APPENDICES

July 2017

HINDS MANAGED AQUIFER RECHARGE PILOT TRIAL

APPENDICES COMPILATION

Submitted to:
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Distribution:

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Golder Associates

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APPENDIX A

Resource Consents, Conditions and Compliance

1.0 CONSENT CONDITIONS REVIEW APPENDIX

This appendix provides a summary of the consent conditions (black text) as well as notes and references regarding the compliance status and location where further information can be found for Year 1 MAR Pilot Trial reporting.

- Consent conditions are presented as black text.
- Compliance summary information is summarised in blue text.
- Red text identifies any conditions that had exceptions relative to consent compliance.

2.0 PILOT TRIAL CONSENTS SUMMARY

The construction and operations of the Pilot Trial have been authorised under consents issued by the Canterbury Regional Council (CRC) and Ashburton District Council (ADC) (Table A1). All of these consents have been exercised through construction of the Pilot Trial site and the initiation of infiltration operations at the site.

Table A1: Resource consents.

Consent number	Consenting authority	Activity	Commencement date	Expiry date
LUC15/0110	ADC	To excavate land	2 Feb 2016	2 Feb 2021
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

3.0 LUC15/0110

The consent conditions applicable to this land use consent are presented below.

1) The activity shall be carried out in accordance with the plans and all information submitted with the application, being:

   - Application form and Assessment of Environmental Effects prepared by Golder Associates and dated December 2015; and
   - The plans labelled "Hinds Managed Aquifer Recharge Scheme, Valetta, Canterbury" and labelled as sheets 1 to 4.

2) All earthworks shall be carried out in accordance with the erosion and sediment control plan submitted as part of the resource consent application.

IN COMPLIANCE. Site was constructed as per consent conditions. An '*as built'* final layout of MAR Site and associated elevations is found in Appendix D, Figure 1.

4.0 CRC162191

4.1 General Conditions

1) The discharge shall be only water sourced from the Rangitata Diversion Race Klondyke intake in accordance with resource consent CRC164281 for the purposes of a Managed Aquifer Recharge trial (MAR).

   IN COMPLIANCE. All recharged water derived from RDR Klondyke intake via Valetta Irrigation Scheme. See Appendix E and Section 4.0 of main report.

2) Water shall be only discharged into land, via the cleaned open race and the infiltration basins constructed in accordance with consent CRC162192 at the MAR site located on the corner of Fraser Road and Timaru Track Road legally described as RES 1959 at or about map reference NZ Topo50 BY20:8916-4955 as shown in attached Plan CRC162191 which forms part of this consent.

   IN COMPLIANCE. All water discharged at the required location. See Appendix E and Section 4.0 of main report.

3) The rate at which water is discharged shall not exceed 302,400 cubic metres per week.

   IN COMPLIANCE. Estimated maximum weekly rate of 68,342 m^3 (i.e., average maximum rate of 113 L/s). See Appendix E and Section 4.0 of main report.

4) The discharge shall cease:

   a. When 30 millimetres or more of rainfall within any 24 hour period as measured at the Hinds Plains Rainfall Monitoring Site at or about NZ Topo50 BY21:9423-2985 in accordance with Schedule One; or

   b. When the flow at the Parakanoi Drain exceeds 2,200 litres per second measured at the Canterbury Regional Council gauge at or about NZ Topo50 BY21:9414-2294 in accordance with Schedule One, which forms part of this consent.

   IN COMPLIANCE. Discharge shutdown for two trigger events where rainfall exceeded >30 mm/24 hours. Refer Section 5.1 of main report and Section 4.0 of Appendix B.

5) The discharge shall resume only after both rainfall and Parakanoi Drain flows return to below trigger values specified in Condition (4)(a) and (b) for a period of at least 48 hours.

   IN COMPLIANCE WITH 1 EXCEPTION. First rainfall trigger event (Event 1 – 26 March 2017), MAR site was shut down from 15:30 on 27 March to 11:15 on 29 March 2017. This was due to communication issues between parties, and was corrected and managed for second trigger event. Note that drains were still nearly 100 % dry, and risk of flooding was extremely unlikely. Refer Section 5.1 of main report and Appendix E.

6) The discharge shall be managed in accordance with Schedule Two, which forms part of this consent.

   IN COMPLIANCE. Schedule 2 refers to automation and operations of the MAR Pilot Trial as well as reference to the Scada and webhosting of near-real time information. Automation and operations were conducted as outlined in Schedule 2. Webhosting of MAR site and related monitoring information was done through a combination of two websites: the MAR operation site (hosted by Scottech, see Section 3.3.4 in main report) and a Community outreach page (CRC hosted, see Section 3.3.5).

7) The consent holder may amend Schedule One and/or Schedule Two at any time subject to the following:

   a. Any amendment shall be:

i. Only for the purpose of dealing with any adverse effects on the environment which may arise as a result of the exercise of this consent; or

ii. Only for the purpose of improving efficacy of the MAR trial; and

iii. Consistent with the conditions of this consent; and

iv. Submitted in writing to and be approved by the Canterbury Regional Council, Attention RMA Monitoring and Compliance Manager, prior to any amendments being implemented.

IN COMPLIANCE. No consent amendments were sought during Year 1 of the Pilot Trial. Project was built, operated and completed as per the consent conditions.

8) The consent holder shall undertake ongoing monitoring of:

a. groundwater quantity

b. groundwater quality

c. surface water quantity

d. surface water quality

In accordance with Schedule Three, which forms part of this consent.

IN COMPLIANCE. During the first quarter of operations (May through July 2016), a number of existing bores were located and used to help replace bores that were going dry due to drought conditions. A final list of bores and a summary of the monitoring programme are presented in Appendix C.

9) The consent holder may amend Schedule Three at any time subject to the following:

a. Any amendments shall be:

i. Only for the purpose of improving efficacy of the monitoring programme and shall not result in reduced quality of monitoring of the discharge; and

ii. Consistent with the conditions of this consent; and

iii. Submitted in writing and to be approved to the Canterbury Regional Council, Attention RMA Monitoring and Compliance Manager, prior to any amendments being implemented.

IN COMPLIANCE. No consent amendments have been sought during Year 1 of this project.

10) The consent holder shall record and maintain monitoring records and submit a review report to the Canterbury Regional Council, Attention RMA Monitoring and Compliance Manager by 30 March each year.

IN COMPLIANCE WITH EXCEPTIONS. This consent was awarded on 25 February 2016. A combination of on-site meetings and follow up summary emails were provided to CRC Compliance personnel (Nic Froude) early in the preconstruction phase (April 2016) and in subsequent email updates through the course of the project's operational period. The MAR site officially commenced operations on the 10 June 2016 and operated for 1 year to 9 June 2017. A follow up compliance meeting was scheduled for 2017, and hosted on 4 April 2017 at CRC. In attendance were CRC Staff: Carly Cushman (Consenting), Simon Woodcock (Consenting) and Sam Aramoana (replacing Nic Froude as MAR site compliance officer). Golder staff Bob Bower (MAR tech lead) and Jane West (Planner) also attended. An overview of the project was provided for CRC staff who were all new to the MAR project. A discussion about consent conditions, project schedule and final reporting was conducted. A decision was made to discuss any variations to consent conditions after the Year 1 final report was completed. The 'review report' in this condition is considered the Hinds Pilot Trial main report (Golder), which will be completed by 30 July 2017. During the Pilot Trial, and at the conclusion of the Pilot Trial, copies of all data (electronic) have been provided to CRC.

11) The Canterbury Regional Council may, once per year, on any of the last five working days of May or November, serve notice of its intention to review the conditions of this consent for the purposes of dealing with any adverse effect on the environment which may arise from the exercise of the consent.

IN COMPLIANCE. No notices were served during Year 1 of this project.

4.2 Schedule One

The following steps shall be taken in the adaptive development of the MAR trigger condition:

Step 1: Drill monitoring bore at CRC weather station located at NZTM 1494284 mE 5129905 mN, install instrument, connect to internet and collect level data. This to be completed prior to the MAR site being operational.

IN COMPLIANCE. Refer Appendix C.

Step 2: Develop and implement an outreach webpage (MAR CRC site) that has the following information:

a. Real time graphs/data for: CRC Parakanoi and Ashburton River flows, new CRC weather station in Parakanoi sub-catchment, new Parakanoi groundwater levels/temperature bore, MAR site bore groundwater levels, and a “MAR PILOT SITE IS (OFF/ON)” indicator at the top of the page.

b. Background information on monitoring programme including information on storms, flooding, groundwater and goals of the MAR project.

c. Analysis and findings (as they become available) relative to flooding, groundwater levels and the role of Ashburton River recharge on the Tarbottons Road monitoring area (Tinwald) which will include data from CRC's Laghmor Creek flow data, CRC's Ashburton River flow data, and from dedicated shallow bore being drilled (prior to MAR site operations) in Tarbottons Road area (Tinwald).

IN COMPLIANCE WITH 1 EXCEPTION. Refer Section 3.3.5 of main report. Note one exception: CRC web-designers were not able to provide the 'MAR PILOT SITE IS (OFF/ON)' indicator at the top of the page.

Step 3: Develop and implement preliminary numerical correlations between the following:

a. New shallow Parakanoi bore with CRC Parakanoi flow gauge. This is to help understand the relationship between groundwater levels and flows in the stream. Data from the MAR pilot site Parakanoi flow monitoring weir will also be used to understand spring flows in the drain.

b. New shallow Parakanoi bore with existing CRC Bore (K37/1792). Determine relationship relative to the 1.7 metre 'trigger correlation', termed PARAKANOI GW – 1.

c. New CRC weather station and CRC Ashburton River gauge used to confirm the proposed 30 mm trigger. This relationship will also provide valuable information on the spatial variation in rainfall events over the entire MAR project area, which will be useful for monitoring the Tarbottons – Laghmor Creek-Ashburton River recharge area.

d. Document the correlation results for the CRC monitoring and compliance team and confirm final numbers going into operations of the MAR site.

IN COMPLIANCE. Due to extreme drought conditions, these correlations (particularly relative to flows) were difficult to assess. However, a summary of this information is provided in Appendix M.

Step 4: Begin operations of the MAR Pilot site under the following Parakanoi sub-catchment trigger conditions:

a. When groundwater is less than correlated PARAKANOI GW – 1, indicate to MAR operations staff that the site shut down potential has arisen. Manage site and Valetta delivery and pond system as needed to allow for shut down.

b. Numerical Trigger for MAR pilot shut down is 30 mm in 24 hour period, or Parakanoi Flow (CRC gauge) is greater than 2,200 L/s. MAR site can recommence operations when both rainfall and Parakanoi Drain flows return to below trigger levels for a 48 hour period.

c. MAR operations staff shall utilise MAR monitoring information and NIWA weather alerts to determine if/when the project might turn off prior to a heavy rainfall event.

d. MAR Pilot Working Group members have MAR site operations (shutdown) smart phone application and are enabled to use on-the-ground knowledge to shut down MAR when conditions are warranted.

IN COMPLIANCE. Due to extreme drought conditions, groundwater in the coastal areas was very low, and the drains were dry. The use of the numerical rainfall trigger (>30 mm) was conducted (Refer Section 5.1 of main report and Appendix E). Golder and Valetta Raceman staff, along with MAR Hinds Chairman, worked to manage MAR operations based on projected wet weather periods (e.g., using weather conditions and ongoing communications). Use of smart phone shut down was managed by 1 designated Valetta Raceman (Giles Pinfold) to ensure consistent operations.

Step 5: Through the first year of the MAR Pilot project, data collection at these sites will help provide a more detailed understanding of these relationships. The trigger values will therefore be reviewed at the end of the first year and any recommendations on changes presented in writing to CRC Monitoring and Compliance team. The analysis on the Tinwald – Ashburton River recharge – Laghmor Creek – CRC and Ashburton weather stations monitoring information will be presented and used to help understand the physical drivers of flooding in that portion of the catchment. Recommendations on ongoing monitoring including changes to current sites will also be presented.

IN COMPLIANCE. A request for changing these conditions was not completed in Year 1 of this Project. MAR technical team suggest revisiting these conditions after final report (Year 2). A summary of this area and the groundwater, rainfall and flow relationships can be found in Appendix M.

4.3 Schedule Two

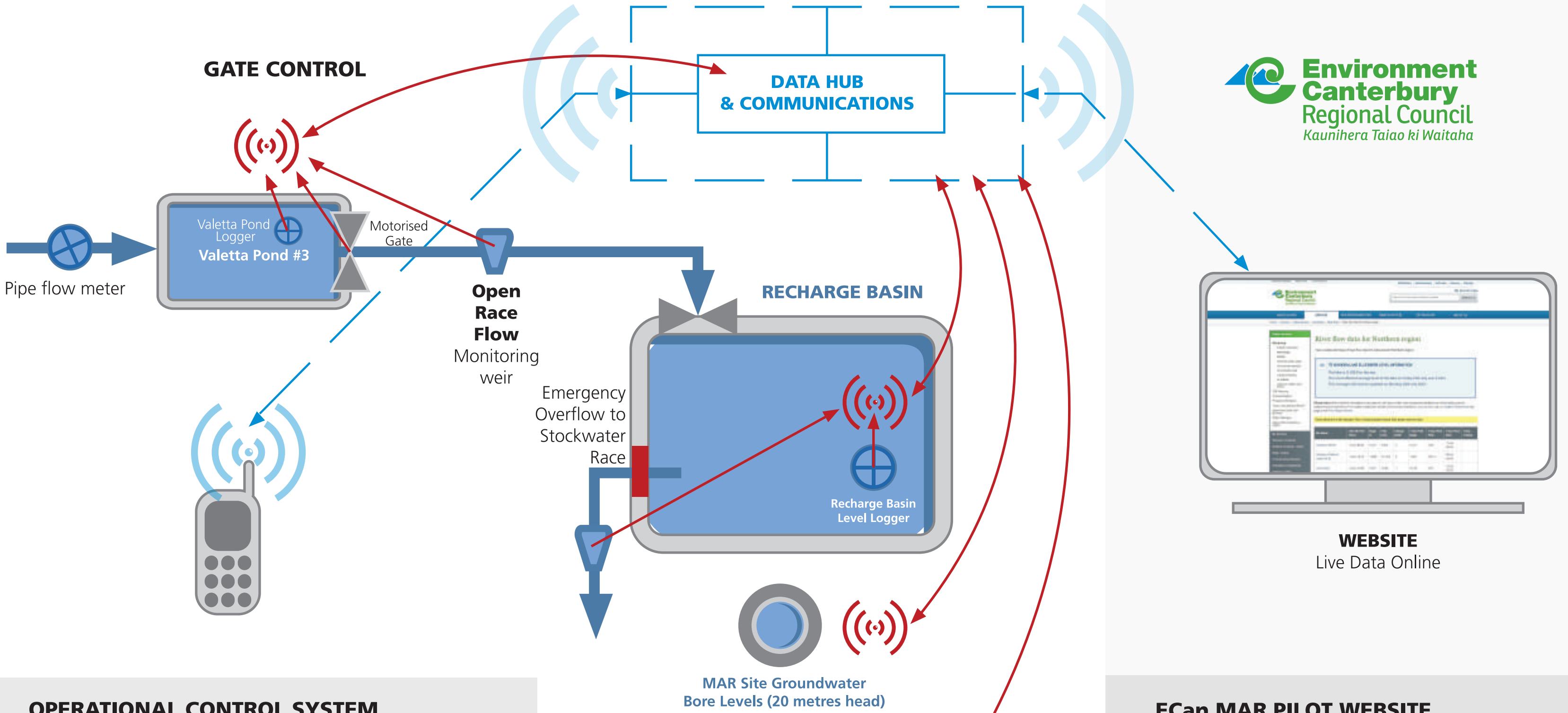
At the MAR site, an automated system for operational flow management shall be designed for the project that includes automated controls and a real-time phone/web access system (Figure 10 below). Radio equipment and control gates will be used to develop a system where MAR operations will be fully automated.

The MAR site consists of a pond (Valetta Pond #3) and recharge basin linked by an 800 m water race. Water enters the Valetta Pond #3 at the MAR site via a piped supply from the Rangitata River. A hydraulic headgate on Valetta Pond #3 will release water through a piped outlet into the existing 800 metre water race. A flow monitoring weir will be located in this race to measure flow on a continuous basis. At the end of the water race, water will either enter the MAR recharge basin via an intake pipe and energy dissipater hood, or be bypassed to adjacent ponds or existing ADC stockwater race. The MAR recharge basin consists of a forebay basin to settle any coarse particulate matter prior to the primary recharge basin. Water then spills through a weir into the recharge basin and infiltrates to groundwater.

A water level logger measuring the recharge basin depth will communicate directly (via radio link) to the flow control-hydraulic gate releasing water from Valetta Pond #3. This will allow the amount of water being sent to the recharge site to be managed based on the effective infiltration rates at the site. This rate is expected to change marginally during operations due to changes in temperature, sediment accumulation and other physical changes.

The hydraulic gate controller will be automated to allow MAR project staff to track the project operations and turn the project off/on via a smart phone application. A start up/shut down controller is also located at the Valetta Pond #3 turn out structure, allowing the ‘on call’ raceman to manually manage the project if required. The site can be managed by MAR project raceman in the event of any issues occurring with the automated system.

IN COMPLIANCE. Refer Section 3.0 of main report.

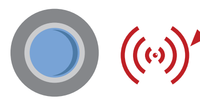


OPERATIONAL CONTROL SYSTEM

- Mobile phone (Text alerts/Control) Project
- Partners – RDR/Valetta/ADC/ECan (Golder)

REAL TIME INFORMATION:

- MAR Project control "on/off"
- Email alerts for levels/operations
- 15 minute data/graphs:
  - Valetta Pond – Weir #1 flow
  - Recharge basin level
  - Drains GW trigger condition levels



ECan MAR PILOT WEBSITE

- AZC – HDWP introduction – CWMS IMPLEMENTATION + Project Partners
- Project information/history and purpose
- Annual Reports
- Project Reports + Photos
- Contact for more information

REAL TIME INFORMATION:

- Link to ECan Drain flows
- MAR Project is "on/off"
- 15 minute data/graphs:
  - MAR SITE GW Levels + temperature
  - Drains GW trigger levels

4.4 Schedule Three

MAR Pilot Monitoring Programme

1.1 Overview

The monitoring programme has been 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 have been incorporated, where appropriate, in the planned pilot trial monitoring programme. Additional targeted monitoring has already been implemented in selected monitoring wells and surface water bodies. Further targeted monitoring is to be instigated once the pilot trial is approved and construction starts.

Monitoring results will be reviewed throughout the term of the pilot project. The monitoring programme is intended to be flexible and subject to ongoing optimisation based on the outcomes of the data reviews.

Details of the monitoring programme for the first year of the pilot trial, including both existing and proposed monitoring sites, are presented in Sections 2.0, 3.0 and 4.0 of this schedule.

1.2 Objectives

The pilot trial monitoring has been designed to provide sufficient data to achieve the following objectives:

Water flows and levels

1) Quantify site effectiveness at recharging water to the underlying aquifer.

2) Assess local groundwater mounding / pressure responses to the recharge operations.

3) Assess long-term groundwater storage / level responses in the underlying aquifer.

4) Track the transport and fate of recharge water within the groundwater system and at discharge zones.

5) Distinguish the changes in drain discharge flows induced by MAR from natural flow variations.

6) Differentiate between groundwater recharge due to MAR and groundwater recharge related to water level changes in the Ashburton River.

7) Monitor the effects of the pilot trial against developed trigger conditions.

Water quality

8) Ensure only high quality water is recharged to the aquifer by the pilot trial.

9) Delineate the effects of the recharged water on nitrate-nitrogen concentrations in the groundwater system.

10) Evaluate processes for the dilution of nitrogen in groundwater.

Other objectives

11) Link the results of the pilot trial back to the ecological and cultural aspirations for the spring-fed waterbodies and groundwater-dependent ecosystems in the catchment.

12) Support ongoing optimisation of the monitoring programme.

2.0 Recharge Water Monitoring

Quantity

Three weirs will be installed at the MAR pilot site (Figure F1) to monitor:

- Outflows from Valetta Pond #3 (MMT1)

- Inflows to the infiltration basin forebay (MMT2)
- Overflows from the main basin (MMT3) to the rerouted diversion race

The weirs will be equipped with vented pressure transducers to measure upstream water levels continuously (15 minute intervals). Manual gaugings will be undertaken to provide calibration data for flow rating curves for each weir. Manual water level measurements will be taken at intervals to confirm the pressure transducer calibration.

Quality

Two water quality samples have been taken for laboratory analysis in May 2015 to assess baseline quality of the recharge water. One sample was taken from the RDR Klondyke diversion and the other from Valetta pond #3 (Figure F1). The Valetta pond #3 is the immediate source of water for the infiltration basin forebay.

Prior to the commencement of the pilot trial, the Valetta pond #3 will be purged and cleaned to manage possible water quality issues relating to the use of standing water. For the same reason, the Valetta pond #3 will be purged and cleaned after any shut down of the trial exceeding one month.

Pilot trial source water will be sampled at the outlet from the Valetta pond #3 before the pond is emptied, after the pond is re-filled and at monthly intervals for the term of the pilot project.

The samples will be sent to an accredited laboratory for analysis. The analysis parameters are listed in Table F1.

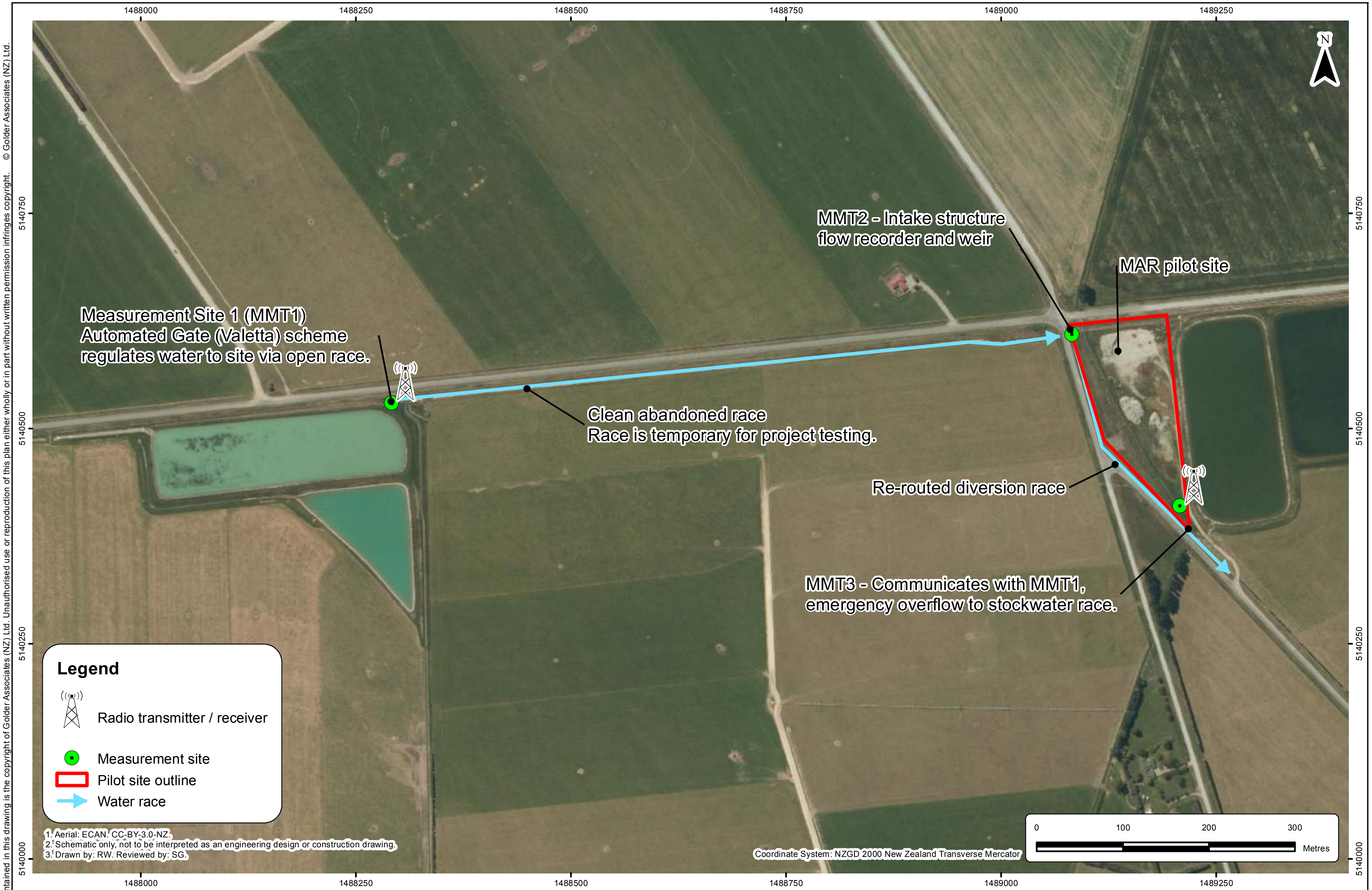
Field measurements of electrical conductivity, turbidity, pH and temperature will be made on all occasions samples are obtained for laboratory analysis.

Table F1: Summary of proposed water quality sampling parameters (Year 1).

Frequency	Analyte									
	Nitrogen (1)	Turbidity	TSS	TOC	EC	Dissolved Reactive Phosphorus/ Total Phosphorus	*E.Coli* and faecal coliform	Hardness	Anions, Cation profile(2)	Dissolved metals(3)
Pre-trial & Start	Recharge water and MAR site monitoring well									
Pre-trial	All pilot trial groundwater, surface water and recharge water monitoring sites								X	X
Monthly	All groundwater, surface water and recharge water sites								X	X
End of Trial	Recharge water and MAR site monitoring well									

Notes: (1) All forms of nitrogen analysed (total nitrogen, total ammoniacal-N, nitrite-N, nitrate-N, total kjeldahl nitrogen.
(2) Ca, Mg, Na, K, hardness, alkalinity, bicarbonate, carbonate, SO_4 and Cl.
(3) As per hills laboratory NZDW suite for metals

IN COMPLIANCE. Appendix C provides information about the final monitoring system for the Pilot Trial. The cleaning of Valetta Pond #3 was conducted by Valetta Irrigation staff in early 2017. The purpose of this 'cleaning' was to remove algae and aquatic plants to remove a food source for ducks. This 'cleaning' was a one-off to lower the number of waterfowl potentially using the ponds. As Valetta Pond #3 was operated continuously (either for MAR and/or for irrigation supplies) for the entire Year 1 operations period, there was never a time where there was 'standing water' as cited in this condition. Given that the condition to drain and shutdown Valetta Pond #3 was only intended as a 'one off' at the start of the project, it is recommended that this condition be reviewed in Year 2.



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TITLE HINDS MAR PILOT TRIAL MONITORING INFRASTRUCTURE

SEPTEMBER 2015

PROJECT 1478110257

F1

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3.0 Groundwater

3.1 Existing Monitoring

Quantity

Monthly and hourly groundwater level data collected by CRC from the regional groundwater monitoring network have been used to assess the baseline groundwater regime. Data recorded from at least seven of these bores during the trial (Table F2, Table F3) will be analysed as part of the pilot trial.

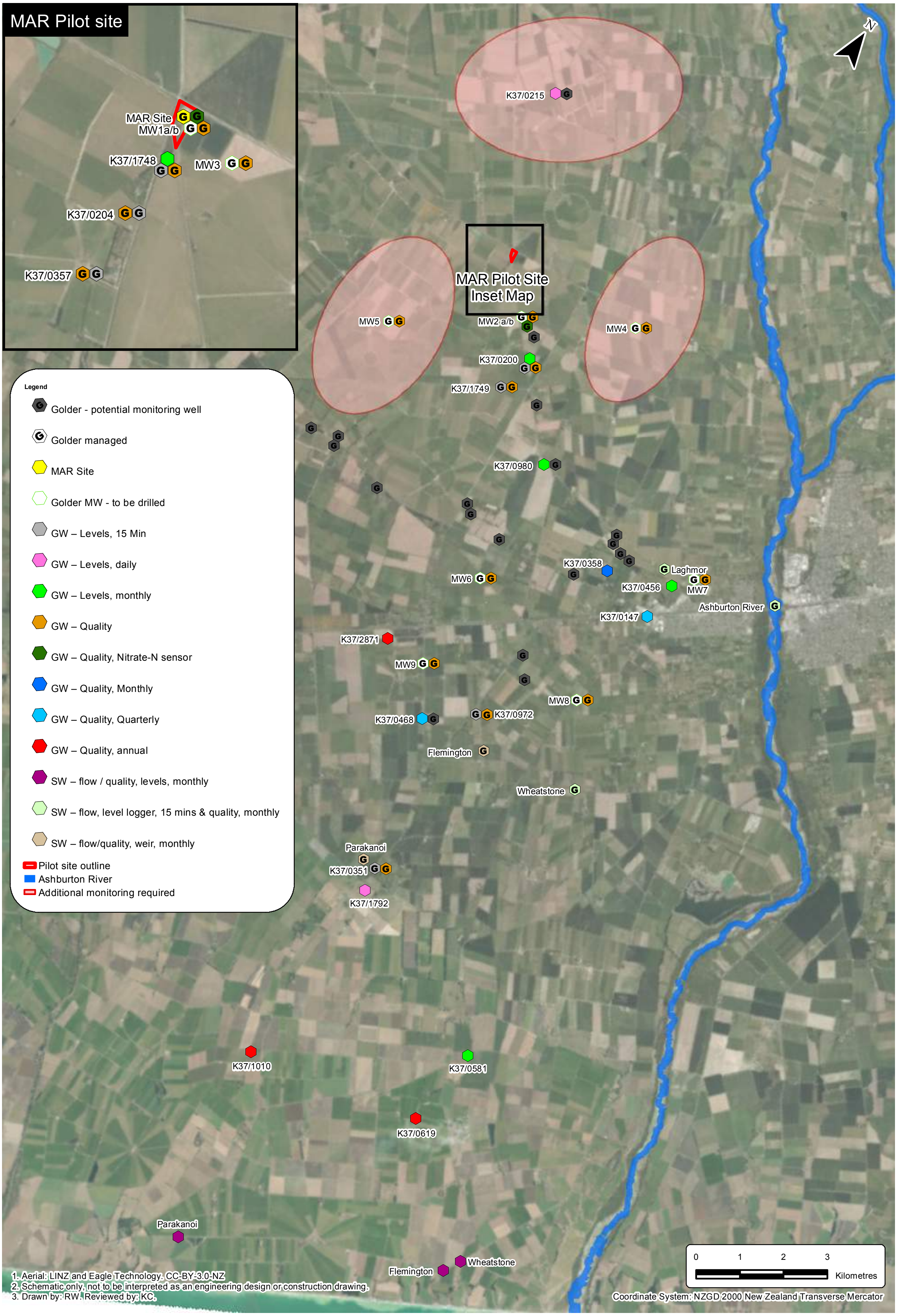
Groundwater level and temperature are being continuously recorded (15 minute intervals) at seven existing monitoring wells (Figure F2) that are not part of the regional groundwater monitoring network using non vented pressure transducers. These transducers were deployed in January 2015. Monitoring will continue through at least the first year of the pilot trial.

A transducer logging barometric pressure at 15 minute intervals was installed in monitoring well K37/1748 in January 2015. These barometric data will be used to adjust groundwater level data for barometric pressure changes. Monitoring of barometric pressure will continue through year one of the MAR pilot trial.

Quality

CRC regularly samples water from monitoring wells both up-gradient and down-gradient of the pilot site as part of their regional environmental monitoring programme. Monthly sampling is carried out by CRC at one site, quarterly monitoring at two sites and annual monitoring at three sites (Table F2, Table F3). It is expected that sampling of these monitoring wells will continue throughout the period of the pilot trial and the water quality analysis data from these sites will be incorporated in the pilot trial evaluation.

One water quality sample was taken from well K37/1748 for laboratory analysis in May 2015. Samples from this well will be obtained and analysed once before the trial begins, weekly in the first month of the trial and continuing on a monthly basis for at least the first year of the pilot trial.



Golder Associates

TITLE HINDS MAR PILOT TRIAL MONITORING NETWORK

SEPTEMBER 2015

PROJECT 1478110257

F2

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Table F2: Groundwater monitoring programme summary.

Station ID	Description	Easting (NZTM)	Northing (NZTM)	Type	Start date
K37/1748 & K37/1748 baro	Golder current	1489140	5140430	Standpipe piezometer	Jan 2015
K37/0204		1489164	5140077		
K37/0357		1489204	5139667		
K37/0200		1490814	5138818		
K37/1749		1490656	5699514		
K37/0972		1494395	5131820		
K37/0351		1494533	5127409		
K37/0215	ECan current	1487848	5144112		1998
K37/0980		1492479	5137017		2003
K37/0456		1496464	5136417		2003
K37/1792		1494635	5126830		2004
K37/0581		1498794	5124957		2003
K37/0358		1495053	5135854		2004
K37/0147		1496402	5135524		2006
K37/2871		1491831	5131711		2009
K37/0468		1493525	5130664		2006
K37/1010		1494686	5122190		2009
K37/0619		1498647	5123099		1997
TBC	Golder additional monitoring wells to be selected from existing water bores	TBC			Sep 2015
TBC					
TBC					
TBC					
TBC					
TBC					
TBC					
TBC					
MW1a/b	Golder to be drilled	1489165	5140684	Nested piezometer	
NW2a/b		Approx 500 – 1,000 m down-gradient of MAR site			
NW3		1489500	5140690	Standpipe piezometer	
NW4		North East of MAR site			
NW5		South West of MAR site			
NW6		Down-gradient - vicinity of SH1			
NW7		Tinwald			
NW8		Spring Heads (Wheatstone)			
NW9		Spring Heads (Parakanoi)			

Table F3: Groundwater monitoring station objectives.

Station ID	Monitoring proposed	Objectives
K37/1748	Transducer (level, temp) 15 minute intervals, quarterly download Water quality samples, pre-trial and monthly, weekly for first month following trial start Manual GW level, monthly (ECan)	Monitor immediate groundwater level and quality response to infiltration.
K37/1748 baro	Transducer (barometric pressure) 15 minute intervals, quarterly download	Provide barometric correction data for groundwater monitoring.
K37/0204	Transducer (level, temp) 15 minute intervals, quarterly download Water quality samples, pre-trial and monthly, weekly for first month following trial start	Monitor groundwater level and quality response to infiltration down-gradient of the pilot trial site.
K37/0357		
K37/0200	Transducer (level, temp) 15 minute intervals, quarterly download Water quality samples, pre-trial and monthly Manual GW level, monthly (ECan)	
K37/1749	Transducer (level, temp) 15 minute intervals, quarterly download Water quality samples, pre-trial and monthly	
K37/0972		
K37/0351		
K37/0215	Transducer (level, temp) daily	Up-gradient control bore monitoring background conditions.
K37/0980	Manual GW level, monthly	Provide data to assess groundwater level and quality responses to infiltration. Link to longer term regional groundwater level trends.
K37/0456	Manual GW level, monthly	
K37/1792	Transducer (level, temp) daily	
K37/0581	Manual GW level, monthly	
K37/0358	Water quality samples, monthly	
K37/0147	Water quality samples, quarterly	
K37/2871	Water quality samples, annual	
K37/0468	Water quality samples, quarterly	
K37/1010	Water quality samples, annual	
K37/0619	Water quality samples, annual	
TBC	Transducer (level, Temp) 15 minute intervals, quarterly download	Monitor groundwater quantity response to infiltration
TBC		
TBC		
TBC		
TBC		
TBC		
TBC		
TBC		
MW1a/b	Transducer (level, temp) 15 minute intervals, quarterly download Water quality samples, pre-trial and monthly, weekly for first month following trial start Sensor - nitrate - nitrogen tracking	Monitor immediate response to infiltration both in groundwater level and quality.
MW2a/b		Track the recharge clean water plume breakthrough curve.
MW3	Transducer (level, temp) 15 minute intervals, quarterly download Water quality samples, pre-trial and monthly, weekly for first month following trial start	Monitor groundwater pressure response at the site and possible effects on existing ponds.
MW4	Transducer (level, temp) 15 minute intervals, quarterly download Water quality samples, pre-trial and monthly	Monitor groundwater response to the north east of the site, to validate groundwater modelling.
MW5		Monitor groundwater response to the south west of the site, to validate groundwater modelling.
MW6		Monitor the springs and drains. Distinguish changes induced by pilot trial from changes due to other recharge processes.
MW7		
MW8		
MW9	Telemetered transducer (level, temp) 15 minute intervals, quarterly download Water quality samples, pre-trial and monthly	Process management monitoring well with trigger groundwater levels.

IN COMPLIANCE. Appendix C provides information about the final monitoring system for the Pilot Trial. Note that due to dry conditions new existing bores were added to this programme to help quantify the project objectives.

3.2 Planned Monitoring

Quantity

Eight further existing water bores (Table F2, Table F3) will be selected through communication with landowners and CRC. Transducers will be set up to log groundwater levels and temperature in these bores. One up-gradient bore will be included in this selection to provide a reference groundwater level dataset.

These sites will be selected based on the following criteria:

1) Existing bores should be screened to intercept the shallow aquifer system (e.g., ~30 to 40 m bgl). If the bore construction details are unknown and no log is available the bore will be sounded for depth.

2) Existing bores should ideally be un-pumped (not used).

3) Existing bores allow for easy sampling of both quality and quantity.

4) Existing CRC monitoring bores should be used if consistent with the other selection criteria.

5) Landowners are notified and willing to allow groundwater quality and quantity information to be collected.

Nine dedicated monitoring wells will be installed to address potential data gaps in areas where there are no existing wells or the existing wells do not meet the selection criteria (Table F4, Figure F2). In summary:

A nested monitoring well (MW1a/b) will be installed at the southern edge of the pilot trial site to enable a greater understanding of the geology of the site and measure immediate response to infiltration both in groundwater quantity and quality.

A second nested monitoring well (MW2a/b) will be drilled approximately 500 to 1,000 m down-gradient from the pilot trial site. This bore will be equipped with a nitrate-nitrogen sensor which will enable the tracking of the recharge water plume through the aquifer.

A monitoring well (MW3) will be drilled to the east of the neighbouring ponds to an approximate depth of 30 m to assess operational mounding and pressure response at the site and possible effects on existing ponds.

Two monitoring wells will be installed to the south west (MW4) and to the north east (MW5) of the pilot trial site. Existing bores in these areas are deemed unsuitable for monitoring based on the above selection criteria. These bores will be used to monitor groundwater responses to the trial and provide data to verify and recalibrate modelling conducted to date.

Three shallow monitoring wells (MW6, MW7 and MW8) will be installed to enable monitoring of groundwater levels close to down-gradient springs and drains. The data will be used to distinguish changes induced by the pilot trial from changes due to other recharge processes.

A shallow monitoring well (MW9, PARAKANOI GW - 1) will be installed downgradient from the site. A continuous level logger providing groundwater temperature and pressure data will be linked to surface recharge operations via synchronised time-series data. Groundwater levels in this well will be monitored against trigger conditions.

Water level and temperature in all bores listed under this section of the appendix will be monitored continuously at 15 minute intervals and downloaded every three months. Water levels will be measured manually for calibration purposes at each of these monitoring wells when the transducer data is downloaded.

Table F4: Proposed monitoring wells (to be drilled).

Well	Location (relative to MAR site)	Diameter (mm)	Depth (m)(1)	Screen length (m) (1)
MW1a	At MAR site	52	30	9
MW1b		32	30	3
MW2a	Down-gradient	52	30	9
MW2b		32	30	3
MW3	350m East	52	30	9
MW4	North East	52	30	9
MW5	South west	52	30	9
MW6	Vicinity of SH1	52	10	3
MW7	Tinwald	52	5	2
MW8	Spring heads (Wheatstone)	52	5	2
MW9	Spring heads (Parakanoi)	52	5	2

Notes: (1) Well depths and screen lengths are approximate and will depend on aquifer properties encountered during drilling.

Quality

Water quality sampling of the receiving groundwater will be undertaken one week prior to the start of the pilot trial with monthly monitoring of 17 bores for at least the first year of the trial (Table F1). Both frequency of water quality monitoring and the analyte list will be reviewed following evaluation of the data after the first year of the trial. A continuous monitoring system for nitrate concentrations in groundwater will be installed in monitoring well MW2a/b, which is to be installed down-gradient from the trial site. The objective is to monitor the breakthrough curve for the clean water plume down-gradient from the trial site. This breakthrough curve will provide data on the rate at which the recharged water physically moves away from the trial site.

IN COMPLIANCE. Appendix C provides information about the final monitoring system for the Pilot Trial. Note that due to dry conditions new existing bores were added to this programme to help quantify the project objectives.

4.0 Surface Water

4.1 Existing Monitoring

Quantity

The surface water monitoring is planned to address two primary objectives:

1) To provide data to enable the interaction between the Ashburton River and the local groundwater system to be evaluated.

2) To monitor the effects of the recharge project on the down-gradient streams.

The following monitoring already being undertaken will provide data to help achieve the above objectives.

- A CRC pressure transducer is installed on the Ashburton River (Figure F2). Quarterly visits are conducted to download the data and conduct rating measurements. Field work will be carried out by CRC staff. The Consent Holder will analyse the data in relation to the objectives above.

- A staff gauge and level logger has been installed in Laghmor Creek with quarterly downloads and rating measurements conducted by the Consent Holder. One of the dedicated shallow groundwater monitoring wells (Section 3.2) will be installed near Tinwald to assist in the assessment of the interaction between the Ashburton River and the local groundwater system.

To monitor the effects of the pilot trial on the down-gradient streams, two weirs have been installed with level loggers to measure flows in the Parakanoi and Flemington Streams (logging at 15 minute intervals, quarterly downloads, ratings and maintenance to be carried out by the Consent Holder). A level logger has also been installed to measure water depth in the Wheatstone Stream. The data collected from the level loggers will be used to develop rating curves to calculate flow. Monitoring of these surface water flow sites will continue through the first year and will be reviewed based on the findings of the data analysis. The CRC monitoring network has provided flow data from the Blees and Flemington Drains at least monthly since 2011, Parakanoi Drain at least monthly since 2004 and Wheatstone Drain on occasion since 2014. This monitoring will continue and the data used as part of the monitoring programme when available.

Quality

Surface water quality is measured at the Wheatstone (quarterly), Blees (monthly), Flemington (monthly) and Parakanoi (monthly) flow monitoring sites on a monthly basis (Table F5, Table F6). These data have been used to assess the baseline water quality assessment for surface waterbodies down-gradient of the pilot trial site. The monitoring will provide data to track any changes in water quality resulting from the trial. The Hinds Drains Working Party samples the surface water quality at 27 sites between the springs and the coast. The nitrate-nitrogen results from this sampling may be used to provide additional water quality data when available.

4.2 Planned Monitoring

In addition to the above surface water monitoring water quality samples will be taken from the Ashburton River and the Golder sites (Table F5, Table F6) during the first year of the pilot trial. The suite of analysis and frequency of sampling is described in Table F1.

Table F5: Surface water monitoring programme summary.

<table>
<tr><th>Station ID</th><th>Description</th><th>Easting (NZTM)</th><th>Northing (NZTM)</th><th>Type</th><th>Start date</th></tr>
<tr><td>Ashburton River</td><td>ECan current</td><td>1498585</td><td>5137749</td><td rowspan="2">Level logger</td><td>Unknown</td></tr>
<tr><td>Laghmor Creek</td><td rowspan="4">Golder current</td><td>1496100</td><td>5136877</td><td rowspan="4">Feb 2015</td></tr>
<tr><td>Parakanoi (McLennons Road)</td><td>1493444</td><td>5127237</td><td rowspan="2">Weir</td></tr>
<tr><td>Flemington (Boundary Road)</td><td>1494871</td><td>5131365</td></tr>
<tr><td>Wheatstone (Boundary Road)</td><td>1497320</td><td>5131557</td><td rowspan="4">Level logger</td></tr>
<tr><td>Blees (Lower Beach Road)</td><td rowspan="3">ECan current</td><td>1501354</td><td>5121019</td><td>Apr 2011</td></tr>
<tr><td>Flemington (Lower Beach Road)</td><td>1501150</td><td>5120618</td><td>Mar 2011</td></tr>
<tr><td>Parakanoi (Lower Beach Road)</td><td>1495752</td><td>5117777</td><td>Jan 2004</td></tr>
</table>

Table F6: Surface water monitoring station objectives.

Station ID	Monitoring proposed	Objectives
Ashburton River	Transducer (level, temp) 15 minute intervals, gauged and downloaded monthly Water quality samples, pre-trial and monthly	Monitor the interaction between the Ashburton River and the local groundwater system and to allow the pilot trial operations and river recharge influences to be differentiated
Laghmor Creek		
Parakanoi (McLennons Road)		Monitor the springs and drains and be able to distinguish changes induced by the pilot trial and changes due to other recharge processes
Flemington (Boundary Road)		
Wheatstone (Boundary Road)		
Blees (Lower Beach Road)	Telemetered transducers (level, temp), daily, gauged and downloaded monthly Water quality samples, monthly	Provide additional data down-gradient of Golder stream / drain monitoring
Flemington (Lower Beach Road)	Telemetered transducers (level, temp), daily, gauged and downloaded monthly Water quality samples, monthly	
Parakanoi (Lower Beach Road)	Telemetered transducers (level, temp), daily, gauged and downloaded monthly Water quality samples, monthly	

IN COMPLIANCE. Appendix C provides information about the final monitoring system for the Pilot Trial. CRC operated all of these sites throughout the Year 1 trial. Note that due to dry conditions there was very little actual data available at these locations. See Section 5.2 of the main report and Appendix E.

5.0 CRC162191

5.1 General Conditions

Limits

1) The works shall be limited to the excavation of land for the purposes of the construction of the Managed Aquifer Recharge site at the corner of Frasers Road and Timaru Track Road, Lagmhor, legally described as RES 1959, RS 37821 and Lot 1 DP 341405 and shown on Plan CRC162192A, which is attached to and forms part of this consent.

2) The works shall be undertaken in accordance with the attached design plans Plan CRC162192B-D, which form part of this consent.

Prior to Construction

3) Prior to the works described in Condition (1) the consent holder shall ensure that all personnel working on the site are made aware of and have access to the contents of this consent document and all associated erosion and sediment control plans and methodology.

4) Prior to commencement of works the consent holder or their agent shall arrange and conduct a pre-construction site meeting between the Canterbury Regional Council Monitoring and Compliance, and all relevant parties, including the primary contractor. At a minimum, the following shall be covered at the meeting:

   a. Scheduling and staging of the works;

   b. Responsibilities of all relevant parties;

   c. Contact details for all relevant parties;

   d. Expectations regarding communication between all relevant parties;

e. Procedures for implementing any amendments;

f. Site inspection; and

g. Confirmation that all relevant parties have copies of the contents of this consent document and all associated erosion and sediment control plans and methodology.

5) At least 10 working days prior to construction commencing, a copy of the Construction Management Plan prepared in accordance with Condition (6) shall be submitted to the Canterbury Regional Council; Attention: RMA Monitoring and Compliance Manager.

During Construction

6) Works shall be undertaken in accordance with a Construction Management Plan that details the measures to ensure compliance with this consent, including but not limited to:

a. A map showing the location of all works;

b. Detailed plans showing the location of sediment control measures, on-site catchment boundaries and sources of run-off;

c. Detailed plans and procedures for managing contaminated soil and groundwater;

d. Procedures for managing contaminants used on site;

e. An erosion and sediment control plan including drawings and specifications of designated sediment control measures;

f. A programme of works including an indicative timeframe;

g. Inspection and maintenance for sediment control measures;

h. The methodology for stabilising the site if works are abandoned; and

i. The methodology for stabilising the site and decommissioning erosion and

j. Sediment control measures after works have been completed.

7) The consent holder may amend the Construction Management Plan in accordance with Condition (6) at any time. Any amendments shall be:

a. Only for the purpose of improving the efficacy of the proposed works including erosion and sediment control measures and shall not result in reduced discharge quality;

b. Consistent with the conditions of this resource consent; and

c. Submitted in writing and approved by the Canterbury Regional Council, Attention RMA Monitoring and Compliance Manager prior to any amendment being implemented.

8) All erosion and sediment control measures shall be installed, undertaken, maintained and decommissioned in accordance with the Environment Canterbury Erosion and Sediment Control Guidelines 2007.

9) The consent holder shall adopt the best practicable options to:

a. Minimise soil disturbance and prevent soil erosion;

b. Prevent sediment from leaving the site;

c. Avoid placing cut or cleared vegetation, debris, or excavated materials in a position such that it may enter surface water.

Spills

10) All practicable measures shall be taken to avoid spills of fuel or any other hazardous substances within the site. In the event of a spill of fuel or any other hazardous substance:

   a. The spill shall be cleaned up as soon as practicable, the stormwater system shall be inspected and cleaned, and measures shall be taken to prevent a recurrence;

   b. The Canterbury Regional Council shall be informed within 24 hours and the following information provided:

      i. The date, time, location and estimated volume of the spill;

      ii. The cause of the spill;

      iii. The type of hazardous substance(s) spilled;

      iv. Clean up procedures undertaken;

      v. Details of the steps taken to control and remediate the effects of the spill on the receiving environment;

      vi. An assessment of any potential effects of the spill; and

      vii. Measures to be undertaken to prevent a recurrence.

Tangata Whenua

11) In the event of any discovery of archaeological material:

   a. the consent holder shall immediately:

      i. Cease earthmoving operations in the affected area and mark off the affected area; and

      ii. Advise the Canterbury Regional Council of the disturbance; and

      iii. Advise Heritage New Zealand Pouhere Taonga of the disturbance.

   b. If the archaeological material is determined to be Koiwi Tangata (human bones) or taonga (treasured artefacts) by Heritage New Zealand Pouhere Taonga, the consent holder shall immediately advise the office of the appropriate runanga (office contact information can be obtained from the Canterbury Regional Council) of the discovery.

   c. If the archaeological material is determined to be Koiwi Tangata (human bones) by Heritage New Zealand Pouhere Taonga, the consent holder shall immediately advise the New Zealand Police of the disturbance.

   d. Work may recommence if Heritage New Zealand Pouhere Taonga Trust (following consultation with runanga if the site is of Maori origin) provides a statement in writing to the Canterbury Regional Council, Attention: RMA Compliance and Enforcement Manager that appropriate action has been undertaken in relation to the archaeological material discovered. The Canterbury Regional Council shall advise the consent holder on written receipt from Heritage New Zealand Pouhere Taonga that work can recommence.

Advice Note: This may be in addition to any agreements that are in place between the consent holder and the Papatipu Runanga. (Cultural Site Accidental Discovery Protocol).

Advice Note: Under the Heritage New Zealand Pouhere Taonga Act 2014 an archaeological site is defined as any place associated with pre-1900 human activity, where there is material evidence relating to the history of New Zealand. For sites solely of Maori origin, this evidence may be in the form of accumulations of shell, bone, charcoal, burnt stones, etc. In later sites, artefacts such as bottles or broken glass, ceramics, metals, etc., may be found or evidence of old foundations, wells, drains, tailings, races or other structures.

Human remains/koiwi may date to any historic period. It is unlawful for any person to destroy, damage, or modify the whole or any part of an archaeological site without the prior authority of Heritage New Zealand Pouhere Taonga. This is the case regardless of the legal status of the land on which the site is located, whether the activity is permitted under the District or Regional Plan or whether a resource or building consent has been granted. The Heritage New Zealand Pouhere Taonga Act 2014 provides for substantial penalties for unauthorised damage or destruction.

Administration

12) The Canterbury Regional Council may, once per year, on any of the last five working days of May or November, serve notice of its intention to review the conditions of this consent for the purposes of dealing with any adverse effect on the environment which may arise from the exercise of the consent.

IN COMPLIANCE. (With this section): Appendix C provides information about the final monitoring system for the Pilot Trial. Note that due to dry conditions new existing bores were added to this programme to help quantify the project objectives.

A pre-construction meeting, hosted by Tarbottons Construction, was conducted at the Hinds MAR site on 5 April 2016. The meeting was attended by Nic Froude (CRC compliance), Tarbottons Construction, and CRC and Golder staff. Pre-construction discussions about dust control, spill control, construction operation and health and safety were discussed. A copy of an email summary of this meeting can be provided upon request (Nic Froude, Bob Bower on 7 April 2016).

A follow up Hinds Operational meeting for discharge of water and operations of the site was hosted on 10 May 2016. At this meeting discussion between RDR, Valetta, Golder and Scottech helped set up the final monitoring programme for the site. An operational plan was developed and circulated that included mobile phone numbers of key personnel, shutdown procedures and relevant consent conditions relative to operations (e.g., rainfall trigger condition). An email of the plan was circulated with CRC (Nic Froude, CRC Compliance Officer for Pilot Trial), other CRC staff, and RDR, Valetta and Golder staff. A copy of this plan can be provided upon request.

As part of the project communications and operations programmes, updates to Hinds MAR Pilot Working Group (Group) and CRC staff were provided approximately fortnightly via email, and/or via monthly Group meetings. Additionally ongoing updates on key issues like rainfall trigger event shut downs, site upgrades and any other operational issues were managed through numerous emails and mobile phone calls.

6.0 CRC164281 - TO TAKE AND USE SURFACE WATER

1) Water shall only be:

   a. diverted from the Rangitata River to the Valetta Irrigation Scheme pipeline via the existing structure at the Rangitata Diversion Race Klondyke intake at NZ Topo50 BY19:5798-5278 at a rate not exceeding 500 litres per second with a volume not exceeding 15,780,000 cubic metres between 1 February and the following 31 January.

IN COMPLIANCE. Refer Section 4.0 of main report and Appendix E.

   b. taken from Valletta Irrigation Scheme Pipeline, between map references(s), NZ Topo50 BY20:8800-4048 and NZ Topo50 BY20:8908-4061, at a rate not exceeding 500 litres per second, with a volume not exceeding 15,780,000 cubic metres between 1 February and the following 31 January.

Advice note: The rate and volume of water diverted under this consent is independent of resource consent CRC011237.

IN COMPLIANCE. Refer Section 4.0 of main report and Appendix E.

2) Water diverted and taken under this consent in combination with Ashburton District Council consent CRC164280 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.

IN COMPLIANCE. Refer Section 4.0 of main report and Appendix E.

3) The taking of water in accordance with Condition (1)(b) shall only occur when water is being diverted at the same or greater rate in accordance with Condition (1)(a).

IN COMPLIANCE. Refer Section 4.0 of main report and Appendix E.

4) Water shall only be used for managed aquifer recharge purposes in accordance with resource consent CRC162191.

IN COMPLIANCE. Refer Section 4.0 of main report and Appendix E.

5) Water diverted shall pass through the fish exclusion device as described in Condition (4) and (5) of resource consent CRC011237.

IN COMPLIANCE. RDRML is required as per irrigation diversion consent to comply with this condition. It is not unique to MAR project operations.

6) The consent holder shall, within three months of the commencement of this consent, install a water level measuring device at the Measurement Site 1 (MMT1) (at or about NZ Topo50 BY20:8828-4053), MMT2 (at or about Topo50 BY20:8908) and MMT3 (at or about NZ Topo50 BY20:8920-4040) in accordance with Plan CRC164281; in a location that will enable the determination of the continuous rate of flow and volume of water being taken to within an accuracy of plus or minus 10 percent, and

IN COMPLIANCE. Refer Section 4.0 of main report and Appendix E.

a. The measuring device shall, as far as is practicable, be installed at a site likely to retain a stable relationship between flow and water level. The measuring device shall be installed and maintained in accordance with the manufacturer's instructions.

IN COMPLIANCE. Refer Section 4.0 of main report and Appendix E.

b. The level of water in the race, and times of abstraction, shall be recorded by tamper-proof electronic recording system such that the level of water is measured at least once every 15 minutes, and a record made either on site or at a remote location via telemetry of the recorded levels such that the flow volume through the site may be derived for time increments not exceeding 60 minutes using the current site rating relationship. The recorded data shall not be changed or deleted by any person, unless twelve months have passed since the date of recording.

IN COMPLIANCE. Refer Section 4.0 of main report and Appendix E.

c. The measuring and recording devices described in clauses 6(a) and 6(b) shall be available for inspection at all times by the Canterbury Regional Council subject to providing adequate protection against vandalism which may require the consent holder's assistance on site to unlock or remove barriers.

IN COMPLIANCE. Refer Section 4.0 of main report and Appendix E.

d. All data from the recording device described in clause 6(b), and the corresponding relationship between the water level and flow, shall be provided to the Canterbury Regional Council on request.

IN COMPLIANCE. Refer Section 4.0 of main report and Appendix E.

e. Maintain a rating curve to convert water levels to flow in accordance with best hydrological practice.

IN COMPLIANCE. Refer Section 4.0 of main report and Appendix E.

7) The Canterbury Regional Council may, once per year, on any of the last five working days of May or November, serve notice of its intention to review the conditions of this consent for the purposes of dealing with any adverse effect on the environment which may arise from the exercise of the consent.

IN COMPLIANCE. Refer Section 4.0 of main report and Appendix E.

8) If this consent is not exercised before 31 March 2019 it shall lapse in accordance with section 125 of the Resource Management Act 1991.

IN COMPLIANCE. Pilot trial has commenced.

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APPENDIX B

Climate Data

1.0 CLIMATE MONITORING STATIONS

Monitoring for the Hinds MAR Pilot Trial includes three climate stations on the Hinds Plains (Figure B1). Between them, these climate stations collect rainfall, temperature and potential evapotranspiration data that are representative of the Pilot Trial area. These climate monitoring stations are:

- Willowby weather station
  - Located in Willowby, approximately 12 km SSE of the Pilot Trial site, CRC monitoring site #319610 provides rainfall and temperature data for the Pilot Trial. Installed in November 2015 specifically for this project, rainfall recorded by this site is also used to monitor the project consent conditions relating to site shut-down during high rainfall events.
  - A full data record is available at https://www.ecan.govt.nz/data/rainfall-data/sitedetails/319610.
- Ashburton Council weather station
  - Located in Ashburton Domain, approximately 10.5 km SE of the Pilot Trial site, NIWA climate station #4778 has been in operation since January 1927 and provides both current and historical rainfall data to support analysis of the Pilot Trial outcomes.
  - A full data record is available through NIWA's CliFlo database, found at https://cliflo.niwa.co.nz/.
- Ashburton Aero AWS
  - Located at the Ashburton Airport, approximately 15 km SE of the Pilot Trial site, NIWA climate station #26170 has been in operation since February 2006 and provides both current and historical potential evapotranspiration (PET) data to support analysis of the Pilot Trial outcomes.
  - A full data record is available through NIWA's CliFlo database, found at https://cliflo.niwa.co.nz/.

2.0 RAINFALL

2.1 Annual Rainfall

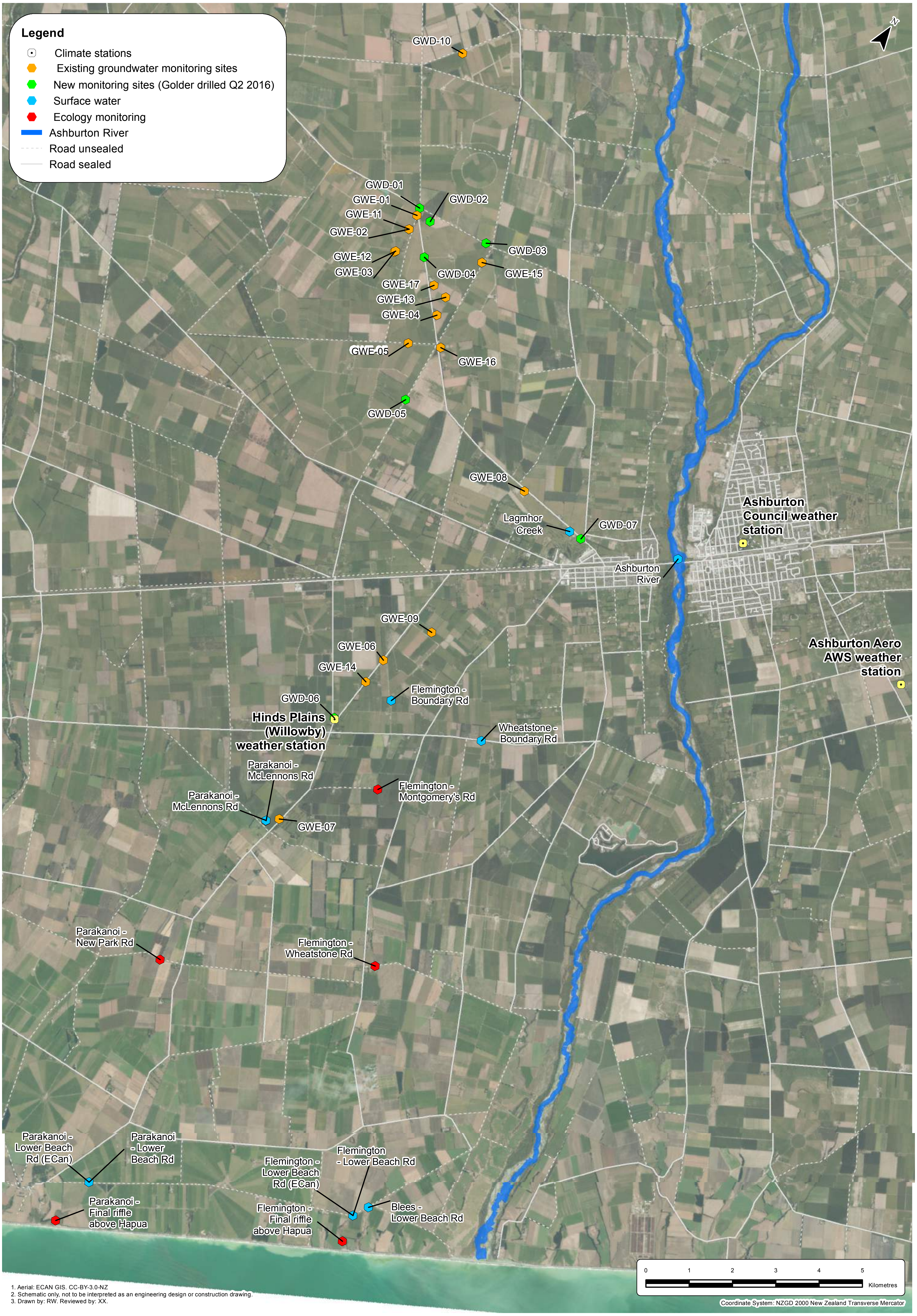
Rainfall data from 1990 to 2016 (Table B1) has been collected from the Ashburton District Council weather station to enable weather patterns during the Pilot Trial to be compared to longer term monthly and annual records. The data indicates that 2015 and 2016 were two of the five driest years recorded during this period (Table B1). During this period there was no indication of ether increasing or decreasing annual rainfall trends (Figure B2).

2.2 Monthly Rainfall

Monthly rainfall data collected from the Ashburton District Council and Willowby weather stations during the Pilot Trial (Table B2) were compared to confirm that a credible link could be made between historical data and Pilot Trial data collected from the Willowby station. There is a good correlation between the Ashburton Council and Willowby monthly rainfall data (Figure B3), although rainfall recorded during June 2016 was anomalously higher in Ashburton than at Willowby.

A comparison of the Willowby monthly rainfall data from the trial period and the longer term Ashburton District Council rainfall dataset (Figure B4) indicates that rainfall experienced at the Pilot Trial site:

- Was less than average during the June to September 2016 period.
- Was substantially more than average during March and April 2017.



Golder Associates

TITLE MAR Command Area Monitoring System

AUGUST 2017

PROJECT 1538632

B1

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Table B1: Monthly rainfall Ashburton Council climate station 1990 to 2017.

Year	Monthly rainfall (mm)												Annual
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
1990	39.7	38.8	39.8	31.7	75.2	27.8	42.9	106.1	38.4	74.4	73.8	44.1	632.7
1991	35.9	65.2	23.7	69.2	58.3	72.8	78.8	21.7	51.0	15.2	66.3	77.9	636.0
1992	22.0	23.4	5.0	23.4	70.9	36.5	93.4	134.9	94.0	80.9	44.7	65.2	694.3
1993	48.3	32.5	32.0	84.2	95.2	16.3	1.7	13.3	98.0	3.2	111.5	66.8	603.0
1994	62.1	68.8	139.2	11.6	28.9	72.5	98.9	3.7	80.6	35.9	32.7	32.8	667.7
1995	55.2	31.9	56.5	44.6	36.6	258.5	37.1	41.8	110.1	49.4	75.1	39.8	833.0
1996	35.1	120.4	106	94.5	44.6	91.3	155.7	60.8	11.9	57.7	71.2	36.2	885.4
1997	108.1	39.4	81.3	75.6	48.4	49.8	29.8	93.9	47.4	41.0	21.4	39.6	675.7
1998	14.9	44.9	65.7	18.6	56.7	58.5	54.2	54.1	22.5	82.6	34.8	20.2	527.7
1999	32.3	61.9	70.7	39.2	8.2	96.6	137.0	26.8	35.8	69.6	99.7	81	758.2
2000	125.4	32.5	87.3	81.6	70.0	47.6	26.9	224.4	87.2	43.6	137.3	21.2	985
2001	50.1	22.5	5.6	13.5	51.7	38.6	100.3	36.9	13.4	90.1	92.3	54.2	469.2
2002	141.5	62.6	19.3	94.0	28.7	82.8	32.8	23.6	47.7	48.3	80.9	40.1	702.3
2003	81.1	45.6	60.0	140.8	64.5	11.8	46.7	50.2	142.9	49.6	51.4	4.0	748.7
2004	77.1	66.5	37.0	43.8	80.5	15.1	34.7	108.3	50.0	65.4	68.3	137.5	784.2
2005	41.8	55.0	86.6	24.0	61.4	16.1	28.7	29.7	40.4	81.0	41.0	38.2	544.3
2006	49.7	44.4	39.9	63.2	100.7	93.0	75.0	63.2	8.3	73.3	71.6	206.1	888.4
2007	33.9	37.6	55.7	35.2	47.0	50.5	78.5	34.0	41.1	77.8	40.8	56.2	588.3
2008	32.7	100.5	29.6	30.8	55.3	90.6	134.2	145.4	65.3	38.3	31.2	106.6	860.5
2009	54.4	106.0	37.8	45.9	137.8	17.0	40.0	37.6	33.0	88.2	17.8	34.4	650.0
2010	69.0	19.3	25.0	36.9	206.3	79.0	44.5	104.7	21.7	31.2	47.1	58.9	743.6
2011	50.5	58.3	55.7	92.8	89.1	32.8	23.5	50.9	41.6	95.7	73.4	76.8	741.1
2012	54.2	59.1	85.8	46.1	17.8	34.6	46.7	156.9	18.5	93.1	89.2	54.4	756.4
2013	78.6	23.8	44.3	83.1	111.5	220.0	26.3	36.1	47.7	47.8	37.4	88.3	844.9
2014	30.6	36.5	124.5	182.9	56.1	57.2	34.4	27.5	31.2	30.5	36.2	56.4	704.0
2015	16.6	57.0	55.0	127.2	5.7	95.3	28.7	30.6	49.3	19.0	12.2	52.4	549.0
2016	87.5	2.7	44.9	22.2	67.8	57.6	16.1	61.1	28.7	57.2	87.0	46.5	579.3
2017	58.1	14.1	109.2	140.7	44.4								
Average	**56.7**	**49.0**	**58.0**	**61.4**	**65.7**	**67.4**	**57.3**	**65.9**	**50.3**	**57.0**	**60.9**	**60.6**	**716.5**

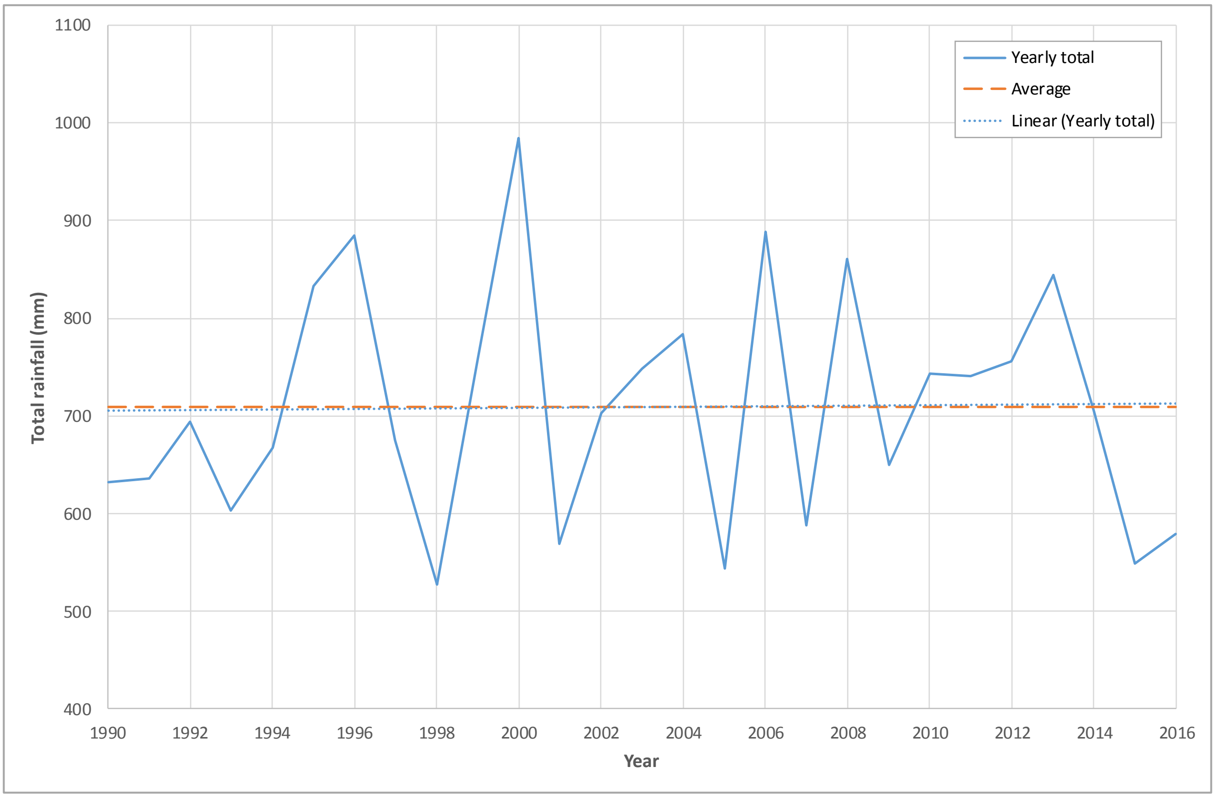

Figure B2: Ashburton Council weather station annual total rainfall 1990 – 2016.

Table B2: Monthly rainfall – Pilot Trial period.

Monitoring Station	Monthly rainfall (mm)											
	2016							2017				
	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
Ashburton	57.6	16.1	61.1	28.7	57.2	87.0	46.5	58.1	14.1	109.2	140.7	44.4
Willowby	20.5	31.0	53.5	18.0	59.5	81.0	55.0	50.5	17.0	103.5	146.5	27.0
Ashburton average (1)	67.4	57.3	65.9	50.3	57.0	60.9	60.6	56.7	49.0	58.0	61.4	65.7

Note: 1) Average rainfall for period 1990 to 2016 (refer Table B1).

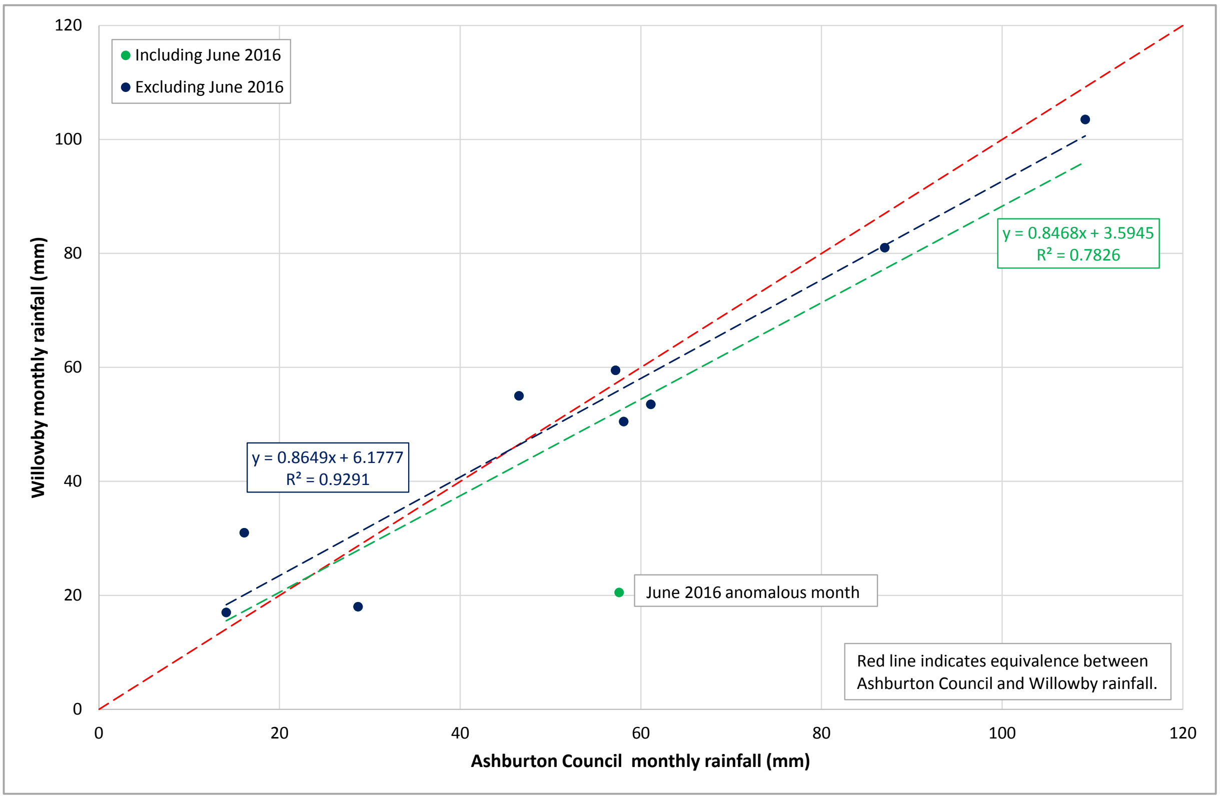

Figure B3: Pilot Trial period monthly rainfall correlation between Willowby and Ashburton District Council climate stations.

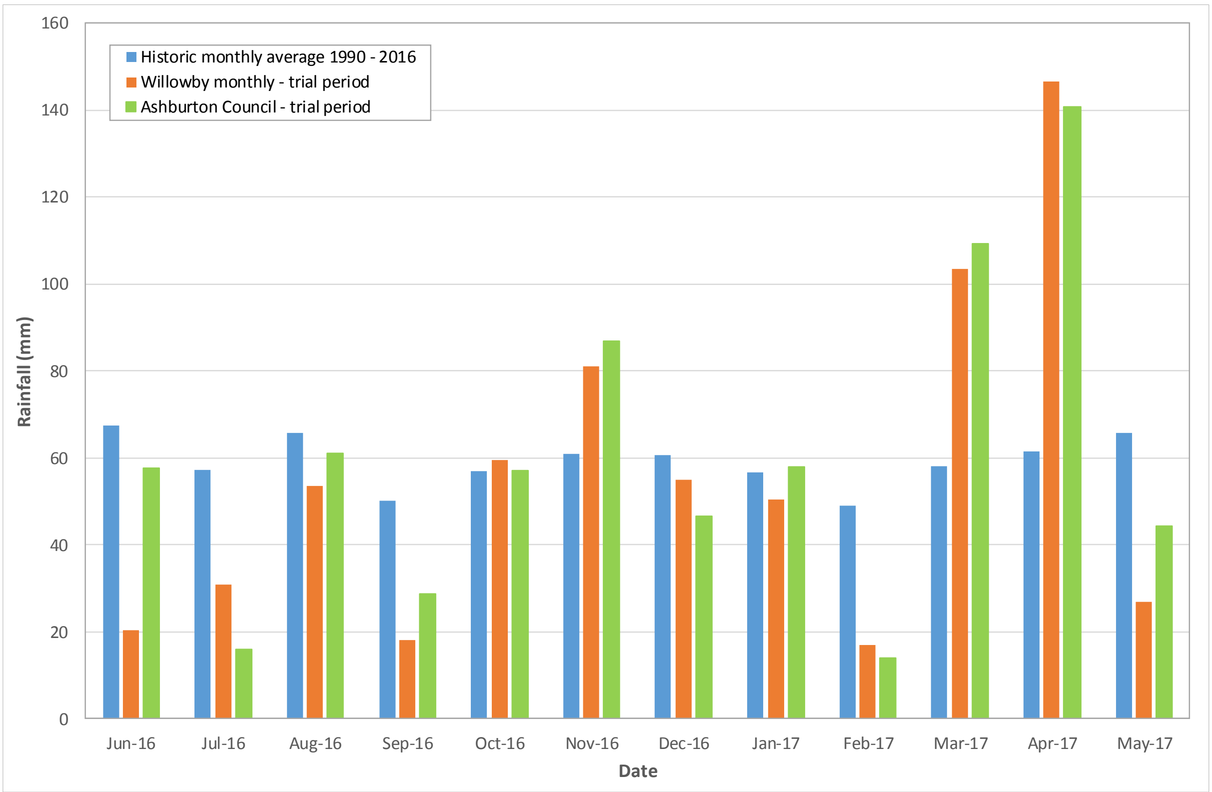

Figure B4: Monthly rainfall during Pilot Trial compared to Ashburton District Council monthly averages 1990 – 2016.

2.3 Daily Rainfall during Pilot Trial Operational Period

Daily rainfall for the Willowby and Ashburton District Council monitoring sites is presented in Figure B5, together with the 30 mm compliance criteria line, above which the Pilot Trial is to shut-down (refer Appendix A).

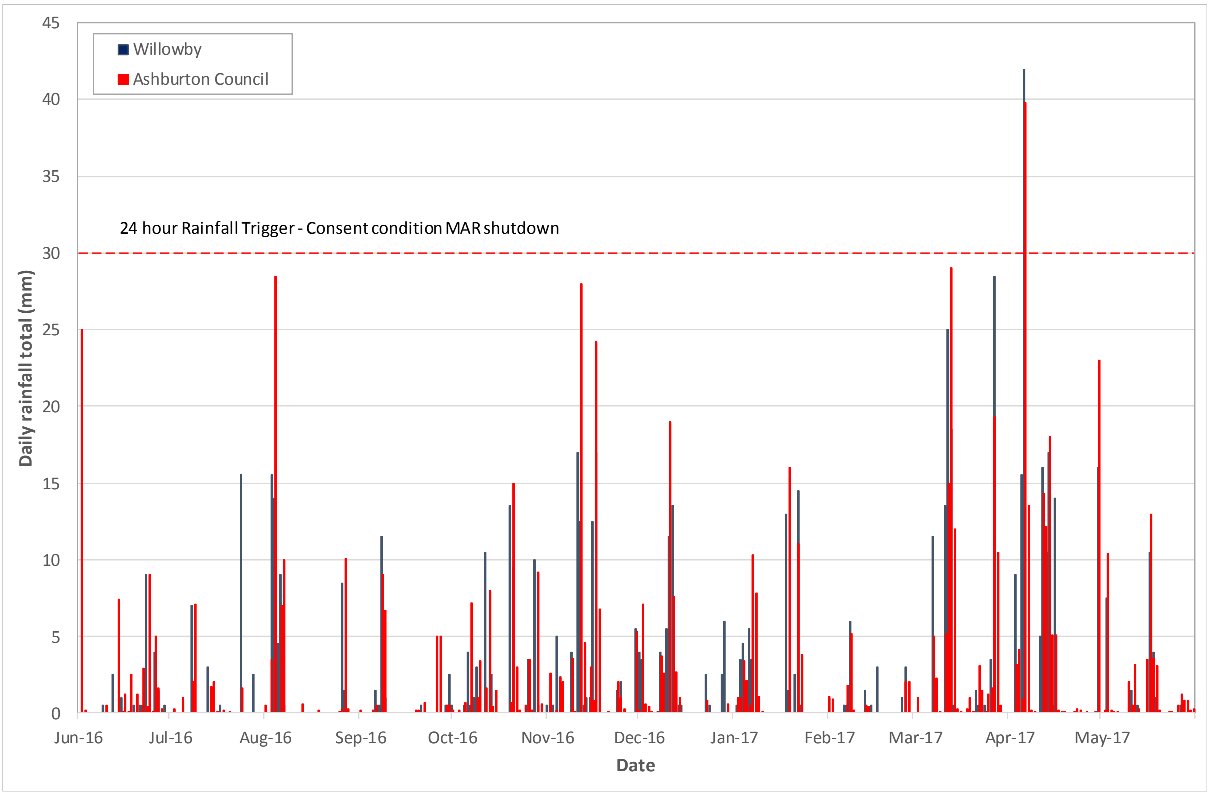

Figure B5: Daily rainfall recorded by Willowby and Ashburton District Council monitoring stations during the trial period.

There is no clear correlation in daily rainfall data between the Willowby and Ashburton Council weather stations from the commissioning of the Willowby station up to the start of the Pilot Trial (Figure B6). The correlation in daily rainfall data during the period of the Pilot Trial is however substantially stronger (Figure B7), possibly reflecting the longer period analysed. Irrespective of the stronger correlation identified for the Pilot Trial period, the data indicates rainfall events within the catchment can often be localised. For this reason, evaluation of groundwater responses around the Pilot Trial area to rainfall events needs to consider the rainfall records from both climate stations.

3.0 POTENTIAL EVAPOTRANSPIRATION

3.1 Monthly Potential Evapotranspiration

Potential evapotranspiration (PET) data has been recorded at the Ashburton Aero AWS weather station since 2006 (Table B3). Annual PET was substantially greater than the 2006 to 2016 average during both 2015 and 2016 (Figure B8). Monthly PET data recorded during the trial period is similar to the monthly PET averaged over the longer record (Figure B9).

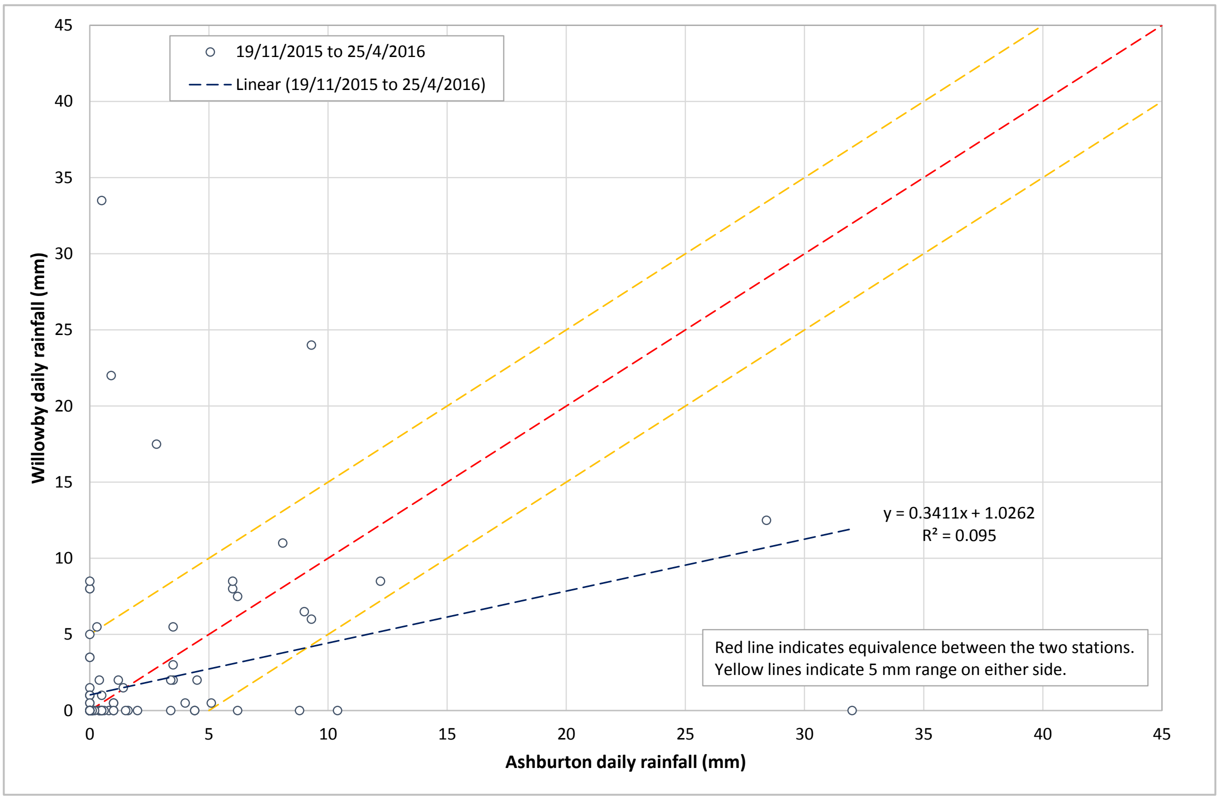

Figure B6: Correlation of pre-trial daily rainfall between Willowby and Ashburton District Council monitoring stations.

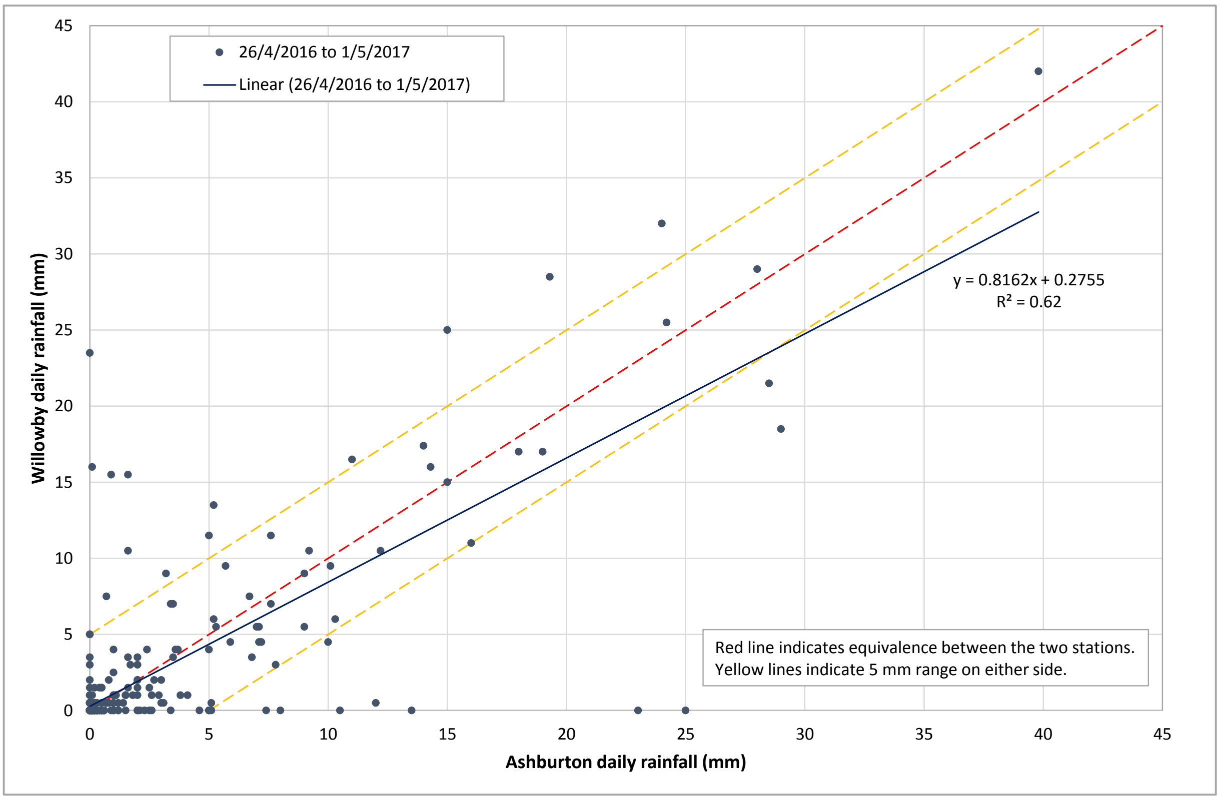

Figure B7: Correlation of trial period daily rainfall between Willowby and Ashburton District Council monitoring stations.

Table B3: Monthly PET Ashburton Aeroclub climate station 2006 to 2017.

Year	Monthly PET (mm)												Annual
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
2006			77.6	61.0	20.7	18.6	22.9	44.6	69.8	111.9	128.4	116.2	
2007	100.3	94.7	90.1	46.0	40.2	20.8	19.7	31.2	59.5	106.2	110.1	126.9	845.1
2008	150.3	111.0	79.8	43.0	22.4	22.8	19.6	27.0	72.5	107.6	139.5	135.1	930.6
2009	170.5	80.9	86.7	60.1	30.9	14.7	20.1	59.0	86.4	87.6	124.2	121.4	942.5
2010	127.5	112.1	93.6	65.7	23.7	14.9	15.1	28.8	76.3	107.1	132.4	147.6	944.8
2011	125.7	110.5	89.2	45.8	28.1	13.2	28.3	35.9	60.5	81.4	125.9	132.4	876.9
2012	139.3	91.2	83.0	48.0	28.5	21.0	19.0	26.9	68.8	95.2	102.8	137.7	861.4
2013	161.7	107.6	79.4	44.3	26.6	15.7	32.8	36.0	58.2	106.4	107.2	126.5	902.4
2014	149.5	105.7	69.5	28.7	38.5	13.3	23.6	42.8	58.2	94.7	147.9	134.4	906.8
2015	148.2	118.4	84.9	52.3	37.4	27.7	27.5	33.2	53.4	112.0	130.6	143.3	968.9
2016	107.3	133.0	92.6	54.0	44.3	15.4	25.7	37.5	46.5	97.5	129.6	158.7	942.1
2017	180.9	137.8	71.9	36.8	20.9								
Average	**141.9**	**109.4**	**83.2**	**49.9**	**31.0**	**18.3**	**22.9**	**36.5**	**66.4**	**101.0**	**124.9**	**132.2**	**912.2**

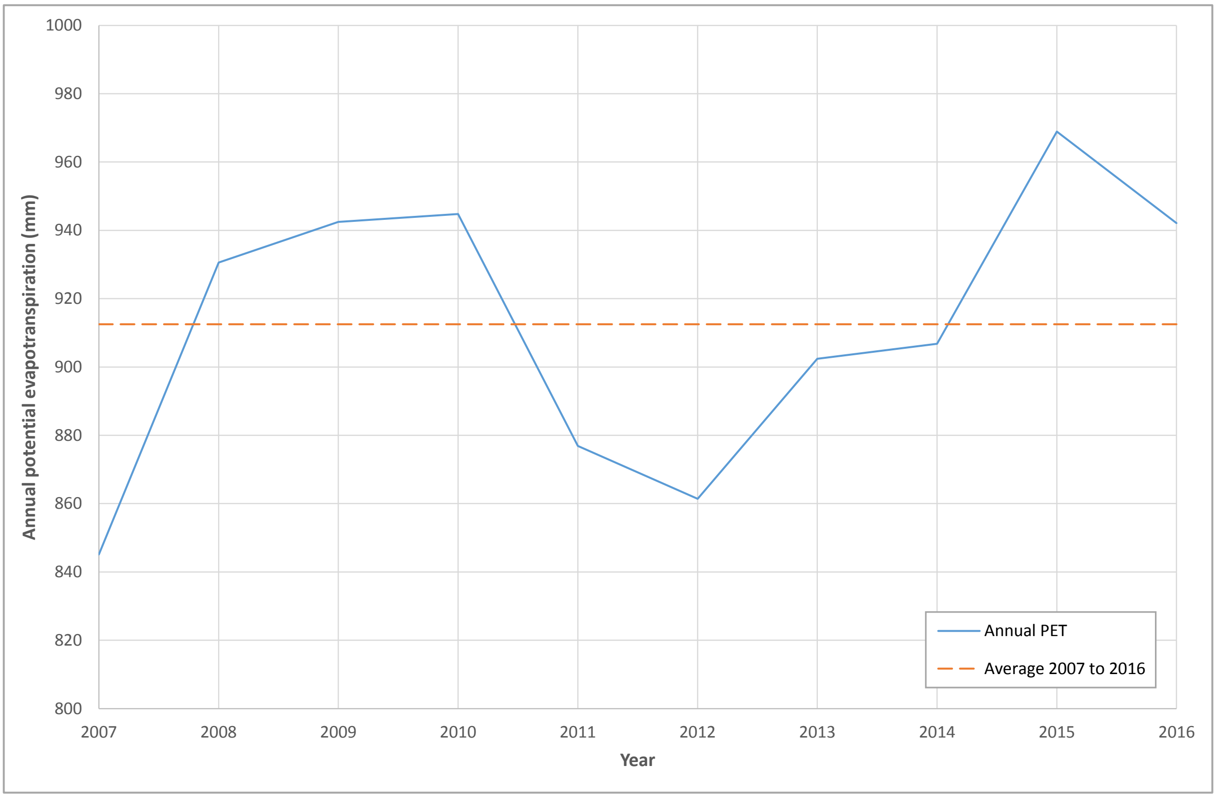

Figure B8: Annual potential evapotranspiration from the Ashburton Aero AWS 2007 - 2016.

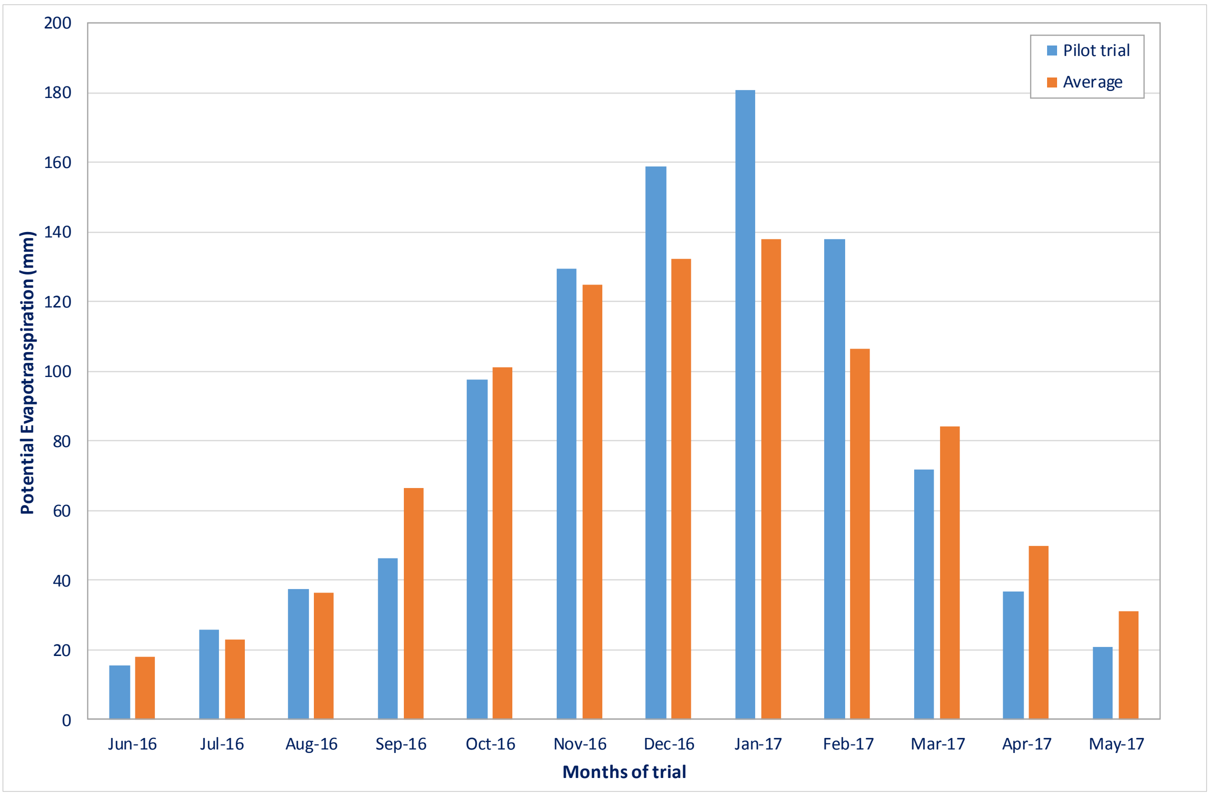

Figure B9: Monthly PET during Pilot Trial compared to monthly averages 2006 – 2016.

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 B10). Rainfall substantially exceeded PET during March and April 2017.

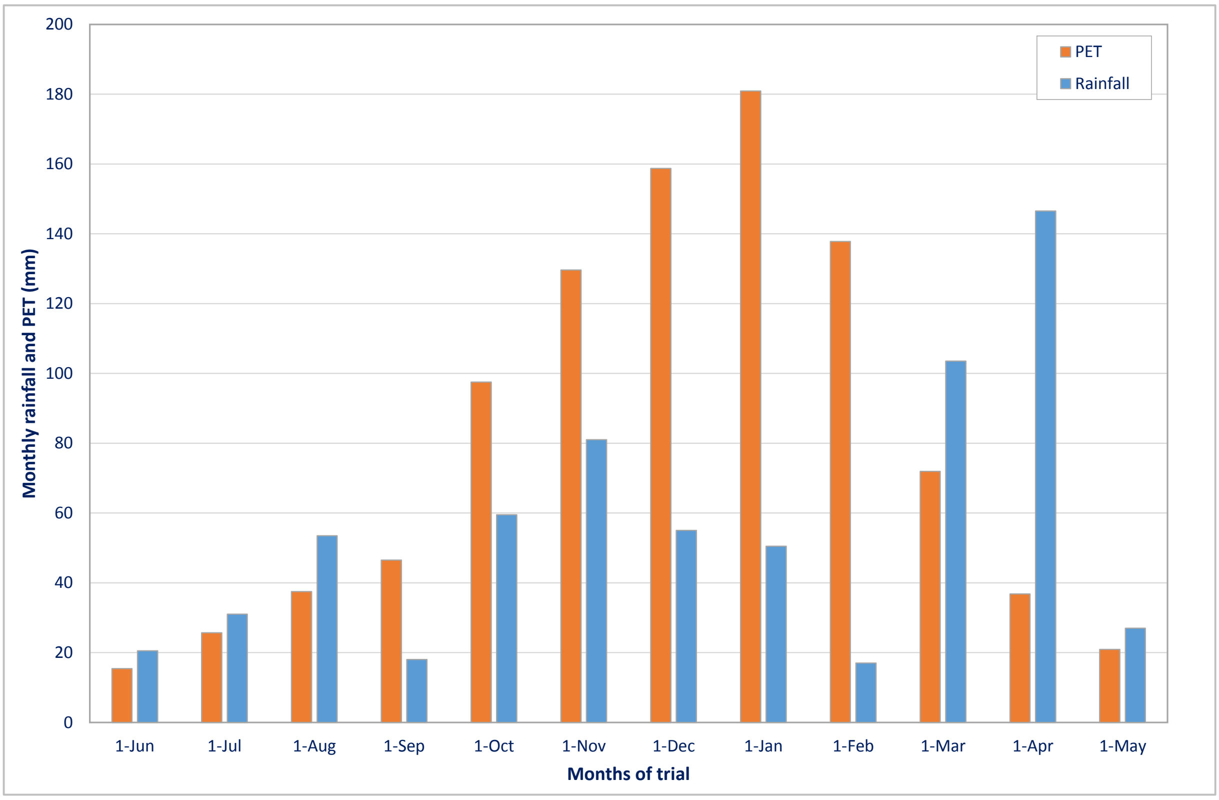

Figure B10: Comparison of monthly rainfall to potential evapotranspiration during the Pilot Trial.

3.2 Daily PET during Pilot Trial Operational Period

There is a strong seasonal trend in daily PET observed during the Pilot Trial period, linked directly to seasonal air temperature variation. Rainfall events exceeding 5 mm were scattered evenly throughout the year. The larger rainfall events were recorded during March and April 2017 (Figure B11), during a period of correspondingly lower than average PET (Figure B9).

4.0 CONSENT COMPLIANCE

A condition of consent for the operation of the Pilot Trial was that Pilot Trial basin inflows should cease if rainfall over a 24 hour period exceeded 30 mm.

Rainfall recorded on a daily basis at the Willowby station during Year 1 only exceeded 30 mm on 6 April 2017 (Figure B11). However, rainfall recorded on a running 24 hour basis identified two rainfall events that triggered consented MAR site shutdowns (> 30 mm/24 hours):

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

2) 56 mm fell between 14:30 on April 5 2017 and 14:20 on April 6 2017.

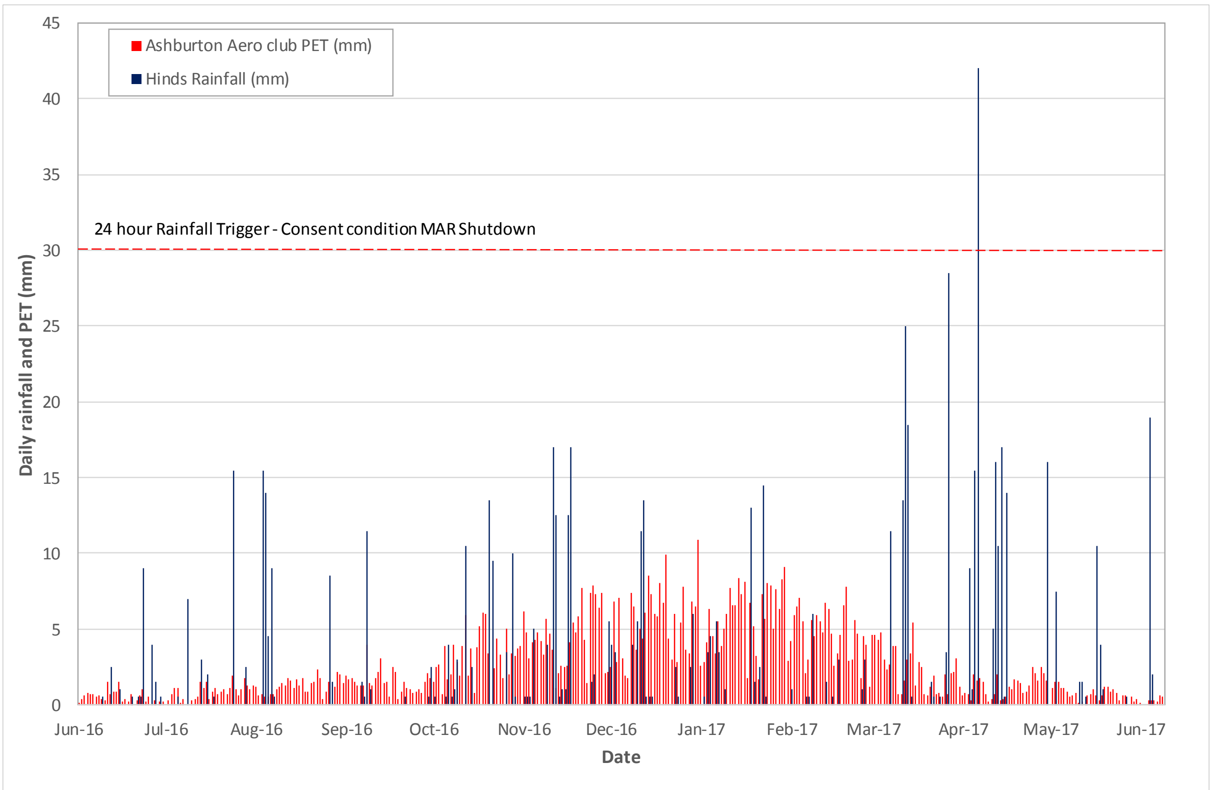

Figure B11: Daily rainfall and PET during Pilot Trial.

Site operations at the MAR Pilot Trial ceased for a shutdown period during:

- Event 1 from 15:30 on 27 March to 11:15 on 29 March
- Event 2 from 09:15 on 6 April to 13:45 on 9 April 2017.

Flows also ceased on 9 April 2017 for Valetta operational reasons (Appendix D). The Pilot Trial therefore operated in compliance with this consent condition.

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APPENDIX C

Pilot Trial Monitoring System

1.0 MAR PILOT TRIAL MONITORING PROGRAMME

1.1 Overview

A site at the corner of Frasers Road and Timaru Track Road in the Hinds Plains catchment was selected as the preferred location for the infiltration basins required for the Managed Aquifer Recharge (MAR) Pilot Trial (Pilot Trial). The site is bordered by two farm ponds to the north-east and an existing water race to the south-west. The infiltration basin is approximately 1.1 ha in size. In addition, flow control equipment was installed on site to enable infiltration rates to be monitored. A groundwater and surface water level and quality monitoring programme was instigated both on-site and within the wider catchment in support of the trial.

The monitoring programme was designed to acquire data to support infiltration management at the site as well as analysis of the Pilot Trial objectives. This project encompasses three physical major programme components; groundwater, surface water and ecology. In all of these components both water quantity and quality are evaluated relative to the following fundamental questions:

- What is the baseline condition for these programme components in the MAR Pilot Trial catchment?
- How does the operation of a MAR site improve, degrade or generally influence the existing conditions?

The programme builds upon a network of existing State of the Environment (SOE) monitoring sites operated and managed by Canterbury Regional Council (CRC). These sites include flow sites, groundwater monitoring bores and ecological survey locations. Additional monitoring for this area comes in the form of community efforts including the Hinds Drains Working Party (HDWP), which worked with DairyNZ, CRC and Fish and Game to monitoring ecology, water quality and flow in the coastal spring-fed waterbodies (drains). Further monitoring was implemented to specifically target key surface and/or groundwater areas likely to be influenced by MAR operations. Finally, a strategic partnership with Canterbury District Health Board, monitored drinking water bores in the project area, which helped to fill out the complete programme objectives.

Details of the monitoring programme specifically implemented for the MAR related objectives stated above for Year 1 of the MAR Pilot Trial, including both pre-existing and new monitoring sites, are documented in this appendix. Other appendices attached to the main report provide detailed information with respect to other monitoring locations and information used to complement this programme (e.g., drinking water monitoring).

1.2 Objectives

The Pilot Trial monitoring programme was designed to provide sufficient data to achieve the following objectives.

Water flows and levels

1) Quantify site effectiveness at recharging water to the underlying aquifer.
2) Assess local groundwater mounding / pressure responses to the recharge operations.
3) Assess long-term groundwater storage / level responses in the underlying aquifer.
4) Track the transport and fate of recharge water within the groundwater system and at discharge zones.
5) Distinguish the changes in drain discharge flows induced by MAR from natural flow variations.
6) Differentiate between groundwater recharge due to MAR and groundwater recharge related to water level changes in the Ashburton River.
7) Monitor the effects of the Pilot Trial against developed trigger conditions.

Water quality

8) Ensure only high quality water is recharged to the aquifer by the Pilot Trial.

9) Delineate the effects of the recharged water on nitrate nitrogen (nitrate-N) concentrations in the groundwater system.

10) Evaluate processes for the removal of nitrogen from groundwater.

Other objectives

11) Link the results of the Pilot Trial back to the ecological and cultural aspirations for the spring-fed waterbodies and groundwater-dependent ecosystems in the catchment.

12) Provide relative and complementary information to support the MAR Science Programme projects including drinking water and automated nitrate-N tracking.

13) Support ongoing optimisation of the monitoring programme.

1.3 Monitoring Programme Layout

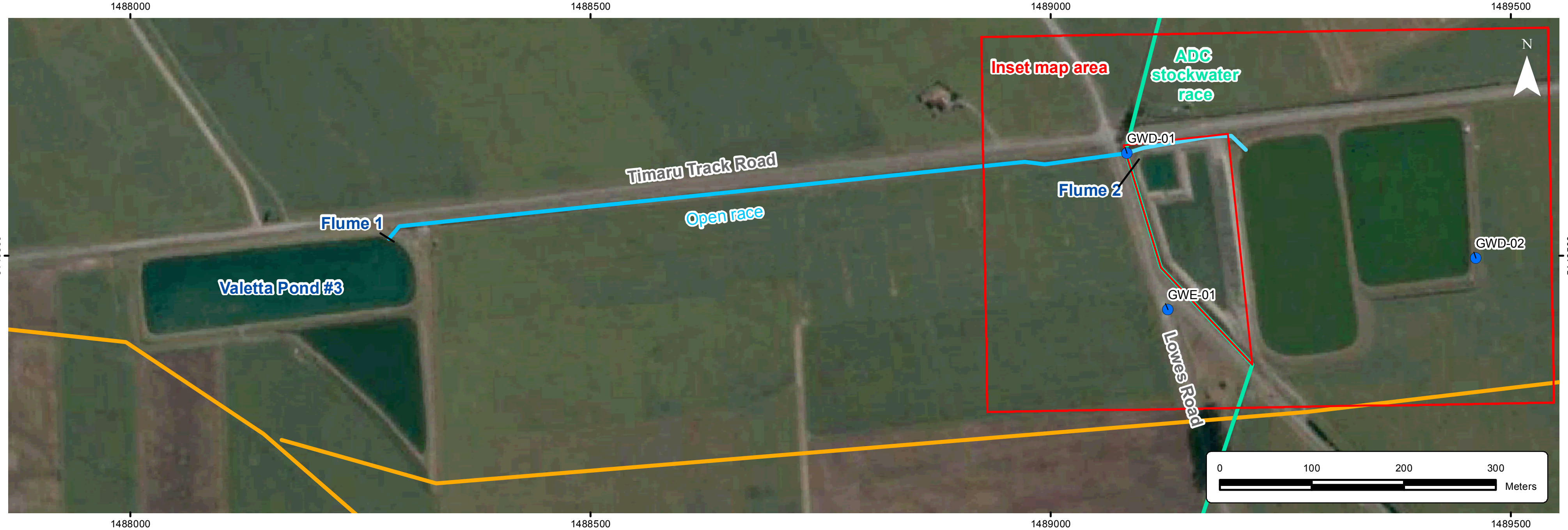
The MAR Pilot Trial monitoring programme needs to be visualised at different scales to gain a good understanding of the monitoring programme as a whole:

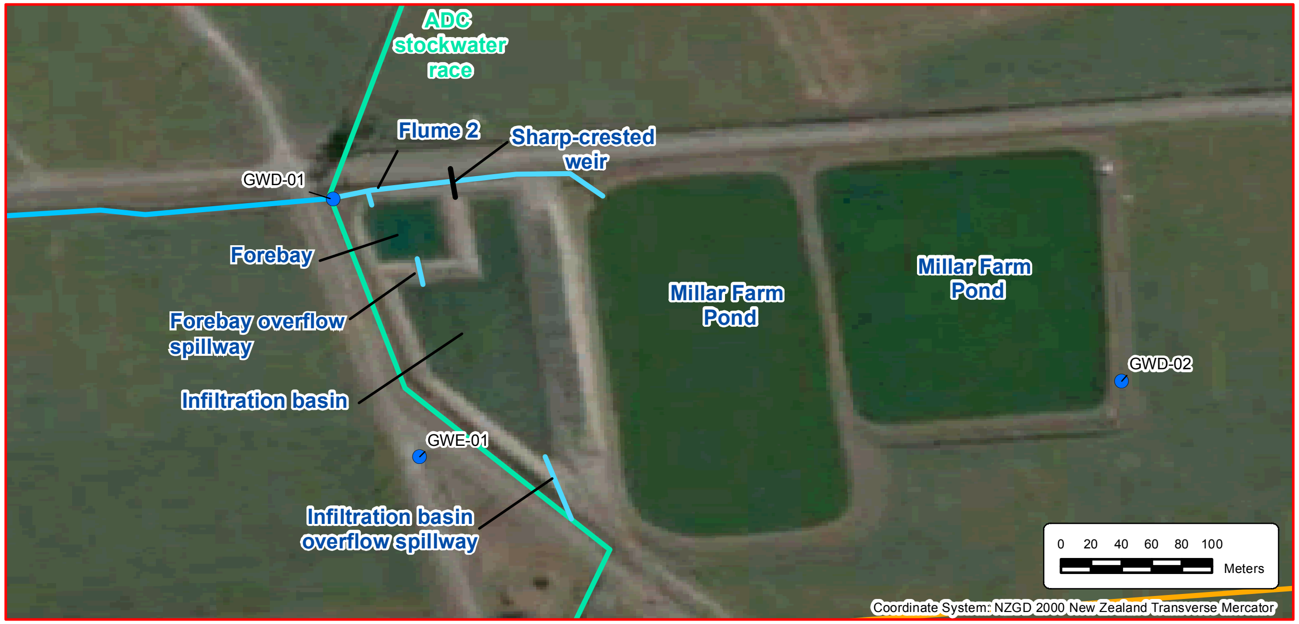
- At the site scale, the monitoring programme includes the water flow and quality monitoring stations on the water race that delivers source water to the Pilot Trial site, water level and quality monitoring in the main infiltration basin and two monitoring wells adjacent to the site (Figure C1).
- At a local area scale, the monitoring programme includes the monitoring wells influenced by MAR operations during Year 1 of the Pilot Trial as well as near field monitoring wells used to evaluate background groundwater level and quality trends for comparison with the MAR influenced wells (Figure C2).
- At a sub-regional scale, the monitoring programme includes all of the monitoring wells installed or accessed for groundwater level and quality data during Year 1 of the trial, together with the surface water flow, ecology and climate monitoring stations (Figure C3).

2.0 CLIMATE

It was important to collect meteorological data for the Hinds Plains to fully understand the hydrologic system within the area. NIWA has been collecting data at several locations within the catchment for many years and has weather stations located at both the Ashburton Council and Airport (Table C1). The climate data used to support the analysis of the Pilot Trial results is summarised in Appendix B.

In addition to the two NIWA weather stations located in Ashburton, a CRC weather station was installed on the Hinds Plains (Figure C3, Table C1) to collect rainfall data used to represent the project area. This near real-time data was available on the CRC website and was used as monitor the basin shut-down trigger condition.





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.

Golder Associates

TITLE HINDS MAR PILOT TRIAL SITE MONITORING PROGRAMME

JULY 2017

PROJECT 1538632

C1

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Golder Associates

TITLE PILOT TRIAL LOCAL AREA MONITORING SITES

AUGUST 2017

PROJECT 1538632

C2

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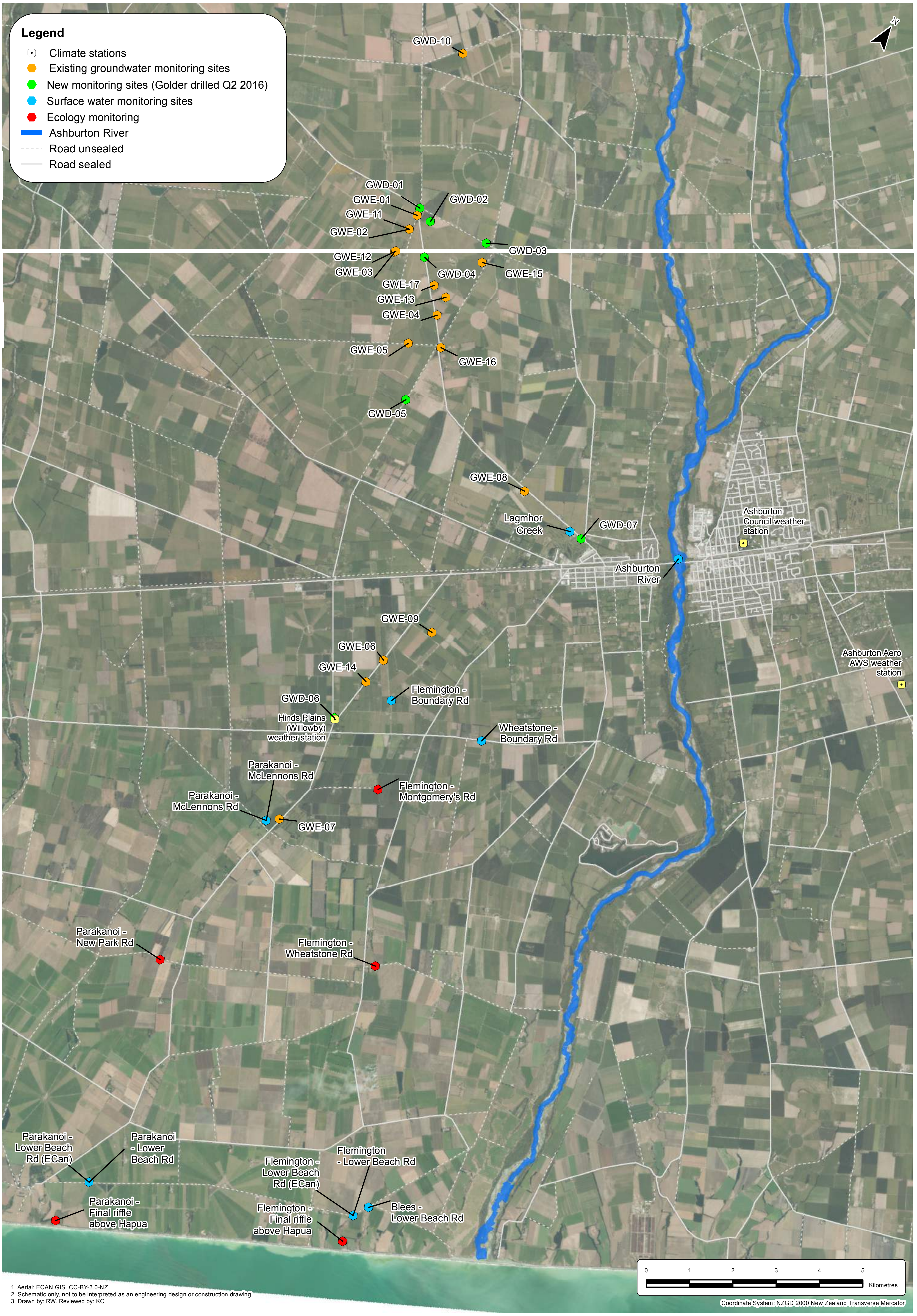

1. Aerial: ECAN GIS. CC-BY-3.0-NZ
2. Schematic only, not to be interpreted as an engineering design or construction drawing.
3. Drawn by: RW. Reviewed by: KC

Golder Associates

TITLE Pilot Trial Wide Area Monitoring Sites

JULY 2017

PROJECT 1538632

C3

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Table C1: Climate monitoring summary.

Station ID	Status	Easting (NZTM)	Northing (NZTM)	Parameters measured	Start date
Ashburton District Council (NIWA #4778)	Pre-existing	1499615	5138625	Rainfall, temperature	Jan 1927
Ashburton Aero AWS (NIWA #26170)		1503633	5138717	Rainfall, temperature, potential evapotranspiration (PET)	Feb 2006
Hinds Plains (Willowby) (CRC #319610)	New	1494238	5129856	Rainfall, Temperature	Nov 2015

3.0 ECOLOGICAL MONITORING

3.1 Introduction

The overall project goals, phases and tasks are presented in the Project Statement for the Hinds MAR Pilot Trial (Golder 2015c). Aquatic ecology monitoring of receiving spring-fed streams was not specified in the Project Statement. However, biological monitoring was to be undertaken to determine if the potential physical and hydrochemical changes brought about by the MAR Pilot Trial would be reflected in their biological communities.

The ecological monitoring was undertaken to:

1) Establish a baseline database for the monitoring sites listed in Table C2.

2) Identify ecological and water quality changes over time that may arise as a result of the arrival of MAR influenced water at monitoring sites on the Parakanoi and Flemington Drains (Table C2).

These two spring-fed waterbodies were selected for investigation as they are located down-gradient from the MAR Pilot Trial site and had particular ecological and cultural values identified by the Hinds Drains Working Party (HDWP, 2016). This ecological monitoring was to occur in conjunction with the proposed surface quality and groundwater quality and level monitoring programme during Year 1 of Pilot Trial operations.

Table C2: Water quality and aquatic ecology monitoring sites.

Sites on Flemington Drain	Sites on Parakanoi Drain
Montgomery's Road	Upstream of Osborne's Road [1]
Wheatstone Road	New Park Road
Lower Beach Road [2]	Long Beach Road [2]
Final riffle above Hapua	Final riffle above Hapua

Notes: 1) Aquatic ecology sampling only as water quality sampling will be occurring at this site as part of Task 3e.
2) Aquatic ecology sampling only as CRC will continue existing surface water quality monitoring programs at these sites.

A total of twelve monitoring rounds were proposed under this programme, with Golder ecological field staff working specifically with Dr Duncan Gray (CRC) on the programme implementation. The timing of these sampling rounds was based on the assumption of at least monthly monitoring during Year 1 of the Pilot Trial. During key high rainfall events, additional site checks were also planned, with a minimum of photo documentation of the sites during these events.

3.2 Existing Ecological Monitoring

The sites were designated to build upon the HDWP survey work done from 2014 through to 2016 (HDWP, 2016) and ongoing work done by CRC to quantify the health and status of these waterways (Meredith, 2014). Additional historical information with respect to the ecology of these coastal drains has been collected by the Department of Conservation (DOC, mudfish) and New Zealand Fish and Game (trout). Many of these drains are also a cultural food gathering source, with long and short fin eels and other native species constituting a resource for the local iwi.

The new ecological survey locations were added to complement the existing information. The objectives for these sites are however specifically focused on trying to measure change relative to the overarching MAR Pilot Trial objectives.

3.3 Pilot Trial Monitoring Programme

Field sampling and monitoring to be undertaken by Golder under this ecological monitoring programme included:

- Water quality sampling at six of the eight sites listed in Table C2. This sampling included in-situ measurements with a handheld meter, as well as taking water samples for laboratory analysis. Parameters for laboratory analysis are specific to ecological monitoring, which complements the wider MAR Pilot Trial water quality monitoring programme. These parameters were chosen by CRC staff Dr Duncan Gray and Dr Adrian Meredith, and include:
  - i) Turbidity
  - ii) Total suspended solids
  - iii) Total nitrogen
  - iv) Total ammoniacal nitrogen
  - v) Nitrate-N plus nitrite-N
  - vi) Total phosphorus
  - vii) Total dissolved phosphorus
  - viii) Dissolved reactive phosphorus
  - ix) Dissolved organic carbon
- Rapid assessments of in-stream habitat, riparian condition, periphyton cover, macrophyte cover/volume at all eight sites listed in Table C2, in line with methods set out in New Zealand stream habitat assessment guidelines (Harding et al. 2009).

The key deliverables for the ecological monitoring program were:

- Site-specific information relative to each of the aquatic ecology monitoring sites including GPS location, property ownership and contact information (where relevant).
- Water quality data from samples collected using a methodology and rigor consistent with the water quality sampling to be undertaken under Task 3e of the Hinds Pilot Trial project statement (Golder 2015a).
- Accurate and consistent aquatic ecology data in digital format (MS Excel file and photographs).

A full description of the analysis and results for this portion of the monitoring programme is available in Appendix M.

4.0 PILOT TRIAL SITE WATER MONITORING

4.1 Quantity

Two weirs (Flumes 1 and 2) were installed at the MAR Pilot Trial site (Figure C1) to monitor:

- Outflows from Valetta Pond #3 (MMT1)
- Inflows to the infiltration basin forebay (MMT2)

The weirs were equipped with vented pressure transducers to continuously measure upstream water levels (15 minute intervals). Manual gaugings were undertaken during the Pilot Trial to provide calibration data for flow rating curves for each weir. Manual water level measurements were also taken at intervals to verify the pressure transducer calibration. Flow ratings measurements for the on-site flumes are presented in Appendix E.

The overflow spillway from the main infiltration basin to the adjacent ADC stockwater race was also set up to monitor any surface water discharges from the MAR site. A stage level recorder installed in the main infiltration basin recorded water levels for several purposes, including quantifying any outflows from this basin. During Year 1 of the Pilot Trial no overflows from the main infiltration basin occurred, so no flow rating measurements are available for the spillway.

Flow management for operational purposes at the Pilot Trial also relied on the availability of near real-time flow information from Valetta's network monitoring system as well as RDRML's flow monitoring systems.

4.2 Quality

Baseline source water quality data for the project was derived from samples taken from the Rangitata River at RDRML Klondyke diversion. RRDML provided data from monthly water quality samples collected since 2012.

Specific to the Pilot Trial, two water quality samples were taken for laboratory analysis in May 2015 to assess baseline quality of the recharge water. One sample was taken from the RDR Klondyke diversion and the other from Valetta pond #3 (Figure C1).

Valetta Pond #3 is the reference location for the measurement of *source water quality* entering the MAR Pilot Trial site (through Flume 1). Prior to the commencement of the Pilot Trial, Valetta Pond #3 was purged and cleaned to remove many years of accumulated algae and to reduce the pond's attractiveness to water fowl as a feeding (dabbling) site. In order to manage possible water quality issues relating to the use of standing water (defined as water sitting in ponds through entire non-irrigation season), a bypass gate was built into the MAR site designs redirecting water to the Millar Farms ponds (adjacent). As Valetta Pond #3 is the control site to measure *source water quality*, monthly samples were collected and sent to two accredited laboratories; the Canterbury Feed and Assessment Laboratory in Ashburton for *E. coli* and total coliforms, and Hill Laboratory in Christchurch for all other analytes. These samples were obtained and analysed to ensure that the quality of *source water* was carefully monitored throughout the recharge operations. The analysis parameters are listed in Table C3.

The existing water race (termed the 'MAR Stockwater Race') that delivers water from Valetta Pond #3 to the Pilot Trial site loses water (incidental recharge) to the underlying groundwater system. Water quality was also measured in the stockwater race in the trial to provide a reference to other recharge sources in close proximity to the MAR site.

Field measurements of electrical conductivity, turbidity, pH and temperature were made on all occasions that samples were obtained for laboratory analysis.

Table C3: Summary of water quality sampling parameters (Year 1).

Frequency	Sample Location: E. coli (MPN/100 ml)	Total coliforms (MPN/100 ml)	Turbidity (NTU)	pH	Electrical conductivity (mS/m)	Total suspended solids (g/m^3)	Nitrogen (1) (g/m^3)	Dissolved reactive phosphorus / total phosphorus (g/m^3)	Hardness (g/m^3 as HCO_3)	Anions, cation profile (2) (meq/L)	Dissolved metals (3) (g/m^3)
Pre-trial (May 2015)	Pilot Trial source water (Valetta Pond #3)	Parameter not sampled			Pilot Trial source water (Valetta Pond #3)		Parameter not sampled				
Pre-trial (May 2016)	All source water, selected surface water and selected groundwater sites		Selected surface water and selected groundwater sites								
Monthly	First six months of Year 1: all source water, surface water and groundwater sites Final six months of Year 1: selected source water, surface water and groundwater sites		All source water, surface water and groundwater sites					First sample round after a new site was added during Pilot Trial			
End of Year 1	Selected source water, surface water and groundwater sites		All source water, surface water and groundwater sites					Parameter not sampled			

Notes: 1) Three forms of nitrogen analysed (total nitrogen, nitrite-N, and nitrate-N.
2) Ca, Mg, Na, K, hardness, alkalinity, bicarbonate, carbonate, SO_4 and Cl.
3) As per Hills Laboratory NZDW suite for metals

5.0 HINDS CATCHMENT SURFACE WATER MONITORING

5.1 Quantity

The surface water monitoring associated with the Pilot Trial was planned to address three primary objectives:

1) To provide data to enable the interaction between the Ashburton River and the local groundwater system to be evaluated.

3) To monitor the effects of the recharge project on the down-gradient coastal drains.

4) To provide a baseline for conditions in these highly impacted, coastal drains to complement both the ecological and water quality sampling programmes.

For the Ashburton recharge specific research questions, data from a CRC operated flow monitoring station on the Ashburton River was acquired. In addition:

- A dedicated shallow groundwater monitoring well GWD-07 (Section 6.0) was installed near Tinwald.
- A rain gauge was installed at Willowby (refer Section 2.0)
- A surface water flow monitoring site consisting of a staff gauge and level logger was installed in Lagmhor Creek close to the Tinwald Golf Club, with quarterly downloads and rating measurements undertaken. The data and outcomes from this research project are documented in Appendix M.

Surface water flow monitoring in preparation for the MAR Pilot Trial began in December 2014, when CRC commissioned Golder to install weirs near the spring-heads of the Wheatstone, Flemington and Parakanoi Drains (Table C4). The purpose of these weirs was to identify the first point of likely influence from a future MAR site. The gauged sites were installed as v-notch weirs. These sites were transferred to CRC management in early 2016 and were incorporated into a wider Hinds coastal drains monitoring programme that CRC was supporting for the HDWP.

Other surface water flow monitoring sites (both temporary and permanent) in the area that may be influenced by MAR water over the duration of the Pilot Trial are also listed in Table C4. The locations of the flow sites on each coastal drain are distributed from the spring-heads to the coast. This distribution supports the evaluation of the spatially variable flows, quality and ecological conditions.

The level loggers installed by Golder to monitor flows in the Parakanoi, Flemington and Wheatstone Drains record water levels at 15 minute intervals, with the data downloaded quarterly. CRC manages these monitoring stations, including data downloads, flow gaugings and site maintenance. The data collected from site gaugings will be used to develop rating curves to calculate flows in these drains. However, during Year 1 of the Pilot Trial these streams have been predominantly dry.

5.2 Quality

Surface water quality is monitored at the flow monitoring sites on the Blees, Flemington and Parakanoi Drains on a monthly basis, and quarterly at the Wheatstone flow monitoring site (Table C3), provided there are flows in these drains at the time of site visits. To date the water quality data available from the Pilot Trial sampling programme is limited as these drains were predominantly dry during Year 1 of the Pilot Trial. These water quality data will be used to assess baseline water quality for spring-fed waterbodies’ down-gradient of the Pilot Trial site over the course of the Pilot Trial.

The HDWP monitors surface water quality at 27 sites in the coastal drains between the spring-heads and the coast. Over the full duration of the MAR Pilot Trial, nitrate-N results from this sampling may be used to support the assessment of the effects of MAR on water quality in the coastal drains.

In addition to the above surface water quantity monitoring, monthly water quality samples were taken from the Ashburton River and Lagmhor Creek during the Year 1 of the Pilot Trial.

Table C4: Primary flow monitoring sites for coastal spring-fed waterbodies.

Lead	Site	Type/Purpose	Parameters	Recording frequency
CRC	Ashburton River at SH1 (68801)	Flow station/CRC SOE and consenting	Flow, stage, temperature and quality	15-minute times series
CRC	Parakanoi at Lower Beach Road (69001)	Flow station/CRC SOE and consenting	Flow, stage and temperature	15-minute time series
CRC	Flemington at Lower Beach Road (69003)	Flow station/CRC SOE and consenting	Flow, stage and temperature	15-minute time series
CRC	Flemington at Lower Beach (69002)	Flow station/CRC SOE and consenting	Flow, stage and temperature	15-minute time series
CRC (Golder)	Lagmhor Creek at Tinwald Golf Course	Temporary flow station (instream rating)/MAR programme	Flow, stage and temperature (quality(1))	15-minute time series
CRC (Golder)	Flemington Drain upstream of Boundary Road	Temporary flow station (v-notch weir)/MAR programme	Flow, stage and temperature (quality(1))	15-minute time series
CRC (Golder)	Wheatstone Drain at Boundary Road	Temporary flow station (instream rating)/MAR programme	Flow, stage, and temperature (quality(1))	15-minute time series
CRC (Golder)	Parakanoi Drain at Mclennons Road	Temporary flow station (v-notch weir)/MAR programme	Flow, stage and temperature (quality(1))	15-minute time series
CRC (HDWP)	Flemington Drain at New Park Road	Temporary flow station (instream rating)/HDPW habitat programme	Flow, stage and temperature (quality(1))	15-minute time series
CRC (HDWP)	Flemington Drain at Montgomery road	Temporary flow station (instream rating)/HDPW habitat programme	Flow, stage and temperature (quality(1))	15-minute time series
CRC (HDWP)	Flemington at Wheatstone Road	Temporary flow station (instream rating)/HDPW habitat programme	Flow, stage and temperature (quality(1))	15-minute time series

Note: 1) Quality of surface water was incorporated into the ecological field programme and reported in Appendix N.

6.0 HINDS CATCHMENT GROUNDWATER MONITORING

6.1 Introduction

Groundwater level and quality monitoring was undertaken in the Hinds MAR Pilot Trial Command Area prior to the start of the Pilot Trial and during Year 1 of the trial. Monitoring at most of the sites documented below is ongoing and expected to continue during Year 2 of the Pilot Trial. With respect to the groundwater monitoring programme:

- The monitoring programme for the period prior to the start of the Pilot Trial is described in Section 6.2.
- The monitoring programme during Year 1 of the Pilot Trial is described in Section 6.3.

- CRC well cards for the wells monitored during Year 1 of the Pilot Trial are provided in Section 7.0 below.
- Borehole logs for the monitoring wells installed as part of the Pilot Trial programme are provided in Section 8.0 below.

6.2 Pre-trial Monitoring

6.2.1 Quantity

Monthly and hourly groundwater level data collected by CRC from the regional groundwater monitoring network has been acquired to enable an evaluation of the baseline groundwater regime relevant to the Hinds MAR Command Area (Table C5). In addition, groundwater level and temperature were continuously monitored using non-vented pressure transducers (15 minute recording intervals) at seven existing wells (Figure C2 and Figure C3) that are not part of the regional groundwater monitoring network. These transducers were deployed in January 2015 and monitoring at these wells is ongoing.

Table C5: Pre-trial groundwater monitoring programme summary.

Pilot Trial ID	Station ID	Description	Easting (NZTM)	Northing (NZTM)	Type	Monitoring start date
Monitored by CRC	K37/0980	CRC regional groundwater monitoring network	1492479	5137017	Standpipe piezometer	2003
	K37/0456		1496464	5136417		2003
	K37/1792		1494635	5126830		2004
	K37/0581		1498794	5124957		2003
	K37/0358		1495053	5135854		2004
	K37/0147		1496402	5135524		2006
	K37/2871		1491831	5131711		2009
	K37/0468		1493525	5130664		2006
	K37/1010		1494686	5122190		2009
	K37/0619		1498647	5123099		1997
GWE-01	K37/1748 & K37/1748 barometric	Additional wells with automated water level monitoring systems deployed by Golder.	1489140	5140430		Jan 2015
GWE-02	K37/0204		1489164	5140077		
GWE-03	K37/0357		1489204	5139667		
GWE-04	K37/0200		1490814	5138818		
GWE-05	K37/1749		1490656	5699514		
GWE-06	K37/0972		1494395	5131820		
GWE-07	K37/0351		1494533	5127409		
GWE-10	K37/0215		1487848	5144112		

A transducer logging barometric pressure at 15 minute intervals was installed inside the casing at monitoring well GWE-01 (K37/1748) in January 2015. These barometric data are used to adjust groundwater level data for barometric pressure changes. Monitoring of barometric pressure at this site is ongoing.

6.2.2 Quality

CRC regularly samples water from monitoring wells both up-gradient and down-gradient of the MAR Pilot Trial site as part of the regional environmental monitoring programme. Monthly sampling is carried out by CRC at one site, quarterly monitoring at two sites and annual monitoring at three sites

One water quality sample was obtained from monitoring well GWE-01 for laboratory analysis in May 2015. Subsequently groundwater sampling for water quality analysis was initiated shortly before the start of the Pilot Trial (Table C6) and continued on a monthly basis during Year 1 of the Pilot Trial.

6.3 Pilot Trial Monitoring

6.3.1 Quantity

In addition to the existing wells monitored prior to the start of the Pilot Trial, eight further existing wells were selected through communication with landowners and CRC for groundwater level monitoring (Table C6). These additional monitoring wells were selected based on the following criteria:

1) Existing wells were screened to intercept the shallow aquifer system (e.g., ~30 m to 40 m bgl). If the well construction details were unknown and no log was available, the well was dipped to determine the depth to the base of the well.

2) Existing wells should ideally be un-pumped (not used).

3) Existing wells should allow for easy sampling of both quality and quantity.

4) Existing CRC monitoring wells should be used, if consistent with the other selection criteria.

5) Landowners should be notified and be willing to allow groundwater quality and quantity information to be collected.

Non-vented monitoring systems were installed in these eight wells to record groundwater levels and temperature.

Seven dedicated monitoring wells (GWD-01 to GWD-07) were installed as part of the MAR Pilot Trial to address potential data gaps in areas where there were no existing wells or the existing wells did not meet the selection criteria (Table C6, Table C7, Figure C2).

Data was recorded from the monitored wells listed in Table C6 to monitor both background groundwater levels within the Pilot Trial Command Area and changes to the local and regional groundwater system caused by the Pilot Trial. Groundwater level and temperature was continuously recorded (15 minute intervals) at these wells using non-vented pressure transducers and downloaded monthly. For calibration purposes, the water levels were also manually measured when the logger data was downloaded. Most of these transducers were deployed prior to commencement of the Pilot Trial and monitoring will continue after the first year of the Pilot Trial.

6.3.2 Quality

Water quality sampling of the receiving groundwater was undertaken one month prior to the start of the Pilot Trial, then monthly monitoring of 24 wells in total for at least the first year of the trial (Table C6,

Table C7, Table C8). Three of these wells were selected during the first months of the Pilot Trial to fill gaps where the current data was thought to be lacking. A number of parameters were sampled throughout the trial (Table C7), with the constant monthly sampling round targeting Total Nitrates and E. *coli*.

Table C6: Groundwater monitoring programme summary.

<table>
<tr><th>Pilot Trial ID</th><th>Station ID</th><th>Description</th><th>Easting (NZTM)</th><th>Northing (NZTM)</th><th>Type</th><th>Quality start date</th><th>Quantity start date</th></tr>
<tr><td>GWE-01</td><td>K37/1748</td><td rowspan="13">Existing wells – quality and quantity</td><td>1489140</td><td>5140430</td><td rowspan="17">Standpipe piezometer</td><td>May 2016 (+ May 2015)</td><td rowspan="7">Jan 2015</td></tr>
<tr><td>GWE-02</td><td>K37/0204</td><td>1489164</td><td>5140077</td><td>Aug 2016 (dry previous)</td></tr>
<tr><td>GWE-03</td><td>K37/0357</td><td>1489204</td><td>5139667</td><td>May 2016</td></tr>
<tr><td>GWE-04</td><td>K37/0200</td><td>1490814</td><td>5138818</td><td>Jun 2016</td></tr>
<tr><td>GWE-05</td><td>K37/1749</td><td>1490656</td><td>5699514</td><td>Sep 2016 (dry previous)</td></tr>
<tr><td>GWE-06</td><td>K37/0972</td><td>1494395</td><td>5131820</td><td>Apr 2017 (dry previous)</td></tr>
<tr><td>GWE-07</td><td>K37/0351</td><td>1494533</td><td>5127409</td><td>Sep 2016 (dry previous)</td></tr>
<tr><td>GWE-08</td><td>K37/3052</td><td>1494768</td><td>5136645</td><td>Jun 2016</td><td>Jan 2016</td></tr>
<tr><td>GWE-09</td><td>K37/1938</td><td>1494937</td><td>5132738</td><td>Dry through trial</td><td>Apr 2016</td></tr>
<tr><td>GWE-10</td><td>K37/0215</td><td>1487848</td><td>5144112</td><td rowspan="3">Jun 2016</td><td>Jan 2015</td></tr>
<tr><td>GWE-12</td><td>K37/1540</td><td>1489205</td><td>5139467</td><td rowspan="2">Jun 2016</td></tr>
<tr><td>GWE-14</td><td>K37/0383</td><td>1494355</td><td>5130930</td></tr>
<tr><td>GWE-17</td><td>K37/2538</td><td>1490378</td><td>5139341</td><td>Sep 2016</td><td>Sep 2016</td></tr>
<tr><td>GWE-11</td><td>K37/1747</td><td rowspan="4">Existing wells – quality only</td><td>1489166</td><td>5140074</td><td rowspan="2">Jun 2016</td><td rowspan="4">N/A</td></tr>
<tr><td>GWE-13</td><td>K37/1649</td><td>1490776</td><td>5139288</td></tr>
<tr><td>GWE-15</td><td>K37/2458</td><td>1490980</td><td>5140409</td><td rowspan="2">Aug 2016</td></tr>
<tr><td>GWE-16</td><td>K37/2603</td><td>1491330</td><td>5138244</td></tr>
<tr><td>GWD-01</td><td>BY20/0149</td><td rowspan="7">Golder drilled – quality and quantity</td><td>1489083</td><td>5140611</td><td rowspan="2">Twin piezometer</td><td rowspan="7">May 2017</td><td rowspan="7">Apr 2016</td></tr>
<tr><td>GWD-04</td><td>BY20/0152</td><td>1489821</td><td>5139744</td></tr>
<tr><td>GWD-02</td><td>BY20/0150</td><td>1489462</td><td>5140497</td><td rowspan="5">Standpipe piezometer</td></tr>
<tr><td>GWD-03</td><td>BY20/0151</td><td>1490768</td><td>5140823</td></tr>
<tr><td>GWD-05</td><td>BY20/0153</td><td>1491358</td><td>5136798</td></tr>
<tr><td>GWD-06</td><td>BY21/0183</td><td>1494234</td><td>5129843</td></tr>
<tr><td>GWD-07</td><td>BY20/0184</td><td>1496559</td><td>5136616</td></tr>
</table>

Table C7: Groundwater monitoring station objectives.

Pilot Trial ID	Station ID	Monitoring method	Objectives
GWE-01	K37/1748	Transducer (level, temp) 15 minute intervals, monthly download. Water quality samples, pre-trial and monthly. Manual GW level, monthly (CRC).	Monitor immediate groundwater level and quality response to infiltration.
	K37/1748 barometric	Transducer (barometric pressure) 15 minute intervals, monthly download.	Provide barometric correction data for groundwater monitoring.
GWE-02	K37/0204	Transducer (level, temp) 15 minute intervals, monthly download. Manual GW level and water quality samples, monthly.	Monitor groundwater level and quality response to infiltration down-gradient of the Pilot Trial site.
GWE-03	K37/0357	Transducer (level, temp) 15 minute intervals, monthly download. Water quality samples, pre-trial and monthly. Manual GW level and water quality samples, monthly.	
GWE-04	K37/0200		
GWE-05	K37/1749	Transducer (level, temp) 15 minute intervals, monthly download. Manual GW level and water quality samples, monthly.	
GWE-06	K37/0972		
GWE-07	K37/0351		
GWE-08	K37/3052		
GWE-09	K37/1938		
GWE-10	K37/0215	Transducer (level, temp) daily (CRC). Manual GW level and water quality samples, monthly.	Up-gradient control well monitoring background conditions.
GWE-11	K37/1747	Water quality samples, monthly.	Monitor groundwater quality response to infiltration down-gradient of the Pilot Trial site.
GWE-12	K37/1540	Transducer (level, temp) 15 minute intervals, monthly download. Manual GW level and water quality samples, monthly.	Monitor groundwater level and quality response to infiltration down-gradient of the Pilot Trial site.
GWE-13	K37/1649	Water quality samples, monthly.	Monitor groundwater quality response to infiltration down-gradient of the Pilot Trial site.
GWE-14	K37/0383	Transducer (level, temp) 15 minute intervals, monthly download. Manual GW level and water quality samples, monthly.	Monitor groundwater level and quality response to infiltration down-gradient of the Pilot Trial site.
GWE-15	K37/2458	Water quality samples, monthly.	Monitor groundwater quality response to infiltration down-gradient of the Pilot Trial site.
GWE-16	K37/2603		
GWE-17	K37/2538	Transducer (level, temp) 15 minute intervals, monthly download. Manual GW level and water quality samples, monthly.	Monitor groundwater level and quality response to infiltration down-gradient of the pilot trial site.
GWD-01	BY20/0149	Transducer (level, temp) 15 minute intervals, monthly download. Water quality samples, pre-trial and monthly. Sensor: nitrate-N tracking	Monitor immediate response to infiltration both in groundwater level and quality.

Pilot Trial ID	Station ID	Monitoring method	Objectives
GWD-02	BY20/0150	Transducer (level, temp) 15 minute intervals, monthly download. Water quality samples, pre-trial and monthly.	Monitor groundwater pressure response at the site and possible effects on existing ponds.
GWD-03	BY20/0151		Monitor groundwater response to the east of the site, to validate groundwater modelling.
GWD-04	BY20/0152	Transducer (level, temp) 15 minute intervals, monthly download. Water quality samples, pre-trial and monthly. Sensor: nitrate-N tracking	Track the recharge clean water plume breakthrough curve.
GWD-05	BY20/0153	Transducer (level, temp) 15 minute intervals, monthly download Water quality samples, pre-trial and monthly	Monitor groundwater response to the south east of the site, to validate groundwater modelling.
GWD-06	BY21/0183		Process management monitoring well with trigger groundwater levels.
GWD-07	BY21/0184		Monitor shallow groundwater near Tinwald. Distinguish changes induced by Pilot Trial from changes due to other recharge processes.
Monitored by CRC	K37/0980	Manual GW level, monthly	Provide data to assess groundwater level and quality responses to infiltration. Link to longer term regional groundwater level trends.
	K37/0456	Manual GW level, monthly	
	K37/1792	Transducer (level, temp) daily	
	K37/0581	Manual GW level, monthly	
	K37/0358	Water quality samples, monthly	
	K37/0147	Water quality samples, quarterly	
	K37/2871	Water quality samples, annual	
	K37/0468	Water quality samples, quarterly	
	K37/1010	Water quality samples, annual	
	K37/0619	Water quality samples, annual	

Table C8: Summary of groundwater monitoring well details.

Pilot Trial ID	Station ID	Well depth (m)	Screen location (m)	Well diameter (mm)
GWE-01	K37/1748	18.00	15.00 – 18.00	100
GWE-02	K37/0204	41.14	unknown	150
GWE-03	K37/0357	27.00	21.00 – 27.00	150
GWE-04	K37/0200	22.80	unknown	95
GWE-05	K37/1749	17.85	15.00 – 17.85	150
GWE-06	K37/0972	9.90	5.00 – 9.90	600
GWE-07	K37/0351	8.30	unknown	580
GWE-08	K37/3052	15.00	unknown	51
GWE-09	K37/1938	10.00	unknown	530
GWE-10	K37/0215	26.20	unknown	100
GWE-11	K37/1747	64.87	61.87 – 64.87	200
GWE-12	K37/1540	66.00	60.00 – 66.00	300
GWE-13	K37/1649	60.00	51.00 – 60.00	300
GWE-14	K37/0383	12.10	unknown	300
GWE-15	K37/2458	60.00	57.00 – 60.00	150
GWE-16	K37/2603	54.00	53.00 – 54.00	150
GWE-17	K37/2538	48.00	45.00 – 48.00	100
GWD-01	BY20/0149	32.00	23.00 – 32.00 26.00 – 32.00	50 32
GWD-02	BY20/0150	32.00	23.00 – 31.80	50
GWD-03	BY20/0151	46.00	33.45 – 45.45	50
GWD-04	BY20/0152	29.80	20.25 – 29.25 23.25 – 29.25	50 32
GWD-05	BY20/0153	34.00	25.10 – 30.50	50
GWD-06	BY21/0183	15.25	6.08 – 15.08	50
GWD-07	BY21/0184	10.52	4.50 – 10.52	50

Continuous monitoring of nitrate-N concentrations in groundwater was tested by Lincoln Agritech as part of the Pilot Trial (refer Appendix K). Two nitrate-N sensors were available and these sensors installed in several monitoring wells during Year 1 of the Pilot Trial, with different objectives and varying degrees of success due to issues with some of the wells. The systems installed were as follows:

- At the start of Year 1 a nitrate-N sensor was installed in monitoring well GWD-01 to monitor nitrate-N concentrations in the regional groundwater aquifer below the Pilot Trial site. This sensor was removed shortly after the trial started as remnant turbidity from the drilling process was affecting the readings.
- A nitrate-N sensor was installed in monitoring well GWD-04 on 19 June 2016 with the objective of monitoring the MAR water plume break-through curve down-gradient from the Pilot Trial site. Monitoring of nitrate-N concentrations in this well is on-going (refer Appendix K).
- After the MAR water plume front passed GWD-04, a nitrate-N sensor was installed in monitoring well GWE-17. This sensor was removed once groundwater abstraction for irrigation resulted in the groundwater table dropping below the cable length for the sensor.
- The above sensor was then installed in GWE-04, and subsequently removed as the groundwater level dropped beyond the cable length.

At the end of Year 1 only one nitrate-N sensor was still installed in a monitoring well at the Pilot Trial.

7.0 MONITORING BORE WELL CARDS

This section contains copies of well cards:

- From the CRC well database for existing wells used for the Pilot Trial monitoring programme.
- For the new monitoring wells installed by Golder to support the Pilot Trial monitoring programme.

The well cards document the locations of the monitoring wells and provide general notes regarding the monitoring well structure and any work done on the wells over time.

MAR project well number: **GWD-01**

ECan well number: **BY20/0149**

Summary

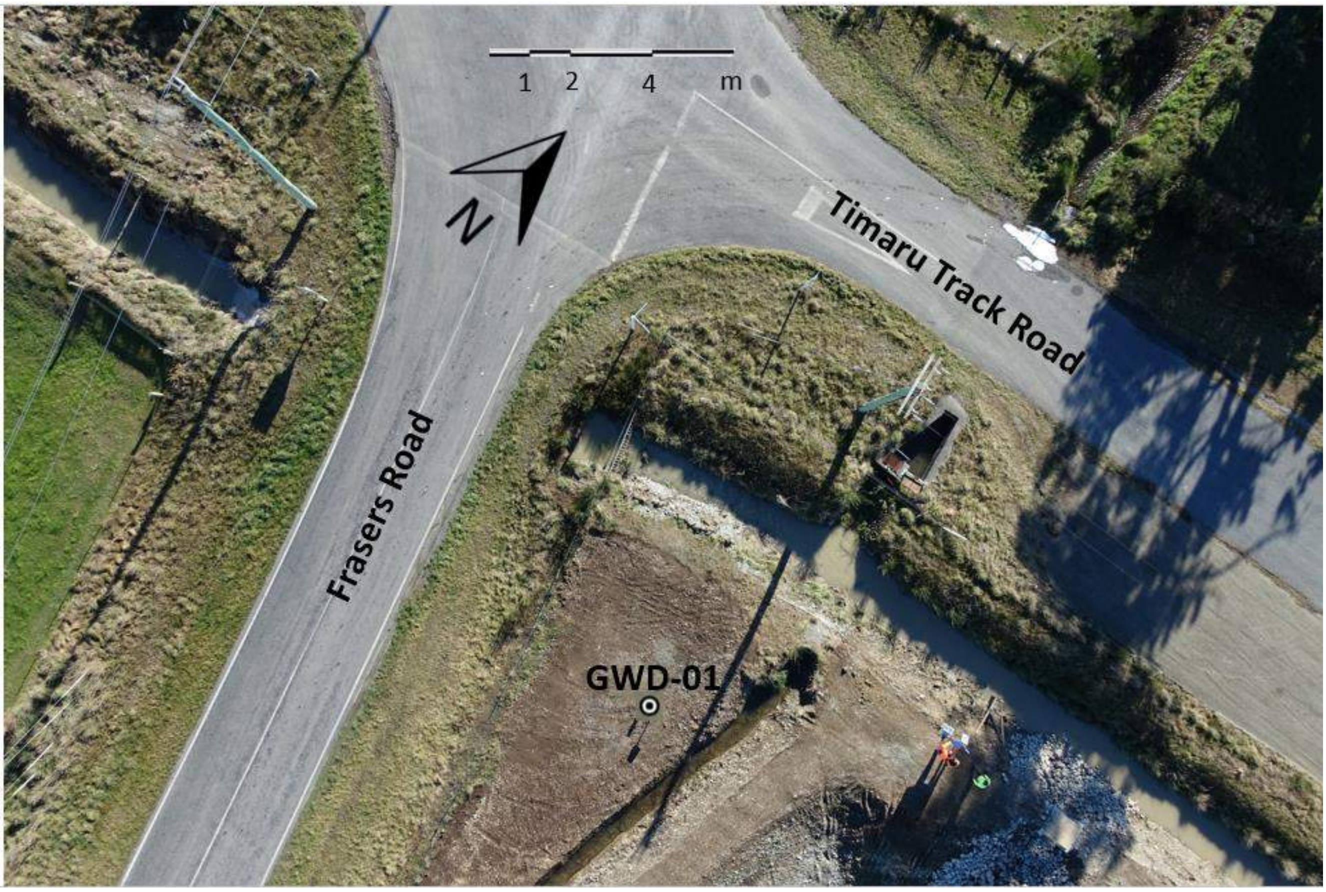
Landowner:	ADC – Andrew Guthrie (03 307 7741)
Location:	Corner Frasers Road and Timaru Track Road
Site Description:	Open land next to stockwater race on MAR site
NZTM X and Y:	1489083 E – 5140611 N
Ground Level Elevation:	141m above sea level
Uses:	Water level and water quality monitoring
Drill Date:	26/02/2016
Well Depth:	32m BGL
Well Diameter:	1 x 50mm pipe, 1 x 32mm pipe (2 piezometers nested)
Well Height:	0.407m above ground level (50mm pipe) 0.407m above ground level (32mm pipe)
Driller:	K. Morris & R Conkie (McMillan Drilling Ltd)
Drilling Method:	Sonic
Well Material:	2 x PVC piezometers and 1 x stainless steel cover

Screens

Screen number	Top of screen (m BGL)	Bottom of screen (m BGL)	Length of screen (m)
1 (50mm pipe)	23.0	32.0	9.0
2 (32mm pipe)	26.0	32.0	6.0

Bore photo (looking south):

Aerial photo:



MAR project well number: **GWD-02**

ECan well number: **BY20/0150**

Summary

Landowner:	Mark Dewhirst (027 227 7244)
Location:	Timaru Track Road
Site Description:	Open land near corner of irrigation pond
NZTM X and Y:	1489462 E – 5140497 N
Ground level Elevation:	137m above sea level
Uses:	Water level and water quality monitoring
Drill Date:	16/02/2016
Well Depth:	32.0m BGL
Well Diameter:	1 x 50mm pipe
Well Height:	0.680m above ground level
Driller:	K. Morris & R Conkie (McMillan Drilling Ltd)
Drilling Method:	Sonic
Well Material:	1 x PVC pipe and 1 x stainless steel cover

Screens

Screen number	Top of screen (m BGL)	Bottom of screen (m BGL)	Length of screen (m)
1	23.0	31.8	8.8

Bore photo (looking south):

Aerial photo:

MAR project well number: **GWD-03**

ECan well number: **BY20/0151**

Summary

Landowner:	Mark Sanders (027 435 4322)
Location:	Timaru Track Road
Site Description:	Open land just off road
NZTM X and Y:	1490768 E – 5140823 N
Ground Level Elevation:	132m above sea level
Uses:	Water level and water quality monitoring
Drill Date:	02/04/2016
Well Depth:	46m BGL
Well Diameter:	1 x 50mm pipe
Well Height:	0.435m above ground level
Driller:	A. Gibellini & S. Marititabua (McMillan Drilling Ltd)
Drilling Method:	Rotary
Well Material:	1 x PVC piezometer and 1 x stainless steel casing

Screens

Screen number	Top of screen (m BGL)	Bottom of screen (m BGL)	Length of screen (m)
1	33.45	45.45	12.0

Bore photo (looking west along Timaru Track Road):

Aerial photo:

MAR project well number: **GWD-04**

ECan well number: **BY20/0152**

Summary

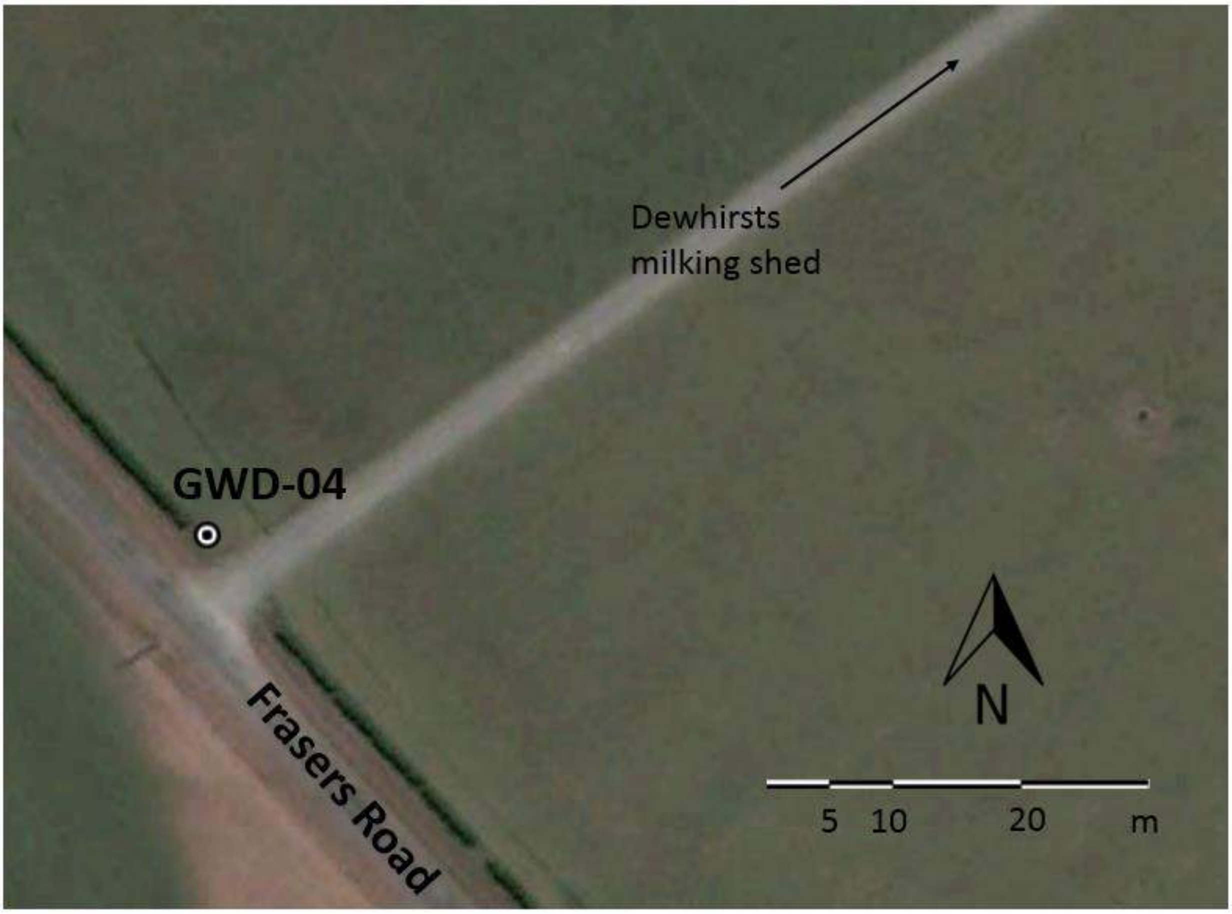
Landowner:	Mark Dewhirst (027 227 7244)
Location:	Frasers Road
Site Description:	Open land just off road at end of hedge
NZTM X and Y:	1489821 E – 5139744 N
Ground Level Elevation:	133m above sea level
Uses:	Water level and water quality monitoring
Drill Date:	31/03/2016
Well Depth:	29.8m BGL
Well Diameter:	1 x 50mm pipe and 1 x 32mm pipe
Well Height:	0.460m above ground level (50mm pipe) 0.520m above ground level (32mm pipe)
Driller:	K. Morris & V. Vasques (McMillan Drilling Ltd)
Drilling Method:	Sonic
Well Material:	2 x PVC piezometers and 1 x stainless steel casing

Screens

Screen number	Top of screen (m BGL)	Bottom of screen (m BGL)	Length of screen (m)
1 (50mm pipe)	20.25	29.25	9.0
2 (32mm pipe)	23.25	29.25	6.0

Bore photo (looking north):

Aerial photo:



MAR project well number: **GWD-05**

ECan well number: **BY20/0153**

Summary

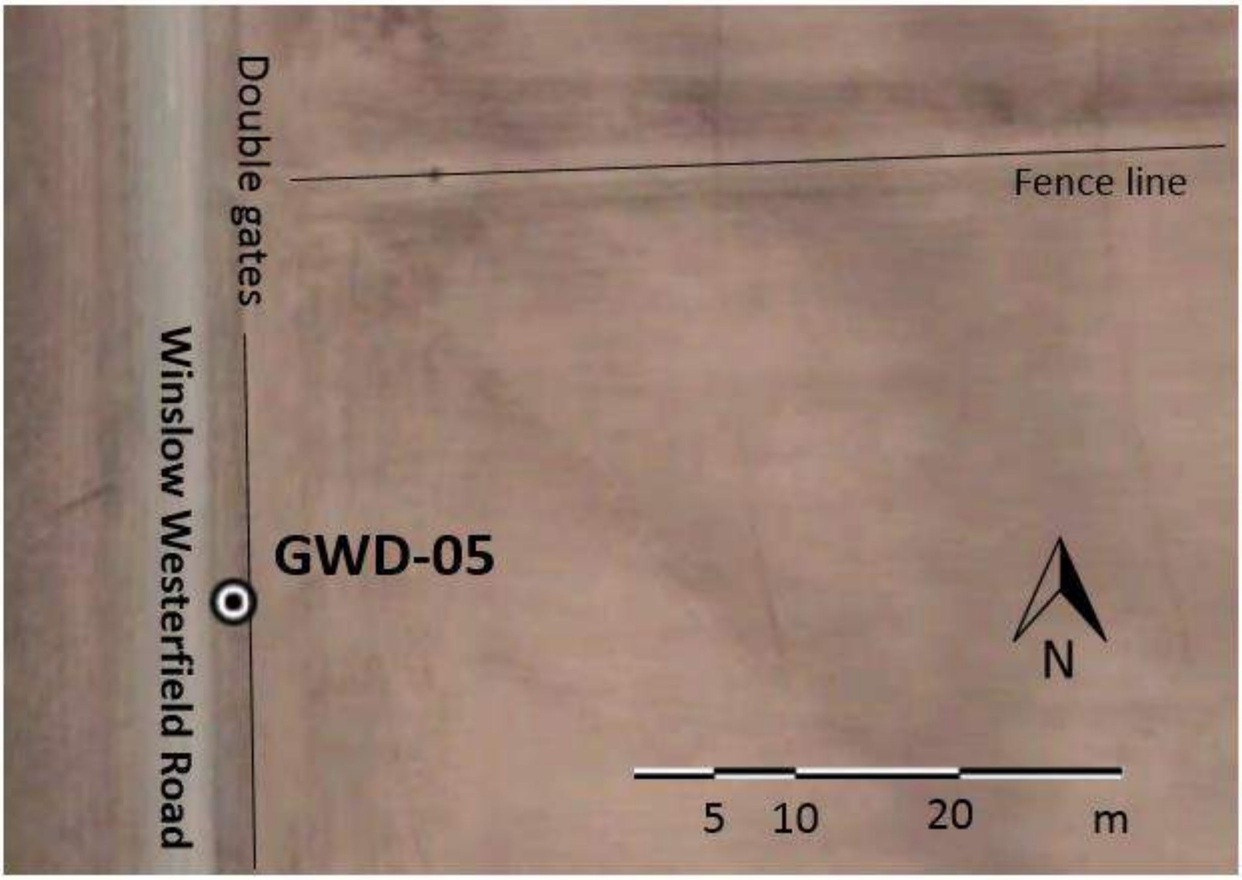
Landowner:	David Keeley (03 303 7039)
Location:	Winslow-Westerfield Road
Site Description:	Open land in flat verge beside road
NZTM X and Y:	1491358 E – 5136798N
Ground Level Elevation:	106m above sea level
Uses:	Water level and water quality monitoring
Drill Date:	07/04/2016
Well Depth:	34m BGL
Well Diameter:	1 x 50mm pipe
Well Height:	0.00m above ground level
Driller:	A. Gibellini & S. Magititabua
Drilling Method:	Rotary
Casing Material:	1 x PVC piezometer and 1 x steel cover

Screens

Screen number	Top of screen (m BGL)	Bottom of screen (m BGL)	Length of screen (m)
1	21.5	30.5	9.0

Bore photo (looking south):

Aerial photo:



MAR project well number: **GWD-06**

ECan well number: **BY21/0183**

Summary

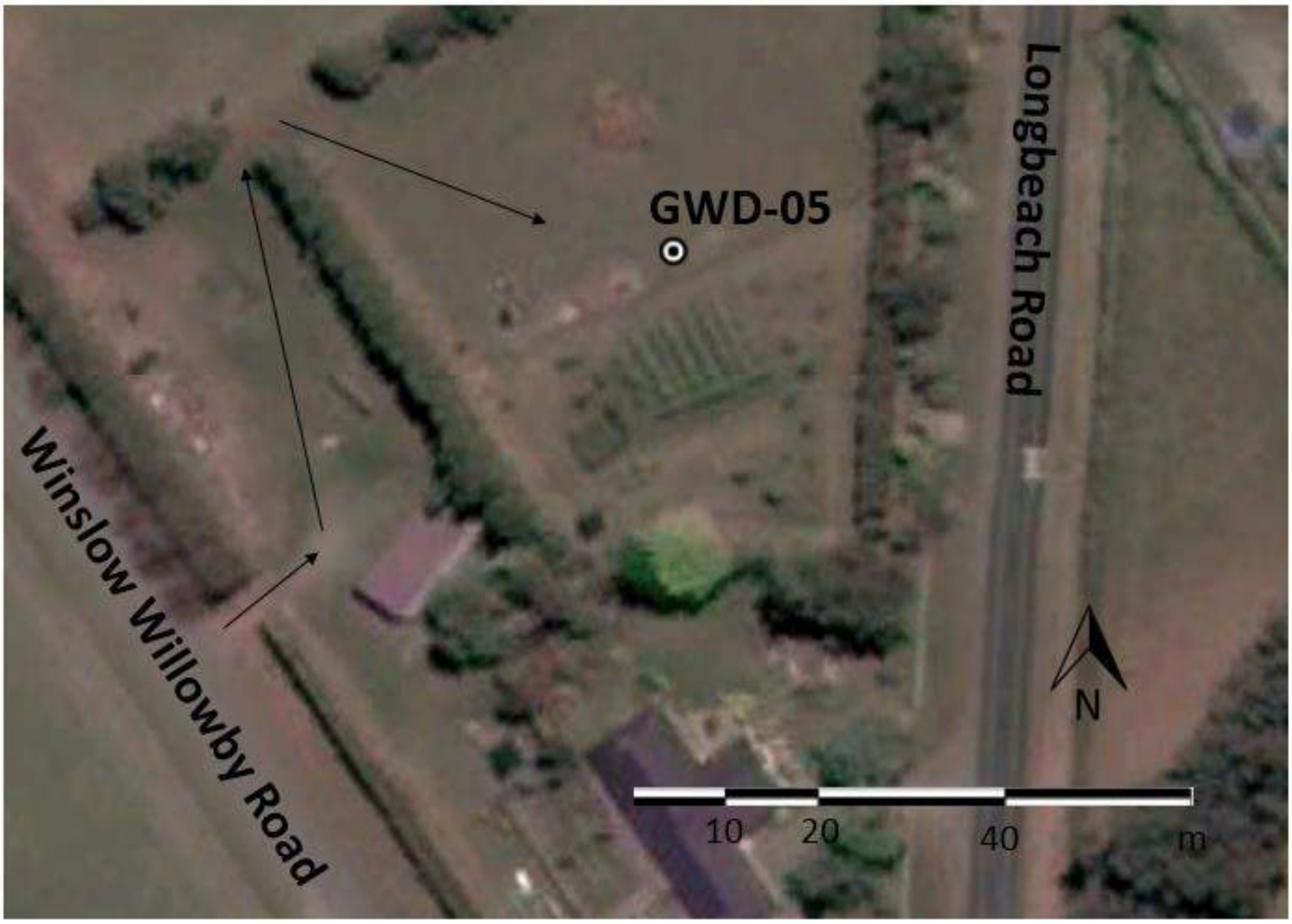
Landowner:	Russel and Vivienne Pearce
Location:	Longbeach Road
Site Description:	Open land near transmitting station
NZTM X and Y:	1494234 E – 5129843 N
Ground Level Elevation:	71m above sea level
Uses:	Water level and water quality monitoring
Drill Date:	17/02/2016
Well Depth:	15.25m BGL
Well Diameter:	1 x 50mm piezometer
Well Height:	0.76 m above ground level
Driller:	K. Morris
Drilling Method:	Sonic
Well Material:	1 x PVC piezometer and 1 x stainless steel casing

Screens

Screen number	Top of screen (m BGL)	Bottom of screen (m BGL)	Length of screen (m)
1	6.08	15.08	9.00

Bore photo (looking west):

Aerial photo:



Golder Associates

MAR project well number: **GWD-07**

ECan well number: **BY21/0184**

Summary

Landowner:	Stuart Tarbotton
Location:	Frasers Road across from Golf Course
Site Description:	Open land next to large trees, near boundary fence
NZTM X and Y:	1496559 E – 5136616 N
Ground Level Elevation:	97m above sea level
Uses:	Water level and water quality monitoring
Drill Date:	19/02/2016
Well Depth:	10.52m BGL
Well Diameter:	50mm pipe
Well Height:	0.930m above ground level
Driller:	K. Morris
Drilling Method:	Sonic
Well Material:	1 x PVC piezometer and 1 x stainless steel casing

Screens

Screen number	Top of screen (m BGL)	Bottom of screen (m BGL)	Length of screen (m)
1	4.50	10.52	6.02

Bore photo (looking west):

Aerial photo:

Bore or Well No: K37/1748

Well Name: LOWES ROAD

Owner: GUYON FARM LIMITED, Mr Dewhirst

Environment Canterbury
Your regional council

Street of Well: LOWES ROAD

File No: CO6C/17424

Locality: LAGMHOR

Allocation Zone: Valetta

NZTM Grid Reference: BY20:89140-40430 QAR 1

CWMS Zone: Ashburton

NZTM X-Y: 1489140 - 5140430

Location Description: Corner of Frasers Rd and Lowes Rd

Uses: Water Level Observation

ECan Monitoring: Monthly Manual

Well Status: Active (exist, present)

Drill Date: 10 Jan 2003

Water Level Count: 186

Well Depth: 18.00m -GL

Strata Layers: 3

Initial Water Depth: -13.35m -MP

Aquifer Tests: 0

Diameter: 100mm

Yield/Drawdown Tests: 0

Measuring Point Ait: 137.67m MSD QAR 1

Highest GW Level: 9.49m below MP

GL Around Well: -0.35m -MP

Lowest GW Level: 17.13m below MP

MP Description: ToC

First Reading: 13 Mar 2003

Last Reading: 21 Jul 2016

Driller: Smiths Welldrilling

Calc. Min. (Below MP): -16.06m -MP

Drilling Method: Rotary/Percussion

Last Updated: 02 Jul 2012

Casing Material: PVC

Last Field Check: 21 Jul 2016

Pump Type: None Installed

Yield:

Aquifer Type:

Drawdown:

Aquifer Name:

Specific Capacity:

Screens:

Screen No.	Screen Type	Top (m)	Bottom (m)	Diameter (mm)	Leader Length (mm)	Slot Size (mm)	Slot Length (mm)
1	Slotted PVC	15	18				

Step Tests:

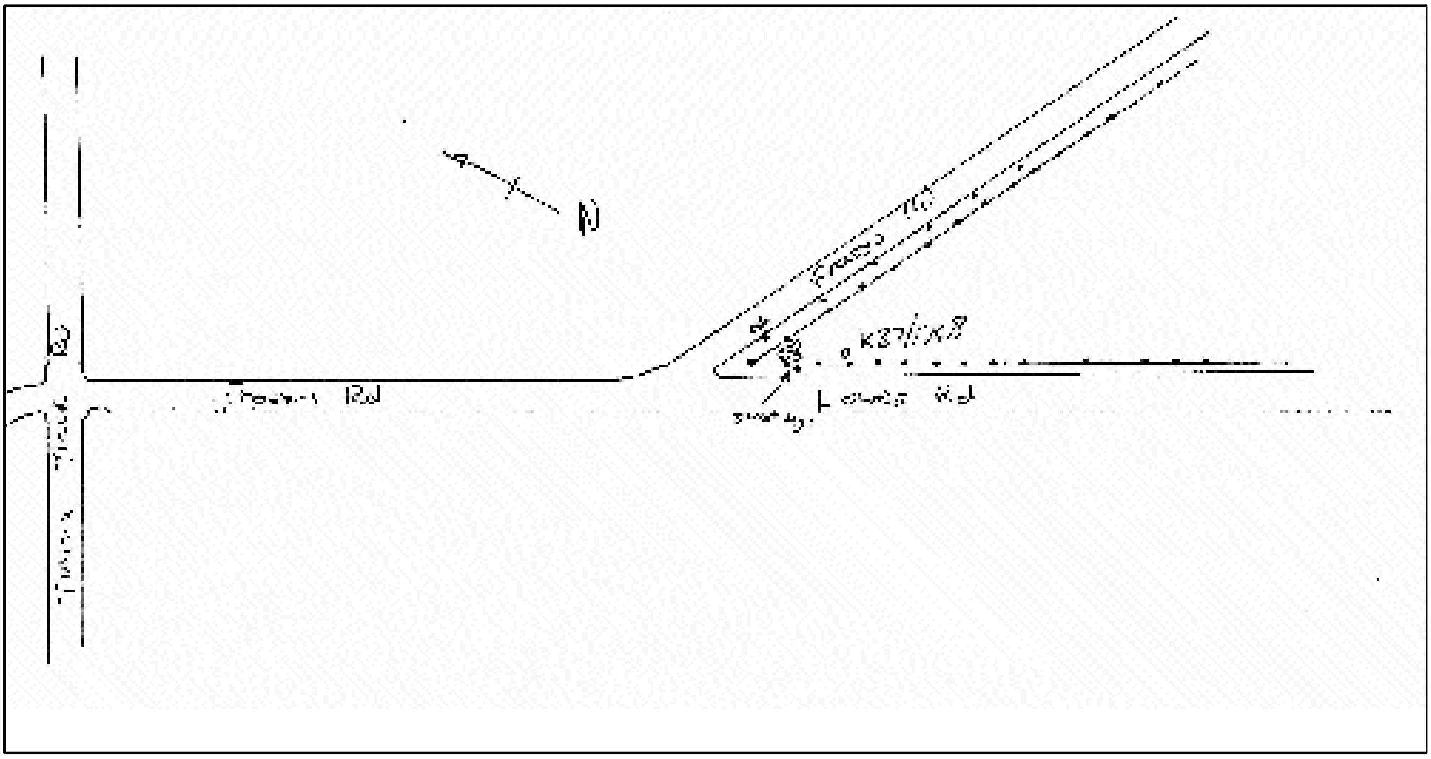
Step Test Date	Step	Yield (l/s)	Drawdown	Duration (mins)

Date	Comments
17 Jan 2003	Gridref changed from: K37:9912-0201
14 Mar 2003	Well drilled for water quality monitoring purposes, as a consent condition. Locked cap - key is with well run folder. 10cm PVC casing inside 15 cm steel casing.
01 Dec 2003	Neighbour, Robert Mangin, says that he has border dykes across road from here - could have significant effect on recharge.
27 May 2004	Water levels seem correlated with flow in nearby irrigation race.
08 Jun 2004	Gridref changed from K37:99108-02036, differential GPS survey, May 2004
01 May 2006	Gridref taken on 5 April 2006 was K37:99108-02037 but not changed from current differential GPS position due to its better accuracy. Depth of well remeasured to 17.82m below measuring point or 17.47m below ground from the original 18m depth
14 Jun 2007	<Note Added from Squalarc> consent montoring for Nitrates and Faecal Coliforms

08 Apr 2008	updated depth based on screen info. Depth was 17.47 m

Aquifer test date(s) where this is the pump bore

Aquifer test date(s) where this is an observation bore



Bore or Well No: K37/0204

Well Name:

Owner: Mr & Mrs D B & J H Pike

Environment Canterbury
Your regional council

Street of Well:	86 LOWES RD	**File No:**	
Locality:	LAGMHOR	**Allocation Zone:**	Valetta
NZTM Grid Reference:	BY20:89164-40077 QAR 1	**CWMS Zone:**	Ashburton
NZTM X-Y:	1489164 - 5140077		
Location Description:	In small shed in farmyard to left of house	**Uses:**	Domestic Supply
ECan Monitoring:			
Well Status:	Active (exist, present)		

Drill Date:		**Water Level Count:**	62
Well Depth:	41.14m -GL	**Strata Layers:**	0
Initial Water Depth:	-22.61m -MP	**Aquifer Tests:**	0
Diameter:	150mm	**Yield/Drawdown Tests:**	0
Measuring Point Ait:	136.17m MSD QAR 1	**Highest GW Level:**	15.73m below MP
GL Around Well:	-0.08m -MP	**Lowest GW Level:**	36.45m below MP
MP Description:	ToC	**First Reading:**	18 Jun 1974
		Last Reading:	13 Apr 2006
Driller:	not known	**Calc. Min. (Below MP):**	-31.22m -MP
Drilling Method:	Unknown	**Last Updated:**	23 Sep 2010
Casing Material:	STEEL	**Last Field Check:**	13 Apr 2006
Pump Type:	Submersible		
Yield:		**Aquifer Type:**	Unknown
Drawdown:		**Aquifer Name:**	
Specific Capacity:			

Screens:

Screen No.	Screen Type	Top (m)	Bottom (m)	Diameter (mm)	Leader Length (mm)	Slot Size (mm)	Slot Length (mm)

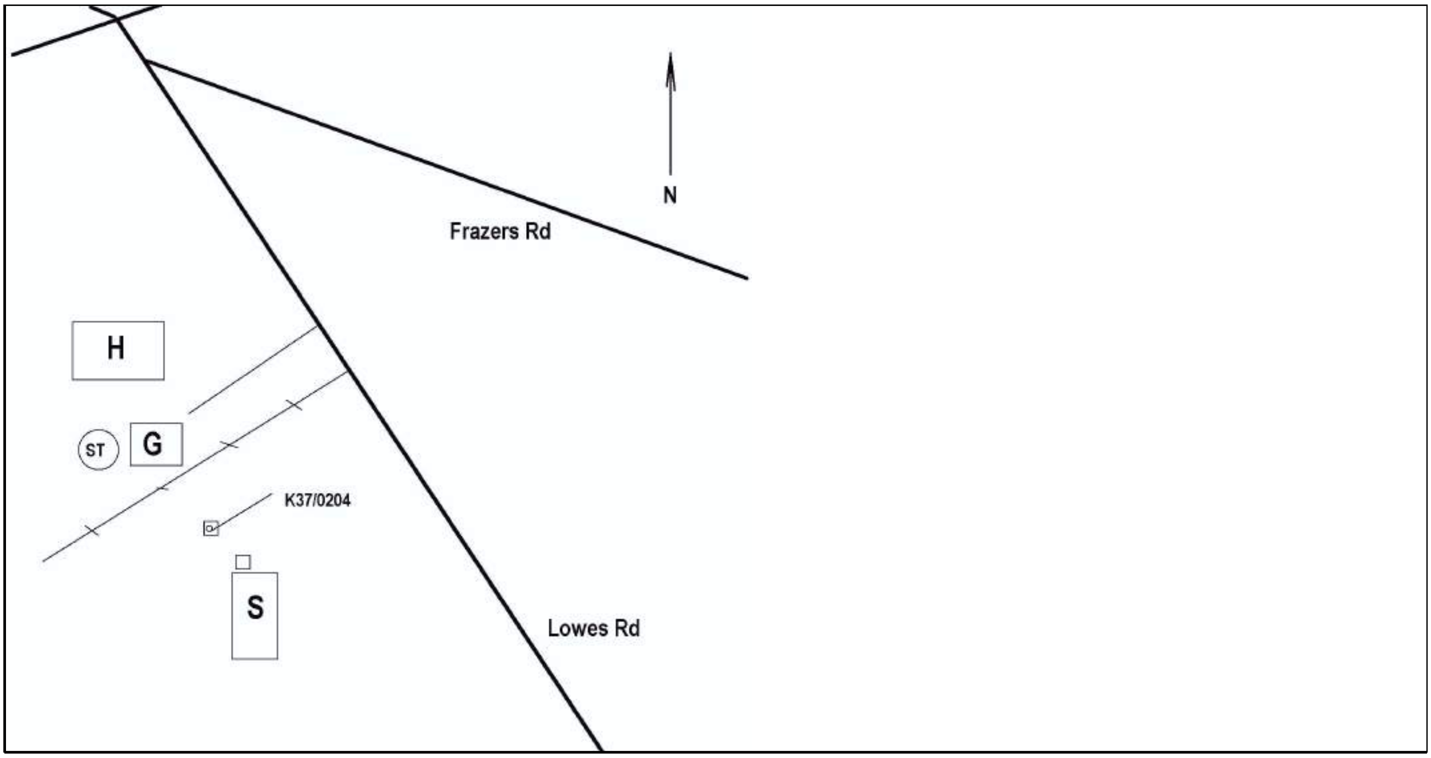
Step Tests:

Step Test Date	Step	Yield (l/s)	Drawdown	Duration (mins)

Date	Comments
15 Sep 2000	SCCB well HA 134.
21 Mar 2003	Gridref changed from: K37:990-021 - but significant doubt as to whether this is the right well. No sign of a well where it was previously located, lease holder (Rob Mangin and farm worker on the property know nothing about a well at this spot. Diameter of well attributed to this number is different (15 cm vs 7.5), but depth is reportedly very similar.
29 Sep 2003	land owners are Andrew & Sue Mills (signed written approvals for CRC032088 Paisley)
08 Jun 2004	Gridref changed from K37:99138-01684, reference RL from 136.169, differential GPS survey, May 2004
14 Jul 2004	Visited during the Hinds-Ashburton Investiagtion.
10 May 2011	First WL reading set as ISWL

Aquifer test date(s) where this is the pump bore

Aquifer test date(s) where this is an observation bore


N
Frazers Rd
H
ST
G
K37/0204
S
Lowes Rd

Bore or Well No: K37/0357

Well Name:

Owner: Mangin, Mr

Environment Canterbury
Your regional council

Street of Well:	Lowes Road	**File No:**	CO6T/00885
Locality:	Lagmhor	**Allocation Zone:**	Valetta
NZTM Grid Reference:	BY20:89196-39456 QAR 1	**CWMS Zone:**	Ashburton
NZTM X-Y:	1489196 - 5139456		
Location Description:	Thru pine hedge from K37/1540 which is in front of milking shed.	**Uses:**	Irrigation
ECan Monitoring:			
Well Status:	Not Used		

Drill Date:	05 Jul 1990	**Water Level Count:**	49
Well Depth:	27.00m -GL	**Strata Layers:**	4
Initial Water Depth:	-5.00m -MP	**Aquifer Tests:**	0
Diameter:	150mm	**Yield/Drawdown Tests:**	1
Measuring Point Ait:	133.43m MSD QAR 2	**Highest GW Level:**	4.19m below MP
GL Around Well:	-0.25m -MP	**Lowest GW Level:**	999.99m below MP
MP Description:	ToC	**First Reading:**	28 Jan 2003
		Last Reading:	13 Apr 2006
Driller:	not known	**Calc. Min. (Below MP):**	-12.14m -MP
Drilling Method:	Cable Tool	**Last Updated:**	08 Nov 2013
Casing Material:	STEEL	**Last Field Check:**	13 Apr 2006
Pump Type:	Submersible		
Yield:	2 l/s	**Aquifer Type:**	Semi-Confined
Drawdown:	1 m	**Aquifer Name:**	
Specific Capacity:	1.73 l/s/m		

Screens:

Screen No.	Screen Type	Top (m)	Bottom (m)	Diameter (mm)	Leader Length (mm)	Slot Size (mm)	Slot Length (mm)
1	Stainless steel	21	27				

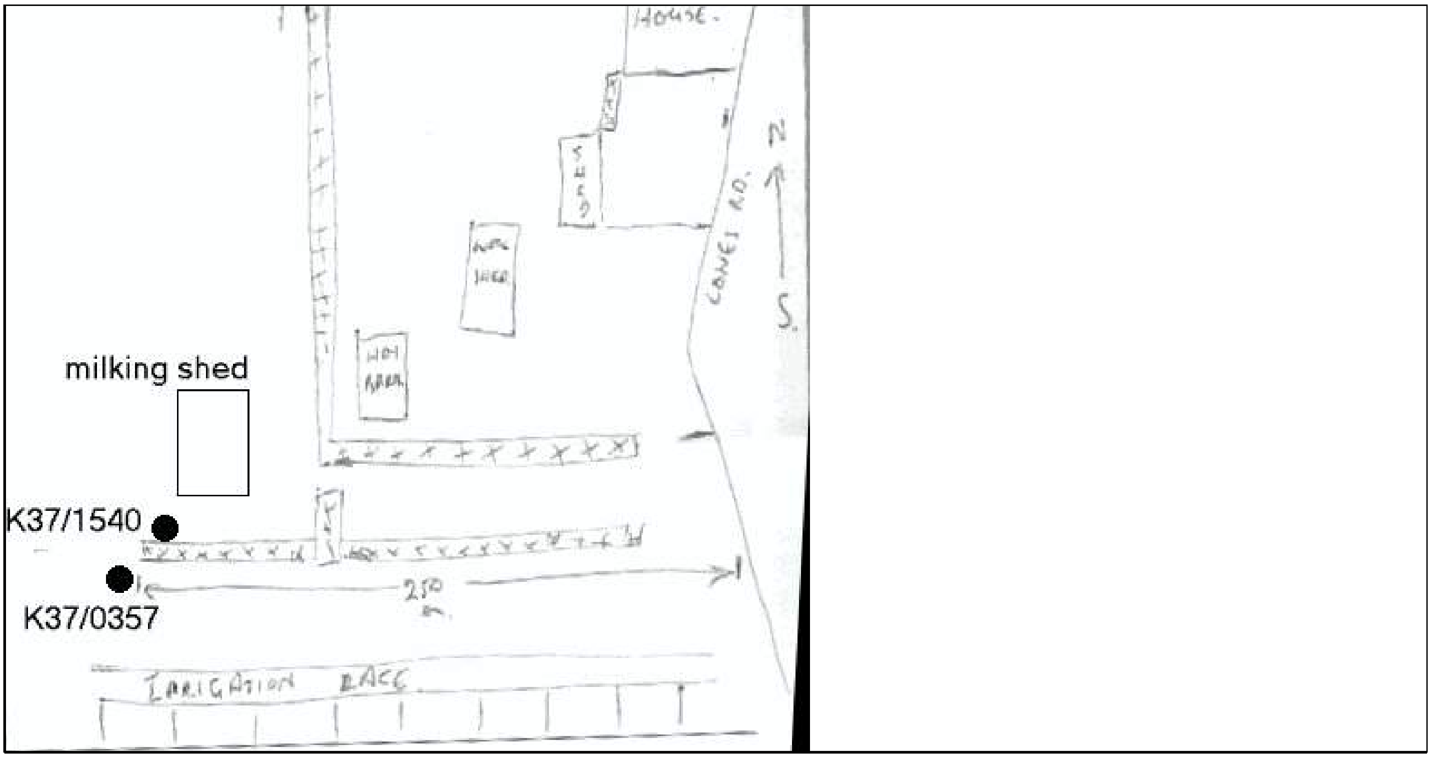
Step Tests:

Step Test Date	Step	Yield (l/s)	Drawdown	Duration (mins)
05 Jul 1990	1	1.9	1.1	180

Date	Comments
01 Dec 2003	Gridref changed from: K37:991-010.
08 Jun 2004	Gridref changed from K37:99166-01060, reference RL from 136.000, differential GPS survey, May 2004
07 Oct 2004	Adjacent paddock, just NE, being redeveloped (laser levelled) 6/10/04. Will effect water levels in well.
08 Apr 2008	updated depth based on screen info. Depth was 26.15 m

Aquifer test date(s) where this is the pump bore

Aquifer test date(s) where this is an observation bore



HOUSE.
N
CONES RD.
S.
milking shed
K37/1540
250 m.
K37/0357
IRRIGATION RACE

Bore or Well No: K37/0200
Well Name: FRASERS RD (PAISLEY)
Owner: Paisley G K

Environment Canterbury
Your regional council

Street of Well: Frasers Road
File No: CO6C/19140
Locality: Lagmhor
Allocation Zone: Valetta
NZTM Grid Reference: BY20:90814-38818 QAR 1
CWMS Zone: Ashburton
NZTM X-Y: 1490814 - 5138818
Location Description: 10 m NE of new well (little shed) in garden in front of house
Uses: Water Level Observation
ECan Monitoring: Monthly Manual
Well Status: Active (exist, present)

Drill Date:
Water Level Count: 356
Well Depth: 22.80m -GL
Strata Layers: 0
Initial Water Depth: -7.62m -MP
Aquifer Tests: 0
Diameter: 95mm
Yield/Drawdown Tests: 0

Measuring Point Ait: 122.14m MSD QAR 1
Highest GW Level: 2.68m below MP
GL Around Well: -0.15m -MP
Lowest GW Level: 999.99m below MP
MP Description: hole in cap
First Reading: 18 Jun 1974
Last Reading: 21 Jul 2016
Driller: not known
Calc. Min. (Below MP): -15.00m -MP
Drilling Method: Unknown
Last Updated: 02 Jul 2012
Casing Material: Steel
Last Field Check: 21 Jul 2016
Pump Type: None Installed
Yield:
Aquifer Type: Unknown
Drawdown:
Aquifer Name:
Specific Capacity:

Screens:

Screen No.	Screen Type	Top (m)	Bottom (m)	Diameter (mm)	Leader Length (mm)	Slot Size (mm)	Slot Length (mm)

Step Tests:

Step Test Date	Step	Yield (l/s)	Drawdown	Duration (mins)

Date	Comments
15 Sep 2000	SCCB well HA 124. First water at 7.62m
19 Apr 2001	Previous owner TARBOTTON C R ownership changed 1/4/01.
08 Jun 2004	Gridref changed from K37:00782-00442, reference RL from 121.761, differential GPS survey, May 2004
14 Dec 2005	Depth measured at 22.8m (changed from 25.29), well dry.
24 Jan 2012	NZMG Easting/Northing updated from:2400796-5700439 Shifted 15m

Aquifer test date(s) where this is the pump bore

Aquifer test date(s) where this is an observation bore


House
K37/0200
10 m
Pagola
New domestic well K37/3312
(using old K37/200 shed)
Shed
Rapid 666

Bore or Well No: K37/1749

Well Name:

Owner: GUYON FARM LIMITED, Mr Dewhirst

Environment Canterbury
Your regional council

Street of Well:	FERRIMANS ROAD	**File No:**	CO6C/17424
Locality:	LAGMHOR	**Allocation Zone:**	Valetta
NZTM Grid Reference:	BY20:90656-37905 QAR 1	**CWMS Zone:**	Ashburton
NZTM X-Y:	1490656 - 5137905		
Location Description:	Across road from K37/0699, thru gate	**Uses:**	Water Level Observation
ECan Monitoring:	Former Ecan monitoring		
Well Status:	Active (exist, present)		

Drill Date:	10 Jan 2003	**Water Level Count:**	126
Well Depth:	17.85m -GL	**Strata Layers:**	3
Initial Water Depth:	-12.06m -MP	**Aquifer Tests:**	0
Diameter:	150mm	**Yield/Drawdown Tests:**	0
Measuring Point Ait:	118.04m MSD QAR 2	**Highest GW Level:**	5.91m below MP
GL Around Well:	-0.36m -MP	**Lowest GW Level:**	999.99m below MP
MP Description:	TOC (steel)	**First Reading:**	13 Mar 2003
		Last Reading:	13 Apr 2015
Driller:	Smiths Welldrilling	**Calc. Min. (Below MP):**	-15.80m -MP
Drilling Method:	Rotary/Percussion	**Last Updated:**	10 Sep 2012
Casing Material:	PVC	**Last Field Check:**	13 Apr 2015
Pump Type:	None Installed		
Yield:	0 l/s	**Aquifer Type:**	
Drawdown:	0 m	**Aquifer Name:**	
Specific Capacity:	0.00 l/s/m		

Screens:

Screen No.	Screen Type	Top (m)	Bottom (m)	Diameter (mm)	Leader Length (mm)	Slot Size (mm)	Slot Length (mm)
1	Slotted PVC	15	18				

Step Tests:

Step Test Date	Step	Yield (l/s)	Drawdown	Duration (mins)

Date	Comments
14 Mar 2003	Gridref changed from: K37:0058-9951. 10cm PVC casing inside 125cm steel. Well drilled for water quality monitoring, key in well run folder for monthly water level measurement.
08 Jun 2004	Gridref changed from K37:00625-99509, differential GPS survey, May 2004
14 Dec 2005	Depth measured at 17.59, changed from 18m. For some reason there has been a constant level of 17.84m - sludge in the bottom of well? But no mud on end of prodder.
01 May 2006	Map reference taken by GPS on 5 April 2006 was K37:00625-99513 but was not changed from previous differential GPS gridref due to its better accuracy. Well was remeasured to 17.85m below measuring point or 17.49m below ground level from its original 17.59m depth
14 Jun 2007	<Note Added from Squalarc> Consent compliance monitoring site for Nitrates and Faecal Coliform. Owner takes sample should put this Squalarc number on so data ends up in Squalarc.
16 Oct 2009	Changed deep GW readings to dry
31 Jan 2011	Has been removed from Manual well run (goes dry)

Aquifer test date(s) where this is the pump bore

Aquifer test date(s) where this is an observation bore

Bore or Well No: K37/0972

Well Name:

Owner: D A J & J R Geddes Family Trust

Environment Canterbury
Your regional council

Street of Well:	LONGBEACH ROAD	**File No:**	CO6C/07035
Locality:	WILLOWBY	**Allocation Zone:**	Valetta
NZTM Grid Reference:	BY21:94394-31571 QAR 2	**CWMS Zone:**	Ashburton
NZTM X-Y:	1494394 - 5131571		
Location Description:	Close to road, beside willow tree	**Uses:**	Irrigation
ECan Monitoring:			
Well Status:	Active (exist, present)		

Drill Date:	22 Oct 1999	**Water Level Count:**	3
Well Depth:	9.90m -GL	**Strata Layers:**	0
Initial Water Depth:	-1.20m -MP	**Aquifer Tests:**	0
Diameter:	600mm	**Yield/Drawdown Tests:**	1
Measuring Point Ait:	78.68m MSD QAR 4	**Highest GW Level:**	1.05m below MP
GL Around Well:	-0.39m -MP	**Lowest GW Level:**	4.47m below MP
MP Description:	ToC	**First Reading:**	24 Jan 2003
		Last Reading:	03 Sep 2003
Driller:	Geoff Moore Contracting	**Calc. Min. (Below MP):**	-3.50m -MP
Drilling Method:	Clam Shell	**Last Updated:**	08 Nov 2013
Casing Material:	STEEL	**Last Field Check:**	03 Sep 2003
Pump Type:	Submersible		
Yield:	47 l/s	**Aquifer Type:**	
Drawdown:	2 m	**Aquifer Name:**	
Specific Capacity:	24.74 l/s/m		

Screens:

Screen No.	Screen Type	Top (m)	Bottom (m)	Diameter (mm)	Leader Length (mm)	Slot Size (mm)	Slot Length (mm)
1	Unknown	5	10				

Step Tests:

Step Test Date	Step	Yield (l/s)	Drawdown	Duration (mins)
22 Oct 1999	1	47	1.9	480

Date	Comments
11 Nov 1999	Well collapsed then redrilled
11 Nov 1999	Well developed for 8 hours by mechanical surging
27 Jan 2003	Gridref changed from: K37:0438-9308
21 Mar 2003	Pumped at around 550 gals/hr and recovery is very fast. On 24 January 2003 the water level during pumping was –8.28m, 16 minutes after pumping stopped the water level had almost stabilised at –4.47 m. Water levels have dropped a little, but this is reportedly not out of the ordinary for a dry summer.
21 Jan 2014	Temporary Waiver Application sent
28 Apr 2016	K37/0972 dry according to consent holder. Needs to apply for a change of conditions to remove bore from consent or apply for a temporary waiver. Last option recommended in 2014 but no application was received.

Aquifer test date(s) where this is the pump bore

Aquifer test date(s) where this is an observation bore

Bore or Well No: K37/0351

Well Name:

Owner: Messrs D J & M J Stoddart

Street of Well:	Longbeach Road	**File No:**	CO6C/08645
Locality:	Willowby	**Allocation Zone:**	Valetta
NZTM Grid Reference:	BY21:94523-27188 QAR 2	**CWMS Zone:**	Ashburton
NZTM X-Y:	1494523 - 5127188		
Location Description:	About 20m from road through gate	**Uses:**	Irrigation
ECan Monitoring:			
Well Status:	Active (exist, present)		

Drill Date:		**Water Level Count:**	3
Well Depth:	8.30m -GL	**Strata Layers:**	0
Initial Water Depth:	-3.10m -MP	**Aquifer Tests:**	0
Diameter:	580mm	**Yield/Drawdown Tests:**	0
Measuring Point Ait:	57.67m MSD QAR 4	**Highest GW Level:**	2.82m below MP
GL Around Well:	-0.77m -MP	**Lowest GW Level:**	3.21m below MP
MP Description:	ToC	**First Reading:**	11 Dec 2002
		Last Reading:	03 Sep 2003
Driller:	not known	**Calc. Min. (Below MP):**	-3.30m -MP
Drilling Method:	Clam Shell	**Last Updated:**	16 Apr 2003
Casing Material:	STEEL	**Last Field Check:**	03 Sep 2003
Pump Type:	None Installed		
Yield:		**Aquifer Type:**	Water Table
Drawdown:		**Aquifer Name:**	
Specific Capacity:			

Screens:

Screen No.	Screen Type	Top (m)	Bottom (m)	Diameter (mm)	Leader Length (mm)	Slot Size (mm)	Slot Length (mm)

Step Tests:

Step Test Date	Step	Yield (l/s)	Drawdown	Duration (mins)

Date	Comments
13 Dec 2002	Gridref changed from: K37:044-888. Well is not currently used - and probably will not be for the next 3-5 years.
07 Nov 2012	temporary waiver on water metering regulation in place, see cocoa

Aquifer test date(s) where this is the pump bore

Aquifer test date(s) where this is an observation bore

Bore or Well No: K37/3052
Well Name:
Owner: S TARBOTTON CONTRACTORS LIMITED

Street of Well:	FRASERS ROAD	**File No:**	CO6C/20873
Locality:	ASHBURTON	**Allocation Zone:**	Valetta
NZTM Grid Reference:	BY21:94768-36645 QAR 2	**CWMS Zone:**	Ashburton
NZTM X-Y:	1494768 - 5136645		
Location Description:	Central LP location	**Uses:**	Water Level Observation
ECan Monitoring:			
Well Status:	Active (exist, present)		

Drill Date:	12 Jul 2007	**Water Level Count:**	3
Well Depth:	15.00m -GL	**Strata Layers:**	4
Initial Water Depth:	-13.00m -MP	**Aquifer Tests:**	0
Diameter:	51mm	**Yield/Drawdown Tests:**	0
Measuring Point Ait:	99.00m MSD QAR 3	**Highest GW Level:**	13.00m below MP
GL Around Well:	-0.30m -MP	**Lowest GW Level:**	13.50m below MP
MP Description:	ToC	**First Reading:**	20 Mar 2008
		Last Reading:	16 May 2008
Driller:	Smiths Welldrilling	**Calc. Min. (Below MP):**	
Drilling Method:	Rotary/Percussion	**Last Updated:**	12 Feb 2009
Casing Material:		**Last Field Check:**	16 May 2008
Pump Type:			
Yield:		**Aquifer Type:**	
Drawdown:		**Aquifer Name:**	
Specific Capacity:			

Screens:

Screen No.	Screen Type	Top (m)	Bottom (m)	Diameter (mm)	Leader Length (mm)	Slot Size (mm)	Slot Length (mm)

Step Tests:

Step Test Date	Step	Yield (l/s)	Drawdown	Duration (mins)

Date	Comments
05 Feb 2008	Gridref changed from: K37:0523-9806
08 Feb 2008	Gridref changed from: K37:0472-9826. New gridref from plan in BCR
08 Feb 2008	Bore A on BCR. Swapped borelog details with K37/3049
10 May 2011	First WL reading set as ISWL

Aquifer test date(s) where this is the pump bore

Aquifer test date(s) where this is an observation bore

Bore or Well No:	K37/1938
Well Name:	
Owner:	Geddes, DAJ & JR

Environment Canterbury
Your regional council

Street of Well:	Longbeach Road	**File No:**	
Locality:	Willowby	**Allocation Zone:**	Valetta
NZTM Grid Reference:	BY21:94937-32738 QAR 2	**CWMS Zone:**	Ashburton
NZTM X-Y:	1494937 - 5132738		
Location Description:	Follow track past shed, on right next to K37/1025	**Uses:**	Stock Supply
ECan Monitoring:			
Well Status:	Active (exist, present)		

Drill Date:		**Water Level Count:**	1
Well Depth:	10.00m -GL	**Strata Layers:**	0
Initial Water Depth:	-0.77m -MP	**Aquifer Tests:**	0
Diameter:	530mm	**Yield/Drawdown Tests:**	0
Measuring Point Ait:	83.74m MSD QAR 4	**Highest GW Level:**	0.77m below MP
GL Around Well:	-0.40m -MP	**Lowest GW Level:**	0.77m below MP
MP Description:	Top of concrete casing	**First Reading:**	04 Jun 2003
		Last Reading:	04 Jun 2003
Driller:	not known	**Calc. Min. (Below MP):**	-1.90m -MP
Drilling Method:		**Last Updated:**	24 Sep 2003
Casing Material:	CONCRETE	**Last Field Check:**	04 Jun 2003
Pump Type:	Centrifugal (Surface)		
Yield:		**Aquifer Type:**	
Drawdown:		**Aquifer Name:**	
Specific Capacity:			

Screens:

Screen No.	Screen Type	Top (m)	Bottom (m)	Diameter (mm)	Leader Length (mm)	Slot Size (mm)	Slot Length (mm)

Step Tests:

Step Test Date	Step	Yield (l/s)	Drawdown	Duration (mins)

Date	Comments
04 Jun 2003	Drilled prior to 1025, used only for stock water when not pumping from 1025.
24 Sep 2003	Well is in ditch, water fills this to above level of casing in wet periods.
10 May 2011	First WL reading set as ISWL

Aquifer test date(s) where this is the pump bore

Aquifer test date(s) where this is an observation bore

Bore or Well No: K37/0215
Well Name: Westerfield
Owner: LOBB, V

Environment Canterbury
Your regional council

Street of Well:	LANGDONS RD	**File No:**	
Locality:	WESTERFIELD	**Allocation Zone:**	Valetta
NZTM Grid Reference:	BY20:87848-44112 QAR 1	**CWMS Zone:**	Ashburton
NZTM X-Y:	1487848 - 5144112		
Location Description:	Pipe at old army camp	**Uses:**	Water Level Observation
ECan Monitoring:	ECan Recorder Network		
Well Status:	Active (exist, present)		

Drill Date:	20 Nov 1942	**Water Level Count:**	2030
Well Depth:	26.20m -GL	**Strata Layers:**	5
Initial Water Depth:	-13.10m -MP	**Aquifer Tests:**	0
Diameter:	100mm	**Yield/Drawdown Tests:**	0
Measuring Point Alt:	162.75m MSD QAR 1	**Highest GW Level:**	3.81m below MP
GL Around Well:	-0.22m -MP	**Lowest GW Level:**	18.26m below MP
MP Description:	ToC	**First Reading:**	12 Jan 1951
		Last Reading:	21 Jul 2016
Driller:	Job Osborne (& Co/Ltd)	**Calc. Min. (Below MP):**	-13.44m -MP
Drilling Method:	Cable Tool	**Last Updated:**	28 Jun 2012
Casing Material:	STEEL	**Last Field Check:**	21 Jul 2016
Pump Type:	None Installed		
Yield:		**Aquifer Type:**	Semi-Confined
Drawdown:		**Aquifer Name:**	
Specific Capacity:			

Screens:

Screen No.	Screen Type	Top (m)	Bottom (m)	Diameter (mm)	Leader Length (mm)	Slot Size (mm)	Slot Length (mm)

Step Tests:

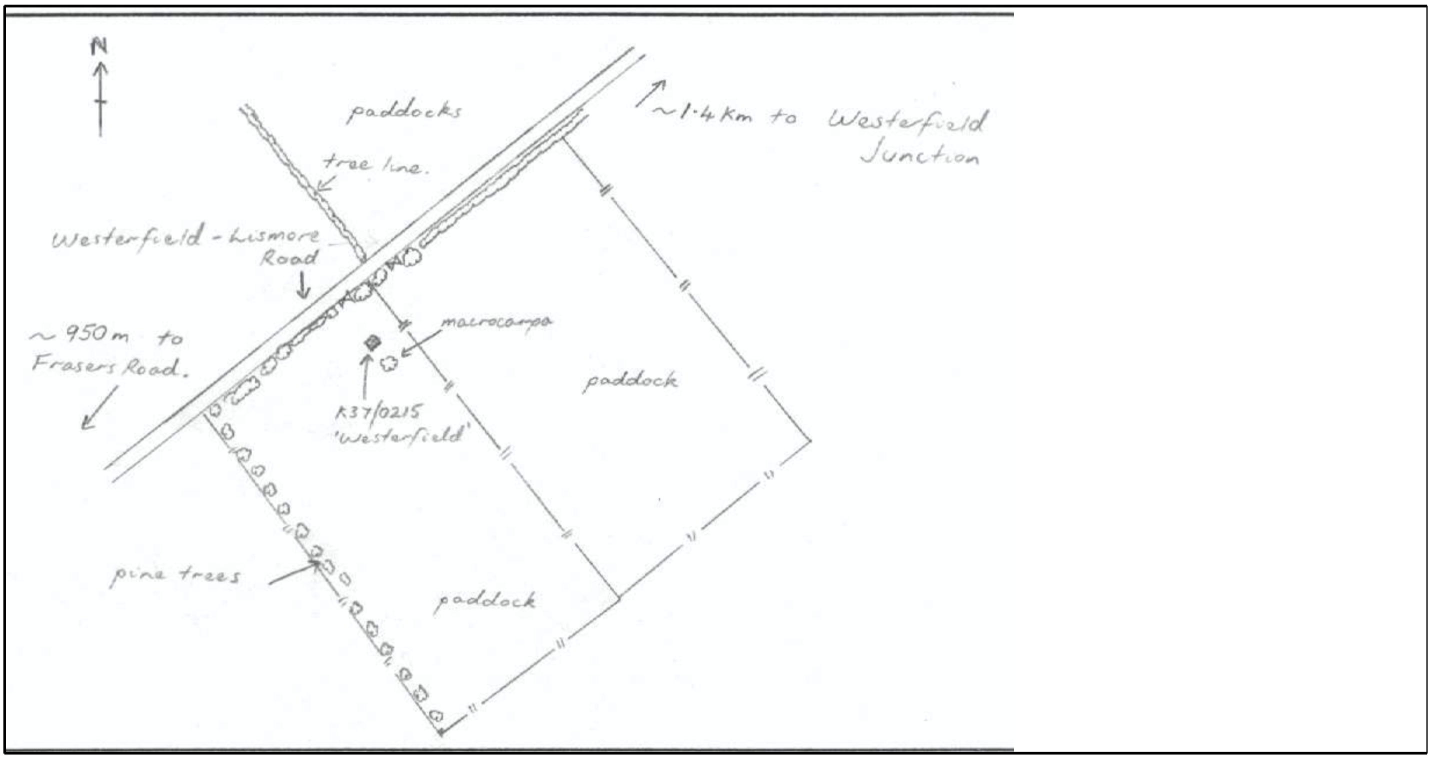
Step Test Date	Step	Yield (l/s)	Drawdown	Duration (mins)

Date	Comments
14 Apr 1999	Recorder on well
08 Jun 2001	Previous owner Ministry of Works (Well #32). SCCB well HA 161.Used during 1939-45 war. Water also brought from springs at source of Laghmor Creek by pumpes, wier/or reservoir installed.
23 Jan 2004	There is a problem with water level data from this well. Water levels after June 1972 are higher and fluctuate less than those before this date. It is possible that the earlier records are from a different well. Likely picking up influence of RDR schemes.
08 Jun 2004	Gridref changed from K37:97819-05712, reference RL from 162.514, differential GPS survey, May 2004
07 Dec 2005	Old logger replaced with diver. Removed pressure transducer (7/12/05) from well as diver string would wind itself around the chain. Set diver to 15.2m below MP
28 Jul 2010	Previous owner Mr Dunn
29 Jul 2010	Measuring point raised by 0.09cm. All water levels prior to 28/7/2010 updated. MP from ground level changed from -0.13 to -0.22, Reference level changed from 162.5 to 162.59.
28 Jun 2012	Previous owner Freeth, James Alexander William

02 Jul 2012	Downwell camera deployed on the 29/6/2012. Wood and stones observed at 23m camera stopped.
21 Jan 2013	Re Graeme's comment 2/7/12: Debris potentially caught on top of screen. Screen potentially from 23 - 26 m bgl (I note this used to be a supply well so it must have a screen)

Aquifer test date(s) where this is the pump bore

Aquifer test date(s) where this is an observation bore



Bore or Well No: K37/1747

Well Name:

Owner: Mangin Dairying Limited

Environment Canterbury
Your regional council

Street of Well: 36 LOWES ROAD

Locality: WESTERFIELD

NZTM Grid Reference: BY20:89166-40074 QAR 2

NZTM X-Y: 1489166 - 5140074

Location Description: Between house and implement shed 6m from K37/0204

ECan Monitoring:

Well Status: Active (exist, present)

File No: CO6C/20026

Allocation Zone: Valetta

CWMS Zone: Ashburton

Uses: Irrigation

Domestic and Stockwater

Drill Date: 06 Apr 2004

Well Depth: 64.87m -GL

Initial Water Depth: -28.05m -MP

Diameter: 200mm

Measuring Point Ait: 138.57m MSD QAR 4

GL Around Well: -0.92m -MP

MP Description: ToC

Driller: McMillan Drilling Ltd

Drilling Method: Rotary/Percussion

Casing Material: STEEL

Pump Type:

Yield: 30 l/s

Drawdown: 11 m

Specific Capacity: 8.44 l/s/m

Water Level Count: 19

Strata Layers: 7

Aquifer Tests: 0

Yield/Drawdown Tests: 8

Highest GW Level: 25.09m below MP

Lowest GW Level: 39.41m below MP

First Reading: 30 Mar 2004

Last Reading: 13 Apr 2006

Calc. Min. (Below MP): -31.40m -MP

Last Updated: 08 Nov 2013

Last Field Check: 13 Apr 2006

Aquifer Type:

Aquifer Name:

Screens:

Screen No.	Screen Type	Top (m)	Bottom (m)	Diameter (mm)	Leader Length (mm)	Slot Size (mm)	Slot Length (mm)
1	Stainless steel	61.87	64.87				

Step Tests:

Step Test Date	Step	Yield (l/s)	Drawdown	Duration (mins)
06 Apr 2004	1	6.667584	0.79	30
06 Apr 2004	2	8.33448	1.12	30
06 Apr 2004	3	12.50172	1.87	30
06 Apr 2004	4	19.92698	3.77	30
06 Apr 2004	5	27.27648	8.52	60
06 Apr 2004	6	29.54952	10.87	60

Date	Comments
24 Mar 2003	Gridref changed from: K37:9909-0185 to reflect a bit of reality. Sketch has house and proposed well much too close to the Lowes Rd - Frasers Rd intersection
30 Mar 2004	Gridref changed from: K37:99175-01660. Depth written on cap - 64.9m?

02 Aug 2004	Grid ref supplied by consent holder Latitude 43degrees 53.049 minutes Longitude 171 degrees 37.217 minutes Site already visited by Grant Davey who took a GPS position of the well head
02 Aug 2004	New address 758 Hackthorne Rd RD 5 Ashburton
25 May 2005	Change of owner as of 9/5/2005.
14 Dec 2005	MP changed from -0.32 - top of MP pipe now higher. Previous levels compensated for this.
21 Jul 2011	Previous owner Mr & Mrs D B & J H Pike

Aquifer test date(s) where this is the pump bore

Aquifer test date(s) where this is an observation bore

13 Jan 2005 - constant - Pump bore: K37/1035

Bore or Well No: K37/1540

Well Name:

Owner: Mangin Dairying Limited

Environment Canterbury
Your regional council

Street of Well:	Lowes Road	**File No:**	CO6C/18501
Locality:	Lagmhor	**Allocation Zone:**	Valetta
NZTM Grid Reference:	BY20:89205-39467 QAR 1	**CWMS Zone:**	Ashburton
NZTM X-Y:	1489205 - 5139467		
Location Description:	In front of milking shed	**Uses:**	Irrigation
ECan Monitoring:			Stock Supply
Well Status:	Active (exist, present)		

Drill Date:	16 Jan 2002	**Water Level Count:**	35
Well Depth:	66.00m -GL	**Strata Layers:**	12
Initial Water Depth:	-21.80m -MP	**Aquifer Tests:**	0
Diameter:	300mm	**Yield/Drawdown Tests:**	1
Measuring Point Ait:	133.68m MSD QAR 2	**Highest GW Level:**	22.91m below MP
GL Around Well:	-0.40m -MP	**Lowest GW Level:**	35.58m below MP
MP Description:	ToC	**First Reading:**	28 Jan 2003
		Last Reading:	13 Apr 2006
Driller:	Smiths Welldrilling	**Calc. Min. (Below MP):**	
Drilling Method:	Rotary Rig	**Last Updated:**	08 Nov 2013
Casing Material:	STEEL	**Last Field Check:**	13 Apr 2006
Pump Type:	Submersible		
Yield:	90 l/s	**Aquifer Type:**	
Drawdown:	18 m	**Aquifer Name:**	
Specific Capacity:	5.00 l/s/m		

Screens:

Screen No.	Screen Type	Top (m)	Bottom (m)	Diameter (mm)	Leader Length (mm)	Slot Size (mm)	Slot Length (mm)
1	Stainless steel	60	66				

Step Tests:

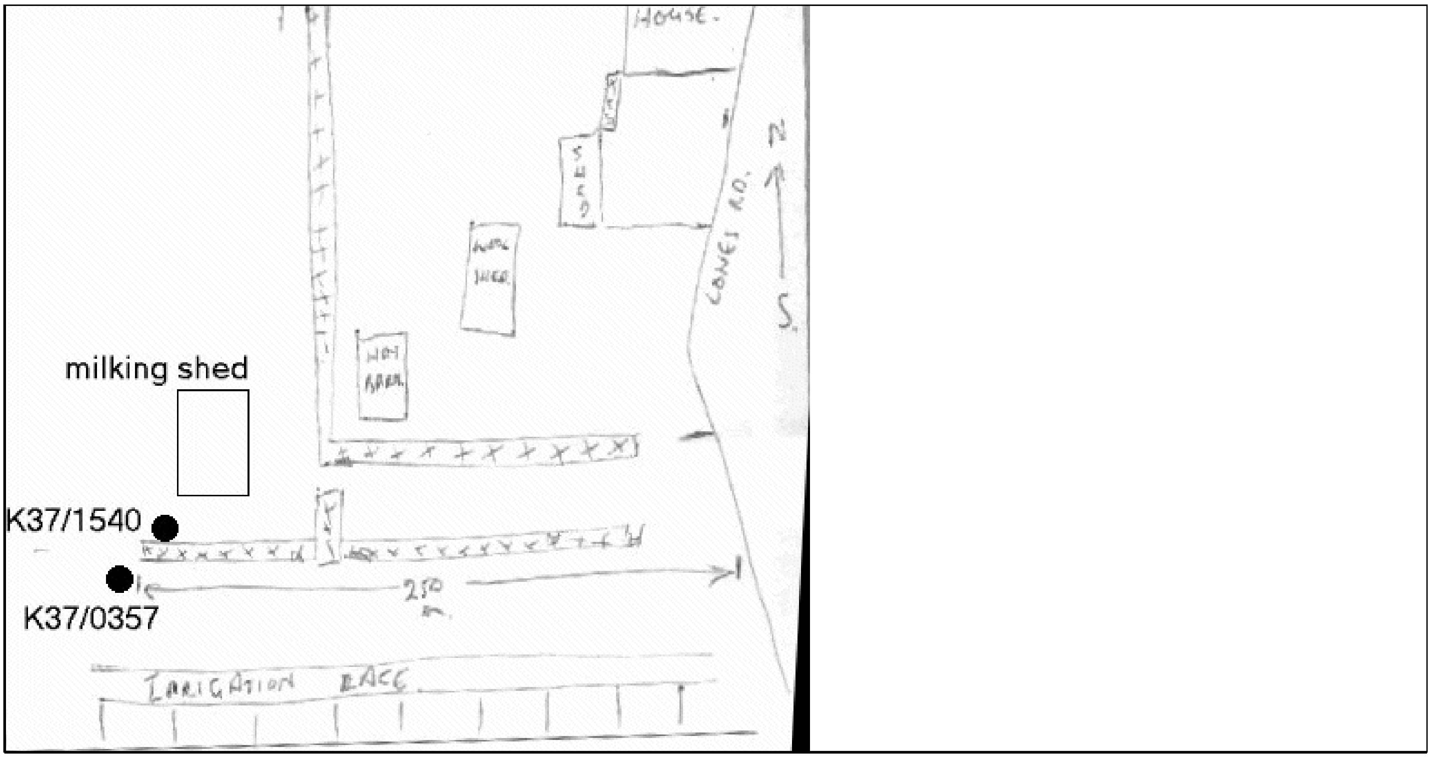
Step Test Date	Step	Yield (l/s)	Drawdown	Duration (mins)
16 Jan 2002	1	90	18	510

Date	Comments
01 Dec 2003	Gridref changed from: K37:9908-0110. Owner, Robert Mangin, says that he is having trouble with water supply from this well at the moment. He suspects that it could be due to late start of border dyke irrigation in the area. Full scale border dyke irrigation has started a month later than usual, a few started in the last week in October, normal rostered supply started in November.
08 Jun 2004	Gridref changed from K37:99186-01060, reference RL from 135.300, differential GPS survey, May 2004

Aquifer test date(s) where this is the pump bore

Aquifer test date(s) where this is an observation bore

13 Jan 2005 - constant - Pump bore: K37/1035


HOUSE.
CONES RD.
N
S.
milking shed
K37/1540
K37/0357
250 m.
IRRIGATION RACE

Bore or Well No: K37/1649

Well Name:

Owner: Mr & Mrs G K & G F Paisley

Environment Canterbury
Your regional council

Street of Well: FRASERS ROAD

Locality: LAGMHOR

NZTM Grid Reference: BY20:90776-39288 QAR 2

NZTM X-Y: 1490776 - 5139288

Location Description: Base of centre pivot, follow track past house from Frasers Rd

ECan Monitoring:

Well Status: Active (exist, present)

File No: CO6C/19140

Allocation Zone: Valetta

CWMS Zone: Ashburton

Uses: Irrigation

Drill Date: 20 Dec 2002

Well Depth: 60.00m -GL

Initial Water Depth: -18.50m -MP

Diameter: 300mm

Measuring Point Alt: 125.88m MSD QAR 4

GL Around Well: -0.36m -MP

MP Description: Top of bung hole

Driller: Smiths Welldrilling

Drilling Method: Rotary/Percussion

Casing Material: STEEL

Pump Type: Submersible

Yield: 39 l/s

Drawdown: 20 m

Specific Capacity: 2.46 l/s/m

Water Level Count: 0

Strata Layers: 7

Aquifer Tests: 0

Yield/Drawdown Tests: 5

Highest GW Level:

Lowest GW Level:

First Reading:

Last Reading:

Calc. Min. (Below MP): -23.10m -MP

Last Updated: 08 Nov 2013

Last Field Check: 03 Dec 2003

Aquifer Type:

Aquifer Name:

Screens:

Screen No.	Screen Type	Top (m)	Bottom (m)	Diameter (mm)	Leader Length (mm)	Slot Size (mm)	Slot Length (mm)
1	Stainless steel	51	57				
2	Slotted Casing	57	60				

Step Tests:

Step Test Date	Step	Yield (l/s)	Drawdown	Duration (mins)
19 Feb 2003	1	24.81	10.1	
19 Feb 2003	2	33.83	15.3	
19 Feb 2003	3	39.09	20.1	375

Date	Comments
26 May 2003	Only total pump test time supplied by driller
10 Jun 2003	Gridref changed from: K37:0074-0084, from location provided in C06C/19140.
03 Dec 2003	Gridref changed from: K37:0073-0094
17 Mar 2011	Gridref changed from: K37:00705-00886 to K37:00748-00897 - as per Warwick Johnston's site visit 13/1/11

Aquifer test date(s) where this is the pump bore

Aquifer test date(s) where this is an observation bore

Bore or Well No: K37/0383

Well Name:

Owner: Mr D A J Geddes

Street of Well:	Longbeach Road	**File No:**	CO6T/01583
Locality:	Willowby	**Allocation Zone:**	Valetta
NZTM Grid Reference:	BY21:94355-30930 QAR 1	**CWMS Zone:**	Ashburton
NZTM X-Y:	1494355 - 5130930		
Location Description:	Beside green shed, v close to road, across road from a house.	**Uses:**	Irrigation
ECan Monitoring:			
Well Status:	Active (exist, present)		

Drill Date:		**Water Level Count:**	6
Well Depth:	12.10m -GL	**Strata Layers:**	0
Initial Water Depth:	-1.00m -MP	**Aquifer Tests:**	0
Diameter:	300mm	**Yield/Drawdown Tests:**	0
Measuring Point Ait:	76.28m MSD QAR 1	**Highest GW Level:**	0.82m below MP
GL Around Well:	-0.25m -MP	**Lowest GW Level:**	3.75m below MP
MP Description:	Top of liner	**First Reading:**	05 Aug 1977
		Last Reading:	24 May 2004
Driller:	not known	**Calc. Min. (Below MP):**	-3.40m -MP
Drilling Method:	Hand Dug	**Last Updated:**	08 Jun 2004
Casing Material:	STEEL	**Last Field Check:**	24 May 2004
Pump Type:	Centrifugal (Surface)		
Yield:		**Aquifer Type:**	Unknown
Drawdown:		**Aquifer Name:**	
Specific Capacity:			

Screens:

Screen No.	Screen Type	Top (m)	Bottom (m)	Diameter (mm)	Leader Length (mm)	Slot Size (mm)	Slot Length (mm)

Step Tests:

Step Test Date	Step	Yield (l/s)	Drawdown	Duration (mins)

Date	Comments
07 Sep 2000	SCCB well HA 25, measured as 12.1m.
27 Jan 2003	Gridref changed from: K37:044-926. Originally approx 1.2m diameter.
08 Jun 2004	Gridref changed from K37:04327-92541, reference RL from 76.276, differential GPS survey, May 2004
21 Jan 2014	Temporary Waiver Application sent

Aquifer test date(s) where this is the pump bore

Aquifer test date(s) where this is an observation bore

Bore or Well No: K37/2458

Well Name:

Owner: GUYON FARM LIMITED

Environment Canterbury
Your regional council

Street of Well:		**File No:**	
Locality:	LAGMHOR	**Allocation Zone:**	Valetta
NZTM Grid Reference:	BY20:90980-40409 QAR 2	**CWMS Zone:**	Ashburton
NZTM X-Y:	1490980 - 5140409		
Location Description:		**Uses:**	Domestic and Stockwater
ECan Monitoring:			
Well Status:	Active (exist, present)		

Drill Date:	10 May 2005	**Water Level Count:**	0
Well Depth:	60.00m -GL	**Strata Layers:**	7
Initial Water Depth:	-21.20m -MP	**Aquifer Tests:**	0
Diameter:	150mm	**Yield/Drawdown Tests:**	4
Measuring Point Ait:	129.17m MSD QAR 4	**Highest GW Level:**	
GL Around Well:	-0.30m -MP	**Lowest GW Level:**	
MP Description:	ToC	**First Reading:**	
		Last Reading:	
Driller:	Smiths Welldrilling	**Calc. Min. (Below MP):**	
Drilling Method:	Rotary Rig	**Last Updated:**	08 Nov 2013
Casing Material:	Steel	**Last Field Check:**	
Pump Type:			
Yield:	11 l/s	**Aquifer Type:**	
Drawdown:	2 m	**Aquifer Name:**	
Specific Capacity:	7.24 l/s/m		

Screens:

Screen No.	Screen Type	Top (m)	Bottom (m)	Diameter (mm)	Leader Length (mm)	Slot Size (mm)	Slot Length (mm)
1	Stainless steel	57	60				

Step Tests:

Step Test Date	Step	Yield (l/s)	Drawdown	Duration (mins)
14 May 2005	1	5.789	0.8	30
14 May 2005	2	7.14	1.05	30
14 May 2005	3	7.89	1.15	30
14 May 2005	4	11.27	1.95	30

Date	Comments
29 Jul 2005	Source of grid ref and QAR unknown

Aquifer test date(s) where this is the pump bore

Aquifer test date(s) where this is an observation bore

Bore or Well No: K37/2603

Well Name:

Owner: MS M D SMITH

Environment Canterbury
Your regional council

Street of Well:

File No:

Locality: ASHBURTON

Allocation Zone: Valetta

NZTM Grid Reference: BY20:91330-38244 QAR 2

CWMS Zone: Ashburton

NZTM X-Y: 1491330 - 5138244

Location Description:

Uses: Domestic and Stockwater

ECan Monitoring:

Well Status: Active (exist, present)

Drill Date: 21 Nov 2005

Water Level Count: 0

Well Depth: 54.00m -GL

Strata Layers: 4

Initial Water Depth: -23.50m -MP

Aquifer Tests: 0

Diameter: 150mm

Yield/Drawdown Tests: 1

Measuring Point Ait: 125.03m MSD QAR 4

Highest GW Level:

GL Around Well: -0.30m -MP

Lowest GW Level:

MP Description: ToC

First Reading:

Last Reading:

Driller: Smiths Welldrilling

Calc. Min. (Below MP):

Drilling Method: Rotary/Percussion

Last Updated: 08 Nov 2013

Casing Material: Steel

Last Field Check:

Pump Type:

Yield: 5 l/s

Aquifer Type:

Drawdown: 1 m

Aquifer Name:

Specific Capacity: 5.07 l/s/m

Screens:

Screen No.	Screen Type	Top (m)	Bottom (m)	Diameter (mm)	Leader Length (mm)	Slot Size (mm)	Slot Length (mm)
1	Stainless steel	53	54				

Step Tests:

Step Test Date	Step	Yield (l/s)	Drawdown	Duration (mins)
24 Nov 2005	1	5.075	1	60

Date	Comments
02 Nov 2005	Deepened K37/0643.
25 Jul 2008	BCR confirms location

Aquifer test date(s) where this is the pump bore

Aquifer test date(s) where this is an observation bore

Bore or Well No:	K37/2538
Well Name:	
Owner:	FULTON HOGAN CANTERBURY LIMITED

Environment Canterbury
Your regional council

Street of Well:		**File No:**	
Locality:	ASHBURTON	**Allocation Zone:**	Valetta
NZTM Grid Reference:	BY20:90378-39341 QAR 4	**CWMS Zone:**	Ashburton
NZTM X-Y:	1490378 - 5139341		
Location Description:		**Uses:**	Water Level Observation
ECan Monitoring:			
Well Status:	Active (exist, present)		

Drill Date:	23 Nov 2005	**Water Level Count:**	0
Well Depth:	48.00m -GL	**Strata Layers:**	5
Initial Water Depth:	-32.80m -MP	**Aquifer Tests:**	0
Diameter:	100mm	**Yield/Drawdown Tests:**	0
Measuring Point Ait:	128.31m MSD QAR 4	**Highest GW Level:**	
GL Around Well:	-0.30m -MP	**Lowest GW Level:**	
MP Description:	ToC	**First Reading:**	
		Last Reading:	
Driller:	Smiths Welldrilling	**Calc. Min. (Below MP):**	
Drilling Method:	Rotary/Percussion	**Last Updated:**	17 Jul 2006
Casing Material:	PVC	**Last Field Check:**	
Pump Type:			
Yield:		**Aquifer Type:**	
Drawdown:		**Aquifer Name:**	
Specific Capacity:			

Screens:

Screen No.	Screen Type	Top (m)	Bottom (m)	Diameter (mm)	Leader Length (mm)	Slot Size (mm)	Slot Length (mm)
1	Slotted PVC	45	48				

Step Tests:

Step Test Date	Step	Yield (l/s)	Drawdown	Duration (mins)

Date	Comments
17 Jul 2006	Another borelog (C06C/11037) exists under this consent number from Smiths Welldrilling drilled on the same date. The bore is 30m deep and 100mm in diameter with a SWL of 17.4m below ground.
17 Jul 2006	The screen is slotted PVC and is screened from 27-30m. There is a small log with this that has 4 stratas listed somewhat different from the correct borelog for this well. No bore number is on this BCR to tie it to any other well.
17 Jul 2006	Currently waiting for a reply to the compliance monitoring letter sent to the driller regarding this extra borelog.

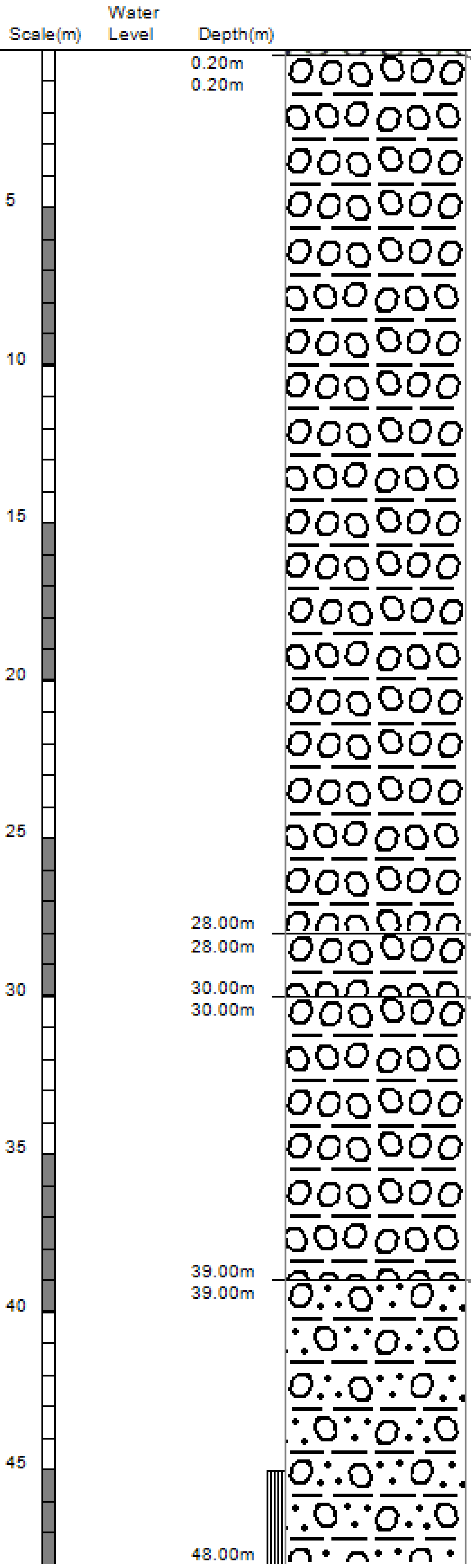
Aquifer test date(s) where this is the pump bore

Aquifer test date(s) where this is an observation bore

Borelog for well K37/2538

Grid Reference (NZTM): 1490378 mE, 5139341 mN
Location Accuracy: 50 - 300m
Ground Level Altitude: 128.0 m +MSD Accuracy: < 0.5 m
Driller: Smiths Welldrilling
Drill Method: Rotary/Percussion
Borelog Depth: 48.0 m Drill Date: 23-Nov-2005

Environment Canterbury Regional Council
Kaunihera Taiao ki Waitaha



Depth(m)	Full Drillers Description	Formation Code
0.20m	soil	
0.20m	soil	
	claybound gravels	
28.00m	claybound gravels	
28.00m	stained claybound gravels	
30.00m	stained claybound gravels	
30.00m	claybound gravels	
39.00m	claybound gravels	
39.00m	claybound sandy gravels	
48.00m		

8.0 MONITORING WELL LOGS

This section contains geological logs for the wells used to monitoring the MAR Pilot Trial, including both existing wells and new wells installed for the specific purpose of monitoring the Pilot Trial.

Of the seven monitoring wells drilled and instrumented for the Pilot Trial:

- Five were initially drilled using a sonic drilling technique, to enable high quality samples of the materials intersected to be obtained and logged. These drillholes were then overdrilled using a rotary air blast (RAB) rig before the monitoring well casing was installed.
- Two monitoring wells were installed using the RAG rig only.

The drillhole logs provided in this section are:

- Golder geotechnical logs for the five sonic drilled holes, for which good samples were available.
- McMillan Drilling Ltd logs for all seven of the monitoring wells installed for the MAR Pilot Trial.
- CRC records of drillhole logs for the existing wells used as monitoring wells for the MAR Pilot Trial.

Bore Log

McMILLAN Drilling GROUP

Client:	Golders Associates
Project:	Hinds MAR Pilot Project, Canterbury
Bore No.:	BH GWD-1
Job No.:	14896

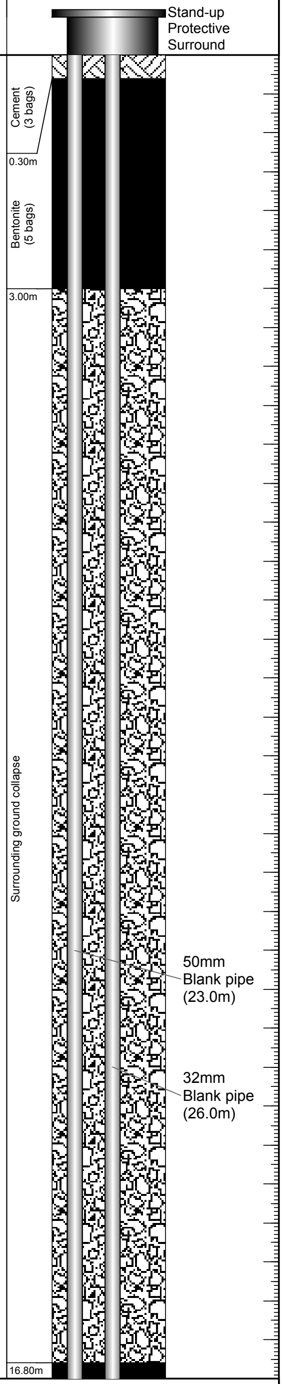
Site Location: Various locations, Hinds
Grid Reference: 1489082.9mE 5140610.97mN NZTM
Rig Operator: K. Morris, V. Vasques
Rig Model & Mounting: Geoprobe 8140LS - track, Cased RAB 102
Date Commenced: 28/01/2016
Date Completed: 26/02/2016
Consent: -
Datum: Ground

Method: Sonic core drilling

Depth (m)	Description
0.00	TOPSOIL.
0.10m	SILT with some gravel; brown. Gravel, fine to medium.
0.37m	Sandy fine to medium GRAVEL with trace silt and cobbles. Silt; brown.
1.35m	Fine to medium GRAVEL with some cobbles.
3.08m	Fine to coarse SAND with some gravel and trace silt; brown. Gravel, fine to medium. Silt; brown.
4.44m	Fine to medium GRAVEL with trace cobbles.
5.90m	Silty fine to medium GRAVEL with trace sand; brown. Sand; fine to coarse.
8.40m	SILT with some gravel; grey. Gravel, fine to medium.
9.00m	Sandy fine to coarse GRAVEL; dark brown.
9.50m	Fine to medium GRAVEL. Possible washing of fine fraction. 10.82 - 12.04m Trace cobbles
12.04m	SILT with some gravel; light brown. Gravel, fine to medium.
13.56m	Fine to medium GRAVEL with trace cobbles. Possible washing of fine fraction. 14.10 - 15.08m Some silt
15.08m	Fine to medium GRAVEL with trace cobbles and silt. Silt; brown.
16.60m	Silty fine to medium GRAVEL; brown.

Run (approx. depth, m)	Recovery
0.0 – 1.4	70%
1.4 – 3.0	70%
3.0 – 4.5	85%
4.5 – 6.0	45%
6.0 – 7.5	100%
7.5 – 9.0	100%
9.0 – 10.5	75%
10.5 – 12.0	50%
12.0 – 13.5	100%
13.5 – 15.0	80%
15.0 – 16.5	85%
16.5 –	100%

Installation & Resources



Remarks

Geotechnical investigation borehole BH GWD-1

Static water levels:
5.77m bgl at casing depth of 5.90m; 28/01/2016, 3:10 pm
5.70m bgl at casing depth of 7.08m; 29/01/2016, 9:45 am
5.70m bgl at casing depth of 10.52m; 1/02/2016, 9:30 am
15.70m bgl at casing depth of 18.12m; 2/02/2016, 12:45 pm
9.99m bgl at casing depth of 24.20m; 3/02/2016, 9:50 am

Samples in core boxes

5000 liters water added

Drivability

1 Easy Push - No Hammer \ Fast Penetration
2 Relatively Easy Push - Light Hammer \ Relatively Fast
3 Medium Push - Consistent Hammer \ Medium
4 Hard Push - Full Hammer \ Somewhat Slow
5 Very Hard Push - Full Hammer \ Very Slow

Additional Resources:

Item	Unit	
Plastic Liner / PVC Splits	m	-
Flush Mounted Toby Box		
- Standard	ea	
- Environmental	ea	
Above Ground Protective Surround	ea	✔
Geotextile Sock	m	-
Hand Clear Location	ea	
Decontaminate Equipment	ea	

Hole Depth: 32.7m

Bore Log

McMILLAN Drilling GROUP	**Client:** Golders Associates	**Bore No.:** BH GWD-1
	Project: Hinds MAR Pilot Project, Canterbury	**Job No.:** 14896

Site Location: Various locations, Hinds
Grid Reference: 1489082.9mE 5140610.97mN NZTM
Rig Operator: K. Morris, V. Vasques
Rig Model & Mounting: Geoprobe 8140LS - track, Cased RAB 102

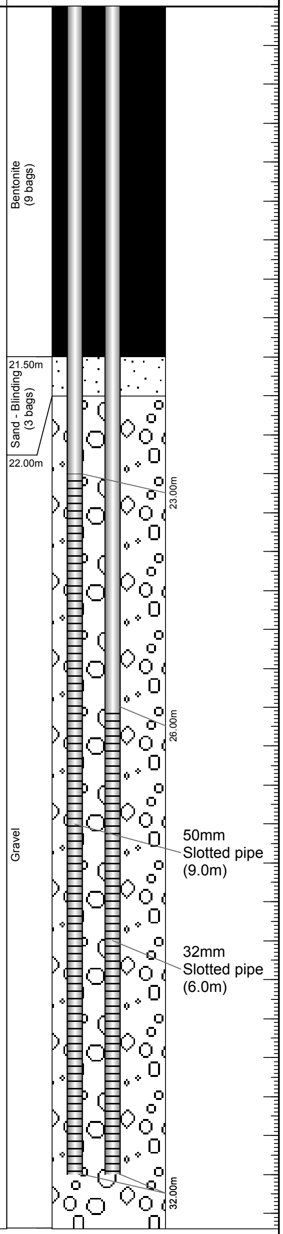
Date Commenced: 28/01/2016
Date Completed: 26/02/2016
Consent: -
Datum: Ground

Description	Depth to top	Method	Recovery
(continued from previous page)		Sonic core drilling	100% (17.0–18.0), 80% (18.0–19.5)
Fine to medium GRAVEL with some silt. Possible washing of fine fraction.	19.04m	Sonic core drilling	
Silty fine to medium GRAVEL.	19.64m	Sonic core drilling	100% (19.5–21.0), 100% (21.0–22.5), 100% (22.5–24.0), 100% (24.0–25.5)
Fine to medium GRAVEL. Possible washing of fine fraction.	26.34m	Sonic core drilling	85% (25.5–27.0), 60% (27.0–28.5)
Silty fine to medium GRAVEL with trace cobbles.	28.76m	Sonic core drilling	100% (28.5–30.0)
Sample not logged.	30.28m	Rotary cored	100% (30.0–32.7)

Column headings: Description, Method, Drivability (1 2 3 4 5), Recovery (25 50 75), Depth, Graphic Log, SPT N-value (Uncorrected) (10 20 30 40 50), In-Situ Tests (Uncorrected), Samples - Permeability tests, Installation & Resources

Depth scale: 17.5, 18.0, 18.5, 19.0, 19.5, 20.0, 20.5, 21.0, 21.5, 22.0, 22.5, 23.0, 23.5, 24.0, 24.5, 25.0, 25.5, 26.0, 26.5, 27.0, 27.5, 28.0, 28.5, 29.0, 29.5, 30.0, 30.5, 31.0, 31.5, 32.0, 32.5

EOH: 32.7m



Remarks

Geotechnical investigation borehole BH GWD-1

Static water levels:
5.77m bgl at casing depth of 5.90m; 28/01/2016, 3:10 pm
5.70m bgl at casing depth of 7.08m; 29/01/2016, 9:45 am
5.70m bgl at casing depth of 10.52m; 1/02/2016, 9:30 am
15.70m bgl at casing depth of 18.12m; 2/02/2016, 12:45 pm
9.99m bgl at casing depth of 24.20m; 3/02/2016, 9:50 am

Samples in core boxes

5000 liters water added

Drivability

1 Easy Push - No Hammer \ Fast Penetration
2 Relatively Easy Push - Light Hammer \ Relatively Fast
3 Medium Push - Consistent Hammer \ Medium
4 Hard Push - Full Hammer \ Somewhat Slow
5 Very Hard Push - Full Hammer \ Very Slow

Additional Resources:

Plastic Liner / PVC Splits	m	-
Flush Mounted Toby Box		
- Standard	ea	
- Environmental	ea	
Above Ground Protective Surround	ea	✔
Geotextile Sock	m	-
Hand Clear Location	ea	
Decontaminate Equipment	ea	

Bore Log

McMILLAN Drilling GROUP

Client: Golders Associates	**Bore No.:** BH GWD-2
Project: Hinds MAR Pilot Project, Canterbury	**Job No.:** 14896

Site Location: Tinwald
Grid Reference: 1489461.78mE 5140497.22mN NZTM
Rig Operator: K. Morris, R. Conkie
Rig Model & Mounting: Geoprobe 8140LS - track

Date Commenced: 10/02/2016
Date Completed: 16/02/2016
Consent: -
Datum: Ground

Description	Depth of base	Method	Recovery
TOPSOIL.	0.05m	Sonic core drilling	75% (0–1.5m)
Fine to medium GRAVEL.	2.00m		85% (1.5–3.0m)
Silty fine to medium GRAVEL with trace cobbles; light brown.	2.92m		80% (3.0–4.5m)
Fine to medium GRAVEL with trace cobbles.	4.44m		85% (4.5–6.0m)
Silty fine to medium GRAVEL with trace cobbles; light brown.	5.96m		100% (6.0–7.5m)
Fine to medium GRAVEL with trace cobbles. Possible washing of fine fraction.	12.04m		100% (7.5–9.0m), 100% (9.0–10.5m), 100% (10.5–12.0m)
Silty fine to medium GRAVEL; brown.			100% (12.0–13.5m), 80% (13.5–15.0m), 80% (15.0–16.5m), 100% (16.5m–)

Column headings: Description, Method, Drivability (1 2 3 4 5), Recovery (25 50 75), Depth, Graphic Log, SPT N-value (Uncorrected) (10 20 30 40 50), In-Situ Tests (Uncorrected), Samples - Permeability tests, Installation & Resources.

Installation & Resources: Stand-up Protective Surround; Cement (2 bags) to 0.30m; Bentonite (7 bags); 50mm Blank pipe (23.0m)

Remarks

Geotechnical investigation borehole BH GWD-2

Static water levels:
8.35m bgl at casing depth of 12.04m; 11/02/2016, 9:45 am
7.20m bgl at casing depth of 19.64m; 12/02/2016, 12:00 pm
6.60m bgl at casing depth of 21.16m; 12/02/2016, 7:00 pm
22.60m bgl at casing depth of 25.00m; 15/02/2016, 11:45 am
25.32m bgl at casing depth of 30.28m; 16/02/2016, 10:00am
24.70m bgl; 17/02/2016, 10:30 am

Samples in core boxes

6000 liters water added

Drivability

1 Easy Push - No Hammer \ Fast Penetration
2 Relatively Easy Push - Light Hammer \ Relatively Fast
3 Medium Push - Consistent Hammer \ Medium
4 Hard Push - Full Hammer \ Somewhat Slow
5 Very Hard Push - Full Hammer \ Very Slow

Additional Resources:

Plastic Liner / PVC Splits	m	-
Flush Mounted Toby Box		
- Standard	ea	
- Environmental	ea	
Above Ground Protective Surround	ea	✔
Geotextile Sock	m	-
Hand Clear Location	ea	
Decontaminate Equipment	ea	

Hole Depth: 32m

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Created: 29/04/2016 2:44:08 p.m.

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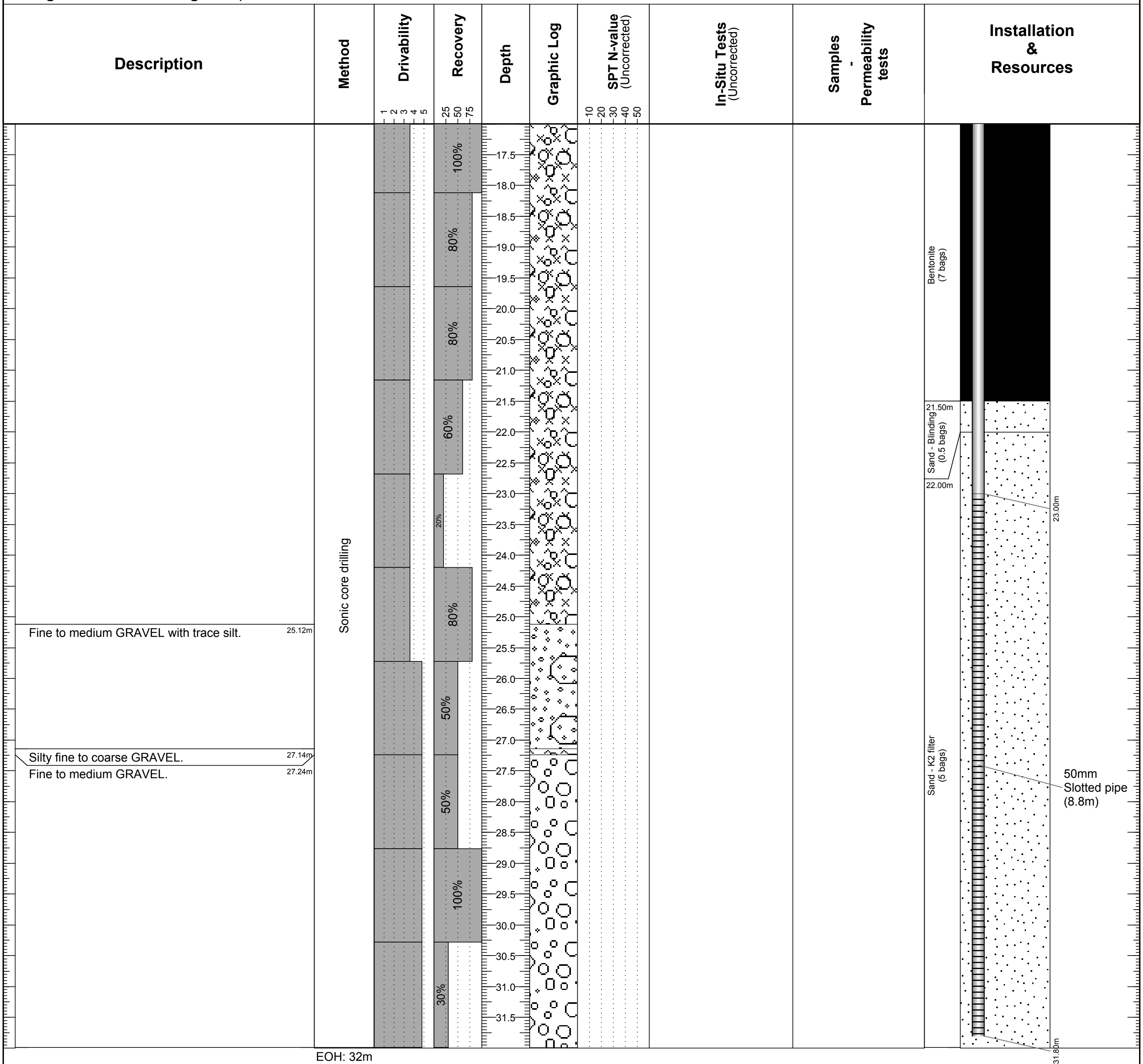
Bore Log

Client: Golders Associates		**Bore No.:** BH GWD-2
Project: Hinds MAR Pilot Project, Canterbury		**Job No.:** 14896

Site Location: Tinwald
Grid Reference: 1489461.78mE 5140497.22mN NZTM
Rig Operator: K. Morris, R. Conkie
Rig Model & Mounting: Geoprobe 8140LS - track

Date Commenced: 10/02/2016
Date Completed: 16/02/2016
Consent: -
Datum: Ground



Remarks

Geotechnical investigation borehole BH GWD-2

Static water levels:
8.35m bgl at casing depth of 12.04m; 11/02/2016, 9:45 am
7.20m bgl at casing depth of 19.64m; 12/02/2016, 12:00 pm
6.60m bgl at casing depth of 21.16m; 12/02/2016, 7:00 pm
22.60m bgl at casing depth of 25.00m; 15/02/2016, 11:45 am
25.32m bgl at casing depth of 30.28m; 16/02/2016, 10:00am
24.70m bgl; 17/02/2016, 10:30 am

Samples in core boxes

6000 liters water added

Drivability

1 Easy Push - No Hammer \ Fast Penetration
2 Relatively Easy Push - Light Hammer \ Relatively Fast
3 Medium Push - Consistent Hammer \ Medium
4 Hard Push - Full Hammer \ Somewhat Slow
5 Very Hard Push - Full Hammer \ Very Slow

Additional Resources:

Plastic Liner / PVC Splits	m	-
Flush Mounted Toby Box		
- Standard	ea	
- Environmental	ea	
Above Ground Protective Surround	ea	✔
Geotextile Sock	m	-
Hand Clear Location	ea	
Decontaminate Equipment	ea	

Hole Depth: 32m

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Bore Log

McMILLAN Drilling GROUP

Client:	Golders Associates
Project:	Hinds MAR Pilot Project, Canterbury
Bore No.:	BH GWD-3
Job No.:	14896

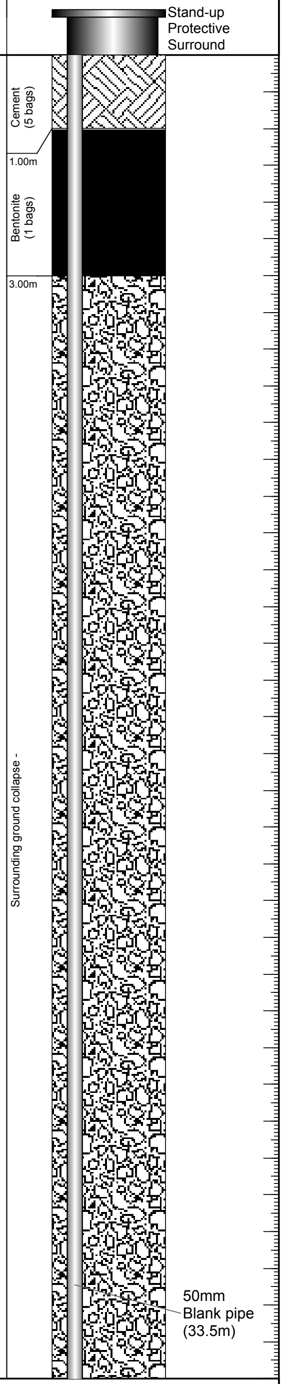
Site Location: Various locations, Hinds
Grid Reference: 1490768.1mE 5140823mN NZTM
Rig Operator: Gibellini, Andy, S. Magititabua
Rig Model & Mounting: Cased RAB 136

Date Commenced: 01/04/2016
Date Completed: 02/04/2016
Consent: -
Datum: Ground

Description	Depth to base	Method	Drivability (1–5)	Recovery (25/50/75)	Depth	Graphic Log	SPT N-value (Uncorrected) (10–50)	In-Situ Tests (Uncorrected)	Samples - Permeability tests
TOPSOIL.	0.40m	Rotary air blast		100%	0.5 … 17.5				
Coarse GRAVEL.	4.00m								
Clayey GRAVEL.	11.00m								
Clayey GRAVEL with some sand. Moist. Sand; brown.									

Depth scale: 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0, 4.5, 5.0, 5.5, 6.0, 6.5, 7.0, 7.5, 8.0, 8.5, 9.0, 9.5, 10.0, 10.5, 11.0, 11.5, 12.0, 12.5, 13.0, 13.5, 14.0, 14.5, 15.0, 15.5, 16.0, 16.5, 17.0, 17.5

Installation & Resources



Remarks

Geotechnical investigation borehole BH GWD-3

Static water level:
37.95m bgl

Drivability

1 Easy Push - No Hammer \ Fast Penetration
2 Relatively Easy Push - Light Hammer \ Relatively Fast
3 Medium Push - Consistent Hammer \ Medium
4 Hard Push - Full Hammer \ Somewhat Slow
5 Very Hard Push - Full Hammer \ Very Slow

Additional Resources:

Plastic Liner / PVC Splits	m	-
Flush Mounted Toby Box		
- Standard	ea	
- Environmental	ea	
Above Ground Protective Surround	ea	✔
Geotextile Sock	m	-
Hand Clear Location	ea	
Decontaminate Equipment	ea	

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Hole Depth: 46m

Created: 29/04/2016 2:44:08 p.m.

Bore Log

McMILLAN Drilling GROUP

Client: Golders Associates

Project: Hinds MAR Pilot Project, Canterbury

Bore No.: BH GWD-3

Job No.: 14896

Site Location: Various locations, Hinds
Grid Reference: 1490768.1mE 5140823mN NZTM
Rig Operator: Gibellini, Andy, S. Magititabua
Rig Model & Mounting: Cased RAB 136

Date Commenced: 01/04/2016
Date Completed: 02/04/2016
Consent: -
Datum: Ground

Description	Method	Drivability (1 2 3 4 5)	Recovery (25 50 75)	Depth	Graphic Log	SPT N-value (Uncorrected) (10 20 30 40 50)	In-Situ Tests (Uncorrected)	Samples - Permeability tests
20.00m Sandy GRAVEL with some clay. Moist.	Rotary air blast		100%	18.5 – 20.0				
22.50m Clayey GRAVEL.				20.5 – 35.5				

Depth scale: 18.5, 19.0, 19.5, 20.0, 20.5, 21.0, 21.5, 22.0, 22.5, 23.0, 23.5, 24.0, 24.5, 25.0, 25.5, 26.0, 26.5, 27.0, 27.5, 28.0, 28.5, 29.0, 29.5, 30.0, 30.5, 31.0, 31.5, 32.0, 32.5, 33.0, 33.5, 34.0, 34.5, 35.0, 35.5

Installation & Resources

- Surrounding ground collapse - (to 27.95m)
- 27.95m Bentonite - K2 filter (2 bags)
- 31.95m Sand - Blinding (2 bags)
- 32.95m Gravel
- 33.45m

Remarks

Geotechnical investigation borehole BH GWD-3

Static water level:
37.95m bgl

Drivability

1 Easy Push - No Hammer \ Fast Penetration
2 Relatively Easy Push - Light Hammer \ Relatively Fast
3 Medium Push - Consistent Hammer \ Medium
4 Hard Push - Full Hammer \ Somewhat Slow
5 Very Hard Push - Full Hammer \ Very Slow

Additional Resources:

Plastic Liner / PVC Splits	m	-
Flush Mounted Toby Box		
- Standard	ea	
- Environmental	ea	
Above Ground Protective Surround	ea	✔
Geotextile Sock	m	-
Hand Clear Location	ea	
Decontaminate Equipment	ea	

Hole Depth: 46m

Bore Log

![McMillan Drilling Group]

McMILLAN Drilling GROUP	**Client:** Golders Associates	**Bore No.:** BH GWD-3
	Project: Hinds MAR Pilot Project, Canterbury	**Job No.:** 14896

Site Location: Various locations, Hinds
Grid Reference: 1490768.1mE 5140823mN NZTM
Rig Operator: Gibellini, Andy, S. Magititabua
Rig Model & Mounting: Cased RAB 136

Date Commenced: 01/04/2016
Date Completed: 02/04/2016
Consent: -
Datum: Ground

Description	Method	Drivability (1 2 3 4 5)	Recovery (25 50 75)	Depth	Graphic Log	SPT N-value (Uncorrected) (10 20 30 40 50)	In-Situ Tests (Uncorrected)	Samples - Permeability tests	Installation & Resources
	Rotary air blast		100%	36.5 – 43.0					Gravel; 50mm Slotted pipe (12.0m)
Clayey GRAVEL. Moist. (43.00m)				43.0 – 46.0					45.45m

Depth scale: 36.5, 37.0, 37.5, 38.0, 38.5, 39.0, 39.5, 40.0, 40.5, 41.0, 41.5, 42.0, 42.5, 43.0, 43.5, 44.0, 44.5, 45.0, 45.5

EOH: 46m

Remarks

Geotechnical investigation borehole BH GWD-3

Static water level:
37.95m bgl

Drivability

1 Easy Push - No Hammer \ Fast Penetration
2 Relatively Easy Push - Light Hammer \ Relatively Fast
3 Medium Push - Consistent Hammer \ Medium
4 Hard Push - Full Hammer \ Somewhat Slow
5 Very Hard Push - Full Hammer \ Very Slow

Additional Resources:

Plastic Liner / PVC Splits	m	-
Flush Mounted Toby Box		
- Standard	ea	
- Environmental	ea	
Above Ground Protective Surround	ea	✔
Geotextile Sock	m	-
Hand Clear Location	ea	
Decontaminate Equipment	ea	

Hole Depth: 46m

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Created: 29/04/2016 2:44:09 p.m.

Bore Log

McMILLAN Drilling GROUP

Client: Golders Associates

Project: Hinds MAR Pilot Project, Canterbury

Bore No.: BH GWD-4

Job No.: 14896

Site Location: Tinwald
Grid Reference: 1489820.64mE 5139744.18mN NZTM
Rig Operator: K. Morris, V. Vasques
Rig Model & Mounting: Geoprobe 8140LS - track, Cased RAB 102

Date Commenced: 04/02/2016
Date Completed: 31/03/2016
Consent: -
Datum: Ground

Description	Depth (m)
TOPSOIL.	
Silty fine to medium GRAVEL with trace cobbles; brown.	0.05m
Fine to medium GRAVEL with trace cobbles. Possible washing of fine fraction.	5.96m
Silty fine to medium GRAVEL; light brown.	7.88m
Fine to medium GRAVEL with trace silt.	9.00m
Silty fine to medium GRAVEL; light brown.	10.82m
11.72m Color changes to dark brown	

Method: Sonic core drilling

Recovery: 85%, 95%, 50%, 100%, 65%, 80%, 65%, 100%, 85%, 100%, 100%, 90%

Depth: 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0, 4.5, 5.0, 5.5, 6.0, 6.5, 7.0, 7.5, 8.0, 8.5, 9.0, 9.5, 10.0, 10.5, 11.0, 11.5, 12.0, 12.5, 13.0, 13.5, 14.0, 14.5, 15.0, 15.5, 16.0, 16.5

Column headings: Description | Method | Drivability (1 2 3 4 5) | Recovery (25 50 75) | Depth | Graphic Log | SPT N-value (Uncorrected) (10 20 30 40 50) | In-Situ Tests (Uncorrected) | Samples - Permeability tests | Installation & Resources

Installation & Resources:
- Stand-up Protective Surround
- Cement (3 bags) — to 1.00m
- Bentonite (1 bags) — 1.00m to 3.00m
- Surrounding ground collapse — 3.00m to 6.75m
- Bentonite (6 bags) — from 6.75m
- 50mm Blank pipe (20.3m)
- 32mm Blank pipe (23.3m)

Remarks

Geotechnical investigation borehole BH GWD-4

Static water levels:
2.70m bgl at casing depth of 10.52m; 4/02/2016, 1:15 pm
10.95m bgl at casing depth of 15.08m; 5/02/2016, 9:15 am

Samples in core boxes

5000 liters water added

Drivability

1 Easy Push - No Hammer \ Fast Penetration
2 Relatively Easy Push - Light Hammer \ Relatively Fast
3 Medium Push - Consistent Hammer \ Medium
4 Hard Push - Full Hammer \ Somewhat Slow
5 Very Hard Push - Full Hammer \ Very Slow

Additional Resources:

Plastic Liner / PVC Splits	m	-
Flush Mounted Toby Box		
- Standard	ea	
- Environmental	ea	
Above Ground Protective Surround	ea	✔
Geotextile Sock	m	-
Hand Clear Location	ea	
Decontaminate Equipment	ea	

Hole Depth: 29.8m

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Created: 29/04/2016 2:44:09 p.m.

Bore Log

McMILLAN Drilling GROUP	Client: Golders Associates	Bore No.: BH GWD-4
	Project: Hinds MAR Pilot Project, Canterbury	Job No.: 14896

Site Location: Tinwald
Grid Reference: 1489820.64mE 5139744.18mN NZTM
Rig Operator: K. Morris, V. Vasques
Rig Model & Mounting: Geoprobe 8140LS - track, Cased RAB 102

Date Commenced: 04/02/2016
Date Completed: 31/03/2016
Consent: -
Datum: Ground

Description	Method	Drivability (1 2 3 4 5)	Recovery (25 50 75)	Depth	Graphic Log	SPT N-value (Uncorrected) (10 20 30 40 50)	In-Situ Tests (Uncorrected)	Samples - Permeability tests	Installation & Resources
	Sonic core drilling		90%	17.5 – 18.0					Bentonite (6 bags)
			100%	18.5 – 19.0					18.75m; Sand - Blinding (3 bags)
			100%	19.5 – 21.0					19.75m; Gravel - ; 20.25m
			85%	21.5 – 22.5					
			85%	23.0 – 24.0					23.25m
			85%	24.5 – 25.5					50mm Slotted pipe (9.0m)
Clayey GRAVEL. (25.72m)	Rotary air blast		100%	26.0 – 29.5					32mm Slotted pipe (6.0m); 29.25m

EOH: 29.8m

Remarks

Geotechnical investigation borehole BH GWD-4

Static water levels:
2.70m bgl at casing depth of 10.52m; 4/02/2016, 1:15 pm
10.95m bgl at casing depth of 15.08m; 5/02/2016, 9:15 am

Samples in core boxes

5000 liters water added

Drivability

1 Easy Push - No Hammer \ Fast Penetration
2 Relatively Easy Push - Light Hammer \ Relatively Fast
3 Medium Push - Consistent Hammer \ Medium
4 Hard Push - Full Hammer \ Somewhat Slow
5 Very Hard Push - Full Hammer \ Very Slow

Additional Resources:

Plastic Liner / PVC Splits	m	-
Flush Mounted Toby Box		
- Standard	ea	
- Environmental	ea	
Above Ground Protective Surround	ea	✔
Geotextile Sock	m	-
Hand Clear Location	ea	
Decontaminate Equipment	ea	

Bore Log

McMILLAN Drilling GROUP

Client: Golders Associates

Project: Hinds MAR Pilot Project, Canterbury

Bore No.: BH GWD-5

Job No.: 14896

Site Location: 360 Winslow Westerfield Road, Maronan
Grid Reference: 1491358.8mE 5136798.9mN NZTM
Rig Operator: Gibellini, Andy, S. Magititabua
Rig Model & Mounting: Cased RAB 136

Date Commenced: -
Date Completed: 07/04/2016
Consent: -
Datum: Ground

Description	Method	Drivability (1 2 3 4 5)	Recovery (25 50 75)	Depth	Graphic Log	SPT N-value (Uncorrected) (10 20 30 40 50)	In-Situ Tests (Uncorrected)	Samples - Permeability tests	Installation & Resources
TOPSOIL.	Rotary air blast		100%						Standard Flush Toby Box
Sandy GRAVEL. (0.40m)				0.5					Cement (5 bags)
Clayey GRAVEL. (0.80m)				1.0 – 9.0					1.00m Bentonite (1 bags); 3.00m Surrounding ground collapse
Sandy GRAVEL. Wet. (9.50m)				9.5 – 10.5					50mm Blank pipe (21.5m)
Sandy GRAVEL with some clay. (11.00m)				11.0 – 16.5					16.00m Bentonite (2

Depth scale: 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0, 4.5, 5.0, 5.5, 6.0, 6.5, 7.0, 7.5, 8.0, 8.5, 9.0, 9.5, 10.0, 10.5, 11.0, 11.5, 12.0, 12.5, 13.0, 13.5, 14.0, 14.5, 15.0, 15.5, 16.0, 16.5

Remarks

Geotechnical investigation borehole BH GWD-5

Static water level:
25.14m bgl; 7/04/2016

Drivability

1 Easy Push - No Hammer \ Fast Penetration
2 Relatively Easy Push - Light Hammer \ Relatively Fast
3 Medium Push - Consistent Hammer \ Medium
4 Hard Push - Full Hammer \ Somewhat Slow
5 Very Hard Push - Full Hammer \ Very Slow

Additional Resources:

Plastic Liner / PVC Splits	m	-
Flush Mounted Toby Box		
- Standard	ea	✔
- Environmental	ea	
Above Ground Protective Surround	ea	
Geotextile Sock	m	-
Hand Clear Location	ea	
Decontaminate Equipment	ea	

Hole Depth: 39.5m

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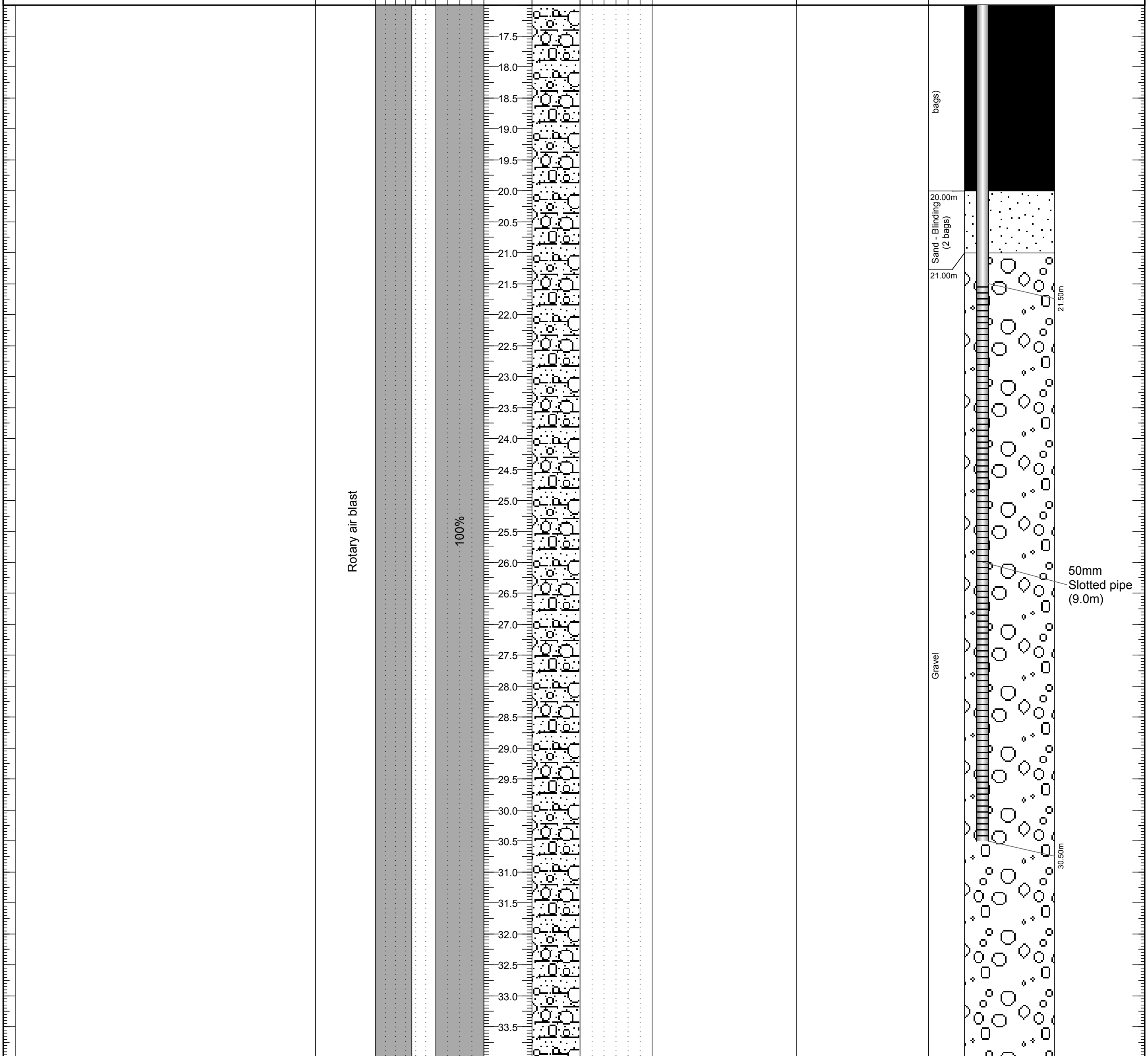
Bore Log

McMILLAN Drilling GROUP	**Client:** Golders Associates	**Bore No.:** BH GWD-5
	Project: Hinds MAR Pilot Project, Canterbury	**Job No.:** 14896

Site Location: 360 Winslow Westerfield Road, Maronan
Grid Reference: 1491358.8mE 5136798.9mN NZTM
Rig Operator: Gibellini, Andy, S. Magititabua
Rig Model & Mounting: Cased RAB 136

Date Commenced: -
Date Completed: 07/04/2016
Consent: -
Datum: Ground

Description	Method	Drivability (1 2 3 4 5)	Recovery (25 50 75)	Depth	Graphic Log	SPT N-value (Uncorrected) (10 20 30 40 50)	In-Situ Tests (Uncorrected)	Samples - Permeability tests	Installation & Resources



Remarks

Geotechnical investigation borehole BH GWD-5

Static water level:
25.14m bgl; 7/04/2016

Drivability

1 Easy Push - No Hammer \ Fast Penetration
2 Relatively Easy Push - Light Hammer \ Relatively Fast
3 Medium Push - Consistent Hammer \ Medium
4 Hard Push - Full Hammer \ Somewhat Slow
5 Very Hard Push - Full Hammer \ Very Slow

Additional Resources:

Plastic Liner / PVC Splits	m	-
Flush Mounted Toby Box		
- Standard	ea	✔
- Environmental	ea	
Above Ground Protective Surround	ea	
Geotextile Sock	m	-
Hand Clear Location	ea	
Decontaminate Equipment	ea	

Bore Log

McMILLAN Drilling GROUP

Client: Golders Associates

Project: Hinds MAR Pilot Project, Canterbury

Bore No.: BH GWD-5

Job No.: 14896

Site Location: 360 Winslow Westerfield Road, Maronan
Grid Reference: 1491358.8mE 5136798.9mN NZTM
Rig Operator: Gibellini, Andy, S. Magititabua
Rig Model & Mounting: Cased RAB 136

Date Commenced: -
Date Completed: 07/04/2016
Consent: -
Datum: Ground

Description	Method	Drivability (1 2 3 4 5)	Recovery (25 50 75)	Depth	Graphic Log	SPT N-value (Uncorrected) (10 20 30 40 50)	In-Situ Tests (Uncorrected)	Samples - Permeability tests	Installation & Resources
Waterbearing GRAVEL. Heavily stained. 37.00m	Rotary air blast		100%	34.5, 35.0, 35.5, 36.0, 36.5, 37.0, 37.5, 38.0, 38.5, 39.0					Gravel

EOH: 39.5m

Remarks

Geotechnical investigation borehole BH GWD-5

Static water level:
25.14m bgl; 7/04/2016

Drivability

1 Easy Push - No Hammer \ Fast Penetration
2 Relatively Easy Push - Light Hammer \ Relatively Fast
3 Medium Push - Consistent Hammer \ Medium
4 Hard Push - Full Hammer \ Somewhat Slow
5 Very Hard Push - Full Hammer \ Very Slow

Additional Resources:

Plastic Liner / PVC Splits	m	-
Flush Mounted Toby Box		
- Standard	ea	✔
- Environmental	ea	
Above Ground Protective Surround	ea	
Geotextile Sock	m	-
Hand Clear Location	ea	
Decontaminate Equipment	ea	

Bore Log

McMILLAN Drilling GROUP

Client: Golders Associates

Project: Hinds MAR Pilot Project, Canterbury

Bore No.: BH GWD-6

Job No.: 14896

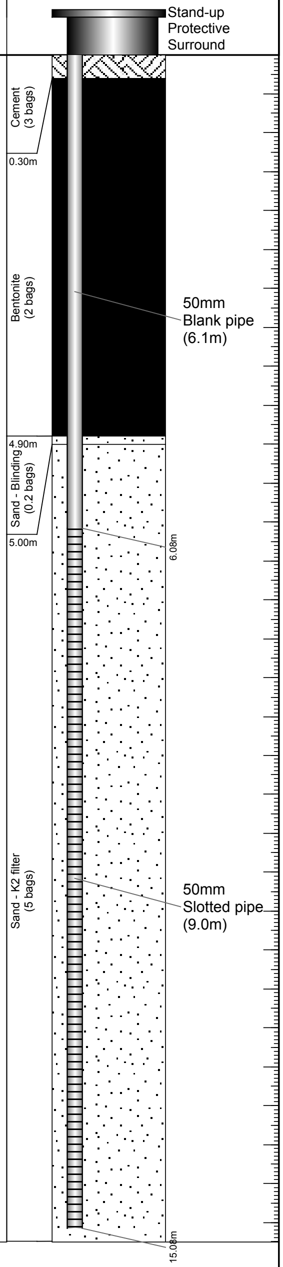
Site Location: 428 Long Beach Road, Willowby
Grid Reference: 1494234mE 5129843.49mN NZTM
Rig Operator: K. Morris
Rig Model & Mounting: Geoprobe 8140LS - track

Date Commenced: 17/02/2016
Date Completed: 17/02/2016
Consent: -
Datum: Ground

Description	Depth to base	Method	Drivability	Recovery
TOPSOIL.	0.10m	Sonic core drilling		
SILT; mottled brown.	1.72m			100%
Silty fine to coarse GRAVEL; mottled brown. 2.92m Fine to medium gravel; 3.84m Trace cobble	7.48m			100%, 100%, 80%, 100%
Fine to medium GRAVEL with trace silt. Possible washing of fine fraction.	8.10m			100%
Silty fine to medium GRAVEL with trace cobbles; brown.	12.04m			100%, 100%, 100%
Fine to medium GRAVEL.	12.66m			100%
Silty fine to medium GRAVEL; brown.	13.56m			
Fine to medium GRAVEL with trace silt. Silt; brown.	15.08m			100%

EOH: 15.25m

Column headings: Description; Method; Drivability (1 2 3 4 5); Recovery (25 50 75); Depth (0.5–15.0); Graphic Log; SPT N-value (Uncorrected) (10 20 30 40 50); In-Situ Tests (Uncorrected); Samples - Permeability tests; Installation & Resources



Remarks

Geotechnical investigation borehole BH GWD-6

Static water level:
9.47m bgl at casing depth of 15.08m; 18/02/2016, 9:09 am

Samples in core boxes

1500 liters water added

Drivability

1 Easy Push - No Hammer \ Fast Penetration
2 Relatively Easy Push - Light Hammer \ Relatively Fast
3 Medium Push - Consistent Hammer \ Medium
4 Hard Push - Full Hammer \ Somewhat Slow
5 Very Hard Push - Full Hammer \ Very Slow

Additional Resources:

Plastic Liner / PVC Splits	m	-
Flush Mounted Toby Box		
- Standard	ea	
- Environmental	ea	
Above Ground Protective Surround	ea	✔
Geotextile Sock	m	-
Hand Clear Location	ea	
Decontaminate Equipment	ea	

Hole Depth: 15.25m

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MCMILLAN Drilling GROUP

Client: Golders Associates

Project: Hinds MAR Pilot Project, Canterbury

Bore Log

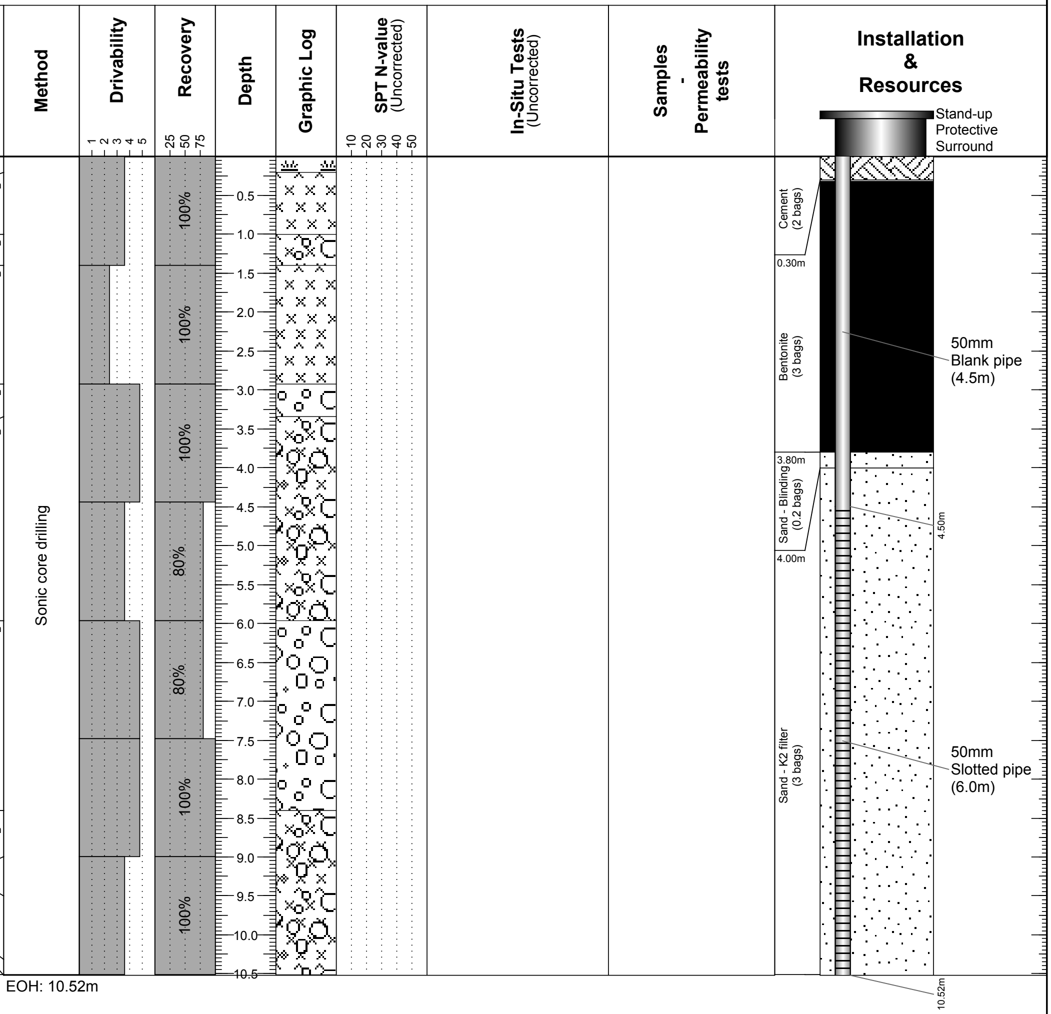
Bore No.: BH GWD-7

Job No.: 14896

Site Location: 163 Tarbottons Road, Tinwald
Grid Reference: 1496559.41mE 5136616.2mN NZTM
Rig Operator: K. Morris
Rig Model & Mounting: Geoprobe 8140LS - track

Date Commenced: 19/02/2016
Date Completed: 19/02/2016
Consent: -
Datum: Ground

Description	Depth to base
TOPSOIL.	0.20m
SILT with trace gravel; mottled light brown. Gravel, fine to medium.	1.00m
Silty fine to medium GRAVEL; light brown.	1.40m
SILT with some gravel; mottled brown. Gravel, fine to coarse.	2.92m
Fine to coarse GRAVEL with trace silt. Silt; brown.	3.34m
Silty fine to coarse GRAVEL; light brown.	5.96m
Fine to medium GRAVEL with trace cobbles and silt. Possible washing of fine fraction.	8.40m
Silty fine to medium GRAVEL with trace cobbles; brown. 9.00 - 9.50m Possible washing of fine fraction. 10.32 - 10.52m Possible washing of fine fraction	



EOH: 10.52m

Remarks

Geotechnical investigation borehole BH GWD-7

Static water level:
3.29m bgl at casing depth of 10.52m; 19/02/2016, 1:50 pm

Samples in core boxes

2000 liters water added

Drivability

1 Easy Push - No Hammer \ Fast Penetration
2 Relatively Easy Push - Light Hammer \ Relatively Fast
3 Medium Push - Consistent Hammer \ Medium
4 Hard Push - Full Hammer \ Somewhat Slow
5 Very Hard Push - Full Hammer \ Very Slow

Additional Resources:

Plastic Liner / PVC Splits	m	-
Flush Mounted Toby Box		
- Standard	ea	
- Environmental	ea	
Above Ground Protective Surround	ea	✔
Geotextile Sock	m	-
Hand Clear Location	ea	
Decontaminate Equipment	ea	

Hole Depth: 10.52m

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Borehole Log

Golder Associates

Project Name: Deep Geological Investigations

Client: Environment Canterbury (ECan)

Location: Hinds MAR Pilot Project, Canterbury

Description: 5 Boreholes

ProjectID: 1538632
Reference: BH GWD-1
North (m): 5140611
East (m): 1489083
Elevation (m): 141
Hole Depth (m): 30.28
Grid: NZTM
Datum: MSL

Description	USC	Moisture Condition	Consistency / Density	Water Observations	Depth (m)	Water Observations	Backfill & Installation
Organic SILT; light brown. Firm; moist; low plasticity; organics, roots (TOPSOIL).		M			0.00		
Gravelly SILT; light brown. Loose; moist; low plasticity; gravels, fine to coarse; subrounded.	GM	M	L		0.50–1.00		
Sandy fine to coarse GRAVEL with some cobbles; light grey. Medium dense to dense; moist; well graded; subrounded to rounded, sand, fine to medium. (Recovered as clean gravels).	GW	M	MD-D		1.50–3.00		
Silty medium SAND; light brown. Loose to medium dense; moist; poorly graded.	SM	M	L-MD		3.00–3.50		
Sandy fine to coarse GRAVEL; grey. Dense; moist; well graded; subangular to rounded; sand, fine to coarse (Recovered as clean gravels). With some cobbles, subrounded below 4.5 m bgl.	GW	M / M-W	D	▼ (~5.7)	3.50–5.90		5.50 Surrounding ground collapse
Gravelly sandy SILT; light brown to grey. Stiff to hard, wet; low plasticity; gravel, fine to medium, subangular to subrounded, sand, medium to coarse. With some cobbles; subrounded below 6.4 m bgl.	ML	W	VSt-H		5.90–7.10	Date/Time: 28/01/2016 3:10:00 PM Casing Depth: 5.9 m bgl Water Depth: 5.77 m bgl	Surrounding ground collapse
Gravelly SILT with some sand; light brown. Hard, wet; low plasticity; gravel, fine to coarse; subangular to subrounded; sand, fine to medium.	ML	W	H		7.10–7.50	Date/Time: 29/01/2016 9:45:00 AM Casing Depth: 7.08 m bgl Water Depth: 5.7 m bgl	Surrounding ground collapse
Silty sandy fine to coarse GRAVEL; light brown. Medium dense; wet; well graded; subangular to subrounded; sand, fine to coarse.	GW	W	MD		7.50–8.40		Surrounding ground collapse
SILT with some gravel; light grey. Hard; wet; low plasticity; gravel, fine to coarse; subrounded to rounded.	ML	W	H		8.40–9.00		Surrounding ground collapse
Sandy fine to coarse GRAVEL with some cobbles; light grey. Dense to very dense; wet; well graded; subrounded to rounded; sand, fine to coarse (Recovered as clean gravels).	GW	W	D-VD	▼	9.00–11.00	Date/Time: 1/02/2016 9:30:00 AM Casing Depth: 10.52 m bgl Water Depth: 5.7 m bgl	Surrounding ground collapse

Driller	Logger	Remarks
K. Morris	LT	
Drill Method / Rig		
Geoprobe 8140LS		
Start Date	**Checked By**	
28/01/2016	BS	
End Date		
03/02/2016		

Borehole logged in accordance with NZGS guideline "Field description of soil and rock" 2005

Hole Depth 30.28m

Borehole Log

Project Name: Deep Geological Investigations

Client: Environment Canterbury (ECan)

Location: Hinds MAR Pilot Project, Canterbury

Description: 5 Boreholes

ProjectID: 1538632
Reference: BH GWD-1
North (m): 5140611
East (m): 1489083
Elevation (m): 141
Hole Depth (m): 30.28
Grid: NZTM
Datum: MSL

Formation	Graphic Log	Description	USC	Moisture Condition	Consistency / Density	Water Observations	Depth	TCR (%)	Water Observations	Backfill & Installation
		Sandy fine to coarse GRAVEL with some cobbles; light grey. Dense to very dense; wet; well graded; subrounded to rounded; sand, fine to coarse (Recovered as clean gravels).	GW	W	D-VD		11.50			Surrounding ground collapse
		Silty fine to medium GRAVEL; light brown. Dense; wet; poorly graded; subangular to subrounded.	GM		D		12.00			
		Gravelly SILT with some sand; light brown. Hard; wet; low plasticity; gravel, fine to medium; subrounded to rounded; sand, fine to medium.	ML		H					
		Silty fine SAND with some gravels; light brown. Loose; wet; poorly graded; gravel, fine, subrounded.	SM		L		12.50 13.00			
		SILT with some gravels and trace sand; light brown. Hard; wet; low plasticity; gravels, fine to corase; subangular to subrounded; sand, fine.	ML		H		13.50			
		Sandy fine to coarse GRAVEL with some cobbles; grey. Dense; wet; well graded; subangular to subrounded; sand, fine to coarse. with some silt below 14.1 m bgl. No silt below 15.08 m bgl. with some silt below 16.60 m bgl.	GW		D	▼ (15.7)	14.00 14.50 15.00 15.50 16.00 16.50			
		Silty fine to coarse GRAVEL with some sand and cobbles; light brown. Very dense; wet; well graded; subrounded to rounded; sand, medium to coarse.	GM		VD		17.00 17.50 18.00		Date/Time: 2/02/2016 12:45:00 PM Casing Depth: 18.12 m bgl Water Depth: 15.7 m bgl	
		Gravelly SILT with some sand; light brown. Hard; wet; low plasticity; gravel, fine to medium; subrounded to rounded; sand; medium.	ML		H		18.50 19.00			
		Sandy fine to coarse GRAVEL; grey. Medium dense; wet; well graded; rounded; sand, medium to coarse. (Recovered as clean gravels).	GW		MD		19.50			
		Gravelly sandy SILT; light brown. Hard; wet; low plasticity; gravel, fine to coarse; rounded; sand, fine to medium.	ML		H		20.00 20.50			
		SILT with some gravels and sand; light brown. Hard; wet; low plasticity; gravel, fine to coarse; subrounded to rounded; sand, fine to medium.					21.00			
		Sandy silty fine to coarse GRAVEL with some cobbles; light brown. Dense; wet; well graded; subangular to rounded; sand, fine to coarse.	GW		D		21.50			

Driller	K. Morris
Drill Method / Rig	Geoprobe 8140LS
Start Date	28/01/2016
End Date	03/02/2016
Logger	LT
Checked By	BS
Remarks	
Hole Depth	30.28m

Borehole logged in accordance with NZGS guideline "Field description of soil and rock" 2005

Project Name: Deep Geological Investigations

Client: Environment Canterbury (ECan)

Location: Hinds MAR Pilot Project, Canterbury

Description: 5 Boreholes

Borehole Log

ProjectID: 1538632
Reference: BH GWD-1
North (m): 5140611
East (m): 1489083
Elevation (m): 141
Hole Depth (m): 30.28
Grid: NZTM
Datum: MSL

Formation	Graphic Log	Description	USC	Moisture Condition	Consistency / Density	Water Observations	Depth	TCR (%)	Water Observations	Backfill & Installation
		Sandy silty fine to coarse GRAVEL with some cobbles; light brown. Dense; wet; well graded; subangular to rounded; sand, fine to coarse.	GW	W	D		22.50, 23.00			Surrounding ground collapse
		Gravelly SILT with some sand; light brown. Hard; wet; low plasticity; gravel, fine to coarse; subrounded to rounded; sand, fine to medium.	ML		H		23.50, 24.00, 24.50, 25.00, 25.50, 26.00		Date/Time: 3/02/2016 9:50:00 PM Casing Depth: 24.2 m bgl Water Depth: 9.99 m bgl	
		Sandy fine to coarse GRAVEL with some cobbles and silt; light brown to grey. Dense; wet; well graded; subangular to subrounded; sand, fine to coarse. (Recovered as clean gravels) .			D		26.50, 27.00, 27.50, 28.00, 28.50			
		Silty fine to medium SAND with some gravels; light brown. Medium dense; wet; wet; poorly graded; gravel, fine to coarse; subrounded to rounded.	SM		MD		29.00, 29.50			
		Silty sandy fine to coarse GRAVEL; light brown. Dense; wet; well graded; subrounded to rounded; sand, fine to coarse.	GW		D		30.00			

EOH: 30.28 m

Driller K. Morris	**Logger** LT	**Remarks**
Drill Method / Rig Geoprobe 8140LS		
Start Date 28/01/2016	**Checked By** BS	
End Date 03/02/2016		Borehole logged in accordance with NZGS guideline "Field description of soil and rock" 2005

Hole Depth
30.28m

Golder Associates

Borehole Log

Project Name: Deep Geological Investigations

Client: Environment Canterbury (ECan)

Location: Hinds MAR Pilot Project, Canterbury

Description: 5 Boreholes

ProjectID: 1538632

Reference: BH GWD-2

North (m): 5140497
East (m): 1489462
Elevation (m): 137
Hole Depth (m): 32.00
Grid: NZTM
Datum: MSL

Formation	Graphic Log	Description	USC	Moisture Condition	Consistency / Density	Water Observations	Depth	TCR (%)	Water Observations	Backfill & Installation
		Organic SILT; dark brown. Firm; moist; low plasticity; organics, amphora (TOPSOIL).								Cement (0.00–0.30)
		Sandy fine to coarse GRAVEL with some silt; grey. Loose to medium dense; moist; well graded; subangular to rounded; sand, fine to medium. (Recovered as clean gravels).		M	L-MD		0.50–2.00			Bentonite (from 0.30)
		Sandy silty fine to coarse GRAVEL; grey. Medium dense; moist; well graded; subangular to rounded; sand, fine to medium.		M	MD		2.50–3.00			Bentonite
		Sandy fine to coarse GRAVEL with some silt; grey. Medium dense; moist; well graded; subangular to rounded; sand, fine to medium. (Recovered as clean gravels).		M	MD		3.00–5.00			Bentonite
		Sandy silty fine to coarse GRAVEL; grey. Medium dense; moist; well graded; subangular to rounded; sand, fine to medium.	GW	M	MD		5.00–6.00			Bentonite
		Sandy fine to coarse GRAVEL with some cobbles; grey. Dense to very dense; wet; well graded; angular to subrounded; sand, fine to coarse. (Recovered as clean gravels).	GW	W	D-VD	▼ (~6.50, ~7.10, ~8.30)	6.00–10.50			Bentonite

Driller	Logger	Remarks
K. Morris	LT	
Drill Method / Rig		
Geoprobe 8140LS		
Start Date	**Checked By**	
10/02/2016	BS	
End Date		
16/02/2016		Borehole logged in accordance with NZGS guideline "Field description of soil and rock" 2005

Hole Depth
32.00m

Project Name: Deep Geological Investigations	ProjectID: 1538632
Client: Environment Canterbury (ECan)	Reference: BH GWD-2
Location: Hinds MAR Pilot Project, Canterbury	North (m): 5140497 East (m): 1489462 Elevation (m): 137 Hole Depth (m): 32.00 Grid: NZTM Datum: MSL
Description: 5 Boreholes	

Borehole Log

Description	USC	Moisture Condition	Consistency / Density	Depth
Sandy fine to coarse GRAVEL with some cobbles; grey. Dense to very dense; wet; well graded; angular to subrounded; sand, fine to coarse. (Recovered as clean gravels).	GW	W	D-VD	11.50
Silty fine to coarse GRAVEL with some sand; light brown. Dense; wet; poorly graded; subangular to rounded; sand, medium to coarse.	GM	W	D	12.00
Sandy SILT with some gravel; brown. Very stiff; wet; low plasticity; gravel, fine to medium; subrounded to rounded; sand, fine to coarse.	ML	W	VSt	12.50
Sandy fine to coarse GRAVEL with some silt; grey to brown. Dense; wet; well graded; subrounded to rounded; sand, fine to medium (Recovered as clean gravels).	GW	W	D	13.00–15.00
Silty fine to medium GRAVEL with some cobbles; light brown. Dense; wet; well graded; subrounded to rounded.	GM	W	D	15.50–16.50
Gravelly SILT with come cobbles; light brown. Hard; wet; low plasticity; gravel, fine to coarse; subrounded to rounded.	ML	W	H	17.00
Silty fine to medium GRAVEL with some sand; light brown to grey. Dense; wet; well graded; subrounded to rounded; sand, fine to medium.	GM	W	D	17.50–18.00
Gravelly sandy SILT; light brown. Hard; wet; low plasticity; gravel, fine to medium; subrounded to rounded, sand, fine to medium.	ML	W	H	18.50–19.00
Silty fine to medium GRAVEL with some sand; light brown to grey. Dense; wet; well graded; subrounded to rounded; sand, fine to medium.	GM	W	D	19.50
Sandy fine to coarse GRAVEL with some cobbles; grey. Dense; wet; well graded; subangular to rounded; sand, fine to coarse. (Recovered as clean gravels).	GW	W	D	20.00–21.50

Water Observations

- Date/Time: 11/02/2016 9:45:00 AM
  Casing Depth: 12.04 m bgl
  Water Depth: 8.35 m bgl
- Date/Time: 12/02/2016 12:00:00 PM
  Casing Depth: 19.64 m bgl
  Water Depth: 7.2 m bgl
- Date/Time: 12/02/2016 7:00:00 PM
  Casing Depth: 21.16 m bgl
  Water Depth: 6.6 m bgl

Backfill & Installation: Bentonite (to 21.50); Sand (from 21.50)

Driller	Logger	Remarks
K. Morris	LT	
Drill Method / Rig		
Geoprobe 8140LS		
Start Date	**Checked By**	
10/02/2016	BS	**Hole Depth** 32.00m
End Date		
16/02/2016		Borehole logged in accordance with NZGS guideline "Field description of soil and rock" 2005

Project Name: Deep Geological Investigations	ProjectID: 1538632
Client: Environment Canterbury (ECan)	Reference: BH GWD-2
Location: Hinds MAR Pilot Project, Canterbury	North (m): 5140497 East (m): 1489462 Elevation (m): 137 Hole Depth (m): 32.00 Grid: NZTM Datum: MSL
Description: 5 Boreholes	

Golder Associates

Borehole Log

Formation	Graphic Log	Description	USC	Moisture Condition	Consistency / Density	Water Observations	Depth	TCR (%)	Water Observations	Backfill & Installation
		Sandy fine to coarse GRAVEL with some cobbles; grey. Dense; wet; well graded; subangular to rounded; sand, fine to coarse. (Recovered as clean gravels).	GW	W	D	▼	22.50 – 24.50			Sand
		Silty fine to coarse GRAVEL with some sand; light brown. Very dense; wet; well graded; subrounded to rounded; sand, fine to coarse.	GM		VD	▼	24.50 – 25.00			
		Sandy fine to coarse GRAVEL with some cobbles; grey. Dense to very dense; wet; well graded; subangular to rounded; sand, fine to coarse. (Recovered as clean gravels).	GW		D-VD	▼	25.00 – 28.50		Date/Time: 15/02/2016 11:45:00 AM Casing Depth: 25 m bgl Water Depth: 22.6 m bgl	
		Silty fine to coarse GRAVEL with some sand; light brown. Very dense; wet; well graded; subrounded to rounded; sand, fine to coarse.	GM		VD		28.50 – 32.00		Date/Time: 16/02/2016 10:00:00 AM Casing Depth: 30.28 m bgl Water Depth: 25.32 m bgl	

EOH: 32 m

Date/Time: 17/02/2016 10:30:00 AM
Casing Depth: 32 m bgl
Water Depth: 24.7 m bgl

Driller	Logger	Remarks
K. Morris	LT	
Drill Method / Rig		
Geoprobe 8140LS		
Start Date	Checked By	
10/02/2016	BS	
End Date		
16/02/2016		Borehole logged in accordance with NZGS guideline "Field description of soil and rock" 2005

Hole Depth
32.00m

Project Name: Deep Geological Investigations

Client: Environment Canterbury (ECan)

Location: Hinds MAR Pilot Project, Canterbury

Description: 5 Boreholes

Borehole Log

ProjectID: 1538632
Reference: BH GWD-4

North (m): 5139744
East (m): 1489821
Elevation (m): 133
Hole Depth (m): 25.72
Grid: NZTM
Datum: MSL

Description	USC	Moisture Condition	Consistency / Density
Gravelly organic SILT; dark brown. Soft; moist; low plasticity; organics, amphora; gravel, medium to coarse, rounded (TOPSOIL).	ML		S
Sandy fine to coarse GRAVEL with some silt and cobbles; light brown to grey. Loose to medium dense; moist; well graded; sand, fine to medium. (Recovered as sandy gravels).	GW	M	L-MD
Sandy silty fine to coarse GRAVEL; light brown to grey. Medium dense; moist to wet; well graded; rounded; sandy, fine to medium.	GM	M-W	MD
Gravelly silty fine to medium SAND; light brown. Medium dense; wet; well graded; gravel, fine to medium, rounded.	SP-SM	W	MD
Sandy fine to coarse GRAVEL with some cobbles; grey. Dense; wet; well graded; rounded; sand, fine to medium. (Recovered as clean gravels).	GW	W	D
Silty fine to coarse GRAVEL with some cobbles; light brown. Dense; wet; poorly graded; rounded; sand, fine.	GM	W	D
Silty sandy fine to coarse GRAVEL; grey. Dense; wet; well graded; rounded; sand, fine to medium.	GM	W	D

Depth scale: 0.50, 1.00, 1.50, 2.00, 2.50, 3.00, 3.50, 4.00, 4.50, 5.00, 5.50, 6.00, 6.50, 7.00, 7.50, 8.00, 8.50, 9.00, 9.50, 10.00, 10.50

TCR (%): 20 40 60 80

Water Observations

Date/Time: 4/02/2016 1:15:00 PM
Casing Depth: 10.52 m bgl
Water Depth: 2.7 m bgl

Backfill & Installation

6.00 Drill cuttings

Driller	Logger	Remarks
K. Morris	LT	
Drill Method / Rig		
Geoprobe 8140LS		
Start Date	**Checked By**	
04/02/2016	BS	
End Date		
09/02/2016		

Borehole logged in accordance with NZGS guideline "Field description of soil and rock" 2005

Hole Depth
25.72m

Project Name: Deep Geological Investigations

Client: Environment Canterbury (ECan)

Location: Hinds MAR Pilot Project, Canterbury

Description: 5 Boreholes

Borehole Log

ProjectID: 1538632
Reference: BH GWD-4
North (m): 5139744
East (m): 1489821
Elevation (m): 133
Hole Depth (m): 25.72
Grid: NZTM
Datum: MSL

Description	USC	Moisture Condition	Consistency / Density	Depth (m)
Silty sandy fine to coarse GRAVEL; grey. Dense; wet; well graded; rounded; sand, fine to medium.	GM	W	D	
Gravelly sandy SILT with some cobbles; light brown. Hard; wet; low plasticity; gravel, fine to medium; rounded, sand, fine to medium.	ML	W	H	11.50
Sandy fine to coarse GRAVEL with some silt; grey. Dense; well graded; rounded; sand, fine to medium. (Recovered as clean gravel).	GW	W	D	12.00–13.00
Silty sandy fine to coarse GRAVEL; light brown. Dense; wet; poorly graded; rounded; sand, fine to medium.	GP-GM	W	D	13.50
Gravelly SILT; light brown. Hard; wet; low plasticity; gravel, fine to coarse; rounded.	ML	W	H	14.00–15.00
Silty fine to coarse GRAVEL with some sand; grey. Dense; wet; well graded; rounded; sand, fine to medium.	GW-GM	W	D	15.50–16.00
Sandy below 16.2 m bgl.	GW	W	D	16.50
Sandy fine to coarse GRAVEL; light brown. Dense; wet; well graded; rounded; sand, fine to medium.	GW	W	D	17.00–17.50
Silty below 17.6 m bgl.	GW	W	D	18.00
Gravelly silty fine to medium SAND; light brown. Medium dense; wet; poorly graded; gravel, fine to medium, rounded.	SP	W	MD	18.50–20.00
Sandy fine to coarse GRAVEL with some cobbles and silt; light brown to grey. Dense; wet; well graded; rounded; sand, fine to medium.	GW	W	D	20.00–21.50

Water Observations:
Date/Time: 5/02/2016 9:15:00 AM
Casing Depth: 15.08 m bgl
Water Depth: 10.95 m bgl

Backfill & Installation: Drill cuttings

Driller	Logger	Remarks
K. Morris	LT	
Drill Method / Rig		
Geoprobe 8140LS		
Start Date	**Checked By**	
04/02/2016	BS	
End Date		
09/02/2016		Borehole logged in accordance with NZGS guideline "Field description of soil and rock" 2005

Hole Depth 25.72m

Golder Associates			
Borehole Log	**Project Name:** Deep Geological Investigations **Client:** Environment Canterbury (ECan) **Location:** Hinds MAR Pilot Project, Canterbury **Description:** 5 Boreholes	**ProjectID:** 1538632 **Reference:** BH GWD-4	**North (m):** 5139744 **East (m):** 1489821 **Elevation (m):** 133 **Hole Depth (m):** 25.72 **Grid:** NZTM **Datum:** MSL

Formation	Graphic Log	Description	USC	Moisture Condition	Consistency / Density	Water Observations	Depth	TCR (%) 20 40 60 80	Water Observations	Backfill & Installation
		Sandy fine to coarse GRAVEL with some cobbles and silt; light brown to grey. Dense; wet; well graded; rounded; sand, fine to medium. No silt below 22.68 m bgl (Recovered as clean gravels).	GW	W	D		22.50 23.00 23.50 24.00 24.50			Drill cuttings
		Sandy silty fine to coarse GRAVEL; light brown to grey. Dense; wet; well graded; subrounded to rounded; sand, fine to medium. (recovered as silty gravels).	GM				25.00			
		Gravelly sandy SILT; light brown. Hard; wet; low plasticity; gravel, fine to medium; sand, fine.	ML		H		25.50			

EOH: 25.72 m

Driller	**Logger**	**Remarks**
K. Morris	LT	
Drill Method / Rig		
Geoprobe 8140LS		
Start Date	**Checked By**	
04/02/2016	BS	**Hole Depth** 25.72m
End Date		
09/02/2016		Borehole logged in accordance with NZGS guideline "Field description of soil and rock" 2005

Project Name: Deep Geological Investigations	**ProjectID:** 1538632
Client: Environment Canterbury (ECan)	**Reference:** BH GWD-6
Location: Hinds MAR Pilot Project, Canterbury	**North (m):** 5129843
Description: 5 Boreholes	**East (m):** 1494234
	Elevation (m): 71
	Hole Depth (m): 15.08
	Grid: NZTM
	Datum: MSL

Golder Associates

Borehole Log

Description	USC	Moisture Condition	Consistency / Density
Organic SILT; dark brown. Soft to firm; moist; low plasticity; organics, amphoraTOPSOIL).	ML	M	S-F
SILT; light brown. Firm; moist; low plasticity.	ML	M	F
Sandy SILT; light brown. Firm; moist; low plasticity; sand, fine.	ML	M	F
Gravelly sandy SILT; light brown to grey. Stiff; moist; low plasticity; gravels, fine to coarse; subrounded to rounded; sand, fine to medium.	ML	M	St
Silty sandy fine to coarse GRAVEL; light brown. medium dense to dense; moist; well graded; subrounded to rounded; sand, fine to medium.	GW	M	MD-D
Sandy fine to coarse GRAVEL with some silt; grey. Dense; wet; well graded; rounded; sand, fine to coarse.	GW	M	D
Silty fine to coarse GRAVEL; light brown. Dense; wet; well graded; rounded; sand, fine to medium.	GM	M	D
Silty gravelly fine to coarse SAND; brown. Medium dense; moist to wet; poorly graded; gravel, fine to medium, rounded.	SP-SM	M-W	MD
With some cobbles below 8.1 m bgl.	SP	M-W	MD
Sandy SILT with some gravels; grey. Hard; wet; low plasticity; gravel, fine to medium; rounded; sand, fine to medium.	MH	W	H
Silty sandy fine to medium GRAVEL; light brown to grey. Dense; well graded; subrounded to rounded; sand, fine to medium.	GW	W	D
Silty fine to medium SAND with gravels; light brown to grey. Dense; wet; poorly graded; gravel, fine to medium; subrounded to rounded.	SM	W	D
Gravelly SILT with some sand; light brown. Hard; wet; low plasticity; gravel, fine to coarse; subrounded to rounded; sand, fine to medium.	ML	W	H

Depth: 0.50, 1.00, 1.50, 2.00, 2.50, 3.00, 3.50, 4.00, 4.50, 5.00, 5.50, 6.00, 6.50, 7.00, 7.50, 8.00, 8.50, 9.00, 9.50, 10.00, 10.50

TCR (%): 20 40 60 80

Water Observations

Backfill & Installation: Cement; 0.30 Bentonite; 4.90 Sand

Driller K. Morris	**Logger** LT	**Remarks**	
Drill Method / Rig Geoprobe 8140LS			
Start Date 19/02/2016	**Checked By** BS		**Hole Depth** 15.08m
End Date 19/02/2016		Borehole logged in accordance with NZGS guideline "Field description of soil and rock" 2005	Page 1 of 2

Project Name: Deep Geological Investigations	**ProjectID:** 1538632
Client: Environment Canterbury (ECan)	**Reference:** BH GWD-6
Location: Hinds MAR Pilot Project, Canterbury	**North (m):** 5129843 **East (m):** 1494234 **Elevation (m):** 71
Description: 5 Boreholes	**Hole Depth (m):** 15.08 **Grid:** NZTM **Datum:** MSL

Borehole Log

Formation	Graphic Log	Description	USC	Moisture Condition	Consistency / Density	Water Observations	Depth	TCR (%)	Water Observations	Backfill & Installation
		Gravelly SILT with some sand; light brown. Hard; wet; low plasticity; gravel, fine to coarse; subrounded to rounded; sand, fine to medium.	ML	W	H					Sand
		Gravelly fine to coarse SAND; light brown. Medium dense; wet; poorly graded; gravel, fine to medium; rounded. With some silt below 12.6 m bgl.	SP	W	MD		11.50, 12.00, 12.50, 13.00			Sand
		Silty fine to medium GRAVEL with some sand; light brown. Dense; wet; well graded; subrounded to rounded; sand, fine to medium.	GW	W	D		13.50			Sand
		Sandy fine to coarse GRAVEL with some silt; light brown. Dense; wet; well graded; subrounded to rounded; sand, fine to medium. (Recovered as clean gravels).	GW	W	D		14.00, 14.50, 15.00			Sand

EOH: 15.08 m

Date/Time: 18/02/2016 9:09:00 AM
Casing Depth: 15.08 m bgl
Water Depth: 9.47 m bgl

Driller	Logger	Remarks
K. Morris	LT	
Drill Method / Rig		
Geoprobe 8140LS		
Start Date	**Checked By**	
19/02/2016	BS	**Hole Depth** 15.08m
End Date		
19/02/2016		Borehole logged in accordance with NZGS guideline "Field description of soil and rock" 2005

Borehole Log

Golder Associates

Project Name: Deep Geological Investigations

Client: Environment Canterbury (ECan)

Location: Hinds MAR Pilot Project, Canterbury

Description: 5 Boreholes

ProjectID: 1538632
Reference: BH GWD-7
North (m): 5136616
East (m): 1496559
Elevation (m): 97
Hole Depth (m): 10.52
Grid: NZTM
Datum: MSL

Description	USC	Moisture Condition	Consistency / Density	Water Observations
Organic SILT; dark brown. Firm; moist; low plasticity; organics, amphora (TOPSOIL).				
SILT with some sand and trace gravel; light brown mottled orange. Firm; moist; low plasticity; sand, fine to medium; gravels, fine to medium, rounded.	ML	M	F	
Sandy fine to coarse GRAVEL with some silt; light brown. Loose to medium dense; moist to wet; well graded; sibrounded to rounded; sand, fine to coarse.	GW	M-W	L-MD	
Gravelly fine to coarse SAND with some silt; light brown. Medium dense; wet; poorly graded; gravel, fine to medium, rounded.	SP	W	MD	
Sandy SILT with some gravel; light brown. Firm to stiff; wet; low plasticity; sand, fine to medium; gravel, fine to medium, subrounded to rounded.	ML	W	F-St	
Sandy silty fine to medium GRAVEL; grey. Medium dense; wet; well graded; subround to rounded; sand, fine to coarse.	GW	W	MD	▼ (3.29 m)
Gravelly SILT with some sand; light brown. Stiff; wet to saturated; low plasicity; gravel, fine to coarse, rounded; sand, medium.	ML	W	St	
Sandy silty fine to coarse GRAVEL with some cobbles; light brown. Medium dense to dense; wet; well graded; subrounded to rounded; sand, fine to coarse; cobbles, rounded.	GW	W	MD	
Gravelly sandy SILT; light brown. Very stiff; wet; low plasticity; gravel, fine to medium, subrounded to rounded; sand, fine to medium.	ML	W	VSt	
Sandy silty fine to coarse GRAVEL with some cobbles; light brown. Medium dense to dense; wet; well graded; subrounded to rounded; sand, fine to coarse; cobbles, rounded.	GW	W	MD-D	

Depth (m): 0.50, 1.00, 1.50, 2.00, 2.50, 3.00, 3.50, 4.00, 4.50, 5.00, 5.50, 6.00, 6.50, 7.00, 7.50, 8.00, 8.50, 9.00, 9.50, 10.00, 10.50

TCR (%): 20 40 60 80

Backfill & Installation: Cement (0–0.30); Bentonite (0.30–3.80); Sand (3.80–10.52)

EOH: 10.52 m

Date/Time: 19/02/2016 12:00:00 AM
Casing Depth: 10.52 m bgl
Water Depth: 3.29 m bgl

Driller	K. Morris
Logger	LT
Drill Method / Rig	Geoprobe 8140LS
Start Date	19/02/2016
Checked By	BS
End Date	19/02/2016
Remarks	
Hole Depth	10.52m

Borehole logged in accordance with NZGS guideline "Field description of soil and rock" 2005

Borelog for well K37/1748

Grid Reference (NZTM): 1489140 mE, 5140431 mN
Location Accuracy: 1 - 2m
Ground Level Altitude: 137.3 m +MSD Accuracy: < 0.1 m
Driller: Smiths Welldrilling
Drill Method: Rotary/Percussion
Borelog Depth: 18.0 m Drill Date: 10-Jan-2003

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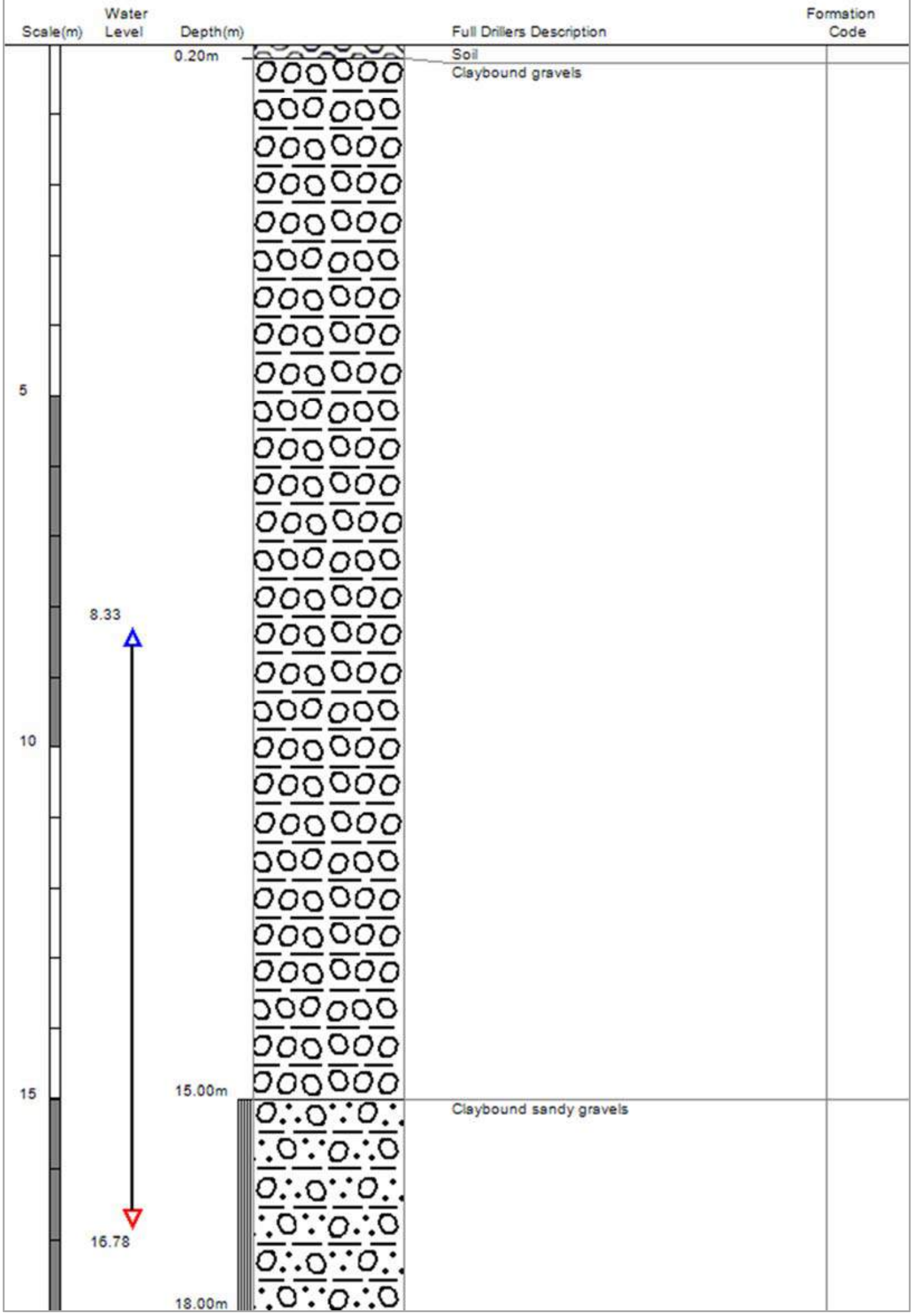
Monitoring well GWE-01



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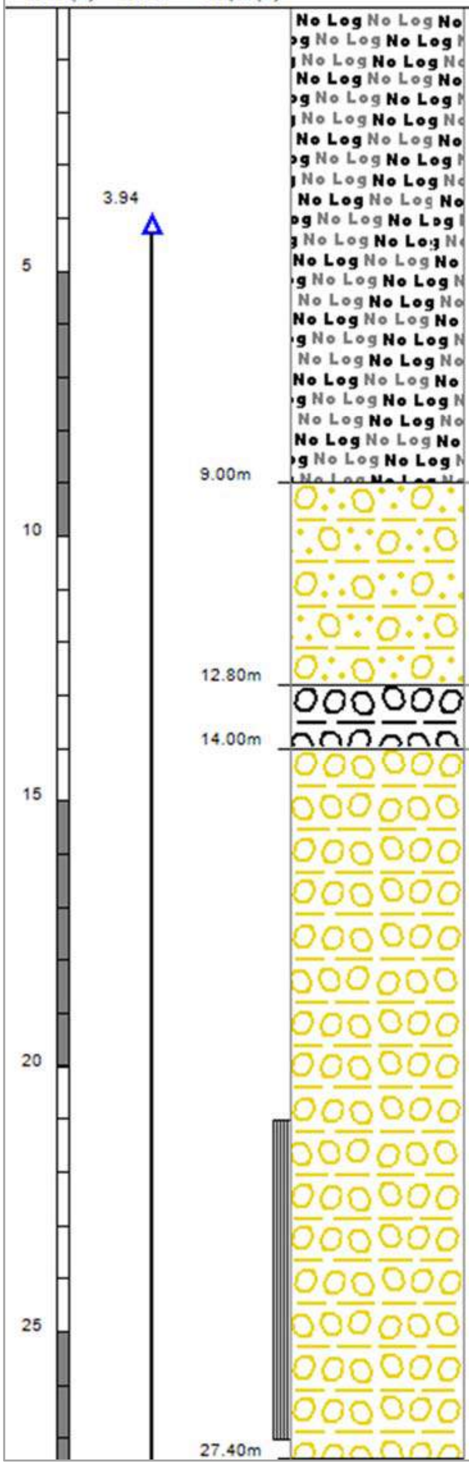
Borelog for well K37/0357

Grid Reference (NZTM): 1489197 mE, 5139457 mN
Location Accuracy: 1 - 2m
Ground Level Altitude: 133.2 m +MSD Accuracy: < 0.5 m
Driller: not known
Drill Method: Cable Tool
Borelog Depth: 27.4 m Drill Date: 05-Jul-1990

Environment Canterbury Regional Council
Kaunihera Taiao ki Waitaha

Monitoring well GWE-03

Scale(m)	Water Level	Depth(m)		Full Drillers Description	Formation Code



Depth(m)	Full Drillers Description	Formation Code
0 – 9.00m	Previous hole dug with clamshell (G moore ?)	
9.00m – 12.80m	Small sandy gravel, some medium gravel, Yellow clay	
12.80m – 14.00m	Small to medium Brown stained gravel, Yellow clay	
14.00m – 27.40m	Small to medium gravels, Yellow clay, Water-bearing at 25.5m	

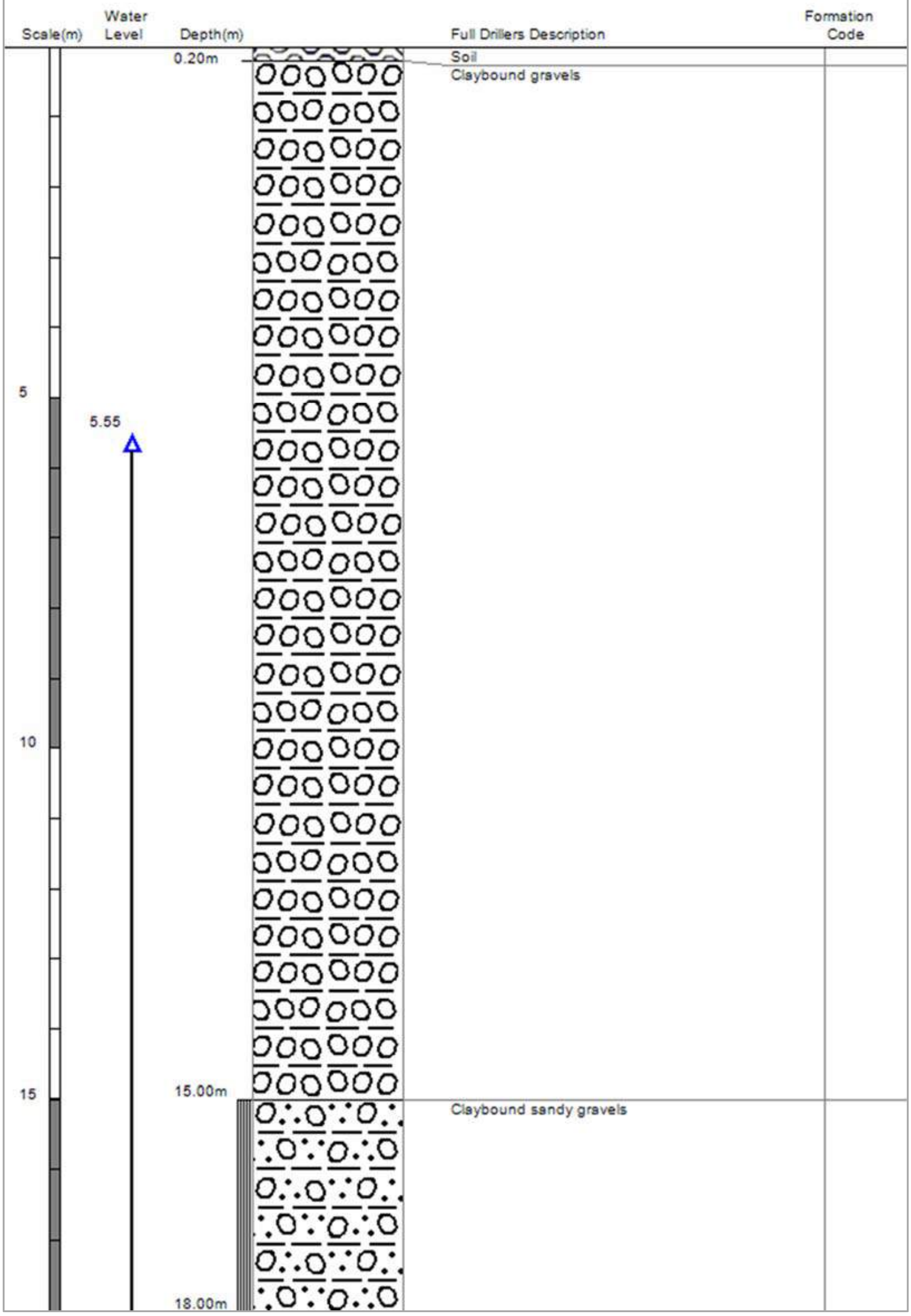
Golder Associates

Borelog for well K37/1749

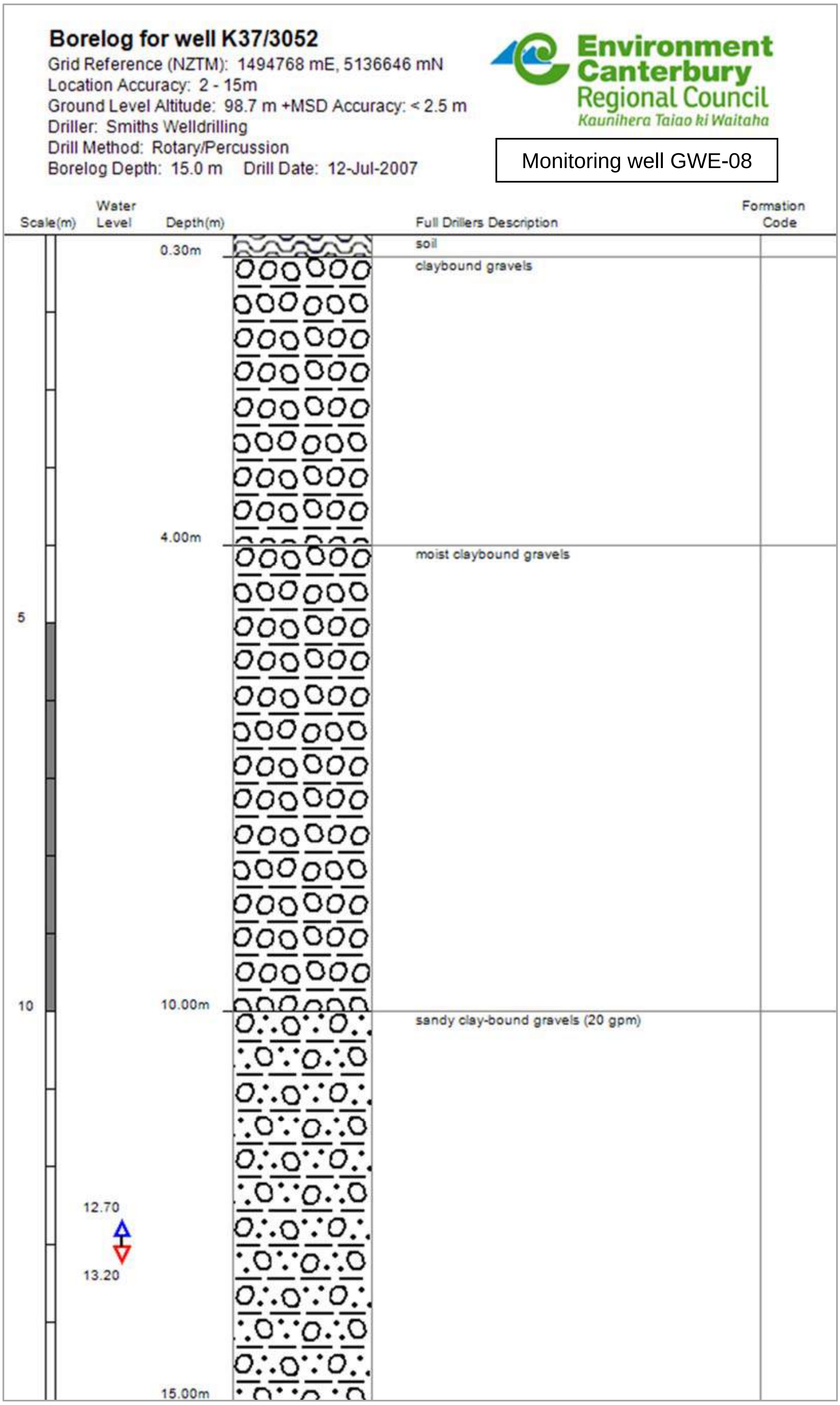
Grid Reference (NZTM): 1490657 mE, 5137905 mN
Location Accuracy: 1 - 2m
Ground Level Altitude: 117.7 m +MSD Accuracy: < 0.5 m
Driller: Smiths Welldrilling
Drill Method: Rotary/Percussion
Borelog Depth: 18.0 m Drill Date: 10-Jan-2003

Environment Canterbury Regional Council
Kaunihera Taiao ki Waitaha

Monitoring well GWE-05



Golder Associates



Borelog for well K37/3052
Grid Reference (NZTM): 1494768 mE, 5136646 mN
Location Accuracy: 2 - 15m
Ground Level Altitude: 98.7 m +MSD Accuracy: < 2.5 m
Driller: Smiths Welldrilling
Drill Method: Rotary/Percussion
Borelog Depth: 15.0 m Drill Date: 12-Jul-2007
Environment Canterbury Regional Council
Kaunihera Taiao ki Waitaha
Monitoring well GWE-08
Scale(m)
Water Level
Depth(m)
Full Drillers Description
Formation Code
0.30m
soil
claybound gravels
4.00m
moist claybound gravels
5
10
10.00m
sandy clay-bound gravels (20 gpm)
12.70
13.20
15.00m

Borelog for well K37/0215

Grid Reference (NZTM): 1487848 mE, 5144113 mN
Location Accuracy: 1 - 2m
Ground Level Altitude: 162.5 m +MSD Accuracy: < 0.1 m
Driller: Job Osborne (& Co/Ltd)
Drill Method: Cable Tool
Borelog Depth: 26.5 m Drill Date: 20-Nov-1942

Environment Canterbury Regional Council
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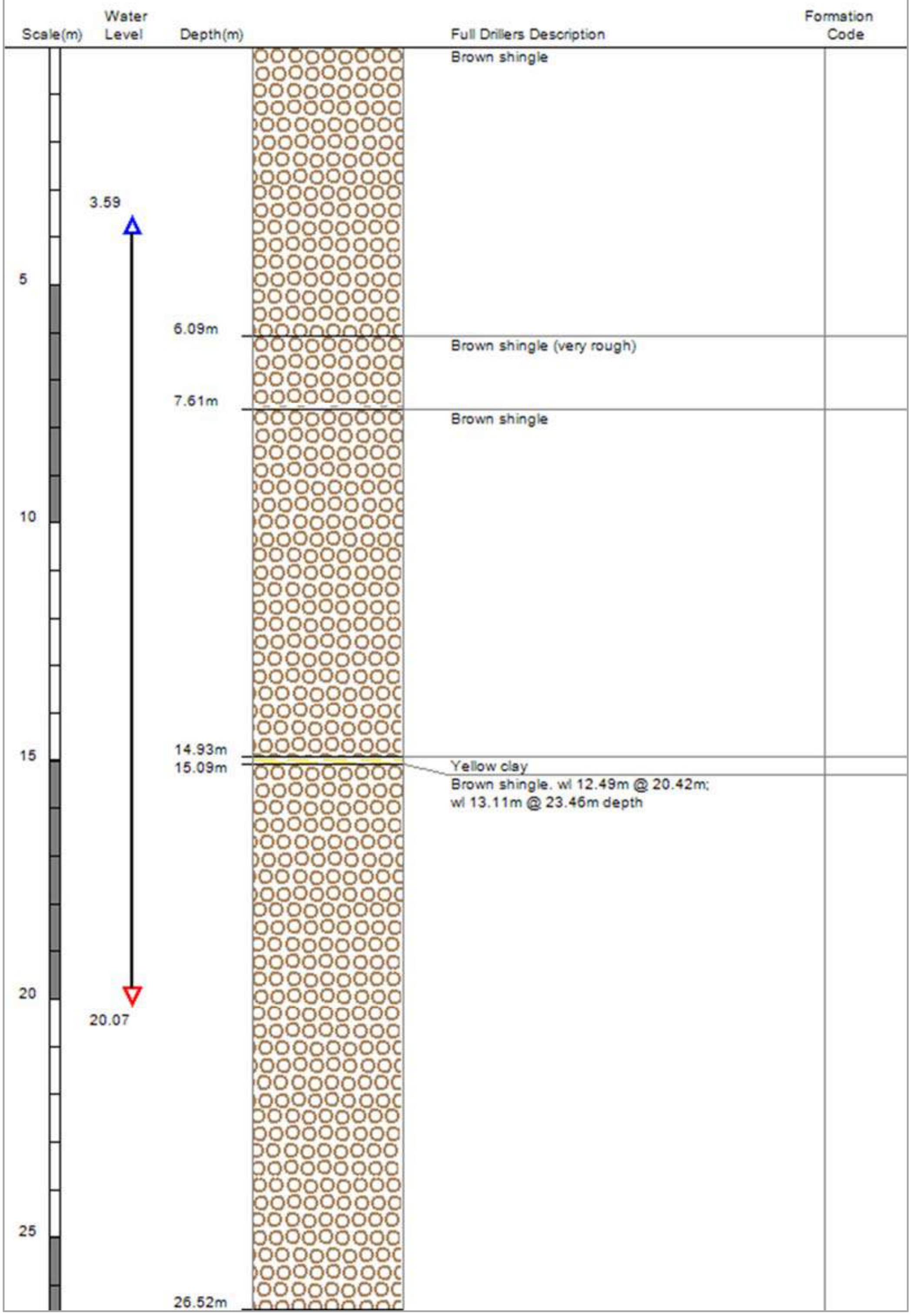
Monitoring well GWE-10



Borelog for well K37/1747

Grid Reference (NZTM): 1489167 mE, 5140075 mN
Location Accuracy: 2 - 15m
Ground Level Altitude: 137.7 m +MSD Accuracy: < 0.5 m
Driller: McMillan Drilling Ltd
Drill Method: Rotary/Percussion
Borelog Depth: 65.0 m Drill Date: 06-Apr-2004

Environment Canterbury Regional Council
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Monitoring well GWE-11

Water Level: 24.17 – 38.49

Scale (m): 13, 26, 39, 52

Depth(m)	Full Drillers Description	Formation Code
0.30m	Earth	
0.30m – 4.00m	Earth Grey gravels	
4.00m – 29.00m	Grey gravels Claybound sandy gravels	
29.00m – 36.50m	Claybound sandy gravels Poorly sorted water-bearing claybound sandy gravels	
36.50m – 45.00m	Poorly sorted water-bearing claybound sandy gravels Moderate to poorly sorted sandy gravels	
45.00m – 57.00m	Moderate to poorly sorted sandy gravels Moderate to poorly sorted sandy gravels and clay	
57.00m – 65.00m	Moderate to poorly sorted sandy gravels and clay Moderate to poorly sorted brown grey sandy gravels some stained	

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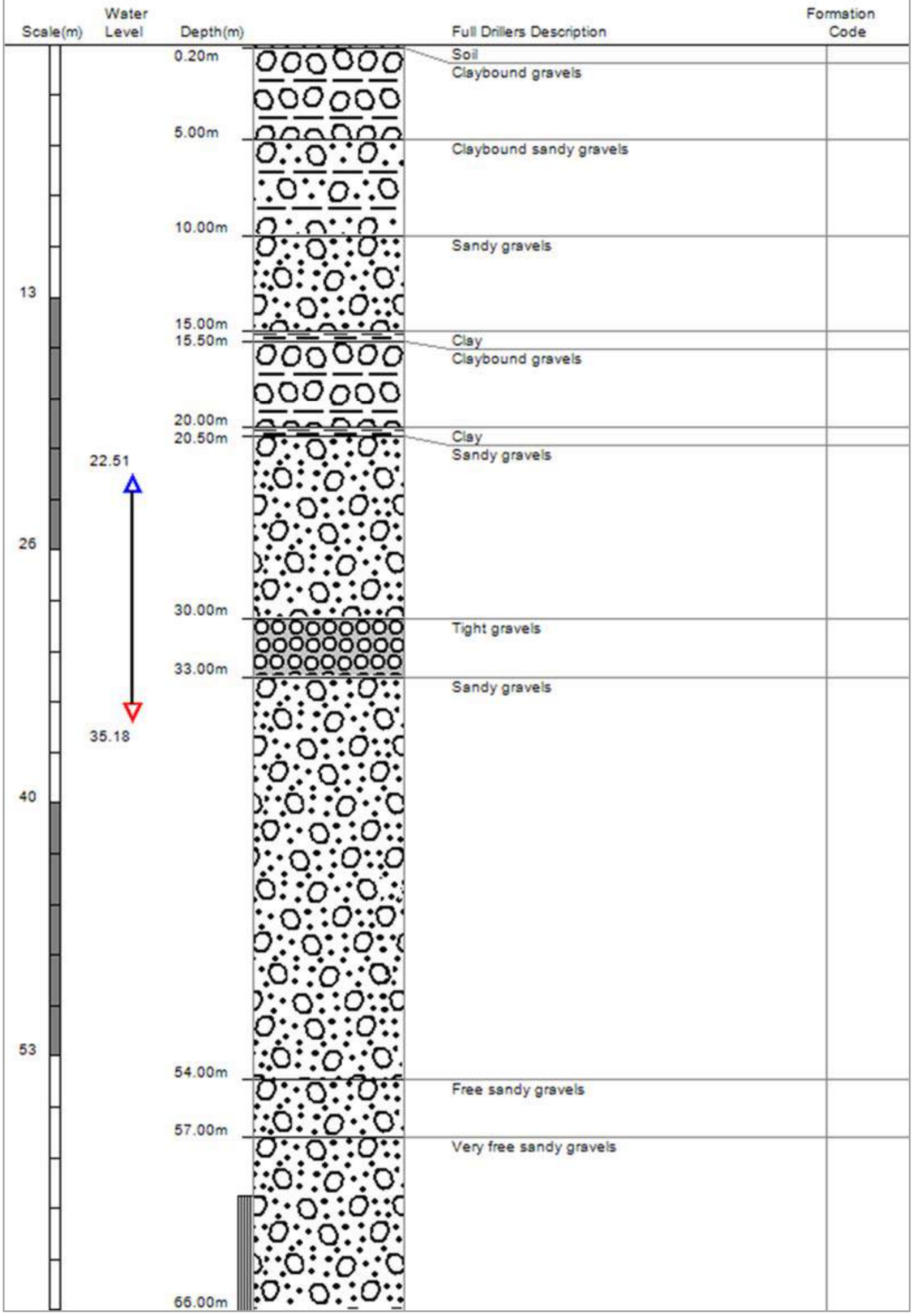
Borelog for well K37/1540

Grid Reference (NZTM): 1489206 mE, 5139468 mN
Location Accuracy: 1 - 2m
Ground Level Altitude: 133.3 m +MSD Accuracy: < 0.5 m
Driller: Smiths Welldrilling
Drill Method: Rotary Rig
Borelog Depth: 66.0 m   Drill Date: 16-Jan-2002

Environment Canterbury Regional Council
Kaunihera Taiao ki Waitaha

Monitoring well GWE-12



Golder Associates

Borelog for well K37/1649

Grid Reference (NZTM): 1490776 mE, 5139288 mN
Location Accuracy: 2 - 15m
Ground Level Altitude: 125.5 m +MSD Accuracy: < 0.5 m
Driller: Smiths Welldrilling
Drill Method: Rotary/Percussion
Borelog Depth: 60.0 m Drill Date: 20-Dec-2002

Environment Canterbury Regional Council
Kaunihera Taiao ki Waitaha

Monitoring well GWE-13

Scale(m)	Water Level	Depth(m)	Full Drillers Description	Formation Code
		0.20m	Soil	
		0.20m	Soil	
		3.00m	Rocks	
		3.00m	Rocks	
			Claybound gravels	
12				
24				
		32.00m	Claybound gravels	
		32.00m	Sandy gravels	
		35.00m	Sandy gravels	
36		35.00m	Claybound sandy gravels	
		40.00m	Claybound sandy gravels	
		40.00m	Claybound gravels	
48				
		51.00m	Claybound gravels	
		51.00m	Free sandy gravels	
		60.00m		

Borelog for well K37/2458

Grid Reference (NZTM): 1490980 mE, 5140409 mN
Location Accuracy: 2 - 15m
Ground Level Altitude: 128.9 m +MSD Accuracy: < 0.5 m
Driller: Smiths Welldrilling
Drill Method: Rotary Rig
Borelog Depth: 60.0 m Drill Date: 10-May-2005

Environment Canterbury Regional Council
Kaunihera Taiao ki Waitaha

Monitoring well GWE-15

Depth(m)	Full Drillers Description	Formation Code
0.50m	Soil	
0.50m	Soil	
	Claybound gravels	
19.00m	Claybound gravels	
19.00m	Sandy gravels	
22.00m	Sandy gravels	
22.00m	Claybound gravels	
30.00m	Claybound gravels	
30.00m	Claybound sandy gravels	
44.00m	Claybound sandy gravels	
44.00m	Sandy gravels	
52.00m	Sandy gravels	
52.00m	Free sandy gravels	
60.00m		

Scale(m): 12, 24, 36, 48

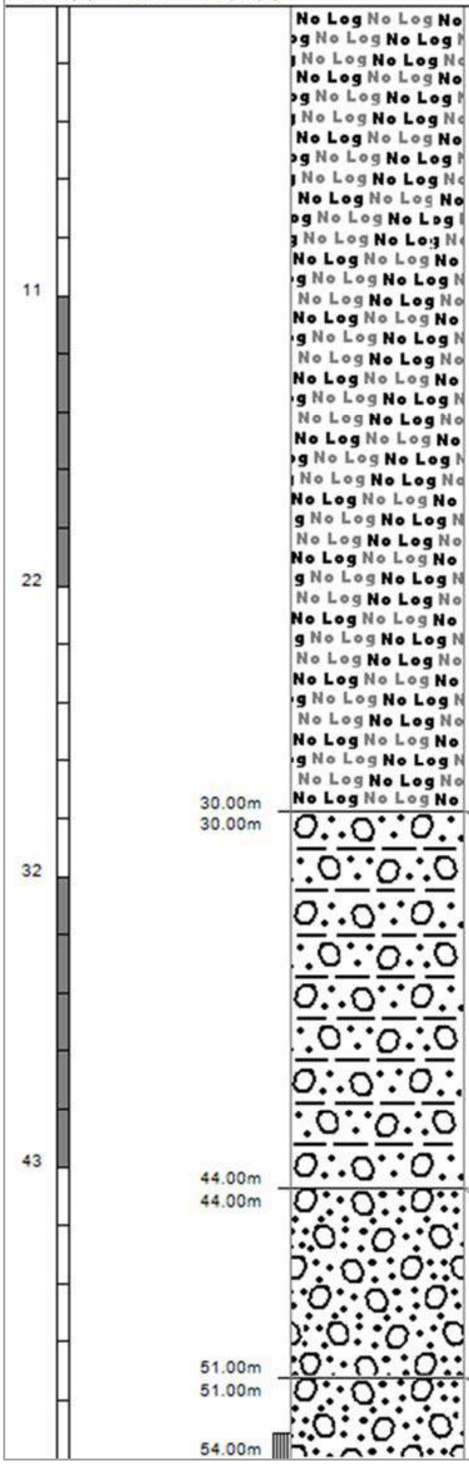
Golder Associates

Borelog for well K37/2603

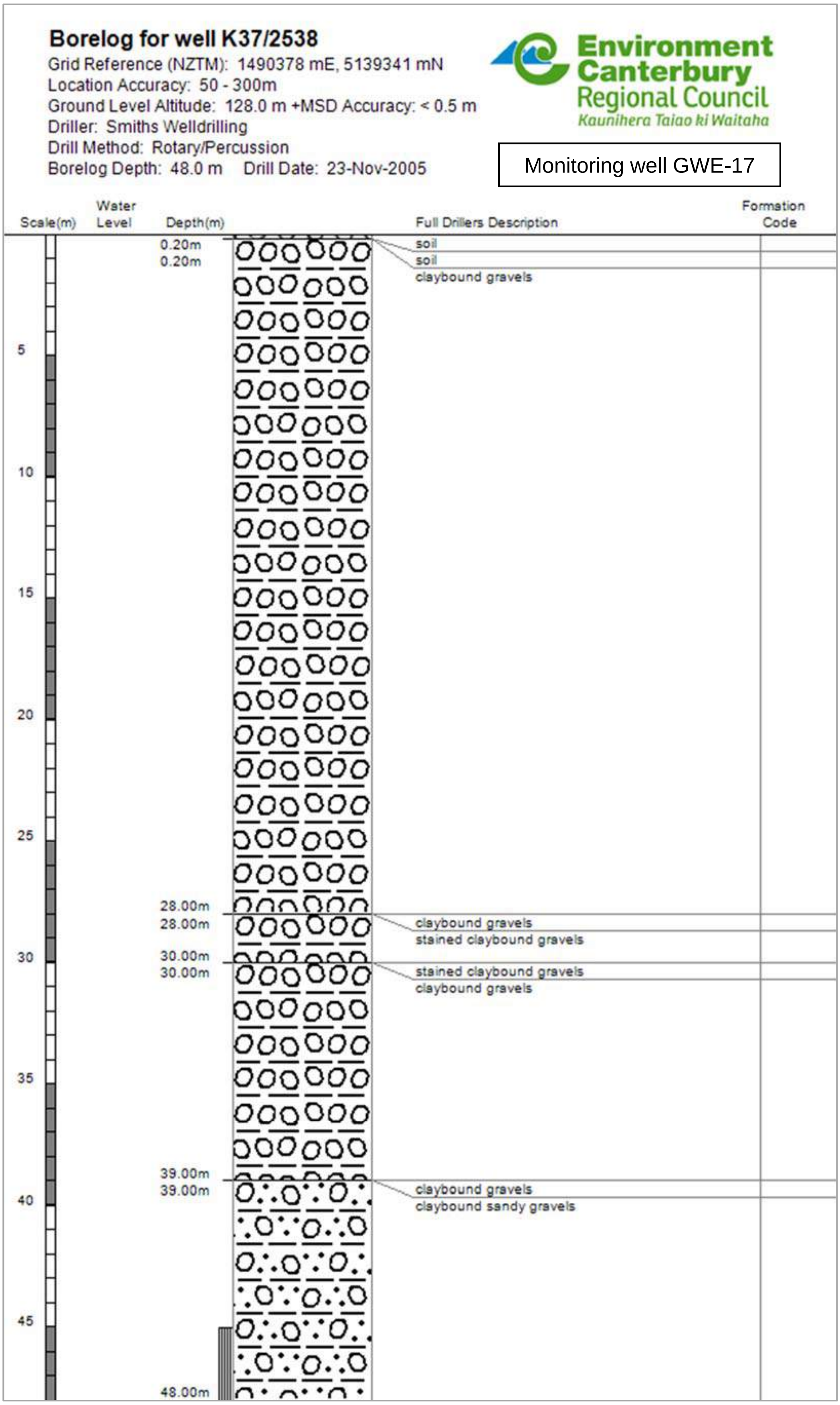
Grid Reference (NZTM): 1491330 mE, 5138245 mN
Location Accuracy: 2 - 15m
Ground Level Altitude: 124.7 m +MSD Accuracy: < 0.5 m
Driller: Smiths Welldrilling
Drill Method: Rotary/Percussion
Borelog Depth: 54.0 m Drill Date: 21-Nov-2005

Environment Canterbury Regional Council
Kaunihera Taiao ki Waitaha

Monitoring well GWE-16



Water Level	Depth(m)	Full Drillers Description	Formation Code
		Borelog for K37/0643	
	30.00m		
	30.00m	Borelog for K37/0643 claybound sandy gravel (deepened from K37/0643)	
	44.00m		
	44.00m	claybound sandy gravel (deepened from K37/0643) sandy gravel	
	51.00m		
	51.00m	sandy gravel free sandy gravel	
	54.00m		


Borelog for well K37/2538
Grid Reference (NZTM): 1490378 mE, 5139341 mN
Location Accuracy: 50 - 300m
Ground Level Altitude: 128.0 m +MSD Accuracy: < 0.5 m
Driller: Smiths Welldrilling
Drill Method: Rotary/Percussion
Borelog Depth: 48.0 m Drill Date: 23-Nov-2005
Environment Canterbury Regional Council
Kaunihera Taiao ki Waitaha
Monitoring well GWE-17
Scale(m)
Water Level
Depth(m)
Full Drillers Description
Formation Code
5
10
15
20
25
30
35
40
45
0.20m
0.20m
soil
soil
claybound gravels
28.00m
28.00m
claybound gravels
stained claybound gravels
30.00m
30.00m
stained claybound gravels
claybound gravels
39.00m
39.00m
claybound gravels
claybound sandy gravels
48.00m

APPENDIX D

Clamshell Hole Layout and Performance

1.0 INFILTRATION BASIN LAYOUT

The Pilot Trial site is located on the corner of Frasers Road and Timaru Track Road in the Hinds Plains catchment. The site consists of two basins, a forebay and a main infiltration basin, together with a water race approximately 900 m in length that delivers water from Valetta Pond #3 to the basins.

At operational water levels the ponded area of the forebay is 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 (Figure D1). The forebay was installed to enable coarse suspended sediment in the water delivered to site to settle and thereby be removed from the water flow before the source water entered the main infiltration basin.

Prior to initiation of the Pilot Trial, a pre-trial infiltration test was conducted from 16 May 2016 to 19 May 2016. Water sourced from Valetta Pond #3 was discharged into the basin at a range of different flow rates for a period of approximately 42 hours, after which the valve controlling the diversion from Valetta Pond #3 was closed. Water levels in the forebay and the infiltration basin were monitored for a further 78 hours until both basins had fallen dry.

Following the pre-trial test, 24 clamshell holes were excavated within the main infiltration basin to increase the infiltration efficiency of the basin. The arrangement of these clamshell holes within the basin is presented in Figure D1. Initially, the holes were dug to a depth of 6 m below ground level (bgl) by an excavator fitted with a one meter clamshell bucket attachment. This excavation method proved inefficient and was abandoned in favour of using a standard bucket excavator. Although the excavation method changed, to maintain clarity for the purposes of this report these excavated holes are referred to as clamshell holes throughout the report.

Each clamshell hole was approximately 1 m wide and 2 m long, with a nominal diameter of approximately 1.5 m, and was excavated to a depth of 6 m bgl. In most cases the excavated material was damp but not saturated until the excavation reached a depth of approximately 5.5 m below ground level. Below that depth water was observed flowing into many of the holes through a clean coarse gravel horizon. Due to stability (safety) risks associated with the excavations, groundwater level measurements, accurate observations of flows and detailed records of the materials excavated were not made.

The clamshell holes were stable during excavation until a depth of approximately 5.5 m bgl was reached. Below that depth the gravel in the hole walls began to slide into the excavation and undercut the walls. The hole wall instability at this depth is likely to be due to the presence of a relatively clean gravel layer with little silt and clay, combined with inflowing groundwater. The water intersected in the clamshell holes was perched, as it was intersected at an elevation substantially above the background groundwater levels recorded from nearby monitoring wells GWE-01 and GWD-01.

Following excavation, the clamshell holes were filled with coarse well-rounded cobbles with little accompanying finer material. This cobble fill would present little to no resistance to downward seepage flows within the clamshell holes during the Pilot Trial. During initial basin filling for the Pilot Trial, water flowing into the infiltration basin would pour into individual clamshell holes, filling these holes to overflow before spreading onward across the basin. During the filling process the clamshell holes were observed to act as small separate basins that could be filled over periods of less than 10 minutes.

2.0 CALCULATED BASIN INFILTRATION RATES

Infiltration rates before and after installation of the clamshell holes within the main infiltration basin have been estimated by evaluating the rate at which the basin drained during four separate shut-down events. The first of these events was at the close of a pre-trial infiltration test performed in May 2016. The other three events were recorded during the Pilot Trial itself and were chosen from a selection of seven possible events as being most representative of the basin behaviour uninfluenced by clogging or other contributing factors (refer to Appendix I for more detail). The three shutdown events chosen for comparison occurred in December 2016, January 2017 and March 2017 (Figure D2).

1. Aerial: ECAN GIS. CC-BY-3.0-NZ
2. Schematic only, not to be interpreted as an engineering design or construction drawing.
3. Vertical analysis results rounded to nearest 0.1m
4. Drawn by: RW/ZM. Reviewed by: RK.

Golder Associates

TITLE MAR PILOT SITE ELEVATION MODEL

JULY 2017

PROJECT 1538632

D1

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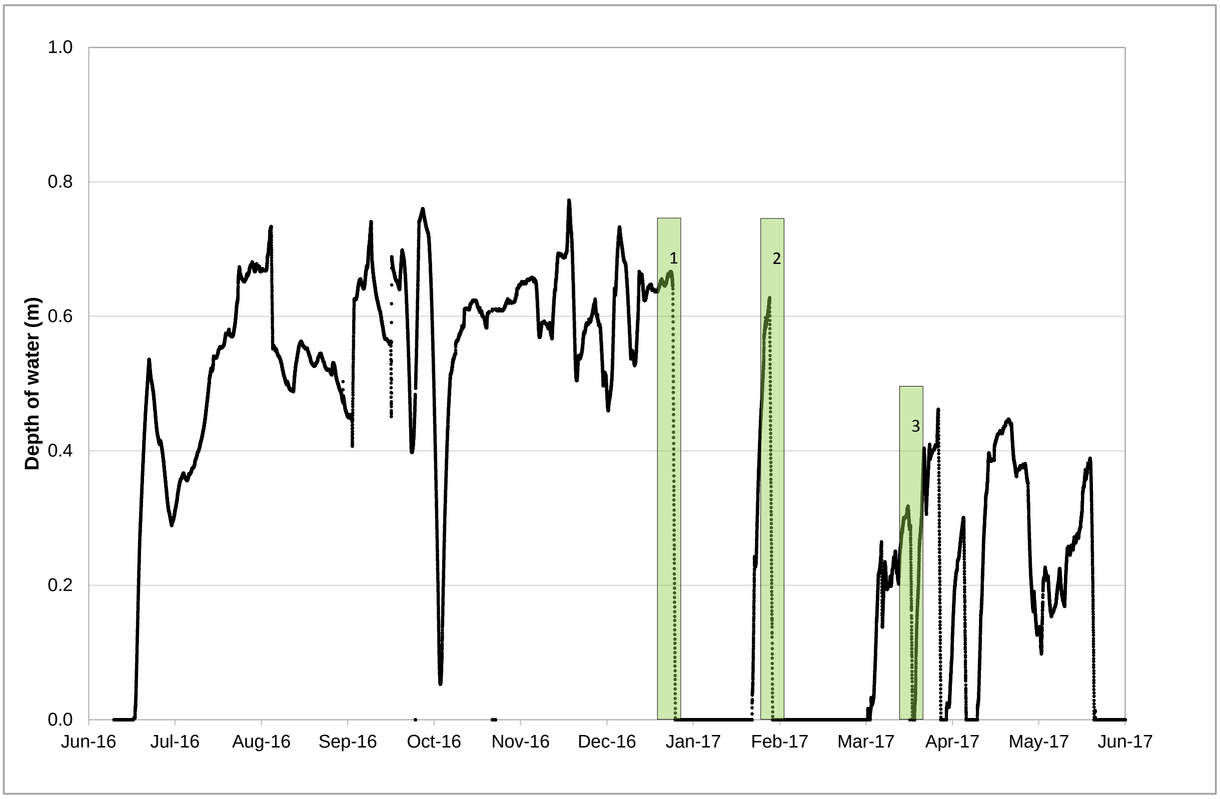

Figure D2: Shutdown events during Pilot Trial for comparison with pre-trial shut down event.

During the pre-trial infiltration test Solinst transducers were deployed to record water levels at two minute intervals within the forebay and main infiltration basin. Following two days of infiltration testing it was identified that air entrapment, as indicated by bubbles rising through the water in the infiltration basin, was a short-term operational issue affecting infiltration rates. The data from the shutdown at the end of the pre-trial test identified a non-linear infiltration rate within the main infiltration basin (Figure D3). The variability in the slope of the recovery curve from the pre-trial test, and therefore of the infiltration rate, may reflect transient adjustments in entrapped air distribution beneath the basin. It took 31.25 hours for the basin to drain, at an average vertical infiltration rate of 0.54 m/day (Table D1).

Water level data from the main infiltration basin was monitored during the Pilot using Solinst Leveloggers set to record at 15-minute intervals. The recovery curves from the three shutdown events listed above (December 2016, January 2017 and March 2017) are almost linear reflecting a stable rate of infiltration once inflows from the Valetta Pond #3 had ceased (Figure D3). The gradient of the trendline matched to the recovery curve recorded from the December 2016 event is steeper than the gradient of the lines matched to the other two recovery curves. This steeper gradient for the December event reflects a more rapid infiltration rate than for the other events (Table D1).

The data and recovery curves recorded from the three shutdown events during the Pilot Trial (which are influenced by the clamshell holes) can be compared with the recovery curve from the pre-trial infiltration test. Infiltration rates from three out of the four recovery curves were calculated to be between 0.5 m/day and 0.6 m/day, including the curve from the pre-trial test. The first shutdown event from the Pilot Trial presented a faster infiltration rate of 0.72 m/day; however it is not clear why this curve differed from the other two Pilot Trial events.

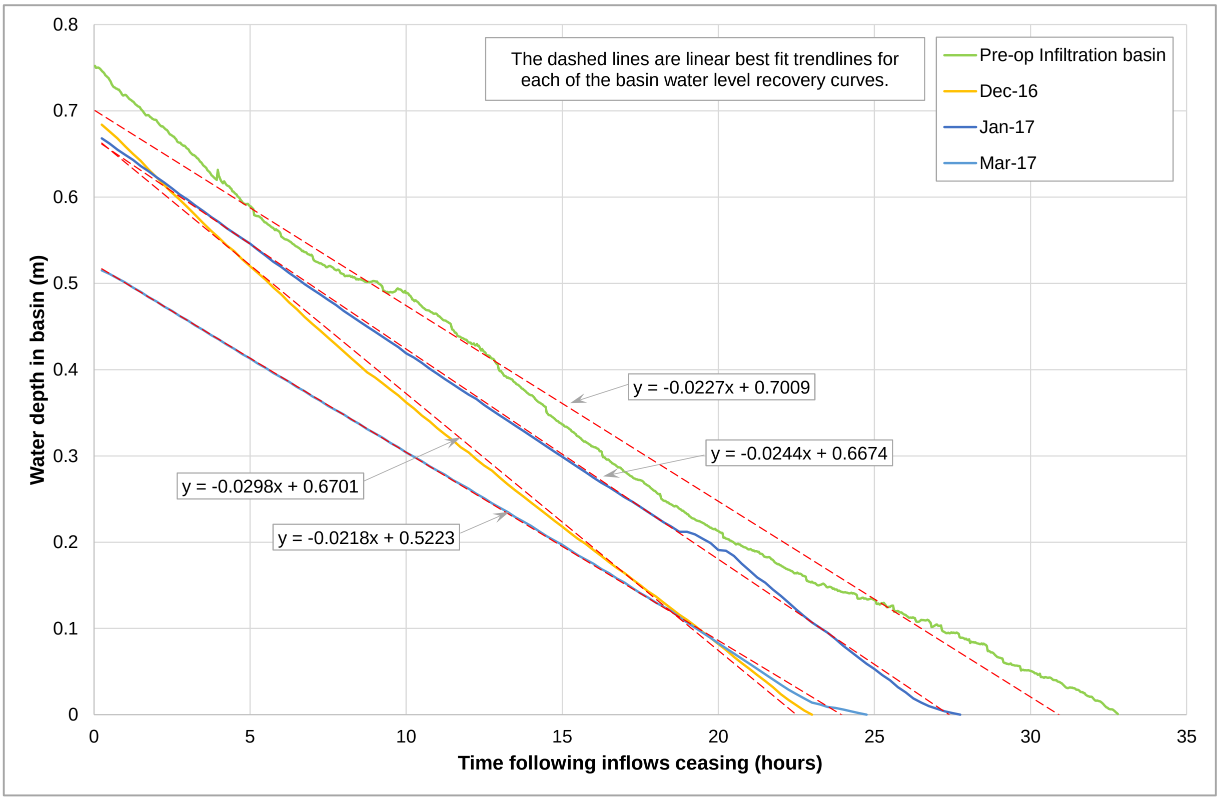

Figure D3: Shutdown recovery curves recorded during periods before and after clamshell hole installation.

Table D1: Basin infiltration rates calculated from water level recovery curves following shut-down events.

Recovery curve evaluated	Climatic factors(1)		Average infiltration rate		
	Rain at Willowby	Ashburton Aeroclub PET (2)	From recovery curves		Incorporating environmental factors
	(mm/day)	(mm/day)	(mm/hour)	(m/day)	(m/day)
18 May 2016 (pre-trial test)	0	0.5 (3)	22.7	0.54	0.54
24-Dec-16	1	2.8	29.8	0.72	0.71
27-Jan-17	0	7.6	24.4	0.59	0.58
28-Mar-17	0	2.1	21.8	0.52	0.52

Notes:
1) Refer to Appendix B for climate station locations and summary data.
2) PET – potential evapotranspiration. Used to approximate pond evaporation for the purposes of this study.
3) Estimated from seasonal trends.

During the pre-trial test shutdown there were also periods of several hours when the infiltration rate increased to be very similar to the 0.72 m/day rate calculated for the first of the Pilot Trial shutdown events. At this stage it is not clear whether these periods of more rapid infiltration reflect more rapid escape of entrapped air or whether the variability of the curve as a whole is influenced by other factors.

Based on the information presented above, there is no convincing evidence to indicate that installation of the clamshell holes resulted in enhanced infiltration rates from the infiltration basin.

3.0 INTERPRETATION OF SITE GEOLOGY

3.1 Information sources

Understanding the geology of the alluvial deposits beneath the site is a key factor in designing improvements to the site with the objective of increasing infiltration rates. The fluviatile deposits of the Canterbury Plains are highly complex and vary greatly in grain size both on a catchment scale and on a hectare scale such as that of the Pilot Trial site.

The design of improvements to the Pilot Trial site needs to focus on site specific geology while taking into account the hydraulic behaviour of the aquifers identified and monitored through the investigations completed during this project. For this reason, the interpretation of the geology at the site has been based on drillhole log from only one of the wells monitored during the Pilot Trial:

- GWD-01 (BY20/0149) – monitoring bore located on site with a depth of 30.28 m bgl.

Monitoring well GWE-01 is also located close to the site; however the geological log from this well lacked sufficient detail to support the lithological interpretation of the site.

The hydraulic behaviour of the aquifers on a local scale and on a wider sub-regional scale has been interpreted based on groundwater level and quality observations made during the excavation of the clamshell holes (refer Section 1.0) and during the Pilot Trial at monitoring wells further from the site, including:

- GWE-01 (K37/1748) – former production, now a monitoring bore located approximately 45 m south of the infiltration basin with a depth of 18 m bgl.
- GWD-02 (BY20/0150) – monitoring bore located approximately 320 m ESE of the centre of the basin with a depth of 32.00 m bgl.
- GWD-04 (BY20/0152) – monitoring bore located approximately 940 m SE of the basin with a depth of 25.7 m bgl.
- GWD-03 (BY20/0151) – monitoring bore located approximately 1,660 m E of the basin with a depth of 46 m bgl.
- GWE-04 (K37/0200) – monitoring bore located approximately 2,310 m E of the basin with a depth of 22.80 m bgl.

Detailed descriptions for these monitoring wells as well as drillhole and well logs are provided in Appendix C. The hydraulic responses of these monitoring wells to the pre-trial infiltration test and to the Pilot Trial operations are documented in Appendix G.

3.2 Drilling techniques used during installation of monitoring bores

Two drilling techniques were used during construction of the seven monitoring wells (GWD-01 to GWD-07) installed to support monitoring of the Pilot Trial. These techniques were sonic core drilling (sonic) and rotary air blast drilling (rotary). Of the seven bores drilled, five used sonic techniques (three re-drilled with rotary rig) and two used rotary techniques only.

The sonic drilling technique produced core that could be accurately logged with respect to depth. The driller's logs however indicate that sonic drilling resulted in a sample recovery rate of between 20 % and

100 %. The accuracy of the lithological description, and therefore the hydrogeological interpretation of the material's behaviour, is therefore degraded by the loss of fine sediments (fines) washed from the core during the drilling and sample recovery process. It cannot be assumed that all of the unrecovered material consists of fines. Even if this was the case, the nature and exact distribution of these fines within any individual section of core recovered cannot necessarily be accurately determined from the description of the recovered sample.

The rotary drilling method was described in the driller's logs as having 100% recovery, however sample recovery under this technique involves high pressure air to lift the cuttings from the drill bit up to the surface rather than producing a core. Consequently the bore logs produced are broad and categorical, with subtle lithological changes not able to be identified with any accuracy. This drilling technique is commonly used for installing water supply bores and partly explains the lack of detail seen in many of the monitoring well cards (Appendix C).

Although the sonic core drilling technique can result in significant loss of fines from the core samples, it was the drilling method that produced the most accurate representation of the subsurface lithology from the two methods used.

3.3 Hydrogeological interpretation

The geological interpretation of the fluviatile deposits underlying the site at a depth of up to 30 m, and their hydraulic behaviour with respect to infiltration is provided in Table D2. It should be noted that the groundwater level in the lowest interpreted aquifer was substantially higher when the monitoring well was installed than when the pre-trial infiltration test started.

Table D2: Lithological sequence beneath Pilot Trial site based on geological log from GWD-01.

Approximate depth below ground level	Description	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)

Based on the lithological interpretation summarised in Table D2, the clamshell holes were effectively excavated through the uppermost unsaturated aquifer. During the excavations it was not observed that any of the holes intersected a silt layer, representative of the upper interpreted aquitard, although the starting elevation for the excavations in the floor of the infiltration basin was between one and two metres below the surrounding natural ground level. The observation of water flowing into the clamshell holes however indicates the likely presence of an aquitard unit beneath the base of these holes, supporting the general interpretation of an upper aquitard presented in Table D2.

The hydraulic levels measured in monitoring wells GWE-01 and GWD-01 prior to the start of the pre-trial infiltration test (Table D2) and the hydraulic responses measured in all of the monitoring wells listed in Section 3.1 (refer Appendix G) indicate the presence of a perched aquifer beneath the site. This perched aquifer has been interpreted as consisting of a buried river paleochannel aligned toward the southeast from the Pilot Trial site.

Beneath the perched aquifer is another interpreted silt aquitard. This lower aquitard overlies the gravel aquifer that has been interpreted as being continuous with the regional aquifer. This interpreted hydraulic connection with the regional aquifer has been based on:

- Depth of the well screen below ground level, which is consistent with other wells used to monitor groundwater trends in the unconfined regional groundwater table.
- The groundwater level prior to the Pilot Trial being consistent with that observed in nearby wells used to monitor the regional groundwater table.
- The groundwater responses to enhanced recharge during the Pilot Trial are consistent with the responses observed in monitoring wells GWD-02 and GWD-03, with the latter being more than 1,600 m to the east of the site.

The groundwater level responses observed in GWE-01 and GWD-01 during the Pilot Trial indicate the aquitard units identified in Table D2 are leaky with substantial seepage downward through both of these units. Estimates of the relative distribution of MAR water between the middle perched aquifer and the regional aquifer have been documented in Appendix G (Table G4).

As documented in Appendix G (Section 5.2), recharge to the regional aquifer during Year 1 of the Pilot Trial resulted in the groundwater level rising by:

- Approximately 4.4 m beneath the centre of the Pilot Trial basin.
- Approximately 4.05 m at a distance of 90 metres from the centre of the basin (GWD-01).
- Approximately 3.61 m at a distance of 320 metres from the centre of the basin (GWD-02).
- Approximately 2.14 m at a distance of 1,660 metres from the centre of the basin (GWD-03).

The large extent of this groundwater mounding together with the relatively small magnitude of groundwater level rise beneath the basin indicates the regional aquifer has substantial capacity to accept additional recharge at this site. This conclusion implies that the key factors limiting the rate of recharge to the aquifers underlying the site are:

1) The thickness of the aquitards interpreted as underlying the site.

2) The vertical hydraulic conductivity of the sediments within these aquitards.

4.0 PILOT TRIAL SITE RECHARGE ENHANCEMENT OPTIONS

4.1 Introduction

As documented in Section 3.3 above, interpretation of the outcomes from the Pilot Trial indicates that the regional aquifer has substantial capacity to accept additional recharge at this site. This additional recharge is over and above that achieved during the Pilot Trial.

Interpretation of the lithological units present beneath the site (Section 3.3) identified silty aquitards from 6 m to 9 m bgl and from 18 m to 26 m bgl. Observations made during the Pilot Trial indicate both of these aquitards, which have been identified on the basis of drillhole log interpretation, act to impede downward seepage flows during the Pilot Trial (refer Section 3.3 above and Appendix G).

These observations imply that further substantial increases in artificial recharge to the regional aquifer beneath the Pilot Trial site would require:

1) Increasing the seepage flows though these silty layers, or

2) Creating preferred seepage flow paths through these silty layers, or

3) Direct injection of water into the regional aquifer.

Options considered for increasing aquifer recharge at this site are therefore focused on improved seepage flows through and past the inferred aquitards, taking into account the existing restrictions on site area.

The following sections provide introductory information regarding options for improving artificial recharge, and limitations for a few options that are unlikely to be viable. The information presented in the following sections is at a high level only and is not intended to imply any recommendations with respect to site enhancements. The following sections also do not take into account:

- Any potential for spatial expansion of the site.
- Construction and operational costs, and therefore potential cost effectiveness of the options presented.
- Issues that may arise with respect to consenting new installations at the site.
- Water quality issues that may arise (e.g., TSS loads, *E. coli*) and appropriate management measures.
- Operational procedures and site management.

The options listed below that offer potential to achieve the above objectives would need to be further developed and subjected to a cost benefit analysis before any decisions on site upgrading are made.

With any modification to the site intended to enhance recharge rates to the regional aquifer, it will be important to ensure groundwater quality objectives with respect to microbiological contaminants (e.g., *E. coli*) continue to be achieved.

4.2 Increased Infiltration Basin Depth

Increasing the depth of the infiltration basin itself was considered as an option to increase infiltration through the floor of the basin. The concept is focused on:

- Reducing the thickness of in-situ sediment material through which infiltrating water must flow to reach the underlying aquifers.
- Increasing the water pressure acting on the floor of the basin that generates the downward seepage.

Deepening the infiltration basin, within reasonable and practical limits, is unlikely to achieve significant gains in recharge rates. The installation of the existing clamshell holes has already increased the effective depth of the infiltration basin by six metres without achieving significant gains in recharge rate.

Deepening the infiltration basin and then installing further clamshell holes, with the objective of creating enhanced seepage paths through the upper aquitard, may be achievable. There is however a practical limit on the depth to which the basin can be increased and the cost effectiveness of implementing this option is likely to be questionable.

In summary, this option for potentially increasing groundwater recharge at the site is unlikely to achieve the objective.

4.3 Deeper Clamshell Holes

When looking to increase the infiltration efficiency of the current Pilot Trial site, one option available is to install clamshell holes (or an equivalent) to a greater depth. Assuming the objective is to increase recharge rates to the regional aquifer, as opposed to the intermediate perched aquifer, the target depth would need to exceed 26 m bgl.

Clamshell holes, as constructed using an excavator, have probably reached a practical depth limit at six metres. Taking into account the stability issues observed in the clamshell hole walls, excavation of unsupported holes to substantially greater depths is unlikely to be a viable option.

Large diameter holes excavated using a bucket auger or similar and supported with temporary steel casing could be constructed and backfilled with cobbles similar to those used for the clamshell holes. During construction the casing would be withdrawn from the hole as the backfill is put in place. This technique could effectively result in deeper backfilled holes with similar hydraulic characteristics to the clamshell holes already in place. The viability of this technique would however need to be confirmed with a drilling contractor.

4.4 Injection Bores

With the need for any subsurface infrastructure to extend past the confining silt layer located from 21 m to 26 m bgl, one option to provide a hydraulic connection between the surface and the regional aquifer is an injection bore. Large diameter bores could be constructed with screens installed in the regional aquifer beneath the Pilot Trial site. The indicated transmissivity of the regional aquifer beneath the site is estimated to be in the order of 2,000 m^2/day (refer Appendix H). An aquifer with this transmissivity has the capacity to accept injected water flows several times greater than those currently reaching the aquifer via the infiltration basin. The bore would need to be installed with an appropriate casing and screen, however such installations are relatively common for MAR purposes overseas.

As with any injection bore, clogging is likely to be an issue requiring management. During the Pilot Trial, TSS concentrations in the source water delivered to the trial site have fluctuated. The highest TSS concentrations measured during the Pilot Trial at the Valetta Pond #3 outflow and in the main infiltration basin were 59 g/m^3 and 36 g/m^3, respectively (Appendix F). On occasion highly turbid water was observed to enter the forebay from the Valetta Irrigation Scheme. However, the TSS concentrations measured in the infiltration basin water were generally less than 10 g/m^3 and were regularly below the laboratory detection limit of 1.5 g/m^3. Provided the inflows to the bore are managed and TSS concentrations are maintained at less than 10 g/m^3, and appropriate bore management measures are included in the operations plan for the site, one or more injection bores could be a viable option for improving the site performance.

5.0 SUMMARY

The Pilot Trial site is located on the corner of Frasers Road and Timaru Track Road in the Hinds Plains catchment. At operational water levels the ponded area of the forebay is 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.

Prior to initiation of the Pilot Trial, a pre-trial infiltration test was conducted during which water was discharged into the basin for a period of approximately 42 hours, after which the inflow was shut down. Water levels in the forebay and the infiltration basin were monitored for a further 78 hours until both basins had fallen dry.

Following the pre-trial test, 24 clamshell holes were excavated within the main infiltration basin to increase the infiltration efficiency of the basin. Each clamshell hole had a nominal diameter of approximately 1.5 m, and a depth of approximately 6 m bgl. The clamshell holes were stable during excavation until a depth of approximately 5.5 m bgl was reached. Below that depth the gravel in the hole walls began to slide into the excavation and undercut the walls. Following excavation, the clamshell holes were filled with coarse well-rounded cobbles. This cobble fill would present little to no resistance to downward seepage flows within the clamshell holes during the Pilot Trial.

Interpretation of the geology at the site indicates two aquitard layers (consisting of gravelly silts) are present between the base of the infiltration basin and the aquifer hydraulically connected to the regional groundwater system. The clamshell holes did not appear to reach the upper aquitard, and they were not deep enough to generate hydraulic seepage pathways through the upper aquitard.

The key factors limiting the rate of recharge to the aquifers underlying the site are:

1) The thickness of the aquitards interpreted as underlying the site.

2) The vertical hydraulic conductivity of the sediments within these aquitards.

Several options have been considered to potentially increase the rate of aquifer recharge at the site. Of these options:

- Increasing the depth of the main infiltration basin is unlikely to present a viable option for both hydrogeological and cost effectiveness reasons.
- Increasing the depth of unsupported clamshell holes is unlikely to present a viable option due to issues with the stability of the excavation walls.
- Installing deeper holes backfilled with cobbles, similar in form to the existing clamshell holes, using a cased drilling technique is an option worth investigating.
- Installing injection bores screened in the regional aquifer system is also an option worth investigating, as this is a technique commonly used for MAR programmes internationally and the hydrogeology of this site appears to be suitable for such a system.

The primary objective of the enhancements to the site introduced in this appendix would be to increase recharge to the regional aquifer system. This would need to be achieved through installing enhanced seepage routes through the two aquitards identified as underlying the site or through injecting MAR water directly to the regional aquifer system.

In any modification to the site intended to enhance recharge rates to the regional aquifer, it will be important to ensure groundwater quality objectives with respect to microbiological contaminants (e.g., *E. coli*) continue to be achieved.

As with the existing infiltration basin, clogging of any additional MAR system installed at the site is a potential issue that would need to be managed.

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APPENDIX E

Recharge Water Volumes

1.0 OVERVIEW – MAR SITE OPERATIONAL FLOW MONITORING

The Hinds MAR project was designed to use alpine water, sourced from the Rangitata River, to replenish groundwater. This water was secured through the temporary (1 year) transfer of unutilised ADC stockwater and consented for use at the MAR Pilot Trial site (Table E1).

ADC maintains a diversion meter which provides 15-minute flow data for stockwater being utilised off the river. The consent stipulates that RDRML can divert up to 500 L/s at their Klondyke intake for delivery to the Pilot Trial site, but not exceed an annual diversion volume of 15,780,000 m^3 between 1 February and 31 January the following year. RDRML's Klondyke intake flow data is compiled as daily average flows, where the *source water* is considered *additional* to RDRML's existing consented take.

The *source water* was conveyed along RDRML's main race to the Valetta Irrigation Scheme intake, where the flow is again measured and compiled as daily average flows. Valetta Irrigation Limited (Valetta) then directs the *source water* to the MAR Pilot Trial site via their piped scheme network and a series of storage ponds, under the same maximum rate and volumetric limits defined in the consent. This water arrives in Valetta Pond #3, from where it can be diverted to the MAR Pilot Trial site via a hydraulically operated gate.

For the purposes of source water flow monitoring and consent compliance assessment, the MAR Pilot Trial site includes the unlined water race from Valetta Pond #3 to the infiltration basin forebay, the forebay and the main infiltration basin. All three components of the site contribute to seepage to the underlying groundwater system and are therefore included in the evaluation of flows to and through the MAR Pilot Trial site.

Flow rates and volumes are measured at three locations at the MAR Pilot Trial site:

- Flow entering the site is measured at Flume 1 (Figure E1), which is the point of MAR Pilot Trial source water diversion relative to the consent conditions.
- The source water then flows approximately 900 m down a leaky open race to Flume 2 (Figure E2), which monitors water flows entering the main MAR Pilot Trial facility. Flow losses to groundwater through the base of the water race can be calculated as the difference between flows recorded at Flumes 1 and 2.
- Water levels are measured in the main infiltration basin at the Pilot Trial site. If the depth of water in the main basin exceeds 2.4 m, the water overflows through the emergency spillway to the adjacent ADC stockwater race. These discharges would be measured using the main basin level logger (stage), with the 'Overflow' spillway acting as a weir (Figure E2).

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 can be calculated based on water levels recorded at Flume 2 (Figure E2).

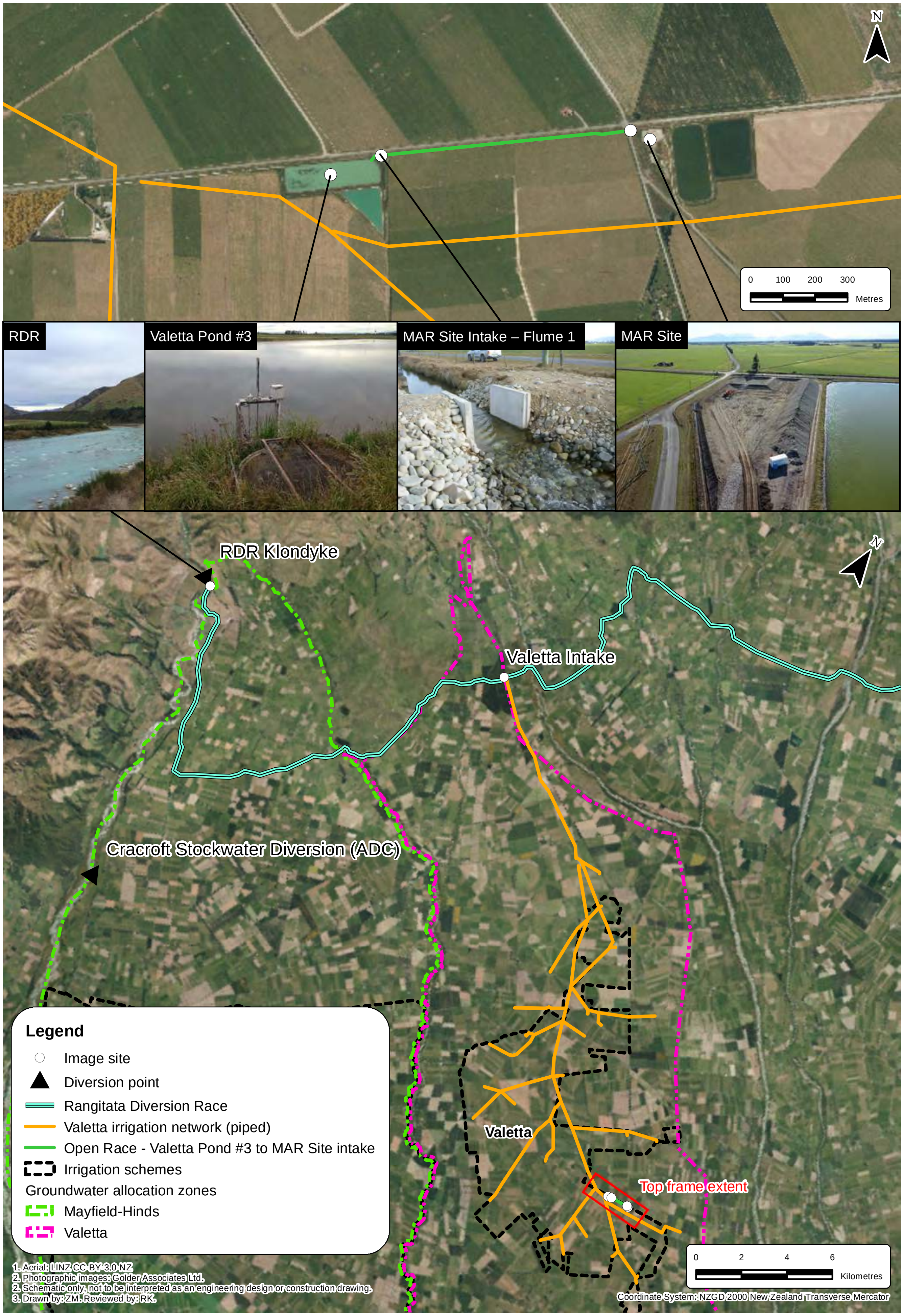
The official *recharge testing period* for Year 1 of the MAR Pilot Trial operated from **10 June 2016 to 9 June 2017**. Several small pre-operational flow events occurred prior to the official start, including an infrastructure commissioning test (16 May 2016 to 18 May 2016), a Valetta Pond #3 bypass flow event (2 June 2016) and an 'Opening Ceremony' (3 June 2016). For the purposes of the flow analysis for consent compliance and operational analysis, this *recharge testing period* was used. The flow analysis is divided between:

1) Water diverted from the Rangitata River and delivered to the MAR Pilot Trial site (Section 2.0); and

2) Water entering the MAR Pilot Trial facility and being recharged to the underlying groundwater system (Section 3.0).

Table E1: Temporary transfer consent and time period information.

Consent number	Consenting authority	Consent type	Start date	End date
CRC164281	CRC	To take and use surface water	25 Feb 2016	25 Feb 2021



Golder Associates

TITLE KEY FLOW DIVERSION AND MONITORING LOCATIONS – MAR SITE DELIVERY SYSTEM

JULY 2017

PROJECT 1538632

E1

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Figure E2: MAR Pilot Trial facility with key site structural and flow measurement locations.

2.0 RANGITATA RIVER TO MAR SITE – FLOW ASSESSMENT

2.1 Flow management

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 Pilot Trial during Year 1. Communications were established between ADC and the RDRML Raceman to ensure that the rate at which *source water* is diverted by RDRML never cumulatively exceeds the ADC stockwater consented take from the Rangitata River. Similarly, communications between RDRML and the Valetta Raceman were established 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.

2.2 Source Water Diversion – Cumulative Flow Assessment

Water flow data provided by both RDRML (pers comm. Ben Curry) and ADC (pers comm. Chris Stanley) was compiled by Golder to assess compliance with several flow constraints relative to the consent (Figure E3):

1) Firstly that the average flow for the RDRML source water diversion did not exceed 500 L/s. The RDRML maximum rate of diversion was measured at around 300 L/s (Figure E3).

2) Secondly, that the cumulative ADC and RDR takes from the river did not exceed either the year round consented limit of 849 L/s or the 1,115 L/s limit[1] authorised between 15 September and 14 May. The results plotted in Figure E3 show that the project was compliant with these diversion consent conditions.

[1] 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.'

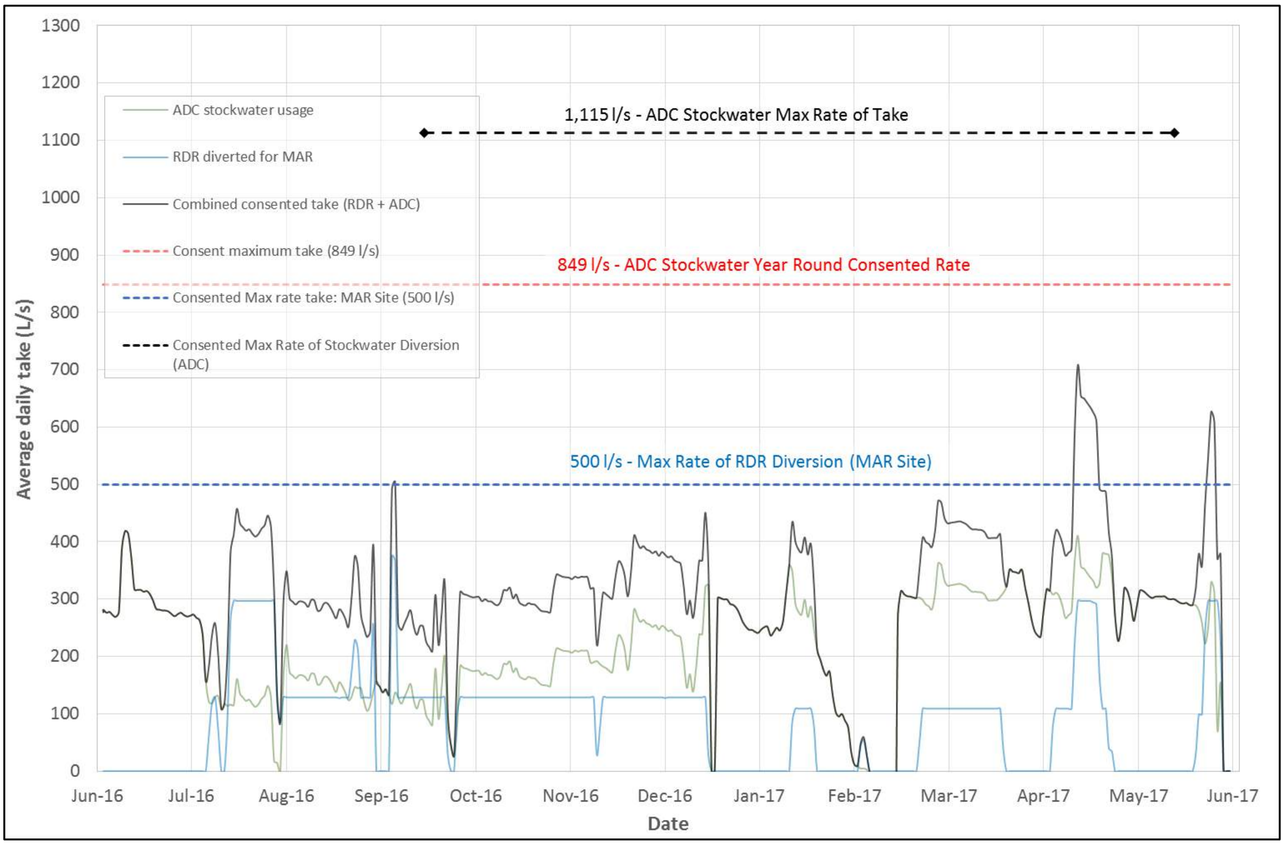

Figure E3: Combined ADC and RDR flows and consent condition thresholds (YEAR 1 data[2]: 10 June 2016 to 9 June 2017).

A review of the diversion data (refer Section 2.3 below) 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.

2.3 Source Water Delivery – Operational Management

During this recharge season both the RDRML and Valetta systems had a several periods when they were shut down due to either scheduled maintenance or, more recently, due to a suspected blockage in the Valetta pipeline. At the time of this report, the suspected blockage was being investigated through a pipeline inspection, and it is surmised that it could be the result of ‘trapped air’ in the pipes (pers comm. Giles Pinfold).

Both irrigation companies were proactive in seeking to keep the MAR Pilot Trial site operating for as long as possible using their existing in-system storage. During Year 1 operations Golder (Bob Bower) worked closely with Valetta (Giles Pinfold) to manage the calls for water and site shutdowns, as well as the ongoing physical operations on site and management issues that arose. Communications were conducted through a combination of verbal (phone), text messages, and emails. The MAR Pilot Trial monitoring system also had mobile phone text alerts set up to keep the operations team aware of changes, enabling 24/7 responses.

[2] RDR Flow data was compiled in daily average flow volumes, ADC provided 15-minute average flows. Both were compiled into daily average flow values for the purposes of this analysis. Note that the standard error range of +/- 8% is applicable to this information, and RDR’s intake flows are approximately 30,000 L/s, given an error range of +/- 2,400 L/s.

Team communication focused on a range of tasks including MAR site start-ups, shutdowns and issues with monitoring equipment or physical delivery of water to the site.

The following are a list of operational challenges faced during this first year of operations:

- **Monitoring Equipment Issues** – Year 1 monitoring equipment issues including MAR site flow flumes indicating higher than actual MAR flows (has been corrected), Valetta Pond #3 flow recorder going offline (23 December 2016) and communication issues from site to local mobile towers (causing website to go offline). These issues are being addressed for Year 2 operations. Notably, Flume 1 had stage recording issues from 5 July 2016 to 2 September 2016. Data collected during that period is expected to underestimate actual flows into the MAR Pilot Trial site.
- **Valetta Pond #3 Leakage** – During 'recharge only' portions of the year, it was noted that Valetta Pond #3 has a slow leakage of water (4 L/s – 5 L/s) that had to be accounted for in the overall project water balance.
- **Conveyance System Issues** – during Year 1 operations, issues arose in the Valetta scheme that either inhibited or outright prohibited MAR water delivery. The RDR was also shut down for required maintenance during Year 1, which was generally managed by using stored water in Valetta's existing ponds. These kinds of regular maintenance issues are to be expected in annual MAR operations. More recently a suspected pipeline blockage required that the Valetta system be shutdown, drained and then inspected with cameras. This particular event caused the MAR site to shut down for the final 21 days of operations (20 May 2017 to 9 June 2017).
- **Peak Irrigation Season Conveyance Limitations** – after a reasonably wet spring and early summer, peak irrigation demand limited the Valetta pipeline flow capacity, and meant the MAR Pilot Trial site was shut down twice: from 23 December 2016 to 18 January 2017 (26 days) and from 26 January 2017 to 1 March 2017 (34 days), with a brief (8 day) operational window in between these periods due to a summer rainfall event.

Wet weather required the Pilot Trial site inflows to cease during Year 1. As per the consent conditions (Appendix A), inflow operations at the site are to be shut down (for a minimum of 48 hours) if either coastal waterbody (drain) flows (Canterbury Regional Council (CRC) site # 69001[3] - Parakanoi at Lower Beach Road) or rainfall (CRC site # 39610[4] - Hinds Plains rainfall station) exceed trigger conditions.

For the Year 1 operations, the Pilot Trial operated for a total of 279 days. Shutdowns of site inflows were based on peak irrigation demand (total 60 days), system delivery issues (total 21 days) and coastal rainfall triggers (5 days).

For the CRC flow gauge on Parakanoi Drain, the trigger value was for flows exceeding 2,200 L/s. This flow rate was not exceeded during Year 1 operations (Figure E4). Conditions in the coastal waterways during Year 1 were consistent with those observed over the past three to four years, with dry conditions persisting even during the normally 'wetter' winter periods. During Year 1, Parakanoi Drain at Lower Beach Road was **dry for 353 days**. Flows were only measured in Parakanoi Drain for 12 days during the period from 10 June 2016 to 9 June 2017.

Rainfall recorded at the Hinds Plains weather station (Figure E4) indicated two rainfall events triggered consented MAR site inflow shutdowns (> 30 mm/24 hours): during Year 1

1) 31 mm of rain fell between 18:30 on 26 March 2017 and 12:00 on 27 March 2017; and
2) 56 mm fell between 14:30 on April 5 and 14:20 on April 6.

Consequently, MAR site inflow operations ceased for shutdown periods during Event 1 from 15:30 on 27 March to 11:15 on 29 March, and during Event 2 from 9:15 on 6 April to 13:45 on 9 April 2017.

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

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

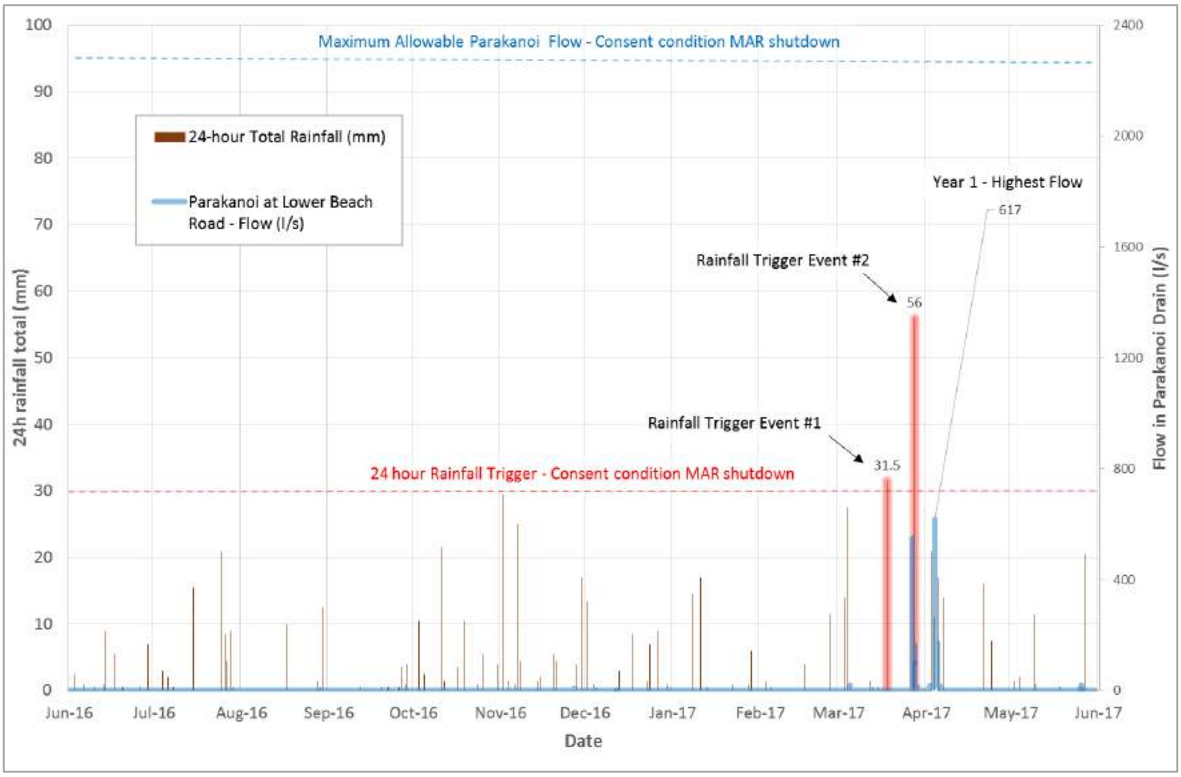

Figure E4: Rainfall and Parakanoi Drain flow at Lower Beach Road: consented trigger analysis results - Year 1 MAR operations.

2.4 Source Water Delivery – Cumulative Flow Assessment

Golder compiled the diversion data sourced from ADC (Chris Stanley, pers comm.), RDRML (Ben Curry, pers comm.) and Valetta (Giles Pinfold pers comm.), as well as from the Pilot Trial site data recorders (Golder/Scottech). RDRML data was provided in daily volumes (m^3/day) whilst ADC, Valetta and the MAR site information were all collected in 15-minute intervals. All parties clearly understood that tracking an average rate of recharge water (~105 L/s) through this large-scale system would be complicated, given that the metering used by both RDRML and Valetta have measurement system accuracy limits exceeding the amount of MAR water being tracked. Complicating the issue of measurement accuracy is the conjunctive nature of the RDR and Valetta systems. Attempting to deliver both irrigation and MAR water through the pipe and storage pond system meant that during peak irrigation demand periods or system shut downs, MAR water resided 'in the system' on its way to being delivered to the MAR Pilot Trial site.

Table E2 provides a water balance for ADC water diverted by RDRML and delivered to the MAR Pilot Trial site via the Valetta distribution system. A total of approximately **2,595,000 m^3** was diverted at Klondyke for Pilot Trial usage, after corrections for system losses and measurement errors have been taken into account. The total volume of recharged water is conservatively estimated at **2,442,000 m^3**, with some additional water still considered 'in system' due to the recent inability to deliver water to the MAR Pilot Trial site (due to a suspected pipeline blockage). This water will be utilised early in Year 2 of Pilot Trial operations. Given these factors, the data indicates that water diverted by RDRML for Pilot Trial use was delivered through the RDR and Valetta systems.

Table E2: 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:	
RDR 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.

3.0 MAR SITE: FLOW MEASUREMENTS AND RATINGS

Flow measurements at the MAR Pilot Trial site are conducted primarily at two locations. Flume 1 (Figure E5) is located below the outflow from Valetta Pond #3, where flow is controlled by a hydraulic gate. A stage recorder (logger) and External Staff Gauge (ESG, attached to the adjacent concrete historic diversion structure) are used to measure this outflow. Flume 2 (Figure E6) is installed in the open race adjacent to the Pilot Trial forebay, with an ESG board and stage recorder (logger), which are used to record flows within four metres of the concrete weir that acts as the discharge point into the Pilot Trial forebay (Figure E2).

Flows through these flumes were measured across the weir structures by CRC and Golder field staff during Year 1 of Pilot Trial operations, and the information used to build the flume rating curves. The final measurement point in the basin is the *overflow* spillway (Figure E2), with water levels upstream from this spillway measured by the main infiltration basin stage recorder (Figure E7). The *overflow* spillway is designed solely as an emergency spillway for the basin. The overflow depth was surveyed at 2.4 m above the basin floor. The operational water depth in the main infiltration basin (through Year 1 of operations) was maintained below 0.8 metres, resulting in no overflows and no flow rating being established for the overflow spillway. The following sections cover the rating programme established for each of the MAR flow sites.

Figure E5: Flume 1 with Valetta Pond #3 gatehouse, ESG board (inset) and logger housing.

Figure E6: Flume 2 with ESG and logger structure.

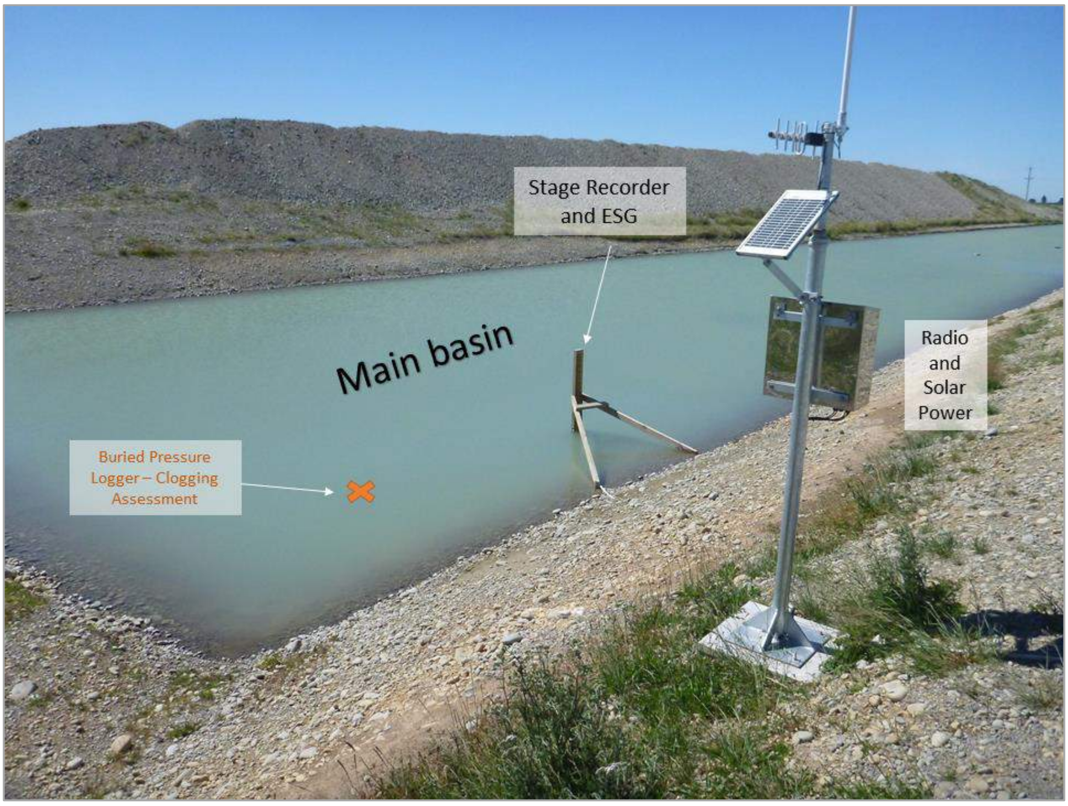

Figure E7: Main basin logger, ESG and solar communications system with location of buried transducer.

3.1 Flume 1 – Flow Measurements and Ratings

Flows through Flume 1 were measured 18 times during the course of the pre-operations and Year 1 of the Pilot Trial. Measurements were taken across the centre of the concrete weir, which provided a consistent and controlled collection process. The first five measurements were taken (May 2016) before the final ESG and real-time logger was established, and were used solely for the purpose of pre-operations infrastructure testing (16 May 2016 to 18 May 2016). The remaining 13 measurements were taken during the course of Year 1, including a flow ramping test on 16 September 2016 to establish an appropriate rating range (Table E3). Rating measurements were collected in accordance with CRC's standard sampling protocols as well as international best practice. ESG board readings were taken at the time of each measurement and used to determine any shifts related to logger variations or drift. All measurements were plotted and visually assessed for consistency with other measurements and against the logger data for the time of measurement.

An initial rating for Flume 1 was established in June 2016 that was deemed as reading 'high' after subsequent measurements. A revised rating was programmed into the logger in November 2016. This rating was further refined in June 2017 when further measurements and issues with the polynomial rating equation (e.g., erratic values when stage values were negative) required a final rating for Year 1 analysis be conducted. The final flow data and manual rating solution equation[5] for Year 1 is presented in Figure E8. A number of flow measurements were deemed to be 'outliers', based on inconsistency with other plotted measurements or they were collected during a period of flow variability in the race. The final flow data for Flume 1 plotted against the rating measurements is shown in Figure E9 for the period from 2 June 2016 to 9 June 2017, which includes the periods just prior to commencing the MAR Pilot Trial.

[5] Final equation after shift to optimise fit of rating around average recharge rate was: flow (y) = $-5.102x^3 + 3132.4x^4 + 15.45x$ – **0.75**, where x = logger stage.

Table E3: Flume 1 flow ratings measurements.

Field measurements					Scott Tech – logger readings						Notes
Who	**Date**	**Time**	**Average ESG**	**Flow (L/s)**	**Date**	**Time**	**Logger Stage**	**Average Flow (L/s)**	**Difference stage (mm)**	**Rating**	
CRC	5/07/16	11:57	0.162	101.7	5/07/16	12:00	0.177	134.8	15.0	Yes	Best Measurement in this range- stage and flows stable
Golder	25/08/16	09:05	0.170	95.9	25/08/16	09:15	0.178	136.9	8.0	No	Stage appears considerably off, non-stable flows. Not used in rating.
Golder	2/09/16	10:30	0.169	97.6	2/09/16	10:45	0.175	92.7	6.5	Yes	Used this measurement to shore up around 101.7 - stage was fluctuating
Golder	2/09/16	14:01	0.105	38.9	2/09/16	14:15	0.113	73.89	8.0	Yes	Best Measurement in this range- stage and flows stable
Golder/CRC	9/16/2015	N/A	N/A	0	16/09/16	09:30	0.012	12.03	---	Yes	Used lowest flow and MAX depth from MMT to estimate synthetic stage zero. Flow measurement max depth at 19.4 l/s 0.06 mm
Golder/CRC	9/16/2016	10:05	0.068	19.4	16/09/16	10:00	0.072	38.40	4.5	Yes	Best Measurement in this range- stage and flows stable
Golder/CRC	9/16/2016	11:27	0.118	59.3	16/09/16	11:30	0.13	69.13	14.5	Yes	Best Measurement in this range- stage and flows stable
Golder/CRC	9/16/2016	12:48	0.270	235.9	16/09/16	13:00	0.271	249.4	1.0	Yes	Best Measurement in this range- stage and flows stable
Golder/CRC	9/16/2016	14:15	N/A	428.1	16/09/16	14:30	0.332	337	---	No	Bad MMT, is not consistent with stage readings, no ESG.
Golder/CRC	9/16/2016	15:05	0.325	342.9	16/09/16	15:15	0.329	333.4	4.0	Yes	Best Measurement in this range- stage and flows stable
Golder/CRC	9/16/2016	15:45	N/A	92.6	16/09/16	16:00	0.173	132.6	---	Yes	Not used in rating. Used this measurement to shore up 101.7 - stage was fluctuating
Golder/CRC	29/11/16	10:57	0.170	92	29/11/16	12:15	0.175	108.9	5.0	No	Not used in rating. Stage fluctuating at time of mmt, outlier, and daylight savings shift for time.
Golder/CRC	28/04/17	10:52	0.140	73.0	28/04/17	11:00	0.143	74.46	3.0	No	Not used in rating. Flows unstable at time of measurement

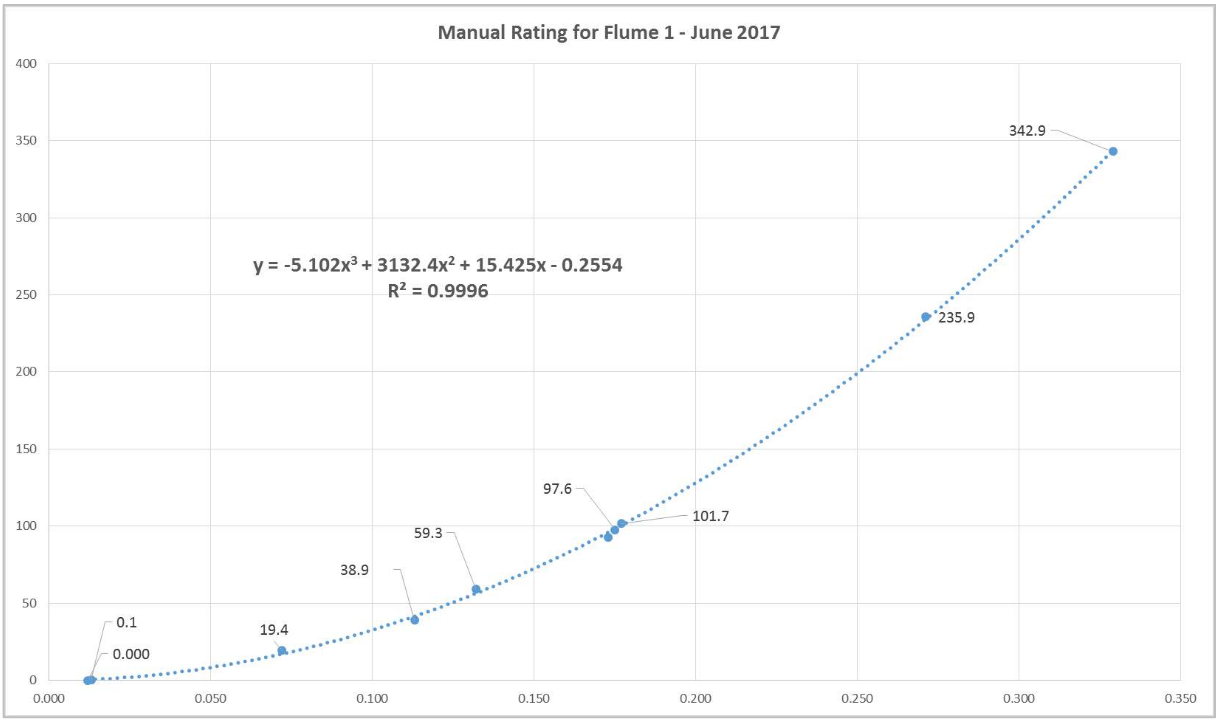

Figure E8: Flume 1 manual rating curve - Year 1 (recorder stage versus measured discharge).

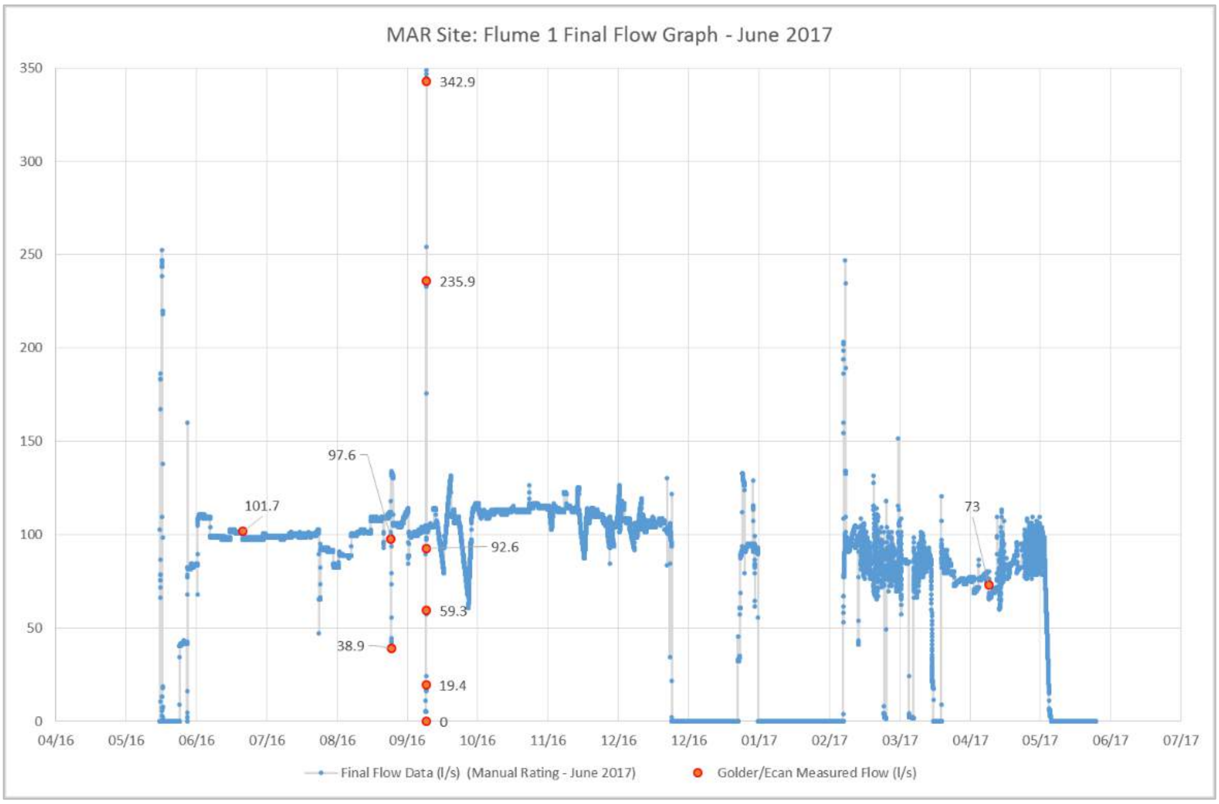

Figure E9: Flume 1 automated flow record versus manual rating measurements – Pilot Trial Year 1.

3.2 Flume 2 – Flow Measurements and Ratings

Flume 2 was measured 17 times during the pre-operational period and Year 1 of the Pilot Trial. Measurements were taken across the centre of the concrete weir, which provided a consistent and controlled collection process. The first six measurements were taken in May 2016 before the final ESG and real-time logger was established, and were used solely for the purpose of pre-operations infrastructure testing (16 May 2016 to 18 May 2016). Zero flow for Flume 2 was determined during these measurements as occurring at an ESG level of 1.0 m. The remaining 11 measurements were taken during Year 1 of the Pilot Trial. These Year 1 measurements included a flow ramping test on 16 September 2016 that was used to establish an appropriate rating range (Table E4).

It should be noted that Flume 2 was often manually gauged in conjunction with Flume 1, which caused some issues with data variability. It was observed that between 45 to 60 minutes of stabilisation time was required for flow changes at Flume 1 to express themselves and stabilise at Flume 2.

As with Flume 1, manual rating measurements were collected in accordance with CRC's standard sampling protocols as well as international best practices. ESG board readings were taken at the time of each measurement and used to determine any shifts related to logger variations or drift. All measurements were plotted and visually assessed against the entire dataset for inconsistencies and against the logger stage data at the time of measurement.

A rating for Flume 2 was established in June 2016. It was revised in November 2016, and then rechecked and finalised in June 2017. The flow data and manual rating solution equation[6] for Year 1 of operations is presented in Figure E10. A number of flow measurements were deemed 'outliers' based on a number of factors, including inconsistency with other measurements or that they were collected during a period of high flow variability in the race. The flow data for Flume 2 plotted against the rating measurements is shown in Figure E11 for the period 2 June 2016 to 9 June 2017, which includes the periods just prior to commencing the MAR Pilot Trial.

3.3 Main Basin Stage Levels and Overflows

Main basin levels were collected for the potential establishment of a rating equation for calculating overflows from the main infiltration basin to the adjacent ADC stockwater race. Through a combination of both an 'as built' engineering survey and a drone aerial-elevation flight of the site, key monitoring point datum (elevations) were determined (Figure E12). The basin floor was almost flat at 136.1 m above mean sea level (amsl) with the overflow spillway at 138.5 m amsl. On this basin, a 2.4 m water depth would be required in the basin before any outflows to the ADC stockwater race would occur. During the excavation and survey work, it was determined through a site inspection that a water depth of approximately 0.8 m should be used as the maximum long-term operational depth. This depth was below the pre-construction ground level, which could be clearly seen in the basin's walls. This operational depth also allowed for an additional 1.6 m water level rise in the basin to accommodate any unintentional high inflow events.

During Year 1 operations, the maximum water depth in the main infiltration basin was 0.77 m, recorded on 11 November 2016 (Figure E13). Prior to the peak-irrigation demand season shut down (red shaded period in Figure E13), the average operating water depth was 0.56 m. Following this shutdown, the site was operated at a lower overall average level of 0.26 m. This change was related to the improved understanding (throughout Year 1) of the effect of MAR water delivery on Valetta scheme performance (pers comm. Giles Pinfold, Valetta Raceman). Valetta now has set rules on when water can be supplied to the Pilot Trial site, based on the total water demand and the need to ensure pipeline water pressure is maintained for delivery to irrigators ('minimum 4 Bar'). The Valetta Raceman also noted that he found it easier after the peak-irrigation period to manually adjust the hydraulic gate settings to maintain Pilot Trial inflows and water levels in the main infiltration basin.

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[6] Final equation after shift to optimise fit of rating around average recharge rate was: flow (y) = $-77.06x^3 + 5520.8x^3 - 8713x + 3964.4$, where x = logger stage.

Table E4: Flume 2 flow ratings measurements.

Field Measurements					Scott Tech - logger							Notes
Who	**Date**	**Time**	**Average ESG**	**Flow (L/s)**	**Date**	**Time**	**Logger Stage**	**Shifted Stage**	**Average Flow (L/s)**	**Difference stage (mm)**	**Rating**	
CRC	5/07/16	12:33	1.160	70.3	5/07/16	12:45	1.157	N/A	103.4	-3.000	No	Outliner, not used in ratings - fluctuating flow
Golder	25/08/16	10:10	1.190	85.0	25/08/16	10:30	1.182	1.188	141.1	-8.000	No	Not used in final rating, ESG showing consistently reading low, corrected data set by shifting by average stage offset used to reset logger stage values in data set.
Golder	2/09/16	10:30	1.161	84.7	2/09/16	10:45	1.157	1.163	140.6	2.000	Yes	Used in final rating, ESG showing consistently reading low, corrected data set by shifting by average stage offset used to reset logger stage values in data set
Golder	2/09/16	13:12	1.160	82.0	2/09/16	13:30	1.15	N/A	106.9	---	No	outliner, not used in ratings - fluctuating flow
CRC	16/09/16	09:30	1.042	N/A	2/09/16	9:45	1.181	N/A	140.3	-0.139	No	Missing flow data.
CRC	16/09/16	11:18	N/A	12.0	16/09/16	11:15	1.049	1.056	23.51	---	Yes	Used for final rating, ESG showing consistently reading high, corrected data set by shifting by average stage offset used to reset logger stage values in data set
CRC	16/09/16	12:37	1.128	46.0	16/09/16	12:30	1.120	1.127	80.90	0.008	Yes	Used for final rating, ESG corrected (High)
CRC	16/09/16	13:29	1.258	199.0	16/09/16	13:45	1.249	1.256	221.80	0.009	Yes	Used for final rating, ESG corrected (High)
CRC	16/09/16	14:37	1.317	302.0	16/09/16	15:00	1.310	1.317	304.90	0.007	Yes	Used for final rating, ESG corrected (High)
CRC/Golder	29/11/16	11:26	1.165	89.0	29/11/16	10:45	1.159	1.166	86.00	0.006	Yes	Used for final rating, ESG corrected (High)
CRC/Golder	28/04/17	10:13	1.145	72.0	28/04/17	10:30	1.140	1.147	68.86	0.005	Yes	Used for final rating, ESG corrected (High)

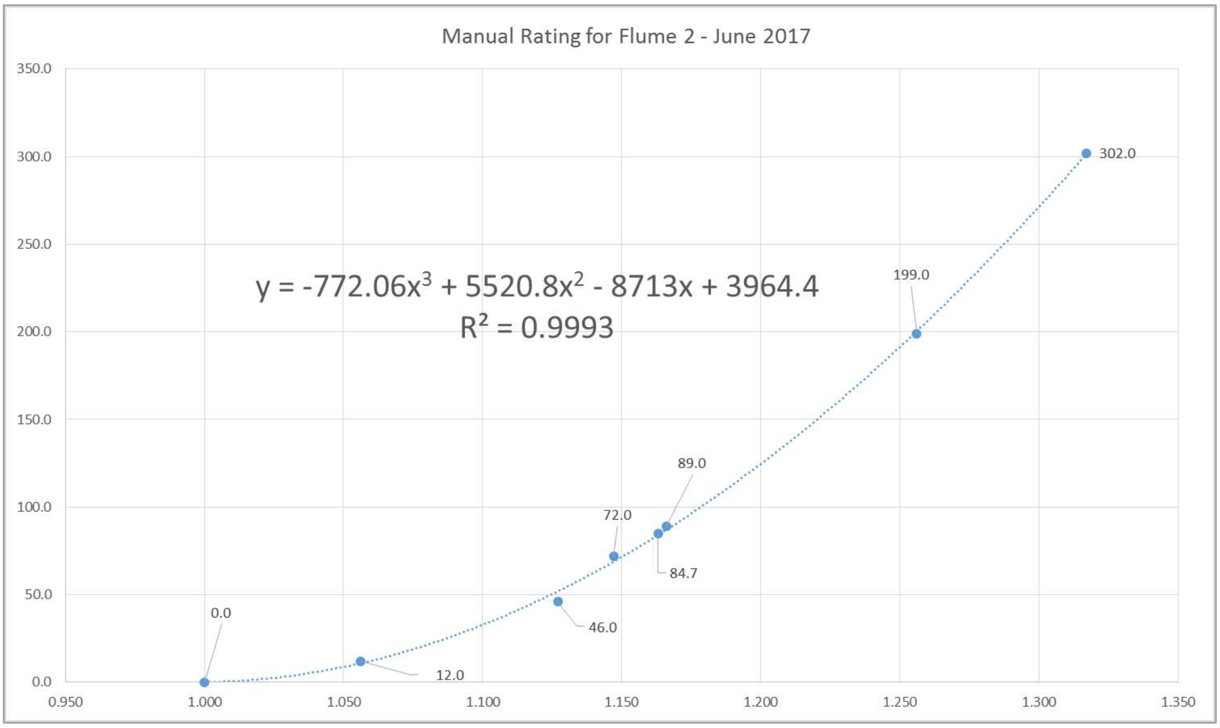


Figure E10: Flume 2 - Final Manual Rating Equation - Year 1 (recorder stage versus measured discharge).

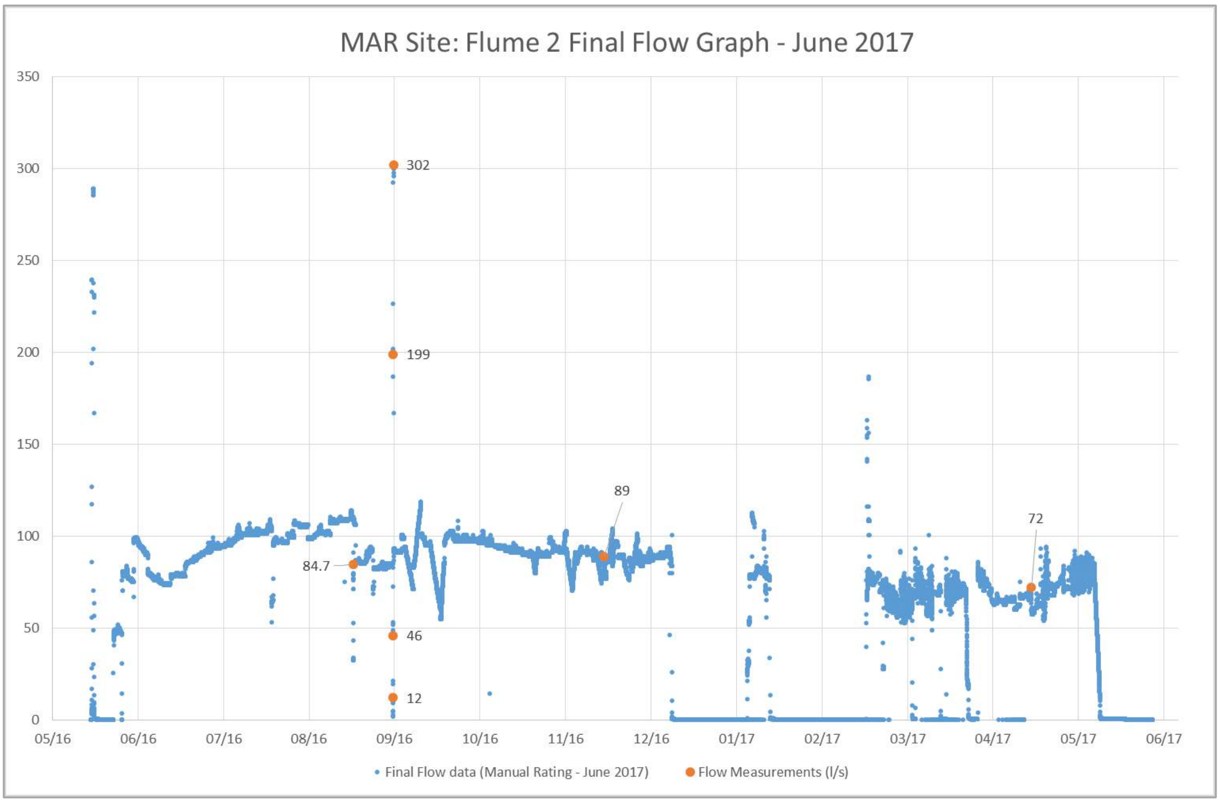
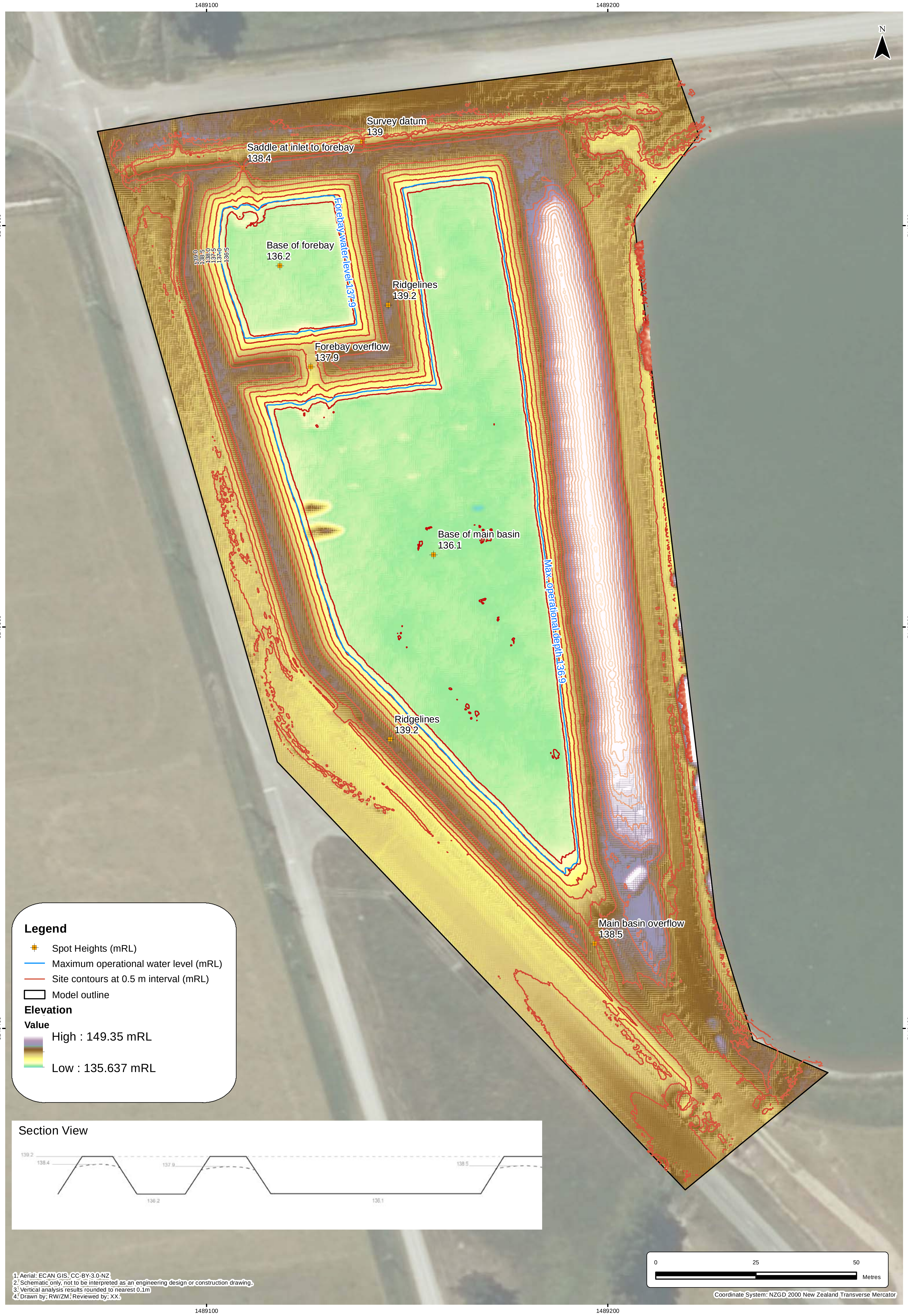


Figure E11: Flume 2 flow versus rating measurements – Year 1.



Golder Associates

TITLE MAR PILOT SITE ELEVATION MODEL

JULY 2017

PROJECT 1538632

E12

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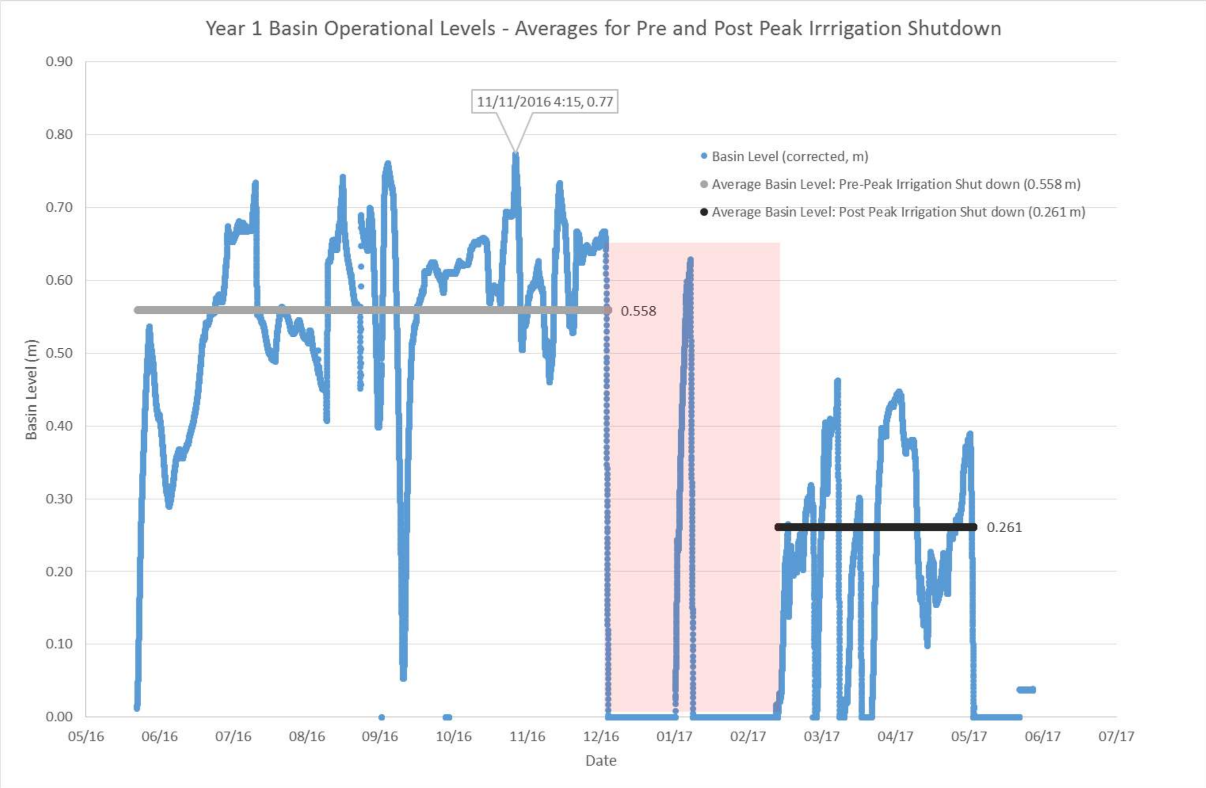


Figure E13: Hinds MAR Site: main basin average operational levels including averages for pre and post irrigation shutdown (red shaded) periods

3.4 Comparison of Flows and Basin Levels

Comparing flows from Flume 1 and Flume 2 with water levels recorded in the main infiltration basin provided a useful check of the ratings and data consistency. Figure E14 shows the data for Year 1 of operations (10 June 2016 to 9 June 2017) and immediately indicated an issue with the Flume 1 data from 5 July 2016 to 6 August 2016. In reviewing field notes, it appears that manual flow measurements were taken on those days. It is surmised that the stage recorder (at the base station) may have been accidently reset (to correct for ESG reading). Therefore, Flume 1 data (used to calculate total MAR volumes) is likely to underestimate the total amount of water entering the site by an estimated[7] 70,000 m^3.

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

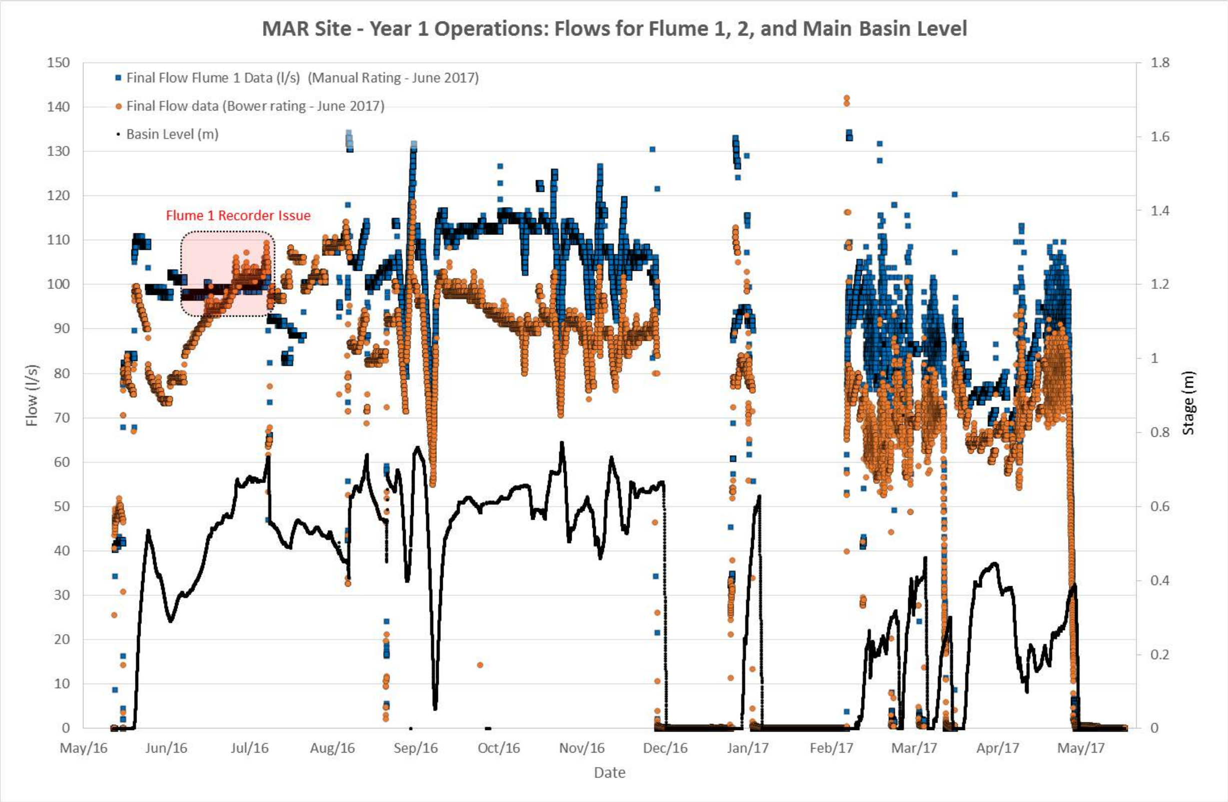


Figure E14: Year 1 operations: Flume 1 and Flume 2 flows with main basin levels.

3.5 Flow Delivery and MAR Site Flow and Level Monitoring Recommendations

Through Year 1 of operations, a considerable amount was learned about water delivery to the MAR Pilot Trial site as well as about the monitoring equipment being used to measure the basin flows and performance. The following is a list of recommendations:

1) Monthly water balance for MAR delivery versus MAR usage provided to RDR and Valetta race operators. This will help to minimise the amount of water sitting in Valetta storage in the event of a delivery issue.

2) Whilst the installation of v-notched or broad-crested weir plates on each of the flumes would be preferable to flow measurements, we do not recommend that they be installed. This is due to two factors. Firstly, Year 2 site upgrades hope to increase the average basin performance and therefore flows, and secondly that the future of the open race (owned by Mangin Farms) is to be determined during Year 2 of the project. If it is replaced by a piped delivery system this would make the flumes obsolete.

3) Subcontractors maintaining on-site real time recording equipment to keep a log book of visits including any changes to recorder levels or resets that were done in the field.

4) Periodic flow measurements to be maintained throughout the year in order to check June 2017 rating accuracies.

5) From Year 3 onward, look at connecting monitoring equipment to the local fibre optic cable network, as mobile tower connections were problematic for basin management and may have led to small gaps in data sets.

4.0 FLOW IN COASTAL SPRING-FED DRAINS

4.1 Background

As part of the overall MAR Command Area monitoring programme, flows in the coastal spring-fed drains were measured. Prior to the MAR Pilot Trial, CRC was measuring flows at three established monitoring sites (Table E5), with the data available online through the CRC internet site. Six additional flow monitoring sites were established prior to commencement of the Pilot Trial to measure the restoration of baseflows (near the upper end of the drains) and at ecological monitoring sites down-gradient toward the coast (Table E5).

The coastal drain monitoring sites collect temperature and stage level data at 15-minute intervals. In-field flow and stage measurements, where available, have been used to derive monitoring site rating curves and drain flow datasets. The surface water stage and flow data for the coastal drains monitoring sites was processed and provided to the MAR technical team by CRC hydrology staff.

Table E5: MAR Command Area - flow monitoring sites.

Coastal drain	Site	Who	Period of record
Parakanoi	McLennons Road (CRC# 169007)	Specific to MAR Programme	03/09/2015 - present
	New Park Road (CRC# 169012)	Specific to MAR Programme	23/11/2015 - present
	Lower Beach Road (CRC# 69001)	CRC	22/04/2004 - present
Flemington	Boundary Road (CRC# 1690067)	Specific to MAR Programme	06/05/2016 - present
	Montgomery's Road (CRC# 169016)	Specific to MAR Programme	21/12/2015 - present
	Wheatstone Road (CRC# 169018)	Specific to MAR Programme	29/01/2016 - present
	Lower Beach Road (CRC# 69003)	CRC	10/03/2011 - present
Wheatstone	Boundary Road (CRC# 1690063)	Specific to MAR Programme	09/03/2015 - present
Blees	Lower Beach Road (CRC# 69002)	CRC	08/04/2011 - present

4.2 Results

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. The MAR Pilot Trial site operated at a peak recharge rate of 110 L/s, and this was insufficient to offset these large scale processes. Consequently, flow throughout the Hinds Coastal drains, and particularly in the MAR command area were essentially dry year round (Figure E15).

The highest flows recorded in Parakanoi Drain (Figure E16) and Flemington Drain (Figure E17) occurred during April 2017. The Blees Drain and Wheatstone Drain recorders remaining dry throughout Year 1 (Figure E18). During some peak rainfall events (e.g., Cyclone Cook), flows were observed in the drains however these flows were often patchy, with observed flows in some upper portions of the drains (groundwater inflow) being immeasurable at the flow monitoring sites (Golder field team observations and pers comm. Hinds Drains residents).

Figure E15: Parakanoi Drain MAR programme weir – comparison winter 2014 (flowing) vs winter 2016 (dry).

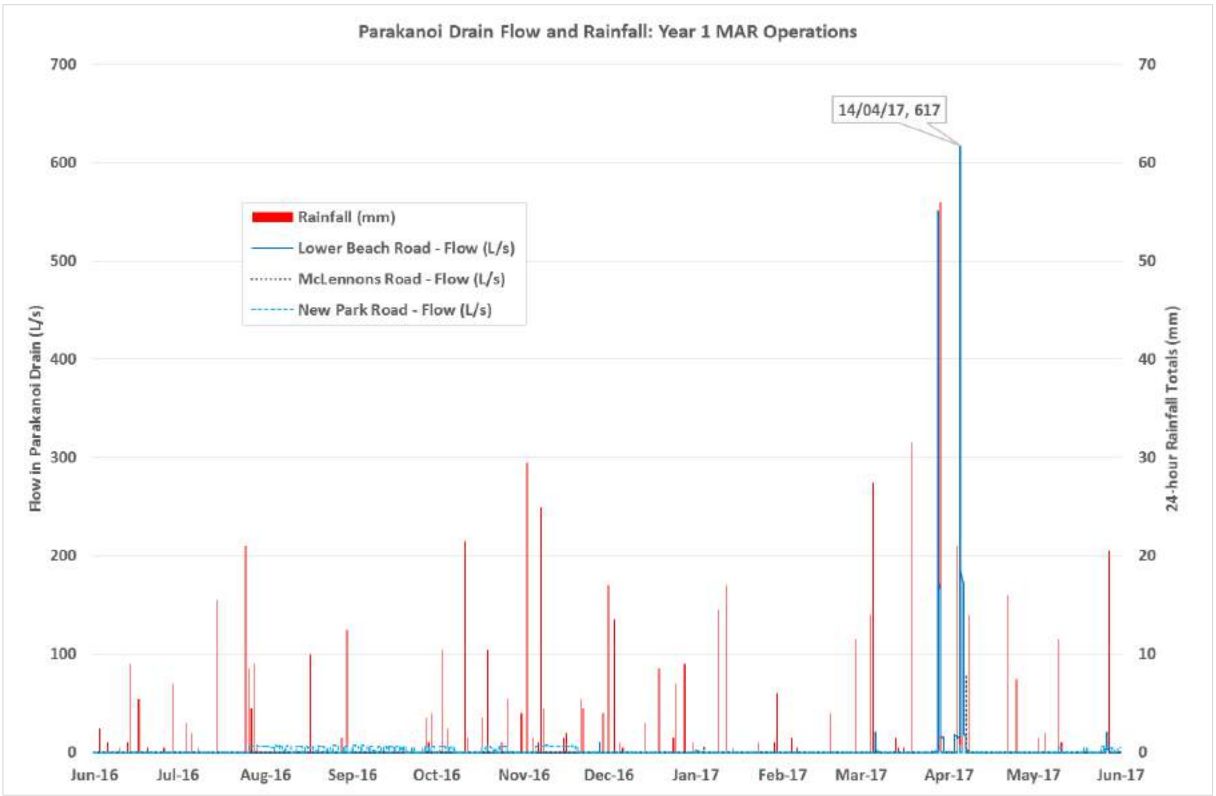


Figure E16: Pilot Trial Year 1: Parakanoi Drain gauge sites - flow (L/s) and rainfall (mm/day).

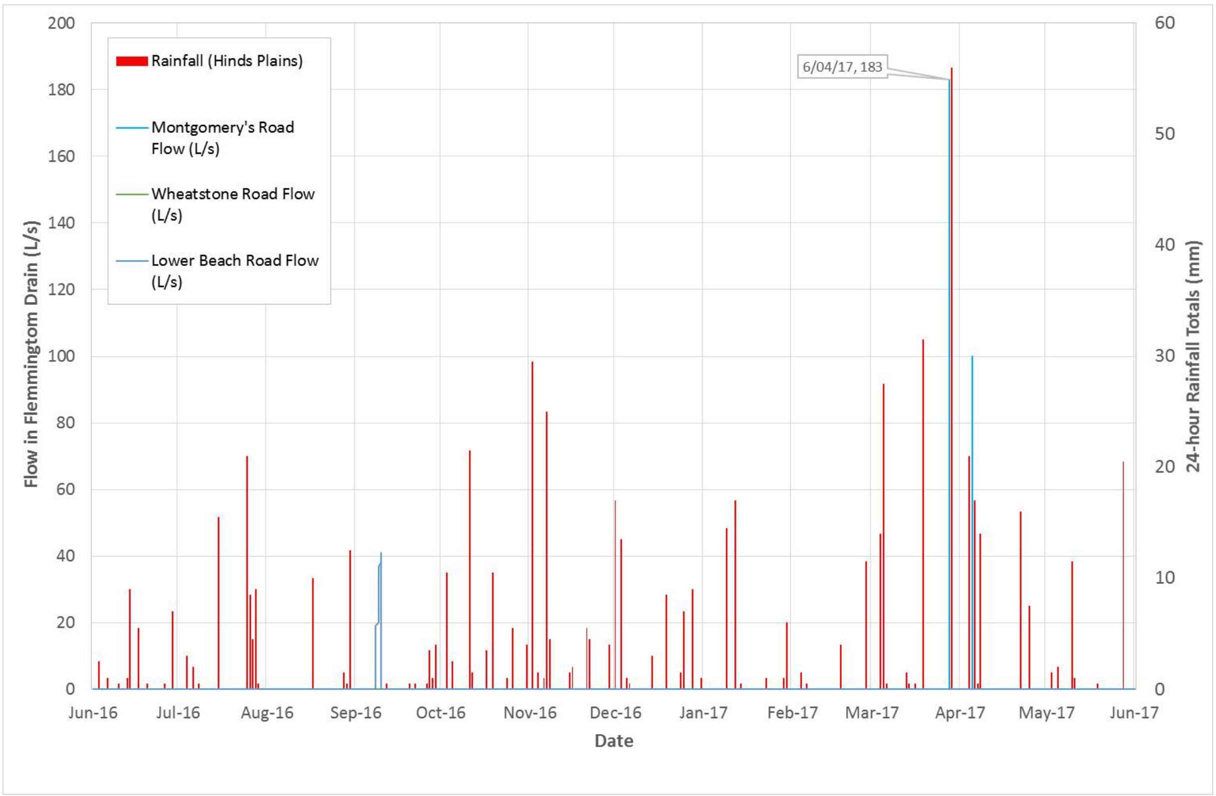


Figure E17: Pilot Trial Year 1: Flemington Drain gauge sites: flow (L/s) and rainfall (mm/day).

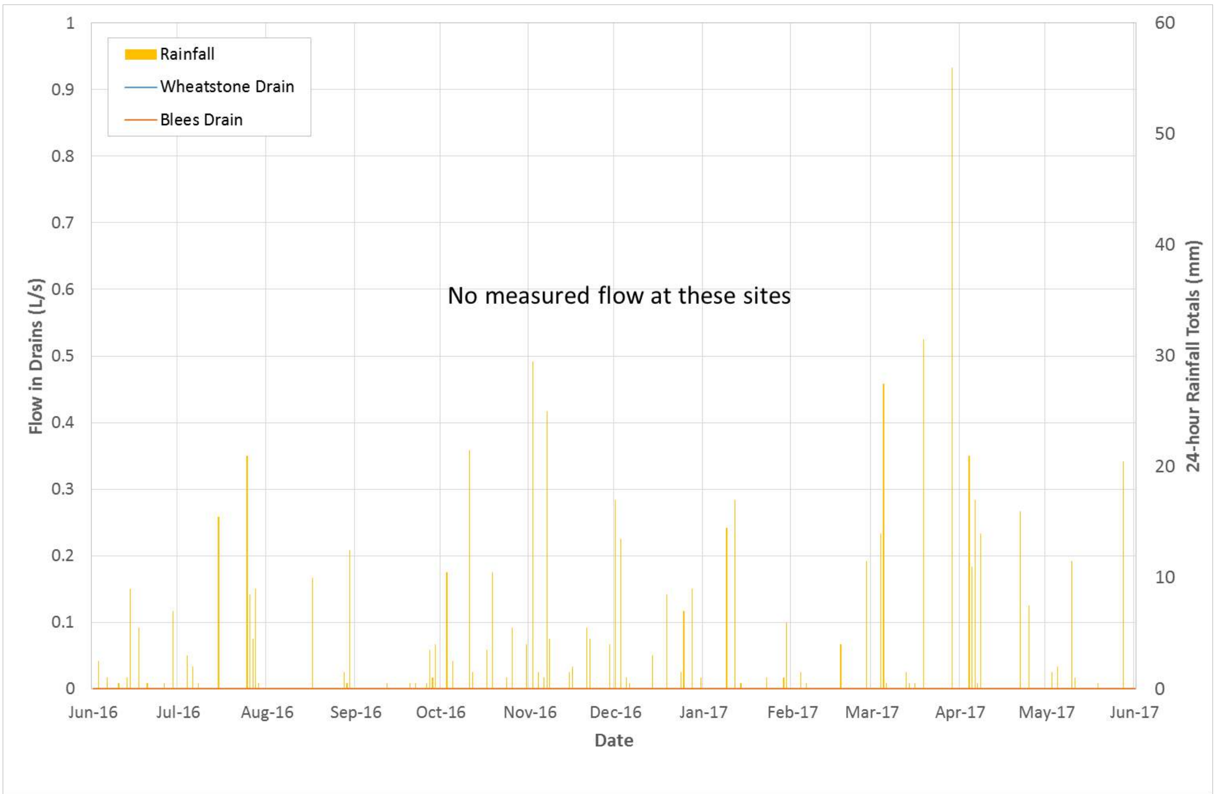


Figure E18: Pilot Trial Year 1: Wheatstone and Blees Drains gauge sites: flow (L/s) and rainfall (mm/day).

APPENDIX F

Source Water Quality

1.0 SOURCE WATER QUALITY MONITORING PROGRAM

1.1 Locations

Source 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 overall catchment area is 1,773 km^2 and the river has a mean flow of approximately 95 m^3/s at RDRML's Klondyke Diversion, where source water for the MAR project is diverted. The Rangitata River, as is true for all of Canterbury's alpine sourced rivers, is considered to have water of exceptional quality as it enters the Canterbury plains.

Water quality information has been collected as part of RDRML's monitoring programme. Of specific relevance to the MAR Pilot Trial, samples for water quality analysis have been collected by RDRML at the Klondyke Diversion and at Valetta Pond #3 since 2012 (Figures 3 and 4 in main report).

The Valetta Irrigation Scheme operates Valetta Pond #3, which is the final pond in the Valetta irrigation network and the immediate source of water for the Pilot Trial. The Valetta Diversion is an outlet from the Valetta Pond #3, which is controlled by a hydraulically operated valve. Water is delivered to the MAR Pilot Trial site from the Valetta Diversion via Flume 1 and an existing 900 m long delivery race (the delivery race) that discharges to the site forebasin (Figure 4 in main report). During the Pilot Trial, source water has been regularly sampled by Golder at Flume 1 (Figure 4 in main report), approximately 20 m downstream from the Valetta Diversion.

Valetta Pond #3 was emptied and cleaned prior to the start of the Pilot Trial to remove food sources for waterfowl to feed on (e.g., vegetation for ducks to dabble on). This work was primarily targeted at helping to reduce the input of bird faecal matter that could have resulted in elevated *E. coli* levels in the Pilot Trial source water. It should be noted however, that faecal levels are naturally found in water bodies throughout Canterbury. The delivery race was also scraped to remove vegetation and material that had accumulated since decommissioning of the race.

Once water reaches the Pilot Trial site, it flows through Flume 2 into the forebay, before discharging into the main infiltration basin (Figure 4 in main report). Water samples have been regularly collected for laboratory analysis from the north-eastern corner of the main infiltration basin, near the monitoring staff gauge, to assess the quality of the Pilot Trial source water before it enters the groundwater system.

Prior to construction of the Pilot Trial infiltration basin, an existing Ashburton District Council (ADC) stockwater race (known as the ADC Stockwater Race) bisected the site. This stockwater race was realigned during construction of the infiltration basin. It is now aligned along the western edge of the basin however, in keeping with the structure of the rest of this race, was not lined during the realignment process. This race is known to lose water to the local groundwater system. These seepage losses have the potential to influence the Pilot Trial water quality results, so regular sampling of the ADC Stockwater Race has been conducted adjacent to GWD-01 at the north-west corner of the Pilot Trial site.

1.2 MAR Programme Monitoring Regime

Schedule

RDRML has collected monthly water quality data from 2012 until present at both the Klondyke Diversion and Valetta Pond #3. Under the MAR Pilot Trial, an initial water quality sample was collected from Valetta Pond #3 in May 2015 to assess baseline quality of the source water. Monthly samples were then collected from each of the source water sampling locations as part of the Pilot Trials monitoring program (Appendix C). Sampling began the month prior to commissioning of the site in May 2016 (Table F1).

Table F1: Summary of MAR Programme water quality sampling parameters.

Frequency	Sample Location										
Period	***E. coli* (MPN/100 mL)**	**Total coliforms (MPN/100 mL)**	**Turbidity (NTU)**	**pH**	**Electrical Conductivity (mS/m)**	**TSS g/m³**	**Nitrogen (g/m³) (1)**	**Dissolved reactive phosphorus / total phosphorus (g/m³)**	**Hardness (g/m³ as HCO_3)**	**Anion / cation profile (2) (meq/L)**	**Dissolved metals (3) (g/m³)**
2012 to 2017	RDR[4] Klondyke and Valetta Scheme Diversions	Parameters not sampled			Parameters now sampled		Only nutrients (e.g. nitrogen and phosphorus)				
Pre-trial (May 2015)	Pilot Trial source water (Valetta Pond #3)	Parameter not sampled			Pilot Trial source water (Valetta Pond #3)		Parameter not sampled				
Pre-trial (May 2016)	All source water, selected surface water and selected groundwater sites		Selected surface water and selected groundwater sites								
Monthly	First six months of trial: All source water, surface water and groundwater sites Final six months of trial: selected source water, surface water and groundwater sites		All source water, surface water and groundwater sites					First sample round after a new site was added during Pilot Trial			
End of Trial	Selected source water, surface water and groundwater sites		All source water, surface water and groundwater sites					Parameter not sampled			

Notes:
(1) Three forms of nitrogen analysed (total nitrogen, nitrite-N, nitrate-N).
(2) Ca, Mg, Na, K, hardness, alkalinity, bicarbonate, carbonate, SO_4 and Cl.
(3) As per Hills Laboratory NZDW suite for metals.
(4) RDR water quality data processed by Hill Labs, Christchurch.

Parameters

Source water quality measurements have primarily been for nitrate-N and microbiological contaminants (coliforms and *E. coli*). At the MAR Pilot Trial site, the range of parameters analysed for source water are the same as those for other sites monitored for water quality under the Pilot Trial (Appendix C). These parameters are summarised in Table F1.

The key water quality parameter, both in evaluating the outcomes of the Pilot Trial and for use as a tracer in identifying the distribution of infiltrated water, is nitrate-N. Concentrations of nitrate-N in the Pilot Trial source water have been consistently very low and contrast strongly with the elevated concentrations measured in baseline groundwater surveys within the Hinds catchment (Appendix H).

Monitoring of the concentration of Total Suspended Solids (TSS) in the Pilot Trial source water at Flume 1 is important for operational assessment purposes. High TSS loads potentially lead to clogging of the infiltration basin floor, decreasing the infiltration rate. An assessment of TSS loads and basin clogging is documented separately (Appendix I).

Monitoring of microbiological contaminants (*E. coli* and total coliforms) is undertaken to provide stakeholders with confidence that infiltration of source water with detectable and potentially elevated colony counts will not result in corresponding contamination of the underlying aquifer water.

2.0 SOURCE WATER QUALITY

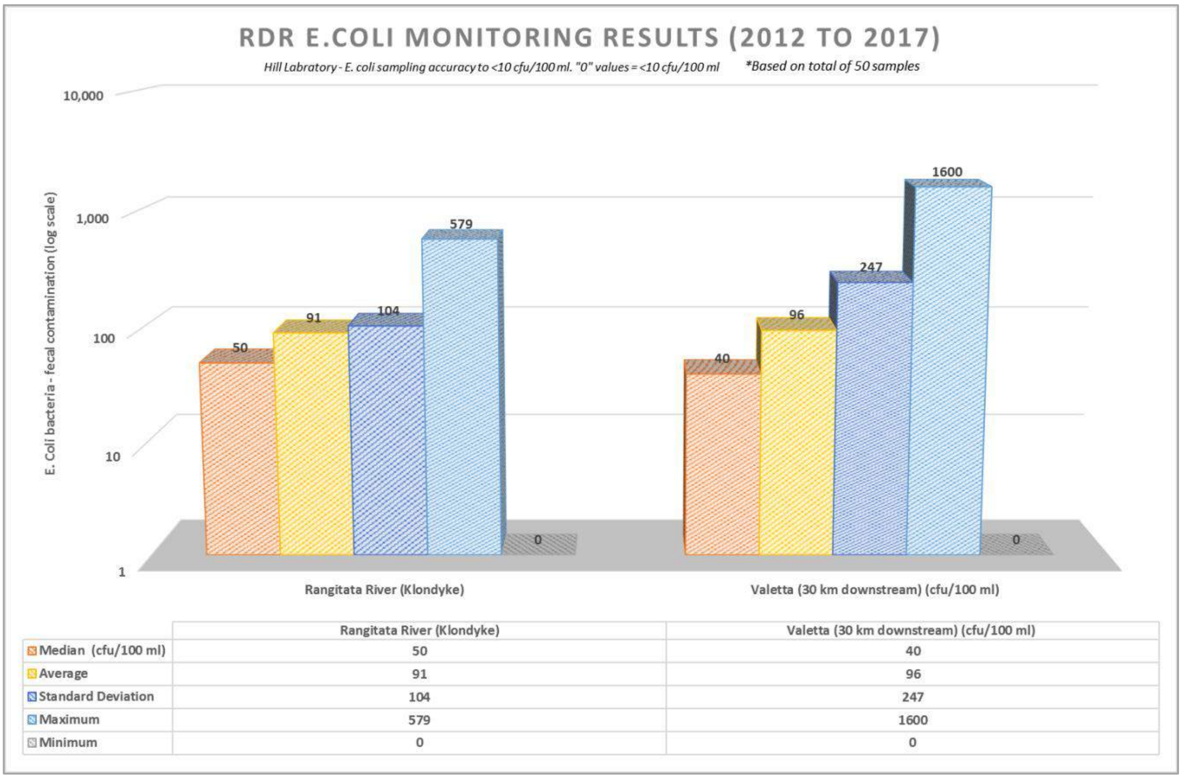
2.1 Rangitata River and Valetta Pond #3

A comparison of Rangitata River water and Valetta Pond #3 water for *E. coli* and nitrate-N is provided in Table F2. Whilst nitrate-N concentrations appear to be consistent between sites, *E. coli* counts are substantially higher at Valetta Pond #3 than at the Rangitata River. Valetta Pond #3 is the third (behind Valetta Ponds #1 and #2) storage pond in sequence in the Valetta irrigation delivery system. It is likely that water fowl droppings are the likely source of the elevated *E. coli* results.

Table F2: Rangitata River and Valetta Pond #3 source water quality statistics.

Statistics	E.Coli (MPN)		Nitrate-N (g/m^3)	
	Rangitata River (Klondyke)	Valetta Pond #3 (MAR Site)	Rangitata River (Klondyke)	Valetta Pond #3 (MAR Site)
Median	50	146	0.03	0.05
Average	91	199	0.04	0.11
Standard deviation	104	56	0.02	0.01
Maximum	579	727	0.10	0.37
Minimum	<10	0	<0.01	<0.01
Number of samples	50	12	50	9

Source water quality data from samples collected from the Rangitata River at the Klondyke Diversion show natural background enteric bacteria concentrations of *E. coli* averaged 91 MPN/100 mL between 2012 and 2017. The maximum recorded value during this period was 579 MPN/100 ml on 2 February 2017 (Figure F1).



	Rangitata River (Klondyke)	Valetta (30 km downstream) (cfu/100 ml)
Median (cfu/100 ml)	50	40
Average	91	96
Standard Deviation	104	247
Maximum	579	1600
Minimum	0	0

Figure F1: RDRML water quality sampling results from Klondyke Diversion and Valetta Pond #3 for E. coli (2012 – 2017).

Results from samples collected at Valetta Pond #3 (30 km down the supply race on the RDR) have been consistent with those from the Rangitata River (Figure F1). The maximum concentration detected was 1,600 MPN/100 mL from a sample collected at Valetta Pond #3 on 2 December 2012.

Analysis of the *E. coli* data from both the Rangitata River and Valetta Pond #3 did not identify any consistent seasonal relationships between summer (peak irrigation season) and autumn, winter and spring (non-peak irrigation season).

A statistical summary of the nitrate-N data from water samples collected at the Rangitata River and Valetta Pond #3 is presented in Figure F2. Measured nitrate-N concentrations were consistently low for both sampling locations, with the average concentration being less than 0.05 g/m^3 for both sites. The maximum concentrations detected were approximately 0.1 g/m^3 nitrate-N at both sites.

2.2 Valetta Pond #3 (Valetta Diversion)

Valetta Pond #3 is the immediate source of water for the Pilot Trial. The quality of the water in Valetta Pond #3 was monitored during the Pilot Trial by sampling water between the Valetta Diversion (discharge from Valetta Pond #3) and Flume 1, which is located immediately downstream from the discharge from Valetta Pond #3. Analysis of results from water samples obtained at Flume 1 are presented in Table F3.

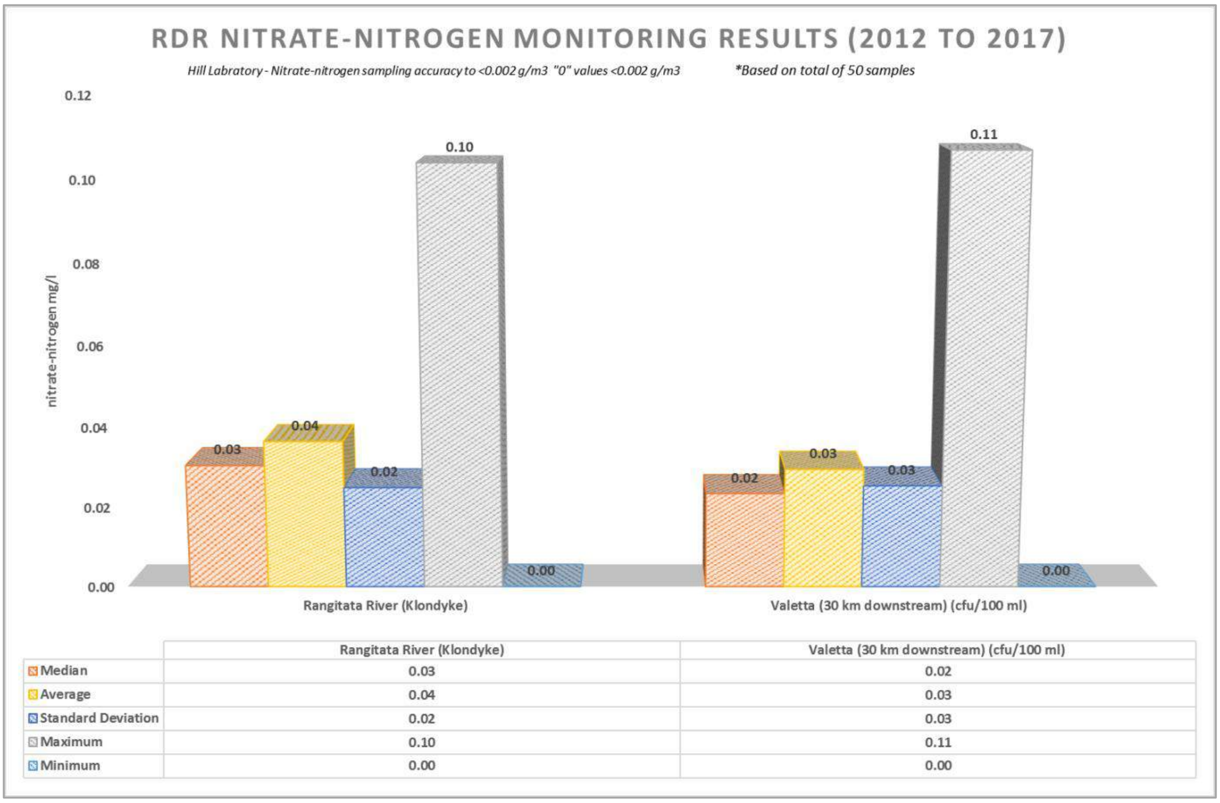


Figure F2: RDRML water quality sampling results from Klondyke Diversion and Valetta Pond #3 for Nitrate-N (2012 – 2017).

General trends in source water quality, as measured at Flume 1, include:

- A seasonal trend in source water temperature, with temperatures increasing through spring and early summer and subsequently declining in autumn (Figure F3).
- A seasonal trend in *E. coli* counts (Figure F3), with the counts being lowest in the period from June to October.
- Low TSS concentrations in winter and elevated concentrations in December and January. It is not clear whether the elevated values detected are seasonal in nature or whether they are related to Valetta Scheme operational activities during these months (Figure F4).
- Very low nitrate-N concentrations.

3.0 MAR INFILTRATION BASIN WATER QUALITY

The MAR infiltration basin water quality results are summarised in Table F4. General trends in infiltration basin water quality include:

- During the spring both *E. coli* and total coliform counts increased substantially from those recorded during the winter. The scale of the increase is similar to that recorded in the source water, although the timing of the increase with respect to the month differs slightly (Figure F5).
- Concentrations of TSS follow similar trends in the source water and the infiltration basin (Figure F6), with the highest concentrations recorded in January.
- The nitrate-N concentrations remain very low but they are generally slightly higher than in the source water (Figure F7).

Table F3: Valetta Pond #3 – water quality analysis results.

Date	Parameters				
	E. coli (MPN/100 mL)	Total coliforms (MPN/100 mL)	Electrical conductivity (mS/m)	Total suspended solids (g/m^3)	Nitrate-N (g/m^3)
05/05/2015	272	Not tested	6.7	1.5	Not tested
12/05/2016	206	1,414	Not tested		0.009
20/06/2016	31	75	Not tested		
26/07/2016	0	150	Not tested		
22/08/2016	2	15	5.4	<1.5	0.036
26/09/2016	26	435	5.3	3.0	0.017
26/10/2016	4	727	5.2	9.0	0.002
21/11/2016	249	1,989	5.0	5.0	0.005
19/12/2016	76	1,414	5.0	190	<0.001
24/01/2017	122	1,300	4.7	59	0.012
20/02/2017	Pilot Trial shut down during peak irrigation period – no water to sample				
27/03/2017	727	1,300	5.2	4.0	0.002
26/04/2017	35	248	5.3	6.0	0.018
22/05/2017	Pilot Trial shut down during maintenance of Valetta system – no water to sample				

Indicates parameter was below Minimum Detection Limit (value given = MDL/2).
Indicates no particles were detected.

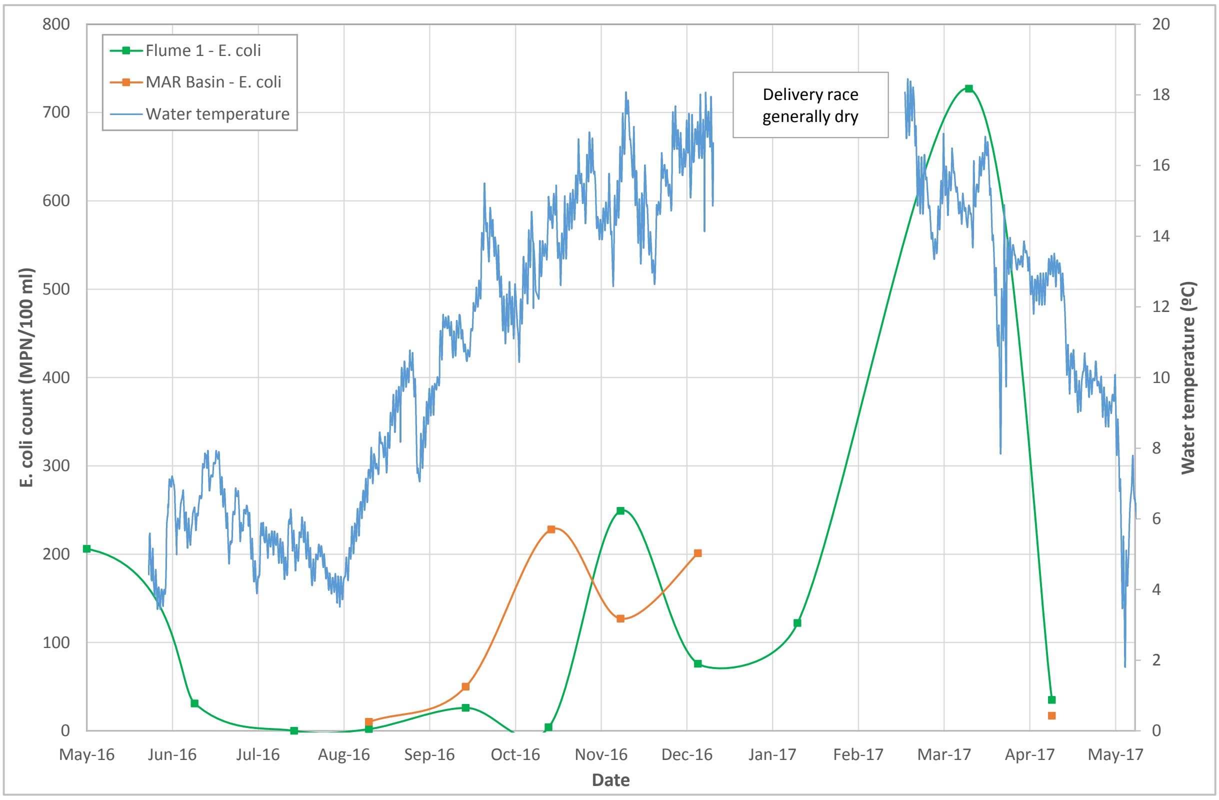


Figure F3: Water temperature and E. coli counts within Pilot Trial source water.

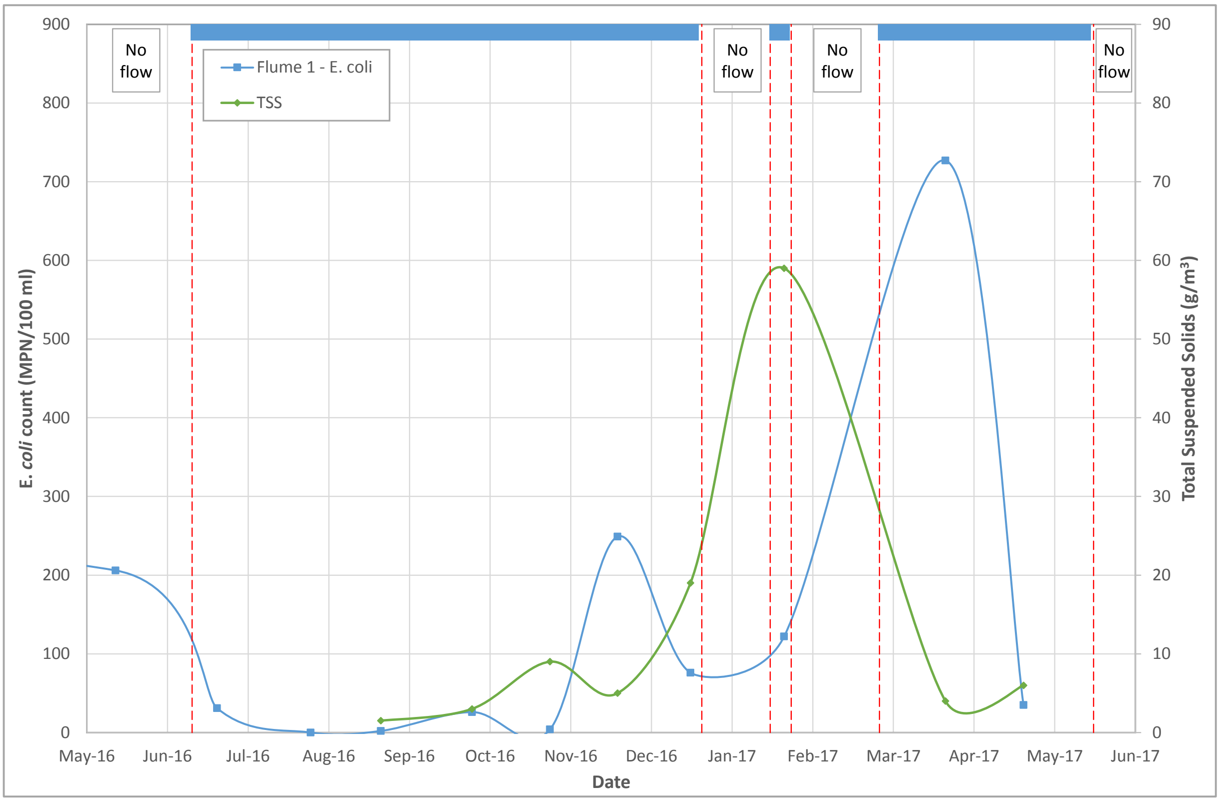


Figure F4: TSS concentration and E. coli counts within Pilot Trial source water.

Table F4: Infiltration basin water quality results.

Date	Parameters				
	E. coli (MPN/100 mL)	Total coliforms (MPN/100 mL)	Electrical conductivity (mS/m)	Total suspended solids (g/m^3)	Nitrate-N (g/m^3)
12/05/2016	Parameter not tested				
20/06/2016	Parameter not tested				
26/07/2016	Parameter not tested				
22/08/2016	10	23	5.3	1.5	0.05
26/09/2016	50	435	5.2	1.5	0.01
26/10/2016	228	2,419	5.7	6.0	0.037
21/11/2016	127	866	5.1	1.5	0.038
19/12/2016	201	2,419	4.9	11.0	0.061
24/01/2017	Parameter not tested		4.8	36.0	0.009
20/02/2017	Pilot Trial shut down during peak irrigation period – no water to sample				
27/03/2017	Parameter not tested		5.0	1.5	0.086
26/04/2017	Parameter not tested		5.3	1.5	0.065
22/05/2017	Pilot Trial shut down during maintenance of Valetta system – no water to sample				

(green) indicates parameter was below Minimum Detection Limit (value given = MDL/2).
(orange) indicates particle numbers were above Upper Detection Limit (value given = UDL.

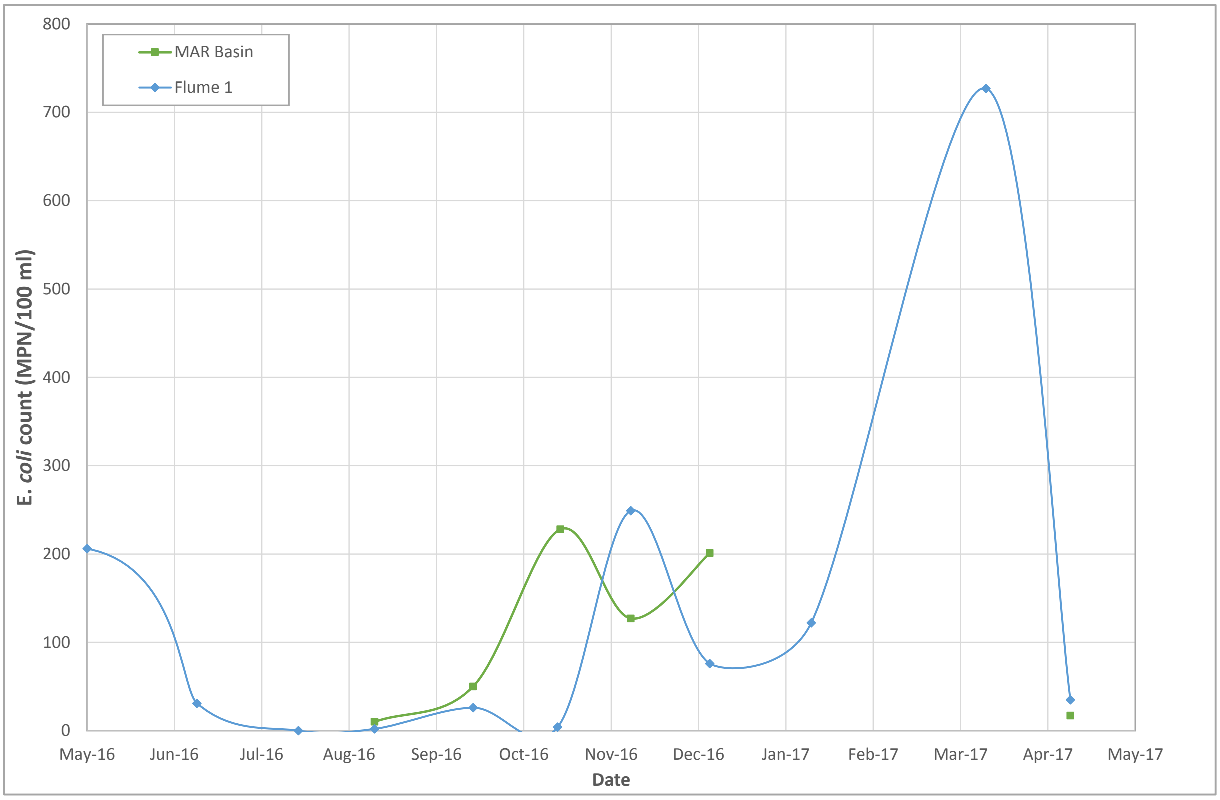


Figure F5: Counts of E. coli in the Pilot Trial source water and MAR infiltration basin water.

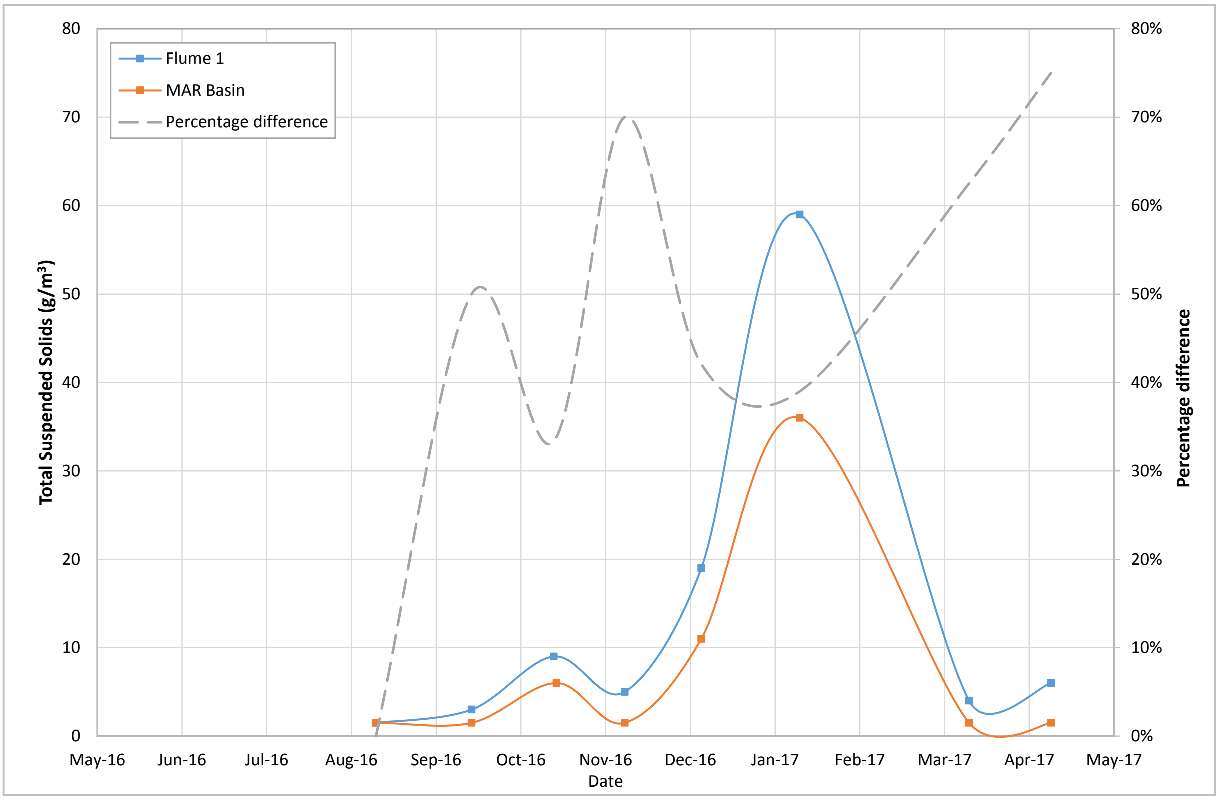


Figure F6: Concentration of TSS in the Pilot Trial source water and MAR infiltration basin water.

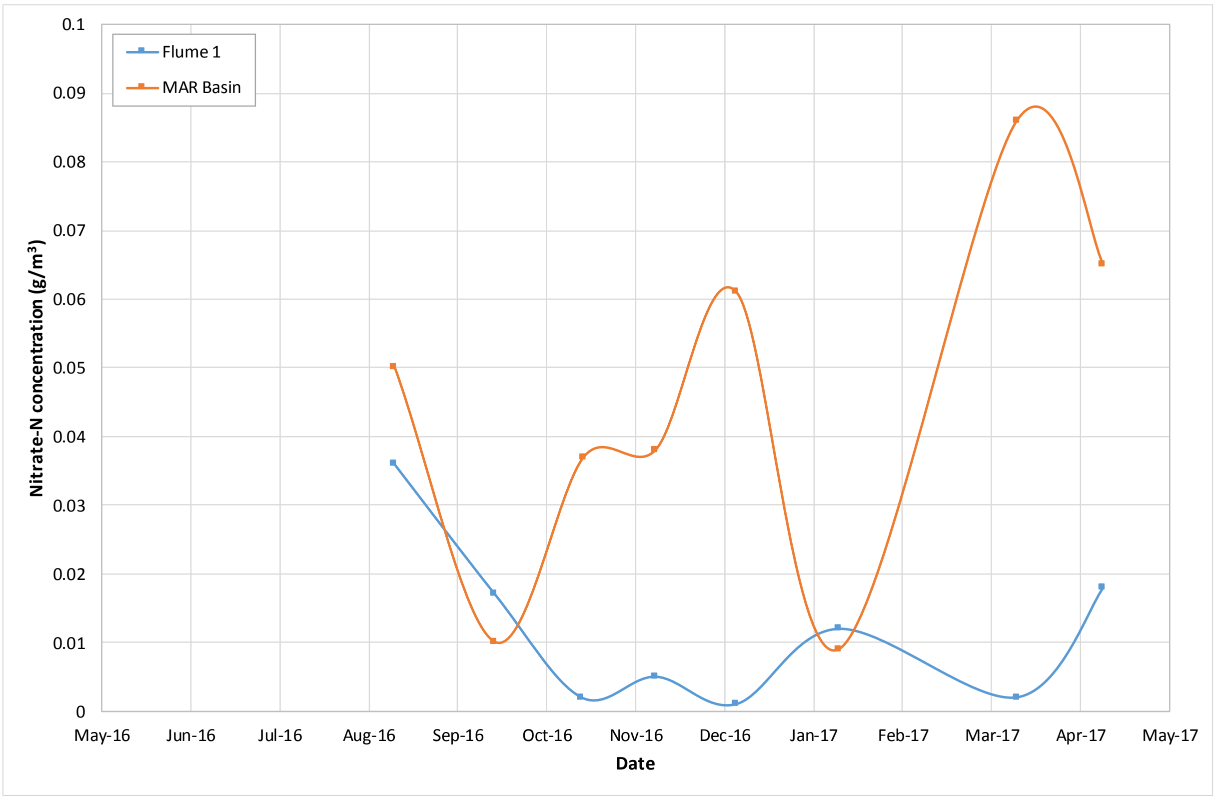


Figure F7: Concentration of nitrate-N in the Pilot Trial source water and MAR infiltration basin water.

4.0 ADC STOCKWATER RACE WATER QUALITY

The ADC Stockwater Race water quality results are summarised in Table F5. General trends in the ADC Stockwater Race include:

- Relatively low *E. coli* and total coliform counts during the winter months compared to the spring and autumn periods.
- The nitrate-N concentrations appeared to be correlated with monthly rainfall (Figure F8).

5.0 DISCUSSION

5.1 TSS

The TSS data presented in Figure F6 appears to show a relatively consistent decrease in concentration between the source water and the infiltration basin water. This consistency implies that the difference is a consequence of sediment settling in the forebay and in the infiltration basin itself. Growth of floating algae within the basin may however be influencing this relationship. The reduction in concentration shown in Figure F6 should therefore not be simply accepted as a direct measure of sediment removal efficiency of the forebay or of the MAR site as a whole.

Table F5: ADC race water quality results.

Date	Parameters				
	E. coli (MPN/100 mL)	Total coliforms (MPN/100 mL)	Electrical conductivity (mS/m)	Total suspended solids (g/m^3)	Nitrate-N (g/m^3)
12/05/2016	154	2,419	Parameter not tested		
20/06/2016	55	727	Parameter not tested		
26/07/2016	30	980	Parameter not tested		
22/08/2016	56	435	7.8	7.0	1.27
26/09/2016	613	2,419	8.1	9.0	0.52
26/10/2016	921	2,419	7.0	22.0	0.48
21/11/2016	100	2,419	11.3	6.0	4.10
19/12/2016	345	2,419	8.8	18.0	1.51
24/01/2017	Parameter not tested		6.7	58.0	0.47
20/02/2017	Parameter not tested		7.1	10.0	0.003
27/03/2017	Parameter not tested		8.3	16.0	1.42
26/04/2017	Parameter not tested		12.2	3.0	4.40
22/05/2017	Parameter not tested		8.1	1.5	0.81

(orange) indicates particle numbers were above Upper Detection Limit for analysis procedure (value given = UDL)
(green) indicates parameter was below Minimum Detection Limit (value given = MDL/2)

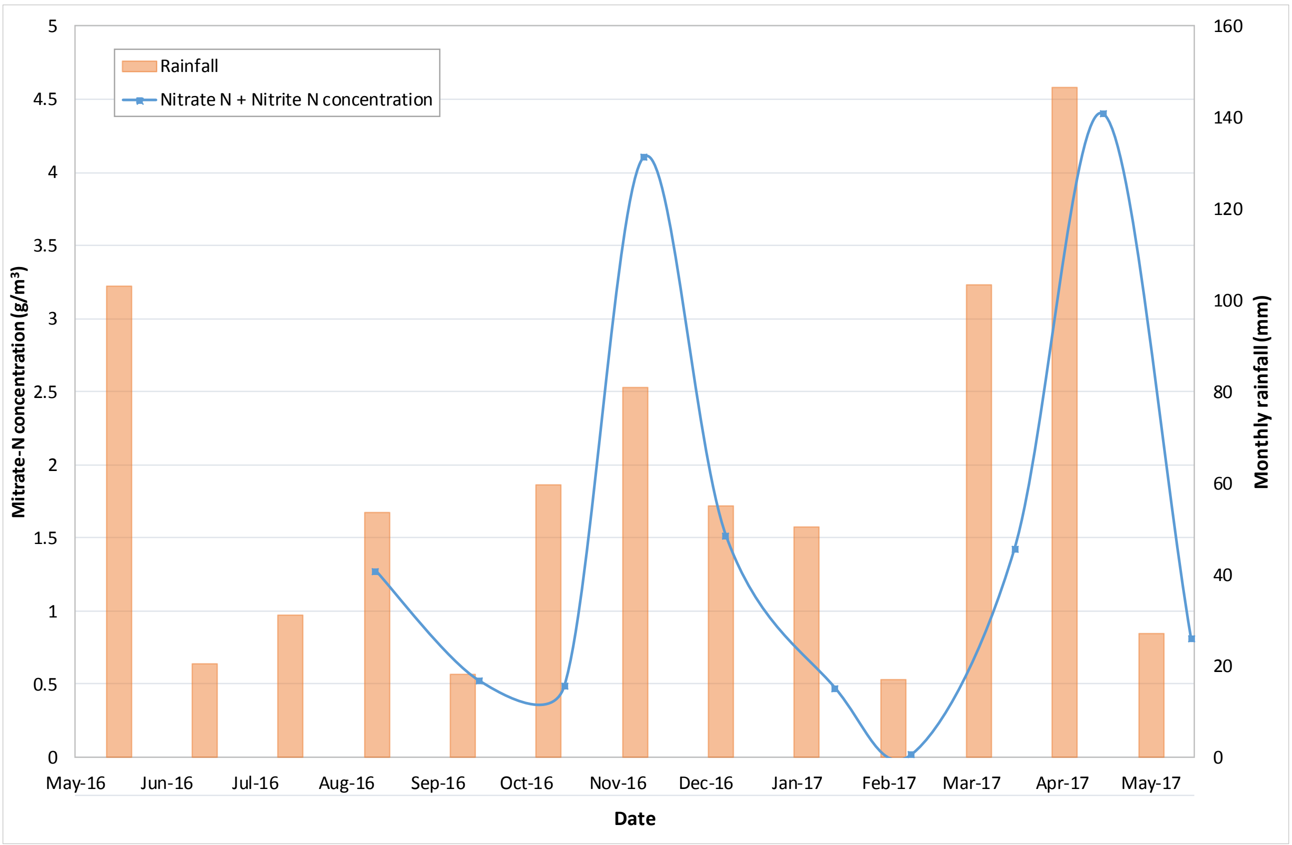


Figure F8: ADC Stockwater Race nitrate-N concentrations and monthly rainfall.

5.2 Nitrate-N

Concentrations of nitrate-N are generally higher in MAR infiltration basin water than the source water (Figure F7). The groundwater table in the area is substantially below the base of the delivery race, and hydraulic gradients from the infiltration basin are outward, indicating groundwater is unlikely to be the source of the additional nitrate-N. Several further potential sources or mechanisms for the observed increase:

1) Run-off during wet weather bringing nitrate enriched water into the delivery race.

2) Faecal matter from birds settling on the infiltration basin and forebay.

3) Accumulation of nitrogen in algae growing within the basin, with occasional releases due to algal die-back.

As this was not an area of focus for the Pilot Trial studies, there is insufficient information available to confirm the source and mechanism for the observed increase in nitrate-N between the source water monitoring point and the infiltration basin.

5.3 *E. coli*

The *E. coli* in the source water and infiltration basin water are likely to primarily be from water fowl either in the Valetta Irrigation Ponds (#1, #2, and #3) and potentially the infiltration basin. It is however, not clear whether the observed trends are linked directly to variations in the number of birds using the ponds or to factors influencing *E. coli* mortality in the Valetta ponds.

Factors influencing *E. coli* mortality include water temperature and sunlight intensity, which are linked.

- Die off rates for *E. coli* in fresh water generally decrease with decreasing temperature.
- Increasing turbidity due to increasing TSS could result in reduced penetration of sunlight into the water column and reduced *E. coli* mortality.

The interrelationships associated with the various factors influencing *E. coli* input to the source and infiltration basin water and mortality rates are complicated. Identification and assessment of these factors with respect to the observed *E. coli* trends in the infiltration basin water is outside the scope of the Pilot Trial.

The correlations between total coliform counts and *E. coli* counts appear to be similar for the source water and the infiltration basin water (Figure F9). The total coliform counts for most of the ADC stockwater race water samples exceeded the laboratory reporting limits, so a relationship with *E. coli* could not be derived (Figure F10).

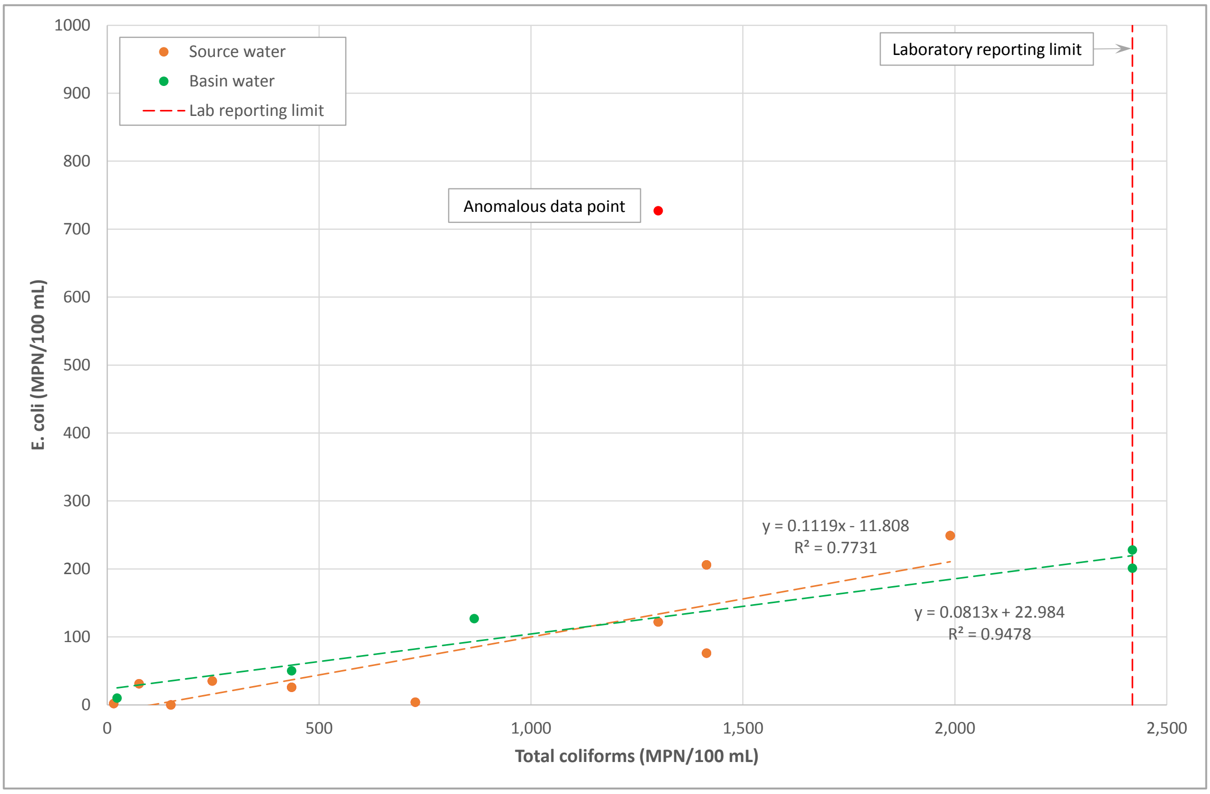


Figure F9: Correlation between total coliforms and E. coli in source water and infiltration basin water.

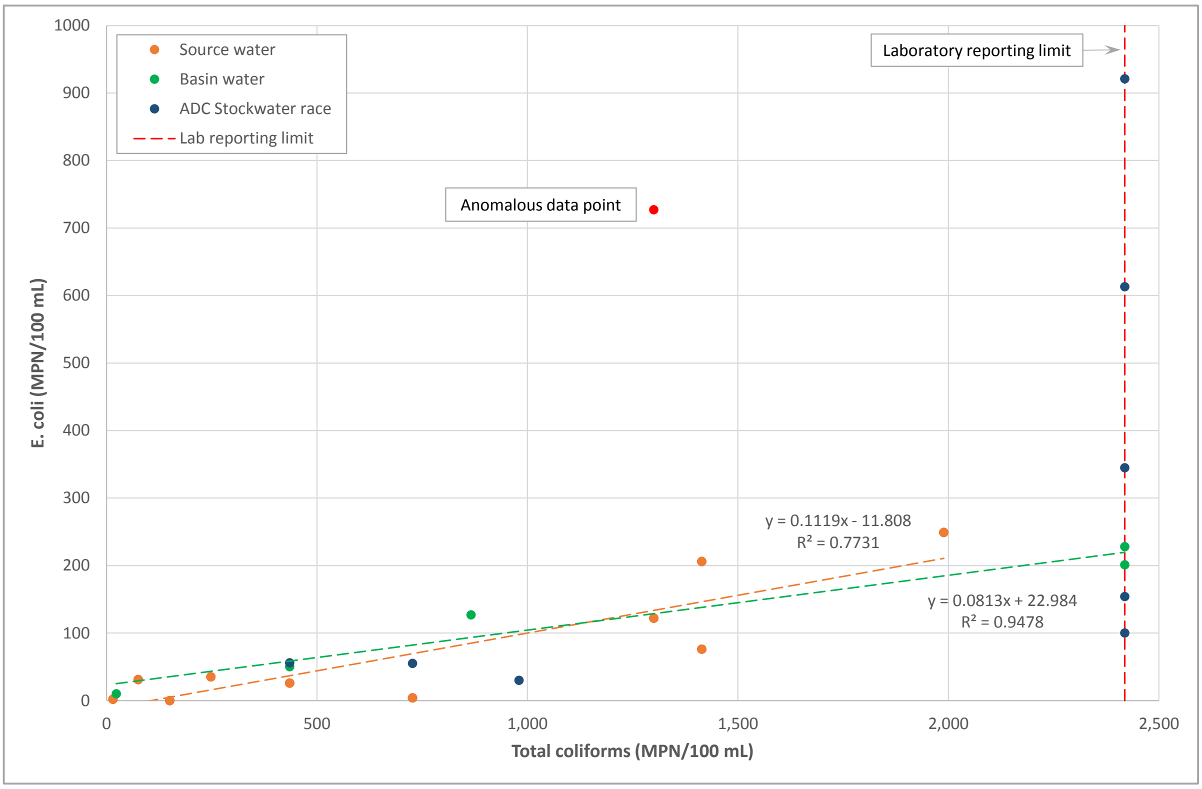


Figure F10: Correlation between total coliforms and E. coli in source water, infiltration basin water and ADC race water.

APPENDIX G

Groundwater Level Responses

1.0 APPENDIX STRUCTURE

This appendix summarises the groundwater responses to the Hinds MAR Pilot Trial in terms of observed changes in groundwater levels and in groundwater temperature. The appendix is divided into the following sections.

- Section 2.0 presents the locations of the monitoring wells used to monitor groundwater levels and temperatures with respect to the Pilot Trial.
- Section 3.0 presents groundwater level and temperature records from the monitoring wells listed in the previous section. The data presented is complete up to June 2017.
- Section 4.0 presents a background discussion on groundwater level responses to infiltration basin operations. This section also presents a comparative evaluation of the observed groundwater level responses from a selection of the monitoring wells.

The information presented in this appendix should be considered in conjunction with the information presented in Appendix H of this report. Appendix H documents the observed changes in groundwater quality in response to the Pilot Trial.

2.0 GROUNDWATER MONITORING WELL LOCATIONS

Groundwater level monitoring to provide data to support the evaluation of groundwater responses to the Pilot Trial operations has been undertaken in seventeen monitoring wells distributed around the infiltration basin site. The locations of these monitoring wells and the monitoring program schedule has been documented in a separate appendix to this report (Appendix B). Information on the distance and direction of these monitoring wells from the infiltration basin and the interpretation as to whether these wells are up-gradient, across-gradient or down-gradient from the basin is provided in Table G1. The locations of the monitoring wells listed in this appendix are shown in Figure G1.

3.0 GROUNDWATER LEVEL AND TEMPERATURE RECORDS

Groundwater level measurements in designated monitoring wells around the Pilot Trial infiltration basin have been undertaken using pressure transducers and data loggers. Manual groundwater level monitoring on a monthly basis has been used for transducer calibration at the start of the recording period, to confirm the recorded trends and to check potential drift in the transducers. The transducers being used for monitoring the trial record absolute pressures. A pressure transducer is installed in the steel protective collar of monitoring well GWD-01 to monitor barometric pressure changes during the trial. All groundwater level records have been corrected for the recorded changes in barometric pressure from this transducer.

The positions of a few transducers installed in groundwater monitoring wells have been changed during the trial for various reasons. The primary reason for shifting these transducers is due to the water level in the monitoring well dropping below the sensor tip during the trial. When this issue has been identified, the transducer has been repositioned deeper in the well, if the transducer was not already very close to base of the well.

Figure G2 to Figure G20 present the monitoring data on which the evaluation of the effects of the Pilot Trial on groundwater level and temperature has been based. Specifically, these figures present:

- The water level records from pressure transducers installed in groundwater monitoring wells, which have been corrected for barometric changes and changes in pressure transducer positions.

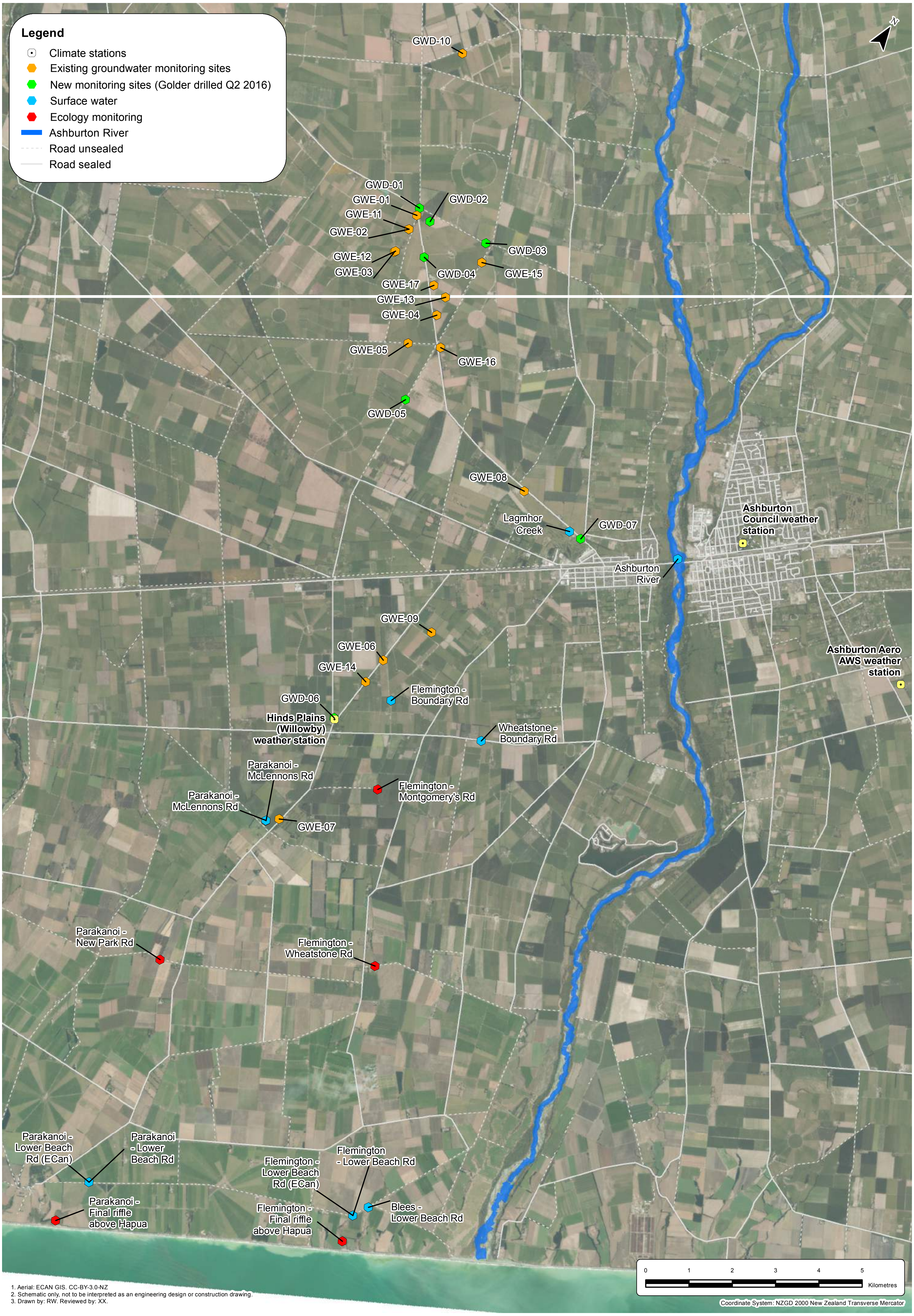
- The manual water level measurements taken during the trial.
- The groundwater temperature trends recorded by the pressure transducers during the Pilot Trial.
- On a separate chart within each figure, the difference between the automated groundwater level measurements and the manual water level measurements at the corresponding date and time.

Each figure has been presented on a single page within this section of the appendix for ease of viewing and interpretation. An interpretation of the collective data from these monitoring wells with respect to the effects of the Pilot Trial on groundwater levels is provided in Section 5.0.

Table G1: Monitoring well locations relative to Pilot Trial infiltration basin.

Monitoring well ID (1)	Screen depth (m)	Distance from infiltration basin (m)	Direction from infiltration basin	Relative direction hydraulically
GWE-01	15 – 18	45	SW	At site
GWE-02	41.14 (2)	364	S	Down gradient
GWE-03	21 – 27	975	S	Across / down gradient
GWE-04	22.8 (2)	2,308	SE	Down gradient
GWE-05	15 – 18	2,931	SSE	Down gradient
GWE-06	5 – 10	10,278	SSE	Down gradient
GWE-07	8.3 (2)	13,397	SSE	Down gradient
GWE-08	15 (2)	6,789	SE	Across / down gradient
GWE-09	10 (2)	9,609	SE	Down gradient
GWE-10	26.2 (2)	3,910	N	Up gradient
GWE-11	61.87 – 64.87	364	S	Down gradient
GWE-12	60 – 66	961	S	Across / down gradient
GWE-13	57 – 60	1,967	ESE	Across gradient
GWE-14	12.1 (2)	10,818	SSE	Down gradient
GWE-15	57 – 60	1,794	E	Across gradient
GWE-16	53 – 54	3,660	SE	Down gradient
GWE-17	45 – 48	1,618	SE	Down gradient
GWD-01	23 – 32 (26 – 32) (3)	19	NW	At site
GWD-02	23 – 31.8	274	E	Across gradient
GWD-03	33.45 – 45.45	1,659	E	Across gradient
GWD-04	20.25 – 29.25 (23.25 – 29.25) (3)	938	SE	Down gradient
GWD-05	21.5 – 30.5	4,236	SSE	Down gradient
GWD-06	6.08 – 15.08	11,741	SSE	Down gradient
GWD-07	4.5 – 10.52	8,325	SE	Across / down gradient

Note: 1) Coloured text reflects monitoring well designations in Figure G24. Well cards and bore logs provided in Appendix C.
2) Screen interval not available so well depth provided.
3) Twin piezometers (23 mm and 52 mm ID installed in same bore for monitoring purposes.



Golder Associates

TITLE MONITORING WELL LOCATIONS

AUGUST 2017

PROJECT 1538632

G1

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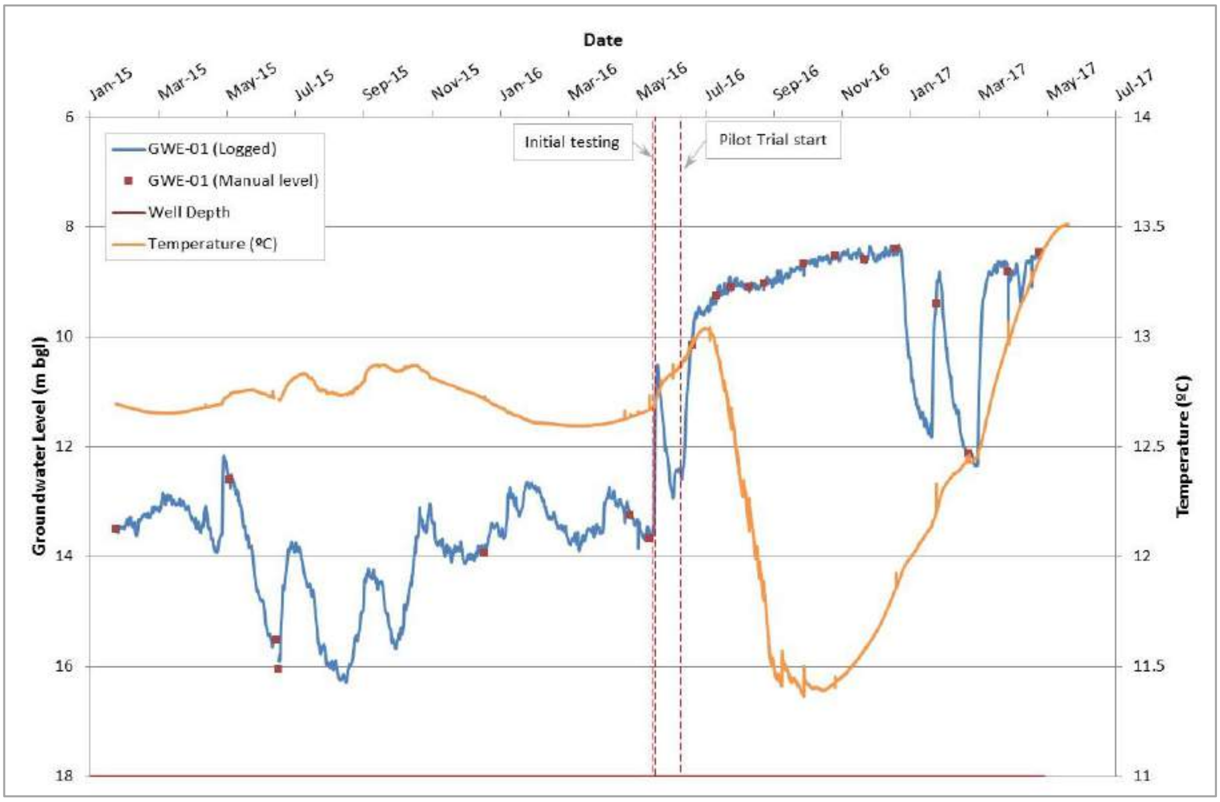


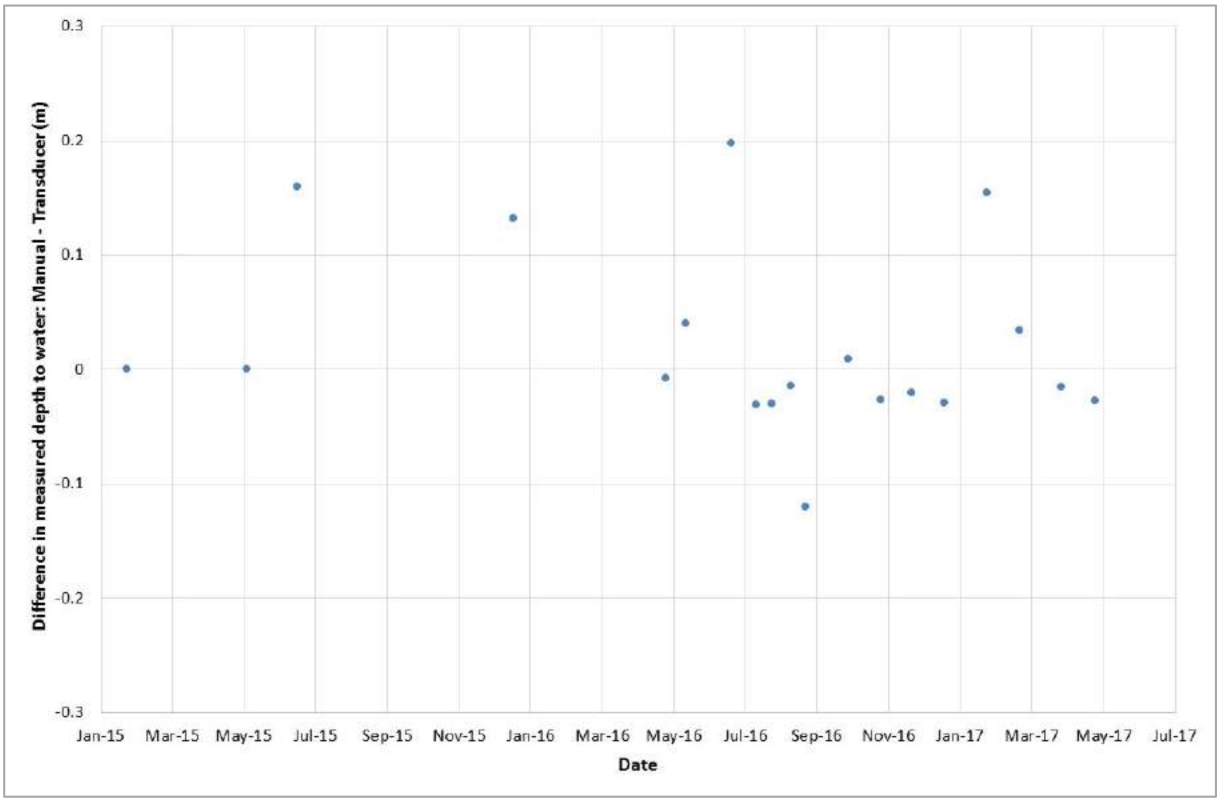
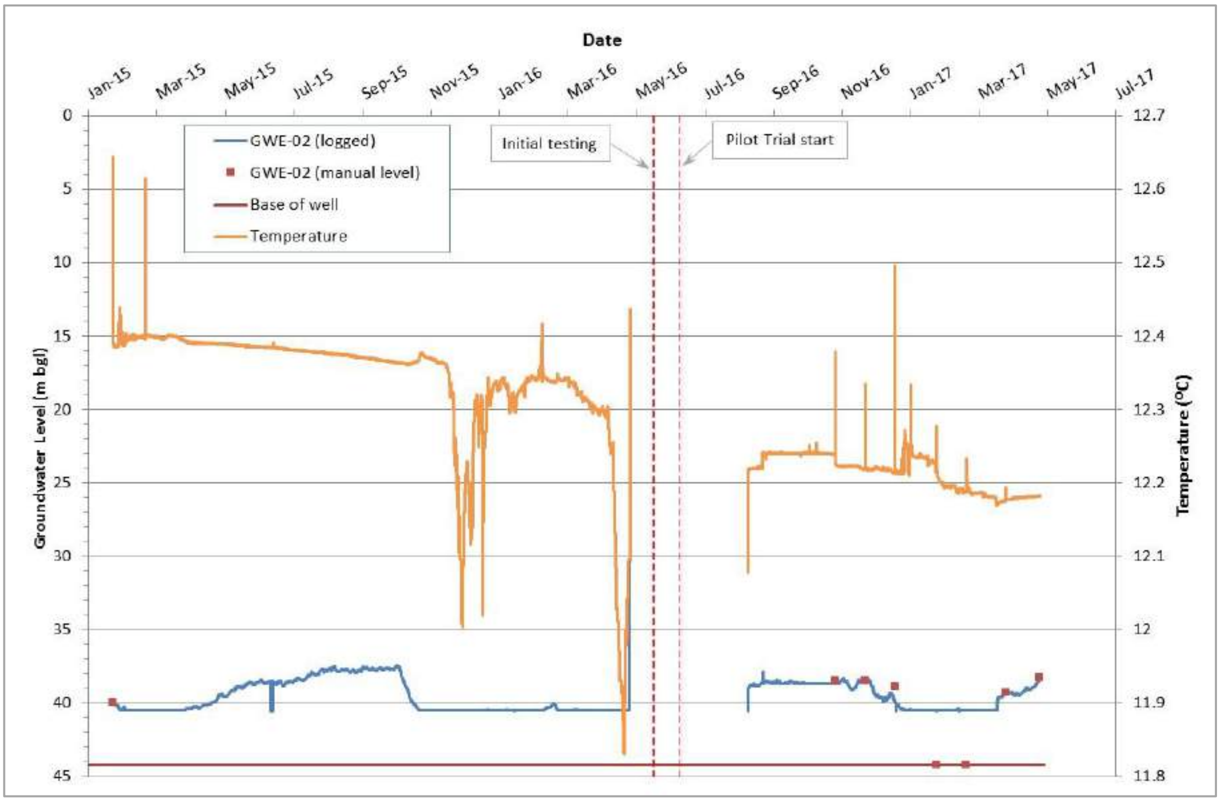


Figure G2: GWE01 depth to groundwater, groundwater temperature and transducer drift charts.



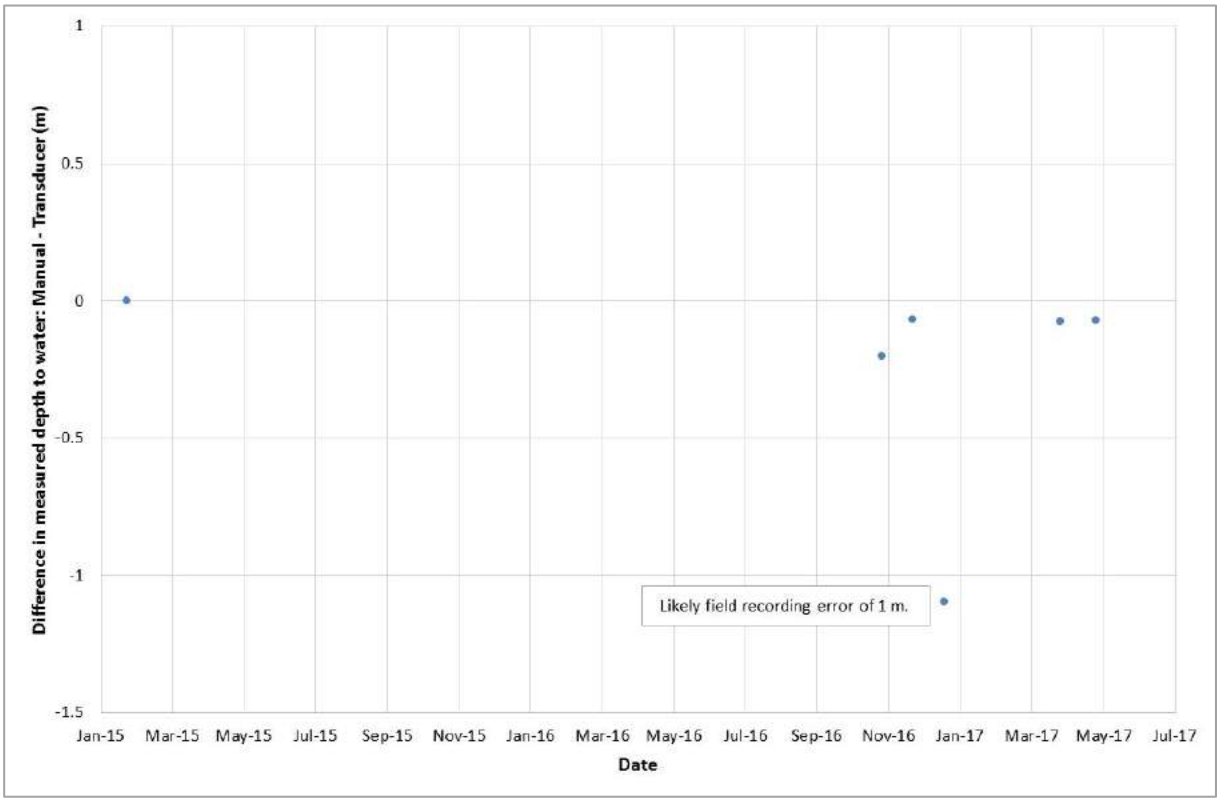


Figure G3: GWE02 depth to groundwater, groundwater temperature and transducer drift charts.

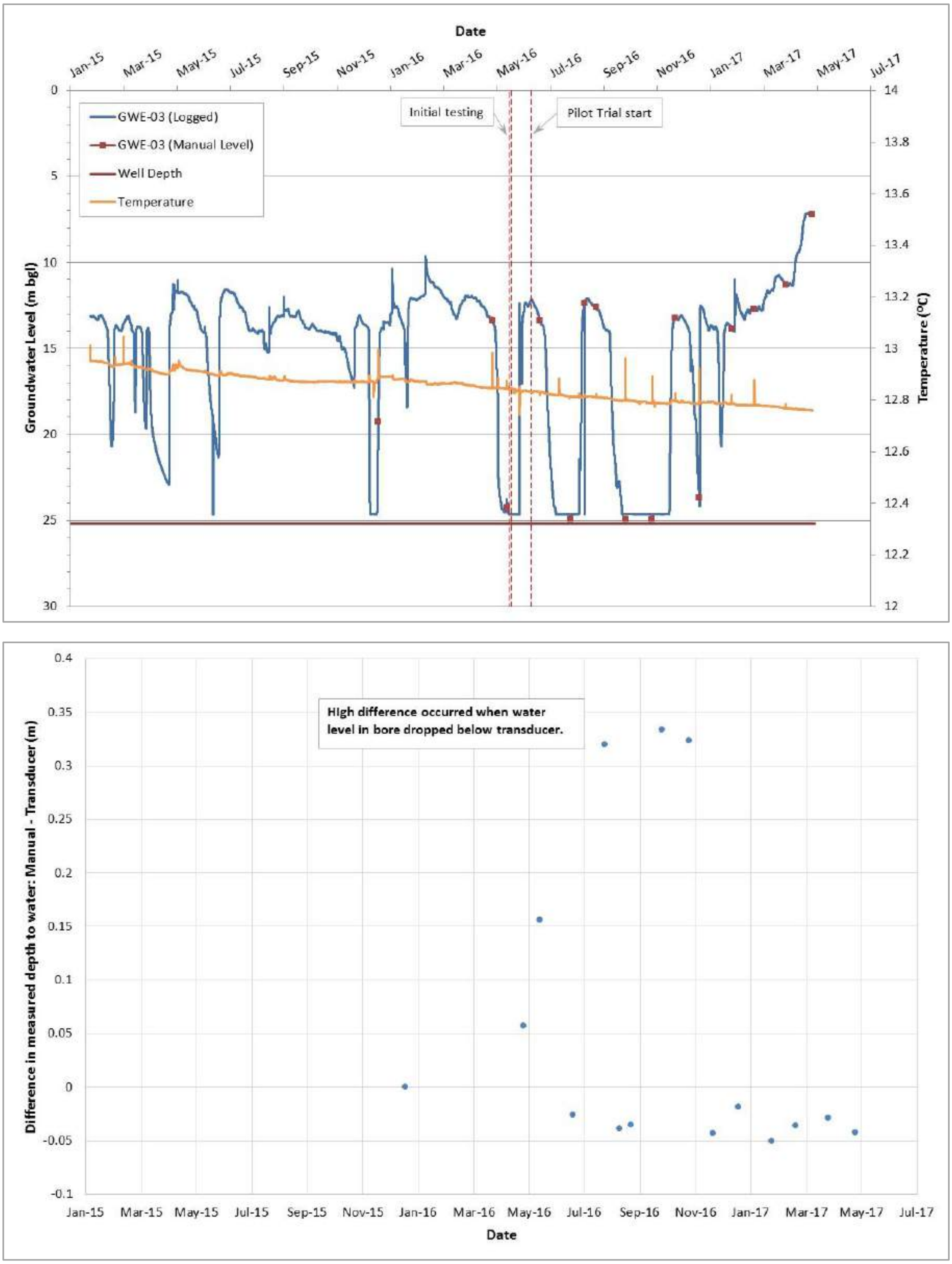
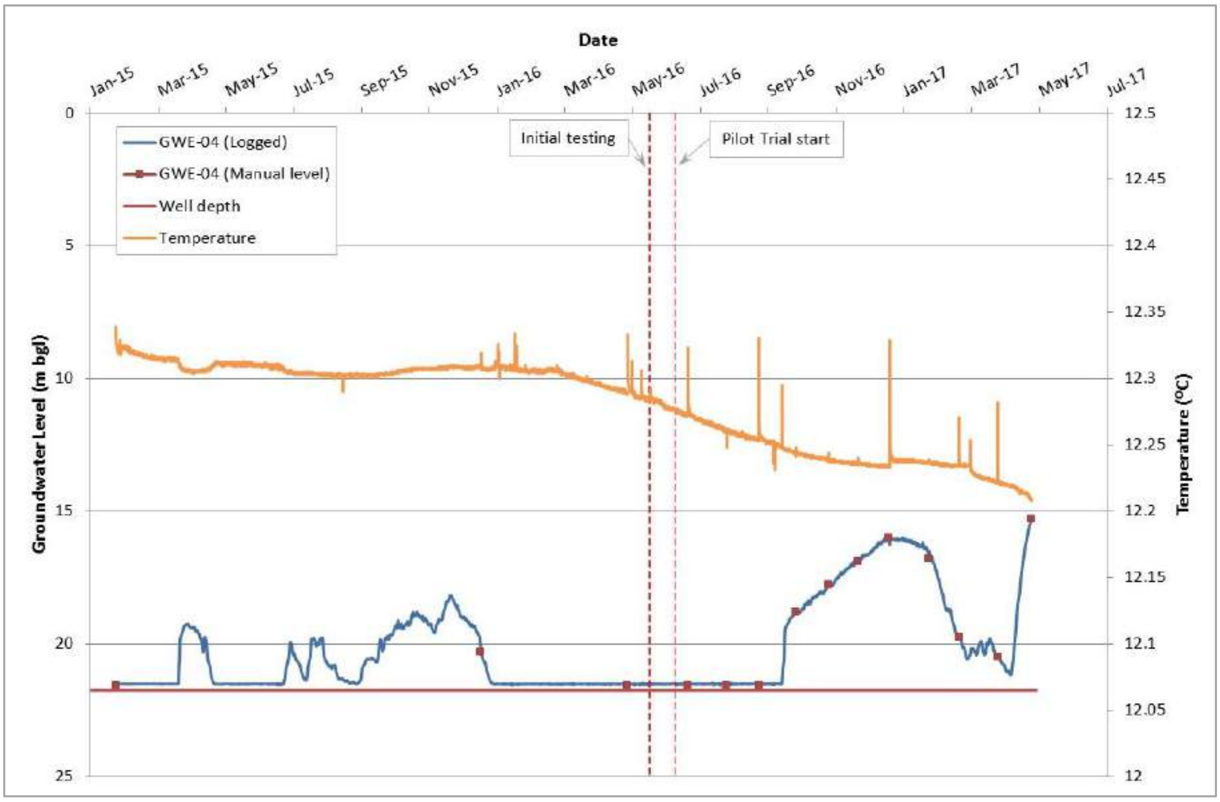


Figure G4: GWE03 depth to groundwater, groundwater temperature and transducer drift charts.



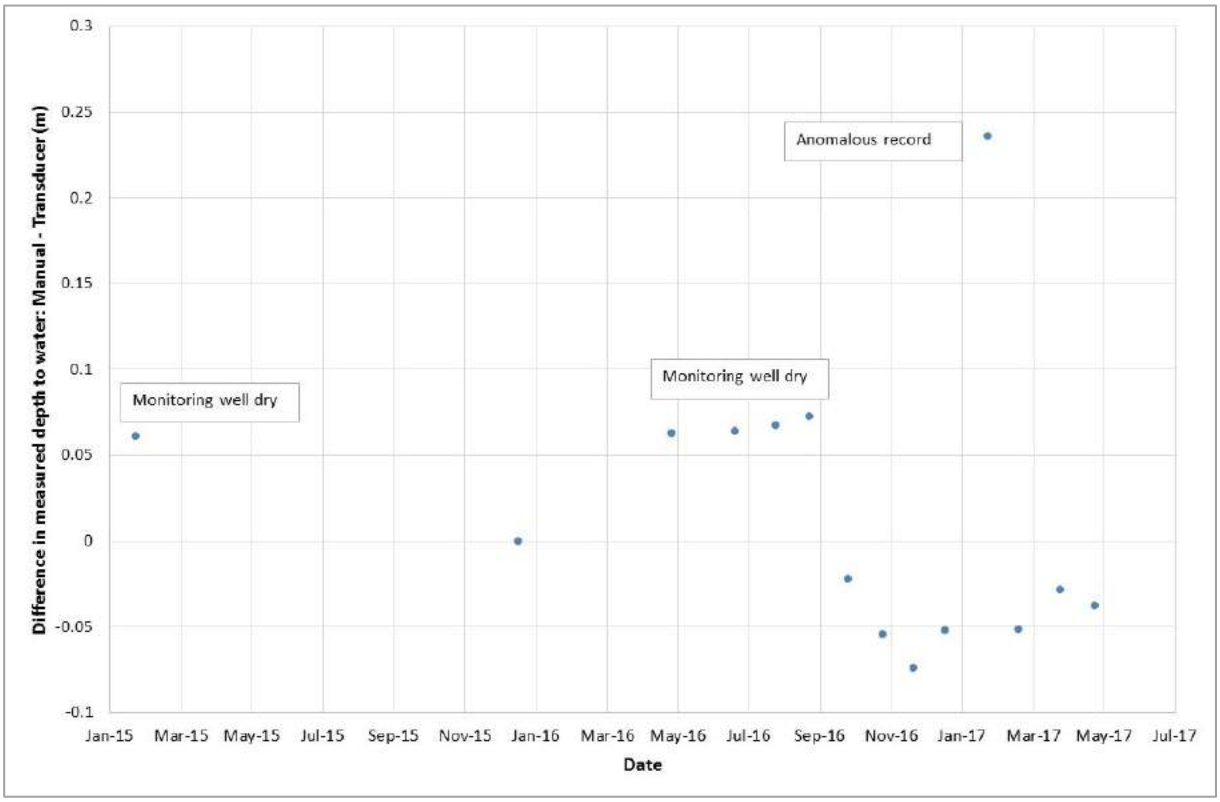


Figure G5: GWE04 depth to groundwater, groundwater temperature and transducer drift charts.

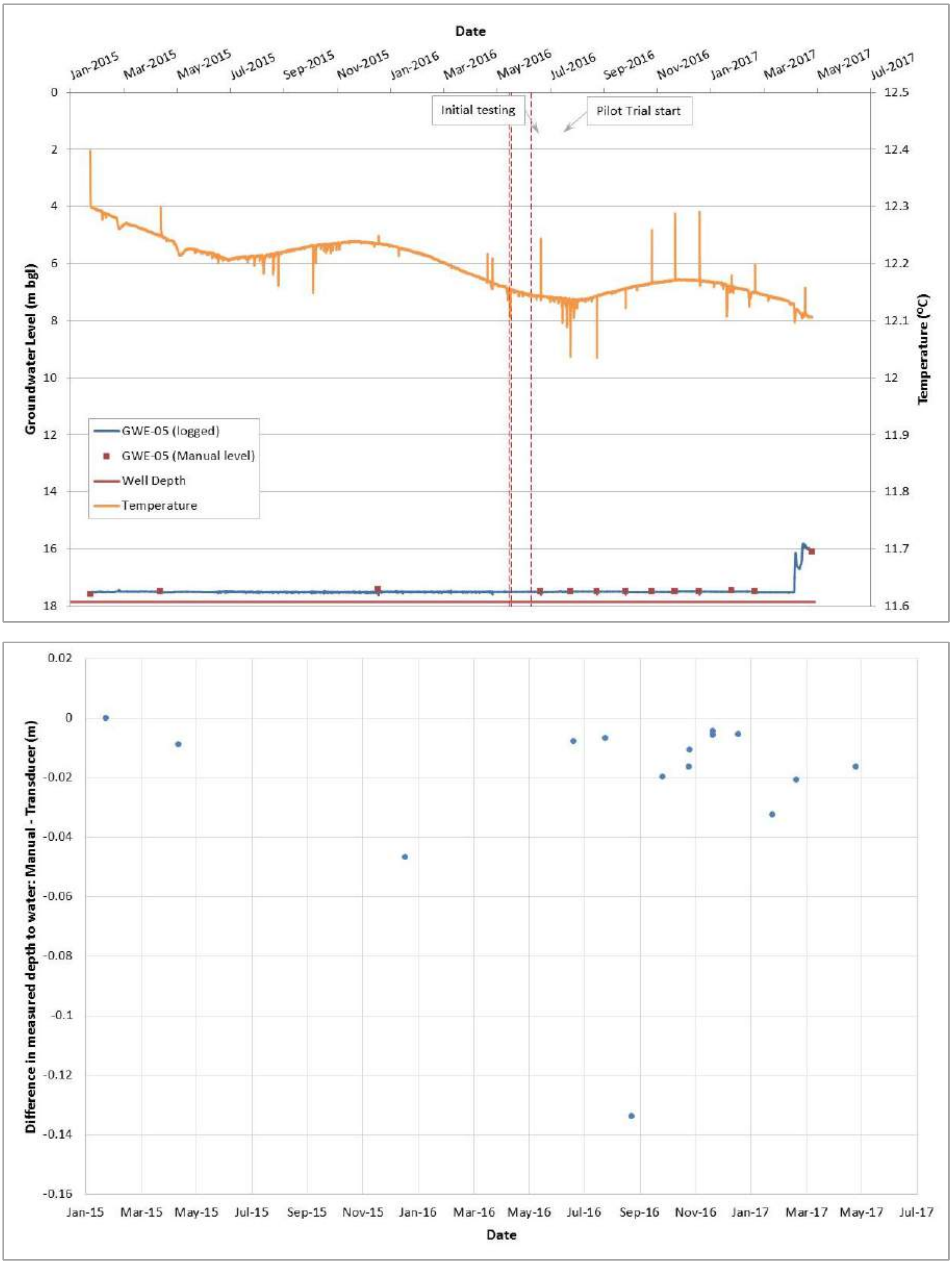
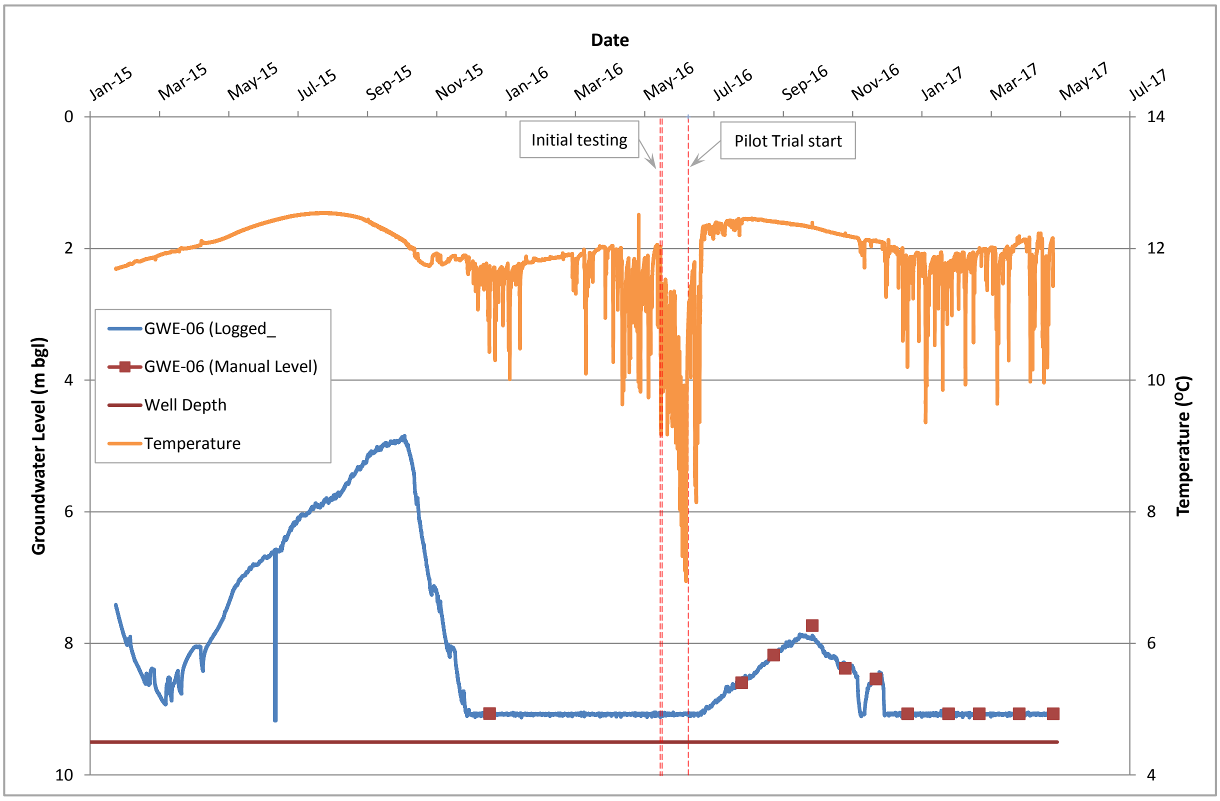


Figure G6: GWE05 depth to groundwater, groundwater temperature and transducer drift charts.



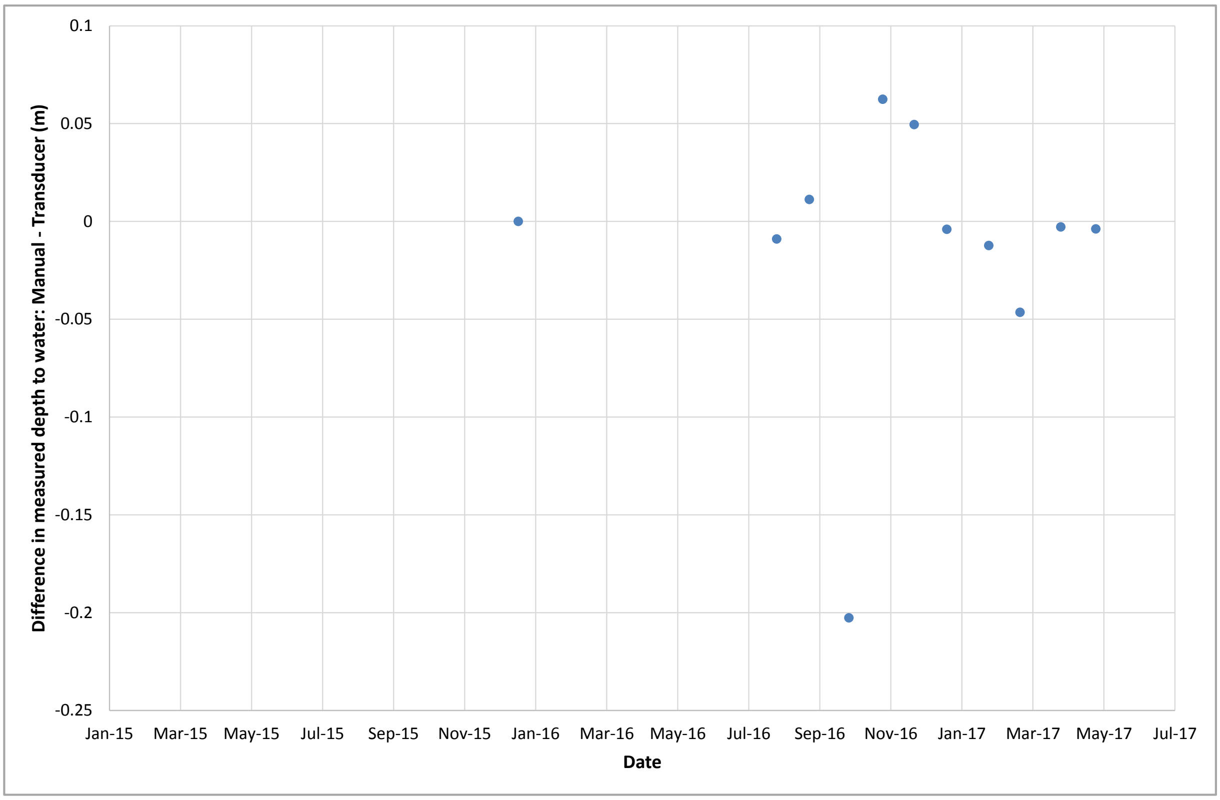
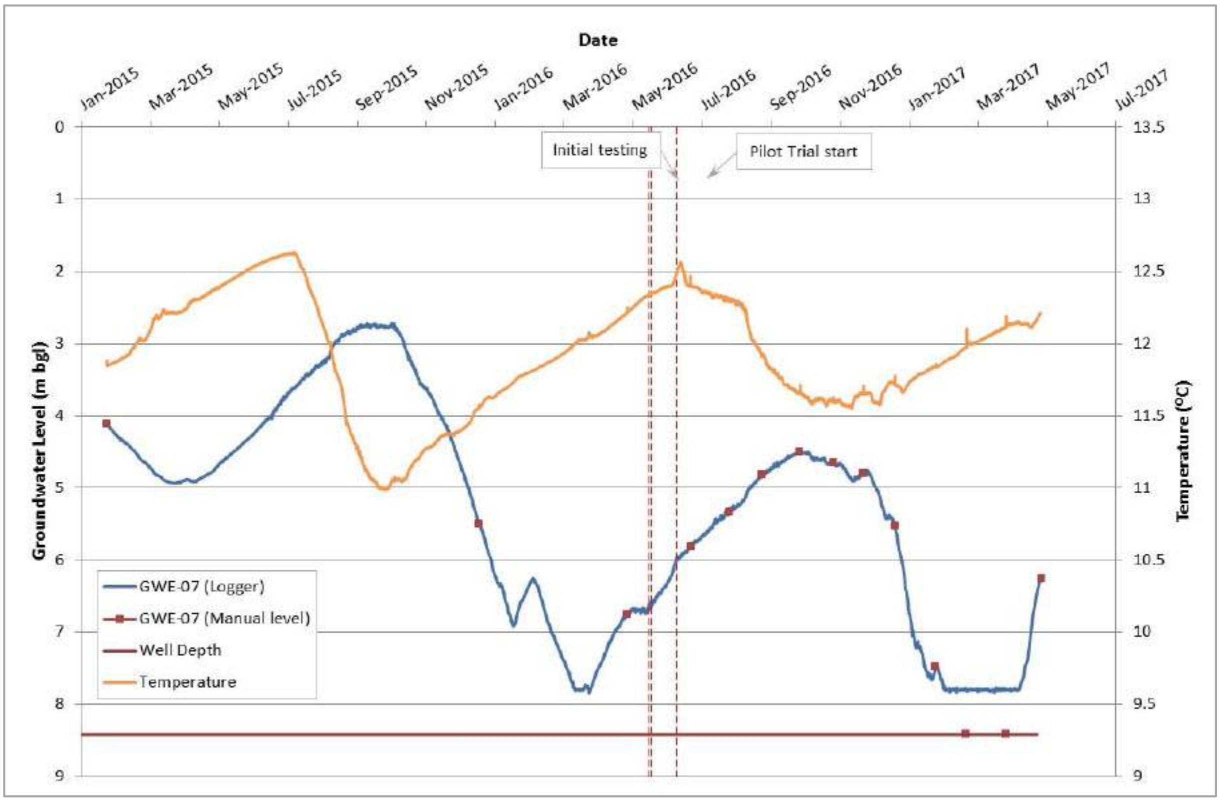


Figure G7: GWE06 depth to groundwater, groundwater temperature and transducer drift charts.



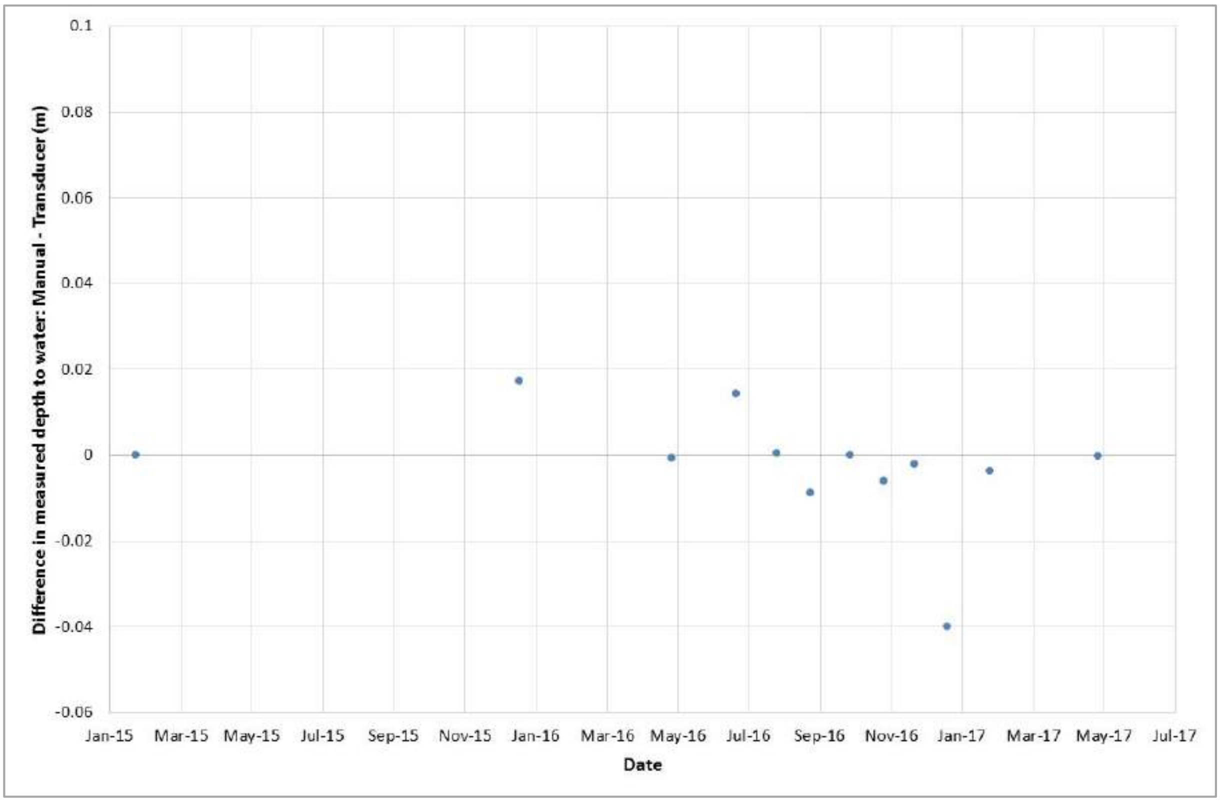
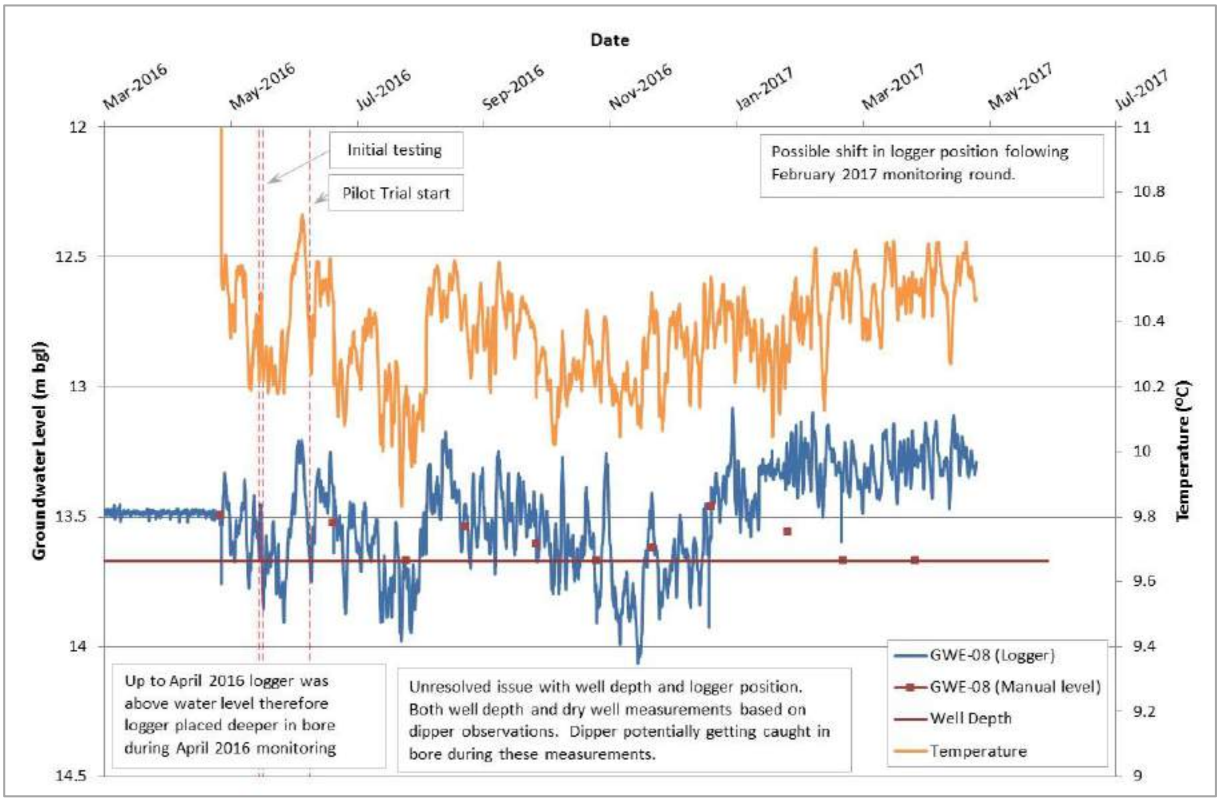


Figure G8: GWE07 depth to groundwater, groundwater temperature and transducer drift charts.



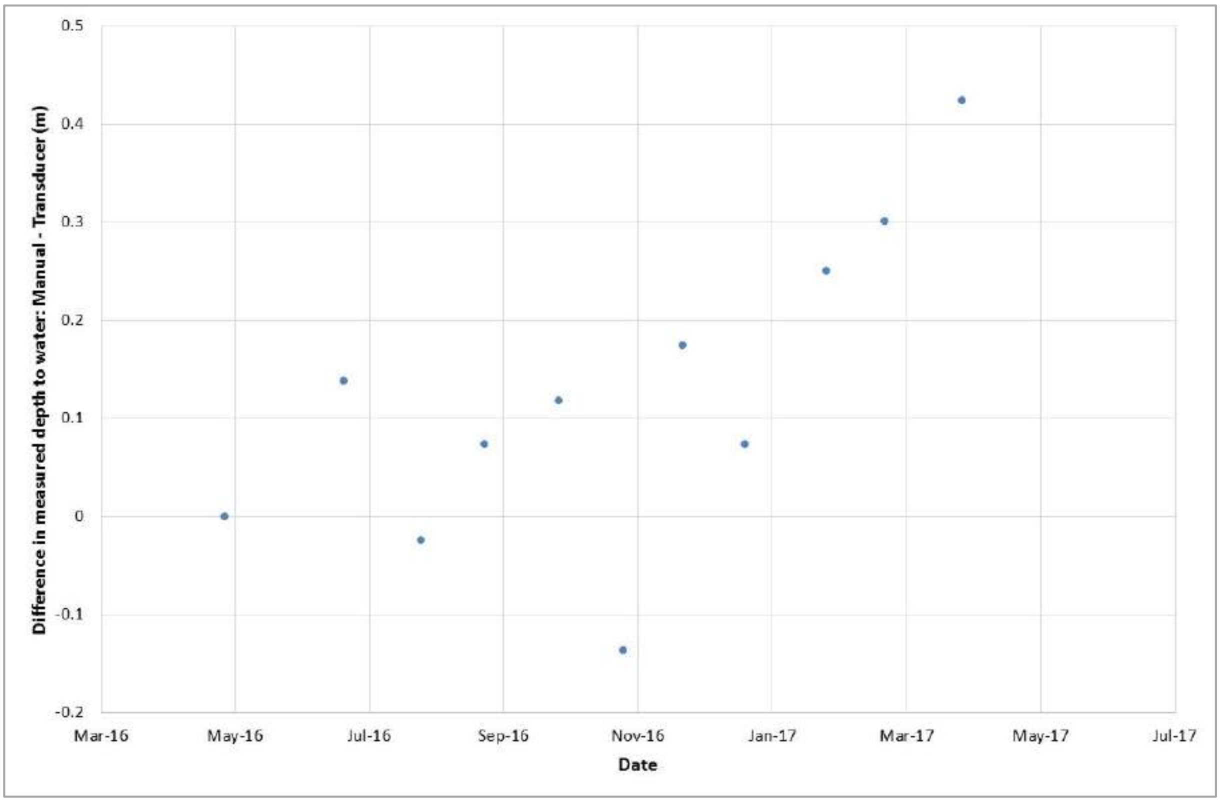
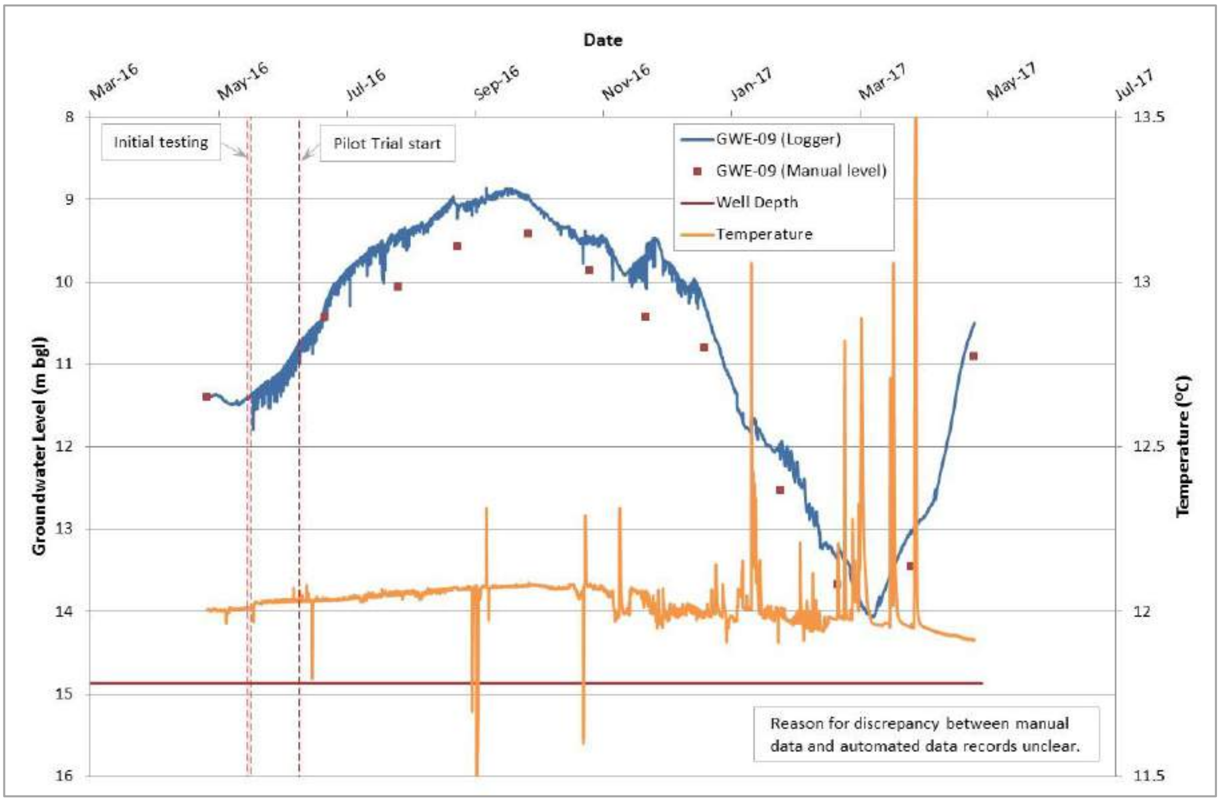


Figure G9: GWE08 depth to groundwater, groundwater temperature and transducer drift charts.



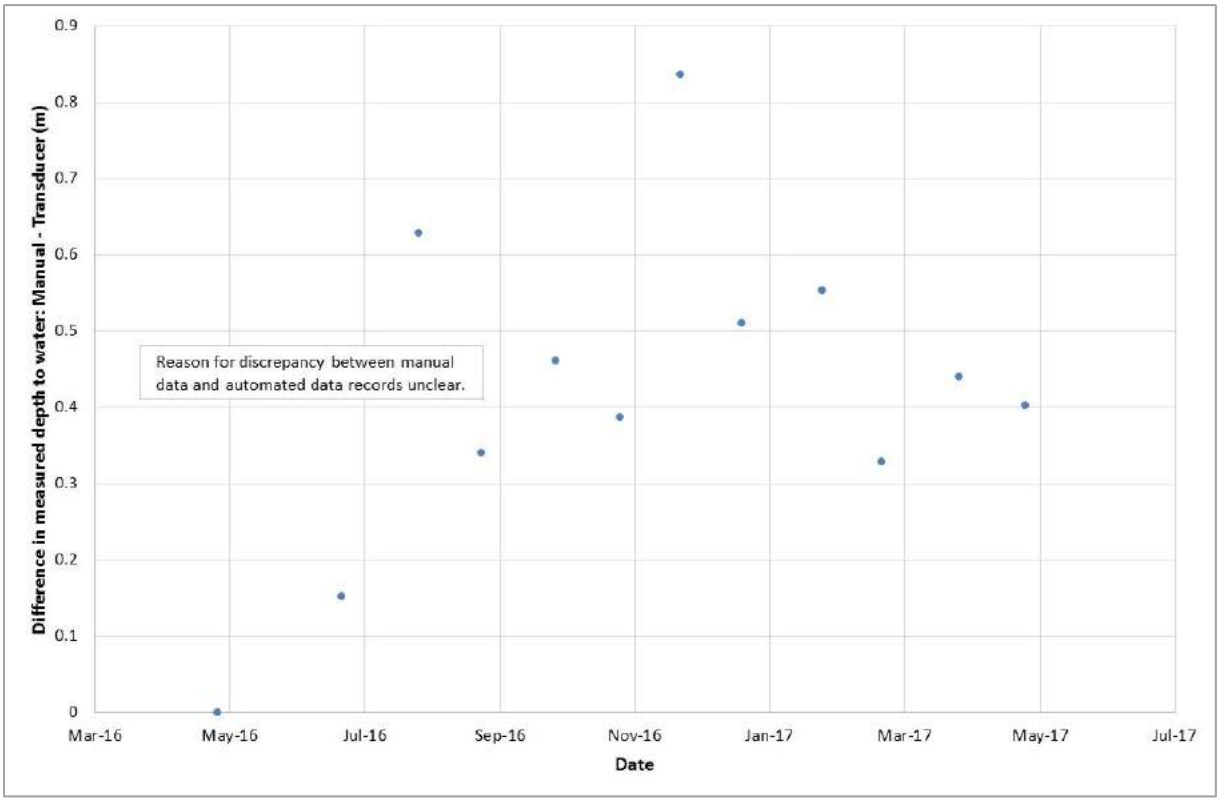


Figure G10: GWE09 depth to groundwater, groundwater temperature and transducer drift charts.

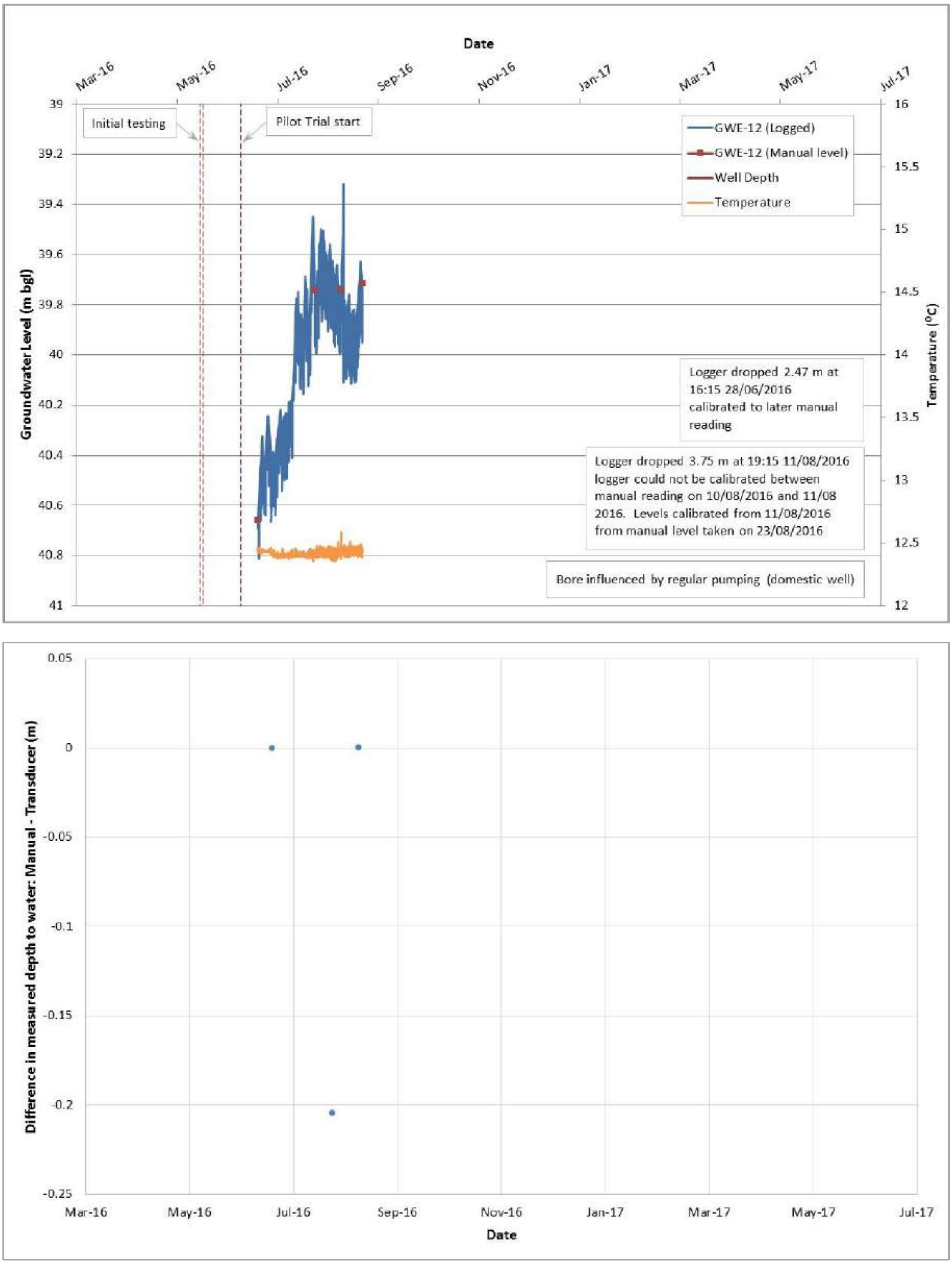
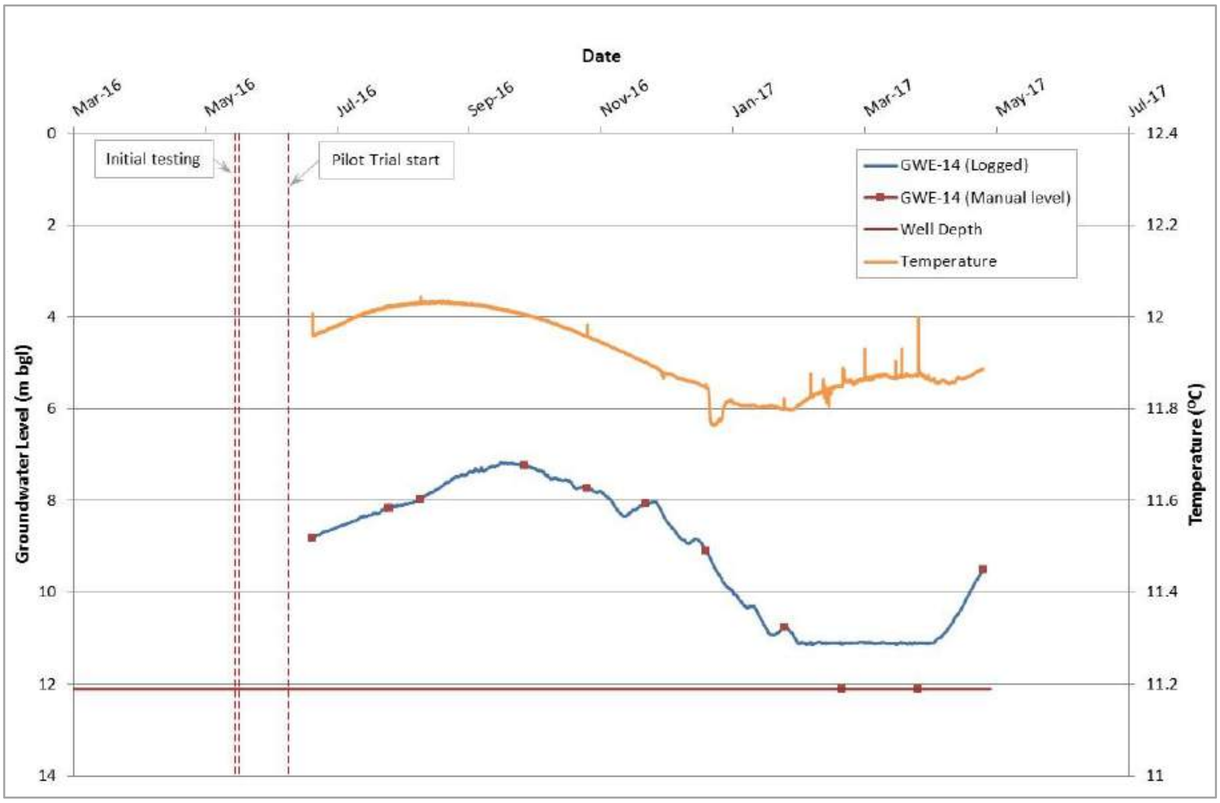


Figure G11: GWE12 depth to groundwater, groundwater temperature and transducer drift charts.



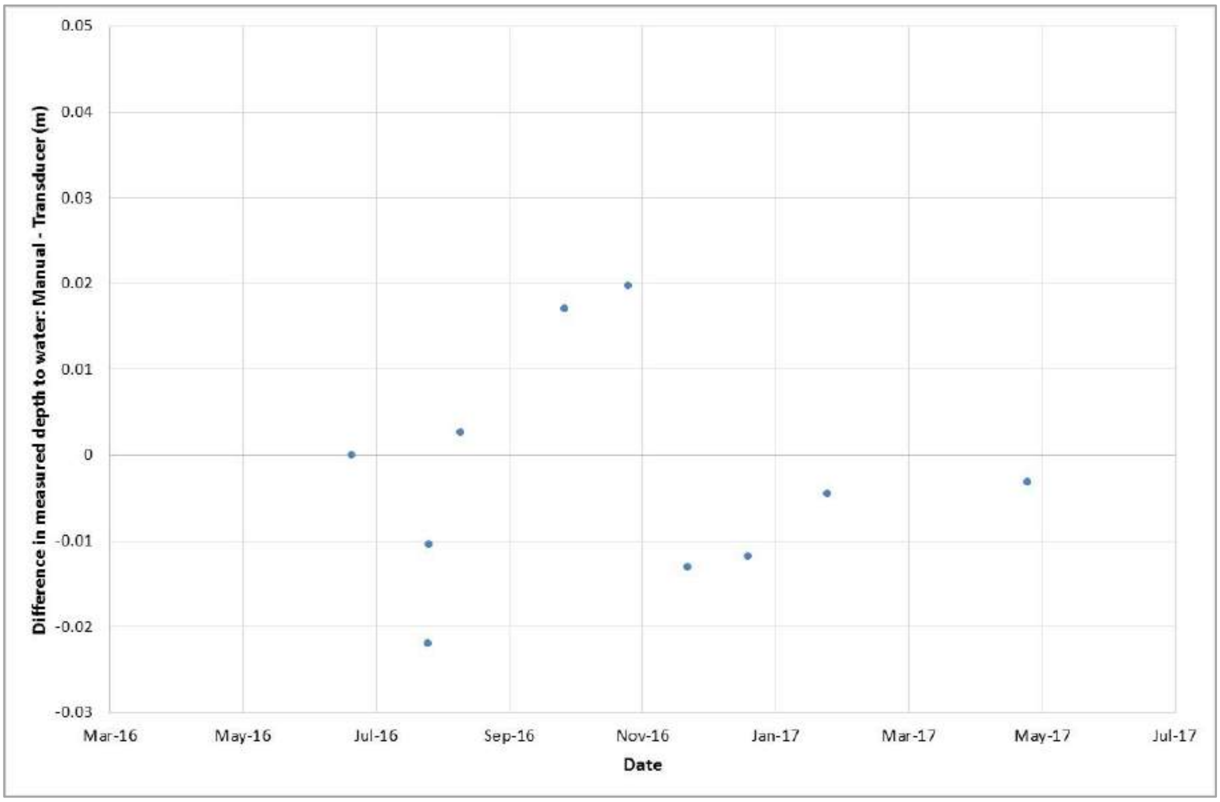


Figure G12: GWE14 depth to groundwater, groundwater temperature and transducer drift charts.

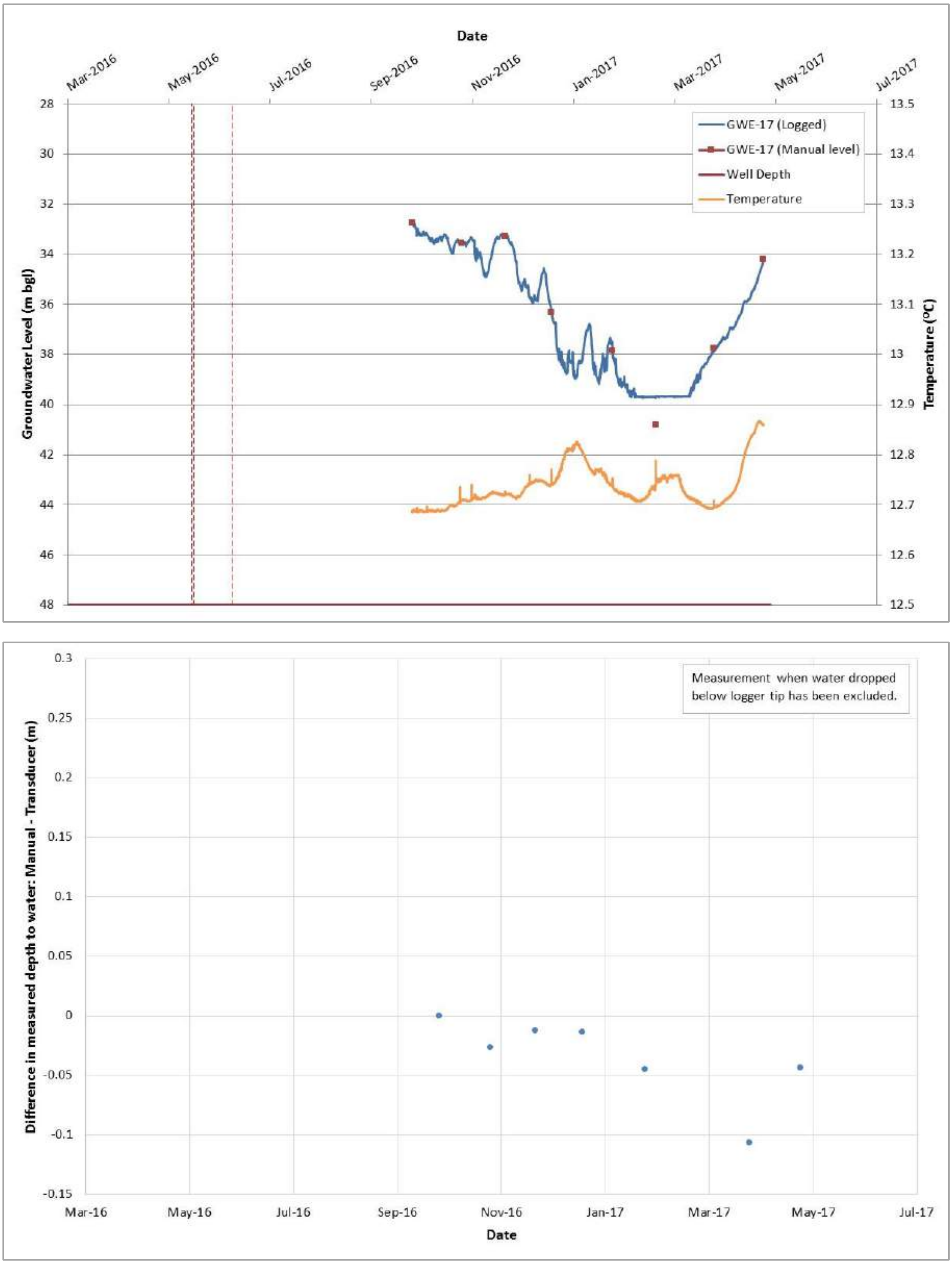
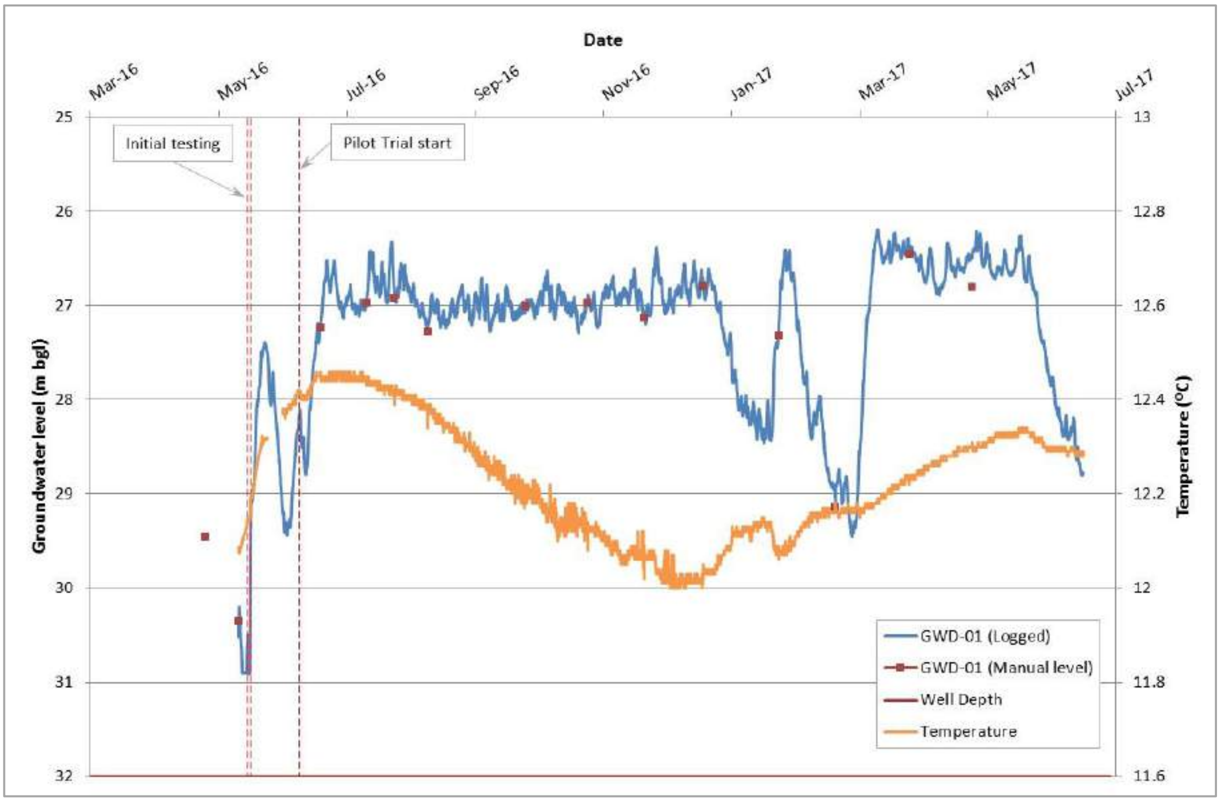


Figure G13: GWE17 depth to groundwater, groundwater temperature and transducer drift charts.



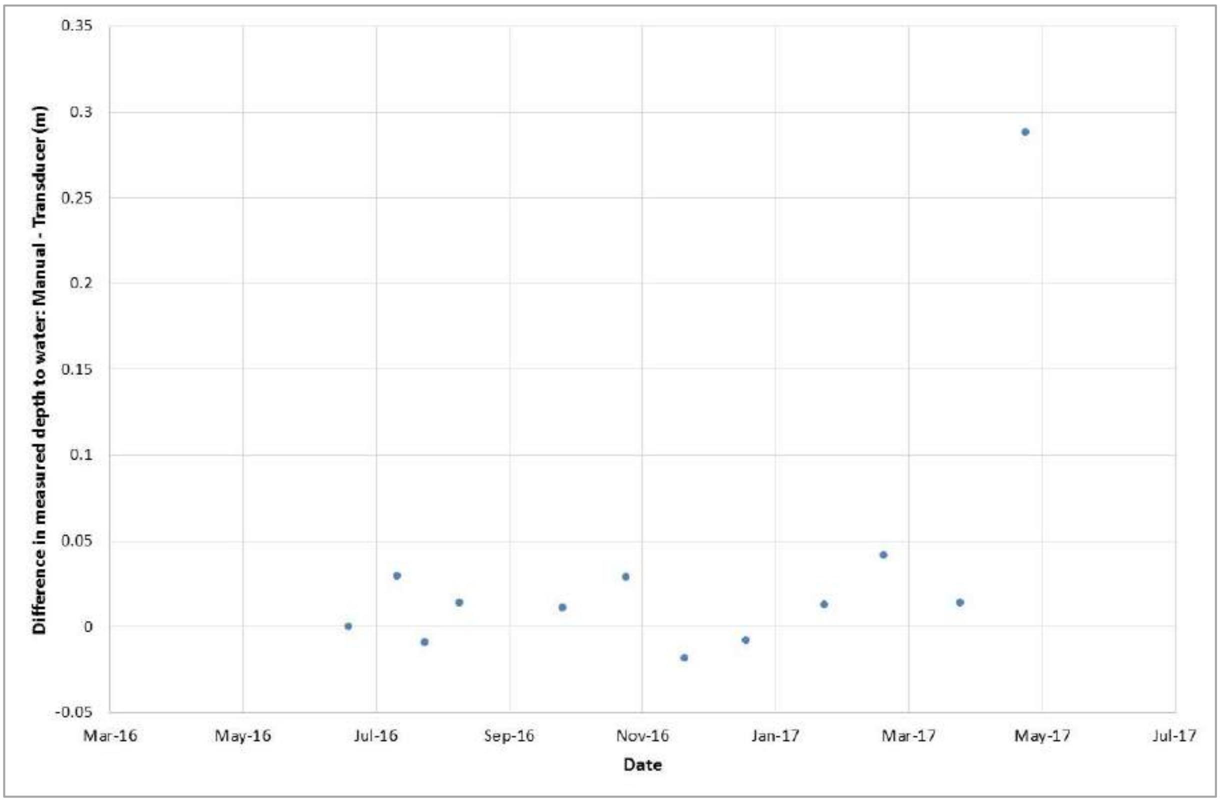


Figure G14: GWD01 depth to groundwater, groundwater temperature and transducer drift charts.

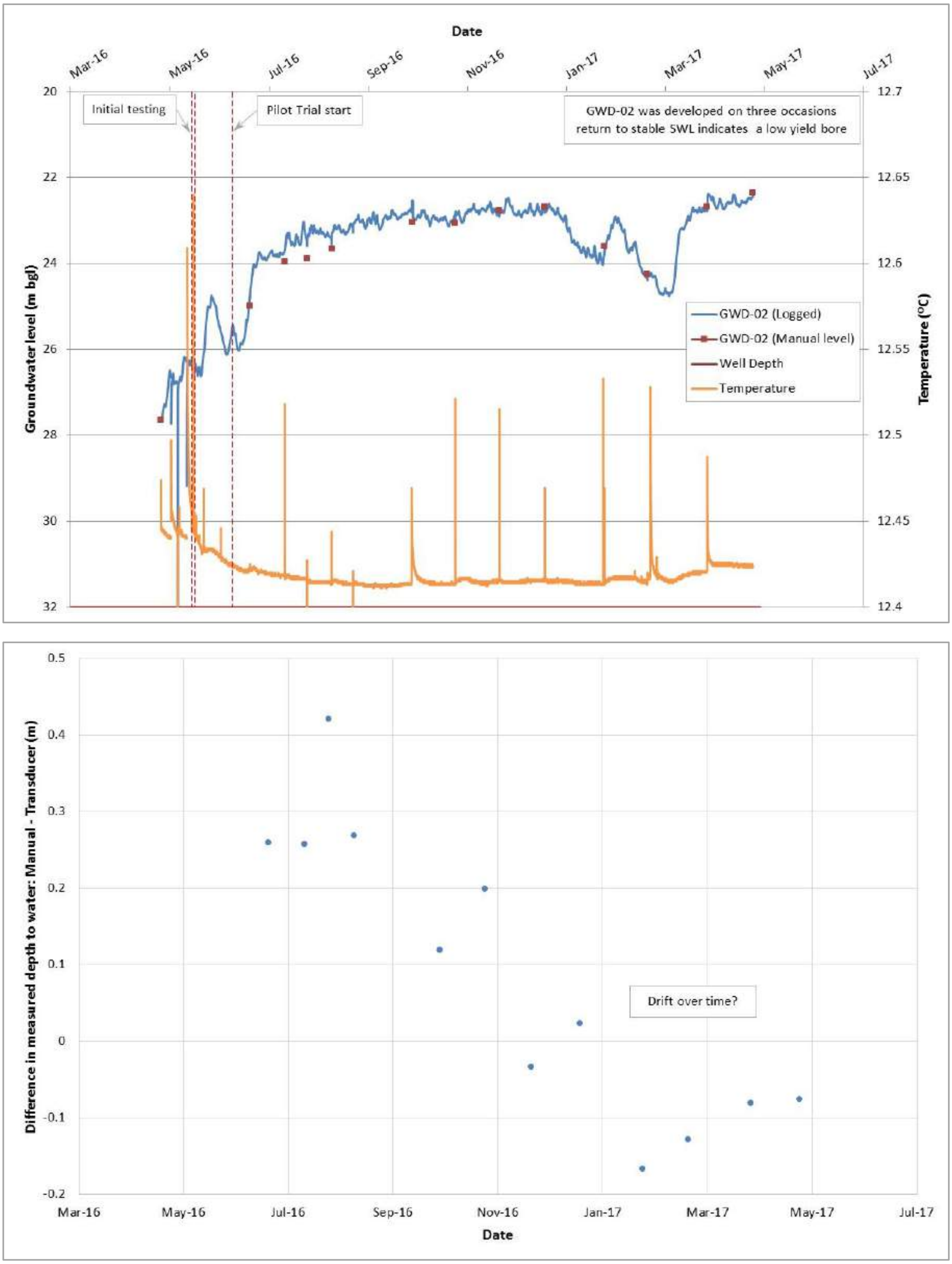


Figure G15: GWD02 depth to groundwater, groundwater temperature and transducer drift charts.

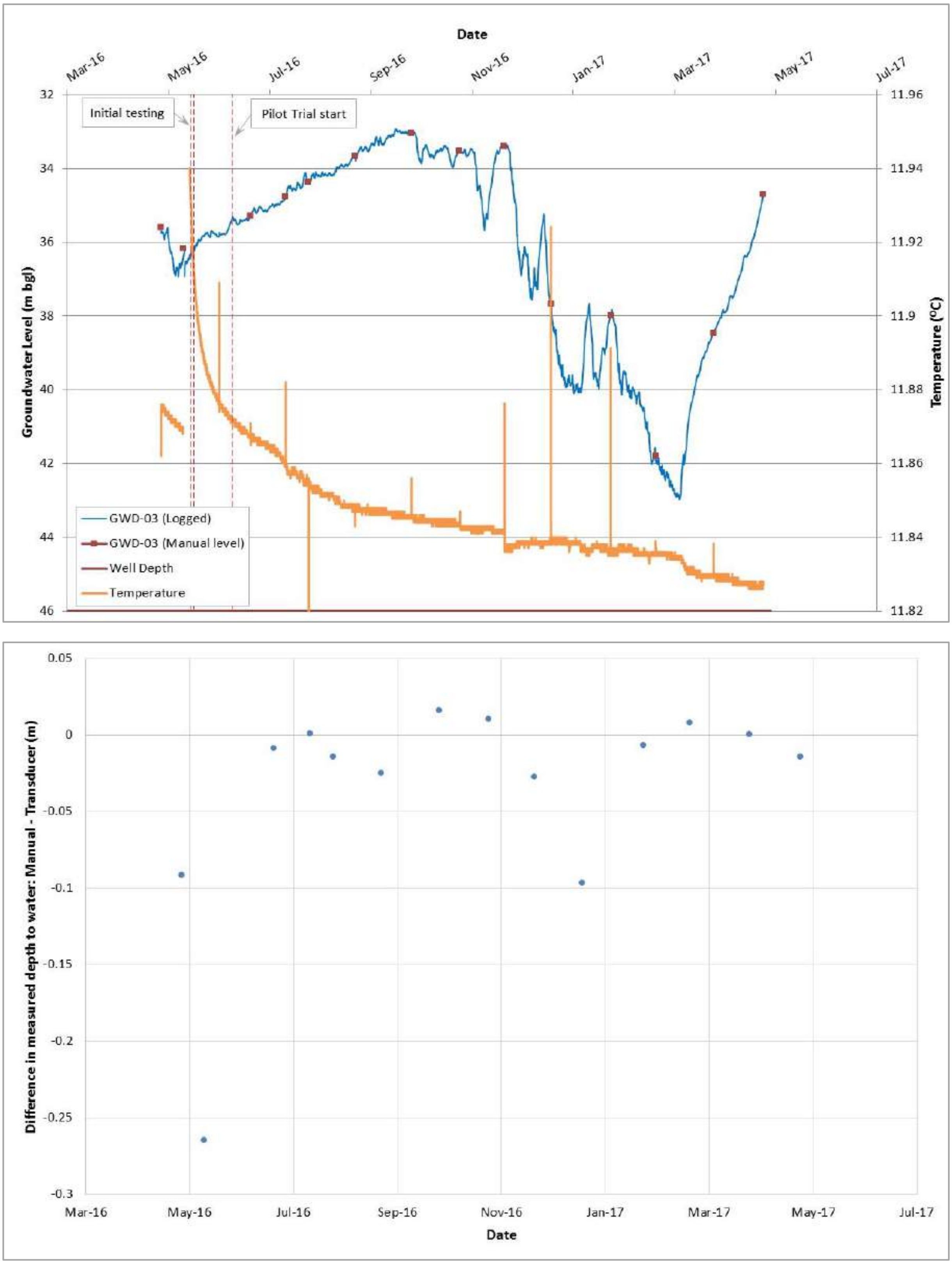


Figure G16: GWD03 depth to groundwater, groundwater temperature and transducer drift charts.

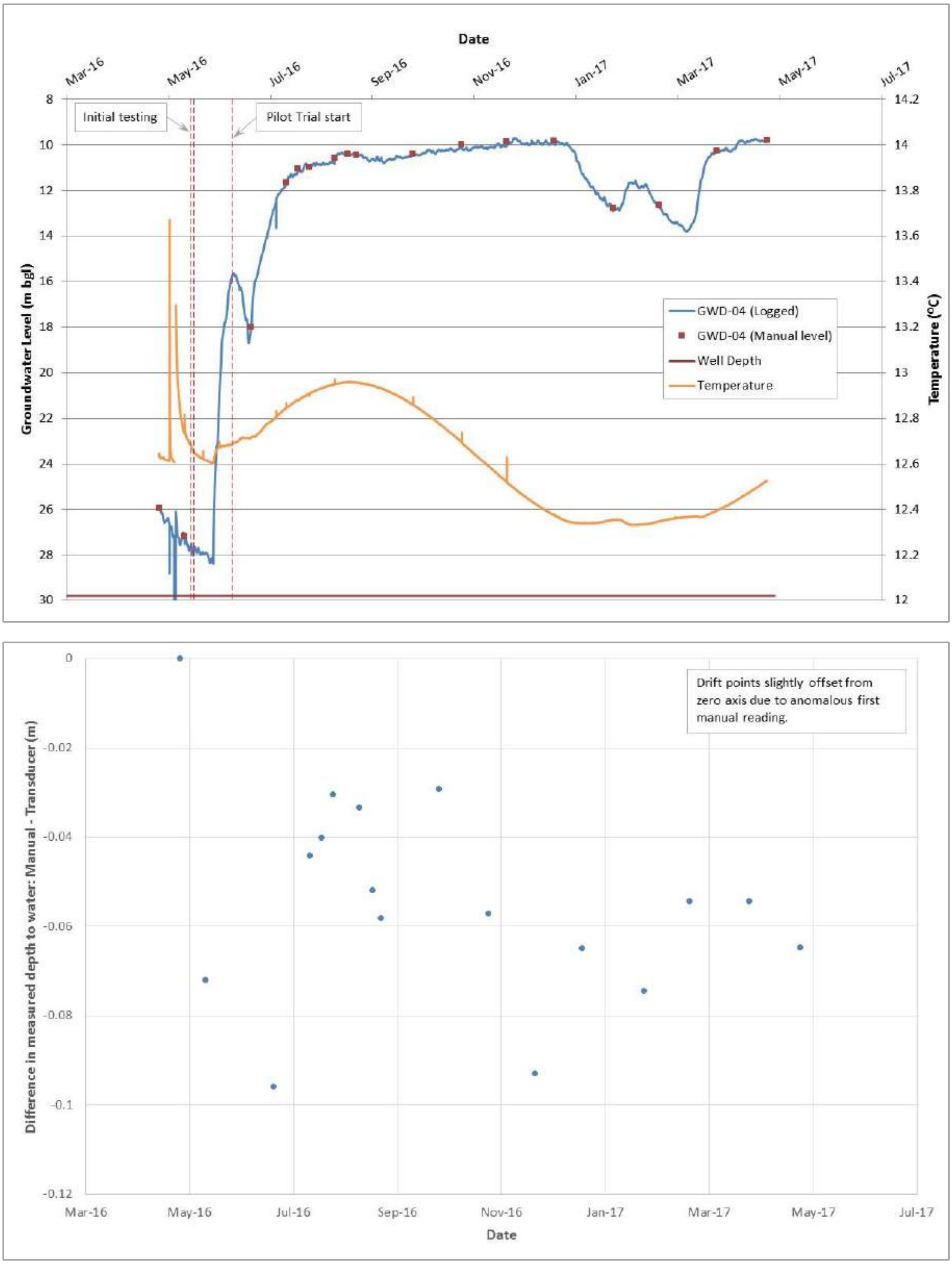
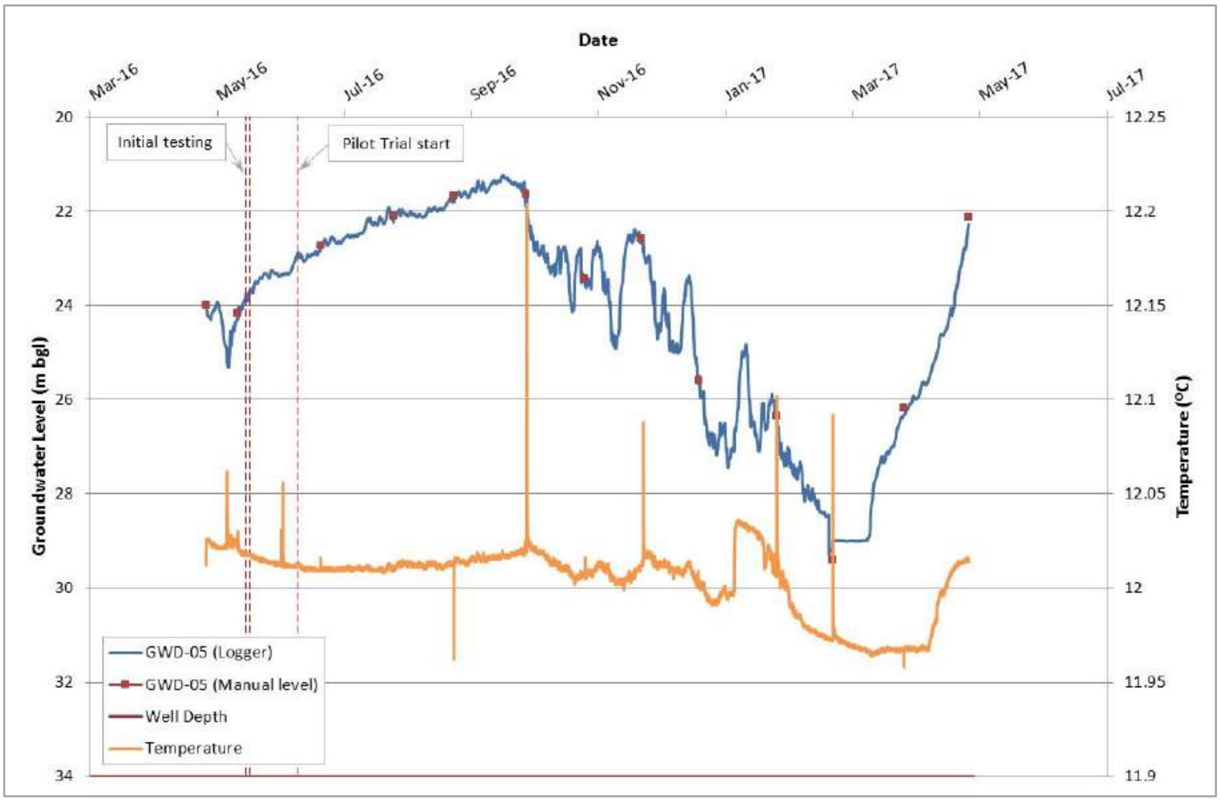


Figure G17: GWD04 depth to groundwater, groundwater temperature and transducer drift charts.



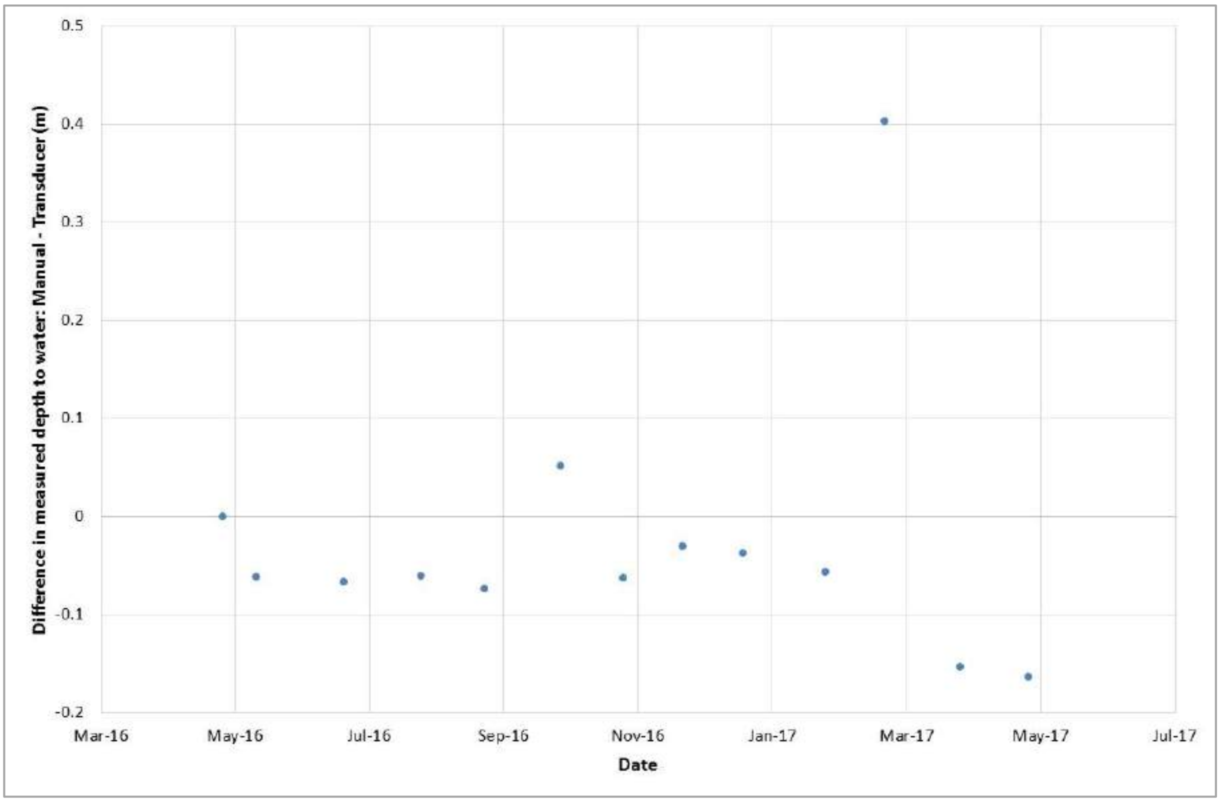


Figure G18: GWD05 depth to groundwater, groundwater temperature and transducer drift charts.

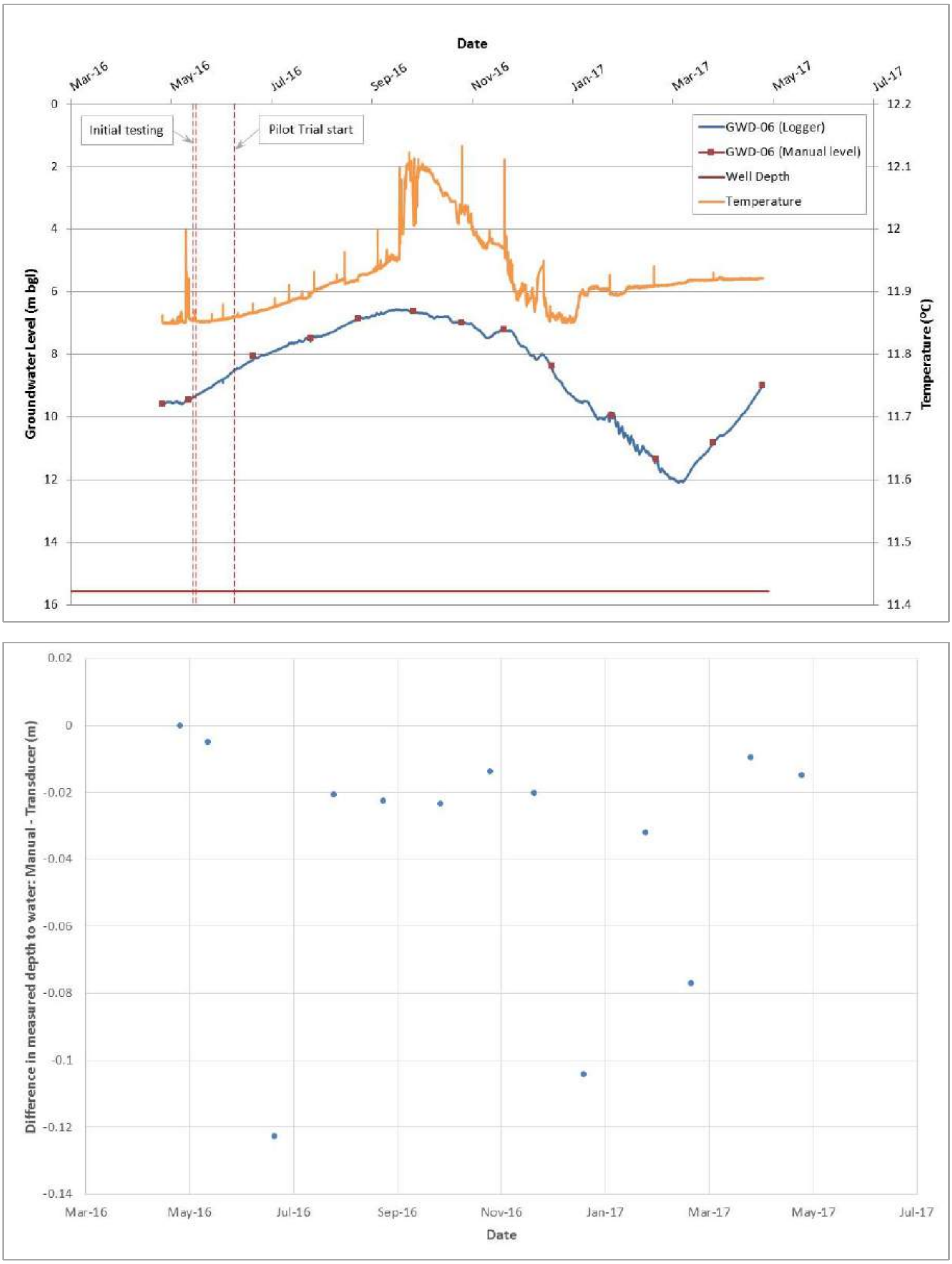
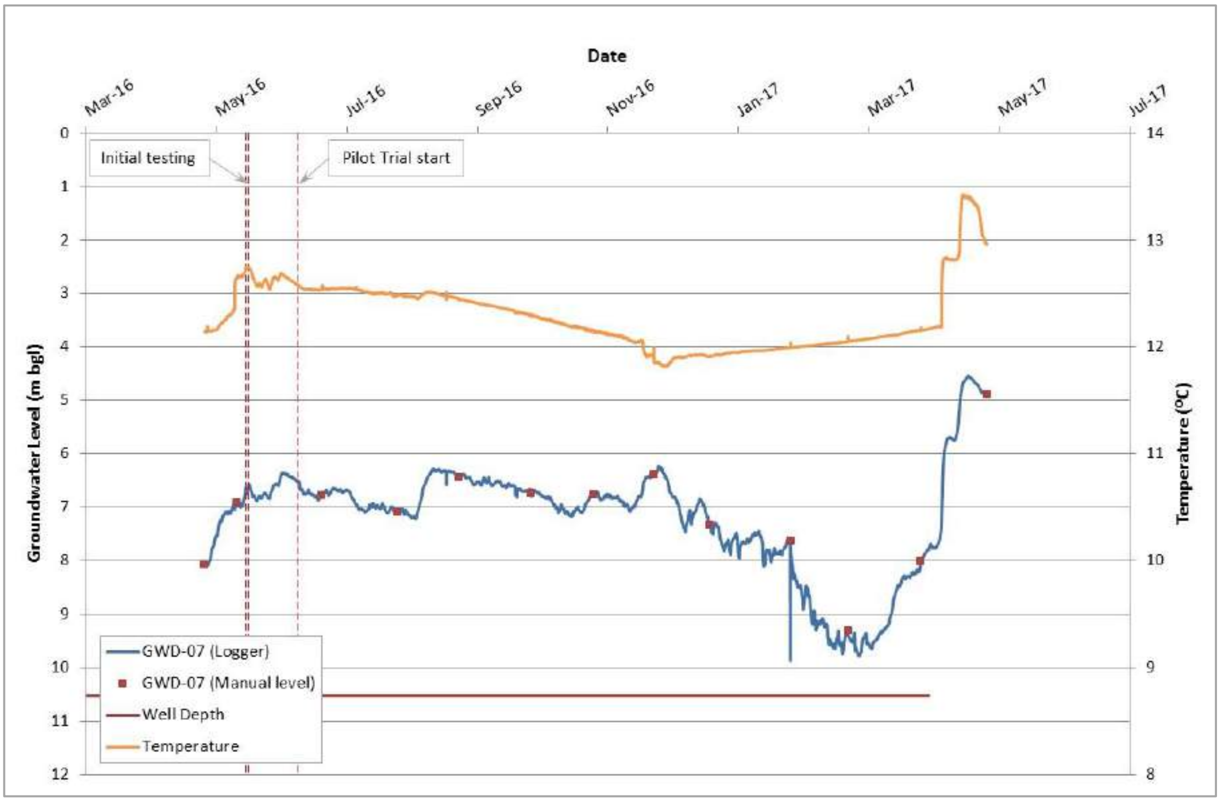


Figure G19: GWD06 depth to groundwater, groundwater temperature and transducer drift charts.



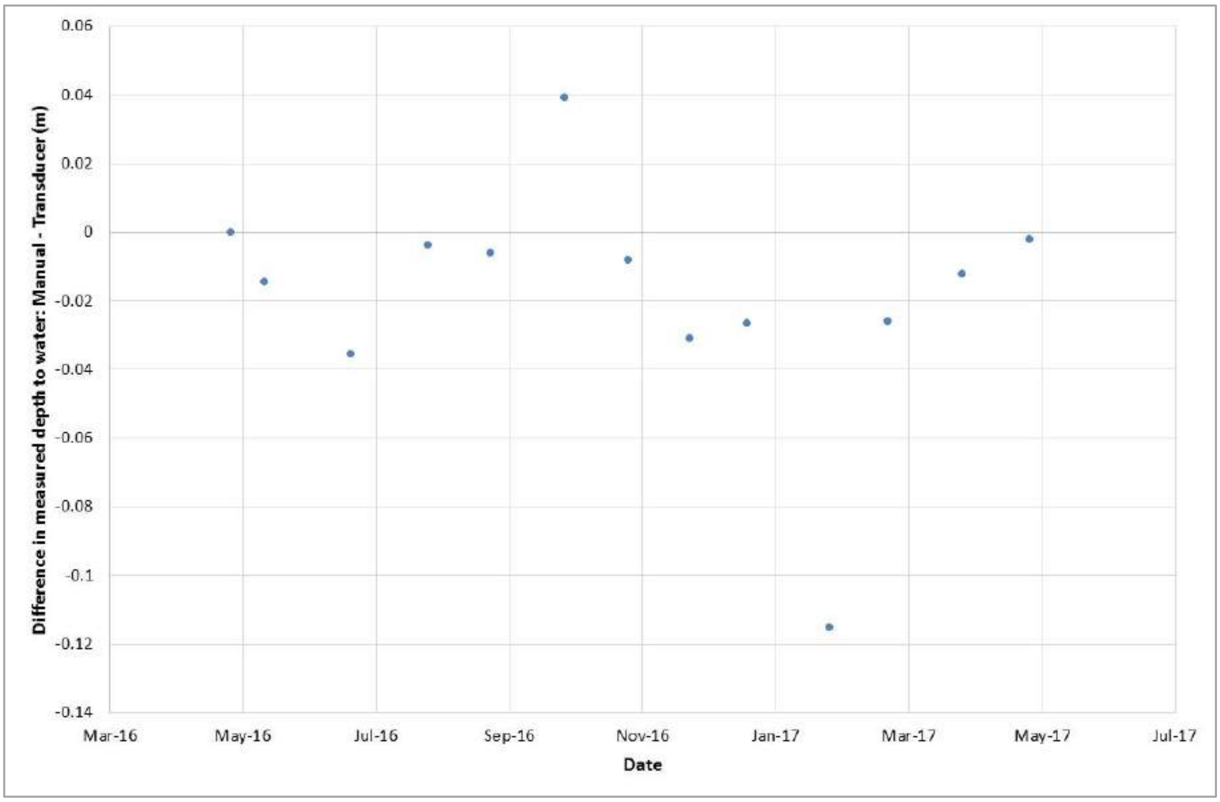


Figure G20: GWD07 depth to groundwater, groundwater temperature and transducer drift charts.

4.0 GROUNDWATER LEVEL RESPONSES TO INFILTRATION

4.1 Introduction

The relevant groundwater system for evaluating the Pilot Trial outcomes 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.

In an unconfined aquifer, a rise in groundwater level means air in the pore spaces of the aquifer above the original groundwater table (the unsaturated zone) is being replaced by water. Correspondingly, groundwater level decreases in an unconfined aquifer represent the drainage of water from previously saturated pore spaces, with these spaces then becoming partly filled with air.

Following the start of recharge operations at an infiltration basin, the downward seepage of groundwater to a shallow regional aquifer does not have an immediate effect on the groundwater table. Time is required for the infiltration water to seep down to the saturated zone of the aquifer and to start increasing the water level 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.

Different aquifer systems respond differently to artificial recharge. The responses summarised in the following sections relate specifically to those observed during the Pilot Trial.

4.2 Effects of Air Entrapment

Filling the infiltration basin with water has two immediate consequences for the unsaturated zone underlying the basin:

1) The air in the unsaturated zone becomes entrapped by the infiltrating water. The pressure of the entrapped air starts to increase due to the weight of the overlying water and the air starts to migrate outward or upward as the water seeps downward from the basin. Some of the migrating air escapes upward, through high permeability zones within the gravels to the floor of the infiltration basin, and is released. The most obvious effect of the outward migration of the entrapped air is the release of bubbles through the ponded water in the infiltration basin. The air also migrates laterally outward to escape through the unsaturated soils around the edges of the basin.

2) As the air pressure in the unsaturated zone beneath the basin increases, the groundwater table beneath the basin is temporarily pushed downward and remains depressed until the air pressure equilibrates with the atmospheric pressure. This effect can be observed in the groundwater level responses recorded from wells very close to the infiltration basin, with an initial drop in groundwater levels even though recharge has been locally artificially enhanced (Figure G21). As the infiltrating water starts to reach the groundwater table, and the air pressure in the soils equilibrates, the groundwater table starts to rise again and subsequently exceeds its initial level. If no air entrapment occurs beneath the basin, the groundwater level simply starts to rise in response to the infiltrating groundwater.

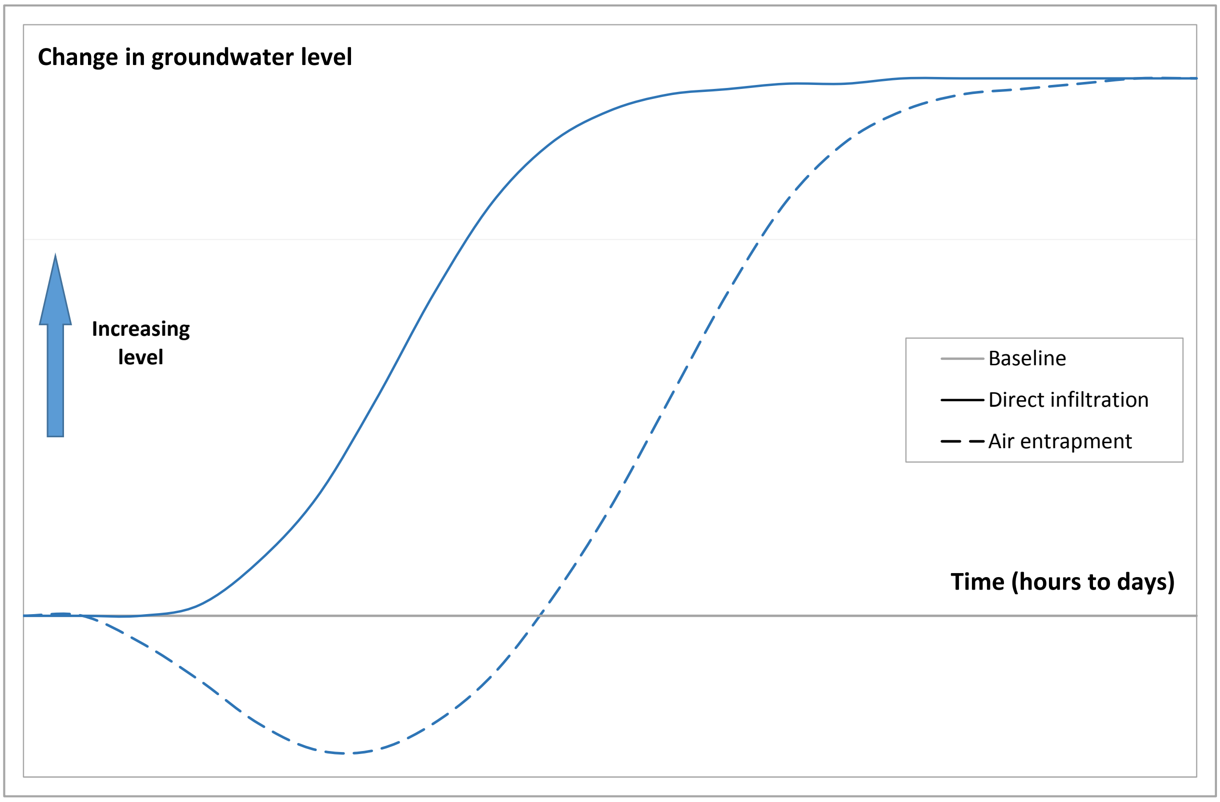


Figure G21: Short term groundwater level responses in monitoring wells beneath infiltration basin.

4.3 Spread of Effects of Infiltration on Groundwater Level

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. One analytical equation used to assess the shape of the groundwater mound is presented in Section 5.2.

As the groundwater mound beneath the basin rises, this rise is propagated laterally outward. The expanding mound is detected at monitoring wells around the basin, with the closest wells reacting first. Generally, the rise in groundwater level at any single monitoring well appears as a smooth gradual curve that settles at a higher level once the mound has stabilised, as shown by the regional groundwater curve in Figure G22.

In the case of the Pilot Trial, some of the MAR water has become channelled through a perched aquifer that has been interpreted as a buried river paleochannel. In cases like this, the infiltrated water in the perched aquifer does not necessarily spread out evenly, but rather flows down-gradient within the buried channel. The groundwater level rises recorded in monitoring wells screened in this perched aquifer tend to occur relatively more rapidly than in the regional aquifer (Figure G22).

At the Pilot Trial site, there is clear evidence to indicate that a few monitoring wells installed and screened in the regional aquifer have also intersected the perched aquifer. Even though the monitoring wells have apparently been correctly installed, and the screen does not extend upward to the perched aquifer, both groundwater level (Figure G23) and groundwater quality responses (refer Appendix H) to the Pilot Trial indicate the monitoring well is reacting to the arrival of water moving through the perched aquifer.

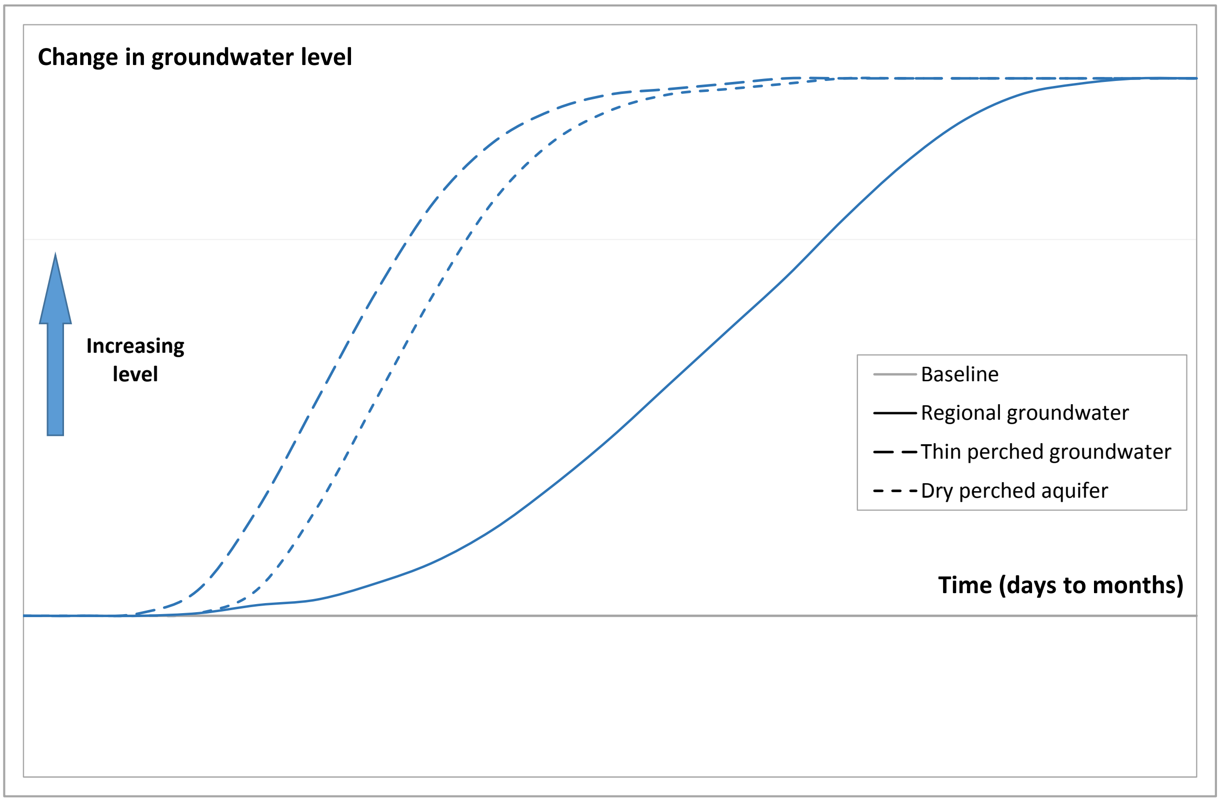


Figure G22: Medium term groundwater level responses in monitoring wells around infiltration basin.

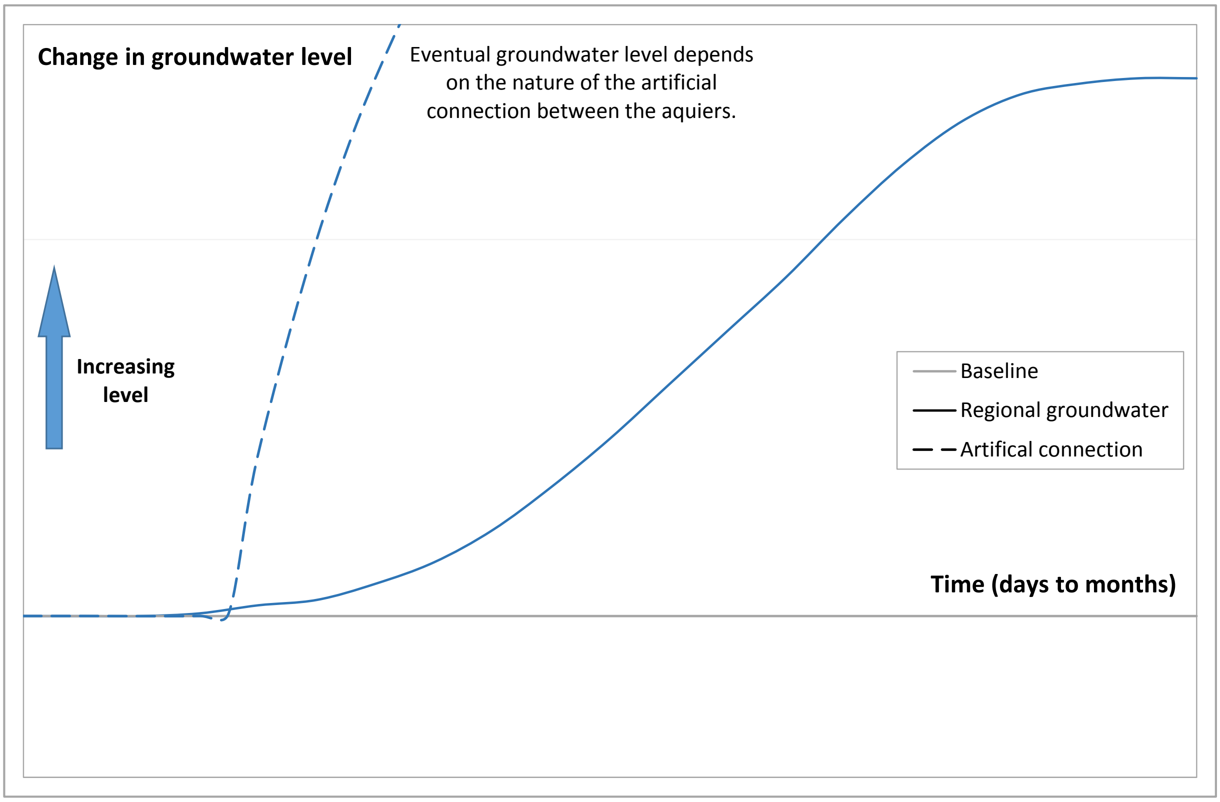


Figure G23: Medium term groundwater responses to perched and regional aquifer interconnection.

In the case of the groundwater level response in the monitoring well, the recorded change in water level starts abruptly and the rise in level is very rapid (Figure G23). The final water level may be much too high to reflect any realistic mounding in the regional aquifer. The most likely scenario is that groundwater is flowing rapidly downward 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 the monitoring well may also 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.

4.4 Comparison of Groundwater Level and Quality Responses

Changes in aquifer water quality, as measured in monitoring wells around the infiltration basin, tend to be considerably delayed in comparison to the pressure response. To effect a change in water quality, the newly introduced water must physically move from the point of infiltration to the point at which the water quality measurements are being made. To do so, the new water physically displaces some of the existing water in the aquifer, either through pushing it laterally outward from the infiltration area or through pushing it downward into a deeper layer within the aquifer. The pressure response to this displacement, which often reflects the movement of the existing water in the aquifer, propagates outward more rapidly than the introduced water can flow.

The primary exception to the rapid pressure response followed by a delayed water quality response described above occurs when the aquifer is mostly or completely unsaturated. In this situation, the aquifer is perched at a level above the regional groundwater table. Natural recharge from the surface seeps downward to the perched aquifer, possibly ponds creating a perched groundwater layer, then leaks further downward to the deeper aquifers of the regional groundwater system.

Introducing water from an infiltration basin to a perched aquifer that is mostly or completely unsaturated in its natural state results in a water quality change propagating outward at almost the same rate as the water level change does. There may be little natural water already in the aquifer so the introduced water does not generate a pressure wave ahead of its own movement. As there is little natural water in the unsaturated aquifer, mixing with the introduced water does not result in substantial changes to the quality of the introduced water.

The extent of the MAR water plume is considered to be the MAR footprint. This footprint in a perched aquifer is unlikely to match the footprint in the regional aquifer, as the two aquifers have different characteristics, different rates of recharge from the infiltration basin and contain different volumes of existing groundwater prior to the start of recharge operations.

5.0 INTERPRETATION OF GROUNDWATER LEVEL RESPONSES

5.1 Groundwater Level Trends

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 G24. The colour coding of the water level records 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. Monitoring during the trial has identified that the groundwater level and groundwater quality trends (refer Appendix H) do not reflect background trends identified from monitoring wells down-gradient from the trial site, with the exception of GWD-07. For this reason, this groundwater level record has not been used to support analysis of the Pilot Trial effects.
- **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. The groundwater level record from GWD-07 generally follows the trends identified in GWE-10, suggesting the Ashburton River has a strong influence on groundwater levels at both locations. This groundwater level record has also not been used to evaluate the effects of the Pilot Trial.

Of the Pilot Trial monitoring wells documented in Section 3.0 and presented in Figure G24, only six wells have shown clear groundwater level responses to the trial (Figure G25). Of these wells, the responses in five (GWE-01, GWD-01, GWD-02, GWD-04 and GWE-04) could be identified and interpreted without the need to correct the data for background changes in groundwater levels.

In each of the above monitoring wells, with the exception of GWE-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. In the case of GWE-04, the well was dry for about the first 120 days following the start of the pre-trial test, so the magnitude and exact timing of the groundwater level response at this site to the Pilot Trial are not well controlled from the test data.

The groundwater level response in the sixth well (GWD-03) needed to be corrected for background groundwater level changes (Figure G26), with the data from GDD-05 being used for this purpose. The interpreted magnitude and timing of the groundwater level response in GWD-03 to the Pilot Trial is presented in Figure G27.

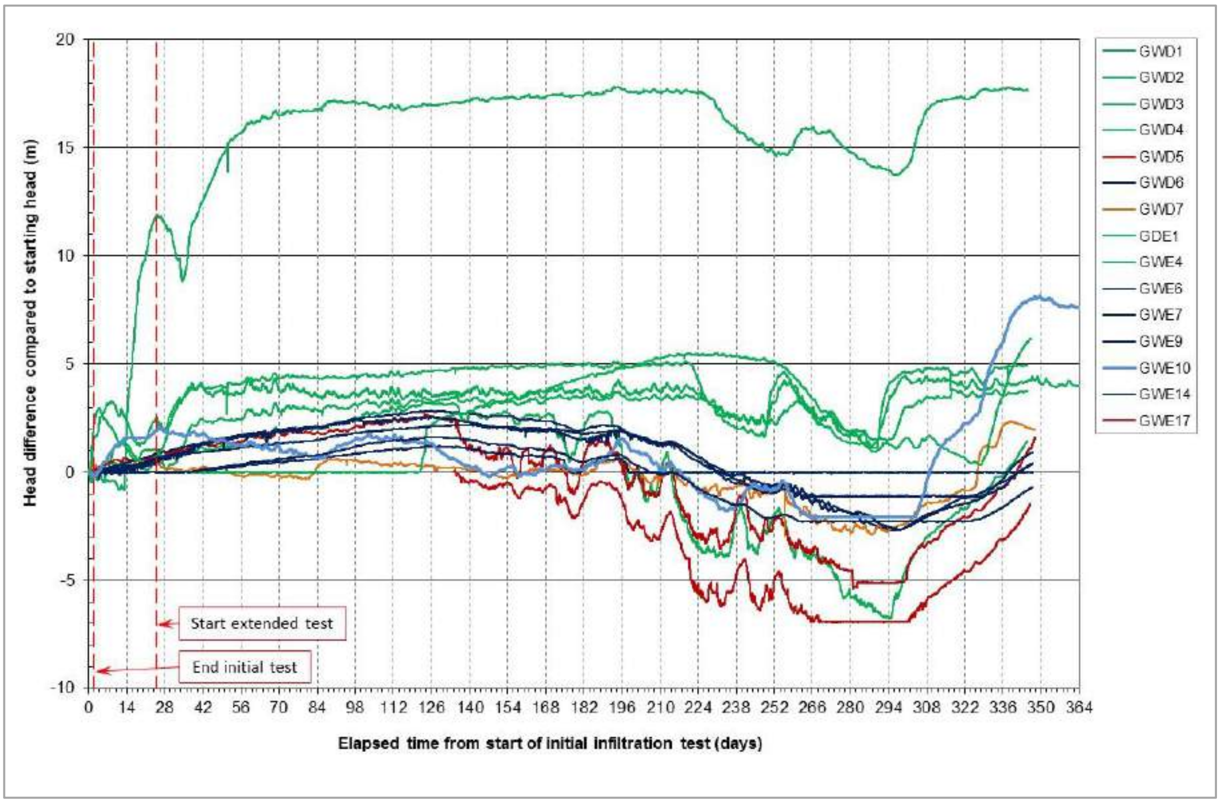


Figure G24: Groundwater level change records for a selection of Pilot Trial monitoring wells.

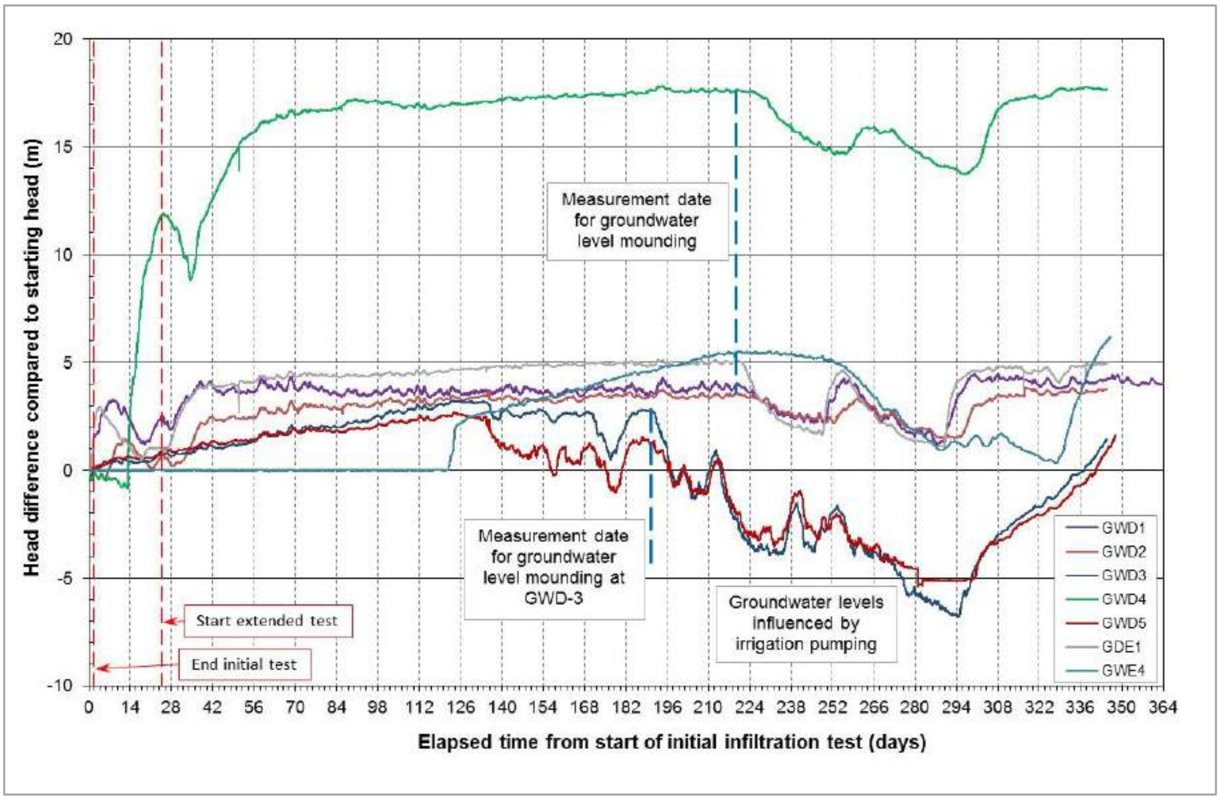


Figure G25: Groundwater level change records for monitoring wells influenced hydraulically by Pilot Trial operations.

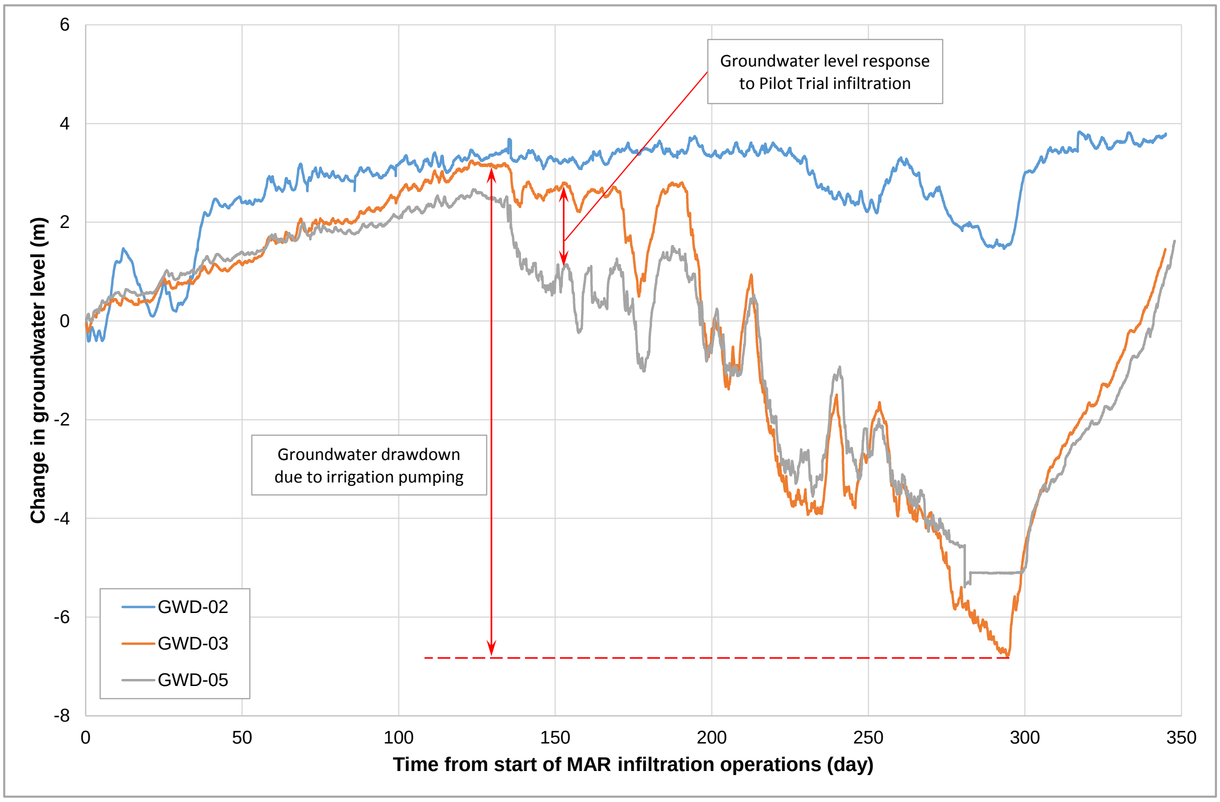


Figure G26: Comparison between groundwater level change records from GWD-03 and GWD-05.

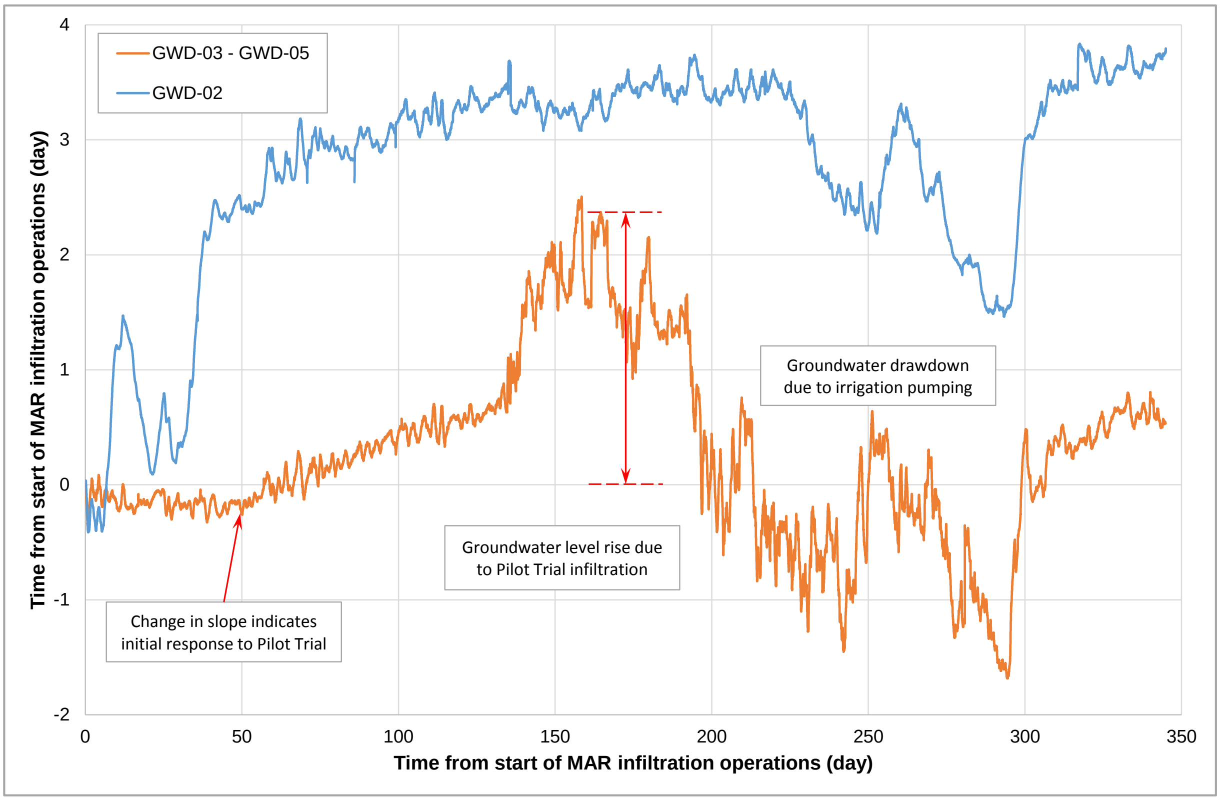


Figure G27: Groundwater level response in GWD-03 corrected for background level trends.

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.

For each of the monitoring wells influenced by groundwater level changes resulting from the Pilot Trial, the above information is presented in Table G2. Two monitoring wells (HWD-04 and GWE-04) that are screened at the regional aquifer level have reacted to groundwater flows and water quality changes within the perched aquifer. This reaction implies that water can freely flow down the outside of these wells, from the upper aquifer to the lower aquifer, and thereby influence both the water quality and level measured in these wells. These two monitoring wells are therefore identified in Table G2 as monitoring the responses of the combined aquifers. This apparent artificially generated connection between the aquifers means that:

1) The magnitude of the groundwater response measured in these wells does not reflect the magnitude of the groundwater level change in either the perched aquifer or the regional aquifer.

2) The water quality data from these two wells is primarily reflecting the quality of water in the perched aquifer.

3) The timing of the groundwater level and quality responses in these wells reflects the rate at which groundwater is flowing through the perched aquifer.

Table G2: Groundwater level responses to Pilot Trial recharge.

Monitoring well	Distance to MAR infiltration basin (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	19	16/05/2016 17:30	1.4	4.05	Regional	Yes
GWE-01	45	17/05/2016 3:00	0.40	5.12	Perched	Yes
GWD-02	274	23/05/2016 8:30	6.6	3.61	Regional	Unclear
GWD-04	938	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	2,308	9/09/2016 10:15	115.7	5.51 (4)	Combined	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.
3) Calculated through comparison of groundwater record with that 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.

The monitoring wells detecting regional aquifer groundwater level responses, are located along a transect effectively aligned toward the east from the Pilot Trial site along Timaru Track Road. This contrasts with the series of monitoring wells that have detected changes in groundwater quality as well as level, which are aligned along a transect toward the southeast from the Pilot Trial site along Frasers Road (Figure G1).

5.2 Groundwater Mounding

In addition to the flow of MAR water toward the southeast in the perched aquifer, the enhanced groundwater recharge to the regional aquifer beneath the Pilot Trial site has resulted in localised “mounding” of the regional groundwater table. Assessment of the extent and magnitude of the groundwater mounding has been done using the equation presented below (Bouwer 2002), which is appropriate for an unconfined aquifer.

$$H_c - H_n = \frac{iR^2}{4T}\left(1 + 2ln\frac{R_n}{R}\right)$$

Where:

H_c = Height of the groundwater mound in the centre of the recharge area.

H_n = Height of the groundwater mound at a specified monitoring point outside the recharge area.

i = The average infiltration rate in the recharge area (total recharge / total area).

T = Transmissivity of the aquifer

R = Equivalent radius of the recharge area.

R_n = Distance from the centre of the recharge area to the specified monitoring point.

Using the above equation, the extent and magnitude of groundwater mounding resulting from the Pilot Trial recharge can be 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 operations during Year 1 (Figure G25) were applied to the equation to calculate a groundwater level change beneath the centre of the basin of 4.40 m (Table G3). Extrapolating outward from the centre of the basin, groundwater level increases were then calculated for distances of up to 2,000 m from the basin (Table G3).

The calculated groundwater level rise at GWD-03 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 (Figure G25).

It is important to recognise that the Pilot Trial does not represent a steady state condition, which is a fundamental assumption incorporated in the calculations. The outward development of a groundwater mound is not instantaneous. Time is required for the groundwater mound to develop and expand outward. As such, the calculated mounding at distances beyond one kilometre from the basin is likely to significantly overestimate the actual rise in groundwater. For this reason, the line indicating the extent and magnitude of calculated groundwater mounding should not be extrapolated beyond what has been presented in Figure G28.

Table G3: Calculated extent and magnitude of groundwater mounding.

Monitoring wells	Distance from centre of basin (m)	Measured groundwater mounding (m)	Calculated groundwater mounding (m)	Hydraulic gradient (m/m)	Volume of groundwater (m^3) (1)	Cumulative volume of groundwater (m^3) (1)
	0		4.40	0.00	0	0
	55		4.22	0.0033	1,403	1,400
GWD-01 (2)	90	4.05	4.05	0.0049	2,202	3,600
	100		4.01	0.0046	806	4,400
	150		3.87	0.0028	5,166	9,600
	200		3.77	0.0020	7,010	16,600
	250		3.70	0.0015	8,798	25,400
	300		3.63	0.00126	10,544	35,900
GWD-02 (2)	320	3.61	3.61	0.00112	4,698	40,600
	350		3.58	0.00107	7,556	48,200
	400		3.53	0.00093	13,935	62,100
	500		3.46	0.00077	32,814	94,900
	600		3.39	0.00063	39,268	134,200
	1,000		3.21	0.00044	219,104	353,300
	1,500		3.07	0.00028	406,852	760,200
GWD-03 (3)	1,659	2.14	3.04	0.00022	159,124	919,300
	2,000		2.97	0.00020	388,243	1,307,500

Notes: 1) A drainable porosity of 0.035 m^3/m^3 is assumed.
2) Measured values used for equation calibration.
3) Measured value used to confirm projection. Groundwater had not reached level before being affected by groundwater abstraction for irrigation purposes.

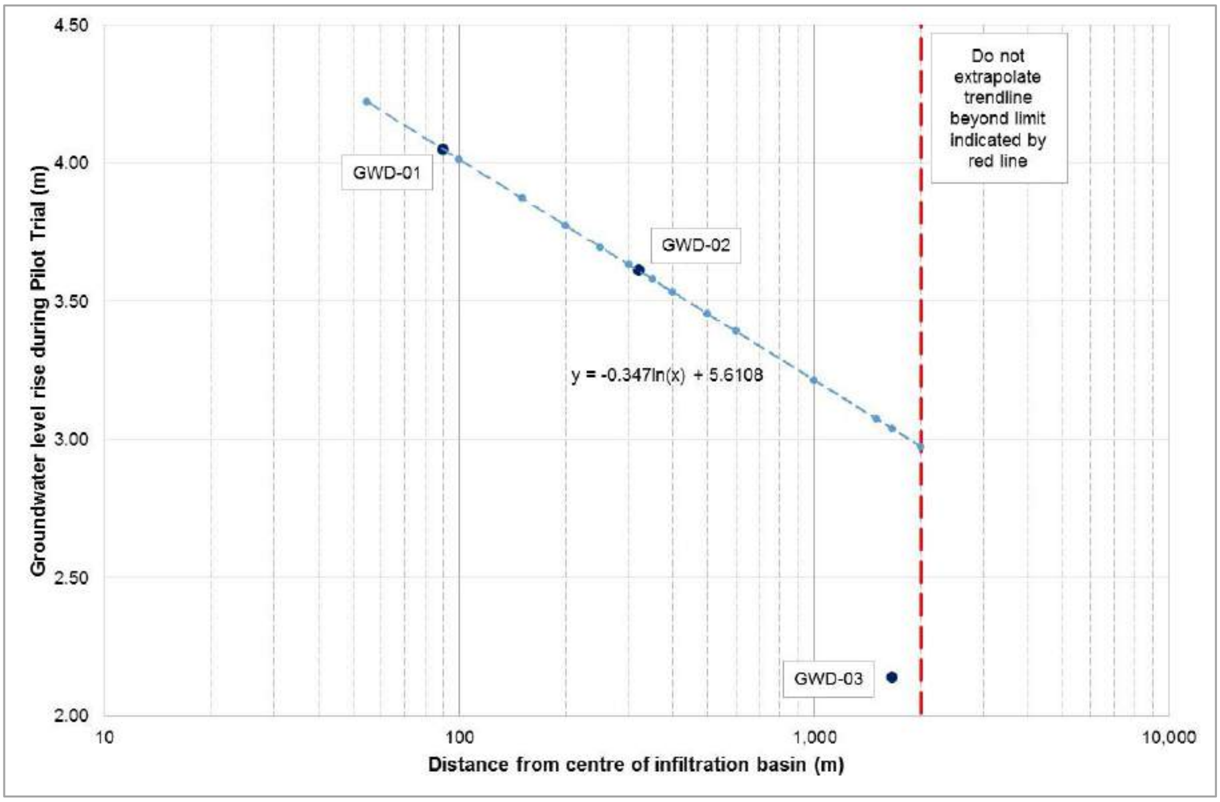


Figure G28: Extent and magnitude of groundwater level rise in regional aquifer transect.

The calculated groundwater rise presented in Figure G28 is independent of the transmissivity of the aquifer. However the rate of recharge from the infiltration basin required to maintain this groundwater mound profile increases with increasing aquifer transmissivity. This link between aquifer transmissivity and the mound profile enables a high level assessment of the potential distribution of the recharge water between the regional aquifer and the perched aquifer to be made.

The transmissivity of the unconfined regional aquifer in the general Pilot Trial area is estimated to be in the order of 2,000 m^2/day (P. Durney, pers comm). Recharge rates for the regional aquifer to maintain this mounding profile have therefore been evaluated covering a transmissivity range from 500 m^2/day to 3,000 m^2/day (Table G4). This initial sensitivity analysis provides a general indication of the potential distribution of MAR water between the two aquifers under different regional aquifer transmissivity scenarios.

Assuming the regional aquifer transmissivity in this area is approximately 2,000 m^2/day, the recharge required to maintain the groundwater mounding profile is approximately 4,360 m^3/day, totalling approximately 1.3 Mm^3 during Year 1 of the Pilot Trial (Table G4). This recharge volume implies the remaining approximately 1.1 Mm^3 of MAR water is diverted through the perched aquifer. The water from the perched aquifer would not remain in this aquifer but would rather seep downward through the underlying layer further down-gradient and thence contribute to the regional aquifer further southeast.

If a drainable porosity of 0.035 m^3/m^3 is applied to the regional aquifer, the recharged volume of water required to maintain the hydraulic gradients of this aquifer profile during Year 1 of 1.3 Mm^3 (Table G4) approximately matches the drainable pore space taken up by the groundwater mound within a radius of 2,000 m of the Pilot Trial site (Table G3). There is evidence to indicate that the groundwater mound may not have extended far past GWD-03 during Year 1, including the form of the breakthrough curve presented in Figure G27.

Table G4: High level MAR water distribution scenarios.

Regional aquifer				Perched aquifer			
Aquifer transmissivity m^2/day	Recharge rate m^3/day	Year 1 volume (m^3)	% of total infiltration	Flow path width (1) (m)	Recharge rate m^3/day	Year 1 volume (m^3)	% of total infiltration
500	1,089	326,745	14	1,002	6,911	2,073,255	86
750	1,634	490,118	20	923	6,366	1,909,882	80
1,000	2,178	653,490	27	844	5,822	1,746,510	73
1,250	2,723	816,863	34	765	5,277	1,583,137	66
1,500	3,267	980,236	41	686	4,733	1,419,764	59
1,750	3,812	1,143,608	48	607	4,188	1,256,392	52
2,000	4,357	1,306,981	54	528	3,643	1,093,019	46
2,250	4,901	1,470,353	61	449	3,099	929,647	39
2,500	5,440	1,632,092	68	371	2,560	767,908	32
2,750	5,990	1,797,099	75	291	2,010	602,901	25
3,000	6,535	1,960,471	82	212	1,465	439,529	18

Notes: 1) A drainable porosity of 0.035 m^3/m^3 is assumed.
2) Measured values used for equation calibration.

5.3 Perched Aquifer Flows

Changes in groundwater levels linked to flows through the perched aquifer have been detected out to GWE-04, approximately 2,308 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 aquifer would have reached a distance of approximately 6,900 m from the basin. This calculation assumes the supply of water to the aquifer continued to exceed the leakage losses through the base of the aquifer, and the shape of the perched aquifer does not change form to the southeast of GWE-04.

Monitoring well GWE-11 did not show a clear groundwater level response to the arrival of MAR water at this location. However, the nitrate-N concentrations detected in samples from GWE-11 decreased substantially approximately 308 days after the start of the initial infiltration test (Table G5). The very slow flow velocity of 1.2 m/day calculated based on the travel time to this well (Table G5) suggests this well is outside the main perched seepage flow channel toward the southeast. If it is assumed 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, the width of the seepage path would be twice the distance from the basin to GWE-11 or in the order of 700 m.

The estimated perched seepage path width based on field observations corresponds reasonably well with the calculated seepage path width of 660 m under the scenario for the regional aquifer with a transmissivity of 2,000 m/day presented above (Table G4). The flow path widths presented in Table G4 have been calculated based on the form of a very low pyramid with a base 6,900 m long and a maximum height of 5 m, which was approximately the amount of groundwater rise recoded in GWE-01 (Table G2) and a drainable porosity of 0.035 m^3/m^3.

A drainable porosity of 0.035 m^3/m^3 used to calculate the volume of groundwater in the regional aquifer mound (Table G3) and the perched aquifer flow path width in Table G4. This porosity corresponds well with the porosity applied to the calibrated 3D groundwater model developed independently to simulate groundwater level and quality changes as a result of the Pilot Trial (refer Appendix N).

Table G5: 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
		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						
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 much shorter than 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.

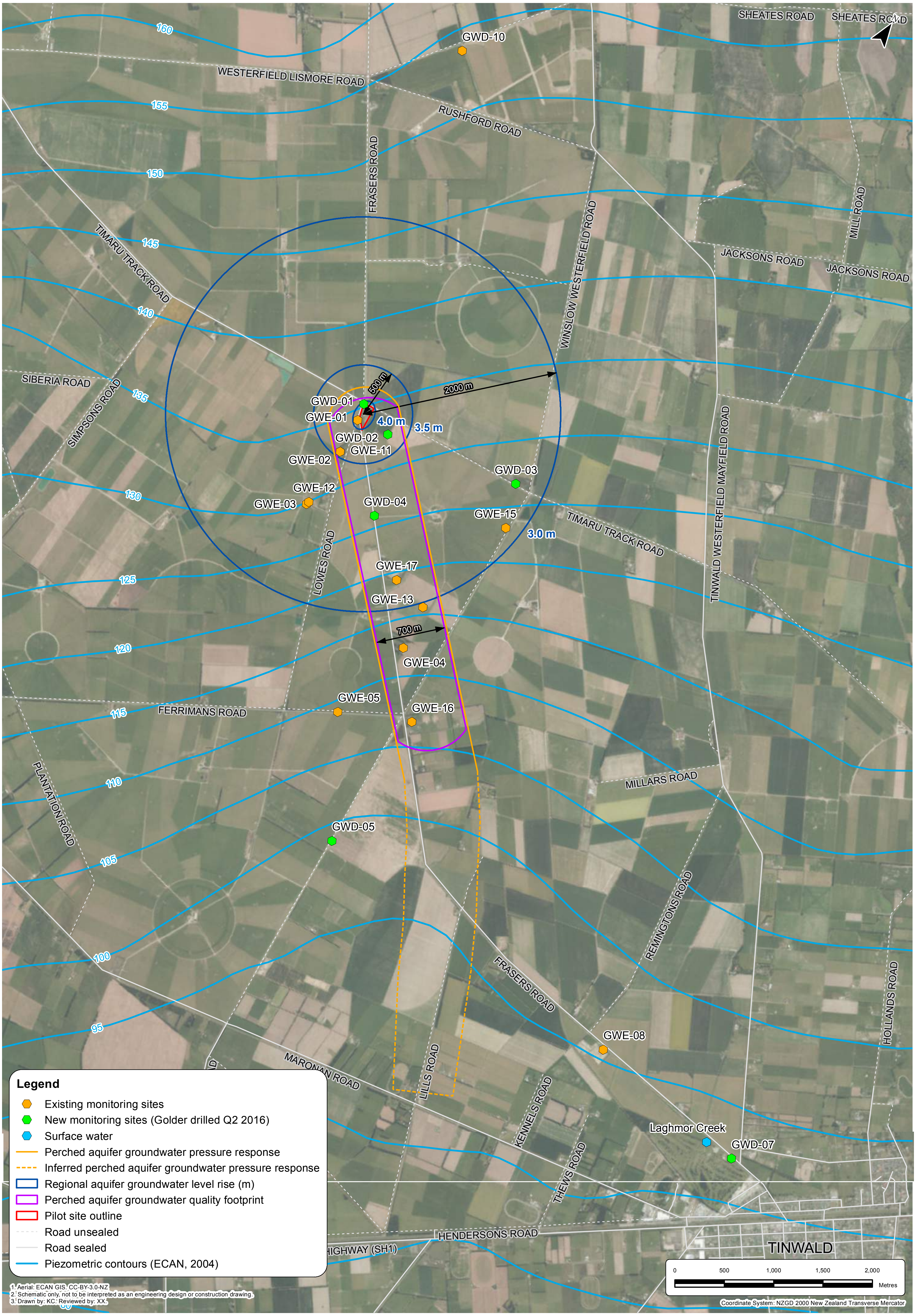
An indication of the likely extent of groundwater level rises resulting from introduction of MAR water to the groundwater system is presented in Figure G29. This layout is based on the analytical assessment of the data presented in this appendix and remains a relatively high level assessment. This layout does however provide a basis for understanding the outcomes of the Pilot Trial during Year 1, and for comparison with the 3D groundwater modelling outcomes presented in Appendix N.

6.0 IMPLICATIONS FOR A GROUNDWATER REPLENISHMENT SCHEME

There are several aspects of the information presented in this report that are important for consideration in the planning and design of a regional GRS.

Firstly, it is important to recognise that 2015 and 2016 were two of the driest years in the Hinds catchment since 1990. During the Pilot Trial, rainfall only substantially exceeded evapotranspiration during March and April 2017 (refer Appendix B).

Groundwater levels in the monitoring wells hydraulically affected by the Pilot Trial all finished Year 1 higher than at the start of the year by between 2 m and 6 m (excluding GWD-04, which did not reflect groundwater level increases). Most of the monitoring wells that were not influenced by the Pilot Trial finished the year with groundwater level similar to those recorded at the start of the year, or showed a drop in level. The exceptions were GWE-10 and GWD-07, both of which may have been influenced by recharge from the Ashburton River.



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: KC. Reviewed by: XX.

Golder Associates

TITLE GROUNDWATER LEVEL & QUALITY RESPONSES TO PILOT TRIAL OPERATIONS

JULY 2017

PROJECT 1538632

G29

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Groundwater mounding in the Regional Aquifer during Year 1 extended to at least 1.6 km from the infiltration basin, and more likely out to 2 km from the basin. At 1.6 km from the basin the observed groundwater level increase as a result of the Pilot Trial exceeded 2 m. This extent of mounding in the regional aquifer implies that MAR sites can potentially be widely spaced and still achieve overlapping effects in terms of increasing groundwater levels in the regional aquifer.

Even at a distance of 1.6 km from the Pilot Trial site (GWD-03) there is clear evidence that the trial operations reduced the groundwater drawdown effects of the seasonal pumping for irrigation purposes.

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APPENDIX H

Groundwater Quality Responses

1.0 APPENDIX STRUCTURE

This appendix summarises the source water groundwater quality responses to the Hind MAR Pilot Trial in terms of observed changes in groundwater levels. The Appendix is divided into the following sections.

- Section 2.0 presents the locations of the monitoring wells used to monitor groundwater quality and the sampling regimes applied to these wells prior to the Pilot Trial and during the trial.
- Section 3.0 summarises the source water quality data for the infiltration basin (refer Appendix E for more detailed information on source water quality).
- Section 4.0 summarises the groundwater quality data acquired during the Pilot Trial, the grouping of monitoring wells for the purposes of analysing the influence of water infiltrated during the trial, baseline trends in nitrate-N concentrations within the Pilot Trial command area prior to the start of the trial and charts comparing the nitrate-N changes in individual monitoring wells with changes in groundwater level during the trial.
- Section 5.0 documents the effects of the introduction of the source water from the infiltration basin to the receiving groundwater beneath the Pilot Trial infiltration basin, focusing on changes in nitrate-N concentrations and the transport of *E. coli* to the groundwater system.
- Section 6.0 summarises the influence the Pilot Trial has had on receiving groundwater quality down-gradient from the site, with a focus on nitrate-N and *E. coli*.
- Section 7.0 presents an interpretation of the extent of the influence the MAR Pilot Trial has had on groundwater quality through Year 1 of the Pilot Trial.
- Section 8.0 provides a summary of the information presented in this appendix and the interpretation of this information with respect to improving groundwater quality down-gradient form the Pilot Trial site.

The information presented in this appendix should be considered in conjunction with the information presented in the following appendices to this report.

- Appendix C documents the groundwater and surface water monitoring locations for the Pilot Trial.
- Appendix E documents source water quality for the Pilot Trial, from the RDR off-take at the Rangitata River through to the Pilot Trial infiltration basin.
- Appendix F documents the observed changes in groundwater level in response to the Pilot Trial.

2.0 WATER QUALITY MONITORING

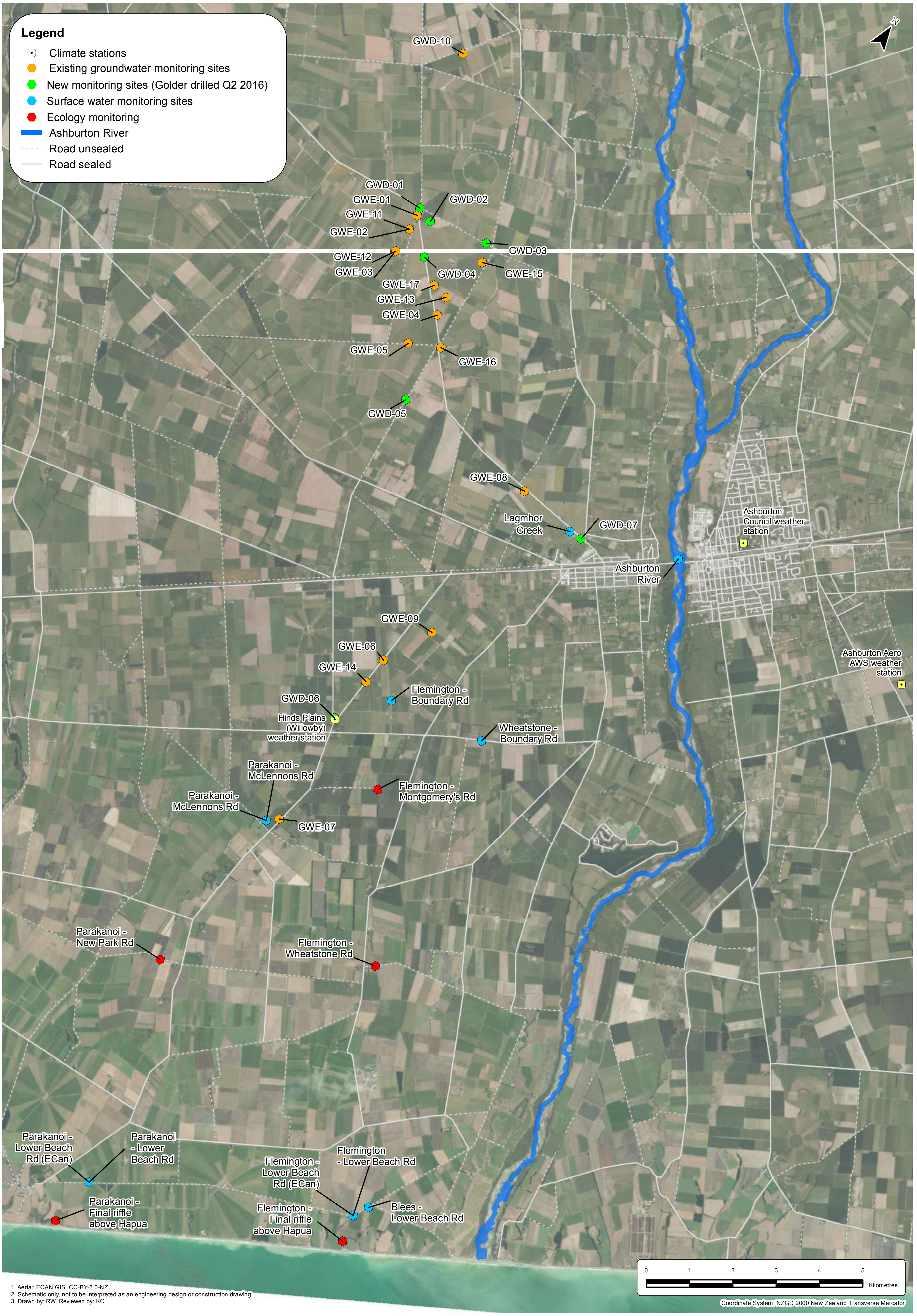
2.1 Locations

Water enters the Pilot Trial infiltration basin via an irrigation water delivery race that is sourced from Valetta pond #3 (Figure 3 of main report), the final pond in the Rangitata Diversion Race (RDR) fed Valetta irrigation network. This is the primary source of water for the Pilot Trial. Source water quality is monitored at both Flume 1 (immediately downstream from Valetta pond #3 outflow) and in the Pilot Trial infiltration basin.

A total of 24 groundwater wells have been monitoring as part of the Pilot Trial (Figure H1). These monitoring wells are documented in Appendix C. Most of the monitored wells are outside the area apparently influenced by recharge water from the Pilot Trial, as identified by increases in groundwater levels (refer Appendix F).

2.2 Sampling and Analysis Regime

Groundwater monitoring was initiated one month prior to commissioning of the Pilot Trial. At that stage the monitoring regime was applied to all wells identified as potential monitoring wells before the beginning of the Pilot Trial. As more wells were identified during the trial, and knowledge of the groundwater response to the trial increased, further wells were added to the project monitoring network. In each case the same sampling and parameter analysis regime was applied (Table H1).



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TITLE **Groundwater Monitoring Well Locations**

JULY 2017

PROJECT 1538632

H1

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Table H1: Summary of water quality sampling parameters (Year 1).

Frequency	**Sample Location**										
Parameter analysed	***E. coli*** **(MPN/100 ml)**	**Total Coliforms (MPN/100 ml)**	**Turbidity (NTU)**	**pH**	**Electrical conductivity (mS/m)**	**TSS (g/m^3)**	**Nitrogen [(1)] (g/m^3)**	**Dissolved reactive phosphorus / total phosphorus (g/m^3)**	**Hardness (g/m^3 as HCO^3)**	**Anions / cation profile [(2)] (meq/L)**	**Dissolved metals [(3)] (g/m^3)**
Pre-trial (May 2015)	Pilot Trial source water (Valetta Pond #3)	Parameter not analysed			Pilot Trial source water (Valetta Pond #3)		Parameter not analysed				
Pre-trial (May 2016)	All source water, selected surface water and selected groundwater sites.		Selected surface water and selected groundwater sites								
Monthly	First six months of trial: all source water, surface water and groundwater sites. Final six months of trial: selected source water, surface water and groundwater sites.		All source water, surface water and groundwater sites					First sample round after a new site was added during Pilot Trial			
End of Trial	Selected source water, surface water and groundwater sites.		All source water, surface water and groundwater sites					Parameter not analysed			

Notes:
1) Three forms of nitrogen analysed (total nitrogen, nitrite-N, nitrate-N.
2) Ca, Mg, Na, K, hardness, alkalinity, bicarbonate, carbonate, SO_4 and Cl.
3) As per Hills Laboratory NZDW suite for metals.

Water quality sampling was undertaken at the monitoring wells on a monthly basis throughout the first year of the Pilot Trial. The groundwater samples were analysed for a range of water quality parameters, as summarised in Table H1. As knowledge of the groundwater response to the trial increased, analysis of samples for *E. coli* and Total Coliforms was restricted to monitoring wells that were clearly being influenced by recharge water.

3.0 SOURCE WATER QUALITY

3.1 Nitrate

A key parameter monitored for the Pilot Trial has been Nitrates. Concentrations of Nitrate-N + Nitrite-N within the Pilot Trial source water were consistently low (Figure H2). This is of significance as one of the major Pilot Trial objectives is to decrease the concentration of Nitrates in the regional groundwater system. The way a MAR scheme will help to achieve this objective is via dilution, requiring a low concentration of Nitrates in the source water.

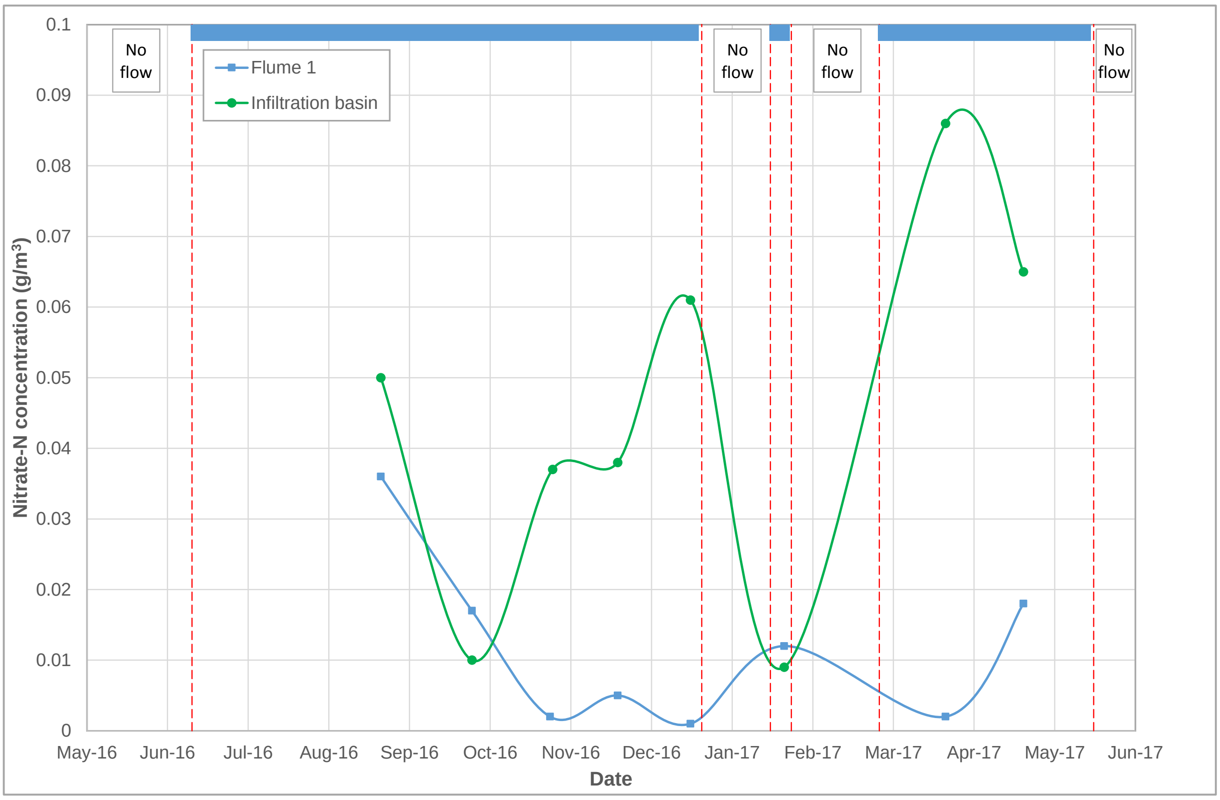

Figure H2: Source water nitrate-N concentrations during the Pilot Trial.

3.2 E. coli

E. coli within the Pilot Trial source waters were also monitored to develop a record that could be used to track any *E. coli* spikes seen in the Pilot Trial bores. *E. coli* levels appear to show a seasonal trend associated with increased water temperatures over the summer months (Figure H3).

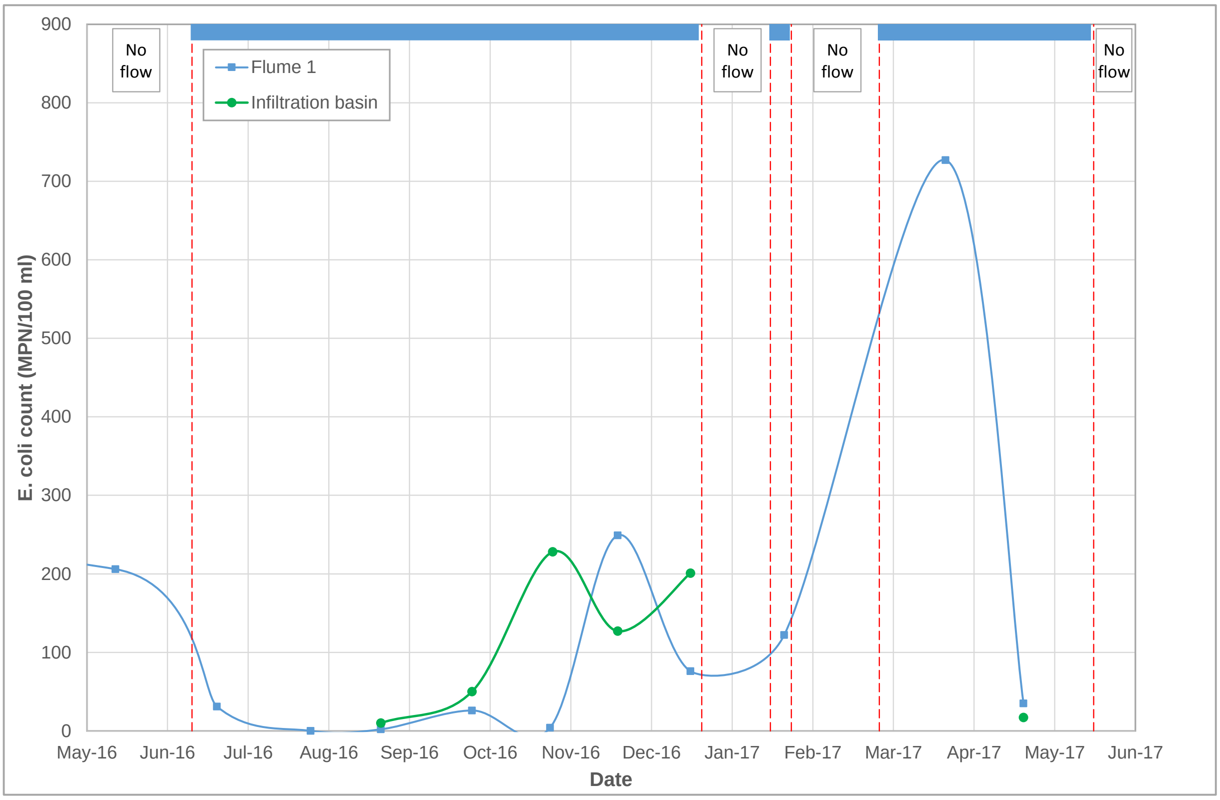

Figure H3: Source water E. coli *counts prior to and during Pilot Trial.*

4.0 GROUNDWATER QUALITY DATA

4.1 Baseline Groundwater Quality Data

Three of the wells monitored for groundwater quality during the Pilot Trial had also been monitored by CRC as part of an environmental monitoring program. Water quality analysis datasets for GWE-1, GWE-5 and GWE-16 extend back as far as 2001 (Table H2).

Table H2: Baseline nitrate-N concentrations in GWE-1, GWE-5 and GWE-16.

Date	Nitrate-N (g/m^3)		
	GWE-1	GWE-5	GWE-16
25/09/2001			6.1
14/12/2001			6.3
09/04/2002			6.1
15/07/2002			5.9
16/10/2002			6.0
27/01/2003	3.5	6.7	5.6
29/04/2003	2.1	0.8	6.1
21/07/2003	5.0	1.2	5.8
20/10/2003	3.3	1.8	5.9
20/01/2004	3.0	7.4	5.2
20/04/2004	0.7	7.2	5.6
26/05/2004	2.8	7.0	
20/07/2004	2.4	5.0	7.6
04/08/2004	2.2	7.4	
18/10/2004	2.1	7.0	6.7
10/11/2004	2.0		
19/01/2005	4.9	8.2	5.8
09/02/2005	4.4	7.6	
18/04/2005	6.0	7.3	5.0
04/05/2005	3.2	7.2	
18/07/2005	2.9	7.3	6.6
17/10/2005	4.0		5.7
17/01/2006	2.4		4.8
14/03/2006	1.6	9.2	
24/04/2006	0.7	9.4	4.9
24/07/2006	4.6	10.7	4.9
16/08/2006	3.5	9.9	
16/10/2006	7.6	15.0	6.1
15/01/2007	6.9	6.4	6.3
16/04/2007	2.7	12.0	6.8
17/07/2007	3.8	10.0	4.5
15/10/2007	3.5	11.0	5.5
23/01/2008	3.8		5.6
29/04/2008	3.1	17.0	5.7
08/07/2008	4.4		5.3
17/07/2013	8.6		
24/04/2014	11.0	11.1	
13/04/2015	7.5		

Data supplied by CRC.

4.2 Pilot Trial Groundwater Quality Data

For the purposes of this report, the groundwater is considered to be the receiving water, with the infiltrated water influencing the quality of the groundwater. During this trial 24 wells have been monitored for groundwater quality. Not all of these wells were monitored at the start of the trial as the monitoring program has been progressively adapted to focus on the area affected by the plume of clean infiltrated water. In some cases issues arose with the monitoring wells, including groundwater levels that dropped below the bottom of the well, resulting in incomplete records for those wells.

Testing of samples from most of the monitoring wells for E. coli was discontinued after it was identified that *E. coli* was not being detected in monitoring wells GWD-01 and GWE-01. These two wells are located adjacent to the Pilot Trial site and were immediately affected by the Pilot Trial operations. If the water quality in these two bores was not influenced by *E. coli* in the source water, then it is very unlikely that wells further from the Pilot Trial site would be affected.

The monthly groundwater nitrate results for all 24 wells within the Pilot Trial monitoring program are provided in Table H3. The monthly groundwater *E. coli* results are presented in Table H4.

4.3 Grouping of Monitoring Wells for Evaluation

The effects of the introduction of MAR water to the quality of water in the aquifer system need 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 (Table H5 and Figure H4). The groups identified in Table H5 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 (refer Section 5.0), 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 (refer Section 6.0).
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 (refer Section 6.0).
4) Eight monitoring wells that are generally located further from the Pilot Trial. The water quality data from bores further afield, such as those installed to monitor groundwater quality in the area of the coastal drains or close to Tinwald, has been excluded from this assessment of background groundwater. This exclusion was due to evidence of the quality of groundwater at these sites being influenced by factors not applicable at or close to the Pilot Trial site. These other factors, such as groundwater interaction with drainage systems and the changing land use toward Tinwald, may need to be taken into account in future water quality assessments, as the MAR plume extends further toward the coast.

Table H3: Groundwater nitrate-N results (g/m^3).

Year		2015	2016								2017					
Month	**Bore ID #**	**May**	**May**	**June**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**March**	**April**	**May**	**June**
GWD-01	BY20/0149		3.2	4.2	3.9	3.3	2.8	2.5	2.2	1.7	1.89	2.3	1.27	1.12	0.93	1.34
GWD-02	BY20/0150		2.6	1.89	2.3	2.9	2.9	2.9	2.3	1.91	2.5	2.8	1.69	1.35	1.54	2.4
GWD-03	BY20/0151		7.6[1]	13.5	13.5	13.8	13.4	13.8	14.2	13.7	12.8	14.0	14.3	14.8	13.1	14.1
GWD-04	BY20/0152		6.2	6.9	3.7	3.0	2.5	2.3	2.5	2.3	2.4	3.0	3.1	2.9	2.5	2.1
GWD-05	BY20/0153		9.0 [1]	13.3	13.1	13.0	12.5	13.2	13.1	13.5	11.3	13.7	15.1	11.6	11	11.1
GWD-06	BY21/0183		11.0	11.8	10.9	11.0	10.5	11.1	10.7	10.6	10.3	10.2	11.7	11.1	10.7	10.6
GWD-07	BY21/0184		3.1[1]	5.0	5.0	6.1	6.9	6.2	3.6	5.6	6.2	6.8	7.4	22.0	18.6	13.7
GWE-01	K37/1748	5.4	3.6	0.71	2.1	1.59	1.32	1.28	0.93	0.53	0.4	0.33	0.175	0.195	0.093	0.47
GWE-02	K37/0204		Well dry			0.012	0.165	0.06	0.12	Well dry			11.0	5.0	3.1	0.65
GWE-03	K37/0357		6.90	19.3	Well dry	27.0	Well dry		28.0	21.0	26.0	21.0	27.0	26.0	23.0	24
GWE-04	K37/0200		Well dry				12.7	13.2	11.6	11.1	8.8	4.9	1.23	4.8	3.2	3.3
GWE-05	K37/1749		Well dry											8.3	Well dry	
GWE-06	K37/0972		Well dry				12.2	12.6	Well dry							12
GWE-07	K37/0351		Added to replace dry bores	13.8	12.4	15.1	13.2	13.8	13.9	14.3	12.9	Well dry		24.0	13.9	13.7
GWE-08	K37/3052			Well dry												
GWE-09	K37/1938			17.6	17.9	16.8	16.5	17.6	17.5	17.7	15.6	9.7	18.6	17.5	15.9	17.7
GWE-10	K37/0215			0.014	0.016	0.015	1.022	0.010	0.071	0.024	0.008	0.01	0.03	0.039	0.043	0.062
GWE-11	K37/1747			11.7	6.3	8.9	N/A	10.5	5.0	10.3	10.5	N/A	11.8	9.6	6.1	1.0
GWE-12	K37/1540			8.2	7.8	7.8	7.4	8.1	8.6	8.5	8.4	8.7	9.6	17.2	10.9	9.2
GWE-13	K37/1649			9.7	9.1	9.6	9.3	9.6	9.4	9.5	9.2	9.5	9.5	9.90	11.5	9.7
GWE-14	K37/0383			11.3	10.5	9.9	9.7	10.7	10.3	10.7	10.10	Well dry		10.0	9.6	9.3
GWE-15	K37/2458		Added to replace dry bores			12.6	11.6	10.8	11.9	11.4	9.2	9.7	10.2	11.0	11.2	11.7
GWE-16	K37/2603					9.7	8.9	10.0	11.3	12.0	11.3	10.9	11.2	11.2	12.2	11.6
GWE-17	K37/2538		Added to replace dry bores				3.8	4.0	4.1	4.1	1.85	0.001	0.001	0.001	0.03	0.039

[1] - indicates sample may have been affected by drillers fluid.
(green) indicates parameter was below Minimum Detection Limit (value given = MDL/2).
(blue) indicates sample could not be collected due to well outlet being submerged.

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Table H4: Groundwater E. *coli* results (MPN/100 ml).

Year		2015	2016								2017					
Month	**Bore ID #**	**May**	**May**	**June**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**March**	**April**	**May**	**June**
GWD-01	BY20/0149		8	0	0	0	0	0	0	0	0	0	0	0	0	0
GWD-02	BY20/0150		0	0	0	0	0	0	0	0	Not tested					
GWD-03	BY20/0151		10	0	1	0	0	0	0	0	0	0	1	0	0	0
GWD-04	BY20/0152		0	0	0	0	0	24	0	201	26	5	9	0	0	0
GWD-05	BY20/0153		10	1	0	0	1	0	0	2	Not tested					
GWD-06	BY21/0183		0	1	0	0	6	3	2	0	Not tested					
GWD-07	BY21/0184		3	2	0	0	0	0	3	0	Not tested					
GWE-01	K37/1748	4	3	0	0	0	0	0	0	0	0	0	19	0	0	0
GWE-02	K37/0204		Dry			0	0	0	0	Dry			Not tested			
GWE-03	K37/0357		3	4	Dry	0	Dry		118	9	Not tested					
GWE-04	K37/0200		Dry				0	0	0	0	0	0	24	7	2	0
GWE-05	K37/1749		Dry											N/A		Dry
GWE-06	K37/0972		Dry				1	25	130	Dry						
GWE-07	K37/0351		Not part of monitoring program	0	0	45	3	1	2	0	Not tested	Dry		Not tested		
GWE-08	K37/3052			Dry												
GWE-09	K37/1938			0	0	0	0	31	0	0	Not tested					
GWE-10	K37/0215			0	0	0	0	24	43	1	Not tested					
GWE-11	K37/1747			0	0	0	N/A	0	0	0	Not tested	N/A	Not tested			
GWE-12	K37/1540			0	0	0	0	0	0	0	Not tested					
GWE-13	K37/1649			0	0	0	0	0	0	0	0	0	0	0	0	0
GWE-14	K37/0383			10	0	0	12	4	1	8	Not tested	Well dry		Not tested		
GWE-15	K37/2458		Not part of monitoring program			0	0	0	0	0	Not tested	1	Not tested			
GWE-16	K37/2603		Not part of monitoring program			0	0	0	0	0	Not tested					
GWE-17	K37/2538		Not part of monitoring program				0	0	0	0	Not tested					

- (yellow) indicates no particles were detected
- (orange) indicates particle numbers were above Upper Detection Limit (value given = UDL)
- (blue) indicates sample could not be collected due to well outlet being submerged

Table H5: Monitoring well groups for groundwater quality evaluation.

Monitoring Well	Distance to edge of MAR infiltration basin (m)	Monitoring well group
GWD-01	19	At Pilot Trial site
GWE-01	45	At Pilot Trial site
GWD-02	274	MAR footprint
GWE-11	364	MAR footprint
GWD-04	938	MAR footprint
GWE-12	961	Near field background
GWE-03	975	Near field background
GWE-17	1,618	MAR footprint
GWD-03	1,659	Near field background
GWE-15	1,794	Near field background
GWE-13	1,967	Near field background
GWE-04	2,308	MAR footprint
GWE-16	3,660	Near field background
GWE-10	3,910	Wide field
GWD-05	4,236	Near field background
GWD-07	8,325	Wide field
GWE-09	9,609	Wide field
GWE-06	10,278	Wide field
GWE-14	10,818	Wide field
GWD-06	11,741	Wide field
GWE-07	13,397	Wide field

For the purposes of this report, the effects of the Pilot Trial on receiving water quality trends have been assessed through comparison of the trends identified from the monitoring wells identified in Groups 1 and 2 above compared to the trends from the monitoring wells identified in Group 3.

4.4 Baseline Groundwater Quality Trends

Between 2001 and 2009 nitrate-N concentrations were monitored in three wells close to the Pilot Trial site. Data from two of these wells, GWE-01 and GWE-16, could be directly compared with the results from samples obtained during the Pilot Trial (Figure H5). The third monitoring well, GWE-05, has not been monitored for groundwater quality during the trial.

From the data presented in Figure H5 there is no indication that nitrate-N concentrations in the vicinity of the Pilot Trial were decreasing prior to the start of the trial. The only clear indication of the decreasing trend in nitrate-N concentrations relates to the water quality in GWE-01 following the start of the trial, with GWE-01 being located approximately 45 m from the infiltration basin.

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H4

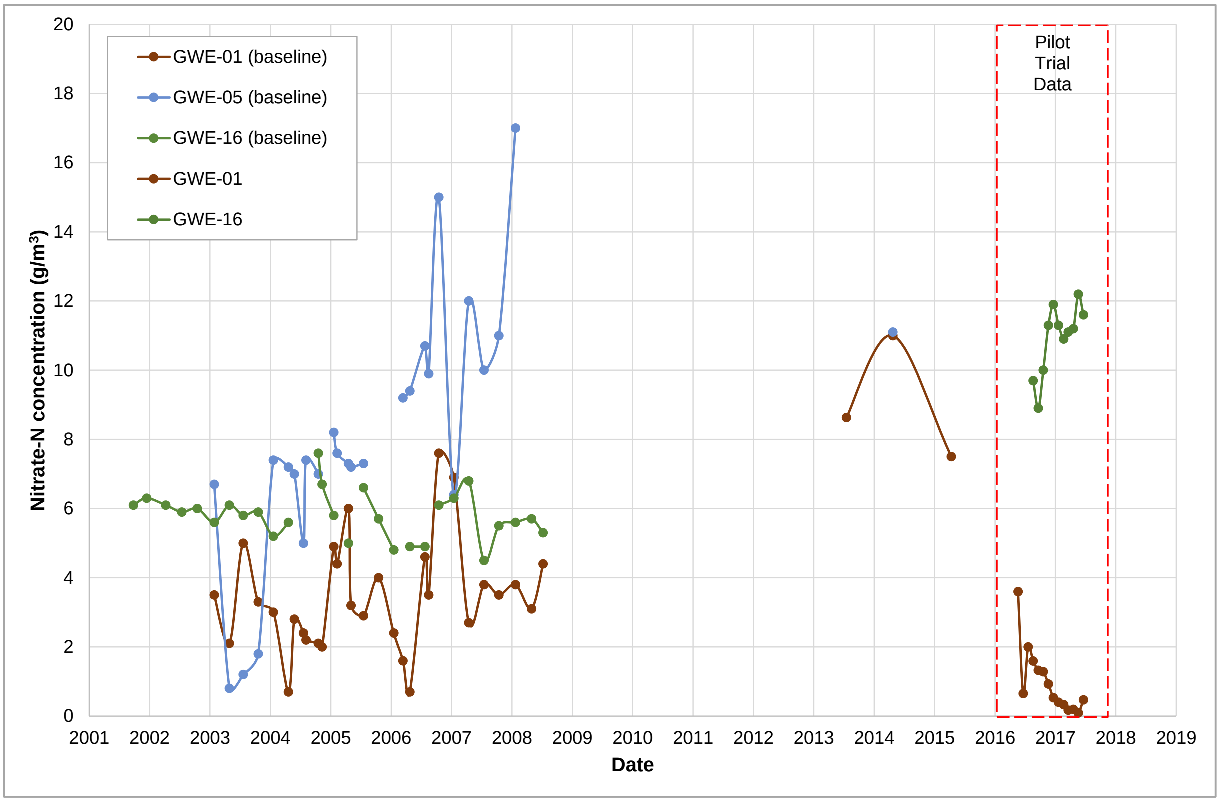


Figure H5: Measured nitrate-N concentrations in groundwater prior to Pilot Trial.

4.5 Groundwater Nitrate and Groundwater Level Charts

4.5.1 Introduction

As discussed in Section 4.3, the groundwater quality records from monitoring wells have been grouped for the purposes of interpretation of the effects of the Pilot Trial on receiving water quality. Not all of the monitoring wells listed in Table H5 were instrumented with pressure transducers or could be dipped to monitor groundwater levels as well as water quality. For the purposes of this report, the effects of the Pilot Trial on receiving water quality trends have been assessed through comparison of the trends identified from the monitoring wells identified in Groups 1 and 2 above compared to the trends from the monitoring wells identified in Group 3.

In this section, the monitoring wells that have records for both groundwater nitrate-N concentration and water level have been grouped according to the listing in Table H5. Charts of nitrate-N concentrations and groundwater levels are presented to enable the related changes in these two parameters to be visualised for each monitoring well.

4.5.2 At-site monitoring wells

The groundwater level and nitrate-N concentration trends in GWE-01 (Figure H6) have been compared to those in GWD-01 (Figure H7). In summary:

- In terms of groundwater level responses to the Pilot Trial operations, the magnitude of the responses, the rapid response times and the clear definition responses all indicate that the groundwater in the perched aquifer at GWE-01 is more responsive to the Pilot Trial than the underlying regional aquifer.

- In terms of nitrate-N concentrations, the rate at which the concentration decreased and the lower final concentration measured during May 2016 at GWE-01 compared to GWD-01 both indicate that the perched aquifer was more dominated by the introduced water than was the regional aquifer.
- During the summer shut-down of Pilot Trial operations the water quality in the perched aquifer continued to improve, whereas the water quality in the regional aquifer at GWD-01 started to return toward the initial water quality observed at this monitoring well.

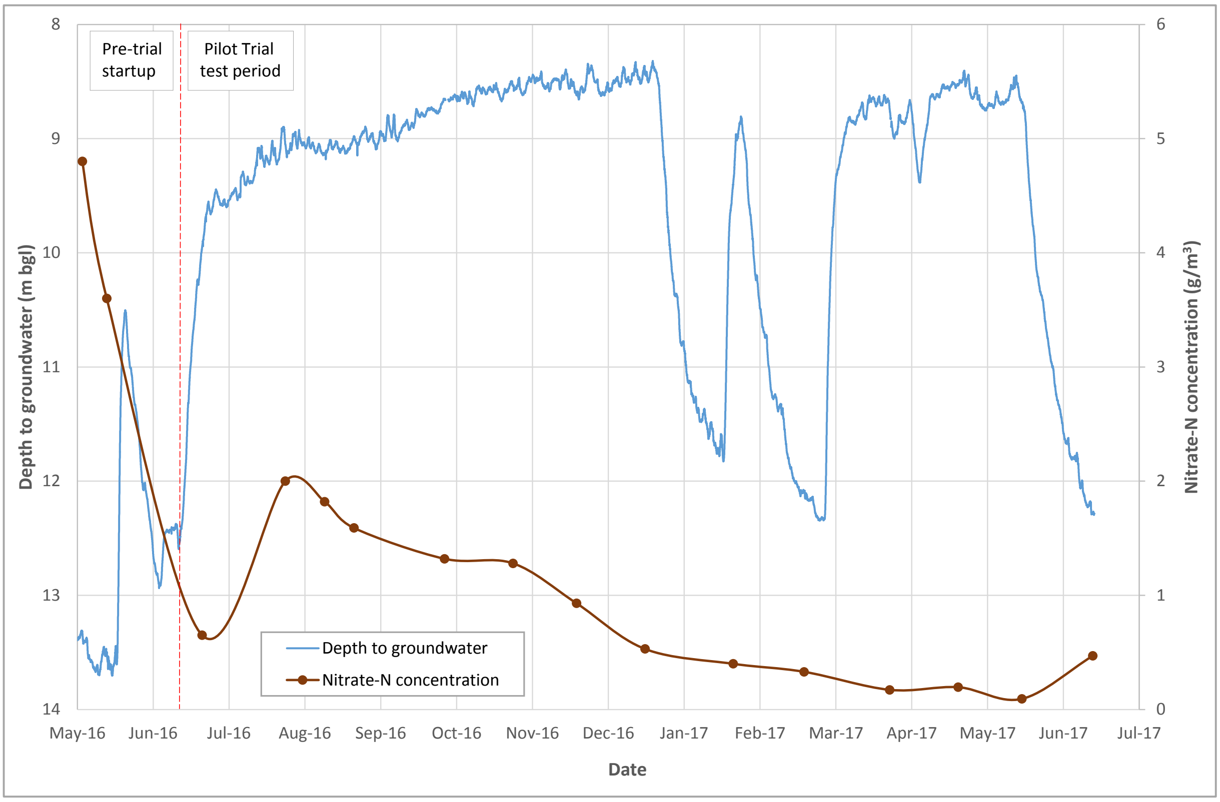


Figure H6: Nitrate-N concentration and groundwater level trend in monitoring well GWE-01.

4.5.3 MAR influenced monitoring wells

The nitrate-N concentrations measured at GWD-02 did not show a consistent or meaningful response to the Pilot Trial (Figure H8). However, it needs to be recognised that the concentrations detected at GWD-02 were already low compared to background concentrations measured from most wells monitored during the trial. It is possible that seepage losses from the overlying Mangin Farm ponds is helping to keep local groundwater nitrate-N concentrations low.

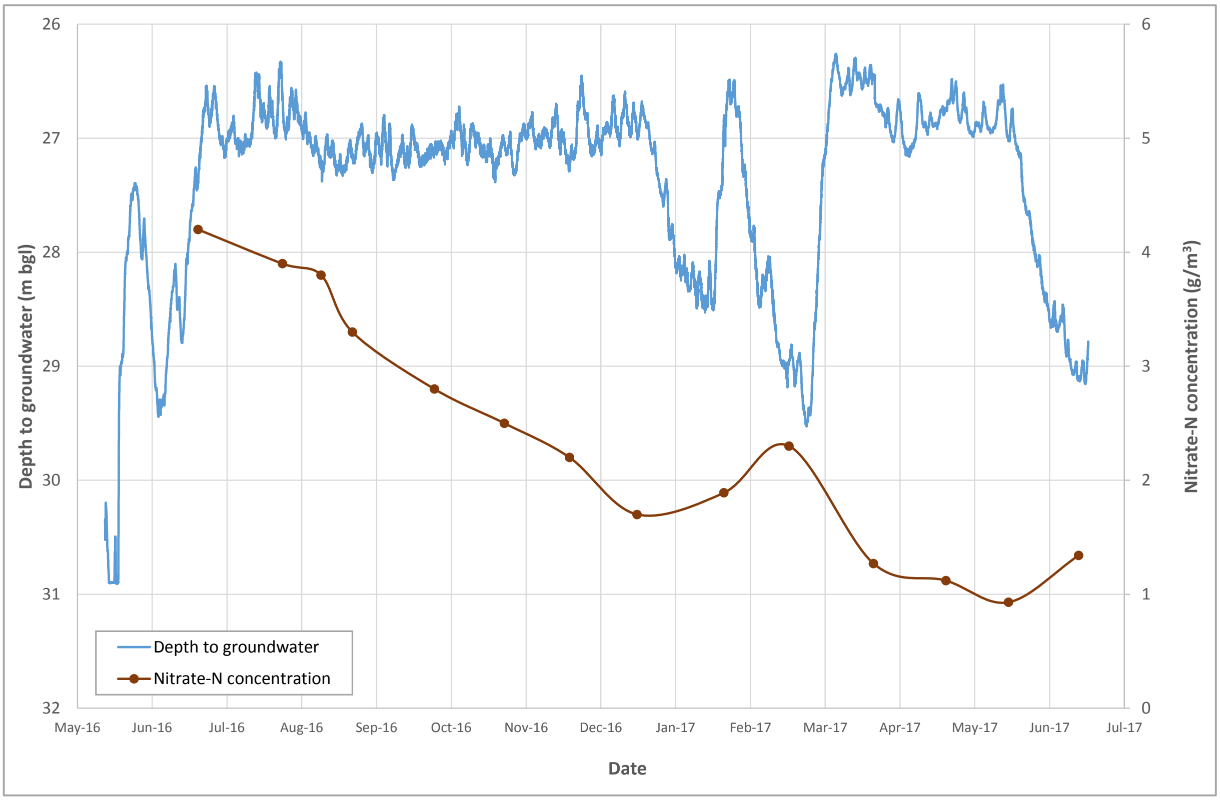


Figure H7: Nitrate-N concentration and groundwater level trend in monitoring well GWD-01.

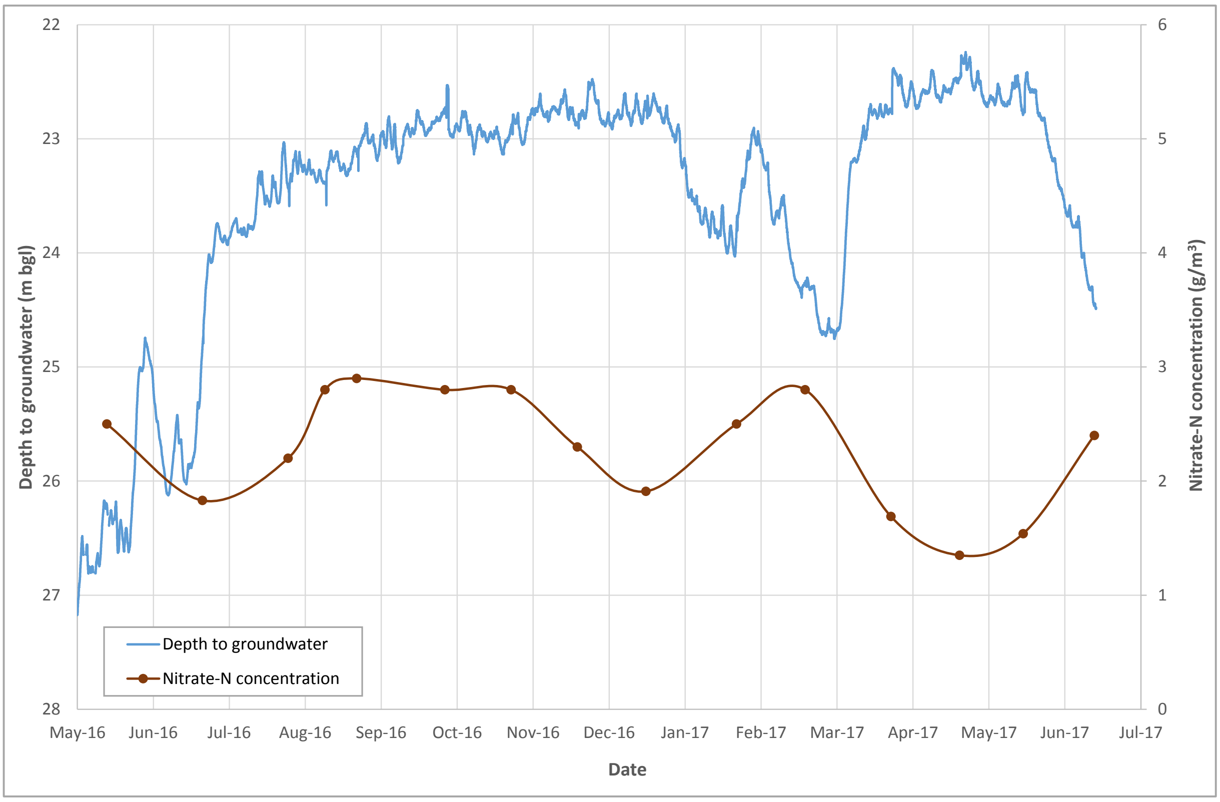


Figure H8: Nitrate-N concentration and groundwater level trend in monitoring well GWD-02.

Monitoring well GWD-04 is located approximately 940 m from the Pilot Trial site and is hydraulically down-gradient from the site. In late May 2016, the water level in this monitoring well increased suddenly and rapidly (Figure H9). By mid-December the water level in the well had increased by approximately 18 m. The rapidity and magnitude of the observed increase indicates introduced water flowing through the perched aquifer reached this bore and flowed downward around the bore into the underlying regional aquifer. The nitrate-N concentration measured at this bore therefore represents a mixture of water from the two aquifers at this point.

The nitrate-N concentrations measured at this well did not improve at the same time as the increase in water level. This delay between the two responses to the Pilot Trial was at least 23 days and is estimated to have been approximately 45 days. The delay, together with the observed changes in water quality in GWE-01 (Figure H6) imply that the introduced water from the Pilot Trial was displacing existing water in the perched aquifer and pushing this water ahead as a pressure response to the trial.

An automated nitrate-N monitoring sensor supplied by Lincoln Agritech was installed in GWD-04 as part of the Pilot Trial monitoring system. This nitrate-N data from the sensor corresponded to the data from the manual samples, with data from this sensor documented separately in Appendix K.

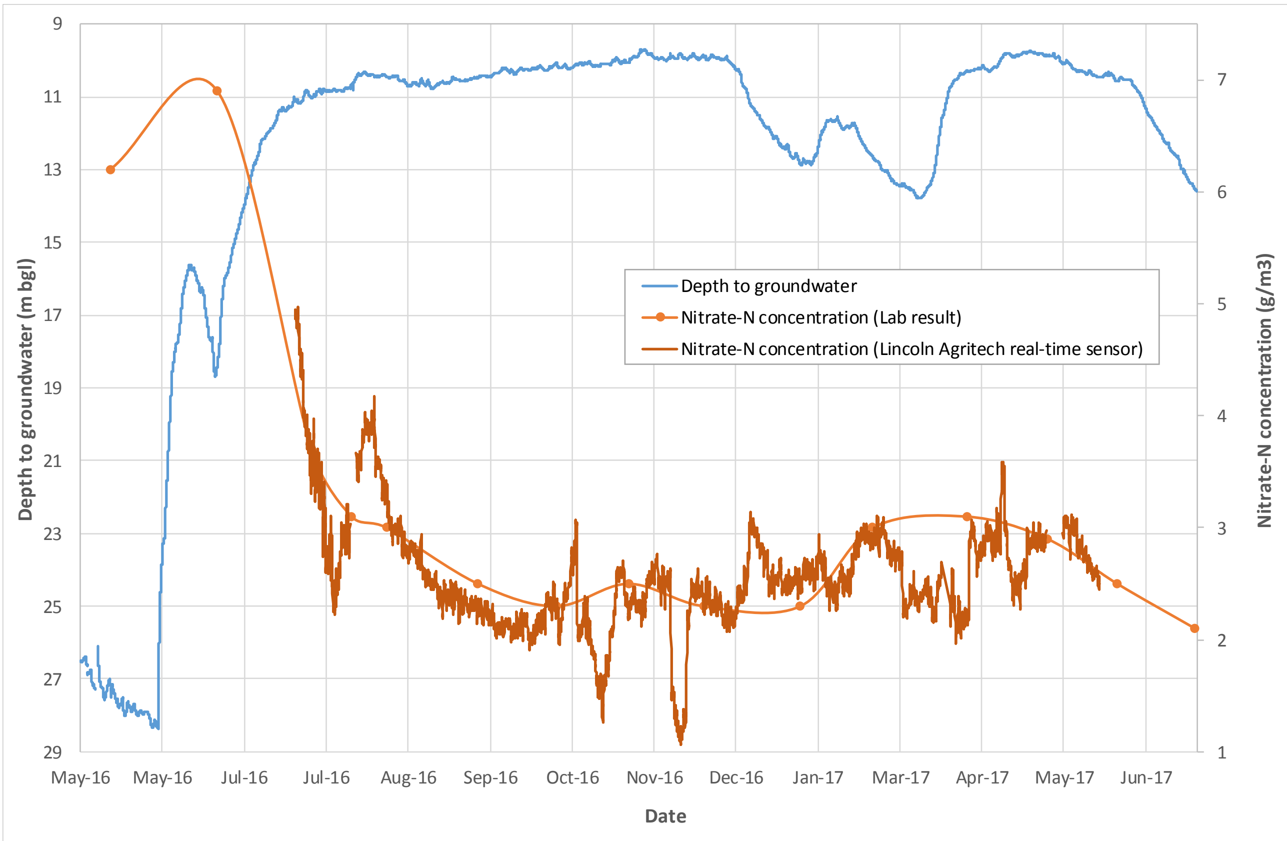


Figure H9: Nitrate-N concentration and groundwater level trend in monitoring well GWD-04.

Monitoring well GWD-07 is located approximately 1,620 m hydraulically down-gradient from the Pilot Trial site and was not initially included in the Pilot Trial monitoring program. The water level in this well may have responded to the Pilot Trial, however by the time monitoring of this well started the water level was decreasing in response to pumping from the regional aquifer for irrigation purposes.

The nitrate-N concentrations measured in samples from GWE-17 decreased substantially after December 2016 and were close to or below the laboratory detection limit from February 2017 onward (Figure H10). These very low concentrations are directly comparable to the concentrations measured in the infiltration basin and imply very little or no mixing with the existing natural groundwater. This interpretation implies the water sampled in this monitoring well has travelled to this point through the perched aquifer, rather than through the deeper regional aquifer system.

Monitoring well GWE-04 is located approximately 2,310 m hydraulically down-gradient from the Pilot Trial site. This monitoring well was dry until 14th September 2016, after which the water level in the well rose rapidly to a depth of approximately 5.5 m in response to the water from the Pilot Trial reaching this point (Figure H11). The nitrate-N concentrations measured in samples from this well started to decrease in response to arrival of the infiltrated water from the trial late in December 2016. The nitrate-N concentration at the end of the trial period is indicative of a mixture of background groundwater and water infiltrated during the trial.

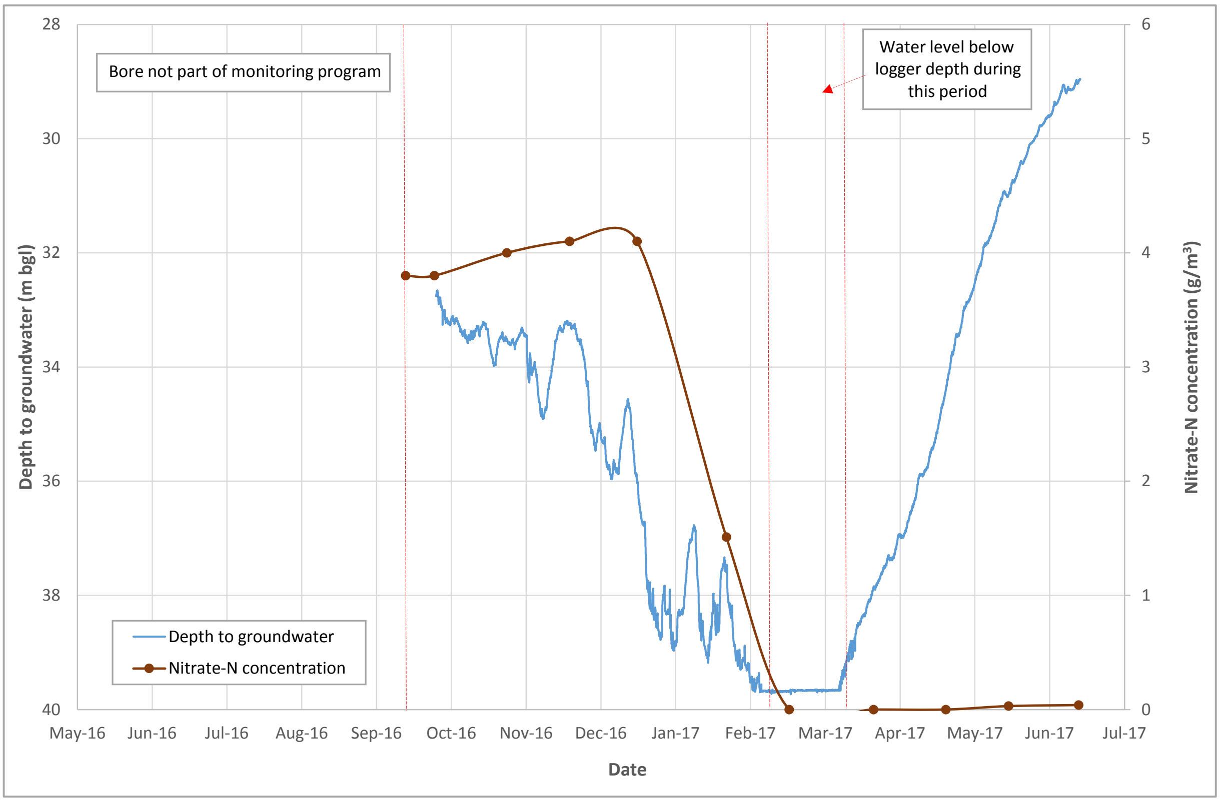


Figure H10: Nitrate-N concentration and groundwater level trend in monitoring well GWE-17.

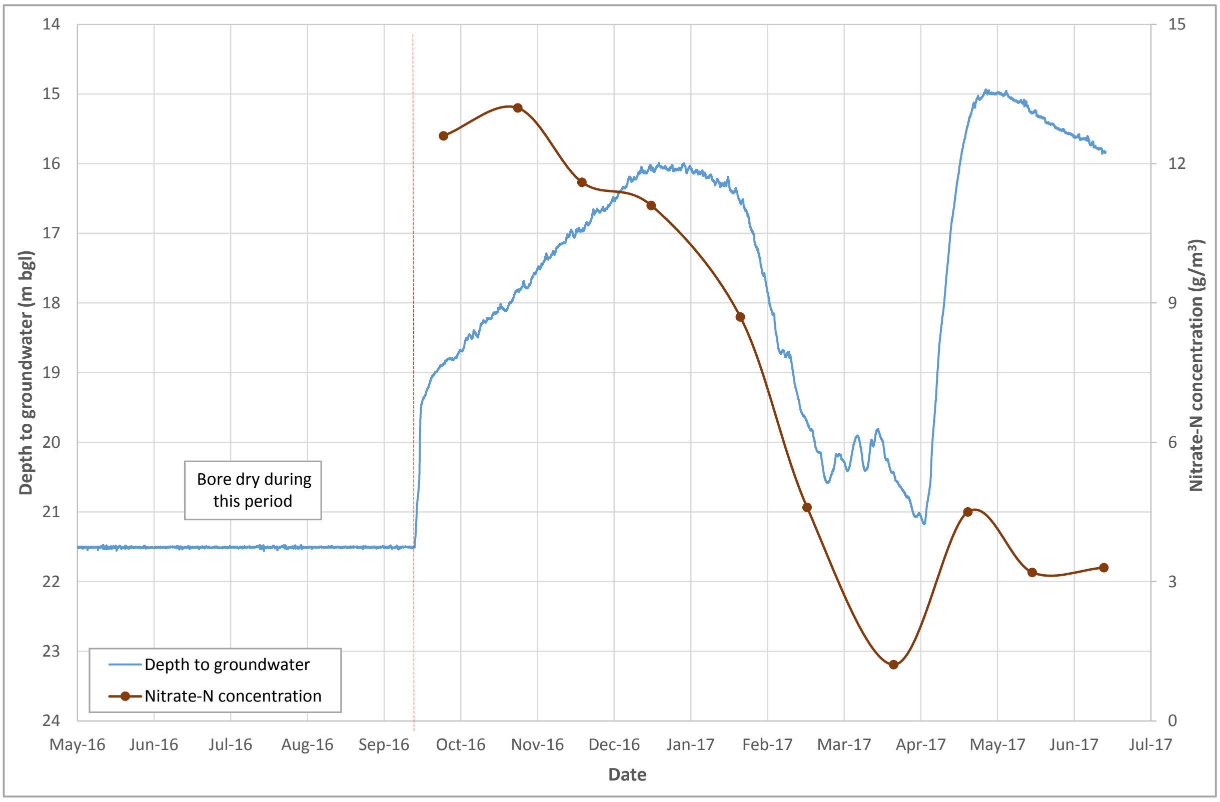


Figure H11: Nitrate-N concentration and groundwater level trend in monitoring well GWE-04.

4.5.4 Other background monitoring wells

There are only two further monitoring wells with continuous good quality groundwater level and nitrate-N datasets obtained as part of the Pilot Trial. One of these wells is GWD-05, which is considered to be representative of a near-field monitoring well with nitrate-N concentrations representative of background water quality in the vicinity of the Pilot Trial (Figure H12). There is no conclusive evidence that either the water level or the water quality in this well responds to the infiltrated water during the Pilot Trial.

Monitoring well GWE-10 is located approximately 3,910 m hydraulically up-gradient form the Pilot Trial. Prior to the start of the Pilot Trial this well was planned to be monitored to provide baseline up-gradient data for the trial. The nitrate-N concentrations measured in samples from this well were however consistently very low for the entire period of the trial (Figure H13). The water quality data together with the anomalously large water level rise measured in GWE-10 after March 2017 suggests a direct hydraulic link with the Ashburton River, which is not evident in the water quality records from any of the other wells monitored for the trial. This water quality dataset has therefore not been considered further for the purposes of evaluating the extent and effects of the water infiltrated during the Pilot Trial.

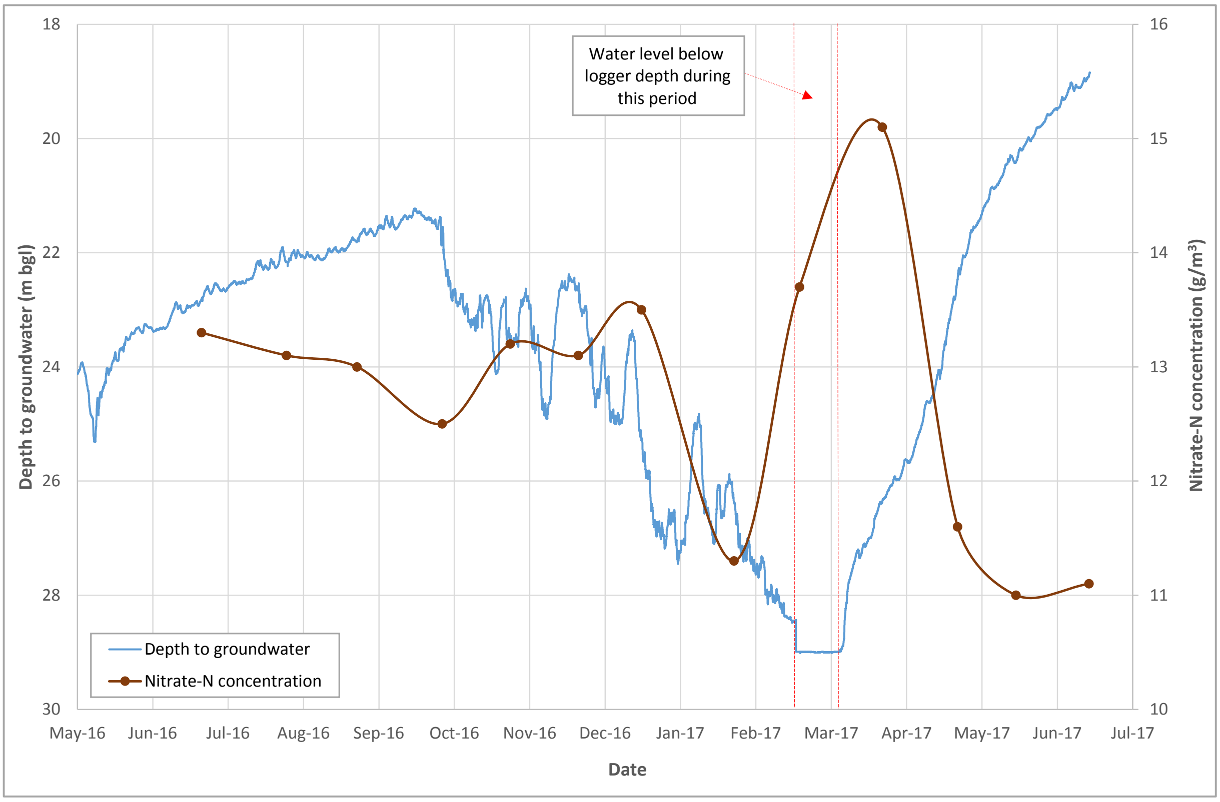


Figure H12: Nitrate-N concentration and groundwater level trend in monitoring well GWD-05.

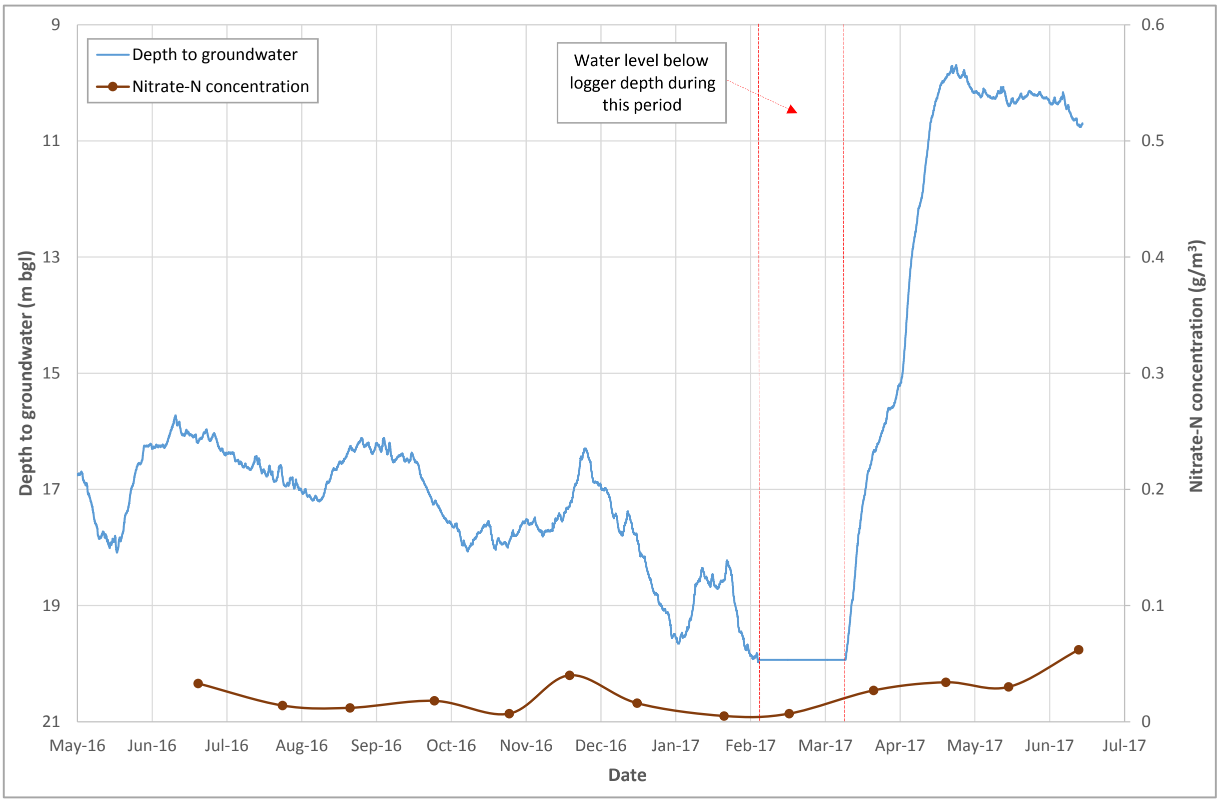


Figure H13: Nitrate-N concentration and groundwater level trend in monitoring well GWE-10.

5.0 WATER QUALITY EFFECTS BENEATH PILOT TRIAL SITE

5.1 Introduction

The effects of the Pilot Trial on the groundwater, 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 and GWD-01. The quality of groundwater in GWE-01 represents the perched groundwater in what appears to be a buried river paleochannel beneath the site. The quality of groundwater in GWD-01 represents the seepage flows within the regional groundwater system beneath the site.

5.2 Nitrate

Nitrate-N concentrations in the source water during the trial (Figure H2) have been substantially lower than those detected in the underlying groundwater, both perched and in the regional system. As a consequence, the initiation of artificial recharge through the floor of the infiltration basin resulted in measured nitrate-N concentrations in the underlying groundwater decreasing (Figure H14).

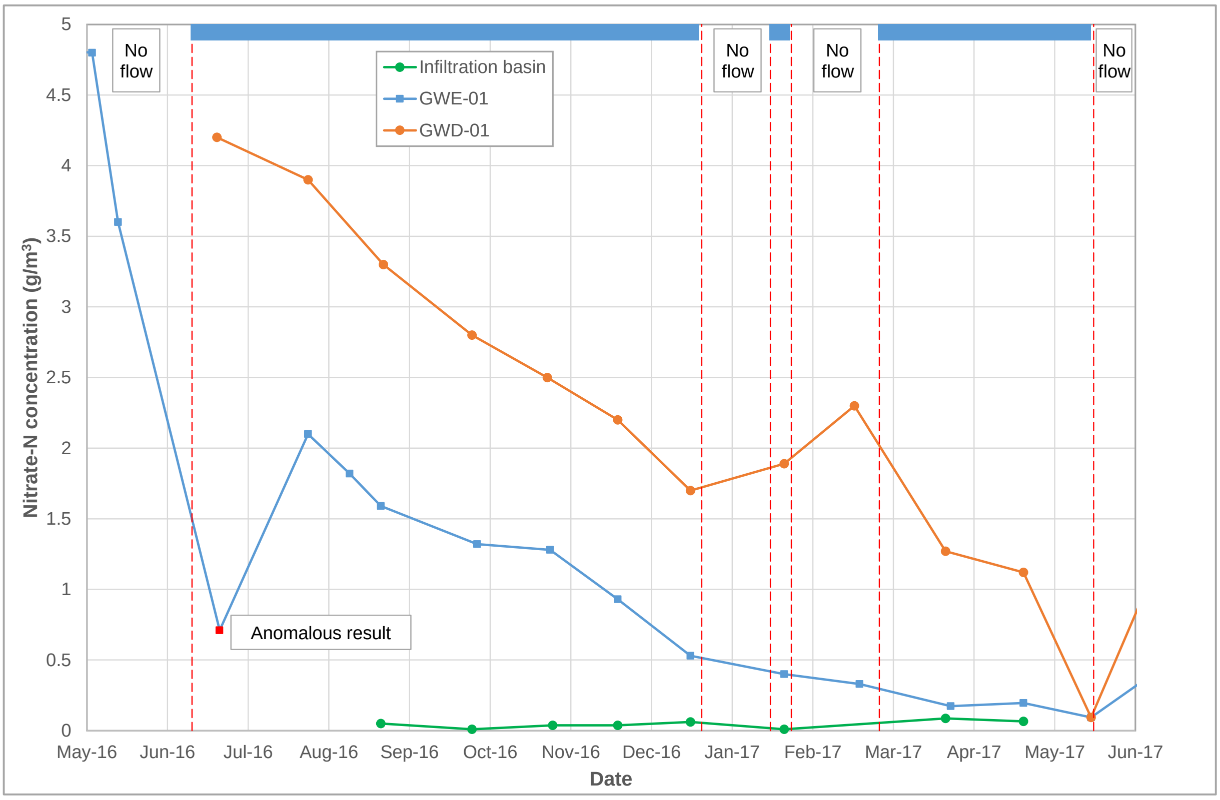


Figure H14: Nitrate-N concentrations in groundwater samples from beneath the Pilot Trial site during the trial.

Since the start of the trial the measured nitrate-N concentrations in samples from GWE-01 have been consistently lower than those from GWD-01. In addition, when trial operations were shut down over the summer period, the concentrations detected in GWD-01 started to increase whereas those from GWE-01 did not.

The above two observations both support the interpretation that the aquifer monitored by GWE-01:

1) Is perched;

2) Had a relatively thin zone of saturation prior to receiving water from the infiltration basin, which means there was not a large volume of water contained in the aquifer at this stage; and

3) Did not have a large through-flow of natural water from up-gradient over the summer period.

In effect, the source water from the trial largely replaced the existing natural water in the perched aquifer beneath the Pilot Trial site. Once this happened, the two-month close of operations at the site over summer was not long enough for water from up-gradient to flow back under the site, to be detected again at GWE-01.

These same two observations also support the interpretation that the aquifer monitored by GWD-01:

1) Is connected to the regional aquifer system;

2) Has a relatively thick saturated zone, which required a substantial volume of new water to be introduced to the aquifer from the overlying infiltration basin in order to gradually reduce the local nitrate-N concentrations in the aquifer.

3) Has a through-flow of natural water with elevated nitrate-N concentrations from up-gradient that was sufficient to result in nitrate-N concentrations starting to increase again within approximately one month of the close of trial operations for the summer.

The interpretation of these observations is that the source water from the trial started to replace the underlying natural groundwater by forming a layer of low-nitrate water on top of the existing higher-nitrate groundwater. As this layer increased in thickness beneath the site, the concentrations of nitrate-N measured in samples from GWD-01 decreased. The two-month close of operations at the site was sufficient to allow incoming natural groundwater from up-gradient to push some of the introduced water away from beneath the site, leading to increasing nitrate concentrations in the groundwater samples from GWD-01.

5.3 E. coli

Although the *E. coli* counts measured in water samples from Flume 1 and from the infiltration basin regularly exceeded 100 MPN/100mL (Figure H3), the *E. coli* counts in water samples obtained from both GWE-01 and GWD01 were normally below the laboratory detection limit (Figure H15). *E. coli* was only detected in one sample from GWE-01 (19 MPN/100mL in March 2017) and this is considered to be an anomalous result as *E. coli* was not detected in subsequent samples from this monitoring well.

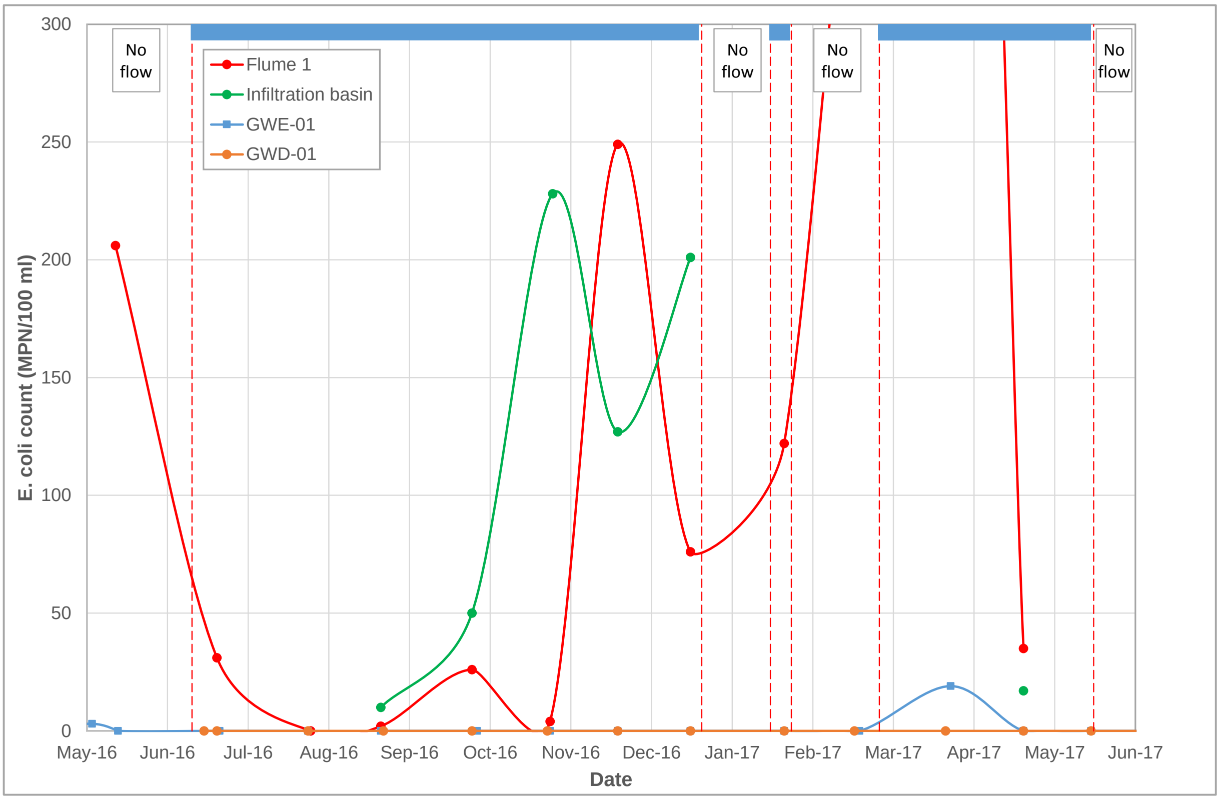


Figure H15: E. coli counts in groundwater samples from beneath the Pilot Trial site during the trial.

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. Processes active in removing *E. coli* from the infiltration water include:

- Capture of bacteria in algal and bacterial mats that developed on the floor of the infiltration basin and fore basin. As these mats would have required time to develop, this process is likely to have become more effective over the period of the trial.
- Retention of *E. coli* on the surfaces of soil and rock particles in both the unsaturated and saturated zones beneath the Pilot Trial basin.
- Die-off of *E. coli* as the infiltrating water passes through both the unsaturated and saturated zones beneath the basin.

The analysis results indicate that *E. coli* removal from the infiltrated water had been effectively achieved before the MAR water had moved laterally more than about 45 m from the infiltration basin in the perched aquifer beneath the site. These results also indicate that any *E. coli* detected in groundwater further from the site are unlikely to have been sourced from the MAR trial.

6.0 PILOT TRIAL INFLUENCE ON GROUNDWATER QUALITY

6.1 Introduction

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 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. Interpretation of groundwater level and quality data indicates this plume is predominantly moving within a perched aquifer, probably consisting of a buried river paleochannel. Downward seepage of water from this perched aquifer results in improvement to the water quality in the underlying regional groundwater system.

The effects of the Pilot Trial on surrounding and down-gradient groundwater, which is considered to be the receiving water for the purposes of this project, have been evaluated by comparing the observed water quality trends within the recharge water plume to background groundwater quality trends. This comparison is therefore between the trends identified in monitoring well groups 1 and 2 with those identified in group 3 (Section 4.3) and is focused on nitrate-N concentrations.

In addition to nitrate-N concentrations, electrical conductivity may be a useful indicator parameter for evaluating the spread of MAR water within the groundwater system. A comparison of electrical conductivity and nitrate-N trends in the groundwater within the MAR footprint down-gradient from the Pilot Trial site is presented in Section 6.3.

Although *E. coli* in the MAR source water does not appear to be influencing the quality of the receiving groundwater at the Pilot Trial site (refer Section 5.3) it is important to monitor any possible spread of microbiological contaminants within the MAR footprint. A summary of the *E. coli* data with respect to the MAR footprint is presented in Section 6.4.

Monitoring well groups 1 and 2 include wells that show clear influence from the spread of MAR water within the perched aquifer and from the spread of water in the regional aquifer alone. This differentiation is addressed separately in Section 7.0.

6.2 Nitrate

The nitrate-N data from the near-field monitoring wells, defined as those wells close to the plume of infiltrated MAR water but not affected by the plume, is summarised in Figure H16. The median nitrate-N concentration in this group of wells has remained relatively stable through Year 1 of the Pilot Trial, as has the range in the values. None of the nitrate-N concentrations detected in water samples from these wells during Year 1 of the Pilot Trial were less than 7 g/m^3. There was no indication of a rising or falling trend in this dataset.

In comparison, the nitrate-N data from the monitoring wells influenced by the plume of infiltrated MAR water shows a clear decreasing trend in the median values (Figure H17). The minimum concentrations detected within this group of bores has also trended downward, reflecting the very low nitrate concentrations in the source water.

The downward trend in maximum concentrations detected in the wells influenced by the MAR water toward the end of Year 1 (Figure H17) is an artefact of the data selection process. During April to June 2017 the nitrate-N concentrations detected in GWE-11, which was the last well to respond to the trial during Year 1, decreased substantially (Figure H18). This decrease resulted in the concentration ranges during these months decreasing although the median nitrate-N concentration for the same group of wells did not decrease correspondingly over this period.

For comparison purposes, the nitrate-N concentrations measured from monitoring wells further afield have been summarised in Figure H19, on the same scale as used in the previous two figures. The relatively large concentration ranges and higher concentrations presented in Figure H19 compared to Figure H16 and Figure H17 reflect the much larger area monitored and the resulting larger range in factors influencing the groundwater quality.

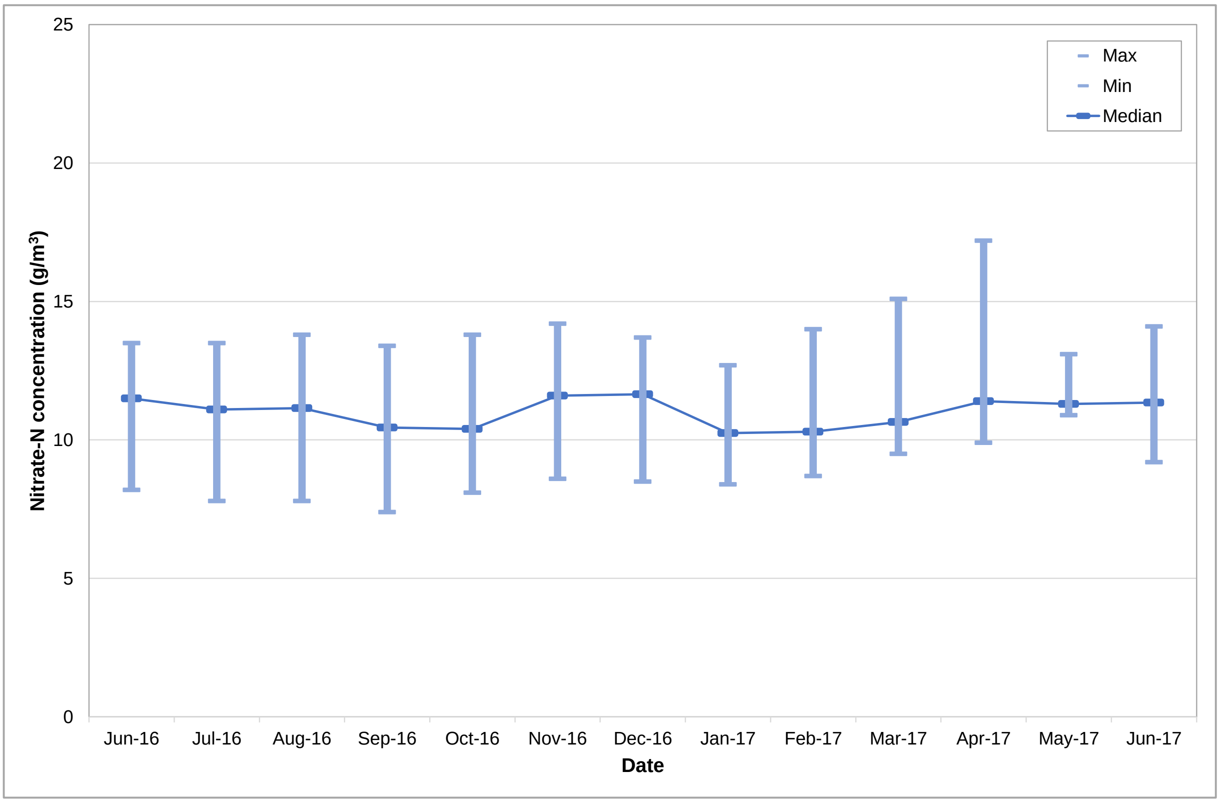


Figure H16: Background nitrate-N trend in near field area.

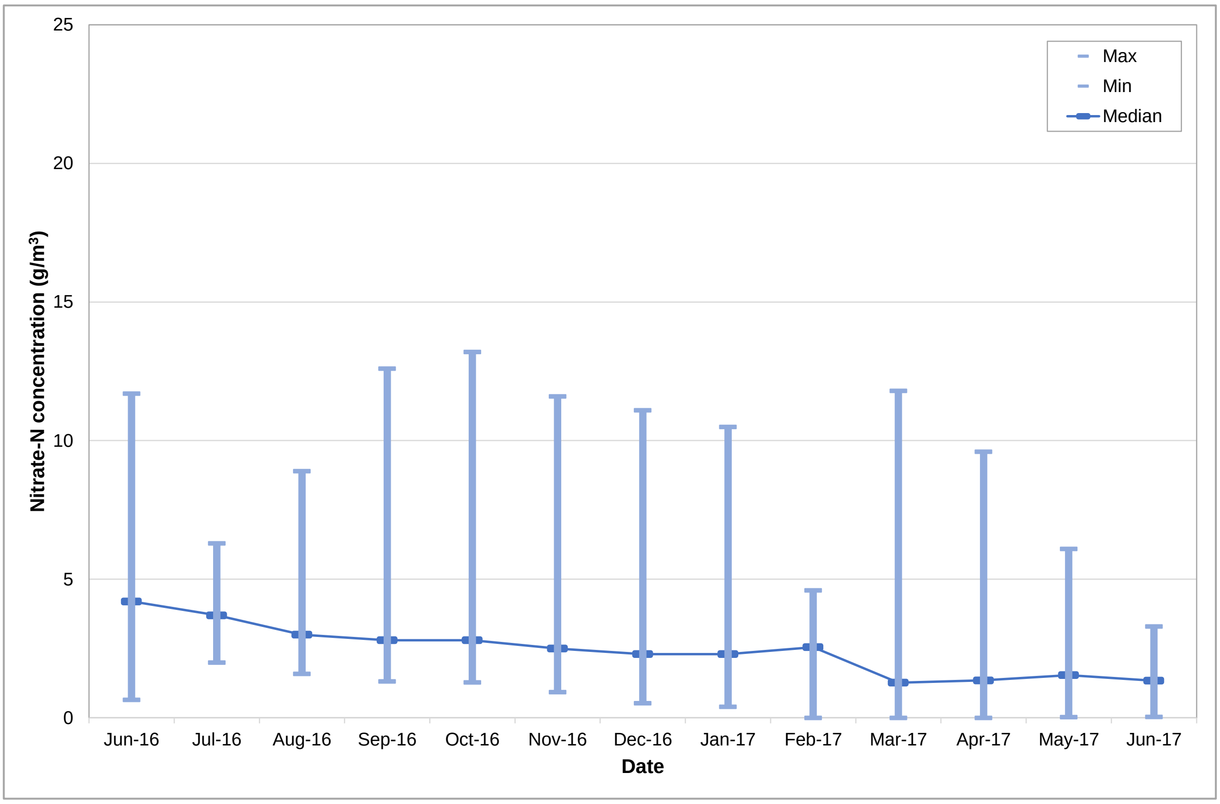


Figure H17: Nitrate-N trend in area affected by Pilot Trial water.

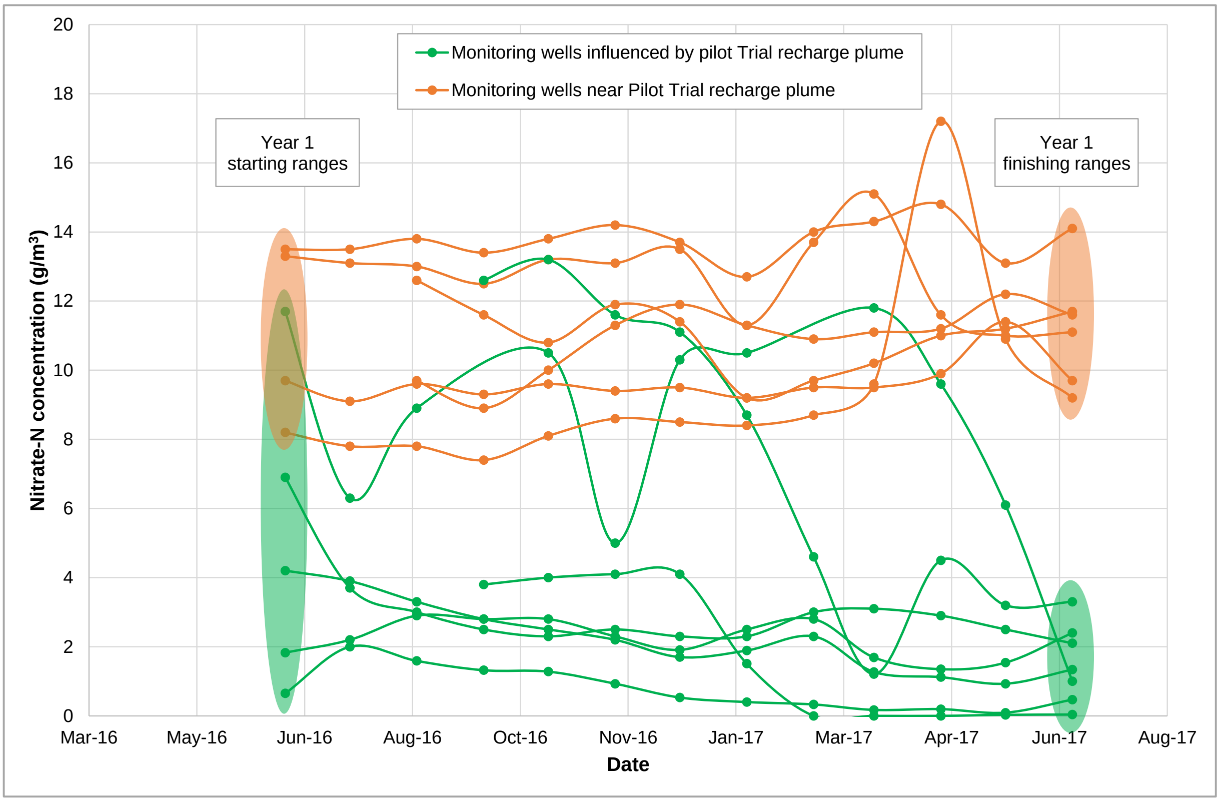


Figure H18: Comparative trends in nitrate-N concentrations for background and plume influenced monitoring wells.

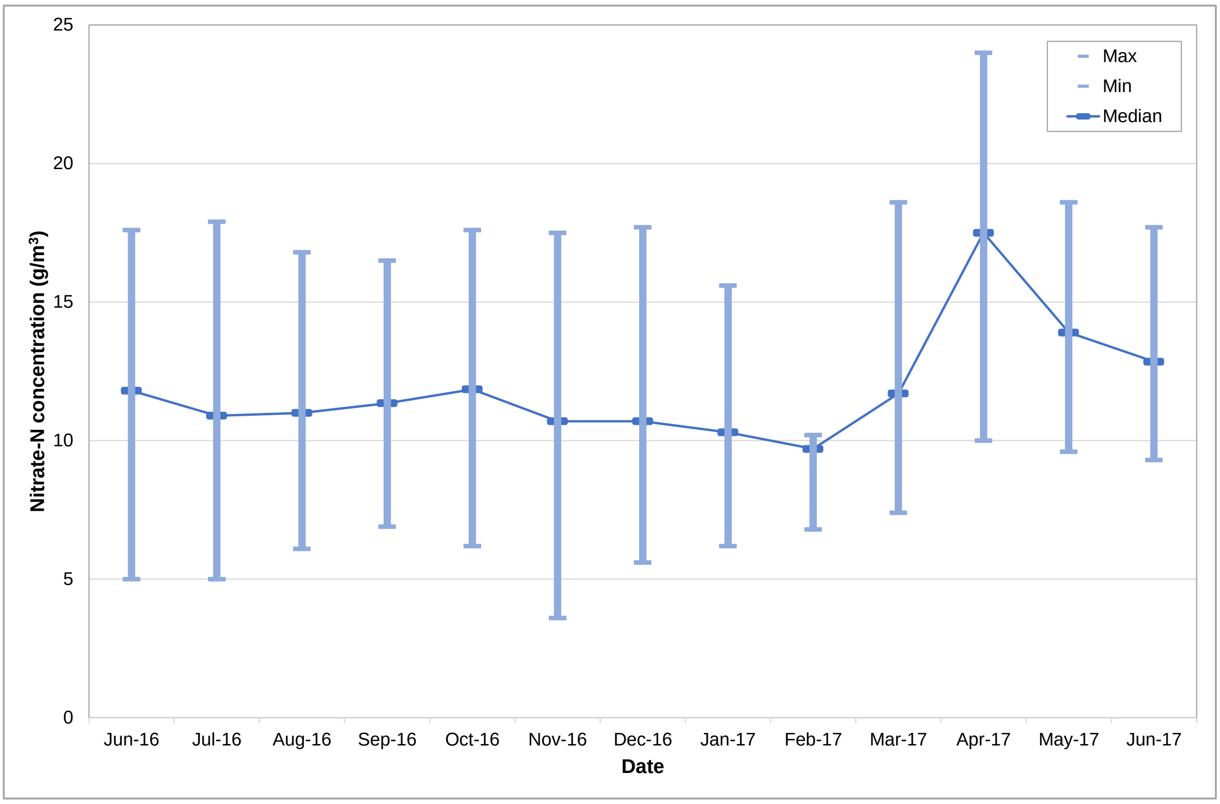


Figure H19: Background nitrate-N trends in wide-field monitoring wells.

6.3 Electrical Conductivity

During Year 1 of the MAR Pilot Trial the electrical conductivity (EC) of the MAR source water as measured in the main infiltration basin was between 4.8 mS/m and 5.7 mS/m. These values contrast strongly with the EC of the receiving groundwater. For example, the EC of the groundwater measured at GWD-05, which is considered to be a near field monitoring well representative of background groundwater conditions, ranged from 26.7 mS/m to 36.4 mS/m during Year 1.

The initiation of infiltration operations at the MAR Pilot Trial site resulted in reductions in both nitrate-N and EC in the underlying receiving groundwater. These changes are reflected in the trends in both parameters recorded during Year 1 from monitoring wells GWE-01 Figure H20), GWD-01 (Figure H21), GWD-04 (Figure H22) and GWE-04 (Figure H23).

At each of the above monitoring wells, there was a linear correlation between nitrate-N concentration and EC trends in the groundwater. These trends appear to reflect a progressive increase in the proportion of MAR source water present in the aquifer at each monitoring well over time (Figure H24).

Further assessment of this observed correlation between nitrate-N and EC trends in the monitoring wells affected by MAR water would be of value, especially in conjunction with automated nitrate-N monitoring, as documented in Appendix K. It appears that the automated monitoring of nitrate-N and EC may offer the opportunity to track in real time the proportion of MAR source water present at monitoring wells located down-gradient from future infiltration sites.

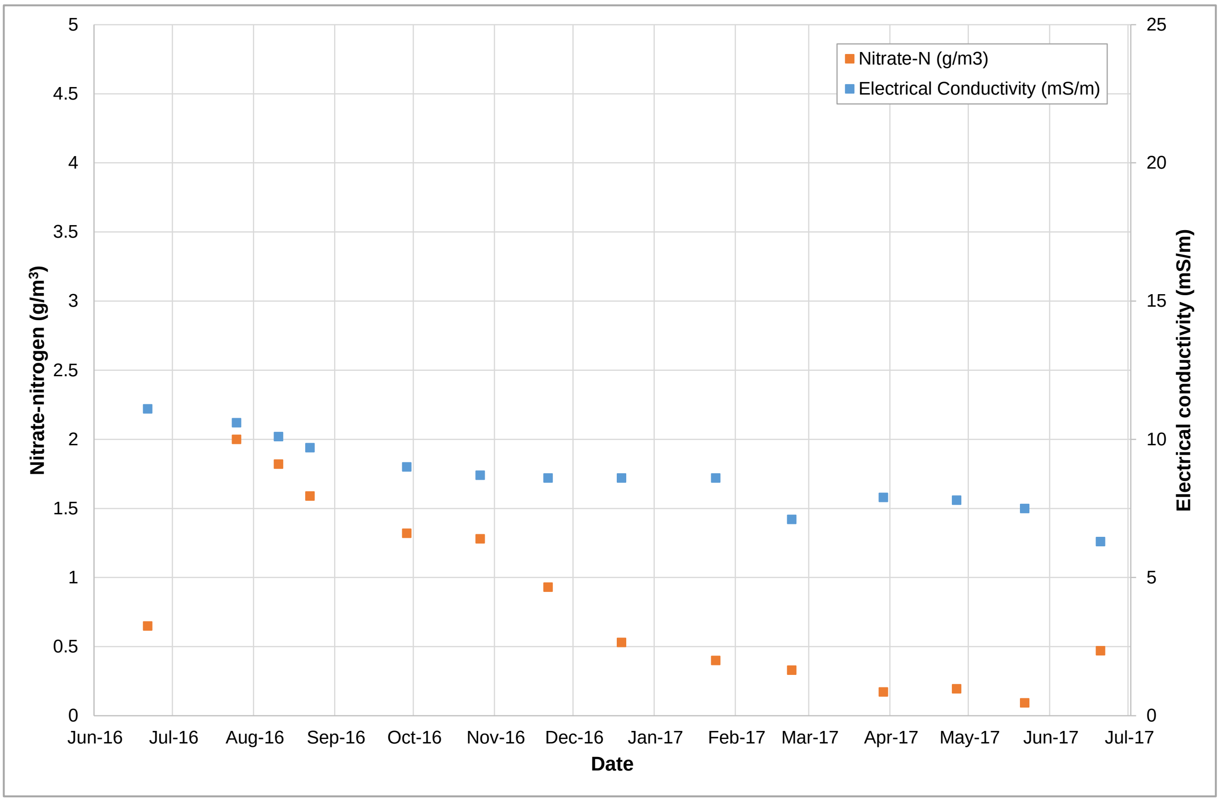


Figure H20: Nitrate-N and electrical conductivity trends at GWE-01 during Year 1.

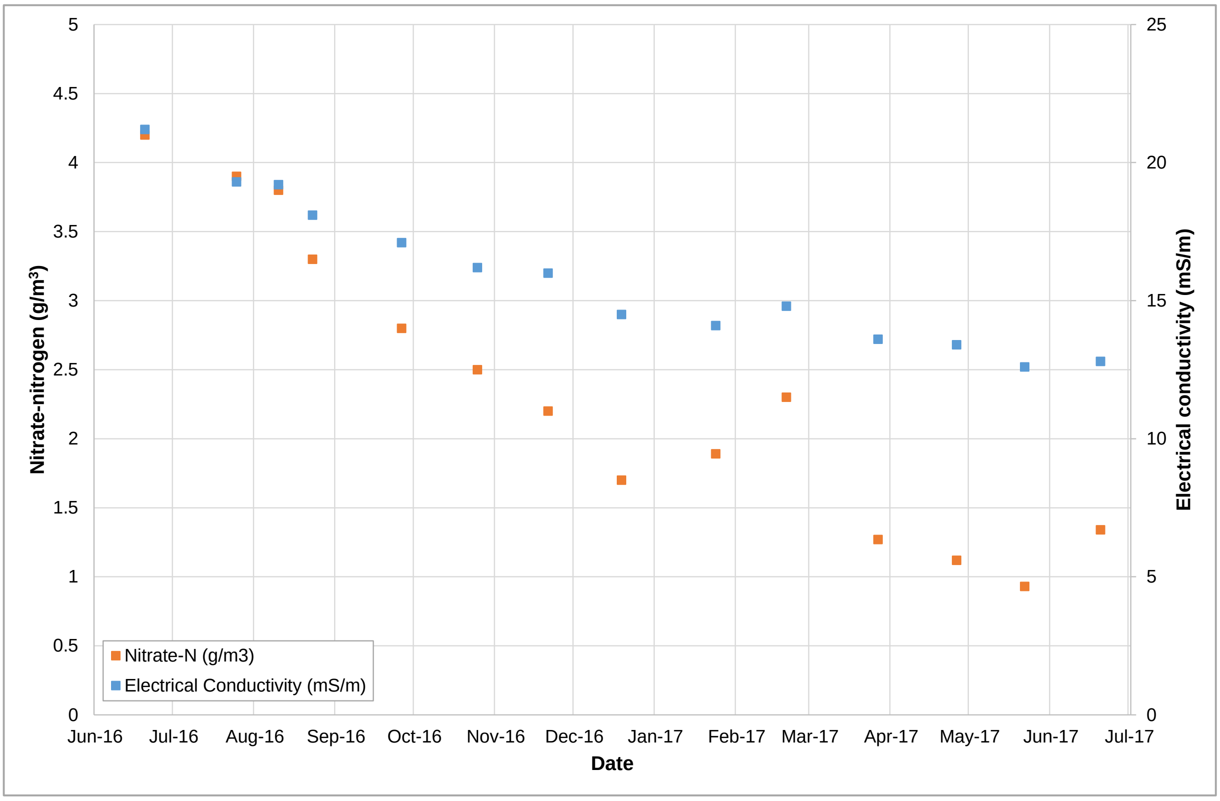


Figure H21: Nitrate-N and electrical conductivity trends at GWD-01 during Year 1.

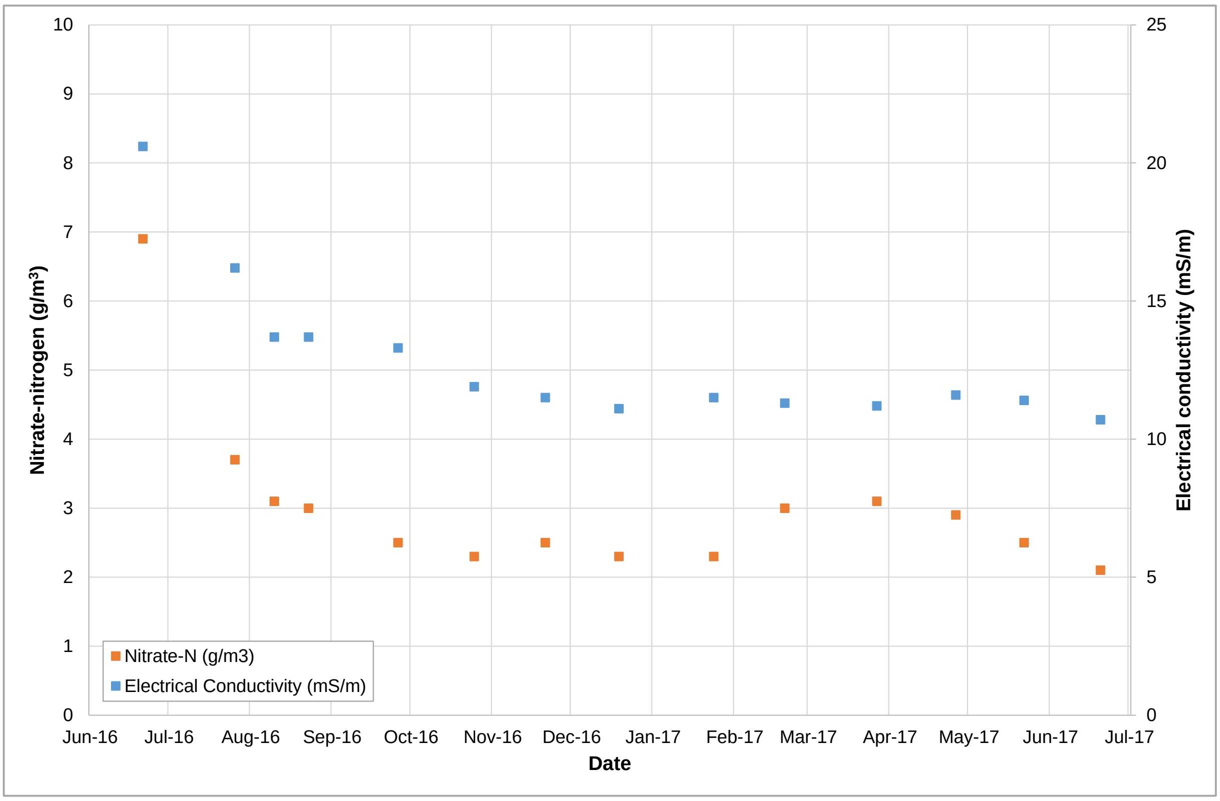


Figure H22: Nitrate-N and electrical conductivity trends at GWD-04 during Year 1.

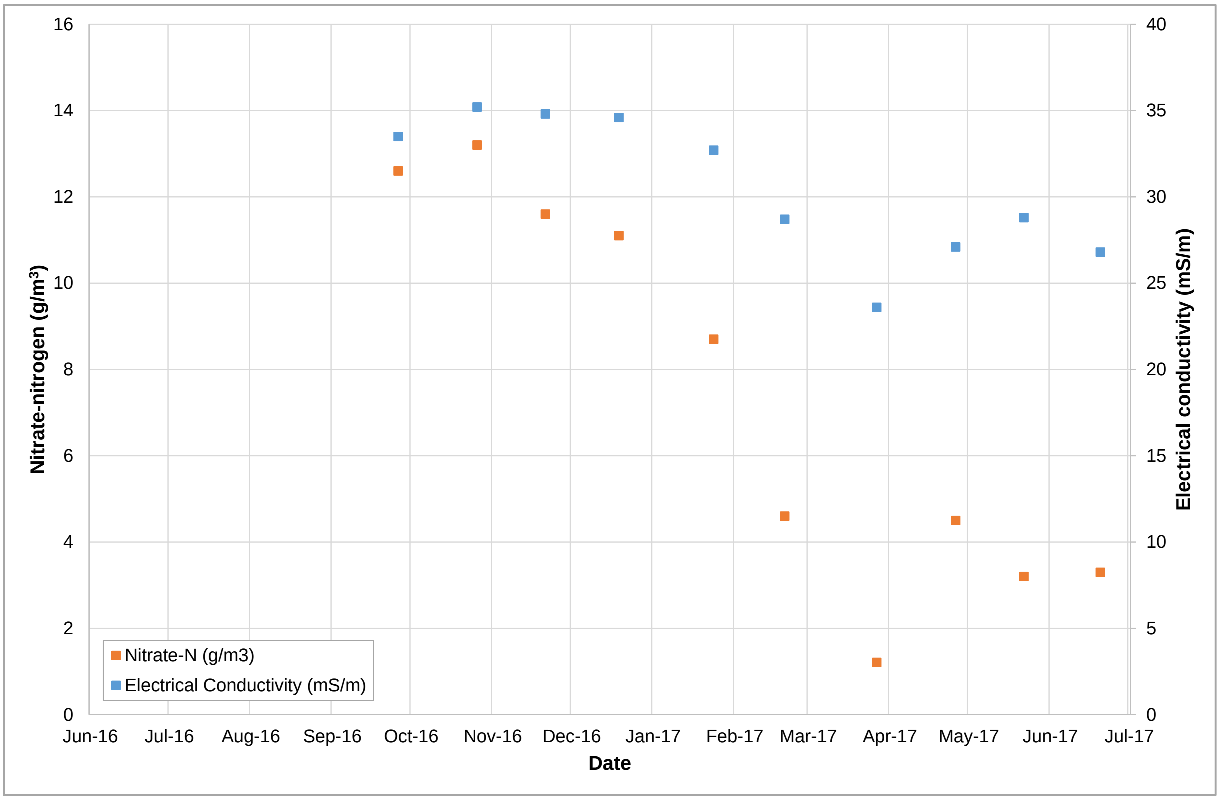


Figure H23: Nitrate-N and electrical conductivity trends at GWE-04 during Year 1.

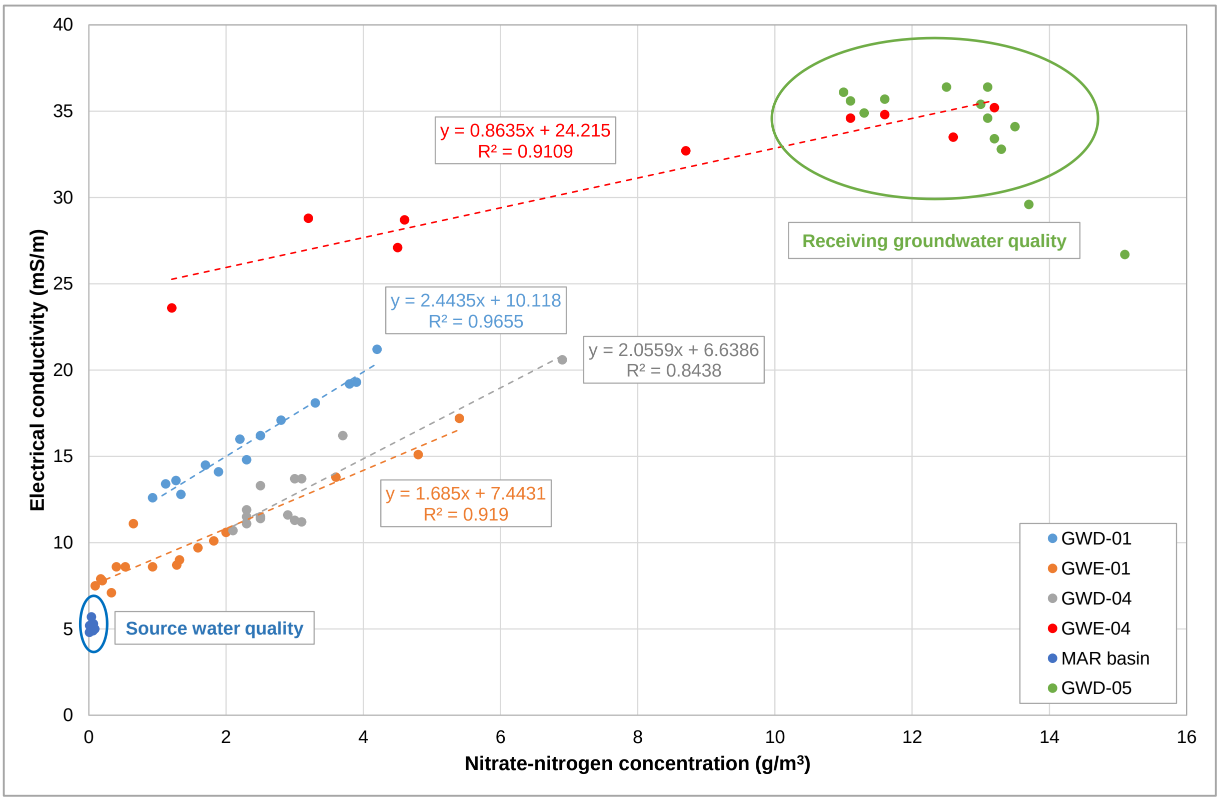


Figure H24: Nitrate-N and electrical conductivity trends from MAR source water to receiving groundwater quality.

6.4 E. coli

The detection of *E. coli* in monitored wells during the Pilot Trial varied apparently randomly, with no connection to the water infiltrated during the trial. As previously documented (Section 5.3) there was no indication from sampling of the closest monitoring wells to the trial site that *E. coli* was being introduced to the aquifer. The summary chart of *E. coli* detections in monitoring wells influenced by the infiltrated water (Figure H25) suggests these wells more often had *E. coli* present than the near field monitoring wells (Figure H26). In the far-field wells, both the ranges in nitrate-N concentrations (refer Section 6.2) and the detected ranges in *E. coli* (Figure H27) indicate a range of influences other than the water from the Pilot Trial.

Field notes from the sampling program indicate that during December 2016 and January 2017 monitoring well GWD-04 was infested with beetles. It is unclear how the beetles gained access to the monitoring well, however the maximum *E. coli* counts recorded during the period from October 2016 through to February 2017 were all from GWD-04. If the results from GWD-04 were removed, the maxima for these months would all be zero.

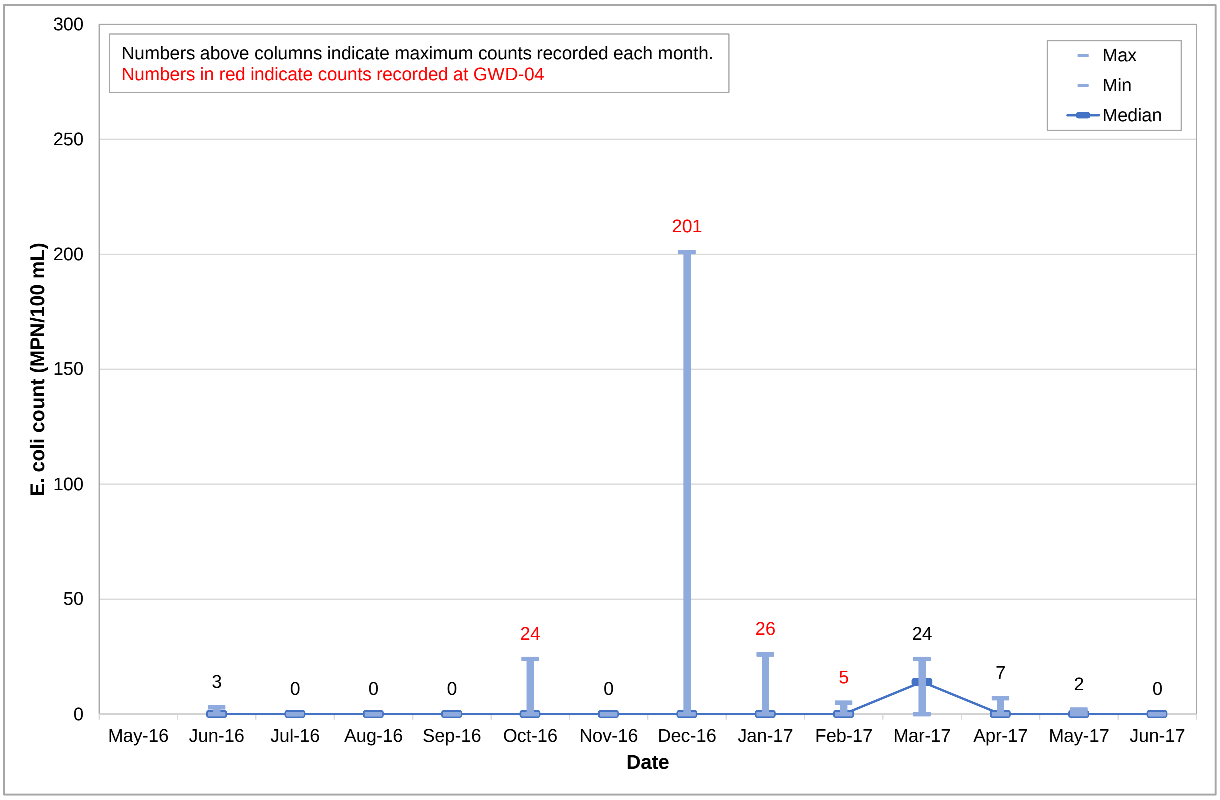


Figure H25: E. coli ranges in wells influenced by infiltrated water.

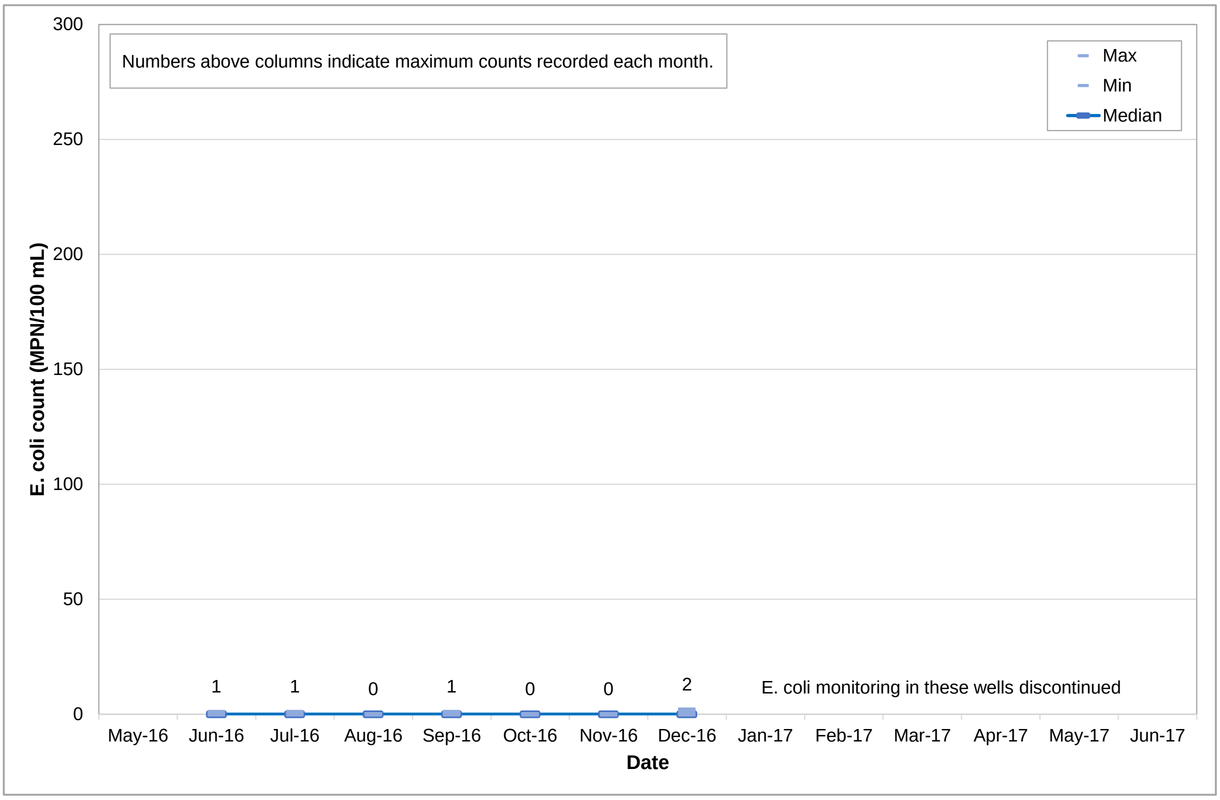


Figure H26: E. coli ranges in near-field monitoring wells.

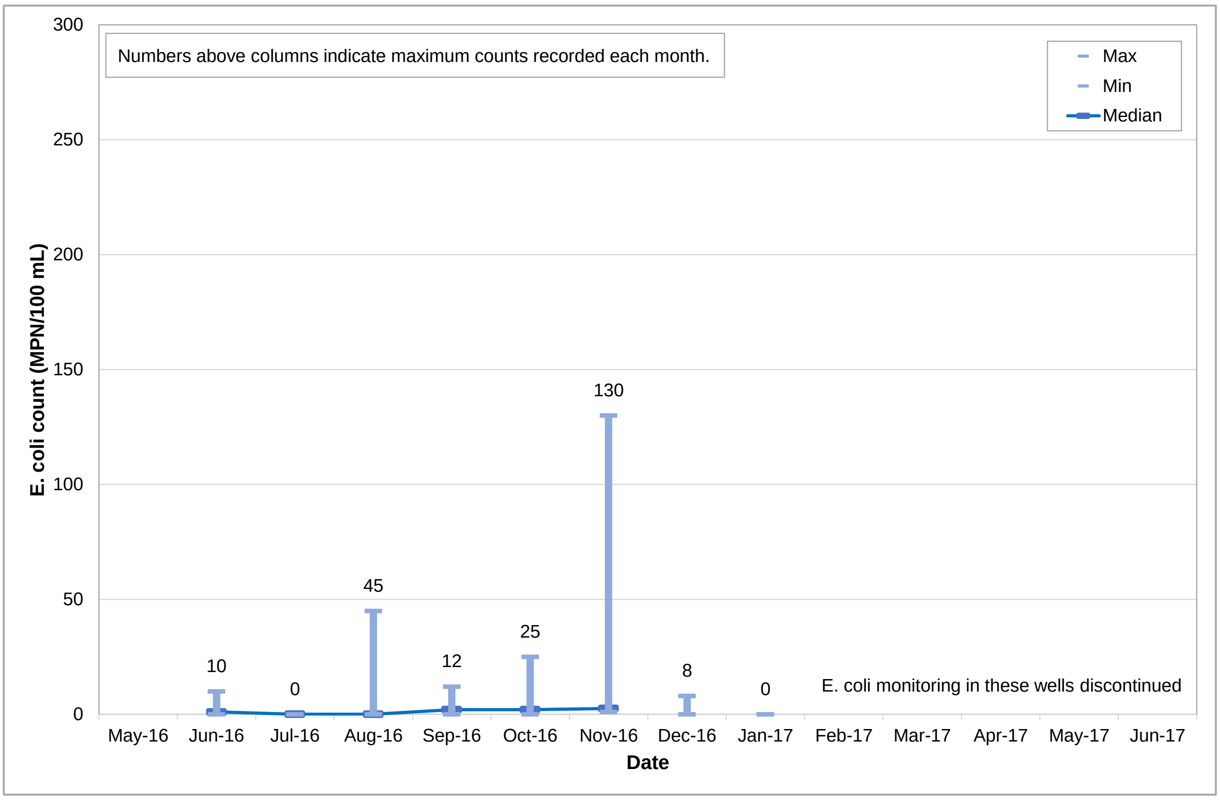


Figure H27: E. coli ranges in far-field monitoring wells.

7.0 EXTENT OF MAR WATER QUALITY EFFECTS 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. Similarly, the rate at which the groundwater pressure response to the trial expanded has been estimated from groundwater level changes in the monitoring wells. A comparison between the timing of water level and water quality responses provides an indication of the delay between the aquifer pressure response and the actual arrival of MAR water.

The groundwater pressure response to the start of the Pilot Trial (Table H6) initially expanded toward the southeast from the trial site at an average of approximately 70 m/day to a distance of one kilometre (measured at GWD-04). Beyond that distance the expansion of the pressure response slowed, with the average velocity being 19 m/day at approximately 2.3 km from the trial site (GWE-04). These average velocities have been calculated for the full distance from the Pilot Trial site out to the relevant monitoring well.

In contrast, the actual MAR water flowed toward the southeast at an average of approximately 20 m/day to a distance of one kilometre from the trial site. Beyond that, the flow rate decreased with the average flow rate as calculated at GWE-04 being approximately 9 m/day (Table H6). Based on these values, the down-gradient flow rate of MAR water during Year 1 of the Pilot Trial was between 30 % and 50 % of the rate at which the water pressure response expanded.

Table H6: 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
		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			

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 much shorter than 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.

The accuracy with which the MAR water flow rate can be estimated is limited by the monthly monitoring well water quality sampling frequency. Even in the case of GWD-04, where an automated nitrate-N sensor was installed (refer Appendix K), this sensor was only installed after the water quality in the well had started to improve in response to the trial. The initial reaction times are estimated to be within a week of the actual time at which water quality changes started.

In the case of the monitoring wells at the Pilot Trial site (GWE-01 and GWD-01), changes in water quality started before the first sample was obtained following the start of the trial. Consequently, an accurate estimate of the time required for a change in water quality to become apparent cannot be made based on the sample results from the Pilot Trial.

Several monitoring wells screened in the regional aquifer have shown water quality responses to the Pilot Trial. However, interpretation of the groundwater level and water quality data suggests all of these monitoring wells were reacting to downward seepage from groundwater flowing through the overlying perched aquifer. The only monitoring well (other than GWD-01) in which the groundwater level response is considered to reflect changes in the regional aquifer groundwater level radiating outward from the Pilot Trial site is GWD-02. Unfortunately, the baseline nitrate-N concentrations in GWD-02 were relatively low prior to the start of the Pilot Trial (refer Section 4.5). Consequently a clearly defined change in nitrate-N concentrations has not been identified in the water quality data from this monitoring well.

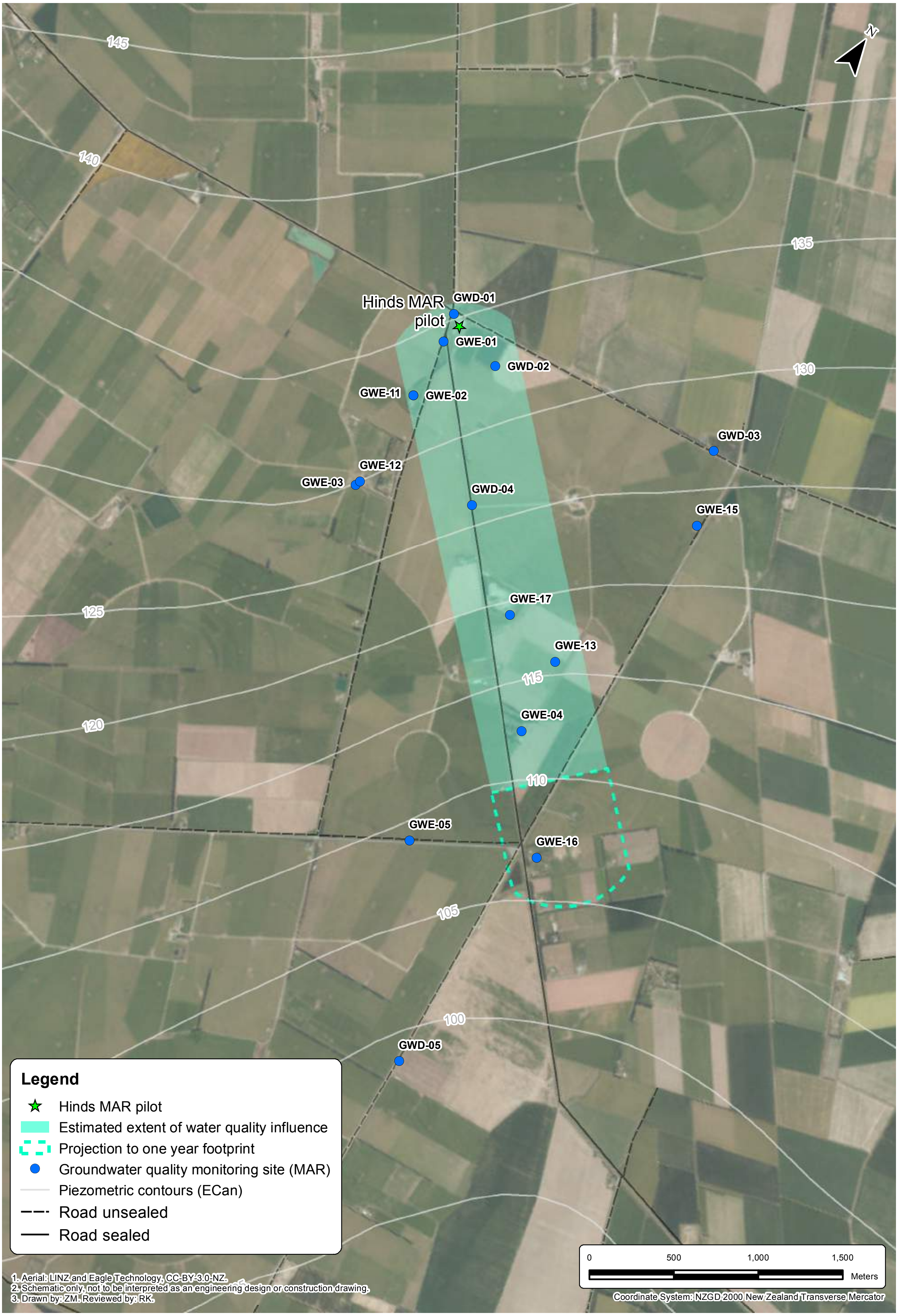
An extrapolation of the MAR water footprint through to the completion of the Pilot Trial Year 1 has been undertaken from the location of monitoring well GWE-04 (Figure H28). This extrapolation has been based on:

- The detection of MAR water at GWE-04 252 days after the start of the Pilot Trial, with a further 113 days transport time remaining during the trial period.
- An average flow velocity of 9 m/day.
- This extrapolation indicated 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. This estimation does however not take into account any slow-down in plume expansion that may have resulted from the summer close-down of MAR operations.
- A width of the MAR water footprint of at least 700 m. This width is based on MAR water being detected in monitoring well GWE-11 approximately 308 days after the start of the trial. The very slow flow velocity of 1.2 m/day calculated based on the travel time to this well (Table H6) suggests this well is outside the main seepage flow channel toward the southeast. It has been assumed 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.

In addition, two further assumptions have been built into the evaluation of the MAR groundwater footprint:

1) The groundwater flow lines indicating the direction of groundwater movement within the perched aquifer are relatively straight.

2) The average flow velocities were not significantly affected by the trial shut-down period over the summer. It is however likely that flows slowed once recharge from the infiltration basin ceased during the summer. It is therefore possible that the average MAR water flow velocity during the periods of active infiltration is higher than estimated from the data from GWE-17 and GWE-04.



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: RK.

Golder Associates

TITLE **HINDS MAR WATER QUALITY INFLUENCE FOOTPRINT**

JULY 2017

PROJECT 1538632

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8.0 SUMMARY

The source water introduced to the receiving groundwater from the Pilot Trial infiltration basin is characterised by very low nitrate-N concentrations and elevated *E. coli* counts.

From the baseline groundwater quality data available from within the command area there is no indication that nitrate-N concentrations in the vicinity of the Pilot Trial were decreasing prior to the start of the trial.

The receiving groundwater immediately below the Pilot Trial site, both in the interpreted perched paleochannel aquifer and in the underlying regional groundwater system, shows an ongoing decrease in nitrate-N concentrations in response to the start of the trial.

Analysis and interpretation of the groundwater quality results from monitoring wells GWE-01 (perched aquifer) and GWD-01 (regional aquifer) during Year 1 of the Pilot Trial indicate that:

- The perched aquifer had a relatively thin zone of saturation prior to receiving water from the infiltration basin and this aquifer did not have a large through-flow of natural water from up-gradient over the summer period.
- The underlying aquifer connected to the regional groundwater system has a relatively thick saturated zone, which required a substantial volume of new water to be introduced to the aquifer from the overlying infiltration basin in order to reduce the local nitrate-N concentrations in the aquifer. The regional aquifer has a through-flow of groundwater with elevated nitrate-N concentrations from up-gradient that is sufficient to result in nitrate-N concentrations starting to increase again within a month of close-down of MAR operations.
- Nitrate-N concentrations in groundwater in both the perched aquifer and the underlying regional aquifer decreased to below 1 g/m^3 during Year 1 of the Pilot Trial. In both cases this represents a mixture of existing groundwater and recharged source water.
- Operations at the Pilot Trial site did not result in increased *E. coli* counts in the groundwater beneath the infiltration basin. This observation implies that *E. coli* are removed from the source water due to attenuation processes including capture in algal and bacterial mats that develop on the floor of the infiltration basin, retention on the surfaces of soil and rock particles and die-off within both the unsaturated and saturated zones beneath the basin.

From the groundwater quality data available from CRC environmental monitoring within the MAR command area, there is no indication that groundwater nitrate-N concentrations in this area were decreasing prior to the start of the Pilot Trial.

Introduction of the source water to the groundwater system has resulted in a plume of low nitrate-N water moving toward the southeast from the 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. Interpretation of groundwater level and quality data indicates this plume is predominantly moving within a perched aquifer, probably consisting of a buried river paleochannel. Downward seepage of water from this perched aquifer results in improvement to the water quality in the underlying regional groundwater system.

Nitrate-N concentrations measured in the monitoring wells influenced by MAR water have decreased from a range of 2.6 g/m^3 to 11 g/m^3 down to a range from 0.47 g/m^3 to 3.3 g/m^3 in June 2017. Substantial decreases in nitrate-N concentrations in the monitoring wells were detected to occur sequentially with increasing distance of the well from the Pilot Trial site (Figure H29).

Nitrate-N concentrations detected in monitoring wells in the near-field area around the area influenced by the MAR water showed no decrease in concentrations over the same time period. During June 2017 the nitrate-N concentrations measured in the near field wells were between 9.2 g/m^3 and 14.1 g/m^3.

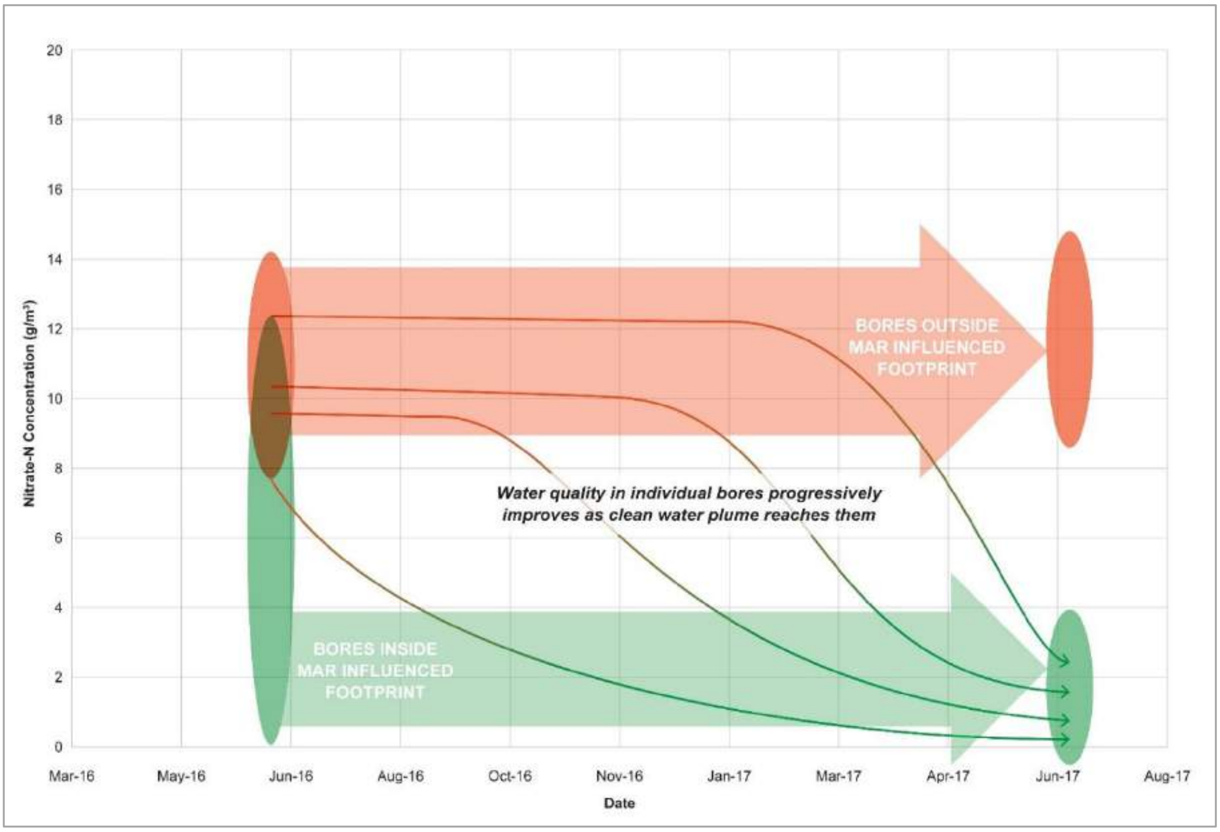

Figure H29: Progressive improvement in groundwater quality as MAR plume expands.

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. Similarly, the rate at which the groundwater pressure response to the trial expanded has been estimated from groundwater level changes in the monitoring wells.

The groundwater pressure response to the start of the Pilot Trial initially expanded toward the southeast from the trial site at an average of approximately 70 m/day to a distance of approximately one kilometre. Beyond that distance the expansion of the pressure response slowed, with the average velocity being 19 m/day out to a distance of approximately 2.3 km from the trial site.

In contrast, the actual MAR water flowed toward the southeast at an average of approximately 20 m/day to a distance of one kilometre from the trial site. Beyond that, the flow rate decreased with the average flow rate as calculated at GWE-04 being approximately 9 m/day (Table H6). Based on these values, the down-gradient flow rate of MAR water during Year 1 of the Pilot Trial was between 30 % and 50 % of the rate at which the water pressure response expanded.

Based on the calculated rate of plume progress toward the southeast, the MAR footprint may have extended as far as 3,300 m southeast from the Pilot Trial site by the end of Year 1 operations. The width of the MAR footprint is estimated to be at least 700 m, based on the observed decrease in nitrate-N concentration at GWE-11.

During Year 1 there were observed linear correlations between nitrate-N concentrations and electrical conductivity (EC) in monitoring wells influenced by MAR water. It appears that the automated monitoring of nitrate-N and EC may offer the opportunity to track in real time the proportion of MAR source water present at monitoring wells located down-gradient from future infiltration sites.

APPENDIX I

Basin Clogging Assessment

1.0 INTRODUCTION

1.1 Background

The Hinds MAR Pilot Trial basin infiltrates water sourced from the Rangitata River, delivered through the Rangitata Diversion Race (RDR) and Valetta Irrigation scheme. The Rangitata River drains an alpine catchment in the Southern Alps of New Zealand's South Island, and during periods of high flow (following rainfall events), transports large volumes of 'Rock Flour' to the ocean, along with volumes of other fine material.

Water supplied to the MAR Pilot Trial via the RDR has passed through several storage ponds, each of which is larger than the MAR infiltration basin. The sediment settling capacity of these ponds combined with the sand trap installed at the intake to the RDR means suspended sediment transported to the MAR Pilot Trial site consists primarily of medium to fine silt particles and clays. Coarser material transported into the forebasin is likely to consist primarily of material eroded from the delivery channel downstream from Valetta Pond #3. In addition, floating organic material and rubbish from the channel is also transported into the forebasin.

Clogging due to physical or biological infilling of sediment pore spaces within the upper 0.2 m of infiltration basins is a common issue requiring management on MAR projects. This infilling of pore spaces decreases the effective porosity and consequently the vertical hydraulic conductivity of the material immediately underlying the basin. Any reduction in hydraulic conductivity of the basin floor leads to reduced infiltration rates through the floor of the basin, assuming the water level in the basin is constant.

The design of the Hinds Pilot Trial site specifically included a forebasin to retain coarse sediment and some of the fine suspended sediment transported to the site in the supplied water. Accumulation of sediment and clogging of the basin floor is therefore expected to occur more rapidly in the forebasin than in the main infiltration basin. Infiltration from the forebasin is however not critical to the success of the trial. For this reason the clogging assessment presented in this appendix is focused on potential clogging and reduced permeability of the main infiltration basin.

1.2 Clogging Evaluation Methods

Clogging can be evaluated through a range of monitoring and analysis processes, including:

1) The continuous monitoring of total suspended sediment concentrations in the water and the calculation of suspended sediment loads introduced to the infiltration basin over time (refer Section 2.0).
2) Visual evaluation of accumulated fine sediment and biological growth on the floor of the basin over time (refer Section 3.0).
3) The sampling and analysis of basin floor material to determine if the grain size distribution changes over time. This process has not been undertaken as part of the Hinds Pilot Trial to date.
4) Analysis of inflow rates and water levels in the basin, to determine if:
    a) The head of water in the basin required to maintain a constant infiltration rate has increased over time, or
    b) The rate of infiltration under a constant head has decreased over time.

    This process has not been undertaken as part of the Hinds Pilot Trial to date due to issues around the accuracy of the measured inflow rates to the site (refer Appendix E).
5) Analysis of the rates of change in water level following the closure of inflows to the basin (refer Section 4.0).
6) Analysis of the hydraulic pressure differential between the basin and a sensor installed in the sediment beneath the basin (refer Section 5.0).

Of the clogging evaluation methods listed, the most sensitive analyses are based on the evaluation of infiltration rates and changes in basin water depth over time (Options 4 and 5 above).

1.3 Pilot Trial Schedule

A commissioning infiltration test was performed at the Pilot Trial site, from 16 to 19 May 2016. The Pilot Trial flow operations began on 10 June 2016 and, depending on supply water availability, ran through its first year of operations to 9 June 2017. Data from both the commissioning test and the main Pilot Trial has been used in evaluating basin clogging.

Data to support the assessment of changes in the pressure head differential through the floor of the infiltration basin covers a period from 16:00 on 15 June 2016, when the continuous flow record began, to 08:00 on 25 December 2016, when the Pilot Trial was temporarily halted due to the onset of the local irrigation season.

2.0 SUSPENDED SEDIMENT LOAD

2.1 Water Flows

The analysis of water flows to the site via the water race from Valetta Pond #3 and the two monitored flumes has been documented in Appendix E. Flows to the site were highly variable through the Year 1 operational period, including several shut-down periods during the summer and autumn due to irrigation water demand and Valetta operational requirements (Figure I1).

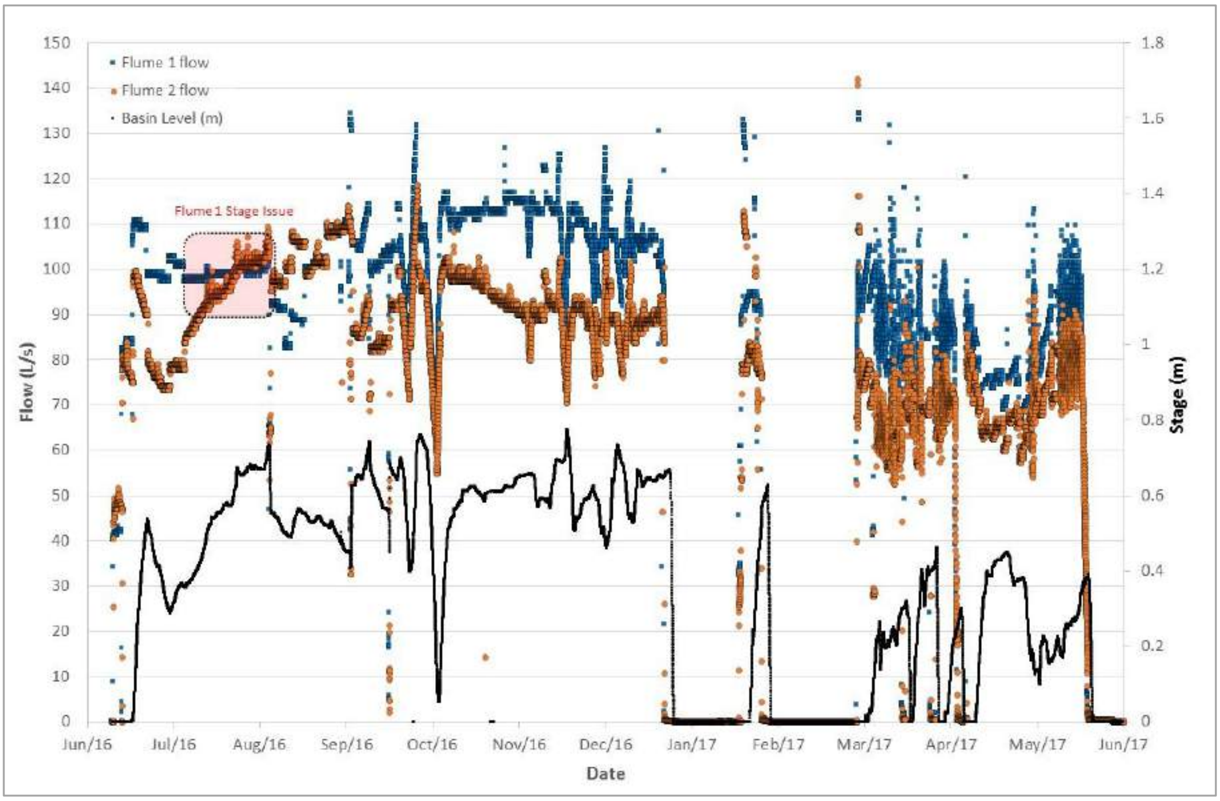

Figure I1: MAR Site - Year 1 flows at Flume 1 and 2 and main infiltration basin water depth.

2.2 Suspended Sediment Concentrations

Samples are taken on a monthly basis from a point in the water race at Flume 1, downstream from Valetta Pond #3, and from a second sampling point in the infiltration basin. These samples are analysed for total suspended solids (TSS) concentrations and other parameters. The analysis results are documented in Appendix F.

There were three main periods of water delivery to the site during Year 1 of the Pilot Trial (Figure I2). The median TSS concentrations measured in water samples obtained from the water race at Flume 2 during these periods were:

- 10 June 2016 – 23 December 2016: 5.0 g/m^3 One of five samples below 1.5 g/m^3 measurement limit.
- 18 January 2017 – 26 January 2017: 59 g/m^3 Only one sample taken (Figure I3a)
- 1 March 2017 – 22 May 2017: 5.0 g/m^3 Only two samples taken (Figure I3b)

The samples taken at Flume 1 during December and January returned higher concentrations than the other samples (Figure I2). Analysis of water samples obtained from the main infiltration basin returned results that indicated the TSS concentrations in the basin reflected trends in concentration identified at Flume 1 (Figure I2).

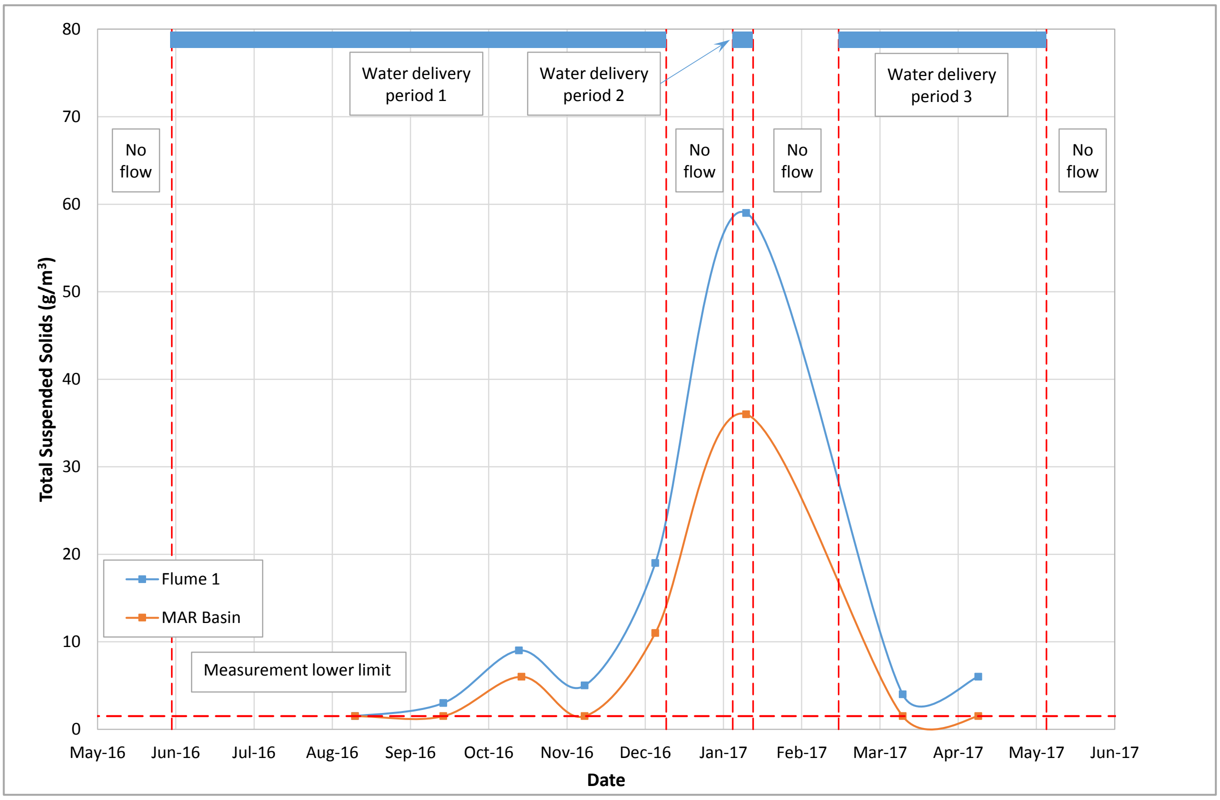

Figure I2: Total suspended solids concentrations in MAR source water.

The suspended sediment concentrations in the water race at Flume 1 are not expected to differ greatly from concentrations at Flume 2, which is the flow entry point to the MAR basin. The race does not offer substantial opportunities for sediment deposition during the Pilot Trial operations and the flows used during the trial are unlikely to have resulted in significant erosion of the race, as they are considerably less than the flows that were formerly delivered to the adjacent farm ponds via this race.

Figure I3: Valetta water race at Flume 2 with (a) normal and (b) high suspended sediment concentrations.

2.3 Suspended Sediment Load Record

The TSS load to the Pilot Trial site has been calculated based on water flows (Section 2.1 and Appendix E) and the median TSS concentrations measured at Flume 1 during the trial (Section 2.2 and Appendix F). The input parameters and outcomes of the TSS load calculations are summarised in Table I1.

Table I1: Pilot Trial suspended sediment mass loads.

Delivery periods	Water delivery periods (days)	Median TSS concentration (g/m^3)	Cumulative volume (m^3)	Cumulative mass (kg)	Sediment load per unit basin area [(1)] (kg/m^2)
Delivery period 1	196	5.0	1,543,542	7,718	0.80
Delivery period 2	8.1	59	53,827	3,176	0.33
Delivery period 3	82	5.0	453,585	2,268	0.24
Total	**286**		**2,050,954**	**13,161**	**1.37**

Note: 1) Basin area of 9,596 m^3 incorporated in calculation.

The sediment load per square metre of basin is averaged across the water area of the entire basin, including the forebasin, at the level of the spillway invert between the forebasin and the main infiltration basin. In terms of sediment settling on the floors of each basin, the loads are likely to vary from location to location as a result of:

- Coarse sediment capture in the forebasin, as was intended with the design (refer Section 3.1).

- Preferential deposition of coarser sediment in the main infiltration basin close to the spillway from the forebasin.
- Stable deposition of fine sediment in the main infiltration basin in basin corners and locations where wave disturbance and sediment re-entrainment is least.
- Deposition of fine sediment close to the eastern side of the basin, where the adjacent artificial ridge created from excavated gravels acts to provide wind protection to the water surface and therefore reduces water disturbance.

2.4 Forebasin Sediment Entrapment

Sands and coarser silts transported along the irrigation water race and discharged into the forebasin are expected to settle out within the forebasin. Based on the observed flows through the forebasin and the dimensions of the forebasin, the estimated critical settling particle diameter is approximately 15 µm, which is a medium silt (Table I2). There are a range of assumptions incorporated in this estimation, including particle density and shape parameters and the lack of short-cutting of water flows across the forebasin. This estimate does however provide an indication of the particle capture efficiency of the forebasin. Observations of sediment plumes in the forebasin support the expectation that a significant component of the sediment transported into the forebasin will settle to the base of the basin rather than being transported to the infiltration basin (Figure I4).

Although some fine silts and clays in the source water may settle out in the forebasin, especially as the forebasin is also acting to infiltrate water to the underlying groundwater, most of these fine sediments are likely to be transported through into the main infiltration basin. This expectation is supported by the observations made of different thicknesses of clogging layers documented in Sections 3.1 and 3.2.

3.0 VISUAL ASSESSMENT OF BASIN FLOOR

3.1 Forebasin

Once the accumulated sediment in the forebasin had dried following the halt to the water supply, an approximately 5 mm thick layer of fine sediment (Figure I5) was measured. The drying process resulted in desiccation and cracking of the sediment crust (Figure I5).

Table I2: Critical particle size estimation.

Parameter	Units	Values
Average inflow rate	m^3/s	0.10
Volume at overflow	m^3	1,876
Average retention time	hours	313
Cross section width at overflow elevation	m	37
Cross section base width	m	27
Water depth at overflow	m	1.8
Pond cross section area at overflow depth	m^2	58
Average flow velocity at overflow depth	m/s	1.7×10^{-3}
Water surface area when forebasin half full	m^2	1,074
Critical settling velocity	m/s	9.3×10^{-5}
	m/hour	0.34
Critical particle diameter	µm	15 (1)

Note: 1) Medium silt has a size range of 6.3 to 20 µm.

Figure I4: Sediment plume from inflow spillway to forebasin.

Algal growth was observed in both the main infiltration basin and the forebasin during the trial. Although samples of the settled material have not been sent to a laboratory for analysis, it is likely that it consists of a combination of clastic particles (sand, silt and clay) and organic material derived from the algal growth.

Figure I5: MAR basin clogging layer as seen in forebasin.

3.2 Main Infiltration Basin

A thin accumulation of fine sediment was observed on some areas of the main infiltration basin (Figure I6). This accumulation occurred primarily close to the outer corners of the basin. Across most of the basin floor the accumulated sediment was too thin to be measured in the field.

The observed settled sediment appears to predominantly consist of:

- Fine clastics (silt and clay) transported through from the forebasin.
- Soil eroded by run-off from the bunds surrounding the basin.
- Remnants from algal growth in the basin.

Figure I6: MAR basin clogging layer as seen in infiltration basin.

4.0 BASIN WATER LEVEL RECOVERY CURVES

4.1 Method

During the course of Pilot Trial Year 1, flows to the site were stopped or substantially reduced on several occasions (Figure I7). In addition, infiltration operations undertaken for the pre-operational testing of the site were also associated with a shut-down process.

A review of the water level recovery curves associated with the events identified in Figure I7 was undertaken prior to analysis of these events. This review indicated that the first event was not appropriate for analysis of assessing basin infiltration rates because:

1) The first event had a substantially slower decrease in water level than the other six events.
2) The water level in the water race upstream from Flume 1 did not decrease to a stage low enough to indicate that flows were no longer entering the basin.
3) The event did not terminate in a dry basin.

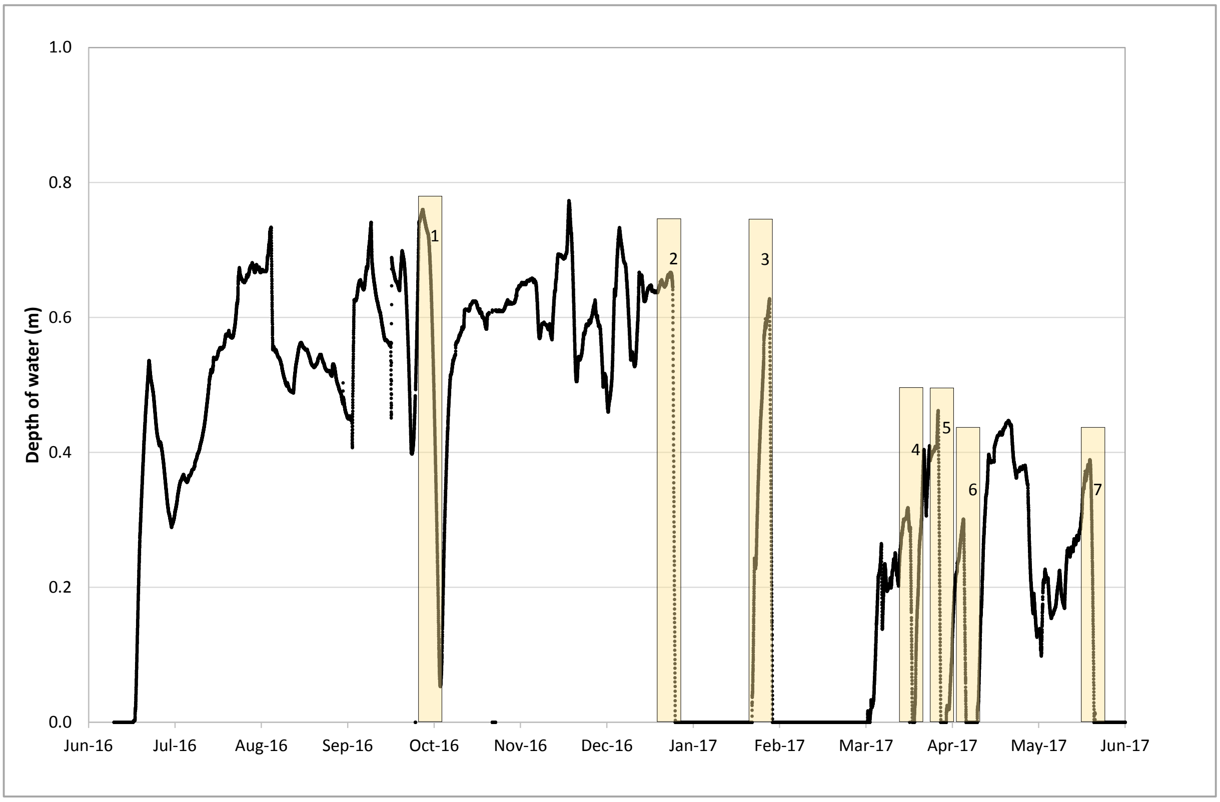

Figure I7: Shut down events during Pilot Trial.

The other six events identified were considered to be appropriate for analysis to evaluate basin infiltration rates. The water level recovery curves for each of these shut-down events, together with the shut-down curves from the pre-operational test were plotted together and compared (Figure I8).

It is likely that all of the recovery curves recorded from the infiltration basin during shut-down events were influenced to some extent by water seeping through from the forebasin into the infiltration basin. The hydraulic connection between forebasin and infiltration basin can however only be demonstrated by comparing the two recovery curves recorded at the end of the pre-operational test. This was the only time during Year 1 that pressure transducers were recording water levels in both basins for a shut-down event.

The recovery curve from the forebasin at the end of the pre-operational test started with a much greater depth of water in the basin. It is likely that the shape of this curve was influenced by the presence of water in the adjacent infiltration basin during this event, as the curves from the forebasin and the infiltration basin match toward the end of the recovery period (Figure I8). The two curves are very closely aligned during the last two hours prior to the basins becoming dry, indicating a hydraulic connection between the two basins. The rapid drop in water level recorded from the forebasin, compared to any of the curves recorded from the infiltration basin, suggests a significant fraction of the forebasin water seeped through to the infiltration basin rather than infiltrating directly downward to the underlying groundwater.

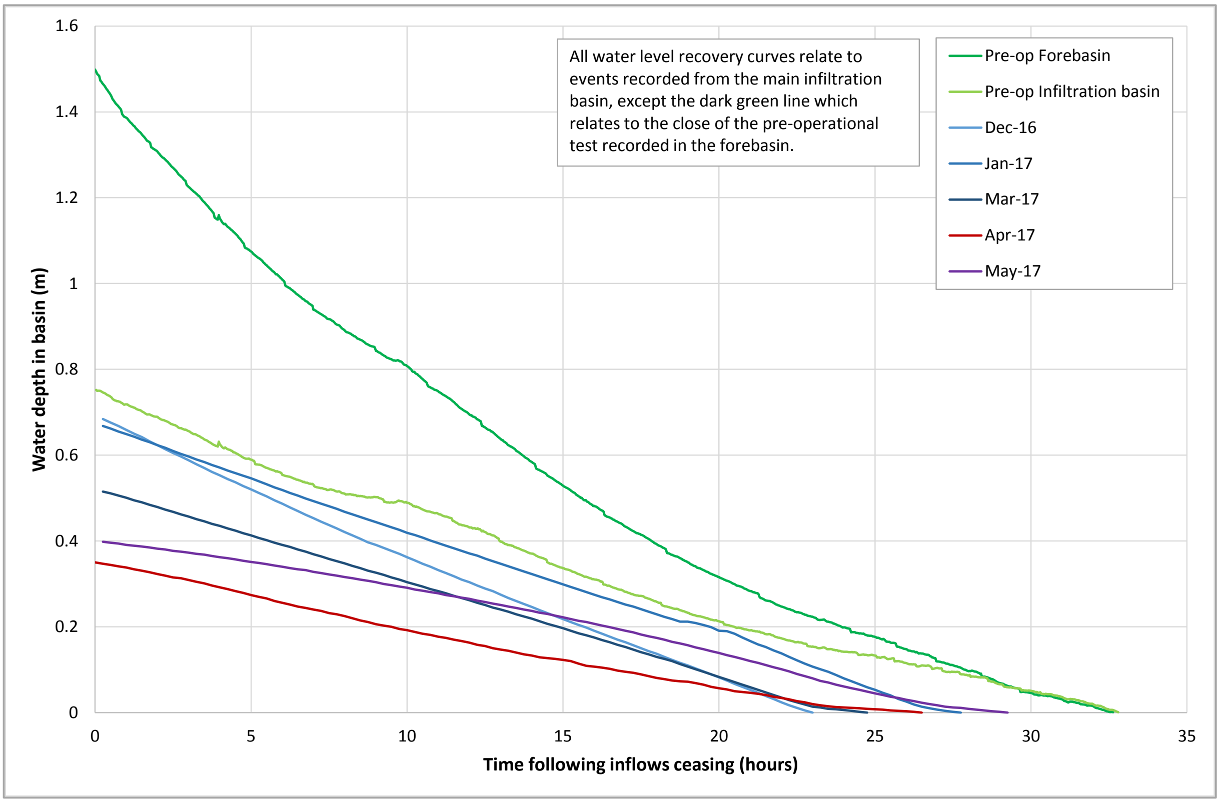

Figure I8: All zero-inflow basin recovery curves from Pilot Trial Year 1.

These two events were evaluated separately. In each case a linear trend line was fitted to the curve to identify the average rate of drop in water level in metres per hour. It was recognised that the curves are not strictly linear, especially as the water level approached the basin floor. Linear trend lines are however sufficient for a general analysis of recharge rates.

4.2 Results

The trend lines fitted to the first four recovery curves indicated the water level in the basin was dropping at average rates of between 22 mm and 30 mm per hour (0.53 to 0.72 m/day) (Figure I9). These curves were all recorded prior to April 2017. The final two recovery curves recorded suggested the rates of water level decline in the infiltration basin following shut down had decreased to between 13 mm and 15 mm per hour (0.31 to 0.36 m/day) (Figure I10).

The only infiltration basin recovery curve from those evaluated that showed a substantial shift in the rate of water level decline was the one recorded at the close of the pre-operational test (Figure I9). In this case the initial rate of water level drop was double the rate when the basin was approaching being empty. As previously noted, this shift may have been due to the hydraulic interconnection and changing hydraulic gradient between the forebasin and the main infiltration basin during the recovery period.

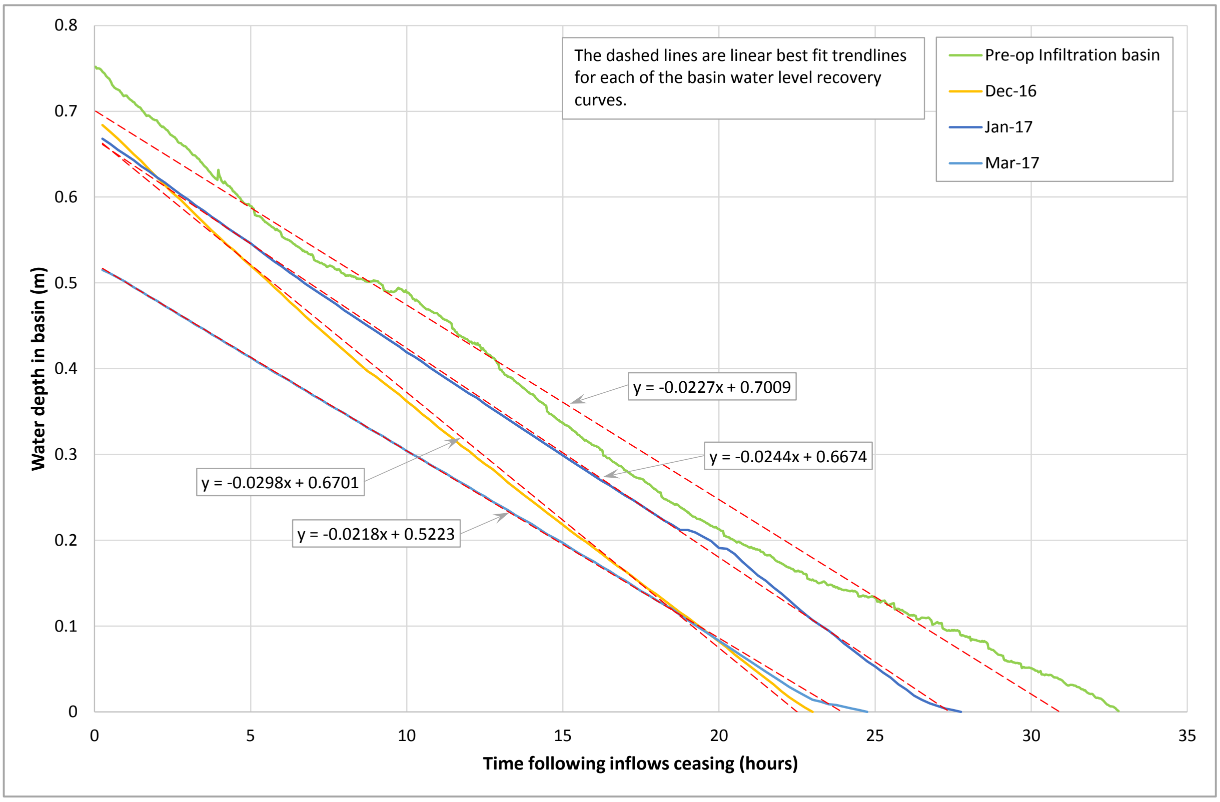

Figure I9: Shut-down water level recovery curves prior to April 2017.

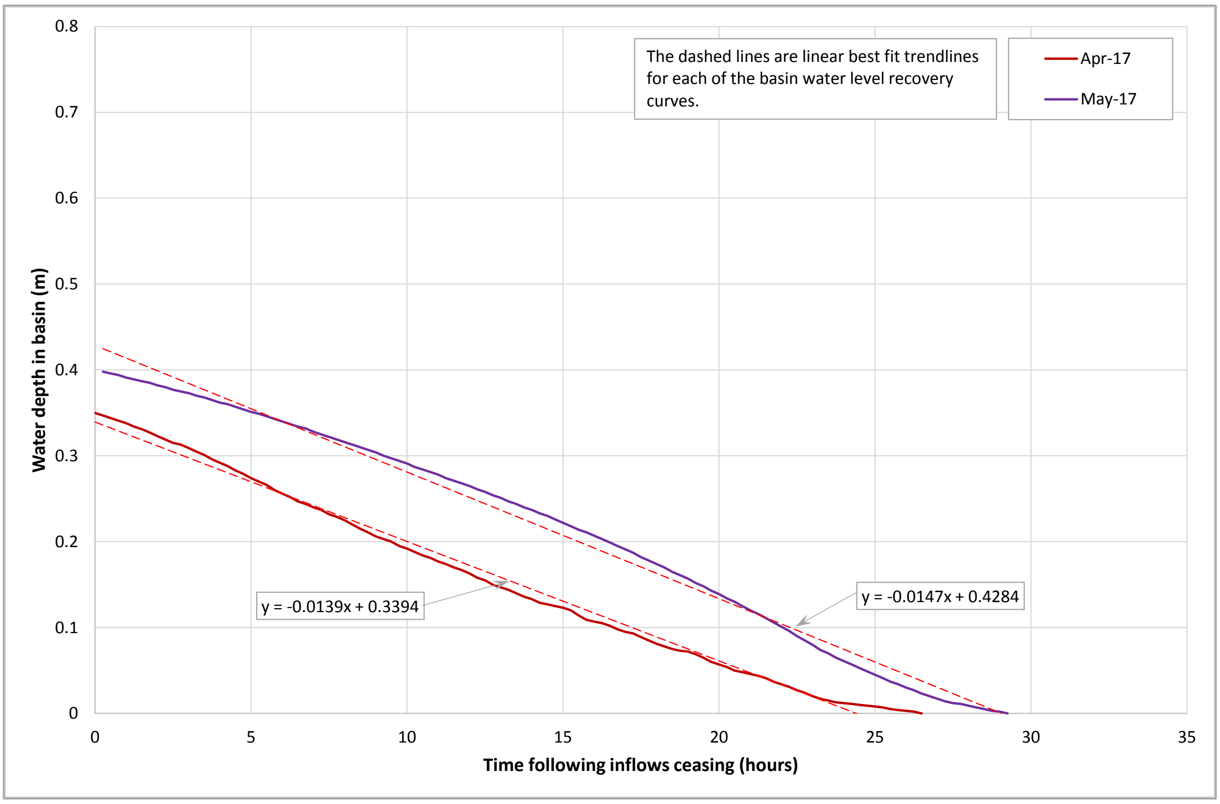

Figure I10: Shut-down water level recovery curves after March 2017.

The rate of decrease in water level recorded from these recovery curves primarily reflects water infiltration rates through the base and sides of the infiltration basin. However, the calculated recovery rates may have been affected by several other factors, which would need to be taken into account when considering basin infiltration rates. These factors include:

1) Seepage from the forebasin to the main infiltration basin. May result in slight under-estimation of infiltration rates for the main infiltration basin. Not taken into account in this calculation due to lack of simultaneous datasets from both basins during most of the recovery periods.

2) Rainfall during the period under evaluation. Significant rainfall recorded at Willowby may have overlapped the recovery curve recorded for April 2017. No rain was recorded during the other events (Table I3).

3) Evaporation losses from the surface of the water in the basin. Evaporation losses are minor compared to the seepage losses (<8 mm/day) but have been taken into account in the recovery curve calculations (Table I3).

4) Water temperature, which may influence water viscosity and therefore capacity to seep into the underlying soil. For the purposes of this study, water viscosity changes have not been taken into account in evaluating observed infiltration rates. Water temperature and therefore viscosity would not influence the observed rate of infiltration, but would influence how this rate is applied in projections of infiltration rates for other days.

Table I3: Basin infiltration rates calculated from water level recovery curves following shut-down events.

Recovery curve evaluated	Climatic factors[1]		Average infiltration rate		
	Rain at Willowby	Ashburton Aeroclub PET [2]	From recovery curves		Incorporating environmental factors
	(mm/day)	(mm/day)	(mm/hour)	(m/day)	(m/day)
18 May 2016 (pre-operational test)	0	0.5 [3]	22.7	0.54	0.54
24-Dec-16	1	2.8	29.8	0.72	0.71
27-Jan-17	0	7.6	24.4	0.59	0.58
28-Mar-17	0	2.1	21.8	0.52	0.52
Average (pre April 2017)			**24.7**	**0.59**	**0.59**
6 – 7 April 2017	42 [4]	1.0	13.9	0.33	0.37
22-May-17	0	0.9	14.7	0.35	0.35
Average (post March 2017)			**14.3**	**0.34**	**0.36**
Overall average			**21.2**	**0.51**	**0.51**

Notes:
1) Refer to Appendix B for climate station locations and summary data.
2) PET – potential evapotranspiration. Used to approximate pond evaporation for the purposes of this study.
3) Estimated.
4) All rainfall was on 6 April and may not have completely or partially overlapped the water recovery curve period.

The average infiltration rate calculated from recovery curves recorded prior to the end of April 2017, and taking into account rainfall and evaporation, was 0.59 m/day (Table I3). On the same calculation basis, the average infiltration rate from the two curves recorded after that date was 0.36 m/day. Although there appears to have been a decline of 40 % in infiltration rate based on the analysis of these curves, the number of curves analysed is small and these results should therefore not be considered in isolation when evaluating groundwater recharge from the basin. The calculated decrease in apparent infiltration rate should also not be taken as a clear indication of basin floor clogging, as this change is effectively interpreted from two data points.

5.0 BASIN FLOOR HYDRAULIC PRESSURE DIFFERENTIAL

5.1 Method

Two Solinst transducers with pressure recording ranges of 10 m and nominal recording accuracy of 0.1 % of the recording range or 0.01 m were installed in the Pilot Trial main infiltration basin:

- One transducer was installed a few millimetres above the floor of the basin, at the northern end of the basin. This transducer, the Basin Transducer (BT), was used to record changes in surface water level within the basin.
- The second transducer was installed approximately 0.2 m beneath the floor of the main infiltration basin, in approximately the centre of the basin. This transducer, the Basin Floor Transducer (BFT), was use to record changes in groundwater pressure surface water level within the basin.

Each transducer recorded pressure head above the transducer at 15 minute intervals.

The two datasets were normalised against the starting water level for each. The datasets were then subjected to a Quality Assessment / Quality Control process, including checks and corrections for missing data or data errors. To evaluate the rate of clogging within the basin over the full 200 day monitored period, the difference between the two head pressure change records was calculated over time and checked for trend.

5.2 Monitoring Data

5.2.1 Raw data

The two raw datasets are presented in Figure I11. No adjustments or corrections have been applied to the datasets presented in this figure.

5.2.2 Corrected data

Two data adjustments have been applied to enable direct comparison of the changes in pressure head recorded at each transducer. These adjustments have been made to normalise the data sets for the hydraulic conditions at the start of the trial. These adjustments were:

1) An adjustment of the complete BT pressure head dataset by 0.11 m to allow for the difference in elevation between the two transducers (pressure head record in Figure I12).
2) An adjustment in the complete calculated head difference dataset of the BT by 0.011 m to align the difference datasets at the start of the record (pressure difference record in Figure I12).

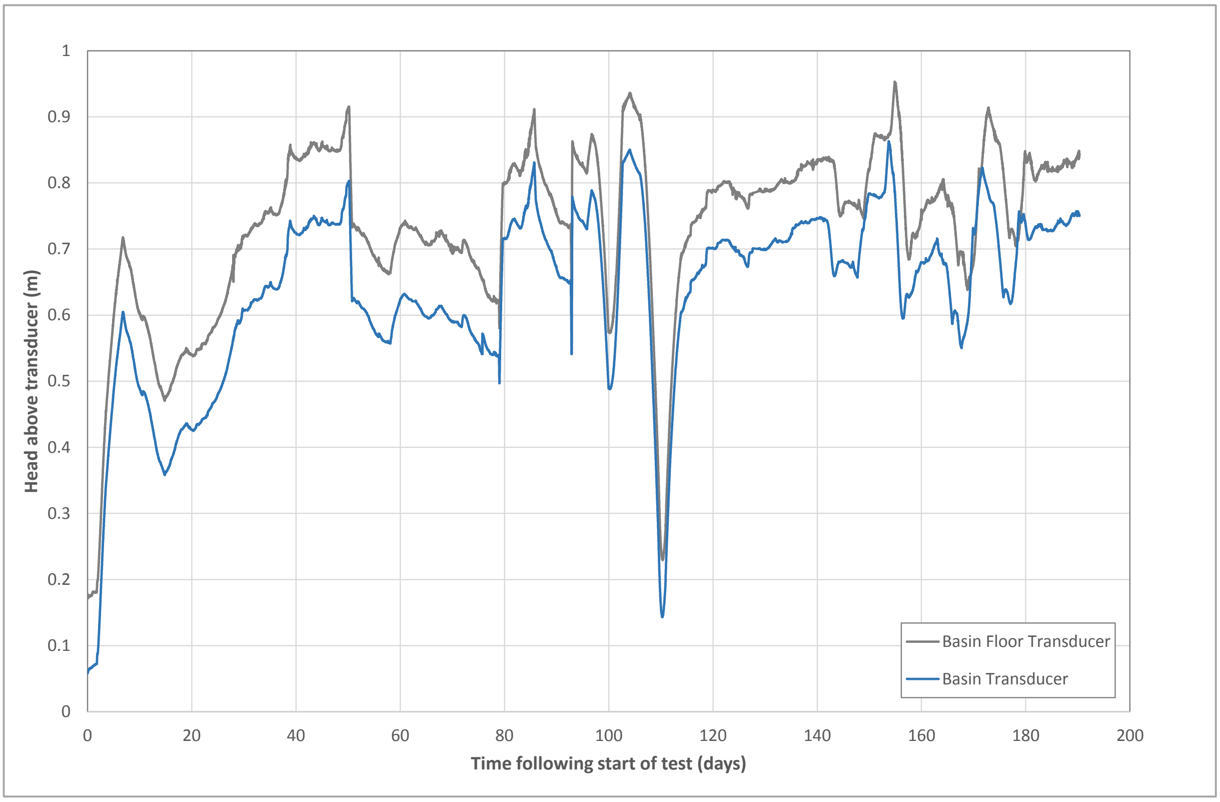

Figure I11: Recorded pressure head above transducers – raw data.

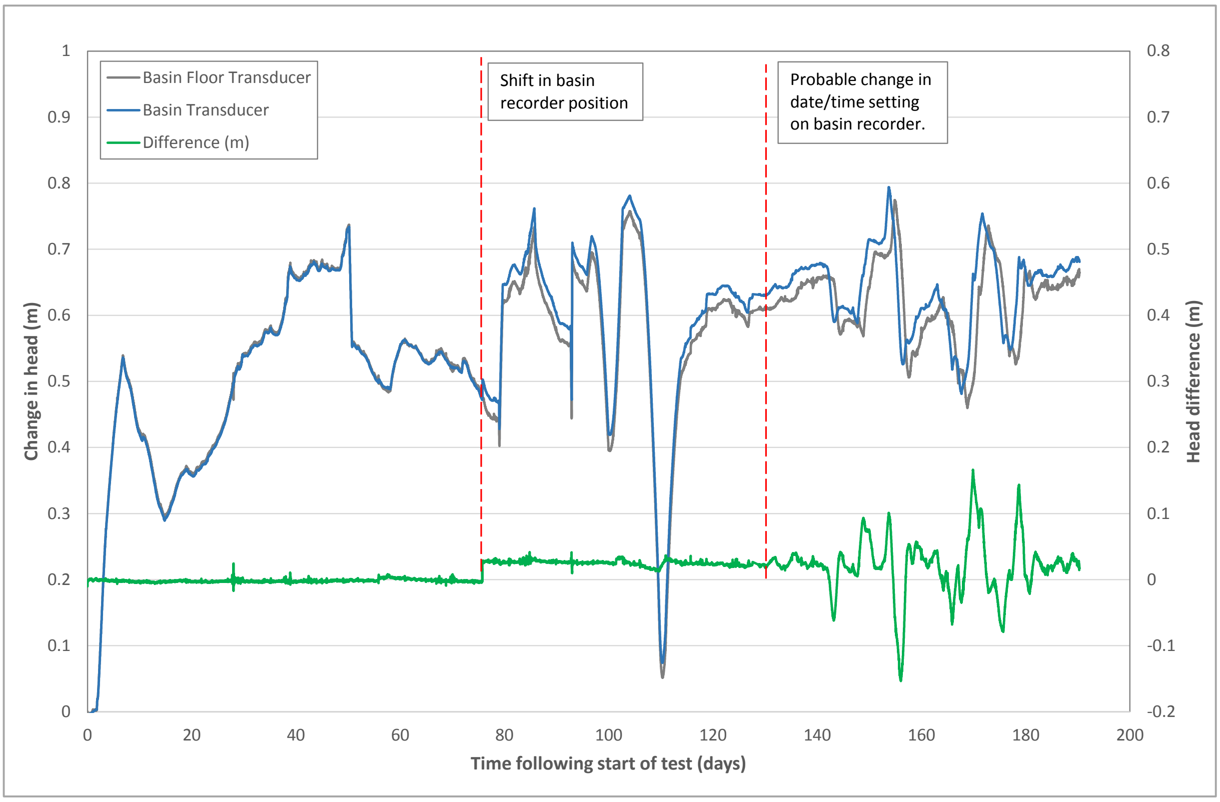

Figure I12: Change in pressure head over time – normalised for starting conditions at each transducer.

Two further corrections have been made to make allowance for instantaneous changes in the data record from the BT. These corrections were:

3) A reduction in all of the recorded pressure head values recorded by the BT of 0.021 m from 10:15 on 30 August 2016 onward (Figure I12). It appears that the position of the BT shifted at this time, although no adjustment in the transducer was recorded in the project field notes. The effect of the shift in the BT is emphasised in the calculated head difference dataset presented in Figure I13.

4) The date and time entry for all recorded elevations from the BT from 16:00 on 23 October 2016 onward has been advanced by 1,650 minutes. It is likely that that the clock on the BT was reset during a data download at about that time, resulting in a clear misalignment of the two raw pressure records from that time onward (Figure I14). Prior to this correction, the calculated head difference from this date onward shows much greater variation than had previously been observed (Figure I13).

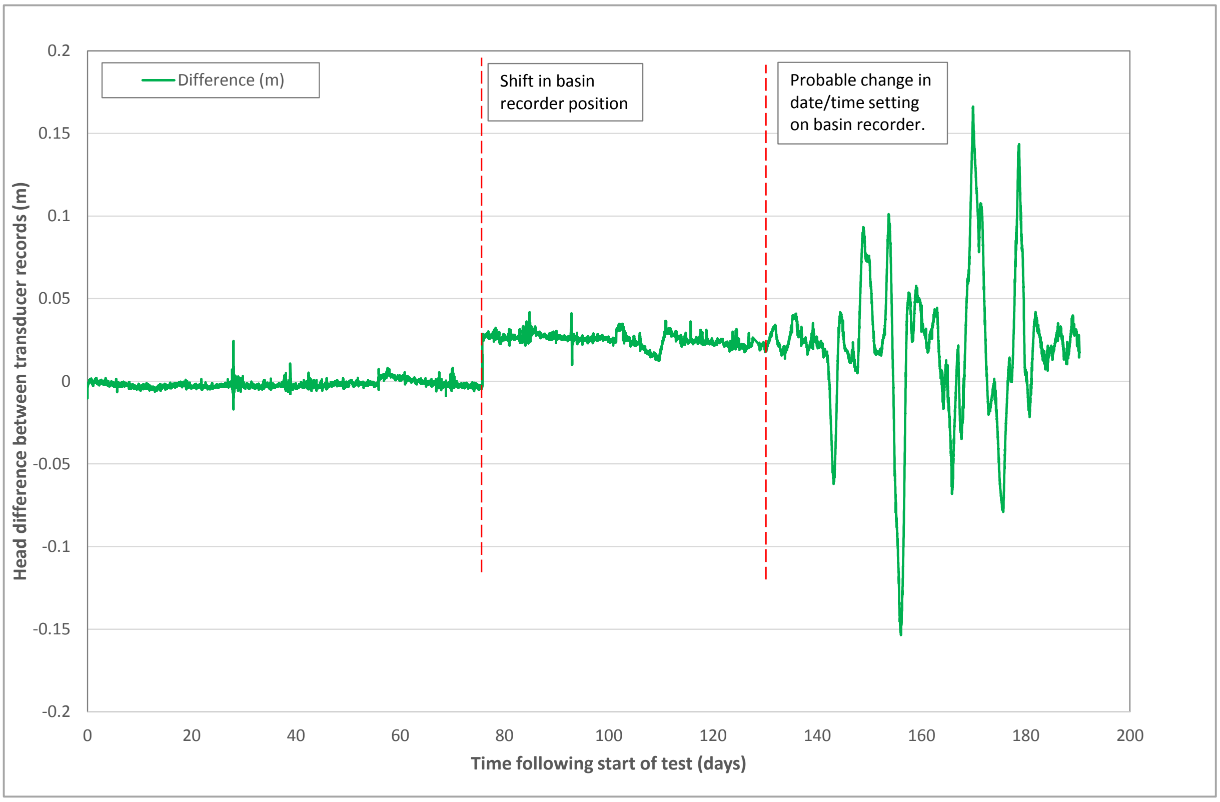

Figure I13: Difference in normalised pressure head between the two transducers over time – raw datasets.

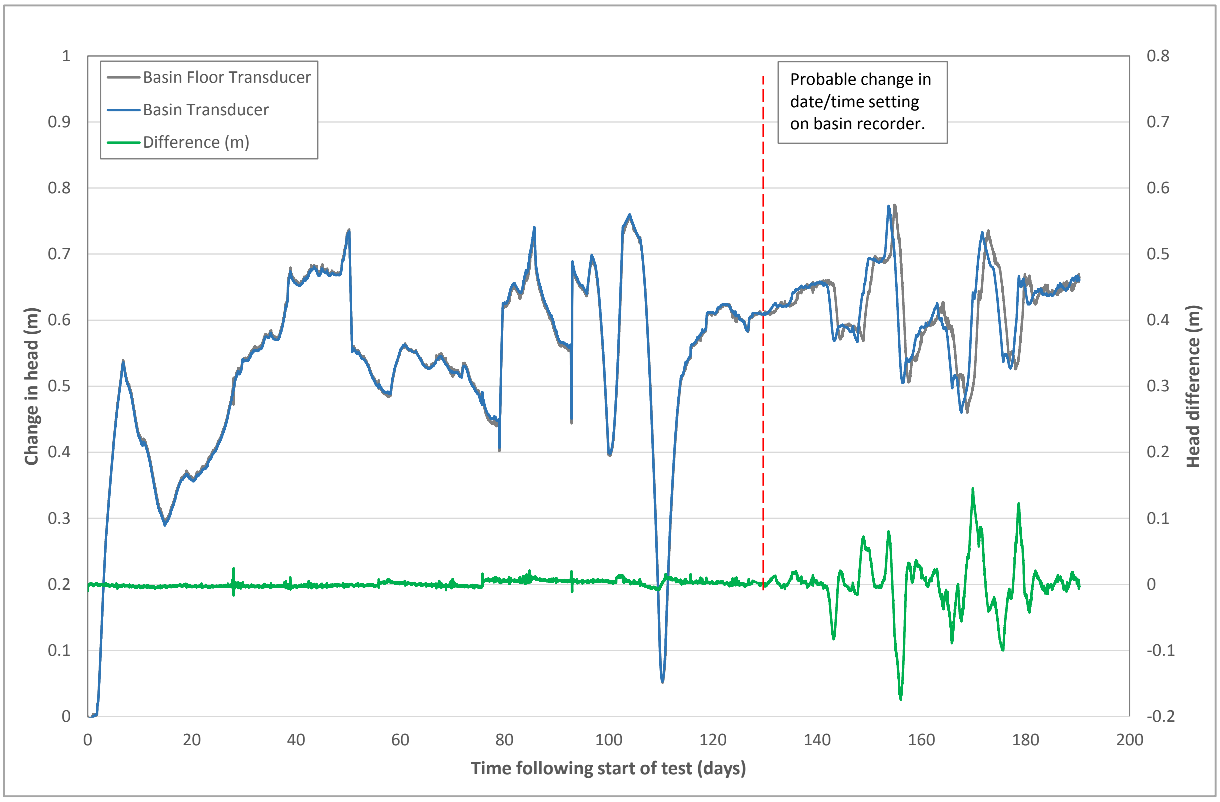

Figure I14: Change in pressure head over time – corrected for the likely change in the BT elevation.

5.3 Results

The two pressure head datasets incorporating the normalising adjustments and the data corrections as described in Section 5.2.1 are presented in Figure I15. The two datasets align very closely and do not appear to diverge over time.

The calculated pressure head difference between the two datasets (Figure I16) emphasises the lack of divergence over time. Although the calculated head difference varies across a range of approximately 0.04 m, there does not appear to be a significant increasing or decreasing trend in this dataset.

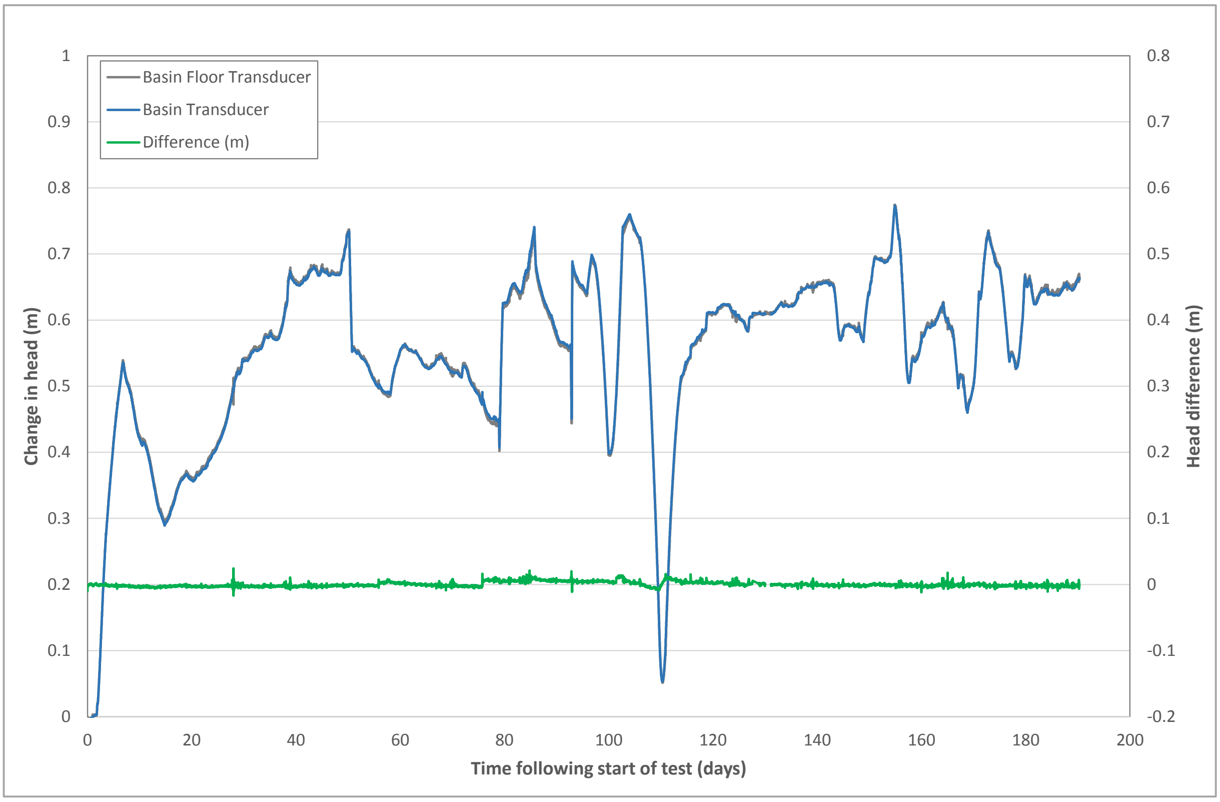

Figure I15: Recorded pressure head above transducers – normalised and corrected datasets.

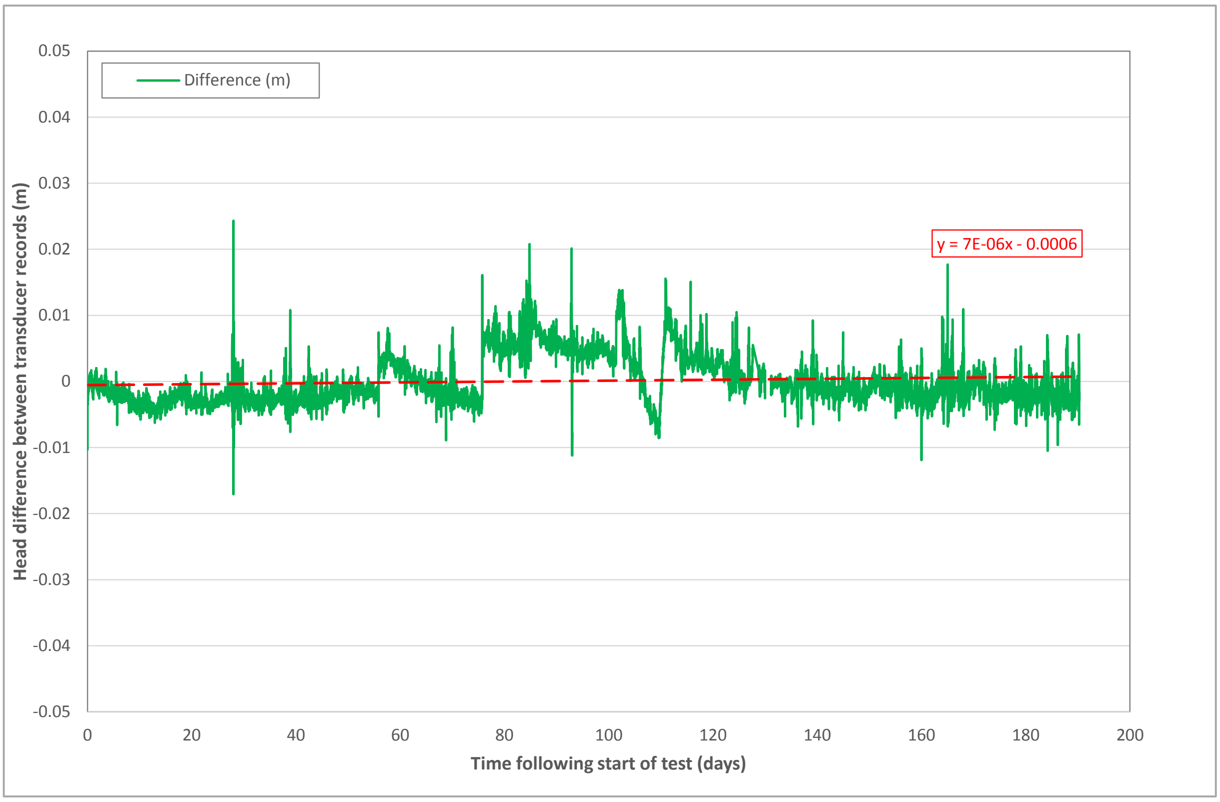

Figure I16: Difference in pressure head between the two transducers over time – normalised and corrected datasets.

6.0 CONCLUSIONS

Clogging of an infiltration basin can be evaluated through a range of monitoring and analysis procedures. Several of these procedures have been applied to evaluating clogging of the infiltration basin floor over the first year of the Pit Trial.

Continuous monitoring of flows to the Pilot Trial site combined with periodic measurement of total suspended sediment concentrations in the source water has been used to provide an estimate of suspended sediment loads to the site. 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.

Visual evaluation has been undertaken of the accumulation of fine sediment and biological growth on the floor of the basin over time. The thickness of sediment accumulated on the floor of the infiltration basin is substantially greater than of sediment on the floor of the infiltration basin.

An analysis of the rates of change in infiltration basin water levels following the closure of inflows to the basin (recovery curves) has been undertaken. This analysis indicates basin floor infiltration rates prior to April 2017 were in the order of 0.59 m/day. Similarly calculated infiltration rates from April and May 2017 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, the number of curves analysed is small 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 basin and a sensor installed in the sediment beneath the basin has been undertaken. An increasing pressure differential would indicate potential clogging of the basin floor. The two water pressure datasets align very closely and do not appear to diverge over time. This data does not indicate clogging of the basin floor took place during the monitored period.

In summary, sediment delivered to the Pilot Trial site in the source water is being deposited preferentially on the base of the forebasin. Fine sediment is however also being deposited on the floor of the infiltration basin. This sediment appears to be primarily composed of clastic materials combined with algal deposits. These deposits do not appear to be affecting the vertical hydraulic gradients through the floor of the infiltration basin. Calculation of infiltration rates for the infiltration basin however suggests these rates may have decreased toward the end of Year 1. The assessment of infiltration rates is the most sensitive means of detecting the effects of basin floor clogging and evaluates clogging across the entire basin rather than just single points.

As with all MAR systems, clogging is an operational issue that needs monitoring and management. The data from the first year of operations is inconclusive regarding any reduction in infiltration rates at the Pilot Trial site through clogging. Sediment is however clearly being deposited in both basins and, without management, would eventually result in a clear decline in the basin performance.

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APPENDIX J

Canterbury Health Board Monitoring

1.0 OVERVIEW: MAR DRINKING SUPPLIES MONITORING AND OUTREACH PROJECT

The Ashburton Zone Committee (AZC) identified that in the Hinds catchment, drinking water wells should meet the New Zealand drinking water standard for nitrate-nitrogen (nitrate-N) and enteric bacteria *E.coli*, now and into the future (AZC, 2014). Scott (2014) found that nitrate-N concentrations in the catchment are *'elevated and increasing in groundwater and spring-fed waterways'* with the maximum concentration often exceeding the drinking water standard (11.3 g/m^3 nitrate-N or 50 g/m^3 nitrate), and average concentration exceeding half the standard[1] (5.7g/m^3).

Indicator bacteria are types of bacteria used to detect and estimate the level of faecal contamination of water. *E. coli* is the most commonly used of these indicators, and is included internationally in most drinking water standards as the preferred approach. The Canterbury District Health Board (CDHB) tracks health issues related to enteric bacteria (bacteria from animal intestines) across Canterbury. Data analysis presented to the AZC (2011) reported that between 2006 and 2010 the Ashburton District had some of the highest rates of reported Campylobacteriosis and other enteric diseases in the regions surveyed (Figure J1). These statistics raise issues of drinking water quality above that of just nitrate, and require that sources of both nutrients and animal faeces are better managed.

The CDHB has the responsibilities to both *improve, promote and protect the health of people and communities; as well as promote the reduction of adverse social and environmental effects on the health of people and communities* (Tully, 2015). Starting in 2008, nitrate-N was identified as a concern for drinking water supplies by CDHB in the Ashburton area. CDHB initiated a work plan with Canterbury Regional Council (CRC) to ensure that those at risk started testing their water and took appropriate action to manage the risks.

A Nitrate Communications Plan was started which provided region wide advice, worked to promote awareness with health professionals and worked with key organizations to deliver consistent messages about the risks of rural private bores. Those identified to be most at risk (nitrate-N, *Methaemoglobinaemia or blue baby syndrome)* were pregnant women and those with bottle fed infants under 6 months of age, with formula made up from water drawn from private bores. The message to this focus group was to have their water tested, and if polluted with nitrate and *E. coli*, to find water from another source, or install a (costly) nitrate removal system. The purpose of this plan was to support efforts that reduce the amount of nitrate entering drinking water supplies (e.g., AZC sub-regional plan), but in the shorter term, work to protect those that are most vulnerable.

In relation to enteric bacteria (e.g., *E. coli* as an indicator of presence of faecal contamination in water samples) CDHB made a number of key recommendations to the AZC (CDHB, 2011) around drinking water supplies. In particular:

1) **Recommendation 4 - Quality:** *While (CDHB) recognizes that provision of safe and wholesome drinking-water (i.e., water treatment) to Ashburton people is primarily the responsibility of the Ashburton District Council, there is a unique opportunity here for the zone committee to protect the source from contamination in the first place through a strong policy statement or plans to safeguard groundwater in this zone from impacts of surface activities and land-use*.
2) **Recommendation 6 – Quantity:** *The plans for diverting some of the groundwater to increase surface water flows should not compromise availability of adequate, good quality water for drinking-water supplies.*

These recommendations reaffirmed the responsibilities of Ashburton District to ensure drinking water supplies in the district are safe and wholesome, but also flagged that changes to groundwater (e.g., lost incidental recharge) for the purpose of increased stream flows, would not come at the expense of adequate drinking water supplies.

[1] (Scott, 2014). 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).

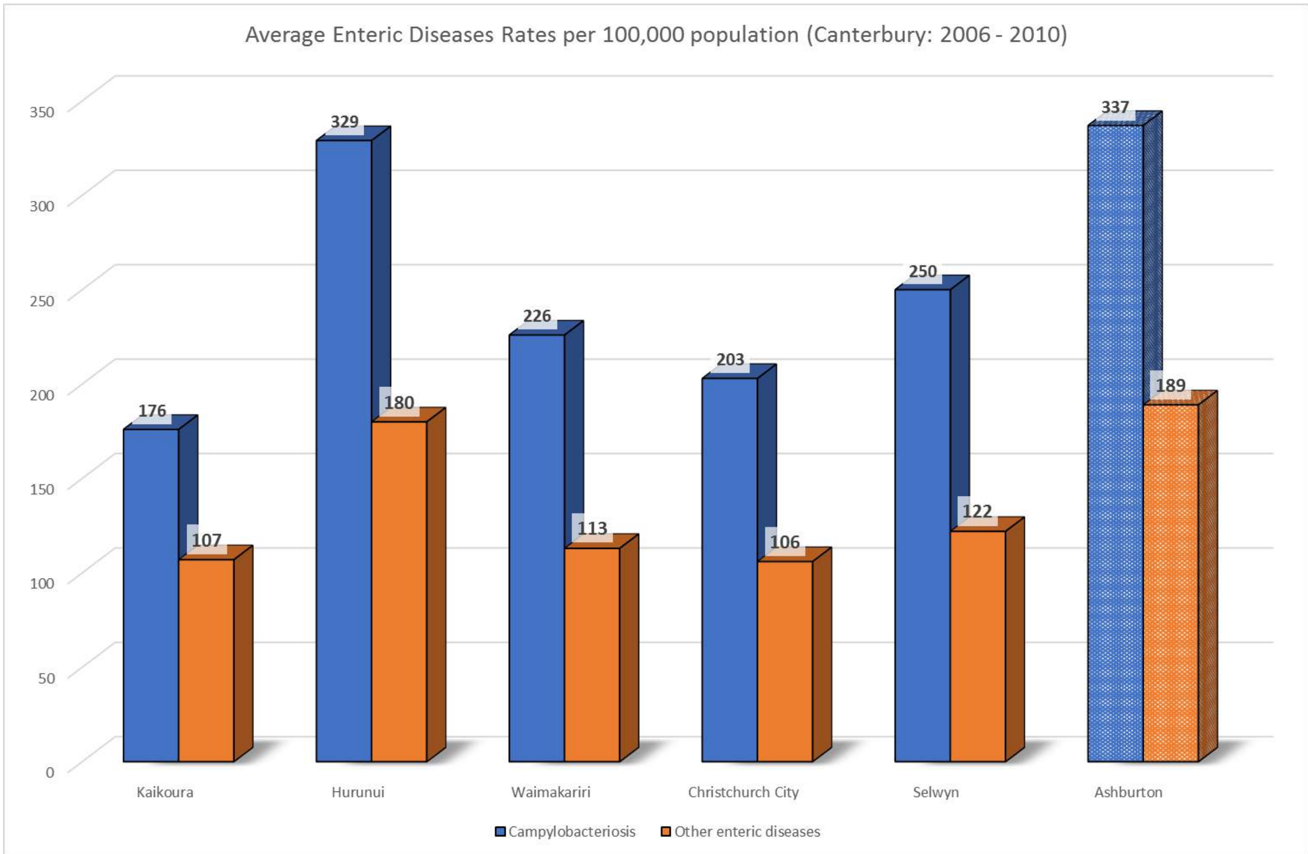

Figure J1: CDHB Enteric Diseases Rates per 100,000 population for Canterbury (CDHB, 2011).

During the Hinds Plains Subregional Hearings (Variation 2 to Canterbury's Land and Water Regional Plan) where MAR was officially recommended for a pilot trial, the Canterbury District Health Board made the following submission on MAR:

> *Application of MAR for diluting nitrate concentrations has significance for drinking water sources as 80% of people in the Hinds catchment utilise their own water supply for domestic use and do not obtain their drinking water from the community supplies operated by the Ashburton District Council. It is therefore appropriate that MAR is strategically engineered to provide effective water quality protection to wells used for drinking water on individual properties from extensive diffuse groundwater pollution from agricultural land-use. This will involve giving technical consideration to the spatial location and scale of MAR with respect to water wells and their screened depth. (CDHB, 2014, page 2[2])*

Early in the development of the Pilot Trial, the MAR technical team worked to establish a partnership with CDHB to help explore the use of MAR as a tool to help better manage drinking water supplies and protect public health amongst 80 % of the people in the Hinds catchment. The following is a summary of results of this partnership for Year 1 of the trial.

[2] http://files.ecan.govt.nz/public/lwrp/variation2/doc/doc2197046.PDF

2.0 OBJECTIVES AND METHODOLOGY

2.1 Project Partnership

The Hinds MAR Pilot Working Group (now Governance 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. This partnership was scoped as two separate works streams to be undertaken during the MAR Pilot Trial Year 1 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.

These coinciding works streams were completed from November 2015 through to July 2017. The methodologies and timelines are covered in the following sections.

2.2 CPH Programme Methodology

Starting in 2015, CDHB and MAR Technical team staff met to set up a partnership monitoring and outreach programme to coincide with the MAR Year 1 testing. The programme included the following steps:

1) In October 2015, CPH initiated their sampling programme of drinking water supply bores located downgradient from the MAR testing site, but inside the MAR command area. This programme was to provide a baseline of drinking water supplies ‘before’ MAR operations for both *E. coli* bacteria and nitrate-N.
2) CPH set up the programme working closely with ADC who have an International Accreditation New Zealand (IANZ) certified laboratory for presence/absence testing of *E. coli*. ADC provided the laboratory support for analysing water samples for *E. coli* whilst CPH gained permission from the Ministry of Health to sample 50 properties for nitrate-N, with results analysed by the Eurofins ELS Ltd (Wellington). CPH staff were identified to do the field sampling programme.
3) ADC provided CPH with property addresses for those in the Hinds/Tinwald region (MAR command area) not on community water supplies. CPH sent out a public wide notice (in letter form) of the project objectives and said staff would select 50 properties to sample for *E. coli* and nitrate-N. There were some additional responses from the public who rang in response to this notice, and they were included in the CPH Programme.
4) Sampling areas were divided into above (up-gradient) and below (down-gradient) from State Highway 1 (SH1). Properties were randomly selected and permission sought by those on the property from the list of respondents.
5) In December 2015, results were received back from the ADC and Eurofins laboratory, analysed, and then mapped. The *E. coli* and nitrate-N results were then posted back to all the individual bore owners in letter form. The letter contained pertinent information about the science and public health matters related to enteric bacteria (*E. coli*) and nitrate. The letter also provided contact information for local suppliers of drinking water treatment systems for the participants to consider.
6) Results were also shared with the MAR technical team who utilised this information to help inform and future adapt the wider MAR water quality programme.

The final stage of this project was for CPH staff (and subcontractors) to provide a review (both technical and from public health perspectives) of the MAR Pilot testing results and provide feedback and ideas to the MAR technical team. It was intended that this partnership would help to better understand the MAR concept and look to how it might best help address the drinking water outcomes sought in the Hinds Catchment.

2.3 MAR Project Drinking Water Quality Sampling and Assessment

The MAR Pilot water quality monitoring programme included sampling in the MAR command area including controls up-gradient from the MAR site and reaching down below SH1 into the shallow groundwater at coastal springs. With regards to *drinking water protection* and the monitoring of MAR sites, standard practice is to monitor closely and specifically both the *source* water being recharged and the *receiving* water in the target aquifer. As aquifers are complex systems, and their many potential influences on groundwater quality, the *receiving* water is typically bores that are directly adjacent to and typically first to respond to the recharge operations.

Work to summarise the *source* water quality is fully documented in **Appendix F**, whilst the summary of the *receiving* water bores (GWE-1, and GWD-1) as well as the complete Hinds MAR groundwater monitoring results are discussed in **Appendix H**.

Starting in May, 2017 and after the results for CDHB's sampling programme were made available, the MAR technical team identified several bores downgradient from the MAR site that had been sampled by CDHB. In June 2017, samples for *E. coli* and nitrate-N were collected at three of these sites in order to start monitoring them going into the Pilot Trial Year 2 monitoring. Additionally, drinking water bores in the near-field MAR influenced clean-water plume area had been added to the monitoring programme, particularly as other bores (initially instrumented for monitoring) went dry, and the drought conditions drove the regional water table downward in 2016 (Table J1). These bores were included in the overall monitoring programme to track the movement of the clean water plume but also provide an opportunity to analyse the results specific to drinking water changes.

Table J1: MAR Pilot Trial site - proximal drinking water bore information.

Site	Depth (metres)	Distance to MAR site (metres)	Relative position	Sampling types
GWE-11	64.8	380	Downgradient	Quality only
GWE-13	60.0	1,600	Downgradient	Quality only
GWE-15	60.0	1,800	Perpendicular to gradient	Quality only

2.3.1 Spatial Mapping for Nitrate-N

One of the important requirements for the overall MAR programme was the need to be able to visualise the spatial distribution of elevated nitrate-N concentrations across the entire Hinds catchment. It is reported that there have not been any large scale CRC investigations of groundwater quality in the Hinds catchment since the early 2000s by Hanson (2002) (per comms Lisa Scott). Additional quality information was assessed by Dommisse (2007) and more recently by CRC (Hanson, Abraham, 2013) but are limited to specific areas in the catchment.

For the purposes of providing a groundwater quality map of the Hinds catchment, and specifically the MAR command area and the targeted higher concentration nitrogen 'hotspot' (e.g., the Tinwald Plume), Golder staff utilised data from CRC's water quality database. This portion of the project was to provide a 'high level' assessment of potential hotspots in the Hinds catchment. The GIS analysis and spatial mapping was completed as follows:

- CRC's available groundwater quality data for the past 10 years (2007 to 2017) for nitrate-N was tabulated for both the Valetta and Mayfield-Hinds groundwater allocation zones (GAZ). A maximum value for each bore was used to represent 'worst' case. Samples for individual bores ranged from single samples to quarterly samples (CRC State of Environment bores), but spatial coverage was determined as a priority over more developed datasets. Bores ranged from shallow (<30 metres below water table) and deep (>30 metres below water table). However, the lack of total spatial coverage required that all bores be used in final map processing.
- Spatial mapping steps included processing the spatial data through a variogram (geostatistical) analysis using OBO Geologic software (Golder). ArcGIS Spatial Analyst - *Ordinary Kriging Tool* (Table J2) was used to generate the final GIS mapping layer using the pre-processed OBO data.

Table J2: ArcGIS spatial analysis - Ordinary Kriging advanced parameters.

Parameter	**Value**
Semi-variogram model	Spherical
Lag size	2,500
Major range	12,000
Partial sill	25.36
Nugget	1
Output cell size	500
Search Radius	Fixed
Distance	15,000

3.0 RESULTS AND DISCUSSION

3.1 CDHB Results

A total of 50 samples were collected for both *E. coli* bacteria and nitrate-N concentrations as part of the CDHB monitoring 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 J2). The results show:

- 44 % (22) of bores were below the recommended average concentration[3] of (5.7 g/m^3 nitrate-N);
- 28 % of the bores were above 5.7 g/m^3 but below the nitrate-N Maximum Acceptable Value (MAV) of 11.3 g/m^3;
- The remaining 28 % (22) 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 only two bores testing positive (4 %). The survey information also reported that of the 50 samples, 17 reported have 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 CDHB results are not shared in map form. Note that the CDHB data was not used to generate the nitrate-N map (Figure J2). Finally, when results were processed, CDHB sent letters to each individual bore owner to make them aware of the results and potential implications.

[3] *An average concentration of 5.7 g/m^3 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).*

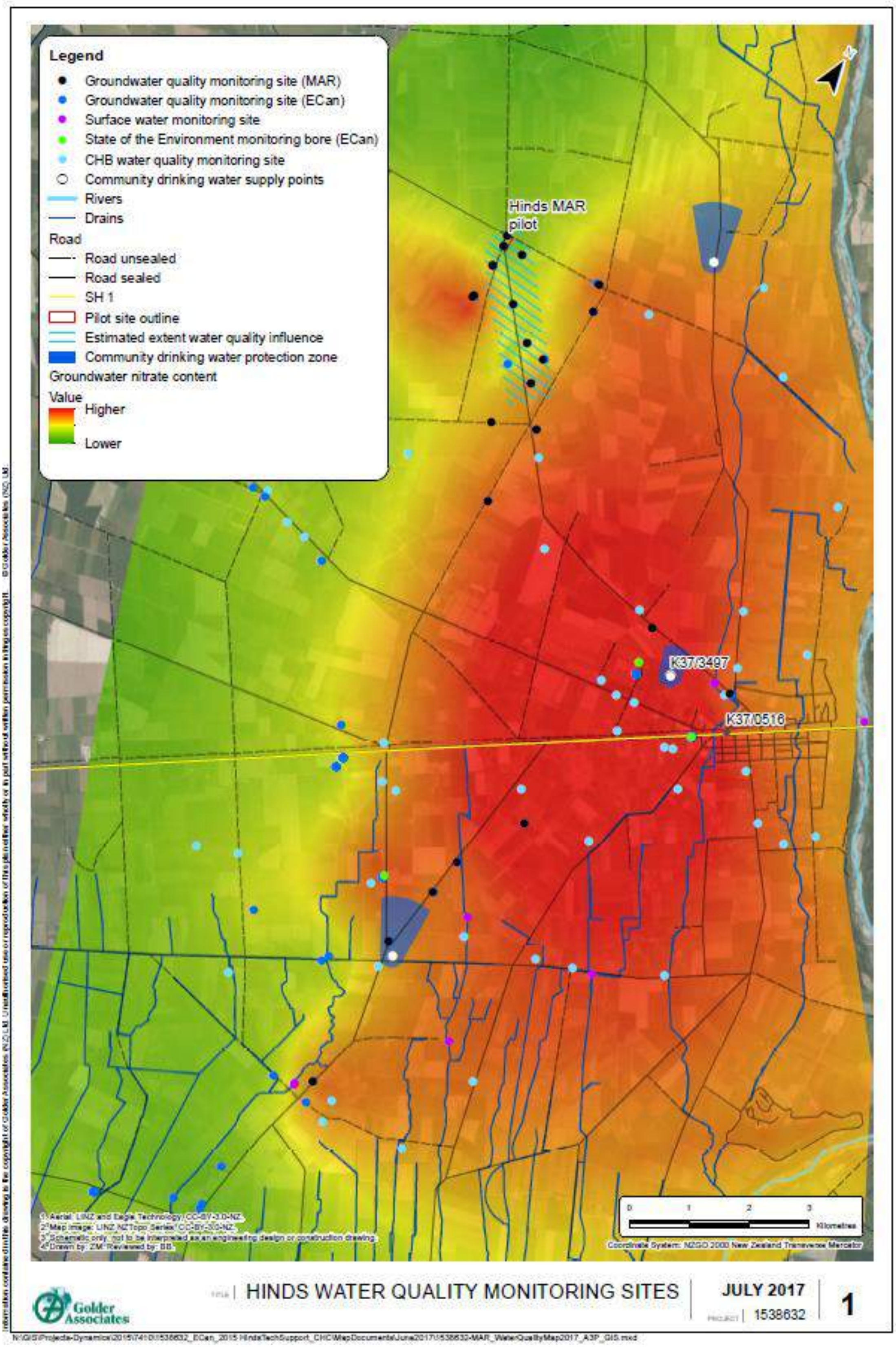

Figure J2: Water quality map of MAR pilot trial area and various surface and groundwater monitoring sites.

3.2 MAR Pilot Trial

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 nitrate-N concentrations of 9.7 g/m^3 and 11.0 g/m^3 respectively. Bore GWE-11 showed signs of MAR influence with some volatile concentration swings between monthly samples early in the year, and then a clear downward trend in the latter portion of Year 1 (Figure J3). 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. Analysis results from Year 1 monitoring (Figure J4) reported only 1 sample with *E. coli* bacteria detected: 1 MPN/100 ml in GWE-15 (February 2017).

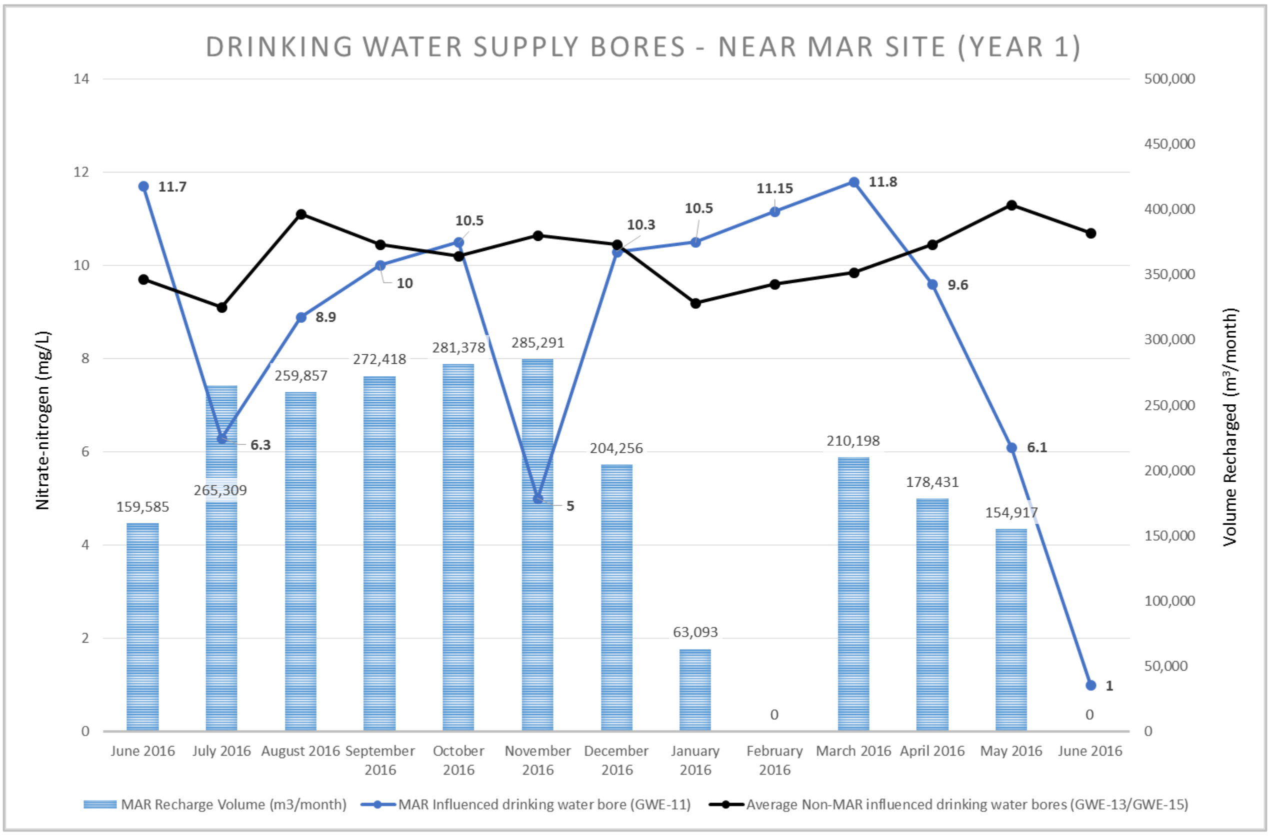

Figure J3: MAR project area - drinking water supply bore response.

3.3 Nitrate Mapping

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. This is due to a combination of the lack of spatial coverage (large portions of catchment missing groundwater bore water quality samples) and lack of vertical resolution (bores available are deeper and may not be representative of the targeted 'shallower' groundwater system). It was generally surmised that areas that showed lower concentrations (green shading in Figure 2), 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. However, areas where data density was quite extensive (e.g., Tinwald hotspot), the confidence in the mapping was improved and therefore was used for the drinking water and MAR command area parts of the final report. The need for an improved spatial understanding of where contamination is more prevalent, particularly for the application of MAR for groundwater quality will require additional field data and continued improvement in the mapping techniques.

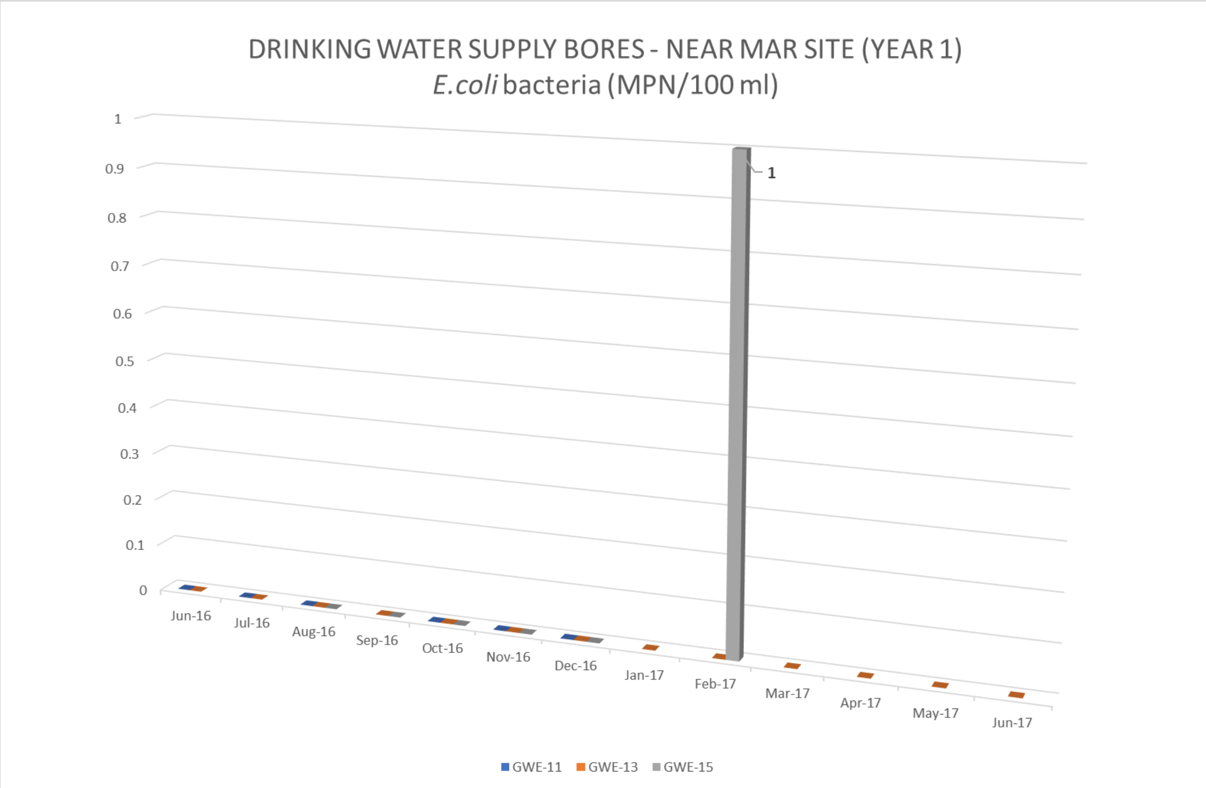

Figure J4: MAR site proximal drinking water bores - E.coli bacteria counts.

4.0 DISCUSSION

The results of both the CDHB and the MAR monitoring programmes indicates that nitrate-N in groundwater is prevalent across the Hinds catchment, but that that more information is required in order to provide a more accurate nitrate groundwater map. 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.

The specific sources of this contamination are unclear but are likely linked to a combination of activities that include agriculture nutrient leaching (both historical and present day), reduction in incidental recharge (closing of stockwater races network and piping), and potentially, point contaminant sources such as failing rural septic systems or site specific land activities. While the MAR project is providing some promising results with specific regards to drinking water sources, the improved management and significant reduction of the sources of this contamination must be improved.

The MAR trial has also shown that the hydrogeology of this portion of the catchment is both complex (with perched paleochannels) as well as hydraulically restrictive with lower surface infiltration rates than is likely found in other portions of the catchment. The combination of these hydrogeologic factors, the numerous potential sources of contamination and the significant number of drinking water supply bores make this area a significant risk when it comes to drinking water supplies.

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 both to decrease the risks through outreach while reducing the amount of contamination in groundwater are needed.

Results from monitoring of near-field area bores during the MAR Pilot Trial indicate that *E. coli* bacteria, during this year of sampling were relatively low in the bores used for drinking. However, given the extremely dry conditions, it is difficult to draw any significant conclusions. Other MAR Pilot Trial monitoring bores did show higher *E. coli* counts and continued monitoring and treatment of drinking water is highly recommended.

Drinking water bores in the MAR near-field bores show at or above the 11.3 g/m^3 nitrate-N drinking water limit, which translates into a significant risk to human health. A drinking water bore located within the MAR footprint, showed beneficial effects with nitrate-N concentrations declining to less than half the drinking water limit.

Mapping of the nitrate-N groundwater concentrations for the MAR command area, and particularly the hotspot located near Tinwald are consistent with CRC mapping[4] which indicate the area 'High Risk' for drinking water in the shallow groundwater system (Figure J2). A review of CRC data and Canterbury Maps indicates that in addition to the numerous private bores, there are three community drinking water bores in the MAR command area. In 2012, another community drinking water bore (K37/0516, depth 46.9 m) was abandoned due to water quality contamination[5] and replaced with a new community drinking water bore (K37/3497) shown in Figure J2.

The results indicate that MAR can play a role in ensuring that drinking water supplies in the 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 river flows) that reduce the net amount of recharge entering groundwater without using MAR as a mitigation, will likely exacerbate these degrading 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.

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[4] A report "Risk maps of nitrate in Canterbury groundwater" explains this map in more detail and can be found on the Canterbury Regional Council website (www.ecan.govt.nz) High Risk areas where nitrate concentrations in shallow groundwater are above the MAV most or all of the time. (Per comms, Lisa Scott)

[5] **K37/0516 Well details**: https://www.ecan.govt.nz/data/well-search/welldetails/SzM3LzA1MTY%3D/SzM3LzA1MTY%3D

APPENDIX K

Automated Nitrate-N Monitoring

Hinds Managed Aquifer Recharge Pilot

Nitrate Temporal Concentration Tracking Project

Report 1365-1-R1

Jens Rekker & Blair Miller
Lincoln Agritech Ltd

13 July 2017

MEASURE. MODEL. MANAGE.

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DOCUMENT ACCEPTANCE

ACTION	NAME	SIGNED	DATE
Prepared By	Jens Rekker	[signature]	13 July 2017
Reviewed By	Clare Houlbrooke, Golder		12 July 2017
Approved By	Blair Miller	[signature]	3 July 2017

EXECUTIVE SUMMARY

The use of an optical nitrate sensor in continuous, down-hole duty with data-logging and telemetry greatly increased the temporal resolution of nitrate concentration tracking at the Hinds MAR Pilot Trial site, near Ashburton. A sensor was installed in a downstream groundwater sampling bore immediately following the onset of long-term MAR water injection in the winter of 2016. A distinct nitrate-nitrogen concentration contrast was available in the monitoring of the effect of MAR injection since the injected water averaged a concentration of 0.05 mgN/L and dispersed into native groundwater at concentrations from 4 to 13 mgN/L.

Within the continuous monitoring framework of the optical nitrate sensor, GWD-04 bore water nitrate concentration was observed to shift from 6.9 mgN/L to 2.5 mgN/L, a generalised dilution of 4.4 mgN/L. 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 1,100 m distance. The role of the perched and regional water table aquifers in dispersing injected low nitrate 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.

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1. INTRODUCTION

1.1 Background

Managed Aquifer Recharge (MAR) is the intentional discharge of surface water in an engineered setting that facilitates enhanced infiltration of water to the underlying aquifer. In the case of the Hinds MAR Pilot Project, the objective was to test the feasibility of injecting surplus stock water derived from alpine surface water sources into the ground to replenish water stocks of the Hinds – Ashburton groundwater system. The groundwater resource between the Ashburton and Hinds rivers had been adversely affected by progressive depletion, declining water table height and increasing shallow groundwater nitrate concentration. A collision of a set of largely independent factors had combined to exacerbate the conditions in the area as follows:

- Intensification of agriculture across the plains had resulted in the following –
    - Increasing requirement for private irrigation schemes, most readily obtained by groundwater bores
    - A drive for increased efficiency of surface water irrigation transmission and utilisation
        - Replacement of leaky water races with buried plastic (HPDE or LPDE) pipelines
        - Reduction in water application rates in the transition from border dyke to spray methods
    - A distinct rise in the leaching load of nitrate-nitrogen through the soil base to the underlying water table, especially under increased bovine urine deposition.
- As a result of the above, subsurface water flows have diminished, recharge has diminished and nitrogen concentrations have risen under the influence of increased nitrogen load and decreased diluent.
- Community expectations for farming environmental performance as thresholds for ecosystem services and key indicators are increasingly approached in ways that attracts media attention.

In addition, national and regional policy initiatives (e.g. National Policy Statement for Freshwater and Canterbury LWRP Plan Change 5) are creating a receptive social environment to new methods for mitigating, or better managing, rural water resources. Managed Aquifer Recharge is one such mitigation method, which has led to it being explored and trialled within the Ashburton Water Zone. This report details the tracking of nitrate-nitrogen concentration in groundwater down-gradient of an infiltration basin operating as part of a Pilot Trial of the Managed Aquifer Recharge technology at a locality called Lagmhor.

The shallow and regional water table aquifers beneath the Lagmhor Pilot Trial site have groundwater nitrate-nitrogen concentrations ranging between 4 and 13 mgN/L, while surface water drawn for the stock water system has a median concentration of 0.055 mgN/L (Hansen and Abraham, 2013). Thus, the infiltration of low nitrate race water through an infiltration basin with no nitrogen leaching potential would introduce water into the aquifers of highly distinct nitrate-nitrogen concentrations. The resulting ‘fresh groundwater plume’ would be expected to stand out from the background in groundwater of moderate and high nitrate-nitrogen concentrations. The MAR Pilot Programme included the targeted installation of groundwater sampling bores, mostly completed in the regional water table aquifer, which were to be sampled monthly. However, in light of the knowledge that groundwater transmission rates would result in shifts in concentration more rapidly than month-to-month, continuous nitrate sensing was added to the monitoring programme. Continuous nitrate monitoring was provided by Lincoln Agritech Ltd (LAL) in the context of its development of a fit-for-purpose, low cost sensor system for utilisation in shallow rural aquifers to provide a measure of agricultural nitrogen impact on ground water quality.

2. METHOD

2.1 Equipment

A Lincoln Agritech prototype groundwater nitrate sensor (Figure 1) was installed at well GWD-04 for the period 19 June 2016 to 15 June 2017. This sensor uses UV absorbance to determine nitrate concentrations in the groundwater. The optical method is considered far more reliable with long term stability a major advantage when compared to Ion selective electrode or colorimetric spectrometer based sensing technologies. The sensor measures a number of wavelengths of UV light to both estimate nitrate concentration and a composite value for turbidity. "Turbidity" in this case could be related to occlusion of light by particles suspended in the water column, but also the build-up of biofilms on the sensor's measurement cell. Periodic cleaning of the measurement cell was carried out when LAL staff checked the sensor, but otherwise the sensor is capable of remote operation with minimal intervention. In bore GWD-04 (BY20/0152) biofilm development was slow and the sensor operated in excess of 2 months between servicing with no issues.

Figure 1: LAL prototype nitrate sensor showing black plastic body, brass 'sinker' and pass-through quartz sight glass

The sensor operates on a 12 volt sealed lead-acid battery with a 10W solar panel to recharge the battery. This power supply also powers the cellular modem that is stored with the battery at the surface (Figure 2). The modem was polled at least weekly to download the internal memory, in order to reduce the need for site visits.

2.2 Installation of Sensor

LAL's prototype nitrate sensor was suspended in the bore (Pilot Trial reference GWD-04 or CRC reference BY20/0152) at a depth of approximately 21 m below ground level (bgl) beginning on 19 July 2016. The monitoring bore was purpose built for the Pilot Trial by sonic drilling methods to 29.5 m bgl and constructed with a long screen intake from 20.25 to 29.25 m bgl in uPVC slotted casing.

The bore GWD-04 was drilled and constructed on 9 February 2016. However, even after three months, in May 2016 the turbidity related to drilling disturbance was still affecting water clarity in the bore's water column. By mid-June the bore water level had risen approximately 17.2 m under the influence of injected MAR water. This allowed the turbid groundwater in the bore water column and annular gravel pack to be flushed and pumped out using a high-head purging pump. Water clarity was restored to sub-10 NTU levels and the nitrate sensor could begin operation without unreasonable turbidity interference. Logging of nitrate concentration began soon after on 19 June 2016 with polling frequency set at one hour.

Figure 2: Bore head of GWD-01 monitoring bore: showing cable for sensor and power supply enclosure.

2.3 Pre-Injection Sampling

Commissioning sampling of the bore was conducted on 12 May 2016, followed by a pre-injection sampling on 21 June 2016. Analysis of bore water on these two occasions found the nitrate-nitrogen concentration to be 6.2 mgN/L and 6.9 mgN/L, establishing a baseline on the ambient groundwater nitrate concentration at bore GWD-04 in the lead-up to MAR injection.

The first injections of low nitrate race water are summarized in the following bullet points and Figure 3:

- **Trial flow**: 16 May 2016 – 19 May 2016
- **Media event**: Afternoon of 3 June 2016
- **Main recharge**: 14 June 2016 – 23 May 2017

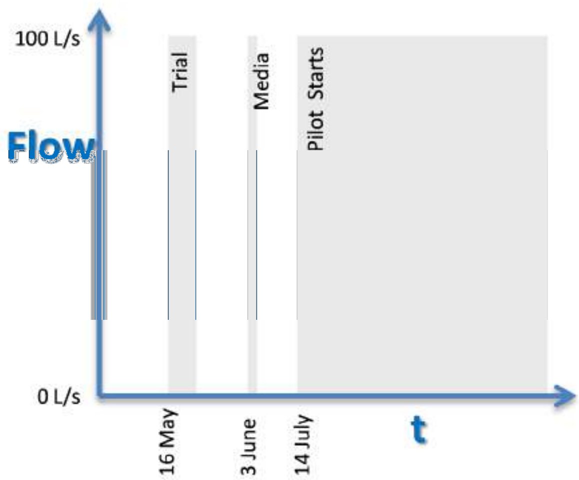

Figure 3: Schematic initial flow schedule

The first sensor measurements of groundwater nitrate-nitrogen in bore GWD-04 were made on 19 July 2016, 35 days after the start of injection, which averaged a concentration of 4.9 mgN/L.

3. MONITORING RESULTS

Approximately 7,670 hourly nitrate measurements were obtained using the nitrate sensor. Gaps in recording occurred in two main periods from 9 August 2016 to 11 August 2016; and 25 April 2017 to 1 May 2017, totalling 8.5 days of data loss. The first of these data losses was a result of failure in the water-tight cable gland and the entry of water into the electronic compartment. A replacement nitrate sensor prototype was installed on 25 August 2016.

The first nitrate-nitrogen measurements taken by the sensor on 20 July 2016 averaged 4.9 mgN/L and proceeded to fall precipitously at a rate of 0.1 mgN/L per day to a trough measurement of 2.3 mgN/L on 3 August 2016. This fall was followed by a rebound in nitrate-nitrogen concentration up to 4 mgN/L in the middle of August 2016. A second extended fall in concentrations was measured from 17 August 2016 to 3 October 2016. Thereafter, the nitrate-nitrogen concentration was observed to achieve an undulating plateau ranging in concentration between 1.0 mgN/L and 3.6 mgN/L. The full chemo-graph and groundwater hydrograph for bore GWD-04 during the first year of MAR Pilot Trial operations are shown in Figure 4. The nitrate sensor measurements are shown on the same date-time and concentration axes as discrete samples taken from bore GWD-04 and either analysed by Hills Laboratories or measured by a TriOS Opus optical nitrate sensor owned by LAL during field checks. A dashed mauve line joins these discrete spot measurements, including the rollover in nitrate-nitrogen concentration at bore GWD-04 from 6.9 mgN/L on 21 June 2016 to 3.7 mgN/L on 26 July 2016, a drop of almost 50% at a rate of 0.1 mgN/L per day.

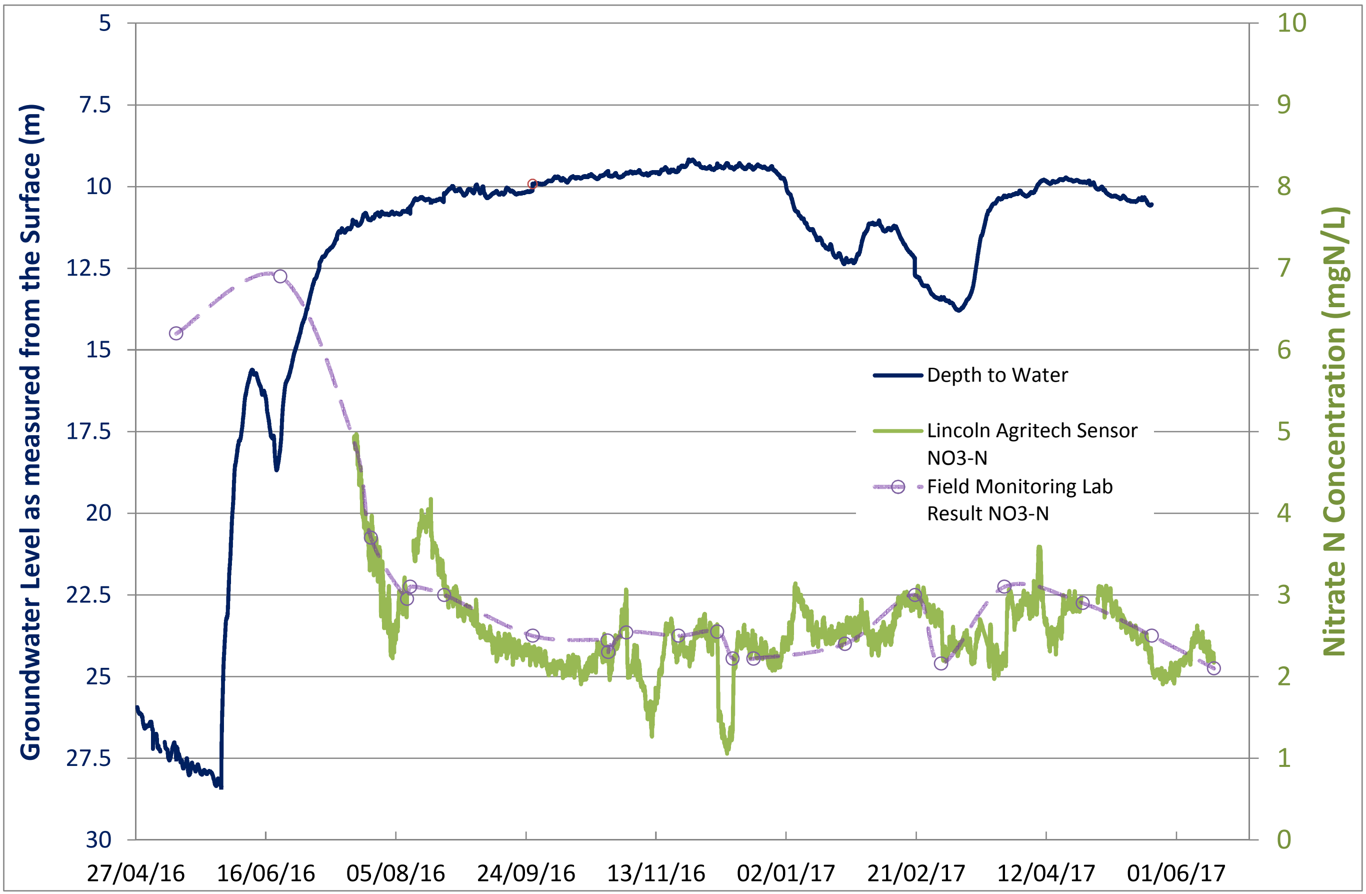

Figure 4: Full chemo-graph and hydrograph of bore GWD-04 from 27 April 2016 to 15 June 2017

The hydrograph for bore GWD-04 displays several changes on state from steady decay of groundwater level down to 28.4 m bgl on 29 May 2016. This was followed by rapid rise in groundwater level at a rate averaging 0.38 m per day up to the first slacking inflection point on 12 July 2016, to a level of 11.6 m bgl. A plateauing in groundwater level ensures until Christmas 2016 when twin dips in groundwater level in the order of 4 m occur over a three month duration, from which the level recovers to the previous plateau until the end of the record on 15 May 2017.

4. INTERPRETATION / ANALYSIS

4.1 Groundwater Level Responses

4.1.1 Background Information

Bore GWD-04 was drilled to a depth of 29.5 m with a geotechnical Sonic drilling rig supplied and crewed by McMillan Drilling Ltd. Two uPVC casings with end slotted sections were installed in the borehole after it was drilled out to a 155 mm diameter:

- 50 mm internal diameter PVC casing with machine slotting from 29.25 – 20.25 m bgl (nitrate sensor)
- 32 mm internal diameter PVC casing with machine slotting from 29.25 – 23.25 m bgl (level logger)

The initial groundwater level measured on 27 April 2016 was 25.94 m bgl. As the area was in the grip of a drought-like extended dry period, groundwater levels were generally declining steadily in Autumn and early Winter 2016. A further 2.5 m of level decline was measured up to 29 May 2016 to a groundwater level of 28.4 m BGL.

Bore GWD-04 was installed about 1.1 km to the SSE of the infiltration basin as plotted in Figure 5. This was also the approximate trend of groundwater flow as measured from level contours constructed from discrete level measurements with respect to Mean Sea Level (MSL). Thus, GWD-04 is roughly 'downstream' of the infiltration basin with respect to mean groundwater flow gradients.

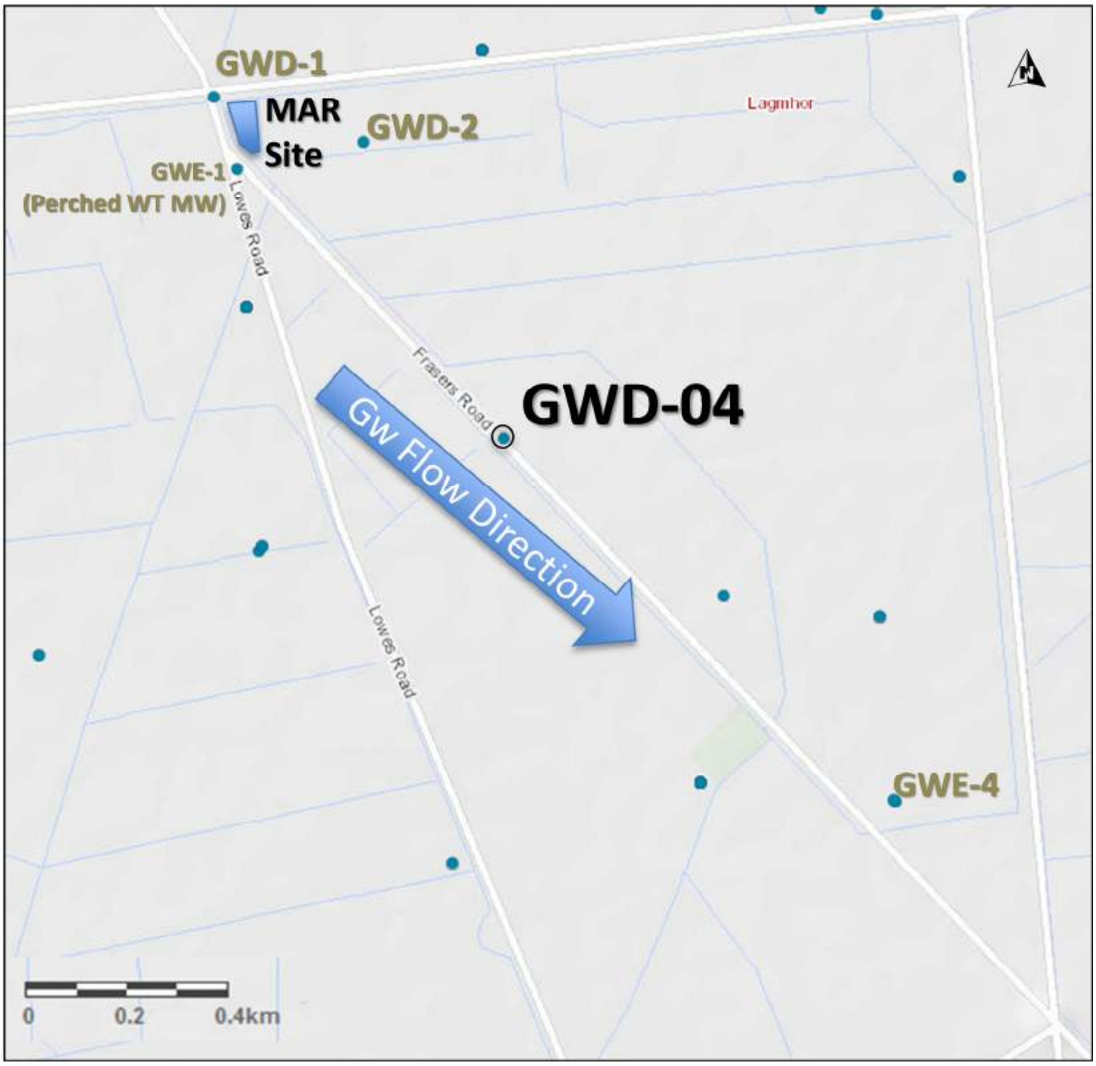

Figure 5: Location of bore GWD-04 relative to the infiltration basin and groundwater flow direction

The hydrogeological arrangement of the subsurface joining the MAR infiltration basin and monitoring bore GWD-04 is schematised in Figure 6.

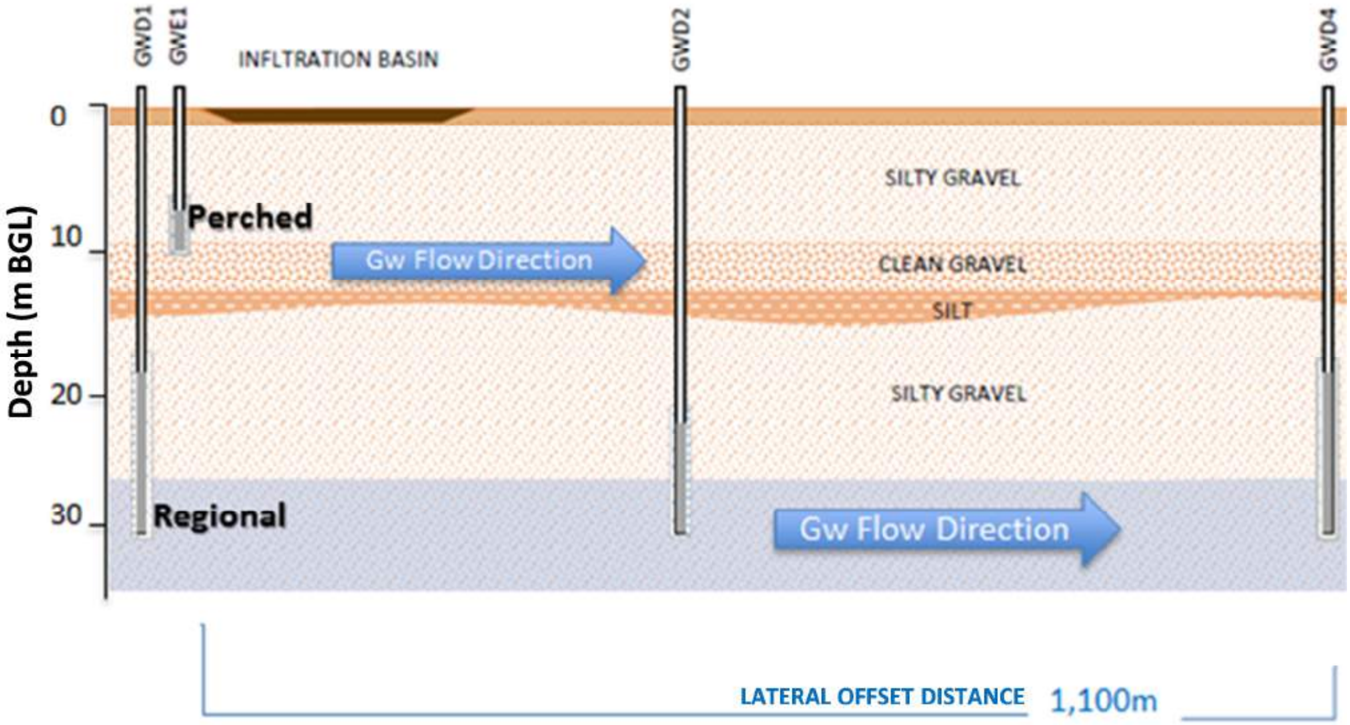

Figure 6: Schematic of the hydrogeological and geo-hydrological stratification of the subsurface deposits joining the infiltration basin and monitoring bore GWD-04

A strongly stratified set of glacial outwash deposits have produced conditions for the development of perched and regional water table geometry beneath the MAR Pilot Trial infiltration basin. The ambient regional groundwater flow gradient and direction is approximately 0.5% and SSE, respectively. The flow direction within the perched water table is thought to be more localised and less is certain about its gradient or direction. However, the regional and perched aquifer flow directions have lines of evidence to consider them coincident or at least sympathetic.

Monitoring bores GWD-01, GWD-02 and GWD-04 in Figure 6 are screened in the regional water table. There are strong lines of evidence that bore GWD-04 provided measurements (in terms of level and nitrate concentration) of the regional water table aquifer prior to the onset of MAR water injection in the same manner as bore GWD-01. Bore GWD-01 lies alongside the infiltration basin forebay. Despite GWD-01's extreme proximity to the infiltration basin and the expectation that its groundwater levels would be most affected by the infiltration of MAR water, the water level in this monitoring bore in the regional aquifer has risen only 2.4 m, from 29.9 m bgl to 27.5 m bgl over the course of the Pilot Trial. Despite that, GWD-04 is not screened across the perched water table and the delayed effect of the MAR injection was to raise water level in the bore within the depth range of the perched water table (see hydrograph in Figure 4). Such manifestations of water table response are consistent with monitoring bore GWD-04 being anomalous in reflecting both the perched and regional water table aquifers. Possible interpretations of this dual water table behaviour in bore GWD-04 are as follows:

- Discontinuities in the drill hole wall material provide a short-circuit from the perched water table aquifer to the bore screen amongst the regional water table
- Bore construction as-built did not follow the required specification, which included the placement of a blinding sand annulus and bentonite seal immediately above the top of slotting at 20.25 m depth. Instead this scenario considers that perched water table aquifer water could percolated down the drill hole annulus to the slotted, gravel-packed intake.
- Natural "windows" in the perching aquitard layer in the vicinity of the monitoring bore permit the percolation of perched water table aquifer water to the regional water table and the bore intake.

Whatever cause for the co-mingling of perched and regional water table aquifer waters in bore GWD-04, there are strong lines of evidence that infiltrating water from the MAR site moved through the ground following the trial period

(16 May 2016 to 19 May 2016) and precipitated the sharp upswing in water levels at bore GWD-04 on 29 May 2016. The best interpretation is that the water moved above the perching layer, presumably in the discrete gravelly silt layers seen discontinuously in the bore logs of GWD-01, GWD-02 and GWD-04 from depths of 8.4 m bgl to 15.1 m bgl. This interpretation is supported by the lack of response to the May 2016 flow trial in surrounding monitoring bores screened in the regional water table aquifer. If the water table response was passed on through the reginal water table aquifer, one would expect this to be mirrored in upswings in water levels in the regional water table bores.

4.1.2 Nitrate Concentration Response to Injection

The initial responses to injection were considered to be transmitted through the perched water table aquifer from the three day trial flow of 16 May 2016 to 19 May 2016. Figure 7 illustrates the responses in hydrograph and chemo-graph of GWD-04, approximately 1,100 m downstream of the MAR site, during the onset of the trial flow event, media day flow event and start of the Pilot Trial.

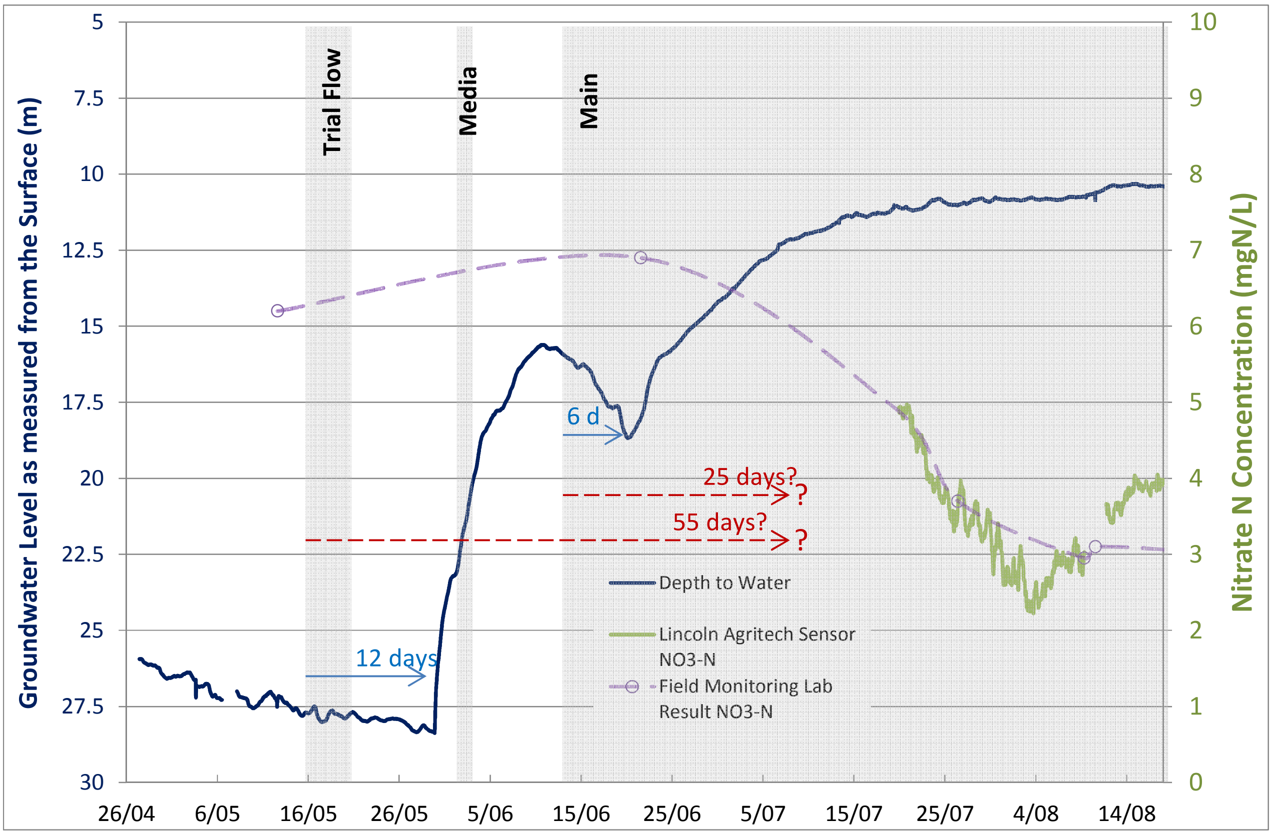

Figure 7: Initial responses to the onsets of injection at the MAR site and observed at GWD-04

The lag between the onset of the Pilot Trial flow and upswing in water levels is relatively reliably inferred at 12 days. The hydrograph rolled over from an interim peak of 15.25 m bgl on 11 June 2016 and began rising again on 20 June 2016, six days after the onset of the Pilot Trial main injection period. These responses to hydrological impulses are reasonably readily attributable. Chemical response as nitrate-nitrogen concentration changes are less readily attributable to the injection impulses. Figure 7 illustrates the ambiguity as to the impulse for nitrate concentration decline, whether from the trial flow or the main injection onset. The most likely proposition is the longer lag between low nitrate injection impulse and change in bore nitrate concentration. Figure 8 examines the second and third inflection points in the GWD-04 hydrograph and nitrate chemo-graph. Due to the nitrate sensor not being installed and operational prior to the trial flow, the first inflection point recorded in the hydrograph on 29 May 2016 was missed from the chemo-graph. The offsets between the inflection points are both 55 days, as plotted graphically in Figure 8 and summarised in Table 1.

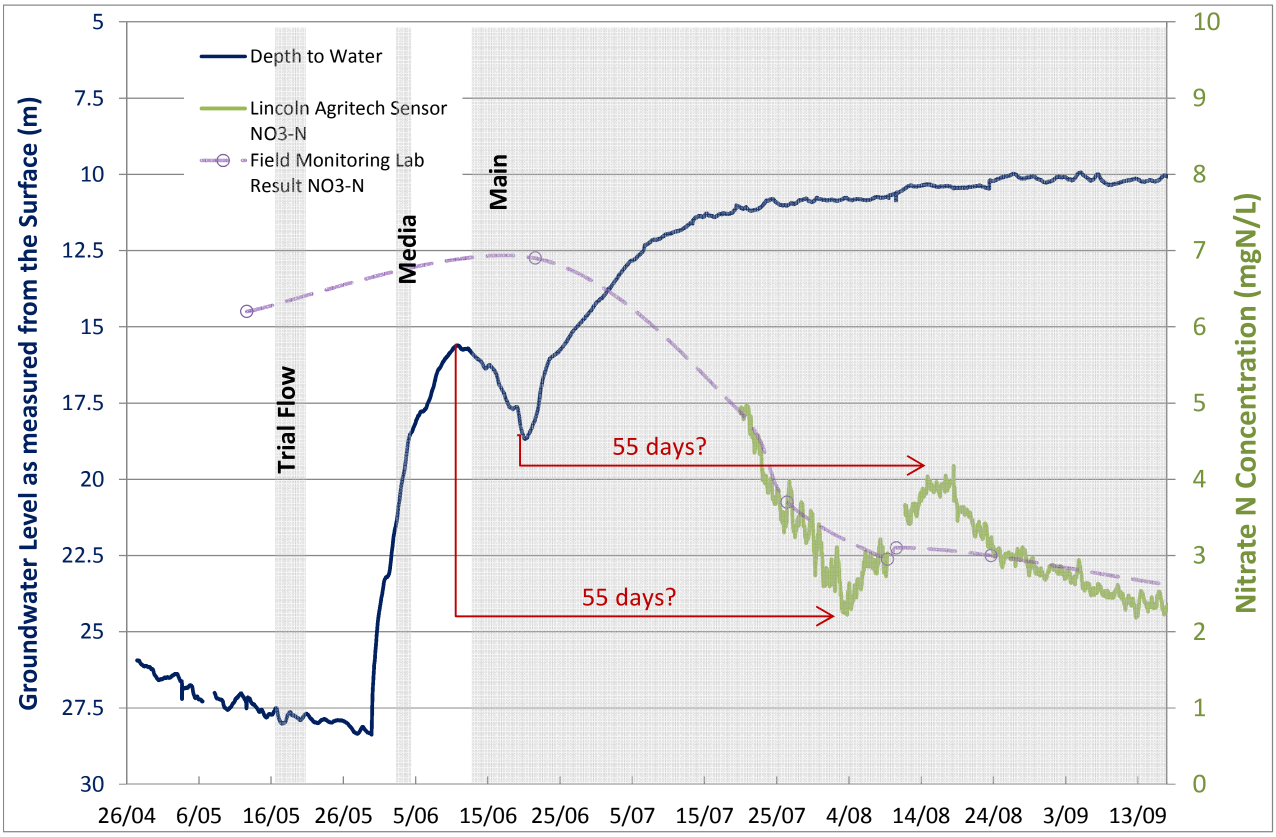

Figure 8: Initial and subsequent responses highlighting the inflection points in the hydrograph and chemo-graph

Table 1: List of Inflection Points and Offset Durations from Figure 8

	Hydrograph	Chemo-graph	Offset (days)
Inflection Point 2	10-Jun-16	4-Aug-16	55
Inflection Point 3	20-Jun-16	14-Aug-16	55
Offset (days)	10	10	

The correspondence in the offset between inflection points as outlined above provides some support for the interpretative scenario outlined below:

1. Water from the pre-trial flow event moves downstream along the perching silt layer and 12 days later induces a sharp water level rise in bore GWD-04, then
2. After an initial displacement of perched high nitrate groundwater into the monitoring bore, low nitrate water from the MAR site arrives and bore water concentration falls by dilution, then
3. The impulse provided by the pre-trial flow event dissipates, the hydrograph peaks at 15.25 m bgl and then the water level begins to fall, then
4. The impulse from the main Pilot Trial injection checks the fall in water level and it begins to rise again steadily, then
5. The peaking of the bore water level previously is followed by the arrival of less low nitrate water at the bore approximately 55 days later, nitrate concentrations rise again, then
6. The renewed rise in the bore water levels is followed by the arrival of additional low nitrate water 55 days later, nitrate concentrations begin to fall again.

The hydrograph and chemo-graph stabilise at stable plateaus of 10 m bgl and 2.5 mgN/L, respectively, under the influence of long-term low nitrate water injection at about 100 L/s at the MAR site.

4.1.3 Dispersion Rates

At the simplest level of consideration, GWD-04 bore water nitrate concentration shifted from 6.9 mgN/L to 2.5 mgN/L, a generalised dilution of 4.4 mgN/L. However, this simplified representation of dispersion of native groundwater with high nitrate by MAR water with low nitrate is too simple, especially if using monitoring bore GWD-04 as reference. This bore undoubtedly integrated perched water table and regional water table aquifer waters as soon as MAR water injection began. Accordingly, bore GWD-04 is representative of the regional water table until about 10 July when water displaced from the perched water arrives at the bore intake bearing low nitrate MAR water (at least in part). Thereafter, the monitoring bore represents a mixture of perched and regional aquifer, with strong portion of MAR water.

Integrating the results of monthly spot sampling from bores other than GWD-04 provides further insight to this question. Figure 9 is a schematic cross-section and an expanded view of the cross-section presented further above in Figure 6. The salient interpretations represented in Figure 9 are as follow:

- MAR water at 0.1 mgN/L mixes with native pore and groundwater to produce a mean perched water table aquifer nitrate-nitrogen concentration of 1.3 mgN/L.
- The lower nitrate water from the perched water table infiltrates down through the semi-permeable silt layers to affect regional water table aquifer with a decline from 4.2 mgN/L to 2.8 mgN/L.
- At bore GWD-04 where there is an active cross connection between the perched and regional aquifers, the reduction in nitrate-nitrogen concentration is more pronounced from 6.9 mgN/L to 2.5 mgN/L, simply because the influence of perched water is greater.
- No perched-regional cross-connection was consider to exist at the deeper GWE-17 bore, although lateral movement of regional groundwater ultimately shifted concentration from 3.8 mgN/L to 0.2 mgN/L
- Perched-regional cross-connection occurred at bore GWE-04 as seen in the water level pulse in November 2016, and ultimately the distinct decline in nitrate nitrogen concentration from 12.7 mgN/L to 4.9 mgN/L in 20 February 2017.

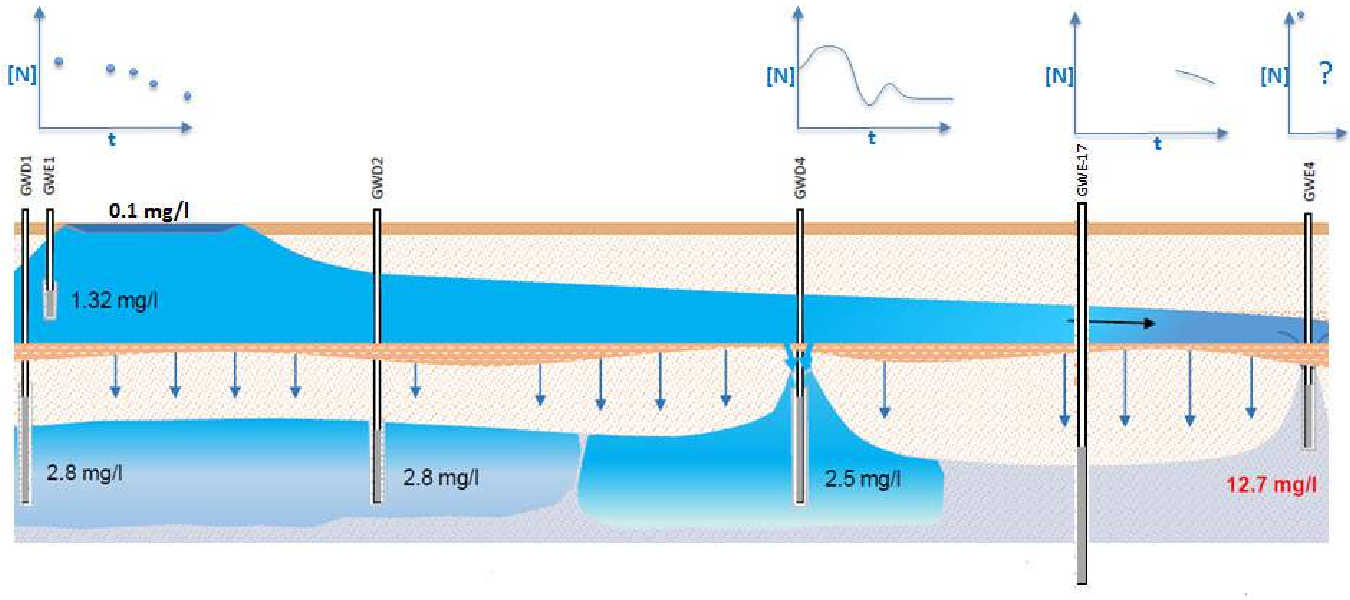

Figure 9: Schematic cross-section of MAR monitoring bores, perched aquifer, regional aquifer and their concentrations at November 2016

5. CONCLUSIONS

The following conclusions are presented, which have relevance to the use of continuous nitrate concentration tracking downstream of the Hinds MAR Pilot Trial site.

1. The Hinds MAR Pilot Trial application had a number of unique factors, including
   i. Rapidly changing groundwater nitrate concentrations, usually groundwater increases or decreases in concentration only slowly,
   ii. The application of groundwater monitoring techniques to tracking a low nitrate plume in the aquifers, usually the plumes tracked are elevated concentrations originating from a high nitrate source area.

2. 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 injections of MAR water into the perched water table aquifer.

3. The interpretation of dispersion of native groundwater by low nitrate MAR water was complicated by the dual pathways taken for mixed groundwater through the ground, namely via the perched water table aquifer and the regional water table aquifer.

4. Current information from continuous nitrate concentration tracking and spot sampling has further high-lighted the dual pathway and the more rapid transport through the perched water table aquifer.

6. REFERENCE

Hansen, C; and Abraham, P. 2013. Cross sections of groundwater chemistry through the Ashburton – Rangitata plain. Environment Canterbury Investigations and monitoring group technical report R13/30, June 2013, ISBN 978-1-927234-99-0, Christchurch.

APPENDIX L

Water Race Losses

1.0 WATER RACE LOSS ASSESSMENT OVERVIEW

The unlined Ashburton District Council (ADC) stockwater race system is a significant contributor of incidental aquifer recharge to the groundwater system beneath the Hinds Plains catchment. As this system is progressively decommissioned and 'water savings' are returned to the Rangitata River and the Ashburton River to increase baseflows in these rivers, this incidental recharge will cease. By 'saving' stockwater losses, we are in turn having a direct and measureable impact on groundwater levels that support flows in the spring-fed coastal waterbodies, affecting rural drinking supplies for residents and also impacting the thousand or more irrigation bores which rely on water for farming activities. It is important to note that stockwater losses have historically played a crucial role in maintaining this highly modified and complex groundwater system.

The concept of enhancing groundwater recharge using MAR during the non-irrigation season was identified as a critical need during the Ashburton Zone Committee sub-regional planning process. As ADC is currently working toward shutting down their stockwater networks, the need to understand how MAR may be used to offset the reduction in incidental recharge is an important part of the MAR Pilot Trial programme. Understanding how effective a leaky open race is at recharging the underlying groundwater, in comparison with an engineered infiltration basin, was identified as a key assessment goal of the Year 1 Pilot Trial monitoring programme.

The unlined ADC stockwater race network is still operational throughout the Hinds Plains catchment. Obtaining an estimate of race losses (incidental recharge), and thereby determining the potential opportunity offered through the use of stockwater races as future MAR sites, is an important issue for the MAR Governance Group.

This appendix provides a short review of existing estimates for water losses from existing water races. An analysis of seepage losses from the water race which forms part of the Hinds MAR Pilot Trial site is also provided in this appendix for comparison with calculated rates of seepage from the main infiltration basin documented in the main report.

2.0 EXISTING RACE LOSS ESTIMATES

In 2012, ADC commissioned a report titled *Ashburton District Council – Water Investigation Project* (OPUS, 2012) that incorporated a review of the ADC stockwater network. The report found the 2,400 km network of open stockwater races that ADC manages supplies water to 233,000 ha of land and services approximately 1,800 properties in the district. The ADC network also provides 14 potable water supplies serving over 10,000 properties.

The report (OPUS, 2012) acknowledged that seepage losses from the ADC stockwater network are a significant source of recharge water to the underlying groundwater system. It was considered that that the specific rates of water loss varied both spatially and temporally. The overall network was reported to 'lose' 82 % of its diverted volume to infiltration, which is consistent with the results from previous analyses undertaken in Canterbury. Another 4 % was calculated as being lost to evaporation and transpiration (plant use). After all physical losses had been accounted for, it was found that only 4 % of the diverted water was used for stock and 5 % used for domestic purposes.

As a source of incidental aquifer recharge (infiltration), seepage losses from the ADC network across the entire Ashburton District were calculated to be approximately 6,776 L/s, totalling approximately 213,689,000 m^3 per year, based on assessed average conditions (OPUS, 2012). For the Hinds Plains Catchment specifically, the total stockwater incidental recharge has been estimated at **3,200 L/s or 100,915,000 m^3/year** (Durney, 2014). This estimate is consistent with estimates documented in other reports dating from 1986 to 2011, which looked at race losses and contributions of incidental recharge to maintain groundwater supplies (Table L1).

Table L1: Incidental recharge from stockwater races - Ashburton District and wider Canterbury.

Source (1)	Year	Catchment / stockwater scheme	Estimated race seepage loss (%)	Rate of recharge (m^3/s)	Total annual recharge (m^3)	Percentage of aquifer's total recharge
Scott & Thorpe	1986	Rakaia to Ashburton Rivers	N/A	3.67	123,000,000	14 %
Beca	1994	Ashburton South Race	75 %	---	---	---
Taylor	1996	Te Waihora/Selwyn	---	2.92	92,000,000	11 %
Agriculture New Zealand	1997	Christchurch/Selwyn aquifer (Paparua Scheme)	80 % – 90 %	0.7	22,075,000	---
De Joux	2000	Orari – Rangitata and Orari-Waihi	75 % – 90 %	---	---	---
Davey	2005	Waimakariri – Ashley Plains	80 %	---	---	---
Brough & Steffens	2008, 2011	Ashburton District Races	85 %	8.88	280,000,000	---
Steffens	2011	Ashburton District Races	---	---	---	19 %
Durney and Ritson	2014	Hinds Plains Catchment	---	3.2	100,915,000	---

Note: 1) Information sourced from OPUS (2012).

3.0 MAR PILOT TRIAL SITE RACE LOSS ASSESSMENT

3.1 Introduction

The Hinds MAR Pilot Trial site incorporates an open irrigation race that historically delivered water from Valetta Pond #3 to nearby farms for flood irrigation (Figure L1). This water race became obsolete when Valetta piped their network. During the design of the MAR Pilot Trial, it was determined that this race was the best mechanism to deliver the quantities of water potentially required for the trial. A memorandum of understanding with the landowner for use of the race was agreed, with the understanding that after 2 years of successful MAR operations an alternative approach to delivering the water would be agreed (Figure L2). .

The race is approximately 900 m long and averages 2.4 m in width, with a total estimated infiltration area of 2,160 m^2. Relative to the MAR site's total infiltration area (forebay and main basin area of 9,600 m^2), the combined total potential infiltration area is 11,760 m^2, with the race representing 18 % of the total.

Flumes were designed and installed at the upstream end of the water race (Flume 1, Figure L3) and at the inflow point to the Pilot Trial forebay (Flume 2). These flumes were designed to accommodate flows of up to 500 L/s through to the site. Both flumes were installed as part of the Pilot Trial programme using pre-formed concrete flumes set in the stock race in a manner that minimised leakage around the flume and provided proper hydraulic channel conditions for manual flow measurements to be taken (Figure L3).

The flumes were instrumented as flow monitoring sites, with stage recorders and ESG boards set up to record water stage, temperature and rated flows every 15 minutes (refer to Appendix E). Race losses were evaluated by comparing flows recorded at Flumes 1 and 2.

Figure L1: MAR Site Delivery Race along Timaru Track between Flume 1 and Flume 2.

Figure L2: Open race delivering water source water to MAR Pilot Trial site (Race bypass and MAR site start up[1], June 2016).

[1] Initial water leaving pond washing recently scrapped race bed materials downgradient. This water was bypassed as per MAR site operations protocols to help manage clogging in main basin and minimise potential bacteria levels from stagnant Valetta Pond #3.

Figure L3: Flume 1 being installed downstream from the Valetta Pond #3 outlet (April 2016).

The race analysis was undertaken through comparisons of manual flow measurement and automated flow records. The objective of the analysis was to derive estimates for the following key study questions:

- What was the rate and variability of seepage losses from the open race during Year 1?
- Were there any signs of increase or decrease in flow losses during Year 1 operations (e.g., indications of clogging)?
- In comparison to the main infiltration basin at the Pilot Trial site, how effective was the race at infiltrating water to the underlying groundwater system?

The following sections document the analyses undertaken in response to these questions and the results from these analyses.

3.2 Manual Record Evaluation

The methodology for collecting the samples was to manually measure flows through Flume 1 and Flume 2 at nearly the same time and under reasonably constant flow conditions. The standard accepted accuracy for instream flow measurements is +/- 8 % (CRC standard). These flow measurements were then used to estimate both the absolute water loss from the water race and the percentage loss relative to inflows at Flume 1.

A total of 13 pairs of flow measurements were initially taken to facilitate the race loss assessment (Table L2). After a review of the flow datasets generated by the automated stage recorders installed at the flumes, it was deemed that measurements (MMT) 8 through 11 (see shaded below in Table L2) were not be used for race loss estimates. These measurements were excluded on the basis that flows at Flume 2 had not had adequate time to stabilise following a change in flows at the Valetta Pond #3 diversion.

Table L2: Manual flow measurements – race loss comparisons.

Comparison MMTS	Date	Flume 1 (L/s)	Flume 2 (L/s)	Losses (L/s)	Percentage race loss
MMT 1	17/05/2016	40.2	34.2	6.0	14.9
MMT 2	17/05/2016	173.6	150.1	23.5	13.5
MMT 3	17/05/2016	225.6	211.8	13.8	6.1
MMT 4	17/05/2016	415.5	388.9	26.6	6.4
MMT 5	17/05/2016	135.4	113.1	22.3	16.5
MMT 6	25/08/2016	95.9	85.0	10.9	11.4
MMT 7	02/09/2016	97.6	84.7	12.9	13.2
MMT 8	16/09/2016	19.4	12.0 (1)	7.4	38.1
MMT 9	16/09/2016	59.3	46.0 (1)	13.3	22.4
MMT 10	16/09/2016	235.9	199.0 (1)	36.9	15.6
MMT 11	16/09/2016	342.9	302.0 (1)	40.9	11.9
MMT 12	29/11/2016	92.0	89.0	3.0	3.3
MMT 13	28/04/2017	73.0	72.0	1.0	1.4

Note: 1) Following review of logger flow records, these measurements were not considered useful for this assessment due to unstable flow conditions.

Flows measurements were made prior to Year 1 operations (May 2016) and near the end of Year 1 operations (April 2017), to assess if race losses had changed over time. Measurements made up to September 2016 (MMT 1 to MMT 7) indicated losses ranging from 6 L/s to 26.6 L/s (average 16.6 L/s loss), and percentage race losses from 6.1 % to 16.5 % (average 12 %). The final two pairs of measurements made during Year 1 (MMT 12 and MMT 13) indicated an average flow loss of 2 L/s and an average percentage race loss of 2.3 %. Whilst only two useful measurement pairs were completed after September 2016, these results suggest that clogging may have been affecting race losses. These results are consistent with the outcomes of the assessment of Pilot Trial main infiltration basin clogging documented in Appendix I.

Inspection of the dry water race during May 2017 indicated that sediment had accumulated at the upstream end of the race (Figure L4). The entire race had been scraped with an excavator in preparation for Year 1 operations so any observed sediment accumulation had occurred during this year. Valetta Irrigation Scheme maintenance work carried out on Valetta Ponds #1 and #2 during the year may have generated suspended sediment loads that could have been carried through into the MAR Pilot Trial site, leading to clogging of the race and basins (G. Pinfold, Valetta Raceman, pers. comm.).

Figure L4: MAR race upstream from Flume 1 showing sediment deposited (red circles) during Year 1.

The nine sets of race loss measurements up to September 2016 were plotted as race inflow (Flume 1) against measured losses (Figure L5) and evaluated using a regression analysis. The results from the final two measurements listed in Table L2 (MMT 12 and 13) appear to diverge from the trend of the regression line fitted to the earlier measurements. The regression suggests that absolute seepage losses increase slightly with increasing inflows, but the losses as a percentage of total inflow decrease within increasing flows. This result is consistent with the concept that as water depth in the race increases the flow rate increases proportionally more quickly than the area of wetted race surface, with the latter being a key factor in infiltration rate.

As a check, the automated flow records for the days during which MMT 12 and MMT 13 were measured (29 November 2016 and 28 April 2017, respectively) were reviewed. The results of the review (Table L3) suggest there may have been issues with the manual measurements, possibly due to rapid changes in flows during the days the measurements were made. The flow losses calculated from the manual measurements may have understated the actual flow losses from the race during those days.

Table L3: Manual flow measurements compared to automated flow measurements.

Parameter	**29/11/2016**	**28/04/2017**
Manual flow loss measurement	3.1	1.0
Automated record		
Minimum flow loss during day	14.6	1.0
Median flow loss during day	17.0	8.5
Maximum flow loss during day	19.3	11.7

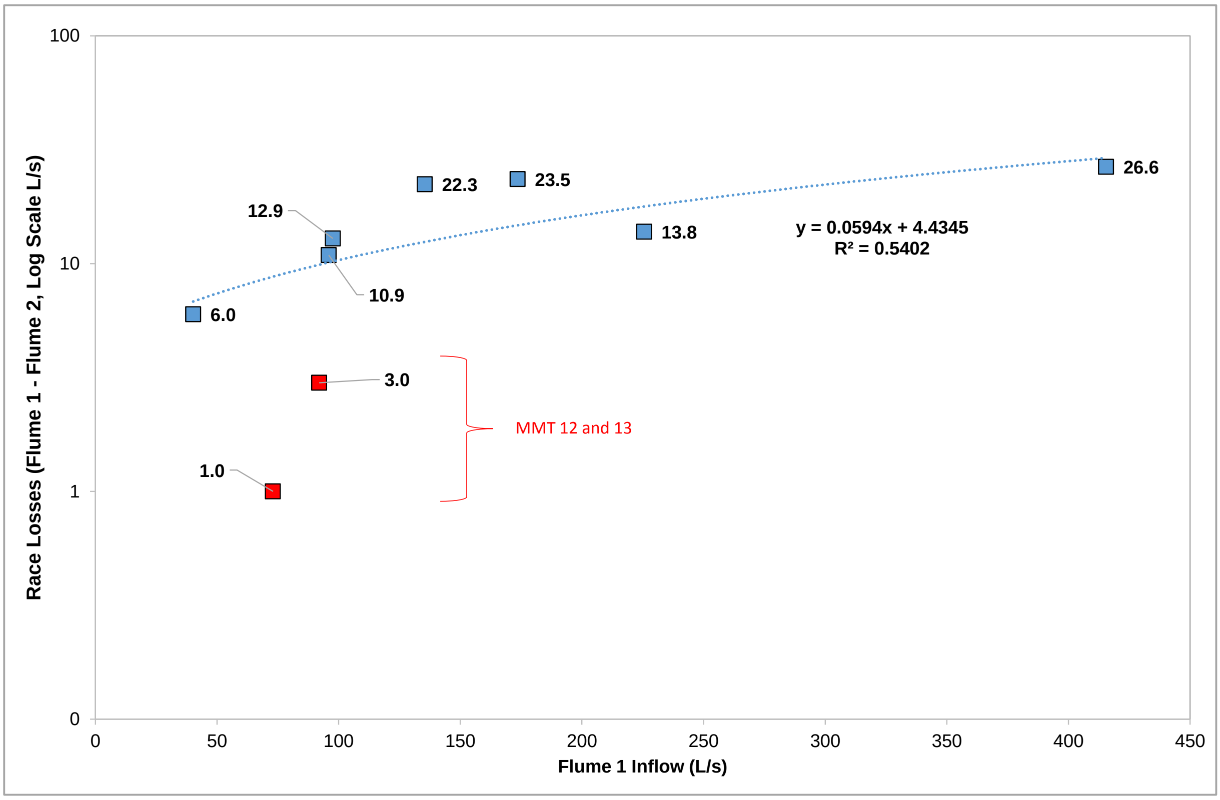

Figure L5: Manual measurements regression: race loss compared to race inflow (Flume 1).

3.3 Automated Record Evaluation

The rated flow records derived for Flume 1 and Flume 2 (for derivation refer to Appendix E) and the water level record for the main infiltration basin were evaluated to identify periods during Year 1 when flows to the Pilot Trial site were reasonably stable for an extended period of time (Figure L6).

A total of seven periods were selected for race loss comparison. During each of these periods the flow data from both Flume 1 and Flume 2 had standard deviations of <2 % of the average flow. These periods were also selected as they are well distributed throughout Year 1 of the Pilot Trial and so present a reasonable indication of race losses prior to and following the peak-irrigation season shut down.

Analysis of the flow data from these seven comparison periods indicates a good correlation between upstream (Flume 1) and downstream (Flume 2) flows (Figure L7). There is a very clear difference in the average flows calculated for all of these comparison periods, even when allowing for a standard +/- 8 % uncertainty range (Figure L8). The calculated race losses during these comparison periods ranged from 12 % to 23 % of the inflow measured at Flume 1. There is no clear increasing or decreasing trend for race losses over time (e.g., due to clogging) apparent from this analysis. The average percentage loss for the race across all comparison periods was 17 % of the inflow at Flume 1.

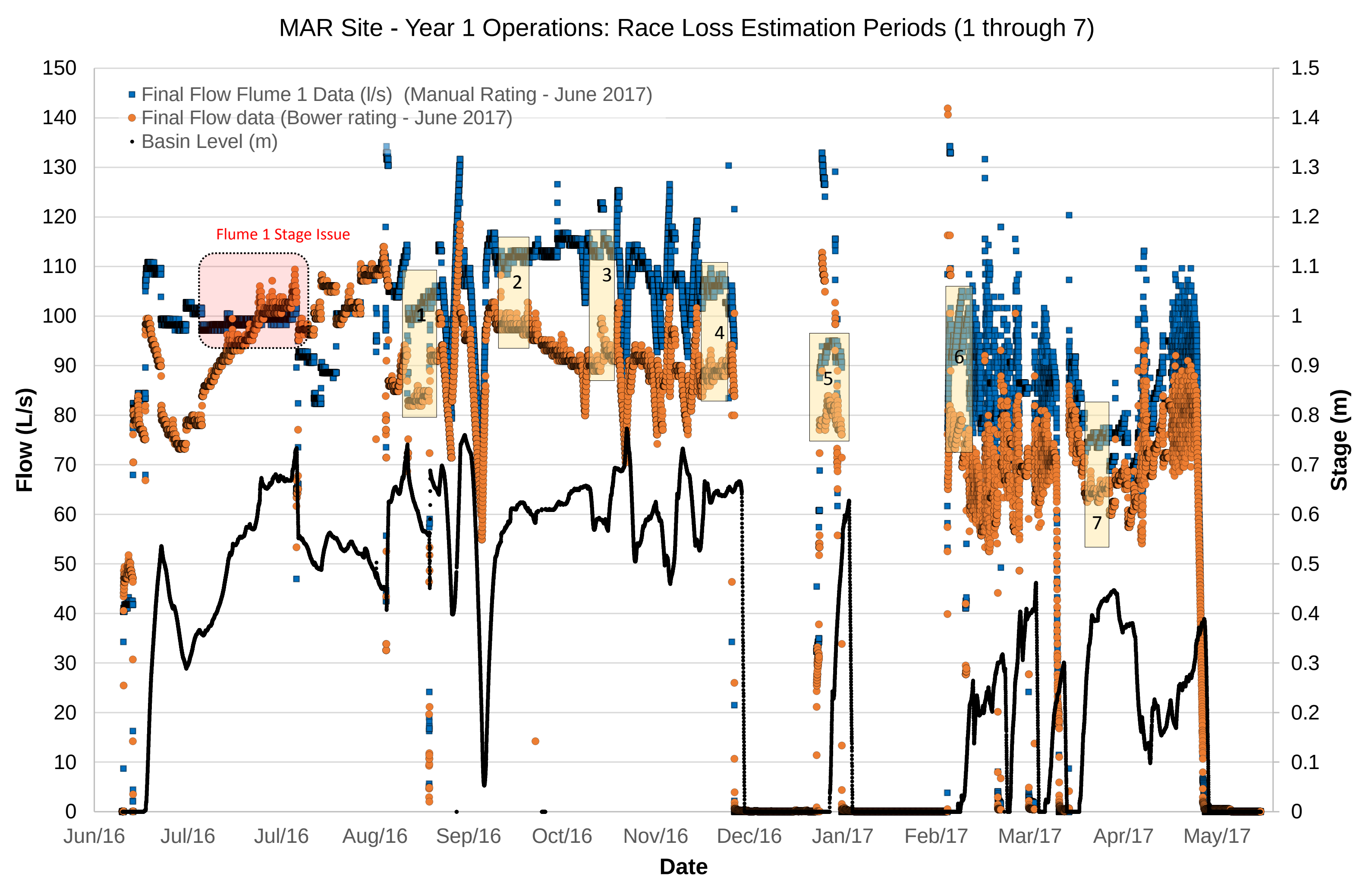

Figure L6: Flume 1 and Flume 2 Year 1 data: comparison of periods of stable flows.

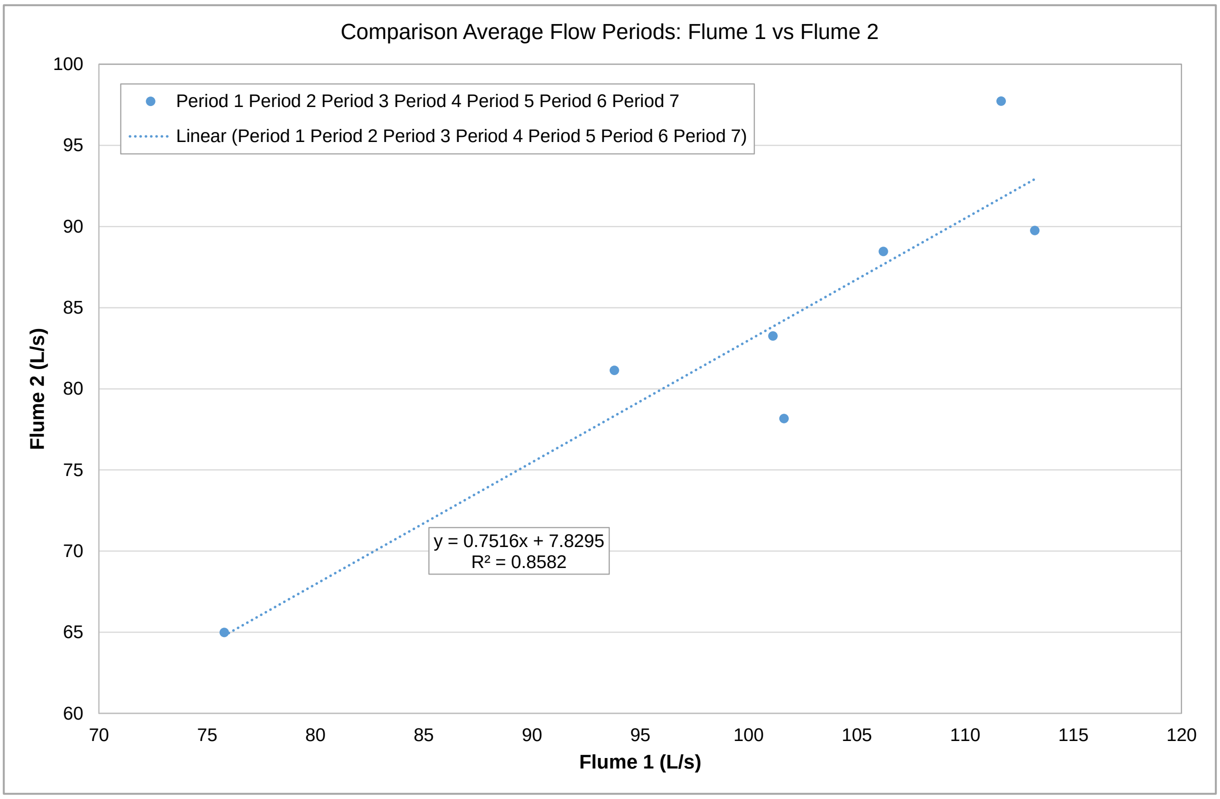

Figure L7: Comparison of flows measured in Flume 1 versus Flume 2.

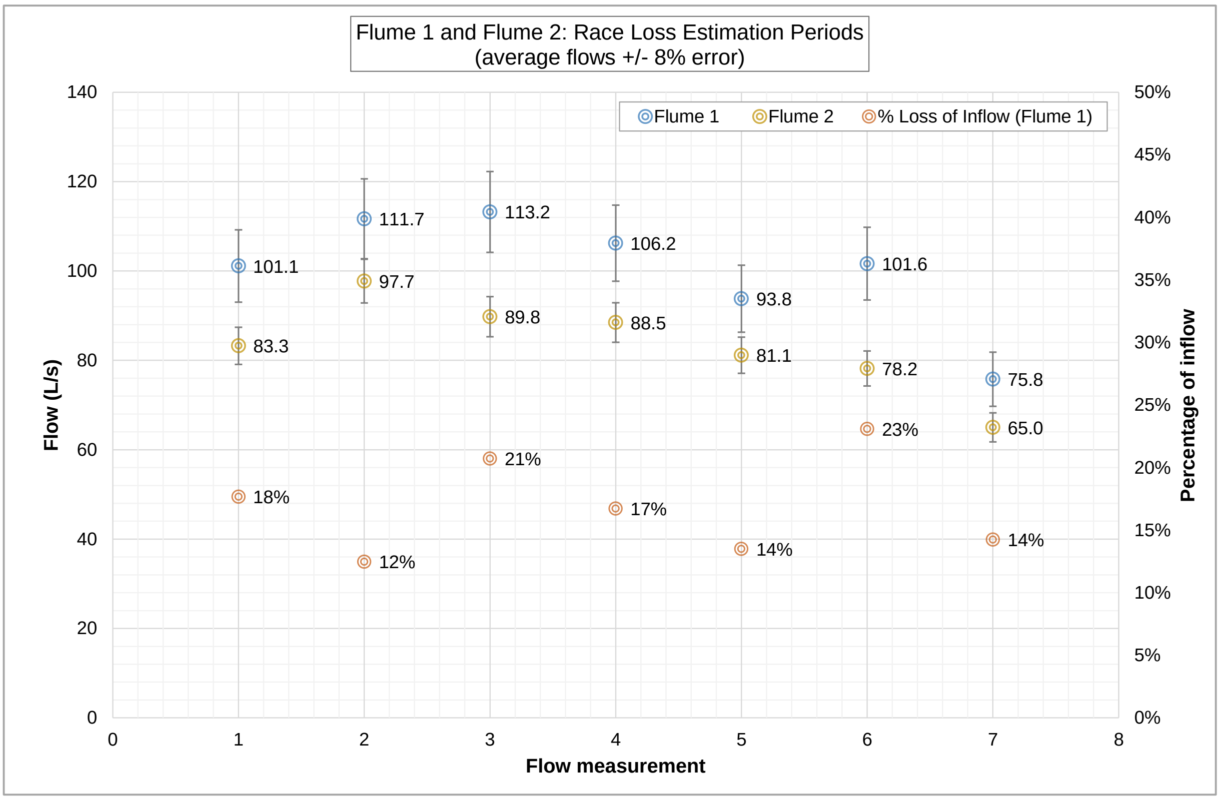

Figure L8: Comparison periods: average flume flows with 8 % uncertainty range and of flow loss percentages.

4.0 SUMMARY

The open water race supplying the MAR Pilot Trial site represents approximately 18 % of the total infiltration area for the combined MAR Pilot Trial facilities. Two methods were used to evaluate race losses during Year 1 of the Pilot Trial: analysis of manual, in-channel measurements and analysis of the automated flow records recorded at Flumes 1 and 2.

Evaluation of manual measurements conducted prior to and during September 2016 indicated flow losses from the water race of approximately 12 % of the inflow at Flume 1. The two manual measurements recorded after September 2016 indicated flow losses from the water race of only 2 % of the inflow at Flume 1. However, review of the automatic flow records for the days of these two measurements indicates they are likely to be underestimates of the actual flow losses on those two days, possibly due to relatively rapid changes in flows in the race on these days.

Evaluation of records derived from the automated flow monitoring stations at Flume 1 and Flume 2 for seven comparison periods of stable flows indicated an average loss for Year 1 operations of approximately 17 % of the inflows. This percentage loss is consistent with the area of the open race representing 18 % of the total infiltration area provided by the MAR Pilot Trial site as a whole.

The collection of the manual in-channel flow data had issues around ensuring stable flows were established at both flumes before commencing the measurement. It was estimated that at least an hour was required after changing flows through Flume 1 before any measurements should be taken. Issues with the automated recording station data and shifts in stage required during development of the final flow rating curves (refer Appendix E) also introduced a degree of uncertainty to the calculated flow rates.

With respect to the objectives of this project, the responses to the original questions are summarised below:

- **What was the rate and variably of the flow losses in the open race?**

  Manual rate and flow record analyses indicate that flow losses from the water race range between 12 % and 17 % of the total water delivered to the Pilot Trial site. The calculated losses from automatic flow measurements average 17 L/s and range from 11 L/s to 23 L/s during Year 1 of Pilot Trial operations. Increasing flow to the Pilot Trial site (through Flume 1) results in increasing losses through the floor of the water race. However, the wetted area of the water race does not increase in a linear relationship with increasing flows through the race. As flows increase, the percentage of water lost to the underlying groundwater system decreases.

- **Were there any signs of increase or reduction in flow losses over the course of Year 1 operations (e.g., clogging)?**

  Physical signs of coarse sediment accumulation in the open race during Year 1 were documented, however the race generally appeared to remain relatively free of clogging materials. The linear layout of the water race and the flow velocities along the race are unlikely to allow large accumulations of fine sediment on the floor of the race. Analysis of flow losses based on a limited number of manual flow measurements suggests race losses may have declined from November 2016 to May 2017. However, evaluation of flow losses based on data from the automated flow monitoring system at the Pilot Trial site does not indicate substantial reductions in race losses occurred during Year 1.

- **Was the race loss different relative to the MAR site with respects to losses?**

  Given that the percentage of inflow water lost to seepage from the race (12 % to 17 %) was similar to the race's area as a percentage of the overall infiltration area for the MAR Pilot Trial site (18 % of the MAR sites and race combined), it appears that there is no distinguishable difference. During early Pilot Trial operations it was surmised that the race may have been more effective at recharging groundwater than the basin (perpendicular to groundwater flow), but the results suggest that they are similarly effective.

5.0 REFERENCES

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Durney P, Ritson J 2014. Water resources of the Hinds/Hekeao Plains catchment: modelling scenarios for load setting planning process. Canterbury Regional Council technical report R14/51. Internet: http://previous.ecan.govt.nz/our-responsibilities/regional-plans/lwrp/variation-2/Pages/supporting-docs.aspx

APPENDIX M

Ashburton River Recharge

1.0 INTRODUCTION

1.1 Background

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 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 of rainfall-linked flood events.

As part of the Pilot Trial, a groundwater monitoring well was installed close to Tinwald (between Tinwald and the Pilot Trial site) to acquire data on groundwater levels in this area during the trial period. In addition, rainfall data from the Ashburton District Council monitoring station (Appendix B) and surface water level monitoring data for the Ashburton River and Lagmhor Creek have been acquired for Year 1 of the Pilot Trial. These datasets have been evaluated to assess:

1) Groundwater level responses at Tinwald to local rainfall events.
2) Groundwater level responses at Tinwald to changes in water levels in Lagmhor Creek and the Ashburton River.
3) Groundwater level responses to the MAR Pilot Trial operations, if any.

Tinwald is not directly down-gradient from the Pilot Trial site, based on interpretation of the hydraulic gradients across the Pilot Trial command area. Numerical groundwater modelling, untaken as part of an assessment of flooding risks to support the application for resource consents for the MAR Pilot Trial, indicated that the trial would not be a significant factor influencing Tinwald groundwater levels (Golder 2016b). Conceptually Tinwald could however be influenced by water recharged through Pilot Trial operations.

Anecdotally, locals identified that groundwater beneath Tinwald is hydraulically linked to Ashburton River flow conditions, with this connection being a major factor in the historical flooding events. Ensuring that monitoring did take place to help verify this assumption was deemed socially and technically practical.

1.2 Historical Flooding Events

Major flooding events in the Ashburton River have occurred infrequently but regularly since the start of European settlement in the 1850’s (Wild 2015). Carters and Lagmhor Creeks flow through the Tinwald urban area. These creeks are understood to originate as springs fed primarily by groundwater connected to the Ashburton River (near Westerfield). During storm events both creeks drain water from the rural catchment to the north of Tinwald as well as local urban stormwater run-off (Boyle 2012). They potentially also carry tail water sourced from ADC stockwater races (Shepherds Brook Creek and Timaru Track).

Carters and Lagmhor Creeks each have the design capacity to transmit flow up to 1 m^3/s. Historically, urban expansion and constriction of channels have exacerbated flooding during larger storm events.

In November 2009 a flood mitigation investigation of Carters and Lagmhor Creeks was produced (Boyle 2009), primarily as a review of an August 2000 flood that inundated large parts of Tinwald. Several recommendations were made regarding management of the stormwater infrastructure in the area. It is not known whether the recommended modifications were made, however flooding events have occurred as a result of high rainfall events in subsequent years.

Floods occurred in the Tinwald area on 19 October 2011 and 30 December 2006. These floods were documented as being associated with a high pre-existing groundwater table (<11 m bgl in K37/0456) and a large ‘cloud burst’ rain event (> 200 mm) that extended over a period of one or two days (Boyle 2009). This combination of factors led to high water levels in the Ashburton River and elevated flows in Lagmhor Creek due to increased surface runoff within the catchment.

2.0 MONITORING DATA

2.1 Monitoring System

Environmental monitoring undertaken as part of the MAR Pilot Trial, or undertaken by CRC under the wider regional environmental monitoring program (Figure M1), includes:

- Rainfall data from the Ashburton Council and Hinds Plains (Willowby) climate stations (Appendix B).
- Groundwater level data from monitoring well GWD-07, located close to the intersection of Frasers Road and Tinwald Westerfield Mayfield Road, to the north of Tinwald (Appendix G).
- Surface water levels in the Ashburton River, measured at State Highway 1.
- Surface water levels in Lagmhor Creek.

2.2 Rainfall Monitoring

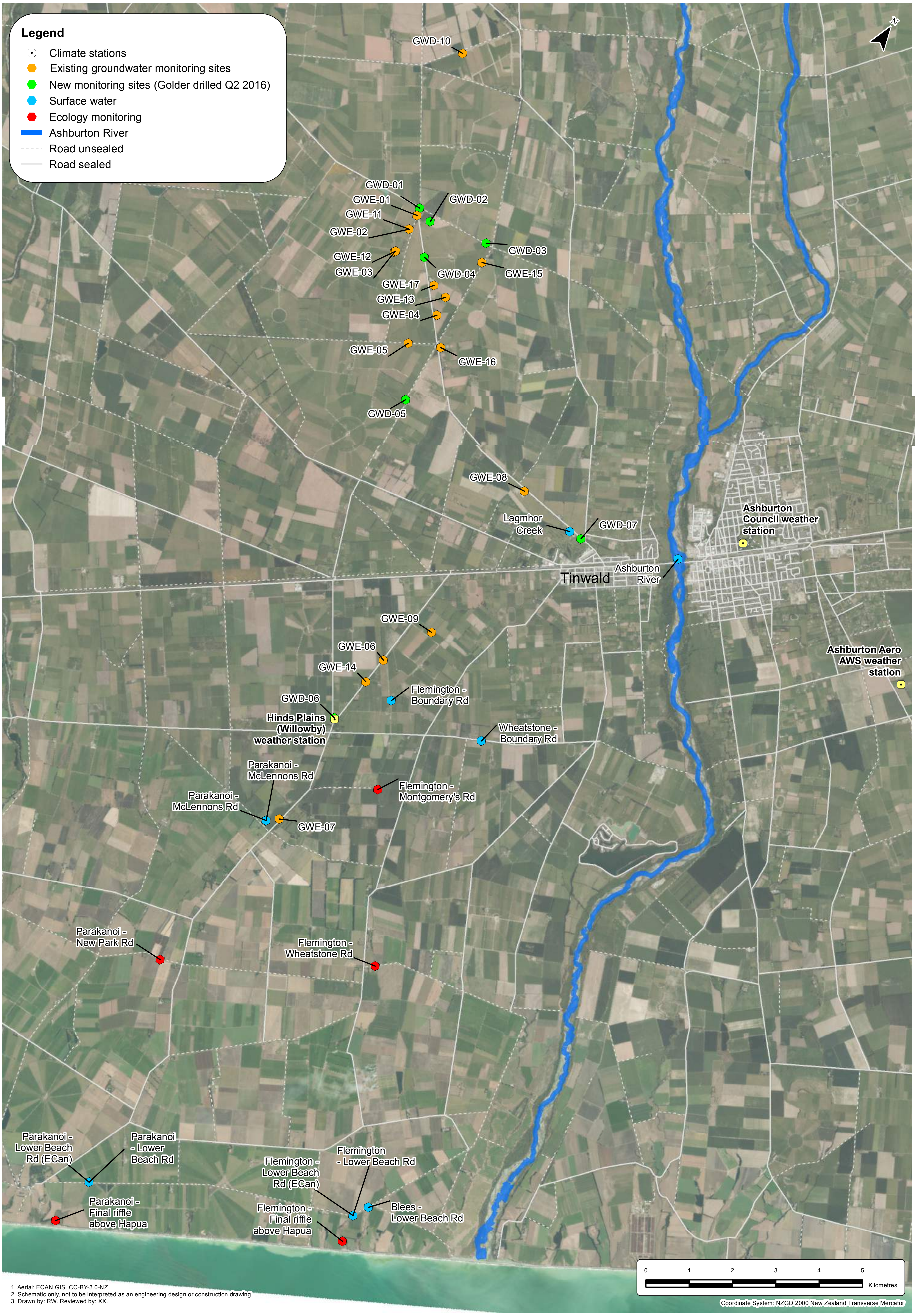
Rainfall monitoring has been conducted at the Ashburton District Council for an extended period, with temperature and daily rainfall totals available through NIWA's CliFlo database. To support the MAR Pilot Trial a dedicated rainfall monitoring station was established by CRC on the Hinds Plains at Willowby to the south of Tinwald, approximately 10 km from the Ashburton station. The correlation between the daily rainfall datasets from these two climate stations for the period leading up to and during the Pilot Trial is weak (refer Appendix B). As the Ashburton District Council weather station is closer to Tinwald (Figure M1), data from this site has been used to represent rainfall for the purposes of assessing groundwater responses to rainfall events at Tinwald.

2.3 Groundwater Monitoring

A shallow monitoring well was installed to a depth of 11.2 m on the corner of Frasers Road and Tinwald Westerfield Mayfield Road (GWD-07) to monitor the groundwater system's response to external influences in the area of Tinward during the Pilot Trial. A Solinst transducer with a pressure recording range of 30 m and nominal recording accuracy of 0.05 % of the recording range (± 0.015 m) was installed to record groundwater levels at 15 minute intervals. Monitoring well GWD-07 is part of the monitoring network deployed for the MAR Pilot Trial (refer Appendix C) and was installed to gather data specifically for this inundation risk study.

In addition to the data from GWD-07, a longer term groundwater level record covering the period since 2003 was obtained from monitoring well K37/0456. This monitoring well is located at Tinwald Golf Club approximately 80 m southwest from GWD-07 and is maintained by CRC.

The data from K37/0456 has not been used to support the analyses presented in this appendix, as the monthly recording frequency is not sufficient for the purpose. It is however clear from the groundwater level record for K37/0456 (Figure M2) that the two drought years 2015 and 2016 (549 mm and 579 mm rainfall, respectively) resulted in the groundwater table at this site in the lead-up to the Pilot Trial being seasonally deeper than during any other time since 2003.



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: XX.

Golder Associates

TITLE MONITORING WELL LOCATIONS

AUGUST 2017

PROJECT 1538632

M1

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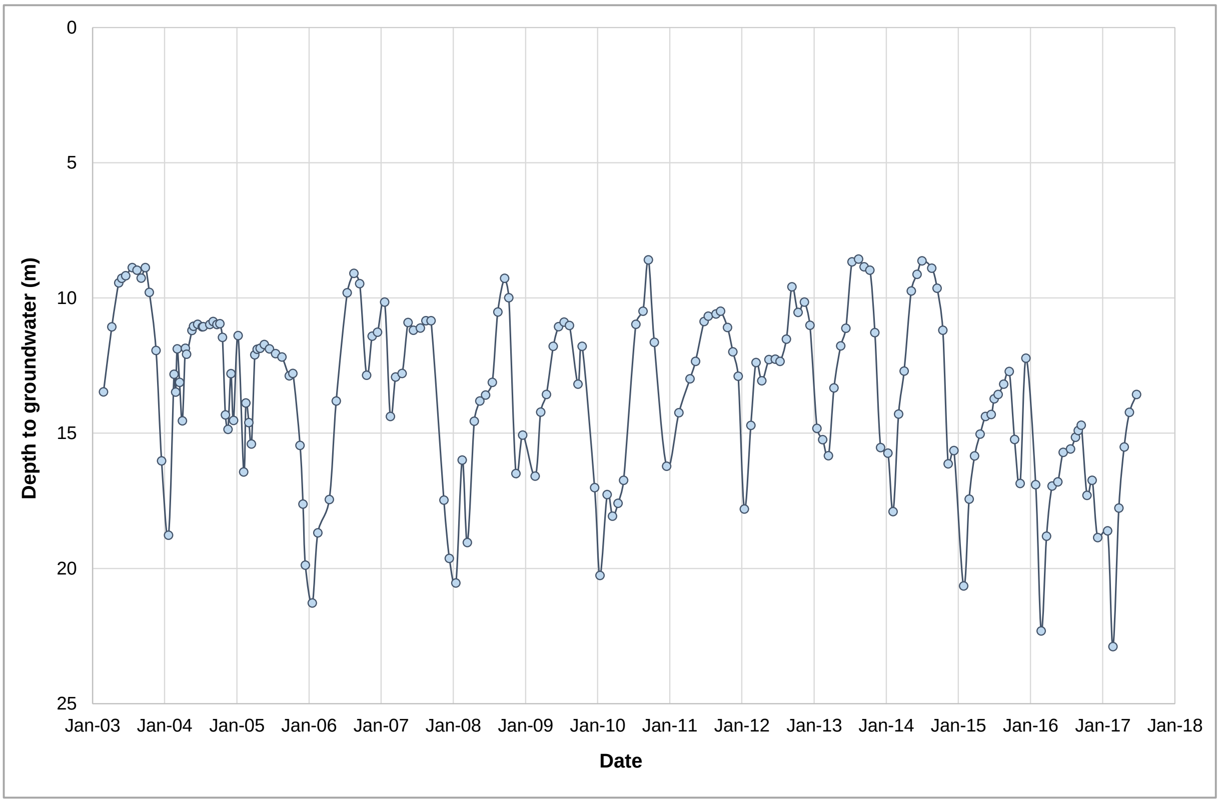

Figure M2: Groundwater level record from monitoring well K37/0456.

2.4 Surface Water Level Monitoring

The surface water and groundwater systems interact with each other in the Hinds catchment. Monitoring of surface water levels in Lagmhor Creek and in the Ashburton River (Figure M1) was therefore a crucial component of this flooding risk study for Tinwald.

At their closest approaches (Figure M1):

- Lagmhor Creek passes approximately 50 m south of monitoring well GWD-07.
- The Ashburton River passes approximately two kilometres east of monitoring well GWD-07.

CRC has monitored the level of the Ashburton River at SH1 for an extended period, with data available at a 5 to 15 minute recording interval. For the purposes of this study, a surface water monitoring site maintained by the CRC was installed on Lagmhor Creek in April 2016. Both datasets covering the period of the Pilot Trial have been acquired from CRC and analysed.

3.0 RESULTS

3.1 Rainfall Effects on Surface Water Levels

A high level comparison has been undertaken between the Ashburton rainfall record for Year 1 and Ashburton River water levels for the same period (Figure M3). This comparison has been undertaken through visually comparing the two datasets as an intensive statistical evaluation of the datasets is outside the scope of this project.

The water level in the Ashburton River does on occasion respond to rainfall events recorded at Ashburton, however more often there is no correlation between increases in river level and Ashburton rainfall events

(Figure M3). Furthermore, the size of the Ashburton rainfall event does not appear to be reflected in the scale of the water level response in the Ashburton River.

High flows in the Ashburton River are generally considered to occur in response to heavy rainfall in the catchment foothills rather than heavy rainfall on the plains. The assessment of the rainfall and river level datasets presented in Figure M3 reflects this interpretation. The periods of higher base flow in the Ashburton River from August through to November may be linked to snow melt in the Southern Alps.

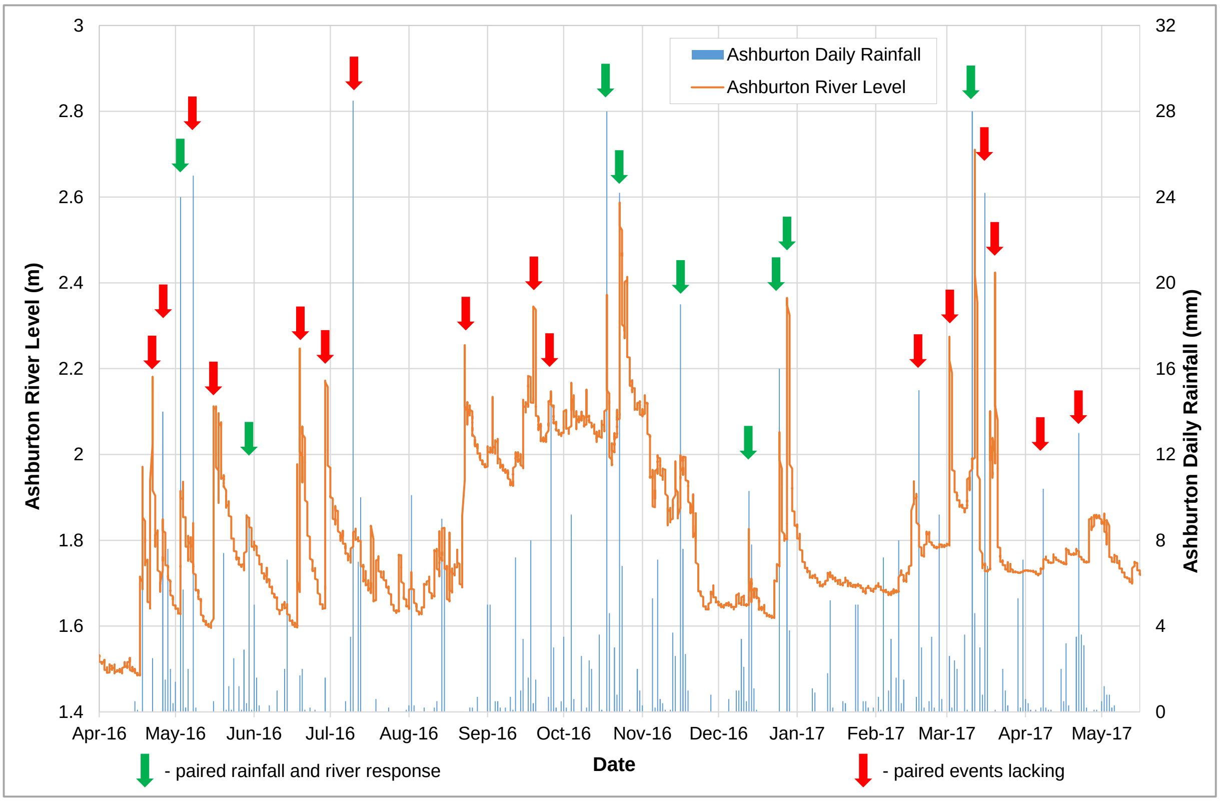

Figure M3: Rainfall effect on Ashburton River level.

A similar visual comparison has been undertaken between the Ashburton daily rainfall record and water levels recorded in Lagmhor Creek (Figure M4). There is no clear evidence from the Year 1 data that water levels in Lagmhor Creek increase in response to rainfall events recorded at Ashburton. This interpretation reflects the nature of Lagmhor Creek, which is a spring fed waterbody that sometimes also carries tail water from ADC stock water races.

On at least six occasions during Year 1 the water level in Lagmhor Creek:

1) Decreased abruptly by up to 0.13 m during or shortly after a significant rainfall event.

2) Less than one week after the decrease, the water level abruptly recovered to the original water level or above this level.

These paired events are thought to be associated with a diversion located within 5 m downstream from the monitoring site and operated by the Tinwald Golf Club (pers comms. CRC). When the diversion intake is increased, the Lagmhor Creek water level upstream from the diversion decreases significantly as backed up water enters the steeper diversion channel. When the diversion is reduced or closed, the opposite occurs and water levels rise upstream from the diversion point. These rises and falls in water level linked to the Tinwald Golf Club diversion would only affect the short stretch of Lagmhor Creek crossing and immediately upstream from the golf club.

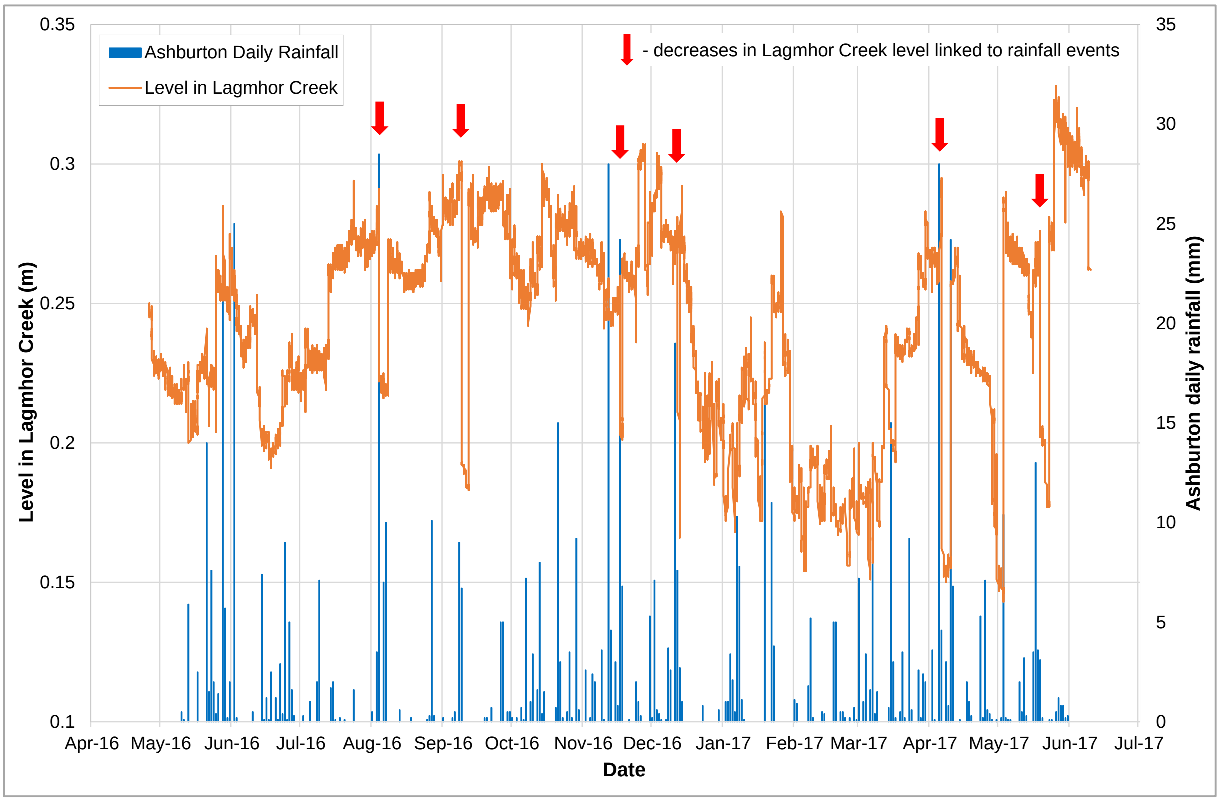

Figure M4: Lagmhor Creek level responses to rainfall events.

3.2 Rainfall Effects on Groundwater at Tinwald

The groundwater level in monitoring well GWD-07 increased in response to rainfall events of 15 mm or more during Year 1 of the Pilot Trial (Figure M5). The magnitude of the groundwater rise in response to rainfall events varied, and there was no observed immediate response to at least two rainfall events of 15 mm or more. The groundwater level at GWD-07 generally responded to these rainfall events within one day.

At GWD-07 the strongest observed groundwater responses to rainfall occurred during March and April 2017 (Figure M5). This was also the period of groundwater recovery following drawdown related to groundwater abstraction for irrigation in the Hinds catchment. These two components of groundwater level rise may have interacted to create an apparent strong response to rainfall events.

In contrast, groundwater responses to specific rainfall events across the wider Hinds catchment during Year 1 of the MAR Pilot Trial was muted or not detectable. Monitoring well GWD-05 is located approximately 5.2 km west from GWD-07, and is closer to the MAR Pilot Trial site. The groundwater level at GWD-05 shows no indication of direct responses to rainfall events recorded at Ashburton (Figure M6). The only clear correlation between rainfall and groundwater levels at GWD-05 occurred during the period of active irrigation pumping in the catchment (Figure M6). In each case of an identifiable correlation between groundwater level rise and a rainfall event, the groundwater level change started in advance of the rainfall. Although further investigation needs to be undertaken, it appears that these observed groundwater level rises may occur in response to the shut-down of groundwater abstraction for irrigation in advance of expected rainfall events.

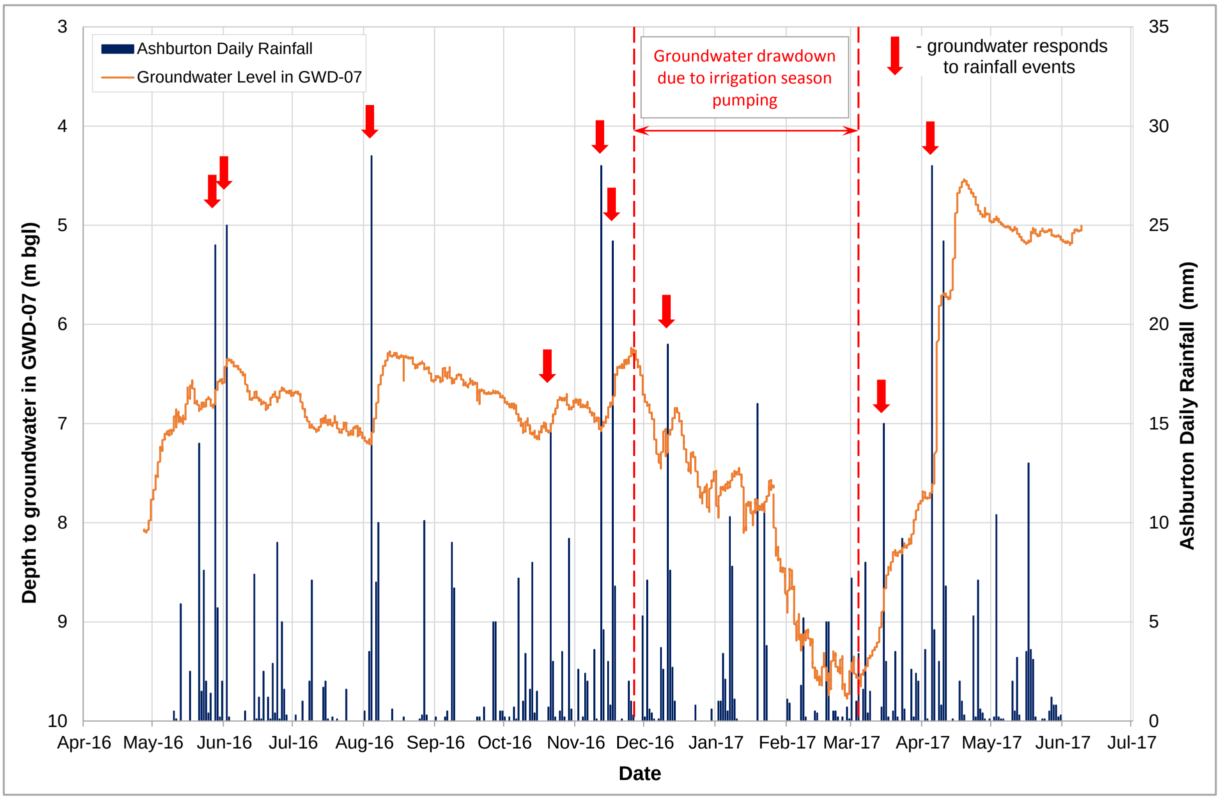

Figure M5: Shallow Tinwald groundwater responses (GWD-07) to rainfall events.

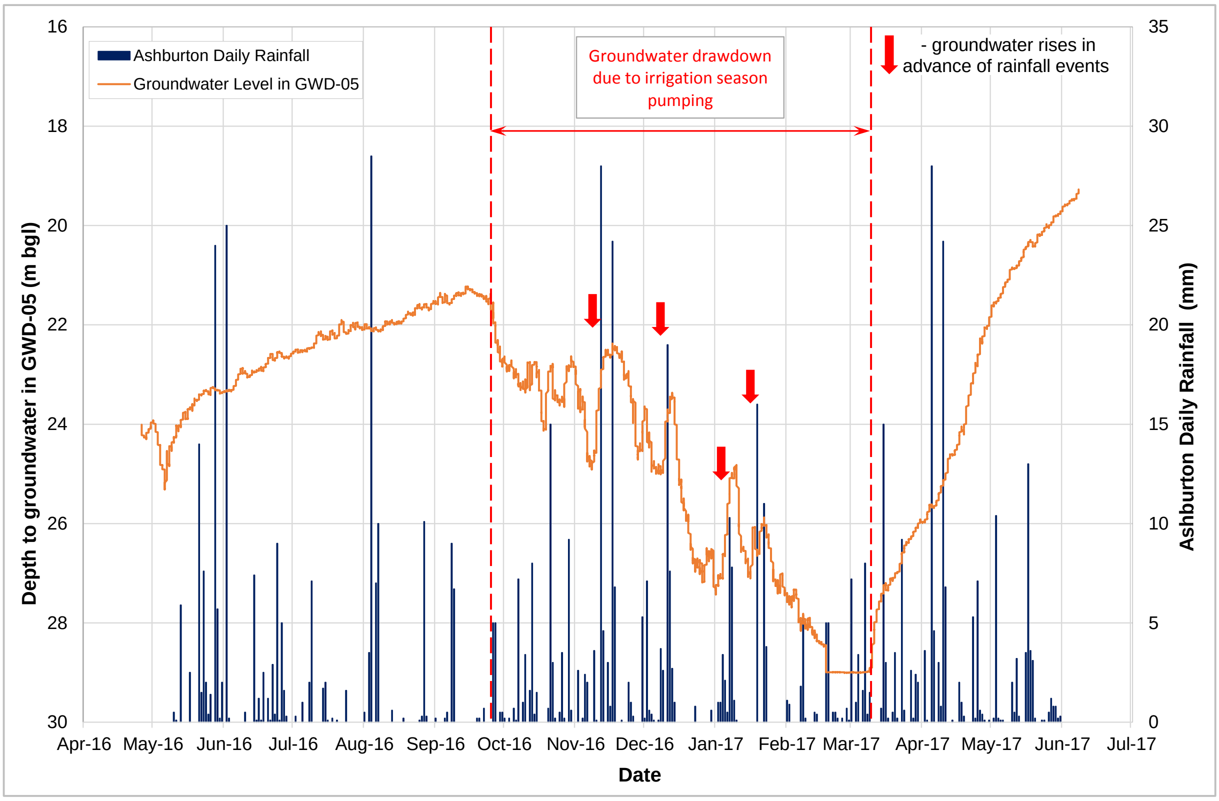

Figure M6: Regional groundwater system (GWD-05) variation compared to rainfall events.

The different responses observed at GWD-07 and GWD-05 may relate to the depth to groundwater at each site. Outside the irrigation period the groundwater at GWD-07 was less than 8 m bgl. In contrast, the groundwater table at GWD-05 was generally more than 20 m bgl during Year 1 of the Pilot Trial. The greater thickness of unsaturated zone, together with the potential for silty aquitards to be present within the unsaturated zone (refer Appendix G), is likely to be the reason for the attenuated responses to rainfall in the MAR Command Area to the west and northwest from Tinwald.

3.3 Ashburton River Effects on Groundwater

The Ashburton River is likely to act as a local hydraulic control for base levels in the groundwater system beneath Tinwald. However, the groundwater level recorded in monitoring well GWD-07 at Tinwald did not appear to respond strongly to rises in the level of the Ashburton River during Year 1 of the Pilot Trial (Figure M7). Of the observed rises in groundwater level at GWD-07 that correlate with increases in water levels in the Ashburton River, only two do not also match with rainfall events of 15 mm or greater (Figure M5).

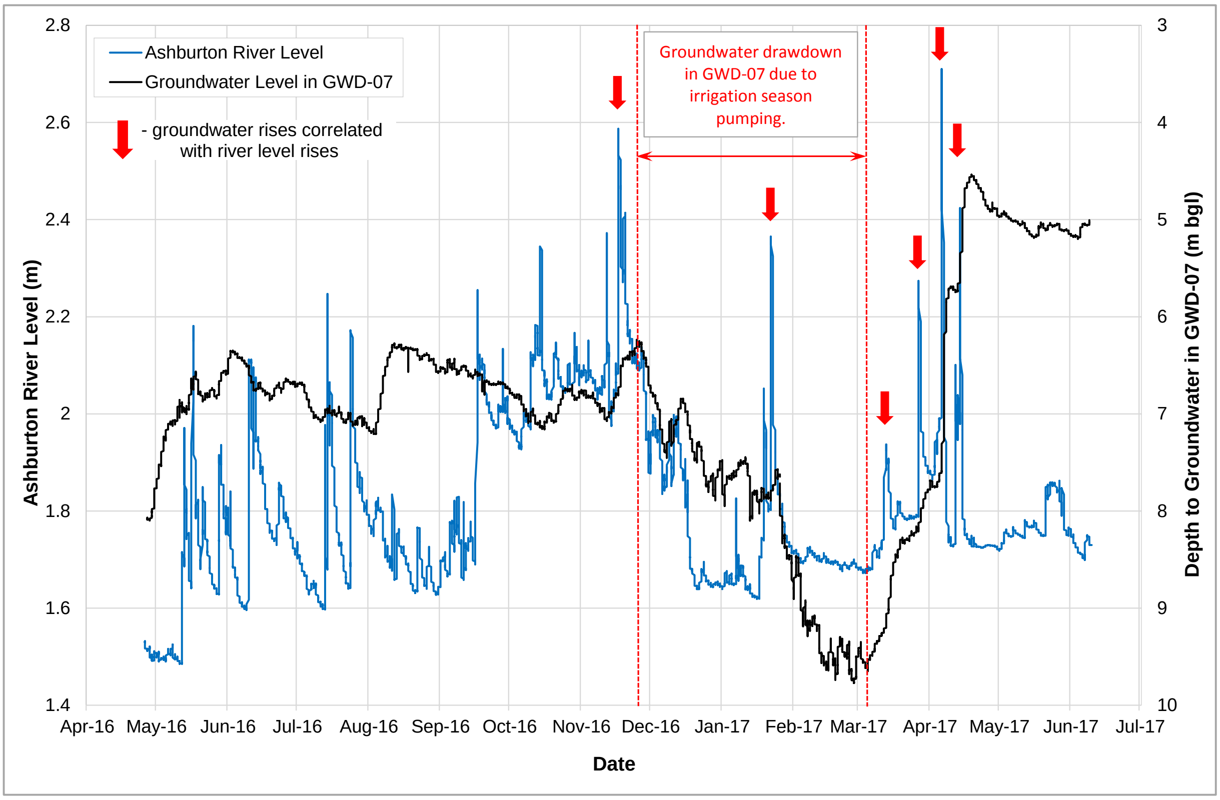

Figure M7: Shallow Tinwald groundwater responses to changes in Ashburton River water level.

The two groundwater level rises that are linked to increases in Ashburton River levels but not to rainfall events both occurred during the irrigation season recovery period: 27 March 2017 and 14 April 2017. These events did occur against a background of two months of unusually high rainfall (March and April 2017) coinciding with the groundwater level recovery from the irrigation season pumping. For these reasons it is not clear from the Year 1 data that the groundwater system at GWD-07 responds significantly to short term high water events in the Ashburton River.

A period of increased base flows occurred in the Ashburton River from mid-September to mid-December (Figure M5), probably a consequence of spring snow melt in the foothills of the Southern Alps. This period of higher river level is not reflected in a corresponding period of higher groundwater levels at GWD-07. However, to the west of Tinwald the seasonal drawdown of groundwater due to pumping for irrigation started at the end of September 2016 (Figure M6). The corresponding drawdown in groundwater at GWD-07 did not appear to start before late November 2016 (Figure M7), which was also when the high base flows in the Ashburton River started to decline. The data from the Pilot Trial Year 1 suggests that irrigation related groundwater drawdown in the area of Tinwald may have been delayed by months due to high base flows in the Ashburton River. More investigation is required into the interaction between seasonal snow melt and groundwater drawdown induced by pumping during the irrigation season to verify this concept.

Ashburton River was augmented by discharges from the RDR for the period from late 2016 through to early 2017 due to flow becoming available as a result of a shutdown of the Highbank Power Station for scheduled maintenance. Although this flow augmentation would have affected water levels in the river, there is no indication that these effects influenced groundwater levels at Tinwald.

3.4 Groundwater Effects on Lagmhor Creek

Lagmhor Creek does not appear to be directly hydraulically linked with the underlying groundwater system, as evidenced by the groundwater at monitoring well GWD-07 being between 4.5 m and 10 m bgl during Year 1 of the Pilot Trial (Figure M8). In contrast the water surface in Lagmhor Creek, which passes approximately 50 m south of GWD-07, is less than 2 m bgl.

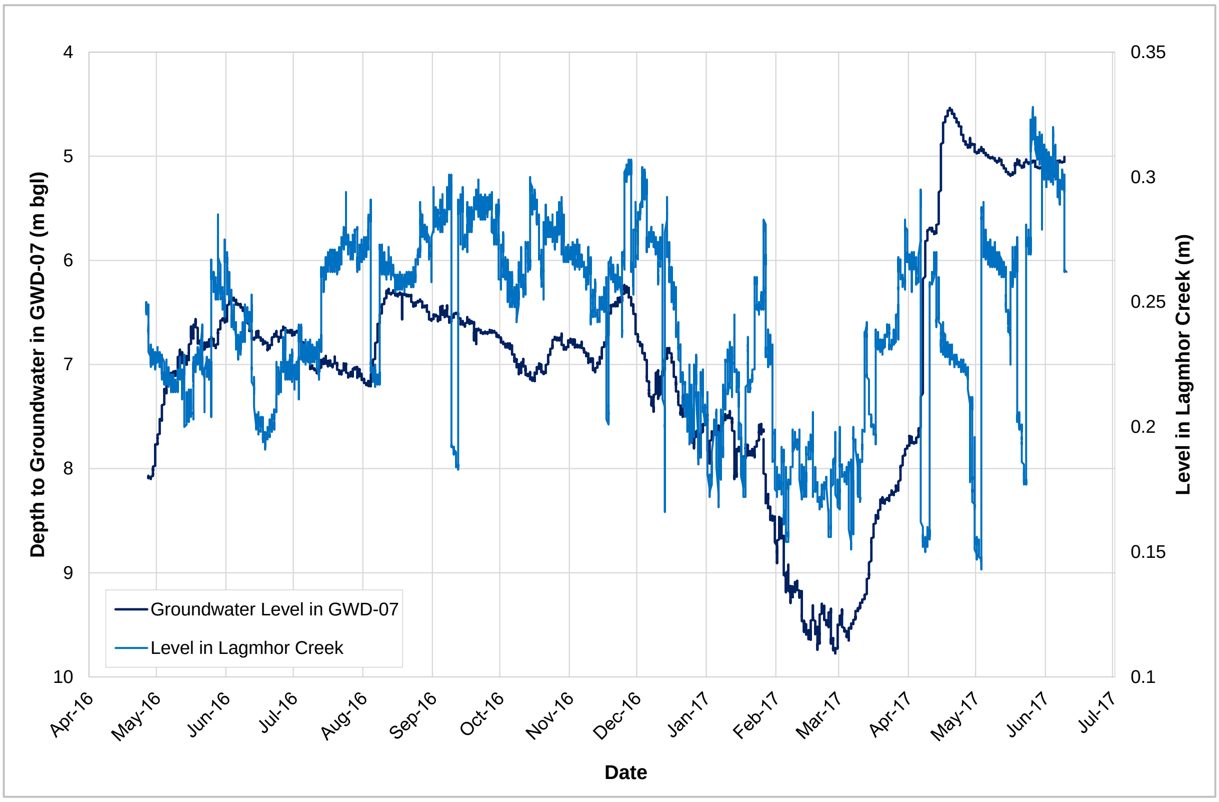

Figure M8: Lagmhor Creek response to groundwater level.

Although there are likely to be seepage losses from Lagmhor Creek to the underlying groundwater system, there is no indication from the two datasets (Figure M8) that the groundwater level at GWD-07 responded to changes in the water level in Lagmhor Creek during year 1 of the MAR Pilot Trial.

Both Lagmhor Creek and groundwater at GWD-07 showed a seasonal decrease from December 2016 through to March 2017. These apparently similar seasonal decrease and subsequent recovery trends in water levels are not necessarily due to a cause and effect relationship. The trends are more likely to be reflecting different seasonal aspects of the natural and land use cycles that influence the hydrological systems of the Hinds catchment.

3.5 Effects of Irrigation Pumping

The strongest single influence on groundwater levels observed across the Pilot Trial Command Area during Year 1 has been that of irrigation pumping (Appendix G). The magnitude and duration of groundwater drawdown due to groundwater abstraction for irrigation exceeded the apparent responses of the groundwater system to rainfall events and fluctuations in the Ashburton River level.

The seasonal variation in groundwater levels associated with groundwater extraction for farming purposes is also apparent in the long-term record from monitoring well K37/0456 (Figure M2). This record indicates groundwater levels at Tinwald generally peak during September, immediately prior to the seasonal irrigation season.

The years of 2015 and 2016 were both drought years (refer Section 2.3). Declining groundwater levels in the Hinds catchment during this period reflected not only the lack of rainfall but also a corresponding increase in water demand for irrigation.

4.0 CONCLUSIONS

The groundwater level record from GWD-07 has shown no indication of groundwater driven flooding in Tinwald during Year 1 of the Pilot Trial. Assessment of the effects of the Pilot Trial on groundwater levels 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. Following the end of the irrigation season the groundwater table recovered rapidly to two metres above the highest levels recorded during Year 1 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. However, it is likely that higher water level events in the Ashburton River during the same period also contributed to the groundwater level recovery. The high groundwater level recorded at Tinwald following April 2017 may be a consequence of the cumulative rainfall in the Hinds catchment during March and April, which was much greater than average for these months.

Groundwater levels at Tinwald rise substantially in response to local rainfall events. Further to the west in the Hinds catchment groundwater levels do not appear to increase in direct response to rainfall events. This difference in response may be linked to the thickness of the unsaturated zone overlying the regional groundwater system in different areas of the catchment, and the potential presence of silty aquitards within this unsaturated zone.

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. There was also no apparent correlation during Year 1 between water levels in Lagmhor Creek and groundwater levels at GWD-07.

Drought in the Hinds catchment during 2015 and 2016, with corresponding higher rates of groundwater abstraction for irrigation purposes, resulted in low groundwater levels at Tinwald during Year 1 of the Pilot Trial. The results of the analyses presented in this Appendix must be considered alongside the low groundwater levels at the start of Year 1. There was no opportunity during Year 1 to observe the effects of substantial rainfall events or flood flows in the Ashburton River combined with preceding high groundwater levels. For this reason further work remains to be done regarding the combinations of factors that lead to flooding at Tinwald.

APPENDIX N

Coastal Drains Ecological Monitoring

1.0 INTRODUCTION

1.1 Background

Historically, water flowed through the Hinds Drains system year-round, providing a permanent aquatic habitat that supported a number of native and non-native fish species (HDWP 2016). However, changes in water management (e.g., groundwater abstraction, stock water race closure, irrigation system changes) coupled with extended summer drought periods and more recent changes in land-use, leading to increased nitrate concentrations, have resulted in declining ecological values of the Hinds Drains (HDWP 2016).

The Hinds Drains Working Party (HDWP) identified that adaptive flow regime control was essential to ensure both improvement and maintenance of aquatic habitats in the drains. It was anticipated that a MAR pilot scheme would help to support sufficient minimum flows in the drains to allow re-establishment of the aquatic habitat and provide dilution of nitrate concentrations.

The MAR pilot project 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

The Hinds Drains Working Party (HDWP 2016) provided specific recommendations related to the MAR Pilot Trial, as well as specific goals for each of the drains. Due to the dry conditions, native and non-native (trout) specie areas were mapped by CRC, Department of Conservation, and Fish and Game technical staff. The maps represent the potential areas in these coastal drains for species to re-establish, provided that MAR can help restore baseflows and that efforts to restore instream and riparian habitat are pursued. These are the overall ecological goals of these drains and will only be achieved through the return of baseflows, which can be supported through MAR. Additional requirements include habitat restoration, reduction of stream-depleting groundwater takes and reduction in nutrient contamination of shallow groundwater. An abbreviated set of drain restoration maps and recommendations is included in **Attachment A**.

1.2 Purpose

Ecological monitoring is an essential component of determining the success of the MAR Pilot Trial for re-establishing aquatic habitats in the Hinds Drains. The purpose of the ecological monitoring of the drains was to determine if the potential physico-chemical changes relating to flow restoration brought about by the MAR pilot would be reflected in the biological communities.

2.0 METHODS

Water quality monitoring was undertaken at two sites on Parakanoi Drain and two sites on Flemington Drain on 12 occasions from April 2016 to April 2017, when there was sufficient water flow in the drains. These four sites, along with one further ecology monitoring site on Flemington Drain, are part of a wider monitoring network established for the Pilot Trial. Further information and maps identifying site locations are provided in Appendix C.

On each occasion, physico-chemical measurements of the drain water were taken using a calibrated handheld water quality meter. During the 6 April 2017 survey, a water sample was collected from each wetted site for nutrient and dissolved organic carbon analyses.

Ecological observations of the wetted habitat in Parakanoi Drain at New Park Road were recorded on two occasions, one in October 2016 and one in November 2016. On each occasion, the in-stream habitat, riparian condition, periphyton percentage cover and macrophyte percentage cover were recorded at each site using the rapid habitat assessment methods outlined in Harding et al. (2009).

Attachment B highlights the difference in aquatic conditions at each site between the summer and winter months.

3.0 RESULTS AND DISCUSSION

The observed flow status in the five sites over the course of the monitoring period are shown in Table N1. 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 hapu (Table N1).

Physico-chemical measurements of the drain water are summarised in Table N2. 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. However, these values may not reflect either the daily minimum or maximum and exceedances of either parameter above or below the tolerance ranges of sensitive species may negatively impact their ability to recolonise the drains. However, it is anticipated that physico-chemical properties of the drain water will be more favourable for sensitive species once there is sufficient flow in the drains.

Based on the three nutrient measurements, nitrate-N concentrations in Parakanoi Drain at New Park Road ranged from 5.2 – 14.4 g/m^3 (Table N2). While the range was highly variable and the data limited, concentrations were within the long-term range for the Hinds Drains (see HDWP 2016). Nitrate-N concentrations in samples collected from 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 g/m^3 (HDWP 2016).

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 (Table N3 and Figure N1). 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 (Table N3). 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.

Table N1: Observed flow status in the Parakanoi and Flemington drains from April 2016 to April 2017.

Site	27/4	22/6	26/7	25/8	2/9	27/9	12/10	25/10	22/11	20/12	25/1	6/4
Parakanoi at McLennons/Osbornes Road	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	n/s
Parakanoi at New Park Road	n/s	Dry	Dry	Low	Low	Low	Low	Dry	Low	Dry	Dry	Low
Parakanoi at Lower Beach Road	n/s	Dry	Dry	Dry	n/s	Dry	Dry	Dry	Dry	Dry	Dry	Low
Parakanoi u/s of hapua	n/s	Dry	Dry	Dry	n/s	Dry	Dry	Dry	n/s	n/s	Dry	n/s
Parakanoi at Surveyors Road	n/s	n/s	n/s	Low	Low	Dry	Dry	n/s	n/s	n/s	Dry	n/s
Flemington at Montgomery's Road	n/s	Dry	Dry	Dry	n/s	Dry	Dry	Dry	Dry	Dry	Dry	Low
Flemington at Wheatstone Road	n/s	Dry	Dry	Dry	n/s	Dry	Dry	Dry	Dry	Dry	Dry	n/s
Flemington at Lower Beach Road	n/s	Dry	Dry	Dry	n/s	Dry	Dry	Dry	Dry	Dry	Dry	n/s
Flemington u/s of hapua	n/s	Dry	Dry	Dry	n/s	Dry	Low	n/s	n/s	n/s	Dry	n/s

Note: n/s = not sampled.

Figure N1: Thin green films growing on the gravel substrate at Parakanoi @ New Park Road during the 25 November 2016 survey.

Table N2: Physico-chemical parameters recorded in the Parakanoi and Flemington Drains during periods of flow.

Parameter	Parakanoi at New Park Road						Parakanoi at Lower Beach Road	Flemington at Boundary Road	Flemington at Montgomery's Road
Date	**25/8/16**	**2/9/16**	**28/9/16**	**12/10/16**	**25/11/16**	**6/4/17**	**6/4/17**	**6/4/17**	**6/4/17**
Wetted width (m)	n/s	n/s	n/s	3.1	3.0	n/s	n/s	n/s	n/s
Depth (m)	n/s	n/s	n/s	0.10	0.13	n/s	n/s	n/s	n/s
Temperature (°C)	13.1	8.0	17.0	12.7	18.5	12.0	12.1	12.1	12.0
pH	7.8	7.8	8.4	8.1	9.0	n/s	n/s	n/s	n/s
Dissolved oxygen (g/m^3)	10.9	9.6	10.7	11.7	12.7	7.8	7.4	8.0	7.5
Dissolved oxygen (% saturation)	104	81	110	110	142	72	68	66	69
Specific conductance (µS/cm)	264	290	300	220	233	430	278	155	178
Turbidity (NTU)	n/s	n/s	1.08	1.01	n/s	83	98	49	51
Water colour	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear
Total suspended solids (g/m^3)	n/s	n/s	2.1	<1.0	n/s	49	64	36	46
Nitrate-N (g/m^3)	n/s	n/s	n/s	n/s	n/s	14.4	0.57	0.43	1.33
Nitrate-N+nitrite-N (g/m^3)	n/s	n/s	8.2	5.2	n/s	14.5	0.64	0.46	1.37
Total Ammoniacal-N (g/m^3)	n/s	n/s	0.014	<0.010	n/s	n/s	n/s	n/s	n/s
Total Nitrogen (g/m^3)	n/s	n/s	8.3	5.2	n/s	n/s	n/s	n/s	n/s
Dissolved Reactive Phosphorous (g/m^3)	n/s	n/s	0.0033	<0.0010	n/s	n/s	n/s	n/s	n/s
Total Phosphorous (g/m^3)	n/s	n/s	0.018	0.013	n/s	n/s	n/s	n/s	n/s
Dissolved Organic Carbon (g/m^3)	n/s	n/s	3.7	n/s	n/s	n/s	n/s	n/s	n/s

Table N3: Percentage cover of periphyton in Parakanoi Drain at New Park Road during the October 2016 and November 2016 ecological surveys.

Periphyton Group	Colour	12 October 2016 Percentage cover (%)	25 November 2016 Percentage cover (%)
Thin mat/film (<0.5 mm thickness)	Green	50	60
	Light brown	50	35
Long filaments (>20mm length)	Green	0	5

4.0 RECOMMENDATIONS

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,

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 monitoring of fish communities is also recommended.

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APPENDIX O

MAR Numerical Modelling

Memo

Date	20/7/2017
To	MAR technical team
CC	
From	Patrick Durney

Predicted effects of the Hinds Managed Aquifer Recharge (MAR) Trial – MAR footprint numerical modelling

I have prepared this memorandum to document numerical modelling of the Hinds MAR trial. I conducted the modelling work to investigate both the actual impacts of the trial and predict the potential impacts over the next four years.

Background

To date the MAR pilot has produced measureable effects in trial monitoring wells several kilometres down gradient. However, we have yet to see the full outcome of five years recharge. To explore the potential longer term impacts of the trial, numerical modelling is required that first reproduces the observed effects from the first year of operation, and then can predict the effects from the remaining trial period. The MODFLOW NWT model described herein is the tool I propose to provide for those predictions.

What I did

I developed a new numerical model of the Hinds MAR trial footprint area using MODFLOW-NWT in the GMS software interface. The last section of this memo 'Model design' delves more deeply into the construction of the model.

Whilst the model is an over-simplification of the study area, it is potentially a useful tool for assessing the likely impact of the MAR pilot. My first step was the construction of a larger domain model (black margin) that I used to derive head boundaries in my smaller model (red margin in Figure 1). This larger domain model extended from the foothills to the sea and from the Ashburton River/Hakatare in the north to the Hinds River/Hekeao in the south. My next step was the development of roughly calibrated steady-state model of the MAR footprint area, I then transformed the steady-state model into a transient simulation that ran from October 2015 to June 2017 for the purpose of solute transport modelling.

Figure 1 Study area model boundaries

Key conceptual assumptions

The concept for the model was developed from the synthesis of ideas put forward by myself, Brett Sinclair and Jens Rekker. I have assumed that the period of 2012 to 2016 represents average climate and groundwater conditions and have produced a steady-state model of the this period, including mean recharge, river flow and observed water level data. Whilst the steady-state assumption is unlikely to be the case, it allows a useful starting point for investigating the potential impacts of the trial. By assuming steady-state, I could use the average water levels and river flows recorded between 2012 and the start of the trial as a baseline for model calibration.

Key mounding assumptions

I assume that mounding only begins when MAR recharge reaches the regional water table and does not occur in any of the previously unsaturated preferential flow channels above water table elevation. Field observations of the fate of MAR recharge water are suggestive of a perched water table retarding the recharge waters passage to the regional water table. However, at a wider spatial scale, the effect of any perched water table can be set aside in examining the consequences of MAR on the regional aquifer system.

Simulation design

After developing the steady-state model, I transformed the model into a transient model with the same conceptual assumptions for mounding and solute transport purposes. I introduced the MAR groundwater recharge in the form of additional recharge. I ran two scenarios, one with and one without MAR to look at the magnitude of change.

I again direct the reader to the 'Model design' section for more information regarding the models developed.

What I found

The model is broadly able to reproduce the observed effects of the MAR trial, though the parameter solution set is far from unique. Although I am able to produce a similar response to that observed from the trial, and the model is fit to investigate the longer-term impacts, the solution is not unique meaning other parameter combinations could produce similar results. The primary consequence of this is to limit the certainty of the modelled results the further we vary the inputs from the calibration data, e.g. the further into the future we model results or the larger the amount of MAR we model. Based upon the Australian modelling guideline for best practice, the model results can be extrapolate up to three times the length of the calibration period, in this case up to three years (three time the trial length).

The model shows that without MAR, the wells we observed responding to both increased water levels would have continued to decline over the trial period due to antecedent drought-related reductions in land surface recharge. This suggests the effects of the MAR trial are greater than those perceived from the trial data alone. The model also shows the effects of the trial are not limited to immediately down gradient but also propagate up gradient as well (Figure 2). Interestingly increases in groundwater levels are simulated to the south west. This is caused by the groundwater mounding from the trial site reducing losses from the stockwater race running past the site, allowing more water to flow down the race network to where it is ultimately lost to groundwater in the south west of the model area.

The water quality results suggest that water quality changes will primarily be experienced immediately down gradient and may extend to 100 m below surface (Figure 3).

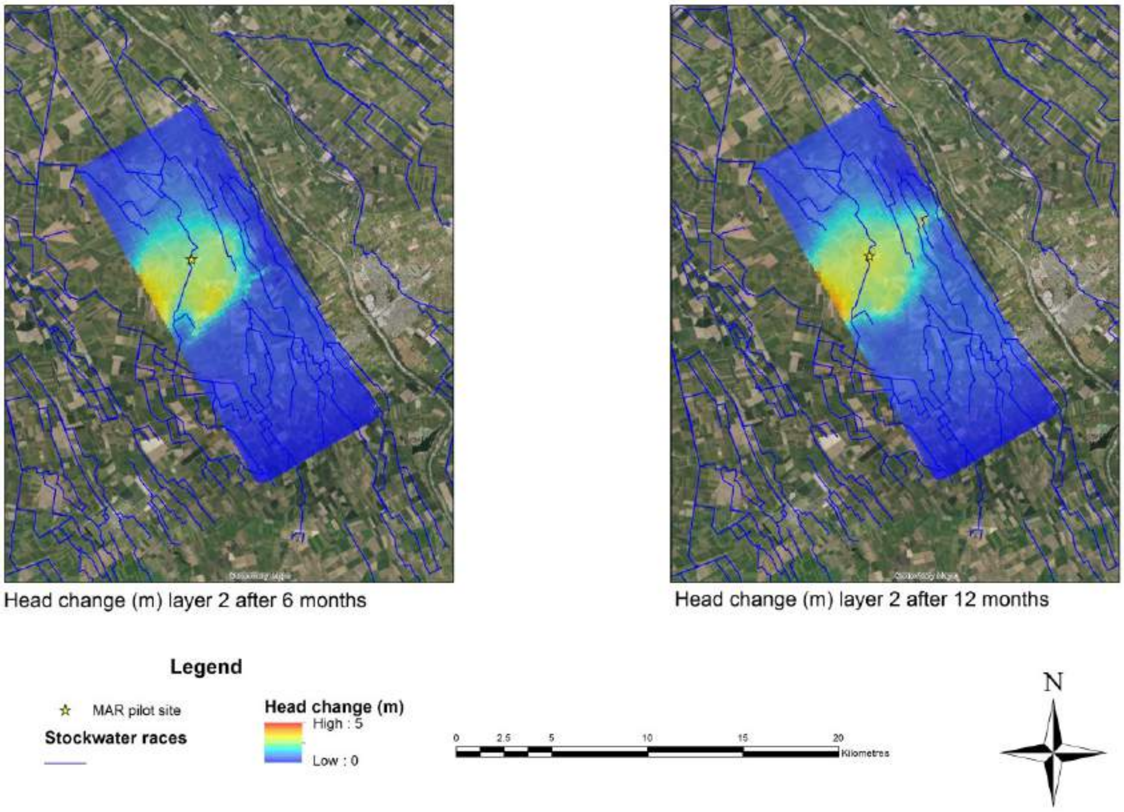

Figure 2 Transient simulation head change after approximately six months and one year (layer 2)

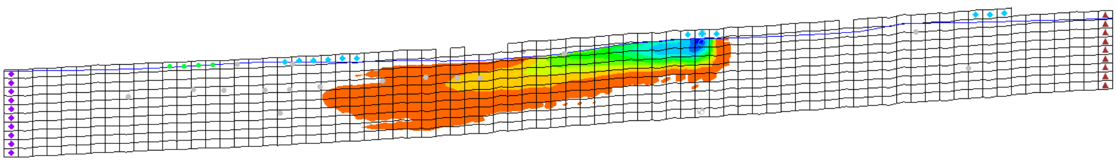

Figure 3 Cross-section through model showing plume of clean water (blue) from MAR trial after one year of operation

Limitations

The modelled results suggest that some boundary effects are occurring specifically along the southwestern boundary. Boundary effects mean the model results are impaired by the presence of boundary conditions. Whilst some of the mounding in the south west area is a result of interactions with surface water features (stockraces) most is caused by boundary effects, meaning model predictions of mounding cannot be relied on in the affected areas. These effects are apparent in (Figure 2) on the southwestern boundary directly in line with the

MAR site, where the model suggest more mounding than I deem reasonable. The existence of proximal model boundary effects mean caution should be used in interpreting the results adjacent to the boundaries.

As stated earlier the model results are non-unique. The definition of non-uniqueness is that although the parameters used in calibration fit the calibration period, other parameter sets may equally define a reasonable solution. The implications of non-uniqueness are residual uncertainties in model predictions. The only way to address this is to perform time intensive and computationally intensive uncertainty modelling which will enable an assessment of the maximum and minimum potential effects. Currently uncertainty assessments are beyond the scope of this work, though I am intending to continually update and recalibrate the model as more observation data becomes available.

What this means

I have produced a functional calibrated local scale steady-state and transient model of the Hinds MAR pilot that can be used to forecast potential effects up to 3 years from the time of writing. The model may also be used to assess the impacts of increasing recharge rates or to examine whether we can expect improved streams flows in the life of the trial as a direct consequence of MAR.

Model design

I developed the model using the NWT package of MODFLOW 2005 as it is a stable, robust solver designed for surface water/groundwater interaction studies and for modelling unconfined aquifers. I experimented with simpler model solver packages, but abandoned these as structural problems prevented their adoption, such as cells beneath the flux boundaries drying causing decoupling of the model from the flux boundary. The decoupling meant the flux boundary no longer provided any input to the model.

Model domain

The model domain extends from several kilometres above the MAR trial site to the start of the Valetta spring-fed streams (Figure 1). In the vertical dimension, the model is ten layers and extends from groundlevel to a uniform 150 m below groundlevel. The first layer terminates 15 m bgl, with each successive layer 15 m thick, thus the model is 150 m thick overall.

Site geology

The geology of the site is typical of the Canterbury plains, with the lithology consisting of an almost dual domain nature. A low permeability matrix dominant sandy gravel with some to minor silt content and a high permeability preferential flow channel of cleaner gravels that carry the majority of flow but make up a small proportion of the physical material (Dann et al 2008, Davey 2005, Durney et al. 2014). Interpretation of the trial observations lends itself to view that there is significant layers of silty sandy-gravel admixtures beneath the site, though we are unable to confirm this from the borehole cuttings. As this geology is not possible to represent at the scale numerical models are built, I have chosen to represent the geology as simply as possible and have varied the permeability using Pilot Point PEST (Doherty, 2003).

Model boundaries

Table 1 shows the boundary conditions of the model, including for each vertical layer. I used a general head boundary for the inland-most boundary with a specified flux target based on the larger-scale model. This allowed me to use the general head boundaries conductance term as a calibration parameter. I used a fixed head for the coastward-most boundary based on the average head in monitoring wells corresponding to the appropriate model layer. All other boundaries such as the northeast and southwest flanks were set to no flow. I based the top of the model on a smoothed version of the 8 m DTM (LINZ, 2012).

Table 1 Model Boundary conditions

Boundary	Boundary type	Specified head (m msl)	Target flux from larger model (m^3/day)
Inland Layer 1	General head	300	10,762
Inland Layer 2	General head	300	10,701
Inland Layer 3	General head	300	10,817
Inland Layer 4	General head	300	11,136
Inland Layer 5	General head	270	33,200
Inland Layer 6	General head	250	33,118
Inland Layer 7	General head	240	33,176
Inland Layer 8	General head	210	11,455
Inland Layer 9	General head	210	11,629
Inland Layer 10	General head	210	11,629
Northern boundary Layer 1-10	No flow	N/A	N/A
Southern boundary Layer 1-10	No flow	N/A	N/A
Coastward boundary layer 1	Fixed Head	61-71	N/A
Coastward boundary layer 2	Fixed Head	65-69	N/A
Coastward boundary layer 3	Fixed Head	63-68	N/A
Coastward boundary layer 4	Fixed Head	61-67	N/A
Coastward boundary layer 5	Fixed Head	62-67	N/A
Coastward boundary layer 6	Fixed Head	61-67	N/A
Coastward boundary layer 7	Fixed Head	60-66	N/A
Coastward boundary layer 8	Fixed Head	59-65	N/A
Coastward boundary layer 9	Fixed Head	57-63	N/A
Coastward boundary layer 10	Fixed Head	57-64	N/A

Recharge

I used a recharge model developed for the Hinds chapter of the Land and Water Regional Plan (LWRP). To update the climate inputs I used the Ashburton Aero climate station, from NIWA's Cliflo website.

Calibration and aquifer parameters

To calibrate the model to groundwater heads I allowed Pilot Point PEST (Doherty, 2003) to find the optimised hydraulic conductivity field as limited by the parameters shown in Table 2. Figure 4 shows the adopted hydraulic conductivities.

Table 2 Parameter range

Layer	Hydraulic conductivity (K_h) (m/day)	Vertical anisotropy (ratio of horizontal - vertical Hydraulic Conductivity K_h/K_v)	Horizontal anisotropy (ratio of $K_{h\ y}/K_{h\ x}$)
1-10	1-500	1-1000	1-5

Model calibration targets

To calibrate the steady state model I used groundwater levels collected between 2012 and 1/6/2016. My calibration stream flows (for spring-fed streams) were targets of zero flow, representative of the study period. Table 3 gives the specific targets and model calibration matches of head at target wells

Table 3 Groundwater observation/calibration targets

Well no.	Observed head (m)	Target standard deviation (m) (set by modeller)	Computed head (m)	Difference between observation and measurement (m)
K37/0147	87.1	1.5	87.1	0.0
K37/0200	106.9	0.5	106.5	0.3
K37/0215	152.1	0.3	151.8	0.3
K37/0456	83.3	1.5	83.2	0.1
K37/0980	95.3	1.5	87.8	7.5
K37/1663	89.3	1.5	87.1	2.2
K37/1748	124.6	0.2	124.2	0.4
K37/1765	83.3	1.5	83.1	0.2
K37/1819	154.4	1.5	153.2	1.2
K37/1829	76.2	1.5	75.8	0.3
K37/2113	137.1	1.5	136.9	0.2
K37/2274	129.6	1.5	128.9	0.8
K37/2275	131.2	1.5	127.7	3.4
K37/2347	85.4	1.5	85.7	-0.3
K37/2810	88.5	1.5	86.8	1.6
K37/3004	126.8	1.5	129.1	-2.3
K37/0357	120.0	1.5	119.0	1.0
K37/0972	72.0	1.5	71.2	0.8
K37/0204	97.0	3.0	109.2	-12.2
BY20/0150	110.0	0.5	109.9	0.1
BY20/0153	82.0	1.5	88.0	-6.0
K37/0383	68.0	1.5	69.8	-1.8
K37/1540	93.0	1.5	91.4	1.6
BY20/0152	105.0	5.0	104.8	0.2
BY20/0183	61.0	10.0	123.3	-62.3
BY20/0149	114.0	1.0	112.6	1.4
BY20/0151	85.0	1.5	89.8	-4.8

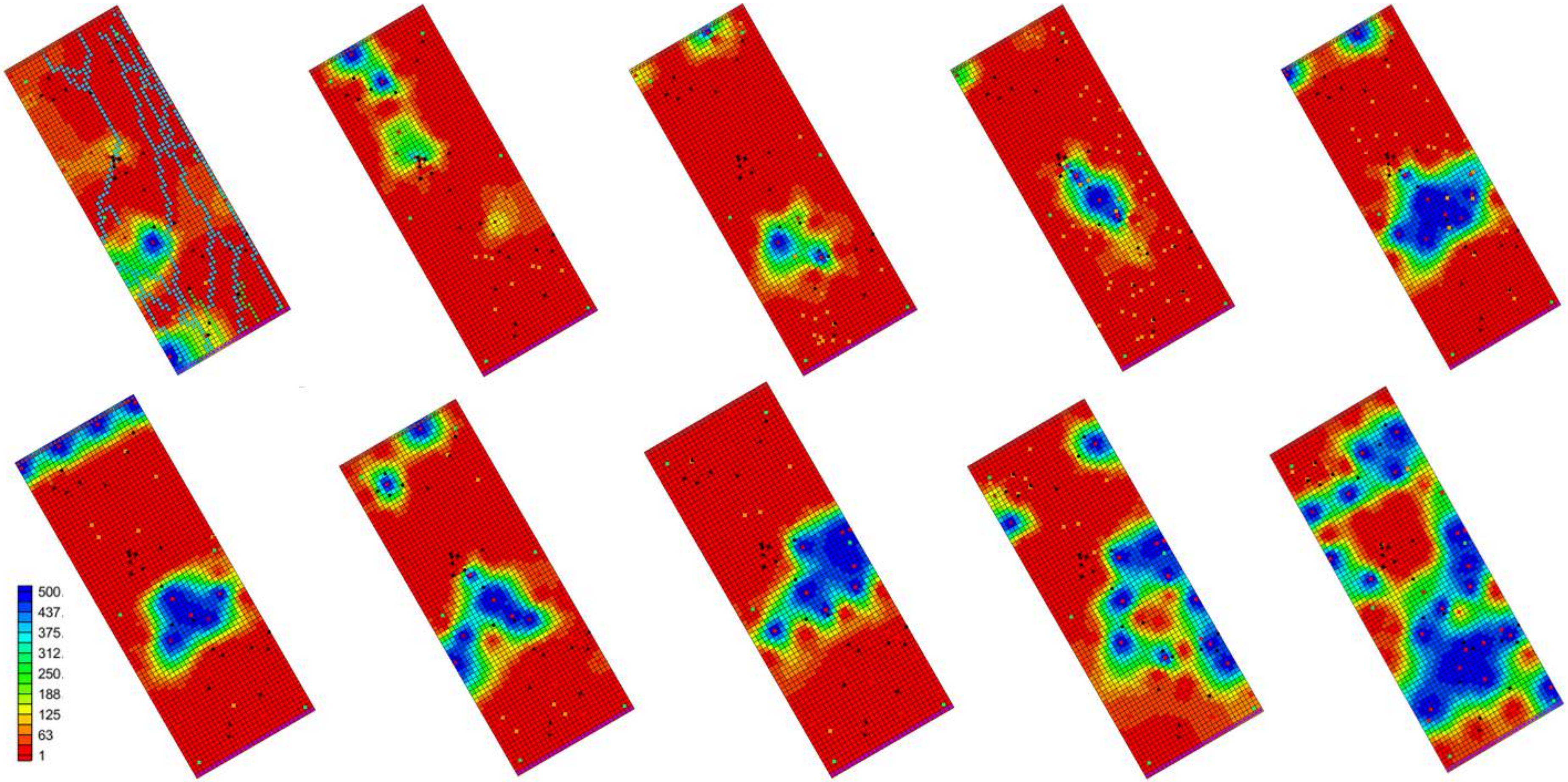

Figure 4 HK (m/d) layers 1 (top left) through 10 (bottom right)

Overall, the steady state calibration results were satisfactory for the purposes of the model, as demonstrated by the data presented in Figure 5 and Figure 6.

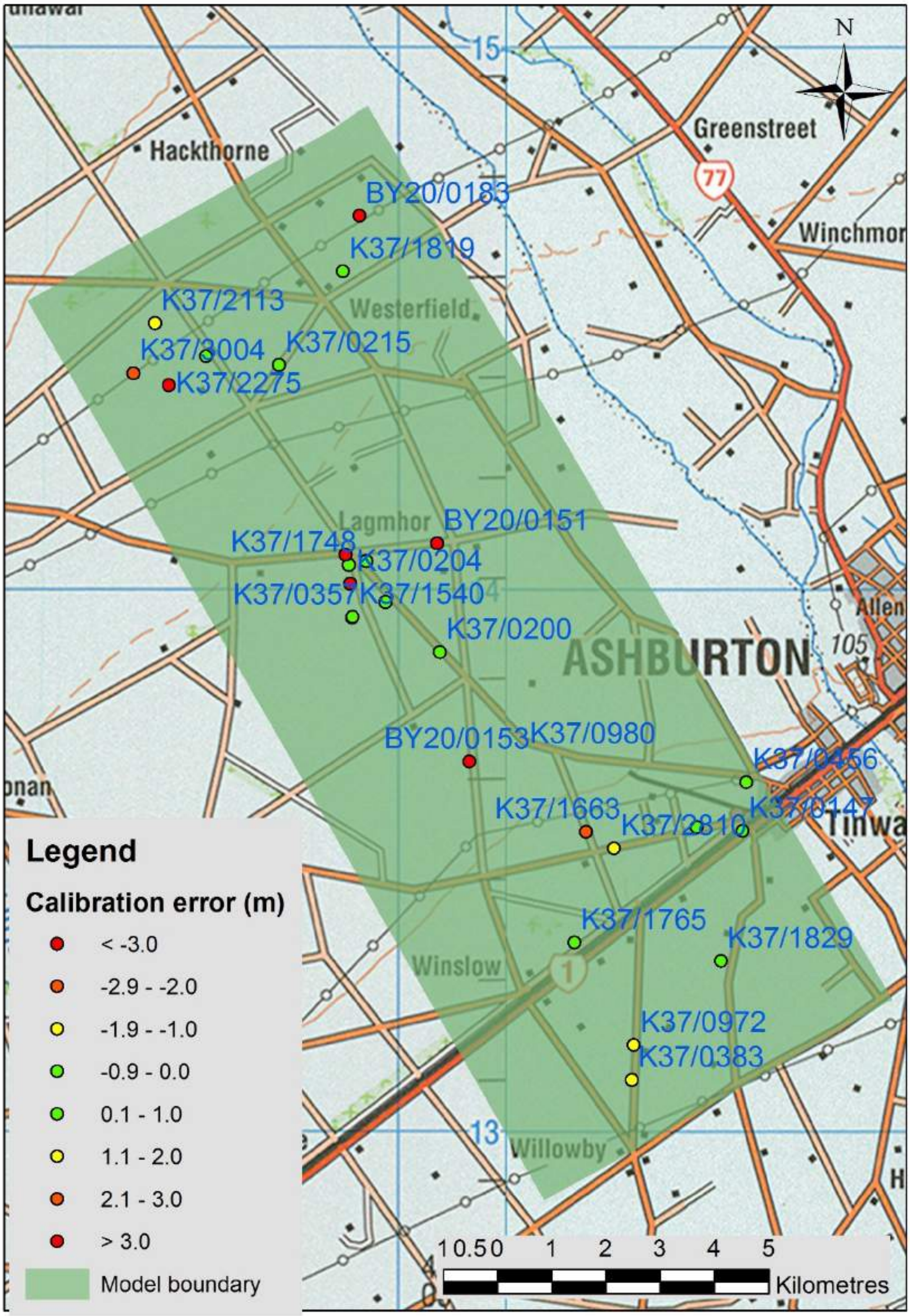

Figure 5 Spatial distribution of modelled head and observed head fit

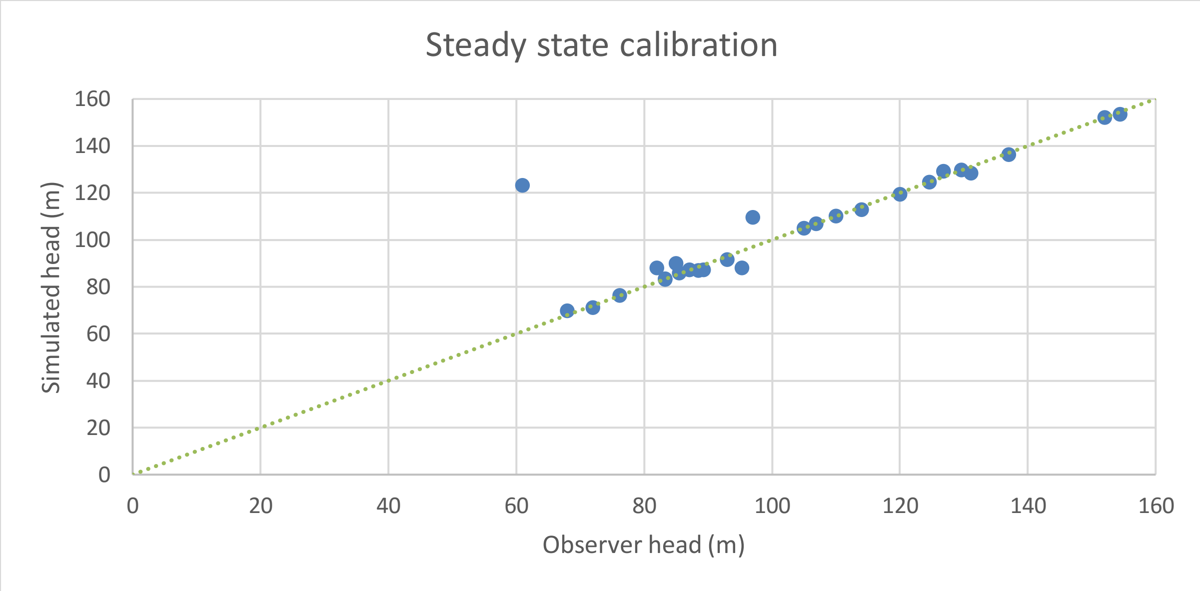

Figure 6 Modelled and observed head showing overall distribution of heads are reasonable

Transient Calibration

After I had completed my steady-state calibration, I transformed the model into a transient version. Due to model run times (approximately 30 minutes), I chose to do a combination of manual and automated Pilot Point PEST calibration of specific yield (S_y) and specific storage (S_s). I calibrated the transient model to the 2015-2017 period. Figure 7 through Figure 9 demonstrate the goodness of fit in a selection of wells. Table 4 gives the adopted S_y and S_s.

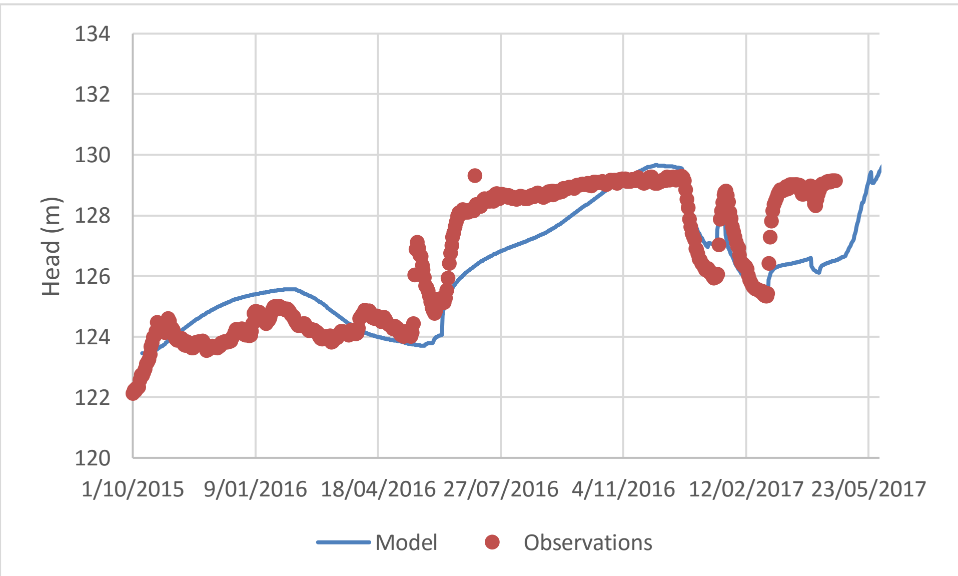

Figure 7 Goodness of fit between modelled and observed levels in well K37/1748

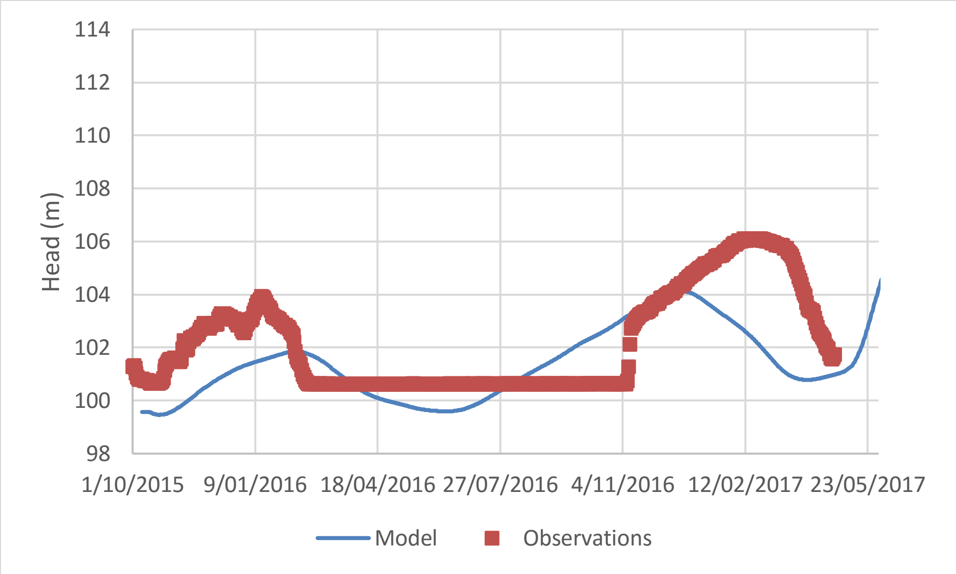

Figure 8 Goodness of fit well K37/0200 (actual well dry ~102m)

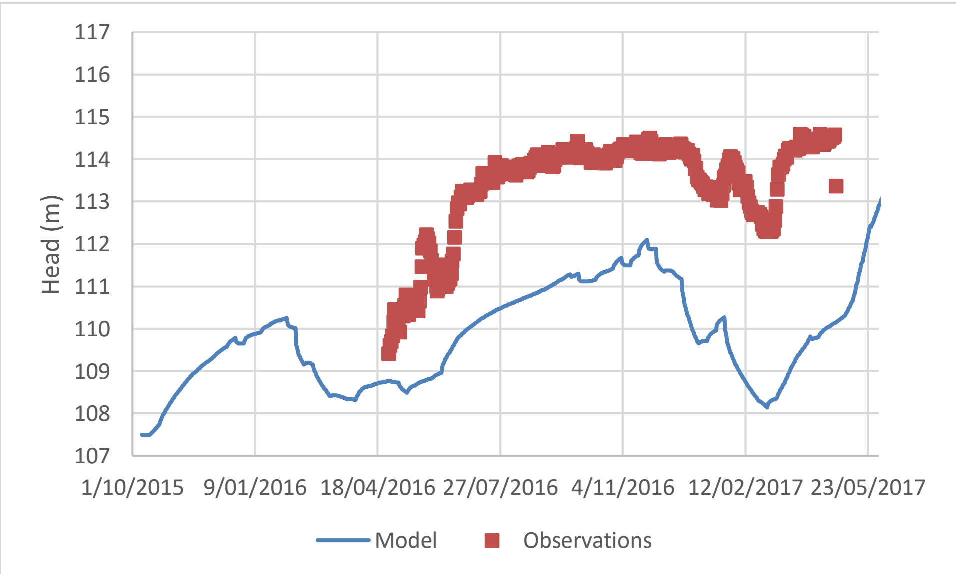

Figure 9 Goodness of fit well BY20/0150

Table 4 Adopted specific yields and storage

Adopted specific yield	Adopted specific storage
0.01-0.17	1e-7

Change in Water Quality

I have produced a transient solute transport model from the flow model documented above. I have applied default advection and dispersion parameters and adjusted porosity to fit breakthrough timing at observation sites. As the model uses a relatively coarse 250 m grid size, I determined that numerical dispersion would be the dominant cause and that only the use of a very small dispersion coefficient was justified. As mentioned the local geology behaves as a dual domain system as such, traditional porosity values of 0.2 to 0.3 are unable to plausibly replicate the observed results. GNS and Environment Canterbury groundwater modellers have been encountering similar problems with traditional porosity values in their Waimakariri model, pers comms. Zeb Etheridge 3/7/2017. I understand GNS used a dual porosity framework for their water quality modelling; I have also experimented with this but am currently using a single porosity value as detailed in Table 5 that shows adopted parameters. Such modelling is designed to represent the extent of the plume of the MAR water rather than a specific concentration justifying the above approach.

Table 5 Water quality settings

Porosity	Dispersion coefficient	Advection model	MAR recharge concentration
0.03	1e-4	Finite difference	1000

I ran the model for the same period as the transient MODFLOW model, to look at the results of the first year of the trial. Figure 10 and Figure 11 show the results of the first year of the MAR trial.

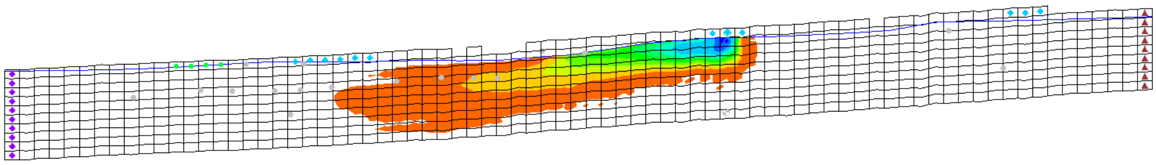

Figure 10 Cross-section of plume from MAR trial after one year of operation

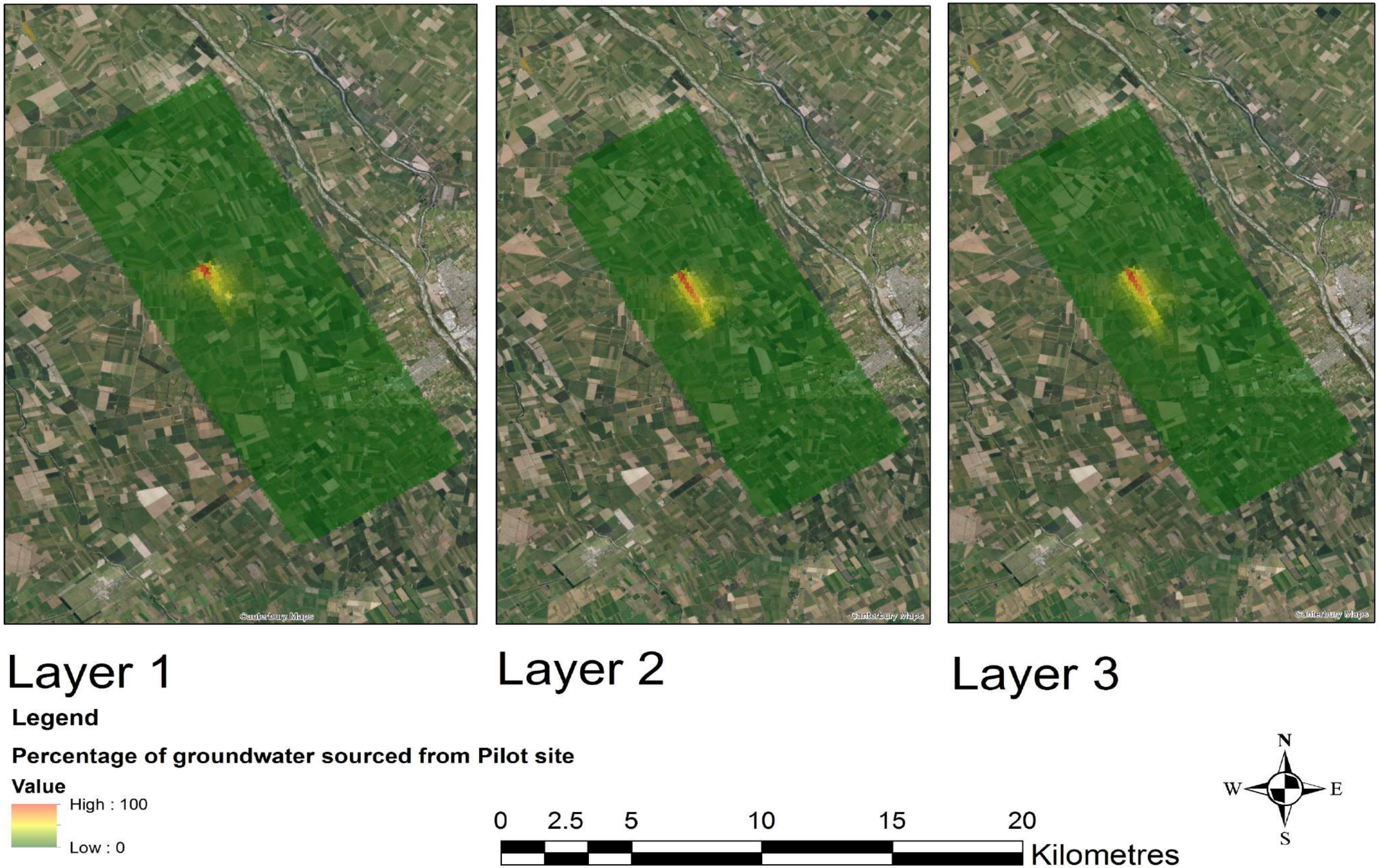

Figure 11 Fresh water plume from MAR pilot site after one year of operation

MAR Pilot: model scenarios

What I've done

To provide an estimate of the impact of the MAR pilot longer term (out to 2020) I have generated an average daily recharge data set based on NIWA's Virtual Climate Station network (VCS) for the period 1972-2016. I averaged values for precipitation and evapotranspiration (ET) at each VCS station for every calendar day. In my recharge model, I applied these precipitation and ET values and modelled average daily recharge. I amalgamated these daily values into 30 day model time-steps applying the results to each water year post June 2017 (including July-December of the 2019-20 water year) in the MODFLOW model. I have assumed the recorded groundwater pumping for the irrigation year 2014/2015 is average and have used this for the extended simulation period.

I have run two scenarios based on this extended recharge data set. Both run from 1/10/2012 to 31/12/2019. The first scenario looked at what might happen if the site continued to operate at the current recharge rate, the second at what the maximum potential rate of recharge might be and what would happen at that rate.

What I've found

Current (120 l/s) recharge out to 2012

I have looked at the head changes and extent of the clean water plume at the current recharge rate out to 2020. To do this I have assumed a continuous recharge at 10,000 m^3/day. This is unlikely due to lack of water availability during the irrigation season. Table 6 presents the estimated head change after one and a half years of operation at select sites, whilst Figure 12 shows the head changes expected across the model area.

Table 6 Head change 120 l/s

Site	Head change year 1	Head change year 3.5
GWD1	2.8	3.2
GWD2	2.8	2.9
GWD3	2.3	2.4
GWD4	3.5	2.7
GWE1	4.2	5.2
GWE2	2.1	3.7
GWE3	3.5	3.5
GWE4	1.1	1.15
GWE12	0.7	0.7

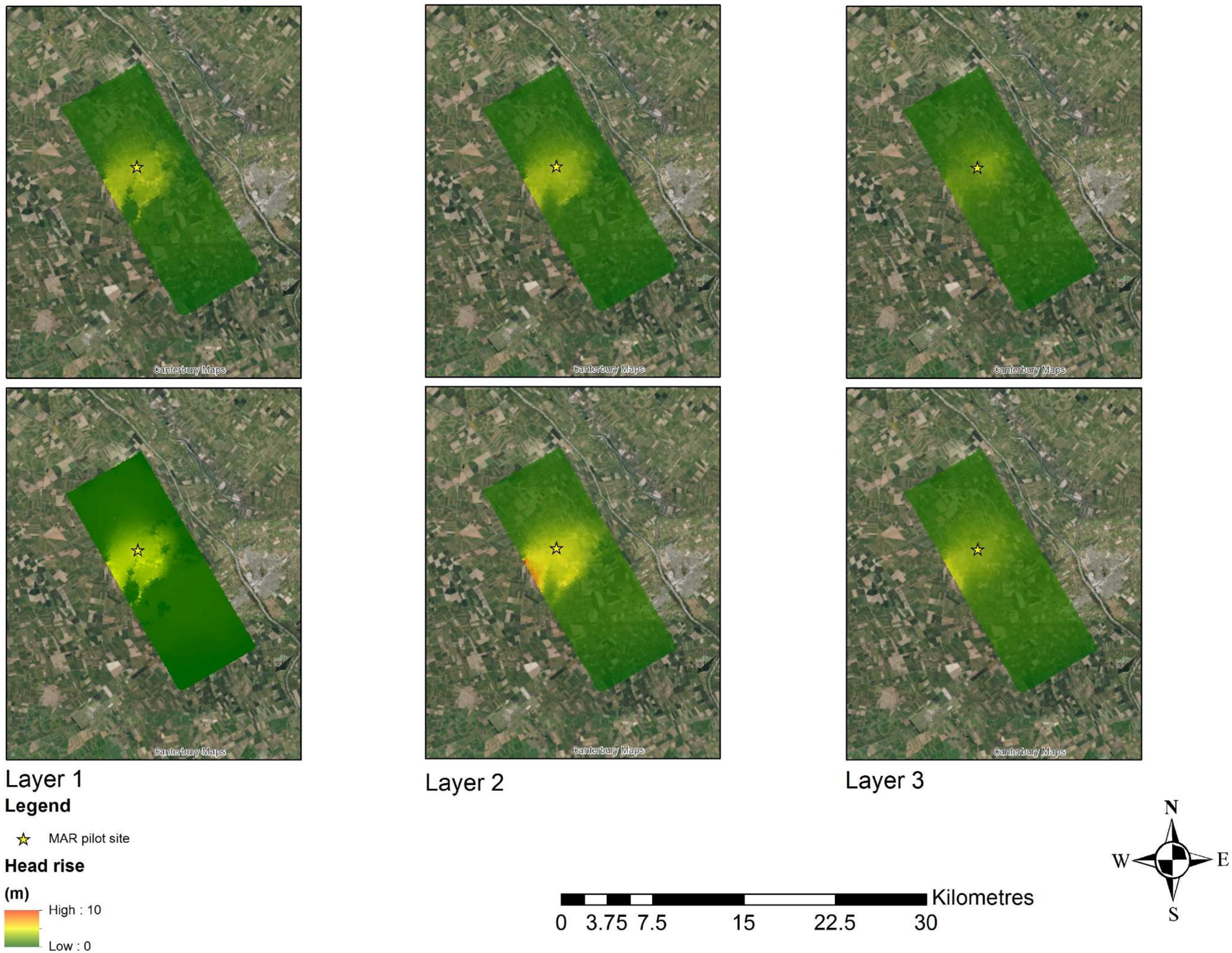

Figure 12 Head changes (m) in layers one to three with the top row showing predicted 2017 head change, and the bottom, 2020 based on a recharge rate of 120 L/s

Solute transport model results

Figure 13 provides an overview of what the clean water plume from the MAR site may look like over the period from 2017 to 2020. Readers will note slight differences in plume extents to the calibrated model detailed in the appendices, a modelling artefact from the assumption of continuous recharge at 10,000 m^3/day from 10/6/2016, rather than the variable rates modelled during calibration.

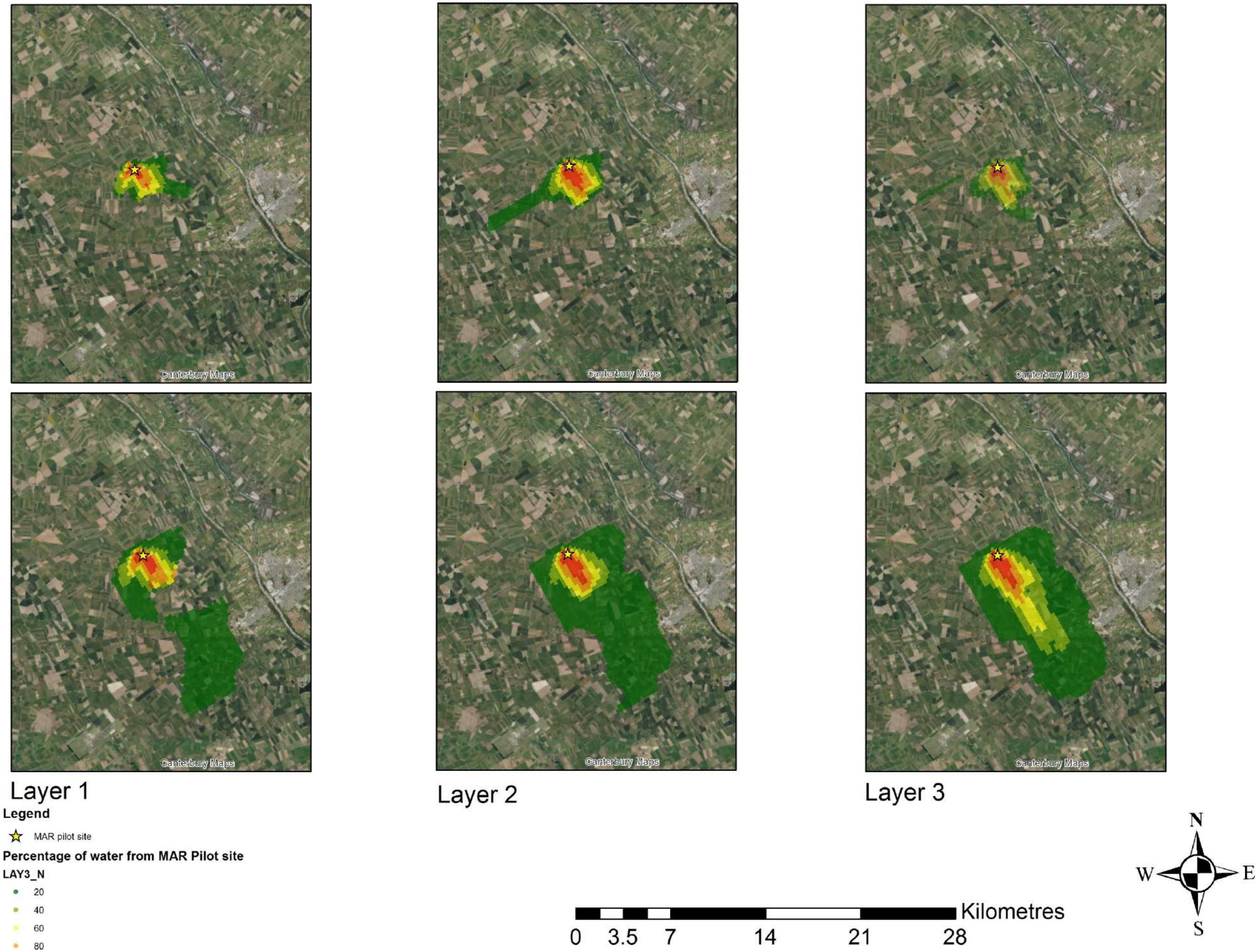

Figure 13 Freshwater plume in model layers 1 through 3 (2017 top and 2020 bottom)

Maximum MAR site recharge potential

I have looked at the maximum long-term (steady-state) rate of recharge that could be applied at the recharge site. To do this I applied a specified head boundary condition at the site of the MAR trial basin. A specified head boundary (changing head boundary type) is essentially an infinite source or sink of water, where water flows into or out of it at a rate required to maintain the specified head in the model. In the model I set a specified head at an elevation one meter below land surface at the MAR site (my attempt to replicate the elevation of water in the MAR Pilot pit). In the model because the surrounding model cells have a lower head than the specified head boundary water flows into the model. I then used the models flow budget tool to identify the volume of water the specified head boundary was supplying into the model to maintain the head.

I estimated the specified head boundary can contribute 320 l/s under average recharge conditions. I have interpreted the specified head recharge rate to be the effective long-term maximum sustainable rate at which water can infiltrate from the MAR Pilot site based on calibrated hydraulic conductivities and average climate and irrigation induced recharge.

I have further tested this estimated maximum sustainable recharge rate using the extended transient model, running 300 l/s (as I believe this number more accurately represents the precision of the model) in the transient model for a period of Jun 2016 to June 2020. The model indicates that the site could potentially sustain this without risk of downgradient flooding.

Figure 14 and Figure 15 show the predicted head rise under 300 l/s recharge, whilst Figure 16 shows the modelled freshwater plume.

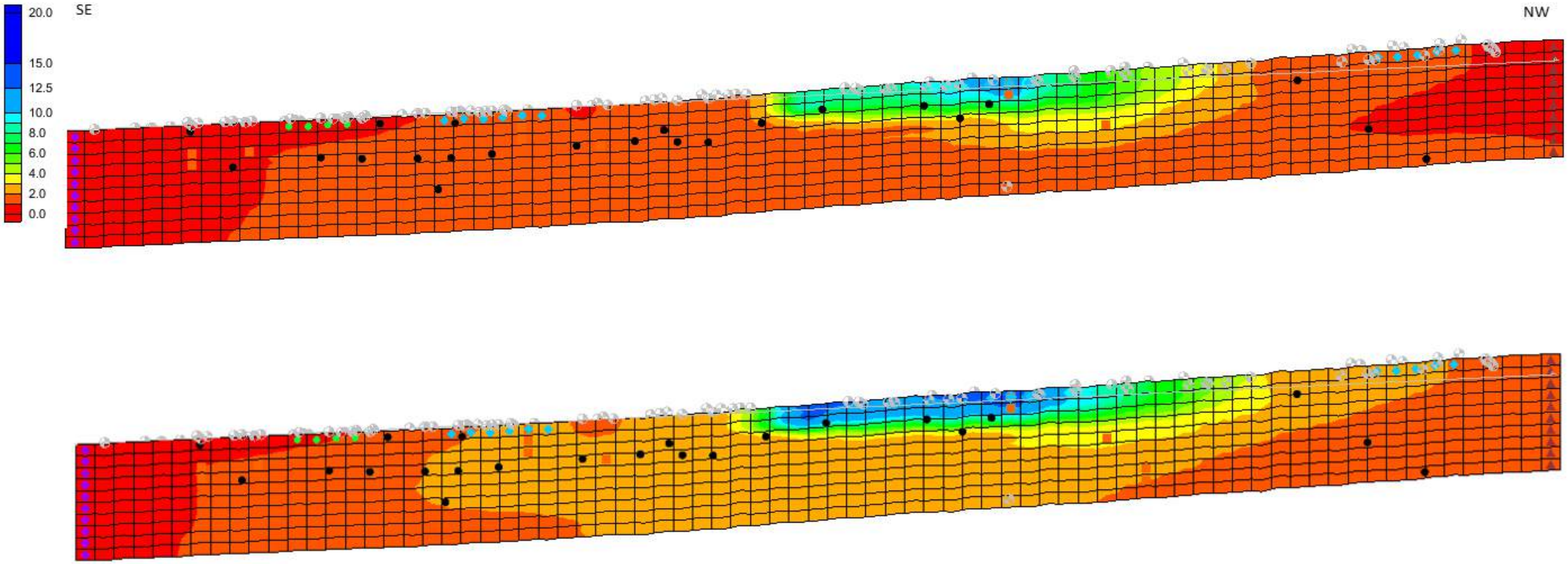

Figure 14 Transect of head change (m) under 300 l/s recharge through MAR site (2017 top, 2020 bottom)

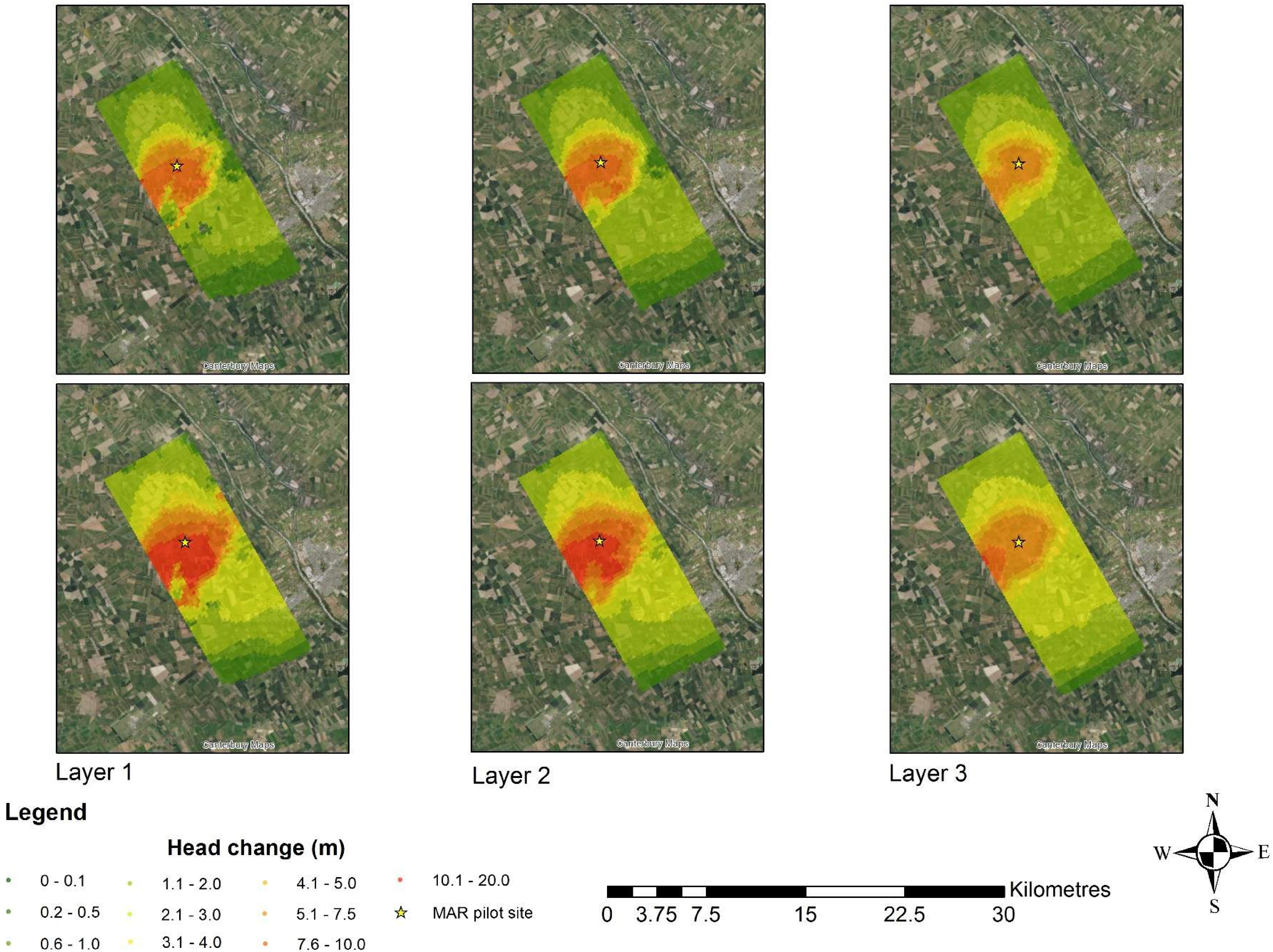

Figure 15 Head change (m) layers 1 to 3 (from left to right) induced by 300 l/s recharge 2017 (top), 2020 (bottom)

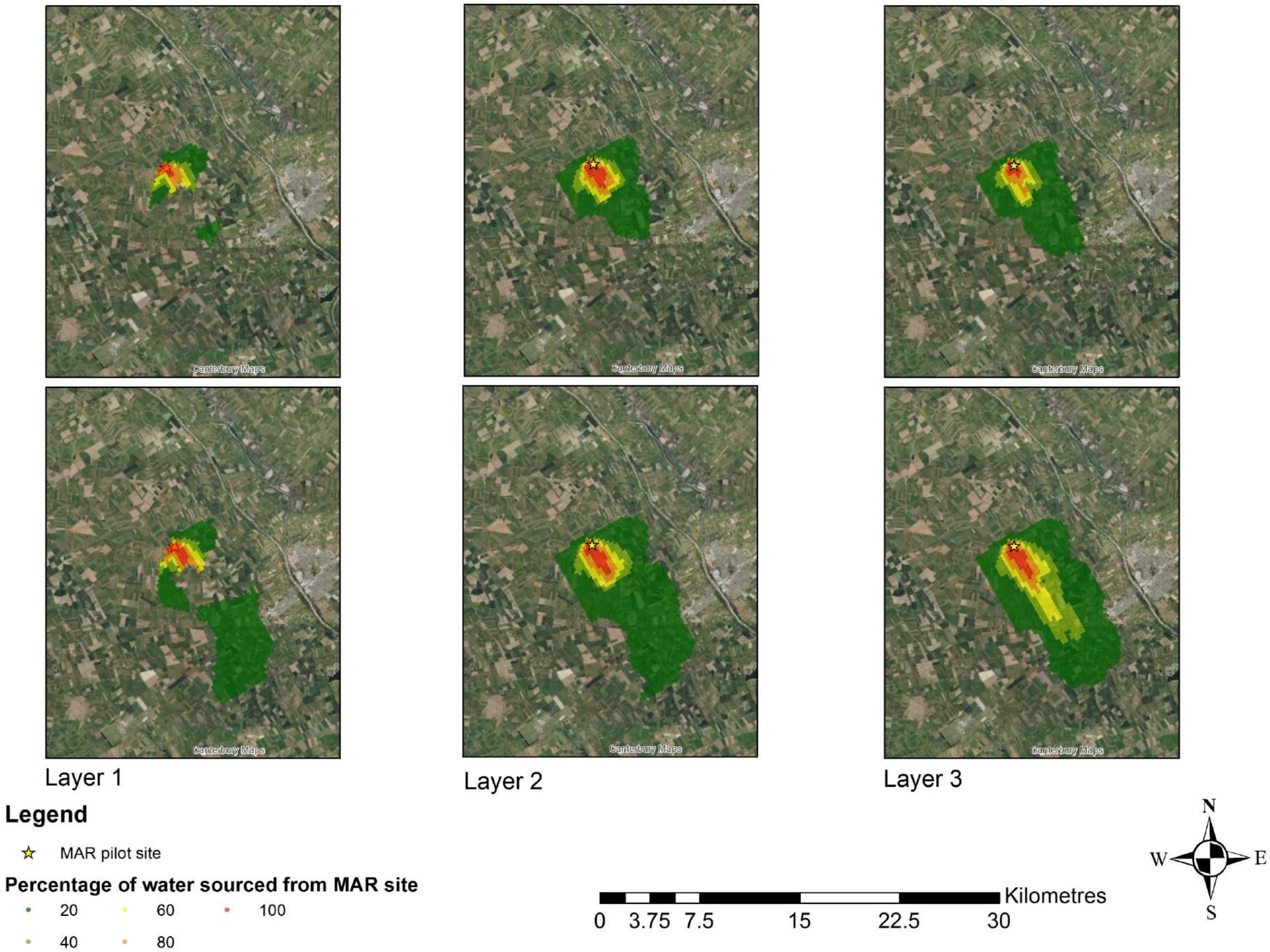

Figure 16 Layer 1 freshwater plume at 2017 top and 2020 bottom at 300 l/s

What this means

The model scenarios indicate two primary points. First, we have yet to see the full potential water quality outcomes of the current recharge rate, and secondly we can theoretically achieve higher recharge rates at the trial site. If we achieve higher recharge rates we can expect larger head changes and greater improvements in water quality.

Analysis of the current recharge rate suggests we have already achieved reasonably significant head gains as a result of less than 120 l/s recharge in the first year. Assuming the rest of the aquifer behaves in a similar manner this suggests that meeting the community's water quantity goals may be relatively easy to achieve. Unfortunately, because actual water particle flow is less dramatic than pressure responses in the aquifer, successfully meeting the catchment wide nitrate target of 6.9 mg/l will require more careful consideration when it comes to placement of recharge sites.

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APPENDIX P

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