Mardie Salt and Potash Project

GROUNDWATER MONITORING & MANAGEMENT PLAN

DOCUMENT CONTROL

K	19-03-2024	Revised to respond to DWER and DCCEEW comments	Mardie Minerals	Matt Spence	Shaun Meredith
J	21-12-2023	Revised to respond to DWER comments	Mardie Minerals	Matt Spence	Spencer Shute
I	21-11-2023	Revised to respond to DCCEEW comments	Mardie Minerals	Arron Minchin	David Boshoff
H	06-11-2023	Revised to respond to DCCEEW comments	Oscar Dalla Pria Bruce Harvey	Spencer Shute	Spencer Shute
G	25-8-2023	Revised with new data	Bruce Harvey	Gavin Edwards	Spencer Shute
F	22-03-2023	Revised per EPA comments	Bruce Harvey	Julie Mahony	Angela Glover
Revision	**Date**	**Description**	**Author**	**Checker**	**Approver**
DOCUMENT NUMBER:		**000-EV-PLN-0005**			

Electronic documents, once printed, are non-controlled and may become outdated.

Refer to the Document Management System for the current version.

PROJECT SUMMARY

Action: To construct and operate the Mardie salt and sulphate of potash project, 80 km south-west of Karratha, Pilbara region, Western Australia.

Mardie Project Approvals: Ministerial Statement (MS) 1211 (replaces the superseded 1175) & EPBC 2018/8236

Optimised Mardie Project Approval: MS 1211, EPBC 2022/9169 (approval pending).

Proponent: Mardie Minerals Pty Ltd (ABN 50 152 574 457)

DECLARATION OF ACCURACY

In making this declaration, I am aware that sections 490 and 491 of the *Environment Protection and Biodiversity Conservation Act 1999* (Cth) (EPBC Act) make it an offence in certain circumstances to knowingly provide false or misleading information or documents. The offence is punishable on conviction by imprisonment or a fine, or both. I declare that all the information and documentation supporting this Monitoring Plan is true and correct in every particular. I am authorised to bind the approval holder to this declaration and that I have no knowledge of that authorisation being revoked at the time of making this declaration.

Signed:

Name:	Shaun Meredith
Position:	Head of Approvals and Government Relations
Organisation:	Mardie Minerals
ABN 50 152 574 457	

Table of Contents

List of Tables

List of Figures

List of Appendices

1. EXECUTIVE SUMMARY

This Groundwater Monitoring and Management Plan (GMMP Rev K) is submitted by Mardie Minerals Pty Ltd (Mardie Minerals) in support of the Mardie Project (Ministerial Statement (MS) 1211, EPBC 2018/8236) and the assessment of the Optimised Mardie Project (EPBC 2019/9169). The GMMP has been developed to align with the Environmental Protection Authority (EPA) Instructions and Templates for Part IV Environmental Management Plans (EPA, 2021a) and the Commonwealth's Environmental Management Plan Guidelines (Commonwealth, 2014).

Since the publication of MS1175, and approval under EPBC 2018/8236, the GMMP has been prepared to include consideration of the Optimised Mardie Project, which received State approval through MS-1211 on 19 October 2023, but has not yet been approved under the EPBC Act.

This GMMP presents the background technical studies, and the risk mitigations, monitoring and management approaches proposed to achieve the relevant environmental objectives.

The GMMP has been prepared to address the specific approval condition requirements (Table 2) and to address comments from DWER and DCCEEW. Significant changes have been made since the last version.

The purpose of the GMMP is to ensure that:

- Changes to the health, diversity, and extent of benthic communities and habitat (including subtidal macroalgae) as a result of changes to surface water, groundwater quality, groundwater regimes, and marine environmental quality associated with the proposal are detected as early as possible (MS1211, B1-3);
- The GMMP works together with the BCHMMPP to ensure overlapping and holistic impacts are managed and monitored (MS1211, B1-4);
- There are no adverse impact to water levels or water quality in Mardie Pool as a result of changes to groundwater regimes or groundwater quality (MS1211, B3-1);
- There are no changes to the health, extent or diversity of intertidal benthic communities and habitat, including mangrove, coastal samphire and algal mat as a result of changes to groundwater regimes or groundwater quality associated with the proposal (MS1211, B3-1);
- Impacts to protected matters are minimised from changes to groundwater (EPBC 2018/8236, 3).

Precautionary Approach

A key focus of the GMMP is to prevent unauthorised impacts to environmental matters and therefore the GMMP describes how these objectives will be met through a precautionary approach to risk and through adaptive management principles, for example in relation to mitigation and management actions, where there may be a level of residual uncertainty.

To demonstrate this precautionary approach, Mardie Minerals is undertaking the progressive filling of ponds with an increased focus on the observation of pond integrity and groundwater conditions through the inclusion of a one-week pause period between each fill level. This progressive approach will allow for the timely implementation of mitigation and management measures should there be changes to groundwater regimes as a result of filling.

Groundwater Modelling

AQ2 consultants have developed the Conceptual Groundwater Model for the project. This model builds on a range of technical inputs and studies and describes the predevelopment groundwater regime. The model describes groundwater in the vicinity of the project as characterised by a dominant hypersaline body of water under the tidal flats with predominantly vertical movement driven by tidal conditions and flooding. It also notes negligible lateral groundwater flow due to the flat groundwater gradients.

This is consistent with findings from a Department of Water and Environmental Regulation (DWER) review of the GMMP in late 2023 which stated that at the groundwater system around Mardie is likely dominated by vertical groundwater flow, which would reduce the potential risks to the adjacent sensitive receptors to the west of the pond infrastructure (e.g. algal mat and mangrove habitats).

In January 2024 AQ2 undertook 2D impact modelling across a number of Cross Sectional Transects under a number of modelled scenarios that would simulate conditions of vertical leakage to groundwater, similar to pre-development tidal inundation for evaporation ponds; downward pressure as a result of water impoundment; and for Mardie Pool, the potential for leakage to groundwater from the crystallisers.

Impact modelling for the Pond 1 transect predicted under a leakage scenario that there would be a potential seasonal increase in groundwater level of up to 0.5m that would be observable 100m on the coastal side of the Pond wall, and a decrease of up to 0.1 m on the upstream side as a result of interrupted coastal inundation.

At Pond 6, tidal inundation downstream will continue and the model prediction of groundwater level downstream are for an overall increase in water level, albeit less than the predevelopment water level variation.

For Mardie Pool, under a leakage scenario there may be short term leaks from the crystallisers however these are expected to be underneath and limited to the immediate vicinity.

These impact modelling results provide Mardie Minerals with a range of potential impacts that are consistent with the sensitivity parameters of the proposed trigger and threshold detection methodology.

Mardie Minerals has engaged AQ2 to complete the final impact modelling transect (Pond 8) by the end of March/early April, and to commence Regional Groundwater Modelling during Q2 2024 using ground-truthed information collected during the progressive filling of the early ponds. The GMMP will be reviewed and updated at the completion of that modelling and the concurrent groundwater data collection will inform the calibration and validation of the conceptual and impact modelling. Importantly, a full suite of mitigations have been proposed based on triggers and thresholds identified in this plan and in the inter-related Benthic Communities and Habitat Monitoring and Management Plan (BCHMMP) to ensure that any unexpected environmental impacts that are observed during this early progressive filling period are identified and managed appropriately.

Mardie Minerals has also committed to annual groundwater model updates every year for the first three years of the project, a time period which reflects achieving a steady operational state for the project.

Monitoring Groundwater Changes

Mardie Minerals groundwater monitoring network comprises 61 bores with the installation of these bores dating from 2021 through to 2023. Pipeline bores have been in place from 2021, Terrestrial Bores from early 2022 and Coastal monitoring bores were installed from July/August 2023. This collective baseline data set is described in the GMMP and includes 6 months of data which has been used for the development of trigger and threshold criteria for the Coastal Monitoring bore network. Mardie Minerals has and will continue to install remote groundwater level and quality instrumentation which provides a more frequent data collection and ability to analyse for changes. This also provides more data security and reliability given the physical challenges in accessing these bores.

Groundwater level data collected since 2021 shows significant seasonal and temporal variation in response to tidal influence, rainfall events and other factors such as barometric pressure and wind direction and speed. This high natural variability diminishes the value in setting fixed groundwater level triggers and thresholds, so instead a methodology has been developed to better distinguish between natural environmental variability and any operationally attributed changes.

A modified M-BACI approach has been developed for the purpose of setting trigger and threshold criteria for groundwater level changes associated with the Coastal Bore Network adjacent to Benthic Communities and Habitats. The approach is consistent with the ANZG guidelines specifying that the triggers and thresholds should be set seasonally, where seasonal variation exists, with the model picking up this seasonality on a continuum. Fixed value trigger and threshold criteria were not considered appropriate given the large daily variation and inconsistency with the modelling methodology.

The statistical strength and sensitivity of this method (Auto Regressive Integrated Moving Average – ARIMA) will provide daily analysis of groundwater changes. This frequency of analysis will provide a Mardie Minerals with rapid awareness of changes that exceed trigger or threshold criteria and will provide detailed information that will inform subsequent investigation, mitigation and management actions.

DAA have tested the ARIMA method using the available groundwater level data and have confirmed a high level of confidence that a simulated groundwater level change of 0.1m or higher is achievable with a minimum three-month data set (Appendices E and K).

Mitigation and Management Measures

The Ponds are designed to facilitate evaporation as part of the production process, so any loss of impounded water represents a loss of product and hence is a critical production issue. This means that any loss of impounded water will be minimised as part of usual operations of the project.

Notwithstanding this, and despite impact modelling indicating that the risk is low, leakage and loss of impounded water to groundwater has the potential to impact environmental values, including to benthic communities and habitats. To address this, Mardie Minerals has proposed a conservative approach to the development of trigger and threshold criteria, particularly in regards to the Coastal Monitoring bores due to the proximity of the Ponds to benthic communities and habitats.

The interaction of any trigger and threshold exceedances outlined in this GMMP will therefore be assessed concurrently with monitoring undertaken in the BCHMMP and also the research findings from the Research Offsets plan which is being assessed concurrently. This will ensure an holistic approach to the management of key flora and fauna. In situations where groundwater changes resulting from the project are having unsanctioned adverse impacts on benthic communities and habitats, mitigations which may include the cessation or reversal of pond filling will be actioned.

Progressive Filling

This GMMP describes an intensively monitored, risk-based approach to the operational phase of the project where Ponds are progressively filled and there is a focussed scrutiny on the performance of the ponds to achieve the required environmental objectives. The full project sequencing is provided in Appendices C and D of the GMMP.

This progressive filling approach is aligned with the precautionary approach in that it allows for near real-time identification, management and (if needed) mitigation of any groundwater related risks that may occur during the initial filling process. The progressive filling approach will also provide information important to the construction, review and validation of the conceptual and numerical groundwater models as per the commitments in Section 3.5.

Regular and ongoing updates on water levels and any trigger or threshold exceedances will be provided to regulatory agencies. Any ongoing concerns will be addressed through clear and open communication.

Conclusions

Mardie Minerals are strongly committed to the protection of the environment in which we plan to operate. We have sought clear and transparent advice from technical experts in their respective fields to help us demonstrate this commitment in this revision of the GMMP. In addition to the reporting and sharing of information proposed throughout this GMMP, we have also added a table in Section 3.5 of this revision to clarify our ongoing commitments for the project, particularly with regards to the review and update of the model and this GMMP. We would welcome ongoing feedback on these reporting and information sharing commitments such that they might be codified in subsequent scheduled revisions of this GMMP.

Proposal name	**Mardie Salt Project** • **Original Project.** • **Optimised Project.**
Proponent name	Mardie Minerals Pty Ltd
Approval references	Original Proposal • Ministerial Statement 1211 (note that MS 1175 is superseded) • EPBC 2018/8236. Optimised Proposal • Ministerial Statement 1211. • EPBC 2022/9169 – approval pending.
Purpose of the Plan	Support the maintenance of the hydrological regimes and quality of groundwater and surface water so that environmental values are protected.
Key environmental factor/s, outcome/s and objective/s	**Key Environmental Factors:** • **Inland Waters:** To maintain the hydrological regimes and quality of groundwater and surface water so that environmental values are protected. • **Benthic Communities and Habitats (BCH):** To protect benthic communities and habitats so that biological diversity and ecological integrity are maintained. **Outcomes and Objectives:** • **Key Environmental Objective:** No changes to the health, extent or diversity of intertidal benthic communities and habitat, including mangrove, coastal samphire and algal mat as a result of changes to groundwater regimes or groundwater quality associated with the proposal. • **Key Environmental Objective:** No adverse impact to water levels or water quality in Mardie Pool or Mt Salt Mound Spring because of changes to groundwater regimes or groundwater quality.
Condition clauses	Original Project • Ministerial Statement 1175 – Condition 3-3 (superseded). • Ministerial Statement 1211 – Conditions B3-1, B3-2, B3-3 and C1-1(3). • EPBC 2018/8236 – Conditions 4, 5, 6, 7. Optimised Project • Ministerial Statement 1211 – Conditions B3-1, B3-2, B3-3 and C1-1(3). • EPBC 2022/9169 – approval pending.
Key components in the Plan	• Groundwater monitoring network and baseline investigations. • Environmental objectives, indicators and triggers and thresholds for investigation and corrective action. • Conceptual and numerical groundwater modelling • Adaptive management, reporting and review
Proposed construction date	Construction of the Project commenced in February 2021
Key operations date	Refer to Section 2.1 of this Plan for timing and staging.
Plan required pre-construction?	No – the GMMP must be approved prior to starting transfer of seawater, brine or waste product into any evaporation or crystalliser pond.

2. CONTEXT, SCOPE AND RATIONALE

2.1 The Proposal

The Mardie Salt and Potash Project (the Project) currently being constructed by Mardie Minerals Pty Ltd (wholly owned by BCI Minerals) is located on the north-west coast of Western Australia in the Pilbara region, approximately 80 km south-west of Karratha (Figure 1).

The Project involves development facilities to produce, process and export high purity industrial grade salt and fertiliser grade sulphate of potash (SOP) from seawater via solar evaporation, crystallisation, raw salt purification and SOP conversion.

The Project was referred to the Environmental Protection Authority (EPA) in April 2018 and approved with conditions under Ministerial Statement 1175 in 2021 (EPA, 2021b) and EPBC 2018/8236 in 2022.

Significant amendments to the original proposal were outlined within the Optimised Mardie Salt Proposal, which was submitted to the EPA and Department of Climate Change, the Environment, Energy and Water (DCCEEW) in March 2022 (Preston, 2022). State approval was granted under Ministerial Statement 1211 in October 2023. Commonwealth approval for the additional project elements is pending and details of the Optimised Mardie Project are provided in this GMMP to support that approval decision.

Figures 2 and 3 provide an overview of the Mardie Project (consistent with EPBC 2018/8236 and MS-1211) and the Optimised Mardie Project (consistent with MS-1211, pending EPBC approval), respectively.

The Optimised Project Area consists of three parts: the Original Proposal Area, the Optimisation Area and the Quarry Area, located 18.5 km south-east of the Optimisation Area (Figure 2). This updated Proposal documents the expansion of concentrator and crystalliser ponds, an increased salt and SOP production rate, new secondary seawater intake option, a port facility laydown area, a quarry and minor changes to the dredge channel.

This GMMP has therefore proposed an approach consistent with both MS 1211 and EPBC 2018/8236 approvals, whilst also identifying those project elements that are components of the Optimised Mardie Salt Project Approval and that have been approved through MS 1211 however have not yet been approved under the EPBC Act.

An updated Groundwater Risk Assessment (GRA) was conducted by AQ2 (2021), previously published in support of the environmental impact assessment (EIA) of the Optimised Proposal and inclusive of the Original Project. The assessment demonstrated that no additional potential receptors would be introduced following the construction of the Optimised Proposal. This Groundwater Monitoring and Management Plan (GMMP) (the Plan) is therefore an extension of previous versions of the GMMP developed in support of the original Proposal and includes the most recent outcomes from groundwater investigations and studies.

Construction is complete for Ponds 1 to 5 but has not been completed for Ponds 6 onwards. The nature of the Project is to be long-term, with a current approved mine life of 60 years.

The filling of the evaporation ponds will commence in the south and gradually move northwards, with the target pond salinity also increasing from south to north. A detailed schedule showing pond filling alongside the relevant bore hole installation and data collection is provided in Appendix C.

The implementation of the GMMP is a direct condition of both EPBC 2018/8236 (Original Proposal) and MS 1211 (Optimised Proposal). The GMMP has been prepared with reference to the *'Instructions on how to prepare Environmental Protection Act 1986 Part IV Environmental Management Plans'* (EPA, 2021c) and the '*Environmental Management Plan Guidelines, Commonwealth of Australia 2014'* (DoE, 2014) in the context of the GMMP being submitted as part of the Approval conditions.

Figure 1 Mardie Project Regional Location

Figure 2 Mardie Project Layout – Original

Figure 3 Mardie Project Layout – Optimised

Figure 4 Pond Salinity and Depth

2.2 Rationale and Approach

2.2.1 Overview

Mardie Minerals has used this GMMP to describe the progressive filling approach for the Original Project in accordance with both the State and Commonwealth approvals, and also to provide information on the Optimised Mardie Project to support an approval decision under the EPBC Act, noting that the Optimised Mardie Project has already received State Approval.

The key elements of the GMMP are:

- Environmental objectives and outcomes for State and Commonwealth matters;
- Supporting technical studies and baseline data;
- Proposed groundwater monitoring network;
- Conceptual hydrogeological model;
- Impact modelling;
- Management indicators and relevant triggers and threshold criteria;
- Linkages to other key management plans;
- Management, mitigation and remediation measures; and
- Review and reporting requirements.

2.2.2 Baseline Data

Collection

To date a significant concern from DWER and DCCEEW in relation to the commencement of pond filling has been the absence of 24 months of baseline groundwater dataset across all bores in the monitoring network. This data was intended to be used to establish trigger and threshold criteria.

In line with the existing approvals, the bore monitoring network needed to model and assess groundwater impacts on the environment has been fully installed. This, combined with longitudinal transect bores established for the Gas Pipeline means that there are now 61 active bores within or nearby the development envelope. Further, and in consultation with the independent modelling consultants (AQ2) and data scientists (DAA), additional bore locations will be identified and installed in Q2 2024 (Section 2.6.13) to guarantee that appropriate data is collected to inform a robust adaptive management program proposed under the sequential pond filling proposal.

Mardie Minerals has been installing telemetry instrumentation across the monitoring bore network, firstly to measure groundwater level, and secondly to measure electrical conductivity and this installation will be completed in Q2 2024. The status of installation is noted in Tables 5,7 and 8 . This will allow a greater frequency of data collection, data analysis and review against triggers and thresholds than a monthly or quarterly physical sampling approach would provide.

Figure 5 shows consolidated groundwater level baseline data collection for the area of Ponds 1 through 8.

Quality

The long-term water level data from the gas pipeline corridor bores, as well as the more recent data from the coastal and terrestrial monitoring bore networks, shows significant temporal variation in response to tidal influence, significant rainfall events and likely other factors such as barometric pressure and wind direction and speed (the latter affect the flooding and persistence of marine waters across the tidal flat) (see Section 3 of Appendix D).

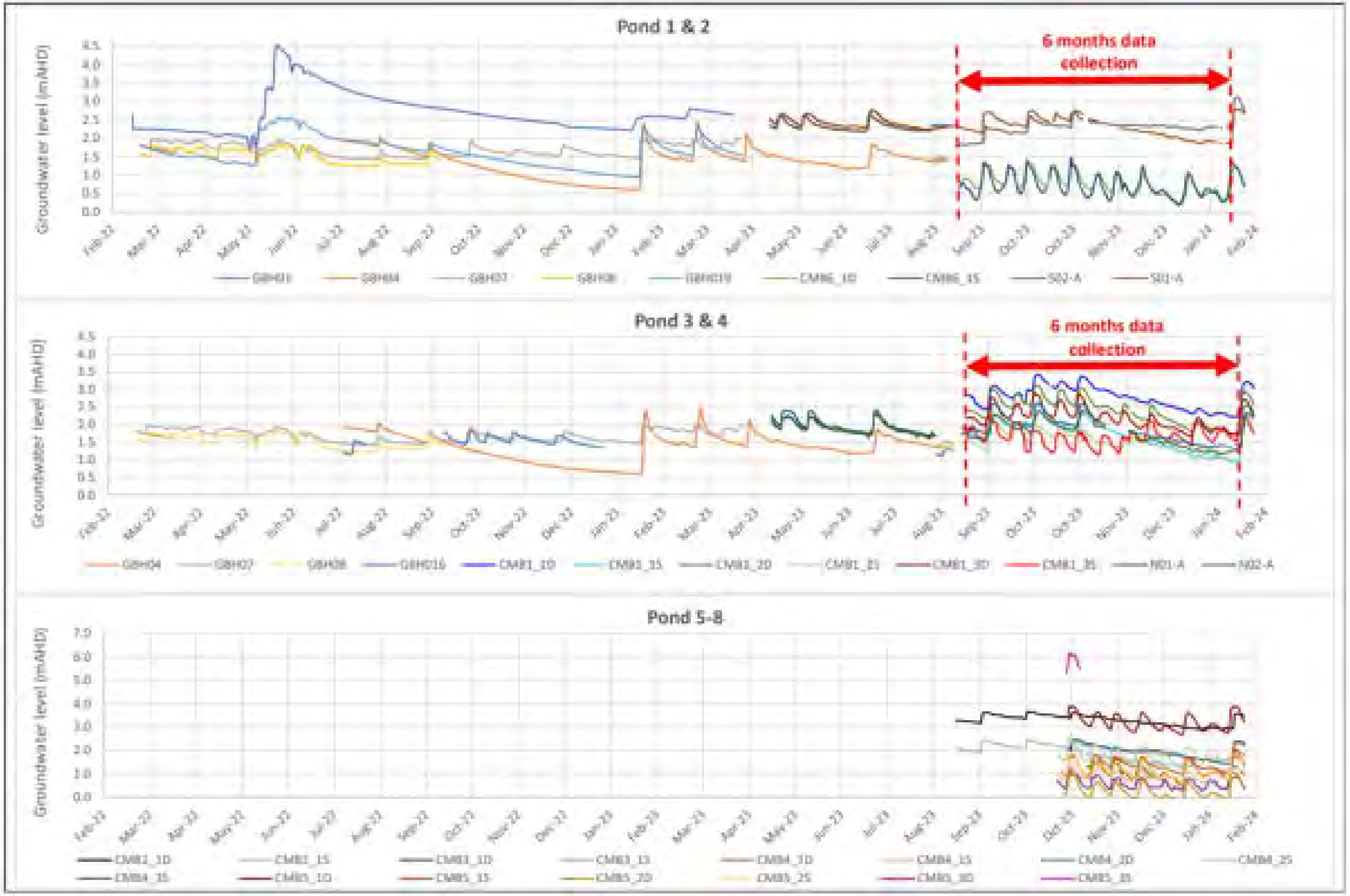
Given this high temporal variability in groundwater levels, it is proposed, following an approach endorsed in ANZG (2018), that a modified Before/After Control Impact (M-BACI) methodology be used to identifying robust triggers and thresholds. The modified M-BACI design uses paired control and detection sites, accounting for natural or pre-existing differences between the sites, to estimate the difference between the reference and potentially impacted site(s). This approach involves:

- Visualisation and analysis of water level and salinity data to understand temporal variability at different temporal scales (daily / monthly / annual).
- Comparison of data from different bores to identify groups with similar patterns of temporal variation.
- Standardisation of water level data to determine how best to pair control and detection sites.

Section 3.1 provides details of proposed indicators with triggers and threshold criteria.

Baseline EC profiling from monitoring bores installed on the western side of the proposed crystallisers to the east of the algal mat areas indicates that hypersaline water is present throughout the water column and that the saltwater interface is much further inland. The EC profiles were stable through five sampling events over 16 months. The recent ground-based Transient Electromagnetic survey also indicated that the hypersaline wedge generated by evaporation in the intertidal zone is 1 km or more inland from the eastern side of the salt flats.

Figure 5 Baseline Data



2.2.3 Progressive Filling Approach

Mardie Minerals is proposing a progressive filling approach where seawater is used for the initial filling of all ponds rather than using a concentrate. This approach is lower risk due to the concentration of the water used and it also facilitates the conditioning of the ponds to develop an *in situ* algal layer that will grow and act as a liner.

This progressive approach will also allow for monitoring data to be carefully observed across the bore network as each pond is filled, and each fill level is conducted. This approach is consistent with the independent DWER review recommendations from late 2023.

The key benefit of this approach is that it provides for additional time between filling for groundwater observations and pond condition observations and if required, for the implementation of mitigation and management actions.

A detailed overview of this approach for Ponds 1 through 6 is provided in Appendix D of this GMMP. Appendix C provides a time-based schedule to accompany the proposed approach and covers all Ponds and Crystallisers.

The key aspects of the filling approach are:

1. To fill ponds in incremental stages of approximately 0.3 m of seawater up to the operational depth and to ensure a 1 week pause between each subsequent filling rise.
2. To progress filling from Ponds 1 through to 6, then Ponds 7 and 8 as per the original Mardie Project approval in a controlled and careful manner. Filling of Pond 9 and the crystallisers is subject to EPBC approval of the Optimised Mardie Project and would be undertaken in accordance with the project description and action as per the relevant assessment documentation.
3. The 1 week pause allows for an observation of pond condition during filling, and concurrent review of groundwater data against the indicators and triggers and thresholds in this GMMP.
4. The 1 week pause allows for the implementation of mitigation and management measures should they be required in an effective and timely manner.

The staged filling activity is consistent with the description of filling that informed the State and Federal approvals for the project with regards to the infrastructure, pumping and depth of filling. The only difference being the addition of 1 week pauses between each fill.

This approach will also facilitate the sharing of data with agencies through the filling of these ponds which is expected to take around 4 months to complete for Ponds 1 through 6, and any exceedances of trigger and threshold criteria will be notified and investigated as described in Sections 3.2 and 3.4.

Agreement amongst technical experts and supported by Conceptual Modelling is that filling Ponds 1 and 2 presents a low environmental risk, as water quality that develops within the first ponds is not materially different to that of seawater. Furthermore, Conceptual Hydrogeology and Coastal Transect Modelling (as detailed in **Error! Reference source not found.**) indicates that there is minimal lateral movement of groundwater from the sabkha to the ocean (or from the ocean inland), and negligible lateral movement of groundwater parallel to the coast, due to the very low permeability of the clay strata beneath the flats (AQ2, 2024). It is therefore expected that changes to the groundwater regime due to loading or seepage from ponds will not propagate far from the ponds (either towards or parallel to the coast).

The collection of operational data will inform the validation of the Conceptual Hydrogeological Model's performance, outcomes and proposed management approaches. Where there is an exceedance of a trigger and/or threshold criteria, the mitigation and adaptive management measures will be implemented to ensure the Groundwater Environmental Objective is achieved.

Fortnightly data provision to Agencies will occur through the Pond 1 and 2 filling and any exceedances of trigger and threshold criteria will be notified and investigated as described in Sections 3.2 and 3.4. An escalating hierarchy of mitigation and management has been included in Table 16 to respond to a threshold exceedance and to mitigate risks until additional investigations have identified actual environmental impacts and effective mitigations are clearly articulated.

2.2.4 DWER Technical Advice / Peer Review Commentary

The DWER Peer Review of the GMMP and technical expert advice informed the development of this GMMP and the phased initial filling of the Ponds.

The peer review was conducted by DWER (Dr Steve Appleyard, Principal Hydrogeologist) in October 2023. The review outlined that based on the data provided from the terrestrial groundwater bores, the groundwater flow in the system is likely to be predominantly vertical and not horizontal, which would reduce the potential risks to the adjacent 'sensitive receptors' to the west including algal mat and mangrove habitat (see section 2.6.1). In parallel Mardie Minerals' consultants had developed a new conceptual hydrogeological model which is consistent with the DWER model.

At a meeting with DWER (October 2023), the following matters were discussed:

- The DWER reviewer recommendation that the transfer of seawater into Ponds 1 and 2 should be undertaken as staged approach, whereby the water depth in the ponds is increased in staged increments over a prolonged period of time (perhaps pausing for 1-2 weeks between each depth rise), to allow the speed and extent of any groundwater mounding from the ponds to be determined.
- In the event that significant mounding occurs, Pond 1 can and will be emptied to mitigate risks until additional work is completed to fully understand the system and risk of environmental impacts.
- Additional work, including modelling, will be undertaken to assess potential impacts from the filling of Ponds 5 and above, to demonstrate the acceptability of operations commencing in these ponds..

On 21 November 2023, a DWER led independent Peer Review was undertaken of the GMMP, the following matters were discussed in the review:

- Based on the data and (modelling) results to date, the Peer Reviewer was of the view that it appeared unlikely that groundwater levels and quality would be significantly impacted at any larger distances from the ponds. However, further work should be undertaken to confirm the proposed conceptual model and to successively reduce the risks and to prepare strategies that could mitigate problems, should they occur.
- Agreement from the Peer Reviewer that filling of the ponds will provide new observations that will be collected during the staged filling of the ponds will indeed help to better inform the next phase of model development and calibration.

2.2.5 Environmental outcomes / objective/s

The GMMP has been developed to meet the relevant State and Commonwealth approval objectives including:

- No impacts within the development envelope greater than that permitted (EPBC 2018/8236)
- Minimising impacts to protected matters from changes to groundwater (EPBC 2018/8236)
- Prevent impacts to the Mardie Pool, terrestrial, intertidal and subtidal protected matters and habitats (EPBC 2018/8236)
- Identify further impacts that may result on protected matters within and/or outside the development envelope (EPBC 2018/8236)
- No development that would have an adverse impact on the ecological function of intertidal and subtidal benthic communities and habitats (MS1211)
- No long-term (greater than five (5) years) net detectable loss of algal mat outside of the proposal footprint (MS1211)
- No loss of subtidal benthic communities and habitat (including subtidal algae) outside the Zones of impact authorised in condition A1-1 (MS1211)

- No adverse impact to water level or water quality in Mardie Pool as a result of changes to groundwater regimes or groundwater quality (MS1211)
- No changes to the health, extent or diversity of intertidal benthic communities and habitat, including mangrove, coastal samphire and algal mat as a result of changes to groundwater regimes or groundwater quality associated with the proposal (MS1211)

2.3 Key Environmental Factors

The key environmental factors considered in this GMMP are Inland Waters and Benthic Communities and Habitats (BCH).

The EPA objective for Inland Waters is *"to maintain the hydrological regimes and quality of groundwater and surface water to ensure that environmental values are protected"* (EPA, 2018).

The EPA objective for Benthic Communities and Habitat (BCH) is *"to protect benthic communities and habitats so that biological diversity and ecological integrity are maintained"* (EPA, 2018).

Secondary factors, which are dependent upon the outcomes to Inland Waters and BCH, are marine fauna and terrestrial fauna (including significant species).

Proposal activities that may affect these factors are described in Table 1.

Table 1 Potential impacts to Inland Waters and/or BCH

Key Environmental Factors: Inland Waters, BCH	
Proposal activities that may affect this factor.	• Evaporation Ponds • Crystalliser Ponds • Bitterns storage dams and pipelines.
Environmental values that may be affected by implementing the Proposal.	• Benthic communities and habitats (BCH), including mangrove, algal mat and samphire communities, as well as the biological systems that they support. • Water levels and/or water quality in Mardie pool as a result of changes to groundwater regimes or groundwater quality. • Protected matters and habitats associated with the Mardie Pool, terrestrial, intertidal and subtidal areas (EPBC 2018/8236). • Livestock watering bores.
Ecosystem health condition / sensitive component of the key environmental factor.	• Groundwater salinity. • Groundwater levels.
Existing and/or potential uses.	• Pastoral Station (cattle).

2.4 Condition Requirements

The Original Mardie Salt Project was approved under the EP Act (Ministerial Statement 1175) in November 2021 and the EPBC Act in January 2022 (EPBC 2018/8236). The Optimised Mardie Project (which includes the Original Mardie Salt Project) was approved under the EP Act (Ministerial Statement 1211) in October 2023 (Ministerial Statement 1175 has now been superseded by MS 1211). EPBC Act approval for the additional project components in the Optimised Mardie Project is pending.

The key conditions of EPBC 2018/8236 and Ministerial Statement 1211 relevant to the Plan are shown in Table 2.

Table 2 Key Conditions of EPBC 2018/8236 and MS 1211 (MS 1175) relevant to the GMMP (Revision K)

Cond. #	Condition Requirement	How/Where addressed in GMMP
EPBC 2018/8236		
3	To minimise **impacts** to **protected matters** from changes to groundwater (the Groundwater Objective), the approval holder must comply with conditions 3-1 to 3-9 of **MS 1211.**	This GMMP (Revision K) and subsequent revisions, as approved by the Delegate, has been prepared to address these conditions through its implementation
4	The approval holder must submit a Groundwater Monitoring and Management Plan (GMMP) to the Minister for approval. The approval holder must not commence operations until the GMMP has been approved by the Minister in writing. The approval holder must implement the approved GMMP. The GMMP must:	Noted. This GMMP (Revision K) and subsequent revisions, as approved by the Delegate, has been prepared to address these conditions through its implementation
	a. be consistent with the Environmental Management Plan Guidelines.	This GMMP (Revision K) for the Mardie Project adheres to the guidance provided under Chapter 4 of Australia's national environment law, the *Environment Protection and Biodiversity Conservation Act 1999* (the EPBC Act) for the preparation of a suitable environmental management plan. This GMMP (Revision K) has been prepared to be consistent with the Environmental Management Plan Guidelines, Commonwealth of Australia 2014
	b. include the outcomes of the Mardie Project Groundwater Memo that is to be implemented, which specifies the locations for the monitoring bores and specifies the modelling to be undertaken to inform the GMMP in order to prevent impacts to the Mardie Pool, terrestrial, intertidal and subtidal protected matters and habitats (the Groundwater Objective). The outcomes of the modelling proposed in the Mardie Project Groundwater Memo must be included as an Appendix to the GMMP.	See Section 2.6.10 of the GMMP. Final technical studies are currently underway for the remainder of the modelling and outcomes prescribed in Mardie Project Groundwater Memo. Timing for the completion of technical studies is provided in Section 3.5, Table 18. Studies completed are described in Section 2.6 The progressive filling approach described in this GMMP supersedes the approach outlined in the memo.
	c. include the information required under condition 3-4 of the WA Approval and how the Groundwater Objective will be met.	This version of the Mardie Project GMMP when implemented will satisfy WA Conditions 3-1(1) and 3-1(4) of Ministerial Statement 1175 noting that Condition 3-4 has been superseded by MS 1211 conditions (described below). See Section 2.3. Relevant WA Approval Conditions including implementation of the Plan are described in Table 2. The GMMP has been prepared to address these conditions through its implementation.
	d. present additional measures based on the outcomes of the modelling undertaken as part of the Mardie Project Groundwater Memo that identify further impacts that may result on protected matters within and/or outside the development envelope.	See Section 2.6.10 of the GMMP. AQ2 Mardie Project Conceptual Groundwater System and Modelling Assessment report prepared for Mardie Minerals dated January 2024 has been provided in **Appendix A** and summarised in Sections 2.6, 2.6.3, 2.6.7, 2.6.8 Section 2.7 provides details on characterisation of the environment and understanding of likely groundwater impacts so that impacts to EPBC protected matters could be identified, management measures designed so that DCCEEW are capable of assessing impacts to Matters of National Environmental Significance
	e. include the details of a review of the draft GMMP by an independent suitably qualified hydrologist and how the recommendations of the independent suitably qualified hydrologist's review have been addressed and resulted in changes to the GMMP.	Section 4.2 and Table 14. Peer Review included in Appendix C. An Audit Review (GMMP Rev H) was undertaken by CyMod on 29 November 2023. The Audit Review undertaken by the independent suitably qualified hydrologist concluded that Mardie Minerals addressed the reviewer's comments adequately (Appendix G). Further details of peer review is provided in Section 4.2.1.
5	In the event that any threshold criterion specified in the GMMP, in accordance with condition 3-4(5) and 3-4(6) of the WA Approval is exceeded, the approval holder must:	Reporting and investigation procedures have been developed following the exceedance of any trigger and threshold values in the GMMP and are described in Section 3.4.

	a. undertake the actions required under condition 3-7 of the WA Approval and provide the same information and the report required under condition 3-7(5) of the WA Approval, to the Department, within the same timeframes as specified under condition 3-7 of the WA Approval.	In the event that monitoring has indicated an exceedance of trigger and threshold values specified in the GMMP then Mardie Minerals will undertake the following:
		• report exceedance in writing to the CEO & DCCEEW;
		• implement appropriate contingency actions required by the GMMP within 7 days of exceedance notification;
		• investigate to determine the cause of the exceedances;
		• investigate and provide to the CEO any potential harm that exceedance may have caused to the environment;
		• provide a report to the CEO within 21 days of the threshold criteria exceedance. Report to include:
		    o details of contingency actions;
		    o effectiveness of the contingency actions;
		    o findings of the investigation into the exceedance;

Cond. #	Condition Requirement	How/Where addressed in GMMP
		○ measures to prevent the threshold criteria being exceeded in the future; ○ measures to prevent, control and abate impacts that may have been caused; and ○ justification of the threshold criteria remaining or being adjusted to better manage outcomes of the GMMP. Timeframes are specified in Section 3.4 of GMMP and in Table 16.
	b. within 6 months of any such exceedance, have the GMMP reviewed by an independent suitably qualified hydrologist to advise if the GMMP needs to be revised to prevent any possibility of the exceedance reoccurring and submit the report of the independent suitably qualified hydrologist to the Department. If the review of the GMMP by an independent suitably qualified hydrologist recommends that the GMMP be revised, the approval holder must submit the revised GMMP to the Department for the approval of the Minister within 8 months of any such exceedance.	GMMP to be reviewed by independent hydrologist as required. Review processes outlined in Section 4.2.
	c. within 6 months of any such exceedance develop a Remediation Plan to be submitted to the Department for the Minister's approval for the any impact(s) to protected matters arising from the exceedance as detailed in the report required under condition 3-7(5) of the WA Approval and condition 5(b).	Exceedance reporting and management actions. Refer to Section 3.4 and Table 16 of the GMMP. This GMMP acknowledges that in accordance with Condition 5(c) of EPBC 2018/8236, exceedance of threshold criteria specified in the GMMP will also trigger the development of a Remediation Plan.
	d. If a Remediation Plan is submitted in accordance with condition 5(c) and that Remediation Plan has not been approved by the Minister in writing within 9 months of the exceedance event, and the Minister notifies the approval holder that the Remediation Plan is not suitable for approval, the Minister may, at least two months after so notifying the approval holder, approve a version of the Remediation Plan revised by the Department. The approval holder must implement the approved Remediation Plan.	Conditions requiring a Remediation Plan are detailed in Section 3.4 reporting of the GMMP. The Remediation Plan is to be reviewed alongside the GMMP by an independent suitably qualified hydrologist within 6 months of the exceedance being reported. The Remediation Plan will describe contingency measures and remediation actions to be undertaken in response to a threshold exceedance
	e. If the Minister determines that it is not possible to remediate the impact of the exceedance, then the approval holder must, within 10 months of the exceedance of the threshold criterion, submit an Offset Strategy specifying how the impact will be offset in accordance with the Environmental Offsets Policy. If the Offset Strategy has not been approved by the Minister in writing within 11 months of the exceedance event, and the Minister notifies the approval holder that the Offset Strategy is not suitable for approval, the Minister may, at least two months after so notifying the approval holder, approve a version of the Offset Strategy revised by the Department. The approval holder must implement the approved Offset Strategy for the remainder of the life of the project.	Mardie Minerals will develop an Offset Strategy to deal with the impact if the Minister or Department considers that it is no longer possible to remediate the impact caused by the exceedance. To be actioned at a time specified in the Offset Strategy and as approved by the Minister.
6	The approval holder must have the GMMP reviewed by an independent suitably qualified hydrologist at least once before every 10-year anniversary of the first approval of the GMMP and subsequently every 10 years for the life of the project or unless specified by the Minister in writing. If the independent suitably qualified hydrologist recommends revision of the GMMP, the approval holder must, within 6 months of receiving the recommendation of the independent suitably qualified hydrologist, submit a revised GMMP addressing the recommendations of the independent suitably qualified hydrologist accompanied by the recommendations of the independent suitably qualified hydrologist to the Department within 3 months of the most recent 10-year anniversary of the first approval of the GMMP, for approval by the Minister.	The current GMMP at the 10-year anniversary of the project must be reviewed by an independent hydrologist and subsequently reviewed every 10 years thereafter. To be actioned at the 10 year anniversary of the Project. Included in Section 4.2 .
7	If a revised GMMP is submitted in accordance with condition 5(b) or condition 6 and that GMMP has not been approved by the Minister in writing within 10 months of the exceedance event, and the Minister notifies the approval holder that the GMMP is not suitable for approval, the Minister may, at least two months after so notifying the approval holder, approve a version of the GMMP revised by the Department.	As per Section 3.4. To be actioned at time of exceedance.
Ministerial Statement 1175 (superseded, included here to comply with requirements under EPBC 2018/8236)		
3-1	The proponent shall ensure that the following outcomes are achieved: (1) no adverse impact to water levels or water quality in Mardie pool as a result of changes to groundwater regimes or groundwater quality;	Addressed in this GMMP - Section 2.2.5 - Section 2.6.7

Cond. #	Condition Requirement	How/Where addressed in GMMP
	(2) no adverse impact to water levels or water quality in Mardie pool as a result of surface water flows associated with the proposal; (3) no changes to the extent of surface water flooding extent during a one (1)-year ARI or changes to tidal inundation as a result of the construction of the intertidal causeway that are greater than predicted in Mardie Project – Environmental Review Document (June 2020); Page 5 of 40 (4) no changes to the health, extent of diversity of more than five (5) ha of intertidal benthic communities and habitat, including mangrove, samphire and algal mat as a result of changes to groundwater regimes or groundwater quality associated with the proposal; (5) decreased freshwater inundation attributable to the project of no more than fifty-two (52) ha of coastal samphire; (6) decreased freshwater inundation attributable to the project of no more than thirteen (13) ha mangroves outside the RRDMMA; and (7) decreased freshwater inundation attributable to the project of no more than 130 ha mangroves within the RRDMMA, subject to the requirements of condition 2-3.	- Section 2.6.11 - Section 2.7 - Section 3.1.3 - Section 3.2
3-3	The proponent shall prepare and submit to the CEO a Groundwater Monitoring and Management Plan.	GMMP Plan for the Mardie Project submitted.
	(1) The proponent shall submit with the Groundwater Monitoring and Management Plan, a peer review of the plan carried out by an independent person or independent persons with relevant expertise determined by the CEO, that provides an analysis of the suitability of the plan to meet the outcomes of conditions 3-1(1) and 3-1(4).	Section 4.2 and Table 14. Peer Review included in Appendix C. An Audit Review (GMMP Rev H) was undertaken by CyMod on 29 November 2023. The Audit Review undertaken by the independent suitably qualified hydrologist concluded that Mardie Minerals addressed the reviewer's comments adequately (Appendix G).
	(2) The proponent shall not commence transfer of seawater, brine or waste product into any evaporation or crystallizer ponds associated with the proposal until the CEO confirmed by notice in writing that the Groundwater Monitoring and Management Plan meets the requirements of condition 3-4.	Noted .
3-4	The Groundwater Monitoring and Management Plan required by condition 3-3 shall:	Noted, This GMMP (Rev K) addresses the primary outcomes of the Project.
	(1) when implemented, substantiate, and ensure that the outcome of conditions 3-1(1) and 3-1(4) will be met;	
	(2) provide the details, including timing, of hydrogeological investigations to be carried out that will: (a) provide a detailed understanding of the hydrological regime in the project area; (b) inform the final design of monitoring that will meet the requirement of condition 3-4(1); and (c) inform the final design of management and mitigation actions that will be implemented to meet the outcomes of conditions 3-1(1) and 3-1(4);	Refer to recent AQ2 Mardie Project Pond 1 Modelling Assessment prepared for Mardie minerals dated October 2023 **Appendix A** and sections 2.6.3 and 2.6.7**.**
	(3) detail the timing of monitoring bore installation and collection of baseline data, providing justification to demonstrate that data will represent baseline where it is collected after the commencement of operations;	GMMP includes update of existing monitoring bores installed (Tables 5, 7 and 8). Mardie Minerals remains committed to monitoring, maintaining and upgrading the monitoring bore network to satisfy the primary objectives and outcomes of the Project and in accordance with the relevant Approval Conditions.
	(4) detail the methodology of seepage recovery actions that will be implemented where seepage from evaporation ponds to groundwater is detected;	Refer to Trigger and Threshold section of GMMP 3.2.
	(5) specify early warning trigger criteria that will trigger the implementation of management and/or contingency actions to prevent non-compliance with conditions 3-1(1) and 3-1(4).	Refer to Trigger and Threshold sections of GMMP under Section 3.1 and 3.2.

Cond. #	Condition Requirement	How/Where addressed in GMMP
	(6) specify threshold criteria to demonstrate compliance with condition 3-1(3).	Trigger and threshold values have been calculated using the most recent groundwater monitoring data to date. The M-BACI method is proposed to implemented as discussed in section 2.2.3. Mardie Minerals are committed to reviewing and continually updating these values once new data is collected following filling the Ponds.
	(7) specify the methodology of a monitoring program to determine if trigger criteria and threshold criteria have been met and meet the requirement of condition 3-4(1).	Refer to Trigger and Threshold sections of GMMP: Sections 3.1 and 3.2.. Groundwater sampling and monitoring program including frequency is included in the GMMP in Section 3.
	(8) specify management and/or contingency actions to be implemented if the trigger criteria required by condition 3-4(5) and/or the threshold criteria required by condition 3-4(6) have not been met; and	GMMP Adaptive Management and Review actions are outlined in Section 4**.**
	(9) provide the format and timing for the reporting of monitoring results against trigger criteria and threshold criteria to demonstrate that the outcomes in conditions 3-1(1) and 3-1(4) have been met over the reporting period in the Compliance Assessment Report required by condition 18-6.	Refer to Compliance Reporting in Section 4 of GMMP.
3-5	The exceedance of a threshold criteria, regardless of whether management actions or threshold contingency actions have been or are being implemented, constitutes non-compliance with these conditions.	Refer to Compliance Reporting in Section 4 of GMMP.
3-6	The proponent shall implement the most recent version of the Groundwater Monitoring and Management Plan which the CEO has confirmed by notice in writing, addresses the outcomes of conditions 3-1(1) and 3-1(4).	Noted.
3-7	In the event that monitoring or investigations at any time indicate an exceedance of threshold criteria specified in the Groundwater Monitoring and Management Plan confirmed under condition 3-6, the proponent shall:	GMMP Reporting requirements including investigative reporting are described in Section 4.

	(1) report the exceedance in writing to the CEO within seven (7) days of the exceedance being identified;	The reporting section (Section 4) of this GMMP includes compliance and regulatory reporting requirements.
		If groundwater monitoring has indicated an exceedance of trigger and threshold values specified in the GMMP then Mardie Minerals will undertake the following:
		• report exceedance in writing to the CEO;
		• implement appropriate contingency actions required by the GMMP within 7 days of exceedance notification;
		• investigate to determine the cause of the exceedances;
		• investigate and provide to the CEO any potential harm that exceedance may have caused to the environment;
		• provide a report to the CEO within 21 days of the threshold criteria exceedance. Report to include:
		  ○ details of contingency actions;
		  ○ effectiveness of the contingency actions;
		  ○ findings of the investigation into the exceedance;
		  ○ measures to prevent the threshold criteria being exceeded in the future;
		  ○ measures to prevent, control and abate impacts that may have been caused; and
		  ○ justification of the threshold criteria remaining or being adjusted to better manage outcomes of the GMMP.

	(2) implement the contingency actions required by the Groundwater Monitoring and Management Plan within seven (7) days of the exceedances being reported and continue implementation of those actions until the CEO has confirmed by notice in writing that it has been demonstrated that the threshold criteria are being met and implementation of the threshold contingency actions are no longer required;	
	(3) investigate to determine the cause of the threshold criteria being exceeded;	
	(4) investigate to provide information for the CEO to determine potential environmental harm or alteration of the environment that occurred due to threshold criteria being exceeded;	
	(5) provide a report to the CEO within twenty-one (21) days of the threshold criteria exceedance being reported. The report shall include: (a) details of contingency actions implemented; (b) the effectiveness of the contingency actions implemented against the threshold criteria; (c) the findings of the investigations required by conditions 3-7(3) and 3-7(4); (d) measures to prevent the threshold criteria being exceeded in the future; (e) measures to prevent, control or abate impacts which may have occurred; and (f) justification of the threshold criteria remaining, or being adjusted based on better understanding, demonstrating that the outcome in conditions 3-1(1) and 3-1(4) will be met.	
3-8	The proponent:	GMMP review is described in Section 4.2. Mardie Minerals will undertake a review of the current GMMP by an independent hydrologist every five years for WA Approval 1175 and every 10 years for the EPBC Approval 2018/8236.
	(1) may review and submit proposed amendments to the Groundwater Monitoring and Management Plan;	
	(2) shall review and submit proposed amendments to the Groundwater Monitoring and Management Plan as and when directed by the CEO; and	

Cond. #	Condition Requirement	How/Where addressed in GMMP
	(3) shall review and submit proposed amendments to the Groundwater Monitoring and Management Plan every five (5) years.	
3-9	The proponent shall continue to implement the Groundwater Monitoring and Management Plan or any subsequent revisions as confirmed by the CEO in condition 3-3, until the CEO has confirmed by notice in writing that the proponent has demonstrated that the environmental outcomes detailed in conditions 3-1(1) and 3-1(4) have been met.	Noted
Ministerial Statement 1211		
A1-1	Groundwater abstraction - No dewatering of groundwater for any reason except to meet the requirements of condition B3-2.	Noted.
B1-1	The proponent must ensure the implementation of the proposal achieves the following environmental outcomes: (4) no change in the health, extent of coverage, or species diversity of intertidal benthic communities more than 100 m seaward of the pond walls as shown in Figure 2; and (5) adverse impacts to intertidal benthic communities are limited to an area within 100 m of the pond wall defined in Figure 2.	Groundwater modelling outcomes described in section 2.6.6 with respect to impacts in proximity to pond walls. BCHMMP linkages to GMMP described in Section 3.1.3 and 3.3.2.
B3-1	The proponent must ensure the implementation of the proposal achieves the following environmental outcomes: - (1) no adverse impact to water levels or water quality in Mardie Pool as a result of changes to groundwater regimes or groundwater quality - (4) no changes to the health, extent or diversity of intertidal benthic communities and habitat, including mangrove, coastal samphire and algal mat as a result of changes to groundwater regimes or groundwater quality associated with the proposal;	Sections 2.3, 3.1.3 and 3.3.2 describe the key environmental objectives and outcomes with respect to these values. Trigger and threshold criteria are established for groundwater level and EC with respect to preventing unauthorized impacts to these values (Section 3.1).
B3-2	The proponent must: 1. implement the Groundwater Monitoring and Management Plan (GMMP; Rev F, submitted March 2023), once updated and approved in accordance with condition B3-3, and subject to the requirements of condition C1-1(3), with the purpose of ensuring the benthic communities and habitat environmental outcomes in condition B3-1 (1) and (4) and condition B1-2 are achieved, monitored, substantiated and satisfy the requirements of conditions C4 and condition C5; and 2. review the GMMP environmental management plan (Rev F, submitted March 2023); within one (1) year of the date of this statement to include: (a) the relationship between the GMMP environmental management plan and the BCHMMP environmental management plan, and how these plans work together to ensure overlapping and holistic impacts are managed and monitored, to ensure the environmental outcomes and objectives relevant to both plans are achieved.	This GMMP (Rev K) has incorporated feedback from DWER and DCCEEW, peer review recommendations, updated technical studies including modelling and data collection from bores installed since 2022.
B3-3	The GMMP (Rev F, submitted March 2023) environmental management plan required by condition B3-2 is to be updated with project specific trigger values at the completion of baseline data collection.	As pre commitments in Section 3.5.
C1-1	The proponent must not undertake: (3) transfer of seawater, brine and/or waste product associated with the Mardie Project until the CEO has confirmed in writing that the environmental management plan required by condition B3-2 has been updated in accordance with condition B3-3 and meets the requirements of condition C4;	Noted.
C2-1	Upon being required to implement an environmental management plan under	Mardie Minerals will implement the GMMP as and when approved by the CEO.

Cond. #	Condition Requirement	How/Where addressed in GMMP
	Part B, or after receiving notice in writing from the CEO under condition C1-1 that the environmental management plan(s) required in Part B satisfies the relevant requirements, the proponent must: (1) implement the most recent version of the confirmed environmental management plan; and (2) continue to implement the confirmed environmental management plan referred to in condition C2-1(1) other than for any period which the CEO confirms by notice in writing that it has been demonstrated that the relevant requirements for the environmental management plan have been met, or are able to be met under another statutory decision-making process, in which case the implementation of the environmental management plan is no longer required for that period.	
C2-2	The proponent: (1) may review and revise a confirmed environmental management plan provided it meets the relevant requirements of that environmental management plan, including any consultation that may be required when preparing the environmental management plan; (2) must review and revise a confirmed environmental management plan and ensure it meets the relevant requirements of that environmental management plan, including any consultation that may be required when preparing the environmental management plan, as and when directed by the CEO: and (3) must revise and submit to the CEO the confirmed environmental management plan if there is a material risk that the outcomes or objectives it is required to achieve will not be complied with, including but not limited to as a result of a change to the proposal.	Noted for future revisions to the GMMP.
C2-3	Despite condition C2-1, but subject to conditions C2-4 and C2-5, the proponent may implement minor revisions to an environmental management plan if the revisions will not result in new or increased adverse impacts to the environment or result in a risk to the achievement of the limits, outcomes or objectives which the environmental management plan is required to achieve.	Noted for future revisions to the GMMP.
C2-6	Confirmed environmental management plans, and any revised environmental management plans under condition C2-4(1), must be published on the proponent's website and provided to the CEO in electronic form suitable for online publication by the DWER within twenty (20) business days of being implemented, or being required to be implemented (whichever is earlier).	Mardie Minerals will publish the GMMP once approved.
C3-1	The proponent must undertake monitoring capable of: (1) substantiating whether the proposal limitations and extents in Part A are exceeded; and (2) detecting and substantiating whether the environmental outcomes identified in Part B are achieved (excluding any environmental outcomes in Part B where an environmental management plan is expressly required to monitor achievement of that outcome).	Monitoring is described in Sections 2.6, 3.1, 3.2 and 3.3.
C3-2	The proponent must submit as part of the Compliance Assessment Report required by condition D2, a compliance monitoring report that: (1) outlines the monitoring that was undertaken during the implementation of the proposal; (2) identifies why the monitoring was capable of substantiating whether the proposal limitation and extents in Part A are exceeded; (3) for any environmental outcomes to which condition C3-1(2) applies, identifies why the monitoring was scientifically robust and capable of detecting whether the environmental outcomes in Part B are met; (4) outlines the results of the monitoring;	Reporting is described in Section 3.4 in accordance with the condition and sub conditions

Cond. #	Condition Requirement	How/Where addressed in GMMP
	(5) reports whether the proposal limitations and extents in Part A were exceeded and (for any environmental outcomes to which condition C3-1 (2) applies) whether the environmental outcomes in Part B were achieved, based on analysis of the results of the monitoring; and (6) reports any actions taken by the proponent to remediate any potential non-compliance.	
C4-1	The environmental management plans required under condition B1-4, condition B2-2, condition B3-2, condition B4-3, condition B5-3, condition B5-4, condition B6-4, condition B6-6 and condition B8-3 must contain provisions which enable the substantiation of whether the relevant outcomes of those conditions are met, and must include: (1) threshold criteria that provide a limit beyond which the environmental outcomes are not achieved; (2) trigger criteria that will provide an early warning that the environmental outcomes are not likely to be met; (3) monitoring parameters, sites, control/reference sites, methodology, timing and frequencies which will be used to measure threshold criteria and trigger criteria. Include methodology for determining alternative monitoring sites as a contingency if proposed sites are not suitable in the future; (4) baseline data; (5) data collection and analysis methodologies; (6) adaptive management methodology; (7) contingency measures which will be implemented if threshold criteria or trigger criteria are met; and (8) reporting requirements.	This GMMP has been prepared in accordance with this Condition.
C4-4	The environmental management plan required under condition B3-2 is also required to: (1) when implemented, substantiate and ensure that the outcome of conditions B3 -1 (1) and B3-1 (4) will be met; (2) provide the details, including timing, of hydrogeological investigations to be carried out that will: (a) provide a detailed understanding of the hydrological regime in the project area; (b) inform the final design of monitoring that will meet the requirement of condition C4-1; (c) inform the final design of management and mitigation actions that will be implemented to meet the outcomes of conditions B3 -1 (1) and B3-1 (4); and (3) detail the timing of monitoring bore installation and collection of baseline data, providing justification to demonstrate that data will represent baseline where it is collected after the commencement of operations.	This GMMP has been prepared in accordance with this Condition.
D1	Non-compliance Reporting	Reporting is described in Section 3.4 in accordance with the condition and sub conditions
D2	Compliance Reporting	Reporting is described in Section 3.4 in accordance with the condition and sub conditions

2.5 Association with other Management Plans

This GMMP provides monitoring and management actions related to possible groundwater seepage and/or mounding from pond filling and operations. Any exceedance of trigger and threshold values in the GMMP will trigger a range of actions (refer Table 17, Section 3.2) which include the implementation of monitoring actions as presented in the approved Benthic Community and Habitat Management and Monitoring Plan (BCHMMP). A summary flowchart of the relationship between the relevant monitoring and management plans is shown in Figure 7.

Similarly, investigations into trigger and threshold exceedances under the BCHMMP will include a review of monitoring data collected under the GMMP, and the implementation of additional monitoring if required.

The GMMP and BCHMMP interrelate to meet conditions 3-1(4) and 6 of MS 1211, and condition 23 of EPBC 2018/8236 (Figure 6). A review of this GMMP alongside the BCHMMP will be completed and submitted by the 19th October 2024 as per Condition B3-2(2) of MS-1211. Adaptive management of this plan in relation to the GMMP is described further in Section 4.

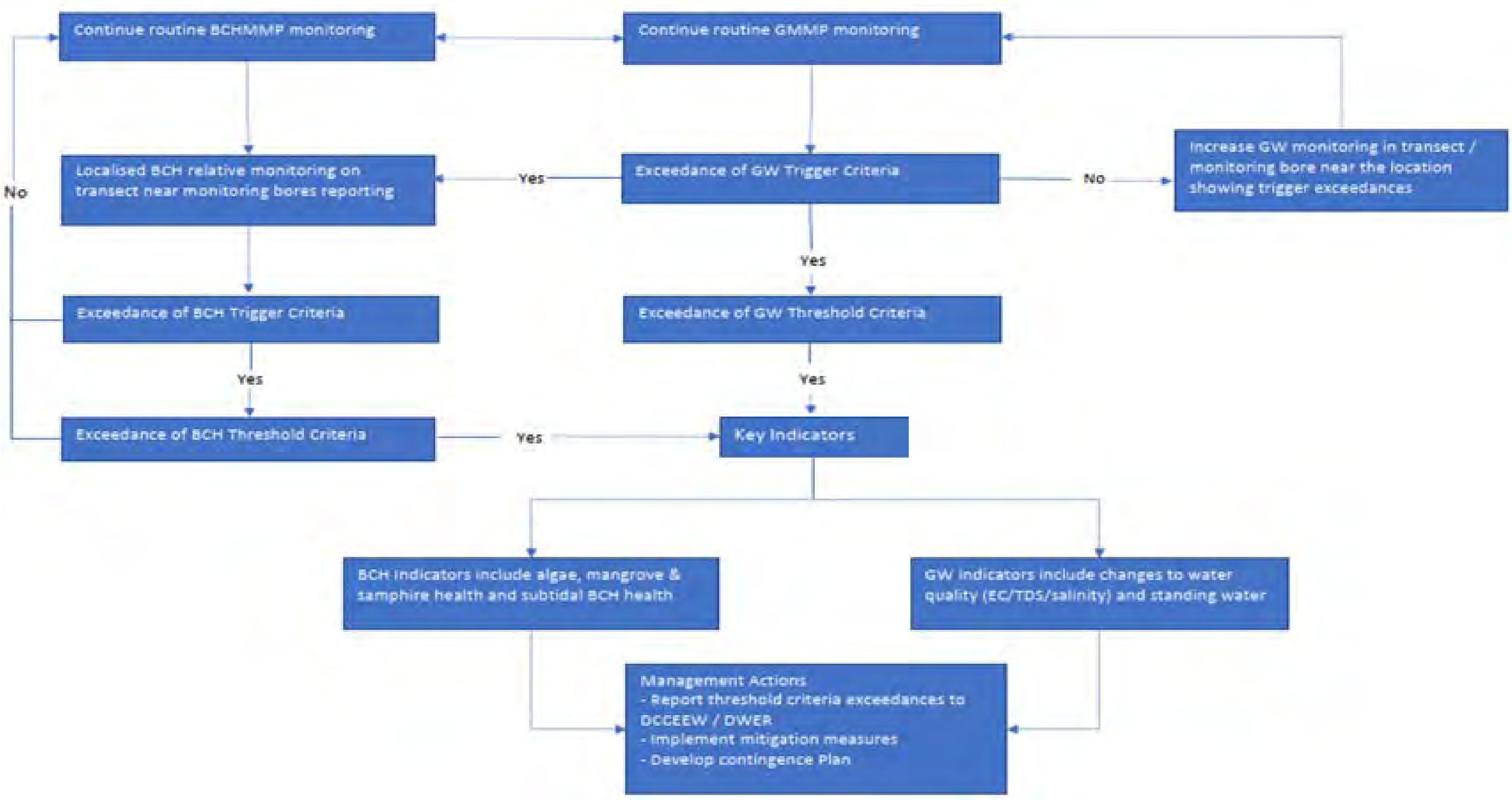


Figure 6 **Flowchart of the relationship between the GMMP and BCHMMP**

2.6 Relevant Technical Studies

There are a number of technical studies that have been undertaken to support the development and /or implementation of this GMMP.

Significant work, including bore installation and monitoring, monitoring at Mardie Pool and Mt Salt, and groundwater modelling, has been completed in support of developing the GMMP for the Original Project and to support the EIA for the Optimised Mardie Project.

A summary of the key studies and investigations that have been undertaken, or are ongoing, is provided in Table 3**.** Further detail on the status of work committed to in 2021, and referred to under EPBC 2018/8236 Condition 4b, is provided in Section 2.6.10.

This GMMP is intended to be reviewed and updated as ongoing investigations progress. Details and timing of the future groundwater investigations at the Mardie Project that will be used to close knowledge gaps and further inform the GMMP have been summarised below.

Table 3 Status of Key Studies and Investigations

Investigation	Details	Status (March 2024)
Terrestrial Monitoring Bore Drilling Program	Installation of monitoring bores in the vicinity of Mardie Pool and evaporation ponds to permit water level and quality investigations.	Completed
Coastal Monitoring Bore Drilling Program	Installation of monitoring bores on the coastal side of evaporation ponds and near the RRDMMA to permit water level and quality investigations.	
Aquifer Testing.	Pumping tests of test bores within the Fortescue Alluvial aquifer and Carnarvon Superficial aquifer to quantify aquifer parameters.	
Conceptual Hydrogeological model and impact modelling across 2D transects	Development of a conceptual model and numerical impact modelling across 4 representative transects for a range of scenarios to estimate potential for environmental impacts from groundwater mounding or seepage from evaporation ponds.	Conceptual model and impact modelling of transects Pond 1, Pond 6 and Mardie Pool completed and attached – App. A. Transect Pond 8 will be completed in March 2024.
Regional Groundwater modelling.	Development of a regional groundwater flow model to assess the potential impacts of the proposed evaporation ponds on the regional groundwater system.	Refer to Section 2.6.10
Mardie Pool Transient Electromagnetic (TEM) Survey.	Non-invasive TEM survey to investigate groundwater salinity distribution in areas where drilling was not permitted by traditional owners.	Completed
Mardie Pool Surface Water/Groundwater	Data collection began October 2022.Ongoing incorporation into conceptualisation and groundwater modelling.	Collection of water level and quality data ongoing on a quarterly frequency.

Investigation	Details	Status (March 2024)
Interaction Investigation.		Groundwater Investigation Report included as Appendix M
Baseline Groundwater level and quality monitoring.	Acquisition of water level, water samples and electrical conductivity (EC) profiles from all monitoring network bores to characterise natural variation and ongoing variations which may be due to effects of the project.	Ongoing monitoring as described in this GMMP for each bore network.
Mt Salt Mound source analysis.	Site visit November 2022 and August 2023 found no discharge was evident at that time. Should artesian water discharge be found at Mt Salt, water samples will be taken to be compared to potential upgradient groundwater sources. Spring source will be investigated through analysis of stable isotopes or radionuclides.	Ongoing quarterly visits will continue noting that to date, there has been no water discharge at the site.
Development of trigger and threshold criteria.	Development of trigger and threshold criteria for groundwater quality from the baseline groundwater quality data.	Triggers and Thresholds developed (See Table and Appendices H and K).

2.6.1 Information Review

Documents and data relevant to the environmental assessment of the Mardie Project were reviewed as background to the Groundwater Risk Assessment (GRA) (AQ2 2021) and have informed the development of this GMMP. A summary is provided in Table 4**Table 4**.

Table 4 Relevant references from the AQ2 data review

Report	Key Considerations
DFS Factual Geotechnical Report (CMW Geosciences 2020)	Soil permeability was measured via in situ falling head tests and laboratory tests on reconstituted samples. All tests measured permeability on a relatively small scale local to the bore and hence may not represent bulk soil permeability.
Seepage Model Results and Potential Environmental Impacts (Soilwater Group 2019)	Seepage modelling is based on the original Eastern Crystallisers location 250m north of Mardie Pool (since moved to 1,000m east). Modelling indicates that downward seepage rate of hypersaline water could vary from 1m/2years to reaching the calcarenite aquifer in 6 months, depending on estimated permeability and seepage rate. Suggested that monitoring bores be installed, and seepage capture bores may be required if seepage is detected.
Detailed flora and vegetation survey for the Mardie Project (Phoenix Environmental Services 2020)	34 significant flora species which may potentially occur within the study area: • One Threatened Flora species • 33 State-listed Priority Flora

Report	Key Considerations
	Recognised groundwater dependent species identified as associated with Mardie Pool. Potential groundwater dependent riparian species *Eucalyptus victrix* identified within ephemeral creek lines further south (Phoenix 2020, Figure 5-8a).
"*Groundwater enhances above ground growth in mangroves*" (Hayes et al. 2018)	Presented the **possibility** that mangroves may use non-saline groundwater and rainwater when available rather than saline water sources. Groundwater flows into the intertidal stimulates organic matter accumulation in above-ground biomass suggesting the availability of non-saline water sources, such as groundwater and rainfall, are important for the growth and productivity of mangrove forests.

2.6.2 Benthic Communities and Habitats

A number of surveys and studies have been undertaken for intertidal Benthic Communities and Habitats (BCH) within the Mardie Project area, including:

- A regional intertidal BCH assessment of mangal (mangroves) and algal mat communities undertaken by Stantec (2018) consisting of a desktop (literature) review, preliminary hydrological modelling, and reconnaissance and targeted field surveys.
- Intertidal BCH assessments undertaken by O2 Marine (2020a), including a comprehensive desktop review of the intertidal BCH in vicinity to the Project and two field surveys (March 2018, December 2018) to collect information to fill any data gaps identified in the desktop review.
- A detailed flora and vegetation survey by Phoenix Environmental Sciences (Phoenix, 2019), including extensive reconnaissance and detailed field surveys to verify and build on desktop reviews compiled using existing information of the Project and its surroundings. Survey effort included two helicopter reconnaissance surveys (August 2017, September 2017), a first phase detailed flora survey (May 2018), a second phase detailed flora survey (August 2018) and an additional survey of extended survey areas (September 2019).
- Actis Environmental Services (2020) conducted a review of the survey effort within samphire communities.

Eight (8) broad intertidal BCH classes were identified and mapped within the Development Envelope and surrounds, as follows:

- Algal Mat
- Closed Canopy (CC) Seaward Mangroves
- Scattered (SC) landward Mangroves
- Samphire/Samphire Mudflat
- Foreshore Mudflat/Tidal Creek
- Rocky Shoreline
- Mudflat/Saltflat
- Sandy Beach

The distribution of mangroves and algal mat in relation to the Mardie Project is shown in Figure 7.

The Benthic Communities and Habitat Monitoring and Management Plan (BCHMMP) was approved by DWER (Rev C) 19 October 2023 and by DCCEEW (Rev D) on the 22 December 2023. Sections 2.5, 3.1.3 and 3.3.2 of this plan describe the connectivity between the BCHMMP and the GMMP.

Figure 7 Mangrove and algal mat distribution in relation to Mardie Project

2.6.3 Conceptual Hydrogeological Model

Model Development and Inputs

AQ2 Consultants have undertaken the Conceptual Hydrological Modelling for the Mardie Project and the most recent update of the modelling is provided as an attachment in Appendix A.

The objective of the groundwater modelling was to predict the potential water level and salinity impacts of seepage (leakage) related to the operation of the Mardie Project on the underlying groundwater system. Available groundwater monitoring, that extends as far back as February 2022, shows fluctuations in groundwater levels due to recharge to groundwater from extremely high tides. As a result, groundwater levels in the modelled catchment are not readily described by a long-term average or steady state water level calibration.

The density dependent flow and transport groundwater models were developed consistent with the hydrogeological understanding described in Section 4 of Appendix A and the principles outlined in the Australian Groundwater Modelling Guidelines (Barnett et al, 2012).

The key hydrogeological inputs to the model include:

- The presence of two significant, distinct unconfined aquifer systems: the Fortescue Alluvial aquifer and the alluvial aquifer of the Coastal Plain
  - The coastal plain alluvial aquifer is generally unconfined and formed in Pliocene / Quaternary sediments. The hydrostratigraphy of the coastal aquifer has been defined through data from geotechnical investigations across the intra-tidal zone and deeper (~30m) investigative test bores in the hinterland area to the south-east.
  - The Fortescue River alluvial valley forms a large aquifer of fresh groundwater across the alluvial fan west of the main river channel. Silt and gravel content is variable both vertically and horizontally, resulting in highly variable aquifer transmissivity and variations in water quality.
- Regional groundwater levels and flow generated from water levels measured in groundwater investigation bores which have been installed since 2019 at Mardie showing flat groundwater gradients and negligible lateral groundwater flow from the sabkha to the ocean and parallel to the coast.
- Groundwater recharge is periodical and associated with high tide infiltration. Some direct recharge to the coastal plain will occur during major rainfall events when extensive flooding overbanks from the water courses and moves as sheet flow across the plain.
- Water quality observations from test pits and bores over a number of years including salinity profiles from north of the Mardie pool, and from deep/shallow bores across the sabkha.
- Hydrogeological parameters derived from constant rate tests and falling/rising head tests carried out in a selection of Test Production bores and monitoring bores across the project site over several campaigns as well as data gathered from previous work in the area.

Conceptual Model

The conceptual hydrogeological model is presented in Figure 8 below and summarised as follows:

Coastal Sabkha

- The dominant groundwater influence in this area is the body of hypersaline water which has developed over an extensive period beneath the tidal flats (the sabkha). It extends for 30 km parallel to the coastline and approximately 5-10km inland and is up to 5km wide (Figure 9).
- Recharge of fresh groundwater water occurs inland and across the hinterland, flowing gradually towards the coast. The fresh water intersects the hypersaline brine of the sabkha inland from the

eastern edge of the tidal zone, where a wedge of hypersaline water is confined by the hydraulic pressure of the fresh water. Diffusion of hypersaline water into the fresh water occurs at this point.

- On the seaward side of the sabkha a seawater-hypersaline interface is present, and the base of the hypersaline plume extends to the sea floor where rapid mixing with sea water occurs.
- During large rainfall flood events, fresh water will flood from creeks and overtop the hypersaline brine of the sabkha to flow across the flats to the ocean. This may dissolve some surficial salt and deposit silt across the sabkha for a short time, however the salt accumulation process will resume at the next high tides following the recession of flooding.
- Climatic conditions characterised by very hot summers, mild winters and variable rainfall, along with evaporation rates of around 3.4 metres per annum, 12 times annual rainfall.

Mardie Pool

- Mardie Pool is likely to become a gaining stream or losing stream depending on the prevailing pool and groundwater levels.
- It will fill to the overflow level during significant rainfall events. After flowing for a short period of time, outflow stops and the level in the pool will fall due to evaporation and loss of water through seepage.
- While the groundwater level in in the surrounding aquifer is lower than the level in the pool Mardie Pool acts as a losing stream. Fresher groundwater will gradually seep into the banks and base of Mardie Pool.
- After extended dry periods the level of water within Mardie Pool falls below the groundwater level noted in adjacent monitoring bores. Analysis of recession curves for the pool indicate that the pool water level is likely being supplemented with groundwater inflow (the pool becomes a gaining stream), hence remaining a permanent surface water feature throughout the dry season.
- Groundwater in bores to the north of Mardie Pool is saline at a depth which is below the base of Mardie Pool. While Mardie Pool is known to become more saline due to evaporation in dry periods, the pool is filled with fresh water during flood events. It is unclear whether saline groundwater contributes to the increase of salinity in Mardie Pool.

Model Durations

The prediction models have been run to predict the impacts of leakage from the ponds and the crystalliser. Based on the expected operation of the project, pond leakage has been simulated assuming that the operational level or the fill level of the ponds persists for the duration of the predictions. The predictions also make assumptions about the duration of leakage from the crystallisers (long term leakage and short-term leakage are simulated even though leakage from the crystallisers would be managed to maximise recovery of product and minimise leakage). The predictions also include variable conditions associated with tidal fluctuations, recharge from tidal inundation and the estimated seasonal fluctuations at Mardie Pool. Predictions were run for the following durations:

- For Pond 1 predictions were run for a period of three years,
- For the crystalliser and Mardie Pool predictions were run for a period of 10 years
- For Pond 6 and the crystalliser, predictions were also run for a period of 10 years

The ponds are located on predominantly low permeability clayey material (AQ2, 2024). The infiltration and storage capacity of this clayey material is limited. As a result, quasi steady state water level and salinity conditions (or equilibrium conditions) are predicted to be reached in and around the area of Pond 1 in less than a year. For the predictions that include the unlikely scenario of long term or persistent leakage from the crystalliser, prediction results also show that the water level impacts of crystalliser leakage also reach quasi steady state water level conditions within 5 years. For predictions that include crystalliser leakage for a period of only a year (the likely operational scenario) a short-term peak in water level is reached consistent with the duration of the leakage period of one year, which is predicted to rapidly dissipate. When leakage from Pond 6 is simulated, quasi steady state water levels are predicted within a year of the simulation of Pond 6 leakage.

The length of the predictions is shorter than the current life of project (estimated to be more than 50 years). The current prediction periods have made a number of assumptions about future tidal and climate conditions based on the current understanding. The predictions have shown the development of steady state water level conditions in and around the proposed project development within the prediction periods simulated.

Figure 8 Conceptual Hydrogeological Model

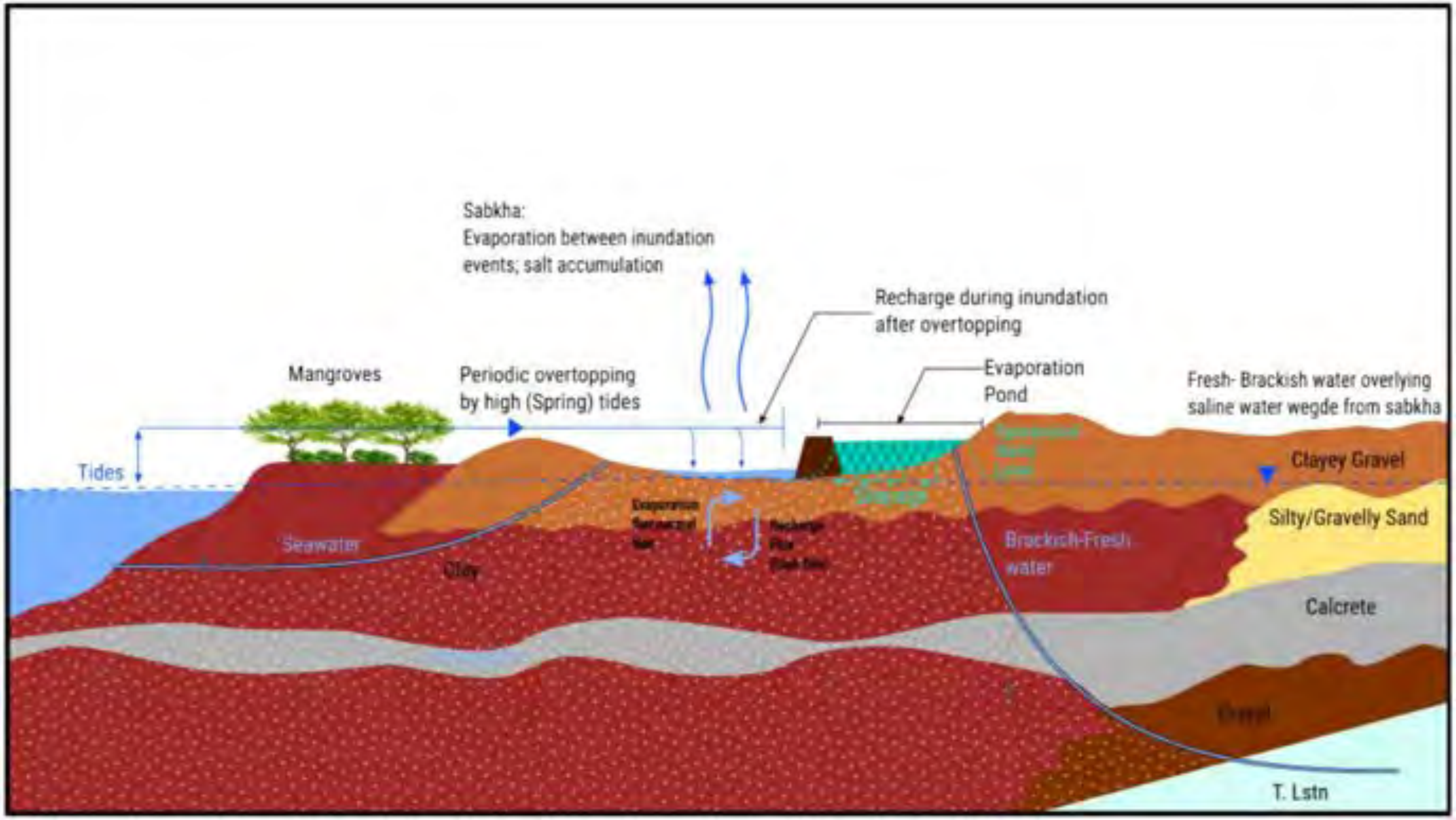


Figure 9 Near-coastal, Sabkha and Inland Alluvial zones

2.6.4 Terrestrial Groundwater Monitoring Bore Network

Eighteen (18) monitoring bores were installed in March-April 2022 to provide data on groundwater characteristics (levels and quality) in the vicinity of Mardie Pool and Mardie Creek, and in areas surrounding the proposed Crystallisers (Figure 10). Baseline data collection commenced from April 2022 across these bores.

Five monitoring bores were installed up hydraulic gradient from Mardie Pool and adjacent to the proposed crystalliser, to serve as an early warning of changes in salinity and water level if hypersaline seepage or mounding from the crystallisers were to occur in future (MP06, MP13 to MP16).

Additional bores were installed parallel to Mardie Creek, outside the heritage buffer zone and between Mardie Pool and the Crystallisers ponds (sites MP02 to MP05), to provide data on groundwater flow directions and gradients between the Crystallisers and Mardie Pool.

Three monitoring bores (MP07, MP11-12) were placed up-gradient from the Primary Crystallisers for background monitoring within the Fortescue Alluvial Valley and three monitoring bores (MP08-10) were installed down gradient from the Secondary and KTMS Crystallisers to detect changes to the groundwater regime due to the crystallisers.

Three bores (MP17, MP18, MP19) were placed along the creek line to the east of Mardie pool to characterise groundwater conditions in the Mardie Creek channel upstream of Mardie Pool. Monitoring bore details are provided below in Table 5.

Figure 10 Terrestrial Groundwater Monitoring Bore Locations

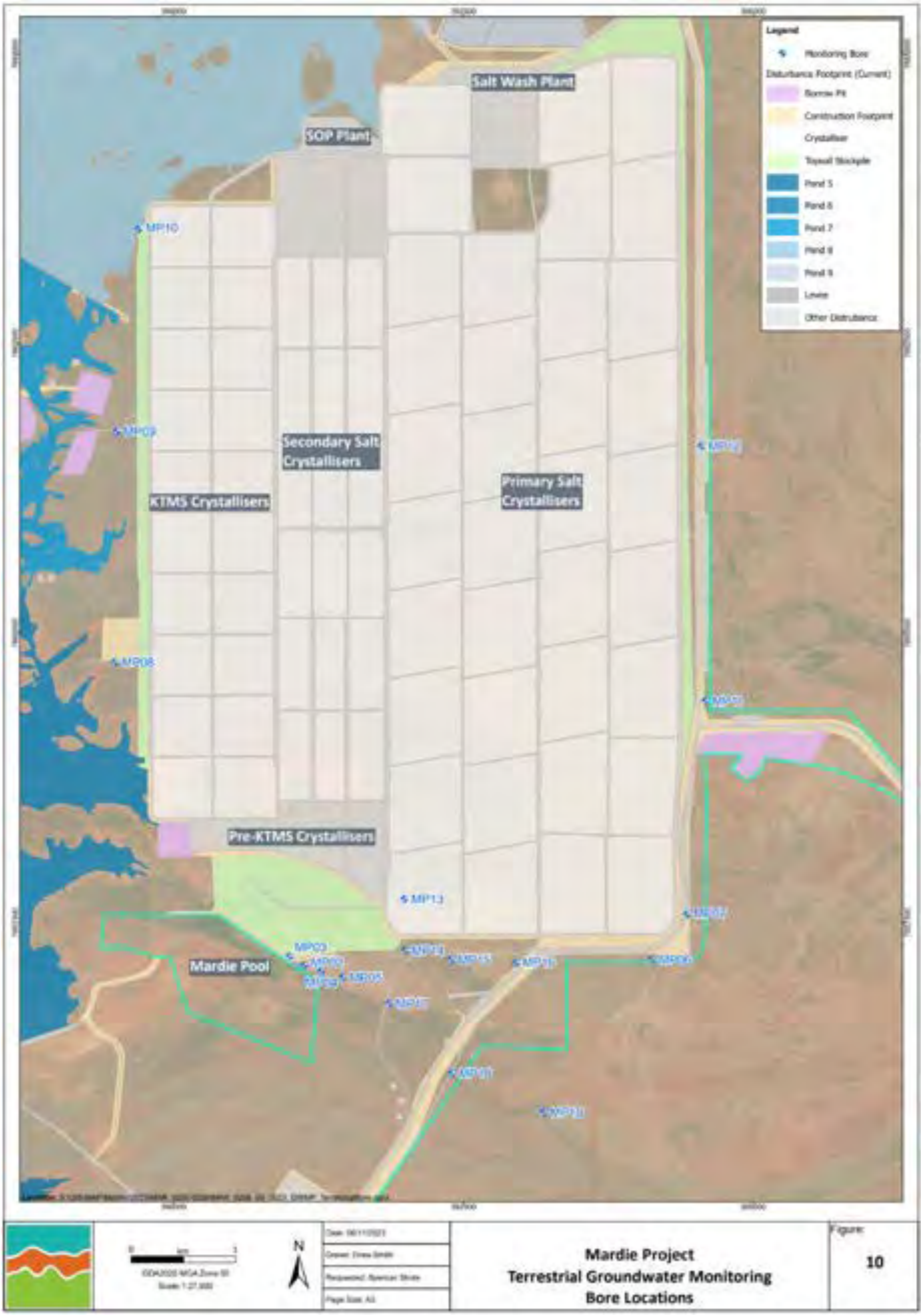


Table 5 Terrestrial Monitoring Network

Location)	Bore ID	Easting (GDA2020, MGA50)	Northing (GDA2020, MGA50)	Design	Purpose	Installation Date	SWL / EC / Telemetry*
Mardie Pool – North Side Outside Channel	MP02	391123	7657129	Fully screened	Second line of detection of seepage from Crystalliser.	4/3/22	N / N / N
	MP03	390990	7657206			5/3/22	Y / N / N
	MP04	391272	7657080			2/3/22	N / N / N
	MP05	391458	7657027			1/3/22	Y / N / N
Primary Crystalliser – Adjacent	MP06	393708	7657166		First line of early detection of seepage from Primary Crystalliser.	10/3/22	N / N / N
Primary Crystalliser – Up Gradient	MP07	394434	7657578		Background monitoring upgradient from Primary Crystalliser.	13/3/22	N / N / N
Secondary/KTMS Crystallisers – Down Gradient	MP08	389493	7659744		Down-gradient monitoring of Secondary Crystalliser.	17/3/22	N / N / N
	MP09	389507	7661739		Down-gradient monitoring of KTMS.	18/3/22	N / N / N
	MP10	389699	7663493			12/2/22	N / N / N
Primary Crystalliser – Up Gradient	MP11	394585	7659412		Background monitoring upgradient from Primary Crystalliser.	16/2/22	N / N / N
	MP12	394558	7661615			14/2/22	N / N / N
Primary Crystalliser – Adjacent	MP13	391991	7657709		First line of early detection of seepage from Primary Crystalliser	20/3/22	N / N / N
	MP14	391996	7657266			22/2/22	N / N / N

Location)	Bore ID	Easting (GDA2020, MGA50)	Northing (GDA2020, MGA50)	Design	Purpose	Installation Date	SWL / EC / Telemetry*
	MP15	392396	7657184			24/2/22	N / N / N
	MP16	392950	7657160			26/2/22	N / N / N
Mardie Creek - Upstream	MP17	391860	7656800		Upstream channel monitoring for base flow, adjacent to crystalliser.	28/2/22	N / N / N
	MP18	392404	7656195		Upstream channel monitoring for base flow.	20/3/22	N / N / N
	MP19	393660	7655367			21/3/22	N / N / N

* This column describes the installation status of Groundwater level loggers, EC loggers, and Telemetry

Groundwater salinity in the terrestrial bores to the north and east of Mardie Pool have exhibited relatively consistent salinity (EC) levels since July 2022 (**Table 6** Terrestrial Monitoring Bore Water Quality Data), coincident with significant rainfall/recharge following a long period of no rainfall. All bores except for those near the tidal flats showed brackish water quality during this time.

Table 6 Terrestrial Monitoring Bore Water Quality Data

Location	EC April 2022 (µS/cm)	EC July 2022 (µS/cm)	EC November 2022 (µS/cm)	EC April 2023 (µS/cm)	EC September 2023 (µS/cm)
MP02	2500	2200	2200	2100	2100
MP03	2800	2100	3300	3400	2200
MP04	1900	4200	2200	2200	2300
MP05	2100	3000	2200	2400	2400
MP06	1400	1400	1500	1500	1500
MP07	1400	1400	1400	1400	1400
MP08	120000	82000	85000	78000	99000
MP09	160000	82000	93000	77000	79000
MP10	190000	99000	100000	93000	95000
MP11	1100	1100	1200	1200	1100
MP12	1100	1200	1200	1400	1200
MP13	8600	7700	7800	7300	7800
MP14	1900	1900	2100	2000	2000
MP15	1500	1600	1700	1600	1600
MP16	1500	1500	1500	1500	1500
MP17	3200	2500	2500	2400	2500
MP18	2500	3600	4700	1500	2500
MP19	2600	550	790	1300	1500
Mardie Pool West	n/a	890	2800	6000	No data
Mardie Pool East	n/a	1100	2500	5900	12000

2.6.5 Gas Pipeline Corridor Monitoring Bore Network

Monitoring bores and vibrating wire piezometers (VWPs) located along the Chevron-Santos pipeline corridor between Ponds 1, 2 and 3 and at the western end of the corridor on the seaward side of Ponds 1 and 3 (the "GBH" series of bores) (Table 7, Figure 11) provide more than two years of detailed water level data for this area (with some breaks in continuity).

Figure 12 display hydrographs from bores which were originally installed for monitoring of the gas pipeline corridor. The chart displays the differing response to rainfall and tidal recharge with distance from the coast. This long-term (18 months) dataset was also used to inform the modelling of the Pond 1 Section (refer Section 2.6.7). The data indicate the following (after Golder 2022):

- Groundwater level behaviour is consistent for monitoring sites located within similar geomorphological domains (in general grouped by similar distance from the coast).
- A significant rise of groundwater level is evident following rainfall events, with up to 2m increase for the inland bores (GBH01/04/19) and variation of 0.5 m for those sites at the western end of the pipeline

corridor near the western side of Ponds 1 and 3. Inundation during rainfall events is characterised by the recorded bore GWL appearing to be above ground level.

- Bores at the western end of the pipeline corridor are affected by both rainfall events and tides, however the bores are not affected by every Spring Tide period. Response appears to be dependent upon whether inundation occurs at the maximum high tide levels in the cycle.
- Groundwater levels in bores GBH07/08/15 appear to become stable for several weeks in July 2022. Water level in all bores is constantly in flux at all other times. The closest bore to the coast, GBH16, exhibits tidal variations in this period.

Four VWP sites were installed in 2021 in the embankment of and adjacent to a trial pond constructed as part of engineering investigations. The location of the sites is provided in **Table 9** (the "VWP" series). The trial pond has since been incorporated into Pond 5. The data from these VWPs indicates the following:

- Tidal response is similar to GBH16 for VWP01/03/04 which are located within the embankments. These VWPs also show similar response to the major rainfall event of May-June 2022.
- VWP02, on the coastal side of the Pond 5 wall, displays a consistent three-week cycle of 0.1 m range which may be due to instrument-related drift (to be confirmed).

From the gas corridor network, a subset of 6 bore/VWPs has been selected to be representative of conditions on the coastal side of the evaporation ponds and will be used in monitoring under this Plan, with Trigger and Threshold values set. These are:

- S01-A, S02-A – coastal side of Pond 1.
- N01-A, N02-A – coastal side of Pond 3.
- VWP01, VWP02 – coastal side of Pond 5.

Table 7 Gas Pipeline Corridor Monitoring Bore Locations

Bore ID	Easting (GDA2020, MGA50)	Northing (GDA2020, MGA50)	Area Monitored	Baseline Collection Start Date	SWL / EC / Telemetry*
GBH16	382760	7650682	Pond 3 western corner	February 2022	Y / N / N
GBH15	383112	7649831	Pipeline Corridor Pond 1/3		Y / N / N
GBH08	383040	7649412			Y / N / N
GBH07	383422	7648484			Y / N / N
GBH04	384257	7646450			Y / N / N
GBH19	384084	7645939			Y / N / N
GBH01	384814	7645073			Y / N / N
N01-A	382834	7651093	Pond 3 western corner	April 2023	Y / N / Y
N02-A	382774	7651011			Y / N / Y
N03-A	382747	7650901			
N03-B	382757	7650800			
N04-A	382742	7650801			
N04-B	382890	7650340			
S01-A	382051	7650222	Pond 1 northern corner	April 2023	Y / N / Y
S02-A	382404	7650023			Y / N / Y
VWP-01	385604	7656160	Pond 5 adjacent sea wall	July 2021	Y / N / N
VWP-02	385610	7656435			Y / N / N
VWP-03	385784	7655525	Pond 5 internal embankment		Y / N / N
VWP-04	385537	7655654			Y / N / N

* This column describes the installation status of Groundwater level loggers, EC loggers, and Telemetry

Figure 11 Gas Pipeline Corridor Monitoring Bore Locations

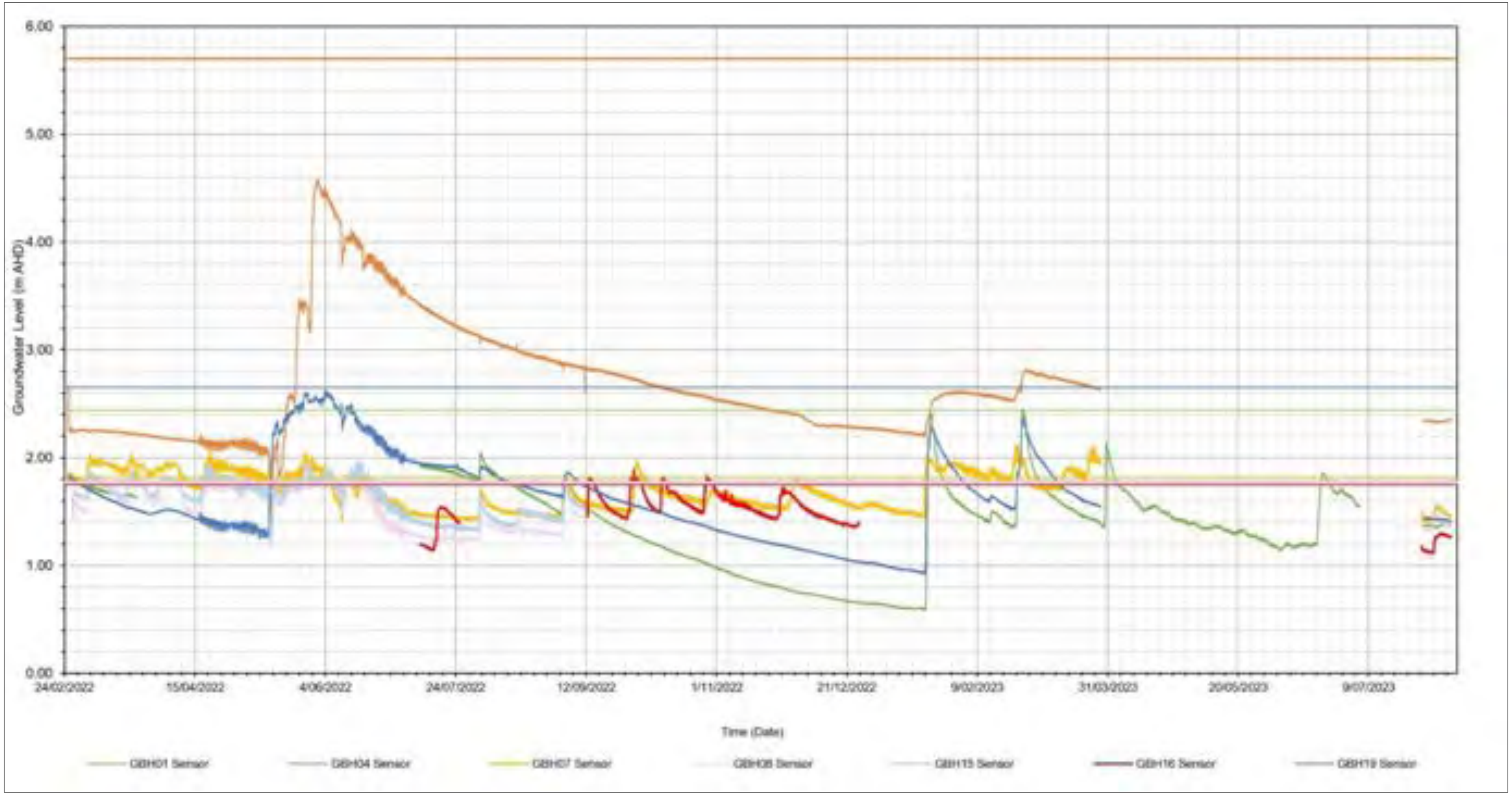


Figure 12 Gas Pipeline Corridor Monitoring Bore Hydrographs (Feb 2022-July 2023)

2.6.6 Coastal Monitoring Bore Network

A coastal monitoring bore network has been installed along the western side of the evaporation ponds. Transects and single nested bore sites have been positioned to assist with characterisation of the groundwater regime beneath the supratidal flats and to permit detection of changes in levels and gradients (vertical and horizontal), and groundwater changes which may be attributed to surface flow variations at the western boundary of the project. Details and the purpose of each monitoring bore is provided below in **Table 8**. The location of the coastal monitoring bores is shown in Figure 13.

Water level loggers are all in place in all coastal monitoring bores and are recording continuous groundwater level data. EC loggers will be installed within each bore, to collect data daily (noting that the trigger/threshold nominated in Table 16 of the GMMP utilize monthly mean/median data). While these EC loggers are on order (delivery time is ~8 weeks from order), Quarterly manual readings at the bores adjacent to Pond 1 and 2 (i.e. CMB6_1S, CMB6_1D, S01A and S02A) will be undertaken, and rental EC loggers will be installed in bores identified as being impact or control sites for early pond filling.

Coastal monitoring bores CMB6_1S, CMB6_1D, S01A and S02A, to the west of Pond 1, are in place and will provide an early warning of any potential impact in the direction of the RRDMMA. Bores RRDMMA_1 and RRDMMA_2 are no longer proposed, as the current evaporation pond footprint design, as updated in 2023, avoids this area (refer to Table 8 of the GMMP).

The coastal bores (CMB bores) have been installed with short screens and sealed to access the groundwater at discrete depths. Bores were installed as deep/shallow pairs adjacent to each other as follows:

- Shallow bores generally have screen from 0.5 to 2mbgl.
- Deep bores generally have 1.5m screen at the base of the casing string (which is variably at 7-10mbgl).
- In most cases a bentonite seal was installed from above the screen up to near surface.

Table 8 Coastal Monitoring Bore Network

Location	Bore ID	Easting (GDA2020, MGA50)	Northing (GDA2020, MGA50)	Purpose	Installation Date	SWL / EC / Telemetry*
Coastal	CMB1_1D	383372	7652041	To quantify the magnitude of vertical hydraulic gradients and vertical variations of salinity. Monitor gradients and salinity in the inter-tidal zone between ponds and the algal mat/ mangrove areas.	16/8/23	Y / N / Y+
	CMB1_1S	383371	7652040		16/8/23	Y / N / Y+
	CMB1_2D	383128	7652269		16/8/23	Y / N / Y+
	CMB1_2S	383129	7652266		16/8/23	Y / N / Y+
	CMB1_3D	382980	7652508		17/8/23	Y / N / Y+
	CMB1_3S	382978	7652508		17/8/23	Y / N / Y+
	CMB2_1D	384936	7654966		16/8/23	Y / N / Y+
	CMB2_1S	384937	7654967		16/8/23	Y / N / Y+
	CMB3_1D	386909	7659595		27/10/23	Y / N / Y+
	CMB3_1S	386816	7659632		6/10/23	Y / N / Y+
	CMB4_1D	386279	7662680		27/9/23	Y / N / Y+

Location	Bore ID	Easting (GDA2020, MGA50)	Northing (GDA2020, MGA50)	Purpose	Installation Date	SWL / EC / Telemetry*
	CMB4_1S	386277	7662679		27/9/23	Y / N / Y
	CMB4_2D	386097	7662766		28/9/23	Y / N / Y
	CMB4_2S	386095	7662768		28/9/23	Y / N / Y
	CMB4_3D	385931	7662835		10/10/23	Y / N / Y
	CMB4_3S	385933	7662834		8/10/23	Y / N / Y
	CMB5_1D	388059	7665542		27/10/23	Y / N / Y+
	CMB5_1S	388054	7665546		9/10/23	Y / N / Y+
	CMB5_2D	387975	7665603		10/10/23	Y / N / Y
	CMB5_2S	387976	7665601		10/10/23	Y / N / Y
	CMB5_3D	387915	7665650		27/10/23	Y / N / Y
	CMB5_3S	387917	7665647		10/9/23	Y / N / Y
	CMB6_1D	378175	7647383		16/8/23	Y / N / Y+
	CMB6_1S	378176	7647381		16/8/23	Y / N / Y+
	N01A	382834	7651093		13/4/23	Y / N / Y+
	N02A	382774	7651011		13/4/23	Y / N / Y+
	N02B	382774	7651011		13/4/23	Y / N / Y
	S01A	382051	7650222		14/4/23	Y / N / Y+
	S02A	382404	7650023		15/4/23	Y / N / Y+
	VWP-01	385604	7656160		26/7/21	Y / N / N
	VWP-02	385611	7656435		27/7/21	Y / N / N
	VWP-03	385784	7656552		28/7/21	Y / N / N
	VWP-04	385537	7655654		29/7/21	Y / N / N
RRDMMA	RRDMMA_1	376108	766310	**Current evaporation pond footprint design avoids this area.**		
	RRDMMA_2	373599	7645025			

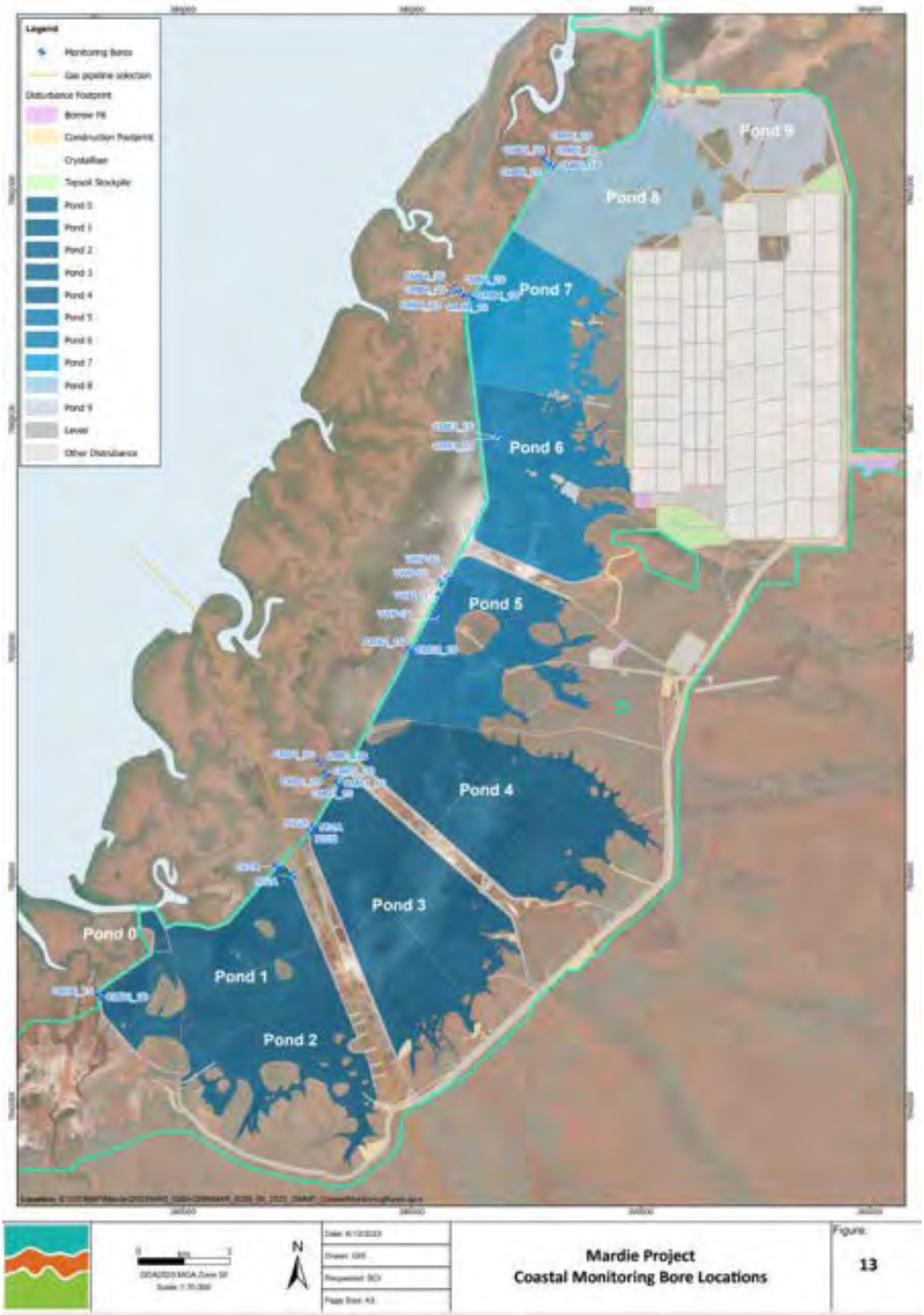
* This column describes the installation status of Groundwater level loggers, EC loggers, and Telemetry. EC loggers being installed by the 22/3/24 are noted with a +

Water level records indicate the following:

- Similar to GBH16 at the western end of the pipeline corridor, these bores exhibit strong response to spring tides which extend inland to this area. Water level increases 0.2-0.3 m over several days across the Spring tide period, followed by gradual recovery (falling) until the next impinging Spring tide.
- The rainfall event of 18-20 June 2023 (total rainfall 32 mm at Mardie BoM site) produced a rapid water level increase of 0.25-0.35 m. Greater response to rainfall was observed in bores on the northern side of the pipeline, possibly indicating preferential pooling of overland flow.

On the coastal sabkha, recharge is driven by cyclic tidal inundation. Hydrographs in Figure 14 provide examples of monitoring bore response to tidal inundation on the sabkha area between Pond 3 and the nearest mangroves to the west. At these locations deep bores are screened at approximately 8-10m below ground level (bgl) and shallow bores are screened across the water table. Water levels at the bores display a distinct rapid recharge at the time of inundation from high Spring tides. Data indicates that the soil profile is generally fully saturated by the first Spring tide which reaches the bore. The following high tides consequently keep the storage full until tides recede in following days to the point where the bore location is not inundated. From this time until the next inundation the water level in the bore gradually falls, while overprinted with a small tidal pressure pulse. The water level recession between inundation events is due to evaporative discharge.

Figure 13 Coastal Monitoring Bore Locations



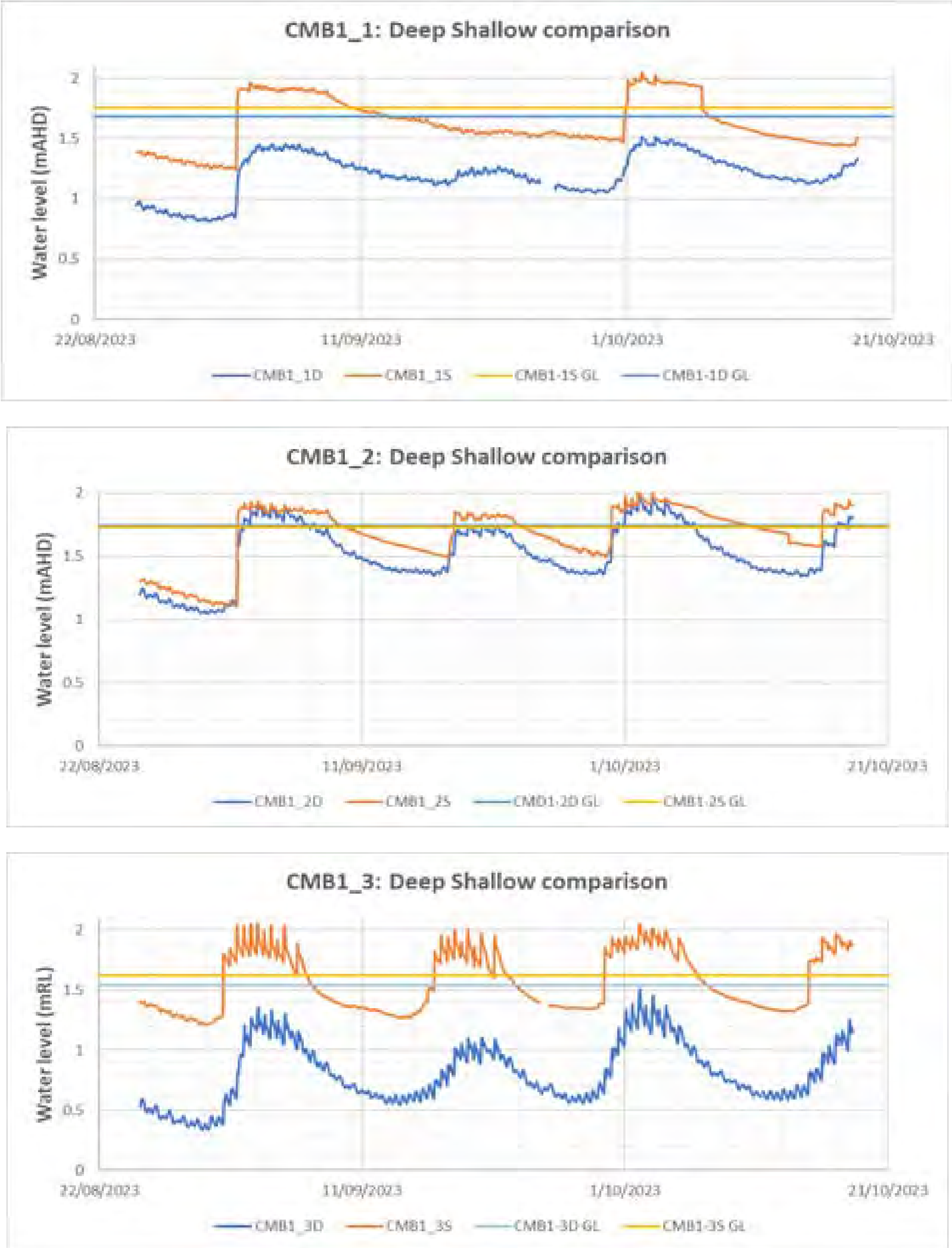


Figure 14 Coastal Monitoring Hydrographs

Hypersaline groundwater was noted across the entire intra-tidal zone and in some deep bores on the upland alluvial plain to the south-east. A selection of deep and shallow bores (2m/~8m pairings) installed on the sabkha in 2023 have consistently displayed the presence of hypersaline water in the EC range 160 000- 200 000 uS/cm (**Table 9**), indicating that the quality of water is similar throughout the soil profile relevant to the receptors in this area (algal mats and mangroves).

One shallow bore adjacent to mangroves and creeks west from Pond 3 (CMB1_3S) presented slightly less hypersaline, likely due to tidal flushing.

Bores adjacent to Pond 1 and a tidal creek at the south end of the project (CMB6_1S/D) presented salinity closer to that of seawater.

Table 9 Coastal Monitoring Bore Network Salinities (at time of installation) (from AQ2 2024)

Bore ID**	Easting GDA2020 MGA50	Northing GDA2020 MGA50	Sample Conductivity (uS/cm)	Calculated TDS* (mg/L)
CMB1_1D	383346	7652050	189000	141000
CMB1_1S	383346	7652050	184000	138000
CMB1_2D	383129	7652268	173000	130000
CMB1_2S	383129	7652268	153000	114000
CMB1_3D	382977	7652509	169000	127000
CMB1_3S	382977	7652509	113000	85000
CMB2_1D	384909	7655003	202000	151000
CMB2_1S	384909	7655003	206000	155000
CMB6_1D	378177	7647380	57000	43000
CMB6_1S	378177	7647380	73000	55000

* assumed conversion factor 0.75, compensated to 25degC at measurement

** D = deep screen 7-10m, S = shallow screen across water table

2.6.7 Impact Modelling Outcomes

Modelling has recently been completed (January 2024) across three transects for the underlying groundwater system with the objective of predicting the water level and salinity impacts of seepage (leakage) related to operation of the ponds. Some vertical seepage is anticipated to occur in a manner similar to the natural tidal inundation groundwater recharge process until the development of a self-sealing algal floor mat and halite crust in the ponds. A seepage (leakage) scenario was therefore used in the impact modelling described below and in Appendix A.

Figure 15 shows the location of the model transects. The full modelling report is provided in Appendix A.

The model was developed using Modflow USG (Panday et al, 2017) operating under the Groundwater Vistas graphical user interface (ESI, 1996 to 2021). The model uses a 2D approach to simulate the flow and salinity conditions under a range of operating scenario's that simulate the conditions of leakage or groundwater pressure affecting the underlying groundwater resource. This results from this approach then inform the monitoring of groundwater changes with the knowledge that a leakage scenario from the ponds should be observable through groundwater observations.

Pond 1 Transect

Three model scenarios were tested in the model and compared to a no development scenario:

1. Leakage from Pond 1 at a decreasing rate of seepage from 237 mm/yr initial to 9mm/yr from year 3 onwards
2. Leakage from the Ponds being a function of water stored
3. As per scenario 2 with enhanced leakage

Prior to the construction and development of Pond 1, the area across the entire sabkha along the modelled section, was also subject to tidal inundation during very high tides. This water collected in the sabkha areas and recharged the underlying shallow groundwater. These shallow groundwater levels were in turn then subject to evaporative losses, driving the development of salinity in the sabkha.

These processes are simulated in the model. The model was developed using Modflow USG (Panday et al, 2017) operating under the Groundwater Vistas graphical user interface (ESI, 1996 to 2021). The model uses a 2D approach to simulate the flow and salinity conditions.

The following observations are made regarding the predicted water levels (Figure 18; s5.2, Appendix A):

- Downstream of Pond 1 model predicted water levels respond to tidal inundation / recharge, with a similar water level trend predicted for all scenarios. For Scenarios 1 to 3, higher water levels are predicted between recharge events when compared to the No Development scenario due to the leakage simulated from Pond 1.
- Under Pond 1 the tidal recharge response is no longer predicted. For Scenario 1, which assumes that the pond and underlying groundwater system are de-coupled, water levels are predicted close to ground level (i.e., the aquifer is predicted to be brim full). For Scenarios 2 and 3, the predicted water level reflects the water level simulated in Pond 1.
- Upstream of Pond 1 water levels are predicted to decrease and no longer show the response to tidal recharge / inundation once the pond is constructed. Water levels are predicted to increase by less than 0.1 m over the duration of the prediction but are lower than those predicted for the No Development Scenario.
- The model predicted salinity profiles show limited change over the prediction period, with some small decreases in salinity predicted resulting from the seepage of less saline water into the top of the profile. Over the prediction period a small decrease of salinity (up to 1,000mg/L) is predicted at the observation points immediately downstream of Pond 1.

Analysis of the model predicted water balance suggests that for Scenarios 2 and 3, which simulate the head dependent leakage out of Pond 1, the predicted rate of leakage drops rapidly after the pond is filled. The rate of leakage out of Pond 1 decreases from around 50 kL/d over the length of the modelled section to less than 1 kL/d, over a period of a month (assuming that the pond is at operational level from the start of Scenarios 2 and 3). Additionally, for Scenario 3, there is not a significantly greater amount of leakage predicted from the base of Pond 1.

In summary, these modelling prediction results suggest that the leakage from the base of Pond 1 is limited by the small amount of aquifer storage and aquifer transmissivity in the aquifer units surrounding the Pond.

Mardie Pool

For Mardie Pool, a leakage scenario from the Crystallisers, a component of the OMP, was undertaken due to their upstream proximity, noting that Pond 6 is downstream of the Mardie Pool and the groundwater gradient is relatively flat and towards the coast.

The modelling predicted that water level and salinity impacts on Mardie Pool resulting from short term leakage from the crystallisers are predicted to be so small as to be very unlikely to cause adverse impacts (Figure 20; Appendix A, s5.3).

Leakage from the crystalliser, in the unlikely event that it occurs, is expected to result in additional discharge of groundwater to Mardie Pool. The nature of Mardie Pool (the area of the upstream surface water catchment relative to the size of Mardie Pool and the maintenance of this catchment during operation of the project) is such that it will likely continue to be flooded and over topped on an annual basis in the future. Any potential leakage from the crystallisers would be managed quickly to prevent loss of production. Water level impacts of any leakage from the crystallisers are therefore predicted to be short-term, and to occur in close proximity to the crystalliser only.

Pond 6 Transect

For Pond 6 the predicted groundwater changes are (Figure 19; App A, s5.4 - noting that this modelling scenario was undertaken to include the OMP):

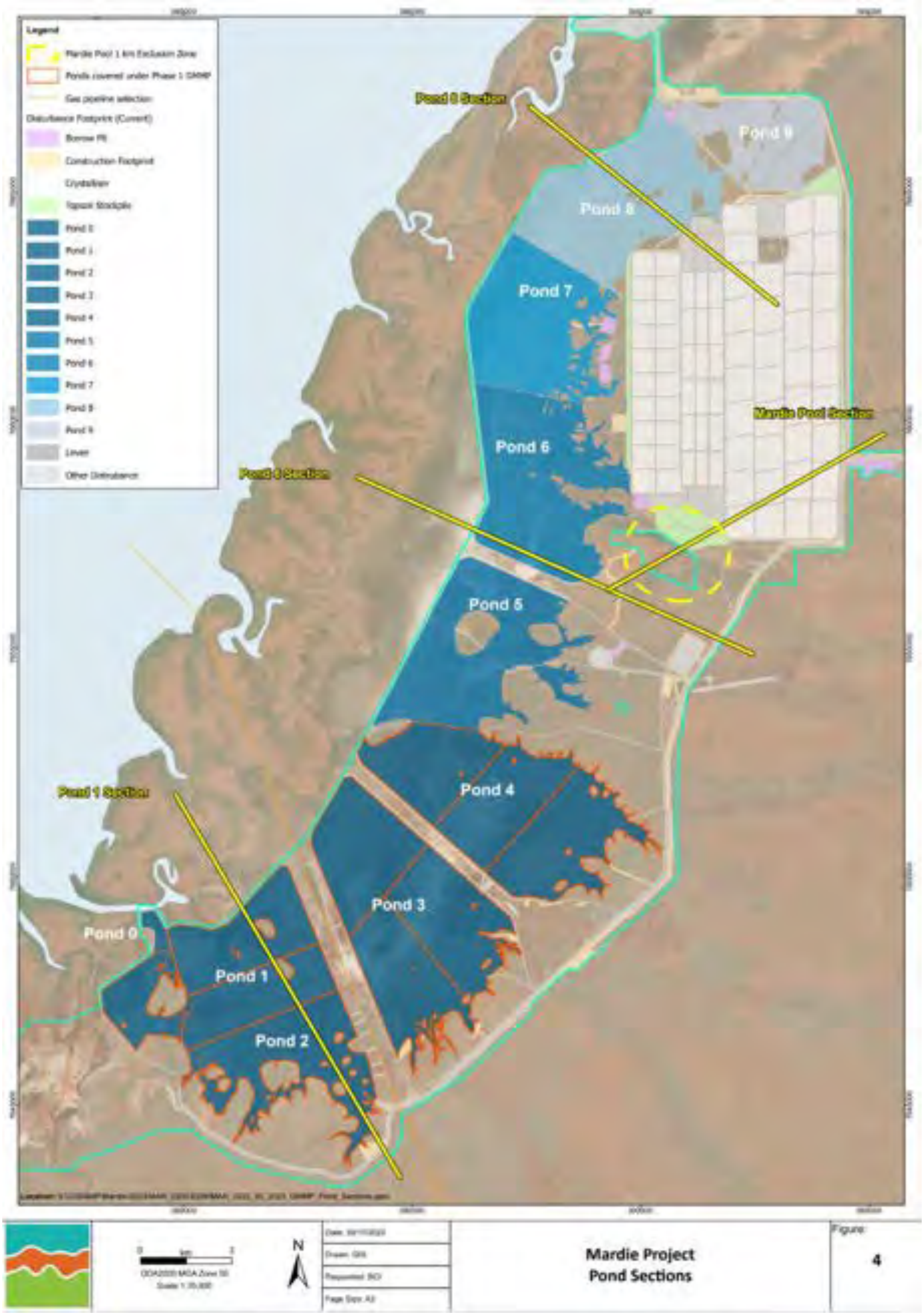
- Downstream at up to 100m from the Pond walls a potential water level increase of up to 0.5m under the modelled scenarios.
- Limited changes to salinity with a potential decrease of up to 1,000 mg/L downstream of Pond 1 against a background of 100,000 mg/L

The predicted variation in water levels is less than the pre-development simulated water level variation at this location. Predicted salinity increases from the operation of Pond 6 are limited to the immediate area and immediately upstream.

Pond 8 Transect

An additional density dependent two-dimensional section model is planned for the northern area of the Project across Ponds 8 and 9. This transect impact modelling is expected to be completed in late March/Early April 2024 and will inform a review of the GMMP with respect to the model findings and the environmental objectives, monitoring network, triggers and threshold criteria described in this GMMP.

Figure 15 Mardie Project Pond Sections



2.6.8 Conceptual and Numerical Model Updates

The collection of operational data, and comparison of this data to model predictions, will provide valuable information on the occurrence of lateral flows, due to preferential flow paths, which can then be added into the model.

Parallel to the filling of Ponds 1 through 6, operational data, additional baseline data and information from studies such as geophysical surveys will be used to update the conceptual and numerical models in order to inform model assumptions and outcomes including lateral flow paths, solute fluxes, groundwater level impacts and EC impacts and related trigger and threshold criteria.

The first model update will occur after the initial filling is complete. Modelling will then occur on an annual basis from the commencement of operations for the first 3 years.

This approach aligns with the suggestion of the DWER peer reviewer that '*model development and calibration should be continued'…* and *'that the new observations will provide some valuable additional constraints'*.

2.6.9 Geophysical Surveys

Mardie Minerals has committed to undertake Geophysical surveys to support the understanding of groundwater relationships with sensitive receptors. These surveys can be effective to monitor changes and supplement the need for the establishment of a denser network of bore holes, particularly adjacent to sensitive areas such as the RRDMA.

In January 2024, Terra Resources commenced a ground electromagnetic survey using the Loupe system for the Mardie Salt/ Potash Project (Figure 16). The purpose of the survey was to investigate whether ground EM survey (Loupe) can be used to detect conductivity variations in the hypersaline groundwater environment of the salt flats. The survey design consists of seven lines fashioned approximately NE-SW along the outer edge of the boundary of BCI mineral's salt ponds. Line length varies from 768m – 3630m. Lines are variably spaced between about ~1500m to ~4000m (Figure 16).

Geophysical survey results will be analysed to determine significance with respect to supporting the GMMP objectives, that is measuring changes to groundwater quality and quantity and will be developed with ongoing annual surveys for the first five years of operations, at which time a steady state review will be undertaken to determine future survey requirements including scope, location and frequency. The recent survey report is provided as Appendix I.

Figure 2: Loupe EM Survey line paths and line names overlaid satellite imagery.

Figure 16 Geophysical Survey January 2024

2.6.10 Groundwater Memo

Condition 4b of the EPBC 2018/8236 approval refers to the Mardie Project Groundwater Memo (Appendix L) and the implementation of the outcomes of the memo to inform the GMMP.

The outcomes listed in the memo and their status includes:

- Mardie Pool Airborne TEM review, completed, see Section 2.6.11
- Mardie Pool Bathymetry Review, completed as part of modelling (Appendix A)
- Geological fault evidence review, completed as part of modelling (Appendix A)
- Coastal Monitoring Bore Network, Section 2.6.6
- Groundwater monitoring approach, Sections 3.1 To 3.3
- Conceptual hydrogeological model, Section 2.6.3 and Appendix A
- Stage 1 Conceptual and Impact Modelling, Section 2.6.7 and Appendix A
- Stage 2 Regional Groundwater Modelling, included as a commitment in Section 3.5

Recommendations made in the Memo have subsequently been implemented where appropriate, for example the investigations into Mardie Pool, or have been updated through additional information and studies. Examples where changes to actions proposed in the memo include the final location and placement of monitoring bores which had to be informed by on-ground conditions, and the impact modelling transect locations which were determined through the finalisation of the conceptual hydrogeological model and were informed by the available data.

The groundwater memo noted that a regional groundwater flow model would be developed to assess the potential impacts of the proposed evaporation ponds on the regional groundwater system. In particular, the potential for the mobilisation of evaporated material to underlying groundwater systems and to regional receptors, In the original memo, this study was in relation to the Original Project only.

This Stage 2 modelling was proposed to occur after the finalisation of Stage 1 modelling which, as described in this GMMP, has been completed with respect to the Conceptual Hydrogeological Modelling. The fourth impact transect model will be completed in late March/earl April 2024. Stage 1 model outcomes have provided a significant improvement in the understanding of some of the potential uncertainties described at the time the memo was written (October 2021). Modelling completed to date suggests that:

- Water level and salinity impacts from operation of the ponds are predicted underneath and immediately downstream of the ponds and are not predicted to extend a significant distance downstream (hundreds of metres) into the areas of mapped mangrove communities.
- Leakage from the crystalliser, in the unlikely event that it occurs, is predicted to have minimal water level and salinity impacts. The nature of Mardie Pool (the area of the upstream surface water catchment relative to the size of Mardie Pool and the maintenance of this catchment during operation of the project) is such that it will likely continue to be flooded and over topped on an annual basis in the future. Water level impacts of short term leakage from the crystallisers (as any potential leakage from the crystallisers would be managed to prevent loss of production) are predicted to occur close to the crystalliser.

Regional groundwater investigations have commenced; 56 bores are currently in place and being monitored to inform future modelling. Additional information collected from these bores during the filling of the early ponds (1-4) will be fundamental to the development of a comprehensive region groundwater model.

Mardie Minerals has committed to complete this regional modelling (Section 3.5) and the timing of this will allow for the inclusion of the conceptual modelling, the impact modelling and the inclusion of the Optimised Mardie Project in the regional modelling, which was not a component of the original proposal in the Groundwater memo.

Any impacts observed during the pond filling process over this 6-month period will be subject to the mitigations outlined in section 3.2, and the outcomes from any implemented mitigations will also inform the regional modelling.

2.6.11 Mardie Pool

Mardie Pool, located approximately 8 kms north of Ponds 1 to 4, is noted to be the only permanent waterhole in close proximity to the Mardie Project. Located 3 km west of Mardie Homestead, Mardie pool varies between 300-500 m long and 1-20 m wide on a seasonally basis).

The relationship between water levels, groundwater/surface water interactions and riparian vegetation was investigated following installation of the monitoring network and baseline data collection. Surface water was sampled from Mardie Pool in February 2020 and was found to be fresh, with EC of 370-960 µS/cm.

Water level logger data for Mardie Pool describes the gradual fall of surface water level over the period from logger installation in October 2022 through to first rainfall inflow in February 2023. This data was analysed to quantify evaporation rates, potential inflow, natural variation of water salinity and levels within the permanent section of the Pool, and its relationship to horizontal and vertical variations of salinity in the surrounding groundwater. On the advice of TOs, it was not appropriate to install a monitoring bore in the pool, and subsequently the logger data was compromised frequently by animals dragging the logger tether rope, causing data disturbances.

Due to restricted access, a non-invasive geophysical survey (Transient Electromagnetics – TEM) was carried out in August 2022 as a substitute.

Analysis of the TEM survey and four quarterly rounds of water quality, water levels and EC depth profiling data from monitoring bores has indicated the following:

- Hypersaline groundwater appeared to be present close to surface near the western end of Mardie Pool in August 2022. There appeared to be a thin lens of less conductive water (i.e. fresher water) (although still very conductive) above the hypersaline water at the western end of the pool at the time of survey, possibly caused by recent recharge of fresh surface water during flooding or by lower saturation of hypersaline water. This is potentially further evidence that the hypersaline groundwater water may interact with Mardie Pool surface water during dry periods.EC depth profiles for bores on the north side of Mardie Creek correlate well with the TEM sections. At MP03, the most westerly bore in the group, saline water was intercepted from-5mRL (with EC increasing to 150000 µS/cm at the base of the bore). Bores MP02 and MP04, further east, exhibit progressively less conductive groundwater.
- Further upstream in the creek line the saline interface is not detected within the depth of investigation of the TEM equipment. North of bore MP17, presence of shallow fresh water is implied by the EM data, while south of MP17 (across Mardie Creek) slightly higher conductivity may be due to higher proportion of wet clay/silt. The most easterly TEM survey line near MP19 indicates a lens of fresher water near surface at the creek crossing.

Impact modelling has been completed for the Mardie Pool transect and is described in Section 2.6.7 and in Appendix A.

Mardie Pool Groundwater Investigations

To develop an understanding of the interactions between Mardie Pool and the existing water table, an assessment of the interactions between groundwater and the Mardie Pool was undertaken and used to inform conceptual and impact modelling as per Appendix A. A key finding from the assessment was that the Mardie Pool is likely to act as both a groundwater source and sink depending on rainfall/drought conditions. The investigation recommends the use of ongoing monitoring programs to contribute to the understanding of processes at the Mardie Pool, for example through ongoing modelling studies. The investigation also recommended the completion of a Salt Balance Study which has been incorporated into the Modelling Report at Appendix A.

The investigations assessment is attached as Appendix M and the Groundwater Modelling report is attached as Appendix A.

2.6.12 Mt Salt Mound Spring

Mt Salt is located approximately 1,400 m directly north from the northern boundary of the evaporation ponds. Commander (1989) describes Mt Salt as a bare, rounded hill formed by a mound spring which rises several metres above the surrounding plain.

Water discharging beneath the summit at Mt Salt was described by Commander (1989) as saline, with TDS measurement of 27,800 mg/L (equivalent EC approx. 40,000 uS/cm). The higher salinity and artesian nature of the discharge above the alluvial plain (and significantly elevated above the estimated regional static water level of 1-2 mAHD) implies a confined source which is isolated from the unconfined alluvial aquifer. Recent aerial photography (via GSWA's Geoview website) shows that very little vegetation is present on Mt Salt, presumably due to unfavourable groundwater salinity and lack of viable soil for vegetation growth. A review of ecological values of the Lower Fortescue River area by Dept of Water (Loomes 2010) does not mention Mt Salt.

The potential effects of the Mardie Project on the Mount Salt Mound Spring were investigated by AQ2 (2021). It was stated that the groundwater flow direction was not likely to carry hypersaline seepage or other potential pollutants (e.g. from the SoP plant) towards Mt Salt. It was also noted that the spring water source was likely to be deep artesian waters (possibly from the Fortescue River or the Birdrong aquifer), further implying that potential leakage from surface sources was unlikely to have any effect at Mount Salt.

Mardie Minerals has committed to ongoing quarterly monitoring of the Spring though it is noted that to date there has been no flow during sampling events to support the collection of samples.

2.6.13 Monitoring Network Expansion

A review of the existing monitoring network has commenced to identify potential locations for additional bores to support the control and reference trigger methodology (Section 3.1.1) and to also provide additional data to support the Stage 2 Regional Groundwater modelling (Section 2.6.10).

Bore selection will require consideration of physical access constraints, land tenure, ongoing access for monitoring and the existing bore network. 17 provides an overview of indicative locations (red circles) being considered. This process is expected to be completed by the end of March 2024 and initial bore drilling to occur in April 2024.

Figure 17 Potential Additional Bore Locations

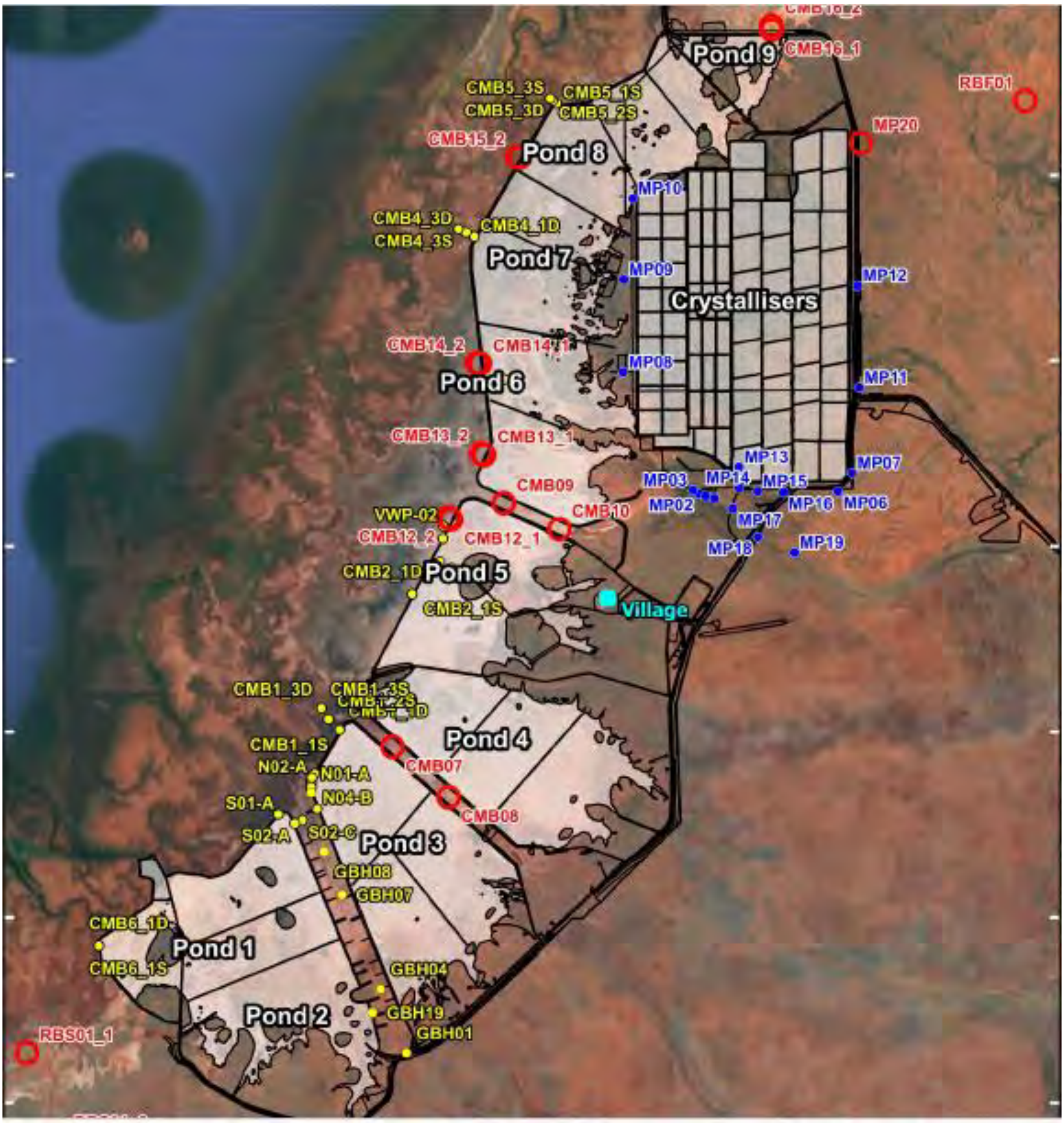


Figure 18 Modelled Impacts to Groundwater and EC – Transect 1

Figure 19 Modelled Impacts to Groundwater and EC – Transect 6

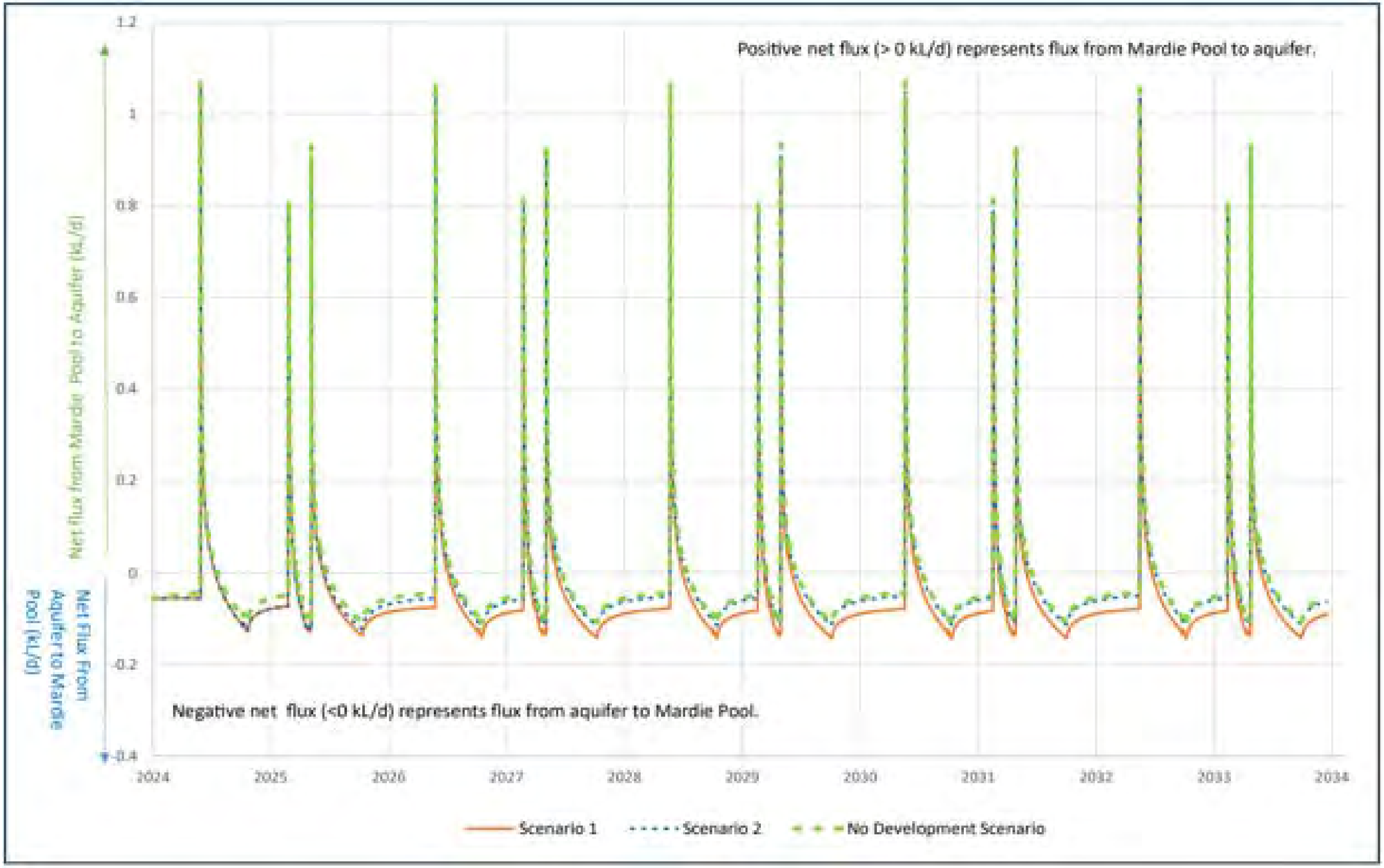


Figure 20 Modelled Impacts to Groundwater and EC – Transect Mardie Pool

2.7 Impacts to Matters of National Environmental Significance (MNES)

With regards to potential groundwater impacts to protected matters, the EPBC Approval requires the GMMP to inform monitoring and management actions to prevent unapproved impacts to the Mardie Pool, terrestrial, intertidal and subtidal protected matters and habitats. It is important to note that not all of the MNES considered under the existing EPBC approval for the original Mardie project have the potential to be impacted by any groundwater changes resulting from this project.

The full list of key protected matters identified in the EPBC Approval for the Original Project is presented below, and Condition 1 of that approval states the impact limits to relevant protected matters within the development envelope:

- *Triodia* grassland habitat
- Open riparian woodlands vegetation (inclusive of *Eucalyptus victrix*)
- Low rocky hill habitat
- Marine turtle nesting beach
- Mangrove
- Benthic communities and habitat
- Tidal channel and ocean habitat
- Coastal samphire
- Algal mat
- EPBC listed terrestrial fauna species including:
    - Pilbara leaf-nosed bat
    - Pilbara olive python
    - Northern Quoll
- EPBC listed marine fauna species including:
    - Marine turtles
    - Green sawfish
    - The short-nosed sea snake
    - Manta rays
    - Humpback whales
    - Australian humpback dolphin
    - Dugong
- EPBC Act flora species including *Minuria tridens*

The controlling provisions for the Optimised Mardie Project Proposal relevant to the GMMP include:

- Listed threatened species and communities (Sections 18 and 18A of the EPBC Act); and
- Listed migratory species (Sections 20 & 20A).

Subsequent surveys to inform the OMP assessment process have been undertaken Numerous surveys have been completed to confirm the presence of listed species in the Mardie area (Preston Consulting 2022) and the following EPBC Act Listed Threatened and Migratory species were identified as the key species of concern:

- Green Sawfish *(Pritis pritis*) – Vulnerable, Migratory
- Red Knot (*Calidris canutus*) – Endangered, Migratory
- Curlew Sandpiper – Critically Endangered, Migratory
- Great Knot (*Calidirs tenuirostris*) – Endangered, Migratory
- Greater Sand Plover (*Charadrius leschenaultia*) – Vulnerable
- Lesser Sand Plover (*Charadrius mongolus*) - Endangered, Migratory
- Eastern Curlew (*Numenius madagascariensis*) – Critically Endangered, Migratory
- Other migratory birds (as described in Preston Consulting, 2022)
- Pilbara Leaf-nosed Bat *(Rhinonicteris aurantius*) - Vulnerable
- Pilbara Olive Python (*Liasis olivaceus barroni*) – Vulnerable
- Grey Falcon (*Falco hypoleucos*) – Vulnerable
- Green turtle (*Chelonia mydas*) – Vulnerable, Migratory
- Flatback turtle (*Natator depressus*) – Vulnerable, Migratory
- Hawksbill turtle (*Eremochelys imbricata*) – Vulnerable, Migratory

Mardie Minerals is committed to ensure that the Project will be implemented in a manner that ensures the ecological integrity and function of the intertidal habitats that support the presence of EPBC Act Listed Threatened species and Migratory Species is maintained. This is evidenced by the additional $372,000 (beyond what has been conditioned) that has been committed to research of Green Sawfish and Migratory birds, as per the recently submitted Research Offsets Proposal.

Potential indirect impacts to the protected matters and MNES include alterations to the groundwater regimes and groundwater quality which may impact the health, extent or diversity intertidal BCH (i.e. mangroves, samphire and algal mats) located westward of the Project Area that support these species.

The key environmental outcomes in relation to this GMMP are noted in Section 2.3 and are the protection of benthic communities and habitats (BCH), including mangrove, algal mat and samphire communities, as well as the biological systems that they support and Protected matters and habitats associated with the Mardie Pool.

The EPBC Approval (Condition 3) notes the requirement to minimise impacts to protected matters as a result of changes to groundwaters (as defined in the approval) and the monitoring protocols and management actions within this GMMP have been designed to ensure indirect impacts associated with changes to groundwater quality and levels are managed to achieve the key environmental outcomes, comply with the EPBC approval conditions and inform the Optimised Mardie Project EPBC approval decision.

2.7.1 Potential environmental impacts and risks

Impacts associated with the filling of Ponds include potential changes to groundwater level and/or quality that may result in indirect impacts to EPBC protected matters and their habitats.

Alterations to the groundwater regimes and groundwater quality have the potential to result in impacts to the health, extent or diversity of intertidal BCH, mangroves, samphire and algal mats that support these species.

Impact pathways relevant to this Plan include:

- Potential Movement of Hypersaline Groundwater as a Result of Hydrostatic Pressure of the Brine in the ponds; and
- Impacts to groundwater regimes and quality due to saline seepage or leaks from evaporation ponds.

Impact modelling was undertaken under a number of scenarios in accordance with the conceptual model and is described in section 2.6.7 and 2.7.3.

A comprehensive Environmental Impact Assessment (EIA) detailing potential impacts was prepared to support approval of the Project under *Part IV of the Environmental Protection Act 1986* (WA) and is provided in the Optimised Project Supplementary Report (Preston Consulting, 2022; Accessible from EPA Services: Optimised Mardie Project).The assessment has noted potential groundwater impacts associated with values consistent with the original project including BCH and Mardie Pool. No additional groundwater dependent ecosystem impacts were noted, particularly in regards to open riparian woodland and *Eucalyptus Victrix* as these areas of riparian vegetation (other than Mardie Pool) are located up hydraulic gradient from the Optimised Project infrastructure by at least 3 km (Preston, 2022; and EPA, 2023).

2.7.2 Commonwealth Significance Guidelines

As per the Commonwealth's Significant Impact Guidelines (2014), when considering whether or not an action is likely to have a significant impact on a MNES it is relevant to consider all potential adverse impacts which result from the action, including indirect and offsite impacts. Potential impacts to MNES were assessed against the Commonwealth's Significant Impact Guidelines (2014) in Section 12.5 of the Optimised Proposal Supplementary Report (Preston Consulting, 2022). Significant impact assessment for impacts to listed threatened species and ecological communities and listed migratory species is provided in Appendix H.

2.7.3 Modelling outcomes

As detailed in sections 2.6.3 and 2.6.7, Conceptual Hydrogeology Modelling and Coastal Transect Modelling was undertaken in January 2024 as part of hydrogeological investigations to characterise the groundwater regime and flow (AQ2, 2024). In the intra-tidal zone and beneath the tidal flats, groundwater gradient is essentially flat. This is indicative of negligible lateral groundwater flow across this zone. There appears to be minimal lateral movement of groundwater from the sabkha to the ocean (or from the ocean inland), and negligible lateral movement of groundwater parallel to the coast, due to the very low permeability of the clay strata beneath the flats. It is therefore expected that changes to the groundwater regime due to loading or seepage from ponds will not propagate far from the ponds (either towards or parallel to the coast).

The conceptual hydrogeological model and Pond 1 and 6 Section modelling confirm that given the nature of the sabkha system, with predominantly vertical circulation and low horizontal permeability, minimal horizontal movement of groundwater is expected following the filling of the Ponds 1 to 6.

Impact modelling was undertaken under a number of potential scenarios. For Pond 1 the predicted groundwater changes are (App A, s5.2):

- Similar water levels downstream of pond 1 due to tidal inundation and recharge, with a potential increase of up to 0.5m within 5m of the pond walls
- Upstream of pond 1, predicted decrease in groundwater level of up to 0.1m

- Limited changes to salinity with a potential decrease of up to 1,000mg/L downstream of Pond 1 against a background of 100,000 mg/L

For Mardie Pool, a leakage scenario from the Crystallisers, a component of the OMP, was undertaken due to their upstream proximity, noting that Pond 6 is downstream of the Mardie Pool and the groundwater gradient is relatively flat and towards the coast.

For Pond 6, under a leakage scenario, the predicted groundwater changes are (App A, s5.4 - noting that this modelling scenario was undertaken to include the OMP):

- Further downstream at up to 100m a potential water level increase of up to 0.5m
- Under the leakage scenario tested, there is a predicted increase in salinity from 108,000 mg/L to 110,000 mg/L

Impact transect modelling across Pond 8/9 will be completed in late March / early April 2024 and will inform a GMMP review as described in Section 2.6.7.

Modelling results are provided in detail in Appendix A and a number of scenarios were tested to simulate either a leakage or groundwater pressure from the Ponds. The model then predicted groundwater level and salinity changes.

As detailed in Section 3 below, groundwater level and salinity have been chosen as the key indicators to measure observed and actual changes to groundwater from leakage or pressure noting that there will be concurrent monitoring of the structural integrity of the ponds to identify and mitigate and leakage and/or spills.

Thus, the risk of impact to BCH from the presence of the ponds is considered to be low. This risk is further mitigated by the ongoing monitoring of both groundwater (levels and quality), and BCH health (under the BCHMMP) adjacent to the ponds. The breaching of triggers for either of these will trigger investigations and, should a significant impact to BCH be attributable to changes in groundwater, BCH is committed to undertaking a range of regulatory actions, including emptying of the ponds, in order to mitigate these impacts.

2.7.4 Risk Assessment

The risk assessment provided in Table 13 is a subset of the Project Environmental Risk Register which is maintained and regularly updated as part of the Mardie Minerals Environmental Management System. The scope of the risk assessment is based on the most recent Conceptual and Impact Hydrogeological Modelling (Appendix A)) and details risks associated with changes to groundwater regimes and groundwater quality.

This Risk Assessment should be considered in conjunction with the BCHMMP risk assessment as the two plans are connected where changes are observed to groundwater and BCH condition and investigation determines that the changes are project related (see Section 3.1.3).

Risk Criteria

Each environmental risk is given a rating in terms of likelihood and consequence using the criteria in Table 10 and Table 11 .

Table 10 Risk criteria matrix: Likelihood of impact occurring

Qualitative measure of likelihood (how likely is it that this event/issue will occur after control strategies have been put in place)	
Highly likely	Is expected to occur in most circumstances
Likely	Will probably occur during the life of the project
Possible	Might occur during the life of the project
Unlikely	Could occur but considered unlikely or doubtful
Rare	May occur in exceptional circumstances

Table 11 Risk Criteria matrix: Consequence of impact

Qualitative measure of consequences (what will be the consequence/result if this issue does occur rating)	
Minor	Minor incident of environmental damage that can be reversed
Moderate	Isolated but substantial instances of environmental damage that could be reversed with intensive efforts
High	Substantial instances of environmental damage that could be reversed with intensive efforts
Major	Major loss of environmental amenity and real danger of continuing
Critical	Severe widespread loss of environmental amenity and irrecoverable environmental damage

A risk score is assigned to inherent and treated risk pathways identified with the project activities. The risk score is assigned using the risk matrix (Table 12) to generate a risk rating of low, medium, high or severe. In general, risk scores can be reduced by implementing a treatment that will reduce the likelihood of the impact from occurring. If a risk is eliminated or substituted, then the consequence can be reduced, reducing the risk score.

Table 12 Risk criteria matrix: Risk levels

	Consequence				
	Minor	**Moderate**	**High**	**Major**	**Critical**
Highly Likely	Medium	High	High	Severe	Severe
Likely	Low	Medium	High	High	Severe

Possible	Low	Medium	Medium	High	Severe
Unlikely	Low	Low	Medium	High	High
Rare	Low	Low	Low	Medium	High

Environmental risk pathways

The risk assessment relies on the comprehensive description of Project activities, so that associated risks and potential impacts can be identified. The aspects and activities of the Project are fully listed in the Project Environmental and Heritage Risk Assessment. Only hazards that result in impacts to groundwater are discussed. The risk assessment is outlined in Table 13 .

Table 13 Risk Assessment

Stressor	Risk	Impact	Protected Matters	Risk Rating			Management	Residual Risk Rating		
				Likelihood	Conseq.	Risk Rating		Likelihood	Conseq.	Risk Rating
Change to groundwater regime and quality	Seepage from Ponds results in alterations to groundwater regimes and quality impacting the environmental values to the BCH west of the evaporation ponds or to the Mardie Pool	Loss or reduction in BCH quality. Loss or reduction in Mardie Pool quality.	• Benthic communities and habitats (BCH) • Mangrove • Algal mat • Samphire communities • Mardie Pool • Open Riparian Woodland (• Green Sawfish (*Pritis pritis*) • Red Knot (*Calidris canutus*) • Curlew Sandpiper (*Calidris ferruginea*) • Great Knot (*Calidirs tenuirostris*) • Greater Sand Plover (*Charadrius leschenaultia*)	Possible	High	Medium	Pond wall integrity monitoring program Implement the Groundwater Monitoring and Management Plan Implement the BCHMMP Mardie Pool Monitoring Impact transect modelling	Unlikely	Moderate	Low

Stressor	Risk	Impact	Protected Matters	Risk Rating			Management	Residual Risk Rating		
				Likelihood	Conseq.	Risk Rating		Likelihood	Conseq.	Risk Rating
			• Lesser Sand Plover (*Charadrius mongolus*) • Eastern Curlew (*Numenius madagascariensis*) • Other migratory birds (as described in Preston Consulting, 2022) • Grey Falcon (*Falco hypoleucos*) • Green turtle *(Chelonia mydas)* • Flatback turtle *(Natator depressus)* • Hawksbill turtle *(Eremochelys imbricata)*							

Stressor	Risk	Impact	Protected Matters	Risk Rating			Management	Residual Risk Rating		
				Likelihood	Conseq.	Risk Rating		Likelihood	Conseq.	Risk Rating
	Groundwater welling as a result of downward pressure	Loss or reduction in BCH quality.		Possible	High	Medium	Self sealing pond floor design Implement the Groundwater Monitoring and Management Plan Implement the BCHMMP	Unlikely	Moderate	Low
	Wastewater treatment plant irrigation waters causes eutrophication in soil and groundwater associated with irrigation field.	Groundwater/soil contamination.		Possible	Moderate	Medium	Construction and operation of the wastewater treatment plant managed under Part V of the Environmental Protection Act.	Unlikely	Moderate	Low
	Inefficiency of oil water separators leads to discharge of hydrocarbon	Decline in soil or groundwater quality leads to contaminated site.		Possible	Moderate	Medium	Discharge of wash water to be regulated under Part V of the EP Act. Contamination regulated under Part V of the EP Act and the Contaminated Sites Act if not remediated	Unlikely	Moderate	Low

Stressor	Risk	Impact	Protected Matters	Risk Rating			Management	Residual Risk Rating		
				Likelihood	Conseq.	Risk Rating		Likelihood	Conseq.	Risk Rating
	contaminated water.									
	Groundwater drawdown from operations of the borefield required to supply water to the camp facilities.	Decline in groundwater quantity		Unlikely	Moderate	Low	Construction and operation of the borefield will be managed under the 5C licence granted under the RIWI Act.			Nil

2.7.5 Environmental Management Measures

The leakage of water from Ponds and pressure on groundwater system has the potential to impact protected matters within the development area and adjacent areas. Modelling was undertaken under these scenarios to develop an understanding of the scale of potential impacts to then inform the development of indicators and relevant trigger and threshold criteria for the implementation of investigation and management actions.

Whilst there is a residual risk of changes to groundwater regimes in the very near vicinity to the Ponds (within 100 m) and hence potential impacts to BCH, the management actions associated with this plan including daily trigger threshold monitoring, the monitoring of Pond wall integrity, mitigation measures such as reversal of pond filling and the BCHMMP management actions are considered appropriate to reduce the likelihood of unauthorised impacts to protected matters.

To the extent any deviation between the onsite measurements and the modelling predictions is observed, an adaptive management has been incorporated into the revised GMMP to ensure the Groundwater Objective is achieved, outlined in greater detail in Section 4. Further to this, as detailed in the Approval conditions, there are subsequent remediation requirements that need to be implemented as part of threshold exceedance investigations and these are described in Section 3.4.3.

2.8 Residual Uncertainties and Precautionary Strategies

The key assumptions and uncertainties, and the status of proposed strategies to address these, are listed in Table 14. Refer also to Appendix C:.

Table 14 Key Assumptions and Uncertainties and Status of Strategies to Address

Item	Assumption/ Uncertainty	Strategy to address uncertainty	Timing	Status of Strategies to Address
1	The hydrogeological model lacks certainty on groundwater conditions in the deeper substrates, particularly to the west of the project.	• Installed shallow and deep boreholes in coastal zones to measure vertical salinity distributions in mangrove stands, algal mats and samphire communities to determine water quality and the existence (or not) of fresh groundwater flows. • Hydraulic testing programme to determine in-situ permeability of gravelly clay layers and potential for transportation of hypersaline seepage from the ponds to BCH and Mardie Pool.	• Terrestrial bores were installed in March 2022. Some coastal bores were installed in February 2022 and additional new coastal bores were installed adjacent to Ponds 1-5 in July 2023. • A series of pumping tests was completed in Q4 2022 to inform the regional groundwater impacts modelling.	• Additional coastal bores up to Pond 8 were installed in October 2023. • AQ2 has completed modelling of the 'Pond 1 Section to predict groundwater impacts following the filling of Pond 1 through 4. • The modelling report is provided in Appendix A of this GMMP.
2	Changes to groundwater levels and quality can be detected and responded to effectively before an ecological impact occurs.	• The inland monitoring bore network around Mardie Pool and Crystallisers has been in place since April 2022 to acquire baseline groundwater level and quality data. • New coastal monitoring bores have been installed adjacent to Ponds 1-5 (in July 2023) and up to Pond 8 (in October 2023) to acquire baseline groundwater water level and salinity data in the intertidal zone. A real-time telemetry system was installed to provide regular data access. • Historical bore/VWP data has been identified and incorporated to the coastal network, providing baseline groundwater levels since July 2021 for Ponds 1-5.	• Baseline groundwater monitoring is in place across inland areas (from April 2022) and Ponds 1 to 5 (from July 2021). • Additional monitoring bores have been installed adjacent to Ponds 1 to 8 (Q3/4 2023).	• Five quarterly monitoring events have been conducted for terrestrial bores. • The coastal monitoring bore network provides real-time data, which helps in detecting any possible leakage and taking prompt investigation and response actions. • The proposed trigger and threshold criteria have been designed to identify project related impacts and consider seasonal variations within an adaptive management context.
3	The level of reliance on 'fresh' groundwater by	• Ensure the groundwater investigation and monitoring network is capable of providing	• Baseline groundwater monitoring is in place across inland areas	• To date there has been no evidence of 'fresh' groundwater in

Item	Assumption/ Uncertainty	Strategy to address uncertainty	Timing	Status of Strategies to Address
	the various benthic primary producer communities at Mardie, including mangroves, samphire wetlands and algal mats over various timeframes requires quantifying.	sufficient information to quantify the use of fresh groundwater by BCH, so that response triggers can be determined to suit the GMMP's objectives. • The monitoring network will gather data to characterise groundwater flow towards coastal receptors. This data will help determine if the network needs expansion, characterise groundwater flow, and quantify natural quality/level ranges to determine appropriate trigger values based on natural groundwater variation.	(from April 2022) and Ponds 1-5 (from July 2021). • Additional monitoring bores have been installed adjacent to Ponds 1-8 (Q3/4 2023).	the vicinity of the evaporation ponds or benthic primary producer communities to the west. • Regional studies being undertaken by WAMSI at several sites along the Pilbara coast have reported similarly high salinities in surface sediments within these communities. • No reliance of 'fresh' groundwater is believed to occur.
4	The ecological water requirements of Mardie Pool are not known with certainty.	• Investigate the true groundwater dependence and salt tolerance of the various vegetation species surrounding Mardie Pool, including *Typha domingensis* and *Melaleuca argentea*. Use outputs in the development of triggers and thresholds in the GMMP. • The groundwater/surface water regime at Mardie Pool is being investigated through the proposed monitoring network, surface water investigations and the use of geophysical survey (TEM) to identify location of the saline water interface and its interaction with Mardie Pool.	• Groundwater and surface water data collected since April 2022 has been used to inform seepage modelling in vicinity of Mardie Pool (nearing completion Q3 2023). Collection and analysis of baseline data will continue until the filling of the adjacent crystallisers.	• Mardie Pool transect modelling was completed in January 2024 and included in Appendix A. • Ongoing monitoring and investigations will inform the next scheduled iteration of the GMMP and supporting modelling.
5	The extents, severity and impact on vegetation of potential groundwater mounding from the ponds is not able to be	• Ensure the monitoring and investigations described in (2) include transects perpendicular to the ponds.	• Baseline groundwater monitoring is in place across inland areas (from April 2022) and Ponds 1 to 5 (from July 2021).	• Noting the conceptual hydrological model (refer Section 2.6.3) and the outcomes of the Pond 1 Transect modelling (refer Section 2.6.76) significant changes to groundwater

Item	Assumption/ Uncertainty	Strategy to address uncertainty	Timing	Status of Strategies to Address
	predicted with reliability, owing to the scale of the project.		• Additional monitoring bores have been installed adjacent to Ponds 1-8 (Q3/4 2023). • Modelling of the 'Pond 1 Transect' completed in October 2023.	levels of quality beyond the immediate vicinity of the evaporation ponds is not expected.
6	The action triggers provided in this GMMP are calculated on baseline data collected to the current time.	• To meet GMMP's objectives, the groundwater investigation and monitoring network must accurately quantify BCH's use of fresh groundwater, allowing for response triggers that align with natural groundwater variations. • Review the triggers and thresholds following groundwater modelling to incorporate knowledge of the regional and local groundwater flow regime.	• Triggers and thresholds have been developed based on the baseline data available to date. • Ponds 1 to 3 filling not predicted to affect Ponds 6 to 9 groundwater levels. Coastal monitoring bores near Ponds 6 to 8 will provide baseline data and trigger review • Fresh groundwater has not been recorded in the vicinity of the evaporation ponds of tidal flats to the west.	• Trigger and threshold values have been developed, following the approach of ANZG (2018), for EC/salinity and groundwater level. • As discussed in Section 3.1.1 due to significant seasonal variations, a modified M-BACI approach for triggers and thresholds for groundwater level has been proposed. • A similar approach is proposed for coastal bore salinity (EC).
7	Brine losses to the environment as seeps and leaks will diminish over time, due to geological and biological processes reducing infiltration rates through the clay floors and walls.	• This assumption may be able to be confirmed through the monitoring described above. Additional investigations would be required for ponds where seepage losses have become an issue.	• A conservative approach, which assumes significantly higher seepage rates than are expected, has been applied in the modelling .This modelling does not predict significant losses of brine or impacts to adjacent groundwater or benthic communities.	• The ongoing monitoring of groundwater levels and quality throughout the coastal monitoring bore network will confirm leakage rates against the model outputs following the commencement of pond filling for Stage 1.
8	Influence of Sino Iron Project dewatering	• The conceptual modelling indicates the potential groundwater drawdown beneath the proposed	• Regional impacts modelling to begin Q3/4 2023.	• Undertake Regional Groundwater Modelling once Stage 1 modelling

Item	Assumption/ Uncertainty	Strategy to address uncertainty	Timing	Status of Strategies to Address
		crystallisers due to dewatering at Sino Iron Mine would be between 0 to 0.3 meters. However, it is also indicated that this drawdown is not likely to have a significant impact on the groundwater regime near the Mardie Project crystallisers and Mardie Pool. • Groundwater modelling will assess the impact of dewatering at Sino Iron on water levels and flow at Mardie Project. The potential for impacts on receptors like Mardie pool, Mt Salt Mound Spring and others will be assessed to determine necessary mitigation measures or monitoring locations.		is completed as noted in Section 2.6.10 and Section 3.5.

3. PROVISIONS OF THE PLAN

3.1 Rationale for Choice of Management Framework

Mardie Minerals recognises that the EPA prefers outcome-based provisions, and these have been maximised in our approach. Mardie Minerals has developed an **outcome-based** management framework for implementation of the GMMP. Outcome-based elements focus on monitoring and evaluating specific measurable outcomes, usually driven by trigger and threshold criteria and are performance based.

The management actions have been designed to meet the overall objective, with the management targets designed to assess the effectiveness of management actions. This Plan also describes the monitoring and reporting approach that will be undertaken to assess the effectiveness of the management actions in meeting the environmental outcomes.

The outcome-based provisions of this Plan are set out in Section 3.2.

3.1.1 Groundwater Level - Coastal Bores / Pipeline Bores

Data Analysis Australia (DAA) was engaged to design a statistically sound method for establishing operational trigger and threshold criteria and an analysis tool to identify groundwater level changes and whether these could be attributed to environmental, or project related causal factors.

Information Review

DAA conducted a thorough analysis of groundwater level data collected from 18 bores on the Mardie site (as detailed in Section 2.6) to determine the most suitable method. A long-term dataset from four bores within the gas pipeline corridor were identified, which captures the long-term (2 years) variability in groundwater levels across the tidal flats. The long-term water level dataset collected from the gas pipeline corridor bores, as well as the more recent data from the coastal monitoring bore network (see Section 2.6.6), shows significant temporal variation in response to tidal influence, significant rainfall events and other factors such as barometric pressure and wind direction and speed (the latter affect the flooding and persistence of marine waters across the tidal flat). The key findings from that review were that bores typically exhibit two types of seasonality with bores nearer the ocean and influenced by tides showing biweekly seasonality and bores further from the ocean showing monthly seasonality. The review also identified that the coastal monitoring network did not have a full 24 months of data as recommended by the ANZG (2018).

ANZG Consistency

Noting the above finding, an alternative approach, endorsed and consistent with ANZG (2018), has been proposed that uses a Modified Before/After Control Impact (BACI) methodology to identify robust triggers and threshold criteria. DAA has proposed a modified Before/After Control Impact (M-BACI) design that is characterised by:

- Careful analysis of bores to find appropriate matching
- Multiple reference bores for each control bore
- Statistical time series analysis techniques (ARIMA)
- Dynamic triggers and thresholds to account for seasonal variability

The proposed methodology also implements a continuous collection of data with daily measurement, over and above the quarterly frequency noted in the ANZG (2018).

The ANZG (2018) guidance states that “model-based inference can be very general and precise from a limited number of sample observations” and that the inference though depends on the availability of data and the system conceptualisation. Further guidance is then provided to address data availability through time series analysis in order to identify long-term trends, seasonal fluctuations and non-seasonal variations.

The proposed methodology utilises a time series method (Auto-Regressive Integrated Moving Average (ARIMA) modelling) because of the richness and temporal variation observed, noting that the guidelines do give reference throughout to accounting for seasonality in an appropriate way, where seasonal factors exist and the ANZG (2018) do reference the ARIMA model.

Summary of the Proposed Methodology and Implementation

A BACI analysis usually considers the mean response (magnitude) of change) before and after impact. The proposed methodology is far more rigorous as it considers changes in temporal trend and seasonality as well as magnitude. It also enables far more timely identification of impacts (close to real time).

Three reference bores that provide the best historical match are found for each impact bore. Pond 1 impact is measured using reference bores located at Pond 3 or Pond 5. Pond 3 impact is measured using reference bores located at Pond 5 or Pond 7 and so on. The methodology enables reference bores to be rematched when needed (for example, when Pond 3 itself is filled, deeming any Pond 3 reference bores impact bores themselves and hence no longer valid as reference bores).

The methodology assumes that if the water level patterns of the impact and reference bores are similar for the last 3-months, then they should remain similar. If they don’t, then any changes may have been caused by an external source. The ARIMA model is fitted to data from the impact bore and its reference bores to predict what we expect to happen at the impact bore for the next seven days. A trigger is defined to occur if observed data are outside the 95% confidence interval.

Trigger and Threshold Criteria

A conservative approach to developing trigger and threshold criteria for detecting groundwater level changes was taken, consistent with ANZG (2018). This approach was recently tested through a Monte Carlo simulation to evaluate how simulated project impacts (0.05 to 0.5m) would be detected and a “false positives analysis” (details in Appendix K).

The triggers and thresholds in Table 16 are based on exceeding 95% confidence intervals over a number of consecutive days. Adding to the conservative nature of the approach is that once operational, the trigger forecasts will be updated daily in real time.

A threshold is exceeded if triggers occur each day for one week or longer, and whilst this method is sensitive to false positive trigger notifications, this will allow for the very close examination of data particularly through the staged filling process.

It is expected that this process may result in a number of “false positive” triggers which will result in detailed data assessment through the investigation process. The Threshold criteria of 1 week has been set to allow for the review and investigation of possible seasonal and environmental factors as opposed to project related impacts.

The approach is consistent with the ANZG guidelines specifying that the triggers and thresholds should be set seasonally, where seasonal variation exists, with the model picking up this seasonality on a continuum. Fixed value trigger and threshold criteria were not considered appropriate given the large daily variation and inconsistency with the modelling methodology.

The criteria will be supported by an analysis and reporting tool being developed by DAA that will provide daily review of data integrity, trigger and threshold alerts and a reporting function at selected frequencies, for example weekly or fortnightly.

Environmental and Incremental Change Detection

With regards to detecting and determining whether changes are environmental, or project driven, the model will highlight the potential changes at such a discrete time interval that the investigation by BCI will be able to assess and determine this.

With regards to the detection of longer term incremental changes, both incremental and immediate changes will be detected by the methodology as a result of comparing the impact bore to reference bores. Incremental deviations/impacts will result in additional triggers and thresholds due to poorer model fits/model predictions.

Impact and Reference Bores

Optimal reference bores were selected for each impact bore using Dynamic Time Warping (DTW). Through advanced statistical analysis, impact and reference bores for Ponds 1 to 4 have been selected and shown in Table 15.

The use of three reference bores for each impact bore improved forecast accuracy and trigger detection as well as being consistent with guidelines (a deviation from just one reference bore suggests a change in the reference bore, rather than the impact bore).

As more data becomes available through the filling of Ponds the DTW will inform a review and selection of impact and reference bores for the rest of the Ponds and for those Ponds where impacts are detected and therefore new Reference bores are deemed necessary.

Any new control or references bores will require a 3-month data set and Section 2.6.13 provides a description of the potential expansion of the monitoring bore network and timing.

Online Tool

An online tool is underdevelopment to be used for real time alerts and data analysis. The online tool is currently under development in prototype model. It is being developed in the statistical package R, using R Shiny. Automated emails will be sent to team members at BCI whenever a trigger or threshold is observed. The tool will show graphical displays of the data (impact and reference bores) to assist with the understanding, review and investigation. Standardised reports (for example, on a monthly basis) will also be generated.

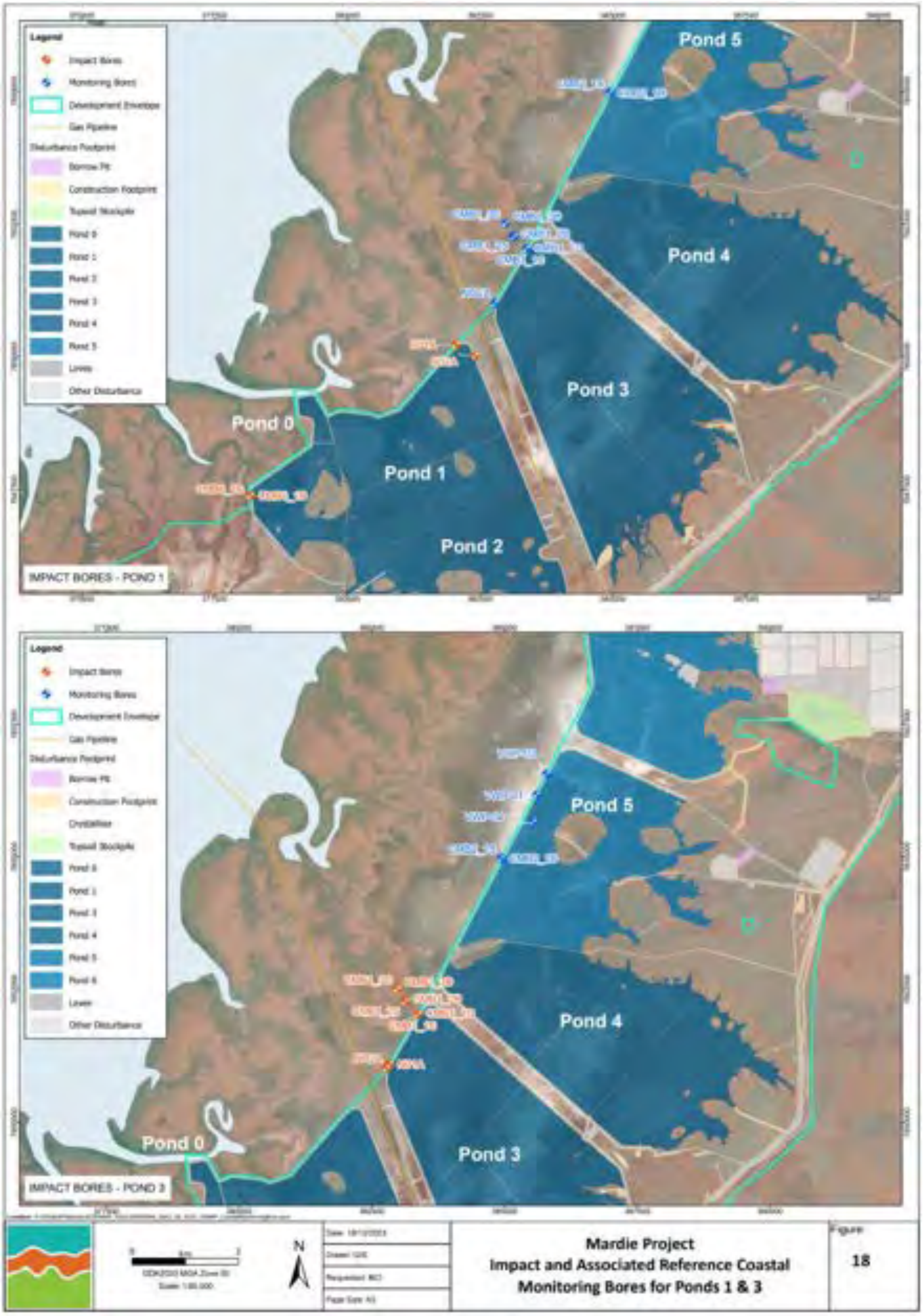
Table 15 Impact and Reference Bore Locations

Location of Bores	Impact Bore ID	Easting (GDA2020MGA50)	Northing (GDA2020, MGA50)	Reference Bore ID	Easting (GDA2020, MGA50)	Northing (GDA2020, MGA50)
Pond 1 (Relevant for Ponds 1 and 2)	CMB6_1D	378175	7647383	CMB1_3D	382980	7652508
				CMB1_2D	383128	7652269
				CMB1_2S	383129	7652266
	CMB6_1S	378176	7647381	CMB1_3D	382980	7652508
				CMB1_2D	383128	7652269
				CMB1_2S	383129	7652266

Location of Bores	Impact Bore ID	Easting (GDA2020MGA50)	Northing (GDA2020, MGA50)	Reference Bore ID	Easting (GDA2020, MGA50)	Northing (GDA2020, MGA50)
	S01-A	382051	7650222	N02-A	382774	7651011
	S01-A	382051	7650222	CMB2_1D	383128	7652269
	S01-A	382051	7650222	CMB2_1S	383128	7652269
	S02-A	382404	7650023	CMB2_1D	383128	7652269
	S02-A	382404	7650023	CMB1_1D	383372	7652041
	S02-A	382404	7650023	CMB2_1S	383128	7652269
Pond 3 (Relevant for Ponds 3 and 4)	CMB1_1D	383372	7652041	CMB2_1D	383128	7652269
Pond 3 (Relevant for Ponds 3 and 4)	CMB1_1D	383372	7652041	CMB3_1D	386909	7659595
Pond 3 (Relevant for Ponds 3 and 4)	CMB1_1D	383372	7652041	CMB3_1S	386816	7659632
Pond 3 (Relevant for Ponds 3 and 4)	CMB1_1S	383371	7652040	CMB2_1S	383128	7652269
Pond 3 (Relevant for Ponds 3 and 4)	CMB1_1S	383371	7652040	CMB2_1D	383128	7652269
Pond 3 (Relevant for Ponds 3 and 4)	CMB1_1S	383371	7652040	CMB3_1S	386816	7659632
Pond 3 (Relevant for Ponds 3 and 4)	CMB1_2D	383128	7652269	CMB2_1D	384937	7654966
Pond 3 (Relevant for Ponds 3 and 4)	CMB1_2D	383128	7652269	CMB2_1S	384937	7654967
Pond 3 (Relevant for Ponds 3 and 4)	CMB1_2D	383128	7652269	CMB3_1S	386816	7659632
Pond 3 (Relevant for Ponds 3 and 4)	CMB1_2S	383129	7652266	CMB3_1D	386909	7659595
Pond 3 (Relevant for Ponds 3 and 4)	CMB1_2S	383129	7652266	CMB2_1S	384937	7654967
Pond 3 (Relevant for Ponds 3 and 4)	CMB1_2S	383129	7652266	CMB2_1D	384936	7654966
Pond 3 (Relevant for Ponds 3 and 4)	CMB1_3D	382980	7652508	CMB4_1D	386279	7662680
Pond 3 (Relevant for Ponds 3 and 4)	CMB1_3D	382980	7652508	CMB5_1D	388059	7665542
Pond 3 (Relevant for Ponds 3 and 4)	CMB1_3D	382980	7652508	CMB5_2D	387975	7665603
Pond 3 (Relevant for Ponds 3 and 4)	CMB1_3S	382978	7652508	CMB5_3S	387917	7665647

Location of Bores	Impact Bore ID	Easting (GDA2020MGA50)	Northing (GDA2020, MGA50)	Reference Bore ID	Easting (GDA2020, MGA50)	Northing (GDA2020, MGA50)
				CMB5_1S	388054	7665546
				CMB4_2S	386095	7662768
	N01-A	382834	7651093	CMB2_1S	384937	7654967
				CMB3_1S	386816	7659632
				CMB2_1D	384936	7654966
	N02-A	382774	7651011	CMB2_1S	384937	7654967
				CMB3_1S	386816	7659632
				CMB2_1D	384936	7654966

Figure 21 Impact and Reference Bore Locations



3.1.2 Electrical Conductivity – Coastal Bores/ Pipeline Bores

EC (salinity) has been chosen as an indicator as an increase from baseline values may indicate an impact from the evaporation or crystallizer ponds (i.e. through brine seepage or changes in groundwater levels or flows associated with changes in hydraulic head) and the groundwater at the location of the bore.

Limited salinity data is currently available from the coastal bore monitoring network, such that the nomination of triggers and thresholds has been based on ANZG (2018) requirements and will be informed by the installation and commencement of EC data logging commencing in late Q1 2024 and into Q2 2024. Using a similar approach to that proposed for the water level criteria, the relationship between nominated 'impact' and 'reference' sites will be used to identify a change. ANZG (2018) states that 'a referential approach is commonly used to derive locally relevant water quality guideline values. In this approach, the natural range of values for key indicators at reference sites is used to provide a suitable baseline for comparison against values derived from a similar 'impact' situations.

3.1.3 Benthic Communities and Habitats - Indicators

Changes to intertidal benthic communities and habitat (BCH), including mangrove, coastal samphire and algal mat could occur as a result of changes to groundwater regimes or groundwater quality.

Thus, the health, extent and diversity of BCH will be monitored in parallel to the indicators above as detailed in the Benthic Communities and Habitats Monitoring and Management Plan (BCHMMP).

The approved BCHMMP has identified the following Indicators which are presented here in the context of the relationship between the two plans. Note that the response to triggers and thresholds associated with BCHMMP indicators will be undertaken through that plan and not the GMMP:

- Algal Mat Health – quarterly replicate transects
- Mangrove Health – quarterly replicate quadrats
- Samphire Health – quarterly replicate quadrats
- Subtidal seagrass Health – quarterly replica transects
- Tidal flood height / surface water height

3.1.4 Mardie Pool – groundwater level and quality

Five quarterly water quality monitoring events have taken place at the terrestrial bores since November 2023. The baseline EC (salinity) (µS/cm) and baseline Bromide (mg/L) data have been used to derive trigger and threshold values (Table 16).

Trigger and threshold values have been derived based on a High Level of Ecosystem Protection (HEPA) which, based on the recommended approaches and trigger values in ANZECC & ARMCANZ (2000), involves the comparison of 'test' data to the 20th and/or 80th percentile of background data. A high level of ecosystem protection (for marine ecosystems in WA) allows for small detectable changes beyond limits of natural variation, but no resultant effect on biota (EPA 2016). This is equivalent to the process recommended for slightly to moderately disturbed ecosystems as described in ANZG (2018).

3.1.5 Mt Salt Mound Spring

It has been suggested that the source of Mt Salt spring be determined through water sample analysis. Personnel have visited Mt Salt on several occasions, the most recent being 23 August 2023, but no water has been present. Anecdotal evidence suggests that the mound spring has not flowed for some time.

Mt Salt Mound Spring is within the coastal hypersaline plume of the tidal flats and also in a direction perpendicular to the dominant groundwater gradient so any seepage from the crystallisers is unlikely to have effect in that direction.

Whilst no criteria have been developed in relation to Mt Salt, Mardie Minerals will continue to regularly visit Mt Salt to check for artesian flow.

Table 16: Trigger and Threshold Values for 'Mardie Pool' monitoring bores

Location	Bore ID	Purpose	Salinity Baseline Median Value EC (µS/cm)[1]	Salinity Trigger Value EC (µS/cm)[2]	Salinity Threshold Value EC (µS/cm)[3]	Bromide Baseline Median Value (mg/L)[4]	Bromide Trigger Levels (mg/L)	Bromide Threshold Levels (mg/L)
Primary Crystalliser – Adjacent	MP06	First line of early detection of seepage from Primary Crystalliser	1500	1500	3000	0.970	0.976	1.94
Mardie Pool – North Side Outside Channel	MP02	Second line of detection of seepage from Secondary Crystalliser	2200	2260	4400	1.8	1.86	3.6
	MP03							
	MP04		2200	2680	4400	1.9	3.58	3.8
	MP05		2400	2520	4800	2.1	2.58	4.2
Primary Crystalliser – Up Gradient	MP07	Background monitoring up-gradient from Primary Crystalliser	1400	1400	2800	0.87	0.9	1.74
Secondary/ KTMS Crystallisers – Down Gradient	MP08	Down-gradient monitoring of Secondary Crystalliser	85000	103200	170000	130	142	260
	MP09	Down-gradient monitoring of KTMS	82000	106400	164000	110	128	220
	MP10		99000	118000	198000	150	162	300
Primary Crystalliser – Up Gradient	MP11	Background monitoring up-gradient from Primary Crystalliser	1100	1200	2200	0.66	0.69	1.32
	MP12		1200	1240	2400	0.72	0.762	1.44
Primary Crystalliser – Adjacent	MP13	First line of early detection of seepage from Primary Crystalliser	7800	8020	15600	8.7	8.76	17.4
	MP14		2000	2020	4000	1.5	1.56	3
	MP15		1600	1620	3200	1.1	1.16	2.2
	MP16		1500	1500	3000	0.95	0.98	1.9
Mardie Creek - Upstream	MP17	Upstream channel monitoring for base flow, adjacent to crystalliser	2500	2640	5000	2.15	4.3	2.18
	MP18	Upstream channel monitoring for base flow	2500	3820	5000	3	6	3.72
	MP19		1300	1720	2600	0.37	0.74	0.658

Notes:
[1]: Baseline value calculated as Median EC of samples collected to date. Values to be revised quarterly as more sample data are acquired.
[2]: Trigger value calculated as sustained quarterly EC increases above the 80% percentile. Values to be revised quarterly as more baseline data is acquired and true seasonal/event-driven variations are measured.
[3]: Threshold value calculated as a quarterly EC increase of 100% of baseline (i.e. doubling). Values to be revised quarterly as more baseline data is acquired and true seasonal/event-driven variations are measured

3.2 Outcome-based Provisions

EPA Factors: Inland Waters and Benthic Communities and Habitats.

EPA Objectives:

- To maintain the hydrological regimes and quality of groundwater and surface water so that environmental values are protected.
- To protect benthic communities and habitats so that biological diversity and ecological integrity are maintained.

EPBC Approval Objectives

- Protection of EPBC matters and habitats associated with the Mardie Pool, terrestrial, intertidal and subtidal areas

Outcome of Pond filling and operations

- No changes to the health, extent or diversity of intertidal benthic communities and habitat, including mangrove, coastal samphire and algal mat, as a result of changes to groundwater regimes or groundwater quality associated with the proposal.
- No adverse impact to water level or water quality in Mardie Pool as a result of changes to groundwater regimes or groundwater quality

Key Environmental Values: benthic communities and habitats, significant fauna and their habitats.

Key impacts and risks: changes to hydrological regimes or water quality.

Table 17 Outcome-based Provisions and Monitoring

Outcome 1 No changes to the health, extent or diversity of intertidal benthic communities and habitat, including mangrove, coastal samphire and algal mat as a result of changes to groundwater regimes or groundwater quality associated with the proposal**					
Indicators:	Response actions:	Monitoring Indicators, Methods, and Locations	Monitoring Timing and Frequency	Reporting	Applicable Approvals
Trigger criterion 1 • Observed data outside of ARIMA 95% confidence interval based on approach developed by Data Analysis Australia (Appendix E & K) [1]. **Threshold criterion 1** • Trigger exceedance observed for one week or longer.	**Trigger criterion 1 actions** • Exceedance reporting (as per Section 3.4.2 of this Plan) • Increased data download frequency to daily to support investigation of trends. • Review of available groundwater level data from all available monitoring bores to determine the temporal and spatial trends. • Investigation undertaken and completed to determine cause of trigger criterion within 1 month of detection. **Threshold criterion 1 actions** Phase 1 • Investigation undertaken to determine cause of threshold exceedance within 1 month of detection. • Implement relevant management actions under the BCHMMP.	**Indicator** • Groundwater level change outside of environmental variation. **Method for data collection and analysis** • Continuous water level monitoring in all impact/reference/coastal monitoring bores – download via telemetry / manual. • Daily analysis **Location of impact / reference monitoring bores** • Coastal and Pipeline Monitoring Bores	Daily Monitoring	As per Section 3.4.	MS 1211, EPBC 2018/8236

[1] Because of the cyclical nature of water levels in the region (biweekly cycles related to tidal influences or monthly cycles), a dynamic approach to trigger definition is required rather than simple thresholds on water levels. Mardie Minerals propose to use an Integrated Moving Average (ARIMA) model to detect changes at the impact bore relative to the reference bores. A trigger is defined to occur when the observed water level is outside of the 95% confidence intervals of the ARIMA model forecasts. Use of three reference bores for each impact bore improved forecast accuracy and trigger detection. This approach can be delivered in real time via an online tool that sends trigger alerts as they are detected or monthly. The impact and associated references bores are shown in Figure 21 and detailed in Table 15.

Outcome 1 No changes to the health, extent or diversity of intertidal benthic communities and habitat, including mangrove, coastal samphire and algal mat as a result of changes to groundwater regimes or groundwater quality associated with the proposal**					
Indicators:	Response actions:	Monitoring Indicators, Methods, and Locations	Monitoring Timing and Frequency	Reporting	Applicable Approvals
	• Suspension of any ongoing pond filling/transfer activities. Phase 2 • Exceedance reporting (as per Section 3.4.2 of this Plan) • Installation and/or operation of seepage recovery bores or other interception method (e.g. trenches) down-gradient from the impact site(s) to recover brine seepage). • If required, seepage recovery, would involve the installation of seepage recovery bores or other interception method (e.g. trenches where viable) down-gradient from the potential seepage source. • The recovered groundwater would be pumped to an appropriate disposal location (likely to be the adjacent evaporation pond). • Additional monitoring bores may also be installed between the between the affected bores and the relevant sensitive receptor to assist in confirming the effectiveness of the seepage recovery. Ongoing review of EC and groundwater level data from adjacent bores to determine the effectiveness of seepage recovery methods. Phase 3 • If response measures are not found to be effective in reducing/reversing the impact, commence controlled emptying of the pond(s) adjacent to the impact site(s).				

Outcome 1

No changes to the health, extent or diversity of intertidal benthic communities and habitat, including mangrove, coastal samphire and algal mat as a result of changes to groundwater regimes or groundwater quality associated with the proposal**

Indicators:	Response actions:	Monitoring Indicators, Methods, and Locations	Monitoring Timing and Frequency	Reporting	Applicable Approvals
Trigger criterion 2 • Mean monthly EC value in impact monitoring bore(s) is greater than 10% above the median baseline value for the reference bore/s **Threshold criterion 2** • Mean monthly EC value in impact monitoring bore(s) baseline is greater than 20% above the median baseline value for the reference bore/s	**Trigger criterion 2 actions** • Exceedance reporting (as per Section 3.4.2 of this Plan) • Increased data download frequency to daily to support investigation of trends. • Review of available EC data from across all available monitoring bores to determine the temporal and spatial trends. Investigation undertaken and completed to determine cause of trigger criterion within 1 month of detection. **Threshold criterion 2 actions** Phase 1 • Exceedance reporting (as per Section 3.4.2 of this Plan) • Investigation undertaken to determine cause of threshold exceedance within 1 month of detection. • Implement relevant management actions under the BCHMMP. • Suspension of any ongoing pond filling/transfer activities. Phase 2 • Installation and/or operation of seepage recovery bores or other interception method (e.g. trenches) down-gradient from the impact site(s) to recover brine seepage). • If required, seepage recovery, would involve the	**Indicator** Electrical conductivity (EC) change outside of environmental variation **Method for data collection and analysis** • EC logger in coastal monitoring bores / download via telemetry/manual. • Manual monitoring for Terrestrial bores where EC logger not yet installed. **Location of impact / reference monitoring bores** • As shown in Figure 21 and described in Table 15	Once telemetry is installed - daily.	As per Section 3.4.	MS 1211, EPBC 2018/8236

Outcome 1 No changes to the health, extent or diversity of intertidal benthic communities and habitat, including mangrove, coastal samphire and algal mat as a result of changes to groundwater regimes or groundwater quality associated with the proposal**					
Indicators:	Response actions:	Monitoring Indicators, Methods, and Locations	Monitoring Timing and Frequency	Reporting	Applicable Approvals
	installation of seepage recovery bores or other interception method (e.g. trenches where viable) down-gradient from the potential seepage source. • The recovered groundwater would be pumped to an appropriate disposal location (likely to be the adjacent evaporation pond). • Additional monitoring bores may also be installed between the between the affected bores and the relevant sensitive receptor to assist in confirming the effectiveness of the seepage recovery. Ongoing review of EC and groundwater level data from adjacent bores to determine the effectiveness of seepage recovery methods. Phase 3 • If response measures are not found to be effective in reducing/reversing the impact, commence controlled emptying of the pond(s) adjacent to the impact site(s).				

Outcome 2: No adverse impact to water levels or water quality in Mardie Pool or Mt Salt Mound Spring because of changes to groundwater regimes or groundwater quality					
No. Indicators:	Response actions:	Monitoring Indicators, Methods, and Locations	Monitoring Timing and Frequency	Reporting	Applicable Approvals
Trigger criterion 1 • EC median value in monitoring bore(s) up-gradient from Mardie Pool display sustained EC increases above the 80% percentile of the baseline for four monitoring events (i.e. quarterly event then three subsequent monthly events). **Threshold criterion 1** • EC median value in monitoring bore(s) up-gradient from Mardie Pool display sustained EC increases above the 80% percentile of the baseline for six monitoring events (i.e. quarterly event then five subsequent monthly events).	**Trigger level actions** • Implement monthly monitoring frequency for water quality at the bore and immediately adjacent bores (where these exist). • Investigation undertaken to determine cause of impact within 1 month of detection. Research undertaken to determine means of mitigating cause of impact if deemed to be attributed to the Proposal. **Threshold criterion 1 exceedance action** • Develop and implement Management Response Plan and mitigation actions within 1 month of threshold exceedance. • Remediation Plan – repeated. Reference 3.3	**Indicator** • Electrical conductivity (EC) Method for data collection and analysis • Water sample from upper 2m of the water column. **Location of monitoring sites** • Terrestrial monitoring bores • Additional monitoring bore sites to be located and installed for Mt Salt Mound Spring (pending modelling results)	• Quarterly groundwater quality sampling. • Monthly monitoring of EC profiles to be implemented within 1 month of trigger criterion being identified, to end of the quarter.	As per Section 3.4.	MS 1211, EPBC 2018/8236
Trigger criterion 2 • Bromide median concentration increases above the 80% percentile	**Trigger criterion 2 actions** • Implement monthly monitoring frequency for water quality and level.	**Indicator** • Groundwater quality parameters (bromide concentration) as	• Quarterly groundwater quality sampling.		MS 1211, EPBC 2018/8236

Outcome 2: No adverse impact to water levels or water quality in Mardie Pool or Mt Salt Mound Spring because of changes to groundwater regimes or groundwater quality					
No. Indicators:	Response actions:	Monitoring Indicators, Methods, and Locations	Monitoring Timing and Frequency	Reporting	Applicable Approvals
for four monitoring events (i.e. quarterly event then three subsequent monthly events). May be bore-specific. • Excludes bores MP08, MP09 and MP10 which exhibit very high baseline Bromide levels. **Threshold criterion 2** • Sustained doubling of the Bromide median concentration for six monitoring events (i.e. quarterly event then five subsequent monthly events). May be bore-specific. • Excludes bores MP08, MP09 and MP10 which exhibit very high baseline Bromide levels.	• Investigation undertaken to determine cause of impact within 1 month of detection. Research undertaken to determine means of mitigating impact if deemed to be attributed to the Proposal **Threshold criterion 2 action** • Develop and implement Management Response • Plan and mitigation actions within 1 month of threshold exceedance.	an indicator of brine derived from sea water. **Method for data collection and analysis** • Water sample from monitoring bores for laboratory analysis. **Location of monitoring sites** • Terrestrial monitoring bores • Additional monitoring bore sites to be located and installed for Mt Salt Mound Spring (pending modelling results)			

3.3 Monitoring Schedule

3.3.1 Groundwater Monitoring

Monitoring commenced in early 2022 across the Terrestrial monitoring bore network and will continue as per Table 17.Owing to accessibility issues associated with the intertidal flats, coastal monitoring bores in areas with limited accessibility have been fitted with depth loggers, set to record water level up to hourly. These remote loggers will be either connected to telemetry systems for remote data download to enable real time checking / or downloaded manually.

Bores in locations which are generally safely accessible should be visited at least quarterly. The current schedule for groundwater monitoring is provided in Table 18 .

A flowchart has been provided in Figure 22 which incorporates actions to be undertaken following any exceedances of trigger and threshold values during routine groundwater monitoring events.

Table 18 Monitoring schedule

Purpose	Location	Parameter/s	Frequency Duration
Terrestrial Monitoring Bores			
Groundwater level	Table 5	Water level	Daily via telemetry and/or Quarterly, where loggers not yet installed
Groundwater quality		EC/pH Bromide	Quarterly
Coastal Monitoring Bores			
Groundwater level monitoring	Tables 7 and 8	Water level	Daily via telemetry or quarterly until installation completed
Groundwater quality		EC	
Ponds			
Structural integrity, leakage and soils associated with evaporation pond walls	All Ponds	Evidence of seepage or spill	Weekly via Site Environmental Management Plan

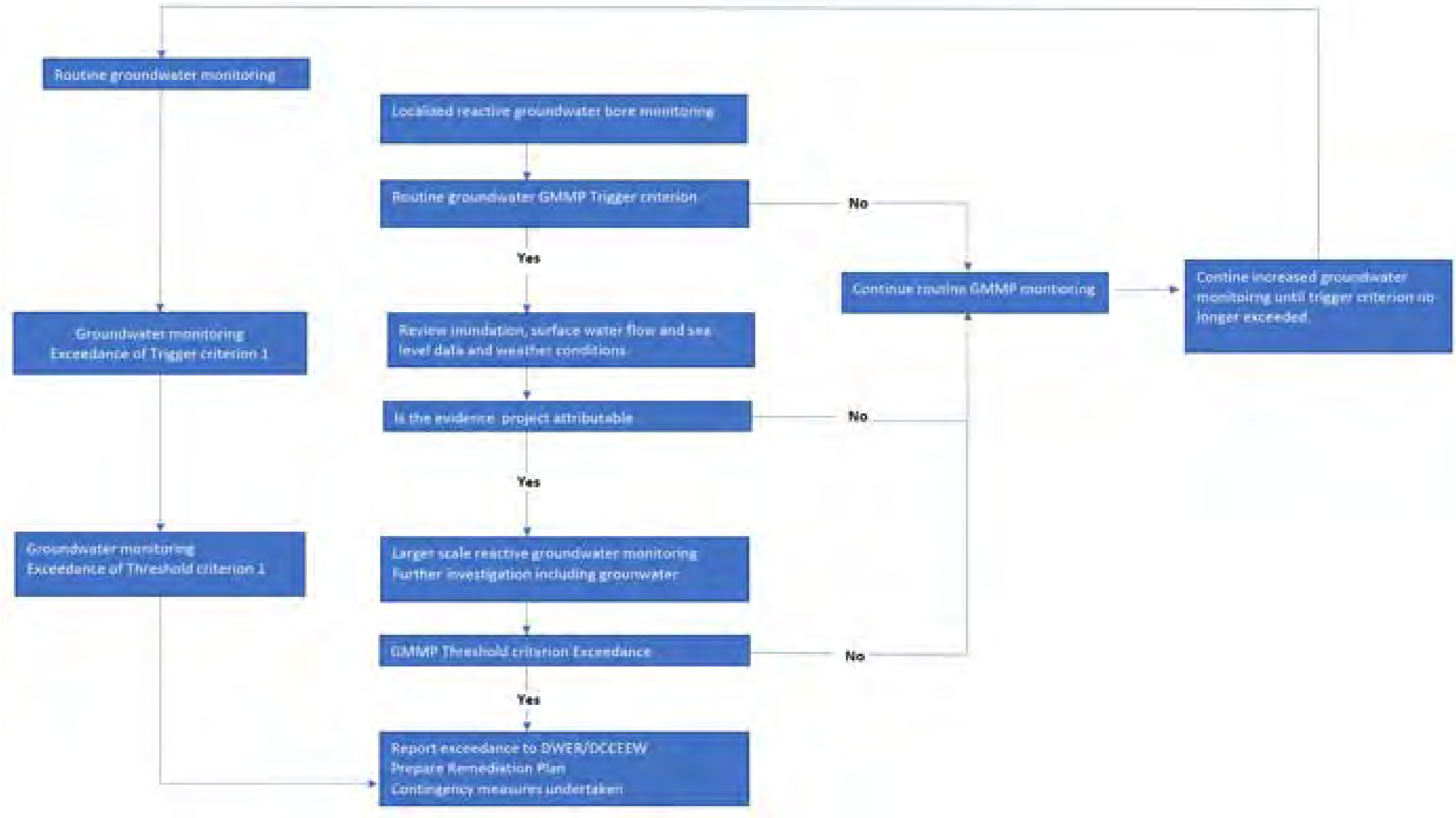


Figure 22 Flowchart for reactive GMMP monitoring

3.3.2 Benthic Communities and Habitats (BCH)

The BCHMMP (Rev E 13/11/23) describes the monitoring and management measures to be implemented by Mardie Minerals to protect the health, diversity, and extent of BCH.

Monitoring will be undertaken quarterly at each site within the first two years, and then on an ongoing bi-annual (at the end of the dry and the wet seasons) frequency:

- Algal Mat Health – quarterly replicate transects
- Mangrove Health – quarterly replicate quadrats
- Samphire Health – quarterly replicate quadrats
- Subtidal seagrass Health – quarterly replica transects
- Tidal flood height / surface water height

If triggers are exceeded, monitoring for investigative purposes will also be undertaken as described in Section 3.1.3.3 of the BCHMMP.. The interaction between the GMMP and BCHMMP is shown in section 2.5.

3.4 Reporting

3.4.1 Compliance Reporting

Monitoring data will be assessed against trigger and threshold criteria and reported in both a quarterly summary report and an annual report to the company CEO. If the trigger or threshold criteria (or both) are exceeded during the groundwater monitoring period, the annual report will include a description of the effectiveness of trigger criteria level actions, and threshold criteria contingency actions that have been implemented to manage the impact, as well as an analysis of trends.

A Compliance Assessment Report (CAR) will be submitted to the Compliance Branch at DWER annually. The CAR will document compliance with conditions of approval including assessment of compliance with management plan requirements where management plans form part of the approval conditions. The CAR will be prepared in accordance with the Post Assessment Guideline for Preparing a Compliance Assessment Report, Post Assessment Guideline No. 3 (OEPA, 2012).

A groundwater summary report will be prepared and submitted to DCCEEW and/or DWER (as required) each calendar year as per the EMP. The report will:

- Summarise groundwater level and quality, identifying any exceedance of trigger and threshold criteria.
- Provide details on contingency actions taken in the event of exceedance of trigger and threshold criteria exceedances.

3.4.2 Regulatory Reporting

Annual monitoring reports, as described above, will be provided to DCCEEW on an annual basis.

In accordance with Conditions of MS 1211 and EPBC 2018/8236, if monitoring or investigations at any time indicate an exceedance of threshold criteria specified in the GMMP, Mardie Minerals will undertake the following actions:

- Report the exceedance(s) to DCCEEW (in writing) within 7 days of the exceedance(s) being identified.
- Implement the threshold contingency actions required by the GMMP and continue to implement those actions until the CEO (and DCCEEW) has confirmed by notice in writing that it has been demonstrated that the threshold criteria are being met and implementation of the threshold contingency actions are no longer required.
- Within 21 days of being aware of the exceedance (MS1211) Mardie Minerals will provide a report to the CEO (and DCCEEW), including the following:
- Details of contingency actions implemented.
- Implemented threshold contingency actions.
- The effectiveness of contingency actions against threshold criteria.
- Investigation findings.
- Measures to prevent the threshold criteria being exceeded in the future.
- Justification of the threshold criteria remaining or being adjusted based on better understanding.
- These actions will be conducted in accordance with criteria set by MS 1175.
- In accordance with Condition 5(b) of EPBC 2018/8236, Mardie Minerals will within 6 months of any such exceedance, have the GMMP reviewed by an independent suitably qualified hydrologist to advise if the GMMP needs to be revised to prevent any possibility of the exceedance reoccurring and submit the report of the independent suitably qualified hydrologist to the Department. If the review of the GMMP by an independent suitably qualified hydrologist recommends that the GMMP be revised, the approval

holder must submit the revised GMMP to the Department for the approval of the Minister within 8 months of any such exceedance.

3.4.3 Remediation Plan

In accordance with Condition 5(c) of EPBC 2018/8236, exceedance of threshold criteria specified in the GMMP will trigger the development of a Remediation Plan to be reviewed alongside the GMMP by an independent suitably qualified hydrologist within 6 months of the exceedance being reported. The Remediation Plan will describe contingency measures and remediation actions to be undertaken in response to a threshold exceedance. This may include the requirement to amend or reduce operations until environmental outcomes are achieved.

If the independent review recommends that the GMMP be revised, Mardie Minerals will submit a revised GMMP to DCCEEW for the approval of the Minister within 8 months of any such exceedance, and an offset strategy to manage impacts where required.

3.4.4 Offset Strategy

In accordance with Condition 5(e) of EPBC 2018/8236, Mardie Mineral's note that if the Minister determines that it is not possible to remediate the impact of the exceedance, then Mardie will, within 10 months of the exceedance of the threshold criterion, submit an Offset Strategy specifying how the impact will be offset in accordance with the Environmental Offsets Policy.

If the Offset Strategy has not been approved by the Minister in writing within 11 months of the exceedance event, and the Minister notifies the approval holder that the Offset Strategy is not suitable for approval, the Minister may, at least two months after so notifying the approval holder, approve a version of the Offset Strategy revised by the Department. The approval holder must implement the approved Offset Strategy for the remainder of the life of the project.

3.5 Commitments Register

Table 16 Commitments Register

GMMP Reference	Commitment	Timing / Deliverable	Approval Reference
Modelling			
2.2, 2.6.5, Appendix A	Conceptual and Impact Groundwater Model and GMMP update: Pond 1 Transect (Ponds 12 and 3)	Completed, 2024. (Report attached to GMMP Rev K).	MS1211 EPBC 2018-8236
2.2, 2.6.5, Table 4	Conceptual and Impact Groundwater Model and GMMP update: Pond 6 Transect (Ponds 4/5 and 6)	Completed, 2024. (Report attached to GMMP Rev K).	MS1211 EPBC 2018-8236
	Conceptual Groundwater Model and GMMP update: Mardie Pool / Crystallisers transect.	Completed, 2024. (Report attached to GMMP Rev K).	MS1211 EPBC 2018-8236
	Conceptual and Impact Groundwater Model Pond 8 Transect for Ponds 8 and 9 and Crystallisers.	Commenced, to be completed in March / April 2024. Subsequent update to GMMP.	MS1211 EPBC 2018-8236
	Conceptual and Impact Groundwater Model *Validation and Calibration* and GMMP update.	Within 12 months of the GMMP approval and on an annual frequency for 3 years after approval of the GMMP.	MS1211, EPBC 2018-8236
2.6.10	Regional Groundwater Model	Commenced, to be completed in Q4 2024. Subsequent update to GMMP.	EPBC 2018-8236 (Groundwater Memo)
Monitoring and Survey			
Table 4	Initial groundwater bore installation	Completed in 2023.	MS1211, EPBC 2018-8236
Table 4	Additional bore installation to support ongoing control/reference bore selection and inform Stage 2 Regional Groundwater Modelling	Selection and installation Q2 2024 (access permitting). Data collection within 2 weeks of installation	MS1211, EPBC 2018-8236
3.1.1	Trigger and Threshold Criteria review and Control/Reference Bore Selection for Pond 4 through 8.	Commenced, to be completed in Q2 2024.	MS1211, EPBC 2018-8236
3.3.1	Water level (VWP) and quality (EC/pH) instrumentation/telemetry installation for existing Coastal and Terrestrial Monitoring Bores.	To be completed in Q2 2024 (excluding those to be manually monitored)	MS1211, EPBC 2018-8236
	Groundwater level / head monitoring	Hourly, with data download via telemetry.	MS1211, EPBC 2018-8236
	Groundwater EC monitoring – Coastal Bores	Hourly, with data download via telemetry.	MS1211, EPBC 2018-8236
	Groundwater EC / pH monitoring – Terrestrial Bores	Quarterly.	MS1211, EPBC 2018-8236

GMMP Reference	Commitment	Timing / Deliverable	Approval Reference
2.6.8	Geophysical Surveys, annually for first 3 years.	Initial Survey completed Q1 2024. Follow up survey 12 months after initial Pond 1 filling	
Table 4	Mardie Pool Surface Water / Groundwater investigation	Completed, 2024. (Report attached to GMMP Rev K) Ongoing Quarterly monitoring.	MS1211, EPBC 2018-8236
Table 4	Mt Salt Mound Spring Monitoring	Commenced in 2022. Quarterly monitoring ongoing.	MS1211, EPBC 2018-8236
2.9.3, 3.3.2	Benthic Communities and Habitat Monitoring	Quarterly for first 2 years, then biannually as per the Benthic Communities and Habitat Monitoring and Management Plan (BCHMMP)	MS1211, EPBC 2018-8236
Investigation and Reporting			
3.1	Weekly Pond Condition Inspections	Weekly initially, with review after 6 months	EPBC 2018-8236
3.1.1	Monthly control and reference bore matching data review to inform ongoing suitability	Monthly, internal report and action when there is a material finding.	MS1211, EPBC 2018-8236
Table 16, 3.1.1	Trigger and Threshold Criteria exceedance investigations	From commencement of operations at a frequency and detail described in this Plan in Table 16.	MS1211, EPBC 2018-8236
3.4.2	Investigation Reporting	Timing as per the investigation protocols in the GMMP, investigation report.	MS1211, EPBC 2018-8236
3.4, 2.5	Review of GMMP monitoring data upon a trigger or threshold exceedance occurring through the BCHMMP	As per timing and details in the BCHMMP	MS1211, EPBC 2018-8236
3.4, 2.5	Review of BCHMMP monitoring and management actions including reactive monitoring whenever a GMMP Threshold exceedance occurs	From commencement of operations at a frequency and detail described in this Plan in Table 16.	MS1211, EPBC 2018-8236
3.4.3	Remediation Plan and independent review of the GMMP	Within 6 months of an exceedance of a threshold trigger being reported	EPBC 2018/8236
3.4.1	Monitoring data assessment and review-internal	Annual Report	Internal Commitment
	Groundwater summary data report – DWER and DCCEW	Quarterly	MS1211, EPBC 2018-8236
	Compliance Assessment Reporting – DWER	Annually	MS1211
	EPBC Compliance Report - DCCEEW	Annually	EPBC 2018/8236
3.4.1	10 year Environmental Performance Report	Within 3 months of the expiry of the ten year period from substantial commencement	MS1211, D2-7
Additional Commitments			

GMMP Reference	Commitment	Timing / Deliverable	Approval Reference
	Agency Communication and Check in: - Fortnightly during Pond filling including data provision	Fortnightly, by phone call / email	NA
2.6.7	Review of GMMP and update	At completion of Pond 8 transect impact modelling, submitted within 3 months as per State and Commonwealth conditions.	MS1211, EPBC 2018-8236
2.5	Review of GMMP alongside the BCHMMP	Within 1 year of MS 1211 approval: by 19 October 2024	MS1211, B3-2 (2)
4.2	GMMP review (internal)	Annually and in response to significant amendments	
4.2	Independent GMMP review by suitably qualified hydrologist, and updated GMMP if required	At least once before every 10 year anniversary of the plan for the life of the project	EPBC 2018/8236

4. ADAPTIVE MANAGEMENT AND REVIEW OF THE PLAN

4.1 Adaptive Management Process

Mardie Minerals is committed to improving environmental results and management practices throughout the implementation of the Project and therefore will use an adaptive management approach for this GMMP. Adaptive management practices will include:

- Monitor and evaluate performance against the outcome-based triggers and thresholds. Perform quarterly reviews of monitoring data and compare data and information against established baseline, trigger and threshold values and ongoing monitoring and reference data.
- Monitor and evaluate the effectiveness of the management actions against the management targets.
- Review of management actions throughout the implementation of the Project, and identification of potential new management measures, methodologies, and technologies that may be more effective.
- Specifying monitoring and reporting procedures to provide for continuous improvement, consistent with an adaptive management approach.
- In the event one or more of the triggers, thresholds or management targets has not been met, or is considered at risk of not being met, review and adjust the management measures and monitoring to ensure the objectives are met, based on what is learned from evaluation of the monitoring data, or any new data that becomes available.
- Review any assumptions considering the monitoring data or any new data that becomes available.
- Review/audit of the outcomes and revisions of the GMMP (discussed further in Section 4.2).

4.2 Review

The approved GMMP will continue to be implemented and should updates or revisions be required based on the outcomes of ongoing modelling and/or gathering of data from additional baseline monitoring, subsequent revisions will be submitted to DCCEEW for review and approval by the Delegate.

GMMP will be reviewed every 12 months and as required following significant amendments for example in response to the adaptive management process outlined above and as described in Table 18.

A separate review, by an independent suitably qualified hydrologist, will be completed at least once before every 10-year anniversary of the first approval of the GMMP, and subsequently every 10 years for the life of the project (unless specified by the Minister in writing). A revised GMMP addressing the recommendations of this review, accompanied by the recommendations of review, will be submitted to the CEO and DCCEEW for approval, within 3 months of the most recent 10-year anniversary of the first approval of the GMMP.

Mardie Minerals will update and submit proposed amendments to the Plan following every review (if that review recommends changes), including each independent hydrologist review.

All reviews will consider:

- Outcomes of monitoring programs.
- Recommendations from the reviewer(s), including that of the independent hydrologist.
- Implementation and effectiveness of management measures and monitoring programs.
- Threshold/trigger criteria and threshold/trigger level actions.
- Changes to relevant legislation, policy, guidelines, management plans and industry practices.
- Changes to operational activities.

- Changes to approval conditions.
- Changes to the conservation status of fauna species.
- The identification of a conservation significant fauna species not previously confirmed within the Project area.
- Recurring incidents of death/injury to a conservation significant fauna species.
- Stakeholder consultation.

4.2.1 Peer Review

An independent peer review was undertaken in 2021 (report dated 5/01/22, Appendix C) with the purpose of providing an assessment and analysis of the suitability of an early version of the GMMP to adequately and correctly address the study outcomes to achieve the objectives with confidence. The peer review was a requirement of Ministerial Statement (1175) 1211 and EPBC 2018/8236 and is included as Appendix C.

The peer reviewer provided a number of recommendations and observations including:

- Justification to demonstrate that generated data will accurately represent the baseline.
    - Provided for in modelling studies and GW level indicator methodology.
- Installing multilevel bores or set of bores with various screen level.
    - Coastal bore network installed – deep and shallow bores.
- Monitoring bores at the location west side of pond 1 and around Robe River delta.
    - Coastal bore network installed – RRDMA avoided.
- Rationalisation for the monitoring well positions and their adequacy.
    - Coastal bore network installed, described in AQ2 reporting.
- Plan and potential steps to minimise identified preliminary triggers.
    - Trigger and threshold criteria, mitigation and management actions.
- Hydrological regime in the project area to address the gaps of the baseline data.
    - Provided for in modelling studies and GW level indicator methodology.
- Establishing an adequate linkage between the investigations and the claimed identification data for the conceptualisation.
    - Conceptualisation in modelling report.
- Deeper discussion of the uncertainties about natural recharge and evaporation estimates and changes.
    - Conceptualisation in modelling report.
- Saline water flow influence on regional groundwater flows paths.
    - Conceptualisation in modelling report.
- Collecting the water quality data for Mardie pool and creeks.
    - Quarterly monitoring since 2022.
- Review and elaboration on the indirect impacts of the project on BCH, availability of historical data.
    - Described in BCHMMP and link to GMMP.
- Estimation of the evapotranspiration, quantification of the acceptable level of impact

  - Conceptualisation in modelling report
- Salt precipitation and dissolution processes in modelling
  - Conceptualisation in modelling report
- Management and mitigation actions of the potential environmental impacts and risks of long-term environmental changes such as climate change.
  - GMMP relevant management and mitigation actions included. Climate Change impacts assessed through EIA process.

The GMMP was subsequently updated to address those matters of relevance under the Federal and State approval conditions noting that a number of observations were considered outside the scope of the GMMP approval conditions.

Following a number of iterations of the GMMP and review by DWER and DCCEEW, a second independent review (Appendix G) was undertaken of the GMMP and the initial peer review recommendations and observations. The review noted that the updated GMMP had adequately addressed the peer review recommendations, and also provided additional observations.

This Revision K represents cumulative updates across bore installation, baseline data gathering and supporting technical studies including modelling. Table 14 provides direct responses to observations and recommendations from these peer reviews.

4.3 Roles and Responsibilities

As outlined in our Environmental Policy, Mardie Minerals is committed to fully complying with applicable environmental laws and regulations and will strive to carry out all activities in a manner that minimises impacts to the environment. Further, Mardie Minerals commits to the sustainable management and efficient use of natural resources, and to the research, development, and management of the surrounding ecosystems.

The GMMP will be implemented within the overarching framework of the BCI Minerals Environmental and Social Management System Framework (June 2021) which includes the responses to incidents, complaints and emergencies, internal review and auditing and implementation of the Mardie Minerals environmental policy.

Mardie Minerals roles and responsibilities relevant to the implementation of the Plan are outlined in Table 17.

Table 17 Roles and Responsibilities for Plan Implementation

Role	Responsibility
Manager Environment and Approvals	Liaise with regulatory authorities as required. Ensure monitoring and management actions are implemented in accordance with this Plan. Ensure reporting to regulatory agencies is undertaken in accordance with this Plan. Manage the review and revision of the GMMP. Lead investigations associated with the plan and monitor and close out corrective actions identified during environmental monitoring or audits Ensure the annual submission of the Ministerial Statement Compliance Assessment Report (CAR) and the annual EPBC compliance report.

Role	Responsibility
	Ensure other reporting is undertaken in accordance with this Plan (including the reporting/submission of documents and data (as required) under EPBC 2018/8236 Conditions 5 to 9).
Site Environmental Advisor/s	Oversee and support the implementation of GMMP monitoring programs, studies and maintain monitoring records. Support reporting, and the provision of data, to regulators as required under this plan. Develop and deliver awareness training programs to personnel, contactors, and visitors with respect to key requirements under this GMMP. Provide advice to relevant BCI personnel and Contractors to assist them to understand their GMMP responsibilities. Ensure all personnel and contractors involved in GMMP surveys and studies are appropriately experienced, qualified and supervised.
Other Staff and Contactors	Ensure that all relevant activities are undertaken in compliance with this GMMP. Report any events or matters through to Mardie Minerals management. Participate in investigation and inspections as required.

5. STAKEHOLDER CONSULTATION

Mardie Minerals has consulted extensively with and will have ongoing consultation with all stakeholders who are affected by the proposal. This includes (but not limited to):

- Indigenous community groups (Wirrawandi Aboriginal Corporation (WAC), Robe River Kuruma Aboriginal Corporation (RRKAC).
- Neighbouring pastoral lease owners (Pastoral Management Pty Ltd (PMPL)).
- Government agencies (EPA, DMIRS, DWER; DBCA, Department of Planning, Lands and Heritage (DPLH); Main Roads Western Australia (MRWA); Pilbara Ports Authority; Department of Climate Change, Energy, the Environment and Water (DCCEEW)).
- Local Government (Shire of East Pilbara and Town of Port Hedland).
- Community / Special interest Groups (Hampton Harbour Boat and Sailing Club, Nickol Bay Sporting Fishing Club, Wildflower Society, Rangelands Natural Resource Management WA, Birds Australia / Birdlife Australia.

Consultation regarding the Mardie Salt Project has included both the Original and the Optimised Proposals. In addition to the consultation completed in relation to the Proposals, additional consultation has more recently been undertaken with key stakeholders in relation to the Plan and will continue throughout the life of the Project.

6. CHANGES TO EMP

The template in Table 21 will be used to document changes made to each subsequent version of this GMMP submitted for agency review and approval.

Table 18 Stakeholder Consultation in relation to the Plan

Complexity of changes			**Minor revisions** ☐	**Moderate revisions** ☐ **Major revisions** ☐
Number of Key Environmental Factors			**One** ☐	**2-3** ☐ **> 3** ☐
Date revision submitted to EPA: DD/MM/YYYY				
Proponent's operational requirement timeframe for approval of revisionReason for Timeframe:				**< One Month** ☐ **< Six Months** ☐ **> Six Months** ☐ **None** ☐
Itemno.	**EMP section no.**	**EMP page no.**	**Summary of change**	**Reason for change**
1.				
2.				
3.				

7. REFERENCES

AQ2, Mardie Project Conceptual Groundwater System and Modelling Assessment (2024).

ANZG 2018. Australian and New Zealand Guidelines for Fresh and Marine Water Quality. Australian and New Zealand Governments and Australian state and territory governments, Canberra ACT, Australia. Available at www.waterquality.gov.au/anz-guidelines.

EPA, Environmental Protection Agency. (2010). Environmental Assessment Guideline No. 5 - Protecting Marine Turtles from Light Impacts

DSEWPaC, Department of Sustainability, Environment, Water, Population and Communities. (2012). *Marine bioregional plan for the North-west Marine Region*.

DoE, Department of the Environment. (2014). Environmental Management Plan Guidelines.

DoE, Department of the Environment. (2015). *Wildlife Conservation Plan for Migratory Shorebirds*. Department of Environment, Commonwealth of Australia. http://www.environment.gov.au/biodiversity/publications/wildlife-conservation-plan-migratory-shorebirds-2016

TSSC, Threatened Species Scientific Committee. (2016). *Conservation advice: Rhinonicteris aurantia (Pilbara form), Pilbara leaf-nosed bat*. Commonwealth of Australia, Canberra, ACT.

EPA, Environmental Protection Agency. (2016a). *Environmental Factor Guideline: Marine Fauna*.

EPA, Environmental Protection Authority. (2016b). *Environmental factor guideline: Terrestrial fauna*. Perth, Western Australia: Environmental Protection Authority.

EPA, Environmental Protection Authority. (2016c). *Technical Guidance: Protecting the Quality of Western Australia's Marine Environment*. Perth, Western Australia: Environmental Protection Authority.

DoEE, Department of the Environment and Energy. (2017a). *EPBC Act Policy Statement 3.21 — Industry guidelines for avoiding, assessing and mitigating impacts on EPBC Act listed migratory shorebird species*. Commonwealth of Australia: Department of the Environment and Energy Retrieved from https://www.dcceew.gov.au/sites/default/files/documents/bio4190517-shorebirds-guidelines.pdf.

DoEE, Department of the Environment and Energy. (2017b). *The Recovery Plan for Marine Turtles in Australia*.

Schoenjahn, J. (2018). *Adaptations of the rare endemic Grey Falcon Falco hypoleucos that enable its permanent residence in the arid zone of Australia.* The University of Queensland,

Pendoley Environmental, Pty Ltd. (2018). *Marine turtle survey of Mardie Salt Project Area – December 2017, January 2018*. Prepared for Phoenix Environmental by Pendoley Environmental.

Pendoley Environmental, Pty Ltd. (2019). *Mardie Salt Project: Marine turtle monitoring program 2018/2019*. Prepared for BCI Minerals Ltd.

Phoenix, Environmental Sciences. (2020). *Level 2 targeted terrestrial fauna survey for the Mardie Project*. Prepared for BCI by Phoenix Environmental Sciences.

Phoenix, Environmental Sciences. (2021a). *Basic (Level 1) terrestrial fauna survey for the Mardie Salt Project Optimisation Area and Quarry Area*. Prepared for BCI by Phoenix Environmental Sciences.

Phoenix, Environmental Sciences. (2021b). *Shorebirds survey of Mardie NE (expansion area).* . Prepared for BCI by Phoenix Environmental Sciences.

Bat Call. (2021). *A review of Pilbara leaf-nosed bat ecology, threats and survey requirements*. Report prepared for the Department of Agriculture, Water and the Environment. Canberra.

EPA, Environmental Protection Agency. (2021a). *How to prepare Environmental Protection Act 1986 Part IV Environmental Management Plans - Instructions*. Perth, Western Australia.

EPA, Environmental Protection Agency. (2021b). *Ministerial Statement 1175 - Mardie Project*.

EPA, Environmental Protection Authority. (2021c). *Instructions on how to prepare Environmental Protection Act 1986 Part IV Environmental Management Plans*. Environmental Protection Authority.

Phoenix, Environmental Services. (2022c). *Long-term migratory shorebird monitoring program for the Optimised Mardie Project*. Prepared for BCI by Phoenix Environmental Sciences.Pendoley Environmental, Pty Ltd. (2022). *Mardie Salt Project: Marine Turtle Monitoring Program 2021/22.* . Prepared for BCI Minerals Ltd. by Pendoley Environmental.

Preston, Consulting. (2022). *Optimised Mardie Project - Supplementary Report*.

Phoenix, Environmental Sciences. (2022a). *Basic (Level 1) terrestrial fauna survey for the Mardie Salt Project Optimisation Area and Quarry Area*. Prepared for BCI by Phoenix Environmental Sciences.

Phoenix, Environmental Sciences. (2022b). *Construction Illumination risk assessment for seabirds and migratory shorebirds for the Mardie Salt Project - Draft*. Prepared for BCI by Phoenix Environmental Sciences.

DCCEEW, Department of Climate Change, Energy, the Environment and Water. (2023). *National Light Pollution Guidelines for Wildlife*. Department of Climate Change, Energy, the Environment and Water, Canberra.

EPA, Environmental Protection Agency. (2023). *Optimised Mardie Project Report 1740*.

Pendoley Environmental, Pty Ltd. (2023a). *Mardie Artificial Light Modelling Stage 1 Report*. Prepared for BCI Minerals Ltd.

Pendoley Environmental, Pty Ltd. (2023b). *Mardie Minerals Development: Artificial light Assessment and Management Plan (Draft)*. Prepared for BCI Minerals Ltd. by Pendoley Environmental.

Pendoley Environmental, Pty Ltd (2023c). *Mardie Salt Project: Marine Turtle Monitoring Program*. Prepared for BCI Minerals Ltd.

Phoenix, Environmental Sciences. (2023a). *Annual Shorebird Monitoring Survey for the Mardie Project*. Prepared for BCI by Phoenix Environmental Sciences.

Phoenix, Environmental Sciences. (2023b). *Long-term migratory shorebird monitoring program for the Optimised Mardie Project*. Prepared for Mardie Minerals by Phoenix Environmental Sciences.

Appendix A: Conceptual Groundwater System and Modelling Assessment (AQ2, 2024)

Mardie Project

Conceptual Groundwater System and Modelling Assessment

Prepared for:

BCI Minerals Limited

January 2024

AQ2 Pty Ltd
Ground Floor, 1 Howard Street
Perth WA 6000 Australia
Tel +61 8 9322 9733
www.aq2.com.au

DOCUMENT STATUS

Version	Purpose of Document	Author	Reviewed By	Review Date
A	Report for client	BPH / KLR	DGS	30 Oct 2023
B	Updated report	BPH / KLR	DGS	2 Nov 2023
C	Updated report	BPH / KLR	DGS	11 Jan 2024
D	Updated report	BPH / KLR	DGS	29 Jan 2024

Prepared by:	AQ2 Pty Ltd ABN 38 164 858 075	Prepared for:	BCI Minerals Limited ABN 21 1206 469 24
T:	(08) 9322 9733	T:	(08) 6311 3400
E:	aq2general@aq2.com.au	E:	info@bciminerals.com.au
W:	www.aq2.com.au	W:	www.bciminerals.com.au
Author:	B Harvey, K Rozlapa		
Reviewed:	D Storey		
Approved:	D Storey		
Version:	D		
Date:	29th January 2024		
AQ2 Ref:	F:\293\3.C&R\L\293 060d.docx		

EXECUTIVE SUMMARY

The Mardie Salt and Potash Project (the project) currently being constructed by BCI Minerals Limited (BCI) is located on the north-west coast of Western Australia in the Pilbara region, approximately 80km south-west of Karratha.

The project area is characterised by coastal salt flats (a sabkha-type environment) with hyper-saline and shallow groundwater. These salt flats are separated from the ocean by a narrow near-coastal zone with sea-water quality groundwater that is influenced by tidal creeks that host mangrove communities. The evaporation ponds for the project will be constructed predominantly on the salt flats and underlain by hyper-saline brine.

Figure ES1 presents the conceptual hydrogeological model for the project area passing through the sabkha and intra-tidal zone. Key points of the conceptual model are summarised below:

- The dominant groundwater influence in this area is the body of hypersaline water which has developed over an extensive period beneath the tidal flats (the sabkha). Analysis of water level data across the sabkha indicates that the groundwater flow within the tidal flat is predominantly vertical.
- Sea water floods across the tidal flats on high spring tides above a certain threshold level. A small amount of seawater remains behind as the tide recedes, within the pore space of the algal mat and near surface sediments, and within localised depressions on the sabkha. Evaporation of the residual sea water occurs between tidal inundation events, concentrating the brine at surface. A small-scale vertical flux process is set up in the near surface which concentrates the brine further in the period of drying between high Spring tides, which may be 7-10 days. The next inundation causes a small amount of recharge of the concentrated brine and crystallised salts into the sub-surface and mixing with the fresh seawater which remains at surface.
- Recharge of fresh groundwater water occurs inland and across the hinterland, flowing gradually towards the coast. The fresh water intersects the hypersaline brine of the sabkha inland from the eastern edge of the tidal zone, where a wedge of hypersaline water is confined by the hydraulic pressure of the fresh water. Diffusion of hypersaline water into the fresh water occurs at this point.
- On the seaward side of the sabkha a seawater-hypersaline interface is present, and the base of the hypersaline plume extends to the sea floor where rapid mixing with sea water occurs. The recharge volume of the hypersaline groundwater from diffusion of fresh water and generation of new hypersaline water at the surface of the sabkha are balanced by discharge of hypersaline water at the western side of the system into the ocean.
- During large rainfall flood events, fresh water will flood from creeks and overtop the hypersaline brine of the sabkha to flow across the flats to the ocean. This may dissolve some surficial salt and deposit silt across the sabkha for a short time, however the salt accumulation process will resume at the next high tides following the recession of flooding.

Figures ES2 and ES3 present the conceptual hydrogeological model for the Mardie Pool area on a section line which crosses the pool from south-west to north-east. Key points of the conceptual model are summarised below:

- Mardie Creek is incised into the overbank deposits on the southern flank of the Fortescue Alluvial Valley. Mardie Pool exists as a deeper section of the creek which remains as a permanent surface water body of variable size.
- Mardie Pool will become a gaining stream or losing stream depending on the prevailing pool and groundwater levels.

- It will fill to the overflow level during significant rainfall events. After flowing for a short period of time, outflow stops and the level in the pool will fall due to evaporation and loss of water through seepage.
- While the groundwater level in in the surrounding aquifer is lower than the level in the pool Mardie Pool acts as a losing stream. Fresher groundwater will gradually seep into the banks and base of Mardie Pool.
- After extended dry periods the level of water within Mardie Pool falls below the groundwater level noted in adjacent monitoring bores. Analysis of recession curves for the pool indicate that the pool water level is likely being supplemented with groundwater inflow (the pool becomes a gaining stream), hence remaining a permanent surface water feature throughout the dry season.
- Groundwater in bores to the north of Mardie Pool is saline at a depth which is below the base of Mardie Pool. While Mardie Pool is known to become more saline due to evaporation in dry periods, the pool is filled with fresh water during flood events.

Calibrated 2D groundwater models have been used to predict:

- The potential for interaction between Pond 1 seepage and the near-coastal hydrological cycle that supports coastal mangrove habitat and the algal mat areas of the intertidal zone.
- The potential for interaction between crystalliser seepage and Mardie Pool.
- The potential for interaction between crystalliser and Pond 6 seepage and the near-coastal hydrological cycle (that also supports coastal mangrove habitat and the algal mat areas of the intertidal zone).

These models, which also include density dependence, have been developed and calibrated using the available measured water level data and salinity profiling for the project area.

Figure ES4 shows the extent of Pond 1 and the areas of algal mat and mangrove communities downstream of Pond 1. An area of Pond 1 will be constructed in a mapped area of algal mat community. Downstream of Pond 1, the tidal inundation will continue over the life of the project. Modelling results suggest that water level impacts of the operation of Pond 1 are predicted to occur as follows:

- Underneath and immediately downstream of Pond 1, with a seasonal increase in water level of up to 0.5m predicted downstream of Pond 1.A seasonal increase in water level up to 0.5m is predicted 100m downstream of Pond 1. The extent of this impact is shown in Figure ES4.
- Upstream of Pond 1 where a water level decrease is predicted, as tidal recharge will be prevented by embankments installed at the downstream end of Pond 1 (refer Figure ES4).

  Further downstream (~3.5km NE from Pond 1) no water level impact of the operation of Pond 1 is predicted.

  Predicted changes in groundwater salinity resulting from the operation of Pond 1 are small and limited to the shallow depths in the area immediately downstream of Pond 1.
- Water level and salinity impacts on Mardie Pool resulting from short term leakage from the crystallisers are predicted to be small. Leakage from the crystalliser, in the unlikely event that it occurs, is expected to result in additional discharge of groundwater to Mardie Pool. The nature of Mardie Pool (the area of the upstream surface water catchment relative to the size of Mardie Pool and the maintenance of this catchment during operation of the project) is such that it will likely continue to be flooded and over topped on an annual basis in the future. Water level impacts of short term leakage from the crystallisers (as any potential leakage from the crystallisers would be managed to prevent loss of production) are predicted to occur close to the crystalliser but are not predicted to persist once leakage from the crystalliser ceases.

Figure ES5 shows the extent of Pond 6 and the crystallisers, and areas of algal mat and mangrove communities downstream of Pond 6. An area of Pond 6 will be constructed over a portion of the mapped algal mat community. Downstream of Pond 6 the tidal inundation will continue over the life of the project. Modelling results suggest that water level impacts of the operation of Pond 6 are predicted to occur as follows:

- Immediately underneath and downstream of Pond 6 - 5m and 10m downstream of Pond 6 water levels are predicted to persist close to ground level as a result of the ongoing leakage from Pond 6. The extent of this impact is shown in Figure ES5.
- Further downstream of Pond 6 (100m), an overall increase in water level is predicted (refer Figure ES5). There is still, some water level variation predicted at this location from the tidal inundation / recharge and leakage from Pond 6. The predicted variation in water levels is less than the pre-development simulated water level variation at this location.
- Upstream of Pond 6, where an increase in water levels of ~ 0.3m is predicted (~ 6km upstream of Pond 6, refer Figure ES5).

  Predicted salinity increases from the operation of Pond 6 are limited to the immediate Pond 6 area and the immediate area upstream, and are not predicted to extend a significant distance upstream of Pond 6.
- Water level impacts of short term leakage from the crystallisers (~ one year duration), simulated as part of the Mardie Pool and Pond 6 predictions, are only predicted underneath and close to the crystallisers and are not predicted to persist once leakage from the crystalliser ceases.
- Salinity impacts of short term leakage from the crystallisers (also simulated as part of the Mardie Pool and crystalliser predictions) are limited to the area of the crystalliser and the area immediately downstream.

Future modelling, including calibration and operational updates, will continue to simulate potential pond and crystalliser leakage using 2D sectional models. Additional modelling for the area across Pond 8 will also simulate the increasing density in the ponds as well as pond seepage.

There has been no substantial stress placed on the natural system during project studies. All interpretations are based on monitoring data from the system within the relatively narrow range of natural conditions. The first significant primary stress outside of the range of natural conditions will be filling the of the first ponds (Pond 1).

It is also the case that the water quality that develops within the first ponds (Pond 1) is not materially different to the range in groundwater salinity that is observed on the coastal plain and sabkha and therefore this filling is comparatively low risk.

Leakage from other ponds (Pond 6) has the potential to result in increases in water level and salinity in the immediate area and immediately upstream and downstream of Pond 6. Potential leakage from the crystallisers would be monitored and managed, and in the unlikely event that there was a significant amount of leakage, the impacts would be short term and limited to the area of the crystalliser.

In the intra-tidal zone and sabkha, groundwater gradient is essentially flat. This is indicative of negligible lateral groundwater flow across this zone. There appears to be minimal lateral movement of groundwater from the sabkha to the ocean (or from the ocean inland), and negligible lateral movement of groundwater parallel to the coast, due to the very low permeability of the clay strata beneath the flats. It is therefore expected that changes to the groundwater regime due to loading or seepage from ponds will not propagate far from the ponds (either towards or parallel to the coast).

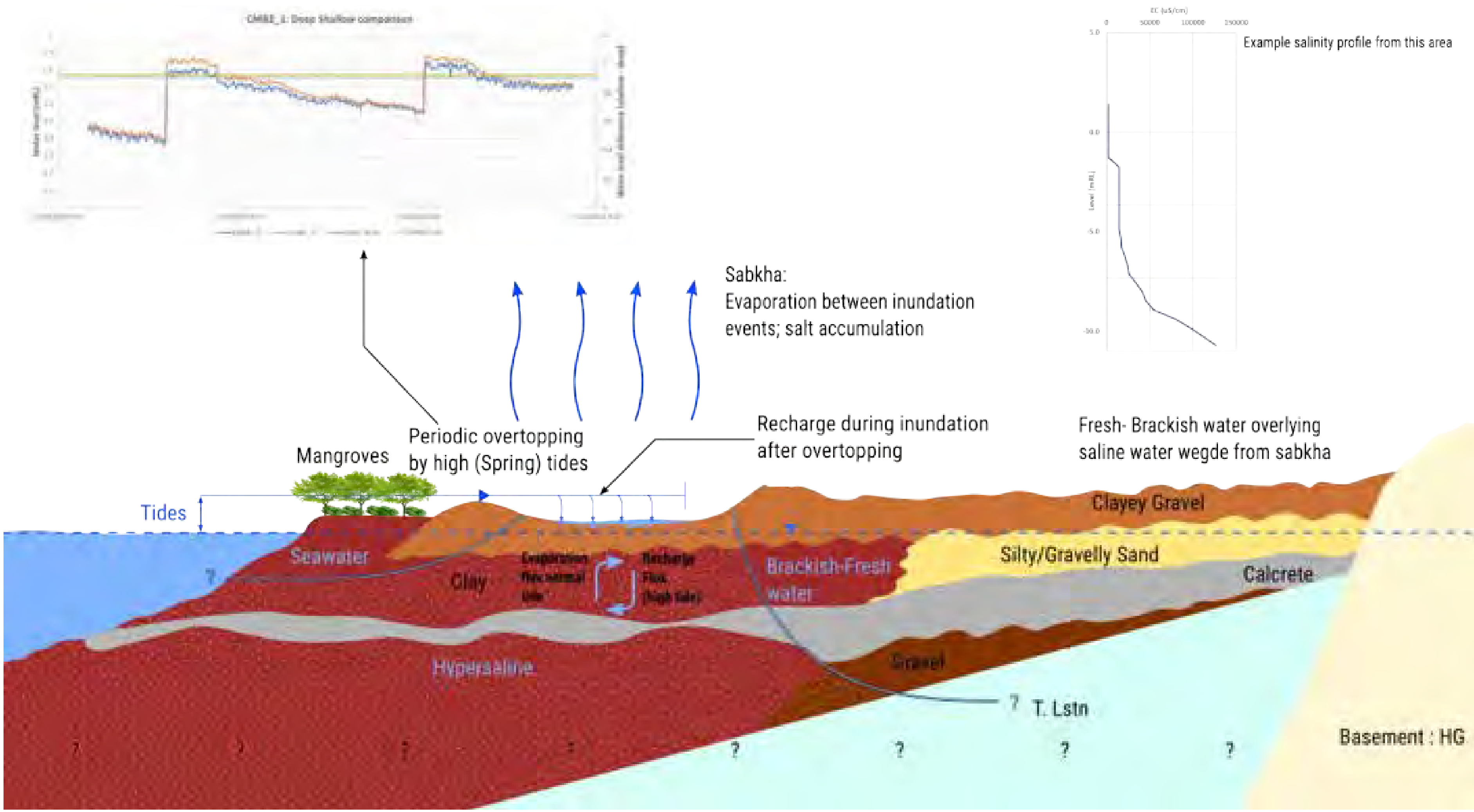


Figure ES1 Conceptual Groundwater Model Across Project Area

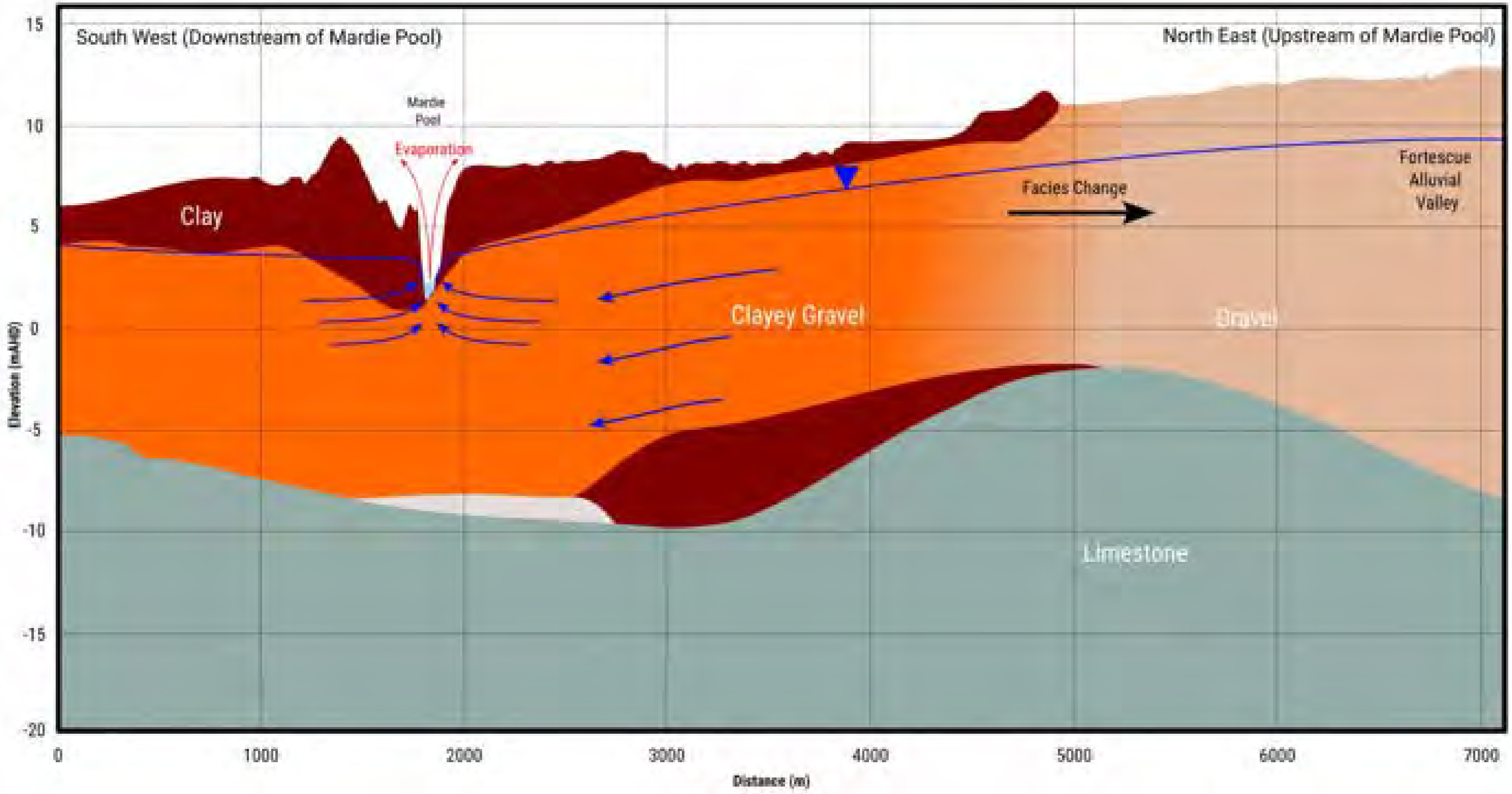


Figure ES2 Conceptual Groundwater Model Across Mardie Pool – Gaining Stream

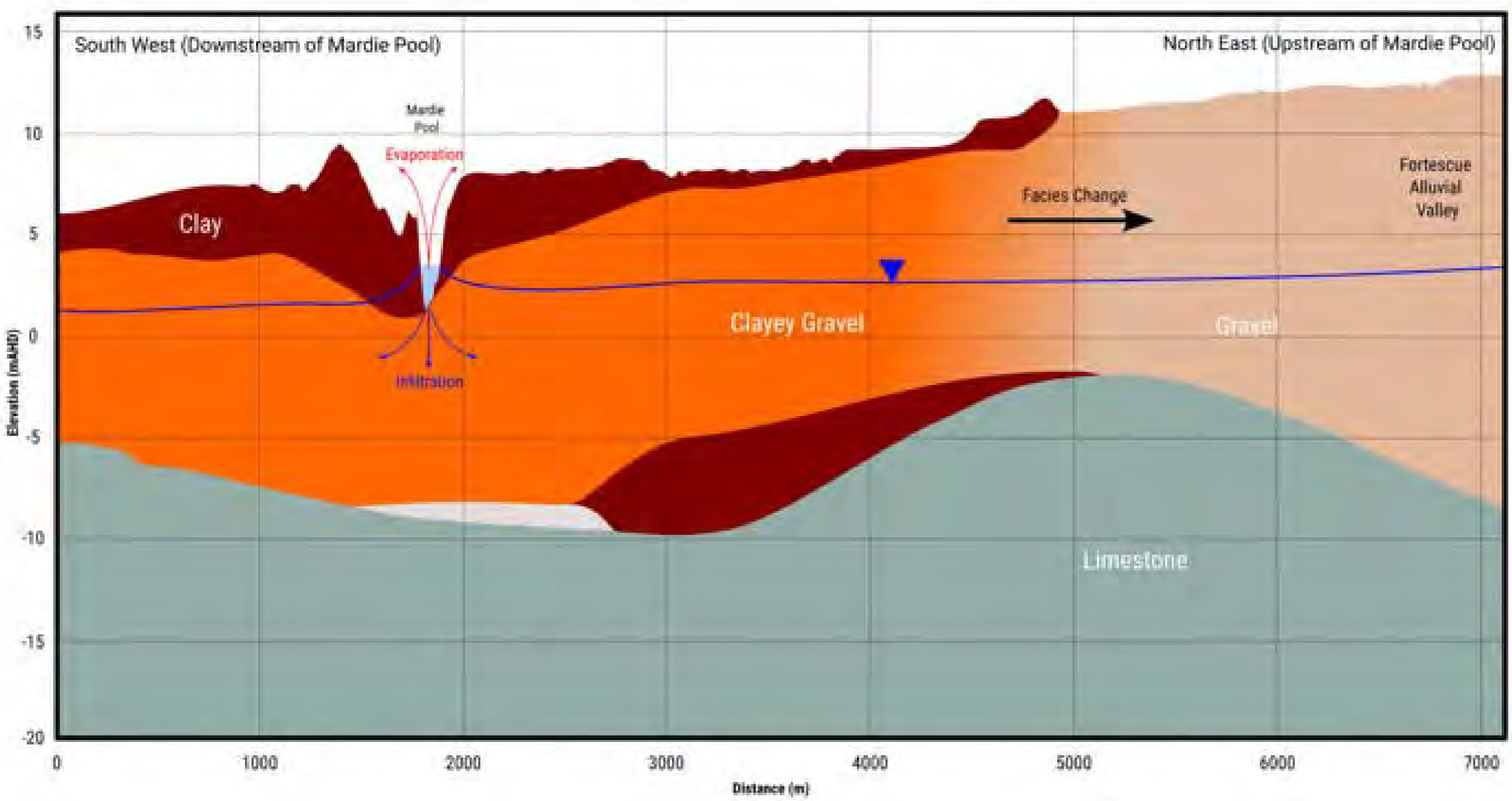


Figure ES3 Conceptual Groundwater Model Across Mardie Pool – Losing Stream

Figure ES4 Summary of Pond 1 Predicted Impacts

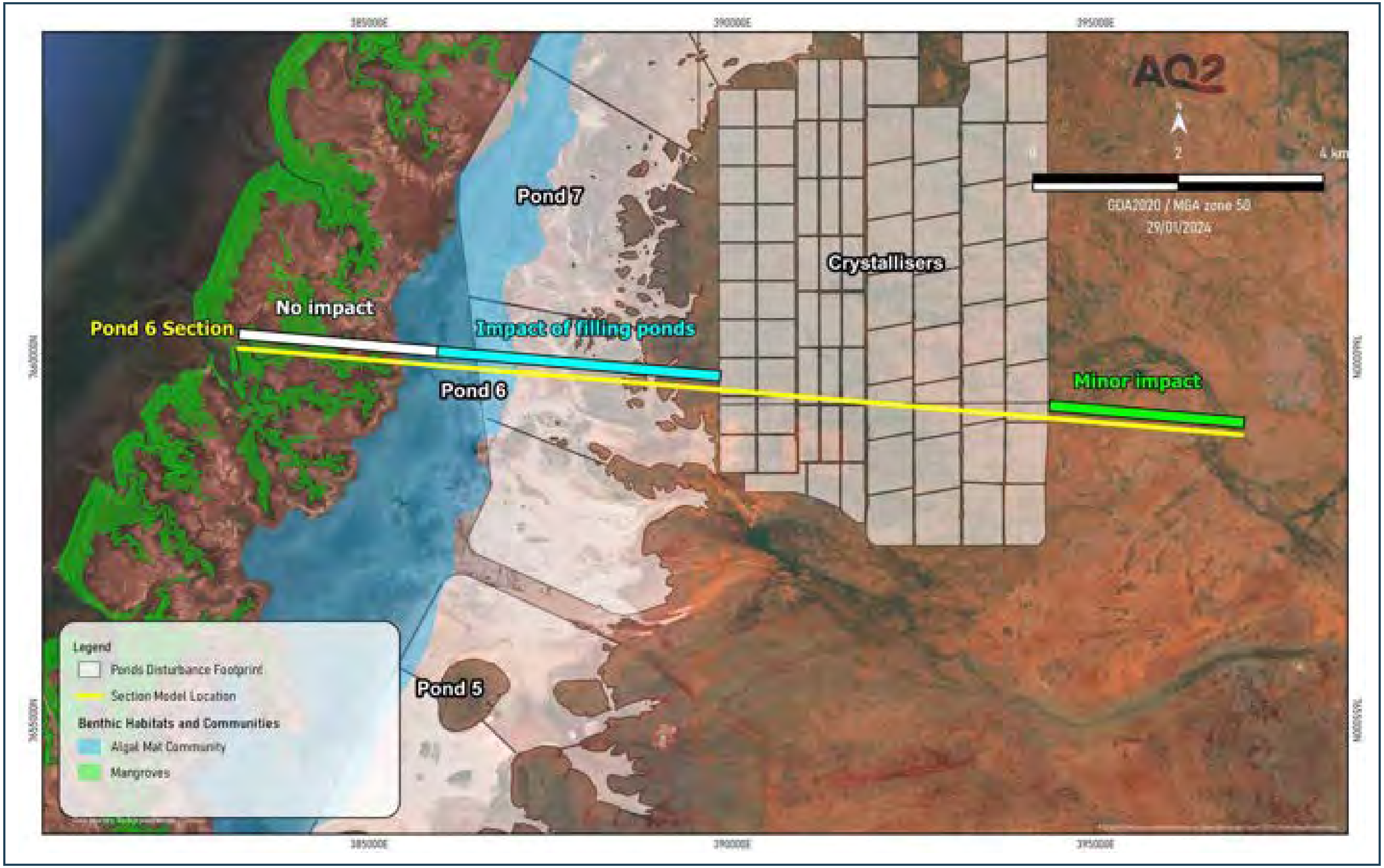


Figure ES5 Summary of Pond 6 and Crystalliser Predicted Impacts

TABLE OF CONTENTS

Tables

Figures

Appendices

1. INTRODUCTION

The Mardie Salt and Potash Project (the project) currently being constructed by BCI Minerals Limited (BCI) is located on the north-west coast of Western Australia in the Pilbara region, approximately 80km south-west of Karratha (Figure 1.1).

The Project involves development facilities to produce, process and export high purity industrial grade salt and fertiliser grade sulphate of potash (SOP) from seawater via solar evaporation, crystallisation, raw salt purification and SOP conversion.

The Project was originally referred to the Environmental Protection Authority (EPA) in April 2018 and approved with conditions under Ministerial Statement 1175 in 2021 (EPA, 2021b) and EPBC 2018/8236 in 2022. Significant amendments to the original proposal have since been outlined within the Optimised Mardie Salt Proposal, which was submitted to the EPA and Department of Climate Change, the Environment, Energy and Water (DCCEEW) in March 2022 (Preston, 2022).

The updated Project Area consists of three parts: the Original Proposal Area, the Optimisation Area and the Quarry Area, located 18.5km south-east of the Optimisation Area (Figure 1.2). This updated Proposal documents the expansion of concentrator and crystalliser ponds, an increased salt and SOP production rate, new secondary seawater intake option, a port facility laydown area, a quarry and minor changes to the dredge channel.

The Project will employ solar evaporation to condense seawater in a series of ponds, resulting in brine feedstock that will be used to produce crystallised salt products. Brine within concentrator ponds will reach 365 parts per million prior to salts being deposited in crystalliser ponds where brine concentration will exceed 600 parts per million before crystallisation. The current indicative layout for the project is illustrated in Figure 1.2.

The project area is characterised by coastal salt flats (a sabkha-type environment) with hyper-saline and shallow groundwater. These salt flats are separated from the ocean by a narrow near-coastal zone with sea-water quality groundwater that is influenced by tidal creeks that host mangrove communities. The evaporation ponds are constructed predominantly on the salt flats and underlain by hyper-saline brine. However, risk assessments conducted by AQ2 (2020) and AQ2 (2021) have indicated the potential for interaction between the Project ponds and the near-coastal zone in the event of seepage from the ponds (and the associated change in relative hydraulic gradients that will result from pond filling operations).

Further inland, salt crystallisers are proposed to be constructed north of Mardie Pool above the fresh water of the Fortescue Alluvial valley aquifer. In the vicinity of the crystallisers water level is 5-8m below ground level. Mardie Pool is of cultural significance and the banks of Mardie Creek harbour several riparian species, however the dominant vegetation in the area is invasive mesquite (Prosopis species).

This document details the conceptual groundwater system and groundwater modelling that has been applied to investigate the potential for lateral movement of saline water in the vicinity of:

- Pond 1,
- The crystallisers and Mardie Pool, and
- Pond 6 and the crystallisers.

Although considered unlikely, changes to the groundwater regime in this area have the potential to impact the near-coastal hydrological cycle that supports coastal mangrove habitat and the algal mat areas of the intertidal zone at Mardie.

Figure 1.1 Project Location (supplied by BCI Minerals)

Figure 1.2 Project Layout (supplied by BCI Minerals)

2. DATA SOURCES

2.1 Available Data

Table 2.1 summarises key data used in the current study. The data originate from a series of hydrogeological investigations undertaken by AQ2 and others since 2019. These studies include:

- Water supply drilling (2019-2022). Originally it was proposed that the project would use groundwater from the in-land eastern edge of the project area (where water quality is brackish) for construction supply. Subsequently, it has been determined these bores will not be used. However, the drilling provided information on the hydrogeology on the eastern edge of the project area where the marine groundwater system interfaces with the fluvial groundwater system of the inland creeks and rivers. Pumping tests were carried out in many supply bores, and the acquired aquifer parameters are used for this study.
- Groundwater monitoring bores drilled across the project area to provide information on water levels and water quality in the near-coastal zone (salt flats) and the inland area north of Mardie Pool. Access to much of this area is problematical with tidal effects and mud flats preventing most vehicular access. Consequently, some of this drilling (in the northern area, 10km north of the modelled section described in this report) has only been completed in October 2023.
- A wide range of geotechnical investigations (2019-2023) have been completed related to the construction of the ponds and infrastructure such as roads and jetties. These investigations provide information on soil properties (i.e., aquifer parameters), water quality and groundwater levels.
- Monitoring has been on-going since April 2022 and progressively increasing as more bores (in the logistically challenging areas) have been installed. Monitoring has provided information on groundwater levels (including the tidal response) and groundwater quality (including salinity profiling to determine the interface between the hyper-saline brine and less saline water on the ocean and landward margins of the project area). Inland and coastal monitoring bores are described in Section 4.

Table 2.1 Data Sources

Data Type	Data Source	Description
Groundwater Levels	Golder (2022) Technical Memo. – Groundwater Level Triggers – Chevron and Santos Pipeline Interface	Water levels from 5 bores spanning the length of the gas pipeline between Ponds 1/2 and 3. Data span February 2022 to August 2023
Groundwater Levels	Coastal Bores with telemetry installed by BCI Minerals	Water levels from 5 deep/shallow bore pairings on sabkha and adjacent to tidal creeks. Data span August 2023 to present.
Groundwater Quality	BCI Minerals/AQ2 field investigations	EC recorded from monitoring bores on the sabkha west of evaporation ponds and test production bores/ stock bores on the inland alluvial plain to the south-east of the ponds. Data span 2019 to present.
Groundwater Quality	CMW Geosciences Geotechnical Investigation	EC of water samples from geotechnical test pits and bores across the pond areas on the sabkha. Data span 2019-2020.
Regional Hydrogeology	Haig (2009) Commander (1993)	Reports describing hydrogeological investigations in the vicinity of the Mardie Project.

Data Type	Data Source	Description
Geology	Hocking et al (1987)	Regional geology and hydrogeology of the Carnarvon Basin
Aquifer Parameters	Recent Hydrogeological investigation and historical published investigations	Regional aquifer parameters have been sourced from published documents. Aquifer testing has been carried out as part of BCI Minerals investigations in a selection of recently installed bores (pumping tests, falling/rising head tests).
Tidal Records and influences	RPS (2019) – Coastal Inundation Study	Tidal modelling which describes the nature of tidal inundation of the coastal sabkha.

3. SETTING

3.1 Physiography

Key physiographic features of the project area relevant to the conceptual hydrogeology are shown in Figure 3.1. These are summarised below:

- An inland zone proximal to the outcrop of Pilbara Craton basement. This area is associated with the outflow of creeks and rivers from inland catchment areas, onto the coastal plain. The zone is marked by coarser sediments along creek channels and drainage lines and alluvial fans. Groundwater quality in this area is fresh to brackish.
- An extensive salt flat or sabkha. Drainage lines from the inland portion of the project area generally dissipate at the edge of the salt flats. The salt flats are a hyper-saline environment or sabkha. They are characterised by hypersaline groundwaters and periodic inundation from high tides.
- A near-coastal zone comprising beach flats and tidal creeks. The tidal creeks are incised into the coastline and are well defined features that fill and drain to varying extents depending on tide level. Periodic high tides breach the upstream margins of the creeks and flood the sabkha immediately inland. The creeks are lined with mangrove communities and are characterised by saline (seawater) water quality.
- Mardie Pool is a permanent water body on Mardie Creek, located on the east side of the coastal sabkha area. Mardie Pool is incised into the overbank clay and gravel deposits of the Fortescue River alluvial valley.

3.2 Climate

The Mardie Project is located on the west coast of the Pilbara region of Western Australia. The Pilbara climate is characterised by very hot summers, mild winters and low, variable rainfall (Sudmeyer, 2016). The region is classified as “hot grassland” under the Köppen classification system. A long-term Bureau of Meteorology (BoM) weather station is present at Mardie Station, with data available from 1907 to the present.

Figure 3.2 presents the long-term monthly average temperature, rainfall and evaporation data for Mardie from BoM. Rainfall is greatest during summer and autumn months (December through May, the “wet season”), resulting from tropical low-pressure systems, cyclones, and localised thunderstorm development. The dry season extends from August to November. The coastal Pilbara is also affected by frontal systems from the south during autumn and winter, resulting in relatively cool spells and occasionally rainfall.

BoM data from 1907 to the present indicates a long-term average annual rainfall of 288mm/a. Data exhibits high annual and monthly variability. Figure 3.3 presents annual rainfall totals from 1907 to 2022. Tropical cyclones produce the most extreme rainfall events and generate 25-34% of the total annual rainfall near the Pilbara coast (Charles et al 2015). The BoM dataset indicates annual rainfall totals ranging from 6.4mm (in 1937) to 886mm (2011).

The mean pan evaporation rate for the project area is approximately 3,400mm/a (BoM, 2006), more than 12 times the mean annual rainfall. Evaporation significantly exceeds mean rainfall across all months (Figure 3.2). There is a large environmental moisture deficit, and this has been important for the development of the sabkha.

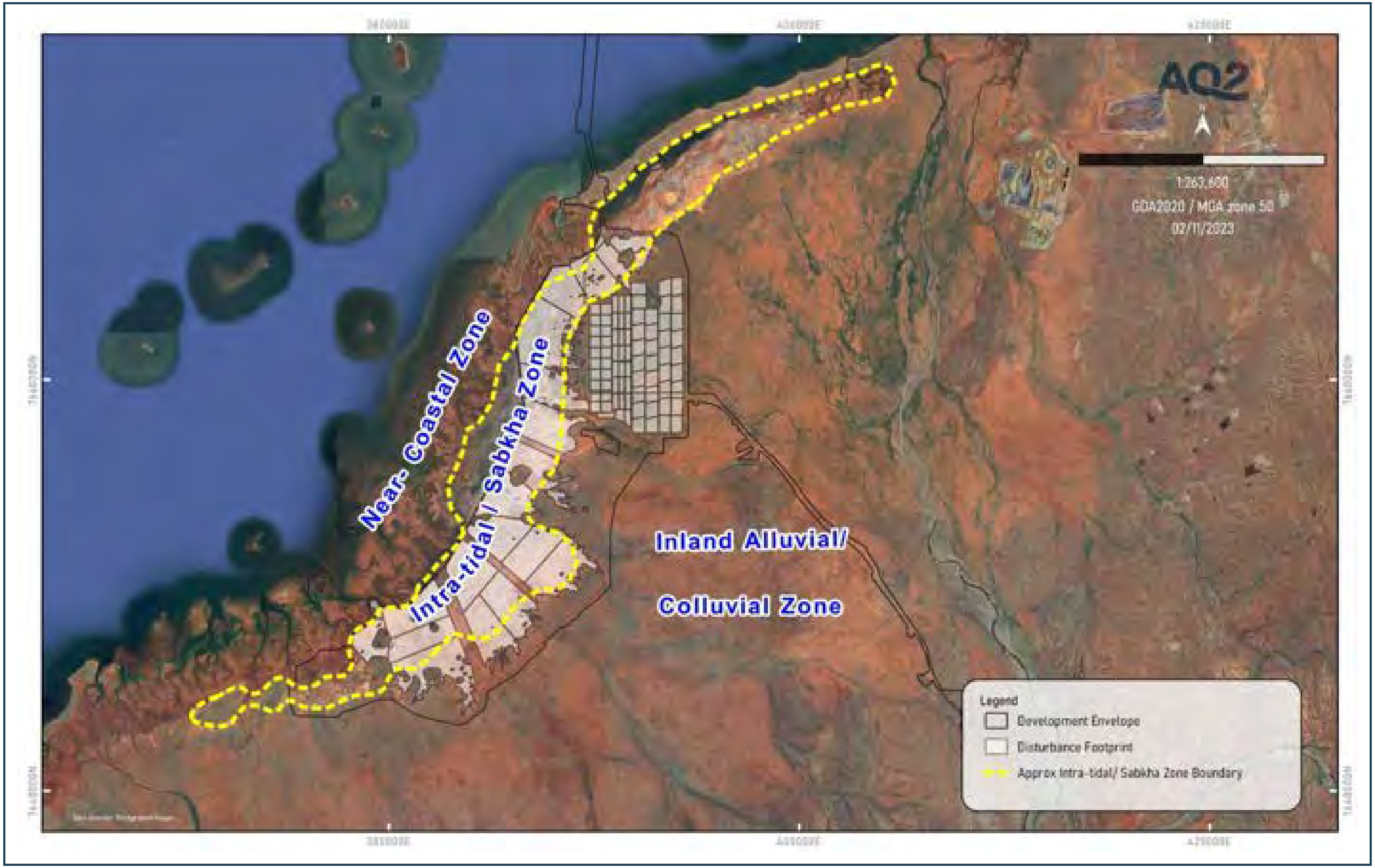


Figure 3.1 Key Physiographic Features of the Project Area

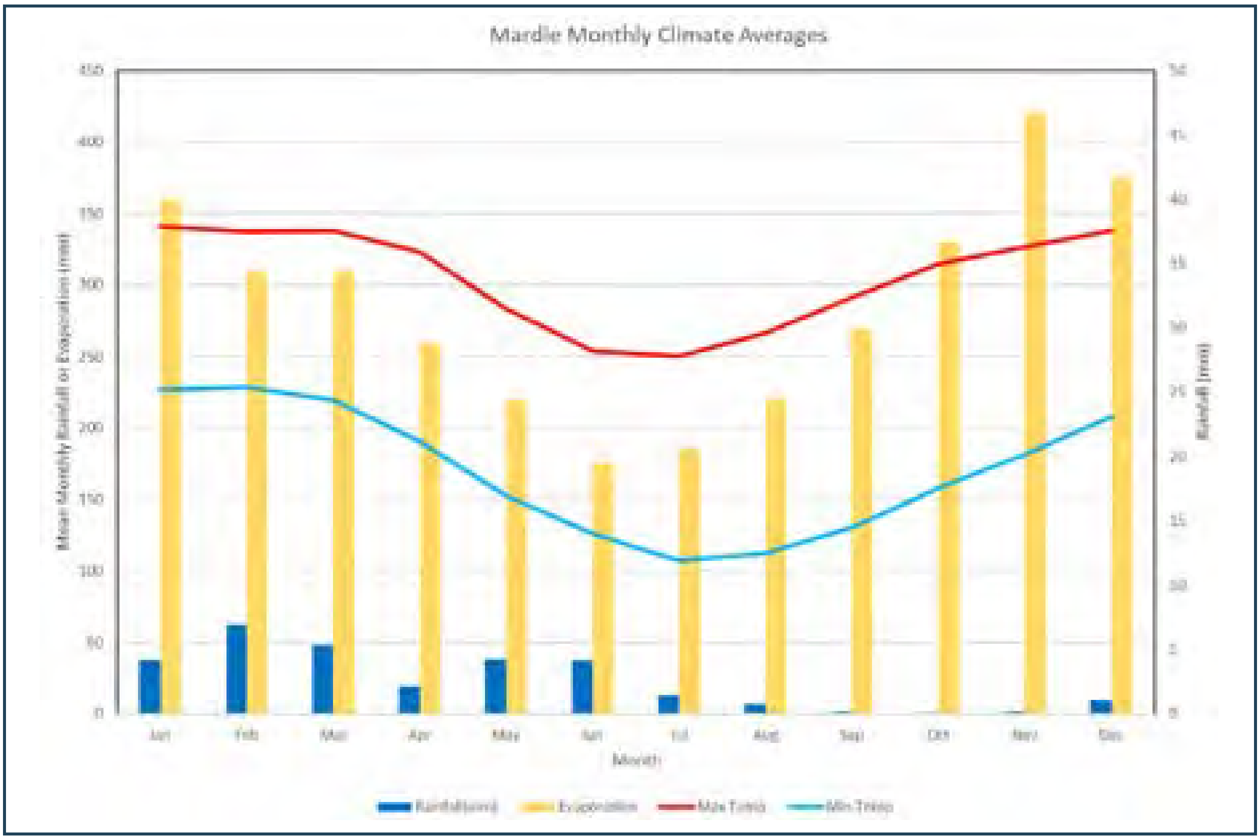


Figure 3.2 Monthly Climate Averages at Mardie

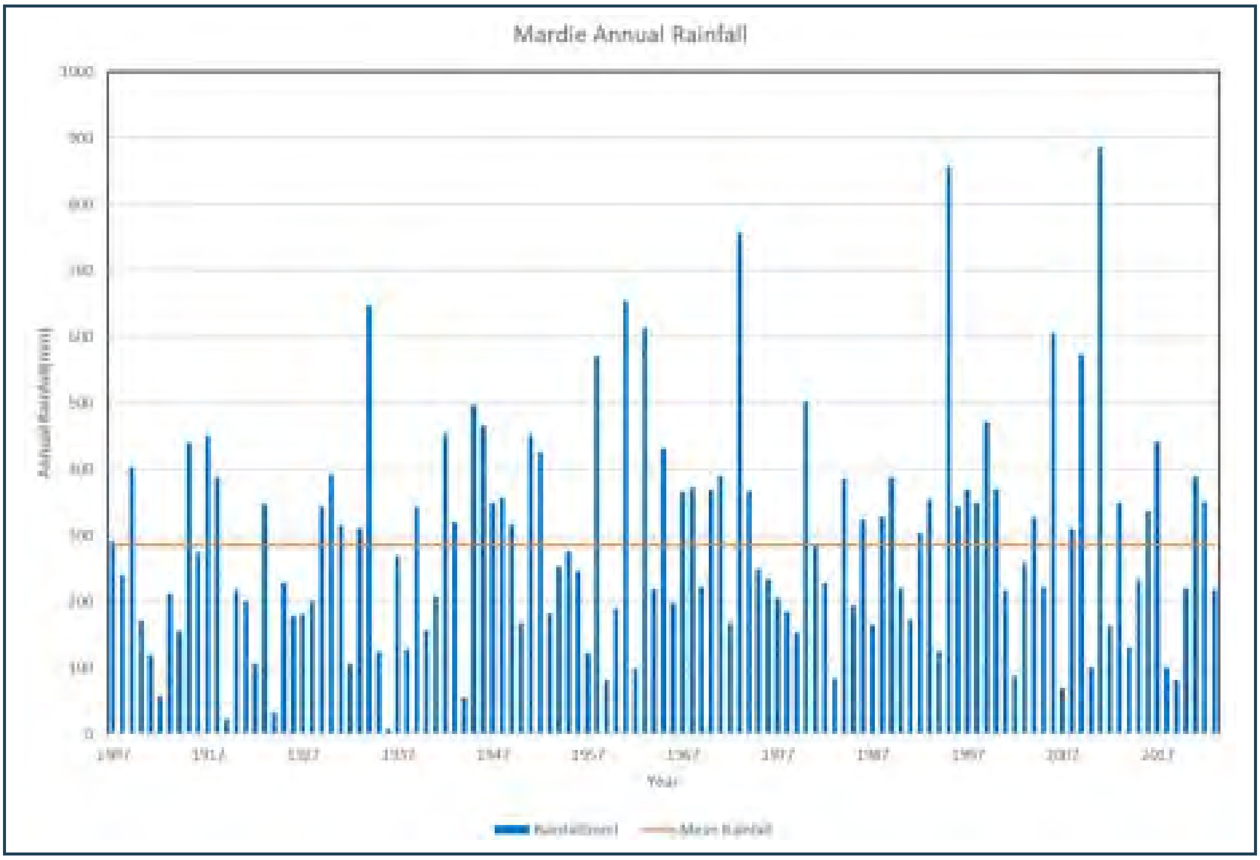


Figure 3.3 Annual Rainfall at Mardie

3.3 Tides

Coastal areas west of the Mardie Project are subject to the significant tidal fluctuations which occur along the Pilbara coastline. The highest tides exceed the elevation of the near-coast topography and result in periodic flooding of the adjacent sabkha areas (immediately inland). Studies by RPS (2021) using offshore tide survey equipment adjacent to the project indicate the naturally occurring maximum tidal range to be approximately 5m, with some variation along the length of project interface with the coastline. Calculated standard tide levels for the tide station presented in RPS (2021) are provided in Table 3.1. A sample tide prediction chart for Mardie (from September 2023) is presented in Figure 3.4.

Table 3.1 Mardie Inner (Aquadopp) significant tide levels

Factor	Acronym	Tide Level (~mAHD)
Highest Astronomical Tide	HAT	2.55
Mean High Water Springs	MHWS	1.92
Mean High Water Neaps	MHWN	0.48
Mean Sea Level	MSL	0.00
Mean Low Water Neaps	MLWN	-0.46
Mean Low Water Springs	MLWS	-1.88
Indian Spring Low Water	ISLW	-2.18
Lowest Astronomical Tide	LAT	-2.52

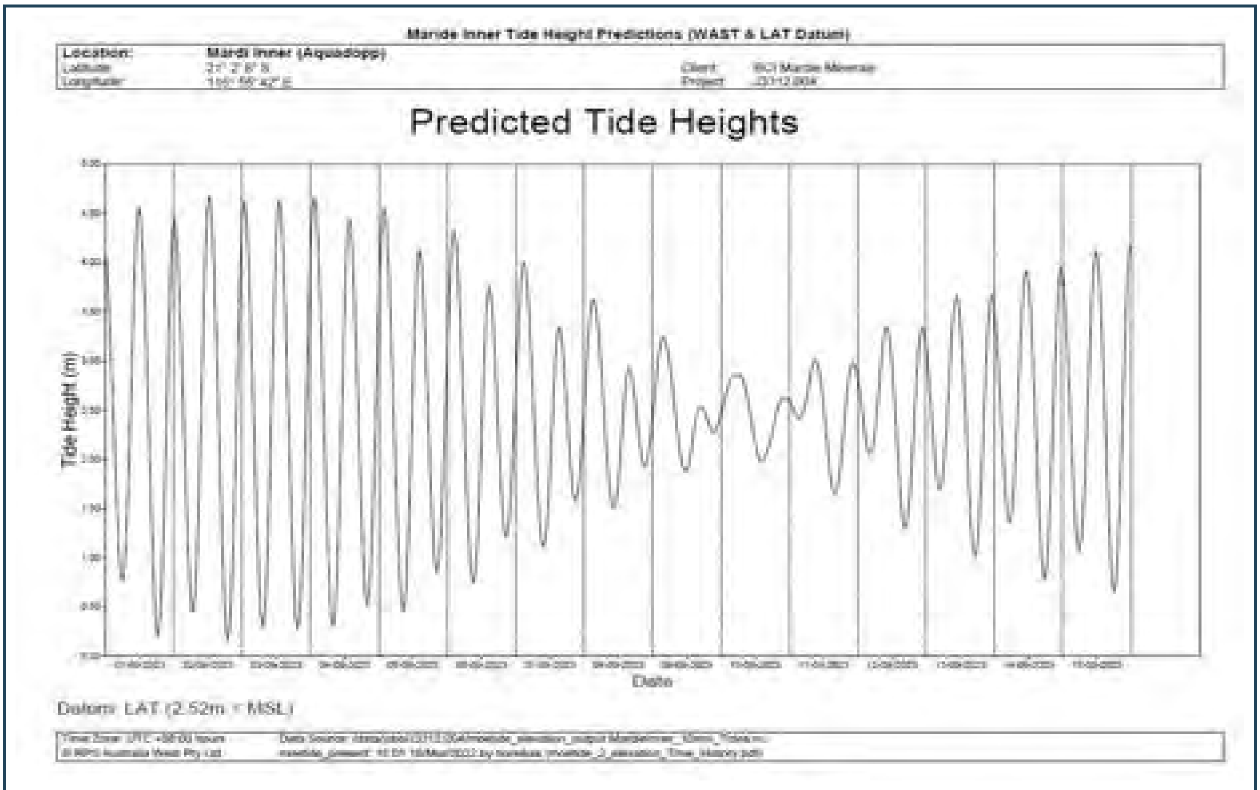


Figure 3.4 Sample Tide prediction chart for Mardie Inner (Aquadopp)

A coastal inundation study by RPS (2019) indicated several features specific to tides at Mardie:

- A small gradient in the amplitude of the tidal wave along the coast, with higher magnitude at the northern end of the project.
- The tidal level required for flooding of the sabkha/claypan area beyond the creeks was found to be lower at the north end. Flooding occurs at tide level of 1.2-1.3mAHD (equivalent) in the north, rising to 1.5-1.7mAHD in the south.

RPS (2019) also states that flooding onto land adjacent to the Mardie Project occurs via several pathways:

- Through the mangrove zone and lower sections of the coast onto the low areas between the tidal creeks.
- Out of the creeks through tributaries and erosion channels, and sheet flow over low points along the banks onto surrounding land.
- Via the ends of the creeks which grade directly onto the sabkha and claypans inland.
- Tidal flooding emanating from each of the sources above merge into one as they expand across the intra tidal zone.

The area of land flooded by the tidal surge depends on the maximum tide level and the areal extent of inundation is limited by both the tide height and the rising topography inland. Simulations by RPS (2019) indicate that water will begin to drain back into the creeks through the same delivery pathways mentioned previously, beginning at the coast at the moment the tide begins to recede. The flood surge across the sabkha may continue over a period of 40-45 minutes even while drainage to the creeks is occurring, due to momentum of the headwaters. Simulations also indicate that drainage of the sabkha may take an extended period depending on the water level attained, and that drainage will be complete by the time of the next low tide at the coast. During the highest spring tides, simulations showed that the sabkha was inundated for 4-6 hours in every 12-hour tide cycle. On recession of tide some water remains in local sinks for a period until seeping in or evaporating. In contrast, it is noted that during neap tides the sabkha may remain in a drying state for 7-10 days. Noting the environmental moisture deficit discussed above, evaporation from the salt flats during these prolonged periods with inundation results in the build- up of salts and the development of hypersaline conditions.

3.4 Ecological Receptors

Several ecological receptors have the potential to be impacted by the Mardie Project.

The EPA raised concerns regarding the presence of an algal mat ecosystem on the supratidal flats which exists within the development envelope and to the west of the proposed evaporation ponds. It was inferred by the EPA that the existence of the algal mats may be due to upwelling or overtopping of 'fresh' (low salinity) groundwater which is thought to bring nutrients to the surface and dilute the hypersaline fluids (which develop due to evaporation). It was also proposed (by EPA) that mangroves require input of fresh groundwater bringing nutrients into the root zone.

Figure 3.5 displays the mapped extent of mangrove species and algal mats at Mardie (O2 Marine, 2020). Proposed ponds are positioned close to mangrove habitat at Evaporation Ponds 1 and 2 in the south, and near Ponds 7/8/9 at the northern end of the project. Evaporation Ponds 3 to 6 are generally greater than 1km from mangrove areas. Ponds are also proposed to be constructed across areas of land mapped as algal mats at the western edge of Ponds 1 to 6, with significant areas of algal mat coverage remaining to the immediate west of those ponds. Ponds 7 and 8 are to cover all algal mat areas at the northern end.

It was proposed by the EPA that potential seepage from the evaporation ponds and possible mounding of groundwater beneath and adjacent to the ponds may cause changes to the groundwater regime which supports coastal ecosystems.

Mardie Pool (Figure 3.5) is also noted as an ecological receptor of cultural significance with the potential to be affected by the presence of evaporation ponds to the west and crystallisers to the north.

The focus of the studies presented in this modelling report is to determine the potential for groundwater regime changes on the coastal side of the evaporation ponds and at Mardie Pool.

3.5 Geological Setting

The project area lies within the Coastal Plain of the northern Carnarvon Basin. Regional surface geology is displayed in Figure 3.6 and bedrock geology in Figure 3.7 (from Haig (2009)). At Mardie the northern Carnarvon Basin extends inland approximately 30km to the south-east, where it onlaps the western edge of the Pilbara Craton and Capricorn Orogen. To the north the onshore part of the basin narrows to intersect the coast near the Fortescue River mouth.

3.5.1 Carnarvon Basin

The stratigraphy of the Carnarvon Basin basement geology below the Coastal Plain is described in Table 3.2. The units comprise Late Devonian to Cretaceous sediments of the Winning Group and Late Carboniferous to Early Permian Lyons Group. Lyons Group sediments overly Proterozoic basement rocks, within 150m of the surface in the north of the Carnarvon Basin.

The Cretaceous Winning Group includes the Nanutarra Formation, Birdrong Sandstone and Yarraloola Conglomerate which are often considered equivalent and have been found in buried channels where major drainages enter the coastal plain (Haig 2009). Lyons group sediments variably separate the Winning Group and Proterozoic basement rocks.

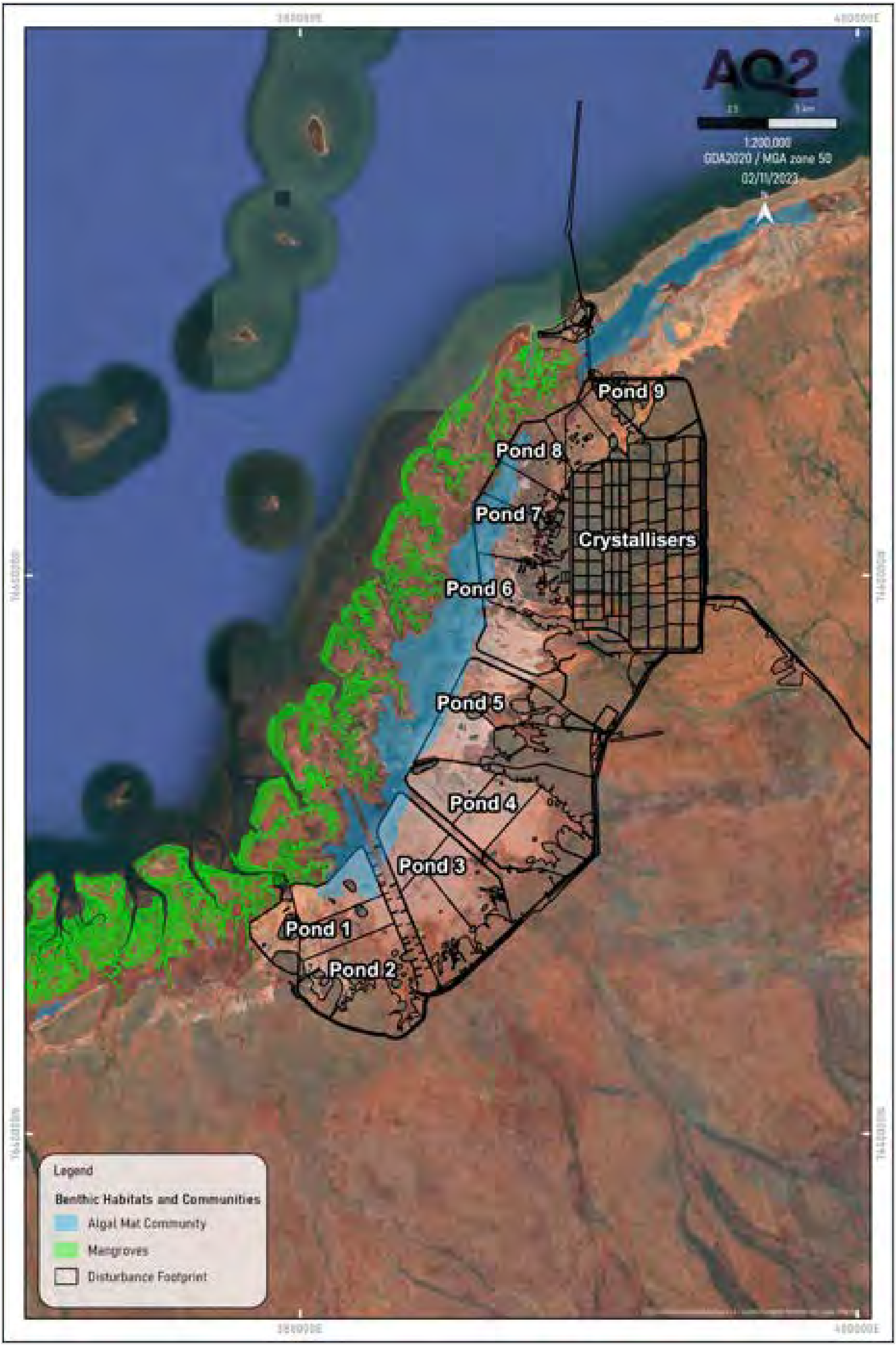


Figure 3.5 Coastal Ecological Receptors

Figure 3.6 Surface Geology of the Mardie Area

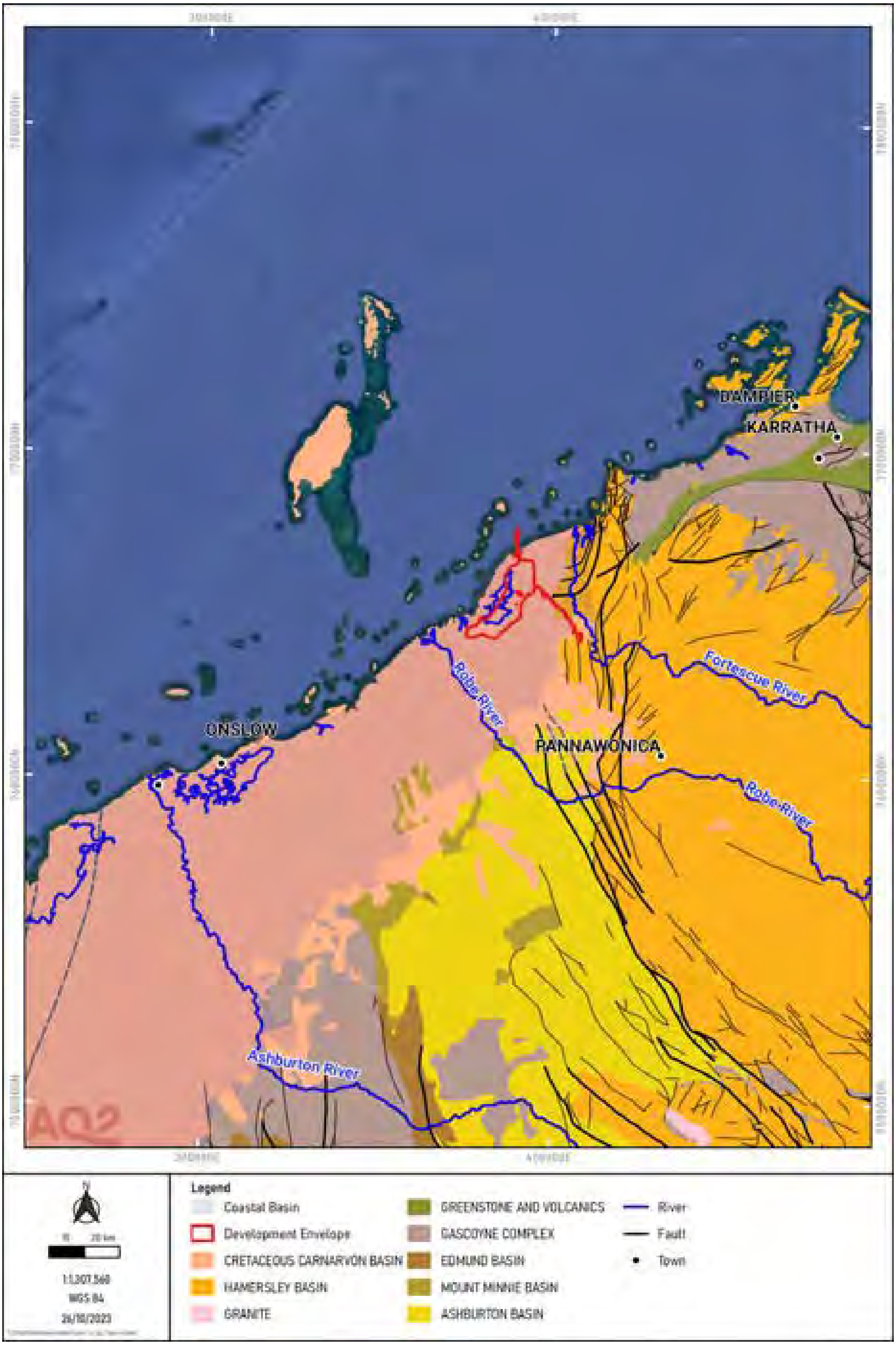


Figure 3.7 Basement Geology of the Mardie Area (after Haig 2009)

Table 3.2 Carnarvon Basin Stratigraphy (from Haig 2009)

Group	Age	Unit	Thickness
Winning	Later Cretaceous	Toolunga Calcilutite	<100m
		Muderong Shale (Mardie Greensand Member)	150m
		Windalia Radiolarite	
		Gearle Siltstone	
	Early Cretaceous	Yarraloola Conglomerate	<300m
		(Nanutarra Formation and Birdrong Sandstone)	
Lyons	Late Carboniferous to Early Permian	Limestone, dolomite, claystone, shale, siltstone and sandstone	>280m

Cainozoic deposits of the Coastal Plain overlie the Carnarvon Basin Sediments from the coast, thinning gradually to meet the exposed Proterozoic basement rocks 30km inland. Shallow geotechnical investigations and hydrogeological drilling indicate a Tertiary/Quaternary sequence on the coastal plain consisting of limestone, calcrete, clay and gravel in variably consolidated forms. At Mardie the following general units have been identified.

3.5.2 Shallow Coastal Deposits

The shallow coastal deposit sequence is outlined in Table 3.3 and described in following sections.

Table 3.3 Alluvial Sequence of the Coastal Plain

Unit	Age	Lithology
Fortescue River alluvium	Quaternary	Clay, calcrete, gravel, cobbles, pisolite, ironstone
Coastal Alluvium	Quaternary	Silt, clay, gravel
Calcrete/Calcareous Claystone	Quaternary	Calcrete/ calcareous claystone (developed within the Coastal Alluvium
Trealla Limestone	Tertiary	Limestone, clay, marl

3.5.2.1 Trealla Limestone

Trealla Limestone is a Tertiary-aged component of the Carnarvon Basin sequence (Haig 2009). It has been identified in many of the deeper boreholes (to 40m) inland to the east of the ponds which have been drilled as part of the groundwater investigation at Mardie. It presents variably as a fine-grained pale limestone, clay or marl, occasionally as chips with conchoidal fracturing and the appearance of calcrete. The Trealla Limestone is thought to be mostly around 15m thick but has been noted at up to 41m. The Trealla Limestone represents a base to the shallow coastal groundwater system and is overlain by various unconsolidated Neogene and Quaternary sediments as outlined below.

3.5.2.2 Calcrete/Calcareous Claystone

Shallow calcrete has formed widely and discontinuously, and generally below alluvial cover within the range of historical groundwater fluctuation, sometimes outcropping where surficial material has since been eroded. Deposits may take the form of carbonate - cemented clay, silt, sand and gravel. The distribution of calcrete is usually associated with historical drainage channels. Significant cavities or solution channels have been intercepted in calcrete in bores inland from the intra-tidal zone during drilling investigations.

3.5.2.3 Coastal Alluvial Sediments

On the coastal plain at Mardie alluvial sediments have been deposited on top of the widespread Trealla Limestone, and sporadically, directly onto basal Carnarvon Basin sediments in the Fortescue Valley alluvials where the meandering river channel eroded the overlying units prior to the deposition of Quaternary alluvials. The alluvial package consists variably of clay, silt, sandy clay and gravel. Near the coast the alluvium is around 15-20m thick. Inland to the south-east the thickness of alluvium increases with the addition of overlying alluvial sand/gravel and pisolite.

3.5.2.4 Fortescue River Alluvium

The Fortescue River valley deposits form an alluvial fan west from the current location of the main river channel to the coast at the north end of the Mardie Project, covering an area of approximately 200km^2 (Commander 1993). The valley fill sequence is up to 30m thick, consisting of a surficial veneer of silt and clay over-bank deposits, overlying gravel and clay layers with intermittent calcrete near the water table.

Commander (1993) indicates that clay layers may be deep red to yellow and white with granules and pebbles, and the yellow clay is similar in presentation to heavily weathered Trealla Limestone. Gravel in the valley consist of rounded cobbles or pebbles of basalt, chert quartz and others, up to 100mm in diameter. These are believed to have been derived from the nearby Mount Bruce Supergroup, in which the adjacent Sino Iron Deposit occurs.

4. HYDROGEOLOGY

The Mardie Project development envelope lies wholly within the bounds of the northern extremity of the onshore Carnarvon Basin. At this location, the Carnarvon Basin sediments dip gently to the north-west, and to the east the Basin onlaps the western edge of the Pilbara Craton approximately 30km inland from the coast. Coastal Plain sediments of clay, gravel and calcrete (often weathered to calcareous claystone) cover the entire area of interest.

4.1 Hydrostratigraphy

At Mardie two significant, distinct unconfined aquifer systems are present: the Fortescue Alluvial aquifer and the alluvial aquifer of the Coastal Plain (the latter referred to by DWER as the Carnarvon Superficial aquifer). The extent of these systems is displayed in Figure 4.1, and the hydrostratigraphy of the systems is presented below.

4.1.1 Coastal Plain Alluvial Aquifer

The coastal plain alluvial aquifer is generally unconfined and formed in Pliocene / Quaternary sediments. The coastal aquifer is in hydraulic connection with confined aquifers within the underlying Carnarvon Basin sediments (Yarraloola Conglomerate, Birdrong Sandstone) (Haig 2009).

The hydrostratigraphy of the coastal aquifer has been defined through data from geotechnical investigations across the intra-tidal zone and deeper (~30m) investigative test bores in the hinterland area to the south-east. Deeper information is limited in the area of the sabkha (due to the logistical difficulties of operating in this area). The generalised hydrostratigraphic units are summarised as follows:

- Alluvial Sand/ Pisolite – cover of unconsolidated alluvial sand and gravel, generally in the unsaturated zone on rising terrain inland from the intra-tidal zone, with moderate to high hydraulic conductivity.
- Silt/clay – thick layer of variably mixed silt, clay and (matrix-supported) gravel up to 10m thick. Low hydraulic conductivity. Extensive beneath the sabkha zone.
- Calcareous Claystone/ Calcrete – sporadically noted across the area in deeper geotechnical test holes. Potentially a zone of marginally higher conductivity than clay when porosity has developed. Deeper test bores inland and up gradient from the sabkha have also intercepted deeper calcrete conglomerate along drainage channels which may extend beneath the sabkha where paleochannels extent into this zone.
- Limestone – extensive basement limestone bedrock unit (likely Trealla Limestone). Not drilled or tested under the sabkha zone.

4.1.2 Fortescue Alluvial Valley

The Fortescue River alluvial valley forms a large aquifer of fresh groundwater across the alluvial fan west of the main river channel. Gravel units within the valley sediments have the highest yield and a total saturated thickness of up to 15m (Commander 1993). Silt and gravel content is variable both vertically and horizontally, resulting in highly variable aquifer transmissivity and variations in water quality. The gravels grade laterally into overbank silt and clay deposits with much lower transmissivity, shallowing significantly near the southern edge of the valley. These overbank deposits are contiguous with the silt and clay unit of the Coastal Plain aquifer. Collectively, these low transmissivity units underlie much of the study area.

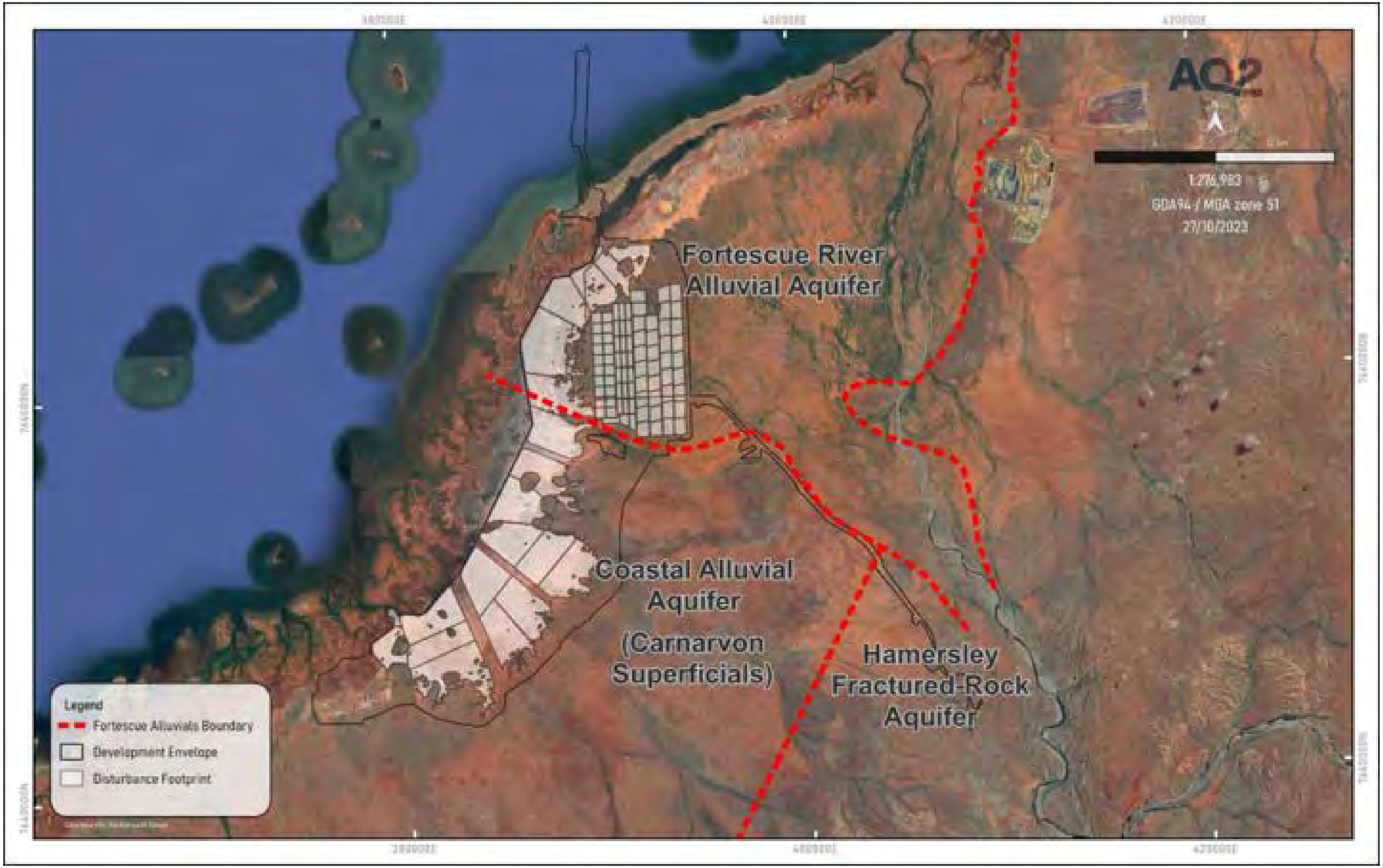


Figure 4.1 Unconfined Aquifer Systems at Mardie

4.2 Groundwater Levels and Flow

Regional groundwater level and flow direction is presented in Figure 4.2, generated from water levels measured in groundwater investigation bores which have been installed since 2019 at Mardie (Figure 4.3). The water table falls from the Fortescue River towards the north-west with iso-potential lines generally parallel to the coast (excluding localised variations due to creeks and hydrostratigraphic differences). To the east of the project the water table gradient is relatively steep and mirrors the rise in terrain (towards the inland zone and shallowing basement).

In the intra-tidal zone and sabkha, the groundwater gradient is essentially flat at approximately 1:5000. This is indicative of negligible lateral groundwater flow across this zone. Based on this, the following are posited:

- There is negligible lateral movement of groundwater from the sabkha to the ocean (or from the ocean inland).
- There is negligible lateral movement of groundwater parallel to the coast.
- In the absence of lateral groundwater movement, the primary water fluxes from the coastal zone are vertical:
  - Periodic recharge (infiltration) during the highest tides when the sabkha are inundated.
  - Evaporation of shallow water from the surface of the coastal flats and sabkha in the periods between inundation. The fine- grained nature of the sediments in this area (silt and clay) will have a large capillary rise and high porosity to support evaporation during this period.

4.3 Recharge

Greatest recharge to the coastal plain aquifer occurs during flooding in locations where the aquifer is in connection with the major rivers and creeks. Some direct recharge to the coastal plain will occur during major rainfall events when extensive flooding overbanks from the water courses and moves as sheet flow across the plain.

Within the alluvial valley, flood recharge at the Fortescue River has been noted to move as a pulse of increased water level towards the coast slowly over several months. Significant recharge generally only occurs with the passing of tropical cyclones or rain-bearing tropical low-pressure systems within the Fortescue River catchment. Monitoring bores north of Mardie Pool have responded with 1.5-2m water level rises in the months following a large rainfall event in June 2022.

On the coastal sabkha recharge is driven by cyclic tidal inundation (outlined in Section 3.3). Hydrographs in Figure 4.4 provide examples of monitoring bore response to tidal inundation on the sabkha area between Pond 3 and the nearest mangroves to the west. At these locations deep bores are screened at approximately 8-10m below ground level (bgl) and shallow bores are screened across the water table. Water levels at the bores display a distinct rapid recharge at the time of inundation from high Spring tides. Data indicates that the soil profile is generally fully saturated by the first Spring tide which reaches the bore. The following high tides consequently keep the storage full until tides recede in following days to the point where the bore location is not inundated. From this time until the next inundation the water level in the bore gradually falls, while overprinted with a small tidal pressure pulse. The water level recession between inundation events is due to evaporative discharge as posited above.

Figure 4.5 displays hydrographs from bores which were originally installed for monitoring of the gas pipeline corridor. The chart displays the differing response to rainfall and tidal recharge with distance from the coast. This long-term (18 months) dataset was also used for modelling of the Pond 1 Section.

Figure 4.2 Groundwater Levels and Flow

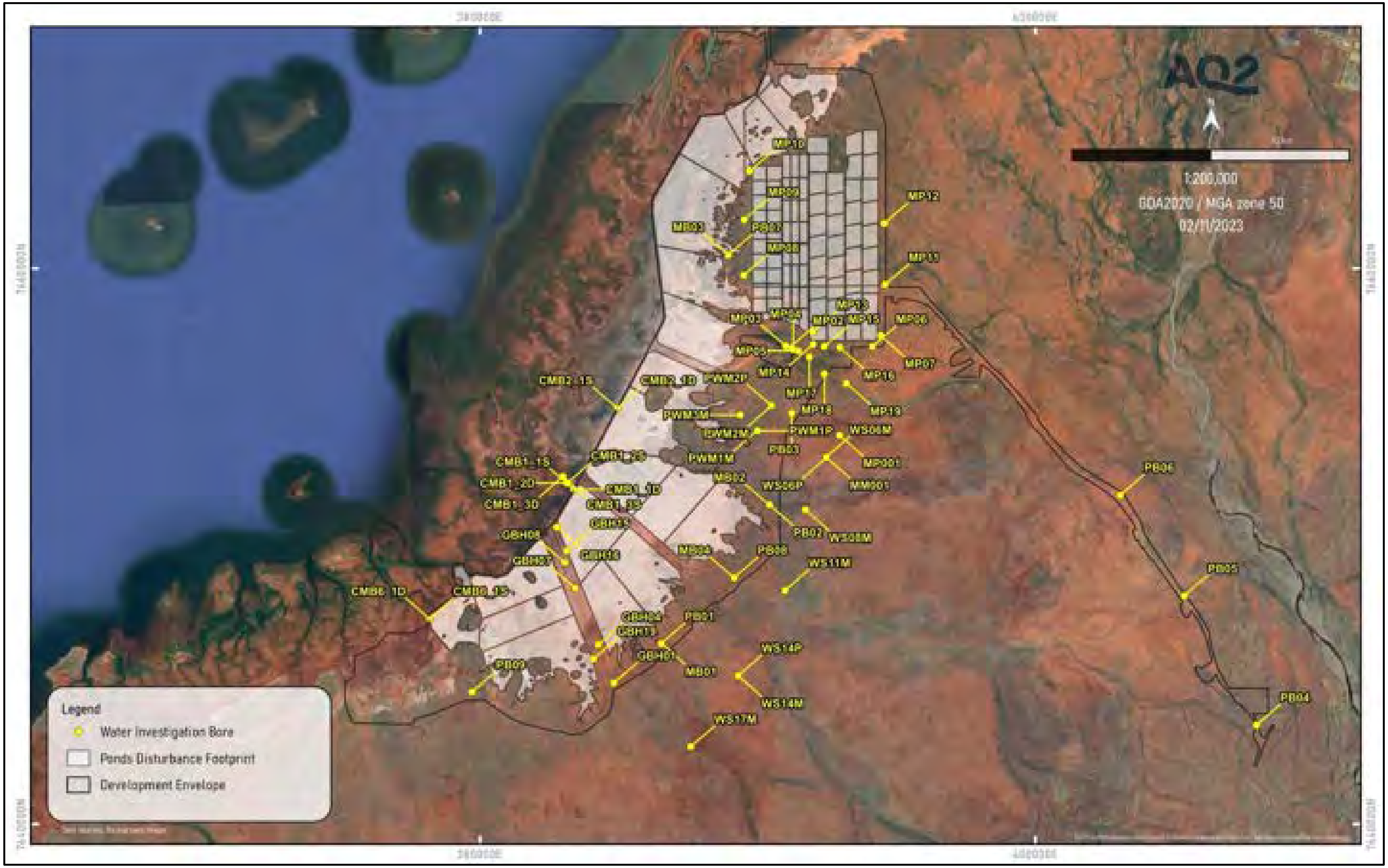


Figure 4.3 Location of Investigation Bores

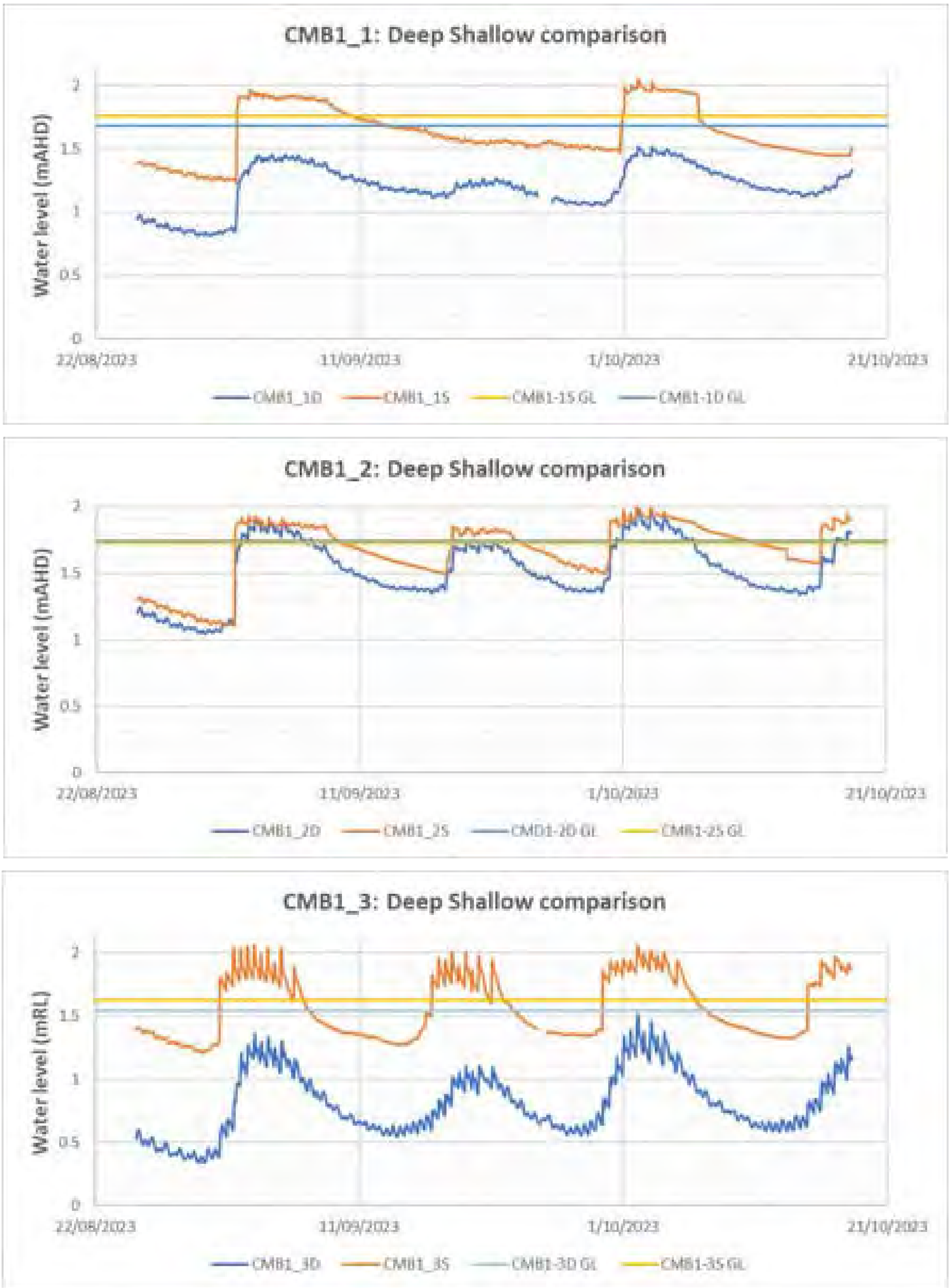


Figure 4.4 Hydrographs from the Sabkha Area adjacent to Pond 3

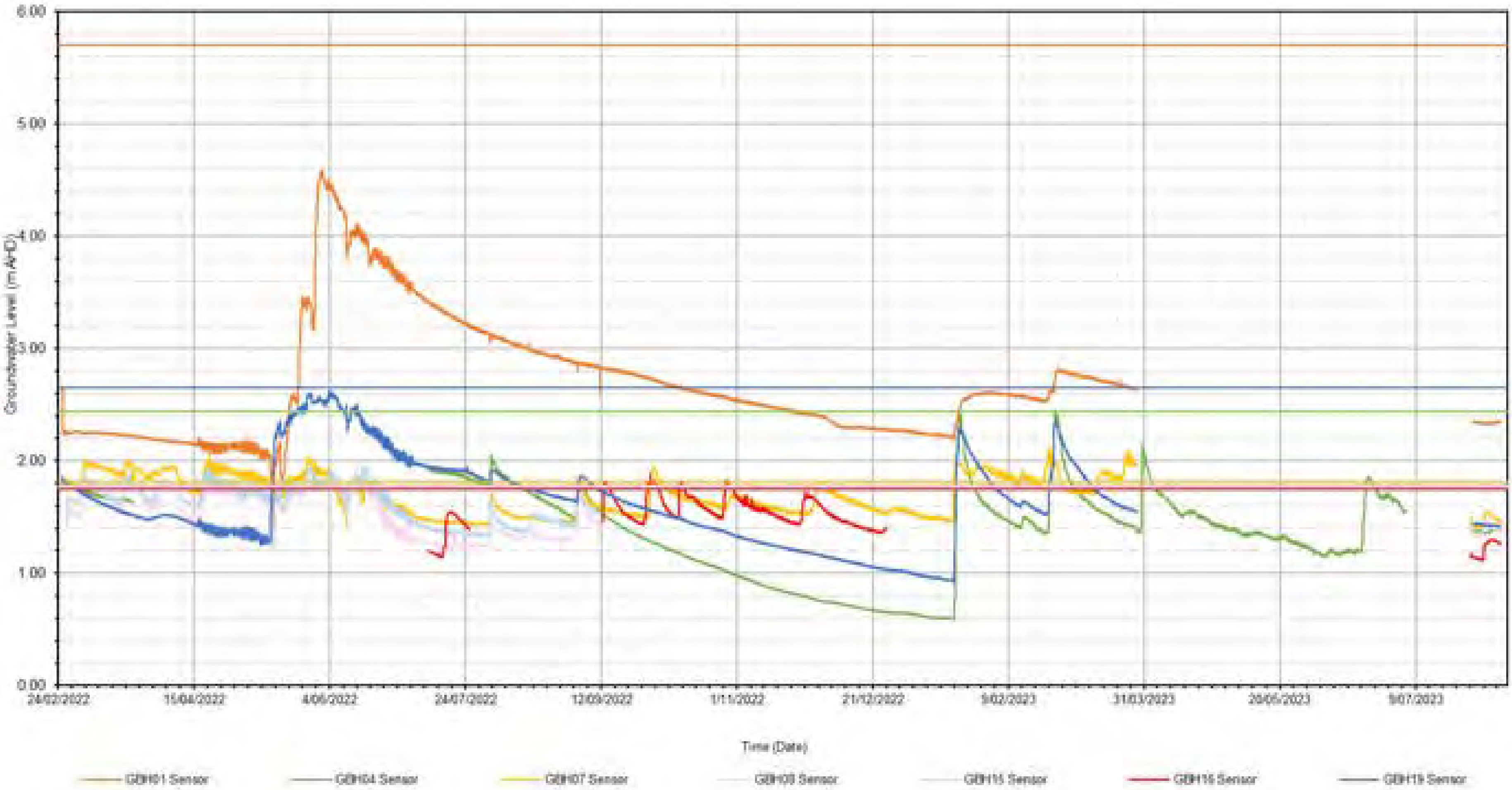


Figure 4.5 Hydrographs from Historical Bores on Gas Pipeline Corridor

4.4 Water Quality

Figure 4.6 displays generalised groundwater salinity (as EC) at Mardie as observed in a large number of test pits and bores over several years. Where salinity profiles have been taken in monitoring bores, the EC used was from deeper in the bores at around 10mbgl. In test production bores EC was taken during pumping tests and is therefore biased towards the EC of the most productive strata.

Fresh water extends down the Fortescue River alluvial valley to meet the saline plume of the tidal flats approximately 7km inland from the coast. Inland from the southern half of the Mardie Project, fresh groundwater within the coastal plain alluvium abuts the saline water interface up to approximately 11km inland.

Hypersaline groundwater was noted across the entire intra-tidal zone and in some deep bores on the upland alluvial plain to the south-east. A selection of deep and shallow bores (2m/~8m pairings) installed on the sabkha in 2023 (Table 4.1) have consistently displayed the presence of hypersaline water in the EC range 160 000- 200 000uS/cm, indicating that the quality of water is similar throughout the soil profile relevant to the receptors in this area (algal mats and mangroves). One shallow bore adjacent to mangroves and creeks west from Pond 3 (CMB1_3S) presented slightly less hypersaline, likely due to tidal flushing. Bores adjacent to Pond 1 and a tidal creek at the south end of the project (CMB6_1S/D) presented salinity somewhat greater than seawater (Table 4.1).

Salinity profiles from several monitoring bores in the river valley north of Mardie Pool display increased salinity at the base of the bore, providing an indication of the location of the saline interface. Examples of the vertical salinity profile are shown in Figure 4.7.

Table 4.1 Salinity in Coastal Bores

Bore ID**	Easting GDA2020 MGA50	Northing GDA2020 MGA50	Sample Conductivity (uS/cm)	Calculated TDS* (mg/L)
CMB1_1D	383346	7652050	189000	141000
CMB1_1S	383346	7652050	184000	138000
CMB1_2D	383129	7652268	173000	130000
CMB1_2S	383129	7652268	153000	114000
CMB1_3D	382977	7652509	169000	127000
CMB1_3S	382977	7652509	113000	85000
CMB2_1D	384909	7655003	202000	151000
CMB2_1S	384909	7655003	206000	155000
CMB6_1D	378177	7647380	57000	43000
CMB6_1S	378177	7647380	73000	55000

* assumed conversion factor 0.75, compensated to 25degC at measurement

** D = deep screen 7-10m, S = shallow screen across water table

4.5 Hydrogeological Parameters

Constant rate tests and falling/rising head tests were carried out in a selection of Test Production bores and monitoring bores across the project site over several campaigns. Hydrogeological parameters were also gathered from previous work in the area. It is noted that pumping tests were undertaken on bores primarily drilled for water supply, targeting cavernous calcrete and gravels around drainage lines on the coastal plain, and within the Fortescue River valley alluvials.

Field information has been combined with published data from similar environments to approximate hydrogeological parameters for the conceptual models presented in this report. A summary of hydrogeological parameters is presented in Table 4.2.

Table 4.2 Summary of Hydrogeological Parameters

Location	Hydrogeological Unit	Source	Hydraulic Conductivity k (m/d)
Coastal Alluvial Inland Zone – upland areas	Calcrete/weathered Calcrete/ gravel/clay targeting drainage lines	Pumping Tests 2022	2.7-60
Fortescue River Valley	Silt/clay/gravel of the alluvial fan	Rising head tests in monitoring bores 2022	0.01-0.31 (Average 0.08)
Coastal Inter-tidal/ Sabkha Zone	Shallow silt/clay/gravel at water table	Rising head tests 2023 (bailed tests, low volume). 4 samples.	0.18-0.43 (Average 0.3)
Coastal Inter-tidal/ Sabkha Zone	Deep (7-10m), presumed silt/clay/gravel (no geological samples)	Rising head tests 2023 (bailed tests, low volume). 3 samples.	0.07-0.54 (Average 0.22)
Fortescue River Valley	Clay and gravel layers of the alluvial valley	Pumping Tests – 3 production bores – Commander (1993)	63-190

Figure 4.6 Generalised Groundwater Salinity Measured as Electrical Conductivity

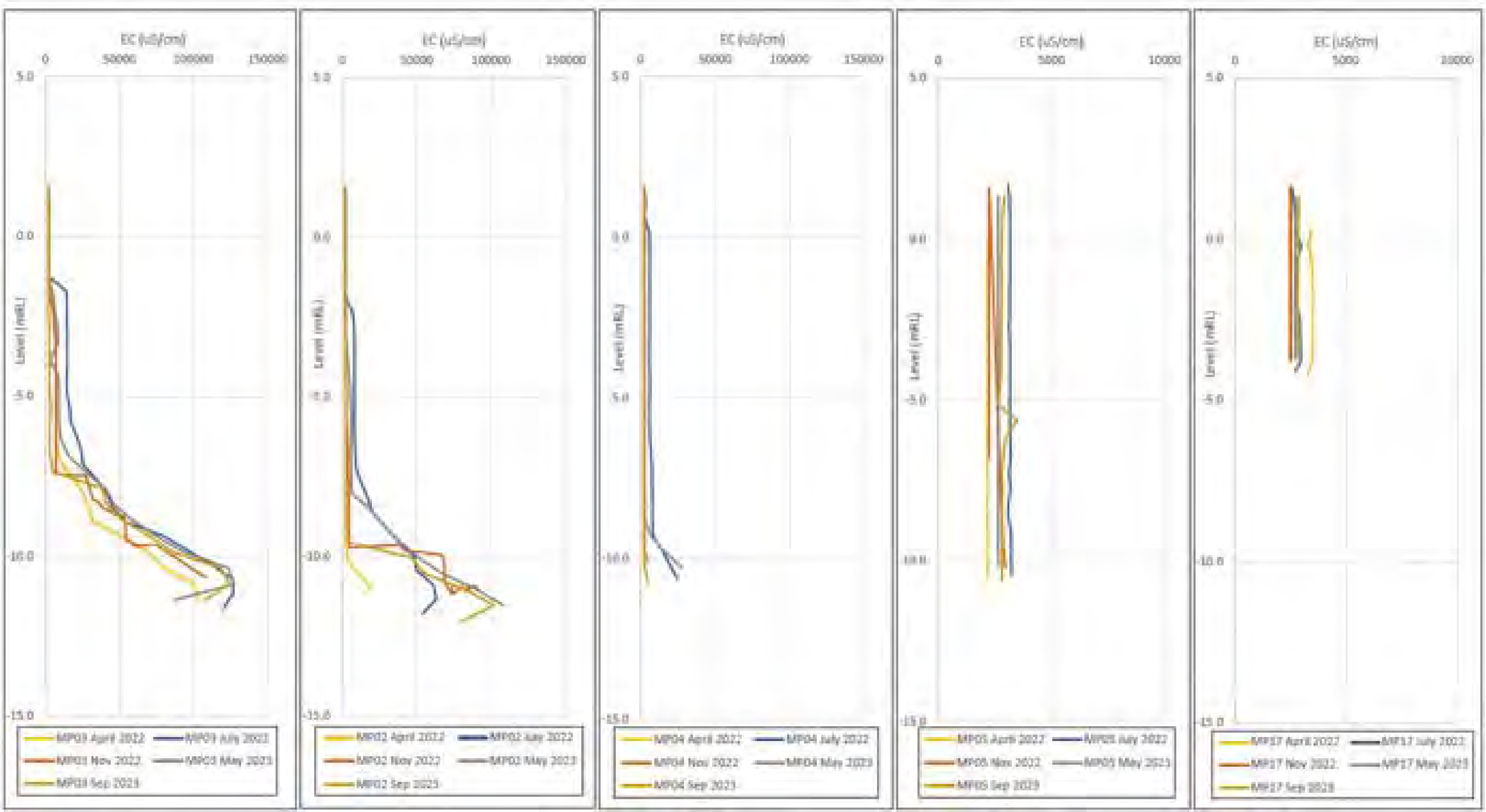


Figure 4.7 Salinity Profiles from Bores North of Mardie Pool

4.6 Conceptual Model - Coastal Sabkha

Figure 4.8 presents the conceptual hydrogeological model passing through Pond 1, the sabkha and intra-tidal zone. The location of the Pond 1 Section and potential locations for future sectional modelling are shown in Figure 4.12.

The dominant groundwater influence in this area is the body of hypersaline water which has developed over an extensive period beneath the tidal flats (the sabkha). It extends for 30km parallel to the coastline and approximately 5-10km inland and is up to 5km wide (see Figure 4.5 for contours of groundwater electrical conductivity). Analysis of water level data across the sabkha indicates that the groundwater flow within the tidal flat is predominantly vertical. Sea water floods across the tidal flats on high Spring tides above a certain threshold level (see Section 3.2). A small amount of seawater remains behind as the tide recedes, within the pore space of the algal mat and near surface sediments, and within localised depressions on the sabkha. Evaporation of the residual sea water occurs between tidal inundation events, concentrating the brine at surface. A small-scale vertical flux process is set up in the near surface which concentrates the brine further in the period of drying between high Spring tides, which may be 7-10 days. The next inundation causes a small amount of recharge of the concentrated brine and crystallised salts into the sub-surface and mixing with the fresh seawater which remains at surface.

Recharge of fresh groundwater water occurs inland and across the hinterland, flowing gradually towards the coast. The fresh water intersects the hypersaline brine of the sabkha inland from the eastern edge of the tidal zone, where a wedge of hypersaline water is confined by the hydraulic pressure of the fresh water. Diffusion of hypersaline water into the fresh water occurs at this point.

On the seaward side of the sabkha a seawater-hypersaline interface is present, and the base of the hypersaline plume extends to the sea floor where rapid mixing with sea water occurs. The recharge volume of the hypersaline groundwater from diffusion of fresh water and generation of new hypersaline water at the surface of the sabkha are balanced by discharge of hypersaline water at the western side of the system into the ocean.

During large rainfall flood events, fresh water will flood from creeks and overtop the hypersaline brine of the sabkha to flow across the flats to the ocean. This may dissolve some surficial salt and deposit silt across the sabkha for a short time, however the salt accumulation process will resume at the next high tides following the recession of flooding.

Figure 4.9 shows the expected conditions once Pond 1 is filled and operational. Shown is the approximate extent of Pond 1, and the expected change in water table resulting from Pond 1 seepage. Also shown is the change to the total recharge process.

4.7 Conceptual Model – Mardie Pool

Mardie Pool is a permanent water body of cultural significance which is incised several metres into the overbank deposits on the south flank of the Fortescue Alluvial Valley. The pool is approximately 300m long and up to 10m wide, with surface area seasonally variable. The Groundwater Interaction Assessment (AQ2, 2023) indicates the following characteristics of surface water- groundwater system at Mardie Pool.

Mardie Pool is likely to become a gaining stream or losing stream depending on the prevailing pool and groundwater levels. Mardie Pool will fill to the overflow level during rainfall events with excess rainfall depth of <1mm across the reporting catchment. After flowing for a short period of time (usually days), outflow stops and the level in the pool will fall due to evaporation and loss of water through seepage. At this time the groundwater level in monitoring bores adjacent to the pool is lower than the level in the pool. After extended dry periods the level of water within Mardie Pool falls below the groundwater level noted in adjacent monitoring bores. Analysis of recession curves for the pool indicate that the pool water level is likely being supplemented with groundwater inflow, hence remaining a permanent surface water feature throughout the dry season.

Large rainfall events result in flushing and filling of Mardie Pool with fresh water. A review of water quality (AQ2 2023) indicated that water salinity increased by a factor 2-3 times over four months from July to November 2022, and was higher again in April 2023. Limited data indicates that the recorded salinity increases may be due to evaporation only, or a combination of groundwater inflows and evaporation.

Figure 4.10 and Figure 4.11 present the conceptual hydrogeological model for the Mardie Pool area on a section line which crosses the pool from south-west to north-east. The figures represent the main scenarios in which Mardie Pool is acting as either a gaining or losing stream.

The groundwater conceptual model for Mardie Pool is summarised as follows:

- Mardie Creek is incised into the overbank deposits on the southern flank of the Fortescue Alluvial Valley. Mardie Pool exists as a deeper section of the creek which remains as a permanent surface water body of variable size.
- Mardie Pool will become a gaining stream or losing stream depending on the prevailing pool and groundwater levels.
- It will fill to the overflow level during significant rainfall events. After flowing for a short period of time, outflow stops and the level in the pool will fall due to evaporation and loss of water through seepage.
- While the groundwater level in in the surrounding aquifer is lower than the level in the pool Mardie Pool acts as a losing stream. Fresher groundwater will gradually seep into the banks and base of Mardie Pool.
- After extended dry periods the level of water within Mardie Pool falls below the groundwater level noted in adjacent monitoring bores. Analysis of recession curves for the pool indicate that the pool water level is likely being supplemented with groundwater inflow (the pool becomes a gaining stream), hence remaining a permanent surface water feature throughout the dry season.
- Groundwater in bores to the north of Mardie Pool is saline at a depth which is below the base of Mardie Pool. While Mardie Pool is known to become more saline due to evaporation in dry periods, the pool is filled with fresh water during flood events. It is unclear whether saline groundwater contributes to the increase of salinity in Mardie Pool.

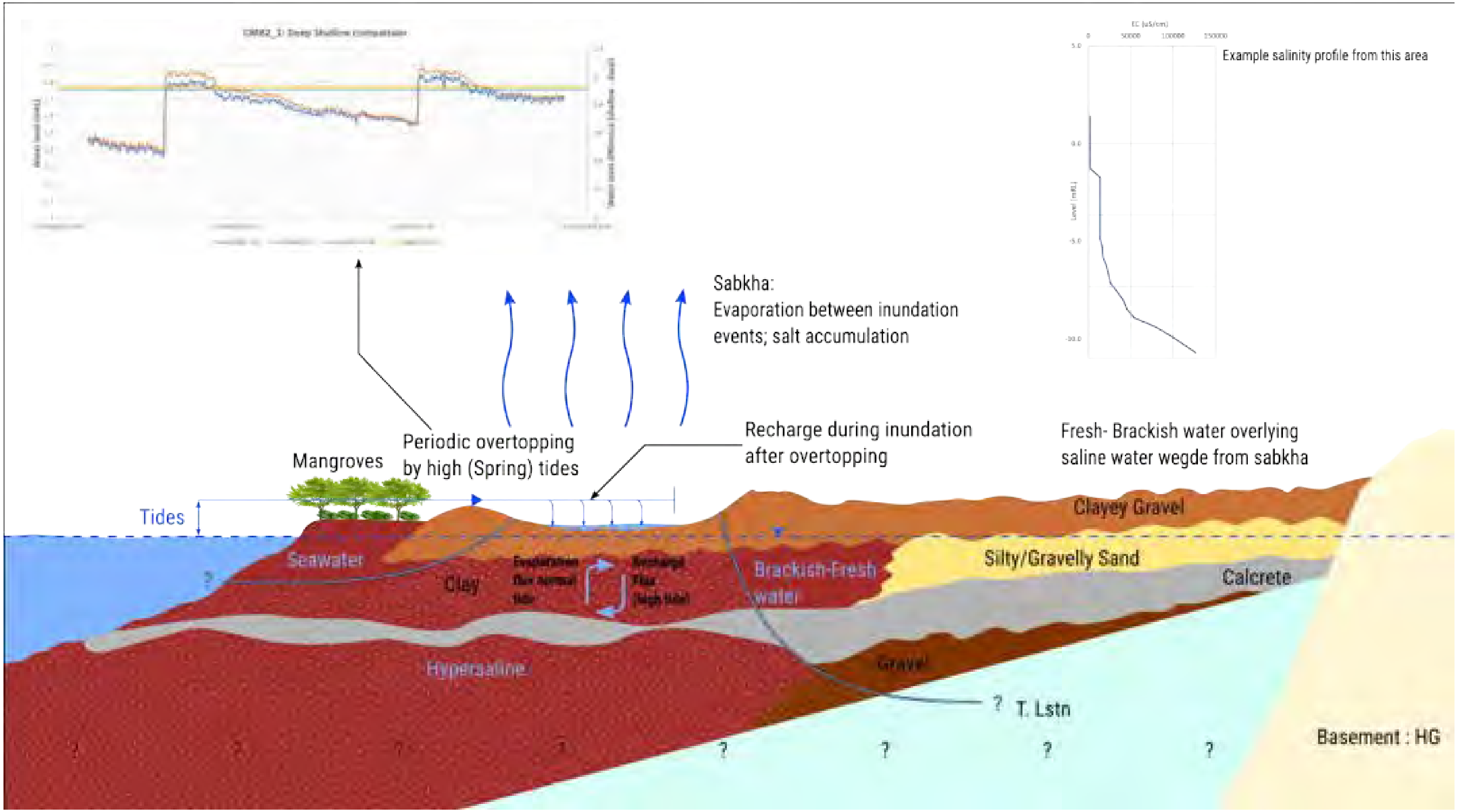


Figure 4.8 Conceptual Groundwater Model for Pond 1 Section

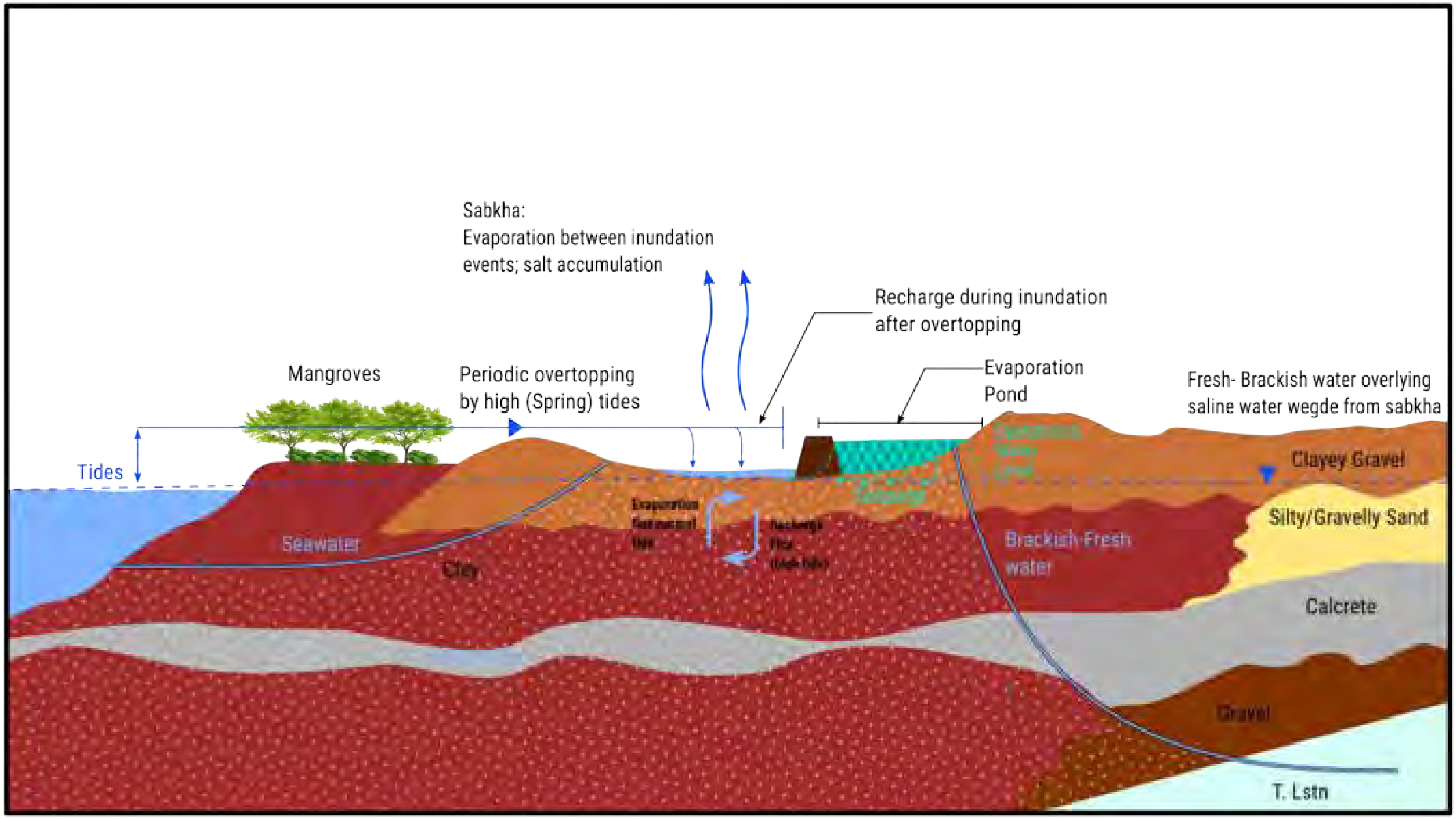


Figure 4.9 Conceptual Groundwater Model for Pond 1 Section – Operational

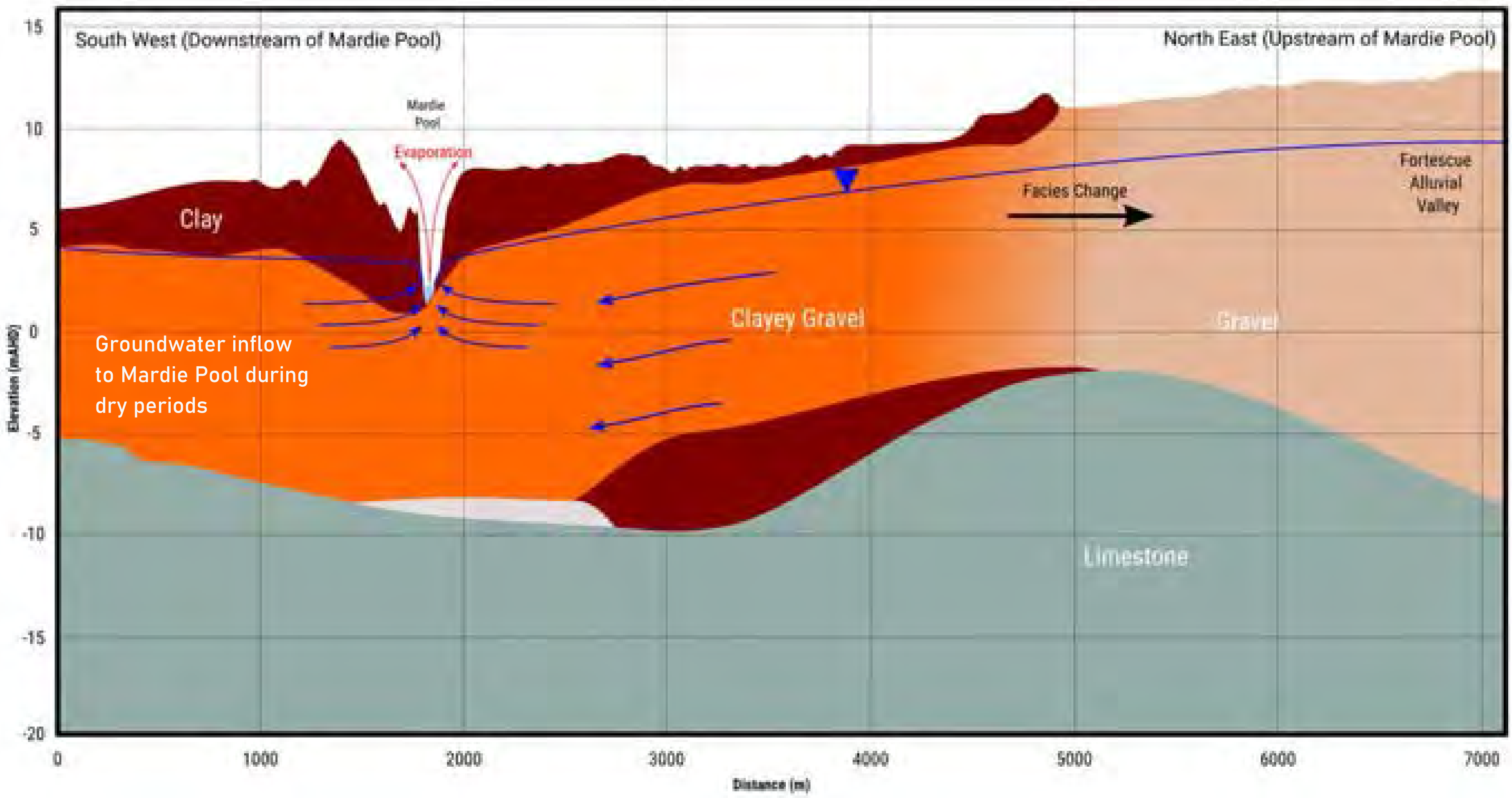


Figure 4.10 Conceptual Groundwater Model Across Mardie Pool – Gaining Stream

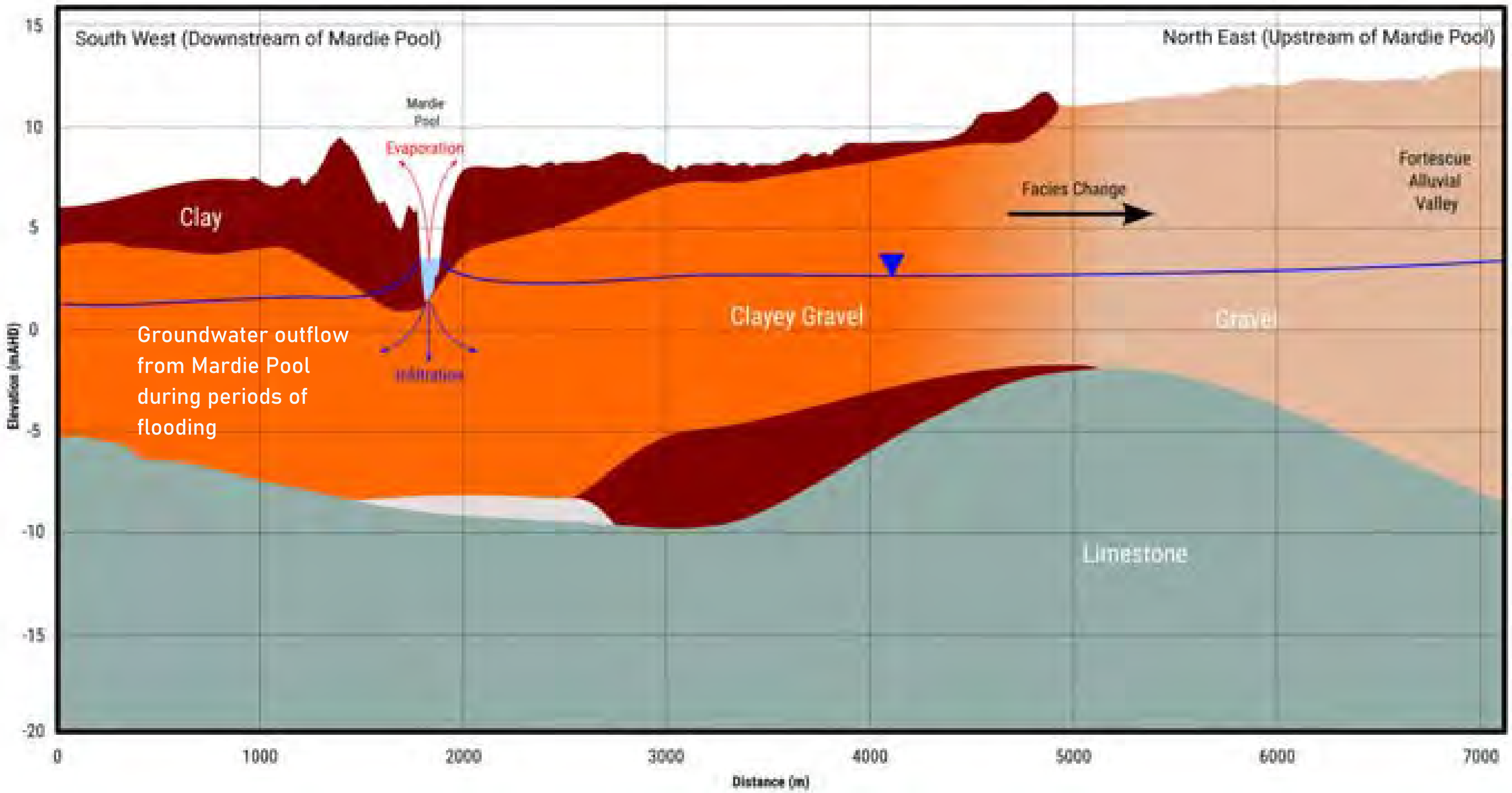


Figure 4.11 Conceptual Groundwater Model Across Mardie Pool – Losing Stream

Figure 4.12 Location of Current and Potential Section Models

5. GROUNDWATER MODELLING

5.1 Objectives

The objective of the groundwater modelling was to predict the water level and salinity impacts of seepage (leakage) related to the operation of the Mardie Project on the underlying groundwater system. Modelling was completed for the areas of:

- Pond 1,
- Mardie Pool and the crystallisers, and
- Pond 6 and the crystallisers.

The density dependent flow and transport groundwater models were developed consistent with the hydrogeological understanding described in Section 4.0 and the principles outlined in the Australian Groundwater Modelling Guidelines (Barnett et al, 2012).

Key features of the groundwater models developed are described in detail in the following sections and summarised below:

- The models were developed using the Modflow USG (Panday et al, 2017) groundwater modelling code operating under the Groundwater Vistas graphical user interface (ESI, 1996 to 2021).
- The density dependent flow and transport modelling uses a two dimensional (2D) or sectional approach to simulate the groundwater conditions in the Mardie Project area. This was considered appropriate:
  - Taking account of the complex data requirements for 3D density dependent modelling and adopting the principle of parsimony (consistent with the modelling guidelines); and
  - Given the predominantly vertical groundwater fluxes that characterise the system.
- The models include the aquifer and aquitard units of the coastal, sabkha and upstream alluvial / limestone areas as appropriate.
- The models simulate the linked groundwater flow and salinity interactions between the coastal, sabkha and upstream alluvial / limestone areas.

Model set up, calibration and predictions for the areas of the project listed above are outlined in the sections below.

5.2 Pond 1

5.2.1 Model Extent

The extent of the modelled section is shown in Figure 5.1. It extends:

- From the coast to a maximum distance of 13.5km to the south-east.
- Across the 1.5km extent of proposed Pond 1.
- Approximately 6.5km upstream of Pond 1.
- A distance of 5.5km downstream of Pond 1 across the sabkha and towards the coast.

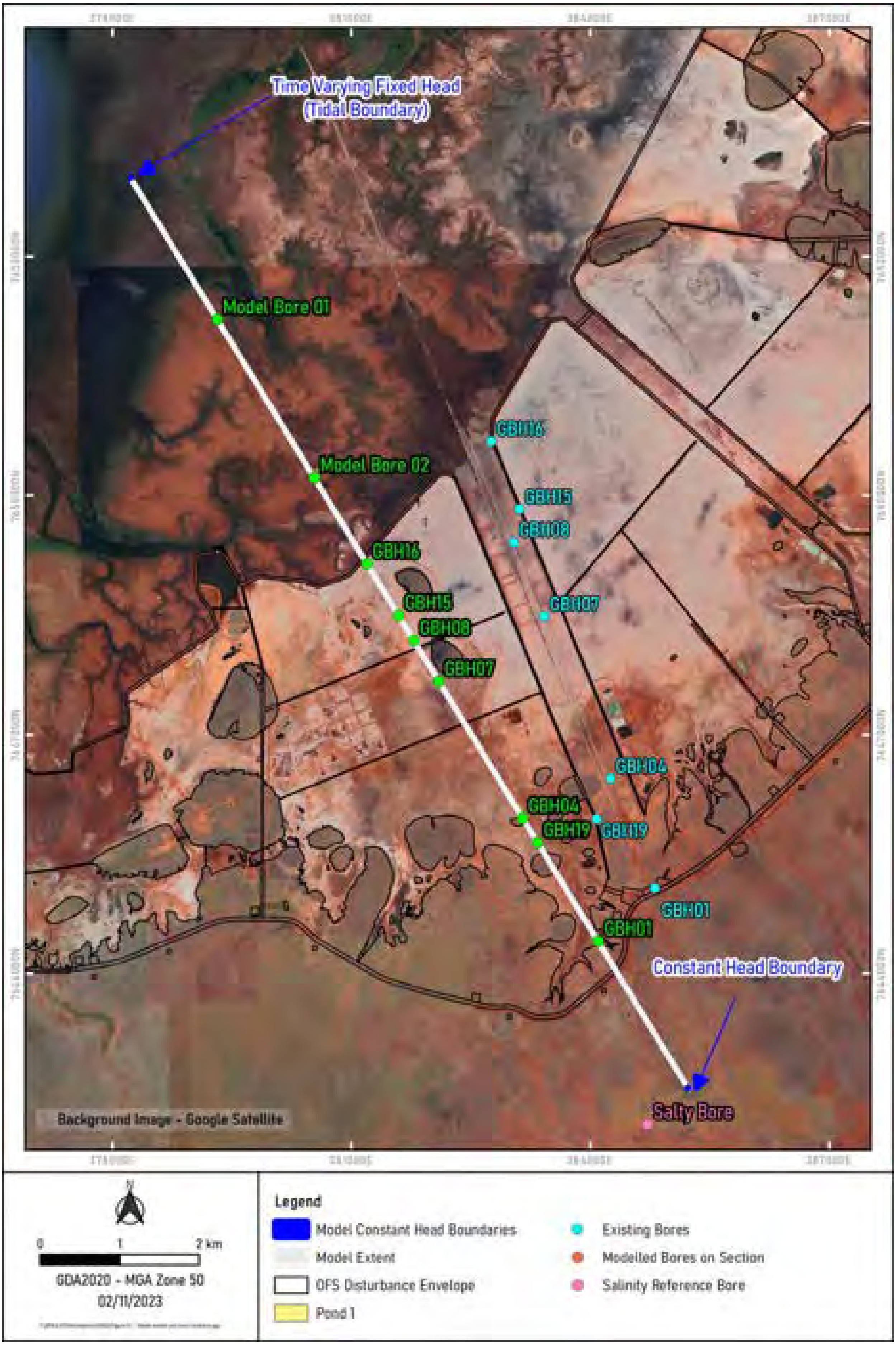


Figure 5.1 Pond 1 Model Extent and Bore Locations

The simulated section is oriented parallel to the inferred direction of the groundwater gradient (refer Section 4.2 and Figure 4.2) by rotating the model grid approximately -65 degrees. The model and all associated data are specified using the GDA 2020 (Zone 50) coordinate system.

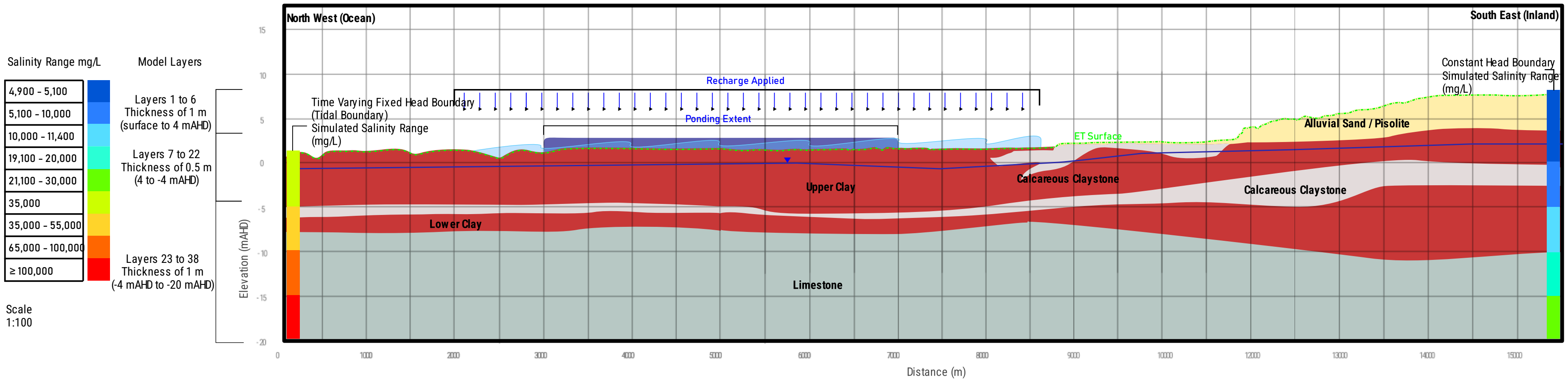
A uniform model grid cell size of 1m and 19 flat laying model layers are utilised to represent the aquifer and aquitard geometry and groundwater gradients. A summary of the model layers is presented in Table 5.1. These model layers are used to represent the upper horizons and the recharge and discharge processes and the underlying sediments and limestone. The model includes a total of 256,500 active model cells.

Table 5.1 Model Layer Summary

Layer	Details
1	Variable layer thickness with ground surface defined by a digital terrain model supplied by BCI. Base set at 0mAHD. Used to simulate upper clay sequence.
2 to 9	Layer thickness of 0.5m. Base of layer 9 set at -4mAHD. Used to simulate upper and lower clay sequences.
10 to 16	Layer thickness of 1m. Base of layer 16 set at -11mAHD. Layers 10 and 11 used to simulate lower clay sequence with layers 12 to 16 used to simulate underlying limestone.
17 to 18	Layer thickness of 2m. Base of layer 18 set at -15mAHD. Used to simulate limestone.
Layer 19	Layer thickness of 5m. Base of layer 19 set at -20mAHD. Used to simulate limestone.

5.2.2 Model Geometry

The extents and thicknesses of key aquifer and aquitard units were defined by the information derived from geotechnical investigations, supplemented with information derived from hydrogeological drilling. The key aquifer units are shown in Section in Figure 5.2.



- Model horizontal discretisation = 1m
- Model vertical discretisation is as indicated above

Figure 5.2 Pond 1 Schematic Model Cross-Section (Northwest to Southeast)

Aquifer property zones were assigned consistent with the hydrogeological section shown in Figure 5.2. Multiple flat lying model layers are used to define hydrogeological units. In general layers 1 to 11 define the upper sediments, with layers 12 to 19 used to simulate the underlying limestone. The hydrogeological units simulated in the model include:

- Upper and lower clay.
- Calcareous claystone.
- Limestone.

Also shown on Figure 5.2 are the key hydrological processes of the area. These are discussed further in Section 5.2.4.

5.2.3 Salinity Conditions

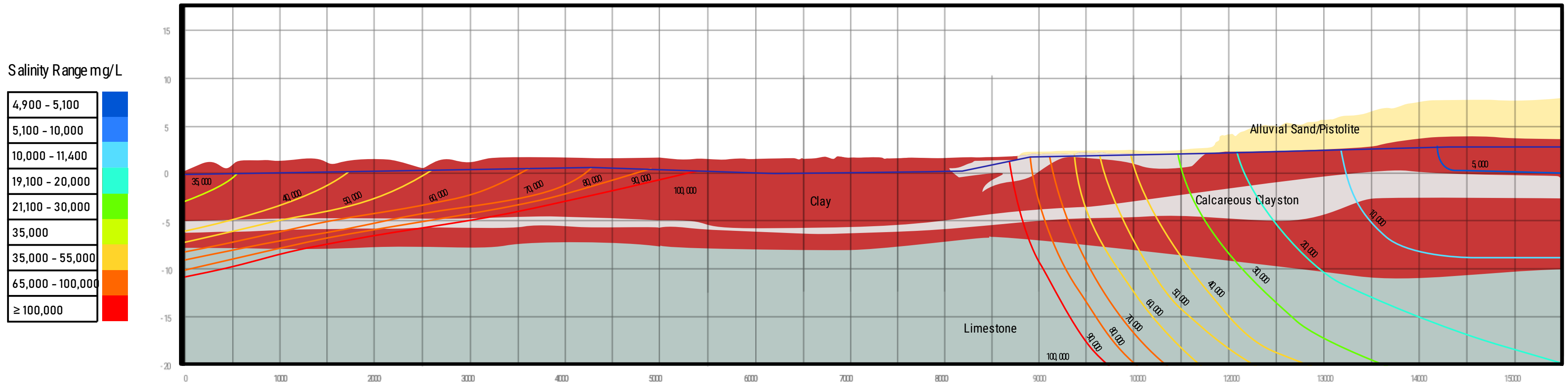
The existing groundwater salinity conditions are used as initial conditions for modelled salinity. The distribution of salinity is based on observed salinity data as described in Section 4.4, with interpretation of the existing water level and hydrogeological conditions used to define the groundwater salinity conditions that result from the tidal flats and the coastal boundary further downstream.

Salinity values (contoured) along the modelled section are displayed in Figure 5.3 and show:

- A salinity range of 35,000 to 100,000mg/L on the northwest model boundary from interactions between the sabkha and the coast.
- A salinity range of around 5,000 to 30,000mg/L on the southeast model boundary.
- A salinity of 100,000mg/L in the sabkha area.

The groundwater model has not been used to simulate the development of the observed salinity conditions over geological time. These result from a complex series of processes including significant rises and fall in sea level during the Pleistocene glacial and pluvial periods and associated climate changes. These were accompanied by a complex interaction between groundwater recharge, evapotranspiration, reflux processes in and around the tidal flats and the coastal boundary over this (geological) period. Simulating this build-up period would require prohibitively long model run times and speculative assumptions about changes in boundary conditions (sea levels) and climate. Rather, the current conditions (distribution of salinity and groundwater levels) were input to the model as a set of starting conditions. The model was then run using the approach outlined in Section 5.3.2 (dynamic calibration of initial conditions) to ensure these conditions were sustained for the current climate, and other assumptions made.

The maximum interpreted groundwater salinity along the Pond 1 section of 100,000mg/L is assumed to have a density of 1,074kg/m^3. Sea water of salinity 35,000mg/L is assumed to have a density of 1,025kg/m^3. Less saline water with a minimum salinity of 5,000mg/L, located close to the upstream model boundary is assumed to have a density of 1,000kg/m^3. The salinity assumed at the upstream end of the section model is based on a measured salinity from monitoring bore Salty Well (refer Figure 5.1). The salinity to density conversions are based on standard estimates / conversions.



Salinity contours generated from May 2023 field data (pre-construction)

Figure 5.3 Pond 1 Model Cross-Section Salinity Contours

5.2.4 Groundwater Inflow and Outflow

Along the model section, observed water levels decrease from the southeast to the northwest (from inland towards the ocean). Head boundary conditions are assigned at the upstream and downstream model boundaries. The downstream boundary is assigned time varying elevations to represent the impact of the varying tide on groundwater levels. The head variation assigned to the downstream boundary is shown in Figure 5.4. The tidal effect is simulated using a 12 hourly or half-day time increment which includes the maximum and minimum of each 24 hour or diurnal tidal cycle (i.e., a notional high boundary for high tide and low boundary level for low tide). A secondary cycle is imposed on the tidal data to reflect the procession from neap tides to spring tides over the course of a month. As no tidal information was available for the Project area for the model calibration period (2021 and 2022) the tidal boundary conditions included in the model calibration and predictions were based on the available data, including:

- Recorded tidal data for Onslow (ongoing Western Australian Department of Transport tidal monitoring).
- Simulated tidal data for the Project area (simulated by RPS, 2019) for the period January 2023 to July 2024.

The available data suggested a similar periodicity in tides. The amplitude of the measured Onslow tidal data was scaled (a reduction in tidal height of 1.8m and an increase in the overall amplitude of 50%), to simulate a greater range between low and high tides to be consistent with the Mardie simulated data.

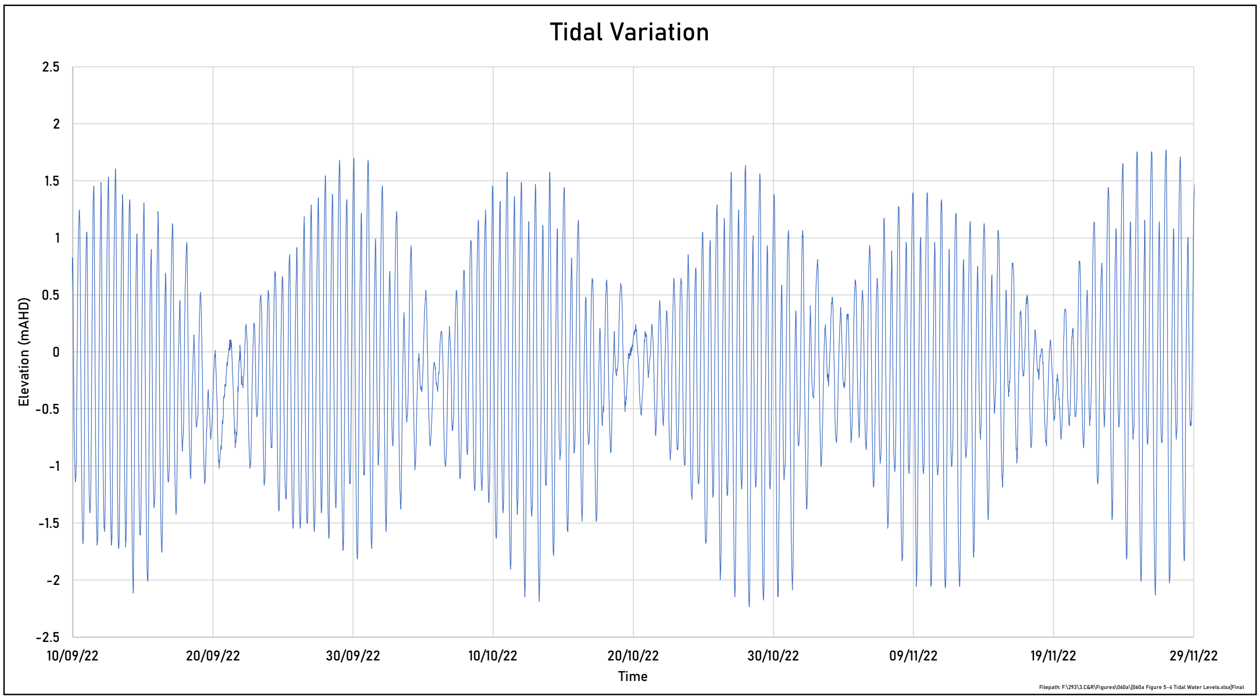


Figure 5.4 Simulated Tidal Fluctuations (Based on Onslow and Simulated Mardie Tidal Data)

The upstream boundary is assigned an elevation of 2mAHD, with the assigned value also corrected for the density of water of varying salinity. The assigned upstream and downstream boundary conditions are shown schematically in Figure 5.2.

Prior to the construction and development of Pond 1, the area across the entire sabkha along the modelled section was also subject to tidal inundation during very high tides. This water collected in the sabkha areas and recharged the underlying shallow groundwater. These shallow groundwater levels were in turn them subject to evaporative losses, driving the development of salinity in the sabkha. These processes are simulated in the model as outlined below:

- During very high tides, the impact of tidal inundation is subject to recharge to groundwater (using the Recharge (RCH) package in Modflow USG) at a very high rate (higher than the ground could accept, at around 2.5m/d) for a period of 1.5 days over the area shown in Figure 5.1. This recharge is assumed to occur at tides at or above an elevation of 1.57m. The recharge to groundwater driven by tidal inundation is assumed to have a salinity of sea water (35,000mg/L).
- A seepage face boundary condition is simulated in the area above ground to limit the rise of groundwater in the recharge area to ground surface and simulate rejected recharge. This is simulated using the Drain (DRN) package in Modflow USG with the drainage conditions set to an elevation equal to 0.05m above ground surface.
- Once the high tide level recharge has ceased, the groundwater system is subject to evapotranspiration. Evapotranspiration from shallow groundwater is simulated using the Evapotranspiration (EVT) package in Modflow USG. Evapotranspirative losses are simulated over the same extent as the recharge. The EVT package uses a depth dependent relationship to simulate ET losses. If modelled water levels are at or above a specified ET surface, specified in this case as ground level elevation, the ET rate occurs at the maximum specified rate. If modelled water levels decline below the ET surface, the simulated ET rate declines linearly to zero as the simulated water level declines to an elevation equal to the ET surface minus the extinction depth. This depth dependent relationship is illustrated schematically in Figure 5.5. The ET surface is set at ground level, with the maximum assigned ET rate extinction depth adjusted during model calibration. The assignment of the maximum assigned ET rate extinction depth in the calibrated model is discussed further in Section 5.3.3.

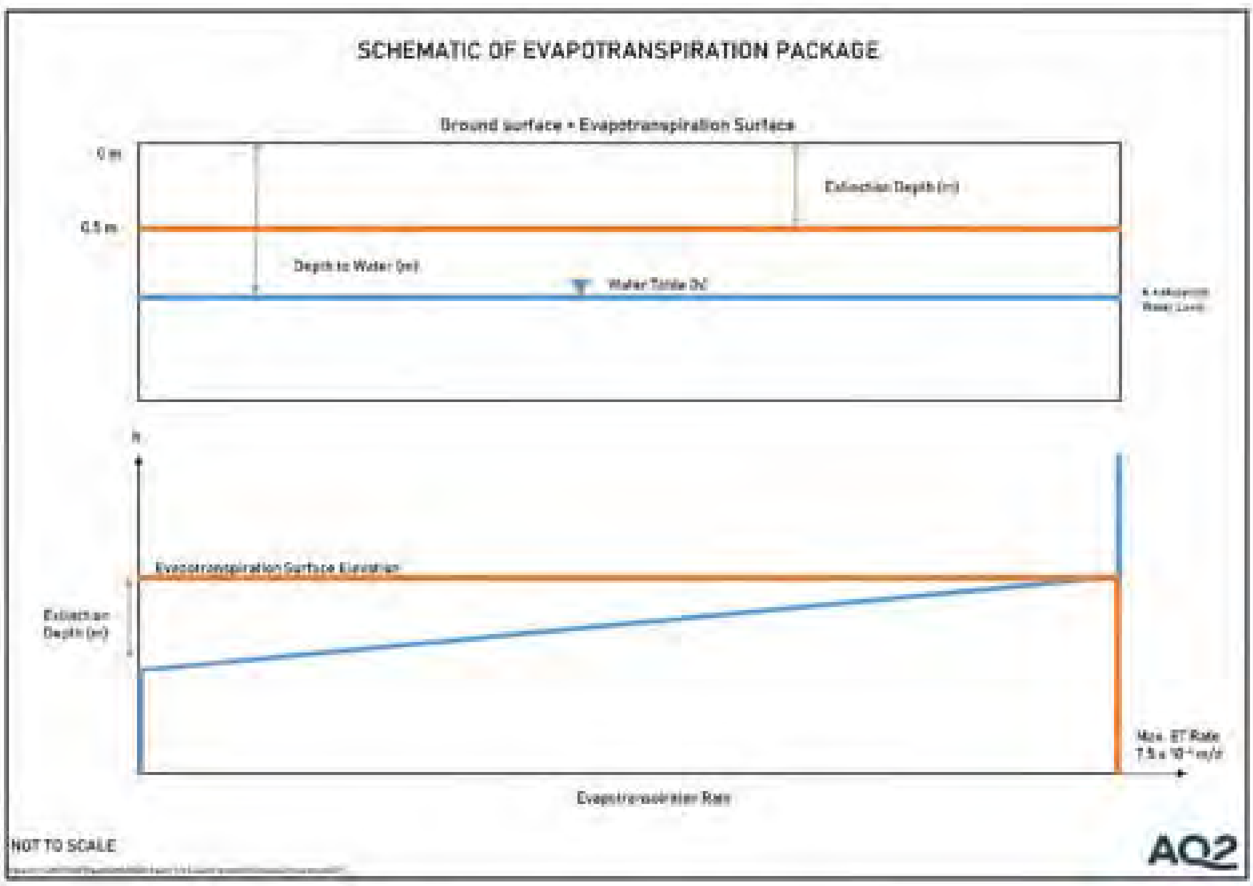


Figure 5.5 Schematic of Evapotranspiration Package

5.2.5 Model Calibration

5.2.5.1 Approach to Model Calibration

Model calibration is the process of demonstrating that the groundwater model replicates measured water level trends or other measured information from the groundwater system of interest. This is achieved by adjusting parameters in a numerical groundwater flow model, within realistic ranges to produce the best match between measured and modelled data (i.e., history matching).

Data available for model calibration includes:

- Water level data from monitoring bores (from downstream to upstream, GBH16, GBH15, GBH08, GBH07, GBH04, GBH19 and GBH01).
- An estimate for tidal variations.

The locations of bores used for model calibration are shown in Figure 5.1. Bores are shown at actual locations as well as the simulated location along the modelled section.

The calibration period of the model extends from 11 September 2022 to 19 May 2023 consistent with the longest period of active groundwater level monitoring and tidal information. The groundwater model was calibrated using a manual or trial and error approach, using 12 hourly time increments or stress periods (periods over which all modelled stresses were held constant).

5.2.5.2 Initial Conditions

Available groundwater monitoring that extends as far back as February 2022, shows fluctuations in groundwater levels due to recharge to groundwater from extremely high tides. As a result, groundwater levels in the modelled catchment are not readily described by a long-term average or steady state water level calibration. To accommodate this, water level conditions for the catchment were simulated using a dynamic calibration process. This process involved running the model for a period of approximately 250 days (or 500, 12 hourly periods) using the recharge, groundwater throughflow and ET conditions described in the preceding sections. Predicted water levels from an applicable time were then used as initial conditions for the next simulation. This process was repeated to generate a set of water level conditions that were appropriate for the start of the model calibration. This process was repeated as appropriate, for example when a change was made to model parameters or boundary conditions.

5.2.5.3 Transient Calibration Results

The location of monitoring bores used for model calibration are shown in Figure 5.1. The measured water levels show the measured responses to tidal fluctuations and high tide recharge at increasing distances from the downstream end of the ponds. Calibration hydrographs showing measured and modelled water level are shown in Figures 5.6 to 5.9. Calibration hydrographs are presented in order of increasing distance from the coastline.

The observed tidal and associated recharge response at bores GBH16, GBH15 and GBH08 is simulated by the model (refer Figure 5.6). Further inland however, the measured responses to rainfall recharge are not well replicated (GBH04 and GBH19 refer Figure 5.7 and GBH01 refer Figure 5.8) as rainfall recharge is not simulated in the current model set up. Overall, however, the magnitude of the measured water levels is replicated by the model.

Predicted salinity profiles at monitoring bores are shown in Figures 5.9 to Figures 5.13. Salinity profiles are shown on two occasions during the model calibration (September 2022 and May 2023) to an elevation of -5mAHD or approximately 7m below ground level. The salinity profiles are the same for both occasions and show that the predicted salinity profiles do not change during the calibration period. No measured salinity profile data is available for model calibration.

The maximum modelled ET rate and ET depth were adjusted during the model calibration process. The best match to measured water level data was obtained when an ET rate of 7.5 x 10^{-4}m/d (275mm/y) or around 8% of the long-term average evapotranspiration of 3,400mm/a (BoM, 2006) was applied. This is consistent with estimates of evapotranspiration from bare soil. Similarly the best match between measured and modelled data was obtained with the extinction depth set at 0.5m. Greater maximum ET rates (up to 7.5 x 10^{-3}m/d or 2,750mm/y) and extinctions depths (of up to 1m) were trialled but were observed to over predict the reduction in water levels between high tide (spring tide) events.

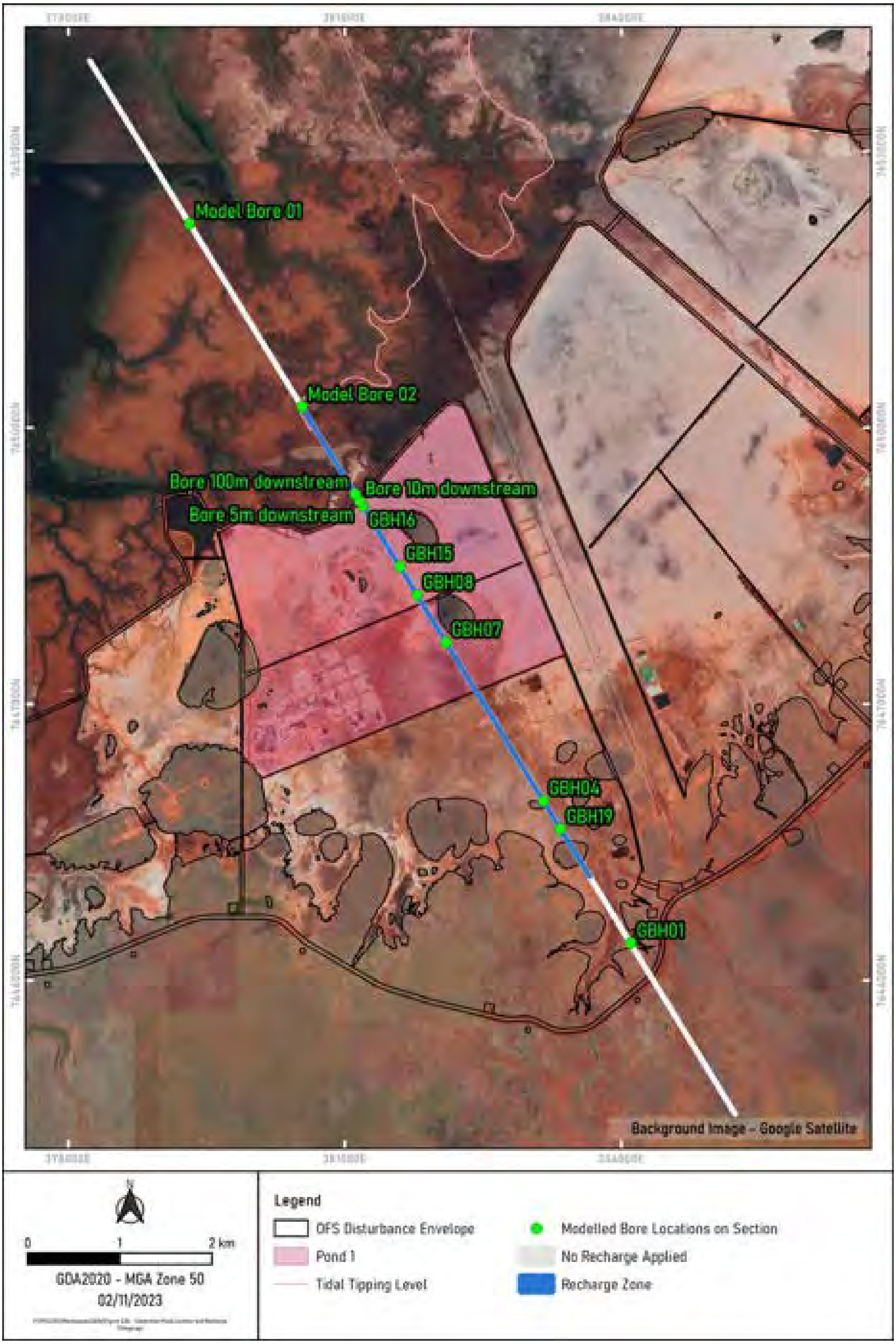


Figure 5.6 Pond 1 Extent of Tidal Inundation Recharge Included in Model Calibration

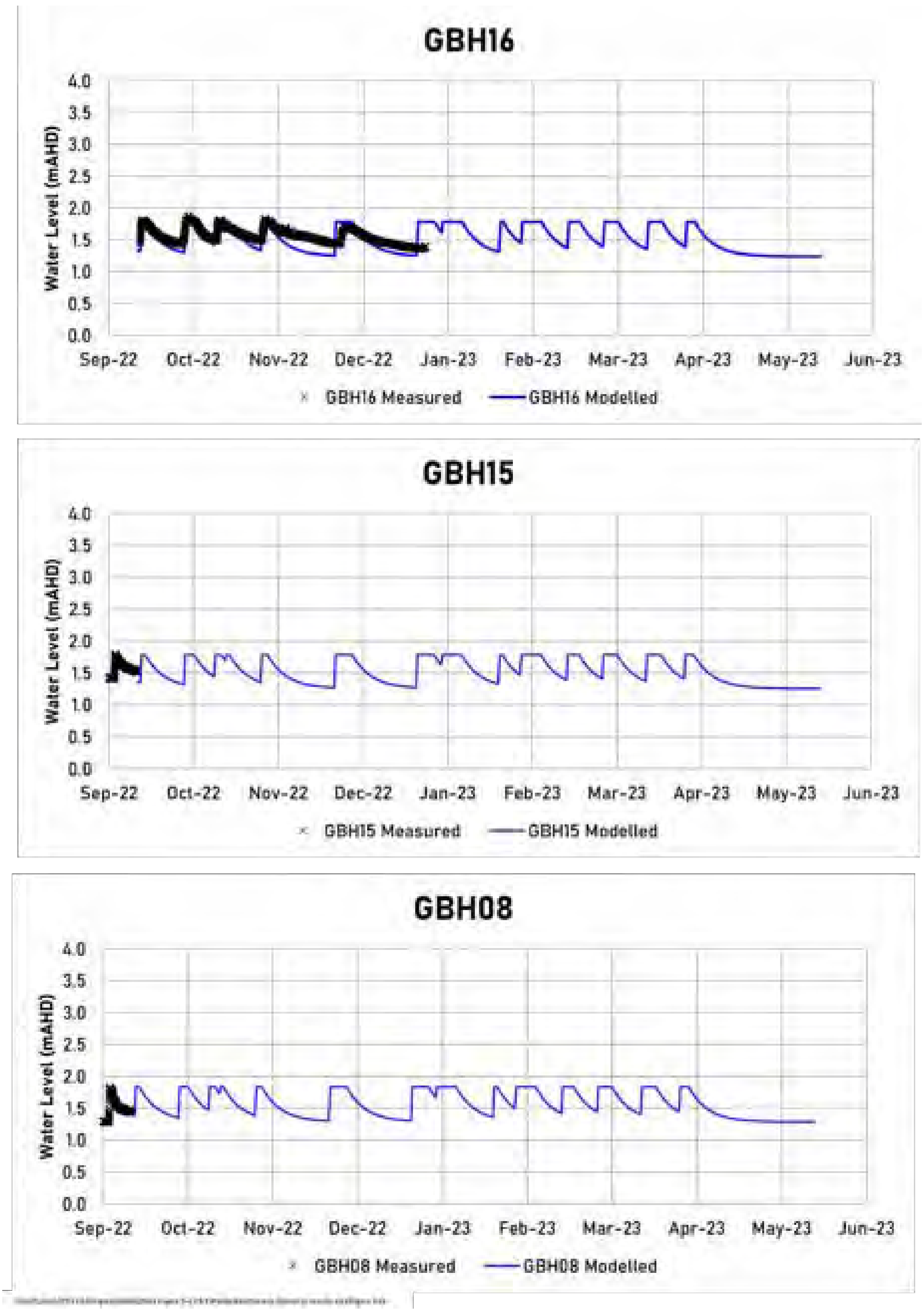


Figure 5.7 Pond 1 Calibration Hydrographs (GBH16, GBH15, GBH08)

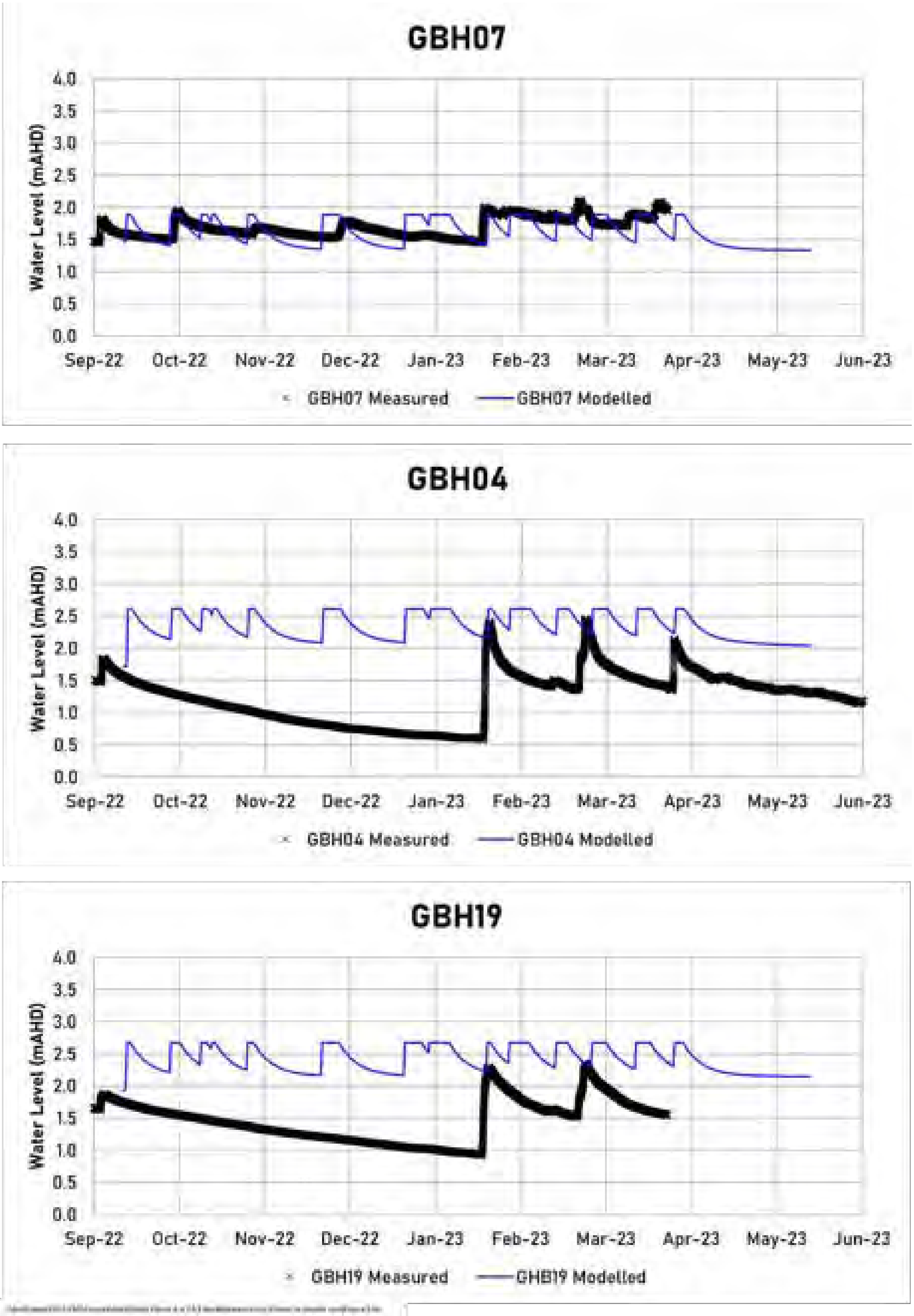


Figure 5.8 Pond 1 Calibration Hydrographs (GBH07, GBH04, GBH19)

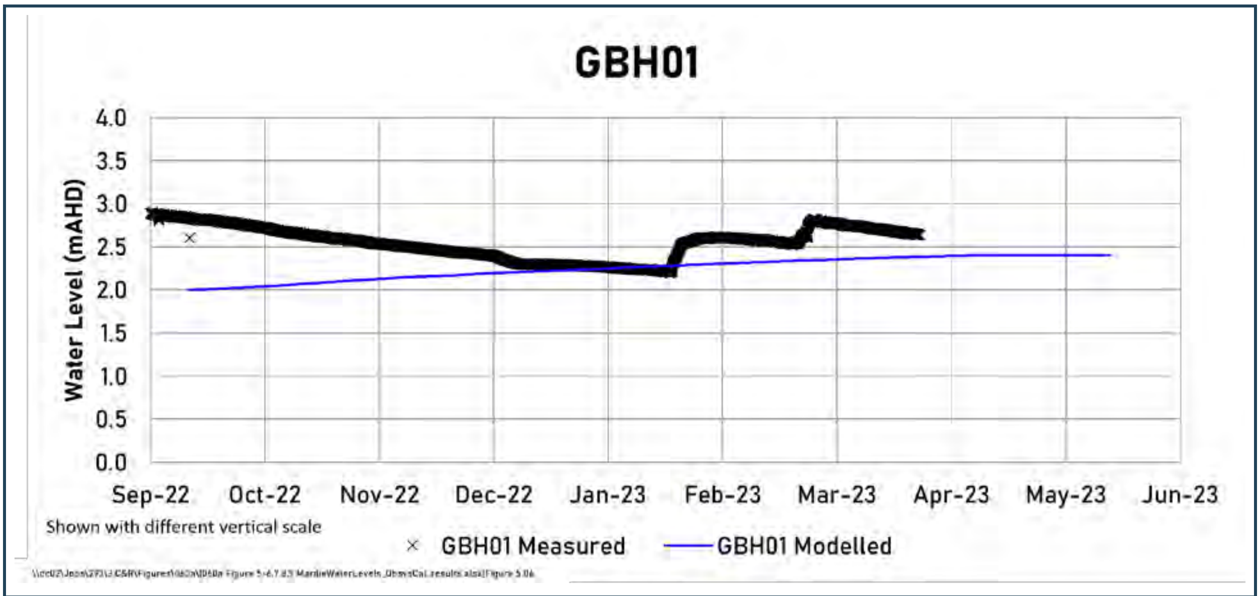


Figure 5.9 Pond 1 Calibration Hydrographs (GBH01)

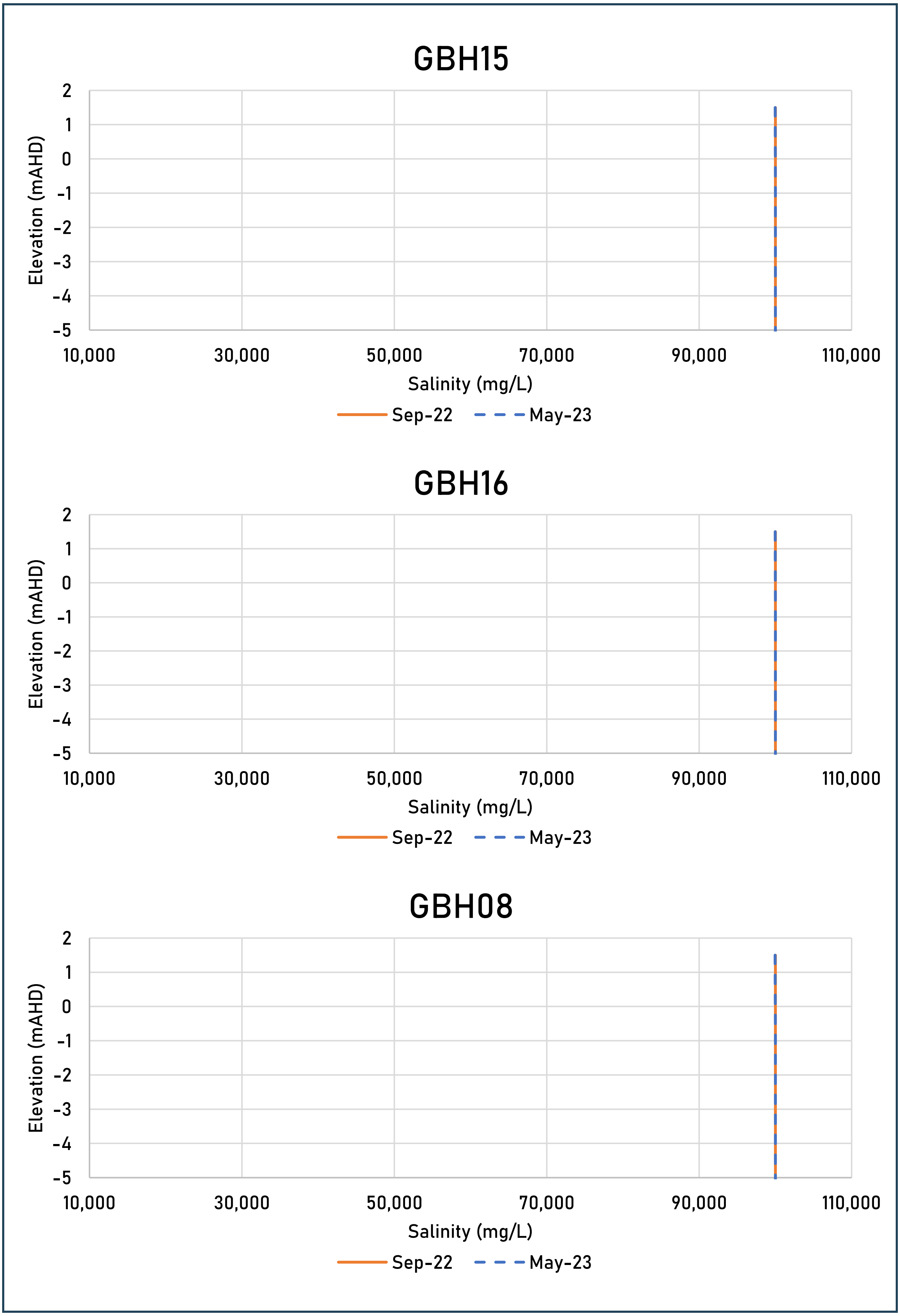


Figure 5.10 Pond 1 Calibration Salinity Profiles (GBH16, GBH15, GBH08)

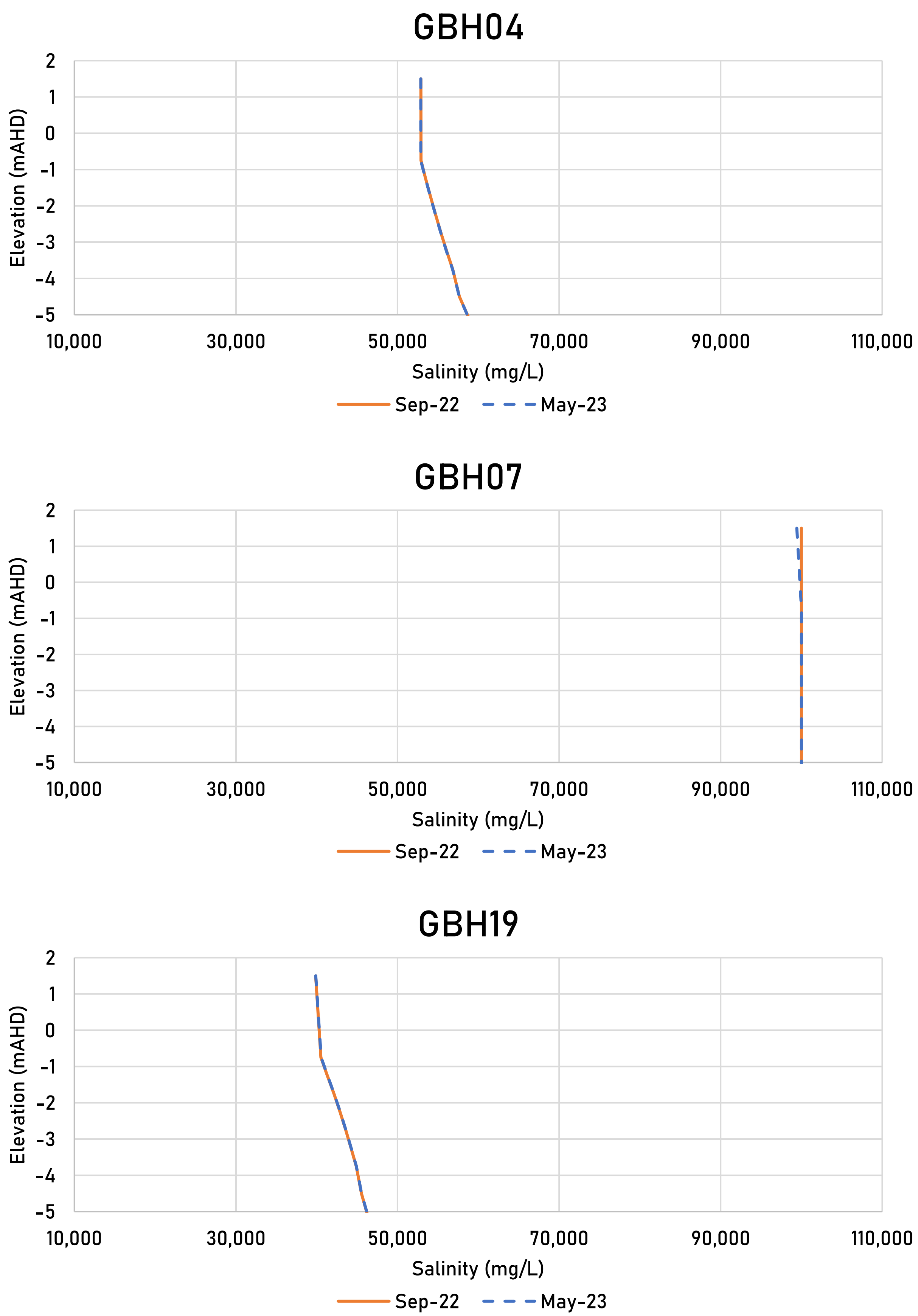


Figure 5.11 Pond 1 Calibration Salinity Profiles (GBH07, GBH04, GBH19)

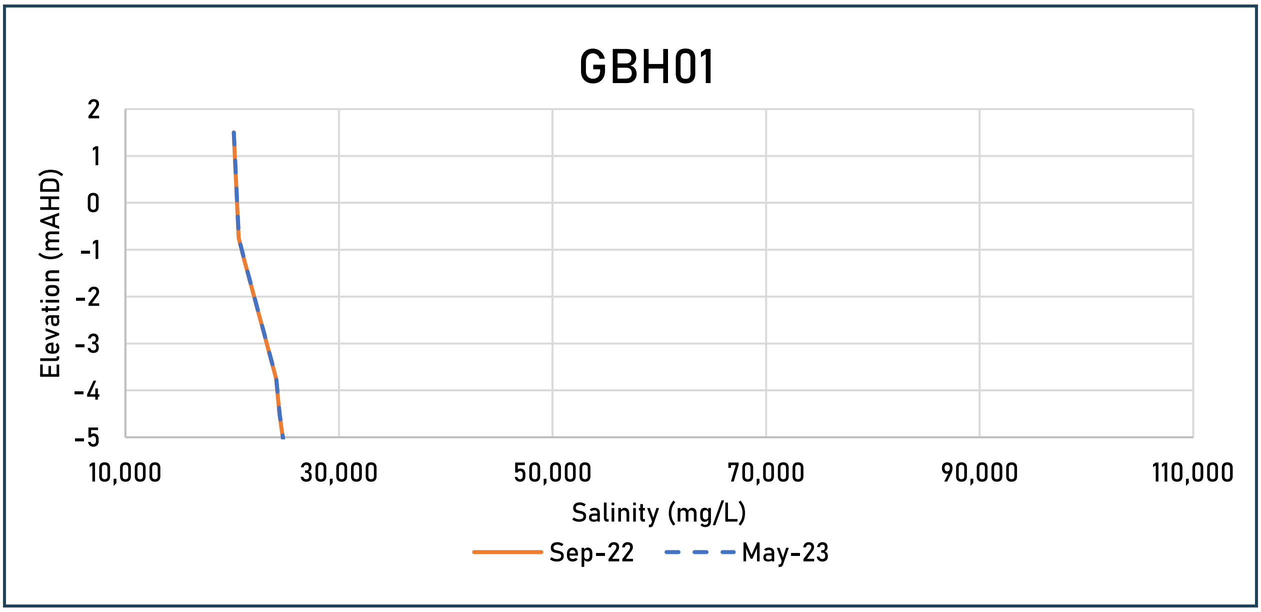


Figure 5.12 Pond 1 Calibration Salinity Profile (GBH01)

Calibrated aquifer parameters are summarised in Table 5.2.

Table 5.2 Calibrated Aquifer Parameters

Aquifer Unit	Horizontal Hydraulic Conductivity (m/d)	Vertical Hydraulic Conductivity (m/d)	Specific Yield (%)	Porosity (%)	Specific Storage (m^{-1})
Upper Clay	0.1	0.01	1	50	1e-6
Calcareous Clay Stone	0.3	0.03	1	35	1e-6
Lower Clay	0.1	0.01	1	50	1e-6
Limestone	2	0.2	1	10	1e-6

Model predicted water and salt balances for the calibration period are presented in Appendix A.

5.2.6 Model Predictions and Results

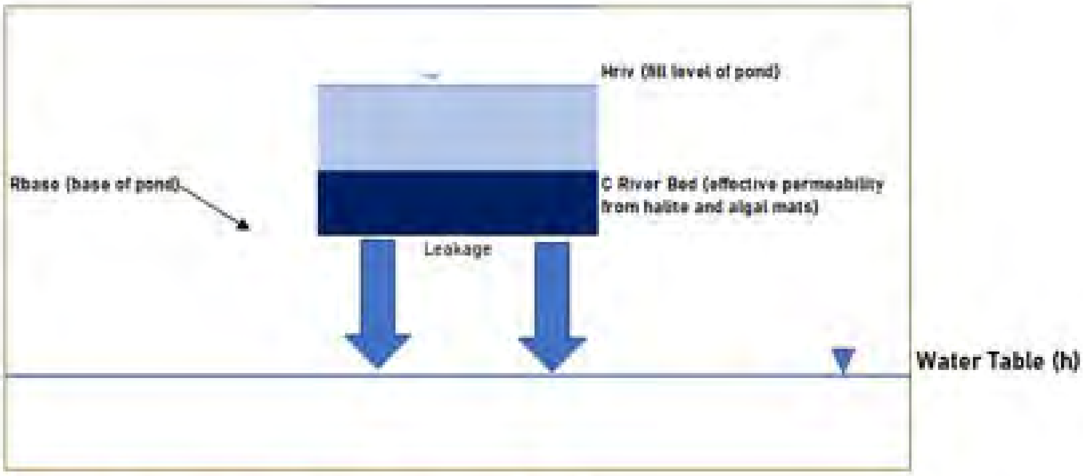
5.2.6.1 Prediction Setup

The calibrated section model was used to simulate the impacts to groundwater of the filling and operation of Pond 1. Currently Pond 1 is planned to be filled with sea water (salinity of 35,000mg/L and density of 1,025kg/m^3) so that it has a pond-water level elevation of 3.4mAHD to a depth of approximately 1.6m above the base of Pond 1 with operation to continue for a period of 50 years. Details of the model prediction are outlined below:

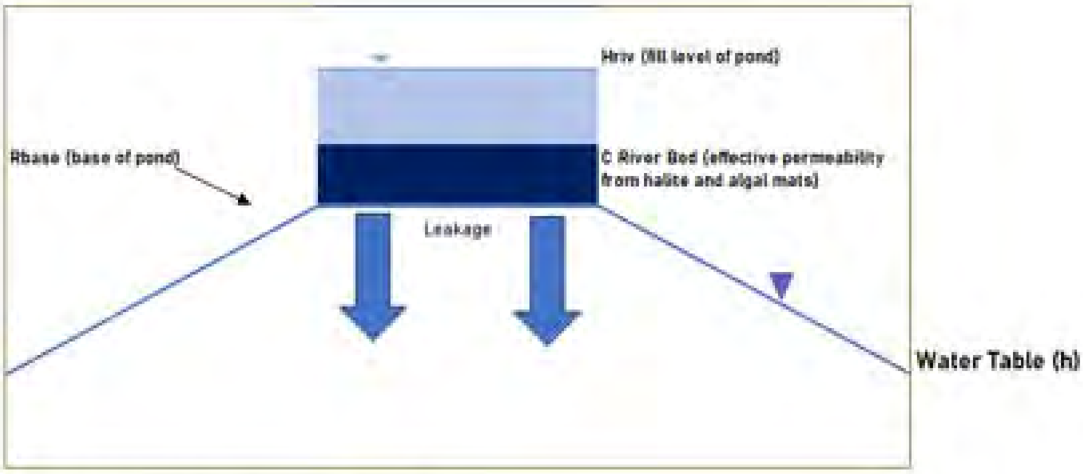
- Initial conditions (groundwater level and salinity) were taken from the end of the calibration model.
- The prediction models were run for a period of three years assuming a 12 hourly stress period (period over which all stresses were held constant). While the life of the Project is much longer than three years, this period was sufficient to show the impacts of filling of the ponds (i.e., a steady state type response was predicted after this period of simulated time with the assumed future conditions).
- The upstream or inflow boundary condition was simulated as per the model calibration (i.e., fixed head corrected for depth at an elevation at the water table of 2mAHD).

- The downstream or coastal boundary was simulated consistent with the approach included in the transient model calibration. Future tidal boundary conditions are simulated assuming an estimated tidal sequence from January 2020 to December 2022.
- The extent of Pond 1 along the modelled section is shown in Figure 5.13. Recharge during spring high tides and evapotranspiration was limited to the area downstream of Pond 1 in model predictions as the tidal inundation will be limited by the embankments constructed around Pond 1 and the remainder of the ponds.
- Leakage from the ponds over the life of the Project will be limited by the algal mats on the salt flats that reduce permeability and the development of a halite crust (caused by precipitation in the ponds). Leakage from the base of Pond 1 has been estimated (Worley, 2019) as outlined below (to reflect to progressive reduction in permeability associated with the algal mat and accumulation of halite):
  - For the first year of operation (Year 0 to 1) the rate of seepage is estimated at 237mm/yr. It is noted that this is a conservatively high value for seepage.
  - For the second year of operation (Year 1 to 2) the rate of seepage is estimated at 30mm/yr.
  - For the third and subsequent years of operation (Year 3 to life of Project) the rate of seepage is estimated at 9.0mm/yr.
- The Project is assumed to operate for a period of more than 50 years. Leakage of the impounded water in Pond 1 is simulated with two approaches namely:
  - *Leakage only, simulated as net recharge* as outlined above (i.e., no head conditions are included to simulate the impact of the ponds, leakage is simulated simply as a flux). Also referred to as Scenario 1.
  - *Leakage from the ponds as a function of the water stored in the ponds*. The head dependent recharge was simulated using the River (RIV) package in Modflow USG. The head in the "river" was assigned to the elevation of the pond water level (3.4mAHD) from the start of the prediction (i.e., no pond filling was simulated), the base of the "river" assigned at the base of the ponds and a low conductance consistent with the algal mat / halite that is anticipated to form in the base of the ponds. The set up of the ponding boundary condition is shown schematically in Figure 5.14. This prediction was also completed to assess the impact of hydraulic loading from the pond (i.e., the head of water contained in the pond). Also referred to as Scenario 2.
  - Leakage from a catastrophic failure of the algal mat / halite crust would most likely also result in significant damage to all of Pond 1 (i.e., the pond and the surrounding embankments would most likely have collapsed). Nevertheless, the impact of a catastrophic pond failure was simulated assuming that leakage occurred under a head dependent boundary (the depth of water in the pond, also simulated using the RIV package in Modflow USG) with an area of enhanced conductance (i.e., vertical permeability) in the centre of the pond 400m long to simulate the zone of failure in the pond lining. Also referred to as Scenario 3.
  - A No Development Scenario was also run to allow the identification of impacts of seepage from Pond 1. The No Development Scenario contained the same tidal recharge and tidal boundary conditions as outlined above.
  - A summary of model runs is presented in Table 5.3.

Figure 5.13 Pond 1 Extent of Tidal Inundation and Recharge Included in Model Predictions



Water table elevation initally below base of pond
Qriver = C*(Hriv-Rbase)



Water table at below base of pond
Qriver = C*(Hriv-h)

K = hydraulic conductivity of river bed / regolith (m/d)
L = length of river across modelled cell (m)
W = width of river (m)
m = thickness of river bed (m)

Figure 5.14 Schematic River / Boundary Condition setup

Table 5.3 Model Prediction Summary

Prediction	Details
Scenario 1	Leakage from Pond 1, simulated as net recharge as the halite / algal mat develops, as outlined below: o For the first year of operation (Year 0 to 1) the rate of seepage is estimated at 237mm/yr. o For the second year of operation (Year 1 to 2) the rate of seepage is estimated at 30mm/yr. o For the third and subsequent years of operation (Year 3 to life of Project) the rate of seepage is estimated at 9.0mm/yr.
Scenario 2	Leakage from the ponds as function of the water stored in the ponds.
Scenario 3	As per Scenario 2, assuming that there is enhanced leakage over a length of 400m, to simulate the failure of the halite / algal mat.
No Development	Includes the calibrated model distribution of tidal recharge and tidal boundary conditions as outlined above only.

5.2.6.2 Prediction Results

Predicted water levels for selected observation locations downstream, upstream and within Pond 1 for Scenarios 1 to 3 are shown in Figures 5.15 to 5.18. Predicted water levels at modelled observation locations 5m, 10m, and 100m downstream of Pond 1 are shown in Figures 5.17 and 5.18. Also shown in Figures 5.15 to 5.18 are the corresponding No Development Scenario predicted water levels. Water levels are shown for a prediction period of three years, as by the time, a quasi steady state water level response has been reached across the modelled catchment, The locations of the modelled observation locations are shown in Figure 5.13. The following observations are made regarding the predicted water levels:

- Downstream of Pond 1 (at Model Bore 01, refer Figure 5.15) model predicted water levels respond to tidal inundation / recharge, with a similar water level trend predicted for all scenarios. For Scenarios 1 to 3, higher water levels are predicted between recharge events when compared to the No Development scenario due to the leakage simulated from Pond 1.
- Under Pond 1 (GBH15, refer Figure 5.15) the tidal recharge response is no longer predicted. For Scenario 1, which assumes that the pond and underlying groundwater system are de-coupled, water levels are predicted close to ground level (i.e., the aquifer is predicted to be brim full). For Scenarios 2 and 3, the predicted water level reflects the water level simulated in Pond 1. Similar water level responses are also predicted for GBH08 (refer Figure 5.16).
- Upstream of Pond 1 (GBH04, refer Figure 5.16) water levels are predicted to decrease and no longer show the response to tidal recharge / inundation once the pond is constructed. Water levels are predicted to increase by less than 0.1m over the duration of the prediction but are lower than those predicted for the No Development Scenario. It is noted, that at this location, as the project develops other interactions with adjacent ponds may influence groundwater behaviour at this location.
- At observation locations immediately downstream of Pond 1 (5m, 10m and 100m, refer Figures 5.17 and 5.18) the maximum predicted water levels are similar for all cases considered as the simulated evaporative flux maintains water levels at this elevation. For Scenario 1, water levels are predicted to decrease during periods of lower tides. For Scenarios 2 and 3 however, water levels are maintained by the simulated pond water level. These is some reduction in predicted water level during period of simulated period of lower tides, however, it is much smaller than that simulated for the No Development / Scenario 1. Compared to the No Development Scenario, Scenarios 2 and 3 predict an increase in water level of up to 0.5m a distance of 5m downstream of Pond 1.

Predicted salinity profiles for Scenarios 1 to 3 and the No Development Scenario for selected modelled observation locations are shown in Figures 5.19 to 5.21 (refer Figure 5.13 for locations). The predicted salinity profiles are shown at the start of the simulation and 18 months after filling of Pond 1 commences. The profiles show the predicted salinity from the water table to an elevation of – 5mAHD or around 7m below ground level. The model predicted salinity profiles show limited change over the prediction period, with some small decreases in salinity predicted resulting from the seepage of less saline water into the top of the profile. Over the prediction period a small decrease of salinity (up to 1,000mg/L) is predicted at the observation points immediately downstream of Pond 1 (refer Figures 5.20 and 5.21).

Model predicted water and salt balances for the end of the model prediction periods are presented in Appendix A.

Analysis of the model predicted water balance suggests that for Scenarios 2 and 3, which simulate the head dependent leakage out of Pond 1, the predicted rate of leakage drops rapidly after the pond is filled. The rate of leakage out of Pond 1 decreases from around 50kL/d over the length of the modelled section to less than 1kL/d, over a period of a month (assuming that the pond is at operational level from the start of Scenarios 2 and 3). Additionally, for Scenario 3, there is not a significantly greater amount of leakage predicted from the base of Pond 1. These prediction results suggest that the leakage from the base of Pond 1 is limited by the small amount of aquifer storage and aquifer transmissivity in the aquifer units surrounding Pond 1.

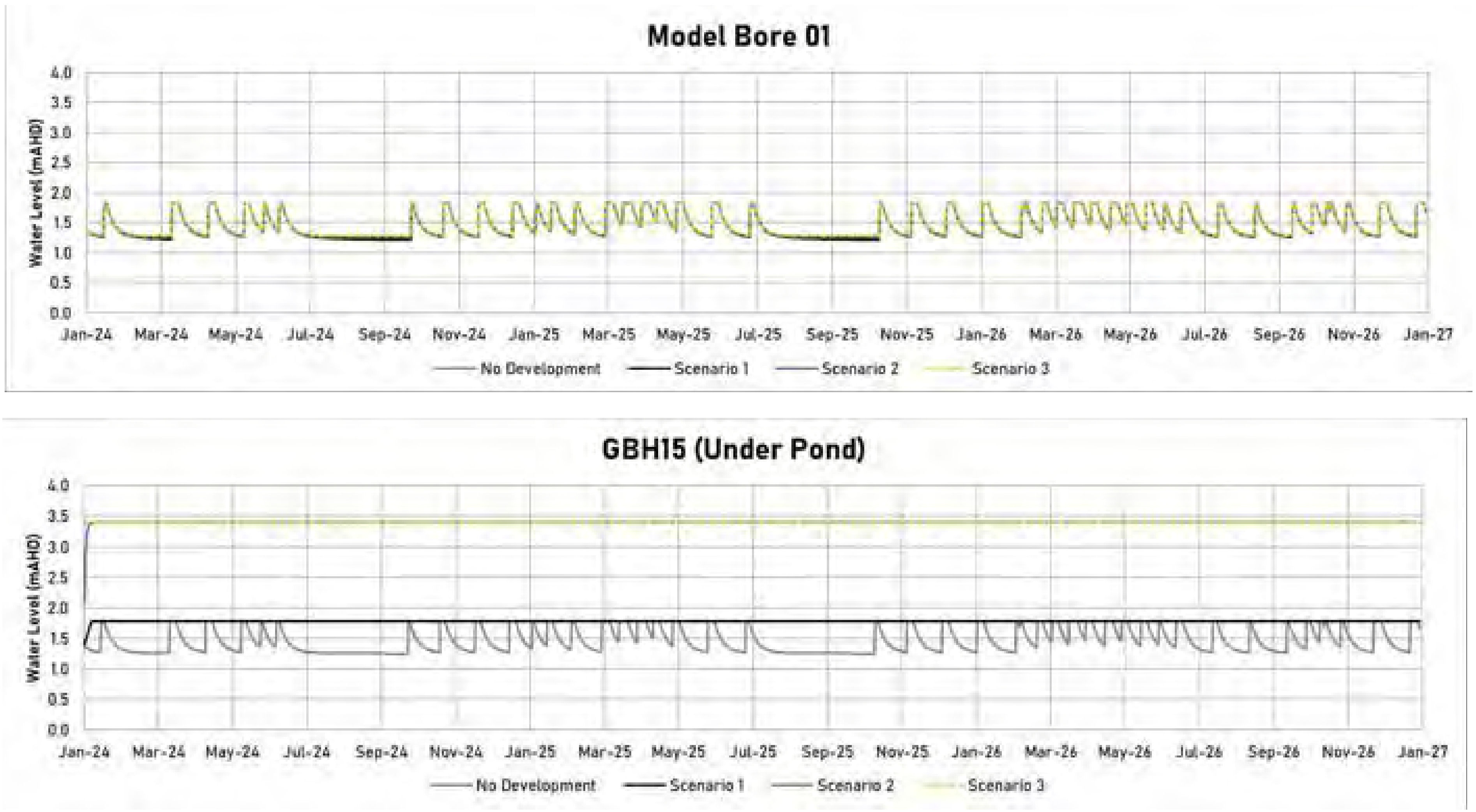


Figure 5.15 Pond 1 Prediction Hydrographs No Development vs Leakage Simulation Scenarios (Model Bore 01, GBH15)

Figure 5.16 Pond 1 Prediction Hydrographs No Development vs Leakage Simulation Scenarios (GBH08, GBH04)

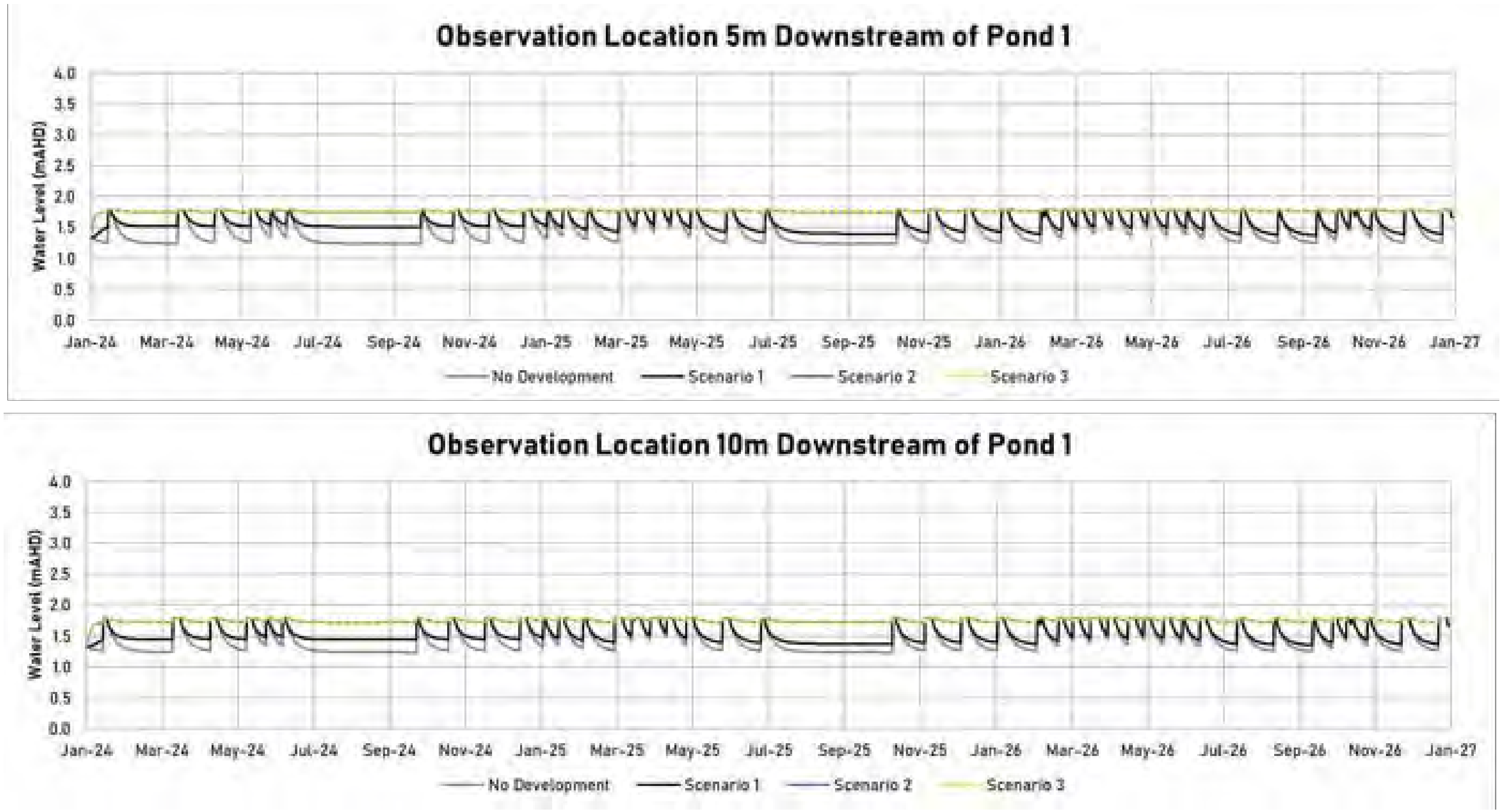


Figure 5.17 Pond 1 Prediction Hydrographs No Development vs Leakage Simulation Scenarios (5m and 10m Downstream of Pond 1)

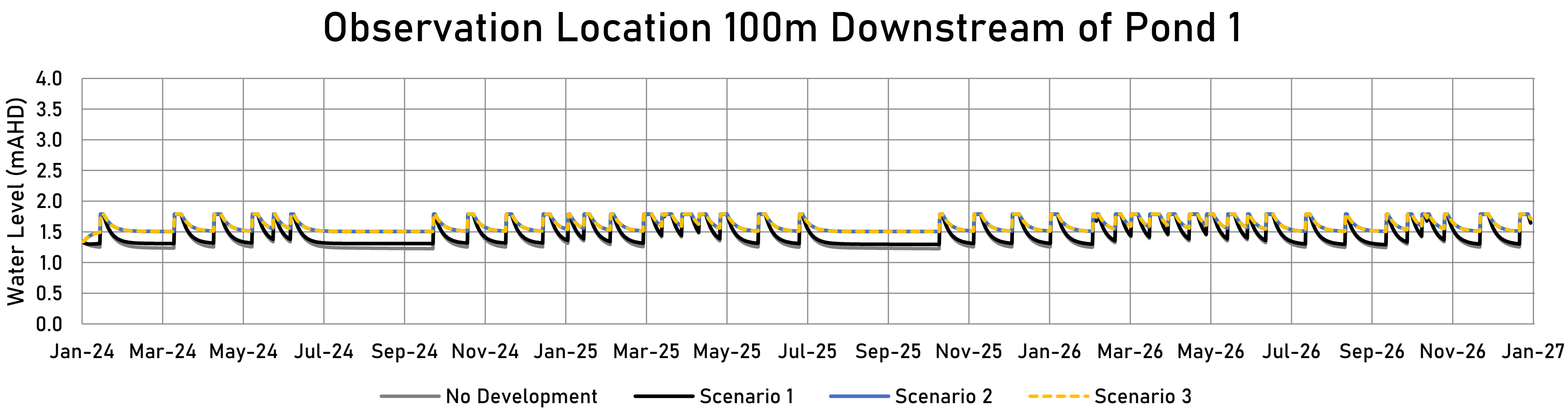


Figure 5.18 ADD Pond 1 Prediction Hydrographs No Development vs Leakage Simulation Scenarios (100m Downstream of Pond 1)

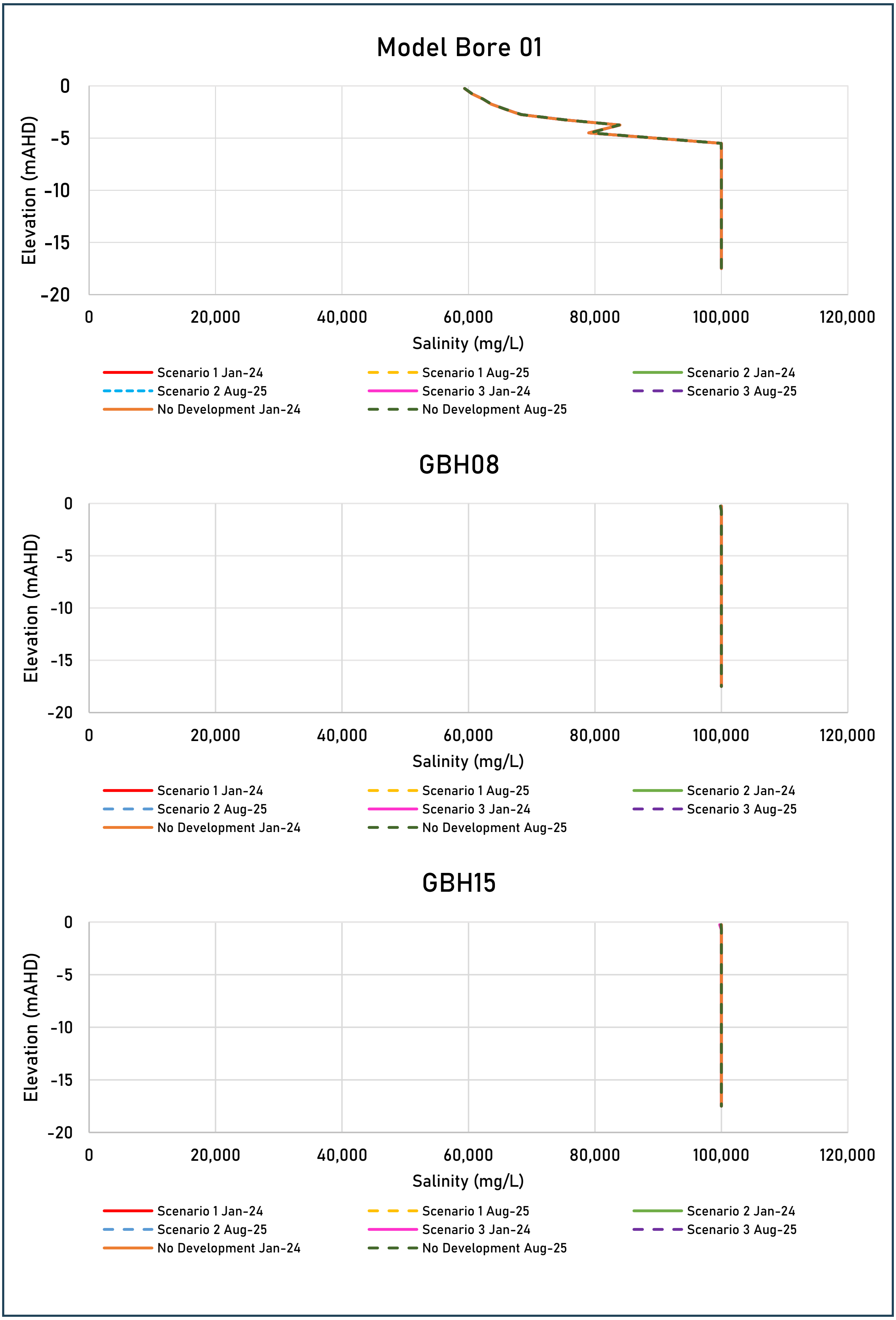


Figure 5.19 Pond 1 Predicted Salinity (Model Bore 01, GBH15, GBH08)

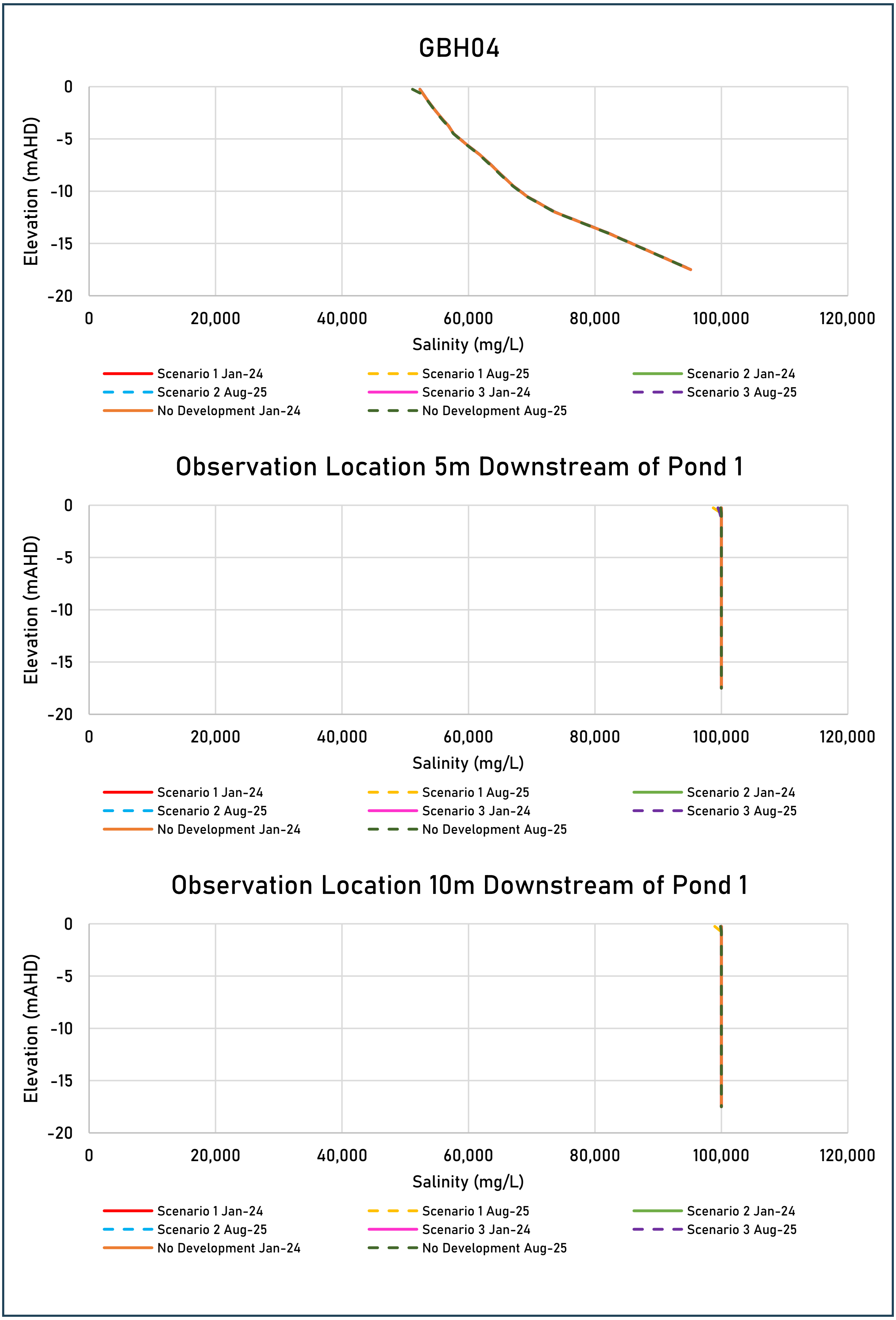


Figure 5.20 Pond 1 Predicted Salinity (Model Bore 04, 5m and 10m Downstream of Pond)

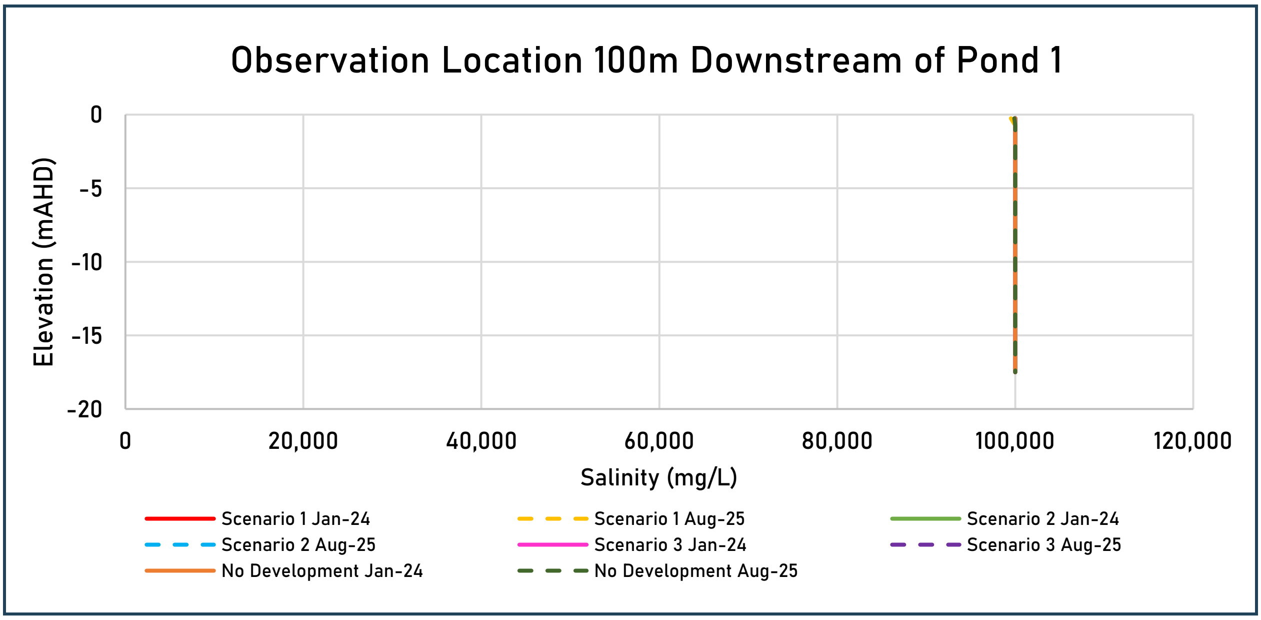


Figure 5.21 Pond 1 Predicted Salinity (100m Downstream of Pond 1)

5.3 Mardie Pool and Crystalliser

5.3.1 Model Grid and Setup

The extent of the Mardie Pool and Crystalliser section model is shown in Figure 5.22. It extends:

- From Mardie Pool to the south-west a maximum distance of 2km towards the sabkha / eastern boundary of Pond 5.
- From Mardie Pool to the north-east a maximum distance of 5km and across the entire extent of the crystallisers and into the area immediately upstream of the crystallisers

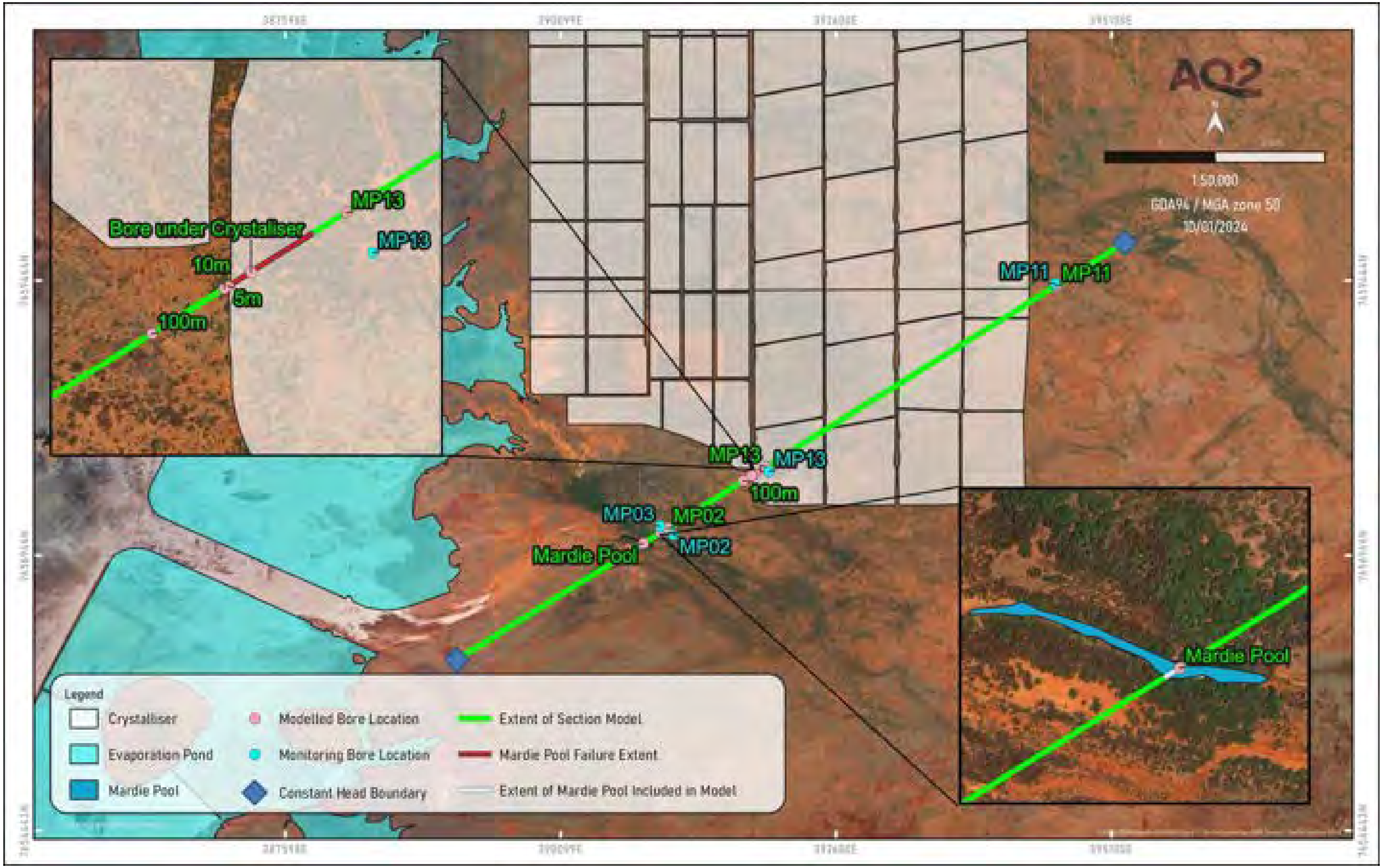


Figure 5.22 Mardie Pool and Crystalliser Model Extent and Bore Locations

The simulated section is oriented parallel to the inferred direction of the groundwater gradient (refer Section 4.2 and Figure 4.2) by rotating the model grid approximately 32 degrees. The model and all associated data are specified using the GDA 2020 (Zone 50) coordinate system.

A uniform model grid cell size of 1m and 20 flat laying model layers are used to represent the aquifer and aquitard geometry and groundwater gradients. A summary of the model layers is presented in Table 5.4. These model layers are used to represent Mardie Pool, the upper aquifer horizons and the recharge and discharge processes and the underlying sediments and limestone. The model includes a total of 143,080 active model cells.

Table 5.4 Model Layer Summary

Layer	Details
1	Variable layer thickness with ground surface defined by a digital terrain model supplied by BCI. Base set at -1mAHD. Used to simulate gravel sequence.
2 to 7	Layer thickness of 1m. Base of layer 7 set at -7mAHD. Used to simulate gravel in the south west and clay in the north east.
8 to 9	Layer thickness of 1m. Base of layer 9 set at -9mAHD. Layers 8 and 9 used to simulate calcrete and clay in the south west
10 to 20	Layer thickness of 1m. Base of layer 20 set at -20mAHD. Used to simulate limestone.

5.3.2 Model Geometry

The extents and thicknesses of key aquifer and aquitard units were defined by the information derived from geotechnical investigations, supplemented with information derived from hydrogeological drilling. The key aquifer units are shown in Section in Figure 5.23.

Aquifer property zones were assigned consistent with the hydrogeological section shown in Figure 5.23.

Multiple flat lying model layers are used to define hydrogeological units. The hydrogeological units simulated in the model include:

- Clayey gravel and gravel simulated in layers 1 to 7.
- Calcrete simulated in layers 8 and 9.
- Clay. Simulated in layers 2 to 7.
- Limestone simulated in layers 9 to 20.

Also shown on Figure 5.23 are the key hydrological processes of the area. These are discussed further in Section 5.3.4.

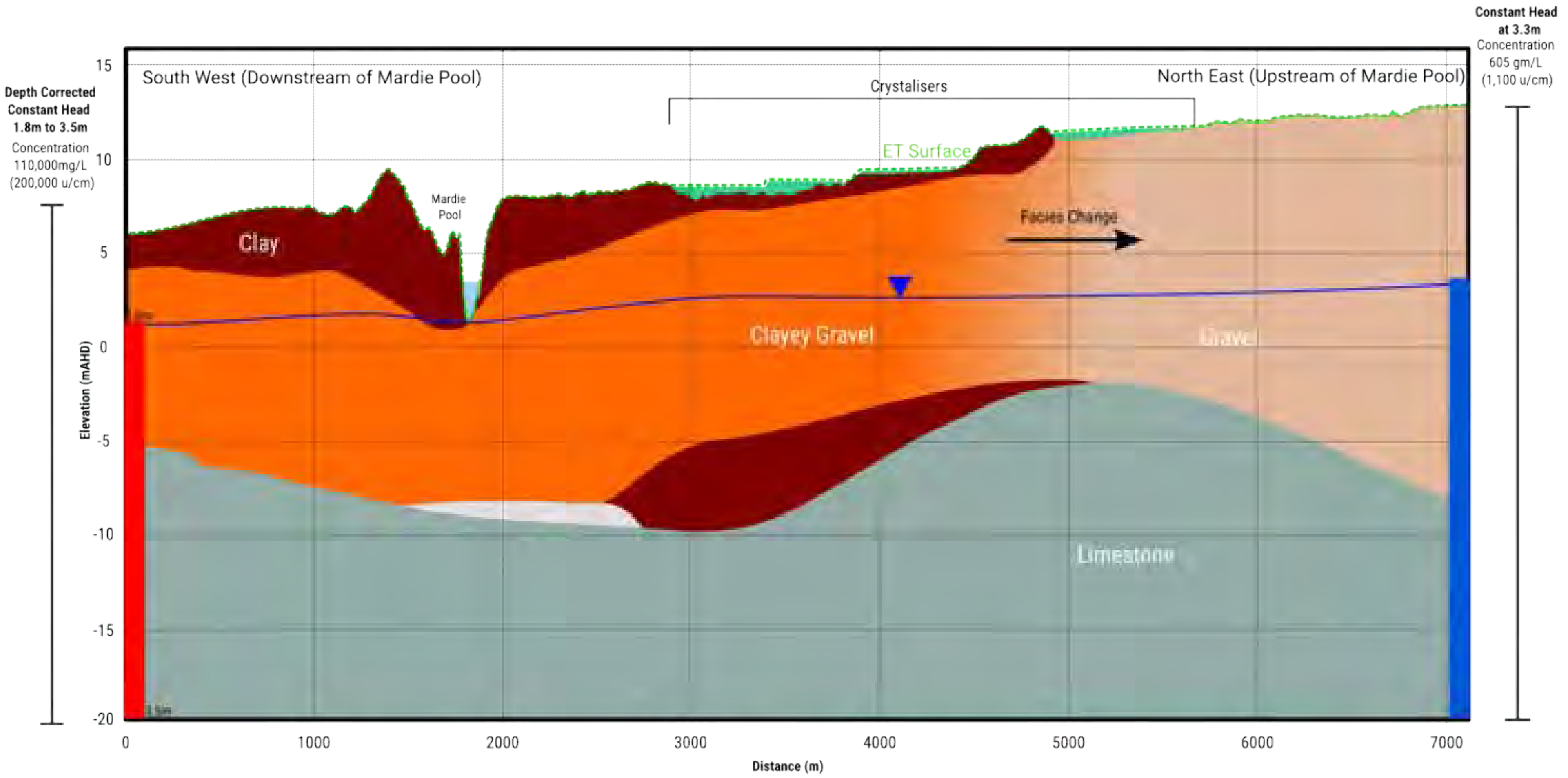


Figure 5.23 Mardie Pool and Crystallisers Schematic Model Cross Section (South West to North East)

5.3.3 Salinity Conditions

The current groundwater salinity conditions are used as initial conditions for modelled salinity. Salinity conditions are assigned as described in Section 5.2.3 and the model was not used to simulate the development of the observed salinity.

The distribution of salinity is based on measured salinity profiles from bores MP03, MP02, MP11 and MP13, measured in May 2023, with interpretation of the existing water level and hydrogeological conditions used to define the groundwater salinity conditions that result from the interactions between the sabkha, Mardie Pool and groundwater inflow from upstream. The salinity of the area immediately surrounding Mardie Pool has not been measured (access constraints) and has been estimated based on the data available for the rest of the area.

Salinity values (contoured) along the modelled section are displayed in Figure 5.24 and show:

- A salinity of up to 4,000mg/L is estimated in the Mardie Pool area.
- Salinity ranges from around 4,000mg/L in the shallow areas surrounding Mardie Pool to ~ 100,000mg/L on the southwest model boundary, resulting from interactions between the Mardie Pool and the sabkha (downstream).
- Upstream of Mardie Pool, salinity reduces to the north east.
- At depth, in the limestone aquifer, salinity decreases from the south west side of Mardie Pool to the north east.

The maximum interpreted groundwater salinity, of 100,000mg/L is assumed to have a density of 1,074kg/m^3. Less saline water with a minimum salinity of 650mg/L, located close to the upstream model boundary is assumed to have a density of 1,000kg/m^3. The salinity to density conversions are based on standard estimates / conversions.

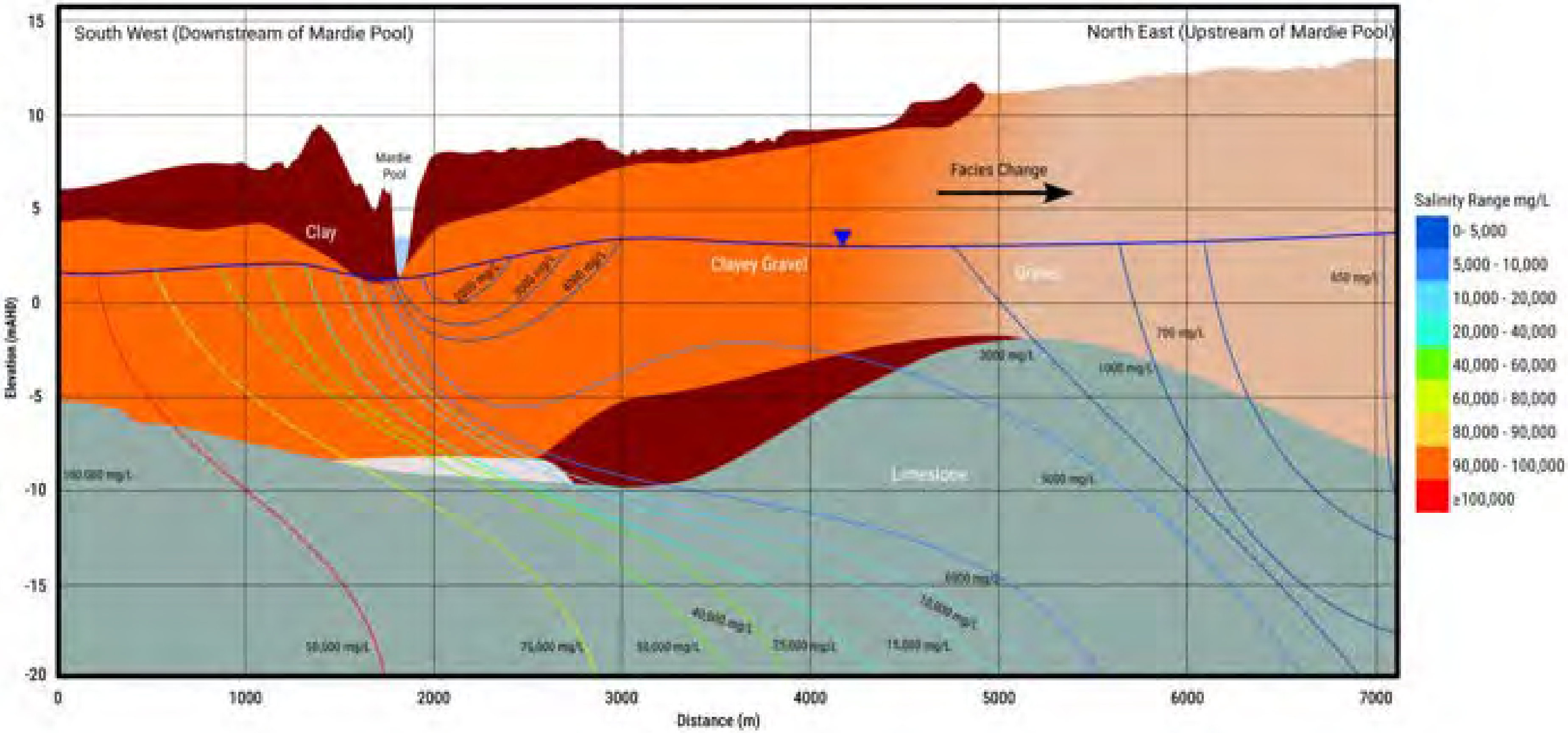


Figure 5.24 Mardie Pool and Crystallisers Model Cross-Section Salinity Contours

5.3.4 Groundwater Inflow and Outflow

Along the model section, observed water levels decrease from the northeast to the southwest (from inland towards Mardie pool and further downstream toward the sabkha). There is also interaction between Mardie Pool and the underlying groundwater.

Head boundary conditions are assigned at the upstream and downstream model boundaries. The upstream boundary is assigned an elevation of 3.3mAHD. This boundary is assumed to be hydrostatic consistent with the fresh water at this location. The downstream boundary is assigned an elevation of 1.82mAHD, with the assigned value corrected for density. The location of assigned upstream and downstream boundary conditions are shown spatially in Figure 5.22 and are shown schematically in Figure 5.23.

The interactions between Mardie Pool and the surrounding aquifers were assessed by AQ2 (2023). The analysis suggested that the interactions between Mardie Pool and the surrounding aquifers depend on the water level in Mardie Pool as summarised below:

- When the water level in Mardie Pool is above the surrounding groundwater levels, in response to rainfall events, there is discharge from Mardie Pool to the surrounding aquifers.
- When the water level in Mardie Pool is below the surrounding groundwater, there will be discharge from the surrounding aquifers to Mardie Pool. The analysis also suggests that groundwater contributes flow to sustain water levels in Mardie Pool during drier periods of the year.

The analysis also suggested that:

- The water storage capacity of Mardie pool is small compared to the size of the upstream catchment such that it is likely that only a small depth of excess rainfall would be sufficient to fill (and flush) Mardie pool.
- The frequency of filling of Mardie Pool is likely to be at least once a year (based on the size of Mardie Pool and the upstream catchment area).
- The spill level of Mardie Pool will limit the rise of groundwater in Mardie Pool with the minimum level constrained by the lowest elevations in Mardie Pool.

Water levels in Mardie Pool are simulated using the River (RIV) package in Modflow USG. This package uses a water level elevation relationship to calculate the recharge from, or discharge to, Mardie Pool. For the current model setup, the river boundary is set up to simulate flow to or from Mardie Pool. The spatial extent of modelled river cells that are used to simulate the filling and emptying of Mardie Pool is shown in Figure 5.22.

To simulate the recharge or discharge, each modelled river cell is assigned a base elevation (RBase), set consistent with the river elevation or invert level, a bed conductance (C) and a stage (HRIV). When the predicted groundwater level in the underlying cell (h) is less than RBase, the relationship in Equation 1 is used to calculated recharge to the underlying aquifer from the river (QRIV):

(1) $QRIV1 = C * (HRIV - Rbase)$

When the predicted groundwater level in the underlying cell (h) is greater than RBase, the relationship in Equation 2 is used to calculated recharge from the underlying aquifer into the river (QRIV2):

(2) $QRIV2 = C * (HRIV - h)$

Where river conductance (C) is calculated by Equation 3 below:

(3) $C = K * L * W/m$

Where:

C = River bed conductance (in m^2/d)

K = River bed hydraulic conductivity (in m/d)

L = Length of river across model cell (in m)

W = Width of river across model in cell (in m)

m = Thickness of river bed material (in m)

These relationships are shown schematically in Figure 5.25.

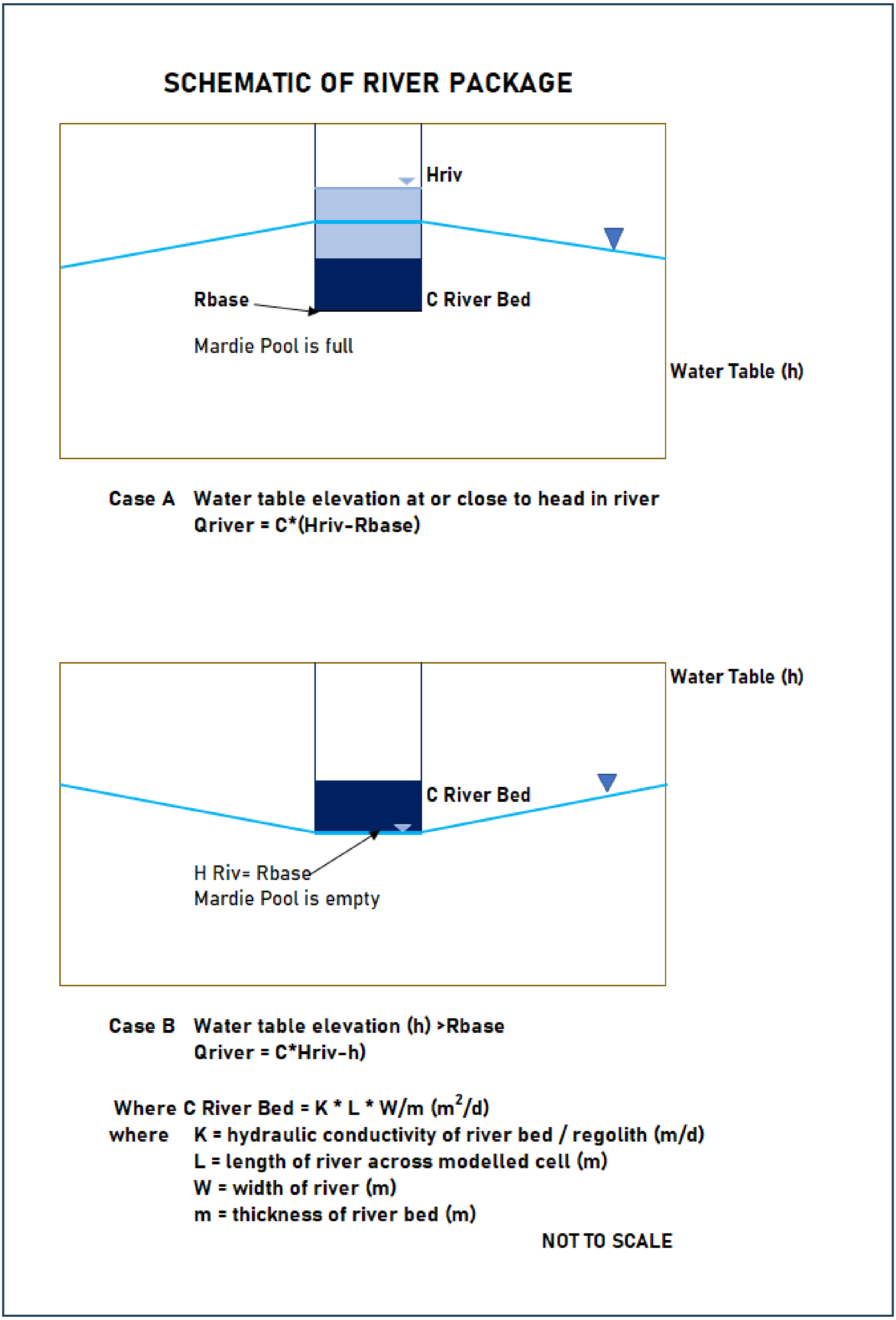


Figure 5.25 Mardie Pool Schematic River Package Setup

The river stage was set consistent with the water level for Mardie Pool, as estimated by AQ2, which ranged from 1.0mAHD (the lowest point in Mardie Pool along the modelled section) to the overflow level of 2.3mAHD. River bed conductance was assigned a value of 1000m^2/d.

Similar to the Pond 1 section, evapotranspiration from shallow groundwater is simulated using the Evapotranspiration (EVT) package in Modflow USG (refer Section 5.2.5.3 and Figure 5.5). ET is assigned at 7.4 x 10^{-4}m/d or 275mm per year. This is the same as the calibrated ET rate used for the Pond 1 model and is approximately 8% of the long term average evapotranspiration of 3.40m/a.

5.3.5 Model Calibration

Data available for model calibration includes:

- Water level monitoring for bores MP02, MP03, MP11 and MP13 over the period January 2022 to May 2023.
- Salinity profiles for bores MP02, MP03, MP11 and MP13, measured in May 2023.

The locations of bores used for model calibration are shown in Figure 5.22. Bores are shown at actual locations as well as the simulated location along the modelled section.

The calibration period of the model, where a comparison between measured and modelled water level is possible, extends from July 2022 to May 2023 consistent with the longest period of active groundwater level monitoring. The model was run using a repeating cycle of Mardie Pool water levels, over a period of ten years to check that a stable pattern distribution of groundwater salinity was predicted. This process was also used to generate a set of initial conditions (similar to the approach used for Pond 1, refer Section 5.2.5.2) as available groundwater monitoring shows fluctuations in groundwater levels due to seasonal interactions with Mardie Pool. Predicted water levels from an applicable time were then used as initial conditions for the next simulation. This process was repeated as appropriate, for example when a change was made to model parameters or boundary conditions.

5.3.6 Transient Calibration Results

The location of monitoring bores used for model calibration are shown in Figure 5.22. Estimated and simulated water levels in Mardie Pool and calibration hydrographs showing measured and modelled water level are shown in Figures 5.26 and 5.27. The model was used to run a 10 year sequence of conditions, based on the estimate Mardie Pool water levels. The measured water levels at MP02 and MP03 show the measured responses to the filling and emptying of Mardie Pool. The measured water levels at MP11 and MP13 show no discernible trend. Overall, however the water level magnitude is matched at MP11 and MP13 and a much smaller variation in water levels is predicted at MP11 and MP13 in response to the water levels simulated in Mardie Pool.

Measured salinity profiles from May 2023 for MP03 and MP02, and MP13 and MP11 are shown in Figures 5.28 and 5.29. Also shown in Figures 5.28 and 5.29 are the predicted salinity profiles from May 2023 and December 2023. The predicted salinity profiles show:

- That the model replicates the May 2023 measured salinity profiles.
- There is little change between the model predicted profiles for May 2023 and the end of the simulated calibration period (December 2032).
- There is some difference between the salinity profiles predicted under Mardie Pool for May 2023 and the end of the simulated calibration period (December 2032). No measured salinity data or profiling is available for below Mardie Pool for comparison between measured and modelled salinity.

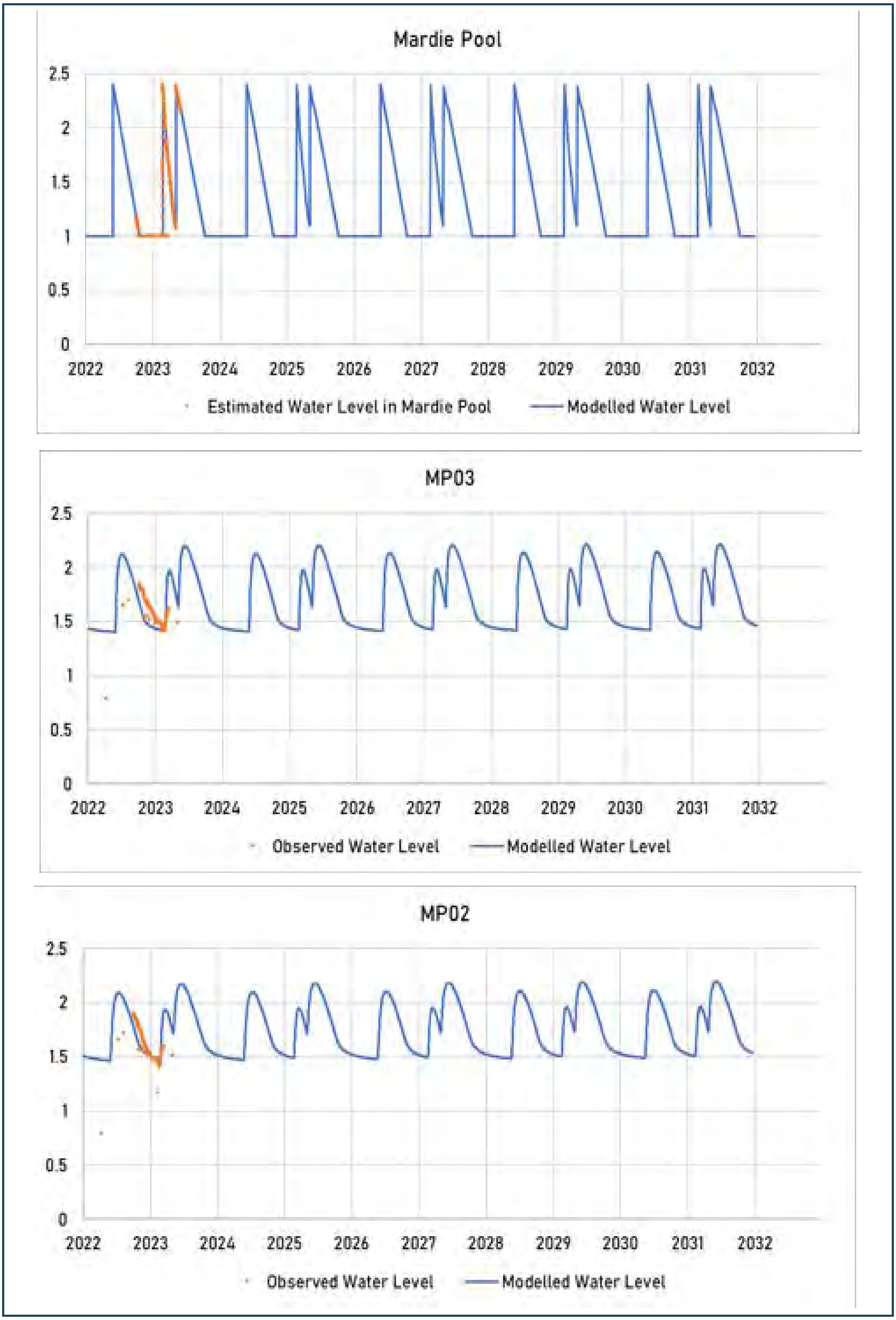


Figure 5.26 Mardie Pool and Crystalliser Calibration Hydrographs Mardie Pool, MP03 and MP0

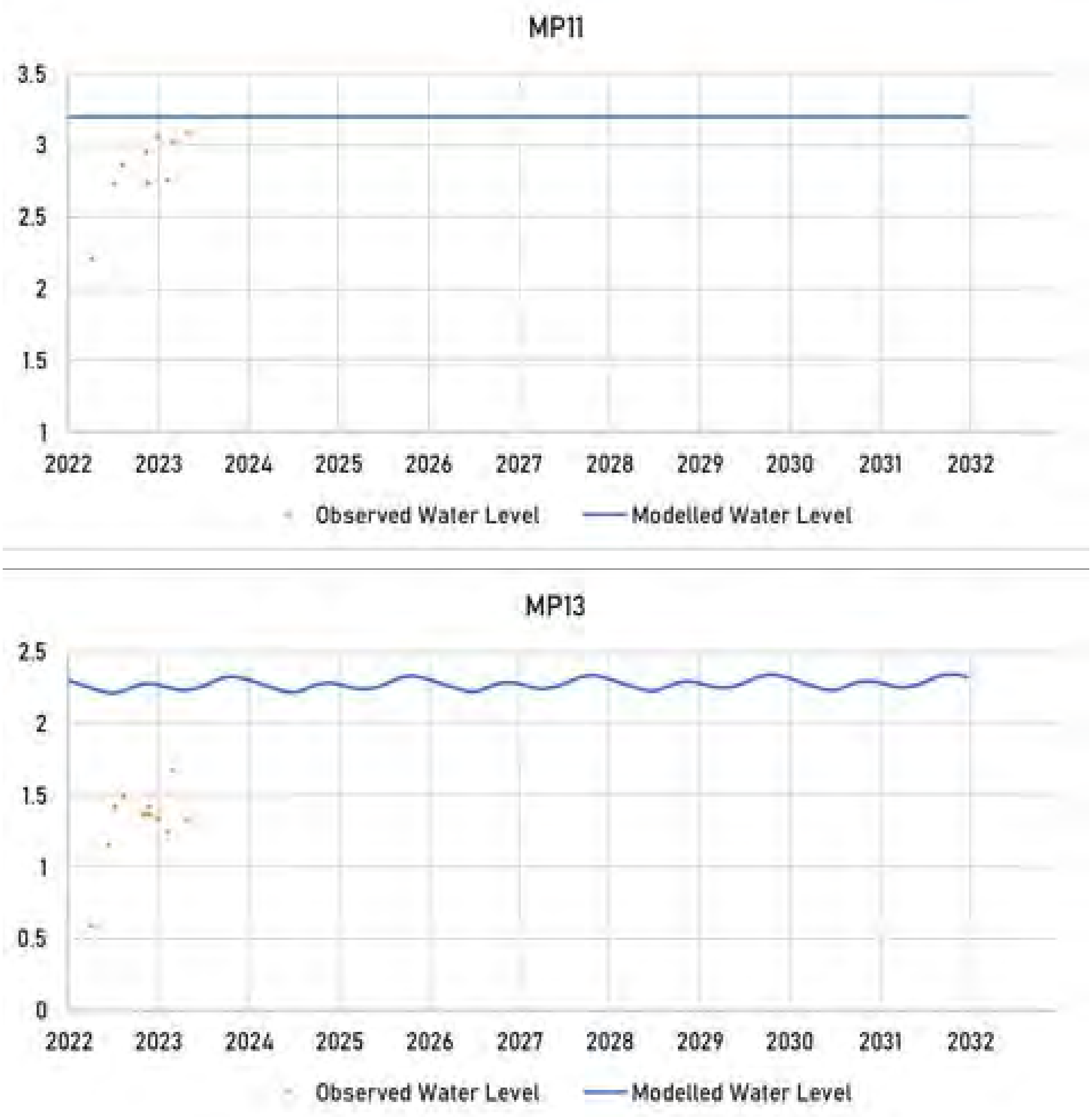


Figure 5.27 Mardie Pool and Crystalliser Calibration Hydrographs MP11 and MP13

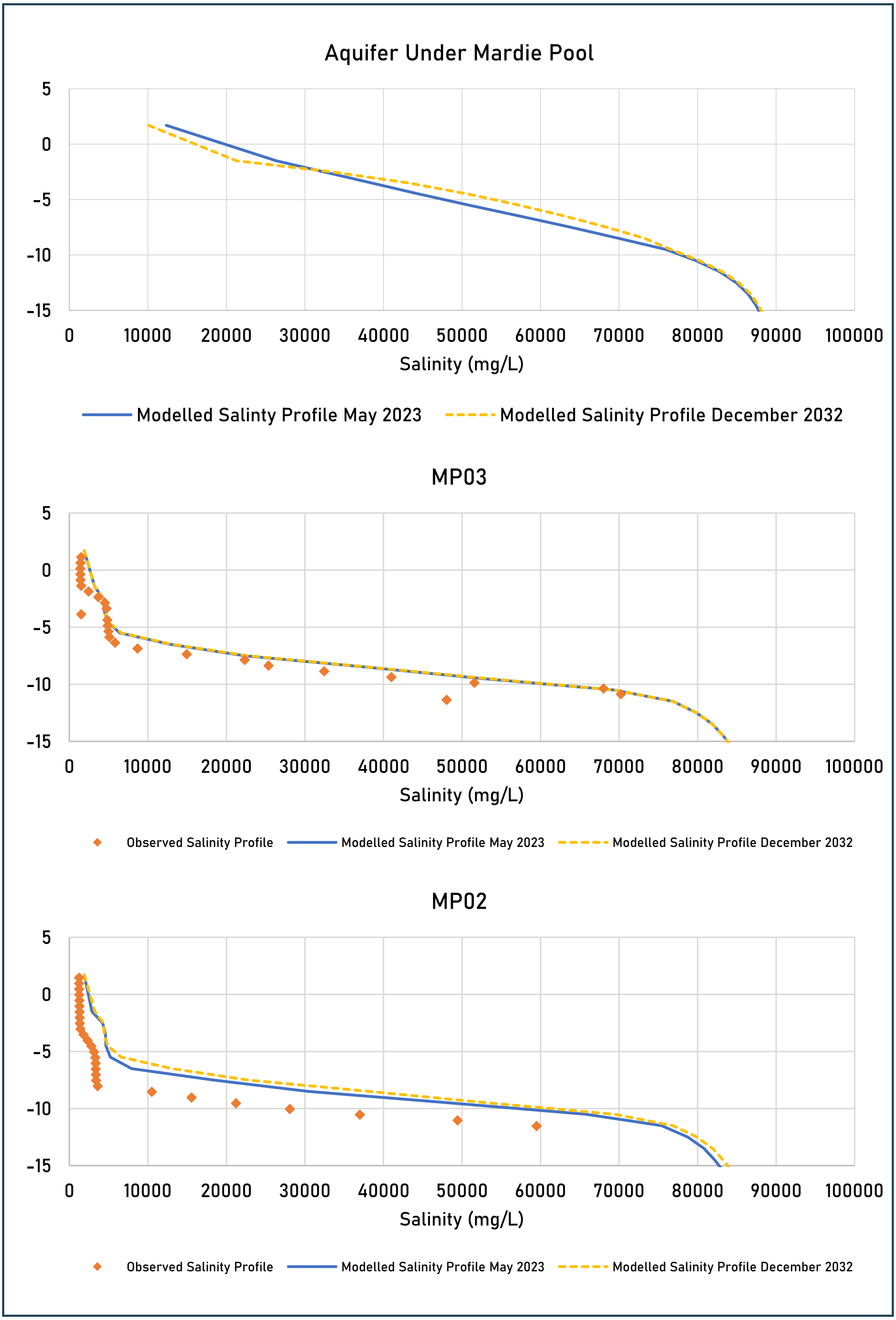
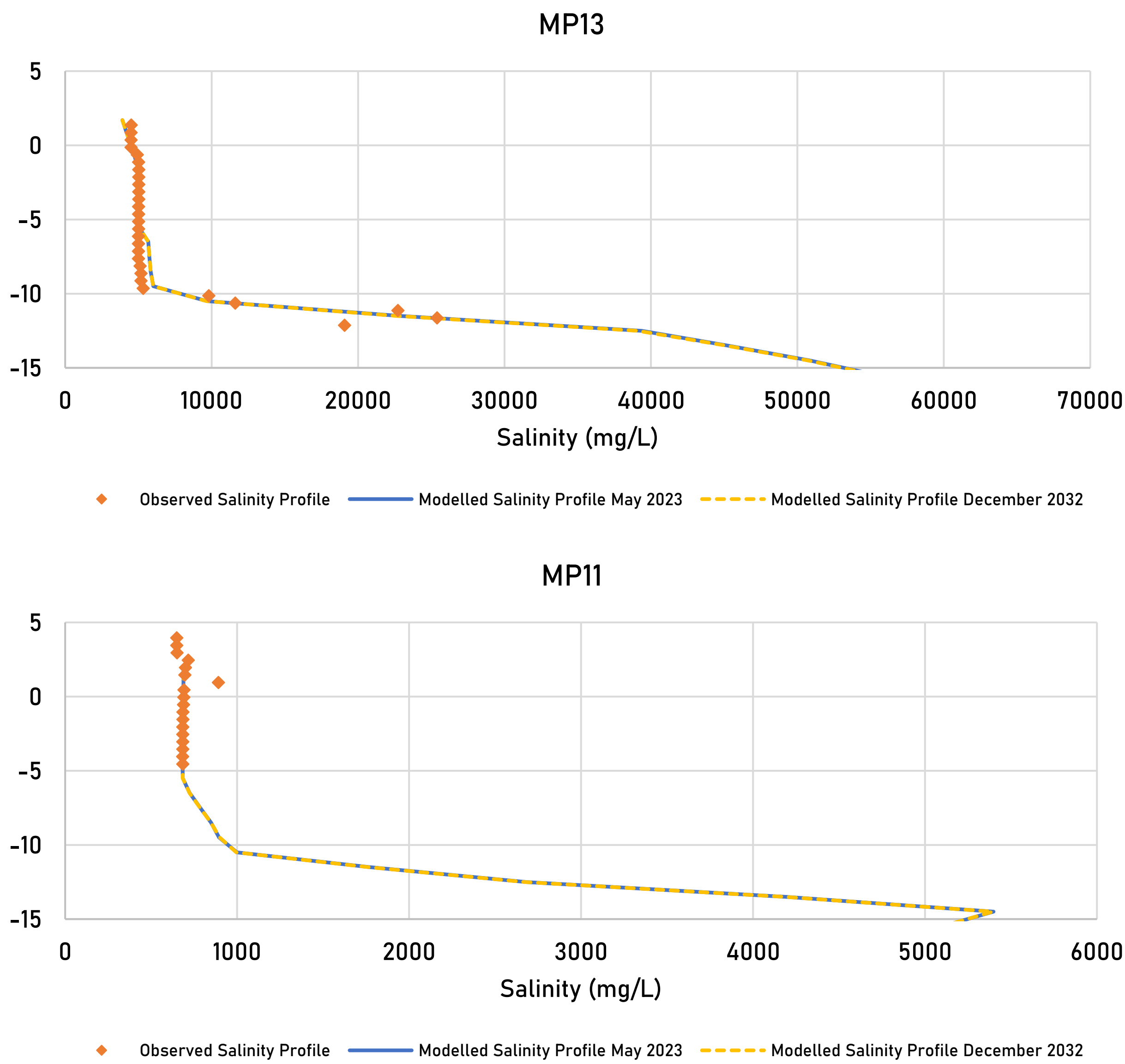


Figure 5.28 Mardie Pool and Crystalliser Calibration Salinity Profiles Mardie Pool. MP03 and MP02



\\dc02\Jobs\293\2.TECH\Analysis\Groundwater Model\Model Results\Section G

Figure 5.29 Mardie Pool and Crystalliser Calibration Hydrographs MP11 and MP13

Calibrated aquifer parameters are shown in Table 5.5.

Table 5.5 Calibrated Aquifer Parameters

Aquifer Unit	Horizontal Hydraulic Conductivity (m/d)	Vertical Hydraulic Conductivity (m/d)	Specific Yield (%)	Porosity (%)	Specific Storage (m^{-1})
Clayey Gravel	1	1	1	40	1e-6
Gravel	5	5	1	40	1e-6
Calcrete	1	1	1	40	1e-6
Lower Clay	0.01	0.001	1	40	1e-6
Limestone	2	0.2	1	20	1e-6

Model predicted water and salt balances for the calibration period are presented in Appendix B.

5.3.7 Model Predictions

The calibrated section model was used to simulate the impacts to groundwater of seepage from the crystallisers, located upstream of Mardie Pool. The crystallisers will produce the final product and will differ in operation from the remainder of the ponds. Leakage from the crystallisers will be limited by the persistence of the final product over the base of the crystallisers. Rather than being a constant source of water to the underlying groundwater system, the impact of the crystallisers has been simulated as a significant failure of an area of the lining of the crystalliser that results in the leakage of very saline water to the underlying groundwater. Details of the model prediction are outlined below:

- Initial conditions (groundwater level and salinity) were taken from the end of the calibration model.
- The prediction models were run for a period of 10 years assuming a daily stress period (period over which all stresses were held constant). While the life of the Project is longer than 10 years, this period was sufficient to show the impacts of the leakage from the crystallisers (i.e., the model predictions showed quasi steady state conditions had been reached).
- The upstream, downstream and Mardie Pool boundary conditions were simulated as per the model calibration.
- The extent of the crystallisers assumed to fail, and result in leakage, is shown in Figure 5.22. A total length of failure of 100m along the section model is simulated.
- The leakage related to the failure of the crystallisers was simulated assuming leakage from the ponds is a function of the water stored in the ponds. The head dependent recharge was simulated using the River (RIV) package in Modflow USG. The head in the "river" was assigned 0.5m above the base of the crystalliser, from the start of the prediction (i.e., no crystalliser filling was simulated), the base of the "river" assigned at the base of the crystalliser (around 4.7mAHD) and a low conductance (1 x 10^{-3}m/d) consistent with the product that is anticipated to form in the base of the ponds. This boundary condition set up is the same as that used for Pond 1 leakage and is shown schematically in Figure 5.14.
- In addition to the operating strategy of the crystallisers, which is assumed to result in negligible leakage to the underlying groundwater, they are also located in an area where the depth to water is approximately 4 to 5m. Model predictions conservatively assume that leakage from the crystallisers to the underlying water table is immediate. In reality saturation of the 4 to 5m unsaturated zone would need to occur before there was ongoing or continuous recharge to the underlying water table.

- Leakage from the crystallisers was simulated for a period of 10 years initially to determine how long it would take for the water level and salinity impacts to be seen at downstream monitoring locations. A further model was run to show the impact of seepage from the crystallisers over a period of a year only. This annual period of leakage would be more consistent with the expected operation of the crystallisers (i.e., an area that was found to leak excessively would no longer be used as part of operations).
- The leakage from the crystalliser was assumed to have a salinity of 273,000mg/L, with an associated density of 1,222.5kg/m^3.
- A No Development Scenario was also run to allow the identification of impacts of leakage from the crystallisers. The No Development Scenario contained the same Mardie Pool simulated boundary conditions as outlined above.

A summary of model runs is presented in Table 5.6.

Table 5.6 Model Prediction Summary

Prediction	Details
Scenario 1	Leakage from the crystalliser as function of the water stored in the crystalliser over a period of 10 years.
Scenario 2	As per Scenario 1 with leakage from the crystalliser simulated for a period of 1 year.
No Development	Includes the calibrated model distribution of tidal recharge and tidal boundary conditions as outlined above only.

5.3.8 Prediction Results

Observation locations (calibration bores and modelled observation locations) are shown in Figures 5.22. Predicted water level hydrographs over the 10 year simulation period, for Scenarios 1 and 2 and the No Development Scenario are shown for:

- Calibration bores located close to Mardie Pool (MP03 and MP02) and Mardie Pool for Scenarios 1 and 2 and the No Development Scenario in Figure 5.30.
- MP11, MP13 and under the crystalliser in Figure 5.31.
- At modelled observation locations, 5, 10 and 100m downstream of the crystalliser in Figure 5.32.

The following observations are made regarding the predicted water levels:

- No predicted water level impact is observed at Mardie Pool (refer Figure 5.30) for any of the prediction scenarios simulated as a result of the configuration used to simulate water levels in Mardie Pool. The impacts at Mardie Pool are discussed in the following sections as impacts to the simulated salinity profile and the model predicted water balance.
- At MP03 and MP02, located close to Mardie Pool, a water level impact of seepage from the crystalliser is predicted soon after the commencement of simulated leakage (refer Figure 5.30). At MP03 and MP02 during the first year of simulated seepage (Scenarios 1 and 2), the water level impact is predicted to be less than 0.2m during both the wet and dry seasons. For Scenario 1, that includes ongoing leakage, the water level impact of seepage is predicted to be up to 0.3m by the end of 2033 (10 year prediction period). For Scenario 2, that only includes leakage for a period of a year, water levels are predicted to be very close to the water levels simulated for the No Development Scenario from 2025 (Year 2) onwards (within 0.1m).

- At MP11 (refer Figure 5.31) a gradual increase in water level is predicted as a result of leakage from the crystalliser over the simulation period. After 2025 (2 years), both Scenarios 1 and 2 predict a water level increase of less than 0.1m. For Scenario 1, by 2033 (10 years), water levels are predicted to be around 0.15m higher than the No Development Scenario. For Scenario 2, water levels are similar to the water levels predicted for the No Development Scenario from 2027 (Year 4) onwards.
- At MP13 and under the crystalliser (refer Figure 5.31) as would be expected water levels are predicted to increase as a result of simulated leakage. At MP13, water levels are predicted to increase by 2.1m after a year for Scenarios 1 and 2. For Scenario 1 water levels are predicted to increase over the simulation period such that by the end of the simulation, water levels for Scenario 1 are around 1.5m higher than the No Development Scenario. For Scenario 2, water levels are predicted to be similar to the No Development Case by 2030 (Year 8), with a difference of less than 0.05m predicted between these two Scenarios by this time.
- Immediately downstream of the crystalliser, at a distance of 5m, 10m and 100m from the crystalliser (refer Figure 5.32) water levels are predicted to increase up to 2m over the first year (Scenarios 1 and 2). The predicted water level increase 5m downstream of the crystalliser is rapid and suggests that the impact of a failure would be detected through regular monitoring over a period of less than a year (i.e. crystalliser operation in this area would likely cease before a measured increase in water level based on changes to recovered product). For Scenario 2, once the simulated leakage ceases, water levels are predicted similar to the No Development Scenario.

Predicted salinity profiles after one, two and ten years (end of 2024, 2025 and 2033) for Scenarios 1 and 2 and the No Development Scenario are shown for the following observation locations (locations of existing bores and modelled observation locations are shown in Figure 5.22):

- The aquifer under Mardie Pool and MP03 in Figure 5.33.
- MP02 and MP11 in Figure 5.34.
- MP13 and under the crystalliser in Figure 5.35.
- At modelled observation locations, 5m and 10m downstream of the crystalliser in Figure 5.36.
- At the modelled observation location 100m downstream of the crystalliser in Figure 5.37.

Divergence between the initial and final salinity profiles illustrates the predicted salinity impacts.

The following observations are made regarding the predicted salinity profiles:

- Very little change in the simulated salinity profile is predicted at MP03 and MP02 (refer Figure 5.33 and 5.34). There is however an increase in salinity predicted in the aquifer underlying Mardie Pool. This salinity increase at Mardie Pool is predicted for Scenario 1 only. The increase in salinity predicted by the end of 2023 (10 years) for Scenario 1 to an elevation of around -15mAHD (~ 16mbgl) is around 10,000mg/L.
- Very little change in salinity is predicted at MP11 (refer Figure 5.34).
- At MP13 (Figure 5.35) minimal salinity increase is predicted during the first few years of the simulation. An increase in salinity of 10,000mg/L at an elevation of -1.5mAHD (or ~9mbgl) is predicted at MP13 by 2023 (10 years) for Scenario 1.
- As would be expected immediately underlying the crystalliser (Figure 5.35), salinity is predicted to increase up to an elevation of -2.5mAHD (depth of ~ 10mbgl). Scenario 1 predicts an increase in salinity from 5,000 to 85,000mg/L to an elevation of -2.5mAHD (or a depth of -10mbgl). For Scenario 2, the predicted increase in salinity is reduced and predicted to increase from ~ 5000 to 13,000mg/L close to the base of the simulated crystalliser (Scenario 2).

- Downstream of the crystalliser (refer Figure 5.36 and 5.37) Scenario 1 predicts an increase in salinity of up to 80,000mg/L (from around 5,000mg/L), 5m downstream of the crystalliser, to an elevation of -2.5mAHD (depth of ~10mbgl) by 2023 (10 years). For Scenario 2, when leakage is only simulated until the end of 2024 (a year), an increase in salinity is not predicted 5m downstream of the crystalliser by the end of 2025 (after 2 years). By the end of 2033 (10 years) however, an increase in salinity of up to around 15,000mg/L is predicted up to an elevation of 2mAHD (~10mbgl) for Scenario 2. Similar results are predicted 10m downstream of the crystallisers.
- No significant increase in salinity is predicted 100m downstream of the crystalliser (refer Figure 5.37).

Model predicted water and salt balances for the end of the model prediction periods are presented in Appendix B.

The predicted water balance (flux) for Mardie Pool over the duration of the prediction, for Scenarios 1 and 2 and the No Development Scenario is shown in Figure 5.38. As outlined in Section 5.3.4, this is simulated using the RIV package in Modflow USG. A net flux that is positive represents recharge from Mardie Pool to the surrounding aquifer (i.e., when there is water in Mardie Pool at an elevation higher than the surrounding aquifers). A net flux that is negative represents discharge from the aquifer surrounding Mardie Pool to Mardie Pool (i.e., when water level in the surrounding aquifer are higher than the simulated level in Mardie Pool). The model predicted water balance for Madie Pool shows:

- A small increase in the flux to Mardie Pool (negative flux) is simulated by Scenarios 1 and 2 during 2024 as a result of leakage from the crystalliser (compared to the No Development Scenario).
- When water is simulated in Mardie Pool (when the net flux in positive), a similar net flux is simulated for Scenarios 1 and 2 and the No Development Scenario.
- For Scenario 1, the predicted net flux from the aquifer to Mardie Pool is more than the No Development Scenario over the duration of the predictions as there is ongoing seepage simulated from the crystalliser. This increase is small compared to the over net flux simulated.
- For Scenario 2, the net simulated flux is very similar to the No Development Scenario by the end of 2026 (year 3 of the simulation) as seepage from the crystalliser ceases at the end of 2024 (end of year 1).

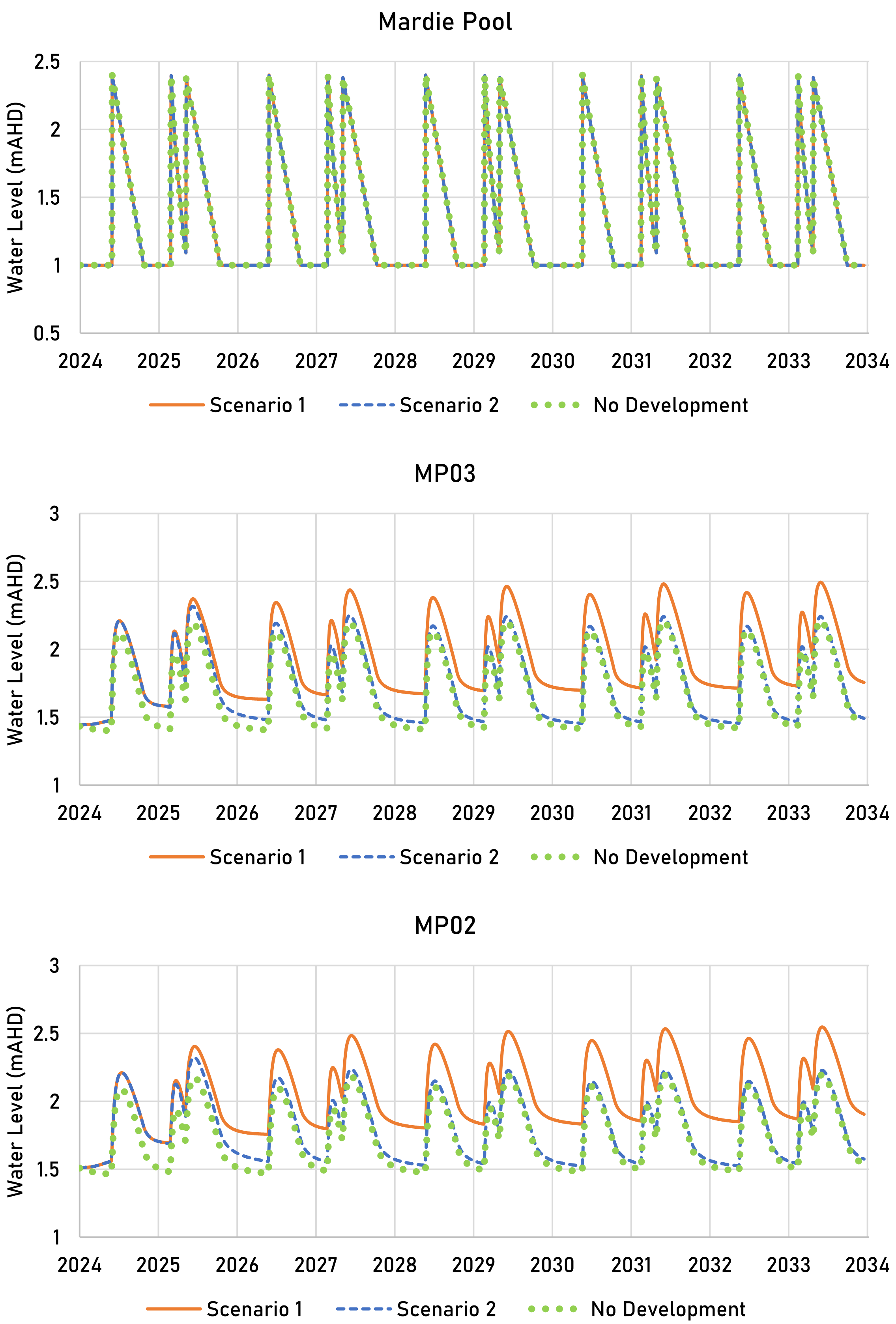


Figure 5.30 Prediction Hydrographs Scenario 1, 2 3 and No Development Mardie Pool, MP03 and MP02

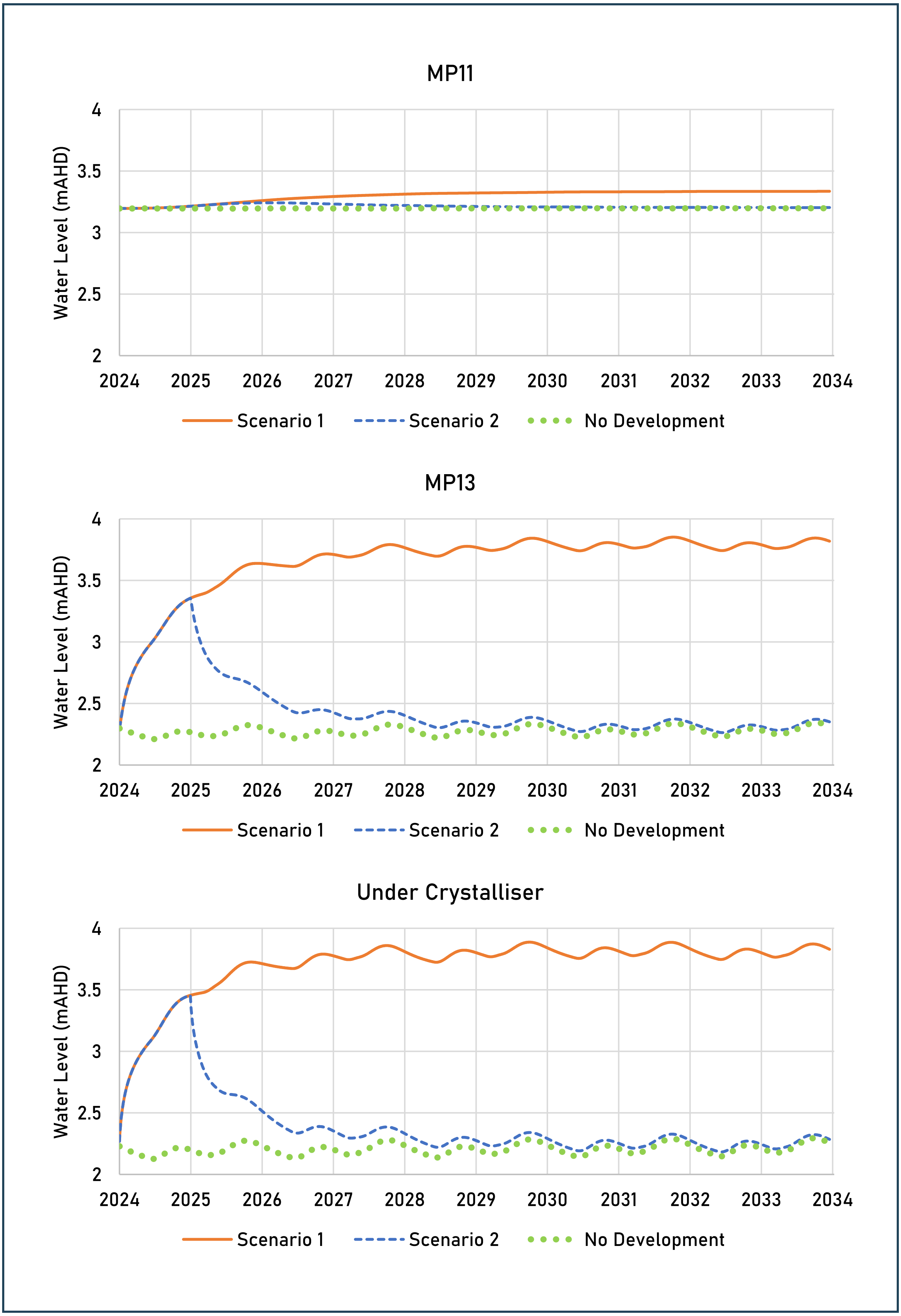


Figure 5.31 Prediction Hydrographs Scenario 1, 2 3 and No Development MP11, MP13 and Under Crystalliser

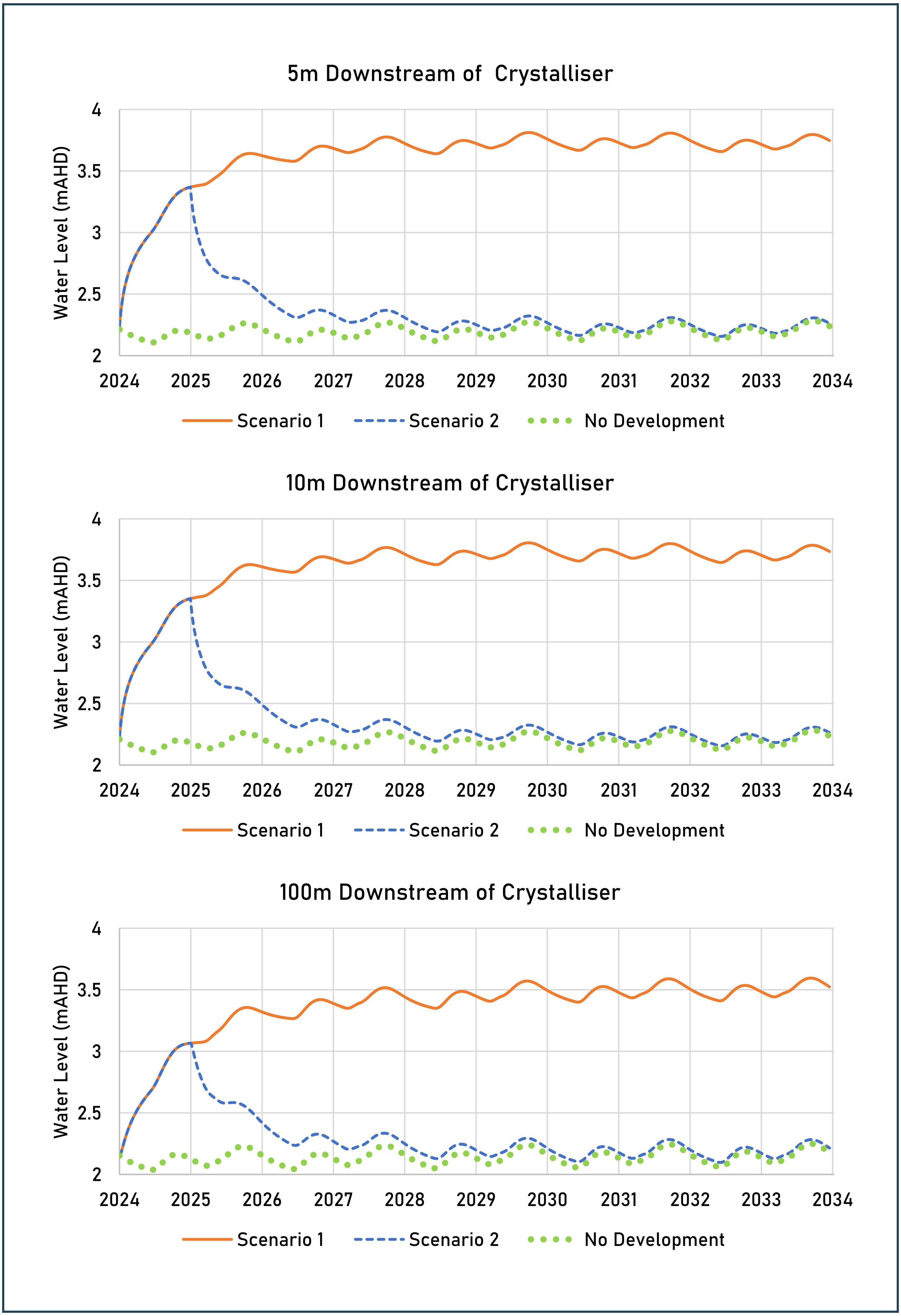


Figure 5.32 Prediction Hydrographs Scenario 1, 2 3 and No Development 5m, 10m and 100m Downstream of Crystalliser

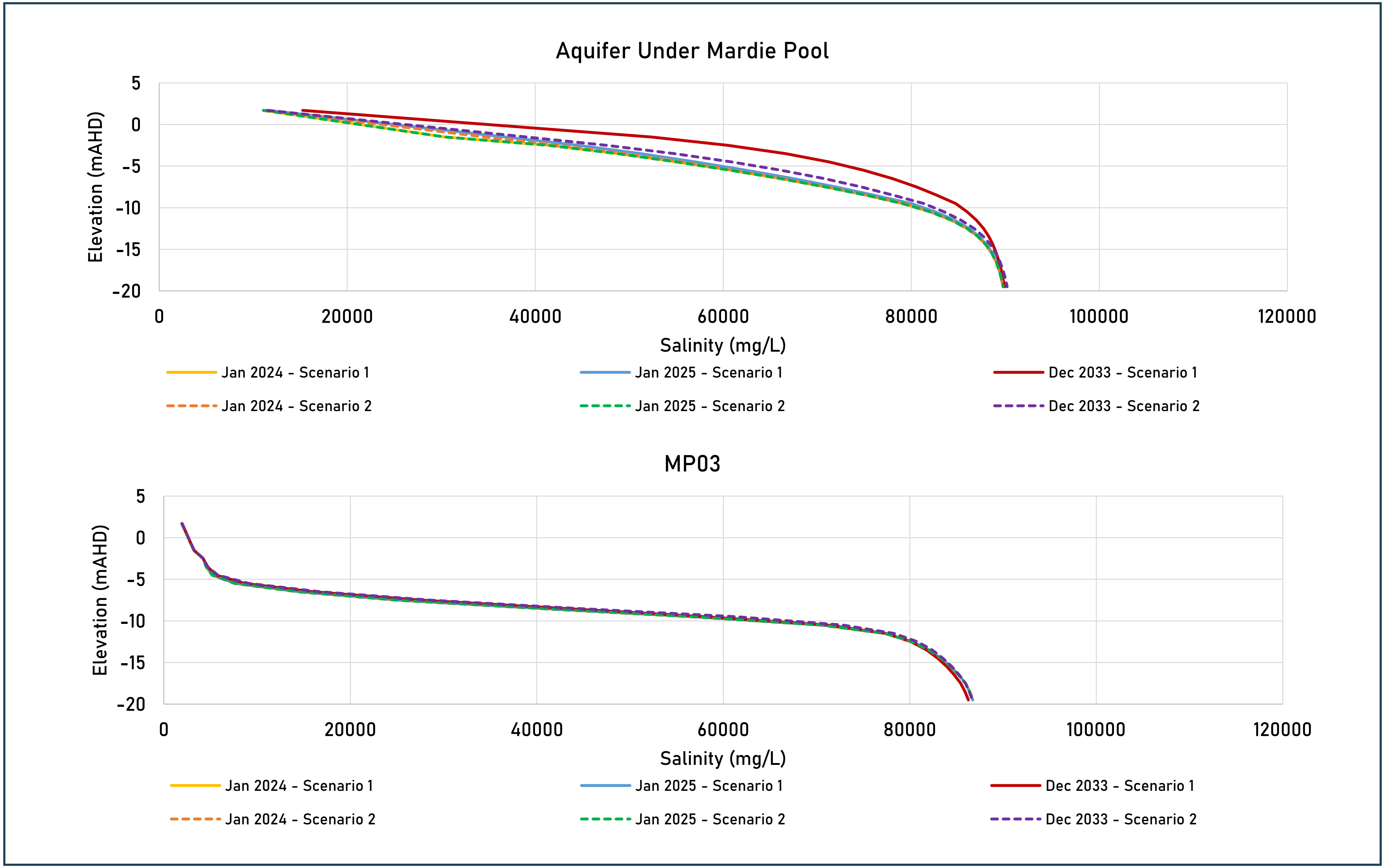


Figure 5.33 Predicted Salinity Scenario 1 and 2 Under Mardie Pool and MP03

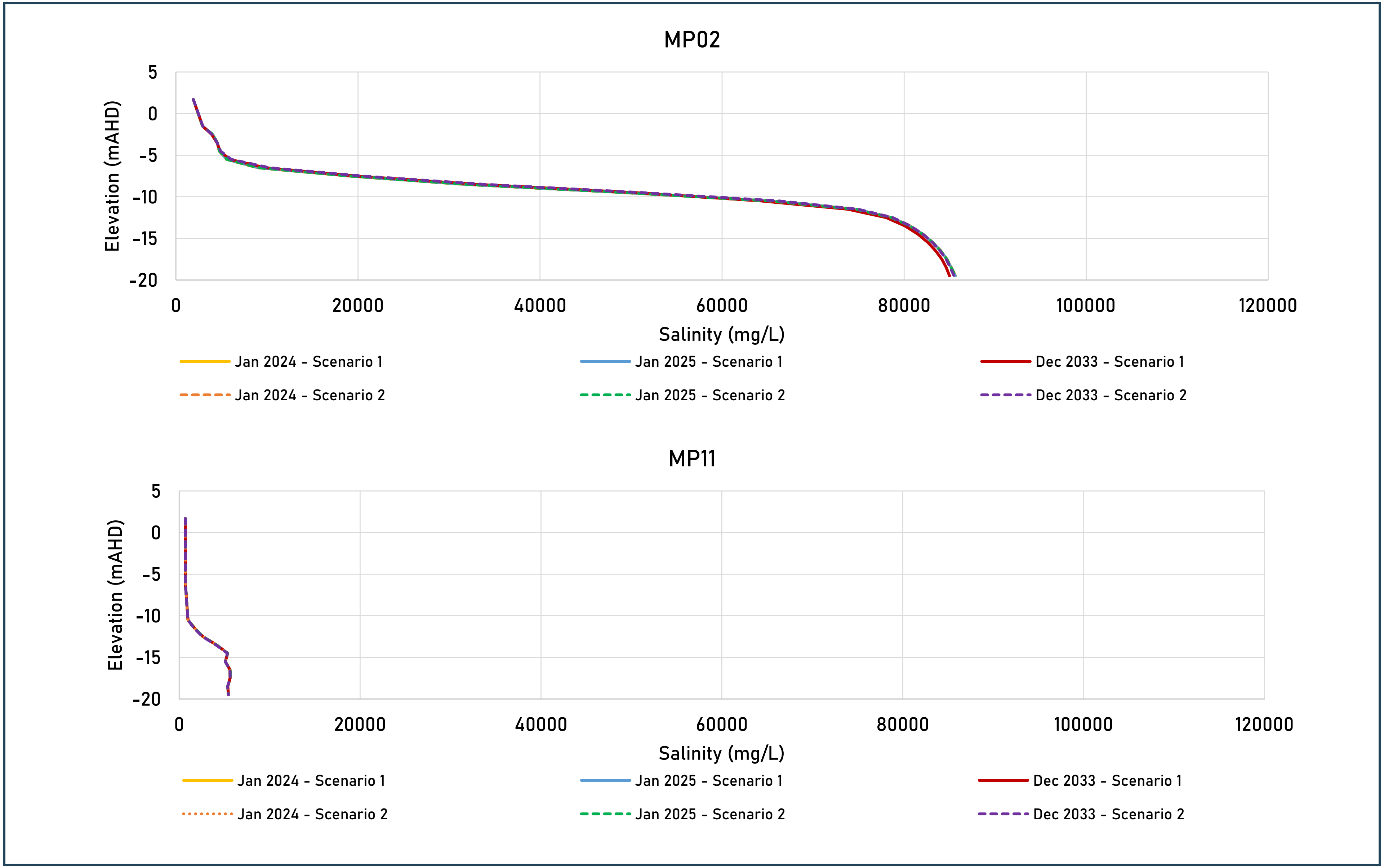


Figure 5.34 Predicted Salinity Scenario 1 and 2 at MP02 and MP11

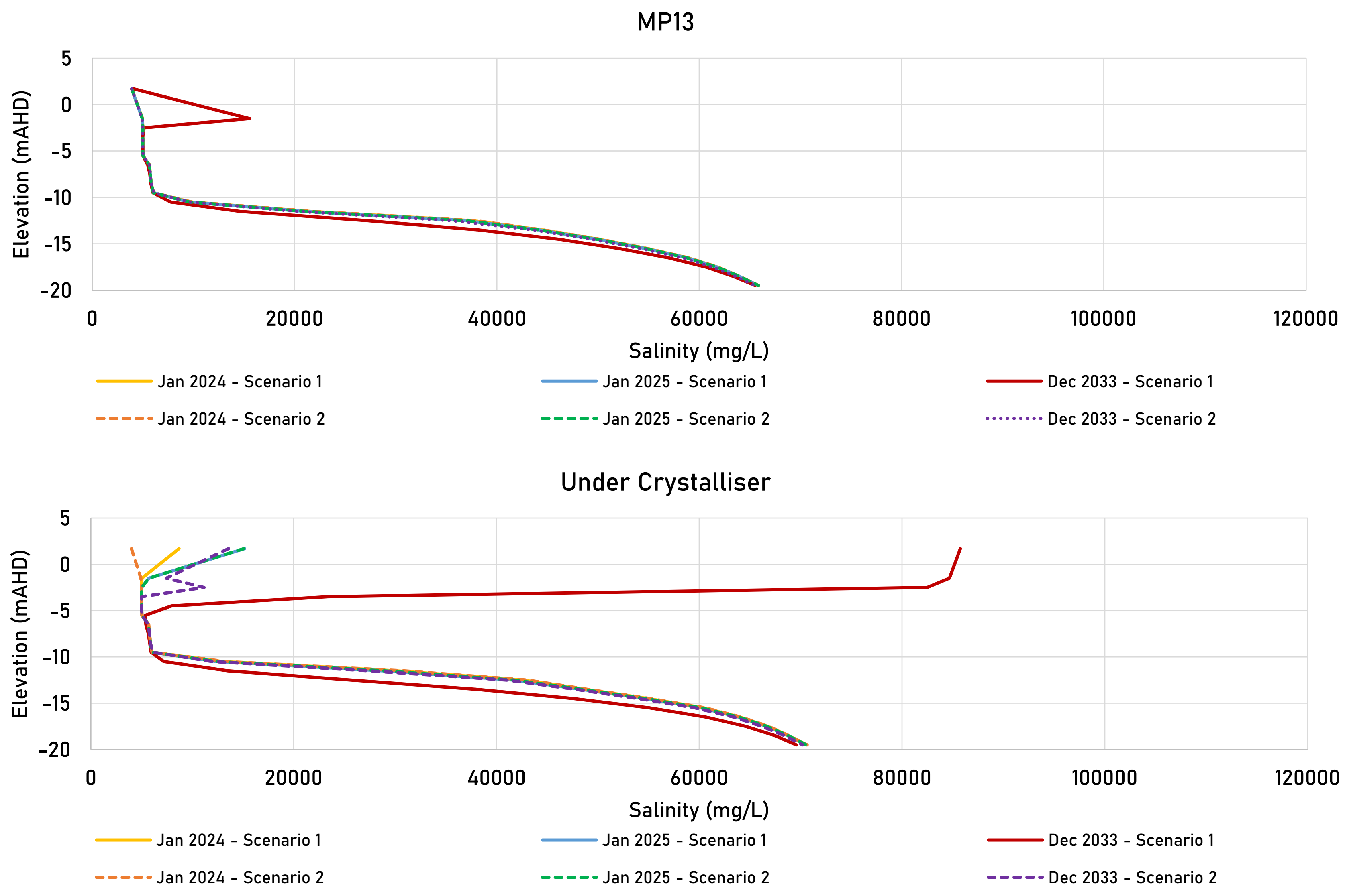


Figure 5.35 Predicted Salinity Scenario 1 and 2 at MP13 and Under Crystalliser

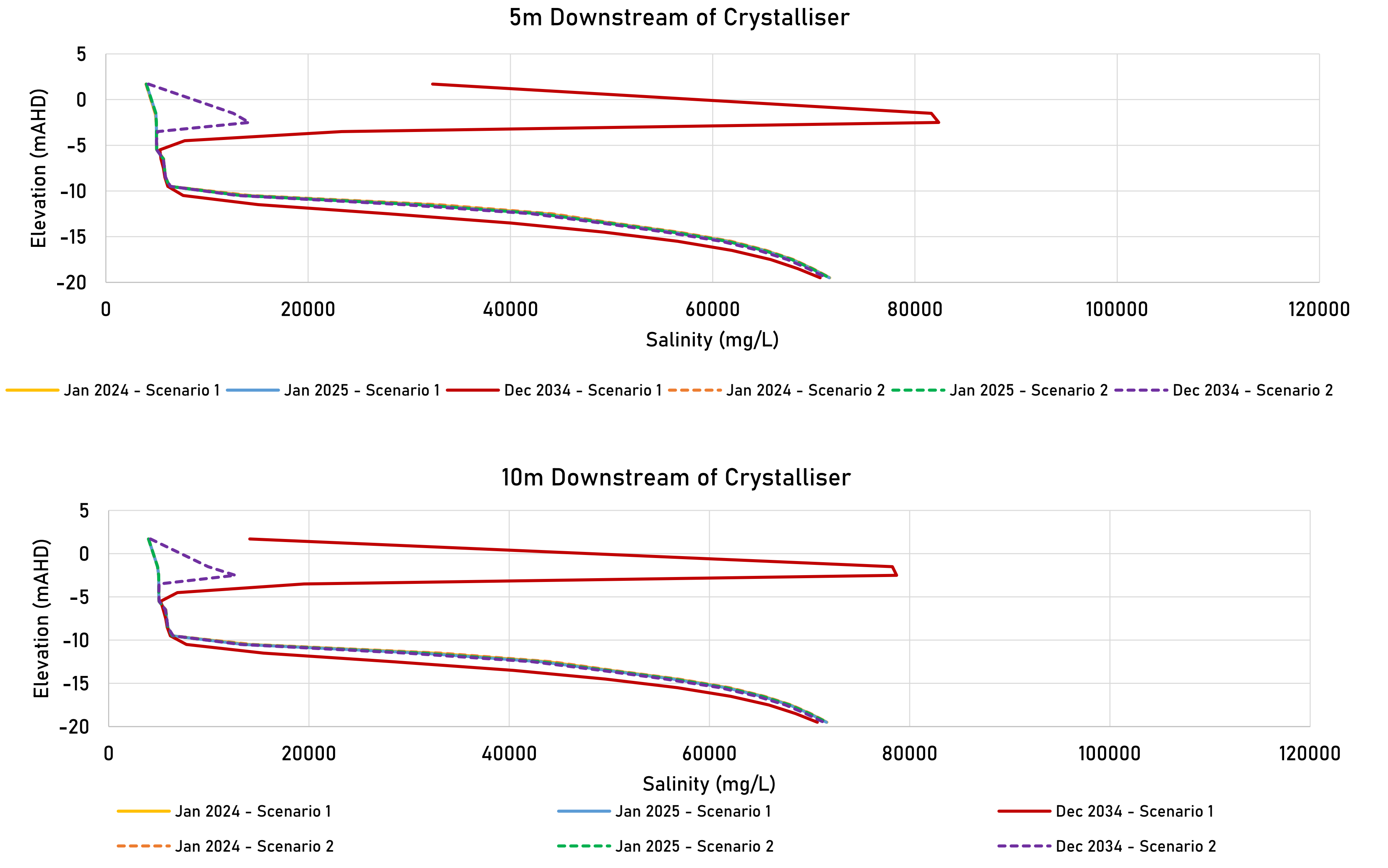


Figure 5.36 Predicted Salinity Scenario 1 and 2 5m and 10m Downstream of Crystalliser

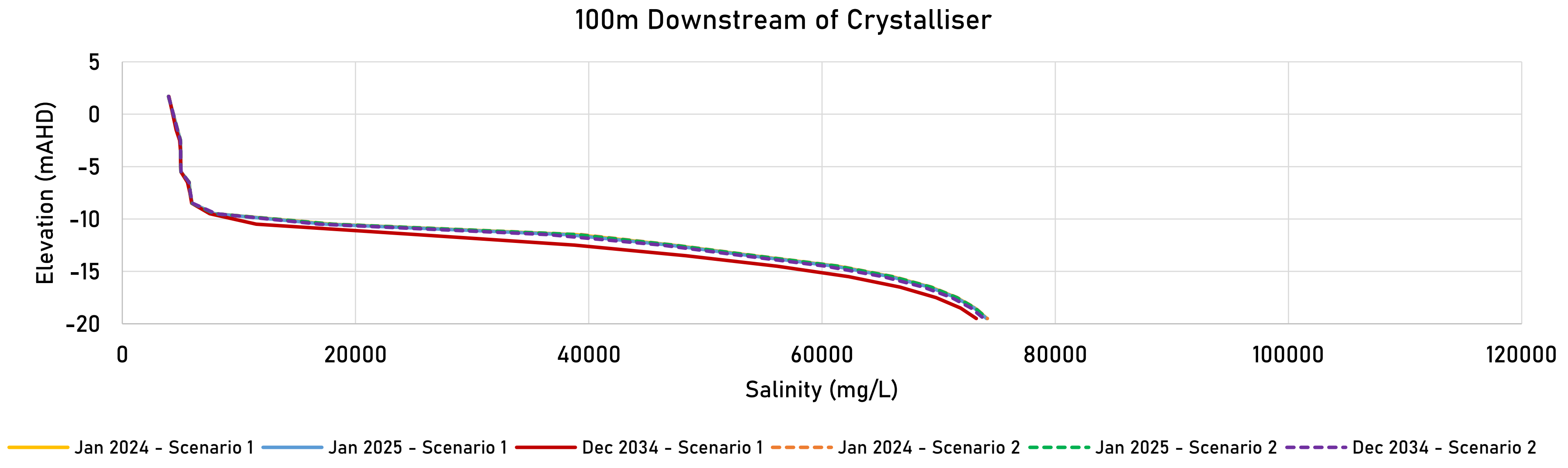


Figure 5.37 Predicted Salinity Scenario 1 and 2 100m Downstream of Crystalliser

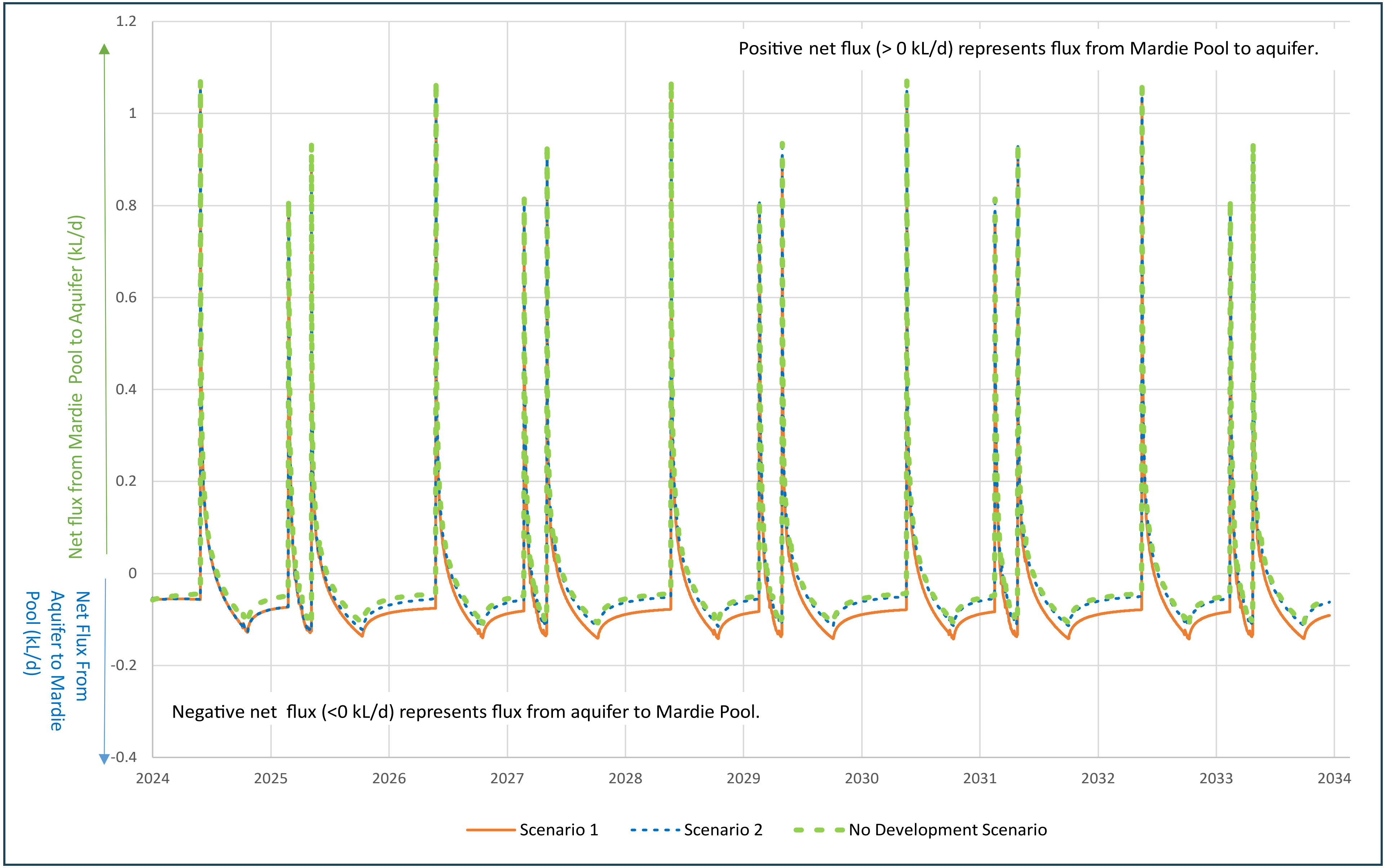


Figure 5.38 Predicted Net Flux – Mardie Pool

5.4 Pond 6 and Crystalliser

5.4.1 Model Grid and Setup

The extent of the Pond 6 and crystalliser section is shown in Figure 5.39. It extends:

- Approximately 3.3km downstream of the western boundary of Pond 6, across the sabkha and towards the coast.
- Upstream of the eastern boundary of Pond 6, and a distance of 4.6km across the extent of the crystallisers and a distance of 2.7km upstream of the crystallisers.

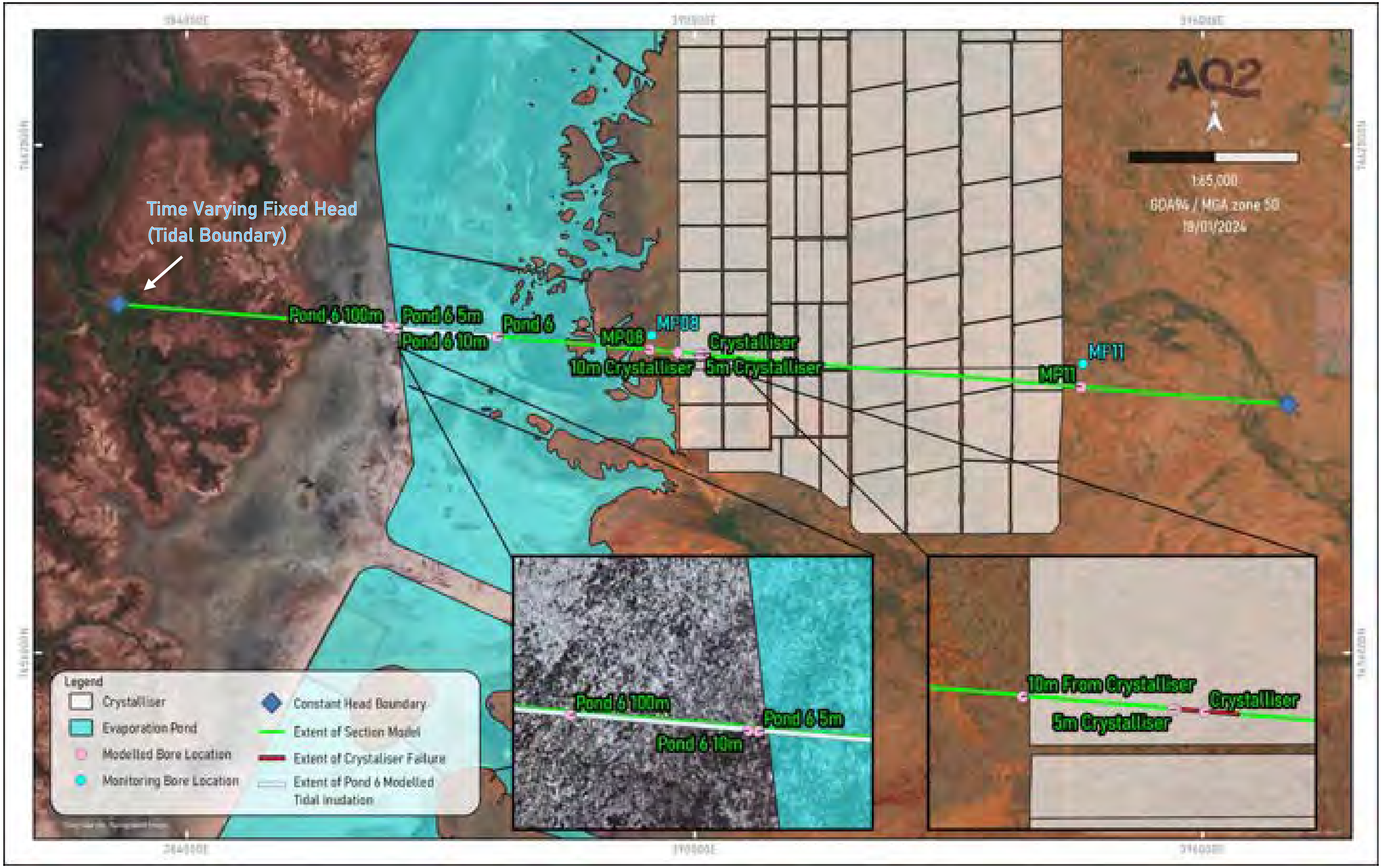


Figure 5.39 Pond 6 Model Extent, Boundary Conditions and Bore Locations

The simulated section is oriented parallel to the inferred direction of the groundwater gradient (refer Section 4.2 and Figure 4.2) by rotating the model grid approximately -5 degrees. The model and all associated data are specified using the GDA 2020 (Zone 50) coordinate system.

A uniform model grid cell size of 1m and 20 flat laying model layers are utilised to represent the aquifer and aquitard geometry and groundwater gradients. A summary of the model layers is presented in Table 5.7. The model layers are used to represent the upper horizons and the recharge and discharge processes and the underlying sediments and limestone. The model includes a total of 277,560 active model cells.

Table 5.7 Model Layer Summary

Layer	Details
1	Variable layer thickness with ground surface defined by a digital terrain model supplied by BCI. Base set at -1mAHD. Used to simulate upper clay sequence.
2 to 7	Layer thickness of 1m. Base of layer 7 set at -5mAHD. Used to simulate clayey gravel and gravel.
5 to 9	Layer thickness of 1m. Base of layer 9 set at -9mAHD. Used to simulate clayey gravel and gravel.
8 to 20	Layer thickness of 1m. Base of layer 20 set at -20mAHD. Used to simulate limestone.

5.4.2 Model Geometry

The extents and thicknesses of key aquifer and aquitard units were defined by the information derived from geotechnical investigations, supplemented with information derived from hydrogeological drilling. The key aquifer units are shown in Section in Figure 5.40.

Aquifer property zones were assigned consistent with the hydrogeological section shown in Figure 5.40. Multiple flat lying model layers are used to define hydrogeological units. In general layers 1 to 8 define the upper sediments, with layers 9 to 20 used to simulate the underlying limestone. The hydrogeological units simulated in the model include:

- Upper clay.
- Clayey gravel.
- Gravel.
- Lower clay.
- Limestone.

Also shown on Figure 5.40 are the key hydrological processes of the area. These are discussed further in Section 5.4.4.

5.4.3 Salinity Conditions

The existing groundwater salinity conditions are used as initial conditions for modelled salinity. The distribution of salinity is based on observed salinity data as described in Section 4.4 (salinity profiles for MP08 and MP11 measured in May 2023) , with interpretation of the existing water level and hydrogeological conditions used to define the groundwater salinity conditions that result from the tidal flats and the coastal boundary further downstream.

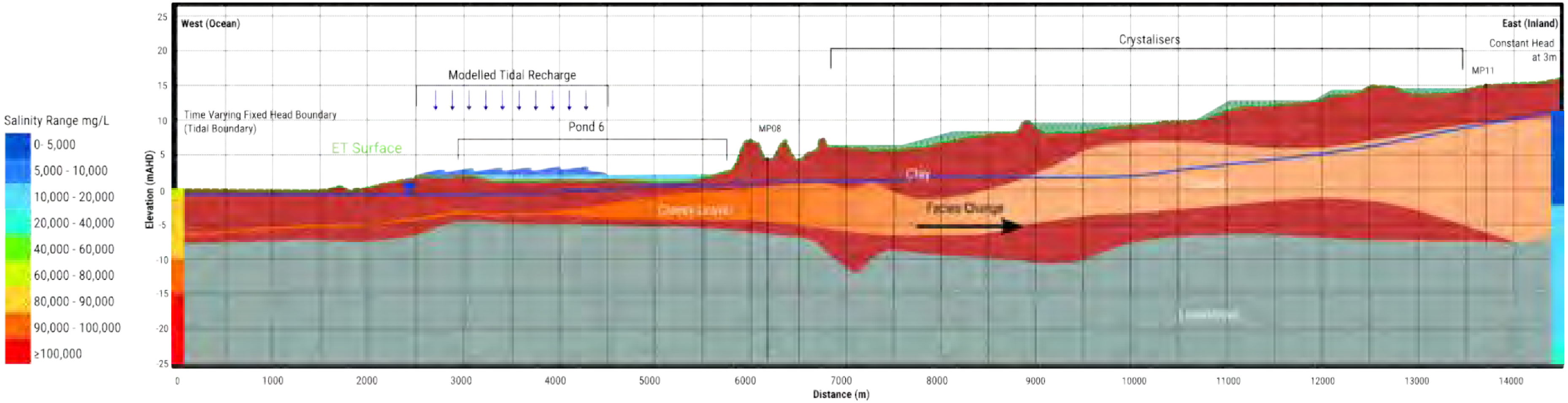


Figure 5.40 Pond 6 Schematic Model Cross Section (West to East)

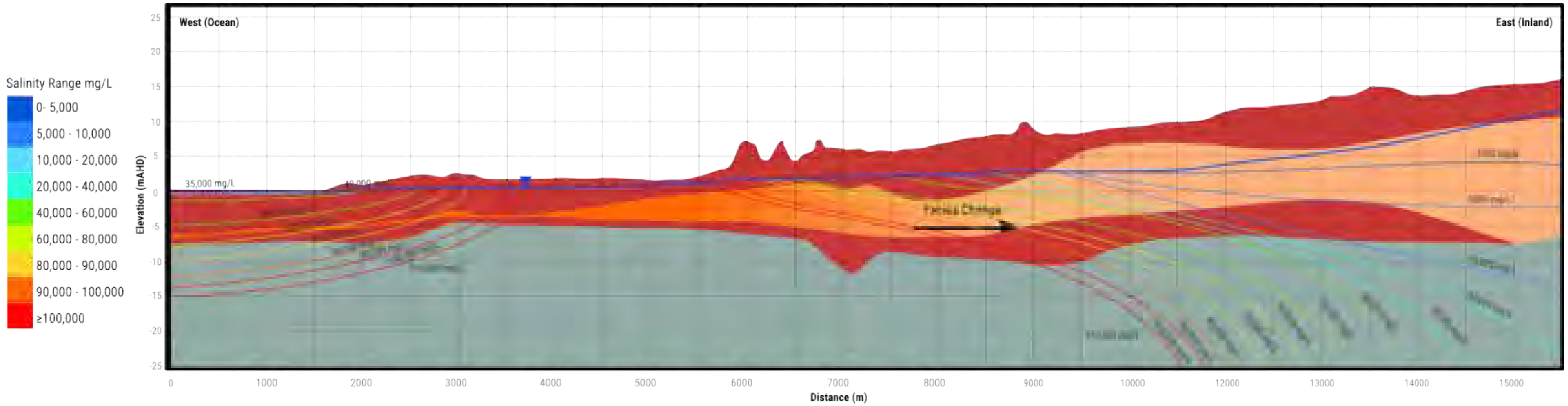


Figure 5.41 Pond 6 Model Cross-Section Salinity Contours (West to East)

Salinity values (contoured) along the modelled section are displayed in Figure 5.41 and show:

- A salinity range of 35,000 to 110,000mg/L on the western model boundary from interactions between the sabkha and the coast.
- A salinity range of around 1,000 to 20,000mg/L on the eastern model boundary.
- A salinity of 110,000mg/L in the sabkha area.

Similar to the Pond 1 and Mardie Pool and crystalliser models, the Pond 6 model has not been used to simulate the development of the observed salinity conditions over geological time and the observed salinity values were used as initial salinity conditions. The dynamic calibration process outlined in Section 5.2.3 was also completed for the Pond 6 and crystalliser model.

The maximum interpreted salinity of 110,000mg/L is assumed to have a density of 1,074kg/m^3. Sea water of salinity 35,000mg/L is assumed to have a density of 1,025kg/m^3. Less saline water with a minimum salinity of 1,000mg/L, located close to the upstream model boundary is assumed to have a density of 1000kg/m^3. The salinity to density conversions are based on standard estimates / conversions.

5.4.4 Groundwater Inflow and Outflow

Along the model section, observed water levels decrease from the east to west (from inland towards the ocean). Head boundary conditions are assigned at the upstream and downstream model boundaries. The downstream boundary is assigned time varying elevations to represent the impact of the varying tide on groundwater levels. The head variation assigned to the downstream boundary is similar to that used for the Pond 1 model (refer Section 5.2.4) with the assigned head variation shown in Figure 5.4.

The upstream boundary is assigned an elevation of 3mAHD. The location of assigned upstream and downstream boundary conditions are shown spatially in Figure 5.39 and also shown schematically in Figure 5.40.

Similar to the Pond 1 section, prior to the construction of Pond 6, the sabkha area along the modelled section was also subject to tidal inundation during very high tides. The hydrological processes described for Pond 1 (refer Section 5.24) were also simulated for the Pond 6 section (recharge from the high tide, simulation of rejected recharge and ongoing evaporative losses). The extent of tidal inundation and related processes simulated is shown in Figure 5.40.

5.4.5 Model Calibration

5.4.5.1 Approach to Model Calibration

Data available for the calibration of the Pond 6 and crystalliser model is limited to two monitoring bores (MP08 and MP11). The locations of these bores are shown in Figure 5.39. Bores are shown at actual locations as well as the simulated location along the modelled section.

The calibration period of the model extends from January 2022 to December 2022 or broadly consistent with the longest period of active monitoring. The model was calibrated using a manual or trial and error approach, using 12 hourly time increments or stress periods (periods over which all modelled stresses were held constant).

5.4.5.2 Initial Conditions

Monitoring data from other areas of the Project shows fluctuations in groundwater levels due to recharge to groundwater from extremely high tides which would also be expected in the Pond 6 area. As a result, groundwater levels in the area of Pond 6 are not readily described by a long-term average of steady state water level calibration. The same dynamic model calibration approach, as described in Section 5.2.5.2 was used to generate initial water level conditions for the Pond 6 model.

5.4.5.3 Transient Calibration Results

The locations of monitoring bores (MP08 and MP11) used for model calibration are shown in Figure 5.39. Also shown in Figure 5.39 is the location of a modelled observation location in the centre of Pond 6 (located in the area of simulated tidal inundation prior to the construction and operation Pond 6).

Measured and modelled water levels for MP08 and MP11 and the Pond 6 modelled observation location are shown in Figure 5.42. The measured water levels at MP08 and MP11 show no regular trends, however the model replicates the magnitude of the measured water levels. The Pond 6 modelled observation location shows the response to the simulated tidal inundation and associated recharge to groundwater. This tidal response and inundation is not simulated at MP08 and MP11.

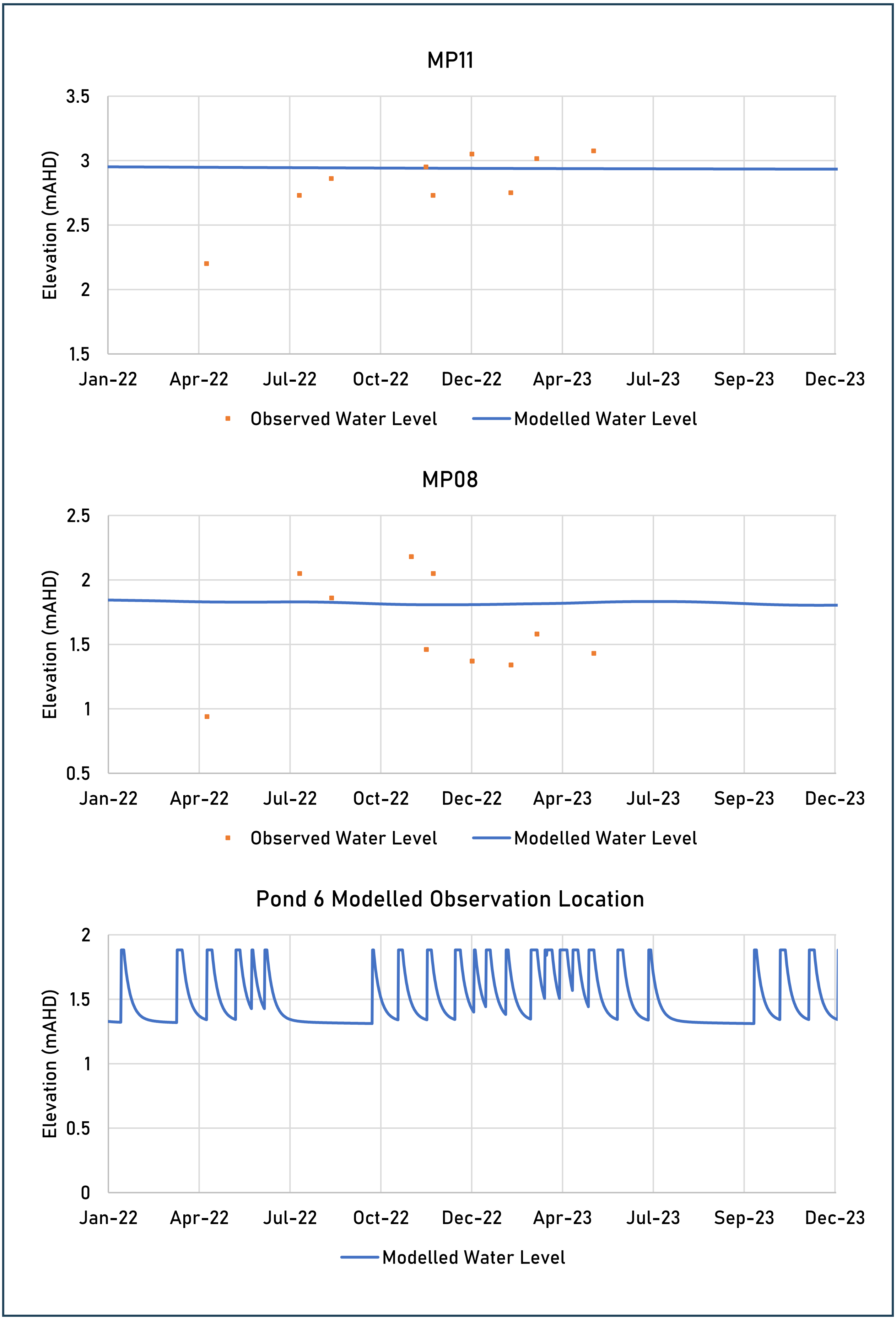


Figure 5.42 Pond 6 Calibration Hydrographs (MP08, MP11 and Pond 6 Observation Location)

The measured and simulated salinity profiles for MP08 and MP11 from May 2023 and the simulated salinity profiles for the Pond 6 modelled observation location (for May 2023) are shown in Figure 5.43. Simulated salinity profiles are also shown for June 2024. The salinity profiles for MP08 and MP11 are matched by the model. The salinity profiles for MP08 and MP11 and the Pond 6 modelled observation location are similar for both occasions and show that the predicted salinity profiles do not change significantly during the calibration period.

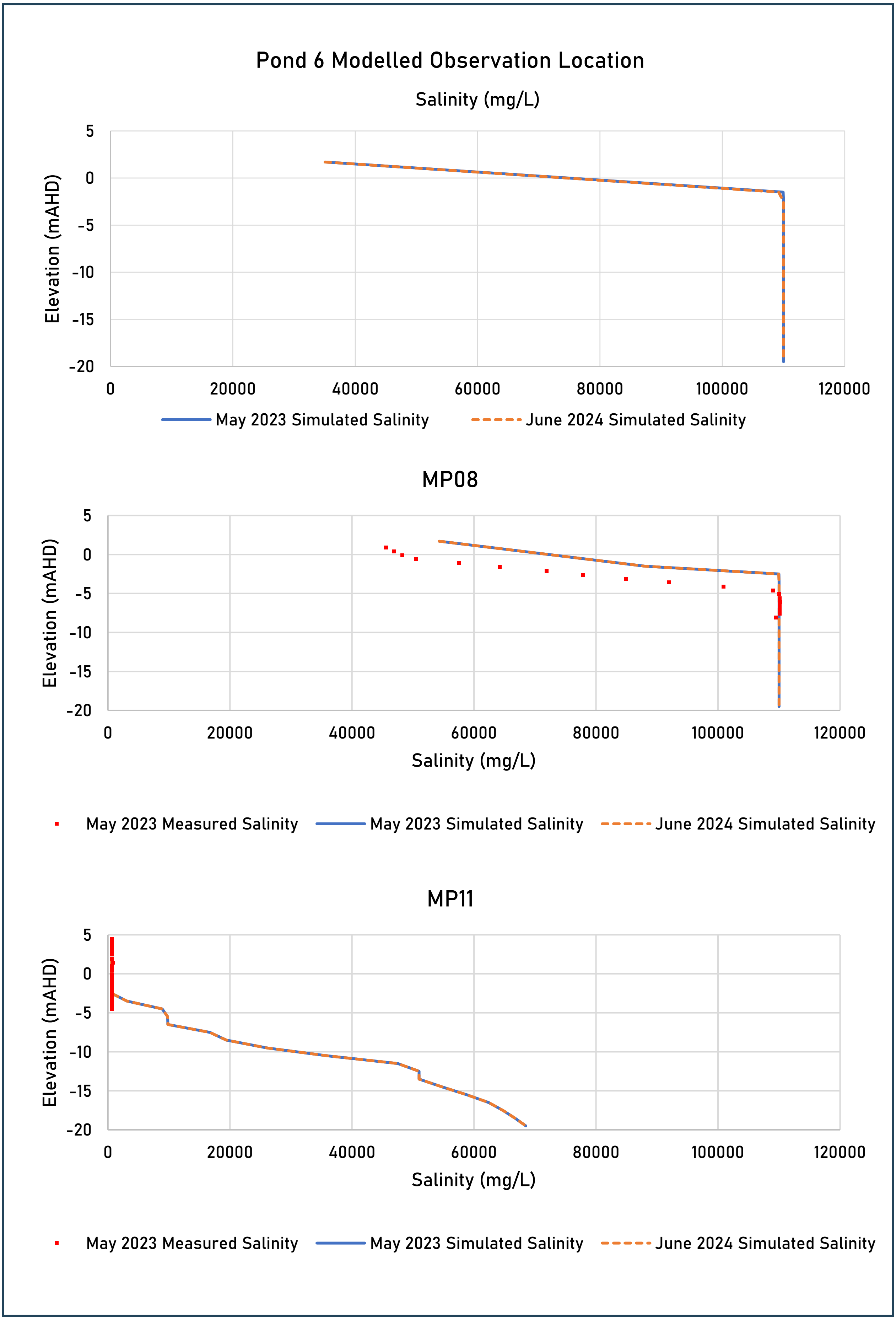


Figure 5.43 Pond 6 Calibration Salinity Profiles Hydrographs (MP08, MP11 & Pond 6 Observation Location)

The maximum modelled ET rate is assigned consistent with the Pond 1 and Mardie Pool and crystalliser models at 7.5 x 10^{-4}m/d or 275mm/y (refer Section 5.2.5.3).

Calibrated aquifer parameters are summarised in Table 5.8.

Table 5.8 Calibrated Aquifer Parameters

Aquifer Unit	Horizontal Hydraulic Conductivity (m/d)	Vertical Hydraulic Conductivity (m/d)	Specific Yield (%)	Porosity (%)	Specific Storage (m^{-1})
Upper Clay	0.1	0.01	1	40	1e-6
Clayey Gravel	1	1	1	40	1e-6
Gravel	5	5	1	40	1e-6
Lower Clay	0.1	0.01	1	40	1e-6
Limestone	2.0	0.2	1	20	1e-6

Model predicted water and salt balances for the calibration period are presented in Appendix C.

5.4.6 Model Predictions

The Pond 6 and crystalliser calibrated section model was used to simulate the impacts to groundwater of leakage from Pond 6 and the crystalliser. As outlined in Section 5.3.7 the crystalliser will produce the final product and will differ in operation from the remainder of the ponds. Leakage from the crystalliser will be limited by the persistence of the final product over the base of the crystalliser. Pond 6 will be filled and operated at an elevation of 3.5mAHD above the base of the pond as part of the ongoing evaporative process of the project. Details of the model predictions are outlined below:

- Initial conditions (groundwater level and salinity) were taken from the end of the calibration model.
- The prediction models were run for a period of 10 years (from 1 January 2024 onwards) assuming a 12 hourly stress period (period over which all stresses were held constant). While the life of the Project is longer than 10 years, this period was sufficient to show the impacts of filling of the ponds (i.e., a quasi steady state type response was predicted).
- The upstream or inflow boundary condition was simulated as per the model calibration (i.e., fixed head at an elevation of 3mAHD).
- The downstream or coastal boundary was simulated consistent with the approach included in the transient model calibration. Future tidal boundary conditions are simulated assuming an estimated tidal sequence from January 2020 to December 2022 (similar to the approach used for the downstream boundary conditions assigned in the Pond 1 model).
- The simulated extent of Pond 6 and the crystalliser along the modelled section is shown in Figure 5.39. Recharge during spring high tides and evapotranspiration was limited to the area downstream of Pond 6 in model predictions as the tidal inundation will be limited by the embankments constructed around Pond 6 and the remainder of the ponds.
- Similar to the other ponds, leakage from Pond 6 over the life of the Project will be limited by progressive reduction in permeability associated with the algal mat and accumulation of halite.

- Leakage from Pond 6 was simulated as a function of the water stored in the ponds. The head dependent recharge was simulated using the River (RIV) package in Modflow USG. The head in the "river" was assigned to the elevation of the pond water level (3.5mAHD) from the start of the prediction (i.e., no pond filling was simulated), the base of the "river" assigned at the base of the ponds (approximately 1.6 to 2.6mAHD) and a low conductance was assigned (1 x $10^{-2}$$m^2$/d) consistent with the algal mat / halite that is anticipated to form in the base of the ponds. The depth of water simulated in Pond 6 is greater than that simulated in Pond 1. This prediction was also completed to assess the impact of hydraulic loading from the pond (i.e., the head of water contained in the pond).
- Rather than being a constant source of water to the underlying groundwater system, the impact of the crystallisers has been simulated as a catastrophic failure of the lining of the crystalliser that results in the leakage of very saline water to the underlying groundwater.
- The leakage related to the failure of the crystallisers was simulated assuming leakage from the crystalliser as a function of the water stored. The head dependent recharge was simulated using the River (RIV) package in Modflow USG. The head in the "river" was assigned 0.5m above the base of the crystalliser (at 8mAHD) from the start of the prediction (i.e., no filling of the crystalliser was simulated), the base of the "river" assigned at the base of the ponds and a low conductance (1 x $10^{-3}$$m^2$/d) consistent with the product that is anticipated to form in the base of the ponds.
- Similar to the Mardie Pool and crystalliser model, predictions for Pond 6 and the crystalliser conservatively assume that leakage from the crystallisers to the underlying water table is immediate. In reality saturation of the 4 to 5m unsaturated zone would need to occur before there was ongoing or continuous recharge to the underlying water table.
- The leakage from Pond 6 was assumed to have a salinity of 127,000mg/L with an associated density of 1,096kg/m^3. The leakage from the crystalliser was assumed to have a salinity of 273,000mg/L, with an associated density of 1,222.5kg/m^3.
- A No Development Scenario was also run to allow the identification of impacts of seepage from Pond 6 and the crystalliser. The No Development Scenario contained the same tidal recharge and tidal boundary conditions as outlined above.

A summary of model runs is presented in Table 5.9.

Table 5.9 Model Prediction Summary

Prediction	Details
Scenario 1	Leakage from Pond 6 simulated using a head dependent boundary condition (RIV) at an elevation 3.5mAHD over the 10 year prediction period. Leakage from failure of the crystalliser over the 10 year prediction period.
Scenario 2	Leakage from Pond 6 simulated using a head dependent boundary condition (RIV) at an elevation 3.5mAHD over the 10 year prediction period. Leakage from failure of the crystalliser over a one year period.
Scenario 3	Leakage Pond 6 only simulated using a head dependent boundary condition (RIV) at an elevation 3.5mAHD over the 10 year prediction period.
No Development	Includes the calibrated model distribution of tidal recharge and tidal boundary conditions as outlined above only.

5.4.7 Prediction Results

Observation locations (calibration bores and modelled observation locations) are shown in Figure 5.39. Predicted water levels over the 10 year simulation period, for Scenarios 1, 2 and 3 and the No Development Scenario are shown for:

- The modelled observation locations under Pond 6, 5m downstream of Pond 6 and 10m downstream of Pond 6 (Figure 5.44).
- The modelled observation location 100m from Pond 6, observation bore MP08 and the modelled observation location under the crystalliser (Figure 5.45).
- The modelled observation locations 5m, 10m downstream of the area of the crystalliser assumed to fail and leak and 10m downstream of the crystalliser (Figure 5.46).
- Observation bore MP11 (Figure 5.47).

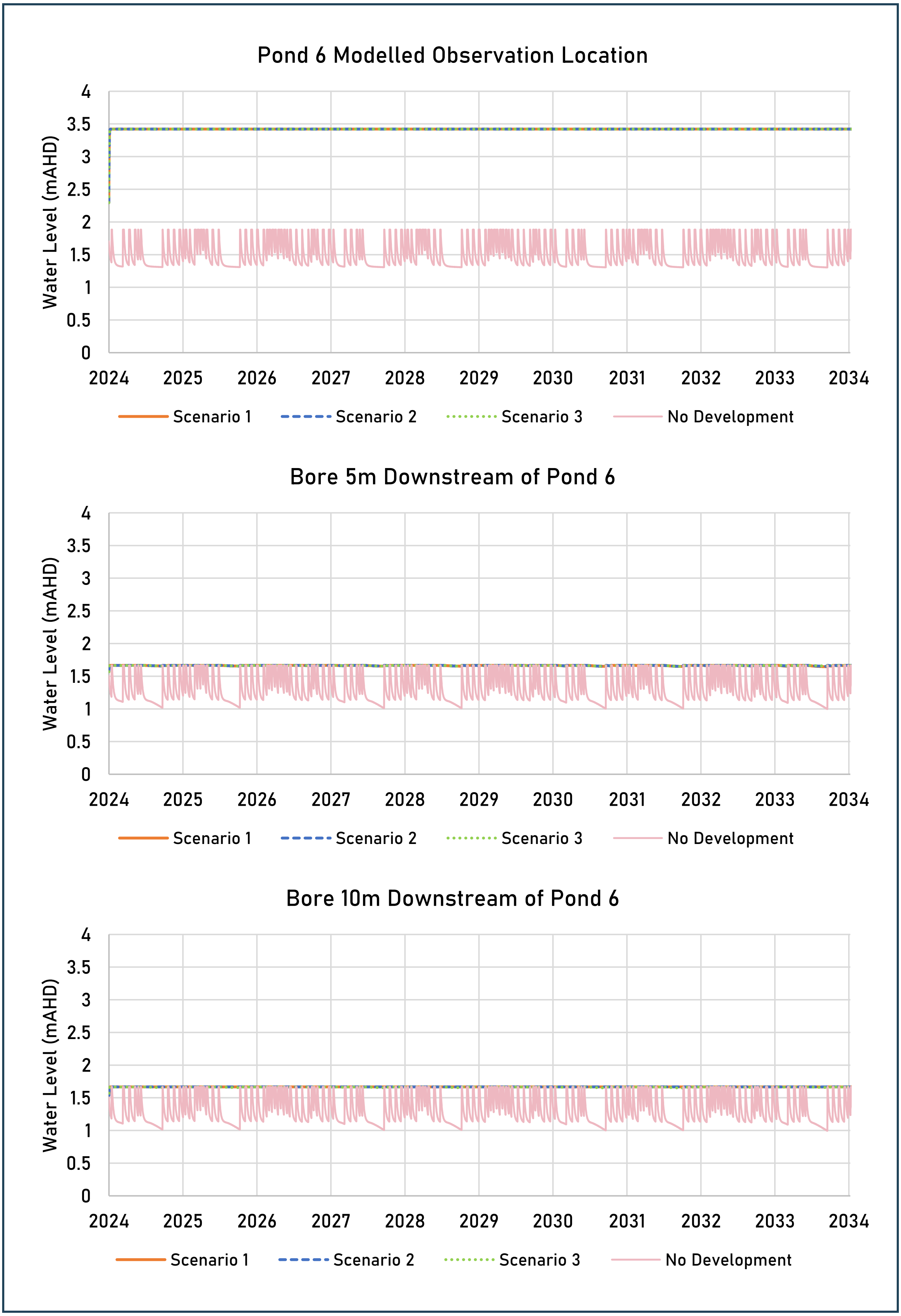


Figure 5.44 Pond 6 Prediction Hydrographs (Pond 6 Observation Location and 5m & 10m Downstream of Pond 6)

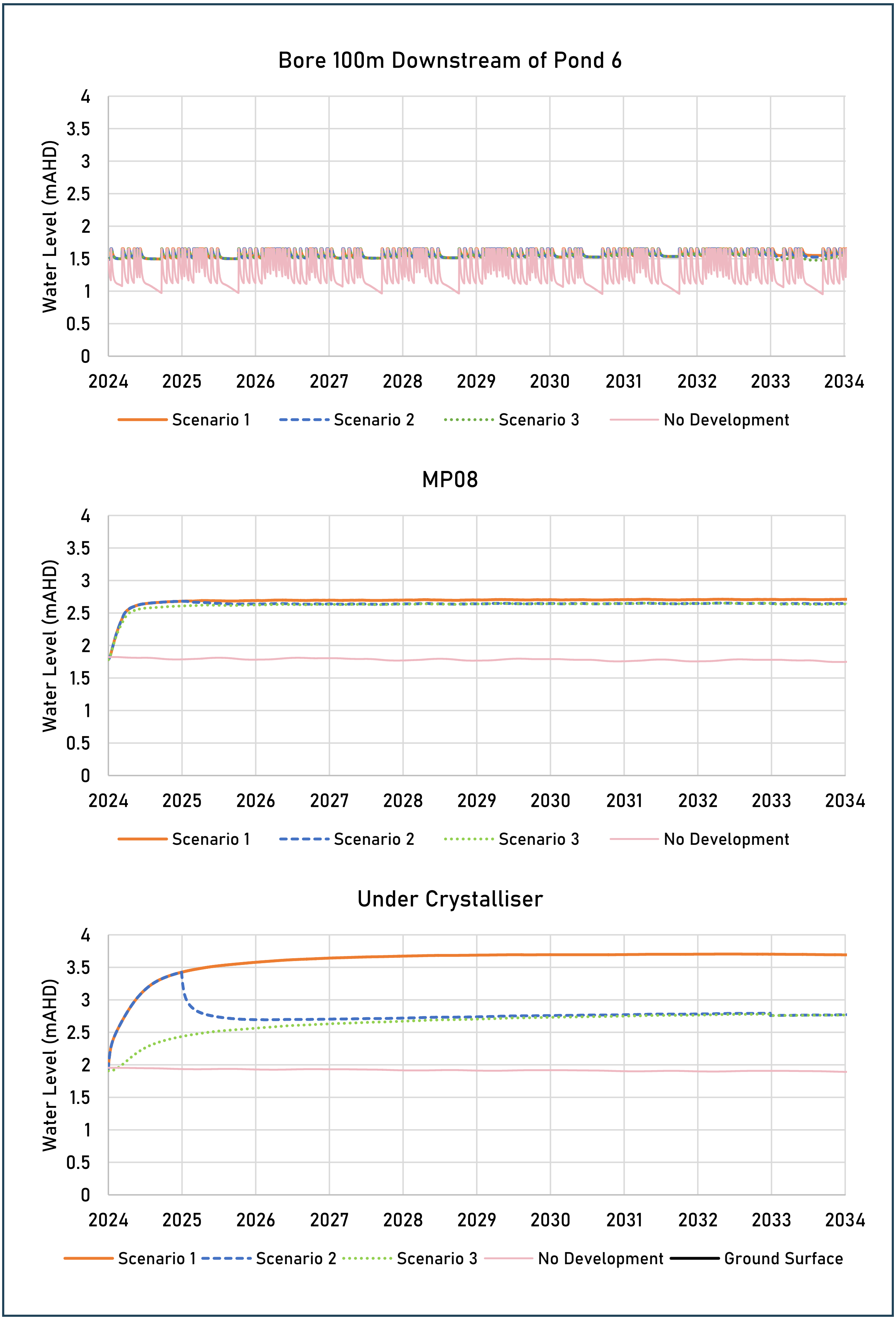


Figure 5.45 Pond 6 Prediction Hydrographs (100m Downstream of Pond 6, MP08 and Under Crystalliser

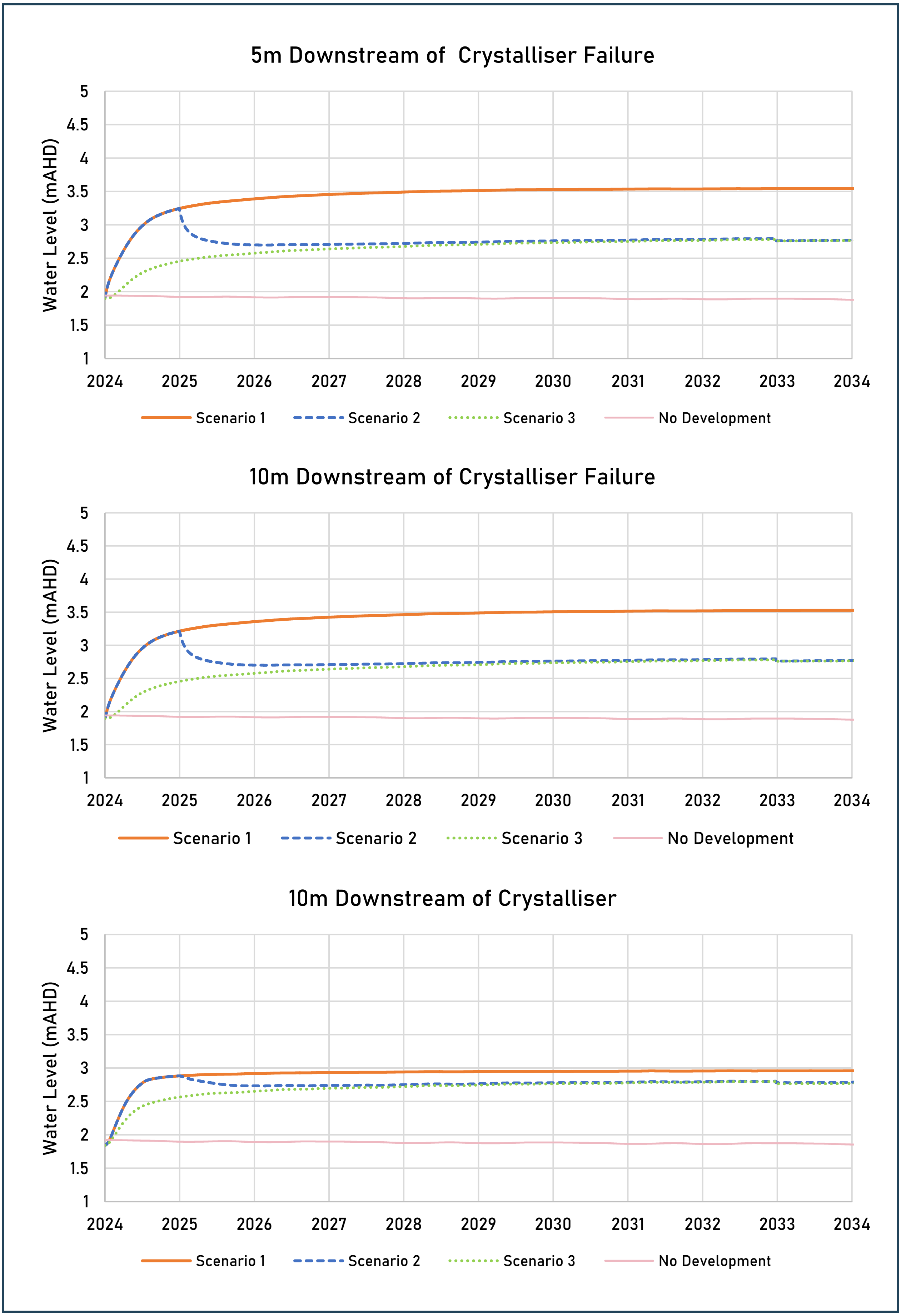


Figure 5.46 Pond 6 Prediction Hydrographs (5m, 10m Downstream of Crystalliser Failure Area and 10m Downstream of Crystalliser)

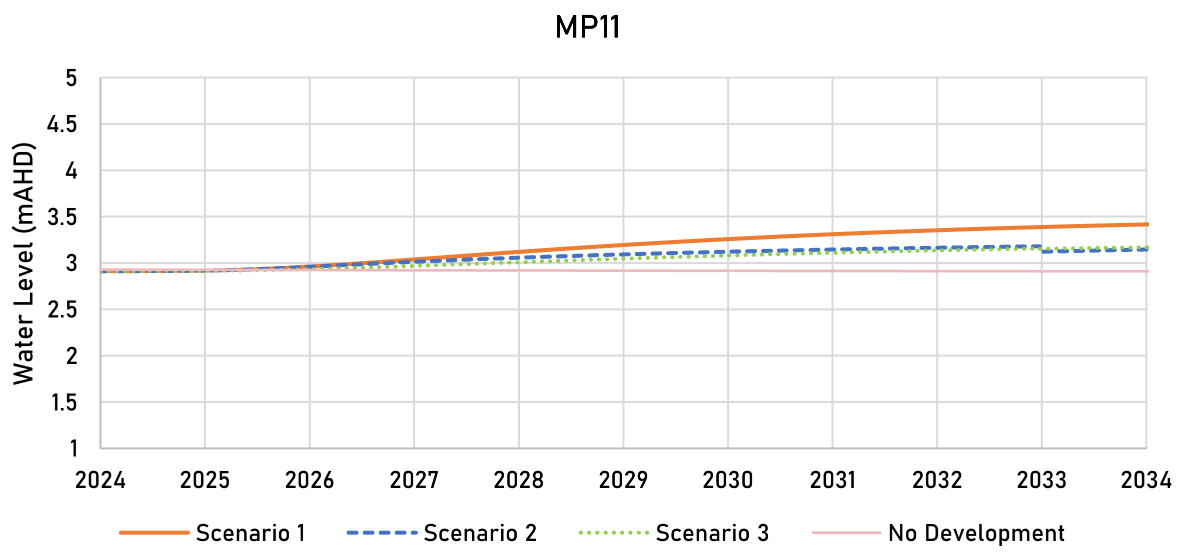


Figure 5.47 Pond 6 Prediction Hydrographs (MP11)

The following observations are made regarding the predicted water levels:

- Simulated water levels at the Pond 6 modelled observation location show an increase of less than 2m associated with the filling and operation of the ponds. The variation in water levels from the tidal inundation is no longer predicted at this location (refer Figure 5.44) due to the construction of Pond 6. Similar water levels are predicted for Scenarios (1, 2 and 3) at this location and suggest that the water level conditions simulated at this location are influenced by Pond 6 only.
- At locations 5m and 10m downstream of Pond 6 (refer Figure 5.44), water levels are predicted to remain close to the maximum water level simulated by the No Development Scenario a result of filling / operation and simulated leakage from Pond 6. Predicted water levels at these locations show some variation in response to tidal inundation, however this response is muted as a result of the constant recharge simulated from the operation of Pond 6 immediately upstream. Similar water levels are predicted for Scenarios (1, 2 and 3) at these locations and suggest that the conditions simulated at these locations are influenced by Pond 6 only. The water level increase simulated is at these locations is up to around 0.7m.
- At a distance of 100m downstream of Pond 6 (refer Figure 5.45) the predicted response to tidal inundation is also reduced (compared to the No Development Scenario) but not to the same degree of the locations 5m and 10m downstream of Pond 6 (refer Figure 5.44). Similar water levels are predicted for Scenarios (1, 2 and 3) 100m downstream of Pond 6 and suggest that the conditions simulated at this location are also influenced by Pond 6 only. The water level increase simulated at this location is up to 0.5m.
- At MP08, upstream of Pond 6, water levels are predicted to increase by less than 1m in response to the filling / operation and simulated leakage from Pond 6 (Figure 5.45). Leakage from the crystalliser is predicted to have a small impact on predicted water level at this location (~ 0.1m by the end of 2023 or after 10 years of leakage from the crystalliser). When leakage from the crystalliser is simulated for 2024 only (a year) in Scenario 2, predicted water levels are similar to Scenario 3 (Pond 6 leakage only case) by the end of 2025 or a year after the simulated leakage ceases. Under operational conditions, the leakage from the crystalliser would be detected and operation of this area of the crystalliser would cease as soon as practical (i.e. most likely less than a year).
- Under the crystalliser (and under the area of the simulated failure) water levels are predicted to increase up to 1.5m for Scenario 1 (continuous leakage from the crystalliser and Pond 6 over the simulation period, refer Figure 5.45). When leakage from the crystalliser is simulated for 2024 only (Scenario 2), a water level increase of 1.5m is predicted over 2024 (Scenario 2) however, once this leakage is assumed to cease, the water level increase in the area of the crystalliser is similar to that predicted by Scenario 3 (leakage from Pond 6 only) and is less than 1m by the end of 2033.
- Similar results are predicted for modelled observation locations 5m and 10m downstream of the crystalliser failure (Figure 5.46). Continuous leakage from the crystalliser and Pond 6 is predicted to increase water levels by around 1.5m at these locations by the end of 2033 (Scenario 1). Simulated leakage from the crystalliser for 2024 only (Scenario 2) is predicted to increase water levels by less than 1.5m; however, when this leakage ceases, the predicted increase in water level (of less than 1m) is similar for Scenario 3 (leakage from Pond 6 only) by the end of 2033.
- For the observation location 10m downstream of the crystalliser (refer Figure 5.46), similar results to the locations in the area of the crystalliser failure are predicted, however the predicted increases in water level are reduced. By the end of 2024, an increase in water level of less than 1m is predicted for Scenarios 1 and 2. By the end of 2033, the maximum predicted increase in water level is 1m (Scenario 1) and less than 1m for Scenarios 2 and 3.
- At MP11, located upstream of the crystalliser the initial increase in water level, for 2024 and 2025, is very small. An increase in water level of less than 0.5m is predicted for Scenario 1 by the end of 2033 (continuous leakage from the crystalliser and Pond 6, refer Figure 5.47). For Scenarios 2 and 3, the predicted increase in water level is also less than 0.5m by the end of 2033.

Predicted salinity profiles at selected times over the 10 year simulation period (January 2024, December 2026, December 2028, December 2030 and December 2033 or at the beginning of the simulation and after 1, 3, 5, 7 and 10 years of operation), for Scenarios 1, 2 and 3 are shown for:

- The modelled observation location under Pond 6.
- 5m, 10m and 100m downstream of Pond 6.
- Observation bore MP08.
- The modelled observation location under the crystalliser.
- 5m, 10m downstream of the crystalliser failure area and 10m downstream of the crystalliser.
- Observation bore MP11.

Divergence between the initial and final salinity profiles illustrates the predicted salinity impacts. Predicted salinity profiles for Scenarios 1 to 3 are discussed below.

Scenario 1

- At the Pond 6 observation location (refer Figure 5.48), salinity is predicted to increase over the simulation period, such that by the end of 2033, the predicted salinity immediately underneath the crystalliser increases from around 108,000mg/L initially to a maximum predicted value of close to 200,000mg/L. The increase in salinity is limited to a depth of 4.2mbgl or around 2.5mAHD.
- At locations 5m and 10m downstream of Pond 6 (refer Figures 5.48 and 5.49), salinity is not predicted to increase close to ground surface. At depths of between 3.2 and 16.7mbgl (-1.5 and -15mAHD) salinity is predicted to increase as higher salinity seepage travels away from Pond 6, with the higher salinity water “sinking” through the profile and by passing the shallower horizons immediately downstream of Pond 6. After 10 years of leakage from Pond 6 (the end of 2033), a salinity of less than 150,000mg/L is predicted between 4.2 and 8.2mbgl (-2.5mAHD to 6.5mAHD) compared to an initial salinity of 110,000mg/L.
- At the modelled location 100m downstream of Pond 6 (refer Figure 5.49), a very small increase in salinity is predicted at depths between 3.2mbgl and 5.2mbgl (-1.5 and -3.5mAHD) by 2033. The predicted increase in salinity is around 2,000mg/L (from 108,000mg/l to 110,000mg/L).
- At MP08, located upstream of Pond 6 and downstream of the crystalliser (refer Figure 5.50), salinity is predicted to increase throughout the upper horizons. Initially the salinity at MP08 is around 88,000mg/L to a depth of 3.2mbgl (or around -1.5mAHD). By the end of 2033, this salinity increases up to a maximum of 115,000mg/L immediately underneath the crystalliser and up to around 110,000mg/L below around -2mAHD (3.7mbgl).
- Underneath the crystalliser (refer Figure 5.50), the salinity is predicted to increase from 73,000mg/L to around 150,000mg/L by 2033. Higher salinity water is predicted to sink into the profile with a salinity of up to 105,000mg/L predicted to a depth of 11.2mbgl (-9.5mAHD) by the end of 2033.
- At locations 5m and 10m downstream of the crystalliser failure (refer Figure 5.51) there is a minor change to the shallow predicted salinity 5m downstream of the crystalliser failure and no predicted change 10m downstream of the area of crystalliser failure. Similar to the salinity simulated downstream of Pond 6, an increase in salinity is predicted at depth as more saline water from the crystalliser sinks into the profile and travels laterally towards these observation locations from the crystalliser. Increased salinity, of up to 100,000mg/L is predicted at these locations to a depth of 10.2mbgl (to -8.5mAHD), compared to the initial salinity of 110,000mg/L assumed to a depth of 5.2mbgl (-3.5mAHD), i.e., the higher salinity water is predicted over an increased depth of 5m by the end of 2033.
- At the modelled location 10m downstream of the crystalliser and MP11 (located upstream of the crystalliser) no change in salinity is predicted by the end of 2033 (Figure 5.52).

Scenario 2

- Similar salinity profiles are predicted for Scenarios 1 and 2 for the Pond 6 observation location and the locations downstream of Pond 6 (refer Figures 5.53 and 5.54).
- As Scenario 2 assumes leakage from the crystalliser for 2024 only, the predicted increase in salinity close to and downstream of the crystalliser is reduced compared to that predicted for Scenario 1. Under the crystalliser (refer Figure 5.55) the increase in salinity is limited to the shallow horizons (to around 81,000mg/L from an initial salinity of 73,000mg/L), with a small increase in salinity, to 110,000mg/L predicted to a depth of 6.2mbgl or -4.5mAHD. At MP08 (refer Figure 5.55) an increase in salinity is predicted, but it is to less than 110,000mg/L over the shallower horizons, to a depth of 4.2mbgl or -2.5mAHD.
- There is a small increase in salinity predicted 5m and 10m downstream of the crystalliser failure area (refer Figure 5.56) by the end of 2033 (salinity of 110,0000mg/L to an increased depth of around 1m or from -3.5mAHD to -4.5mAHD or from 5.2mbgl to 6.2mbgl).
- Similar to Scenario 1, at the modelled location 100m downstream of the crystalliser and MP11 (located upstream of the crystalliser, refer Figure 5.57) no change in salinity is predicted by the end of 2033.

Scenario 3

- For Scenario 3, similar increases in salinity as those predicted for Scenarios 1 and 2, are predicted at:
  - The Pond 6 observation point and the observation point 5m downstream of Pond 6 (refer Figure 5.58), and
  - The observation points 10m and 100m downstream of Pond 6 (refer Figure 5.59).

  Similar to Scenario 2, these results suggest that the salinity at these locations in not impacted by simulated leakage from the crystalliser.
- At MP08 (refer Figure 5.60) the Scenario 3 results show a reduced increase in salinity compared to Scenario 1, but a similar increase in salinity to Scenario 2.
- As would be expected for Scenario 3, when no leakage from the crystallisers is simulated, no increase in salinity is predicted under the crystalliser (refer Figures 5.60 and 5.61), downstream of the crystalliser (refer Figure 5.62) or upstream of the crystalliser at MP11 (refer Figure 5.62).

Model predicted water and salt balances for the end of the model calibration and prediction periods are presented in Appendix C.

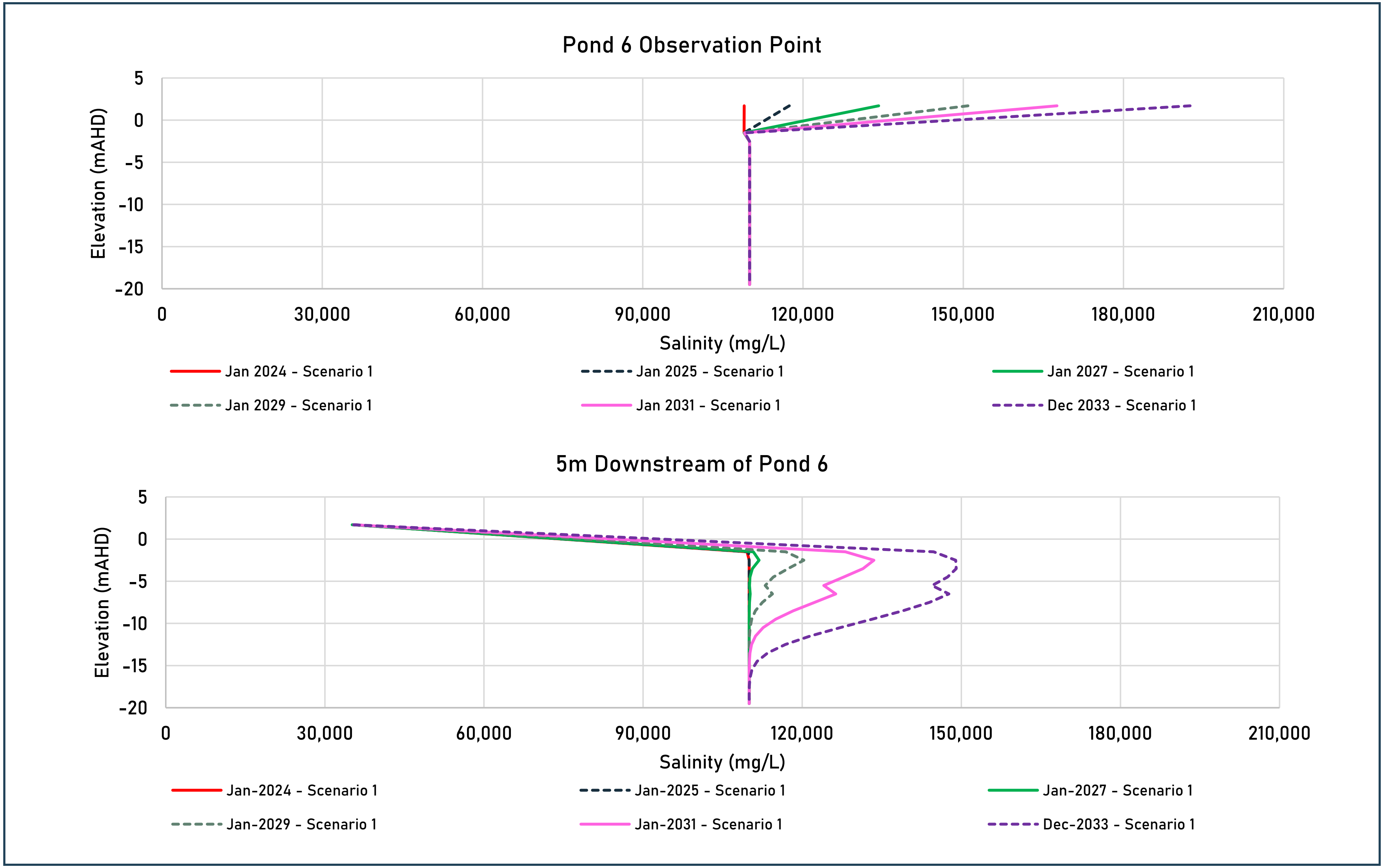


Figure 5.48 Pond 6 Predicted Salinity Scenario 1 (Pond 6 Observation Point and 5m Downstream of Pond 6)

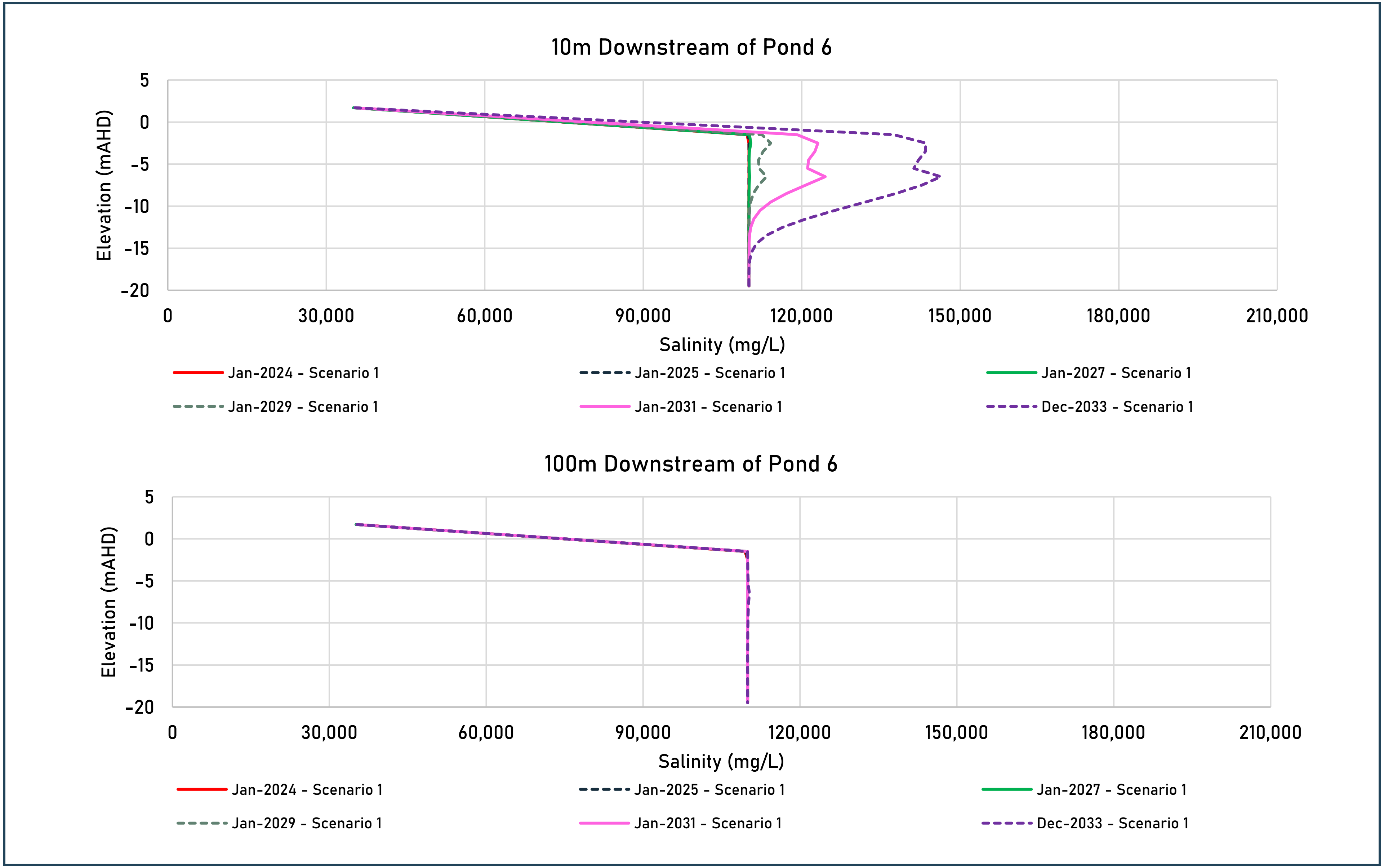


Figure 5.49 Pond 6 Predicted Salinity Scenario 1 (10m and 100m Downstream of Pond 6)

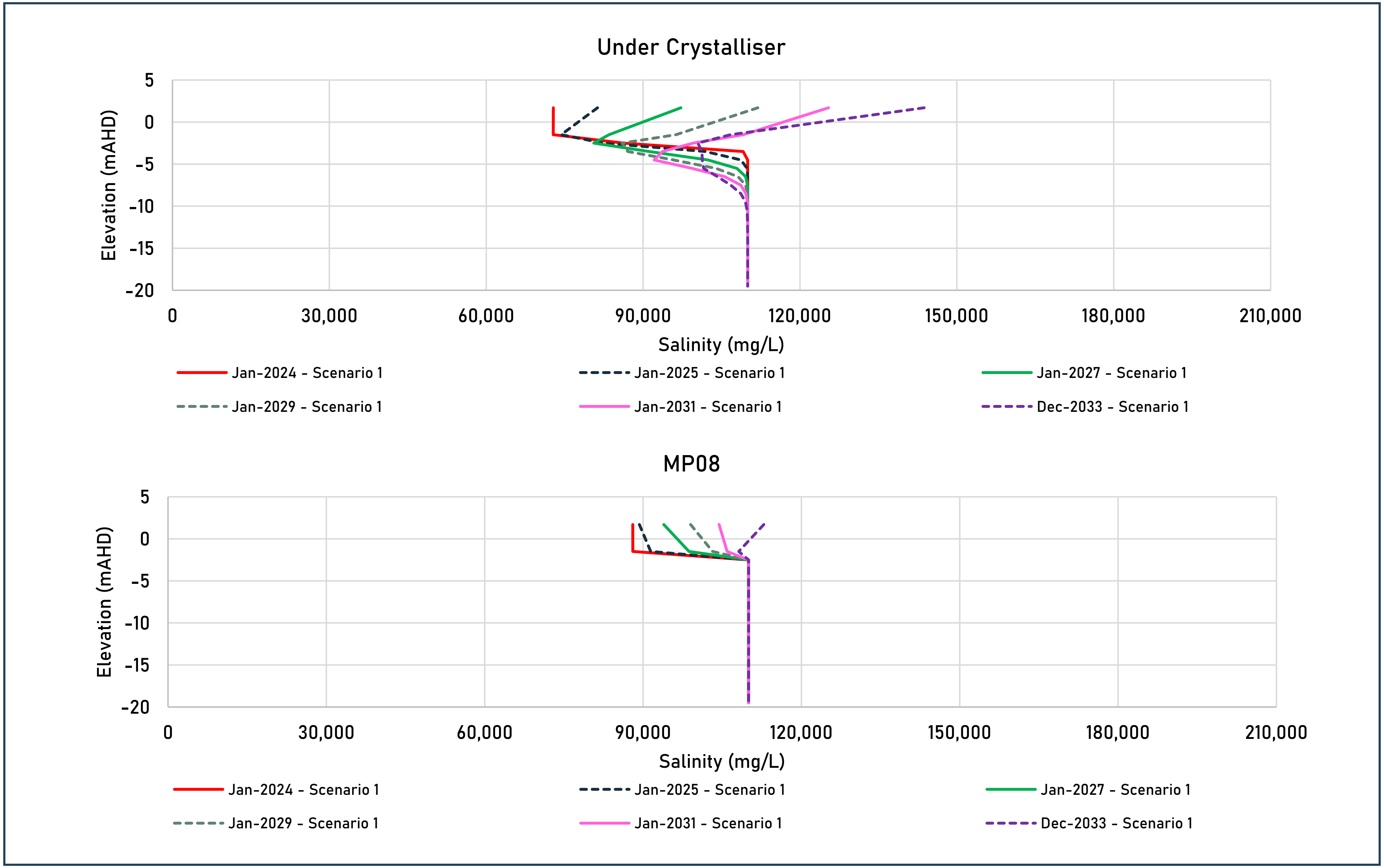


Figure 5.50 Pond 6 Predicted Salinity Scenario 1 (MP08 and Under Crystalliser)

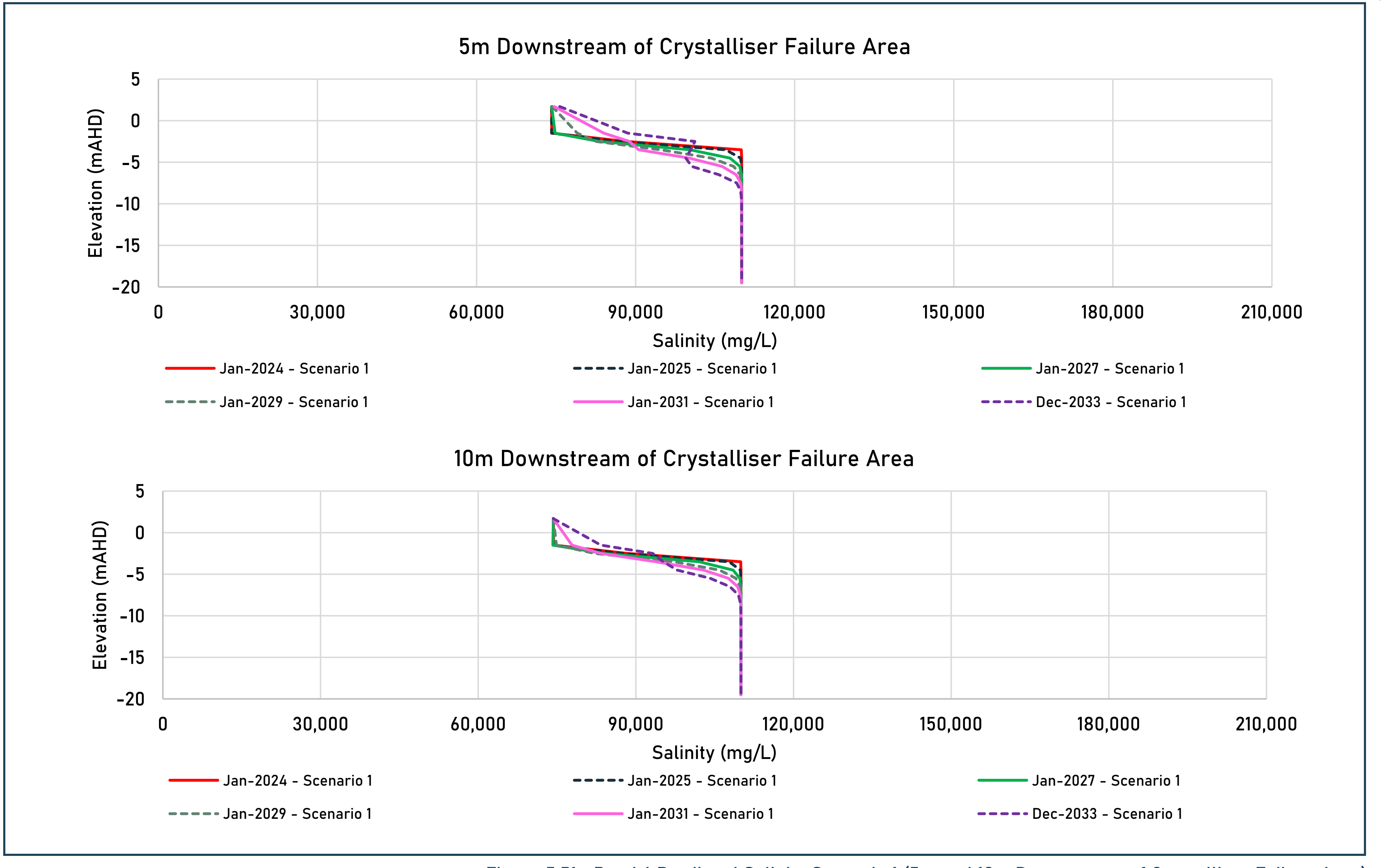


Figure 5.51 Pond 6 Predicted Salinity Scenario 1 (5m and 10m Downstream of Crystalliser Failure Area)

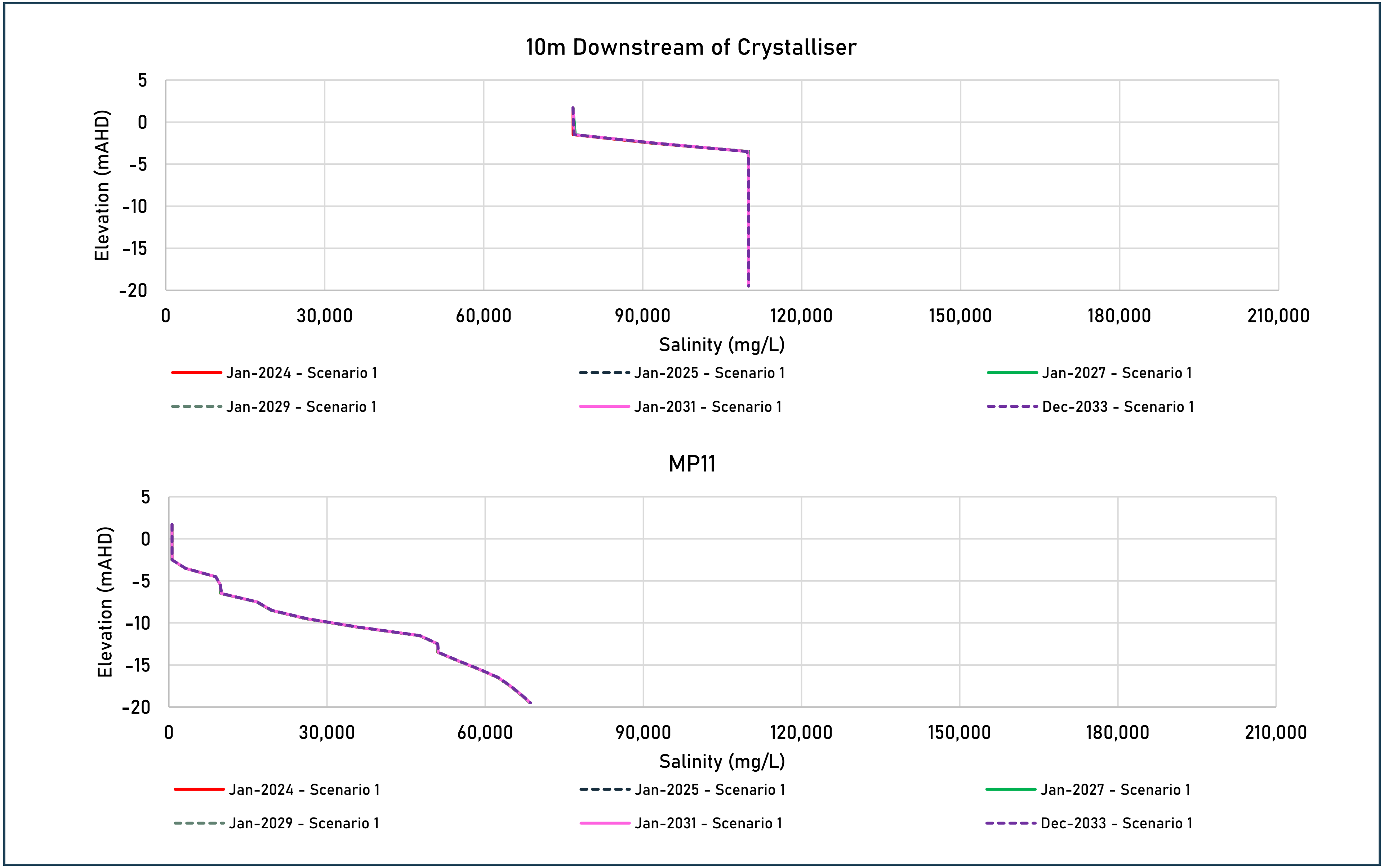


Figure 5.52 Pond 6 Predicted Salinity Scenario 1 (10m Downstream of Crystalliser and MP11)

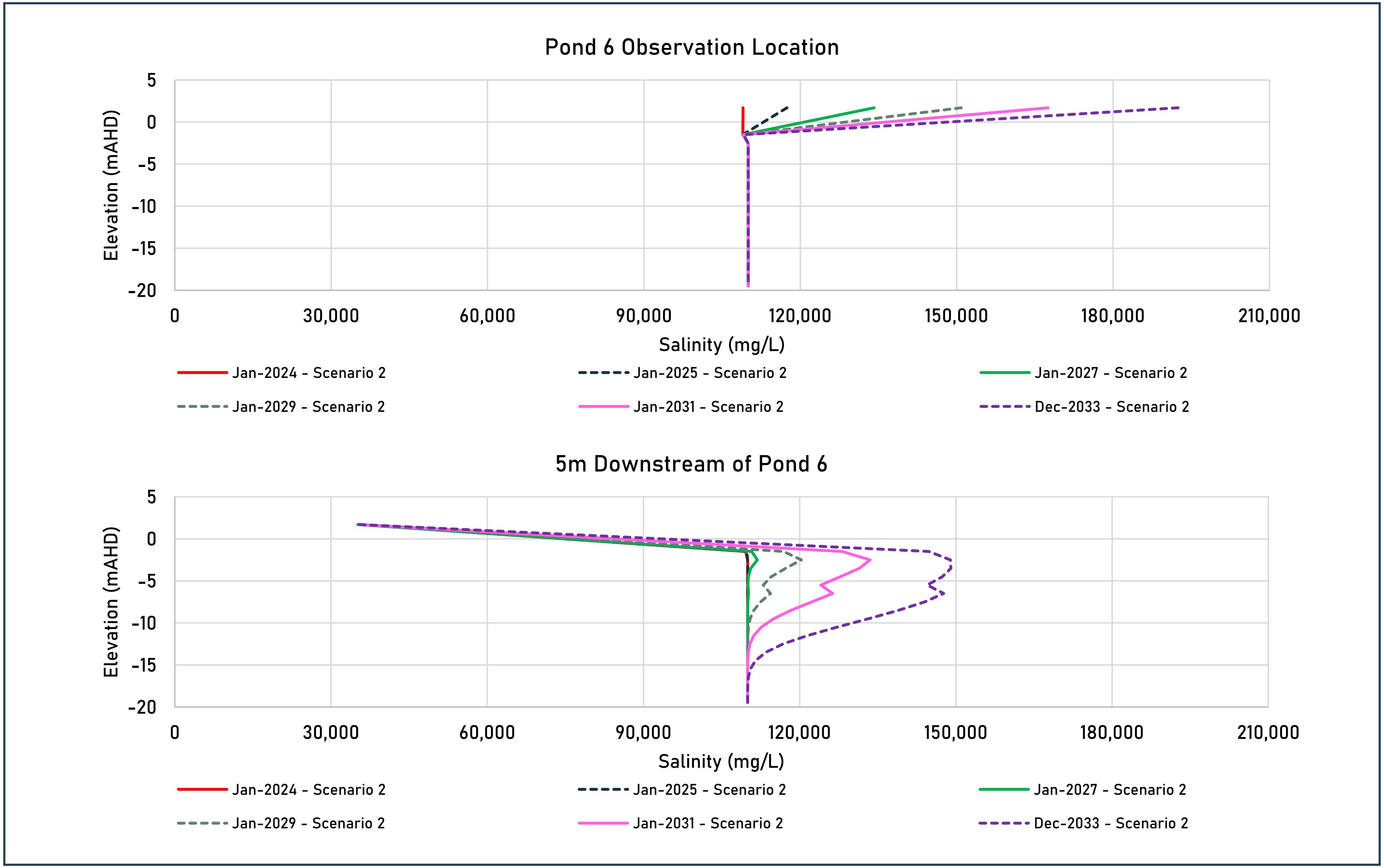


Figure 5.53 Pond 6 Predicted Salinity Scenario 2 (Pond 6 Observation Point and 5m Downstream of Pond 6)

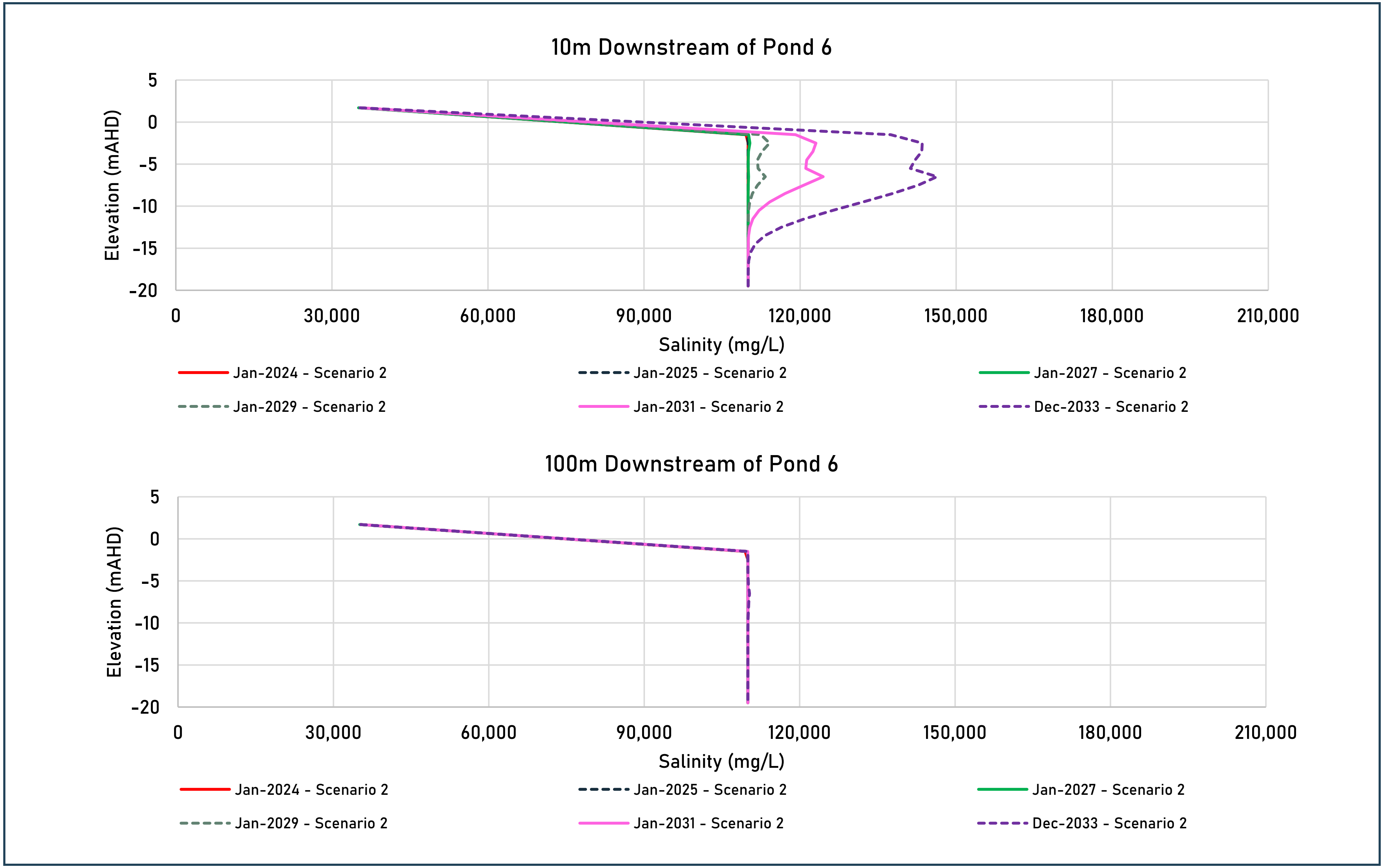


Figure 5.54 Pond 6 Predicted Salinity Scenario 2 (10m and 100m Downstream of Pond 6)

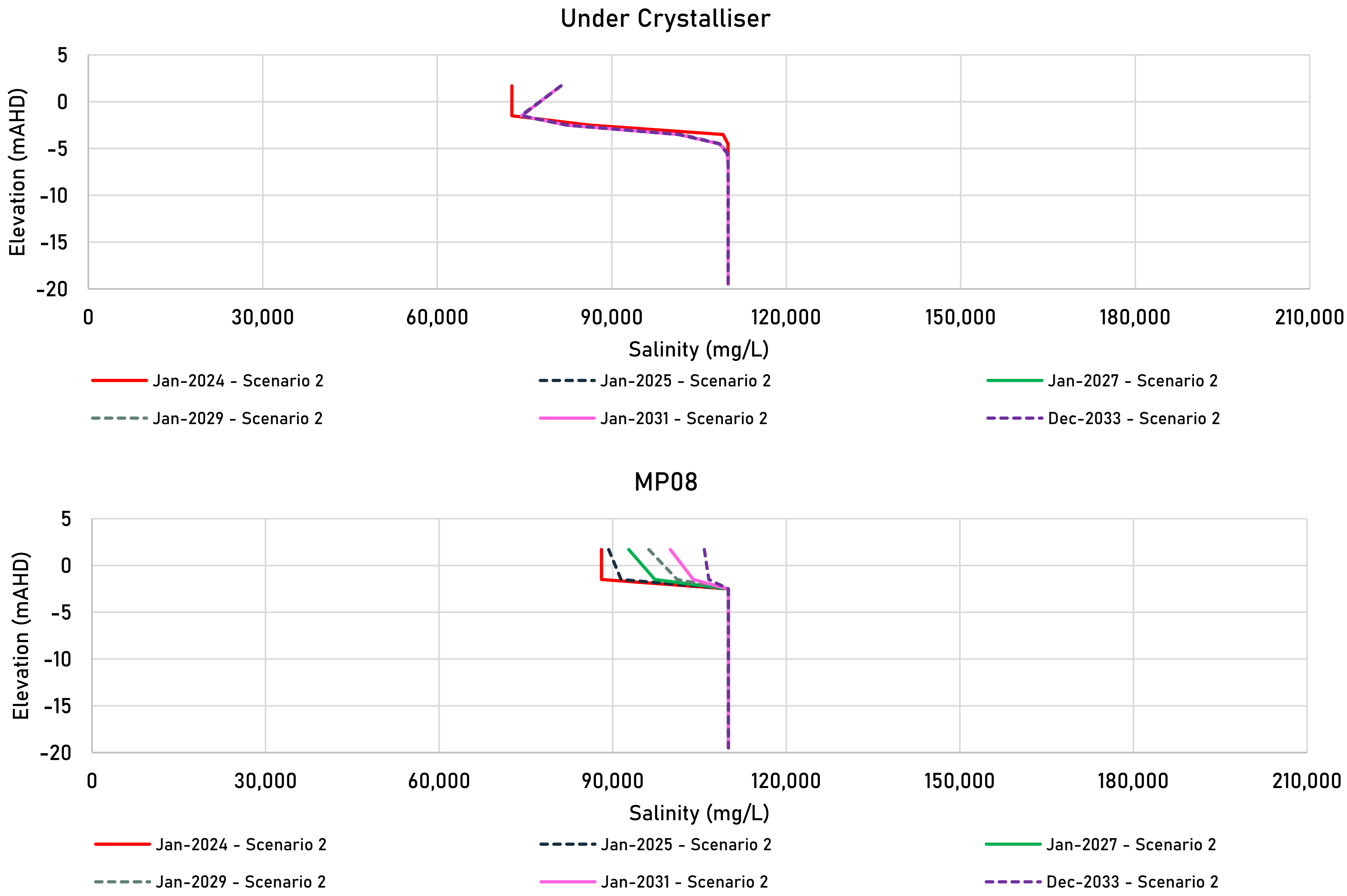


Figure 5.55 Pond 6 Predicted Salinity Scenario 2 (MP08 and Under Crystalliser)

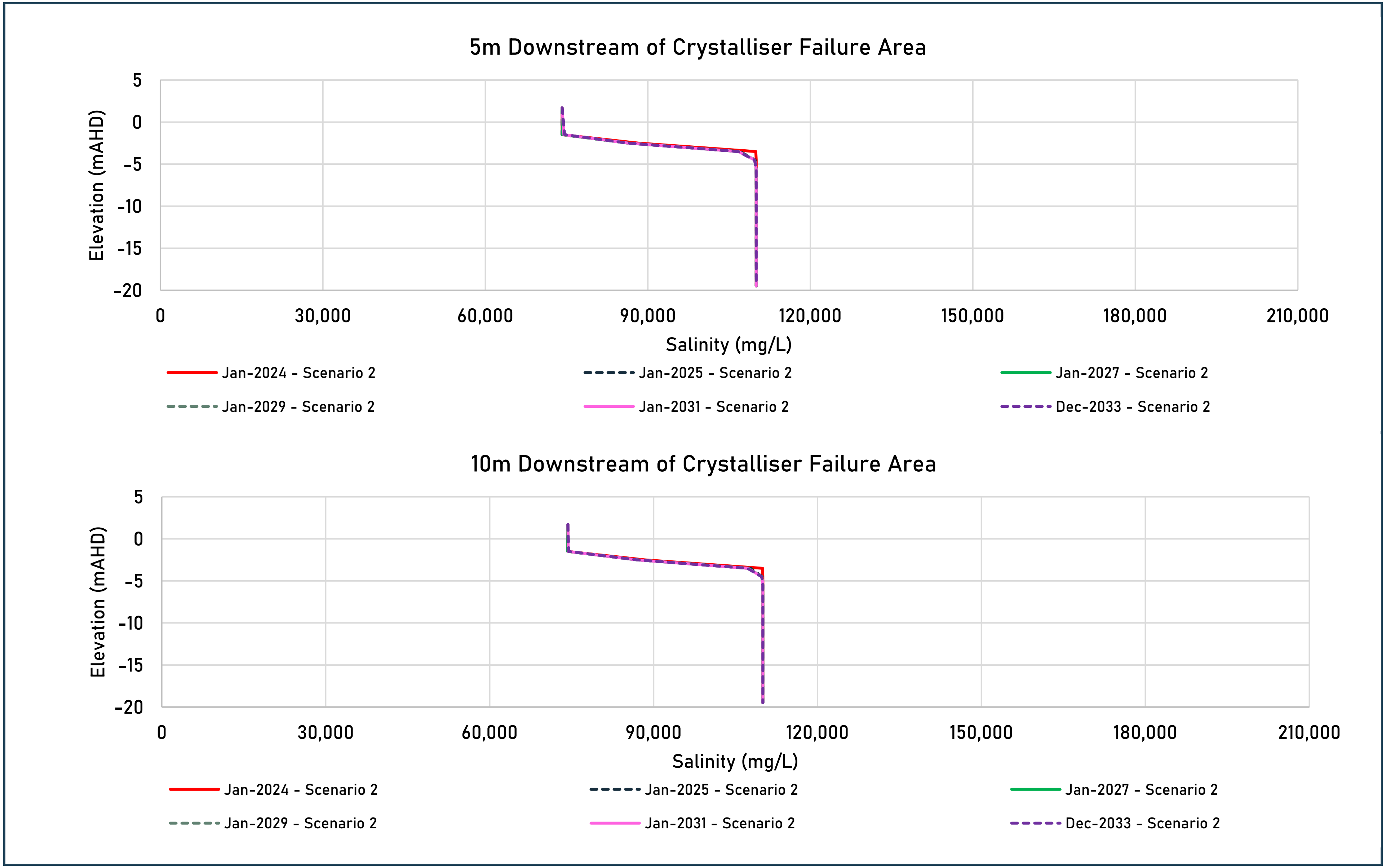


Figure 5.56 Pond 6 Predicted Salinity Scenario 2 (5m and 10m Downstream of Crystalliser Failure Area)

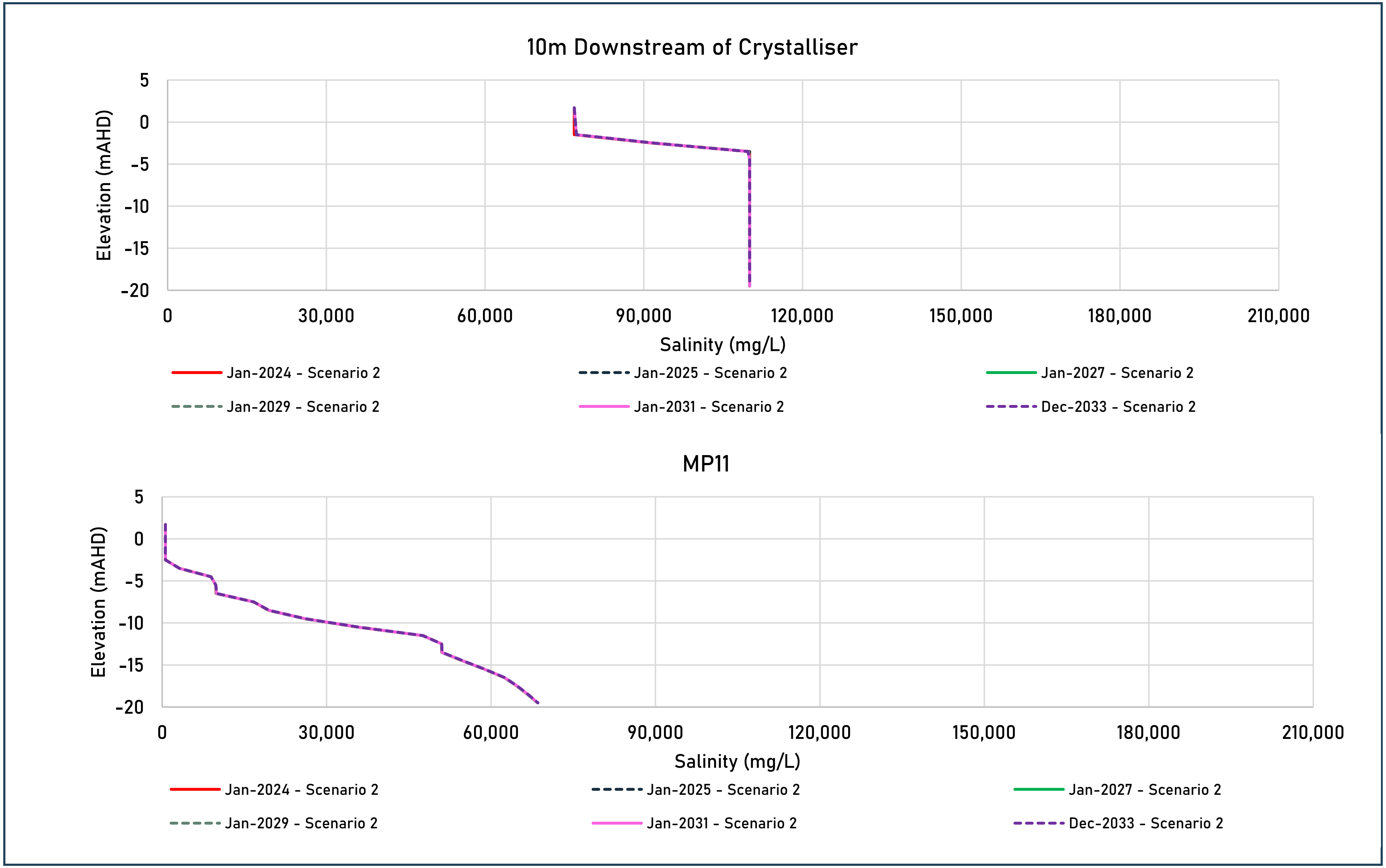


Figure 5.57 Pond 6 Predicted Salinity Scenario 2 (10m Downstream of Crystalliser and MP11)

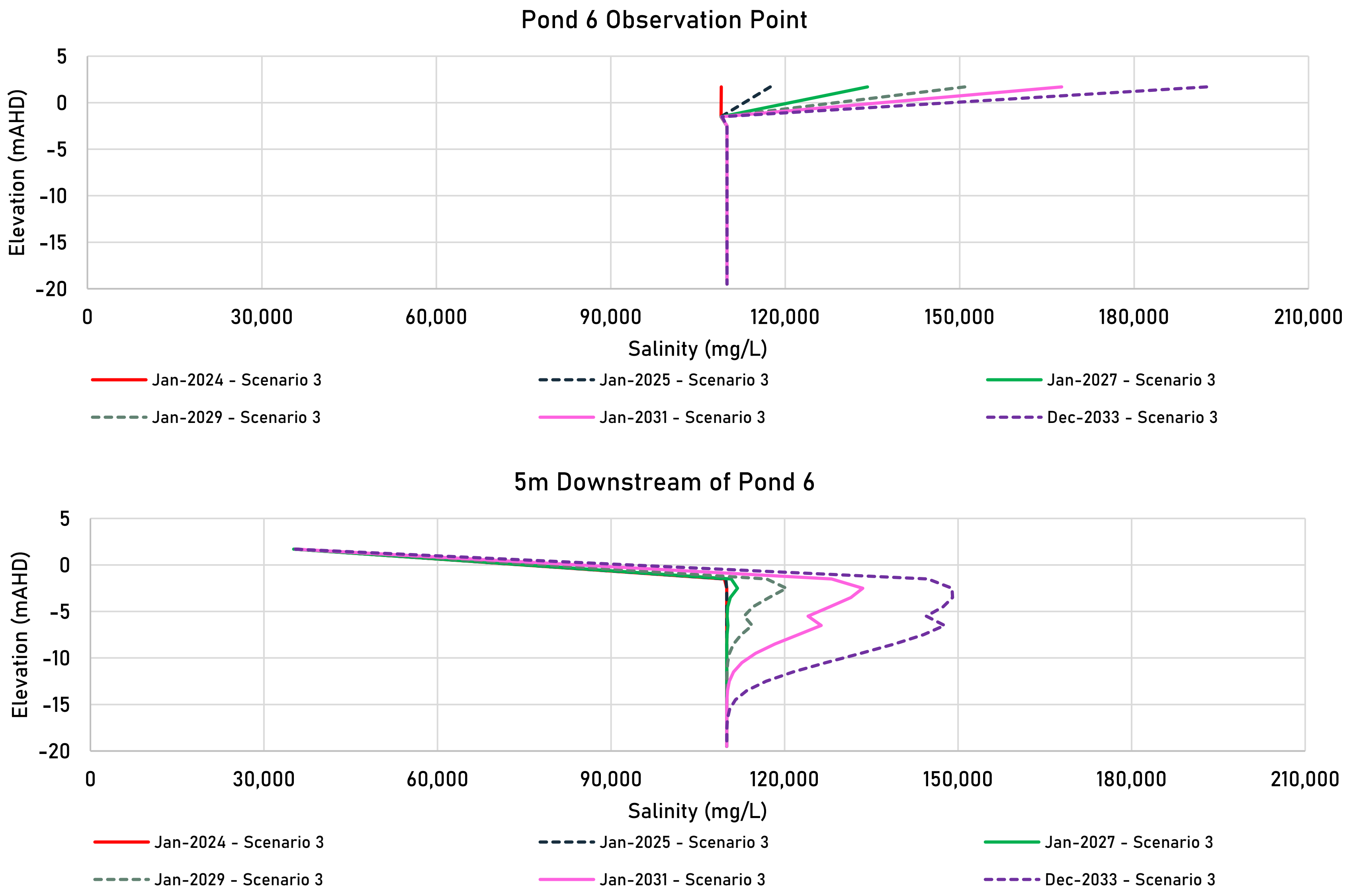


Figure 5.58 Pond 6 Predicted Salinity Scenario 3 (Pond 6 Observation Point and 5m Downstream of Pond 6)

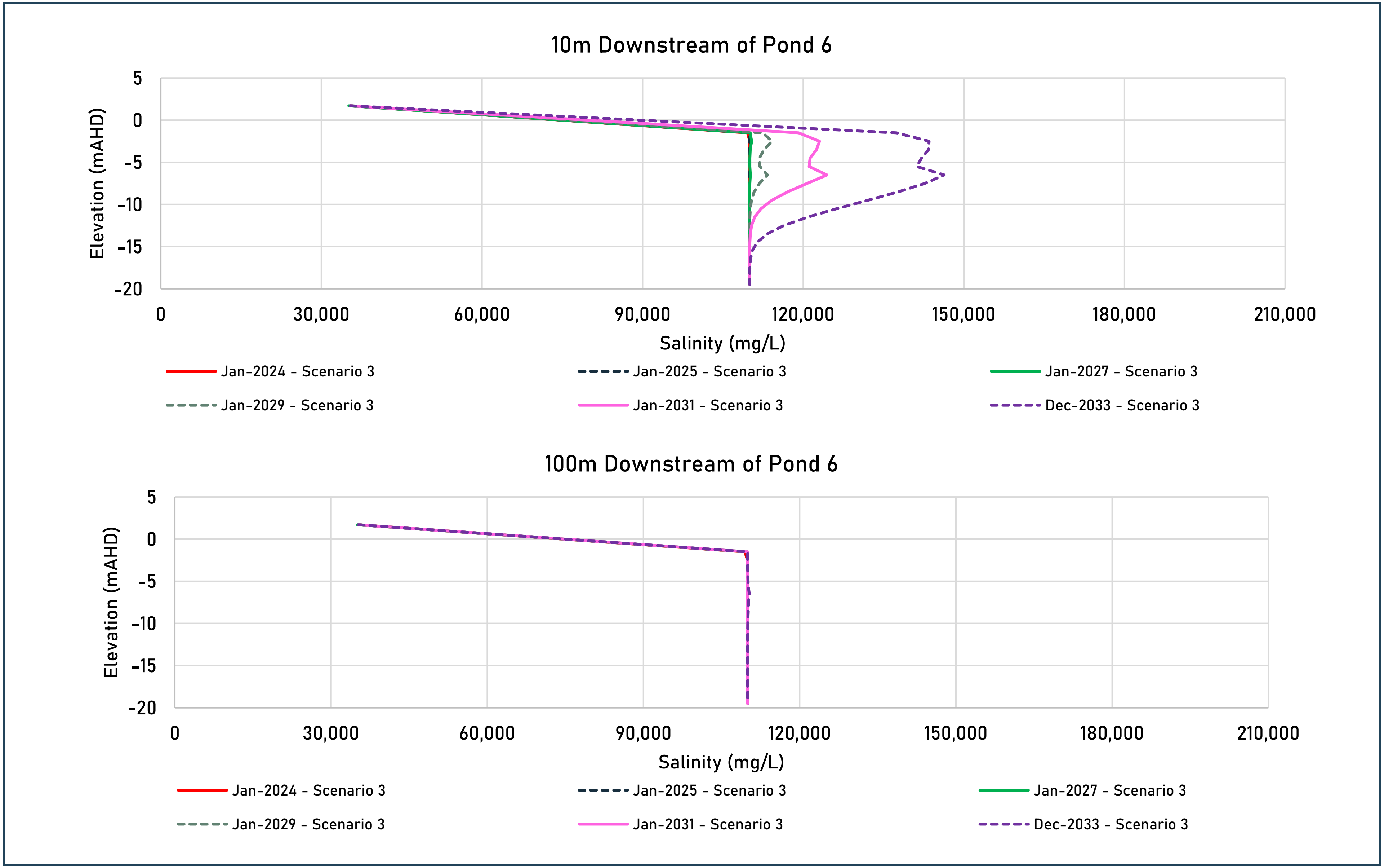
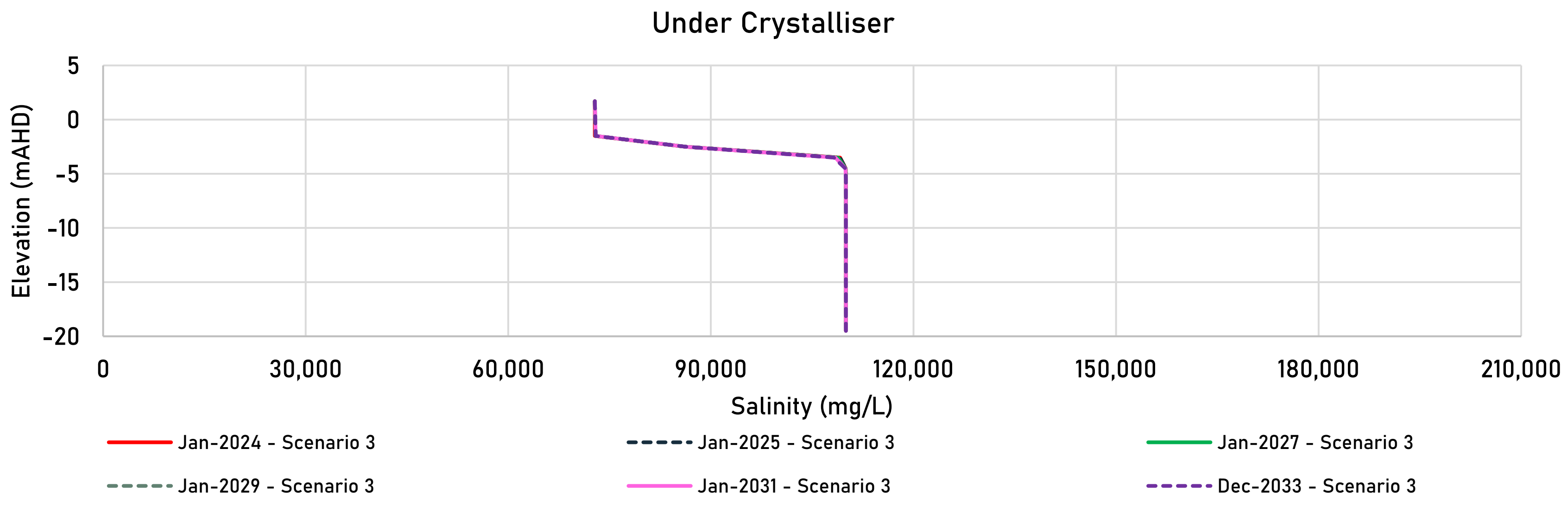


Figure 5.59 Pond 6 Predicted Salinity Scenario 3 (10m and 100m Downstream of Pond 6)



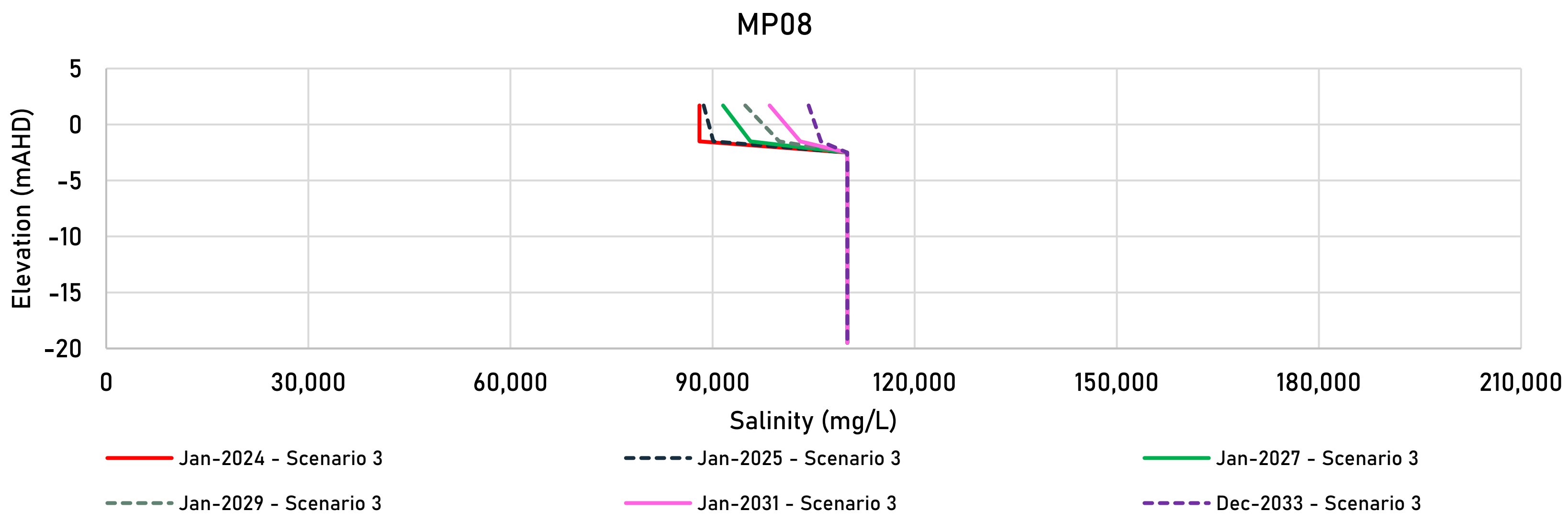


Figure 5.60 Pond 6 Predicted Salinity Scenario 3 (MP08 and Under Crystalliser)

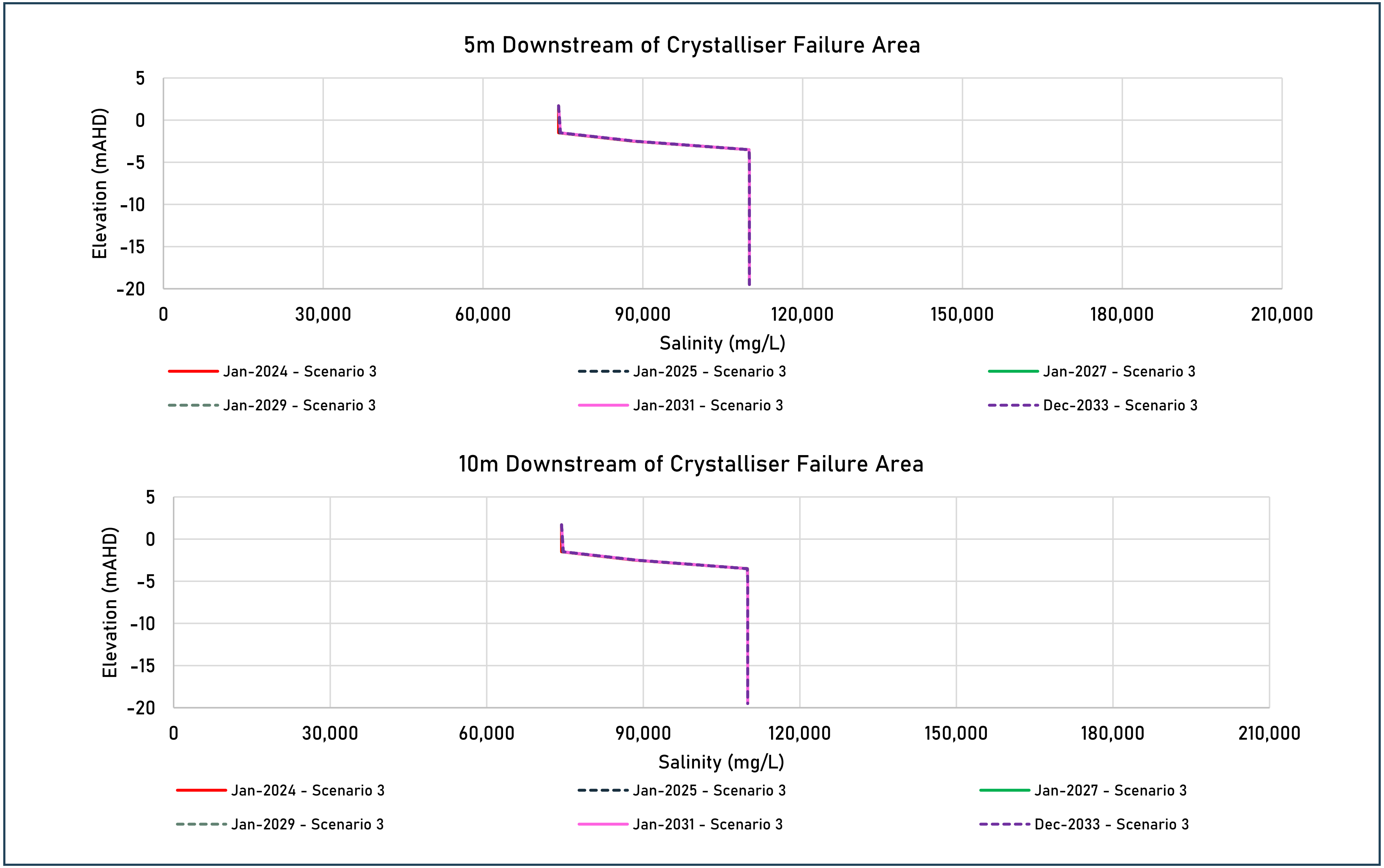
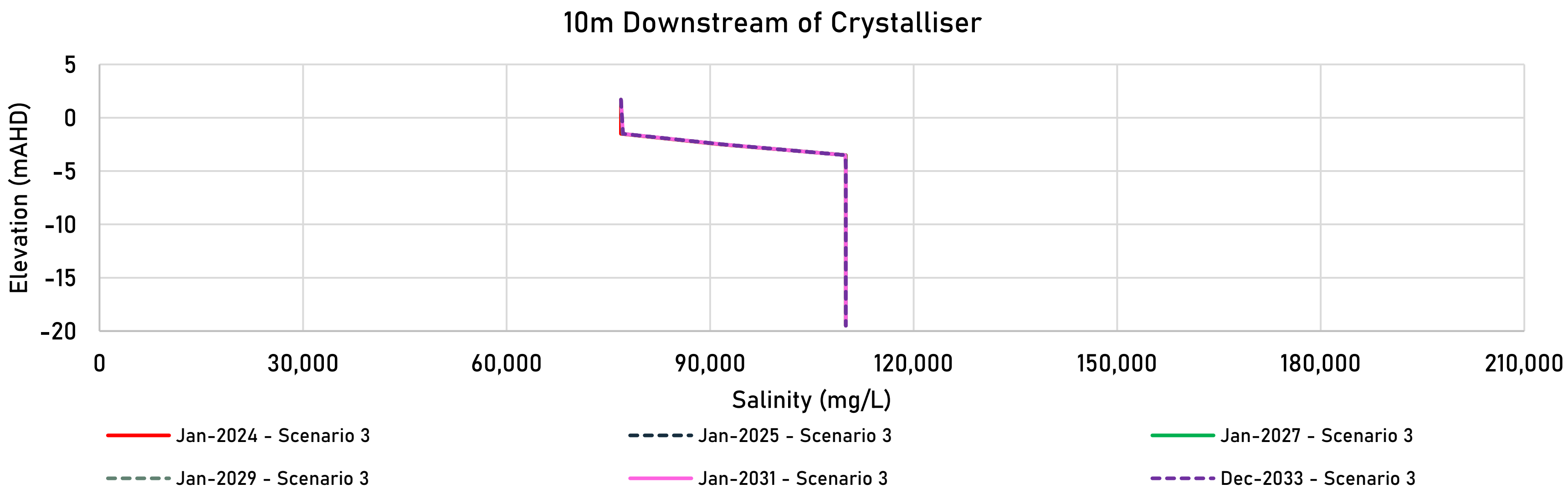


Figure 5.61 Pond 6 Predicted Salinity Scenario 3 (5m and 10m Downstream of Crystalliser Failure Area)



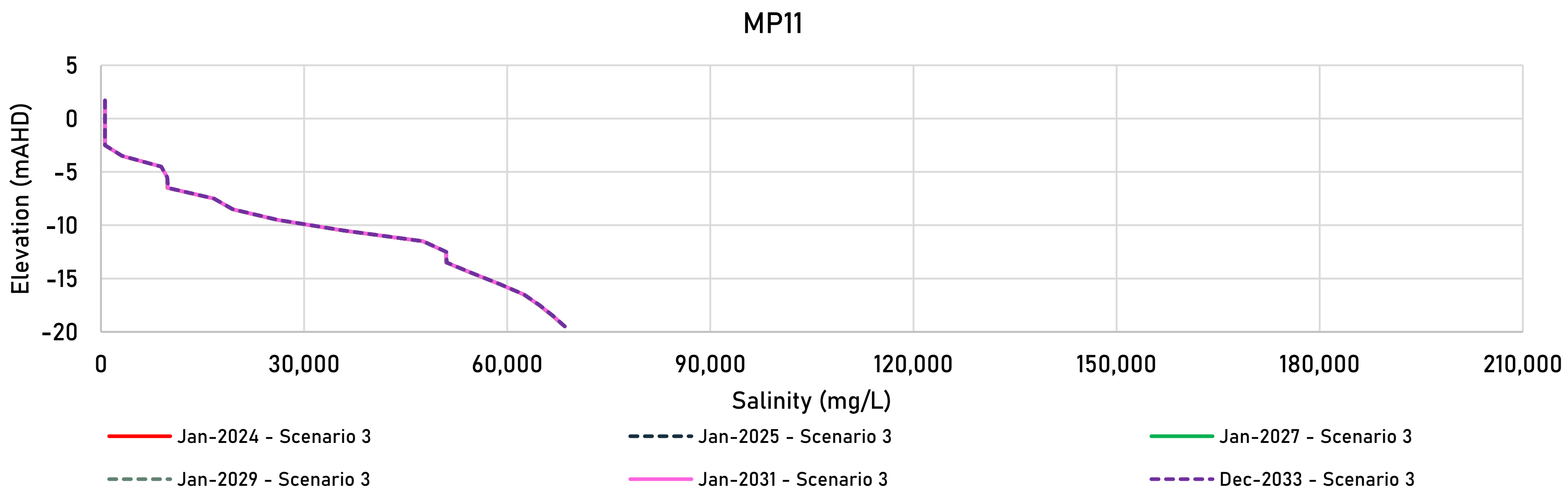


Figure 5.62 Pond 6 Predicted Salinity Scenario 3 (100m Downstream of Crystalliser and MP11)

5.5 Modelling Limitations and Uncertainties

A density dependent flow and transport modelling approach has used the available data to provide a representation of the groundwater conditions underlying, upstream and downstream of the Project area. The model has been used to simulate the impacts on groundwater of the operation of Pond 1 (filling with sea water), the operation of the crystallisers and the interactions with Mardie Pool and the operation of Pond 6.

There is inherent uncertainty in all long-term hydrogeological modelling. More confidence in model predictions will only be achieved with longer term operational data that imposes operational scale aquifer stress and provides more information on the responses to the aquifers in and around the Project to the development and filling of ponds.

The groundwater models have been developed using the available data and include the synthesis of data collected as part of geotechnical and targeted hydrogeological investigations. The model confidence level classification (as per the National Water Commission Guidelines, Table 2-1 (Barnett et al, 2012)) is Class 1 in some areas (the lowest confidence levels) with increased confidence in some areas resulting in some criteria of a Class 2 model being satisfied. Overall the models are considered to have a Class 1 confidence level and are suitable for the purpose of predicting groundwater impacts at this level of study.

As with all models, there are limitations associated with the data availability, conceptualisation and representation of dynamic flow processes.

The following list identifies where limitations in the model features and / or data availability have been identified:

- The models were set up to simulate the regional aquifer system and predict the response to the operation of Pond 1, the crystalliser and Pond 6. The models simulate the major hydrostratigraphic units identified and do not provide a representation of small-scale features.
- The models are calibrated assuming uniform aquifer parameters across the simulated aquifer units included. Additional zonation of hydrogeological units has not been included as data is not available to support this approach.
- The models are calibrated to available water level monitoring data from nearby monitoring bores. These monitoring bores show the aquifer response to:
  - tidal inundation over a period of several years (Pond 1).
  - the filling and emptying of Mardie Pool (Mardie Pool and Crystalliser model).
- The models have also been used to simulate current (measured) salinity profiles where data are available (Mardie Pool and crystalliser model and the Pond 6 and crystalliser model). Where salinity data are not available, the current understanding of the regional system is used to define salinity conditions that result from the interactions between the coast (sea water interface), the sabkha and the upstream fresher aquifer system.
- A water balance study for Mardie Pool has been used to define the conditions that could be expected at Mardie Pool, as there is no access to Mardie Pool currently.
- The models are calibrated to the measured groundwater responses and available salinity profiles. No operational monitoring data is currently available to calibrate the model.
- As outlined above the Pond 1 model is calibrated to the diurnal response to tidal variations and also the groundwater response to tidal inundation. The tide data used to simulate both the diurnal and inundation responses has been synthesised from measured tidal data from Onslow and simulated tidal data for the Project area. As such the Pond 1 model calibration (and predictions) only include an approximation to the tidal influence of the Project area. A similar diurnal response to tidal variations is included in the Pond 6 model, however no data are available to calibrate the model to this response.

- Long term predictions do not account for potential climate change and the subsequent impact on evaporation and rainfall conditions in the catchment in the future.

The following assumptions and limitation are included in model predictions:

- A set of groundwater salinity conditions has been derived from available data and used as initial salinity conditions for the calibration of all models and predictions. The model has not been used to develop these salinity conditions over long periods of (geological) time.
- The Pond 1 and the Pond 6 and Crystalliser models use a synthesised tidal data set (as outlined above) as a direct model input (i.e., the coastal model boundary).
- The Mardie Pool and crystalliser model uses a synthesised tidal data set as a direct model input (i.e., the Mardie Pool water level).
- Leakage from Pond 1 is simulated consistent with the seepage estimates available (Worley, 2019) and assuming that the head in the pond drives water into the underlying aquifers. Actual leakage rates will be dependent on the rate of development of a halite crust and algal mats in the base of the pond.
- Leakage from Pond 1 and Pond 6 is also simulated via direct recharge from the base of the pond, and as a function of the water stored in the ponds (i.e., filling to the operational level). This approach simulates leakage assuming hydraulic loading from the impounded water.
- Leakage from the crystalliser is simulated as a function of the water stored in the ponds (i.e., filling to the operational level of 8.5mAHD) as a result of a failure of the lining of the crystalliser. This approach simulates leakage assuming hydraulic loading from the impounded water.
- There is still uncertainty in the changes to aquifer parameters that may occur (to the already low permeability and storage material underlying the ponds). Loading of the profile has been simulated using hydraulic head to drive water from Pond 1, Pond 6 and the crystalliser to the underlying aquifer (as outlined in the point above).
- No unsaturated flow processes have been considered in the current model set ups.
- The models simulate varying leakage through the floor of Pond 1 and Pond 6 and the crystalliser (if it fails) and does not include seepage through the upstream or downstream embankments.

6. FUTURE WORK

The modelling approach outlined in Section 5.0 was developed to predict the impact of the development and filling of Pond 1, Pond 6 and the operation of the crystalliser on the underlying groundwater system and on Mardie Pool. As part of the overall study to support the Project an additional density dependent two-dimensional section model is planned for the northern area of the Project (across Pond 8).

Future modelling will continue to simulate the risks of pond leakage using 2D sectional models. This is considered appropriate because:

- The approach adheres to the principles of parsimony. The data that would be required for meaningful 3D density dependent modelling over the entire project area and the associated model run times, would be prohibitive.
- The primary groundwater fluxes in the system are vertical. The lateral movement of groundwater within the sabkha and tidal flats is negligible (as groundwater gradients are flat). This provides more confidence in the assessment of vertical fluxes with a 2D model and the appropriate surface area over which these fluxes occur can then be applied as a scaling factor.
- The primary stress is being applied perpendicular to the groundwater contours (i.e., it is a stress imposed over the sabkha area by ponds / seepage) and any lateral movement of water that does occur will occur along the steepest induced hydraulic gradient (i.e., between the pond and the ocean). Any such lateral flux would be assessed with the 2D model.

7. SUMMARY OF PREDICTED IMPACTS

Calibrated 2D groundwater models have been used to predict:

- The potential for interaction between Pond 1 seepage and the near-coastal hydrological cycle that supports coastal mangrove habitat and the algal mat areas of the intertidal zone.
- The potential for interaction between crystalliser seepage and Mardie Pool.
- The potential for interaction between crystalliser and Pond 6 seepage and the near-coastal hydrological cycle (that also supports coastal mangrove habitat and the algal mat areas of the intertidal zone).

These models, which also include density dependence, have been developed and calibrated using the available measured water level data and salinity profiling for the project area.

Figure 7.1 shows the extent of Pond 1 and the areas of algal mat and mangrove communities downstream of Pond 1. An area of Pond 1 will be constructed in a mapped area of algal mat community. Downstream of Pond 1, the tidal inundation will continue over the life of the project. Modelling results suggest that water level impacts of the operation of Pond 1 are predicted to occur:

- Underneath and immediately downstream of Pond 1, with a seasonal increase in water level of up to 0.5m predicted 10m downstream of Pond 1. A seasonal increase in water level up to 0.5 m is predicted 100 m downstream of Pond 1. The extent of this impact is shown in Figure 7.1.
- Upstream of Pond 1, where a water level decrease is predicted as tidal recharge will be prevented by embankments installed at the downstream end of Pond 1 (refer Figure 7.1).

  Further downstream (~3.5km NE from Pond 1) no water level impact of the operation of Pond 1 is predicted.

  Predicted changes in groundwater salinity resulting from the operation of Pond 1 are small and limited to the shallow depths in the area immediately downstream of Pond 1.
- Water level and salinity impacts on Mardie Pool resulting from short term leakage from the crystallisers are predicted to be small. Leakage from the crystalliser, in the unlikely event that it occurs, is expected to result in additional discharge of groundwater to Mardie Pool. The nature of Mardie Pool (the area of the upstream surface water catchment relative to the size of Mardie Pool and the maintenance of this catchment during operation of the project) is such that it will likely continue to be flooded and over topped on an annual basis in the future. Water level impacts of short-term leakage from the crystallisers (as any potential leakage from the crystallisers would be managed to prevent loss of production) are predicted to occur close to the crystalliser but are not predicted to persist once leakage from the crystalliser ceases.

Figure 7.2 shows the extent of Pond 6, the crystallisers, and areas of algal mat and mangrove communities downstream of Pond 6. An area of Pond 6 will be constructed within a mapped area of algal mat community. Downstream of Pond 6 the tidal inundation will continue over the life of the project. Modelling results suggest that water level impacts of the operation of Pond 6 are predicted to occur as follows:

- Immediately underneath and downstream of Pond 6 - 5m and 10m downstream of Pond 6 water levels are predicted to persist close to ground level because of the ongoing leakage from Pond 6. The extent of this impact is shown in Figure 7.2.
- Further downstream of Pond 6 (100m), an overall increase in water level is predicted to occur (refer Figure 7.2). There is still some water level variation predicted at this location from the tidal inundation / recharge and leakage from Pond 6. The predicted variation in water levels is less than the pre-development simulated water level variation at this location.

- Upstream of Pond 6, where an increase in water levels of ~ 0.3 m is predicted (~ 6 km upstream of Pond 6, refer Figure 7.2).
- Predicted salinity increases from the operation of Pond 6 are limited to the immediate Pond 6 area and the area upstream, and are not predicted to extend a significant distance upstream of the Pond 6.
- Water level impacts of short-term leakage from the crystallisers (~ one year duration), simulated as part of the Mardie Pool and Pond 6 predictions, are only predicted to occur underneath and close to the crystallisers and are not predicted to persist once leakage from the crystalliser ceases.
- Salinity impacts of short-term leakage from the crystallisers (also simulated as part of the Mardie Pool and crystalliser predictions) are limited to the area of the crystalliser and the area immediately downstream.

The water quality that will develop within the first ponds is not materially different to the range in groundwater salinity that is observed on the coastal plain and sabkha and therefore this filling is comparatively low risk. Leakage from other ponds (Pond 6) and potential leakage from the crystalliser will have a water quality that has the potential to result in greater increases in salinity in the areas of the ponds and the crystalliser. These increases are generally predicted to occur in the vicinity of Pond 6 and the crystalliser.

There has been no substantial stress placed on the natural system during project studies. All interpretations are based on monitoring data from the system within the relatively narrow range of natural conditions. The first significant primary stress outside of the range in natural conditions will be filling the of the first ponds (Pond 1). The ponds will exert a hydraulic stress; however, a key difference is that the water level in the ponds will be sustained constantly (as opposed to the periodic highs that result from tides).

Figure 7.1 Summary of Pond 1 Predicted Impacts

Figure 7.2 Summary of Pond 6 and Crystalliser Predicted Impacts

8. REFERENCES

AQ2, 2023. Mardie Project – Mardie Pool Groundwater Interaction Assessment. AQ2 Memo Report 293Q 059b. Prepared for BCI Minerals, November 2023.

Barnett et al, 2012. Australian groundwater modelling guidelines, Waterlines report, National Water Commission, Canberra.

Charles, S, Fu, G, Silberstein, R, Mpelasoka, F, McFarlane, D, Hogson, G et al. 2015, 'Hydroclimate of the Pilbara: past, present and future. A report to the Government of Western Australia and industry partners from the CSIRO Pilbara Water Resource Assessment', CSIRO Land and Water, Australia.

CMW Geosciences 2020. Mardie Salt Project DFS Factual Geotechnical Report Mardie WA. Report PER2018-0091AN Rev1. August 2020.

Commander, DP 1994a, Hydrogeology of the Fortescue River Alluvium, Ashburton Plain, Carnarvon Basin: Western Australian Geological Survey, Report 37 professional papers 1994, p. 101–124.

ESI (1996 – 2021). Groundwater Vistas. Environmental Solutions Inc.

Golder, 2022. Groundwater Level Triggers – Chevron and Santos Pipeline Interface. Technical Memorandum 21506176-002-M-Rev0 Prepared for BCI Minerals, November 2022.

Hocking, R.M., Moors, H.T. and Van De Graaff, J.E., 1987. Geology of the Carnarvon Basin Western Australia. Geological Survey of Western Australia Bulletin 133.

Haig, T 2009, The Pilbara coast water study, Department of Water, Hydrogeological record series, Report HG34, 183 p.

O2 Marine 2020. Mardie Project – Intertidal Benthic Communities and Habitat. Report R1800007. Prepared for Mardie Minerals Pty Ltd., 2 April 2020

Panday, Sorab, Langevin, C.D., Niswonger, R.G., Ibaraki, Motomu, and Hughes, J.D., 2017, MODFLOW-USG version 1.4.00: An unstructured grid version of MODFLOW for simulating groundwater flow and tightly coupled processes using a control volume finite-difference formulation: U.S. Geological Survey Software Release, 27 October 2017, https://dx.doi.org/10.5066/F7R20ZFJ

RPS, 2019, 'BCI Mardie Salt Project – Coastal Inundation Studies.' Report prepared for BCI Minerals. October 2019.

RPS, 2021, 'Cape Preston West Port Facilities Tidal Datum Establishment'. Report prepared for BCI Minerals. November 2021.

Sudmeyer, R 2016, 'Climate in the Pilbara', Bulletin 4873, Department of Agriculture and Food, Western Australia, Perth.

Worley, 2019. Technical Memorandum Prepared for Mardie Salt and Potash Project. September 2019.

APPENDIX A
MODEL PREDICTED WATER AND SALT BALANCES
POND 1

Table A1 – Predicted Total Water Balance for Transient Calibration

Water Balance Component	In (kL)	Out (kL)
Storage	426.50	421.19
Density Storage	364.61	1.57
Constant Head	42.42	50.87
Recharge	998100.00	0.00
Drain	0.00	997774.82
Evapotranspiration	0.00	685.93
Total	998933.53	998934.38
	IN - OUT	-0.85
	Percent Discrepancy	0

Table A2 – Predicted Total Mass Balance for Transient Calibration

Density Mass Balance	In (kg)	Out (kg)
Mass Storage	33039970	4376400
Prescribed Concentrations	5499300	2700310
Constant Head	0.00	0.00
Recharge Mass	2411917830	0.00
Evapotranspiration	0.00	0.00
Drain Mass	0.00	2443380390
Total	2450457100	2450457100
	IN - OUT	9.54E-07
	Percent Discrepancy	0

Table A3 – Predicted Total Water Balance for Scenario 1

Water Balance Component	In (kL)	Out (kL)
Storage	415.80	421.29
Density Storage	58.89	5.60
Constant Head	169.85	188.20
Recharge	600487.49	0.00
Drain	0.00	600020.39
Evapotranspiration	0.00	497.16
Total	601132.04	601132.64
	IN - OUT	-0.6012
	Percent Discrepancy	0

Table A4 – Predicted Total Mass Balance for Scenario 1

Density Mass Balance	In (kg)	Out (kg)
Mass Storage	423000.11	27941.77
Prescribed Concentrations	9779.55	10274.22
Constant Head Mass	0.00	0.00
Recharge Mass	21017062.04	0.00
Drain Mass	0.00	21411625.71
Evapotranspiration Mass	0.00	0.00
Total	21449841.70	21449841.70
	IN - OUT	2.25E-03
	Percent Discrepancy	0

Table A5 – Predicted Total Water Balance for Scenario 2

Water Balance Component	In (kL)	Out (kL)
Storage	385.02	443.94
Density Storage	60.19	7.45
Constant Head	169.78	188.26
Drain	0.00	599489.43
River	580.05	0.00
Evapotranspiration	0.00	695.34
Recharge	599628.75	0.00
Total	600823.79	600824.41
	IN - OUT	-0.62
	Percent Discrepancy	0

Table A6 - Predicted Total Mass Balance Scenario 2

Density Mass Balance	In (kg)	Out (kg)
Mass Storage	404879.45	51618.67
Prescribed Concentrations	9777.94	10276.22
Constant Head	0.00	0.00
Drain Mass	0.00	21360070.55
River Mass	20301.80	0.00
ET Mass	0.00	0.00
Recharge Mass	20987006.25	0.00
Total	21421965.44	21421965.44
	IN - OUT	-1.26E-04
	404879.45	51618.67

Table A7 – Predicted Total Water Balance Scenario 3

Water Balance Component	In (kL)	Out (kL)
Storage	385.01	443.96
Density Storage	60.28	7.45
Constant Head	169.78	188.26
Drain	0.00	599489.43
River	583.58	3.61
Evapotranspiration	0.00	695.34
Recharge	599628.75	0.00
Total	600827.39	600828.05
	IN - OUT	-0.66
	Percent Discrepancy	0

Table A8 – Predicted Total Mass Balance Scenario 3

Density Mass Balance	In (kg)	Out (kg)
Mass Storage	405147.73	51652.48
Prescribe Concentrations	9777.92	10276.19
Constand Head Mass	0	0
River Mass	20425.23	357.15
Drain Mass	0.00	21360071.30
Evapotranspiration Mass	0	0
Recharge Mass	20987006.25	0.00
Total	21422357.12	21422357.12
	IN - OUT	-1.32E-03
	Percent Discrepancy	0

Table A9 – Predicted Total Water balance No Development Scenario

Water Balance Component	In (kL)	Out (kL)
Storage	1505.97	1531.60
Density Storage	216.01	12.53
Constant Head	168.24	189.06
Drain	0.00	3083685.35
Evapotranspiration	0.00	2267.20
Recharge	3085792.50	0.00
Total	3087683	3087686
	IN - OUT	-3.02
	Percent Discrepancy	0

Table A10 – Total Predicted Mass Balance for No Development Scenario

Density Mass Balance	In (kg)	Out (kg)
Mass Storage	1480016.9	70604.6
Prescribe Concentrations	9732.56	10289.76
Constant Head Mass	0	0
Drain Mass	0.00	109411592.66
Evapotranspiration Mass	0	0
Recharge	108002737.50	0.00
Total	109492486.97	109492486.97
	IN - OUT	1.69E-03
	Percent Discrepancy	0

APPENDIX B
MODEL PREDICTED WATER AND SALT BALANCES
CRYSTALLISERS AND MARDIE POOL

Table B1 – Predicted Total Water Balance for Transient Calibration

Water Balance Component	In (kL)	Out (kL)
Storage	132.42	133.34
Density Storage	6.91	12.61
Constant Head	1796.98	1562.95
River	133.48	230.61
Evaporation	0.00	0.00
Total	2069.79	2069.78
	IN - OUT	8.90E-03
	Percent Discrepancy	0.00

Table B2 – Predicted Total Mass Balance for Transient Calibration

Density Mass Balance	In (kg)	Out (kg)
Mass Storage	12981.82	28697.64
Constant Head	193495.28	174237.25
River Mass	6.67	3548.88
Evapotranspiration	0.00	0.00
Total	206483.77	206483.77
	IN - OUT	1.00E-07
	Percent Discrepancy	0.00

Table B3 – Predicted Total Water Balance for Scenario 1

Water Balance Component	In (kL)	Out (kL)
Storage	124.30	155.76
Density Storage	18.27	51.46
Constant Head	1757.14	1575.17
River	306.59	336.98
Evaporation	0.00	86.89
Total	2206.30	2206.27
	IN - OUT	2.87E-02
	Percent Discrepancy	0.00

Table B4 – Predicted Total Mass Balance for Scenario 1

Density Mass Balance	In (kg)	Out (kg)
Mass Storage	31856.83	93661.72
Constant Head	192530.88	174271.63
River Mass	49760.47	6214.84
Evapotranspiration	0.00	0.00
Total	274148.18	274148.19
	IN - OUT	-9.72E-04
	Percent Discrepancy	0.00

Table B5 – Predicted Total Water Balance for Scenario 2

Water Balance Component	In (kL)	Out (kL)
Storage	140.02	142.11
Density Storage	15.19	30.67
Constant Head	1783.49	1566.72
River	145.23	258.30
Evapotranspiration	0.00	86.14
Total	2083.93	2083.93
	IN - OUT	-9.10E-03
	Percent Discrepancy	0.00

Table B6 - Predicted Total Mass Balance Scenario 2

Density Mass Balance	In (kg)	Out (kg)
Mass Storage	28379.60	48129.77
Constant Head	192757.92	174186.72
River Mass	4988.60	3809.64
Evapotranspiration	0.00	0.00
Total	226126.13	226126.13
	IN - OUT	-9.74E-05
	Percent Discrepancy	0.00

Table B7 – Predicted Total Water balance No Development Scenario

Water Balance Component	In (kL)	Out (kL)
Storage	132.42	133.34
Density Storage	6.91	12.61
Constant Head	1796.98	1562.95
River	133.48	230.61
Evapotranspiration	0.00	130.27
Total	2069.79	2069.78
	IN - OUT	8.90E-03
	Percent Discrepancy	0.00

Table B8 – Total Predicted Mass Balance for No Development Scenario

Density Mass Balance	In (kg)	Out (kg)
Mass Storage	12981.82	28697.64
Constant Head	193495.28	174237.25
River Mass	6.67	3548.88
Evapotranspiration	0.00	0.00
Total	206483.77	206483.77
	IN - OUT	-1.00001E-07
	Percent Discrepancy	0.00

APPENDIX C
MODEL PREDICTED WATER AND SALT BALANCES
POND 6 AND CRYSTALLISER

Table C1 – Predicted Total Water Balance End of Transient Calibration

Water Balance Component	In (kL)	Out (kL)
Mass Storage	2376.04	2365.40
Prescribed Concentrations		
Density Storage	28.76	15.94
Constant Head	1391.92	504.74
Recharge Mass Flux	3761698.75	0.00
Drain Mass Flux	0.00	3759383.24
Evapotranspiration	0.00	3226.15
Total	3765495.47	3765495.46
	IN - OUT	-2.29E-05
	Percent Discrepancy	0.00

Table C2 – Predicted Total Mass Balance End of Transient Calibration

Density Mass Balance	In (kg)	Out (kg)
Mass Storage	38446.33	47727.69
Prescribed Concentrations	38597.60	13003.76
Density Mass	0.00	0.00
Constant Head	0.00	0.00
Recharge Mass	41081293.75	0.00
Drain Mass	0.00	41097606.23
Evapotranspiration	0.00	0.00
Total	41158337.68	41158337.68
	IN - OUT	9.69E-08
	Percent Discrepancy	0.00

Table C3 – Predicted Total Water Balance End of Scenario 1 (10 years)

Water Balance Component	In (kL)	Out (kL)
Mass Storage	1016.58	1126.87
Prescribed Concentrations		
Density Storage	84.74	369.10
Constant Head	1398.91	526.79
River Mass Flux	8833.53	0.00
Recharge Mass Flux	1209807.50	0.00
Drain Mass Flux	0.00	1210329.29
Evapotranspiration	0.00	8789.14
Total	1221141.27	1221141.19
	IN - OUT	7.09E-02
	Percent Discrepancy	0.00

Table C4 – Predicted Total Mass Balance End of Scenario 1 (10 years)

Density Mass Balance	In (kg)	Out (kg)
Mass Storage	392176.01	1204058.98
Prescribed Concentrations	128569.76	43749.65
Density Storage	0.00	0.00
Constant Head	0.00	0.00
River Mass Flux	1148255.27	0.00
Recharge Mass Flux	42343262.50	0.00
Drain Mass Flux	0.00	42764454.91
Evapotranspiration	0.00	0.00
Total	44012263.53	44012263.54
	IN - OUT	-2.34E-03
	Percent Discrepancy	0.00

Table C5 – Predicted Total Water Balance End of Scenario 2 (10 years)

Water Balance Component	In (kL)	Out (kL)
Mass Storage	1021.87	1106.23
Prescribed Concentrations		
Density Storage	80.42	348.92
Constant Head	1402.38	524.43
River Mass Flux	8677.34	0.00
Recharge Mass Flux	1209807.50	0.00
Drain Mass Flux	0.00	1210322.59
Evapotranspiration	0.00	8687.28
Total	1220989.50	1220989.46
	IN - OUT	-9.96E-04
	Percent Discrepancy	0.00

Table C6 - Predicted Total Mass Balance End of Scenario 2 (10 years)

Density Mass Balance	In (kg)	Out (kg)
Mass Storage	389388.30	1159771.91
Prescribed Concentrations	145806.65	46923.03
Density Storage	0.00	0.00
Constant Head	0.00	0.00
River Mass Flux	1104659.62	0.00
Recharge Mass Flux	42343262.50	0.00
Drain Mass Flux	0.00	42776422.13
Evapotranspiration	0.00	0.00
Total	43983117.07	43983117.07
	IN - OUT	3.27E-03
	Percent Discrepancy	0.00

Table C7 – Predicted Total Water Balance End of Scenario 3 (10 years)

Water Balance Component	In (kL)	Out (kL)
Mass Storage	1017.69	1099.98
Prescribed Concentrations		
Density Storage	81.45	349.66
Constant Head	1402.55	523.41
River Mass Flux	2612.20	0.00
Recharge Mass Flux	1209807.50	0.00
Drain Mass Flux	0.00	1210322.32
Evapotranspiration	0.00	8680.59
Total	1214921.39	1220975.95
	IN - OUT	-6.05E+03
	Percent Discrepancy	0.00

Table C8 – Predicted Total Mass Balance End of Scenario 3 (10 years)

Density Mass Balance	In (kg)	Out (kg)
Mass Storage	390954.56	1156874.91
Prescribed Concentrations	145793.39	46923.21
Density Storage	0.00	0.00
Constant Head	0.00	0.00
River Mass Flux	1100688.04	0.00
Recharge Mass Flux	42343262.50	0.00
Drain Mass Flux	0.00	42776900.38
Evapotranspiration	0.00	0.00
Total	43980698.50	43980698.50
	IN - OUT	-5.48E-03
	Percent Discrepancy	0.00

Table C9 – Predicted Total Water Balance for End of No Development

Water Balance Component	In (kL)	Out (kL)
Mass Storage	2376.04	2365.40
Prescribed Concentrations		
Density Storage	28.76	15.94
Constant Head	1391.92	504.74
Recharge Mass Flux	3761698.75	0.00
Drain Mass Flux	0.00	3759383.24
Evapotranspiration	0.00	3226.15
Total	3765495.47	3765495.46
	IN - OUT	-2.29E-05
	Percent Discrepancy	0.00

Table C10 – Predicted Total Mass Balance for No Development

Density Mass Balance	In (kg)	Out (kg)
Mass Storage	38446.33	47727.69
Prescribed Concentrations	38597.60	13003.76
Density Mass	0.00	0.00
Constant Head	0.00	0.00
Recharge Mass	41081293.75	0.00
Drain Mass	0.00	41097606.23
Evapotranspiration	0.00	0.00
Total	41158337.68	41158337.68
	IN - OUT	9.69E-08
	Percent Discrepancy	0.00

AQ2 Pty Ltd
ABN 38 164 858 07

Ground Floor
1 Howard Street
Perth WA 6000
Tel +61 8 9322 9733

www.aq2.com.au

Memo

To	Spencer Shute, Matt Spence	Company	Mardie Minerals Pty Ltd
From	Bruce Harvey, Duncan Storey	Job No.	293H
Date	21/12/2023	Doc No.	032c
Subject	Mardie Project – Ongoing Investigation and Monitoring Program - Revised		

1. INTRODUCTION

Mardie Minerals' Mardie Project is located on the Pilbara coastline of Western Australia, approximately 100 km south-west of Karratha (Figure 1). The project includes the construction of extensive evaporation ponds and crystallisers for the extraction of salt products from sea water.

The initial environmental impact assessment for the Mardie Project identified that the understanding of the risks posed to vegetation, local groundwater and pools as a result of saline seepage from the Project's proposed concentration and crystallisation ponds should be improved. A Groundwater Risk Assessment (GRA) was provided to Mardie Minerals by AQ2 in 2020 (AQ2 document 293C_009b). The GRA document discussed the potential impacts the preliminary project plan may have on groundwater receptors in the vicinity of Mardie Pool and coastal habitats. The areas of focus for this were:

- Potential impacts due to the location of secondary salt crystallisers, which under the original (or DFS) project are proposed to be located north-east of Mardie Pool near the south-western boundary of the Fortescue River alluvial valley.
- Risk to coastal vegetation (primarily mangrove habitat) due to possible seepage of hypersaline water from Evaporation Ponds 1-9 and Primary Crystallisers into the near-coast groundwater system.

Concern has since been raised regarding the presence of an algal mat ecosystem on the supratidal flats which exists beneath and to the west of the proposed location of the Evaporation Ponds. It was inferred that the existence of algal mats may be due to upwelling or overtopping fresh groundwater which was thought to bring nutrients to surface and dilute the hypersaline fluids (which develop due to evaporation). It was unclear whether the coastal groundwater regime at Mardie is similar in structure to this concept. Vertical distribution of salinity beneath the salt flats, and the location of the seawater interface were also undefined across much of the development envelope.

AQ2 was engaged by Mardie Minerals to propose a monitoring bore network which would permit the ongoing long-term monitoring of groundwater quality in the vicinity of sensitive receptors.

2. DFS PROJECT LAYOUT

Proposed DFS project layout is presented in Figure 1. Key characteristics of the layout are:

- Concentrator and Primary crystalliser ponds extending along approximately 25 km of coastal supratidal salt flats.
- Seawater intake to be at the southern-most pond, with brine concentration increasing in ponds to the north.
- Western sea wall of the ponds is proposed to be adjacent to or impinging upon mapped algal mat habitat on the lower (western) side of the supratidal flats.
- Secondary crystalliser ponds are proposed to be located immediately north of Mardie Pool on the eastern side of the main concentrator ponds.

Under the revised Optimised Mardie Project, the layout has been amended, with the crystallisers moved north and back from the coast.

3. FURTHER INVESTIGATIONS

While substantial research has already been carried out to characterise the hydrogeological regime at the Mardie Project, it has been identified that further background investigations will enhance knowledge and assist in future groundwater management. In particular several avenues for further work have been noted to close data gaps.

Proposed Timing of Investigations: Prior to operations commencing

Status: Completed January 2023

3.1 Airborne Electromagnetic Data

An Airborne Electromagnetics (AEM) survey was flown in the area in 2010 by Fugro Airborne Surveys. The survey has wide line spacing, however lines do cross Mardie Creek in several places. It had been postulated that reprocessing of the AEM data may provide information relevant to the salinity profile of water in the near surface.

The AEM survey data has been used for regional analysis of bulk conductivity distribution and its relationship to salinity measured in monitoring bores. The vertical resolution of 10m (between conductivity-depth slices) was thought unlikely to be improved significantly by reprocessing to allow more detail to be resolved in the near-surface.

Instead of reprocessing TEMPEST data, a Loupe TEM ground geophysics survey was commissioned and carried out in August 2022, with survey lines targeting accessible areas around Mardie Pool as well as existing tracks. Processed Loupe TEM data provided approximately 1m horizontal and vertical resolution of bulk conductivity along survey lines, contributing to the understanding of salinity distribution in groundwater around Mardie Pool.

3.2 Mardie Pool Bathymmetry

Bathymmetric data for Mardie Pool may be useful when characterising the nature of the potential fresh water lens which may encompass the pool and surrounding subsurface.

Due to the wishes of traditional owner groups for personnel to avoid entering Mardie Pool or placing any permanent structures within it, it was determined that the physical shape of the Mardie Pool may be assessed through a combination of methods, being:

- Historical and ongoing terrestrial photos of the Pool over a range of water level conditions (i.e., between Mardie Pool being empty and full);
- Drone footage of Mardie Pool during both flood / wet and dry periods;
- Improved terrestrial location/elevation survey to determine the RL of the Pool water surface as seen in historical photos; and
- Non-permanent installation of a depth logger within the Pool to assist with assessment of Mardie Pool water levels.

All of these methods have been in use since October 2022 to build a 3-dimensional bathymetric profile for Mardie Pool under the current access constraints.

3.3 Geological Controls on Creek and Pool Development

It was noted by DAWE that Mardie Creek may have developed coincident with a mapped geological fault. The available geological and geophysical mapping has been assessed for correlations between basement faulting near Mardie Pool. Mardie Creek did not appear to coincide with faults mapped in published geological mapping (Yarraloola 1:250 000 Geology) or those presented in the Airborne EM report (Fugro Airborne Surveys 2010). Results of drilling also indicate that Mardie Pool is likely hosted entirely within the clay/gravel overbank deposits of the Fortescue River alluvial fan. Therefore, no correlation was drawn between the location of the creek and any mapped faults.

4. PROPOSED MONITORING BORE NETWORK

4.1 Terrestrial Bores - Mardie Pool and Crystallisers

Proposed Timing: 6 months prior to filling of adjacent ponds

Status: Completed March-April 2022

Surface water in Mardie Pool is variably less or more saline than groundwater in the regional bores. It is likely that a freshwater lens exists within the pool and the adjacent unconfined aquifer, forming a zone of fresher water above the denser (saline) regional groundwater and extending up the creek valley. Water level and quality of the fresh water in Mardie Pool is probably maintained through dry seasons by base flow from the upstream and lateral alluvial channel sediments. The pressure head created by baseflow has possibly acted to prevent ingress of the surrounding denser water, counteracting the slight density difference. An increase in the salinity of the regional groundwater or a change in the groundwater level (as may be caused by seepage from the ponds) may therefore lead to changes in the fresh-saltwater interface through density equalisation; this may in turn affect the quality of the water feeding Mardie Pool (from AQ2 2020).

A series of monitoring bores was installed adjacent to the Secondary Crystalliser upgradient from Mardie Pool to serve as an early warning of changes in salinity and water level which could be evident if seepage were to occur from the crystallisers (Figure 2 - MP05, MP13 to MP16).

Additionally bores were installed parallel to Mardie Creek, outside the heritage buffer zone and between Mardie Pool and the Secondary Crystalliser (Figure 2, sites MP02 to MP04).

A series of similar bores was placed up-gradient from the Primary and Secondary Crystallisers for background monitoring (MP06 to MP10). To characterise base flow in the Mardie Creek channel, three bores (MP17, MP18, MP19) were placed along the creek line upstream from the Secondary Crystallisers.

A background bore (MP01) proposed for the southern side of Mardie Pool was not permitted by the traditional owner group. All bores were fully screened from water table to nominally 15-20 mbgl to allow for salinity profiling with depth.

All original proposed Terrestrial bore locations and purposes are described in Table 1. Several bore locations were adjusted during installation to reflect pond layout design changes, while maintaining the original design purpose and functionality.

It was proposed to install a second series of closely spaced nested or fully screened bores adjacent to Mardie Pool. These bores were not permitted to be installed due to restricted access (heritage).

Table 1 Terrestrial Monitoring Network

Location	Bore ID	Proposed Easting	Proposed Northing	Design	Purpose
Mardie Pool – Outside Channel	MP01	390722	7657005	Fully screened	Background monitoring – Not installed due to heritage constraints
	MP02	390829	7657151	Fully screened	Second line of detection of seepage from Secondary Crystalliser
	MP03	390717	7657192	Fully screened	
	MP04	390943	7657131	Fully screened	
Secondary Crystalliser – Adjacent	MP05	391120	7657108	Fully screened	First line of early detection of seepage from Secondary Crystalliser
	MP13	390950	7657224	Fully screened	
	MP14	391049	7657161	Fully screened	
	MP15	391216	7657046	Fully screened	
	MP16	391326	7656967	Fully screened	
	MP17	392366	7656651	Fully screened	
Secondary Crystalliser – Up Gadient	MP06	393360	7656788	Fully screened	Background monitoring up-gradient from Secondary Crystalliser
	MP07	394436	7657258	Fully screened	
Primary Crystalliser	MP08	389491	7659742	Fully screened	Down-gradient monitoring of Secondary, upgradient of Primary
	MP09	389506	7661737	Fully screened	Background monitoring up-gradient from Primary Crystalliser
	MP10	389698	7663491	Fully screened	
Mardie Creek - Upstream	MP17	392366.2	7656651	Fully screened	Upstream channel monitoring for base flow, adjacent to crystalliser
	MP18	392540	7656043	Fully screened	Upstream channel monitoring for base flow
	MP19	395142	7655015	Fully screened	Upstream channel monitoring for base flow

4.2 Coastal Bores - Mangroves and Algal Mat Ecosystems

Proposed Timing of Installation: 6 months prior to filling of adjacent ponds

Status: Completed June - October 2023

The groundwater regime which supports coastal ecosystems at the Mardie Project (mangrove habitat adjacent to tidal creeks, and algal mat communities on the supratidal flats) may potentially be disrupted by seepage from evaporation ponds. It is conceivable that groundwater seepage and mounding beneath evaporation ponds, should it occur, may result in changes to groundwater gradients and quality near these receptors.

To permit detection and mitigation of potential induced groundwater regime changes, a monitoring bore network has been installed along the western side of the planned evaporation ponds prior to commissioning. The original proposed network is described in Figure 3 and Table 3. Final locations have been adjusted to reflect minor pond layout design changes, while maintaining the original design purpose and functionality. The network consists of the following:

- Three transects of bore sites, each consisting of three sets of bores between the sea wall of the ponds and the nearest mangrove stands;
- Two further sites adjacent to the sea wall of the evaporation ponds, within mapped areas of algal mat habitat, and
- Each bore site having two discrete monitoring bores screened individually (one near the water table and one at depth), to quantify the magnitude of vertical hydraulic gradients and vertical variations of salinity.

The transects are designed to facilitate monitoring for water quality and hydraulic gradients which may quantify the delivery of fresh water to mangrove stands as suggested in some literature (e.g. Hayes et al 2018).

Two individual monitoring sites have been placed to enable detection of vertical hydraulic gradients (and changes in these gradients) which may aid the delivery of moisture and nutrients to the algal mat ecosystems existing on the supratidal flats, as detailed by Porada et al (2007).

Table 3 Coastal (Playa) Monitoring Network

Location ID	Easting	Northing	Type	Purpose
Playa Site 1_1	383214.2	7651847	Transect	Monitor gradients and salinity near mangroves
Playa Site 1_2	382967.4	7652073		
Playa Site 1_3	382699.4	7652277		
Playa Site 2_1	384792.6	7654721	Single	Monitor gradients and salinity near algal mat habitat
Playa Site 3_1	386135.7	7657344	Single	Monitor gradients and salinity near algal mat habitat
Playa Site 4_1	386299.9	7660800	Transect	Monitor gradients and salinity near mangroves
Playa Site 4_2	385758.8	7660974		
Playa Site 4_3	385193.4	7661163		
Playa Site 5_1	387315.4	7664443	Transect	Monitor gradients and salinity near mangroves
Playa Site 5_2	387219.8	7664484		
Playa Site 5_3	387120.8	7664524		

5. GROUNDWATER MONITORING AND INVESTIGATION PROGRAM

5.1 Water Quality

The groundwater monitoring program commenced for each area soon after network installation.

Ongoing monitoring of inland (Terrestrial) bores consists of installed logger or quarterly visits to each bore during which the following parameters are recorded:

- Quarterly static groundwater level.
- Quarterly electrical conductivity and pH profiling in fully screened bores.

Logger data from several sites to characterise groundwater level changes in greater detail. Water quality samples have been taken from selected bores for laboratory analysis on a quarterly cycle since inception (March 2022). Water quality and level data is now available across several wet and dry seasons including significant rainfall events, and is now sufficient to determine background parameters. Following filling of adjacent ponds, laboratory sample collection may be reduced to half-yearly or as advised by regulators.

Due to accessibility restrictions in the coastal area (tides, risk of bogging), remote monitoring equipment has been installed in the coastal bores. Data collection consists of:

- Hourly groundwater level via loggers and telemetry
- Initial in-situ salinity (EC) measurements (Quarterly)
- EC logger installation with monthly (at least) downloads (Pending)

Field and laboratory data will be assessed to determine the need for adjustment of the monitoring regime, or intervention in the event that water quality parameters exceed criteria set in the Groundwater Monitoring and Management Plan.

5.2 Hydraulic Testing

Where possible monitoring bores have been tested to determine hydraulic parameters of the various geological formations. Investigation has taken the form of falling head tests, rising head tests or micro-pumping tests. Hydraulic parameters have and will be used as input to groundwater and seepage modelling.

5.3 Periodic Review

Ongoing results from acquisition of new hydrogeological information will permit the overall groundwater monitoring and investigation program to be regularly reviewed for suitability. Where necessary the network design and monitoring program will be altered or expanded to reflect needs of the ongoing investigations. This will allow for in-progress adjustment of the drilling programs (bore locations and design), recommendations for future drilling investigations, and changes to testing methods. Results of data analysis and seepage modelling may also inform future decisions for bore placement, design and testing.

6. GROUNDWATER AND SEEPAGE MODELLING

AQ2(2020) identified opportunities for improvement of seepage modelling previously undertaken for the Mardie Project. The hydrogeology of the area has been studied in detail as part of mining dewatering and water supply projects located further inland, however, the interactions between fresh and more saline water in the area of the proposed ponds require further quantification, including groundwater recharge processes. Of particular interest are the freshwater recharge processes associated with Mardie Pool, and the reflux processes and salinity exchanges associated with water that is understood to support areas of algal mats near the Project area.

6.1 Staged Modelling Process

A staged approach will be applied to the groundwater modelling investigation, whereby sectional modelling representative of the key process areas (seawater ponds, brine ponds and crystalliser ponds) is undertaken progressively. In this form, each modelled section should be completed before the commencement of pond operations in the represented location.

Once pond operations start in a specified area, data from adjacent groundwater monitoring bores (levels, salinity) may be used to refine the conceptual understanding and inform future modelling. In this way progressive improvement of modelling methods and results should occur with each new section model. Learnings will be applied to new models and retrospectively where re-modelling of earlier sections is carried out.

Modelling results to date have indicated that the predominant groundwater movement and effects will occur perpendicular to the coast (parallel to the dominant flow direction), and that induced flow changes will not propagate northward along the pond train. Therefore, it is implied that modelling which is completed at a particular pond area before filling of that pond will not be affected by the filling of ponds earlier in the pond sequence.

As significant results become available (and conceptual understanding is improved), the GMMP should be updated to reflect these progressive modelling results as required. The proposed staged modelling schedule is outlined in Table 4.

Table 4 Proposed Modelling Schedule

Representative Section	Project Element(s)	Status	Projected Modelling Completion
Pond 1	Ponds 1-4	Complete	Complete
Pond 6	Ponds 5-7	In progress	5 January 2024
Mardie Pool	Crystallisers	In progress	5 January 2024
Pond 8	Ponds 8-9	Pending	Early February 2024

Groundwater underlying the project area is hypersaline near the coast as a result of evapo-concentration, and fresher at locations further inland. There is also the potential for groundwater recharge, from surface water flows, that may also periodically recharge the system. Management of the evaporation ponds may intercept some of the recharge across the coastal flood plain area. At present it is not well understood:

- If vegetation in the area of Mardie Pool utilises fresher, recent recharge to groundwater, and if this fresher water persists for significant periods of time or support Mardie Pool.
- How reflux processes support algal mats located in the project area.

The sectional modelling work is designed to assess the potential for the conditions outlined above to exist under a range of plausible hydrogeological conditions for the area.

6.2 Modelling Approach

6.2.1 Data Review and Conceptualisation

Data review is ongoing to underpin the development of each conceptual hydrogeological section . Key aspects of the conceptual hydrogeological models are :

- Development of a static hydrostratigraphic model for the project area (using Leapfrog Geo). This takes the form of a 3D representation of the major hydrogeological units, topography, water table and groundwater salinity. This will also highlight areas of potential groundwater-surface water interaction. Outputs from this model are being used as key inputs to the sectional modelling approaches outlined below.
- Interpretation of hydrostratigraphic pressures, gradients and salinity as they apply to the groundwater flow system and recharge and discharge processes.
- Estimates of hydraulic parameters from:
  - Analysis of data from hydrogeological testing.
  - Analysis of any Particle Size Distribution (PSD) data that may have been collected from geotechnical investigations.
- Identification of areas or sources of groundwater recharge including recharge from rainfall associated flood plain and flood channels.
- Identification of areas or points of groundwater discharge including groundwater outflow to the coast and surface pools, evapotranspiration from vegetation and shallow water tables.
- Estimates of groundwater recharge and discharge based on regional groundwater gradients.
- Catchment water balances are being developed based on regional groundwater levels, recharge and discharge estimates and the hydrogeology of the project area.
- Identification of key components of the catchment water balance that may result from development of the ponds (for example groundwater recharge and discharge processes).

The ongoing review will identify any data gaps or critical uncertainties with the conceptual model that require attention as part of the groundwater modelling.

6.2.2 Sectional Modelling

Density dependent groundwater flow modelling is being used to assess the groundwater conditions in and around the proposed Project ponds. This type of modelling simulates groundwater flow and also includes the interactions between waters of varying salinity (fresh, brackish, saline and hyper-saline). An assessment of hydraulic loading effects due to overbearing mass of above-ground structures and varying density brine will also be incorporated into the modelling.

To allow simulation of the hydrogeological conditions across the Project site, modelling will simulate appropriately located sections in 2 dimensions. These sections are aligned in the direction of groundwater flow and extend from upstream of the ponds, across the pond areas and the areas of vegetation and pools and to the coastline. Using this approach, hydrogeological variability and salinity conditions across the project area can be simulated. A number of section models may also be combined, or "extruded" to simulate processes that are not readily simulated with a 2 Dimensional (2D) modelling approach. This could include pond leakage or concentrated flow channel recharge.

For each section ongoing work is developing the following hydrogeological framework that includes:

- The groundwater flow system of the area, with maximum groundwater levels upstream of the proposed ponds and flows down gradient towards the coast.
- Groundwater flow components that are influenced by groundwater salinity (for example the flow of denser groundwater flow from coast areas inland, or the development of salinity driven flows under coastal evaporation areas or near the salt water interface).
- Key aquifer units within the alluvial aquifer (gravels, sands, clays) as they may impact the interactions between groundwater recharge and discharge processes.
- Aquifer parameters for key aquifer hydrogeological units.
- Groundwater recharge and discharge processes, including:
  - inflow from upstream,
  - outflow to downstream / the coastal salt water interface,
  - diffuse overland flow recharge,
  - focussed or river channel recharge (noting that if this is important a number of 2D models will need to be "extruded" or given a meaningful width to simulate these processes),
  - use by groundwater dependent vegetation (evapotranspiration), and
  - evaporative losses from shallow water tables.

These conditions are used as model inputs, and the models are being used to simulate the resulting groundwater conditions of interest, including water levels and salinity distributions (i.e., fresh water pools and groundwater salinity distributions).

As far as practicable, the models will be used to simulate observed conditions (groundwater levels and observed groundwater salinities). The extent to which this results in model calibration depends on the data available at each section location. A set of hydrogeological conditions would normally be deemed plausible if the model is able to simulate groundwater levels and salinities using defendable or reasonable aquifer parameters. The current level of uncertainty may mean that the range of aquifer parameters could be large. To address this, the approach includes ranges of aquifer parameters as well as the potential for a hydrogeological uncertainty to influence the outcomes (i.e., the types of aquifer units may be varied as well as the parameters used to define each aquifer unit). This approach is proposed to prevent bias in the assessment. Depending on the complexity of the models developed, it may be possible to use some automated calibration techniques, however it is anticipated that the majority of the work will be completed using a manual model calibration approach.

Key outcomes of the modelling include:

- The hydrogeological conditions that could support zones of fresh water in the areas of the proposed ponds, and the reflux processes that may support algal mats.
- Areas of enhanced permeability that result in enhanced recharge or greater groundwater flow.
- Barriers to flow that prevent the movement of more saline water.
- Area of uncertainty that required further investigation.
- Flow processes in areas upstream of the proposed ponds, for input into the regional flow modelling.

The modelling approach, set up, simulation, results and recommendations are being included in staged reports (as more section modelling results become available) to allow review as well as provide information required for approval / environmental documents.

6.2.3 Regional Groundwater Modelling

Groundwater abstraction was originally proposed for the Mardie Project. In the context of the project as currently designed, there is no groundwater abstraction for process water supply or pond operations.

Therefore, regional groundwater modelling (to assess cumulative impacts in conjunction with pumping from the Sino Iron project) is no longer recommended.

6.2.4 Reporting

Work will be documented in progressive reports when each phase of the staged modelling program is complete. The reports will include details on the following:

- The outcomes of the data review and hydrogeological conceptualisation;
- Groundwater model development;
- Model calibration;
- Model predictions and uncertainty (or sensitivity);
- Discussion of the model limitations and areas of remaining uncertainty; and
- Conclusions and recommendations for future work.

We trust this memo report meets your requirements. Please contact us if you have any queries.

Regards,

Bruce	*Duncan*
Hydrogeologist	Director / Consulting Hydrogeologist

Author: BPH, KLR(21/12/23)
Checked: DGS (21/12/23)
Reviewed: DGS (21/12/23)

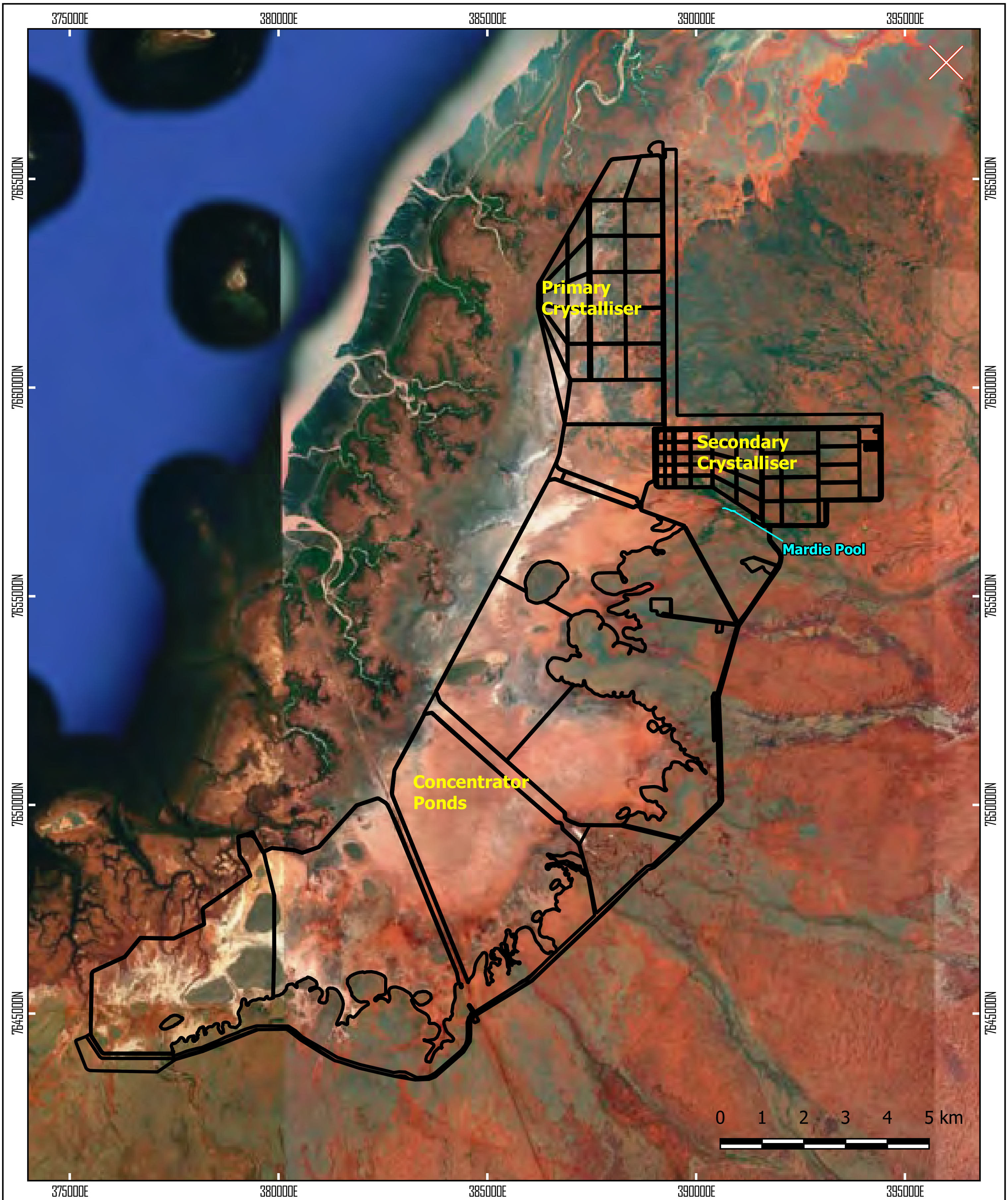
Attached:
Figure 1 Location and Site Layout
Figure 2 Terrestrial Monitoring Network
Figure 3 Coastal Monitoring Network

References

AQ2, 2020. *Mardie Project – Desktop Groundwater Risk Assessment*. Memo Report prepared for Mardie Minerals Ltd. November 2020.

Hayes MA, Jesse A, Welti N, Tabet B, Lockington D, Lovelock CE. *Groundwater enhances above- ground growth in mangroves.* J Ecol. 2019;107:1120–1128. https://doi.org/10.1111/1365-2745.13105

Porada H, Bouougri,E. and Ghergut,J., 2007. Hydraulic conditions and mat-related structures in tidal flats and coastal sabkhas.



Legend

DFS Disturbance Footprint

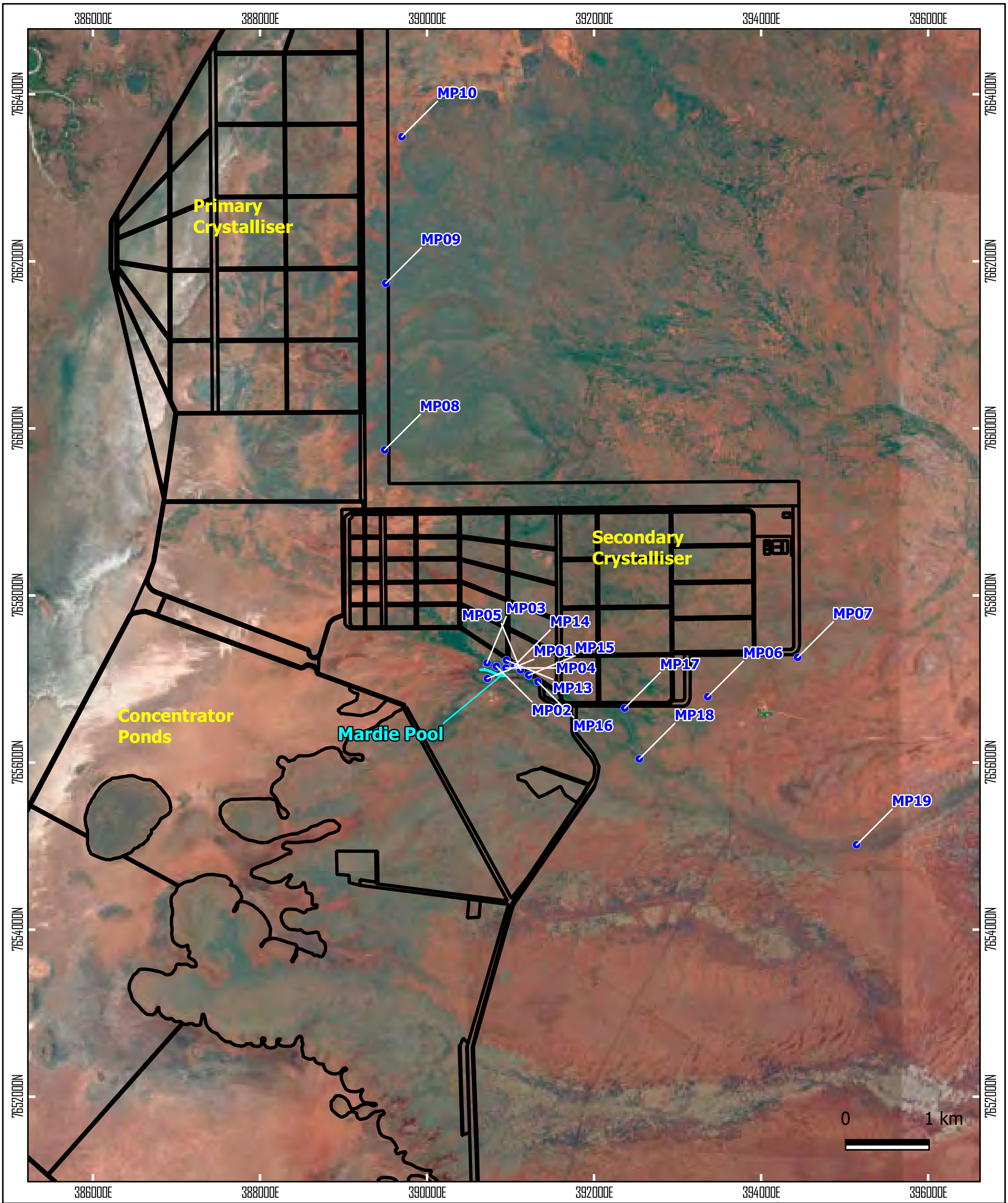
Mardie Pool

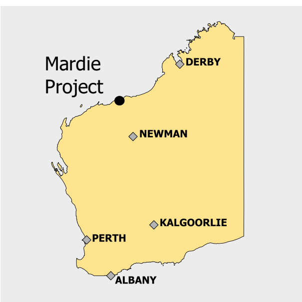
AQ2

Figure 1

Location and Site Layout

AUTHOR: BPH	REPORT NO: 032a	Notes and Data Sources:
DRAWN: BPH	JOB No: 293	Base image (C) Google Maps
DATE: 15/10/2021	Coordinates: MGA Zone 50	DFS Site Layout supplied by Mardie Minerals





Legend

DFS Disturbance Footprint

AUTHOR: BPH
DRAWN: BPH
DATE: 11/11/2021

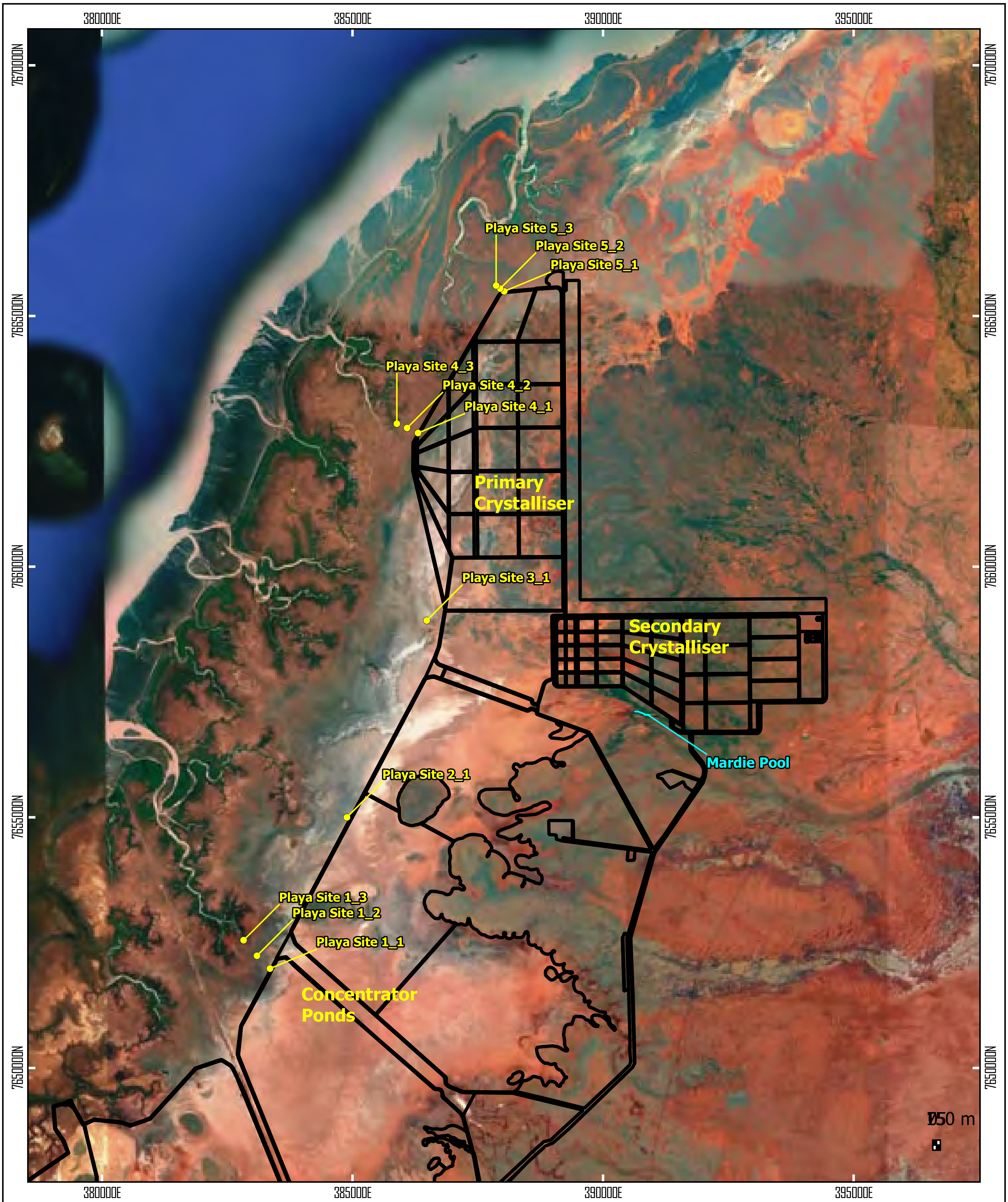
REPORT NO: 032b
JOB No: 293
Coordinates: MGA Zone 50

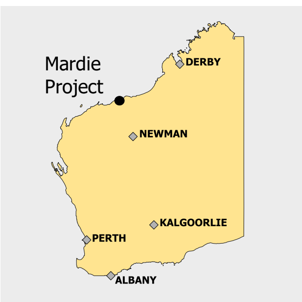
Notes and Data Sources:
Base image (C) Google Maps
DFS Site Layout supplied by Mardie Minerals

AQ2

Figure 2

Terrestrial Monitoring Network





Legend

- Coastal Monitoring Network
- DFS Disturbance Footprint
- Mardie Pool

AUTHOR: BPH
DRAWN: BPH
DATE: 15/10/2021

REPORT NO: 032a
JOB No: 293
Coordinates: MGA Zone 50

Notes and Data Sources:
Base image (C) Google Maps
DFS Site Layout supplied by Mardie Minerals

AQ2

Figure 3

Coastal Monitoring Network

Appendix B: Mardie Project – Status of Hydrogeological Investigations (AQ2 , 21 December 2023)

AQ2 Pty Ltd
ABN 38 164 858 07

Ground Floor
1 Howard Street
Perth WA 6000
Tel +61 8 9322 9733

www.aq2.com.au

Memo

To	Spencer Shute, Matt Spence	Company	Mardie Minerals Pty Ltd
From	Bruce Harvey, Duncan Storey	Job No.	293H
Date	21/12/2023	Doc No.	032c
Subject	Mardie Project – Ongoing Investigation and Monitoring Program - Revised		

1. INTRODUCTION

Mardie Minerals' Mardie Project is located on the Pilbara coastline of Western Australia, approximately 100 km south-west of Karratha (Figure 1). The project includes the construction of extensive evaporation ponds and crystallisers for the extraction of salt products from sea water.

The initial environmental impact assessment for the Mardie Project identified that the understanding of the risks posed to vegetation, local groundwater and pools as a result of saline seepage from the Project's proposed concentration and crystallisation ponds should be improved. A Groundwater Risk Assessment (GRA) was provided to Mardie Minerals by AQ2 in 2020 (AQ2 document 293C_009b). The GRA document discussed the potential impacts the preliminary project plan may have on groundwater receptors in the vicinity of Mardie Pool and coastal habitats. The areas of focus for this were:

- Potential impacts due to the location of secondary salt crystallisers, which under the original (or DFS) project are proposed to be located north-east of Mardie Pool near the south-western boundary of the Fortescue River alluvial valley.
- Risk to coastal vegetation (primarily mangrove habitat) due to possible seepage of hypersaline water from Evaporation Ponds 1-9 and Primary Crystallisers into the near-coast groundwater system.

Concern has since been raised regarding the presence of an algal mat ecosystem on the supratidal flats which exists beneath and to the west of the proposed location of the Evaporation Ponds. It was inferred that the existence of algal mats may be due to upwelling or overtopping fresh groundwater which was thought to bring nutrients to surface and dilute the hypersaline fluids (which develop due to evaporation). It was unclear whether the coastal groundwater regime at Mardie is similar in structure to this concept. Vertical distribution of salinity beneath the salt flats, and the location of the seawater interface were also undefined across much of the development envelope.

AQ2 was engaged by Mardie Minerals to propose a monitoring bore network which would permit the ongoing long-term monitoring of groundwater quality in the vicinity of sensitive receptors.

2. DFS PROJECT LAYOUT

Proposed DFS project layout is presented in Figure 1. Key characteristics of the layout are:

- Concentrator and Primary crystalliser ponds extending along approximately 25 km of coastal supratidal salt flats.
- Seawater intake to be at the southern-most pond, with brine concentration increasing in ponds to the north.
- Western sea wall of the ponds is proposed to be adjacent to or impinging upon mapped algal mat habitat on the lower (western) side of the supratidal flats.
- Secondary crystalliser ponds are proposed to be located immediately north of Mardie Pool on the eastern side of the main concentrator ponds.

Under the revised Optimised Mardie Project, the layout has been amended, with the crystallisers moved north and back from the coast.

3. FURTHER INVESTIGATIONS

While substantial research has already been carried out to characterise the hydrogeological regime at the Mardie Project, it has been identified that further background investigations will enhance knowledge and assist in future groundwater management. In particular several avenues for further work have been noted to close data gaps.

Proposed Timing of Investigations: Prior to operations commencing

Status: Completed January 2023

3.1 Airborne Electromagnetic Data

An Airborne Electromagnetics (AEM) survey was flown in the area in 2010 by Fugro Airborne Surveys. The survey has wide line spacing, however lines do cross Mardie Creek in several places. It had been postulated that reprocessing of the AEM data may provide information relevant to the salinity profile of water in the near surface.

The AEM survey data has been used for regional analysis of bulk conductivity distribution and its relationship to salinity measured in monitoring bores. The vertical resolution of 10m (between conductivity-depth slices) was thought unlikely to be improved significantly by reprocessing to allow more detail to be resolved in the near-surface.

Instead of reprocessing TEMPEST data, a Loupe TEM ground geophysics survey was commissioned and carried out in August 2022, with survey lines targeting accessible areas around Mardie Pool as well as existing tracks. Processed Loupe TEM data provided approximately 1m horizontal and vertical resolution of bulk conductivity along survey lines, contributing to the understanding of salinity distribution in groundwater around Mardie Pool.

3.2 Mardie Pool Bathymmetry

Bathymmetric data for Mardie Pool may be useful when characterising the nature of the potential fresh water lens which may encompass the pool and surrounding subsurface.

Due to the wishes of traditional owner groups for personnel to avoid entering Mardie Pool or placing any permanent structures within it, it was determined that the physical shape of the Mardie Pool may be assessed through a combination of methods, being:

- Historical and ongoing terrestrial photos of the Pool over a range of water level conditions (i.e., between Mardie Pool being empty and full);
- Drone footage of Mardie Pool during both flood / wet and dry periods;
- Improved terrestrial location/elevation survey to determine the RL of the Pool water surface as seen in historical photos; and
- Non-permanent installation of a depth logger within the Pool to assist with assessment of Mardie Pool water levels.

All of these methods have been in use since October 2022 to build a 3-dimensional bathymetric profile for Mardie Pool under the current access constraints.

3.3 Geological Controls on Creek and Pool Development

It was noted by DAWE that Mardie Creek may have developed coincident with a mapped geological fault. The available geological and geophysical mapping has been assessed for correlations between basement faulting near Mardie Pool. Mardie Creek did not appear to coincide with faults mapped in published geological mapping (Yarraloola 1:250 000 Geology) or those presented in the Airborne EM report (Fugro Airborne Surveys 2010). Results of drilling also indicate that Mardie Pool is likely hosted entirely within the clay/gravel overbank deposits of the Fortescue River alluvial fan. Therefore, no correlation was drawn between the location of the creek and any mapped faults.

4. PROPOSED MONITORING BORE NETWORK

4.1 Terrestrial Bores - Mardie Pool and Crystallisers

Proposed Timing: 6 months prior to filling of adjacent ponds

Status: Completed March-April 2022

Surface water in Mardie Pool is variably less or more saline than groundwater in the regional bores. It is likely that a freshwater lens exists within the pool and the adjacent unconfined aquifer, forming a zone of fresher water above the denser (saline) regional groundwater and extending up the creek valley. Water level and quality of the fresh water in Mardie Pool is probably maintained through dry seasons by base flow from the upstream and lateral alluvial channel sediments. The pressure head created by baseflow has possibly acted to prevent ingress of the surrounding denser water, counteracting the slight density difference. An increase in the salinity of the regional groundwater or a change in the groundwater level (as may be caused by seepage from the ponds) may therefore lead to changes in the fresh-saltwater interface through density equalisation; this may in turn affect the quality of the water feeding Mardie Pool (from AQ2 2020).

A series of monitoring bores was installed adjacent to the Secondary Crystalliser upgradient from Mardie Pool to serve as an early warning of changes in salinity and water level which could be evident if seepage were to occur from the crystallisers (Figure 2 - MP05, MP13 to MP16).

Additionally bores were installed parallel to Mardie Creek, outside the heritage buffer zone and between Mardie Pool and the Secondary Crystalliser (Figure 2, sites MP02 to MP04).

A series of similar bores was placed up-gradient from the Primary and Secondary Crystallisers for background monitoring (MP06 to MP10). To characterise base flow in the Mardie Creek channel, three bores (MP17, MP18, MP19) were placed along the creek line upstream from the Secondary Crystallisers.

A background bore (MP01) proposed for the southern side of Mardie Pool was not permitted by the traditional owner group. All bores were fully screened from water table to nominally 15-20 mbgl to allow for salinity profiling with depth.

All original proposed Terrestrial bore locations and purposes are described in Table 1. Several bore locations were adjusted during installation to reflect pond layout design changes, while maintaining the original design purpose and functionality.

It was proposed to install a second series of closely spaced nested or fully screened bores adjacent to Mardie Pool. These bores were not permitted to be installed due to restricted access (heritage).

Table 1 Terrestrial Monitoring Network

Location	Bore ID	Proposed Easting	Proposed Northing	Design	Purpose
Mardie Pool – Outside Channel	MP01	390722	7657005	Fully screened	Background monitoring – Not installed due to heritage constraints
	MP02	390829	7657151	Fully screened	Second line of detection of seepage from Secondary Crystalliser
	MP03	390717	7657192	Fully screened	
	MP04	390943	7657131	Fully screened	
Secondary Crystalliser – Adjacent	MP05	391120	7657108	Fully screened	First line of early detection of seepage from Secondary Crystalliser
	MP13	390950	7657224	Fully screened	
	MP14	391049	7657161	Fully screened	
	MP15	391216	7657046	Fully screened	
	MP16	391326	7656967	Fully screened	
	MP17	392366	7656651	Fully screened	
Secondary Crystalliser – Up Gadient	MP06	393360	7656788	Fully screened	Background monitoring up-gradient from Secondary Crystalliser
	MP07	394436	7657258	Fully screened	
Primary Crystalliser	MP08	389491	7659742	Fully screened	Down-gradient monitoring of Secondary, upgradient of Primary
	MP09	389506	7661737	Fully screened	Background monitoring up-gradient from Primary Crystalliser
	MP10	389698	7663491	Fully screened	
Mardie Creek - Upstream	MP17	392366.2	7656651	Fully screened	Upstream channel monitoring for base flow, adjacent to crystalliser
	MP18	392540	7656043	Fully screened	Upstream channel monitoring for base flow
	MP19	395142	7655015	Fully screened	Upstream channel monitoring for base flow

4.2 Coastal Bores - Mangroves and Algal Mat Ecosystems

Proposed Timing of Installation: 6 months prior to filling of adjacent ponds

Status: Completed June - October 2023

The groundwater regime which supports coastal ecosystems at the Mardie Project (mangrove habitat adjacent to tidal creeks, and algal mat communities on the supratidal flats) may potentially be disrupted by seepage from evaporation ponds. It is conceivable that groundwater seepage and mounding beneath evaporation ponds, should it occur, may result in changes to groundwater gradients and quality near these receptors.

To permit detection and mitigation of potential induced groundwater regime changes, a monitoring bore network has been installed along the western side of the planned evaporation ponds prior to commissioning. The original proposed network is described in Figure 3 and Table 3. Final locations have been adjusted to reflect minor pond layout design changes, while maintaining the original design purpose and functionality. The network consists of the following:

- Three transects of bore sites, each consisting of three sets of bores between the sea wall of the ponds and the nearest mangrove stands;
- Two further sites adjacent to the sea wall of the evaporation ponds, within mapped areas of algal mat habitat, and
- Each bore site having two discrete monitoring bores screened individually (one near the water table and one at depth), to quantify the magnitude of vertical hydraulic gradients and vertical variations of salinity.

The transects are designed to facilitate monitoring for water quality and hydraulic gradients which may quantify the delivery of fresh water to mangrove stands as suggested in some literature (e.g. Hayes et al 2018).

Two individual monitoring sites have been placed to enable detection of vertical hydraulic gradients (and changes in these gradients) which may aid the delivery of moisture and nutrients to the algal mat ecosystems existing on the supratidal flats, as detailed by Porada et al (2007).

Table 3 Coastal (Playa) Monitoring Network

Location ID	Easting	Northing	Type	Purpose
Playa Site 1_1	383214.2	7651847	Transect	Monitor gradients and salinity near mangroves
Playa Site 1_2	382967.4	7652073		
Playa Site 1_3	382699.4	7652277		
Playa Site 2_1	384792.6	7654721	Single	Monitor gradients and salinity near algal mat habitat
Playa Site 3_1	386135.7	7657344	Single	Monitor gradients and salinity near algal mat habitat
Playa Site 4_1	386299.9	7660800	Transect	Monitor gradients and salinity near mangroves
Playa Site 4_2	385758.8	7660974		
Playa Site 4_3	385193.4	7661163		
Playa Site 5_1	387315.4	7664443	Transect	Monitor gradients and salinity near mangroves
Playa Site 5_2	387219.8	7664484		
Playa Site 5_3	387120.8	7664524		

5. GROUNDWATER MONITORING AND INVESTIGATION PROGRAM

5.1 Water Quality

The groundwater monitoring program commenced for each area soon after network installation.

Ongoing monitoring of inland (Terrestrial) bores consists of installed logger or quarterly visits to each bore during which the following parameters are recorded:

- Quarterly static groundwater level.
- Quarterly electrical conductivity and pH profiling in fully screened bores.

Logger data from several sites to characterise groundwater level changes in greater detail. Water quality samples have been taken from selected bores for laboratory analysis on a quarterly cycle since inception (March 2022). Water quality and level data is now available across several wet and dry seasons including significant rainfall events, and is now sufficient to determine background parameters. Following filling of adjacent ponds, laboratory sample collection may be reduced to half-yearly or as advised by regulators.

Due to accessibility restrictions in the coastal area (tides, risk of bogging), remote monitoring equipment has been installed in the coastal bores. Data collection consists of:

- Hourly groundwater level via loggers and telemetry
- Initial in-situ salinity (EC) measurements (Quarterly)
- EC logger installation with monthly (at least) downloads (Pending)

Field and laboratory data will be assessed to determine the need for adjustment of the monitoring regime, or intervention in the event that water quality parameters exceed criteria set in the Groundwater Monitoring and Management Plan.

5.2 Hydraulic Testing

Where possible monitoring bores have been tested to determine hydraulic parameters of the various geological formations. Investigation has taken the form of falling head tests, rising head tests or micro-pumping tests. Hydraulic parameters have and will be used as input to groundwater and seepage modelling.

5.3 Periodic Review

Ongoing results from acquisition of new hydrogeological information will permit the overall groundwater monitoring and investigation program to be regularly reviewed for suitability. Where necessary the network design and monitoring program will be altered or expanded to reflect needs of the ongoing investigations. This will allow for in-progress adjustment of the drilling programs (bore locations and design), recommendations for future drilling investigations, and changes to testing methods. Results of data analysis and seepage modelling may also inform future decisions for bore placement, design and testing.

6. GROUNDWATER AND SEEPAGE MODELLING

AQ2(2020) identified opportunities for improvement of seepage modelling previously undertaken for the Mardie Project. The hydrogeology of the area has been studied in detail as part of mining dewatering and water supply projects located further inland, however, the interactions between fresh and more saline water in the area of the proposed ponds require further quantification, including groundwater recharge processes. Of particular interest are the freshwater recharge processes associated with Mardie Pool, and the reflux processes and salinity exchanges associated with water that is understood to support areas of algal mats near the Project area.

6.1 Staged Modelling Process

A staged approach will be applied to the groundwater modelling investigation, whereby sectional modelling representative of the key process areas (seawater ponds, brine ponds and crystalliser ponds) is undertaken progressively. In this form, each modelled section should be completed before the commencement of pond operations in the represented location.

Once pond operations start in a specified area, data from adjacent groundwater monitoring bores (levels, salinity) may be used to refine the conceptual understanding and inform future modelling. In this way progressive improvement of modelling methods and results should occur with each new section model. Learnings will be applied to new models and retrospectively where re-modelling of earlier sections is carried out.

Modelling results to date have indicated that the predominant groundwater movement and effects will occur perpendicular to the coast (parallel to the dominant flow direction), and that induced flow changes will not propagate northward along the pond train. Therefore, it is implied that modelling which is completed at a particular pond area before filling of that pond will not be affected by the filling of ponds earlier in the pond sequence.

As significant results become available (and conceptual understanding is improved), the GMMP should be updated to reflect these progressive modelling results as required. The proposed staged modelling schedule is outlined in Table 4.

Table 4 Proposed Modelling Schedule

Representative Section	Project Element(s)	Status	Projected Modelling Completion
Pond 1	Ponds 1-4	Complete	Complete
Pond 6	Ponds 5-7	In progress	5 January 2024
Mardie Pool	Crystallisers	In progress	5 January 2024
Pond 8	Ponds 8-9	Pending	Early February 2024

Groundwater underlying the project area is hypersaline near the coast as a result of evapo-concentration, and fresher at locations further inland. There is also the potential for groundwater recharge, from surface water flows, that may also periodically recharge the system. Management of the evaporation ponds may intercept some of the recharge across the coastal flood plain area. At present it is not well understood:

- If vegetation in the area of Mardie Pool utilises fresher, recent recharge to groundwater, and if this fresher water persists for significant periods of time or support Mardie Pool.
- How reflux processes support algal mats located in the project area.

The sectional modelling work is designed to assess the potential for the conditions outlined above to exist under a range of plausible hydrogeological conditions for the area.

6.2 Modelling Approach

6.2.1 Data Review and Conceptualisation

Data review is ongoing to underpin the development of each conceptual hydrogeological section . Key aspects of the conceptual hydrogeological models are :

- Development of a static hydrostratigraphic model for the project area (using Leapfrog Geo). This takes the form of a 3D representation of the major hydrogeological units, topography, water table and groundwater salinity. This will also highlight areas of potential groundwater-surface water interaction. Outputs from this model are being used as key inputs to the sectional modelling approaches outlined below.
- Interpretation of hydrostratigraphic pressures, gradients and salinity as they apply to the groundwater flow system and recharge and discharge processes.
- Estimates of hydraulic parameters from:
  - Analysis of data from hydrogeological testing.
  - Analysis of any Particle Size Distribution (PSD) data that may have been collected from geotechnical investigations.
- Identification of areas or sources of groundwater recharge including recharge from rainfall associated flood plain and flood channels.
- Identification of areas or points of groundwater discharge including groundwater outflow to the coast and surface pools, evapotranspiration from vegetation and shallow water tables.
- Estimates of groundwater recharge and discharge based on regional groundwater gradients.
- Catchment water balances are being developed based on regional groundwater levels, recharge and discharge estimates and the hydrogeology of the project area.
- Identification of key components of the catchment water balance that may result from development of the ponds (for example groundwater recharge and discharge processes).

The ongoing review will identify any data gaps or critical uncertainties with the conceptual model that require attention as part of the groundwater modelling.

6.2.2 Sectional Modelling

Density dependent groundwater flow modelling is being used to assess the groundwater conditions in and around the proposed Project ponds. This type of modelling simulates groundwater flow and also includes the interactions between waters of varying salinity (fresh, brackish, saline and hyper-saline). An assessment of hydraulic loading effects due to overbearing mass of above-ground structures and varying density brine will also be incorporated into the modelling.

To allow simulation of the hydrogeological conditions across the Project site, modelling will simulate appropriately located sections in 2 dimensions. These sections are aligned in the direction of groundwater flow and extend from upstream of the ponds, across the pond areas and the areas of vegetation and pools and to the coastline. Using this approach, hydrogeological variability and salinity conditions across the project area can be simulated. A number of section models may also be combined, or “extruded” to simulate processes that are not readily simulated with a 2 Dimensional (2D) modelling approach. This could include pond leakage or concentrated flow channel recharge.

For each section ongoing work is developing the following hydrogeological framework that includes:

- The groundwater flow system of the area, with maximum groundwater levels upstream of the proposed ponds and flows down gradient towards the coast.
- Groundwater flow components that are influenced by groundwater salinity (for example the flow of denser groundwater flow from coast areas inland, or the development of salinity driven flows under coastal evaporation areas or near the salt water interface).
- Key aquifer units within the alluvial aquifer (gravels, sands, clays) as they may impact the interactions between groundwater recharge and discharge processes.
- Aquifer parameters for key aquifer hydrogeological units.
- Groundwater recharge and discharge processes, including:
  - inflow from upstream,
  - outflow to downstream / the coastal salt water interface,
  - diffuse overland flow recharge,
  - focussed or river channel recharge (noting that if this is important a number of 2D models will need to be "extruded" or given a meaningful width to simulate these processes),
  - use by groundwater dependent vegetation (evapotranspiration), and
  - evaporative losses from shallow water tables.

These conditions are used as model inputs, and the models are being used to simulate the resulting groundwater conditions of interest, including water levels and salinity distributions (i.e., fresh water pools and groundwater salinity distributions).

As far as practicable, the models will be used to simulate observed conditions (groundwater levels and observed groundwater salinities). The extent to which this results in model calibration depends on the data available at each section location. A set of hydrogeological conditions would normally be deemed plausible if the model is able to simulate groundwater levels and salinities using defendable or reasonable aquifer parameters. The current level of uncertainty may mean that the range of aquifer parameters could be large. To address this, the approach includes ranges of aquifer parameters as well as the potential for a hydrogeological uncertainty to influence the outcomes (i.e., the types of aquifer units may be varied as well as the parameters used to define each aquifer unit). This approach is proposed to prevent bias in the assessment. Depending on the complexity of the models developed, it may be possible to use some automated calibration techniques, however it is anticipated that the majority of the work will be completed using a manual model calibration approach.

Key outcomes of the modelling include:

- The hydrogeological conditions that could support zones of fresh water in the areas of the proposed ponds, and the reflux processes that may support algal mats.
- Areas of enhanced permeability that result in enhanced recharge or greater groundwater flow.
- Barriers to flow that prevent the movement of more saline water.
- Area of uncertainty that required further investigation.
- Flow processes in areas upstream of the proposed ponds, for input into the regional flow modelling.

The modelling approach, set up, simulation, results and recommendations are being included in staged reports (as more section modelling results become available) to allow review as well as provide information required for approval / environmental documents.

6.2.3 Regional Groundwater Modelling

Groundwater abstraction was originally proposed for the Mardie Project. In the context of the project as currently designed, there is no groundwater abstraction for process water supply or pond operations.

Therefore, regional groundwater modelling (to assess cumulative impacts in conjunction with pumping from the Sino Iron project) is no longer recommended.

6.2.4 Reporting

Work will be documented in progressive reports when each phase of the staged modelling program is complete. The reports will include details on the following:

- The outcomes of the data review and hydrogeological conceptualisation;
- Groundwater model development;
- Model calibration;
- Model predictions and uncertainty (or sensitivity);
- Discussion of the model limitations and areas of remaining uncertainty; and
- Conclusions and recommendations for future work.

We trust this memo report meets your requirements. Please contact us if you have any queries.

Regards,

Bruce *Duncan*

Hydrogeologist Director / Consulting Hydrogeologist

Author: BPH, KLR(21/12/23)
Checked: DGS (21/12/23)
Reviewed: DGS (21/12/23)

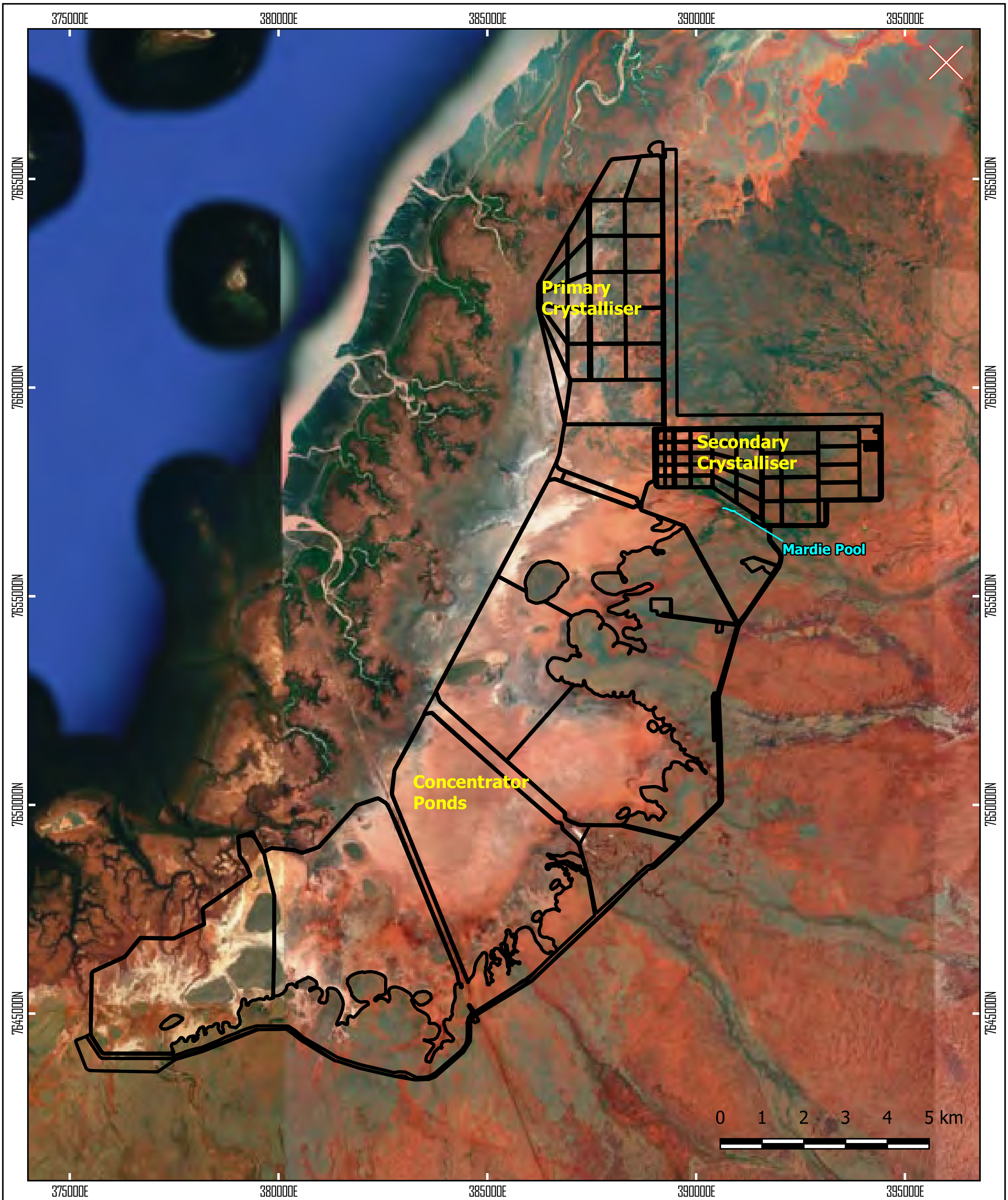
Attached:
Figure 1 Location and Site Layout
Figure 2 Terrestrial Monitoring Network
Figure 3 Coastal Monitoring Network

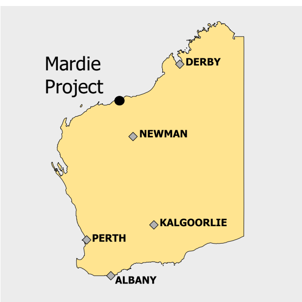
References

AQ2, 2020. *Mardie Project – Desktop Groundwater Risk Assessment*. Memo Report prepared for Mardie Minerals Ltd. November 2020.

Hayes MA, Jesse A, Welti N, Tabet B, Lockington D, Lovelock CE. *Groundwater enhances above- ground growth in mangroves.* J Ecol. 2019;107:1120–1128. https://doi.org/10.1111/1365-2745.13105

Porada H, Bouougri,E. and Ghergut,J., 2007. Hydraulic conditions and mat-related structures in tidal flats and coastal sabkhas.





Legend

DFS Disturbance Footprint

Mardie Pool

AQ2

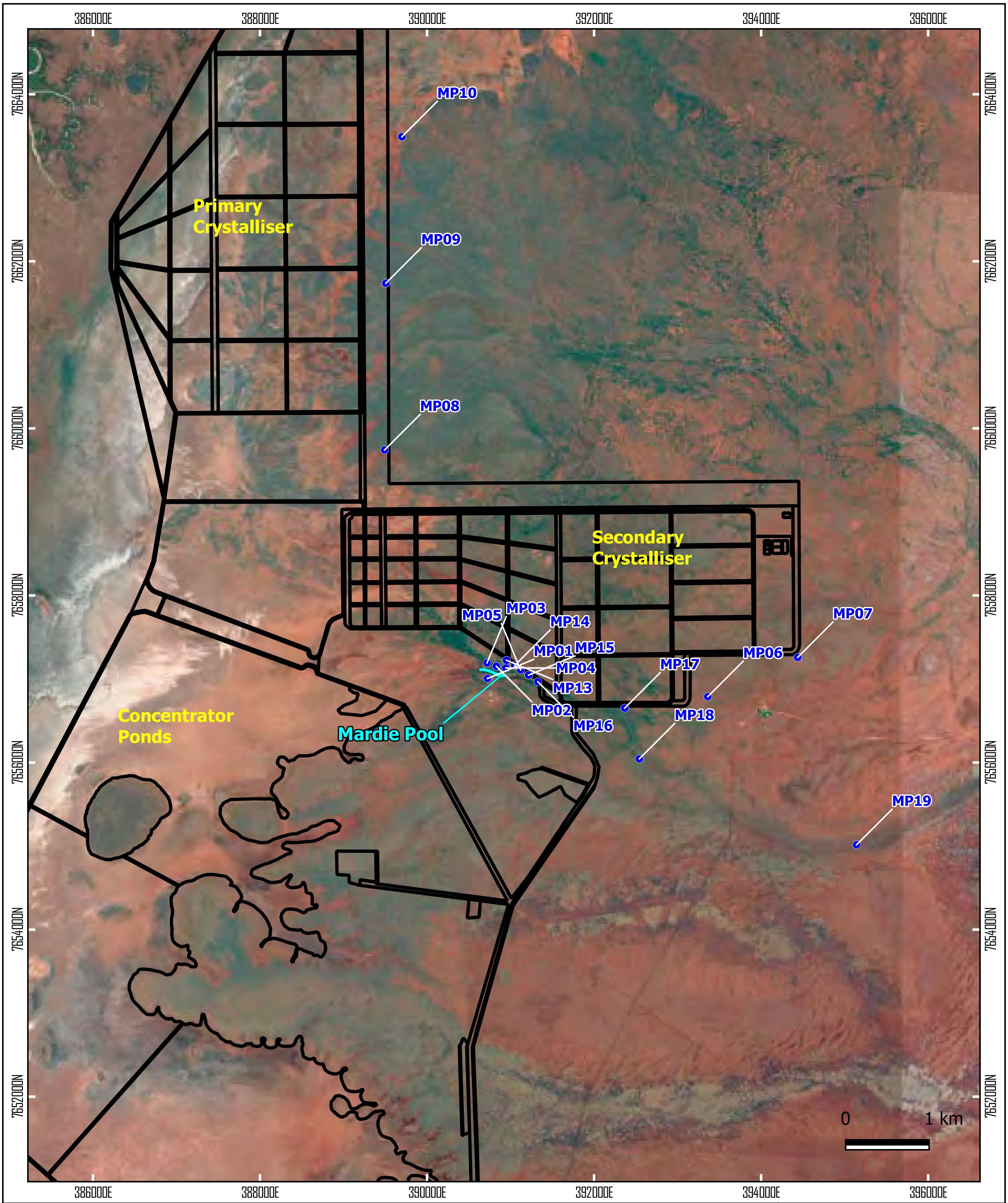
Figure 1

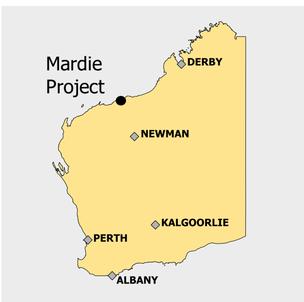
Location and Site Layout

AUTHOR: BPH
DRAWN: BPH
DATE: 15/10/2021

REPORT NO: 032a
JOB No: 293
Coordinates: MGA Zone 50

Notes and Data Sources:
Base image (C) Google Maps
DFS Site Layout supplied by Mardie Minerals





Legend

DFS Disturbance Footprint

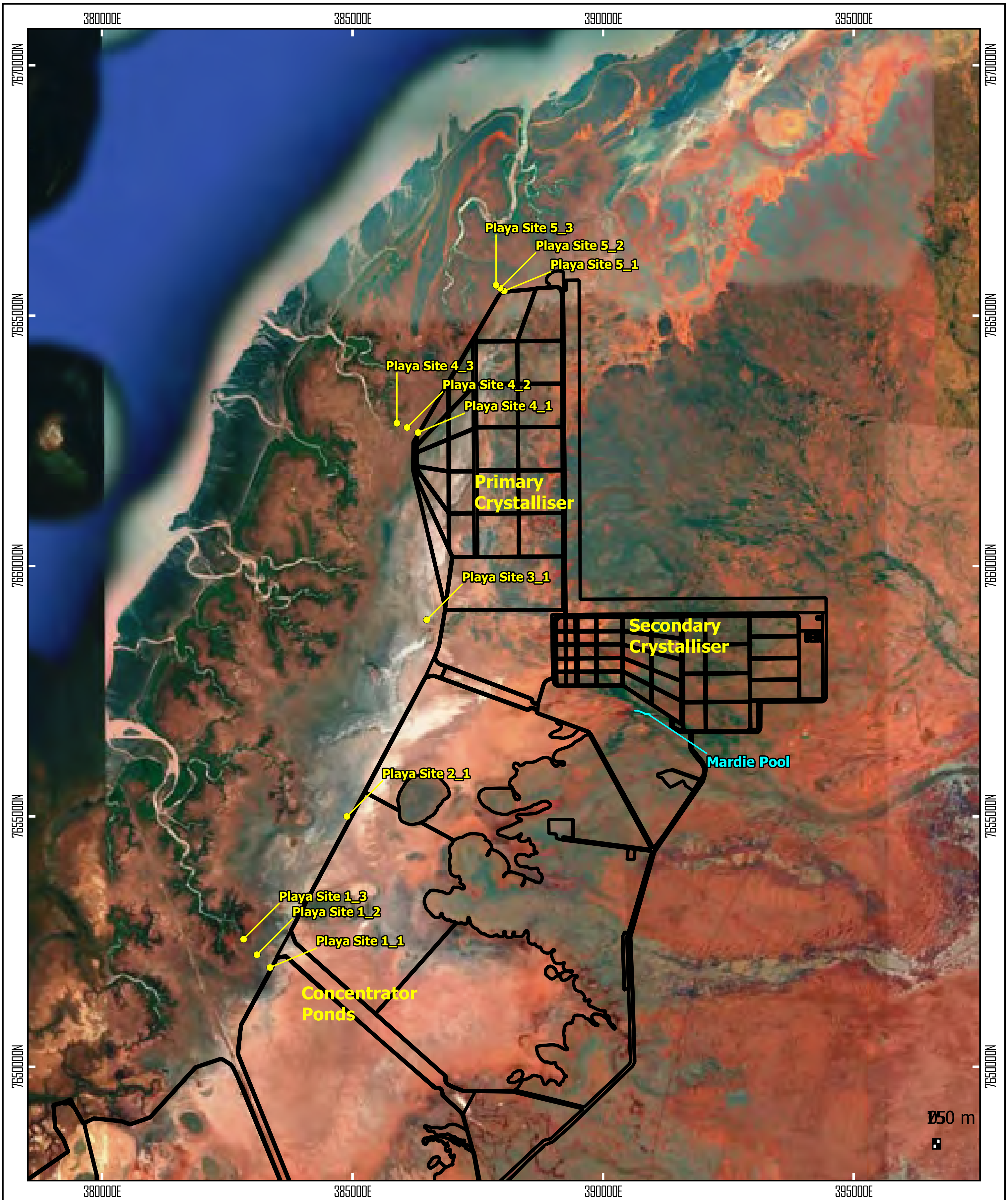
Figure 2

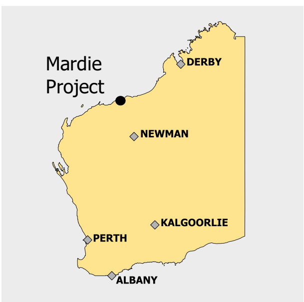
Terrestrial Monitoring Network

AUTHOR: BPH
DRAWN: BPH
DATE: 11/11/2021

REPORT NO: 032b
JOB No: 293
Coordinates: MGA Zone 50

Notes and Data Sources:
Base image (C) Google Maps
DFS Site Layout supplied by Mardie Minerals





Legend

- Coastal Monitoring Network
- DFS Disturbance Footprint
- Mardie Pool

AUTHOR: BPH	REPORT NO: 032a	Notes and Data Sources: Base image (C) Google Maps DFS Site Layout supplied by Mardie Minerals
DRAWN: BPH	JOB No: 293	
DATE: 15/10/2021	Coordinates: MGA Zone 50	

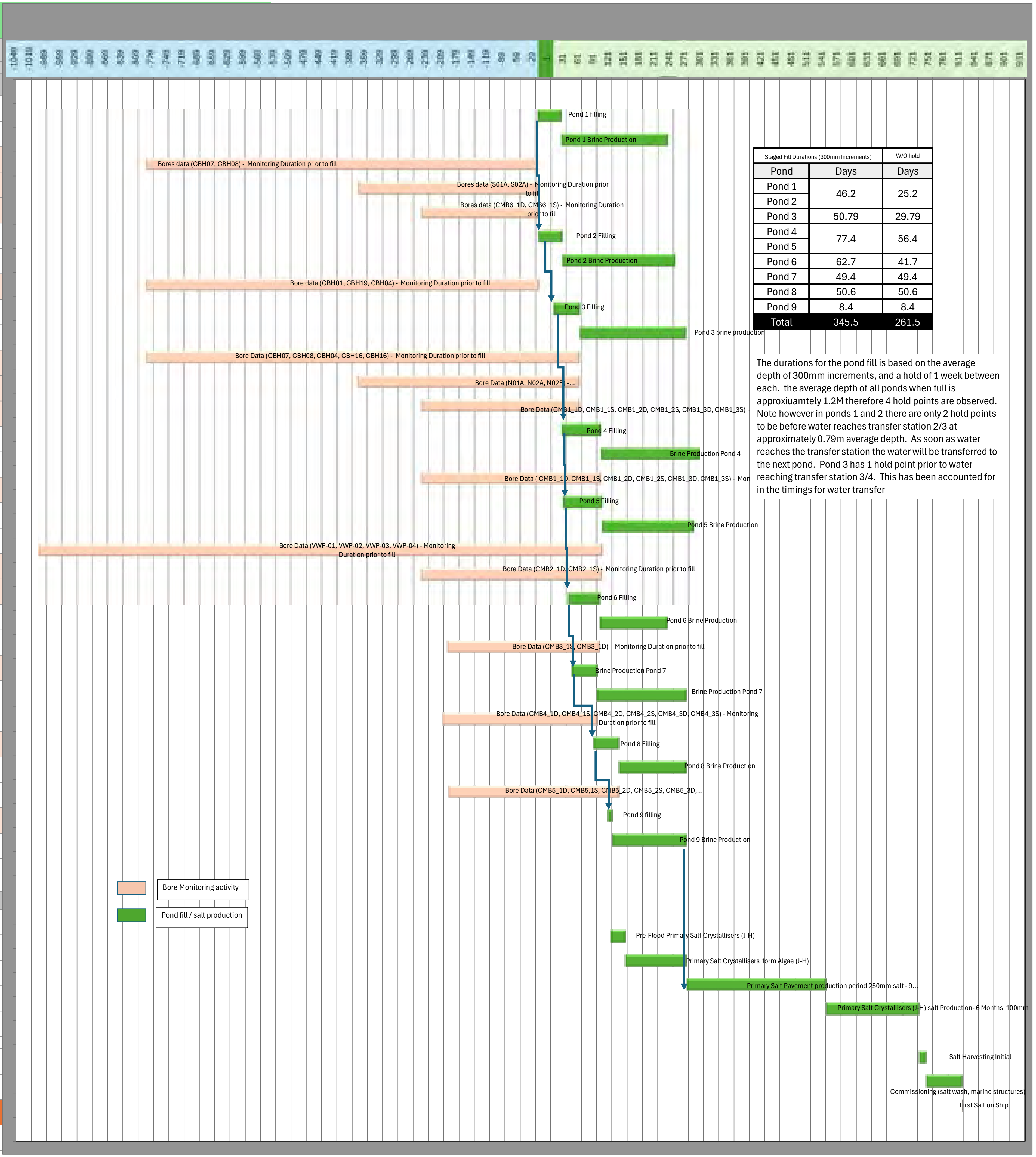
Figure 3

Coastal Monitoring Network

Appendix C: Pond Filling Schedule

Stage Filling Of Pond Schedule

Activity Name	Start	Finish
Pond fill times		
Pond 1 filling	1	44.2
Pond 1 Brine Production		
Bores data (GBH07, GBH08) - Monitoring Duration prior to fill	-769	
Bores data (S01A, S02A) - Monitoring Duration prior to fill	-352	
Bores data (CMB6_1D, CMB6_1S) - Monitoring Duration prior to fill	-228	
Pond 2 Filling	2	46.2
Pond 2 Brine Production	46.2	270.2
Bore data (GBH01, GBH19, GBH04) - Monitoring Duration prior to fill	-771	
Pond 3 Filling	31.14	82
Pond 3 brine production	81.93	291
Bore Data (GBH07, GBH08, GBH04, GBH16, GBH16) - Monitoring Duration prior to fill	-851	
Bore Data (N01A, N02A, N02B) - Monitoring Duration prior to fill	-435	
Bore Data (CMB1_1D, CMB1_1S, CMB1_2D, CMB1_2S, CMB1_3D, CMB1_3S) - Monitoring Duration prior to fill	-310	
Pond 4 Filling	46.38	124
Brine Production Pond 4	123.78	317
Bore Data (CMB1_1D, CMB1_1S, CMB1_2D, CMB1_2S, CMB1_3D, CMB1_3S) - Monitoring Duration prior to fill	-352	
Pond 5 Filling	49.38	127
Pond 5 Brine Production	126.78	307
Bore Data (VWP-01, VWP-02, VWP-03, VWP-04) - Monitoring Duration prior to fill	-1106	
Bore Data (CMB2_1D, CMB2_1S) - Monitoring Duration prior to fill	-355	
Pond 6 Filling	59.55	122
Pond 6 Brine Production	122.25	255
Bore Data (CMB3_1S, CMB3_1D) - Monitoring Duration prior to fill	-299	
Brine Production Pond 7	67.29	117
Brine Production Pond 7	116.69	293
Bore Data (CMB4_1D, CMB4_1S, CMB4_2D, CMB4_2S, CMB4_3D, CMB4_3S) - Monitoring Duration prior to fill	-303	
Pond 8 Filling	109.37	160
Pond 8 Brine Production	159.97	293
Bore Data (CMB5_1D, CMB5,1S, CMB5_2D, CMB5_2S, CMB5_3D, CMB5_3S) - Monitoring Duration prior to fill	-334	
Pond 9 filling	138.51	147
Pond 9 Brine Production	146.91	293
Operations		
Salt Stream		
Pre-Flood Primary Salt Crystallisers (J-H)	143.69	172.69
Primary Salt Crystallisers form Algae (J-H)	172.69	291.69
Primary Salt Pavement production period 250mm salt - 9 months (J-H)	292.69	565.69
Primary Salt Crystallisers (J-H) salt Production- 6 Months 100mm	566.69	748.69
Salt Harvesting Initial	749.69	762.69
Commissioning (salt wash, marine structures)	762.69	833.69
First Salt on Ship	833.69	833.69



Staged Fill Durations (300mm Increments)		W/O hold
Pond	Days	Days
Pond 1	46.2	25.2
Pond 2		
Pond 3	50.79	29.79
Pond 4	77.4	56.4
Pond 5		
Pond 6	62.7	41.7
Pond 7	49.4	49.4
Pond 8	50.6	50.6
Pond 9	8.4	8.4
Total	345.5	261.5

The durations for the pond fill is based on the average depth of 300mm increments, and a hold of 1 week between each. the average depth of all ponds when full is approxiuamtely 1.2M therefore 4 hold points are observed. Note however in ponds 1 and 2 there are only 2 hold points to be before water reaches transfer station 2/3 at approximately 0.79m average depth. As soon as water reaches the transfer station the water will be transferred to the next pond. Pond 3 has 1 hold point prior to water reaching transfer station 3/4. This has been accounted for in the timings for water transfer

Appendix D: Staged Filling of Ponds

APPENDIX D – STAGED FILLING OF PONDS

The transfer of seawater will be undertaken as staged approach, whereby the water depth in the ponds is increased in four staged increments over a period of time (pausing between each depth rise), to allow the concurrent monitoring of groundwater levels and observations of Pond wall integrity and performance.

A minimum of 6 months of groundwater level baseline data will be collected before commencement of filling of any Pond (or Pond group) and therefore there will be both sequential and progressive filling of Ponds (or Pond Groups) and parallel filing where this pre-requisite has been achieved.

The proposed approach to the staged filling is described as follows and shown in the Figures below:

Ponds 1 and 2: Filling Stage 1 and hold point - average depth 0.3m

- The 6-month groundwater baseline pre-requisite was achieved at mid-February 2024
- Primary Seawater Intake pumps (PSWI) will pump water into the adjacent settlement pond (known as 'Pond 0').
- Seawater will then flow from Pond 0 into evaporation Pond 1 (following removal of the temporary coffer dam currently preventing seawater entry into evaporation Pond 1) at a rate of 60,000 m3 (or 60,000 KL) p/hr.
- The filling of Pond 1 will continue for a further 4 days until an average water depth of 0.3m is achieved.
- The total approximate volume moved will be 3,000,000m3.
- As the water depth exceeds an average depth of 0.22m seawater will begin to enter Pond 2.
- The water depth will be maintained as close as possible to 0.3m for a minimum of 7 days, at which point Stage 2 will commence.
- All pumps are fitted with flow meters and water volumes transferred to all ponds will be recorded and used alongside pond level gauges to ensure the correct fill points are met.

Ponds 1 and 2: Filling Stage 2 and hold point - average depth 0.6m

- The filling of Pond 1 and Pond 2 will continue for a further 7 days until an average water depth of 0.6m is reached.
- The water depth will be maintained as close as possible to 0.6m average depth for a minimum of 7 days, at which point stage 3 will commence.
- The estimated volume of seawater is 6,000,000m3 over this period.
- At the conclusion of this Stage 2, the progressive filling of Pond 3 will commence via transfer station 2/3 – the 6-month groundwater baseline pre-requisite was achieved by mid-February 2024.

Ponds 1 and 2: Filling Stage 3 and hold point – average water depth 0.9m

Pond 3, Filling Stage 1 and hold point - average depth 0.3m

- The filling of Pond 1 and Pond 2 will continue for a further 8 days until an average water depth of 0.9 m is achieved;
- The water depth will be maintained as close as possible to 0.9m for a minimum of 7 days, at which point stage 4 will commence.

- The estimated volume of seawater pump is 6,000,000m3 over this period.
- Stage 1 Filling of Pond 3 will commence to a depth of 0.3m.

Ponds 1 and 2: Filling Stage 4 and hold point – average water depth 1.2m

Pond 3, Filling Stage 2 and hold point - average depth 0.6m

- The filling of Pond 1 and Pond 2 will continue for a further 6 days until an average water depth of 1.2m is reached;
- The water depth will be maintained as close as possible to 1.2m average depth for a minimum of 7 days,
- The estimated volume of seawater pump is 6,200,00m3 over this period.
- Filling of ponds 1 and 2 have now reached capacity (19,000,000m3)
- At this point we are in operational phase and as approvals are obtained for all additional pond, pumping will continue via PSWI.
- The filling of Pond 3 will continue until an average water depth of 0.6m is reached.
- The water depth will be maintained as close as possible to 0.6m average depth for a minimum of 7 days, at which point stage 3 will commence.

Pond 3 (Stages 3 and 4) and Progressive Filling of Ponds 4 &5, then Pond 6

- The above methodology will be applied to the remaining ponds 3-6, whereby filling of the ponds will occur in 0.3m average water depth increments, and at each point will be held for a period of 7 days
- Ponds 4 and 5 will commence filling once the groundwater baseline data prerequisite is achieved which will be in early-May 2024.
- Pond 6 will commence filling once the groundwater baseline data prerequisite is achieved which will be in early-May 2024.

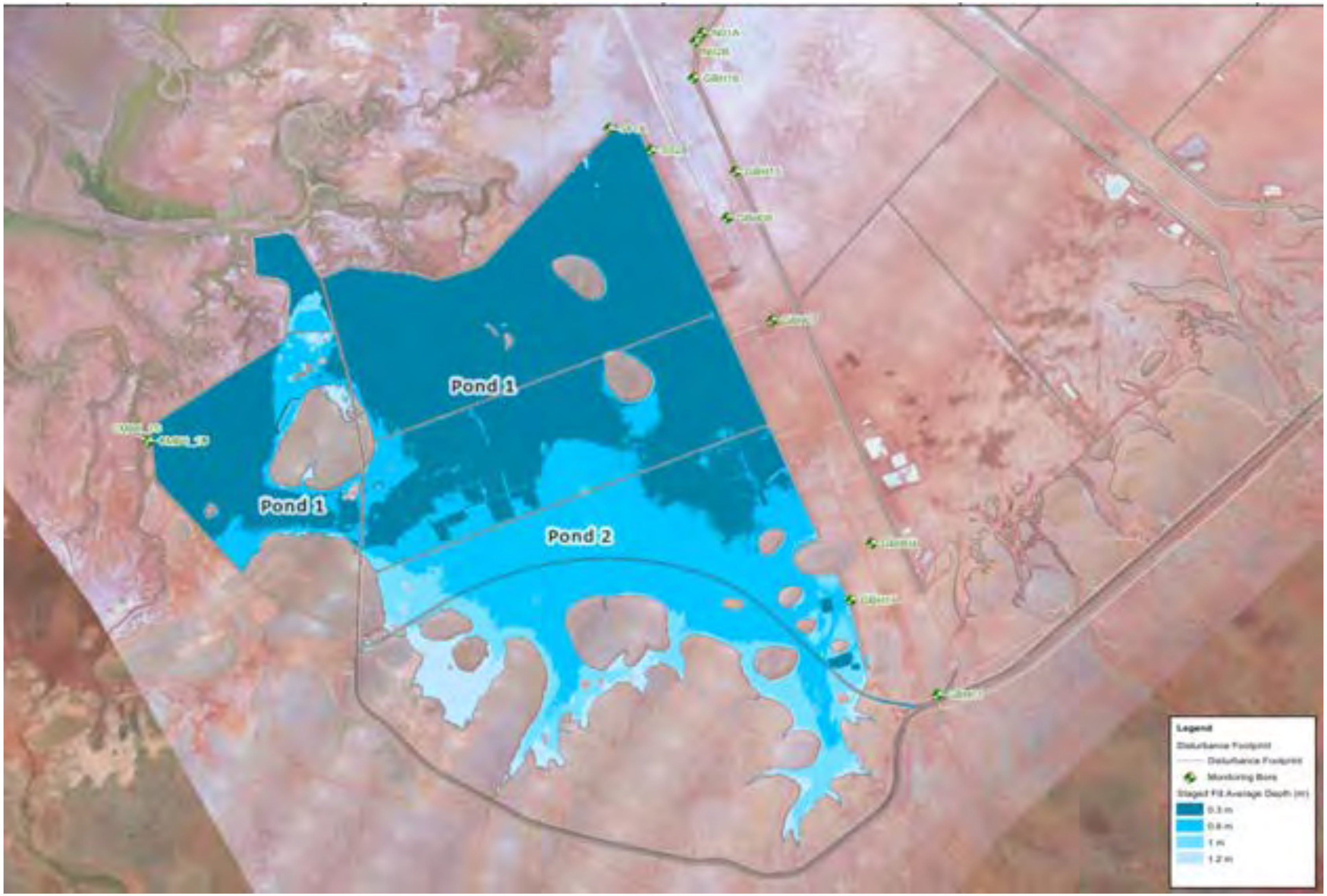


Figure 1 Ponds 1 and 2 Staged Fill Extents

Figure 2 Pond 3 Staged Fill Extents

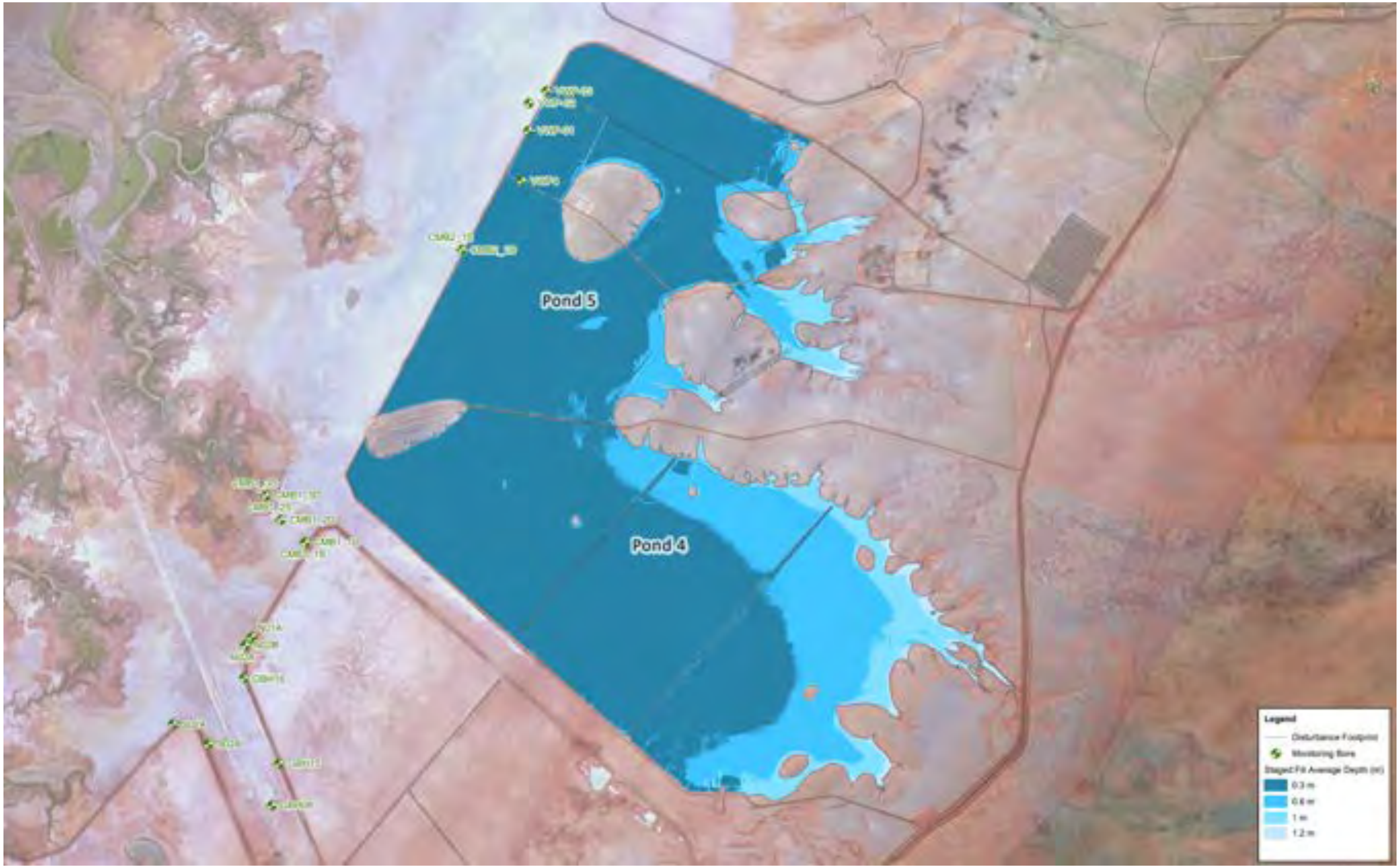


Figure 3 Ponds 4 and 5 Staged Fill Extents

Figure 4 Pond 6 Staged Fill Extents

Appendix E: Mardie Project – Groundwater Monitoring (DAA 2023)

Mardie Project Groundwater Monitoring

December 2023

Project: BCIMinerals/1

STRATEGIC INFORMATION CONSULTANTS

Mardie Project Groundwater Monitoring

December 2023

Client: BCI Minerals Ltd

Project: BCIMinerals/1

Consultants: Anna Hayes
Dr Fiona Evans
Dr Alyce Russell
Sam Joyner

Data Analysis Australia Pty Ltd
97 Broadway
Nedlands, Western Australia 6009
(PO Box 3258 Broadway, Nedlands 6009)
Website: www.daa.com.au
Phone: (08) 9468 2533
Email: daa@daa.com.au
A.C.N. 009 304 956
A.B.N. 68 009 304 956

Executive Summary

BCI Minerals are building a series of solar salt evaporation ponds by the coast at Mardie in Western Australia. There is a possibility that the filling of the ponds will impact local groundwater leading to rising groundwater levels or increased groundwater salinity. They engaged Data Analysis Australia to design a statistically sound method for determining operational trigger thresholds to determine whether groundwater levels differ beyond what would be considered normal after pond filling.

Data Analysis Australia conducted a thorough preliminary analysis of groundwater level data collected from 18 bores on the Mardie site. Medium-term data (around two years) was available for four bores and short-term (around three months) data was available for 14 coastal bores near planned Ponds 1, 3 and 5.

Our proposed method for monitoring groundwater is a variation of a Before/After Control Impact (BACI) design using two to three months of data. This effectively restricts the "Before" component of the BACI design to a relatively short time period and we therefore add an extra requirement that the impact and reference bores closely match in their temporal patterns.

This approach allows us to dynamically re-assign impact and reference bores to take full advantage of the data available. Impact bores will be used to detect potential impacts of each pond as it is filled. The impact of Pond 1 will be measured by comparison with reference bores at Ponds 3 and 5. The impact of Pond 3 will be measured by comparison with reference bores at Pond 5, and so on. This process will continue to move up through the ponds until all ponds are filled, with additional bores being installed as required.

To determine optimal reference bores for each impact bore, we compare the groundwater level data using a process called Dynamic Time Warping (DTW). Once suitable reference bores have been selected for each impact bore, we can detect changes using Auto-Regressive Integrated Moving Average (ARIMA) models that use data from the impact and reference bores to forecast expected ground levels at the impact bore. A change trigger is defined to occur when what happens is not within the 95% confidence intervals of the forecasts. We tested this approach using the medium-term bore data to ensure that it works well in different scenarios.

We examined whether using multiple bores improved model forecasts and found that using three reference bores for each impact bore was optimal.

In summary, our recommended monitoring program will:

1. Use the three best-matching reference bores for each impact bore.
2. Fit an ARIMA model to forecast expected groundwater levels at the impact bore using the last two to three months of data from the impact and reference bores.
3. Trigger that a change has occurred if the forecast is outside of the 95% confidence levels, with a higher level trigger alert of the 99% confidence level is exceeded.

4. If a trigger occurs, plots of impact and reference bore data must be assessed visually to determine whether a site inspection is required.

Because the ARIMA models for the Pond 3 impact bores provided poorer forecasts than this for the Pond 1 bores, we recommend that additional reference bores be installed at Pond 5. Additional reference bores at other ponds will be required as ponds are filled. We recommend installing additional bores as soon as possible so that data are available for matching, including reference bores that can be used after all the ponds have been filled.

The monitoring program should ideally be run in real time and Data Analysis Australia can develop an online tool for this purpose. The tool will have the ability to re-calculate bore matches based on recent data, estimate ARIMA models and determine if trigger or threshold events have occurred. It will send trigger and threshold alerts automatically by email as they occur and can be accessed at any time by BCI Minerals to view plots of the impact and bore data for visual assessment of trigger events or for routine monitoring.

Our recommended monitoring program is dynamic in the way it detects matching reference bores, estimates statistical models and detects trigger events. We also recommend that the monitoring program itself is dynamic, with regular reviews and continuous improvement of the methodology.

The recommendations in this report are based on a number of assumptions. Most crucially, we have assumed that the filling of ponds will not impact any of the reference bores located at as-yet unfilled ponds. Other assumptions are that groundwater level is a suitable proxy for salinity and that external effects will influence both the impact and reference bores by similar amounts. Each of these assumptions should be more thoroughly tested once the ponds begin filling and more data become available.

Ideally, reviews of the program methodology should be conducted before Pond 3 is filled, if new long-term reference bores are installed (in which case the methodology review should be conducted prior to filling successive ponds) and then less frequently after all ponds are completed (if this is supported by the data).

Table of Contents

1. Introduction

BCI Minerals are building a series of solar salt evaporation ponds by the coast near Onslow in Western Australia. There is a possibility that filling the ponds will impact local groundwater leading to rising groundwater levels or increased groundwater salinity. BCI Minerals have engaged Data Analysis Australia to design a statistically sound method for determining operational trigger thresholds to determine whether groundwater levels differ beyond what would be considered normal after pond filling.

Two gas pipeline corridor bores were installed in July and September 2021. Data from these bores shows significant temporal variation in response to tidal influence, rainfall events and likely other factors such as barometric pressure and wind direction and speed. This suggests that the impact of pond filling will be confounded with the effects of tides and weather and therefore comparisons of bore data from before and after ponds are built will not lead to meaningful criteria for detecting their impact.

BCI Minerals have installed 14 bores for collecting ground water data in August and 2023 (Figure 1). Four bores installed on the gas pipeline corridor are unlikely to experience changes in ground water level associated with the pond filling and can potentially be used as reference or control sites to compare with ten coastal bores, including six that run in a transect perpendicular to the wall of Pond 3 which can identify potential impacts of the filling of Ponds 1, 2, or 3. An additional eight coastal bores are being installed this month along two transects perpendicular to the wall of Pond 5. Medium term data have been obtained for four bores west of Pond 5.

This report documents a preliminary analysis of the available bore data prior to designing a Before/After Control Impact (BACI) methodology to identifying robust triggers and thresholds for detecting potential impacts of pond filling. The proposed BACI design will use paired reference and impact sites, accounting for natural or pre-existing differences between the sites, to estimate the difference between the reference and potentially impacted site.

In summary this work performs:

1. Visualisation and analysis of water level to understand temporal variability at different temporal scales (daily / monthly / annual).
2. Comparison of data from different bores to identify groups with similar patterns of temporal variation.
3. Standardisation of water level to determine how best to pair reference and impact sites.
4. Development of appropriate methodology for comparing reference and impact sites and identifying whether impacts have occurred.
5. Initial development of a monitoring program.

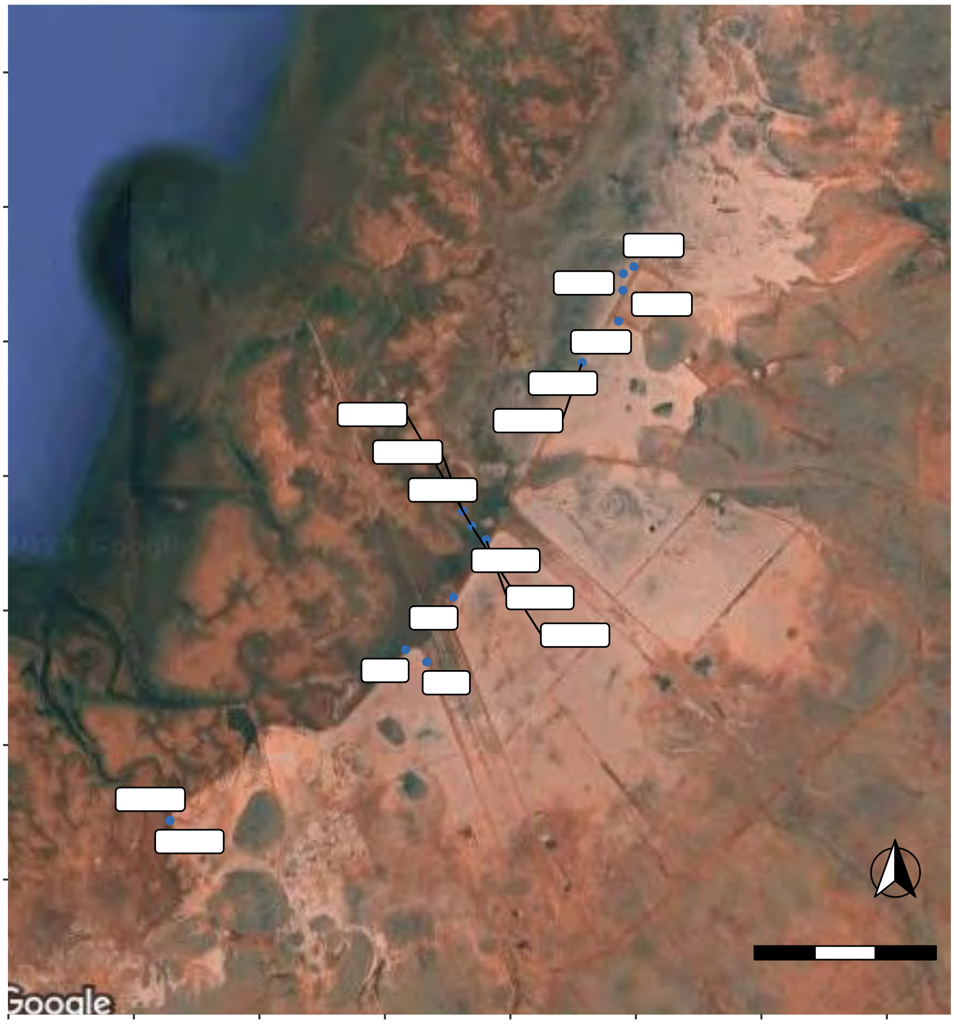


Figure 1. Location of available monitoring bores.

2. Data Used in This Report

Water level data (in metres) is available since late 2021 for the medium-term VWP bores and from August 2023 for all other bores (Table 1). This results in a three-month overlap and only approximately 3 months for the more recently installed bores.

Table 1. Available bore data.

Bore ID	Pond	Start Date	End Date
CMB6_1D	1	2023-08-17	2023-11-05
CMB6_1S	1	2023-08-17	2023-11-05
S01-A	1	2023-08-11	2023-11-04
S02-A	1	2023-08-13	2023-11-04
CMB1_1D	3	2023-08-16	2023-11-05
CMB1_1S	3	2023-08-16	2023-11-05
CMB1_2D	3	2023-08-16	2023-11-05
CMB1_2S	3	2023-08-16	2023-11-05
CMB1_3D	3	2023-08-17	2023-11-05
CMB1_3S	3	2023-08-17	2023-11-05
N01-A	3	2023-08-12	2023-11-04
N02-A	3	2023-08-12	2023-11-04
CMB2_1D	5	2023-08-16	2023-11-05
CMB2_1S	5	2023-08-16	2023-11-05
VWP_01	5	2021-07-26	2023-11-15
VWP_02	5	2021-07-26	2023-11-15
VWP_03	5	2021-07-26	2023-11-15
VWP_04	5	2021-07-26	2023-11-15

The data contains readings sampled at various times throughout each day, so for simplicity and consistency we aggregated the data to daily means.

In addition to the bores above, we also investigated Pond 5 bores as impacts, with two additional Pond 5 bores acquired, and 11 Pond 8 bores (installed in late October and early November) as reference bores.

Table 2. Additional bore data acquired for Pond 5 and Pond 8.

Bore ID	Pond	Start Date	End Date
CMB3_1D	5	2023-10-28	2023-12-18
CMB3_1S	5	2023-10-26	2023-12-18
CMB4_1D	8	2023-11-08	2023-12-18
CMB4_1S	8	2023-10-21	2023-12-18
CMB4_2D	8	2023-11-08	2023-12-18
CMB4_2S	8	2023-10-21	2023-12-18
CMB4_3S	8	2023-10-21	2023-12-18
CMB5_1D	8	2023-10-27	2023-12-18
CMB5_1S	8	2023-10-24	2023-12-18
CMB5_2D	8	2023-10-24	2023-12-18
CMB5_2S	8	2023-10-24	2023-12-18
CMB5_3D	8	2023-10-26	2023-12-11
CMB5_3S	8	2023-11-06	2023-12-18

However, a quick analysis of this data determined that the Pond 8 bores are currently inadequate for use as reference bores. The time period of the available data is too short to determine appropriate matches yet. Given references for Pond 5 impact bores are not necessary yet, we recommend that matching with reference bores from Pond 8 be performed when more data is available. This will likely be in early/mid-January when there will be closer to three months of bore data available. As such, we will only discuss the bores from Table 1 in this report.

3. Preliminary Data Investigation and Implications for Monitoring

3.1 Medium-Term Trends from VWP Bores

We use data from the medium-term VWP bores to investigate medium-term trends and groundwater variability that might be expected to occur at the other bores in the future noting that for long-term analysis, at least 10 years of data would be required to understand seasonal and interannual variation. Groundwater levels for these bores is shown in Figure 2. All four bores show a downward trend in groundwater levels but without longer-term data, we cannot be sure that this trend is not part of a larger cycle. They exhibit similar patterns of variation with no clear seasonality. Increases in groundwater occur each year in June/July, which could be due to winter rainfall.

Data from these bores shows significant temporal variation as well the downward trend and possible seasonal influences that may be due to rainfall and tide events.

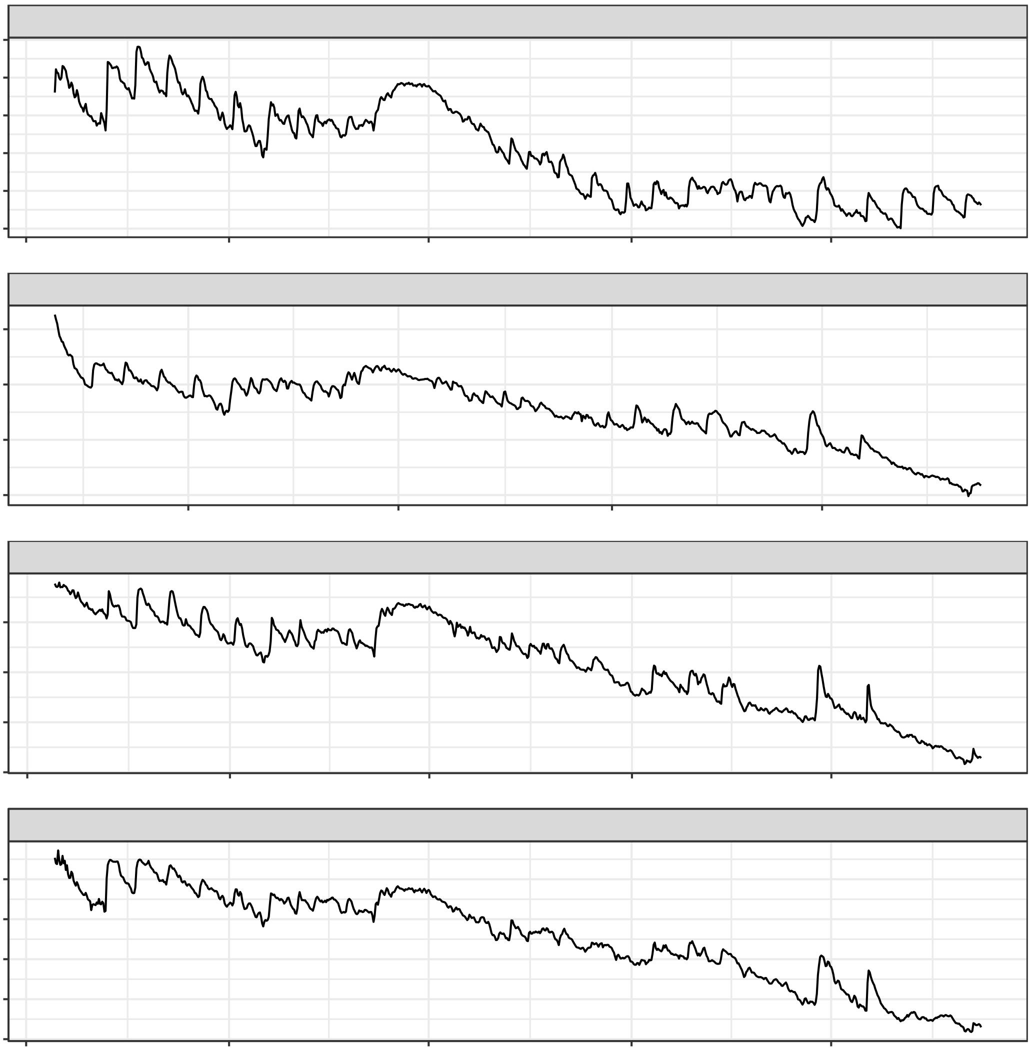


Figure 2. Daily groundwater levels for VWP bores.

3.2 Short-term trends for Coastal Bores

Figure 3 shows groundwater levels for coastal bores that may be potentially impacted. The bores do not show any downward trend as seen at the VWP bores, but this may be due to insufficient data duration.

Pond 1 bores CMB6_1D and CMB6_1S appear to have biweekly cycles, as do the bores that are closer to the coast along the transect extending from Pond 3. Pond 5 bores have a monthly cycle that is similar to the N01-A and N02-A bores at Pond 3. Pond 3 bores CMB_1D and CMB1_S have less regular cycles than the other bores.

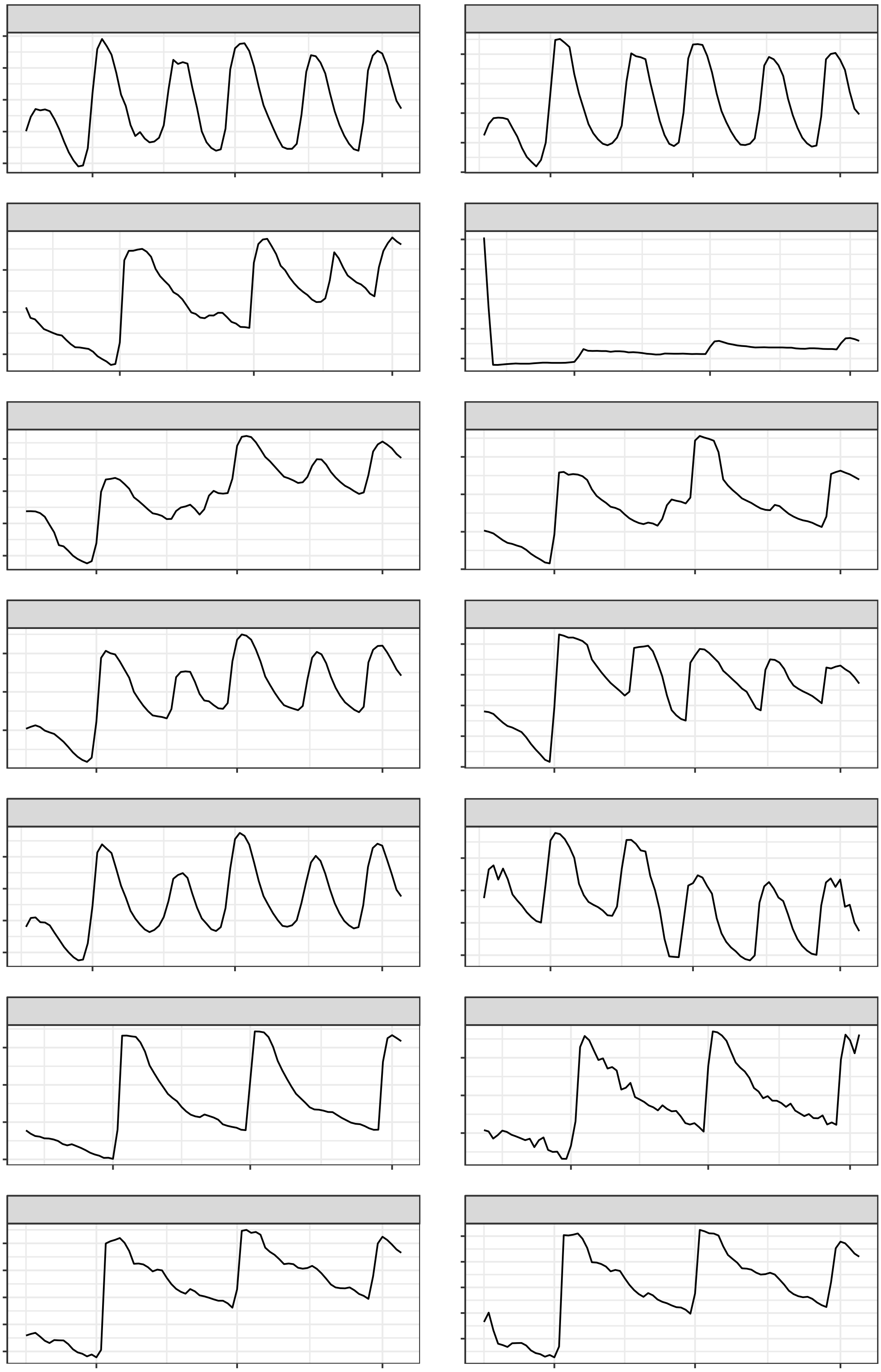


Figure 3. Daily groundwater levels for coastal bores (2023).

3.3 Effects of Rain on Groundwater Levels

Groundwater levels are likely affected by rainfall events. We obtained rainfall data from Onslow (the closest weather station operated by the Australian Bureau of Meteorology) to consider the effects of rainfall events on groundwater levels at the VWP bores. Figure 4 shows that rainfall events tend to align with bumps in groundwater levels, most notably in the few months before July 2022, but other increases in groundwater levels do not suggesting that rainfall is not the only driver of groundwater level increases. Moreover, the magnitude of rainfall events does not correspond to similar magnitudes of groundwater rises. It is possible that local Mardie rainfall differs to Onslow rainfall; this can be tested using Mardie weather station data if it is available.

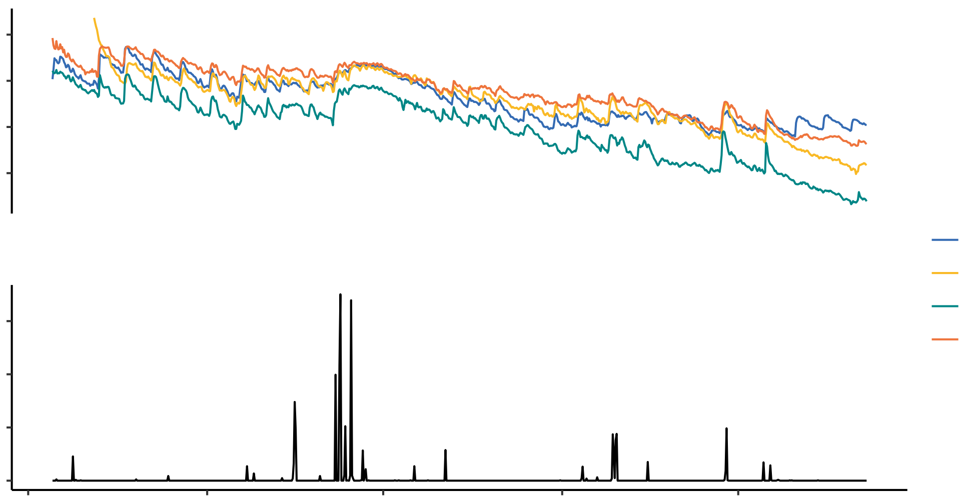


Figure 4. Daily groundwater levels and rainfall for VWP Bores.

3.4 Effects of Tides on Groundwater Levels

The other external factor likely to significantly affect groundwater levels is tides. Five-minute interval tide data were extracted from the Pilbara Ports Authority portal at nearby Ashburton (location identifier MOF). Daily aggregates of maximum tide were calculated and compared with the bore groundwater level data.

The medium-term VWP bores do not appear to be influenced by tides (Figure 5).

However, some coastal bores have a pattern similar to that of the tide data (Figure 6), with approximately fortnightly frequency. Other bores exhibit a monthly pattern (not pictured here).

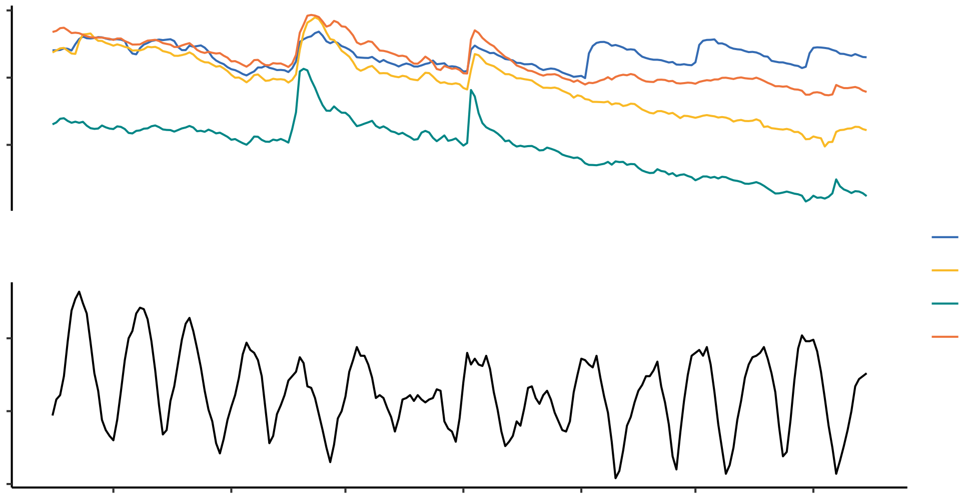


Figure 5. Daily groundwater levels and maximum tide for VWP bores.

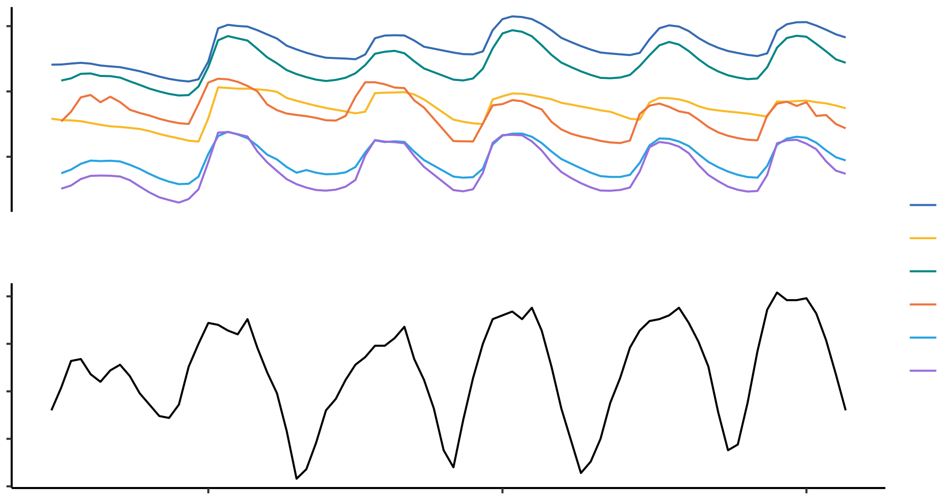


Figure 6. Daily groundwater levels and maximum tide for bores exhibiting tidal response.

3.5 Relationships Between Bores

At times, groundwater levels for the four VWP bores follow similar patterns, but the relationships between the bores can change for reasons unknown.

Between the three months of August and November of 2022, the relationship between the VWP bores was tight, as shown below in Figure 7. All four bores increased and decreased at much the same times albeit with different magnitudes.

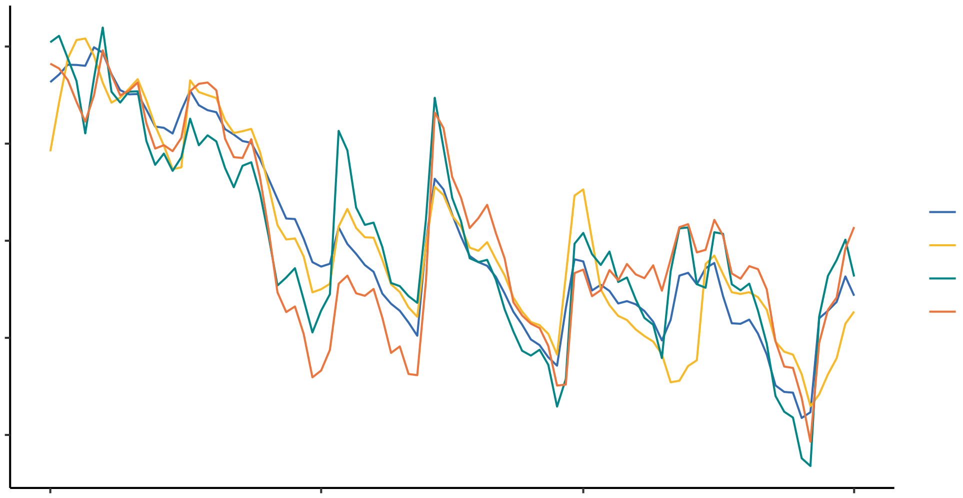


Figure 7. August to November 2022 VWP groundwater levels.

However, the relationships between these bores are not always consistent and a recent change illustrates this (Figure 8). The groundwater pattern of VWP_01 has diverged from those of the other bores, with spikes at the start of September, October, and November 2023 that are either not present or not as prominent in the other bores.

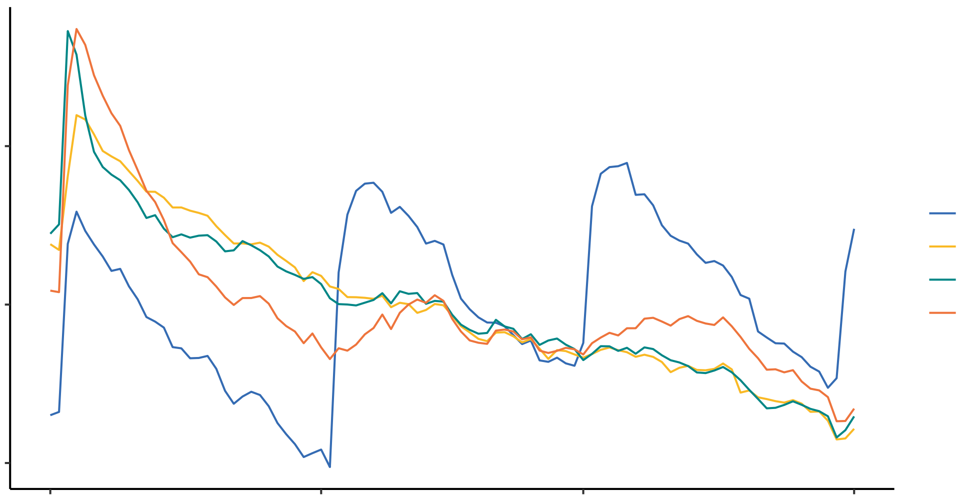


Figure 8. August to November 2023 VWP groundwater levels.

This has implications for Mardie Project groundwater monitoring. A traditional Before-After-Control-Impact (BACI) design would install two monitoring bores **prior** to the potential impact. Data from a control or reference site (where you do not expect changes to take place) are used to analyse changes at the impact site (where changes *may* take place). An example is shown in Figure 9, which shows a clearly evident change in the impact bore relative to the reference bore.

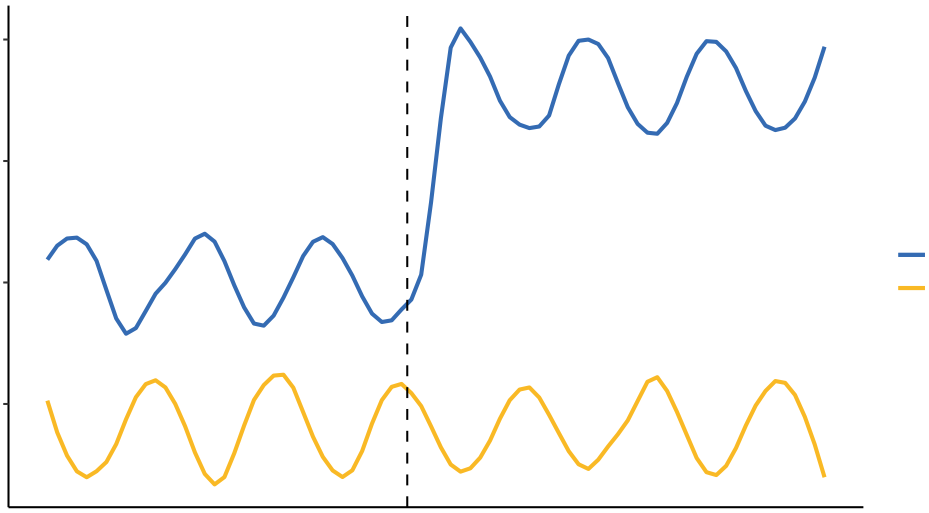


Figure 9. Example BACI Data showing a detectable impact.

However, this requires a consistent (but not necessarily close) relationship between the reference and impact bore.

Based on the August to November 2022 VWP groundwater levels, any of these four bores could be used as a reference-impact bore pair as they consistently move together. However, the changing relationship seen in the August to November 2023 data would complicate their use for monitoring.

4. Monitoring Program Methodology

4.1 BACI Design

Our proposed method for monitoring groundwater is a variation of a Before/After Control Impact (BACI) design.

Because our preliminary data investigation showed that relationships between bores are likely to change for unknown reasons, a traditional BACI design is not appropriate. We recommend selecting reference bores that exhibit a recent match with an impact bore, based on the most recent two to three months of data.

We are effectively restricting the "Before" component of the BACI design to a relatively short time period and therefore add an extra requirement that the impact and reference bores closely match in their temporal patterns, which will allow us to detect changes in that match due to any impact of the ponds.

While we add the extra requirement because of the potential for significant changes in the historical data, we perform due diligence on the data available in the next section to determine that the current bores are sufficient data surrogates for historical data.

This approach allows us to dynamically re-assign impact and reference bores to take full advantage of the data available. Impact bores will be used to detect potential impacts of each pond as it is filled. The impact of Pond 1 will be measured by comparison with reference bores at Ponds 3 and 5. The impact of Pond 3 will be measured by comparison with reference bores at Pond 5, and so on. This process will continue to move up through the ponds until all ponds are filled, with additional bores being installed as required.

It is possible that using multiple bores as reference to a single impact bore will improve detection of impact. A key benefit of this is also that there is added redundancy. We are only measuring how the relationship between the bores change, and if that relationship changes because of the reference bore (perhaps because of a faulty sensor or some other external event) we could falsely attribute it to the impact bore. Multiple bores would give us an extra point of reference to narrow down which bore has changed. This will be investigated further in the report.

4.2 Bore Data Matching

To determine optimal reference bores for each impact bore, we compare the groundwater level data using a process called Dynamic Time Warping (DTW). DTW calculates the **DTW distance** between two time series sequences, applying a warping to ensure patterns separated by small time frames are still matched. Smaller distances occur for better matches.

To first account for bores having different magnitudes and scales, we standardise the water levels by subtracting the mean and dividing by the standard deviation. The effect of this is shown below in Figure 8.

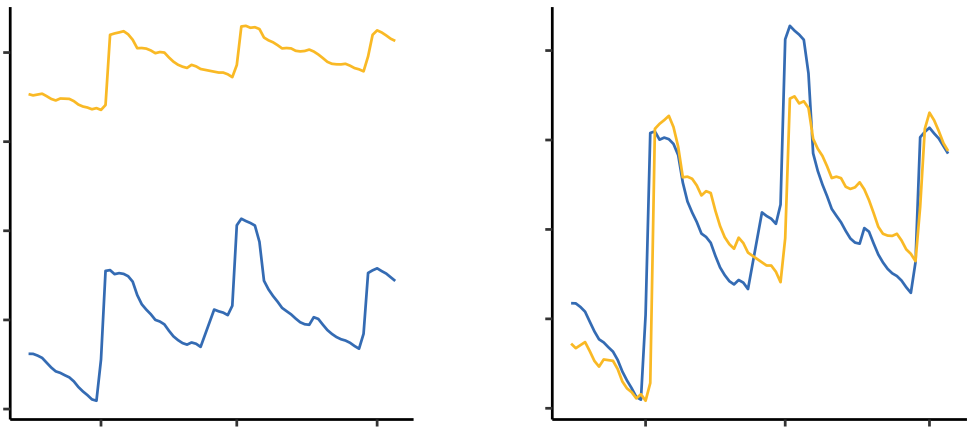


Figure 8. Water level standardisation for CMB2_1D (yellow) and CMB1_1S (blue).

We compared all combinations of bores that could possibly act as impact and reference pairs to create a heatmap to show appropriate matches (Figure 9). Lighter squares indicate better matches, darker indicate worse, and the white dots denote the best three matches. The heatmap lets us see the best reference bores for each impact bore, while also seeing how well the other bores match. For example, impact bore S01-A matches well with many potential reference bores (most of the CMBs, the N0 bores, and VWP_01). However, CMB1_3D and CMB1_3S only match with six bores due to its location, and the matches are not particularly good. CMB1_3S, in particular, has no good matches, but VWP_01 is the best match available.

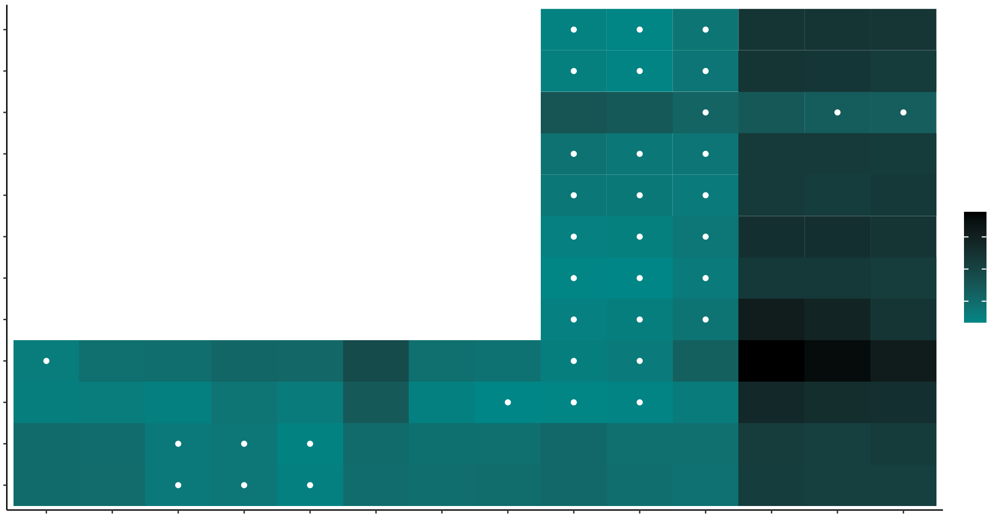


Figure 9. Heatmap showing similarity between potential impact and reference bores (white dots indicate the best four matches for each impact bore).

See Appendix 1 for maps and distance plots of the best three matches.

4.3 Trigger Detection Using ARIMA Confidence Intervals

Once suitable reference bores have been selected for each impact bore, we need a way of deciding whether a significant change has occurred in the impact bore relative to the reference bore. The overall scale of the impact might be different at different times due to tide and weather events. We therefore need a dynamic method of determining what the scale of the trigger should be.

This is essentially a statistical problem and we recommend a statistical solution.

Statistical methodology for doing this would fit a model to the time series data and predict what we would expect to happen next. If what happens is not within the bounds of what we expect, then a trigger occurs. Note that a trigger point does not mean the change is a result of the nearby pond being filled; a more thorough check will be needed. It might be the case, for example, that heavy rainfall didn't drain as effectively from the ground around the impact bore due to the topography of the area.

We recommend using an Auto-Regressive Integrated Moving Average (ARIMA) model. ARIMA models are commonly used in forecasting, including groundwater level and water quality monitoring[1], because of their ability to account for seasonal trends in the data. In this context, the ARIMA model would use data from the impact and reference bores as input variables to forecast expected ground levels at the impact bore. That means it should follow the seasonality and general trend of the impact bore,

[1] De Moraes Takafuji, E. H., da Rocha, M. M. and Manzione, R. L. (2019). Groundwater Level Prediction/Forecasting and Assessment of Uncertainty Using SGS and ARIMA Models: A Case Study in the Baura Aquifer System (Brazil). *Natural Resources Research* 28. https://doi.org/10.1007/s11053-018-9403-6

with any changes in the reference bores reflected in the model and expected values of the impact bore.

Because reference bores may experience changes with time lags or leads compared to impact bores, we tested the use of including lag-lead reference bore data in the models and found that including lags and leads of 1 day reduced model error and provided better forecasts.

A **trigger point** is defined using confidence intervals for the forecasts[2]. When the true value doesn't lie within those confidence intervals, then a trigger occurs.

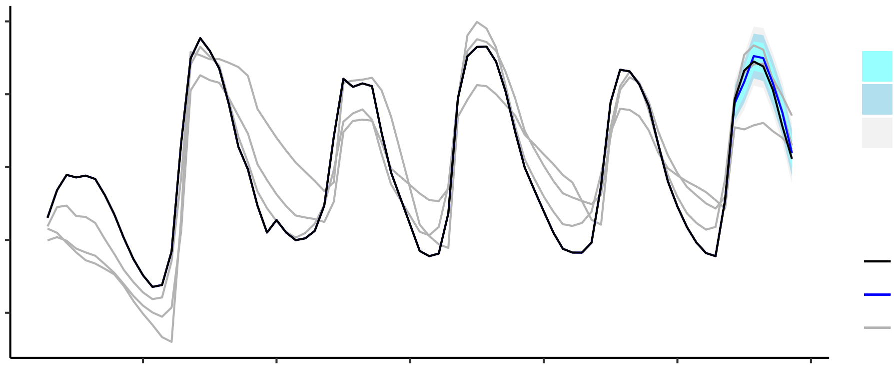


Figure 10. Standardised historical and expected water levels for an impact bore (CMB6-1D) and its reference bores.

We use the medium-term VWP data to demonstrate and assess the performance of this process. Two examples are shown using VWP_01 as an impact bore and the other three VWP bores as reference bores.

First, we consider a sudden spike that occurred in all bores leading into the 2022 winter (Figure 4). The impact bore changes its pattern quickly, but the reference bores do as well. The model successfully forecasts this change and *does not* trigger that a change has occurred in the impact bore relative to the reference bores. This is despite long history of the actual impact bore remaining relatively steady.

[2] Barrientos-Torres, D., Martinez-Rios, E. A., Navarro-Tuch, S. A., Pablos-Hach, J. L. and Bustamante-Bello, R. (2023). Water Flow Modeling and Forecast in a Water Branch of Mexico City through ARIMA and Transfer Function Models for Anomaly Detection. *Water* 15(15). https://doi.org/10.3390/w15152792

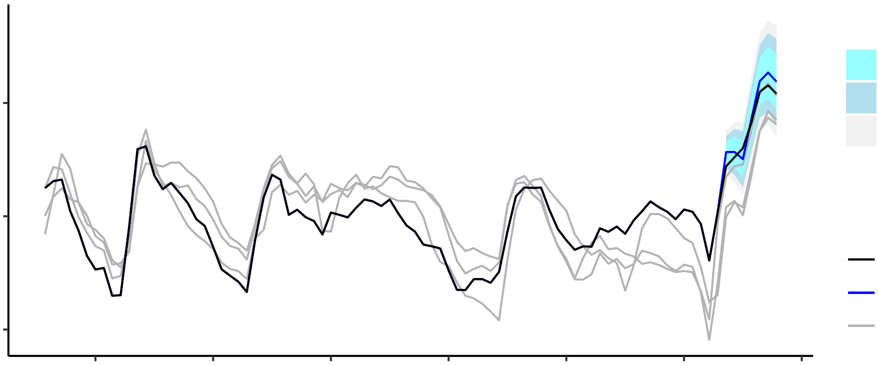


Figure 11. Change detection for impact bore VWP_01 (no change expected).

Secondly, we consider a divergence of VWP_01 from the other bores that occurred in late 2023 (Figure 12). While the other three bores continue moving relatively similarly, VWP_01 changes pattern. The model forecasts that that VWP_01 water levels will remain low based upon the reference bore data, but the observed water levels are vastly different from the forecast. This triggers that a change has occurred (though obviously not as a result of pond filling.) These trigger points are shown by the red points.

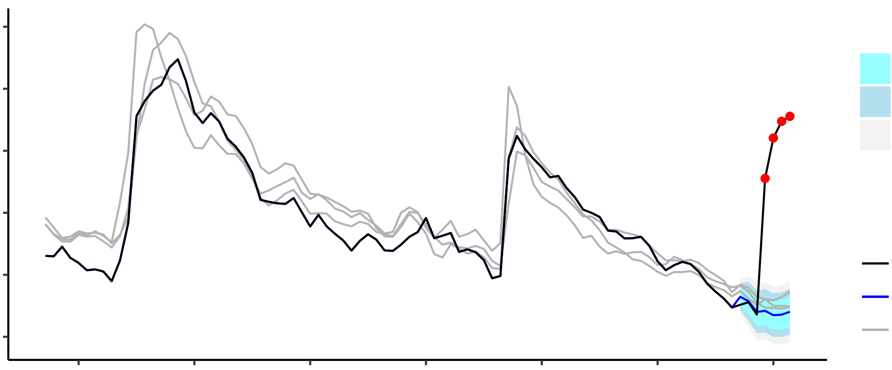


Figure 12. Change detection for impact bore VWP_01 (change expected).

4.4 Optimal Reference Bores for Trigger Detection

Having outlined the methodology for trigger detection using ANOVA confidence intervals, it remains to work out whether to use one or more reference bores for each impact bore, and how to choose which should be used. We compare using the best one, two, three, four, or five reference bore pairings based on DTW distance and evaluate each option for how well the ARIMA forecast fits the observed impact bore water levels.

Two key metrics are evaluated: the accuracy of the ARIMA model for predicting impact bore data and the size of the confidence intervals for detecting triggers. The accuracy is vital for ensuring good predictions and the size of the confidence interval will determine how sensitive the model is to sharp changes. Too sensitive and the model will trigger when it shouldn't (a false positive), but not sensitive enough and it won't trigger when it should (a false negative). As such, we aim to minimise the Root Mean Square Error (RMSE) and strike a balance in the width of the confidence intervals.

The RMSE results varied for bores installed to measure impact at different ponds, with Pond 1 RMSE much smaller than Pond 3 RMSE (Figure 13). The best three matches provides the best result for Pond 1 bores and either the best match or the best three gave the best result for Pond 3 bores. The width of the 95% confidence intervals for Pond 5 bores was lower using the best three matches (Figure 14) and we therefore conclude that using the best three matches is optimal for both ponds, noting that the Pond 3 models are much poorer than those for Pond 1.

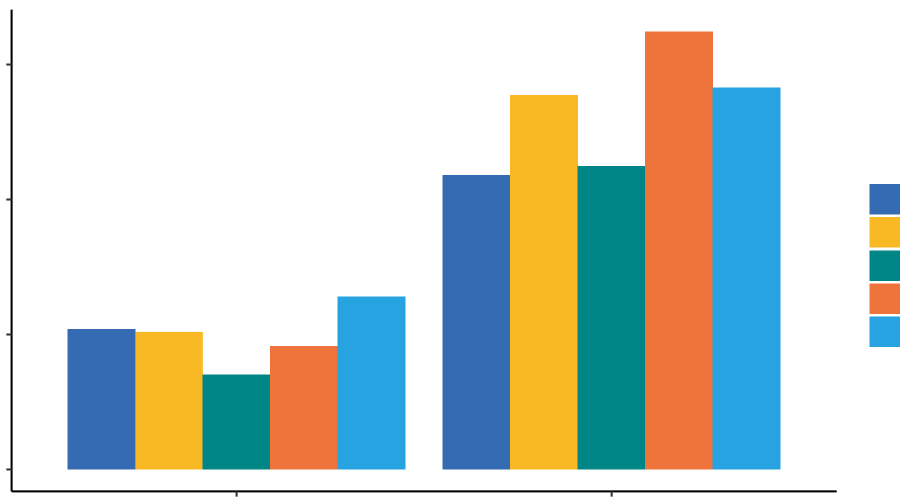


Figure 13. Median RMSE for ARIMA models using the best 1, 2, 3, 4 and 5 matches for Pond 1 and Pond 3 impact bores.

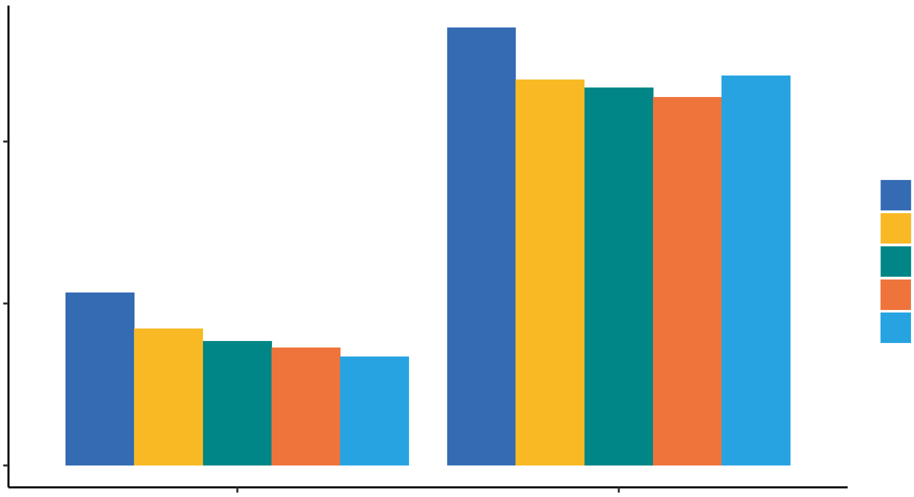


Figure 14. Mean 95% confidence interval width for ARIMA models using the best 1, 2, 3, 4 and 5 matches for Pond 1 and Pond 3 impact bores.

4.5 Impact and Reference Bores

Based on the results of the previous section, we identified the optimal reference bores for each impact bore at Pond 1 and Pond 3 as being the best three matches based on the DTW distance (Table 3).

However, noting that the ARIMA models for the Pond 3 impact bores fit more poorly than those for the Pond 1 impact bores, which is largely caused by the poor matches for CMB1_3D and lack of any good matches for CMB1_3S, additional reference bores should be installed and analysed to determine if they provide better references for Pond 3 bores.

Table 3. Recommended impact and references bores (best three matches).

Impact Bore ID	Pond	Reference Bores
CMB6_1D	Pond 1	CMB1_3D, CMB1_2D, CMB1_2S
CMB6_1S	Pond 1	CMB1_3D, CMB1_2D, CMB1_2S
S01-A	Pond 1	N02-A, CMB2_1D, CMB2_1S
S02-A	Pond 1	CMB2_1D, CMB1_1D, CMB2_1S
CMB1_1D	Pond 3	CMB2_1D, CMB2_1S, VWP_01
CMB1_1S	Pond 3	CMB2_1S, CMB2_1D, VWP_01
CMB1_2D	Pond 3	CMB2_1D, CMB2_1S, VWP_01
CMB1_2S	Pond 3	VWP_01, CMB2_1S, CMB2_1D
CMB1_3D	Pond 3	CMB2_1S, VWP_01, CMB2_1D
CMB1_3S	Pond 3	VWP_01, VWP_04, VWP_03
N01-A	Pond 3	CMB2_1S, CMB2_1D, VWP_01
N02-A	Pond 3	CMB2_1S, CMB2_1D, VWP_01

We note that this is the best matching *at this time*, based on approximately three months of data.

4.6 Selection of Confidence Intervals

To determine which level of confidence interval should be used, we ran the models for each of the impact bores for the most recent week of data[3] to determine the number of times a change event would be triggered (Table 1).

Table 4. Trigger events for different confidence intervals

Impact Bore	Pond	80% CI Triggers	90% CI Triggers	95% CI Triggers	99% CI Triggers
CMB6_1D	Pond 1	0	0	0	0
CMB6_1S	Pond 1	1	0	0	0
S01-A	Pond 1	1	1	1	0
S02-A	Pond 1	1	1	1	1
CMB1_1D	Pond 3	0	0	0	0
CMB1_1S	Pond 3	1	0	0	0
CMB1_2D	Pond 3	1	0	0	0
CMB1_2S	Pond 3	1	0	0	0
CMB1_3D	Pond 3	0	0	0	0
CMB1_3S	Pond 3	1	1	0	0
N01-A	Pond 3	5	5	5	5
N02-A	Pond 3	6	6	6	3

The number of triggers points decreases as the confidence interval increases. This means that less false positives will occur (triggers detected but no actual change), but it may also increase the number of false negatives (no trigger detected when actual change occurs). Based on this, we recommend using a combination the 95% confidence intervals, with a higher-level trigger alert if the 99% confidence level is exceeded.

5. Conclusion and Recommendations

5.1 Monitoring Program

In summary, the monitoring program will:

1. Use the three best-matching reference bores for each impact bore.
2. Fit an ARIMA model to forecast expected groundwater levels at the impact bore using the last two to three months of data from the impact and reference bores.
3. Trigger that a change has occurred if the forecast is outside of the 95% confidence level, with a higher level trigger alert of the 99% confidence level is exceeded.
4. If a trigger occurs, the plots of impact and reference bore data must be assessed visually to determine whether a site inspection is required.

Because of the lack of good matches for some impact bores at Pond 3, we recommend that additional reference bores be installed at Pond 5. Additional reference bores at other ponds will be required as ponds are filled. We recommend installing additional

[3] Future reviews can consider how this might vary for forecasts made at different times.

bores as soon as possible so that data are available for matching, including reference bores that can be used after all the ponds have been filled.

5.2 Real-time Trigger Detection Tool

The monitoring program should ideally operate in real time. Data Analysis Australia can develop an online tool that allows this.

The tool will have the ability to automatically estimate ARIMA models and determine if trigger events have occurred. It will send trigger alerts by email as they occur and it will allow BCI Minerals to view plots of the impact and bore data for visual assessment of trigger events or for routine monitoring.

5.3 Review and Continuous Improvement

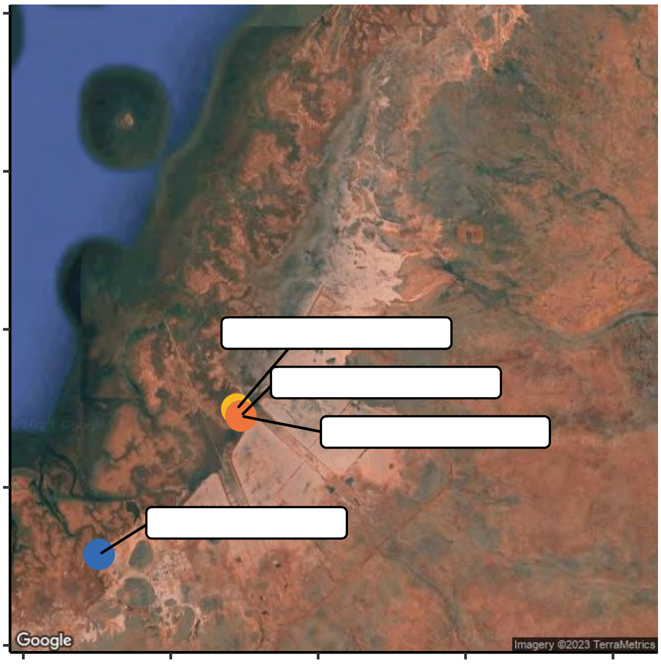
Our recommended monitoring program is dynamic in the way it detects matching reference bores, estimates statistical models and detects trigger events. We also recommend that the monitoring program itself is dynamic, with regular reviews and continuous improvement of the methodology. This may include, for example, appropriate refinement of the trigger confidence interval threshold.

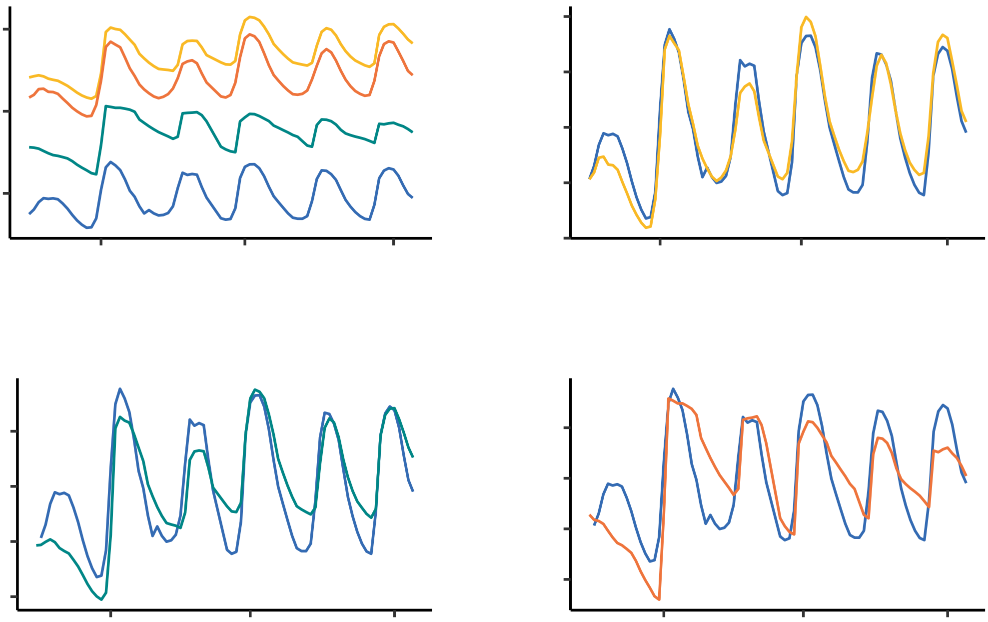
The recommendations in this report are based on a number of assumptions. Most crucially, we have assumed that the filling of ponds will not impact any of the reference bores located at as-yet unfilled ponds. Other assumptions are that groundwater level is a suitable proxy for salinity and that external effects will influence both the impact and reference bores by similar amounts. Each of these assumptions should be more thoroughly tested once the ponds begin filling and more data become available.

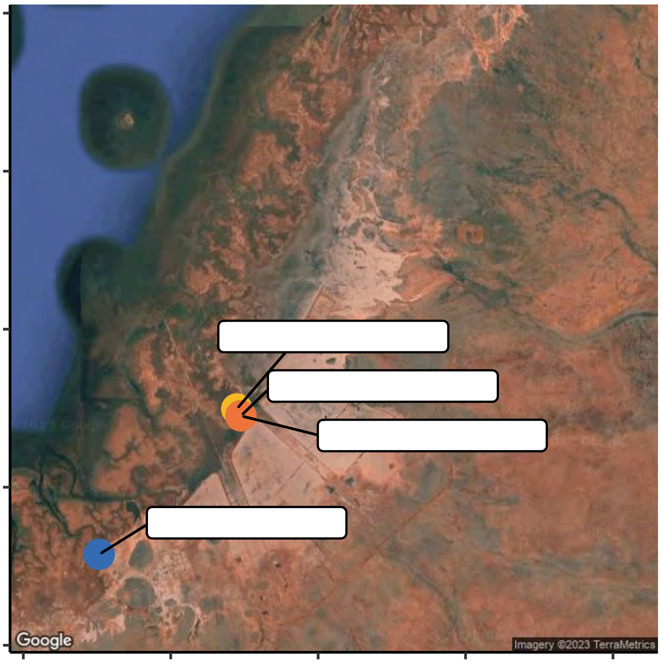
Ideally, reviews of the program methodology should be conducted before Pond 3 is filled, if new long-term reference bores are installed (in which case the methodology review should be conducted prior to filling successive ponds) and then less frequently after all ponds are completed (if this is supported by the data).

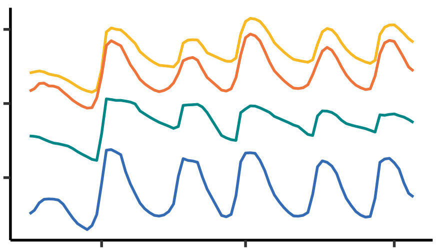
Additionally, we recommend that selection of reference bores for Pond 5 impact bores be performed in early/mid-January.

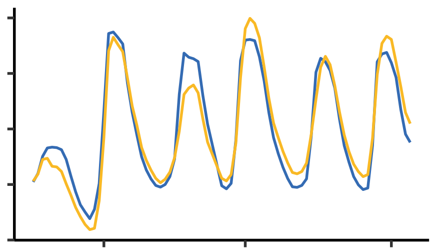
Appendix A. Best Three Reference Bores for each Impact Bore

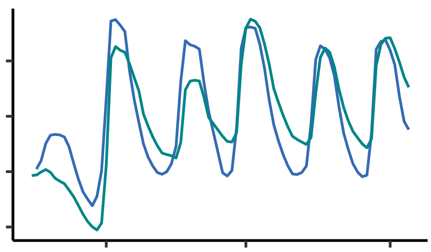


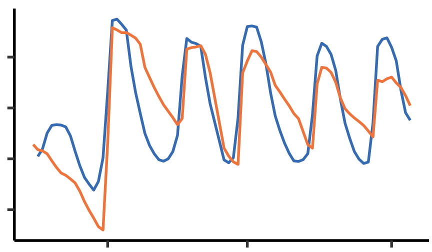



Google
Imagery ©2023 TerraMetrics

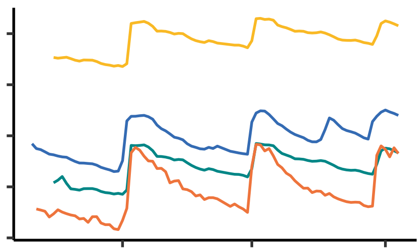


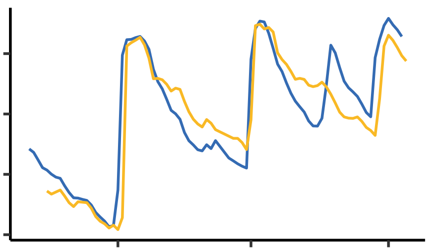


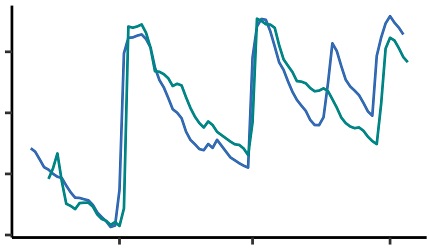


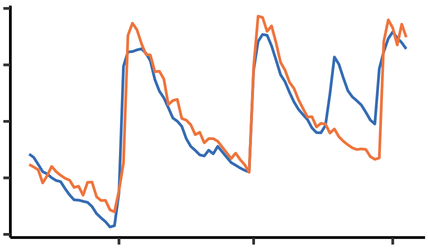



Google
Imagery ©2023 TerraMetrics

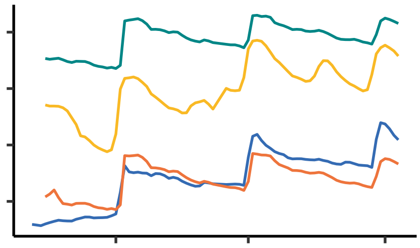


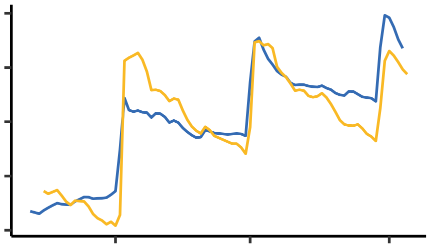


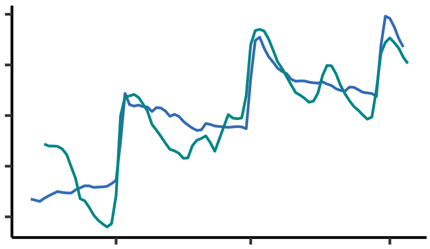


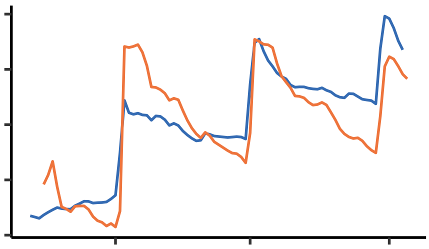


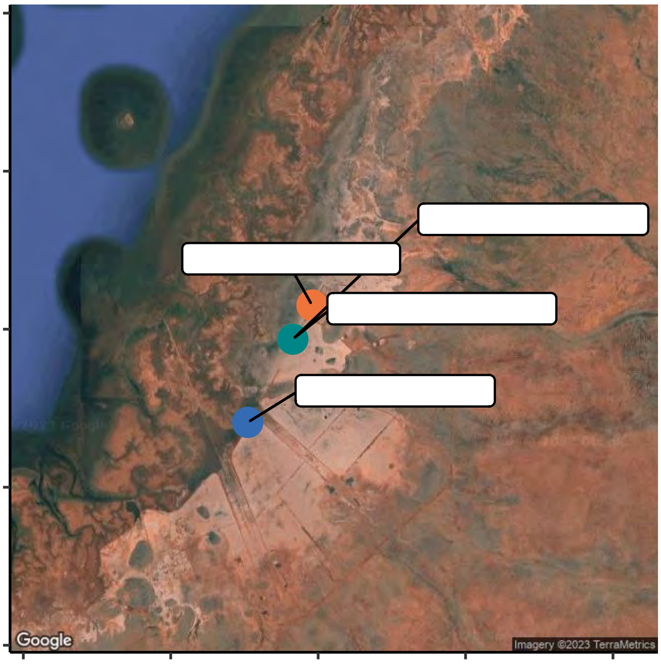

Google
Imagery ©2023 TerraMetrics

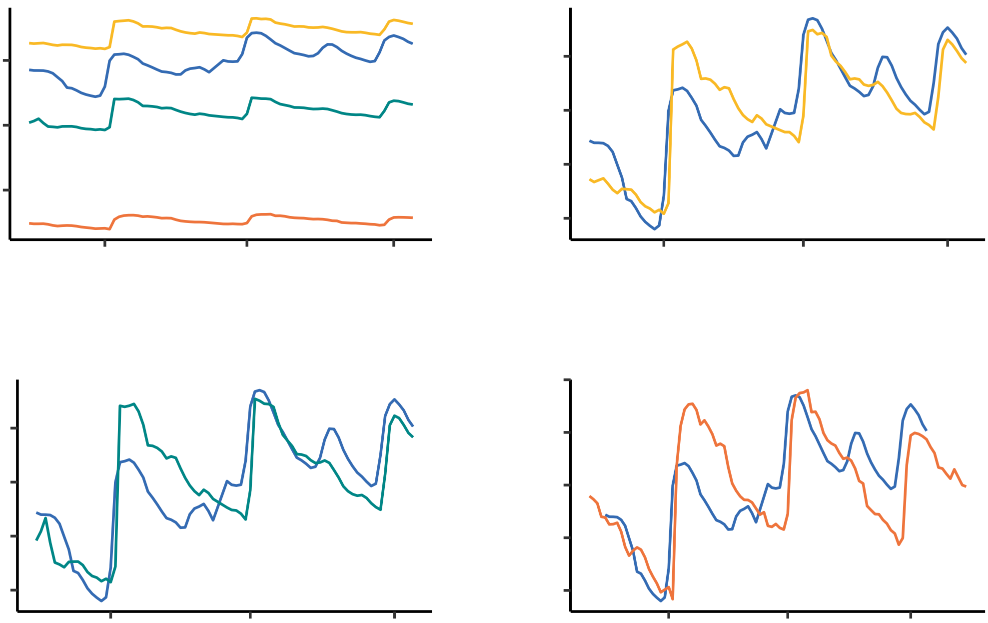




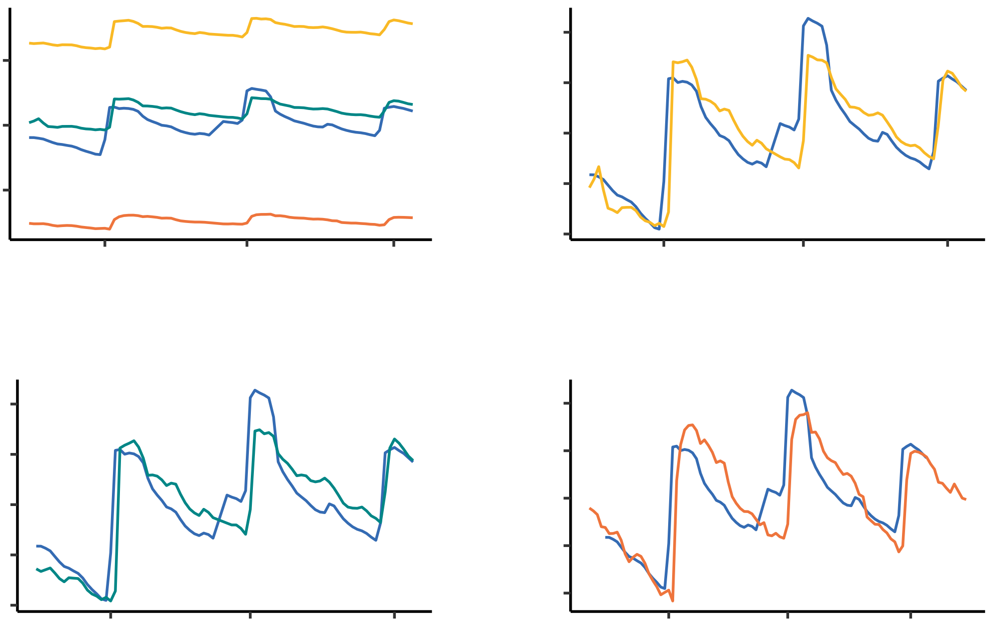


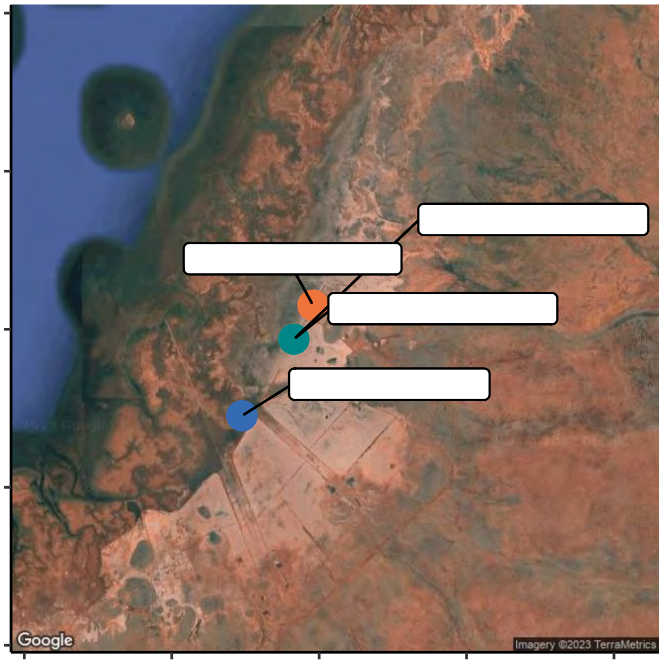


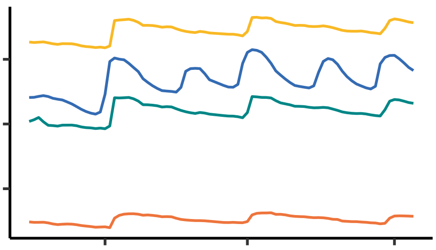

Google
Imagery ©2023 TerraMetrics

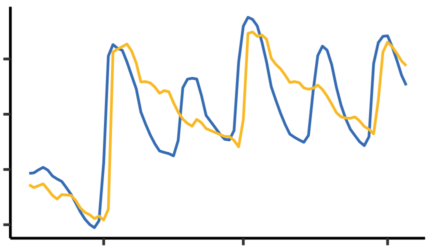


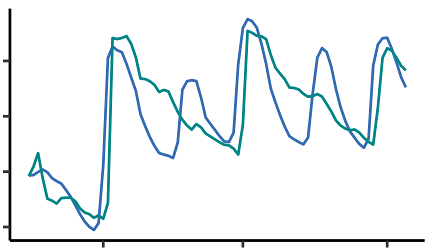

Google
Imagery ©2023 TerraMetrics

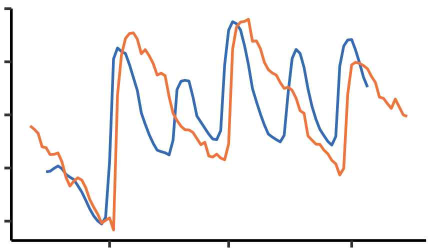


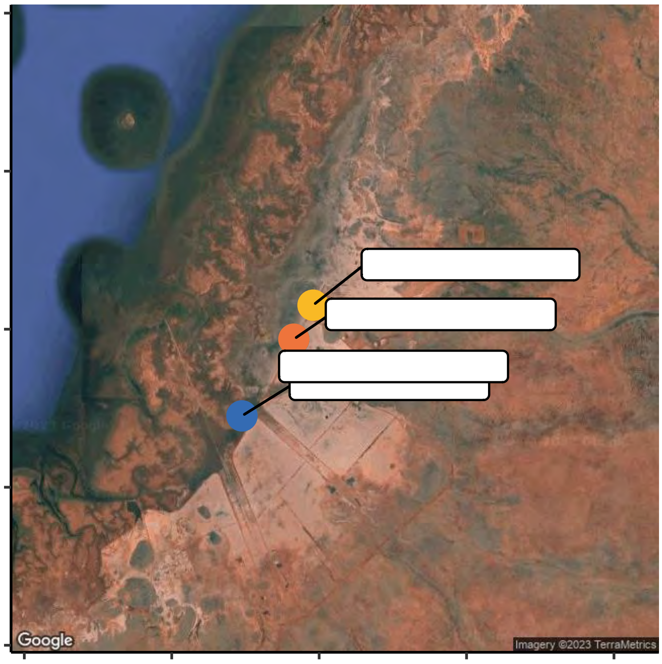

Google
Imagery ©2023 TerraMetrics

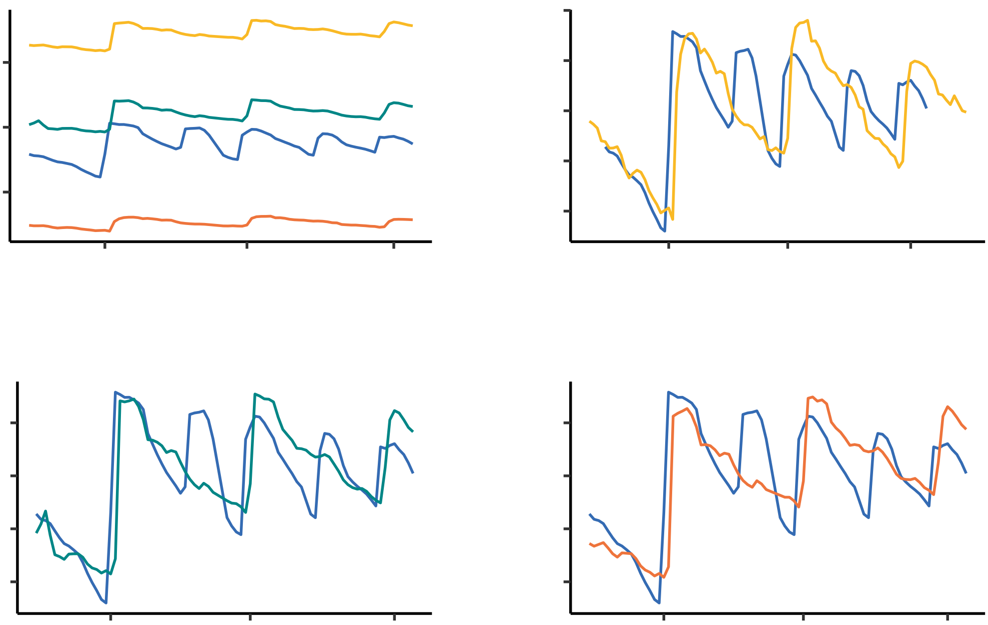


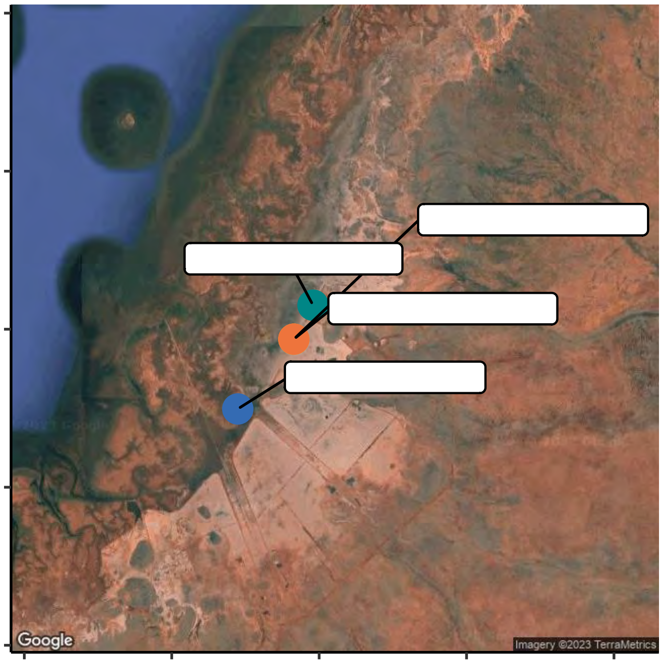


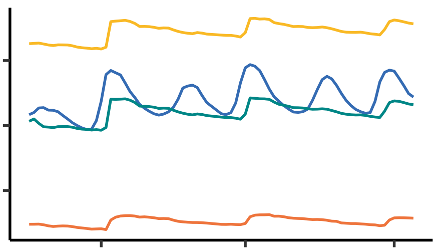


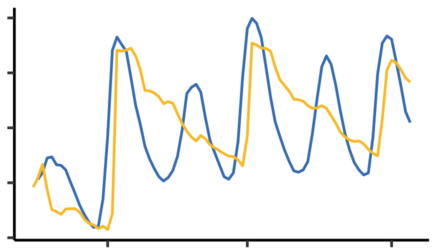


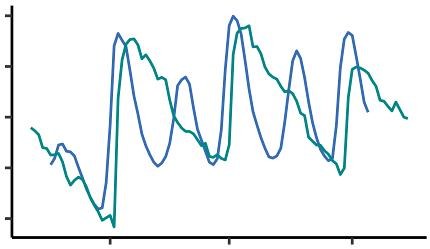

Google
Imagery ©2023 TerraMetrics

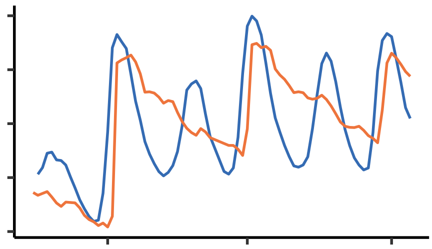


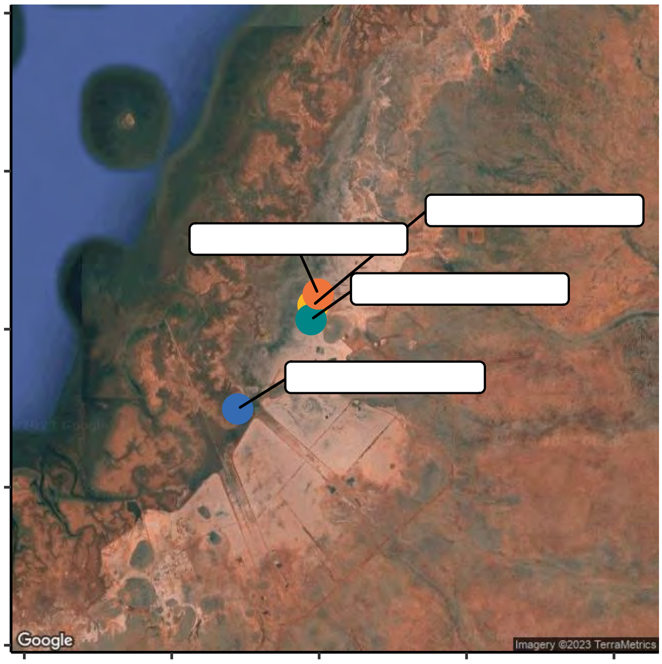

Google
Imagery ©2023 TerraMetrics

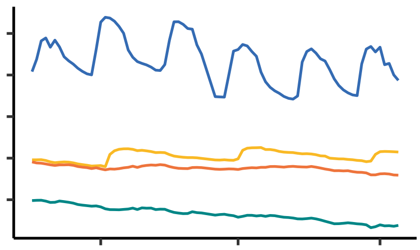


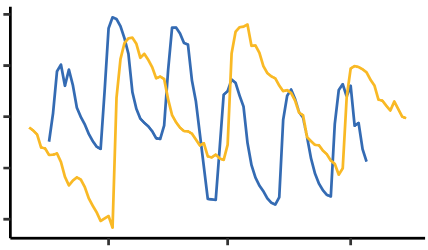


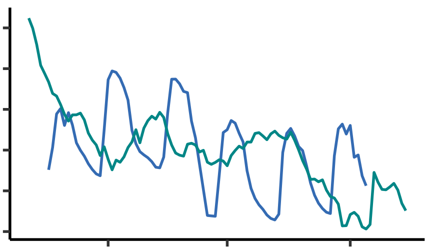


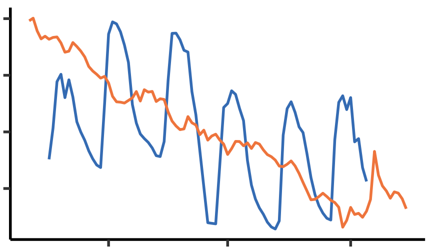


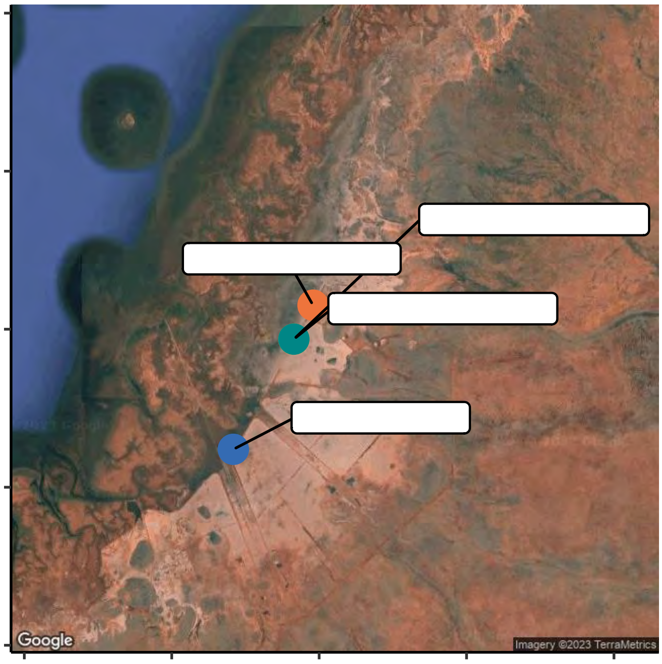

Google
Imagery ©2023 TerraMetrics

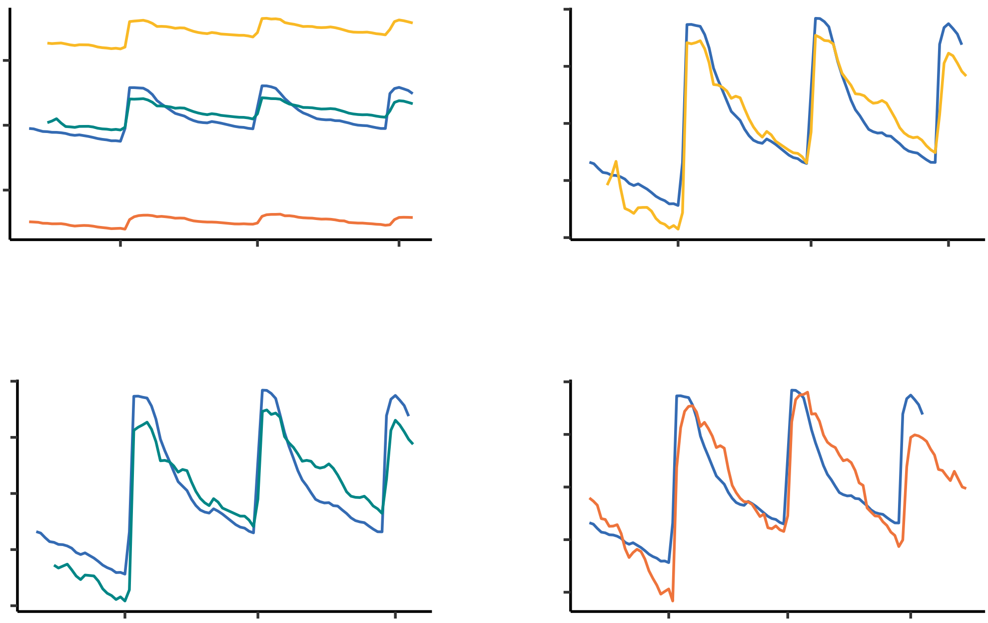


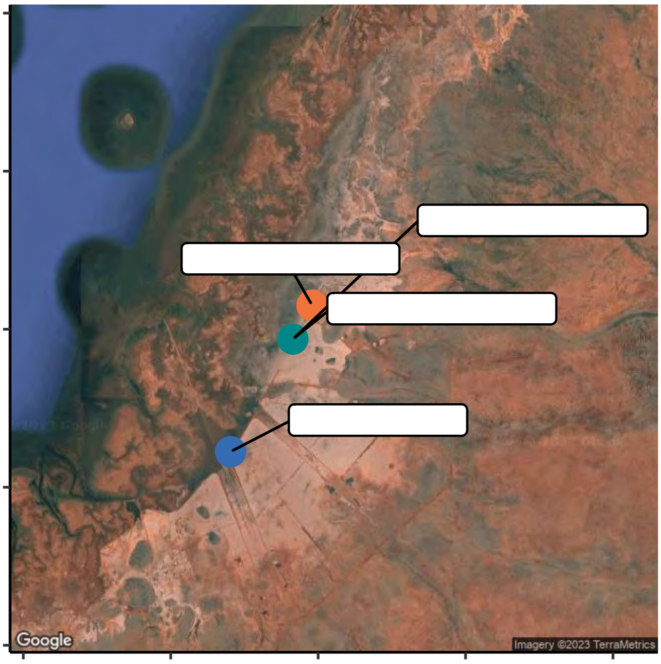


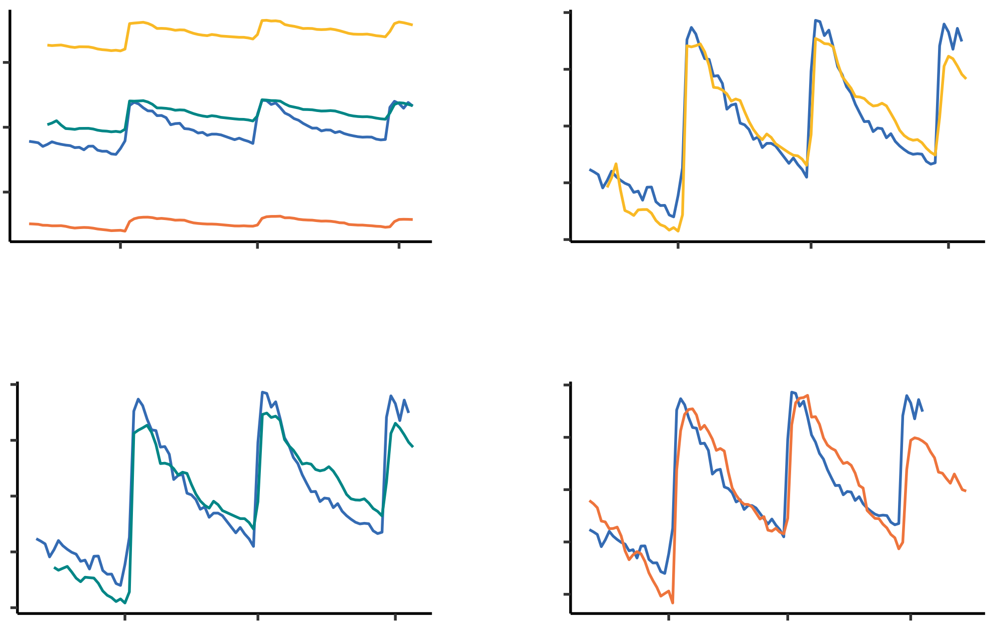





Google
Imagery ©2023 TerraMetrics




Google
Imagery ©2023 TerraMetrics



Data Analysis Australia – About Us

Helping organisations make great decisions and new discoveries by making data meaningful

This has been Data Analysis Australia's express purpose since we were founded in 1988.

We achieve this through our diverse and evolving skill sets covering all areas of statistical and data science analysis. Setting us apart is our focus on generating meaningful **insights from data**, working with clients from all sectors and industries to solve their real problems.

Data Analysis Australia's services and principal areas of expertise include:

- **Survey sampling**, questionnaire design, weighting, standard errors, analysis and review.
- **Evaluations** of programs and pilot trials.
- **Modelling** of industrial, mining and business processes.
- **Business analysis** and evidence based decision making.
- **Forecasting**, of people, workforces, building, energy and asset needs.
- **Data analysis**, to understand true relationships and insights from data.
- **Statistical modelling**, including regression, time series analysis, classification and clustering analysis.
- **Experimental design** and analysis.
- **Reviews** of statistical papers and methodologies.
- **Expert witness** and legal work.
- **Dashboards** and interactive tools.
- **Big data** management and analysis.

Having worked with hundreds of government and private clients locally, nationally and internationally, Data Analysis Australia has built a reputation of trust and delivery in all that we do.

Website: www.daa.com.au
Phone: (08) 9468 2533
Email: daa@daa.com.au

Appendix F: Peer Review of GMMP

Review of Groundwater Monitoring & Management Plan for Mardie Salt and Potash Project

***Document Number:* BCI-ADM-TEM-011 Rev 2**

Document Date: 14 Dec2021

Mardie Project Groundwater Monitoring and Management Plan - Optimised Design

Purchase Order No: 291473

Purchase Order Date: 22 DEC 2021

Reviewer:

Behzad Ataie-Ashtiani

ABN: 78 315 775 052

Email: Behzad.AtaieAshtiani@Flinders.Edu.Au

Tel: +61 4 6979 8912

Review report Number: BAA-Review "BCI-ADM-TEM-011-Rev 2"

Date of review report: 5 January 2022

ABSTRACT

The proposal of Mardie Salt and Potash Project, an evaporative solar facility for high quality salt and suphate of potash production, located at Mardie, approximately 80 km southwest of Karratha, in the Pilbara region of Western Australia. The Mardie Project Groundwater Monitoring and Management Plan - Optimised Design (GWMMP-OD) describes the monitoring and management measures to be implemented by Mardie Minerals during the construction and operation of the Project; to ensure minimal residual impact on the groundwater dependent ecosystems and other vegetation, by minimising changes to groundwater regimes. GWMMP-OD consists of sections including context, scope and rationale, baseline data, potential ecological stressors, monitoring and investigations, review, responses to protentional environmental impacts, reporting, groundwater and seepage modelling, adaptive management and review, and stakeholder consultation. GWMMP-OD proposal was reviewed independently, prior to submission to WA Department of Water and Environment Regulation (DWER) for approval. It contains the required information based on relevant conditional clauses of Ministerial Statement No 1175.

Herein, GWMMP-OD proposal was independently reviewed. This review has the same pattern as the GWMMP-OD report and presents the comments and assessment of each specific section of GWMMP-OD separately, in the hope to improve the clarity of the project and bring forward a different perspective. Although the plan has been designed appropriately and aligned with the current guidelines, it needs to be revised based on the review comments. Following the implementation, a secondary review of the new version of GWMMP-OD is required.

Some of the important comments are concerning: justification for the monitoring well positions and their adequacy, plan and potential steps to minimise these preliminary triggers, monitoring the magnitude of vertical hydraulic gradients and vertical variations of salinity monitoring the magnitude of vertical hydraulic gradients and vertical variations of salinity, establishing linkage between the investigations and the claimed identification data for the conceptualisation, and management and mitigation actions of the potential environmental impacts and risks of long-term environmental changes such as climate change.

1. INTRUDUCTION

The review report is to assess the Mardie Project Groundwater Monitoring and Management Plan - Optimised Design (GWMMP-OD). The Groundwater Monitoring & Management Plan (GWMMP), document number BCI-ADM-TEM-011 Rev 2, dated 14-Dec-2021. The GWMMP-OD incorporated the monitoring network design and outlining the proposed future works by AQ2 (Proposed Investigation and Monitoring Program - Revised Layout). The GWMMP-OD will be submitted to the WA Department of Water and Environment Regulation (DWER) by Mardie Minerals Pty Ltd (Mardie Minerals).

The proposal of Mardie Salt and Potash Project, an evaporative solar facility for high quality salt and suphate of potash (SoP) production, is located at Mardie, approximately 80 km southwest of Karratha, in the Pilbara region of Western Australia (WA). The GWMMP-OD describes the monitoring and management measures to be implemented by Mardie Minerals during the construction and operation of the Mardie Project (the Proposal or the Project) to minimise the impact on the groundwater dependent ecosystems and other vegetation. The key two objectives of GWMMP-OD are: (1) to plan groundwater monitoring network and additional baseline investigations and (2) to propose groundwater recovery systems to protect the environmental values. The potential sensitive receptors - namely mangroves, algal mat, samphire and sub-tidal Benthic Communities and Habitat (BCH)- are assessed as secondary parameters to assess changes in groundwater.

The purpose of this report is to provide an independent peer review of the GWMMP, and to assess and analyse the suitability of GWMMP to adequately and correctly address the study outcomes to achieve the objectives with confidence. The specific condition under which this peer review is required, are condition clauses 3-3 and 3-4 of Ministerial Statement No 1175 which are quoted in the following. Condition 3-4 specifies conditions that the GWMMP must address.

> *3-3 The proponent shall prepare and submit to the CEO a Groundwater Monitoring and Management Plan.*
>
> *(1) The proponent shall submit with the Groundwater Monitoring and Management Plan, a peer review of the plan carried out by an independent person or independent persons with relevant expertise determined by the CEO, that provides an analysis of the suitability of the plan to meet the outcomes of conditions 3-1(1) and 3-1(4).*
>
> *(2) The proponent shall not commence transfer of seawater, brine or waste product into any evaporation or crystalliser ponds associated with the proposal until the CEO confirmed by notice in writing that the Groundwater Monitoring and Management Plan meets the requirements of condition 3-4.*
>
> *3-4 The Groundwater Monitoring and Management Plan required by condition 3-3 shall:*
>
> *(1) when implemented, substantiate and ensure that the outcome of conditions 3-1(1) and 3-1(4) will be met;*
>
> *(2) provide the details, including timing, of hydrogeological investigations to be carried out that will:*
>
> *(a) provide a detailed understanding of the hydrological regime in the project area;*
>
> *(b) inform the final design of monitoring that will meet the requirement of condition 3-4(1); and*

(c) inform the final design of management and mitigation actions that will be implemented to meet the outcomes of conditions 3-1(1) and 3-1(4);

(3) detail the timing of monitoring bore installation and collection of baseline data, providing justification to demonstrate that data will represent baseline where it is collected after the commencement of operations;

(4) detail the methodology of seepage recovery actions that will be implemented where seepage from evaporation ponds to groundwater is detected;

(5) specify early warning trigger criteria that will trigger the implementation of management and/or contingency actions to prevent non-compliance with conditions 3-1(1) and 3-1(4).

(6) specify threshold criteria to demonstrate compliance with condition 3-1(3).

(7) specify the methodology of a monitoring program to determine if trigger criteria and threshold criteria have been met and meet the requirement of condition 3-4(1).

(8) specify management and/or contingency actions to be implemented if the trigger criteria required by condition 3-4(5) and/or the threshold criteria required by condition 3-4(6) have not been met; and

(9) provide the format and timing for the reporting of monitoring results against trigger criteria and threshold criteria to demonstrate that the outcomes in conditions 3-1(1) and 3-1(4) have been met over the reporting period in the Compliance Assessment Report required by condition 18-6.

The GWMMP consists of 10 sections including: (1) Context, scope and rationale, (2) Baseline data, (3) Potential ecological stressors, (4) Monitoring and investigations, (5) Review, (6) Responses to Protentional environmental impacts, (7) Reporting, (8) Groundwater and seepage modelling, (9) Adaptive management and review, and (10) Stakeholder consultation. The approach that is used in this review, is to follow the same format as the GWMMP-OD and present the comments and assessment of each specific section of GWMMP-OD separately. In a final section of the report all the major comments and major concerns are summarized.

2. REVIEW of the GWMMP-OD

2.1. Context, scope and rationale

GWMMP-OD clearly described the proposal elements, the location of ponds and infrastructure, and the key environmental factors. Groundwater dependent vegetation and ecosystems, as well as vegetation adjacent to ponds that may be sensitive to groundwater mounding are the environmental values that may be impacted by Mardie Project. The scope and requirements as specified within Condition 3-4 of Ministerial Statement 1175 and management objectives were carefully defined.

2.1.1. Comments on 2.1

- Considering the expected operating life of the project of greater than sixty years, management and mitigation actions of the potential environmental impacts and risks of long-term environmental changes such as climate change could be addressed.
- Based on Benthic Communities and Habitat Monitoring and Management Plan (dated 10 November 2020) the project activities may directly affect BCH, including mangrove habitat, algal mat habitat, samphire mudflat habitat, and vegetated sub-tidal habitat. The indirect impacts of the project on BCH have also been properly listed, however discussion of indirect impacts can be suggested.
- A management objective for groundwater base on Management Objectives section (1.5) is "*Ensure that indirect impacts to vegetation and ecosystems because of changes to groundwater regimes are minimised*". To further clarify discussion of, how can the impact be quantified and what level of impact is acceptable, and which party is responsible for the endorsement of minimised impacts based on ongoing monitoring are important points to emphasise.

2.2. Baseline data

The updated Groundwater Risk Assessment (GRA) for the revised Project layout by AQ2 (2021) was considered to define the baseline data and the potential impacts of the Project on groundwater receptors in the vicinity of Mardie Pool and coastal habitats. A summary of the relevant findings of AQ2 data review was provided in the Table 4 of GWMMP-OD. Conceptual geological models proposed based on Soilwater Group (2019) and CMW (2020) studies, some differences were noticed between these models. The current groundwater quality was established based on several sources. To address the gaps of the baseline data expansion investigations was suggested to achieve the objectives confidently.

2.2.1. Comments on 2.2

- Figures 5, 6 and 7 shows the conceptual and cross section geological profiles. It is helpful to show the cross-section lines in the plan view of the site (e.g. Figure 4).
- Is it possible to provide and illustrate the borehole locations that have been considered for defining the current groundwater quality? Is it possible to provide the contours of groundwater salt concentrations?
- It was stated that "*The groundwater in the calcarenite aquifer is brackish to saline with better quality being associated with the Mardie-pool creek line (likely to result from recharge)*". Is Mardie-pool a freshwater lens or a gaining surface water body (i.e. getting discharged by groundwater)?

- It was stated that "*Previous investigations at Mardie have indicated that the sea water interface (SWI) is well inland of the coast*.". Is a SWI investigation (e.g., field measurements and if required numerical modelling) required to find out the SWI interface?
- Water quantity (flux) and quality (salinity or EC) should be measured in creeks.
- It is recommended that the contours of water table and salt concentrations before and after project to be measured and provided.
- In the relevant section to further investigations to address the gaps of the baseline data, addition of more detailed discussion of the hydrological regime in the project area, can be beneficial. Further justification to demonstrate that generated data will accurately represent baseline is recommended.

2.3. Potential ecological stressors

Ecological stressors for the optimised layout were described. Appropriately, further investigation by applying density flow modelling was suggested to study seepage of hypersaline water from evaporation ponds and crystallisers. Fortescue alluvial aquifer formations was explained, and riparian vegetation of Fortescue River valley were illustrated. It was thought that only Mardie Pool riparian vegetation could potentially be impacted by hypersaline seepage from crystallisers. Coastal vegetation, mangrove habitat and algal mats, are within the development envelop and to the west of the proposed evaporation ponds. Key assumptions and uncertainties were identified and itemised.

2.3.1. Comments on 2.3

- It is recommended to include the salt precipitation and dissolution processes in modelling investigations and if required collect the relevant data.
- It is helpful to add the cross-section lines (location) on Figure 8 (Fortescue alluvial aquifer cross section) in the plan view of the site.
- In the key assumptions and uncertainties section the extreme scenarios and conditions including climate change, storms and floods may be addressed. There is uncertainty about natural recharge and evaporation estimates and changes.
- The soil properties and characteristics such as porosity and permeability change due to the salt precipitation and dissolution in porous media, it is recommended to consider a one-dimensional modelling that includes these processes. Based on this analysis the groundwater recharge due to the project may be influenced considerably.
- "*The actions triggers provided in this GMMP are preliminary only*", what is the plan and potential steps to prevent and minimise these preliminary triggers?
- The considered strategy to address uncertainty is "*Ensure the groundwater investigation and monitoring networks is capable of providing sufficient information to quantify the use of fresh groundwater by BCH, so that response triggers can be optimised to suit the GMMP's objectives*.". Is the information sufficient? How are triggers optimised?
- It was assumed that "*Brine losses to the environment as seeps and leaks will diminish over time, due to geological and biological processes reducing infiltration rates through the clay floors and wells*.". "*This assumption may be able to be confirmed through the monitoring described above. Additional investigations would be required for ponds where seepage losses have become an issue*.". It is a fair assumption, yet further and adjustable sampling, and modelling is required. It is advised to provide the quantitate requirements to implements these strategies.

2.4. Monitoring and investigations

Ongoing investigations including Airborne Electromagnetics survey, Mardie Pool bathymetry, and geological fault on Creek and pool development were mentioned. Terrestrial and coastal groundwater monitoring bore networks for Mardie pool and crystallisers, and mangrove and algal mat ecosystems were proposed. Nineteen bores were considered as terrestrial monitoring network phase 1. The technical and legitimate constraints to locating the groundwater monitoring bores such as land tenure boundaries, Aboriginal heritage, and Project footprint design were mentioned. On the assumption of future access to heritage areas around Mardie Pool a Phase 2 of terrestrial monitoring network including 6 bores was proposed. Installation of a monitoring bore network be installed along the western side of the planned evaporation ponds were planned as coastal bore network with three transects of bore sites, each consisting of three sets of bores. Bore installation schedule was described. The groundwater monitoring program including water quality measurement, hydraulic testing and monitoring schedule details were provided.

2.4.1. Comments on 2.4

- Monitoring network bores positions and timings were well explained for sensitive environmental groundwater dependent ecosystems. However, the justifications for the monitoring well positions and their adequacy need further expansion.
- Vertical groundwater gradient and therefore vertical groundwater flow and salinity transport, around crystallisers and evaporation pools, is likely due to the density dependent flow and convective flow. It is recommended, to consider multilevel bores or set of bores with various screen level, in the monitoring bore networks to measure the magnitude of vertical hydraulic gradients and vertical variations of salinity.
- It is suggested that the water quality data for Mardie pool and creeks to be collected in the same time period as when the groundwater monitoring networks are sampled .
- There is no costal monitoring bore at the location west side of pond 1 and around Robe River delta. Isn't the vegetation patch at the location environmentally sensitive? If so, necessary monitoring bores need to be discussed.

2.5. Review

Groundwater monitoring and investigation program may need to be reviewed and readjusted following the analysis of incoming field results as well as the numerical modelling outcomes.

2.5.1. Comments on 2.5

- The review procedure of the results is strongly supported. It is required that the adjusted GWMMP with details and including the outcomes of field and modelling investigations to be peer reviewed independently and endorsed.

2.6. Responses to Protentional environmental impacts

It was considered that the potentially be affected receptors were Mangrove habitat, Algal mat habitat, and Mardie Pool. It was considered that potential mitigation measures would be proposed after the groundwater flow and quality regime investigation. Response measures including more frequent monitoring, seepage recovery and mitigation measures were suggested.

2.6.1. Comments on 2.6

Due to the lack information, the responses to protentional environmental impacts are vague at this stage. The early warning trigger criteria is also ambiguous. Condition 3-4 requires, "*detail the methodology of seepage recovery actions*" and "*specify early warning trigger criteria*". To meet these criteria, the GWMMP needs to receive necessary approval, to initiate the project to be able to collect required preliminary data, and subsequently provide a more comprehensive assessment and report, for the expansion and finalisation of the plan.

2.7. Reporting

The format and timing for the reporting as a Compliance Assessment Report for the Compliance Branch at the Office of the Environmental Protection Authority were given.

2.7.1. Comments on 2.7

- There is no comment for this section, it was well delivered.

2.8. Groundwater and seepage modelling

Groundwater modelling was effectively utilised to simulate the hydrogeological conditions in the Project area for quantification of fresh and saline water interactions, groundwater recharge into Mardie pool, and groundwater exchanges with the areas of algal mats. A two staged approach was proposed for the study: Stage 1 the interactions between fresher and more saline water close to the coast and around the evaporation ponds, and Stage 2 to simulate the potential interactions of the proposed ponds on the regional groundwater flow system. Modelling approach including data review and conceptualisation, Stage 1 modelling, and Stage 2 regional groundwater modelling were described.

2.8.1. Comments on 2.8

- For the data review and conceptualisation, a list of identification information has been listed, , for example *"Identification of areas or sources of groundwater recharge including recharge from rainfall associated flood plain and flood channels."*, "*Identification of areas or points of groundwater discharge including groundwater outflow to the coast and surface pools, evapotranspiration from vegetation and shallow water tables*", and "*Estimates of groundwater recharge and discharge based on regional groundwater gradients*.". However, it is not very clear how some the information that have been mentioned that would be identified from the investigation data. It is recommended that a clear linkage between the available data and field investigation, and the claimed identification data for the conceptualisation is established in the report.
- Regarding the Stage 1 modelling: Are the unsaturated zone flow and transport processes considered in the simulation? Are the salt precipitation and dissolution processes and their impacts on hydrogeologic properties included in the simulation? Is there any historical data existing? and how the evapotranspiration is estimated?
- Stage 2 regional groundwater modelling is "*the development of a regional groundwater flow model to assess the potential impacts of the proposed evaporation ponds on the regional groundwater system*". It seems there is an implied assumption that saline water flow (either as seawater intrusion or infiltration from the evaporation ponds) has no influence on groundwater flows paths, what are the justifications for these assumptions and what are the available supporting evidence?

- What are the available historical data for history matching in the Stage 2 regional groundwater modelling?

2.9. Adaptive management and review

An adaptive management approach is applied for improving environmental results and management practices throughout the implementation of the project. Annual review of data, evaluation of monitoring and management outcomes against management targets and the objectives, review of management actions, and identification of potential new management measures and technologies were considered for implementation of the adaptive management approach.

2.9.1. Comments on 2.9

- There is no comment for this section.

2.10. Stakeholder consultation

Formal approval would be sought from DWER for any significant revisions to the GMMP. The main points arising from the submission to the public and WA government departments, including DWER, DAWE and DBCA were included. The plan appropriately emphasises and ensures that incidents, reports and complaints would be recorded, investigated, and acted on in a timely fashion. Regular meetings between groundwater users and stakeholder are maintained. Cultural and Heritage Management Plans and formal working agreements with the YM and KM traditional owner groups will be conducted.

2.10.1. Comments on 2.10

- There is no comment for this section.

3. CONCLUSION

The purpose of this report was to provide an independent peer review of the GWMMP-OD. The suitability of the GWMMP-OD to address the study outcomes adequately and correctly was assessed in depth, and based on this review, the plan has been designed in alignment with the excepted guidelines, however it requires specific improvements to meet its objectives with confidence. Some technical comments were made in an endeavour to provide further modifications and clarifications to the project outlined. Following the implementation of the review comments, a secondary review of the new version of report is required.

In summary, the main aspects that GWMM-OD need further improvements and elaboration include:

- Justification to demonstrate that generated data will accurately represent the baseline
- Installing multilevel bores or set of bores with various screen level
- Monitoring bores at the location west side of pond 1 and around Robe River delta
- Rationalisation for the monitoring well positions and their adequacy
- Plan and potential steps to minimise identified preliminary triggers
- Hydrological regime in the project area to address the gaps of the baseline data
- Establishing an adequate linkage between the investigations and the claimed identification data for the conceptualisation
- Deeper discussion of the uncertainties about natural recharge and evaporation estimates and changes
- Saline water flow influence on regional groundwater flows paths
- Collecting the water quality data for Mardie pool and creeks
- Review and elaboration on the indirect impacts of the project on BCH, availability of historical data
- Estimation of the evapotranspiration, quantification of the acceptable level of impact
- Salt precipitation and dissolution processes in modelling
- Management and mitigation actions of the potential environmental impacts and risks of long-term environmental changes such as climate change.

Appendix G: Audit of BCI's Responses to Peer Review (CyMod 2023)

CyMod Systems
Applied Numerical Modelling

2 Vellender Rd
Bedfordale, WA
Mobile: 0417924540

November 29, 2023

Mr. S. Shute
Manager, Environment and Approvals
BCI Minerals
Level 2, 1 Altona Street, West Perth, WA 6005

Re: Audit of BCI's Responses to Reviewer's Comments of BCI GMMP

Dear Spencer,

Please find attached a summary of the audit of the reviewer's comments as outlined in:

Review of Groundwater Monitoring & Management Plan for Mardie Salt and Potash Project Document Number: BCI-ADM-TEM-011 Rev 2 Document Date: 14 Dec 2021 Mardie Project Groundwater Monitoring and Management Plan - Optimised Design.

It is noted the review was undertaken in 2021, and consequently some of the reviewer's comments may be outdated with respect to the most recent Groundwater Monitoring and Management Plan (GMMP).

The audit finds that most of the reviewer's questions and suggestions have been acted upon in version H of the GMMP. The attached table summarizes BCI's response to relevant reviewer comments.

Consequently, BCI has addressed the reviewer's comments adequately, as shown in Table 15 of the GMMP, which is consistent with my audit.

I have also provided some additional comments outside of the audit, that may be helpful in finalizing the GMMP, as listed below:

- Report including Appendix A requires proof reading.
- It is recommended to include a figure in Appendix A of the simulated water level response in observation bore 100 m from the embankment.
- Given the life of the project, a longer period of model simulation is recommended.
- The presentation of some of the model results uses inappropriate vertical scaling, which tends to obscure the shallow water table response; and
- It is anticipated that subsequent modelling will need to be undertaken to quantify uncertainty and the sensitivity of model aquifer parameters, which will help to confirm the relevance of base line data.

Section	Main recommendation by Reviewer	How addressed in GWMMP
2.2.1	*Figures 5, 6 and 7 shows the conceptual and cross section geological profiles. It is helpful to show the cross-section lines in the plan view of the site (e.g., Figure 4).* *Is it possible to provide and illustrate the borehole locations that have been considered for defining the current groundwater quality?* *Is it possible to provide the contours of groundwater salt concentrations?*	Not sure what Figures the reviewer is referring to but suggest the following: • Monitor bores are normally represented in red, while production bores are blue; • Referenced bores should be highlighted on each figure with an item in the legend referring to the cross section or groups of bores. See Appendix A, figure 4.6 for contoured salt concentrations
2.2.1	It was stated that "*The groundwater in the calcarenite aquifer is brackish to saline with better quality being associated with the Mardie-pool creek line (likely to result from recharge)*." Is Mardie-pool a freshwater lens or a gaining surface water body (i.e., getting discharged by groundwater)?	The conceptualization and quantification of the hydrogeological regime is incomplete in the Mardie Pool area. The conceptual and numerical models for this area are scheduled to be completed by the first quarter 2024
2.2.1	*It is recommended that the contours of water table and salt concentrations before and after project to be measured and provided.*	The water level and water quality data as outlined in the GMMP will be analyzed and reported on prior to and during the life of the project.
2.2.1	*In the relevant section to further investigations to address the gaps of the baseline data, addition of more detailed discussion of the hydrological regime in the project area, can be beneficial. Further justification to demonstrate that generated data will accurately represent baseline is recommended.*	Data will be collected up to 6 months prior to the operation of the evaporation ponds, providing a baseline and to inform the regional groundwater model. Appendix A presents an updated conceptual hydrogeological model of the Pond 1 area. A numerical model has been developed and used to simulate 3 years pond operation.
2.3	*It is recommended to include the salt precipitation and dissolution processes in modelling investigations and if required collect the relevant data.*	The modelling of salt precipitation and dissolution processes have previously been state as considered to small scale for inclusion in the proposed regional groundwater modelling. Note, the modelled scenarios of Pond 1 (which are not regional) use a salt precipitation process (as well as algal matts)

Section	Main recommendation by Reviewer	How addressed in GWMMP
		to justify reducing the leakage through the pond floor.
2.3	*It is helpful to add the cross-section lines (location) on Figure 8 (Fortescue alluvial aquifer cross section) in the plan view of the site.*	Figure may no longer be in the document. See comment in Item 2.2.1
2.4	*There is no coastal monitoring bore at the location west side of pond 1 and around Robe River delta. Isn't the vegetation patch at the location environmentally sensitive? If so, necessary monitoring bores need to be discussed.*	CMB6_1 (shallow and deep) bores have been installed west of Pond 1, subsequent to the review. Bores are suitable for establishing vertical gradients.
2.5 -2.8	*Reviewer comments sections 2.5-2.8*	Covered in Table 15 of version H of the GMMP

Appendix H Statement against the Significance Guidelines for MNES

Significant impact guidelines inform the impact assessment of MNES required under the EPBC Act. In accordance with these guidelines, the assessment of 'Listed threatened species and communities' is presented within the context of the following key concepts:

- Habitat critical to the survival of a species
- Any population for species listed as Endangered or Critically Endangered under the EPBC Act and an 'important population' for species listed as Vulnerable under the act).

'Habitat critical to the survival of a species,' refers to areas that are necessary:

- For activities such as foraging, breeding, roosting, or dispersal
- For the long-term maintenance of the species or ecological community (including the maintenance of species essential to the survival of the species or ecological community)
- To maintain genetic diversity and long-term evolutionary development
- For the reintroduction of populations or recovery of the species or ecological community.

Such habitat may include, but is not limited to, habitat identified in a recovery plan for the species or ecological community as habitat critical for that species or ecological community, and/or habitat listed on the Register of Critical Habitat maintained by the Minister under the EPBC Act (DoE 2013).

An 'important population' is a population that is necessary for a species' long-term survival and recovery. This may include populations identified as such in recovery plans, and/or that are:

- Key source populations either for breeding or dispersal;
- Populations that are necessary for maintaining genetic diversity
- Populations that are near the limit of the species range (DoE 2013).

An assessment of significance for each MNES species is presented in this chapter and reflects additional information provided by survey information presented after the submission of the EPBC referral.

- Listed Threatened Species and Ecological Communities

BCI understands that the MNES Guidelines state that an action is likely to have a significant impact on an listed threatened species if there is a real chance or possibility that it will meet a under of specific criteria detailed in the MNES Guidelines.

An assessment against each criterion is provided in the below table:

Consideration	Impact prediction and assessment
lead to a long-term decrease in the size of an important population of a species	In accordance with condition B3-1(4) of MS 1211, BCI must ensure the implementation of the proposal results in no changes to the health, extent or diversity of intertidal benthic communities and habitat, including mangrove, coastal samphire and algal mat as a result of changes to groundwater regimes or groundwater quality associated with the proposal. Noting the above, the Project will be implemented in a manner that ensures the ecological integrity and function of the intertidal habitats that support the presence of EPBC Act Listed Threatened species. The implementation of the GMMP, including monitoring protocols and management actions, will ensure the protection and maintenance of ecological function from indirect impacts associated with changes to groundwater quality. Noting the above, although no Important Populations for green sawfish, marine reptiles or protected shorebirds necessary for these species' long-term survival or recovery have been identified to occur within or adjacent to the Project area, the habitat that supports these species will be maintained. Furthermore, the intertidal habitats adjacent to the Project area are known to be widespread and found elsewhere in the border region. It is therefore considered unlikely that the Project will lead to a long-term decrease in the size of an important population of a species
reduce the area of occupancy of an important population	The maintenance of ecological integrity and function of the intertidal habitats, through the implementation of the GMMP, will ensure that the area of occupancy is not reduced as a result of the indirect impacts associated with changes to groundwater regimes and quality.
fragment an existing important population into two or more populations	The maintenance of ecological integrity and function of the intertidal habitats, through the implementation of the GMMP, will ensure that the intertidal habitat will not be modify, destroy, remove, isolate, or decrease the availability or quality of habitat to the extent that the species could decline or be fragmented.
adversely affect habitat critical to the survival of a species	The Project will be implemented in a manner that ensures the ecological integrity and function of the intertidal habitats that support the presence of EPBC Act Listed Threatened species are maintained. The intertidal habitats adjacent to the Project area are known to be widespread and found elsewhere in the border region. It is therefore considered unlikely that the Project will adversely affect habitat critical to the survival of a species, including breeding, foraging, nesting or dispersal habitat.
disrupt the breeding cycle of an important population	The Project will be implemented in a manner that ensures the ecological integrity and function of the intertidal habitats that support the presence of EPBC Act Listed Threatened species are maintained. The intertidal habitats adjacent to the Project area are known to be widespread and found elsewhere in the border region. It is therefore considered unlikely that the Project will disrupt the breeding cycle of an important population.
modify, destroy, remove or isolate or decrease the availability or quality of habitat to the extent that the species is likely to decline	Due to the known locations of mating, nesting, inter-nesting, and foraging habitats of Listed Species in the wider region, including the maintenance of ecological function and ecosystem integrity of intertidal habitat, the indirect impact associated with the proposed action are unlikely that to decrease the quality of habitats. Furthermore, it is unlikely that the filling of Ponds 1-4 would modify, destroy, remove, isolate, or decrease the availability or quality of habitat to the extent that the species could decline.

result in invasive species that are harmful to a vulnerable species becoming established in the vulnerable species' habitat	Improved weed management as a consequence of the action will minimise the potential for the introduction or spread of weeds. No feral pest species will be introduced by the action however there may be opportunities for improved management.
introduce disease that may cause the species to decline	The Project will be managed in a manner that prevents the introduction of disease that could impact listed species. It is considered highly unlikely that an impact pathway of this nature will.
interfere substantially with the recovery of the species.	The Project will be managed in a manner that reduces the presence of ferals, limits the anthropogenic activities interfering with local populations and reduces the spread of disease.

Listed Migratory Species

The MNES Guidelines have been applied to migratory shorebirds in the project area (Significance Table below), to demonstrate that the proposed action is likely to have a significant impact on a migratory species, taking into consideration the below criteria:

- substantially modify (including by fragmenting, altering fire regimes, altering nutrient cycles or altering hydrological cycles), destroy or isolate an area of important habitat for a migratory species
- result in an invasive species that is harmful to the migratory species becoming established in an area of important habitat for the migratory species, or
- seriously disrupt the lifecycle (breeding, feeding, migration or resting behaviour) of an ecologically significant proportion of the population of a migratory species.

Consideration	Impact prediction and assessment
substantially modify (including by fragmenting, altering fire regimes, altering nutrient cycles or altering hydrological cycles), destroy or isolate an area of important habitat for a migratory species	Unlikely to occur. The intertidal habitat that support migratory bird species are unlikely to modified by the presence of salt ponds. The roosting habitat is widespread along the broader coastline and is unlikely to isolate, fragment of disrupt the lifecycle of a population of migratory shorebird species to the effect that their ecological function or viability at a local or regional scale will be significantly affected.
result in an invasive species that is harmful to the migratory species becoming established in an area of important habitat for the migratory species, or	Unlikely to occur. The proposed action does not provide opportunity for movement of invasive species; area already supports invasive weed species.
seriously disrupt the lifecycle (breeding, feeding, migration or resting behaviour) of an ecologically significant proportion of the population of a migratory species.	Unlikely to occur. The roosting habitat is widespread along the broader coastline and is unlikely to isolate, fragment of disrupt the lifecycle of a population of migratory shorebird species to the effect that their ecological function or viability at a local or regional scale will be significantly affected.

Appendix H: Statement Against Significant Guidelines for MNES

Appendix H Statement against the Significance Guidelines for MNES

Significant impact guidelines inform the impact assessment of MNES required under the EPBC Act. In accordance with these guidelines, the assessment of ‘Listed threatened species and communities’ is presented within the context of the following key concepts:

- Habitat critical to the survival of a species
- Any population for species listed as Endangered or Critically Endangered under the EPBC Act and an ‘important population’ for species listed as Vulnerable under the act).

‘Habitat critical to the survival of a species,’ refers to areas that are necessary:

- For activities such as foraging, breeding, roosting, or dispersal
- For the long-term maintenance of the species or ecological community (including the maintenance of species essential to the survival of the species or ecological community)
- To maintain genetic diversity and long-term evolutionary development
- For the reintroduction of populations or recovery of the species or ecological community.

Such habitat may include, but is not limited to, habitat identified in a recovery plan for the species or ecological community as habitat critical for that species or ecological community, and/or habitat listed on the Register of Critical Habitat maintained by the Minister under the EPBC Act (DoE 2013).

An ‘important population’ is a population that is necessary for a species’ long-term survival and recovery. This may include populations identified as such in recovery plans, and/or that are:

- Key source populations either for breeding or dispersal;
- Populations that are necessary for maintaining genetic diversity
- Populations that are near the limit of the species range (DoE 2013).

An assessment of significance for each MNES species is presented in this chapter and reflects additional information provided by survey information presented after the submission of the EPBC referral.

- Listed Threatened Species and Ecological Communities

BCI understands that the MNES Guidelines state that an action is likely to have a significant impact on an listed threatened species if there is a real chance or possibility that it will meet a under of specific criteria detailed in the MNES Guidelines.

An assessment against each criterion is provided in the below table:

Consideration	Impact prediction and assessment
lead to a long-term decrease in the size of an important population of a species	In accordance with condition B3-1(4) of MS 1211, BCI must ensure the implementation of the proposal results in no changes to the health, extent or diversity of intertidal benthic communities and habitat, including mangrove, coastal samphire and algal mat as a result of changes to groundwater regimes or groundwater quality associated with the proposal. Noting the above, the Project will be implemented in a manner that ensures the ecological integrity and function of the intertidal habitats that support the presence of EPBC Act Listed Threatened species. The implementation of the GMMP, including monitoring protocols and management actions, will ensure the protection and maintenance of ecological function from indirect impacts associated with changes to groundwater quality. Noting the above, although no Important Populations for green sawfish, marine reptiles or protected shorebirds necessary for these species' long-term survival or recovery have been identified to occur within or adjacent to the Project area, the habitat that supports these species will be maintained. Furthermore, the intertidal habitats adjacent to the Project area are known to be widespread and found elsewhere in the border region. It is therefore considered unlikely that the Project will lead to a long-term decrease in the size of an important population of a species
reduce the area of occupancy of an important population	The maintenance of ecological integrity and function of the intertidal habitats, through the implementation of the GMMP, will ensure that the area of occupancy is not reduced as a result of the indirect impacts associated with changes to groundwater regimes and quality.
fragment an existing important population into two or more populations	The maintenance of ecological integrity and function of the intertidal habitats, through the implementation of the GMMP, will ensure that the intertidal habitat will not be modify, destroy, remove, isolate, or decrease the availability or quality of habitat to the extent that the species could decline or be fragmented.
adversely affect habitat critical to the survival of a species	The Project will be implemented in a manner that ensures the ecological integrity and function of the intertidal habitats that support the presence of EPBC Act Listed Threatened species are maintained. The intertidal habitats adjacent to the Project area are known to be widespread and found elsewhere in the border region. It is therefore considered unlikely that the Project will adversely affect habitat critical to the survival of a species, including breeding, foraging, nesting or dispersal habitat.
disrupt the breeding cycle of an important population	The Project will be implemented in a manner that ensures the ecological integrity and function of the intertidal habitats that support the presence of EPBC Act Listed Threatened species are maintained. The intertidal habitats adjacent to the Project area are known to be widespread and found elsewhere in the border region. It is therefore considered unlikely that the Project will disrupt the breeding cycle of an important population.
modify, destroy, remove or isolate or decrease the availability or quality of habitat to the extent that the species is likely to decline	Due to the known locations of mating, nesting, inter-nesting, and foraging habitats of Listed Species in the wider region, including the maintenance of ecological function and ecosystem integrity of intertidal habitat, the indirect impact associated with the proposed action are unlikely that to decrease the quality of habitats. Furthermore, it is unlikely that the filling of Ponds 1-4 would modify, destroy, remove, isolate, or decrease the availability or quality of habitat to the extent that the species could decline.

result in invasive species that are harmful to a vulnerable species becoming established in the vulnerable species' habitat	Improved weed management as a consequence of the action will minimise the potential for the introduction or spread of weeds. No feral pest species will be introduced by the action however there may be opportunities for improved management.
introduce disease that may cause the species to decline	The Project will be managed in a manner that prevents the introduction of disease that could impact listed species. It is considered highly unlikely that an impact pathway of this nature will.
interfere substantially with the recovery of the species.	The Project will be managed in a manner that reduces the presence of ferals, limits the anthropogenic activities interfering with local populations and reduces the spread of disease.

Listed Migratory Species

The MNES Guidelines have been applied to migratory shorebirds in the project area (Significance Table below), to demonstrate that the proposed action is likely to have a significant impact on a migratory species, taking into consideration the below criteria:

- substantially modify (including by fragmenting, altering fire regimes, altering nutrient cycles or altering hydrological cycles), destroy or isolate an area of important habitat for a migratory species
- result in an invasive species that is harmful to the migratory species becoming established in an area of important habitat for the migratory species, or
- seriously disrupt the lifecycle (breeding, feeding, migration or resting behaviour) of an ecologically significant proportion of the population of a migratory species.

Consideration	Impact prediction and assessment
substantially modify (including by fragmenting, altering fire regimes, altering nutrient cycles or altering hydrological cycles), destroy or isolate an area of important habitat for a migratory species	Unlikely to occur. The intertidal habitat that support migratory bird species are unlikely to modified by the presence of salt ponds. The roosting habitat is widespread along the broader coastline and is unlikely to isolate, fragment of disrupt the lifecycle of a population of migratory shorebird species to the effect that their ecological function or viability at a local or regional scale will be significantly affected.
result in an invasive species that is harmful to the migratory species becoming established in an area of important habitat for the migratory species, or	Unlikely to occur. The proposed action does not provide opportunity for movement of invasive species; area already supports invasive weed species.
seriously disrupt the lifecycle (breeding, feeding, migration or resting behaviour) of an ecologically significant proportion of the population of a migratory species.	Unlikely to occur. The roosting habitat is widespread along the broader coastline and is unlikely to isolate, fragment of disrupt the lifecycle of a population of migratory shorebird species to the effect that their ecological function or viability at a local or regional scale will be significantly affected.

Appendix I: Geophysical Survey Report

TERRA RESOURCES
(ABN 695 223 502 99)

MARDIE PROJECT
Loupe EM Acquisition and Processing Report

BCI Minerals Ltd.

TECHNICAL REPORT

GDA94 MGA50 – Mardie Station, Western Australia

DISTRIBUTION

Bruce Harvey (AQ2)
Barry Bourne (Terra Resources)

Author
C. Mortimore
Geophysicist

Table of Contents

Table of Figures

1. INTRODUCTION

In January 2024, Terra Resources commenced a ground electromagnetic survey using the Loupe system for BCI Minerals Ltd. at their Mardie Salt/ Potash Project in Western Australia.

This report summarised the acquisition, processing and display of the EM data.

2. GEOPHYSICS – LOUPE EM

Loupe TEM is a portable, time-domain electromagnetic (EM) system that is specifically designed for near-surface conductivity measurements (Street et al. 2018, Figure 1).

It consists of 2 components: a transmitter (Tx) and a receiver (Rx) that are connected by a single cable with a separation of 10 m.

The transmitter has a multi-turn coil and with a current of 20 A at effective area of 4.538 m^2, it produced a maximum moment of 90.76 Am^2. For this survey, the transmitter was operated at 75 Hz and used a 50 % duty cycle with an on/off time at 8 μs.

The receiver has a 3-component coil, whereby each axial component has a 100 kHz bandwidth with an effective area of 200 m^2. The receiver records signals at over 500000 per second at 24-bit resolution and produces a measurement of the secondary field at every second.

Figure 1: Illustrations of the transmitter (left) and receiver system (right) (obtained from Street et al. 2018).

2.1. SCOPE AND SURVEY DESIGN

The objective of this survey was to investigate whether ground EM survey (Loupe) can be used to detect conductivity variations in the hypersaline groundwater environment of the salt flats.

The survey design consists of seven lines fashioned approximately NE-SW along the outer edge of the boundary of BCI mineral's salt ponds. Line length varies from 768m – 3630m. Lines are variably spaced between about ~1500m to ~4000m.

Figure 2: Loupe EM Survey line paths and line names overlaid satellite imagery.

2.2. ACQUISITION

The acquisition took place over the Mardie coastal/ tidal plains from 22nd of January, 2024 to 24th of January, 2024.

The crew mobilised on the 21st of January, 2024 and returned to Perth on 26th of January, 2024.

The total acquired line distance is **12, 364 meters**.

The crew was based at BCI's Mardie village/ site during the survey and the data was uploaded to the office at the end of each day for review and initial QA/QC.

Line 3 had to be modified in the field due to restrictions about working over the gas pipeline. The actual line path was shifted ~347m to the north to avoid this hazard.

The terrain is mostly flat and shrubbery is minimal. Muddy conditions, especially around local gullies created some challenge with acquisition, especially in terms of vehicle accessibility. An additional ~4km is estimated to have been walked with equipment due to inaccessibility of some lines via vehicle. Especially along northern lines (lines 5 and 6).

Figure 3: Loupe EM crew members setting up for acquisition.

2.2.1. System Specifications

Transmitter	
Base Frequency	75 Hz
Current	20 A
Effective Area	4.538 m^2
Maximum Moment	90.76 Am^2
Number of Turns	13
Waveform	50% duty cycle, bi-polar square

Receiver	
Receiver (Rx) Type	3-axis coil with a common centre point
Receiver (Rx) effective area (after amplification)	200 m^2
Gain	10

Transmitter and Receiver	
Transmitter (Tx) and Receiver (Rx) Horizontal Separation	10 m

2.3. PROCESSING

2.3.1. QA/QC

Preliminary QC was done in real-time. Real-time signal processing involved stacking, filtering power line fields, windowing, and motion noise removal. After acquisition, the data was manually de-noised and cleaned before being transformed into conductivity depth images (CDI).

2.3.2. Conductivity Depth Imaging (CDI)

Data that has passed QA/QC was then processed using the maximum current algorithm developed by Fullagar Geophysics to produce conductivity depth images (CDI).

Two transforms were performed. The first is on the XZ components together and the parameters of the transform are given below.

Modelled Components	X and Z
Number of Channels (X- and Z-components)	11
Sharpening	0
Maximum Number of Iterations	10

Waveform	
Time Window - Middle (μs)	Time Window - Width (μs)
125.0	43.7
164.7	55.6
220.2	75.4
293.7	99.2
390.9	134.9
521.8	182.5
693.5	240.1
923.6	319.4
1228.2	424.6
1633.9	565.5
2173.6	748.0

The second transform was performed on the X component alone and the parameters of this transform are given below.

Modelled Components	X
Number of Channels (X)	16
Sharpening	0
Maximum Number of Iterations	10

Waveform	
Time Window - Middle (μs)	Time Window - Width (μs)
29.8	11.9
39.7	15.9
53.6	19.8
69.4	23.8
93.3	31.8
125.0	43.7
164.7	55.6
220.2	75.4
293.7	99.2
390.9	134.9
521.8	182.5
693.5	240.1
923.6	319.4
1228.2	424.6
1633.9	565.5
2173.6	748.0

Negative values in the early time channels meant that early channels were nulled during the transform from time domain to conductivity variation with depth. Early time negative values are a function of system geometry and high conductivity of the surface and subsurface. The X-component transform was performed in order to maximise the amount of positive early time data in order to resolve a greater portion of the upper surface as the Z-component shows a greater number of negative channels.

3. RESULTS

A CDI database was produced in tabulated ASCII format that is readily imported into the client's workspace.

The composite figures below, summarise the results of the survey along each line. Raw data is shown as channel amplitude profiles in the top two figures. The first figure shows channel amplitude variation of the Z-component data. The second image shows channel amplitude variation of the X-component data. Only channels without noise are displayed. In the Z-component, this is channel 13- 23 and in the x-component this is channels 7-23. In line 4, a more conductive line, channel 13 of the Z-component still shows some negative values as a function of very high conductivity.

Below these are conductivity depth sections from the transforms. The X only transform is on top and the XZ transform is below that. The blue line above both of these sections is of the RL surface. The transform results are shown as a depth offset by that RL surface and are coloured by conductivity variation. The colour stretch has been kept consistent across the line figures for comparison reasons but the stretch of the provided grds can be locally adjusted to suit. The y-axis is vertically exaggerated for display purposes but is provided on an isotropic scale in grd form. Distance from the start of the line is shown on the x-axis. This distance corresponds with that shown on the line map to the right.

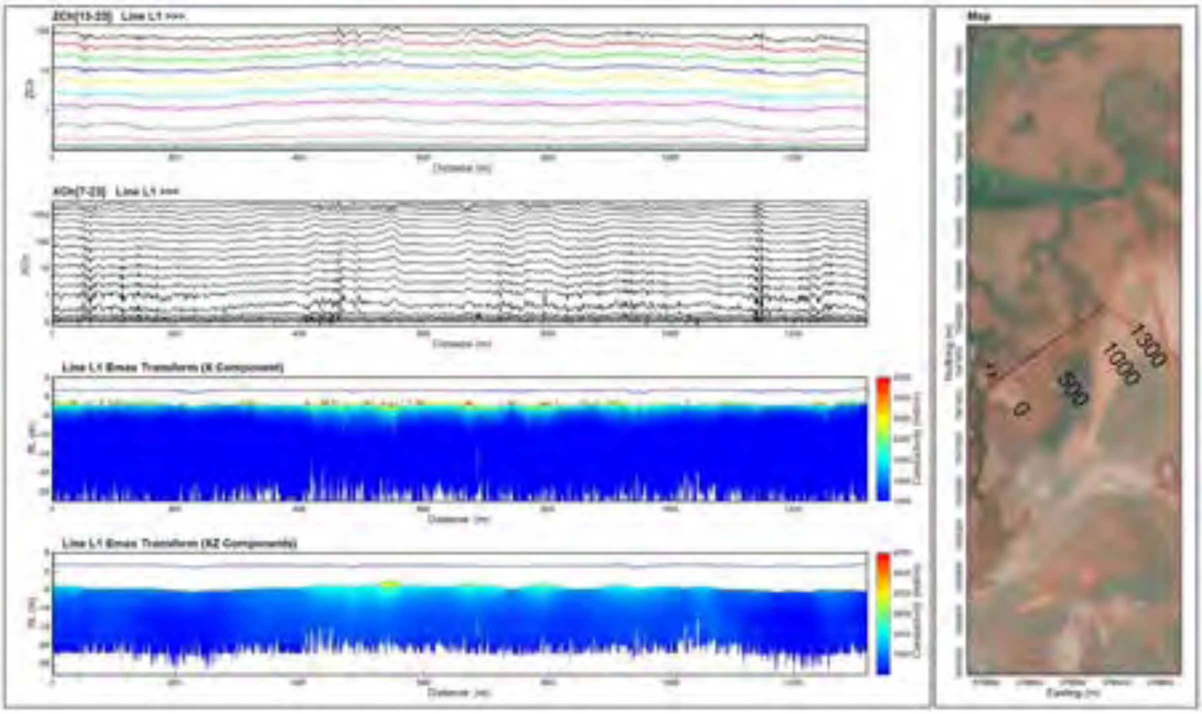


Figure 4. Line 1: Conductivity depth imaging (CDI) at vertical exaggeration. Colour stretch in linear scale of 1000-4000 mS/m.

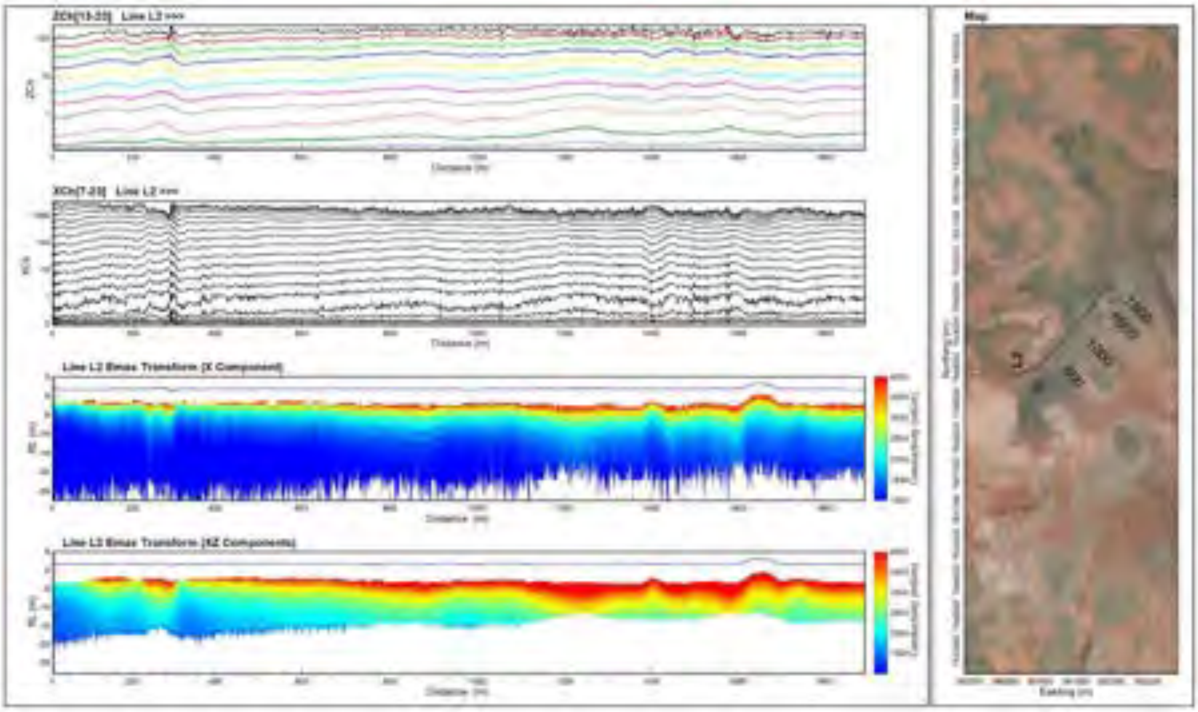


Figure 5. Line 2: Conductivity depth imaging (CDI) at vertical exaggeration. Colour stretch in linear scale of 1000-4000 mS/m.

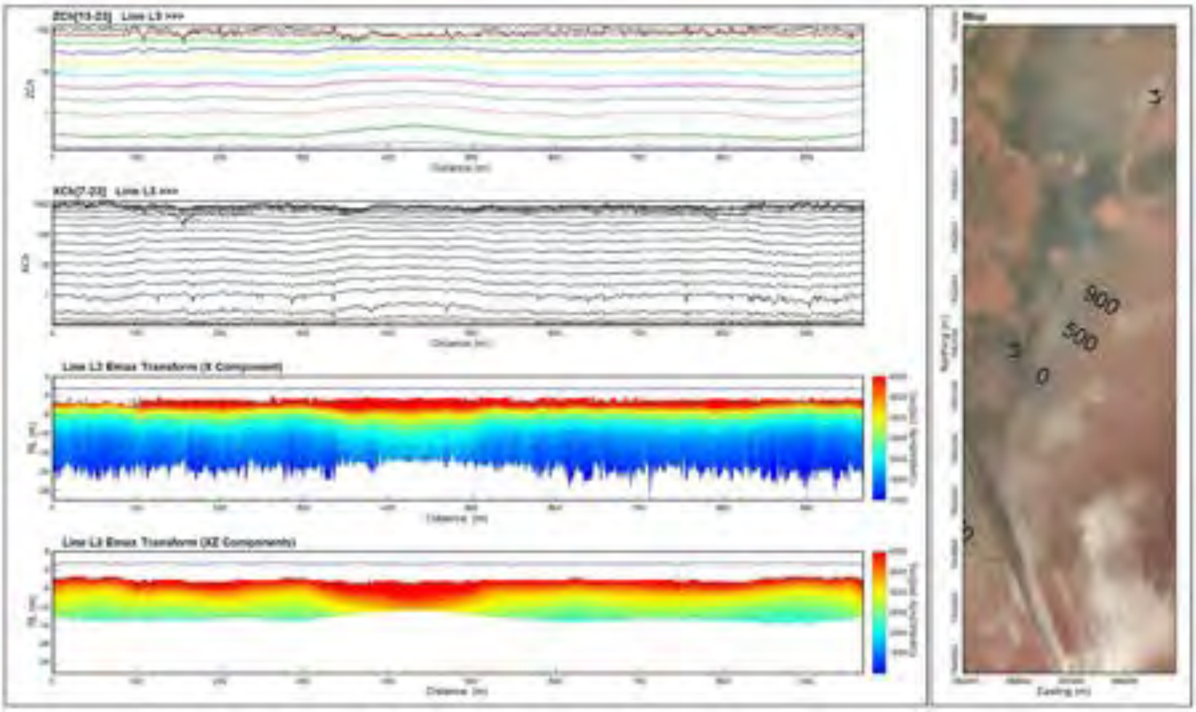


Figure 6. Line 3: Conductivity depth imaging (CDI) at vertical exaggeration. Colour stretch in linear scale of 1000-4000 mS/m.

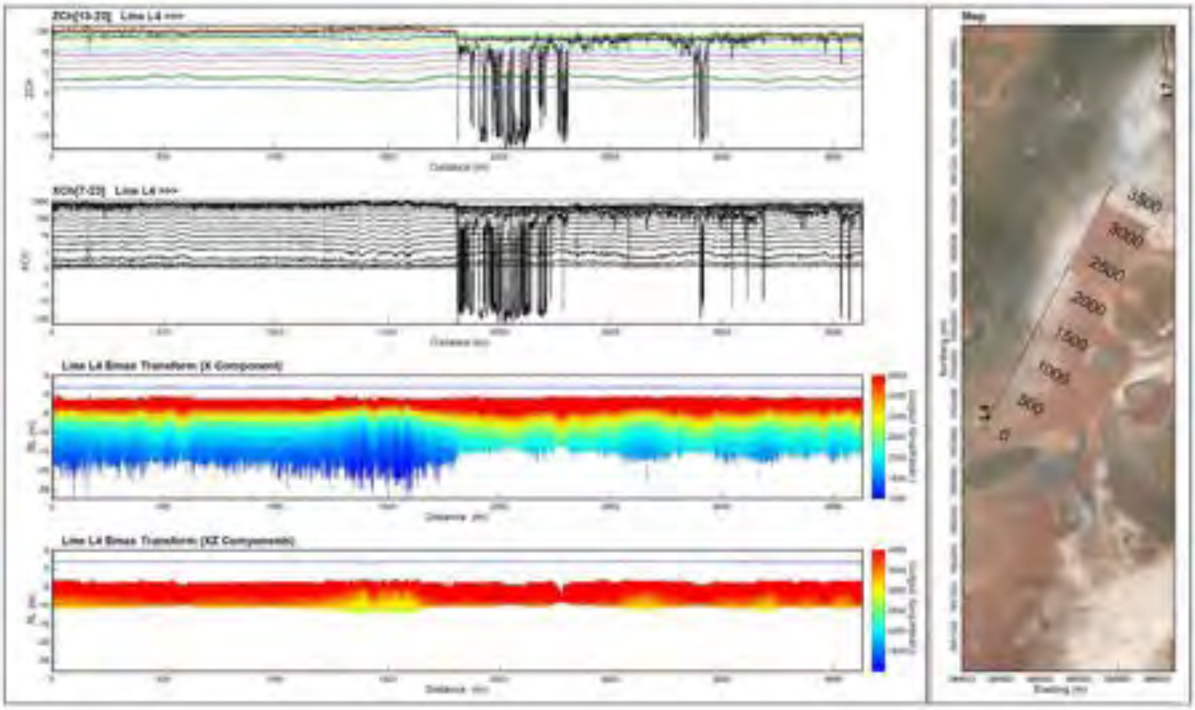


Figure 7. Line 4: Conductivity depth imaging (CDI) at vertical exaggeration. Colour stretch in linear scale of 1000-4000 mS/m.

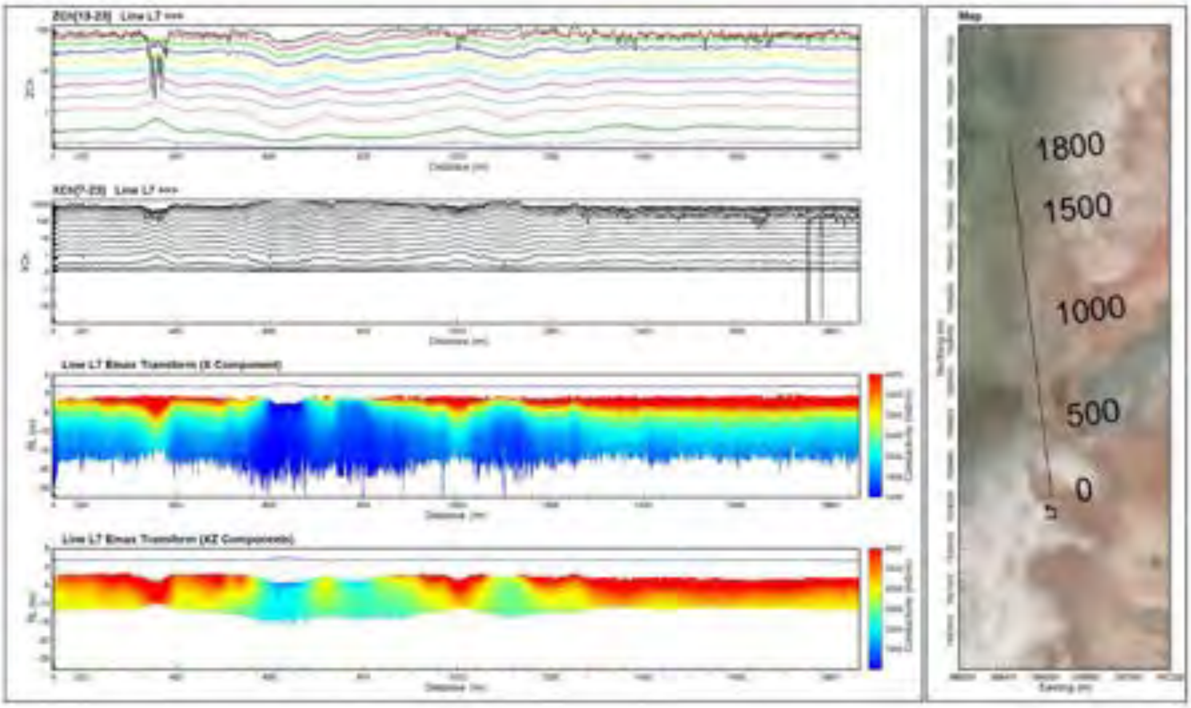


Figure 8. Line 7: Conductivity depth imaging (CDI) at vertical exaggeration. Colour stretch in linear scale of 1000-4000 mS/m.

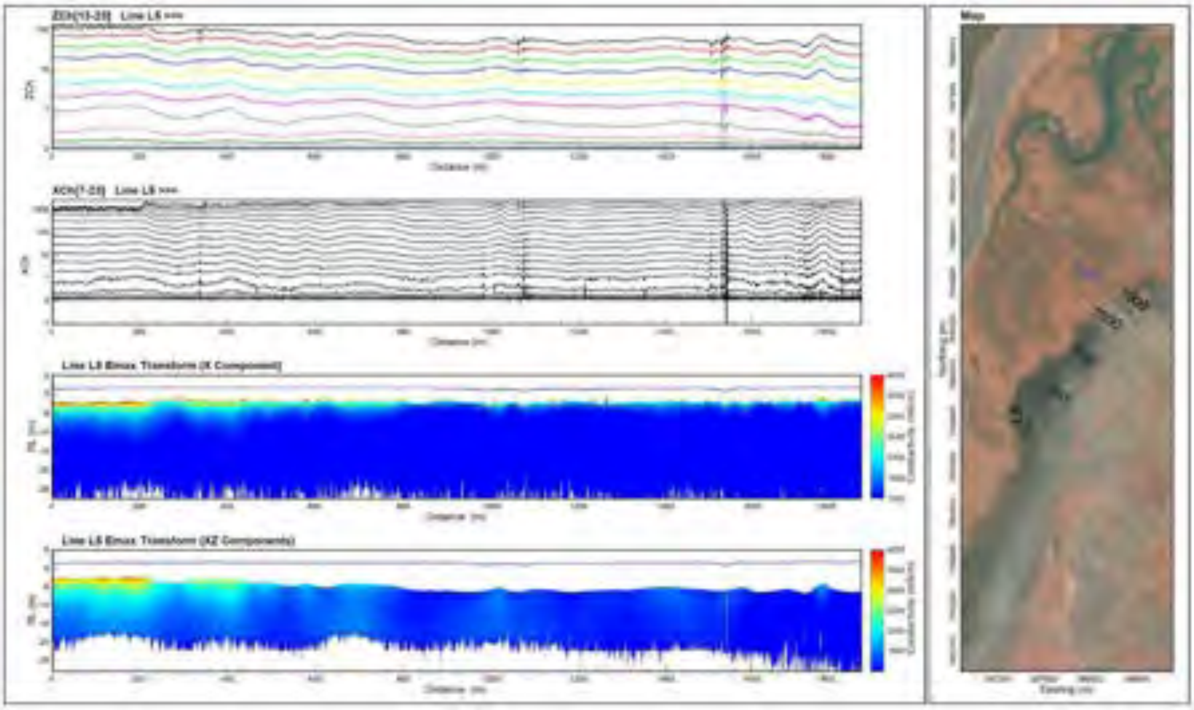


Figure 9. Line 5: Conductivity depth imaging (CDI) at vertical exaggeration. Colour stretch in linear scale of 1000-4000 mS/m.

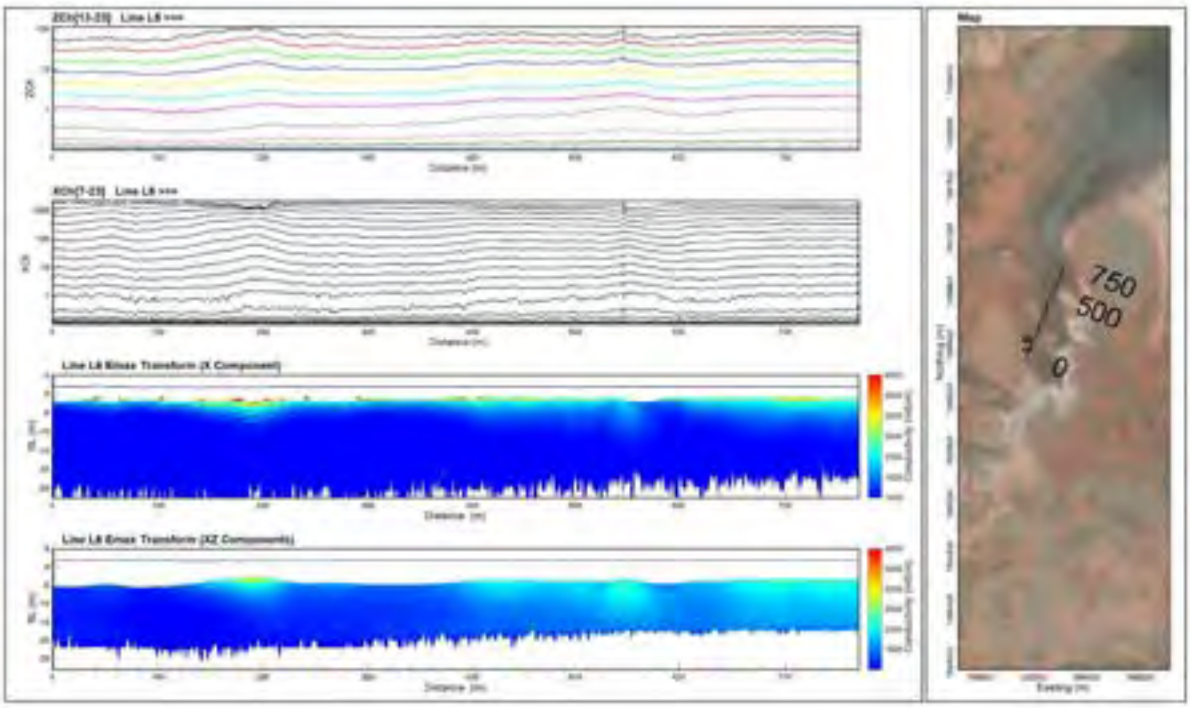


Figure 10. Line 6: Conductivity depth imaging (CDI) at vertical exaggeration. Colour stretch in linear scale of 1000-4000 mS/m.

4. SUMMARY

The Loupe EM raw data is of good quality with less time been spent on QA/QC. This is a function of flat terrain, minimising operator generated noise, and a lack of infrastructure.

Loupe survey data over the Mardie Project area has been processed and Emax transform was completed on X and XZ components.

More conductive areas are observed toward the centre and north of the coastal plains. There is a notable increase in conductivity in line 4, which is over the centre of the coastal plain. Lines 1, 2 and 6 show the lowest maximum conductivity values and are furthest away from the centre. There is a notable change in the conductivity midway through line 4 which coincides with an apparent change in the cover composition as observed in the satellite imagery.

Overall conductivity is very high with values ranging between 74 to ~14000mS/m across the project area. This is derived from the X-component transformation which includes more positive time channel data. Boreholes were plotted on the maps (blue) and the conductivity of the groundwater was compared to the values produced from the Loupe EM transforms. Observed conductivity is a function of the material, porosity, interconnectivity of the pore matrix and pore fluid contents. Therefore, conductivity is expectedly slightly less than that of directly measured saline fluids.

In the very highly conductive areas, the transform on the Z-component data is more challenging and null values were observed with greater frequency. Conductivity values derived from XZ transformations show values between 330 and 5800 mS/m. The range derived from the XZ component transform are less because of null values in the early time channels, therefore the X component range is likely a better reflection of the conductivity variation.

The data shows that the system can resolve up to ~-25m of data in this environment but negative values (expected in highly conductive terrains) in the early time data means an approximate loss of resolution in the upper ~-5m of the subsurface. The depth to positive data varies as a function of conductivity. The system geometry- separation between the transmitter and receiver- means that resolving up to 0m depth is unlikely. However, specialist calibration of the data to suit highly conductive environments may help resolve some of this missing space. This investigation is currently ongoing and may require a second issue of this acquisition report.

5. REFERENCES

Gregory Street, Andrew Duncan, Peter Fullagar & Richard Tresidder (2018)
LOUPE - A Portable EM Profiling System, ASEG Extended Abstracts, 2018:1, 1-3, DOI: 10.1071/ASEG2018abW10_3G

Appendix J: DWER Comments Response

Document review comments sheet

Document title	**Groundwater Monitoring and Management Plan**
Revision number	Document number - 000-EV-PLN-0005, Revision number - J
Statement no	1211
Condition no	B3-2
Review date	6 February 2024

The Department of Water and Environmental Regulation (DWER) has reviewed the Mardie Salt and Potash Project Groundwater Monitoring and Management Plan, BCI Minerals, Revision I, 21 November 2023 against the requirements of condition B3-2, and the recommendations made in an independent peer review of the GMMP (Rev H, 2023).

DWER considers the plan requires amendments before it can be approved for implementation. Please address the comments in the following table and amend the plan accordingly.

Item	EMP section	DWER comments	Proponent response
1.	Table 16	Trigger criterion 1 is based on monthly sampling and the required action is to implement monthly monitoring at the bore(s). Undertaking more monitoring is not considered an appropriate management action. While table 16 has been updated, the management action to develop a response plan once a threshold is breached is not appropriate. The specific management and mitigation actions to be implemented, should a threshold be breached, need to be set out within the GMMP to provide confidence that management options will be effective in resolving the exceedance. **Please provide appropriate and timely management actions in response to the exceedance of trigger criteria and threshold values.**	Table 17 of the GMMP has been updated to address the comments.
2.	limitations of the Modelling	While the current information based on the available data from the site indicates low hydraulic conductivity and concludes that the lateral transport of saline water through groundwater system is unlikely to occur, the peer reviewer indicates lateral transport should not be discounted. Enhanced lateral flow could occur, if the stratigraphy below and adjacent to the ponds was resembling the stratigraphy shown in Figure 3 in AQ2 (2021a) (Cross Section – Fortescue River). Whilst it is stated that conceptual model will be updated if unsupported by the monitoring data, this has not been committed to within the plan and the peer reviewer's comments have been discounted. **Prior to re-submission of the next version of the Plan, please rerun the conceptual model to include the potential for lateral flow due to preferential flow paths and solute fluxes.**	An updated conceptual model undertaken in January 2024 is attached in Appendix A and discussed in Section 2.6.3. Impact modelling is also provided in Section 2.6.7 and Appendix A. Further modelling updates and commitments are detailed in Section 2.6.8, 2.6.10 and Section 3.5.
3.	Reliability of the Modelling	The reliability of the conceptual model is dependent on its ability to reproduce the observation data (such as hydraulic heads and salinities). In the present modelling study, only one conceptual model was tested and compared against observation data. There was agreement between simulation results and observations for several observation boreholes, but this relationship was quite poor for other observation boreholes (specifically GBH07, GBH01, GBH04 and GBH19). Based on this result, it is recommended that model development and calibration should be continued, and alternative conceptual models should be tested against observational data to ensure the current model has the best fit. **Prior to re-submission of the next version of the Plan, please rerun the conceptual model to predict impacts over the life of the project.**	An updated conceptual model undertaken in January 2024 is attached in Appendix A and discussed in Section 2.6.3. Impact modelling is also provided in Section 2.6.7 and Appendix A. Justification for model duration is provided in section 2.6.3. Further modelling updates and commitments are detailed in Section 2.6.8, 2.6.10 and Section 3.5

Item	EMP section	DWER comments	Proponent response
4.	Conceptual model figures	When the model is re-run, please provide the following figures as part of the modelling report: **- An additional figure corresponding to Figure 4.8 (Conceptual Groundwater Model for Pond 1 Section) that shows the conceptual model after the construction of the ponds would be helpful.** **- Update Figure 5.2 (Schematic Model Cross-Section, Northwest to Southeast) to show the applied spatial discretisation of the model.** **- Confirm what time point in the model is represented in Figure 5.3 (Model Cross-Section Salinity Contours).**	A new Figure 4.9 has been created in the Modelling Report and is also provided in the GMMP as Figure 9. Figures 5.2 and 5.3 have been updated in the report in Appendix A.
5.	Effectiveness of Monitoring Network	Related to the above suggestions, should lateral flow and solute transport occur, it is quite likely that it will occur in a non-uniform manner, i.e., an excursion of pond water will unlikely occur as a uniform plume and will therefore not easily be discovered by widely spaced monitoring boreholes. Rather than building a denser network of groundwater monitoring boreholes, it would be more effective to undertake repeat geophysical surveys along specific lines along the seaward fringes of the ponds to monitor for relative changes in between surveys. **Please include the provision for repeating geophysical surveys along specific lines and seaward fringes of ponds to monitor for relative changes occurring between surveys.**	Initial Geophysical survey was conducted in January 2024, details are provided in Section 2.6.9 and Appendix I. A commitment to ongoing surveys has been made, see Section 2.6.8 and Section 3.5.
6.	Reliability of Monitoring Data	There is currently not enough reliable data to define robust and defendable trigger and threshold criteria for management actions, therefore, alternative approaches are needed. BCI has recommended a BACI methodology but there is concern that the completed construction of Ponds 1 and 2 has already altered the environment which prevents the establishment of baseline data that are accurate representative of the pre-development environment. This concern maybe addressed by the ongoing statistical analysis, most importantly the analysis of the long-term water level data from the gas pipeline corridor bores. The use of probes and data loggers will also allow a better understanding of the dynamics of both heads and salinity, while the value of the quarterly measurements is mostly derived from the obtained salinity profiles. Note, however, that salinity profiles in long screened wells could be biased if the monitoring well was screened over a depth zone that shows a vertical hydraulic gradient. In this case, intra borehole flow could occur and measured salinities would not be representative of the surrounding aquifer. To address limitations in baseline data, it is recommended that probes and data loggers be installed in all monitoring boreholes to record hydraulic heads and electrical conductivity. Quarterly hydraulic head measurements are not considered to be appropriate for a dynamic system such as this. A comparison of continuous data will make it easier to unravel hydraulic head and salinity changes and to more clearly attribute them to specific events. **Please confirm that:** **- EC loggers will be installed in all bores prior to staged filling of ponds** **- Monitoring bores are in place west of pond 1 and around the RRDMMA** **- Monitoring bores are multilevel or have multiple screen levels.**	Additional details provided in the report with regards to: - Borehole installation dates and data collection (Tables 5,7,8) including the status of loggers and sensor installation including for EC - Status of GW level baseline data (Figure 5) - trigger and threshold methodology and justification (Section 3.1, and Appendices E and K with regards to Coastal Bore Monitoring for GW level) Coastal monitoring bores CMB6_1S, CMB6_1D, S01A and S02A, to the west of Pond 1, are in place and will provide an early warning of any potential impact in the direction of the RRDMMA. Bores RRDMMA_1 and RRDMMA_2 are no longer proposed, as the current evaporation pond footprint design, as updated in 2023, avoids this area. The coastal bores (CMB bores) have been installed with short screens and sealed to access the groundwater at discrete depths. Bores were installed as deep/shallow pairs adjacent to each other as follows: • Shallow bores generally have screen from 0.5 to 2mbgl. • Deep bores generally have 1.5m screen at the base of the casing string (which is variably at 7-10mbgl). In most cases a bentonite seal was installed from above the screen up to near surface.
7	Model reassessment and recalibration	Groundwater model reassessment and recalibration is essential annually for at least 5 years until baseline data has been incorporated into the model and some stresses and groundwater responses are evident (e.g. seepage from ponds, compaction by water columns, changes to vertical and lateral recharge mechanisms) as described in Section 6 of *AQ2 Mardie Project – Conceptual Groundwater System and Modelling Assessment, November 2023*. The need to correct for density of pond water based on salinity is important for future analysis of groundwater flow mechanisms to ensure the impacts of additional ponds are accurately represented. **Please include a commitment to reassess and calibrate the groundwater model annually for at least 5 years from the approval of the GMMP.**	A commitment has been made to undertake annual model validation and calibration annually, for 5 years from GMMP approval. See section 3.5

Item	EMP section	DWER comments	Proponent response
11.	Geophysical survey methods	As mentioned above, caution must be taken regarding the proposed use of geophysical surveys and the overall BACI principle. - **It is required that geophysical survey methods are tested and represented, and further justification is provided for the BACI model, including a power analysis to inform EPAS decision making and examples of where a similar approach using short time windowed data have been used.** - **Geophysical survey methods and systems must be tested onsite to determine whether any geophysical method is sufficiently sensitive and diagnostic to handle the range of salinities expected.** - **The BACI method of monitoring impacts to groundwater levels and salinity is a reasonable approach, however, this must be supported by examples, both published and project specific to fully justify the approach.**	Initial Geophysical survey was conducted in January 2024, details are provided in Section 2.6.9 and Appendix I). A commitment to ongoing surveys has been made, see Section 2.6.9 and Section 3.5. Details on the M_BACI / ARIMA data analysis method used for the Coastal Bore GW level monitoring is provided in Section 3.1.1. and in Appendices E and K
12.	Staged filling approach	The filling of ponds 1 and 2 provides the opportunity to collect reliable data in order to develop the groundwater model and monitoring triggers. Any statistical method of setting triggers requires comprehensive baseline data over a few climatic cycles prior to operational impacts. To understand seasonal impacts a minimum of 12 months of data is required. **Please clarify the timeline (i.e. the period of time for collection of monitoring data after filling of each pond) for the staged filling of ponds 1 and 2 and model validation, as well as touch points with DWER, prior to the filling of subsequent ponds to confirm that the filling of the ponds form part of a monitoring approach that will enable validation of the conceptual model and impact predictions.** **In addition, as discussed in the meeting on the 1st February 2023, if pond 3 is to be included in the staged filling approach, please provide further information to confirm that:** - **The model has been rerun to account for the filling of pond 3 and any subsequent potential for groundwater impacts** - **Monitoring data and a revised conceptual model informed by data collected during the staged filling of ponds 1 through 3 will be provided to DWER after twelve months.** - **An analysis of the suitability of triggers and thresholds, as well as management actions informed by the outcomes of the staged filling approach.** DWER would be supportive of receiving interim updates on the progress of the staged filling approach and monitoring outcomes after six months of data collection.	The GMMP describes the progressive filling of Ponds 1 through 6 in detail in Appendix D. Appendix C provide the schedule for filling all Ponds and crystallisers. This approach includes additional periods for data collection and observation between the progressive filling layers. MM's precautionary approach during the progressive filling has been described in the Executive Summary and through relevant sections of the report including Section 2.2.3. Commitments with regards to monitoring, modelling and GMMP updates and review are described in Section 3.5 Updated information on boreholes and data collection is provided through Section 2.6. New content with regard to the Conceptual Hydrogeological Model and Impact Modelling is provided in sections 2.6.3 and 2.6.7 respectively. Expanded information on Triggers and thresholds and specific mitigation and management measures in Sections 3.1 and 3.2 The provision of updated and additional Technical supporting information in Appendices A, J, K, L and M.
13.	General	**Prior to resubmission of the GMMP, please ensure that:** - **Only one version of the GMMP is submitted for EPA and DCCEEW, review** - **The submission includes a table which outlines individual changes in the GMMP and where those changes have been made. For example, section 2.6, page 50, has been updated to include xx.** - **The revised management plan adheres to the [Instructions on how to Prepare Environmental Management Plans]**	A clean and tracked changes version of the updated GMMP are provided. A supporting table summarising changes for each section is provided to address these comments but does not form part of the GMMP. The GMMP has been prepared with reference to WA and Commonwealth EMP guidelines as stated in Section1.

Appendix K: Triggers and Thresholds Methodology

DATA
STATISTICS

ANALYSIS
MATHEMATICS

AUSTRALIA
INFORMATION

Mardie Project Groundwater Monitoring – Methodology Review

February 2024

Project: BCIMINERALS/2

STRATEGIC
INFORMATION
CONSULTANTS

Mardie Project Groundwater Monitoring

December 2023

Client: BCI Minerals Ltd

Project: BCIMINERALS/2

Consultants: Anna Hayes
Dr Fiona Evans
Dr Alyce Russell
Sam Joyner

Data Analysis Australia Pty Ltd
97 Broadway
Nedlands, Western Australia 6009
(PO Box 3258 Broadway, Nedlands 6009)
Website: www.daa.com.au
Phone: (08) 9468 2533
Email: daa@daa.com.au
A.C.N. 009 304 956
A.B.N. 68 009 304 956

Executive Summary

BCI Minerals are building a series of solar salt evaporation ponds by the coast at Mardie in Western Australia. There is a possibility that the filling of the ponds will impact local groundwater leading to rising groundwater levels or increased groundwater salinity. They engaged Data Analysis Australia to design a statistically sound method for determining operational trigger thresholds to determine whether groundwater levels differ beyond what would be considered normal after pond filling (BCIMINERALS/1, *Mardie Project Groundwater Monitoring*, December 2023).

A second project (BCIMINERALS/2) will review the monitoring methodology now that an additional three months of data are available and implement an online real-time monitoring and reporting system.

This preliminary report:

1. Evaluates the selection of reference bores for detecting impact at Ponds 1 and 3.
2. Evaluates the number of false positives expected using different confidence levels.
3. Conducts a power analysis to demonstrate that three months is a suitably long timeline for detecting impact.
4. Uses the results to evaluate the definition of a trigger (i.e. which confidence level should be used).

The results show that:

- Pairing of impact and reference bores must consider the data availability of the reference bores as time-series models cannot be estimated if there is too much missing data.
- False positive are to be expected from this approach btu can be minimised by increasing the confidence level from 95% to 99%.
- When sufficient data are available, a three-month baseline is adequate for detecting simulated impacts of 0.1 metre or higher. This is true when using either 95% or 99% confidence intervals.

The choice of an appropriate confidence level for defining triggers and thresholds requires a balance between the number of false positives requiring action where none is needed and the ability to detect true impact. This preliminary work suggests that using a 95% confidence interval can be expected to result in some degree of false positive but is likely to detect impact when it really does occur. Use of a 99% confidence interval will result in fewer false positive without reducing the detection of true impacts.

Table of Contents

1. Introduction

BCI Minerals are building a series of solar salt evaporation ponds by the coast at Mardie in Western Australia. There is a possibility that the filling of the ponds will impact local groundwater leading to rising groundwater levels or increased groundwater salinity. They engaged Data Analysis Australia to design a statistically sound method for determining operational trigger thresholds to determine whether groundwater levels differ beyond what would be considered normal after pond filling (BCIMINERALS/1).

Data Analysis Australia conducted a thorough preliminary analysis of groundwater level data collected from 18 bores on the Mardie site. Medium-term data (around two years) was available for four bores and short-term (around three months) data was available for 14 coastal bores near planned Ponds 1, 3 and 5.

We proposed a method for monitoring groundwater based on a Before/After Control Impact (BACI) design using three months of baseline data. Because the "Before" component of the BACI design is restricted to a relatively short time period, we added extra requirements that the impact and reference bores closely match in their temporal patterns as measured using Dynamic Time Warping (DTW).

Impact bores will be used to detect potential impacts of each pond as it is filled. The impact of Pond 1 will be measured by comparison with reference bores at Pond 3. The impact of Pond 3 will be measured by comparison with reference bores at Pond 5 and 8, and so on. This process will continue to move up through the ponds until all ponds are filled, with additional bores being installed as required.

Mardie bores typically exhibit two types of seasonality with bores nearer the ocean and influenced by tides showing biweekly seasonality and bores farther from the ocean showing monthly seasonality. BACI analysis usually tests for differences in the before and after mean data using linear mixed models and cannot handle trends and seasonality. We therefore recommended that impact detection be performed using Auto-Regressive Integrated Moving Average (ARIMA) models, a technique widely used to evaluate impact of health interventions (with or without controls)[1].

ARIMA models fitted to data from the impact and reference bores are used to forecast expected ground water level at the impact bore on any day. A change trigger is defined to occur when what happens is not within the 95% confidence intervals of the

---

[1] Schaffer, A.L., Dobbins, T.A. & Pearson, SA. Interrupted time series analysis using autoregressive integrated moving average (ARIMA) models: a guide for evaluating large-scale health interventions. BMC Med Res Methodol 21, 58 (2021). doi: 10.1186/s12874-021-01235-8.

Lopez Bernal J., Cummins S. and Gasparrini A. The use of controls in interrupted time series studies of public health interventions. Int J Epidemiol. 2018 Dec 1;47(6):2082-2093. doi: 10.1093/ije/dyy135.

Ewusie J.E., et al., Methods, Applications and Challenges in the Analysis of Interrupted Time Series Data: A Scoping Review. J Multidiscip Health. 2020 May 13;13:411-423. doi: 10.2147/JMDH.S241085.

forecasts. A threshold event is defined when a trigger is detected on seven consecutive days.

The ARIMA approach enables impact detection in real time rather than after collecting data for a longer period of time, which in this case would necessarily be quarterly to avoid issues with seasonality.

This project (BCIMINERALS/2) will review the monitoring methodology now that an additional three months of data are available and implement an online real-time monitoring and reporting system.

This report will:

5. Evaluate the selection of reference bores for detecting impact at Ponds 1 and 3.
6. Evaluate the number of false positives expected using different confidence levels.
7. Conduct a power analysis to demonstrate that three months is a suitably long timeline for detecting impact.
8. Use the results to evaluate the definition of a trigger (i.e. which confidence level should be used).

2. Data Used in This Report

Water level data (in metres) is available for bores located at Pond 1 and Pond 3 from August 2023, for two Pond 5 bores from August 2023 and for the remainder of the bores at Ponds 5 and 8 from October or November 2023 (Table 1). This means we now have a six-month record for Pond 1 and 3 bores but only 3 months for the more recently installed bores at Ponds 5 and 8.

Table 1. Available bore data.

Bore	Pond	Start Date
CMB6_1D	1	2023-08-17
CMB6_1S	1	2023-08-17
S01-A	1	2023-08-11
S02-A	1	2023-08-14
CMB1_1D	3	2023-08-16
CMB1_1S	3	2023-08-16
CMB1_2D	3	2023-08-16
CMB1_2S	3	2023-08-16
CMB1_3D	3	2023-08-17
CMB1_3S	3	2023-08-17
N01-A	3	2023-08-12
N02-A	3	2023-08-12
CMB2_1D	5	2023-08-16
CMB2_1S	5	2023-08-16

Bore	Pond	Start Date
CMB3_1D	5	2023-10-28
CMB3_1S	5	2023-10-26
CMB4_1D	8	2023-11-08
CMB4_1S	8	2023-10-21
CMB4_2D	8	2023-11-08
CMB4_2S	8	2023-10-21
CMB4_3S	8	2023-10-21
CMB5_1D	8	2023-10-27
CMB5_1S	8	2023-10-24
CMB5_2D	8	2023-10-24
CMB5_2S	8	2023-10-24
CMB5_3D	8	2023-10-26
CMB5_3S	8	2023-11-06

The data contains readings sampled at various times throughout each day, so for simplicity and consistency we aggregate the data to daily means.

3. Impact and Reference Bores

While Pond 1 impact-reference bore pairings remain unchanged, the reference bores for Pond 3 impact bores have been updated using recently collected data for Ponds 5 and 8 (Table 2).

Table 2. Recommended impact and references bores (best three matches).

Impact Bore	Pond	Reference Bores
CMB6_1D	Pond 1	CMB1_3D, CMB1_2D, CMB1_2S
CMB6_1S	Pond 1	CMB1_3D, CMB1_2D, CMB1_2S
S01-A	Pond 1	N02-A, CMB2_1D, CMB2_1S
S02-A	Pond 1	CMB2_1D, CMB1_1D, CMB2_1S
CMB1_1D	Pond 3	CMB3_1S, CMB2_1D, CMB3_1D
CMB1_1S	Pond 3	CMB3_1S, CMB2_1S, CMB2_1D
CMB1_2D	Pond 3	CMB2_1S, CMB2_1D, CMB3_1S
CMB1_2S	Pond 3	CMB2_1S, CMB2_1D, CMB3_1D
CMB1_3D	Pond 3	CMB4_1D, CMB5_1D, CMB5_2D
CMB1_3S	Pond 3	CMB5_3S, CMB5_1S, CMB4_2S
N01-A	Pond 3	CMB3_1S, CMB2_1S, CMB2_1D
N02-A	Pond 3	CMB3_1S, CMB2_1S, CMB2_1D

4. False Positives

Preliminary work indicated that false positives are likely; that is, triggers detected when no true impact occurred. They may be due to environmental factors affecting the impact bore but not the reference bores, because the impact-reference bore matching was not ideal or because the fitted ARIMA was not optimal.

Now that we have an additional three months of data, we can assess the number and of false positives that would have occurred if the monitoring system had been operational for the last 3 months and consider improvements to bore pairing and the form of the ARIMA model used to ensure accurate trigger detection.

Table 3 shows the number of false positives that would have occurred if impact detection had been operational for 97 days from 2 November 2023 to 6 February 2024 using deferent confidence levels for detection.

Table 3. Number of false positives 2 November 2023 to 6 February 2024 (97 days).

Impact Bore	Pond	90% CI	95% CI	99% CI
CMB6_1D	Pond 1	11	8	3
CMB6_1S	Pond 1	12	9	7
S01-A	Pond 1	3	2	1
S02-A	Pond 1	2	1	0
CMB1_1D	Pond 3	18	14	12
CMB1_1S	Pond 3	19	15	13
CMB1_2D	Pond 3	13	10	8
CMB1_2S	Pond 3	15	14	8
CMB1_3D	Pond 3	16	12	9
CMB1_3S	Pond 3	22	16	12
N01-A	Pond 3	11	9	7
N02-A	Pond 3	19	15	9
Total		**161**	**125**	**89**

5. Power Analysis

DWER have requested a **power analysis** to determine whether there us a suitable long baseline period for detecting impact (meeting 22 January 2024). This is relatively simple for standard BACI analysis of mean response but is more complex for impact detection using ARIMA models which requires a **simulation study**[2]:

We performed a Monte Carlo simulation to evaluate how well the current methodology using a three-month baseline period would detect different types of simulated impacts on any day between 2 November 2023 and 6 February 2024 (the same 97-day period used for assessing false positives). We simulated impacts as follows a gross change in groundwater level of 0.05, 0.1, 0.25 and 0.5 metres from what actually occurred.

Data were missing for some impact bores and their reference bores during the 97-day period (Table 4) and it was not possible to simulate artificial impacts on those days.

[2] Hawley S., et al., Sample size and power considerations for ordinary least squares interrupted time series analysis: a simulation study. Clin Epidemiol. 2019 Feb 25; 11:197-205. doi: 10.2147/CLEP.S176723.

Table 4. Summary of missing data for Pond 1 and 3 impact bores and their reference bores with missing data during the 97-day period from 2 November 2023 to 6 February 2024.

Impact Bore	Pond	Missing Days
S01-A	Pond 1	17
S02-A	Pond 1	3
N01-A	Pond 3	17
N02-A	Pond 3	18
CMB4-1D	Pond 8	6
CMB5_3S	Pond 8	4

Figure 1 shows the percentage of gross changes detected as triggers when using the proposed using a 95% confidence interval.

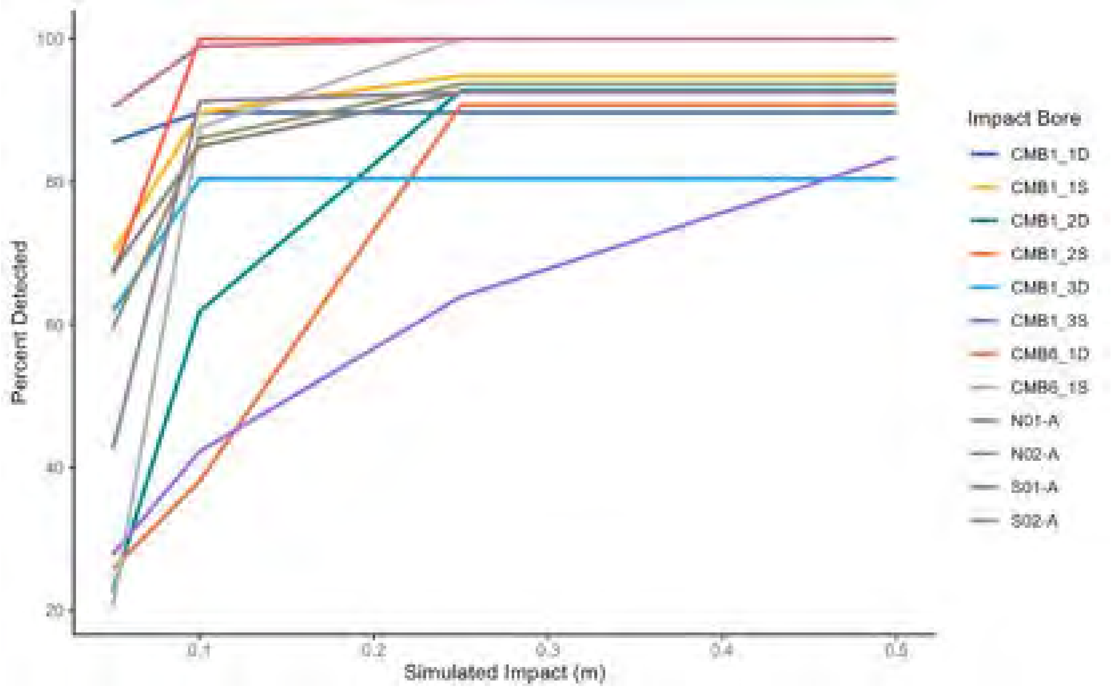


Figure 1. Percentage of simulated impacts (in the form of gross changes) in water level detected as triggers using a 95% confidence interval.

Gross changes greater than or equal to 0.1 metres were detected 85 to 100 % of the time for eight of the twelve Pond 1 and 3 impact bores. For bore S01-A, this was reduced to around 75%; this was largely due to missing data for that bore. The other four bores – CMB1_2D, CMB1_2S, CMB1_3S and CMB1-3D – had lower detection rates because their reference bores had missing data. This can be avoided by considering missing data when selecting reference bores.

Figure 2 shows the percentage of gross changes detected as triggers when using the proposed using a 95% confidence interval. The results were largely unchanged from those using a 99% confidence interval except that small (less than 0.1 metre simulated impacts were detected more poorly. However, given that water levels exhibit seasonal variation of above 1 metre, it is unlikely that any true impact would lower than 0.1 metres and we do not believe this is a flaw in the methodology.

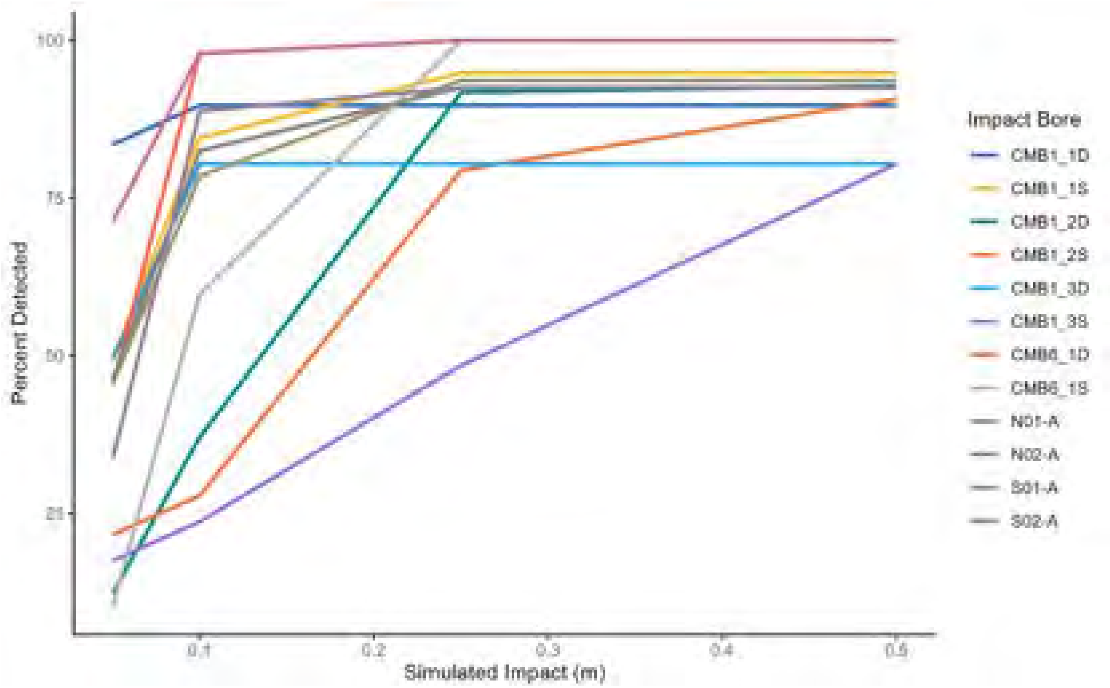


Figure 2. Percentage of simulated impacts (in the form of gross changes) in water level detected as triggers using a 99% confidence interval.

6. Conclusions about Triggers and Thresholds

The choice of an appropriate confidence level for defining triggers and thresholds requires balancing the chance of false positives requiring action where none is needed and the ability to detect true impact. This preliminary work suggests that the choice of a 95% confidence interval can be expected to result in some degree of false positive but is likely to detect impact when it really does occur. Use of a 99% confidence interval will result in fewer false positive without reducing the detection of true impacts.

Data Analysis Australia – About Us

Helping organisations make great decisions and new discoveries by making data meaningful

This has been Data Analysis Australia's express purpose since we were founded in 1988.

We achieve this through our diverse and evolving skill sets covering all areas of statistical and data science analysis. Setting us apart is our focus on generating meaningful **insights from data**, working with clients from all sectors and industries to solve their real problems.

Data Analysis Australia's services and principal areas of expertise include:

- **Survey sampling**, questionnaire design, weighting, standard errors, analysis and review.
- **Evaluations** of programs and pilot trials.
- **Modelling** of industrial, mining and business processes.
- **Business analysis** and evidence based decision making.
- **Forecasting**, of people, workforces, building, energy and asset needs.
- **Data analysis**, to understand true relationships and insights from data.
- **Statistical modelling**, including regression, time series analysis, classification and clustering analysis.
- **Experimental design** and analysis.
- **Reviews** of statistical papers and methodologies.
- **Expert witness** and legal work.
- **Dashboards** and interactive tools.
- **Big data** management and analysis.

Having worked with hundreds of government and private clients locally, nationally and internationally, Data Analysis Australia has built a reputation of trust and delivery in all that we do.

Website: www.daa.com.au
Phone: (08) 9468 2533
Email: daa@daa.com.au

Appendix L: Groundwater Memo

Level 4, 56 William Street
Perth WA 6000

Tel +61 8 9322 9733
www.aq2.com.au

AQ2 Pty Ltd
ABN 38 164 858 075

Memo

To	Dale VanBeem, Angela Glover	Company	Mardie Minerals Pty Ltd
From	Bruce Harvey, Duncan Storey	Job No.	293H
Date	12/10/2021	Doc No.	032b
Subject	Mardie Project – Proposed Investigation and Monitoring Program		

1 INTRODUCTION

Mardie Minerals' Mardie Project is located on the Pilbara coastline of Western Australia, approximately 100 km south-west of Karratha (Figure 1). The project includes the construction of extensive evaporation ponds and crystallisers for the extraction of salt products from sea water.

The initial environmental impact assessment for the Mardie Project identified that the understanding of the risks posed to vegetation, local groundwater and pools as a result of saline seepage from the Project's proposed concentration and crystallisation ponds should be improved. A Groundwater Risk Assessment (GRA) was provided to Mardie Minerals by AQ2 in 2020 (AQ2 document 293C_009b). The GRA document discussed the potential impacts the preliminary project plan may have on groundwater receptors in the vicinity of Mardie Pool and coastal habitats. The areas of focus for this were:

- Potential impacts due to the location of secondary salt crystallisers, which at DFS level are proposed to be located north-east of Mardie Pool near the south-western boundary of the Fortescue River alluvial valley.
- Risk to coastal vegetation (primarily mangrove habitat) due to possible seepage of hypersaline water from Evaporation Ponds 1-9 and Primary Crystallisers into the near-coast groundwater system.

Concern has since been raised regarding the presence of an algal mat ecosystem on the supratidal flats which exists beneath and to the west of the proposed location of the Evaporation Ponds. It was inferred that the existence of algal mats may be due to upwelling or overtopping fresh groundwater which is thought to bring nutrients to surface and dilute the hypersaline fluids (which develop due to evaporation). It is unclear whether the coastal groundwater regime at Mardie is similar in structure to this concept. Vertical distribution of salinity beneath the salt flats, and the location of the seawater interface are also undefined across much of the development envelope.

AQ2 has been engaged by Mardie Minerals to propose a monitoring bore network which will permit the ongoing long-term monitoring of groundwater quality in the vicinity of sensitive receptors.

2 DFS PROJECT LAYOUT

Proposed DFS project layout is presented in Figure 1. Key characteristics of the layout are:

- Concentrator and Primary crystalliser ponds extending along approximately 25 km of coastal supratidal salt flats.
- Seawater intake to be at the southern-most pond, with brine concentration increasing in ponds to the north.
- Western sea wall of the ponds is proposed to be adjacent to or impinging upon mapped algal mat habitat on the lower (western) side of the supratidal flats.

- Secondary crystalliser ponds are proposed to be located immediately north of Mardie Pool on the eastern side of the main concentrator ponds.

3 ONGOING INVESTIGATIONS

While substantial research has already been carried out to characterise the hydrogeological regime at the Mardie Project, it has been identified that further background investigations will enhance knowledge and assist in future groundwater management. In particular several avenues for further work have been noted to close data gaps.

3.1 Airborne Electromagnetic Data

An Airborne Electromagnetics (AEM) survey was flown in the area in 2010 by Fugro Airborne Surveys. The survey has wide line spacing, however lines do cross Mardie Creek in several places. It has been postulated that reprocessing of the AEM data may provide information relevant to the salinity profile of water in the near surface. Enquiries will be made into the feasibility of reprocessing this data, and the likelihood of gaining further meaningful information from this.

3.2 Mardie Pool Bathymmetry

Bathymmetric data for Mardie Pool may be useful when characterising the nature of the potential fresh water lens which may encompass the pool and surrounding subsurface. Where possible the shape of the base of the pool will be determined through an appropriate method (eg physical measurement of cross-sections from watercraft). It is understood that access to the pool may be difficult during the wet season, and also due any heritage restraints.

3.3 Geological Controls on Creek and Pool Development

It has been noted by DAWE that Mardie Creek may have developed coincident with a mapped geological fault. Evidence for this is to be investigated as there may be some implications for the conceptual model for Mardie Creek and other creeks in the area.

4 PROPOSED MONITORING BORE NETWORK

4.1 Terrestrial - Mardie Pool and Crystallisers

Surface water in Mardie Pool is less saline than groundwater in the regional bores. It is likely that a freshwater lens exists within the pool and the adjacent unconfined aquifer, forming a zone of fresher water above the denser (saline) regional groundwater and extending up the creek valley. Water level and quality of the fresh water in Mardie Pool is probably maintained through dry seasons by base flow from the upstream alluvial channel sediments. The pressure head created by baseflow has possibly acted to prevent ingress of the surrounding denser water, counteracting the slight density difference. An increase in the salinity of the regional groundwater or a change in the groundwater level (as may be caused by seepage from the ponds) may therefore lead to changes in the fresh-saltwater interface through density equalisation; this may in turn affect the quality of the water feeding Mardie Pool (from AQ2 2020).

Due to the heritage agreements that Mardie Minerals currently has in place which prevent access for clearing and structures within 50 m of Mardie Pool, the monitoring network at this location is proposed to be installed in two phases. In Phase 1 a series of monitoring bores will be placed adjacent to the Secondary Crystalliser upgradient from Mardie Pool to serve as an early warning of changes in salinity and water level which could be evident if seepage were to occur from the crystallisers (Figure 2 - MP05, MP13 to MP16).

Additionally bores will be installed parallel to Mardie Creek, outside the heritage buffer zone and between Mardie Pool and the Secondary Crystalliser (Figure 2, sites MP02 to MP04). These bores will assist in gaining an accurate characterisation of groundwater flow direction between the crystalliser and Mardie Pool, outside the likely fresh water lens. They will also serve to monitor for water variations not captured by the bores adjacent to the Secondary crystalliser. A background bore

(MP01) will also be installed on the southern side of Mardie Pool. All bores will be fully screened from water table to nominally 15 mbgl to allow for salinity profiling with depth.

Also in the first phase of drilling, a series of similar bores will be placed up-gradient from the Primary and Secondary Crystallisers for background monitoring (MP06 to MP10).

To characterise base flow in the Mardie Creek channel, three bores (MP17, MP18, MP19) will be placed along the creek line up stream from the Secondary Crystallisers.

All proposed Terrestrial Phase 1 bore locations and purposes are described in Table 1.

Presuming future access can be gained to heritage areas around Mardie Pool, in Phase 2 (before construction and commissioning of crystallisation ponds), it is proposed to install a series of closely spaced nested or fully screened bores adjacent to the pool. These sites are displayed as FMP01 to FMP06 in Figure 3. The Phase 2 bores will assist in characterising and monitoring the groundwater system surrounding the pool. In particular the existence and extent of the conceptual fresh water lens providing base flow and permanency to Mardie Pool will be investigated.

Table 1: Terrestrial Monitoring Network Phase 1

Location	Bore ID	Easting	Northing	Proposed Design	Purpose
Mardie Pool – Outside Channel	MP01	390722	7657005	Fully screened	Background monitoring
	MP02	390829	7657151	Fully screened	Second line of detection of seepage from Secondary Crystalliser
	MP03	390717	7657192	Fully screened	
	MP04	390943	7657131	Fully screened	
Secondary Crystalliser – Adjacent	MP05	391120	7657108	Fully screened	First line of early detection of seepage from Secondary Crystalliser
	MP13	390950	7657224	Fully screened	
	MP14	391049	7657161	Fully screened	
	MP15	391216	7657046	Fully screened	
	MP16	391326	7656967	Fully screened	
	MP17	392366.2	7656651	Fully screened	
Secondary Crystalliser – Up Gadient	MP06	393360	7656788	Fully screened	Background monitoring up-gradient from Secondary Crystalliser
	MP07	394436	7657258	Fully screened	
Primary Crystalliser	MP08	389491	7659742	Fully screened	Down-gradient monitoring of Secondary, upgradient of Primary
	MP09	389506	7661737	Fully screened	Background monitoring up-gradient from Primary Crystalliser
	MP10	389698	7663491	Fully screened	
Mardie Creek - Upstream	MP17	392366.2	7656651	Fully screened	Upstream channel monitoring for base flow, adjacent to crystalliser
	MP18	392540	7656043	Fully screened	Upstream channel monitoring for base flow
	MP19	395142	7655015	Fully screened	Upstream channel monitoring for base flow

Table 2: Terrestrial Monitoring Network Phase 2

Location	Bore ID	Easting	Northing	Proposed Design	Purpose
Mardie Pool	FMP01	390792	7657082	Nested	Characterise and monitor potential freshwater lens at Mardie Pool
	FMP02	390798	7657095		
	FMP03	390804	7657107		
	FMP04	390785	7657065		
	FMP05	390676	7657139		
	FMP06	390953	7657043		

4.2 Coastal - Mangroves and Algal Mat Ecosystems

Possible seepage from the evaporation ponds which are planned to extend along the coast at the Mardie Project has the potential to disrupt the groundwater regime which supports coastal ecosystems (mangrove habitat adjacent to tidal creeks, and algal mat communities on the supratidal flats). It is conceivable that groundwater seepage and mounding beneath evaporation ponds, should it occur, may result in changes to groundwater gradients and quality near these receptors.

In response it is proposed that a monitoring bore network be installed along the western side of the planned evaporation ponds prior to commissioning (Figure 4). The network would consist of the following:

- Three transects of bore sites, each consisting of three sets of bores between the sea wall of the ponds and the nearest mangrove stands;
- Two further sites adjacent to the sea wall of the evaporation ponds, within mapped areas of algal mat habitat, and
- Each bore site having two discrete monitoring bores screened individually (one near the water table and one at depth), to quantify the magnitude of vertical hydraulic gradients and vertical variations of salinity.

The proposed transects are designed to facilitate monitoring for water quality and hydraulic gradients which may quantify the delivery of fresh water to mangrove stands as suggested in some literature (e.g. Hayes et al 2018).

Two proposed isolated monitoring sites will enable detection of vertical hydraulic gradients (and changes in these gradients) which may aid the delivery of moisture and nutrients to the algal mat ecosystems existing on the supratidal flats, as detailed by Porada et al (2007).

It is noted that drilling in playa area has previously been extremely challenging due to the soft surface of the tidal flats. Geotechnical equipment has been bogged for extended periods during previous campaigns. Access and logistics for installing bores in this area will be difficult, and may need to be progressed as accessibility increases during pond construction (eg via built embankments).

Table 3: Coastal (Playa) Monitoring Network

Location ID	Easting	Northing	Type	Purpose
Playa Site 1_1	383214.2	7651847	Transect	Monitor gradients and salinity near mangroves
Playa Site 1_2	382967.4	7652073		
Playa Site 1_3	382699.4	7652277		
Playa Site 2_1	384792.6	7654721	Single	Monitor gradients and salinity near algal mat habitat.
Playa Site 3_1	386135.7	7657344	Single	Monitor gradients and salinity near algal mat habitat
Playa Site 4_1	386299.9	7660800	Transect	Monitor gradients and salinity near mangroves

Playa Site 4_2	385758.8	7660974		
Playa Site 4_3	385193.4	7661163		
Playa Site 5_1	387315.4	7664443	Transect	Monitor gradients and salinity near mangroves
Playa Site 5_2	387219.8	7664484		
Playa Site 5_3	387120.8	7664524		

5 GROUNDWATER MONITORING AND INVESTIGATION PROGRAM

5.1 Water Quality

The groundwater monitoring program will begin for each area soon after network installation, once groundwater conditions in the bores have reached equilibrium. It is anticipated that sufficient monitoring episodes will take place before construction to determine baseline parameters.

Ongoing monitoring would consist of installed logger or quarterly visits to each bore during which the following parameters will be recorded:

- Static groundwater level.
- Electrical conductivity and pH profiling in fully screened bores.
- Electrical conductivity and pH at specific intervals in discretely screened bores.

Water quality samples will be taken from selected bores for laboratory analysis on a quarterly cycle for 2 years to determine background parameters. Following this period laboratory samples will be analysed half-yearly or as advised by regulators.

Field and laboratory data will be assessed to determine the need for adjustment of the monitoring regime, or intervention in the event that water quality parameters exceed trigger levels set in Groundwater Monitoring and Management Plans to be implemented for the project. It is proposed that additional remediation/abstraction bores will be emplaced down gradient of monitoring bores (ie between the crystallisers and Mardie Creek/Pool) if in future it is evident that seepage is occurring at any location, as indicated by the regular monitoring.

5.2 Hydraulic Testing

Where possible all monitoring bores will be tested to determine hydraulic parameters of the various geological formations. Investigation will likely take the form of falling head tests, rising head tests or micro-pumping tests. Hydraulic parameters will be used as input to groundwater and seepage modelling.

5.3 Review

Incoming results from drilling and acquisition of new hydrogeological information will permit the overall groundwater monitoring and investigation program to be reviewed for suitability. As is found necessary the network design and monitoring program will be altered to reflect needs of the ongoing investigation. This will allow for in-progress adjustment of the drilling program (bore locations and design), recommendations for future drilling investigations, and changes to testing methods. Results of data analysis and seepage modelling may also inform future decisions for bore placement, design and testing.

6 GROUNDWATER AND SEEPAGE MODELLING

AQ2(2020) identified opportunities for improvement of seepage modelling previously undertaken for the Mardie Project. The hydrogeology of the area has been studied in detail as part of mining dewatering and water supply projects located further inland, however, the interactions between fresh and more saline water in the area of the proposed ponds require further quantification, including groundwater recharge processes. Of particular interest are the fresh water recharge processes associated with Mardie Pool, and the reflux processes and salinity exchanges associated with water that is understood to support areas of algal mats near the Project area.

The requirements of the current assessment are to use a groundwater modelling approach to simulate the hydrogeological conditions in the Project area. We propose a two staged approach. The first part of the study (Stage 1) will be designed to simulate the interactions between fresher and more saline water close to the coast and in the area of the evaporation ponds, while the second part (Stage 2), will address the potential interactions of the proposed ponds on the regional groundwater flow system.

The evaporation ponds are proposed to be located close to the coast. Groundwater underlying the project area is saline, as a result of evapo-concentration, and / or interactions with the salt / sea water interface associated with the coast. There is also the potential for groundwater recharge, from surface water flows, that may also periodically recharge the system. Management of the evaporation ponds may intercept some of the recharge across the coastal flood plain area. At present it is not well understood:

- If vegetation in the area of Mardie Pool utilises fresher, recent recharge to groundwater, and if this fresher water persists for significant periods of time or support Mardie Pool.
- How reflex processes support algal mats located in the project area.

The Stage 1 modelling work is designed to assess the potential for the conditions outlined above to exist under a range of plausible hydrogeological conditions for the area. Stage 2 modelling will assess the impact of the Project on the regional groundwater flow system.

6.1 Approach

6.1.1 Data Review and Conceptualisation

The data review will underpin the development of a conceptual hydrogeological model of the project area. Key aspects of the conceptual hydrogeological model will be:

- Development of a static hydrostratigraphic model for the project area (using Leapfrog Geo). This will be a 3D representation of the major hydrogeological units, topography, water table and groundwater salinity. This will also highlight areas of potential groundwater-surface water interaction. Outputs from this model will also be used as key inputs to the Stage 1 and Stage 2 modelling approaches outlined in Sections 2.2 and 2.3 below.
- Interpretation of hydrostratigraphic pressures, gradients and salinity as they apply to the groundwater flow system and recharge and discharge processes.
- Estimates of hydraulic parameters from:
  - o Analysis of data from hydrogeological testing.
  - o Analysis of any Particle Size Distribution (PSD) data that may have been collected from geotechnical investigations.
- Identification of areas or sources of groundwater recharge including recharge from rainfall associated flood plain and flood channels.
- Identification of areas or points of groundwater discharge including groundwater outflow to the coast and surface pools, evapotranspiration from vegetation and shallow water tables.
- Estimates of groundwater recharge and discharge based on regional groundwater gradients.

- Catchment water balances will be developed based on regional groundwater levels, recharge and discharge estimates and the hydrogeology of the project area. These water balance estimates, that reflect groundwater levels in the modelled catchment, will also be used as calibration targets for the regional numerical modelling.
- Identification of key components of the catchment water balance that may result from development of the ponds (for example groundwater recharge and discharge processes).

The review will be completed and any data gaps or critical uncertainties with the conceptual model will be identified that will require attention as part of the proposed groundwater modelling.

6.1.2 Stage 1 Modelling

We propose to complete density dependent groundwater flow modelling to assess the groundwater conditions in and around the proposed Project ponds. This type of modelling simulates groundwater flow and also includes the interactions between water of varying salinity (fresh, brackish, saline and hyper-saline). The requirement to include the density dependent processes adds computation time due to the additional calculations required. There is also the requirement for a more refined model discretisation to simulate salinity gradients (i.e., more model cells / elements and layers). It is also known from previous modelling studies, that regional density dependent flow systems can be difficult to simulate. An assessment of hydraulic loading effects due to overbearing mass of above-ground structures and varying density brine will also be incorporated into the modelling.

To allow simulation of the hydrogeological conditions across the Project site, we propose an approach that simulates 5 sections, in 2 dimensions. These sections would be aligned in the direction of groundwater flow and extend from upstream of the ponds, across the pond areas and the areas of vegetation and pools and to the coastline. Using this approach, we can simulate hydrogeological variability across the project area as well as the salinity conditions. A number of section models can also be combined, or "extruded" to simulate processes that are not readily simulated with a 2 Dimensional (2D) modelling approach. This could include pond leakage or concentrated flow channel recharge.

For each of the 5 sections we will develop the following hydrogeological framework that includes:

- The groundwater flow system of the area, with maximum groundwater levels upstream of the proposed ponds and flows down gradient towards the coast.
- Groundwater flow components that are influenced by groundwater salinity (for example the flow of denser groundwater flow from coast areas inland, or the development of salinity driven flows under coastal evaporation areas or near the salt water interface).
- Key aquifer units within the alluvial aquifer (gravels, sands, clays) as they may impact the interactions between groundwater recharge and discharge processes.
- Aquifer parameters for key aquifer hydrogeological units.
- Groundwater recharge and discharge processes, including:
    - inflow from upstream,
    - outflow to downstream / the coastal salt water interface,
    - diffuse overland flow recharge,
    - focussed or river channel recharge (noting that if this is important a number of 2D models will need to be "extruded" or given a meaningful width to simulate these processes),
    - use by groundwater dependent vegetation (evapotranspiration), and
    - evaporative losses from shallow water tables.

These conditions will be used as model inputs, and the models will be used to simulate the resulting groundwater conditions of interest, including water levels and salinity distributions (i.e., fresh water pools and groundwater salinity distributions). To date we have completed similar modelling assessments using the groundwater flow modelling package FeFlow[1]. FeFlow is a finite element groundwater flow package that also simulates density dependent flow. Until recently, FeFlow was the most suitable programme for this application, however Modflow-based finite difference codes can now efficiently simulate density dependent flow. The requirement to use FeFlow or a Modflow based code will be assessed as part of the study.

As far as practicable, the models will be used to simulate observed conditions (groundwater levels and observed groundwater salinities). The extent to which this results in model calibration will depend on the data available. A set of hydrogeological conditions would normally be deemed plausible if the model is able to simulate groundwater levels and salinities using defendable or reasonable aquifer parameters. The current level of uncertainty may mean that the range of aquifer parameters could be large. To address this, the approach will include ranges of aquifer parameters as well as the potential for a hydrogeological uncertainty to influence the outcomes (i.e., the types of aquifer units will be varied as well as the parameters used to define each aquifer units). This approach is proposed to prevent bias in the assessment. Depending on the complexity of the models developed, there may be the possibility to use some automated calibration techniques, however it is anticipated that the majority of the work will be completed using a manual model calibration approach.

Key outcomes of the modelling will include:

- The hydrogeological conditions that could support zones of fresh water in the areas of the proposed ponds, and the reflux processes that may support algal mats.
- Areas of enhanced permeability that result in enhanced recharge or greater groundwater flow
- Barriers to flow that prevent the movement of more saline water.
- Area of uncertainty that required further investigation.
- Flow processes in areas upstream of the proposed ponds, for input into the regional flow modelling.

The modelling approach, set up, simulation, results and recommendations will be included in a report to allow review as well as provide information required for approval / environmental documents.

6.1.3 Stage 2 Regional Groundwater Modelling

6.1.3.1 Model Setup and Calibration

Stage 2 modelling will involve the development of a regional groundwater flow model to assess the potential impacts of the proposed evaporation ponds on the regional groundwater system. Operation of the ponds will involve the concentration of salts and any potential impacts of these ponds would involve the mobilisation of evaporated material and their movement (by dissolution) into the underlying groundwater and to any receptors in the area (for example the Fortescue River or mining / dewatering operations, located approximately 20 km) to the east.

The regional groundwater model will incorporate key elements of the hydroeological conceptual model including the outcomes of the Stage 1 model. The numerical model will have a practical run time, which will be more easily achieved as it will not be necessary to simulate salinity and density effects. The model will also be developed consistent with groundwater modelling guidelines for model development, calibration and predictions.

We propose to use a Modflow based groundwater modelling code operating under the Groundwater Vistas graphical user interface. Modflow Surfact and Modflow USG both includes adaptive time-stepping (for numerical efficiency) while the Modflow USG also allows for computational efficiency through cell size. As part of the Stage 1 assessment, it may be that FeFlow is more suitable for this

---

[1] DHI 1979 – 2021. FEFLOW Finite Element Simulation System for Subsurface Flow and Transport Processes.

assessment, and there is also the flexibility to use that for the regional groundwater flow model. FeFlow allows for flexible grid design and automatic time stepping.

The model will include the Project area and include aquifer extents and suitable boundary conditions to simulate conditions upstream, including the Fortescue River aquifers and nearby mining operations. The model will be calibrated to pre-development or steady state conditions, and any historical data will be used to complete history matching (transient calibration). Model calibration performance will be assessed using standard techniques (calculation of standard error measures) and inspection of predicted groundwater level contours and model generated water balances.

There may be some advantages in using automated calibration techniques during model calibration, depending on data availability, however we anticipate calibrating the model using a manual approach. We propose to use an automated approach to remove any bias based on current understanding. This will include running the model over a very wide range of parameters and assessing standard measures of error. This will include log normal distributions of permeability and Half -normal distributions of storage. This will also be used to guide the uncertainty analysis and allow an assessment of non-uniqueness of the calibration data set.

6.1.3.2 Model Predictions, Sensitivity and Uncertainty

Model Predictions

Model predictions will be completed using the calibrated model. To demonstrate the impacts of the project on the regional groundwater system will require showing that there will be no movement of groundwater from the project area to either the Fortescue River and associated aquifer or mining operations to the east. To demonstrate this, we anticipate running the model over the life of the project, assuming time varying seasonal conditions and demonstrating flow paths from the pond areas over the life of the project using particle tracking. Particle tracking software (for example MODPATH (Pollock, 2016)[2] or mod-PATH3DU (reference, 2014-2017)[3] use modelled flow components to predicted flow paths. In this case, flow paths would be run forward, originating from the project ponds over the life of the mine. This would simulate flows paths associated with normal operation of the ponds under the ambient groundwater regime, or, if for example the ponds were to leak and release water of higher salinity or evaporated products were to be dissolves and recharge the underlying groundwater.

Model Sensitivity

Model sensitivity is sometimes addressed by observing model calibration performance to changes in aquifer parameters as part of the model calibration process. Key metrics can be derived to assess model sensitivity, however in areas with limited data for model calibration, these metrics often point to sensitivities that are clear from the hydrogeological conceptualisation. In recent studies in similar environments, automated approaches to assess sensitivity have lead to such conclusions (e.g. large aquifers, with limited monitoring data and potentially high storage show the potential for sensitivity).

To assess model sensitivity, we propose to include:

- Key uncertainties that have been identified in the hydrogeological conceptualisations; and
- Areas of model sensitivity observed during model calibration.

No model re-calibration will be completed. Model predictions will be re-run with changes to key aquifer parameters (or multiple parameters) to produce a range of outcomes. We have included a budget allowance to assess model sensitivity to changes in model parameters for the Base Case.

---

[2] Pollock, D.W., 2016, User guide for MODPATH Version 7- A particle tracking model for MODFLOW: US Geological Survey Open-File Report 2016 -1086, 35p, http://dx.doi.org/10.3133/ofr20161086

[3] Papadopolous and Associates, Inc. University of Waterloo. mod-PATH3DU A Groundwater Path and Travel Time Simulator Version 2.0.0 12/2017.

Model Uncertainty

Model uncertainty analysis as it applies to groundwater modelling can be described as using more than one calibrated model to predict a range of outcomes. Each of the calibrated models include feasible aquifer parameters, or an alternate hydrogeological conceptualisation to achieve an acceptable model calibration. This approach is designed to address model non-uniqueness.

To assess the range of impacts, we would complete an uncertainty analysis rather than a sensitivity analysis (i.e., the model would be recalibrated after parameter changes). If uncertainty analysis (as opposed to sensitivity analysis is completed), it is a more robust way of addressing model non-uniqueness. This approach will involve running more than one calibrated model to predict a range of dewatering rates and impacts. We propose that a number of uncertainty models could be developed:

- If an alternate hydrogeological conceptualisation is included, then this will be one of the uncertainty runs with another included to address parameter uncertainty.
- Some of the uncertainty runs may not require model re-calibration, which would also identify the non-uniqueness of the calibrated models.

6.1.3.3 Reporting

All work will be documented in a final report. The final report will include details on the following:

- The outcomes of the data review and hydrogeological conceptualisation;
- Groundwater model development;
- Model calibration;
- Model predictions and uncertainty (or sensitivity);
- Discussion of the model limitations and areas of remaining uncertainty; and
- Conclusions and recommendations for future work

We trust this memo report meets your requirements. Please contact us if you have any queries.

Regards,

Bruce	***Duncan***
Hydrogeologist	Director / Consulting Hydrogeologist

Author: BPH,KLR(12/11/21)
Checked: DGS (15/10/21)
Reviewed: AH (15/10/21)

Attached:

Figure 1: Location and Site Layout
Figure 2: Terrestrial Monitoring Network Phase 1
Figure 3: Terrestrial Monitoring Network Phase 2
Figure 4: Coastal Monitoring Network

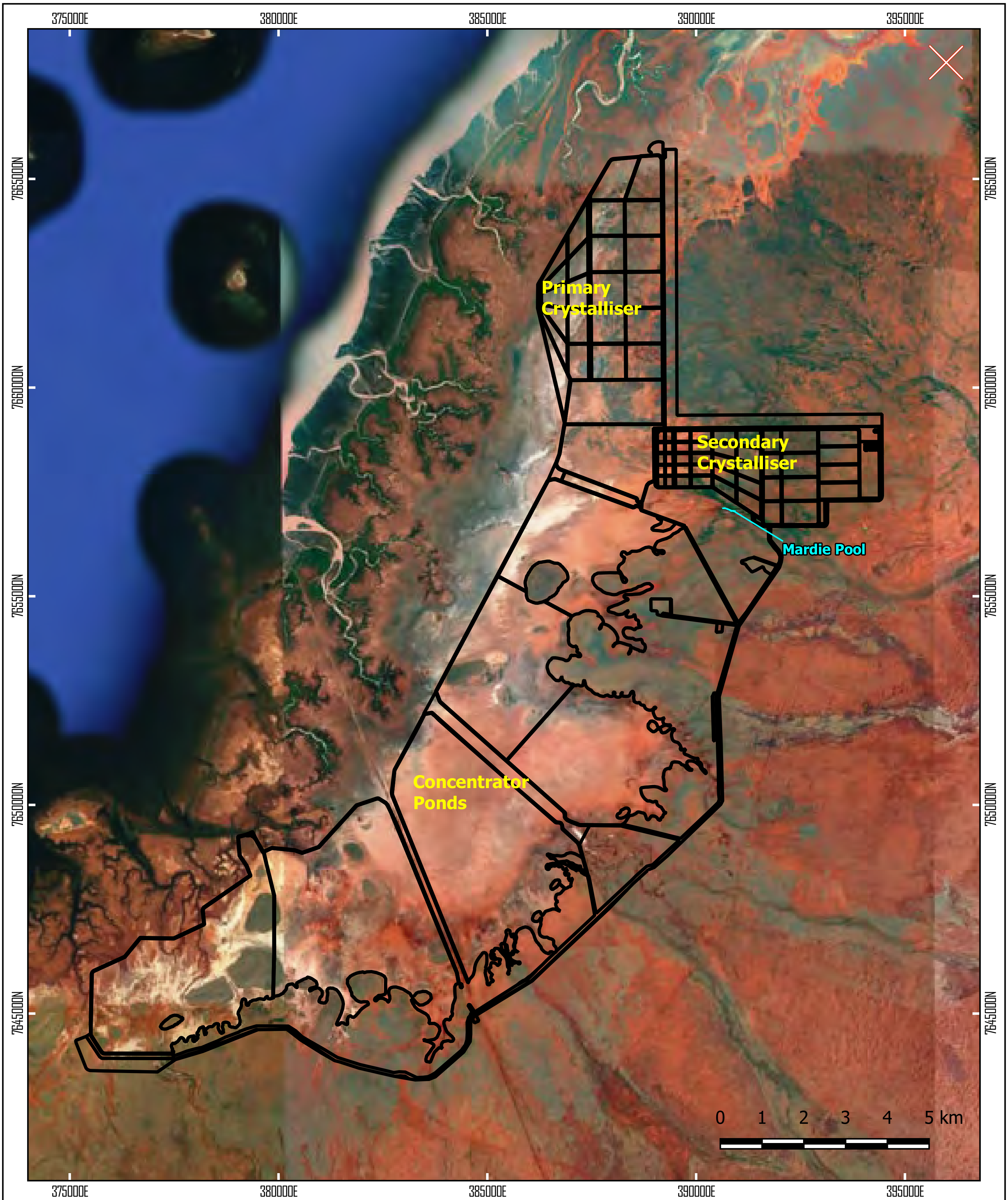
References

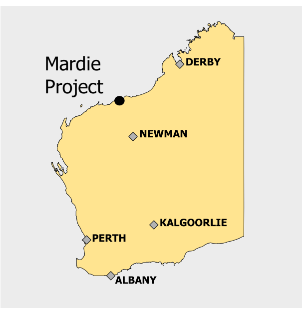
AQ2, 2020. *Mardie Project – Desktop Groundwater Risk Assessment*. Memo Report prepared for Mardie Minerals Ltd. November 2020.

Hayes MA, Jesse A, Welti N, Tabet B, Lockington D, Lovelock CE. *Groundwater enhances above-ground growth in mangroves.* J Ecol. 2019;107:1120–1128. https://doi.org/10.1111/1365-2745.13105

Porada H, Bouougri,E. and Ghergut,J., 2007. *Hydraulic conditions and mat-related structures in tidal flats and coastal sabkhas.*

FIGURES





Legend

DFS Disturbance Footprint

Mardie Pool

AUTHOR: BPH

DRAWN: BPH

DATE: 15/10/2021

REPORT NO: 032a

JOB No: 293

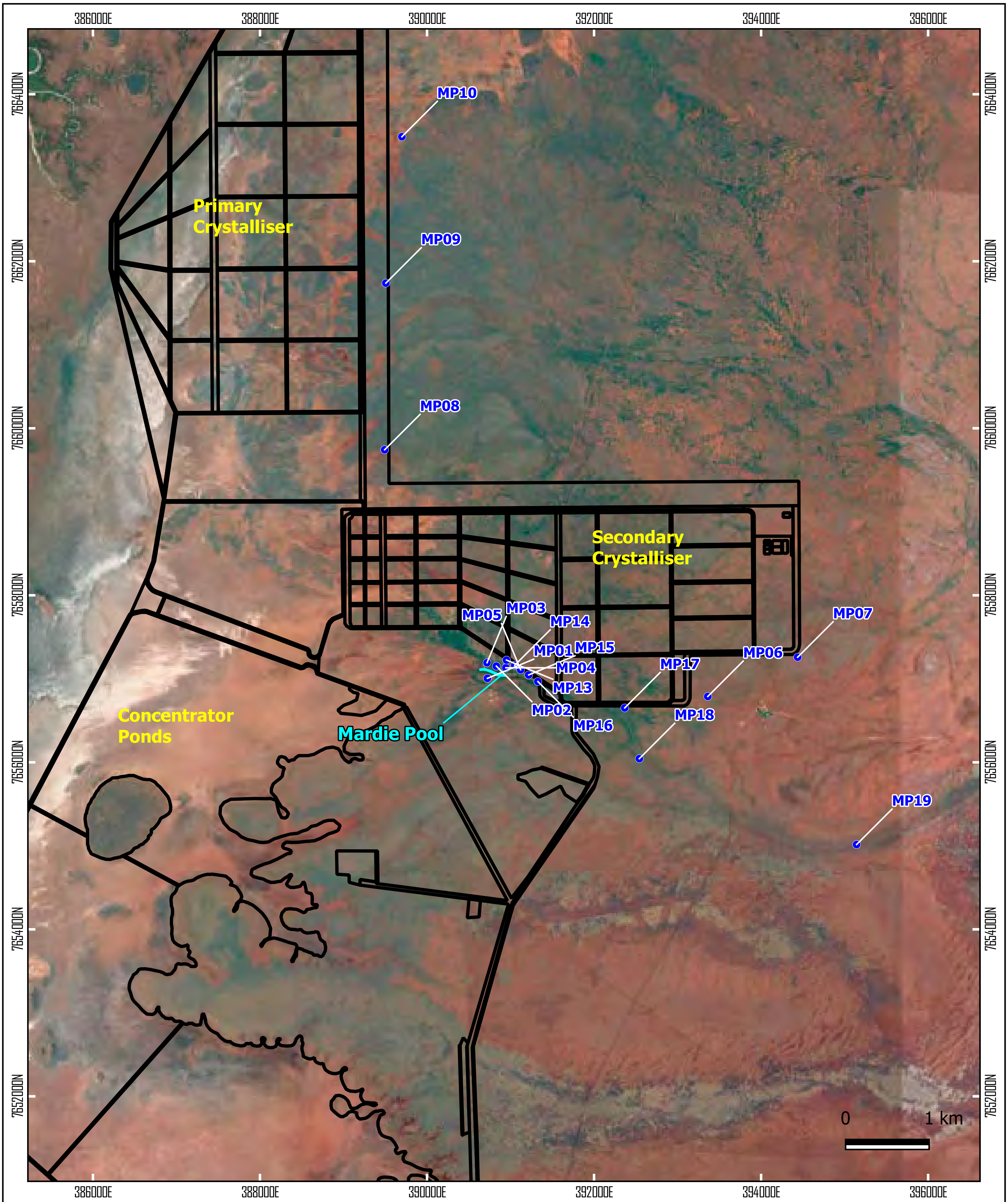
Coordinates: MGA Zone 50

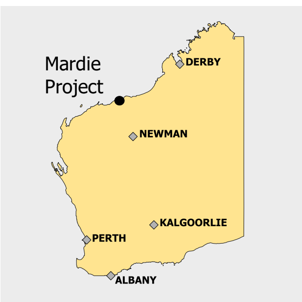
Notes and Data Sources:
Base image (C) Google Maps
DFS Site Layout supplied by Mardie Minerals

AQ2

Figure 1

Location and Site Layout





Legend

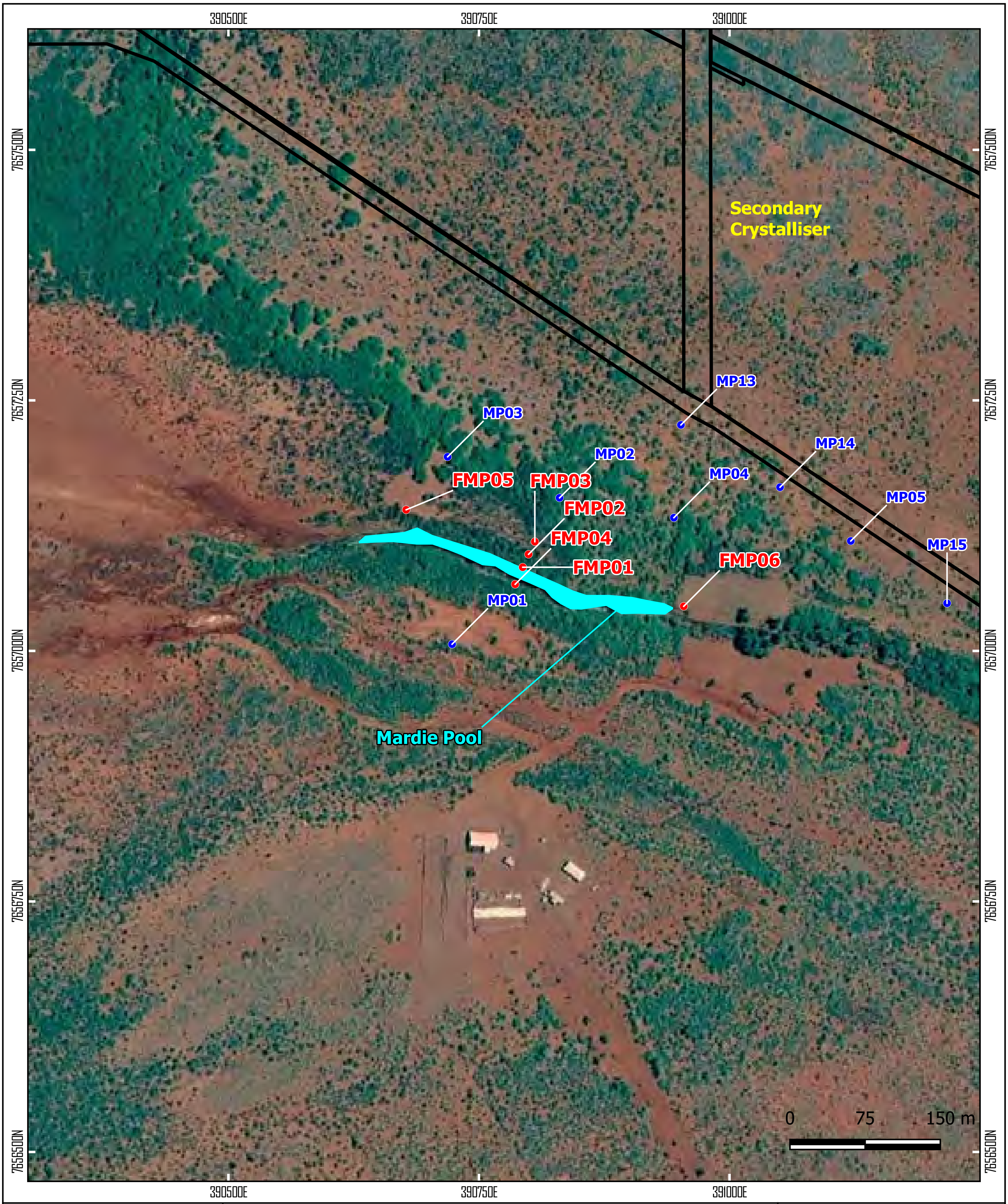
DFS Disturbance Footprint

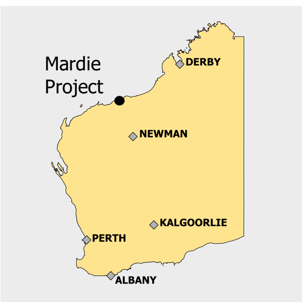
AUTHOR: BPH	REPORT NO: 032b	Notes and Data Sources:
DRAWN: BPH	JOB No: 293	Base image (C) Google Maps DFS Site Layout supplied by Mardie Minerals
DATE: 11/11/2021	Coordinates: MGA Zone 50	

AQ2

Figure 2

Terrestrial Monitoring Network P ase





Legend

- Terrestrial Monitoring Network - Phase 2
- Terrestrial Monitoring Network - Phase 1
- DFS Disturbance Footprint

AUTHOR: BPH
DRAWN: BPH
DATE: 11/11/2021

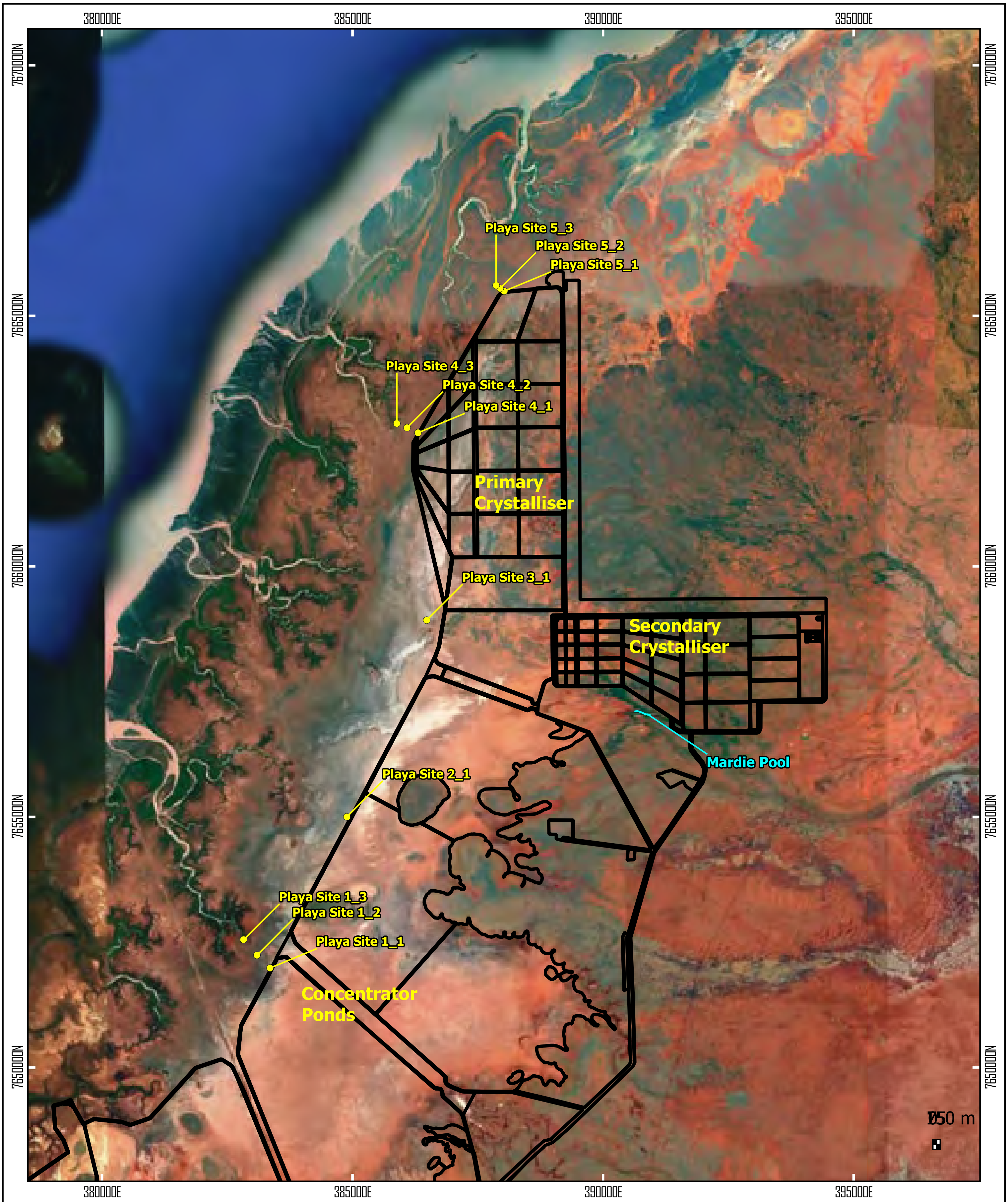
REPORT NO: 032b
JOB No: 293
Coordinates: MGA Zone 50

Notes and Data Sources:
Base image (C) Google Maps
DFS Site Layout supplied by Mardie Minerals

AQ2

Figure 3

Terrestrial Monitoring Network - Phase 2 (with Phase 1)



Legend

- Coastal Monitoring Network
- DFS Disturbance Footprint
- Mardie Pool

AUTHOR: BPH	REPORT NO: 032a	Notes and Data Sources:
DRAWN: BPH	JOB No: 293	Base image (C) Google Maps
DATE: 15/10/2021	Coordinates: MGA Zone 50	DFS Site Layout supplied by Mardie Minerals

AQ2

Figure 4

Coastal Monitoring Network

Appendix M: Groundwater Interaction Assessment

AQ2 Pty Ltd
ABN 38 164 858 07

Ground Floor
1 Howard Street
Perth WA 6000
Tel +61 8 9322 9733

www.aq2.com.au

Memo

To	Spencer Shute	Company	BCI Minerals
From	Mark Nicholls	Job No.	293Q
Date	16 November 2023	Doc No.	059b
Subject	Mardie Project – Mardie Pool Groundwater Interaction Assessment		

Spencer,

Please find below our technical memo outlining our preliminary assessment of the interactions between groundwater and the Mardie Pool.

1. BACKGROUND

1.1 Introduction

The Mardie Salt Project is located on the Pilbara coastline of Western Australia, approximately 100km south-west of Karratha. The project includes the construction of extensive brine concentration ponds and crystallisers for the extraction of salt products from sea water. Environmental impact assessment work for the Mardie Project has identified that developing an understanding of the risks posed to vegetation, local groundwater, and pools because of saline seepage from the ponds is important. This is of particular importance due to the proximity of the culturally and environmentally significant permanent waterhole known colloquially as Mardie Pool to the secondary crystallisation ponds.

To attempt to develop an understanding of the interactions between Mardie Pool and the existing water table, available monitoring data has been assessed. Monitoring data has been collected from a water level logger in Mardie Pool plus water level loggers installed in adjacent groundwater monitoring bores.

The conceptual water balance model for the Mardie Pool is that changes in water level with time are caused by the difference between water inputs and outputs from the pool. The water inputs are thought to be only rainfall runoff and (potentially) groundwater inflow. The water outputs are thought to be only evaporation and (potentially) groundwater outflow. The following memo outlines the assessments which have been completed to attempt to confirm if groundwater is an inflow or outflow to the pool.

1.2 Hydrology

The Mardie Pool sits within an incised area of a local drainage line. The surface water catchment area upstream of the pool is estimated to be 5,830ha. Given the flat nature of the terrain along the coastal flats in the region, the exact catchment area is difficult to define, and under large flood events, drainage lines are likely to overtop to form a single large, interconnected area of inundation.

2. AVAILABLE DATA

The following data was used as part of the assessment:

- Water level monitoring data from bores adjacent to Mardie Pool.
- Mardie Pool water level logger and survey data from between 5 October 2022 and 23 August 2023. During this period, a pool (rainfall) recharge event followed by a recession of pool water level was recorded.
- Evaporation rates for Western Australia, including Morton's shallow lake evaporation rates (SILO) and small dam evaporation losses (Department of Agriculture).
- Local LIDAR and survey data to estimate the pool bathymetry.
- SRTM ground surface elevation data (to define the catchment to the Mardie Pool).

Note that there is considerable uncertainty within many of the data sets used for this assessment, notably:

- The Mardie Pool data logger is not installed in a fixed position. Therefore:
  - The exact elevation of the logger (and therefore, the elevation data that the logger data represents) is not known with certainty.
  - Each time the logger is removed to download data, it is installed in a different position.
  - It appears that cattle accessing Mardie Pool for water disturb the position of the water level logger, such that there are many jumps in the data.
  - AQ2 has analysed the available data and modified the Mardie Pool water RLs to smooth out step changes in recorded water levels which appear to be as a result of logger disturbance. There is therefore a reasonable level of confidence in the trend in water level changes, but less confidence in what the actual RL of the pool surface is with time.
- The catchment area for Mardie Pool has been defined based on SRTM data. Given how flat the area is in proximity to Mardie Pool, the catchment area is difficult to design with certainty.
- Evaporation data from different sources have been used. It is not known how representative these evaporation rates would be to actual evaporation losses from Mardie Pool.
- There is some uncertainty in the Mardie Pool bathymetric data, with the LIDAR data and survey point data being inconsistent. It is not clear if large rainfall events since the LIDAR data was surveyed have changed the bathymetry of Mardie Pool. In general, AQ2 has placed greater confidence in the recent survey point data than the LIDAR data.

3. DATA ASSESSMENT

The objective of this assessment is to determine the interactions between Mardie Pool and groundwater and any changes in flow direction (in or out of Mardie Pool) that could be supported by the current understanding under observed hydrological conditions. To develop a hydrological conceptual understanding of Mardie Pool (the pool, the following analyses were completed:

- Physical dimensions of the pool were determined using terrain data.
- A pool water level timeseries was developed from measured and observed data.
- Pool water level timeseries was compared to nearby bore water level data.
- Catchment runoff rates were estimated for rainfall events recorded in the monitoring data.
- Pool recession rates were compared with evaporation rates to indicate if the pool recession rate is greater or lower than what would occur if evaporation was the only mechanism of water loss from the pool.
- Measured salinity in the pool was reviewed to estimate if there is a net gain or loss of salt from the pool with time.

3.1 Mardie Pool Dimensions

The survey data for Mardie Pool was used to determine the 'overflow' level of the pond, extending to the downstream drainage line. A stage (pool depth) vs. storage volume relationship was determined up to the 'overflow' level. It is important to note the many limitations when developing the stage/volume relationship, including the poor-quality bathymetry data. Despite these constraints, the following key observations from the available data were made:

- The pool is typically in the order of 300m in length and 10m in width.
- Estimated elevation of the base of Mardie Pool is 0.1mRL.
- Estimated overflow elevation of Mardie Pool is 2.4mRL.
- The estimated storage volume up to the overflow elevation is 4,800m^3.

3.2 Pool Water Level Data Review

The pool water depths which were recorded between 5 October 2022 and 25 August 2023 at 1-hour intervals by the installed water level logger were reviewed and adjustments to the data were made to remove data where large water level changes (>100mm) were recorded in the data in successive readings. [Note that some of these changes may be accurate due to rainfall events, but generally, no explanation to the large changes in water level could be made.] This created a time-series of data where there was a degree of reliability in the trend in water level changes rather than the actual elevation of the pond water level. This water level trend data was then fixed to the following observed water level data points:

- Survey elevation of the edge of the pond water level on 14 November 2022 of 0.77mRL.
- Anecdotal evidence that the pool overtopped (i.e., reached 2.4mRL) following the February 2023 rainfall event (27 February 2023).
- Drone photos of the pool on 8 May 2023 following a rainfall event indicating the pool was overflowing (i.e., at least 2.4mRL pool elevation).

The “Compiled Water Logger Data” timeseries is plotted in blue Figure 3.1 and the observed water levels are shown in black.

A further “observed” water level point was available based on interpreting a drone photograph of the pool from January 2023. The water level in the pool only appeared to be marginally lower than the surveyed water level point from November 2022. The rate of water level reduction observed in the logger data was significantly greater than the difference between the observed pond water level in November 2022 and January 2023. Fixing the logger data to the November 2022 survey water level and using the logger trends results in a water level at about 0.4mRL, which would make the pool significantly smaller than what was observed in the drone photos.

A ”Best Estimate Water Level” is plotted in grey on Figure 3.1. This represents our best estimate of the water levels based on the taking into account the range of information available.

It was noted that the monitored water levels did not appear to show changes on a sub-daily timescale which would be reflective of tidal influences.

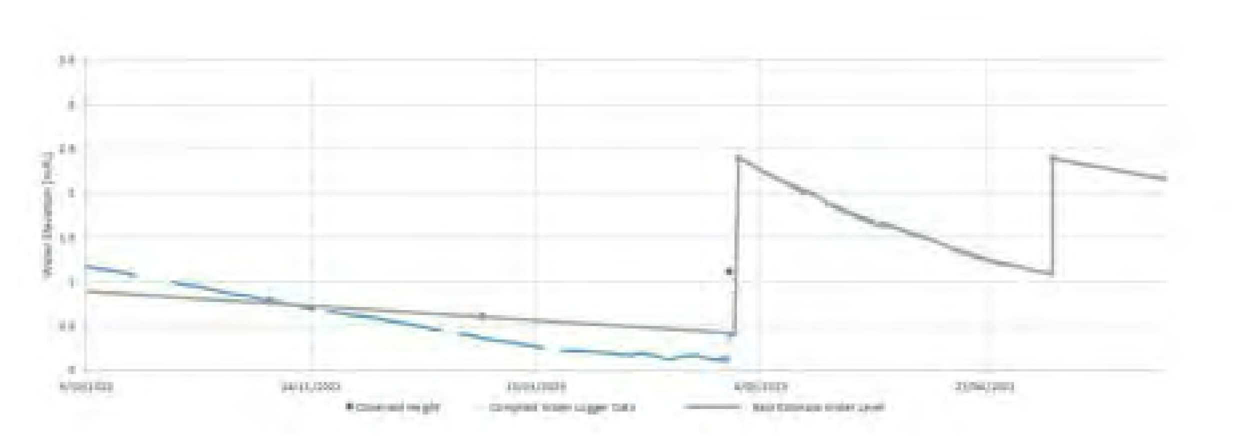


Figure 3.1 Observed Mardie Pool Water Level, compiled Water Logger Data & Best Estimate Water Level

A comparison between the pool water levels and rainfall data recorded at the Mardie weather station was also completed (refer Figure 3.2Observations include:

- Successive days of rainfall during February 2023 resulted in water levels increasing in Mardie Pool. A total of 97.5mm of rain fell across a five-day period. During that period, the highest daily rainfall recorded was 37.5mm.
- A significant rain event on 8 May (50mm), led to a rise in water levels in Mardie Pool. The pool level rose to at least 2.38mRL (based on a drone image).
- The peak water level in the pool as a result of both the February and May rainfall events was 2.38mRL, which is the pool overflow point.
- Following both rainfall events, the water levels in the pool subsided again.
- The monitored water levels pool water levels did not appear to show changes which would be reflective of tidal influences on a sub-daily timescale.

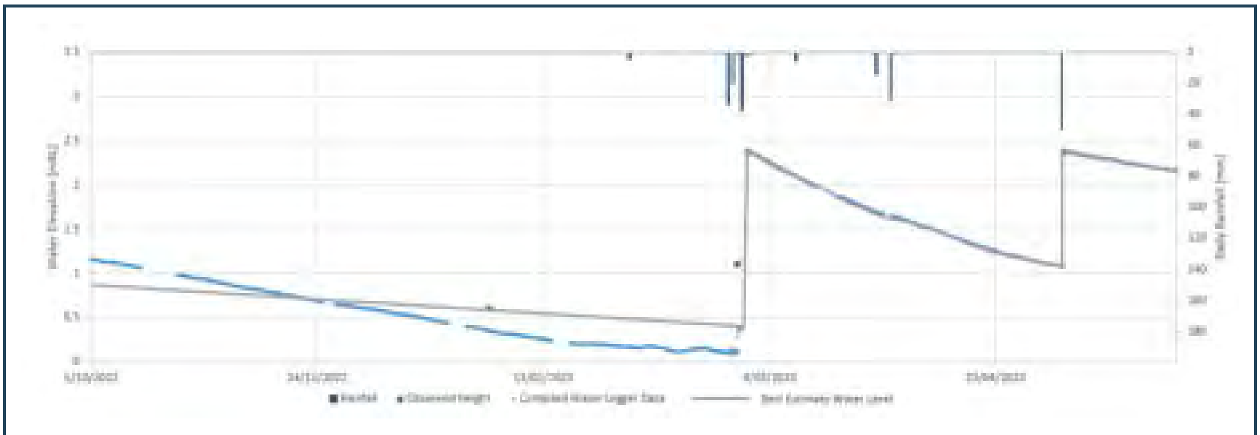


Figure 3.2 Mardie Pool Water Level vs Rainfall

3.3 Pool Water Levels Compared to Groundwater Levels

The observed pool water levels were compared with the water levels in adjacent monitoring bores (refer Figure 3.3). The bore water level monitoring data was only available until 19 March 2023.

The following observations were made when comparing the bore water level and the Best Estimate Mardie Pool Level:

- Prior to the February rainfall event, the groundwater levels were at a higher elevation to the Mardie Pool water level and were receding at a rate generally consistent with the Best Estimate Mardie Pool recession.
- The February rainfall event results in the groundwater elevations rising, but with a muted response compared to the Mardie Pool rise. The Mardie Pool level is thought to have risen above the groundwater level following the rainfall event.
- At the point that the groundwater elevation data ceases, the groundwater elevation appears to be relatively constant. If the groundwater elevation started to recede at the same rate as observed prior to the February rainfall event, it is likely that the pool water level would have fallen below the groundwater elevation again prior to the May rainfall event.
- If a similar magnitude of groundwater recharge occurred from the May rainfall event, it is likely that the Mardie Pool level would have temporarily risen above the groundwater level again.
- Based on these observations, it appears that following an extended dry period, the Mardie Pool level is typically below the groundwater elevation. However, following a runoff event, water levels within the pool rise above the adjacent groundwater elevation.

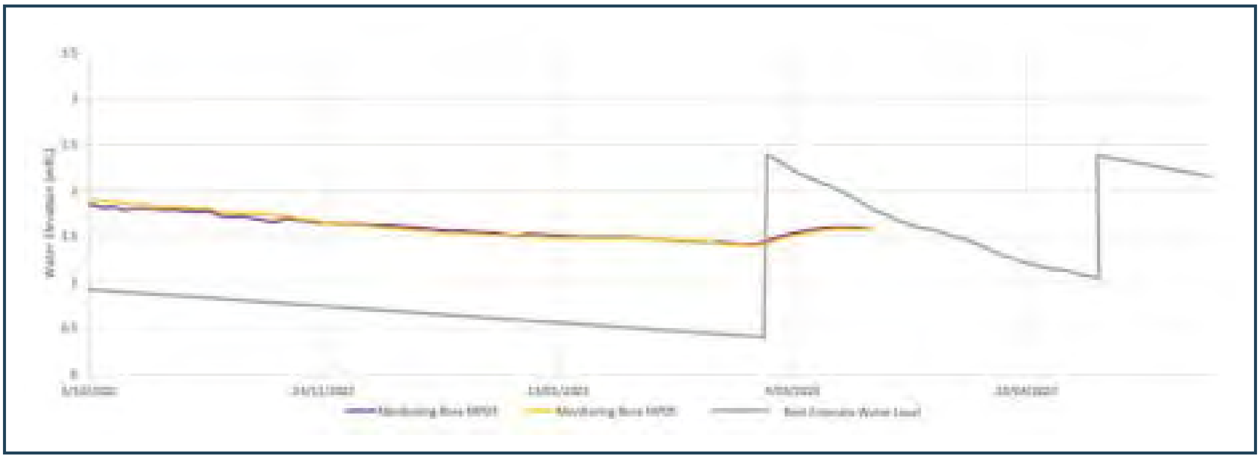


Figure 3.3 Mardie Pool Water Level Compared to Adjacent Bore Data

3.4 Catchment Runoff

The water storage volume within Mardie Pool below the overflow point is estimated to be 4,800m^3. Given an estimated upstream catchment area of 5,830ha (58,300,000m^2), Mardie Pool would only need to receive an excess rainfall depth (i.e., rainfall that exceeds infiltration and results in runoff) across this catchment area of <1mm to generate sufficient runoff for Mardie Pool to overtop (if it were empty at the commencement of the rainfall event). Therefore, any rainfall event large enough to activate runoff from the full catchment is likely to cause Mardie Pool to overtop.

3.5 Pool Recession Rates

The Best Estimate pool water level recession rate was compared to the expected recession rates calculated by adopting commonly used evaporation loss rates. If the Best Estimate pool recession rate exceeds what can be attributed solely to evaporation losses, it implies the existence of an additional water loss mechanism (such as losses to groundwater). Conversely, if the Best Estimate recession rate is lower than what would be anticipated from evaporation alone, it suggests that an additional source of water is contributing to the pool water balance (such as groundwater inflow).

The two following evaporation data sets were used to model two separate potential evaporation driven recession curves (Evaporation Only Model):

- Morton's shallow lake evaporation rates (sourced from SILO data base) for the Mardie Weather Station coordinates. These rates are calculated from meteorological conditions measured at nearby weather stations and are provided on a daily time-step.
- Average monthly estimates for evaporation losses from small dams (agricultural dams) for Exmouth (Department of Agriculture 1987). The corresponding monthly average evaporation rate was applied during each month that the pool recession rate was compared.

The comparison (Evaporation Only Model) was achieved by completing the following steps:

- Evaporation Only Model starts on 5 October 2022 assuming the Best Estimate pool water level at this date.
- At each time step, the water level is reduced by the evaporation loss at that timestep. Two curves are produced; one using SILO's Morton's Shallow Lake Evaporation and one using Department of Agriculture's Dam Evaporation Loss.
- If rainfall occurred at that timestep, the difference between the rainfall depth and evaporation depth was used to increase (or decrease) the pond depth. This assumes no runoff to the pond occurs; just direct rainfall over the pond area. The February and May rainfall events are the only major events occurring during the observation period which would be likely to have catchment runoff contribute water to the pond. Only minor rainfall events occurred during the rest of the observation period.
- The Evaporation Only Model is reset to the Best Estimate pool water level during the February and May rainfall events. The evaporation recession calculations commence again at this point.

The comparison between the water levels simulated Evaporation Only Model and the observed Mardie Pool water level is shown in Figure 3.4.

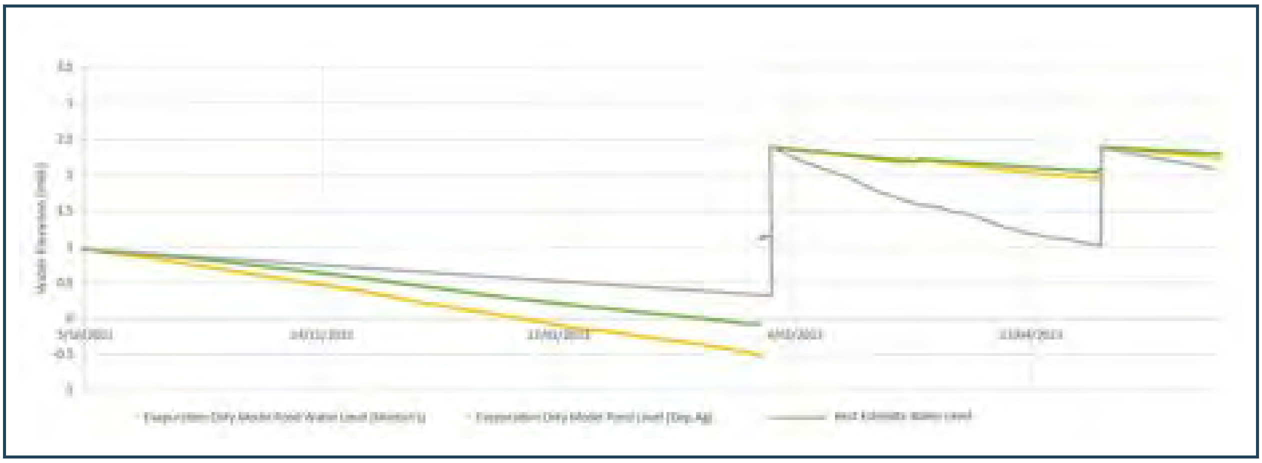


Figure 3.4 Evaporation Only Models vs Observed Mardie Pool Water Level Recession

The following observations are made from this data:

- Between the start of the comparison and the February rainfall event, the Best Estimate Mardie Pool recession rate is significantly less than the Evaporation Only Models. This indicates that the pool water level was likely being supplemented with groundwater inflow. This is consistent with the comparison of the water level in the observation bores being higher than the pond water level during this period. Note that the Morton's Shallow Lake Evaporation rates are higher than the Department of Agriculture's dam evaporation rates.

- Following the February rainfall event, the Best Estimate Mardie Pool water level recession is significantly faster than the Evaporation Only Models, particularly immediately following the rainfall event. A similar trend is seen following the rain event in May. This indicates that the pool may be losing water through groundwater seepage during this period.
- The Best Estimate Mardie Pool water level recession rate reduces with time following the February rainfall event, indicating that the rate of groundwater outflow likely reduces during this period.
- Immediately prior to the May rainfall event, the Best Estimate Mardie Pool water level is higher than it was before the start of pool water level data collection. However, note, as discussed above, the Best Estimate pool water level before the February rainfall event was derived by drawing a straight line through two observed water level data points, and does not match the trends in the logger data.

3.6 Uncertainties

The following uncertainties are inherent within this assessment (as discussed above):

- There is a degree of uncertainty in the datum of the Mardie Pool water levels.
  - The Best Estimate pool water levels shown prior to the February rainfall event have been derived by drawing a straight line from two “known” water levels; one surveyed at the edge and one derived from drone footage of the pool. The straight line assumes that the recession rate was constant over the period.
  - It was assumed, based on drone photographs, that the pool overflowed during the February and May rainfall events. The overflow elevation of the pool was based on a survey of where the overflow point would be (but this elevation does not align with the DEM survey of the pool).
  - The Best Estimate pool recession rates after the rainfall events assume that the rate of water level decline measured in the water level logger (once water level changes exceeding 100mm/hr are removed) are accurate.
- It is not clear if the Mardie Pool water level datum and the groundwater bore datum are consistent.
- No further water level records from the monitoring bores are available after 19 March 2023, which is shortly after the rainfall event with occurred on 26 February 2023. This means that a comparison between the pond water and groundwater levels is not possible after this point in time (including what the groundwater response was to the May 2023 rainfall event.

When further water levels are available (from the observation bores and the pool), it is recommended that the graphs in this report are extended and a more definitive conclusion on the interaction between Mardie Pool and groundwater levels may be possible.

3.7 Water Quality Review

Water quality (salinity) measurements from Mardie Pool have been taken on three occasions during the 2022 to 2023 period (refer Table 3.1). The data shows a significant increase in salinity in the pool between July 2022 and November 2022, and then a further increase to April 2023. The July 2022 water quality sample was taken prior to the installation of the pool water logger and 6 weeks after a significantly large rainfall event occurred (276mm over the month prior to July 2022)

Between the July and November 2022 water quality measurements, no large rainfall events occurred, and the 2-3 times increase in salinity could potentially be due to evaporation (only) or a combination of both saline groundwater inflows and evaporation (noting that evaporation rates are lower during the July to November period compared to November to April).

A further 2-3 times increase in salinity was measured between November 2022 and April 2023, despite the February 2023 rainfall event which would have been expected to result in a lowering of salinity in February 2023.

Without additional water quality data (and correlating water elevation data) it is difficult to use the data to provide further evidence of the hydrological connection between the groundwater and Mardie Pool. Ideally, the data could be used to demonstrate that (with time) the mass of salt within the pool changes, which may then provide evidence of groundwater inflow or outflow from the pool (on the assumption that no salt is removed via evaporation). It is recommended that a combination water level/EC probe be installed in the pool to allow water quality measurements to be recorded at an increased frequency.

Table 3.1 Measured Electric Conductivity in Mardie Pool

	15 July 2022	24 November 2022	30 April 2023
Pool West [$\mu S/cm^2$]	890	2800	6000
Pool East [$\mu S/cm^2$]	1100	2500	5900

4. SUMMARY AND CONCLUSIONS

Based on the assessments conducted and outlined in this report, it is likely that the pool alternates between periods of discharging water through the groundwater and periods of receiving water through the groundwater (i.e., groundwater source and sink) in response to rainfall event/drought events. It appears that groundwater contributes flow to sustain the water levels in Mardie Pool during dry periods of the year. However, following large rainfall events, it is probable that pool water levels exceed those of the adjacent groundwater table, leading to temporary water outflow from the pool through groundwater.

The water storage capacity of the pool is small compared to the size of the upstream catchment such that it is likely that only a small depth of excess rainfall would be sufficient to fill (and flush) the pool. The pool would then act to initially empty via evaporation and discharge to groundwater until the pool water level falls sufficiently for groundwater to report to the pool.

It is acknowledged that there is uncertainty in this assessment due to the quality of the pool water level monitoring data.

The following is recommended to reduce this uncertainty:

- Extend the graphs presented in this report as additional data is downloaded from the Mardie Pool logger and the loggers in the adjacent groundwater bores. With time, additional inflow events to Mardie Pool will occur such that multiple recession events can be analysed.
- Continue to take drone footage of the pool at regular intervals to allow reference pool water elevations to be estimated. Drone footage prior to and following any significant rainfall events would assist in reducing the uncertainty in the analysis be providing further "observed" pool levels to fix the water level logger data to. Consideration of surveying some visual reference points may make conversion of drone footage to pool water levels more accurate in the future.
- Install a combination water level/EC sensor in the pond or collect water quality samples at more regular intervals (and immediately following an inflow event) to allow a correlation between TDS and evaporation rates to be made during a pool recession event.
- Confirm that the same vertical datum is used for the survey of the bores and the pool bathymetry (including the pool overflow point).

- Consider completing a volumetric water balance and salt mass balance on the pool to further improve the conceptualisation of the Mardie Pool's relationship with groundwater. The above recommendations would be required to be completed to reduce the uncertainty in the inputs to the model (in particular, the pool bathymetry and water quality measurements). If the uncertainty in inputs to the model were reduced it may be possible to be more definitive about the relationship between pool water levels and groundwater inflow/outflow and it may be possible to quantify the flux of groundwater inflow/outflow from the pool.
- Estimate the frequency of filling and / or overtopping of Mardie Pool based on rainfall analysis.

The work completed has allowed AQ2 to include the following key inputs in the model being developed for Mardie Pool and the surrounding aquifers:

- The spill / maximum water level in Mardie Pool and the elevation of the base of Mardie Pool (i.e., the minimum and maximum water levels in Mardie Pool).
- The water level profile of Mardie Pool.
- The frequency of filling of Mardie Pool. The size of the catchment area of Mardie Pool and th analysis completed suggests that the pool would fill (to the overflow level) at least once a year.

These estimates of the behaviour of Mardie Pool have been included in the model calibration and are key in simulating the measured groundwater to filling and emptying of Mardie Pool at nearby groundwater monitoring bores (MP03 and MP02). These estimates will also be used for model predictions.

We trust that this report meets your current requirements. Please contact us should you require additional information.

Regards,

Tamar Haviv	*Mark Nicholls*
Water Resources Engineer	Consulting Water Resources Engineer

Author:	TH	(09/11/2023)
Checked:	MN	(12/11/2023)
Reviewed:	KR	(13/11/2023)

REFERENCES

Department of Agriculture 1987. 'Evaporation Data of Western Australia', Resource Management Technical Report No.65. Prepared by Luke GJ, Burke KL and O'Brien TM.

Queensland Department of Environment and Science 2023. *SILO – Australian climate data from 1889 to yesterday*. viewed. 10 October 2023 https://www.longpaddock.qld.gov.au/silo

Appendix N: DCCEEW Comments

Table 1. Department of Climate Change, Energy, the Environment and Water comments on the Groundwater Monitoring and Management Plan (Revision J) for the Optimised Mardie Project (EPBC 2022/9169)

Number/type	DCCEEW Comment	BCI Interim Responses
1. Review Context	The Department has received internal expert advice on Rev J of the Groundwater Monitoring and Management Plan (GMMP). The Department notes the following limitations/constraints in the review: 1. That the new conceptual model, monitoring program, and staged approach were presented to the Department for review for the first time in this version of the management plan (December 2023). 2. That the management scope of Rev J was limited to ponds 1-3 rather than covering the entirety of the project. 3. The Department understands that not all data and modelling available at the time was incorporated into Rev J (see DCCEEW comments 16 Feb 2024), and that further data has since been collected. 4. That further work has been undertaken on the plan in response to comments from the WA EPA and that some of the concerns listed here may already be addressed in a subsequent version of the plan. In particular, the Department recognises that it has been communicated to Mardie Minerals that the GMMP must be functional as a management tool and require effective mitigation and management measures (based on appropriate evidence) which are actionable and enforceable. *5.* The Department was only able to undertake detailed review of the GMMP (Rev J) which was provided for review. As a result, the Department understands that some of the comments provided here may be resolved in future versions. However, the comments as based on expert internal advice, should be useful in identifying what information is required by the Department to assess the impacts to MNES as a result of changes to groundwater. 6. Where the proponent has addressed comments in a subsequent version of the plan, please identify where this has been addressed within the document in the response, noting section/pages. Please also provide a 'tracked changes' version.	Point 1 – noted – Revision K includes a further updated Conceptual and Impact Groundwater Model completed in January 2024; updated supporting material for the Monitoring Approach and updated detail on the operational timing. Point 2, The GMMP will address EPBC 2018/8236 Point 3 – data through to February 2024 has been used. Point 4 – Noted Point 5 – Noted, responses below. Point 6 – Noted – a tracked changes version and a change reference table will be provided.
2. Outstanding comments	The Department has attempted to consolidate all outstanding comments into this document. This includes the high-level comments provided on February 16 2024 which are expanded upon here. The Department does recommend referring to these comments for overview/reference. **Table 2** of this document contains the comments referred to in the comments on February 16. These comments are referred to throughout Table 1 of this document however are presented in full in **Table 2** as the comment history provides important context around matters the Department raised during the assessment stage and which have not been resolved. These matters were first raised during in September stage and are considered essential understanding to support both an adequate and effective GMMP as well as the Optimised assessment. The Department did not provide individual responses to the April 2023 proponent response in Table 2 as the previous response that requested information be provided in future revisions remained relevant. That these comments be addressed has been continuously requested in subsequent Departmental comments. **Action: Please provide responses to the comments in Table 2, be sure to address all unresolved points in the comment history. Please demonstrate how the new approach addresses these comments and where in the revised GMMP the appropriate management measures are included and discussed. Where appropriate provide requested information/modelling. Where Table 2 comments are referred to in Table 1 please respond to both comments. Comments may be repeated where appropriate.**	Para 1: Noted. Para 2: The GMMP addresses the current EPBC 2018/8236 condition and provides additional information relevant to the Optimised Mardie Project. Para 3: Noted. Action Para: Comments inserted into Tables 1 and 2 with GMMP Rev K references
3. Summary of DCCEE	**The Department is of the view that the GMMP and the information supporting it is not sufficient for the Department to assess the potential impacts to MNES.** The impacts **to the environment as a result of the project** have not been modelled or where they have, the data has not been incorporated into the reviewed plan. As a result, it is fundamentally not possible for the	Para 1: The primary purpose of Rev K GMMP will be to address the relevant conditions under EPBC 2018/8236. As an assessment input to EPBC 2022/9169, BCI are seeking to ensure the right balance of information where relevant – for

Number/type	DCCEEW Comment	BCI Interim Responses
W Conclusions	Department to assess the acceptability of the impacts of the project to Matters of National Environmental Significance (MNES) via impacts to receptors such as Benthic Communities and Habitats (BCH) and Mardie Pool. As stated, the Department understands that some additional modelling which may contribute to identifying impact pathways may, at the time of writing, now be available but notes it was unable to be assessed as part of this review. Additionally, the Department remains concerned that there is insufficient baseline data to inform suitable models. In lieu of collecting additional baseline data per the ANZG 2018 or in meeting the requirement of the WA EPA (DWER comment #12, 7 Feb 2024), the Department understands that Mardie Minerals proposes to utilise the BACI monitoring approach, however the Department is not of the view that the proposed method and supporting monitoring network will be sufficient to compensate for the lack of baseline data. **As a result, the Department is, at this time, of the view that there are fundamental issues related to how the inadequate understanding of the system and subsequently, the understanding of the impacts of the project and their management, will be resolved. It is the Department's view that this understanding must be achieved to support a Management Plan that allows the Department to understand the impacts to MNES as a result of changes to groundwater.** The Department's key findings/concerns are summarised below and expanded in subsequent comments: 1. <u>**Baseline - The proponent has not achieved a sufficient baseline**</u> A) The Department is guided by the minimum requirements for baseline data as presented in the ANZG (2018). The ANZG recommendation indicates the minimum amount of data required to achieve an environmental understanding which the Department views as adequate to understanding environments and subsequent impacts. **B) As a result, the Department does not consider the baseline data collected for the project area and provided to the Department to date, to provide a sufficient level of understanding of the environment and to inform the models.** This is true for all sites across the project per the data provided with Rev J. This includes the inland bores and the coastal bores (Comment #5). C) It is the Department's position that an understanding of the environment be achieved that is in alignment with the goals of the ANZG 2018 recommendation. When considering strategies proposed by Mardie Minerals to measure, model, and manage potential changes to groundwater which may impact MNES, in lieu of the required baseline data, the Department considers whether the objectives underpinning the ANZG (2018) recommendation are satisfied and whether the alternatives are sufficient to compensate for the level of understanding intended to be achieved by the ANZG 2018 recommendation. **Deviations from the guidelines must be sufficiently justified. Where modelling, monitoring, management, and mitigation methods are proposed to compensate for insufficient baseline data these must be sufficiently justified and supported by reputable evidence.** D) The proponent has put forward a monitoring program to compensate for the lack of data. The Department does not consider that there is an adequate understanding of the environment and impacts of the project to determine if the general monitoring, modelling, and statistical strategy proposed by the proponent is able to achieve the expected environmental outcomes. E) The Department notes that given the onsite works already undertaken, a true baseline is unable to be achieved. It is unclear how the proponent intends to measure, and subsequently remediate, environmental impacts. It is the responsibility of the Department to consider this information in its assessment of both management plan adequacy and in the decision to approve or not approve the Optimised Mardie Project. Again, it is the view of the Department that the monitoring strategies proposed are insufficient to achieve this required understanding.	example in the Modelling – given that no approval decision has been made for 2019/9169. Para 2: Updated Model in s2.6 and App A includes impact modelling. The monitoring and trigger/threshold criteria approach proposed is consistent with the ANZG 2018: underlying principles [Philosophy and guiding principles (waterquality.gov.au)] DAA Data scientists have undertaken an analysis (App's E & K GMMP Rev K) that demonstrates the ability to identify groundwater changes. Para 3: As described above, the consideration of the Original and Optimised projects in the GMMP is important to addressing this comment. BCI would like to progress the GMMP in a similar way to the BCHMMP which has been approved for the Original Project, whilst still also providing the supporting material needed for the OMP approval decision. Dot Point 1A,1C: ANZG provide guidance on data for setting guideline values, including for data sets other than 24 months [Derivation and assessment against guideline values (waterquality.gov.au)]. The methodology provided in Rev K will respond to the ANZG requirements. Dot Point 1B: As this is a comment on baseline data for the groundwater modelling, this has been addresses in the latest Modelling Report which is to be provided in Rev K. Dot Point 1D: The mechanism for impact pathways are: water leakage and seepage from ponds (Condition 8), ground water changes (Condition 4 and 5) and direct disturbance. The BCHMMP (Condition 23) also provides a mechanism for the monitoring and management with respect to impacts to MNES. Dot Point 1E: Construction commencement was approved for the original project. Dot Point 2 – Updated modelling does use baseline data and does identify potential impacts through a number of transects (Appendix A, s2.6.7) Dot Point 2A, 2B, 2C - Updated Model described in s2.6.3 and App A and addresses this comment with regards to the Conceptual Model. Dot Point 2D – Comment below for E(II) and 4. Dot Point 2E I, II, III – model has been rerun including consideration of lateral flow, with multiple scenarios, model has been rerun appropriate to the project characteristics noting that reaches steady state within 3 years and then there are no operating changes to the project, there is no groundwater abstraction either. Dot Point 2E IV, V – refers to Comment 4 and 11, response below,

Number/type	DCCEEW Comment	BCI Interim Responses
	2. **<u>Modelling – the modelling supporting Rev J does not identify potential impacts of the project and is not supported by baseline data</u>** **Conceptual hydrogeological model** A) The hydrogeological model presented in Appendix A of the GMMP is not adequate to identify impacts or adequately conceptualise the site's hydrogeological system. (see comment 3) B) The modelled conceptualisation does not describe or consider impact pathways. Without pathways to guide and focus the modelling approach, it is not possible to validate whether or not a model adequately characterises potential impacts. C) The proposed model does not consider any potential changes to the system as a result of the project itself being undertaken. D) The Department does not consider the presented methodology to be adequate. See E(II) and comment #4. E) **A more complete and detailed conceptual understanding must be achieved. The Department recommends the following actions:** I. Rerun the model to account for lateral flow per the DWER comment 2, Feb 7 2024. II. Rerun the model with alternative calibration discussed in Comment #4 and with the three scenarios run multiple times to verify the model outputs and better predict real-world conditions. III. Rerun the model for the anticipated life of the project plus the time needed for the groundwater system to return to equilibrium state (Comment #4 and DWER comment 3, Feb 7 2024). IV. Rerun the model incorporating climate change scenarios into the hydrogeological modelling (Comment #4). V. The conceptual model must consider the potential changes the project may have on the environment – including changes to both surface water and groundwater regimes and the interactions between see Comment #4 and Comment #11). 3. **<u>Fundamental environmental processes key to understanding the potential impacts to MNES are not understood and cannot be understood without additional data.</u>** A) **All potential impacts must be modelled.** Where there is insufficient baseline data to sufficiently understand and model the potential impacts (e.g. groundwater contributions to algal mats and Mardie Pool) a conservative approach could be taken (see Comment #7). i.e. assume that the worst-case scenario is true and build triggers, thresholds, and management measures around that assumption (see Comment #3 and Table 2) B) The GMMP does not demonstrate an understanding of the current relationship between groundwater and Mardie pool and the algal mats and how that may be affected by recharge processes. The Department is of the view that there is insufficient evidence to make any conclusions on the contribution of groundwater to Mardie Pool and the algal mats, mangroves. (see Comments #11-#15) C) The interaction between surface water and groundwater is not adequately considered, particularly in relation to recharge processes. Given the potential contribution of recharge processes to the above receptors (among potential others) and that the construction of the project may impact these processes, this must be understood. 4. **<u>Monitoring - The proposed monitoring program to compensate for lack of data is inadequate / the impacts to the project are not measurable</u>** A) **The BACI method as discussed in ANZG 2018 could be able to provide triggers and thresholds however the Department does not consider the proposed BACI method to be consistent with the methods of the ANZG guidelines (see DCCEEW comments 6,7,11, from & Feb 2024) (and see comment 7 below).**	Dot Point 3A, 3B, 3C – Impact modelling undertaken for a number of scenarios and project aspects relevant to the Original Project and to an extent, the OMP. Modelling describes recharge processes, and the EIA also assessed the impacts of the ponds on hydrology and hydrogeology for the Original Project. Dot Point 4A - Refer to comments above on M-BACI and methodology and ANZG. Dot Point 4B: The GMMP is for the original project and considers expanded bore network for the Optimised Project. Dot Point 4CI: a modified M-BACI approach has been used and provided in Rev K. Dot Point 4CII: Has been adopted for original project, to be discussed regarding OMP. Dot Point 4CIII: Telemetry in place for last 6 months for GW level, is being extended to EC, awaiting procurement/installation. Dot Point 4D: Approach discussed above noting it is detectable change that is the key GMMP objective outside of environmental factors. Dot Point 4E: Modelling has sought and used relevant data where available and this is described in the report. Note that there do not appear to be relevant regional WQ guideline values available for this location. Dot Point 5: This appears to be in reference to the OMP – the approved project has described impacts to MNES and protected matters. Dot Point 5A: See proposed progressive filling approach (s2 App D) which is consistent with the Action and the project description, albeit with a 1 week pause between each rise in volume. Dot Point 5B: See proposed progressive filling approach (s2 App D) which is consistent with the Action and the project description, albeit with a 1 week pause between each rise in volume. Modelling approach to be discussed given update in January, and additional modelling being undertaken in March/April 2024. Dot Point 5C: There is over 6 months of baseline data for Ponds 1 and 2, 3 and 4 and will be described in the GMMP. (s2 App D) Dot Point 6A: EPBC 2018/8236 describes permitted impacts to MNES, defines what protected matters are, and the purpose of the GMMP with regards to potential impacts outside of the approval. In regard to the GMMP informing the OMP approval process, this to be discussed as to how the plan can and should do that. Dot Point 6B: See responses above to Points 1 through 4.

Number/type	DCCEEW Comment	BCI Interim Responses
	B) The installed bore network was designed to support the original investigation program as part of the approval for the original Mardie Project (EPBC 2018/8236). **The Department does not consider the network to be sufficient to support the currently proposed conceptual model and management plan to measure and detect impacts to groundwater across the project area and surrounds.** C) The Department offers the following recommendations to improve the proposed monitoring approach: I. Implement/employ the M-BACI method (see Comment #7). II. Improve the bore monitoring network to ensure the entire project area and surrounds is adequately represented in monitoring efforts and that each pond has multiple reference sites as required by the M-BACI method (see Comment #7). III. Establish monitoring bore network that collects continuous data, in place of quarterly bore measurements (per DWER comment #6, Feb 7 2024). D) Triggers and thresholds should be set and then ideally not change. E) In the absence of suitable baseline data, other relevant values like regional or catchment scale values, could be used to support the proposed modelling and monitoring regime with **sufficient justification.** **5. <u>Due to the lack of information on potential impacts the Department is unable to determine the acceptability of the following aspects of the proposed strategy</u>** A) Whether the staged filling of ponds 1 and 2 (whereby water is proposed to be added x amount at a time with a pause period of x) is appropriate. (see Comment #16) B) Whether the sequential filling of the ponds in general with sequential modelling is an appropriate strategy C) Whether the filling of ponds 1 and 2 without baseline data could be considered low risk (see Comment #16) **The Department will consider additional information provided by Mardie Minerals that may address or justify the identified gaps, however before the staged approach can be properly considered the above concerns must be addressed.** **6. Conclusion:** A) The Department is of the view that there is insufficient understanding of the environment, that the impacts of the project are not understood and that the proposed monitoring and management is insufficient. B) Points 1-4 above summarise the Department's assessment of the ability of the reviewed GMMP to manage impacts to groundwater due to the project. C) This fundamental lack of understanding leaves the Department in the position of being unable to assess impacts to MNES under the EPBC Act. D) At the root of the issue is an absence of baseline data and subsequent understanding of the environment. The Department is of the view that the proposed methods to compensate for this are not adequate. E) The Department makes some recommendations on how Mardie Minerals may improve or otherwise approach achieving an acceptable, evidence-based management plan however reiterates that pre-impact (as much as possible) baseline data provides an understanding of environments not easily achieved otherwise and that alternative methods proposed or undertaken run the risk of proving to be inadequate over time and/or of further compromising the capacity for the environmental objectives to be achieved.	Dot Point 6C: See response above re Dot Point 6A Dot Point 6D: Two issues raised: Baseline data is available for the GMMP as described above. For EPBC 2018/8236 the environment is described and the BCHMMP approved. For OMP, this is to be discussed. Dot Point 6E: Noted.

Number/type	DCCEEW Comment	BCI Interim Responses
4. Modelling	**<u>The hydrogeological model presented in Appendix A of the GMMP is not adequate to identify impacts or adequately conceptualise the site's hydrogeological system.</u>** The GMMP's present understanding of the hydrogeological conceptualisation continues to be inadequate. A) The model presented in Appendix A of the GMMP does not conceptualise the project area, only a two-dimensional transect of Pond 1. B) Additionally, the modelling presented does not appear to incorporate any predicted effects the project may have on the environment, and C) the simulated duration does not include the whole duration of the project and the time taken for the site to return to equilibrium state. D) The proposed model does not consider any potential changes to the system as a result of the project itself being undertaken – without including the effects of the project in the modelling, it is fundamentally not possible to identify or predict any impacts that the project may pose. **Action: All models must include potential changes to the system as a result of the project itself being undertaken.** E) Calibration of the model is described as being undertaken using a manual trial and error approach and that the model was run for three scenarios. The results of the manual calibration suggest that the model as presented, does not adequately predict real-world conditions. The Department recommends the adoption of modelling methodologies presented in Barnett *et al* 2012. **Action: Please rerun each of these scenarios' multiple times (e.g. Monte Carlo approach) in order to better verify model outputs.** F) Given the proposed life of the project, the model's simulated duration is too short to adequately predict long-term impacts and alterations to the system. The simulated duration should be extended to the anticipated life of the project plus the time needed for the groundwater to return to an equilibrium state. This matter was raised in DWER's independent peer review. **Action: Please rerun the model for the anticipated life of the project plus the time needed for the groundwater system to return to equilibrium state and as requested by DWER comment 3, Feb 7 2024** G) The proposed model does not consider the potential influence of climate change on the hydrogeological system. **Action: Please incorporate climate change scenarios into the hydrogeological modelling, using approaches consistent with current national guidelines (Ball et al. 2019) for the anticipated life of the project plus the time needed for the groundwater system to return to an equilibrium state.** H) The Department reiterates the need for outstanding modelling to include a density-driven flow analysis, and to incorporate the regional groundwater system (see Comment #6) . The Department also provided comments during the assessment process on modelling which have not been addressed in the GMMP or supporting information. These include but are not limited to: I. **Table 2 Comment 3** – How has hydraulic loading been incorporated into the models? II. **Table 2 Comment 6** - This comment identifies a series of key questions that should be investigated by the modelling: III. What will the hydraulic loading from the ponds do to the groundwater flow direction? IV. How will the expected change in flow direction impact on the surface and groundwater interactions	Para 1: the Model has been updated and provides conceptualisation of the hydrogeological system as well as impacts. Point 2A, 2B, 2D: the Model has been updated in Appendix A and provides conceptualisation of the hydrogeological system as well as impacts across 3 distinct transects. Point 2C: the Modelling Report discusses modelling durations noting that the specific characteristics of the project – surface ponds, and their interactions with groundwater. Point 2E: Calibration was undertake using groundwater data and tidal information. To discuss directly with modellers. Point 2F: Model duration, as raised above. Has been responded to in the AQ2 Modelling. *"The Pond 1 section has been run for a predictive period of 3 years, determined as indicative for understanding potential impacts associated with filling. Other sections have been/will be run for 10 years. The modelling of each section will be re-run to cover the total Project life, once the initial model validation step has been completed (i.e. there's little sense in extending the model duration until BCI is confident that the current model setup is correct and predictions reliable)".* Point 2G : Flooding and hydrology modelling was undertaken on multiple scenarios in the Original Project EIA. A separate study on Storm modelling was undertaken under a number of scenarios also. Point 2H: Regional Groundwater Modelling timing and commitment has been made see Section 3.5. Last Para: Modelling has been updated. Some of the questions here are conceptual in nature and are based on an alternative conceptualisation that has not been proposed. Compensatory measures detailed in the review, remediation and offset components of the GMMP.

Number/type	DCCEEW Comment	BCI Interim Responses
	(freshwater recharge processes) with Mardie Pool? V. How will this expected change in flow direction impact on the algal mats, mangroves, etc? VI. Will this project cause saline groundwater to move towards the Fortescue Alluvial Aquifer? VII. What is the volume and direction of seepage from the ponds and what are the likely impacts? DCCEEW has previously commented that the proposed modelling may be unable to answer all questions. Please describe how these questions will be answered by the proposed modelling regime. It is the Department's view that this understanding should be achieved prior to commencement and should inform the management plan. Please fully justify any proposal to not provide this modelling. Please fully address the comment history of **Table 2, Comment #6** and any other comments related to modelling. **Action: Please provide a complete modelling suite. Where modelling is proposed to be completed in the future/after commencement this must be sufficiently justified and supported with compensatory measures.**	
5. Conceptual Model – Baseline	A) The Department recommends that modelling be underpinned by 24 months of contiguous data across the entirety of the modelled system. B) Given this recommendation, the coastal bores have not been operational long enough to validate the modelling of tidal flat groundwater system. Further: I. The model is not supported by an adequate amount of baseline data. II. The specific groundwater level data underpinning the model is not presented, and hence cannot be interrogated for adequacy. Appendix A lists the data as from five bores across Ponds 1-3, spanning February 2022 to August 2023, and from five deep/shallow bore pairs in the tidal flats, spanning August 2023 to November 2023. As the data values used in the model are not presented, the Department concludes the values are the monitoring results from five distinct and non-contiguous months presented in the GMMP (e.g. BCI Mineral 2023b, Table 6, p. 42). The presented approach, of five discrete months in one part of the system that do not overlap with monitoring elsewhere in the system, is inadequate. **Action: The Department recommends the ongoing acquisition of baseline data per the ANZG 2018 guidelines and DWER comment #12, Feb 7 2024 and that the model be updated using consecutive monitoring data, as per ANZG 2018 and DWER comment 6, Feb 7b 2024.** C) The ANZG (2018) standard of minimum of 24 months has not been achieved and is considered necessary to develop a baseline prior to undertaking any of the works associated with the project. Given that the works already undertaken as part of the original proposal prevent a true environmental baseline from being acquired, it is unclear how the proponent proposes to ensure acquisition of an adequate environmental baseline. D) The Department also notes that filling Pond 1 before appropriate baseline data has been collected will further prevent the collection of an adequate baseline data set (also see Comment #17 on Pond 0).	Point A, B: the GMMP presents the data that has been used for the most recent modelling. Point C, D – ANZG are guidelines and response above outlines how the trigger/thresholds will be proposed in this context.

Number/type	DCCEEW Comment	BCI Interim Responses
	Action: The Department will review proposed methods for measuring impacts in lieu of adequate baseline data. All deviations from ANZG 2018 must be sufficiently justified.	
6. Cumulative/regional impact modelling	A) Cumulative Impact modelling and the influence of the Sino Iron Mine dewatering, informed by monitoring data, was proposed by the proponent at the Optimised Project referral stage (AQ2 2021) and has not been completed/considered in the GMMP. B) Mardie Minerals made the following response to Departmental comments on this matter in November 2023: *"An important overarching context is that the Mardie project does not extract any groundwater, therefore any impact to groundwater flow is minimal. Impacts would be limited to small amounts of leakage (if that occurs) which would propagate in shallow aquifers in the dominant direction of flow. These shallow aquifers are already characterised by very shallow and saline groundwater with levels controlled by evaporation from tidal flats.* *As Sino Iron Project is the major groundwater water user in the area it should be upon Sino Iron to model the propagation of their drawdown regionally along with how any such propagation may affect the local groundwater system (at Mardie Pool for example). Any impact due to drawdown from Sino Iron will only reduce the groundwater gradient towards Mardie Pool, increasing travel times of any potential seepage. Applying a source-pathway-receptor concept, the direct assessment of impacts by the Mardie project should be limited to shallow groundwater seepage; the only stress the project may impose on the system. The 2D sectional models provide appropriate information for mitigation measures to be designed in the event low rates of seepage occur into shallow aquifers."* C) The Department does not agree that it is the responsibility of Sino Iron to model the impacts of their project to Mardie Pool. It is the responsibility of Mardie Minerals to understand the impacts of the project in the context of the existing environment, including the environment as impacted by regional projects existing at the time of the referral. D) Given the absence of adequate baseline data or comprehensive impact modelling, the Department does not consider Mardie Mineral's conclusions on likely scale and severity of impacts to be justified. The Department is of the view that the cumulative modelling would be supported by relevant environmental data. Any additional modelling of the project should be undertaken as it may supplement the currently poor environmental understanding. E) The Department also notes **Table 2 Comments 4, 15 and 16** which describe the role of regional modelling to detect relationships to important sites such as Fortescue alluvial aquifer and Mt Salt Mound Spring and contain commitments by Mardie Minerals to undertake these investigations. **Action: Please complete the regional/cumulative impact modelling. Current models do not consider what changes and impacts the project will have on the existing groundwater system and develop and include mitigation measures for these impacts into the GMMP.**	Regional Modelling commitment included, refer to Section 3.5. Point D – Modelling has been updated as described above including impact modelling. Point E – Mt Salt monitoring updated in GMMP – Site visit November 2022 and August 2023 found no discharge was evident at that time. Commitment made for quarterly monitoring. As part of the OMP bores, three have been installed for (MP07, MP11-12) down gradient from the Secondary and KTMS Crystallisers to detect changes to the groundwater regime due to the crystallisers.
7. Monitoring	A) The Department does not agree with the conclusion that temporal variability in the system prevents the development of traditional triggers and threshold (GMMP Rev J page 7), or that triggers developed under traditional approaches would need to be revised daily GMMP Rev J page 236). The Department believes that this is more likely due to inadequate baseline data rather than a truly unpredictable system. B) The Department is of the view that the BACI method, **as described in ANZG (2018)** would be suitable for deriving triggers and thresholds for monitoring and management. <u>**The Department does not consider the variation of the BACI methodology as described in the GMMP to be suitable.**</u> I. Given the Department's stance on the ANZG 2018 recommendation regarding adequate baseline data (see comment 2-2). The Department does not consider three months of data to be sufficient to provide a baseline accounting for seasonal variation nor to justify the claim that "relationships between bores are likely to change for unknown reasons." II. Given that the GMMP notes that the project area is highly variable, both spatially and temporally, it is unclear how the proposed spatially limited number of monitoring bores will be adequately representative of the whole	As described above, an approach consistent with ANZG is proposed. Point B, BI, BIII, CI, CII, CIII, CIV, D – See comments above #4(3) – this is what has been proposed with a modified approach as DCCEEW recommend that takes into account the frequency of data collection and environmental factors consistent with ANZG: There are no default Guidelines available for the Indian Ocean drainage division at that link nor for Marine DGV's.

Number/type	DCCEEW Comment	BCI Interim Responses
	project area and surrounds. It is the Department's view that the existing bore network (which was designed to support the data collection requirements of the previously planned approach of the groundwater memo) is no longer appropriate for the newly proposed approach and that an expanded monitoring network would be required to adequately monitor the spatial extent of the project site and surrounds. III. The proposed BACI approach describes a 'dynamic' approach in which impacts in one pond will be compared against reference bores located in later ponds. The Department does not consider this approach suitable especially given the absence of adequate baseline data as: i. Impacts are only able to be monitored while reference bores are themselves not impacted. ii. There is no long-term control reference against which the whole action can be compared. C) The Department recommends the employment of the M-BACI approach suggested by Underwood (1992) and endorsed by the ANZG 2018. An appropriate supporting monitoring network: I. Should ensure that adequate monitoring is available to represent the whole project area and surrounds II. Include multiple appropriate control/reference sites, outside of the ponds for each impacted site (pond) III. Should be maintained as part of the impact monitoring for the anticipated life of the project, plus the time needed for the groundwater system to return to an equilibrium state in the case of potential lagging impacts IV. Should demonstrate a relationship between proposed bore pairings as supported by adequate data. D) Triggers and thresholds - It may be appropriate in the absence of baseline data to use conservative triggers and thresholds in line with ANZG 2018 standard Default Guideline Values as part of a monitoring strategy. **Action: Please provide details of an updated monitoring program and accompanying bore network that will address the above comment**	
8. Mitigation measures	A) The GMMP proposes to manage impacts through development of dedicated mitigation measures within six months of an impact being detected. This approach is not adequate, especially given that an exceedance in the early stages will imply an insufficient understanding of the environment. B) The Department reiterates the need for the GMMP to include commitments to (at a minimum) **standard practice remediation and mitigation measures**, to enable responsive management of exceedances, rather than the current absence of any detailed measures. C) Mitigation measures proposed where a baseline/understanding has not been achieved should, at a minimum: I. Utilise appropriate and conservative triggers (see Comment #7) II. Employ standard practice remediation and mitigation measures to enable responsive management of exceedances. Where uncertainty in the system remains standard practice measures should be improved upon. III. Remediation measures must be prepared in advance (see DCCEEW comment #1, 16 Feb 2024) **Action: Revise the GMMP to include strengthened remediation and mitigation measures.**	Updated GMMP includes mitigation measures in Section 3.2, reporting and remediation in section 3.4, Adaptive management in section 4.1 As per EPBC 2018/8236 condition (Condition 5), a remediation plan is to be developed within 6 months of a threshold exceedance, not in advance.
9. Potential Impacts	A) Without an assessment of impact pathways (see comment #3 and #4) and adequate conceptualisation of the project area, it is not possible to draw conclusions on the potential risks posed to the algal mats, mangrove habitats or Mardie Pool. The potential impacts of the following are not understood: I. Saline intrusion II. Decline or interruption of groundwater supply III. Alteration to surface and groundwater regimes B) The Department notes that additional impacts are possible and should be considered in the plan and supported by appropriate data and modelling.	As described above, there is an updated conceptual and numerical impact model. There are clearly defined approved impact limits in the EPBC 2018/8236 and clear conditioning for impacts over and above these. Updated modelling in Rev K including impacts will provide detail for uncertainty outside the approved project conditions as well as adaptive management and remediation.

Number/type	DCCEEW Comment	BCI Interim Responses
10. Peer Review • Appendix C and Appendix G	A) The Department has considered the audit of the peer review provided in Appendix G in response to DCCEEW comments regarding Condition 4 of the 2018/8236 conditions. B) The Department does not consider that the Flinders University peer reviewer recommendations (Appendix C) have been met. The audit's position that several recommendations are adequately addressed appears to be based on the outcome of planned but incomplete works. The Department considers these works to be critical to understanding the action and its impacts – including but not limited to: I. The absence of hydrogeological conceptualisation of the Mardie Pool and other potentially impacted receptors II. Absence of water contour and salinity data prior to undertaking the action (baseline data) Action: **Please address reviewers comments.**	Rev K has been updated to describe peer review comments and how addressed or responded to in s4.2.1 and s2.2.4
11. Surface water and ground water interactions	A) The GMMP does not present discussion or assessment of interactions between surface water and groundwater. Given these systems are likely to be linked and alterations to one may potentially pose an impact pathway to the other, the Department requires this to be assessed and incorporated into the project's hydrogeological conceptualisation. B) The Department also notes **Table 2, Comment #18** and the commitment to provide a Flood Management Plan **Action: Please complete investigations and incorporate into GMMP. Please be sure to carefully consider extensive comments on this matter in Table 2**.	The GMMP is targeted on groundwater matters, however surface and groundwater interaction are described through the conceptualisation in App A.
12. Characterisation of groundwater contributions to algal mats and other receptors	A) The Department has continuously raised the matter of how surface water diversions due to pond construction may reduce recharge across the coastal flood plain area and how this may impact riparian vegetation and algal mats. The groundwater use of these receptors is not well understood. In comments received November 2023, Mardie Minerals stated the following: "*Recharge of fresh groundwater water occurs inland and across the hinterland, flowing gradually towards the coast. The fresh water intersects the hypersaline brine of the sabkha inland from the eastern edge of the tidal zone, where a wedge of hypersaline water is confined by the hydraulic pressure of the fresh water. Diffusion of hypersaline water into the fresh water occurs at this point. These is no evidence that the mangroves or algal mats receive 'recharge' from terrestrial flows, with the sabkha understood to be a barrier between the terrestrial and 'marine' Systems*" B) The Department agrees that no evidence has been presented to suggest that mangroves or algal mats receive recharge from terrestrial flows but also that no evidence has been presented to the Department to suggest that recharge is not received. Table 3, Comment #2 demonstrates the Department's ongoing concerns on this matter. C) Given the absence of both an adequate understanding of the regional hydrogeological system, and of modelling that incorporates the potential effects or the project's evaporation ponds of the system, the Department reiterates the need for these interactions to be better understood. In the absence of baseline data to form conclusions on the contribution of groundwater to algal mats and mangroves, the worst-case scenario that mangroves and algal mats are dependent on groundwater for survival should be adopted, modelled and appropriate mitigation measures developed (see Comment #7). **Action: Please fully address the DCCEEW comments from Sep 2022 and Dec 2022 for comment 2 – how has the uncertainty been addressed and how does the new models and monitoring methods address these concerns? The Department notes the commitment to include changes to surface flow and retention as input to recharge for groundwater impact modelling. Please address**	Impacts assessed prior to the Approval with relevant conditions in regards to changes to surface water and intertidal regimes. BCHMMP approved by DCCEEW. Updated modelling considers this impact.

Number/type	DCCEEW Comment	BCI Interim Responses
13. Mt Salt Mound Spring	A) Assessment of the potential groundwater dependency or contamination risk for the Mt Salt Mound Spring has not been completed. The Department has previously commented that noting that sampling of the spring was not possible under no-flow conditions, the potential impacts may be inferred by considering a range of aquifer connectivity, salinity and groundwater flow (regional and localised/project-induced) scenarios (table 3 items 4,5,16). B) The Department notes the importance of regional modelling in determining impacts to Mt Salt Mound Spring. See **Table 2 Comments 4, 15 and 16** for details. **Action: Please update the plan with an assessment of the impacts to the Mt Salt Mound Spring once investigations have been completed.**	New section 2.6.12 in Rev K on Mt Salt Mound Spring. To discuss noting no flows at the spring and the use of other acceptable methods for "inference" at this and other locations. See responses above on regional modelling comments.
14. Mardie Pool	A) The proposed monitoring regime for the Mardie Pool bores is unclear. In order to ensure the Pool is adequately protected, the Department recommends a monitoring regime be developed based either on the results of the conceptual modelling or by taking the most conservative approach, where the worst case scenario (that Mardie Pool is dependent on groundwater) is assumed and the potential impacts are modelled and considered in the monitoring and management measures. B) The Department also recommends the proposed modelling of Mardie Pool incorporates the monitoring data collected from the MP series bores. C) Please address the concerns of the Department regarding the proposed recovery of seepage in the vicinity of Mardie Pool. The Department has expressed concern (**Table 2, Comment #15**) that the proposed recovery measures may themselves cause impacts to Mardie Pool. Please demonstrate that the investigations committed to by BCI in (**Table 2, Comment #15**) have been undertaken and how this has been considered in the GMMP.	New Section 2.6.11 on Mardie Pool included including surface/groundwater interaction; monitoring; modelling. Mardie Pool transect has been completed in the Model. Refer to Appendix A.
15. GDEs	A) It is unclear if the groundwater dependent GDEs have been considered or assessed in the development of the GMMP. While *Eucalyptus victrix* is acknowledged as a potential GDE (BCI Mineral 2023b, p. 29), the GMMP does not describe how this species was assessed, how it is proposed to be protected, nor any survey effort to identify other GDEs. B) Potential impact pathways to riparian vegetation remain unclear. These should be considered in light of their potential impacts to MNES. **See also Table 2, Comment 13** **Action: Please indicate how the assertion that there are no other GDEs in the project area outside *E. victrix* was determined and please include potential impact pathways to riparian vegetation and downstream impacts to MNES.**	Section 2.7 of the GMMP updated with respect to Original and Optimised project impacts to GDEs.
16. Ponds 1 and 2 staged approach	**NOT ENOUGH INFORMATION TO ASSESS THIS MATTER** A) The Department does not agree that there is evidence that the proposed approach of filling ponds 1 and 2 to 'stress the system' is the best way to test the conceptual model. Mardie Minerals have not presented adequate data to justify the conclusion that the approach will not have impacts to the algal mats and mangroves adjacent to the pond system. The Department is of the view that filling of ponds 1 and 2 risks causing potential impacts that: I. Cannot be detected as the impact pathways have not been assessed and the baseline conceptualisation is inadequate (see Comments 3,4,5 and 7 for recommendations to assist resolution) II. Cannot be managed (no adequate measures proposed and without a baseline the nature of the impact is unclear) III. Cannot be remediated (as without baseline data, an adequate state for a remediated impact or environment cannot be defined) and IV. Take place in a system that is not well understood – given the inadequate hydrogeological conceptualisation (see Per comment #2 of Table 3 (attachment) regarding that contribution of groundwater to algal mats. **Conclusion:** It is the department's view that there is insufficient information to conclude that the filling of the early ponds is low risk. The Department notes that the comparatively low salinity of the early ponds is not the only factor being considered by the	The Proposed progressive filling approach is detailed in the GMMP. It is not inconsistent with the Action, as it is staged fills with an additional pause between each fill. The purpose of this approach is to provide an observational window of GW levels/Pond condition, following each fill event (circa 300 mm). It will also allow for the implementation of investigation/mitigation should triggers or thresholds be reached. There is no new operational risk as the water levels proposed are consistent with the Action and the EPBC approval. The proposed model validation during this process is to validate/calibrate the predicted impacts. See comments above regarding Modelling and updated material in App A See section 3 of the GMMP for management actions. There are conditions regarding remediation that are available for the Project. See comments above regarding Modelling and updated material in App A

Number/type	DCCEEW Comment	BCI Interim Responses
	Department in this conclusion and that a number of processes are not sufficiently understood or considered for the matter of the risk of ponds 1, 2 (and 3) being filled to be assessed.	
17. Pond 0	**NOT ENOUGH INFORMATION TO ASSESS THIS MATTER** A) The Department remains concerned that the filling of Pond 0 may further impair the capacity to develop an adequate baseline conceptual understanding of the project area. Any impact attributable to pond 0 is currently deemed unable to be detected and as a result any future baseline monitoring would falsely incorporate that impact as baseline data and hence be unable to monitor it. B) Further, as Pond 0 is not referred to anywhere in the text of the GMMP, the nature and the intended management of Pond 0 is unclear. **Action: Please incorporate consideration of the effect the filling of Pond 0 has had on the system in modelling scenarios and include mitigation and management measures for Pond 0 in the revised plan. Please take into consideration that the impact attributable to pond 0 is currently unable to be detected and any future baseline monitoring would falsely incorporate that impact as baseline data and hence be unable to monitor it.**	Pond 0 is within the Development Envelope of the project. Baseline monitoring used for Modelling and for Trigger Threshold development is described in the GMMP, including Figure 5, and includes dates back to 2021. Since the commencement of that monitoring, Pond development has occurred and the proposed trigger and threshold methodology has been adopted to detect both environmental and project groundwater level changes, independent of historical disturbance such as pond construction or Pond 0 filling.

References:

ANZG 2018, *Australian and New Zealand guidelines for fresh and marine water quality. Australian and New Zealand Governments and Australian state and territory governments,* Canberra ACT. Available [online] https://www.waterquality.gov.au/anz-guidelines.

AQ2 2021, *Mardie Project – Proposed Investigation and Monitoring Program – Revised Layout.* Dated 16 November 2021.

Ball J, Weinmann E, Kuczera G 2019. *Book 3 of Australian Rainfall and Runoff Peak Flow Estimation. Australian Rainfall and Runoff A Guide to Flood Estimation.* Available [online]: http://book.arr.org.au.s3-website-ap-southeast-2.amazonaws.com/ Accessed 15 February 2024.

Barnett B, Townley L, Post V, Evans R, Hunt R, Peeters L, Richardson S, Werner A, Knapton A, Boronkay A, Weathergill D, 2012. *Australian Groundwater Modelling Guidelines.* Available [online]: (PDF) Australian Groundwater Modelling Guidelines (researchgate.net) Accessed 19 February 2024.

BCI Minerals 2023b. *Mardie Salt and Potash Project GROUNDWATER MONITORING AND MANAGEMENT PLAN* (Revision J). Dated 12 December 2023.

Underwood AJ 1992. *Beyond BACI: the detection of environmental impact on populations in the real, but variable, world.* Journal of Experimental Marine Biology and Ecology 161(2), 145–178.

Table 21. Outstanding comments from Response to Submissions with comment history

No.	DCCEEW comment on response – September 2022	Proponent response – December 2022	DCCEEW comment on response – December 2022	Proponent Response – February 2023	DCCEEW comment on Response - February 2023	Proponent Response – April 2023	BCI Interim Response March 2024
1	There are numerous highly relevant studies and data acquisitions that have not started or are currently taking place, particularly in relation to Mardie Pool. The data and information that these will provide will be fundamental in updating the groundwater and seepage modelling (Paragraph 8) and to better understand the likely impacts and so what further monitoring and mitigation maybe required. Please provide a schedule of when all these data gathering will be undertaken and how it will be used to update the modelling.	A revised GMMP has been provided in Appendix 1. Ongoing monitoring works and review points are outlined in Table 17, Section 4.2 of the GMMP.	**Partially addressed** Baseline data and conceptualization are still insufficient. See further comments below.	*No response provided*	**Not addressed**	See responses below.	Rev K updated to included status of all investigations and commitments in relation to ongoing studies.
2	The previous conceptual groundwater model stated 'perched' freshwater is no longer valid based on a literature and data review (BCI Minerals 2022a, p. 7). However, this new data and information are not presented. The GGMP is then stated that there is only hypersaline groundwater beneath the ponds that "likely" provides a density-driven barrier. The Department needs further clarification of this assumption. The presence of a 'density barrier' does not preclude shallow fresh water moving along the top of this barrier, especially after rainfall and overland flow, nor the ability for perched fresher water to remain for a period of time. This mechanism would be impacted by hydraulic loading from the crystalliser and evaporation ponds (Paragraphs 5 and 8). As noted in Table 4, "mangroves use non-saline groundwater and rainwater when available rather than saline water sources. Groundwater flows into the intertidal stimulates organic matter accumulation in above-ground biomass suggesting the availability of non-saline water sources, such as groundwater and rainfall, are important for the growth and productivity of mangrove forests". Please add.	A revised GMMP has been provided as Appendix 1. Section 2.2 of the GMMP notes that the Soilwater Group (2019) cross sections originally interpreted groundwater level incorrectly beneath the salt flats. Soilwater Group referred to leakage from gravel lenses during excavation as perched water whereas this may have been from zones below the regional water table. All geotechnical test pits and piezometers released water which was determined to be hypersaline. There appears to be no evidence to show presence of fresh water within this area from the data available (although it may be present deeper). This will be investigated through the installation of the coastal monitoring network with deep/shallow bores and transects (Section 2.5.8 of the GMMP).	**Partially addressed.** There are not sufficient baseline data to inform the conceptualization of the movement of fresh and saline waters under non-disturbed conditions and understand functional processes. The potential impacts of hydraulic loading, seepage and mounding, especially relative to landscape and ecological features have not been evaluated. The Department notes that from Fig. 15 (BCI Minerals 2022, p. 80) that geotechnical test pits are predominantly located on the seaward edge of the development footprint and do not appear representative of the spatial (or temporal) zonation, potential local scale diversity and detailed coastal channels which are necessary to identify natural variation across the project footprint and in specific geographic areas. The spatial and temporal representativeness of this monitoring layout should be considered (especially in the context of natural variation,	Changes in surface flow and retention for different areas will be inputs to recharge for the groundwater impacts modelling. Geotechnical test pits were used to gather geotechnical information to inform the engineering design, and therefore were located for that purpose. The data has been used opportunistically where other groundwater/subsoil information (e.g. from GW monitoring bores) is not available. Section 2.5.7 (page 27), Table 8 (page 29) and Figure 14 (page 77) of GMMP describe the coastal network. Section 3.2.1 - Table 15 (page 54) of GMMP describes the monitoring schedule. Further updates to the	**Partially Addressed** Please provide a revised GMMP for a review when the data becomes available.	Data is not yet available. Table 6 of GMMP has been updated to reflect current timing.	Since comments in September 2022, the Coastal Borehole Monitoring Network has been installed and data collection commenced as described in Rev J (provided to DCCEEW in December 23) and to be further described in Rev K. 6 months of baseline data has been used for guidelines and trigger/threshold criteria, data from 2022 onwards has been used in modelling undertaken in January 2024 and provided as Appendix A. Updates of technical studies status is provided.

No.	DCCEEW comment on response – September 2022	Proponent response – December 2022	DCCEEW comment on response – December 2022	Proponent Response – February 2023	DCCEEW comment on Response - February 2023	Proponent Response – April 2023	BCI Interim Response March 2024
			project infrastructure and operations and model development, including sensitivities and uncertainty for predicting impacts). Along with revisions of the hydrological conceptualization. Changes to surface flows and runoff /recharge are not discussed. The lack of freshwater observed at shallow depth in the intertidal zone should be further evaluated with local rainfall and seasonal water table information and appropriate conceptualization of this zone. There is broad alluvium underlaying the numerous coastal creeks that may be impacted as a result of project hydrological changes. The interruption to channel and sheet flow and potential recharge associated with this freshwater should be further investigated. Further, section 2.5.8 provides detailed proposed installation and monitoring plans with no supporting figure to locate sites, monitoring parameters or frequency. The proposed monitoring network designs are not assessable as a possible 'installation schedule".	GMMP will be made following groundwater impacts modelling.			
3	The Department notes that there is acknowledgement of hydraulic pressure (loading) caused by the evaporation ponds (BCI Minerals 2022a, p. 8) (and assumedly the crystalliser ponds) which has been repeatedly raised by the Department on the original Mardie Project. Please clarify how this loading has been incorporated into the density flow modelling. As outlined in the point above, this understanding is a critical part of any modelling.	A revised GMMP has been provided as Appendix 1. The density dependent groundwater flow modelling (Section 2.8 of the GMMP) is scheduled to be undertaken in Q1 2023. The resulting report will outline incorporation of hydraulic loading of various intensity into the model (due to increasing ponds salinity across the Proposal).	**Partially addressed** The conceptualization provided in Section 2.8 is likely too limited (coarse) for detailed consideration of the likely risks of seepage and mounding in different and complex environments. Consideration of these hydrological change at multiple scales will be necessary to inform possible impacts and determine appropriate mitigation measures. It is noted in Table 14 (BCI Minerals 2022, pp. 50) that disturbance of algal mats (benthic habitat) is to be limited to a	By the February 2023 monitoring round almost one full year of data (WL, EC, Mardie Pool levels) will be available up until the end of the dry season when Mardie Pool is at lowest level. The conceptualisation will be reviewed in Feb 2023 to inform the modelling using all available drilling and testing data. Local and regional variations in	**Partially Addressed** Please provide the data and a revised GMMP for a review when the data becomes available.	Data is not yet available. Table 6 of GMMP has been updated to reflect current timing.	Since comments in September 2022, the Coastal Borehole Monitoring Network has been installed and data collection commenced as described in Rev J (provided to DCCEEW in December 23) and to be further described in Rev K. 6 months of baseline data has been used for guidelines and trigger/threshold

No.	DCCEEW comment on response – September 2022	Proponent response – December 2022	DCCEEW comment on response – December 2022	Proponent Response – February 2023	DCCEEW comment on Response - February 2023	Proponent Response – April 2023	BCI Interim Response March 2024
			maximum of 5 hectares.	groundwater regime will be described. The GMMP will be revised to demonstrate hydrogeological changes at multiple scales when conceptualisation has been revised and the groundwater modelling investigation has provided this information. At this time, there will be sufficient data to compare a full year of SW/GW water levels to understand changes in GW flow over the wet and dry periods. Mardie Pool levels and logger data will be provided. Figure 16-18 (pages 79-80) of GMMP provide TEM survey profiles indicating distribution of salinity. Data pack was provided on 28 November 2022 (email to EPA) and in Appendix 1 to the GMMP.			criteria, data from 2022 onwards has been used in modelling undertaken in January 2024 and provided as Appendix A. Updates of technical studies status is provided.
4	The optimised project may impact on the Fortescue Alluvial Aquifer. It is not possible for the Department to assess what the impacts from the Primary Crystalliser may be especially as the primary cited reference – Commander 1989 – does not appear in the reference list. Similar commentary applies to the Mt Salt Mound Spring. However, the Department does agree that the height of the spring above normal land surface does strongly suggest that the source is a confined rather than a near-surface aquifer. Please provide.	A revised GMMP has been provided as Appendix 1. Commander 1989 was provided in reference list in page 354 of the ERD and reference list of the GMMP. Mt Salt (Section 2.2.5) is referenced in Commander (1989), Hocking et al (1987) and William (1968). All are provided in references in the GMMP.	**Partially addressed** The Department acknowledges the references are provided however the current information about the mound spring remains insufficient for the purpose of determining potential hydrological impacts of the project.	There is very little information available about Mt Salt mound spring. The Spring is not currently flowing. Mardie Minerals agrees to check regularly for spring flow, quarterly with monitoring round. If the spring is not flowing, Mardie Minerals is unable to obtain any direct information about the historical source of	**Partially addressed** The Department acknowledges the commitment to quarterly monitoring of the Mt Salt mound and the installation of the monitoring bores outlined in Table 9 (to be determined) However, please ensure the	Agree. There is very little info available about Mt Salt Mound Spring. When the Spring is not flowing, the proponent cannot sample. Undertake to check regularly, likely quarterly with groundwater monitoring round. If the spring is not flowing, Mardie	Updates provided in relation to Mt Salt Mound Spring. Commitment in S3.5 regarding regional groundwater modelling.

No.	DCCEEW comment on response – September 2022	Proponent response – December 2022	DCCEEW comment on response – December 2022	Proponent Response – February 2023	DCCEEW comment on Response - February 2023	Proponent Response – April 2023	BCI Interim Response March 2024
				the spring water and therefore may be unable to quantify potential impacts. Although it may be possible to model for a number of potential source scenarios.	uncertainty of the impacts highlighted in the GMMP (page 21) is integrated into the Table 8, since the placement and outcome of the monitoring mentions the influence of the Sino Iron Ore Project as the key uncertainty that will need to be addressed, which on page 21 the objective is to ensure that test the density-driven seepage and groundwater flow direction is assessed. Please note that the lack of information on the Mt Salt mound will result in the Department taking a precautionary approach due to the lack of scientific certainty about the impacts from the proposed action.	Minerals is unable to obtain any direct information about the historical source of the spring water and therefore unable to quantify potential impacts, although it may be possible to model for a number of potential source scenarios.	
5	The issues in regard to Mt Salt Mound Spring can be resolved via water chemistry analysis to confirm it is sourced from a deeper confined aquifer. Please provide.	A revised GMMP has been provided as Appendix 1. Please see response to Item 10 of this table and Section 2.2.5 of the GMMP.	**Not addressed** Section 2.2.5 does not appear to exist in the current iteration of the GMMP. DCCEEW is unclear how the response to Item 10 relates to this comment. The proponent has been unable to perform the requested work as the Mount Salt Spring has been dry on recent attempts. The proponent has committed to periodically visiting Mount Salt Springs to	GMMP has been edited to fix section heading formatting issues under Section 2, it should read as: Section 2.2.5 (page 13) Mt Salt Mound Spring. Table 2 (page 4) of GMMP indicates commitment to make quarterly visits to Mt	**Partially Addressed** Please see comments above.	See responses above.	Updates provided in regards to Mt Salt Mound Spring in s2.6.12 noting the spring is not producing water to facilitate sample collection.

No.	DCCEEW comment on response – September 2022	Proponent response – December 2022	DCCEEW comment on response – December 2022	Proponent Response – February 2023	DCCEEW comment on Response - February 2023	Proponent Response – April 2023	BCI Interim Response March 2024
			attempt to carry out this work, which Department appreciates may take an unknown period. Please outline the commitment and timeframes to undertake this work.	Salt to check for artesian flow.			
6	The Department agrees in principle to the groundwater and seepage modelling set out in pages 29- 33 (BCI 2022a). However, the Department is concerned that while it appears that there will be two models developed – density- driven and groundwater flow they may be trying to answer too many questions which could compromise the ability of the models to adequately assess the potential impacts. The Department is of the view that there are 3 main and 2 sub- questions that need to be answered by the modelling, which include the following: What will the hydraulic loading from the ponds do to the groundwater flow direction? How will the expected change in flow direction impact on the surface and groundwater interactions (freshwater recharge processes) with Mardie Pool? How will this expected change in flow direction impact on the algal mats, mangroves, etc? Will this project cause saline groundwater to move towards the Fortescue Alluvial Aquifer? What is the volume and direction of seepage from the ponds and what are the likely impacts? Consequently, some smaller question specific models may be more appropriate to answer these questions. For the first question the change in groundwater flux is also important.	A revised GMMP has been provided as Appendix 1. See Section 2.8 of the GMMP for description of the proposed groundwater modelling which will investigate the potential effects of the Proposal on all of these factors. Modelling is scheduled to take place in Q1 2023.	**Not addressed** Note earlier DCCEEW comments along with comments included in this review. Additionally, the outline provided for the stage 1 (density dependent) modelling does not provide the basis for creating five separate sections and this should be explained to facilitate understanding how the collected baseline data are able to provide representative information for the objectives. The proposed baseline monitoring and modelling needs to be able to achieve the "outcomes" proposed on p. 48 (BCI Minerals 2022). Further details of the discretized model should be considered against conceptualizations and potential parameters in order to evaluate their utility. It is noted that hydrogeological references to date appear to be more representative of a large non-coastal land area with only limited detail about coastal area, processes or variation. Details about how the impacts of hydraulic loading, hypersaline seepage and sea walls will be quantified in the model is not addressed. Please address.	The Proposal is across a very large area, such that no amount of monitoring is going to uncover all possible hydrogeological variations. The number of model sections and their location is flexible and could change throughout the investigation depending on what the data indicates and what is discovered during the modelling process. Conceptual models will be reviewed and revised in the early stages of the modelling based on the latest available data (noting that coastal data will not be available in Q1 2023). Mardie Minerals will document the details of the work as it progresses. The investigation is not prescriptive and will be guided by the ongoing outcomes of modelling and by the input of further field data as it is acquired. The modelling processes undertaken for hydraulic loading and hypersaline seepage will be documented when this work is carried out.	**Not addressed** Modelling is needed to assess the impacts / questions as described in earlier comments. Please ensure the questions asked are addressed in the updated GMMP.	Data is not yet available. Table 6 of GMMP has been updated to reflect current timing.	Modelling has been updated using bores installed in 2023 and data from 2022. This includes an updated conceptual model and impact modelling across three representative transects. Updates on Mardie Pool monitoring, modelling and ongoing studies is included s2.6.11 and AppA.
7	Please clarify if the investigations only include epistemic uncertainty i.e., parameter	A revised GMMP has been provided as Appendix 1. See	**Partially addressed**	**Noted**			Modelling has been updated using bores installed in 2023 and

No.	DCCEEW comment on response – September 2022	Proponent response – December 2022	DCCEEW comment on response – December 2022	Proponent Response – February 2023	DCCEEW comment on Response - February 2023	Proponent Response – April 2023	BCI Interim Response March 2024
	uncertainty. Given the lack of data and information for the project area the proponent should also investigate aleatory uncertainty (e.g., the influence of natural variability on outcomes - e.g., starting water levels or severity of wet/dry sequences). Please provide.	Section 2.8 of this GMMP for a description of the proposed groundwater modelling which will investigate the potential effects of the Proposal. Various climate scenarios including drought and high rainfall wet season will be investigated although it is known that Mardie rainfall is inconsistent. Modelling is scheduled to take place in Q1 2023.	Model representation should be at appropriate scales. The proposed climate change risk assessment (BCI Minerals 2022, p. 15) states they will measure hydraulic gradients in response to the project and sea level rise to assess the effects of the project. Baseline data does not account for changes in coastal topography, physical processes and geographical and ecological zonation that affects ecological and hydrological systems. Also see response to Item 2.				data from 2022. This includes an updated conceptual model and impact modelling across three representative transects. Updates on Mardie Pool monitoring, modelling and ongoing studies is included s2.6.11 and AppA..
8	The proposed monitoring appears to be adequate, though there is a need to get accurate water level measurements for Mardie Pool. However, Departments notes that there may need to be some reconsideration and additional monitoring once the results of the modelling have been provided.	A revised GMMP has been provided in Appendix 1. Modelling results (Section 2.8 of the GMMP) will be used to adaptively alter the monitoring network and promote the necessity for further or additional investigations if required.	**Partially addressed** The data currently available are not sufficient to inform understanding of hydrology associated with Mardie pool. The approach to providing adequate justified conceptualization is ad-hoc and should be refined with additional information and data. Please address.	Review of surface water and groundwater conceptualisation at Mardie Pool to be carried out in Feb 2023. Additional data is constantly being acquired and will be integrated into the GMMP.	**Not addressed.** DCCEEW will review the surface water and groundwater conceptualisation once available and the revised GMMP has been provided.	Noted. Data is not yet available. Table 6 of GMMP has been updated to reflect current timing.	Modelling has been updated using bores installed in 2023 and data from 2022. This includes an updated conceptual model and impact modelling across three representative transects. Updates on Mardie Pool monitoring, modelling and ongoing studies is included s2.6.11 and AppA..
9	The Department remains concerned that the proponent still states that further investigations are still required to understand the relationships and interactions between surface and groundwater for Mardie Pool. This information is critical in order to understand what the impacts to Mardie Pool from the project, if any, will be. Please indicate how this understanding will be achieved (confirm it will be done using the TEM or in combination with other means), what and when it will be integrated into the GGMP and how this be captured in the monitoring and management.	A revised GMMP has been provided as Appendix 1. Section 2.2.3 of the GMMP describes groundwater investigations, surface water investigations and TEM geophysical surveys completed or underway at Mardie Pool. Initial TEM results are presented and interpreted, while more integration with groundwater/surface water data will be carried out during review following pumping tests to update the conceptual model for modelling (Q1 2023). The modelling will be used to refine mitigation strategies for Mardie Pool.	**Partially addressed** The DCCEEW notes the preliminary and forthcoming analyses. The conceptualisation of hydrogeology surrounding Mardie Pool still remains unclear, despite repeated requests, and impacts cannot yet be reliably predicted. Please provide this information, commitments and timeframes to progress the GMMP.	At the February 2023 monitoring round almost one full year of data (WL, EC, Mardie Pool levels) will be available up until the end of the dry season when Mardie Pool is at lowest level. The conceptualisation will be reviewed in Feb 2023 to inform the modelling, when able to compare full year of SW/GW levels and understand changes in GW flow. Mardie Pool levels and logger data will be provided.	**Partially addressed.** DCCEEW notes the commitment to provide further data on Mardie pool conceptualisation of hydrogeolical modelling. DCCEEW will review this once it is available and the revised GMMP has been provided.	Data is not yet available. Table 6 of GMMP has been updated to reflect current timing.	Modelling has been updated using bores installed in 2023 and data from 2022. This includes an updated conceptual model and impact modelling across three representative transects. Updates on Mardie Pool monitoring, modelling and ongoing studies is included s2.6.11 and AppA..

No.	DCCEEW comment on response – September 2022	Proponent response – December 2022	DCCEEW comment on response – December 2022	Proponent Response – February 2023	DCCEEW comment on Response - February 2023	Proponent Response – April 2023	BCI Interim Response March 2024
10	The Department notes that it can be interpreted from the proponent's response that they are implying that Mardie Pool is surface rather than groundwater fed (or a mixture of both). However, the Department does not agree with this implication. The increased salinity that was recorded could be due to evapo-concentration of the pool water near the surface with fresher water (groundwater supplied) present deeper in the pool. Given the size of Mardie Pool it is unlikely that there would be much inter- zone mixing or the potential for overturning i.e., the density contrast due to salinity causing the water column to flip. Please clarify.	A revised GMMP has been provided as Appendix 1. Ongoing collection of Mardie Pool salinity and level data, along with bore data, will lead to review of the conceptual model for surface water / groundwater interaction at Mardie Pool (Section 2.2.3 of the GMMP). Water level in Mardie Pool is falling rapidly and may lead to development of a gaining pool. This will be investigated through until heavy rainfall events cause stream flow.	**Partially addressed** DCCEEW would like to review future data and analyses when these become available.	Mardie Minerals can provide a copy of data in March 2023 for the full cycle of seasons (wet/dry/wet).	**Partially addressed** DCCEEW notes the commitment to provide further data on Mardie pool. DCCEEW will review this once it is available and the revised GMMP has been provided.	Data is not yet available. Table 6 of GMMP has been updated to reflect current timing.	Modelling has been updated using bores installed in 2023 and data from 2022. This includes an updated conceptual model and impact modelling across three representative transects. Updates on Mardie Pool monitoring, modelling and ongoing studies is included.
11	The Department is highly supportive of the use of Transient ElectroMagnetics (TEM). The Department considers this dataset critical, if located 'correctly', to understanding what the potential impacts to Mardie Pool will be. Please address the following: However, the locations of the TEM have not been clearly identified. Further, it is not clear from the document and the response how the TEM will provide the necessary information n to understan d the interaction s referred to in the preceding paragraph (the outputs are like cross-sections rather than in 3D). The Department also believes that these data can be obtained in 'real time' thought this doesn't seem to be acknowledged by the proponent nor any indication given as to when it will be available for use in the updated modelling.	A revised GMMP has been provided as Appendix 1. Details of the TEM survey are provided in Section 2.2.3 of the GMMP, including maps describing location and conductivity sections. The conductivity distributions indicated from the TEM data are being used to update the conceptual model for groundwater / surface water interaction at Mardie Pool and to provide input to the density-dependent groundwater modelling.	**Partly addressed** Please discuss the potential for real-time TEM monitoring.	It is the view of AQ2/Mardie Minerals that real time geophysical monitoring will be expensive and only provide single point data of limited value. Changes to the groundwater regime are better investigated by acquisition of levels/EC profiles etc, which is already implemented.	**Partly Addressed** DCCEEW notes that further modelling will be provided to update the conceptual model of the groundwater and surface water interaction with the Mardie Pool and the potential impacts from density dependent groundwater changes. Please provide the conceptual model and further groundwater modelling when available. Based on this new information the GMMP will need to be revised to provide appropriate mitigation, monitoring (if TEM is not used then assess the suitability of Audio-frequency Magnetotellurics (AMT)), and contingency measures that will	The GMMP has been revised with the conceptual model outcomes. Table 6 of GMMP has been updated to reflect current timing for the remaining drilling and modelling.	Modelling has been updated using bores installed in 2023 and data from 2022. This includes an updated conceptual model and impact modelling across three representative transects. Updates on Mardie Pool monitoring, modelling and ongoing studies is included s2.6.11 and AppA.. The Mardie Pool Transient Electromagnetic (TEM) Survey has been completed to support the OMP assessment process.

Australian Government
Department of Climate Change, Energy, the Environment and Water

No.	DCCEEW comment on response – September 2022	Proponent response – December 2022	DCCEEW comment on response – December 2022	Proponent Response – February 2023	DCCEEW comment on Response - February 2023	Proponent Response – April 2023	BCI Interim Response March 2024
					need to be implemented.		
12	• Please provide details on the locations, lithology, groundwater salinity and the results of the pump tests to allow the Department to assess the adequacy of these investigations. • Please clarify if the pump tests were conducted when there is surface water flow to allow for and understanding of whether drawdown in the river is occurring. This data will be required to update the modelling to provide confidence of any predicted impacts and how these impacts will be appropriately managed.	A revised GMMP has been provided as Appendix 1. Aquifer tests are being completed in Q4 2022 (Section 2.5.6 of the GMMP). Details of testing locations have been supplied in a separate data package as an appendix to the GMMP.	**Partially addressed** Please provide when data is available.	Aquifer tests on test bores across the Proposal area have now been completed (late December). This data is being analysed and results can be provided in March 2023.	**Noted**		Modelling has been updated using bores installed in 2023 and data from 2022. This includes an updated conceptual model and impact modelling across three representative transects. Updates on Mardie Pool monitoring, modelling and ongoing studies is included s2.6.11 and AppA..
13	The Department agrees that it is unlikely, though not impossible, that the riparian vegetation would be impacted. However, this should be reviewed once all the proposed studies and updated modelling is done to confirm this claim. Please provide timeframes on when this data will be gather and integrated into the GMMP.	A revised GMMP has been provided as Appendix 1. Section 4.4, Table 17 of the GMMP states timeframes for collection of data which will be integrated into the GMMP following modelling (after Q1 2023). Potential impacts to riparian vegetation will be assessed through this regional groundwater impacts modelling (Section 2.8) and mitigation measures will be provided in the revised GMMP if determined to be required.	**Partially addressed** Section 4.4 does not appear in the current document (BCI Minerals Ltd 2022 Mardie Salt and Potash Project – Groundwater Monitoring and Management Plan – Optimised Mardie Project). It is assumed that the riparian vegetation mentioned is that associated with Mardie Pool. Please clarify the potential pathways for impact described and conceptualized for the project.	Incorrect Section number indicated. Refer to Section 4.3 - Table 17 (pages 57-58) of GMMP for timing of integration of the ongoing studies and data collection. Riparian vegetation includes that associated with Mardie Pool, Mardie Creek and other sites identified within the Proposal area (Phoenix 2020), as well as areas in the Fortescue Valley identified in Loomes (2010). Potential pathways for impact will be outlined during conceptual model review undertaken in the first stages of the groundwater impacts modelling.	**Partially addressed** DCCEEW notes pathways for impact will be incorporated into the GMMP and will review once the groundwater impacts modelling is complete.	Noted. Table 6 of GMMP has been updated to reflect current timing.	Modelling has been updated using bores installed in 2023 and data from 2022. This includes an updated conceptual model and impact modelling across three representative transects. Updates on Mardie Pool monitoring, modelling and ongoing studies is included s2.6.11 and AppA..
14	The Referral Documentation and Advisian 2021 modelling demonstrate changes to the extent of surface water flooding, overland flows, and intertidal flow regimes, all of which will have impacts to downstream Benthic Communities and	*No response provided.*	**Not addressed** Note earlier responses about conceptualization and representation of spatial and temporal variability. It is noted that Figure 11 (BCI Minerals	Impact on outflows of creeks is discussed in Advisian surface water studies (Advisian, 2021). Potential changes to	**Not addressed**	Data is not yet available. Table 6 of GMMP has been updated to reflect current timing.	The BCHMMP has been developed and subsequently approved and describes the connection with the GMMP.

No.	DCCEEW comment on response – September 2022	Proponent response – December 2022	DCCEEW comment on response – December 2022	Proponent Response – February 2023	DCCEEW comment on Response - February 2023	Proponent Response – April 2023	BCI Interim Response March 2024
	Habitats. Therefore, please confirm there will be a revision to the Benthic Community Habitat Monitoring and Management Plan (BCI-MAR-EMP-01) that will be developed and amended based on the new modelling and impacts from the proposed action. Section 8.5 and Table 38 demonstrates that intertidal BCH will likely be impacted to changes due to hydrology.		2022, p. 75) shows significant drainages south of the Fortescue River catchment. The impact on outflows from these river systems (and potential for recharge and stratification) i.e. surface water / ground water interactions has not been addressed.	groundwater recharge resulting from ponds (concentration and redirection of surface flow, retention time) will be incorporated into the regional impacts groundwater modelling.			
15	In regard to potential impacts to Mardie Pool, the Department notes that the only effective mitigation will be groundwater pumping and the issues with this have been proposed by the Department previously as a measure. In summary, depending on where the pumping is conducted and the volume to be extracted, this mitigation may directly impact Mardie Pool. Please consider this as mitigation measure and how this will be integrated into the GMMP.	A revised GMMP has been provided as Appendix 1. Proposed mitigation measures are described in Section 4.1 of the GMMP. The preferred locations for recovery bores will be determined following impacts modelling for leakage and mounding scenarios (Section 2.8 of the GMMP) in Q1/Q2 2023. Potential impacts of the recovery bores will be assessed, and the contingency recovery design will be adjusted to minimise possible impacts to receptors.	**Not addressed** Mitigation or prevention of an impact should not potentially contribute to further impact. Appropriate conceptualization and problem solving need to be applied and a range of solutions or scenarios evaluated to determine appropriate actions that do not contribute further impacts. Any mitigation activities should not impact on Mardie Pool. Please address.	Noted and previously stated. Scenario modelling will be completed to determine recovery design to avoid impacts at Mardie Pool. Depending on location of potential recovery bores, extra monitoring bores will be appropriately placed to permit detection and avoidance of impacts. Revision and detail of the monitoring/mitigation design will be documented in future versions of the GMMP following groundwater impacts modelling.	**Not addressed** Please see the comments above in regards to the Mardie Pool.	See responses above.	Modelling has been updated using bores installed in 2023 and data from 2022. This includes an updated conceptual model and impact modelling across three representative transects. Updates on Mardie Pool monitoring, modelling and ongoing studies is included s2.6.11 and AppA..
16	• The Department notes that the Original Mardie project did not include the Mt Salt Mound Spring. • Please clarify how the Fortescue River supplies deep artesian water to this Mt Salt Mound Spring . The proponent should take samples from the spring and all viable sources and conducted a full chemical analysis to determine what is the likely source of the spring. Please provide. • While the source of the spring remains an unknown the changes in groundwater flow due to the hydraulic loading from the crystallizer ponds may impact on this spring. The Department lacks certainty in the source of	A revised GMMP has been provided as Appendix 1. Mt Salt is described in Section 2.2.5 of the GMMP – References found for Mt Salt implied that the source of the spring was either Fortescue River deep sediments via artesian route or Birdrong artesian aquifer. Mardie Minerals visited Mt Salt in September 2022 and found no spring present, and anecdotally the spring has not flowed for many years. Therefore, no source analysis can be carried out. Regional groundwater modelling (Section 2.8 of the GMMP) will be used to show potential impacts (or not) to Mt	**Not addressed** The regional groundwater model may determine the potential for impact through groundwater drawdown. The combined information of seepage and inflow or mounding on the water table and the potential for hypersaline water transference to the aquifer associated with Mt Salt are two separate issues that need to be addressed at scales suitable to adequately inform this evaluation of risk. Further evidence needs to be provided to the Department to support claims that no impacts to Mt Salt will occur. Please consider providing the proposed model as	Potential for contamination at Mt Salt will be assessed through groundwater seepage and impacts modelling (during Q1/Q2 2023). The resulting groundwater model can be supplied once generated/updated. Mt Salt will be visited quarterly to search for artesian discharge (which is not currently present) for sampling to assist with source analysis.	**Not addressed** Please see the comments above in regards to the Mt Salt mound.	See responses above.	Modelling has been updated using bores installed in 2023 and data from 2022. This includes an updated conceptual model and impact modelling across three representative transects. Updates on Mardie Pool monitoring, modelling and ongoing studies is included s2.6.11 and AppA..

No.	DCCEEW comment on response – September 2022	Proponent response – December 2022	DCCEEW comment on response – December 2022	Proponent Response – February 2023	DCCEEW comment on Response - February 2023	Proponent Response – April 2023	BCI Interim Response March 2024
	the spring and will require sampling from the spring and all viable sources and chemical analysis to determine the likely source to allow assessment of impacts and changes in groundwater flow due to the hydraulic loading from the crystallizer ponds. Please provide.	Salt and if necessary, devise mitigation strategies.	evidence. Please address.				
17	• Please provide a discussion of the cumulative impacts of the two projects and how these impacts compared to the predicted impacts of the project to date. Include a detailed discussion about management actions to mitigate impacts on inland waters which provide confidence that impacts can be managed to meet the EPA's objectives for this factor in the absence of long-term monitoring data and detailed modelling of cumulative impacts.	A revised GMMP has been provided as Appendix 1. Cumulative impacts of Mardie Project and Sino Iron Project will be assessed through regional impacts modelling (Section 2.8 of the GMMP) scheduled for Q1 2023. Strategies for management and mitigation of impacts on inland waters will be developed using scenario modelling, while groundwater monitoring (levels/quality) has been underway since April 2022 (Section 3.2). Monitoring data and aquifer testing (Q4 2022- Section 2.5.6) will inform the modelling. This modelling will be used to determine if any mitigation is required to prevent impacts.	**Not addressed** The proponent's response does not address the concerns raised about potential cumulative impacts of the project on regional groundwater. Adequate conceptualization and knowledge of the pre-disturbed environment, processes and potential project impacts is required to hypothesize cumulative impacts at a scale commensurate with this development. Again, it is noted that hinterland creeks, channel and sheet flow and surface- groundwater interactions are not well described in the current information. Please address.	Cumulative impacts of Mardie Project and Sino Iron Project will be assessed through regional impacts modelling (Section 2.8 (page 45) of GMMP) scheduled for Q1/Q2 2023. Strategies for management and mitigation of impacts on inland waters will be developed using scenario modelling, while groundwater monitoring (levels/quality) has been underway since April 2022 (Section 3.2 (page 54) of GMMP) for the inland area. Monitoring data and aquifer testing (Q4 2022 - Section 2.5.6 (page 27) of GMMP) will inform the modelling. This modelling will be used to determine what mitigation is required to prevent potential impacts for a range of possible scenarios.	**Not addressed** Please see the comments above in regards to the Mt Salt mound.	See responses above.	Modelling has been updated using bores installed in 2023 and data from 2022. This includes an updated conceptual model and impact modelling across three representative transects. Updates on Mardie Pool monitoring, modelling and ongoing studies is included s2.6.11 and AppA..
18	The Department agrees the Flood Management Plan should be developed once the detailed design is completed. However, given its importance, this should be done and presented as soon as possible. Please confirm.	Noted. Mardie Minerals will provide a copy of the Flood Management Plan as soon as practicable, once the detailed design has been completed.	**Not addressed** See response at Comment 25. " Note earlier responses about conceptualization and representation of spatial and temporal variability. It is noted that Figure 11 (BCI Minerals 2022, p. 75) shows significant drainages south of the Fortescue River catchment. The impact on	*Not addressed*	**Not addressed**	Data is not yet available. Table 6 of GMMP has been updated to reflect current timing.	No Flood Management Plan requirement under the EPBC 2018/8236 conditions. This may be an OMP assessment review comment.

No.	DCCEEW comment on response – September 2022	Proponent response – December 2022	DCCEEW comment on response – December 2022	Proponent Response – February 2023	DCCEEW comment on Response - February 2023	Proponent Response – April 2023	BCI Interim Response March 2024
			outflows from these river systems (and potential for recharge and stratification) i.e. surface water / ground water interactions has not been addressed.”				
19	Monitoring measures for Benthic Communities and Habitats (BCH) are done through satellite acquired data which is download each quarter (BCI Minerals 2022, pp. 30 - 32). The Department will also require regular in-field monitoring for a period of time be conducted as a means of calibration. The proponent should also consider changing the frequency of the data being downloaded change to be monthly, certainly in the short- term, so that the proponent is able to identify changes to BCH earlier and conduct management strategies as soon as change has been detected.	As discussed in Item 5, multispectral imagery will be used for a Pilot study to run concurrent with on-ground monitoring for five years. Multispectral monitoring will only be implemented if the Pilot study described in Section 2.2 of the BCHMMP determines that there is a clear correlation with field data collected over a period of five years.	**Partly Addressed** Please discuss the proposed monitoring frequency of satellite-acquired data.		**Partially addressed** DCCEEW notes that the revised BCHMMP includes reactive field-based monitoring will be triggered by various events. However, given the uncertainty identified in the GMMP in section 2.5.3 and Table 8 of the unknown sensitivity to changes in groundwater to these BCH, then regular monitoring will need to be undertaken that is informed by the further information gathered as part of the GMMP in Table 8, Item 3 and triggers for monitoring network applied in the BCHMMP. Please address.	Refer to Table 6 of GMMP.	The BCHMMP has been approved and describes the monitoring and management activities of relevance.

References:

ANZG 2018, *Australian and New Zealand guidelines for fresh and marine water quality. Australian and New Zealand Governments and Australian state and territory governments,* Canberra ACT. Available [online] https://www.waterquality.gov.au/anz-guidelines.

AQ2 2021, *Mardie Project – Proposed Investigation and Monitoring Program – Revised Layout.* Dated 16 November 2021.

Ball J, Weinmann E, Kuczera G 2019. *Book 3 of Australian Rainfall and Runoff Peak Flow Estimation. Australian Rainfall and Runoff A Guide to Flood Estimation.* Available [online]: http://book.arr.org.au.s3-website-ap-southeast-2.amazonaws.com/ Accessed 15 February 2024.

Barnett B, Townley L, Post V, Evans R, Hunt R, Peeters L, Richardson S, Werner A, Knapton A, Boronkay A, Weathergill D, 2012. *Australian Groundwater Modelling Guidelines.* Available [online]: (PDF) Australian Groundwater Modelling Guidelines (researchgate.net) Accessed 19 February 2024.

BCI Minerals 2023b. *Mardie Salt and Potash Project GROUNDWATER MONITORING AND MANAGEMENT PLAN* (Revision J). Dated 12 December 2023.

Underwood AJ 1992. *Beyond BACI: the detection of environmental impact on populations in the real, but variable, world.* Journal of Experimental Marine Biology and Ecology 161(2), 145–178.