INDEPENDENT REVIEW OF THE GISBORNE MAR PROJECT – MAR PILOT SITE AND INJECTION TRIALS

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Independent Review of the Gisborne MAR Project – MAR Pilot Site and Injection Trials.

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Executive Summary

The following report provides results of an independent review of the Gisborne Managed Aquifer Recharge (MAR) Project.

Background and Aims

The Gisborne District Council are considering the development of an operational MAR Scheme to alleviate declining groundwater levels and increasing salinity trends within the Makauri Aquifer, Poverty Bay Flats. Under the current configuration, surface water would be harvested from the Waipaoa River and injected into the confined Makauri Aquifer via a number of MAR bores. A minimum injection volume of 600,000 m^3/annum is envisaged.

The aim of the independent review is to:

- Provide an opinion as to whether the Gisborne Council should progress toward a full-scale MAR Scheme.
- Identify any key risks for the project that are not addressed from work to date.

Suitability of the Makauri Aquifer for a Full-Scale MAR Scheme

In our opinion the Makauri Aquifer is a suitable target for an operational MAR Scheme.

- The aquifer exhibits very high transmissivity due to very coarse grainsize which will facilitate:
  - High well capacity.
  - Lower potential for clogging.
  - High capacity to transmit water level (pressure) increase over long distances and alleviate the current water level decline.
- A relatively thin, coarse grained aquifer will exhibit a high proportion of effective porosity and rapidly transport lower salinity injected water to points of extraction and alleviate the current salinity increase.
- The aquifer is comprised of gravels with no significant sulphides identified that might result in water quality or chemical clogging risks.
- The aquifer is understood to be laterally extensive which provides the capacity to accept water and to distribute pressure throughout the aquifer.

Approach to Injection

In our opinion the proposed method of injection (circa 600,000 m^3 injected during winter over multiple injection bores) is likely to meet expectations of the GDC, specifically, to alleviate groundwater declines and to improve salinity.

The planned Scheme targets a minimum injection volume of 600,000 m^3 over a winter injection season. Based on an injection volume of 100,000 m^3 / bore a minimum of six bores will be required to satisfy this volume.

Alleviation of groundwater level decline

Injection of 600,000 m^3 per annum of water will significantly improve the aquifer water balance. Current extraction is estimated at 900,000 m^3 per annum. Injection of a similar volume will largely offset this use. The high aquifer transmissivity means that water level increase will be readily transmitted through the aquifer.

Alleviation of groundwater salinity rise.

The salinity of injected water (River water) is in the order of 400 µs/cm. The natural salinity of the groundwater in use is in the order of 700 to 1500 µs/cm. This is suited to irrigation of crops in the region.

Ongoing pumping results in a cone of drawdown generated during the summer pumping season. This has drawn in saline groundwater and resulted in salinity rise at some observation bores since 1990. In one case salinity has increased by ~900 µs/cm over a 30-year period. This equates to an annual salinity rise of 30 µs/cm/annum. If this trend continued across a wider area it would likely reduce the beneficial use of the Makauri Aquifer.

The injection of lower salinity groundwater by the MAR scheme will reduce the groundwater salinity at the point of injection by displacement and dilution. Additionally, injection of lower salinity MAR water at the margin of saline intrusion will also act as a hydraulic barrier (both lateral intrusion and vertical) and reduce the ongoing rate of salinity rise.

Key Risks to the Project

The following present the most important risks to this Project:

Clogging: Reduction in bore capacity by physical clogging with solids entrained in source water is the key risk for this project. This risk has been confirmed by the work completed to date however additional detail is provided here. The risk is not only reduced bore performance due to clogging immediately around the well screen but also deposition of fines into the aquifer that may cause a permanent reduction in hydraulic conductivity away from the screen that cannot be rectified.

- Source turbidity can be reduced by:
  - Obtaining source water from the shallow aquifer bores installed near the River, using the shallow aquifer as a filter.
  - Other forms of filtration or sediment reduction, including constructed wetlands, settling ponds or mechanical filters.
- Clogging of well screens can be managed by backflushing:
  - Backflush cycles are typically driven by time or head increase and will be site specific.
  - Backflush pumping rate should be higher (ideally twice as high) as the injection rate.
- Clogging can be managed via filtration prior to injection. Filters should be designed considering particle size distribution of the source water.

Emerging contaminants: PFAS and derivatives have been identified at other MAR sites in Australia. PFAS contaminant risk for the Gisborne MAR Scheme should be assessed via a catchment scale risk assessment and periodic sampling.

Artesian Conditions: There is a possibility that injection of water at bores in elevated terrain would induce artesian conditions in areas of lower terrain. This should be assessed by modelling the scheme and analysing the resulting aquifer water level with reference to topography.

Bore Construction: MAR bore design should prevent the vertical movement of groundwater and permanently confine the groundwater to the specific zone (or zones) in which it originally occurred (per NZS4411-2001). This can be achieved with inert PVC casing and a grout sealed annulus.

Recommendations

1. Construct a groundwater flow and solute transport model and use this to simulate injection at the Gisborne MAR Scheme. The aim is to:

    - Optimise bore spacing.
    - Locate bores to achieve maximum salinity and water level benefits.
    - Assess the risk of artesian conditions to 3rd party bores.

2. Establish agreed water quality criteria for operational injection. This should consider sampling frequency and limits for:

    - Turbidity, salinity and pH.
    - Pesticides and Nutrients.
    - E.coli.
    - Heavy metals.
    - PFAS and other emerging contaminants.
    - Hydrocarbons.

3. Ensure future bores comply with NZ construction standards, specifically to include cementing of the annulus to reduce inter-aquifer leakage.

Contents

List of Tables

1 Introduction

The following report provides results of an independent review of the Gisborne Managed Aquifer Recharge (MAR) Project. The Gisborne District Council (GDC) are considering the development of an operational MAR Scheme to alleviate declining groundwater levels and increasing salinity trends within the Makauri Aquifer, Poverty Bay Flats. Under the current configuration, surface water would be harvested from the Waipaoa River and injected into the confined Makauri Aquifer via a number of MAR bores. An initial injection volume in the order of 600,000 m^3/annum is envisaged.

1.1 Project Aims

The aim of the independent review is to:

- Provide an opinion as to whether the Gisborne Council should progress toward a full-scale MAR Scheme.
- Identify any key risks for the project that are not addressed by the work to date.

1.2 Scope of Work

Scope of work for the independent review was outlined in the Groundwater Science (GWS) proposal[1] dated 8th September 2020. Proposed tasks for the review are outlined in Table 1.1.

As the project progressed some additional tasks were added. These included:

- Review of headwork design and downhole pump configuration for the trial MAR bore. The intent was to identify areas that could be optimised for future MAR trials and active operations. The work was undertaken by GWS with input from Adelaide based pump contractor Total Water Resources (TWR)[2].
- Comparison of standards for bore construction in Australia and New Zealand. This task was undertaken to compare broad scale similarities and differences between the jurisdictions.
- Benchmarking of the Poverty Flats MAR Scheme against comparable MAR Schemes / Projects in Australia.

1.3 Content for Review

Reports for the review were accessed via the following link or provided directly by the GDC. Key reports reviewed for this Project are listed in Table 1.2.

https://www.gdc.govt.nz/managed-aquifer-recharge-reports/

[1] GDC-20-1-P0001

[2] TWR have undertaken significant pump and headwork installations at operational MAR Schemes on the Adelaide Plains, South Australia. They have significant experience trouble shooting and resolving pump / headwork related issues for MAR applications.

Table 1.1: Scope of Work for the Independent Review – Gisborne MAR Project.

Component	Review tasks
Geology and Hydrogeology, Source water options and availability	Geology including aquifer geometry, lithological properties and spatial variability
	Aquifer Hydraulics – Capacity to accept the planned injection rate and volume. Number of wells and well spacing to achieve target volumes.
	Aquifer volumetric storage capacity and potential to accept seasonal injection cycles, including risk of artesian conditions at 3rd party wells. Review of aquitard thicknesses to inform safe operating pressures.
	Review selected source water options – availability, quality and timing.
MAR Pilot Site	Drilling and well completion methods, geological and lithological interpretation.
	Test pumping design and set up
	Hydraulic analysis and interpretations from test pumping / short to long term injection trials.
	Evaluation of water quality and injectant breakthrough
	Geochemical, physical and biological clogging assessment and suitability of methods. Review assumptions that underpin risk evaluation and outcomes.
Reporting	Identify data gaps and residual risks for proceeding to a full-scale MAR Scheme.
	Provide assessment as to whether the proposed MAR Scheme is scientifically defensible and will achieve target outcomes.
	Preliminary assessment of bore field configuration, assumptions for seasonal harvest volumes and bore injection rates.
	Peer Review (internal)

Table 1.2: Reports reviewed to support this Project.

Year	Author	Title
1993	Barber, J.L.	Groundwater of the Poverty Bay Flats
2014	Haughey, R.	Overview of the potential for Managed Aquifer Recharge as a component for Freshwater Management in the Poverty Bay Flats.
2014	Golder	Poverty Bay Groundwater Management - MAR Feasibility Stage 1A - Conceptual Model
2014	Golder	MAR Feasibility Assessment and Goldsim Groundwater Management Tool (Stage 1B)
2015	Golder	Poverty Bay Managed Aquifer Recharge - Pilot Trial - Hydrogeology and Water Quality
2016	Golder	Poverty Bay Managed Aquifer Recharge - Pilot Trial Options Analysis
2017	Golder	Poverty Bay Managed Aquifer Recharge - Initial Injection Test
2017	Golder	Results 2017 Injection Trial - Poverty Bay Managed Aquifer Recharge Pilot Project
2020	Golder	Gisborne MAR Stage 2 Injection Trial - Monitoring Period 2018 - 2020
2020	Golder	Gisborne MAR Stage 3 Injection Trial - Interim Monitoring Report - August 2020
2020	Golder	Gisborne MAR Stage 3 Injection Trial - Interim Monitoring Report - December 2020
2020	Golder	Gisborne MAR Project - 2017 - 2020 Injection Trials

2 Results

The following section outlines results from the review following the format of Table 1.1. Key review comments are summarised followed by discussion.

2.1 Regional Geology and Hydrogeology – Makauri Aquifer

This component of the review was undertaken to assess the suitability of the geology and source water options for an operational MAR Scheme. We understand that the Makauri Aquifer was selected for MAR on the basis that:

- The resource is heavily utilised for groundwater extraction in the central portion of the Poverty Bay Flats. Groundwater levels have declined and recovery is not being achieved on a consistent basis during winter rest periods. The need to safe-guard the aquifer for future use is a key management requirement for GDC.
- The current water license allocations are not fully utilised. Pumping of full license allocations could result in further declines to the groundwater resource.
- Groundwater salinity is gradually increasing. This is understood to be occurring via through-flow of more saline groundwater from western and / or southern portions of the Poverty Bay Flats.

Based on the review it is apparent that:

- The Makauri Aquifer is regionally extensive and confined by a significant thickness of clays, silts and interbedded gravels. The aquifer has sufficient permeability[3] to support a full-scale MAR Scheme.
- The aquifer in the Central Poverty Bay Flats comprise gravel, pebbles and cobbles of alluvial origin. Some calcareous material (shells / limestone) has also been noted within bore logs and identified by x-ray diffraction analysis (XRD). The silt and clay content (as matrix to the gravels) is not specified in reports reviewed to date.
- Recharge to the aquifer is predominantly from the north where the aquifer outcrops. Recharge occurs via direct infiltration from the Waipaoa River. An assumed component of recharge is inferred to occur via basement on the eastern margins of the Basin.

2.1.1 Review comments – Geology and Hydrogeology.

Key reports were reviewed to understand the regional hydrogeology of the Poverty Bay Flats. Key review comments for consideration by Council are outlined in Table 2.1.

[3] Transmissivity.

Table 2.1: Key Review Comments on the Geology and Hydrogeology

Item	Attribute	Comment	Suitability for MAR	Recommendations / Implications for MAR
1	Aquifer Thickness, lithological properties and spatial variability	The Makauri Aquifer has been documented as continuous and regionally extensive across the Poverty Bay Flats. The thickest portion of aquifer is identified in the area to the north-east of the Pilot MAR Site (Barber, 1993).	✓	Subject to land access / logistics, construct future MAR Bores in thicker portions of the Makauri Aquifer. This will optimise bore yields and reduce construction risks with screen placement.
		Some uncertainty exists with respect to the extent of the Makauri Aquifer near the coast and offshore. At the Site of the MAR Scheme and to the north-east, this boundary condition is unlikely to materially impact goals of the MAR Scheme. However, it may result in water level rises in low lying regions, if a low permeability boundary exists near the coast. This could result in higher than expected pressure conditions at coastal locations which could result in or exacerbate artesian pressure conditions at 3rd party wells.	✓	Uncertainty / sensitivity analysis should be undertaken to assess the sensitivity of model predictions (i.e., predicted head rises) to the offshore boundary condition. This could have implications for head predictions and artesian extent.
		Regionally the Makauri Aquifer has been quantified as highly permeable, with transmissivities in the range of 300 to 2500 m^2/day. This is highly favourable for a 600 ML/annum MAR Scheme. For comparison, many MAR Schemes on the Adelaide Plains report transmissivities in the order of 80 to 250 m^2/day, with annual injection volumes ranging from 100,000 to 800,000 m^3 / annum per Scheme.	✓	Expansion of the Scheme will require groundwater modelling to confirm optimal bore spacing. This should consider both pressure level response, freshwater plume development and potential to generate artesian conditions. Groundwater modelling should also evaluate head build up via injection under pressure (i.e. injecting with head above ground at the injection bore). This would have the benefit of 'banking' water rapidly and has potential to reduce the number of MAR bores required.
		Golder (2020) recommends that additional exploration drilling be undertaken to fill data gaps in key areas. This will assist with inputs to the groundwater model for aquifer / aquitard geometry and sediment reactivity. This work may be beneficial in key locations, however may not be feasible due to cost implications.	to note	Golder to clarify areas with data poor / uncertain coverage which would benefit from drilling.

Item	Attribute	Comment	Suitability for MAR	Recommendations / Implications for MAR
2	Aquifer Hydraulics - capacity of aquifer to accept proposed injection volumes	Based on available data (drillers logs, description of the aquifer e.g. Barber, 1993; Golder - numerous reports) we understand that regionally the aquifer is highly permeable and transmissive. High transmissivity will enable relatively rapid transfer of aquifer pressure to key areas of interest.	✓	We agree that the aquifer is sufficiently permeable to receive the target injection volumes proposed for the project. Aquifers with a transmissivity in the order of 600 to 800 m^2/day will easily accept an annual injection volume of 600,000 m^3/annum provided operational issues such as clogging are managed to acceptable levels.
3	Aquifer Hydraulics - aquifer storage capacity	The Makauri Aquifer is confined by a significant thickness of silts and clays. In the future, Council may elect to inject under pressure (above ground and at higher flow rates than achieved to date) to bank water rapidly when source water is available.	To note	Whilst the depth to water is relatively shallow, the overlying aquitard is sufficiently thick and of low permeability. Injection under pressure[4] could increase flow volumes during the winter season enabling water to be stored more rapidly. This could reduce risk associated with quality of source water in the Waipaoa River, given its relatively high turbidity levels noted during winter. NOTE: this option would require additional assessments to inform safe operating pressures along with regional effects from groundwater level rise (i.e. potential for artesian conditions).
4	Aquifer Hydraulics - artesian conditions	To date, no assessment has been undertaken to evaluate potential for artesian conditions across the Poverty Bay Flats. Recharge via gravity will raise water levels at the local to regional scale which may result in 3rd party bores becoming artesian. The risk profile is likely to be more apparent where bores are located in topographically lower positions compared to the injection bores. Artesian pressure conditions **could** result in flowing bores where bores are not constructed to contain artesian pressures. This has the potential to damage 3rd party bores and supporting infrastructure (e.g. pump electricals, housing around bores). Under a best case scenario it could water log soils.	To note	Undertake groundwater modelling to predict pressure effects during full scale MAR. Evaluate susceptible areas that may become artesian. Assess what 3rd party bores may be present in the zone of artesian pressure (if any). Assess whether 3rd party bores have been pressure cemented (to avoid leakage outside the bore casing) and have appropriate headworks to contain artesian pressure (enclosed headworks). Consider implications of flowing wells including damage to infrastructure or waterlogging near the 3rd party bore.
				Subject to results from modelling, undertake a water bore survey to determine what 3rd party bores exist in areas of high artesian risk. Assess whether abandoned bores have potential to flow that have not been decommissioned. This should include discussion with the

[4] i.e. running injection pressures above ground.

Item	Attribute	Comment	Suitability for MAR	Recommendations / Implications for MAR
				landowner to understand previous bore histories (there may be no publicly available data for older water bores, including their locations).
				Subject to results from modelling, develop a groundwater monitoring program to detect and respond to artesian conditions. Monitoring should be undertaken to track the response of the aquifer during operational injection. The program could be used to pre-emptively cap / seal any 3rd party bores with open headworks (if trends indicate the bore may flow in the future). Any monitoring can be used for model calibration.
5	Ambient groundwater quality (salinity)	We understand that ambient groundwater in the Makauri Aquifer is generally fresh, however more saline groundwater is observed in the western and southern portions of the Poverty Bay Flats (Makauri Aquifer)	✓	Future locations and spacing for MAR bores should be optimised via groundwater modelling. This should consider water quality benefits by targeting locations on the fringe of the freshwater zone (nominally between the fresher and more saline portion of the Makauri Aquifer). Predictive outputs can be used to determine if the freshwater plume will reach the intended targets i.e. zone of high intensity use / cone of drawdown.
		Increasing salinity has been noted in bores targeting the Makauri Aquifer. The impact of this change has not been quantified with respect to the change in beneficial use of the aquifer. This is important when discussing EC benefits from the operational MAR Scheme. To date there has been no beneficial use target set for the Scheme.	To note	Consider what EC threshold is appropriate to conserve beneficial use values for existing horticulture. Undertake groundwater modelling (solute transport / plume tracking) to evaluate whether MAR will achieve the EC benefit set for the Project.
6	Aquitard Thickness and safe operating pressures	Review of geological logs indicates a significant thickness of overburden sediments and low permeability silt above the Makauri Aquifer. This is positive from a MAR potential as the injectant will remain confined within the target aquifer.	✓	Injectant likely to remain within confined Makauri Aquifer. Possible upward or downward leakage through aquitards but volumes likely low and not material to Project goals.
7	Source water quality	The existing MAR bore utilise an infiltration gallery adjacent to the Waipaoa River. We understand this results in turbidity fluctuations that coincide with River levels / flow rates.	to note	Consider extraction from the shallow aquifer further from the River. This could provide source water with lower turbidity that the existing gallery. A sampling program of existing shallow bores may be warranted prior to committing to drilling. This should include sampling for suspended

Item	Attribute	Comment	Suitability for MAR	Recommendations / Implications for MAR
				solids, turbidity and key analytes of interest (metals, pesticides, nutrients etc).
		Discussion surrounding source water chemistry (ecoli., emerging contaminants) should consider the end use of groundwater at 3rd party pumping centres. Ecoli is likely to breakdown with suitable residence time in the Makauri Aquifer, whilst emerging contaminants may only present an issue if water was utilised as a drinking water source. We understand that Makauri Aquifer water is predominantly used as an irrigation source across the Poverty Bay Flats. Low quantities of the above contaminants are unlikely to material impact 3rd party users on this assumption.	✓ / to note	Assess implications for emerging contaminants reaching 3rd party bores, should these be higher than background concentrations already in the aquifer. Will emerging contaminants change the beneficial use of the aquifer?
		The possible presence of PFAS and derivatives has not been documented in reports reviewed to date. This analyte is an 'emerging contaminant' linked to fire-fighting foams.	To note	Assess potential for PFAS contamination within the upstream catchment (Waipaoa River Catchment). Evaluate risk (if any) for operational injection. NOTE: we understand that sampling for PFAS & derivatives was undertaken during August and September 2020, with no detection. However, the risk profile from the upstream catchment has not been evaluated. A full catchment risk assessment would add benefit as part of Feasibility studies.
8	Bore Construction Methods - Regional	We understand that many bores across the Poverty Bay Flats have been constructed across multiple aquifers without pressure cementing i.e. isolating upper aquifers from lower aquifers via a pressure-grout seal. This may express as a management issue in the future as steel casing corrodes and the bores provide a pathway for water to move vertically (between aquifers). This could result in pressure loss in aquifers and potential migration of groundwater (for example upward leakage from the Makauri into the shallow aquifer, or vice versa).	To note	Future wells targeting multiple / confined aquifers should be pressure cemented to prevent inter-aquifer leakage.
				Consider a strategy for achieving driller compliance and reviewing drilling methodologies in the Gisborne Area.

Item	Attribute	Comment	Suitability for MAR	Recommendations / Implications for MAR
		The lack of a cement seal in 3rd party bores may result in pressure losses from the confined Makauri Aquifer into the overlying aquifers, particularly in areas where MAR is focussed.		Per above.

2.2 MAR Pilot Site

The following comments have been collated during review of the MAR pilot site, including review of drilling methodologies, test pumping design, hydraulic response, evaluation of water quality and hydrogeochemical data. Summary comments are provided as Table 2.2. Principal reports reviewed are from Golder over the period 2017 to 2020.

Table 2.2: Key Review Comments on the MAR Pilot Site.

Item	Attribute	Comment	Suitability for MAR	Recommendations / Implications for MAR
1	Drilling and Well Completion Methods, Lithological Properties	Insufficient information has been provided on the bore lithology for the Makauri Aquifer. Drillers logs and available reports describe the aquifer as containing 'gravels'. However, the particle size distribution of the target aquifer is not known other than general descriptions provided in drilling logs (e.g. Honnor Drilling as cited in Golder, 2017).	To note	Whilst screen design does not appear to impact bore performance or efficiency, future MAR bores should be supervised and logged by a hydrogeologist to quantify particle size distribution of the target aquifer. This will inform screen selection to maximise bore efficiency. Data on grain size distribution and should be incorporated into future drilling reports. i.e. silt and clay content, time taken to complete bore development.
		The location of the MAR pilot site appears to be a suitable location with respect to major pumping centres, transmissivity and groundwater salinity (on the fringe of the fresher and higher salinity parts of the aquifer). However, the aquifer thickness is only 2.5 m. Future MAR sites should target thicker portions of the aquifer to maximise injection flow rates.	✓	Target thicker portions of the Makauri Aquifer for future MAR bores. Ensure screen placement occurs through the most permeable part of the Makauri aquifer. Avoid placing screens across low permeability aquitards and / or carbonaceous material. This has potential to silt the bore and block screens.
		The method for the MAR bore construction has potential to allow vertical movement of water into non-target aquifers, due to steel casing being uncemented from ground surface to the top of the aquifer. A number of design aspects can be improved for future bore construction. The adjacent comments are considered as minimum bore construction requirements.	✘	Pressure cementing of the casing annulus to prevent inter-aquifer leakage. The steel surface control casing was not pressure cemented, nor the PVC liner which was backfilled with pea gravel.
				The basis for the screen selection was not outlined in the drilling report (Golder, 2017). For future MAR bores it is recommended to undertake particle size analysis with the screen matched to aquifer grain size. Screen aperture should be selected using the concept of '60% passing' to optimise bore efficiency. This may require airlift development for an extended time period (30-40 hours) to purge fine grains silts / clays once the screen has been inserted.

Item	Attribute	Comment	Suitability for MAR	Recommendations / Implications for MAR
				Whilst the tender clarification process (emails between Golder, Honnor Drilling, GDC dated 24th Sept 2017) outline the basis and clarification for bore construction, the driving of steel casing does not consider long term impacts to the resource. Steel casing will eventually rust and in this case, could result in mixing between aquifers that is not intended. The Steel also provides a potential source of incompatible materials in proximity to pump equipment. This may be the source of iron deposition as noted on the bore pump / screens per recent MAR trials. Construction and pressure cementing with inert PVC is recommended.
			To note	Where possible, conduct geophysical logging to confirm the exact depth interval / properties of the aquifer (gamma, neutron, induction, resistivity, caliper). This can optimise screen placement for deeper MAR bores.
2		The MAR Pilot bore was backfilled with bentonite and gravel to isolate the Makauri Aquifer from the lower sand unit.	✗	Whilst there is no evidence for bentonite failure, future backfill across multiple confined aquifers should occur via the setting of a cement plug to eliminate thief zones, prevent inter aquifer leakage and prevent unintended pressurization of non-target aquifers.
3	Test Pumping Design and Setup	Step discharge tests / specific capacity	✓	Step discharge testing and evaluation of specific capacity is a suitable method to evaluate impacts from potential clogging.
		Constant rate discharge test analysis: A uniform aquifer thickness of 3 m was applied to calculate the hydraulic conductivity of the nearby monitoring bores (Golder, 2017, Appendix B). It is not clear whether this thickness was adopted from lithology logs of nearby monitoring bores or adopted as an assumption. For example, if the aquifer thickness was 6 m, the calculated hydraulic conductivity would be half.	to check	Check basis / assumption for aquifer thickness at nearby monitoring bores. Clarify and assess implications, if any.

Item	Attribute	Comment	Suitability for MAR	Recommendations / Implications for MAR
	Injection Tests	Specific capacity analysis: the Golder Trial Reports (2019, 2020) indicate that physical clogging is the primary mechanism for the specific capacity reduction. Figure 19 of Golder (2020, 22/12/2020) indicates that specific capacity stabilised during the late-stage trial period in September and October 2019. Is there potential mechanism for this stabilisation?	For assessment	It is not clear whether the stabilised trend is reflective of the system approaching 'steady state' or whether further SC declines are likely during extended injection periods (months). Some uncertainty exists on long term performance and clogging of the aquifer (particularly at distance from the bore screen).
4	Evaluation of water quality and injectant breakthrough	Field results demonstrate that solute is transferred rapidly from the injection bore with breakthrough of injectant detected at nearby observation bores (Golder, 2020). This has positive implications for salinity improvement of the aquifer.	✓	Rapid displacement of ambient groundwater will produce rapid reduction in aquifer salinity, a key goal of the Gisborne MAR Scheme.
		The aquifer is completed in a relatively thin portion of the Makauri Aquifer (2.5 m thick) which results in rapid displacement of ambient groundwater. Qualitatively, a thicker Makauri aquifer will take longer to displace ambient groundwater. This may result in longer lead in time before salinity benefits are realised in thicker portions of the aquifer.	to note	Via groundwater modelling, assess freshwater plume development and sensitivity of aquifer thickness to EC benefit. Undertake groundwater modelling to optimise bore placement for future MAR sites, considering all factors (EC benefit, pressure benefit, logistical aspects, environmental aspects, proximity and supply of source water).

5	Geochemical, physical and biological clogging	The chief cause of clogging is attributed to particulate matter from source water turbidity. If this is the primary mechanism for clogging (SC reduction), then particulate matter will accumulate in the aquifer near to the bore screen during ongoing injection.	to note	Physical clogging can be further managed by:
				
				• Source turbidity control:
				  ○ Intake further from the River from a suitability designed bore.
				  ○ Filtration matched to particle size distribution of source water.
				  ○ Alternative water source with lower turbidity.
				
				• Backflushing
				  ○ More frequent

Item	Attribute	Comment	Suitability for MAR	Recommendations / Implications for MAR
				○ Backflushing rate to occur at a rate higher than injection (ideally 2 x the injection rate)
		Pumping rate during backflushing should be higher than the injection rate.	to note	It is understood that backflushing occurs at rates that approximate the average injection rate (~15 L/s). Backflushing should ideally occur at 2 x the injection rate. This will assist with agitating the formation and removal of fines, particularly at pump start up. The frequency and period of backflushing should be evaluated on a site by site basis and include an evaluation of turbidity during the backflush phase.
		Iron has been noted on the pump during the non-injection periods (pump idle phase - Golder, 2020), however it is not clear whether this material has also accumulated during active MAR injection.	to note / confirm	Iron accumulation provides indication of galvanic processes from stray charge. This could occur from various on-ground sources including electric fences, generators or other machinery with direct current. It is recommended to assess whether any of these sources can be eliminated prior to a 2021 trial.
				Consider the placement of a zinc anode (sacrificial anode) downhole to assess corrosion potential and avoid iron accumulation on the pump / screen. Additionally, the steel surface control casing could be a source of incompatible metals. Future MAR bores should utilise inert materials for casing materials (e.g. PVC).
		The lack of pyrite in bore cuttings indicates that mobilising of heavy metals is relatively low risk under an operational MAR Scheme.	✓	To note

2.3 Headwork Design – Existing MAR Bore.

The following general comments have been made during an assessment of headwork designs for the existing MAR bore. This review is not exhaustive and could benefit from a detailed site visit / inspection from a specialist MAR contractor i.e. pump contractor who specialises in MAR.

Table 2.3: Review comments on headwork design.

Attribute	Comment	Suitability for MAR	Recommendations / Implications for future MAR
Well headwork design	The well headwork design could be improved for future MAR bores. Significant bends in the pipework and inline componentry (e.g. gate values) have potential to introduce turbulence to the injectant after sourcing from the gallery.	To note / consider	Future headworks should to be simplified to optimise laminar flow. Bends should be 45 degrees not 90 degrees.
			Consider by-passing filters during the 2021 injection trial to assess effects. Assess whether filter turbulence has potential to reduce bore efficiency.
			Optimise future headwork designs using examples from successful MAR Schemes.
Backflush / Scour Cycle	Backflushing of the bore should occur at a higher flow rate than the injection flow rate. This will assist in removing introduced turbidity within the Makauri gravels.	to note	Ensure that pumping rate during backflush cycle is higher than the injection rate. Target is to pump at 2 x the injection rate. Specification for downhole pumps to consider flow rate requirement for backflushing.
Running of the pump	The electric pump should be operated on a regular basis to keep the motor dry, whilst rotation of the motor forces lubricant through the seals maintaining their integrity. This may also assist clearing iron precipitation if this remains a problem (per recommendation in Golder, 2020).	to note	Operate the pump on a regular basis to prevent long term damage. Weekly for 10 mins or monthly for 20 mins particularly during non-injection / idle phases.
Downhole componentry - pressure ratings	The downhole componentry should be pressure rated to eliminate leakage into electrical componentry. Situations have known to occur where leakage into the electrical cable has resulted in water seeping into cables, up through the bore and into the electrical control box (at the ground surface - M. Pulford, pers comm., 2020). This would be particularly critical for injection under pressure (injection under artesian conditions).	to note	Consider operational bore pressures and ensure downhole componentry is pressure rate / fit for purpose. This will reduce potential infrastructure / electrical damage during operational injection.

Attribute	Comment	Suitability for MAR	Recommendations / Implications for future MAR
Downhole componentry - incompatible elements	Future injection lines should consider the use of layflat / crusader hose to reduce the potential for incompatible elements within the borehole. The injection line should be placed a suitable distance below the water table (>5 m) to avoid cascading of injectant (per current practise – Golder, 2019).	to note	Evaluate and agree on preferred downhole componentry for future MAR bores. This will optimise infrastructure spending and avoid costly retrofitting which has been a common problem with MAR in Australia.
Surface componentry - stray charge	Galvanic / electrical processes can occur due to source of stray charge in proximity to the MAR bore. This may explain the potential iron deposition on the pump and bore screen.	to assess	Assess what electrical sources are near to site that could provide a source of stray charge (generators, electric fences etc). Where possible mitigate / eliminate.
		to consider	Consider cathodic protection via the use of a sacrificial anode (zinc anode). This may eliminate preferential corrosion of MAR bore componentry. To consider implementing for the 2021 trial.

2.4 Bore Consent Conditions

A review of Bore Consent conditions was undertaken to compare standard bore construction practises between New Zealand with Australia. The purpose of the work was to:

- Assess potential differences between the jurisdictions with respect to bore construction and permitting requirements.
- Evaluate the level of detail stipulated in minimum bore construction / drilling standards.
- Assess the practical outworking and effectiveness of bore consent conditions with respect to compliance.
- Provide learnings for future bore construction in the Gisborne Area.

A general comparison between the two jurisdictions is presented as Table 2.4. Key differences noted include the following:

- Australian water bore licenses stipulate the Class of permit / Drillers License for drilling of a borehole. This automatically determines the minimum standards to be implemented for completion of the hole. For example, a Class 2 construction permit requires cementing of the bore annulus to separate overlying and underlying aquifers (confined conditions). This requirement ensures that the supervising driller has adequate competency to separate aquifers.
- Compliance with permit conditions is actively enforced in most Australian jurisdictions with dedicated Drilling Inspectors. This ensures that drillers are held accountable for bore construction practises. Typically the Drilling Inspection requires notification at the commencement of drilling. They can then plan to be on-site during key construction stages.
- Minimum bore construction methods in Australia have been developed by the Industry and Regulators as a National initiative between the States. The standards build on learnings from water bore drilling over the past ~100 years. The Minimum Bore Construction Standards are regularly updated (currently in 4th Edition).
- Implications for leaking bores in Australia is well understood, particularly given that many overlying aquifers in Australia are saline with large implications for failed bores (saline aquifers have and do contaminate freshwater aquifers). Decommissioning programs have been implemented at considerable cost by the Commonwealth and State Governments, for example, the Great Artesian Basin Sustainability Initiative (GABSI). This initiative has been ongoing for the past ~20 years to cap, seal and decommission flowing bores in Central Australia.
- In Australia, when bores are constructed a completion report is submitted to the relevant State Government. Submitted information is standardised and most jurisdictions have public databases housing borehole information. This data public and available on-line.

As a general summary, Australian standards are more detailed and prescriptive, with significant implications for non-compliance. Compliance is enforced by suitability trained / experienced officers who are familiar with / have worked in the drilling industry. Drilling data (for both construction and decommissioning) is submitted to Government Agencies for upload to the State's online databases.

Whilst New Zealand standards have comparable goals, there does not appear to be a technically based compliance mechanism to validate that bores have been constructed to appropriate standards. This leaves construction methods and compliance in the hands of the driller. Additionally, from information reviewed there is no reference to Drillers Licenses or Drillers Competency required for construction in complex, multiple aquifer systems. It is not clear how drillers demonstrate:

1) They understand their obligations with respect to minimum construction standards and separation of aquifers.

2) Have suitable competency and training to achieve compliance.

3) Understand the short and long term implications of material selection, including the potential for casing to fail (corrode) resulting in inter-aquifer leakage.

Table 2.4: General comparisons between Australian and New Zealand Bore Consent Standards (focus on South Australia and Gisborne examples).

Item	South Australia / Australia	Gisborne Region / New Zealand
Drilling report required post drilling?	Standard bore completion report to be supplied by the driller outlining bore lithology and construction details, including depth to water, salinity, casing depth / diameter and cementing details. Required for new bores and decommissioning / backfilling of existing bores. This information is publicly available via online databases.	Yes, bore log required for submission to Council including lithology, construction methods and materials. NZS4411 outlines that 'A properly completed New Zealand Water Bore Data Form also needs submitting' once the bore has been constructed. Access to bore data at request of the Council – not currently available online.
Drilling Specification	Drilling to be in accordance with General Specification for Well Drilling Operations (South Australia). This follows the minimum construction requirements for water bores in Australia and is a prescriptive document. Local States also issue site specific consent conditions as required by local water allocation / sharing plans. Significant fines for non-compliance.	Drilling to follow New Zealand bore construction standards (NZS4411). These standards while suitable, are not explicit or prescriptive compared to the Australian Bore Construction Standards / Specifications.
Water samples required?	Yes, at intersection of each water cut and at the end of drilling. SA Government analyse for salinity and pH. Laboratory Testing not required for submission post drilling.	Yes, two samples required. Samples must be analysed for hydro-chemical suite and test at a laboratory.
Strata samples required?	Typically no, but yes if drilling in a data poor area and specifically requested on the bore consent / permit.	Subject to Council request.
Well data included on database for online access?	Yes, each State have their own water bore database available on-line. A National water bore database is also available ((Australian Groundwater Explorer) however this has less detail than local databases. See relevant examples per links below. https://www.waterconnect.sa.gov.au/Systems/GD/Pages/Default.aspx http://www.bom.gov.au/water/groundwater/explorer/map.shtml	Data available upon request from GDC. Local weblink is available, however website is preliminary. http://hilltop.gdc.govt.nz/data.hts?Service=WFS&Request=GetFeature&TypeName=BoreReferenceData

Item	South Australia / Australia	Gisborne Region / New Zealand
Bore / Drilling Consent Required	Yes, well construction permit / works license required before drilling can commence. Driller must sight permit before commencing work. Heavy fines for non-compliance.	Yes, bore consent required for drilling of any new bore. Must be available for inspection by GDC. No bore consent required for bore decommissioning. Council does not get information on what has been abandoned / decommissioned.
Requirement to separate aquifers?	Yes, in multiple aquifers or confined conditions. This is mandated as a condition of the permit. Also, the Minimum Water Bore Construction requirements state that: *All aquifers and permeable zones, other than the intended production zone, should be adequately cemented off to prevent interconnection or wastage between zones of differing pressure or water quality. Cementing should be from bottom upwards in a continuous process (p.g. 76, MCRWBA).* Practically the above is managed via Licensing Drillers to ensure they have set competencies for operating in specific hydrogeological conditions. For example, Class 1 drillers are only licensed to drill in single aquifers and do not have demonstrated competency in pressure grouting. Class 2 drillers have demonstrated competency drilling and sealing boreholes in multiple aquifer environments. They licensed to drill both Class 1 and Class 2 drillholes.	Yes, bore consent conditions state the following: '*The construction of the bore shall not allow the leakage of water from one water bearing formation to another. In practice this will mean that some form of grouting will be required to prevent water leakage between water bearing layers at different levels'.* '*When conditions become sub-artesian in some deeper aquifers the possibility exists that water may leak from the higher aquifers into the lower aquifers. Suitable grouting shall be performed to prevent this possibility. In practice these requirements will mean that grouting must be performed from the confining layer immediately above the water bearing layer which is being tapped up to ground surface'.* Compliance for bore construction is undertaken by GDC Officers, not a Drilling Inspector (P. Hancock, pers comm., 2021). They may or may not have the relevant experience to judge a suitable bore completion / technique.
Grouting Requirements in Artesian conditions	Yes, if a Class 3 permit is issued, the Driller must have a license consistent with a Class 2 License, but with a high pressure / temperature endorsement for operating in artesian conditions. Aquifers must be pressure cemented to prevent artesian flows and seepage losses. Headworks need to be sealed (closed in) to prevent leakage at the headworks.	*In artesian conditions suitable grouting shall be performed to prevent water leakage between geological formations. Water leakage between water bearing formations is not acceptable'.*
Bore Inspection during grouting / construction ?	Yes, specified in the permit to notify the Drilling Inspector 24 hrs prior to drilling.	Yes, Council to be given 24 hours' notice prior to construction of the bore. They may send a representative to inspect.
Disinfection of the bore ?	*Drilling equipment that has been used should be disinfected to prevent the transfer of microbiological organisms (bacteria) between sites.*	Disinfectant must be added to the bore post drilling, to prevent iron bacteria contamination from drilling rods, equipment etc.

Item	South Australia / Australia	Gisborne Region / New Zealand
	AND: *All water supply bores should be disinfected.*	Also: '*Drilling equipment shall be sufficiently clean to prevent adverse effects on groundwater quality*' (NZS4411 - 2001).
Bore abandonment / decommissioning	Chapter 18 of Minimum Construction Requirements for Water Bores in Australia: *'Failed or unwanted bores should be decommissioned to restore, as far as possible, the aquifer isolation that existed before the bore was drilled and constructed'.* *AND* *'Decommissioning by fully grouting from the bottom of the bore to the surface is the preferred method for all bores. The original construction of the bore should be considered and the need to seal the annular space via perforating the casing and grouting'.*	Bores are to be grouted with cement using a 'suitable method'. Cementing to occur from the base of the bore to within 1.5 m of the ground surface. NZS4411-2001 states: '*Decommissioned holes and bores intersecting groundwater shall be sealed to prevent the vertical movement of groundwater, and to permanently confine the groundwater to the specific zone (or zones) in which it originally occurred.'*
Tiering of drillers licenses	*The bore shall be constructed by a suitably qualified driller who possesses the appropriate experience and the relevant class of licence that the state or territory deem necessary (Minimum Construction Requirements for Water Bores in Australia, Edition 4).*	Not specified in any consent or standard
	Individual drillers are licensed, not the drilling company.	
	Detailed requirements for driller licenses outlined in Chapter 2 & Chapter 4 of Minimum Construction Requirements for Water Bores in Australia. The Class of license allows them to drill in specific aquifer types which automatically stipulates the type of bore to be drilled (open annulus in Class 1 or pressure cemented / tremmie cemented in Class 2 & 3).	
Pumping Test Required ?	No, not a legislative requirement. However, may be required to support a license or mining lease application in areas very close to existing bore users.	Yes, mandated as part of Bore Construction Requirements (Appendix H21). Bore construction schedule requests pumping test to quantify transmissivity, aquifer storage and where possible bore efficiency. Specifies the type of pumping test to be conducted (constant rate, step test) and bores to be monitored. Constant rate tests require bores to be pumped at or greater than the rate of operational pumping. Recovery data post pumping also required.

Item	South Australia / Australia	Gisborne Region / New Zealand
Pumping test report required		Yes. Detail is specified in the Bore Construction Requirements. Council to endorse methodology and require notification. Also: *'If the bore is to be used for purposes that require a water right to be issued, a pump test shall be carried out that meets the requirements of the Council's pumping test specifications'.*
Metering required?	Yes, licensed water use requires metering and submission of an annual meter read. Specifications are outlined in the *South Australian Licensed Water Use Metering Specification (DEW, 2019).*	Yes, specifications outlined in Appendix H21. Meter must be installed per manufacturing recommendations. "*Pipe to remain full at all times*".

2.5 Other Review Comments – Editorial

The following comments could assist future interpretation of pressure responses and trends.

Item	General comments to improve readability and data interpretation	Recommendation
1	Golder graph water level response as m RL (with respect to sea level). Whilst useful for comparing between individual bores, plotting as depth to water would illustrate where groundwater level resides with respect to ground surface. This can be more informative with respect to evaluating pressure related risks and the potential for artesian conditions during operational injection.	Show ground surface level on water level graphs to enable assessment of potential for artesian conditions.

2.6 Benchmarking the Poverty Flats MAR Scheme against Other MAR examples

A benchmarking exercise was undertaken to compare the Gisborne MAR Scheme against similar examples from Australia. Seven MAR Schemes in Australia were selected that have been evaluated extensively or have been actively operating for the past 5-10 years. Each MAR Scheme was reviewed to highlight key aquifer attributes and the strengths and limitations. Results of the comparison are provided as Table 2.5.

The Australian examples include those from water utilities, councils, mining and private operators. Most schemes harvest stormwater from a combination of rural and urban catchments and have design volumes in the order of 100,000 - 800,000 m^3/annum. Their need for construction was variable and included:

- Reduce reliance on mains water which is expensive ($3.24/$m^3$) and subject to water restrictions during drought.
- Improve the water quality of native groundwater for use in irrigation.
- Provide a back-up drinking water supply in times of drought / bushfires. The latter rendered surface water untreatable due to river fouling.
- Disposal of surplus mine water extracted from dewatering.

It should also be noted that funding for a number of Council / Private MAR Schemes benefited from significant Federal Funding during 2008-2012 i.e. Australian Government funding. This was a response to extensive drought in south-eastern Australia (Millennium Drought).

Comparison against Gisborne MAR Scheme

When comparing the Gisborne MAR Scheme with selected Australian examples it is apparent that:

- The Gisborne MAR Scheme has very high transmissivity (600-800 m^2/day) when compared to most other Australian MAR Schemes. Operational Schemes in Australia generally report transmissivity in the order of 50 to 250 m^2/day.
- Source water is readily available from the Waipaoa River. Some urban MAR Schemes in South Australia suffer from unreliable stream flow, especially in lower rainfall years when runoff is reduced.
- Some Australian examples have treatment wetlands to reduce turbidity prior to injection.
- Most Australian MAR Schemes inject under pressure at 10 to 65 m above ground. An exception is the Mitchell River MAR Scheme in eastern Victoria. This Scheme is limited to gravity injection only due to proximity of nearby 3rd party bores.
- Some schemes have had problems with flowing bores (urban Adelaide). This has been addressed by progressive capping / backfilling of bores as required by the Risk Management Plans. MAR proponents have generally borne the cost on behalf of the landowner.
- In some cases clogging and reduced injection performance was hampered by bore design and construction methods. This included standardised screens (not matching screens to aquifer particle size analysis), incomplete or poor cementing of the bore annulus and bores not being adequately developed (to purge residual drilling muds and fine grained material).

Table 2.5: Key Attributes of Various MAR Schemes in Australia and Comparison with the Gisborne MAR Scheme.

Scheme Name	Operated By	Reason for MAR Scheme	MAR Design Target (m^3/annum)	Source Water / Catchment	Aquifer Type	Date of Construction	Still Operating?	Aquifer Transmissivity (m^2/day)	Static water level (m bgl)	Turbidity Limit (NTU)	Injection under pressure?	Key strengths	Operational Constraints	Reference
Gisborne MAR Scheme	Gisborne District Council	Offset rising salinity. Increase pressure levels across Poverty Flats.	600,000 (minimum)	Waipaoa River – semi-rural catchment	Gravel, confined (Makauri Aquifer)	2017 - in progress	Feasibility phase	600-800; higher in other portions of the Makauri Aquifer	~6	Nominally < 5; to be confirmed	No, gravity	Very permeable aquifer	Turbidity is relatively high in Waipaoa River.	Various Golder and Gisborne District Council Reports
												Reliable water flows in Waipaoa River	Timing of extraction must occur when flow > 4000 m3/day	
												Rapid development of freshwater plume observed during MAR trials	MAR bore design could be optimised to improve performance. Some corrosion noted during MAR trials	
Mitchell River ASR Scheme, Victoria, Australia	East Gippsland Water	Bore field originally constructed as an emergency water supply in response to bushfires in upper catchments. This blackened the Mitchell River for an extended period. Post 2008 bore field converted to a MAR Scheme for drinking supply purpose.	Initially 200,000 Planned 500,000	Mitchell River - National park and farmland catchments	Confined Gravel & Sand Aquifer, Overlain by alluvial clays	2008	Yes	80-200	10	10	No, via gravity. Licensing conditions / 3rd party bores prevent injection under pressure.	Injection of good quality water available from Mitchell River. Enables banking of MAR water for use during low River flows or emergency situations (drains the Victorian High Country which is prone to bushfires which reduce River water quality)	Screens not matched to particle size analysis - bore efficiency could be improved.	AGT, (2015)
												Permeable gravel aquifer. Bores yield at 10 to 20 L/s.	Pumps and headworks designed for pumping bores, not MAR. Pump and headwork infrastructure needs optimising. E.g.. Pumps run off curve at start up; original design did not have scouring (backflush line) to purge entrained silts / fine sand.	
												Native groundwater quality is low (200 to 700 mg/L). Good recovery efficiency.	Very close to 3rd party wells - tight licensing restrictions makes injection under pressure un-feasible. Tight limits on timing of pumping and drawdown - no more than 10% drawdown at existing 3rd party wells	
													Clogging noted from suspended solids and bacterial growth, resulting in a reduction in specific capacity. Airlifting has improved performance.	
Oaklands Park MAR Scheme	City of Marion	Augment water supply for Council. Used for irrigation of Council parks and ovals, sold to 3rd parties for secondary uses (not drinking water)	500,000 (Phase 1); 700,000 (Phase 2)	Sturt River - combination of rural and urban catchments	Limestone and calcareous sand, confined by 45 m thick clays	2011-2014	Yes	100-250	12	20	Yes, up to 28 m above ground. Occurs via 4 MAR bores in close proximity (200 m apart)	Source water is reliable and of good quality during low to moderate flow. Becomes more turbid during storm events (high flows)	Operates in close proximity to two other MAR Schemes. Cumulative impacts have resulted in artesian pressure conditions and flowing bores. Council and nearby operators have paid to backfill or install headworks on approx. 8-10 bores.	Groundwater Science (2018)
												Purpose built wetland effective at removing turbidity via vegetation (natural filtering).	Some bores have flowed that were not on Government databases.	
												Native groundwater is fresh to brackish (800- 1400 mg/L). Recovered water suitable for irrigation of parks and ovals.	Some pH issues immediately post wetland construction, now resolved.	

Scheme Name	Operated By	Reason for MAR Scheme	MAR Design Target (m^3/annum)	Source Water / Catchment	Aquifer Type	Date of Construction	Still Operating?	Aquifer Transmissivity (m^2/day)	Static water level (m bgl)	Turbidity Limit (NTU)	Injection under pressure?	Key strengths	Operational Constraints	Reference
Morphettville Racecourse ASR Scheme	South Australian Jockey Club	Improve water quality of native groundwater (brackish aquifer), make suitable for irrigation of racecourse grounds.	300,000	Sturt River - combination of rural and urban catchments	Limestone and calcareous sand, confined by 30 m thick clays	2003	Yes	200-500	10	20	Yes, 10-15 m above ground	Purpose built wetland effective at removing turbidity via vegetation. Two bores consistently inject 150-180 ML/annum Native groundwater is brackish (1400-1800 mg/L) - freshwater plume has developed over past 15 years resulting in recovered water suitable for intended use. Supplies most of racecourse irrigation needs. Reduces soil sodicity. Simple engineering design, low maintenance bore field.	Operates in close proximity to two other MAR Schemes. Cumulative impacts have resulted in artesian pressure conditions and flowing bores. Council and nearby operators have paid to backfill or install headworks on approx. 8-10 bores.	Groundwater Science (2020)
Glenelg Golf Club ASR Scheme	Glenelg Golf Club	Improve water quality of native groundwater. Recovered water used for turf irrigation	~250,000	Urban Stormwater	Limestone, calcareous sandstone, confined by ~70 m of stiff clay.	~2010	Yes	35-50	1-7 m	20	Yes, max operating limit 65 m above ground	Simple design - treatment wetlands are effective at reducing turbidity. Consistently achieve 80-200 ML/annum via 3 MAR bores. Has created freshwater plume around injection bores, resulting in efficient recovery of low salinity water.	Headworks are aging, not maintained efficiently and have corroded. Requires operating budget. Scheme constructed with assistance from Federal Funding. Funding no longer available for bore maintenance. SCADA system not user friendly, difficult to extract and interpret data. Requires updating. One MAR well has recently failed due to production of sand. Destroyed a pump. Replacement of bore very expensive > 100,000 AUD inc pumps.	AGT (2005; AGT (2007). Groundwater Science (2020).
Linde Reserve ASR Scheme	City of Payneham, Norwood, St Peters	Augment water supply for parks and ovals	30,000 (small scale Scheme)	Stormwater - 2nd Creek	Fractured Rock, confined by 40 m clays	~2014	Yes	8	13	20	Yes, 50-65 m above ground	Recovered water is suitable quality for intended use Aquifer is confined - limited impacts to 3rd parties to date	MAR Scheme heavily engineered, faults consistently reported with scheme tripping out during injection season. Many call outs from 3rd party contractors. High turbidity in catchment due to upstream industrial use. Reduces available source water during rainfall events. Aquifer is low transmissivity and has high pressure build up during injection. Small scheme, marginally to sub-economic. Limited by aquifer capacity and poor source water quality.	AGT, 2010; AGT, 2014; EPA Licence 32664 (2017)
Company 1	Confidential	Inject surplus water captured from mining	Long term injection trial (> 6 months)	Tertiary Sand Aquifer, Confined	Tertiary Sand Aquifer, confined by ~10 m of clay	2014	No	20-1000 (dependent on zone targeted)	~20	NA - Trial stage	Yes, however trial terminated early due to clogging / casing leakage	High yield potentially available due to coarse nature of sands	Trial terminated early due to surface expression of water and concentric circles noted around bore headworks / plinths. Indicates upward leakage for bore annulus.	Confidential

Scheme Name	Operated By	Reason for MAR Scheme	MAR Design Target (m^3/annum)	Source Water / Catchment	Aquifer Type	Date of Construction	Still Operating?	Aquifer Transmissivity (m^2/day)	Static water level (m bgl)	Turbidity Limit (NTU)	Injection under pressure?	Key strengths	Operational Constraints	Reference
													Bore design not suited to MAR - applied conventional production bore methods. Tremie cementing did not result in adequate annulus seal outside of casing. Inadequate bore development resulted in low specific capacity in bores Threaded casing resulted in leaks through the casing screws. Injection line did not extend below the water table, resulting in cascading and a loss of bore efficiency. Iron bacteria development through the injection trial Screen apertures were selected at a uniform size, not specific to aquifer lithology. Bores not pressure tested to confirming casing integrity and ability to withstand injection pressures.	
Byards Road	City of Onkaparinga	Recycle stormwater for on-selling and use in parks and ovals	800,000	Stormwater from surrounding semi-rural / urban catchment	Fractured rock, semi-confined	2012	inefficiently - currently offline. Maximum volume achieved of ~50,000,^{3}/annum. Well below design target.	10	2 to 5	20	Yes, initially planned at 60 m above ground	Designed as part of a broader recycled water distribution network	Source water from catchment unreliable and turbid. Insufficient volume to meet design targets Carp in treatment wetland increases turbidity Interconnection with shallow aquifer. Surface expression of water during operational injection. Limits potential volumes. Low hydraulic conductivity of aquifer. Injection method relies on very high injection pressures that are not compatible with aquifer capacity. . Incompatible elements in downhole infrastructure - corrosion of downhole equipment and pumps. Scheme currently off-line. Very expensive (>$1M AUD) with little return.	EPA Licence 42362 (2019) City of Onkaparinga Tender Brief (2018)

3 Discussion

This review has been commissioned to evaluate information presented from existing MAR Trials and to assess the suitability of MAR on the Poverty Bay Flats. Specifically, the review has been undertaken to:

- Assess whether the Makauri Aquifer is a suitable target for an operational MAR Scheme.
- Assess whether the proposed method of injection (circa 600,000 m^3 per annum, injected during winter over multiple injection bores) is likely to meet expectations of the GDC, specifically, to alleviate groundwater declines and to improve salinity.
- Outline residual risks and data gaps not identified / addressed by studies to date.

Further discussion on specific areas is presented as follows.

3.1 Regional Geology, Hydrogeology and Water Quality

3.1.1 Geology and Hydrogeology

The Poverty Bay Flats has been described as a sedimentary aquifer system surrounded to the north, east and west by older basement rocks. The aquifer systems are complex and at the local scale variable, but in general understood reasonably well due to a large number of boreholes constructed in the region.

Reviews to date indicate that the Makauri Aquifer is confined, fresh to brackish in quality and overlain by a significant thickness of overburden sediments. With respect to aquifer characteristics the following is beneficial for MAR:

- The permeability of the aquifer (hydraulic conductivity) is high which supports a rapid transfer of pressure away from the bore. This indicates that large scale injection could occur over a winter injection period.
- The aquifer is confined by a suitable thickness of silts and clays. This indicates that injection could occur under pressure compared to the gravity method currently employed.
- Aquifer geochemistry indicates that the rock is silica +- limestone based, with few sulphides noted in drilling logs. High risk minerals have not been identified that could release heavy metals due to aeration with MAR water. Main geochemical reactions noted include cation exchange and iron precipitation on pumping equipment. The latter is interpreted to result from stray charge with the driving mechanism yet to be eliminated.
- Solute migrates rapidly from the MAR bore with potential to reach 3rd party users relatively quickly. This supports the notion that EC benefits will be realised due full scale implementation.

In summary, based on geology the aquifer appears to be a suitable target for MAR. Uncertainty that exists with respect to the geology / hydrogeology includes the following:

- The coastal boundary condition is poorly constrained with respect to the continuation of the Makauri Aquifer offshore. The positioning of this boundary may have an implication for regional groundwater levels and artesian extent resulting from MAR. This uncertainty should be addressed during future model construction.
- The silt and clay content of the Makauri Aquifer is poorly documented. Work reviewed to date (mainly drillers logs) describes the formation as ‘gravels, sand, shingle’. No information is presented to determine the particle distribution and overall silt / clay content. This has implications for screen design and rectification of clogging related issues i.e. injection into sand / gravel with a high silt content may be more difficult to rectify via backflushing / airlifting, compared to a gravel or sand that is ‘clean’ i.e. low silt / clay content.

- Aquifer thickness variations over the short to medium distance. It is not clear whether the thickness is predictable with respect to MAR bore placement, and hence, whether an exploration program would be required to support future bore siting. Given the relatively low cost with respect to MAR infrastructure, a pilot drilling program is recommended prior to construction of MAR bores. Results could be used to for multiple purposes including:

  1) Confirmation of aquifer thickness.

  2) Obtain representative samples for future screen designs.

  3) Provide aquifer geometry data for the groundwater model.

  Any pilot bores can be completed as observation bores for use in future MAR.

- The depth to water across the region has not been presented. Whilst the focus has been interpreting groundwater flow direction (with respect to a common datum) and water level rises between MAR / observation bores, presenting depth to water can assist identifying areas that are or may become artesian. This will help to prioritise areas with higher risk from flowing bores, should a full MAR Scheme be implemented.

- It is not clear how many 3rd party bores exist in the Region. Implementation of MAR will result in water levels rising. This could result in artesian pressure conditions over a wide area and result in flowing bores that do not have headworks to contain artesian pressures. This could result in waterlogging of soils, damage to equipment and as a worst case flooding of property (houses, sheds, land, commercial properties).

The above aspects need to be addressed via:

1) Groundwater modelling to predict pressure impacts under preferred MAR layouts.

2) Prediction of the artesian extent and number of 3rd party bores within the artesian extent.

3) If required, water bore surveys and landowner interviews to confirm bore status, use, construction methods and to determine what infrastructure could be at risk if a bore was to flow.

3.1.2 Potential Liability – Flowing Bores

During a detailed risk assessment Council would need to consider who is responsible should a bore flow. For example, who would pay for headwork modifications, bore decommissioning and repair of infrastructure if damage occurred?

3.1.3 Source water quality

A number of Council studies have presented possible water sources for use in MAR. The current method of extraction from a gallery appears reasonable in that:

- Water of a good quality (low salinity, average turbidity <3 NTU) has been obtained. This is comparable to successful MAR projects from Australian examples e.g. Adelaide Plains.

- Sufficient volume of source water is available during the peak injection season (winter). This availability of source water is known to be a major obstacle to MAR in some locations.

However, the trial to date indicates an average turbidity < 3 NTU results in a reduction in MAR efficiency with an accompanying drop in bore specific capacity (Golder, 2020). Assuming an average suspended solid concentration of 1.5 mg/L, this could result in ~150 kg of material being added over a winter injection season (assuming an annual injection volume of 100,000 m^3). Backflushing appears to be removing a portion of the silt very close to the bore screen, however it appears unlikely that 150 kg of material has been removed over successive backflushing cycles.

The above emphasises the need for a suitable backflushing and bore maintenance plan over the life of the MAR Scheme. This is particularly paramount on the assumption that the Scheme would be operated as an Aquifer Storage Transfer and Recovery Scheme (ASTR) where water is not removed from the same injection bore. Thus, as currently proposed there is less opportunity to purge and remove silt introduced by injection during the summer irrigation season.

Other methods to improve water quality could also include:

- Sourcing water from an infiltration gallery / shallow aquifer connected to the River. This would enhance bank infiltration and filtering and possible improvement in source water quality. Careful design of the infiltration gallery could be undertaken to optimise turbidity in the source water i.e. construct such that production zone in the gallery is adequately matched to shallow aquifer grain size.

- Optimising filters to match particle size distribution of the source water. It is understood that the filters are 100 micron which is much larger than the average particle size of the source water. Thus to date, filters are largely ineffective as part of the MAR injection trial.

- Sourcing water from a lower turbidity source (treatment plant). The economics of this option would need to be considered with respect to cost vs benefit.

- Construction of a wetland near to the MAR bore. The wetland would need to be engineered such that source water is filtered naturally via vegetation. This is consistent with many MAR Schemes in urban areas of South Australia.

- Settling ponds that allow water to be entrained for a sufficient period of time. It is understood that the GDC have existing capacity of 13,000 m^3. The effectiveness of these ponds to remove turbidity (at a rate suitable for MAR) could be evaluated.

3.2 MAR Pilot Site

3.2.1 Drilling Methods and Construction Methodology

As outlined in Section 2, the construction methodology of the MAR bore could be improved to ensure that:

- Groundwater does not return to the surface during active injection.

- Seepage losses are minimised between the target aquifer and overlying / underlying units.

- Incompatible metals are eliminated that have potential to be corrode and be a source of clogging (e.g. steel surface control casing per the pilot MAR bore).

- The bore does not result in seepage loss to non-target aquifers when the steel eventually fails.

A key requirement for future bore construction includes the following:

- Pressure cementing of the casing annulus to ensure an effective seal.

- Screen is matched to grain size analysis. Generally speaking the screen should be designed to allow '60% passing' of aquifer material.[5]

- Bore purging / development is undertaken for sufficient duration to ensure the maximum amount of fine material is removed from the production interval.

- Materials are constructed with inert material to reduce corrosion.

[5] Subject to particle size distribution. Clearly if cobbles are the dominant grain size (e.g. 100 mm material) 60% passing will not be possible.

3.2.2 Test pumping design and set-up, hydraulic analysis and interpretations.

The design of the pumping and injection set-up is conventional and generally consistent with best practise. Evaluation of specific capacity is a useful method for evaluating bore efficiency and potential for clogging. This should continue along with periodic step testing to evaluate bore performance.

3.2.3 Water quality and injectant breakthrough

The positioning of observation bores has enabled the detection of injectant during the 2019 and 2020 Trials. The results confirm that native groundwater is displaced with low salinity injectant with dispersive mixing occurring at the injection plume fringe (Golder, 2020). This result indicates that injection into the Makauri aquifer is likely to result in a relatively rapid EC reduction proximal to the MAR bore.

The above work should be supported by setting agreed EC reduction targets for the potential MAR Scheme. From reports reviewed to date this is currently unknown. Any agreed reduction should meet end user requirements understood to be irrigated horticulture. The timeframe and uncertainty associated with meeting these targets should also be assessed.

3.2.4 Geochemical, physical and biological clogging

Significant assessment has been undertaken to measure and detect clogging mechanisms in trials to date. Results indicate that physical clogging is the primary cause (Golder, 2019; Golder, 2020). This has expressed as a reduction in specific capacity during the injection trials.

Practically speaking most source waters will contain residual turbidity and physical clogging will need to be managed via backflushing of bores. This could be supported by airlifting (essentially re-development of the bore) outside of the injection season.

Cation exchange appears to occur rapidly in results to date. This is not expected to result in an adverse impact to target water quality. Likewise, whilst not seen to date there does not appear to be a significant risk with respect to iron precipitation or biological clogging. Sterilization of drilling equipment prior to future MAR bore construction is recommended to avoid introduction of iron bacteria to any new MAR site.

3.2.5 MAR Injection Pressures

A critical review of the MAR pilot site has been undertaken. The results indicate that the aquifer has behaved acceptably under MAR with highest volumes achieved during 2020 (104,000 m^3 over winter harvest season).

Practically, the MAR injection bore is potentially under-utilised with respect to transmissivity and head rise recorded during 2017-2020 MAR Trials. This most likely results from limiting the injection pressure below ground surface. Theoretically, larger injection volumes could be achieved from an individual MAR bore via injection under pressure (water levels above ground at the injection bore). The advantage of running under artesian conditions is that:

- Higher instantaneous flow rates could be achieved which would maximise available source water.
- Fewer MAR bores would be required for a full-scale MAR Scheme.
- Fewer resources would be required for MAR bore maintenance, particularly with respect to backflushing and / or airlifting on a seasonable basis.
- Less operational costs.

It is recommended to undertake scenario testing as part of groundwater modelling. It may be possible to run the scheme with fewer bores and hence, divert savings to other areas of the Project. If implemented a risk assessment would need to be undertaken that considers:

- Maximum permissible head above ground level (that considers aquitard thickness and safe operating pressures).
- Potential for artesian conditions and flowing bores (in addition to the 'gravity scenario').

4 Data Gaps and Residual Risks

During the review the following data gaps / residual risks were noted:

- Target EC reduction to meet Project objectives has not been specified. This needs to be determined to evaluate the measure of success for the proposed MAR Scheme.
- Solute transport modelling to assess development and migration of the freshwater plume. This should be undertaken to determine whether injection is likely to benefit users as intended for the Project.
- Groundwater modelling to assess the potential to generate artesian pressure conditions. This is required to assess cumulative effects from multiple MAR bores injecting across the region. This has potential to raise water levels at the local to district scale during the winter injection season.
- Subject to above, undertake an assessment of the location and number of 3rd party bores that may become artesian. This would include an evaluation of headwork condition and bore status.
- Presence of pFAS / PFoS within the Waipaoa River Catchment. This is an emerging contaminant particularly near airports and other firefighting training areas. An evaluation of potential risk is recommended.
- Long term risks of physical clogging away from the bore screen. This could occur as source water moves away from the bore screen, allowing gradual deposition of fine-grained particulates at distance from the bore. This is unlikely to be removed effectively from the aquifer during backflushing cycles. The only mitigation strategy is to reduce turbidity in the source water (e.g. filtration). Long term impacts of injecting higher turbidity water is a steady reduction in specific capacity over the long term. This may result in a reduction of injection volumes at individual MAR bores.
- Impact of the coastal boundary condition on modelled pressure rises. This information is yet to be addressed via groundwater modelling (or constrained further via coastal drilling).
- Potential to inject under pressure (i.e. above ground). This would enable more rapid banking of water with potential to reduce the number of bores for an operational MAR Scheme.

5 Conclusions & Recommendations

5.1 Conclusions

Based on the review the following is apparent:

- The aquifer is sufficiently permeable and suited to MAR. A full-scale MAR Scheme is achievable provided physical clogging (source water quality) can be managed to acceptable levels.

- There is potential for geochemical reactions within the aquifer, however based on evidence to date this is not a chief cause for bore performance issues.

- Further work is required to evaluate the most appropriate bore field layout for a full-scale MAR Scheme. This should include an assessment to determine whether EC and pressure targets can be realised.

- Potential 3rd party impacts have not been addressed via groundwater modelling. This is required to evaluate the potential for artesian conditions at the regional scale.

- Future headwork designs should aim to achieve laminar flow conditions. Ninety-degree bends that introduce turbulence should be avoided.

- Bore design should prevent the vertical movement of groundwater and to permanently confine the groundwater to the specific zone (or zones) in which it originally occurred (per NZS4411-2001). This can be achieved with inert (PVC) casing and grout sealed annulus.

5.2 Recommendations

In addition to recommendations identified by Golder, GDC to consider the following:

- Future MAR bores should be pressure cemented through the entire casing annulus. This will prevent inter-aquifer leakage and pressure loss during active injection.

- Construction of future MAR bores should be supervised by a hydrogeologist. This will be beneficial to confirm:

  1) Bore is constructed to the agreed design, including pressure cementing of the casing annulus.

  2) Representative material is collected for screen design via particle size analysis.

  3) Bore is suitability developed to optimise bore efficiency.

  4) Bore construction details are adequately captured and included in reports (basis for screen selection, particle size distribution etc).

- Design and agree on an optimal headwork design for future MAR bores. Headworks should be designed to optimise laminar flow entering the bore. Headwork bends should be minimised and where possible fabricated at 45 degrees, rather than 90 degrees. Where possible, filters should be located further from the headworks to allow for stabilisation of turbulence prior to injection.

- Ensure backflushing cycles occur at a higher rate than the average injection rate (e.g. 2 x the injection rate). This will assist with removing turbidity near to the bore screen. Note: the existing downhole pump in the MAR pilot bore is rated to pump at approx. 15 L/s. A larger pump would be required to satisfy the above.

- Undertake turbidity sampling of backflush water. This can be undertaken to compare the average turbidity entering the bore vs outgoing turbidity under a backflush cycle. Results can be used to determine whether residual sediment is remaining within the aquifer formation.

- Consider obtaining source water from an overlying aquifer, rather than the Waipaoa River. Alternatively, construct infiltration galleries further from the River to reduce the extraction of sediment laden water.

- Undertake groundwater modelling to predict the potential for artesian pressure conditions from the preferred MAR layout. Potential effects of near coastal boundary conditions should be evaluated via sensitivity / uncertainty analysis.

- Subject to above, assess the number and status of 3rd party bores within the artesian extent. This should be undertaken to determine whether:

  1) Bores have headworks to contain artesian pressures.

  2) What risks may be posed to infrastructure / property should a bore flow.

  3) Possible liabilities for headwork modifications / decommissioning of bores in the artesian extent. The responsibility for sealing / capping flowing bores would need to be considered by GDC. If Council is held responsible an operational budget will be required to seal key bores.

- Undertake groundwater modelling to track the freshwater plume resulting from injection. Confirm that the freshwater plume will satisfy target salinity reductions to meet end user requirements.

- Consider bypassing the spinner filters for part / all of the 2021 Injection Trial. This should be considered to determine the potential effects of air entrainment during the filtering process. This recommendation is on the assumption that majority of the suspended sediment is below the filter cartridge size of 100 micron, and for this reason the existing filters are generally ineffective.

- Consider airlifting MAR bores at the end of each injection season. This will assist in alleviating clogging from suspended solids / turbidity.

Recommendations that are advisable, but not critical for future MAR include the following:

- Prior to drilling of MAR Injection Bores, undertake a pilot drilling program at each MAR Site. This will ensure that the target aquifer is suitable with respect to thickness and grain size. Any pilot drilling can be used to obtain particle size data for screen selection of future MAR Bores. Data from drilling can be used to understand aquifer geometry for implementation in the groundwater model.

- Conduct a pre-emptive water bore survey to determine what 3rd party wells are in proximity to the MAR Bores. This can be used to confirm the status of existing and previously abandoned water bores.

- Geophysically log boreholes to quantify aquifer intervals and confirm the exact zone for screen placement.

- Consider running the Scheme under pressure to maximise injection rates and available source water.

References

Barber, J. L (1993). *Groundwater of the Poverty Bay Flats – A Brief Synopsis*. Report by J. L. Barber, Water Conservator, February 1993.

Golder, (2017). *Results 2017 Injection Trial – Poverty Bay Managed Aquifer Recharge Pilot Project*. Submitted to Gisborne District Council, 30th June 2017.

Golder, (2020). *Gisborne MAR Stage 2 Injection Trial - Monitoring Period 2018 – 2020*. February 2020.

Golder, (2020). *Gisborne MAR Stage 3 Injection Trial - Interim Monitoring Report - August 2020*. 18th August 2020.

Golder, (2020). *Gisborne MAR Stage 3 Injection Trial - Interim Monitoring Report - December 2020.* 7th December 2020.

Golder, (2020). *Gisborne MAR Project – 2017 – 2020 Injection Trials*. Submitted to Gisborne District Council. December 22nd 2020.

Hancock, P written comms., (2021). Written communications to Paul Magarey, December 2020.

Honnor Drilling (2017). Written communications to Gisborne District Council (Tender Clarifications). Response to previous tender submission dated 14th December 2016.

National Uniform Drillers Licensing Committee (2020). *Minimum Construction Requirements for Water Bores in Australia.* Fourth edition.

Pulford, M., pers comm. (2021). Personal communication between Mick Pulford, Jess Page and Paul Magarey. 14th January 2021.

References for Australian Based MAR Schemes

AGT (2005). *Glenelg Golf Club Well Completion Report – Wells 8 and 9.* October 2005.

AGT (2007). *Well Completion Report Well 18 (PN 126377).* Report Prepared for Glenelg Golf Club. AGT Report NO: 2007/30.

AGT (2010) *Hydrogeological Investigations Dunstone Grove – Linde Reserve*. Prepared by Australian Groundwater Technologies Pty Ltd. AGT Report No. 2010/996

AGT (2014). *Linde Reserve Aquifer Storage and Recovery Scheme Risk Assessment*. Report prepared for city of Norwood, Payneham & St Peters. AGT Report no 1340-14-CAX. 21st August 2014.

AGT (2015). *Strategic Review of the Mitchell River Aquifer Storage and Recovery Scheme*. Prepared for East Gippsland Water. AGT Report no: 1441-15-EAC. 2nd December 2015.

Groundwater Science (2020). *Annual ASR Reporting - Morphettville Racecourse ASR Scheme*. Unpublished report.

Groundwater Science (2020). *Annual ASR Reporting, Glenelg Golf Club*. Unpublished report.

Groundwater Science (2018). *Oaklands Park Aquifer Storage and Recovery Scheme – Groundwater Modelling and Risk Assessment – 2018.* Report prepared for City of Marion.

EPA License 34682 (2017). *Corporation of the City of Norwood, Payneham & St Peters. Licence to Discharge stormwater to underground aquifers.* Commencement date 01 August 2017.

EPA License 42632 (2019). *City of Onkaparinga, Licence to Discharge stormwater to underground aquifers Byards Road, Dalkeith Road and Hart Road.*

City of Onkaparinga (2018). *Briefing documents to support sale of Water Assets. Tender Brief (2018).* City of Onkaparinga.