

# WGA

WALLBRIDGE GILBERT  
AZTEC

Hinds/Hekeao MAR  
Governance Group

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

### **APPENDICES**

Job No. 171076 / Rev D  
30 August 2018

# WGA

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### Revision History

Rev	Date	Issue	Originator	Checker	Approver
A	16/07/2018	Tech Lead review	C Houlbrooke	B Sinclair / B Bower	B Bower
B	20/07/2018	MAR GG Chairman review	C Houlbrooke / B Sinclair	B Bower	B Bower
C	30/08/2018	Final Report	C Houlbrooke	B Bower	B Bower

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# APPENDIX A

## LAGMHOR TRIAL

### CONSENT

### COMPLIANCE

This appendix outlines compliance with the operational Resource Consents for the Lagmhor MAR site. The excavation consents (Consents LUC15/0110 - To excavate land and CRC162192 - To excavate land) were utilised in Year 1 during construction of the site. No Lagmhor MAR site construction works have been carried out in Year 2, the period between June 2017 and May 2018.

During the Year 2 period an application was made to Environment Canterbury to revise the consent conditions and supporting schedules for the Consent to Discharge Water into Land (CRC162191). On 18 May 2018, a new resource consent (Discharge Water into Land CRC184617) was granted for operations at the site. The changes to conditions included rainfall and drain flow trigger conditions for the ceasing of MAR water discharge. The new condition requires both rainfall (>30 mm/24 hours at Hinds Plains) and flow in Parakanoi Drain (>2,200 L/s as measured at Lower Beach Road) to be exceeded before the Lagmhor site is required to cease operations. Other small changes to the conditions included changes to the frequency of monitoring samples and real-time website access to the data. These changes are reflective of the 'as built' system and the practical operation of the site.

Given that the new Consent was granted in the final two weeks of Year 2 operations and became less restrictive (in terms of trigger conditions), the following review of conditions focuses on compliance under the former Consent (CRC162191).

## **CRC162191 - TO DISCHARGE WATER INTO LAND**

### **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 Section 3.2 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 Section 3.2 of main report.

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

**IN COMPLIANCE.** Calculated maximum weekly rate is 65,370 m<sup>3</sup> for any 7-day period during Year 2. See Section 3.2 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 eight trigger events where rainfall exceeded >30 mm/24 hours. Refer Section 3.2 of main report. Three events exceeded 2,200 L/s in Parakanoi Drain. The site was not operational during these times (**Table A1**).

- 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.

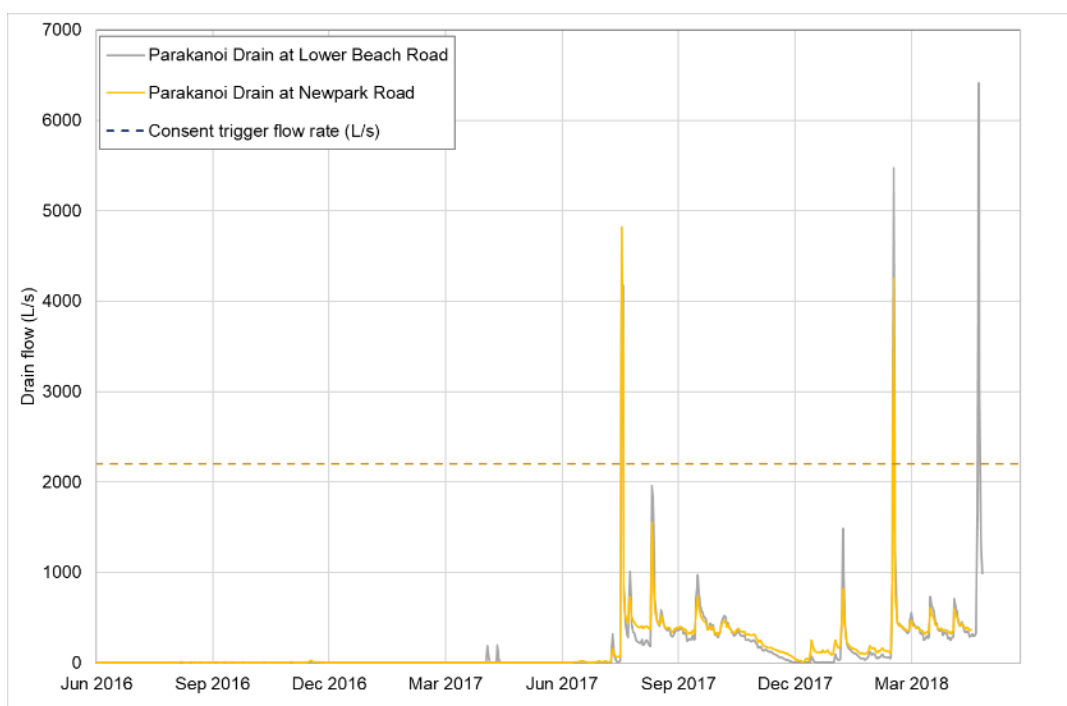
IN COMPLIANCE. As shown in Figure 9 in main report and Table A1.

**Table A1: Timing of large flow events in Parakanoi Drain.**

Flows in drains over 2,200 L/s	Parakanoi Drain at Lower Beach Road	Lagmhor Trial Flume 1 flow ceased until:	Time between trigger drain flow and site re-start
Date	Flow (L/s)	Day & time	Days
21/07/2017	4,214	25/07/2017 8:30	3
22/07/2017	4,164		
21/02/2018	5,474	23/02/2018 9:30	2
29/04/2018	6,411	2/05/2018 11:15	2
30/04/2018	3,011		

- 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) and the Environment Canterbury project website. User names and passwords for the operations data website have been provided to the Environment Canterbury compliance team.



**Figure A1. Parakanoi Drain flows and consent trigger level.**

- 7) The consent holder may amend Schedule One and/or Schedule Two at any time subject to the following:
- 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.** A new consent with conditions and schedules was granted in May 2018 (CRC162191).

- 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.** A list of monitoring wells and a summary of the monitoring programme are presented in Section 2 of the main report.

- 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.** A new consent with conditions and schedules was granted in May 2018 (CRC162191).

- 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.** A new consent with conditions and schedules was granted in May 2018 (CRC162191). The new date for submitting the review report is 31 August each year. This report provides the record of monitoring records for review by Canterbury Regional Council.

- 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.

## **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 Year 1 report.

**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 Lagmhor 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 Year 1 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. This condition was removed in the new consent (CRC162191) with direct access to real time data for the site given to Environment Canterbury compliance team.

**Step 3:**

Develop and implement preliminary numerical correlations between the following:

- d. 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.
- e. New shallow Parakanoi bore with existing CRC Bore (K37/1792). Determine relationship relative to the 1.7 metre 'trigger correlation', termed PARAKANOI GW – 1.
- f. 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 –Lagmhor Creek-Ashburton River recharge area.
- g. Document the correlation results for the CRC monitoring and compliance team and confirm final numbers going into operations of the MAR site.

IN COMPLIANCE. Year 1 Lagmhor report (Golder, 2107) found that at the reduced recharge rate (~100 L/s, originally modelled for 500 L/s) the MAR site does not cause a mounding effect on the shallow aquifer near the drains (K37/1792). Year 1 report found that the combined rainfall (30 mm/24 hour) and Parakanoi Drain flow was the most appropriate condition when exercised in tandem. Therefore, in the new consent, the condition was changed to continue with just rainfall and flow as a trigger.

**Step 4:**

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

- h. 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.

- i. 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.
- j. 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.
- k. 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.** The site was operated to these conditions throughout the Year 2 testing period, by the designated site operations manager (per comms Giles Pinfold).

**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 – Lagmhor 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 completed in Year 2 based on data from Year 1.

## 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.** The as-built designs for the site and actual field conditions did not warrant the automation of the gate as feasible. This condition is satisfied by MHV Water's existing automated water supply system which is operated via smart phones to control the flow from Valetta Pond #3 entering the MAR site.

## SCHEDULE THREE

### MAR Pilot Monitoring Programme

**IN COMPLIANCE.** Environment Canterbury science team revised the monitoring programme frequency and site locations for the Year 2 period. Frequency generally changed from monthly to quarterly sampling and closer monitoring well sites were reduced in favour of additional downgradient sites. Changes to this monitoring programme were revised in the new version of the consent, granted in May 2018.

#### 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 3.2 of main report.

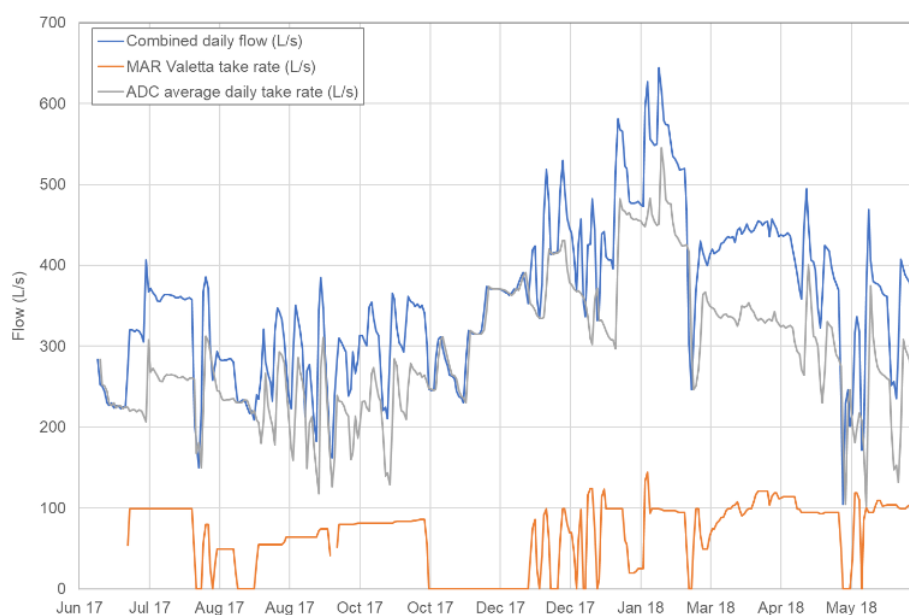
- b. taken from Valetta Irrigation Scheme Pipeline, between map references(s), NZ Topo50 BY20:8800-4048 and NZ Topo50 BY20:8908-4061, at a rate not exceeding 500 litres per second, with a volume not exceeding 15,780,000 cubic metres between 1 February and the following 31 January.

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

**IN COMPLIANCE.** Refer Section 3.2 of main report.

- 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 3.2 of main report.



**Figure A2. Ashburton District Council (ADC) average daily take combined with RDR MAR Valetta average daily take.**

- 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 3 of main report.](#)

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

[IN COMPLIANCE. Refer Section 3.2 of main report.](#)

- 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 Year 1 main report.](#)

- 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 Year 1 main report.](#)

- 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 Year 1 main report.](#)

- 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 Year 1 main report](#)

- 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. Data has not been requested.](#)

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

[IN COMPLIANCE. Refer Section 4.0 of Year 1 main report.](#)

- 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.](#)

- 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

## GROUNDWATER LEVEL CHARTS

## GROUNDWATER RESPONSES TO RAINFALL

### Seasonal Rainfall

During the 2014-2015 and 2015-2016 years (measured from June to the following May), prior to the start of the trial, rainfall in the catchment was substantially below average for this area of Canterbury (Table 7 of main report). Rainfall during Year 1 of the trial (2016-2017) was about average and Year 2 of the trial (2017-2018) was a very wet year. These differences in annual rainfall are reflected in the recorded groundwater levels in monitoring wells screened at the regional aquifer level (Figure C1):

1. Remaining at similar levels throughout Year 1.
2. Rising substantially from the start of Year 2 (July 2017) to the end of Year 2.

These differences primarily reflect the differences in seasonal rainfall patterns between an average rainfall year (Year 1) and a very wet year (Year 2), together with the relative length and intensity of the irrigation pumping seasons.

The regional groundwater levels measured in each of the five dedicated monitoring wells screened at the regional aquifer level (Figure B1) responded to rainfall on a seasonal or monthly basis:

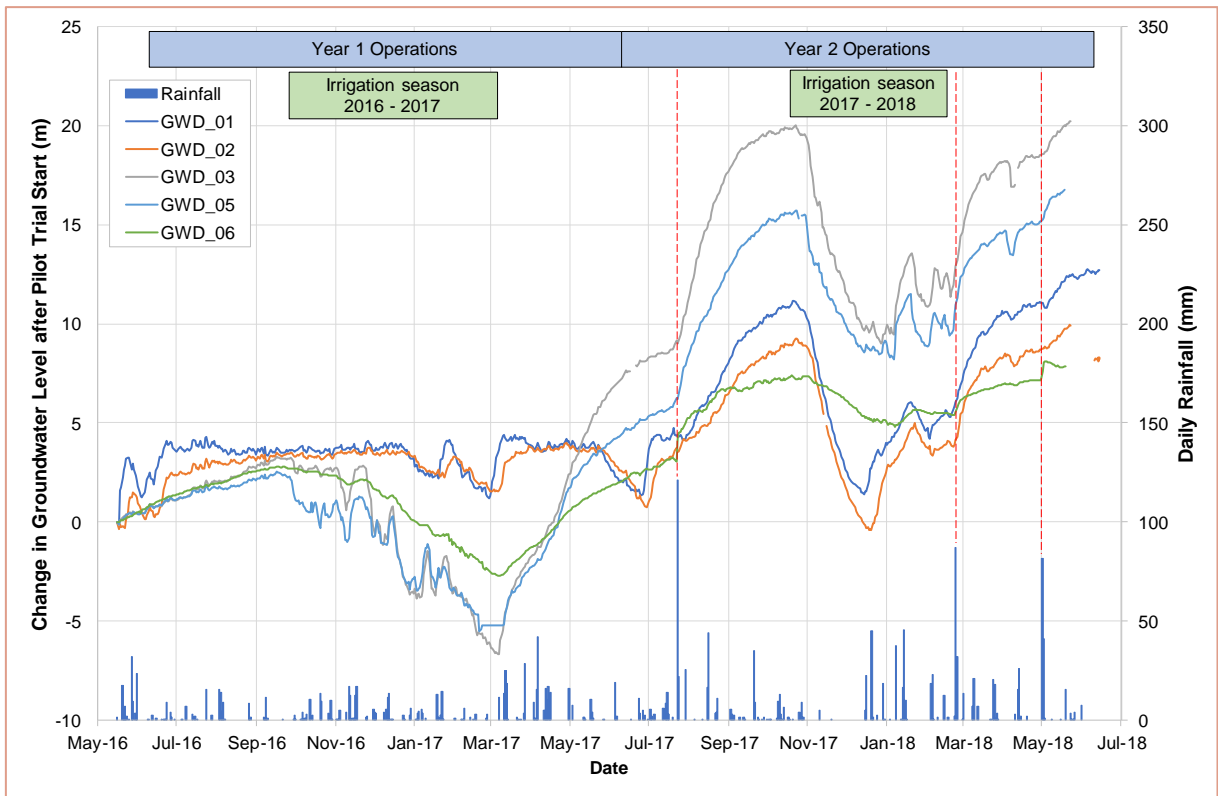
- July 2017 was a very wet month, with the rainfall recharge enhancing existing rising groundwater level trends, leading to groundwater level rises of up to 12 m.
- February and April 2018 were substantially wetter than average, including major rainfall events, and coincided with the close of the irrigation pumping period. This resulted in a rapid rise in groundwater levels from the end of February of between 4 m and 10 m.
- November 2017 was the driest month recorded during the two years of the Lagmhor Trial. This month coincided with the start of the 2017 irrigation pumping season, resulting in rapid drawdown of groundwater levels in the order of 9 m to 10 m.

Groundwater levels in monitoring wells GWD-01, GWD-02 and GWD-03 also responded to the Lagmhor Trial operations (refer Section 3.4.3 main report).

### Significant Rainfall Events

Three major rainfall events exceeding 80 mm within a 24-hour period were recorded during the first two years of the Lagmhor Trial. The groundwater level responses to these events in most of the monitoring wells screened at the regional aquifer level occurred over extended periods of time (Figure B1). In each case these events also occurred during periods at or following the close of an irrigation season. The groundwater levels were already rising due to the close of seasonal pumping and the responses from these rainfall events overprinted these existing trends. In summary, the rise in groundwater level produced by a combination of seasonal water level recovery following irrigation and the recharge from single events was:

- Between approximately 4 m and 10 m following the 121 mm rainfall event of 22 July 2017.
- Between approximately 4.5 m and 6.5 m following the 87 mm rainfall event of 21 February 2018.
- Exceeded one metre following the 81.5 mm rainfall event of 29 April 2018, with the response to this event still underway at the end of the Year 2 monitoring period.



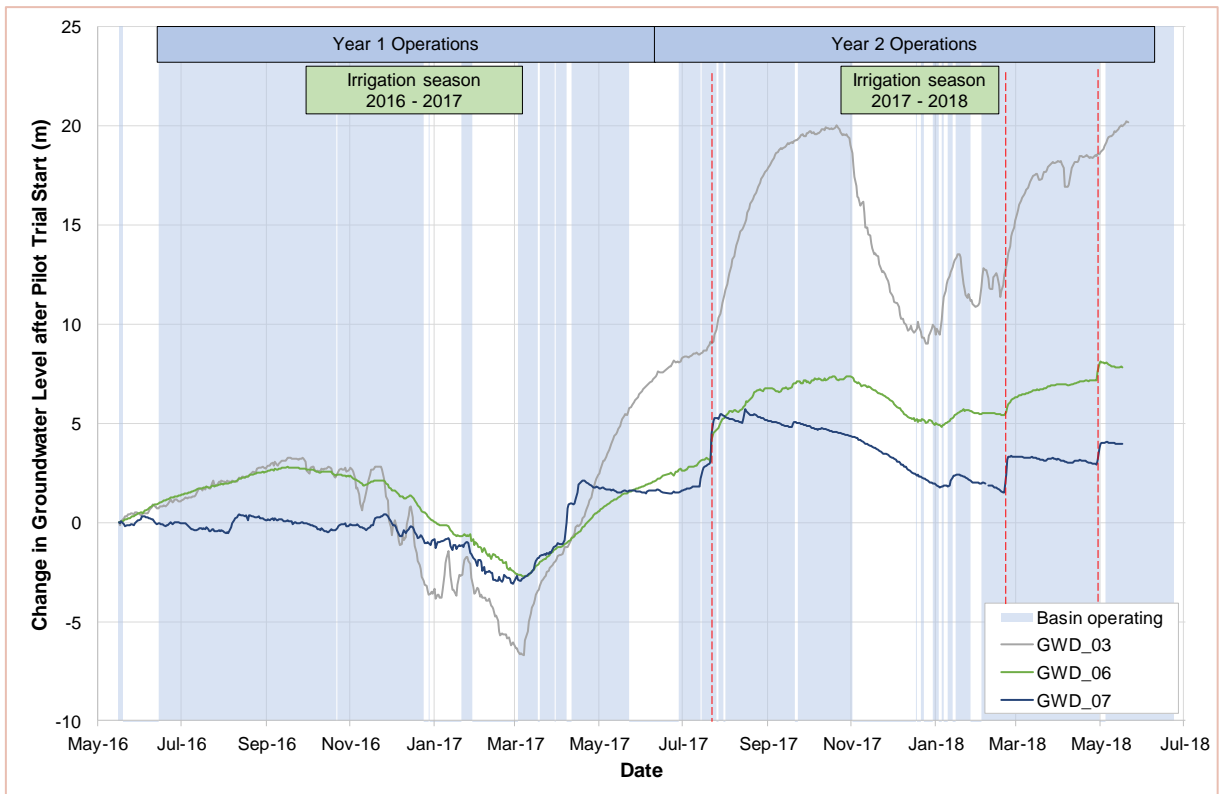
**Figure B1. Groundwater level responses at regional aquifer level (AQ3) to rainfall events.**

In contrast, two of the Lagmhor Trial monitoring wells screened at the regional groundwater level, GWD-06 and GWD-07, record immediate and clear responses to major rainfall events (Figure B2Figure). Both monitoring wells are in areas where the relatively shallow regional groundwater table discharges directly into surface springs or drains. The largest immediate response to a specific rainfall event recorded during the Lagmhor Trial to date was an increase in groundwater level of 2.2 m in GWD-07 following the 121 mm rainfall of 22 July 2017 (Table C1). Water levels in monitoring well GWD-07 may however be influenced by recharge from Lagmhor Creek (Golder 2017).

**Table B1: Groundwater level responses to major rainfall events – GWD-05 and GWD-07.**

Rainfall event	Rainfall magnitude (mm)	Change in groundwater level (m)	
		GWD-05	GWD-07
<b>22 July 2017</b>	121	1.5	2.2
<b>21 February 2018</b>	87	0.74	1.7
<b>29 April 2018</b>	82	1.0	1.1

Interpretation of the hydraulic behaviour of the shallow groundwater system close to these coastal monitoring wells means it is unlikely that there were significant perched aquifers and underlying unsaturated layers in these areas during the trial period. The unconfined shallow groundwater table in these areas appears to be hydraulically connected to the up-gradient regional groundwater system and water levels in the monitoring wells respond to major rainfall events accordingly.



**Figure B2. Groundwater level responses to rainfall events in wells influenced by surface water bodies.**

Two of the Lagmhor Trial monitoring wells, GWE-01 and GWD-04, measure the hydraulic behaviour of the perched aquifer (AQ2) beneath and to the south of the trial site (Golder 2017). In GWE-01, located approximately 45 m from the site, groundwater levels rose less than one metre in response to the major rainfall events (Figure B3). Following the third of these rainfall events (29/4/2018) the groundwater level at GWE-01 decreased rather than increased. In comparison, groundwater levels at GWD-04, located approximately 938 m from the basin, rose by up to two metres in response to the major rainfall events.

The difference in responses between the two perched aquifer monitoring sites is interpreted to be due to:

1. The shut-down of MAR operations in response to substantial rainfall events has a more immediate effect on groundwater levels at GWE-01 than at GWD-04.
2. The decrease in groundwater level at GWE-01 following the May 2018 event (Figure B3) probably reflects the site shut-down at that time.
3. The relative influence of water from the MAR infiltration basin compared to rainfall recharge at the two sites.
4. The groundwater in the perched aquifer at GWE-01 is predominantly sourced from the infiltration basin.
5. The perched aquifer at GWD-04 is likely to contain a larger component of water derived from natural rainfall recharge.



**Figure B3: Groundwater level responses in perched aquifer (AQ2) to rainfall.**

## GROUNDWATER LEVEL GRAPHS

Automated groundwater level and groundwater temperature monitoring results are shown in Figures B4 to B13. Groundwater level responses have been reviewed in Section 3.4 of the main report and above. The graphs in this appendix show groundwater levels relative to ground level. Groundwater temperature records are shown on the plots and responses are highly variable between monitoring wells. The groundwater temperature responses were assessed in the Year 1 report (Golder, 2017).

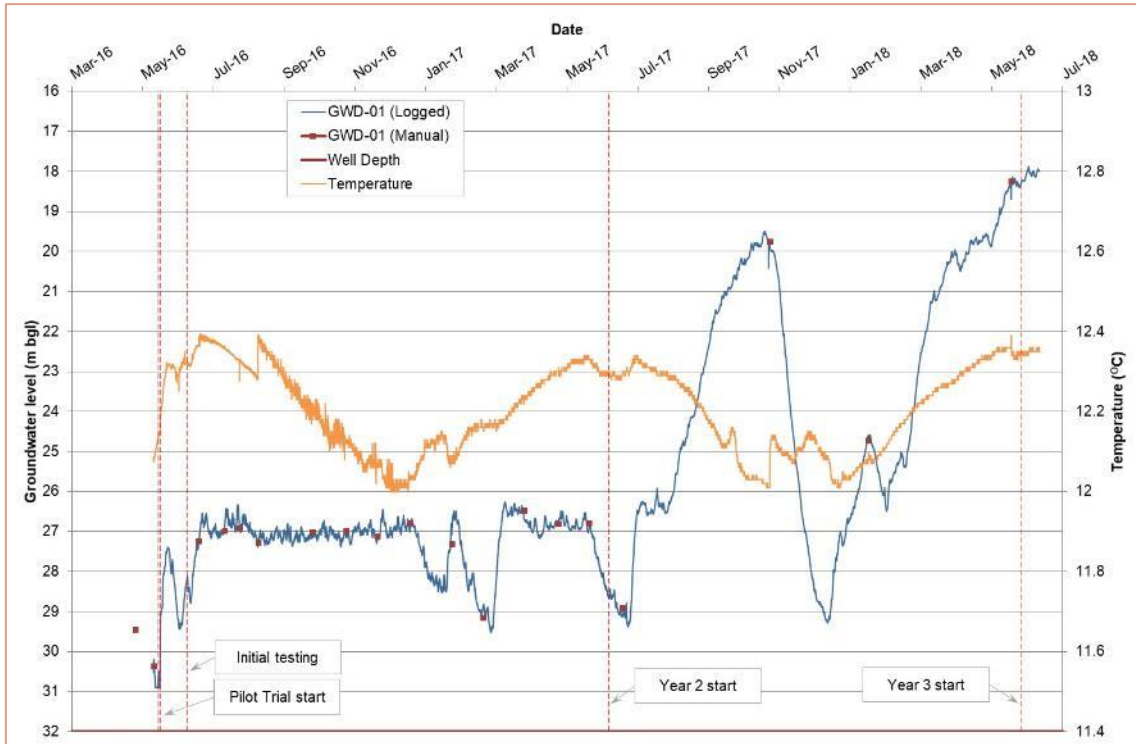


Figure B4. Groundwater level and temperature record for Monitoring Well GWD-01.

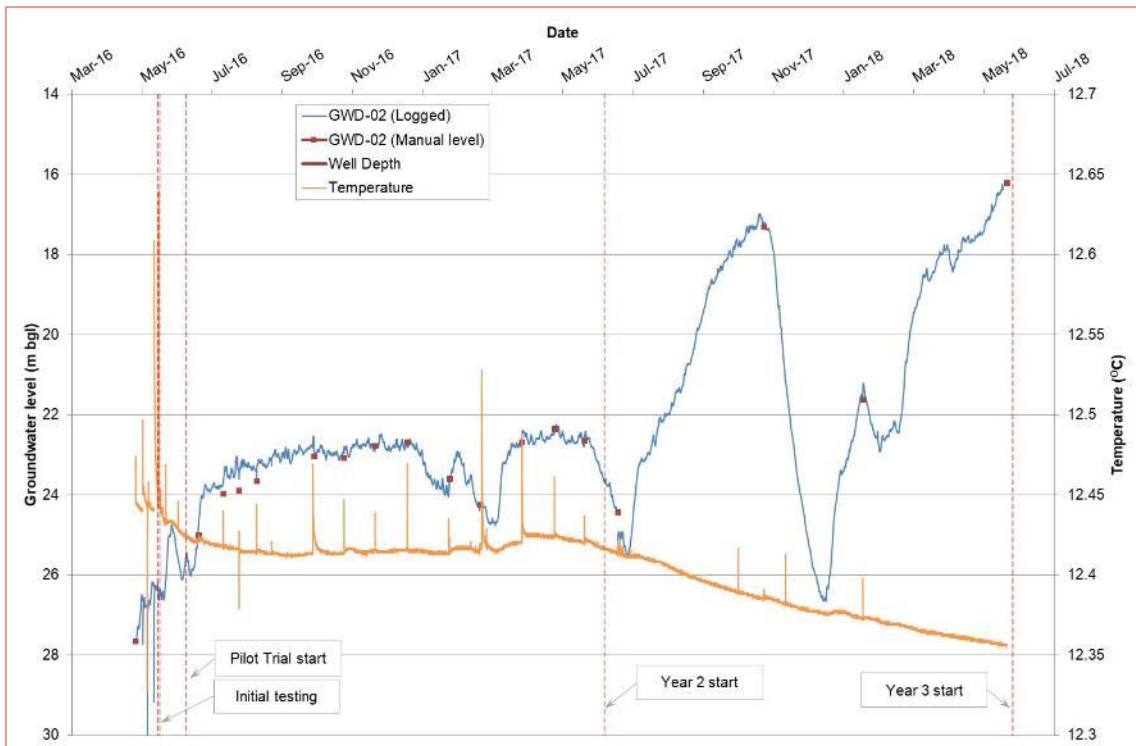


Figure B5. Groundwater level and temperature record for Monitoring Well GWD-02.

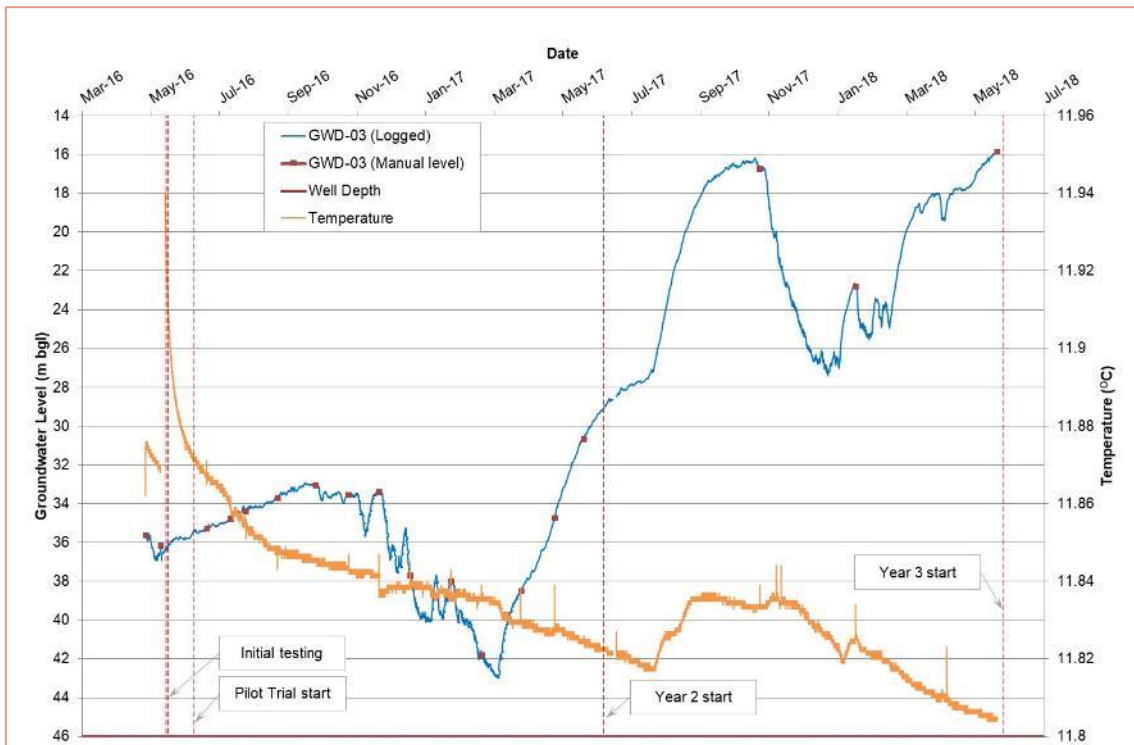


Figure B6. Groundwater level and temperature record for Monitoring Well GWD-03.

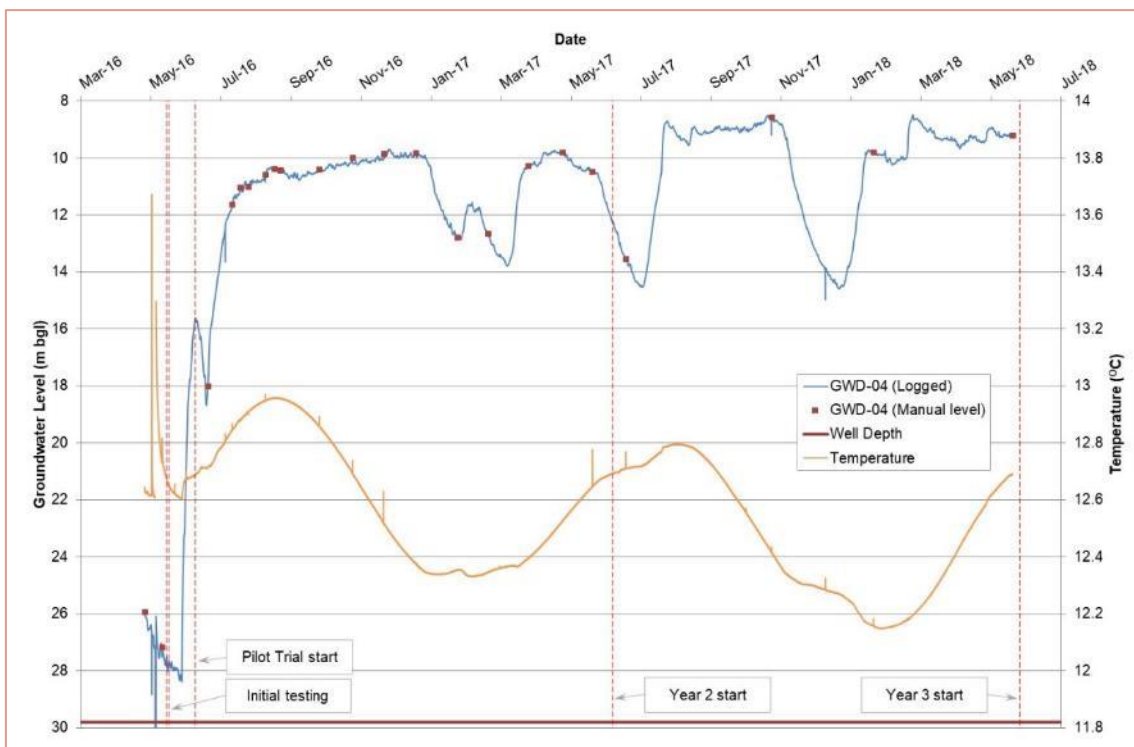


Figure B7. Groundwater level and temperature record for Monitoring Well GWD-04.

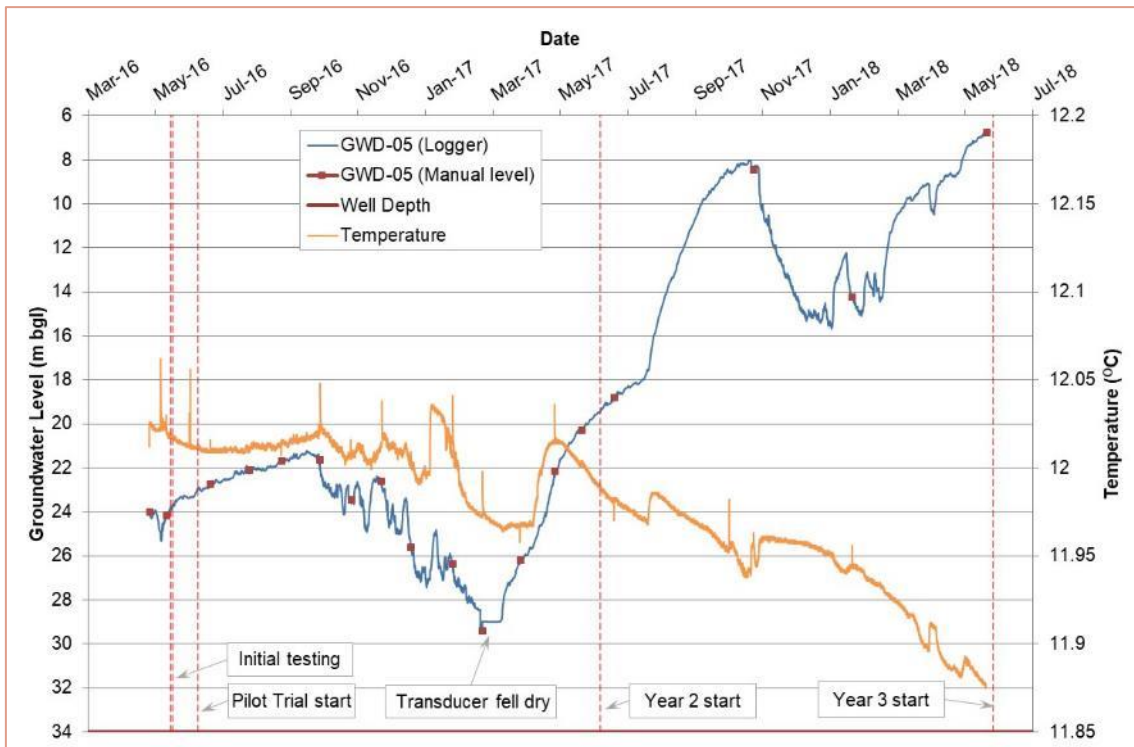


Figure B8. Groundwater level and temperature record for Monitoring Well GWD-05.

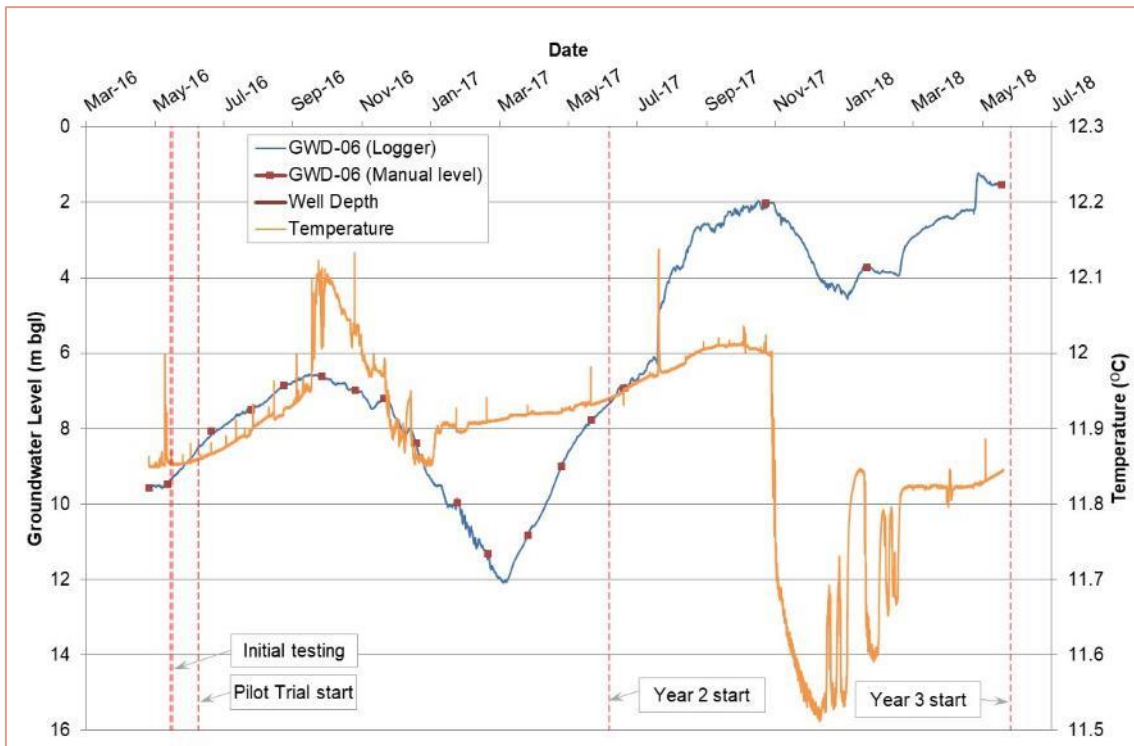


Figure B9. Groundwater level and temperature record for Monitoring Well GWD-06.

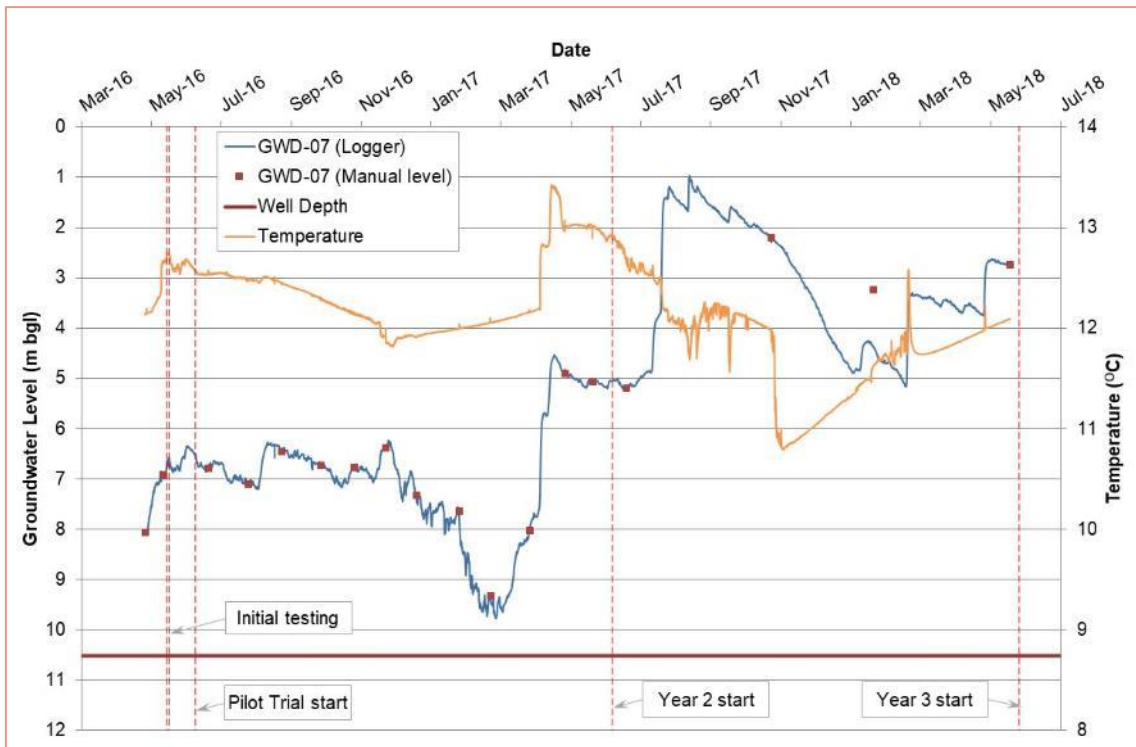


Figure B10. Groundwater level and temperature record for Monitoring Well GWD-07.

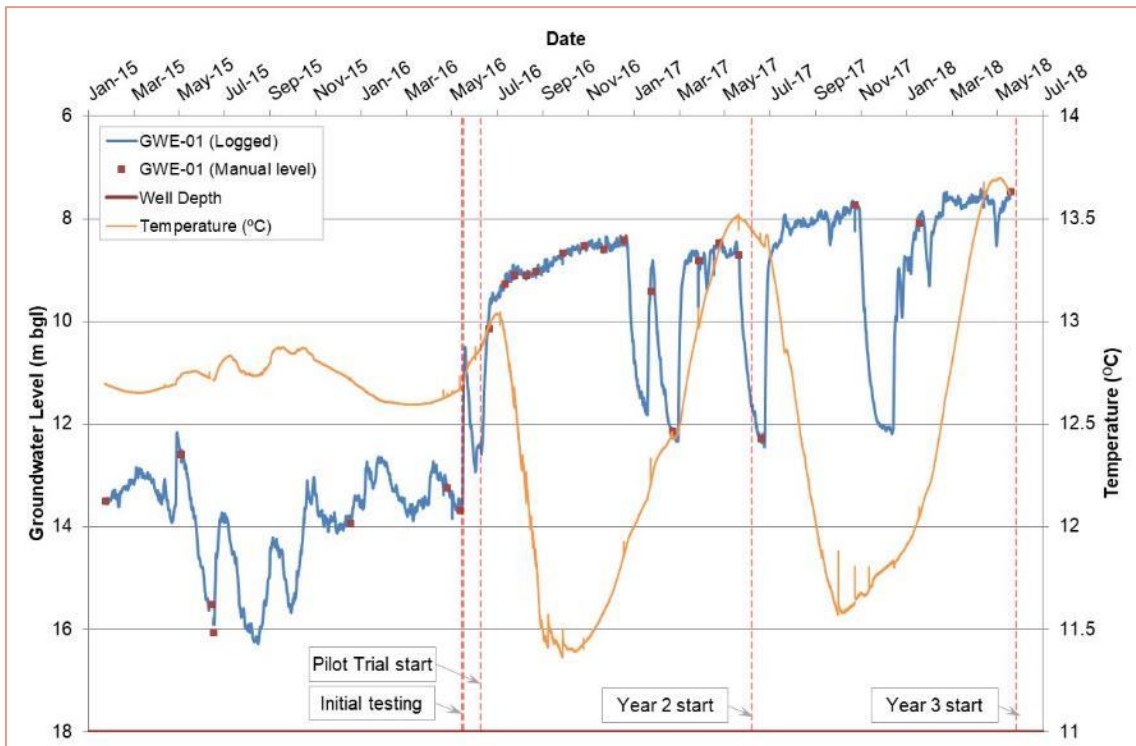


Figure B11. Groundwater level and temperature record for Monitoring Well GWE-01.

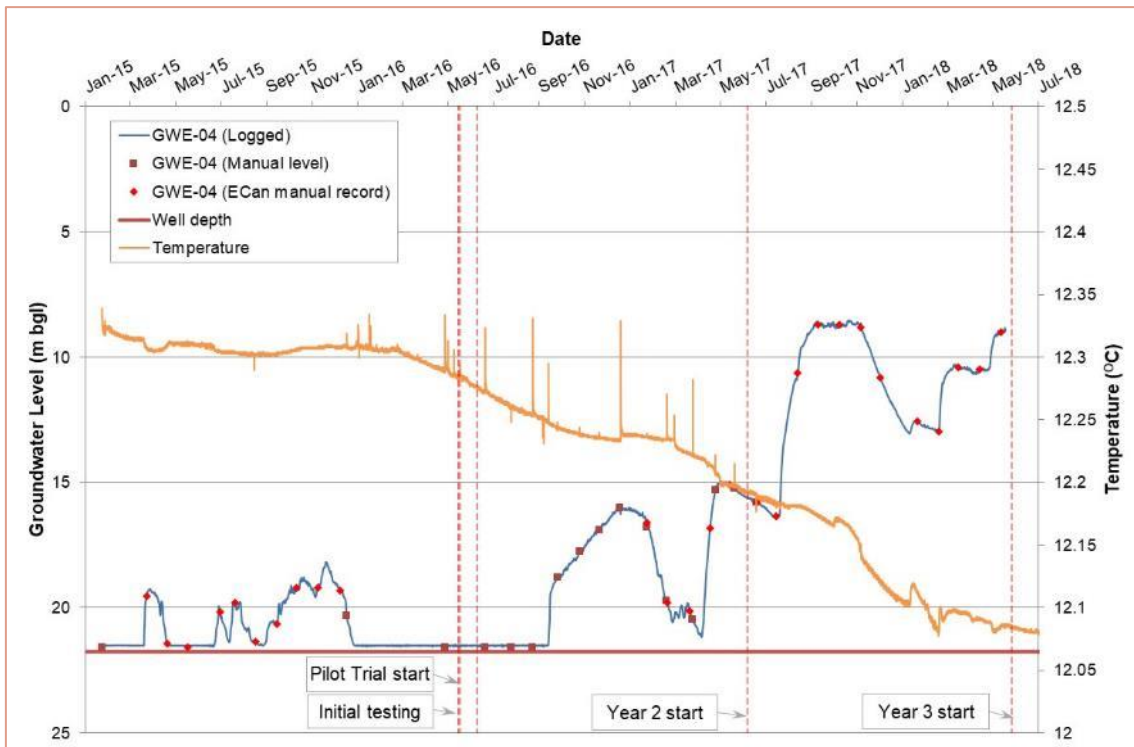


Figure B12. Groundwater level and temperature record for Monitoring Well GWE-04.

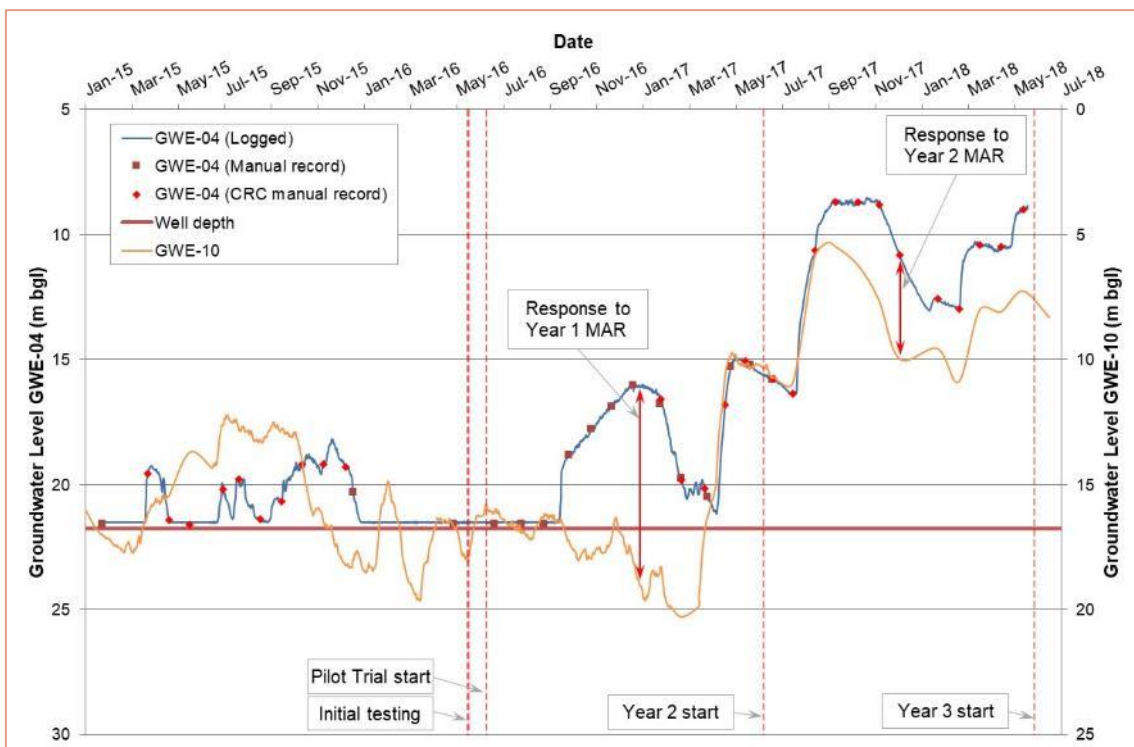


Figure B13. Groundwater level record for Monitoring Well GWE-04 compared to trends in GWE-10.

## LONG-TERM GROUNDWATER LEVEL MONITORING

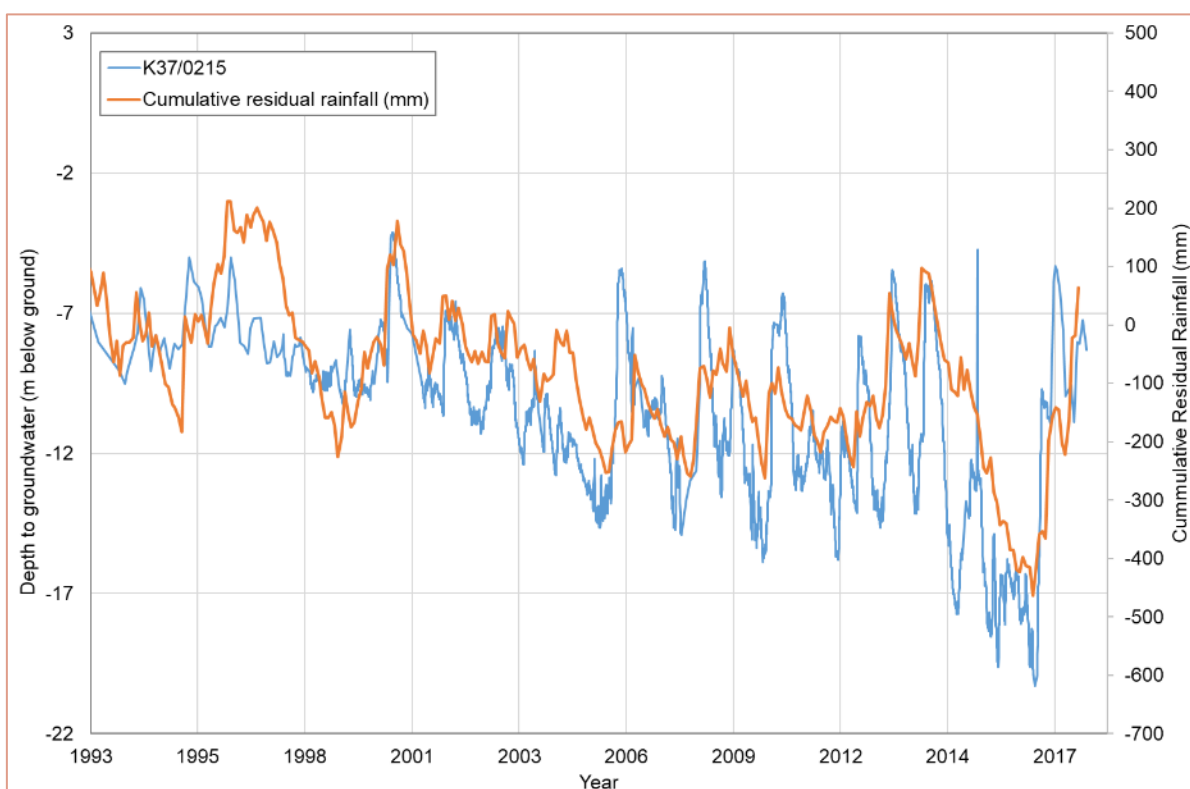
Long-term monitoring sites managed by Environment Canterbury in proximity to the Lagmhor Trial site have been considered during analysis of the groundwater level responses to the trial. Many of the sites have manual water level readings recorded, which give some indication as to the long-term trends in groundwater level. These records are not necessarily detailed enough for separation of any MAR related groundwater level responses from the background trends. Comparison of the record from an up-gradient monitoring well (K37/0215 or GWE-10) to cumulative residual rainfall was used as a visual assessment on the dominance of land surface recharge (Ferdowsian et al. 2001). The bore shows additional pumping effects and strong groundwater level rises in August/September 2006, 2008, 2010 and 2012, which could be related to surface water recharge (Figure B14). However, the groundwater level record from K37/0215 appears to be dominated by rainfall recharge. This record was therefore used as a baseline to compare against long-term water level responses in monitoring wells closer to the Lagmhor Trial site.

Compared to the baseline monitoring well (K37/0215 or GWE-10), records from the other long-term monitoring wells in the area show:

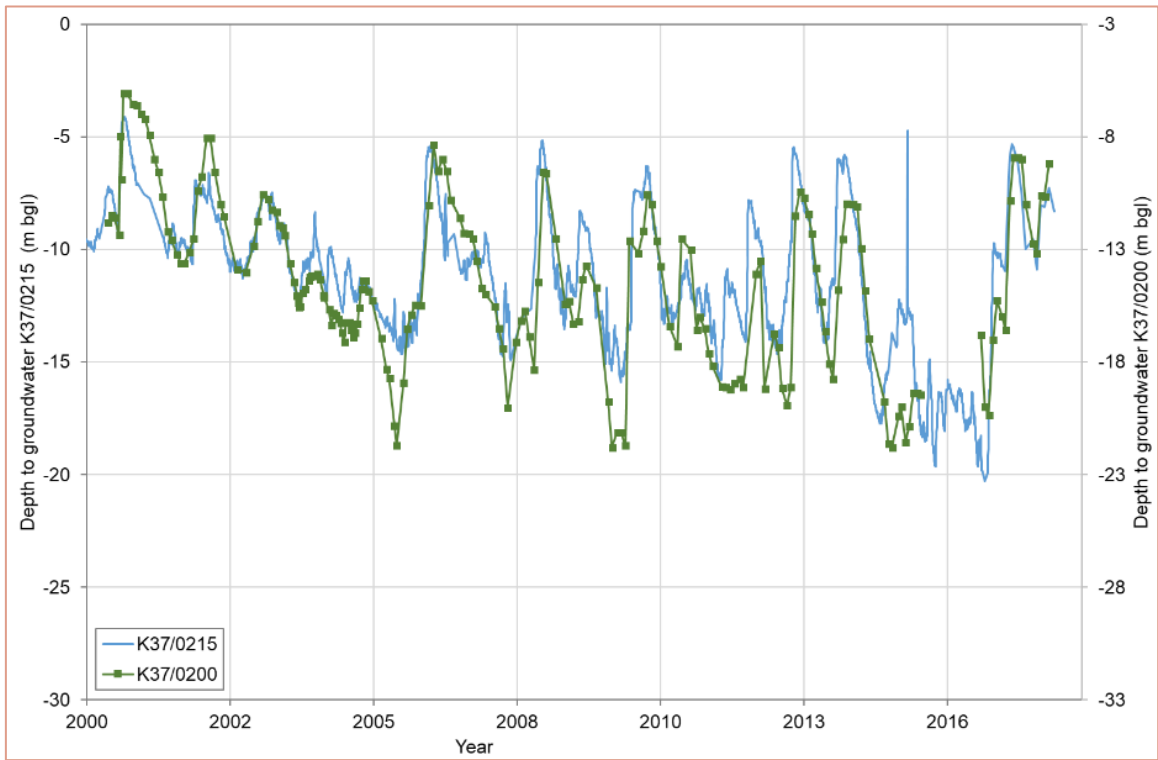
- Similar declines in groundwater levels in response to the very dry years 2014 and 2015.
- Similar responses to the recent high rainfall period in Year 2 of the trial (2017-2018).

Significant and obvious deviations from the baseline were not observed in the long-term records from the regional aquifer monitoring wells.

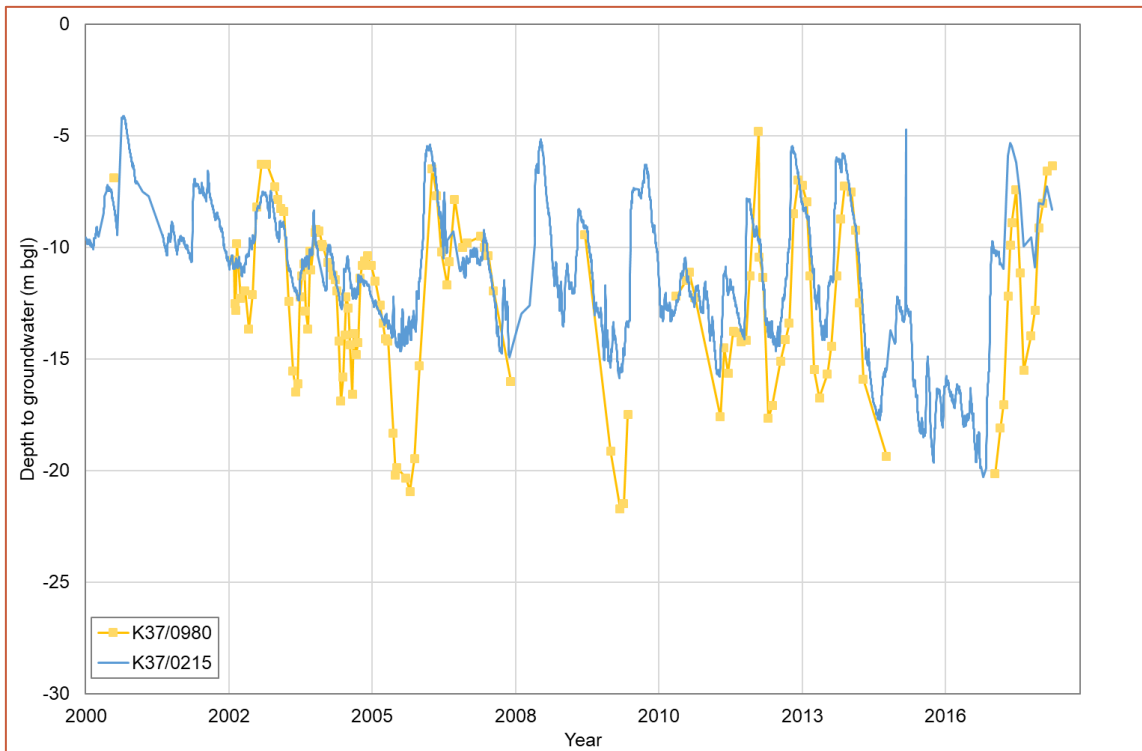
Monitoring Well K37/1748 (GWE-01) is screened in the perched aquifer and shows a different water level response to rainfall and MAR recharge compared to the long-term record from K37/0215 (Figure B19) and other long-term monitoring wells. Monitoring well K37/1792 (GWE-10) shows a subdued response compared to K37/0215 due to its position close to groundwater discharge in the drainage network.



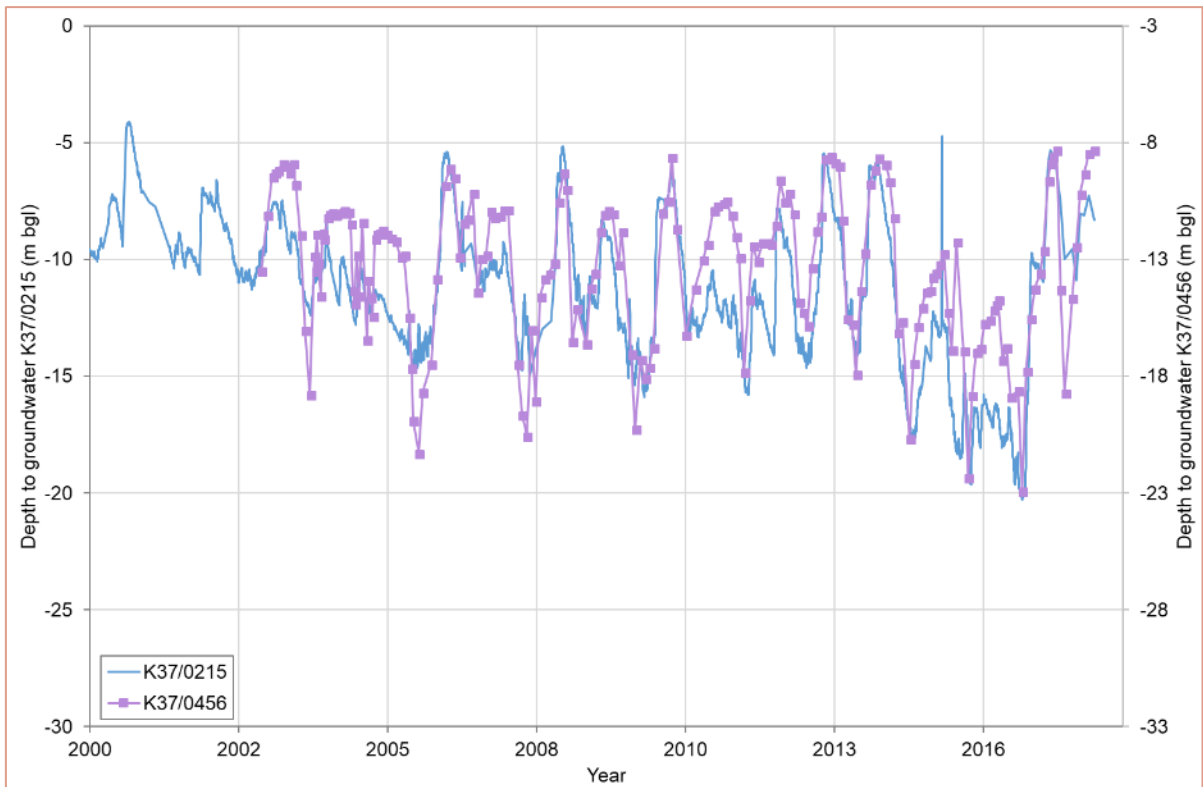
**Figure B14. Long-term groundwater level record for monitoring well K37/0215 (GWE-10) compared to cumulative residual rainfall.**



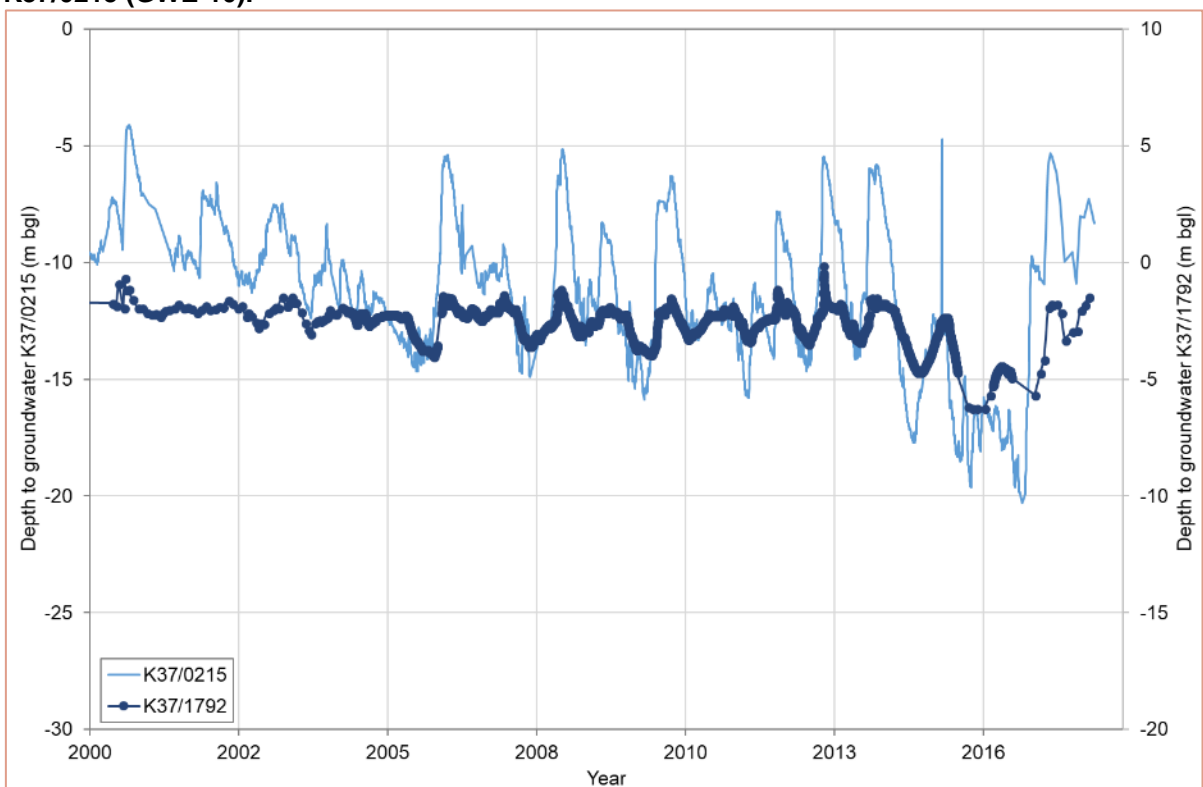
**Figure B15. Long-term groundwater level record for K37/0200 (GWE-04) compared to baseline levels in K37/0215 (GWE-10).**



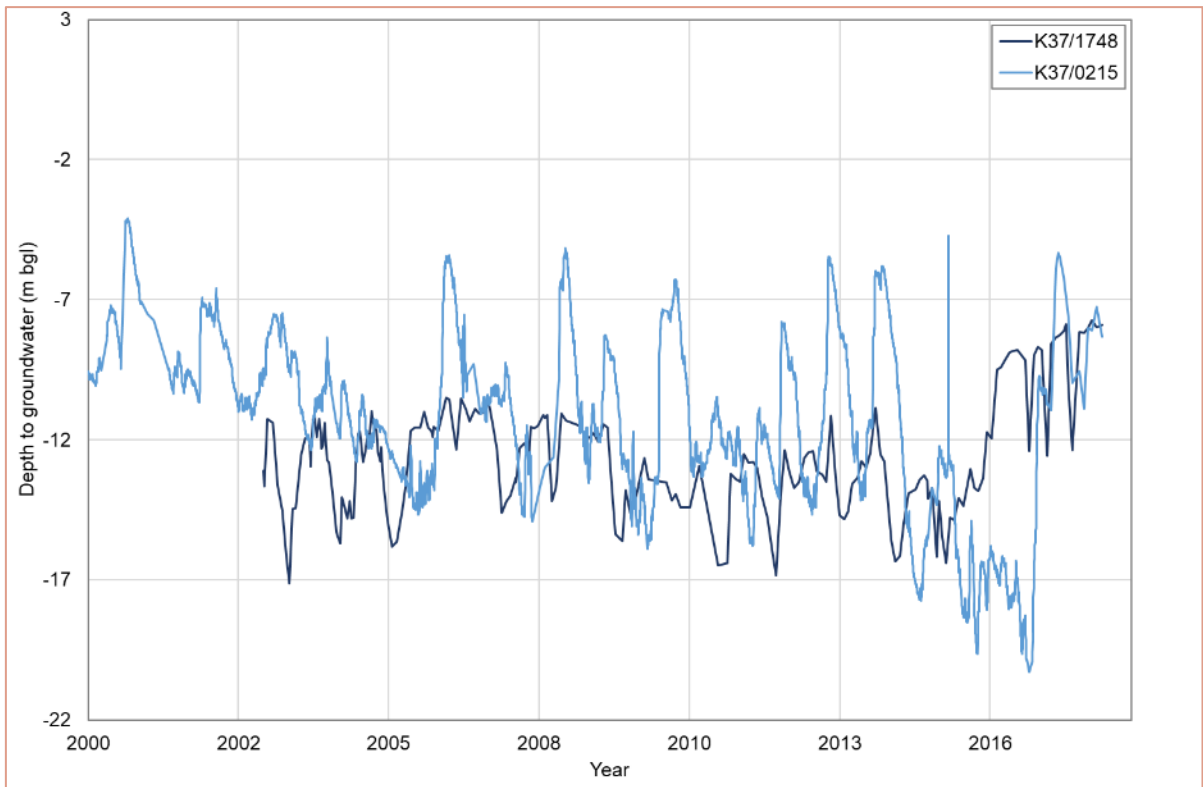
**Figure B16. Long-term groundwater level record for K37/0980 compared to baseline levels in K37/0215 (GWE-10).**



**Figure B17. Long-term groundwater level record for K37/0456 compared to baseline levels in K37/0215 (GWE-10).**



**Figure B18. Long-term groundwater level record for K37/1792 compared to baseline levels in K37/0215 (GWE-10).**



**Figure B19. Long-term groundwater level record for K37/1748 (GWE-01) compared to baseline levels in K37/0215 (GWE-10).**

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# APPENDIX C

## WATER QUALITY CHARTS

## GROUNDWATER QUALITY RESULTS

Groundwater quality results for six key parameters are presented in **Table CC1**. The following graphs show nitrate-N and electrical conductivity results in MAR influenced monitoring wells and one background monitoring well (GWD-05, Figure C4). The assessment of the water quality results is presented in Section 3.5 of the main report. Monitoring wells within the clean water plume maintained low concentrations of nitrate-N and electrical conductivity in Year 2. Groundwater quality responses to the clean water plume are considered to be observed (by changes in measured values over time) in four of the new 2018 monitoring sites (monitoring wells K37/0751, K37/0980, K37/2324 and K37/3146).

**Table C1: Groundwater quality results Year 2 summary.**

WGA Site Name	Site Name	Date	Electrical Conductivity (uS/cm)	Nitrate-N (mg/L)	Chloride (mg/L)	pH (Field)	E. coli (MPN/100ml)	Hardness (g/m <sup>3</sup> as CaCO <sub>3</sub> )
GWD-01	BY20/0149	25/10/2017	12.6	0.81	1.6	7.6	< 1	54
		18/01/2018	11.4	0.81	1.2	7.46	< 1	40
		21/05/2018	9.5	0.49	0.6	7.44	<1	35
GWD-02	BY20/0150	25/10/2017	17.6	1.43	1.8	7.5	< 1	73
		19/01/2018	23.7	1.83	1.7	7.38	< 1	94
		24/05/2018	22.5	1.57	1.7	7.7	<1	91
GWD-03	BY20/0151	25/10/2017	29.3	14.4	13	7.2	< 1	105
		18/01/2018	31.4	13.8	13.7	7.02	< 1	110
		9/04/2018	30.17	16.8	13.4	6.52	< 1	102
		24/05/2018	30.3	14.3	12.7	7.23	<1	110
GWD-04	BY20/0152	25/10/2017	9.6	1.85	3	7	< 1	35
		22/01/2018	11.8	2.6	3.2	7.18	< 1	42
		23/05/2018	11.2	2.2	2.7	7.02	<1	41
GWD-05	BY20/0153	25/10/2017	34.6	12	15.6	7.6	< 1	131
		22/01/2018	35.7	11.5	16.6	7.34	< 1	127
		23/05/2018	33.3	12.2	15.4	7.66	<1	127
GWD-06	BY21/0183	25/10/2017	28.3	11.7	14.2	6.8	< 1	99
		22/01/2018	32.3	13.8	17.7	5.83	< 1	106
		23/05/2018	30.8	14	15.7	6.71	<1	104
GWD-07	BY21/0184	25/10/2017	36.5	14.1	26	6.9	< 1	131
		18/01/2018	21.2	4.2	14.2	6.57	< 1	70
		7/02/2018	27.92	7.7	20	6.12	< 1	95
		21/05/2018	35.2	13.7	22	6.73	<1	118
K37/0502	K37/0502	23/01/2018	36.2	16.6	13.4	6.71	< 1	130
		18/05/2018	38.1	20	16.6	6.75	<1	141
K37/0751	K37/0751	24/01/2018	25.6	9.5	11	7.28	< 1	90
		31/05/2018	16.2	6.4	5.7	8.11	<1	56
K37/0980	K37/0980	23/01/2018	26.7	12.1	11.7	7.8	< 1	93
		30/05/2018	17	7.8	8.3	7.63	<1	57
K37/1468	K37/1468	17/01/2018	22.9	10.6	10.8	7.23	< 1	77
		30/05/2018	20.4	10	9.3	7.26	<1	70
GWE-01	K37/1748	25/10/2017	7	0.67	1.3	7.2	< 1	24
		19/01/2018	7.6	1.1	1.2	7.45	< 1	25

WGA Site Name	Site Name	Date	Electrical Conductivity (uS/cm)	Nitrate-N (mg/L)	Chloride (mg/L)	pH (Field)	E. coli (MPN/100ml)	Hardness (g/m <sup>3</sup> as CaCO <sub>3</sub> )
		21/05/2018	6.7	0.47	1.1	7.64	<1	22
K37/2166	K37/2166	24/01/2018	39.5	21	19.3	7	<1	137
		31/05/2018	40.3	23	18.8	6.97	<1	146
K37/2324	K37/2324	23/01/2018	32.6	15.4	15.2	6.78	<1	114
		30/05/2018	21.7	10.4	9.7	7.32	<1	73
GWE-16	K37/2603	17/01/2018	24.9	11.2	10.5	7.17	<1	89
		18/05/2018	20.6	9.9	9.5	7.3	<1	71
K37/3146	K37/3146	23/01/2018	35.5	17.7	20	7.01	<1	123
		14/03/2018	16.2	7.3	7.1	7.3	<1	53
		31/05/2018	16.4	7.1	7.1	7.75	<1	57

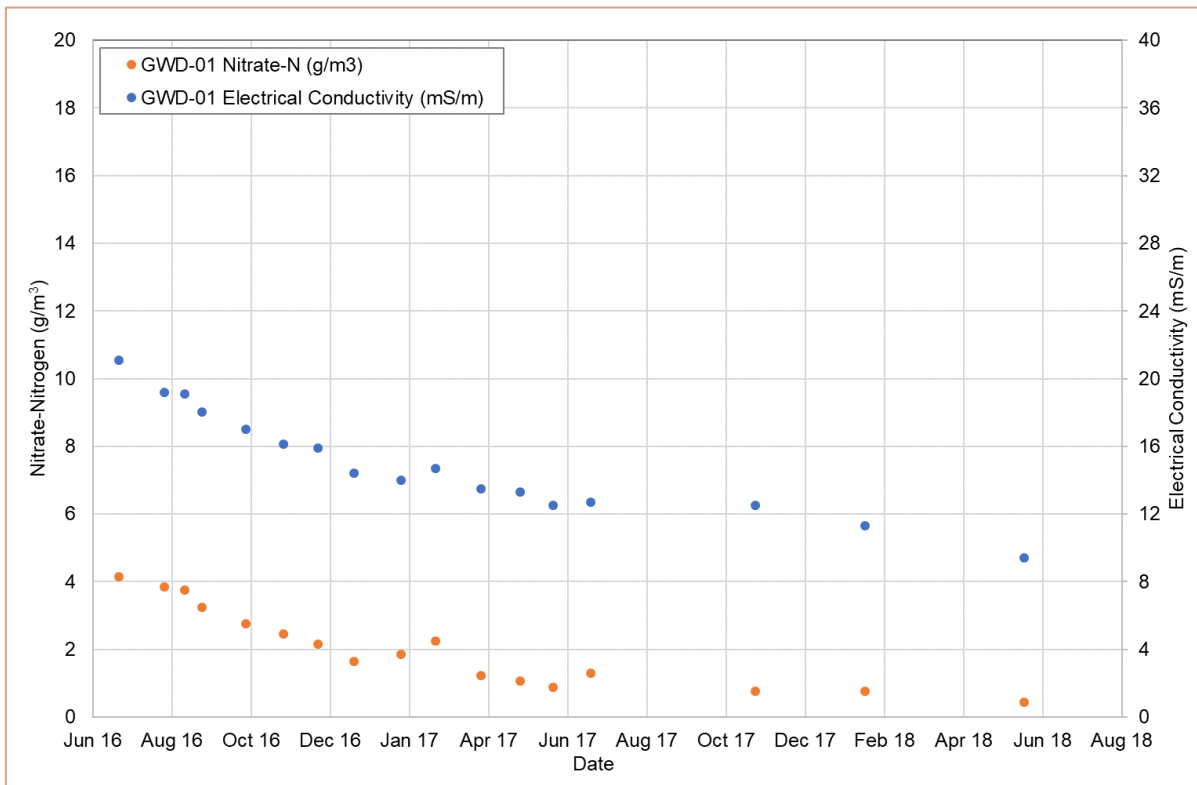
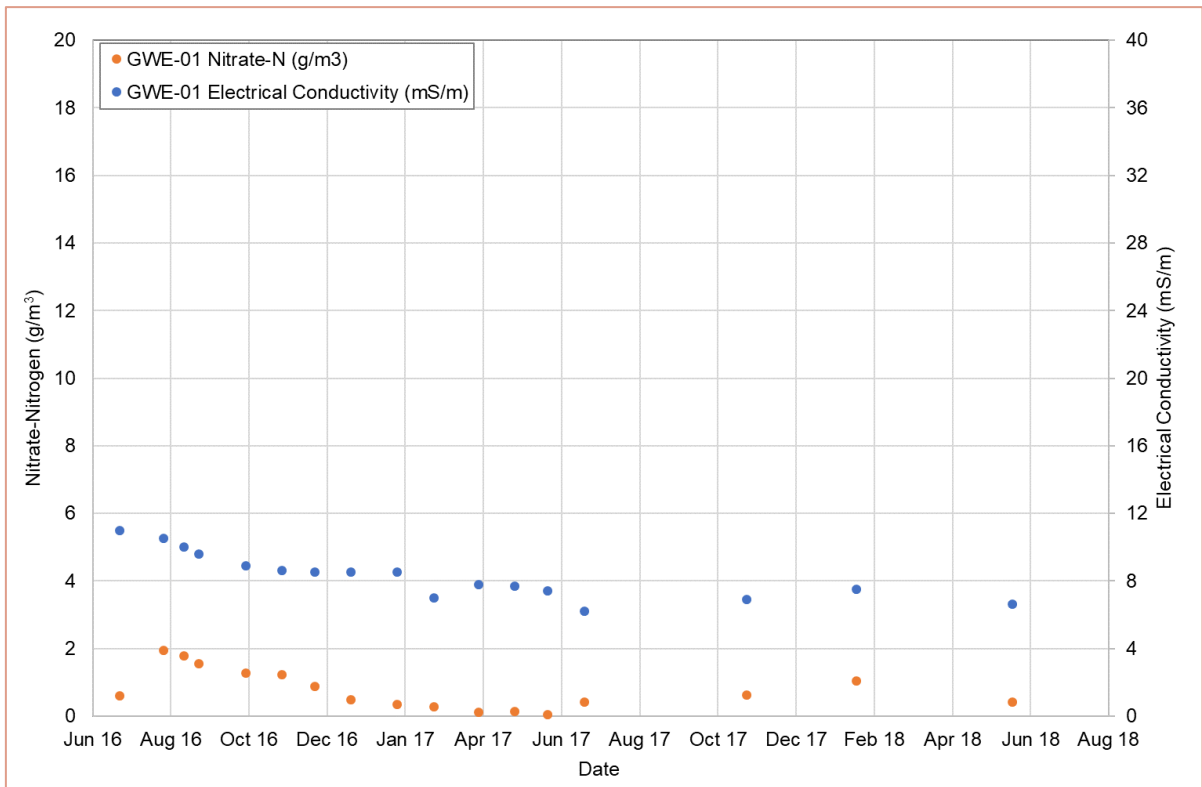
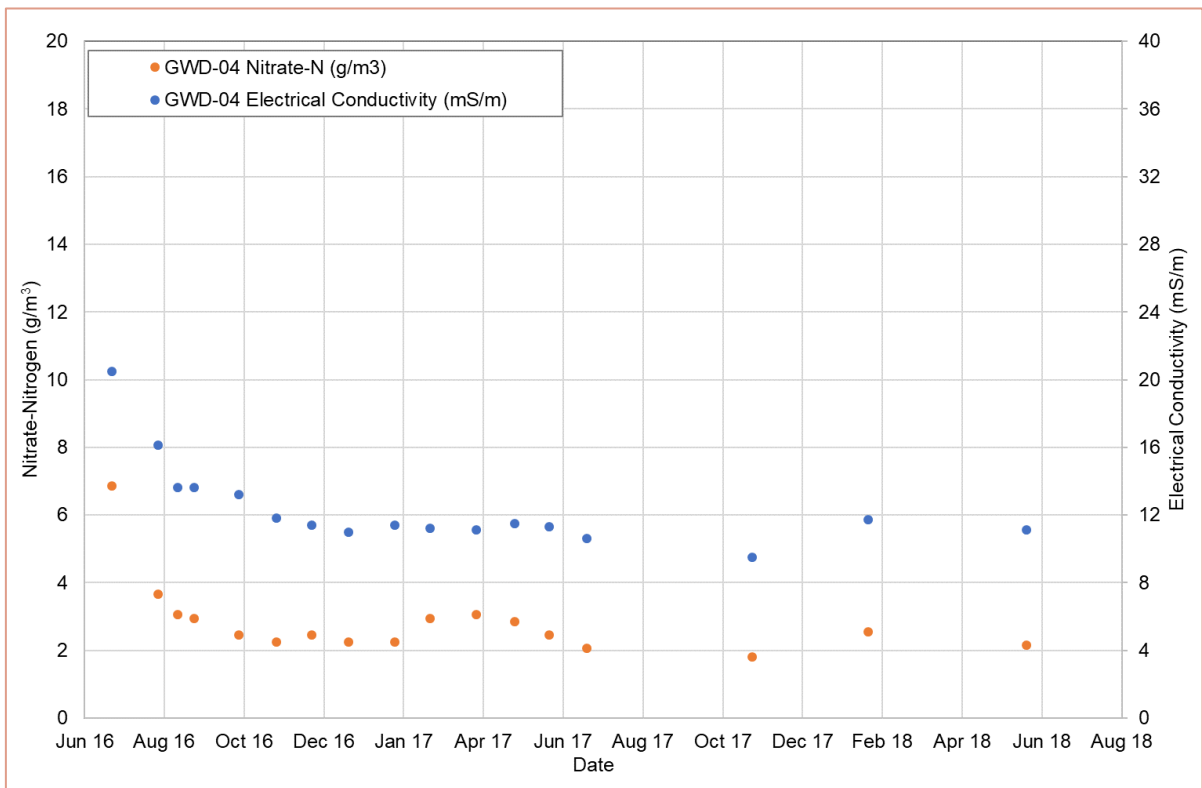


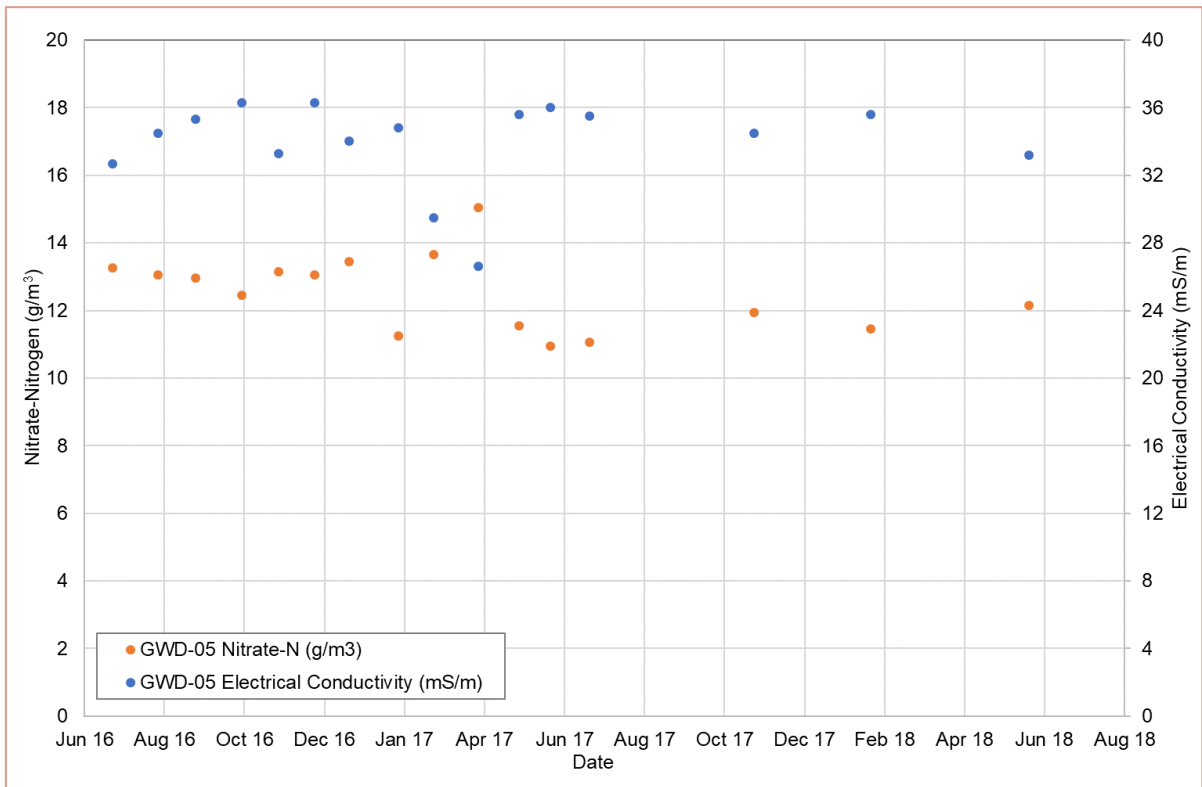
Figure C1: Water quality results in monitoring well GWD-01.



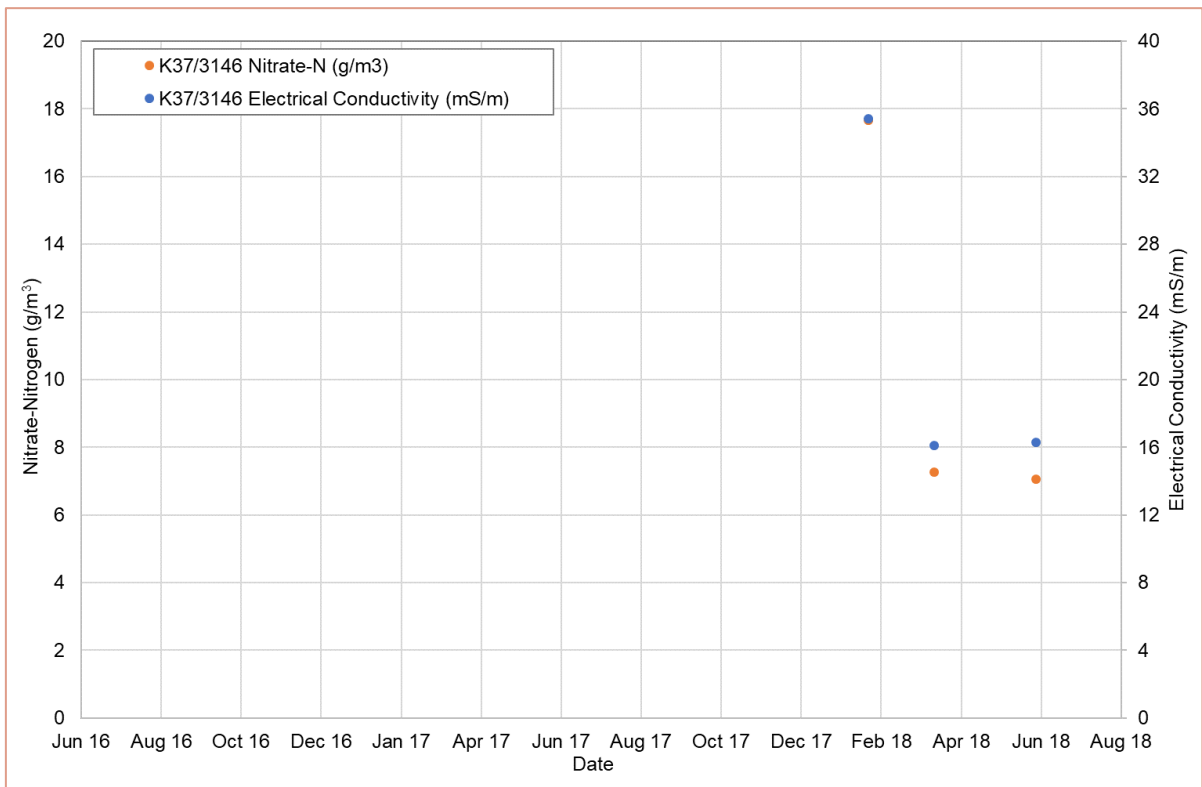
**Figure C2: Water quality results in monitoring well GWE-01.**



**Figure C3: Water quality results in monitoring well GWD-04.**



**Figure C4: Water quality results in monitoring well GWD-05 (outside of the clean water plume).**



**Figure C5: Water quality results in monitoring well K37/3146.**

## SURFACEWATER QUALITY RESULTS

The following graphs show Nitrate-Nitrite-Nitrogen (NNN) and electrical conductivity results in local spring-fed drains. Results show a seasonal fluctuation in the long-term results (Figures C6 and C7). Higher NNN concentrations occur in winter periods. Boundary Drain monitoring sites show an increasing trend in NNN over the monitoring period since 2014 (Figures C6 and C7). Data gaps exist in the Flemington Drain monitoring sites due to the drains being dry. Sites FL-01 and FL-04 were dry for much of the period from December 2014 to August 2017. No changes in water quality have been observed yet in the drains which can be attributed to the MAR clean water plume. This is as expected based on the speed of movement of the clean water plume and its current mapped position. Drain flow rates are presented in Section 3.6.1 of the main report.

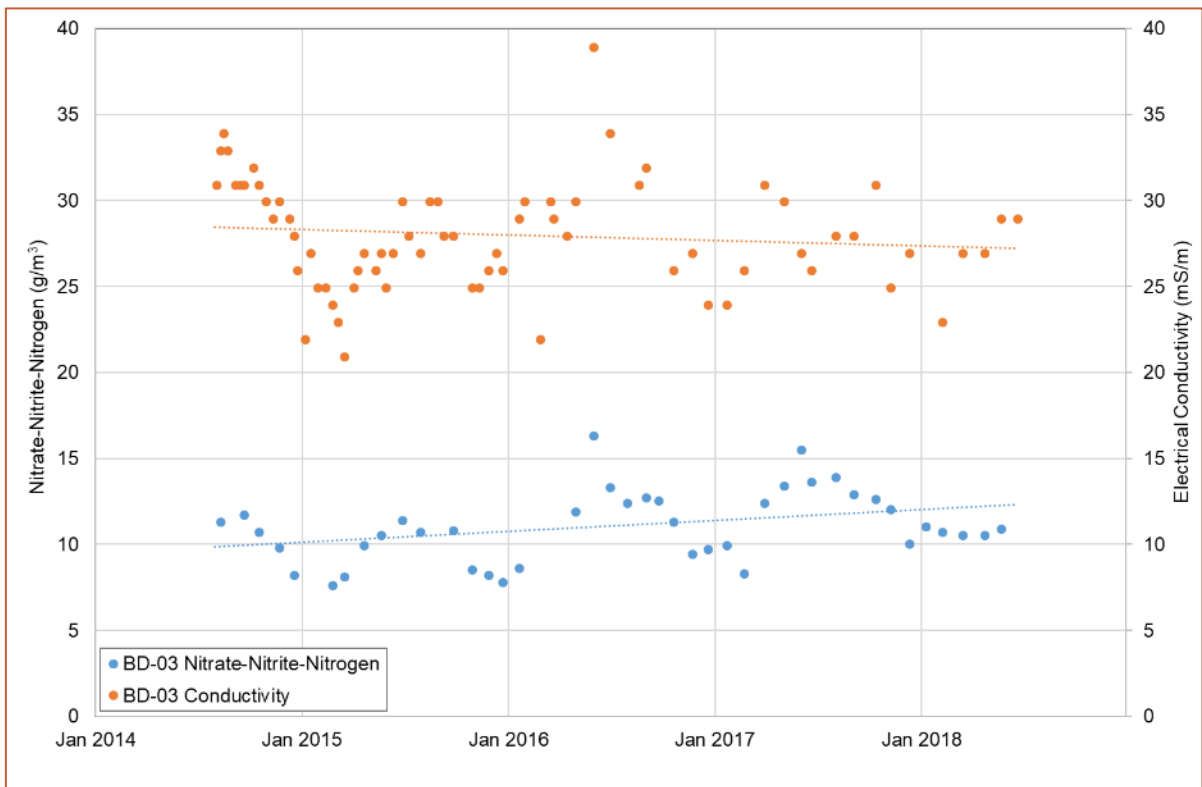
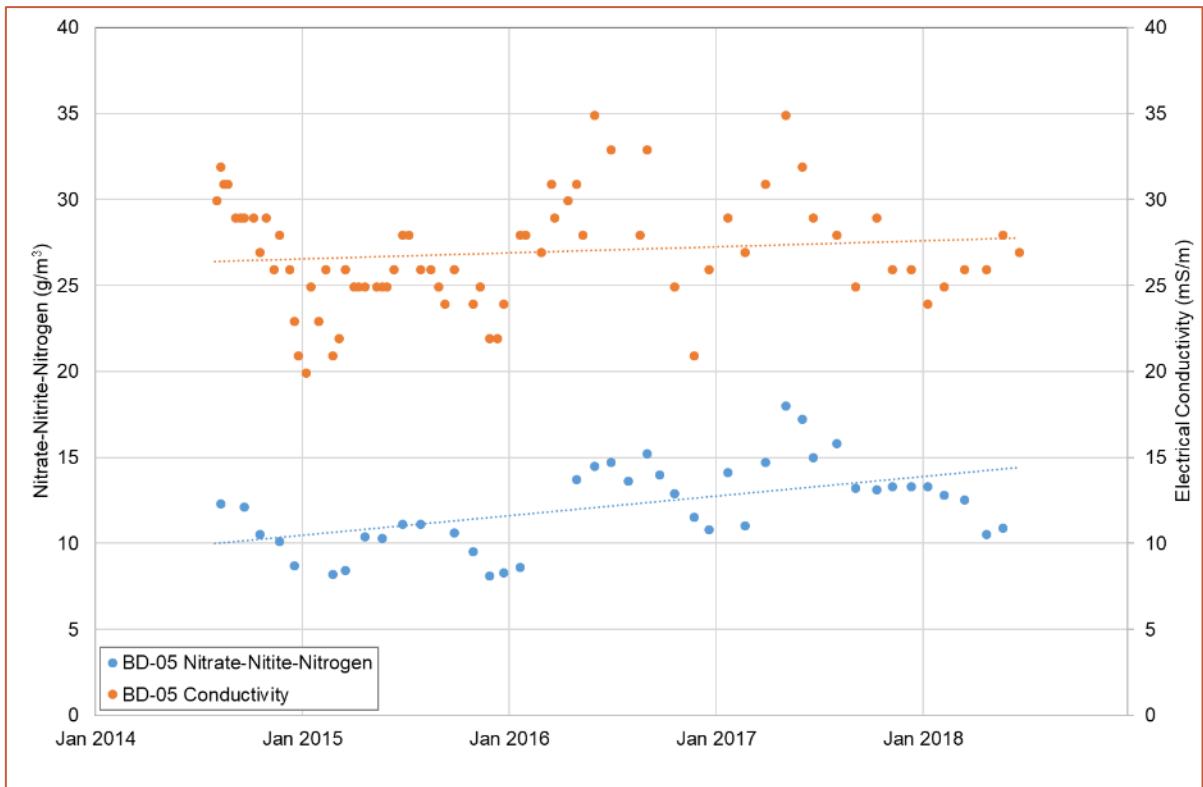
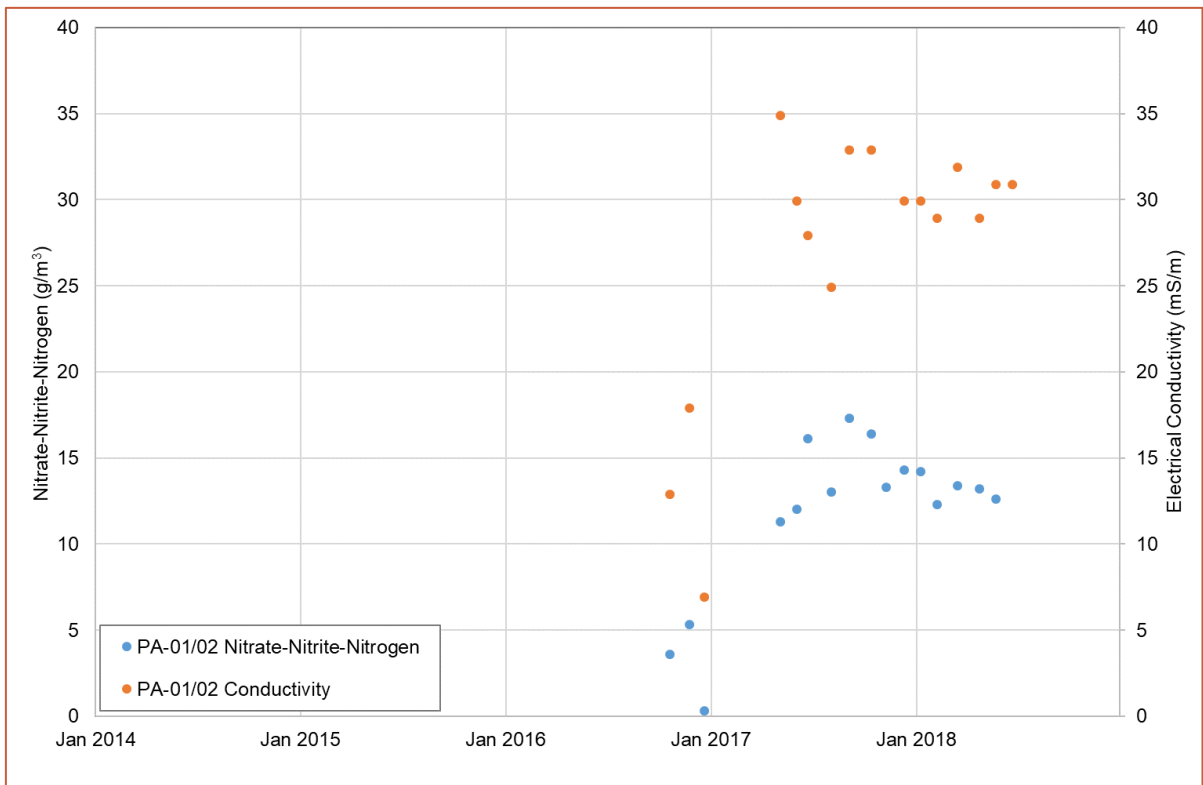


Figure C6: Water quality results in monitoring Boundary Drain site 3 (Poplar Rd at Davidsons Rd).

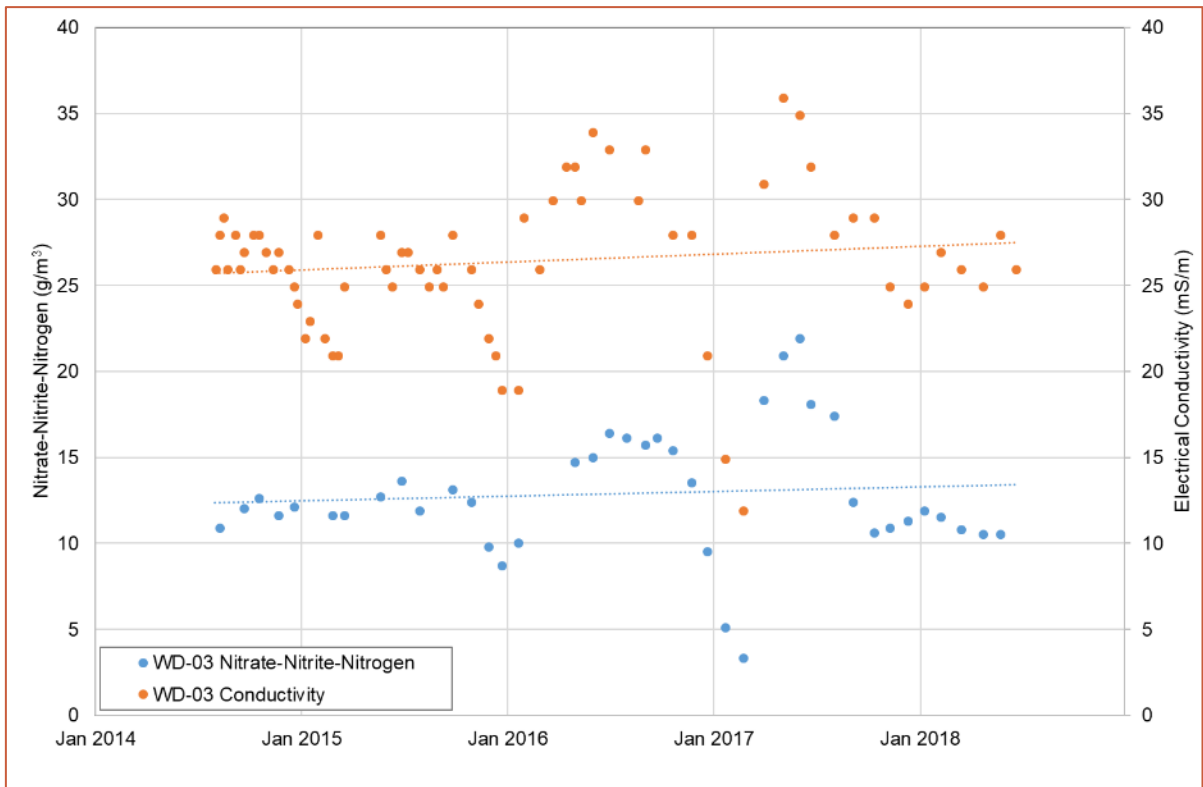


**Figure C7: Water quality results in monitoring Boundary Drain site 5 (Trig Pole Rd 100 m south of Davidsons Rd).**

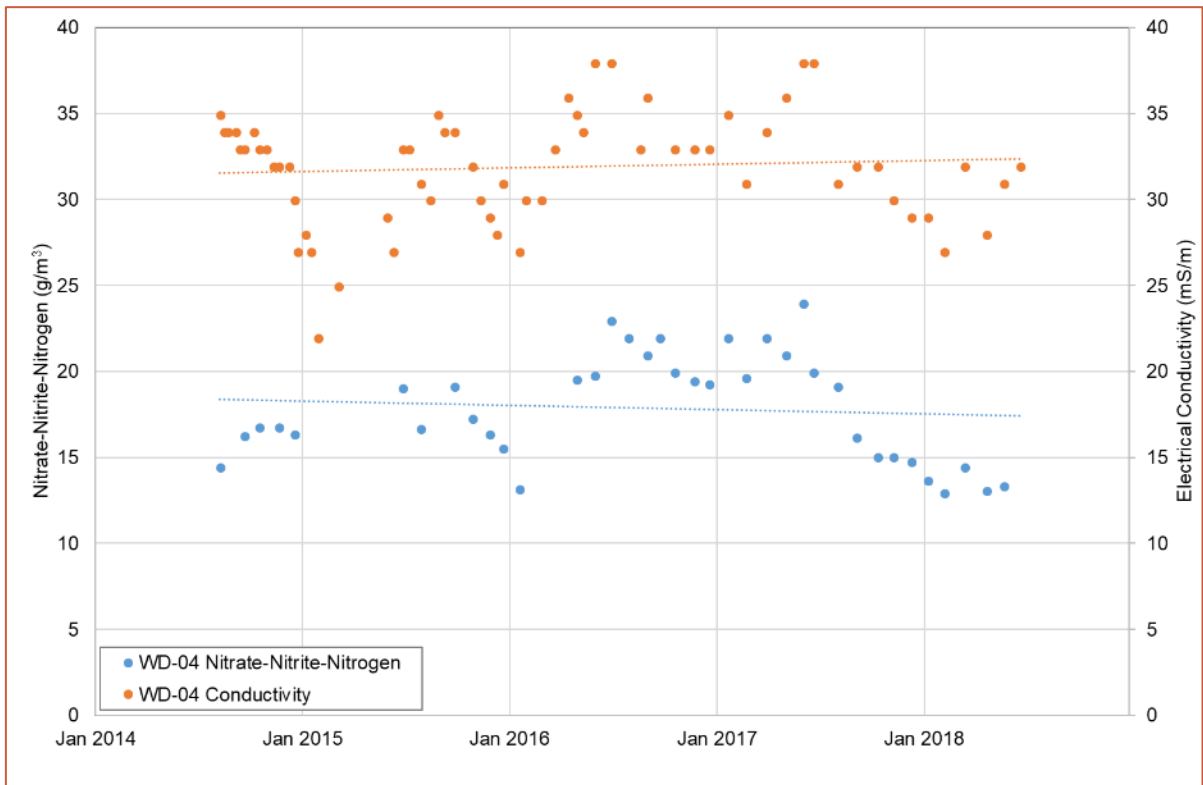


**Figure C8: Water quality results in monitoring Parakanoi Drain site 1. Note: Samples prior to September 2017 were collected from a different location in Parakanoi Drain named PA02.**





**Figure C11: Water quality results in monitoring Windermere Drain site 3 (Mainstem below Boundary Rd 300m north of Windermere Rd).**



**Figure C12: Water quality results in monitoring Windermere Drain site 4 (Corner Windermere Rd and Boundary Rd).**

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# APPENDIX D

## BASIN CLOGGING

## INTRODUCTION

Basin infiltration rates are affected by a range of factors, some of which change over time. When these factors change, the infiltration rates at the site also generally change as a consequence. Factors that change over time include:

- Depth of water in the basin.
- Clogging of the basin floor and underlying soils, including:
  - Physical clogging from imported sediment, when suspended solids enter the soil pore spaces.
  - Physical clogging through compaction of the existing soils beneath the basin.
  - Biological clogging, which occurs when bacteria, algae or fungi form biofilms on the soil particles or across the floor of the basin.
  - Geochemical clogging linked to changes in clay chemistry and therefore structure and physical behaviour.
- Degree and form of soil saturation underlying and surrounding the basin, including:
  - Hydraulic clogging, which occurs when the groundwater level within the surrounding shallow subsurface rises (e.g., due to increased rainfall recharge), thereby reducing the rate at which MAR water can escape downward and laterally outward from the basin.
  - Gas clogging, which occurs when air or other gases are trapped beneath a layer of infiltrating water, either from the basin or from high intensity rainfall events, thereby reducing infiltration rates.
  - An increase in water content within unsaturated zones beneath the basin, or a shift from unsaturated to saturated conditions, can result in increased permeability of the soils affected and therefore increased seepage rates from the overlying basin.

Most of the above factors have possibly influenced infiltration rates at the Lagmhor Trial site at various times during the first two years of the trial. Assessments and observations made during Year 1 (Golder 2017) indicated:

1. Air entrapment beneath the basin at the start of the trial potentially reduced initial infiltration rates.
2. The interpreted presence of a lower permeability layer (aquitarde AQT1) at a depth of approximately 6 m to 9 m beneath the site (refer Table 10 of the main report) limited downward seepage rates from the basin to the underlying aquifers.
3. Physical and biological clogging of the basin floor may have occurred, however the evidence for a measurable reduction in infiltration rates over time was not conclusive.

In addition to the above factors, the likely presence of an unsaturated zone beneath the shallow aquitarde may have also reduced downward seepage beneath the basin. Air filling the pore spaces in the unsaturated zone would reduce the hydraulic conductivity and therefore downward water transmission rates compared to a fully saturated column of soils beneath the basin.

## YEAR 2 BASIN PERFORMANCE

Observations of the basins and delivery race at the end of Year 1 identified a small amount of accumulated sediment in the forebay, but only a light covering in the main basin. Observations at the end of Year 2 identified an increased thickness of accumulated sediment in the forebay and sections of the delivery race, but only a light covering again in the main basin.

Following site shutdown at the end of Year 2, the stored water in the forebay took over two weeks to infiltrate, compared with approximately one day for the stored water in the main basin to infiltrate. This significant reduction in forebay infiltration rate will have affected overall site performance. As information is not available on sediment accumulation over time, a more detailed assessment of the reduction in forebay performance over time cannot be undertaken.

Other factors that could have influenced infiltration rates at the site were assessed using main basin water level recovery curves following six site shutdown events recorded during the first two years of site operations. These factors included:

- water depth in the basin;
- antecedent rainfall conditions;
- depth to perched and regional groundwater tables beneath the basin.

Some potential correlations were identified between the above factors and infiltration rates, however only a small number of data points (six) have been assessed. As the Lagmhor Trial progresses and data from additional shut-down events becomes available, the outcomes from these assessments will become more statistically reliable.

### **Assessment Techniques**

Changes in infiltration performance at the Lagmhor Trial site have been evaluated for Year 2 using five techniques:

1. Evaluating evidence from on-going physical site observations.
2. Comparing water level recovery curves in the basin following site shut-down events, to assess if the directly calculated infiltration rates have changed over time.
3. Comparing source water flow rates through Flume 2 with the water levels recorded in the main infiltration basin, to assess if the depth to inflow relationship has changed over time.
4. Comparing main basin infiltration rates to antecedent rainfall conditions.
5. Comparing main basin infiltration rates to underlying groundwater levels.

Of techniques two and three, the more accurate assessment of infiltration rates over time is considered to be derived from the assessment of water level recovery curves because:

- There are few data corrections required to address external factors, such as rainfall.
- The rate of infiltration is measured directly rather than calculated from other forms of data, such as inflow rates.
- Recovery curves are not subject to a significant uncertainty linked to calibration error or channel variability, such as applies to flow calculations based on rating curves.
- The water level dataset has a relatively small uncertainty factor.

### **On-site Observations**

A small accumulation of fine sediment and algal material was observed on the main basin floor during Year 1 (Golder 2017). No significant subsequent increase in accumulated material was observed by July 2018 (Figure D1). No evidence of significant clogging of this basin has been gained from direct physical observation of the site.

In contrast, a layer of accumulated sediment and algal matter several millimetres thick was observed in the forebay at the end of Year 1 (Golder 2017). A substantially greater accumulation of sediment in the forebay had occurred by July 2018 (Figure D2). The sediment accumulated in the forebay during Year 2 appears to be primarily silt deposits derived from storm events rather than fine glacial till material from the Rangitata River (Pers. comms. Brett Painter, 19 July 2018). The minor erosion of the spillway sides at the entrance to the forebay that occurred during a high flow start to the Year 1 pre-trial test may have contributed to the sediment in the forebay. However, the amount of eroded material was small compared to the amount of accumulated sediment in the forebay.

By the end of Year 2 sediment had also accumulated on sections of the floor of the delivery race between the Valetta #3 Pond and the forebay (Figure D3). The finer sediment on the floor of the race was visually similar to the material accumulated in the forebay.

No mechanical cleaning of the basins has been conducted since the site construction in April 2016.



**Figure D1: Photograph of main basin floor (B. Painter, 18 July 2018).**



**Figure D2: Photograph of forebay floor (B. Painter, 18 July 2018).**



**Figure D3: Photograph of delivery race floor (B. Painter, 18 July 2018).**

Direct observations by the Site Manager in late Year 2 provide clear evidence that seepage through the floor of the forebay has been substantially reduced through clogging (Pers. comms. Giles Pinfold, email 9 July 2018). Shortly after the end of Year 2 (4 July 2018) a shutdown of the site occurred. The forebay continued to hold water for several weeks after both the main infiltration basin and the delivery race had fallen dry (Figures D4 & D5, Pers. comms. Brett Painter, email 18 July 2018). This water had not accumulated from rainfall as only 5.6 mm had fallen (Ashburton Aero climate station) through this two-week period.



**Figure D4: Settling basin (forebay) five days after flow to the Lagmhor Trial site ceased (9 July 2018).**



**Figure D5: Settling basin (forebay) two weeks after flow to the Lagmhor Trial site ceased (18 July 2018).**

Although the July 2018 shut-down event occurred after the close of Year 2, an initial assessment of the seepage rate through the sides and floor of the forebay was undertaken (Table D1). The estimated recovery rate of 119 mm/day contrasts strongly with the average recovery rate of 1,163 mm/day calculated from water level data from the pre-trial performed prior to the start of Year 1 operations (May 2016). Although the two events are not directly comparable as there were other factors influencing the recovery rate following the pre-trial (e.g. air entrapment, wetting front expansion), it is still clear that clogging has affected the infiltration performance of the forebay.

The recovery rates presented in Table D1 do not equate directly to the infiltration rates presented for the main basin in the following sections. Under operational conditions there is seepage from the forebay to the main basin. This seepage has been observed during site start-up events but not measured under operational conditions. Consequently, the recovery rates provided in Table D1 are expected to slightly exceed infiltration rates for the forebay.

**Table D1: Calculated forebay recovery rates, July 2018.**

Date / time	Water depth (m)	Time interval (days)	Recovery rate (mm/day)
<b>Measured at close of Year 1 pre-trial (Golder 2017)</b>			
18/05/2016 8:56	1.59		
19/05/2016 17:44	0	1.367	1,163
<b>Forebay (observed during July 2018)</b>			
4/07/2018 10:00	1.8		
18/07/2018 16:58	0.1 <sup>(1)</sup>	14.3	119 <sup>(2)</sup>

**Note:** 1) Estimated average remaining water depth across the forebay  
 2) Incorporating rainfall in the infiltration rate calculation does not change this value.

### Main Basin Infiltration Rates from Recovery Curves

Infiltration basin water level recovery curves recorded during the first two years of site operations are presented in Figure D6. To ensure reasonable comparability of datasets for the infiltration rate assessment, the curves analysed were required to meet the following criteria:

1. The site shut down was preceded by at least a week of stable operational water levels in the infiltration basin.
2. The site shut down led to the basin falling dry.
3. The water depths in the infiltration basin at the time of shut-down were within the normal site operating range of 0.5 m to 0.8 m.
4. The recovery curve shown on a depth versus time chart (Figure D6) is a relatively straight line, indicating there were no significant external factors (e.g. rainfall, slow shut-down) influencing the water level recovery.

The recovery curves from the first two years of operations at the Lagmhor Trial meeting the above criteria are shown as solid lines in Figure D6. The dashed lines in Figure D6 represent recorded events that meet the first two criteria above but not one of the latter two. The events that meet the above criteria have been defined as “selected events” for assessments and charts in the following sections of this appendix. The events that do not meet all of the above criteria are defined as “remaining events”.

The six curves that meet the above criteria have been converted into infiltration rates (mm/day), calculated on a running 60-minute average (Figure D7 and D8). Infiltration rates calculated from these recovery curves generally varied between 500 mm/day and 950 mm/day. There is a general trend for the infiltration rates to decrease as the water levels in the basin decrease following site shut-down (Figure D9).

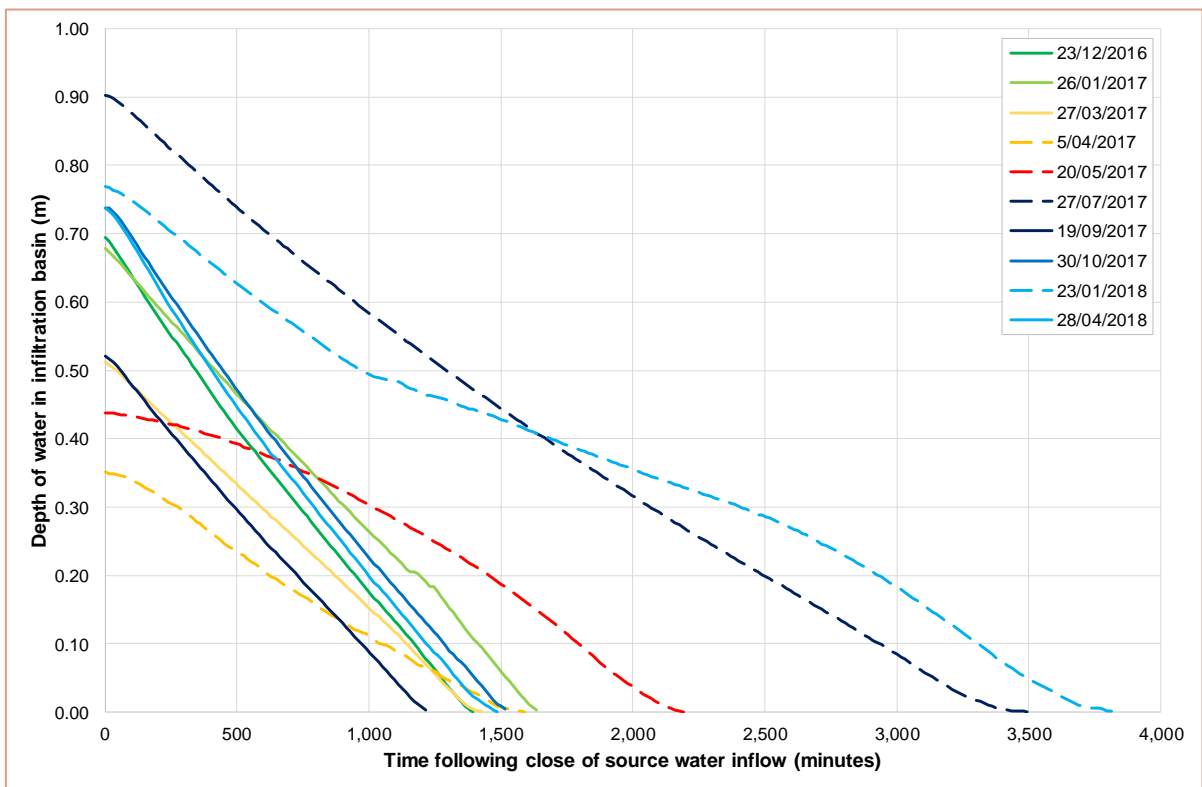


Figure D6: Main infiltration basin recovery curves following site shut down events.

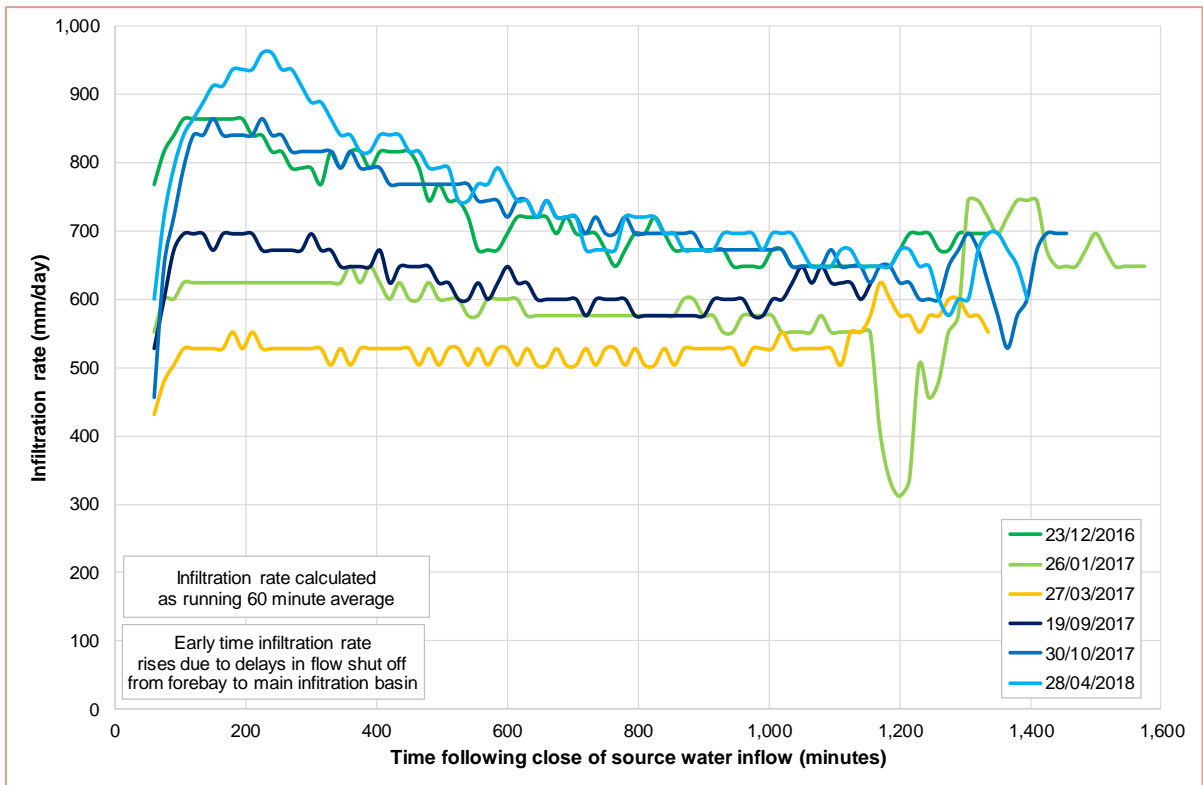


Figure D7: Infiltration rates calculated against time from selected basin recovery curves.

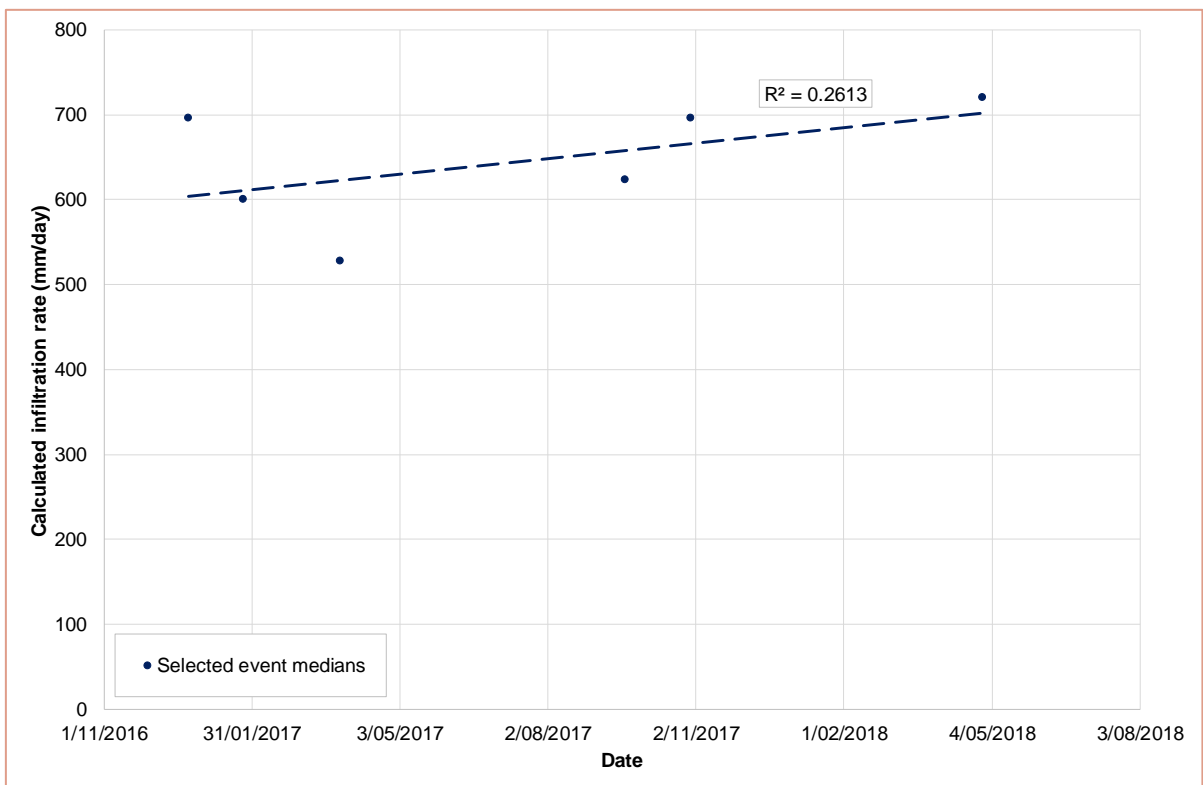
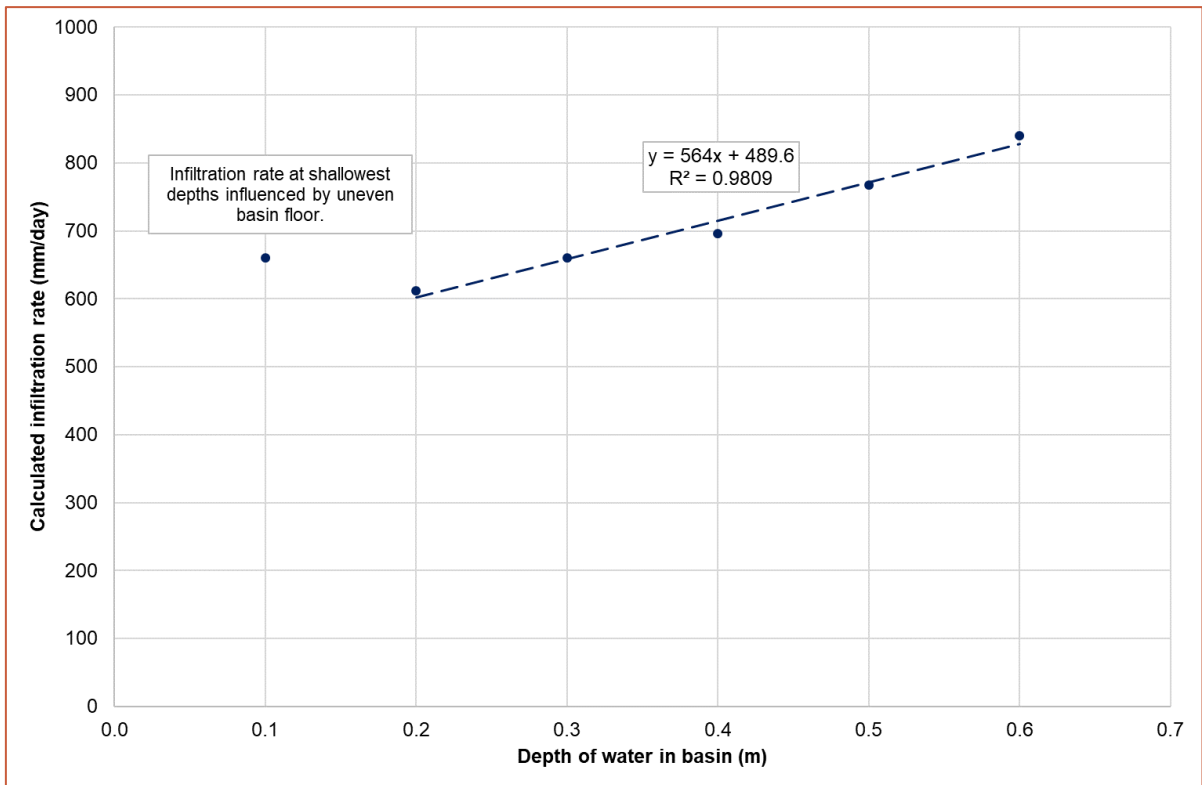


Figure D8: Infiltration rates from selected main basin recovery curves.



**Figure D9: Infiltration rates compared to water depth from selected basin recovery curves.**

#### **Infiltration Rates Calculated from Lagmhor Trial Site Inflows**

An assessment of average longer-term infiltration rates can be made based on the calculated flow rates into the combined forebay and main infiltration basin (Flume 2). The distribution of water infiltrated from the forebay compared to the main basin is not specifically calculated using this method. However, a general range of infiltration rates can be determined based on the flows measured at Flume 2 (Table D2). These infiltration rates derived from inflows are comparable to the rates assessed from basin recovery curves. The results suggest the combined basins have slightly lower rates in comparison to early infiltration rates in Year 1 (based on same area and higher flow rates).

If it is assumed that infiltration from the forebay is negligible, the consequent infiltration calculated for the main basin (920 mm/day) would be similar to the rate calculated for the combined settling basin and main basin (945 mm/day) in late 2016 (Golder 2017).

Assessment of the infiltration rates during Year 1 (Golder 2017) indicated the water losses from the delivery race to the underlying groundwater system were a significant component of the overall site infiltration. During Year 2 the flow losses to infiltration from the delivery race have been calculated to average:

- Approximately 670 mm/day from August to October 2017, based on a loss of 17 L/s
- Approximately 859 mm/day during February to May 2018, based on a loss of 22 L/s

These calculated infiltration rates are similar to the rates calculated for the main basin.

Clogging of the forebay base is a contributing factor to the reduced infiltration performance of the Lagmhor Trial site. This reduced performance is evidenced by reduced overall flow rates at both Flume 1 and Flume 2 during Year 2 compared to Year 1.

**Table D2: Infiltration rates based on Flume 2 inflow rates.**

Assessed period	Average daily flow		Infiltration rate through combined forebay and main basin	Infiltration rate through main basin with assumed infiltration from forebay <sup>(1)</sup>	Infiltration rate through main basin with no infiltration from forebay <sup>(2)</sup>
	L/s	m <sup>3</sup> /day	mm/day	mm/day	mm/day
Year 1 – Average flow: October – December 2016	90	7,776	945	-	-
Year 2 – Average flow: August – October 2017	53	4,546	566	649	675
Year 2 – Average flow: March – April 2018	72	6,193	720	894	920

**Note:** 1) Assumes forebay has 119 mm/day infiltration rate  
 2) Assumes forebay base is clogged and contributes negligible infiltration.

**Infiltration Rates Compared to Antecedent Rainfall Conditions.**

A comparison of infiltration rates against antecedent rainfall conditions has been undertaken, with antecedent periods of 10, 20 and 30 days considered (Table D3). In each case inverse correlations have been identified between antecedent rainfall conditions and infiltration rates (Figure D10 to D12), that is, infiltration rate decreases with increasing antecedent rainfall. However, the small number of data points means these correlations should be interpreted with caution.

**Table D3: Infiltration rates compared to antecedent rainfall conditions.**

Site shut-down date <sup>(1,2)</sup>	Median infiltration rate <sup>(3)</sup> (mm/day)	Infiltration rate 0.3 to 0.2 m basin depth <sup>(4)</sup> (mm/day)	10 day antecedent rainfall (mm)	20 day antecedent rainfall (mm)	30 day antecedent rainfall (mm)	Maximum rainfall event during previous 30 days (mm)
23/12/2016	696	672	3.5	38.5	55	13.5
26/01/2017	600	552	32	36.5	59	14.5
27/03/2017	528	504	34.5	92	106.5	28.5
19/09/2017	624	600	37	50.5	65.5	35 <sup>(5)</sup>
30/10/2017	696	672	14.5	25.5	53	13
28/04/2018	720	696	0	45.5	48.5	26

**Notes:** 1) Rainfall values are totalled up to 9:00 am on the day of the shut-down.  
 2) Data excluded from the analyses are presented in Table D5.  
 3) Infiltration rate calculated as the median from the time that inflows to the basin ceased.

- 4) Infiltration rate calculated as the median for the period when water depth in the basin was between 0.3 m and 0.2 m.
- 5) Rainfall event occurred on the day before the shut-down.

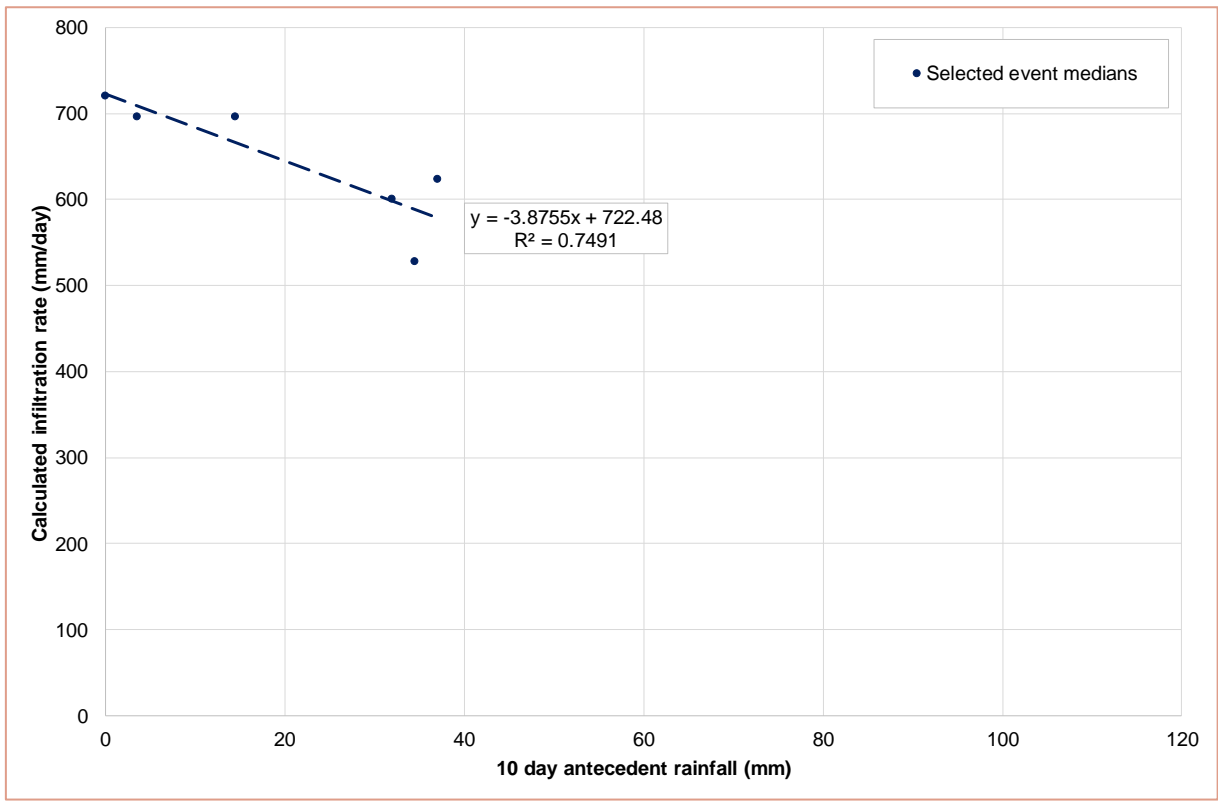


Figure D10: Infiltration rates compared to 10 day antecedent rainfall.

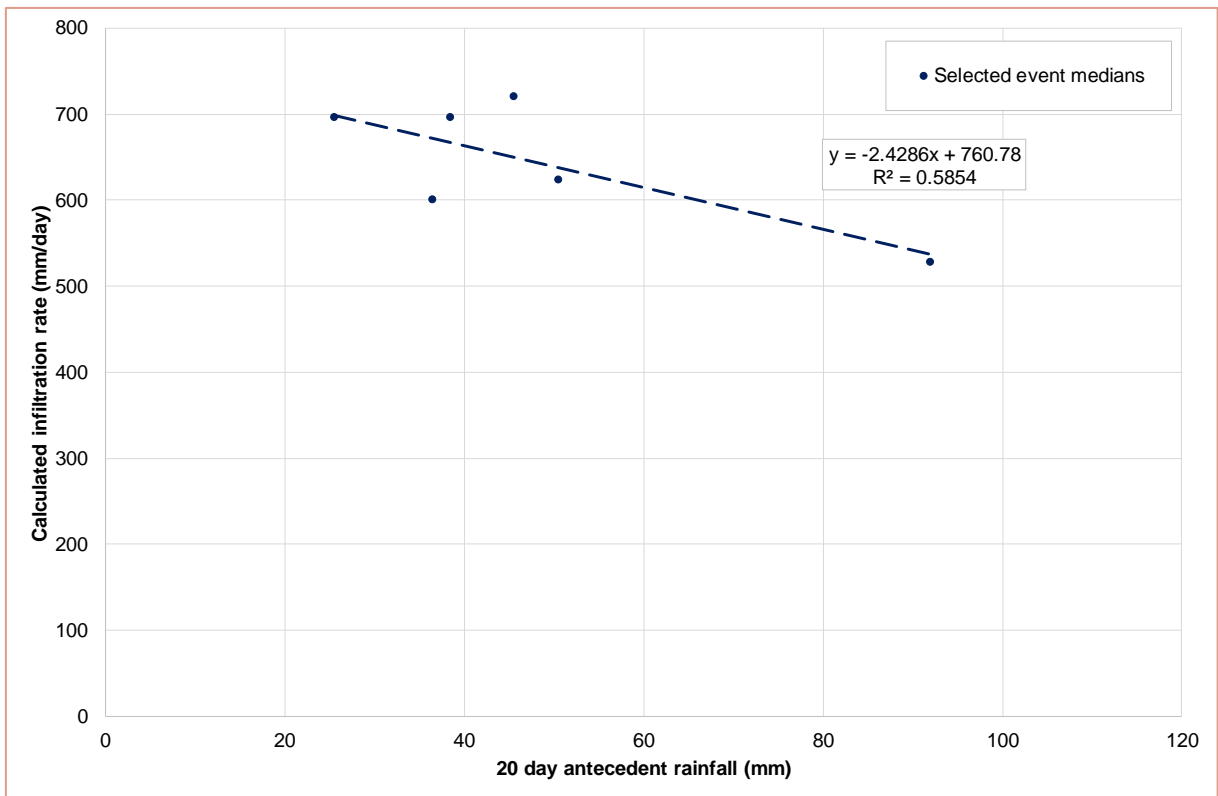
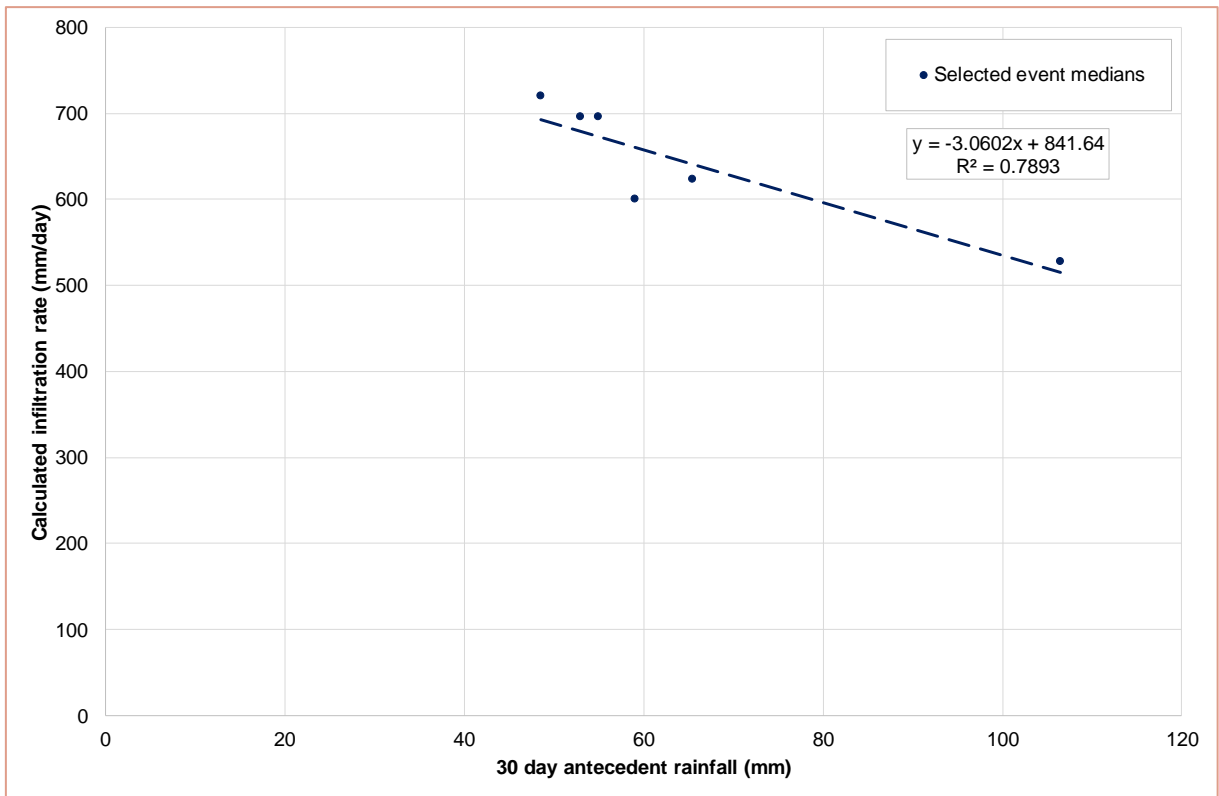


Figure D11: Infiltration rates compared to 20 day antecedent rainfall.



**Figure D12: Infiltration rates compared to 30 day antecedent rainfall.**

### **Infiltration Rates Compared to Underlying Groundwater Levels**

Infiltration rates calculated from recovery curves have been compared to the depth to water in the perched and regional aquifers underlying the Lagmhor Trial site, as measured at the time of shut-down (Table D4). The infiltration rates presented in Figures D13 to D15 are calculated for water depths in the basin of between 0.3 m and 0.2 m, to provide for consistency between events. The median infiltration rates calculated from the full recovery curves were greater, however changing to these values did not substantially change the charts or the interpretations presented below.

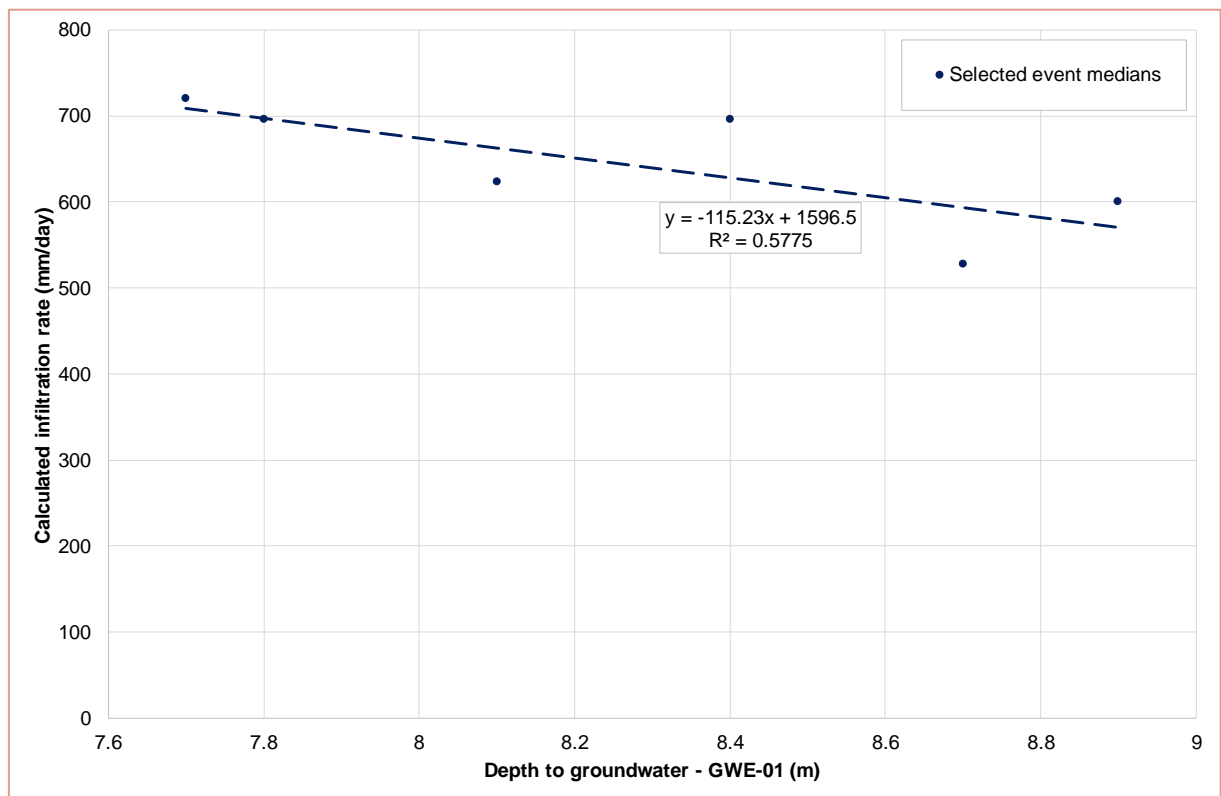
An inverse correlation has been identified between infiltration rate and depth to groundwater in the perched aquifer (AQ2) beneath the site (Figure D13), that is, infiltration rate decreases with increasing depth to groundwater. In addition, inverse correlations have been identified between infiltration rates and the depth to groundwater in the regional aquifer (AQ3), both beneath the site (Figure D14) and down-gradient from the site (Figure D15).

The small number of data points assessed means these correlations should be interpreted with caution. These correlations do not necessarily equate to cause and effect relationships.

**Table D4: Infiltration rates compared to depth to groundwater beneath Lagmhor Trial site.**

Site shut-down date <sup>(1,2)</sup>	Median infiltration rate <sup>(3)</sup> (mm/day)	Infiltration rate 0.3 to 0.2 m basin depth <sup>(4)</sup> (mm/day)	Groundwater depth GWE-01 (m)	Groundwater depth GWD-01 (m)	Groundwater depth GWD-05 (m)
23/12/2016	696	672	8.4	27.3	26.4
26/01/2017	600	552	8.9	26.9	26.4
27/03/2017	528	504	8.7	26.9	26.4
19/09/2017	624	600	8.1	21.0	9.4
30/10/2017	696	672	7.8	20.2	8.6
28/04/2018	720	696	7.7	19.6	8.6

- Notes:**
- 1) Rainfall values totalled up to 9:00 am on the day of the shut-down.
  - 2) Data from recovery curves excluded from the following analyses are presented in Table D6.
  - 3) Infiltration rate calculated as a median from the time that inflows to the basin ceased.
  - 4) Infiltration rate calculated as a median for the period when water depth in the basin was between 0.3 m and 0.2 m.



**Figure D13: Infiltration rates compared to depth to groundwater at GWE-01.**

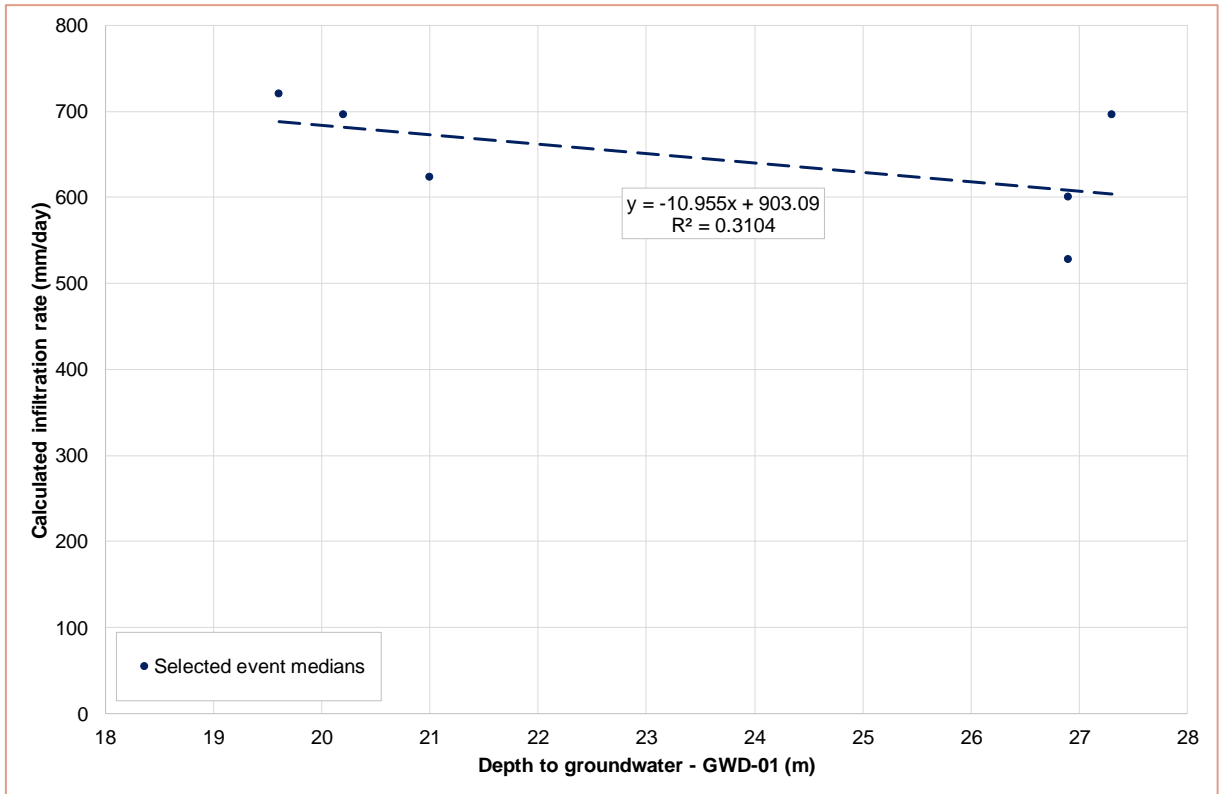


Figure D14: Infiltration rates compared to depth to groundwater at GWD-01.

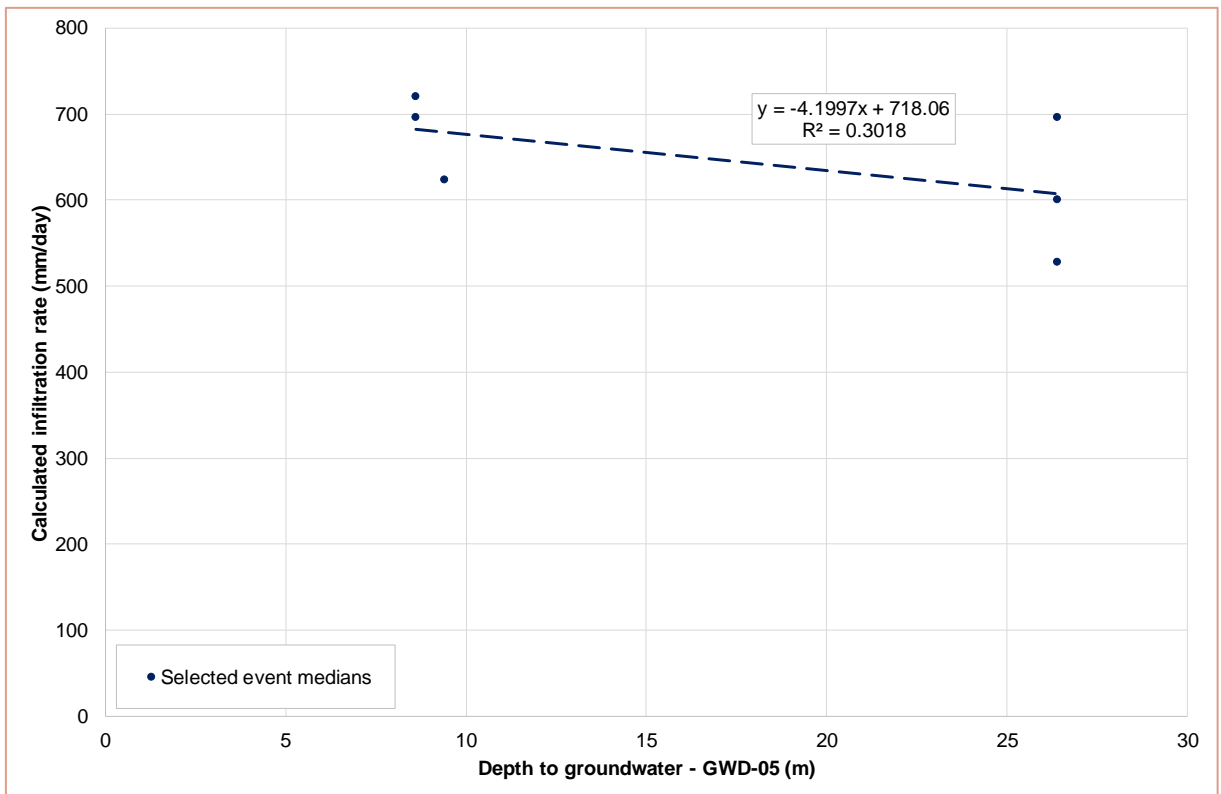


Figure D15: Infiltration rates compared to depth to groundwater at GWD-05.

The data from the main infiltration basin recovery curves excluded from the analyses documented above are presented in Tables D5 and D6 for completeness. Any analysis of the data presented in these tables should be treated with caution as there are additional factors influencing these recovery curves, not all of which are identified in this document.

**Table D5: Data excluded from analysis of infiltration rate and antecedent rainfall.**

Site shut-down date <sup>(1)</sup>	Median infiltration rate <sup>(2)</sup> (mm/day)	Infiltration rate 0.3 to 0.2 m basin depth <sup>(3)</sup> (mm/day)	10 day antecedent rainfall (mm)	20 day antecedent rainfall (mm)	30 day antecedent rainfall (mm)	Maximum rainfall event during previous 30 days (mm)
5/04/2017	336	408	54	60	129	28.5
20/05/2017	312	312	19	26.5	42.5	16
27/07/2017	384	336	144.5	176	189.5	121
23/01/2018	288	264	0.5	110.5	130	45.5

- Notes:**
- 1) Rainfall values are totalled up to 9:00 am on the day of the shut-down.
  - 2) Infiltration rate calculated as the median from the time that inflows to the basin ceased.
  - 3) Infiltration rate calculated as the median for the period when water depth in the basin was between 0.3 m and 0.2 m.
  - 4) Rainfall event occurred on the day before the shut-down.

**Table D6: Data excluded from analysis of infiltration rate versus groundwater depth.**

Site shut-down date <sup>(1)</sup>	Median infiltration rate <sup>(2)</sup> (mm/day)	Infiltration rate 0.3 to 0.2 m basin depth <sup>(3)</sup> (mm/day)	Groundwater depth GWE-01 (m)	Groundwater depth GWD-01 (m)	Groundwater depth GWD-05 (m)
5/04/2017	336	408	8.8	26.9	25.8
20/05/2017	312	312	8.5	27.2	20.3
27/07/2017	384	336	8.1	26.5	16.0
19/09/2017	624	600	8.1	21.0	9.4
23/01/2018	288	264	7.9	25.0	14.2

- Notes:**
- 1) Rainfall values totalled up to 9:00 am on the day of the shut-down.
  - 2) Infiltration rate calculated as a median from the time that inflows to the basin ceased.
  - 3) Infiltration rate calculated as a median for the period when water depth in the basin was between 0.3 m and 0.2 m.

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# APPENDIX E

## WGA MEMORANDA ON SITE UPGRADE

## TECHNICAL MEMORANDUM

DATE: 23 October 2017

JOB NUMBER: 171076 - Task 2.3

TO: Peter Lowe, Chairman (MAR Governance Group),  
Patrick Durney, CRC Monitoring Programme Leader

ATTENTION: Hinds / Hekeao MAR Governance Group Members

SUBJECT: Hinds Lagmhor Pilot Trial - Site Upgrade Assessment Method and Process

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### 1. INTRODUCTION

#### 1.1 Background

The Year 1 operational outcomes of the Hinds Lagmhor Pilot Trial successfully demonstrated the application of Managed Aquifer Recharge (MAR) to enhance groundwater storage and quality in Canterbury aquifers. Consequently, the Managed Aquifer Recharge Governance Group (MARGG) is proceeding with the identification of new MAR test sites within the catchment and development of test procedures for these sites under the Year 2 programme.

Analysis of the data from Year 1 indicates that the regional aquifer underlying the Pilot Trial site can accept substantially greater recharge volumes than was achieved through basin infiltration during the first year of the trial. None of the information or results arising from Year 1 suggest that the existing Lagmhor site cannot be upgraded to support a substantially higher recharge rate.

Given the observed improvements in groundwater storage and quality during Year 1, a further area of investigation for Year 2 is the potential for enhancing the recharge performance of the site. This memorandum, provided under Task 2.3 of the Hinds – Hekeao Scoping Study, reviews options for additional investigations at the site to improve recharge rates. A generic summary of tools that could be utilised to enhance the site performance is also presented.

It has been assumed, for the purposes of this memorandum that simply making changes to the site and monitoring the outcomes is not a favoured approach. A defensible scientific basis for the design of any proposed changes to the site, together with a clearly defined objective to the changes, is required.

Any new investigation procedures tested at the Lagmhor site should be considered for use in investigating new MAR sites. Successful and cost-effective investigation procedures built into the overall site investigation package would help to reduce the risk of sites being developed and then underperforming.

#### 1.2 Site Performance - Year 1

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

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Interpretation of the site hydrogeology based on Year 1 monitoring data and drill hole logs from the monitoring wells suggested the infiltration rate was limited by lower permeability layers or bands of finer grained silts and clayey material within the unsaturated zone beneath the site. An interpretation of the lithological sequence and the hydrogeological behaviour of the various units beneath the Pilot Trial site is summarised in Table 1, which has been sourced from the Hinds Managed Aquifer Recharge Phase 1 Report (Golder Associates 2017).

**Table 1: Interpreted Lithological Sequence Beneath Pilot Trial Site.**

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

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

A substantial fraction of the Year 1 infiltrated water flowed away from the site within a perched aquifer. This water did not contribute to recharge of the regional groundwater system directly beneath the site. It did however contribute recharge to the regional aquifer down-gradient from the site. This observation indicated that there are not only low permeability layers in the unsaturated zone beneath the site but also well connected high permeability (preferential) flow paths.

It is important to recognise that the concept of clearly defined, low permeability layers is a simplification of the site geology. The number, extent, thickness and continuity of various lithological units beneath the site is uncertain. However, this layer concept is useful for considering investigations required to support the design of a site upgrade.

The demonstrated effects of site operations during Year 1 included:

- Groundwater level effects on the regional aquifer over 1.6 km from the site.
- Groundwater level and quality effects in a perched aquifer over 2.3 km from the site.

These effects were achieved through the infiltration of water at rates in the order of 100 L/s during much of Year 1. The potential water delivery rate to the site is substantially greater, with the original planning based on a delivery rate of up to 500 L/s.

Installation of the clamshell holes beneath the floor of the infiltration basin did not substantially influence infiltration rates implying that upgrades limited to the upper six metres beneath the basin are unlikely to improve recharge performance.

### 1.3 Memorandum Scope

In addition to the introduction, this memorandum is divided into two sections.

- 1) Section 2 outlines investigation methods that could be applied at the site to identify and better define the hydrogeological factors limiting recharge rates. This section also presents recommendations on which methods should be applied, justification for the selected methods; and cost estimates to complete the investigations.
- 2) Section 3 provides a summary of the tools that could be applied to enhance the site performance. This summary is not exhaustive and is not intended to form the basis for the design of site changes. The aim is to provide an indication of the types of tools that may be applied to improve the site recharge performance and the advantages and disadvantages of each tool.

## 2. SITE INVESTIGATIONS

### 2.1 Investigation Criteria

In the options and recommendations provided below, several assumptions and guiding principles have been incorporated. These assumptions and principles include:

- 1) Objective: Any investigation method would need to be able to substantially reduce the uncertainty regarding the hydraulic behaviour of the soils beneath the Lagmhor Pilot Trial site, with a focus on the zone between the regional groundwater table and the ground surface. Considering the test schedule provided below, it is likely that this zone would incorporate a series of saturated and unsaturated layers at the time of testing. Test methods therefore need to take the variability in saturation into account.
- 2) Schedule: Any investigations need to be completed and the results incorporated in a summary document submitted to the MARGG by late December, in time for decisions to be reached on the site upgrade during the coming summer irrigation season when water supply to the Lagmhor site will presumably cease. This requirement would generally rule out the use of equipment currently unavailable in New Zealand.
- 3) Costs: The investigation costs need to be approximately in line with the itemised budget documented in the Hinds-Hekeao MAR Scoping Study approved by the MARGG (dated 5 October 2017).
- 4) Applicability: The investigation methods, if successfully demonstrated, should represent cost-effective options for the investigation of new MAR test sites prior to the full development of these sites.
- 5) Package development: The recommended investigation methods should, if possible, fit into a cost-effective package of investigation tools that could provide full assessment of the soils and hydrogeological units underlying the Lagmhor Pilot Trial site and, by extension, other MAR test sites.

### 2.2 Investigation Components

Two general options for further investigation of the Lagmhor site are available:

- Intrusive investigations, such as further drilling, excavations, etc.
- Non-intrusive investigations, such as tests in existing drillholes and surface geophysics.

#### 2.2.1 Intrusive investigation options

Intrusive investigations to supplement existing knowledge of the site have been considered, including:

- 1) Additional drilling in the base of the main infiltration basin, with drill core recovery for interpretation.
- 2) Geotechnical testing, such as the use of a cone penetrometer test (CPT) rig, to investigate variations in the soil strength and geotechnical behaviour beneath the floor of the main infiltration basin.

These intrusive investigation options have been considered against the criteria listed in Section 1.3 and ruled out at this point for the following reasons:

- Currently there is limited availability of drilling and geotechnical testing rigs, therefore it is unlikely that intrusive investigations at the site could be completed within the available timeframe.
- The costs involved in undertaking intrusive investigations, either using a drilling rig or a geotechnical test rig, would exceed the available budget. Especially given that investigations would need to be carried out at several points within the basin to provide a substantial improvement in the current understanding of the subsurface, as required under the first of the above criteria.
- Intensive drilling investigations of any sort are unlikely to represent a cost-effective component of an investigation package that could be applied to evaluate new MAR sites. Individual drillholes are likely to be needed for the installation of site monitoring systems at new MAR sites. However, these monitoring systems would generally be installed after a new test site has been identified, initial testing completed and intensive testing approved.

#### 2.2.2 Non-intrusive investigation options

Three general forms of non-intrusive investigations to supplement existing knowledge of the site have been considered:

- 1) Surface geophysical surveys.
- 2) Down-hole geophysical tests.
- 3) Tracer tests coupled with surface geophysics.

In each case some form of on-site geophysical monitoring will be required. The investigation costs are linked to the level of detail required and therefore investigation intensity.

Surface geophysical survey techniques available in New Zealand and considered as options include:

- Ground penetrating radar (GPR). A proven technology. A GPR survey is however only likely to penetrate to a depth of up to 10 m.
- Electrical resistivity (ER). A proven technology.
- Transient electromagnetic (TEM). A proven technology.
- Reflection and refraction seismic. A proven technology.
- Seismo-electric. A promising technology that is still under development and not widely used. We consider this to be an unproven technique that may however offer benefits in the future. At this point we have therefore excluded it from further consideration.

Down-hole geophysical survey techniques available in New Zealand that potentially offer clear benefits in evaluating the Lagmhor site are effectively limited to a natural gamma radiation logging.

Tracer tests that could be appropriately performed at the Lagmhor site and monitored without the need for underground sensors or monitoring systems are limited to the use of salty water as the tracer and monitoring the flows using electrical conductivity or electrical resistivity techniques.

## 2.3 Investigation Components Review

### 2.3.1 Target Definition

The investigation target depth ranges from about 10 m to 40 m below ground level, for practical site upgrade reasons. It is already clear that any upgrade would need to enhance seepage to depths considerably greater than six metres below the bottom of the basin, which is the maximum depth achieved in the existing clamshell holes. In addition, the total depth for site upgrade options may need to extend below the regional groundwater level measured at the start of Year 1, which is the reason for the lower limit for the survey penetration.

We expect at least two or more low permeability layers occur beneath the site, which are interpreted to have resulted in at least two perched groundwater lenses above the regional groundwater table. At this stage these lower permeability layers are estimated to be at depths of between 8 m to 18 m below the floor of the infiltration basin. Both layers are considered to be leaky, as evidenced by the regional groundwater table responding fairly quickly to the Year 1 MAR recharge. However, it is expected that both layers will support perched groundwater following the close of the 2017 infiltration operations. As such, these perched saturated layers may be detectable in the geophysical surveys and, if detected, may help in our interpretation of the hydrogeological system beneath the site.

### 2.3.2 Seismic Reflection or Refraction

- A seismic survey can identify the structure of the sub-surface but not the actual materials present. The survey therefore is required to be “calibrated” against geological or geophysical logs of boreholes (GWD-01) for ground truthing purposes.
- For practical purposes a reflection survey is normally limited to > 20 m depth. Saturated sediments however have a substantially high P-wave velocity than unsaturated sediments, which means perched layers of saturated sediments can be easily distinguished at shallower depths using a refraction survey.
- For the detection of shallow perched groundwater layers, a refraction seismic survey is more appropriate than a reflection seismic survey. There is no real minimum depth limit on the detection of saturated layers within a sedimentary column. A refraction survey may also be able to pick up the base of the saturated zone, which would approximately correspond to the base of a lower permeability layer
- The reliability of seismic surveys is a function of the inversion algorithms used to interpret the signal response. Sometimes, due to rapid transit times of the signals, the definition of the upper surface layers (< 5 m) is poor.

### 2.3.3 Ground Penetrating Radar (GPR)

- GPR is a very quick and therefore a lower cost-effective survey method. It can identify the structure of the sub-surface but not the actual materials present. The survey therefore is required to be “calibrated” against geological or geophysical logs of boreholes (GWD-01) for ground truthing purposes.
- GPR does not distinguish between saturated zones and lithological / mineralogical units. It will however normally pick up the groundwater table clearly.
- The survey depth is likely to be limited to < 15 m approx. Ground penetration decreases when highly conductive materials are present, such as silts and clays, and increases with more clean sand and gravel layers. Longer antenna lengths can increase ground penetration depth, but this comes at a cost of reduced resolution of the geological structures.
- If a material is too conductive, which potentially includes a saturated layer, the radar signal is adsorbed and loses further penetration. This feature may be useful in the case of the Lagmhor site for detecting the shallowest perched groundwater layer. A potential risk using this method is that it may only define the geological structures down to the uppermost perched groundwater table, with no further penetration.

### 2.3.4 Electrical Resistivity

- Resistivity surveys are useful for investigating highly conductive materials, such as fine silts and clays (exactly the opposite of radar surveys), which is why they are often used in tandem.
- There is no limit to their penetration however they function best in materials with high clay content.
- Resolution is not as good as with GPR, resulting in increased uncertainty regarding the geological features detected.
- Perched groundwater layers should be easily detectable.

### 2.3.5 Transient Electromagnetic Survey

- Generally used in New Zealand to detect shallow features such as buried cables, metal tanks and other metal objects. Used overseas for mapping of groundwater at depths of several tens of metres.
- Results are highly dependent on the accuracy of the measurements and calibration against down hole geophysics is required to achieve better interpretation.
- The depth of penetration depends on the area covered by the transmitter cable.
- Experience with using this method for groundwater and geological surveys in New Zealand is limited.

### 2.3.6 Natural Gamma Down-hole Logging

- Natural gamma rays are primarily generated from the decay of naturally occurring potassium, which tends to be concentrated in clays and clay-derived rocks. Down-hole surveys are commonly used to identify clay-rich layers, including clay-bound gravels.
- Surveys can be performed in bores with any type of casing, however the sensitivity decreases in larger diameter bores with a significant thickness of standing water between the sensor and the bore wall.
- The survey does not detect groundwater and is not normally affected by the degree of ground saturation.
- This type of downhole survey is commonly used in conjunction with surface geophysical surveys to link soil or rock type with the geological structures.

### 2.3.7 Tracer Testing

- Saline water has a higher electrical conductivity than natural fresh water. Following the close of infiltration operations for Year 2, saline water could be infiltrated through a small basin excavated into the base of the main infiltration basin. The downward and lateral movement of the saline water can be tracked using surface geophysics.
- This technique is commonly used internationally to investigate groundwater flows within a saturated aquifer. It is however not clear that this technique can be used to monitor the movement of water downward and laterally through a series of perched aquifers. This technique was included in this list as it does offer the possibility of directly tracking the movement of water out of the infiltration basin down into and within the regional groundwater system.

## 2.4 Recommendations and Estimated Costs

Based on the information provided above, WGA recommends undertaking further investigations of the Lagmhor site after the infiltration programme for 2017 has finished and the basins no longer contain water. These investigations should consist of:

- 1) A refraction seismic survey across the site, with at least one of the seismic lines intersecting the location of GWD-01. This survey should identify perched groundwater layers, the regional groundwater table and clearly defined fine-grained strata to depths of up to 40 m.
- 2) A GPR survey line matching the refraction seismic line that intersects GWD-01. The purpose is to determine if GPR, which is a very cost-effective technique, generated similar outcomes to the refraction seismic survey in terms of identifying the geological layering and groundwater table beneath the basin.
- 3) Undertake natural gamma down-hole logging in monitoring wells GWD-01, GWE-01, GWD-03 and GWD-04. All four monitoring wells could be surveyed in a single day. The inclusion of GWE-03 provides a comparison point for one of the new MAR sites already identified for initial investigation.

The estimated costs provided by contractors to undertake the work listed above is summarised in Table 2.

**Table 2: Estimated costs.**

Investigation component	Estimated cost (excl GST)
Seismic refraction survey of four seismic lines, data processing, analysis and interpretation	\$ 15,760
GPR survey line (if undertaken in conjunction with the refraction survey), data processing, analysis and interpretation	\$ 900
Down-hole gamma logging of four monitoring wells (one day), including interpretation and documentation	\$ 2,000
<b>Total</b>	<b>\$ 18,660</b>

## 3. RECHARGE ENHANCEMENT OPTIONS

### 3.1 Background

An interpretation of the lithological sequence and the hydrogeological behaviour of the various units beneath the Pilot Trial site was summarised in Table 1. Clamshell holes installed to depths of six metres below the floor of the main infiltration basin did not result in increased infiltration rates. The reasons for the lower than expected infiltration rate and the lack of effect from the clamshell holes were summarised in Section 1.2 above. There is no reason to expect that additional shallow infiltration holes or trenches installed as a site upgrade would result in a different outcome.

Enhanced recharge at the site therefore depends on the installation or development of flow paths or conduits downward through any zones of lower permeability materials that are present beneath the infiltration basin.

### 3.2 Objectives

The specific objectives of any upgrade are still to be defined, however two potential objectives could be:

- 1) Enhance recharge to the interpreted perched aquifer and thereby increase flows within this aquifer toward the southeast beneath Fraser Road toward the Tinwald nitrate hotspot.
- 2) Enhance recharge to the regional groundwater system and thereby further improve water supply security for local groundwater users dependent on this aquifer.

There are a range of options available for upgrading the site to improve recharge rates, either to the perched aquifer or to the regional groundwater system. A few of these options are summarised below.

In addition, the expected longevity of any upgrades needs to be considered. Preferential water flows through these channels or conduits, compared to through the floor of the basin, also implies higher sediment loads being delivered to these channels and therefore increased risk of clogging.

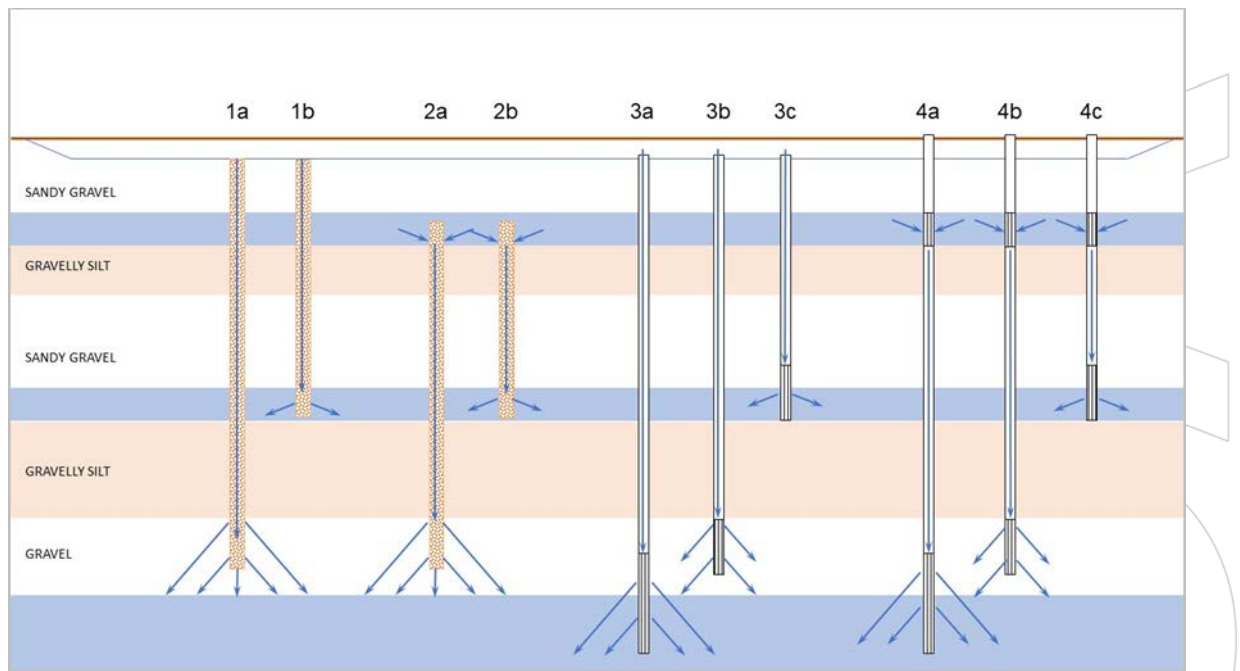
Management of this risk to ensure a long effective operational period needs to be considered as one of the objectives of any site upgrade.

### 3.3 Deep recharge holes

One or more deep recharge holes filled with clean cobbles, of a similar diameter and style to the clamshell holes, can potentially be installed using a bucket auger or a bucket rig. Locally available rigs should be able to excavate holes of this size to depths of 30 m if required. During excavation the hole can be held open by a temporary steel casing, which is progressively withdrawn as the hole is filled with cobbles. Deep recharge holes can be installed extending from the floor of the infiltration basin to either the regional aquifer (see Figure 1, Option 1a) or to the perched aquifer (Option 1b).

Once installed, the flow rates through these deep recharge holes cannot be managed. Sediment loads carried by the water flows would need to be managed within the infiltration basin, as clogging of the cobble filled holes cannot be reversed.

**Figure 1: Recharge system upgrade options.**



An option for managing the risk of clogging would be to install blind recharge holes (Figure 1, Options 2a and 2b). Instead of opening directly into the infiltration basin, the upper end of the hole is refilled with finer gravelly sands, similar in nature to the material excavated from the hole. Water flows into the blind holes would be derived from water recharged to the uppermost six metres below the basin. The floor of the basin would act to remove most of the sediment load and the water entering the recharge hole should be carrying relatively low sediment loads.

### 3.4 Recharge Wells

Recharge wells of 100 mm or 150 mm diameter, similar to small water bores, could be installed as conduits for water flows down into the target aquifers (Figure 1, Options 3a, 3b, 3c). These wells would be similar structures to normal water bores but function in the opposite manner. They would consist of steel cased wells, with a steel screen installed at the target depth. The screen can be installed either within the target aquifer (Options 3a and 3c) or in the unsaturated zone above the target aquifer (Option 3b), which is termed a “dry hole”.

Recharge wells that penetrate to the target aquifer offer an advantage over deep recharge holes in that a pump can be installed in the bore. Pumping water out of the well means flows through the well screen are reversed and accumulated silt that may be clogging the screen can be flushed out of the hole and discharged away from the basin. Reverse flows are used in practically all MAR wells internationally to maintain well efficiency. Back flushing the well periodically is however unlikely to be a practical means of managing clogging by itself. Further measures would probably be needed to be installed within the infiltration basin to reduce the sediment concentrations in the water being introduced to the well. ‘Dry wells’, as indicated by their name, cannot be backwashed.

One means of reducing sediment loads to recharge wells is the use of double screened wells (Figure 1, Options 4a, 4b and 4c). In a similar manner to the blind recharge holes, these wells would take water

in through a screen positioned in the uppermost perched aquifer and discharge it to a deeper aquifer through a second screen. Again, the sandy gravels in the uppermost six metres beneath the basin floor would act as a filter to reduce the sediment loads entering the well. The well casing would extend above the operational water level in the basin and be capped to prevent water entry directly from the basin.

There are other methods for managing sediment loads prior to the water entering the recharge wells. One potential solution would be to build a specialised filter cap (e.g. a sand layer) and under-drain system that would help to filter the water before it entered the recharge well. Discussions between WGA and Stuart Tarbotton's staff have identified several options in the event that site investigation outcomes indicate that an upgrade should proceed.

### 3.5 Water Treatment in Basin

Irrespective of the design of the recharge system identified as being the most cost-effective over the long term, one of the primary requirements will be to manage sediment loads and potentially biological growth within the recharge hole or well.

The suspended sediment concentrations measured in the infiltration basin during Year 1 were generally low (regularly less than the detection limit of 2 g/m<sup>3</sup>). Under a flow rate of 100 L/s, this concentration converts to a mass load in the order of 17 kg/day. In a well with a screen, reduced efficiency through clogging would be detectable within a few days.

Regular short backflushing operations would help to manage clogging. However, the most effective means of maintaining the efficiency of a recharge hole or well is to minimise sediment concentrations in the water entering the conduit. As described above, blind holes or double screened wells are one means of achieving this objective. Other options include:

- Passively filtering the water in the infiltration basin before it reaches the conduit intake.
- Modifying the design of the forebay to improve sediment removal before the water reaches the main infiltration basin.

### 3.6 Consenting

A recharge system for the site in which water from the basin is introduced directly to a target aquifer may require a new resource consent. The primary issue to be considered in a consenting process would be managing the introduction of biological contaminants (*E. coli*) to the aquifer.

During Year 1 of the Pilot Trial monitoring indicated that *E. coli* present in the water in the infiltration basin was not transported in seepage water to the lower perched aquifer beneath the basin or to the regional groundwater system. Designing a site upgrade to continue to utilise the natural *E. coli* filtering capacity of the soils would potentially offer advantages during any consenting process.

Pathogen attenuation in aquifers associated with MAR activities has been extensively researched over the past decade. The results of these studies have universally concluded that up to three log removal of pathogens can be achieved (e.g., from 100 MPN/100 mL down to 1 MPN/100 mL). In the case of *E. coli*, three log removal can be achieved within 10 days residence time of the recharged water in the aquifer.

## 4. SUMMARY

The regional aquifer underlying the Pilot Trial site can accept substantially greater recharge volumes than was achieved through basin infiltration during the first year of the trial. None of the information or results arising from Year 1 suggest that the existing Laghmor site cannot be upgraded to support a substantially higher recharge rate.

A cost-effective upgrade for the Laghmor Pilot Trial site needs to be informed by additional site investigations prior to the design, costing and undertaking of the upgrade. WGA recommends that geophysical investigations at the site be undertaken, once recharge operations for the 2017 season have been completed, with these investigations consisting of:

- A refraction seismic survey, combined with a single survey line of ground penetrating radar
- Natural gamma down-hole logging of up to four existing monitoring wells.
- The total estimated cost of the above investigations is \$18,660 + GST.

Successful and cost-effective investigation procedures developed at the Lagmhor Pilot Trial site can be built into a standardised site investigation package for new MAR sites to reduce the risk of underperforming sites being developed.

The specific objectives of any site upgrade need to be confirmed prior to upgrade design work starting.

Site upgrade options should be focused on installing or developing preferred flow paths or conduits downward through any zones of lower permeability materials that are present beneath the infiltration basin. Options include the installation of deep cobble-filled recharge holes and recharge wells. The equipment and expertise to install these recharge systems is available in Canterbury.

Clogging of the artificial flow paths or conduits is an operational issue that would require management, preferably through the reduction of sediment loads entering the recharge systems. Installation of artificial flow paths or conduits to enhance recharge rates to the underlying aquifers may require a resource consent. The most likely consenting issue needing to be addressed would be the risk of biological contamination (e.g., *E. coli*) of the receiving water in the aquifer.

If you require clarification on any of the approaches or methods presented in this Technical Memorandum please do not hesitate to contact the undersigned.

Yours faithfully



Brett Sinclair  
for  
**WALLBRIDGE GILBERT AZTEC**

BS:BB:RM:nd



## TECHNICAL MEMORANDUM

DATE: 6 December 2017

JOB NUMBER: 171076 - Task 2.3

TO: Peter Lowe, Chairman (Hinds / Hekeao MAR Governance Group),  
Brett Painter, CRC Project Manager  
Mark Trewartha, CRC Technical Lead

ATTENTION: Hinds / Hekeao MAR Governance Group Members

SUBJECT: Hinds Lagmhor Pilot Trial - Site Upgrade Assessment Outcomes and Recommendations

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### 1. LAGMHOR PILOT TRIAL SITE UPGRADE RECOMMENDATIONS

Based on the information presented in this memorandum, WGA recommends that:

- 1) The Hinds / Hekeao MAR Governance Group (MARGG) proceed (**GO**) with an upgrade to the Lagmhor Pilot Trial site through the installation and testing of the 'dry well' MAR technology early in 2018. The objective of this installation is to test the efficiency of the design to increase recharge to the perched aquifer located at a depth of approximately 9 m to 18 m below the floor of the existing infiltration basin but not directly connected to the regional groundwater table (25 m to 32 m below ground level). The proposed 'dry well' design is shown as 1b in Figure 5.
- 2) That a passive filtration system be installed as part of the dry well upgrade to reduce the potential suspended sediment load to the dry well and thereby help to manage the risk of clogging and transport of possible particle-bound bacteria in the source water.
- 3) That the existing Pilot Trial groundwater level and quality monitoring programme be revised to enable adequate evaluation of the changes in water levels and quality related to the MAR upgrade testing.

The above recommendations are made to enable the efficiency and viability of dry wells to be evaluated as a Hinds-specific MAR tool. These recommendations are also made with the objective of enhancing the performance of the existing Pilot Trial site and utilising the existing site monitoring infrastructure to test various options for application across the catchment. If the proposed dry well proves effective, installations of similar design may be used at other sites around the catchment, and may provide a more cost-effective approach to MAR.

WGA recognises that the direct infiltration of water to an aquifer used as a source of water for food production or as a drinking water supply carries inherent risks of contamination. The proposed infiltration dry well has been designed to address these risks through:

- Continuing to utilise water from a high-quality source (Rangitata River).
- The installation of engineered water filtering measures.
- The avoidance of direct discharge of source water into the regional groundwater table.
- Maximising the natural attenuation provided by subsurface soils.
- Regular monitoring of source and receiving water quality.

Upgrade recommendations have been partially costed, with total costs expected to be within the allocated project budget (Task 2.5).

Information supporting the above recommendations is presented in the following memorandum.

## 2. INTRODUCTION

### 2.1 Background

The Year 1 operational outcomes of the Hinds Lagmhor Pilot Trial successfully demonstrated the application of Managed Aquifer Recharge (MAR) to enhance groundwater storage and quality in Canterbury aquifers (Golder, 2017). Analysis of the data from Year 1 indicated that the regional aquifer underlying the Pilot Trial site can accept substantially greater recharge volumes than were achieved through basin infiltration during the first year of the trial.

The Year 1 results suggest that the existing Lagmhor site can be upgraded to support a substantially higher recharge rate. Furthermore, the site offers excellent opportunities for testing of other MAR designs and tools due to the existing groundwater monitoring system and the availability of greater flows to the site if required.

WGA recommended further investigation of the Lagmhor MAR Pilot Trial site to support the GO / NO GO decision for a site upgrade. These investigations, which consisted of combined surface and down-hole geophysical investigations, were approved at a meeting of the MARGG on 27 October 2017.

Recharge operations at the site ceased approximately 12 days prior to the geophysical surveys. This was done to provide the survey teams access to the floor of the infiltration basin for survey lines. At the time of the survey the floor of the infiltration basin was dry.

### 2.2 Upgrade Testing Objectives

Enhanced recharge at the Lagmhor site depends on the construction or development of flow paths or conduits downward through interpreted zones of lower permeability materials that are present beneath the infiltration basin. Impeding layers beneath infiltration sites is a well-documented issue in MAR site management, leading to localised mounding and reduced recharge rate efficiencies. During the design and consenting process for the Lagmhor MAR Pilot site, the potential for mounding to occur was considered. The initial testing of what were termed 'clamshell holes' was incorporated into the final construction plan with the installation of 26 holes to a depth of approximately six metres distributed across the floor of the infiltration basin.

Although the clamshell holes were not successful at increasing infiltration rates, they did provide valuable information on how the sub-surface beneath the site functions hydraulically. These holes appear to have been completed to just above a shallow aquitard, probably consisting of a clayey silt layer. This aquitard induced groundwater mounding beneath the basin and limited the overall recharge rate. WGA's interpretation is that the clamshell holes did not increase infiltration rates as they did not penetrate through the silt aquitard.

The proposed objectives of the upgrade include:

- 1) Installing and testing a MAR tool that could be widely utilised as part of the planned Hinds Groundwater Replenishment Scheme.
- 2) Design testing to manage clogging (at the surface) to ensure its operational longevity and cost effectiveness for catchment-wide application.
- 3) Enhance overall recharge rates at the Lagmhor MAR Pilot site and thereby increase the flows and volume of high quality water moving southeast beneath Fraser Road toward the Tinwald nitrate hotspot.
- 4) Develop a MAR upgrade design (dry well) that continues to maximise the natural attenuation of surface water contaminants provided by the soil aquifer treatment (SAT) process.
- 5) Enhance the amount of recharge to the regional groundwater system and thereby further improve water supply security for local groundwater users dependent on this aquifer and increase the opportunity to improve baseflow conditions in the coastal drains.

A range of options for upgrading the site to improve recharge rates are summarised below. In addition, the expected longevity of any upgrade design needs to be considered. Infiltration basins capture sediments at the surface, allowing for easy drying and removal and thereby easier management of clogging. Preferential water flow through an artificial conduit, such as a dry well, increases the risks of clogging which is more difficult to manage downhole. Management of this risk to ensure a long effective operational period needs to be one of the objectives of any site upgrade.

## 2.3 Memorandum Scope

In addition to the introduction, this memorandum is divided into four sections.

- 1) A summary of the site geophysical investigation results, and interpretation of these results, in conjunction with the outcomes from the Year 1 Pilot Trial monitoring to support the decision process for an upgrade of the site.
- 2) A technical recommendation (GO / NO GO) based on the interpretation of the geophysical test results together with the data derived from the Year 1 monitoring of the Pilot Trial.
- 3) A MAR site upgrade concept design to manage the risk of clogging of the flow routes installed as part of the site upgrade.
- 4) An estimate of costs for the MARGG to consider, which takes on board CRC consenting / compliance considerations (e.g. water to water contact).

## 3. SITE INVESTIGATIONS AND OUTCOMES

### 3.1 Completed Work

Geophysical testing at the MAR site was approved by the MARGG to determine if an upgrade was reasonable. The geophysical investigations were performed by two sub-contractors, Field Technical Services Ltd (Adrian Field) and Southern Geophysical Ltd (Christian Ruegg). The site investigations they undertook were:

- 1) Natural gamma down-hole logging in monitoring wells GWD-01, GWE-01, GWD-02, GWD-03 and GWD-04. All five monitoring wells were surveyed in a single day (Field Technical Services Ltd).
- 2) A refraction seismic survey across the site, with at least one of the seismic lines intersecting the location of GWD-01. It was anticipated this survey should identify perched groundwater layers, the regional groundwater table and clearly defined fine-grained strata to depths of up to 40 m (Southern Geophysical Ltd).
- 3) A GPR survey line matching the refraction seismic line that intersects GWD-01. The purpose is to determine if GPR, which is a very cost-effective technique, generated similar outcomes to the refraction seismic survey in terms of identifying the geological layering and groundwater table beneath the basin (Southern Geophysical Ltd).

This section provides the background information and results from these investigations.

#### 3.1.1 Site performance summary for Year 1

Interpretation of the site hydrogeology based on Year 1 monitoring data and drill hole logs from the monitoring wells suggested the infiltration rate was limited by lower permeability layers or bands of finer grained silts and clayey material within the unsaturated zone beneath the site. An interpretation of the lithological sequence and the hydrogeological behaviour of the various units beneath the Pilot Trial site is summarised in Table 1, which has been sourced from the Hinds MAR Phase 1 Report (Golder, 2017).

Potentially groundwater bearing layers are identified in Table 1, from top to bottom, as AQ1 to AQ3, with the aquitards identified in sequence as AQT1 and AQT2. This reference numbering is also used later in this memorandum to clearly identify the units discussed.

**Table 1: Interpreted lithological sequence beneath pilot trial site.**

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

- Notes**
- 1) Based on geological log from Monitoring Well GWD-01.
  - 2) Approximated from Year 1 monitoring data.
  - 3) Assumed complete saturation of uppermost gravels beneath basin.

During the trial, each of the potentially groundwater bearing layers beneath the site appeared to fill up until the groundwater pressure in each layer was at approximately the level interpreted as the base of the overlying aquitard. In the case of the uppermost groundwater bearing layer (AQ1), the infiltrating water is interpreted to have filled this unit completely in the area beneath the basin. This observation implies that:

- 1) The aquitards restricted the downward seepage rate from the basin.
- 2) The lateral hydraulic pressure gradients driving water outward from beneath the basin did not reach their full potential in either of the two lower aquifers (AQT2 and AQT3).

Installation of the clamshell holes beneath the floor of the infiltration basin did not substantially influence infiltration rates, based on monitoring of a short period of 'pre-clamshell hole' recharge testing (May 2017). During the trial, the uppermost perched groundwater layer would have become filled with recharge water, irrespective of the presence of the clamshell holes. The underlying aquitard limited downward flows, inducing mounding which limited the overall recharge performance.

The measured effects of site operations during Year 1 included:

- Groundwater level effects on the regional aquifer (AQT1) over 1.6 km from the site.
- Groundwater level and quality effects in a perched aquifer (AQT2) over 2.3 km from the site.

The actual effects extended over a considerably larger area by the end of Year 1.

These effects were achieved through the infiltration of water at a maximum average rate of 113 L/s during much of Year 1. The potential rate of water delivery to the site is substantially greater, with the original planning based on a delivery rate of up to 500 L/s.

### **3.1.2 Groundwater Levels – Pilot Trial Site Year 2**

The evaluation of the geophysical survey data needs to take account of groundwater levels at the time of the survey. Specifically, the outcomes from the refraction seismic survey need to be evaluated in conjunction with groundwater level data.

The geophysical surveys at the Lagmhor Pilot Trial site were undertaken during 13 to 16 November 2017. Rainfall during the period from August to September 2017 was unusually heavy, which was reflected in regional groundwater levels rising substantially during this period, as shown in the groundwater level data from Monitoring Well GWD-01 (Figure 1). At the time of the surveys, regional groundwater levels were still well above the levels recorded immediately prior to the start of the Pilot Trial, however they were declining rapidly.

The rapid rise and subsequent decline in groundwater levels during the August to November period would normally be expected to be reflected in perched groundwater level trends. The groundwater level record from Monitoring Well GWE-01 (Figure 2) indicates that the winter rainfall from August to September did not have a measurable effect on perched groundwater beneath the Pilot Trial site. The perched groundwater level as measured at GWE-01 appears to have been controlled by recharge water from the MAR site.

### **3.1.3 Natural Gamma Down-hole Logging**

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

The natural gamma bore logging was undertaken by Field Technical Services Ltd, as summarised in Table 2. The final report from the logging programme is attached to this memorandum.

**Table 2: Monitoring wells logged for natural gamma.**

Monitoring wells logged	Maximum logging depth (m)	Notes
GWD-01	6.5	Sonde blocked at 6.5m true depth
GWD-02	30.8	Sonde reached full hole depth
GWD-03 <sup>(1)</sup>	28.0	Sonde reached full hole depth
GWD-04	11.5	Sonde blocked at 11.5m true depth
GWE-01	17.5	Sonde reached full hole depth

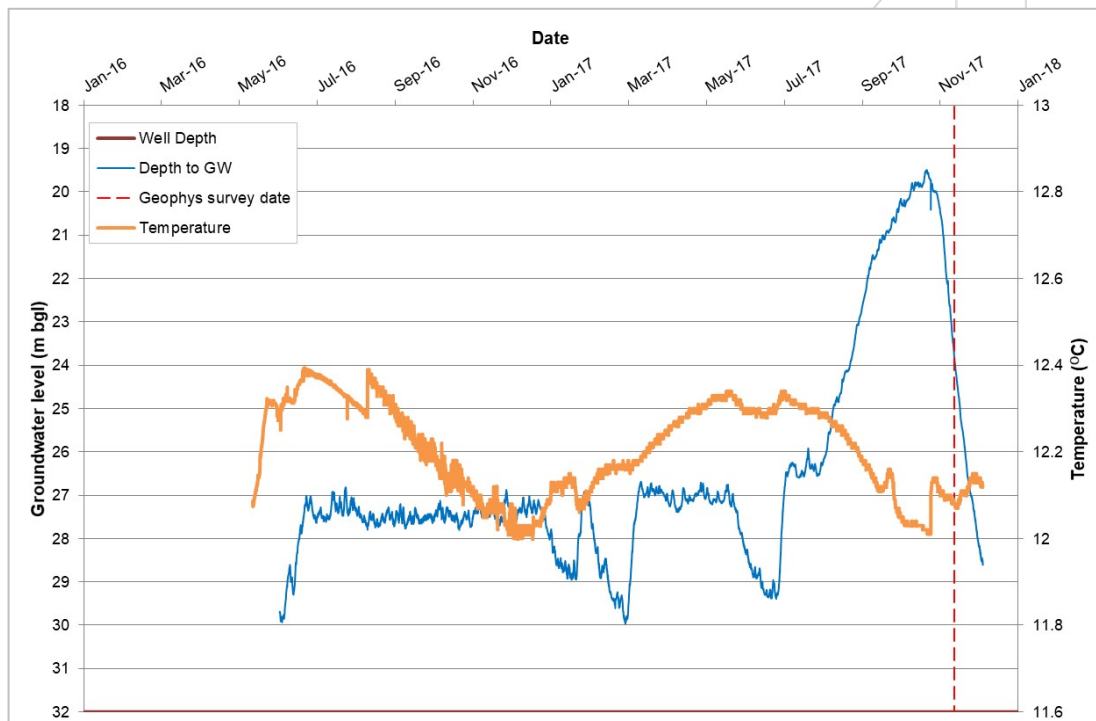
**Notes** 1) Monitoring well GWD-03 was not originally planned for gamma logging.

A hydrogeological interpretation of the natural gamma logs is presented in Figure 3. The dashed red lines in Figure 3 are used to interpret corresponding lithologies and hydrogeological features intersected in each of the monitoring wells.

Unfortunately, only one of the monitoring wells surveyed near the Pilot Trial site (GWD-02) provided a log that extended past a depth of 17 m, which means a confident interpretation of potentially continuous groundwater bearing layers below this depth cannot be provided from this data.

Summarising the information presented in Figure 3:

- A unit relatively high in silt and clay is present between depths of approximately 5 m and 9 m bgl in each of the monitoring wells. This is considered to represent the uppermost minor aquitard (AQT1).
- A clay rich unit was identified at depths of between 19 m and 26 m in GWD02 and GWE01. This unit may form part of a lower aquitard (AQT2).
- The logs clearly show the presence of silty / clayey units in stark contrast to clean gravel units, and consequently demonstrate the value of undertaking natural gamma logs to support future monitoring bore evaluation.



**Figure 1: Depth to groundwater in Monitoring Well GWD-01.**

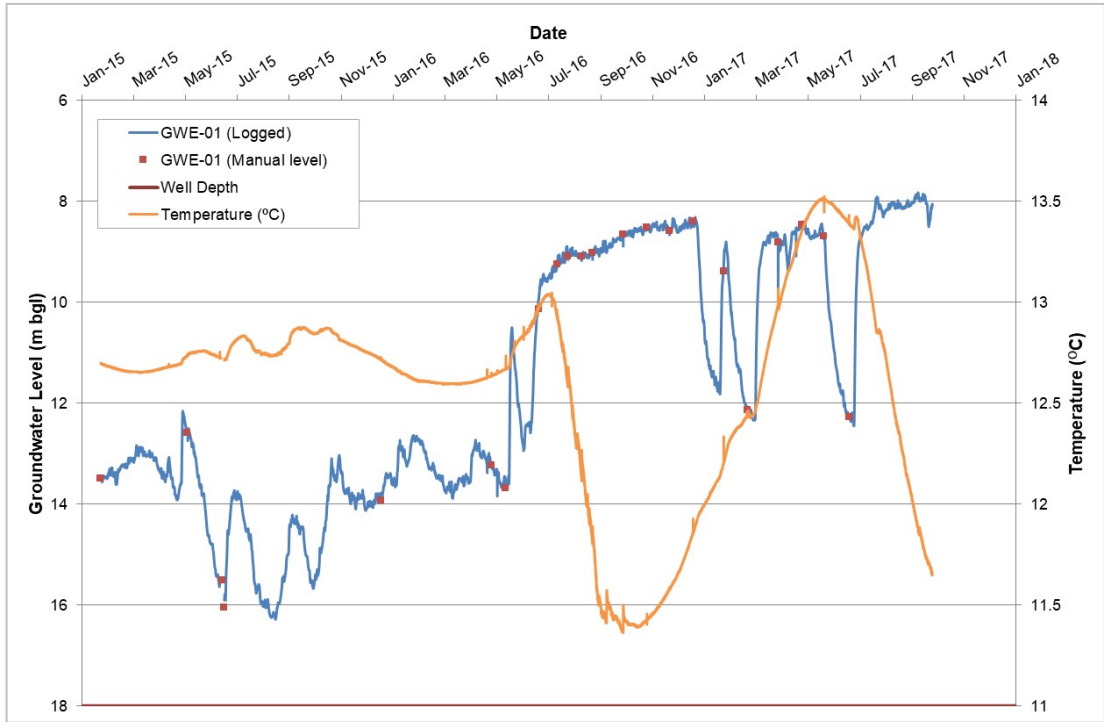


Figure 2: Depth to groundwater in Monitoring Well GWE-01.



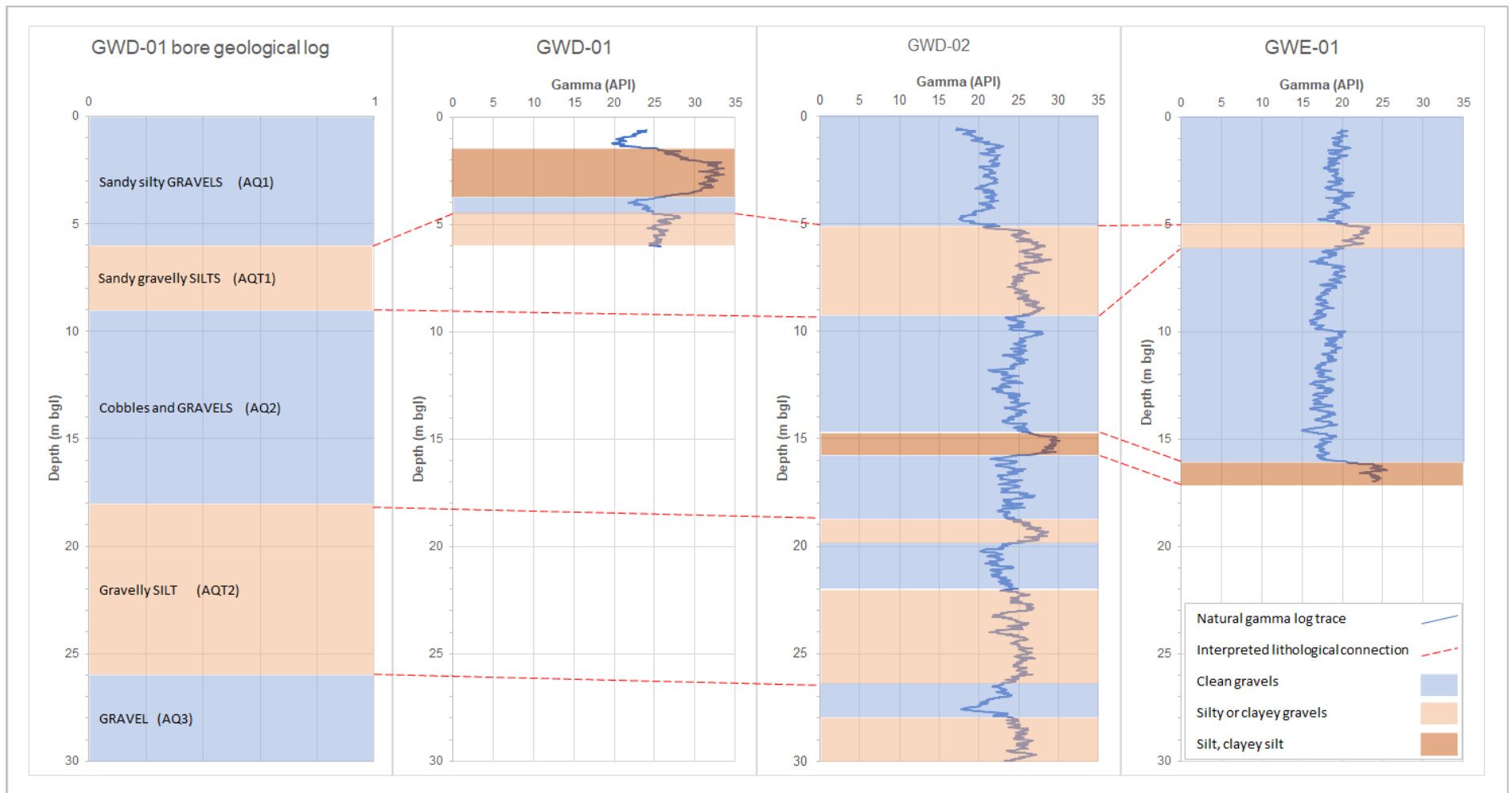


Figure 3: Natural gamma log interpretation for bores close to Lagmhor Pilot Trial site.

### 3.1.4 Seismic Refraction Survey

A seismic survey was performed by Southern Geophysics Ltd to identify the structure of the sub-surface geology. A survey of this type identified changes between different lithological units rather than identifying the actual materials present. The survey therefore is required to be “calibrated” against geological or geophysical logs of boreholes (GWD-01) for ground truthing purposes.

Saturated sediments have a substantially higher P-wave velocity than unsaturated sediments. This means perched layers of saturated sediments can be distinguished at shallow depths using a refraction survey. The refraction survey could also pick up the base of saturated zones, which is interpreted to correspond approximately to the base of lower permeability layers.

The locations of the survey lines summarised in Table 3 are shown in Figure 4.

**Table 3: Seismic refraction survey lines.**

Survey line	Description	Length (m)
Seismic Refraction 1	Eastern side of MAR site	193.5
Seismic Refraction 2	Southwestern side of MAR site	141.1
Seismic Refraction 3	Western side of MAR site	136.3
Seismic Refraction 4	Northern side of MAR site	131.3

Each of the four seismic refraction survey lines show rapidly increasing P-wave velocities from the surface to the 1,300 m/s contour at between 3 m and 5 m depth. This <500 m/s to 1,300 m/s zone is suggested to represent unsaturated or very low saturation soils. The depth at which the 1,300 m/s velocity is exceeded is similar to the limit of GPR survey penetration (refer Section 2.1.3), which supports the interpretation of a perched groundwater table at this depth.

The Southern Geophysics report attached to this memorandum indicates the rest of the refraction profiles show gradually increasing P-wave velocities with some velocity inversions. The lower velocity zones likely indicate soils with a lower saturation. The refraction profiles in the attached report have been simplified to show three zones:

- 1) <500 m/s to 1,300 m/s (unsaturated)
- 2) 1,300 m/s to 1,500 m/s (partially saturated)
- 3) 1,500 m/s to >1,800 m/s (saturated)

The interpretation of degree of saturation for each of these three zones should be treated with caution as the velocity changes may also be related to changes in soil type.

In the case of Seismic Refraction Line 1, the inversion of the seismic wave velocities suggests the presence of a shallow aquitard layer at a depth of between 4 m and 6 m below ground level. The results from Seismic Refraction Lines 3 and 4 suggest the aquitard is at a greater depth, from about 8 m to 10 m below the floor of the infiltration basin.

### 3.1.5 Ground Penetrating Radar (GPR)

A GPR survey identifies the structure of the sub-surface in terms of boundaries between different materials, however it does not identify the actual materials present. GPR does not distinguish between saturated zones and lithological / mineralogical units. If a material is too conductive, which potentially includes a saturated layer, the radar signal is adsorbed and loses further penetration. For this reason, GPR will normally pick up a shallow groundwater table clearly.

Ground penetration decreases when highly conductive materials are present, such as silts and clays, and increases with more clean sand and gravel layers.

GPR is a very quick and therefore cost-effective surface geophysical survey method. It does however need to be “calibrated” against geological or geophysical logs of boreholes (GWD-01) for ground truthing purposes. Although the natural gamma log of GWD-01 could not be completed, the existing geological log for the monitoring well was sufficient for this purpose.

Only one GPR line was originally planned as part of the project. During the time required to complete the four seismic refraction lines however, eight GPR survey lines of various lengths were also completed by Southern Geophysics (Table 4, Figure 4). Detailed documentation of the GPR survey is provided in the attached report by Southern Geophysics.

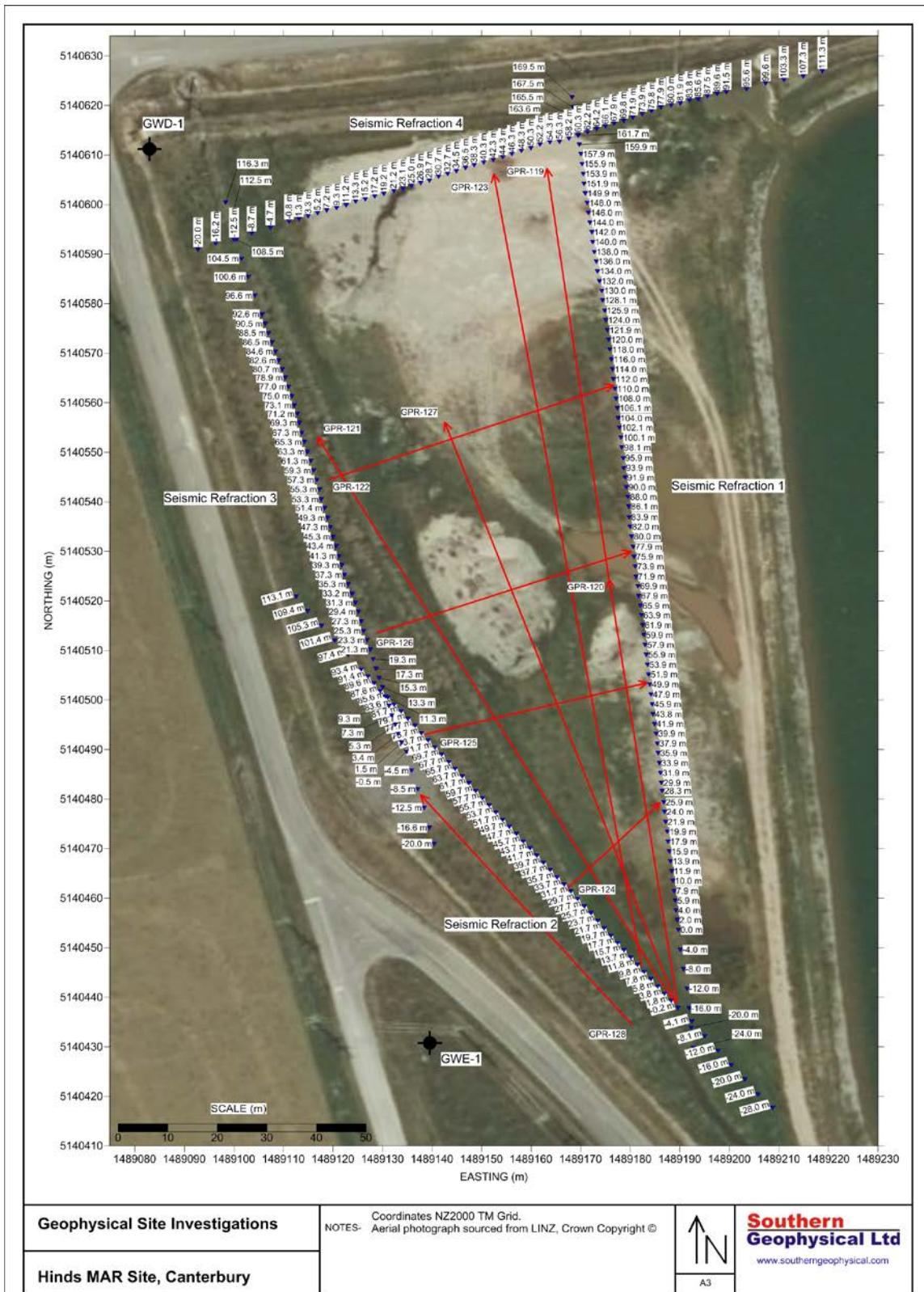


Figure 4: Surface geophysical survey line locations.

**Table 4: GPR survey lines.**

Survey line	Orientation	Description
GPR119 – GPR120	N / S	Eastern side of MAR site – inside basin
GPR121	SE / NW	Western side of MAR site – inside basin
GPR122	W / E	Northern side of infiltration basin
GPR123	N / S	Eastern side of MAR site – inside basin
GPR124	SW / NE	Southern end of MAR site – inside basin
GPR125	W / E	Centre of infiltration basin
GPR126	W / E	Centre of infiltration basin
GPR127	SE / NW	Northern side of infiltration basin
GPR128	SE / NW	Southeastern side of site, outside basin.

Most of the survey lines did not result in ground signal penetration of more than 3 m to 5 m below ground level, with the depth of penetration being variable along each survey line. This depth of penetration is interpreted to reflect the depth to the shallowest perched groundwater table at the time of the survey. This groundwater level is similar to the groundwater level observed in the clamshell holes during their construction.

Localised geological features are detectable in the GPR survey line results. In addition, features corresponding to clamshell holes are also very clear in some survey lines (e.g., GPR127). These features are however not of major interest for the purposes of this memorandum as they are all above the level of the upper aquitard (AQT1) that is interpreted to be supporting the shallow perched groundwater table.

### 3.1.6 Summary

Overall, the outcomes from the Year 1 Pilot Trial monitoring, the refraction seismic and GPR surface geophysical surveys and the natural gamma downhole logs are consistent with the interpretation of the presence of a shallow aquitard (AQT1) beneath the infiltration basin. At the time the investigation work was undertaken, and during Year 1, this aquitard supported a perched groundwater layer derived from the MAR site, with this groundwater mounding limiting the recharge rate from the infiltration basin.

A deeper aquitard (AQT2) is clearly present beneath the site, based on interpretation of the monitoring results from Year 1 of the Pilot Trial. This layer is identifiable in the natural gamma log for GWE-01, however it has not been detected in the refraction seismic survey results. The reason for this may be the high regional groundwater table at the time of the geophysical survey, which was close to the base of the lower aquitard (AQT2). Consequently, there may not have been a clear unsaturated zone below the base of this aquitard to be detected at the time of the survey.

The combined information from the various lines of investigation supports the Interpretation of the presence of two aquitard layers beneath the site, with depths generally as indicated in Table 1. In the opinion of WGA, potential site upgrades can be evaluated based on the information provided.

## 4. LAGMHOR PILOT TRIAL SITE UPGRADE CONCEPT DESIGN

### 4.1 Understanding Soil Aquifer Treatment (SAT) and Water Quality Risk Management

In designing MAR sites as part of a catchment-specific Groundwater Replenishment Scheme (GRS), the protection of potable or drinking water supplies is a critical criterion. Decades of international research as well as results from long running MAR systems around the world provide a substantial body of knowledge on which we can build for the site upgrade testing.

The recharge water being used for the Hinds MAR Pilot site is of high quality. The Rangitata River source water contains low nutrient concentrations and natural or 'background' enteric bacteria levels are likely sourced from water fowl residing on irrigation storage ponds.

The Pilot Trial Year 1 results (Golder, 2017) indicated that enteric bacteria (e.g. *E. coli*) measured in the source water were removed as the source water percolated down through the underlying soils and into the regional groundwater system. Year 1 groundwater quality monitoring results indicated that *E. coli* present in the water in the infiltration basin was not transported in seepage water to the lower perched groundwater beneath the basin (AQ2) or to the regional groundwater system (AQ3). This means that SAT reduced the *E. coli* counts in water seeping through the silty gravels below the infiltration basin by up to three log range within a vertical distance of 15 m.

The design of the dry well to deliver source water to the perched aquifer at the site (AQ2) means that the infiltrated water would need to seep through at least six to ten metres of silty gravels before it would enter the regional groundwater system. Designing a site upgrade to continue to utilise the natural *E. coli* filtering capacity of the soils would potentially offer advantages during any consenting process. The mechanisms of this natural filtering of surface contaminants as they move through soils is a widely known and studied biophysical process. The terms 'natural water purification' or in the application of treating wastewater, soil aquifer treatment (S.A.T.). *'In soils, clay minerals, iron hydroxide, and humic matter as well as microorganisms located in the subsurface have high decontamination capacities.'* (Baalke, 2008). These natural processes were studied extensively starting in the 1980s for applications in helping to polish effluent from treatment plants. *'As the effluent moves through the soil and the aquifer, it can undergo significant quality improvements through physical, chemical and biological processes.'* (Rice & Bouwer 1984).

The significant uptake of recycled water (e.g. wastewater) for MAR projects in Australia has led to a considerable amount of research in these natural biophysical filtering process. Some of the earliest investigations undertaken as part of the Bolivar reclaimed water aquifer storage and recovery research trial (Martin and Dillon (eds.) 2005). This study concluded that a 2 to 3 log removal of the bacteriophage MS2 was achieved within 15 days water residence time in a confined carbonate aquifer. In addition:

*"E. coli cells were never detected in the recovered waters in numbers >1 cfu per 100 ml, despite consistent detection of E. coli cells in the treated effluent in the ponds in numbers greater than 1 × 10<sup>4</sup> cells per 100 ml (Fig. 1). Coliphage and enteroviruses were never detected in the recovered water or native groundwater, despite being regularly detected in the treated effluent entering the infiltration ponds. This indicates that the viruses were being removed to below detection limits (approximately 10 enteroviruses in 1 l, and 1 bacteriophage in 500 ml) during the 80 and 100 m passage through the aquifer between the ponds and the recovery bores."*

Similarly, in the State of California (United States), the use of dry wells for stormwater infiltration has been widely studied. An early draft provided to WGA documents the water quality improvements achieved to groundwater. The baseflow of the Santa Ana River is primarily treated wastewater, with high flows dominated by cleaner stormwater. Data collected for most studies show no immediate impacts, and no apparent trends to indicate the stormwater infiltration is negatively impacting groundwater at the studied sites. Other studies appearing in the summary provided by Hutchinson (2017) concluded that:

*"Results of the Phase III monitoring for the Los Angeles Basin Water Augmentation Study are in agreement with results from previous phases of the project. Based on monitoring to date, there is no evidence of significant degradation of groundwater quality due to long-term infiltration of urban storm water. These results are not only significant from the aspects of human and watershed health, but are useful and practical for permit writers and city planners, as well as provide confidence that stormwater based ordinances can safely encourage infiltration as means to augment groundwater supplies."*

This natural filtering mechanism has been studied beyond its application for nutrients and enteric bacteria including research into the tracking *emerging pollutants* such as endocrine disrupting compounds such as steroidal hormones. *'Results from field sites that have been operational for more than 13 years indicated no breakthrough of the target compounds in ground water samples collected downstream of the surface spreading operation.'* (Mansell & Drewes, 2004).

Whilst there are well studied benefits of natural filtering or SAT, there are some areas of concern around specific pollutants. Studies of the attenuation of selected microbial pathogens during recharge of treated effluent have confirmed that pathogen type is also a significant factor influencing attenuation during artificial recharge.

Toze & Hanna (2002) found that viruses persisted longer than bacteria in an aquifer receiving tertiary treated effluent using aquifer storage and recovery. It was also determined in this study that differences in attenuation varied between different groups of bacteria and viruses, even between closely related viral species such as poliovirus and coxsackievirus. Similarly, varying rates in attenuation between different pathogen types have been observed in a shallow aquifer receiving secondary treated effluent (Toze et al., 2003).

WGA conceptual designs have considered the Year 1 testing results coupled with international research on SAT and natural attenuation of contaminants. The final dry well is designed to retain a soil filtration capacity for the recharged water and avoids recharging directly into the regional groundwater table. Building on the current site monitoring, additional water quality monitoring of the recommended dry well coupled with potential additional water quality parameters will help to manage risks.

## 4.2 Water Quality Management

Irrespective of the design of the recharge system identified as being the most cost-effective over the long term, one of the primary requirements will be to manage sediment loads and potentially biological growth within the dry well.

The suspended sediment concentrations measured in the infiltration basin during Year 1 were generally low (regularly less than the detection limit of 2 g/m<sup>3</sup>). Under a flow rate of 100 L/s, this concentration converts to a mass load in the order of 17 kg/day. Clogging of the dry well would occur rapidly if it was accepting a sediment load of this magnitude. The most effective means of maintaining the efficiency of a dry well is to minimise sediment concentrations in the water entering the hole.

Following a review of options, the preferred management measure to reduce sediment loads to the dry well is the construction of a specialised sand filter and collector drain system. The collector drains would deliver the water directly to the top of the dry well. Discussions between WGA and Stuart Tarbotton's staff have identified several filter layout options.

## 4.3 Physical Conceptual Options

In a previous memorandum to the MARGG (WGA 2017), options were identified for the construction of deep dry wells or injection bores to enhance recharge beneath the site. These options are summarised in Figure 5, however the details of each option are not repeated in this memorandum.

Since the last MARGG meeting, the concept of recharge wells (Options 3 and 4, a to c in Figure 5) has been dropped from current consideration as a site upgrade option, for the following reasons:

- 1) The costs for constructed wells (e.g. steel casing, screens, etc) are almost certainly considerably higher than allowed for under the site upgrade budget.
- 2) Considerable work would be required to finalise the detailed design for any of these wells, with the more complicated options (Series 4) requiring the most work. It is not clear that this work can be completed in reasonable time to enable a tendering and detailed costing process to be completed and installation of the well by the end of February 2018.

Regarding the dry wells (Options 1 and 2, a to b in Figure 5), two options have been dropped from consideration at this stage. The conceptual designs for Options 1a and 2a were put forward on the basis that water from either the infiltration basin or the shallowest perched groundwater (AQ1) would be guided directly down to the regional groundwater table. Relative to consenting this would be a 'discharge of water to water' which is more problematic. The installation of these deep dry wells (1a or 2a) could be associated with an increased risk of introducing pathogens to the regional groundwater system.

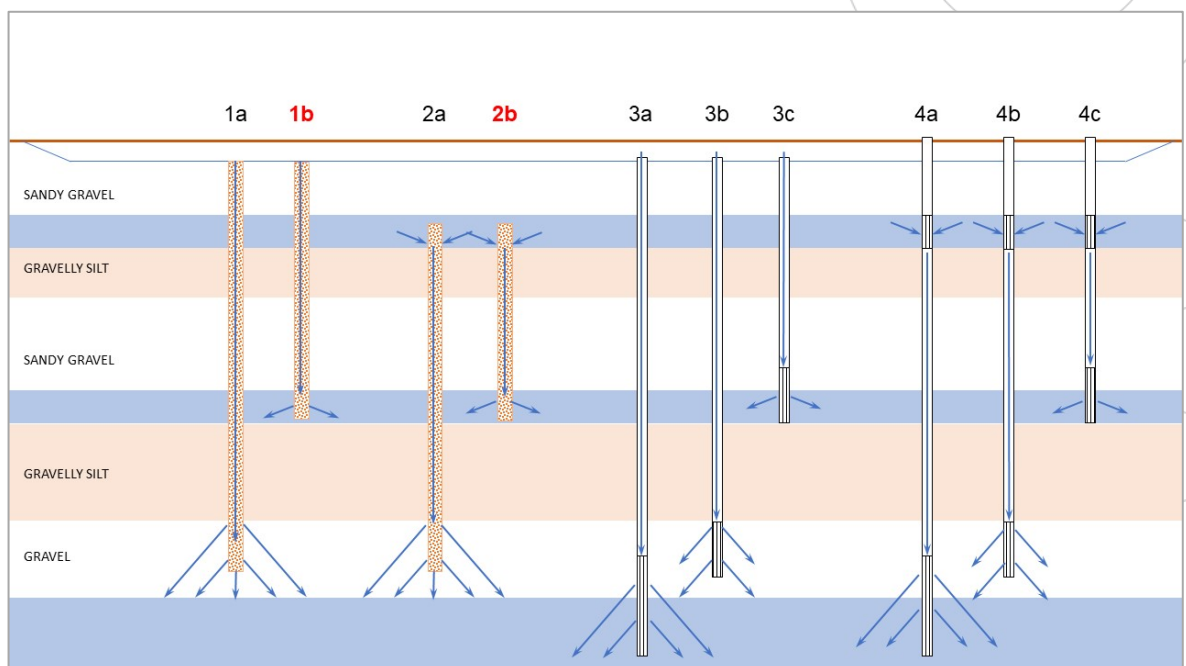


Figure 5: Potential recharge site upgrade options (WGA, 2017).

It is important to remember the outcomes with respect to pathogen (*E. coli*) removal observed during Year 1 of the Pilot Trial (refer Section 4.1). Monitoring during Year 1 indicated that a 3 log removal of *E. coli* from seepage water in the layered saturated / unsaturated zone beneath the infiltration basin was occurring within a vertical distance of 15 m. Installing a dry well to infiltrate water past the upper aquitard would still leave a vertical distance in the order of eight to ten metres between the infiltration point and the underlying groundwater in the regional aquifer (AQ3). Substantial attenuation of remaining pathogens would also occur during lateral groundwater flows within the perched aquifer (AQ2) and the regional aquifer.

#### 4.4 Dry Well Concept Recommendation

A dry well of a similar diameter and style to the clamshell holes, can potentially be installed using a specialised Kelly Rig. Locally available rigs can excavate holes of this size to depths of 30 m if required. During excavation the hole can be held open by a temporary steel casing, which is progressively withdrawn as the hole is backfilled. The fill would be clean gravel at depth, to reduce the risk of pit wall erosion and collapse, with clean cobbles used to fill the upper sections of the completed hole.

Sediment loads carried by the source water would need to be managed by a complementary surface passive-filtering system, as clogging of a dry well cannot be easily corrected. This type of surface filtering system would be applicable for Option 1B where water flows in from the surface (Figure 5).

An option for managing the risk of clogging would be to install a blind dry well (Figure 5, Option 2b). Instead of opening directly into the infiltration basin, the upper end of the hole is refilled with finer gravely sands, similar in nature to the material excavated from the hole. Flows into the blind holes would be derived from water recharged to the uppermost six metres below the basin. The floor of the basin would act to remove most of the sediment load and the water entering the dry well should be carrying relatively low sediment loads.

Option 1b is preferred over Option 2b because the flow rates achievable using Option 2b are likely to be lower than the flow rates achievable using Option 1b.

Based on information provided in Sections 4.1 and 4.4, it is highly unlikely that the efficiency of SAT and pathogen removal observed during Year 1 of the Pilot Trial will be significantly degraded through installation of the recommended dry well.

WGA recommends that an upgrade to the Lagmhor Pilot Trial site incorporate a dry well based on the Option 1b layout presented in Figure 5.

#### 4.5 Dry Well and Filter Bed Concept Design

The concept design for the dry well consists of:

- A drilled hole of 1.2 m or 1.5 m diameter to a depth of approximately 18 m below ground level (bgl).
- Steel casing lining the dry well to a depth of approximately 2.5 m bgl, with a stick-up above the floor of the infiltration basin of approximately 1.5 m.
- A lockable cap installed on top of the steel casing, to provide access as required.
- A steel 50 mm or larger piezometer installed inside the dry well and screened at the base of the well.
- Clean gravel fill in the dry well from the base of the well up to a depth of approximately 8 m bgl.
- Coarse clean cobble fill in the dry well from 8 m bgl to approximately 0.5 m bgl.
- A platform to access the top of the dry well for monitoring and maintenance purposes.

The concept design for the sand filter system consists of:

- Four slotted pipe collector drains, each up to 10 m long and 200 mm diameter, installed in shallow trenches radiating from the dry well casing.
- A medium sand bed approximately 500 mm thick covering the collector drains.
- A silt / gravel bund approximately 500 mm high retaining the sand bed.
- A thin layer of cobbles capping the sand bed to reduce the risk of erosion of the sand

The preferred location of the dry well would be at the northern end of the infiltration basin, for the following reasons:

- Three sides of this area are already enclosed by the outer walls of the infiltration basin or the forebay bund.
- There is little water movement in this area to erode the sand filter or to bring suspended sediment to the filter.
- This area does not intersect a vehicle access route.

The filter bed would however need to be designed and installed to avoid disturbing or interfering with the existing infiltration basin water level monitoring system.

## 5. COST ESTIMATE

A full cost estimate for the proposed site upgrade is not yet available. An indicative cost for the most expensive component of the project is however provided in Table 5.

Components yet to be costed include:

- Collector drains and sand filter system for management of suspended solids and clogging risk.
- A steel piezometer to be installed for water quality and level monitoring in the dry well.
- An automated flow meter to monitor infiltration rates in the dry well.
- Site design and (if necessary) consenting costs together with construction supervision costs

**Table 5: Indicative costs for dry well installation (McMillians Civil, 5 December 2017).**

Description	Indicative cost (excl GST)
Mobilisation / Demobilisation. Crane (40 tonne) and Drilling Rig (45 tonne), dry well casing	\$ 18,000
Drill and install temporary casing <ul style="list-style-type: none"> <li>• 0 m to 9 m @ 1.5m diameter</li> <li>• 9 m to 18 m @ 1.2m diameter</li> </ul>	\$ 16,400
Extract casings, supply and backfill with suitable drainage material	\$ 5,890
Supply of permanent 1.5 m diameter casing @ 4 m long	\$ 6,630
Permanent lid arrangement	\$ 3,650
<b>Indicative total</b>	<b>\$ 50,570</b>

If you require clarification on any of the information presented in this Technical Memorandum please contact the undersigned.

Yours faithfully



Brett Sinclair

for

**WALLBRIDGE GILBERT AZTEC**

### Attachments:

- 1) FTS 2017. Hinds MAR Gamma Logging of Pilot Site Wells. Contract 1008-17/18. Summary of work performed: 13th to 24th November 2017. Report prepared by Field Technical Services Ltd for Canterbury Regional Council.
- 2) SG 2017. Hinds managed aquifer recharge: geophysical site investigation. Report prepared by Southern Geophysical Ltd for Canterbury Regional Council.

BB:nd

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- Bekele E., Toze S., Patterson B. & Higginson S., 2011. Managed aquifer recharge of treated wastewater: water quality changes resulting from infiltration through the vadose zone. *Water Research* 45 (2011) 5764-5772.
- Golder Associates (NZ) Ltd, 2017. Hinds Managed Aquifer Recharge Pilot Trial – Phase 1 Report. 1538632-7410-024-R-Rev2, 88 pages. Prepared for Canterbury Regional Council.
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- Mansell J. & Drewes J. E., 2004. Fate of Steroidal Hormones During Soil-Aquifer Treatment. *Journal Groundwater Monitoring and Remediation*. DOI: 10.1111/j.1745-6592.2004.tb00717.x
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- Toze, S. & Hanna J. 2002. The survival potential of enteric microbial pathogens in a treated effluent ASR project. In: *Management of Aquifer Recharge for Sustainability* (ed. by P. Dillon), 139–142. Balkema Publishers, Australia.
- Toze, S., Hanna, J., Smith, T., Edmonds, L. & McCrow, A. 2004. Determination of water quality improvements due to the artificial recharge of treated effluent. In: *Wastewater Re-use and Groundwater Quality* (ed. by J. Steenvoorden & T. Endreny) (Proc. Symp. HS04 IUGG2003, July 2003, Sapporo, Japan). IAHS Publ. 285. IAHS Press, Wallingford, UK
- Toze S., Hanna J. & Smith T., 2004. Determination of water quality improvements due to the artificial recharge of treated effluent. *Wastewater reuse and Groundwater Quality* (proceedings of symposium HS04 held during IUGG2003 at Sapporo, July 2003) IAHS Publ. 285, 2004.
- Toze 2004 Pathogen survival in groundwater during artificial recharge. *Wastewater reuse and Groundwater Quality* (proceedings of symposium HS04 held during IUGG2003 at Sapporo, July 2003) IAHS Publ. 285, 2004.
- Toze S., Bekele E., Page D., Sidhu J. & Shackleton M., 2010. Use of static quantitative Microbial Risk assessment to determine pathogen risks in an unconfined aquifer used for managed aquifer recharge. *Water Research* 44, 1038-1049.

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# APPENDIX F

## NEW MAR SITE RESOURCE CONSENT AND TEST ANALYSES

**Table F1: New MAR sites water source and flow measurement type.**

<b>Site MAR ID</b>	<b>Water Source</b>	<b>Flow Measurement Type</b>
3	Valetta pipeline to supply headworks	Inline flow meter (electronic/mechanical)
4	Valetta pipeline to farm-pond to siphon	Inline flow meter (electronic/mechanical)
5	Valetta pipeline to Valetta Pond #2 to siphon	Inline flow meter (electronic/mechanical)
6	BCI - RDR Race: BCI pipeline using fire emergency valve and lay-flat hose	Inline flow meter (electronic/mechanical)
7	Valetta pipeline direct to soakage pit	Inline flow meter (electronic/mechanical)
8	Valetta pipeline to farm-pond to siphon	Inline flow meter (electronic/mechanical)
9	MH open race to farm pond to siphon	Inline flow meter (electronic/mechanical)
10	MH open race to siphon	V-Notch Weir with level logger
11	MH open race to siphon	V-Notch Weir with level logger
12	MH open race to siphon	V-Notch Weir with level logger
13	MH open race to farm pond to siphon	Inline flow meter (electronic/mechanical)
14	MH open race to farm pond to siphon	Inline flow meter (electronic/mechanical)
15	MH open race to farm pond to siphon	Inline flow meter (electronic/mechanical)
16/17	MH open race to farm pond to siphon	Inline flow meter (electronic/mechanical)
18	MH race direct to soakage pit (via weir)	V-Notch Weir with level logger

Resource Consent for MAR Test Sites - CRC182576

**RESOURCE CONSENT CRC182576**

*Pursuant to Section 104 of the Resource Management Act 1991*

**The Canterbury Regional Council (known as Environment Canterbury)**

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GRANTS TO:	Canterbury Regional Council
A DISCHARGE PERMIT (S15):	to discharge water to land
COMMENCEMENT DATE:	24 Jan 2018
EXPIRY DATE:	24 Jan 2023
LOCATION:	Various Location at Hinds Area

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**SUBJECT TO THE FOLLOWING CONDITIONS:**

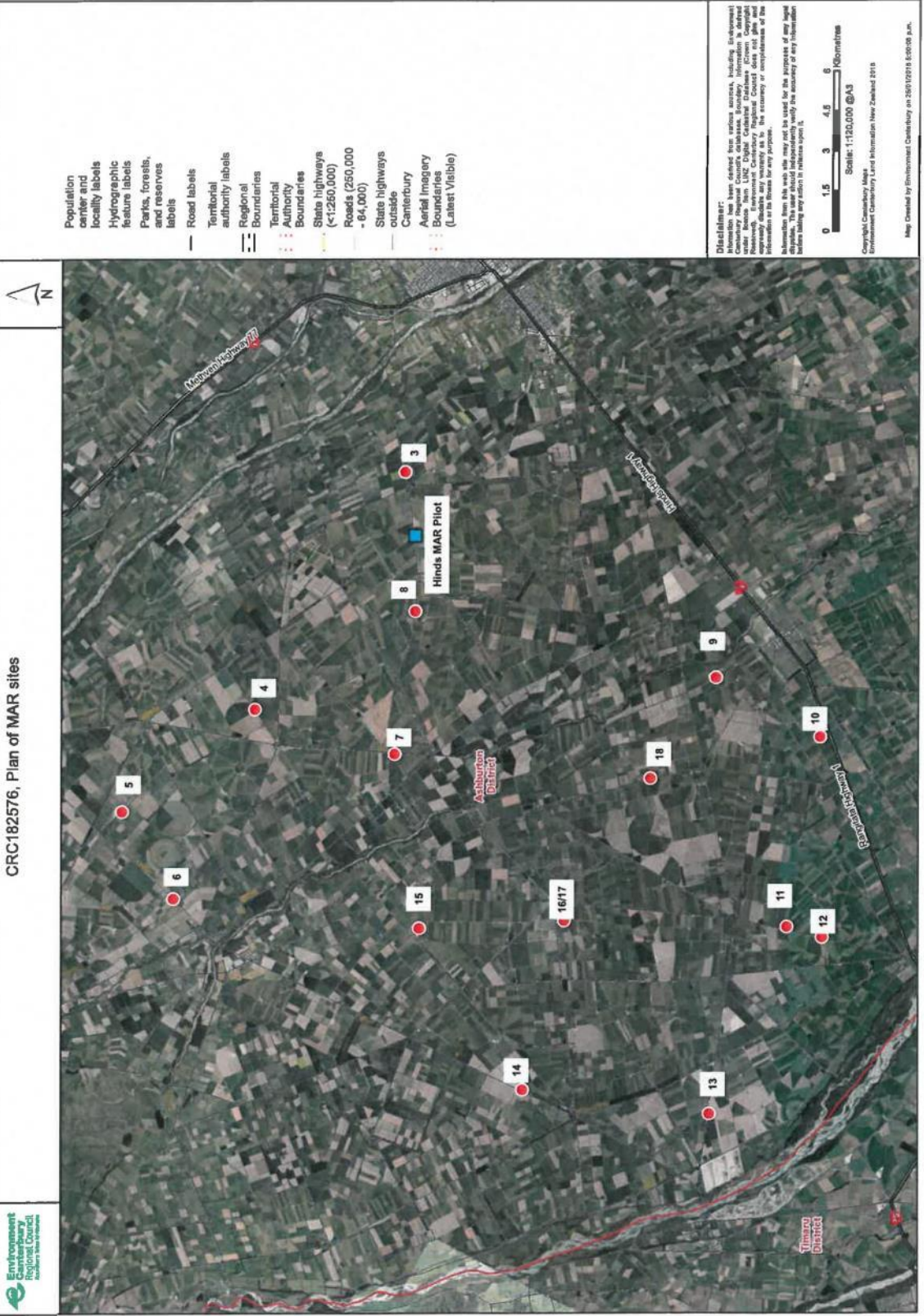
- 1 The discharge shall be only:
  1. Water sourced from the Rangitata Diversion Race Klondyke intake in accordance with resource consent CRC164281 and;
  2. Sodium chloride for use as a tracer;for the purposes of a Managed Aquifer Recharge trial (MAR).
  
- 2 Water shall be only discharged into land, via the cleaned open races and the soak pits at the MAR test sites located on Plan CRC182576, which forms part of this consent.
  
- 3 The concentration of tracer discharged shall not exceed 200 mg/L.
  
- 4 The rate at which water is discharged at each site listed in Schedule One(a) shall not exceed:
  - a. 50 litres per second;
  - b. In combination with CRC162191 shall not exceed 500 litres per second, and 302,400 cubic metres per week; and
  - c. In combination with any other resource consent listed in Schedule One(b) shall not exceed 1,300 litres per second.
  
- 5 The discharge shall be managed in accordance with Schedule Two, which forms part of this consent.

- 6 The consent holder may amend Schedule One and/or Schedule Two at any time subject to the following:  
Any amendment shall be:
1. 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
  2. Only for the purpose of improving efficacy of the MAR trial; and
  3. Consistent with the conditions of this consent; and
  4. Submitted in writing to and be approved by the Canterbury Regional Council, Attention RMA Monitoring and Compliance Manager, prior to any amendments being implemented.
- 7 The consent holder shall undertake on going monitoring of:
- a. groundwater quantity; and
  - b. groundwater quality.
- In accordance with Schedule Three, which forms part of this consent.
- 8 The consent holder may amend Schedule Three at any time subject to the following:
1. Any amendments shall be:
    1. Only for the purpose of improving efficacy of the monitoring programme and shall not result in reduced quality of monitoring of the discharge; and
    2. Consistent with the conditions of this consent; and
    3. Submitted in writing and to be approved to the Canterbury Regional Council, Attention RMA Monitoring and Compliance Manager, prior to any amendments being implemented.
- 9 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 31 July each year.

- 10 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.

**Issued at Christchurch on 26 January 2018**

Canterbury Regional Council



## Resource Consent CRC182576 – Schedule One and Two

### CRC182576 - Schedule One Schedule One (a)

SITE NAME	NZTM X	NZTM Y
MAR Hinds 3	1491569	5140996
MAR Hinds 4	1482800	5146607
MAR Hinds 5	1478667	5151727
MAR Hinds 6	1475537	5149758
MAR Hinds 7	1480909	5141381
MAR Hinds 8	1486255	5140558
MAR Hinds 9	1483857	5129339
MAR Hinds 10	1481524	5125386
MAR Hinds 11	1474335	5126619
MAR Hinds 12	1473962	5125289
MAR Hinds 13	1467237	5129516
MAR Hinds 14	1468189	5136588
MAR Hinds 15	1474293	5140342
MAR Hinds 16/17	1474686	5135049
MAR Hinds 18	1480097	5132032

### Schedule One (b)

The following consents can be used in conjunction with resource consent CRCXXXXXX:

-

(this Schedule will be updated if and when further water becomes available).

### CRC182576 - Schedule Two

At the MAR test sites, manual flow management shall be maintained and monitored via a water meter and recorded on a data logger, with data downloaded on a monthly basis.

The individual MAR test sites consist of an existing irrigation pond or irrigation canal/race, and a soakage pit. Water will be pumped or gravity fed to each soakage pit from the adjoining pond or race; and rates will be monitored to ensure that the surrounding bund is not over-topped and flooding does not occur. Within the soakage pit, ponding shall not occur on the surface for more than 24 hours. Discharge rates will be controlled initially by ECan, then by either / or Mayfield-Hinds-Valetta racemen or the farmer on whose land the MAR test site is sited. A weekly schedule of discharge rates at each site shall be maintained and distributed to ensure that the rate of discharge does not exceed the rate of diversion from the Rangitata River under CRC164281. Discharge rates will be determined using real-time data from the pilot MAR site, subtracted from the total rate of diversion from the Rangitata River to the MHV Irrigation Scheme pipeline. Flow meters and data loggers will be installed at each site and will time stamp a pulse at least once every 60 seconds.

Water levels in each soakage pit will be monitored via an in-situ water level probe, and if the standing water level is less than 1 metre below ground level then the rate of discharge shall be ceased or reduced to allow water levels to drop.

If water levels are unable to be reduced, then the discharge shall cease for 24 hours to allow water levels to drop. Once the discharge is re-started water levels will be actively monitored and the rate of discharge adapted to ensure that water levels to not exceed the trigger level above again.

## 1 MAR Test Site Monitoring Programme

### 1.1 Overview

The monitoring programme has been designed to acquire data to support infiltration management at each site as well as analysis of the MAR trial outcomes. Components of the Canterbury Regional Councils (CRC) regional monitoring programme will be incorporated, where appropriate, in the planned monitoring programme; in addition to monitoring being undertaken in accordance with consent CRC162191 (the pilot MAR site).

Monitoring results will be reviewed throughout the term of the 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 are presented in Sections 2.0 and 3.0 of this schedule.

### 1.2 Objectives

The MAR 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 and Hinds Rivers.
- 7) Monitor the effects of the MAR trial against developed trigger conditions.

#### Water quality

- 8) Ensure only high quality water is recharged to the aquifer by the MAR 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 MAR 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

Flow meters and data loggers will be installed at each site to measure inflows to the soakage pits continuously (60 second intervals).

Data will be downloaded and supplied to CRC at regular intervals throughout the duration of the consent.

Discharge rates will be determined using real-time data from each MAR test site, subtracted from the total rate of diversion from the Rangitata River to the MHV Irrigation Scheme pipeline. A weekly schedule of discharge rates at each site shall be maintained and distributed to ensure that the rate of discharge does not exceed the rate of diversion from the Rangitata River under CRC164281.

### Quality

Source water will be sampled for *E. coli* at the point of discharge weekly. If *E. coli* levels exceed 500 MPN/100mL then a resample will be taken to try and determine the cause of the concentration. If levels exceed 700 MPN/100mL then the discharge shall cease until remediation of the concentration has occurred.

## 3.0 Groundwater 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 one piezometer at each site will be analysed as part of the trial.

One piezometer will be installed within the soakage pit at each site to measure water levels in the surrounding aquifer. A second piezometer will be installed down-gradient of the soakage pit at approximately 5 – 6 m distance. Each piezometer will be equipped with pressure transducers to measure water levels continuously (60 second intervals). Data will be downloaded and supplied to CRC at regular intervals throughout the duration of the consent.

CRC maintains a network of barometric loggers that will be used for any groundwater level corrections.

If water levels in the soakage pit piezometer are less than 1 m below ground level, the discharge shall cease, or the rate of discharge will be reduced to ensure that groundwater mounding does not adversely affect the aquifer.

Additional downgradient monitoring wells will be used for water levels measurements if and where possible.

### Quality

Where wells at a depth of less than 20 m below ground level are located within 1 km of a MAR test site they will be sampled prior to the first exercise of the consent and if discharge waters exceed 700 MPN further testing will be undertaken for *E. coli*.

Samples will be analysed for nitrate-nitrogen and *E. coli*, as well as other water quality samples if necessary.

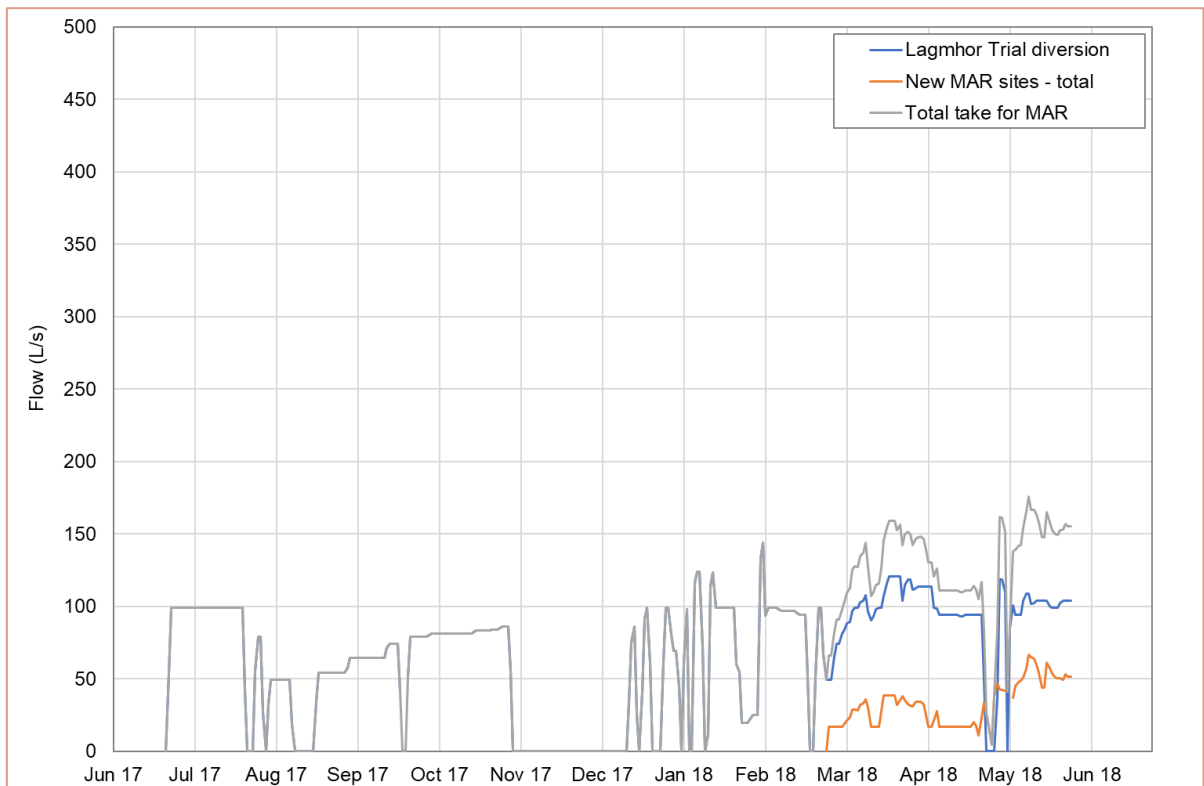
## COMPLIANCE REPORT – CRC 182576

Table F1 indicates compliance with consent conditions to 31 July 2018 for the resource consent for MAR test sites (CRC182576) as shown above.

**Table F1: Compliance status CRC182576.**

Condition Number	Statement of compliance
1.	Compliant. Water was sourced only from RDR Klondyke
2.	Compliant. Water was only discharged via the soak pits as planned (CRC 182576)
3.	Compliant. No tracer was used.
4.	Compliant. Each site did not exceed: <ul style="list-style-type: none"> <li>• 50 L/s (as per Figures F14, F20, F26, F32, F38, F44)</li> <li>• 500 L/s in combination with CRC162191 and 302,400 cubic metres per week. Figure F1 shows that the rate of take reached a peak of 175 L/s so well below the 500 L/s limit.</li> <li>• 1,300 L/s in total with consents in Schedule 1 which is empty (Figure F1). Total take less than 175 L/s.</li> </ul>
5.	Generally Compliant. Some exceedances of groundwater level less than 1 m below ground occurred in three sites. <b>Compliant</b> Schedule One <ul style="list-style-type: none"> <li>• No other current listed consents</li> </ul> Schedule Two <ul style="list-style-type: none"> <li>• Water flow records were made and downloaded monthly.</li> <li>• No flooding or ponding occurred due to MAR site operations</li> <li>• Water level monitored in soakage pit</li> </ul> <b>Non-Compliant</b> Schedule Two <ul style="list-style-type: none"> <li>• Groundwater level was sometimes less than 1 m below ground level in the following sites: MAR08 and MAR09. MAR16 had levels less than 1 m below ground for a brief period during testing</li> <li>• Figure 3 to 8 show monitored groundwater levels in the piezometer located within the soakage pit (P1) for all tested sites.</li> <li>• MAR08 would often breach the 1 m trigger and required frequent adjustments to the flow rate</li> <li>• MAR09 had shallow groundwater levels before the testing started. Rainfall recharge on 29 April 2018 caused the levels to rise above the 1 m trigger and the local groundwater levels have slowly declined since this time.</li> </ul>
6.	Compliant. No amendments to Schedules One/Two were made.

7.	<p>Compliant.</p> <p>Monitoring was carried out of both groundwater quantity and quality as per Schedule Three:</p> <ul style="list-style-type: none"> <li>• Flow meters and dataloggers installed in all operational sites.</li> <li>• Source water samples tested for E. coli. and results presented in report (Figure F2). One exceedance of the 500 MPN/100 ml and one of the 700 MPN/100 ml occurred during the testing period to July 2018.</li> <li>• Four bores less than 20 m deep were sampled prior to site operation at two MAR sites; <ul style="list-style-type: none"> <li>• MAR09 - K3/0246 as per Schedule Three requirements and in addition the up-gradient bore K37/1031.</li> <li>• MAR12 - BY20/0148 and K37/0245 as per Schedule Three requirements.</li> </ul> </li> <li>• No bores located within 1 km and less than 20 m deep from site MAR08 were able to be sampled. To comply with the Schedule Three requirement to test for E. coli when the source water exceeded 700 MPN/100ml samples were collected from the piezometers on site as per discussions with Environment Canterbury staff.</li> <li>• All water quality result data has been supplied to Environment Canterbury.</li> </ul>
8.	Compliant. No amendments to Schedules Three were made.
9.	<p>Non-Compliant. Delay to submission of report by one month.</p> <p>Review report containing monitoring records is contained within this Appendix (F) and main report Section 5. Recommend change date for consistency with resource consent CRC162191 (Lagmhor Trial) to be 31 August each year.</p>
10.	<p>Compliant.</p> <p>No review carried out by Canterbury Regional Council.</p>



**Figure F1: Total MAR take rate combined with Lagmhor Trial.**

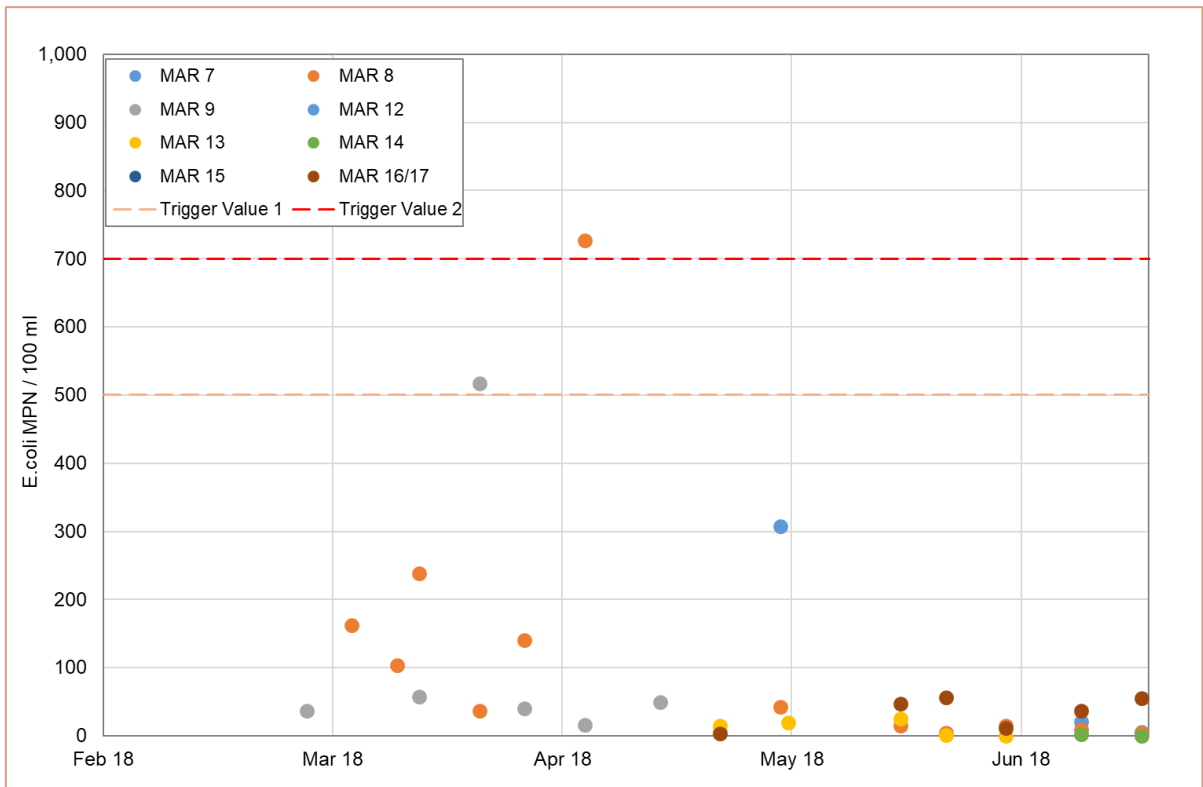


Figure F2: Source water quality *E. coli* results Year 2.

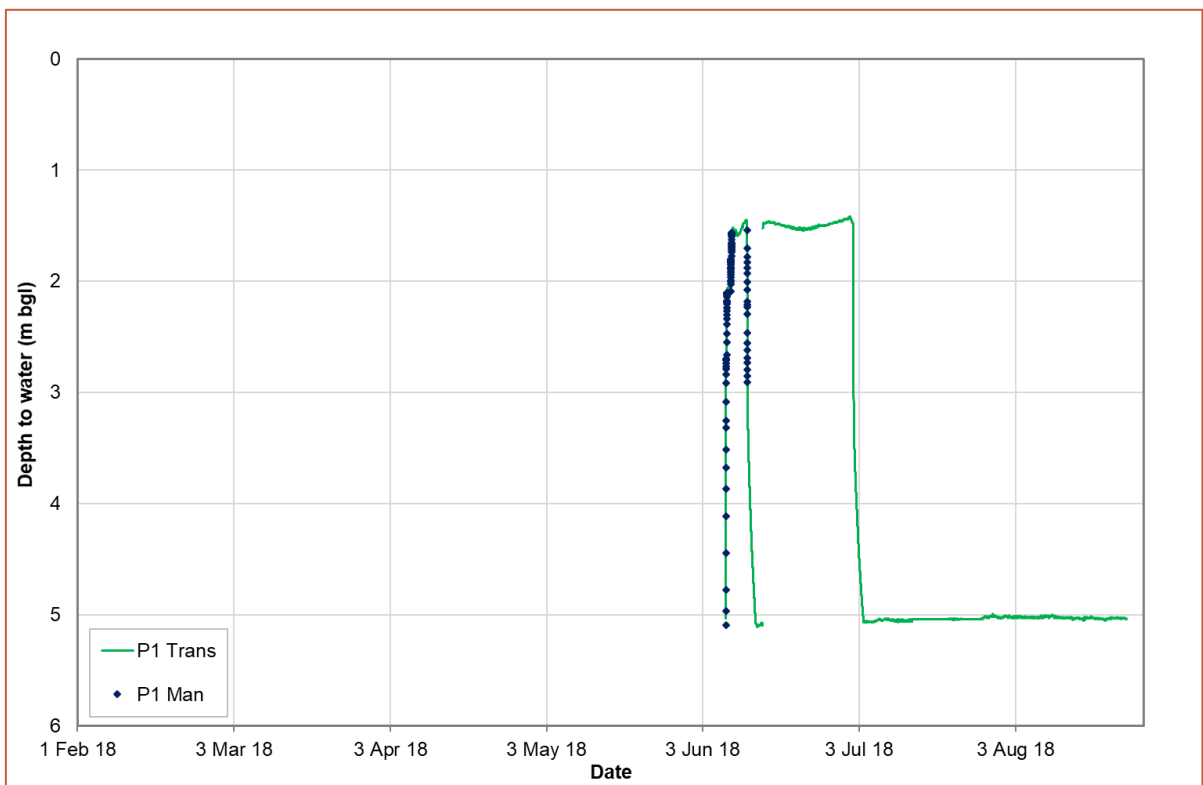
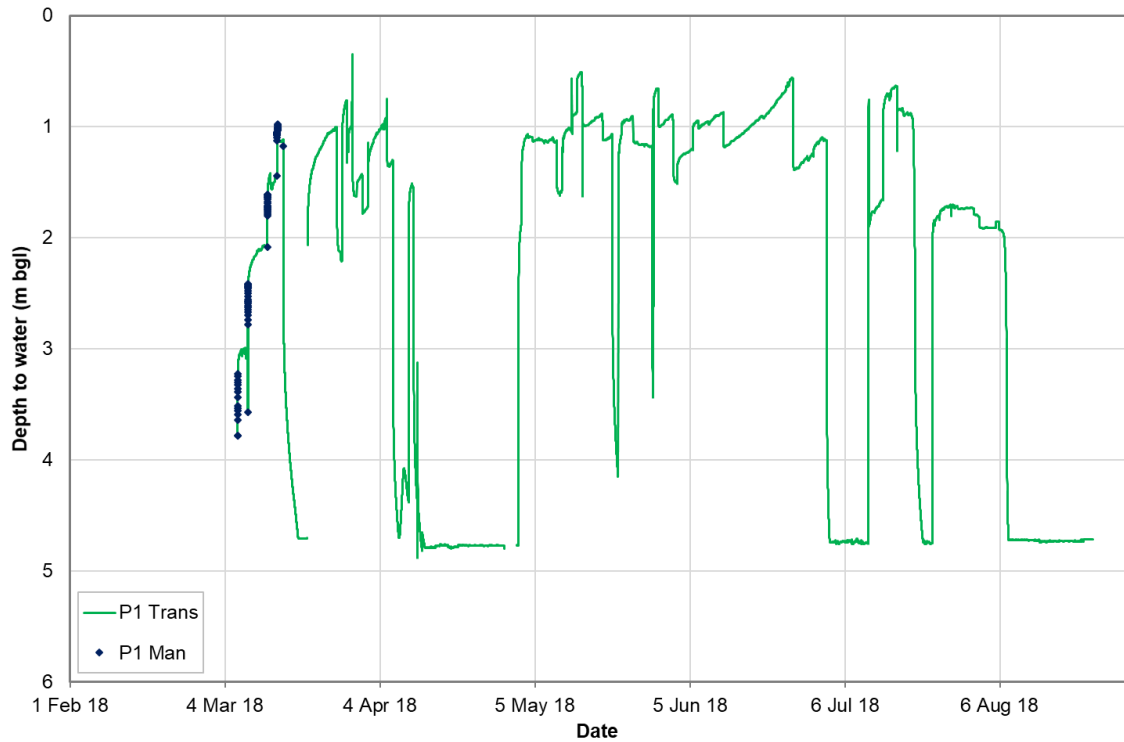
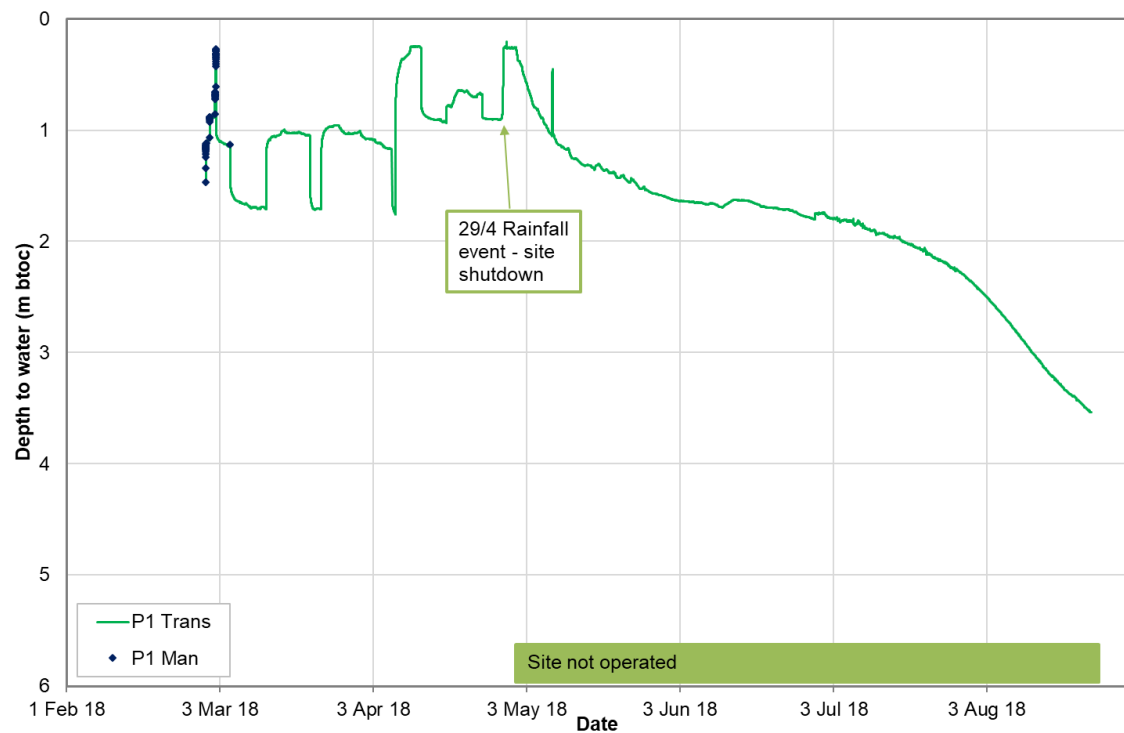


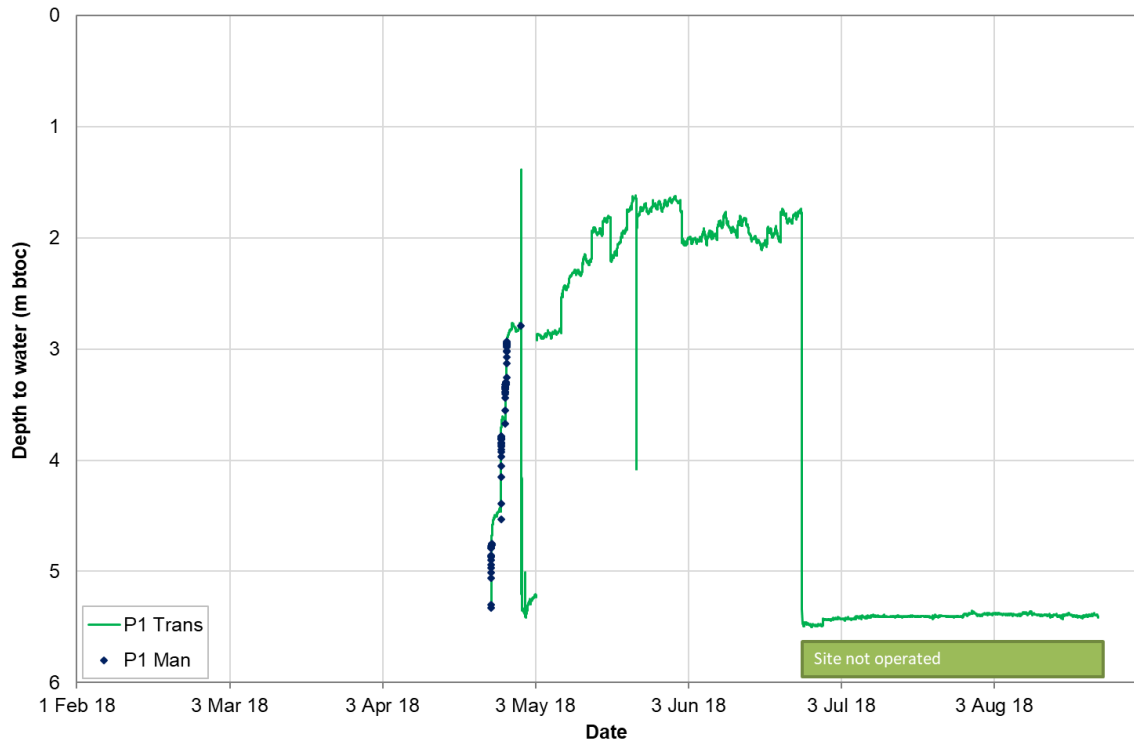
Figure F3: Groundwater levels in MAR07 from piezometer located within the soakage pit (P1).



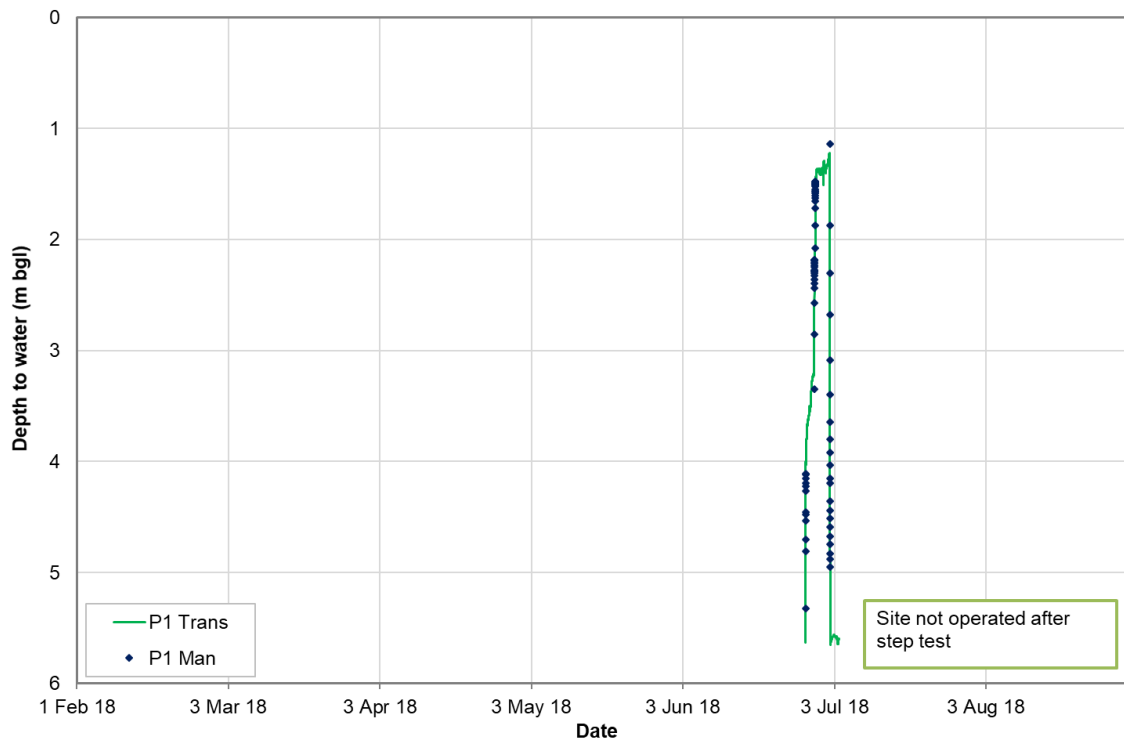
**Figure F4: Groundwater levels in MAR08 from piezometer located within the soakage pit (P1).**



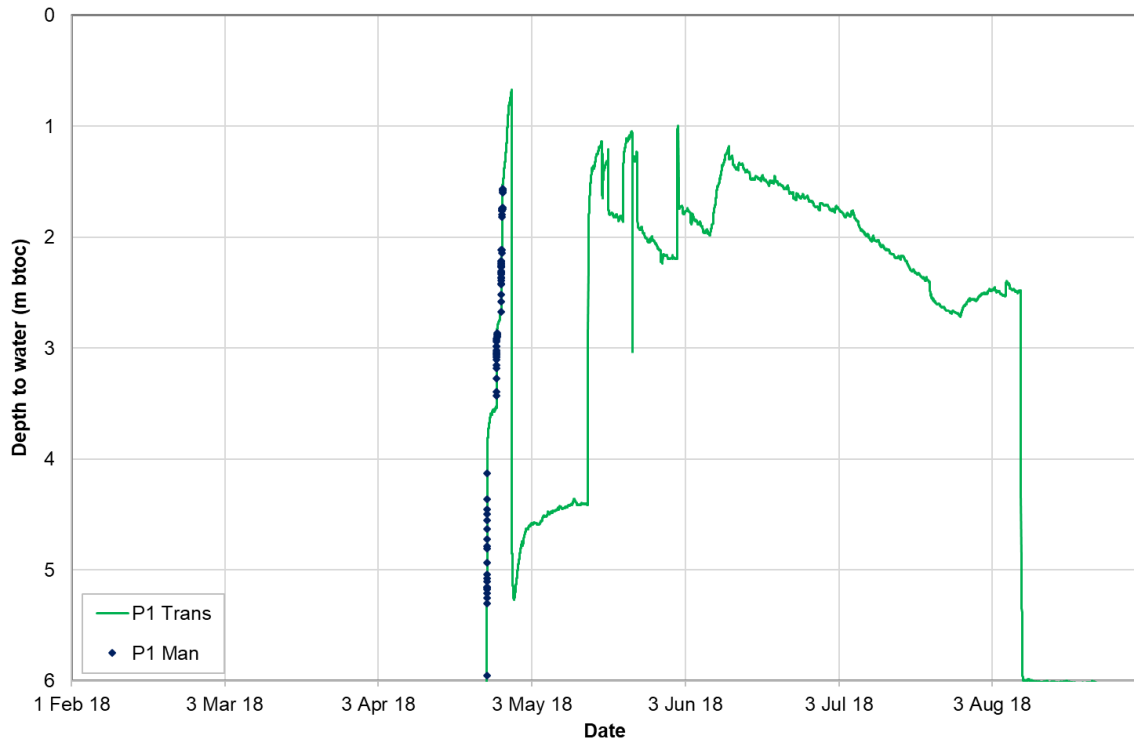
**Figure F5: Groundwater levels in MAR09 from piezometer located within the soakage pit (P1).**



**Figure F6: Groundwater levels in MAR13 from piezometer located within the soakage pit (P1).**



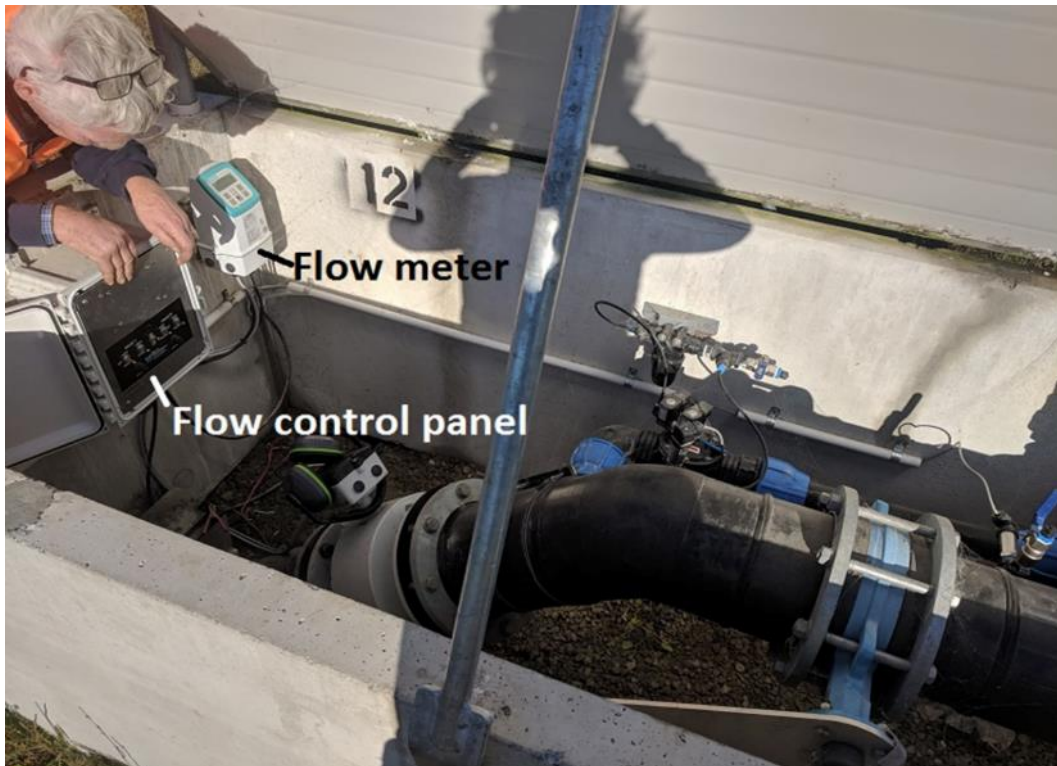
**Figure F7: Groundwater levels in MAR15 from piezometer located within the soakage pit (P1).**



**Figure F8: Groundwater levels in MAR16 from piezometer located within the soakage pit (P1).**

**SITE INFORMATION**

**SITE: MAR07**



**Figure F9: MAR07 site flow control and monitoring system.**



**Figure F10: MAR07 site overview.**

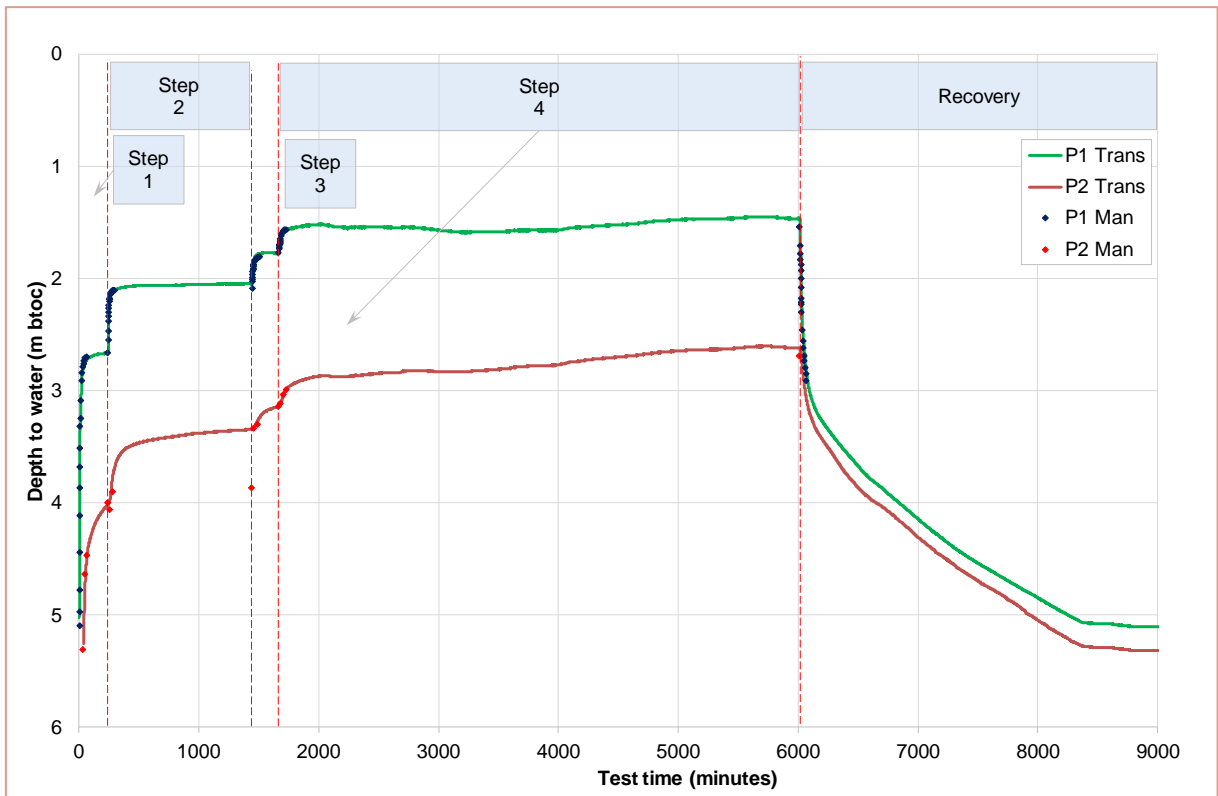


Figure F11: MAR07 test depth to water data - manual and automatic records.

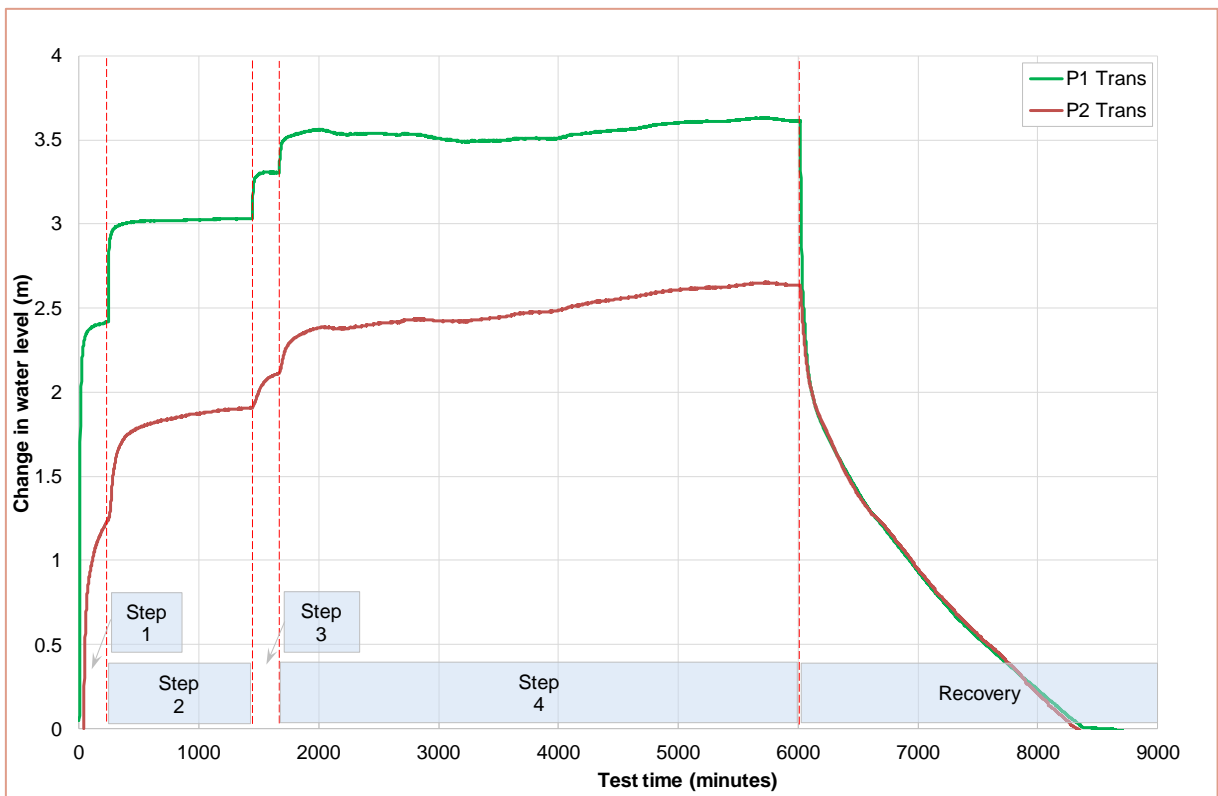


Figure F12: MAR07 test changes in water level recorded in piezometers P1 and P2.

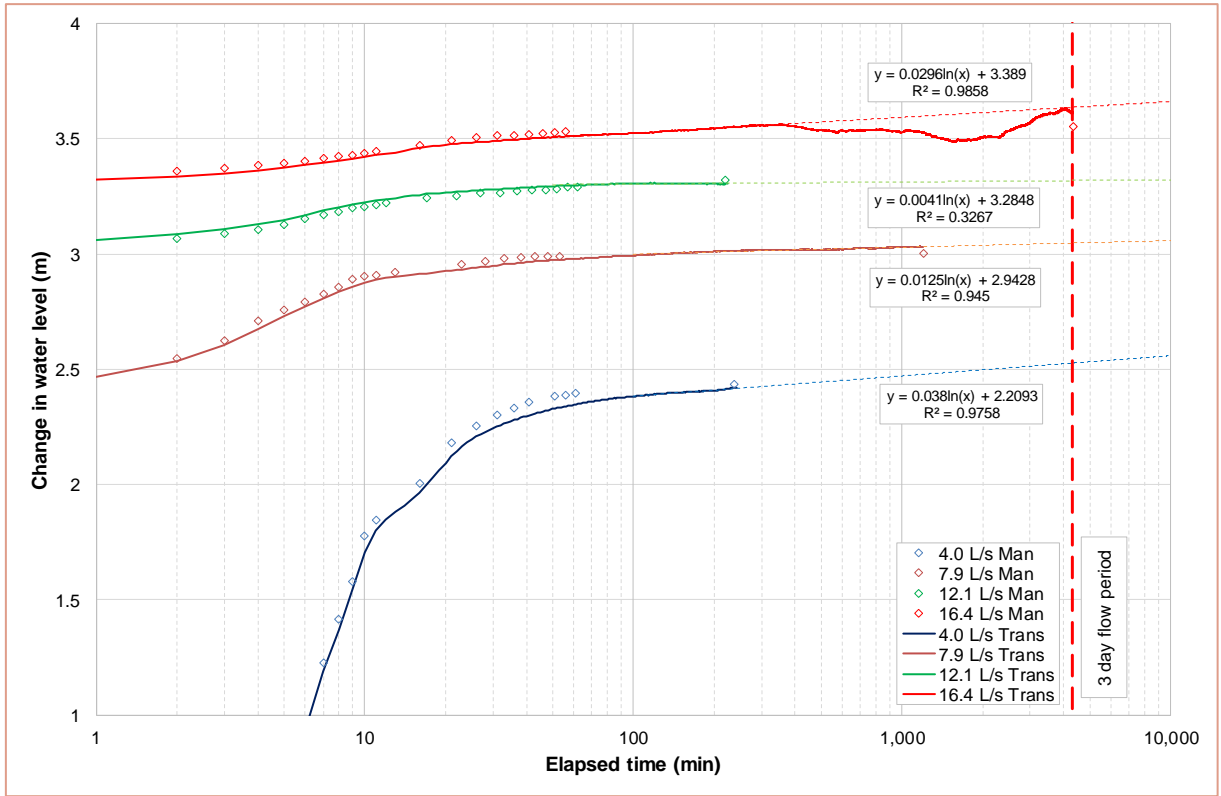


Figure F13: MAR07 test changes in water level recorded in piezometer P1 for each flow step.

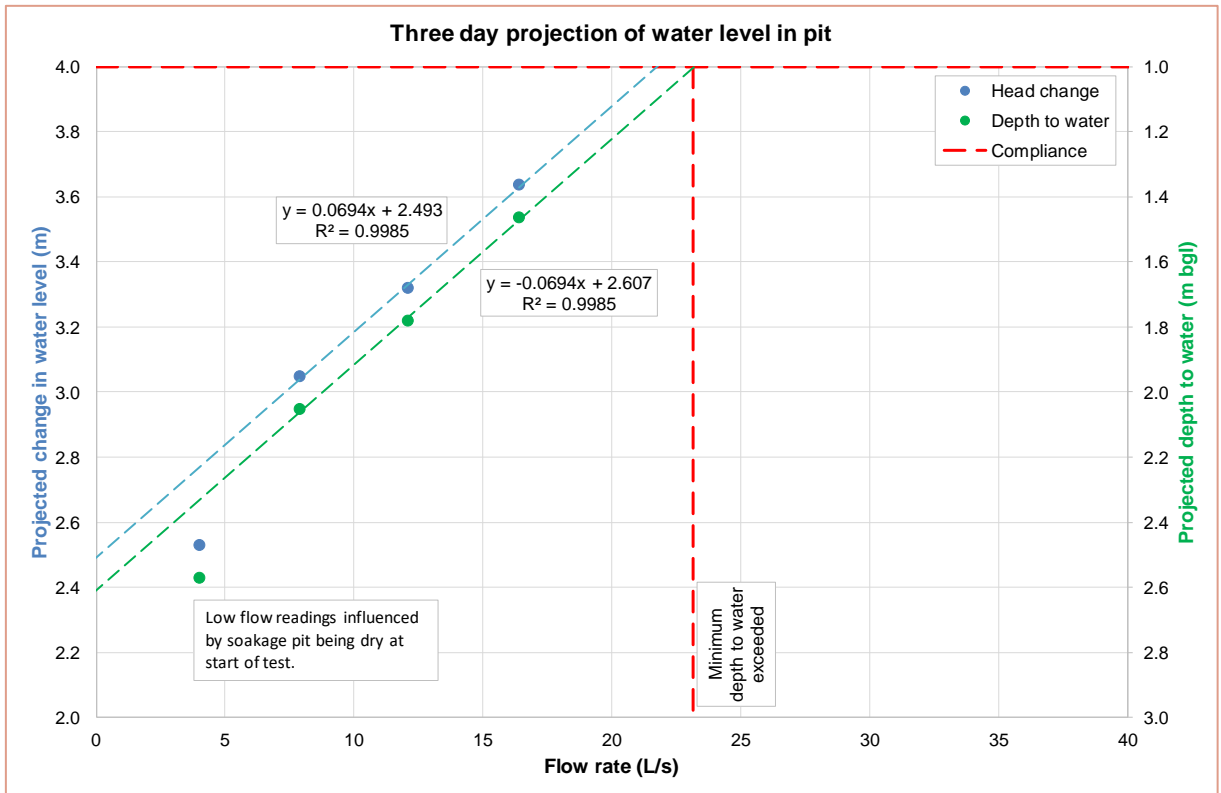


Figure F14: MAR07 site projected water level changes following three days infiltration.

**SITE: MAR08**



**Figure F15: MAR08 site overview.**



**Figure F16: MAR08 site flow control system.**

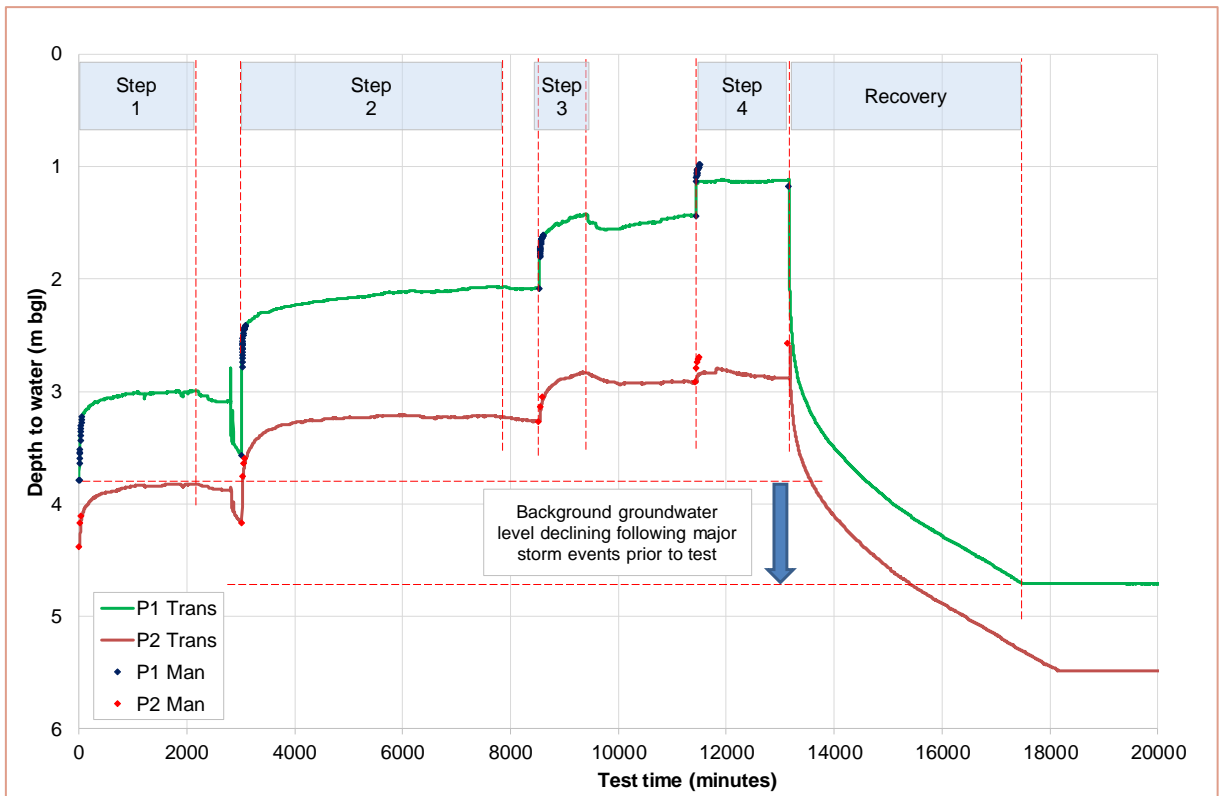


Figure F17: MAR08 test depth to water data - manual and automatic records.

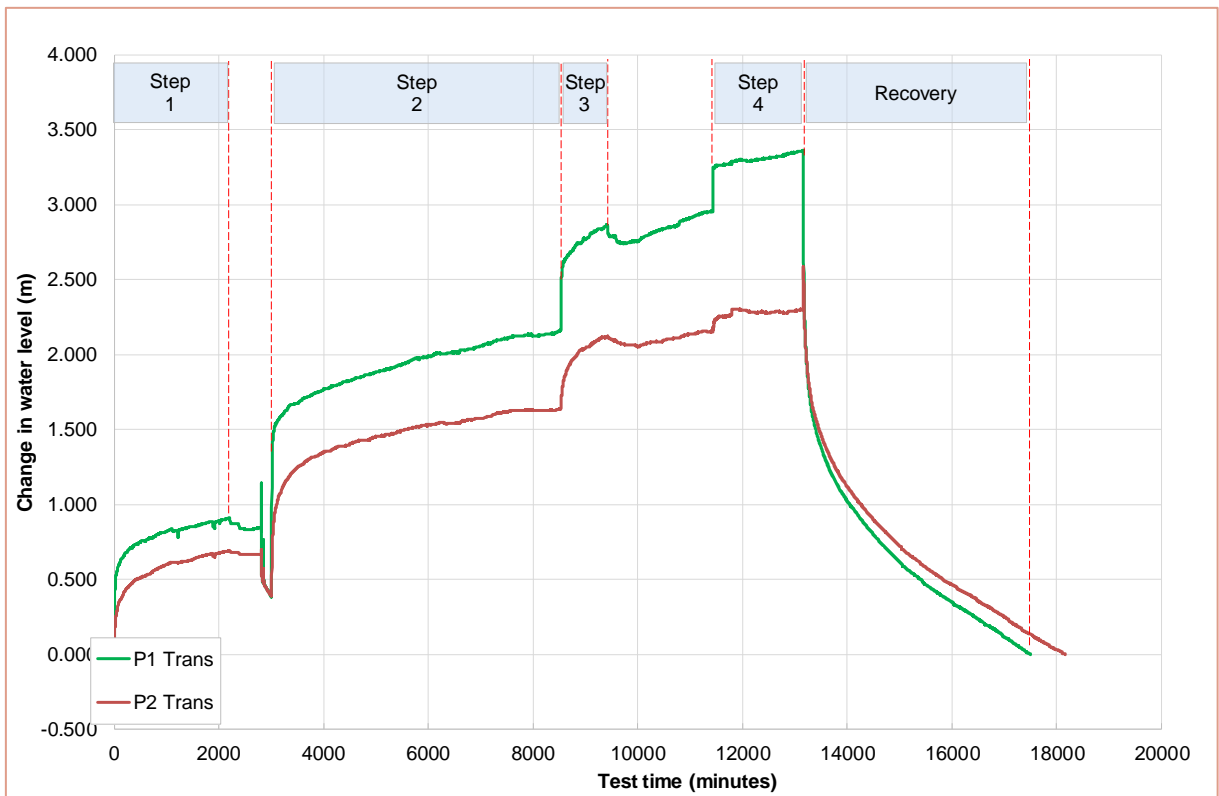


Figure F18: MAR08 test changes in water level. piezometers P1 and P2, corrected for background trends.

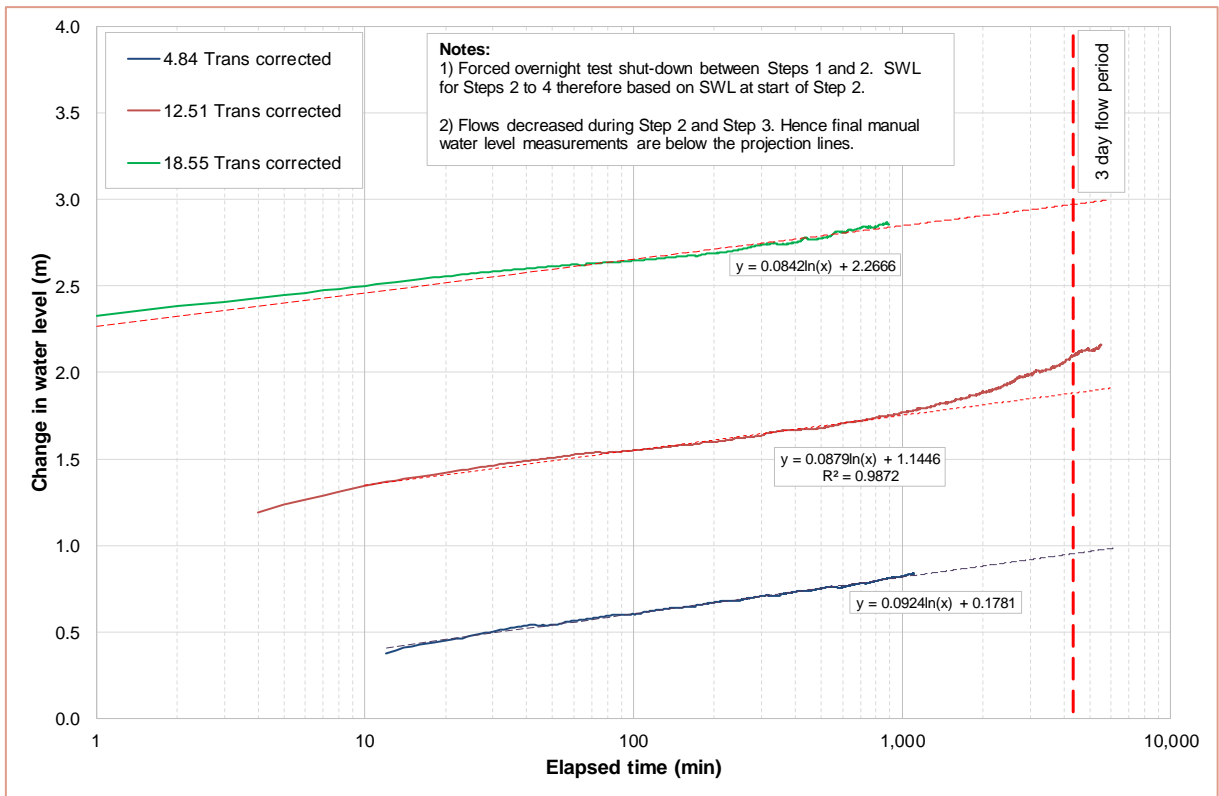


Figure F19: MAR08 test changes in water level recorded in piezometer P1 for three flow steps.

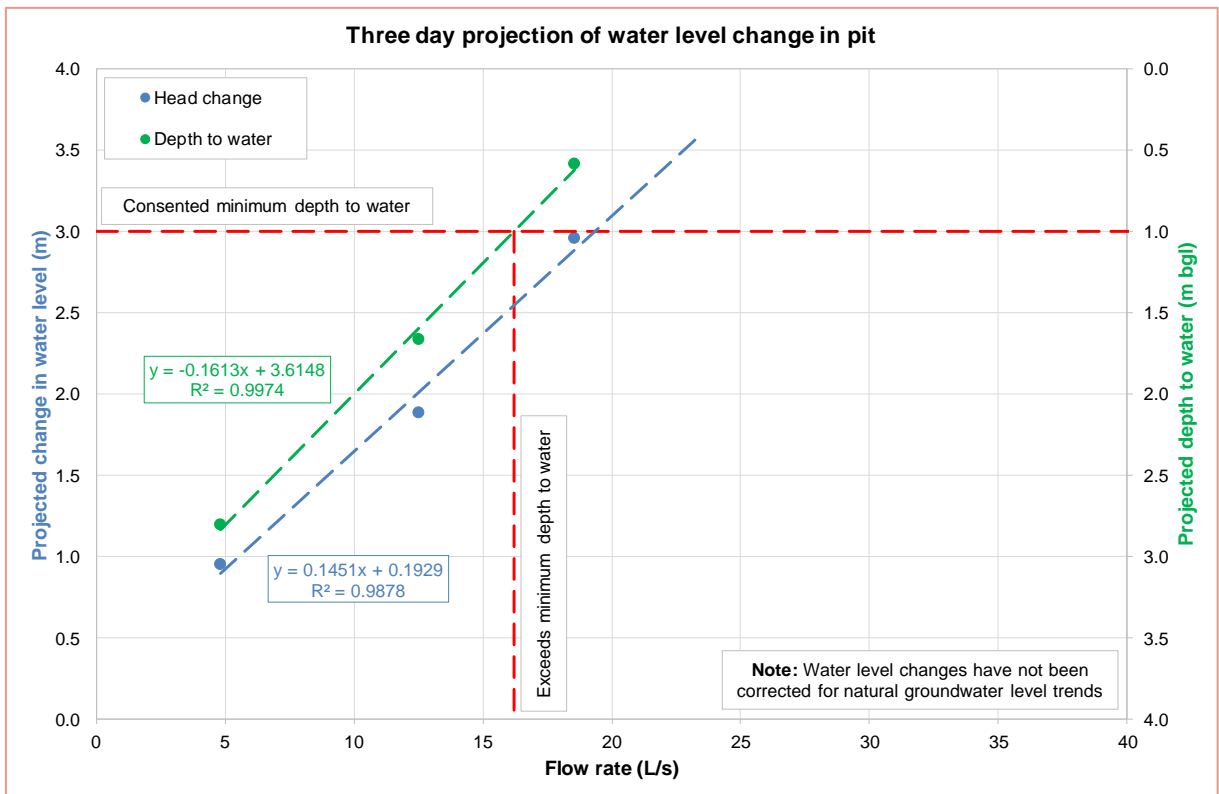


Figure F20: MAR08 site projected water level changes following three days infiltration.

**SITE: MAR09**



**Figure F21: MAR09 site overview.**



**Figure F22: MAR09 P3 monitoring well.**

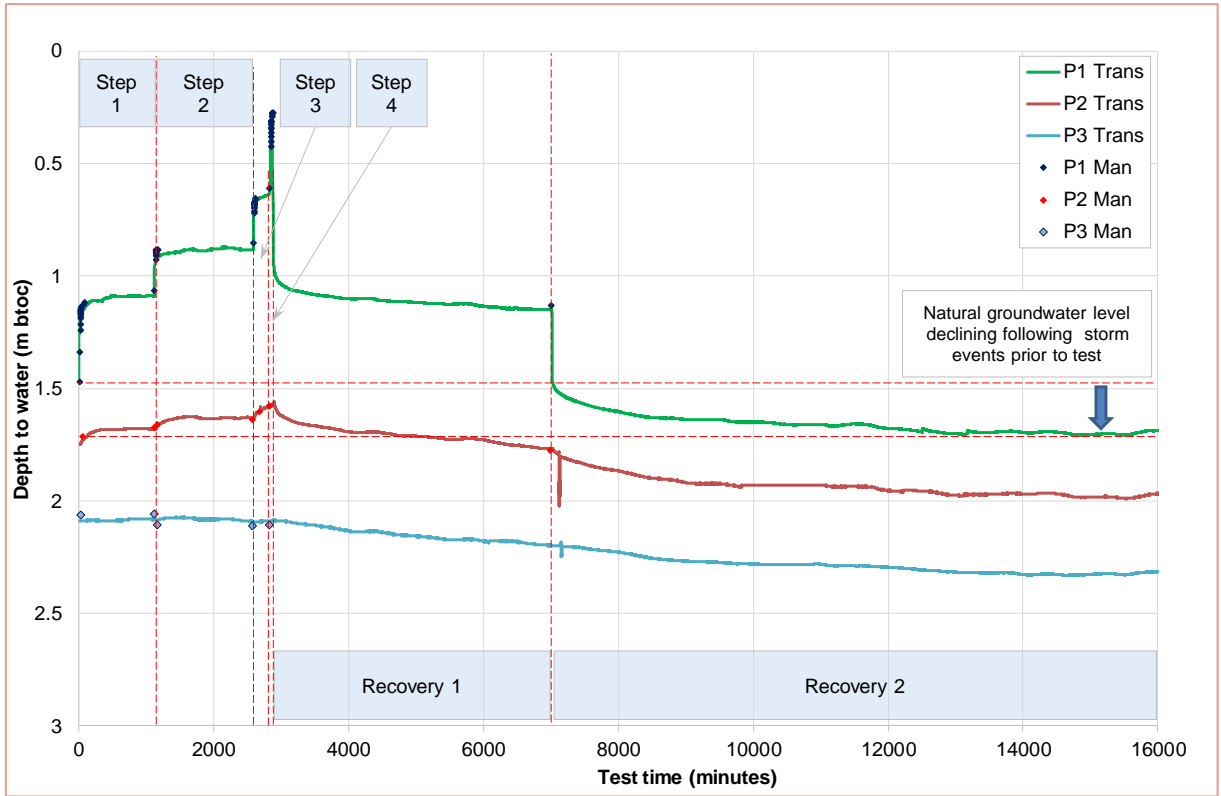


Figure F23: MAR09 test depth to water data - manual and automatic records.

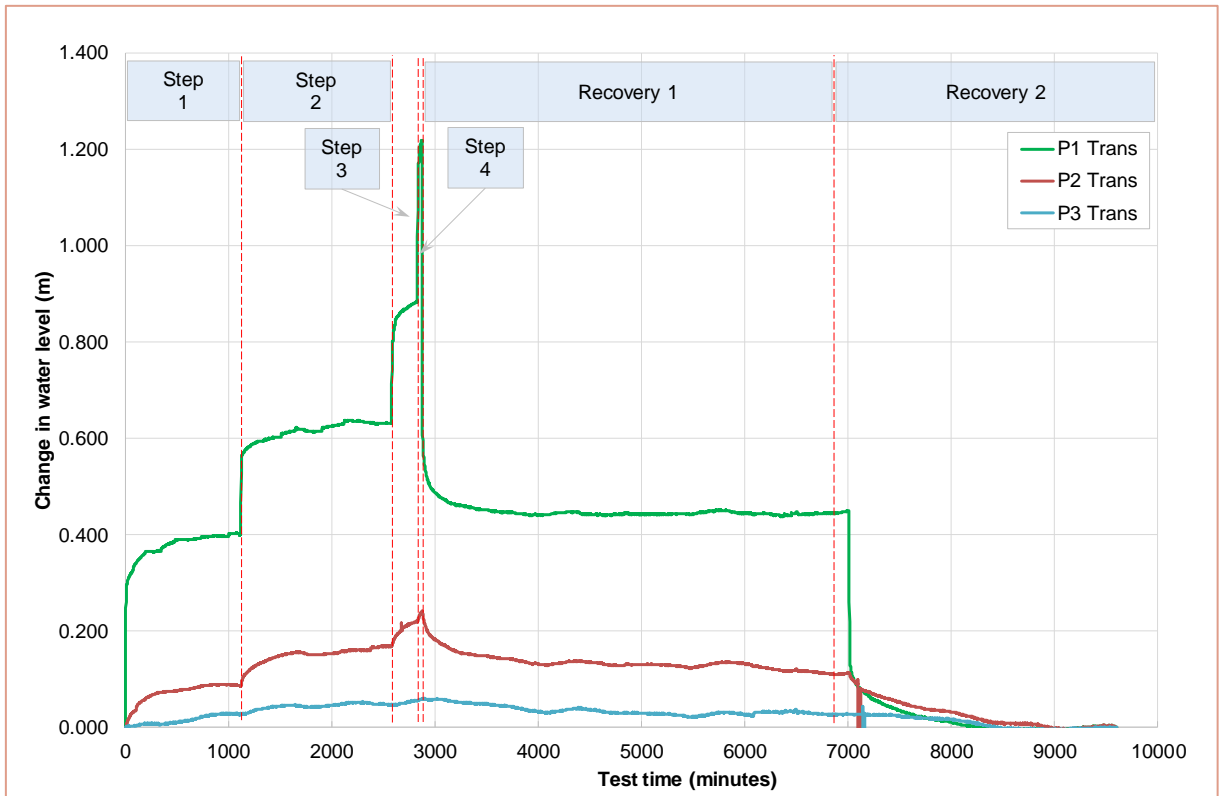


Figure F24: MAR09 test changes in water level recorded in piezometers, corrected for background groundwater level changes.

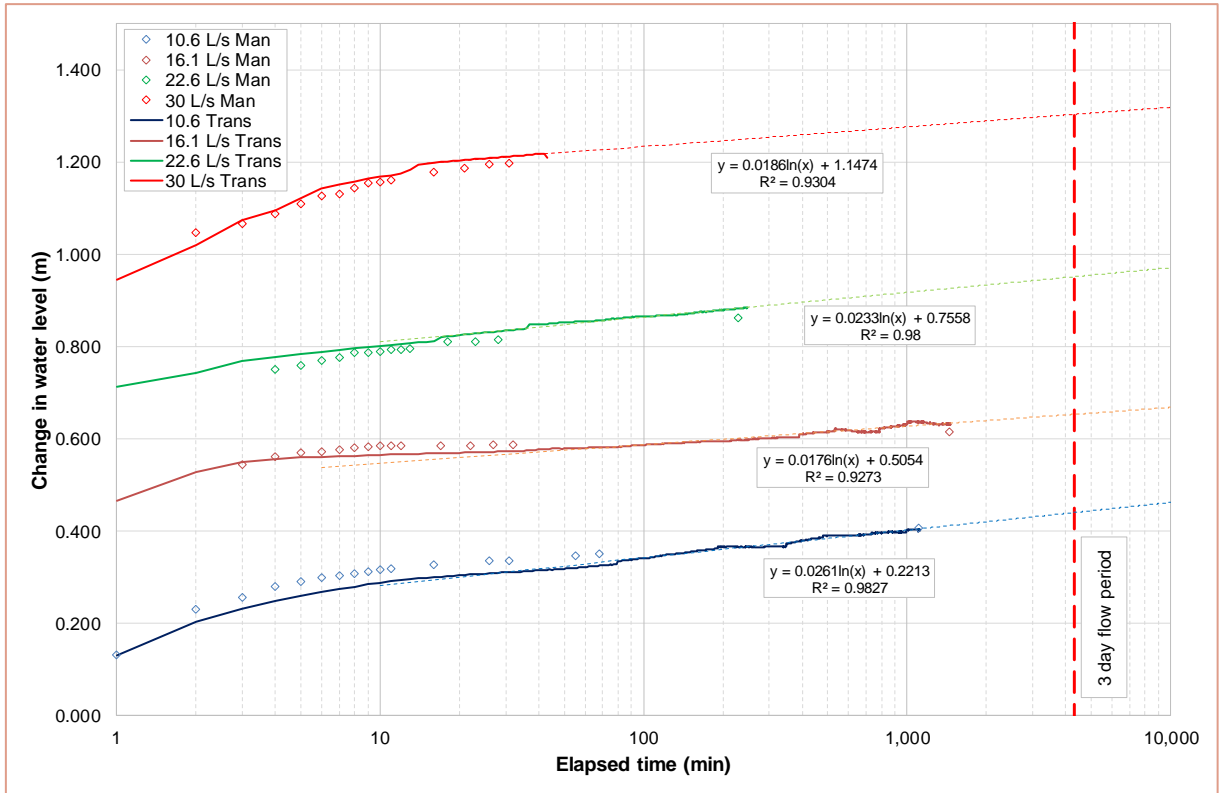


Figure F25: MAR09 test changes in water level recorded in piezometer P1 for each flow step.

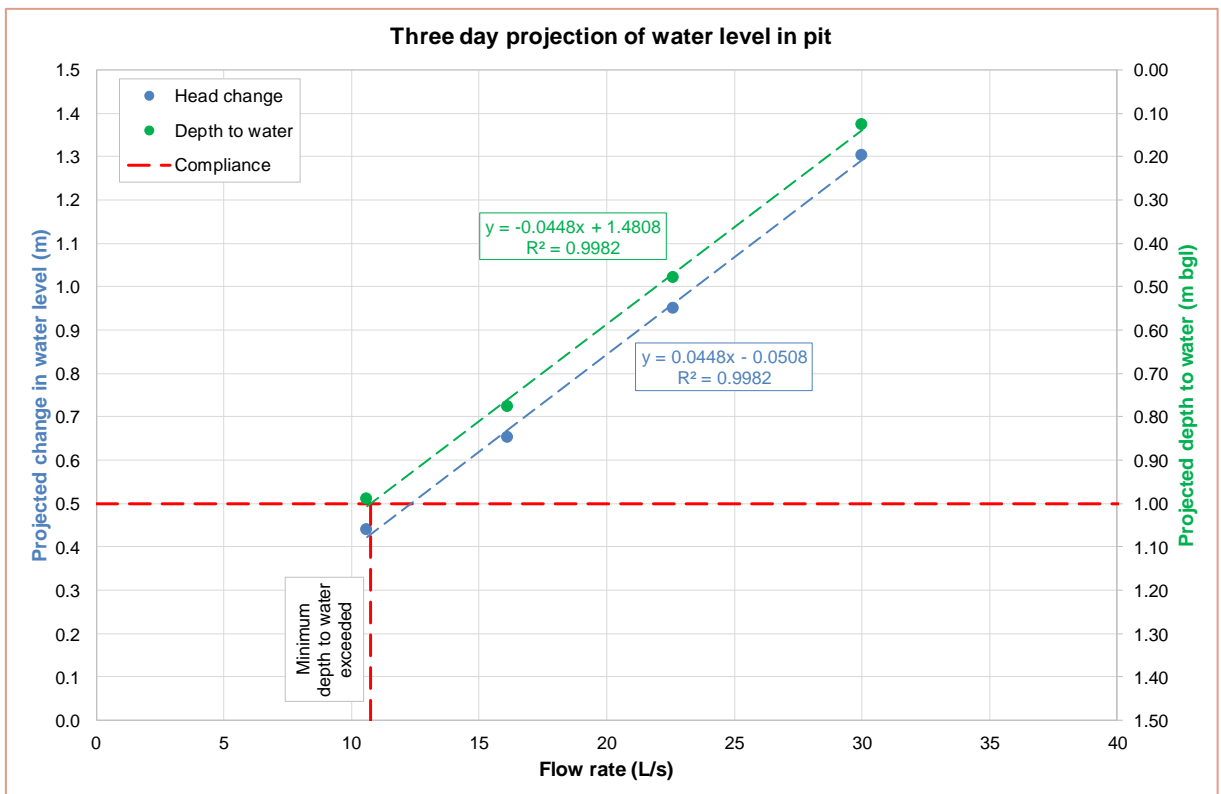


Figure F26: MAR09 site projected water level changes following three days infiltration.

**SITE: MAR13**



**Figure F27: MAR13 site overview.**



**Figure F28: MAR13 site flow control system.**

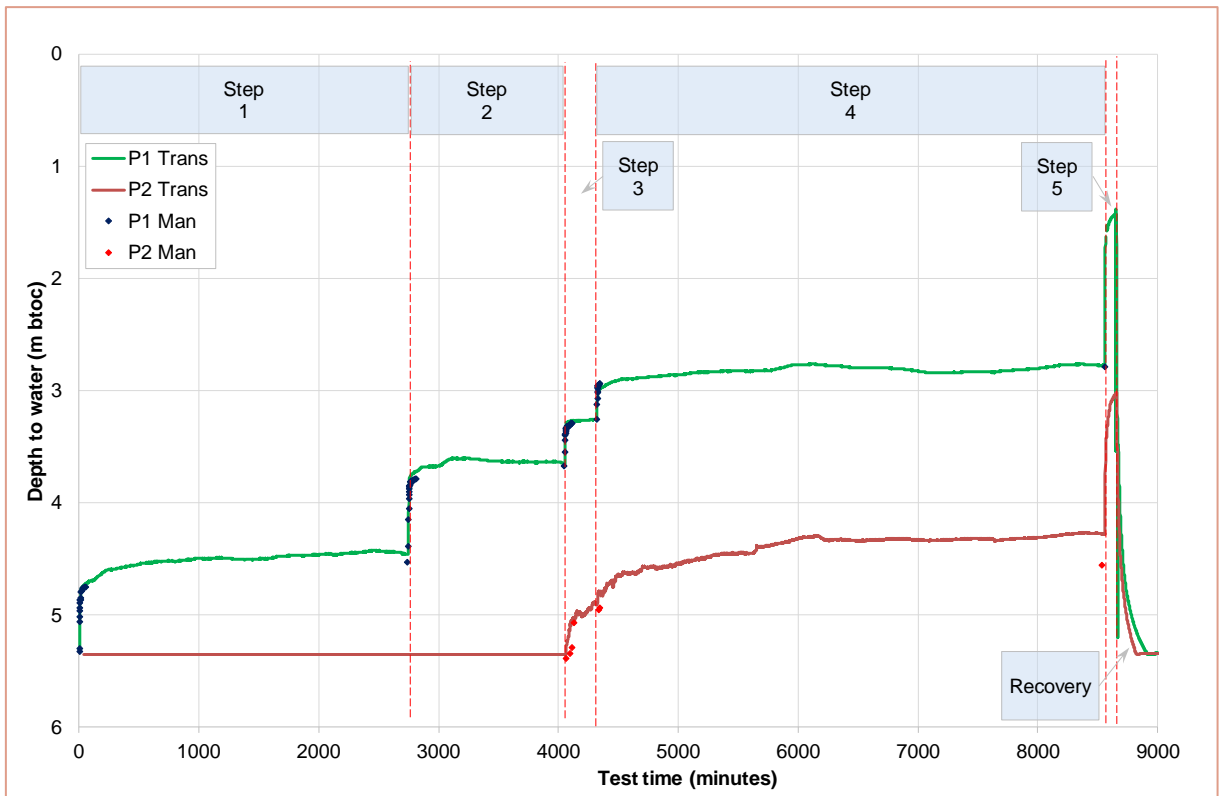


Figure F29: MAR13 test depth to water data - manual and automatic records.

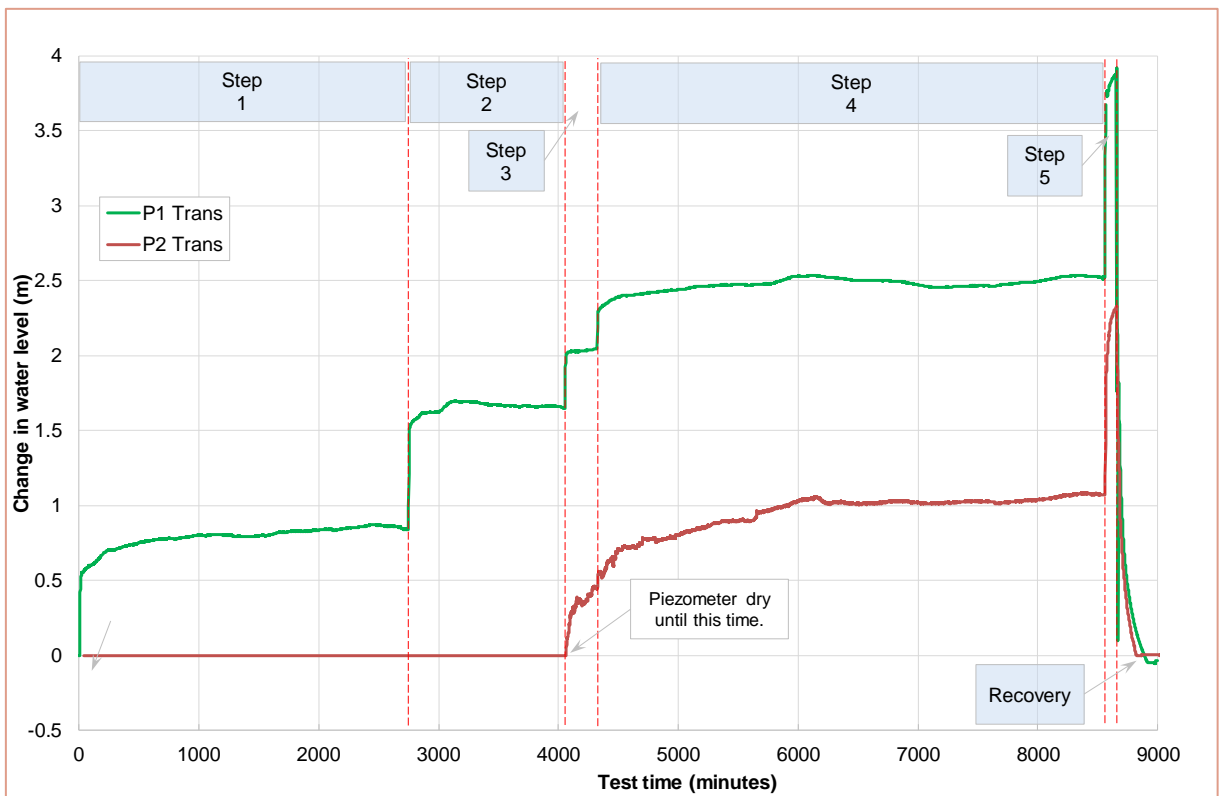


Figure F30: MAR13 test changes in water level recorded in piezometers P1 and P2.

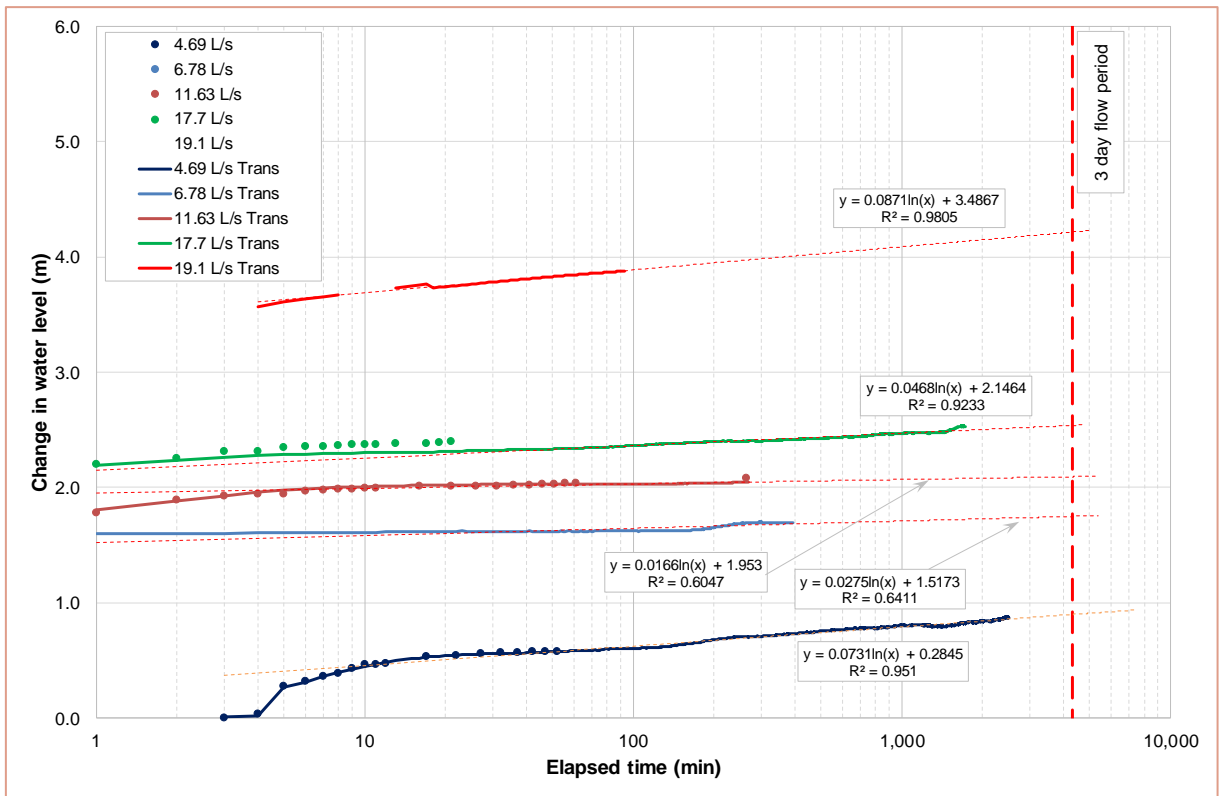


Figure F31: MAR13 test changes in water level recorded in piezometer P1 for each flow step.

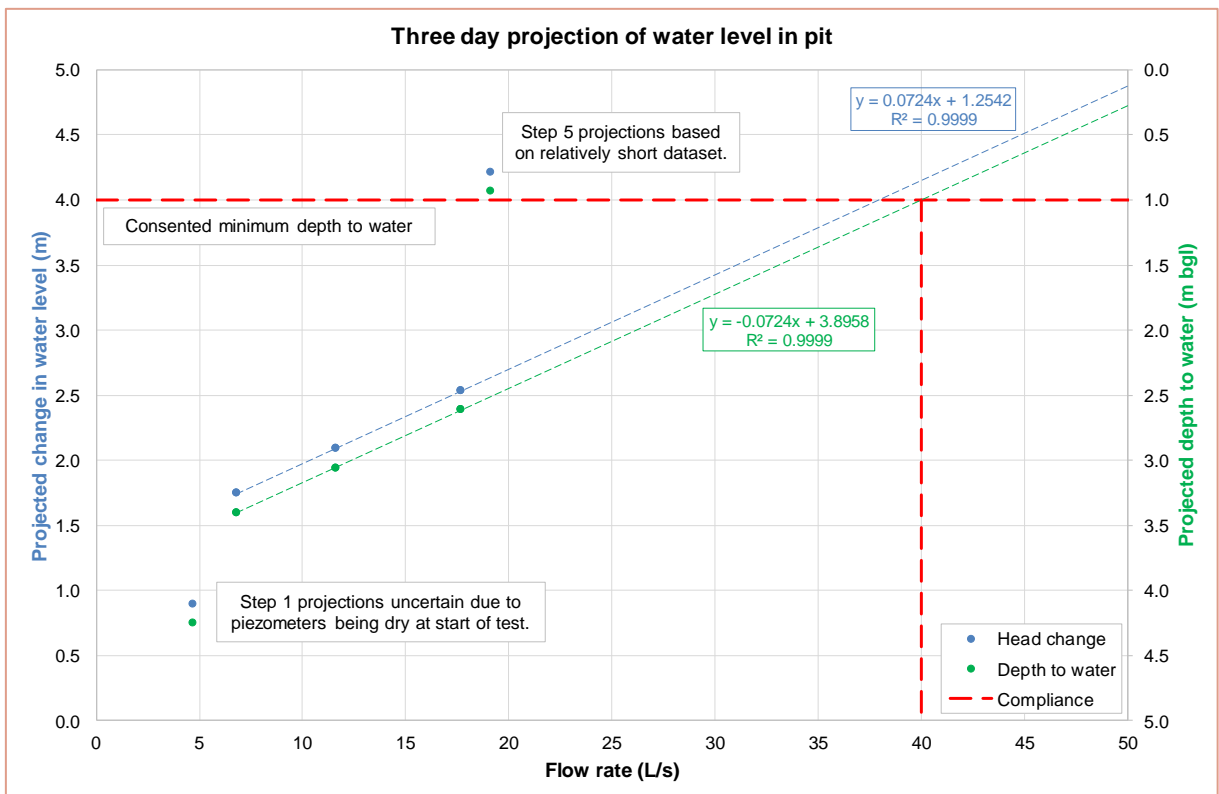


Figure F32: MAR13 site projected water level changes following three days infiltration.

**SITE: MAR15**



**Figure F33: MAR15 site overview.**



**Figure F34: MAR15 site piezometer locations.**

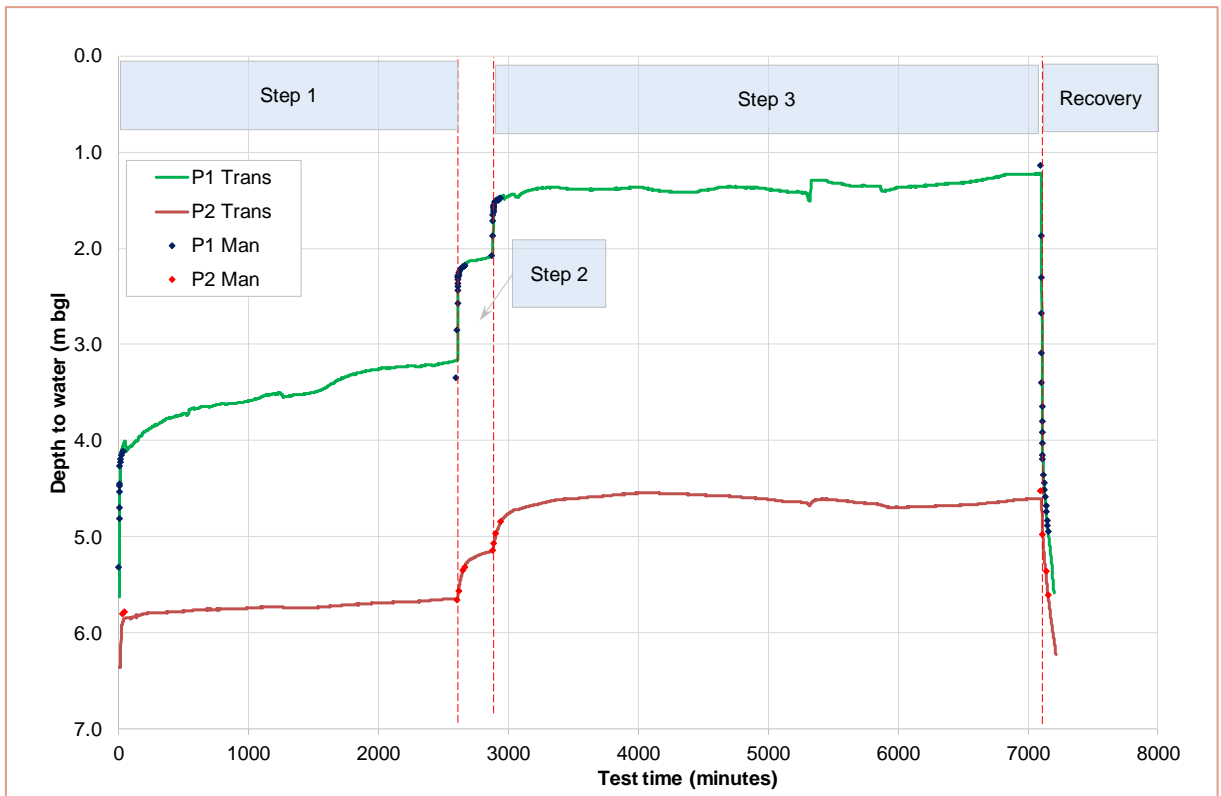


Figure F35: MAR15 test depth to water data - manual and automatic records.

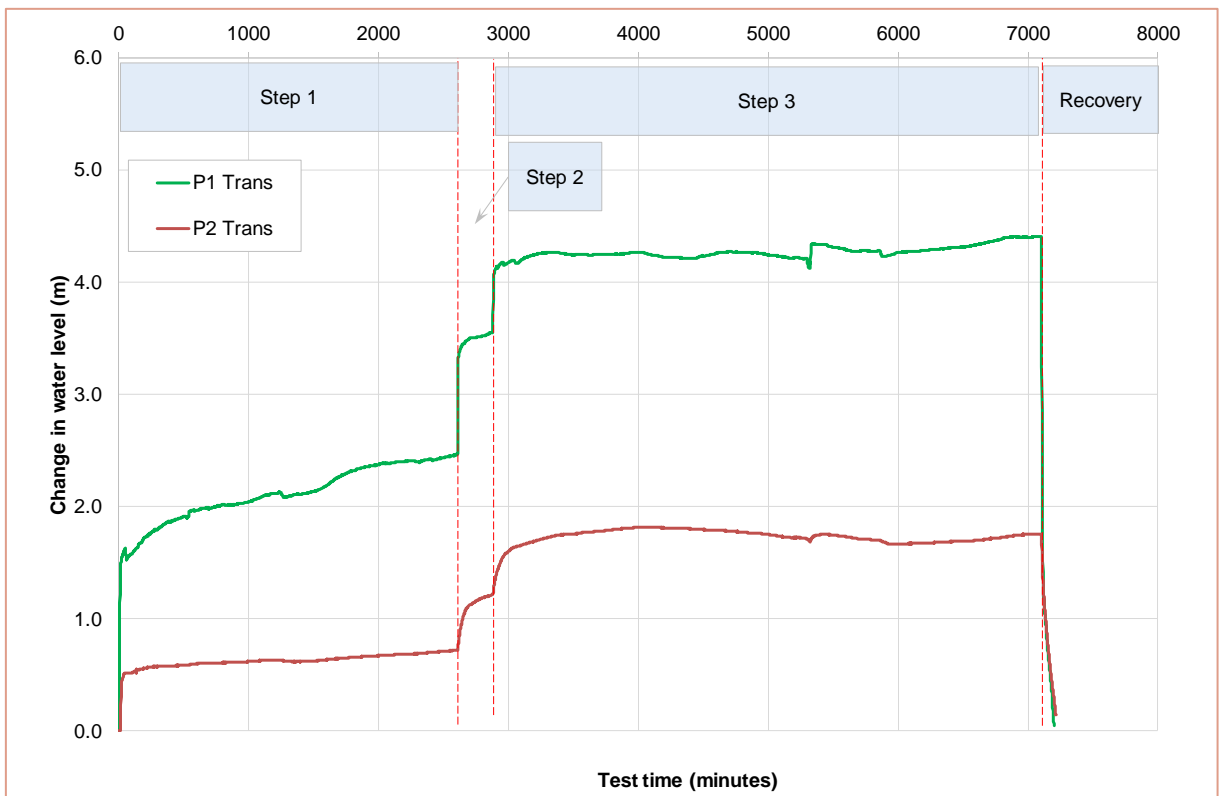


Figure F36: MAR15 test changes in water level recorded in piezometers P1 and P2.

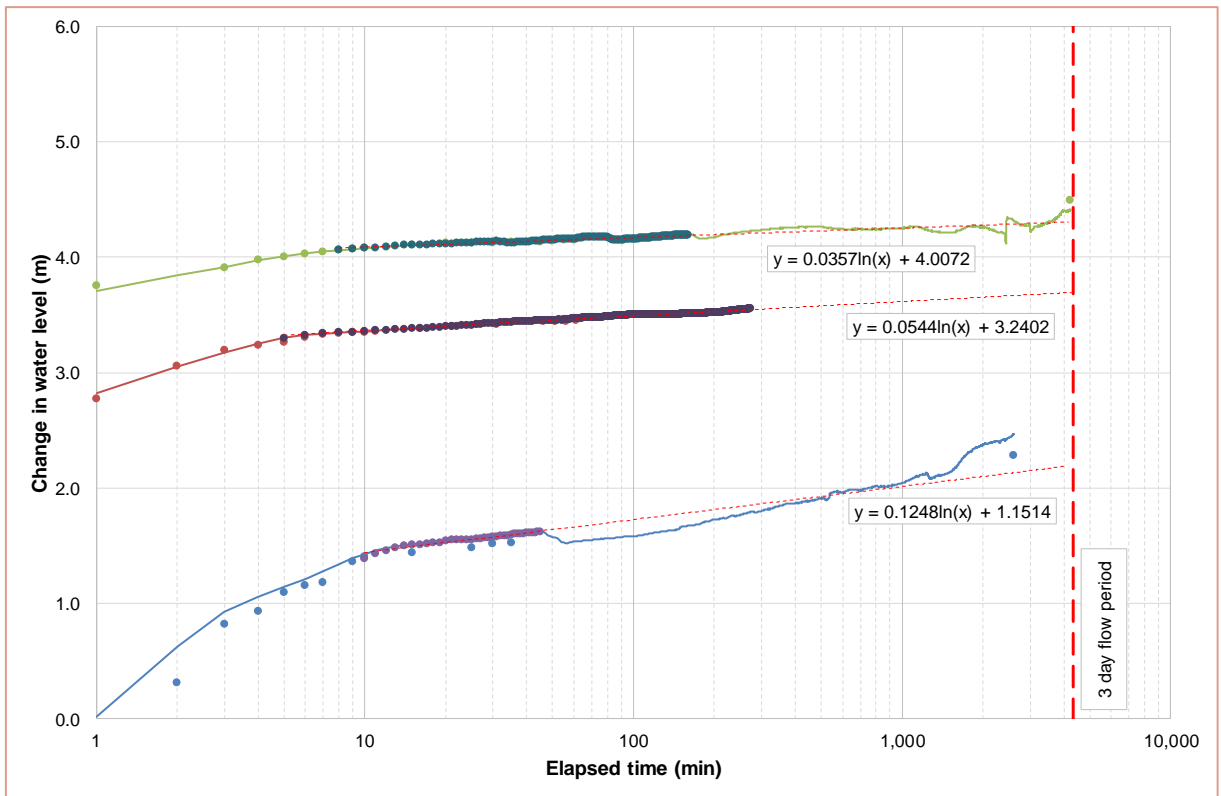


Figure F37: MAR15 test changes in water level recorded in piezometer P1 for each flow step.

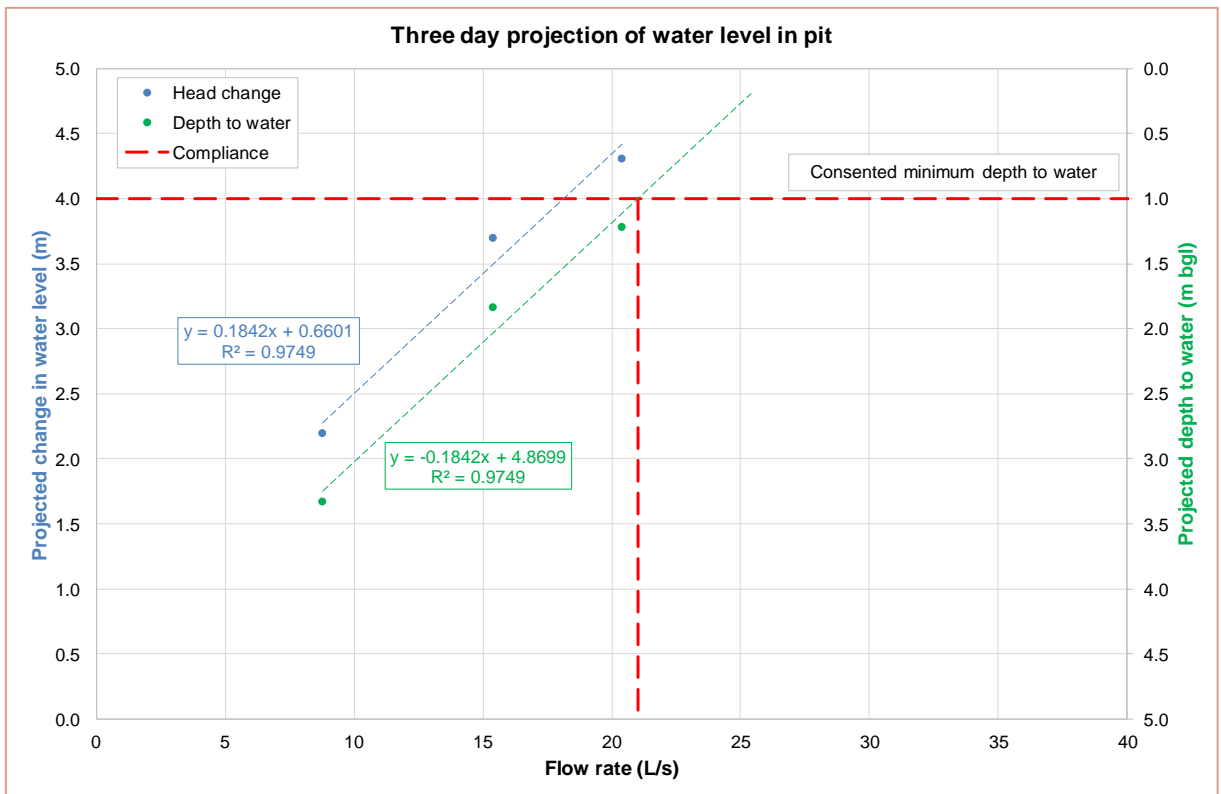


Figure F38: MAR15 site projected water level changes following three days infiltration.

**SITE: MAR16**



**Figure F39: MAR16 and MAR17 site overview.**



**Figure F40: MAR16 and MAR17 site piezometer locations.**

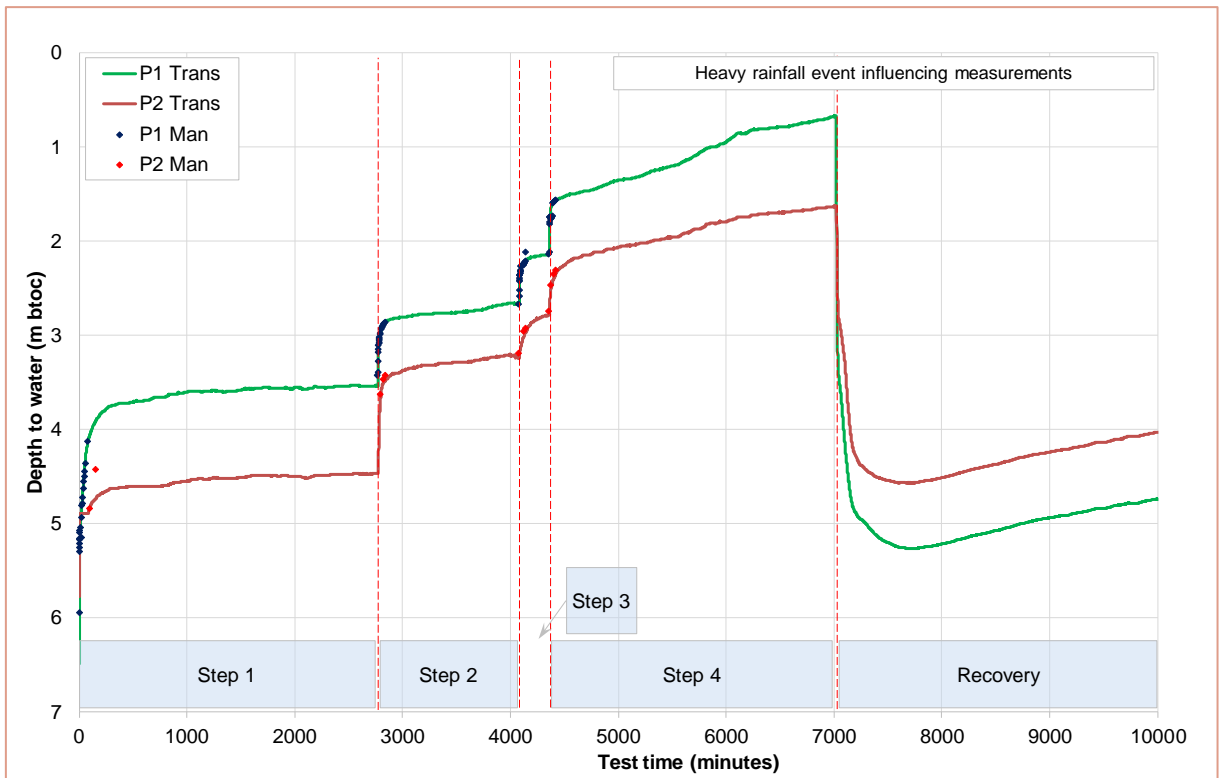


Figure F41: MAR16 test depth to water data - manual and automatic records.

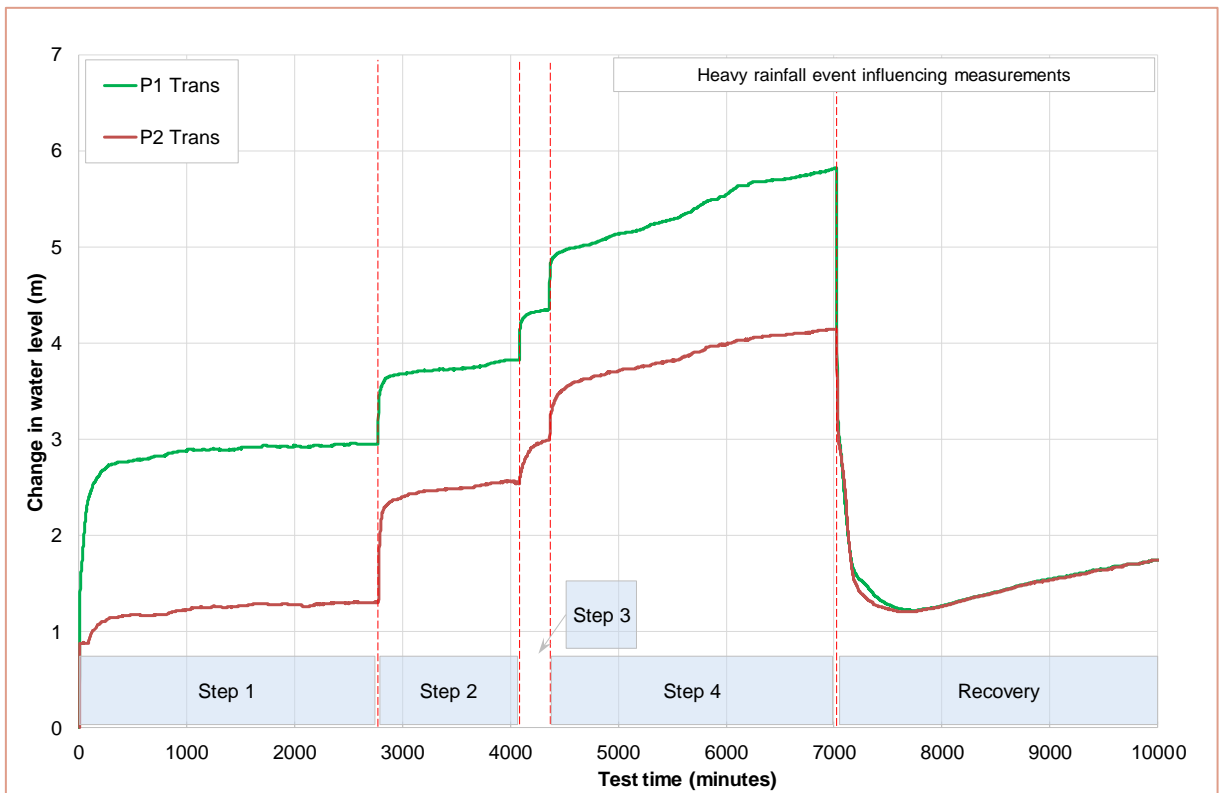


Figure F42: MAR16 test changes in water level recorded in piezometers P1 and P2.

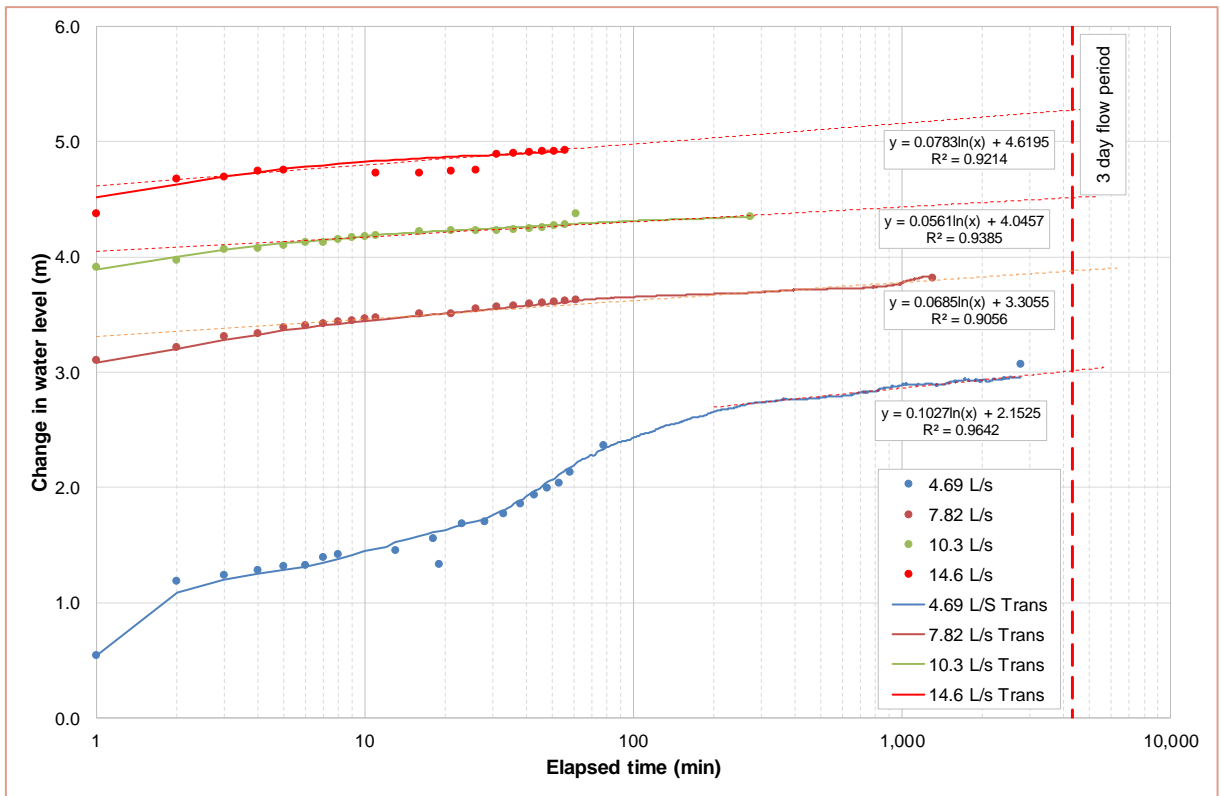


Figure F43: MAR16 test changes in water level recorded in piezometer P1 for each flow step.

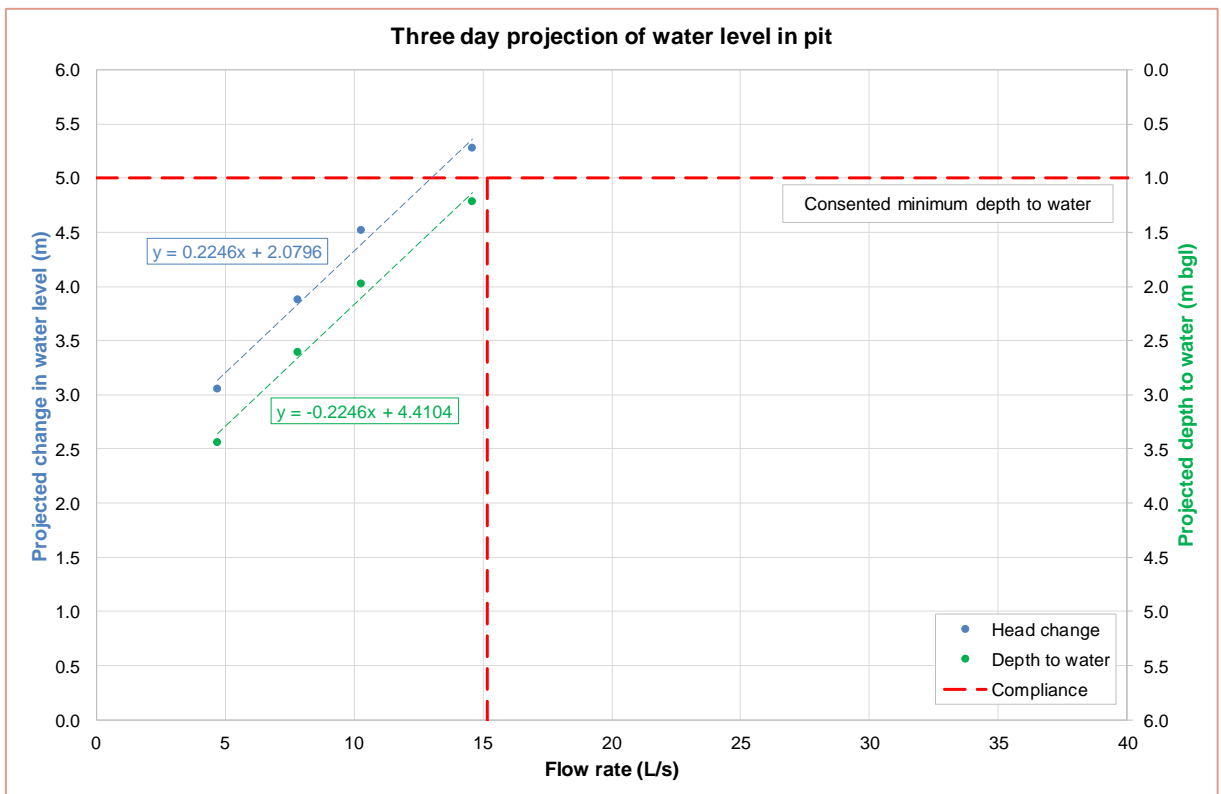


Figure F44: MAR16 site projected water level changes following three days infiltration.

## SITE PERFORMANCE SUMMARY

The performance of the soakage pits tested to date and presented in detail in the preceding sections of this appendix can be summarised in three charts. In Figure F37, the change in water level recorded in the soakage pit piezometer for each test is plotted against the flow rates applied in the test. The lower the slope of the resulting lines, the better the performance of the soakage pit.

In Figure F38 the same data has been presented as in Figure 37, however the axes have been swapped around. In effect, the lines indicate how much water can be infiltrated at each soakage pit at any flow rate within the range tested. The slope of the lines presented in Figure F37 indicates a “specific infiltration” rate in L/s/m, which is approximately equivalent to the specific yield of a production bore. If the natural groundwater level in the area of the soakage pit intersects the base of the pit, the “specific infiltration” value for the pit can be used to estimate the flow rate the pit can accept.

Finally, in Figure F39 a maximum potential infiltration rate is plotted against the “specific infiltration” for each soakage pit. The maximum potential infiltration rate is the product of the “specific infiltration” and the depth to water within the soakage pit at the time of the test. The calculated maximum potential infiltration rate also assumes that the water level in the pit may not approach to within one metre of the ground surface. This is a condition of the resource consent authorising this test programme. The best performing soakage pits are those identified toward the upper right corner of the chart in Figure F39. Pits identified toward the lower right corner of Figure F39 have good infiltration rates, but their overall performance is most likely restricted by shallow depths to groundwater during the test. As some of these tests were performed during a very wet period of 2018, with high groundwater levels, it is likely that their overall performance will improve during drier periods.

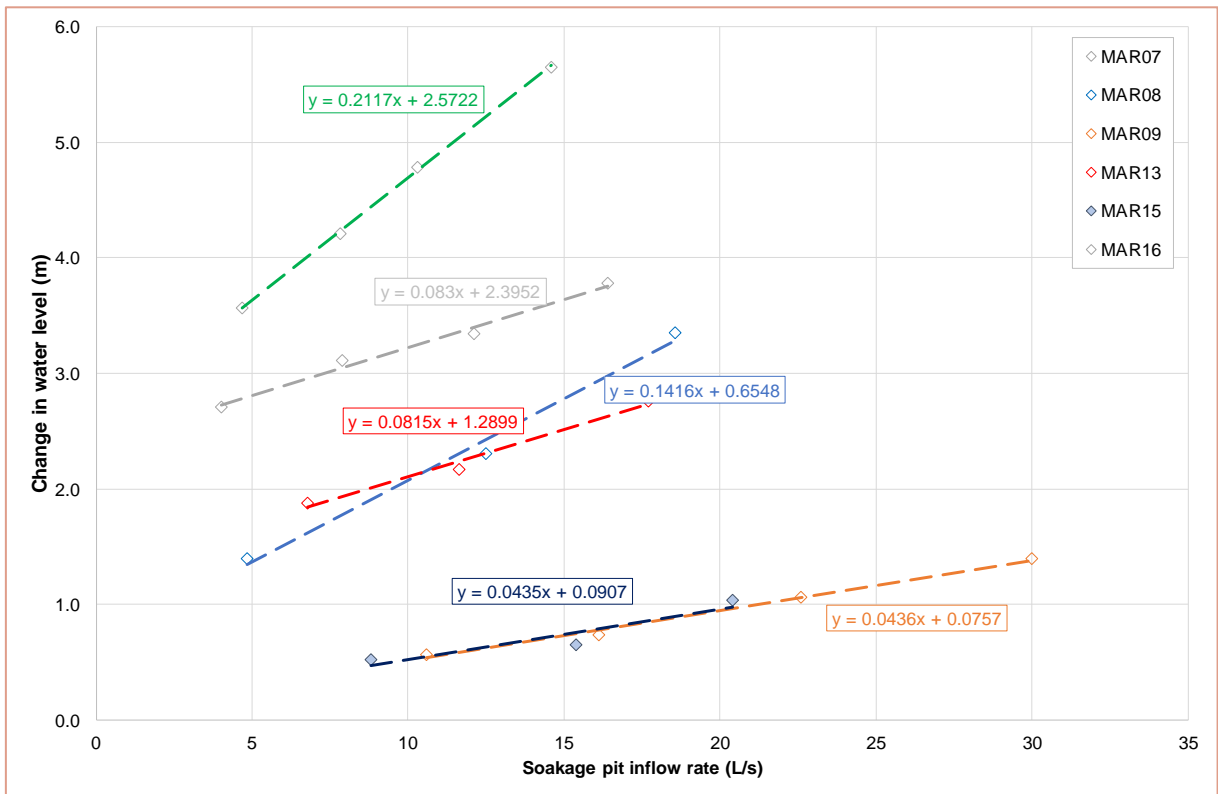


Figure F45: In-pit change in water level with increasing inflows to pit – at 365 day projection.

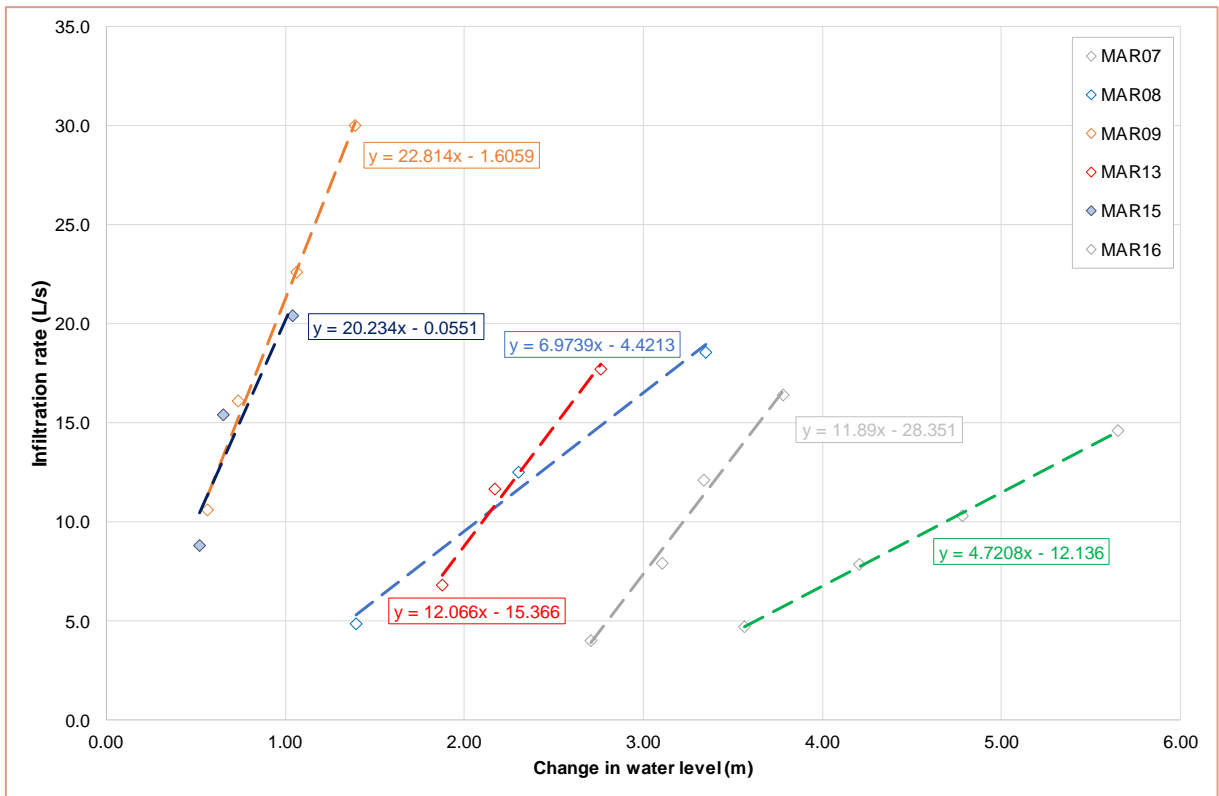


Figure F46: Infiltration rate related to in-pit change in water level – at 365 day projection.

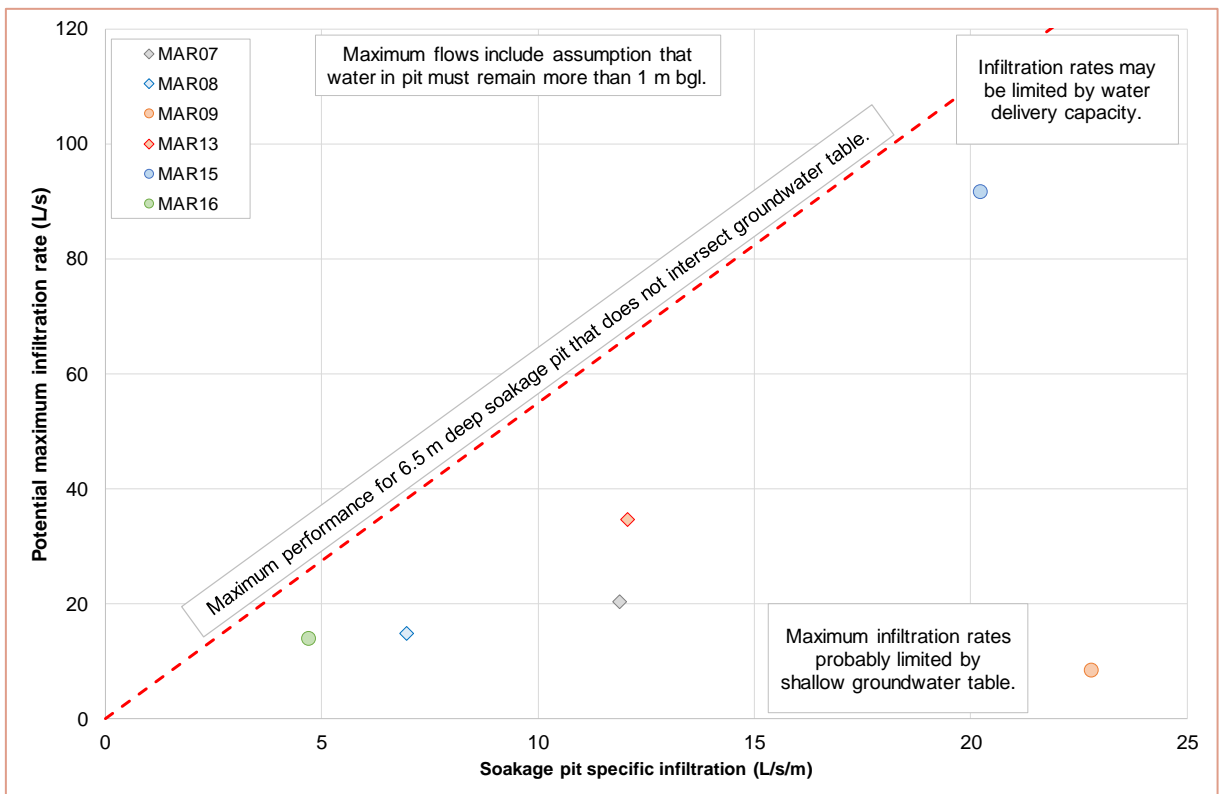


Figure F47: Soakage pit specific infiltration and maximum infiltration rate over one year.



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