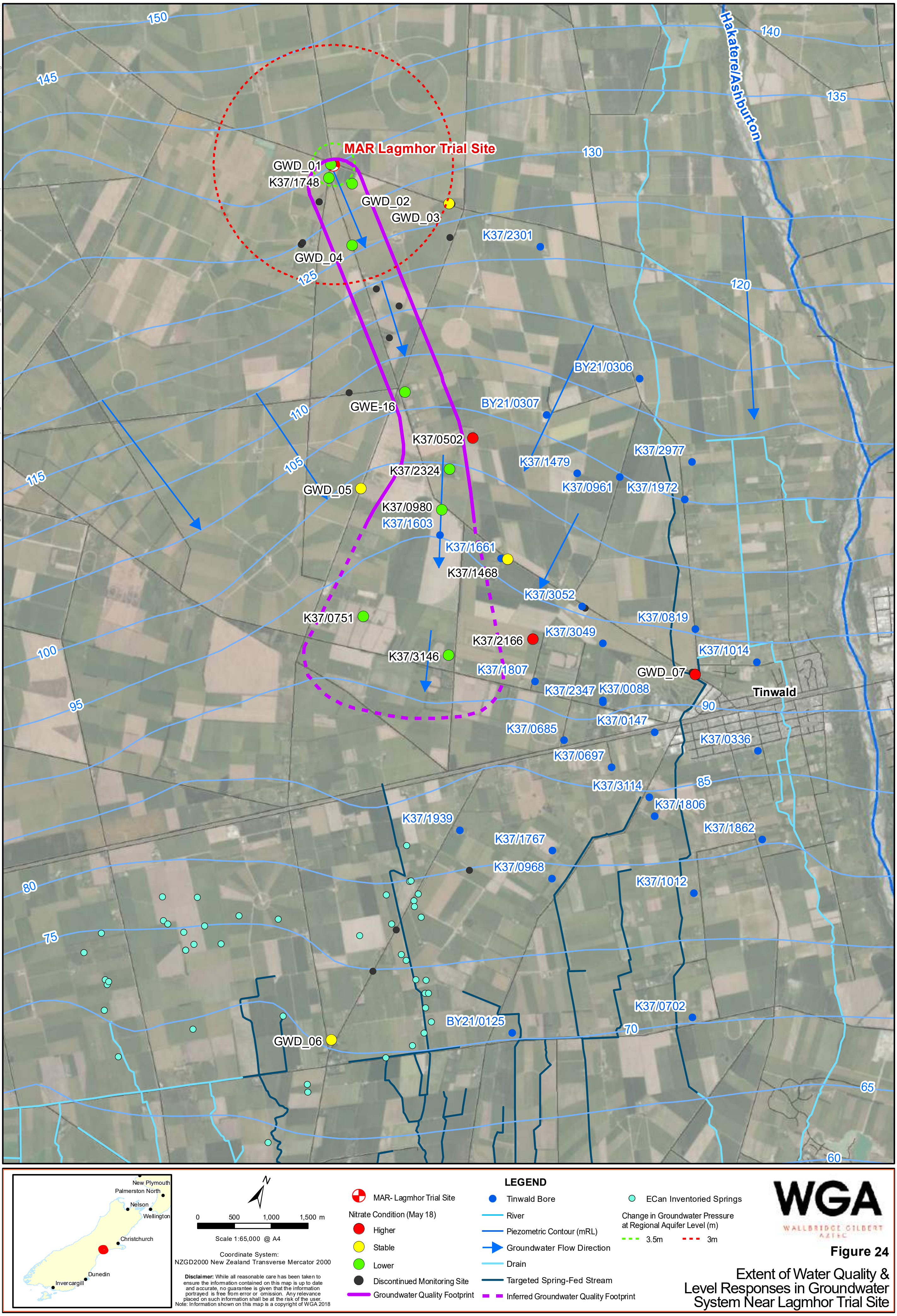


Figure 24
Extent of Water Quality & Level Responses in Groundwater System Near Lagmhor Trial Site

3.5.3 Automated Nitrate-N Monitoring

Automated nitrate-N monitoring was continued by Lincoln Agritech Limited (Lincoln Agritech) during Year 2 of the trial. The automated recordings were generally close to the laboratory results and gave a more detailed understanding of the fluctuations in nitrate-N concentration. Some breaks in the data occurred due to algae build up on the sensor (**Figure 25**). Regular cleaning and maintenance of the sensor is required. The frequency of automated results provided by Lincoln Agritech has reduced to daily averages.

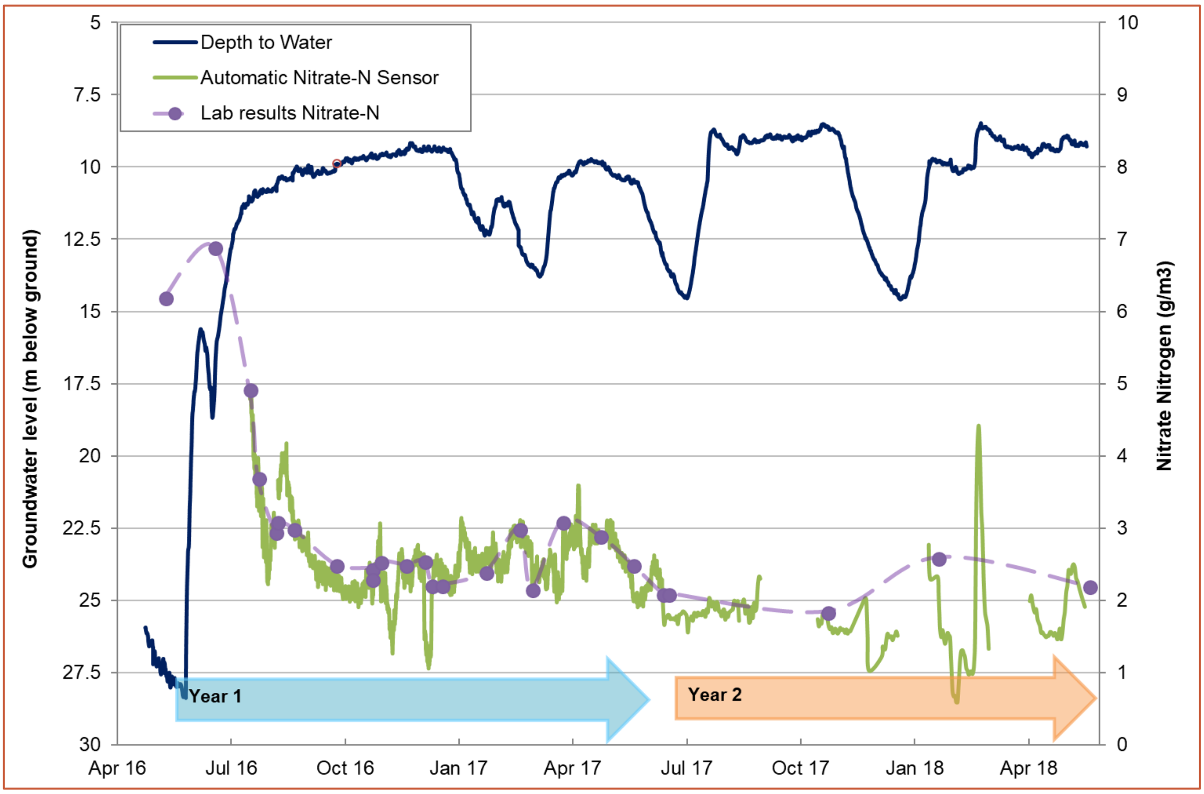


Figure 25: Nitrate-N concentrations in monitoring well GWD-04 (BY20/0152).

A significant spike in nitrate-N concentrations was observed in late February 2018 following a significant rainfall event (21 February 2018). This rainfall event caused a rapid rise in the groundwater levels in the monitoring well of approximately 1.5 m. Given the timing of the rainfall event in the summer period when soil nitrate-N concentrations are building up (because of soil mineralisation processes) local recharging water was consequently high in nitrate-N. Groundwater nitrate-N concentrations rapidly (6 days) declined back to a normal range of nitrate-N concentrations (1 to 2 g/m^3). The monitoring shows that groundwater nitrate-N concentrations have remained low in the area influenced by the clean water plume even after a high rainfall season.

3.6 SPRING-FED STREAMS/DRAINS RESPONSES

3.6.1 Flow

Local drains and spring-fed streams had been dry for an extended period during Year 1 (353 days). During Year 2 the drains began to flow following the large rainfall event in July 2017. Groundwater levels rose regionally in response to the high rainfall event and therefore provided baseflow to the local springs and drains (**Figure 26**). Drain baseflow appears to be supported when groundwater levels rise to approximately 4 m or less below ground level. However, there were periods in February 2018 where the flow in Flemington Drain at Montgomery Road dropped suddenly while groundwater levels remained stable (**Figure 27**). This could be due to surface water takes from the drain or stream-depleting local shallow groundwater pumping.

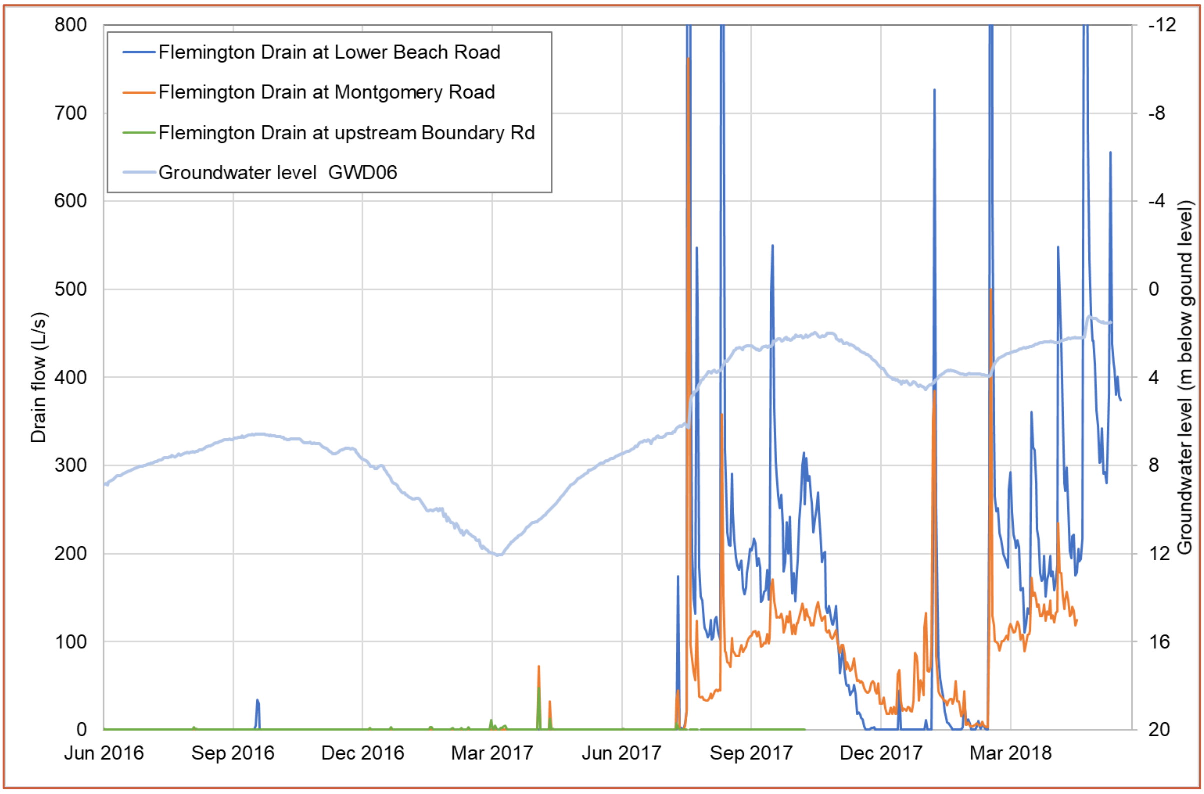


Figure 26: Flow below 800 L/s in Flemington Drain monitoring sites and groundwater levels in nearby monitoring well GWD-06.

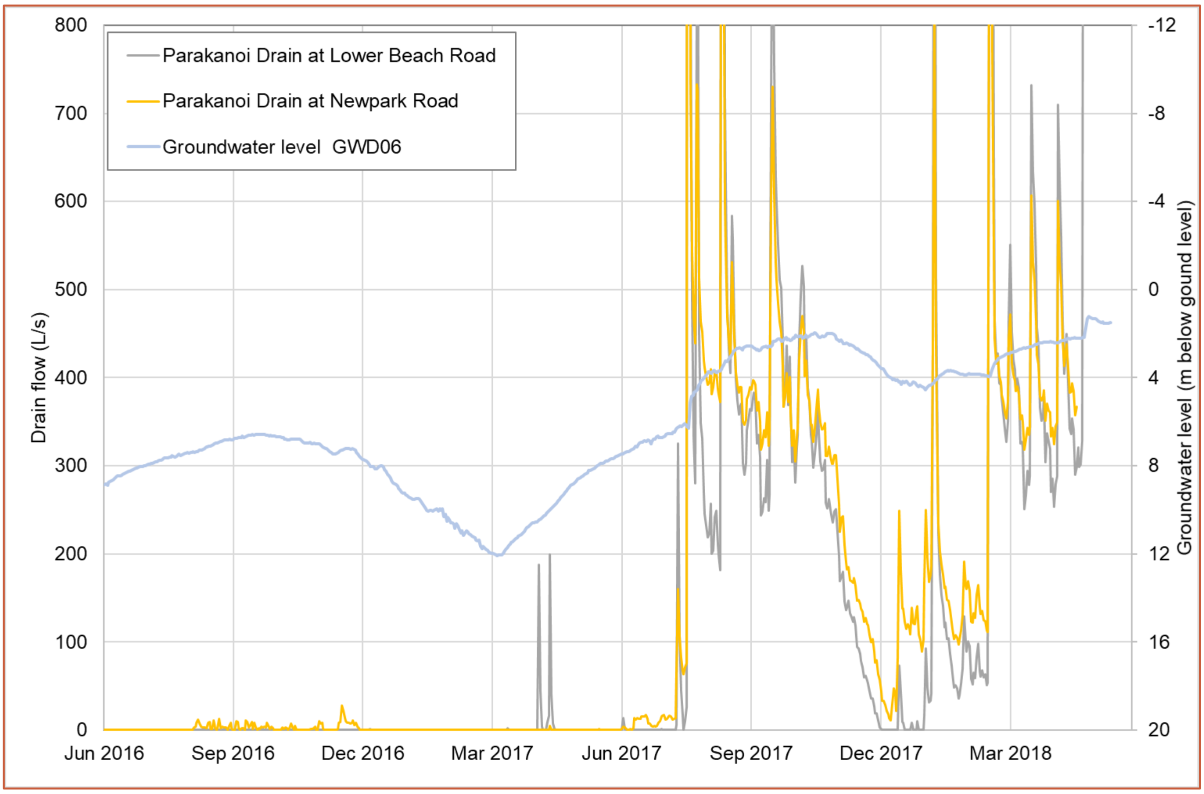


Figure 27: Flow below 800 L/s in Parakanoi Drain monitoring sites and groundwater levels in nearby monitoring well GWD-06.

Another indicator of the effects of abstraction from the Flemington Drain is the cross over in flow rates between the upstream site (Montgomery Road) and downstream site (Lower Beach Road) during November 2017. Spring-fed systems would generally gain flow in a downstream direction.

By comparison, the flows in Parakanoi Drain are higher in the upstream location (Newpark) compared with the downstream site (Lower Beach Road). Drain flows recovered at a similar time to the Flemington Drain although the flow rates are greater in the Parakanoi Drain.

3.6.2 Quality

Water quality sampling carried out by Fish and Game in the local spring-fed streams and drains have been plotted for Nitrate Nitrite Nitrogen (NNN) and electrical conductivity in Appendix C. Seasonal fluctuations are observed in the drains with generally lower NNN concentrations reported for sampling events carried out in early January. Maximum reported NNN concentrations reached approximately 10 g/m^3 in May 2018.

The nitrate-N concentrations in local groundwater observed in GWD-06 showed an increase to 14 g/m^3 in May 2018 (**Figure 28**). Effects of the clean water plume have not yet been observed in proximity to GWD-06. Provided the rate of plume advance remains consistent with the observed rate during Years 1 and 2, any changes in water quality at this distance (an estimated further 4.5 km from the edge of the clean water plume) would not be expected for at least another year.

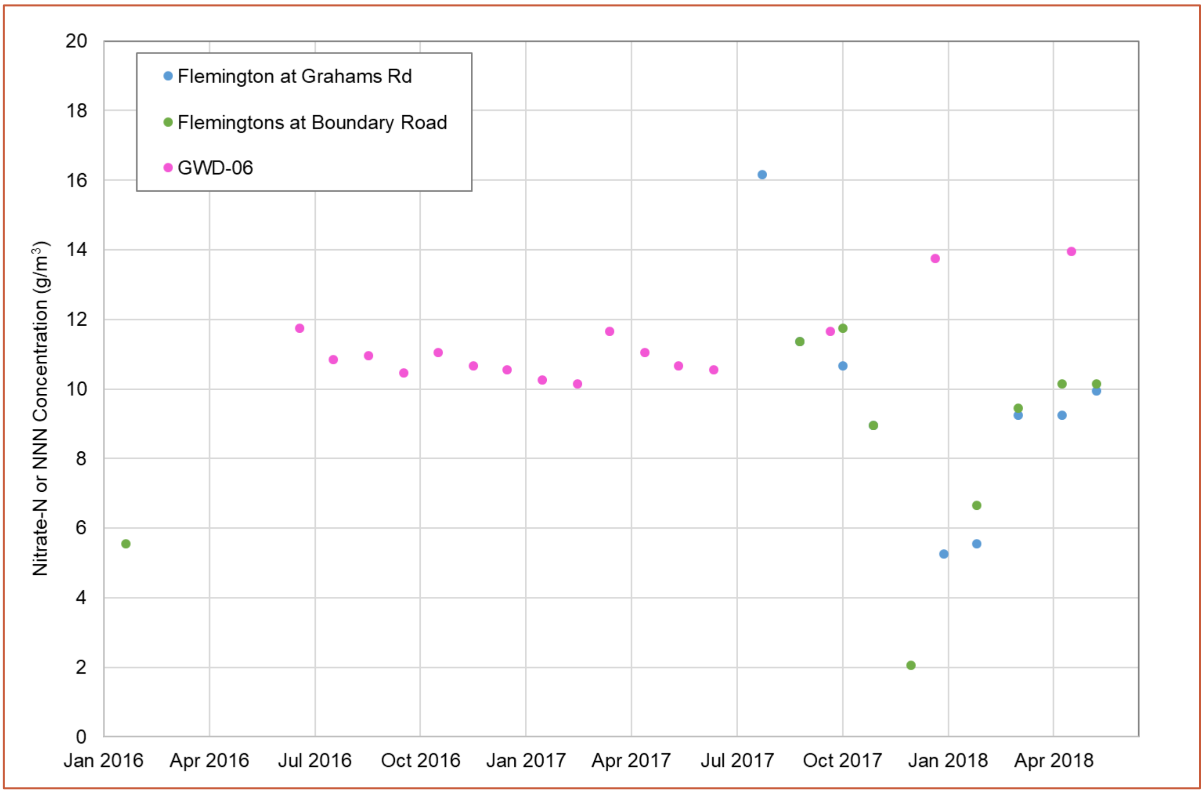


Figure 28: NNN concentrations in Flemington Drain and nitrate-N in nearby monitoring well GWD-06.

3.6.3 Ecology

Year 2 ecology monitoring of the spring-fed streams/drains was conducted by staff from the Environment Canterbury science team. Ecological monitoring included a combination of water quality monitoring, invertebrate sampling (using SHMAK D2 Method) and electro-fishing was carried out at the eight monitoring locations in the Flemington Drain and Parakanoi Drain (**Figure 4**).

The electro-fishing survey of Flemington and Parakanoi Drains (1/2/2018) was conducted by Dr Duncan Gray and Dr Adrian Meredith. The survey results indicated no fish were found at any of the survey sites. It was surmised that the drying reaches of the waterways close to the mouths (near sea) prevented many fish from recolonising the streams, which are recovering from an extended dry period. It was inferred that the invertebrate communities were changing over time. Given the potential arrival of the Lagmhor 'clean water plume' into the springs feeding these streams/drains, careful monitoring of these sites during Year 3 is deemed prudent.

4 LAGMHOR SITE UPGRADE

4.1 OBJECTIVES

Analysis of the Lagmhor Trial monitoring data indicated that the aquifers underlying the site can accept substantially greater recharge volumes than was achieved through basin infiltration during the first year of the trial. One of the objectives for Year 2 was to investigate the potential for enhancing the recharge performance of the Lagmhor Trial site.

4.2 BACKGROUND

Infiltration rates from the Lagmhor Trial site are in the order of 100 L/s (Section 3.2). This flow rate was less than had been expected based on the outcomes of site pre-feasibility testing. Following an initial test of the Lagmhor infiltration basin at the start of Year 1, a total of 24 clamshell holes were excavated to depths of six metres in the floor of the main infiltration basin to enhance the infiltration rates. Monitoring of infiltration rates showed that installation of the clamshell holes did not result in a substantial increase in infiltration rates.

Interpretation of the site hydrogeology from the Year 1 trial results suggests that MAR water infiltration to the regional groundwater table was restricted by lower permeability layers (bands of finer grained silts and clayey material) within the unsaturated zone beneath the site (Section 3.3). These lower permeability layers (aquitards) are located deeper than the six metre clamshell holes installed during Year 1.

In order to better understand the underlying site hydrogeology, to support site upgrade designs to achieve increased recharge rates, several investigation options were reviewed (WGA memo dated 23 October, Appendix E). Selected site investigations were then carried out to assess the best upgrade options to increase the overall recharge rate at the site.

The conceptual design and consenting of a site upgrade were completed in Year 2 (refer to documents attached in Appendix E). Construction of the site upgrade is planned for Winter/Spring 2018.

4.3 SITE INVESTIGATIONS

4.3.1 Investigation Options

Several options were considered for investigating local site hydrogeology, including:

- Intrusive investigations:
  - Additional drilling in the base of the main infiltration basin.
  - Geotechnical testing, such as the use of a cone penetrometer test rig.
- Non-intrusive investigation options:
  - Surface geophysical surveys.
  - Down-hole geophysical tests in existing monitoring wells.

– Tracer tests coupled with surface geophysics.

4.3.2 Investigation Method

Based on a thorough review of the available investigation techniques within the required budget and timeframes, the following investigation techniques were recommended by WGA and approved by the MAR Governance Group:

- A refraction seismic survey across the site to identify perched groundwater layers, the regional groundwater table and fine-grained layers to depths of up to 40 m.
- Ground Penetrating Radar (GPR) survey to identifying the geological layering and groundwater table beneath the basin.
- Natural gamma down-hole logging in monitoring wells GWD-01, GWE-01, GWD-03 and GWD-04.

4.3.3 Investigation Results

Natural Gamma Down-hole Logging

Natural gamma rays are primarily generated from the decay of naturally occurring potassium, which tends to be concentrated in clays and clay-derived rocks. Down-hole surveys are commonly used to identify clay-rich layers, including clay-bound gravels. A natural gamma survey does not detect groundwater and is not normally influenced by the degree of ground saturation. A hydrogeological interpretation of the natural gamma logs is presented in **Figure 29**.

Summarising the results from natural gamma down-hole logging:

- A unit relatively high in silt and clay is present between depths of approximately 5 m and 9 m bgl, which is considered to represent the uppermost minor aquitard (AQT1).
- A clay rich unit was identified at depths of between 19 m and 26 m bgl in GWD02 and GWE01. This unit may form part of a lower aquitard (AQT2).

Seismic Refraction Survey

A seismic survey was performed by Southern Geophysics Ltd to identify the structure of the sub-surface geology. One seismic refraction line (Line 1) indicated the presence of a shallow aquitard layer at a depth of between 4 m and 6 m below the floor of the infiltration basin. The results from the two other lines (Lines 3 and 4) suggested the aquitard is at a greater depth, from about 8 m to 10 m below the floor of the infiltration basin.

The deeper aquitard (AQT2), identifiable in the natural gamma log for GWE-01, has not been detected in the refraction seismic survey results. At the time of the geophysical survey, the regional groundwater table was close to the base of the lower aquitard (AQT2). Consequently, there may not have been a clear unsaturated zone below the base of AQT2 to be detected by the seismic survey.

Ground Penetrating Radar (GPR)

A GPR survey identifies the structure of the sub-surface in terms of boundaries between different materials. GPR will normally pick up a shallow groundwater table clearly. Eight GPR survey lines of various lengths were completed (Memo dated 6 December 2017, attached in Appendix E). The results of the survey lines were interpreted to indicate that the depth to the shallowest perched groundwater table was 3 m to 5 m below ground level at the time of the survey.

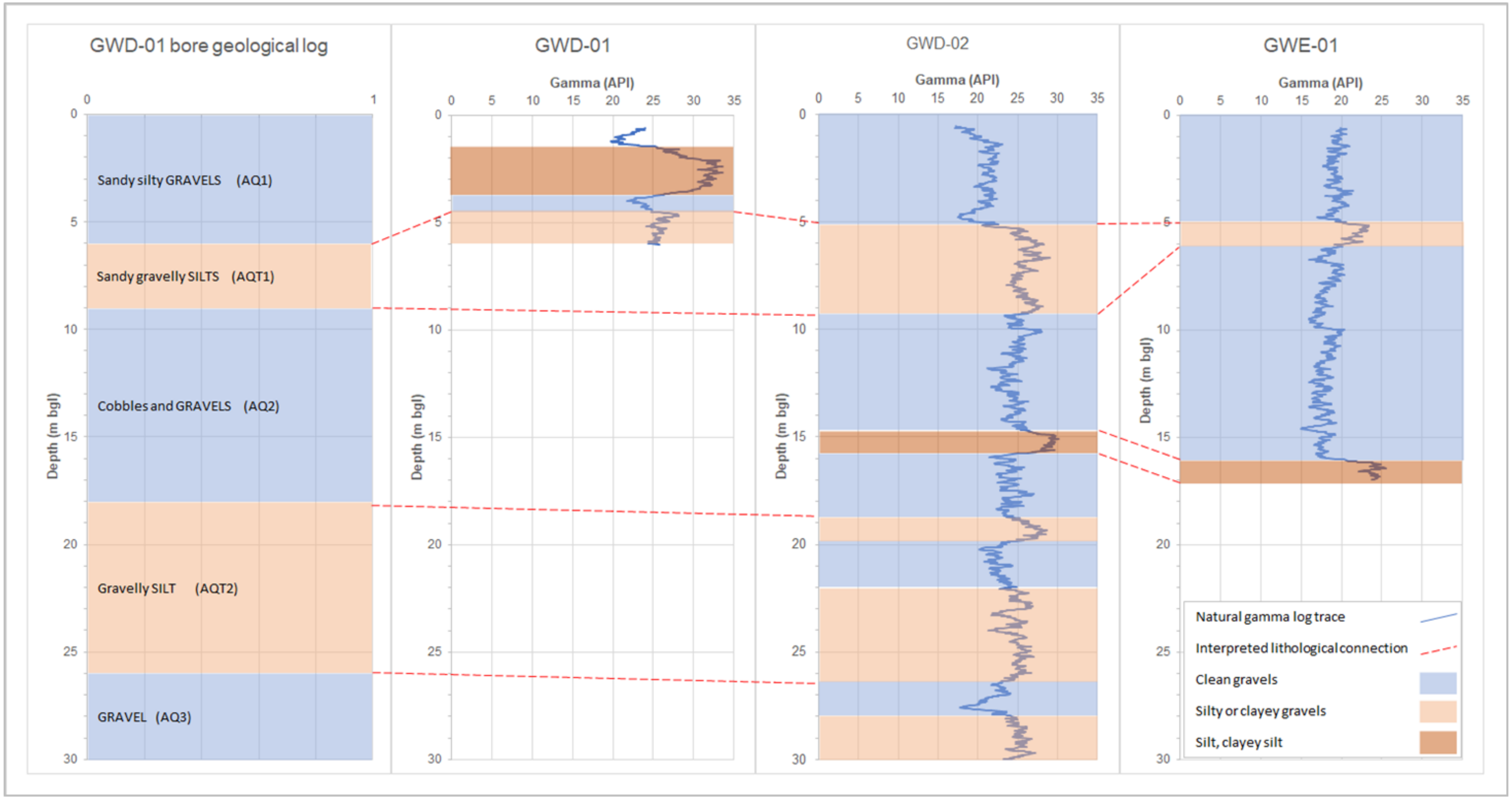


Figure 29: Natural gamma log interpretation for bores close to Lagmhor Trial site (locations shown in Figure 4).

4.3.4 Summary

Overall, the outcomes from the Lagmhor Trial monitoring, the results from the seismic refraction and GPR surface geophysical surveys and the natural gamma downhole logs are consistent with the interpretation of the presence of a shallow aquitard (AQT1) beneath the infiltration basin. This aquitard supports a perched layer of groundwater derived from the MAR site, with this groundwater mounding limiting the recharge rate from the infiltration basin.

A deeper aquitard (AQT2) is identifiable in the natural gamma log for GWE-01. The presence of this aquitard is consistent with the hydrogeological interpretation of the Year 1 trial results.

The combined information from the various lines of investigation supports the interpretation of the presence of two aquitard layers beneath the site. This information was used to support the design of site upgrade options, which would seek to direct source water past these layers and increase the overall site recharge efficiency.

4.4 RECHARGE ENHANCEMENT OPTIONS

4.4.1 Upgrade Options

A range of options were considered for upgrading the site to improve recharge rates. These options target either the perched AQ2 aquifer or the regional groundwater system.

The options considered were:

- One or more deep recharge holes (known as "dry wells") filled with clean cobbles. Deep recharge hole options include extending from the floor of the infiltration basin to either the regional aquifer (see **Figure 30**, Option 1a) or to the perched aquifer (Option1b). A significant consideration in this option was that once installed, any sediment clogging in these deep recharge holes cannot be reversed. This means that sediment loads carried by the source water require management within the infiltration basin.
- Blind recharge holes (**Figure 30**, Options 2a and 2b) to manage potential clogging. Instead of opening directly into the infiltration basin, the upper end of these holes is refilled with finer gravelly sands to remove most of the sediment load.
- Recharge wells similar to small water bores, which could be installed as conduits for water flows down into the target aquifers (**Figure 30**, Options 3a, 3b, 3c). These consist of steel cased wells (known as "dry holes"), with steel screens installed in either the target aquifer (Options 3a and 3c) or in the unsaturated zone above the target aquifer (Option 3b).
- One means of reducing sediment loads to recharge wells is the use of double screened wells (**Figure 30**, Options 4a, 4b and 4c). In a similar manner to the blind recharge holes, these wells would take water in through a screen positioned in the uppermost perched aquifer and discharge it to a deeper aquifer through a second screen.

Minimisation of sediment concentrations in the source water entering the conduit is the best way to initially reduce the risk of physical clogging within the recharge hole or well. Therefore, passive filtering of the water in the basin or modification of the forebay was considered as part of the upgrade.

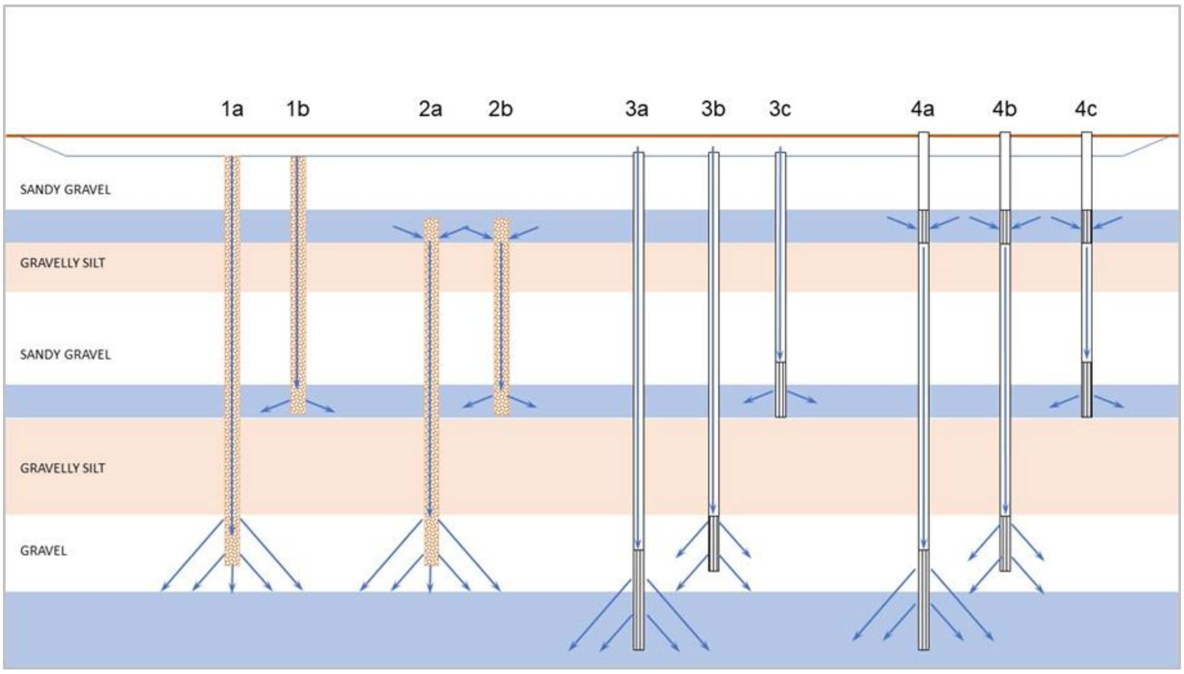


Figure 30: Recharge upgrade options targeting perched and regional groundwater systems.

4.4.2 Upgrade design and consenting

A WGA recommendation to proceed with the upgrade was approved by the MAR Governance Group on 6 December 2017 (WGA memo in Appendix E).

The MAR Governance Group-approved design was a dry well (termed 'soakage system') of a similar diameter and fill material to the existing clamshell holes (**Figure 30**, Options 1b). During excavation the hole is planned to be held open by a temporary steel casing, which is progressively withdrawn as the hole is backfilled with clean cobbles. Approximately eight metres of steel casing will remain at the top of the soakage system to ensure source water is delivered past the upper aquitard layer. Clogging of this upgrade is a risk as sediment transported into the soakage system cannot be easily removed. Sediment carried to the site in the source water is to be managed by settling in the forebay and in the main infiltration basin, supported by a complementary surface passive-filtering system.

During the first two years of the Lagmhor Trial, Soil Aquifer Treatment (SAT) has effectively removed *E. coli* from the infiltrated water to the extent that no pathogens were detected in water obtained from the perched or regional aquifers beneath the site during Year 2. A review of SAT processes by WGA indicates installation of the recommended soakage system is unlikely to significantly degrade the efficient pathogen removal observed during Year 1 of the Lagmhor Trial.

The concept design for the soakage system consists of:

- A drilled hole of 1.2 m diameter to a depth of approximately 18 m below ground level (bgl).
- Steel casing lining the dry well to a depth of approximately 8.0 m bgl, with a stick-up above the floor of the infiltration basin of approximately 1.5 m.
- A steel 50 mm or larger piezometer installed inside the dry well and screened at the base of the well.
- Clean gravel fill in the dry well from the base of the well up to a depth of approximately 8 m bgl.
- Coarse clean cobble fill in the dry well from 8 m bgl to approximately 0.5 m bgl.
- Access to the top of the dry well for monitoring and maintenance purposes.

Resource consents were applied for on 1 February 2018 granted on 17 April 2018. The consent for the upgrade is included in Appendix E. Conceptual designs for the upgrade are shown in the consent.

5 HINDS PLAINS NEW MAR SITES

5.1 INTRODUCTION

As part of the overall Hinds MAR Scoping Study, the MAR Governance Group (MAR GG) approved an initial testing programme for up to 16 new sites. A consent to operate these sites was approved by Environment Canterbury, with testing beginning in February 2018.

The overall testing programme is comprised of two phases:

1. **Initial testing programme (Task 4.2).** This is a short, technically focused phase where the hydraulic behaviour of each site is tested and recorded.
2. **On-going testing operations (Task 4.3).** Following a successful initial testing (Phase 1) process, a 'tested' site then becomes *operational* in nature. Each site is then operated to maximise the amount of recharge, collect on-going basic water quality and groundwater level data and observe any longer-term changes in flow rates or general conditions.

5.2 OBJECTIVES

The primary outcome for testing of the 16 new sites is to improve understanding of the wider MAR potential across the entire Hinds-Hekeao catchment. The results of these tests are to be used to support the development of a business case for a Groundwater Replenishment System (GRS) within the Hinds/Hekeao Plains catchment. The following is a list of key programme objectives:

- **Methodology:** Develop a site-selection and monitoring programme methodology that can be used to roll out the GRS programme under a global consenting approach.
- **Scientific Testing:** Locate and field test up to 16 new MAR sites across the Hinds catchment, to provide the MAR GG with feasibility and scalability information for the development of a business case to support development of a GRS.
- **Utilise up to 500 L/s:** Combined with the Lagmhor Trial site and the Hekeao/Hinds River Project, demonstrate a capacity to utilise all of the 500 L/s of stockwater currently available from ADC.
- **Catchment Outcomes:** Test MAR sites in different areas from the upper catchment to positions near spring-fed streams/drains, to address various quality and quantity outcomes required of the GRS programme.
- **Value Added Testing**: If a test location is suitable, quantify any additional benefits through either existing or additional monitoring. For example, if the test location is near an area with historically high nitrate levels indicated by existing Environment Canterbury bores. Use this information to demonstrate MAR application to the larger catchment outcomes.
- **Outreach/GRS Programme Momentum***:* Utilise the field testing programme as part of outreach efforts to enable more people to become aware and participate in the development of the GRS including site road signage for new locations.
- **Cost Effective MAR Tool Development***:* Evaluate different designs (e.g., soakage pits)
- **Local technical development**: Use the test programme to help upskill staff from the local community in the technical skills required for monitoring and site-evaluation.

5.3 METHOD

5.3.1 Site Selection

An initial site selection process was developed for the Hinds/Hekeao Plains by evaluating a range of physical and spatial factors. The primary considerations that went into the initial site selections were:

- Access to source water and quality of source water
- Access to site (land ownership) and local community interest
- Distance to natural recharge (e.g., Hekeao/Hinds River)
- Depth to the water table
- Interpreted groundwater flow direction (e.g., local or down-gradient benefits)
- Proximity of historical groundwater nitrogen issues
- Overall location relative to general GRS concepts
- Proximity of community drinking water supplies
- Proximity of potential monitoring bores
- Geostatistical modelling indicative permeability in top 30 metres (i.e. high, medium, low)

Twelve initial potential new test sites were visited during a field trip on 15 September 2017 where WGA, Environment Canterbury, Irricon, MPI and MAR GG members met to discuss merits of each site. A decision matrix was then generated to help prioritise the sites from a MAR suitability perspective, based on the selection criteria listed above. Further discussions with Environment Canterbury and WGA staff helped to develop an assessment methodology and a final list of sites was presented to the MAR GG for consideration. The final sites were chosen through an iterative process based on additional site visits, spatial distribution and reliability of source water delivery. Figure 1 shows the final locations of the new MAR test sites and a list of the sites is presented in Appendix F.

5.3.2 Water delivery infrastructure

MAR water is delivered to the new MAR test sites through the MHV Water irrigation scheme infrastructure. The network is separated into two major systems:

- An open channel network previously known as the Mayfield-Hinds Irrigation Scheme, and
- A piped network previously known as the Valetta Irrigation Scheme.

Multiple designs have been developed and applied for source water delivery, from the open channel delivery races or the piped network to the MAR soakage pits. The most common design supplies water from either the open channel or piped network to an existing on-farm irrigation pond. Pond water is then delivered to a MAR site via a siphon that discharges directly to a soakage pit (**Figure 31**). A second design supplies water directly from the open channel irrigation network via a siphon or v-notch weir to a soakage pit (**Figure 32**). A third design discharges directly from the Valetta pipeline to a soakage pit (**Figure 33**). A complete list of site specific designs is provided in Appendix F. Each design has advantages and disadvantages. The challenges identified in the testing are discussed in Section 5.4.1.

Sites that incorporate a siphon into the design have flow measurement recorded using an inline electronic flow meter. Sites that have water delivered without a siphon have flow measurement recorded using a v-notch weir and level logger.

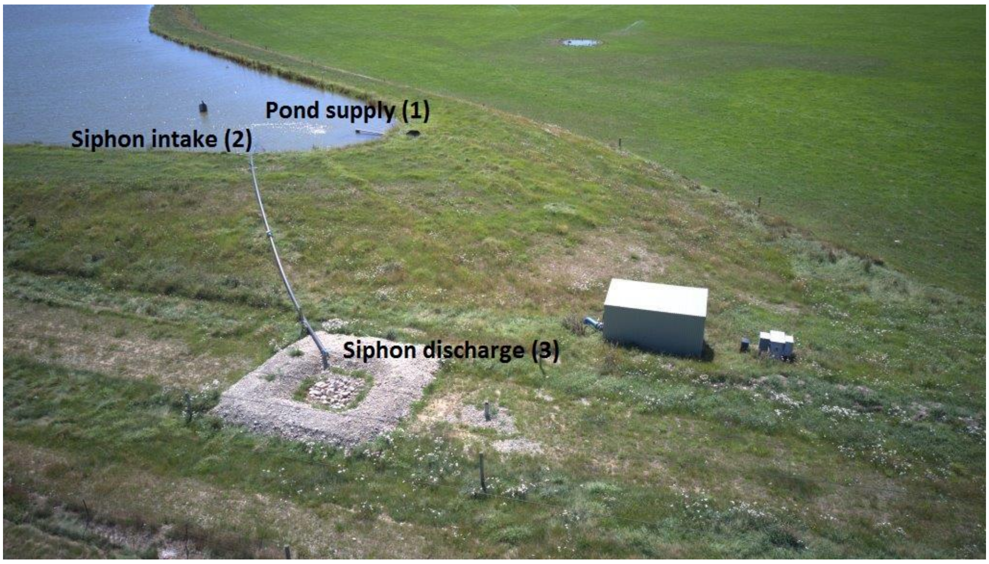


Figure 31: MAR Site #8 showing Valetta pipeline discharge (1), irrigation pond, siphon intake (2) and soakage pit discharge (3).

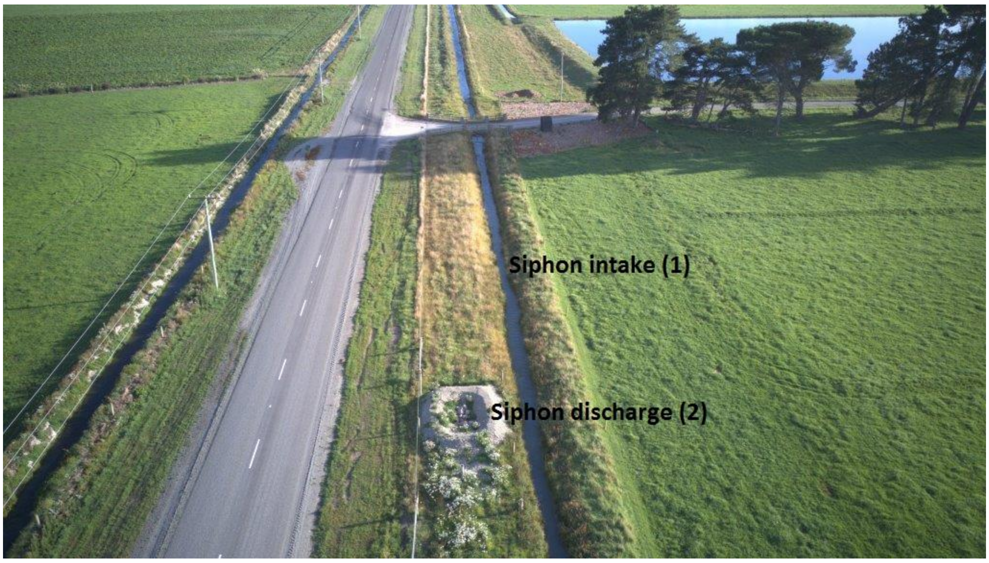


Figure 32: MAR Site #12 showing subsurface siphon intake (1) from an open race and discharge to the soakage pit (2).

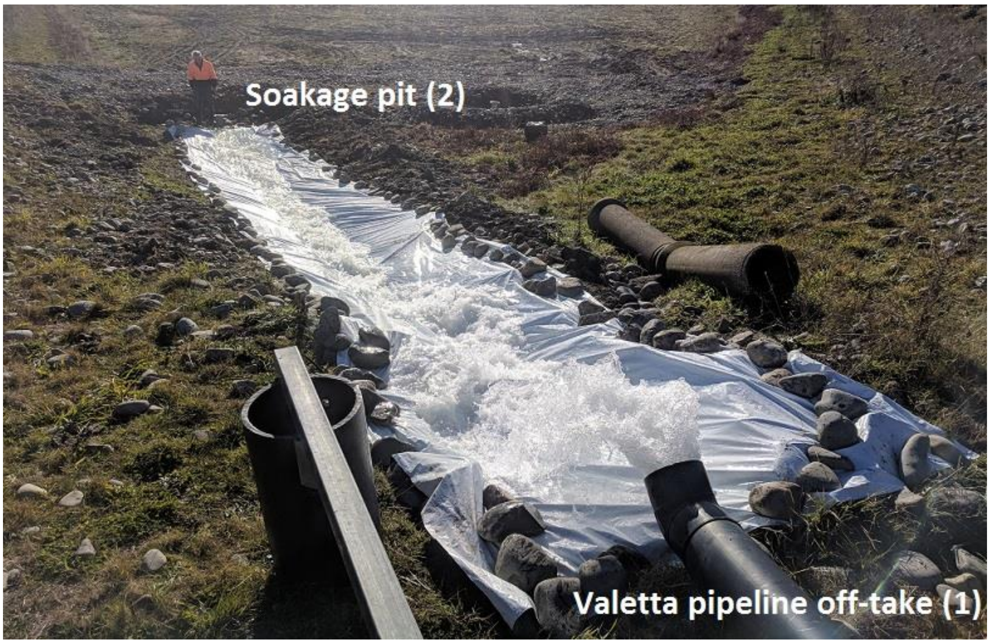


Figure 33: MAR Site #7 showing water discharge from a Valetta pipeline off-take (1) to the soakage pit (2).

5.3.3 Design and construction

A standardised design and site layout was implemented for all new test sites. The purpose of the standardised design is to ensure that hydraulic properties are uniformly tested across all hydrogeology types. A cross section of the design is presented in **Figure 42**.

Each test site consists of:

- Two pits, approximately five to six metres apart:
  - Infiltration pit, excavated to depth of 6 m, diameter approximately 1.5 m, and backfilled with clean cobbles.
  - Monitoring well pit, excavated to depth of 6.5 m, diameter approximately 1.5 m, and backfilled with material excavated from the pit.
- One steel standpipe piezometer installed in each pit, with the base of the standpipe sitting on the floor of the pit. Each piezometer is instrumented with a pressure transducer and data logger.
- An approximately 1 m high bund, constructed from compacted fine soils, surrounding the infiltration pit to retain any overflow water from the test. The monitoring well pit is outside the bund.
- In general, a gravity-fed water delivery line from the nearest water supply to the infiltration pit, fitted with a section of steel pipe through the bund, a digital flow meter and a valve to control flow rates to the pit. However, as described in Section 5.3.2, this delivery system varies depending on source water delivery system at each site.

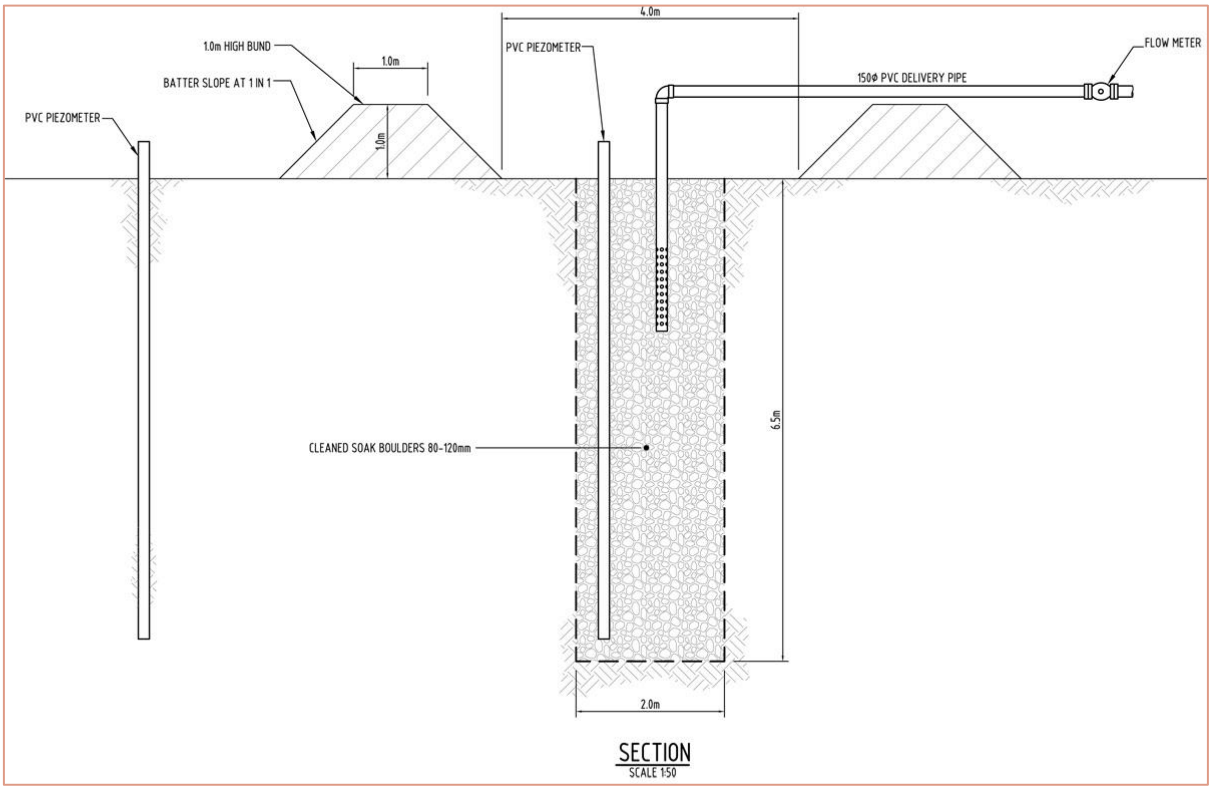


Figure 34: Cross-section of the standardised soakage pit.

5.4 OPERATIONS

The delivery of water and discharge rates at each MAR test site is managed by MHV Water staff. Historically, flow ceases in the MHV Water open race network at the end of the irrigation season. This restriction generally limits the delivery of water for MAR use to the irrigation season (i.e., September to May). In comparison, the Valetta pipeline can deliver water for MAR use throughout the year.

5.4.1 Challenges

During site construction, initial hydraulic testing and continued operations, multiple challenges were identified and resolved. These include:

- Pond siphons can lose their prime over time. As sites are checked at a maximum of 7-day intervals, it can be several days before a siphon is reactivated after this occurs.
- Changes in source water head (i.e., pond or race water levels) can have a strong influence on the flow rate through a siphon to a soakage pit. For example, a siphon may be set at a predetermined flow. As pond levels decline, the flow rate through the siphon may decline significantly in response. Alternatively, an increase in pond levels and flow through the siphon may inadvertently contribute to a breach of consent conditions (**Figure 35**). This is particularly difficult to manage at sites that are supplied directly from the open race network, where substantial changes in flow can occur throughout an irrigation season.

Figure 35: Red tag on floating level gauge indicates groundwater level compliance change (left in compliance and right outside compliance) following a change in pond water level.

5.5 HYDRAULIC TESTING

A series of hydraulic tests are being conducted on the new MAR test sites to characterise infiltration rates across the Hinds/Hekeao Plains. The key objectives of the initial hydraulic testing are to:

- Determine the infiltration rates achievable from a standard size test pit.
- Monitor and record infiltration flow data to enable a comparison between the sites tested and rating of the sites for further development.
- Determine if the infiltration rates or in-pit water levels change over time during the test, indicative of clogging risk.
- Determine how the “bulb” of introduced water expands within the surrounding soil during the test.
- Monitor and record infiltration water quality to demonstrate that a standardised MAR site can be operated without putting the quality of the underlying groundwater at risk from microbiological contamination.

5.5.1 Method

Each hydraulic testing consists of:

- A stepped increase in inflow rates, to determine the maximum infiltration rate for the soakage system.
- A period of constant inflow to the soakage system.
- A recorded recovery period after inflows to the soakage system have ceased.

Following the initial hydraulic testing, each site undergoes long-term soakage testing. Long-term flow rates are determined per site using data collected during the initial hydraulic testing. This long-term flow rate is determined based on a combination of:

- Water available for allocation under the water take resource consent.
- The flows accepted by the site and the trends in groundwater level at the site.
- The location of the site and prioritisation of the site under the catchment MAR test programme.

Weekly site visits are made during the long-term soakage testing. During these visits the following tasks are completed and documented:

- The groundwater level in piezometers on site are measured and recorded.
- The flow rate is recorded and adjusted to ensure ongoing compliance with consent conditions.

- A sample of the source water is obtained and delivered to a laboratory for analysis. The samples are analysed for *E. coli* and total suspended solids.
- Any physical changes to the site are photographed and the photographs included in the site record.
- Site shut-downs, either planned or due to unexpected conditions, are documented and monitored as per the procedure for the recovery stage of the soakage test.

5.5.2 Results

Hydraulic testing began on the first new MAR site on 28 February 2018 (MAR09). As of the 6 August 2018, hydraulic testing has been completed at six of the sixteen planned sites. Prior to and during the early testing period, major rainfall events occurred that contributed to an elevated groundwater level resulting in local and regional flooding, as described in Section 3.1. The elevated groundwater level influenced results of the hydraulic testing at some sites by reducing hydraulic head space, thus reducing the maximum infiltration rates. More recently, groundwater levels have receded, thereby allowing greater potential infiltration rates in soakage pits that intersect the groundwater table.

Results of the hydraulic testing are summarised in **Table 9**. The table shows the static groundwater level, and the flow rate used for each step test. The 'specific infiltration' is a measure of flow rate per change in head and relates to the site-specific hydraulic properties. The 'maximum potential 365-day infiltration rate' is a long-term projection that assumes a static background groundwater level (equal to groundwater levels during the test) and potential site-specific limitations. For example, MAR09 has a relatively high 'specific infiltration', however the shallow groundwater table at that site limited the maximum flow rate during the testing period.

Table 9: Step rate test results and long-term flow rate projections

Site ID	Step 1 flow (L/s)	Step 2 flow (L/s)	Step 3 flow (L/s)	Step 4 flow (L/s)	Step 5 flow (L/s)	Depth to SWL (m bgl)	Specific infiltration (L/s/m)	Maximum potential 365-day flow (L/s) (1)
MAR07	4.0	7.9	12.1	16.4		5.1	12	20
MAR08	4.8	12.5	18.6	22.2		3.76	7.0	15
MAR09	10.6	16.1	22.6	30.0		1.43	23	8
MAR13	4.7	6.8	11.6	17.7	19.1	5.15	12	35
MAR15	8.8	15.4	20.4	(2)		5.53	20	92
MAR16	4.7	7.8	10.3	14.6		6.49	4.7	14

Note: 1) Maximum flow potential is subject to changing groundwater level if the soakage pit intersects a shallow groundwater table.
2) MAR15 test prematurely terminated due to heavy rainfall.

5.5.3 Site Comparison

A visual comparison of site performance is provided in **Figure 36**. The results show that the new MAR test sites can typically receive long-term flow rates between 15 L/s and 30 L/s. An assessment of how representative these results are for the entire catchment will be undertaken once the testing programme has been completed.

Given the elevated groundwater level conditions during the testing, the results indicate a conservatively low infiltration performance at some sites. As groundwater levels recede, the maximum flow rate at these sites is expected to increase.

5.5.4 Source Water Quality

Water quality data is collected from the outflow pipe at each operational MAR site on a weekly basis as per consent CRC182576. The consent outlines two water quality trigger values related to *E. coli*:

1. Values exceeding 500 MPN/100 ml require immediate resampling to determine the cause, and
2. Values exceeding 700 MPN/100 ml require discharge to cease immediately and sampling of nearby shallow bores.

Source water quality data collected over the course of site testing is summarised in **Figure 37**. The results show source water *E. coli* values typically under 50 MPN/100 mL. Trigger values were exceeded at two different times. One count of 517 MPN/100 mL was observed at site MAR09, which triggered a resample. One count of 727 MPN/100 mL was observed at site MAR08, which triggered a site shutdown and sampling of a single nearby bore, as per consent conditions.

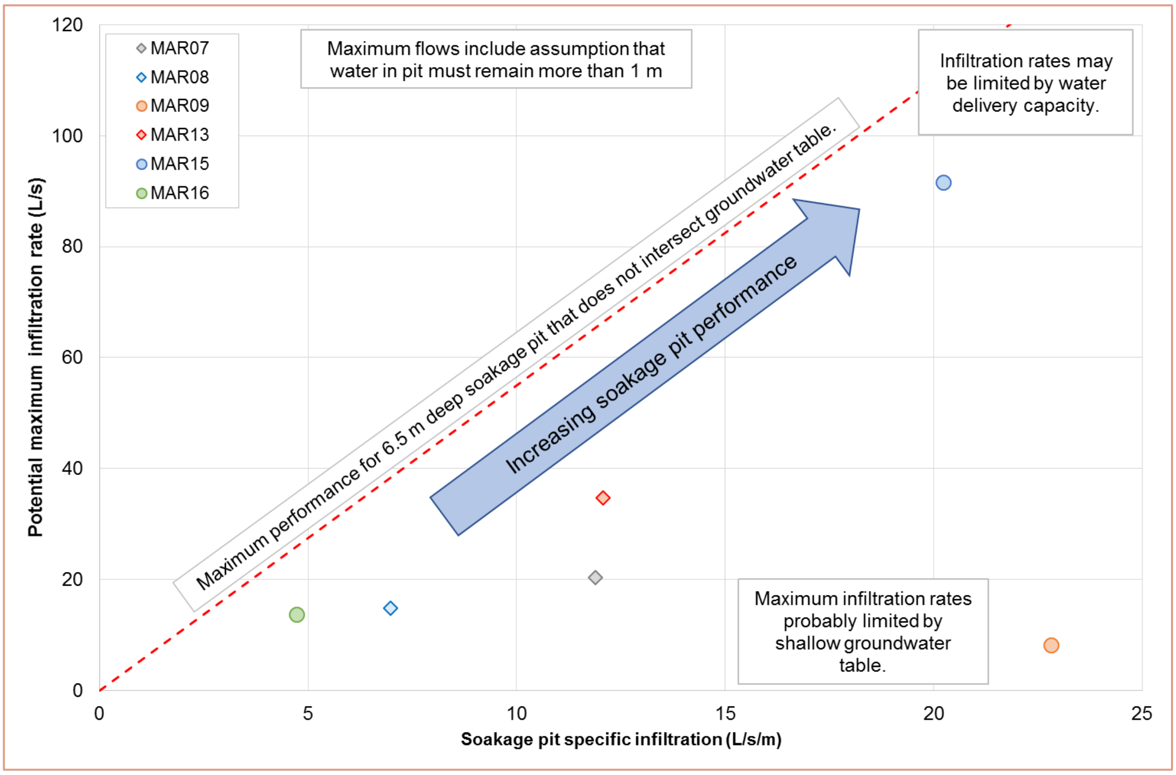


Figure 36: MAR test site projected performance and maximum infiltration rates.

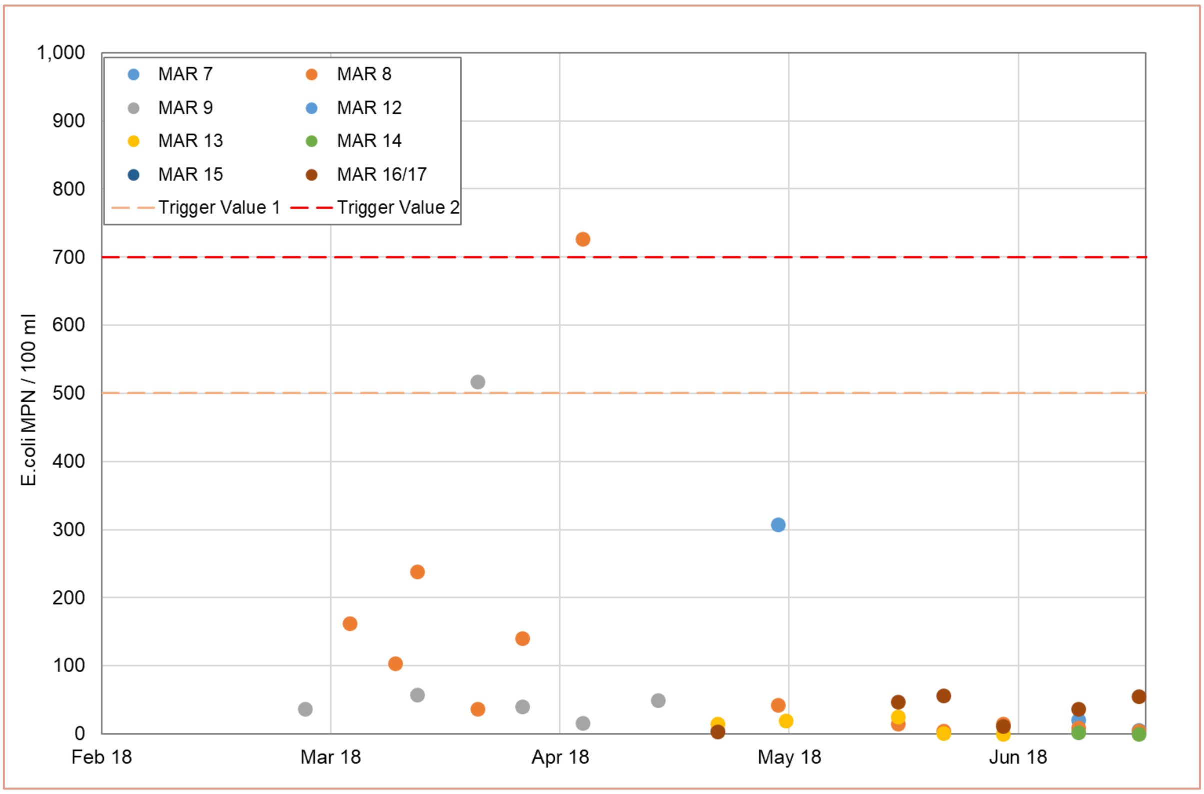


Figure 37: MAR test site source water quality

5.5.5 Water Delivery

MAR flow data is recorded by two types of flow meters. Sites MAR07 and MAR09 use existing volumetric flow meters, without a data logger. Sites MAR08, MAR13 and MAR16/17 use a flow meter with integrated data logger. As a result, flow rates at sites MAR07 and MAR09 must be estimated between known volume totals. In comparison, sites MAR08, MAR13 and MAR16/17 give flow data logged at minute intervals that show water delivery over time.

Flow data has been continuously recorded from 28 February 2018. A download of flow data took place on 19 June 2018. The cumulative volume of each site is presented in **Figure 38**. Hydraulic testing of site MAR15 was conducted shortly after the download, and is therefore missing from this site water delivery summary:

- Site MAR07 – Testing began 7 June 2018 and received water continuously for 3 weeks. Water delivery ceased due to infrastructure maintenance requirements. Total site volume infiltrated was 12,646 m^3.
- Site MAR08 – Testing began 6 March 2018. Water delivery has ceased multiple times over five months. The interruptions have related to the siphon losing prime, a breach of consent conditions related to water quality, and elevated groundwater level. Total site volume infiltrated was 111,709 m^3.
- Site MAR09 – Testing began 28 February 2018 and ran continuously until mid-April 2018. Flow ceased due to elevated groundwater level caused by several large rainfall events. Total site volume infiltrated was estimated to be 81,000 m^3, with the estimate arising due to a recent power loss to the flow meter.
- Site MAR13 – Testing began 24 April 2018 and ran continuously until end of June 2018. Water delivery was ceased due to a faulty flow meter. Total site volume infiltrated was 102,267 m^3.
- Site MAR16/17 – Testing began 24 April 2018. Source water delivery ceased on one occasion due to a large rainfall event on 29 April 2018. On 14 May 2018 the site was switched back on and has run uninterrupted since. Total site volume infiltrated was 44,766 m^3.

Cumulatively, this means that 352,388 m^3 of groundwater recharge was provided as of 19 June 2018.

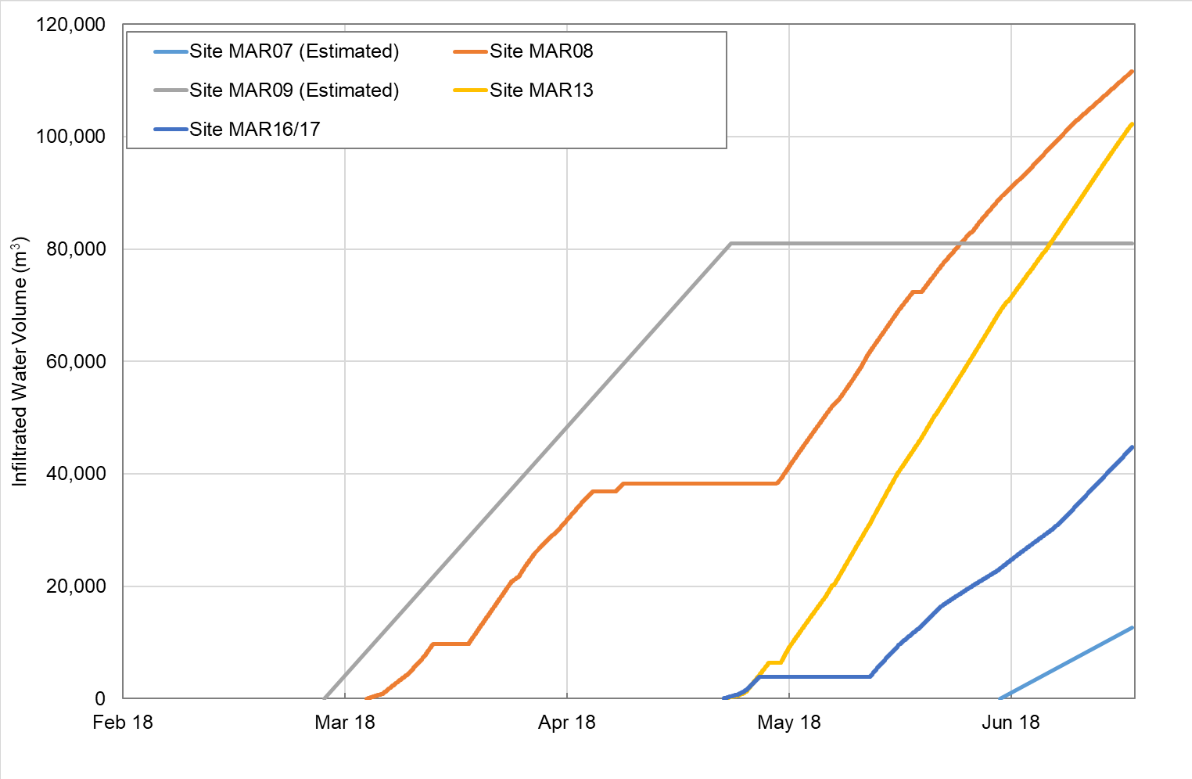


Figure 38: Cumulative volume of source water delivered per MAR test site.

5.6 LEARNINGS

This project has provided learning opportunities related to hydraulic testing and the operation of multiple MAR site designs on the Hinds/Hekeao Plains. The results shown in **Section 5** demonstrate the effectiveness of using smaller MAR sites as a tool for regional groundwater recharge. Operating the smaller MAR sites also has both individual and collective challenges. A summary of the learnings to date include:

- **Water quality sampling** – Current consenting requires weekly testing of *E. coli* collected from each MAR site discharge point. Scaling up the number of sites across a catchment will contribute to practical and economic difficulties.
- **Source water protection** - The open race sections of the MHV Water irrigation scheme are relatively unprotected from external contamination, in comparison to the Valetta pipeline. A review of the water delivery system to each individual MAR site would help improve source water security.
- **Site design feedback** – MAR sites supplied directly from an open race proved difficult to maintain a steady flow rate. This is caused by fluctuations of flow in the supplying race that may change substantially over a week. In comparison, MAR sites that derive water from a pond typically have much steadier flow rates and are overall easier to manage. The irrigation ponds also provide storage, which allows a MAR site to continue operation despite water delivery restrictions (e.g., water restrictions due to low flows in the Rangitata River).
- **Moving to automation** – Flow rates at all new MAR test sites are operated manually through the butterfly valve on the siphon and recorded in the internal memory of the flow meter. The butterfly valves are typically highly sensitive. For example, a half turn adjustment of the valve typically increases a siphon's flow rate in the range of 1 L/s to 5 L/s and can unintentionally cause a greater increase in groundwater level than intended. This can lead to a subsequent breach of consent conditions. Automating the flow rates and telemetering the flow and groundwater level monitoring has the potential to maximise water delivery and reduce breaches to consent conditions.

6 HEKEAO/HINDS RIVER PROJECT

6.1 OBJECTIVES

The objective of the Hekeao/Hinds River Project (HHRP) is initially to increase the magnitude and reliability of baseflows in the Hekeao/Hinds River and thereby improve the river ecology. This objective is to be achieved through the planned introduction of water sourced from the Rangitata River to two groundwater recharge areas located close to the Hinds River South Branch (**Figure 1**).

The project has been designed to incorporate a range of beneficial outcomes (Figure 39) that have been clearly identified by various stakeholders in the community whilst still working toward achieving the targets for environmental restoration, reversing declining trends in groundwater levels, and improving groundwater quality in the catchment. It is highly consistent with the outcomes sought by the Ashburton Zone Committee ZIP, aspirations of the MAR GG, and focuses specifically on priorities identified by Te Rūnanga o Arowhenua.

Figure 39: Multiple Objectives for the HHRP.

6.2 METHOD

The HHRP involves supplementing the Hekeao/Hinds River flows (and associated biodiversity and potable supply enhancements) through introduction of water sourced from the Rangitata River and delivered via the Rangitata Diversion Race (RDR). This water consists of un-utilised consented stockwater currently being provided for the Managed Aquifer Recharge (MAR) testing programme by the Ashburton District Council (ADC).

The project site is located on the Hinds River South Branch in the Upper Hinds River catchment (Figure 1). The natural flood plain of the Hinds River South Branch is to be used as an infiltration area, with up to 200 L/s (daily average) of source water routed from the RDR to the proposed recharge areas and percolating through the soils adjacent to the Hinds River, recharging the underlying shallow groundwater. As this groundwater moves down-gradient and radially outward from the site, it will result in an increase in baseflows in the Hekeao/Hinds River as well as recharge the regional aquifer system. Given the proximity of the recharge activity to the river, the term Near River Recharge (NRR) has been used to describe the physical process.

A key design criterion for the HHRP is to minimise the risk of direct ‘mixing of waters’ (water from one river directly discharging to another river), by agreement with Te Rūnanga o Arowhenua. The ‘passing of the water through soils’ on river flood plains, thereby recharging shallow groundwater near the river, is the physical method being used to accommodate this criterion.

Another key design feature of this project arises out of Te Rūnanga o Arowhenua’s interest and overall benefit in re-establishing native riparian/terrestrial plant species on these flood plain areas. These areas are currently heavily covered in Scottish broom, gorse, blackberry and Cotoneaster sp., with large patches of *Muehlenbeckia australis* in places. The use of a technique called ‘seed bombing’ with native plant species will be conducted at the initial stages of the HHRP. Direct planting of additional species will also be undertaken. As increased recharge provides more consistent shallow groundwater, this will help native plants to re-establish and begin to reclaim this 24 ha area of river valley flats.

The overall HHRP area includes two designated recharge (infiltration) areas located on the historic flood plain. Water will be delivered via an open channel to recharge Area 1 (**Figure 40**). A delivery race will divert any water not recharged in Area 1, down-river past a natural oxbow or wetland area, to Area 2 (**Figure 40**). Both Area 1 and Area 2 appear to be natural geomorphological features of the Hinds River South Branch formed prior to the construction of the RDR and Hinds River syphon.

Area 1 will be designed to combine natural raised topographical mounds with some artificial bunding (excavator) to separate the low-lying recharge area from the river. This design feature is key to ensuring recharged water is filtered through the natural floodplain and minimising the risk of direct flow into the river. The delivery race is designed to ensure that any water not recharged in Area 1 is directed past the wetland area to Area 2. Given the geology of these flood plain areas (e.g., depositional materials ranging from large cobbles, to gravels and sedimentary silts), it is envisaged that most of the recharge will occur in Area 1, with Area 2 available to accept any excess.

The wetland located between the two recharge areas is a key feature of the HHRP as it provides habitat for eel and other fish species. Intermittent drying and perennial low flows during summer months limits the ability of eel (tuna), kanakana (lamprey) and other fish species to establish in the wetland. Consistent, year-round baseflows derived from Area 1 recharge will help to transform this wetland from a low productivity habitat to a more diverse and consistent refuge. Fish passage is possible to this wetland area through a natural channel connecting the lower area to the Hinds River South Branch, which is currently normally dry, as well as through a high flow connection to the river at the mid-point of the wetland.

The HHRP is designed to operate consistently throughout the year when the consented ADC water is available and the RDR is physically able to deliver the water. During large regional rainfall events, the recharge operations will be curtailed to avoid contributing to local flood flows.

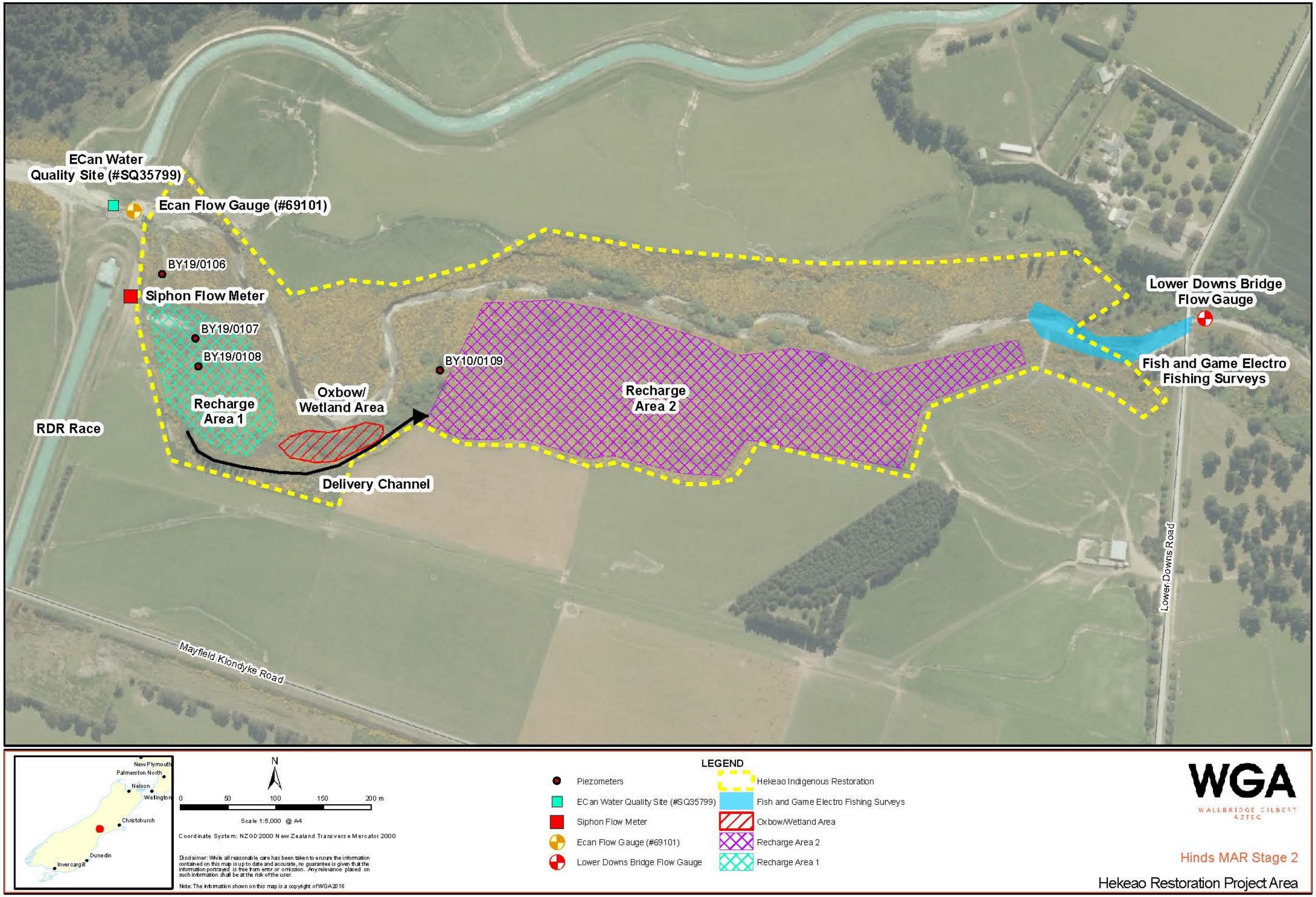


Figure 40: HHRP Site Overview.

6.3 MONITORING

A comprehensive monitoring programme has been designed to identify the extent of beneficial effects to river flows and groundwater levels. Monitoring for the HHRP will consist of both quality and quantity measurements for groundwater and surface water resources (**Table 10**, **Figure 40**). As a part of the overall 'testing' of the HHRP, an evaluation of the changes in surface water quality and quantity from the increase in Hinds River South Branch baseflows is planned. Monitoring is also planned to support an understanding and validation of the expected beneficial changes in aquatic habitat, native and non-native fish species and overall stream health.

Table 10: HHRP Monitoring Sites and Sampling Frequencies.

Monitoring Category	Parameter	Location	Sampling Frequency
Quantity	Recharge source water	Project Syphon from RDR	15-minute flow
	River upstream (control)	ECan South Branch upstream of project (#69001)	15-minute flow
	River downstream (effects)	Temporary Gauge on South Branch at Lower Downs Bridge	15-minute flow (temp)
	Site groundwater	Levels – all 4 site piezometers	15-minute level (temp)
	River (control)	Site Inflow Source (#SQ35799)	Monthly
Quality	Groundwater	ECan and ADC monitoring bores (including Mayfield Community Supply - K37/3290)	As is sampled by ECan/ADC
	River upstream (control)	Site Inflow Source (#SQ35799)	Monthly
	River downstream (effects)	Temporary Gauge on South Branch at Lower Downs Bridge	Monthly
	Site groundwater (receiving)	BY19/0107	Monthly
	Regional groundwater quality (receiving)	ECan and ADC monitoring bores (including K37/3290)	Monthly
Aquatic Ecology	River downstream (effects)	Recharge Above Temporary Gauge on South Branch at Lower Downs Bridge	Annually (Fish and Game, ECan)

6.4 CURRENT PROJECT STATUS

Resource consent for the operation of the HHRP was applied for on 28 June 2018. At the time of preparing this report the consent process was still ongoing and not yet granted. A tentative community native planting day and site commissioning is being planned for spring 2018. Representatives from the Mātaitai Committee at Te Rūnanga o Arowhenua are expected to be in attendance and have offered a traditional blessing as part of the commissioning.

7 HINDS/HEKEAO PLAINS BASELINE WATER QUALITY

7.1 OVERVIEW AND OBJECTIVES

In 2017, the MAR Governance Group technical support team identified that an improved spatial understanding of groundwater and surface water quality across the Hinds/Hekeao Plains was needed. Whilst some portions of the catchment had extensive monitoring information, data in other areas was sparse, leading to an incomplete understanding of the overall water quality baseline. Additionally, data was being collected by a range of entities (e.g., Hinds Drains Working Party, local and regional government, etc) but it was not being collected and compiled into a comprehensive baseline database. This more comprehensive understanding of water quality was flagged as a critical need, both for the development of the GRS as well as to help the farm community and their efforts to make significant 'on farm' management changes and reduce nutrient reductions.

The main objectives for this project were twofold;

1) Improve communication and coordination between all relevant data sources to create a more complete picture of the overall water quality and a shared database, and

2) Develop a programme to generate an overall improved baseline water quality map which would help to inform the overall GRS design and assist the on-farm nutrient reduction efforts.

In addition to the MAR trial monitoring programme discussed in this report, there are other entities known to be collecting water quality data in the Hinds/Hekeao Plains including;

a) MAR GG automated nitrate groundwater sensors programme (two sites, one bore in each Groundwater Allocation Zone).

b) Environment Canterbury – State of the Environment (SOE) surface and groundwater monitoring programme.

c) Environment Canterbury – Special Science Projects (e.g., Tinwald Investigation).

d) Ashburton District Council – Community water supply monitoring.

e) Canterbury District Health Board – Special Projects (e.g., Tinwald Investigation 2016).

f) Hinds Drains Working Party (HDWP) – streams/drains water quality monitoring.

g) MHV Water Ltd – Special investigations including surface and groundwater water quality monitoring and a groundwater aging study.

h) Other individual landowners and private citizens.

This project was anticipated to be started in 2017 and be completed in late 2018 / early 2019. This section summarises the process to date in achieving these two community objectives.

7.2 RESULTS TO DATE

Communications with the known entities collecting water quality data was conducted allowing the following summary of current programmes to be generated. At the time of this report, data was insufficient to generate a robust catchment-wide baseline water quality map.

7.2.1 Hinds/ Hekeao Plains Monitoring and Special Investigations

Hinds/ Hekeao Plains wide groundwater quality monitoring is carried out by Environment Canterbury in 27 monitoring wells as part of their State of the Environment monitoring and reporting. These monitoring sites are shown in **Figure 42**. A range of shallow wells and deep wells are monitored to assess water quality changes within the shallow and deep groundwater system. Wells range from 5 m deep to 160 m deep and are distributed throughout the Hinds/Hekeao Plains.

In addition, a study is being carried out by Environment Canterbury in Tinwald (Tinwald Nitrate Investigation) which involved sampling 33 wells used as domestic water supplies. These wells were sampled between February and April 2018 as described in Section 2.6.2 and at locations shown in **Figure 23**. Further analysis on the source of nitrate-N in the wells is currently underway and a report is due late 2018.

Other general sources of data include Ashburton District Council (ADC) which collects water quality data for three community supply bores in the catchment, in the townships of Hinds, Mayfield and Ashburton (south of Ashburton River). Bacterial and nitrate information is collected monthly and used as part of their reporting requirements for community supplies. The Hinds Drains Working Party, working with Fish and Game, Dairy NZ and Environment Canterbury, has been collecting nitrate information for spring-fed stream/drains sites in the lower catchment since 2015 as outlined in Section 3.6. MHV Water has also started special investigations into water quality across the district, which will help to cover the areas with sparse coverage of groundwater quality data.

7.2.2 Automated Nitrate Monitoring

Dedicated automated nitrate sensors provide a more comprehensive ‘real time’ understanding of nitrate concentrations in groundwater compared to laboratory sampling. In Year 1 the first sensor was installed and operated (in monitoring well GWD-04) as outlined earlier in this report (Section 3.5.2).

In late 2017, Lincoln Agritech Limited installed an additional automatic nitrate sensor in a monitoring well (BY20/0148) close to the new MAR site number 12 and shown in **Figure 1**. This site is a purpose-built monitoring well drilled in 2016 and situated in an irrigated paddock close to a known high nitrate-N area. Groundwater quality was previously monitored in a nearby well located 330 m to the north east since 1988 (K37/0245, 19.8 m deep). The new monitoring well (BY20/0148) is 20.45 m deep and the results from the automated nitrate-N logger in this well (BY20/0148) are shown in Figure 41. Nitrate-N concentrations have ranged between 15 g/m^3 and 20 g/m^3 in the Year 2 monitored period. Historical nitrate-N concentrations in the nearby monitoring well (K37/0245) were below 8 g/m^3 prior to 2006.

The automated nitrate-N sensor required regular maintenance to clear biofilm build-up which disrupted the automated results during March and April 2018 (**Figure 41**). More regular cleaning, maintenance and a period of more frequent sampling would assist in calibrating the sensor to the local monitoring well conditions. The difference between the December 2017 laboratory result and the automated sensor is considered to be potentially due to a number of factors including flushing of the well during sampling and standard error of the sensor. As more sampling and results from laboratory testing are gained the automated sensor results can be reviewed and calibrated if needed.

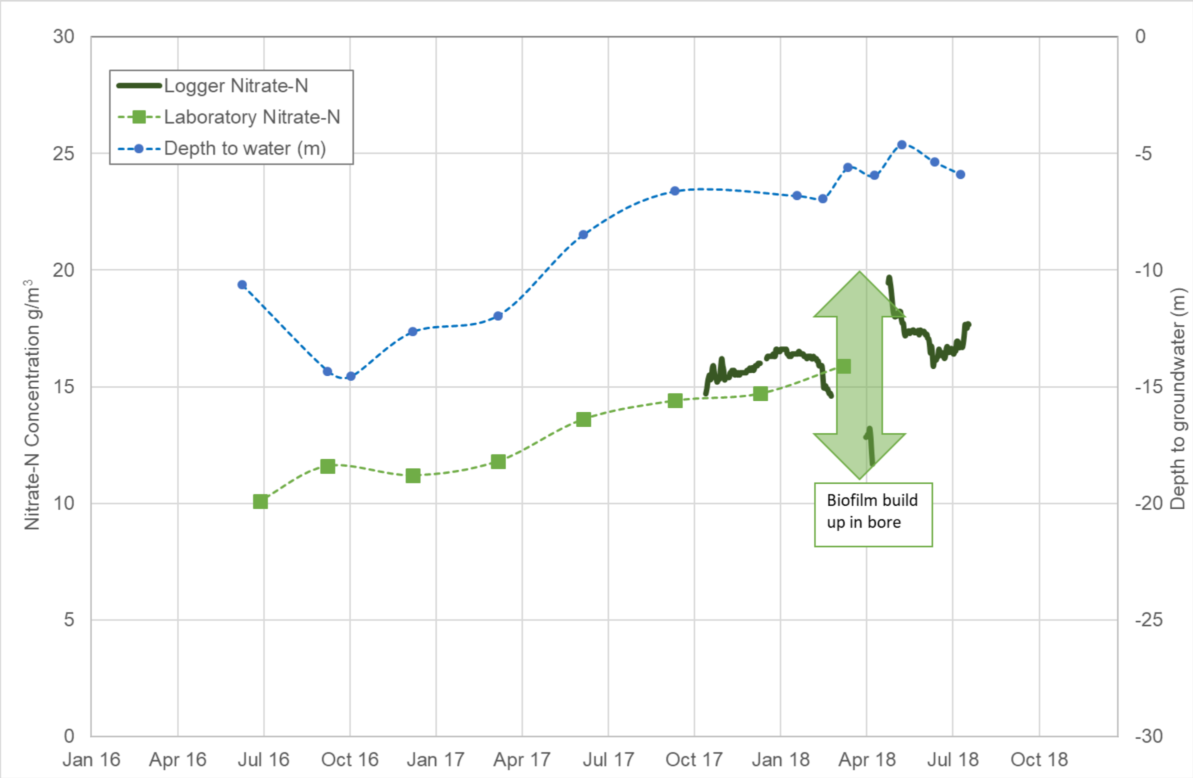


Figure 41: Automated and laboratory results for samples from monitoring well BY20/0148.

7.3 NEXT STEPS

Communications between the various water quality data collection entities and a review of spatial coverage has indicated that there remain large gaps in our current baseline water quality. A Hinds/Hekeao Plains '***Water Week'*** data collection and community outreach project is being initiated by MHV Water. Current plans for Water Week include community based 'water quality sample' collection points (potentially local schools) where, after a careful outreach campaign, water samples from hundreds of domestics and irrigation bores could be collected and processed for nitrate concentration and enteric bacterial analysis. It is anticipated that this project will be initiated in late 2018 or early 2019. Individual testing results will be email confidentially back to the participants whilst the wider baseline database generated will be used to construct a 'snapshot' water quality map for the catchment. Results from long term monitoring sites such as the Environment Canterbury State of the Environment wells will help to refine confidence in the results.

Another important Environment Canterbury output will be an update of the current average 2018/2019 nitrate-N concentrations from the State of the Environment monitoring well network. This value is the water quality target which all the catchment programmes (e.g., on-farm mitigations, MAR activities, etc) are being tracked against.

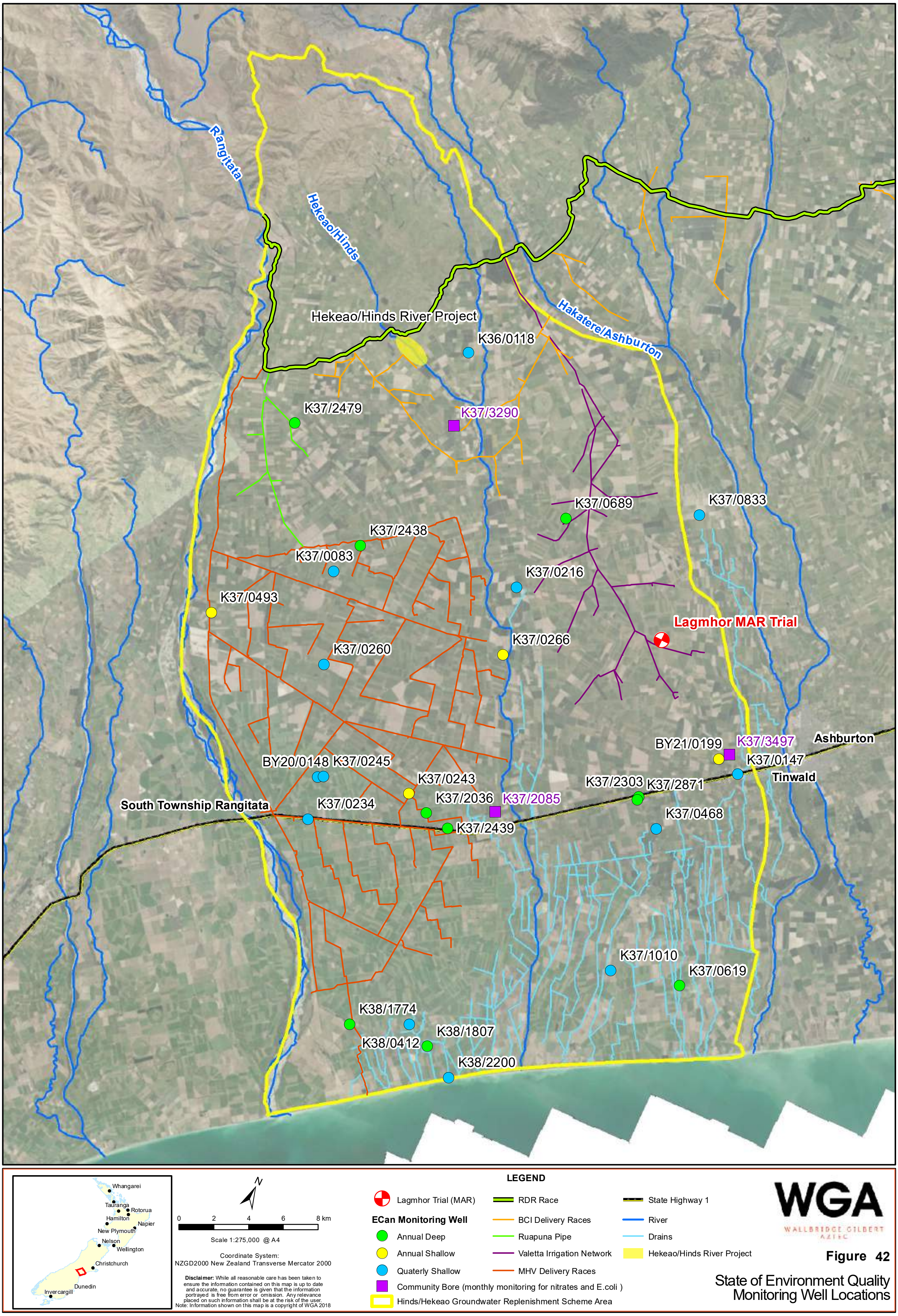


Figure 42

State of Environment Quality Monitoring Well Locations

Document Path: K:\JOBS\2017\171001 - 171100\171076 - Hinds MAR Stage 2\05 Sketches\ArcGIS\Projects\171076_Fig_42_State of Environment Quality Monitoring Wells.mxd

8 DISCUSSION AND RECOMMENDATIONS

8.1 LAGMHOR YEAR 2 MAR TRIAL

8.1.1 Trial Site Forebay Clogging

Flow rates of source water into the Lagmhor Trial site have varied during the first two years of operation (**Figure 10**). Site operations during 2016 were however relatively stable, as were site operations since March 2018. Comparing these two periods it is evident that site inflows were higher and the operating water level in the main basin lower in 2016 than in 2018. Clogging of the forebay is likely to be the main reason for these differences, as this would result in:

1. Reduced total infiltration from the Trial site.
2. More source water spilling from the forebay through into the main basin, thereby raising basin water levels even if the infiltration rate in the basin has not declined.

WGA recommends:

- Cleaning of the forebay during Year 3 to improve infiltration rates at the site.

8.1.2 Main Basin Infiltration Rates

There are benefits of a wetter year for groundwater levels and stream flows. However, very wet years also present challenges in terms of quantifying groundwater level responses to the Lagmhor Trial in isolation from the seasonal responses. Analysis of water level responses to the trial have been made based on comparisons with background monitoring data, and changes from groundwater levels measured at the start of the trial. A map of the interpreted extent and magnitude of the MAR groundwater pressure response (mounding) at the regional aquifer level is presented in **Figure 24**.

To better understand the spatial distribution of groundwater level responses it is important to measure the absolute groundwater elevations. This information would assist understanding of the propagation of groundwater level responses at regional and perched aquifer levels.

WGA recommends:

- Surveying of the monitoring well-head levels to enhance the assessment of groundwater mounding and water flows in the regional aquifer.

8.1.3 Clean Water Plume Extent

The plume of ‘clean’ infiltrated source water is considered to have moved further to the southwest as projected in Year 1. This rate of movement is expected to change with variations in aquifer conditions. It appears that the plume has moved past all of the currently monitored wells in line with the clean water plume movement.

The issues with interpreting data from single data points was highlighted in the Tinwald samples. Water quality from monitoring well K37/1939 is lower in nitrate-N than surrounding wells but this could be due to ambient conditions rather than progression of the clean water plume to this point. Therefore, new monitoring sites are recommended within the area expected to be influenced by the MAR plume in the next two years. Progress of the MAR plume towards the spring-fed streams and drains can then be better understood.

Historical springs in the upper catchment of the Flemington Drain (Davey 2003) are much closer to the interpreted clean water plume than GWD-06. Some of these springs are within the area that may be encompassed by the clean water plume during Year 3 of Lagmhor Trial operations. Some of these springs may no longer exist due to landscape changes since surveys were undertaken. However, a focus on identifying remaining springs in the upper Flemington Drain catchment and monitoring these springs for water quality changes should be considered for Year 3 of the trial.

WGA recommends:

- New potential monitoring wells be identified, site access arranged, and sampling initiated as soon as possible to capture groundwater quality data prior to arrival of the plume.
- A survey of springs within the upper catchment of Flemington Drain be undertaken and water quality sampling from the springs initiated. The objective is to identify any potential change in spring water quality as the clean water plume extends into the catchment of Flemington Drain.

8.2 LAGMHOR SITE UPGRADE

This task is on-going, and WGA recommends proceeding with upgrade and start of operation within Year 3. Monitoring to be carried out to assess the effectiveness of the upgrade.

8.3 HINDS/HEKEAO PLAINS NEW SITES

This task is on-going, and WGA recommends proceeding with the project as planned to test a further 10 sites. Based on the learnings from the new site testing WGA recommends the following:

- Further test MAR16/17 to assess spacing requirements of these soakage systems.
- Review as-built site designs and provide recommendations for improvement.
- A review of monitoring requirements for water quality sampling to determine if weekly sampling of *E. coli* is required.
- A review of potential automation systems and costs for long-term soakage sites.
- A review of suspended solids management for sites where water is derived from water races.

8.4 HEKEAO/HINDS RIVER PROJECT

This task is on-going, and WGA recommends proceeding with construction and operation of the site in Year 3 once consent has been granted. Monitoring to be carried out to assess the effectiveness of the project to achieve objectives.

8.5 HINDS/HEKEAO PLAINS BASELINE WATER QUALITY

This task is on-going, and WGA recommends proceeding with:

- A Hinds/Hekeao Plains ‘Water Week’ data collection and community outreach project.
- Review and analysis by Environment Canterbury of State of Environment monitoring wells to update the current average 2018/2019 nitrate-N concentration.
- Develop a baseline water quality map of the Hinds/Hekeao Plains.

- More frequent site maintenance of the automated nitrate-N sensors in both monitoring wells to manage biofilm build-up.
- Review of laboratory results in comparison with the automated nitrate-N sensors to allow calibration. A period of more frequent monitoring may be required to calibrate the senor to local monitoring well conditions.

9 CONCLUSIONS

9.1 LAGMHOR TRIAL YEAR 2

Prior to the start of the Lagmhor Trial the Hinds/Hekeao Plains had been subject to two drought years. Year 1 of the Trial had average rainfall. Year 2 has provided an opportunity to assess the behaviour of the infiltration basin and underlying groundwater system in very wet conditions, compared to the previous year.

During Year 2 approximately 1,854,000 m^3 was recharged through the Lagmhor Trial site. This volume compares to 2,442,000 m^3 recharged during Year 1. Operations were disrupted more by rainfall and irrigation requirements during Year 2 than during Year 1. Flow rates to the site varied during Year 2, peaking at about 95 L/s. Of this flow, approximately 22 L/s was infiltrated to groundwater through the base of the delivery race.

Total infiltration rates at the Lagmhor Trial site varied significantly during Year 2. Forebay infiltration has decreased substantially due to the observed clogging by accumulated sediment. An assessment of main basin infiltration rates during six shutdown periods suggests that infiltration rate may be influenced by depth of water in the basin, antecedent rainfall and depth to underlying groundwater.

The clean water plume generated by the Lagmhor Trial continued to propagate to the south east, advancing at rate of approximately 11 m/day, which is similar to that observed during Year 1. The plume is considered to have migrated a distance of seven kilometres from the Trial site and appears to be spreading out at the southern end. This spreading is probably due to variations in the aquifer conditions (less contained by paleochannel conditions).

Water quality in the receiving groundwater beneath the Trial site continues to be good, with *E. coli* not detected in the clean water plume. Nitrate concentrations in the clean water plume remained low, even with the increased leaching of nitrates from the topsoil during the very wet periods of Year 2. Water quality responses in shallow groundwater and springs within the upper catchment of Flemington Drain may start to appear during Year 3 of the trial.

9.2 LAGMHOR SITE UPGRADE

The combined information from the various lines of investigation allowed the interpretation of the presence of two aquitard layers beneath the Lagmhor Trial site. This information was used to support the design of site upgrade to direct source water past these restricting layers and increase the overall site recharge efficiency. The upgrade to the site will progress in August 2018 and the effectiveness of the upgrade will be assessed in Year 3.

9.3 HINDS PLAINS NEW SITES

To date (August 2018) six new sites have been tested with a total of 352,388 m^3 of groundwater recharged. The combined Year 2 recharge volume for the Hinds/Hekeao Plains is approximately 2,206,000 m^3 including the Lagmhor Trial.

The results show that the new MAR test sites can typically receive long-term flow rates between 15 L/s and 30 L/s. High groundwater levels due to rainfall events in the recharge period have restricted flow rates at some sites. The MAR testing project will continue over the next few months to implement testing of the remaining 10 sites.

9.4 HEKEAO/HINDS RIVER PROJECT

Through community consultation the Hekeao/Hinds River Project has developed a range of beneficial outcomes for stakeholders whilst working toward achieving the targets for environmental restoration, reversing declining trends in groundwater levels, and improving groundwater quality in the catchment.

A resource consent application was lodged in June 2018 and the consent process is still underway. The project will progress with construction and monitoring in Year 3.

9.5 HINDS/HEKEAO PLAINS BASELINE WATER QUALITY

Improved spatial understanding of groundwater and surface water quality across the Hinds/Hekeao Plains has been identified as a need. Whilst some portions of the catchment have extensive monitoring information, data in other areas is sparse, leading to an incomplete understanding of the overall baseline water quality. To improve the understanding of baseline water quality a community-based water quality snapshot is planned. An updated map of baseline water quality is recommended to support a Groundwater Replenishment Scheme.

10 REFERENCES

Ashburton Zone Committee (AZC) 2011. Ashburton Zone Implementation Programme, 2014. 56 p

Ashburton Zone Committee (AZC) 2014. Ashburton Zone Committee addendum; Hinds Plains area. March 4, 2014.

Bower R, 2014. Hinds/Hekeao Plains Technical Overview – sub-regional planning development process. Canterbury Regional Council technical report R14/79

Davey G 2003. Hinds Plains Springs. Canterbury Regional Council technical report U03/79.

Durney P, Ritson J 2014. Water resources of the Hinds/Hekeao catchment: modelling scenarios for load setting planning process. Canterbury Regional Council technical report R14/51.

Ferdowsian R, Pannell DJ, McCarron C, Ryder AT, Crossing L 2001. Explaining groundwater hydrographs: separating atypical rainfall events from time trends. AJSR 39(4):861–875.

Golder 2015a. Resource consent application and assessment of effects on the environment. Managed aquifer recharge - Hinds Plains catchment. Report produced for Canterbury Regional Council by Golder Associates (NZ) Limited. Golder report 1478110257-004. September 2015.

Golder 2016. Hinds/Hekeao Catchment groundwater system – geostatistical modelling of the aquifer lithologies. Report produced for Canterbury Regional Council by Golder Associates (NZ) Limited. Golder report 1543988-7410-002. September 2016.

Golder 2017. Hinds Managed Aquifer Recharge Pilot Trial – Phase 1 Report. Submitted to Canterbury Regional Council. 28 July 2017.

NIWA 2017. New Zealand Climate Summary: July 2017. Report issued by the National Institute for Water and Atmospheric Research. 3 August 2017.

WGA 2017. Lagmhor MAR Pilot Trial site monitoring – Year 2. Technical memorandum to Hinds MAR Governance Group from WGANZ Pty Ltd. WGA document 171076me002. Dated 18 October 2017.

Bob Bower
PRINCIPAL HYDROLOGIST/NZ REGIONAL MANAGER

Telephone: +64 29 201 2996

Email: bbower@wganz.co.nz

ADELAIDE
60 Wyatt Street
Adelaide AUSTRALIA
adelaide@wga.com.au

CHRISTCHURCH
4 Ash Street
Christchurch Central
Christchurch NZ

HAMILTON
10 Bisley Road
Ruakira Research Centre
Hamilton NZ

AUCKLAND
Generator Level 1, 28 Customs Street East
Auckland Central
Auckland 1010

WALLBRIDGE GILBERT AZTEC

www.wganz.co.nz