REPORT

August 2015

POVERTY BAY MANAGED AQUIFER RECHARGE

Pilot Trial - Hydrogeology and Water Quality

Submitted to:
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Golder Associates

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List of Abbreviations and Units

Abbreviation/Unit	Name
DBP	Disinfection by-product
FwAG	Freshwater Advisory Group
g	Grams
g/m^3	Grams per cubic metre
GDC	Gisborne District Council
Golder	Golder Associates (NZ) limited
GRS	Groundwater Replenishment Scheme
ha	Hectare
HAAs	Halogenated acetic acids
HANs	Haloacetonitriles
km	Kilometre
L/s	Litres per second
LTV	Long term trigger value
m	Metre
m bgl	Metres below ground level
m^2/day	Metres squared per day
m^3/day	Cubic metres per day
MAR	Managed Aquifer Recharge
NTU	Turbidity
RL	Relative level
STV	Short term trigger value
THMs	Trihalomethanes
µS/cm	Micro Siemens per centimetre – measure of electrical conductance
WTP	Water Treatment Plant
XRD	X-Ray Diffraction

1.0 INTRODUCTION

1.1 Background

The Gisborne District Council (GDC) has identified long term water availability in the Poverty Bay area as being a potentially limiting factor in future regional development. Irrigation for horticultural purposes is one of the main uses of water across the Poverty Bay Flats. A substantial proportion of the water used for irrigation is derived from groundwater. Reviews of groundwater levels in the Poverty Bay Flats area have identified declining groundwater level trends as an environmental and water supply reliability issue. These trends are linked to increasing groundwater abstraction for irrigation purposes.

The GDC is investigating water management options to stabilise groundwater level trends and increase water supply reliability in the Poverty Bay area. One option under investigation is the use of Managed Aquifer Recharge (MAR), to replenish and sustain groundwater yields from aquifers beneath the Poverty Bay Flats. Golder Associates (NZ) Limited (Golder) was commissioned by GDC to undertake a pre-feasibility assessment for a MAR program.

The key outcomes of the Stage 1A (Golder 2014a) pre-feasibility assessment of the Poverty Bay MAR project, were:

- The Makauri Aquifer is prospective candidate for a MAR pilot project due to its relatively high usage, declining groundwater level trends, broad extent and good transmissivity.
- The combination of treated water that is potentially available outside the irrigation season and existing infrastructure (e.g., Gisborne water supply reservoirs and delivery systems) provides an opportunity for a successful groundwater replenishment scheme (GRS).
- A system of direct water injection through bores is a clear option for Makauri Aquifer groundwater replenishment and was recommended for further design and pilot testing.

Following further investigations and modelling during Stage 1B of the pre-feasibility assessment (Golder 2014b), it was concluded that MAR has the potential to replenish and support sustainable groundwater yields from the Makauri Aquifer beneath the Poverty Bay Flats.

GDC are now seeking to proceed with a pilot injection trial to the Makauri Aquifer (the “Pilot Project”). The purpose of this report is to provide GDC with information to support the design and final costing of the Pilot Project, together with an assessment of the consequences of injecting water into the Makauri Aquifer. This report is to be used as a technical supporting document for the resource consent applications for the Pilot Project.

1.2 Scope of Work

This technical report has been produced to provide supporting information needed by GDC, to support the resource consent applications needed for the Pilot Project. The scope of this report covers deliverables set out in Golder proposal 1415771-002-P-Rev0 (20 April 2015) under tasks outlined for Stage 2A of the Poverty Bay MAR project.

Finalise bore position and depth

- Work with GDC and the Poverty Bay community to refine the location for the injection bore.
- Confirm and finalise the source water for the trial and the quality criteria for the injection water.
- Undertake a survey of bores located close to the preferred pilot site to determine suitability for trial monitoring.
- Produce detailed bore designs for a tender process where drilling companies provide final cost estimates.

Water quality assessment

- Support GDC in obtaining and testing water samples from nearby private bores.

- Evaluate the additional groundwater quality data collected around the preferred pilot site to determine the geochemical reactions and interaction likely to result from the Pilot Project.
- Integrate the water quality data into a hydrogeochemical model for the site and assess the consequences of injecting water to the geochemically reduced environment of the Makauri Aquifer.

This report also provides information on:

1) The planned position and depth of the pilot injection bore
2) Local hydrogeological conditions for the site
3) Potential water sources for the Pilot Project
4) Chosen Pilot Project monitoring bores
5) Bore design details to support the contractor tender process
6) Local groundwater quality
7) The consequences of injecting water to the Makauri Aquifer.

1.3 Poverty Bay Future Water Storage Needs

The GDC, through guidance and input from the Freshwater Advisory Group (FwAG), has conducted a future water resource supply and demand study (GDC 2011). This study indicated that increasing water demand could be limited by declining or uncertain supplies. This limitation may lead to constrained economic growth and degraded environmental outcomes for the district.

Changing climate patterns are expected to lead to increased rainfall variability, including prolonged droughts and/or more frequent high intensity rain events. This expectation of increased rainfall variability makes proactive and longer-term planning a key element for water resource management.

Ongoing gains in irrigation efficiencies assist in the conservation of surface and groundwater resources. Using increasing efficiency as a sole management approach has, however, been shown to limit further opportunity. This is particularly true when water resources are deemed to be over-allocated and declining, or when the opportunity to actively replenish supplies is deemed feasible and cost effective.

Improved management of water storage for the Poverty Bay Flats area will be needed in order to provide for increasing demand while at the same time improving environmental outcomes for the district. This improved management may be in the form of purpose-built surface storage or through improved management of groundwater resources, or a combination of both in an integrated water management system.

Some of the highest unit prices for irrigated land in New Zealand occur in the Gisborne area (Doak et al. 2004). Consequently, irrigated horticulture is expanding over land previously used for dry-land sheep farming or other pasture uses. The combined economic value of irrigation across the Poverty Bay Flats is in the order of $18 million annually (Golder 2014b). Groundwater makes up a significant portion of the water needed to meet current and future demands in Poverty Bay Flats area.

1.4 Poverty Bay Groundwater Replenishment Scheme

The potential for developing a GRS in the Poverty Bay area based on MAR is being investigated due to the current pressure on groundwater allocation. Under the current abstraction rates, the Makauri Aquifer is experiencing a trend of declining water storage during irrigation seasons. This trend is occurring despite incomplete utilisation of water allocated under existing groundwater take consents. This groundwater allocation pressure is combined with likely tighter future limits on surface water abstraction and increasing water demand by existing users.

The area has potential for further investment in high value productive activities, provided greater long term security of water supply is achieved. The area has limited options for surface water storage. Local catchments are characterised by highly erodible sediments, resulting in silt-laden rivers and geotechnical and siltation problems for dam storage. Therefore MAR presents a good option for water storage in the area.

A correctly operated GRS should have few environmental effects, provided the quality of the water injected or infiltrated to the aquifer is acceptable. The physical footprint of a GRS for the Makauri Aquifer is potentially small. If water source and treatment systems need to be developed, the footprint and effects would however need to be evaluated on a case-by-case basis. In general the environmental and cultural effects of a new water source and recharge system should be considerably less than, for example, a new water supply dam.

The existing private abstraction bores accessing the Makauri Aquifer represent a significant capital investment. This aquifer, when actively replenished and managed, may be able to act as an effective water distribution system linking these bores with a GRS. This is one of the aspects of a GRS that will require further assessment and modelling based on the outcomes of the trial.

2.0 PROPOSED PILOT PROJECT

2.1 Introduction

The primary finding from the MAR pre-feasibility assessments (Stages 1A and 1B) was that a pilot trial is required to demonstrate the viability of a GRS focused on the Makauri Aquifer to improve the security of future water supply in the Poverty Bay area. Funding has been secured to design, plan and implement a MAR pilot trial based on the direct injection of water from the Mangapoike Dams into the Makauri Aquifer. During the initial development of this Pilot Project, a back-up source water option was also identified. This option entails the sourcing of water from the Waipaoa River through the Waipaoa Augmentation Plant. The effects of using this back-up source water for the Pilot Project have also been identified and evaluated in this report.

The objectives of the pilot trial include:

- Confirming the Makauri Aquifer properties in the area of the trial injection bore.
- Confirming the rate at which water can be injected to the Makauri Aquifer at the pilot trial site and the extent and magnitude of groundwater level rise in the Makauri Aquifer that occurs as a consequence of the trial.
- Confirming projections for localised changes in aquifer water quality during and following the trial.
- Optimising injection bore management procedures.
- Validating the use of a GRS to support water management and supply security planning in the Poverty Bay area.

2.2 Location

The proposed location for the MAR pilot is 2028592 E, 5713365 N (NZTM), adjacent to the water tanker refilling station at the Waipaoa Augmentation Plant. Two further potential injection bore locations have also been identified on the same site. The reasons for defining additional bore locations are documented later in this section.

The position of the injection bore for the Pilot Project (Figure 1) has been selected for the following beneficial reasons:

- Proximity to two source water options:
  - Treated source water from Mangapoike Dams through the water supply pipe network.

- A back-up source water supply option from Waipaoa River through the Waipaoa Augmentation Plant.

- Location of the site to the west of the area with the greatest density of takes for water from the Makauri Aquifer as well as the greatest observed drawdown effects on the aquifer. This area of high groundwater abstraction is approximately 3 km to the northeast of the Pilot Project site, which places the Pilot Project in proximity to the area of greatest stress on the aquifer.
- There are only a few active bores with consented takes accessing the Makauri Aquifer close to the Pilot Project site. Specifically, the bores associated with the largest consented groundwater takes are mostly located in the high use area to the northeast of the Pilot Project site. For this reason, groundwater level responses to the injection trial at the planned monitoring bores are less likely to be masked by aquifer responses to pumping from individual private bores.
- Site access and permissions. The property located at the Waipaoa Augmentation Plant, is owned by and managed by GDC, allowing for easy access and permissions. In addition, this site also allows for on-going management of the injection bore and associated infrastructure by GDC if the Pilot Project demonstrates the viability of a GRS for the Makauri Aquifer.

The above benefits of choosing this particular site also result in some associated risks. These risks relate to the relatively low density of drillholes in this area. The low local drillhole density creates some uncertainty around the exact lithological sequences (Section 3.3) and the hydraulic properties of the Makauri Aquifer beneath the site (Section 3.4). The extent of any limitations these risks impose with respect to the amount of water that may be injected to the aquifer during the trial will be identified during the pilot hole drilling and pumping test phases of the project. These risks are however considered to be operational in nature rather than relating to the potential environmental effects of the trial.

Due to the uncertainty regarding the thickness and properties of the Makauri Aquifer, two additional potential injection bore locations have been identified on the same site (Figure 1). The location of the trial injection bore will be finalised once the pilot hole drilling has been completed.

2.3 Injection Bore Conceptual Design

Golder has prepared conceptual bore design information of sufficient detail to enable drilling companies to provide a fully costed proposal for the completion of the proposed injection bore (Appendix A). The information provides contractors with scope to recommend different drilling methodologies, casing and screen options.

For costing purposes the injection bore is proposed to be up to 85 m deep, with a 6 m long screen. This initial design is based on lithological logs from nearby bores (Section 3.3). A pilot-hole will be drilled to confirm the lithologies and the thickness of the target aquifer at the site, prior to installation of the injection bore. The finalised bore construction and screen placement will be based on the outcomes from this pilot-hole drilling and may differ from the initial proposed design. The pilot-hole will be finished as a standpipe piezometer and used for monitoring of the groundwater level and water quality effects during the Pilot Project. The injection bore will subsequently be constructed a few metres from the pilot-hole.

The drilling method and completion of the injection bore will be consistent with best practice for this aquifer type and the requirements for injection bores. The annulus spaces for both the standpipe piezometer and the injection bore will be well sealed above the target aquifer to ensure no hydraulic connection develops between the Makauri Aquifer and any overlying shallow aquifer.

Injection of water will be closely monitored and controlled using flow control systems at the bore head. The injection bore head and flow control system is proposed to be covered by a lockable shed to ensure site security. The source water for injection will be delivered to the site through GDC’s pipe network, as outlined in Section 2.5.

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3. Schematic only, not to be interpreted as an engineering design or construction drawing.
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TITLE LOCATION OF PROPOSED INJECTION BORE

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2.4 Bore Testing and Aquifer Characterisation

The proposed injection bore will be pump tested, with the data obtained being used to calculate the local aquifer properties, including hydraulic conductivity and storativity. The plan for hydraulic testing is outlined in Appendix A and involves:

- A 24 hour stepped rate pumping test, including a monitored groundwater recovery period. The stepped rate test is to include four different flow rate steps at 100 minutes each, followed by a recovery period. The data from this test is to be used to evaluate the bore efficiency and improve planning of flow rates for the injection trial.
- An allowance for an aquifer rest day between the step test and constant rate test.
- A 72 hour constant rate pumping test carried out on the injection bore followed by a monitored recovery period of the same length. The data from this test is to be used to evaluate the aquifer characteristics.

Frequent manual and automated water level measurements in the test bore and observation bores will be carried out at predefined intervals throughout the tests. The data from these tests will be analysed and the results used to finalise planning for the injection trial.

During the pumping test program water samples will be obtained for analysis. The data will be used to check the projections for local aquifer water quality presented in this report.

2.5 Pilot Project Source Water Options

2.5.1 Primary Option - Mangapoike Dams

Golder understands that up to approximately 100,000 m³ of water is potentially available from the Mangapoike Dams (Clapcott Dam and Williams Dam) and the Te Arai Bush Catchment between July and September for use in the Pilot Project. Water from the dams and bush catchment is treated at the Waingake Water Treatment Plant (WTP) and conveyed via gravity flow (with boosting as required) through the GDC reticulation system. This water is delivered as treated drinking water (Section 4.4.2.1) through the conveyance pipeline and is therefore suitable for use as injection water in the trial.

The water can be supplied to the Pilot Project at a rate of up to 15 L/s. GDC water supply engineers have stated that pipeline capacity is sufficient to supply both existing users and the Pilot Project outside the irrigation season. On this basis, sourcing water from the Mangapoike Dams is the preferred option for the Pilot Project. The amount of water actually available for the Pilot Project will be at the discretion of the GDC water supply engineers, who can provide the source water only after their supply needs have been fulfilled.

The proposed MAR trial will involve installing a commercial standard "off take" in the water supply pipe line that feeds the tanker filling station located at the site. Flow meters are planned to be installed on the GDC supply side of the off take and at the injection flow control system at the bore head works.

2.5.2 Secondary Option - Waipaoa Augmentation Plant

The Waipaoa Augmentation Plant was commissioned in 1991 as an alternative or back-up supply to augment the Waingake water supply, and could be used as a source of direct injection water for the Pilot Project. The plant has the capacity to produce water volumes up to 200 L/s or 17,000 m³/day (GDC 2008). GDC holds resource consent to take up to 13,392 m³/day from the Waipaoa River at the plant. These volumes would be easily sufficient for the purposes of the planned MAR Pilot Project.

The regional arm of council has established a minimum river flow of 600 L/s at the Matawhero Bridge and 1.3 m³/s at the Kanakanaia Bridge. Water take restrictions may be applied if the flows drop below these rates. Flows below these rates have not been observed to date and restrictions have never applied (GDC 2008). The minimum flows may be subject to change in a proposed Regional Water Plan due for notification in 2015. The minimum flow at Matawhero is unlikely to be continued whereas the minimum flow at Kanakanaia may remain in place following notification (Dennis Crone, GDC, pers comm.). Following development of the Regional Water Plan and increasing water demand, flow restrictions may apply in the future.

If there is insufficient water available from the Waingake WTP due to seasonal conditions during the trial injection period, the Waipaoa Augmentation Plant offers a back-up water source option. Water produced by the Waipaoa Augmentation Plant is of drinking water quality. This water is therefore of a suitable standard for injection before delivery to the bore head injection system (Section 4.4.2.2).

2.6 Operational Water Quality Management Requirements

A successful Pilot Project will be based on efficient replenishment of the Makauri Aquifer with high quality water. The quality of the source water used in the Pilot Project is important for the following reasons:

- The injection of the source water into the Makauri Aquifer, and consequent mixing of this water with the receiving groundwater, should generally not lead to a decline in the receiving water quality due to the introduction of contaminants with the source water.
- The use of good quality source water will help to manage the risk of chemical, biological or physical clogging of the injection well screen (refer Section 4.5.3). In addition, well maintenance costs will be reduced if well clogging issues can be successfully managed through the use of good quality source water.

For the above reasons the quality of the water available from the Waingake WTP (Section 4.4.2.1) and the Waipaoa Augmentation Plant (Section 4.4.2.2) has been carefully assessed to ensure the above risks can be successfully managed during the Pilot Project.

The water sourced from the Waingake WTP and Waipaoa Augmentation Plant will have been treated with chlorine, which will assist in managing potential issues associated with microbiological clogging during injection. Clogging risks are discussed further in Section 4.5.3 and potential risks associated with disinfection by-products discussed in more detail under Section4.5.4.

3.0 EFFECTS ON GROUNDWATER LEVELS AND FLOWS

3.1 Hydrogeology

The aquifer system beneath Poverty Bay Flats consists of a series of sand and gravel units within Quaternary age sediments infilling a sedimentary basin to the west and northwest of Gisborne City. Five main aquifers have been identified from surface mapping and drilling. These include three shallow aquifers which are hydraulically linked to surface water bodies and two deeper aquifers. These aquifers are used extensively for irrigation and commercial purposes, and domestic supply.

Toward the coast, the geological interpretation indicates the aquifers will be predominantly sandy rather than a continuation of the gravel deposits. The gravel aquifers may therefore not have a strong hydraulic connection to the ocean. There is a thick low permeability sediment layer from a former estuary which acts to restrict the hydraulic connection between the shallow aquifers and the deeper aquifers, over the southern half of the basin. In the northern areas the deeper aquifers are closer to the surface and the main area of groundwater recharge to the Makauri Aquifer is considered to be north of Ormond (Golder 2014a).

3.2 Makauri Aquifer

The confined Makauri Aquifer is the aquifer targeted for the proposed Pilot Project. This aquifer is the main source of water for irrigation purposes on the Poverty Bay Flats. Groundwater levels in this aquifer have shown declines related to increased groundwater abstraction (Golder 2014a, 2014b). The hydrogeology of the aquifer system beneath Poverty Bay Flats, and the Makauri Aquifer specifically, is summarised in a separate report by Golder (2014a).

The Makauri Aquifer covers an area of at least 6,000 ha beneath the Poverty Bay Flats, from Caesar Road in the north to the Gisborne city outskirts in the south. The Makauri Aquifer is shallower beneath the northern edge of the flats (-45 m RL at Ormond) dipping down to -60 m RL in the middle of the basin (White et al. 2012). The aquifer has a thickness of between 5 m and 20 m, with the aquifer being thickest in the middle of the basin and thinning toward the coast. Although the aquifer was at one time considered to pinch out completely before reaching the coast, lithological logs from bores near the coast indicate a thin gravel layer is locally present (White et al. 2012). The Makauri Aquifer contains some limestone gravels generated from the limestone outcrops on the surrounding hills.

3.3 Local Lithology

Lithologies intersected by bores within 2 km of the proposed injection site are summarised in Appendix B. Most logs from bores in the vicinity of the planned injection bore are similar to that from bore GPD115 (Figure 2), which indicates a blue clay layer (45 m to 72 m bgl) overlying the Makauri Aquifer (gravel and sand 72 m to 75 m bgl). Generally, logs from bores close to the pilot site show a gravel or sand layer at a depth of approximately 70 m to 80 m bgl.

Logs from bores to the north-east (500 m to 1,500 m from the site) in the vicinity of Matawai Road (Figure 2), show a relatively consistent gravel layer at 70 m to 71 m bgl. The Makauri Aquifer appears to be well defined and of consistent thickness in this area.

To the west, on the western side of the Waipaoa River, the gravels are less consistent, with variable depths from 60 m to 80 m bgl. The aquifer is described in the log from GPJ040 as gravel, poorly sorted sub-angular to rounded (65 m to 73 m bgl). Other nearby bores (e.g., GPJ044) in the western area showed no indication of water bearing gravels at similar levels.

Bore GPD147, to the southeast of the planned trial site, has a different lithological log to the logs from other nearby bores, with blue clay intersected from 63 m to 89 m bgl. This bore is screened from 104 m to 114 m bgl, which is deeper than the Makauri Aquifer bores in the area and generally corresponds to the underlying confined Matokitoki Aquifer. The water level responses recorded from bore GPD147 are similar to patterns observed in the Makauri Aquifer bores suggesting it may be hydraulically connected to the Makauri Aquifer.

In conclusion, the differences between the lithologies intersected by bores in this area emphasise the variability of sedimentary deposits in a riverine environment. There is some risk that the gravel layer of the Makauri Aquifer is thin or not present in the proposed drilling area. Based on this information, the location for the trial injection bore was targeted at the northeastern corner of the GDC owned site because the Makauri Aquifer is expected to increase in thickness in this direction. The planned pilot-hole will be used to confirm the depth and thickness of the Makauri Aquifer.

3.4 Aquifer Hydraulic Properties

Interpolation of pumping test data results for the Makauri Aquifer indicates transmissivity ranges from 500 m²/day to 1,500 m²/day across 80 % of the aquifer (Golder 2014b). Local pumping test results are available for three bores completed in the Makauri Aquifer within 1.5 km of the Pilot Project site (Table 1). The closest result is 456 m²/day, from bore GPD115. A similar transmissivity is expected for the Makauri Aquifer beneath the proposed trial site. This is considered to be a conservative estimate for planning of the Pilot Project as a transmissivity similar to the higher values presented in Table 1 would enable higher water injection rates. The storativity from the pumping test carried out on bore GPD135 (Table 1) has been used for initial projections of aquifer responses to the trial.

The planned 72 hour constant rate pumping test and the stepped rate test will provide more specific information on the aquifer hydraulic properties at the proposed trial site. Following the pumping tests the projected groundwater level responses to the planned injection trial (Section 3.8) will be re-modelled.

Table 1: Results of pumping tests performed on bores near the Waipaoa Augmentation Plant.

Bore No.	Bore drill date	Bore depth (m)	Screen position (m bgl)	Transmissivity (m²/day)	Storativity
GPD135	N/A	71	69.2 - 71	424	0.00027
GPD089	1/01/1983	85.3	80.7 - 85.3	1,155	0.0012
GPD115	20/03/1987	75.1	73.1 - 75.1	456	N/A
GPE034	16/11/1982	70	unknown	1,280	N/A
GPD007	N/A	70.1	unknown	383	0.000015

Note: N/A – Not available

1. Aerial: GDC 2012, CC-BY-3.0-NZ.
2. Schematic only, not to be interpreted as an engineering design or construction drawing.
3. Drawn by: RW. Reviewed by: AP.

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TITLE BORES CLOSE TO PILOT PROJECT SITE

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3.5 Baseline Groundwater Levels

Groundwater levels in bores in the vicinity of the proposed injection site (Figure 3) have been monitored by GDC for more than 30 years. Groundwater level trends in bore GPJ040 (Figure 4), which is approximately 1.5 km west of the site, have been analysed in detail and are typical of the trends across the Makauri Aquifer as a whole. Seasonal pumping drawdown has generally been increasing over the past 30 years in response to increased water demand (Golder 2014b).

Groundwater level trends in the Makauri Aquifer indicate abstraction over the past decade has been balanced by long-term inflows to the aquifer from the wider hydrological system. During drought years; however, volumes abstracted from the Makauri Aquifer appear to exceed the annual recharge for the aquifer. The Makauri Aquifer is reaching a limit in its capacity to recover, as shown by the multi-year recovery periods following drought seasons. In addition, the actual groundwater abstracted during drought years to date appears to be considerably less than the volumes already consented for abstraction.

Maps of piezometric surfaces for the Makauri Aquifer, based on data recorded during one summer (7 January 2009) and one winter (25 August 2008), were presented in Golder (2014b). The variation between winter and summer levels and the overall groundwater gradients in the Makauri Aquifer beneath the Poverty Bay Flats were also described in that report. These seasonal variations are expected to be generally consistent from one year to the next. The abstraction of groundwater for irrigation during summer means the hydraulic gradients and groundwater flow directions beneath the site change seasonally.

During August 2008 (winter) the groundwater gradient beneath the Pilot Project site was toward the south, at approximately 0.0003 m/m. During January 2009 (summer) the groundwater gradient was toward the northeast, at approximately 0.001 m/m. These gradients differ slightly in detail year on year, depending on the amount of water abstracted from the Makauri Aquifer each irrigation season but maintain a similar overall pattern. They provide a good indication of the seasonal groundwater flow patterns beneath the planned trial injection site. During winter groundwater flow in the Makauri Aquifer would be toward the south. During summer, groundwater abstraction for irrigation would result in groundwater flow beneath the injection site being toward the northeast.

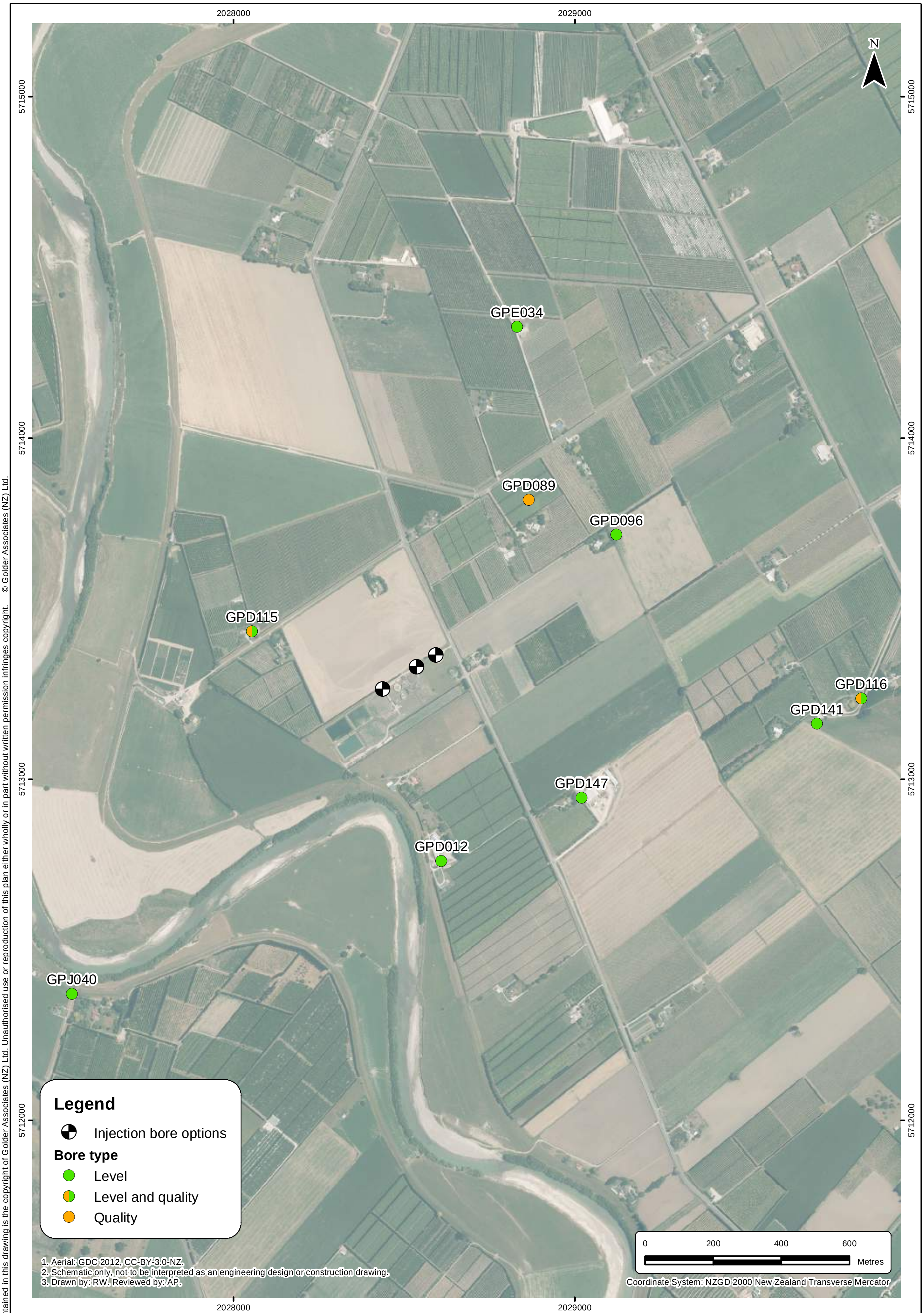
Groundwater levels in the Makauri Aquifer have been measured on a weekly basis in eight bores close to the proposed trial site since May 2015 (Table 2 and Figure 5). A shallow bore screened in the overlying unconfined aquifer will be added to the monitoring suite once either a suitable bore is identified by GDC or a shallow standpipe piezometer is installed in the pilot-hole at the Pilot Project site.

3.6 Nearby Bores

There are 123 bores on the GDC bore database within 2 km of the proposed injection site (Figure 2). Of these bores, 61 % or 75 bores are of unknown depth or less than 25 m deep. Due to the presence of the thick confining bed overlying the Makauri Aquifer, these shallow bores are unlikely to be impacted by the proposed MAR injection trial. Despite increased hydraulic heads in the Makauri Aquifer during the injection stage of the trial, the confining bed (aquitard) will inhibit upward movement of water from the Makauri Aquifer into the shallow aquifer, thereby ensuring water quality in the shallow aquifer will not be affected by the trial.

There are 44 bores with depths between 50 m to 115 m deep within 2 km of the proposed injection (Appendix B, Table B2). A conservative assumption can be made that these bores are potentially screened in the Makauri Aquifer. Six of these bores are monitored for long term water level and seven are monitored for water quality by the GDC on a regular basis (Figure 2).

Management measures to mitigate the potential risk of nearby bores becoming artesian during the trial are presented in Section 3.8.



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TITLE LOCATIONS OF GROUNDWATER MONITORING WELLS FOR TRIAL

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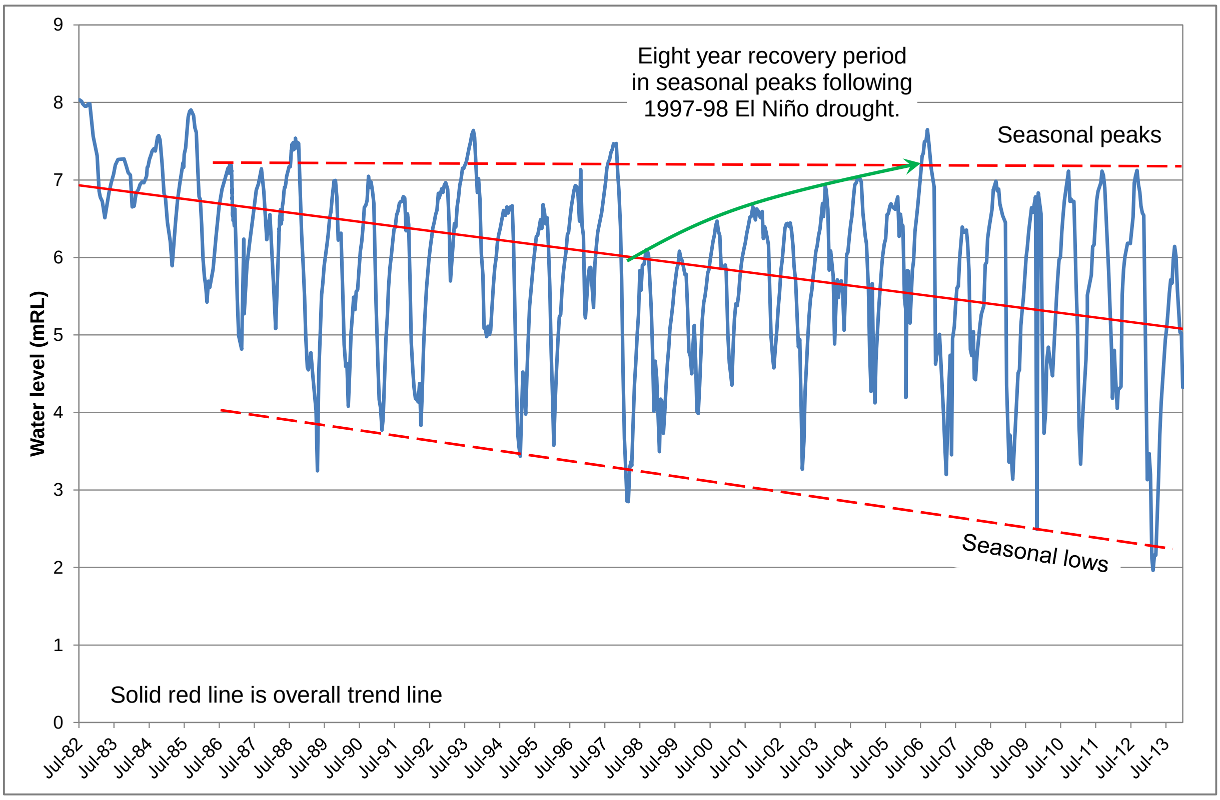

Figure 4: Groundwater level trends in Makauri Aquifer (bore GPJ040).

Table 2: Monitoring bores close to proposed injection site.

Bore	Owner	Aquifer	Monitoring	Screen depth (m)
GPD089	Alexander Kemp	Makauri	Quality	80.7 - 85.3
GPD096 (1)	Michael Gibbins	Makauri	Level	81.4
GPD115 (1)	Brian Baty	Makauri	Level and quality	71.6 - 75.1
GPD116 (1)	Graham Family Trust	Makauri	Level and quality	70.1 - 76.2
GPD141 (1)	Antony Leach	Makauri	Level	72.9 - 75.3
GPD147 (1)	Darrell Williams	Matokitoki	Level	104 - 114
GPE034 (1)	Lochiel Investments Ltd	Makauri	Level	70
GPJ040 (1)	GDC	Makauri	Level	65.8 - 80.0
GPD012 (1)	Cameron Mechanical	Makauri	Level	60.9
Pilot-hole deep piezometer	GDC	Makauri	Level and quality	TBC
Pilot-hole shallow piezometer (2)	GDC	TBC	Level	TBC

Note: 1) Baseline monitoring underway.
2) May be installed if no appropriate existing shallow aquifer bore identified for monitoring.

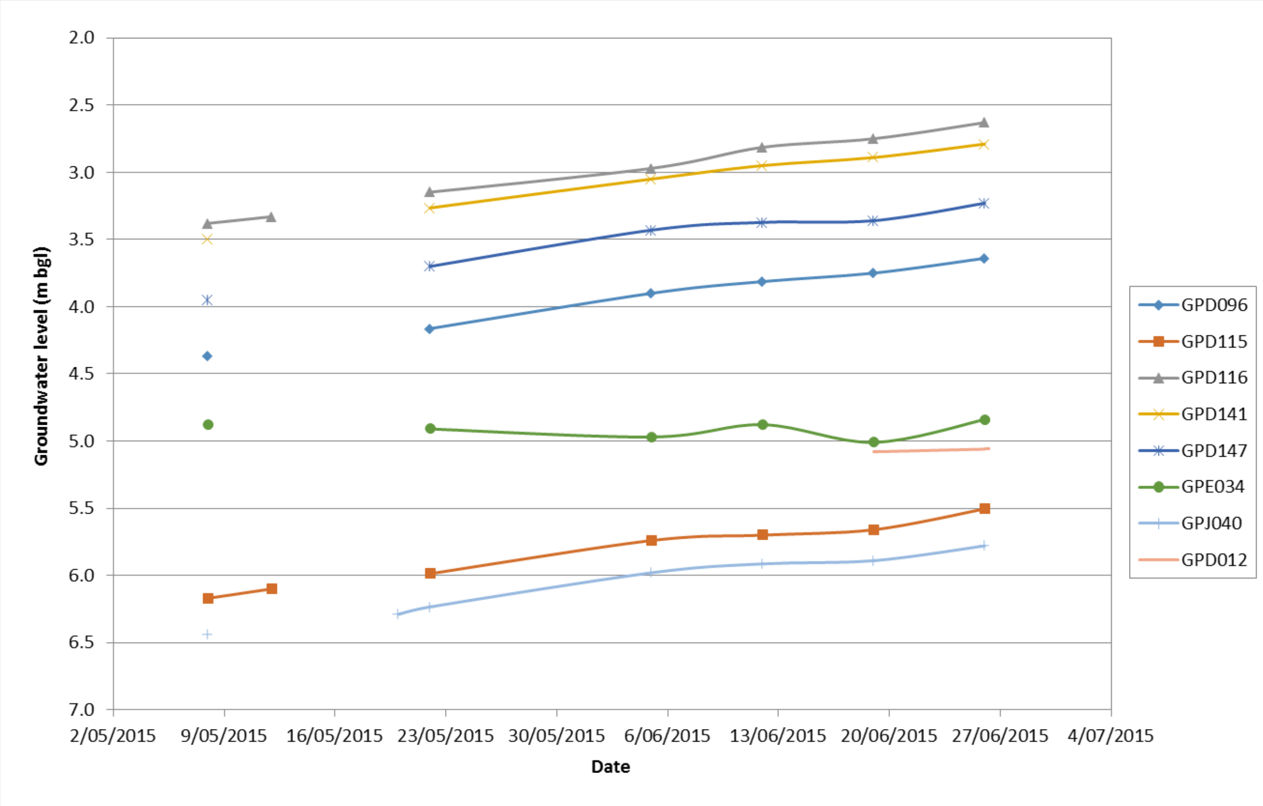

Figure 5: Initial groundwater level monitoring results from wells near proposed injection site.

3.7 Nearby Consented Groundwater Takes

There are several consented groundwater takes from the Makauri Aquifer within a 2 km radius of the proposed injection bore (Figure 6 and Appendix B, Table B3). However there are only two consented takes within a 1 km radius of the proposed injection bore that are also considered to be tapping the Makauri Aquifer. Consented groundwater abstractions within 1 km of the proposed injection site include the following:

- Bore GPD115 (Makauri Aquifer). Consent holder B.R. & C.A. Baty has a water permit to take 210 m^3/day and the monitored take volume was recorded as 3,360 m^3/year for the 2012-2013 irrigation season. This bore is included for monitoring of water quality and groundwater levels.
- Bore GPD089 (Makauri Aquifer). Consent holder A.B. & B.N. Kemp Partnership is consented to take 100 m^3/day and the monitored take volume was recorded as 7,953 m^3/year for the 2012-2013 irrigation season. This bore is included for targeted monitoring of water quality.
- Bore GPD147 (Matokitoki Aquifer) has two associated consent holders Chrisp Agriculture and G. Armstrong, and Bushmere Investments Ltd. They are consented to take 1,350 m^3/day and the monitored take volume was recorded as 49,791 m^3/year for the 2012-2013 irrigation season. This bore is included for monitoring of water quality and groundwater levels.
- Bore GPD004 and transfer to bore GPD183 (both in Shallow Fluvial Aquifer). Consent holders J.D.S. & J.M. Dymock are consented to take 114 m^3/day and the monitored take volume was recorded as 10,109 m^3/year for the 2012-2013 irrigation season.

1. Aerial: GDC 2012, CC-BY-3.0-NZ.
2. Schematic only, not to be interpreted as an engineering design or construction drawing.
3. Drawn by: RW, Reviewed by: AP.

Golder Associates

TITLE CONSENTED GROUNDWATER ABSTRACTIONS NEAR THE PROPOSED INJECTION SITE

AUGUST 2015

PROJECT 1415771

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3.8 Effects on Groundwater Levels

During the injection phase of the trial, groundwater levels in the Makauri Aquifer will rise in the area around the trial site. The water is planned to be injected during the July to September period, which is naturally a period of groundwater level rise or recovery. The objective of applying artificial recharge is to increase the total volume of recharge to the aquifer.

During the injection program Makauri Aquifer groundwater levels in the vicinity of the injection bore will increase, with the highest levels being at the bore. Over time this increase in groundwater level will be transmitted outward within the aquifer. When injection ceases the groundwater level in the immediate vicinity of the bore will start to decline again and stabilise, while the pressure response to the recharged water will still be travelling outward within the aquifer. For this reason, the increased groundwater levels around the bore will be more pronounced during the injection period than after the test.

Groundwater level responses to the proposed injection trial have been calculated using the Theis equation, which assumes that the aquifer is of unlimited extent and little or no leakage will occur. The Golder (2014b) report analysed the hydraulic responses of the aquifer and concluded that the Makauri Aquifer is hydraulically connected across most of the aquifer. Although some leakage may occur to overlying and underlying aquifers, this leakage would act to reduce the water level changes in the Makauri Aquifer resulting from the trial. Therefore, the assumptions incorporated in the calculation used to assess groundwater level changes are considered to be appropriate and conservative. A range of hydraulic parameters have been used in calculating the projected change in groundwater levels. These are:

- Transmissivity between 450 and 750 m^2/day
- Storativity between 0.0002 and 0.0005

The results from the pumping tests performed on the injection bore will be used to refine the projected water level responses of the aquifer to the planned injection trial. This process will enable the final planning of injection rates and the water level monitoring systems for the nearest monitoring bores.

The calculated groundwater level responses, based on the aquifer parameter ranges presented above, are summarised in Table 3 and Table 4. The trial is not expected to cause water levels in nearby Makauri Aquifer bores to rise above ground level. The water is planned to be injected into the aquifer under gravitational pressure and is therefore not projected to create artesian conditions in the Makauri Aquifer. If the aquifer transmissivity is lower than expected however, small overpressures may be required to achieve the planned injection rates. As the water in the supply pipeline is under pressure, these overpressures can be achieved without the need for additional pumping equipment.

Water levels in bore GPD147, apparently screened in the Matokitoki Aquifer, have been relatively shallow in the past (Figure 8). This bore has been monitored since 1992 and levels have been within approximately 0.5 m of the ground surface (based on estimated ground level elevations). The water level measured in June 2015 was 3.2 m bgl (Table 4). Refined projections for water level responses based on data from the pumping tests will be used to reassess the risk of potential artesian conditions developing at this bore. Monitoring and mitigation measures with respect to bore GPD147 are described in Sections 5.1 and 6.0.

Table 3: Projected groundwater level increase from water injection at 1,000 m^3/day for 100 days.

Distance from injection bore (m)	Projected groundwater level rise (m)
10	1.6 - 2.7
100	1.2 - 2.0
300	0.9 - 1.4
500	0.8 - 1.3
1,000	0.6 - 1.1
1,200	0.6 - 1.0
1,400	0.5 - 0.9
2,000	0.5 - 0.9

Table 4: Projected effects on bores with known groundwater levels.

Bore No.	Aquifer	Elevation (m RL)	Bore depth (m)	Water level (m bgl)	Water level (m RL)	Distance from trial site (m)	Transmissivity (m^2/d)	Level monitoring	Water level rise (m)	Projected final water level (m bgl)
GPD115	Makauri	10.9	75.1	5.48 (2)	5.4	542	456	Long term	1.3	4.18
GPD147	Matokitoki (1)	7.9	114	3.2 (2)	4.7	599		Long term	1.2	2.0
GPD012	Makauri	9.6	60.9	5.06 (2)	4.6	604		Targeted	1.2	3.86
GPD096	Makauri	8.9	81.4	3.6 (2)	5.3	636		Targeted	1.2	2.4
GPE034	Makauri	10.3	70	4.8 (2)	5.5	991	1,280	Long term	1.1	3.7
GPD141	Makauri	7.4	75.3	2.8 (2)	4.6	1,136		Long term	1.1	1.7
GPD116	Makauri	7.7	76.2	2.6 (2)	5.1	1,256		Targeted	1.0	1.6
GPD135	Makauri	7.9	71	4.6 (3)	3.3	1,299	424	Not monitored	1.0	3.6
GPD007	Makauri	8.5	70.1	5.5 (3)	3.0	1,426	383	Not monitored	0.9	4.6
GPJ040	Makauri	10.9	80	5.8 (2)	5.1	1,458		Long term	0.9	4.9
GPI032	Makauri	12.4	81.3	6.04 (3)	6.4	1,586		Long term	0.9	5.14
GPJ066	Makauri	7.4	82.3	5.5 (3)	1.9	2,101	1,006	Long term	0.9	4.6

Note: 1) Defined as Matokitoki Aquifer due to depth and water quality characteristics. Groundwater level records form this bore are however similar to those from bores screened in the Makauri Aquifer.
2) Measured June 2015.
3) Level from GDC bore database.

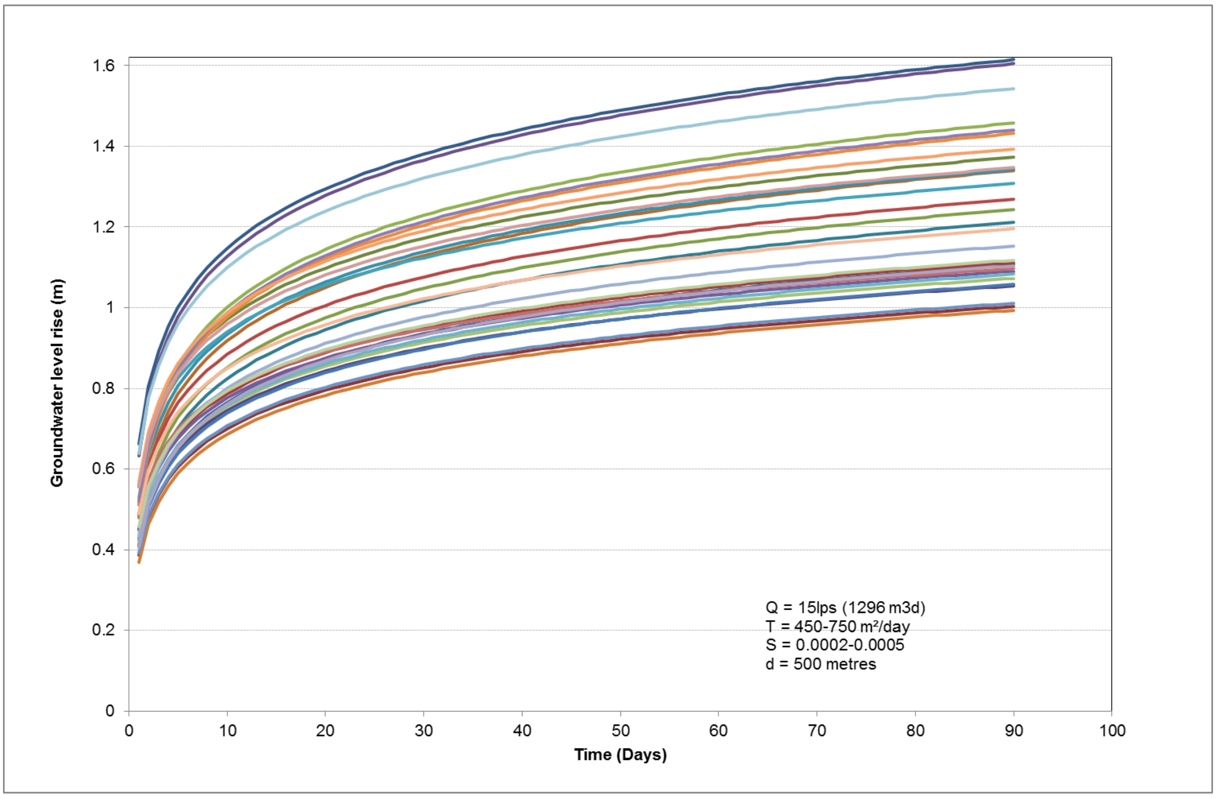


Figure 7: Range of potential groundwater level rise at 500 m from proposed injection site.

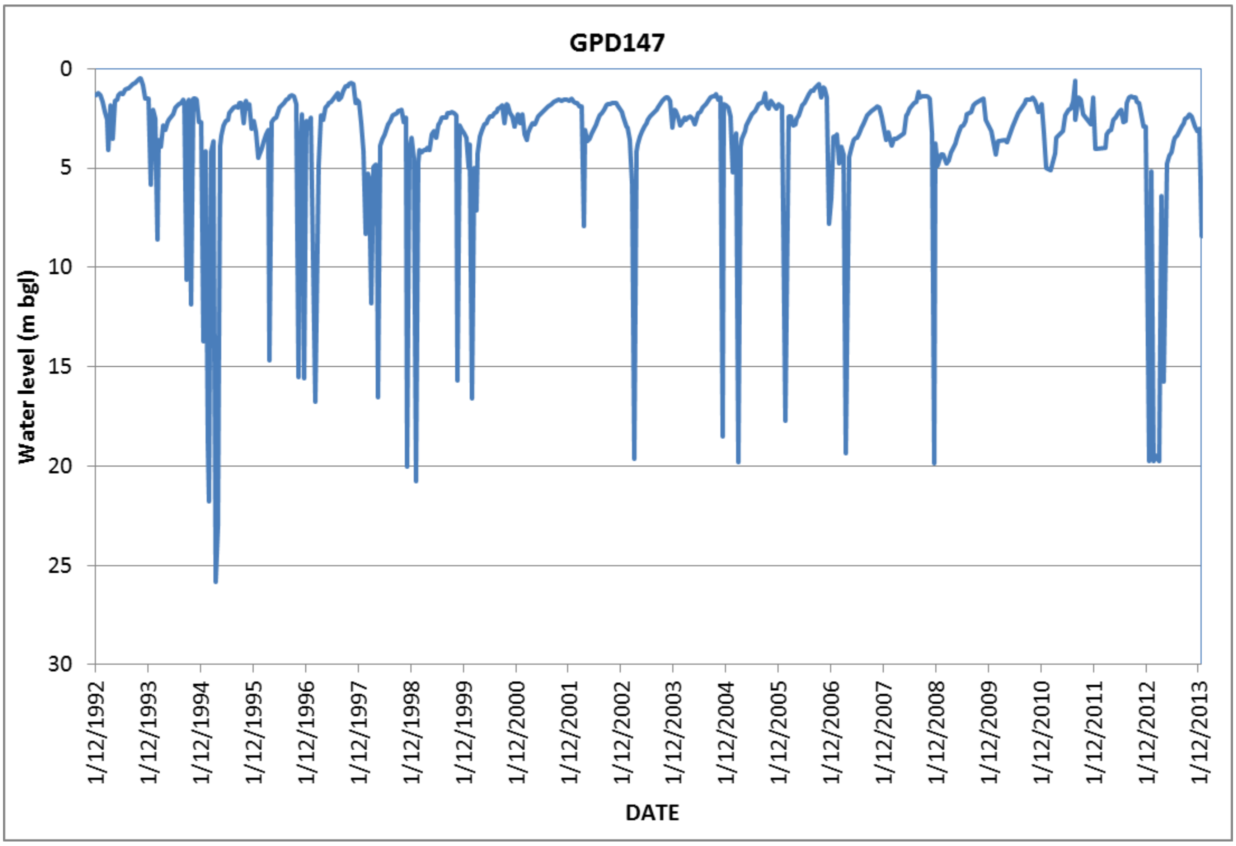


Figure 8: Depth to water in bore GPD147, 1992 to 2013.

3.9 Effects on Aquifer and Aquitard Materials

The proposed water injection program is not considered likely to affect the materials or properties of the Makauri Aquifer in general. The potential for localised clogging effects in the immediate vicinity of the injection bore are assessed in Section 4.5.3 and is considered a bore operational issue.

Concerns have been raised during the community consultation process regarding a perceived “fracking” of the receiving aquifer. The planned water injection is intended to increase aquifer recharge following the drawdown of groundwater during a pumping season. This enhanced recharge should not be confused with high pressure injection of fluids into rock aquifers for fracking purposes, which is typically carried out in the oil and gas industry. Fracking is undertaken at very high pressures (>19,000 kPa) in order to fracture the target rocks and thereby physically increase the permeability of the rock mass. The difference between fracking and MAR is that the proposed recharge is to simply replace water that has been removed from the aquifer during previous pumping seasons.

3.10 Induced Seismicity

Concerns have been raised during the community consultation process regarding the potential for water injection during the Pilot Project to result in induced seismicity. Induced seismicity is an observed issue linked to the injection of waste water into deep aquifers, which is a practice used by the shale oil and gas industry. Shale oil and gas waste water is injected under pressure into deep rock aquifers that are already basically full. This process over-pressurises the aquifers and locally forces water into existing faults. Where a fault is already under stress and “locked”, the injection of water under pressure can “unlock” the faults and induce a small earthquake.

The aquifers beneath the Poverty Bay Flats are compact sediments, including gravels, sands, silts, clays. In contrast, the aquifers used to store shale oil and gas waste water are typically deep “hard rock” aquifers. The Poverty Bay sediments are low strength, compared to rock aquifers. Faults in the sediment pile under the Poverty Bay flats would not be expected to “lock” existing faults, either in the sediments or in the deeper bedrock. Injection of water to these sediment (gravel) aquifers is therefore not expected to induce movement on faults in this area.

The Makauri Aquifer does not appear to be hydraulically connected to the bedrock beneath the Poverty Bay flats, except possibly where bedrock rises to outcrop around the edges of the flats. Injection of water to the Makauri Aquifer is therefore not expected to lead to water loss downward through silt and clay layers into either the underlying Matokitoki Aquifer or to bedrock. Any “locked” faults in the area will be locked at points well below the base of the sediment pile. Earthquakes registered along the East Coast are triggered from freeing of locked points at depths of kilometres rather than tens of metres.

3.11 Groundwater Level and Flow Summary

It is proposed to inject up to 100,000 m^3 of drinking standard water over a period from July to September at a rate of up to 15 L/s. The proposed injection bore will be carefully sealed off from the upper aquifers. The source water will be supplied to the site via the GDC water supply network.

Based on our preliminary assessment using the available information from nearby sites on the aquifer hydraulic properties, the proposed Poverty Bay MAR Pilot Project is not considered to have a significant effect on any surrounding bore users or on the aquifer. There is however the potential that one nearby bore (GPD147) may become artesian during the trial. Monitoring and mitigation measures with respect to this bore are described in Sections 5.1 and 6.0, respectively.

The Pilot Project will be carefully monitored and data gathered will be analysed during the trial so that the hydraulic responses in the aquifer can be applied to the design of any future GRS.

4.0 EFFECTS ON WATER QUALITY

4.1 Introduction

Assessment of the Pilot Project requires a sound understanding of the potential water quality effects that may result when treated surface water is injected into the Makauri Aquifer at the preferred pilot injection site. These effects include short-term effects during the injection program and long-term effects from storage of injected water in the aquifer. A three-tiered water quality assessment has been undertaken with respect to:

- Groundwater in the vicinity of the injection site.
- Injection water from two possible sources identified by the GDC.
- Potential water mixing interactions that may occur during injection and storage.

Groundwater in the Poverty Bay Flats area and potential injection water from the Mangapoike Dams have been previously characterised by Golder on a regional basis in the Stage 1B feasibility assessment report (Golder 2014b). This characterisation was completed prior to selection of the preferred injection pilot injection site described in Section 2.0. The water quality assessment presented here is intended to update and supplement previous work completed by Golder and the GDC, and has a specific emphasis on:

- Makauri Aquifer groundwater quality in the vicinity of the preferred pilot injection site.
- Quality of water from the two injection water sources proposed for the MAR pilot program; Gisborne City Water Supply from the Waingake Water Treatment Plant (WTP) and from the Waipaoa Augmentation Plant.
- Potential water quality effects of injection, including the potential for formation of secondary mineral precipitates and disinfection byproducts (DBPs).

This water quality assessment is intended to support a consent application required for the MAR pilot program and to provide a basis for the MAR pilot program management strategy.

4.2 Available Source and Receiving Water Quality Information

Water quality data from the following sources were reviewed by Golder to support this water quality assessment:

- Primary and secondary injection source water quality data:
  - Gisborne City water quality monitoring results for treated water at the Venturi Hut at Campion College. This data is from the city's ongoing municipal water supply monitoring program.
  - Gisborne City water quality monitoring results for treated water at the Waipaoa Augmentation Plant. Due to the infrequent operation of this facility, comprehensive annual monitoring results were only available for a single potable water sample collected on January 16, 2014. This data is from the city's ongoing municipal water supply monitoring program.
- Receiving water (groundwater) quality data:
  - Three groundwater samples were collected by GDC personnel on the 12th of May 2015 at three privately owned wells (GPD089, GPD115, and GPD116) located within 1.5 km of the preferred pilot injection site. The samples were analysed for a comprehensive suite of water quality parameters including major ions, metals, nutrients, and DBPs.
  - Water quality monitoring data, generated as part of the long term GDC environmental monitoring program, for well GPD115. Samples were collected approximately every four months from March 1992 to September 2013 (ongoing) and analysed for fluid parameters, major ions, nutrients, disinfectants, and a suite of metals.

- Annual groundwater pesticide survey results for six groundwater wells located within five km of the preferred pilot injection site (ESR 2014).
- Water quality data from the GDC environmental monitoring database for all routinely monitored wells within the Poverty Bay Flats area and contained the same analytical suite as for GPD 115 but with varying periods of record.

4.3 Groundwater Quality

4.3.1 Basis of Makauri Aquifer groundwater quality assessment

For the purpose of this assessment, “local groundwater” is defined as groundwater present in the Makauri Aquifer at the preferred Pilot Project site. Local groundwater was characterized based on both historical and current water quality data (i.e., from samples collected in May 2015 for this assessment) available for three wells located within 1.5 km of the preferred pilot injection site. The depths and locations of the wells are listed in Table 5 and the locations are identified in Figure 2. These three wells are screened within the Makauri Aquifer, the proposed target for injection.

Table 5: Potential groundwater quality monitoring wells for the Pilot Project.

Well ID	Screen interval (m bgl)(1)	Location relative to preferred pilot injection site	Status
GPD089	80.7 – 85.3	600 m north	Well not monitored by GDC
GPD115	71.6 – 75.7	600 m west	Well used for water quality and water level monitoring by GDC
GPD116	70.1 – 76.2	1,200 m east	Well used for water quality and water level monitoring by GDC

Note: 1) Information sourced from GDC water bore database.

4.3.2 General groundwater quality summary

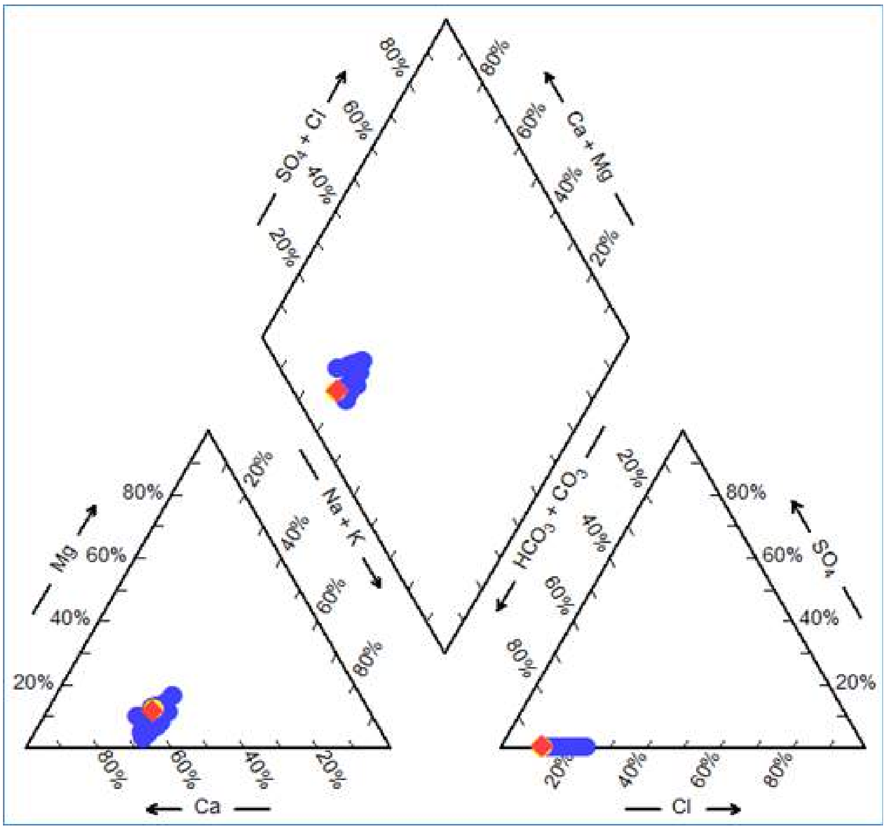
Local groundwater in the Makauri Aquifer has a generally stable pH at a neutral to alkaline level (7.0 to 7.3 at all three wells in May 2015, and for the past decade at GPD115) and is classified as a “very hard” water according to the elevated concentrations of calcium and magnesium (hardness typically >400 g $CaCO_3/m^3$).

The local groundwater is chemically reducing, consistent with the previous characterisation of the aquifer presented in Golder (2014b). All three samples of local groundwater collected and analysed in May 2015 had low concentrations of dissolved oxygen (0.04 g/m^3 to 2.3 g/m^3) and low oxidation reduction potential values that ranged from 85 mV to 117 mV. Ammoniacal nitrogen, the reduced species of nitrogen, was the only nitrogen detected in these samples and ranged in concentration from 0.6 g/m^3 to 3.8 g/m^3. No sulfate was detected in groundwater at any of the irrigation wells (<0.5 g/m^3).

Total and dissolved concentrations of iron and manganese indicated that most iron was present in the solid phase (i.e., on average dissolved concentrations were 10 % of the total) and most manganese was dissolved. These two metals are typically sensitive to changes in the oxidation state of the water and would typically form metal oxide precipitates at a neutral pH in oxygenated water. The fractionation between dissolved and solid forms suggests that the reduced conditions in the aquifer may support limited mobility of iron and general mobility of manganese.

Most major ions have generally stable concentrations in the local groundwater, as shown in time series plots for fluid parameters, major ions, and metals included in Appendix C. The long term monitoring results for groundwater at GPD115 indicated that the concentrations of most parameters are stable or only increased slightly over time. These results are generally consistent with the May 2015 results for groundwater sampling and analysis at GPD089, GPD115, and GPD116. One long term trend at GPD115 was a general increased in chloride concentrations over time (from 60 g/m^3 to 115 g/m^3 during the period from 2005 to 2013). This trend coincided with a general increase in electrical conductivity for the same period. The changes appeared to be localized to GPD115, as chloride concentrations detected in water from GPD089 and GPD116 were similar to pre-2005 levels at GPD115.

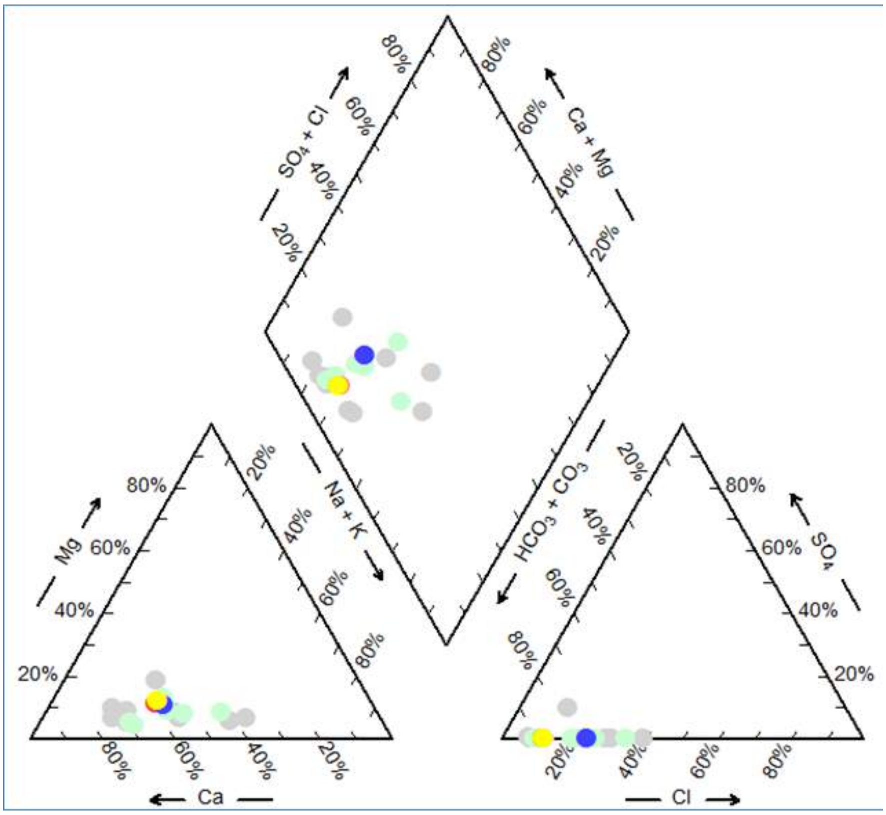
The local groundwater type is classified as Ca-HCO_3 based on the elevated concentrations of calcium and alkalinity related to leaching of limestone-bearing sediments present in the Makauri Aquifer, or at the source of the groundwater. Groundwater samples collected at GPD115 during the last decade (i.e. 2005 through 2015) are presented in a Piper diagram in (Figure 9), which shows the water type has remained generally consistent.



- Blue dots – data from GPD115, 2005 to 2015.
- Yellow dot – data from GPD116, May 2015.
- Pink dot – data from GPD089, May 2015.

Figure 9: Makauri Aquifer groundwater quality Piper plot – data from GPD115, GPD116 and GPD089.

Groundwater at other locations in the Makauri Aquifer is consistent with a Ca-HCO_3 water type in the wells near the preferred pilot injection site. A Piper diagram presented in Figure 10 provides a comparison for 19 Poverty Bay Flats groundwater wells screened in the Makauri Aquifer. Groundwater in wells closest to the preferred pilot injection site (blue, red and yellow symbols) is similar in quality to groundwater out to a distance of 5 km from the injection site (light green symbols), while groundwater more than 5 km away (grey symbols) is slightly more variable (e.g., higher sodium concentrations).



- Blue, red and yellow circles - local groundwater
- Light green circles - wells between 2 km and 5 km from the preferred pilot location.
- Grey circles - wells more than 5 km away from the preferred pilot location.

Figure 10: Makauri Aquifer groundwater quality Piper plot – data from third and fourth quarter of 2013.

4.3.3 Metals

Metals were analysed in the local groundwater samples collected in May 2015 (i.e. at wells GPD089, GPD115 and GPD116) and in samples from the long term monitoring at GPD115. Complete results tables and time trend plots for aluminium, iron, and manganese are included in Appendix C. In summary, the results of these analyses showed:

- Aluminium was typically not detected (<0.003 g/m^3) or detected only slightly above the detection limit in long term monitoring at GPD115. No detectable dissolved aluminium and low total aluminium concentrations in the May 2015 samples (<0.003 g/m^3 to 0.21 g/m^3) indicated that most aluminium was present as fine colloid particulates suspended in the groundwater.
- Long term total iron concentrations at GPD115 typically remained in the range from 3 g/m^3 to 10 g/m^3, however results were occasionally as high as 18 g/m^3. Elevated total iron concentrations appeared to occur in winter months (i.e., June 2008, July 2009, August 2011 and 2012, and April 2013) when irrigation demand is typically lowest. The reason for the variations in concentration was not identified although it may be related to seasonal variations in pumping activity at the bore itself. As shown in Figure 10 and the time series graphs in Appendix C, most other parameters did not change in concentration during the winter months.
- Total iron concentrations in local groundwater samples from May 2015 were similar to the historical range at GPD115. Dissolved iron (0.06 g/m^3 to 1.56 g/m^3) comprised only 10% of total iron (5.6 g/m^3 to 9.6 g/m^3).

- Manganese concentrations were generally stable at GPD115 over time (0.49 to 1.17 g/m^3), the May 2015 samples showed that approximately 90 % of manganese was dissolved (i.e., dissolved concentrations ranged from 0.5 g/m^3 to 1.43 g/m^3 while total concentrations ranged from 0.57 g/m^3 to 1.58 g/m^3)
- Concentrations of dissolved antimony, beryllium, cadmium, chromium, copper, lead, selenium, tin and uranium (Table C1 in Appendix C) did not exceed their respective detection limits in local groundwater (May 2015 sampling event).
- Dissolved arsenic, barium, boron, lithium, molybdenum and zinc concentrations were generally low and consistent in local groundwater at the three wells (May 2015 sampling event) (Table C1 in Appendix C).

Analysis of metals in local groundwater generally indicated the water was of good quality, although it possibly contained some fine suspended clay or colloids. The suitability of local groundwater for domestic and agricultural consumption is described in relation to regulatory guidance in Section 4.3.6.

4.3.4 Disinfection by-products

The three groundwater samples collected at wells GPD089, GPD115 and GPD116 near the preferred pilot injection site were tested for parameters that may lead to formation of disinfection by-products (DBPs) including dissolved organic carbon, chlorine, and chloramines. A single groundwater sample collected from well GPD115 was tested for DBPs to provide a baseline for the Makauri Aquifer prior to construction of a pilot injection well. Results of this analysis included:

- Free chlorine was detected at a low concentration (0.06 g/m^3) in groundwater at GPD116 and not detected at GPD115 and GPD089.
- Dissolved organic carbon was not detected in groundwater at any of the three wells
- Analysis of chloramines (i.e., mono, di and trichloramines) detected dichloramine at a low concentration (0.08 g/m^3) in groundwater at GPD116.
- No halogenated acetic acids (HAAs), haloacetonitriles (HANs), or trihalomethanes (THMs) were detected in the groundwater sample obtained from GPD115.

The potential for DBP formation during the pilot injection is discussed in Section 4.5.2.

4.3.5 Pesticides

The Makauri Aquifer is a confined aquifer at least 40 m to 80 m below ground level beneath the Poverty Bay Flats. There is likely to be some recharge to the Makauri Aquifer from overlying aquifers and the river at the western end of the Poverty Bay Flats. There is however no indication of a recharge connection from overlying surface waterways or agricultural land across the middle and eastern sections of the flats. Groundwater dating indicates the water in the aquifer at the preferred pilot injection site was typical of a ‘closed system’ and approximately 80 to 100 years old (Taylor 1994). Therefore, it is considered unlikely that local groundwater in the Makauri Aquifer would contain pesticides, or other industrial chemicals that may be released by agricultural activities that occur on the land surface.

Historical water quality data that includes pesticide analyses was obtained from a national survey of pesticides. This survey included groundwater in the Poverty Bay Flats area (ESR 2014). Two of the six groundwater wells sampled within 5 km of the proposed injection trial site were greater than 20 m deep. Well GPE006 is located approximately 3.5 km north and GPB009 is located 4.5 km east of the proposed injection trial site. No pesticides were detected in groundwater samples obtained from either well (ESR 2014).

4.3.6 Suitability for irrigation or livestock drinking water

The primary uses of groundwater abstracted from the Makauri Aquifer include crop irrigation and livestock drinking water. In this section the results of the local groundwater sampling and analysis program conducted in May 2015 are compared to criteria for irrigation water and livestock drinking water uses.

Suitability of the local groundwater for irrigation was assessed according to four criteria:

- Agricultural irrigation water quality long-term trigger values (LTVs) and short-term trigger values (STVs) included in ANZECC (2000):
  - Concentrations of dissolved aluminium, arsenic, beryllium, boron, cadmium, chromium, copper, fluoride, lead, lithium, molybdenum, nickel, selenium, uranium, and zinc were less than their respective LTVs and STVs in local groundwater.
  - Dissolved iron concentrations ranged from 0.06 g/m^3 to 1.56 g/m^3 and exceeded the LTV of 0.2 g/m^3 at GPD115 and GPD116.
  - Dissolved manganese concentrations ranged from 0.5 g/m^3 to 1.43 g/m^3 and exceeded the LTV of 0.2 g/m^3 at all three wells.
- Fouling potential for irrigation water (ANZECC 2000):
  - Neutral to alkaline pH values indicated local groundwater may have a moderate fouling potential.
  - Elevated hardness concentrations (380 g to 580 g $CaCO_3/m^3$) exceed the criteria of 350 g $CaCO_3/m^3$, indicating local groundwater may have fouling potential.
  - The Langelier Saturation Index (LSI) for groundwater ranged from -0.005 to 0.19 and indicated a limited fouling potential.
  - Overall, the groundwater has a low to moderate potential for fouling of pumping or irrigation equipment.
- Corrosion potential for irrigation water (ANZECC 2000):
  - Neutral to alkaline pH values indicated local groundwater may have a limited corrosion potential.
  - Ryznar index values ranged from 6.5 to 7.0 and indicated a moderate potential for corrosion.
  - The potential for corrosion (e.g., to irrigation equipment including well screens, pipes, and irrigators) is considered low to moderate.
- Sodium Adsorption Ratio (SAR):
  - Local groundwater SAR values were low and ranged from 1.5 to 1.9. No risk to sensitive crops (e.g., avocados, nuts and citrus) is likely for SAR values less than 3.0.

Suitability of the local groundwater for livestock drinking water is assessed according to the recommended water quality trigger values (low risk) for heavy metals and metalloids in livestock drinking water (ANZECC 2000):

Concentrations of dissolved aluminium, arsenic, beryllium, boron, cadmium, chromium, copper, fluoride, iron, lead, manganese, molybdenum, nickel, selenium, uranium, and zinc were less than their respective recommended livestock drinking water quality trigger values (low risk) in local groundwater.

4.3.7 Pilot Project groundwater quality

Groundwater quality at GPD115 (Table 6) has been selected to represent groundwater in the geochemical effects modelling. This water quality was chosen because long-term data is available from monitoring at GPD115, groundwater quality was stable over time and GPD115 water quality was generally similar to GPD089 and GPD116 in the May 2015 sampling event.

Table 6: Summary of GPD115 groundwater quality used for model-input.

Parameter [1]	Units	N [2]	Median [3]	Winter only [4]
Fluid parameters				
pH	unitless	56	7.1	7.1
Temperature	°C	51	15	15.1
Turbidity	NTU	1	7	-
Electrical conductivity	µS/cm	56	1,110	1,230
Total dissolved solids	g/m^3	1	720	-
Total alkalinity	g $CaCO_3/m^3$	56	520	530
Hardness	g $CaCO_3/m^3$	56	420	460
Disinfectants				
Free chlorine	g/m^3	1	<0.05	-
Major Ions				
Calcium	g/m^3	56	140	172
Chloride	g/m^3	56	68.5	94
Magnesium	g/m^3	56	16.9	7.3
Potassium	g/m^3	56	8.85	9.6
Sodium	g/m^3	56	83	87
Sulfate	g/m^3	54	<0.5	<0.5
Nutrients				
Nitrate	g/m^3	1	<0.002	-
Nitrite-N	g/m^3	1	<0.002	-
Total ammoniacal-N	g/m^3	55	3.7	3.7
Dissolved reactive phosphorus	g/m^3	54	<0.004	<0.004
Metals				
Aluminum (dissolved)	g/m^3	1	<0.003	-
Aluminum (total)	g/m^3	1	<0.0032	<0.0032
Iron (dissolved)	g/m^3	1	1.56	-
Iron (total)	g/m^3	56	4.77	16.9
Manganese (dissolved)	g/m^3	1	0.66	-
Manganese (total)	g/m^3	56	0.57	0.68

Notes:
1) Results are shown for selected parameters. All results are included in Appendix C, Table C2.
2) Parameters with a single data point were measured during the May 2015 sampling event.
3) Parameters with >50 data points were measured by GDC's long term irrigation monitoring program and a median value is presented for the period March 1992 through September 2013.
4) Results in the 'Winter Only' column represent median values for 17/6/2008, 8/7/2009, 9/8/2011, 21/8/2012, and 30/4/2013 when iron concentrations were seasonally elevated. N=5 for this column.

4.4 Injection Water

4.4.1 Water sources

Injection water will be supplied to the Pilot Project site through the existing Gisborne City water supply network after treatment at either the Waingake WTP or the Waipaoa Augmentation Plant. The Waingake WTP is the primary water source for the Pilot Project and the Waipaoa Augmentation Plant is the back-up source.

The injection period for the Pilot Project is proposed to occur during winter months, so it is likely that injection water drawn from the Gisborne City water supply system would consist of water from the Waingake WTP, which is derived from the Mangapoike Dams and the Te Arai River Bush Catchment. The relative volumes of water sourced from the dams and the bush catchment would most likely vary during the injection period depending on water demand, seasonal effects and water quality in the Te Arai River.

The Waipaoa Augmentation Plant takes water from the Waipaoa River to produce potable water. This plant is typically only used as a back-up for the Gisborne water supply during peak demand in summer and when the Waingake WTP requires maintenance. The Waipaoa Augmentation Plant is included in this assessment because it is a possible back-up source of injection water and may be a favoured source for other logistical reasons.

4.4.2 Water quality

The two potential water sources for the pilot injection are both drinking water sources for Gisborne City. These sources are subject to a rigorous monitoring program to ensure the water supply meets drinking water quality standards for human consumption. Because drinking water standards are at least as stringent as those for irrigation and livestock drinking water, the injection water also meets the ANZECC (2000) criteria for the agricultural uses that were evaluated for groundwater in Section 4.3.6. This assessment therefore focuses on the possible effects of injecting water of potable quality into the Makauri Aquifer.

4.4.2.1 Gisborne City water supply from Waingake WTP

The Waingake WTP is the main source of treated water to the Gisborne City water supply system. This WTP receives water from the Mangapoike Dams (Clapcott, Sang and Williams dams) and the Te Arai River bush catchment. The relative amount of water from these two water sources varies seasonally, depending on the amount of storage in the dams and the quality of water in the Te Arai River. If turbidity in the Te Arai River is low (<3 NTU is typical for dry conditions) water from the two sources is blended evenly. With increased rainfall the turbidity of the Te Arai River water increases and the amount of river water included in the Waingake WTP supply is decreased (e.g., raw water at the WTP contains 30 % Te Arai River water if turbidity increases to 6 NTU). The Mangapoike Dams supply all raw water to the Waingake WTP if turbidity in the Te Arai River exceeds 10 NTU.

As described in Section 4.2, water quality monitoring in the Gisborne City water supply includes daily measurements of routine water quality parameters (i.e., fluid parameters and free available chlorine) and annual screening for an extended suite of parameters (i.e., fluid parameters, major ions, metals, nutrients, and disinfection residuals) at the Venturi Hut at Campion College which is located approximately 5 km southeast of the Pilot Project site. Treated water at the Venturi Hut monitoring location is considered equivalent to the water that would be delivered to the preferred pilot injection site from the Waingake WTP.

Water quality of this treated water source is summarized in Table 7 and described with the following:

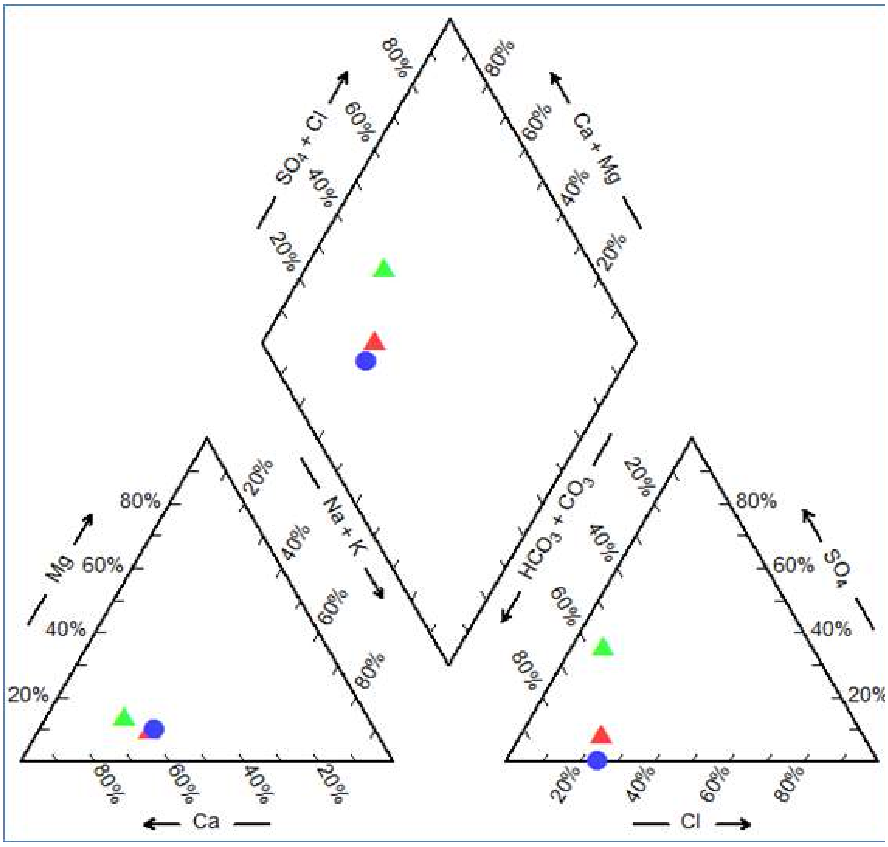
- The treated drinking water typically has an alkaline pH, with a low turbidity and TDS concentrations.
- Because water in the Mangapoike Dams and Te Arai River Bush Catchment is mostly from rain water, it has a low hardness concentration (median: 49 g $CaCO_3/m^3$) and is classified as "soft" water.
- Major ion concentrations were generally low in the 2014 and 2015 annual sampling results. The water is classified with a Ca-HCO_3 water type (Figure 11).
- The nutrients nitrate and dissolved reactive phosphorus were detected at low concentration in the treated water.

- Metals concentrations were low and did not exceed maximum acceptable values for inorganic determinands of health significance in the New Zealand Drinking Water Standards (Ministry of Health 2008).
- Chloramines were not detected in the 2015 annual chemical survey (9 March 2015).

Table 7: Summary of Gisborne City water supply quality at Venturi Hut.

Parameter	Units	n	Median
Fluid Parameters			
pH	s.u.	1,066	7.8
Turbidity	NTU	1,066	0.1
Electrical conductivity	µS/cm	1,066	160
Total dissolved solids	g/m^3	1,066	104
Total alkalinity	g $CaCO_3/m^3$	1,066	55
Hardness	g $CaCO_3/m^3$	1,066	49
Disinfectants			
Free chlorine	g/m^3	1,066	0.95
Combined chlorine	g/m^3	2	0.09
Major Ions			
Calcium	g/m^3	2	17
Chloride	g/m^3	2	11
Magnesium	g/m^3	2	1.5
Potassium	g/m^3	2	0.68
Sodium	g/m^3	2	9.3
Sulfate	g/m^3	2	4.8
Nutrients			
Nitrate	g/m^3	2	0.007
Nitrite-N	g/m^3	2	<0.002
Total ammoniacal-N	g/m^3	2	<0.010
Dissolved reactive phosphorus	g/m^3	2	0.009
Metals			
Aluminum	g/m^3	2	0.15
Iron	g/m^3	2	<0.02
Manganese	g/m^3	2	0.001
Chloramines			
Monochloramine	g/m^3	1	<0.05
Dichloramine	g/m^3	1	<0.05
Trichloramine	g/m^3	1	<0.05

Note: Results are shown for selected parameters. All results are included in Appendix C, Table C2.



- Blue circle – median local groundwater.
- Green triangle - Waingake WTP water.
- Red triangle - Waipaoa Augmentation Plant water

Figure 11: Water quality Piper plot – data from local groundwater, Waingake WTP and Waipaoa Augmentation Plant.

4.4.2.2 Gisborne City water supply from Waipaoa Augmentation Plant

A potable water sample collected directly from the Waipaoa Augmentation Plant in March 2014 is summarized in Table 8 and described with the following:

- Treated water from the Waipaoa Augmentation Plant has an alkaline pH and low turbidity.
- Because raw water is sourced from the Waipaoa River, which originates in a limestone catchment, the treated water has elevated calcium and magnesium concentrations and is classified as “very hard” water.
- All major ion concentrations were higher than in water from the Waingake WTP, but based on the relative concentrations the treated water was also classified as Ca-HCO_3 type water (Figure 11).
- Nutrients were detected at low concentrations in the treated water.
- Metals concentrations were low and did not exceed maximum acceptable values for inorganic determinands of health significance in the New Zealand Drinking Water Standards (Ministry of Health 2008).

- Dichloramine was detected at a concentration slightly above the detection limit in the 2014 annual chemical survey (16 January 2014). This sample was collected directly from the plant, which is typically where chloramines would most likely be detected due to their relatively rapid rates of decay.

Table 8: Summary of Gisborne City water quality from the Waipaoa Augmentation Plant.

Parameter	Units	n	Result
Fluid Parameters			
pH	s.u.	1	7.9
Turbidity	NTU	1	0.27
Electrical conductivity	µS/cm	1	548
Total dissolved solids	g/m^3	-	-
Total alkalinity	$g\ CaCO_3/m^3$	1	170
Hardness	$g\ CaCO_3/m^3$	1	230
Disinfectants			
Free chlorine	g/m^3	1	1.2
Combined chlorine	g/m^3	1	0.15
Major Ions			
Calcium	g/m^3	1	77
Chloride	g/m^3	1	19
Magnesium	g/m^3	1	9.1
Potassium	g/m^3	1	3.1
Sodium	g/m^3	1	27
Sulfate	g/m^3	1	99
Nutrients			
Nitrate	g/m^3	1	0.169
Nitrite-N	g/m^3	1	<0.02
Total Ammoniacal-N	g/m^3	1	0.002
Dissolved reactive phosphorus	g/m^3	1	0.169
Metals			
Aluminum	g/m^3	1	0.169
Iron	g/m^3	1	<0.02
Manganese	g/m^3	1	0.002
Chloramines			
Monochloramine	g/m^3	1	<0.05
Dichloramine	g/m^3	1	0.09
Trichloramine	g/m^3	1	<0.05

Notes: Results are shown for selected parameters. All results are included in Appendix C, Table B2.

4.5 Potential Water Quality Effects

Water quality effects are described in this section so as to provide a site-specific update to the assessment presented in the Stage 1B report (Golder 2014b). The water quality of the individual sources assessed in the previous two sections is considered here with respect to the potential effects of the blended water quality (i.e., in the aquifer following injection), including the potential for chemical clogging and the formation of DBPs.

4.5.1 General comparison of water types

As described for local groundwater and the potential injection sources, each water source is dominated by alkalinity and calcium, such that they are classified as $Ca\text{-}HCO_3$ type-waters. Treated water from the Waipaoa Augmentation Plant is the most similar to median local groundwater at the preferred pilot injection location, as shown by close alignment of the two points on a Piper diagram (Figure 11). Treated water from the Waingake WTP is generally more dilute and softer than the relatively hard surface water and groundwater present at the Poverty Bay Flats. Total dissolved solids concentrations are not routinely measured, but differences in electrical conductivity between the Waingake WTP, Waipaoa Augmentation Plant and local groundwater (170 µS/cm, 548 µS/cm, 1,230 µS/cm) indicate that the groundwater contains a higher load of dissolved constituents than the treated water.

4.5.2 Conceptual model

The conceptual model shown in Figure 12 illustrates how injection water and groundwater may interact in the Makauri Aquifer as it is injected into the aquifer through the well screen. The injected water, which is assumed to be saturated with oxygen from surface water sources, will displace the low-oxygen, and most likely geochemically reduced, natural groundwater from around the well screen when it is injected. This displacement will create a 'bubble' of injected water that gradually transitions to natural groundwater in a fringe zone. Chemical reactions between the two water types would most likely occur in this fringe zone. As the injection process continues, this fringe zone will be pushed progressively further from the injection well.

Natural groundwater flow past the well screen occurs according to the local hydraulic gradient, or an artificial gradient created by nearby irrigation demand. In Figure 12 this is represented by the asymmetric shape of the injected water bubble. The regional flow velocity in the Makauri Aquifer was estimated to be approximately 180 m per year under winter hydraulic conditions (Golder 2014b). Depending on the size of the bubble created during injection, the well screen may remain within the bubble for months following the completion of the injection process. Water mixing will be predominantly in a lateral direction within the Makauri Aquifer. The low permeability of the overlying and underlying confining layers limits the potential for vertical mixing with water in these confining layers. It is unlikely injected water would mix with water from the overlying Waipaoa Gravel Aquifer or the deeper Matokitoki Aquifer due to the confined nature of the Makauri Aquifer at the site of the injection trial.

This conceptual model forms the basis for geochemical modelling performed to assess the potential for chemical clogging during MAR injection and storage (Section 4.5.3). The range of mixing ratios included in modelling are represented in this conceptual model by the gradation in injected water moving away from the well screen.

4.5.3 Chemical precipitation and clogging

4.5.3.1 Potential for clogging

Bore efficiency is one focus for the management of injection bores, as any reduction in the hydraulic efficiency of the bore results in reduced injection rates and increased bore remediation cost. Chemical, biological or physical clogging of injection surfaces or well screens is a problem encountered in many injection bores. Even a successful injection bore is likely to suffer from clogging issues, with appropriate management measures required.

It is important to recognise that clogging is an issue that would affect the efficient injection of water through the bore screen and surrounding gravel pack rather than an issue for the wider aquifer. As such, this is an operational issue requiring management rather than an environmental issue affecting other users or the hydraulic behaviour of the aquifer as a whole.

Chemical, biological and physical clogging of the bore could occur during injection or storage through a range of processes that have been described previously in the Stage 1B report (Golder 2014b). Chemical clogging, principally iron precipitation, was identified in the Stage 1B work as the most likely form of clogging that may occur during the MAR pilot injection program.

Consideration needs to be given to the potential change in the redox state of the groundwater system immediately around the injection bore. It is possible that the introduction of aerated source water will facilitate increased iron precipitation. The change in redox state from anerobic to aerobic plus the potential food source (iron) may also facilitate colonisation by iron bacteria.

Iron bacteria however tend to colonise and cause clogging in high water flow velocity areas such as near the pump intake or within the bore screen. As such, this is an issue for bore maintenance rather than an environmental issue for the aquifer. Microbiological clogging is not anticipated to arise as a substantial issue because the source water will contain low concentrations of chlorine from the treatment process which will assist in controlling microbiological activity in and immediately around the bore.

4.5.3.2 Potential for chemical clogging in local groundwater

The amount of chemical precipitate material that may form in an aquifer affected by chemical clogging is generally controlled by four factors:

- Ambient iron concentrations in the aquifer water
- The amount of water injected
- The dissolved oxygen concentrations in the injected water
- The extent of the zone where waters of different qualities mix.

A chemical clogging assessment presented in the pre-feasibility work report for this project (Golder 2014b) indicated that iron oxide minerals could precipitate when surface water is injected into groundwater in the Poverty Bay Flats area. A site-specific geochemical model that encompasses the newly collected data has therefore been developed to characterise the potential for chemical clogging to occur in the aquifer around the injection bore or in the bore itself. The geochemical model included two scenarios:

- Injection of water from the Waingake WTP into local groundwater at the Pilot Project site. Injection water quality was represented by the median water quality at the Venturi Hut monitoring location (Table 7) and groundwater quality was represented by the median water quality at well GPD115 (Table 6).
- Injection of water from the Waipaoa Augmentation Plant into local groundwater at the Pilot Project site. Injection water quality was represented by the 16 January 2015 analysis of potable water at the Waipaoa Augmentation Plant (Table 8) and groundwater quality was represented by the median water quality at well GPD115 (Table 6).

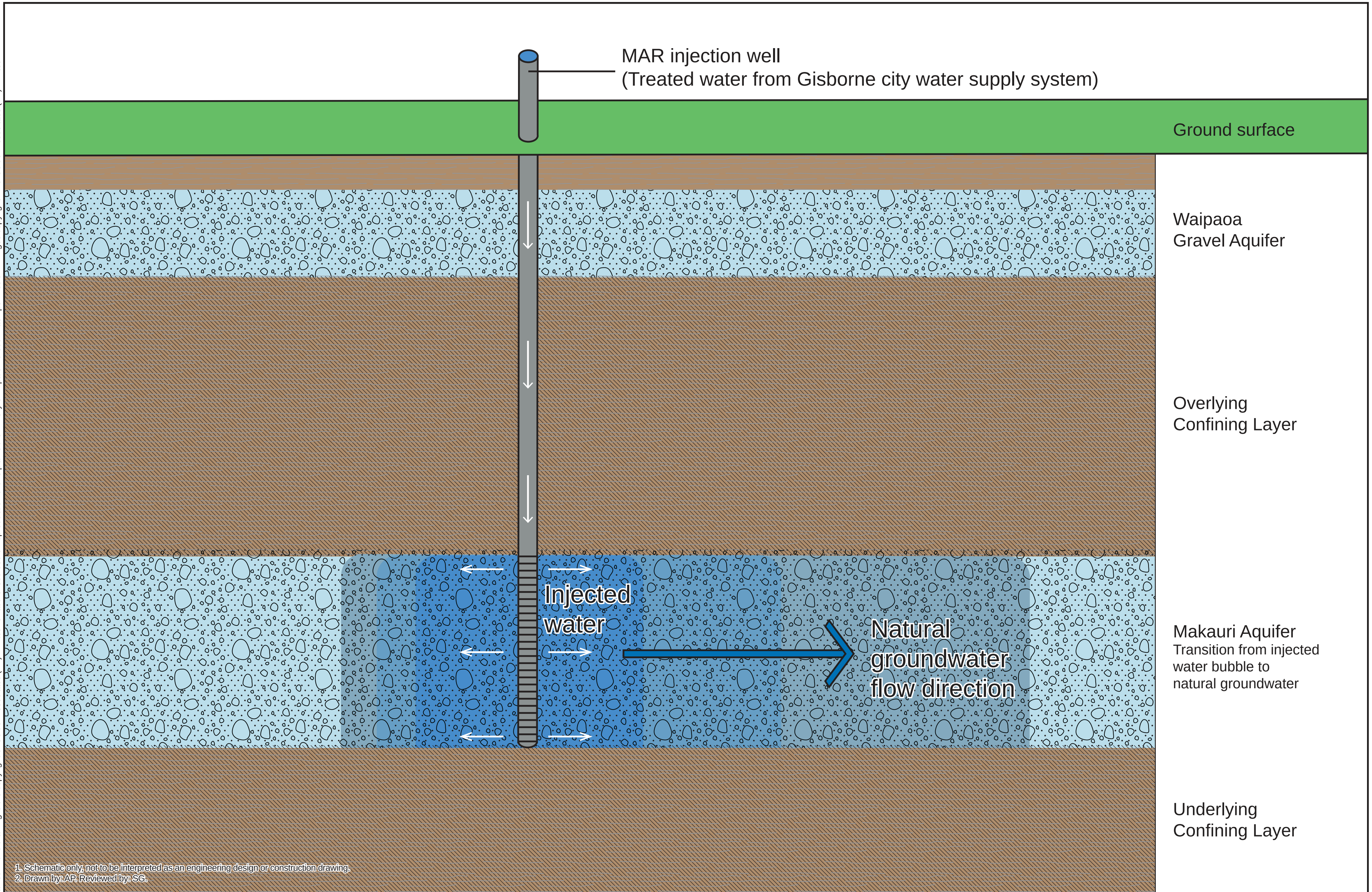
4.5.3.3 Model assumptions

The geochemical model incorporated the following assumptions:

- Water from the treatment plants will be injected directly into groundwater with no additional treatment.
- The model results relate to a theoretical litre of pore space in the aquifer.
- Groundwater quality in the Makauri Aquifer at the Pilot Plant site may be represented by water from production bore GPD115.
- Iron and aluminium present in groundwater occurs predominantly in the solid phase (i.e., >90 %). It is assumed that only the dissolved iron or aluminium could be oxidised and precipitate as a result of MAR operations.
- The groundwater at irrigation well GDP115 appears to be affected by seasonal changes related to pumping rates, near-screen well effects, or other influences that cause the iron concentration to increase in winter and decrease in summer (time series graph presented in Appendix C). These fluctuations are relevant to groundwater quality at the preferred pilot injection site because the injection activities would likely occur during winter. A second version of the model was developed to examine the effects winter conditions may have on the chemical clogging potential, and parameterised with the median groundwater quality data for winter months presented in Table 6. A dissolved iron

concentration of 2.7 g/m^3 was estimated for this period based on 16 % of total iron being present in the dissolved phase (i.e., the same ratio as in the May 2015 sample collected at GPD115).

- The modelling included only simple mixing of fluids, focused on saturation and precipitation evaluations for common aluminium, iron and manganese secondary minerals. The potential for groundwater and injection water to interact with suspended sediments (e.g., colloids or clays present in groundwater) and minerals already present in the aquifer was not assessed.
- The model accounts for direct precipitation without kinetic restraints (i.e., all reactions were simulated as occurring instantaneously). During injection activities the net rate of precipitation may be slower than predicted by the model, such that the subsequent dispersion and dilution of injected water would result in less precipitates forming than predicted.



1. Schematic only, not to be interpreted as an engineering design or construction drawing.
2. Drawn by: AP. Reviewed by: SG.

Golder Associates

TITLE CONCEPTUAL MODEL OF MAR INJECTION PROCESS AND POTENTIAL GEOCHEMICAL INTERACTIONS

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4.5.3.4 Model results

Model results for the two potential injection scenarios under typical (i.e., May 2015) and conservative (i.e., winter months with elevated iron concentrations) conditions are presented in Figure 13. The results indicate the following chemical changes will occur as treated water is injected into groundwater:

- Groundwater pH will increase during injection to reach a pH equivalent to the injection water source at complete injection. The rate of pH change will be buffered by ferrihydrite precipitation (i.e., consumption of hydroxyl ions by iron oxidation) such that the pH will increase by less than 0.2 pH units after approximately 60 % injection.
- Iron will precipitate as ferrihydrite ($Fe(OH)_3$) during injection. The iron oxidation and precipitation reactions are driven by oxygenated surface water with a high redox potential being injected into the reduced groundwater that has a low redox potential.
- Given the conditions measured during the May 2015 sampling event, the mass of ferrihydrite that may precipitate during injection and storage is low (<0.04 g/m^3) and is a function of the low iron concentrations in the source water (<0.02 g/m^3) and local groundwater (1.56 g/m^3 at GPD115). The maximum amount of precipitation will occur at complete injection (i.e., 100 % surface water injected).
- Given the higher-iron conditions that may occur during winter months, the mass of ferrihydrite that may precipitate during injection and storage is also low (<0.04 g/m^3), but the precipitation will occur earlier in the injection cycle.
- Siderite ($FeCO_3$) will not reach saturation during injection from either water source.
- Precipitation of manganese as manganite ($MnO(OH)$) and aluminium as aluminium hydroxide ($Al(OH)_3$) will not occur as these minerals do not reach saturation.
- Aluminium and manganese concentrations will occur according to the relative amounts of each water type present in the aquifer. Aluminium concentrations will increase with injection because the treated water source contains more aluminium than the natural groundwater. Manganese concentrations are higher in groundwater, so will decrease with injection.
- The model results indicate treated water injected into groundwater at the preferred pilot injection site has a relatively low potential for chemical clogging.

4.5.3.5 Discussion

When considering the results from the water quality modelling it is important to relate these outcomes back to the conceptual model documented in Section 4.5.2. During trial operations a groundwater / injection water mixing zone will be created. This zone will be gradually pushed further from the injection well as the trial progresses. By the end of the trial injection period a bubble of injected water quality will have been created in the Makauri Aquifer around the injection well.

At the end of the trial and in the immediate vicinity of the bore within the "bubble" created during the injection phase the water quality will predominantly reflect the quality of the injected water. Within the surrounding mixing zone the water quality at any particular point will depend on the proportion of injected water that has reached that point, with the quality indicated in Figure 13. Beyond the mixing zone the quality of water in the aquifer will be unaffected.

Following the close of the trial the bubble of injected water will be transported slowly away from the point of injection (including towards abstraction wells during the irrigation season). The direction and rate of movement will depend on the seasonal groundwater gradients as described in Section 3.5. The injected water quality in the bubble will also start to disperse and become mixed with natural groundwater. Over time the injected water quality bubble will dissipate and the groundwater quality in this area of the Makauri Aquifer will equilibrate to reflect that of the wider aquifer.

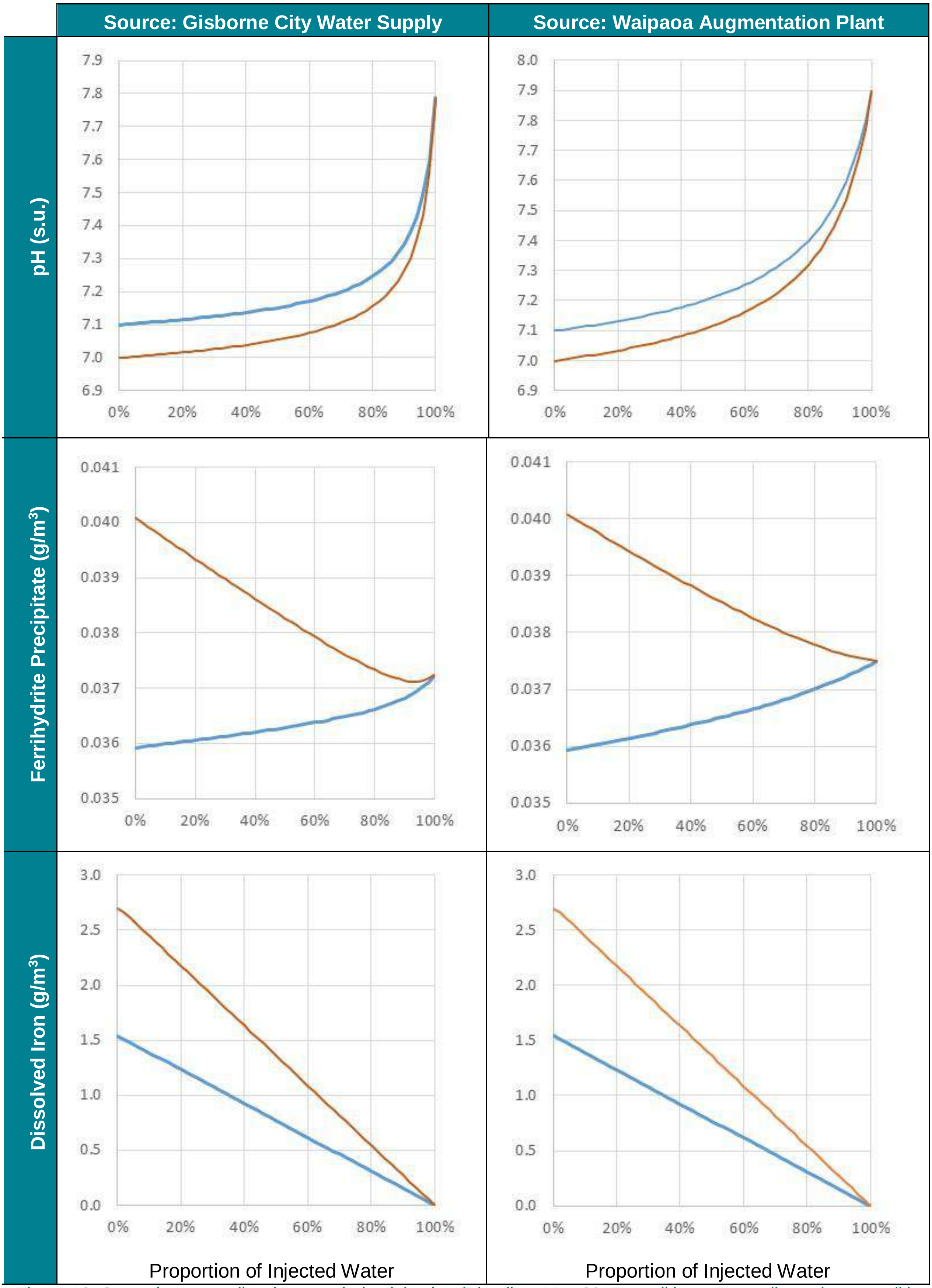

Figure 13: Groundwater quality changes during injection (Blue line: May 2015 conditions; Brown line: winter conditions).

There is a possibility that the injected water may react with the sediments of the Makauri Aquifer, leading to changes in water quality that have not been identified in the water quality modelling. For this reason samples of the aquifer sediments will be obtained during the drilling program and subjected to mineralogical and geochemical tests. The outcomes of these tests will be evaluated to assess the risk to water quality during the trial. In addition, groundwater sampling from a standpipe piezometer installed in the pilot-hole at the Pilot Project site during the trial will enable changes in groundwater quality close to the injection bore to be measured during and following the injection period. One of the reasons for undertaking the trial is to enable groundwater quality observations to be made, rather than relying on water quality modelling to support any future GRS in the Poverty Bay Flats area.

4.5.4 Potential for disinfection by-product formation in Makauri Aquifer

4.5.4.1 Introduction

Chlorinated disinfection agents, such as chlorine and chloramine, are commonly used in water treatment plants to:

- Destroy pathogenic microbes.
- Oxidise taste/odour-forming compounds.

Provide a disinfectant residual so water can reach the consumer’s tap safe from microbial contamination.

If disinfectants remain in the treated water that is injected into an aquifer, they may react with naturally present fulvic and humic acids, amino acids, and other natural organic matter, to produce a range of DBPs. Some of these DBPs have been linked to health issues, including cancer and reproductive disorders. Consequently these compounds are regulated in water supply systems. A conceptual model for the reaction sequence leading to these DBPs is shown in Figure 14.

DBPs may not be detectable in water produced from a treatment plant. They can however also form within the water supply distribution network. In the case of a MAR system, DBPs can form in the aquifer if the injected water contains disinfection agents. The different species and concentrations of DBPs vary according to the type of disinfectant used, the dose of disinfectant, the concentration of natural organic matter and bromide/iodide, the time since dosing, temperature and pH of the water (Koivusalo & Vartiainen 1997). The two injection water sources and local groundwater are characterised in this section with respect to their potential to form DBPs during storage.

4.5.4.2 Site specific assessment

Water from both the Waingake WTP and the Waipaoa Augmentation Plant is unlikely to contain significant concentrations of DBPs, and is therefore suitable for use in the MAR pilot injection, based upon:

- **Disinfectants are present at acceptable concentrations in treated water:** Free Available Chlorine (FAC) concentrations at the Venturi Hut ranged from 0.64 g/m^3 to 1.28 g/m^3 between July 2012 and June 2015 with a median of 0.95 g/m^3. The FAC concentration remained in the New Zealand Drinking Water Guidelines acceptable range for aesthetic determinands (0.6 g/m^3 to 1.0 g/m^3) (Ministry of Health 2008) for approximately 75 % of the time. Any concentrations that fell outside the acceptable range were slight exceedances, up to a maximum concentration of 1.28 g/m^3.
- **Lack of organic precursors:** The presence of organic matter in treated water at the Venturi Hut or at the Waipaoa Augmentation Plant as measured by light absorbance at 254 nm. Results were generally low and suggest organic carbon is not present in the treated water.
- **Lack of chlorine consumption in distribution system:** The relatively stable FAC concentrations at the Venturi Hut suggested that chlorine consumption within the approximately 30 km of water supply pipelines between the Waingake WTP and the Venturi Hut is low.

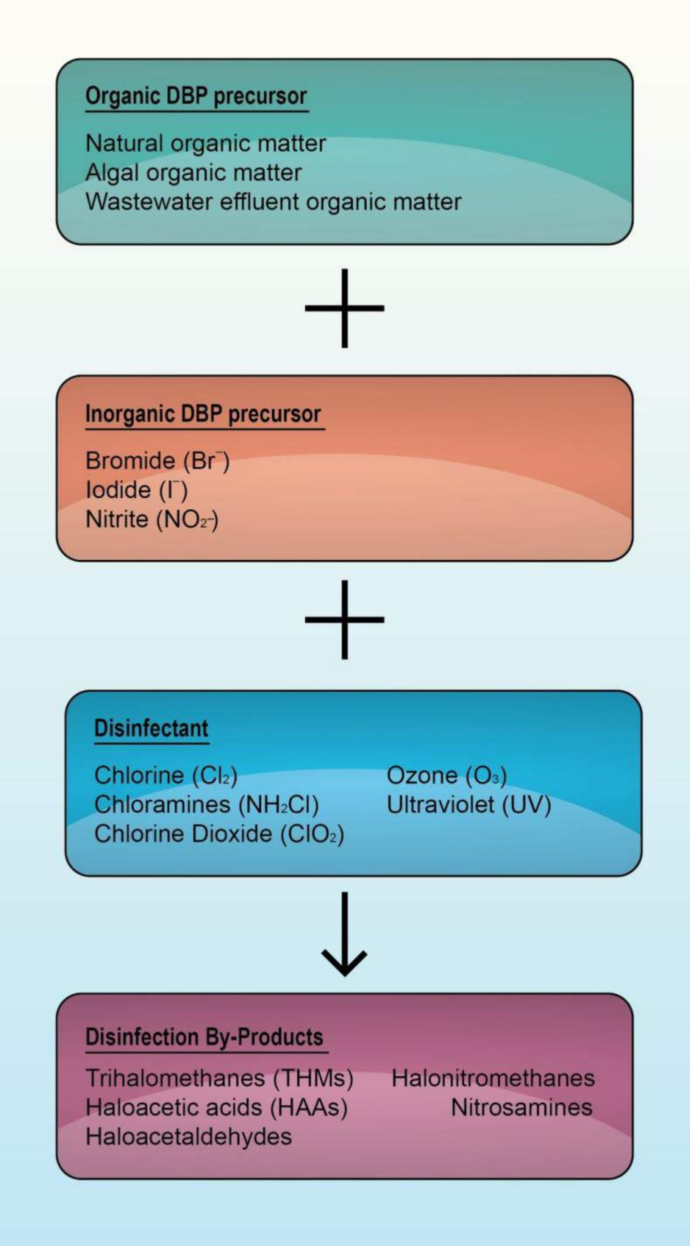

Figure 14: Formation process for disinfection by-products.

- **Lack of nitrite precursor:** Nitrite, an inorganic precursor to DBPs, was not detected in the water supply system during annual sampling at the Venturi Hut in 2014 and 2015 or at the Waipaoa Augmentation Plant in 2014 (<0.002 g/m^3).

- **Low temperature:** DBP formation rates are inhibited at low temperatures (Kirmeyer 2004). The MAR pilot injection will occur during winter months when the water temperature at the Venturi Hut monitoring point typically ranges from 9º C to 12º C.

- **Source control for Waipaoa Augmentation Plant:** Operation of the Waipaoa Augmentation Plant is sporadic, so limited historical disinfection monitoring data is available. However, the plant is located close to the preferred pilot injection site. It is therefore assumed that disinfectant dose rates could also be adjusted at the plant to meet MAR pilot injection criteria.

The potential for DBPs to form in local groundwater at the preferred pilot injection site is considered low for the following reasons:

- **Lack of organic precursors:** No organic matter was detected in local groundwater in samples collected in May 2015 (i.e. <0.5 g/m^3 total organic carbon).
- **Lack of nitrite precursor:** Nitrite was not detected in local groundwater in samples collected in May 2015 (<0.002 g/m^3).
- **Neutral pH:** The rate of DBP formation typically decreases with increasing pH (Kirmeyer 2004). The local groundwater pH is neutral to alkaline. However, because the types of DBPs formed vary according to pH, water quality monitoring is planned to detect any DBPs that arise as a result of the trial (refer Section 5.2).
- **Attenuation of DBPs during long-term storage:** The storage period for the MAR pilot injection is likely to be significantly longer than the time DBPs remain mobile in groundwater. HAAs attenuate very rapidly, typically within a few days, due to aerobic microbial activity that would develop near the well. THMs may initially increase for a day or two until the chlorine has fully reacted in the aquifer, but then concentrations attenuate, typically within several weeks, due to anaerobic microbial activity once the oxygen in the injected water becomes depleted. Brominated THM species attenuate first, followed by chloroform. Both THM and HAA attenuation processes occur simultaneously as a range of redox conditions may occur in the pore spaces around the injection well screen.

The proximity of the monitoring bore(s) to the injection bore will assist with assessing water quality changes that occur within the aquifer during injection.

4.6 Water Quality Summary

The results of the water quality assessment show that the proposed sources of treated water are generally suitable for injection into the Makauri Aquifer at the preferred pilot injection site. The following points summarize the findings:

- Local groundwater is of reasonable quality and generally suitable for irrigation and livestock drinking. Dissolved iron and manganese concentrations slightly exceeded LTV values for irrigation of sensitive crops.
- Alkalinity and hardness concentrations are elevated in the Makauri Aquifer, similar to water in the Waipaoa River, which originates from a similar limestone-bearing catchment. The hardness of groundwater has a moderate potential for fouling.
- Chloride concentrations increased between approximately 2006 and 2015 in local groundwater at GPD115. The proposed MAR pilot injection water sources contain chloride at low concentrations so may improve groundwater quality.
- Injection water supplied from the Gisborne City water supply is treated to drinking water standards and is of good quality.
- Free available chlorine present in the injection water should help prevent biological clogging by inhibiting the growth of the iron oxidising bacteria.
- Generally low concentrations of dissolved metals (i.e., aluminium, iron, and manganese) in the potential injection water and groundwater at the preferred pilot injection site suggest that there is limited potential for chemical clogging. Most metals occur in groundwater at low concentrations, or as suspended colloids or clay particles.
- Seasonal iron concentration changes in local groundwater (i.e., higher concentrations in winter months and lower concentrations in summer months) may be related to near-well effects. If these effects are

also observed in groundwater at the injection well, a possible strategy to reduce the potential for chemical clogging may include pumping groundwater until iron concentrations decline to a stable level.

As treated water will be used for injection, residual chlorine will be present and therefore a potential exists for DBP formation within the aquifer as a result of the injection program. However, the results of this assessment indicate the potential for DBP formation during the injection period is low due to low organic matter concentrations in groundwater and injection water, the low water temperature expected during a winter injection, a lack of nitrite precursors in groundwater, and the neutral to alkaline pH of groundwater. Biological activity in the aquifer should also substantially reduce any DBP concentrations that may develop in the aquifer over relatively short periods of time. This means the risk of DBP transport in groundwater away from the trial site is low. In addition, the monitoring of groundwater quality in the standpipe piezometer close to the injection bore will enable the detection of any DBP concentrations that may develop and apply management measures if necessary (refer Section 6.0).

5.0 MONITORING

5.1 Water Level and Flow Monitoring

The flow of water into the injection bore will be carefully monitored at the bore head works. This data will be analysed throughout the injection trial so that the responses in the aquifer can be analysed and assessed. The final project report will detail the flow rates and total volume of water injected into the Makauri Aquifer. The capacity for the injection flow rates and groundwater levels to be monitored in real time also provides opportunity for unexpectedly high groundwater levels to be identified and managed as described in Section 6.0.

Groundwater level monitoring for the duration of the MAR pilot project is proposed for the nine targeted monitoring sites (Table 2) and one additional shallow bore. Water levels in the standpipe piezometer installed during drilling will be monitored throughout the injection and recovery. Bore GPD147 will be carefully monitored for potential artesian conditions resulting from the trial.

5.2 Water Quality Monitoring

Based on the results of this water quality assessment, acquisition of data in the following areas has been included in planning of the Pilot Project:

- Drill cuttings will be collected for mineralogical analysis by X-Ray Diffraction (XRD) and thin section petrography when the injection well is drilled. Mineralogical analysis could be used to identify minerals that may react due to changing chemical conditions in the aquifer (e.g., metal sulfides), consume residual chlorine (e.g., organic matter in the gravel aquifer) or become mobile in groundwater as fine suspended sediments (e.g., clay minerals).
- Improve the current understanding of iron mobility in local groundwater by analysing dissolved and total iron concentrations in the routine monitoring samples collected from the piezometer installed in the pilot drillhole and from GPD115 (closest production well to the preferred pilot injection site monitored by GDC).
- Continue to assess DBP formation based on water quality data gathered at each stage of the project.
- Perform a down-hole camera inspection of the injection well screen following completion of the injection trial to confirm the effectiveness of the clogging management measures incorporated in operational procedures for the trial.

6.0 MITIGATION MEASURES

The Pilot Project will be carefully monitored to observe the effects of the injection on the surrounding aquifer and bores. Significant adverse effects are not expected from the injection. If the monitoring of water levels or groundwater quality shows potential for adverse effects, the injection can be reduced through the flow control system or ceased altogether if deemed necessary.

There is a slight risk of artesian conditions developing at bore GPD147 during the trial. This bore will be monitored during the trial and if it appears that artesian conditions may develop the following steps may be taken:

- The bore head may be sealed to prevent water discharge.
- The injection rate for the trial may be decreased to reduce the rate of water level rise in the aquifer.

If significant concentrations of DBP are detected in water samples obtained from the standpipe piezometer installed in the pilot bore, measures will be instigated to reduce the concentration of free chlorine in the source water prior to injection. The injection process may be temporarily closed down while these measures are instigated. If necessary, the injected water could potentially be recovered from the aquifer by pumping it back out through the injection bore. This water recovery would be an extension of the backwashing process used for bore maintenance as described below.

The management of clogging is an operational matter rather than a potential environmental issue. A range of management measures can be implemented during the Pilot Project operations to address clogging issues should they arise (Golder 2014b). Backwashing and periodic mechanical rehabilitation of the injection well may be used to minimize the issues associated with physical clogging. Biological clogging can be minimized or prevented by injecting treated water containing residual chlorine to manage biological growth. Geochemical clogging can be managed through using the injection bore for the sole purpose of groundwater recharge rather than as a combined injection and recovery bore.

7.0 CONCLUSIONS

The proposed Poverty Bay MAR Pilot Project involves injecting up to 100,000 m^3 of treated water to the Makauri Aquifer through a specifically designed injection bore. Based on our assessment of the aquifer and geochemical conditions the proposed Pilot Project is not considered to have a significant effect on any surrounding bore users or the aquifer. Data gathered during the Pilot Project will be carefully analysed during the injection trial so that the responses in the aquifer can be used to support the design of any future catchment GRS.

The planned monitoring program has been designed to enable mitigation measures to be carried out during the project if any adverse effects are observed.

The proposed Pilot Project has been designed to generate information for the assessment of GRS options to support water management for the region. MAR has the potential to replenish and support sustainable groundwater yields from aquifers beneath the Poverty Bay Flats.

8.0 LIMITATIONS

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

9.0 REFERENCES

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APPENDIX A

Bore design – For Tendering Purposes

INITIAL BORE DESIGN

The information provided below is to support drilling companies in putting together a detailed estimate for the construction of a bore suitable to enable the injection of water into the confined Makauri Aquifer, Poverty Bay Flats, Gisborne. The proposed location of the bore is generally as shown in Figure A1, to be confirmed following a utilities check.

It is planned to drill a pilot hole to confirm the lithological units beneath the site and provide information to support the final design of the injection bore. The injection bore design, including casing and screen diameter, screen length and bore depth will be finalised based on observations from the pilot hole and through discussion between the drillers, GDC and Golder. For the purposes of developing a cost estimate, we have assumed the target Makauri Aquifer is 6 m thick at the pilot site and the base of the aquifer is at a depth of 85 m. Terminal depth for drilling is assumed to be at a depth of 87 m to allow the base of the aquifer to be clearly identified and to provide for a sump in the injection bore.

Suitably qualified Drilling Contractors are invited to tender for this project and should prepare a cost estimate taking into account the following tasks and assumptions:

1) Prior to drilling:
    a. Undertake a site suitability assessment including carrying out a utilities check.
    b. Supply a copy of the company's health and safety procedures to GDC and to manage health and safety on site during drilling.
2) Drill a pilot hole to a depth of approximately 87 m.
    a. Record a detailed lithology log and retain (bag) subsurface samples at 1 m intervals.
    b. Install a 52 mm ID standpipe piezometer in the pilot hole, including a 6 m screen.
3) Drill and install an injection bore. For tendering purposes, please assume:
    a. All drilling equipment to be sterilised prior to mobilisation to site.
    b. The terminal depth for the bore is approximately 87 m.
    c. Drilling will intersect a shallow gravel aquifer to 20 m depth. Below that depth the lithologies will consist of inter-bedded silty/clay aquitards until the target aquifer is intersected.
    d. The Makauri Aquifer is estimated to have a thickness of approximately 6 m at the pilot site, so a 6 m telescopic screen will be required and will be selected based on the sieve analysis results conducted on the bulked samples taken from pilot hole.
    e. An appropriate sump (maximum 1.5 m) will be required beneath the screen.
    f. Bore requires to be completed with a concrete collar and pad (at least 1 m^2).
    g. Bore head will need to be sealed with a bolted D flange with casing above ground 300 mm to 500 mm.
    h. It is anticipated that a minimum of 4 hours will be required for bore development but may be longer. If mud rotary drilling is proposed, a chemical mud revert must be added to assist in breaking down the drilling muds. It is assumed that the development will be completed by airlifting.
    i. Quotes for two injection bore diameter options (200 mm and 254 mm) completed with either steel or Class 12 uPVC casing will be required. If PVC casing is proposed, casing using bell joint (glued and screwed) is preferred over threaded casing.

j. On completion bore is to be pressure tested by the drilling contractor to 1250 kPa to ensure no cracks breaks or leaks have occurred in the casing .

k. Rock chip samples will be required to be obtained by the driller from discrete layers above and within the target aquifer for chemical analysis.

l. Bore completion is to comply with the requirements of New Zealand Drilling standards NZS4411.

4) The driller is to provide suitably qualified staff to manage and monitor pumping tests as described below. Pumping test support is to be incorporated in the estimated costs. For tendering purposes, please assume the following is required:

a. Provision of a calibrated water flow meter, pump, generator, orifice weir and flow control valve, and the taking of manual water level measurements and flow measurements.

b. Communications with Golder hydrogeologists during pumping test scheduling and design.

c. A 24 hour stepped rate pumping test, including a monitored recovery period, is to be undertaken. The test is to include 4 different flow rate steps rates at 100 minutes each, followed by the recovery period. The flows are to be monitored by the Drilling Contractor, with manual checks to confirm calibration of any flow meter used. The depth to water in the injection bore is to be manually monitored by the Drilling Contractor for the duration of the active pumping period and for 100 minutes following the close of pumping.

d. A bore rest day between tests.

e. A 72 hour constant rate pumping test, followed by a monitored recovery period of the same length.

f. Frequent manual water level measurements in the test bore and observation bores will be required at predefined intervals throughout the tests. Work with Golder hydrogeologist and GDC staff to cover required monitoring as detailed in the pumping test schedule. Some automated monitoring equipment will be supplied by Golder.

g. The driller is to control the water flow disposal area during pumping test and ensure flooding or erosion does not occur. There is potential to use an open drain following discussion with GDC staff.

5) Tidy up of site following drilling completion.

6) As a separately identified line item in the proposal, an allowance should be made for the driller to remain on-site for one day following the completion of the pumping tests to provide support in the installation of equipment required at the well head and inside the bore for an injection pilot test. The supply of the injection system itself is being costed separately and does not form part of this requested cost estimate.

In the proposal the drilling company is to supply an hourly rate as well as overall costs, so prices can be compared.

Details to be outlined in the driller's estimate should include:

- Grout (full annular or pressure grout) – take into consideration that we need to ensure the bore is well sealed above the target aquifer.
- Costing - state what casing schedule has been used in the driller's estimate.

Notes:

1) The depth of the finalised injection bore will be determined following the pilot hole drilling. An assumption of an 87 m deep bore has been made. Based on review of logs from nearby bores the target aquifer is likely to be between 70 m deep and 85 m deep.

2) The drillers should take into account the potential long term use of the bore as both an injection bore and an occasional production bore when considering the construction and installation requirements.

For the purposes of enabling a direct cost comparison between injection bore installation costs, the Drilling Contractor is required to complete Table 1 in addition to providing their usual cost estimate documentation.

Table 1: Schedule of rates for drilling costs per well for 200 mm and 250 mm diameter cased wells.

DRILLING COSTS	200 mm Class 12 uPVC (Per Well)		250 mm class 12 uPVC (per Well)	
General Items Mobilisation, demobilisation, site setup, site clean-up, drilling fluid removal, night site security, day security, equipment sterilisation.				
Well Drilling				
Precollar and cement	6 m			
Drilling to 87 m	87 m			
Case to 79 m and pressure cement	per m			
Standby for geophysical logging				
Airlift development	3 hrs min			
Stainless steel wire wound telescopic screen 6 m (aperture to be advised) with 1.5 m blank at base				
Drilling consumables, drilling muds, cement mud revert	Per bag			
Concrete collar & pad				
Additional items D Flange, sludge pump, safety fencing,				
Other				
Pressure test of Bore casing to 1250 kPa				
Stepped rate pumping test performance and monitoring				
Constant rate pumping test performance and monitoring				
Total per well (excl GST)				
Variable items				
Additional airlift development	per hr		per day	
Additional working rate e.g. lost circulation	per hr		per hour	
Additional case & cement	per m		per m	
Reaming and hole conditioning (wiper trips)	per hr		per hr	
Additional drilling	per m		per m	
Additional standby rate	per hour		per hour	
Top up cement & additional drilling muds	per bag		per bag	

Golder Associates

TITLE BORE DRILLING LOCATION

AUGUST 2015

PROJECT 1415771

A1

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APPENDIX B

Groundwater data summary

Table B1: Lithological logs for bores within 1 km of proposed injection site.

Bore No.	Easting (m)	Northing (m)	Start Depth (m)	End Depth (m)	Lithology
GPD005	2029020	5713897	0.0	65.0	Surface clay then silt
			65.0	71.0	Gravel and sand
GPD089	2028866	5713819	0.0	80.7	Brown clay then blue and grey silt layers and some timber at 45.8
			80.7	85.3	Gravels
GPD094	2029610	5713664	0.0	3.0	Brown silt
			3.0	70.1	Grey silt and shells and timber with a shallow pumice layer at approx. 61.0m which produced approx. 3000 gph
			70.1	76.2	Sands timber and gravel
GPD115	2028054	5713434	0.0	11.6	Brown clay
			11.6	15.8	Blue gravels
			15.8	31.0	Blue clay
			31.0	31.4	Timber
			31.4	44.0	Soft blue clay
			44.0	45.1	Coarse sand and timber
			45.1	71.6	Layers of soft and firm blue clay
			71.6	72.5	Gravel sand and clay cemented
			72.5	75.3	Tight large blue gravels
GPD117	2029110	5712361	0.0	4.6	Brown silt
			4.6	60.9	Grey silt
			60.9	70.1	Pumice then silt
			70.1	76.2	Sands shells timber and gravels
GPD141	2029710	5713163	0.0	5.5	Yellow silt
			5.5	72.9	Blue silt 72.28 sandy muddy gravel
			72.9	75.3	Clean large gravel
			75.3	77.5	Muddy gravel

GPD147	2029020	5712946	0.0	3.8	Topsoil and brown clay soft
			3.8	29.5	Blue sticky clay firmer with depth occasional pieces of wood and vegetation
			29.5	37.0	Blue sand odd small stones and traces of shell gas amongst
			37.0	44.0	Blue clay as above 3.8 to 29.5, quite firm and sticky
			44.0	61.0	Blue silt sand layers traces of pumice signs of gas
			61.0	63.0	Silty sand with sandstone rubble
			63.0	86.0	Light blue very stiff clay
			86.0	89.0	Brown yellow clay stiff
			89.0	93.5	Blue clay stiff and dense
			93.5	94.5	Blue silt soft and easy to drill
			94.5	95.5	Tight clay
			95.5	96.0	Blue silt bound gravel
			96.0	96.7	Conglomerate stones and clay to sand
			96.7	97.0	Blue sand and gravel
			97.0	101.0	Blue fine sand odd stone
			101.0	103.5	Blue silty sand odd stone
			103.5	103.7	Free blue gravel
			103.7	104.0	Tight claybound gravel concrete
			104.0	109.5	Free gravel clean and well sorted odd piece of wood
			109.0	0.0	Stiff blue clay

GPE034	2028831	5714327	0.0	3.0	Brown silt
			3.0	66.1	Grey silt timber and shells
			66.1	70.0	Sands and gravels

GPJ040	2027525	5712371	0.0	0.2	Top soil
			0.2	4.0	Brown silt
			4.0	5.5	Greybrown silt
			5.5	6.2	Pumice coarse grey brown clay silt
			6.2	6.5	Pumice coarse grey brown clay silt
			6.5	7.5	Pumice layer stratified with dark bands greybrown claysilt
			7.5	9.8	Bluegrey clay silt with wood leaves and peat
			9.8	9.9	Pumice layer
			9.9	13.2	Bluegrey clay silt with wood and leaves odd freshwater snail and fragment of cemented sandstone
			13.2	13.3	Pumice layer
			13.3	15.0	Bluegrey claysilt large quantity of wood and leaves
			15.0	17.4	Bluegrey claysilt less wood and leaves than above strata
			17.4	30.0	Bluegrey claysilt with wood fragments and shells
			30.0	50.0	Claysilt with wood fragments
			50.0	56.7	Sand and fine gravel shells
			56.7	58.2	Silt and sand with shells
			58.2	62.2	Clay silt with shells
			62.2	65.8	Clay silt
			65.8	73.0	Gravel poorly sorted subangular to rounded siltstone sandstone limestone greywacke
			73.0	80.0	Silt

GPJ044	2027507	5712360	0.0	3.7	Brown clay
			3.7	8.2	Grey silt
			8.2	9.8	Timber
			9.8	22.9	Grey silt with more timber
			22.9	30.5	Grey blue silt and fine sands
			30.5	36.6	Sand and small gravel
			36.6	42.7	Large gravel
			42.7	67.1	Grey silt
			67.1	68.6	White pumice
			68.6	74.7	Grey blue silt with some timber
			74.7	82.3	Fine blue sands
			82.3	90.0	Grey blue silt
			90.0	104.0	Blue pug

Table B2: Bore search results for all bores within 2 km of proposed injection trial site.

Bore number	Location	Bore depth (m)	Distance from injection (m)	Elevation above mean sea level (m)	Aquifer
GPD090	Bushmere Road	58	320	10.2	
GPD089	(Wp98,Pt) Jackson Rd	85.3	530	9.3	Makauri
GPD115	(Wp98,Pt) 54 Bolitho Rd	75.1	542	10.9	Makauri
GPD147	(Wp98) 370 Bushmere	114	599	7.9	Matokitoki
GPD012		60.9	604	9.6	
GPD096	Bushmere Rd Nr Jackson Rd	81.4	636	8.9	Makauri
GPD005	Jackson Rd Waerenga-A-Hika	71	683	8.9	Makauri
GPE034	(Pt) Jackson Rd	70	991	10.3	Makauri
GPD094	Shw.2 Waerenga-A-Hika	76.2	1,061	7.8	Makauri
GPD014	S Hway 2	57.9	1,123	7.4	
GPD141	Cnr Jackson Rd & Shw 2	75.3	1,136	7.4	Unknown
GPD116	409 Matawai Rd Sh2 (Wp97)	76.2	1,256	7.7	Makauri
GPE011	Bushmere Road	73.1	1,260	12.5	
GPD009	Shwd Waerenga-A-Hika	71.6	1,268	8.0	
GPD140		76.2	1,268	8.0	Makauri
GPD008	(Wp98) 475 Matawai Rd S.H.2	70.1	1,296	8.4	Makauri
GPD135	(Pt) Shw.2 Nr O'grady Rd	76.2	1,299	7.9	Makauri
GPJ092	20 Eade Road Gisborne	70	1,406	10.0	Makauri
GPJ043	20 Eades Road	70	1,407	11.2	
GPD015	Shw.2 Nr O'grady Rd,Hika	75	1,423	7.1	
GPD007	(Pt) 9 Jackson Rd	70.1	1,426	8.5	Makauri
GPE012	S Hway 2 B/W Jackson & Harper Roads	68	1,452	8.9	Unknown
GPJ040	Eades Rd	80	1,458	10.9	Makauri
GPF038	8 O'grady Rd	70	1,525	7.3	
GPE010	Bushmere Rd	73.8	1,527	13.0	
GPF105	Shw.2 Hika Nr Jackson Rd	71	1,533	8.9	Unknown
GPF094	O'grady Rd Waerenga-A-Hika	72.2	1,550	7.3	Makauri
GPF163	23 Ogrady Road	70	1,584	7.4	
GPI032	(Wp99) 437 Kirkpatrick Rd	81.3	1,586	12.4	Makauri
GPJ090	Eade Road	152.4	1,621	9.4	
GPF091	23 O'grady Rd	71.9	1,672	7.4	
GPF093	23 O'grady Road	74	1,676	7.5	Makauri
GPJ068	Kirkpatrick Road	72	1,690	9.5	Unknown
GPJ041	Wharekopae Road	66	1,698	8.2	
GPJ042	(Wp00) 175 Wharekopae Road	66.1	1,698	8.2	Makauri
GPJ061	Patutahi Rd	68.5	1,838	7.8	
GPJ059	259 Wharekopae Road	91.4	1,878	10.0	
GPE029	Bushmere Road	72	1,901	12.6	
GPF034	(Wp98) 73 O'grady Road	73.1	1,912	6.8	
GPJ046	Wharekopae Road	60.9	1,931	7.4	

Bore number	Location	Bore depth (m)	Distance from injection (m)	Elevation above mean sea level (m)	Aquifer
GPE008	S Hway 2	67	1,970	9.9	
GPJ070	(Wp95) 96 Wharekopae Rd	68.6	1,979	7.5	Makauri
GPF144	O'grady Road	105.5	1,987	7.4	Makauri
GPF025	S Hway 2 B/W Ferry And Harper Roads	73	1,998	10.1	

Table B3: Consented groundwater takes within 2 km of the proposed injection.

Bore	Consent holder	Take location	Easting	Northing	Aquifer	Consented volume per day (m³)	Consented rate of take (L/sec)	Total use (m³/year)
GPD116	Tony Leach	408 Matawai Rd	2029841	5713237	Makauri	0	0	0
GPI032	A & K McKay	437 Kirkpatrick Rd	2027259	5714224	Makauri	110	3.8	261
GPD089	A B & B N Kemp P/ship	97 Jackson Rd	2028866	5713819	Makauri	100	3	7,953
GPD008	A C & P V Gayford	475 Matawai Rd	2029641	5714126	Makauri	100	3	0
GPJ014	A W & A M Hope	369 Kirkpatrick Rd	2027306	5713261	Shallow Fluvial	44	1	418
GPD185	W Mortleman	458 Matawai Road	2029755	5713952	Makauri	0	0	0
GPI032	Lanark Orchard	436 Kirkpatrick Rd	2027259	5714224	Makauri	0	0	0
GPD115	B R & C A Baty	54 Bolitho Rd	2028054	5713434	Makauri	210	3.8	3,360
GPD147	Bushmere Investments Ltd	370/384 Bushmere Rd	2029020	5712946	Matokitoki	1,350	25	49,791
GPF091	Haisman Family Trust	24 Ogrady Road	2030110	5714065	Makauri	0	0	0
GPD147	Chrisp Agriculture and G Armstrong	370/384 Bushmere Rd	2029020	5712946	Matokitoki	0	0	0
GPJ070	P R Duncan		2028204	5711424	Makauri	110	2.5	10,774
GPJ065	Patutahi Golf Club	175 Wharekopae Rd	2027797	5711777	Shallow Fluvial	100	3.8	2325
GPI018	I E Tietjen	447 Kirkpatrick Rd	2027302	5714454	Shallow Fluvial	480	5.55	532
GPD172	D W Amor	297 Matawai Rd	2030180	5712867	Shallow Fluvial	1,090	15.7	0
GPD124-LEFT	D W Amor	297 Matawai Rd	2030444	5712747	Shallow Fluvial	1,090	15.7	258
GPD124-RIGHT	D W Amor	297 Matawai Rd	2030444	5712747	Shallow Fluvial	1,090	15.7	300

Bore	Consent holder	Take location	Easting	Northing	Aquifer	Consented volume per day (m^3)	Consented rate of take (L/sec)	Total use (m^3/year)
GPD004	J D S & J M Dymock	99 Jackson Rd	2028567	5713554	Shallow Fluvial	114	2.25	10,109
GPD116	JP & MA Graham	409 Matawai Rd	2029841	5713237	Makauri	200	5.6	0
GPJ011	F J Lewis & A W Hope	367 Kirkpatrick Rd	2027306	5713461	Shallow Fluvial	0	0	0
GPF038	TBD Ltd	8 O'Grady Rd	2030038	5713849	Makauri	17.5	5	7,518

APPENDIX C

Water Quality data summary

GROUNDWATER

Local groundwater quality monitoring data is summarised in this section in time series graphs and tables. The water quality data were provided by GDC from long term monitoring at local production well GPD115. Groundwater samples were also collected at production wells GPD089, GPD115, and GPD116 in May 2015 and the results of analysis of these samples are shown on each graph for comparison with long term trends.

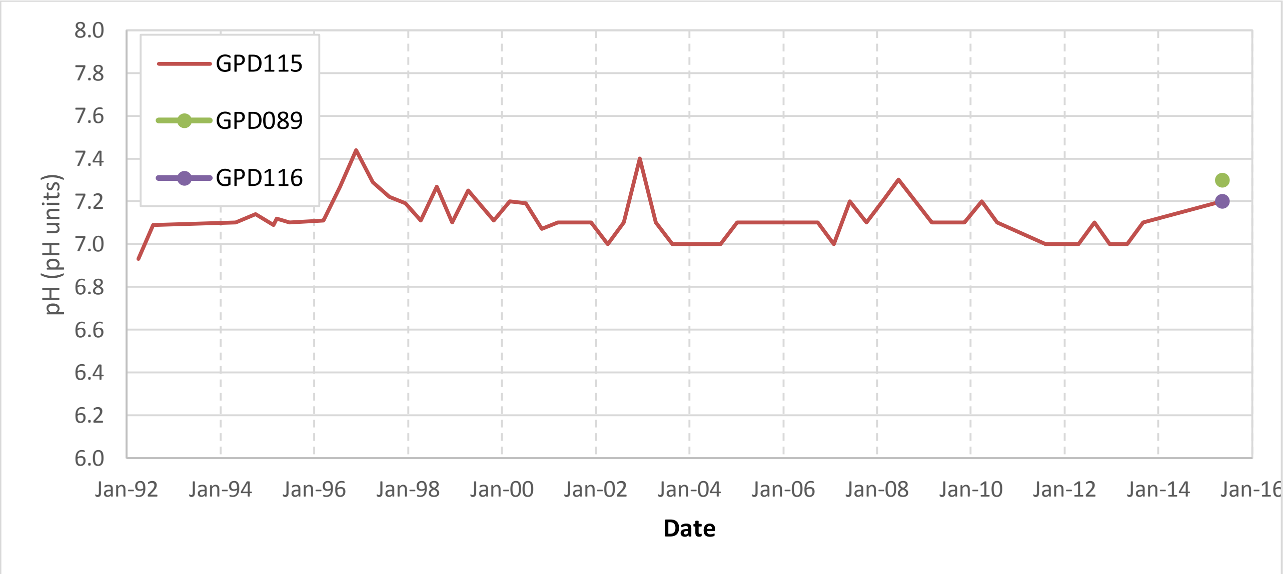

Figure C1: pH.

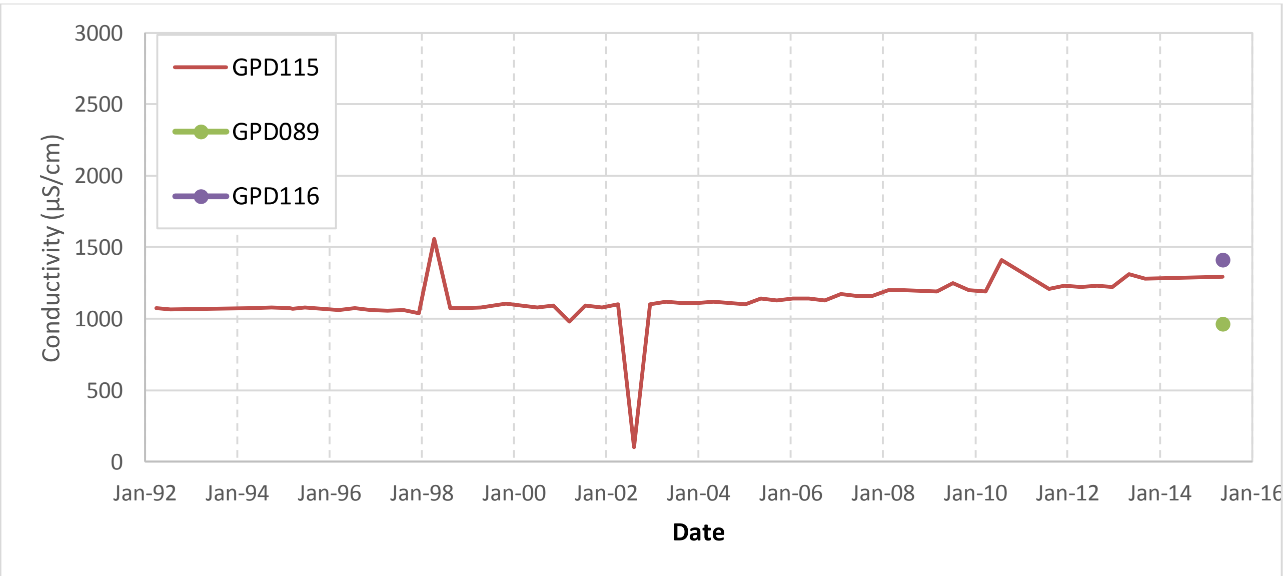

Figure C2: Electrical conductivity.

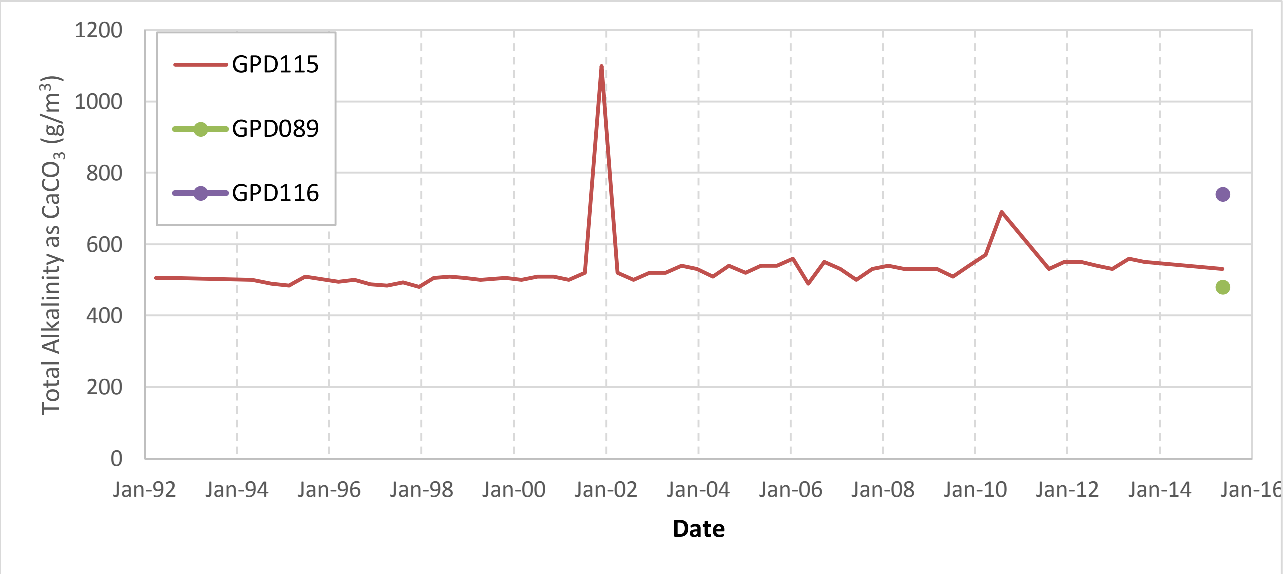

Figure C3: Total alkalinity.

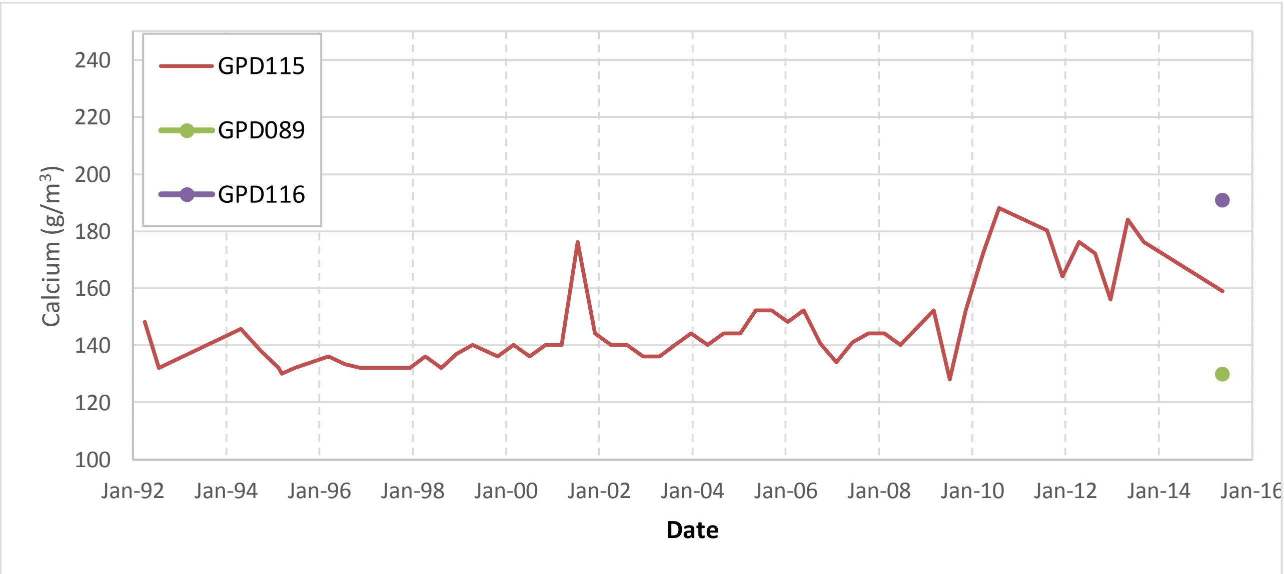

Figure C4: Calcium.

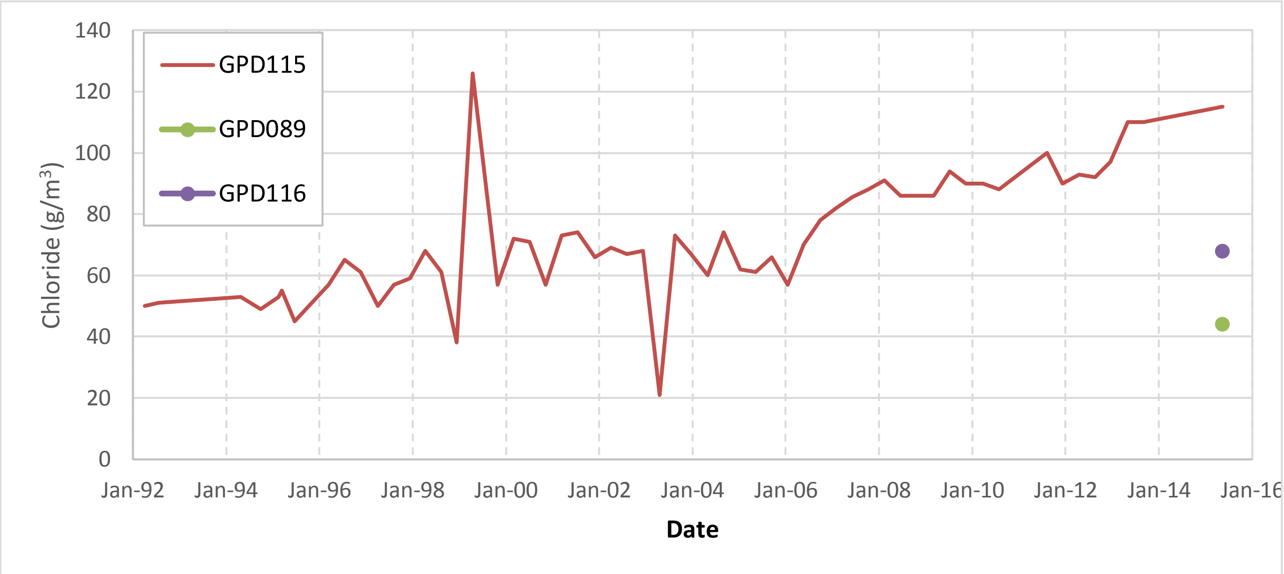

Figure C5: Chloride.

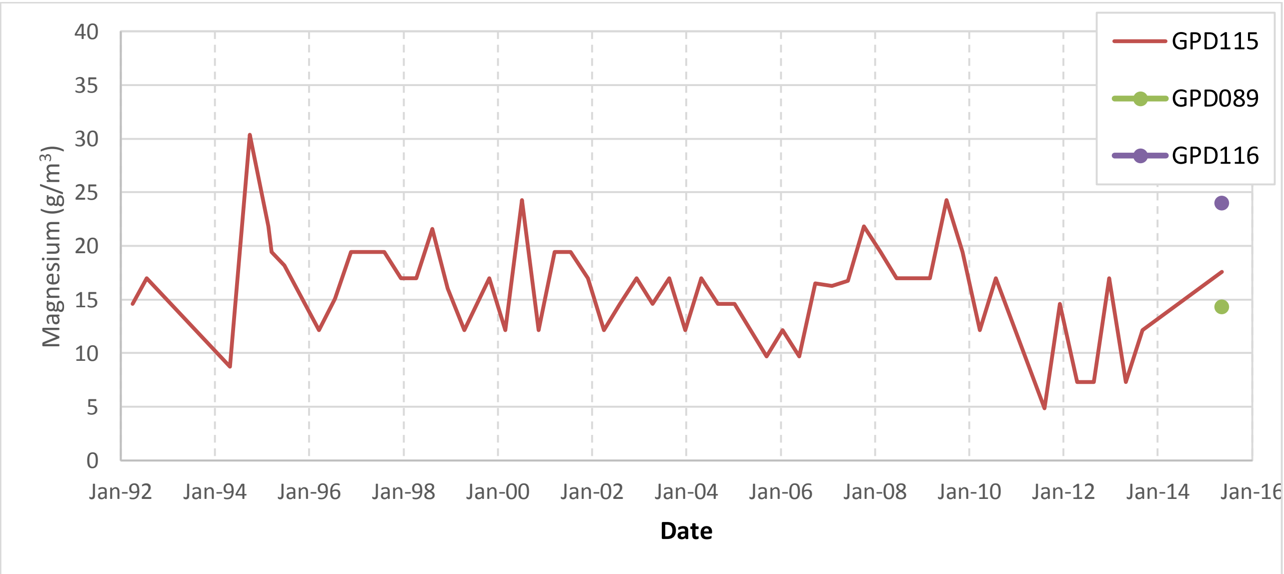

Figure C6: Magnesium.

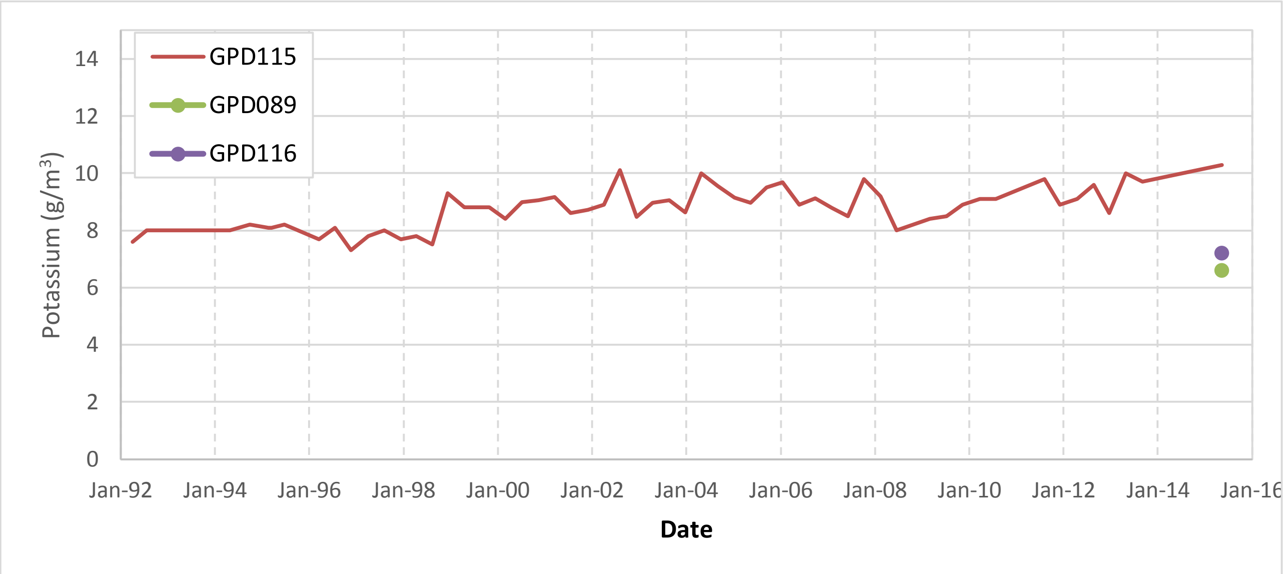

Figure C7: Potassium.

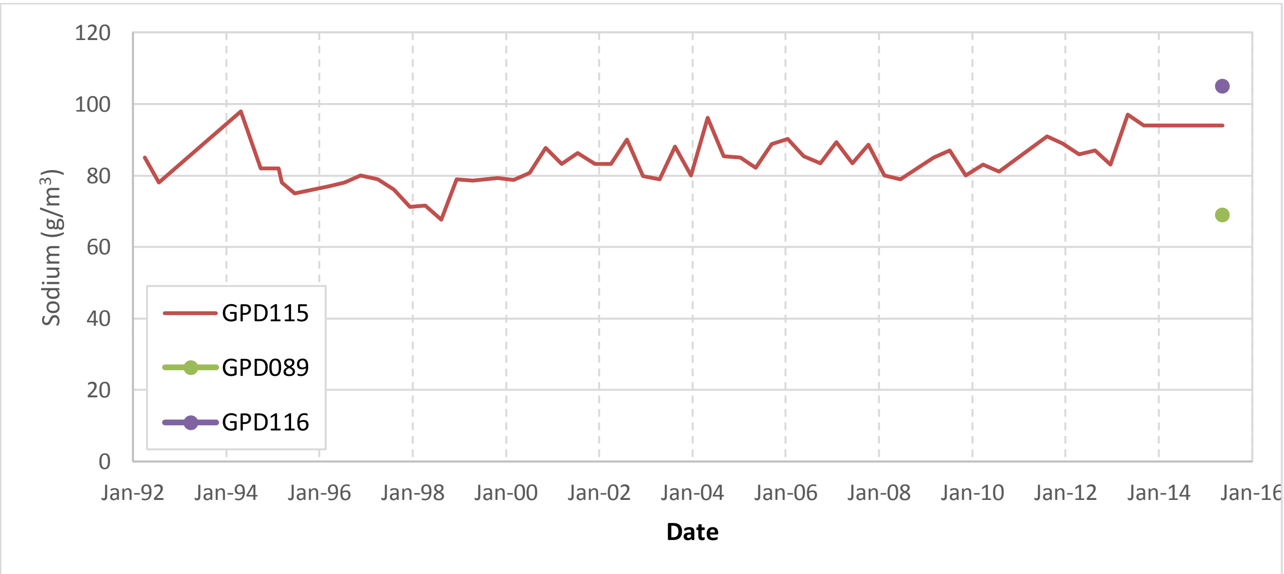

Figure C8: Sodium.

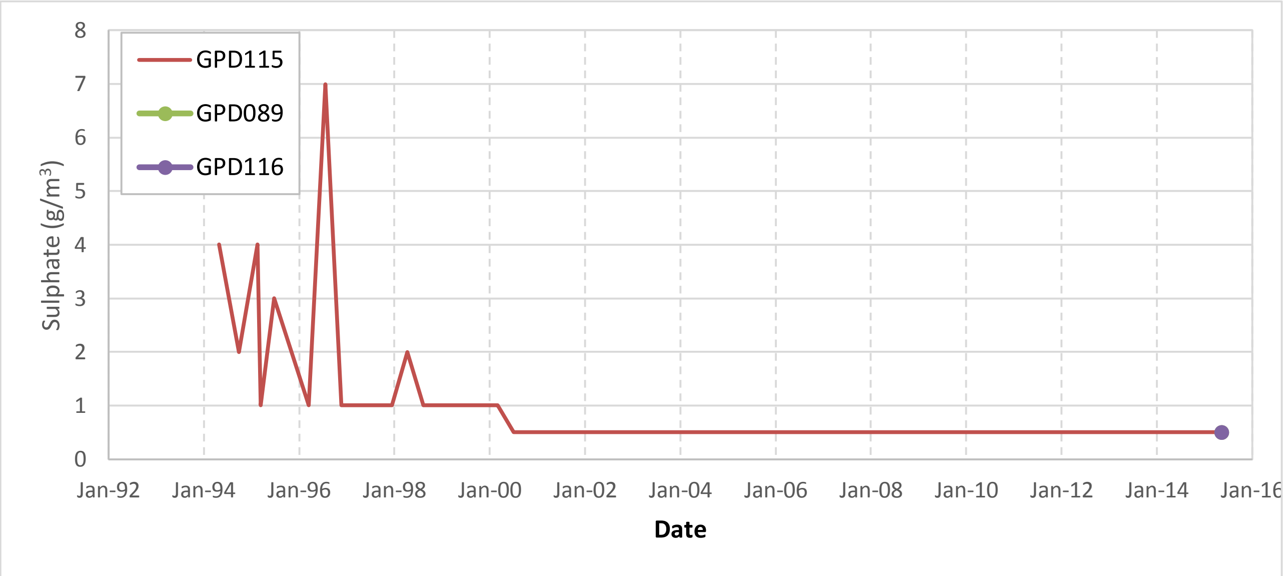

Figure C9: Sulfate.

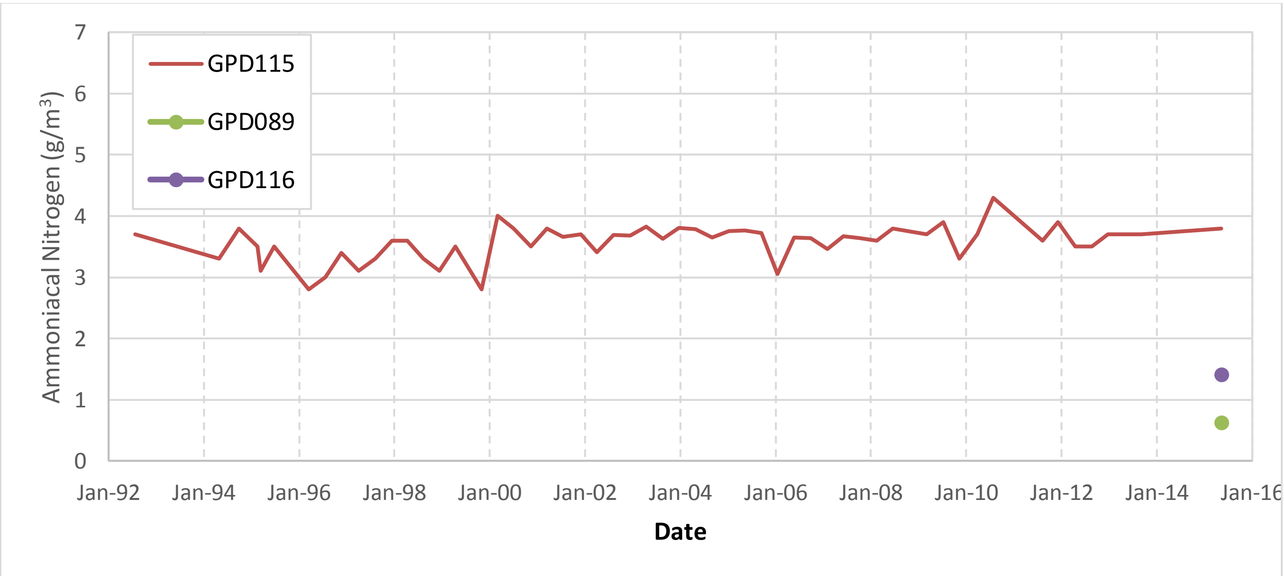

Figure C10: Ammoniacal nitrogen.

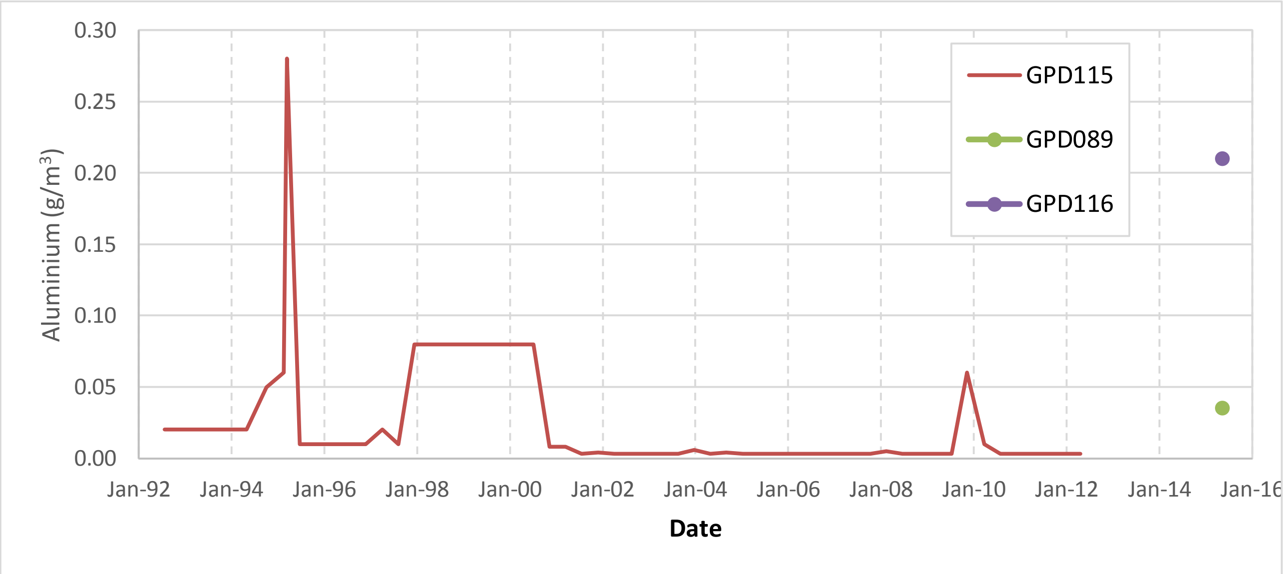

Figure C11: Total aluminium.

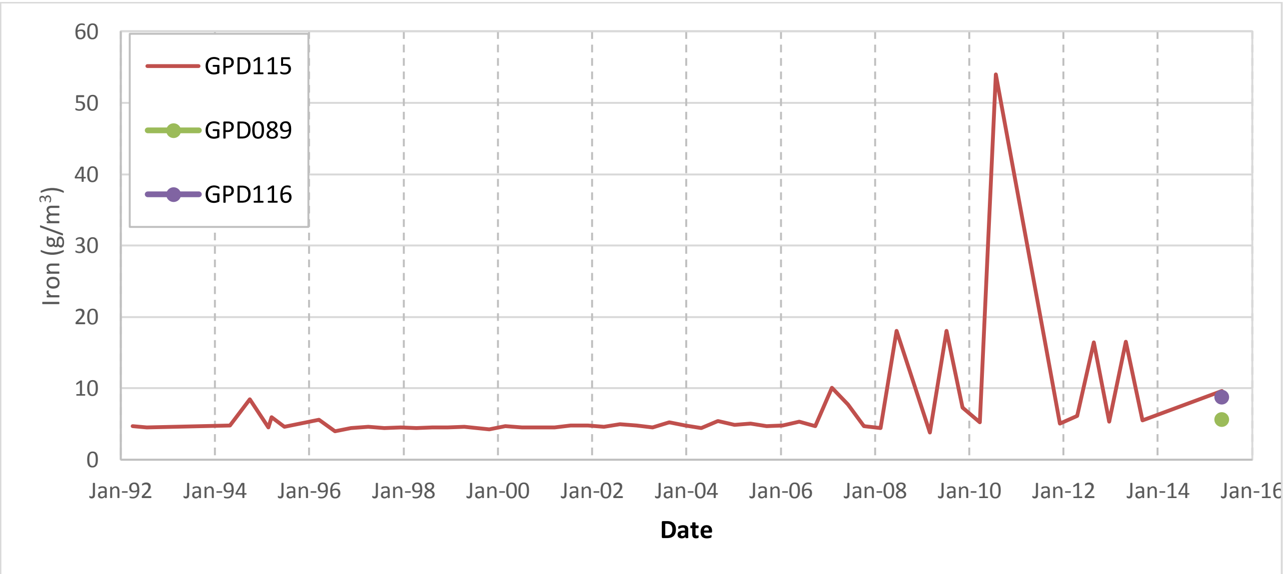

Figure C12: Total iron.

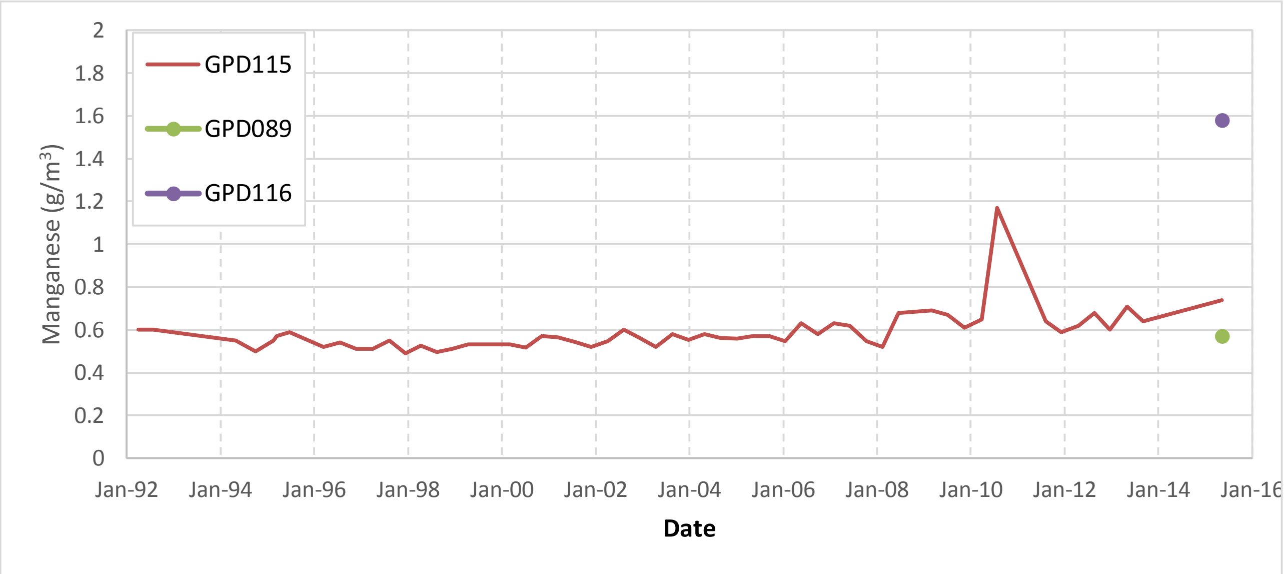

Figure C13: Total manganese.

Table C1: Groundwater sample analysis results from May 2015 sampling event.

Parameter	Units	GPD115	GPD089	GPD116
Field Water Quality Measurements				
Sample Date		12-May-2015 10:23 am	12-May-2015 11:03 am	12-May-2015 12:00 pm
Temperature	ºC	15.2	15	15
Conductivity	µS/cm	1,318	993	1,432
pH	s.u.	7.07	7.3	7.06
Turbidity	NTU	7.0	2.9	21.6
Dissolved oxygen	%sat	0.4	24	4
Dissolved oxygen	g/m^3	0.04	2.3	0.4
ORP	mV	117.6	105	85
Sample appearance	-	clear	clear	clear
Sample odour	-	odourless	odourless	odourless
General Water Quality Parameters				
Total alkalinity	g/m^3 as $CaCO_3$	530	480	740
Bicarbonate	g/m^3 at 25°C	650	580	900
Total hardness	g/m^3 as $CaCO_3$	470	380	580
Total suspended solids	g/m^3	21	18	40
Total dissolved solids	g/m^3	720	570	850
Chloride	g/m^3	115	44	68
Chlorite	g/m^3	<0.005	<0.005	<0.005
Fluoride	g/m^3	0.3	0.29	0.25
Total phosphorus	g/m^3	0.182	0.055	0.46
Total sulphide	g/m^3	<0.002	<0.002	<0.002
Sulphate	g/m^3	<0.5	<0.5	<0.5
Dissolved organic carbon	g/m^3	<0.5	<0.5	<0.5
Total organic carbon	g/m^3	<0.5	<0.5	<0.5
Chlorine, Free and Combined				
Free chlorine	g/m^3	<0.05	<0.05	0.06
Combined chlorine	g/m^3	<0.08	<0.08	<0.08
Nutrients				
Total ammoniacal-N	g/m^3	3.8	0.62	1.4
Nitrite-N	g/m^3	<0.002	<0.002	<0.002
Nitrate-N	g/m^3	<0.002	<0.002	<0.002
Nitrate-N + Nitrite-N	g/m^3	<0.002	<0.002	<0.002
Dissolved reactive phosphorus	g/m^3	<0.004	<0.004	<0.004
Total phosphorus	g/m^3	0.182	0.055	0.46
Metals				
Dissolved aluminium	g/m^3	<0.003	<0.003	<0.003
Total aluminium	g/m^3	<0.0032	0.035	0.21
Dissolved antimony	g/m^3	<0.0002	<0.0002	<0.0002
Dissolved arsenic	g/m^3	0.0044	<0.0010	0.0034

Parameter	Units	GPD115	GPD089	GPD116
Dissolved barium	g/m^3	3.3	3	1.63
Dissolved beryllium	g/m^3	<0.00010	<0.00010	<0.00010
Dissolved boron	g/m^3	0.24	0.198	0.25
Dissolved cadmium	g/m^3	<0.00005	<0.00005	<0.00005
Dissolved calcium	g/m^3	159	130	191
Dissolved chromium	g/m^3	<0.0005	<0.0005	<0.0005
Dissolved copper	g/m^3	<0.0005	<0.0005	<0.0005
Dissolved iron	g/m^3	1.56	0.06	0.97
Total iron	g/m^3	9.6	5.6	8.8
Dissolved lead	g/m^3	<0.00010	<0.00010	<0.00010
Dissolved lithium	g/m^3	0.046	0.04	0.054
Dissolved magnesium	g/m^3	17.6	14.3	24
Dissolved manganese	g/m^3	0.66	0.5	1.43
Total manganese	g/m^3	0.74	0.57	1.58
Dissolved molybdenum	g/m^3	0.0033	0.0012	0.0012
Dissolved nickel	g/m^3	<0.0010	0.003	<0.0010
Dissolved potassium	g/m^3	10.3	6.6	7.2
Dissolved selenium	g/m^3	<0.0010	<0.0010	<0.0010
Dissolved sodium	g/m^3	94	69	105
Dissolved tin	g/m^3	<0.0005	<0.0005	<0.0005
Dissolved uranium	g/m^3	<0.00002	<0.00002	<0.00002
Dissolved zinc	g/m^3	0.0079	0.105	0.0135
Chloramines				
Monochloramine	g/m^3	<0.05	<0.05	<0.05
Dichloramine	g/m^3	<0.05	<0.05	0.08
Trichloramine	g/m^3	<0.05	<0.05	<0.05
Halogenated Acetic Acids				
Bromochloroacetic acid	g/m^3	<0.0005	-	-
Dibromoacetic acid	g/m^3	<0.0005	-	-
Dichloroacetic acid	g/m^3	<0.0005	-	-
Monobromoacetic acid	g/m^3	<0.0005	-	-
Monochloroacetic acid	g/m^3	<0.005	-	-
Trichloroacetic acid	g/m^3	<0.0010	-	-
Total HAA	g/m^3	<0.010	-	-
Halogenated Volatile Disinfection By-Products				
Bromochloroacetonitrile	g/m^3	<0.00014	-	-
Bromodichloromethane	g/m^3	<0.00007	-	-
Bromoform (tribromomethane)	g/m^3	<0.00007	-	-
Carbon tetrachloride	g/m^3	<0.0007	-	-
Chloroform (Trichloromethane)	g/m^3	<0.007	-	-
Chloropicrin	g/m^3	<0.0003	-	-
1,2-Dibromo-3-chloropropane	g/m^3	<0.0003	-	-

Parameter	Units	GPD115	GPD089	GPD116
Dibromoacetonitrile	g/m^3	<0.0003	-	-
Dibromochloromethane	g/m^3	<0.00007	-	-
1,2-Dibromoethane (ethylene dibromide, EDB)	g/m^3	<0.0003	-	-
1,1-Dichloro-2-propanone	g/m^3	<0.0003	-	-
Dichloroacetonitrile	g/m^3	<0.0003	-	-
Tetrachloroethene (tetrachloroethylene)	g/m^3	<0.00014	-	-
1,1,1-Trichloro-2-propanone	g/m^3	<0.0003	-	-
Trichloroacetonitrile	g/m^3	<0.0003	-	-
1,1,1-Trichloroethane	g/m^3	<0.00014	-	-
Trichloroethene (trichloroethylene)	g/m^3	<0.00007	-	-
Total Trihalomethanes (THM)	g/m^3	<0.007	-	-

INJECTION WATER

Potential injection water quality monitoring data is summarised in this section in time series graphs and tables. The water quality data presented in this appendix were provided by GDC from routine monitoring at the Venturi Hut at Campion College.

Analytical results from two extended suite samples collected at the Venturi Hut in 2014 and 2015 and a single sample collected at the Waipaoa Augmentation Plant in 2014 are presented in Table C2.

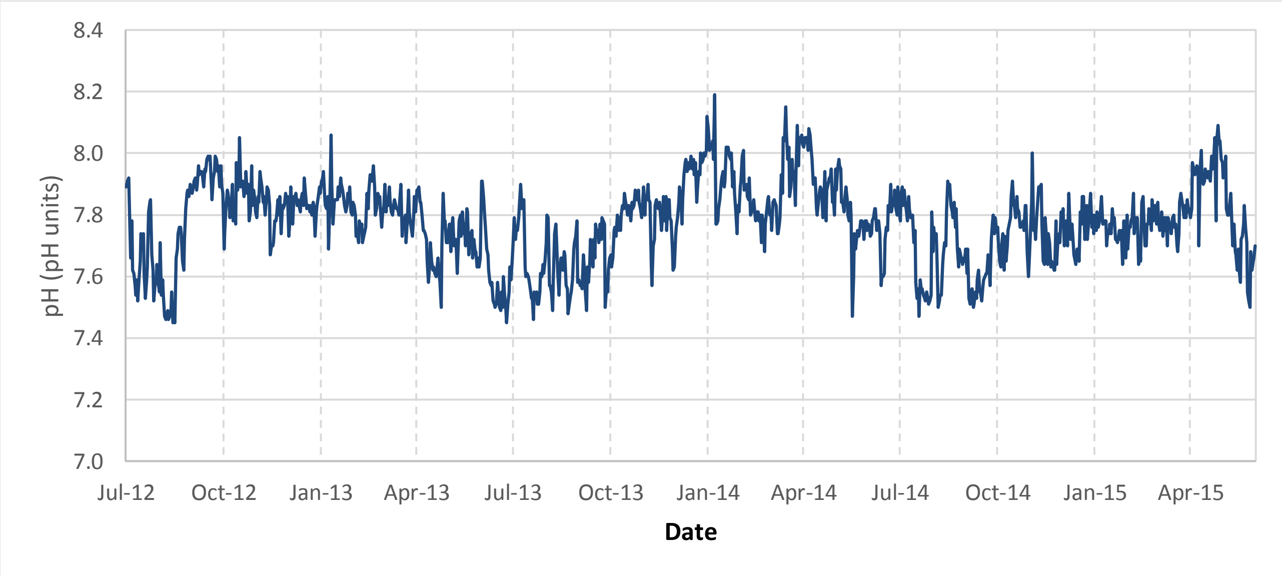

Figure C14: pH at Venturi Hut.

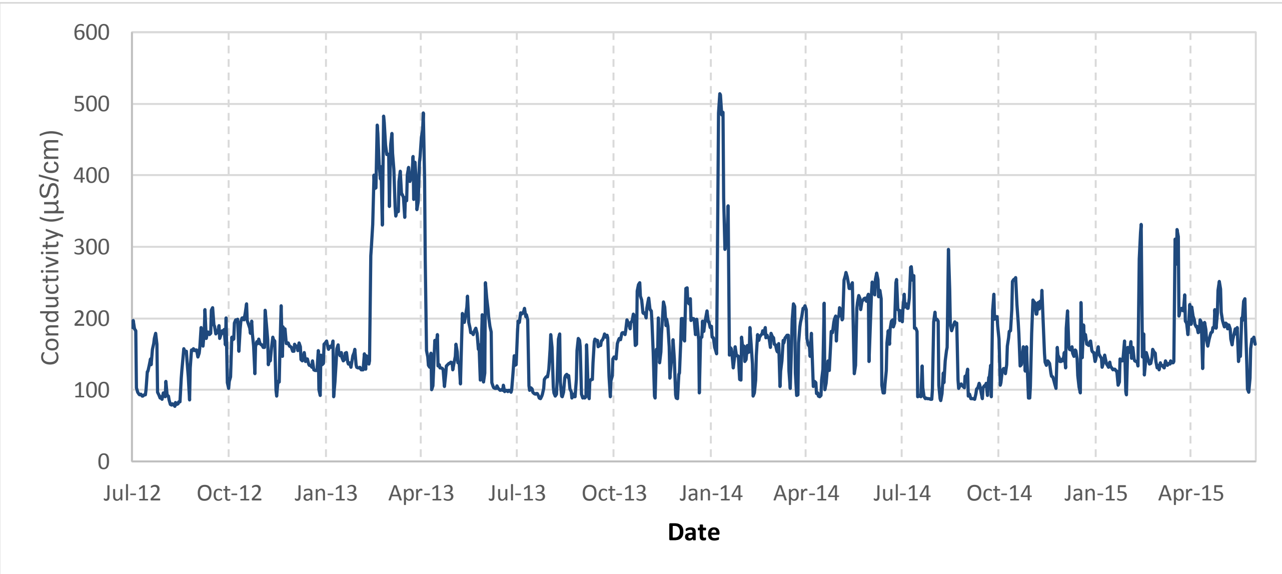

Figure C15: Electrical conductivity at Venturi Hut.

Figure C16: Temperature at Venturi Hut.

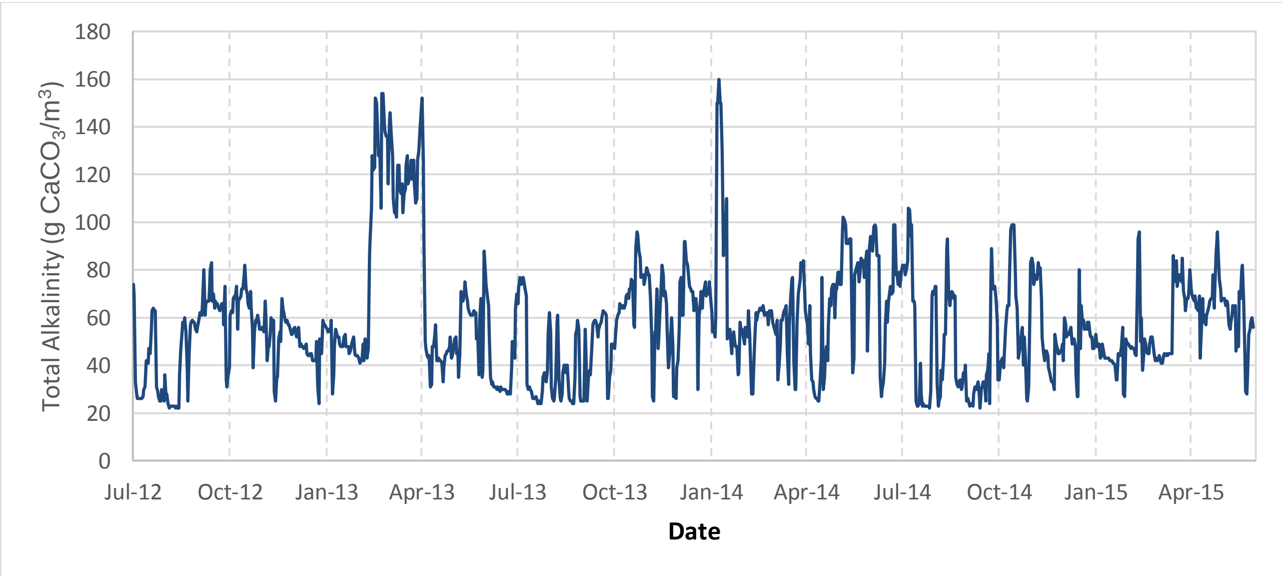

Figure C17: Total alkalinity at Venturi Hut.

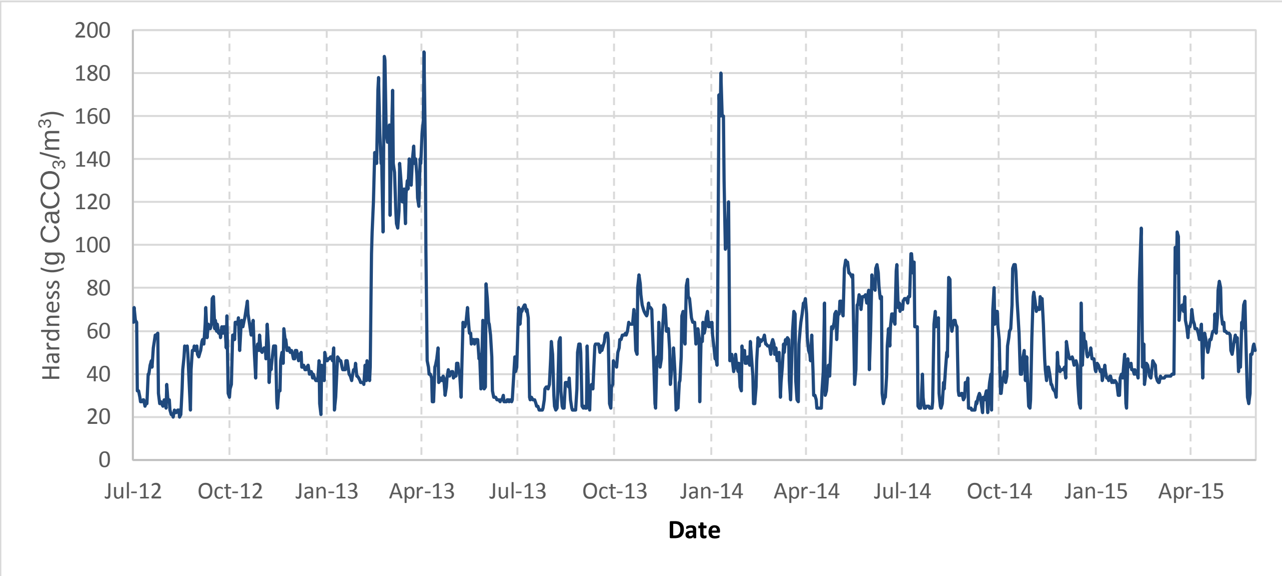

Figure C18: Hardness at Venturi Hut.

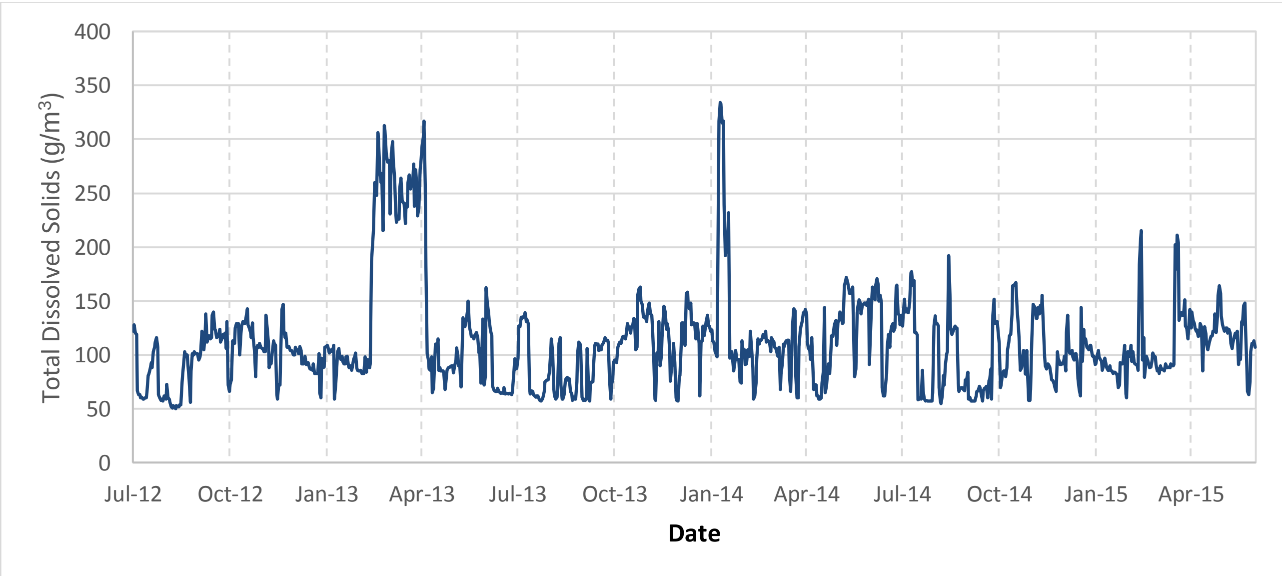

Figure C19: Total dissolved solids at Venturi Hut.

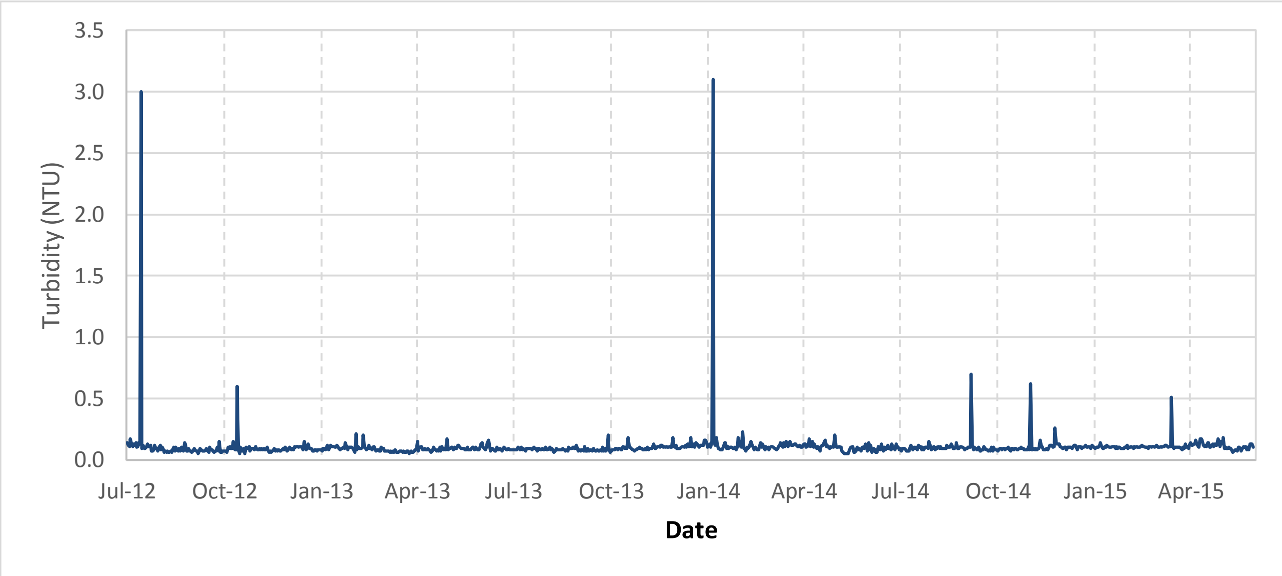

Figure C20: Turbidity at Venturi Hut.

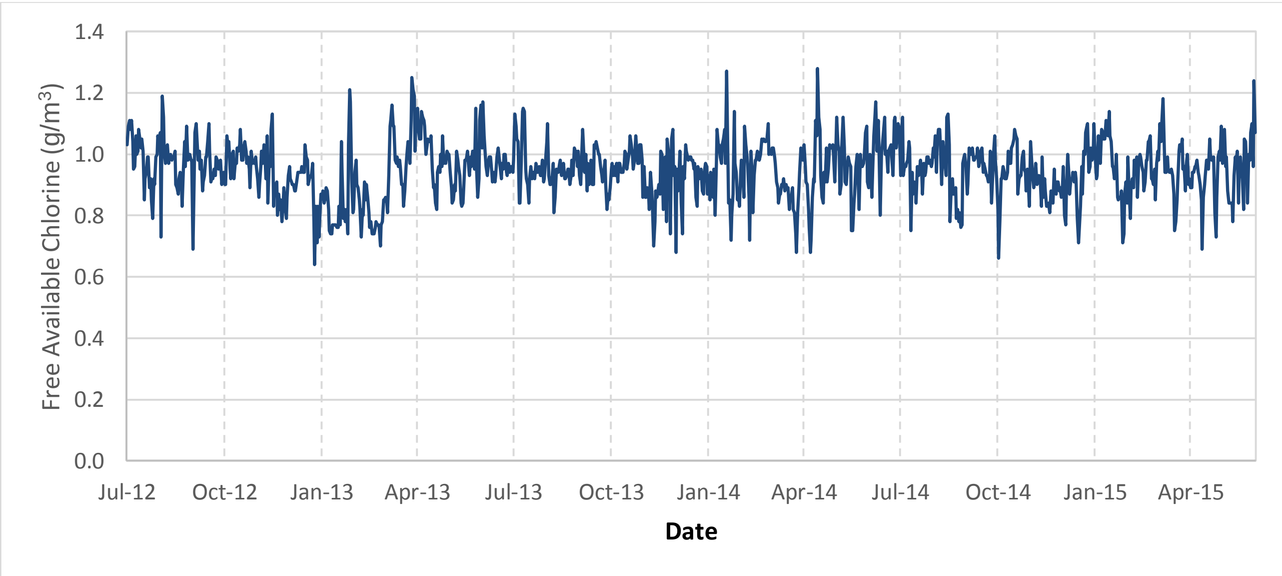

Figure C21: Free available chlorine at Venturi Hut.

Table C2: Potential injection water sample analysis results from 2014 and 2015 sampling events.

Parameter	Units	Venturi Hut	Venturi Hut	Waipaoa Augmentation Plant
Field Water Quality Measurements				
Sample Date		09-Mar-2015 7:25 am	04-Mar-2014 11:50 am	01-Jan-2014
pH	s.u.	7.6	7.7	7.9
Conductivity	µS/cm	137	154	54.8
Turbidity	NTU	0.16	0.09	0.27
General Water Quality Parameters				
Total alkalinity	g/m^3 as $CaCO_3$	44	56	170
Bicarbonate	g/m^3 at 25°C	54	68	210
Total hardness	g/m^3 as $CaCO_3$	44	53	230
Chloride	g/m^3	11.5	11.4	19.1
Chlorite	g/m^3	<0.005	<0.005	<0.005
Chlorate	g/m^3	-	-	<0.005
Fluoride	g/m^3	0.80	0.08	0.12
Reactive silica	g/m^3	9.2	10.0	8.3
Sulphate	g/m^3	4.1	5.4	99
Absorbance at 254 nm	SU cm^{-1}	0.017	0.016	0.029
Chlorine, Free, Combined and Chloramines				
Free chlorine	g/m^3	0.98	0.88	-
Combined chlorine	g/m^3	0.09	<0.08	-
Chloramines				
Monochloramine	g/m^3	-	<0.05	<0.05
Dichloramine	g/m^3	-	<0.05	0.09
Trichloramine	g/m^3	-	<0.05	<0.05
Nutrients				
Total ammoniacal-N	g/m^3	<0.010	<0.010	<0.01
Nitrite-N	g/m^3	<0.002	<0.002	<0.002
Nitrate-N	g/m^3	0.007	0.007	<0.002
Nitrate-N + Nitrite-N	g/m^3	0.007	0.007	0.002
Dissolved reactive phosphorus	g/m^3	0.010	0.007	<0.004
Metals				
Aluminium	g/m^3	0.147	0.160	0.169
Antimony	g/m^3	<0.0002	<0.0002	<0.0002
Arsenic	g/m^3	<0.0010	<0.0010	<0.001
Barium	g/m^3	0.0077	0.0108	0.09
Beryllium	g/m^3	<0.00010	<0.00010	<0.0001
Boron	g/m^3	0.042	0.047	0.128
Cadmium	g/m^3	<0.00005	<0.00005	<0.00005
Calcium	g/m^3	15.5	18.7	77
Chromium	g/m^3	<0.0005	<0.0005	<0.0005

Parameter	Units	Venturi Hut	Venturi Hut	Waipaoa Augmentation Plant
Copper	g/m^3	0.0006	0.0006	0.0007
Iron	g/m^3	<0.02	<0.02	<0.02
Lead	g/m^3	<0.00010	<0.00010	<0.0001
Lithium	g/m^3	0.0025	0.0036	0.02
Magnesium	g/m^3	1.36	1.60	9.1
Manganese	g/m^3	0.0005	0.0007	0.0020
Total Mercury	g/m^3	<0.00008	<0.00008	<0.00008
Molybdenum	g/m^3	<0.0002	<0.0002	0.0014
Nickel	g/m^3	<0.0005	<0.0005	0.0007
Potassium	g/m^3	0.59	0.77	3.1
Selenium	g/m^3	<0.0010	<0.0010	<0.0010
Silver	g/m^3	<0.00010	<0.00010	<0.00010
Sodium	g/m^3	9.0	9.6	27
Tin	g/m^3	<0.0005	<0.0005	<0.0005
Uranium	g/m^3	<0.00002	<0.00002	0.00042
Zinc	g/m^3	<0.0010	<0.0010	<0.0010

APPENDIX D

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