28 July 2017

HINDS MANAGED AQUIFER RECHARGE PILOT TRIAL

Phase 1 Report

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REPORT

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Distribution:

Lowe (Chairman) Hinds MAR Governance Group, Ashburton Zone Committee, Ashburton District Council, Te Rūnanga o Arowhenua, Forest and Bird, Fish and Game, RDRML, MHV Water, CDHB, Eifflelton Irrigation, BCI, and IAF (MPI)

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Forward

The Hinds/Hekeao Managed Aquifer Recharge pilot trial is a result of the local community taking ownership of its water quantity and quality issues. The Ashburton Water Zone committee started the process with extensive community consultation intended to give the local community ownership of issues that had to be addressed.

ECan Plan Change 2 identified the community aspiration of reaching a nitrate N level in ground water of 6.9 g/m3 by 2035. The required on farm nutrient loss reduction of 36% by 2035 is one part of the solution, MAR is expected to be the other part of the solution.

The Ashburton Water Zone committee formed a subcommittee, Hinds Drains Working Party to make recommendations for the coastal side of the catchment. The HDWP was also tasked with progressing a pilot MAR trial.

Significant constructive partnerships were built up starting in the HDWP process and following through in to the MAR pilot trial project. This includes Te Rūnanga o Arowhenua, Ashburton Zone Committee, Environment Canterbury, Ashburton District Council, Department of Conservation, Fish & Game, Forest & Bird, Canterbury District Health Board, and Golder Associates working alongside the local community.

During the construction period local irrigation companies Valetta Irrigation, RDRML, MHIS, ECIS and BCI have provided cash and technical input to make the project a success.

It is recognized that the expertise of Golder Associates, Tarbotton Contractors and Lincoln Agritech played a valuable part in getting trial site up and running.

Funding was sought and granted by the Ministry of Primary Industries. MPI have proved to be a valuable partner in this project.

On behalf of the Hinds/Hekeao community I would like to thank those partners involved.

This report clearly demonstrates that Managed Aquifer Recharge alongside on farm mitigation can address a number of the water quality and quantity issues this catchment faces.

PG Lowe

Peter Lowe
Chairman

July 2017

Executive Summary

As demand for water across New Zealand continues to rise, there is an increasing need to pursue alternative options for surface water storage while ensuring that flows in rivers are protected. Similarly, water quality has become a national issue of concern with recreational uses, ecological habitat, drinking water supplies and cultural values all feeling the effects of land use intensification. The need to address catchment-scale water quantity and quality issues is enabled through the Canterbury Water Management Strategy (CWMS).

Zone committees have been set up under the CWMS to find solutions to community water issues through collaboration and consultation processes. A scoping study into the feasibility of applying Managed Aquifer Recharge (MAR) to the Hinds / Hekeao Plains (Hinds) catchment to help the local community meet agreed objectives documented in the Zone Implementation Plan Addendum was completed and accepted by the Ashburton Zone Committee. The final Hinds Plains Solutions Package approved by CRC Commissioners provided for *water augmentation* (including MAR) as one of a number of catchment management measures.

A prefeasibility assessment was undertaken that identified a preferred location for a Hinds MAR Pilot Trial to demonstrate the application of MAR within the catchment. Resource consents authorising the Pilot Trial for a period of five years were granted by CRC and Ashburton District Council (ADC) and work on the Pilot Trial was initiated.

The Pilot Trial site consists of a 900 m long water race that delivers water from Valetta Pond #3, a forebay designed to capture suspended sediment transported in the incoming source water and a main basin or primary infiltration area. During the Pilot Trial flows to the forebay have been monitored using water level sensors at two flumes, one at either end of the water race. Water levels and water quality have been monitored in the infiltration basin and surrounding groundwater throughout Year 1 of the trial.

The Pilot Trial site and supporting surface water, groundwater, ecological and climate monitoring programme covers a sub-catchment of the Hinds Plains totalling over 255 km^2 spanning from up-gradient monitoring bores through to flow sites near the coast.

The key outcomes for the 5-year Pilot Trial (Golder 2015) were to demonstrate the 'proof of concept' of MAR to help achieve the overall catchment outcomes for quantity and quality. In this 5-year period there were three primary objectives:

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

In the context of quantifying the water quality relationship between surface water recharged and the groundwater directly affected by this recharged water, the terms *source water* and *receiving water* are used, respectively.

Maximum recharge rates for the site averaged at 113 L/s with the site operating for 279 days. Recharge operations were halted during Year 1 due to a planned shutdown period during peak irrigation season (60 days), delivery system maintenance (21 days) and two rainfall shutdowns based on specific trigger conditions set for the Pilot Trial (5 days). A comparison of infiltration rates between the open leaky race with the Pilot Trial main site indicated on average the race performed similarly to the main site, averaging a 17% loss in 19% of the infiltration area.

Infiltration rates during most of the Pilot Trial operational period have been calculated at between 0.5 m/day and 0.6 m/day (5,000 to 6,000 m^3/day/ha ponded area). Infiltration rates may have declined later in the year to approximately 0.34 m/day due to clogging. Total recharged water during Year 1 of the Pilot Trial is conservatively estimated at **2,442,000 m^3**. After the Year 1 MAR usage was accounted for, a total remaining volume of **13,338,000 m^3** remained unutilised (i.e., was not taken from the Rangitata River) under the Pilot Trial consent to utilise ADC stockwater for MAR pilot testing.

During Year 1, total suspended sediment concentrations were generally below 10 g/m^3 at the discharge point form the Valetta Pond #3. Concentrations were reduced as water moved through the forebay and were regularly below the minimum detection limit of 1.5 g/m^3 in the infiltration basin. Based on recorded water flows to the forebay and total suspended sediment concentrations, a total sediment mass of approximately 13 tonnes has been deposited in the two basins during Year 1.

Sediment build-up throughout the MAR Pilot Site has contributed to a reduction in calculated infiltration rates for the main basin (down to approximately 0.34 m/day) toward the end of Year 1. Such sediment build-up (clogging) is a standard MAR operational issue requiring on-going monitoring and management.

Water recharging a groundwater system initially changes groundwater levels through a pressure response. The actual plume of recharge water travels at a slower rate behind the pressure response. Recharged water at the Pilot Trial site has become distributed between a perched aquifer (with the primary seepage flow direction being toward the southeast from the site) and the underlying regional unconfined aquifer (with a groundwater pressure response radiating outward from the site). The groundwater monitoring system installed for the Pilot Trial detected groundwater changes in both the perched and the regional aquifers, providing the data on which the evaluation of the Pilot Trial outcomes has been based.

Increased groundwater flows and levels in the **perched aquifer** via pressure response were estimated to have reached a distance of about 6.9 km from the Pilot Trial site by the end of Year 1. The plume of low nitrate water in the perched aquifer is estimated to have travelled about 3.3 km from the Pilot Trial basin by the end of Year 1. Changes in groundwater levels in the perched aquifer of 5.12 m and 5.54 m have been measured in monitoring wells at distances of 45 m and 2,308 m respectively from the centre of the infiltration basin. At 2,308 m from the basin the average velocity of the advancing pressure wave in the perched aquifer was approximately 19 m/day.

Groundwater level increases in the **regional groundwater table** of 4.05 m, 3.61 m and 2.14 m have been measured in monitoring wells at distances of 90 m, 320 m and 1,660 m respectively from the centre of the infiltration basin. Based on these observed groundwater level changes in the regional aquifer, the Pilot Trial resulted in increased groundwater levels and storage via pressure response over an area of at least 12 km^2 surrounding the infiltration basin.

Measured nitrate-nitrogen concentrations in the infiltration basin water were consistently below 0.09 g/m^3, substantially lower than the concentrations detected in the underlying groundwater (both perched and in the regional system) prior to the trial. Recharge through the floor of the infiltration basin has resulted in measured nitrate-N concentrations in the receiving groundwater beneath the site decreasing from greater than 4 g/m^3 to less than 1 g/m^3. Measured nitrate-nitrogen concentrations in down-gradient groundwater influenced by water from the Pilot Trial have reduced from approximately 14 g/m^3 to less than 4 g/m^3. Ashburton Zone Committee's goal is to reduce average annual groundwater concentrations of nitrate-nitrogen in the Hinds catchment to <6.9 g/m^3 by 2035.

The median *E. coli* count in water from the infiltration basin during Year 1 was 88 MPN/100 mL, with a maximum detected count of 228 MPN/100 mL. These source water E. coli levels, whilst above the drinking water standard of 1 MPN/100 mL, are typical of such surface water. *E. coli* counts in samples obtained from groundwater beneath the site during the trial, both in the perched aquifer and the regional unconfined aquifer, were predominantly below the laboratory detection limit. These observations indicate that passive soil aquifer treatment in and beneath the floor of the infiltration basin substantially removed *E. coli* from the infiltrated water before the water reached the nearest monitoring wells located less than 50 m from the edge of the infiltration basin. Any *E. coli* detected in groundwater further from the site are unlikely to have been sourced from the MAR Pilot Trial.

Prior to the start of the trial there was a perceived risk of increased flooding frequency and magnitude in low-lying areas within the catchment due to rising groundwater levels induced by the MAR Pilot Trial. The Tinwald suburb, close to the Ashburton River was an area specifically identified by the community as having a history with rainfall-linked flood events. Groundwater level increases due to MAR Pilot Trial operations did not extend as far as Tinwald during Year 1 and therefore did not contribute to any surface water ponding that may have been observed in Tinwald during this time.

The outcomes from 3D groundwater modelling of the effects of the MAR Pilot Trial operations on groundwater have produced similar outcomes to those calculated analytically from on-site observations. This successful simulation of the MAR Pilot Trial outcomes enables simulations of similar MAR sites across the catchment to be undertaken with increased confidence, in support of the design of a wider Groundwater Replenishment Scheme for the catchment.

During Year 1 the Pilot Trial operated in general compliance with all conditions attached to the resource consents authorising the trial. Overall, the Year 1 operations at the Hinds MAR Pilot Trial have successfully achieved the key objectives of demonstrating the viability of MAR to:

1) Improve groundwater quality in the aquifers beneath and down-gradient from the trial site

2) Increase stored groundwater volumes in the aquifers surrounding the trial site.

No 'fatal flaws' have been identified in the use of MAR to support the AZC in achieving community objectives for groundwater quality and levels within the Hinds catchment. However, significant questions remain on matters such as 'what are the optimal MAR site designs?' and 'where will the future source water come from and how much will it cost?' These questions will be addressed in the next phase of the project.

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ABBREVIATIONS

ADC	Ashburton District Council
AZC	Ashburton Zone Committee
bgl	below ground level
BOD	Biological Oxygen Demand
CRC	Canterbury Regional Council
CWMS	Canterbury Water Management Strategy
DO	dissolved oxygen
Drains	Hinds Plains spring-fed waterbodies (used interchangeably)
E. coli	*Escherichia coli,* indicator bacteria of faecal contamination
GAZ	Groundwater Allocation Zone
GDE	Groundwater-Dependent Ecosystems
GIS	Geographic Information System
Golder	Golder Associates (NZ) Limited
g/m^3	grams per cubic meter (concentration) or mg/L (used interchangeably)
GRS	Groundwater Replenishment Scheme
HMPWG	Hinds MAR Pilot Working Group
HDWP	Hinds Drains Working Party
L/s	Litres per second (rate of flow)
LWRP	Canterbury Land and Water Regional Plan
MAR	Managed Aquifer Recharge
MH	Mayfield – Hinds Irrigation Ltd
MOU	Memorandum of Understanding
m^3/s	cubic meters per second (rate of flow)
Nitrate-N	Nitrate-Nitrogen
NRRP	Natural Resources Regional Plan
Real time	Defined for this project as 15-minute data intervals
RDR	Rangitata Diversion Race
RDRML	Rangitata Diversion Race Management Ltd
RMA	Resource Management Act 1991
SCADA	supervisory control and data acquisition
SAT	Soil aquifer treatment
TOC	total organic carbon
TSA	targeted stream augmentation
TSS	total suspended solids
Valetta	Valetta Irrigation Ltd
ZIPA	Zone Implementation Plan Addendum

1.0 INTRODUCTION

1.1 Background

As demand for water across New Zealand continues to rise, there is an increasing need to pursue alternative options for surface water storage while ensuring that flows in rivers are protected. Similarly, water quality has become a national issue of concern with recreational uses, ecological habitat, drinking water supplies and cultural values all feeling the effects of land use intensification. Large concerted efforts by regional governments, research organisations and national farming groups are focused on reducing the amount of nutrients leaching into aquifers and rivers. The need to address catchment-scale water quantity and quality issues is acknowledged through the Canterbury Water Management Strategy (CWMS) for the Canterbury Mayoral Forum.

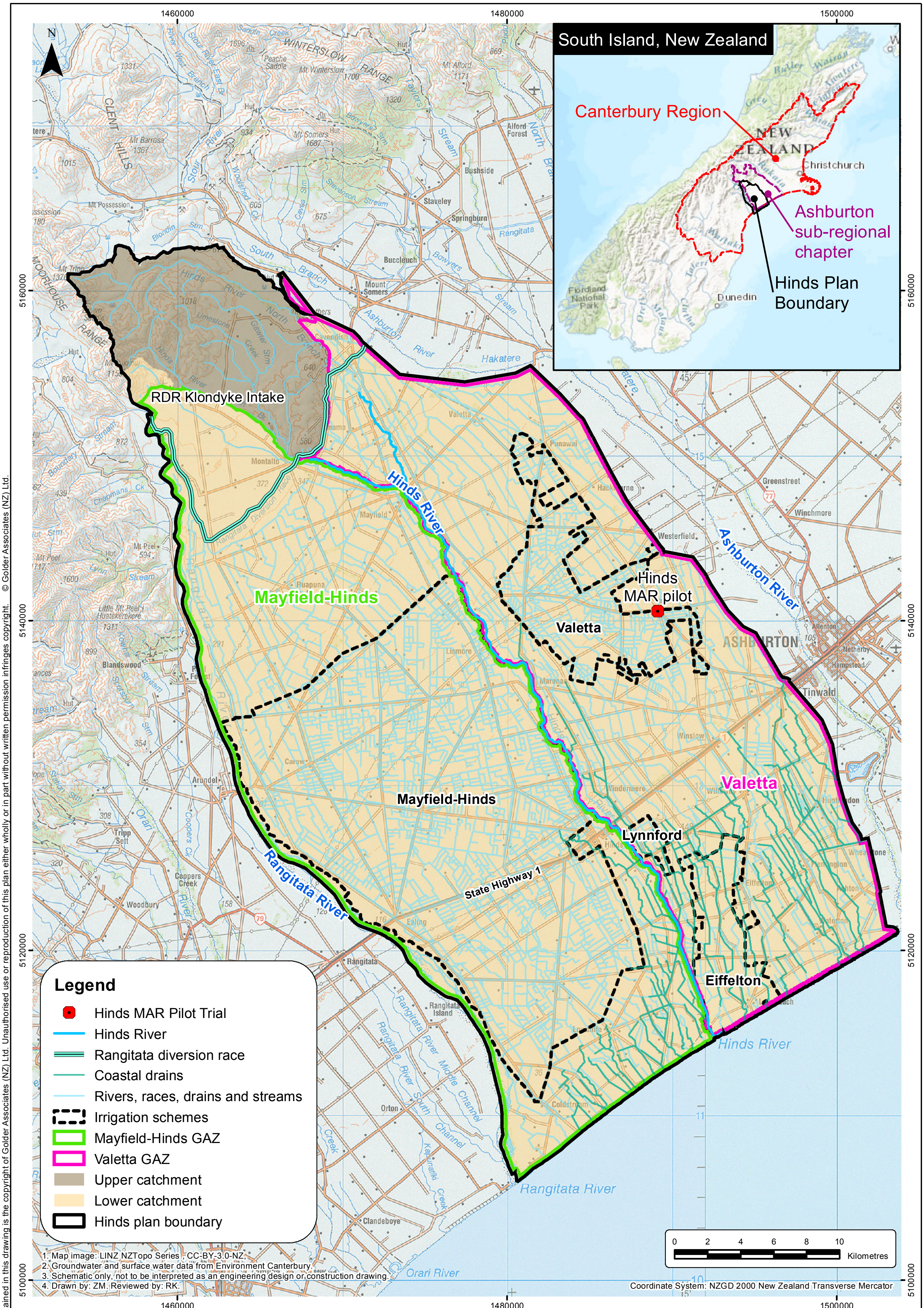
Zone committees have been set up under the CWMS to find solutions to community water issues through collaboration and consultation processes. The Ashburton Zone Committee (AZC) has released a Zone Implementation Plan (ZIP), and more recently a Zone Implementation Plan Addendum (ZIPA) (AZC 2014). A scoping study into the feasibility of applying Managed Aquifer Recharge (MAR) to the Hinds / Hekeao Plains (Hinds) catchment (Figure 1) to help the local community meet agreed objectives documented in the ZIPA has been completed and accepted by the AZC (Golder 2014a). A number of comparative or *relative change* scenarios were modelled to provide the community with a means to evaluate the use of MAR (and other mitigations) as a component of a Solutions Package (Durney and Ritson 2014). MAR in this package would need to be implemented at the catchment-scale, and thus developed into a Groundwater Replenishment Scheme (GRS). The final Solutions Package was approved by CRC Commissioners and provided for *water augmentation* as one of a number of catchment management measures. These recommendations were then progressed as a sub-regional (Hinds Catchment) plan change to Environment Canterbury's Land and Water Regional Plan. Plan Change 2 to the Canterbury Land and Water Regional Plan (LWRP) includes new policies and rules to enable augmentation of water resources, via Targeted Stream Augmentation (TSA) and MAR.

In this process, MAR is a term used to describe a set of established and proven physical tools designed to purposefully recharge clean water to targeted aquifers for the restoration, enhancement, and future protection of water resources. The core purpose of MAR is to support the sustainable management of groundwater for economic, cultural, environmental, and social benefits.

In keeping with the "consultation and collaboration" approach of the CWMS, the development and operation of the Pilot Trial has been guided initially by the Hinds Drains Working Party (HDWP) and then the Hinds MAR Pilot Working Group (HMPWG), with input from the AZC, ADC, Te Rūnanga o Arowhenua and other catchment stakeholders. The HDWP was set up under the ZIPA to represent all relative stakeholders for the coastal spring-fed waterways (drains) including Department of Conservation, Fish and Game, Forest and Bird, sub-catchment farmers, CRC drainage engineers, two AZC members, CRC technical staff and a representative from Te Rūnanga o Arowhenua. The HDWP and HMPWG members were specifically tasked to guide the design, implementation and operations and review the results for the MAR pilot project.

During the HDWP consultation process, the members specifically reviewed local concerns about MAR, including issues such as the perception that MAR would exacerbate historic coastal flooding in the drains and practical matters such as what sources were available to provide the recharge water needed for a trial (Golder, 2015a, Golder 2015). In the HDWP's final recommendations, the MAR pilot project was selected for a site near Lagmhor. This area of the catchment sits in the Valetta Groundwater Allocation Zone (GAZ) which has:

- Degraded groundwater quality conditions relative to environmental and drinking water values including elevated concentrations of nitrogen (nitrate-N), particularly in the 'hot spot', near the Ashburton suburb of Tinwald.
- Over allocation of groundwater consents coupled with declining incidental recharge in the form of irrigation efficiencies, piping and the decommissioning of the district stockwater race systems.
- Declining groundwater storage (levels) leading to acute reductions in base flows in spring-fed waterbodies causing intermittent supply, and the "drying" up of habitat and cultural values.



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TITLE BOUNDARY OF THE HINDS/HEKEAO PLAINS CATCHMENT AREA

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A prefeasibility assessment was subsequently undertaken that identified a preferred location for a Hinds MAR Pilot Trial (the "Pilot Trial") to demonstrate the application of MAR within the catchment (Golder 2014b). Following technical investigations at the preferred location, applications (Golder 2015) were lodged with CRC and Ashburton District Council (ADC) seeking authorisation for the Pilot Trial. These applications were approved (refer Section 1.5) and work on the Pilot Trial was initiated.

1.2 Introduction to MAR in the Hinds Catchment

The first use of artificial recharge of groundwater dates back to early Chinese history (475 – 221 BC), where channels were used to infiltrate water into the ground (Legg 2017). In the second half of the 20th century it was commonly referred to as groundwater or artificial recharge (Bouwer 2002). The term Managed Aquifer Recharge or MAR started to be used more broadly during the early 21st century, particularly in relation to replenishing groundwater for longer term water sustainability (Dillion 2002).

World-wide, there are a large number of approaches for the development of MAR. The approaches are, by necessity, tailored to address the unique physical and social settings that make up the framework of each groundwater management challenge. MAR in itself is not a "one size fits all" approach, but a process of using known principles and adapting proven techniques to address site specific challenges. The International Groundwater Resource Assessment Centre (IGRAC), located in the Netherlands, keeps an updated online inventory[1] of more than 1,200 MAR case studies from around the world. These case studies demonstrate that the tools of MAR can be adapted to help resolve a highly diverse set of global water management issues at a wide range of scales.

One such approach at addressing groundwater management issues is through a community-based consultation process (Bower et al. 2010). This process presents MAR as a set of physical water management tools used to proactively support a catchment-scale groundwater storage balance: recharge vs discharge (conceptually depicted in Figure 2). This approach helps to frame MAR in the context of water balance processes that drive the amount and quality of water available over extended periods of time.

Catchment-scale groundwater issues necessitate community-scale solutions. In seeking these solutions, it is important to understand that all decisions regarding catchment land and water use management may influence the factors controlling the key inputs and outputs for the groundwater system and therefore have implications for the sustainability of the resource being managed. Such decisions may, for example, include the reduction of incidental recharge through the implementation of water efficiency programmes, or the ongoing intensification of land use practices. These are common issues that may not be convenient to acknowledge, but through community consultation and collaboration processes, can be resolved. While individuals may hold diverse views on the values of a groundwater resource, there is a fundamental need for water to be managed to be clean, available and to continue its life supporting function for the environment.

Within the Hinds Catchment and in many catchments around the world there is a common narrative regarding modern development of groundwater resources in rural, agricultural catchments. This theme is an evolution from leaky, hand-dug surface water races diverting water from rivers to the increased pumping of groundwater after the invention of submersible pumps. Incidental (or accidental) aquifer recharge occurred for decades due to the application of less efficient water use practices such as border dyke irrigation and leaky stockwater races. Economic pressures eventually gave rise to a modern era of 'reducing our losses' and putting that water to 'better uses'. These shifts have led to substantial changes in groundwater flow systems, with the sustainability of these systems propped up and dependent on the inefficient historical water supply and irrigation practices that are now being progressively replaced. MAR in this context is not only a physical set of tools to artificially enhance aquifer recharge, it is also a means by which these interdependencies may be considered and emerging issues addressed.

[1] https://www.un-igrac.org/ggis/mar-portal

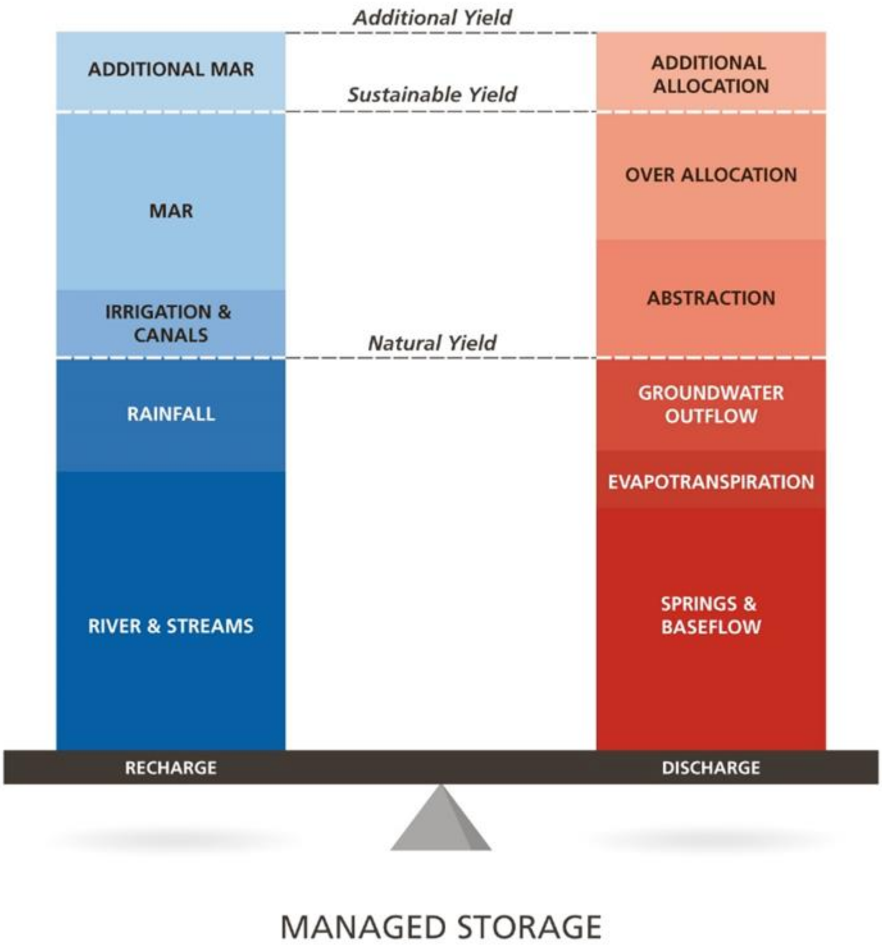


Figure 2: Groundwater storage balance using the tools of MAR (Bower et. al. 2010).

While MAR encompasses the individual tools, sustainable groundwater management at the catchment-scale can be achieved through the development of Groundwater Replenishment Systems or in New Zealand 'Schemes' (GRS). For New Zealand's current water storage discussions, the application of this particular 'MAR leading to GRS' approach is conceptualised in a paper by Bower & Sinclair (2016). In the case of the Hinds Catchment, an understanding of the application of MAR to manage water supply and quality has been progressed through a series of field trials in various parts of Canterbury including a short-term[2] Hinds River recharge trial and the current infiltration basin Pilot Trial (Golder, 2012a, 2012b).

Through the CWMS process, and numerous numerical modelling projects, the Ashburton Zone Committee decided that the application of MAR needed to be trialled for the purposes of achieving their desired catchment outcomes, and therefore was included in their final ZIP Addendum (AZC 2014) and documented in supporting technical information (Bower 2014, and Golder 2014a). Following these recommendations being officially accepted by the CRC Commissioners (2014), work began with both the HMPWG and CRC technical staff to determine the prefeasibility of a Hinds MAR Pilot project (Golder 2014b). This led to the selection of a final testing site near Lagmhor, an Assessment of Environmental Effects (AEE) and consenting process (Golder 2015a, 2015b).

For the Hinds catchment it is important to note that MAR is not intended to be a stand-alone solution to resolve catchment-scale water management issues. AZC's final solutions package (AZC 2014) outlined

[2] Four day trial, of approximately 10.0 m3/s of water from RDR race down the Hinds River (Golder, 2012a, Golder 2012b).

other critical, catchment-scale changes that were required to occur next to any potential development of a MAR - GRS system (Table 1). Note that the testing of MAR was required for both the water quality and quantity outcomes for the catchment. But in order to achieve the catchment-wide desired outcomes, following a successful MAR pilot project, the development of a GRS was required.

Table 1: Primary catchment-scale changes required to achieve AZC outcomes for the Hinds Catchment.

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)	The requirement for individual Farm Environment Plans (FEPs)
Implement a MAR Pilot Trial project for proof of concept testing – increasing storage	Implement a MAR Pilot Trial project for proof of concept testing – clean water addition

In the scoping study (Golder 2014a) and during the AEE process (Golder 2015) the concept of applying MAR to the Hinds Plains catchment took into account the generally unconfined nature of the shallow groundwater across the catchment. The concept was to apply a larger infiltration basin style approach to an area where the depth-to-groundwater would reduce the possibly of groundwater mounding to affect the recharge efficiency of the site. The water availability for the trial (up to 500 L/s from ADC stockwater) and the ability to deliver that rate to a MAR site (Valetta pipe network) were key considerations in the development of the trial site. Further, the identification of the Tinwald area nitrogen 'hot spot' as representing one of the more significant areas of contamination in Canterbury, as well as addressing the community concerns around coastal flooding, helped to solidify the Lagmhor site as the best-placed location for further testing.

1.3 Pilot Trial Objectives

The key outcomes for the 5-year Pilot Trial (Golder 2015) were to demonstrate the 'proof of concept' of MAR to help achieve the overall catchment outcomes for quantity and quality. In this 5-year period there were three primary objectives:

1) Increase groundwater levels and overall groundwater storage near the site,

2) Decrease concentrations of nitrate-N in groundwater near the site, and

3) To increase baseflows and improve water quality in the down-gradient coastal spring-fed waterbodies (drains).

Due to the effects of an extended drought and also to significantly lower than expected basin recharge rates, the Pilot Trial did not influence down-gradient coastal spring-fed waterbodies. It did however influence groundwater levels and quality in the vicinity of the recharge site. Extensive modelling work (Golder 2015a, 2015b) undertaken in preparation for the Pilot Trial indicated that the likely footprint of the Pilot Trial effects was highly dependent on the actual recharge rate achieved. A modelled rate of 500 L/s was used to define a MAR command area based on the area having potentially measurable groundwater level or quality changes. Other portions of this MAR command area, including the area where flooding risk was historically known to be high, were not modelled to be impacted by the MAR Pilot Trial, but were incorporated in the monitoring programme as part of a risk management approach.

1.4 Pilot Trial General Description

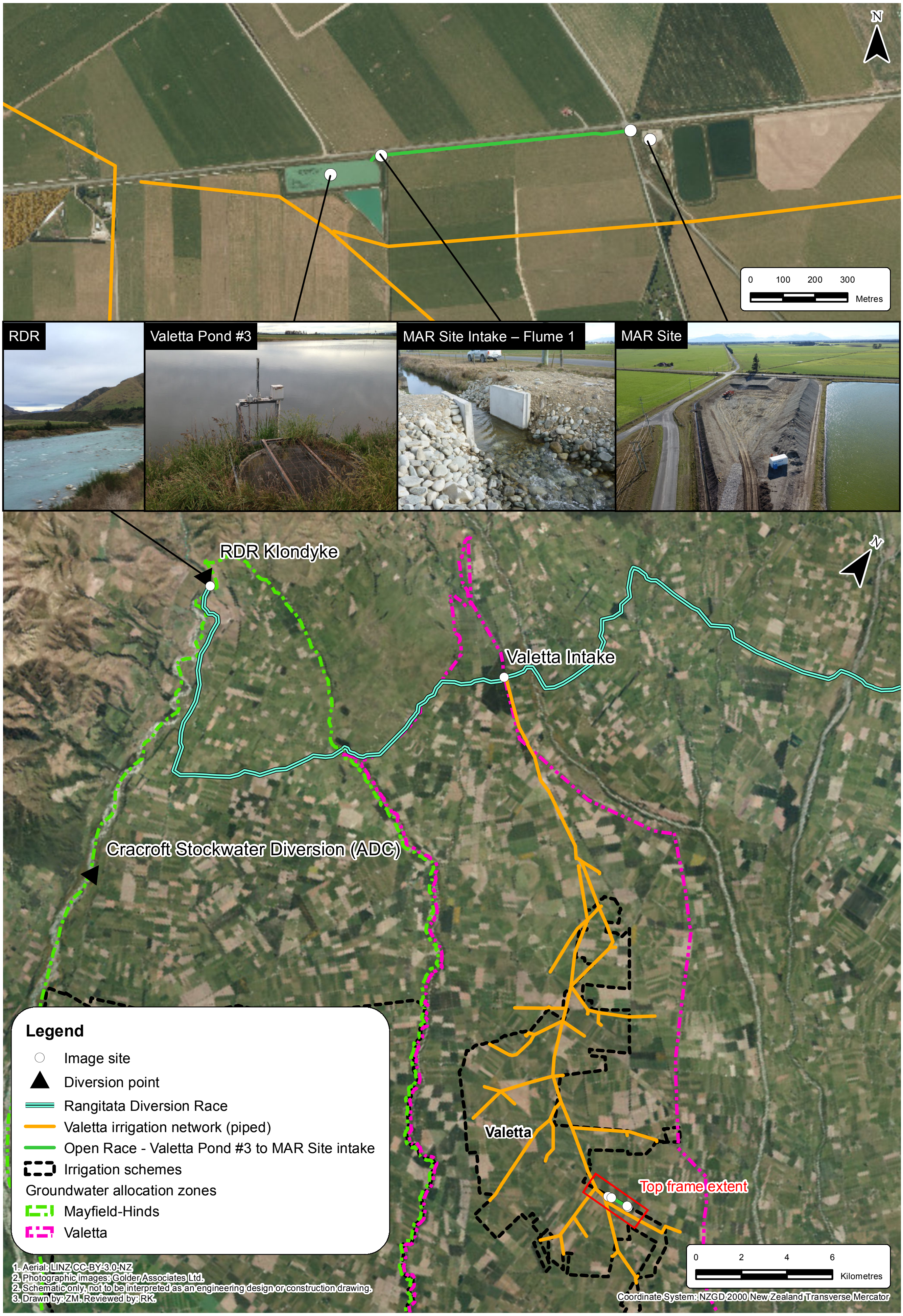
The MAR Pilot Trial design is the product of several years' extensive community consultation, sub-regional plan changes and a considerable amount of technical analysis and reporting. The site-specific designs, consenting and monitoring programme including operating (trigger) conditions related to rainfall and coastal flooding are presented in a series of reports by Golder (2014b, 2015a, and 2015b).

The Pilot Trial is consented to recharge up to 500 L/s[3] unutilised ADC stockwater, sourced from the Rangitata River and delivered (through the Rangitata Diversion Race (RDR) and Valetta Irrigation Scheme) to the corner of Frasers Road and Timaru Track (Figure 3). One of the Pilot Trial consents authorises water for recharge (MAR source water) to be diverted by Rangitata Diversion Race Management Ltd (RDRML) at their Klondyke diversion. A memorandum of understanding (MOU) on the project between ADC, RDRML and Valetta was set up to ensure that MAR water could be delivered for the trial. Due to delivery capacity (pipeline) limits during the peak irrigation season, source water is only delivered if consented (and requested) irrigation water has already been delivered.

Source water leaves the Valetta system from Valetta Pond #3 and enters the Pilot Trial site at Flume 1 (Figure 3). Flow rates, stages and water quality information including temperature is collected at Flume 1 as the water flows past and down a 900 m long open race to Flume 2 (Figure 4). A water quality bypass gate allows water to be shunted (if required) to two adjacent farm storage ponds (Figure 5). Flow rates, stage and some water quality information is collected at Flume 2 as water enters the Pilot Trial forebay. The forebay is effectively designed as a sediment settling and infiltration basin, helping to remove coarser sediments entering the site before spilling into the main basin.

In the context of quantifying the water quality relationship between surface water recharged and the groundwater directly affected by this recharged water, the terms *source water* and *receiving water* are used respectively. This is an important factor in the safe operations of any MAR site, particularly in regards to protecting drinking water supplies. The main basin is the primary infiltration area for the Pilot Trial, with water levels maintained well below the point of overflow. A monitoring well (GWD-01) located adjacent to the forebay, which represents the dedicated initial *receiving water* monitoring point, records groundwater levels and temperature in the regional aquifer beneath the site.

[3] CRC 4.0 CRC162191 302,400 cubic metres weekly or 15.7 Mm3 annually.



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TITLE PILOT TRIAL SOURCE WATER DIVERSION AND DELIVERY SYSTEM MAP

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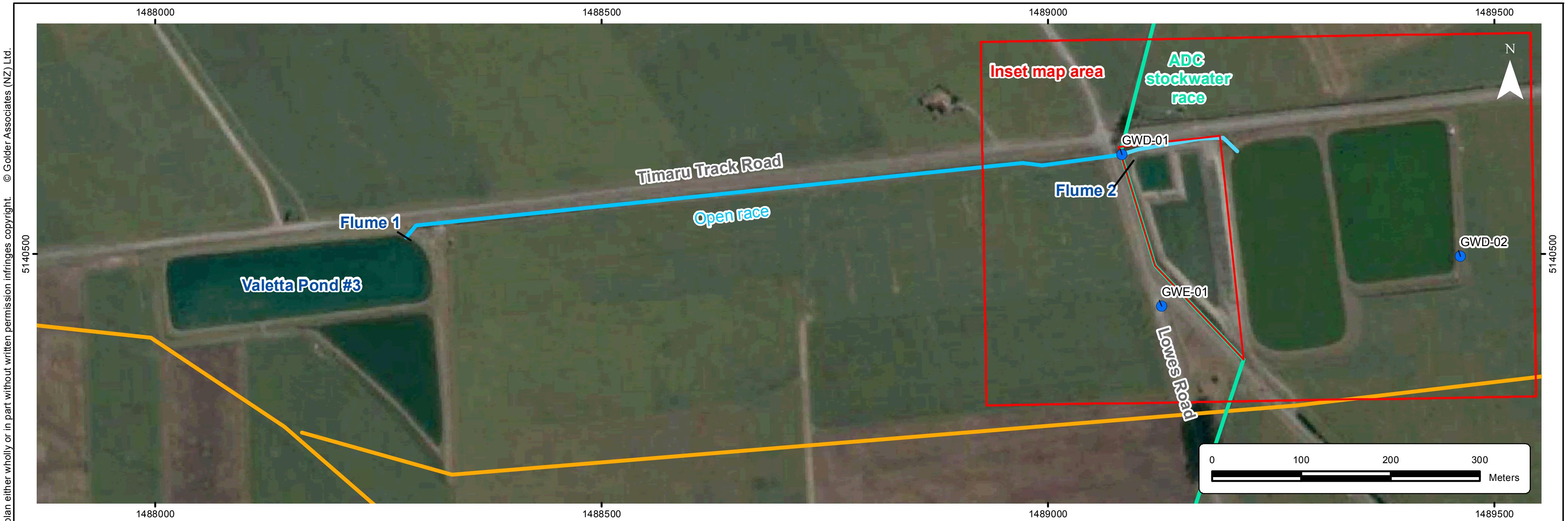

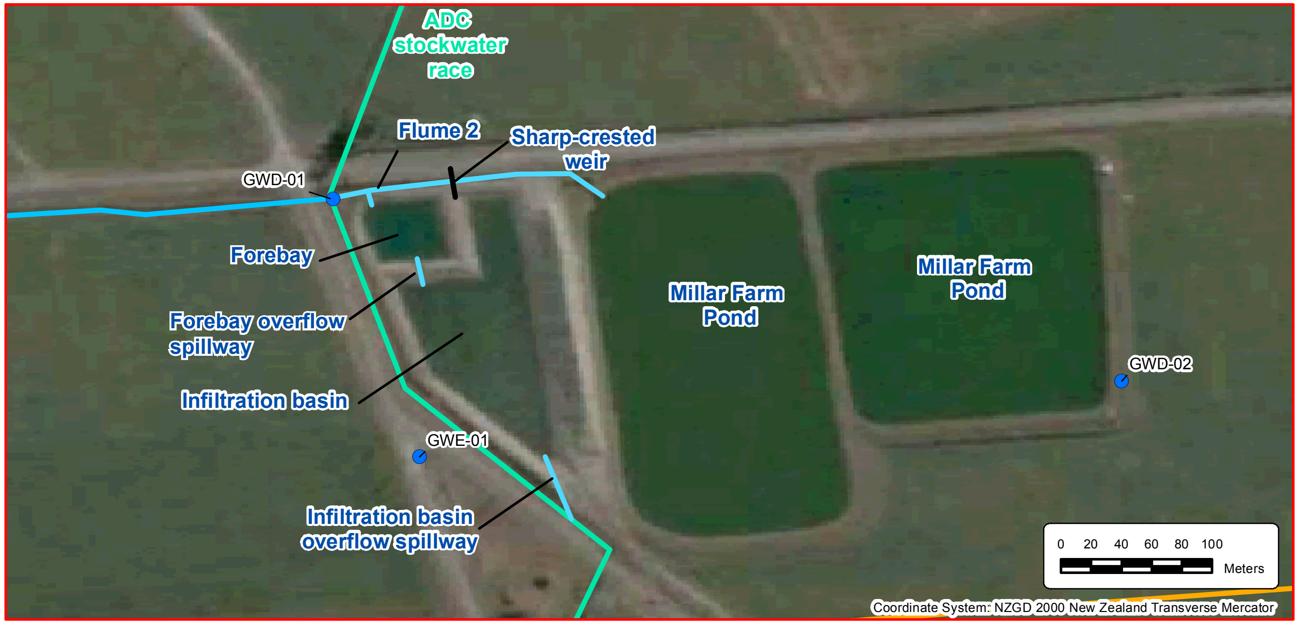

Legend

- Pilot site outline
- Groundwater quality monitoring site
- ADC open stockwater race
- Open Race - Valetta Pond #3 to MAR Site intake
- Valetta irrigation network (piped)

1. Aerial: LINZ + Eagle Technology, CC-BY-3.0-NZ.
2. Schematic only, not to be interpreted as an engineering design or construction drawing
3. Drawn by: ZM. Reviewed by: BS.

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TITLE HINDS MAR PILOT TRIAL SITE MONITORING PROGRAMME

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Figure 5: Pilot Trial main site overview.

The monitoring programme and MAR site were constructed from March through May 2016 with pre-operational testing after construction undertaken in May 2016. The operational and environmental monitoring programme encompasses surface water, groundwater and rainfall monitoring sites designed to cover four trial related spatial areas (Figure 6) which are:

1) **The 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.

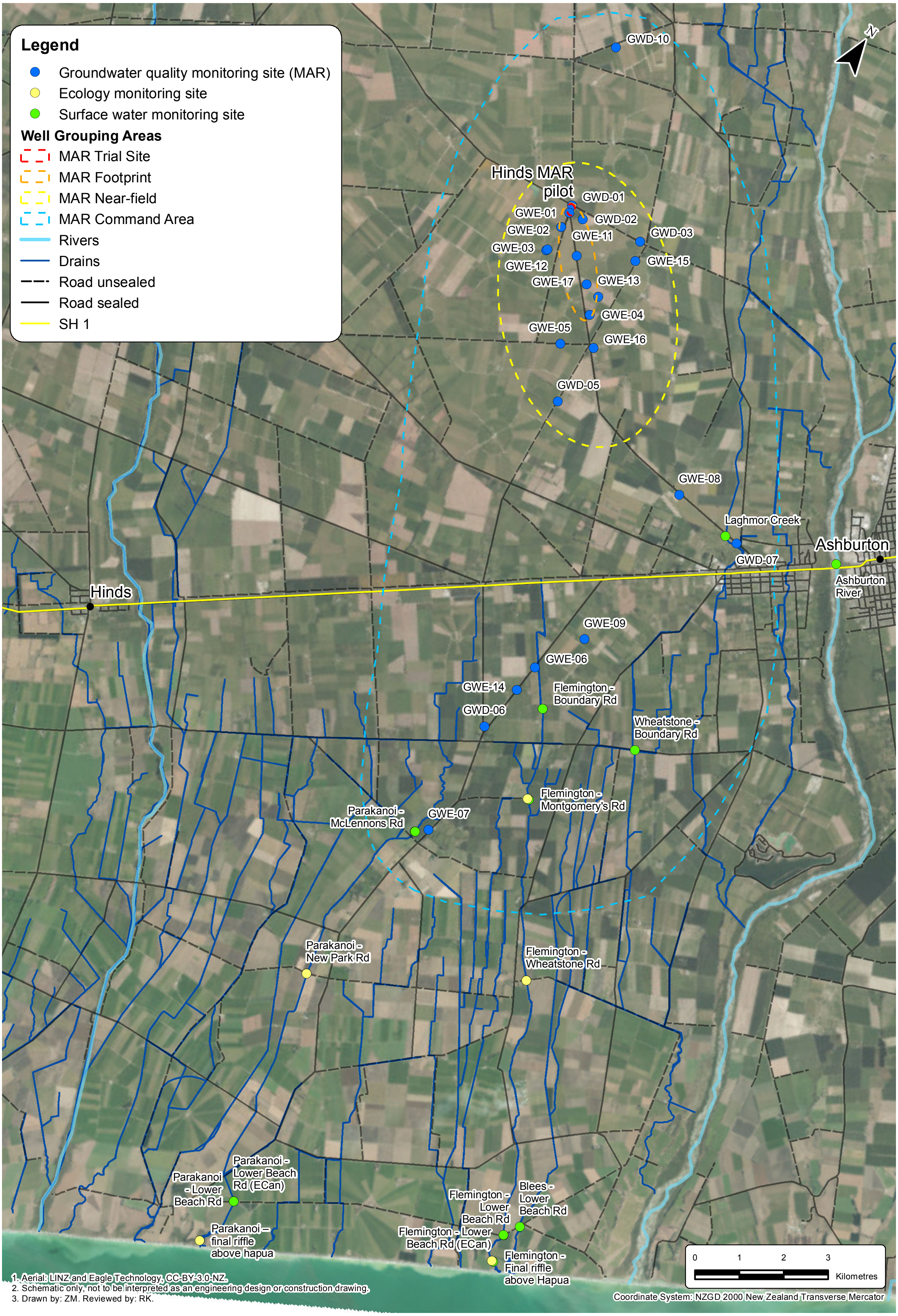
2) **The MAR Footprint** – the specific area where MAR operations directly influence water levels and quality.

3) **MAR Near-field** – the area directly adjacent to, but not influenced by MAR operations. This area provides the baseline comparison information used in the analysis.

4) **MAR Command Area** – sub-catchment portion of the Hinds Plains catchment which encompasses the key targets of the MAR site including Tinwald-area nitrate-N hotspot, coastal spring-fed waterbodies and depleted Valetta GAZ zone. A monitoring programme was set up inside this area to encompass these features and collect data to record baseline conditions. 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 portion of the Hinds.

The MAR technical team, strategic partners and community members undertook extensive efforts to provide public outreach and education of this Pilot Trial. An official opening ceremony (3 June 2016) was attended by representatives from Te Rūnanga o Arowhenua, CRC commissioners, the ADC mayor and a wide range of strategic partners, media and technical support staff. The AZC appointed Hinds MAR Pilot Working Group (HMPWG) replaced the HDWP as project manager with CRC as the holder of the resource consents authorising the MAR operations at the site. The MAR technical team also hosted a follow up Site Community Opening Day which was well attended on 15 June 2016 (Figure 7). In addition, two websites have been established as part of both the outreach programme and to support real-time site management operations.

A strategic partnership provided funding for the project, which was sourced from CRC, the Ministry for Primary Industries (MPI) Irrigation Acceleration Fund (IAF), RDRML and four community irrigation schemes (Mayfield-Hinds, Valetta, Barrhill Chertsey, and Eiffleton). A technical working group that included staff and representatives from Forest and Bird, Fish and Game, CRC, ADC, Golder, Lincoln Agritech, Scottech, Canterbury District Health Board (CDHB) all provided and/or supported the design, monitoring, operations, compliance and technical analysis that encompassed the Pilot Trial. The local contractor, Tarbottons Construction Ltd, led the final designs and construction as well as managing any ongoing site maintenance needs.



Golder Associates

TITLE PILOT TRIAL GROUPED MONITORING AREAS

JULY 2017

PROJECT 1538632

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Figure 7: Pilot Trial Outreach: Opening Ceremony with officials from ADC, CRC and Te Rūnanga o Arowhenua, 3rd June 2016 (left), Community Open Day, 15th June 2016 (right).

Additional public outreach include presentations to update AZC, ADC, farmer groups, Ashburton Rotary club meetings, as well as media interviews and letters to the editor, article publications and papers presented at national and international technical conferences. Site tours also were facilitated with both a small carpark and site information sign as well as planned visits with a wide range of community members, politicians and other interested parties from other parts of Canterbury working on similar water management issues.

1.5 Consents and Consent Conditions

In summary, the Pilot Trial operated throughout Year 1 in compliance with the conditions attached to the consents listed in Table 2.

The construction and operations of the Pilot Trial have been authorised under consents issued by the CRC and ADC (Table 2). 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 provided in Appendix A.

Table 2: Resource consents authorising the MAR Pilot Trial.

Consent number	Consenting authority	Activity	Commencement date	Expiry date
CRC162191	CRC	To discharge water into land	25 Feb 2016	25 Feb 2021
CRC162192	CRC	To excavate land	25 Feb 2016	25 Feb 2021
CRC164281	CRC	To take and use surface water	25 Feb 2016	25 Feb 2021
LUC15/0110	ADC	To excavate land	2 Feb 2016	2 Feb 2021

1.6 General Scope of Report

The general scope of this report and the attached appendices is to document the broad work areas undertaken during the first operational year (Phase 1) of the Pilot Trial, with specific reference to:

- Relevant aspects of the Hinds / Hekeao Plains catchment environmental background and how these aspects relate to the operations of the Pilot Trial.
- The monitoring data collected during this period and the analyses undertaken to evaluate these data.
- The conclusions arising from the results of these analyses regarding the effectiveness of the Pilot Trial in achieving the objectives listed in Section 1.3.

- Recommendations for ongoing work at the Pilot Trial site with respect to the development of a more comprehensive GRS within the Hinds / Hekeao Plains catchment.

1.7 Appendix Compendium

Most of the technical data derived from the MAR Pilot Trial monitoring programme and detailed analyses undertaken to support the assessment of the Pilot Trial are documented in a separate compendium of appendices. The key information and outcomes from the appendices are summarised within the body of this report. However, this report should be considered in conjunction with the appendices provided in the compendium. Guidance on the information contained in each of the appendices contained in the compendium is provided below.

- Appendix A presents a complete list of the conditions attached to the consents authorising the MAR Pilot Trial, a summary of compliance with the conditions and guidance regarding the location of supporting documentation of consent compliance within the main report or attached appendices.
- Appendix B documents climate monitoring data acquired during Year 1 of the Pilot Trial together with longer term baseline data from the Hinds Catchment.
- Appendix C documents the environmental and operational monitoring programme for the Pilot Trial. This appendix also documents the monitoring sites used to provide data to support analyses undertaken as part of the Pilot Trial, including monitoring well logs and well cards from CRC.
- Appendix D documents the clamshell holes installed in the base of the main infiltration basin and presents an assessment of the effectiveness of these holes in increasing infiltration rates at the site. This appendix also summarises options for modification of the Pilot Trial site to increase recharge rates to the underlying groundwater system.
- Appendix E documents the flows and volumes of source water derived from the Rangitata River and delivered to the MAR Pilot Trial site.
- Appendix F documents the quality of the source water for the Pilot Trial, including relevant aspects of Rangitata River water quality, the quality of water in the Valetta Pond #3 and in the main infiltration basin.
- Appendix G documents the groundwater level and temperature data acquired from the Pilot Trial monitoring programme. This appendix also presents an evaluation of the effects of Pilot Trial operations on groundwater levels in the underlying groundwater system, including the extent and magnitude of these effects.
- Appendix H documents the receiving groundwater quality data, including long term baseline data from the Pilot Trial command area, background data from monitoring wells unaffected by the Pilot Trial and data form the monitoring wells influenced by the trial. This appendix also presents an evaluation of the effects of MAR operations on receiving groundwater quality beneath the Pilot Trial site and on the sider groundwater system down-gradient from the site.
- Appendix I presents the data acquired during Year 1 of the Pilot Trial to enable an evaluation of infiltration basin clogging. This appendix also documents the evaluation of this data and presents the outcomes with respect to clogging issues requiring management at the site.
- Appendix J presents an assessment of groundwater quality within the Pilot Trial command area, with specific reference to three drinking water supply bores located within this area.
- Appendix K presents a report by Lincoln Agritech on the use of an automated nitrate-N monitoring system used during the Pilot Trial to detect changes in nitrate-N concentrations in groundwater monitoring wells during Year 1 of the trial.

- Appendix L documents the calculation of losses from the water race between Valetta Pond #3 and the Pilot Trial site and presents the infiltration rates calculated for the base of the water race during Year 1.
- Appendix M documents groundwater levels from monitoring well GWD-07, which was installed close to Tinwald, rainfall data from Ashburton and surface water level data from the Ashburton River and Lagmhor Creek. This appendix also presents an assessment of the factors influencing groundwater levels at Tinwald, including the influence of the Pilot Trial on groundwater levels in this area during Year 1 of the trial.
- Appendix N documents ecological monitoring work undertaken to evaluate potential effects of the MAR Pilot Trial at the coastal drains during Year 1 of the trial.
- Appendix O presents a summary of work undertaken by CRC on numerical monitoring of the effects of the MAR Pilot Trial on groundwater levels and quality during Year 1 of the trial and projections of these effects for the consented period of the trial.
- Appendix P contains a statement of limitations with regards to the information presented in this report and the attached appendices.

2.0 PILOT TRIAL BACKGROUND

2.1 Catchment Overview

The project area is located on the Canterbury Plains south of Ashburton, between the Rangitata River and Ashburton / Hakatere River, bounded up-gradient by the Canterbury foothills and down-gradient by the Pacific Ocean. These two alpine rivers are fed mainly by rain and snowmelt from the Southern Alps and provide source water for an extensive system of irrigation and stockwater distribution races in the catchment. The Upper Hinds River / Hekeao catchment includes the foothill-fed drainage areas of the north and south branches of the Hinds / Hekeao River (Figure 1) and ranges in elevation from 1,153 m amsl to sea level.

The Hinds River is located in middle of the Hinds Catchment and separates it into the Mayfield Hinds and Valetta groundwater allocation zones, flows from the foothills to the sea, with the mid-reaches of considered intermittent, losing flow naturally to groundwater recharge. The Lower Hinds / Hekeao River reach benefits from the subsequent natural returns of groundwater, making it perennial in the lower sections of the catchment. The coastal section of the Hinds / Hekeao River is also supplemented by flow from a number of spring-fed waterbodies. During episodic rain events, typically during winter, the Hinds / Hekeao River does run continuously from its headwaters to the ocean. The coastal Lowland Waterways catchment area has more than 30 spring-fed waterbodies that make up both a natural stream and anthropogenic drainage network.

The Rangitata Diversion Race (RDR) diverts water from the Rangitata River and pumps water from the Rakaia River. The RDR was designed to feed irrigation schemes and hydropower, which is produced on the main RDRML race at the Montalto (1.9 MW) and Highbank (28 MW) operated by TrustPower (TrustPower[4]). Irrigation schemes in the catchment include Mayfield-Hinds, Valetta (now combined with Mayfield-Hinds), and BCI. Other irrigation schemes are Eiffelton, which relies on spring-fed waterbodies and supplementary groundwater pumping, and the Lynnford, which relies solely on surface flows (Durney and Ritson 2014). ADC also maintains a network of stockwater races that divert water from the two alpine rivers to provide a water supply throughout the year.

The villages of Hinds, Mayfield and Tinwald (a suburb of Ashburton) are some of the agricultural-based communities within this catchment. Farming is the primary source of employment and income for many people who live in the catchment. In recent years, a transition from pastoral agricultural activities (e.g.,

[4] https://www.trustpower.co.nz/

sheep, arable, and deer) to more intensive irrigated activities (e.g., dairy and dairy support) has transformed both farming operations and the local and regional economy. Economically, the Ashburton zone, which includes the Hinds / Hekeao catchment, represents a significant portion of New Zealand's National Gross Domestic Product (25 % in 2010) and approximately 43 % of the nation's arable production (Taylor 2014).

Recent intensification of farming based on irrigation, and the transition to dairy farming, has resulted in significant changes to the water quality and ecological health of the catchment. Agricultural-related contaminants in groundwater, rivers, and spring-fed waterbodies include nitrate-nitrogen (nitrate-N), phosphorus, sediments and faecal bacteria, and have shown increasing trends (Scott 2013).

The Hinds / Hekeao River and associated lowland streams and drains are a local resource and used to be considered a regional resource for recreational opportunities. Local people and fishers describe the river and some drains as having had significant local recreational value for both fishing and swimming in the past (the middle of the last century) and argue that this resource has declined significantly with longer periods of dry river bed and declining ecological conditions. The lower Hinds / Hekeao River retains low values as a trout fishery (Bower 2014).

The quality of drinking water within the Hinds catchment is of concern for the Ashburton zone committee. The CWMS lists as one of its first order priorities community supplies and the Ashburton zone committee has stated that protection and improvement of water quality over time is of paramount importance. They have also stated that they wish to ensure water quality is available for full range of uses including drinking water. The zone addendum has stated it will support ADC initiatives to improve community water supplies and initiatives to protect domestic water supplies. AZC support ECAN, ADC and CDHB to continue to investigate, communicate and implement appropriate options to address the nitrate levels that exceed New Zealand Drinking Water Standards in groundwater wells that supply some individual households.

2.2 Catchment Physical Settings

Average annual precipitation within the Hinds catchment ranges from 614 mm at the coast to approximately 950 mm on the foothills at the top of the plains, with winter snow only found above 500 m amsl. Durney and Ritson (2014) reported that since 1980 to 2014, there has been a minor natural decline in overall rainfall in the Hinds catchment, which played a 'minor decline' in changes seen in the groundwater resources. Golder found that rainfall data collected from 1990 to 2016 showed that 2015/2016 were two of the five driest years recorded during this period (Appendix B). No overall trend toward decreasing rainfall was identified from the data for this period. New Zealand's National Institute of Water and Atmosphere's (NIWA) climate change projections for Canterbury show a 10% increase in droughts by 2040 (NIWA, 2011).

The Canterbury Plains are a product of a complex and high energy fluvial and alluvial depositional environments. The geology of this aquifer system is dominated by Quaternary glacial outwash fans and plains formed of fluvial river materials deposited over a basement of bedrock. Thick alluvial gravel sequences have been deposited and reworked by the large river systems crossing the plains, including the Rangitata, Hinds and Ashburton Rivers. This environment has resulted in the superposition of complex sequences of glacial and inter-glacial deposits (Golder 2016) resulting in a formation that is variable and heterogeneous in structure.

Most of the groundwater beneath the Hinds / Hekeao Plains is derived from water that drains down through the soils on the plains (Durney and Ritson 2014). This drainage is often called Land Surface Recharge (LSR) and it consists of net sum of the natural rainfall and irrigation water percolating through the soils as drainage, minus the water lost to evapotranspiration from the soils and plants.

The groundwater system of the Hinds / Hekeao Plains catchment is hydraulically linked to the Rangitata and the Ashburton / Hakatere Rivers. The upper stretches of these rivers in the catchment serve to recharge the regional groundwater system. Similarly, the Hinds River also recharges the groundwater system when it is carrying water (Durney & Ritson 2014).

Groundwater in the shallower parts of the aquifer tends to flow through higher permeability zones toward the spring-fed waterways near the coast. The spring-fed waterbodies of the Hinds / Hekeao Plains consist of a series of highly modified drains that either connect to larger drains or discharge directly to the sea. These reaches are steeper than typical lowland streams in Canterbury and retain more natural meandering stream forms, especially in areas with higher coastal cliffs. The steep eroded stream channel areas are referred to as 'dongas' and contain ponded areas and coastal lagoons (hāpuas) behind the beach.

For further information specific to the geology, hydrogeology and water resources of the Hinds / Hekeao Plains catchment, see Davey (2003, 2006a, 2006b), Dommisse (2005, 2006) and Durney and Ritson. (2014).

2.3 Hydrogeology, Hydrology, Ecology and Cultural Values

Degrading water quality in both ground and surface water coupled with declining groundwater levels and spring-fed baseflows and degrading ecological habitat in the Hinds catchment is well documented in Durney and Ritson (2014), Scott (2013) and Meredith (2014).

Specific to the MAR command area, bore GWE-4 (K37/0200, shown in Figure 6) has one of CRC's longer periods of record for groundwater levels in the Hinds Catchment. Figure 8 provides a conceptualised groundwater-balance of changing storage levels as they related to historic water management changes for GWE-4 (Golder, 2014). Data suggests a shift from the pre-1996, groundwater levels were generally higher driven mainly by border dyke irrigation and the complete network of ADC leaky stockwater races. Pre-1990s there was also very little groundwater pumping, as irrigation bores numbers remained low until the mid-1990s (Golder, 2014a). Despite interspersed wetter and drought years, groundwater levels, and flows in the coastal drains remained relatively consistent (Golder, 2014a). From the approximately 1995/1996 to present dramatic reductions in the rate of incidental recharge including the move to more efficient irrigation practices (e.g., sprinklers) coupled with dramatic increases in groundwater pumping lead to a steep declining trend in groundwater levels and the frequent drying of this and other shallower bores in the area. The more recent drought conditions (2014 to 2016) have clearly exacerbated conditions, but are not in itself the primary drivers of these large mass balance changes to groundwater storage.

Locally collected records of bore water quality near the Pilot Trial site show a trend consistent with that Scott (2013) reported for shallow and deep groundwater in the Hinds Catchment with increasing concentrations of nitrate-nitrogen (Figure 9). For example, shallow bore records near the MAR site show nitrate-N levels ranging from 1.0 to 5.0 g/m^3 in 2003 and 2004 to levels of approximately 11.0 g/m^3 in 2014. Another MAR footprint bore had records showing levels of 1.0 g/m^3 in 2003, reaching 17.0 g/m^3 by 2008.

Results from the CRC environmental monitoring programme have demonstrated that *E. coli* bacteria concentrations are high in the drains and detectable in the groundwater of the Hinds Plains (Bower, 2014). Deep groundwater generally meets the drinking-water standard for *E. coli*, but each year between 10 and 20% of samples from shallow groundwater fail to meet the standard (Figure 10). Bacteria concentrations in shallow groundwater show an increasing trend. There do not appear to be any long-term trends in bacterial concentrations in the drains, but this may be because concentrations are so high they are often at or near laboratory detection limits. Section 4.6 contains a comprehensive summary of groundwater quality for the Pilot Trial.

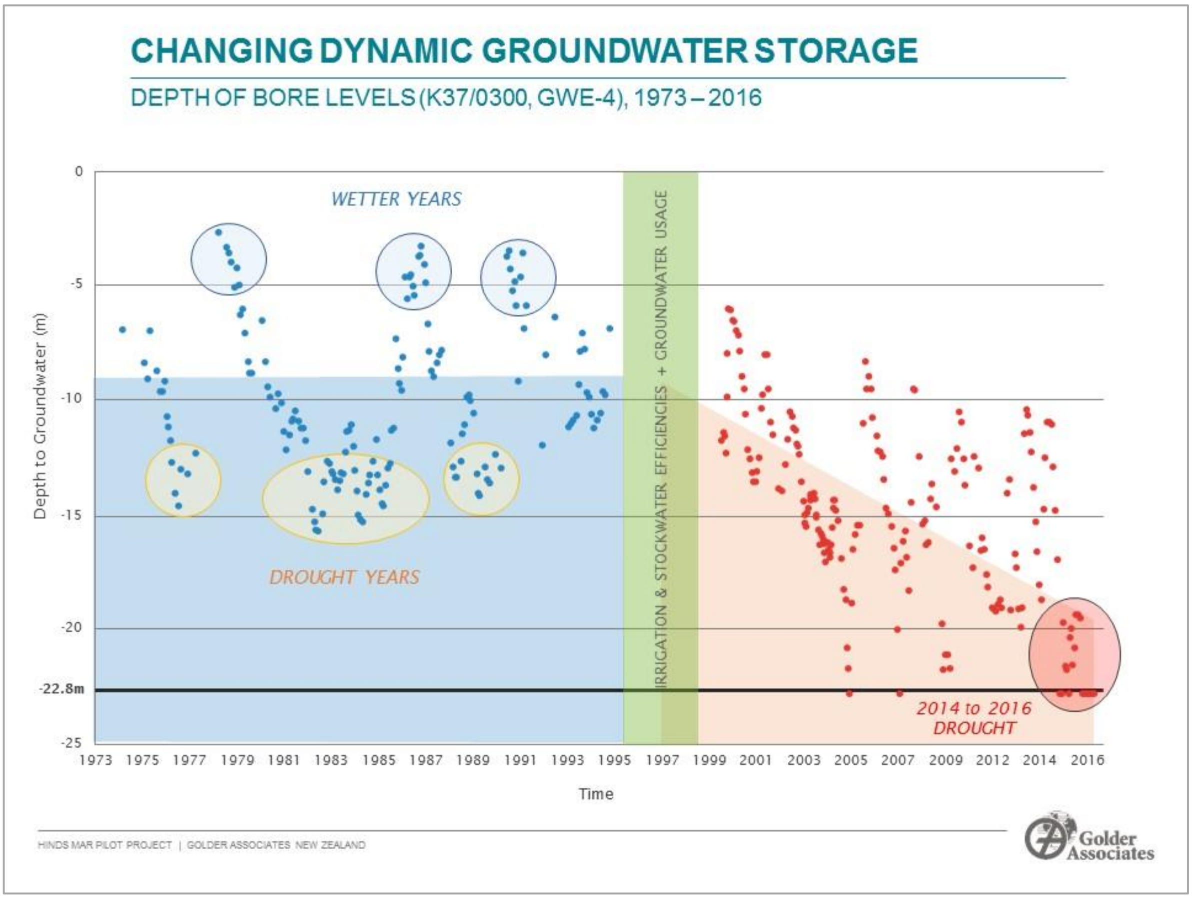

Figure 8: Long term groundwater record for MAR near-field bore (GWE-4, K37/0200, depth 22.8 m bgl).

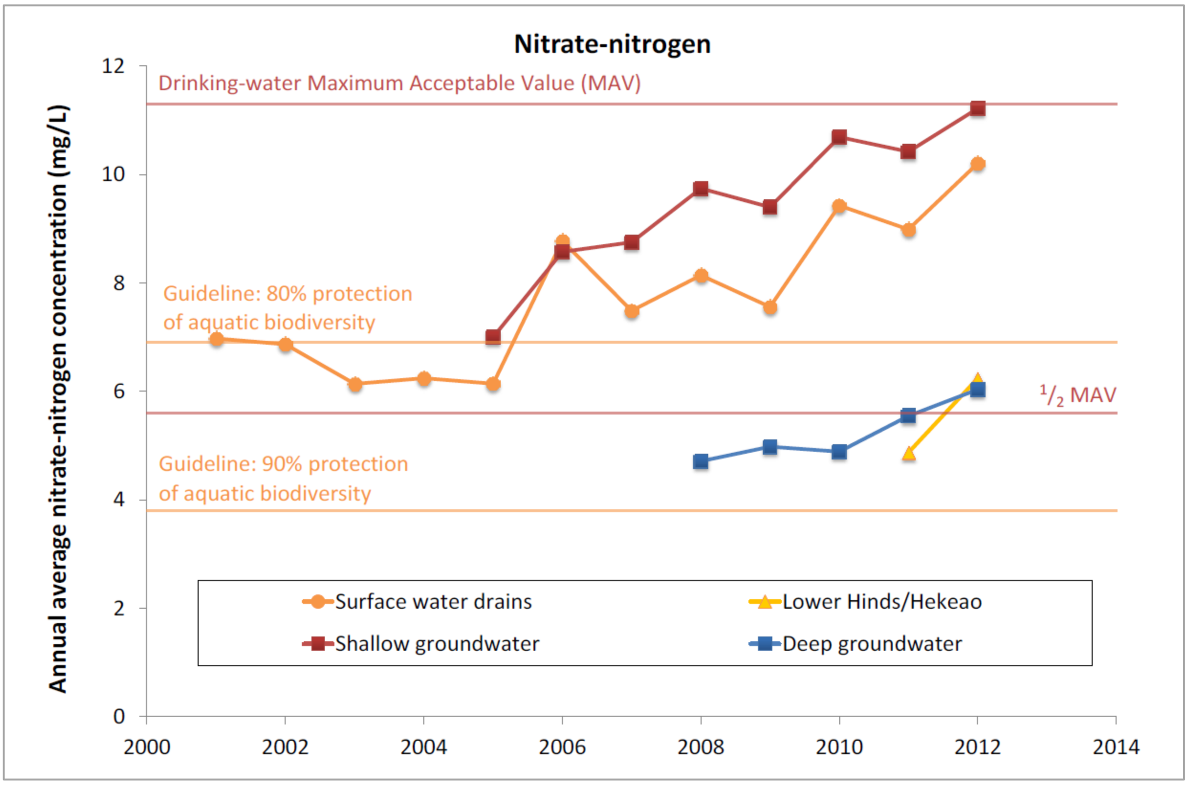

Figure 9: Hinds Catchment nitrate-N trends in groundwater (Scott 2013).

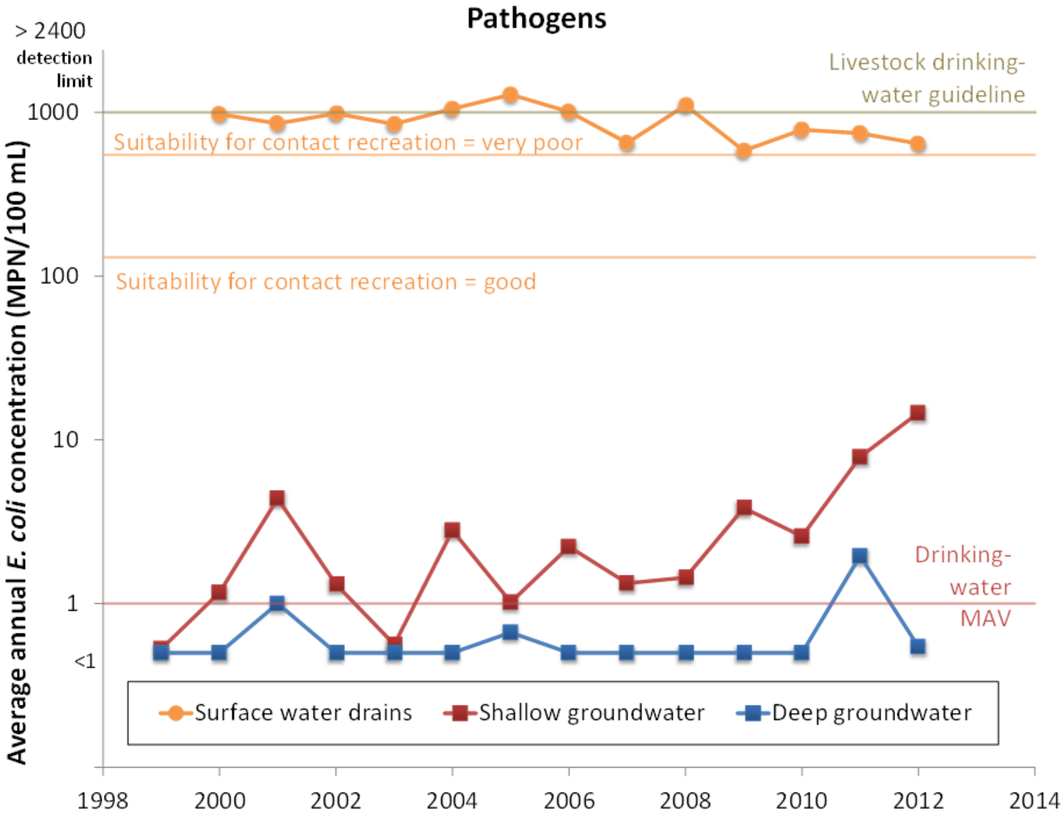

Figure 10: Annual average concentrations of E. coli in monitoring wells and spring-fed waterbodies (Bower, 2014)

The Hinds Drains Working Party members conducted a monitoring programme that included; water quality, flow, electro-fishing, and stream habitat surveys from 2014 to 2016 (HDWP, 2016). The report noted that the management of these drains needed to balance the need for coastal drainage cultural and ecological values. Conditions in these drains had drastically changed from historical conditions under enhanced incidental recharge from borderdyke irrigation. From 2014, the drought conditions exacerbated already declining groundwater levels and degrading water quality conditions. Drains such as Parakanoi Drain, once a stronghold of native species and trout (Meredith et al. 2014), went completely dry for extended periods as did others north of the Hinds River (Figure 11).

Results from more than 460 samples collected by the HDWP water quality monitoring programme indicated concentrations of nitrate-nitrogen ranging up to a maximum of 21.0 g/m^3 median value of 9.25 g/m^3 with average concentration of 8.63 g/m^3. Concentrations were typically higher than the Hinds Plains target nitrate-nitrogen average annual concentration of 6.9 g/m^3 (AZC and HDWP, 2016).

Durney and Ritson (2014) provided a summary of hydrological conditions including flow summaries (2004 to 2014). For the drains directly below the MAR site, mean flows ranging from 125 L/s (Flemington Drain) to 230 L/s (Parakanoi Drain) (Figure 11). Several fish rescues were conducted on drains north of the Hinds by HDWP members to help save stranded eels and other native fish species including threatened Canterbury Mudfish (Figure 12).

Ecological and cultural values in the drains are considered highly impacted based on both the dry conditions and the quality of groundwater entering the drains via springs and seeps. Cultural values such the gathering of mahinga kai (Maori traditional food gathering) are particularly at risk from high levels of faecal contamination in the drains (Tipa, 2013).

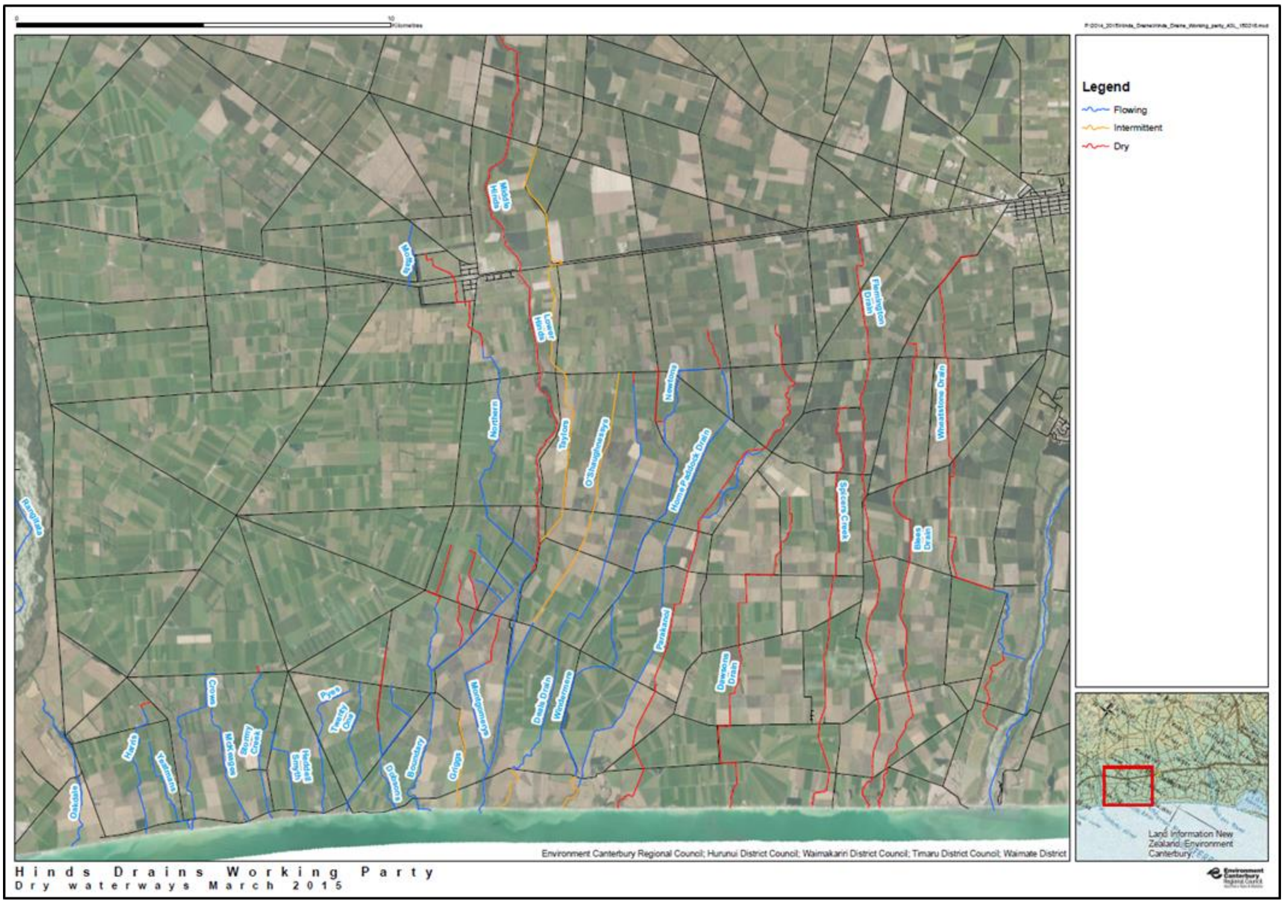

Figure 11: Hinds Catchment Coastal Spring-fed Streams (Drains) - flow status map (HDWP, 2016).

Figure 12: Canterbury Mudfish (HDWP, 2016).

2.4 MAR Site Characterisation

During the development of the project, ADC made up to 500 L/s (15,780,000 m^3/year) available for testing of MAR for a 1 year period. Using that target recharge rate, Golder worked with the HDWP and Valetta board members to determine where in the Valetta area, MAR could be potentially tested at that flow rate. The selection process for a final MAR testing involved the weighing of variety of both physical, logistical and practical factors including; delivery infrastructure (e.g., Valetta Pipeline), relative proximity to key targets: coastal drains and the Tinwald area, land availability (e.g., ADC gravel storage), and rural neighbours that were supportive of the trial concept.

Golder (2015a, 2015b) provides a comprehensive summary of the physical characterisation and modelling work conducted to evaluate the Pilot Trial site as a potential MAR testing location. Both soils information and discussion with farmer managers adjacent to the site indicated that this was location of relatively free-draining soils. Proximal bore logs near the site (e.g., GWE-1, etc.,) showed geology to comprise of claybound gravels mixed with sandy gravels. Anecdotal information from local earthworks contractors indicate that at least one ‘clay pan’ layer were also prevalent in the area, which helped inform the physical site testing.

Physical testing of the site was conducted through two separate percolation tests combined with Seep/W modelling (Figure 13). A total of two percolation tests were conducted (Test 1 – depth 1 m, Test 2 – depth 6 m) based on ‘clay pan’ anecdotal information. Modelling suggested that the site could potentially recharge the available 500 L/s of ADC water, however it was clearly stipulated that Pilot Trial testing was needed to determine an actual overall achievable recharge rate. Note that during the two percolation tests, no ‘clay pan layer’ was found. The final decision to proceed with this particular site was based on both these physical assessment results as well as the overarching MAR testing objectives and practical water infrastructure settings.

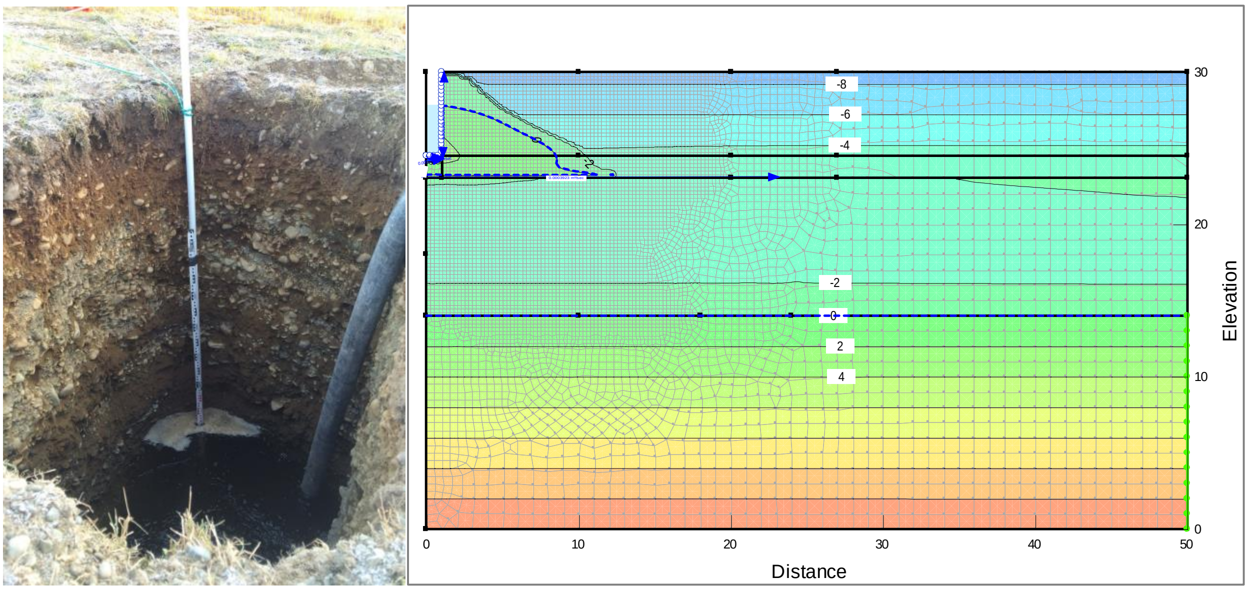

Figure 13: Second Percolation Testing Pit with Seep/W modelling (screenshot) physical site testing programme at Pilot Trial Site (Golder, 2015a)

3.0 PILOT TRIAL TESTING PROGRAMME

3.1 Introduction

The Pilot Trial site and supporting surface water, groundwater and climate monitoring programme covers an sub-catchment of the Hinds Plains totalling over 255 km^2 spanning from up-gradient monitoring bores through to flow sites at the coast. The MAR Command Area which sits inside this sub-catchment area, (encompassing the groundwater monitoring bores and spring-heads), and covers an area of approximately 150 km^2 (Figure 6). The overall monitoring programme including ecology, flows, groundwater, and climate stations is shown in Figure 6. The MAR Pilot Trial site is located at the head of the MAR command area and has specific, near-real-time monitoring and automation at the site.

3.2 Source water diversion and delivery system

The Hinds MAR project was designed to use alpine water sourced from the Rangitata River to replenish underlying groundwater. This water was secured through the temporary (initially 1 year) transfer of unutilised ADC stockwater and consented for use at the MAR site (Table 2). ADC maintains a diversion meter, which provides 15-minute flow data for stockwater being diverted from the river. The consent stipulates that RDRML can divert up to 500 L/s for delivery to the MAR site at their Klondyke intake, but not exceeding an annual volume of 15,780,000 m^3 between 1 February and the following 31 January. RDRML's Klondyke intake flow data is compiled as daily average flows, with the *source water* considered *additional* to RDRML existing consented take.

The *source water* is then conveyed along the RDR to the Valetta scheme intake, where again it is compiled as daily average flows. Valetta then directs the *source water* to the MAR site via their piped scheme network as well as a series of surface storage ponds under the same maximum rate and volumetric limits outlined in the consent. This water arrives in a Valetta storage pond (#3), where it can be diverted into the MAR site through a remotely controlled hydraulic gate. The start of the MAR site is designated as the water passing through Flume 1. For more detailed information see Appendix E.

3.3 Infrastructure and Monitoring at Pilot Trial Site

3.3.1 Dedicated Monitoring Bore Drilling Programme

Starting in February 2016, a drilling programme was initiated to enhance the location and type of groundwater monitoring to be conducted for the Pilot Trial. Sonic drilling was conducted on 7 new dedicated monitoring bores, which were placed to both help quantify the groundwater directly beneath the site (GWD-1) as well as bores that helped to fill in large gaps in the spatial coverage of existing and available irrigation bores (Figure 14). Sonic cores were catalogued and boxed being logged both in the field (driller) as well at Golder's offices by a geologist.

The information from these sonic drillhole logs were useful in understanding the subsurface beneath the site and were used in the final conceptual interpretation of Pilot Trial water level and quality responses (See Appendix M). Monitoring bores were drilled up to 45 m bgl, and casing size ranged from 32 to 50 mm. Two 100 mm bores (GWD-1 and GWD-4) were installed with both 32 mm and 50 mm internal casings, these two bores designed for the installation of the specialised automated nitrate-N monitoring equipment (See Appendix D).

Figure 14: Pilot Trial dedicated monitoring bore drilling programme: Sonic drill rig and boxed core (GWD-1, March 2016).

3.3.2 Site Description

The Pilot Trial site consists of an infiltration basin system constructed by Tarbottons Ltd on a site owned by ADC at the intersection of Timaru Track Road, Lowes Road and Frasers Road, Ashburton (Figure 6). The consent holder for the project is CRC. Site construction commenced in March 2016 and concluded in early June (Figure 15).

The total infiltration surface area potentially available is 1.05 ha, consisting of a 0.14 ha forebay and a main infiltration basin that has an area of 0.90 ha (Figure 5). At operational water levels, the ponded area of the forebay is still approximately 0.14 ha and the ponded area of the infiltration basin at a water depth of 0.8 m is 0.69 ha. Taking into account the saturation of the bund between the two basins, the recharge footprint for the combined basins is approximately 0.90 ha.

Site construction involved significant earth works and the fabrication of various water structures including concrete weirs. All excavated materials were kept on-site and used in both the construction of the basin bunds, or kept in storage on the north-eastern side of the main basin. This was to allow for the restoration of the site should the Pilot Trial be deemed by the community as being unsuccessful.

A site construction and erosion control plan was included in the Assessment of Environmental Effects (AEE) and section 92 consenting documents (Golder 2015a, 2015b). An extensive health and safety programme was also developed and managed by the Pilot Trial management team and included site inductions, a traffic control plan, appropriate site signage and a detailed evaluation and documentation of the potential of health and safety risks for the site. The site is now managed to this plan by Valetta staff.

Figure 15: Site construction including excavation of main basin and storage of native materials on site (April 2016).

3.3.3 Clamshell holes

The design and construction of clamshell holes was included in the final consented site plan, based on percolation testing conducted at this location in 2015 and successful techniques applied to maximise recharge rates at other MAR infiltration sites (Bower et al. 2010). The purpose of these clamshell holes was to help enhance the infiltration of water from the main basin through any subsurface, less permeable materials immediately beneath the site. It was also surmised that they may help to reduce potential air entrapment that could occur as the basin is filled for operations.

A total of 24 clamshell holes[5] were installed in early June following a short pre-trial infiltration testing period (Figure 16). Clamshell holes were approximately 6.0 m in depth, which was the excavation capability limit for the equipment used, with a nominal 1.5 m radius. Each hole was filled with materials from the excavation that were washed then selecting for large sizes (cobbles). A review of the operational performance of the clamshell holes is summarised in Section 4.8.1.

3.3.4 Site monitoring infrastructure

The main features of the site include a delivery race (from Valetta Pond #3), which contains a bypass gate allowing water to be flushed through to two adjacent farm storage ponds (Figure 5) and, an intake flume (Flume #2), which measures flow entering the Pilot Trial site. Water entering the site is retained in the forebay, which allows sediments picked in the open race to settle. Water then overflows into the main infiltration basin where the water depth is measured at a main basin level recorder. In the unlikely event of basin levels getting too high, an emergency overflow spillway would allow excess flows to be directed into an adjacent open stockwater race. During initial site construction, this ADC stockwater race (Westerfield Main), which typically carries between 20 L/s and 30 L/s (per comms ADC staff), was rerouted from flowing directly across the site. The new water race alignment is adjacent to Fraser's Road (Figure 5).

A dedicated groundwater monitoring well (GWD-1) was established adjacent to the forebay near Flume 2, and is used for the monitoring of both groundwater levels and quality.

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[5] Contractors name for the type of excavation equipment used to construct some of the holes. Others were constructed using a standard bucket excavator

Figure 16: Construction of Main Basin Clamshell Holes (June 2016).

3.3.5 Site flow and water quality monitoring points

Water quality and quantity monitoring is conducted at several points from the MAR site intake (Flume 1) through to the main basin and groundwater directly below the site (Figure 4). The surface water flow rates and stages are measured at three locations at the MAR site (refer Appendix C). Flow leaving Valetta Pond #3 and entering the site are measured at Flume 1 (Figure 17), which is the point of diversion relative to site consent conditions. The water then travels approximately 900 m down a leaky, open race to Flume 2 (Figure 18). Flume 2 is used to measure the amount of water entering the main MAR facility. Flow losses through infiltration through the base of the water race can be calculated as the difference in flows recorded at Flumes 1 and 2.

If the main basin water levels exceeded 2.4 m depth, overflows are measured using the main basin level logger (stage), with the 'Overflow' spillway acting as an outflow weir (Figure 5). This flow can be quantified by developing a rating from level data collected from the main basin recorder (Figure 19). Water bypassing the Pilot Trial site, in accordance with the water quality consent conditions, and directed to the adjacent farm ponds (Millar Farms) flows over a sharp-crested weir that is used as a bypass gate, and is measured based on water levels recorded at Flume 2 (Figure 5).

Flow measurements at the MAR site are conducted primarily at the following two locations.

1) Flume 1 (Figure 17) is located immediately below the outflow from the Valetta Pond #3, which is controlled by an electronic hydraulic gate (in house). The flume is fitted with a stage recorder (logger) and an External Staff Gauge (ESG) attached to the adjacent concrete diversion structure.

2) Flume 2 (Figure 18) is at the outflow point from the open race to the MAR forebay. This flume is fitted with an ESG and stage recorder (logger) within four metres of the concrete weir that controls flow into the MAR forebay (Figure 5).

Figure 17: Flume 1 with Valetta Pond gate house, ESG board (inset) and logger housing.

Figure 18: Flume 2 with ESG and logger structure.

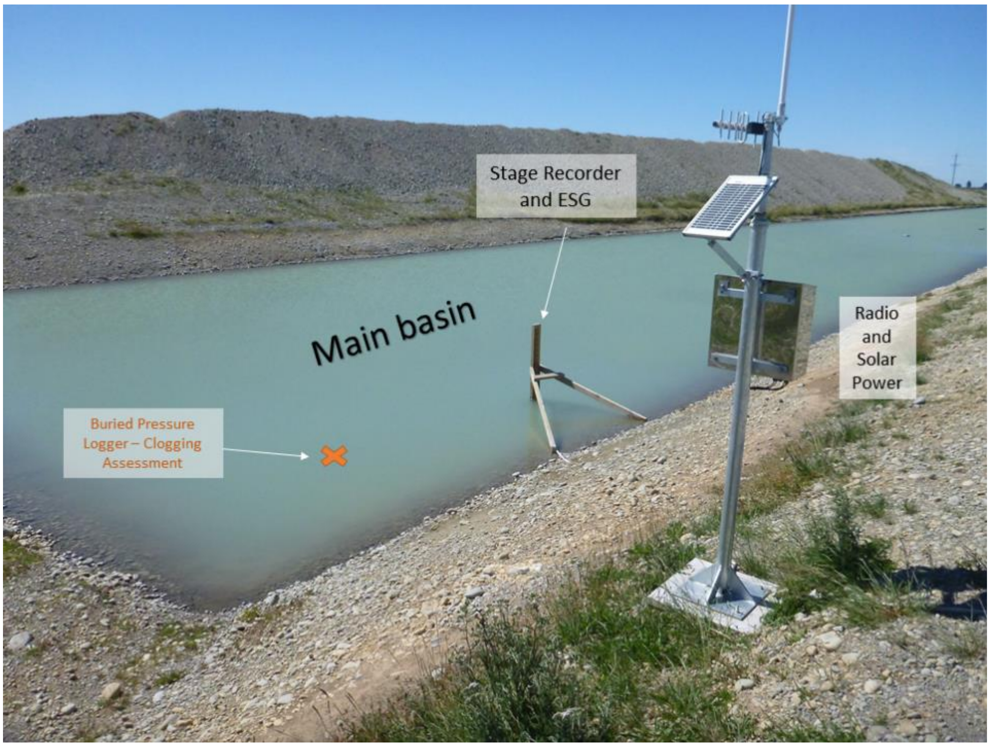


Figure 19: Main Basin level logger, ESG and solar communications with location of buried transducer.

3.3.6 Project websites and near-real-time operational systems

Two websites were developed for the project, one to help provide outreach and information to the general public (Figure 20) and the other for day-to-day operations and monitoring (Figure 21).

The outreach website (*Ecan.govt.nz/hinds-MAR)* had videos, pictures, background reports and information along with access to real time water quality and quantity data being collected. It was found that it continues to provide a good mechanism for transmitting information to both the local community as well as national and international enquires.

The operational website provides key information on flows, basin levels, temperature and source water delivery information which was critical for the successful managing of Year 1 operations. During the trial water quality samples have been collected from both the main basin and GWD-01. The information provided was temperature, flows, levels and volumes for the following sites: Valetta Pond #3, Flume 1, Flume 2, MAR bore (GWD-01), main basin and with online links to the CRC flow gauge Parakanoi at Lower Beach Road and Hinds Plains rain gauge. The last two sites are required due to the coastal flooding trigger condition.

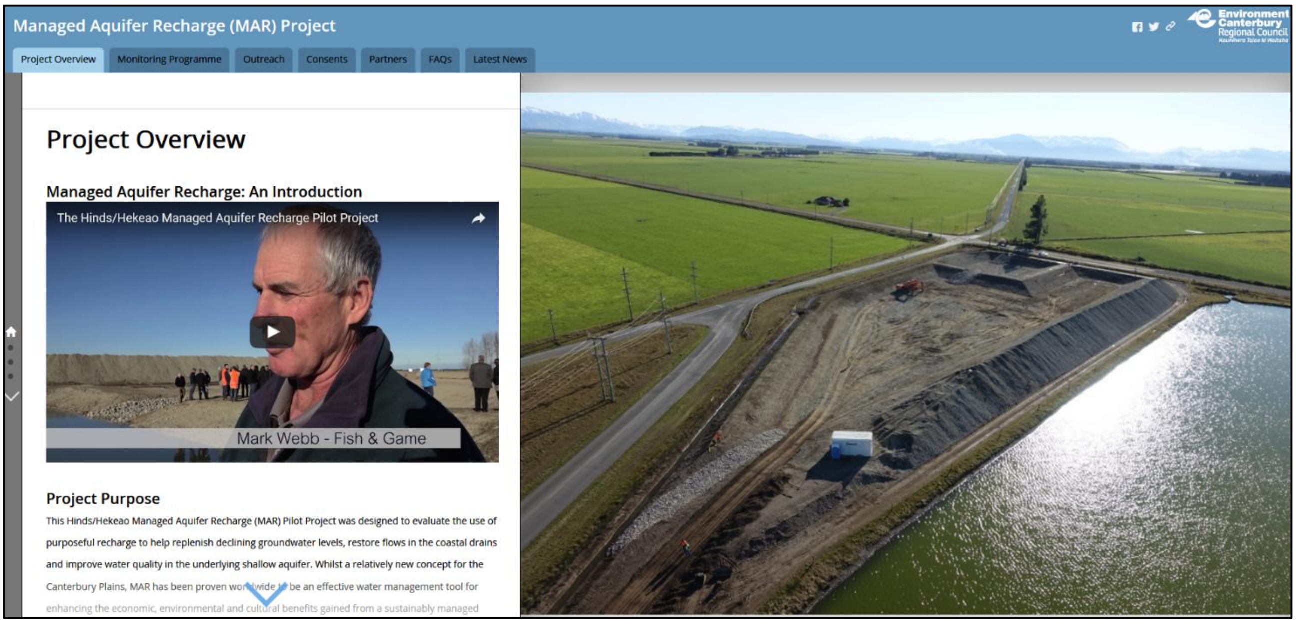


Figure 20: Official MAR outreach website.

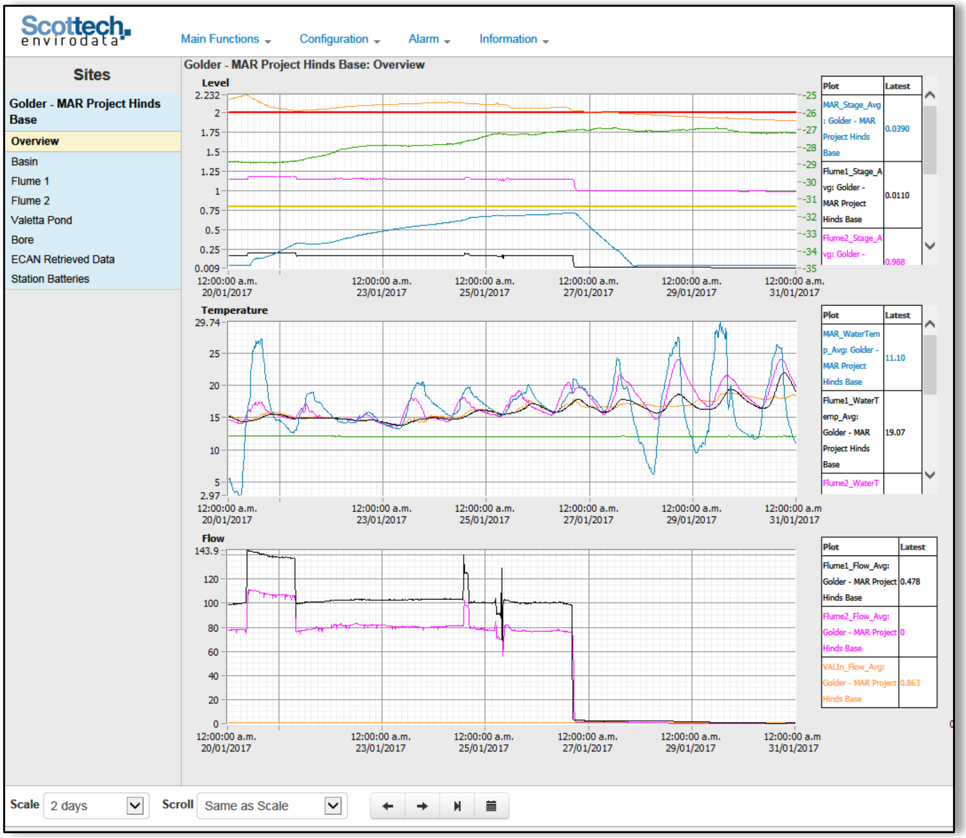


Figure 21: MAR operational website near-real time interface (2 Days in January 2017)

3.4 MAR command area monitoring system

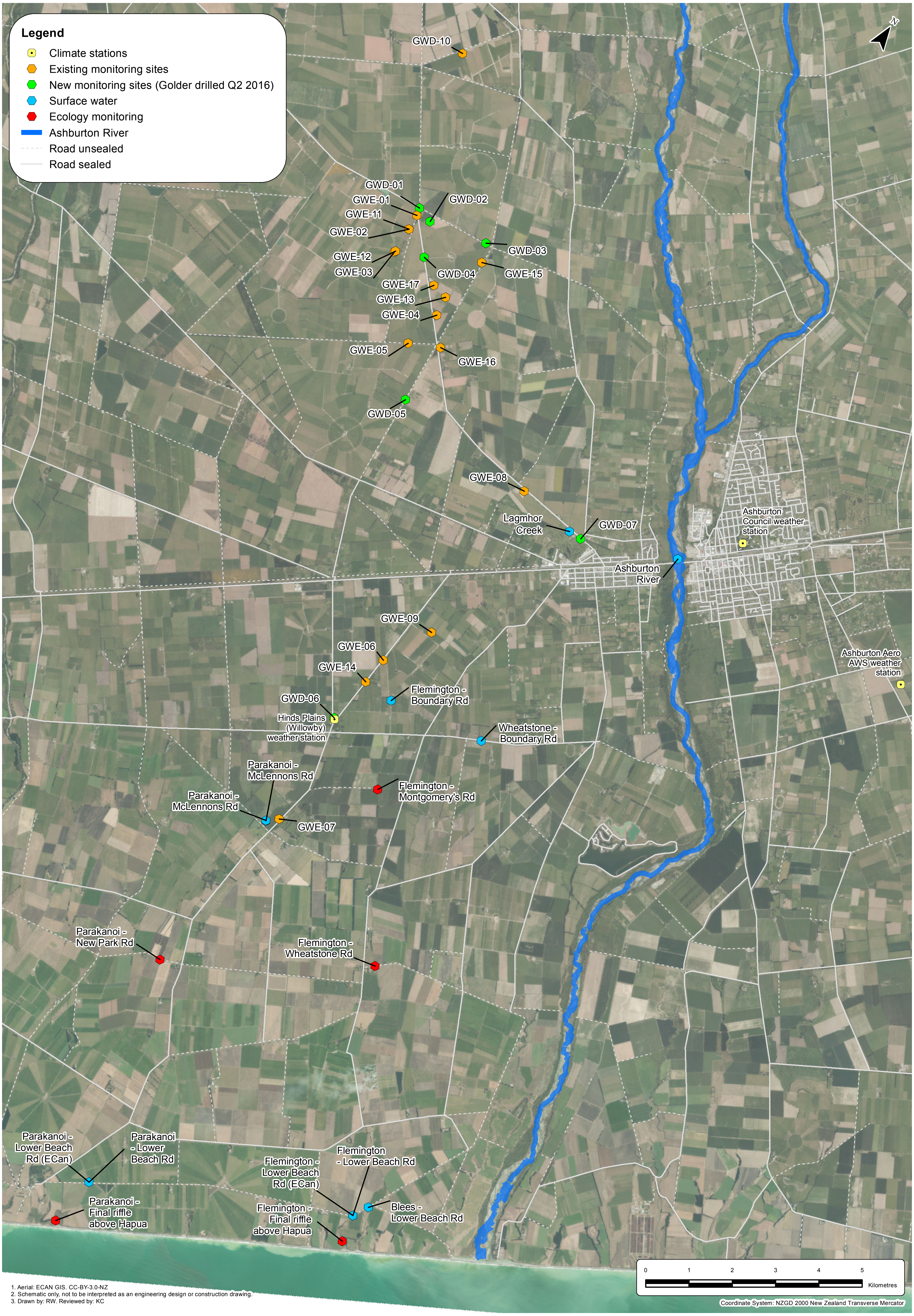
A groundwater and surface water level and quality monitoring programme was instigated both on-site and within the wider catchment to support the Pilot Trial (Figure 22). The monitoring programme was designed to acquire data to support infiltration management at the site as well as analysis of the Pilot Trial outcomes. Components of CRC's regional monitoring programme were incorporated, where appropriate, in the Pilot Trial monitoring programme. Additional targeted monitoring was also implemented at selected monitoring wells and surface water bodies. The locations of the environmental monitoring sites for the Pilot Trial are presented in detail in Appendix C.

Details of the monitoring programme for the first year of the Pilot Trial, including both pre-existing and new monitoring sites, are presented in Appendix E of this report. Parameters monitored include:

- Climate – rainfall and potential evapotranspiration (Appendix B)
- Ecology – habitat and species present (Appendix N)
- Source water used for recharge – quality and quantity (Appendix E and Appendix F)
- Receiving water (groundwater) – quantity and quality (Appendix G, and Appendix H)
- Surface waters – quantity and quality (Appendix E and Appendix N)
- Groundwater – quantity and quality (Appendix G and Appendix H)

Pilot Trial monitoring site descriptions and objectives are summarised including parameters tested on the samples collected. These are listed in Appendix C. During the Pilot Trial the water quality parameters for field or laboratory testing generally included:

- Microbiological parameters: *E. coli* and total coliforms
- Total nitrogen, nitrate-N, nitrite-N
- Turbidity and total suspended solids
- pH, temperature and electrical conductivity



1. Aerial: ECAN GIS. CC-BY-3.0-NZ
2. Schematic only, not to be interpreted as an engineering design or construction drawing.
3. Drawn by: RW. Reviewed by: KC

Golder Associates

TITLE MAR Command Area Monitoring System

JULY 2017

PROJECT 1538632

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3.5 Surface Water and Ecology

As part of the overall MAR command area monitoring programme, flows and ecology were monitored in the coastal spring-fed drains (Figure 6). The MAR Pilot Trial was modelled at a recharge rate of 500 L/s to potentially support baseflows in the following drains (moving from Ashburton River south west along coast):

- Wheatstone Drain
- Blees Drain
- Flemington Drain
- Parakanoi Drain

Other spring-fed drains in this area that may also show benefits are:

- Spicers Drain
- Dawsons Drain

Flow measurements, water quality and ecological surveys including a macrophyte survey were conducted at a number of key locations in each of these drains. A summary of the methods, specific results and summary discussions for both flow and ecology in Section 5.2 with more detailed summaries are presented in Appendices E and N.

4.0 MAR PILOT TRIAL RESULTS – FOOTPRINT AND NEAR-FIELD

4.1 Trial Schedule – Year 1

The official *recharge testing period* for the MAR site operated from **10 June 2016 to 9 June 2017**. Several small pre-operational flow events occurred prior to the official start including:

- An infrastructure commissioning test (16 May 2016 to 18 May 2016).
- A Valetta Pond #3 bypass flow event (2 June 2016).
- The 'Opening Ceremony' (3 June 2016).

However, for the purposes of the analysis for consent compliance and flow inputs for the Pilot Trial in general, the official *recharge testing period* of 10 June 2016 to 9 June 2017 constituted the **Year 1** timeframe. For evaluations of groundwater quality and level responses to the Pilot Trial, a starting date of 16 May 2016 has been used, as many of the monitoring systems reacted to the commissioning test (pre-trial testing) before the *recharge testing period* started. In each technical evaluation, the appropriate analysis starting date has been defined in the appropriate appendix and section of the report.

4.2 Climate

Data from three climate monitoring stations, the Willowby, Ashburton Council and Ashburton Aero AWS (Figure 6), have been used to support the evaluation of groundwater levels for the Pilot Trial and for operational purposes. The climate data acquired for the Pilot Trial and the associated analyses are documented in Appendix B.

During the trial period the total rainfall of 663 mm was recorded at the Willowby rainfall station, substantially less than annual Potential Evapotranspiration (PET) recorded by NIWA for the Ashburton Aero AWS of 959 mm. Annual Potential Evapotranspiration (PET) during both 2015 and 2016 was substantially greater than the 2006 to 2016 average recorded at the Ashburton Aero AWS. A comparison of the Willowby monthly rainfall data from the trial period and the longer term Ashburton Council rainfall dataset (Figure 23) indicates the following regarding rainfall experienced at the Pilot Trial site:

- June to September 2016 period was less than 10-year average rainfall
- March and April 2017 period had higher than 10-year average rainfall.

Monthly PET data recorded during the trial period was however similar to the corresponding monthly PET values over the same 10-year period.

During the trial period the total PET of 959 mm exceeded the total rainfall of 663 mm recorded at the Willowby rainfall station. This was primarily due to PET substantially exceeding rainfall during September to February (Figure 24). Rainfall substantially exceeded PET during March and April 2017.

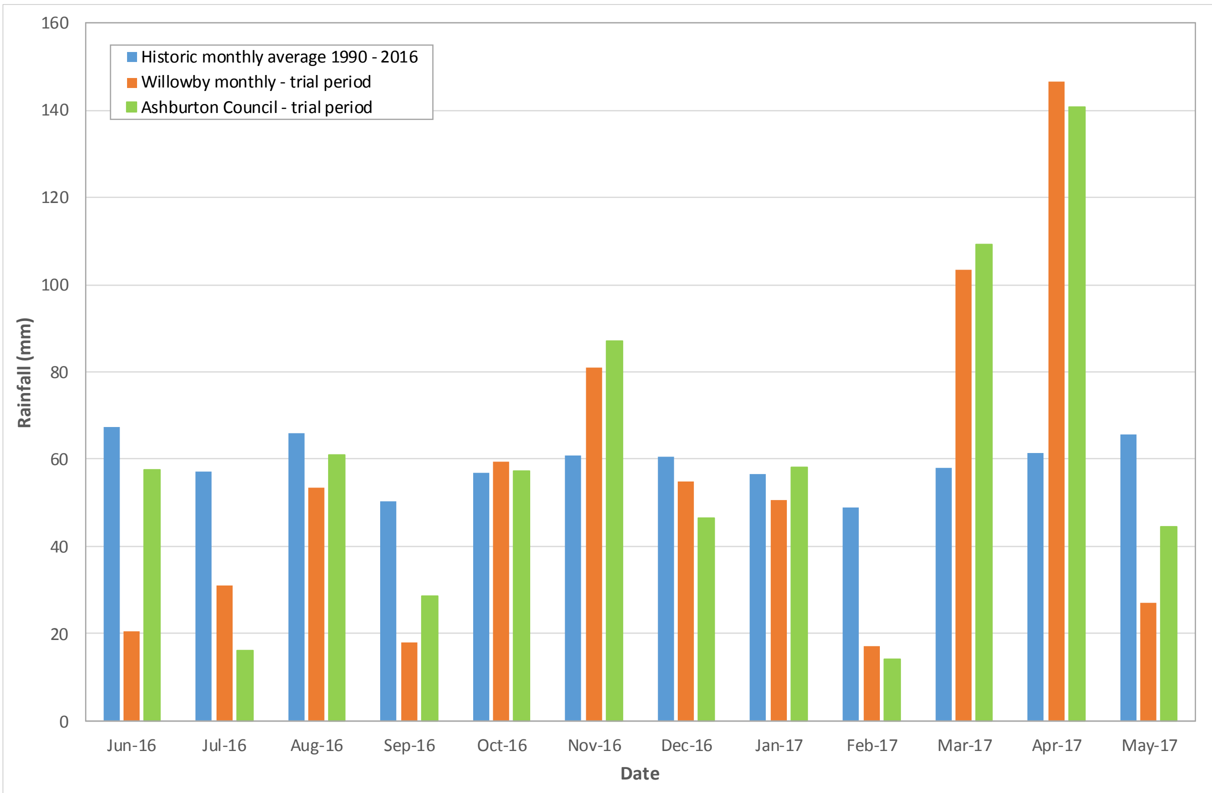


Figure 23: Monthly rainfall at Ashburton during Pilot Trial compared to monthly averages 1990 – 2016.

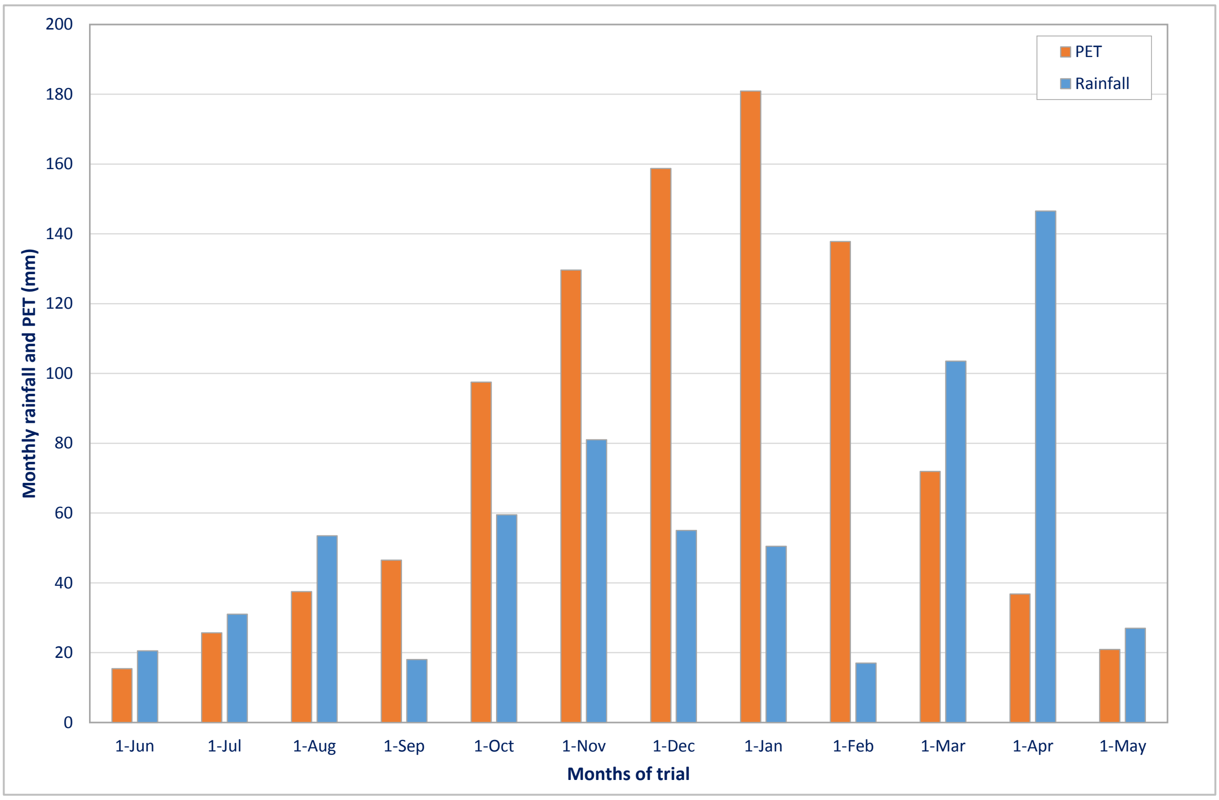


Figure 24: Comparison of monthly rainfall to potential evapotranspiration during the Pilot Trial.

4.3 Pilot Trial Flow Rates and Volumes Recharged

The flow analysis is divided between water being diverted from the Rangitata River (Section 4.3.1) and delivered to the MAR site (Section 4.3.2), and the water flowing through the MAR facility and being recharged into the underlying groundwater system (Section 4.3.3).

4.3.1 Source water delivery – overview

A working agreement between ADC and RDRML was formed as part of the operational plan for the management of the *source water* used for the MAR site. Communications were established between ADC and the RDRML raceman to ensure that the rate at which *source water* was diverted by RDRML never cumulatively exceed the ADC stockwater consented take from the Rangitata River. Similarly, communications between RDRML and the Valetta raceman to make a call on source water from the river were established. This was done to ensure that water diverted from the river was in fact delivered to the MAR site for use in aquifer recharge operations. The following two sections review the data collected relative to the conditions under consent CRC164281.

4.3.2 Source water diversion – Rangitata rate assessment

Under the resource consent (CRC164281) authorising the diversion of Rangitata River water to the MAR site, flow rates and volumes were defined as:

- The average flow for the RDRML source water diversion may not exceed 500 L/s.

- The cumulative ADC and RDRML takes from the river may not exceed either the year round consent condition of 849 L/s or the 1,115 L/s limit[6] permitted annually between 12 September and 14 May.

Data provided by both RDRML (per comms Ben Curry) and ADC (per comms Chris Stanley) has been compiled to assess compliance with these flow constraints (Figure 25). The results indicate that the project was compliant with the regards to flow limitations attached to the diversion consent.

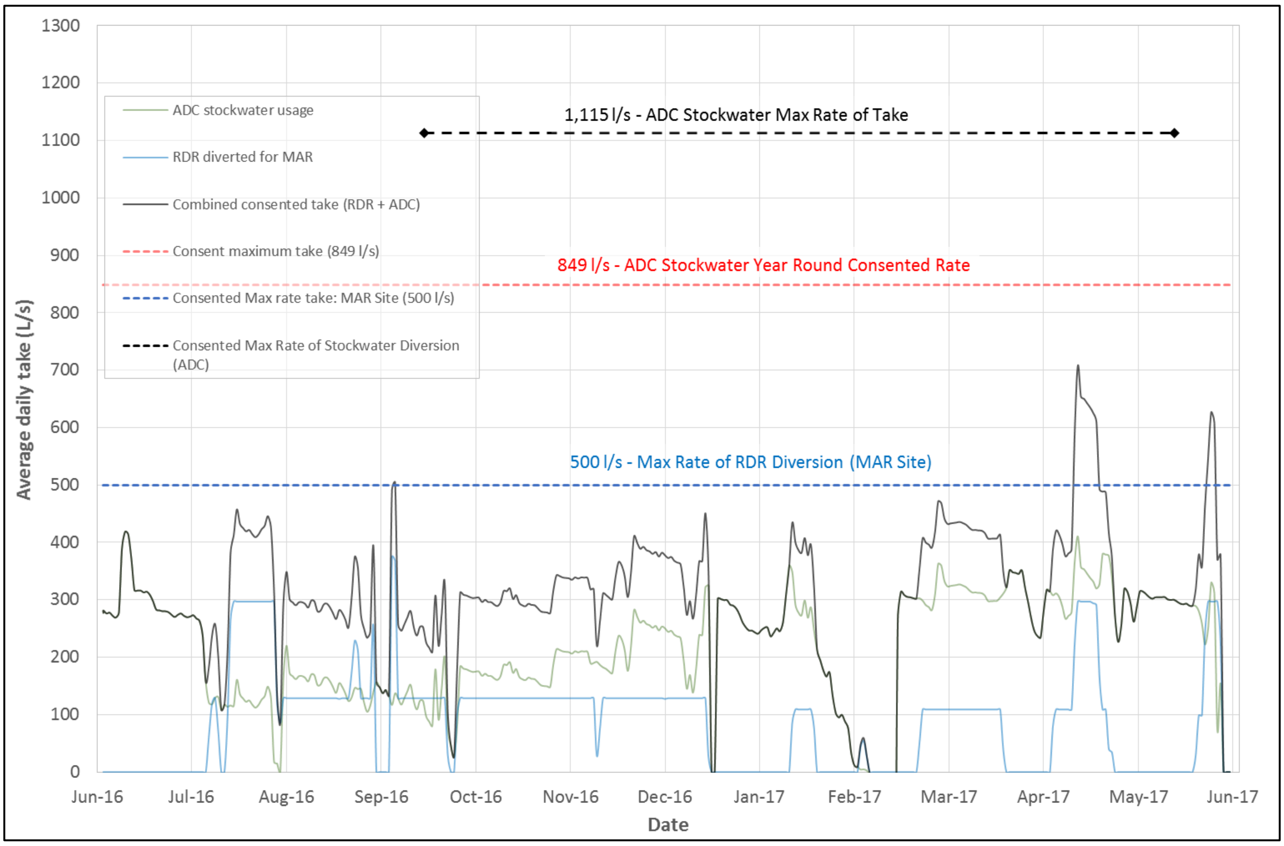


Figure 25: Combined ADC and RDRML flows and consent condition thresholds (YEAR 1 Data: 10 June 2016 to 9 June 2017).

A review of the diversion data (refer Section 4.3.4) indicates that there remains a substantial amount of additional available water under the existing ADC consent. Analysis indicates that after the Year 1 MAR usage was accounted for, a total volume of **13,048,000 m^3**, with an average daily flow rate of 524 L/s (15 May to 14 September) and 828 L/s (15 September to 14 May) remains available in the Rangitata River for use under this consent (details presented in Appendix E).

4.3.3 Pilot Trial flow rates and total recharge volumes

Following the field measurements and subsequent final ratings for Flume 1 and Flume 2 being completed, calculations for total race losses and total recharge rates and volumes were calculated (See Appendix E (Ratings) and Appendix L (average rates and race losses).

Inflow rates at Flume 1 represent the overall recharge rate for the Pilot Trial. Recharge rates varied throughout Year 1, ranging from as high as 113 L/s (early in Year 1) to 75.8 L/s (late in Year 1). Losses (recharge) from the open race measured between Flume 1 and 2 ranged from 12% to 23% with an average loss of approximately 17% of intake flow rate (Figure 26).

[6] Consent CRC164281 – 'shall not exceed 849 litres per second, unless diverted and taken during the period extending from 15 September in any year to 14 May in the following year it shall not exceed 1,115 litres per second for no more than 14 consecutive days over any period of four weeks during that time.'

The race represents approximately 19 % of the recharge footprint (2,150 m^2 for race, at 800 mm depth is 9,200 m^2 for basin) of 11,350 m^2 area. Whilst there are some measurement errors and difficulties in establishing 'overall recharge rate averages' in this dynamic flow environment, it is surmised that the race was roughly equivalent to the basins in overall recharge rate performance (refer Section 4.3.6). The results toward the end of the Year 1 operations and from early in the Year 2 operations suggest that some clogging may have occurred post the peak-irrigation shutdown period. It is unclear in comparing the early and late Year 1 race losses if clogging played any role in recharge rates. Further investigations are required in Year 2 coupled with checks of the new Flume flow ratings to ascertain the apparently changing site conditions.

Figure 26: Open race delivering water source water to MAR Pilot Site (Race bypass and MAR site start up, June 2016)

Comparing flows from Flume 1 and Flume 2 with that of main basin stage levels provided a useful check of the ratings and data consistency. Figure 27 shows the data for Year 1 operations and denotes an issue that was found through this flow data comparison. The Flume 1 stage data from 5 July 2016 to 5 September 2016 appears to significantly underestimate the amount of water entering the Pilot Trial. In reviewing field notes, it appears that manual flow measurements were taken on those dates. It is surmised that the stage recorder (at the base station) may have been accidently reset (to correct for changes in manual ESG reading). Using the Flume 2 data and adding a positive flow adjustment based on average race losses, the total recharge volume was estimated[7] at an additional 70,000 m^3.

[7] Using 13.3 L/s race loss to estimate Flume 1 inflow and calculate unaccounted for volume of water.

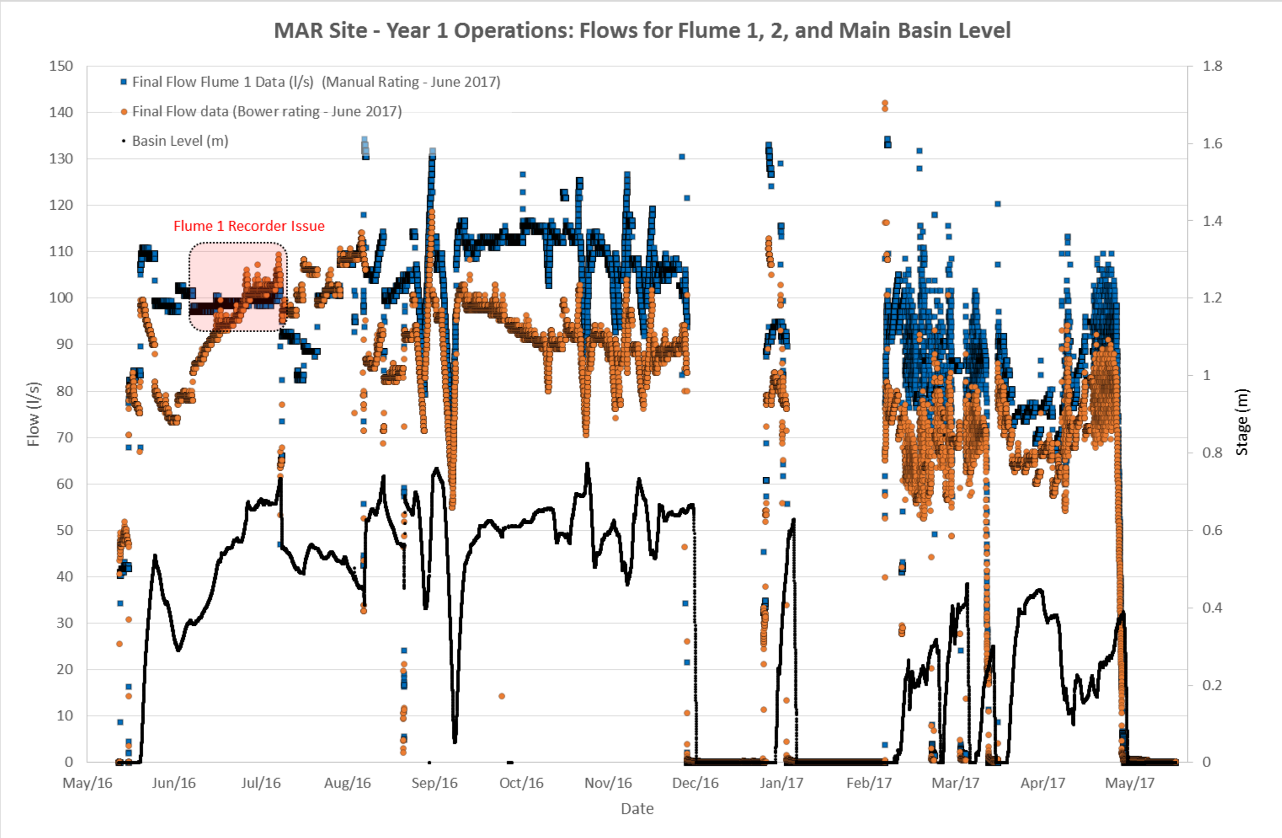


Figure 27: Year 1 operations: Flume 1 and Flume 2 flows compared to infiltration basin levels.

4.3.4 Source water delivery to MAR site – volumetric water balance

During this recharge season, both the RDRML and the Valetta systems had several periods where they were shut down due to either scheduled maintenance or more recently due to a suspected blockage in the Valetta pipeline. The issues that arose with respect to reliability of supply are documented in Appendix E. Both irrigation companies were proactive in seeking to keep the MAR site operating for as long as possible using their existing in-system storage. See Appendix E for more detailed information.

A water balance for the ADC water diverted by RDRML and delivered to the MAR site via Valetta distribution system is provided in Table 3. In summary:

- Approximately **2,595,000 m^3** was diverted at Klondyke for MAR site usage, after corrections for system losses and measurement errors have been taken into account.
- Year 1 total recharged water is conservatively estimated at **2,442,000 m^3** with some additional water still considered to remain 'in system' due to the recent inability to deliver the water to the MAR site. This 'in system' water will be used early in the Year 2 MAR site operations.

The data indicates that water diverted by RDRML for the purposes of the MAR site usage was delivered to the site through the RDR and Valetta system, or will be delivered early in Year 2 of site operations.

Table 3: Water Balance - Hinds MAR site conveyance and recharge usage: annual volumes.

Point of Measurement	**Year 1: Total Volumes (m^3) (1)**
Total available under ADC consented take.	15,780,000
Diversion and Delivery:	
RDRML Diversion from Rangitata River (at *Sandtrap gauge*) of ADC consented unutilised stockwater	2,732,000
Measurement accuracy (2) and conveyance system losses (3) (~5 %)	137,000
Total Delivered – Phase 1 Testing	**2,595,000**
Recharge Operations:	
Flume 1 stage error – estimated additional volume recharged(4)	70,000
Recharged: pre-trial flume and basin operational testing (15 May – 18 May 2016)	30,000
Recharged: Hinds MAR site operations (10 June 2016 – 9 June 2017)	2,342,000
Total Recharged – Phase 1 Testing	**2,442,000**
Additional water stored(5) in Valetta Ponds for Phase 2 (Year 2) operations	153,000
2016-17 total recharge project balance	2,595,000
Water Balance: diverted minus delivered	~0
Water remaining available under ADC consented take (total available less total diverted from Rangitata River under Phase 1 testing)	**13,048,000**

Notes: 1) Values rounded to +/- 1,000 m^3.
2) MAR recharge rates (~105 L/s) falls 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) During trial the MAR operations team (Email: Giles Pinfold, on 3 January 2017) noted that Valetta Pond #3 had some leakage in the order of 4 – 5 L/s, or up to 141,912 m^3 annually. An estimate for conveyance losses relative to MAR water delivery has been provided.
4) Flume 1 stage error also likely underestimated recharge volume by approximately 70,000 m^3 (refer Appendix E).
5) Valetta pipeline issues limited the operations of the MAR site from approximately 20 May until 9 June 2017. Water diverted for MAR was captured and stored in the Valetta's in-line storage ponds, which carry a total capacity of approximately 400,000 m^3. The 224,236 m^3 or approximately 24 MAR operational days (at 105 L/s) will be utilised for MAR operations in the 10 June 2017 to 9 June 2018 recharge season.

4.3.5 Pilot Trial forebay water levels

Water surface area and storage volume curves for the combined forebay (aka fore basin) and main basin are provided in Figure 28 and Figure 29, respectively. The floors of the two basins are at very similar elevations. Overflow from the forebay to the main basin occurs at a water depth of 1.8 m. Overflow from the main basin through the emergency spillway to the adjacent ADC stockwater race occurs when the water depth reaches 2.4 m.

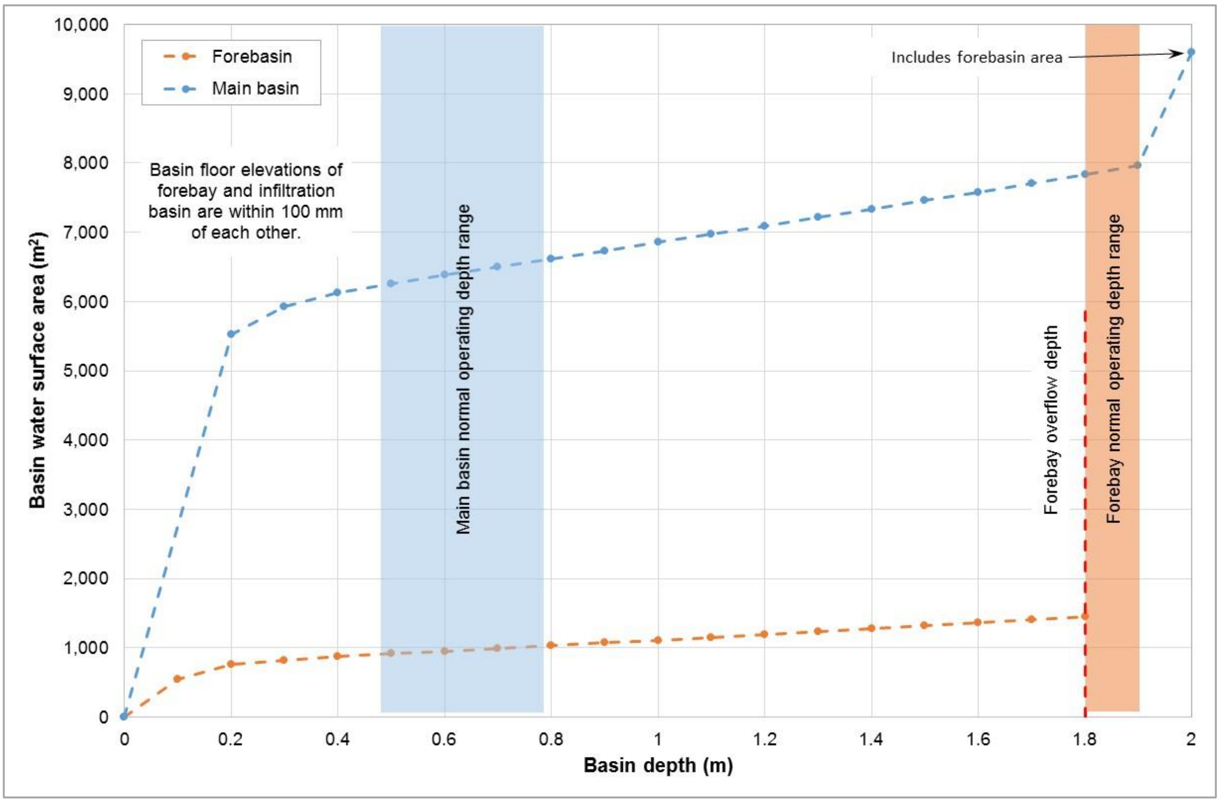


Figure 28: Water surface area to depth relationship.

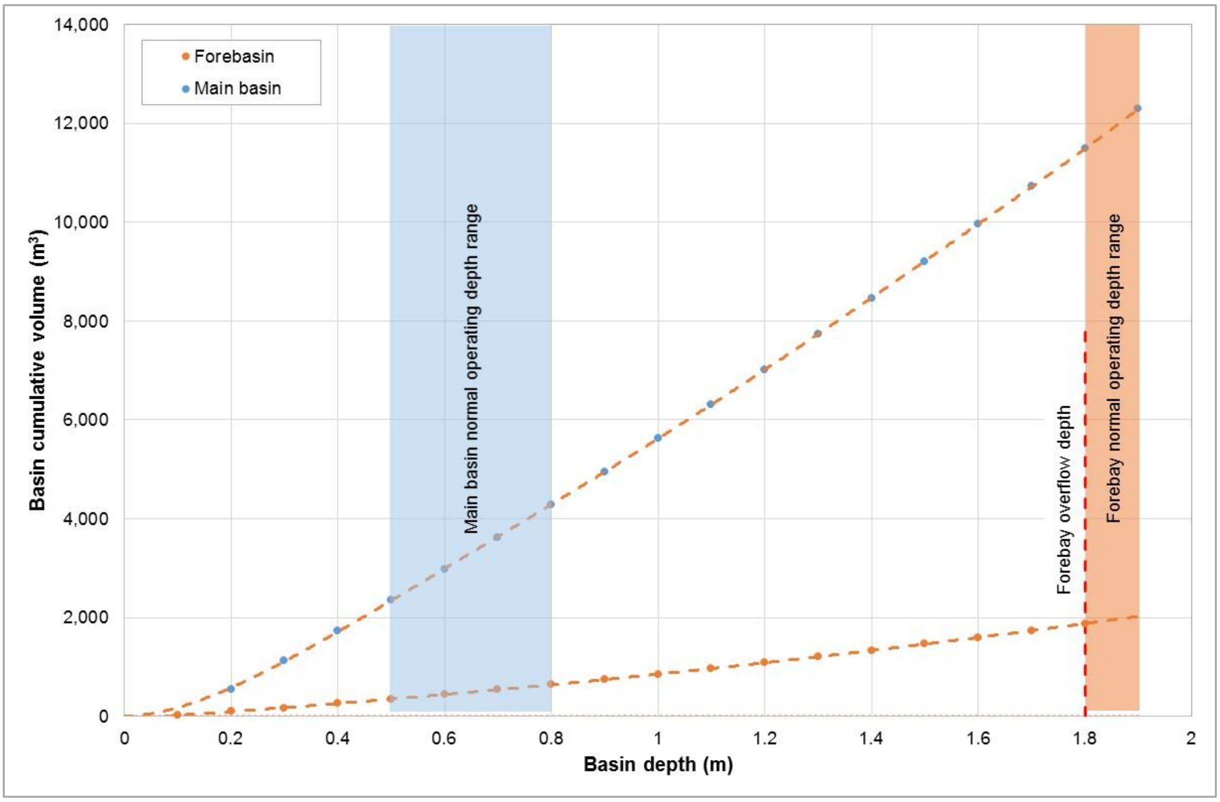


Figure 29: Water volume to depth relationship.

4.3.6 Infiltration rates

Infiltration rates have been evaluated for the main infiltration basin but not for the forebay. The evaluation of infiltration rates has been based on monitored water level decreases following several operational shut-down events (refer Appendix I, Table I3). Infiltration rates for much of the trial, corrected for rainfall and PET, have been calculated at between 0.5 m/day and 0.6 m/day (5,000 to 6,000 m^3/day/ha ponded area). Infiltration rates may have declined later in the Pilot Trial to approximately 0.34 m/day possibly due to clogging (refer Section 4.8.3).

Infiltration rates for the forebay have not been calculated from water level recovery curves during shutdown events as there was no pressure transducer installed in the forebasin during the Pilot Trial. The only recovery curve recorded from the forebay was at the close of the pre-trial infiltration test (refer Appendix I). It is likely that seepage from the forebay to the main infiltration basin had a substantial influence on the forebay recovery curve during most of this shutdown event. Air entrapment beneath the basin may also have influenced the recovery curve. For these reasons no evaluation has been made of infiltration rates through the base of the forebay.

4.4 Source Water Quality

The recharge water originates from the Rangitata River, diverted by RDRML at their Klondyke diversion. The Rangitata River flows 120 km from the Southern Alps, entering the ocean approximately 30 km north of Timaru. The Rangitata River, as is true for all of Canterbury's alpine sourced rivers, is characterised by very low nitrate-N concentrations as it enters the Canterbury plains (refer Appendix F). Data collected at the Klondyke diversion (2012 to June 2017) showed median nitrate-N at 0.03 g/m^3 and background *E. coli* levels at median of 50 MPN/100 mL. Relative to the concentrations found in most surface waters and groundwater within the Hinds catchment, the nitrate-N concentrations measured in the Rangitata River are very low (refer Appendix H). The background *E. coli* levels, whilst still above the drinking water standard of 1 MPN/100 ml, are typical of such surface water.

Water enters the Pilot Trial infiltration basin through the Valetta irrigation and infrastructure system described in Section 3.3.2. This source water has been sampled monthly at both the outflow from Valetta Pond #3 (Flume 1) and in the main Pilot Trial infiltration basin. The samples have been analysed for the parameters listed in Table F1 of Appendix F.

Nitrate-N is a key sampling parameter because one of the key Pilot Trial objectives was to decrease the nitrate-N concentration in the regional groundwater system. The MAR scheme utilises dilution to meet this objective, so it is crucial nitrate-N concentrations in the source waters are low. Monitoring indicated that the nitrate-N concentrations in the source water were consistently:

- Below 0.04 g/m^3 at Flume 1 (Table F2).
- Below 0.09 g/m^3 in the main infiltration basin (Table F4).

E. coli counts within the source waters fluctuated with seasonal changes in water temperature. Monitoring of *E. coli* counts at the following sites indicated:

- Flume 1:
  - Median for Year 1 was 55 MPN/100 mL.
  - Maximum for Year 1 was 727 MPN/100 mL during March 2017 (Table F2).
- Main infiltration basin:
  - Median for Year 1 was 88 MPN/100 mL.
  - Maximum for Year 1 was 228 MPN/100 mL during October 2016 (Table F4).

Clogging is a common issue requiring management in infiltration basins (refer Section 4.8.3). It is therefore important to ensure low-turbidity source water is supplied to the Pilot Trial infiltration basin. Turbidity and Total Suspended Solids (TSS) were monitored at monthly intervals at both Flume 1 and in the main infiltration basin. TSS in the Valetta Pond #3 water has been observed to spike following large rainfall events in the foothills from which the RDRML water is sourced.

During the Pilot Trial TSS concentrations were generally below 10 g/m^3 at Flume 1. Concentrations were reduced as water moved through the forebay and were regularly below the minimum detection limit of 1.5 g/m^3 in the infiltration basin. During Year 1 of the trial a total sediment mass estimated to be in the order of 13 tonnes has been deposited in the two basins at site. An assessment of basin clogging has been summarised in Section 4.8.3.

4.5 Groundwater Level Responses

4.5.1 Introduction

This section summarises the data supporting the assessment of groundwater level responses to the Pilot Trial operations and the interpreted extent and magnitude of those responses. The detailed assessment of the groundwater responses to the Pilot Trial is presented in Appendix G.

Groundwater level monitoring to provide data to support the evaluation of groundwater responses to Pilot Trial operations has been undertaken in seventeen monitoring wells distributed around the infiltration basin site. Groundwater level and temperature records from automated monitoring systems installed in these wells, together with the manual monitoring records and sensor drift charts (differences between manual and automated records) are provided in Section 3.0 of Appendix G.

The groundwater system that is of relevance to the evaluation of the outcomes of this Pilot Trial consists primarily of unconfined gravel aquifers. These units are either:

- Directly connected to the catchment wide groundwater system with similar groundwater level and quality trends to bores of similar depth elsewhere in the catchment; or
- Localised perched aquifers with groundwater level and quality trends more directly related to recharge and land uses directly above these aquifers.

Following the start of recharge operations at an infiltration basin, the downward seepage of groundwater to a shallow regional aquifer may not have an immediate effect on the groundwater table. In many cases the development of preferred seepage paths can result in almost immediate rise in the underlying groundwater level in response to the basin recharge. In other cases the presence of thick unsaturated zones, low permeability layers and convoluted seepage paths results in slowed seepage to the saturated zone of the aquifer and delayed water table responses in the aquifer.

Groundwater directly beneath the infiltration basin responds first to the artificial recharge. As groundwater levels beneath the basin rise, the accumulating groundwater starts to flow laterally outward from beneath the basin. If there are several aquifer layers beneath the basin, the aquifers respond to the recharge in order of depth; the shallowest responding first, provided the intervening low permeability layers are leaky.

4.5.2 Groundwater level monitoring data

Changes in groundwater level over time for a selection of wells monitored during the Pilot Trial since the start of the pre-trial test are presented in Figure 30. The colour coding of the water level records in in Figure G24 have been chosen to reflect groups of wells with characteristic groundwater level trends. Specifically:

- **Green:** These records are from monitoring wells that were influenced by groundwater level changes linked to Pilot Trial operations
- **Red:** These records are from monitoring wells that were strongly influenced by groundwater abstraction for irrigation purposes, with very similar groundwater level trends.

- **Dark blue:** These records are from monitoring wells located to the southeast of SH1.
- **Light blue:** This record is for GWE-10 which was intended to be used as an up-gradient background monitoring well.
- **Ochre:** This record is for GWD-07, which was installed to monitor the effects of the Pilot Trial on the groundwater system in the area of Tinwald.

Of the Pilot Trial monitoring wells documented in Appendix G, and presented in Figure 30, only six wells have shown clear groundwater level responses to the trial (Figure 31). In two of these monitoring wells, GWE-04 and GWD-03, the groundwater level responses occurred after the start of the main Pilot Trial. In the other four monitoring wells, GWE-01, GWD-01, GWD-02 and GWD-04, the initial groundwater level responses to the Pilot Trial occurred before the start of the main trial. This means these initial responses reflect the operations from the pre-trial infiltration test undertaken in May 2016. For this reason the assessment of the effects of the Pilot Trial on groundwater levels have been based on:

- The distance from the centre of the infiltration basin to the monitoring well.
- The timing of the initial responses observed in monitoring wells, when compared to the start of the initial pre-trial infiltration test on 15 May 2016.
- The magnitude of the change in groundwater level observed in the monitoring well.

One monitoring well screened at the regional aquifer level (GWD-04) has reacted to groundwater flows and water quality changes within the perched aquifer. It is this interconnection that has resulted in the apparent groundwater level change of up to 18 m in GWD-04 in response to the Pilot Trial operations. This reaction implies that water can freely flow down the outside of this well, from the upper aquifer to the lower aquifer, and thereby influence both the water quality and level measured in this well. This monitoring well is therefore identified in Table 4 as monitoring the responses of the combined aquifers.

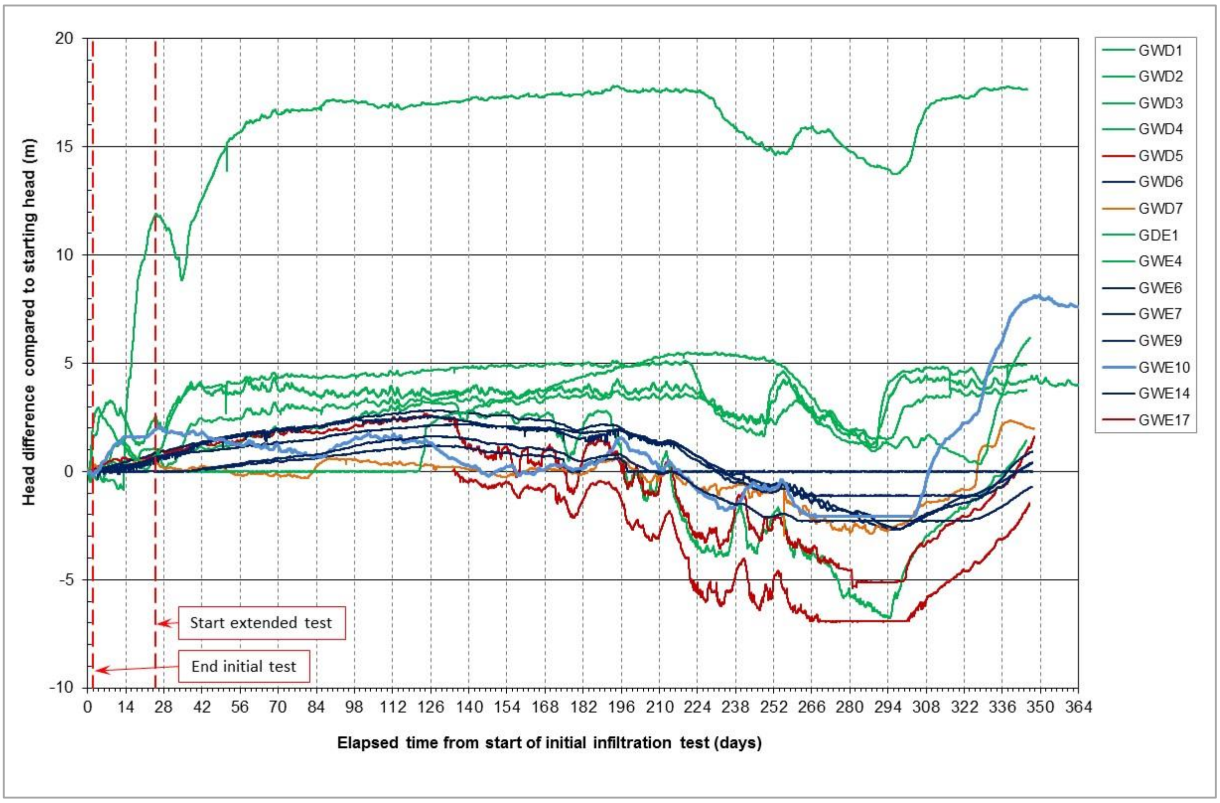


Figure 30: Groundwater level change records for a selection of Pilot Trial monitoring wells.

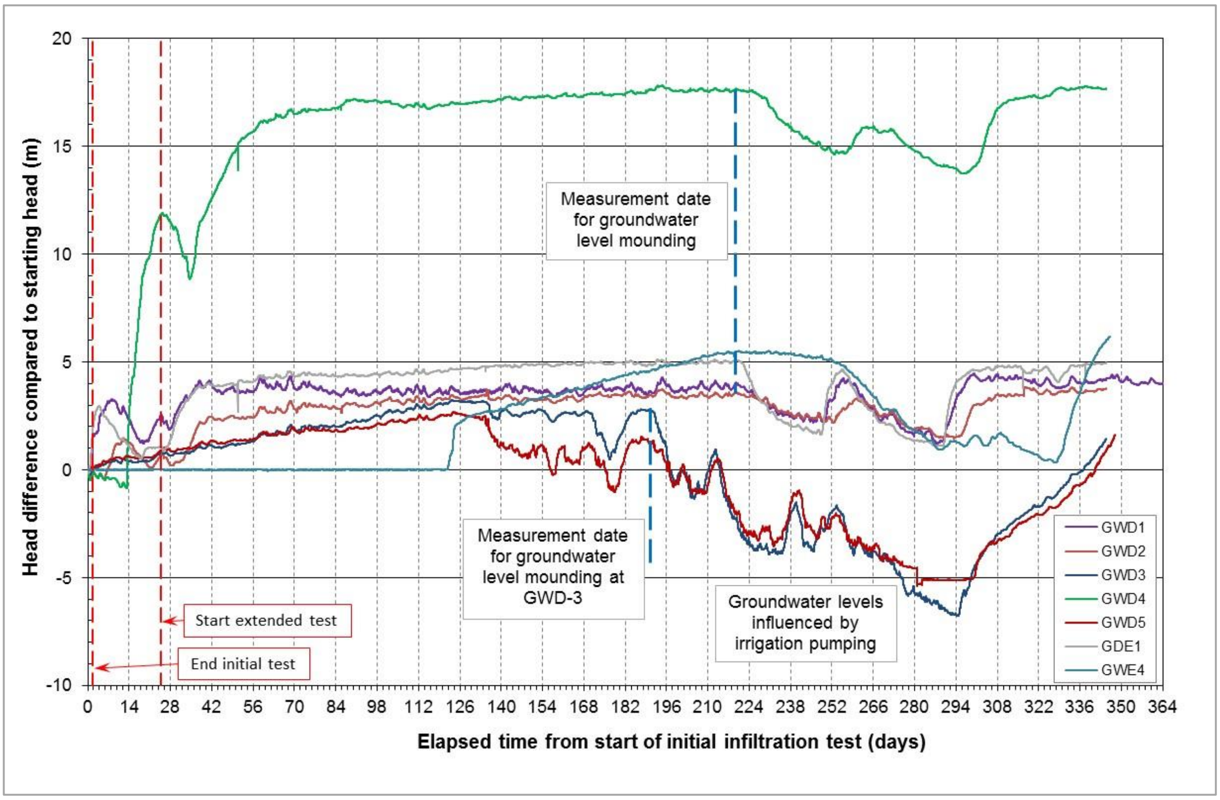


Figure 31: Groundwater level change records for monitoring wells influenced hydraulically by Pilot Trial operations.

The interpretation of the presence of a perched aquifer beneath, and extending to the southeast of, the Pilot Trial site has been based on the following observations:

- The difference in static water levels at the start of the pre-trial infiltration test between the shallow well close to the site and the deeper well:
  - GWE-01: 18 m deep and groundwater at approximately 13.5 m bgl.
  - GWD-01: 32 m deep and groundwater at approximately 30.8 m bgl.
- The sudden and very large gain of approximately 18 m in apparent groundwater level recorded in monitoring well GWD-04 in response to the Pilot Trial operations.
- The sudden appearance of water in the previously dry monitoring well GWE-04, which is only 22.8 m deep and located approximately 2,300 m from the infiltration basin. In addition, the water level in the monitoring well has risen approximately 5.5 m since first detected during the Pilot Trial period. Finally, the nitrate-N concentrations in water from this well have decreased from approximately 13 g/m^3 to approximately 3 g/m^3 during the Pilot Trial period.
- Groundwater levels in monitoring wells GWD-03, GWD-05 and GWE-17 reacting to groundwater pumping for irrigation purposes whereas the groundwater level recorded in GWE-04 did not react to the groundwater abstraction.

This apparent artificially generated connection between the aquifers observed in GWD-04 means that:

1) The magnitude of the groundwater response measured in this well does not reflect the magnitude of the groundwater level change in either the perched aquifer or the regional aquifer.
2) The water quality data in this well is primarily reflecting the quality of water in the perched aquifer.
3) The timing of the groundwater level and quality responses in this well reflects the rate at which groundwater is flowing through the perched aquifer.

Table 4: Groundwater level responses to Pilot Trial recharge.

Monitoring well	Distance to centre of MAR site (m)	Response date / time	Response delay (days) (1)	Water level increase (m)	Aquifer affected	Water quality influence
Start of initial infiltration test		15/05/2016 14:30				
GWD-01	90	16/05/2016 17:30	1.4	4.05	Regional	Yes
GWE-01	105	17/05/2016 3:00	0.40	5.12	Perched	Yes
GWD-02	320	23/05/2016 8:30	6.6	3.61	Regional	Unclear
GWD-04	1,040	29/05/2016 22:00	13.2	17.68 (2)	Combined	Yes
GWD-03	1,659	5/07/2016 14:30	49.9	2.14 (3)	Regional	No
GWE-04	2,410	9/09/2016 10:15	115.7	>5.51 (4)	Perched	Yes

Note: 1) Days from the start of the initial (pre-trial) infiltration test to the first indication of a pressure response in the monitoring well.
2) Magnitude of water level rise due to localised connection around monitoring well between perched aquifer and regional aquifer. Refer Section 4.5.4.
3) Calculated as difference in level compared to background groundwater trend as represented by record from GWD-05.
4) Magnitude of water level rise due to localised connection around monitoring well between perched aquifer and regional aquifer. Total rise in water level in the well is unclear as well was dry at the start of the trial.

4.5.3 Regional groundwater table mounding

As the water seeping downward from the infiltration basin reaches the groundwater table, the groundwater level rises and starts to create a groundwater mound. The height of the mound increases over time, resulting in hydraulic gradients developing in a radially outward direction from beneath the basin. These gradients reflect the movement of groundwater within the aquifer away from the area of enhanced infiltration. The height and extent of the groundwater mound created by the artificial recharge primarily depends on the transmissivity of the aquifer and the rate at which water is being added to the aquifer.

The extent and magnitude of groundwater mounding in the regional aquifer resulting from the Pilot Trial recharge has been evaluated based on groundwater level rise measurements from two monitoring wells outside the recharge area. Groundwater level increases measured in monitoring wells GWD-01 and GWD-02 after 220 days of Year 1 operations (Figure 31) were applied to the equation to calculate a groundwater level change beneath the centre of the basin of 4.40 m. Extrapolating outward from the centre of the basin, groundwater level increases were then calculated for a distance of up to 2,000 m from the basin (Figure 32).

The calculated groundwater level rise at GWD-03, which is considerably further from the basin than the above two wells, was then compared to the observed rise as a check to the validity of the calculation. The difference between the theoretical rise of 3.04 m and the observed rise of 2.14 m is reasonable, especially as the rise in groundwater at GWD-03 was prematurely halted by the effects of groundwater abstraction for the irrigation season. For reasons described in Appendix G, the line indicating the extent and magnitude of calculated groundwater mounding should not be extrapolated beyond what has been presented in Figure 32.

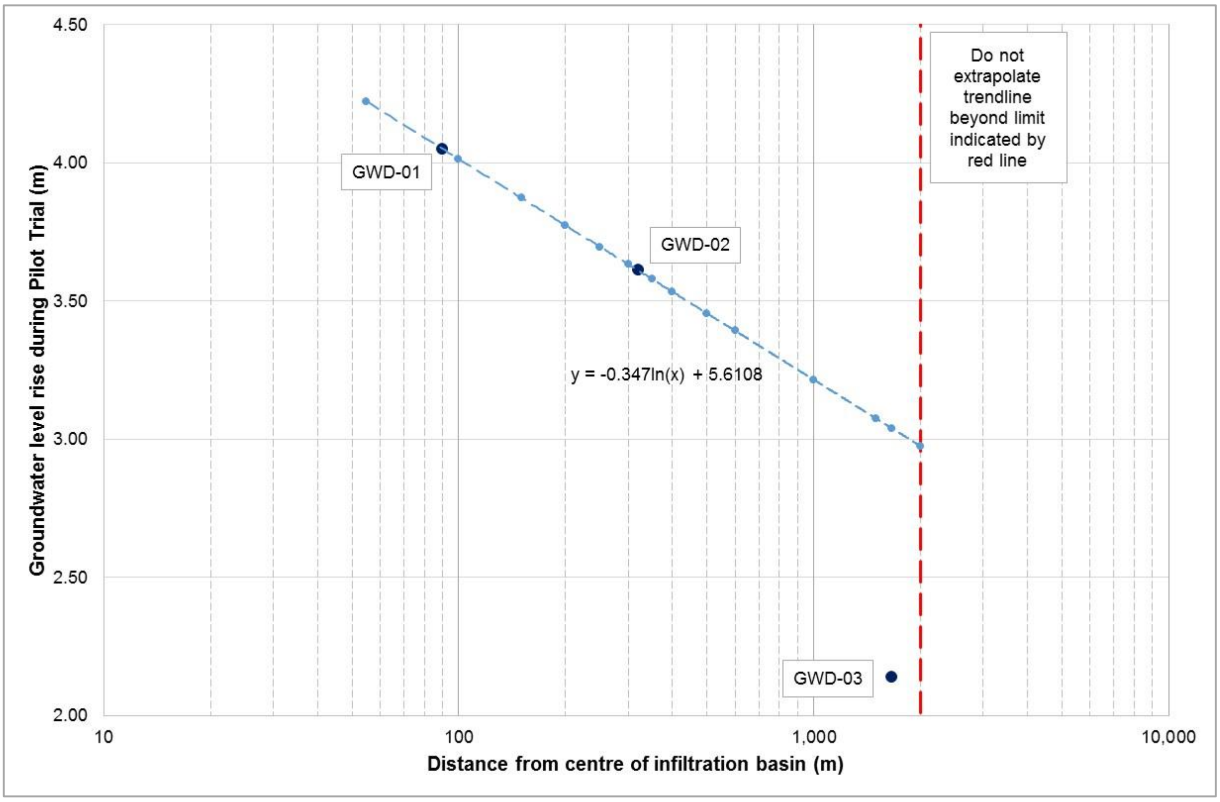


Figure 32: Extent and magnitude of groundwater level rise in regional aquifer transect.

The measured changes in groundwater level and the calculated extent and magnitude of groundwater mounding from the trial indicate the Year 1 Pilot Trial operations resulted in groundwater mounding of three metres or more out to a radial distance of two kilometres from the centre of the Pilot Trial basin (Figure 35).

4.5.4 Perched groundwater flows

The recorded change in groundwater level in GWD-04 starts abruptly, the rise in level is very rapid and the final groundwater level is much too high to reflect any realistic mounding in the regional aquifer. These observations imply that groundwater is flowing past GWD-04 in a perched aquifer. When this flow reached GWD-04, rapid downward seepage probably occurred from the perched aquifer to the underlying regional aquifer through disturbed ground around the outside of the monitoring well. The final groundwater level recorded from GWD-04 may not reflect the groundwater level within the perched aquifer, as the downward seepage of water around the well may result in localised drawdown of the perched aquifer groundwater.

Changes in groundwater levels linked to flows through the perched aquifer have been detected out to GWE-04, approximately 2,310 m from the infiltration basin. At this distance from the basin the average velocity of the advancing pressure wave in the perched aquifer was approximately 19 m/day.

At that rate of advance, after one year the pressure wave in the perched aquifer would have reached a distance of approximately 6,900 m from the basin, assuming simply linear extrapolation from the observed responses. This calculation also assumes the supply of water to the aquifer has continued to exceed the leakage losses through the base of the aquifer, and the form and hydraulic characteristics of the perched aquifer do not change to the southeast of GWE-04. The arrival of MAR water at the monitoring wells screened in or influenced by this perched aquifer has been delayed in comparison to the pressure response, as described in Section 4.6.

The perched seepage path width has been estimated based on:

- Field observations of groundwater quality changes at GWE-11, indicating a path width of approximately 700 m.

- An estimated recharge water balance between the regional aquifer and the perched aquifer (refer Section 5.3 in Appendix G) indicating a seepage path width of approximately 660 m.

These independent estimates correspond reasonably well with each other.

The observations on the direction of the flow in the perched aquifer, the calculated rate of pressure wave advance in the aquifer and the calculated length and width of the perched aquifer pressure response to the Pilot Trial have been combined to provide an indication of the area of pressure response to the Pilot Trial in the perched aquifer (Figure 35).

4.6 Groundwater Quality Response to Pilot Trial Operations

4.6.1 Introduction

The effects of introducing MAR water on the quality of water in the aquifer system needed to be assessed taking into account:

- The degree of connection between the aquifer and the Pilot Trial site.
- The monitoring wells actually influenced by MAR water.
- The need to clearly distinguish background water quality trends close to the Pilot Trial site.

For this reason, the monitoring wells sampled as part of the Pilot Trial monitoring program have been separated into four groups (refer Section 4.3 of Appendix H). The groups have been defined under the following categories:

1) Two monitoring wells, GWD-01 and GWE-01 are considered to provide data representative of the immediate receiving water quality and the effects of MAR on this quality, with:
   a) GWD-01 representing the regional aquifer groundwater quality beneath the Pilot Trial site,
   b) GWE-01 representing the water quality in a perched aquifer beneath the Pilot Trial site.
2) Five monitoring wells outside the immediate area of the site but influenced during the trial period by MAR water (MAR footprint area).
3) Seven monitoring wells that are located close to the Pilot Trial site but did not show any clear influence from MAR water and are therefore considered to provide representative near-field background water quality trends (near field area).
4) Eight monitoring wells that are generally located further from the Pilot Trial and are influenced by a wider variety of factors (far field area).

The areas covered by these water quality monitoring fields are presented in Figure 6.

4.6.2 Receiving water quality

The effects of the Pilot Trial on the groundwater quality, which is considered to be the receiving water for the purposes of this project, have been evaluated by comparing the source water quality to the groundwater quality as measured in monitoring wells GWE-01 (perched aquifer) and GWD-01 (regional groundwater system).

Nitrate-N concentrations in the source water during the trial (Figure 33) have been substantially lower than those detected in the underlying groundwater, both perched and in the regional system. Artificial recharge through the floor of the infiltration basin has resulted in measured nitrate-N concentrations in the underlying receiving groundwater decreasing from greater than 4 g/m^3 to less than 1 g/m^3 (Figure 33).

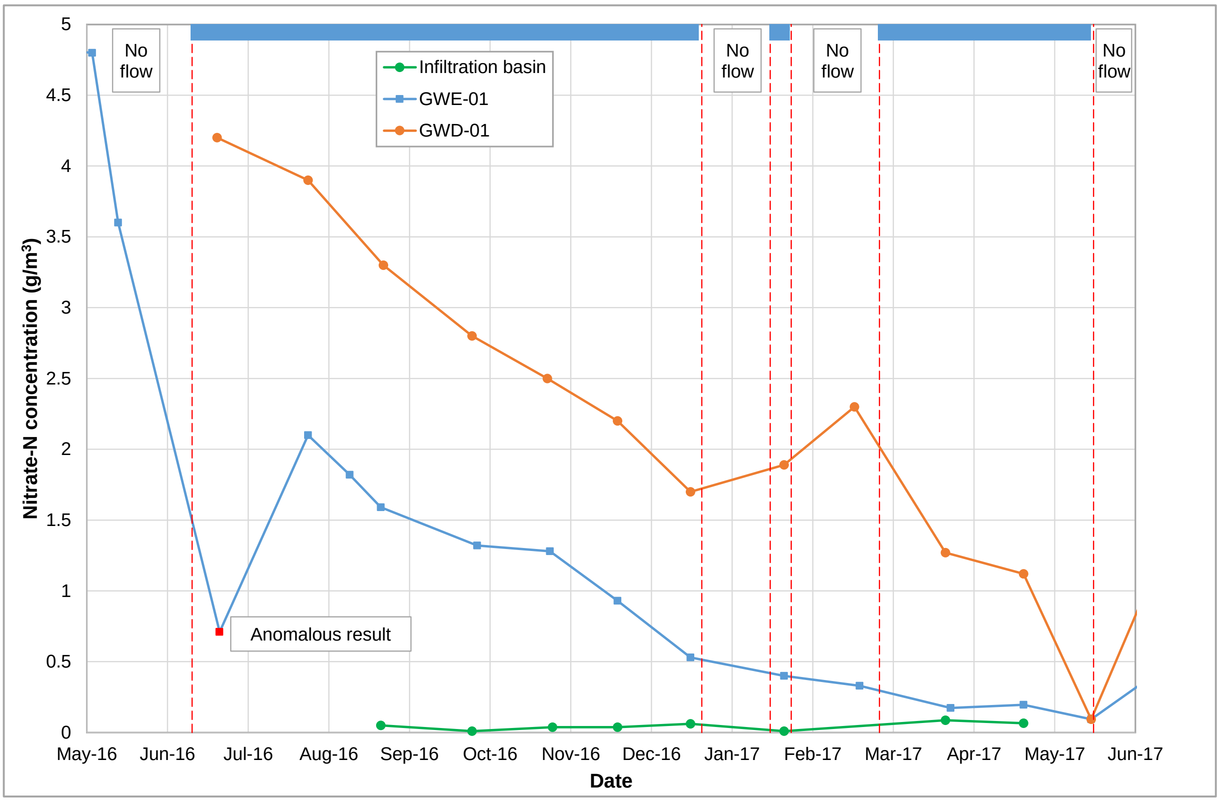


Figure 33: Nitrate-N concentrations in groundwater samples from beneath the Pilot Trial site during the trial.

Although the *E. coli* counts measured in water samples from Flume 1 and from the infiltration basin regularly exceeded 100 MPN/100mL, the *E. coli* counts in water samples obtained from both GWE-01 and GWD01 were normally below the laboratory detection limit. These observations indicate that the *E. coli* in the source water were substantially removed from the infiltrated water before it reached monitoring well GWE-01, which is about 45 m from the infiltration basin. These results indicate that any *E. coli* being detected in groundwater further from the site are unlikely to have been sourced from the MAR Pilot Trial.

Electrical conductivity (EC) of the groundwater in both aquifers decreased in response to the artificial recharge. There is a strong correlation between the trends in nitrate-N concentrations and the EC in the receiving water (refer Appendix H).

In summary, the infiltration of water during the Pilot Trial has resulted in a clear reduction in nitrate-N concentrations in the underlying receiving groundwater and has not resulted in a measurable increase in *E. coli* concentrations in the groundwater.

Further details on the effects of the Pilot Trial on receiving water quality are provided in Section 5.0 of Appendix H.

4.6.3 MAR Footprint water quality

There are two key water quality parameters that were used throughout the study to understand and track the MAR Pilot Trial water footprint. Nutrients in the form of nitrate-N and faecal sourced enteric bacteria, measured by the indicator *E. coli*.

Nitrate-N

Introduction of the source water from the basin to the groundwater system has resulted in a plume of low nitrate-N water moving toward the southeast from the MAR Pilot Trial site. This plume has been progressively detected in the form of significantly decreasing nitrate-N concentrations in monitoring wells up to 2.3 km from the trial site.

Background nitrate-N data from near-field monitoring wells, defined as those wells close to the plume of infiltrated MAR water but not affected by the plume, has been assessed and documented in Appendix H. This data demonstrates the median background nitrate-N concentration has remained relatively stable through Year 1 of the Pilot Trial. None of the nitrate-N concentrations detected in water samples from wells considered to indicate background conditions Year 1 of the Pilot Trial were less than 7.0 g/m^3. There was no indication of a rising or falling trend in this dataset.

In contrast, the nitrate-N data from the monitoring wells influenced by the plume of infiltrated MAR water shows a decreasing trend in the median values (Figure 33). The minimum concentrations detected within this group of bores has also trended downward, reflecting the very low nitrate-N concentrations in the source water.

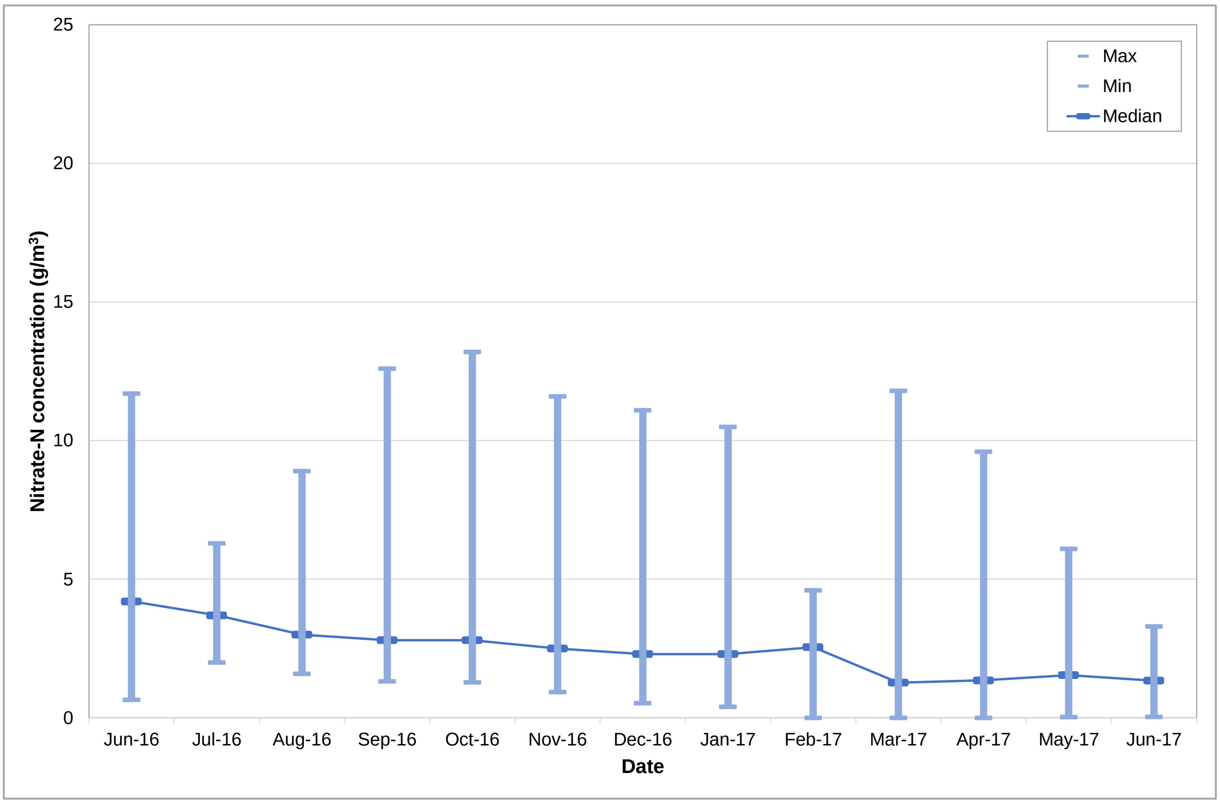
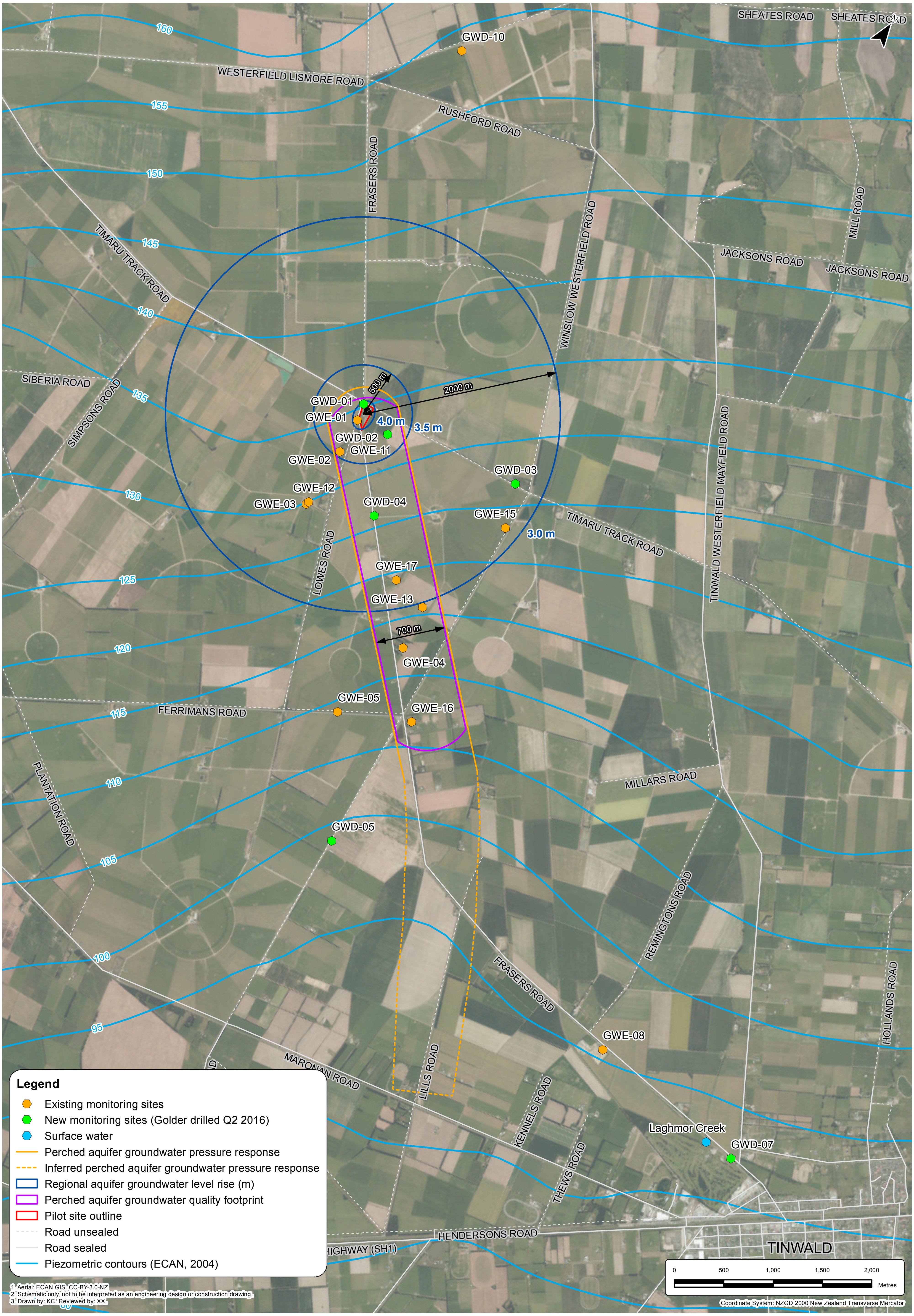


Figure 34: Nitrate-N trend in MAR water quality footprint.

The rate at which infiltrated MAR water has spread during Year 1 of the Pilot Trial has been estimated from nitrate-N concentration changes at monitoring wells within the MAR water quality footprint. To date all of the detected changes to groundwater quality within the MAR water quality footprint appear to be linked to the movement of water through the interpreted perched aquifer toward the southeast.

The rate at which MAR water flowed toward the southeast in the perched aquifer was an average of approximately 20 m/day to a distance of one kilometre from the trial site (See Appendix H). Beyond that, the flow rate decreased with the average flow rate, as calculated at GWE-04, being approximately 9 m/day (Table 5). The supporting calculations of groundwater flow rates based on water quality breakthrough times in wells monitored for the Pilot Trial are provided in Appendix H.

Extrapolation of the MAR water plume that defines the MAR footprint indicates that by the end of Year 1 the plume of MAR water may have reached a distance of 3,300 m southeast from the Pilot Trial site, based on a flow rate of 9 m/day (Figure 35). However, this estimation does not take into account any slow-down in plume expansion that may have resulted from the summer close-down of MAR operations.



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MAR FOOTPRINT - YEAR 1

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MAR water was detected in monitoring well GWE-11 approximately 308 days after the start of the trial, as indicated primarily by a substantial decrease in the measured nitrate-N concentrations in the well. The very slow flow velocity of 1.2 m/day calculated based on the indicated travel time to this well suggests this well is outside the main recharge water seepage plume in the perched aquifer, which is oriented toward the southeast. Assuming the MAR water plume is symmetrical on each side of a flow line extending from the infiltration basin toward the southeast, approximately parallel to Frasers Road, and GWE-11 marks one side of the MAR footprint, the width of the MAR water footprint is estimated to be at least 700 m.

Table 5: Pilot Trial groundwater pressure and quality response times.

Monitoring well	Distance from Infiltration basin (m)	Pressure response after start of Pilot Trial		Water quality response after start of Pilot Trial		Water quality response / pressure response (days/days)
		Initial reaction (days)	Average velocity (m/day)	Initial reaction (days)	Velocity (m/day)	
Perched aquifer – parallel to flow direction [1]						
GWE-01 [2]	45	0.69	66			
GWD-04	938	13	71	45	21	0.30
GWE-17	1,618	67 [3]	24 [3]	216	7	0.31
GWE-04	2,308	122	19	252	9	0.48
Perched aquifer – perpendicular to flow direction [1]						
GWE-11 [4]	364			308	1.2	
Regional aquifer						
GWD-01 [2]	19	1.4	14			
GWD-02 [5]	274	7.8	35			
GWD-03	1,659	49.9	33			

Notes: 1) Only monitoring well GWE-01 terminates in the perched aquifer. The other three are interpreted to be strongly influenced by seepage flows through the perched aquifer based on pressure response characteristics and water quality responses.
2) Water quality response is much shorter than the interval between sampling rounds. Reaction time cannot be accurately assessed.
3) Estimated through interpolation between response times from GWD-04 and GWE-04
4) Groundwater level and pressure response could not be monitored in GWE-11.
5) Low pre-trial nitrate-N concentrations at GWE-02 resulted in no clear water quality response.

E. coli

The detection of *E. coli* in monitored wells during the Pilot Trial varied apparently randomly, with no correlation with to the water infiltrated during the trial. The summary chart of *E. coli* detections in monitoring wells influenced by the MAR water (Figure H20) suggests that these wells more often had *E. coli* present than the near field background monitoring wells. However, most of the highest counts were from samples obtained from monitoring well GWD-04, in which terrestrial beetles were found during sampling with the attendant risk of contamination unrelated to the Pilot Trial.

4.7 MAR Pilot Trial Groundwater Interpretation

Part of the role of this Pilot Trial is help general members of the community visualise and understand the basic concepts of MAR. The aquifer system beneath the MAR site is highly complex. There are at least two perched aquifers that contained groundwater during the trial and which are not distributed uniformly. The data presented in this report and associated appendices reflects this complexity. The following simplified interpretation of the observations made and the groundwater recharge process during Year 1 has therefore been provided in a narrative form to support the continued education of the Hinds Community.

Beneath the infiltration basin of the Pilot Trial lies a series of mixed alluvial silts, sands and gravels as summarised in Table 6. The shallowest gravels are generally unsaturated and are underlain by a silty layer forming a thin leaky aquitard. The middle gravels form an unconfined perched aquifer, which has a limited width and probably constitutes a buried river paleochannel aligned toward the southeast parallel to Frasers Road. The floor of the perched aquifer consists of a gravelly silt layer that allows leakage through to the underlying gravel that forms part of the unconfined regional aquifer.

The infiltration basin and the clamshell holes installed in the floor of the basin were constructed within the uppermost gravel unit. Monitoring well GWE-01 is screened in the perched aquifer and GWD-01 is screened in the underlying regional aquifer (Figure 36).

At the start of Pilot Trial operations, the source water spread across the infiltration basin and trapped air in each of the gravel aquifers. This air became pressurised from the weight of the water in the basin, temporarily pushing the groundwater levels in both the perched aquifer and the regional aquifer downward. As the infiltrating water seeped downward the entrapped air was forced toward to the edge of the basin or escaped upwards as bubbles rising through the floor of the basin. As the water infiltrated downward the *E. coli* in the source water either died off or adhered to the materials through which the water passed.

Table 6: Lithological sequence beneath Pilot Trial site.

Approximate depth below ground level	Description (1)	Hydrogeological description	Groundwater table depth prior to Pilot Trial operations
0 - 6 m	Silty sandy GRAVELS	Unsaturated minor aquifer	-
6 m - 9 m	Sandy gravelly SILTS	Minor aquitard	
9 m - 18 m	Cobbles and GRAVELS, probably constituting a buried river paleochannel	Perched highly permeable aquifer	13.5 m (GWE-01)
18 m - 26 m	Gravelly SILT	Aquitard	
26 m - > 30 m	GRAVEL	Highly permeable aquifer connected to the regional groundwater system	29.5 m (GWD-01)

Note: 1) Based on drillhole log from GW-01, located at the Pilot Trial site.

As the infiltrating water reached the perched aquifer, the water level in this aquifer started to rise and seepage flows toward the southeast along the buried river channel increased. The existing nitrate enriched water in the perched aquifer was pushed in front of and mixed with the clean MAR water. Based on the water quality monitoring, it was determined that practically no *E. coli* reached this perched aquifer with the infiltrating water.

As the groundwater level in the perched aquifer rose, leakage through the floor of this aquifer increased. Shortly afterward the infiltrating water reached the groundwater of the regional aquifer. The groundwater level in the regional aquifer correspondingly rose and seepage moved radially outward from beneath the basin, starting to form a broad groundwater mound centred on the basin. Nitrate-N concentrations in the existing groundwater beneath the basin started to decrease as the original groundwater was either displaced outward by the newly arriving MAR water or became mixed with and diluted by the new water.

The perched MAR water flowing southeast parallel to Frasers Road reached the nearest monitoring well (GWD-04) and seeped rapidly down around the well into the underlying regional aquifer. The water level in the well rose suddenly and rapidly. Behind the initial pressure wave of high nitrate water in the perched aquifer came the flow of lower nitrate water from the Pilot Trial. When the cleaner water reached the monitoring well nitrate-N concentrations in the groundwater around the well decreased as the local groundwater in the regional aquifer was displaced (Figure 36). This pressure wave and plume of low nitrate water subsequently passed two further monitoring wells along Frasers Road (GWE-17 and GWE-04) with the latter being situated more than 2,300 m from the infiltration basin.

In the meantime, the groundwater mound beneath the basin had exceeded 4 m in height and resulted in a water level rise at GWD-02 of more than 3 m. Groundwater at GWD-03 (some 1,600 m to the east of the infiltration basin) started to rise as the pressure response to the Pilot Trial activities reached this point. Some 130 to 150 days after the start of Pilot Trial operations the regional groundwater level under the basin had risen by an estimated 4.4 m. The rise in groundwater at GWD-02 was about 3.6 m and at GWD-03 was about 2.1 m. Water quality improvements in the regional aquifer were only detected at GWD-01, close to the basin, although the nitrate-N concentration at GWD-02 had been relatively low before the trial and any improvement due to the arrival of the MAR water may not have been detected.

Groundwater abstraction for irrigation purposes started about 130 days after the start of the Pilot Trial. Groundwater levels at most of the monitoring wells screened in the regional aquifer started to drop in response. Groundwater levels in the regional aquifer within a few hundred metres of the Pilot Trial basin remained steady, as did the water levels in bores influenced by the perched aquifer.

Increased groundwater flows and levels in the perched aquifer were estimated to have reached a distance of about 6.9 km from the Pilot Trial site by the end of Year 1, approaching Maronan Road. This estimation has incorporated several assumptions and should be tested during Year 2 of the Pilot Trial through further monitoring along the line of the advancing MAR water plume. The plume of low nitrate water in the perched aquifer has however progressed more slowly and is estimated to have passed Ferrimans Road, about 3,300 m from the Pilot Trial basin, by the end of Year 1. Again, further monitoring during Year 2 of the Pilot Trial can be designed to confirm progress of this plume.

At the end of Year 1, the water levels in all of the monitoring wells influenced by the Pilot Trial were at least 1 m above their respective levels at the start of the year, and in most cases more than 3 m higher. In wells not influenced by the Pilot Trial, groundwater levels at the end of the year were at levels similar to or below the respective levels at the start of the year. This increase in groundwater level at the end of Year 1 probably covers an area of some 12 km^2, centred on the Pilot Trial site (Figure 35 and Appendix G). Pilot Trial operations in Year 2 can build on the groundwater storage gains made during Year 1.

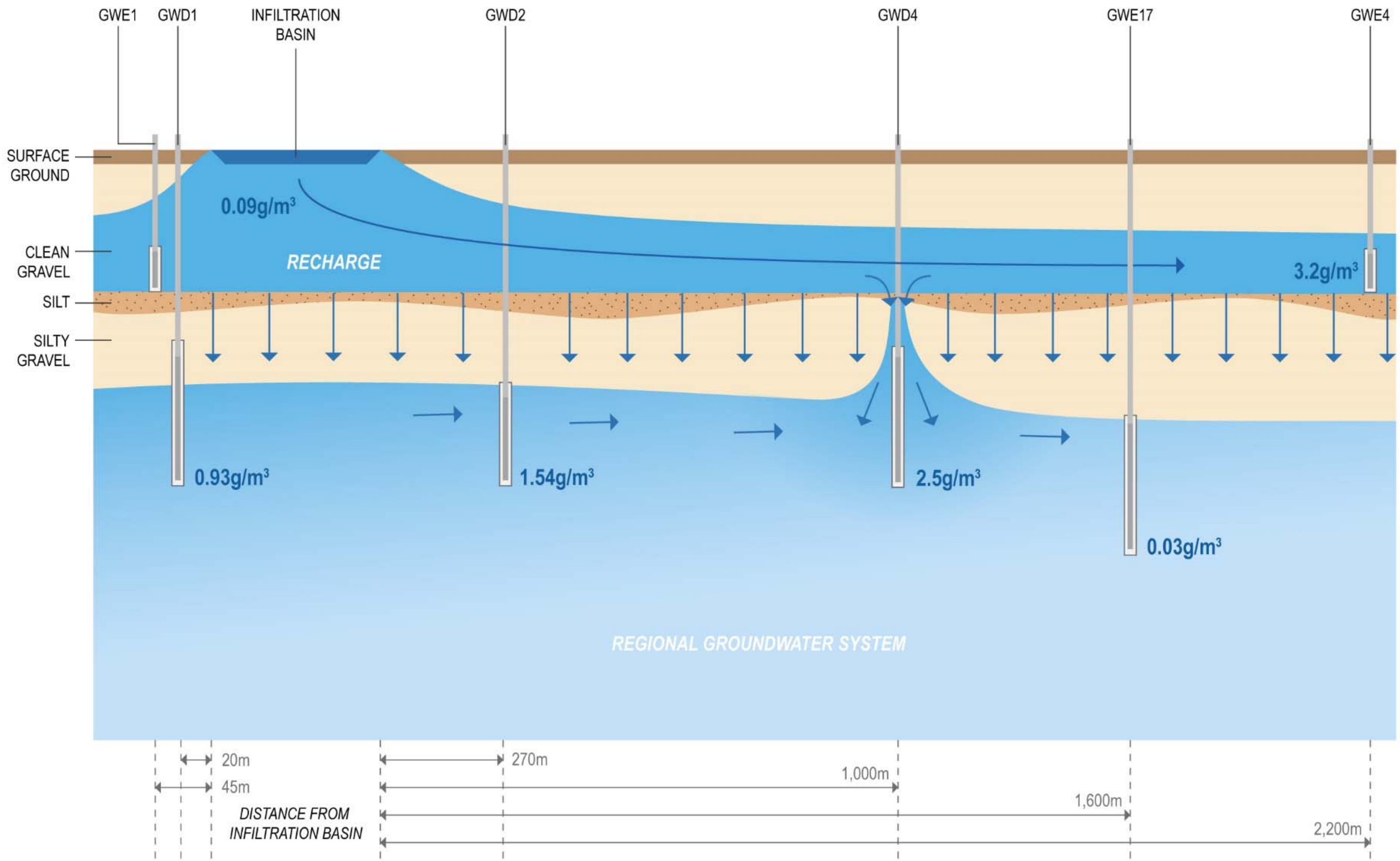


Figure 36: Conceptual groundwater system cross section.

4.8 Operational Review

4.8.1 Clamshell holes

Following an initial infiltration test at the Pilot Trial site, 24 clamshell holes were excavated in the floor of the main basin to a maximum depth of approximately six metres. This was the maximum practically achievable excavation depth with the equipment available. The clamshell holes were filled with clean well rounded cobbles. Documentation of these clamshell holes and an evaluation of the effectiveness of these holes in increasing average infiltration rates for the basin is provided in Appendix I.

Observations during the start-up of the main trial indicated the cobble-filled clamshell holes only enhanced downward seepage for a short period (See Appendix I). Once these holes were full to overflow, the average infiltration rate for the basin was not significantly greater than what it had been prior to construction of the clamshell holes. This observation indicated the aquitard located at an indicated depth of 6 to 9 m beneath the ground level at the site remained a limiting factor in infiltration.

The limiting factor to seepage rates from the floor of the basin to the underlying perched aquifer and the regional aquifer appears to be the average vertical hydraulic conductivity (permeability) of the sedimentary layers overlying these aquifers. The clamshell holes were not deep enough to create direct, highly permeably, hydraulic connections between the basin and the underlying aquifers.

Taking into account the apparent transmissivity of the regional aquifer underling the site, it is likely that installing direct hydraulic connections from the basin to this aquifer would result in substantially increased recharge rates. The planning and installation of such connections would need to take into account other operational and environmental factors that present risks to the eventual outcome of testing these systems. These factors and the associated risks include:

- The attraction of sediments from the infiltration basin to the connecting systems, resulting in clogging of the system over time, which is an operational (reducing the effective recharge rate) rather than an environmental risk. Passive treatment systems to reduce potential sediment loads to the connecting systems can be designed and installed. However, it is unlikely that all sediment would be removed from the flows and clogging would remain a medium to long term risk requiring management.

- The groundwater quality assessment (Appendix H) demonstrated that *E. coli* is mostly removed from the infiltrating water before that water reaches the nearest monitoring wells to the site. This process of natural filtration of recharge water as it infiltrates through the soils is termed Soil Aquifer Treatment (SAT), a concept widely studied and documented in the field of water recycling and MAR using wastewater (Rice & Bouwer 1984). Any upgrades for the site to increase the overall recharge rate will need to be designed to help maintain the natural filtering of water as it passes through the subsurface soils to limit the amount of faecal bacteria in groundwater.

4.8.2 Operational water depth in infiltration basin

Evaluation of the infiltration rates from the main infiltration basin has indicated that these rates do not change significantly with ponding depth within the basin (Appendix I). On the basis of the observations made to date, operational recharge efficiency in terms of infiltration rate is not a key driver at this site in maintaining ponding depths within a specific range.

The currently designated operational depth range of 0.5 m to 0.8 m appears to provide for adequate warning and time for intervention if pond levels move outside this range. If an automated flow management system is installed at the outflow from the Valetta Pond #3, and linked to the water level in the main basin, then the operational water level range may be reconsidered taking into account other operational factors, such as flow adjustment frequency.

4.8.3 Basin clogging

The evaluation of basin clogging through Year 1 is documented in Appendix I. Basin clogging was evaluated through a range of monitoring and analysis processes, including:

1) The monitoring and calculation of suspended sediment loads in the source water delivered to the Pilot Trial site.
2) Visual evaluation and photo documentation of accumulated fine sediment and biological growth on the floor of the basin
3) Analysis of the rates of change in infiltration basin water level following several operational shut-downs through the course of the year.
4) Analysis of the hydraulic pressure differential between the basin and a sensor installed in the sediment beneath the basin.

During Year 1 of the trial a total sediment mass estimated to be in the order of 13 tonnes has been deposited in the two basins at site. This equates to a basin floor sediment load of approximately 1.4 kg/m^2.

The thickness of sediment accumulated on the floor of the forebay is substantially greater than sediment on the floor of the infiltration basin. This visual assessment attests to the efficiency of the forebay in achieving the design objective of retaining suspended sediment from the source water. At least some of the accumulated sediment in both basins is the result of biological activity in the basin ponds as well as some potential sluffing of basin walls from wind and wave erosion activities.

Infiltration rates for the main basin have been calculated based on water level recovery curves following operational shut-downs. Prior to April 2017 calculated infiltration rates were in the order of 0.59 m/day. During April and May 2017 infiltration rates were slower at approximately 0.36 m/day. Although there appears to have been a decline of 40 % in infiltration rate based on the analysis of these curves, only six curves have been analysed to date and these results should therefore not be considered in isolation when evaluating groundwater recharge from the basin.

Analysis of the hydraulic pressure differential between the pond in the main infiltration basin and a sensor installed beneath the floor of the basin during the period from 15 June 2016 to 22 December 2016 has not identified a change in the differential over time. This pressure differential evaluation data does not indicate clogging of the basin floor took place during the monitored period.

In summary, clogging is an operational issue that needs monitoring and management, as with all MAR systems. Calculated infiltration rates for the main basin may have decreased toward the end of Year 1. Sediment is clearly being deposited in both basins and, without management, would eventually result in a decline in the basin performance.

5.0 MAR PILOT TRIAL RESULTS – COMMAND AREA

5.1 Coastal Flooding Trigger Conditions

Coastal flooding in the drains based on historic incidental recharge from border dyke irrigation was a major concern of the community. Golder (2015a, 2016a) conducted modelling and provided the HDWP, CRC engineers and CRC consent planners with a comprehensive assessment around the risks of flooding as they related to the MAR site. Worst case scenario modelling used the 500 L/s max rate and looked at the likely outcomes to flows in the coastal drains, showing only small changes. However, as part of the consent, trigger conditions for high rainfall and flow events in the coastal area were set up to help mitigate the community concerns.

As per the MAR Pilot Trial consent conditions (*CRC162191)*, operations at the site are to be shut down (minimum of 48 hours) if either coastal waterbodies (drains) flows (CRC Gauge# 69001[8], Parakanoi @ Lower Beach Road) **or** rainfall (CRC #39610[9], Hinds Plains Rainfall Site) exceed their trigger levels. Trigger levels for rainfall was >30 mm in a 24 hour period, as measured at the Hinds Plains site. For the CRC gauge at Parakanoi Drain, the trigger level was flood flows over 2,200 L/s. Conditions in the coastal waterways during Year 1 were consistent with those observed over the past 3-4 years, with dry conditions persisting even during the normally 'wetter' winter periods.

While flows in the Parakanoi Drain never exceeded its trigger condition, rainfall did on two separate events (Figure 37). The two rainfall events (> 30 mm/24 hours) that triggered a consented MAR site shutdowns as follows:

- Event 1 – 31 mm fell between 18:30 on 26 March and 12:00 on 27 March 2017

  Shutdown 1 – from 15:30 on 27 March to 11:15 on 29 March

- Event 2 – 56 mm fell between 14:30 on April 5 and 14:20 on April 6.

  Shutdown 2 - from 9:15 on 6 April to 13:45 on 9 April 2017.

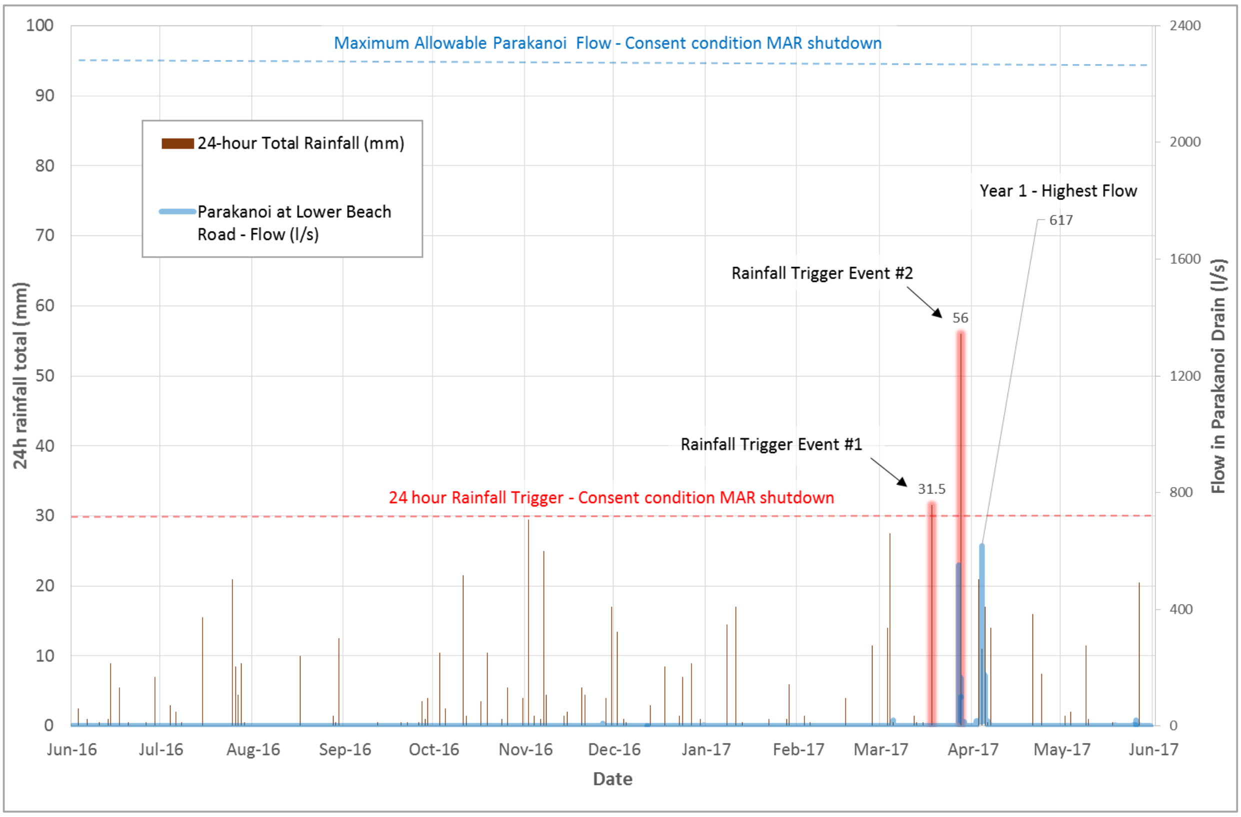


Figure 37: Rainfall and Parakanoi at Lower Beach Road Flow: Consented Trigger Analysis Results - Year 1 MAR Operations.

[8] https://www.ecan.govt.nz/data/riverflow/sitedetails/69001

[9] https://www.ecan.govt.nz/data/rainfall-data/sitedetails/319610

5.2 Flows, Quality and Ecology in the Coastal Drains

As part of the overall MAR command area monitoring programme, flows at ten sites in the coastal spring-fed drains were sampled (Appendix E). A combination of ongoing drought conditions and the catchment-scale water management changes (e.g., piping and groundwater abstractions) have led to extremely low groundwater levels. As these coastal drains are spring-fed, the conditions in the drains were extremely dry for most of Year 1 of the Pilot Trial (Figure 38). The MAR site operating at a peak recharge rate of 110 L/s was insufficient to offset these large-scale processes. Parakanoi Drain measured at Lower Beach Road (#69001) had a median flow of 195 L/s and an average flow of 230 L/s for the period 2004 to 2014 (Durney, and Ritson 2014) with a maximum flow of 5,446 L/s.

During Year 1, Parakanoi Drain at Lower Beach Road was **dry for 353 days**, and had some flow only 12 days during the period from 10 June 2016 to 9 June 2017. For Year 1 operations Parakanoi at Lower Beach Road had a median flow of 0 L/s, an average flow of 1.4 L/s and a maximum flow of 617 L/s. Parakanoi and Flemington both had their highest flows recorded in April 2017 (Figure 39) with Blees and Wheastone Drains recorders remaining dry for the entire testing period. During some peak rainfall events (e.g., April's Cyclone Cook) flow in the drains was recorded, but often it was patchy with flow in the upper portion of the drains (groundwater inflow) but no measureable values at the flow sites (Golder field team and per comms Hinds Drains residents). These flows were likely driven mainly by rainfall-runoff.

Figure 38: Parakanoi Drain MAR programme weir – comparison winter 2014 (flowing) vs winter 2016 (dry)

Ecological monitoring was conducted at 5 sites spread over Parakanoi and Flemington Drains including a hapua. Wetted habitat was observed in Parakanoi Drain at New Park Road on six monitoring occasions, on one occasion in Flemington Drain at Montgomery's Road and at the final riffle upstream of the hapua (see Appendix N).

Physico-chemical measurements of the drain water based on the spot measurements (typically measured early afternoon), temperature, pH and dissolved oxygen concentrations were all within the range capable of supporting aquatic life.

Water quality information was also collected at the ecology sites, with nitrate-N concentrations in Parakanoi Drain at New Park Road (14.4 mg/L) above the long term median concentrations for the Hinds Drains (9.25 mg/L, HDWP 2016). Nitrate-N concentrations in Parakanoi Drain at Lower Beach Road, Flemington Drain at Montgomery's Road and Flemington Drain at Boundary Road were well below the Hinds Plains target nitrate-N concentrations of 6.9 mg/L (HDWP 2016). These results are consistent with the values collected by CRC and HDWP and summarised in Section 2.3.

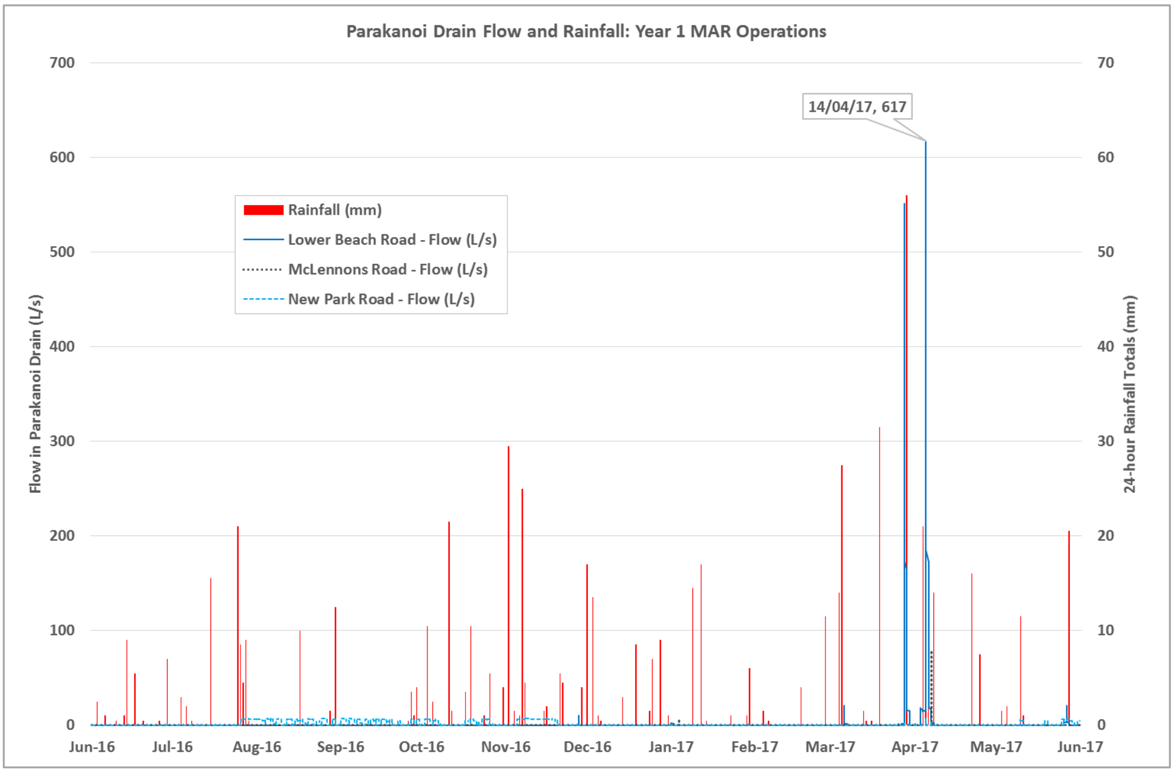


Figure 39: Year 1 Operations Period: Parakanoi Drain gauge sites - flow (L/s) and rainfall (mm/day)

Figure 40: Thin green films growing on the gravel substrate at Parakanoi @ New Park Road during the 25 November 2016 survey.

During the ecological surveys of Parakanoi Drain at New Park Road, the percentage cover of periphyton (benthic algae growing on the surface of substrates) was 100 %, comprised mainly of thin mats/films (Figure 40). Both diatoms (light brown films) and green algae (green films) were dominant during the October survey, while green algae were the dominant group during the November survey. No submerged aquatic plants were recorded during the two surveys, while the floating macrophyte duckweed (*Lemna minor*) was recorded at 1 % cover during the November survey.

Drought related low flows during the first year of the MAR Pilot Trial did not provide sufficient water to maintain a wetted habitat in the drains over the course of the year. Early periphyton colonisation in the Parakanoi Drain when there was sufficient water indicates the potential of the drain to support some form of aquatic community. Connectivity between the drains and streams in the lower catchment did not occur due to insufficient drain flow. While airborne dispersal of periphyton and macroinvertebrates will result in colonisation of the drains, fish colonisation will be reliant on connectivity between the drains and streams to establish passage for the fish. This is anticipated to occur once normal flow conditions resume.

5.3 Ashburton River Recharge and Tinwald Flooding

One of the key objectives of the Hinds MAR Pilot Trial is to demonstrate the potential for artificially enhanced recharge to increase groundwater storage (levels) within the Hinds catchment. An area of concern to the local community with respect to the Pilot Trial was a perceived risk of increased flooding frequency and magnitude in low-lying areas within the catchment. The Tinwald suburb, close to the Ashburton River, was an area specifically identified by the community as having a history with rainfall-linked flood events. A CRC report (Boyle 2009) considered the flooding risks on both Lagmhor Creek and Carters Creek, which flow through the Tinwald area. These creeks are understood to originate from springs fed by the Ashburton River (near Westerfield). They potentially also carry some tail water sourced from ADC stockwater races (Shepards Brook Creek and Timaru Track).

Relative to the Pilot Trial, this Tinwald area is not directly down-gradient from the Pilot Trial relative to piezometer flow lines, but conceptually could be influenced by recharged water. Numerical modelling, untaken as part of assessment of flooding risks, indicated that MAR would not be a significant factor influencing Tinwald groundwater levels (Golder 2016b). Anecdotally, locals also identified that this Tinwald area is hydraulically linked to Ashburton River flow conditions and that was a major factor in the historical flooding events. However, ensuring that monitoring did take place to help verify this assumption was deemed socially and technically practical.

The assessment of the groundwater and surface water responses to rainfall and surface water levels summarised in this section is presented in detail in Appendix M.

A shallow monitoring well was installed in April 2016 (GWD-07) to monitor groundwater levels in the Tinwald area. The groundwater level data from this well has been evaluated through comparison with rainfall records from the Ashburton Council climate monitoring station and water level records for Lagmhor Creek and the Ashburton River.

The groundwater level record from GWD-07 has shown no indication of groundwater driven flooding in Tinwald during Year 1 of the Pilot Trial (Figure 41). Assessment of the effects of the Pilot Trial on groundwater levels (refer Section 4.5) has clearly shown that groundwater level increases due to Pilot Trial operations did not extend as far as Tinwald during Year 1. Pilot Trial operations have therefore not contributed to any surface water ponding that may have been observed in Tinwald during Year 1.

In terms of scale and duration, the most pronounced groundwater level change observed at Tinwald during Year 1 was the drawdown resulting from groundwater pumping during the irrigation season (Figure 41). Following the end of the irrigation season the groundwater table recovered rapidly to two metres above the highest levels recorded prior to the start of the irrigation season. This rapid recovery in groundwater level was due partly to a series of substantial rainfall events that occurred in late March and April 2017 (Figure 41). However, it is likely that higher water level events in the Ashburton River during the same period also contributed to the groundwater level recovery (Figure 42). The ongoing high groundwater level following April 2017 may be a consequence of the cumulative rainfall in the Hinds Catchment during March and April being much greater than average for these months (refer Section 4.2).

Outside the period affected by irrigation pumping, rises in groundwater levels were principally the result of local rainfall events (Figure 41). Higher water levels in the Ashburton River, including the extended period of higher water during spring and early summer that was probably a result of snow melt in the Southern Alps, did not appear to strongly influence groundwater levels at Tinwald during Year 1 (Figure 42).

There was no apparent correlation during Year 1 between water levels in Lagmhor Creek and groundwater levels at GWD-07. There was also no apparent correlation during Year 1 between water levels in Lagmhor Creek and in the Ashburton River (refer Appendix M).

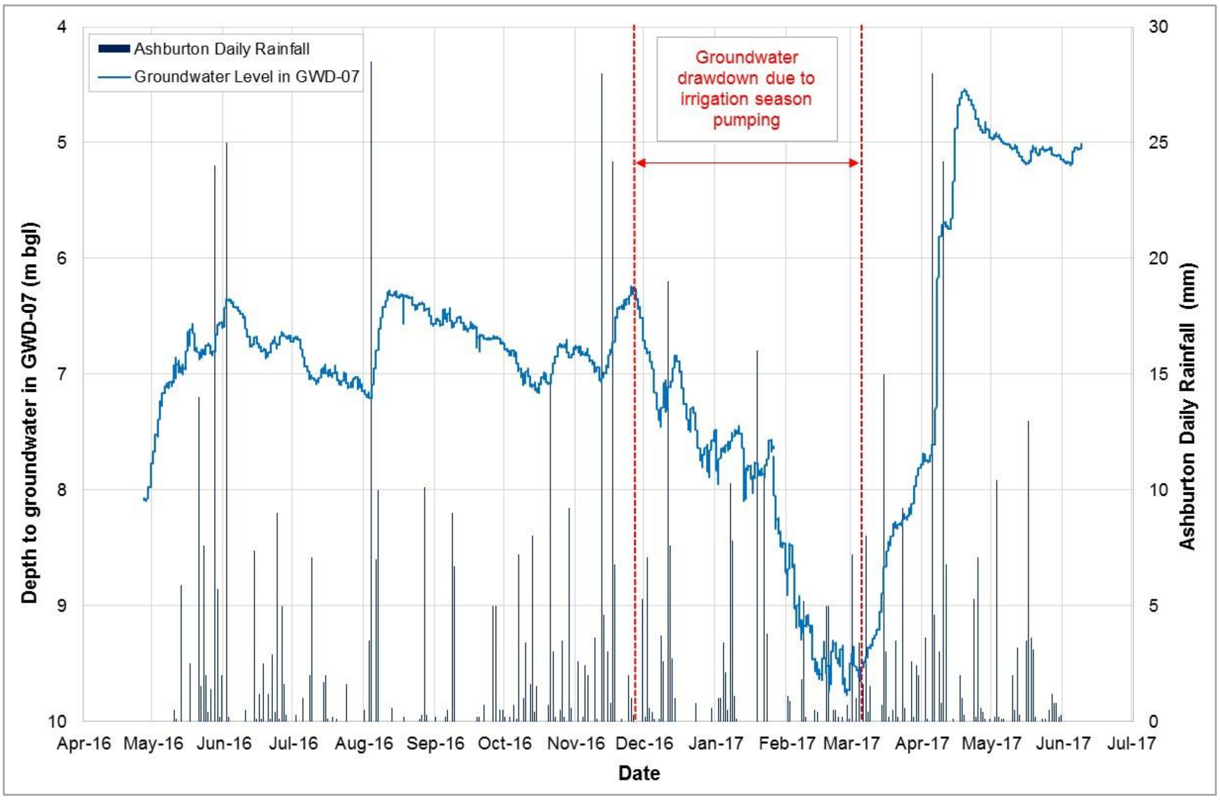


Figure 41: Shallow Tinwald groundwater responses (GWD-07) to rainfall events.

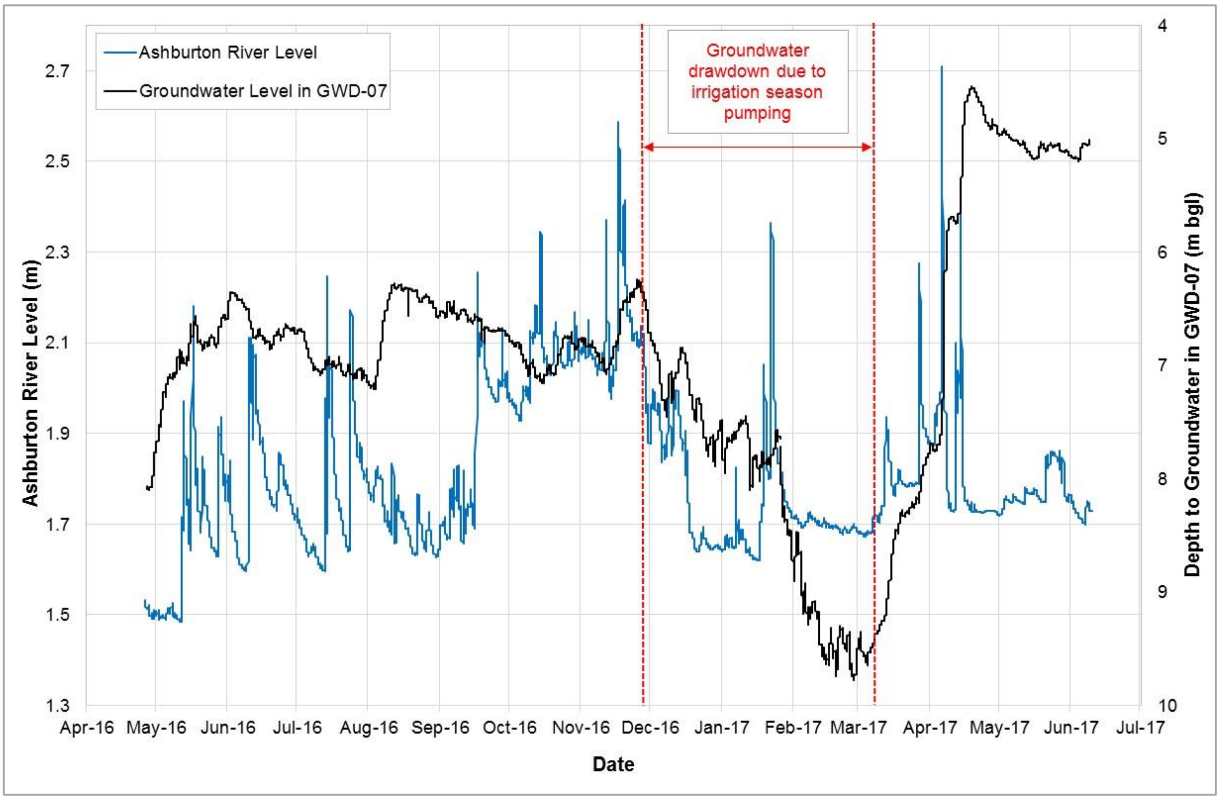


Figure 42: Shallow Tinwald groundwater responses to changes in Ashburton River water level.

6.0 PILOT TRIAL - SCIENCE PROGRAMME

6.1 Introduction

Four parallel projects were initiated starting in 2015, to complement the MAR Pilot Trial. These projects sought to form partnerships with key groups interested in water issues that AZC and the wider Hinds catchment community sought.

1) A project with Canterbury District Health Board (CDHB) looked specifically the potential implications of MAR on drinking water in the district.
2) A second project involved a partnership with Lincoln Agritech who are developing a *cutting edge* automated, low cost, temporal, nitrate tracking device. If successful this device could be used throughout New Zealand by farm managers as a low cost means to regularly measure the nitrate-N in groundwater. This would complement the extensive national investment in farm-systems programmes like Overseer™ and help move the management of nutrients forward with in-field, real time data.
3) The third project was commissioned by CRC and carried out by geologic modelling experts from Golder, who explored the use of geostatistical modelling tools to help understand where MAR sites may be best placed, and how this information may be used to improve the numerical models used in Canterbury.
4) The CRC hydrogeology team led the last of the four projects, which built on the extensive groundwater modelling done previously for the Hinds subregional zone committee process as well as support for the Hinds Drains Working Party and Hinds MAR Pilot Working Group. A 3D numerical groundwater model covering the Pilot Trial area was constructed and calibrated using Modflow. This model was used to simulate the Pilot Trial and replicate the Pilot Trial results in terms of groundwater mounding and changes in groundwater quality. The objective was to provide a sense of what continued operations at the Pilot Trial site may achieve over the life of the consent (2016 to 2021).

6.2 Drinking Water Assessment – Science Program

The Hinds MAR Pilot Working Group formed a research and outreach partnership with CDHB in order to understand how MAR might play a role in the better management of drinking water supplies in the Hinds catchment (see Appendix J for more information). This partnership was scoped as two separate work streams to be undertaken during the Year 1Pilot MAR testing period:

- Community & Public Health (CPH), a division of the Canterbury District Health Board (CDHB) and Ashburton District Council (ADC) conducted a public outreach and drinking water sampling programme (CPH Programme) prior to the start of MAR Year 1 operations.
- The MAR technical team integrated drinking water quality sampling parameters and relevant water supply bores into the Year 1 testing programme specifically to complement and extend the CPH Programme. The role of CPH staff (and subcontractors) was to review and provide feedback on the summarised MAR Pilot Trial testing results and final report. A nitrate-N GIS mapping analysis was included in this work to provide a spatial interpretation of the distribution of nutrients in groundwater.

The CDHB programme involved forming a partnership with ADC, who has a responsibility to ensure drinking water supplies in the district are safe, and initiated a 'free drinking water bore sampling' programme for 50 bores in the MAR Command area. Whilst there are many important parameters that help determine if water is fit for human consumption, two parameters were measured for this project; nitrate-N (g/m^3) and the presence/absence of *E. coli* (enteric indicator bacteria of faecal contamination). A public notice went out in letter form to addresses in the area of interest. The programme ran from October to December 2015, with results being shared exclusively with the participants via a letter. The letter included contextual information on the meaning of their individual results as well as contact information for local retailers of home-use drinking water treatment systems. Those results were shared with the MAR technical team and provided a snapshot of the drinking water supplies (private bores).

The MAR technical team also considered drinking water, in both its larger MAR command area monitoring programme but also more specifically to this partnership, in the MAR near-field and MAR water-quality footprint area. A summary of the command area findings can be found in Section 4.6. In the MAR nearfield and water quality footprint area, three bores which provide drinking water were sampled as part of the overall programme. The MAR technical team also conducted some advanced GIS spatial analysis in order to help provide a visualisation of the Tinwald 'hot spot' (Appendix J).

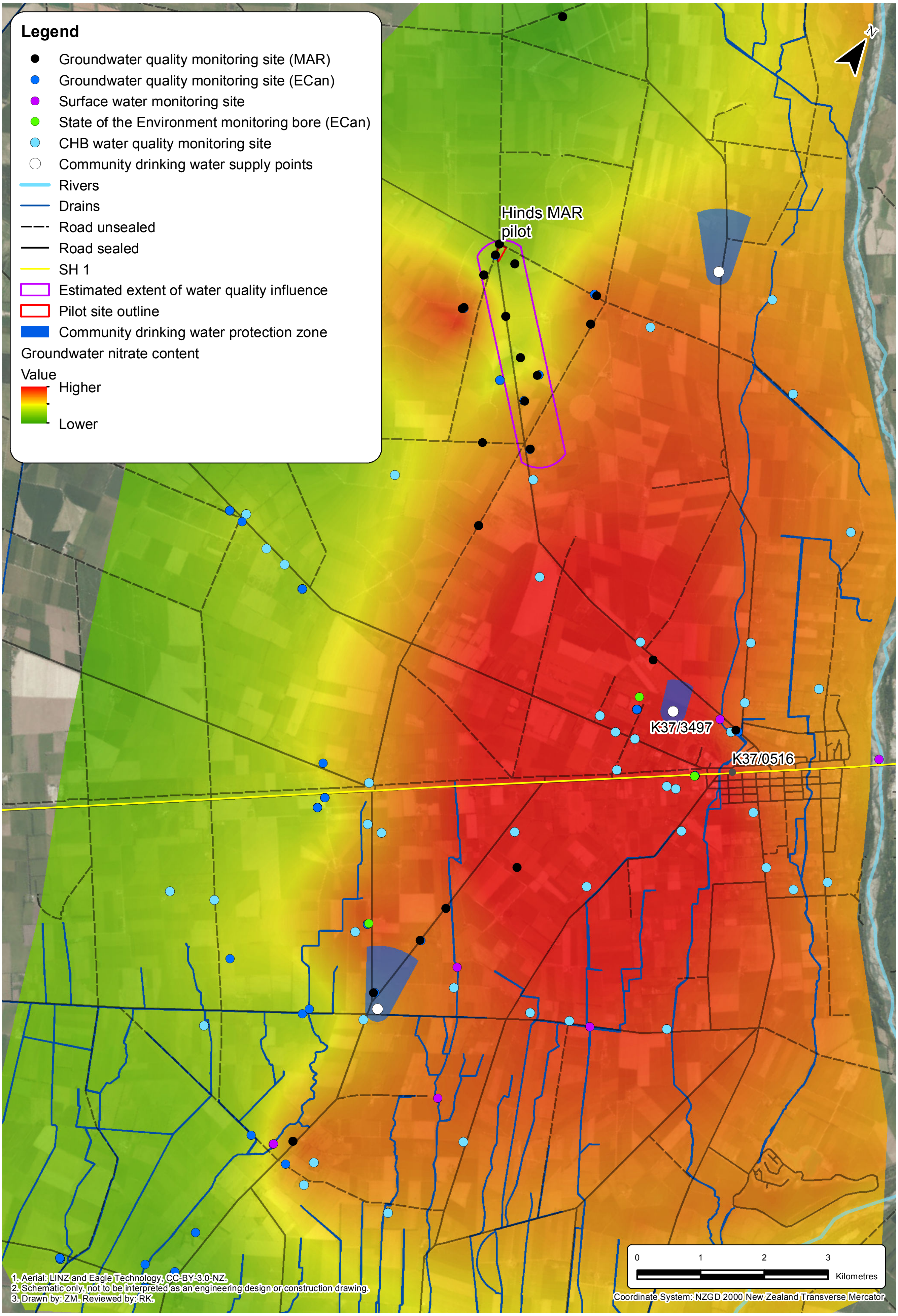
6.2.1 Drinking water results and discussion

For the CDBH programme bores were randomly selected but fell generally inside the MAR command area, both above and below State Highway 1 and down-gradient from the MAR site (Figure 43). For the 50 bores sampled for nitrate-N, the results indicate:

- 44 % (22) of the bores were below the recommended average concentration[10] of (5.7 g/m^3);
- 28 % of the bores were above 5.7 g/m^3 but below the Maximum Acceptable Value (MAV) of 11.3 g/m^3;
- The remaining 28 % (22) of bores were measured above the MAV, with the maximum recorded value at 20.7 g/m^3.

Reported bore depths ranged from quite shallow (7 m below ground level, bgl), to deep (80 m bgl) with 28 % of participants unsure of their bore depth. *E. coli* samples were analysed for presence versus absence, with two bores testing positive (4 %). The survey information also reported that of the 50 samples, 17 reported having some form of water treatment (e.g., charcoal filters, etc.), with another 16 not specifying treatment or were unsure if their water was treated. Due to the confidential nature of this project, the numerical results are not shared in map form.

[10] *An average concentration of 5.7 g/m3 in shallow groundwater is considered to ensure that not more than 10% of samples exceed the Maximum Acceptable Value for drinking-water in a given year. This is based on statistical relationships developed from Canterbury monitoring data (Hanson, 2012).*



Golder Associates

TITLE RELATIVE NITRATE-N CONCENTRATIONS IN GROUNDWATER IN THE MAR PILOT TRIAL AREA

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6.2.2 MAR Pilot Trial Drinking Water – Results and Discussion

Data collected at three bores (GWE-11, GWE-13, and GWE-15) that were reported to provide drinking water to rural properties were collected during Year 1 MAR operations. Bores GWE-13 and GWE-15 showed no clear indication that they were influenced by the MAR clean water plume (footprint), and averaged 9.7 g/m^3 and 11.0 g/m^3 respectively. Bore GWE-11 showed signs of MAR influence with some large variability in concentrations between monthly samples early in the year, and then a clear downward trend in the latter portion of Year 1 (Figure 44). GWE-13 and GWE-15 were averaged to represent MAR near-field (outside the MAR footprint) drinking water concentrations, while total monthly recharge volumes and GWE-11 were plotted to provide an assessment drinking water changes. *E. coli* bacteria results from Year 1 monitoring reported only 1 sample with 1 MPN/100 ml in GWE-15 (February 2017).

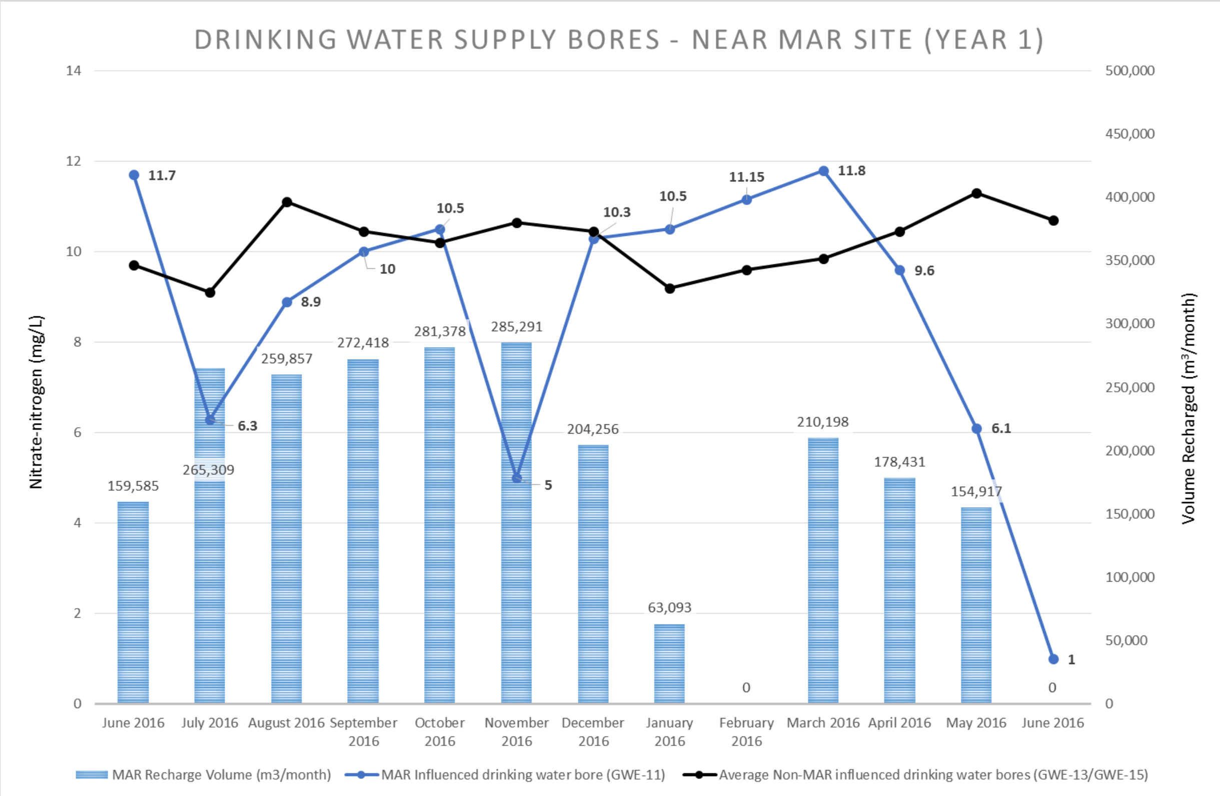


Figure 44: MAR project area - drinking water supply bore response.

The analysis of the spatial data coupled with discussions with CRC water quality scientists indicated that a catchment wide assessment of nitrogen 'hotspots' was challenging. A combination of the lack of spatial coverage (large portions of the catchment were missing groundwater bore water quality samples) and vertical resolution (bore depths are often deeper and not representative of the targeted 'shallower' groundwater system), makes the use of this mapping less robust for a catchment-level assessment. It was generally surmised that areas that showed lower concentrations (green shading in Figure 44), were less likely to be the product of actual *lower concentrations* of nitrate-N, but more likely an artefact from the lack of data in that area.

The results of both the CDHB and the MAR monitoring programmes indicates that nitrate-N in groundwater is prevalent across the Hinds Plains catchment, but further monitoring to increase the spatial coverage and density of samples is required in order to provide a more accurate nitrate groundwater map of the entire Hinds Catchment. In the MAR command area, the hotspot covering an area around the Ashburton suburb of Tinwald and extending both up-gradient and down-gradient from SH1 is likely one of the most significant in the catchment with concentrations as high as 28 g/m^3 nitrate-N.

Results from MAR programme and near-field area bores indicate that *E. coli* bacteria, during Year 1 of the Pilot Trial were relatively low in the bores used for drinking. However, given the dry conditions, it is difficult to draw any significant conclusions. Other MAR programme monitoring bores did show higher *E. coli* counts and continued monitoring and treatment of drinking water is highly recommended. Water quality data from drinking water supply bores in the MAR near-field area indicate nitrate-N concentrations at or above the 11.3 g/m^3 drinking water limit, which translates into a significant risk to human health. A drinking water bore within the MAR footprint showed beneficial effects, with nitrate-N concentrations declining to less than half of the drinking water limit.

The CDHB and ADC monitoring and outreach programme provided a snapshot of drinking water in this area, but also an approach to provide outreach to the general public on the risks associated with drinking water. Conversations with the community have revealed that awareness of risks of untreated drinking water, particularly in the coastal drains portion of the catchment are known. Reports of people either installing a treatment system or moving their domestic supply source to deeper bores are prevalent. However, continued efforts to decrease the risks through outreach while also reducing the amount of contamination in groundwater are needed.

6.3 Nitrate Temporal Concentration Tracking Project – Science Programme

A MAR Pilot Trial partnership was formed between CRC, Golder and Lincoln Agritech to utilise a state-of-art prototype nitrate-N sensor to track the results of the Pilot Trial (See Appendix K for more information).

The use of an optical nitrate-N sensor in continuous, down-hole duty with data-logging and telemetry greatly increased the temporal resolution of nitrate-N concentration tracking at the Hinds MAR Pilot Trial site. A sensor was installed in a downstream groundwater sampling bore (GWD-4) immediately following the onset of long-term MAR water injection in the winter of 2016 (Figure 45). A distinct nitrate-N concentration contrast due to the MAR Pilot Trial was apparent in the monitoring data, with the MAR water averaging 0.05 g/m^3 while the native groundwater ranged from 4 g/m^3 to 13 g/m^3.

Figure 45: Bore head of GWD-01 monitoring bore: showing cable for sensor and power supply enclosure.

Within the continuous monitoring framework for the optical nitrate-N sensor, GWD-04 bore water nitrate-N concentration was observed to shift from 6.9 g/m^3 to 2.5 g/m^3, a generalised dilution of 4.4 g/m^3 (Figure 46). Analysis into lag times for the transport of low nitrate water through the perched water table aquifer determined that an approximate delay of 55 days was apparent over a distance of 1,100 m. The role of the perched and regional water table aquifers in dispersing low nitrate MAR water was better understood. However, the presence of an obvious perched – regional aquifer cross-over at the continuous monitoring bore did complicate the examination of dispersion rates and confounded further analysis.

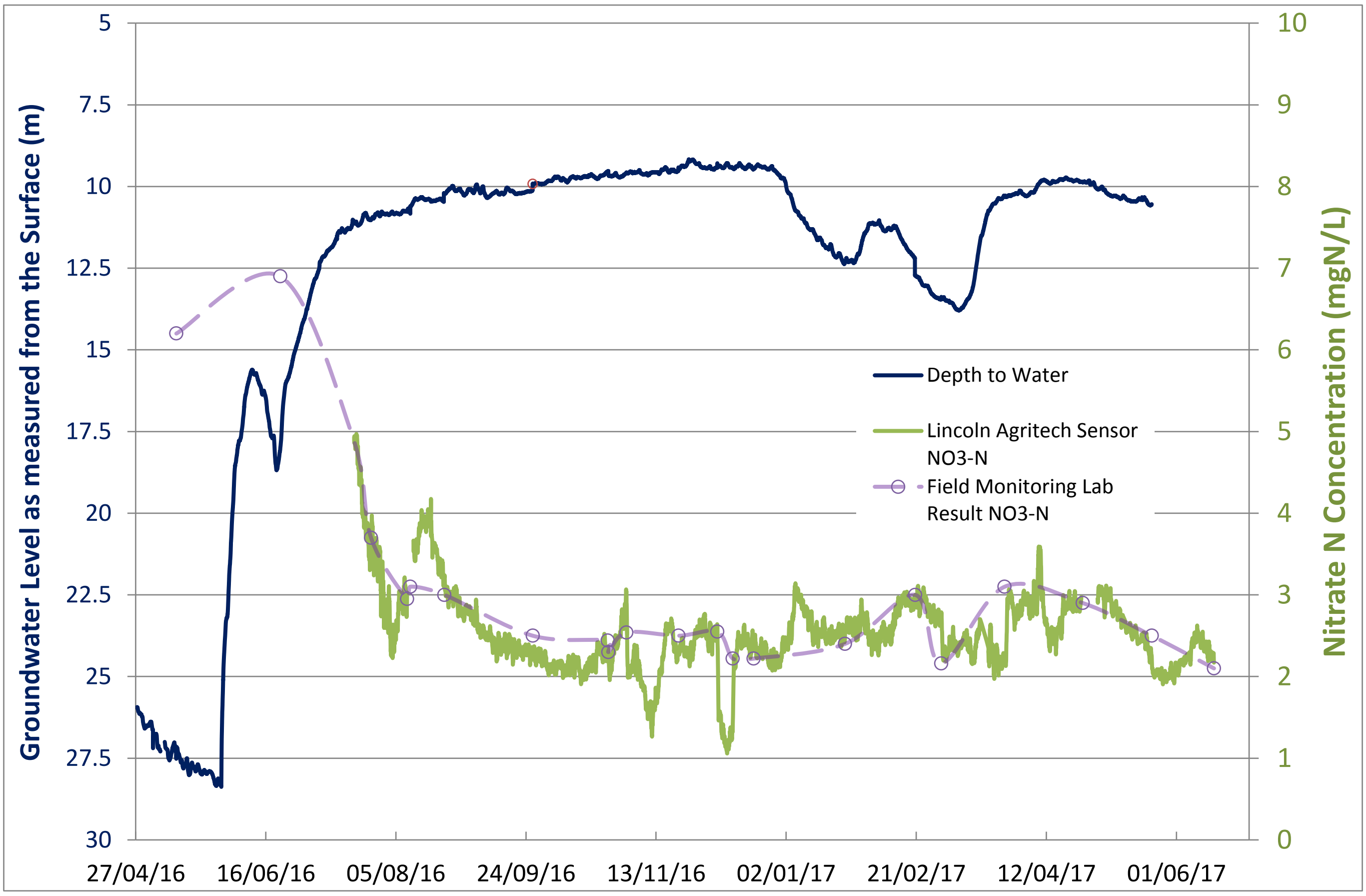


Figure 46: Full chemo-graph and hydrograph of bore GWD-04 from 27 April 2016 to 15 June 2017

Lincoln Agritech provided the following project observations:

- The Hinds MAR Pilot Trial application of continuous nitrate-N concentration tracking had a number of unique factors. The first is that groundwater nitrate-N concentrations changed rapidly in this trial, whereas groundwater usually increases or decreases in concentration much more slowly. A second unique factor is the application of groundwater monitoring techniques to tracking a low nitrate plume in the aquifers, as the plumes usually tracked are elevated concentrations originating from a high nitrate source area.
- The higher temporal resolution of a continuous sensor in bore GWD-04 allowed interpretation of the groundwater travel lag time to be more reliably estimated at 55 days from the onset of MAR water recharging the perched water table aquifer.
- The interpretation of dispersion of native groundwater by low nitrate MAR water was complicated by the dual pathways taken for recharged groundwater, namely via the perched water table aquifer and the regional water table aquifer.
- Current information from continuous nitrate-N concentration tracking and spot sampling has further high-lighted the dual pathway and the more rapid transport through the perched water table aquifer.

6.4 Geostatistical Analysis of Lithological units – Science Programme

A project commissioned in conjunction with the Hinds Catchment CRC numerical modelling and the MAR Pilot Trial was conducted through 2015 and 2016. A final report was delivered to CRC in September 2016 titled *Hinds/Hekeao Catchment Groundwater System: Geostatistical Modelling of Aquifer Lithologies* (Golder 2016). This report is not attached in the Appendices, but is available from CRC.

This project focused on exploring the application of state-of-the-art geostatistical modelling techniques (used commonly in the mining industry) for potential use in exploring the rapid generation of multiple stochastic geological models to enable the assessment of the role geological uncertainty plays in the ultimate fate and transport of contaminants. Geological uncertainty refers to the uncertainty introduced in numerical models by the chosen conceptual models and their inherent shortcomings in true representation of the hydrogeological system. Geological uncertainty is the single largest contributor to uncertainty of transport (water quality) results. The only way to address this is through the development and calibration of multiple conceptual models (Refsgaard et al., 2012). It is hoped that should the approach prove successful in this purpose it may help bookend the range of expected contaminant transport pathways at a regional scale for the Hinds catchment.

The development of the geostatistical model for the catchment is consistent with the other Science Programme partnership projects in that new techniques are being trialled to better understand the geology, and at a coarse level the permeability relating to infiltration (MAR site locations) and connectivity (fate and transport of clean water to target high nitrate areas). This is also consistent with AZC recommendations (ZIP Addendum) to continually; *Improve the Tool Box* (Rec. 4.3) where 'Environment Canterbury work with researchers, industry groups and others to improve the accuracy and confidence in tools' (AZC, 2014).

The initial trial of this technique focused on mapping the permeable horizons of the depositional geology of the Hinds catchment which includes both groundwater allocation management units in the catchment; the Mayfield-Hinds and Valetta Groundwater Allocation Zones (GAZ). It consisted of developing two geostatistical models, the Hinds Regional Geostatistical Model (HRGM) that covers the entire Hinds catchment and a second higher resolution model focused specifically on the coast (Hinds Coastal Geostatistical Model, HCGM). In the development of the regional model (HRGM) feature sizes were defined with model cell resolution of 250 m long, 250 m wide and 3 m thick. Across the 65 km long, 45 km wide and 0.15 km thick model, 18 million model cells were generated. By definition, this model was looking at catchment or macro-scale features in the Hinds.

In the chosen approach, a *training image* was utilised to provide a conceptual geological model of lithological relationships to support the modelling algorithm (Figure 47). These MPS tools provide an entirely different approach to aquifer delineation than traditional methods.

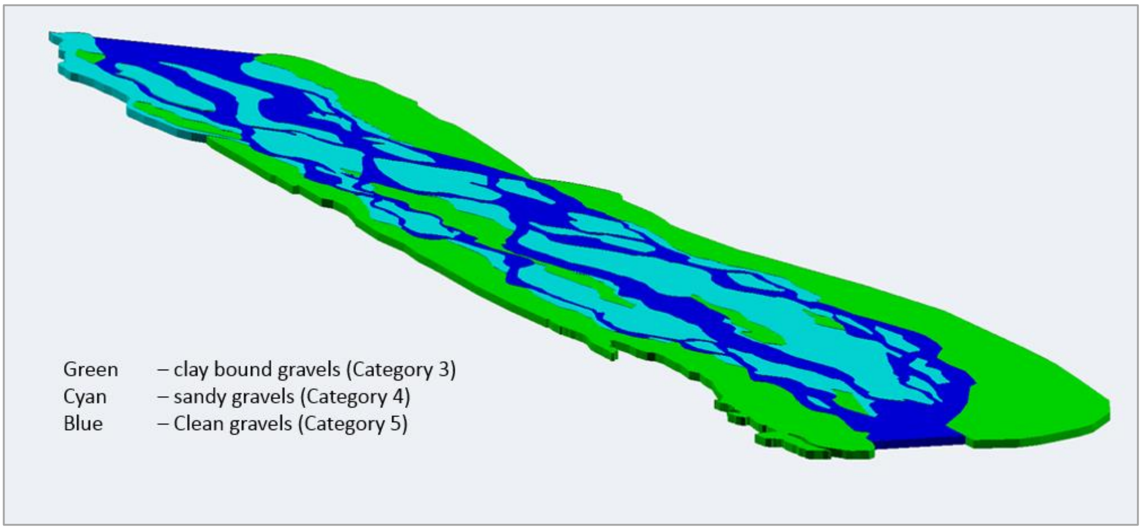
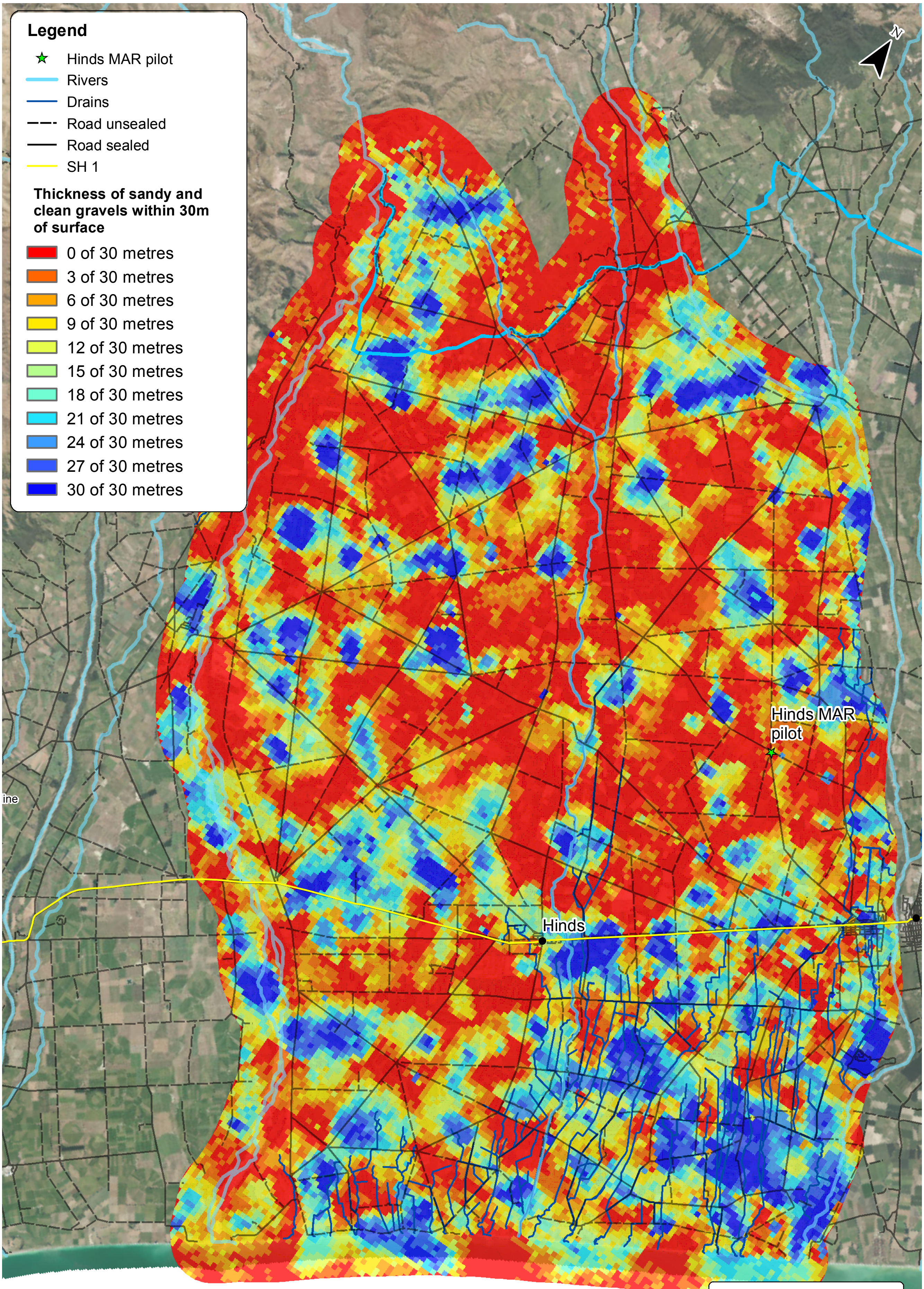


Figure 47: An example of a Rakaia River training image used in Geostatistical modelling approach.

Using CRC's database, 3,045 unique wells were utilised in modelling the lithology of the Hinds plains. The final outputs from each of Golder's models represent the most statistically robust outcome based on 100 probable model iterations. Geological codes in this database were simplified into five classes, with the authors adopting colloquial drilling terms such as claybound gravels. As such, the classes adopted do not refer to true lithologies but rather inferred permeability descriptive lithological categories ranging from low (silts / clays) to high (clean gravels). From the model outputs, maps were generated that provide a coarse, catchment-scale visualisation of areas where permeability (particularly for the shallow lithology) are estimated to be higher through to lower (Figure 48). The map, which summarises the results for the top 30 m of the 150 m model, is a potential tool to help find MAR sites where shallow, higher permeability materials may provide higher infiltration rates. The Pilot Trial results have reinforced the need for identifying potential areas in the catchment where higher permeability may support new MAR sites for further field testing.

Following on from the final project report and new information being provided by the Pilot Trial, there have been a number of recommendations on future use of these kinds of techniques. These recommendations include:

- Integrating historical geological reports and previous field investigations to improve the conceptualisation of the lithology in the Hinds.
- Validating the model outcomes against aquifer test data held by Environment Canterbury
- Conducting a field verification programme to assess the validity of the modelling results. This programme should include validation of new models against MAR Pilot Trial results and/or new bores being drilled and logged in the catchment.
- Working closely with CRC to continue to refine and improve their well log database, including potentially random well log validation to determine the extent of poor quality drill logs as well as to determine the extent of clay content using various geophysical techniques (e.g., natural gamma, neutron, and induction downhole logs).
- Re-running the model with a less complex Training Image possibly with a reduction in the number of simulated lithological categories.
- Likewise, varying some of the specific modelling parameters (sample search distances, increasing the ratio of well samples to simulated sample, and varying the overall number of samples included for each cells interpolation).



1. Aerial: LINZ and Eagle Technology, CC-BY-3.0-NZ.
2. Schematic only, not to be interpreted as an engineering design or construction drawing.
3. Drawn by: ZM. Reviewed by: KC.

Coordinate System: NZGD 2000 New Zealand Transverse Mercator

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TITLE MPS MODELLED SANDY AND CLEAN GRAVELS WITHIN 30M OF SURFACE

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6.5 MAR Pilot Trial Numerical Modelling – Science Programme

Numerical modelling of the Pilot Trial has been undertaken by the CRC (Appendix O) to provide the following context:

- Reproducing the observed effects on groundwater levels and groundwater quality from the first year of operation.
- Using the model to extrapolate the effects of the Pilot Trial over the five-year period of the trial.

A transient numerical model covering much of the Hinds MAR Pilot Trial command area was constructed and calibrated using MODFLOW-NWT in the GMS software interface. Whilst the model is an over-simplification of the hydrogeology of the study area, it is potentially a useful tool for assessing the likely impact of the Pilot Trial. The model structure, input parameters and modelling results are documented in detail in a memorandum included in Appendix N.

The model indicates that without MAR, the groundwater levels in the wells that have been observed to respond to the Pilot Trial would have continued to decline over the trial period due to antecedent drought-related reductions in land surface recharge. The model indicates the water level effects of the Pilot Trial propagate outward from the trial site both down-gradient and up-gradient (Figure 50).

The scale of the simulated groundwater mounding presented (in Figure 49 and Figure 50) is similar in magnitude and extent to the groundwater mounding in the regional aquifer derived from analytical calculations (Appendix G) and presented in Figure 35. The extent of simulated mounding to the southwest of the site (Figure 49 and Figure 50) is exaggerated due to effects arising by interaction of the simulated mound with the model edge.

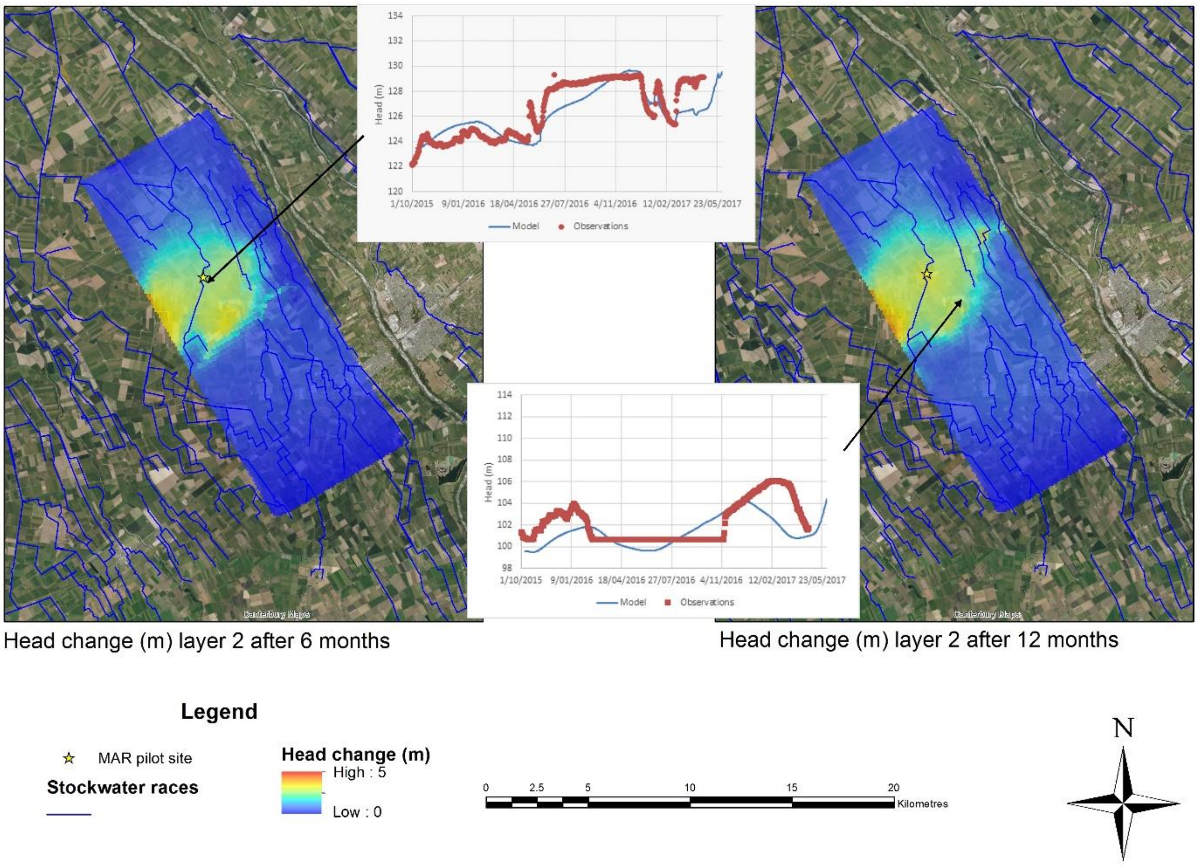

Figure 49: Modelled groundwater level increase after approximately six months and one year (layer 2).

A transient solute transport model has been constructed in MT3DMS code based on the numerical 3D groundwater flow model described above. The transport model was designed to simulate the flow of MAR water within the regional groundwater system. At its current state of development, it cannot simulate the movement of water in the perched aquifer beneath and to the southeast of the site.

The model outcome indicates a plume of water sourced from the Pilot Trial site moved toward the south from the infiltration basin during Year 1 (shown in Figure 51 and Figure 52). The extent of the MAR water plume is similar in both length and width to the plume derived from field observations and analytical calculations (Figure 35). The orientation of the plume is slightly more toward the south than the plume alignment presented in Figure 35.

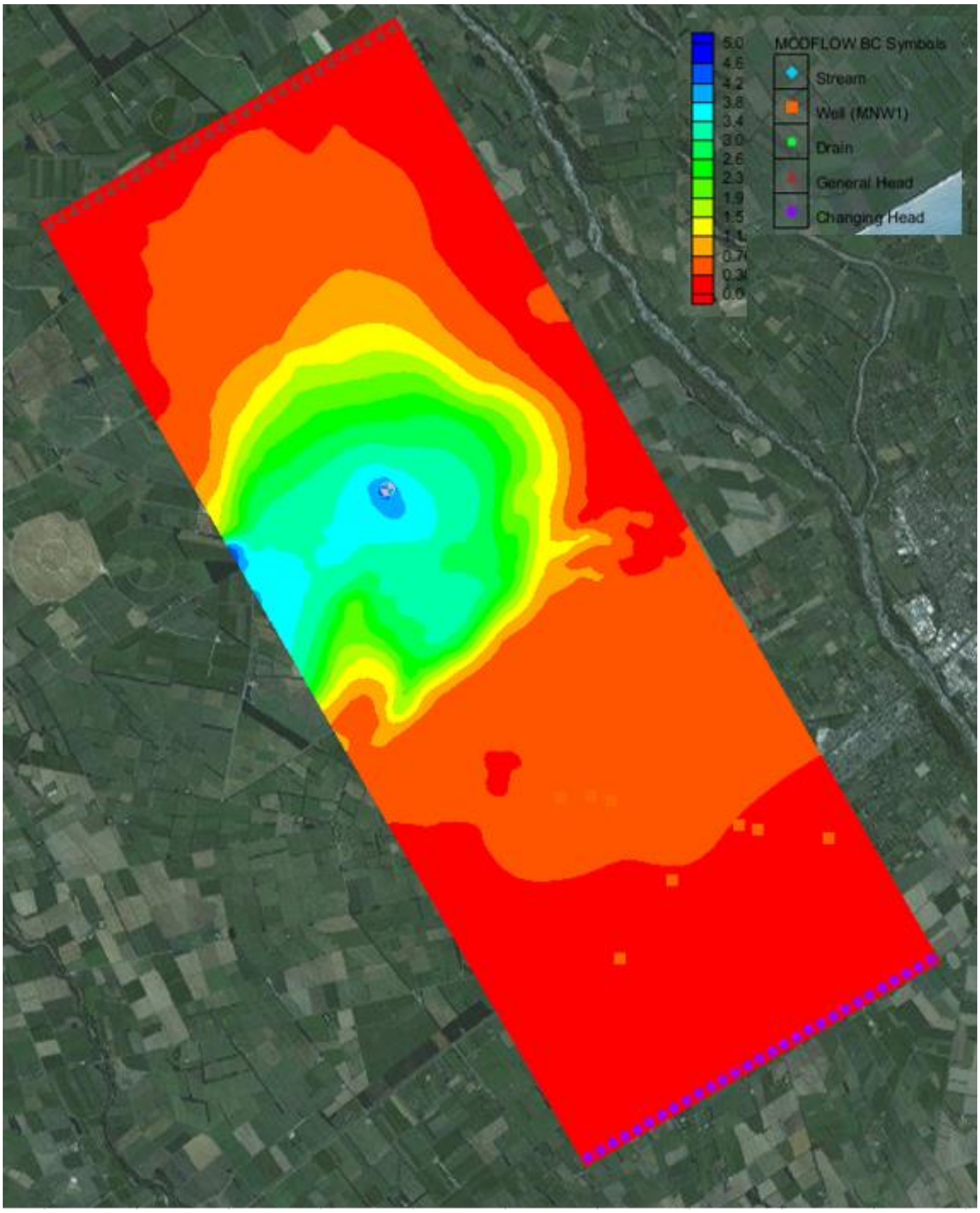

Figure 50: Finer scaled version of modelled groundwater level increases after approximately six months (layer 2).

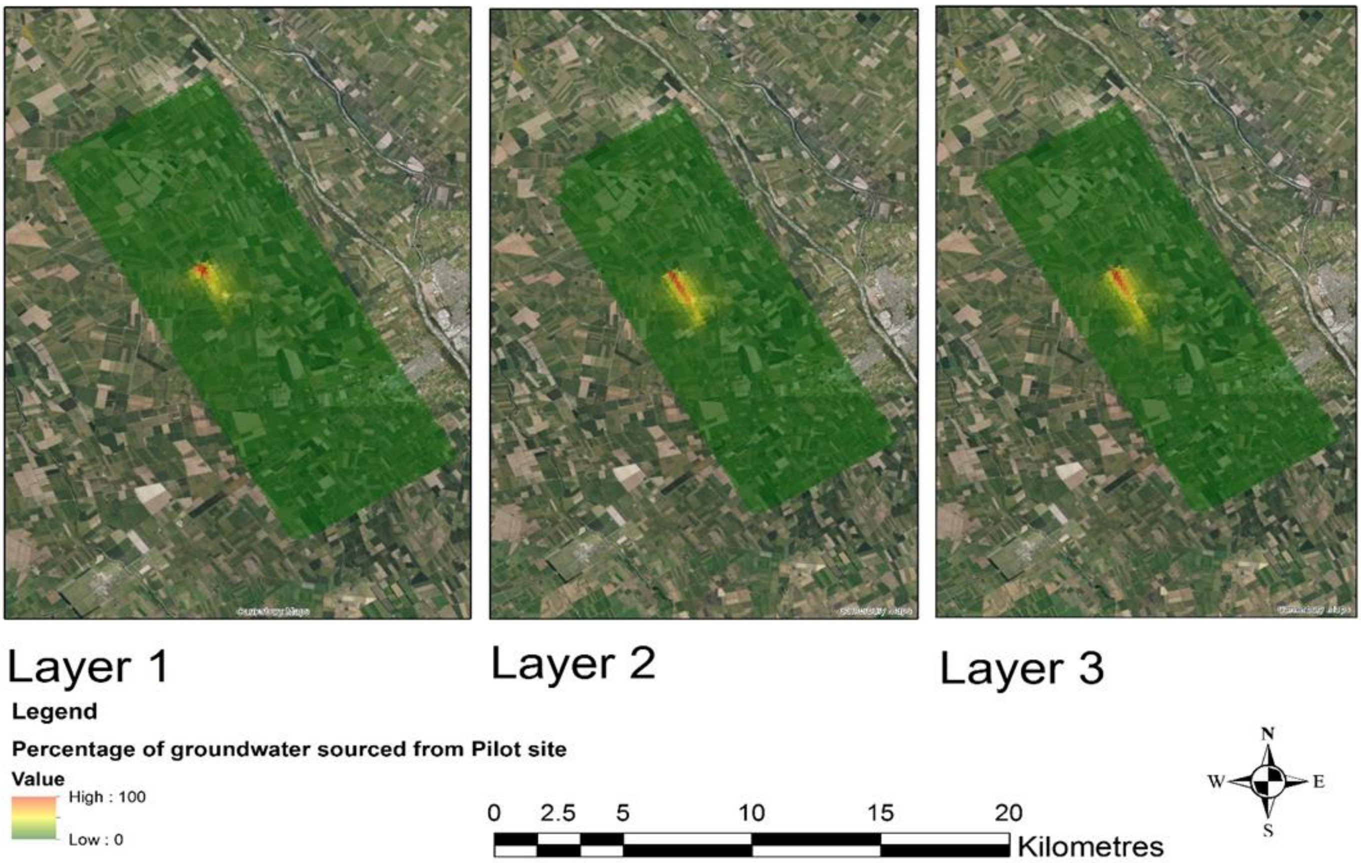

Figure 51: Extent of the simulated MAR water plume in the Pilot Trial MODFLOW model at the end of Year 1.

The numerical modelling undertaken by CRC has successfully reproduced both the regional groundwater mounding and the MAR water plume that have been independently delineated using analytical equations. Reasonable extrapolation of the effects of the Pilot Trial operation over a period of three or four years should provide an indication of the extent of the MAR water plume over that period. This modelling was undertaken and documented in a separate memorandum, also attached in Appendix N.

The most extensive plume of MAR water derived from the model is presented in Figure 53 and Figure 54. The outcome indicates that ongoing operation of the Pilot Trial through to 2020 may generate a clean water plume that extends from the infiltration basin to beyond SH1. The lateral dispersion factor incorporated in the model may have resulted in a somewhat optimistic width to the plume, however this figure still provides an indication of the Pilot Trial outcomes during the upcoming two to three years.

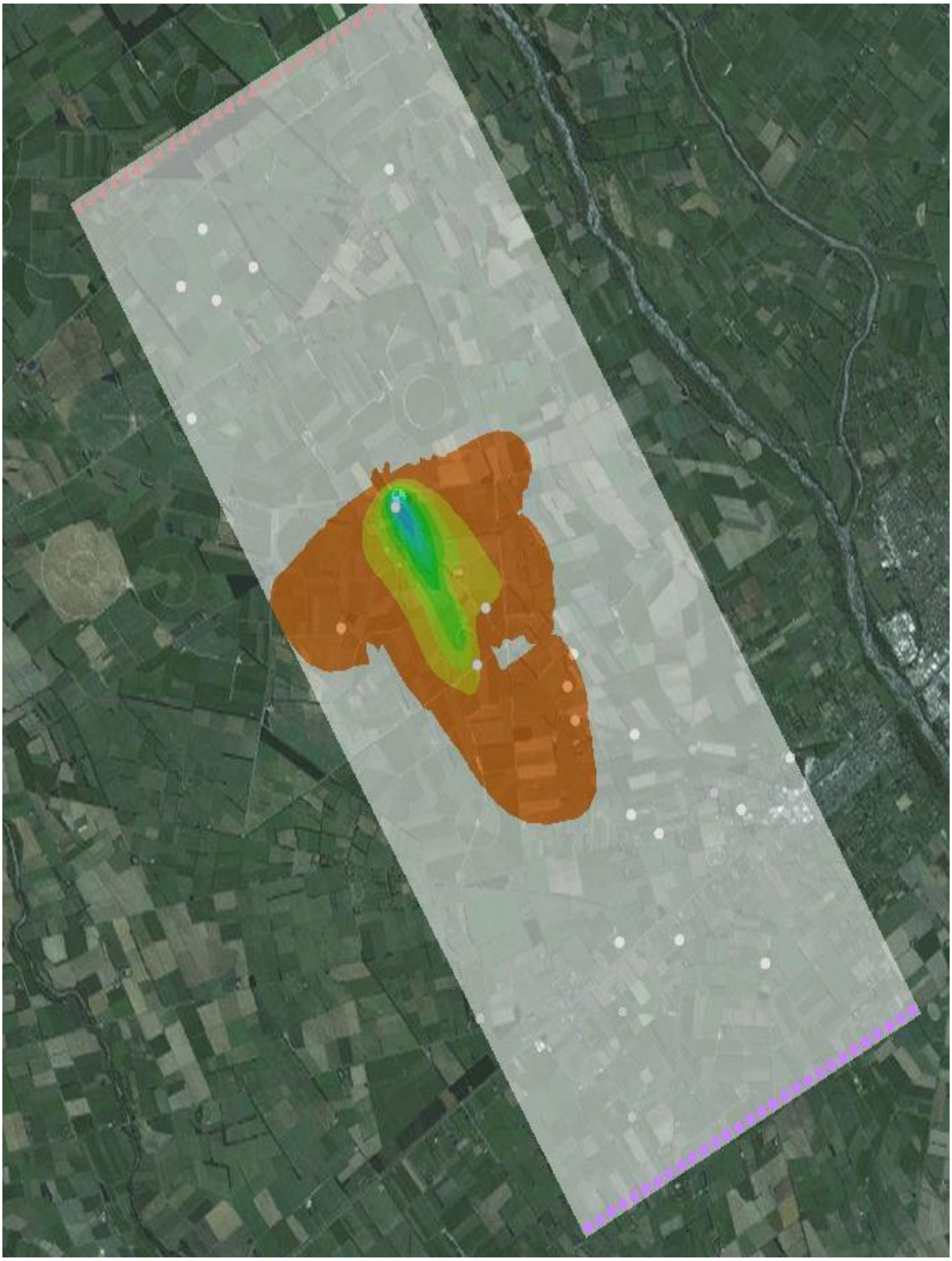

Figure 52: Finer scale map showing extent of MAR water plume in layer 3 of the Pilot Trial MODFLOW model at the end of Year 1.

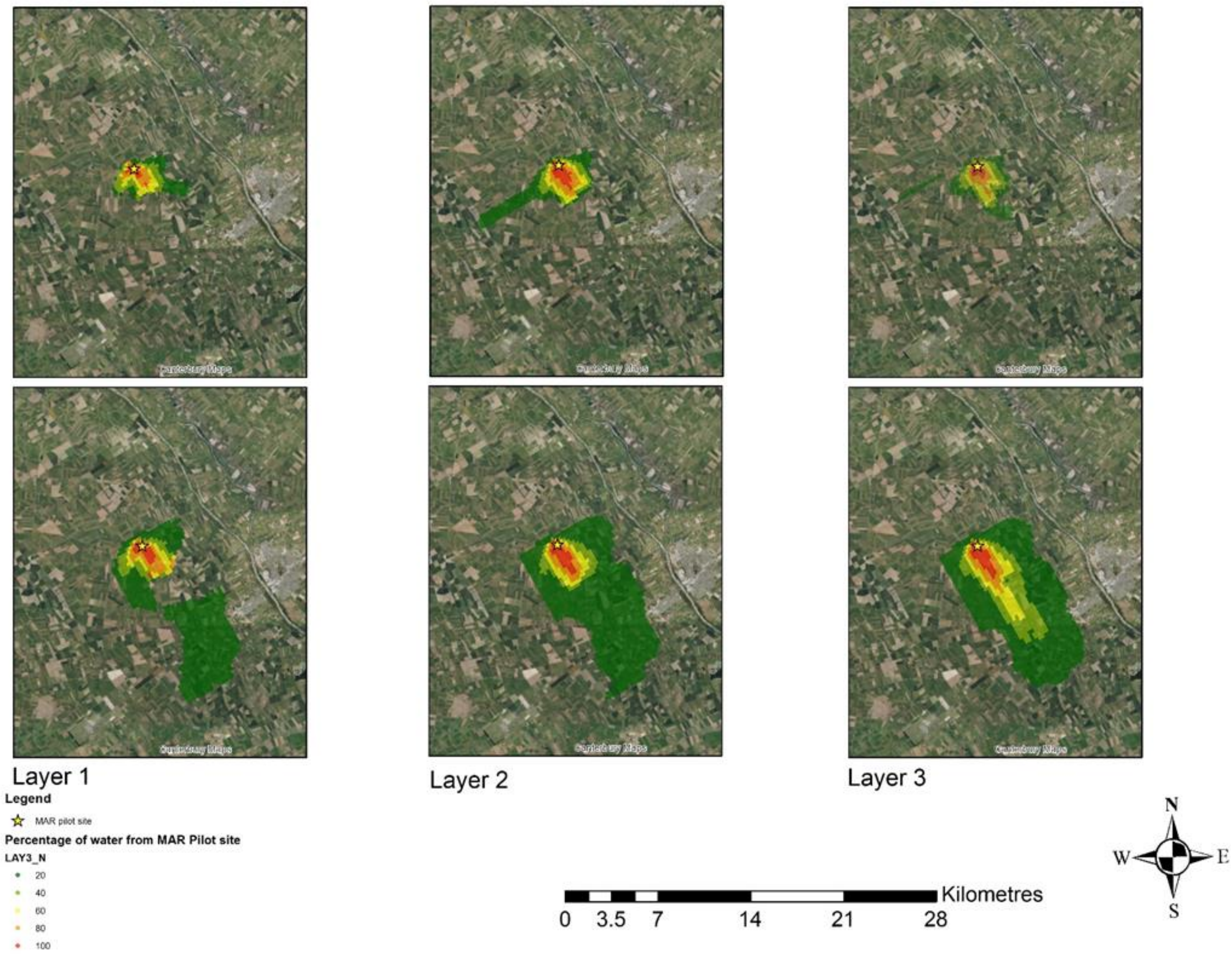

Figure 53: Simulated freshwater plume in layers 1 through 3 of the Pilot Trial MODFLOW model by 2017 top and 2020 bottom.

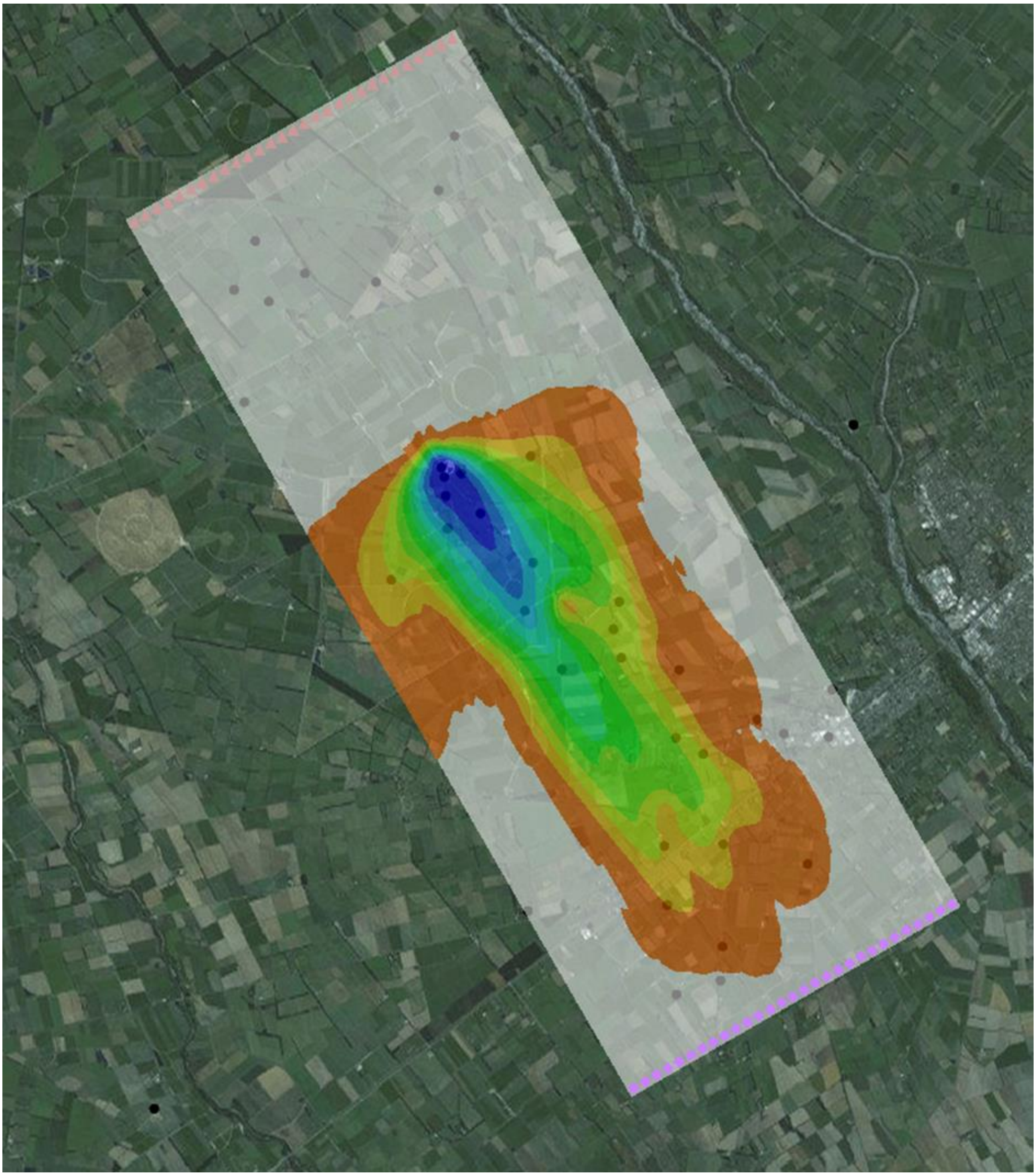

Figure 54: Finer scale map of simulated freshwater plume in layer 3 of the Pilot Trial MODFLOW model by 2020.

7.0 GROUNDWATER REPLENISHMENT SCHEME APPLICABILITY

7.1 Introduction

Year 1 of the MAR Pilot Trial monitoring and analysis programme has provided extensive field-based research on the applicably of MAR as a tool for water management in the Hinds Plains Catchment. Strategic partnerships have generated complementary information over this period that significantly improves our understanding of current and potential future applications for MAR. This section summarises the Year 1 results in the context to the overall community goals, both for the current MAR site and for the implementation of a catchment wide groundwater replenishment scheme.

7.2 Pilot Trial Objectives and Outcomes Discussion

While there has been a significant amount of field-based information generated from this trial, the five years of consented operations have three key objectives (Section 1.3). These objectives are:

- **Objective 1:** Increase groundwater levels and overall groundwater storage in the vicinity of the site.

  Outcome 1: Field measurements and numerical and analytical modelling clearly indicate the operation of the Pilot Trial increased groundwater levels and storage over an area of 12 km^2 surrounding the infiltration basin.

- **Objective 2:** Decrease concentrations of nitrate-N in groundwater in the vicinity of the site.

  Outcome 2: Field data (including laboratory water quality analysis results and data from automated nitrate-N monitoring equipment) and analytical and numerical modelling results clearly indicate the operation of the Pilot Trial decreased nitrate-N concentrations in groundwater within the MAR water quality footprint area.

- **Objective 3:** To increase baseflows and water quality in the down-gradient coastal spring-fed waterbodies (drains).

  Outcome 3: Both field measurements and analytical modelling indicate that the Pilot Trial has not yet achieved increased flows in down-gradient coastal spring-fed waterbodies (drains). As outlined in Section 5.1, given the final location chosen for the Pilot Trial, this was the objective least likely to be achieved in Year 1. Other factors that played a role specific to this objective during Year 1 were the extreme background on-going drought conditions and the final recharge rate achieved at the site (maximum of 110 L/s).

  Whilst the coastal spring-fed waterbodies remained mostly dry during Year 1, CRC's water quality numerical modelling indicates that subsequent years of MAR operations should move the clean water into the vicinity of the spring-heads that provide water to the drains. Therefore, a recommendation to upgrade or enhance the current MAR site (if found technically feasible) would be pertinent in order to achieve this outcome.

7.3 Lagmhor Pilot Trial Site – Years 2 to 5 (consented)

The Pilot Trial site has 4 years remaining on its 5 year consent to test MAR at this location. ADC has approved the use of the unutilised stockwater totalling 500 L/s for another year (May 2017). Funding for ongoing operations at the site has already been pledged by several strategic partners. The primary reasons that this site was selected for the trial (e.g., Tinwald hotspot, declining groundwater and baseflows to spring-fed drains) as well as the critical risks surrounding drinking water in this area remain significant issues in the Hinds sub-catchment area. As MAR is a physical tool, the ongoing adaptation of this tool to the unique Canterbury and more specifically Hinds hydrogeology and soil context is vital to achieve the community objectives for the trial and for the wider catchment.

There are numerous overseas examples of technical solutions applied to situations similar to those at the Lagmhor site. Just as the community looked to trial MAR for the first time based on overseas examples, it is recommended that internationally proven techniques should be mixed with New Zealand's purported 'kiwi ingenuity' in order to find practical, workable and cost effective approaches to safely recharge groundwater at this and other sites within the Hinds Plains catchment.

Whilst there may be other locations in the catchment where infiltration rates (based on higher permeability geology) would be greater, the fact remains that the development of tools to improve recharge in areas that demand replenishment (e.g., Tinwald hotspot) is vitally important in addressing the overall objectives for the entire catchment.

Finally, there are a number of key issues that need to be addressed over the next 4 years at the site:

- Clogging may potentially have occurred during the final months of MAR, operations; early Year 2 flume measurements will help determine revised flume ratings. Recharge rates toward the end of Year 1, and results from early in Year 2 indicate that some clogging of the basin may be occurring. It is recommended that this be further evaluated and potentially that the site be dried and managed for sediment accumulation.
- Any further plans to automate the Valetta Pond #3 gate that supplies water to the MAR site should be placed on hold until plans for the open race (e.g., piping) are confirmed.
- The MOU signed with the landowner of the Pilot Trial open race allowed the use of it for 2 years. During Year 2 of the project, plans to future proof water delivery to the MAR site need to be concluded.
- Updates to the MAR website to include this report and other relevant information should be undertaken.
- Potential upgrades to the site should follow a step-wise approach to investigate options (e.g., dry wells). The proposed approach includes techniques such as geophysics to get a better understanding of the subsurface and trialling low cost 'prototype' solutions at the site before consenting and construction commitments.

7.4 Future Scalability of MAR into a Groundwater Replenishment Scheme

Following review of the Pilot Trial objectives and results, it is proposed that the overall Year 1 operations have achieved their key objective of demonstrating the viability of MAR to improve groundwater quality and quantity in the Hinds Plains Catchment. There are no 'fatal flaws' identified from the works completed to date but significant questions remain on matters such as 'what are the optimal MAR site designs?' and 'where will the future source water come from and how much will it cost?' These questions will be addressed in subsequent phases of the project.

Key learnings have been achieved. Foremost is the complexity of the subsurface and the need to carry out appropriate characterisation of the sites ahead of establishing infrastructure to ensure that the MAR system will operate sustainably.

The results from Year 1 of the Pilot Trial will be presented to the Hinds MAR Governance Group (Governance Group) in Ashburton, on **3 August 2017**. This group was appointed and members approved by the Ashburton Zone Committee in February 2017. The Governance Group has been appointed to manage the operations of the Pilot Trial, help to lead the development of new MAR sites in the Hinds catchment and, from March 2017 to May 2018, develop a business case and final set of recommendations for the implementation of a Hinds Plains Groundwater Replenishment Scheme.

At the time of this report, and related to the goal to test MAR for Objective 3 (increase baseflows to support ecological and cultural outcomes), designs and partnerships were being formed for a potential new MAR site, called the Near River Recharge (NRR) project, located on the Upper South Fork of the Hinds River. This project seeks to apply the principles of MAR, targeting the near river groundwater system in a critical habitat area of the Hinds catchment. Coupled with physical recharge are tentative plans to restore native riparian species and monitor and assess direct instream benefits to aquatic species. Tentative plans are also being developed to work with Te Rūnanga o Arowhenua, Fish and Game, ADC, RDRML, and community volunteers to look at the urgent needs of the catchment's ecological and cultural values, whilst continuing to enhance the groundwater system.

8.0 RECOMMENDATIONS

Recommendations arising out of the results of the Year 1 work undertaken on the Pilot Trial relate to two general themes:

1) Ongoing development and management of the existing Pilot Trial site, and
2) Development of a wider GRS for the Hinds/Hekeao Plains catchment.

Golder recommends that ongoing recharge operations at the existing Pilot Trial site (Years 2 through 5) should seek to achieve the following site specific objectives:

- Improve the sensitivity of the existing source water flow monitoring to the Pilot Trial site, taking into account the potential for increased flows as the infiltration efficiency of the site is increased.
- Retrofitting of an automated flow management system to the Valetta Pond #3 outflow, linked through the existing SCADA system at the site to water depth in the main infiltration basin.
- Continue to operate the automated nitrate-nitrogen tracking equipment at GWD-4. Will provide vital information on concentration changes relative to irrigation, rainfall and MAR on/off periods.
- Demonstrate the potential for the annual accumulation of groundwater storage gains, leading to a progressive increase in local groundwater storage.
- Improved definition of the extent of increases in stored groundwater achieved, to support an improved evaluation of the density of MAR sites required to meet groundwater storage objectives of a catchment wide GRS.
- Extend the groundwater monitoring network toward the southeast to enable the tracking of the MAR water plume within the perched aquifer toward the Tinwald hotspot. Additional up-gradient monitoring bores installed in both perched and deeper aquifers could assist in gaining an understanding of the quality of groundwater arriving at the MAR Pilot Project site.
- Add the drinking water bores identified in the CDHB programme to the current down-gradient monitoring network. Sample these for nitrate-N and *E. coli* quarterly as these bores could help track the clean water plume through areas where there are fewer existing irrigation bores that could be used for monitoring.
- Test to see if there is an accumulation on N in the vertical soil profile due to dry conditions waiting to be flushed to the aquifer in next wet period.
- Improve monitoring of groundwater levels and quality focused at the regional aquifer level, with a key objective of identifying the extent of groundwater quality improvement at this level.
- Review the monitoring network to improve the value proposition for ongoing monitoring. Ensure monitoring allows improved assessment of conservative parameters that help with source identification and other parameters affecting objectives.
- Assess, and where appropriate, consent and install improvements to the Pilot Trial site with the objective of testing systems to enhance groundwater recharge rates at the site. The aim of these improvements is to increase both the magnitude and extent of artificial groundwater storage centred on

the site and the extent of groundwater quality improvements. This testing will help to better inform the decision making process regarding potential new sites with similar physical settings in the Hinds Catchment, as well as across Canterbury.

- Protect and enhance drinking water supplies in the MAR command area and Tinwald hotspot, whilst continuing to use the Pilot Trial as a vehicle to better educate the Ashburton community on the risks surrounding drinking water supplies.
- Increase base flow discharges to targeted coastal drains. CRC surveys of these drains in the early 2000s flagged them as some of the strongest flowing and best habitat environments in Canterbury (Meredith 2002).
- Over the medium term, improve the quality of groundwater that discharges to targeted spring-fed coastal drains.
- Measure Dissolved Oxygen and other parameters indicating potential denitrification processes in groundwater as part of the shallow groundwater monitoring programme in the coastal area.
- Analyse source and receiving water temperature data relative to clogging and recharge rates (e.g., conductivities and viscosities).
- Seek to calibrate the MAR Command Area groundwater model using metered groundwater pumping to show effects of different MAR rates and volumes.
- Utilise the results of the CRC numerical modelling and automated nitrate-N tracking to better quantify the findings for the Pilot Trial. These additional projects were undertaken in parallel to the Pilot Trial, but the information they generated could help with analysis of trial results during Year 2. This analysis would also help to improve and better support the development of other MAR sites in the catchment.
- Drill additional monitoring bores in this area to help manage the ‘up-gradient controls’ of the operating site and help to better understand the water quality challenges for this portion of the Hinds Catchment.
- Inspect bore GWD-4 for issues with well head protection, perhaps utilising a camera down the bore for a better understanding of possible surface connections (e.g., terrestrial beetle access routes).

Golder also recommends that ongoing operations at the existing Pilot Trial site (Years 2 through 5) should seek to achieve the following objectives with respect to developing a catchment wide GRS programme:

- A Pilot Trial investigation be initiated early in Year 2 that looks at all the physical information generated by the project (e.g., sonic cores, etc) coupled with geophysical techniques to explore potential site upgrades to enhance recharge rates. A go/no-go process is recommended using enhanced field techniques combined with consideration of international best practices to design potential upgrade options such as dry wells.
- Protect and enhance drinking water supplies in the MAR command area and Tinwald hotspot, whilst continuing to use the Pilot Trial as a vehicle to better educate the Ashburton community on the risks surrounding drinking water supplies.
- Improve the development and adaptive management of systems designed to minimise the potential for negative effects of artificial recharge activities with regards to land drainage and coastal flooding, with a key focus on the integrated management approach for additional sites and trials.
- Identify and apply new techniques for tracking the movement of infiltrated water within the aquifer system, with a focus on non-intrusive cost-effective techniques that could potentially be applied at a catchment wide scale.
- Integrate the existing statistical assessment of lithological units within the Hinds/Hekeao Plains catchment to planning new MAR trial sites and an overall GRS for the catchment.

- Ecological monitoring is an essential component of understanding the role the MAR pilot scheme plays on re-establishing the aquatic habitat and can help inform the design and operation of future schemes where aquatic habitat restoration is one of the objectives. Continuation of the ecological monitoring over the lifetime of the pilot scheme is recommended with the addition of Periphyton biomass and community composition, and macroinvertebrate community composition. Monitoring of the fish communities is also recommended when sufficient flows that result in connectivity between the drains and the lower river network have been maintained in the system for at least two months.
- The results from the CDHB drinking water sampling and outreach survey indicate that MAR can play a role in ensuring that drinking water supplies in this Tinwald area are safe by recharging with freshwater. It should also be noted that making catchment-scale water management changes (e.g., shifting stockwater to enhance rivers flows) that reduce the net amount of recharge entering groundwater without using MAR as a mitigation, will likely exacerbate these degraded conditions. This area should continue to be a significant focus of any plans to enhance and increase clean water recharge using MAR while also working to reduce the amount of contamination entering the aquifer from all potential land use activities. The targeted and timely use of MAR to help manage and protect drinking water supplies should be further supported by continued efforts at outreach and education on the risks surrounding drinking water supplies.

9.0 CONCLUSIONS

This technical report provides facts and figures that underpin the application of a concept called Managed Aquifer Recharge in the Hinds catchment. From a start in 2012 with the Hinds River test and through the sub-regional planning hearings for the Hinds Catchment, the concept of MAR was focused on conceptualisations and numerical projections. This Pilot Trial report represents a departure from speculation and moves us toward one of practical testing, learning and adaptive change management.

The testing of this concept through the Pilot Trial has been successful and the community has already started to look to the next steps required to further develop this tool.

Throughout the course of this project, it has become much more apparent that whilst the technical needs of this project are substantial, it will only be successful if the Hinds Catchment community continues to build upon the strategic partnerships, the consultative conversations and the collaborative approach that the project was based on. Without that community leadership, water management changes that seek to balance economic, environmental, social and cultural outcomes would be impossible.

In February 2017, Peter Lowe (chairman) presented a request to the AZC to form a community based group tasked with developing MAR at the catchment scale. His presentation stated three key features that were critical to tackling the issue of catchment-wide groundwater management. These were:

Community Owned

Community Driven

Community Led

10.0 REPORT LIMITATIONS

Your attention is drawn to the document, “Report Limitations”, as attached in Appendix P. The statements presented in that document are intended to advise you of what your realistic expectations of this report should be, and to present you with recommendations on how to minimise the risks to which this report relates which are associated with this project. The document is not intended to exclude or otherwise limit the obligations necessarily imposed by law on Golder, but rather to ensure that all parties who may rely on this report are aware of the responsibilities each assumes in so doing.

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