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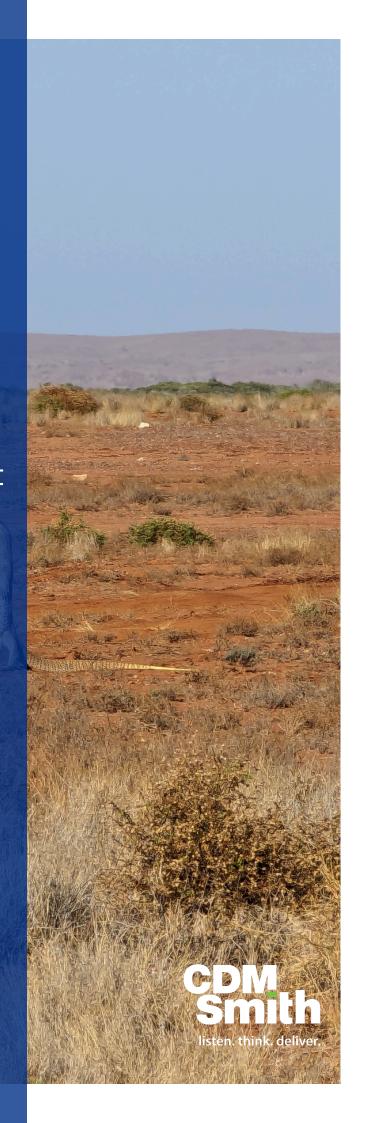
# Report

Eramurra Solar Salt Project

- Site Setting and
Groundwater Baseline
Update - ESSP-EN-14TRPT-0052

PREPARED FOR:

Geosyntec Consultants Pty Ltd





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# **Document history & status**

Revision	Date issued	Reviewed by	Approved by	Date approved	Revision type
А	14 Oct 2024	J. Pretzsch-Kalsgaard	A. Tyson	14 Oct 2024	Internal draft
В	14 Oct 2024	A. Tyson	J. Pretzsch-Kalsgaard	15 Oct 2024	Internal draft
С	26 Oct 2024	J. Fawcett	J. Pretzsch-Kalsgaard	31 Oct 2024	Internal draft
D	15 Nov 2024	J. Fawcett	J. Pretzsch-Kalsgaard	15 Nov 2024	Final draft

# **Distribution of copies**

Version	Date issued	Quantity	Electronic	Issued to
0	15 Oct 2024	1	PDF	Geosyntec
1	1 Nov 2024	1	PDF	Geosyntec
2	15 Nov 2024	1	PDF	Geosyntec
3	21 Mar 2025	1	PDF	Geosyntec

Last Saved:	21 March 2025
File Name:	Geosyntec-1001852-RPT-001-3
Author:	Jakob Pretzsch-Kalsgaard, Frankie Dean, Sarah McDonald, Zlatko Eterovic
Project Manager:	Jakob Pretzsch-Kalsgaard
Client:	Geosyntec Consultants Pty Ltd
Document Title:	Eramurra Solar Salt Project – Site Setting and Groundwater Baseline Update – ESSP-EN-14- TRPT-0052
Document Version:	Final
Project Number:	1001852



### **Section 1 Introduction**

### 1.1 Background

Leichhardt Salt Pty Ltd (Leichhardt) is currently seeking environmental approval for the Eramurra Solar Salt Project (the Project), located approximately 55 km west-southwest of Karratha on the Pilbara coast of Western Australia (Figure 1-1). The Project proposes utilising seawater and natural solar evaporation processes to produce a concentrated salt product.

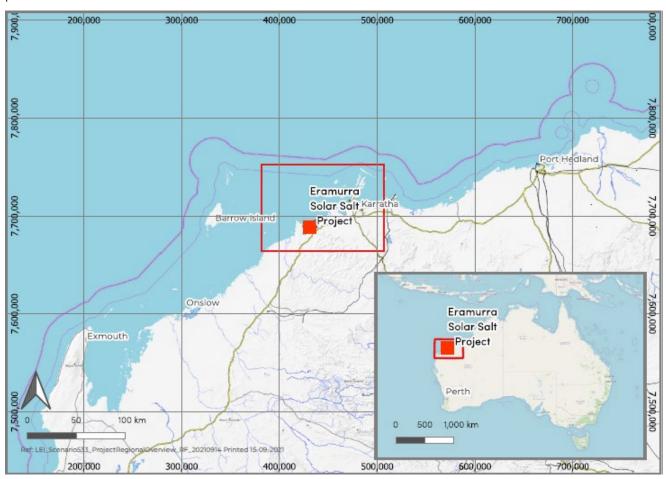


Figure 1-1 Project location overview (Source: Leichhardt)

Salt production will occur from a series of evaporation ponds where water will flow through successive ponds over the Project area and evapo-concentrate. A production rate of up to 6.8 million tonnes per annum (Mtpa) is being targeted which will include approximately 100 km² (10,000 Ha) of concentration pond area, 20 km² (2,000 Ha) of crystalliser area, processing area, seawater intake and disposal lines and other associated infrastructure (Figure 1-2).

The perimeter embankment around the concentration ponds and the pad for the crystalliser area will likely alter the site hydrology and surface water flows towards the Indian Ocean as well as groundwater flow paths and tidal flooding of the Project land parcels. These activities have the potential to impact environmental values (EVs) residing within the Project area such as algal mat communities known to occur in the onshore environment.

Leichhardt is currently preparing an Environment Review Document (ERD) to support the Project's environmental approvals. To inform the development of this document, Geosyntec Consultants Pty Ltd (Geosyntec) is assisting Leichhardt in undertaking environmental studies for the Project and has engaged CDM Smith Australia Pty Ltd (CDM Smith) to provide hydrogeological support and assist in understanding the potential impacts of seepage and mounding associated with the proposed project infrastructure.



#### 1.2 Previous studies

To date CDM Smith has completed the following hydrogeological studies for the Project:

- A review of the available baseline data for the Project to assess the likelihood of seepage and mounding to
  occur as a result of salt farming and the data gaps to be addressed to complete seepage modelling (CDM
  Smith, 2022; Appendix A).
  - This review found the main uncertainty of the site is conceptual and that preliminary modelling could proceed using a broad set of assumptions to assist in understanding the potential effects as well as guiding the collection of future baseline data to reduce the uncertainty in further modelling.
- A technical memorandum to investigate the potential for groundwater interaction with Noorea Soak (CDM Smith, 2023a; Appendix B).
  - This study found Noorea Soak is likely a surface water supported feature and is unlikely to receive groundwater inflows.
- A groundwater effects assessment and groundwater flow modelling report to assist in understanding the direct effects to groundwater EVs as a result of the Project development (CDM Smith, 2023b; Appendix C).
  - This study found the Project development is likely to result in saline seepage induced mounding that from a groundwater perspective mainly impacts upon terrestrial vegetation and stock water wells within a 1 to 3 km buffer zone surrounding the ponds.
- A groundwater drilling program to collect additional baseline data of Project EVs and reduce conceptual
  uncertainty in the hydrogeological conceptualisation (CDM Smith, 2024; Appendix D).
  - This study assisted in gathering additional water level data, assessing stratigraphic thicknesses and understanding the hydrogeological function of the Project's groundwater EVs.

Since submission of the previous groundwater effects assessment for the Project (CDM Smith, 2023b), additional groundwater and surface water monitoring events have been completed at the site in November 2023, February and June 2024 by Land and Water Consulting (WA) Pty Ltd (LWC). The most recent report available for these monitoring events represents the November 2023 and February 2024 period (LWC, 2024).

# 1.3 Objective and scope

The objective of this report is to update the site setting and conceptualisation presented in the previous groundwater effects assessment report (CDM Smith, 2023b; Appendix C) with additional information and data obtained from field programs completed since this submission (i.e. CDM Smith, 2024 and LWC, 2024). Using this information and data, the report aims to update the hydrogeological conceptualisation with particular note to:

- Provide additional detail on the sabkha-like groundwater flow conditions at the site, with the nature and extent of saline groundwater interfaces identified on the conceptual diagram schematic.
- Provide additional justification on the current conceptualisation of Noorea Soak and Devils Pool, i.e. that these EVs are thought to lack connectivity to groundwater.
- Provide additional detail regarding the distribution and thicknesses of geological units shown in the previous hydrogeological conceptual cross sections.



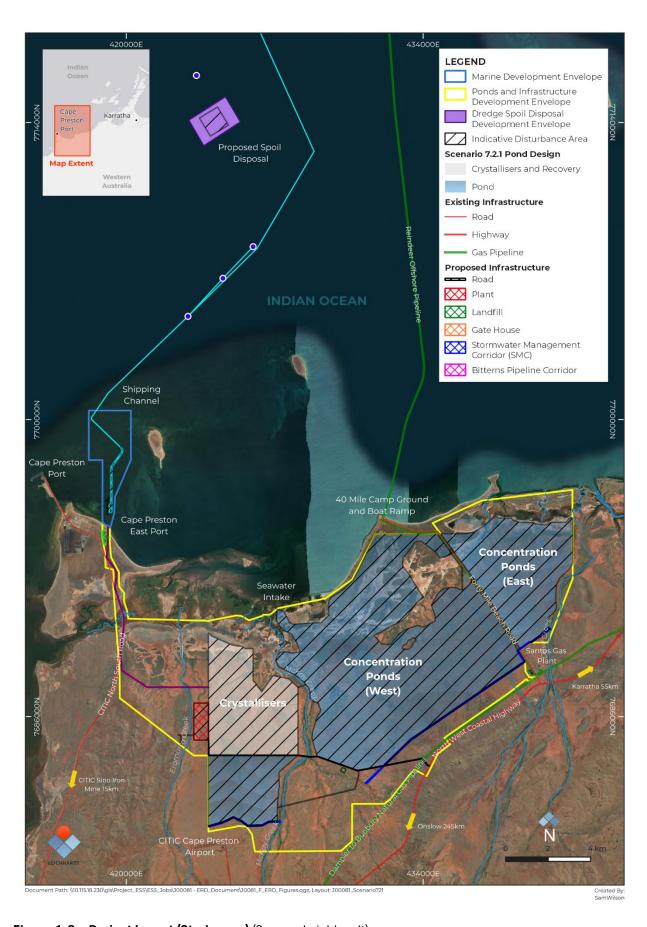


Figure 1-2 Project layout (Study area) (Source: Leichhardt)

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# **Section 2 Context setting**

#### 2.1 Climate

#### 2.1.1 Overview

The nearest Bureau of Meteorology (BoM) climate station that has continuous records of both temperature and rainfall data is the Karratha Aero weather station (No. 004083), which is located approximately 40 km northeast of the Project (BOM, 2022a). Data from the Dampier Salt weather station have been used to represent temperature and rainfall patterns for the Project area, while Scientific Information for Landowners (SILO) data have been used to derive evaporation rates.

#### 2.1.2 Temperature

The Project area experiences a broad temperature regime, where the mean annual daily minimum and maximum temperatures are around 21 and 32.5°C, respectively. The mean maximum monthly temperatures range between around 26.5°C in winter to 36.2°C during summer (Figure 2-1).

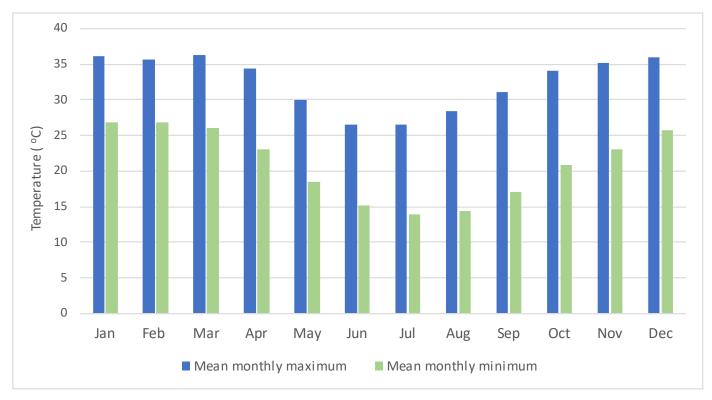


Figure 2-1 Mean monthly minimum and maximum temperatures

#### 2.1.3 Rainfall and evaporation

Mean rainfall data for the Project is around 290 mm/y with most rainfall occurring between January and June. Annual pan evaporation rates for the Project average around 3,200 mm/y (SILO station number 004083), far exceeding precipitation for every month of the year. Mean monthly rainfall and evaporation data are shown in Figure 2-2.



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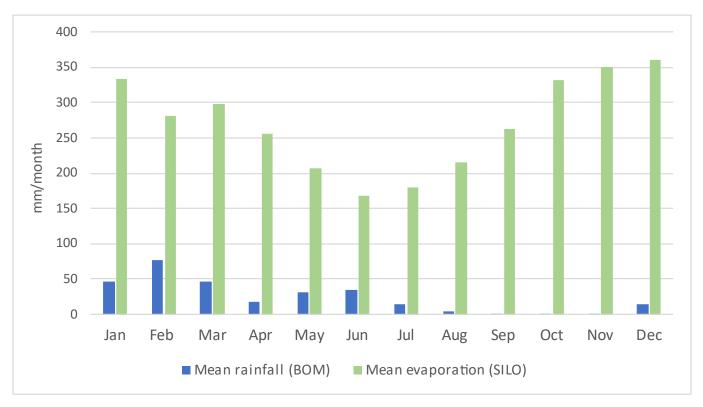


Figure 2-2 Mean monthly rainfall versus mean monthly evaporation

## 2.2 Topography and hydrology

#### 2.2.1 Topography and landforms

The topography of the Project area and catchments are presented in Figure 2-3. A description of the topography and landforms observed within the Project area is presented by LWC (2022a) and is summarised below:

- The site fringes a low-lying coast. The central and eastern parts of the Project area comprise a line of coastal beach ridges, dunes and cheniers forming a coastal barrier rising locally to over 12 m along the crest of the main dune.
- A backwater of inter and supra tidal flats has formed behind the coastal barrier. Several small (high tide) islands are present in the backwater providing evidence of former coastlines which are now partially buried beneath the backwater lagoonal sediments.
  - Sabkha-like environments (i.e. salt flats or saline mudflats) are common in low lying areas adjacent to the coast, formed through the interaction of surface and groundwater with evaporites. These environments are characterised by high salinity, shallow water tables and periodic flooding.
  - The site 1 m LIDAR digital elevation model (DEM) indicates the backwater and inter / supra tidal flats form a topographic low point at the site ranging between 0 and 5 m AHD.
- Inland of the inter and supra tidal flats is an area of alluvial outwash, falling at a gradient of about 1 m in 300 m from the southeast towards the northwest.



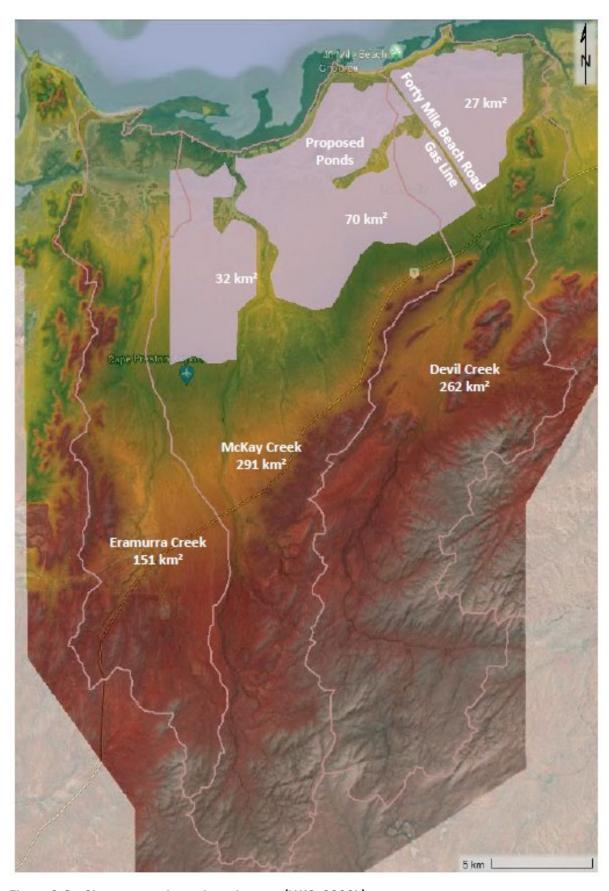


Figure 2-3 Site topography and catchments (LWC, 2022b)



#### 2.2.2 Hydrology

The Project area resides within three sub-catchment areas belonging to Eramurra Creek, McKay Creek and Devil Creek forming a combined catchment area of around 704 km² (LWC, 2022c). Due to the high evaporation rates and low rainfall within the region, no natural permanent water bodies are known to exist within the Project area, however, the Project hosts a number of ephemeral water courses and soaks/pools that have been documented to dry out on occasion (CDM Smith, 2023b; LWC, 2024) (refer Section 2.5 for further description on the latter). These water courses drain the greater catchment northwards towards the coast via three main ephemeral creeks following areas of lower topographic relief:

- Eramurra creek
  - Located on the western side of the Project area, adjacent to the proposed crystalliser ponds.
- McKay creek
  - Located within the central Project area between the proposed crystalliser and concentration ponds.
- Devil Creek
  - The largest creek within the Project area and present along the eastern edge of the site, which together with Eramurra Creek, drains a larger inland area to the Project's east.

Surface water monitoring has been ongoing since 2021 on a biannual basis with the latest monitoring data collected in November 2023 and reported by LWC (2024). The current monitoring schedule for surface water spans 15 sites within the main creeks and smaller drainage lines across the site and range from locations inland of the proposed evaporation ponds to areas closer to the coast that experience tidal fluctuations (Figure 2-4 - left). A map of the current surface water sampling locations is shown in Figure 2-5.

Surface water monitoring events completed historically indicate creeks are generally dry. This finding is consistent with the most recent monitoring event where surface water samples were collected from only three locations within creek outlets along the coast (SW01, SW02 and SW06) with the remaining creek sampling points having no water present. Photos showing a coastal creek sampling point, and an inland (dry) sampling point are presented in Figure 2-4. Absence of regular water within the site's drainage lines is also observed from logger data downloaded from the Project's surface water gauging stations (Figure 2-6) which indicate fluctuations of water associated with monitoring points along the coast and dry creeks further inland.





Figure 2-4 Surface water sampling locations SW02 (coastal sampling point – left) and SW04 (inland sampling point – right) (LWC, 2024)





Figure 2-5 Surface water and groundwater monitoring locations (LWC, 2024)



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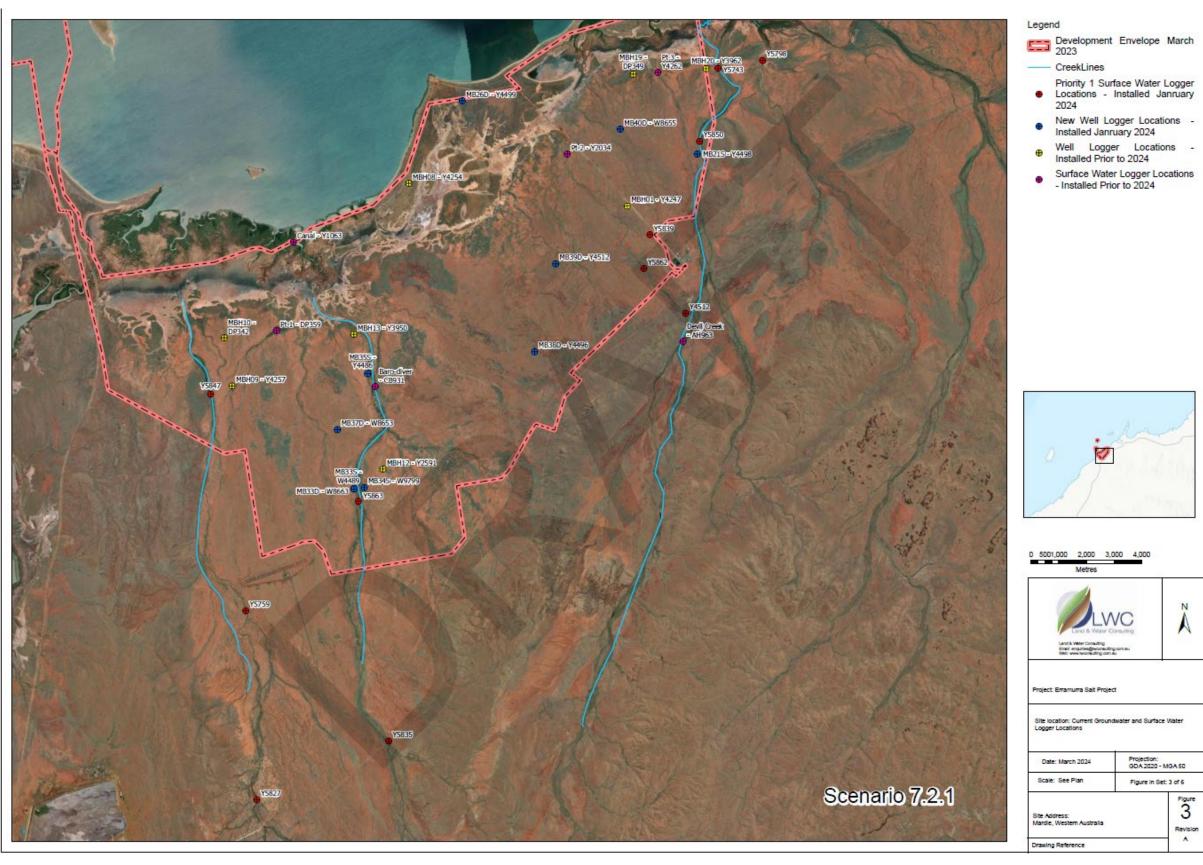


Figure 2-6 Surface water and groundwater data logger locations (LWC, 2024)

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### 2.3 Geology

The Project area is located within the Pilbara Craton geological province which comprises Archean aged volcanic and sedimentary rocks of more than 3,600 Ma. The Pilbara Craton has been subject to a long history of tectonics and orogeny with various igneous intrusions occurring and deposition of shelf sediments such as the Hamersley Basin containing extensive banded iron-formation (BIF) deposits.

Local to the Project area, the Pilbara Craton is overlain by a number of Cainozoic sedimentary units comprising marine muds and silts, coastal sands and beach deposits, limestone, alluvial/colluvial sands and clays as well as residual calcretes and eluvial sands from weathered granitoid rocks (Hickman and Strong, 2000). These sediments are underlain by granitic basement belonging to the Dampier Granitoid Complex which has been intruded by a series of cross cutting dolerite and gabbro dykes. Geological investigations by CMW (2020) and CDM Smith (2024) indicate surface expressions of the basement exist within the central and eastern portions of the Project area often within eroded creek beds. However, in general, the depth to basement distribution is currently not well understood.

The stratigraphy most relevant to the Project area is presented in Table 2-1, while the surface geology is shown in Figure 2-7.

Table 2-1 Summary the Project area stratigraphy (Hickman and Strong, 2000)

Age	Age Unit		Description	Thickness
			Qhm – Marine mud and silt on supratidal to intertidal flats; includes intertidal deposits with mangroves.	
	ıary	Quatamam	Qhms – Coastal sand in beach deposits and dunes; marine sand reworked by wind; includes reworked alluvium near deltas; shelly sand.	~1 - 25 m
Cainozoic	Quaternary	Quaternary Sediments	Qpmb – Coastal limestone; lime-cemented shelly sand, dune sand and beach conglomerate.	~1 - 23 111
Cai			Qs – Eolian sand, red/yellow, wind-blown sand; local sand ridges	
			Qaa/Qab/Qrg – Undifferentiated alluvium/colluvium/eluvium; clay, silt, sand and gravel associated with river, creeds and floodplain deposits.	
	,	Tertiary Sediments	Czaa/Czcb – Consolidated alluvial sand and silt; Colluvium, dissected by recent drainage, with gilgai surfaces in areas of expansive clay.	~5 – 25 m
Proterozoic	Tertiary	Undifferentiated Volcanics	d/o – Dolerite and gabbro dykes.	>5,000 m <sup>[1]</sup>
	Fortescue Group		AF - Basaltic and andesitic lavas, siliciclastic sedimentary rocks, chert, minor pyroclastic rocks and carbonates. Dolerite dyke or sill.	5,000 - 6,500 <sup>[1]</sup>
Archean	Meso-Archean	Pilbara Supergroup	Ao - Includes multiply deformed and metamorphosed greenstones dominated by basalt, chert, banded iron-formation, ultramafic rocks, with locally abundant felsic and sedimentary rock.	15,000 - 35,000 m <sup>[1]</sup>
٩	Meso-	Dampier Granitoid Complex	Ag - Monzogranite, granodiorite, undivided granites, granitic gneiss, migmatite.	>5,000 m <sup>[1]</sup>
	Archean Archean duora Gronb		AR - Massive and pillow basalt with local basal peridotitic komatiite; minor chert, BIF, and shale. Includes strongly foliated amphibolite-chlorite schist.  Metamorphosed to amphibolite or upper greenschist facies.	2,000 – 3,500 m <sup>[1]</sup>

Notes: 1. Geoscience Australia (2022)



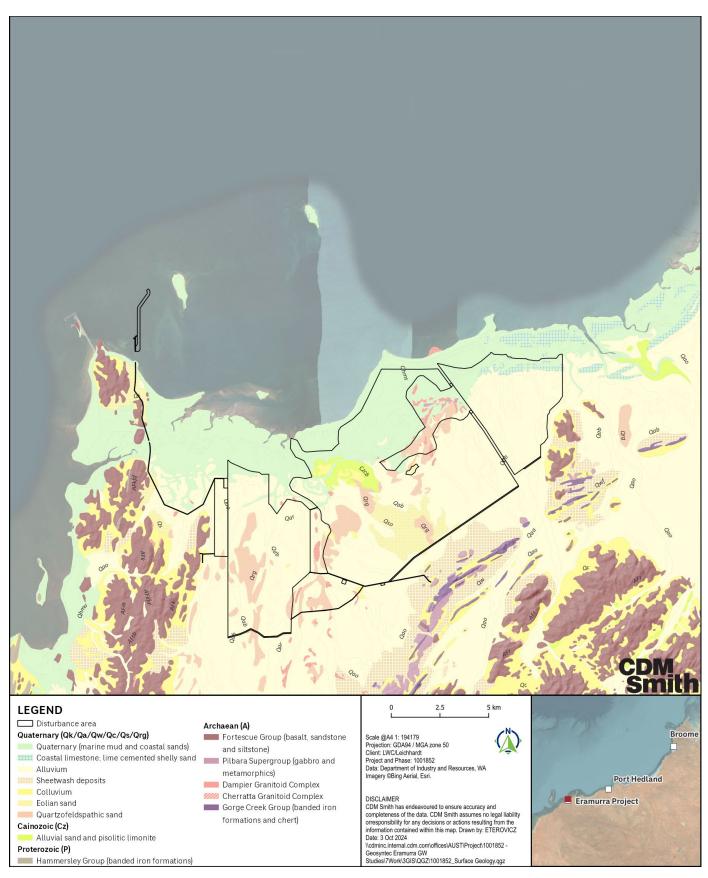


Figure 2-7 Surface geology



## 2.4 Hydrogeology

#### 2.4.1 Hydrostratigraphy

#### 2.4.1.1 Overview

A summary of the Project area's hydrostratigraphic units (HSUs) is presented in Table 2-2 based on knowledge obtained from field investigations by CMW (2022), LWC (2022a) and CDM Smith (2024). Further discussion regarding the latest drilling results for the Project and how this has changed the current understanding of the site hydrostratigraphy is provided in Section 2.4.1.3. Cross sections showing the Project stratigraphy is presented as part of the conceptual hydrogeological model in Section 2.6.

The monitoring bore drilling completed within the Project area between 2023 and 2024 (CDM Smith, 2024) identified the presence of an extensive covering of eluvium comprising of highly weathered crystalline basement rocks belonging to undifferentiated volcanics and the Dampier Granitoid Complex. Drilling indicates the eluvium acts as an aquifer of low to moderate permeability and likely forms the main water bearing unit over the Project area (refer to Section 2.4.1.3 for further detail). Differences in geological interpretation has meant this HSU was previously classified as "Tertiary sediments, extremely weathered/residual soil" in prior assessments. The hydrostratigraphy presented in Table 2-2 has therefore been adjusted to rename this HSU as eluvium. Note, a degree of uncertainty still exists in understanding a detailed distribution of these HSUs especially with regards to HSU 6 and 7 (basement) and HSU 5 (Tertiary alluvium) thought to occur within paleochannels within the northeast of the Project area within the vicinity of the Santos Gas Pipeline.

Table 2-2 HSU categorisation

HSU [number]	Stratigraphy	HSU Type	Thickness (m)	Descriptions and basis of categorisation
1. Eolian sand	Quaternary sediments [Qhms, Qs]	Aquifer (unconfined where outcropping)	~1-25	<ul> <li>Present north and east of the tidal flats as dune and sandy islands consisting of a silty sand</li> <li>Generally, not a deep unit and likely to be unsaturated</li> </ul>
2. Mangrove or Lagoonal muds	Quaternary sediments [Qhm, Qpmb]	Aquifer (unconfined or local confining/semi confining bed)	~1-6	<ul> <li>Present at the surface in the coastal areas beneath concentrator ponds R1, P2 and PE1) comprising interlaminated clay, silt and sandy clay, very soft to firm and stiff</li> <li>Up to 6 m deep near the coast so may be saturated</li> </ul>
3. Alluvial outwash	Quaternary sediments [Qaa, Qab] and residual soil	- comming bear	~1-5	<ul> <li>Present at surface across much of the site as braided channel gravels associated with modern watercourses and sheetwash gravel as a thin veneer (&lt;20 cm) over residual soil (CMW, 2022), deeper near drainages</li> <li>Where present as sheetwash this is likely to be unsaturated</li> </ul>
4. Eluvium (highly weathered basement)	Quaternary sediments [Qrg], Undifferentiated Volcanics [d/o], Dampier Granitoid Complex [Ag]	Aquifer (semi- confined)	~1-40	<ul> <li>Underlays alluvial outwash comprised of highly weathered and unconsolidated weathered basement material of gravels and clays</li> <li>Likely most monitoring wells intersect this unit, forming the most extensive and main water bearing unit (CDM Smith, 2024)</li> </ul>
5. Paleochannel and tertiary alluvium	Tertiary sediments [Czaa/Czcb]	Aquifer (semi confined)	~5-25	<ul> <li>Exact location uncertain, thought to occur near coastline in the Project's northeast in areas of former riverine incisions (CMW, 2022)</li> <li>Difficult to distinguish between this HSU, eluvium and alluvial outwash due to similar host rock</li> </ul>
6. Weathered basement	Crystalline basement [d/o, Ag]	Aquifer (confined / semi confined)	1-20?	<ul> <li>Present in geophysics at 10 m below surface 100 m from coast and at the surface to 5 m deep further inland (CMW, 2022)</li> <li>Thickness uncertain, overlays less permeable basement</li> </ul>



HSU [number]	Stratigraphy	HSU Type	Thickness (m)	Descriptions and basis of categorisation
7. Crystalline basement		Aquifer (confined / semi confined)	>5,000	<ul> <li>Deepest unit</li> <li>Present in geophysics from 500-1,000 m inland from the coast at around 7 m depth (CMW, 2022)</li> <li>Encountered from 1 m depth to &gt;48 m depth (CDM Smith, 2024)</li> </ul>

#### 2.4.1.2 Hydraulic properties

A summary of the estimated permeability of the key HSUs is presented in Table 2-3 based on field testing completed to date. Where field tests have not been completed for a HSU, literature values and parameter predictions from the Project's calibrated groundwater model (CDM Smith, 2023b) have been used as a guide. To date the following studies have been completed that inform the permeability of the Project HSUs:

- Triaxial and hydrometer permeability tests by Leichhardt (2015).
  - Investigated 27 locations across 40 Mile Beach and Eramurra South collecting 54 samples from the shallow subsurface (soil).
  - Results show very low permeability, averaging between around 7 x 10<sup>-4</sup> to 3 x 10<sup>-3</sup> m/d between sites.
- Test pitting, cone penetrometer tests (CPT), oedometer tests and triaxial permeability tests by CMW (2022).
  - Included 250 test pits, 68 CPT tests and 68 surface samples for triaxial permeability testing.
  - Majority of laboratory test results require further analysis to estimate permeability, however, oedometer tests indicate hydraulic conductivity of alluvial outwash to range between  $1 \times 10^{-2} 1 \times 10^{-4}$  m/d.
- Slug testing by LWC (2022b)
  - Completed five slug tests within a variety of HSUs ranging from alluvial outwash, eluvium and potentially paleochannel fill.
  - Estimates of hydraulic conductivity derived for four bores ranging from 0.07 to 1.7 m/d.
- Groundwater modelling by CDM Smith (2023b)
  - Developed a density dependant groundwater flow model for the Project using an ensemble of 100 model realisations to provide probabilistic predictions of groundwater heads and salinity. The 100 realisations are designed to explore the potential model outcomes based upon a range of hydraulic property combinations with each realisation containing a different set of parameters and calibrated to hydraulic head observations.
  - The geometric mean of the 100 calibrated models, which represents the most likely case, used a combination of literature and triaxial and hydrometer permeability tests to set the calibration bounds and shows hydraulic conductivity to be in the range of 0.1 m/d for the sedimentary cover (HSUs 1 to 5) and 1 x 10<sup>-5</sup> m/d for the basement HSUs (HSU 6 and 7).
- Groundwater monitoring drilling by CDM Smith (2024)
  - Airlift yields measured during monitoring bore development provide qualitative insights into the permeability of the host formations.
  - Airlift yields ranged from dry in basement wells to <0.1 L/s in eluvium and weathered basement and up to 2 L/s in possible paleochannel fill. Further detail provided in Section 2.4.1.3.

Collectively these studies indicate a generally low permeability shallow cover sequence that is underlain by sediments of low to moderate permeability and low permeability basement. Further work should be completed to obtain additional estimates of hydraulic conductivity from the deeper HSUs, particularly from wells installed within the eluvium and basement to assist in better understanding any permeability changes with depth. Analysis of the CMW (2022) test results would also assist in improving the understanding of how permeability might vary across the Project area.

A map showing the relative positions of sampling locations from the above sources is shown in Figure 2-8 (from CDM Smith 2022).



Table 2-3 Summary of estimated hydraulic conductivity for key HSUs

HSU	Hydraulic conductivity - (m/d)	Airlift yield (L/s)	Test (s)	Source / description
1. Eolian sand	[1] 1 x 10 <sup>-1</sup> – 10 [2] 1 x 10- <sup>1</sup> - 1	-	Triaxial permeability & hydrometer permeability	<ul> <li>[1] Based on hydrometer and triaxial test samples inferred from (Leichhardt, 2015) to be collected from coastal sands</li> <li>[2] Qualitative assessment of moderate to high permeability (CMW, 2022)</li> </ul>
2. Mangrove or Lagoonal muds	[1] 1 x 10 <sup>-5</sup> – 1 x 10- <sup>2</sup> [2] 1 x 10 <sup>-3</sup> - 1 x 10 <sup>-1</sup>	-	Triaxial permeability & hydrometer permeability	<ul> <li>[1] Based on hydrometer and triaxial test samples inferred from (Leichhardt, 2015) to be collected from mangrove / lagoonal muds</li> <li>[2] Qualitative assessment of low to moderate hydraulic conductivity (CMW, 2022)</li> </ul>
3. Alluvial outwash	[1] $1 \times 10^{-5} - 1 \times 10^{-2}$ [2] $1 \times 10^{-4} - 1 \times 10^{-2}$ [3] $1 \times 10^{-4} - 1 \times 10^{-3}$	-	Triaxial permeability, hydrometer permeability & oedometer	<ul> <li>[1] Based on hydrometer and triaxial test samples from Eramurra South (Leichhardt, 2015)</li> <li>[2] Based on oedometer tests by CMW (2022</li> <li>[3] Qualitative assessment of low to very low hydraulic conductivity (CMW, 2022)</li> </ul>
4. Eluvium (highly weathered basement)	[1] 0.06 - 1.7 [2] 0.07	<0.1 up to 1 L/s	Slug test	<ul> <li>[1] Three slug tests estimating hydraulic conductivity completed for this HSU (LWC, 2022a)</li> <li>[2] Geometric mean of combined sedimentary cover (HSUs 1 - 5) from calibrated groundwater model (CDM Smith, 2023b)</li> <li>Airlift yields measured post bore development by CDM Smith (2024) indicate low to moderate permeability</li> </ul>
5. Paleochannel and tertiary alluvium	0.6	1.5-2	Slug test	<ul> <li>One slug test estimating hydraulic conductivity from MB03 possibly screened within a paleochannel (LWC, 2022a)</li> <li>Airlift yields measured post bore development at MB26d (CDM Smith, 2024) indicate moderate to high permeability</li> </ul>
6. Weathered basement	1 x 10 <sup>-3</sup> 1 x 10 <sup>-1</sup>	<0.1	-	<ul> <li>Qualitatively estimated by CMW (2022) which suggest low to moderate (along joint system) permeability of weathered basement</li> <li>Bores drilled into this unit observed low yields (&lt;0.1L/s) indicating low permeability (CDM Smith, 2024)</li> </ul>
7. Crystalline basement	1 x 10 <sup>-5</sup> - 1 x 10- <sup>4</sup>	Dry - <0.1	-	<ul> <li>Hydraulic conductivity based on range of calibrated groundwater hydraulic conductivity values (CDM Smith, 2023b)</li> <li>Bores drilled into this unit were dry or very low yielding (dry to &lt;0.1L/s) indicating very low permeability (CDM Smith, 2024)</li> <li>Slow recovery of water levels within MB33d following drilling and construction (days to months) (CDM Smith, 2024; LWC, 2024)</li> </ul>



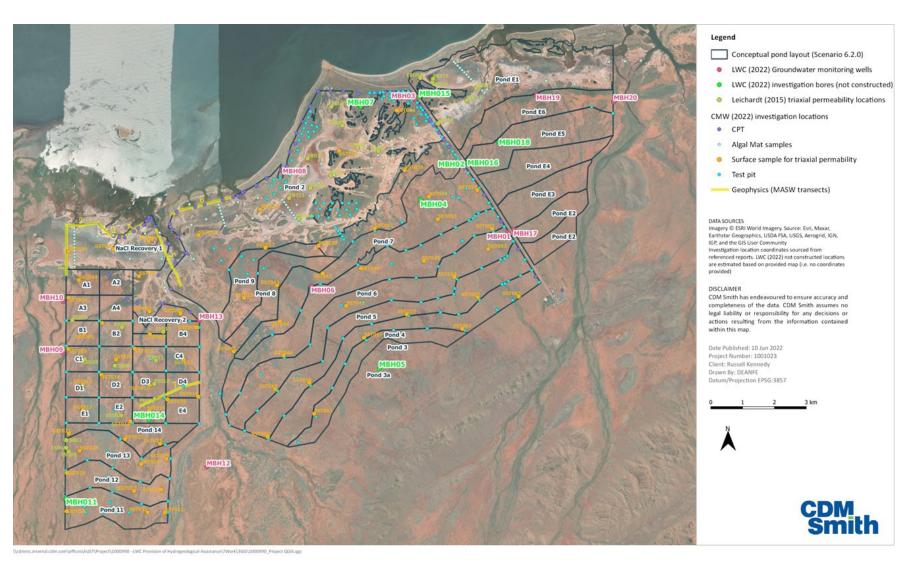


Figure 2-8 Relative position of sampling locations from reviewed reports (CDM Smith, 2022)

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#### 2.4.1.3 Updates to hydrostratigraphy

Recent drilling within the Project area encountered highly variable ground conditions and yields which collectively has led to an improved understanding of the site hydrostratigraphy (CDM Smith, 2024; Appendix D). Ten additional monitoring bores (MB21s, MB26d, MB33d, MB33s, MB34s, MB35s, MB37d, MB38d, MB39d and MB40d) were drilled between December 2023 and January 2024 and range in depth from 15 m to 60 m below ground level (bgl). Locations of the monitoring bores are shown in Figure 2-9, while a summary of the monitoring bore construction is presented in Table 2-4. A summary of the drilling observations (by bore) is provided in Table 2-5. Bores that were either not drilled or backfilled after drilling are denoted in Figure 2-9 and represented in Table 2-5 as N/A.

#### The drilling program found:

- Surficial deposits dominate the Project area and generally comprise alluvial outwash, residual soil and eluvium (highly weathered basement). The eluvium unit appears to be extensive, supporting the observation of a deep weathering profile over most of the Project area and forms the main water bearing unit.
- Given the common source rock, degree of weathering and drilling method employed (rotary air blasting), it can be difficult to distinugish between straitgraphic units. Boundaries between the cover stratigraphy generaly remain poorly defined.
- Variable depth to bedrock ranging from zero (i.e. outcropping in creeks and east of MB21s) to greater than 48 m (the depth of the deepest well that did not encounter competent basement MB38d) farther inland / from creeks. A rapid change in basement depth occurs to the west of McKay Creek that may be suggestive of faulting. Without structural information, it is unclear whether the basement topography is controlled by faulting or folding.
- Groundwater during drilling was generally intercepted between around 10 and 12 m bgl, although as shallow as 8 m and as deep as 36 m. For many bores, water was encountered at the base of the elluvium and contact with underlying basement rocks.
- Variable airlift yields during drilling ranging from dry conditions at MB36s to less than 0.1 L/s at MB37, 38, 39 and 40d and as high as 5 L/s at MB26d.
- Airlift yields measured during well development, which are representative of stratigraphy, indicate:
  - Yields of up to 2 L/s from the potential paleochannel (HSU5) (MB25d).
  - Yields ranging from <0.1 L/s to 0.6 L/s in the eluvium (HSU4).</li>
  - No yield to <0.1 L/s and unsustained flow from the basement HSUs (HSU6 and 7).</li>



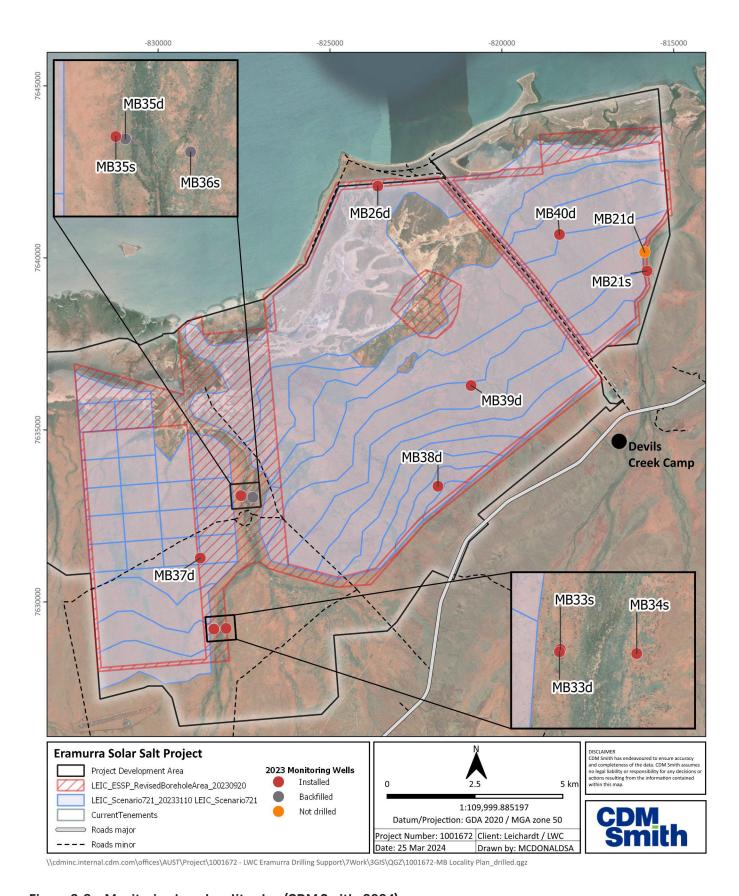


Figure 2-9 Monitoring bore locality plan (CDM Smith, 2024)



Table 2-4 Monitoring Bores Drilling and Construction Summary (CDM Smith, 2024)

Bore ID	Coordinates <sup>[1]</sup> GDA2020 Z50	Elevation (mAHD)	Drilled Depth (mbgl) <sup>[2]</sup>	Screened geology	Screened interval (mbgl)	Gravel pack (mbgl)	Bentonite seal (mbgl)	Stick up (m)	Depth to water (m btoc) <sup>[2]</sup> (LWC, 2024)
MB21s	0440329 E 7691543 N	11.65	24	Dolerite dyke or outcropping basalt	17 - 23	16 - 23	15-16	0.99	8.43
MB21d	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
MB26d	0432867 E 7694530 N	4.35	36	Potential paleochannel	19 - 25	18 - 25	16-18	1.2	4.91
MB33s	0427265 E 7682331 N	16.73	20	Eluvium	14 - 20	13 - 20	12-13	0.9	6.94
MB33d	0427261 E 7682320 N	16.86	60	Granodiorite (Dampier Granitoid Complex)	54 - 60	53 - 60	52 - 53	0.99	7.26
MB34s	0427608 E 7682312 N	17.03	20	Eluvium	17 - 20	16 - 20	15 - 16	0.75	7.22
MB35s	0428313 E 7686043 N	6.96	15	Eluvium	12 - 15	11 - 15	10 - 11	1.00	5.14
MB35d	0428356 E 7686032 N	10.92	42	N/A	N/A	N/A	N/A	N/A	N/A
MB36s	0428649 E 7685974 N	9.88	20	N/A	N/A	N/A	N/A	N/A	N/A
MB37d	0427028 E 7684363 N	12.55	42	Granodiorite (Dampier Granitoid Complex)	36 - 42	35 - 42	34 - 35	1.07	7.16
MB38d	0433931 E 7685886 N	23.37	49.6	Eluvium or Tertiary alluvium	43.6 - 49.6	42.6 - 49.6	40.6 - 42.6	1.06	17.87
MB39d	0435086 E 7688672 N	12.31	27	Granodiorite (Dampier Granitoid Complex)	21 - 27	19 - 27	18 - 19	1.08	8.64
MB40d	0437922 E 7692766 N	8.15	60	Granodiorite (Dampier Granitoid Complex)	57 - 60	56 - 60	54 - 56	0.89	5.22

Notes

- 1. Coordinates and elevation (AusGeoid09) collected by Murray and Associated Pty Ltd by a registered surveyor using a Trimble R10 GNSS with horizontal accuracy of +/- 15 mm and vertical accuracy of +/- 25 mm
- 2. mbgl denotes metres below ground level, mbtoc denotes metres below top of casing
- 3. N/A denotes not applicable, well either not drilled or backfilled see Figure 2-9



Table 2-5 Drilling observation summary (CDM Smith, 2024)

Bore ID	Observations
MB21s	Drilling intercepted water at around 10 m after which water (~1.5-3 L/s) was observed each time the drill string was raised to flush the hole. Loose formation encountered from 10 m through to 15 m caused hole stability issues. Dolerite was encountered from approximately 16 m which slowed the rate of penetration.
	Drilling was ceased after water returns led to a blowout at the collar. The bore was installed and screened in the shallow groundwater within the dolerite.
MB21d	This hole was not drilled due to time constraints.
MB26d	Drilling intercepted water at around 10 m after which hypersaline water (-5L/s at >160 mS/cm) was observed each time the drill string was raised to flush the hole. A dense black clay layer was encountered at 15 – 19 m with loose wet sands beneath. Hole stability issues were encountered at 36 m within a gravelly sand unit. Drilling, therefore, ceased and the casing screen was installed in the sandstone underlying the black clay layer (19 – 25 m) in the highly saline aquifer.
MB33s	Drilling intercepted water at around 12 m after which water (~0.2L/s) was observed each time the drill string was raised to flush the hole. Easy drilling occurred through the shallow subsurface dominated by sandy gravels with weathered quartz gravels intercepted at 12 m and granodiorite basement encountered from around 16m.
	Drilling ceased at 20 m after the collar blew out due to excessive water down the hole. The bore was installed and screened within the contact of the gravel and granodiorite basement.
MB33d	Drilling initially commenced in December 2023 at MB33d with water intercepted at 12 m. Water yields (<0.1L/s) and unstable ground conditions led to a blowout within the hole at around 18m which prevented drilling from continuing. The hole was grouted to surface to improve hole stability.
	Drilling resumed in January 2024 with no water intercepted. Competent granodiorite basement was encountered at around 20 m and remained unchanged to target depth (60 m). Minimal to no water was observed in the bedrock.
MB34s	Drilling intercepted water at around 10 m with minimal amounts of water noted each time the drill string was raised to flush the hole (<50 L). Easy drilling conditions were noted through the weathered rock and clayey gravel which extended to depth at 20 m. No issues were noted during drilling.
MB35s	Drilling intercepted water at around 13 m after which water (-1 L/s) was observed each time the drill string was raised to flush the hole. Drilling continued to 15 m with no issues noted, and casing screen installed within clayey sand at the base of the hole.
MB35d	Drilling initially commenced in December 2023 at MB35d with water intercepted at 13 m. Water returns (~1 L/s) and unstable ground conditions led to a blowout within the hole at around 33 m which prevented drilling from continuing. The hole was grouted to surface to improve hole stability.
	Drilling resumed in January 2024 and water was intercepted at 6 m with little to no grout found in chip returns. Drilling continued to 33 m with several hole blockages noted. A rock roller bit was used to clear the hole and run surface casing down to 15 m to assist with reducing water returns. Sample returns were minimal for much of the drilling due to swelling clays clogging the drill string. The hole was abandoned at 42 m and grouted to surface due to swelling clays, hole stability and flooding of the drill pad with water returns leading to unsafe operating conditions.
MB36s	No water was intercepted during drilling of MB36s. Competent granodiorite basement was encountered at around 2 m and remained unchanged to target depth (20 m).  At the end of hole, a plug was inserted, and the hole backfilled to prevent injury to fauna.
MB37d	Drilling intercepted water at around 36 m with minimal amounts of water (<0.1 L/s) noted each time the drill string was raised to flush the hole. Dry gravely clays were observed within the first 30 metres and proved easy to drill. Competent granodiorite basement was encountered at 33 m and corresponded with the first water cut at 36 m. Bore screen was installed beneath the first water cut within the granodiorite basement. No issues were encountered during drilling or installation of the bore.



Bore ID	Observations	
MB38d	Drilling intercepted water at around 21 m after which water (<0.1 L/s) was observed each time the drill string was raised to flush the hole. Water and muds were required to flush the hole and alleviate blockages caused by clay material downhole. Hole stability issues occurred (24 m) due to silty clays which required further flushing and mud injection to stabilise the hole. Fine silts and clays caused further blockages to the air hose and cyclone leading to the hole collapsing between rod changes and rod pulls. Due to the persistent difficult drilling conditions and risk of further hole collapse and rod entrapment, drilling was ceased at 49.6 m and the bore installed and screened within the sandy gravels at the base of the hole.  Ground conditions caused what was initially thought to be a cave in at (33 m), however the PVC casing and gravel pack were able to be installed below this point.	
MB39d	Drilling intercepted water at around 12 m after which water (<0.1 L/s) was observed each time the drill string was raised to flush the hole. Gravelly sand and sandy gravel were logged in the shallow subsurface which transitioned to weathered granodiorite basement at around 12m. Competent basement rock was encountered at 15 m and drilling was ceased shortly after at 27 m. The bore screen was installed within the basement at the bottom of the hole. No issues were encountered during drilling or installation of the bore.	
MB40d	Drilling intercepted water at around 12 m after water (<0.1 L/s) was observed each time the drill string was raised to flush the hole. Sandy/gravelly clays were encountered within the upper 4 m of the subsurface coarsening to sand and gravels to around 10 m. Wet clays led to a blockage in the sample hose at (12 m), otherwise drilling continued to 60 m with no issues observed. Varying degrees of weathered granodiorite basement were noted between 10 and 60 m.  Recent groundwater gauging and sampling from this bore by LWC identified a bend in the casing at 10 m. This was not observed during drilling, installation and development.	

#### 2.4.2 Groundwater levels and flow

#### 2.4.2.1 Groundwater levels

A total of 21 monitoring bores have been installed across the Project area to date (Figure 2-10). Groundwater levels within these wells vary from less than around 3 m bgl in areas near the coast (MB03) to more than 17 m bgl farther inland (MB38d). While the monitoring bores are installed within a variety of stratigraphy, generally bores can be classified by two groups:

- 1. Shallow monitoring bores installed within the sedimentary cover sequence.
- 2. Deep monitoring bores installed within the crystalline basement.

Water levels taken from the Project's monitoring bores indicate little difference in groundwater heads between the shallow sedimentary cover and deeper basement HSUs. This is supported by groundwater heads at nested site MB33 where recent monitoring by LWC in July 2024 (Figure 2-10), found water levels within MB33d (basement) have recovered to be within around 20 cm of MB33s (sedimentary cover). Following bore construction and development in January 2024, water levels within MB33d measured around 23 m bgl, some 16.5 m deeper than MB33s and is now understood to have represented water levels that had not fully recovered within the bore. Although additional nested sites are recommended to better understand the hydraulic gradient with depth, the latest water level monitoring from nested site MB33 may suggest a degree of connection between the sedimentary cover sequence and the underlying basement. Further monitoring from these sites (water levels, quality and rainfall) to develop a timeseries of data, may also assist in better understanding the relationship between the sedimentary and basement HSUs. The slow recovery of water levels within MB33d after installation (estimated to have occurred over days to months) also supports the conceptualisation of a low permeability basement unit.



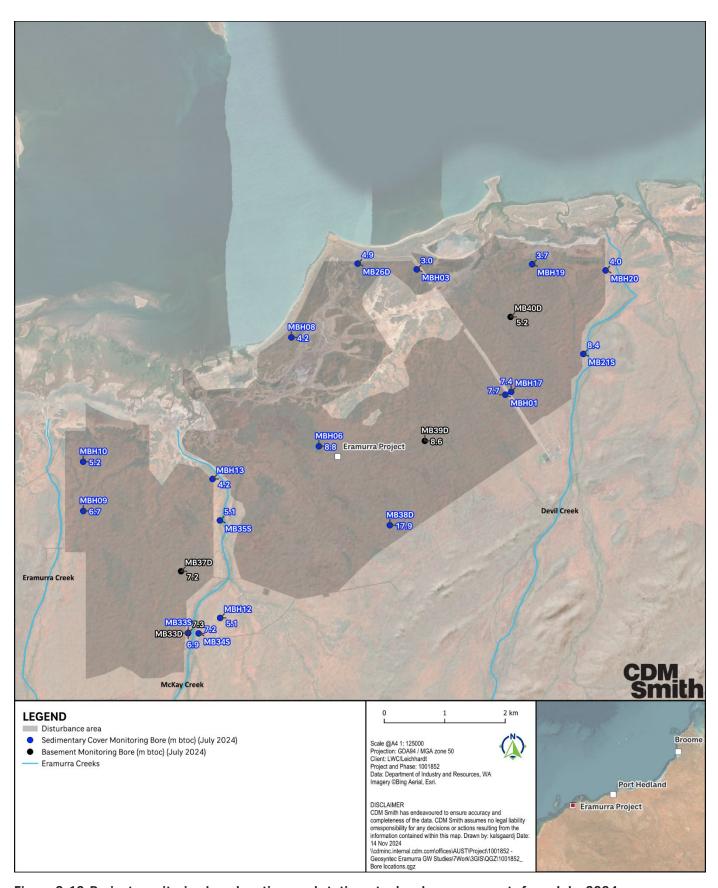


Figure 2-10 Project monitoring bore locations and static water level measurements from July, 2024



To assist in collecting temporal water level data, pressure transducer data loggers (PTDLs) have been installed within the Project site's monitoring bores, beginning with MB10 and MB19 in December 2021, MB01, MB08, MB09, MB12 and MB13 in February 2023 and the ten new monitoring bores (MB21s, MB26d, MB33s, MB33d, MB34s, MB35s, MB37d, MB38d, MB39d and MB40d) in January 2024. At the time of reporting, PTDL records were only available for bores installed prior to the 2023/2024 drilling program. Hydrographs of these wells are shown in Figure 2-11 as per (LWC, 2024). The data indicate water levels are generally stable, ranging between 3 and 9 m below top of casing (m btoc). A general trend of increasing groundwater elevation appears over the period of record, albeit with a slight decrease in groundwater levels during the November 2023 monitoring event.

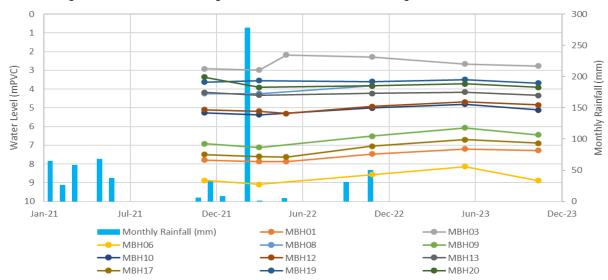


Figure 2-11 Groundwater well water levels across monitoring events (LWC, 2024)

#### 2.4.2.2 Groundwater elevations and flow direction

Groundwater head contours have been developed using the latest available groundwater level data for the Project and are presented in Figure 2-12. The contours are representative of groundwater heads measured during the July 2024 monitoring event undertaken by LWC. Groundwater elevations range from approximately 11 m AHD in the southeast to near sea level (i.e. 0 m AHD) adjacent to the coast. Within the inter- and supratidal flats (i.e. sabkha), where a natural low point in the topography exists, groundwater modelling by CDM Smith (2023b) predicts the high levels of evapotranspiration experienced within the Project area, contribute to lower the groundwater levels beyond sea level causing groundwater inflow from the ocean. There is currently little water level information available to support a detailed understanding of groundwater levels and flow conditions within the backwater area. A drilling program targeting coastal EVs, cultural EVs (Noorea Soak) and basement stratigraphy (including incomplete monitoring bores in the 2023/2024 program), is planned as part of further environmental baseline studies to support the Project's ERD.

Water level data from monitoring bores adjacent to the Project's ephemeral drainages (within 150 m) suggests groundwater could be encountered at around 2 m beneath creek beds. Eucalypt vegetation is document to occur within the Project's creeks (refer Section 2.5) and would be expected to access groundwater at such depths through evapotranspiration. When accounting for evapotranspiration, water levels beneath the Project's creeks are expected to be several metres deep. This aligns with the depth in which water has generally been encountered during drilling (10-12 m bgl) (CDM Smith, 2024) and the lack of streamflow observations and permanent inundation along creek beds. Further discussion regarding recharge, discharge and EVs is provided in Section 2.4.4 and Section 2.5 respectively.

In general, the water level data indicate groundwater flows in a north to northwest direction across the Project area which is observed through a steady decline in groundwater elevation in this direction at an average gradient of around 0.001 (~10 m of vertical rise over a 7 km horizontal distance). Groundwater flow is also understood to occur in a southeast direction as inflow from the ocean (refer to Section 2.4.4 for further detail). Addition of the newly installed monitoring wells (MB21 to MB40) generally does not change the groundwater flow direction from prior assessments, however, does provide greater resolution of groundwater heads across the site and suggests a flatter gradient than previously shown by CDM Smith (2023b).



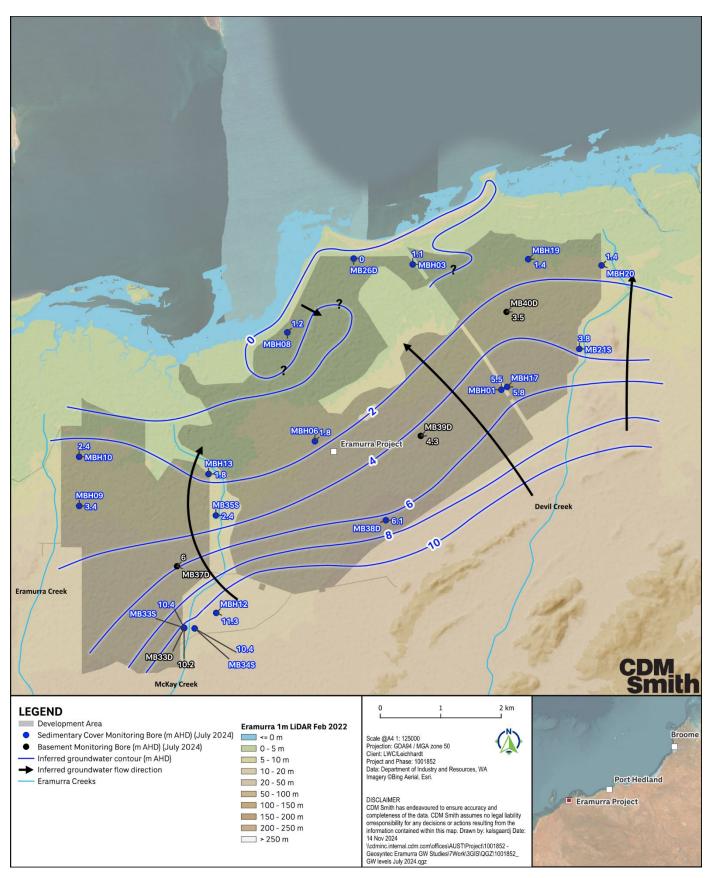


Figure 2-12 Inferred groundwater elevation contours and flow direction (July 2024)



#### 2.4.3 Groundwater quality (salinity)

The most recent available water quality data for the site was collected in November 2023 and February 2024 by LWC (2024). These data indicate groundwater salinity within the Project area ranges from 710 mg/L (MBH33S) to 130,000 mg/L (MBH26D) Total Dissolved Solids (TDS), with the highest reported TDS concentrations tending to be in groundwater wells in close proximity to the coast. As reported by LWC (2024), all groundwater wells exceed the salinity criterion of 600 mg/L for Australian Drinking Water Guidelines Aesthetic and Recreational Water – Aesthetics and is generally neutral to acidic (6.4 - 8.8 pH) with the exception of MBH012 (pH = 12), MB33D (pH = 13) and MB40D (pH = 12).

The latest groundwater quality data have been used to provide an updated map of groundwater salinity over the Project area (Figure 2-13). This figure shows a strong hypersaline interface in the backwater (sabkha) areas adjacent to the coast with relatively steep salinity gradients to the north and south of this feature. To the north of the feature, a reverse saline water interface exists between the backwater areas and the ocean, whereas to the south of the backwater areas and coastline, groundwater salinity decreases substantially with distance from these features and in proximity of ephemeral drainages where it is likely recharge occurs (discussed further in Section 2.4.4). Although the groundwater salinity of the basement monitoring bores is fairly consistent with shallow monitoring bores, a notable difference in salinity is observed between nested sites MB33s (710 mg/L) and MB33d (17,000 mg/L) where salinity ranges by more than 16,000 mg/L. This observation supports the conceptualisation of shallow recharge occurring through the ephemeral drainages and may also suggest groundwater salinity increases with depth, either as a function of longer residence times of recharging groundwater or MB33d intersecting deeper fractures hosting saline groundwater.



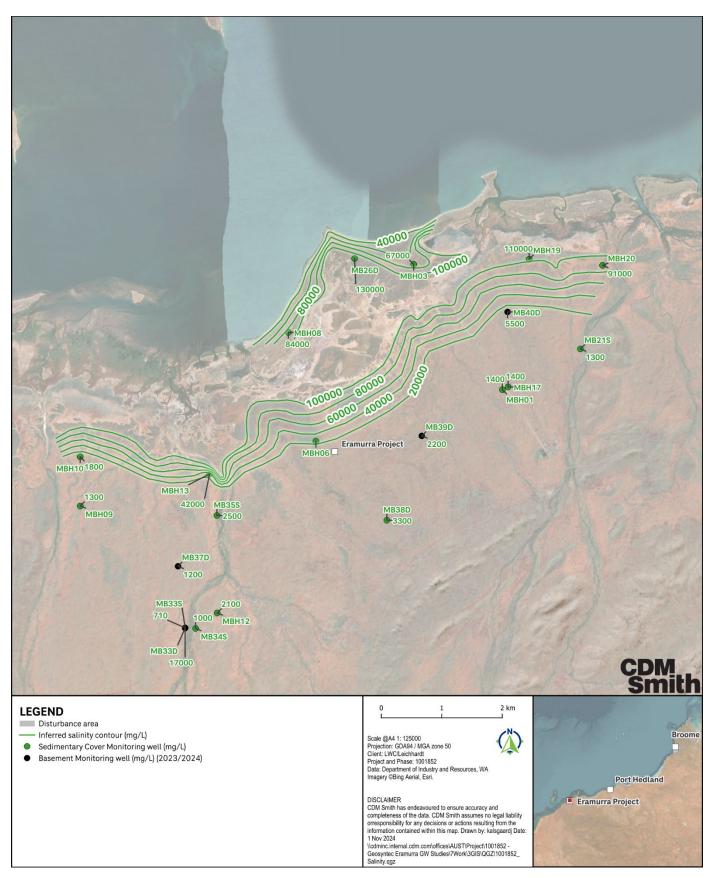


Figure 2-13 Interpreted groundwater salinity 2023/2024 sampling periods



While the updated salinity contours share some spatial similarities with those previously interpreted for the Project's density flow model (CDM Smith, 2023b; Appendix C, Figure 9-5), the latest results show notable fluctuations in groundwater salinity when compared to historical measurements (Figure 2-14). From a spatial sense, monitoring bores with the highest fluctuations are generally located to the northeast of the Project area and closer to the coast. For many of these wells, the TDS measurements taken in November 2023 represent the lowest concentration to date and appears to reflect a downwards trend in salinity over time. It should be noted that the size of the current monitoring dataset limits the ability to draw definitive and statistical conclusions from the current data. Further investigation is required to better understand the process(s) which could be contributing to the salinity fluctuations.

The existing groundwater model (CMD Smith, 2023b) uses groundwater salinity measurements from earlier in the dataset that are generally higher than the most recent monitoring results. A limitation of the model is that the predictions are dependent on the initial density condition such that an environment with higher baseline concentrations (such as those reported in the existing groundwater model) is likely to experience a smaller change in salinity than an environment with lower baseline salinity due to hypersaline seepage from the evaporation ponds. Recognising this limitation, future groundwater models developed for the Project may need to consider both a low and high salinity baseline scenario to account for the uncertainty in salinity fluctuations and the potential changes to the baseline salinity as a result of the Project's development.

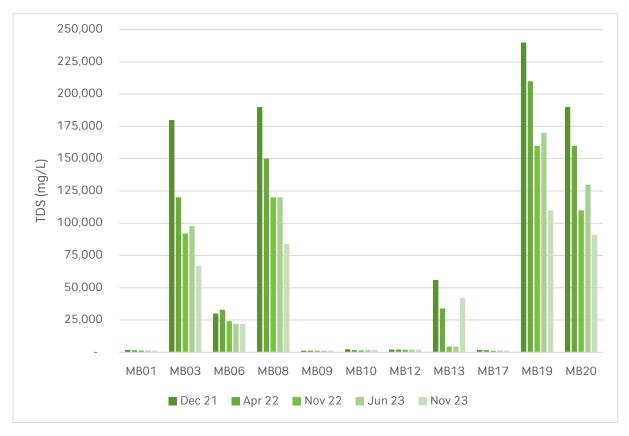


Figure 2-14 Summary of TDS measurements over groundwater monitoring events (LWC, 2023b; 2024)

#### 2.4.4 Groundwater recharge/discharge

Groundwater recharge in the Project area is thought to occur primarily through diffuse rainfall recharge and as leakage beneath ephemeral streams. This concept is supported by groundwater salinity measurements from the Project's monitoring bores where in general shallow bores adjacent to creeks and away from the coast observe lower salinities than deeper bores and those closer to the coast. Groundwater modelling by CDM Smith (2023b) (Appendix C; Table 9-4) predicts a component of groundwater inflow (~1.2 ML/d) also occurs from the ocean to the adjacent backwater areas. Inflow of groundwater from the coast can be interpreted through site observations of groundwater heads shown in Figure 2-12 prior where groundwater elevations in monitoring bores adjacent to the coast (MB26D, MBH08 and MBH03) range between 0 and 1.2 m AHD. With the elevation of the low-lying backwater areas ranging between 0 and 5 m depth, groundwater beneath this is area are expected to be influenced by evapotranspiration which, as predicted



by the Project's groundwater model, creates a natural depression in groundwater heads that results in drawing of water from the coast.

Recharge rates for the Project area have been estimated using deep drainage data from the Australian Water Outlook database (BOM, 2023). This database suggests annual deep drainage between 1985 and 2022 varies between 2 and 18% of rainfall with a mean of 6%, or 17.4 mm/y when considering the mean recorded rainfall for Karratha. While these values were used to inform the calibration of the Project's groundwater flow model (CDM Smith, 2023b), the geometric mean recharge rate from the 100 calibrated model realisations (considered the most likely scenario) is more than an order of magnitude lower at around 0.3% for the sedimentary cover and around 0.1% for the bedrock. This suggests the Project area experiences low recharge rates, potentially lower than what is estimated regionally.

Groundwater discharge is expected to occur predominantly as evapotranspiration within the backwater areas adjacent to the coast, where depth to water is shallow. While a component of groundwater inflow has been predicted from the ocean (~1.2 ML/d), groundwater modelling (CDM Smith, 2023b; Appendix C; Table 9-4) predicts a smaller quantity of outflow (~0.25 ML/d) may also occur as net outflow towards to the coast. Net outflow (i.e. the resulting outflow after other hydrogeological processes have taken place) is expected to vary depending on the timing and magnitude of the tidal system, amount of evapotranspiration, surface water inflows and the interaction of groundwater and surface water connection along the coast. Discharge to the ocean is considered most likely to occur away from the low-lying backwater areas which are dominated by evapotranspiration processes and/or in areas with higher permeability that allow for faster transport of groundwater towards the coast.

Observations from recent groundwater monitoring (LWC, 2024) and groundwater drilling (CDM Smith, 2024) suggest the depth to water beneath the Project's ephemeral drainages is at least several metres deep. This observation suggests groundwater is unlikely to discharge to creeks directly, however, due to the depth to groundwater being within the rooting depth potential of eucalypt species which reside in the Project's drainages, it is likely groundwater discharge occurs through evapotranspiration from these vegetation species. As such, the extinction depth to which evapotranspiration processes can discharge groundwater is therefore, likely to vary across the Project area, with a deeper extinction depth expected within and around drainage lines. To assist in understanding the potential variations in evapotranspiration extinction depths, further studies are required to investigate the rooting depth of terrestrial vegetation within the Project's creeks.

#### 2.4.5 Groundwater and surface water interaction

The most notable interaction between groundwater and surface water is expected to occur within the backwater areas adjacent to the coast, due to the low topography of the landform: inflows are predicted to occur from a combination of (i) the ocean, (ii) as upgradient flow further inland, (iii) tidal flow and (iv) inundation from rainfall. Outflows from this landform are predicted to occur via (i) evapotranspiration and, (ii) as minor outflows to the coast (depending on tidal movement and permeability of coastal aquifers) (CDM Smith, 2023b).

Evapotranspiration within the backwater area forms a sabkha-like environment, where salts are precipitated above the saline water table hosted by lagoonal muds and marine sediments. As shown in Figure 2-13 using the latest salinity data, the result of these evaporative processes generates a hypersaline interface adjacent to the coast where concentrations currently exceed 100 g/L TDS and can reach as high 240 g/L based on historical water quality monitoring. This interpretation is generally consistent with the saline interface predicted by the Project's density dependent groundwater flow model (CDM Smith, 2023b) albeit some differences in salinity concentrations and extent of the saline interface inland. The development of hypersaline groundwater beneath this feature is likely to result in density driven groundwater fluxes as salts infiltrate downwards into the underlying sediments. Although this area lacks deep drill holes to measure the change in salinity with depth, it is conceptualised salinity will increase with depth beneath and away from this feature (refer to schematics presented in Section Figure 2-6). An increase of groundwater salinity with depth is observed at one nested monitoring site (MB33s and MB33d) where reported salinities vary by more than 16 g/L TDS between deep and shallow bores (refer Figure 2-13 above).

Further drilling along the coastal areas is planned as part of further environmental baseline studies to support the Project's ERD which will provide additional data and information to support the understanding of the sabkha-like environment.



#### 2.5 Environmental values

#### 2.5.1 Overview

An environmental value (EV) is defined as those qualities of the environment or an environmental element or an environmental receptor that society values to make it suitable to support particular ecosystems and human uses. Once established, EVs require protection, both during operations and long term post mine closure, from the effects of mining operations. Any changes to physical and quality aspects of groundwater resources, or to the physical characteristics of groundwater systems as a consequence of development of the Project have the potential to adversely affect existing and possible future EVs that are exposed to these changes. Two broad categories of EVs are defined under the Environmental Protection Act 1986:

- Ecosystem health.
- Beneficial use.

Using this classification, the EVs identified within the Project area are presented in Table 2-6 and illustrated in Figure 2-15. The following sections present an overview of existing and possible future groundwater EVs that might be exposed to changes to the groundwater baseline. They include groundwater EVs identified within and downstream of the Project.

Table 2-6 Identified Project area environmental values

Environmental value		Groundwater dependence
Ecosystem health	Wetlands	⊠ None identified
	Wild rivers	⊠ None identified
	Springs and pools	☑ Localised pools/soaks (Noorea Soak and Devils Pools) disconnected from groundwater, and supported by localised surface water run-off
	Groundwater dependent ecosystems	✓ Stygofauna identified ✓ Terrestrial vegetation identified
	Ecosystems supporting significant amenity, recreation and cultural values	☑ Terrestrial vegetation, likely has cultural value  ☑ Localised pools/soaks (Noorea Soak and Devils Pools) have identified cultural value
	Saline lakes, estuaries and near shore ecosystems	<ul><li>☑ Algal mats identified</li><li>☑ Samphire communities identified</li><li>☑ Priority Ecological Community (PEC) identified</li></ul>
	Aquatic vegetation	☑ Mangrove communities identified
Beneficial use	Drinking water supplies	⊠ None identified
	Water supplies supporting significant commercial activities, e.g. mining and pastoral	☑ Stock water wells identified
	Inland waters with high levels of active and passive recreation including multiple use wetlands	⊠ None identified
	Inland waters with significant cultural or aesthetic values	□ Localised pools/soaks (Noorea Soak and Devils Pools) have identified cultural value
Other	Critical infrastructure	☑ Santos Gas Pipeline



#### 2.5.2 Stygofauna

Bennelongia (2022) reports stygofauna are present within the Project area hosted by alluvial sediments and potentially in near shore paleochannel environments and/or gravelly deposits in permanently flowing creek beds. However, the Project area reportedly does not contain any restricted subterranean species (Bennelongia, 2022) meaning the habitat is non-unique and the consequence of such an event would be limited to the extent impacted by the salinity increase.

#### 2.5.3 Groundwater dependent terrestrial vegetation (GDE Atlas)

The GDE Atlas (BOM, 2022b) has identified low to moderate potential GDEs exist within the southern regions of the Project area. More detailed site-specific vegetation mapping indicates the presence of eucalypt species within the drainage lines of the creeks in the area. Although the potential groundwater dependence is mapped as low, these species are known to sometimes access groundwater. Groundwater drilling completed between November 2023 and December 2024 (CDM Smith, 2024), found depth to water adjacent to many of the site drainages ranges between 10 and 12 m which is within the potential rooting depth of these species. Based on the interpreted groundwater levels for the site (refer Section 2.6) it is possible this EV accesses groundwater, however, the rooting depth and specific water use patterns of the local eucalypt species is not currently understood. This EV, however, is known known to be resilient to changes in water availability and utilise multiple water sources, however, saline water is understood to limit groundwater use for this EV.

#### 2.5.4 Terrestrial vegetation (Priority Ecological Community)

A Priority Ecological Community (PEC) has been mapped in the northeast region of the Project area, between the coast and evaporation pond PEO1. This Coastal Dune PEC is described by the Department of Biodiversity, Conservation and Attractions as: Coastal dune native tussock grassland dominated by Whiteochloa airoides (Priority 3) Tussock grassland of Whiteochloa airoides occurs on the landward side of foredunes, hind dunes or remnant dunes with white or pinkish white medium sands with marine fragments. There may be occasional Spinifex longifolius tussock or Triodia epactia hummock grasses and scattered low shrubs of Olearia dampierii subsp. Dampierii, Scaevola spinescens, S. cunninghamii, Trianthema turgidifolia and Corchorus species (C. walcottii, C. laniflorus).

#### 2.5.5 Algal mats and samphire

A number of salt resilient vegetation species have been mapped within the Project area including algal mat and samphire communities. These communities predominantly exist within the low-lying backwater areas that are subject to groundwater, tidal and surface water inflows.

#### 2.5.6 Aquatic vegetation (mangroves)

Leichhardt has mapped a number of mangrove communities along the coastal areas adjacent to the Project. Occurrences of mangrove communities within the Project area are shown in Figure 2-15. The frequency and period of high tides (wetting and drying phase) controls the distribution of mangrove sub species. Mangrove species use sea water, groundwater and fresh water sourced from direct rainfall precipitation depending on the state of the tide. Saline sources of water contribute to sub surface growth while fresher water supplies are critical to surface foliage growth (Hayes et al., 2019, Gabler et al., 2017 and Osland et al., 2018).

#### 2.5.7 Stock water wells

The Project area is currently designated as pastoral land. Anecdotal information obtained during groundwater monitoring events (LWC, 2022b) indicate a number of windmills are present within the Project area which pump groundwater for livestock.

The BOM groundwater explorer database (BOM, 2022c) indicates six wells (two within the evaporation pond areas and four surrounding these areas) exist. The status of these wells (i.e. whether they are currently in operation) is unknown. This assessment will focus on the four wells residing outside of the evaporation pond areas: 50109390, 50108619, 50108618 and 50108614.



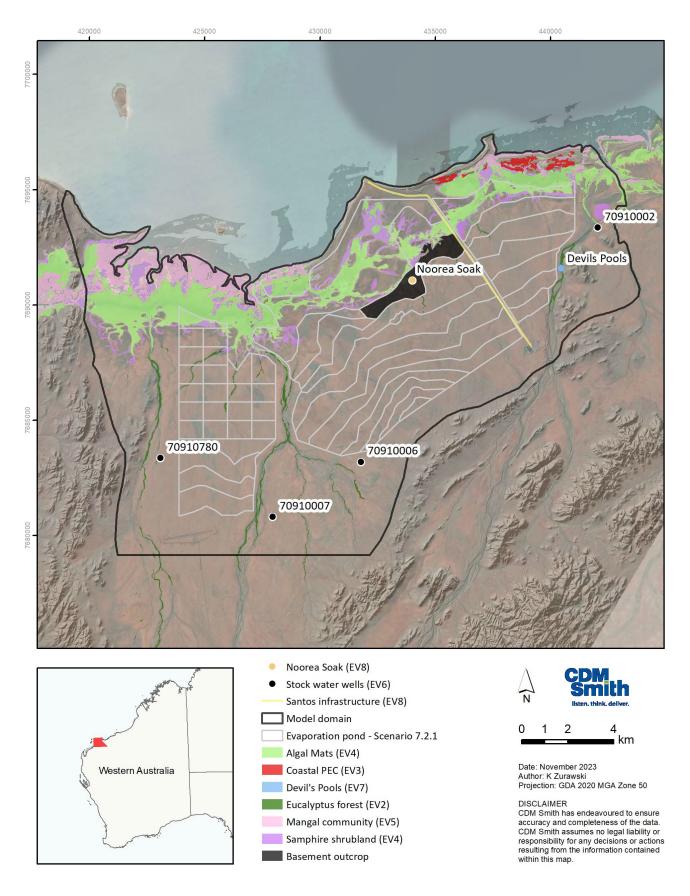


Figure 2-15 Identified environmental values within the Project area (EV1 - stygofauna not shown)



#### 2.5.8 Cultural and spiritual (soaks and pools)

#### 2.5.8.1 Overview

Cultural surveys completed within the Project area indicate a range of aboriginal heritage significance exist including artifacts, camp sites and engravings. These EVs have been considered within the groundwater studies due to potential impacts from groundwater/surface water interactions arising from development of the evaporation ponds. At least two surface water features (Norea Soak and Devils Pool) are documented to occur within the Project development envelope which have cultural and spiritual values. These features are pictured in Figure 2-15 and described in greater detail within this section.

#### 2.5.8.2 Noorea Soak

The Noorea Soak is located within the central point of the western concentration ponds in a topographical low point that is underlain by crystalline basement outcrop (Figure 1-2). Available information from both aerial imagery and remote sensing suggests Noorea Soak dries out on occasion and is not a permanent water feature. While groundwater contributions to this feature are possible, depth to water from the nearest groundwater monitoring bores (MB06 at ~1 km and MB39d at ~1.5km, Figure 2-10) measures around 8.5 and 9 m below top of casing respectively. Groundwater monitoring to date indicates little fluctuation (<1 m) of groundwater heads suggesting that discharge of groundwater to the Noorea Soak is unlikely to occur from seasonal fluctuations in groundwater elevation. CDM Smith (2023b) predicts, groundwater heads would need to increase by more than 2 m for discharge to occur to this feature. Furthermore, granitic basement rock underlying the Noorea Soak is thought to be very low permeability (ranging between 1 x  $10^{-5}$  to 1 x  $10^{-4}$  m/d according to CDM Smith (2023b)) and very unlikely to support the storage and transmission of groundwater in large quantities. Due to the lack of permanent inundation, depth and fluctuation of groundwater in the surrounding areas, and permeability of the underlying basement stratigraphy, it is unlikely the soak currently receives substantial groundwater inflows and more likely the case this feature is driven by surficial pooling within the topographic low point it resides.

A more detailed review of the hydrogeology of Noora Soak is provided as Appendix A. In order to obtain additional data to inform the conceptual understanding of this feature, a monitoring bore closer to Noorea Soak is planned. Future monitoring events should also aim to collect a surface water sample from the soak (should water be present) such that a comparison with groundwater can be made.





Figure 2-16 Field photographs of outcropping basement in the area of Noorea Soak (source: Leichhardt)

#### 2.5.8.3 Devils Pool

Devils Pool is an ephemeral surface water feature located in an area of elevated basement geology characterised by underlying low permeability igneous rock. An indication of the permanence of surface water at Devils Pool is provided by the DEA Multi Year Water Observation Statistics from Landsat data. This a statistical summary that combines all years (2004 to near present) and plots the percentage of wet observations that were observed in the landscape. According to these data, Devils Pool holds water less than 2% of the time. This observation is supported by surface water monitoring in the area which indicates dry conditions within Devils Pool and Devils Creek for the majority of time since monitoring began in December 2021 (LWC, 2023a). Images collected from the most recent monitoring round in November 2023 are shown in Figure 2-18 with dry conditions observed at both Devils Pool surface water gauging point (Y5850, pictured on the left) and Devils Creek surface water sampling point (SW11, pictured on the right). Locations of these sampling points are shown in Figure 2-5 and Figure 2-6 previously.

Monitoring data since January 2024 from Devils Pool surface water logger is shown in Figure 2-19 with comparison made against Karratha rainfall data. Monitoring records indicate minor fluctuations over the period of record that lack correlation with rainfall data. The observed fluctuations are therefore most likely attributed to changes in atmospheric pressure as opposed to surface water flows.

Additional data to support the current understanding of Devils Pool has been obtained from recent groundwater drilling investigations undertaken in the vicinity of Devils Pool (CDM Smith, 2024). Drilling of MB21s, located around 150 m adjacent to Devils Pool, encountered groundwater at around 10 m bgl. When viewing the recent groundwater levels (~8.5 m bgl) with respect to creek bed elevations, the observed depth to groundwater suggests groundwater discharge to Devils Creek and Pool is unlikely.



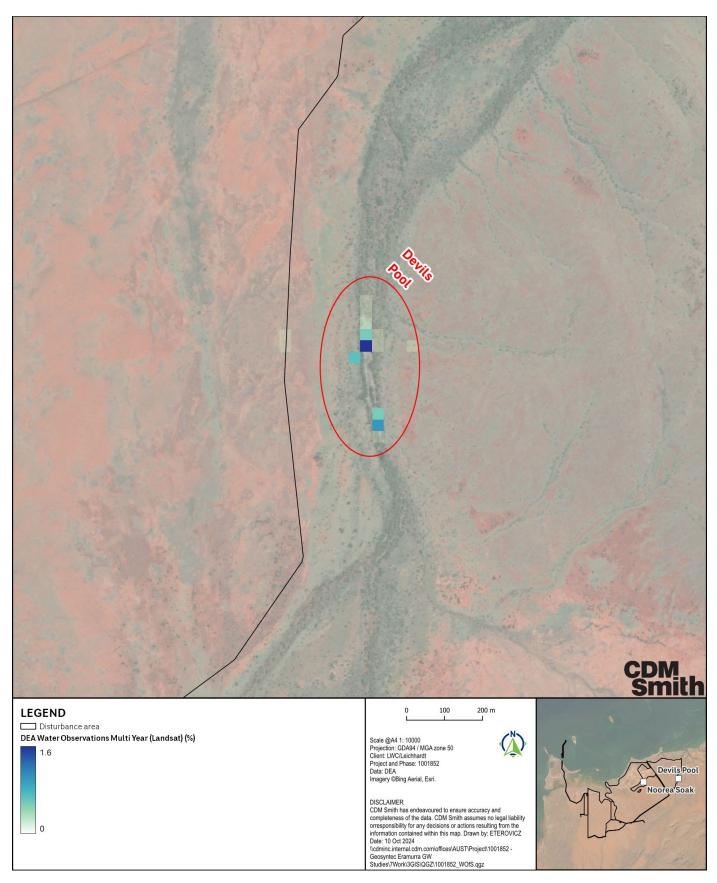


Figure 2-17 Percentage of Landsat observations in which water is detected (2004 to present)





Figure 2-18 Devils pool surface water logger location (Y5850 - left) and Devils Pool surface water sampling location (SW11 - right) (LWC, 2024)

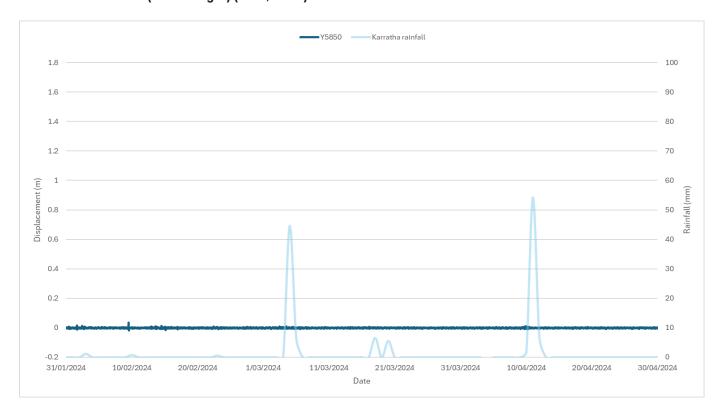


Figure 2-19 Devils Pool surface water logger (Y5850) records

#### 2.5.9 Santos Gas Pipeline

The Santos Gas Pipeline presents as the only developed infrastructure within the Project area. The pipeline extends for around 10.5 km from the coast to a transfer station located adjacent to the North-West Coastal Highway (Figure 2-15).



#### 2.6 Conceptual hydrogeological model

Figure 2-20 and Figure 2-21 present a conceptual hydrogeological model of the Project area. The model has been revised since earlier versions presented by CDM Smith (2022) and CDM Smith (2023b) to include additional information obtained from drilling and sampling programs completed during 2023/2024 and expected salinity gradients. The following describes the updates to the hydrogeological conceptualisation:

- Noorea Soak and Devils Pool are conceptualised as surface water features which experience pooling following rain events due to the low-lying topography and low permeability of underlying basement rocks. These features are unlikely to currently receive substantial groundwater inflows which is evidenced by the lack of permanence of water (remote sensing, stream gauge and surface water sampling) and depth of groundwater beneath the soaks.
- Given the relatively shallow interception of groundwater near surface water drainages (generally between 10 and 12 m), it is possible the eucalypt species within creek lines are to some extent groundwater dependent and are contributing to groundwater discharge through evapotranspiration (CDM Smith, 2024).
- The Project area may experience large fluctuations in groundwater salinity particularly in the northeast and closer to the coast. Further investigation is required to better understand the process(s) which could be contributing to the observed salinity fluctuations.
- Groundwater discharge is expected to occur predominantly as evapotranspiration within the backwater areas adjacent to the coast, where depth to water is shallow. The resulting effect generates a hypersaline interface adjacent to the coast where concentrations currently exceed 100 g/L TDS and can reach as high 240 g/L historically. Density driven groundwater fluxes are expected beneath this feature as salts infiltrate downwards into the underlying sediments. Salinity is expected to increase with depth beneath and away from this feature.
- Highly variable depth to bedrock ranging from zero (i.e. outcropping in creeks and east of MB21s) to greater than 48 m (MB38d) farther inland / from creeks. A rapid change in basement depth occurs to the west of McKay Creek that may be suggestive of faulting. Without additional structural information, it is unclear whether the basement topography is controlled by faulting or folding.
- The sedimentary cover sequence and the underlying basement potentially show a degree of connection (inferred from similar water levels between nested bores MB33s and MB33d), however, further evidence from additional nested monitoring sites and monitoring data is required to understand the relationship between the sedimentary and basement HSUs.

Encompassing the latest updates to the hydrogeological conceptualisation, the following points present the key elements of the model in full:

- 1. Rainfall is low (<300 mm), far lower than mean evaporation at around 3,200 mm/y. Rainfall mostly occurs between January and June as intense rainfall associated with low pressure systems and cyclones passing from the Indian Ocean.
- 2. Sheetflow and shallow incised channel flow is likely to occur following intense rainfall in the area that drains towards the coast.
- 3. Ponding within isolated shallow surface depressions and backwater areas can occur following storm events or tidal movements where evaporation takes place resulting in concentration of salts and infiltration to the water table. No permanent water bodies are known to exist within the Project area with creeks, soaks and pools (Noorea Soak and Devils Pool) known to dry out on occasion and unlikely to receive groundwater inflows.
- 4. Fresh groundwater recharge likely occurs through diffuse infiltration of rainfall across the Project area and surface water infiltration and infiltration via creek beds during surface water flow. Topographic lows subjected to marine water flooding during high tide and storm surges are areas of saline groundwater recharge.
- 5. Surficial deposits for most of the Project area comprise mainly of alluvial outwash and residual soil and highly weathered basement (eluvium) (CDM Smith, 2024). Depth to bedrock is extremely variable, ranging from zero (i.e. outcropping) to greater than 48 m bgl.



- a. The alluvium consists of both thin sheetwash deposits (less than 20 cm thick) and underlain by residual soil of low permeability varying between around  $1 \times 10^{-4}$  and  $1 \times 10^{-1}$  m/d.
- b. A thick and generally extensive cover of eluvium (highly weathered basement) that forms the main water bearing unit within the Project area. Hydraulic conductivity of this unit is estimated to range between 1 x 10<sup>-1</sup> and 1 m/d (LWC, 2022a).
- c. Coastal deposits comprise mangrove and lagoonal sediments characterised by clays (medium to high plasticity and generally 1 m and up to 2.5 m thick) of low permeability (1 x  $10^{-5}$  to 1 x  $10^{-1}$  m/d) accompanied by coastal sand and beach deposits of moderate to high permeability (1 x  $10^{1}$  to 10 m/d) (CMW, 2022).
- 6. The basement geology comprises Archean aged rocks of the Dampier Granitoid Complex which outcrop in a number of locations across the site and are intruded by dolerite dykes varying in width from 0.1 to 10 m (CMW, 2022). Permeability of this layer is expected to be low, at around 1 x 10<sup>-3</sup> to 1 x 10<sup>-1</sup> m/d for moderately weathered basement and 1 x 10-5 to 1 x 10<sup>-4</sup> m/d for crystalline basement (CDM Smith, 2023b). Depth to basement is highly variable and suggestive of extensive weathering processes. A rapid change in basement depth occurs to the west of McKay Creek that may be suggestive of faulting. At this stage it is unclear whether the basement topography is controlled by faulting or folding (CDM Smith, 2024).
- 7. Groundwater is present within varying stratigraphy across the site (LWC, 2022a) with the shallow sedimentary cover sequence (HSUs 1 to 5) possibly connected to deeper underlying basement HSUs (HSUs 6 and 7) (Section 2.4.2.1). Groundwater flow occurs to the northwest from inland towards to the coast and in some locations, southeasterly from the ocean towards the backwater areas.
- 8. Groundwater heads generally vary between 3 m and 9 m bql, and up to 17 m bql further from the coast.
- 9. Groundwater discharge primarily occurs as evapotranspiration within the backwater sabkha-like areas adjacent to the coast with a minor component discharging to the ocean (CDM Smith, 2023b). Discharge may also occur from terrestrial vegetation that possibly access groundwater beneath the ephemeral drainages across the Project area (CDM Smith, 2024).
- 10. Concentration of salts is expected to occur as a result of high evapotranspiration rates leading to the formation of brine in sediments below the backwater areas. Brine beneath this feature forms a hypersaline interface adjacent to the coast that increases in salinity with depth through density driven fluxes. Groundwater salinity over the Project area may fluctuate particularly in areas nearest the coast. With distance from the coast, groundwater salinity generally decreases and experiences less fluctuation (Section 2.4.3).



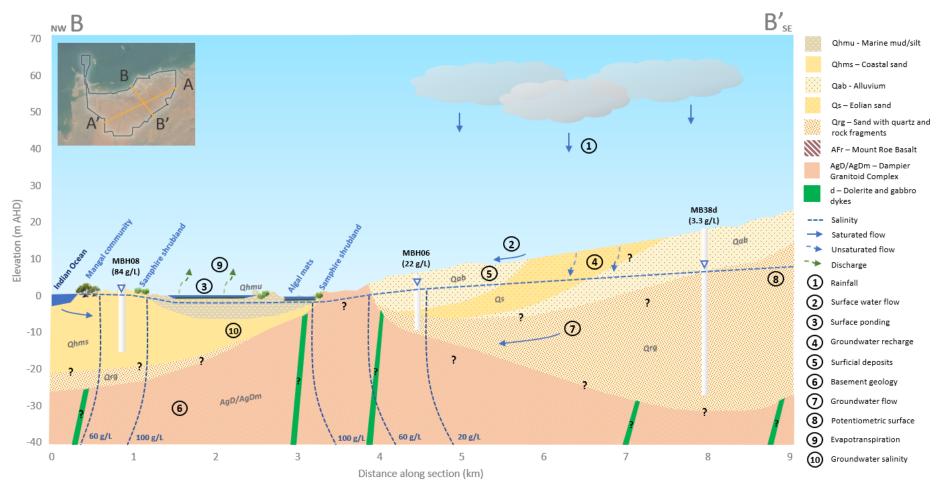


Figure 2-20 Conceptual hydrogeological model (NW-SE)

listen. think. deliver.



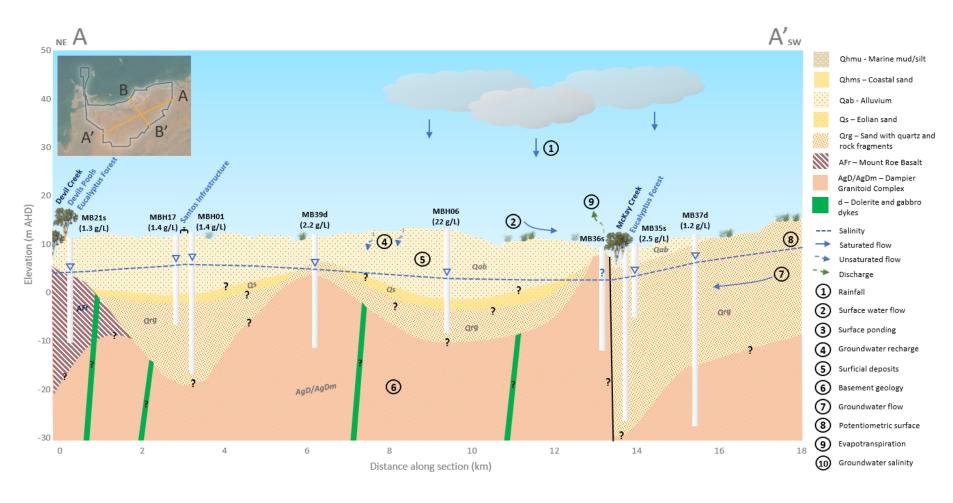


Figure 2-21 Conceptual hydrogeological model (NE-SW)



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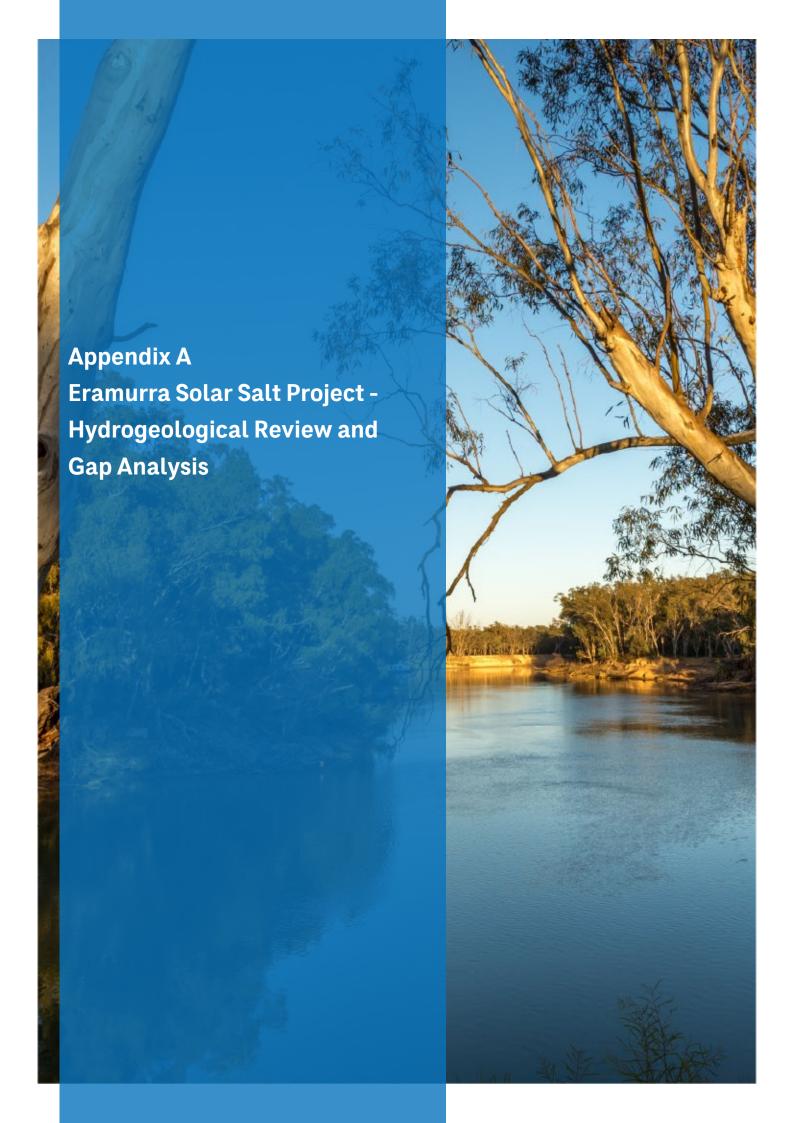
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Level 2, 238 Angas Street Adelaide SA 5000

10 June 2022

Project Number: 1000990

Dr Karen Mackenzie Land and Water Consulting Principal Geochemist 191 St Georges Terrace Perth, WA, 6000

Dear Karen

RE: Eramurra Solar Salt Project – Review of hydrogeological information and gap analysis

#### 1 Introduction

Land and Water Consulting (LWC) is currently undertaking a baseline hydrogeological investigation and groundwater quality assessment at Leichhardt Industrials Pty Ltd (Leichardt) Eramurra Solar Salt Project (the Project) on the Pilbarra coast, Western Australia (Figure 1). The Project proposes utilising seawater and natural solar evaporation processes to produce a concentrated salt product. A production rate of up to 4 Million tonnes per annum (Mtpa) is being targeted which will include a 90 km² (9,000 Ha) of concentrator area, 20 km² (2,000 Ha) of crystalliser area and 2 km² (200 Ha) bitterns, processing area, seawater intake and disposal lines and other associated infrastructure.

Salt production will occur from a series of evaporation ponds where water will flow through successive ponds over the Project area and evapo-concentrate. The perimeter embankment around the concentrator ponds and the pad for the crystalliser area will likely alter existing waterways flowing towards the Indian Ocean as well as tidal flooding of the Project land parcels. The highly saline water within the concentrator area has potential for increasing salinity of local surface water, however, the potential impacts to groundwater quality are currently unknown.

LWC have requested CDM Smith Australia Pty Ltd (CDM Smith) provide hydrogeological support for the baseline investigations and assist in understanding the potential impacts of seepage and mounding associated with the proposed project infrastructure.

This letter forms the first deliverable (Deliverable 1) as outlined in a proposal (LWC-1000990-PRP-001-0) issued to LWC on 16 December 2021 and summarises our review of the currently available information and data, likelihood of seepage and mounding to occur as a result of the Project and key data gaps to be addressed to complete seepage modelling.



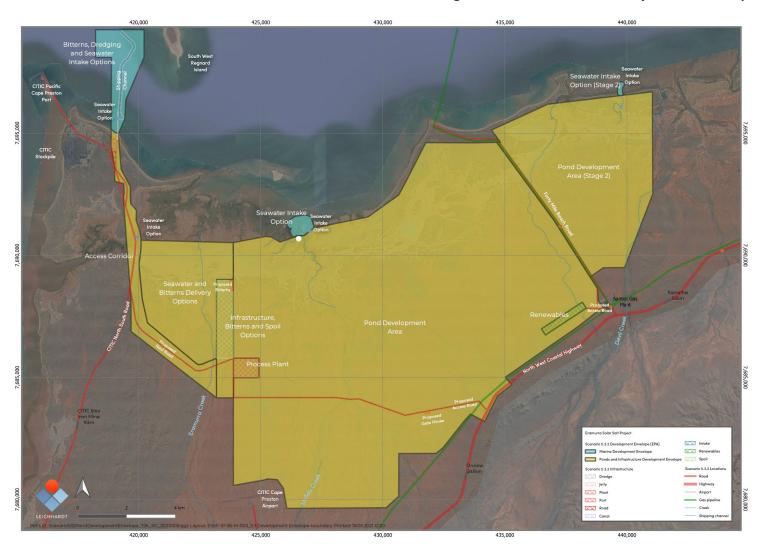


Figure 1 Eramurra Industrial Salt Project Location







Figure 2 Current conceptual layout (Scenario 6.2.0)





### 2 Review of Hydrogeological Information

LWC has provided CDM Smith with the following reports (Table 1) for review which inform various aspects of the baseline condition of the Project. Table 2 provides a summary review of the reports.

Table 1 Report register

Reference	Reference Report title Descri		Document no.
Leichardt, 2015	Eramurra Industrial Salt Project, Pilbara WA. Results of 2015 Field Soil Sampling, Climatic Measurements & Permeability Test Work	Field soil sampling and permeability test report	2015 FIELD REPORT E47-3072 FINAL
CMW Geosciences, 2020	Eramurra Salt, Cape Preston, WA. Geotechnical Desk Top Study Report for Eramurra Salt Ponds (August, 2020)	Geotechnical desk top study for the Eramurra salt ponds	PER2020-0143AC Rev0 Desk Top Report
LWC, 2021a	Desktop study of soils, sediments and groundwater quality. Eramurra Salt Project, Pilbara Coast (March, 2021)		LWC-W-AO-ASS-FR001
LWC, 2021b	Recommendations from soil, sediment, hydrology and hydrogeological deskstudy (March, 2021)	Recommendations letter of the soil, sediments and groundwater quality desktop study	LWC-W-AO-L-FR001
CMW Geosciences, 2022	Eramurra Salt Project, Cape Preston East, Western Australia. Geotechnical Investigation Report (March, 2022)		PER2020-0143AM Rev 1
LWC, 2022	December 2021 Groundwater Well Installation and Monitoring Event. Eramurra Salt Project (April, 2022)	Groundwater well installation and monitoring event report (December 2021)	W-AO-03-Eramurra -Dec 2021 Groundwater Well Installation and Monitoring Event – DR001 – Low Res





Table 2 Summary of Eramurra baseline reports

Source	Summary	Key findings (related to hydrogeological conceptualisation)
Leichardt, 2015	Document contains a project introduction and details of a field investigation conducted in November 2015. The field investigation includes 27 locations in two primary areas; 40 Mile Beach (19 samples from 15 locations) and Eramurra South (13 samples from 12 locations), which correspond to the proposed salt concentrator and crystalliser locations respectively. In addition two climatic data loggers were established at each location to measure solar evaporation rates.  Results show very low permeability in the topmost soil layers, preventing percolation and therefore limiting losses from evaporation pond establishment. Data indicates Eramurra is well suited to the establishment of a solar salt operation and climatic data collected is consistent with published historical data which shows characteristically high evaporation rates.	<ul> <li>Samples from 40 Mile Beach results:</li> <li>Material consists of poorly sorted material ranging from clay to sand with minor contents of fine-grained gravel in some samples</li> <li>Hydrometer permeability: 8.3 x 10<sup>-5</sup> m/s to 1.8 x 10<sup>-9</sup> m/s (mean 2.5 x 10<sup>-8</sup> m/s)</li> <li>Tri-Axial permeability: 8.2 x 10<sup>-8</sup> m/s to 1.5 x 10<sup>-10</sup> m/s (mean 9.5 x 10<sup>-9</sup> m/s)</li> <li>Tri-Axial values significantly less compared to that calculated from grain size with the mean value indicating water movement to be very low at the pond base.</li> <li>Samples from Eramurra South results:</li> <li>Material has a uniform grain size distribution ranging from clay to sand</li> <li>Hydrometer permeability: 4.2 x 10<sup>-8</sup> m/s to 6.7 x 10<sup>-10</sup> m/s (mean 8.3 x 10<sup>-9</sup> m/s) Actual permeabilities are likely less due to electrostatical interactions.</li> <li>Tri-Axial permeability: 2.7 x 10<sup>-8</sup> m/s to 6.9 x 10<sup>-11</sup> m/s (mean 9.1 x 10<sup>-9</sup> m/s)</li> <li>These values are considered low, indicating highly suitable percolation rates.</li> <li>Two climatic stations were installed at the project areas and there is no statistical difference between the values collected at the two locations. Climatic data recorded supports BOM data for the area and is consistent with very high rates of solar evaporation.</li> </ul>
CMW Geosciences, 2020	A desktop study comprising a technical review of available geological and geomorphology reports, maps, and data. This desktop study focuses on geotechnical considerations and includes production of thematic maps which are used in conjunction with other data (terrestrial and bathymetric contours, satellite images and aerial photography) to create interpretative layers and delineate seven terrain units: Unit 1 Beach Sands, Unit 2 Former beach ridges and dunes, Unit 3 Thin sand over intra-supratidal flats, Unit 4 Inter- supra- tidal flats, Unit 5 Alluvial Outwash, Unit 6 Rock Outcrop and Adjacent thin Soils and Unit 7 Mangrove and Intertidal Muds.	<ul> <li>Most embankments will be founded on alluvium outwash materials (Unit 5) which will likely have relatively low permeabilities expect where they are crossed by creeks and channels.</li> <li>Some of the alluvial materials have weathered to form Gilgai, which is used to form embankments could results in desiccation cracking within embankment and possible seepage and internal erosion.</li> <li>The seaward embankment is formed by the current coastal dune or will be constructed on the dune. The dune (Unit 1) is anticipated to comprise sand, and cemented sand although former beach ridges containing coarse sand shells and gravel will be present and create potential seepage paths.</li> <li>In the west a breach of the coastal dune has resulted in significant regular tidal inundation bringing into the backwater area fine-grained marine sediments (Unit 4) which are anticipated to be several metres thick especially where they obscure palaeo-channels associated with former riverine incision during times of lower sealevel in the relatively recent geological past (late Pleistocene).</li> </ul>





Source	Summary	Key findings (related to hydrogeological conceptualisation)
LWC, 2021a	A desktop study to review data and information informing ground conditions at the location of the	• Groundwater levels in the ASS areas (tidal and flood areas) are likely to be at sea level or 0.5m below current ground surface.
	Eramurra Salt project, including review of sediment, soil and groundwater quality. Sediment composition and ASS risk as well as its relationship to	<ul> <li>Groundwater gradient will likely be very shallow with groundwater persisting at around the same level from sub-tidal to distal regions.</li> </ul>
	groundwater quality was summarised by terrain unit	• Groundwater level in distal zone is around 5- 6m below ground level (or at least 6m below top of casing).
	as described by CMW Geosciences (2020).	• Limited data exists regarding groundwater quality at the site. Water quality will reflect the hydrogeological conditions (flow regime) and composition of the aquifer (i.e. sand vs clay dominance):
		<ul> <li>Unit 1 Beach Sands – uncemented dune sands offer good aquifer properties and freshwater may be present following rainfall. Groundwater will increase in salinity as water evaporates leaving additional carbonates and possibly sulfate deposits.</li> </ul>
		<ul> <li>Unit 2 Former beach ridges and dunes – as Unit 1.</li> </ul>
		<ul> <li>Unit 3 Thin sand over intra-supra-tidal flats – sediments are moist as they can act as a less transmissive layer where rainwater ponds. Water quality in the sands and muds may be relatively fresh compared to seawater, with low concentrations of trace as the water entrained may be rainwater.</li> </ul>
		<ul> <li>Unit 4 Inter- supra- tidal flats – groundwater quality will have a low oxygen content, neutral to alkaline pH, salinities are potentially seasonally variable, sulfate and trace element concentrations may be lower than in oxidised areas.</li> </ul>
		<ul> <li>Unit 5 Alluvial Outwash – groundwater is likely to have higher salinities than seawater due to the evaporative environment.</li> </ul>
		<ul> <li>Unit 6 Rock Outcrop and Adjacent thin Soils – the rocks are unlikely to be an aquifers as they are present as dykes (vertical or semi vertical forms). Cross cutting dyke may compartmentalise an aquifer limiting flow may increase salinities in an aquifer and reduce oxygen levels if oxidisable matter is present.</li> </ul>
		<ul> <li>Unit 7 Mangrove and Intertidal Muds – as Unit 4. Groundwater may have measurable quantities of hydrocarbon present.</li> </ul>
		<ul> <li>Given the proximity to the ocean, the likely flat gradient and the highly evaporative conditions it is likely groundwater will be highly saline (greater salinity than seawater). In the areas where inundation by creeks occur, water entrained in the pore spaces of these sediments may have lower salinities than seawater.</li> </ul>





Source	Summary	Key findings (related to hydrogeological conceptualisation)
LWC, 2021b	Follow on from the desktop study analysis — recommendations as to the type of field studies required to establish a baseline for the natural conditions of the site, including guidance as to suitable methods, location and frequency of data collection.  The desk study found little information on the hydrogeological conditions at the site. To improve the hydrogeological conceptualisation at the site (hydrostratigraphy, watertable elevations, hydraulic properties, hydraulic gradients, groundwater — surface water interactions and groundwater quality) field works were recommended.	It is likely that there is both freshwater and saline groundwater at site. Freshwater may exist as lenses above the more dense, saline groundwater and also within the creek bed gravels. More generally, groundwater may be saline and acidic. The presence of dykes, although not aquifer themselves, may impose upon the groundwater flow field beneath the site. The dykes may act as aquicludes, interrupting flow fields, but the water table surface can be expected to be subtle reflection of topography with flow toward the sea. If the dykes intersect, compartmentalisation of the aquifer may occur, this can lead to water level rises locally in response to seepage from the proposed ponds due to the relatively low expected hydraulic conductivity of the dykes.  To improve the hydrogeological conceptualisation at the site the following field works were recommended:  Installation of a network of groundwater monitoring wells (shallow (4 to 6 m) and deep wells (>8 m) – it is not recommended to install nested wells but wells should be paired to be in close proximity to each other):  — within the footprint of the ponds and concentrator, and upgradient of the project.  — Outside the footprint of the project for compliance monitoring  — Shallow sentinel wells positioned between the proposed pond walls and the Santos pipeline alignment to provide a compliance point and action level for possible groundwater level impacts within the pipeline alignment (note, wells already exist in this area and additional drilling may not be required)  — Screens should not cross hydrostratigraphic units and should aim to straddle the watertable  Monthly gauging of existing wells (preferably those with known construction information) should be initiated as soon as possible





#### CMW Geosciences, 2022

Results of geotechnical investigation of the Eramurra Salt Project including field mapping, algal mat sampling, geophysics survey, test pitting, electric friction cone penetrometer tests and surface sampling for triaxial permeability testing.

Interpretive geological and geomorphological maps were produced as part of this study as well as updates to the geological model for the site. The Engineering Geology overview map is included as Attachment 1 and the Geomorphology overview map as Attachment 2. The cross section from the Geophysics are included as Attachment 3.

Eleven geomorphological units were defined and mapped for the site. Most of the site lies within the unit "alluvial outwash/residual soil", a gently dipping and generally planar land surface. This land surface contains extensive areas of Gilgai and beneath this landform the superficial materials are of mixed geological origin – they contain alluvial outwash material (transported) as well as in situ weathering products (residual soil) derived from underlying bedrock. Bedrock exposure has occurred due to riverine scour in the larger creeks.

There are also extensive outcrops of igneous rock which has been exposed due to rainwater and sheet flow eroding the overlying weathered rock. Dolerite dykes are mapped across the site (historic geological map) and the more prominent dykes have been mapped as part of this study where they outcrop. The dykes vary in width from 100 mm to about 10 m.

An inferred palaeochannel based on refusal levels of CPTs is present near the ocean on the eastern side of Pond 2 containing sand and gravel with some clay to a maximum depth of -18 m AHD (although previous investigations suggest this palaeochannel extends to -45 m AHD (1989 Geopiko report – not available for this study) – the current CPTs could be refusing on layer of cobble and pebbles).

The geological material is described based on area:

- Geophysics in the area of the <u>Crystalliser Pond (A1 to E4 in current layout)</u> did not detect evidence for the presence of bedrock within the top 5 m. Test pits indicate EW to HW granite or metasediment present at >1.5 m to 3.5 m depth in this area, overlain by clay and sandy clay (high plasticity). It is expected that this clay when moisture conditioned and compacted will have a very low permeability (likely <1x10-8 m/s) which will have a propensity to crack.
- Concentrator Ponds 3 to 14 (P3a to P14 in the current layout) are located almost exclusively on the Outwash/Residual Surface, similar to the materials underlying the Crystalliser Ponds. The major exception is the presence of scattered extensive outcropping rock or inferred shallow rock (<1 m), most concentrated in the eastern parts of Ponds 8 and 9. The presence of shallow rock makes earthmoving difficult and ground preparation may create a permeable layer allowing seepage to occur under Pond Walls. A "presence of rock" impediment also exists along the northern parts of Pond 9 and Pond 10 where sheets of calcarenite are present. The presence of calcarenite create the potential for seepage of brine through the floor of the pond which not only results in loss of fluid but erosion and piping of the foundation material resulting in potential subsidence and sinkholes. Note; in the most recent design these ponds have been changed to accommodate the outcropping rock.
- Concentrator Ponds 1 and 2 (R1 and P2 in the current layout) are located within mangrove mud areas characterised by very soft and soft clays (medium to high plasticity) at the surface (generally 1 m thick but up to 2.5 m thick) underlain in turn by an inter-bedded sand and firm to stiff clay horizon. The lower clays layer is of such a strength and stiffness that it is unlikely to greatly impact the stability and settlement of pond embankments up to 3.5 m in height, whereas the upper clay upper clay is detrimental to short term embankment stability.

Geophysics undertaken using GPR and MASW interprets depth to bedrock based on interpreted material hardness and stiffness. Along the coastal wall transects the interpreted depth to "soft rock or moderately hard rock" is greater than 10 m. T-1 and T-5 extend inland from the coastal wall by 1.5 to 2 km and show decreasing depth to "soft rock or moderately hard rock" further inland. In Transect 1, this material classification is interpreted at 10 m depth within 100 m progress





inland, rising to 5 m depth 500 m inland. From 500 m inland to 1.5 km inland the "soft rock or moderately hard rock" is 0 to 5 m from the surface and "moderately hard to hard rock" is within 7 m of the surface. Transect 5 shows a slightly deeper weathering profile. Transect 7 is within the crystalliser ponds and indicates "soft rock or moderately hard rock" at the surface to deeper than 20 m and "moderately hard to hard rock" at 15 m depth for only 200 m of the profile. The geophysics report states: "The absence of shallow bedrock may be attributed to the weathering profile at the site resulting in a non-distinct and gradational boundary between the residual sediment and underlying rock and as such a reflection interface not being present in the GPR dataset. Furthermore with reference to the supplied test pit logs, where encountered at the site, rock is highly or extremely weathered GRANITE recovered as a soil with remnant structure. This material typically has similar electro-magnetic properties to the overlaying sediment and as such discrimination between the two would not be possible using the GPR method."

Permeability tests on predominantly clayey materials derived from residual soils and compacted to 95% maximum modified compaction range between  $2.89 \times 10^{-8}$  m/s and  $1.06 \times 10^{-9}$  m/s. This material was tested as it is considered to be a potential pond wall building material. Qualitative estimations were made regarding the permeability of materials likely to be encountered in the pond floors on site based on site observations:

Engineering geological unit	Description	Qualitative estimate of relative permeability	Approximate/broad permeability values (m/s)
Mangrove mud	Interlaminated clay, silt, sand	Low (vertical); low to moderate (horizontal)	10-8 (vertical); 10-8 to 10-6 (horizontal)
Lagoonal mud	Interlaminated clay, silt, sand	Low (vertical; low to moderate (horizontal)	10 <sup>-8</sup> (vertical); 10 <sup>-8</sup> to 10 <sup>-6</sup> (horizontal)
Eolian Sand	Silty sand	Moderate to high	10 <sup>-6</sup> to 10 <sup>-5</sup>
Beach rock (surface outcrop)	Open textured and vuggy	Very high	>10-4
Residual soil	Clay and sandy clay	Low to very low	10 <sup>-9</sup> to 10 <sup>-8</sup>
Granitoid rocks (EW) exposed in crystalliser pond floor cuts	Sandy gravel, clayey gravelly sand and gravelly sandy clay	Low to moderate	10 <sup>-8</sup> to 10 <sup>-6</sup>
Doleritic dyke (EW) exposed in crystalliser pond floor cuts	As for granitoid rocks but skewed towards finer soil mixtures	Low	10-8
Shallow/outcropping calcarenite	Highly to moderately weathered calcarenite	High to very high	10 <sup>-5</sup> to >10 <sup>-4</sup>
Shallow/outcropping rock	Highly to moderately weathered granitoid/ doleritic rock	Low to moderate (along joint system)	10 <sup>-8</sup> to 10 <sup>-6</sup>





Source	Summary	Key findings (related to hydrogeological conceptualisation)
LWC, 2022	Report details methodology and results of the December 2021 dry season groundwater monitoring event to inform the Hydrogeological Baseline Assessment of the project. The event included groundwater monitoring well installation (20 drilled locations with 11 installed wells ranging from 5.5 to 25.5 m deep), groundwater elevation gauging and sampling event, hydraulic conductivity testing of screened intervals at 5 wells and deployment of two groundwater level loggers and three surface water level loggers.  A combination of shallow and deeper wells were proposal to target possible perched aquifer/sub surface creek flow as well as the deeper fractured rock regional aquifer. Monitoring wells were installed between 29/11 and 18/12 2021. Whilst drilling occurred at each of the proposed groundwater investigation locations, construction of groundwater monitoring well was not undertaken at some locations as groundwater was not encountered during the drilling program to the target depth of 23 m BGL.	The lithology encountered comprised alternating layers of predominantly gravelly sand/ clay material and sandy clay/ clayey sand material. The lithological logs do not identify rock but rather describe soil texture (i.e. highly weathered rock may present as "clay" and this is not differentiated in the bore logs).  Groundwater was not present in any one single lithological unit and was identified at varying depths in varying formations.  The depth to groundwater across the network ranged from 2.92 m PVC (MBH03) to 8.872 m PVC (MBH06). At the time of reporting, surveyed elevation data for the newly installed monitoring wells was not available. Consequently, there was insufficient data to interpret groundwater flow direction. It is expected that groundwater flow direction would be towards the coast in a westerly/ north westerly direction.  Purging and development during the program indicated good recovery rates except for MBH06 and MBH013 where lower recharge rates were observed. Slug testing at four wells indicates hydraulic conductivity values between 0.06 to 1.7 m/d in the saturated aquifer materials.  Groundwater sampled from monitoring wells across the network reported TDS concentrations ranging from 1,200 mg/L (MBH09) to 240,000 (MBH19). At the lower end of the spectrum, groundwater is marginally suitable for drinking water purposes, however, higher salinity waters may be suitable only for the maintenance of marine ecosystems. The groundwater wells with the highest reported TDS concentrations tend to be nearer to the coastline. All waters appear to be dominated by sodium-chloride-potassium type waters (MBH012 to a lesser extent).  Concentrations of pH, TDS, major cations/anions, various metals/metalloids and nutrients were reported above the adopted guidelines criteria for drinking water, recreation, freshwater, marine water, irrigation and/or livestock water use.





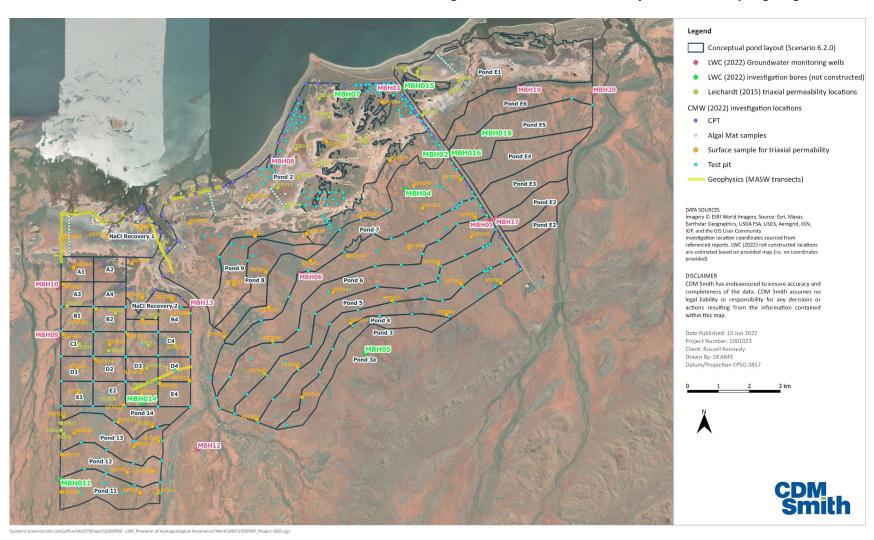


Figure 3 Relative position of sampling locations from reviewed reports





Based on the above, the following draft hydrogeological conceptualisation has been developed by CDM Smith:

- The physiography of the area is highly varied, and results from erosional and depositional processes acting on the area's bedrock geology (Leichardt, 2015)
- The basement geology consists of Archaen Dampier Granitoid Complex geologies. Basement geologies are expressed as foliated and metamorphosed granodiorite & monzogranite forming occasional tors, overlain by Quaternary sands (Leichardt, 2015). Basement rocks outcrop in a number of locations across the site and consist of granite (within incised creeks or weathered to tors) and igneous rock exposed by rainfall and sheet flow and dolerite dykes varying in width from 100 mm to 10 m (CMW, 2022). The main area of bedrock outcrop is between P7 and P2.
- Basement rocks are overlain by varying recent deposits depending on the proximity to the coast. The surface deposits for most of the site consist of alluvial outwash and residual soil (CMW, 2022). Depth to bedrock in the alluvial outwash/residual soil area is extremely variable, ranging from zero (i.e. outcropping) to greater than 28.5 m (the depth of the deepest well that did not encounter competent rock MBH01). The geophysics survey completed for the CMW 2022 shows depth to "moderately hard to hard rock" greater than 15 m depth in the area of the crystalliser pond (only present over a 200 m length of section) up to within 7 m of the surface in Transect 1 within 500 m of the coastal wall.
- CMW (2022) observations including areas of lush vegetation, discontinuous boulders and slight increases ins surface relief point to "a highly variable and undulating granite subcrop/outcrop buried beneath residual soils of variable thickness and transported alluvium". The alluvium is described as both thin sheetwash deposits (less than 20 cm thick) and alluvium associated with recent and palaeo surface drainage. The residual soil is described as sandy clay with gravel and clay with sand.
- Closer to the coast, Ponds PE1 and P2 are located within mangrove mud areas characterised by very soft and soft clays (medium to high plasticity) at the surface (generally 1 m thick but up to 2.5 m thick) underlain in turn by an inter-bedded sand and firm to stiff clay horizon (CMW, 2022). There are also areas of sand dunes and beach rock within the footprint of these ponds consisting of sand and gravel.
- Groundwater is present within varying lithological units across the site (LWC, 2022). Detailed discussion of geology based on the groundwater drilling program has not yet been reported.
- During the LWC drilling program, where rock was present in the near surface, the bore was dry and not installed. Depth to groundwater varied from 2.3 to 8.3 m below ground level (bgl), with the shallowest depth to water at the coast (<4 m bgl) and deeper groundwater recorded inland. Given the gently sloping nature of the landscape, it is likely the watertable is very flat in this area.</p>
- Hydraulic conductivity of saturated aquifer materials indicates low to moderate permeability (0.06 m/d to 1.7 m/d) where tests were completed. One well tested (MBH09) could not be analysed to a lack of useable early to mid time data, indicating a potentially higher hydraulic conductivity.
- Groundwater recharge is likely through infiltration of rainfall across the broad area and infiltration via creek beds when the creeks flow. The hydrological catchment is small and does not extend far beyond the southern boundary of the site. Given the topography, the local shallow groundwater catchment is likely to be similarly small. Average rainfall in the area is between 250 and 400 mm per year, however this is generally intense rainfall related to passage of cyclones (Leichardt, 2015).
- Groundwater discharge is likely to the ocean. CMW (2022) noted areas near the coast where shallow groundwater seeps occur beneath calcrete deposits. The depth to groundwater in these areas is measured to be 3 to 4 m bgl and therefore these discharge zones are likely related to local, temporary, perched groundwater systems associated with rainfall events.





A key uncertainty in the conceptual model is the identification and distribution of hydrostratigraphical units. A draft hydrostratigraphical sequence is presented in Table 3 based on the drilling results, geophysics results and geological descriptions provided in CMW (2022) and LWC (2022) investigation reports.

Table 3 HSU categorisation

HSU	Descriptions and basis of categorisation
Moderately hard to hard rock (less weathered)	<ul> <li>Deepest unit.</li> <li>Present in geophysics from 500-1,000 m inland from the coast at around 7 m depth.</li> <li>Encountered in some drilled bores from 1 m depth to 12.5 m depth.</li> <li>Outcrops in the area between P2 and P7.</li> <li>Bores drilled into this unit were not installed due to lack of water indicating very low permeability.</li> </ul>
Soft rock to moderately hard rock (moderately weathered)	<ul> <li>Present in geophysics at 10 m below surface 100 m from coast to at the surface to 5 m deep further inland.</li> <li>At surface to more than 20 m deep in area of crystalliser ponds.</li> <li>CMW (2022) suggest low to moderate (along joint system) permeability</li> </ul>
Soft rock or stiff sediment (extremely weathered/residual soil)	<ul> <li>Present from surface or shallow subcrop across much of site and includes extremely weathered rock or residual soil.</li> <li>Extends to depth of more than 28.5 m (deepest well) in some areas.</li> <li>Groundwater monitoring wells likely screened in this HSU or alluvial outwash.</li> <li>Given the residual soil and alluvial outwash are from the same host rock and travel distance for transported material is likely to be minimal (given small catchment), it is difficult to distinguish between this HSU and alluvial outwash.</li> <li>Slug tests possibly represent this unit – k = 0.06 to 1.7 m/d, although CMW (2022) predict low to very low permeability for residual soil. The slug tests have been corrected fro gravel pack effect in the analysis but it is possible the high k results represent disturbance around the well instead of aquifer hydraulic conductivity.</li> </ul>
Alluvial outwash	<ul> <li>Present at surface across much of the site as braided channel gravels associated with modern watercourses and sheetwash gravel as a thin veneer (&lt;20 cm) over residual soil.</li> <li>Where present as sheetwash this is likely to be unsaturated.</li> <li>Where present as channel gravel or as palaeochannel infill may be saturated or seasonally saturated.</li> <li>MBH03 may be screened within the palaeochannel identified in this area and returned a k from slug testing of 0.6 m/d.</li> </ul>
Mangrove or Lagoonal muds	<ul> <li>Present at the surface in the coastal areas beneath R1, P2 and PE1 consisting of interlaminated clay, silt and sandy clay, very soft to firm and stiff.</li> <li>Up to 6 m deep near the coast so may be saturated.</li> <li>Low vertical k and moderate horizontal k (CMW, 2022)</li> </ul>
Eolian sand	<ul> <li>Present north and east of the tidal flats as dune and sandy islands consisting of a silty sand</li> <li>Generally not a deep unit and likely to be unsaturated.</li> <li>Moderate to high permeability (CMW, 2022)</li> </ul>

Estimated indicative cross sections based on the review of information are provided in Figure 4. The three sections represent three likely scenarios for the layout and distribution of the HSUs in the sub surface perpendicular to the coastline and along groundwater flow paths towards the coast. Groundwater flow and distribution in water quality





will vary along each of these sections mainly driven by the presence and/or absence of basement highs and paleo channels, as such the potential risk of the project may vary depending on the exact nature of the HSUs.

The key groundwater risks for the project are as follows:

- The water that infiltrates the surface will flow with regional groundwater towards the coast. If the rate of infiltration is greater than the capacity of the saturated geology to transmit the water, mounding may occur. Depending on the depth to watertable, the mounding may reach the base of the ponds which can reduce the effectiveness of the evaporation basins and may present stability issues for the embankments.
- Where the basement high outcrops (or subcrops above the watertable), this presents a potential barrier to groundwater movement which may make mounding more likely (i.e. the groundwater may "back up" behind the low permeability rock).
- The location, orientation and extent of buried palaeochannels will have an unknown effect on the flow of groundwater. These features may present a conduit for flow or present a hydraulic barrier, depending on the permeability of the material.
- Groundwater discharge will occur along the coast and may increase if the rate of seepage is greater than natural
  infiltration of rainwater or decrease if the seepage rate is lower. The increase or decrease in discharge and the
  possible change in groundwater chemistry may impact coastal ecosystems.





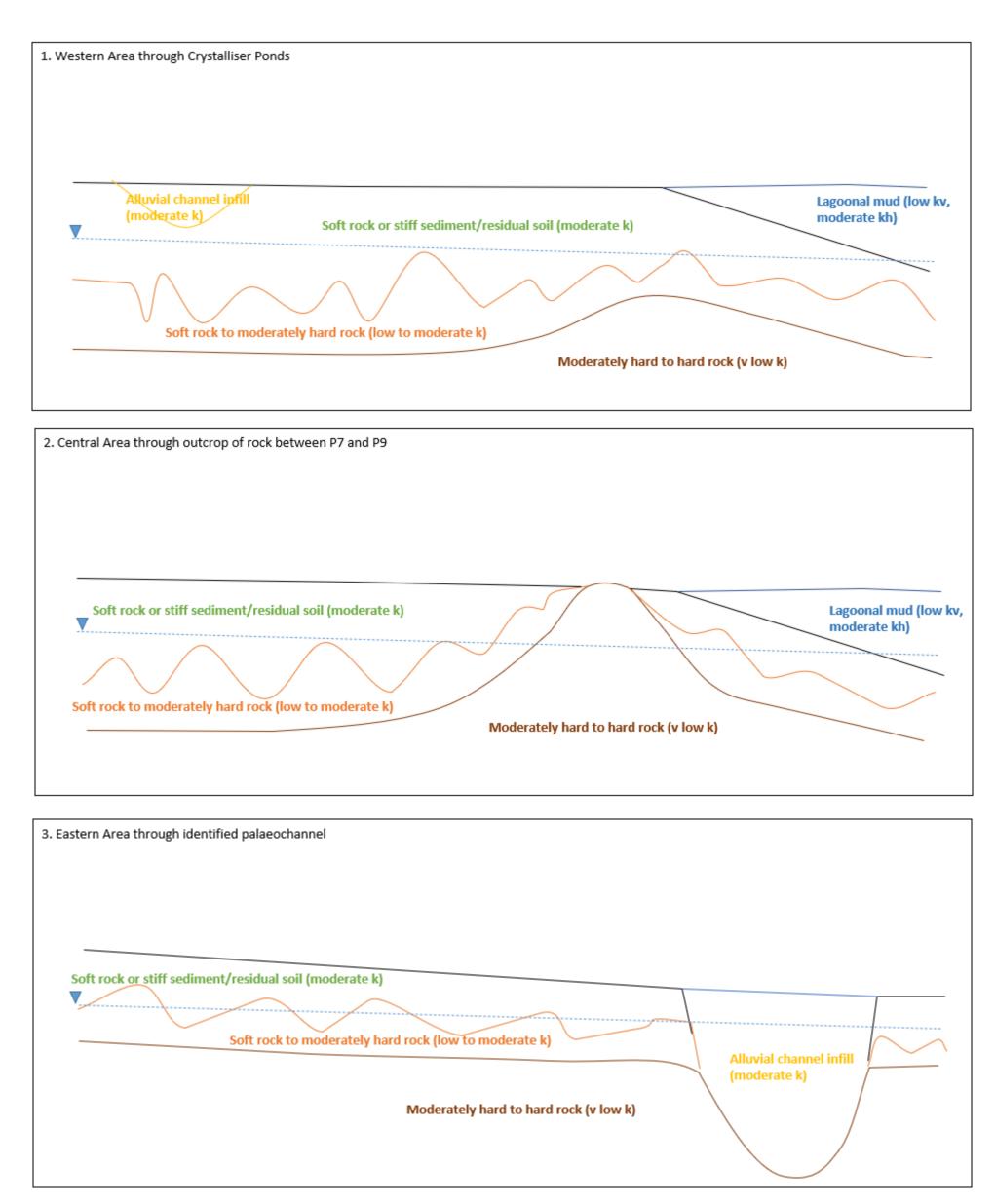


Figure 4 Conceptual cross sections of HSUs at the site



#### 3 Gap Analysis

Seepage modelling can be used to assess the project risks. A summary of data required to complete seepage modelling and the current status of data for the site is shown in Table 3. At present there is sufficient data to undertake seepage modelling at the site, however, there are still some uncertainties to be considered. It should be noted that for a site of this size, there will always be a degree of uncertainty and therefore the seepage modelling should aim to cover a broad range of scenarios that could be encountered at the site.

Further work to address the data gaps presented below may help to constrain the results of the modelling, however the effort to gather additional data may not be commensurate with the gains in constraining outputs of the model. An initial round of seepage modelling can be used to identify the parameters that most impact the outputs (i.e. the most sensitive parameters) and the further work can be focussed on those parameters.

Table 4 Data gap analysis

Data type	Description of existing data	Data gaps and recommended work
Geological conceptualisation	CMW has presented terrain units, engineering geology mapping, geophysics for specific areas and the results of shallow investigations. This data suggests relatively shallow soils underlain by rock for most of the site, with marine sediments nearer the coast. However, the results of the LWC drilling shows the depth to bedrock to be more variable across the alluvial outwash area.	Geophysics profiles along the direction of groundwater flow (likely to be perpendicular to the coastline flowing towards the coast) will assist in identifying potential barriers to groundwater flow. Seepage modelling conducted before this data is available will assume a set of possible geological cross sections based on the currently available data.
Hydrogeological conceptualisation	Depth to groundwater in 11 groundwater monitoring wells for one groundwater monitoring event.  Distribution of HSUs is unclear and the presence of perched or isolated confining conditions is unknown.	Groundwater elevation contours and inferred groundwater flow direction – survey the top of casing for all installed monitoring wells and then complete conversions to groundwater elevation from measured depth to water. Note, density corrections (pressure head) may also be required given the range of salinities seen across the monitoring network.  Seepage modelling conducted before this data is available will assume a range of watertable geometries based on the currently available data.
Climate	Rainfall is low and daily data available from nearby Karratha Aero. Pan evaporation is available for Port Headland, however, evaporation rates will be impacted by salinity.	Allowance for changing climate – complete literature review of WA guidelines for considering a changing climate.  Seepage modelling conducted before this data is available will assume a set increase or decrease in rainfall of 5% for future scenarios.  Evaporation rates – Leichardt to provide evaporation rates (assuming this has been modelled as part of the project feasibility).
Surface soil permeability	Surface permeability test results from 2015 study – there is good spatial coverage of surface permeability results but no soil infiltration testing has been completed to correlate these laboratory results with in situ conditions	In situ soil permeability conditions – complete infiltration tests at select sites to correlate laboratory results with site specific conditions.  Seepage modelling conducted before this data is available will assume infiltration rates from laboratory test represent in situ conditions.





Data type	Description of existing data	Data gaps and recommended work
Aquifer permeability	Slug testing has been completed on 5 wells but 1 was not analysable	Limited hydraulic conductivity data – slug test all wells on the site using data loggers and displacement with a solid slug that causes 1 m displacement. Conduct literature review into likely permeability of other HSUs.
		Seepage modelling conducted before this data is available will assume a range of hydraulic conductivities based on the currently available data.
Risk profile of the project in relation to groundwater receptors	LWC has identified environmental values for the site broadly but specific groundwater receptors have not been identified.	Identification of specific groundwater receptors for assessing risk – literature review and discussions with field staff.
Project details	Layout of ponds and order of filling has been provided	Timeframe for pond filling and the expected hydraulic head in each pond is required for the seepage modelling. A set of likely scenarios can be discussed with Leichardt prior to modelling.

#### **4 Future Works Program**

Based on the data and information provided, the key uncertainty associated with the progression of the seepage modelling is conceptual uncertainty, specifically the distribution of hydrostratigraphical units and the hydraulic parameters associated with each unit. Seepage modelling can be undertaken using a broad set of assumptions and the results of the seepage modelling can guide the future works program by identifying the most sensitive parameters (i.e. the parameter that most affect the outcome).

Sincerely

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#### Attachments

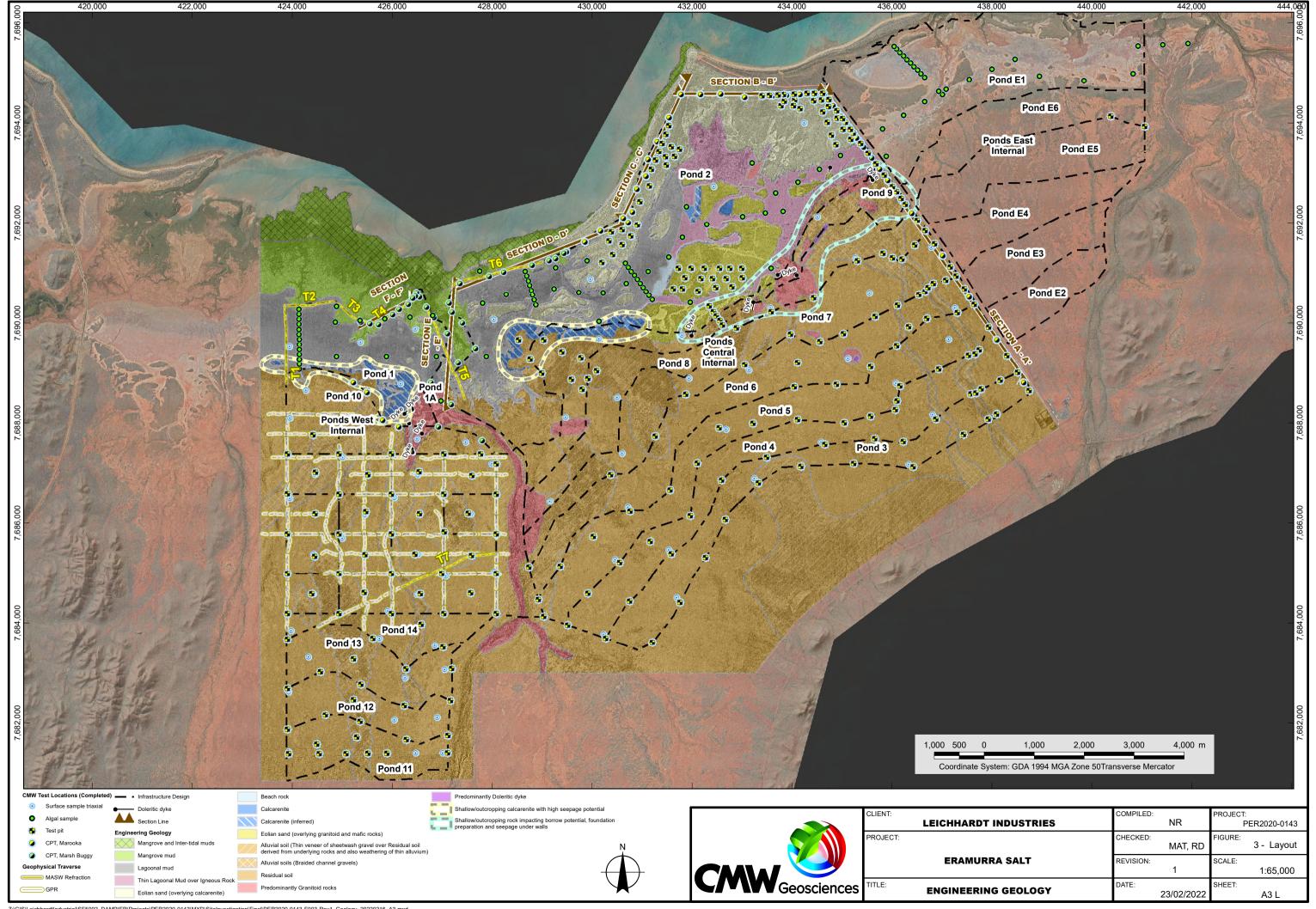
- 1. Engineering Geology Map (Figure 3 from CMW, 2022)
- 2. Geomorphology Map (Figure 2 from CMW, 2022)
- 3. Cross sections from Geophysics report (Appendix C from CMW,2022) location of transects can be seen on Attachment 1
- 4. Subsurface sections based on CPT results (Figure 4 from CMW, 2022) location of sections can be seen on Attachment 1





Attachment 1: Engineering Geology Map (Figure 3 from CMW, 2022)

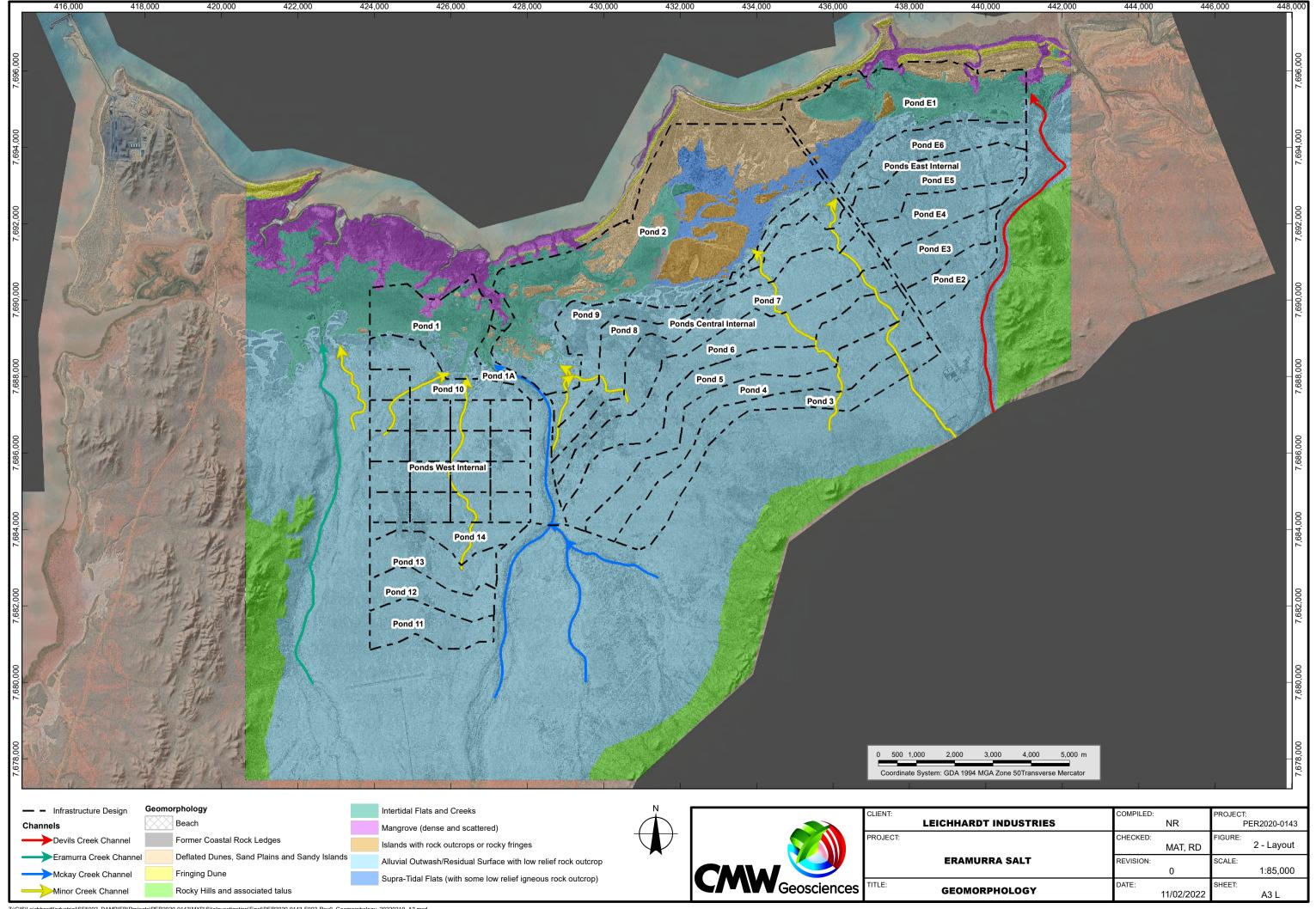






# Attachment 2: Geomorphology Map (Figure 2 from CMW, 2022)







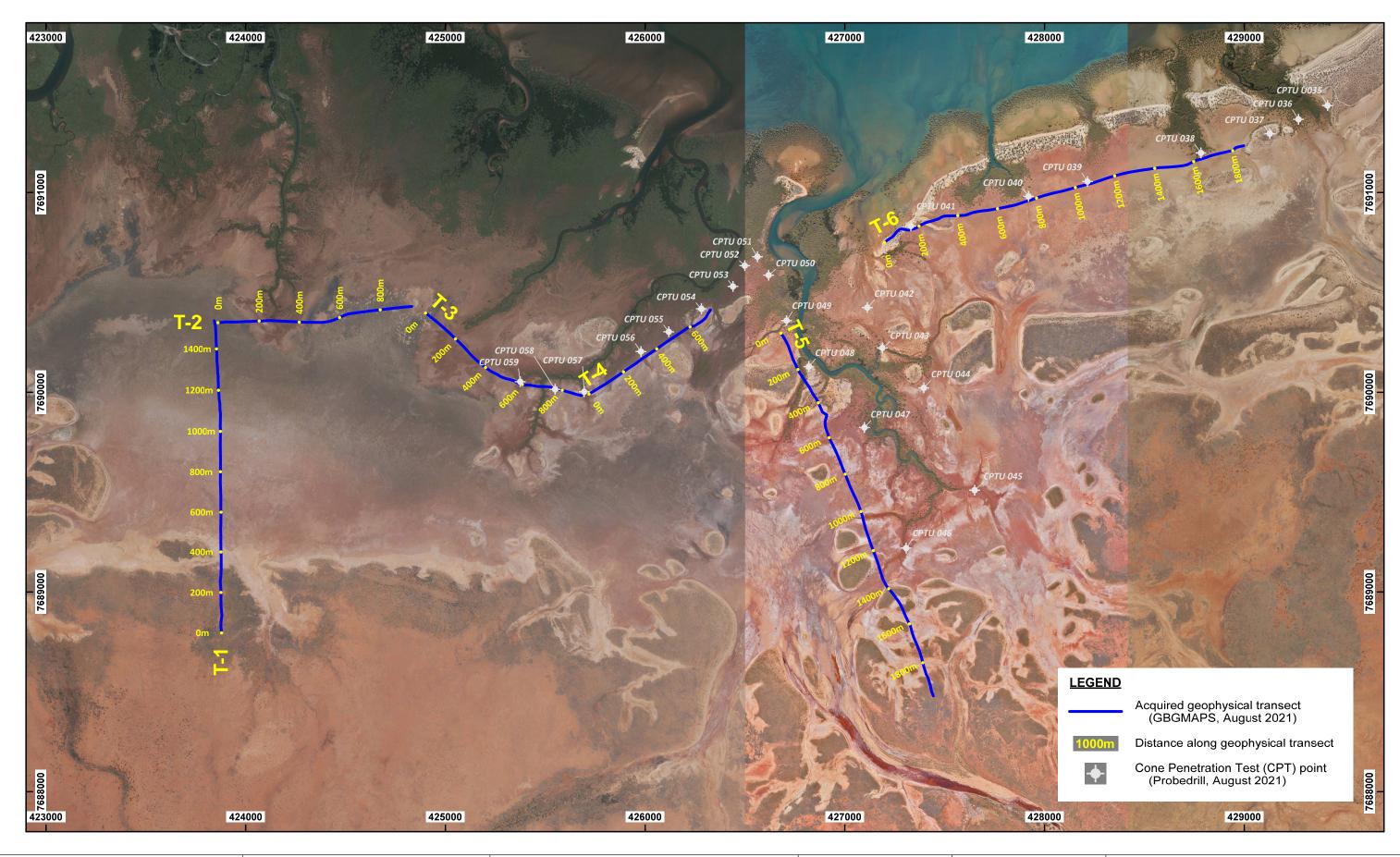
Attachment 3: Cross sections from Geophysics report (Appendix C from CMW,2022) – location of transects can be seen on Attachment 1





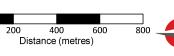
## GEOPHYSICAL INVESTIGATION FOR ERUMURRA SOLAR SALT PROJECT, MARDIE WESTERN AUSTRALIA

#### **SEA WALL INVESTIGATION SITE MAP**



<u>NOTES</u>

Drawing to be used in conjunction with Report 70631. Map Projection GDA94 MGA Zone 50. Aerial image from Landgate, May 2018.



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GEOPHYSICAL INVESTIGATION FOR		Scale	1:17,500	Drawn	AHWS
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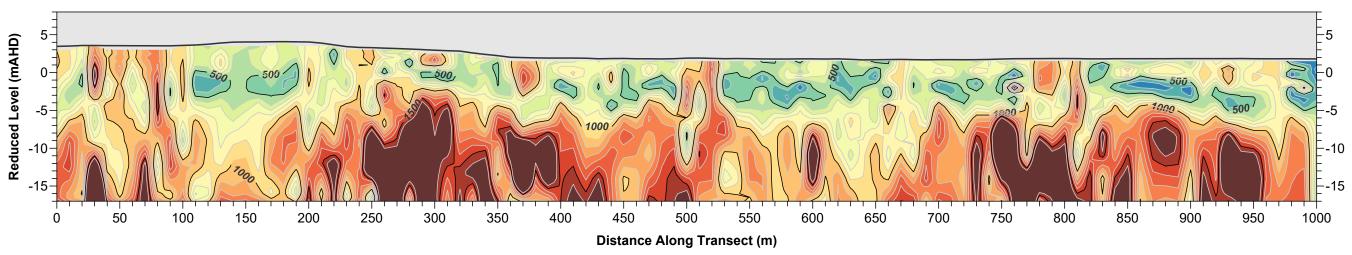


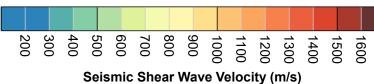


# GEOPHYSICAL INVESTIGATION FOR ERUMURRA SOLAR SALT PROJECT, MARDIE WESTERN AUSTRALIA

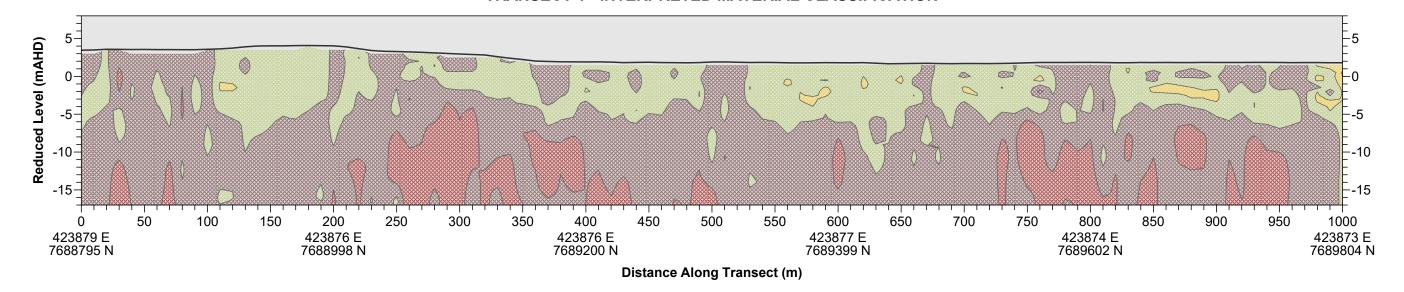
#### **MULTI-CHANNEL ANALYSIS OF SURFACE WAVE PROFILING**

#### TRANSECT 1 - SEISMIC SHEAR WAVE VELOCITY MODEL





#### **TRANSECT 1 - INTERPRETED MATERIAL CLASSIFICATION**



#### Seismic Shear Wave Velocity Material Classification

Class	S-wave Velocity (m/s)	Description
S.1	Equal to or greater than 1500	Moderately hard to hard rock
S.2	750 to less than 1500	Soft rock to moderately hard rock
S.3	350 to less than 750	Very stiff sediment or soft rock
S.4	175 to less than 350	Medium dense to stiff sediment
S.5	Less than 175	Loose to medium dense sediment

Paper Size

Drawn

Revision

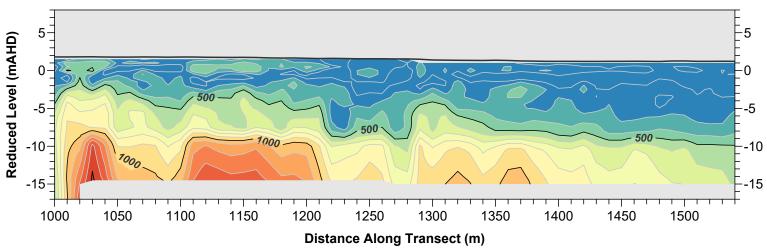
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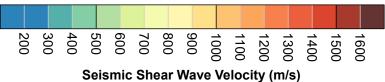
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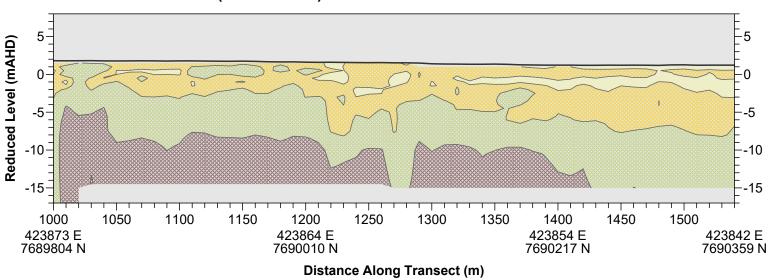
# GEOPHYSICAL INVESTIGATION FOR ERUMURRA SOLAR SALT PROJECT, MARDIE WESTERN AUSTRALIA MULTI-CHANNEL ANALYSIS OF SURFACE WAVE PROFILING

#### TRANSECT 1 (CONTINUED) - SEISMIC SHEAR WAVE VELOCITY MODEL





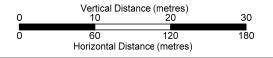
#### TRANSECT 1 (CONTINUED) - INTERPRETED MATERIAL CLASSIFICATION



#### Seismic Shear Wave Velocity Material Classification

Class	S-wave Velocity (m/s)	Description
S.1	Equal to or greater than 1500	Moderately hard to hard rock
S.2	750 to less than 1500	Soft rock to moderately hard rock
S.3	350 to less than 750	Very stiff sediment or soft rock
S.4	175 to less than 350	Medium dense to stiff sediment
S.5	Less than 175	Loose to medium dense sediment

#### NOTES



	CLIENT CMW GEOSCIENCES	Date	17 September 2021
	GEOPHYSICAL INVESTIGATION FOR ERAMURRA SOLAR SALT PROJECT, MARDIE WESTERN AUSTRALIA	Scale	1:3000 H, 1:500 V
		Drawing	70631-03

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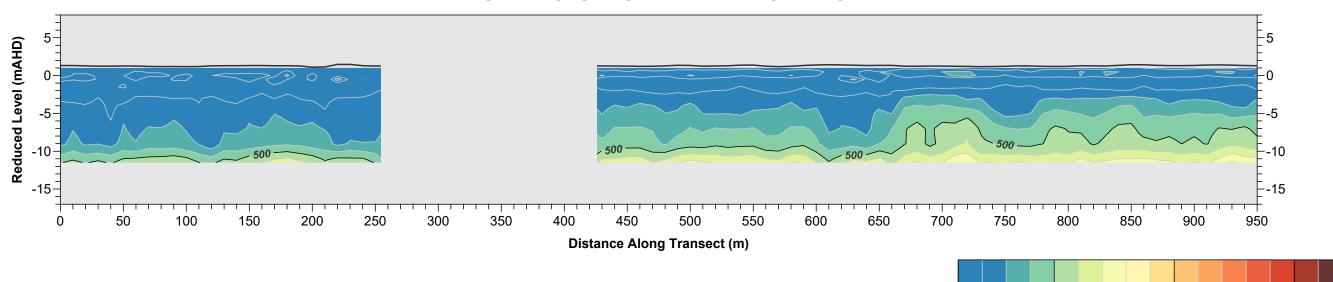
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Revision



# GEOPHYSICAL INVESTIGATION FOR ERUMURRA SOLAR SALT PROJECT, MARDIE WESTERN AUSTRALIA **MULTI-CHANNEL ANALYSIS OF SURFACE WAVE PROFILING**

#### TRANSECT 2 - SEISMIC SHEAR WAVE VELOCITY MODEL





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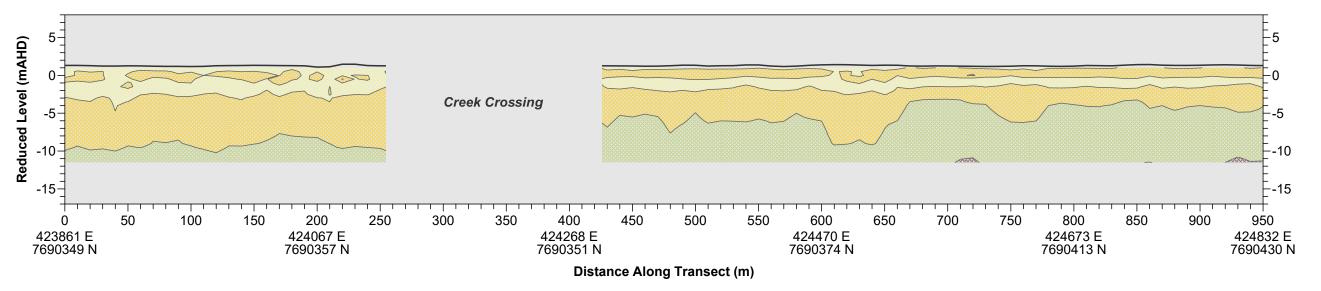
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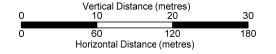
#### TRANSECT 2 - INTERPRETED MATERIAL CLASSIFICATION



#### Seismic Shear Wave Velocity Material Classification

Class	S-wave Velocity (m/s)	Description		
S.1	Equal to or greater than 1500	Moderately hard to hard rock		
S.2	750 to less than 1500	Soft rock to moderately hard rock		
S.3	350 to less than 750	Very stiff sediment or soft rock		
S.4	175 to less than 350	n 350 Medium dense to stiff sediment		
S.5	Less than 175	Loose to medium dense sediment		

# Drawing to be used in conjunction with Report 70631. Map Projection GDA94 MGA Zone 50. Aerial image from Landgate, May 2018.

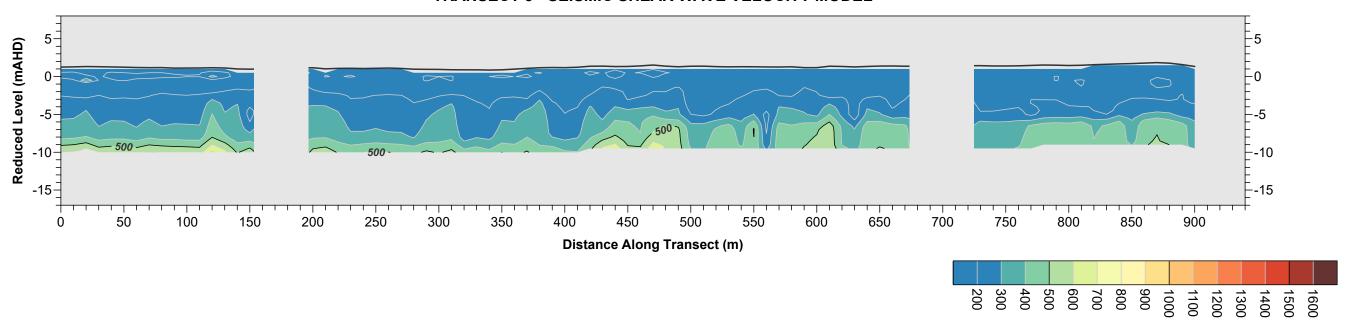


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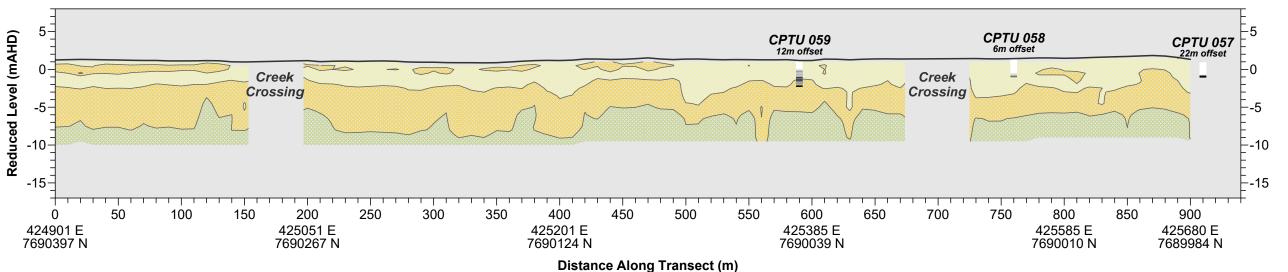


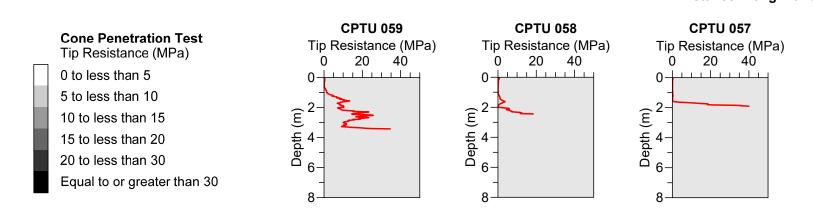
# **MULTI-CHANNEL ANALYSIS OF SURFACE WAVE PROFILING**

# TRANSECT 3 - SEISMIC SHEAR WAVE VELOCITY MODEL



#### TRANSECT 3 - INTERPRETED MATERIAL CLASSIFICATION





CLIENT

# Seismic Shear Wave Velocity Material Classification

Class	S-wave Velocity (m/s)	Description	
<b>S.1</b> Equal to or greater than 1500		Moderately hard to hard rock	
S.2	750 to less than 1500	Soft rock to moderately hard rock	
S.3	350 to less than 750	Very stiff sediment or soft rock	
S.4	175 to less than 350	Medium dense to stiff sediment	
S.5	Less than 175	Loose to medium dense sediment	

Seismic Shear Wave Velocity (m/s)

IOTES

Drawing to be used in conjunction with Report 70631. Map Projection GDA94 MGA Zone 50. Aerial image from Landgate, May 2018.

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Horizontal Distance (metres)				

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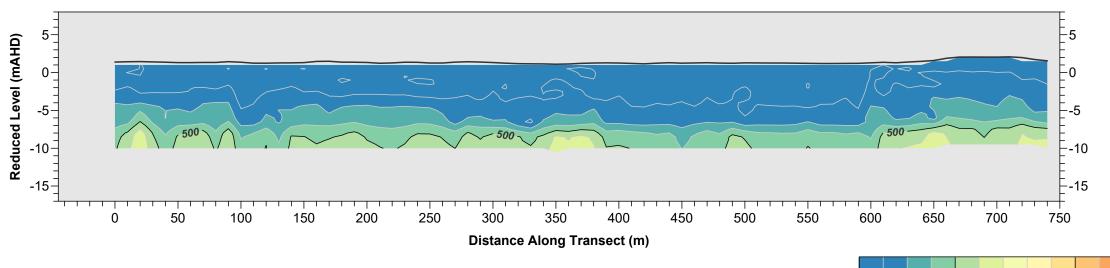


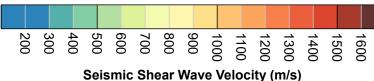
Level 1, 2 Sabre Crescent, Jandakot WA 6164 PO Box 3526, Success WA 6964 Telephone: (08) 6436 1599 Email: info@gbgmaps.com.au



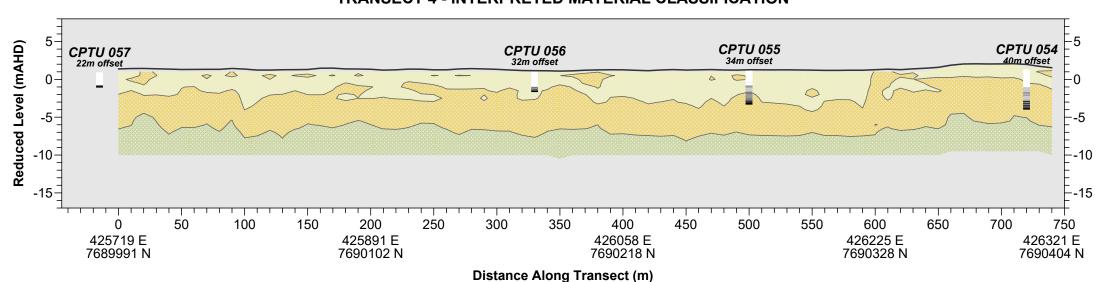
# **MULTI-CHANNEL ANALYSIS OF SURFACE WAVE PROFILING**

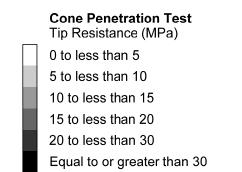


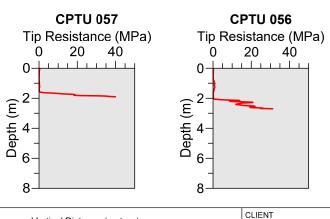


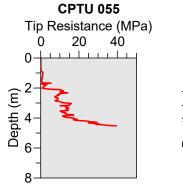


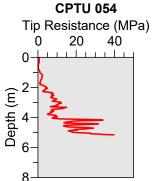
# TRANSECT 4 - INTERPRETED MATERIAL CLASSIFICATION











# Seismic Shear Wave Velocity Material Classification

Class	S-wave Velocity (m/s)	Description
S.1	Equal to or greater than 1500	Moderately hard to hard rock
S.2	750 to less than 1500	Soft rock to moderately hard rock
S.3	350 to less than 750	Very stiff sediment or soft rock
S.4	175 to less than 350	Medium dense to stiff sediment
S.5	Less than 175	Loose to medium dense sediment

IOTES

Drawing to be used in conjunction with Report 70631. Map Projection GDA94 MGA Zone 50. Aerial image from Landgate, May 2018.

Vertical Distance (metres)				
0	10	` 20 ′	30	
0	60	120	180	
Horizontal Distance (metres)				

CLIENT	CMW GEOSCIENCES
ERAMURRA	GEOPHYSICAL INVESTIGATION FOR A SOLAR SALT PROJECT, MARDIE WESTERN AUSTRALIA

 Date
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 Scale
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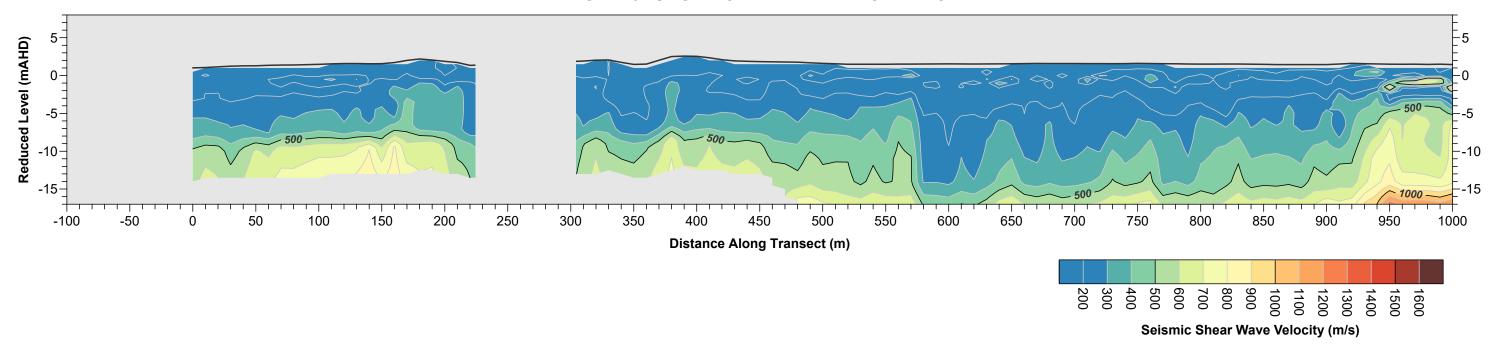


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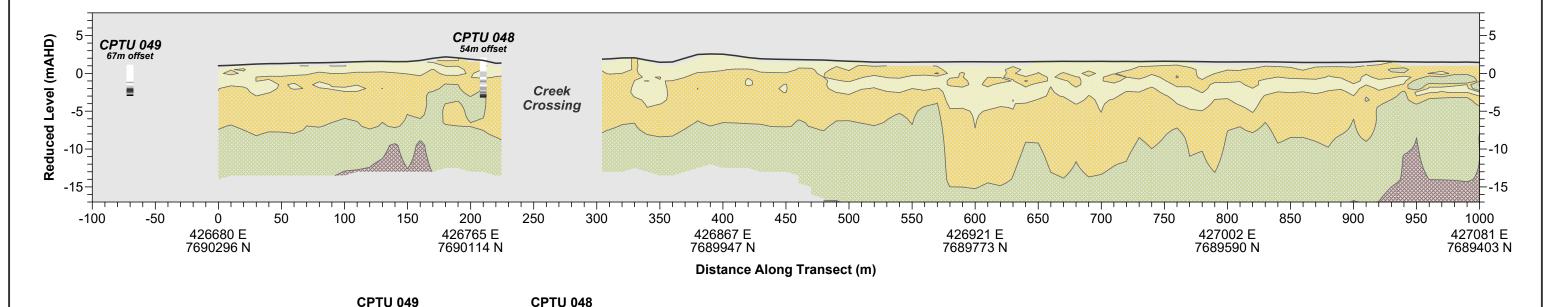


# **MULTI-CHANNEL ANALYSIS OF SURFACE WAVE PROFILING**

#### TRANSECT 5 - SEISMIC SHEAR WAVE VELOCITY MODEL



#### TRANSECT 5 - INTERPRETED MATERIAL CLASSIFICATION





NOTES

Drawing to be used in conjunction with Report 70631.

Map Projection GDA94 MGA Zone 50.

Aerial image from Landgate, May 2018.

Vertical Distance (metres)
0 10 20 30
0 60 120 180
Horizontal Distance (metres)

CLIENT CMW GEOSCIENCES

Date 17 September 2021 Paper Size

GEOPHYSICAL INVESTIGATION FOR ERAMURRA SOLAR SALT PROJECT, MARDIE WESTERN AUSTRALIA

Drawing 70631-07 Revision



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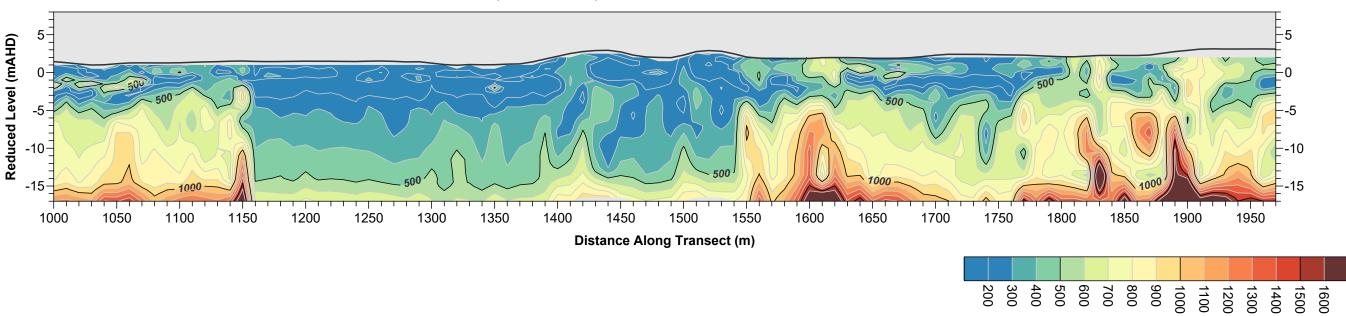
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evel 1, 2 Sabre Crescent, Jandakot WA 6164 PO Box 3526, Success WA 6964 Telephone: (08) 6436 1599 Email: info@gbgmaps.com.au

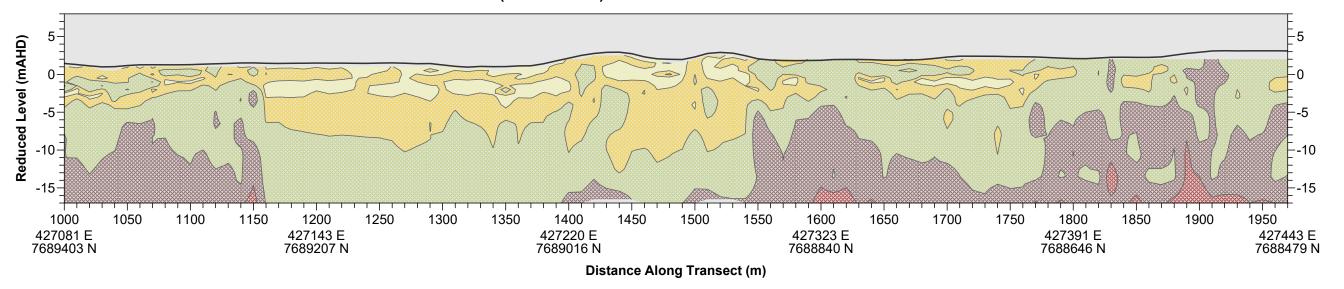


# GEOPHYSICAL INVESTIGATION FOR ERUMURRA SOLAR SALT PROJECT, MARDIE WESTERN AUSTRALIA MULTI-CHANNEL ANALYSIS OF SURFACE WAVE PROFILING

# TRANSECT 5 (CONTINUED) - SEISMIC SHEAR WAVE VELOCITY MODEL



# TRANSECT 5 (CONTINUED) - INTERPRETED MATERIAL CLASSIFICATION

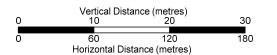


# Seismic Shear Wave Velocity Material Classification

Class	S-wave Velocity (m/s)	Description
S.1	Equal to or greater than 1500	Moderately hard to hard rock
S.2	750 to less than 1500	Soft rock to moderately hard rock
S.3	350 to less than 750	Very stiff sediment or soft rock
S.4	175 to less than 350	Medium dense to stiff sediment
S.5	Less than 175	Loose to medium dense sediment

Seismic Shear Wave Velocity (m/s)

	<u>NOTES</u>
	Drawing to be used in conjunction with Report 70631. Map Projection GDA94 MGA Zone 50.
ı	Aerial image from Landgate, May 2018.



CLIENT	CMW GEOSCIENCES	Date	17 September 2021
GEOPHYSICAL INVESTIGATION FOR		Scale	1:3000 H, 1:500 V
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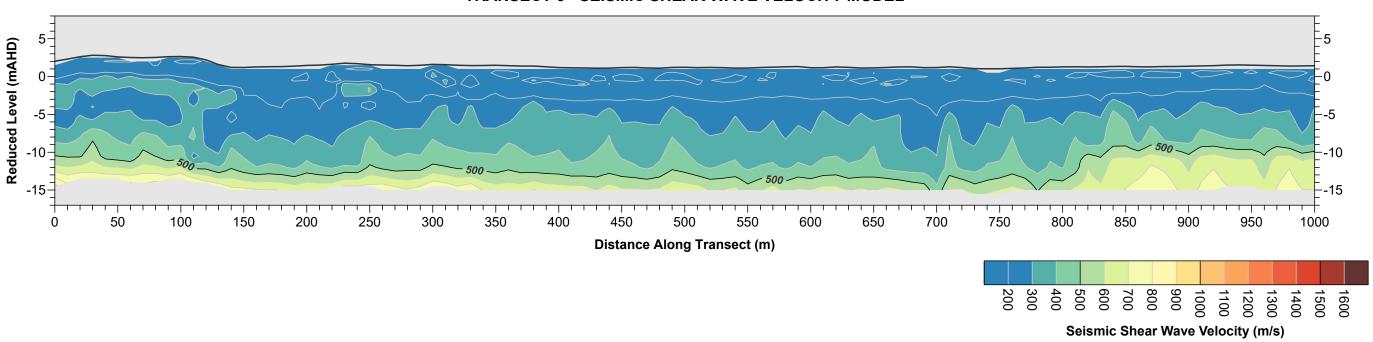
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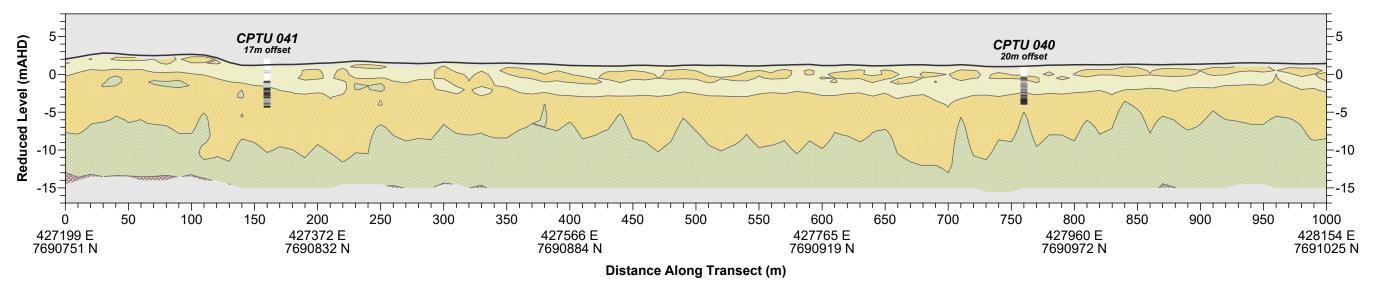


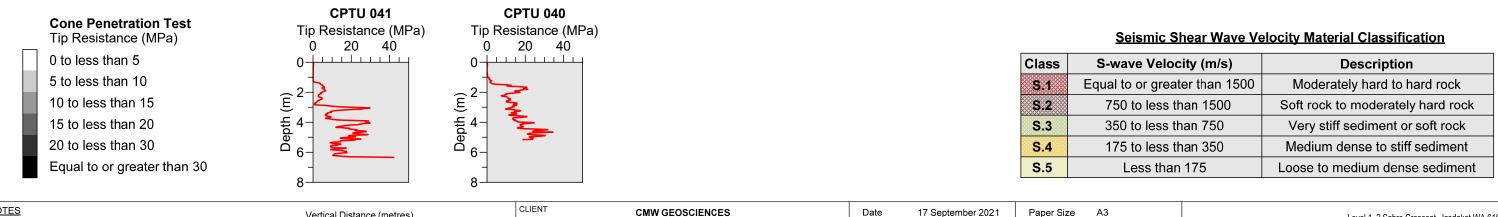
# **MULTI-CHANNEL ANALYSIS OF SURFACE WAVE PROFILING**

# TRANSECT 6 - SEISMIC SHEAR WAVE VELOCITY MODEL



# TRANSECT 6 - INTERPRETED MATERIAL CLASSIFICATION





Drawing to be used in conjunction with Report 70631.

Map Projection GDA94 MGA Zone 50.

Aerial image from Landgate, May 2018.

Vertical Distance (metres)
0 10 20 30
0 60 120 180
Horizontal Distance (metres)

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Date 17 September 2021

GEOPHYSICAL INVESTIGATION FOR ERAMURRA SOLAR SALT PROJECT, MARDIE WESTERN AUSTRALIA

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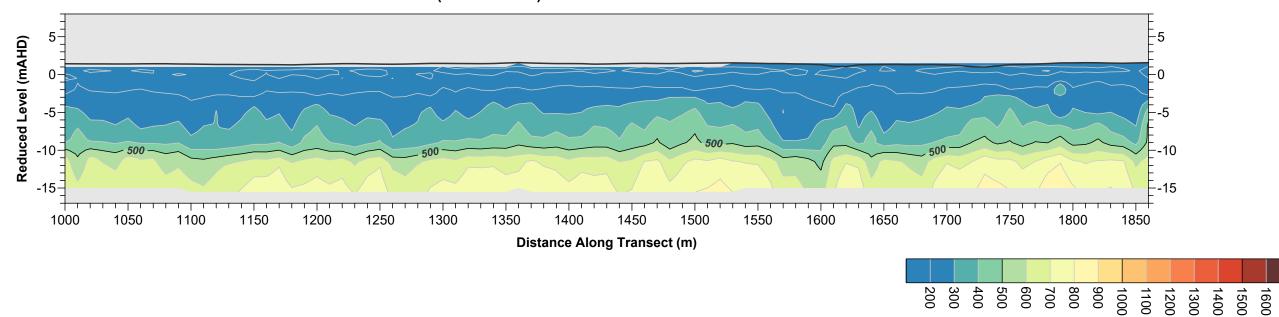
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evel 1, 2 Sabre Crescent, Jandakot WA 6164 PO Box 3526, Success WA 6964 Telephone: (08) 6436 1599 Email: info@gbgmaps.com.au

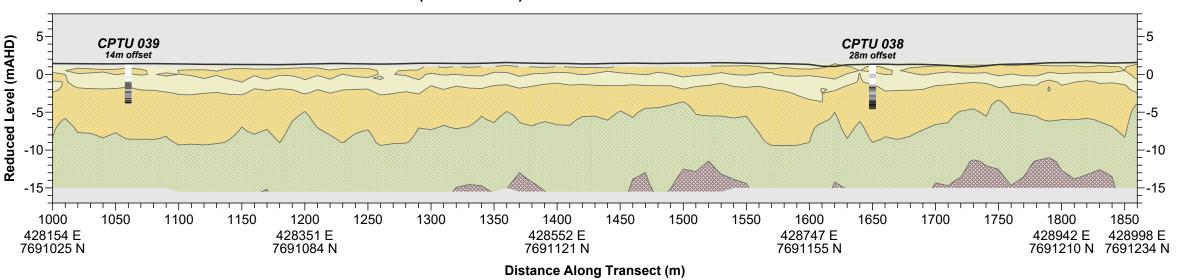


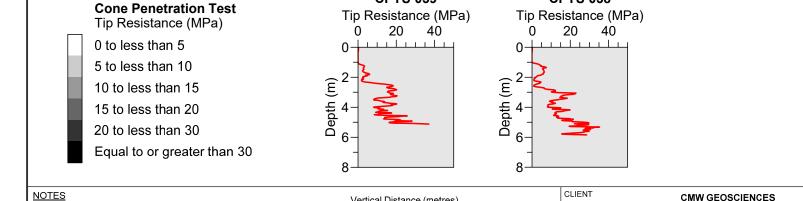
# GEOPHYSICAL INVESTIGATION FOR ERUMURRA SOLAR SALT PROJECT, MARDIE WESTERN AUSTRALIA <u>MULTI-CHANNEL ANALYSIS OF SURFACE WAVE PROFILING</u>

# TRANSECT 6 (CONTINUED) - SEISMIC SHEAR WAVE VELOCITY MODEL



# TRANSECT 6 (CONTINUED) - INTERPRETED MATERIAL CLASSIFICATION





**CPTU 039** 

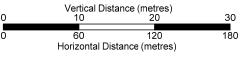
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# Seismic Shear Wave Velocity Material Classification

Class	S-wave Velocity (m/s)	Description
S.1	Equal to or greater than 1500	Moderately hard to hard rock
S.2	750 to less than 1500	Soft rock to moderately hard rock
S.3	350 to less than 750	Very stiff sediment or soft rock
S.4	175 to less than 350	Medium dense to stiff sediment
S.5	Less than 175	Loose to medium dense sediment

Seismic Shear Wave Velocity (m/s)

Drawing to be used in conjunction with Report 70631. Map Projection GDA94 MGA Zone 50. Aerial image from Landgate, May 2018.



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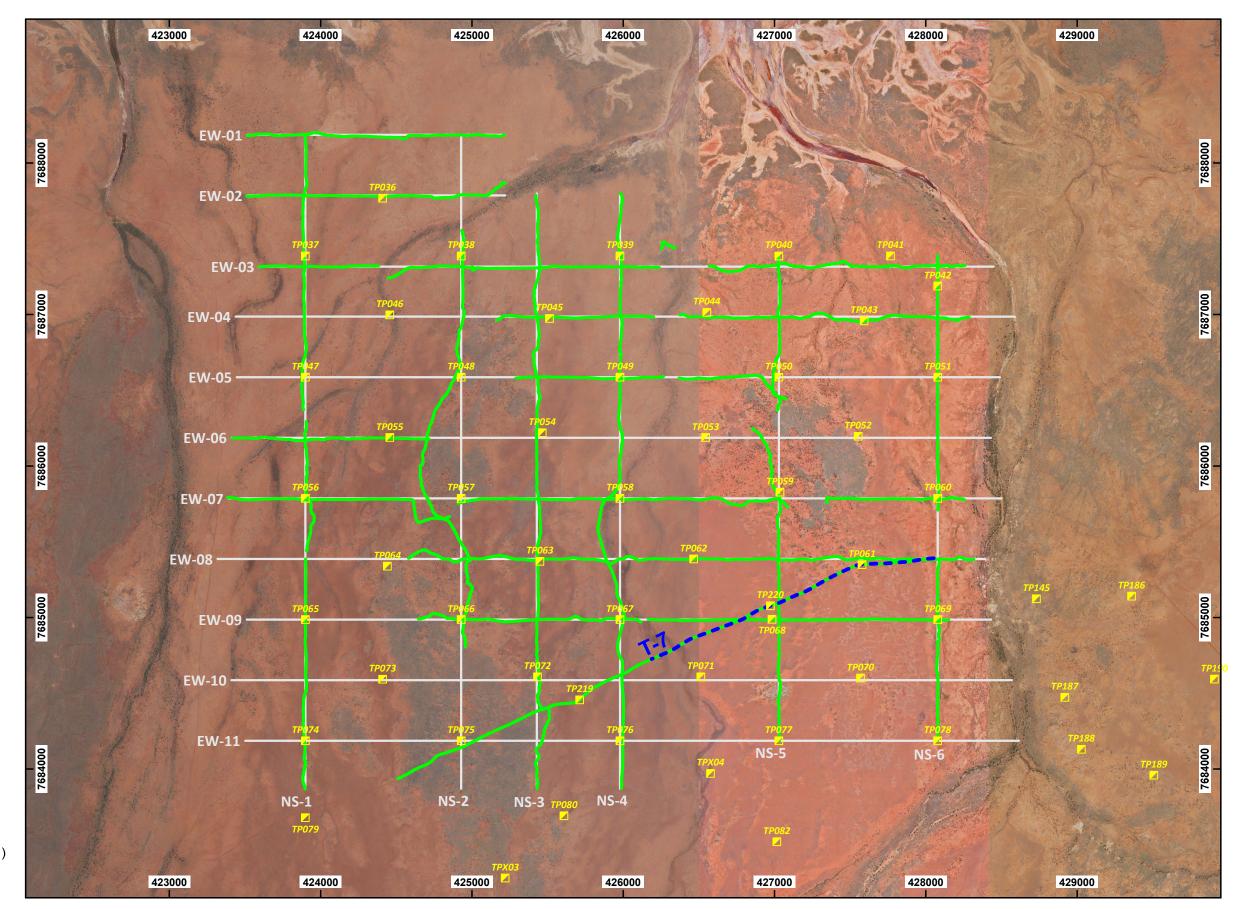
GBGMAPS

Advanced Subsurface Investigations

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# GEOPHYSICAL INVESTIGATION FOR ERUMURRA SOLAR SALT PROJECT, MARDIE WESTERN AUSTRALIA **CRYSTALLISER PONDS INVESTIGATION SITE MAP**



# **LEGEND**

Acquired geophysical transect, Ground Penetrating Radar (GBGMAPS, August 2021)

Proposed geophysical transect Ground Penetrating Radar

Acquired geophysical transect, Multichannel Analysis of Surface Waves (GBGMAPS, August 2021)

Test Pit (TP) location (CMW, August 2021)

Drawing to be used in conjunction with Report 70631. Map Projection GDA94 MGA Zone 50. Aerial image from Landgate, May 2018.



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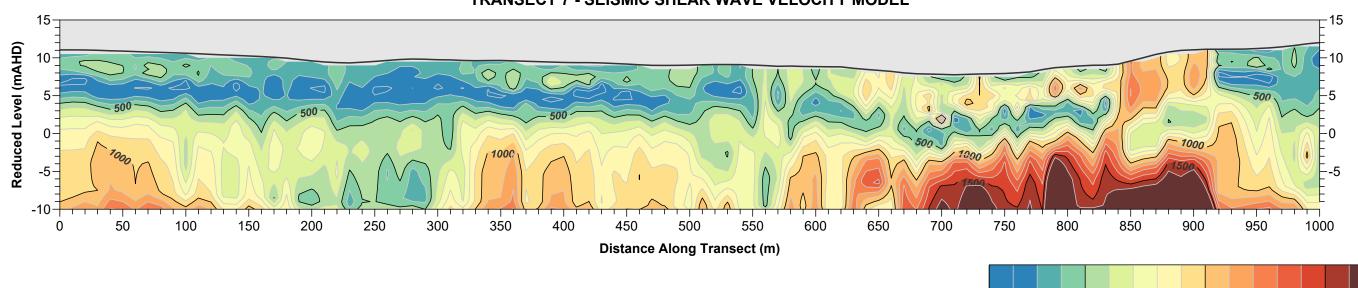
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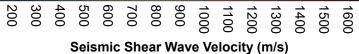




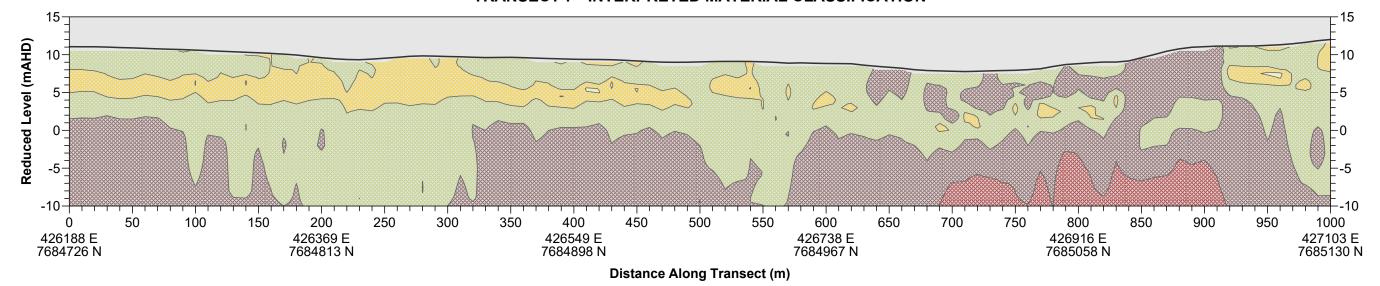
# **MULTI-CHANNEL ANALYSIS OF SURFACE WAVE PROFILING**

# TRANSECT 7 - SEISMIC SHEAR WAVE VELOCITY MODEL





#### TRANSECT 7 - INTERPRETED MATERIAL CLASSIFICATION



# Seismic Shear Wave Velocity Material Classification

Class S-wave Velocity (m/s)		Description
S.1	Equal to or greater than 1500 Moderately hard to hard rock	
S.2	\$.2 750 to less than 1500 Soft rock to moderately hard rock	
S.3	.3 350 to less than 750 Very stiff sediment or soft rock	
S.4	S.4 175 to less than 350 Medium dense to stiff sedimen	
S.5	Less than 175	Loose to medium dense sediment

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ı	Drawing to be used in conjunction with Report 70631.
ı	Map Projection GDA94 MGA Zone 50.
ı	Aerial image from Landgate, May 2018.

NOTES

	Vertical Dista	ance (metres)	
0	10	` 20 ′	30
0	60	120	180
	Horizontal Dis	tance (metres)	

CLIENT CMW GEOSCIENCES	Date	17 September 2021
GEOPHYSICAL INVESTIGATION FOR	Scale	1:3000 H, 1:500 V
ERAMURRA SOLAR SALT PROJECT, MARDIE WESTERN AUSTRALIA	Drawing	70631-12

Paper Size

Drawn

Revision

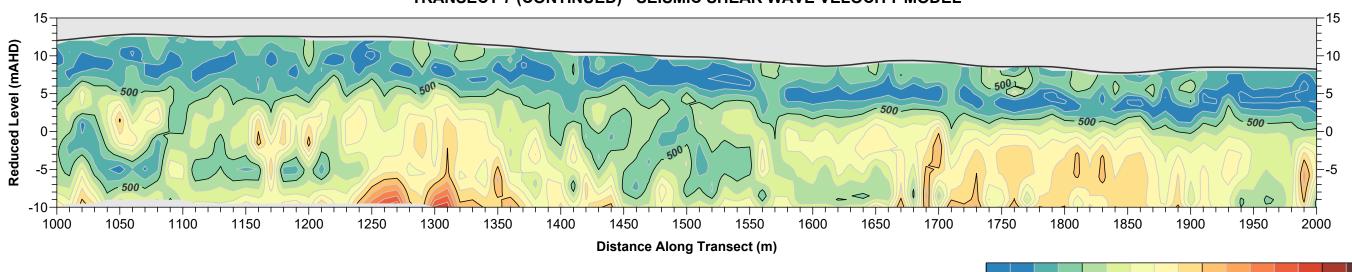
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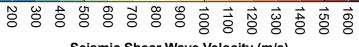
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# **MULTI-CHANNEL ANALYSIS OF SURFACE WAVE PROFILING**

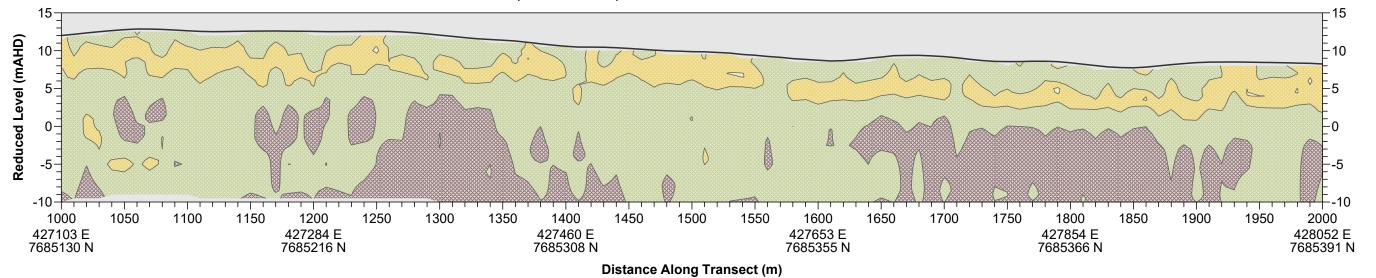
# TRANSECT 7 (CONTINUED) - SEISMIC SHEAR WAVE VELOCITY MODEL





Seismic Shear Wave Velocity (m/s)

# TRANSECT 7 (CONTINUED) - INTERPRETED MATERIAL CLASSIFICATION



# **Seismic Shear Wave Velocity Material Classification**

Class	S-wave Velocity (m/s)	Description
S.1	Equal to or greater than 1500	Moderately hard to hard rock
S.2	2 750 to less than 1500 Soft rock to moderately hard roc	
S.3	350 to less than 750	Very stiff sediment or soft rock
S.4	175 to less than 350 Medium dense to stiff sediment	
S.5	Less than 175	Loose to medium dense sediment

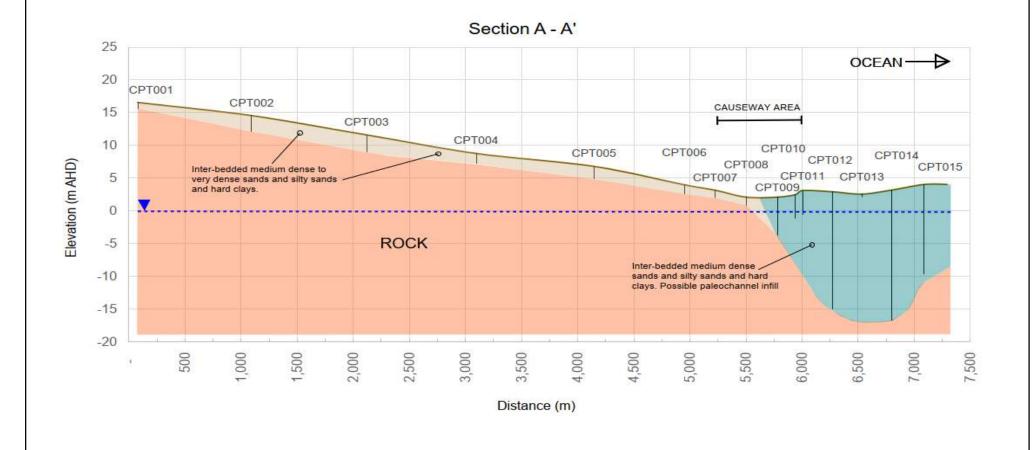
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Land and Water Consulting 1000990 Eramurra Solar Salt Project – Review of hydrogeological information and gap analysis

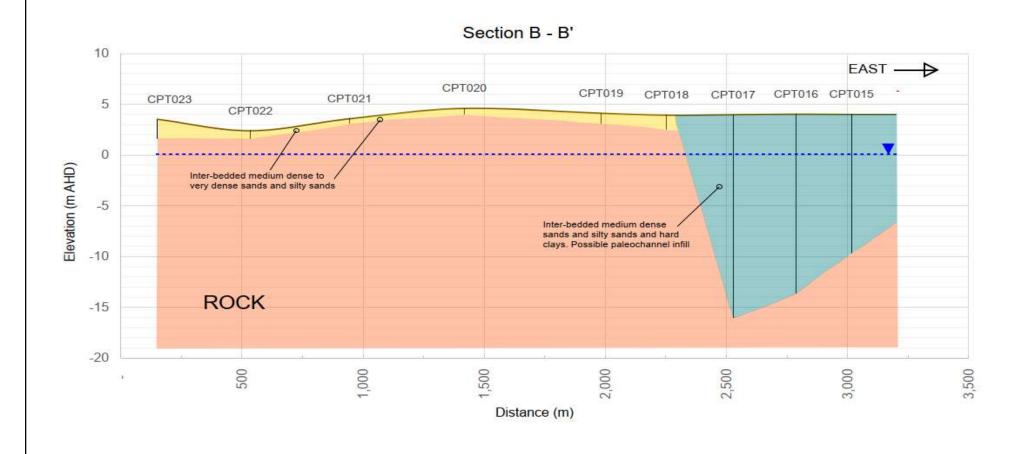
Attachment 4: Subsurface sections based on CPT results (Figure 4 from CMW, 2022) – location of sections can be seen on Attachment 1





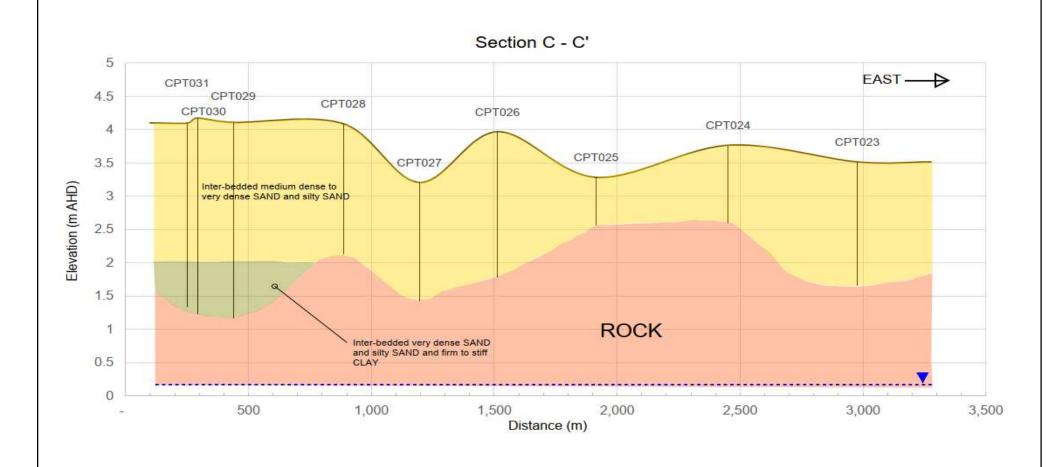
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Project:	ERAMURRA SALT PROJECT	Figure: 4 - A
Title:	CROSS SECTION A-A'	Date: 10/02/2022



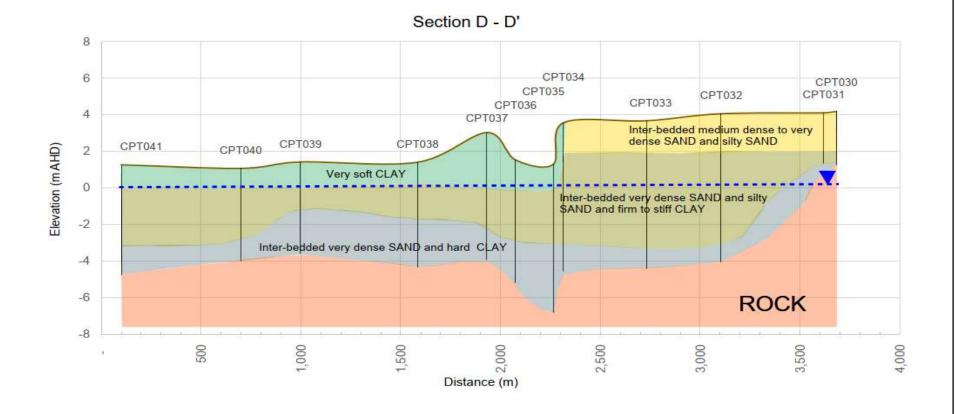
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Client: LE	EICHHARDT INDUSTRIALS PTY LTD	Project: PER2020-0143
Project:	ERAMURRA SALT PROJECT	Figure: 4 - B
Title:	CROSS SECTION B-B'	Date: 10/02/2022



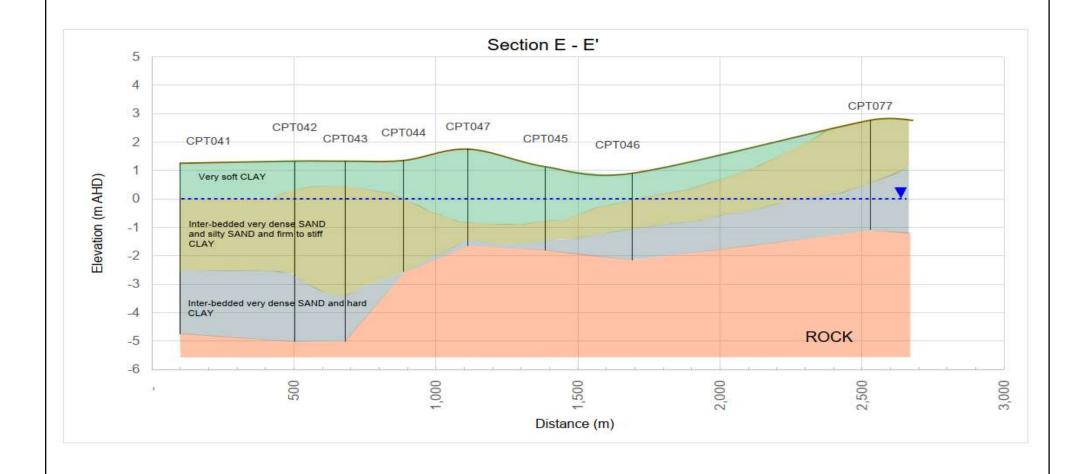


Client: LEICHHARDT INDUSTRIALS PTY LTD	Project: PER2020-0143
Project: ERAMURRA SALT PROJECT	Figure: 4 - C
Title: CROSS SECTION C-C'	Date: 10/02/2022



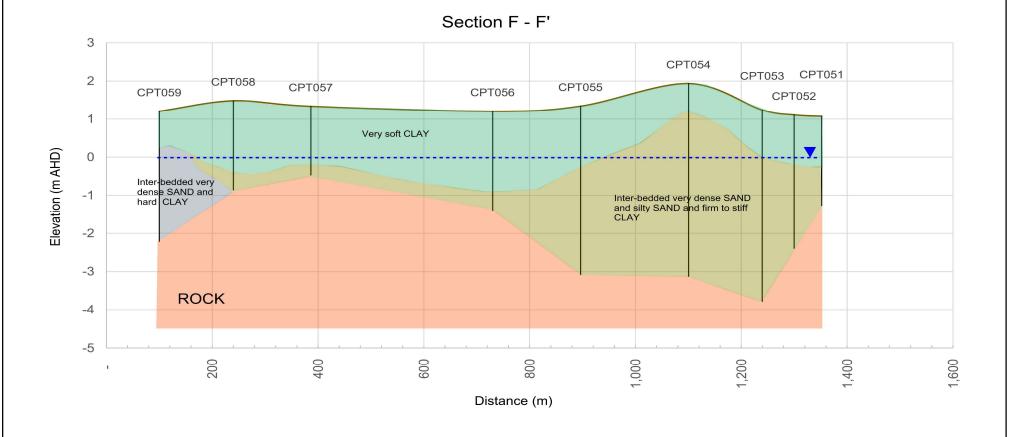


Client: LEI	CHHARDT INDUSTRIALS PTY LTD	Project: PER2020-0143
Project:	ERAMURRA SALT PROJECT	Figure: 4 - D
Title:	CROSS SECTION D-D'	Date: 10/02/2022

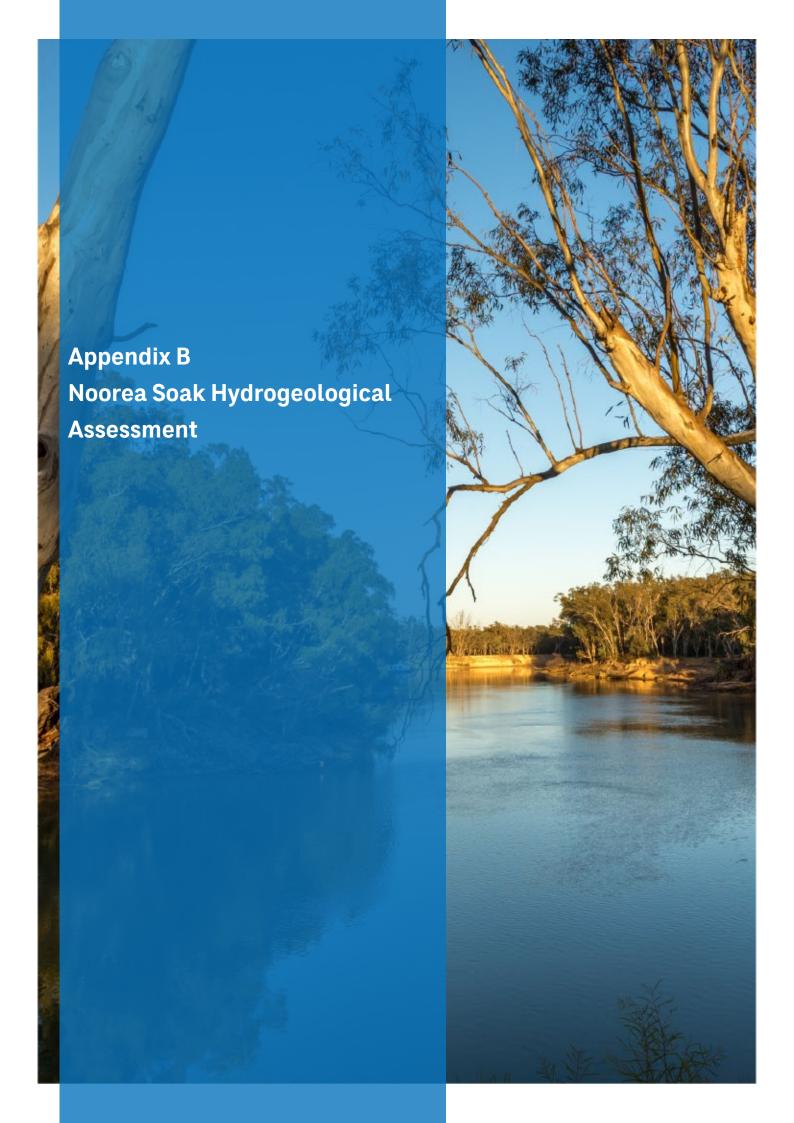




	Client: LEICHHARDT INDUSTRIALS PTY LTD		
	Project: ERAMURRA SALT PROJECT	Figure: 4 - E	
	Title: CROSS SECTION E-E'	Date: 10/02/2022	



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(		Client:	LEICHHARDT INDUSTRIALS PTY LTD	Project: PER2020-0143
		Project:	ERAMURRA SALT PROJECT	Figure: 4 - F
	Geosciences	Title:	CROSS SECTION F-F'	Date: 10/02/2022





# Memorandum

Date: 29 June 2023

Subject: Noorea Soak hydrogeological assesssment

This technical memorandum aims to provide the following:

- A baseline hydrogeological setting for the Noorea Soak,
- An assessment of potential changes due to project activities to water levels and chemistry at the Noorea Soak based on the groundwater model developed for the site, and
- A review of the potential impacts to the Noorea Soak based on the above.

This document is meant to be read in conjunction with the Groundwater Effects Assessment, where more detail about the project, groundwater setting and groundwater modelling can be found.

# **Baseline Hydrogeology**

This baseline hydrogeology has been compiled from the existing hydrogeological conceptual model, field observations, remote sensing and a compilation of aerial imagery sourced from Google Earth Pro historical imagery tool and Esri Wayback Historical Imagery (<a href="https://livingatlas.arcgis.com/wayback/#active=6984&ext=116.35704,-20.88289,116.37388,-20.87407&localChangesOnly=true">https://livingatlas.arcgis.com/wayback/#active=6984&ext=116.35704,-20.88289,116.37388,-20.87407&localChangesOnly=true</a>).

#### Geology

The Noorea Soak is located in area of elevated basement geology, with basement outcrops observed in the area of the Soak. The Soak is labelled on the geology map (Figure 1) of the area which shows the basement outcrop in the area of the soak to consist of granitoid rock. This is overlain by eluvial sand.

Photos of the area have been collected by Leichhardt on a number of occasions and show the outcropping basement (Figure 2) and the presence of water at the soak. The photos align with the geological mapping of eluvial sand overlying granitoid rocks that appear to be relatively unweathered.

During field investigations the granite was encountered in some drilled bores however these were not installed due to lack of water indicating very low permeability.



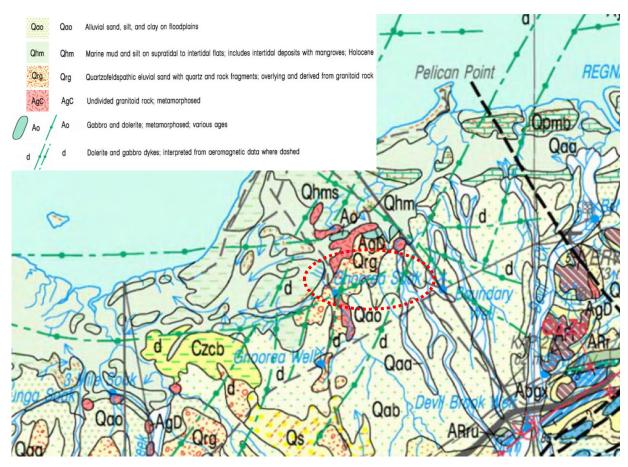


Figure 1 Clip of the geology map (1:250,000 Geological Survey Dampier-Barrow Island Map, Geological Survey of Western Australia)



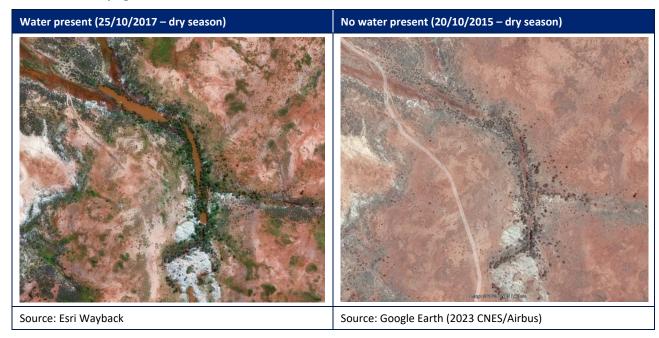
Figure 2 Field photographs of outcropping basement in the area of Noorea Soak (photos provided by Leichhardt)



# **Aerial imagery and site photos**

Aerial imagery sourced from Google Earth Pro historical imagery tool and Esri Wayback Historical Imagery (https://livingatlas.arcgis.com/wayback/#active=6984&ext=116.35704,-20.88289,116.37388,-20.87407&localChangesOnly=true) is shown in chronological order in Attachment 1. There are 13 images from October 2011 to September 2022. The imagery shows that there is often water in the soak, although not permanently. Of the 13 images, three show the soak with no water. The images are a mixture of dry and wet season and the amount of water in the soak does not appear to correlate in any significant way to the amount of rainfall recorded at Karratha Aero BoM station (IDCJAC0009), although this station is over 40 km away and rainfall over this area is expected to vary significantly.

Table 1 Varying water conditions at Noorea Soak



Site photos provided by Leichhardt show water in the soak on two occasions; 5<sup>th</sup> April 2021 and 17<sup>th</sup> August 2020. On other occasions the site was visited the soak was not photographed. In the three months preceding April 2021, 122.7 mm rainfall was recorded at Karratha Aero and in the three months preceding August 2020, 82.7 mm was recorded. There looks to be less water in the soak in the August photos and the outcropping basement granitoid can be clearly seen at the base of the pond.





Figure 3 Site photos (provided by Leichhardt) showing water in the soak on 5<sup>th</sup> April 2021 (blue points) and 17<sup>th</sup> August 2020 (green points)

# **Remote sensing**

Remote sensing data from the Sentinel 2 satellite has been downloaded and processed to assist in detecting the timeseries presence of water at the Noorea Soak. The normalised difference water index (NDWI) bands 3 and 8A can be used to determine the presence of water on the land surface. This data had been processed for a polygon shape around the soak. The timeseries represents the maximum NDWI in the polygon for that satellite image and shows that water was only detected in 12 out of 293 satellite passes (Figure 4). It should be noted that the grid size for this data is 10x10m and therefore the NDWI can only show when the pool size is greater than this grid size.



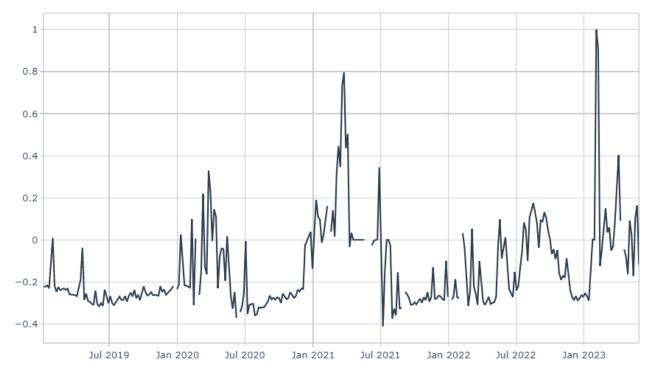


Figure 4 NDWI timeseries for polygon around Noorea Soak

#### **Summary**

The available information suggests that Noorea Soak is not a permanent water feature and is therefore not likely to receive groundwater inflows. The feature is at the end of the local and regional groundwater system and would therefore be expected to be permanently inundated if it was receiving groundwater.

The rock underlying the Noorea Soak is very low permeability basement rock and is very unlikely to support the storage and transmission of groundwater.

The current conceptualisation of Noorea Soak is that it is a surface water supported feature that collects water during rainfall and runoff events due to its location in the landscape (i.e. a depression in the ground at the bottom of the catchment) and then holds the water for a period of time after runoff has ceased. The water is unable to seep into the very low permeability basement rock (or seeps very slowly) and therefore can only exit the feature through evaporation.

This feature is unlikely to be an aquatic GDE but is assessed as a cultural and spiritual value (EV).



# Potential changes to conditions (direct effects)

The framework for this assessment and more detail around the methodology and the groundwater modelling that informs this assessment is presented in the main report. The direct effects to groundwater arising from water affecting activities (WAAs) at the site are shown in Table 1.

**Table 2 Identified Direct Effects** 

10/	NA ()	Direct effects (pathway)			Considered
VV/	AA (source)	Category	ID	Description	herein?
WAA1	Surface excavations (water	Quantity	DE1 – Increased recharge	Mounding of groundwater levels due to increased infiltration and seepage from evaporation ponds	☑
	impoundment)	Quality	DE2 – Change in salinity	Change in salinity (generally an increase) of groundwater as a result of evapo- concentrated water infiltrating to the water table	Ø
				In some areas the pond salinity may be lower than the existing groundwater (i.e. where there is hypersaline groundwater in the north east of the model domain) and salinity may decrease	
		Altered GW/SW interactions	DE3 – Change in groundwater levels	Change in groundwater levels as a result of water impoundment	☑
			DE4 – Change in groundwater flow	Change in groundwater flow as a result of water impoundment	Ø
		Aquifer disruption	-	Surface excavations do not physically disrupt underlying aquifers	X

# Quantity

The predicted groundwater elevation (RSWL) contours after 100 years of operations are shown in Figure 4– the location of the Noorea Soak is indicated by the label "DPLH 11871". Predicted time-series groundwater levels at this location is shown in Figure 5. The mean and range of predicted groundwater levels from the 100 calibrated model realisations are represented by solid lines and colour shades, respectively.



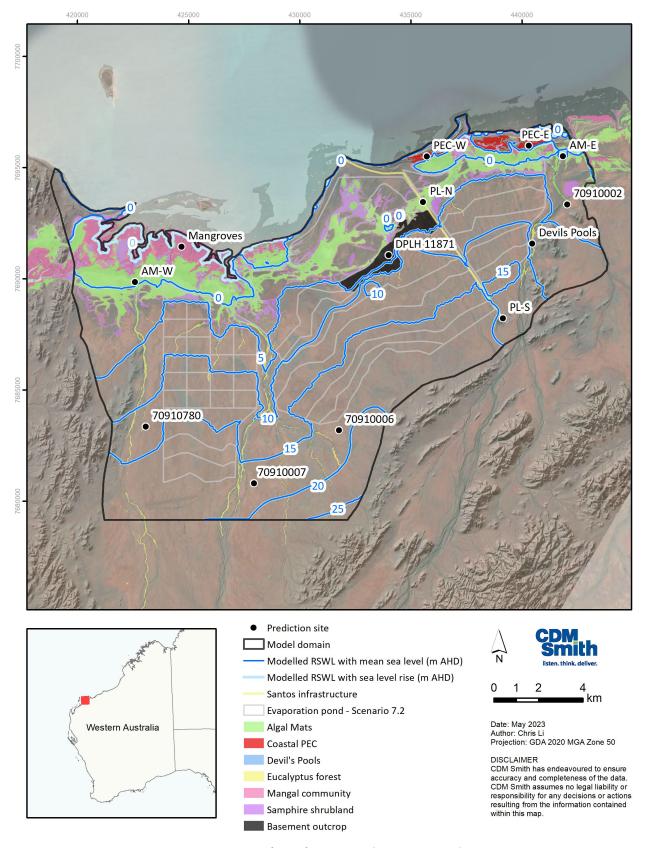


Figure 5 Predicted groundwater elevation (RSWL) contours after 100 years of operations



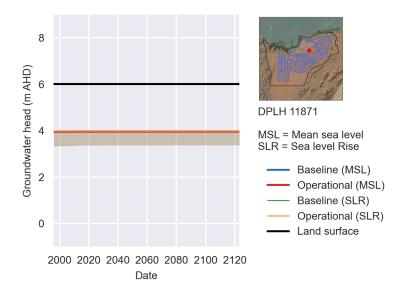


Figure 6 Predicted groundwater level change at DPLH 11871 (Noorea Soak)

The results indicate that the groundwater elevations at the soak are unlikely to change over the operational period of the ponds. The soak is located in an area of basement outcrop in the model and the very low hydraulic conductivity assigned to this unit is likely to be responsible for the limited change observed at the prediction point. The groundwater head is largely controlled by ET, which keeps the watertable at least 2 m below the surface.

#### **Predicted Salinity**

Predicted time-series groundwater salinity at the Noorea Soak (DPLH 11871) prediction point is shown in Figure 5. The mean and range of predicted groundwater salinity from the 100 calibrated model realisations are represented by solid lines and colour shades, respectively.

The results indicate that groundwater salinity at the soak is unlikely to change over the operational period of the ponds. All 100 calibrated model realisations align. These results are likely to be due to the very low permeability of the basement rock on which the soak is located (i.e. saline plume cannot move quickly through the basement rock).

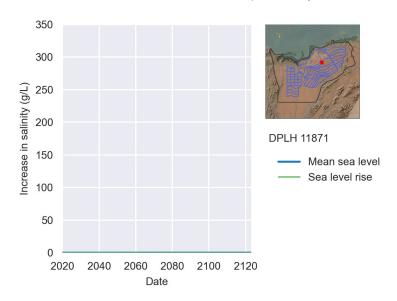


Figure 7 Predicted groundwater salinity change at DPLH 11871 (Noorea Soak)



# Impact Assessment (exposure assessment and threat assessment)

Table 6-1 presents a summary of the possible exposure pathways between direct effects (source) and the Noorea Soak receptors. Any active exposure pathways would be discussed further as part of the threat assessment, however in this case there are no identified active pathways.

Table 3 Possible exposure pathways between WAA 1 (water impoundment) and the Noorea Soak EV

Direct Effect		Indirect (EV) effect)	Active pathway (linkage)?	Carried forward to threat assessment?
Quantity	DE1 – Increased recharge	Increased recharge from water impoundment could increase the quantity of water connected to springs and pools	No, groundwater modelling predicts no change the water levels at the soak over the prediction period and therefore there is no mechanism via groundwater for the pond to cause increased recharge to the soak.	X
Quality	DE2 – Change in salinity	Increased salinity from water impoundment could impact the environmental water requirements of springs and pools	No, groundwater salinity in the area of the soak is not predicted to increase over the prediction period.	$\boxtimes$
Altered GW/SW	DE3 – Change in groundwater levels	Change in groundwater levels from water impoundment could change the interaction of groundwater and surface water in the springs and pools	No, as per DE1, groundwater levels are not expected to increase in the area of the soak.	X
interactions	DE4 – Change in groundwater flow	Change in groundwater flow from water impoundment could alter flow processes connected to springs and pools	<b>No</b> , groundwater flow conditions are not expected to change in the vicinity of the soak.	$\boxtimes$

The results indicate there is no active pathway between the ponds and the soak via groundwater. This, combined with the likelihood that the soak does not currently receive groundwater, means there is a low risk of impact from the ponds to the soak via groundwater processes.



# **Attachment 1: Aerial imagery for Noorea Soaka**

# Image Information Date: 31/10/2011 Source: Google Earth (2023 Maxar Technologies) Days since last rain: 112 (7 mm on 11/07/2011) Rain in the previous 30 days: 0 mm End of dry season Date: 07/01/2013 Source: Google Earth (2023 Maxar Technologies) Days since last rain: 10 (0.6 mm on 28/12/2013) Rain in the previous 30 days: 0.6 mm Wet season



# Information

Date: 29/09/2013

Source: Google Earth (2023 CNES/Airbus)
Days since last rain: 95 (202 mm on 26/06/2013)

Rain in the previous 30 days: 0 mm

Dry season



Date: 20/10/2015

Source: Google Earth (2023 CNES/Airbus)

Days since last rain: 10 (0.3 mm on 10/10/2015)

Rain in the previous 30 days: 0.3 mm

End of dry season





# Information Image Date: 14/09/2016 Source: Esri Wayback Days since last rain: 17 (0.6 mm on 28/08/2016) Rain in the previous 30 days: 0.6 mm Dry season Date: 25/10/2017 Source: Esri Wayback Days since last rain: 77 (0.6 mm on 09/08/2017) Rain in the previous 30 days: 0 mm Dry season



# Information Image Date: 15/06/2018 Source: Google Earth (2023 CNES/Airbus) Days since last rain: 8 (0.8 mm on 07/06/2018) Rain in the previous 30 days: 55.4 mm Dry season Date: 30/01/2020 Source: Esri Wayback Days since last rain: 19 (12.2 mm on 11/01/2020) Rain in the previous 30 days: 47.2 mm Wet season



# Information Date: 01/01/2021 Source: Google Earth (2023 CNES/Airbus) Days since last rain: 7 (1.2 mm on 25/12/2020) Rain in the previous 30 days: 69 mm Wet season Date: 24/02/2021 Source: Esri Wayback Days since last rain: 7 (0.6 mm on 17/02/2021) Rain in the previous 30 days: 73.2 mm Wet season



# Information Image Date: 13/10/2021 Source: Esri Wayback Days since last rain: 113 (9.2 mm on 22/06/2021) Rain in the previous 30 days: 0 mm Dry season Date: 21/07/2022 Source: Esri Wayback Days since last rain: 40 (0.4 mm on 11/06/2022) Rain in the previous 30 days: 0 mm Dry season



# Information

Date: 12/09/2022

Source: Google Earth (2023 Airbus)

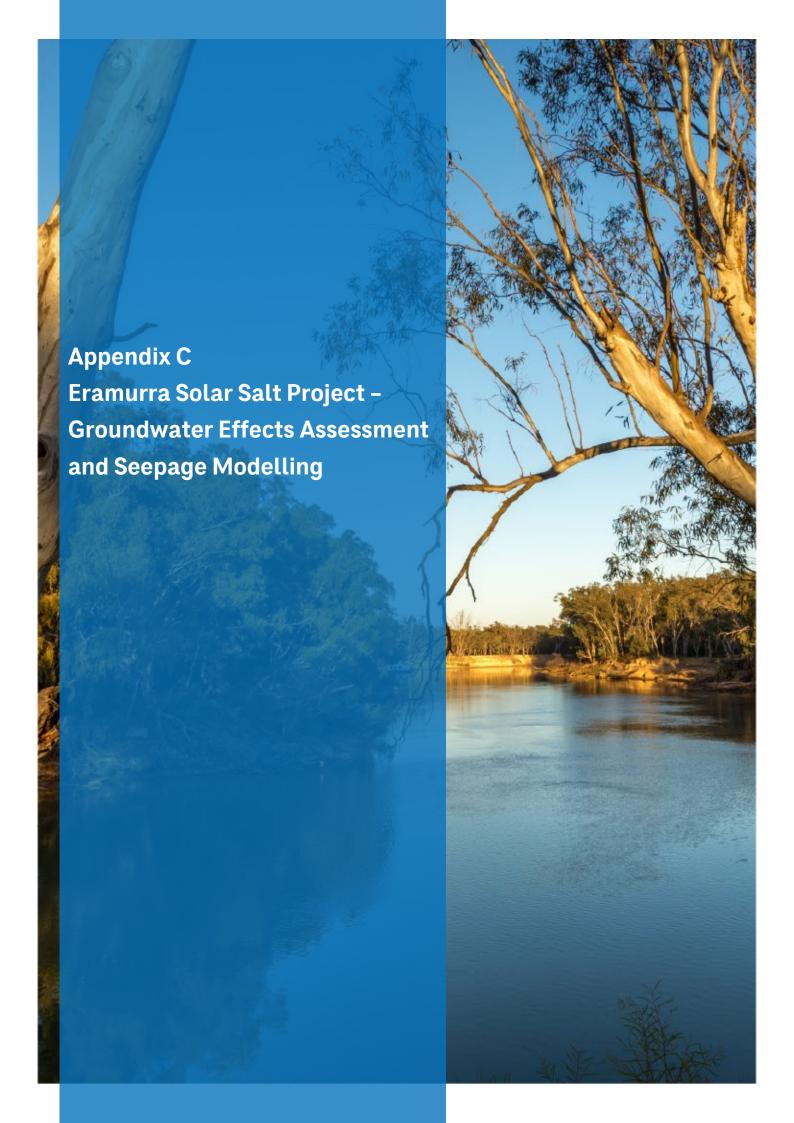
Days since last rain: 8 (0.2 mm on 04/09/2022)

Rain in the previous 30 days: 18.5 mm

Dry season

# Image

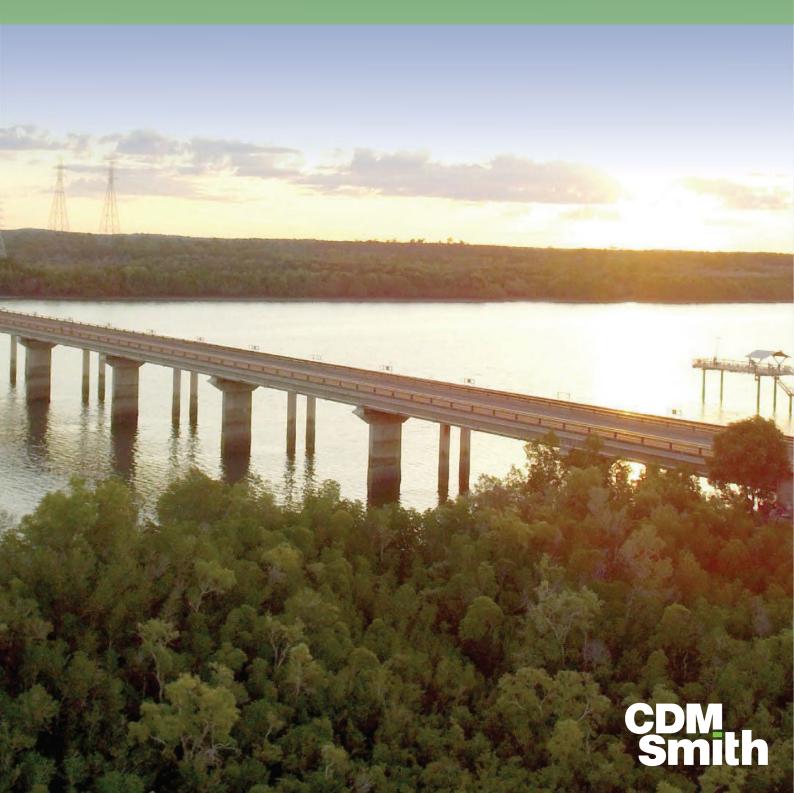




# LWC WA Pty Ltd

# **Eramurra Solar Salt Project – Groundwater Effects Assessment and Seepage Modelling**

13 December 2023



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# **Document history & status**

Revision	Date issued	Reviewed by	Approved by	Date approved	Revision type
А	20 May 2023	J. Fawcett	F Dean	23 May 2023	Draft
В	27 Jun 2023	J. Fawcett	F. Dean	27 Jun 2023	Final draft – review comments addressed
С	16 Nov 2023	J. Fawcett	J. Pretzsch-Kalsgaard	16 Nov 2023	Final draft – updated pond design 7.2.1
D	11 Dec 2023	J. Fawcett	J. Pretzsch-Kalsgaard	13 Dec 2023	Final – updated pond design 7.2.1

# **Distribution of copies**

Version	Date issued	Quantity	Electronic	Issued to
0	23 May 2023	1	PDF	LWC
1	27 Jun 2023	1	PDF	LWC
2	17 Nov 2023	1	PDF	LWC
3	13 Dec 2023	1	PDF	LWC

Last Saved:	13 December 2023	
File Name:	LWC-1001511-RPT-001-3	
Author: Dr Chris Li, Jakob Pretzsch-Kalsgaard, Frankie Dean		
Project Manager: Jakob Pretzsch-Kalsgaard		
Client:	LWC WA Pty Ltd	
Document Title:	Eramurra Solar Salt Project – Groundwater Effects Assessment and Seepage Modelling	
Document Version:	Final	
Project Number:	1001511	
Leichhardt Document no.	ESSP-EN-21-TRPT-0001	

### **Section 1 Introduction**

### 1.1 Background

Leichhardt Salt Pty Ltd (Leichhardt) is currently seeking environmental approval for the Eramurra Solar Salt Project (the Project), located approximately 55 km west-south-west of Karratha on the Pilbara coast of Western Australia (Figure 1-1). The Project proposes utilising seawater and natural solar evaporation processes to produce a concentrated salt product.



Figure 1-1 Project location overview (Source: Leichhardt)

Salt production will occur from a series of evaporation ponds where water will flow through successive ponds over the Project area and evapo-concentrate. A production rate of up to 6.8 million tonnes per annum (Mtpa) is being targeted which will include approximately a 100 km² (10,000 Ha) of concentration pond area, 20 km² (2,000 Ha) of crystalliser area, processing area, seawater intake and disposal lines and other associated infrastructure (Figure 1-2). This report and the associated groundwater model assess the Indicative Disturbance Envelope Scenario 7.2 rev 1.0 as provided.

The perimeter embankment around the concentration ponds and the pad for the crystalliser area will alter the site hydrology and surface water flows towards the Indian Ocean as well as groundwater flow paths and tidal flooding of the Project land parcels. These activities have the potential to impact environmental values (EVs) residing within the Project area such as algal mat communities known to occur in the onshore environment. The potential impacts to the EVs and the groundwater system are currently unknown.

Leichhardt identified a number of further studies necessary to meet the approval requirements in an extract of the draft Environmental Scoping Document (ESD) report for the Project. The ESD forms part of the broader Environment



Review Document (ERD) currently being prepared to support the Project's environmental approvals. The studies relevant to CDM Smith's scope are:

- 102. Undertake a study to predict the quantity and quality of likely seepage of saline water from salt ponds and potential mobilization into the surrounding environment and potential for soil contamination.
- 138. Undertake a hydrogeological study.
- 144. Characterise the baseline hydrological and hydrogeological regimes and water quality, both in a local and regional context, including but not limited to the water levels·, stream flows (ephemeral and flowing), climate, flood patterns, and water quantity and quality¹.
- 139. Undertaken a groundwater model to assess the following:
  - Impacts on the surface-groundwater interaction, groundwater flow directions and hydraulic loading by proposed structures.
  - b. Hydraulic loading surface expressions and subsequent impacts on vegetation.
  - c. The influence of density-driven flow induced by seepage from structures, and subsequent impacts to vegetation.
  - d. The extent of seawater intrusion and how this may be influenced by the Proposal, with subsequent flow-on impacts.

Land and Water Consulting WA Pty Ltd (LWC) is assisting Leichhardt in undertaking environmental studies for the Project and has engaged CDM Smith Australia Pty Ltd (CDM Smith) to provide hydrogeological support and assist in understanding the potential impacts of seepage and mounding associated with the proposed project infrastructure.

### 1.2 Previous Studies

CDM Smith completed a review of the available baseline data for the Project to determine the likelihood of seepage and mounding to occur as a result of salt farming and the data gaps to be addressed to complete seepage modelling (CDM Smith, 2022). The key findings of this review are:

- The main uncertainty associated with the progression of the seepage modelling is conceptual uncertainty, specifically the distribution of hydro-stratigraphic units (HSUs) and the hydraulic parameters associated with each unit.
- Preliminary seepage modelling can be undertaken using a broad set of assumptions and the results of the seepage modelling can guide the future works program by identifying the most sensitive parameters (i.e. the parameter that most affect the outcome).
- Further modelling would likely be required at completion of additional baseline studies aimed at reducing the conceptual and predictive uncertainty.

### 1.3 Objective and Scope

The objective of this report is to understand the impact salt farming (the Project) will have on local groundwater resources and receptors (EVs). This will be achieved by:

- Development of a groundwater seepage model to:
  - Determine the magnitude of seepage to be released from the proposed infrastructure.

<sup>&</sup>lt;sup>1</sup> CDM Smith scope relating only to groundwater quantity. All baseline studies form LWCs scope.



- Assess if the seepage has the potential to create groundwater mounding, with particular focus along the Santos Gas Pipeline alignment and existing and planned infrastructure to determine how the identified groundwater environmental values (EVs) might be impacted, taking into account the current intertidal processes.
- Impacts on the surface-groundwater interaction, groundwater flow directions and hydraulic loading by proposed structures and whether seepage will result in surface expressions from the evaporation ponds.
- Complete a high-level groundwater effects assessment identifying the source (s), pathway (s), and receptor (s) associated with the Project development.



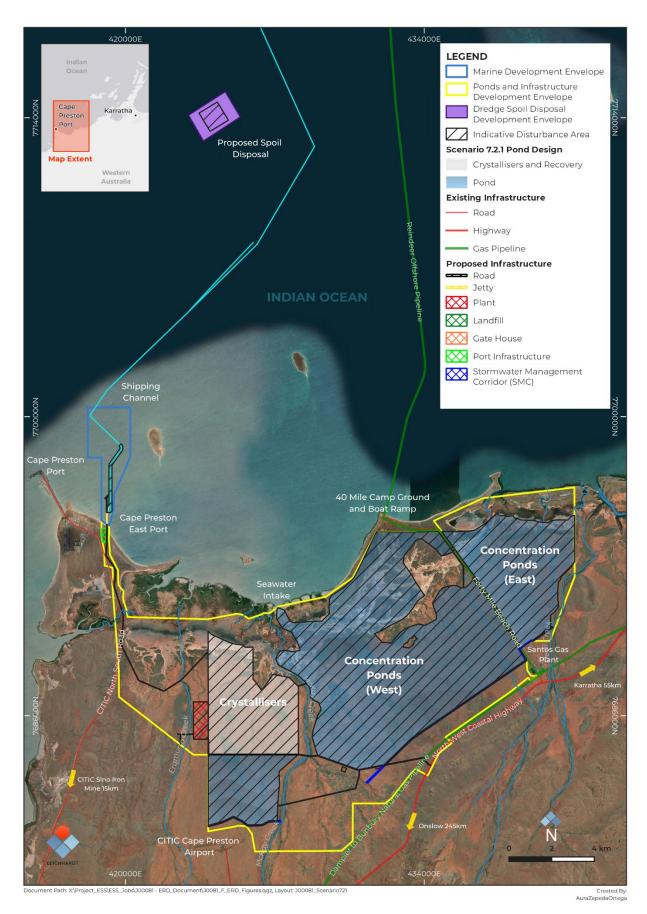


Figure 1-2 Project layout (Study Area) (Source: Leichhardt)



### Section 2 Preliminary Groundwater Effects Assessment Framework

The National Water Commission (NWC) mining risk framework (Howe, 2011) has been adopted to provide structure for the water effects assessment. The framework incorporates seven steps, the first five of which are addressed by this report:

- Step 1 involves setting the context for assessing potential water-related effects arising from a proposed operation. The Project context is described in LWC's desktop and field assessments (LWC, 2021, 2022a) and summarised in Section 3 of this report.
- Step 2 involves the setting of management objectives. Preliminary management objectives are presented in Section 4 along with the EVs identified for the Project.
- Steps 3 to 4 provide the source-pathway-receptor analysis for the effects assessment.
  - Step 3 considers the direct groundwater effects linked to mine water affecting activities (WAAs), with the
     WAAs forming the 'source' component and the direct effects (altered water resource condition) forming the 'pathways' component. The direct effects assessment is presented in Section 5.
  - As part of Step 3, groundwater seepage modelling has been completed to inform the impact of the direct effects resulting from WAAs on the receiving environment and is presented in Appendix A.
  - Step 4 considers the potential exposure of EVs to direct effects, essentially forming the 'receptor' component of the analysis. This assessment is presented in Section 6.
- Step 5 brings together the outcomes of Steps 3 and 4 to complete the effects assessment and involves identifying threats posed to EVs identified as being at risk from WAAs.
  - Threat assessment is central to the typical environmental approvals process, serving to assess the actual
    consequences arising from WAAs not just in terms of direct effects (altered water resource condition) but
    more importantly in terms of possible EV response (such as loss of biodiversity or reduced water access for
    other users) and engagement with stakeholders.
- Step 6 involves making an informed decision as to the potential for adverse effects to arise to EVs.
  - This is where the task of communicating risk management strategies to stakeholders commences.
  - The nature of water resources does not always lend complete certainty to risk characterisation in regard to understanding the way the system works and how it will respond to WAAs.
- Step 7 involves establishing monitoring infrastructure, where deemed necessary, and implementing an appropriate program of data collection, evaluation and analysis, which is a fundamental component of any effects assessment process.

Figure 2-1 provides an illustration of the framework.



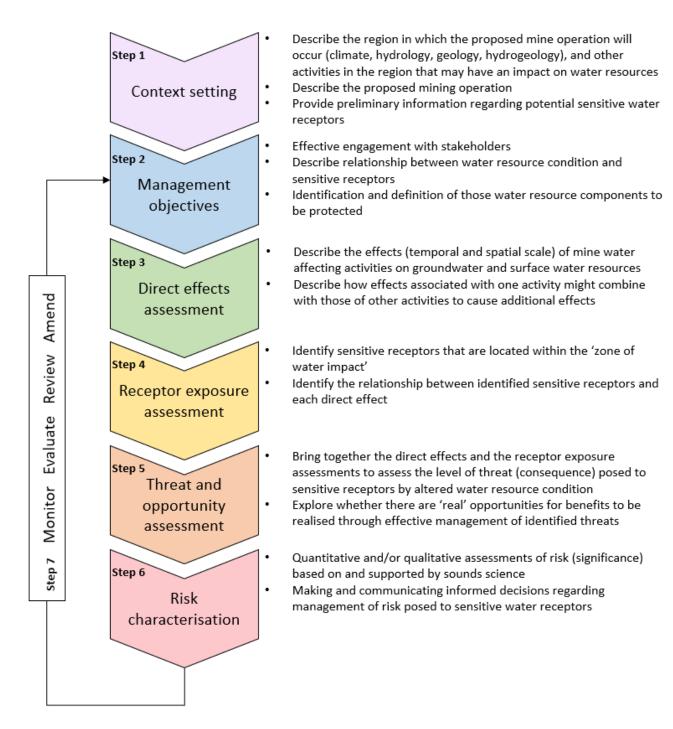


Figure 2-1 Flowchart for assessing the effects of mining on water resources (Fuentes et al. 2014)



### **Section 3 Context Setting (Step 1)**

### 3.1 Climate

#### 3.1.1 Overview

The nearest Bureau of Meteorology (BoM) climate station that has continuous records of both temperature and rainfall data is the Karratha Aero weather station (No. 004083), which is located approximately 40 km northeast of the Project (BOM, 2022a). Data from the Dampier Salt weather station have been used to be represent temperature and rainfall patterns for the Project area, while Scientific Information for Landowners (SILO) data have been used to derive evaporation rates.

### 3.1.2 Temperature

The Project area experiences a broad temperature regime, where the mean annual daily minimum and maximum temperatures are around 21 and 32.5°C, respectively. The mean maximum monthly temperatures range between around 26.5°C in winter to 36.2°C during summer (Figure 3-1).

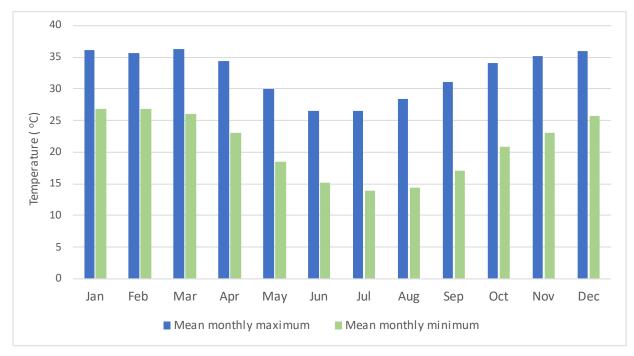


Figure 3-1 Mean monthly minimum and maximum temperatures

#### 3.1.3 Rainfall and Evaporation

Mean rainfall data for the Project is around 290 mm/y with most rainfall occurring between January and June. Annual pan evaporation rates for the Project average around 3,200 mm/y (SILO station number 004083), far exceeding precipitation for every month of the year. Mean monthly rainfall and evaporation data are shown in Figure 3-2.



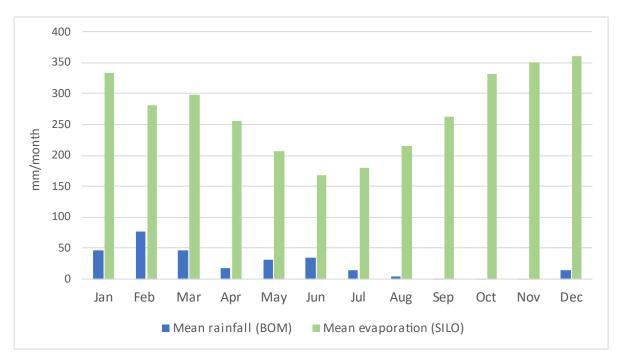


Figure 3-2 Mean monthly rainfall versus mean monthly evaporation

### 3.2 Topography and Hydrology

A description of the topography and hydrology of the Project area is presented by LWC (2022a) and is summarised below:

- The site fringes a low-lying coast. The central and eastern parts of the Project area comprise a line of coastal beach ridges, dunes and cheniers forming a coastal barrier rising locally to over 12 m along the crest of the main dune.
- A backwater of inter and supra tidal flats has formed behind the coastal barrier. Several small (high tide) islands
  are present in the backwater providing evidence of former coastlines which are now partially buried beneath the
  backwater lagoonal sediments.
- Inland of the inter and supra tidal flats is an area of alluvial outwash, falling at a gradient of about 1 m in 300 m from the southeast towards the northwest.
- Surface water drainage over the Project area generally occurs from south to north following areas of lower topography including:
  - Several small creeks dissect the alluvial outwash plain roughly coincidental with the position of the Northwest Coastal Highway.
  - A larger creek (Devil Creek) is present along the eastern edge of the site, which together with Eramurra Creek, drains a larger inland area to the Project's east.
  - McKay Creek dissects the centre of the Project area and measures around 1 m deep by 3 m wide.

Hydrology studies are currently being completed for the Project which will inform further baseline information on the region.

### 3.3 Geology

The Project area is located within the Pilbara Craton geological province which comprises Archean aged volcanic and sedimentary rocks of more than 3,600 Ma. The Pilbara Craton has been subject to a long history of tectonic and



orogeny with various igneous intrusions occurring and deposition of shelf sediments such as the Hammersley Basin containing extensive banded iron-formation (BIF) deposits.

Local to the Project area, the Pilbara Craton is overlain by a number of Cainozoic sedimentary units comprising marine muds and silts, coastal sands and beach deposits, limestone, alluvial/colluvial sands and clays as well as residual calcretes and eluvial sands from weathered granitoid rocks (Hickman and Strong, 2000). These sediments are underlain by granitic basement belonging to the Dampier Granitoid Complex which has been intruded by a series of cross cutting dolerite and gabbro dykes. Geological investigations by CMW (2020) indicate surface expressions of the basement exist within the central and eastern portions of the Project area often within eroded creek beds. However, in general, the depth to basement distribution is currently not well understood.

The stratigraphy most relevant to the Project area is presented in Table 3-1, while the Dampier-Barrow Island 1:250K geological map (Hickman and Strong, 2000), in which the Project area is encompassed, is provided in Appendix B.

Table 3-1 Summary the Project area stratigraphy (Hickman and Strong, 2000)

Age		Unit	Description	Thickness
Cainozoic	Quaternary	Quaternary Sediments	Qhm – Marine mud and silt on supratidal to intertidal flats; includes intertidal deposits with mangroves.  Qhms – Coastal sand in beach deposits and dunes; marine sand reqorked by wind; includes reworked alluvium near deltas; shelly sand.  Qpmb – Coastal limestone; lime-cemented shelly sand, dune sand and beach conglomerate.  Qaa/Qab/Qrg – Undifferentiated alluvium/colluvium/eluvium; clay, silt, sand and gravel associated with river, creeds and floodplain deposits.	~1 – 15 m
	iary	Tertiary Sediments	Czaa/Czcb – Consolidated alluvial sand and silt; Colluvium, dissected by recent drainage, with gilgai surfaces in areas of expansive clay.	~5 – 25 m
Proterozoic	Tertiary	Undifferentiated volcanics	d/o – Dolerite and gabbro dykes.	>5,000 m <sup>[1]</sup>
	Neo-Archean	Fortescue Group	Basaltic and andesitic lavas, siliciclastic sedimentary rocks, chert, minor pyroclastic rocks and carbonates. Dolerite dyke or sill.	5,000 – 6,500 [1]
Archean	Meso-Archean	Pilbara Supergroup	Includes multiply deformed and metamorphosed greenstones dominated by basalt, chert, banded iron-formation, ultramafic rocks, with locally abundant felsic and sedimentary rock.	15,000 – 35,000 m
Arc	Meso-A	Dampier Granitoid Complex	Monzogranite, granodiorite, undivided granites, granitic gneiss, migmatite.	>5,000 m <sup>[1]</sup>
	Paleo- Archean	Roebourne Group	Massive and pillow basalt with local basal peridotitic komatiite; minor chert, BIF, and shale. Includes strongly foliated amphibolite-chlorite schist. Metamorphosed to amphibolite or upper greenschist facies.	2,000 – 3,500 m <sup>[1]</sup>

Notes: 1. Geoscience Australia (2022)



## 3.4 Hydrostratigraphy

Table 3-2 presents a draft hydro-stratigraphic sequence based on the drilling results, geophysics results, and geological descriptions provided in CMW (2022) and LWC (2022a) investigation reports. As reported by CDM Smith (2022), a degree of uncertainty currently exists in understanding the distribution of these HSUs especially with regards to HSU 6 (Dampier Granitoid Complex) and HSU 3 (alluvial outwash) thought to occur within paleochannels within the northeast of the Project area within the vicinity of the Santos Gas Pipeline. The current conceptual understanding of the Project hydrostratigraphy is presented in the following subsection.

Table 3-2 HSU categorisation

HSU [number]	Туре	Descriptions and basis of categorisation
[1] Quaternary Sediments – Eolian sand	Undetermined (unsaturated, unconfined aquifer)	<ul> <li>Present north and east of the tidal flats as dune and sandy islands consisting of a silty sand</li> <li>Generally, not a deep unit and likely to be unsaturated</li> <li>Moderate to high permeability (CMW, 2022)</li> </ul>
[2] Quaternary Sediments – Mangrove or Lagoonal muds	Aquifer (unconfined or local confining/semi confining bed	<ul> <li>Present at the surface in the coastal areas beneath R1, P2 and PE1 consisting of interlaminated clay, silt and sandy clay, very soft to firm and stiff</li> <li>Up to 6 m deep near the coast so may be saturated</li> <li>Low vertical k and moderate horizontal k (CMW, 2022)</li> </ul>
[3] Tertiary Sediments – Alluvial outwash	Aquifer (unconfined)	<ul> <li>Present at surface across much of the site as braided channel gravels associated with modern watercourses and sheetwash gravel as a thin veneer (&lt;20 cm) over residual soil</li> <li>Where present as sheetwash this is likely to be unsaturated</li> <li>Where present as channel gravel or as paleochannel infill may be saturated or seasonally saturated</li> <li>MBH03 may be screened within the paleochannel identified in this area and returned a k from slug testing of 0.6 m/d</li> </ul>
[4] Tertiary Sediments? – Soft rock or stiff sediment (extremely weathered/residual soil)	Aquifer (unconfined)	<ul> <li>Present from surface or shallow sub-crop across much of site and includes extremely weathered rock or residual soil</li> <li>Extends to depth of more than 28.5 m (deepest well) in some areas</li> <li>Groundwater monitoring wells likely screened in this HSU or alluvial outwash</li> <li>Given the residual soil and alluvial outwash are from the same host rock and travel distance for transported material is likely to be minimal (given small catchment), it is difficult to distinguish between this HSU and alluvial outwash</li> <li>Slug tests possibly represent this unit – k = 0.06 to 1.7 m/d, although CMW (2022) predict low to very low permeability for residual soil. The slug tests have been corrected for gravel pack effect in the analysis but it is possible the high k results represent disturbance around the well instead of aquifer hydraulic conductivity</li> </ul>
[5] Dampier Granitoid Complex (weathered) – Soft rock to moderately hard rock (moderately weathered)	Aquifer (unconfined)	<ul> <li>Present in geophysics at 10 m below surface 100 m from coast to at the surface to 5 m deep further inland</li> <li>At surface to more than 20 m deep in area of crystalliser ponds</li> <li>CMW (2022) suggest low to moderate (along joint system) permeability</li> </ul>
[6] Dampier Granitoid Complex	Aquifer (confined / semi confined)	<ul> <li>Deepest unit</li> <li>Present in geophysics from 500-1,000 m inland from the coast at around 7 m depth</li> <li>Encountered in some drilled bores from 1 m depth to 12.5 m depth</li> <li>Outcrops in the area between P2 and P7</li> <li>Bores drilled into this unit were not installed due to lack of water indicating very low permeability</li> </ul>



### 3.5 Conceptual Hydrogeological Model

Figure 3-3 presents a conceptual hydrogeological model of the Project area. The model has been revised since earlier versions presented by CDM Smith (2022) to include further descriptions of hydrogeological processes and predicted groundwater flow from the groundwater modelling completed as part of Appendix A. The following describes the key elements of the model:

- 1. Rainfall is low (<300 mm), far lower than mean evaporation at around 3,200 mm/y. Rainfall mostly occurs between January and June as intense rainfall associated with low pressure systems and cyclones passing from the Indian Ocean.
- 2. Sheetflow and shallow incised channel flow is likely to occur following intense rainfall in the area that drains towards the coast.
- 3. Ponding within isolated shallow surface depressions and backwater areas can occur following storm events or tidal movements where evaporation takes place resulting in concentration of salts and infiltration to the water table.
- 4. Fresh groundwater recharge likely occurs through diffuse infiltration of rainfall across the Project area and surface water infiltration and infiltration via creek beds during surface water flow. Topographic lows subjected to marine water flooding during high tide and storm surges are areas of saline groundwater recharge.
- 5. Surficial deposits for most of the Project area consist of alluvial outwash and residual soil (CMW, 2022). Depth to bedrock in the alluvial outwash/residual soil area is extremely variable, ranging from zero (i.e. outcropping) to greater than 28.5 m (the depth of the deepest well that did not encounter competent rock MBH01).
  - a. The alluvium is described as both thin sheetwash deposits (less than 20 cm thick) and alluvium associated with recent and palaeo surface drainage.
  - b. The residual soil is described as sandy clay with gravel and clay with sand.
  - c. Mangrove mud areas characterised by very soft and soft clays (medium to high plasticity) at the surface (generally 1 m thick but up to 2.5 m thick) underlain in turn by an inter-bedded sand and firm to stiff clay horizon (CMW, 2022). There are also areas of sand dunes and beach rock within the footprint of these ponds consisting of sand and gravel.
- 6. The basement geology consists of Archean aged rocks of the Dampier Granitoid Complex. Basement geologies are expressed as foliated and metamorphosed granodiorite and monzogranite forming occasional tors, overlain by Quaternary sands (Leichhardt, 2015). Basement rocks outcrop in a number of locations across the site and consist of granite (within incised creeks or weathered to tors) and igneous rock exposed by rainfall and sheet flow and dolerite dykes varying in width from 0.1 to 10 m (CMW, 2022).
- 7. Groundwater is present within varying lithological units across the site (LWC, 2022a). Hydraulic conductivity of saturated aquifer materials indicates low to moderate permeability (0.06 to 1.7 m/d) where tests have been completed.
- 8. Depth to groundwater varies from around 2.3 to 8.3 m below ground level (bgl), with the shallowest depth to water at the coast (<4 m bgl) and along the Santos Gas Pipeline while deeper groundwater is recorded further inland. Salinity corrected groundwater elevations from the November 2022 groundwater monitoring event undertaken by LWC ranged from 1.88 mAHD at MBH03 (in the north-western extent of the project area, closest to the coast) to 11.72 mAHD at MBH12 (in the south-eastern extent of the project area, furthest from the coast) (LWC, 2023). Limited time series data indicate no significant increases in water level with the exception of a minor increase at MBH03 located near the coast (LWC, 2023).
- 9. Groundwater discharge likely occurs as evapotranspiration within the backwater areas adjacent to the coast. These areas are slightly lower in elevation than the ocean which enables groundwater flow from the ocean to the backwater areas and from inland towards the coast. This is evidenced by groundwater quality data which shows a hypersaline buffer zone exists in the backwater areas. The groundwater discharge conceptualisation is discussed further in Appendix A. Some groundwater discharge to the ocean may occur where conditions allow.



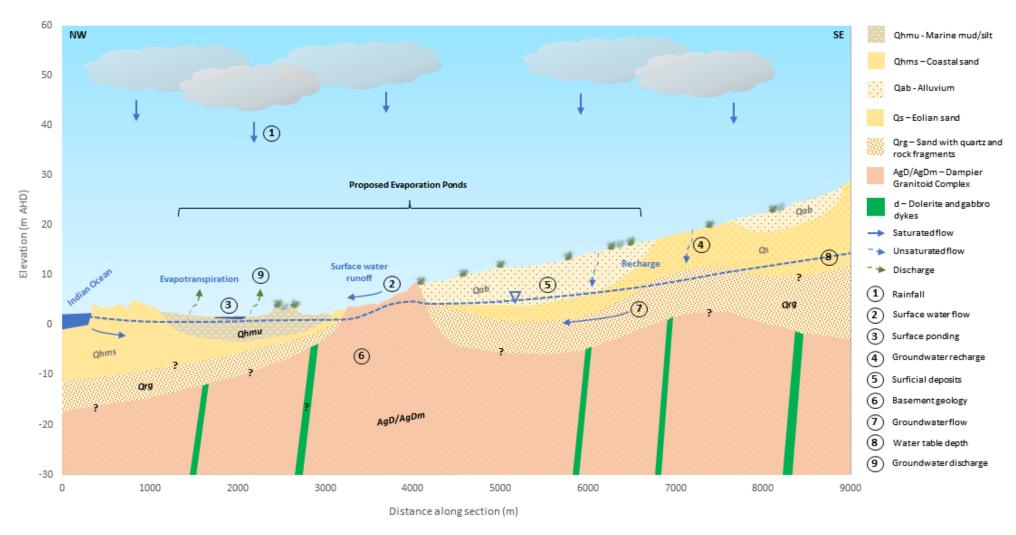


Figure 3-3 Conceptual hydrogeological model



# Section 4 Management Objectives and Environmental Values (Step 2)

### 4.1 Management Objectives

As per the EPA guidance for Inland Waters (EPA, 2018) and DMIRS guidance (DMIRS, 2020), the key objective for Project groundwater management is as follows:

 Maintain the hydrological regimes and quality of groundwater and surface water so that environmental values are protected.

EVs are defined in EPA (2018) as water dependent ecosystems, amenity, cultural values, recreation, public drinking water supplies, and agriculture and industry (e.g. mining) use of water. In broad terms then, the effects assessment presented in this report is required to take into account the maintenance of the beneficial use of water resources, and the maintenance of ecological services.

To address the overall objective of Project water management, the EPA requires consideration of the following (EPA, 2019):

- Development activities (or mine water affecting activities (WAAs)) that have the potential to alter hydrological regimes and impact on water dependent ecosystems and other EVs.
- Waste management approaches to minimise discharge to the environment.
- The effect of water use, land management and waste discharge on water quality, local hydrological regimes and EVs supported by inland waters.

### 4.2 Environmental Values (Receptor)

Three broad categories of groundwater related EVs have been defined for the purpose of this assessment:

- Ecosystem health.
- 2. Beneficial use.
- 3. Other non-groundwater EVs.

Table 4-1 presents the identified EVs and their likely occurrence within the Project area, while Figure 4-1 presents these graphically. The EVs have been identified in collaboration with LWC and Leichhardt. Note, with the exception of the Santos Gas Pipeline and Noorea Soak, only groundwater related EVs are considered in this assessment.

Table 4-1 Identified groundwater environmental values

Environmental value		Description	Considered herein?
	EV1 – Stygofauna	Bennelongia (2022) reports stygofauna are present within the Project area hosted by alluvial sediments and potentially in near shore paleochannel environments and/or gravelly deposits in permanently flowing creek beds.	
Ecosystem health	EV2 – Groundwater dependent terrestrial vegetation (GDE Atlas)	The GDE Atlas (BOM, 2022b) has identified low to moderate potential GDEs exist within the southern regions of the Project area. More detailed site-specific vegetation mapping indicates the presence of eucalypt species within the drainage lines of the creeks in the area. Although the potential groundwater dependence is mapped as low, these species are known to sometimes access groundwater, although saline water will limit this use.	



# Section 4 Management Objectives and Environmental Values (Step 2)

Environmental	value	Description	Considered herein?
	EV3 – Terrestrial vegetation (Priority Ecological Community)	A Priority Ecological Community (PEC) has been mapped in the north east region of the Project area, between the coast and evaporation pond PEO1. This Coastal Dune PEC is described by the Department of Biodiversity, Conservation and Attractions as:  Coastal dune native tussock grassland dominated by Whiteochloa airoides (Priority 3)  Tussock grassland of Whiteochloa airoides occurs on the landward side of foredunes, hind dunes or remnant dunes with white or pinkish white medium sands with marine fragments. There may be occasional Spinifex longifolius tussock or Triodia epactia hummock grasses and scattered low shrubs of Olearia dampierii subsp. Dampierii, Scaevola spinescens, S. cunninghamii, Trianthema turgidifolia and Corchorus species (C. walcottii, C. laniflorus).	Ø
	EV4 – Algal mats and samphire	A number of salt resilient vegetation species have been mapped within the Project area including algal mat and samphire communities. These communities predominantly exist within the low-lying backwater areas that are subject to groundwater, tidal and surface water inflows.	Ø
	EV5 – Aquatic vegetation (mangroves)	Leichhardt has mapped a number of mangrove communities along the coastal areas adjacent to the Project.	
	Aquatic GDEs	The GDE Atlas (BOM, 2022b) has identified no potential aquatic GDEs exist within the Project area. There are some known soaks and pools in the Project area, however, based on the hydraulic setting, historic aerial imagery and remote sensing data (Digital Earth Australia's Water Observations from space (WOfs)), these pools are not permanent and therefore unlikely to receive groundwater inflow such that aquatic GDEs would be supported. Specific pools and soaks (Devils Pool and Noorea Soak) have been identified as cultural values and are discussed in the context of this EV grouping.	区
	EV6 – Stock water wells	The Project area is currently designated as pastoral land. Anecdotal information obtained during groundwater monitoring events (LWC, 2022a) indicate a number of windmills are present within the Project area which pump groundwater for livestock.  The BOM groundwater explorer database (BOM, 2022c) indicates six wells (two within the evaporation pond areas and four surrounding these areas) exist. The status of these wells (i.e. whether they are currently in operation) is unknown. This assessment will focus on the four wells residing outside of the evaporation pond areas: 50109390, 50108619, 50108618 and 50108614.	Ø
Beneficial use	Domestic water supply	Groundwater is unlikely to be suitable for domestic water use purposes without prior treatment. Therefore, this EV is not considered for further assessment.	$\boxtimes$
	Non-potable water use	Although no non-potable uses of groundwater in the area are currently document, there exists an option for potential use.	X
	EV7 – Cultural and spiritual (springs and pools)	Cultural surveys completed within the Project area indicate a range of aboriginal heritage significance exist including artifacts, camp sites and engravings. These EVs are not reliant upon for groundwater and are not considered by this assessment.  An area of naturally occurring pools (Devil Creek Pool) has been identified to exist within Devil Creek to the east of the Project area and is considered further in this assessment. This value is <b>not</b> being considered as an aquatic GDE, but within cultural values.	Ø



# Section 4 Management Objectives and Environmental Values (Step 2)

Environmental value		Description	Considered herein?
	EV8 – Cultural and spiritual (soaks)	Site surveys have identified the presence of a soak (Noorea Soak) within elevated basement geology which outcrops west of the Santos Gas Pipeline in a gap between the proposed evaporation ponds. Remote sensing investigations (CDM Smith, 2023; Appendix C) suggest this EV is not a permanent water feature and is unlikely to currently receive substantial groundwater inflows. The soak is conceptualised to be supported by surface water runoff that collects during rainfall events due to its location within a natural landscape depression.  Although not a groundwater EV, it is recognised this EV has potentially signific spiritual importance and as such, has been included further in this assessment to investigate the changes to the groundwater system beneath the soak.	
Other	EV9 – Santos Gas Pipeline	The Santos Gas Pipeline presents as the only developed infrastructure within the Project area. The pipeline extends for around 10.5 km from the coast to a transfer station located adjacent to the North-West Coastal Highway (Figure 4-1).	Ø

Notes: ⊠ - no ☑ - yes

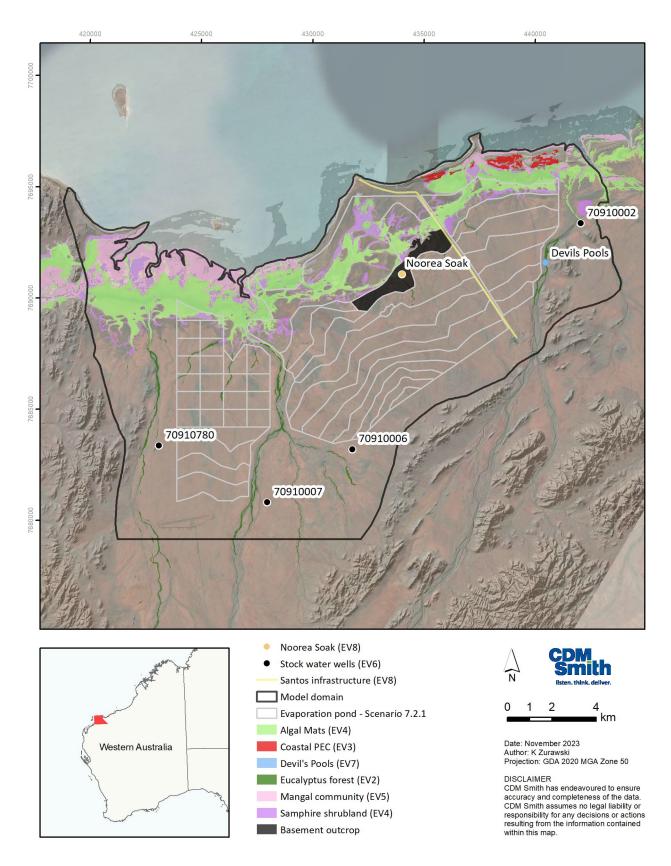


Figure 4-1 Identified environmental values within the Project area (EV1 - stygofauna not shown)

### **Section 5 Direct Effects Assessment (Step 3)**

### 5.1 Overview

According to the NWC framework (Howe, 2011), direct effects are changes to physical and/or quality aspects of water, resources or the changes to the physical characteristics of groundwater and/or surface water systems, as a consequence of WAAs. A direct effects assessment seeks to describe the linkage(s) between each of the potential WAAs (i.e. sources) and the applicable potential direct effect(s) (i.e. pathways) for groundwater and surface water. A schematic of this framework is illustrated earlier in this report as Step 3 in Figure 2-1.

### **5.2** Groundwater Affecting Activities (Source)

WAAs are any activity that have the potential to alter water resources from baseline conditions, for example, the abstraction of groundwater for water supply. In a source-pathway-receptor analysis, WAAs can otherwise be thought of as sources. Table 5-1 lists the WAAs identified within the Project area. Note, due to the stage of the Project design and the preliminary nature of this assessment, only one WAA is considered herein. Other potential WAAs such as supporting facilities (WAA2) and evaporation ponds at closure (WAA3) are at this stage excluded from this assessment. This approach focuses on the main WAA to which the direct effects have been modelled.

Table 5-1 Identified WAAs (Sources)

WAA (source) ID	Description	Considered herein?
WAA1 – Water impoundment	Surface excavations are expected to take place during construction of the evaporation ponds which will change the topography of the landscape. The current design of the evaporation pond will span an area of around 12,800 ha (roughly 10 km long and 20 km wide). The development area is shown earlier in Figure 1-2.	N
	Nominal evaporation pond elevations are understood to be around 2.5 m high so that at least 0.5 m of clearance exists above the water level within each evaporation pond. During operations, a mean rate of approximately 241 GL/yr of seawater will be pumped to the evaporation ponds and allowed to evapo-concentrate.	
WAA2 – Supporting	Several supporting facilities will be required to maintain operation of the Project. These facilities are likely to include:	X
facilities	Construction of access roads	
	Construction of workshops and offices	
	Construction of pump stations and pipe infrastructure	
WAA3 – Evaporation ponds at closure	Following decommissioning of the Project, the evaporation ponds will remain open and exposed to the environment. The development envelope at this stage is estimated to be around 20,000 ha.	X



### **5.3** Direct Effects

### 5.3.1 Overview

The NWC framework defines four (4) categories of direct effects to groundwater arising from WAAs:

- 1. Altered groundwater quantity.
- 2. Altered groundwater quality.
- 3. Altered surface water groundwater interactions.
- Physical disruption of aquifers.

Table 5-2 describe the linkage(s) between the identified WAAs and the applicable potential direct effect(s) for groundwater. Note, only the direct effects with a relevant WAA have been considered further in this assessment.

**Table 5-2 Identified Direct Effects** 

WAA (source)		Direct effects (pathway)			
		Category	ID	Description	herein?
	Surface excavations (water impoundment)	Quantity	DE1 – Increased recharge	Mounding of groundwater levels due to increased infiltration and seepage from evaporation ponds	Ø
	impoundments	Quality	DE2 – Change in salinity	<ul> <li>Change in salinity (generally an increase) of groundwater as a result of evapoconcentrated water infiltrating to the water table</li> <li>In some areas the pond salinity may be lower than the existing groundwater (i.e. where there is hypersaline groundwater in the north east of the model domain) and salinity may decrease</li> </ul>	Ø
		Altered GW/SW interactions	DE3 – Change in groundwater levels	Change in groundwater levels as a result of water impoundment	Ø
			DE4 – Change in groundwater flow	Change in groundwater flow as a result of water impoundment	Ø
		Aquifer disruption	-	Surface excavations do not physically disrupt underlying aquifers	X
WAA2	Supporting facilities (roads, buildings, pumping and pipe infrastructure)	Quantity	DE5 – Decreased recharge	Decreased groundwater levels due to decreased recharge as a result of less permeable or impermeable infrastructure	X
		Quality	DE6 – Contaminated groundwater	Contaminated groundwater from operation of site infrastructure, i.e. diesel spills etc	X
		Altered GW/SW interactions	DE7 – Change in groundwater levels	Change in groundwater levels as a result of permeable or impermeable infrastructure	X
		Aquifer disruption	-	Supporting facilities do not physically disrupt underlying aquifers	X
WAA3	Evaporation ponds at closure	Quantity	DE8 – Decreased recharge	Decreased groundwater levels due to decreased recharge as a result of less permeable evaporation ponds	X
		Quality	DE9 – Increased salinity	Persistent increased salinity as a result of increased soil salt content from evaporation ponds. Expected to become less saline over time	X



WAA (source)	Direct effects (pathway)			
	Category	ID	Description	herein?
	Altered GW/SW interactions	DE10 – Change in groundwater levels DE11 – Change in groundwater flow	<ul> <li>Persistent change in groundwater levels as a result of remnant evaporation ponds</li> <li>Persistent change in groundwater flow as a result of remnant evaporation ponds</li> </ul>	X
	Aquifer disruption	-	• N/A	X

In order to provide an estimation of the direct effects caused by WAA1 – water impoundment, a three-dimensional numerical groundwater model has been developed, the full details of which are presented in Appendix A. The following sub-sections describe the direct effects with regards to the categories presented in Table 5-2.

To assess the likely direct effects of the evaporation pond operation on the identified site EVs, four scenarios have been considered:

- 1. A baseline scenario with the mean sea level at 0 m AHD the future conditions are assumed to be identical to the historical conditions without any evaporation pond operations. The mean of historical climate was used for the future period.
- 2. An operation scenario, with the mean sea level at 0 m AHD similar to the baseline scenario except for the introduction of evaporation pond operations that were set up in the model as per Section A.3.7.
- 3. A baseline scenario with a sea level rise of 0.9 m this scenario assesses the impact of sea level rise and how it affects the groundwater system response to the evaporation pond operations. The sea level rise of 0.9 m is consistent with the scenario considered in studies for the approved Mardie Salt Project (RPS, 2019) and guidelines provided by the WA EPA (2016) on the expected sea level rise. The mean of historical climate was used for the future period.
- 4. An operation scenario with a sea level rise of 0.9 m similar to the baseline scenario above except for the introduction of evaporation pond operations that were set up in the model as per Section A.3.7.

Running both baseline and operational scenarios for the two sea level cases allows a difference between baseline and operation to be calculated to assess the impact of the project operations. The results presented in the following maps show the differences that operations make under the mean sea level scenario and the sea level rise scenario.

Predictive uncertainty analysis has been performed using the Type 3 technique described in Middlemis and Peeters (2018), involving stochastic modelling and Bayesian probability quantification. This means effectively analysing the similarities and differences between the predictions from 100 calibrated model realisations in the context of this study. The maximum groundwater head or salinity across the 100 calibrated groundwater model realisations represents the worst case scenario. These have not been presented on maps and rather are shown in the timeseries plots as a probability outcome.

To assess the direct effects of water impoundment with respect to the location of the identified EVs, predicted time-series groundwater level hydrographs and salinographs at selected locations have been prepared with positions annotated on the figures in this section. Sites PL-S (Pipeline South) and PL-N (Pipeline North) have been selected to assess the direct effects of evaporation pond operations on the Santos Gas Pipeline infrastructure. Specifically, site PL-S is located at the Santos pumping station slightly upgradient (in terms of groundwater flow) of the evaporation ponds and site PL-N is located closer to the coast, in proximity to the evaporation ponds and the backwater area accommodating the algal mat communities. Sites, AM-W and AM-E, assess the direct effects to the algal mat and samphire communities, whereas site Devil's Pools assesses the direct effects to Devil's Pools and eucalypt species within Devil Creek. Similarly, sites PEC-E and PEC-W assess the direct effects to the coastal Priority Ecological



Community (PEC). The other locations (Mangroves, 70910002, 70910006, 70910007 and 70910780) have been positioned with respect to EVs and named accordingly.

#### 5.3.2 Quantity

The predicted groundwater level change for the mean sea level and sea level rise scenarios within the top model layer after 100 years of evaporation pond operations are shown in Figure 5-1. To maintain readability, only the predicted groundwater change (and associated summarised discussion) is provided within this section. The predicted groundwater levels (mAHD) for the four scenarios are shown in Appendix A, along with a full discussion of the modelling results.

The baseline model (i.e. no operation) shows a high evaporation zone in the area adjacent to the coast where groundwater ET develops a natural depression in the water table that draws water from the south and the northern sea boundary. This zone coincides with the location of the algal mat and samphire communities, possibly due to the evapo-concentration processes creating a hypersaline environment that may act as a protective mechanism for these communities. For algal mats, similar relationships are noted within the region (e.g. Shark Bay) and globally (Edgcomb and Bernhard, 2013).

The operation scenario results (with mean sea level) suggest the evaporation ponds have a large control on the groundwater levels. In particular, groundwater mounding beneath the evaporation ponds results in a steeper hydraulic gradient that causes more groundwater discharge to the backwater area and sea. Under the operational scenario, the water table depression mentioned above in the northern part of model domain (i.e. to the immediate west of PL-N) is largely dissipated, which is expected as the current design pond layout results in seepage recharge being directly applied to this area. Mounding, as defined by the extent of the 1 m contour (Figure 5-1 and Figure 5-2), is generally restricted to within a 1 km buffer zone surrounding the evaporation ponds, although extends to around 3 km along the west of the crystallisers and around 2 km east of the Eastern Pond Development Area.

The sea level rise scenario results are largely similar to the operation scenario results, albeit some minor differences in groundwater levels (refer to Appendix A for comparison). This scenario is considered optimistic for algal mat and samphire species, as a higher sea level will result in a steeper hydraulic gradient causing more inflow to the backwater areas, maintaining the hypersaline environment these EVs may be reliant upon (Edgcomb and Bernhard, 2013). For mangrove communities, sea level rise will likely impact habitat availability and disrupt the wetting and drying processes of the EVs residing within the tidal zone, although mostly restricted to areas immediately adjacent to the coast to the northwest of the Project area.

Predicted time-series groundwater levels at locations selected to illustrate changes at receptors are shown in Figure 5-3 and Figure 5-3. The mean groundwater level predictions from the 100 calibrated model realisations are represented by solid lines for each scenario whereas the range of these predictions (i.e. the predictive uncertainty) are represented by transparent colour shades.



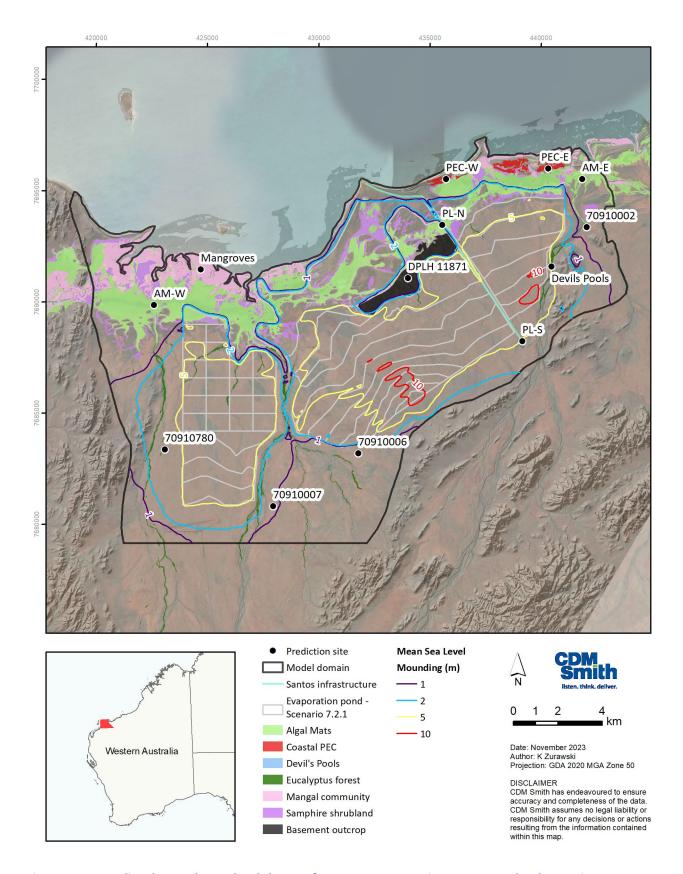


Figure 5-1 Predicted groundwater level change after 100 years operation – Mean sea level scenario

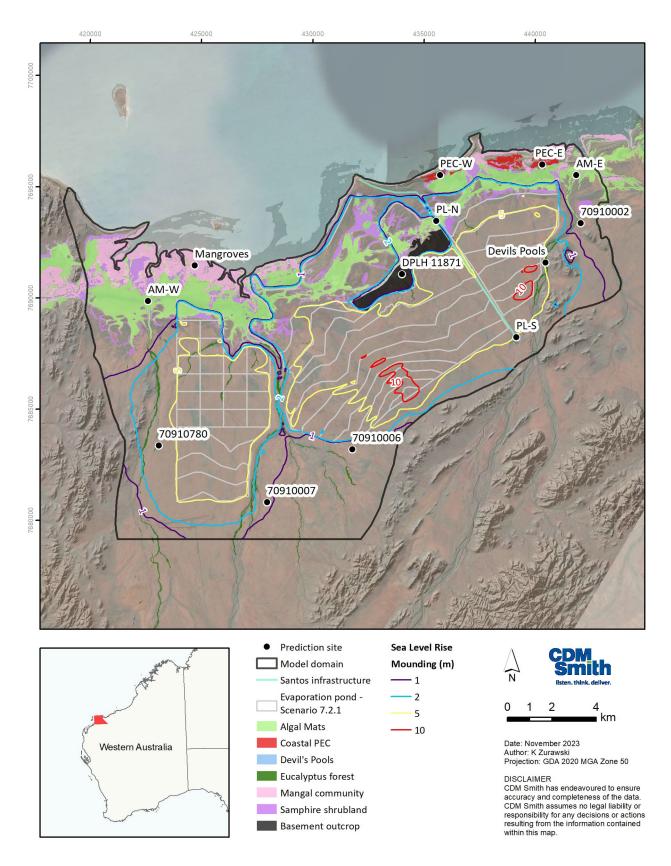


Figure 5-2 Predicted groundwater level change after 100 years operation – sea level rise scenario

#### EV3 - Coastal PEC

Groundwater levels at sites PEC-E and PEC-W are predicted to increase only marginally (< 0.5 m) – under the mean sea level rise scenario the mean of the 100 calibrated models shows no areas of the PEC where groundwater level rise is greater than 0.5 m inside or outside the evaporation ponds. The predictive uncertainty analysis shows a relatively large range. The upper range is kept at approximately 2 m below the land surface at both sites throughout the simulation period, which is likely to be a result of groundwater ET and therefore water logging is not predicted in the model. It should be noted the mean of the 100 models indicates the water level ranges between 3 to 4 m below the ground surface. The sea level rise scenario shows a slightly higher groundwater level at both sites, as a higher sea level reduces the hydraulic gradient towards the sea, slightly enhancing the groundwater mounding in the evaporation pond areas and the surroundings.

#### EV4 and EV5 - Algal mats / samphire and mangroves

Sites AM-E (Algal Mats East), AM-W (Algal Mats West) and Mangroves have been selected to assess the impact of evaporation pond operations on the algal mat and mangrove communities outside the evaporation ponds in the eastern and western parts of the model domain. The predicted groundwater levels at these sites are largely constant throughout the simulation period for all the scenarios. This suggests groundwater ET may be sufficient to buffer the impact from the pond operations and sea level rise at these sites despite their proximity to the ponds and the coast. Under the mean sea level rise scenario, the mean of the 100 calibrated model realisations shows 3% of algal mats area, 2% of samphire shrubland area and less than 1% of mangal community area will experience more than 0.5 m groundwater level rise outside of the evaporation ponds.

#### EV6 - Stock water wells

The predicted groundwater levels at the stock water wells varies considerably depending on the location. Groundwater levels within stock water wells 70910002 and 70910006 are predicted to rise only marginally (<0.5 m) whereas wells 70910007 and 70910780, are predicted to rise by between 1 to 3 m. This suggests the influence of water impoundment is relatively large near the western crystalliser ponds, consistent with modelling results shown in Figure 5-1 and Figure 5-2. The predictions show little variation in groundwater levels over the long-term between the mean sea level scenario and sea level rise scenario, which is expected given the distance of these wells from the coast.

#### EV2 and EV7 - Terrestrial Vegetation and Devil's Pools

The groundwater level at Devil's Pools is similarly predicted to increase by around 3 m over both the mean sea level scenario and sea level rise scenario following Project development (remains below the land surface throughout the simulation period). Little is currently known about this EV and whether the pools represent permanent expressions of groundwater, nor does the model attempt to simulate this feature explicitly; however, the results suggest water levels in this area will likely increase. Should this occur, Devils Pools, eucalypt species residing within Devils Creek, as well as creeks adjacent to the evaporation pond areas, will likely be affected. Under the mean sea level rise scenario, the mean of the 100 calibrated model realisations shows, 53% of the area of the mapped eucalypt species will experience greater than 0.5 m groundwater level rise outside of the evaporation ponds.

#### EV8 – Noorea Soak

Within the vicinity of Noorea Soak the mean of the 100 calibrated model realisations shows no change in groundwater levels during the operational period (Figure 5-4). Similarly, there is no discernible increase associated with sea level rise at this EV, which is expected given the distance from the coast. The soak is located in an area of basement outcrop in the model and the very low hydraulic conductivity assigned to this unit is likely to be responsible for the limited change observed at the prediction point. The groundwater head is largely controlled by ET, which keeps the watertable at least 2 m below the surface.

#### EV9 - Santos Gas Pipeline

Under all scenarios, the groundwater level at site PL-S, despite being located upgradient of the evaporation ponds, is predicted to rise considerably over time (increasing by approximately 5 m by year 100) due to seepage recharge and



### **Section 5** Direct Effects Assessment (Step 3)

groundwater mounding. The modelled groundwater level is below the land surface throughout the simulation period. The impact of sea level rise on this site is minimal, which is expected given its distance from the coast.

The model results at site PL-N show a slightly smaller rise in groundwater levels. Given the relatively shallow groundwater level at this site, the impact of evaporation pond seepage and the resulting groundwater mounding is believed to be dampened by groundwater ET. As per site PL-S, the impact of sea level rise on this site is minimal and the modelled groundwater level is below the land surface throughout the simulation period.



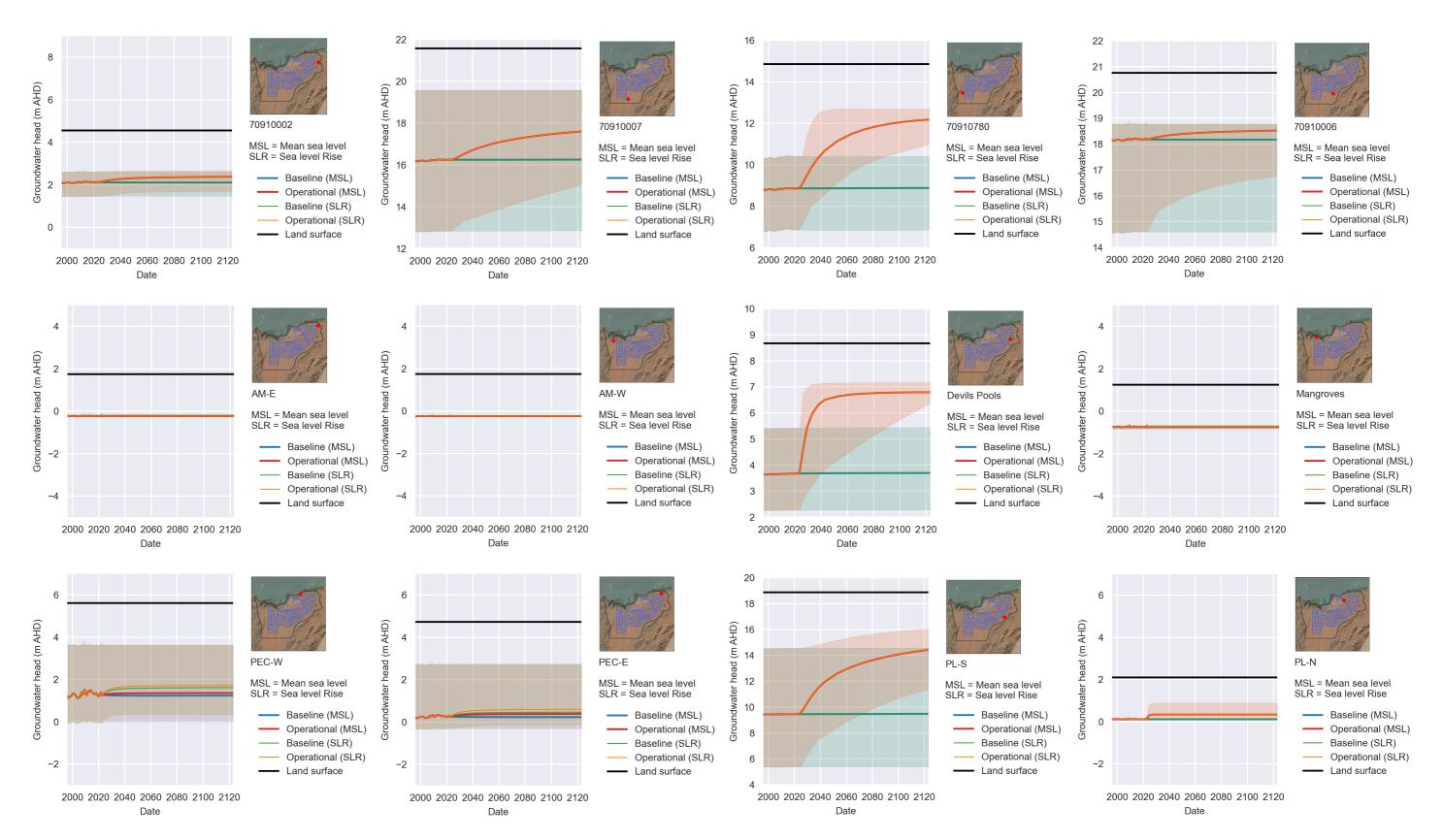


Figure 5-3 Predicted groundwater level change at selected locations (shading represents the range of prediction results from the 100 model realisations)

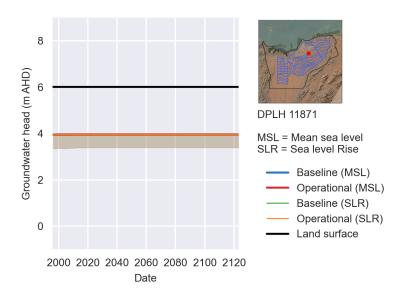


Figure 5-4 Predicted groundwater level change Noorea Soak

### 5.3.3 Predicted Salinity (Quality)

The mean of predicted groundwater salinity distribution across the 100 calibrated model realisations for the top model layer after 100 years of evaporation pond operations are shown in Figure 5-5 and Figure 5-6 for the mean sea level scenario and sea level rise scenario, respectively. To maintain readability, the vegetation receptors have been excluded from these figures and time series salinity changes to these EVs are instead illustrated in Figure 5-7 and Figure 5-8. Note, due to the limited salinity data available, the solute transport model has not been calibrated and therefore, the salinity predictions contain a considerable level of uncertainty.

The mean sea level scenario results (Figure 5-5) suggest the evaporation ponds largely control the salinity of groundwater, particularly in areas beneath the evaporation ponds, pond perimeters and creeks where salinity is predicted to exceed 210 g/L. These areas coincide with a shallow water table as a result of groundwater mounding which in turn, increases groundwater ET and salinity. The salinity impact, however, is predicted to be constrained within a "buffer zone" of less than around 1 km surrounding the ponds although extends to around 2 to 3 km along the west of the crystallisers. These results are consistent with the sea level rise scenario (Figure 5-6), where only minor salinity increases occur within the coastal areas to the north of the evaporation ponds due to the influence of sea level rise and subsequent higher rates of groundwater ET.

To assess the direct effects of water impoundment with respect to the location of the identified EVs, predicted time-series salinographs (for the same locations described earlier) have been prepared and are shown in Figure 5-7 and Figure 5-8. Note, given the paucity of salinity data informing the solute transport and density components of the model, considerable uncertainty exists in these results. Therefore, it is considered more appropriate to present the changes in salinity for this discussion rather than the predicted concentrations. This allows the direct effects to be assessed in a relative sense rather than an absolute sense where uncertainty exists.



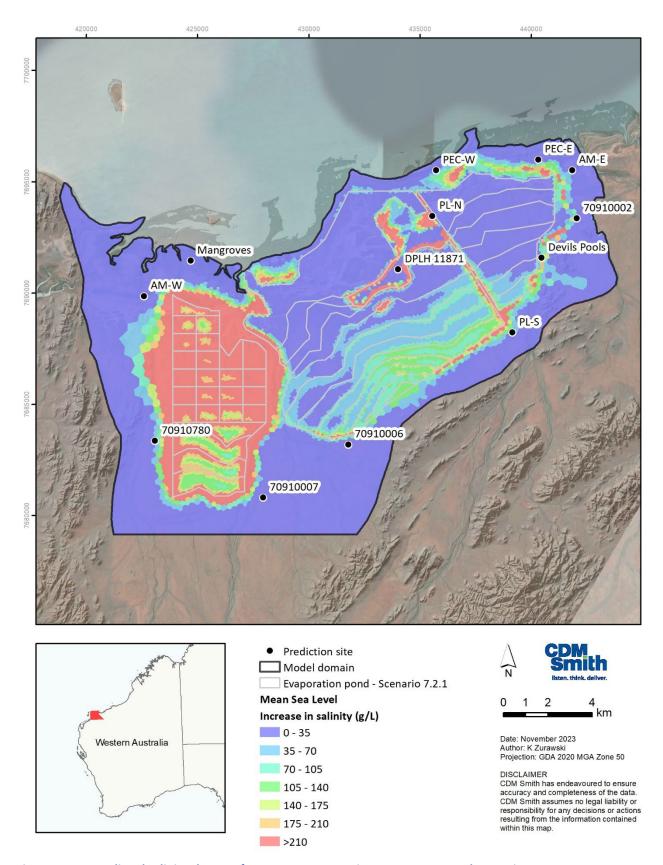


Figure 5-5 Predicted salinity change after 100 years operation – Mean Sea Level Scenario

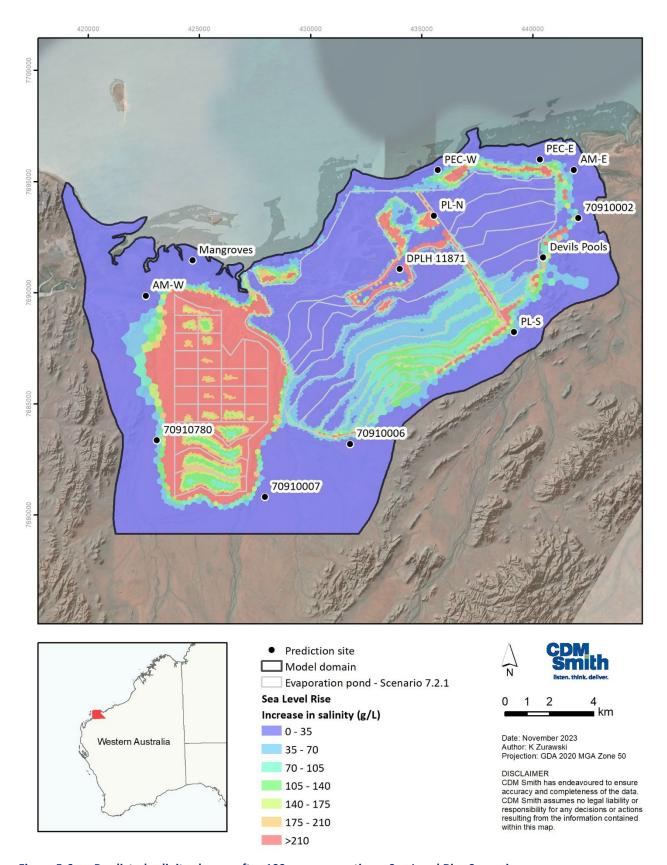


Figure 5-6 Predicted salinity change after 100 years operation – Sea Level Rise Scenario

#### EV3 - Coastal PEC

Groundwater salinity at PEC-E and PEC-W is predicted to increase gradually over time. Given their proximity to the evaporation ponds, the rate of increase is lower than expected, suggesting part of the saline inflow from the pond areas may have been intercepted by groundwater ET in the backwater areas before reaching PEC-E and PEC-W. The sea level rise scenario shows a lower salinity level at both sites due to its higher sea level (and hence a smaller hydraulic gradient towards the sea) compared to the mean sea level scenario. The uncertainty analysis suggests there is a potential for the saline inflow from the pond areas to reach PEC-E and PEC-W before being intercepted by groundwater ET, which is likely to depend on the permeability in this area (i.e. the saline inflow will propagate more rapidly in a more permeable setting). Under the mean sea level rise scenario, the mean of the 100 calibrated model realisations shows 91% of the coastal PEC mapped area will experience a salinity rise greater than 5 g/L outside the evaporation ponds.

#### EV4 and EV5 – Algal mats / samphire and mangroves

As stated, sites AM-E, AM-W and Mangroves have been selected to assess the direct effects of evaporation pond operations on the algal mat and mangrove communities outside the evaporation ponds in the eastern and western parts of the model domain.

The predicted groundwater salinity at AM-E and AM-W gradually increases over the simulation period for the mean sea level and sea level rise scenarios, which is expected given their proximity to the saline plume. The salinity change at these two sites is predicted to be approximately 30 g/L at AM-E and 10 g/L at AM-W over 100 year of evaporation pond operations. The predictive uncertainty analysis suggests the saline plume has the potential to reach these two sites, causing groundwater salinity to increase substantially. Under the mean sea level rise scenario, the mean of the 100 calibrated model realisations shows 38% of the agal mat mapped area and 30% of the samphire shrubland mapped area will experience a salinity rise greater than 5 g/L outside the evaporation ponds.

Meanwhile, groundwater salinity at site Mangroves is predicted to remain largely constant over time. However, the uncertainty analysis suggests the potential of inflow from the sea boundary, the evapo-concentration of which may cause the salinity to increase notably over time at this site. This increase was found to be more profound for the sea level rise scenario. Note that this potential impact is likely to be a result of sea level rise, which is a natural process, instead of the evaporation pond operations. Under the mean sea level rise scenario, the mean of the 100 calibrated model realisations shows 14% of the mangal community mapped area will experience a salinity rise greater than 5 g/L outside the evaporation ponds.

#### EV6 - Stock water wells

The predicted groundwater salinity at the stock water wells varies considerably depending on the location. Groundwater salinity is predicted to increase notably (by around  $50 \, \text{g/L}$ ) at 70910002 and 70910780, possibly due to the lateral expansion (i.e. parallel to the coast) of the saline plume. In contrast, 70910006 and 70910007 show a minimal increase in groundwater salinity as they are located upgradient (in terms of groundwater flow fields) of the evaporation ponds.

The predictive uncertainty analysis indicates the modelled salinity at these sites contains a large uncertainty. The worst-case conditions (i.e. the upper bound of colour shades) suggest the salinity may increase substantially beyond the salt tolerance of cattle, which typically ranges between 4 and 5 g/L (ANZECC, 2000), potentially rendering these stock water wells inoperable. To reduce this uncertainty, it is recommended to collect water samples at each stock water well so the threat of the evaporation pond operations can be better understood.

### EV2 and EV7 - Terrestrial Vegetation and Devil's Pools

Groundwater salinity within Devil's Pools is predicted to increase substantially over time, which will likely impact the eucalypt species residing within Devil's Creek as well as the pools themselves. The predictive uncertainty analysis indicates the rate of salinity increase can be rapid, reaching almost 300 g/L within approximately 20 years of evaporation pond operations. No effect from sea level rise is observed at this EV. Under the mean sea level rise



scenario, the mean of the 100 calibrated model realisations shows 53% of the mapped area of eucalypt species will experience a salinity rise greater than 5 g/L outside the evaporation ponds.

#### EV8 - Noorea Soak

Within the vicinity of Noorea Soak the mean of the 100 calibrated model realisations shows no change in salinity during the operational period in either the mean sea level or sea level rise operational scenarios. Similar to the direct effects predicted for groundwater level increases, these results are likely due to the very low permeability of the basement rock for which the soak is located (i.e. the saline plume cannot move quickly through the basement rock).

#### EV9 - Santos Gas Pipeline

Under both the mean sea level and sea level rise scenarios, groundwater salinity at site PL-S, is predicted to increase over time showing a mean increase of around 60 g/L. Both scenarios having identical predicted salinity suggests the impacts of sea level rise is not observed at this site. Conceptually this is understandable due to the distance of the site from the coast. However, the uncertainty analysis suggests, the salinity at this site has the potential to increase to more than 300 g/L.

Groundwater salinity predictions at site PL-N show a larger rise in salinity (with a mean increase slightly above 150 g/L), possibly due to the evapo-concentration of the shallow saline plume in this area. The uncertainty analysis suggests the rate of increase in salinity could be very rapid, exceeding 300 g/L after a few years of evaporation pond operations. For most of the operational period the impact of sea level rise is insignificant, although increases slightly over the later periods of operation likely due to the proximity to the coast.



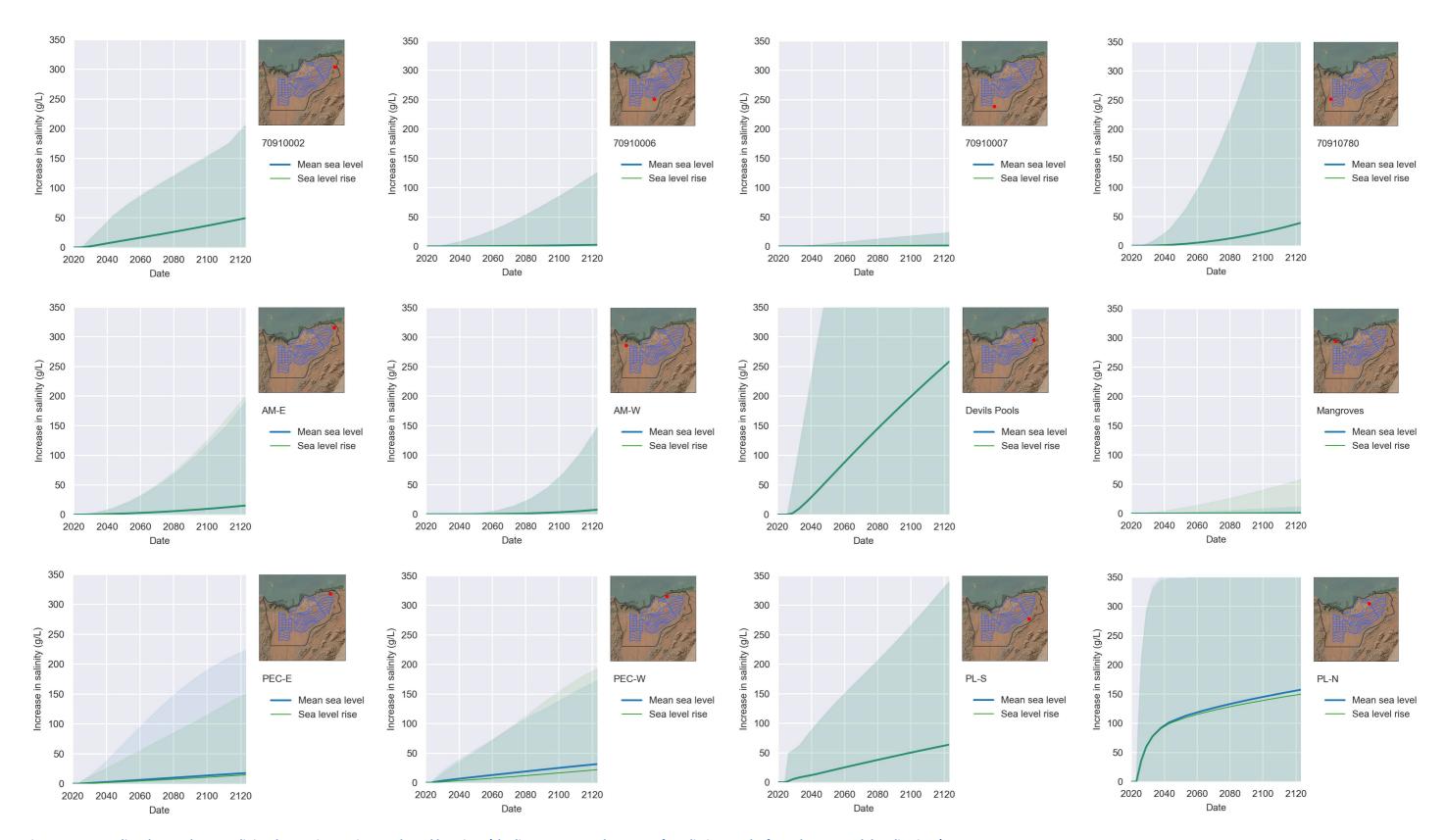


Figure 5-7 Predicted groundwater salinity change time series at selected locations (shading represents the range of prediction results from the 100 model realisations)

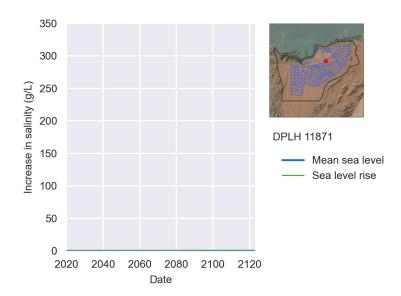


Figure 5-8 Predicted groundwater salinity change time series at Noorea Soak

### 5.3.4 Altered Groundwater / Surface Water Interactions

The impoundment of water within the evaporation ponds alters recharge to the groundwater systems causing an increase in groundwater levels. The change in groundwater levels alters the groundwater flow dynamics. The implications of this system change are discussed below. Water impoundment is also expected to reduce the quantity of surface water runoff, although this report does not attempt to quantify this impact (refer to the surface water effects assessment instead).

A mass balance of the groundwater model has been prepared to illustrate how the groundwater recharge and discharge processes are expected to change and is summarised in Table 5-3. The results show the mean predicted mass balance across the 100 calibrated model realisations after 100 years of evaporation pond operations and how the mass balance is predicted to change against the baseline conditions. For context of this discussion the baseline scenario suggests the major groundwater inflows are rainfall and inflow from the sea, while the major groundwater outflow is groundwater ET in low-lying areas. Under both scenarios (i.e. mean sea level scenario and sea level rise scenario) groundwater flow is changed due to water impoundment within the evaporation ponds, although, to varying degrees.

For the mean sea level conditions, the operation scenario indicates the major groundwater inflow is seepage from the evaporation ponds. Inflow from the sea only shows a slight reduction compared to the baseline scenario and occurs mostly in the western part of the model domain (see the 0 m AHD contour in Figure 9-10 in Appendix A Figure 9-10). The operation scenario shows a lower rainfall recharge than that of the baseline scenario as rainfall recharge is not applied in the evaporation pond areas (Appendix A).

The major groundwater outflow for the operation scenario is groundwater ET in areas adjacent to the evaporation ponds where groundwater levels are elevated due to pond seepage. There is also a notable outflow component attributed to groundwater discharge to the evaporation ponds. This is due to the design pond layout that may induce a cascading effect on groundwater flow. For instance, an upgradient pond at 20 m AHD will raise the underlying groundwater to a similar level (mounding), which will in turn induce groundwater discharge to the downgradient pond at 18 m AHD. The groundwater mounding also has an impact on the hydraulic gradient, inducing more groundwater outflow to the sea, although to a lesser extent than the discharge mechanisms already described.

The sea level rise scenario shows a considerable increase in inflow from the sea, while the other inflow components are largely similar to the operation scenario. The increase in inflow from the sea is mostly offset by a similar increase in groundwater ET in areas adjacent to the coast, suggesting groundwater ET may buffer the impact from sea level rise.



Table 5-3 Predicted mass balance at 100 years into the future

		Mean sea level scenario		Sea level rise scenario	
Component	Description	Baseline (kL/d)	Operation (kL/d)	Baseline (kL/d)	Operation (kL/d)
Storage IN	Decrease in storage	16	3	15	4
Constant Head IN	Inflow from sea	1,137	1,075	2,656	2,535
River Leakage IN	Seepage from evaporation ponds	0	14,334	0	13,875
GHB IN	Regional inflow	30	20	30	20
Recharge IN	Rainfall recharge	2,066	1,390	2,066	2,066
Total IN	Total inflow	3,248	16,822	4,767	18,500
Storage OUT	Increase in storage	1	41	1	40
Constant Head OUT	Outflow to sea	238	513	116	293
River Leakage OUT	Discharge to evaporation ponds	0	4,719	0	4,993
ET OUT	Groundwater ET	2,987	11,325	4,625	12,947
GHB OUT	Regional outflow	6	10	6	10
Drain OUT	Seepage drain	0	85	0	86
Total OUT	Total outflow	3,232	16,694	4,749	18,370
Percentage discrepancy	Difference between inflow and outflow	0.5%	0.8%	0.4%	0.7%

The modelling shows a mean pond seepage (over 100 years of operations) of 25,652 kL/d, ranging between 16,052 and 41,038 kL/d across the 100 calibrated model realisations. With a total pond area of 11,872 Ha, the pond seepage translates to a mean of 79 mm/y, ranging between 49 and 126 mm/y. Note that the riverbed conductivity value was selected in a conservative manner (Appendix A).

The predicted increase in salt discharge to the sea, calculated as the difference between the operation and baseline scenarios, is shown in Figure 5-9 for the mean sea level and sea level rise scenarios. The increase in salt discharge is greater for the mean sea level scenario due to its lower sea level and hence a steeper hydraulic gradients towards the sea (compared to the sea level rise scenario).

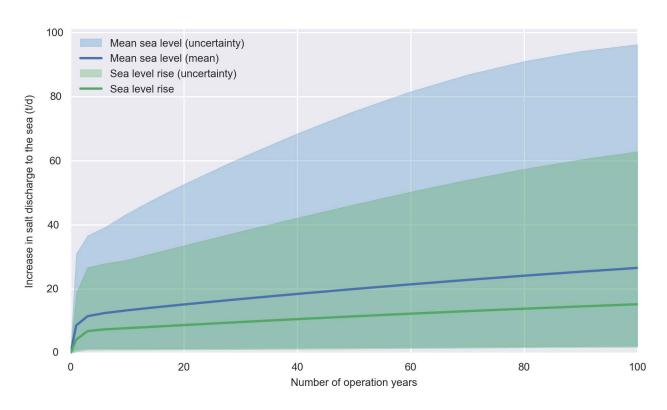


Figure 5-9 Predicted salt load (tonnes per day) to the sea

# **Section 6 Environmental Value Exposure Assessment (Step 4)**

#### **Exposure Pathway and Linkages** 6.1

An exposure pathway describes the process by which a direct effect can alter baseline water conditions such that an EV's environmental water requirement<sup>2</sup> (EWR) are impacted. For example:

- Water impoundment (a source) causes mounding of the water table (direct effect), an exposure pathway exists if:
  - Mounding decreases the depth to the water table causing water logging of soils reliant upon by phreatophytic vegetation (EV).
  - Groundwater salinity increases resulting in reduction or removal of suitable stygofauna (EV) habitat.
- Clearance of algal mat and terrestrial communities to allow construction of salt farming related infrastructure will have an effect on distribution of Evs within the Project development area, but as ecological clearance is not considered as a direct groundwater effect associated with a WAA, it therefore, is not considered in the EV exposure assessment.

Table 6-1 presents a summary of possible exposure pathways between direct effects (source) and potentially sensitive groundwater and surface water related Evs (receptors) that have been identified in the Project area respectively. The active exposure pathways are discussed further as part of the threat assessment in Section 7.

Note, with the exception of stygofauna, this assessment focuses only on the groundwater related EVs outside of the evaporation pond footprint and the exposure pathways connected to these EVs.

<sup>&</sup>lt;sup>2</sup> The amount of water required to sustain an EV, with a minimum risk of degradation.



Table 6-1 Possible exposure pathway for potential groundwater related Evs

Environmental value (receptor)	Direct effect		Indirect (EV) effect	WAA (source)	Active pathway (linkage)?	Carried forward to threat assessment?
	Quantity	DE1 – Increased recharge	Increased recharge from water impoundment could impact stygofauna habitat	WAA1 – Water impoundment	Yes, groundwater modelling (Figure 5-1, Figure 5-2 and Figure 5-3) predicts mounding of the water table will occur, however, this will not result in a reduction in stygofauna habitat.	X
	Quality	DE2 – Change in salinity	Increased salinity from water impoundment could impact stygofauna habitat		Yes, groundwater modelling (Figure 5-5, Figure 5-6 and Figure 5-7) predicts groundwater salinity within the Project area will increase by up to the point of salt saturation during operations. This will likely impact stygofauna habitat.	Ø
EV1 – Stygofauna		DE3 – Change in groundwater levels	Change in groundwater levels from water impoundment could impact stygofauna habitat		Yes, however, as discussed, this will not result in a reduction in stygofauna habitat.	X
	Altered GW/SW interactions	DE4 – Change in groundwater flow	Change in groundwater flow from water impoundment could impact stygofauna		Yes, groundwater modelling predicts the Project will change groundwater flow resulting in greater discharge to the coast rather than the current condition where groundwater flows from the coast inland with virtually no discharge to the ocean. This process, however, is unlikely to impact stygofauna habitat significantly, as stygofauna are thought to exist predominantly in areas further inland and outside of the hypersaline backwater zone adjacent to the coast.	X
	Quantity	DE1 – Increased recharge	Increased recharge from water impoundment could increase the quantity of water relied upon by terrestrial vegetation		<b>Yes,</b> groundwater modelling predicts water impoundment will increase the water levels from baseline conditions within the vicinity of the evaporation ponds, however, this impact is mostly localised and limited to a small corridor of around 1 to 3 km surrounding the evaporation ponds (refer to Figure 5-1, Figure 5-2 and Figure 5-3). These impacts may cause water logging of soils within creeks adjacent to the ponds.	Ø
EV2 – Groundwater dependent terrestrial	Quality	DE2 – Change in salinity	Increased salinity from water impoundment could impact the EWR of terrestrial vegetation		Yes, groundwater modelling (Figure 5-5, Figure 5-6 and Figure 5-7) predicts groundwater salinity will increase significantly from baseline conditions under the evaporation ponds. However, as per above, the most likely scenario will result in a zone of influence that is mostly limited to the evaporation pond areas within a 1 km buffer zone, although the zone of influence could potentially (within the uncertainty analysis predictions) extend up to 3km surrounding the evaporation ponds. This will likely have an adverse impact on vegetation located within drainages between the evaporation ponds, along the Santos Gas Pipeline and within Devil Creek. Terrestrial vegetation located greater than 1 km away are unlikely to be impacted and vegetation located greater than 3 km are highly unlikely to be impacted.	Ø
vegetation (GDE Atlas)	Altered GW/SW interactions	DE3 – Change in groundwater levels	Change in groundwater levels from water impoundment could increase the duration of surface water inundation within creeks altering groundwater and surface water flows and impact terrestrial vegetation		Yes, as per EV2, DE1 exposure pathway.	Ø
		DE4 – Change in groundwater flow	Change in groundwater flow from water impoundment could alter the availability of water being sourced by terrestrial vegetation		No, groundwater modelling predicts the Project will change groundwater flow resulting in greater discharge to the coast rather than the current condition where groundwater flows from the coast inland with virtually no discharge to the ocean. This process, however, is unlikely to impact terrestrial vegetation that might be reliant on groundwater to some extent as they are thought to occur in areas further inland where change to groundwater flow processes is minimal and restricted mainly to a small area within and surrounding the evaporation ponds. Furthermore, terrestrial vegetation over majority of the model domain is classified as low potential GDEs (BOM, 2022b).	X
	Quantity	DE1 – Increased recharge	charge Increased recharge from water impoundment could increase the quantity of water reporting to the Coastal PEC		No, groundwater modelling predicts most of the increased recharge will be discharged via groundwater ET and as outflow to the sea. Outside of the evaporation pond areas, the zone of water level influence remains relatively constrained to within a 1 km buffer zone and no expressions of groundwater or permanent wetting is predicted.	X
EV3 – Terrestrial vegetation (Priority Ecological	Quality	DE2 – Change in salinity	Increased salinity from water impoundment could impact the EWR of the Coastal PEC		Yes, groundwater salinity at the Coastal PEC is expected to rise gradually over time. However, the rate of increase is lower than expected (although with a high degree of uncertainty), suggesting part of the saline inflow from the pond areas may have been intercepted by groundwater ET in the backwater areas before reaching the PEC. The mean scenario shows a limited salinity rise of 35 to 70 mg/L for the PEC closest to the ponds, whereas the maximum scenario shows a salinity rise across almost all of the PECs. Therefore, the PEC closest to the ponds has a high likelihood of impact whereas the PEC closer to the sea has a lower likelihood of impact.	Ø
Community)	Altered GW/SW	DE3 – Change in groundwater levels	Change in groundwater levels from water impoundment could cause permanent water logging or impact how the Coastal PEC accesses groundwater		<b>No,</b> In the area of the PEC the water level is predicted to remain within 0.5 m of the baseline and in the upper range of the uncertainty analysis is still predicted to be 2 m below the surface (kept low by ET). Given the type of vegetation within this community, root systems are unlikely to extend to this depth.	X
	interactions	DE4 – Change in groundwater flow	Change in groundwater flow from water impoundment could alter the availability of water being sourced by the Coastal PEC		Yes, groundwater modelling predicts the Project will change groundwater flow resulting in greater discharge to the coast rather than the current condition where groundwater flows from the coast inland with virtually no discharge to the ocean. However, this is not expected to impact the Coastal PEC as the change in flow has minimal impact on the groundwater levels or recharge to the vegetation in this community.	☒



Environmental value (receptor)	Direct effect		Indirect (EV) effect	WAA (source)	Active pathway (linkage)?	Carried forward to threat assessment?
			Increased recharge from water impoundment could increase the quantity of water reporting to algal mat and samphire communities		No, groundwater modelling predicts most of the increased recharge will discharged via groundwater ET and as outflow to the sea. Outside of the evaporation pond areas, the zone of water level influence remains relatively constrained to within a 1 km buffer zone (Figure 5-1, Figure 5-2 and Figure 5-3), however, no expressions of groundwater or permanent wetting is predicted, suggesting the impact to algal mat and samphire communities from increased groundwater recharge is negligible, but possible.	X
		DE2 – Change in salinity			Yes, groundwater modelling predicts a minor increase to groundwater salinity in the areas immediately adjacent to the evaporation ponds in the northeast and northwest of the Project. Salinity is predicted to increase by around 10 to 30 g/L under the operation and sea level rise scenarios, however, the uncertainty analysis shows it is possible the saline plume reaches these receptors which would increase salinity substantially. Therefore, the impact of salinity to groundwater will most likely be small, although may range considerably if the worst-case scenario occurs, and limited mostly to within a 1 km buffer zone surrounding the evaporation ponds.	Ø
EV4 – Algal mats and Samphire	Quality		Increased salinity from water impoundment could impact the EWR of algal mat and samphire communities		As neither Algal mat nor samphire are groundwater dependant species, direct effects relating to groundwater quality (i.e. increased salinity) will only pose as an exposure pathway should groundwater become contacted with these EVs. Groundwater discharge is not expected in areas other than through groundwater ET or direct discharge to the coast. The salinity of groundwater discharging to the coast is predicted to be equal to seawater and slightly higher (up to 140 g/L) in very localised areas. Hagemann (2010) reports some hypersaline cyanobacteria which make up algal mats can function in environments of nearly saturated brines. Given the current hypersaline environment in which the algal mats exist, it is likely these species will be tolerable to similar extremes.	
					Therefore, the impact from increased groundwater salinity to algal mats is expected to be localised to areas along the coast where groundwater discharges, however, algal mats are expected to be resilient to the predicted salinity increases. Salinity impacts to samphire might occur should their habitat (i.e. the backwater areas) become permanently inundated.	
	Altered GW/SW interactions	DE3 – Change in groundwater levels	Change in groundwater levels from water impoundment could cause permanent water logging disrupting the wetting and drying processes of algal mat and samphire communities		Yes, cross sections (AM-W and AM-E) predicted by the Eramurra groundwater model that are located within algal mats adjacent (~1 km distance) to the evaporation ponds, indicate no change in groundwater levels is expected. Minor change in groundwater levels is likely immediately adjacent to the evaporation ponds which may impact the wetting and drying processes of algal mats and samphire; however, permanent inundation is not predicted and groundwater mounding surrounding the evaporation ponds is unlikely to have a significant effect on the wetting and drying cycles within the backwater area.	⊠
		DE4 – Change in groundwater flow	Change in groundwater flow from water impoundment could alter the groundwater processes that enable the hypersaline habitat of algal mat and samphire communities		Yes, the predicted change in groundwater flow will result in some additional flow occurring towards the ocean (under the most likely operation scenario), which might impact algal mats that exist within tidal areas that coincide with groundwater discharge. This direct effect, however, will not change the overall flow process towards the backwater areas meaning an adverse effect is not expected to samphire. The impact to samphire will depend on water logging and salinity change and tolerance of this EV to those changes	Ø
	Quantity	DE1 – Increased recharge	Increased recharge from water impoundment could increase the quantity of water reporting to mangrove vegetation		<b>No</b> , groundwater modelling (Figure 5-1, Figure 5-2 and Figure 5-3) predicts water levels within the mangrove areas will not increase as a result of water impoundment due to the hypersaline backwater zone buffering the increased recharge through increased groundwater ET.	☒
EV5 – Aquatic vegetation (mangroves)	Quality	DE2 – Change in salinity	Increased salinity from water impoundment could impact the EWR of mangrove vegetation		Yes, groundwater modelling (Figure 5-5, Figure 5-6 and Figure 5-7) indicates the mangrove site to be relatively insensitive to the operations, possibly due to the buffer provided by ET in the low-lying area. Given its proximity to the sea, this area is more susceptible to sea water intrusion in the sea level rise scenario. The salinity level is further increased by evapo-concentration (hence it can go beyond the sea salinity of 35 g/L), although this is an effect of sea level rise, not of the operations.	Ø
	Altered GW/SW	DE3 – Change in groundwater levels	Change in groundwater levels from water impoundment could disrupt the wetting and drying cycles of habitat hosting mangrove vegetation		No, as per EV4, DE1 exposure pathway, wetting and drying cycles are unlikely to be impacted as groundwater levels in mangrove areas are unlikely to increase	×
	interactions	DE4 – Change in groundwater flow	Change in groundwater flow from water impoundment could alter the groundwater discharge processes connected to mangrove vegetation	1	Yes, groundwater modelling (Table 5-3) predicts the groundwater outflow to the sea will increase by around 500 kL/d under the mean sea level scenario and 300 kL/d under the sea level rise scenario.	Ø
	Quantity	DE1 – Increased recharge	Increased recharge from water impoundment could increase the quantity of water relied upon for stock water use		Yes, groundwater modelling (Figure 5-1, Figure 5-2 and Figure 5-3) predicts the water quantity available to stock water wells will increase as a result of the Project development affecting stock water wells 70910007 and 70910780 and increasing water levels by between around 1 to 3 m. As this effect alone is not adverse it has not been considered further.	X
EV6 – Stock water wells	Quality	DE2 – Change in salinity	Increased salinity from water impoundment could impact the EWR of stock water use		Yes, notable increases at stock wells 70910002 and 70910780 are likely (around 50 g/L). There is a high degree of uncertainty in the modelled salinity. The worst-case conditions (i.e. the upper bound of the uncertainty analysis) suggest the salinity may increase substantially beyond the salt tolerance of cattle, which typically ranges between 4 and 5 g/L (ANZECC, 2000), potentially rendering all the stock water wells inoperable. Based on the modelling, wells 7091006 and 7091007 are less likely to be impacted by salinity rises.	Ø



Environmental value (receptor)	Direct effect		Indirect (EV) effect	WAA (source)	Active pathway (linkage)?	Carried forward to threat assessment?
	Altered GW/SW	DE3 – Change in groundwater levels	Change in groundwater levels from water impoundment could cause an increase in water levels in stock water wells		Yes, as per EV5, DE1 exposure pathway.	☒
	interactions	DE4 – Change in groundwater flow	Change in groundwater flow from water impoundment could alter flow processes connected to stock water wells		Yes, as per EV5, DE1 pathway, stock water wells will receive additional groundwater flow from the evaporation ponds.	X
	Quantity	DE1 – Increased recharge	Increased recharge from water impoundment could increase the quantity of water connected to springs and pools		Yes, groundwater modelling (Figure 5-1, Figure 5-2 and Figure 5-3) predicts water levels in the Devils Pools area will increase by around 3 m. This impact alone is unlikely to result in an adverse effect to the cultural values of this EV, however in combination with increased salinity could impact the values.	
EV7 – Cultural	Quality	DE2 – Change in salinity	Increased salinity from water impoundment could impact the EWR of springs and pools		Yes, groundwater salinity (Figure 5-7) within Devil's Pools is predicted to increase by around 260 g/L over the 100 years of operation, and in the worst case scenario this increase could occur within 20 years of operation.	Ø
and spiritual (springs and pools)	Altered GW/SW	DE3 – Change in groundwater levels	Change in groundwater levels from water impoundment could change the interaction of groundwater and surface water in the springs and pools		Yes, as per EV6, DE1 pathway, groundwater levels are expected to increase in areas around Devils Creek which will change the groundwater/surface water interactions. This impact alone is unlikely to result in an adverse effect to the cultural values of this EV, however, in combination with increased salinity could impact the values.	Ø
	interactions	DE4 – Change in groundwater flow	Change in groundwater flow from water impoundment could alter flow processes connected to springs and pools		Yes, groundwater flow conditions will likely change from flowing north (current predicted conditions) to flowing east from the evaporation ponds following water impoundment, however, this impact alone is unlikely to result in an adverse effect to this EV.	X
	Quantity	DE1 – Increased recharge	Increased recharge from water impoundment could increase the quantity of water connected to springs and pools		<b>No,</b> groundwater modelling predicts no change the water levels at the soak over the prediction period and therefore there is no mechanism via groundwater for the pond to cause increased recharge to the soak.	X
EV8 – Cultural	Quality	DE2 – Change in salinity	Increased salinity from water impoundment could impact the environmental water requirements of springs and pools		No, groundwater salinity in the area of the soak is not predicted to increase over the prediction period.	X
and spiritual (soaks)	Altered GW/SW	DE3 – Change in groundwater levels	Change in groundwater levels from water impoundment could change the interaction of groundwater and surface water in the springs and pools		No, as per DE1, groundwater levels are not expected to increase in the area of the soak.	×
	interactions	DE4 – Change in groundwater flow	Change in groundwater flow from water impoundment could alter flow processes connected to springs and pools		No, groundwater flow conditions are not expected to change in the vicinity of the soak.	×
	Quantity	DE1 – Increased recharge	Increased recharge from water impoundment could increase the quantity of water beneath the Santos Gas Pipeline		Yes, groundwater modelling predicts substantial rise in groundwater level at the Santos Gas Pipeline transfer station (located upgradient of the ponds) of around 5 m and a smaller rise (less than 0.5 m) at the northern end of the pipeline. The modelled groundwater level is below the land surface and below the elevation of the pipeline (1.2 m bgl) throughout the simulation period as the rise is dampened by ET and therefore no direct adverse effect is likely.	X
EV9 – Santos Gas Pipeline	Quality	DE2 – Change in salinity	Increased salinity from water impoundment could impact Santos Gas Pipeline		No, saline groundwater has the potential to impact the pipeline directly (depending on the material) should groundwater come into contact with the pipeline and the concrete formations (where they occur) causing corrosion that can be problematic should it reach the steel structure within. The pipeline is installed to 1.2 m bgl and groundwater is not expected to reach this level. In addition, the pipeline has been designed in consideration of the saline environment and in accordance with appropriate Australian Standards (AS2885.1) that address matter of corrosion mitigation.	X
	All and Courter	DE3 – Change in groundwater levels	Change in groundwater levels from water impoundment could cause surface expressions (seepage) of groundwater impacting the Santos Gas Pipeline		Yes, as per EV7, DE1 exposure pathway.	
	Altered GW/SW interactions	DE4 – Change in groundwater flow	Change in groundwater flow from water impoundment could alter flow processes beneath the Santos Gas Pipeline		Yes, groundwater modelling predicts groundwater flow will occur as mounding slightly up gradient of the evaporation ponds and increase quantities of water beneath the Santos Gas Pipeline. However, this impact alone is unlikely to result in an adverse effect to this EV.	X



# **Section 7 Threat Assessment (Step 5)**

#### 7.1 Overview

The threat assessment brings together the direct effects and EV exposure assessments to provide the basis from which to assess consequences arising from development activities (Project WAAs). This assessment involves consideration of direct effects (altered groundwater resource condition, such as water table depth and groundwater quality) and, importantly, EV (or indirect) effects, such as loss of biodiversity or reduced water access by third parties (Howe, 2011).

#### 7.2 Inherent Threats

In a pre-mining sense, the primary inherent threats posed to groundwater resources in the Project area include:

- Climate variability with extended periods of drought likely to result in reduced infiltration of rainwater that fills the soil reservoir and provides inflows to drainages supporting ecosystems such as terrestrial vegetation. The area is expected to contain the resilience and resistance mechanisms that deal with the natural variability at present such that these mechanisms can evolve to be resilient to future changes in climate.
- Seal level rise estimates of sea level rise (EPA, 2016) suggest climate change could lead to a sea level rise of around 0.9 m within 100 years. This has the potential to result in loss of habitat for EVs located within close proximity of the shoreline within this tidal range. However, groundwater modelling predicts a relatively subdued impact for the Project area with less outflow of groundwater occurring to the sea and a minor change in groundwater levels mostly in the northwest of the Project area. Surface water modelling (LWC, 2022b) suggests climate change (i.e. sea level rise and increased rainfall) may increase water levels within McKay and Devil Creeks in areas closest to the ocean and contribute to increased water levels surrounding the evaporation ponds. The increases, however, are not expected to significantly alter the sediment dynamics of the creek systems.
- Pest and weed invasion.

From an anthropological perspective, pre-existing development is uncommon apart from pastoral activities and associated roads/tracks from the Santos Gas Pipeline development. Karratha township is located some 55 km to the northeast of the development envelope.

# 7.3 Degree of Existing Stress on Groundwater

As stated, current land use within the Project area includes pastoral activities where a number of windmill operated stock water wells are utilised and operation of the Santos Gas Pipeline. These activities are thought to have minimal impact on the existing groundwater system and as such, pre-existing WAAs are unlikely to result in cumulative effects alongside the proposed Project.

# 7.4 Potentially Threatened Environmental Values

#### 7.4.1 Overview

Table 7-1 provides a summary of the active exposure pathways and potentially threatened groundwater Evs. A total of eight Evs are potentially threatened by the Project, however, this impact is expected to be mostly limited to within a 1 km buffer zone surrounding the evaporation ponds and highly unlikely (although possible) to occur up to 3 km. The results suggest the Evs are likely to be impacted by direct effects relating to (i) increased recharge, (ii) increased salinity, (iii) change in groundwater levels and (iv) change in groundwater flow. These direct effects will require



management to decrease the likelihood of the indirect effects occurring. Discussion regarding the threat to each EV is presented in the below subsections.

Table 7-1 Summary of the identified potentially threatened environmental values

Environmental value (receptor)	Direct effect (pathway)	WAAs (source)
EV1 – Stygofauna	DE2 – Change in salinity	WAA1 – Water impoundment
EV2 – Groundwater dependent terrestrial vegetation (GDE Atlas)	DE1 – Increased recharge DE2 – Change in salinity DE3 – Change in groundwater levels	
EV3 – Terrestrial vegetation (Priority Ecological Community)	DE2 – Change in salinity	
EV4 – Algal mats and Samphire	DE2 – Change in salinity DE4 – Change in groundwater flow	
EV5 – Aquatic vegetation (mangroves)	DE2 – Change in salinity DE4 – Change in groundwater flow	
EV6 – Stock water wells	DE2 – Change in salinity	
EV7 – Cultural and spiritual (springs and pools)	DE1 – Increased recharge DE2 – Change in salinity DE3 – Change in groundwater levels	

#### 7.4.2 EV1 – Stygofauna

Bennelongia (2022) identified 11 species of stygofauna within the Project area. These stygofauna communities will likely be impacted by direct effects involving changes to the groundwater salinity. As shown in Figure 7-1, stygofauna are generally restricted to salinities of less than 10 g/L within the Pilbara region with some instances of salt-adapted stygofauna species occurring at salinity levels close to and slightly greater than sea water (35 g/L), although reportedly much less common. Groundwater modelling predicts the salinity of the groundwater under the evaporation ponds will increase to the salt saturation point, increasing by up to 350 g/L. It is unlikely stygofauna existing within the Project area will be resilient to such increases in salinity resulting in a consequence of elimination. However, the Project area reportedly does not contain any restricted subterranean species (Bennelongia, 2022) meaning the habitat is non-unique and the consequence of such an event would be limited to the extent impacted by the salinity increase.

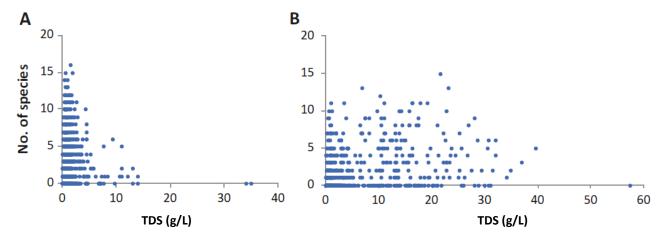


Figure 7-1 Comparative salinity tolerances of stygofauna in the Pilbara (a) and Yilgarn (b) (Halse, 2018)

Outside of the Project area, salinity impacts (as discussed) are expected to be localised and restricted to within a 1 km buffer zone surrounding the evaporation ponds under the most likely scenario and up to 3 km under within the



bounds of the uncertainty analysis (Figure 5-5 and Figure 5-6). Stygofauna are unlikely to exist within the downgradient areas (backwater areas and intertidal dunes) due to the present hypersaline environment (>35 g/L and up to >240 g/L). However, the surrounding areas to the Project are considered as suitable habitat for subterranean fauna (Bennelongia, 2022).

Given this information, the threat to stygofauna as a result of the Project development is expected to be localised to the evaporation ponds and a small extent outside of these areas impacted by salinity increases and unlikely to have a significant impact in terms of the conservation of fauna communities more regionally (Bennelongia, 2022).

#### 7.4.3 EV2 – Groundwater dependent terrestrial vegetation (GDE Atlas)

Occurrences of eucalypt species within the Project area are shown earlier in Figure 4-1. This EV will likely be impacted by direct effects involving increased recharge, increased salinity and increased groundwater levels. Groundwater levels are predicted to increase by around 3 m within the creeks and drainages within the Project area, notably Devil Creek to the Project's east and McKay Creek situated between the evaporation ponds in the centre of the Project area. This may cause water logging of the unsaturated root zone, impacting the reserve of fresher soil water used by the trees for transpiration, as these species cannot draw water from completely saturated soil (below the water table).

Eucalypts are found to occur in a wide range of geological settings and are well adapted and resilient to extreme conditions having the ability to access multiple sources of soil moisture (both shallow and deep) due to their dimorphic root structure. Based on the climate of the Project area, eucalypt species are likely to exhibit Case 2 or Case 5 type root distributions as shown in Figure 7-2. When Eucalypts become waterlogged, they are known to form 'adventitious roots' at or just above the water table as an avoidance mechanism to rising water levels (Clements et al., 1978). This suggests the ability of Eucalypts to resist water logging is reflective of their ability to source adventitious roots as a means to avoid stresses rather than tolerate them. Should groundwater levels rise as predicted (i.e. around 2 to 3 m within creeks and drainages) this will result in a reduced unsaturated zone that will require the vegetation to adapt their water sourcing. The consequence of a permanent rise by this magnitude will likely result in some stresses to the vegetation (which these species are resilient to) such as reduced canopy growth, reduced root development of the deeper root systems and production of adventitious roots. Permanent loss of vegetation is not expected provided an unsaturated zone remains (i.e. the Eucalypts are not exposed to permanent inundation). The modelling predicts an unsaturated zone will remain. It should be noted that the changes to groundwater level and salinity are expected to occur relatively quickly (within a few years) and therefore a temporary, short-term loss of condition (such as leaf loss) may occur as the plants adapt to a loss of deeper roots while the adventitious roots establish and the canopy rebounds. This can be managed by running fresh water down the creeks in the early years of development if necessary.

Eucalypt species are also likely to be threatened by increases in groundwater salinity, should these species access groundwater for periods of time. Eucalypts are highly resilient to changes in weather patterns and adaptable in terms of their water sourcing (i.e. soil water vs groundwater, or both) and therefore, will likely be able to exist without a groundwater supply for sustained periods, unless unanticipated waterlogging occurs. However, salinity increases to the groundwater at the predicted concentrations will likely affect the vadose zone and impact the water (groundwater) uptake during dry periods when fresher waters supplies are diminished. Eucalypt species are documented to viably use groundwater with salinity of less than around 13 g/L, while they have also been shown to use groundwater between 7 to 21 g/L (CDM Smith, 2021). These tolerance ranges are far below the predicted salinity increases at the Project's creeks, for which increases of almost 350 g/L are expected in some locations. The consequence of such a direct effect is increased tree stress during dry periods and potential permanent loss of vegetation.

Increased groundwater levels may also threaten eucalypts should this change the groundwater – surface water interactions. Shallower groundwater levels will extend the periods of surface water inundation within creeks from the baseline condition. This effect alone generally will not result in an adverse effect unless it induces a prolonged period of water logging that entirely inundates the unsaturated zone or combines with direct effects associated with salinity



increases, e.g. if the surface water becomes saline as a result of groundwater interactions, or groundwater from beneath the evaporation ponds seep to within these drainages. The consequence of such a direct effect is increased tree stress during dry periods, reduction of the number and frequency of emergent saplings and potential permanent loss of vegetation.

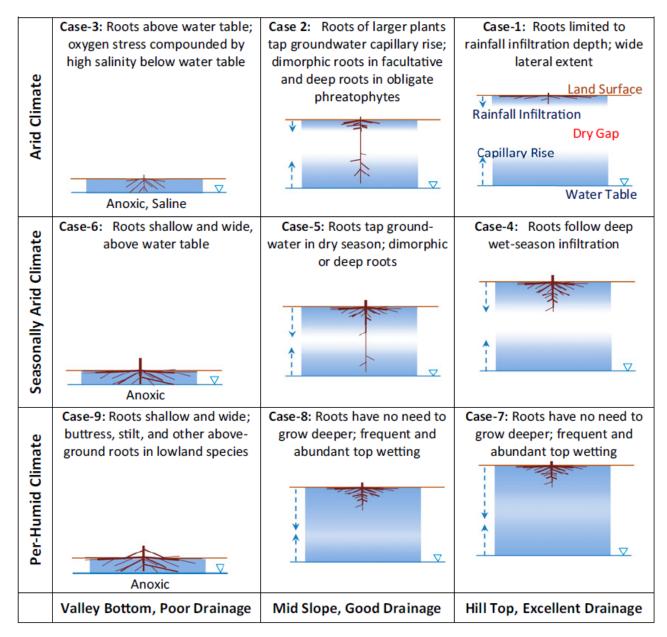


Figure 7-2 Hydrologic framework for rooting depths along climate and depth to water gradients (Fan et al. 2017)

#### 7.4.4 EV3 - Terrestrial vegetation (Priority Ecological Community)

The PEC mapped near the site is related to coastal dune native tussock grassland dominated by Whiteochloa airoides. Only minimal mounding is expected in this location due to the effect of ET in the area of this EV (i.e. low lying coastal area with a shallow watertable). The groundwater salinity in the region of the PEC is predicted to increase gradually over the operational period. The non sea level rise scenario shows a greater degree of increase than the sea level rise scenario because the rise in sea level reduces the hydraulic gradient to the sea and results in concentration of salt in the near shore environment.



Given the location of this EV close to the shore and adjacent to the algal mat communities, it is likely the plant species residing here have a high degree of salt tolerance. The predicted baseline salinity at this EV is 60 to 30 g/L (PEC-E and PEC-W locations respectively) with a range between 9.6 and 118 g/L across the models. The baseline depth to groundwater at this locality is around 4 m and therefore it is unlikely the plants are accessing groundwater as their primary water source. If groundwater does rise to within the root zone of the plants, this is unlikely to affect the primary water source (rainfall) and the grasses would be expected to continue using this source and not groundwater.

#### 7.4.5 EV4 – Algal Mat and Samphire

Occurrences of samphire and algal communities within the Project area are shown earlier in Figure 4-1.

Samphires species have evolved high drought tolerance due to their succulent articles (leaves) and woody roots. They are arid zone plants which tolerate heat, cold, drought and hypersaline conditions (Louis Moir-Barnetson et al., 2014). It is important to note that while they persist in highly saline environments, a key survival mechanism is that when fresher water sources (direct rainfall) occur, they are able to quickly recover by growing fine white adventitious roots and initiating rapid shoot growth, ensuring foliage production. As long as surface water inputs (i.e. rainfall and flood waters) are able to maintain soil moisture levels sufficient to meet samphire water use requirements under all but extreme climate regimes, they are able to persist. No groundwater level change is predicted at these locations and therefore the more saline groundwater is unlikely to come into contact with the samphire and as such they are considered at low risk as the system of water access does not change.

Algal mats are similar to mangroves, however, require lower energy tidal environments, and as such occur within the inland extent of Mangrove communities, fringing with Samphire communities (Biota, 2005). This EV has no actual subsurface structure and are therefore only impacted if the surface of the tidal flats is altered. As such the threat to algal mats from changes to groundwater is considered low but within spatial samphire EV grouping.

#### 7.4.6 EV5 - Aquatic Vegetation (Mangroves)

Occurrences of mangrove communities within the Project area are shown earlier in Figure 4-1. The frequency and period of high tides (wetting and drying phase) controls the distribution of mangrove sub species. Mangrove species use sea water, groundwater and fresh water sourced from direct rainfall precipitation depending on the state of the tide. Saline sources of water contribute to sub surface growth while fresher water supplies are critical to surface foliage growth (Hayes et al., 2019, Gabler et al., 2017 and Osland et al., 2018). This EV will likely be impacted by direct effects involving increased salinity and change in groundwater flow. Groundwater salinity in areas where mangroves are present is not predicted to increase, however, could under a worst-case scenario, increase by up to 60 g/L, although highly unlikely. Therefore, it is unlikely mangrove communities will be impacted by increases to groundwater salinity.

Changes in groundwater flow may also potentially threaten mangrove communities. Under the mean sea level scenario groundwater discharging to the coast is predicted to increase from 238 kL/d up to around 513 kL/d equating to an increased salt load of around 26 t/d however, can range between around 2 and 97 t/d. These discharges may interrupt the natural wetting and drying processes of mangroves adjacent to the pond areas and place additional stress on the vegetation species. However, it is important to note that the change in groundwater flux does not manifest in an increase in the water table within these zones, as that is controlled by the evaporative discharge volumes. Therefore, the consequence of increases in groundwater discharge volumes may be minor, as long as this discharge volume does not interrupt the low tide function of recharge to the estuarine sediments from direct rainfall.

In addition, given the total water balance of the site and the distance of the coastline, such increases in groundwater outflow and salt load are considered negligible and unlikely to meaningfully impact mangrove communities.

#### 7.4.7 EV6 – Stock Water Wells

Stock water wells have the potential to be impacted by changes in groundwater salinity. Under the most likely scenario, stock wells 70910006 and 70910007 are unlikely to be impacted. Under the worst case for these wells and in



the most likely case for wells 70910002 and 70910780, the salinity is expected to increase by around 50 g/L. The predicted baseline concentrations for these wells range as follows:

- 70910780: 1.2 g/L (ranging between 0.5 and 1.4 g/L).
- 70910007: 1.0 g/L (ranging between 0.4 and 1.2 g/L).
- 70910006: 3.4 g/L (ranging between 1.0 and 4.7 g/L).
- 70910002: 180.5 g/L (ranging between 94.2 and 350.6 g/L).

These results indicate that 70910002 already has a salt level beyond the salt tolerance of cattle, which typically ranges between 4 and 5 g/L (ANZECC, 2000) and that in the most likely scenario 70910780 salinity will also rise above the cattle tolerance. For 70910006 the modelling indicates even the small increase predicted in the most likely scenario may render this bore unusable for stock given its high baseline salinity. Under the most likely scenario, the salinity at 70910007 will remain useable for stock although under the worst-case conditions salinity may increase by around 30 g/L.

It should be noted that current groundwater modelling has not assessed the influence pumping from these stock water wells will have and whether this WAA could draw hyper saline water from under the evaporation ponds to the wells. Additionally, there is a high uncertainty as to the predicted baseline groundwater salinity of the stock water wells such that the threat to this EV cannot be assessed with confidence. The consequence of this direct effect is loss of stock watering infrastructure.

Leichhardt have indicated in an email correspondence dated 7 September 2022, that impacted stock watering wells will be relocated. This will eliminate the threat of stock watering infrastructure loss to pastoral lease owners.

#### 7.4.8 EV7 – Cultural and Spiritual (Spring and Pools)

Devil's Pools, a surface water body located within Devil Creek to the east of the Project has the potential to be impacted by changes in groundwater salinity as a results of a groundwater level increase. Note, an increase in salinity or groundwater levels alone would not produce an impact to the pools, it is the combination of water level rise and salinity increase that could change the character of the pools.

Groundwater salinity in the Devil Creek area is predicted to increase by around 260 g/L after around 100 years of operation (Figure 5-7) and under the worst case this increase could occur within 20 years of the beginning of operation. Groundwater levels are predicted to rise by around 3 m but remain 2 m below the ground surface. It is possible that the combination of these effects could cause the pools to switch from temporary fresh water to permanent saltwater pools.

It should be noted that little is known about the current condition of this EV and whether the pools represent permanent expression of groundwater or if such a connection exists. A review of Google Earth historic aerial imagery and Digital Earth Australia's Water Observations from space (WOfs) indicates the pool does not contain water permanently and is therefore not currently likely to be supported by groundwater. However, the rise in predicted groundwater levels caused by mounding (increase of around 3 m) could increase the chances of groundwater intersecting this EV. The predicted increase in salinity will likely alter the role of Devil's Pools in providing a source of water to associated ecology. Ongoing environmental monitoring of this EV is recommended.

# 7.5 Opportunities

Opportunities related to water management in the Project area are limited, largely because of the undeveloped nature of the area, however, the Project does present the following opportunities:

 Collection of groundwater data (quantity and quality) that can be used to improve the knowledgebase for remote groundwater systems of Western Australia. This should include measurement of groundwater quality (notably salinity) for stock water wells and other EVs such as Devil's Pools for which currently there is a paucity of baseline data.



- Replacement and improvement of stock water wells under 'make good' arrangements between Leichhardt and Pastoral landowners.
- Alternative long-term industrial water supply (should an industrial water supply be developed) for the region and possible future enterprises.
- Effective waste management should evaporation ponds and facilities be rehabilitated or maintained in a manner with minimal environmental impact.
- Potential conversion of evaporation ponds for other water related beneficial uses.



## **Section 8 Conclusions**

This report presents the results of a groundwater effects assessment for the Eramurra Solar Salt Project. To inform the Project related effects, a density driven flow model has been developed to investigate the potential for the Project to impact the key EVs within the Project area. The following form the key conclusions of this assessment:

#### **Hydrogeological Conceptualisation**

- The majority of groundwater inflow occurs from the sea and rainfall, while the groundwater outflow occurs
  mostly as groundwater ET in low-lying backwater areas (not discharged to the sea) under pre-operation
  (baseline) conditions.
- Seepage from the evaporation ponds may lead to greater groundwater discharge to the sea. This impact, however, will likely be dampened by increased groundwater ET in the backwater areas as a result of additional infiltration from the evaporation ponds.
- The impact of sea level rise is expected to be limited to the area immediately adjacent to the coast in the northwest of the Project area, possibly due to the buffering of groundwater ET within the backwater areas.
- The long-term seepage recharge rate is estimated to range between 50 and 124 mm/y.

#### **Effects to Environmental Values**

- The overall impact of the Project will likely be limited to a 1 km buffer zone surrounding the evaporation ponds and unlikely to threaten EVs more regionally. Regarding specific threats to the identified EVs:
  - The threat to stygofauna as a result of the Project development is expected to be localised to the
    evaporation ponds and a small extent outside of these areas impacted by salinity increases and unlikely to
    have a significant impact in terms of the conservation of fauna communities more regionally.
  - Algal mat and samphire communities are unlikely to be threatened by the Project due to their tolerance of hypersaline conditions.
  - Eucalypt species within McKay and Devil Creek that occur within 1 km of the evaporation ponds, and within
     Eramurra Creek up to 3 km from the evaporation ponds will likely be threatened by the Project
     development and potentially result in permanent loss of vegetation.
  - Mangrove communities are unlikely to be affected by the Project as the direct effects from water impoundment are buffered by increased groundwater ET within the backwater area separating the mangrove communities from the evaporation ponds.
  - Two stock water wells (70910002 and 70910780) will likely become inoperable due to salinity increases in the groundwater. Other stock water wells are unlikely to be impacted by groundwater salinity increases, however, the uncertainty in the salinity predictions is large and the baseline salinity is unknown and will need to be confirmed to understand the threat to stock water wells. Additionally, the influence of pumping from stock water wells has not been assessed to predict whether groundwater abstractions could draw hyper saline groundwater from under the evaporation ponds to these wells.
  - Devil's Pools will likely be threatened by significant increases in groundwater salinity. Little is known about
    the current condition of this EV and whether the pools represent permanent expression of groundwater or
    if such a connection exists and therefore, it is unknown whether these pools will be affected by an increase
    in recharge, groundwater levels and changes in groundwater flow.



#### Recommendations to improve the risk assessment

- Assess the water use patterns of the existing eucalypt species to better determine water sources, rooting depths, and resilience against groundwater salinity increases.
- Develop an integrated monitoring program for coastal species, combining field-based assessments and high
  definition remote sensing to better understand the condition trends of the communities and therefore
  understand the Project related threats.
- Install groundwater monitoring wells directly inland, between the Project and the coastal values to monitor the progression of the saline plume during and post operation. Monitoring of these bores can provide validation of the current hypothesis that an increase in groundwater flux will not manifest into an increase in the water table. A monitoring well (or wells) located near Devil's Pools is also recommended and monitoring wells adjacent to existing eucalypt species that are identified to be at risk. Surface water levels and chemistry should also be monitored at Devil Pools. A groundwater monitoring and management plan is being developed concurrent to this report that addresses the monitoring recommendations described.
- Update the existing groundwater model with additional information and data collected during later stages of environmental studies.
  - This update should incorporate additional data for groundwater levels, groundwater quality, spatial distribution and thicknesses of hydrostratigraphy, ET depth and additional hydraulic parameter testing (including size distribution data). Particular focus should be given for updating the model with a variable ET depth where collected data support the revision from a standard uniform depth.
  - Use of the surface water model to parameterise, or at least validate, the groundwater model and vise versa.
  - These recommendations are not exhaustive; however, it is envisaged the tasks described should be completed at a minimum.



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CDM Smith, 2023

#### A.1 Overview

A three-dimensional numerical groundwater model has been developed to provide an estimation of mounding caused by the evaporation pond operations and the effect of the Project on the site EVs. Due to the limited data availability, the modelling has been completed in a simplified and conservative manner to ensure the impact of mounding is not underestimated. The preliminary modelling has been independently reviewed by Hydro Geo Enviro (2022), the comments of which have been addressed and described in this report.

## A.2 Model Objectives

The objectives of the groundwater modelling are to:

- Estimate the magnitude of seepage that may be induced from the proposed infrastructure over 100 years of operation.
- Assess if the seepage has the potential to create groundwater mounding, with a particular focus along the Santos
  Gas Pipeline alignment and existing and planned infrastructure to determine how the current hydrology of the
  algal mat communities and terrestrial groundwater dependent ecosystems (GDEs) may be impacted over 100
  years of operation.
- Determine impacts on the surface-groundwater interaction, groundwater flow directions and hydraulic loading caused by the proposed structures and whether seepage will result in surface expressions of groundwater over 100 years of operation.

These objectives allow for an assessment of the groundwater-related effects posed by the Project. The modelling results have been used to inform the effect assessment for the Project.

#### A.3 Model Construction

#### A.3.1 Numerical Code

The Eramurra groundwater model has been developed using the numerical code MODFLOW-USG (Panday et al., 2013). This numerical code is part of the MODFLOW suite that is the industry standard for groundwater modelling. MODFLOW-USG has been adopted due to its support for unstructured grid and local cell refinement. In addition, this numerical code can simulate density driven flow through the DDF package that is numerically robust and efficient.

#### A.3.2 Model Domain and Grid

The model domain defines the spatial extent of simulation and needs to be sufficiently large to avoid the boundary conditions at the model edges from influencing the model results (known as boundary effect). At the same time, it is often desirable to align the model edges with natural features such as the coastline and topographic highs (Anderson et al., 2015). Given these considerations, the resulting Eramurra model domain (Figure 9-1) is bounded by the coastline to the north and topographic highs to the west and southeast, with an arbitrary boundary set to the south and east that is approximately 2 km from the proposed evaporation ponds to minimise the boundary effect. The model domain spans a distance of around 25 km in the east-west direction and around 18 km in the north-south direction, with the origin (i.e. bottom left corner) located at Easting 418 796 Northing 7 679 155 (GDA 2020 MGA, Zone 50).

Model gridding, also known as spatial discretisation, is a process of dividing the continuous subsurface into discrete model cells. In general, finer model cells lead to a better spatial resolution but at the expense of computational efficiency. This limitation can be mitigated greatly through the use of unstructured grid, where cells can be refined within areas of interest without extending the refinement to the model edges (unlike traditional MODFLOW). Among the various types of unstructured grid, Voronoi grid is numerically robust in that it guarantees perpendicular groundwater flow directions between cells for accurate finite-volume simulation.



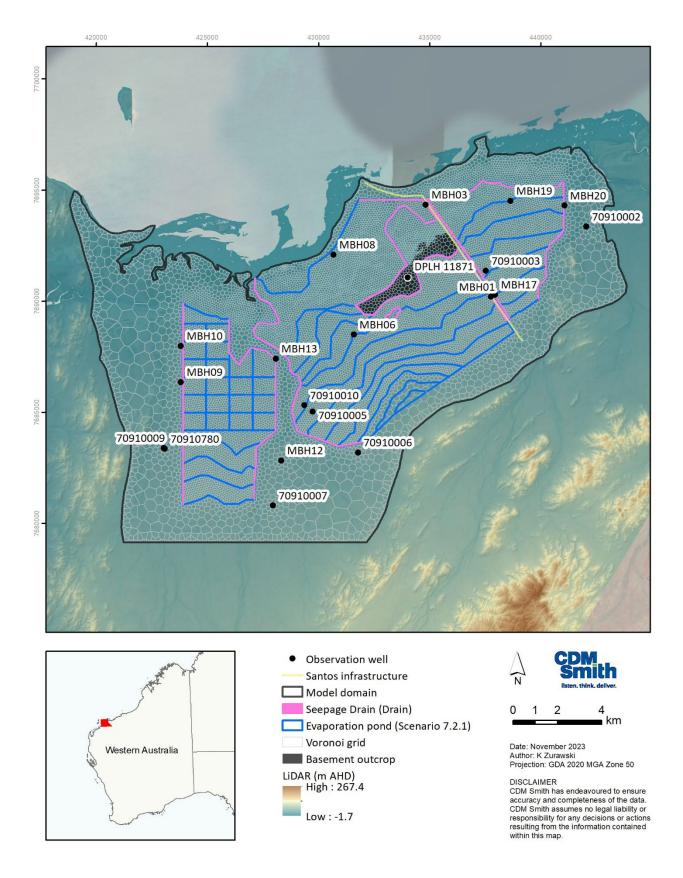


Figure 9-1 Model domain and grid

Algomesh version 2 (HydroAlgorithmics, 2020) has been used to generate the Voronoi grid for the Eramurra groundwater model (Figure 9-1), with an edge length (i.e. distance between cell nodes) of up to 150 m within the evaporation ponds and around the observation wells, and up to 1,500 m in the outer part of the model domain.

#### A.3.3 Model Layering and Elevations

There are two broad hydrostratigraphic units (HSUs) that control the groundwater flow conditions in the Project area:

- 1. An overlying sedimentary unit that consists of residual soils and outwash.
- 2. An underlying bedrock unit that is much less permeable to groundwater flow.

Given the permeability contrast, the Eramurra groundwater model only simulates the sedimentary unit and assumes no flow for the bedrock unit. The thickness of the sedimentary unit is spatially variable, ranging from 0 (i.e. outcropping bedrock) to greater than 28.5 m (CDM Smith, 2022). Due to the limited data availability, a constant thickness of 30 m is assumed for the sedimentary unit. This assumption is likely to overestimate the thickness and hence transmissivity of the sedimentary unit over the Project area, which is considered conservative as it ensures the impact of evaporation pond operations is not underestimated (i.e. impact will propagate more rapidly in a higher transmissivity setting). However, at a more local scale, where the actual aquifer thickness may be less than the assumed constant thickness (i.e. 30 m), greater discharge to the surface may be expected (Hydro Geo Enviro, 2022). Nevertheless, the impact of this assumption is expected to be dampened by the calibration process (e.g. hydraulic conductivity may be lowered for areas where the layer thickness is overestimated and vice versa). To provide a better vertical resolution for density driven flow simulation, the sedimentary unit was split into three model layers (Figure 9-2), each with a nominal thickness of 10 m.

The elevation surface for the top model layer is based on the LiDAR dataset (Figure 9-3) provided by LWC. The LiDAR dataset has a spatial resolution of 5 m and provides complete coverage for the model domain, where the elevation values have been averaged for each groundwater model cell. The model domain is bounded by topographic highs to the west and southeast. Within the model domain, the elevations are generally flat and gradually reduce towards the coast.

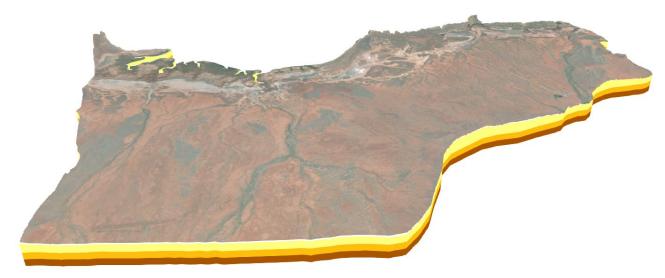


Figure 9-2 Model cross section illustrating the sedimentary unit being split into three layers for density driven flow simulation



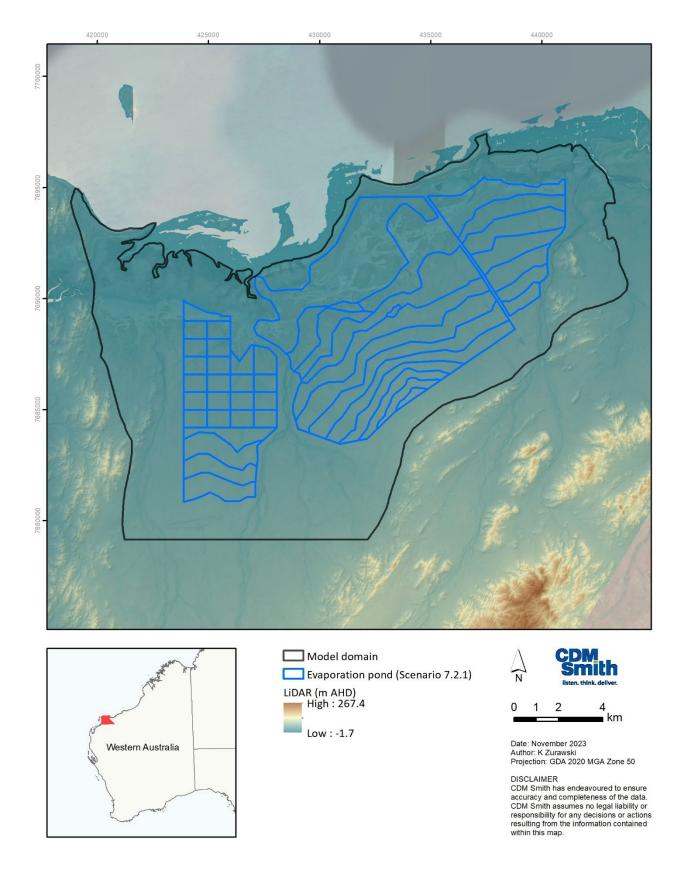


Figure 9-3 Topography



#### A.3.4 Boundary Conditions

Boundary conditions are used to simulate the key physical processes of a given groundwater system that are relevant to the model objectives. In the context of this study, the key processes that are discussed in this section include:

- Regional groundwater inflows.
- Seawater-groundwater interactions.
- Seepage recharge from evaporation ponds (in scenario modelling only).
- Rainfall recharge.
- Groundwater evapotranspiration (ET).

#### A.3.5 Regional Groundwater Inflows

Regional groundwater generally flows towards the coast, entering the model domain from the south and southeast. This process is simulated using the MODFLOW General Head Boundary (GHB) package. GHB cells are implemented along the southern and south-eastern model edges (Figure 9-4) where regional groundwater is anticipated to enter the model domain. A hydrostatic equilibrium is assumed by applying the same GHB setup across all model layers. The head values were interpolated from nearby groundwater level observations and remain constant over time. The conductance term controls the magnitude of groundwater flux across the GHB and has been estimated from model calibration.

#### A.3.6 Seawater-Groundwater Interactions

The sea boundary along the northern model edge is represented using the MODFLOW Constant Head (CH) cells (Figure 9-4). The head value has been set to the mean sea level of 0 m AHD based on RPS (2021) and remain constant over time. A hydrostatic equilibrium is assumed by applying the same CH setup across all model layers.

As the overall model objective (Section A.2) is to estimate the impact of evaporation pond operations on the groundwater system in the long term (i.e. over 100 years of operation), the shorter term processes such as intertidal processes are not explicitly simulated in the groundwater model.

As part of the uncertainty analysis, an additional scenario was set up to assess how sea level rise affects the impact of evaporation pond operations on the groundwater system (Section 0). In this scenario the sea level is raised by 0.9 m for the future period, consistent with the scenario considered in studies for the approved Mardie Salt Project (RPS, 2019) and guidelines provided by the WA EPA (2016) on the expected sea level rise associated with future climate change.

#### A.3.7 Seepage from Evaporation Ponds

The proposed evaporation pond operations are expected to induce seepage and enhance groundwater recharge. This process is simulated using the MODFLOW River (RIV) package. The river stages and base elevations are based on the pond design (Figure 9-4) that has been provided by Leichhardt (Scenario 7.2). The river boundary conditions are only active in the future period during predictive simulation and remain constant over time.

The conductance term controls the magnitude of groundwater flux across the river boundary and is calculated as the product of riverbed conductivity and cell area, assuming a riverbed thickness of 1 m. The riverbed conductivity is based on Leichhardt (2015), which reports permeability tests on predominantly clayey materials derived from residual soils and compacted to 95% maximum modified compaction, ranging between  $1.06 \times 10^{-9}$  and  $2.89 \times 10^{-8}$  m/s (9.16 x  $10^{-5}$  to  $2.5 \times 10^{-3}$  m/d). This material was tested as it is considered to be a potential pond wall building material. To ensure the impact of pond seepage is not underestimated, the maximum permeability value of  $2.5 \times 10^{-3}$  m/d has been used as the riverbed conductivity for the conductance calculation. Depending on the cell area, the resulting riverbed conductance ranges between 1 and 72 m<sup>2</sup>/d.



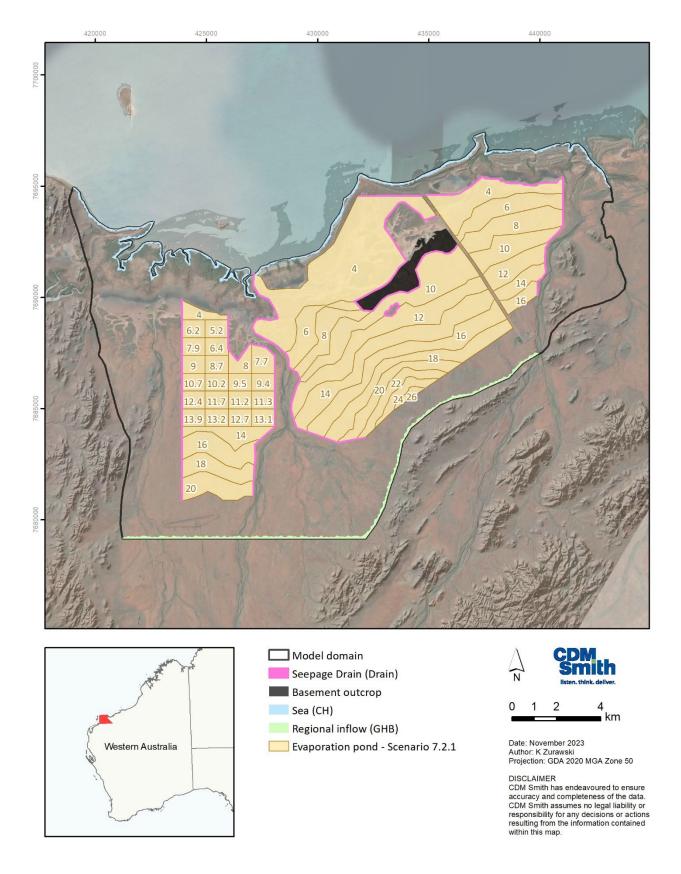


Figure 9-4 Model boundary conditions



#### A.3.8 Seepage Drain

Seepage drains are planned to be constructed along part of the evaporation pond boundaries (Figure 9-4) with a nominal width of 25 m to allow for seepage from the evaporation ponds to be pumped back into the ponds. The drains are simulated using the MODFLOW Drain Package. The drain boundary conditions are only active in the future period during predictive simulation and remain constant over time.

The drain stage is assumed to be 1.5 m below the ground surface. The conductance term controls the magnitude of groundwater discharge to the drain cells and has been derived in a similar manner to the riverbed conductance (Section A.3.7), ranging between 1 and 11  $m^2/d$ .

#### A.3.9 Rainfall Recharge

Rainfall may partially percolate through the soil and eventually reach the water table, becoming groundwater recharge. Rainfall rates for the study area were sourced from the Karratha Aero weather station from SILO (station number 004083). The rainfall rates are assumed to be spatially uniform but allowed to vary over time. For scenario modelling, the mean of historical rainfall (over the calibration period) has been used for the future period.

Regarding the estimation of rainfall recharge, the Chloride Mass Balance method is considered inappropriate for the study area as there are multiple sources of chloride deposition, including rainfall and sea spray aerosols (Hydro Geo Enviro, 2022). As such, the deep drainage data from the Australian Water Outlook database (Bureau of Meteorology, 2023) was used instead to inform the expected range of groundwater recharge. The selected location (latitude -20.889 degrees, longitude 116.363 degrees) shows the annual deep drainage from 1985 to 2022 to vary between 2% and 18% of rainfall, with a mean of 6% of rainfall. These values were used to set the initial value and bounds for the calibration of recharge. For scenario modelling, rainfall recharge is assumed to be zero in the evaporation pond areas, because recharge will be captured in the ponds.

#### A.3.10 Groundwater Evapotranspiration

Shallow groundwater may be lost to the atmosphere through a combination of evaporation and transpiration, which are referred to as groundwater ET. Note, this process is different from the ET of soil water in the unsaturated zone. Groundwater ET is simulated using the MODFLOW EVT package, which requires potential ET and extinction depth as inputs.

Potential ET represents the rate of groundwater ET that would occur if the water table was at the land surface. The potential ET rates for the Project area have been sourced from the Karratha Aero weather station from SILO (station number 004083). Pan evaporation is considered too high to be used as potential ET as pan evaporation assumes unlimited water availability. Instead, the FAO56 estimates (Allen et al., 1998) have been adopted, which is based on the Penman-Monteith equation and is the approved standard for the U.N. World Meteorological Organisation. The potential ET rates are assumed to be spatially uniform but allowed to vary over time. For scenario modelling, the mean of historical FAO56 (over the calibration period) has been used for the future period. Similar to rainfall recharge, groundwater ET is assumed to be zero in the evaporation pond areas.

Extinction depth defines the depth below which groundwater ET ceases to occur. In this study, the extinction depth has been set to the typical value of 2 m and assumed to remain constant spatially and temporally.

#### A.3.11 Hydraulic Parameters

Hydraulic conductivity of the saturated sedimentary unit indicates low to moderate permeability, ranging between 0.06 to 1.7 m/d based on four slug tests (CDM Smith, 2022). Following the recommendation from Hydro Geo Enviro (2022), considerations have also been given to the grain size distribution data from Leichhardt Industrials Pty Ltd (2015), which reports a wider range of hydraulic conductivity values between 0.005 and 4 m/d. These datasets show a geometric mean of 0.1 m/d (rounded) for hydraulic conductivity. A vertical hydraulic conductivity anisotropy ratio (Kh/Kv) of 10 is initially assumed, which is the typical value for sedimentary formations. An initial specific storage of



10<sup>-4</sup> m<sup>-1</sup> and specific yield of 0.1 (same for porosity) were adopted based on the literature (Anderson et al., 2015; Chowdhury et al., 2022; Fetter, 2018). These values were used as the initial parameters and refined during calibration.

Hydraulic conductivity for the bedrock outcrop area (Figure 9-1) is initially assumed to be four orders of magnitude lower than the sedimentary unit (i.e.  $1 \times 10^{-5}$  m/d) across all model layers. A vertical hydraulic conductivity anisotropy ratio of 1 is initially assumed, which is the typical value for bedrock units. An initial specific storage of  $10^{-6}$  m<sup>-1</sup> and specific yield of 0.01 (same for porosity) have been applied for this bedrock outcrop area (Anderson et al., 2015; Chowdhury et al., 2022). These values were used as the initial parameters and refined during calibration.



#### A.3.12 Time Period Setup

The historical calibration model covers the time period between June 1996 and December 2022, consisting of 57 stress periods. The first stress period is a steady-state period that represents the equilibrium conditions and provides the initial conditions for the subsequent transient periods. These 56 transient stress periods are generally annual periods, except near the time periods when groundwater level observations are available, where the stress periods were refined to monthly to provide better temporal resolution.

The predictive simulation extends 100 years into the future by including 14 additional transient stress periods, the length of which gradually increases from yearly to 10-yearly.

#### A.3.13 Solute Transport and Density Driven Flow

Groundwater movement is driven by hydraulic head gradients but under certain circumstances, density variations exert an important control on the flow as well. Fluid density is a function of concentration, temperature, and to a much lesser extent, fluid pressure (Post and Simmons, 2022). Given the large salinity contrast between seawater, groundwater and pond seepage in the Project area, density driven flow simulation is considered warranted.

Simulation of density driven flow is complex due to the problem of "two-way coupling", where groundwater flow is dependent on density, density is dependent on solute concentration, and solute concentration is dependent on the velocity of groundwater flow (Anderson et al., 2015). For the Eramurra groundwater model, density driven flow is simulated using a combination of MODFLOW-USG's packages, including BCT and PCB for advection-dispersion solute transport and DDF for density driven flow.

For advection-dispersion solute transport, concentration settings for the boundary conditions are detailed in Table 9-1 Appendix A. Initial concentrations (Figure 9-5) have been interpolated from the bore salinity data collected by LWC (2022a). The area of hypersaline groundwater observed in the northeast corner, is discussed below (Section A.5.4). Dispersion is commonly understood as the smearing of solute concentration and is simulated using a uniform value of 100 m for longitudinal dispersivity, 10 m for transverse dispersivity and 1 m for vertical dispersivity (Gelhar et al., 1992).

For density driven flow, a value of 1000 kg/m³ has been used for the density of freshwater at a concentration of 0 g/L, and 1025 kg/m³ for the density of seawater at a concentration of 35 g/L (Post and Simmons, 2022). These parameter values are used to derive the relationship between fluid density and concentration.

MODFLOW-USG performs solute transport simulation using implicit numerical schemes that are unconditionally stable and do not impose a restriction on the time-step size as the explicit schemes do (e.g. SEAWAT). Therefore, the time-step size for transport is the same as that used for flow, and no sub-steps are required for the transported simulation (Panday, 2022).

**Table 9-1** Boundary condition concentrations

Boundary condition	Concentration (g/L)	Source
Sea (CH)	35	Post and Simmons (2022)
Regional inflow (GHB)	1 - 9	LWC (2022)
Rainfall recharge (RCH)	0.015	Kus et al. (2011)
Seepage recharge (RIV)	49 - 378	Provided by Leichhardt on a pond-by-pond basis (see Figure 9-5 for the spatial distribution)



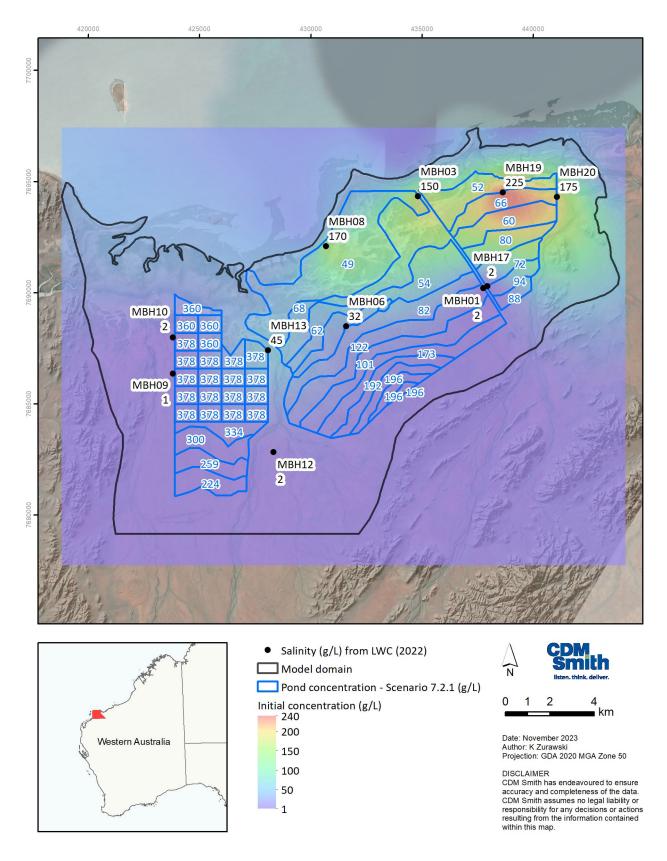


Figure 9-5 Initial model concentrations and pond concentrations



### A.4 Model Calibration

#### A.4.1 Overview

Groundwater modelling requires parameters to be assigned on a cell-by-cell basis, the spatial resolution of which can rarely be fully supported by field data. As such, model parameters are commonly estimated through calibration, a process of adjusting parameters until the model outputs fit the field observations.

Model calibration is susceptible to non-uniqueness, where there are numerous combinations of parameters that can yield a similar fit to the field observations. To address the issue of non-uniqueness, a transient calibration has been performed in a stochastic manner for the Eramurra groundwater model to capture how the groundwater system responded to the historical changes in rainfall and groundwater ET.

#### A.4.2 Calibration Targets

Groundwater level observations have been sourced from LWC (2023 and 2022a) and the government database through the BoM Groundwater Explorer. As part of quality assurance, the observation datasets have been evaluated thoroughly to remove any outliers and erroneous data. This resulted in a total of 15 observation wells (with 42 transient water level measurements), comprising 11 MBH wells from LWC (2023 and 2022a) and 4 wells from BoM. The distribution of observation wells provides a good spatial coverage for the model domain (Figure 9-1). Groundwater level observations have been averaged for the corresponding stress periods and assigned a weight of 1.

#### A.4.3 Calibration Approach

Automatic model calibration has been performed using PESTPP-IES (White, 2018), a member of the PEST++ suite that is the industry standard for groundwater model calibration and uncertainty analysis. PESTPP-IES is a stochastic technique that uses the iterative ensemble smoother method (Chen and Oliver, 2013) to develop and calibrate multiple model realisations (i.e. plausible parameter combinations) simultaneously. For the Eramurra groundwater model, 100 model realisations have been developed and calibrated.

A highly parameterised modelling approach has been undertaken using pilot points, a calibration technique where parameters are estimated at discrete pilot point locations and then interpolated to the remaining model cells (Doherty et al., 2010). This technique allows parameters to vary spatially in a less biased manner through using observation data to provide insights into the spatial distribution of parameters (instead of predefining parameter zones).

For the Eramurra groundwater model, there are a total of 3,081 pilot points, with 237 pilot points separately for horizontal hydraulic conductivity, vertical hydraulic conductivity anisotropy ratio, specific storage, specific yield and rainfall recharge for each model layer (except for recharge where pilot points are in the top layer only). GHB conductance has also been included in the calibration but in a simpler manner where the conductance value is assumed to be spatially uniform for parsimony reasons.

Table 9-2 shows the calibration parameter settings, including the initial values and bounds. The hydraulic conductivity settings for the sedimentary unit are based on slug tests and grain size distribution data (Section A.3.11), with a slightly expanded range to account for local heterogeneities. The same parameter settings have been applied to GHB conductance. Hydraulic conductivity for the bedrock outcrop is initially assumed to be four orders of magnitude lower than that of the sedimentary unit and allowed to vary by  $\pm 1$  order of magnitude. Recharge is expressed as percentage of rainfall (resembling the concept of infiltration capacity) and allowed to vary spatially but remain constant over time in the calibration (in comparison, rainfall is assumed to be spatially uniform but temporally variable). Due to the limited data availability, the remaining parameter settings are largely based on the literature (Anderson et al., 2015; Chowdhury et al., 2022; Fetter, 2018).



Table 9-2 Parameter settings for model calibration

Parameter	Unit	Formation	Initial value	Lower bound	Upper bound
Undraudia aandustivitus	m /d	Sedimentary	1 x 10 <sup>-1</sup>	1 x 10 <sup>-3</sup>	5 x 10 <sup>0</sup>
Hydraulic conductivity	m/d	Bedrock	1 x 10 <sup>-5</sup>	1 x 10 <sup>-6</sup>	1 x 10 <sup>-4</sup>
Vertical hydraulic conductivity		Sedimentary	1 x 10 <sup>1</sup>	1 x 10 <sup>0</sup>	1 x 10 <sup>2</sup>
anisotropy ratio	-	Bedrock	1 x 10 <sup>0</sup>	1 x 10 <sup>0</sup>	1 x 10 <sup>2</sup>
Specific storage	m <sup>-1</sup>	Sedimentary	1 x 10 <sup>-4</sup>	1 x 10 <sup>-5</sup>	1 x 10 <sup>-4</sup>
Specific storage	111 -	Bedrock	1 x 10 <sup>-6</sup>	1 x 10 <sup>-7</sup>	1 x 10 <sup>-5</sup>
Specific viold		Sedimentary	1 x 10 <sup>-1</sup>	5 x 10 <sup>-2</sup>	2 x 10 <sup>-1</sup>
Specific yield	-	Bedrock	1 x 10 <sup>-2</sup>	1 x 10 <sup>-3</sup>	5 x 10 <sup>-2</sup>
Dainfall racharga	% of rain	Sedimentary	1%	0.01%	10%
Rainfall recharge	% OI falfi	Bedrock	0.1%	0.01%	1%
GHB conductance	m²/d	-	1 x 10 <sup>-1</sup>	1 x 10 <sup>-3</sup>	5 x 10 <sup>0</sup>

#### A.5 Calibration Results

#### A.5.1 Calibration Performance

Figure 9-6 compares the observed and simulated groundwater levels, where the data points and error bars indicate the mean and range of simulated water levels from the 100 calibrated model realisations, respectively. The diagonal reference line represents the ideal situation where the simulated water levels fit the observed water levels perfectly. Data points that are closer to the reference line generally indicate a better calibration performance.

The calibrated model ensemble shows a mean root mean square error (RMSE) of 0.5 m (ranging between 0.4 and 0.8 m) and a mean scaled root mean square (SRMS) error of 4.6% (ranging between 3.5% and 6.9%). Typically, a RMSE of less than 1 m and a SRMS of less than 5% are considered excellent in terms of calibration performance. The cloud of data points is centred around the reference line, suggesting no substantial bias towards overestimation or underestimation.

For readability reasons, hydrographs comparing the observed and simulated groundwater levels are shown in Appendix 1 (Section A.8). Most hydrographs show a good fit between the observed and simulated water levels. Observation well 70910005 shows the largest misfit with a mean absolute residual of 1.5 m. This well shows a water level of 12.3 m AHD and is in proximity (< 500 m) to another well 70910010, which shows a substantially lower water level of 5.1 m AHD at a similar time. Assuming negligible measurement error, this steep hydraulic gradient may be caused by local heterogeneities that are not intended to be captured by the groundwater model given the difference in scale and the limited data availability.

A number of observation wells (e.g. MBH01 and MBH03) show an increased water level during the November 2022 monitoring event (LWC, 2023). Given the minimal groundwater-affecting activities in the area, this increase (assuming negligible measurement error) is likely to be caused by rainfall recharge. However, the Karratha Aero weather station (station number 004083) shows no records of rainfall for the two months prior to the monitoring event (19 Sep to 19 Nov). This suggests the observed increase in water level may be caused by notable rainfall event(s) that is not captured by the Karratha Aero weather station and hence not reflected in the groundwater model.



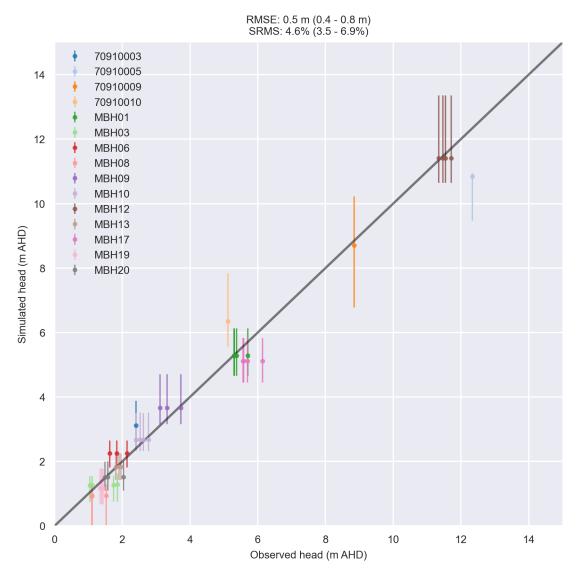


Figure 9-6 Comparison of observed and simulated groundwater levels

#### A.5.2 Calibrated Parameters

Table 9-3 shows the calibrated parameter statistics. Hydraulic parameters are commonly assumed to be log-normally distributed (Rehfeldt et al., 1992), hence the geometric mean (across all corresponding model cells and across the 100 calibrated model realisations) can be seen as a proxy for the most likely outcome. The 5<sup>th</sup> and 95<sup>th</sup> percentiles of the parameters are also included in Table 9-3 to inform the parameter uncertainty.

Compared to the initial values, the sedimentary unit shows a lower calibrated value for horizontal hydraulic conductivity, specific storage and recharge by approximately an order of magnitude. Meanwhile, the calibrated value for the vertical hydraulic conductivity anisotropy ratio and specific yield remain similar to their initial counterparts. A similar pattern is observed for the bedrock outcrop, except for specific storage and recharge, which remain similar to the initial values. The GHB conductance is reduced by approximately an order of magnitude as a result of the calibration.



Table 9-3 Calibrated parameter statistics

Parameter	Unit	Formation	Geomean	5 <sup>th</sup> percentile	95 <sup>th</sup> percentile
Hydraulic	/ el	Sedimentary	7.3 x 10 <sup>-2</sup>	2.3 x 10 <sup>-3</sup>	2.1 x 10 <sup>0</sup>
conductivity	m/d	Bedrock	9.0 x 10 <sup>-6</sup>	1.0 x 10 <sup>-6</sup>	9.7 x 10 <sup>-5</sup>
Vertical anisotropy		Sedimentary	1.1 x 10 <sup>1</sup>	1.3 x 10 <sup>0</sup>	8.9 x 10 <sup>1</sup>
ratio for hydraulic conductivity	-	Bedrock	2.3 x 10 <sup>0</sup>	1.0 x 10 <sup>0</sup>	1.6 x 10 <sup>1</sup>
Considirate was	1	Sedimentary	5.1 x 10 <sup>-5</sup>	1.5 x 10 <sup>-5</sup>	1.0 x 10 <sup>-4</sup>
Specific storage	m <sup>-1</sup>	Bedrock	1.7 x 10 <sup>-6</sup>	2.2 x 10 <sup>-7</sup>	9.0 x 10 <sup>-6</sup>
Consideration		Sedimentary	9.6 x 10 <sup>-2</sup>	5.2 x 10 <sup>-2</sup>	1.8 x 10 <sup>-1</sup>
Specific yield	-	Bedrock	1.0 x 10 <sup>-2</sup>	1.6 x 10 <sup>-3</sup>	4.7 x 10 <sup>-2</sup>
Deiofell veebeure	0/	Sedimentary	0.3%	0.02%	6.2%
Rainfall recharge	% of rain	Bedrock	0.1%	0.01%	0.3%
GHB conductance	m²/d	-	1.5 x 10 <sup>-2</sup>	1.6 x 10 <sup>-3</sup>	9 x 10 <sup>-2</sup>

The geometric mean (across the 100 model realisations) of calibrated hydraulic conductivity for the top model layer is shown in Figure 9-7. The figure shows zones of high permeability in the western and south-eastern part of the model domain, and zones of low permeability in the north-eastern and central part of the model domain, with the latter having the potential to act as a semi-barrier separating the western crystalliser ponds from the other concentrator ponds.

#### A.5.3 Sensitivity Analysis

Due to the stochastic approach adopted in this study, sensitivity analysis needs to be undertaken in a different manner using the concept of relative uncertainty reduction of parameter (Manewell and Doherty, 2021) that is defined as follows:

$$r_i = (1 - \frac{\sigma_i^{post}}{\sigma_i^{prior}})$$

where  $r_i$  is the relative uncertainty reduction of parameter i,  $\sigma_i^{prior}$  is the prior uncertainty of parameter i (i.e. the standard deviation of parameter i across the 100 realisations before calibration), and  $\sigma_i^{post}$  is the posterior uncertainty of parameter i (i.e. the standard deviation of parameter i across the 100 realisations after calibration). This approach is based on the rationale that the uncertainty (i.e. the standard deviation across the 100 realisations) of a more sensitive parameter would be reduced more by calibration, and vice versa.

Figure 9-8 shows the results of sensitivity analysis for the Eramurra groundwater model. Due to the randomness employed by PESTPP-IES, the results should be interpreted qualitatively instead of quantitatively. The GHB conductance was found to be the most sensitive to the calibration, possibly due to its control on the regional groundwater inflow and its proximity to a number of observation wells (Figure 9-1). The horizontal hydraulic conductivity and recharge of the sedimentary unit were also found to be highly sensitive to the calibration, while the storage properties were found to be relatively insensitive.



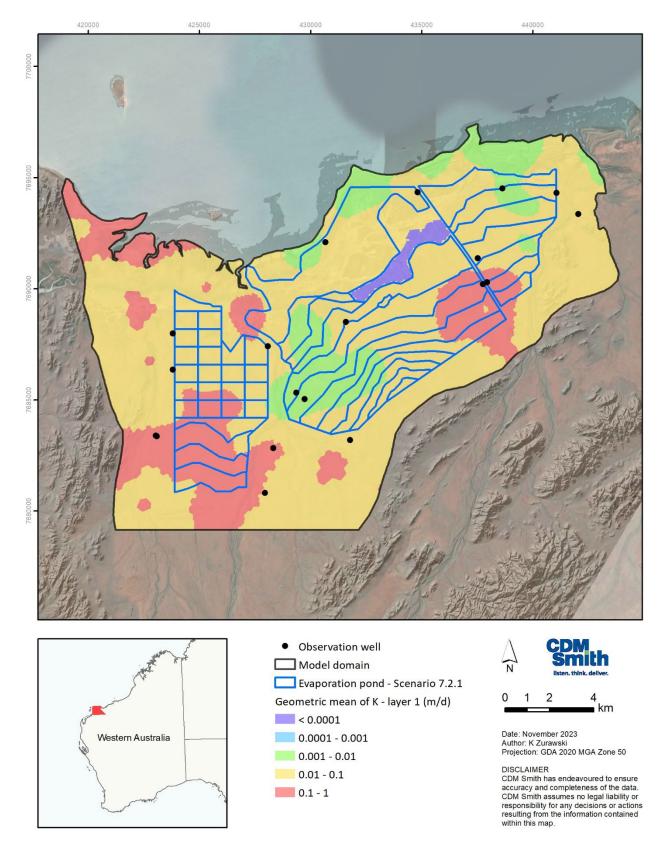


Figure 9-7 Geometric mean of calibrated hydraulic conductivity (K) for the top model layer



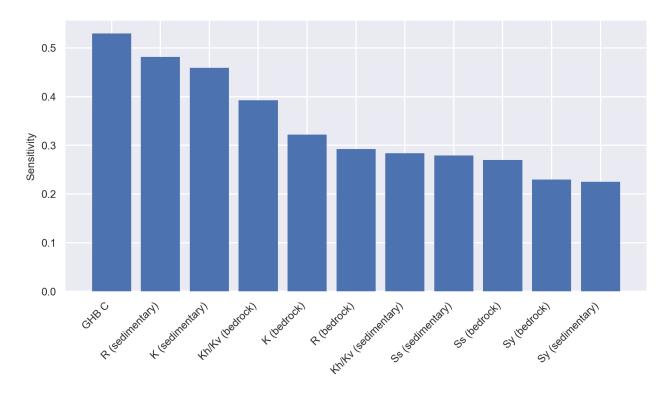


Figure 9-8 Sensitivity analysis

#### A.5.4 Calibrated Groundwater Level Contours and Salinity Distribution

The mean of modelled groundwater level contours across the 100 calibrated model realisations for the top model layer at the end of calibration period are shown in Figure 9-9. As expected, groundwater generally flows from south to north.

The area to the north of the main 0 m AHD contour suggests the major groundwater discharge process may not be dominated by discharge to the sea as previously anticipated, but as groundwater ET in low-lying areas. The land surface elevation in these areas is very close to or slightly below the mean sea level, where groundwater ET develops a natural depression in the water table that draws water from the south and the northern sea boundary.

This conceptualisation is further supported by the groundwater salinity data collected by LWC (2022a), which reports 150 g/L at MBH03, 170 g/L at MBH08, 175 g/L at MBH20 and 225 g/L at MBH19 (Figure 9-5). These salinity values are 4 to 6 times greater than the salinity of sea water (~35 g/L). Given the minimal groundwater-affecting activities in the Project area, the salinity measurements reflect the long-term impact of evapo-concentration of groundwater, surface water and storm surge/spring tide marine water onlap. These low-lying areas coincide with the algal mat communities (Figure 9-1) location, suggesting the algal mats are relying on the hypersaline environment as a protective mechanism as similar relationships are noted within the region (e.g. Shark Bay) and globally (Edgcomb and Bernhard, 2013).

The mean of modelled salinity distribution across the 100 calibrated model realisations for the pre-operational conditions is also shown in Figure 9-9, with a spatial pattern that largely follows the initial concentration (Figure 9-5). Some salinity highs are found near the creeks where evapo-concentration causes salinity to rise over time.



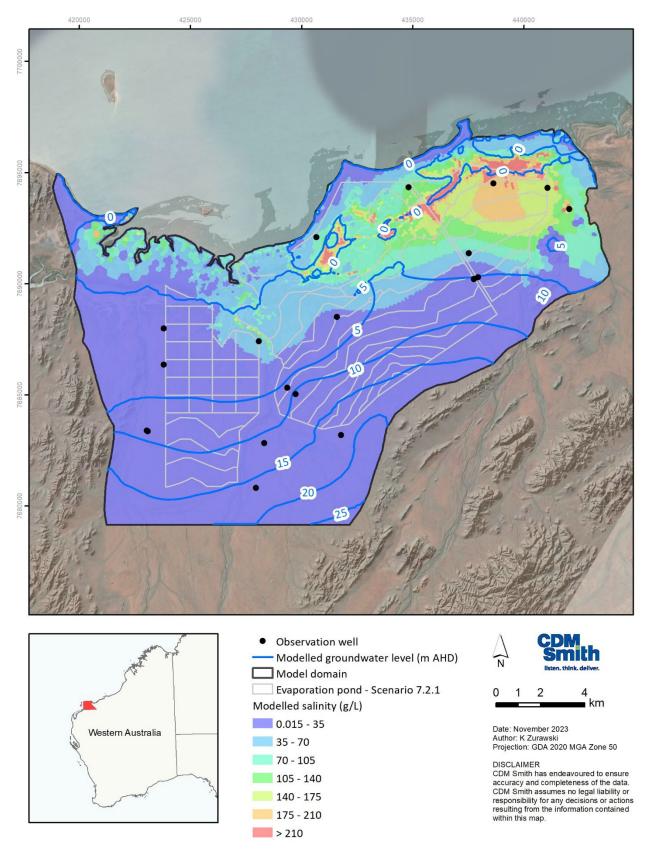


Figure 9-9 Modelled groundwater level contours and salinity distribution for the pre-operation conditions



#### A.5.5 Calibrated Mass Balance

Table 9-4 shows the mean water balance across the 100 calibrated model realisations for the steady-state period and at the end of calibration (Dec 2022). Consistent with Section A.5.4, groundwater ET at topographic lows is the major groundwater discharge process. This process creates a natural depression in the water table that draws a considerable volume of water from the northern sea boundary (from the south as well but to a much lesser extent as indicated in Table 9-4). The steady-state results suggest recharge to be the major inflow process in the long term, while results at the end of calibration show minimal recharge as no rainfall is recorded for Dec 2022. The lack of rainfall recharge in this month is compensated by a reduction in storage (note that this is defined as storage inflow by MODFLOW – water inflow to the aquifer from storage) and a slight increase in inflow from the sea boundary. In contrast, regional flows across the GHB are a relatively minor component of the water balance.

The total inflow in Table 9-4 is identical to the total outflow with a zero percent discrepancy for both stress periods, indicating numerical stability and complying with the Australian Groundwater Modelling Guidelines (Barnett et al., 2012) requirements.

	Stead	dy-state	End of calibration (Dec 2022)		
Component	Inflow (kL/d)	Outflow (kL/d)	Inflow (kL/d)	Outflow (kL/d)	
Storage	-	-	1579	13	
Sea boundary (CH)	1099	216	1184	235	
Groundwater ET	-	2874	-	2538	
Recharge	1967	-	0	-	
Regional flow (GHB)	30	6	30	6	
Total	3096	3096	2792	2792	
Percentage discrepancy		0%	0%		

Table 9-4 Mass balance for the calibrated steady-state model for the pre-operation conditions

# A.6 Scenario Modelling and Uncertainty Analysis

#### A.6.1 Overview

To assess the likely direct effects of the evaporation pond operation on the identified site EVs, four scenarios have been considered:

- A baseline scenario with the mean sea level at 0 m AHD the future conditions are assumed to be identical to the historical conditions without any evaporation pond operations. The mean of historical climate was used for the future period.
- 2. An operation scenario with the mean sea level at 0 m AHD similar to the baseline scenario except for the introduction of evaporation pond operations that were set up in the model as per Section A.3.7.
- 3. A baseline scenario with a sea level rise of 0.9 m this scenario assesses the impact of sea level rise and how it affects the groundwater system response to the evaporation pond operations. The sea level rise of 0.9 m is consistent with the scenario considered in studies for the approved Mardie Salt Project (RPS, 2019) and guidelines provided by the WA EPA (2016) on the expected sea level rise. The mean of historical climate was used for the future period.
- 4. An operation scenario with a sea level rise of 0.9 m similar to the baseline scenario above except for the introduction of evaporation pond operations that were set up in the model as per Section A.3.7.



Predictive uncertainty analysis has been performed using the Type 3 technique described in Middlemis and Peeters (2018), involving stochastic modelling and Bayesian probability quantification. This technique is mathematically robust through sampling the posterior prediction distribution. This seemingly complex concept can be understood as analysing the similarities and differences between the predictions from the 100 calibrated model realisations in the context of this study.

#### A.6.2 Predicted Groundwater Levels

The mean of predicted groundwater level contours across the 100 calibrated model realisations for the top model layer after 100 years of evaporation pond operations are shown in Figure 9-10. This figure includes results from the mean sea level scenario (Scenario 2) and sea level rise scenario (Scenario 4). Note the baseline model results (Scenarios 1 and 3) are largely identical to the model calibration results (Figure 9-9) and hence not shown in Figure 9-10 for clarity reasons.

The baseline model results show a high evaporation zone (i.e. the area to the north of the main 0 m AHD contour in Figure 9-9) where groundwater ET develops a natural depression in the water table the draws water from the south and the northern sea boundary. This zone coincides with the location of the algal mat and samphire communities, possibly due to the evapo-concentration processes creating a hypersaline environment that may act as a protective mechanism for these communities. For algal mats, similar relationships are noted within the region (e.g. Shark Bay) and globally (Edgcomb and Bernhard, 2013).

Results from the mean sea level operation scenario suggest the evaporation ponds have a large control on the groundwater level contours. In particular, groundwater mounding beneath the evaporation ponds results in a steeper hydraulic gradient that causes more groundwater discharge to the sea. Under this scenario, the water table depression mentioned above in the northern part of model domain (i.e. to the immediate west of PL-N) is largely dissipated, which is expected as the current design pond layout results in seepage recharge being directly applied to this area. Outside this area (e.g. areas near AM-W and AM-E in Figure 9-10), the extent of high evaporation zone appears to remain largely similar to that of the baseline scenario (Figure 9-9).

Results from the operation scenario with sea level rise are largely similar to the mean sea level scenario results, with the 0 m AHD contour along the coast (note this is different from the 0 m AHD contour near site AM-W) in the western part of the model domain being pushed towards the south due to the elevated sea level. From the perspective of algal mat and samphire communities, the sea level rise scenario is considered optimistic as a higher sea level will result in a steeper hydraulic gradient and cause more inflow from the sea towards the high evaporation zone/algal mat area, maintaining the hypersaline environment these receptors may be reliant on (Edgcomb and Bernhard, 2013). However, for mangrove communities, sea level rise will likely impact habitat availability and disrupt the wetting and drying processes of the EVs residing within the tidal zone. The modelling results suggest the impact of sea level rise is relatively localised and mostly limited to the area immediately adjacent to the coast to the northwest of the Project area.



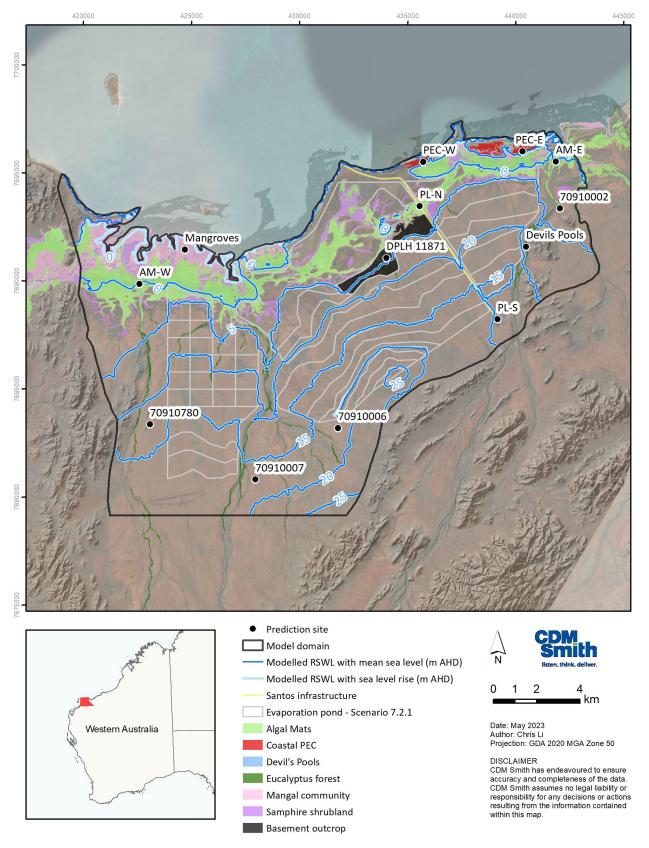


Figure 9-10 Predicted groundwater elevation (RSWL) contours after 100 years of evaporation pond operations



To assess the direct effects of water impoundment within the evaporation ponds with respect to the location of the identified EVs, predicted time-series groundwater levels at selected locations have been prepared and are shown in Figure 9-11 and Figure 9-12 with positions annotated in Figure 9-10. The mean and range of predicted groundwater levels from the 100 calibrated model realisations are represented by solid lines and colour shades, respectively. Sites PL-S (Pipeline South) and PL-N (Pipeline North) have been selected to assess the direct effects of evaporation pond operations on the Santos Gas Pipeline infrastructure. In particular, site PL-S is located at the Santos pumping station slightly upgradient (in terms of groundwater flow) of the evaporation ponds, while site PL-N is located closer to the coast, in proximity to the evaporation ponds and the backwater area accommodating the algal mat communities. Sites AM-W and AM-E assess the direct effects to the algal mat and samphire communities, whereas site Devil's Pools assesses the direct effects to Devil's Pools and eucalypt species within Devils Creek. Similarly, sites PEC-E and PEC-W assess the direct effects to the coastal Priority Ecological Community (PEC). The other locations (Mangroves, 70910002, 70910006, 70910007 and 70910780) have been positioned with respect to EVs and named accordingly.

#### EV3 - Coastal PEC

Groundwater levels at sites PEC-E and PEC-W are predicted to increase only marginally (< 0.5 m) – under the mean sea level rise scenario the mean of the 100 calibrated models shows no areas of the PEC where groundwater level rise is greater than 0.5 m inside or outside the evaporation ponds. The predictive uncertainty analysis shows a relatively large range. The upper range is kept at approximately 2 m below the land surface at both sites throughout the simulation period, which is likely to be a result of groundwater ET and therefore water logging is not predicted in the model. It should be noted the mean of the 100 models indicates the water level ranges between 3 to 4 m below the ground surface. The sea level rise scenario shows a slightly higher groundwater level at both sites, as a higher sea level reduces the hydraulic gradient towards the sea, slightly enhancing the groundwater mounding in the evaporation pond areas and the surroundings.

#### EV4 and EV5 - Algal mats / samphire and mangroves

Sites AM-E (Algal Mats East), AM-W (Algal Mats West) and Mangroves have been selected to assess the impact of evaporation pond operations on the algal mat and mangrove communities outside the evaporation ponds in the eastern and western parts of the model domain. The predicted groundwater levels at these sites are largely constant throughout the simulation period for all the scenarios. This suggests groundwater ET may be sufficient to buffer the impact from the pond operations and sea level rise at these sites despite their proximity to the ponds and the coast. Under the mean sea level rise scenario, the mean of the 100 calibrated model realisations shows 3% of algal mats area, 2% of samphire shrubland area and less than 1% of mangal community area will experience more than 0.5 m groundwater level rise outside of the evaporation ponds.

#### EV6 - Stock water wells

The predicted groundwater levels at the stock water wells varies considerably depending on the location. Groundwater levels within stock water wells 70910002 and 70910006 are predicted to rise only marginally (<0.5 m) whereas wells 70910007 and 70910780, are predicted to rise by between 1 to 3 m. This suggests the influence of water impoundment is relatively large near the western crystalliser ponds, consistent with modelling results shown in Figure 5-1 and Figure 5-2. The predictions show little variation in groundwater levels over the long-term between the mean sea level scenario and sea level rise scenario, which is expected given the distance of these wells from the coast.

#### EV2 and EV7 – Terrestrial Vegetation and Devil's Pools

The groundwater level at Devil's Pools is similarly predicted to increase by around 3 m over both the mean sea level scenario and sea level rise scenario following Project development (remains below the land surface throughout the simulation period). Little is currently known about this EV and whether the pools represent permanent expressions of groundwater, nor does the model attempt to simulate this feature explicitly; however, the results suggest water levels in this area will likely increase. Should this occur, Devils Pools, eucalypt species residing within Devils Creek, as well as creeks adjacent to the evaporation pond areas, will likely be affected. Under the mean sea level rise scenario, the mean of the 100 calibrated model realisations shows, 53% of the area of the mapped eucalypt species will experience greater than 0.5 m groundwater level rise outside of the evaporation ponds.



#### EV8 – Noorea Soak

Within the vicinity of Noorea Soak the mean of the 100 calibrated model realisations shows no change in groundwater levels during the operational period. Similarly, there is no discernible increase associated with sea level rise at this EV, which is expected given the distance from the coast. The soak is located in an area of basement outcrop in the model and the very low hydraulic conductivity assigned to this unit is likely to be responsible for the limited change observed at the prediction point. The groundwater head is largely controlled by ET, which keeps the watertable at least 2 m below the surface.

#### EV9 - Santos Gas Pipeline

Under all scenarios, the groundwater level at site PL-S, despite being located upgradient of the evaporation ponds, is predicted to rise considerably over time (increasing by approximately 5 m by year 100) due to seepage recharge and groundwater mounding. The modelled groundwater level is below the land surface throughout the simulation period. The impact of sea level rise on this site is minimal, which is expected given its distance from the coast.

The model results at site PL-N show a slightly smaller rise in groundwater levels. Given the relatively shallow groundwater level at this site, the impact of evaporation pond seepage and the resulting groundwater mounding is believed to be dampened by groundwater ET. As per site PL-S, the impact of sea level rise on this site is minimal and the modelled groundwater level is below the land surface throughout the simulation period.



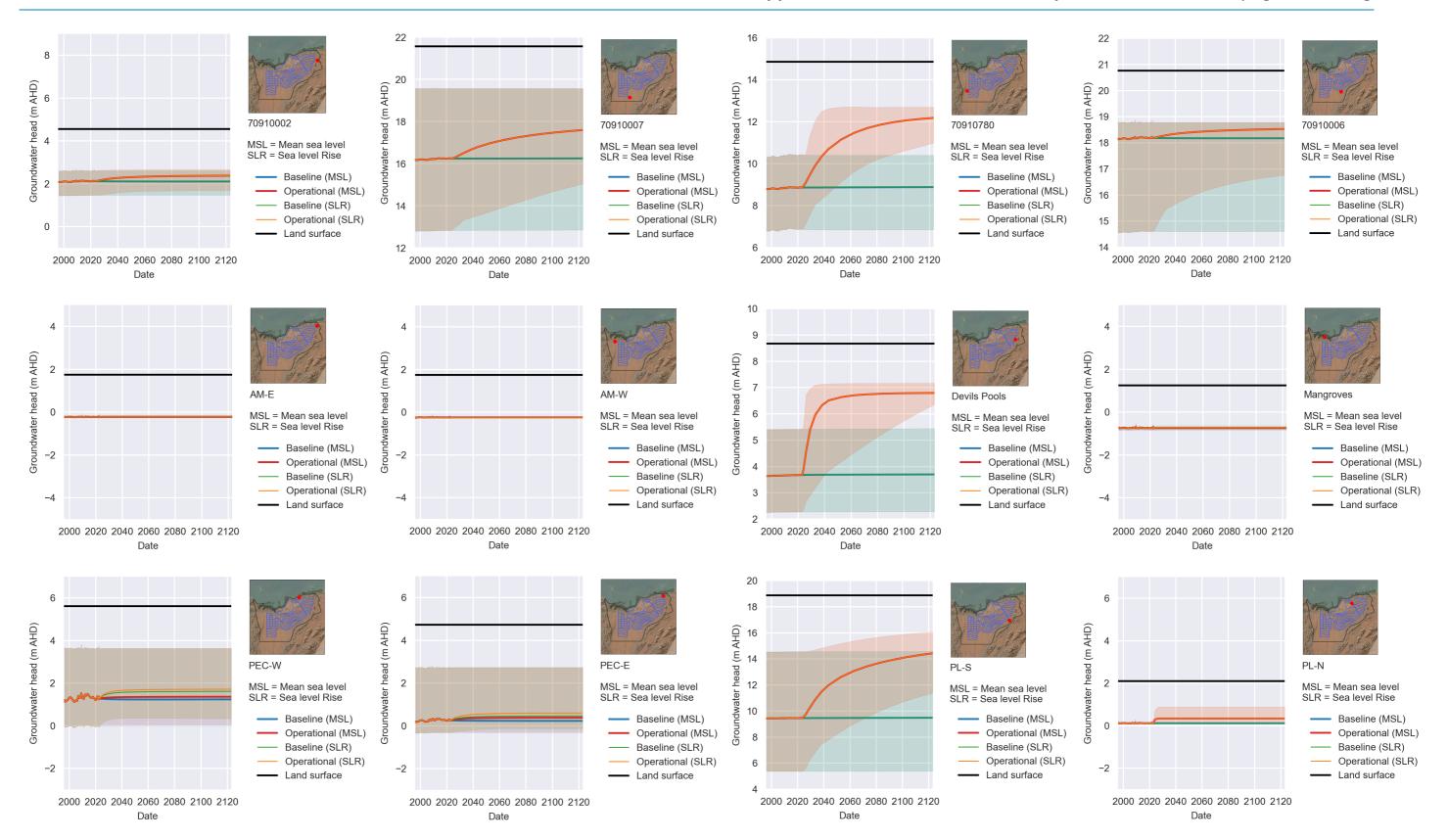


Figure 9-11 Predicted groundwater level change at selected locations

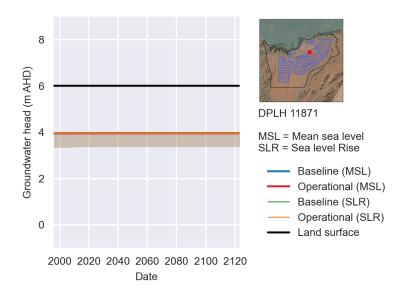


Figure 9-12 Predicted groundwater level change Noorea Soak

#### A.6.3 Predicted Salinity

The mean of predicted groundwater salinity distribution across the 100 calibrated model realisations for the top model layer after 100 years of evaporation pond operations are shown in Figure 9-13 and Figure 9-14 for the mean sea level scenario and sea level rise scenario, respectively. To maintain readability, the vegetation receptors have been excluded from these figures and time-series salinity changes to these EVs are instead illustrated in Figure 9-15 amd Figure 9-16. Note, due to the limited salinity data available, the solute transport model has not been calibrated and therefore, the salinity predictions contain a considerable level of uncertainty.

The mean sea level scenario results (Figure 9-13) suggest the evaporation ponds largely control the salinity of groundwater, particularly in areas beneath the evaporation ponds, pond perimeters and creeks where salinity is predicted to exceed 210 g/L. These areas coincide with a shallow water table as a result of groundwater mounding which in turn, increases groundwater ET and salinity. The salinity impact, however, is predicted to be constrained within a "buffer zone" of less than around 1 km surrounding the ponds. These results are consistent with the sea level rise scenario (Figure 9-14), where only minor salinity increases occur within the coastal areas to the north of the evaporation ponds due to the influence of sea level rise and subsequent higher rates of groundwater ET.



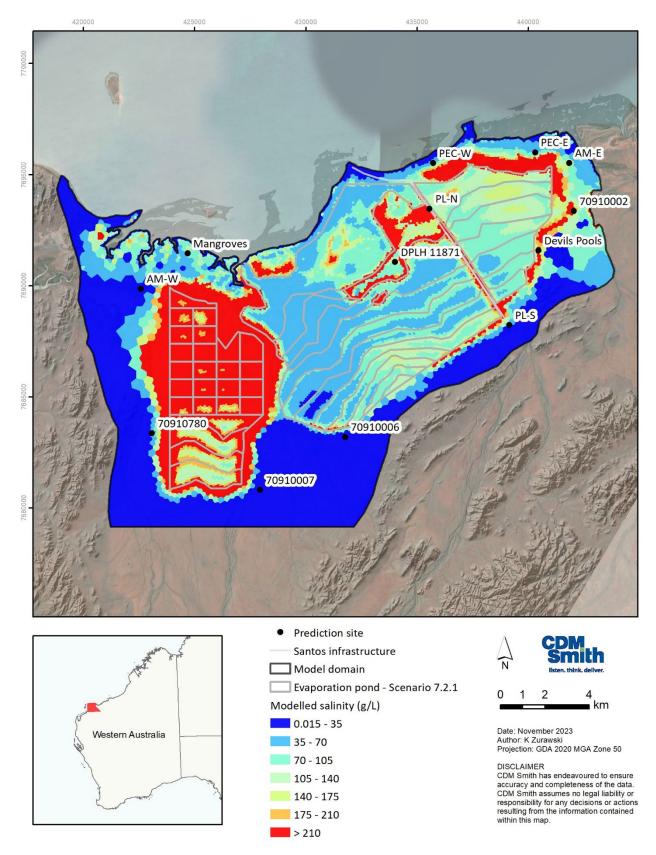


Figure 9-13 Predicted salinity distribution for the operation scenario (mean sea level) 100 years after the evaporation pond operations



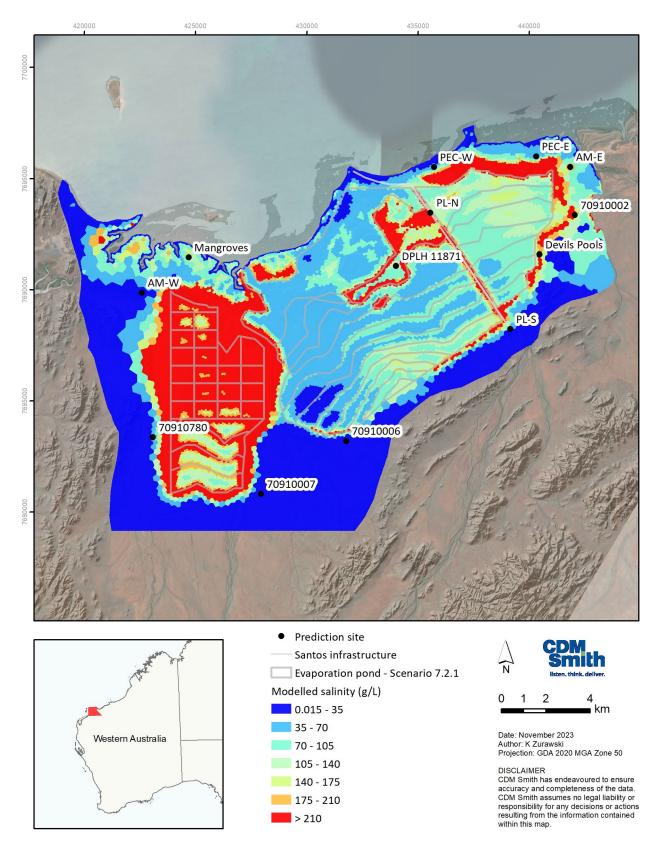


Figure 9-14 Predicted salinity distribution for the operation scenario (sea level rise) 100 years after the evaporation pond operations



To assess the direct effects of water impoundment in the evaporation ponds with respect to the location of the identified EVs, predicted time-series salinographs (for the same locations annotated earlier on Figure 9-13) have been prepared and are shown in Figure 9-15 and Figure 9-16. Note, given the paucity of salinity data informing the solute transport and density components of the model, some uncertainty exists in these results. Therefore, it is considered more appropriate to present the changes in salinity for this discussion rather than the predicted concentrations. This allows the direct effects to be assessed in a relative sense rather than an absolute sense where uncertainty exists. As stated, sites PL-S and PL-N have been selected to assess the direct effects of evaporation pond operations on the Santos Gas Pipeline infrastructure. Sites AM-W and AM-E assess the direct effects to the algal mat and samphire communities, whereas site Devil's Pools assesses the direct effects to Devil's Pools and eucalypt species within Devil Creek. Similarly, sites PEC-E and PEC-W assess the direct effects to the coastal PEC. The other locations (Mangroves, 70910002, 70910006, 70910007and 70910780) have been positioned with respect to EVs and named accordingly.

#### EV3 - Coastal PEC

Groundwater salinity at PEC-E and PEC-W is predicted to increase gradually over time. Given their proximity to the evaporation ponds, the rate of increase is lower than expected, suggesting part of the saline inflow from the pond areas may have been intercepted by groundwater ET in the backwater areas before reaching PEC-E and PEC-W. The sea level rise scenario shows a lower salinity level at both sites due to its higher sea level (and hence a smaller hydraulic gradient towards the sea) compared to the mean sea level scenario. The uncertainty analysis suggests there is a potential for the saline inflow from the pond areas to reach PEC-E and PEC-W before being intercepted by groundwater ET, which is likely to depend on the permeability in this area (i.e. the saline inflow will propagate more rapidly in a more permeable setting). Under the mean sea level rise scenario, the mean of the 100 calibrated model realisations shows 91% of the coastal PEC mapped area will experience a salinity rise greater than 5 g/L outside the evaporation ponds.

#### EV4 and EV5 – Algal mats / samphire and mangroves

As stated, sites AM-E, AM-W and Mangroves have been selected to assess the direct effects of evaporation pond operations on the algal mat and mangrove communities outside the evaporation ponds in the eastern and western parts of the model domain.

The predicted groundwater salinity at AM-E and AM-W gradually increases over the simulation period for the mean sea level and sea level rise scenarios, which is expected given their proximity to the saline plume. The salinity change at these two sites is predicted to be approximately 30 g/L at AM-E and 10 g/L at AM-W over 100 year of evaporation pond operations. The predictive uncertainty analysis suggests the saline plume has the potential to reach these two sites, causing groundwater salinity to increase substantially. Under the mean sea level rise scenario, the mean of the 100 calibrated model realisations shows 38% of the agal mat mapped area and 30% of the samphire shrubland mapped area will experience a salinity rise greater than 5 g/L outside the evaporation ponds.

Meanwhile, groundwater salinity at site Mangroves is predicted to remain largely constant over time. However, the uncertainty analysis suggests the potential of inflow from the sea boundary, the evapo-concentration of which may cause the salinity to increase notably over time at this site. This increase was found to be more profound for the sea level rise scenario. Note that this potential impact is likely to be a result of sea level rise, which is a natural process, instead of the evaporation pond operations. Under the mean sea level rise scenario, the mean of the 100 calibrated model realisations shows 14% of the mangal community mapped area will experience a salinity rise greater than 5 g/L outside the evaporation ponds.

#### EV6 – Stock water wells

The predicted groundwater salinity at the stock water wells varies considerably depending on the location. Groundwater salinity is predicted to increase notably (by around 50 g/L) at 70910002 and 70910780, possibly due to the lateral expansion (i.e. parallel to the coast) of the saline plume. In contrast, 70910006 and 70910007 show a minimal increase in groundwater salinity as they are located upgradient (in terms of groundwater flow fields) of the evaporation ponds.



The predictive uncertainty analysis indicates the modelled salinity at these sites contains a large uncertainty. The worst-case conditions (i.e. the upper bound of colour shades) suggest the salinity may increase substantially beyond the salt tolerance of cattle, which typically ranges between 4 and 5 g/L (ANZECC, 2000), potentially rendering these stock water wells inoperable. To reduce this uncertainty, it is recommended to collect water samples at each stock water well so the threat of the evaporation pond operations can be better understood.

#### EV2 and EV7 – Terrestrial Vegetation and Devil's Pools

Groundwater salinity within Devil's Pools is predicted to increase substantially over time, which will likely impact the eucalypt species residing within Devil's Creek as well as the pools themselves. The predictive uncertainty analysis indicates the rate of salinity increase can be rapid, reaching almost 300 g/L within approximately 20 years of evaporation pond operations. No effect from sea level rise is observed at this EV. Under the mean sea level rise scenario, the mean of the 100 calibrated model realisations shows 53% of the mapped area of eucalypt species will experience a salinity rise greater than 5 g/L outside the evaporation ponds.

#### EV8 - Noorea Soak

Within the vicinity of Noorea Soak the mean of the 100 calibrated model realisations shows no change in salinity during the operational period in either the mean sea level or sea level rise operational scenarios. Similar to the direct effects predicted for groundwater level increases, these results are likely due to the very low permeability of the basement rock for which the soak is located (i.e. the saline plume cannot move quickly through the basement rock).

#### EV9 - Santos Gas Pipeline

Under both the mean sea level and sea level rise scenarios, groundwater salinity at site PL-S, is predicted to increase over time showing a mean increase of around 60 g/L. Both scenarios having identical predicted salinity suggests the impacts of sea level rise is not observed at this site. Conceptually this is understandable due to the distance of the site from the coast. However, the uncertainty analysis suggests, the salinity at this site has the potential to increase to more than 300 g/L.

Groundwater salinity predictions at site PL-N show a larger rise in salinity (with a mean increase slightly above 150 g/L), possibly due to the evapo-concentration of the shallow saline plume in this area. The uncertainty analysis suggests the rate of increase in salinity could be very rapid, exceeding 300 g/L after a few years of evaporation pond operations. For most of the operational period the impact of sea level rise is insignificant, although increases slightly over the later periods of operation likely due to the proximity to the coast.



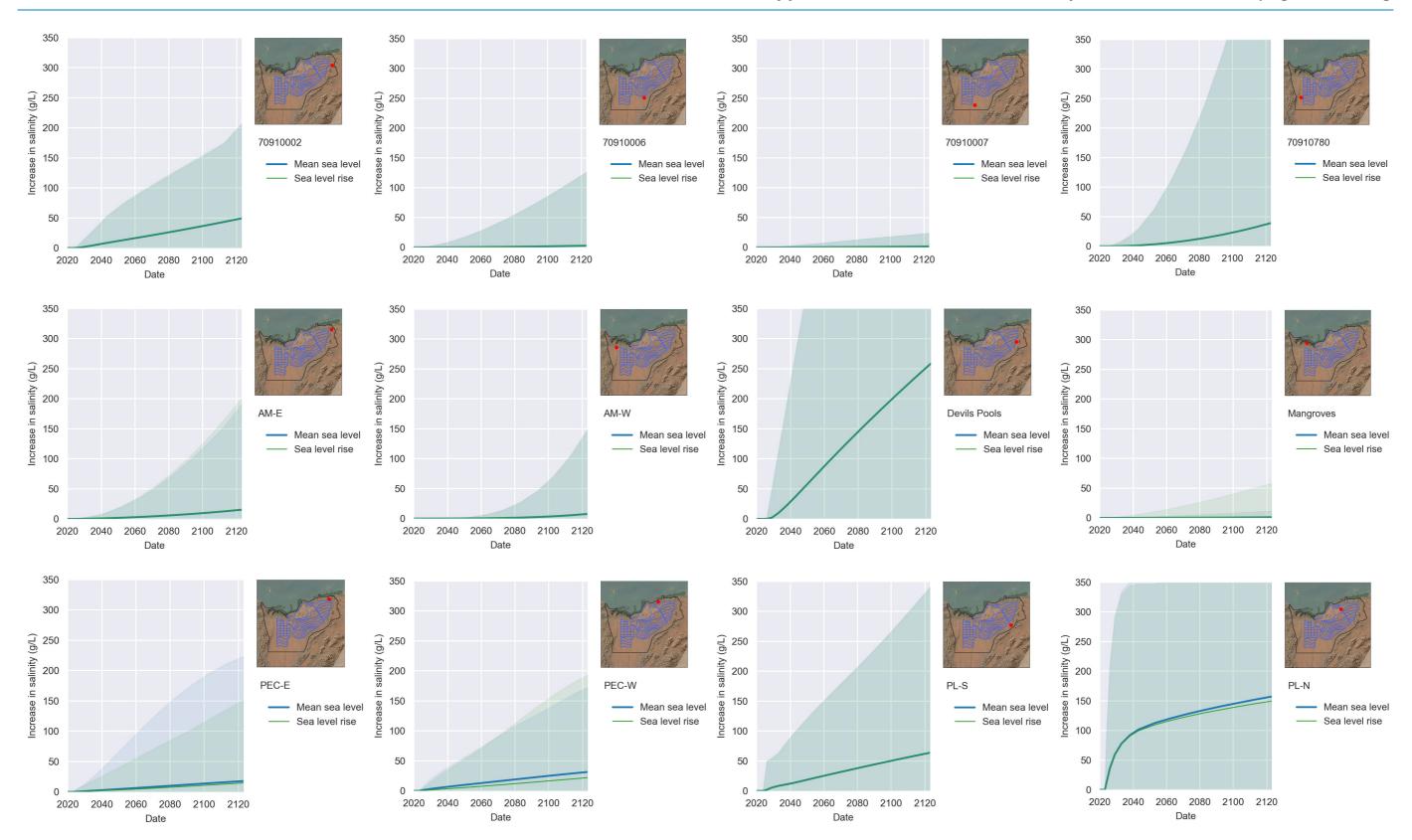


Figure 9-15 Predicted groundwater salinity change time series at selected locations (shading represents the range of prediction results from the 100 model realisations)

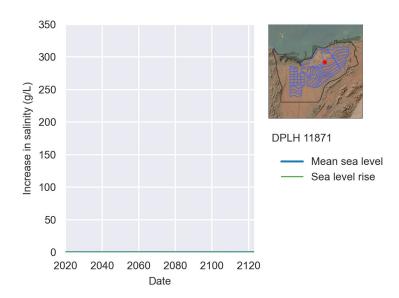


Figure 9-16 Predicted groundwater salinity change time series at Noorea Soak

#### A.6.4 Predicted Mass Balance

Table 9-5 shows the mean predicted mass balance across the 100 calibrated model realisations after 100 years of evaporation pond operations and how the mass balance is predicted to change against the baseline conditions. As discussed in Section A.5.5, the baseline scenario suggests the major groundwater inflows are rainfall recharge and inflow from the sea, while the major groundwater outflow is groundwater ET in low-lying areas. Under both scenarios (i.e. mean sea level scenario and sea level rise scenario) groundwater flow is changed due to water impoundment within the evaporation ponds, although, to varying degrees.

Table 9-5 Predicted mass balance at 100 years into the future

		Mean sea level		Sea level rise	
Component	Description	Baseline (kL/d)	Operation (kL/d)	Baseline (kL/d)	Operation (kL/d)
Storage IN	Decrease in storage	16	3	15	4
Constant Head IN	Inflow from sea	1,137	1,075	2,656	2,535
River Leakage IN	Seepage from evaporation ponds	0	14,334	0	13,875
GHB IN	Regional inflow	30	20	30	20
Recharge IN	Rainfall recharge	2,066	1,390	2,066	2,066
Total IN	Total inflow	3,248	16,822	4,767	18,500
Storage OUT	Increase in storage	1	41	1	40
Constant Head OUT	Outflow to sea	238	513	116	293
River Leakage OUT	Discharge to evaporation ponds	0	4,719	0	4,993
ET OUT	Groundwater ET	2,987	11,325	4,625	12,947
GHB OUT	Regional outflow	6	10	6	10
Drain OUT	in OUT Seepage drain		85	0	86
Total OUT	Total outflow	3,232	16,694	4,749	18,370
Percentage discrepancy	Difference between inflow and outflow	0.5%	0.8%	0.4%	0.7%





For the mean sea level conditions, the operation scenario indicates the major groundwater inflow is seepage from the evaporation ponds. Inflow from the sea only shows a slight reduction compared to the baseline scenario and occurs mostly in the western part of the model domain (see the 0 m AHD contour in Figure 9-10). The operation scenario shows a lower rainfall recharge than that of the baseline scenario as rainfall recharge is not applied in the evaporation pond areas (Section A.3.8).

The major groundwater outflow for the operation scenario is groundwater ET in areas adjacent to the evaporation ponds where groundwater levels are elevated due to pond seepage. There is also a notable outflow component attributed to groundwater discharge to the evaporation ponds. This is due to the design pond layout (Figure 9-4) that may induce a cascading effect on groundwater flow. For instance, an upgradient pond at 20 m AHD will raise the underlying groundwater to a similar level (mounding), which will in turn induce groundwater discharge to the downgradient pond at 18 m AHD. The groundwater mounding also has an impact on the hydraulic gradient, inducing more groundwater outflow to the sea, although to a lesser extent than the discharge mechanisms already described.

The sea level rise scenario shows a considerable increase in inflow from the sea, while the other inflow components are largely similar to the operation scenario. The increase in inflow from the sea is mostly offset by a similar increase in groundwater ET in areas adjacent to the coast, suggesting groundwater ET may buffer the impact from sea level rise.

The modelling shows a mean pond seepage (over 100 years of operations) of 25,652 kL/d, ranging between 16,052 and 41,038 kL/d across the 100 calibrated model realisations. With a total pond area of 11,872 Ha, the pond seepage translates to a mean of 79 mm/y, ranging between 49 and 126 mm/y. Note that the riverbed conductivity value was selected in a conservative manner (Section A.3.7).

The predicted increase in salt discharge to the sea, calculated as the difference between the operation and baseline scenarios, is shown in Figure 9-17 for the mean sea level and sea level rise conditions. The increase in salt discharge is greater for the mean sea level scenario due to its lower sea level and hence a steeper hydraulic gradients towards the sea (compared to the sea level rise scenario).



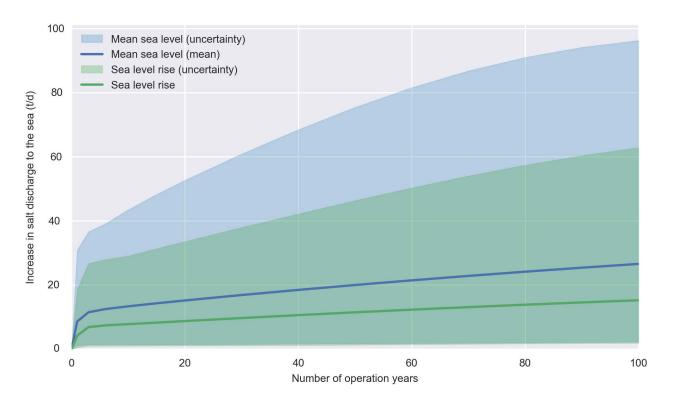


Figure 9-17 Predicted salt load (tonnes per day) to the sea

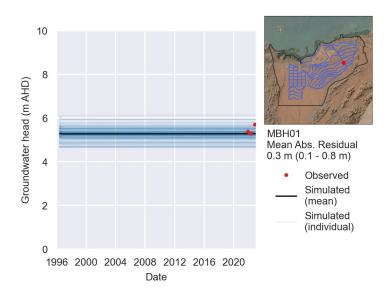
### A.7 Conclusions

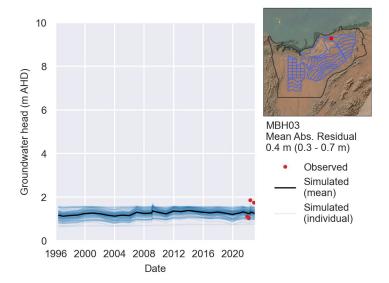
The following form the key conclusions of this assessment:

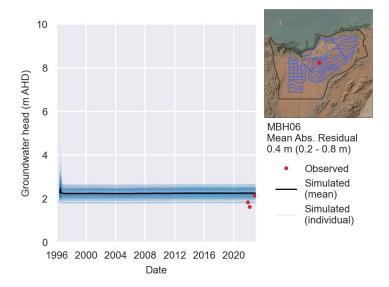
- The majority of groundwater inflow occurs from the sea and rainfall, while the groundwater outflow occurs mostly as groundwater ET in low-lying areas (not discharge to the sea) under pre-operation (baseline) conditions.
- Seepage from the evaporation ponds may lead to greater groundwater discharge to the sea. This impact, however, will likely be dampened by increased groundwater ET in the low-lying areas as a result of additional infiltration from the evaporation ponds.
- The impact of sea level rise is expected to be limited to the area immediately adjacent to the coast in the northwest of the Project area, possibly due to the buffering of groundwater ET within the backwater areas.
- The long-term seepage recharge rate is estimated to range between 49 and 126 mm/y.



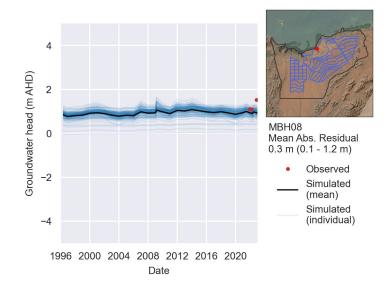
# A.8 Appendix 1 – Calibrated Hydrographs

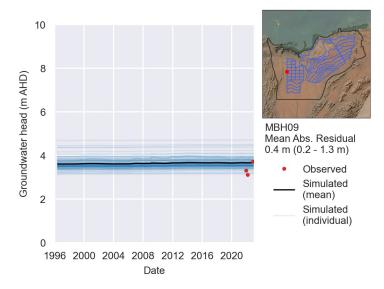


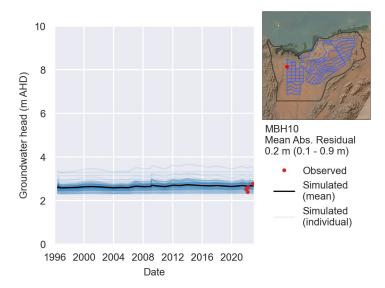




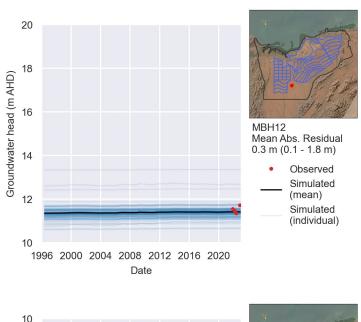


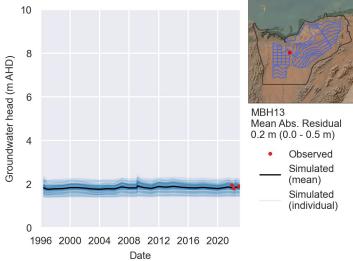


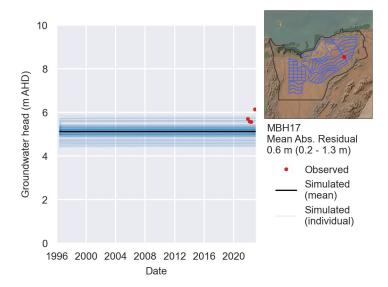




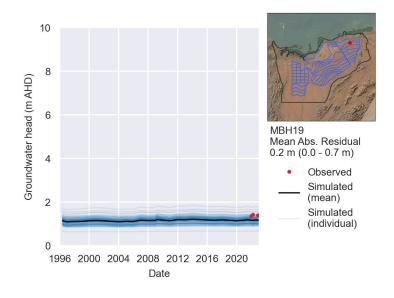


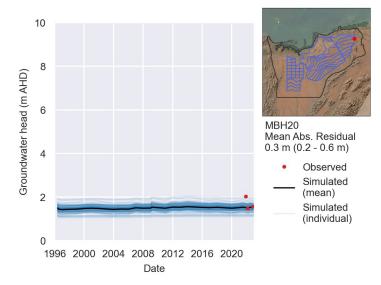


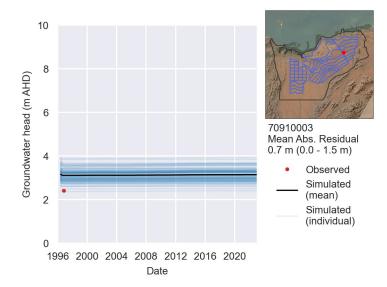




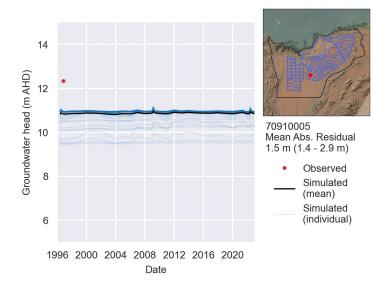


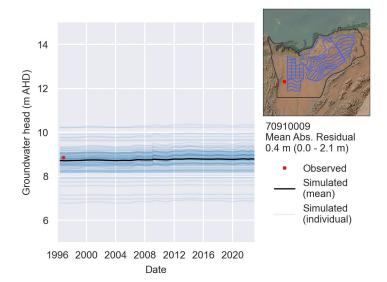


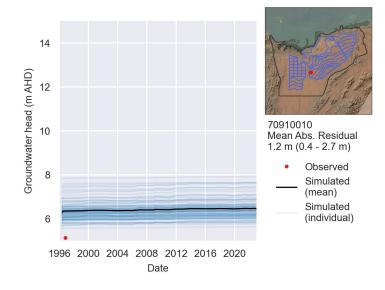








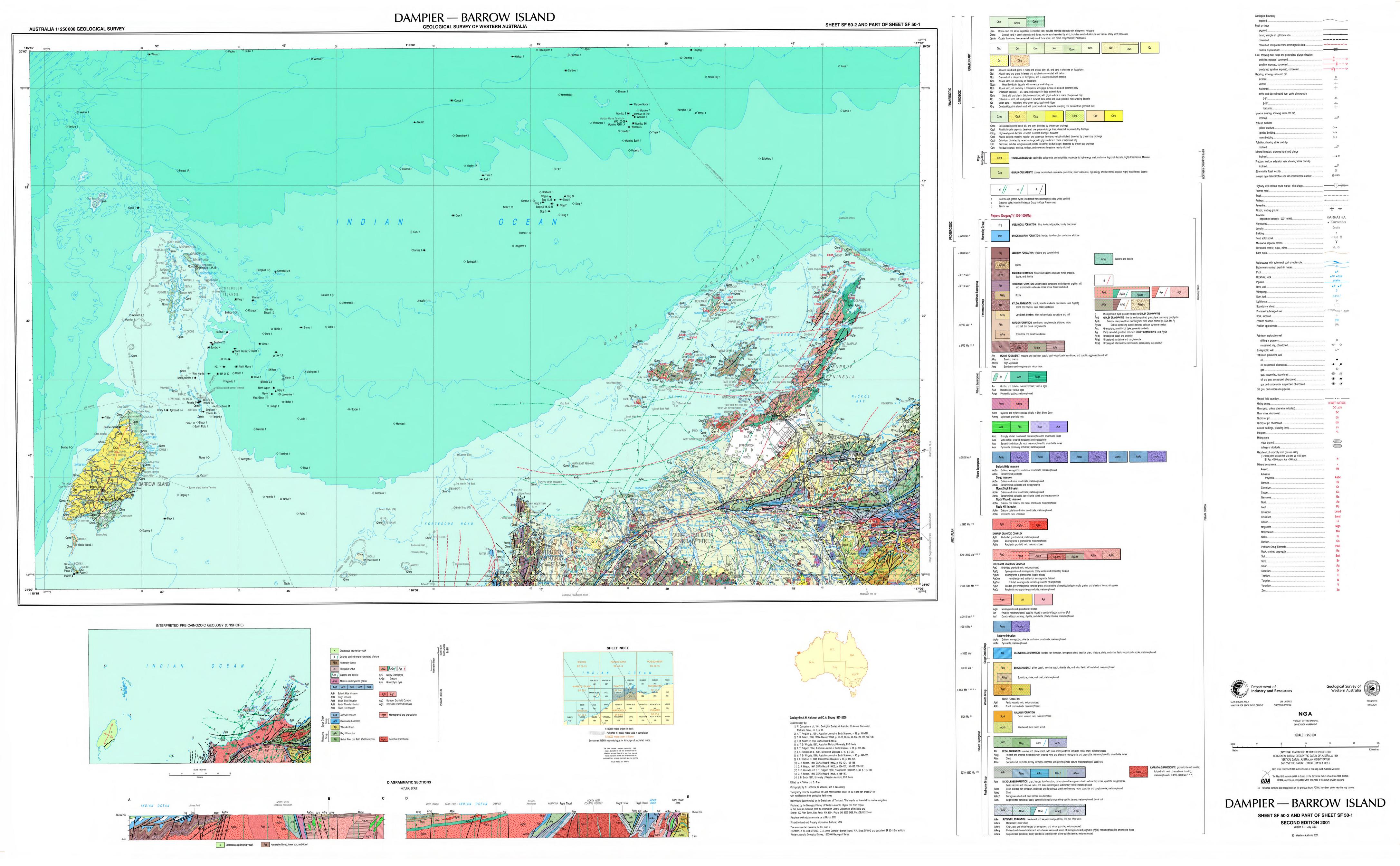






# **Appendix B Dampier-Barrow Island 1:250K Geological Map**

Hickman and Strong (2000)



# **Appendix C Noorea Soak Hydrogeological Assessment**



# Memorandum

Date: 29 June 2023

Subject: Noorea Soak hydrogeological assesssment

This technical memorandum aims to provide the following:

- A baseline hydrogeological setting for the Noorea Soak,
- An assessment of potential changes due to project activities to water levels and chemistry at the Noorea Soak based on the groundwater model developed for the site, and
- A review of the potential impacts to the Noorea Soak based on the above.

This document is meant to be read in conjunction with the Groundwater Effects Assessment, where more detail about the project, groundwater setting and groundwater modelling can be found.

# **Baseline Hydrogeology**

This baseline hydrogeology has been compiled from the existing hydrogeological conceptual model, field observations, remote sensing and a compilation of aerial imagery sourced from Google Earth Pro historical imagery tool and Esri Wayback Historical Imagery (<a href="https://livingatlas.arcgis.com/wayback/#active=6984&ext=116.35704,-20.88289,116.37388,-20.87407&localChangesOnly=true">https://livingatlas.arcgis.com/wayback/#active=6984&ext=116.35704,-20.88289,116.37388,-20.87407&localChangesOnly=true</a>).

#### Geology

The Noorea Soak is located in area of elevated basement geology, with basement outcrops observed in the area of the Soak. The Soak is labelled on the geology map (Figure 1) of the area which shows the basement outcrop in the area of the soak to consist of granitoid rock. This is overlain by eluvial sand.

Photos of the area have been collected by Leichhardt on a number of occasions and show the outcropping basement (Figure 2) and the presence of water at the soak. The photos align with the geological mapping of eluvial sand overlying granitoid rocks that appear to be relatively unweathered.

During field investigations the granite was encountered in some drilled bores however these were not installed due to lack of water indicating very low permeability.



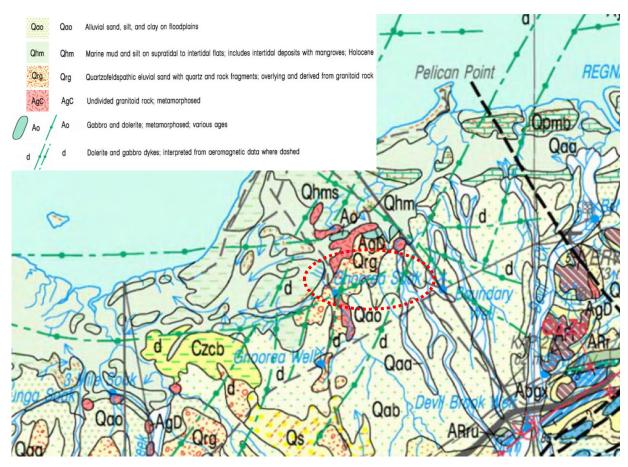


Figure 1 Clip of the geology map (1:250,000 Geological Survey Dampier-Barrow Island Map, Geological Survey of Western Australia)



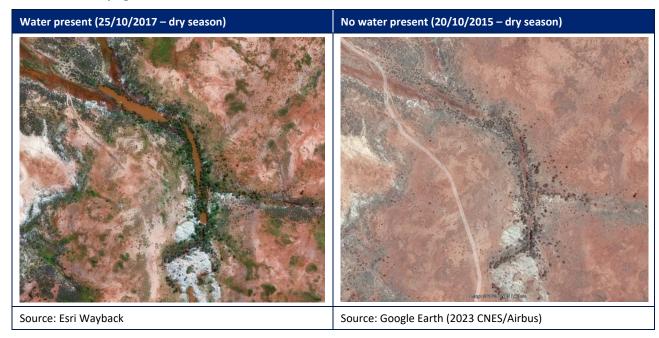
Figure 2 Field photographs of outcropping basement in the area of Noorea Soak (photos provided by Leichhardt)



#### **Aerial imagery and site photos**

Aerial imagery sourced from Google Earth Pro historical imagery tool and Esri Wayback Historical Imagery (https://livingatlas.arcgis.com/wayback/#active=6984&ext=116.35704,-20.88289,116.37388,-20.87407&localChangesOnly=true) is shown in chronological order in Attachment 1. There are 13 images from October 2011 to September 2022. The imagery shows that there is often water in the soak, although not permanently. Of the 13 images, three show the soak with no water. The images are a mixture of dry and wet season and the amount of water in the soak does not appear to correlate in any significant way to the amount of rainfall recorded at Karratha Aero BoM station (IDCJAC0009), although this station is over 40 km away and rainfall over this area is expected to vary significantly.

Table 1 Varying water conditions at Noorea Soak



Site photos provided by Leichhardt show water in the soak on two occasions; 5<sup>th</sup> April 2021 and 17<sup>th</sup> August 2020. On other occasions the site was visited the soak was not photographed. In the three months preceding April 2021, 122.7 mm rainfall was recorded at Karratha Aero and in the three months preceding August 2020, 82.7 mm was recorded. There looks to be less water in the soak in the August photos and the outcropping basement granitoid can be clearly seen at the base of the pond.





Figure 3 Site photos (provided by Leichhardt) showing water in the soak on 5<sup>th</sup> April 2021 (blue points) and 17<sup>th</sup> August 2020 (green points)

#### **Remote sensing**

Remote sensing data from the Sentinel 2 satellite has been downloaded and processed to assist in detecting the timeseries presence of water at the Noorea Soak. The normalised difference water index (NDWI) bands 3 and 8A can be used to determine the presence of water on the land surface. This data had been processed for a polygon shape around the soak. The timeseries represents the maximum NDWI in the polygon for that satellite image and shows that water was only detected in 12 out of 293 satellite passes (Figure 4). It should be noted that the grid size for this data is 10x10m and therefore the NDWI can only show when the pool size is greater than this grid size.



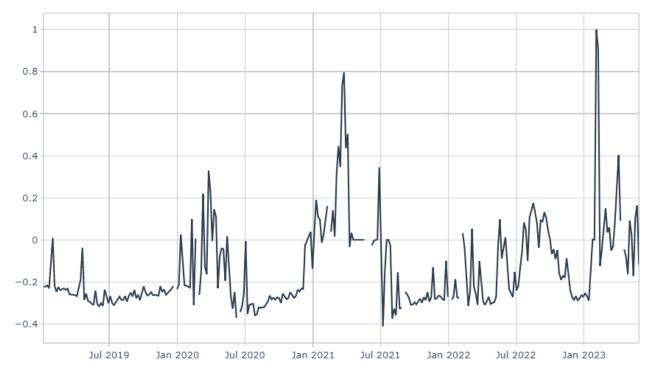


Figure 4 NDWI timeseries for polygon around Noorea Soak

#### **Summary**

The available information suggests that Noorea Soak is not a permanent water feature and is therefore not likely to receive groundwater inflows. The feature is at the end of the local and regional groundwater system and would therefore be expected to be permanently inundated if it was receiving groundwater.

The rock underlying the Noorea Soak is very low permeability basement rock and is very unlikely to support the storage and transmission of groundwater.

The current conceptualisation of Noorea Soak is that it is a surface water supported feature that collects water during rainfall and runoff events due to its location in the landscape (i.e. a depression in the ground at the bottom of the catchment) and then holds the water for a period of time after runoff has ceased. The water is unable to seep into the very low permeability basement rock (or seeps very slowly) and therefore can only exit the feature through evaporation.

This feature is unlikely to be an aquatic GDE but is assessed as a cultural and spiritual value (EV).



# Potential changes to conditions (direct effects)

The framework for this assessment and more detail around the methodology and the groundwater modelling that informs this assessment is presented in the main report. The direct effects to groundwater arising from water affecting activities (WAAs) at the site are shown in Table 1.

**Table 2 Identified Direct Effects** 

WAA (source)		Direct effects (pathway)			Considered
		Category	ID	Description	herein?
WAA1	WAA1 Surface excavations (water impoundment)	Quantity	DE1 – Increased recharge	Mounding of groundwater levels due to increased infiltration and seepage from evaporation ponds	
		Quality	DE2 – Change in salinity	Change in salinity (generally an increase) of groundwater as a result of evapo- concentrated water infiltrating to the water table	Ø
				In some areas the pond salinity may be lower than the existing groundwater (i.e. where there is hypersaline groundwater in the north east of the model domain) and salinity may decrease	
		interactions groun DE4 – Cha	DE3 – Change in groundwater levels	Change in groundwater levels as a result of water impoundment	Ø
			DE4 – Change in groundwater flow	Change in groundwater flow as a result of water impoundment	Ø
		Aquifer disruption	-	Surface excavations do not physically disrupt underlying aquifers	X

#### Quantity

The predicted groundwater elevation (RSWL) contours after 100 years of operations are shown in Figure 4– the location of the Noorea Soak is indicated by the label "DPLH 11871". Predicted time-series groundwater levels at this location is shown in Figure 5. The mean and range of predicted groundwater levels from the 100 calibrated model realisations are represented by solid lines and colour shades, respectively.



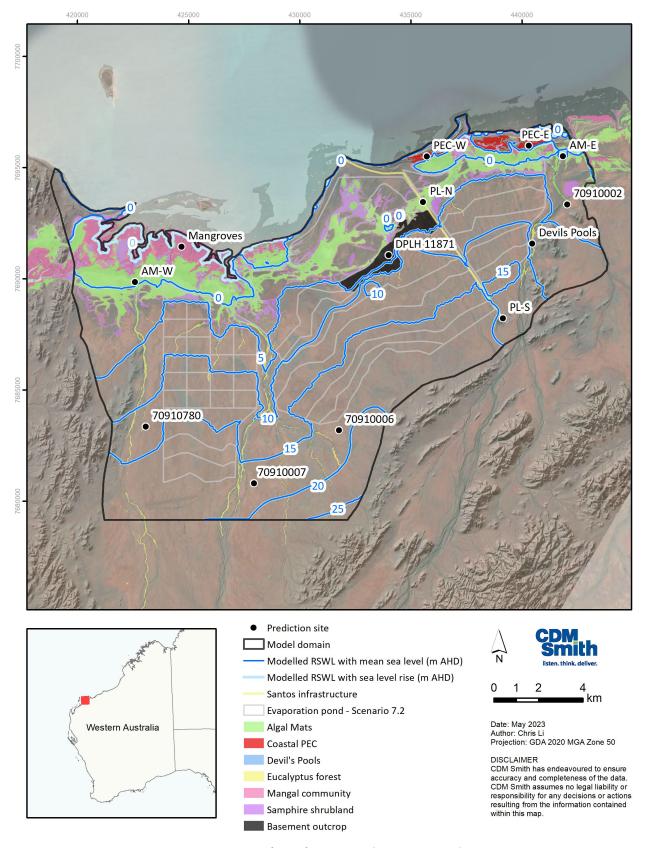


Figure 5 Predicted groundwater elevation (RSWL) contours after 100 years of operations



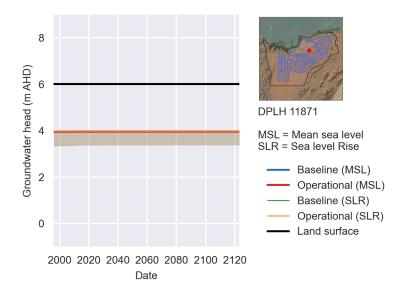


Figure 6 Predicted groundwater level change at DPLH 11871 (Noorea Soak)

The results indicate that the groundwater elevations at the soak are unlikely to change over the operational period of the ponds. The soak is located in an area of basement outcrop in the model and the very low hydraulic conductivity assigned to this unit is likely to be responsible for the limited change observed at the prediction point. The groundwater head is largely controlled by ET, which keeps the watertable at least 2 m below the surface.

#### **Predicted Salinity**

Predicted time-series groundwater salinity at the Noorea Soak (DPLH 11871) prediction point is shown in Figure 5. The mean and range of predicted groundwater salinity from the 100 calibrated model realisations are represented by solid lines and colour shades, respectively.

The results indicate that groundwater salinity at the soak is unlikely to change over the operational period of the ponds. All 100 calibrated model realisations align. These results are likely to be due to the very low permeability of the basement rock on which the soak is located (i.e. saline plume cannot move quickly through the basement rock).

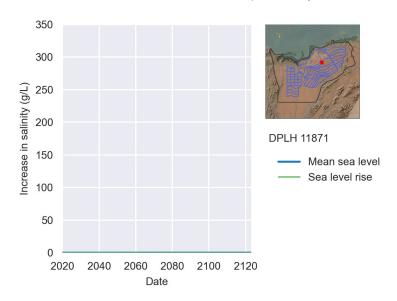


Figure 7 Predicted groundwater salinity change at DPLH 11871 (Noorea Soak)



# Impact Assessment (exposure assessment and threat assessment)

Table 6-1 presents a summary of the possible exposure pathways between direct effects (source) and the Noorea Soak receptors. Any active exposure pathways would be discussed further as part of the threat assessment, however in this case there are no identified active pathways.

Table 3 Possible exposure pathways between WAA 1 (water impoundment) and the Noorea Soak EV

Direct Effect		Indirect (EV) effect)	Active pathway (linkage)?	Carried forward to threat assessment?
Quantity	DE1 – Increased recharge	Increased recharge from water impoundment could increase the quantity of water connected to springs and pools	No, groundwater modelling predicts no change the water levels at the soak over the prediction period and therefore there is no mechanism via groundwater for the pond to cause increased recharge to the soak.	X
Quality	DE2 – Change in salinity	Increased salinity from water impoundment could impact the environmental water requirements of springs and pools	the soak is not predicted to increase over the prediction period.	
Altered GW/SW interactions	DE3 – Change in groundwater levels	Change in groundwater levels from water impoundment could change the interaction of groundwater and surface water in the springs and pools	No, as per DE1, groundwater levels are not expected to increase in the area of the soak.	X
	DE4 – Change in groundwater flow	Change in groundwater flow from water impoundment could alter flow processes connected to springs and pools	<b>No</b> , groundwater flow conditions are not expected to change in the vicinity of the soak.	X

The results indicate there is no active pathway between the ponds and the soak via groundwater. This, combined with the likelihood that the soak does not currently receive groundwater, means there is a low risk of impact from the ponds to the soak via groundwater processes.



# **Attachment 1: Aerial imagery for Noorea Soaka**

# Image Information Date: 31/10/2011 Source: Google Earth (2023 Maxar Technologies) Days since last rain: 112 (7 mm on 11/07/2011) Rain in the previous 30 days: 0 mm End of dry season Date: 07/01/2013 Source: Google Earth (2023 Maxar Technologies) Days since last rain: 10 (0.6 mm on 28/12/2013) Rain in the previous 30 days: 0.6 mm Wet season



#### Information

Date: 29/09/2013

Source: Google Earth (2023 CNES/Airbus)
Days since last rain: 95 (202 mm on 26/06/2013)

Rain in the previous 30 days: 0 mm

Dry season



Date: 20/10/2015

Source: Google Earth (2023 CNES/Airbus)

Days since last rain: 10 (0.3 mm on 10/10/2015)

Rain in the previous 30 days: 0.3 mm

End of dry season





# Information Image Date: 14/09/2016 Source: Esri Wayback Days since last rain: 17 (0.6 mm on 28/08/2016) Rain in the previous 30 days: 0.6 mm Dry season Date: 25/10/2017 Source: Esri Wayback Days since last rain: 77 (0.6 mm on 09/08/2017) Rain in the previous 30 days: 0 mm Dry season



# Information Image Date: 15/06/2018 Source: Google Earth (2023 CNES/Airbus) Days since last rain: 8 (0.8 mm on 07/06/2018) Rain in the previous 30 days: 55.4 mm Dry season Date: 30/01/2020 Source: Esri Wayback Days since last rain: 19 (12.2 mm on 11/01/2020) Rain in the previous 30 days: 47.2 mm Wet season



# Information Date: 01/01/2021 Source: Google Earth (2023 CNES/Airbus) Days since last rain: 7 (1.2 mm on 25/12/2020) Rain in the previous 30 days: 69 mm Wet season Date: 24/02/2021 Source: Esri Wayback Days since last rain: 7 (0.6 mm on 17/02/2021) Rain in the previous 30 days: 73.2 mm Wet season



# Information Image Date: 13/10/2021 Source: Esri Wayback Days since last rain: 113 (9.2 mm on 22/06/2021) Rain in the previous 30 days: 0 mm Dry season Date: 21/07/2022 Source: Esri Wayback Days since last rain: 40 (0.4 mm on 11/06/2022) Rain in the previous 30 days: 0 mm Dry season



#### Information

Date: 12/09/2022

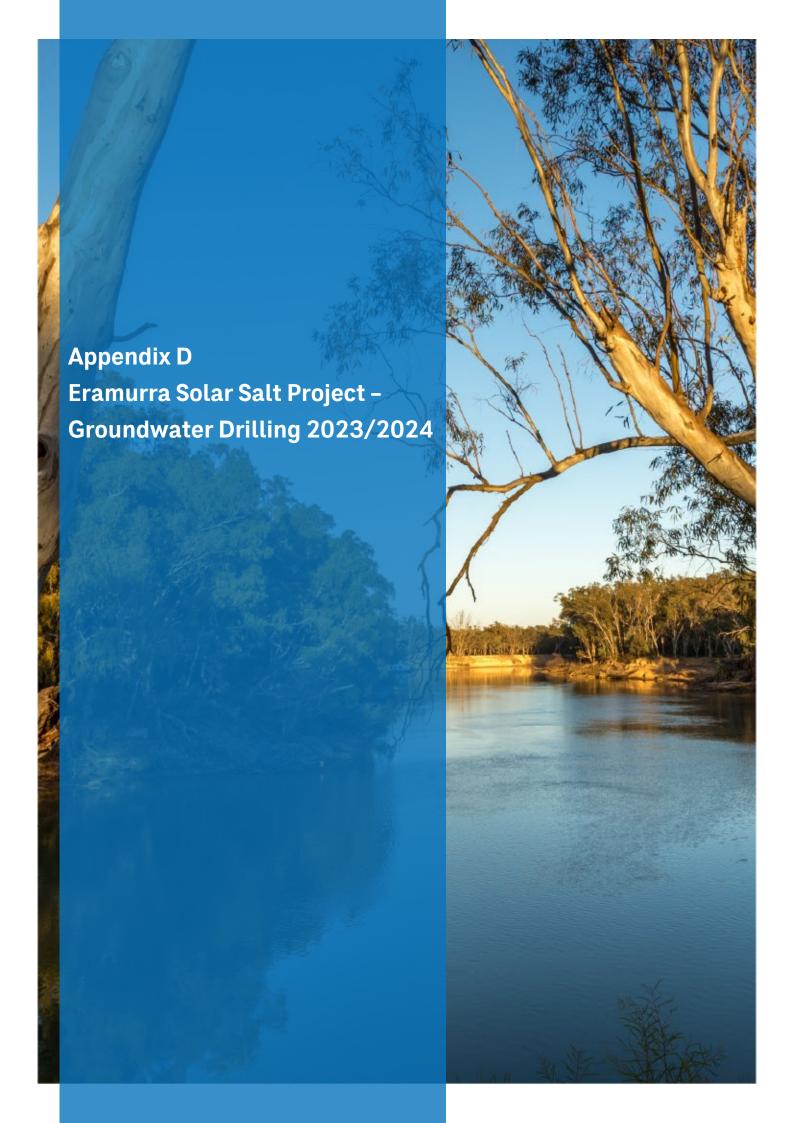
Source: Google Earth (2023 Airbus)

Days since last rain: 8 (0.2 mm on 04/09/2022)

Rain in the previous 30 days: 18.5 mm

Dry season





### **CDM SMITH AUSTRALIA**

Suite 1, Level 4, 140 Ann Street Brisbane City QLD 4000 australia@cdmsmith.com

# Report

Eramurra Solar Salt Project
- Groundwater Drilling
2023/2024

#### PREPARED FOR:

Land and Water Consulting (WA) Pty Ltd





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# **Document history & status**

Revision	Date issued	Reviewed by	Approved by	Date approved	Revision type
А	02 Feb 2024	J. Pretzsch-Kalsgaard	-	-	Internal Draft
В	08 Feb 2024	J. Fawcett	J. Pretzsch-Kalsgaard	08 Feb 2024	Internal Draft
С	26 Mar 2024	J. Pretzsch-Kalsgaard	-	-	Internal Draft
D	28 Mar 2024	J. Fawcett	J. Pretzsch-Kalsgaard	28 Mar 2024	Final Draft

# **Distribution of copies**

Version	Date issued	Quantity	Electronic	Issued to
0	16 Feb 2024	1	PDF	LWC
1	28 Mar 2024	1	PDF	LWC

Last Saved: 28 March 2024		
File Name: LWC-1001672-RPT-001-1		
Author: Reece Adam, Sarah McDonald, Jakob Pretzsch-Kalsgaard		
Project Manager: Jakob Pretzsch-Kalsgaard		
Client:	LWC WA Pty Ltd	
Document Title:	Eramurra Solar Salt Project – Groundwater Drilling 2023/2024	
Document Version:	Final	
Project Number: 1001672		

listen. think. deliver.



# **Section 1 Introduction**

#### 1.1 Overview

Land and Water Consulting (LWC) engaged CDM Smith Australia Pty Ltd (CDM Smith) on behalf of Leichhardt Salt Pty Ltd (Leichhardt) to provide field hydrogeological support services for the drilling and construction of groundwater monitoring bores at Leichhardt's Eramurra Solar Salt Project (the Project). The Project is located approximately 55 km west-south-west of Karratha on the Pilbara coast of Western Australia.

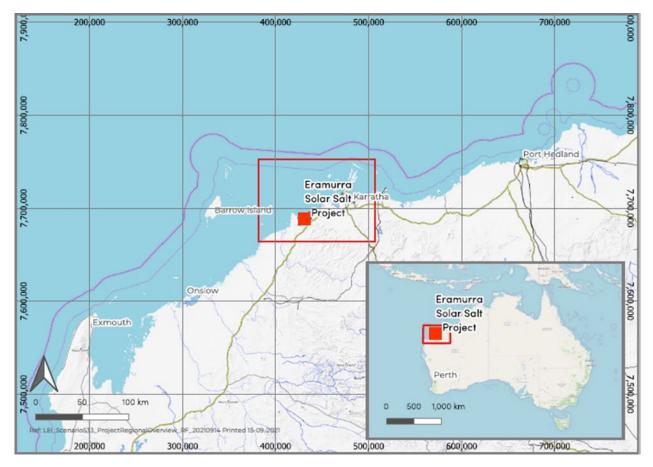


Figure 1-1 Project locality plan

# 1.2 Background

Leichhardt is currently completing pre-feasibility studies for the Project which plans to generate up to 6.8 million tonnes per annum (Mtpa) of salt from a series of evaporation ponds through evapo-concentration which will include approximately a 100 km² (10,000 Ha) of concentration pond area, 20 km² (2,000 Ha) of crystalliser area, processing area, seawater intake and disposal lines and other associated infrastructure.

CDM Smith has been assisting LWC and Leichhardt with groundwater related studies for the Project since 2021 which has involved a review of baseline groundwater data and the development of a groundwater model to assist in understanding the impact of the Project's development on groundwater related environmental values (EVs). While these studies have proved useful in gauging the preliminary Project related effects, it is expected collection of further baseline data will be necessary as Leichhardt progress with environmental approvals for the Project.



To meet the requirements of ongoing approvals, Leichhardt is planning drilling and construction of up to 40 additional groundwater monitoring bores and 9 sentinel bores within the Project area to develop a greater understanding of the baseline condition as well as providing long-term monitoring of key EVs. Due to a combination of land access challenges and timing of environmental approvals for some of the monitoring bore locations, 13 monitoring bores, which predominantly target EVs within the Project area, have been selected for drilling beginning in December 2023. The remaining monitoring bores are planned for completion later in the Project's timeline pending land access approvals and drilling contractor availability. Data collected from the drilling campaign will be used to update the groundwater model, from which updated predictions of the Project's impacts to groundwater related EVs can be assessed

A drilling plan of the proposed monitoring bores is presented in Table 1-1 while the bore locations are shown in Figure 1-2.

Table 1-1 Monitoring bore drilling plan

Bore ID	Target	Bore Type	Target Depth
MB21d	Devils Pools	Deep	40
MB21s	Devils Pools	Shallow	10
MB26d	Paleo Channel/Ocean	Deep	40
MB33d	Terrestrial Veg	Deep	60
MB33s	Terrestrial Veg Shallow		20
MB34s	Terrestrial Veg	Shallow	20
MB35d	Terrestrial Veg	Deep	60
MB35s	Terrestrial Veg	Shallow	20
MB36s	Terrestrial Veg	Shallow	20
MB37d	Basement	Deep	60
MB38d	Basement	Deep	60
MB39d	Basement	Deep	60
MB40d	Basement	Deep	60

This factual report summarises the outcomes of the drilling and construction at the Eramurra Solar Salt Project completed between December 2023 and January 2024.



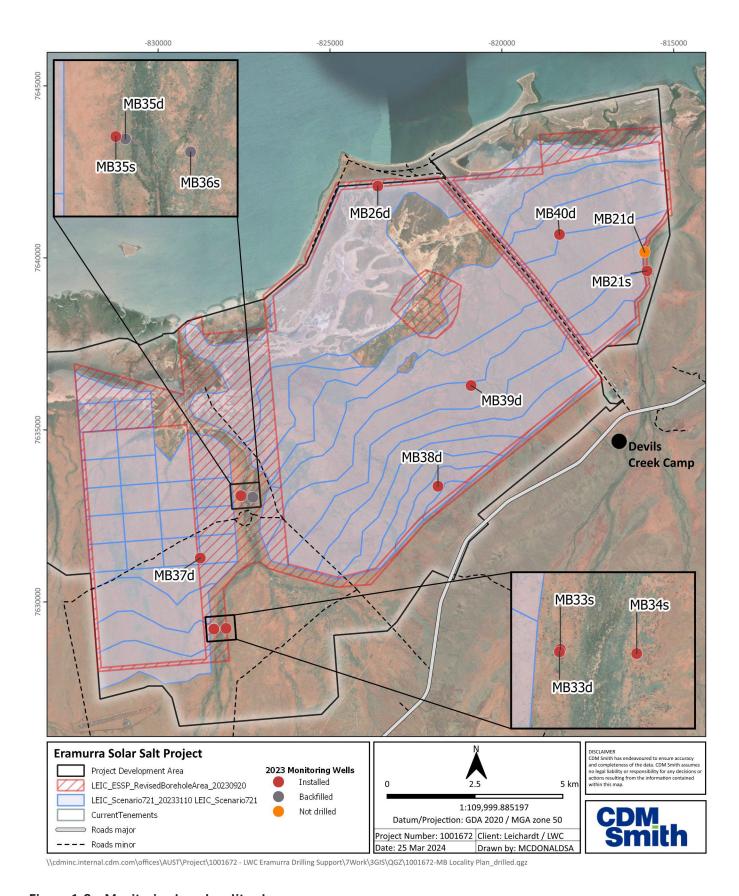


Figure 1-2 Monitoring bore locality plan



# 1.3 Scope of Work

CDM Smith has been engaged to complete the following tasks as part of the Eramurra Solar Salt Project Groundwater Drilling Program:

- Provide field support to supervise groundwater drilling for up to 21 days including:
  - Maintenance of Health Safety and Environment (HSE) documentation.
  - Lithological logging.
  - Collection of hydrogeological and drilling observations (i.e. water cuts, ground conditions, airlift yields, water quality etc).
  - Verification of drillers work charges (labour and materials).
  - Mobilisation and demobilisation (included in 14-day swing, although excluded from the SOW).
- Compilation of field data and summarise the drilling results within a brief drilling completion report (this report).
- Project management including issuing of daily drilling reports, support to field staff, project coordination/communications.
- Provision of an updated hydro-conceptualisation based on the results of the drilling program completed.



# **Section 2 Monitoring Bore Drilling and Construction**

#### 2.1 Overview

Ten monitoring bores (MB21s, MB26d, MB33d, MB33s, MB34s, MB35s, MB37d, MB38d, MB39d and MB40d) were drilled and constructed between December 2023 and January 2024.

Drilling and bore construction were completed by Soil Mechanics Pty Ltd (Soil Mechanics) under direct contract with Leichhardt. Works were conducted under the supervision of a licensed water well driller and in accordance with *Minimum Construction Requirements for Water Bores in Australia* (Edition 4) outlined by NUDLC (2020). Drilling was undertaken using conventional downhole hammer (rotary air-blast; RAB) drilling techniques using a Hanjin 8-TM rig with a separate plant containing an air compressor.

The following sub-sections outline the monitoring bore design, drilling and construction methodology and results collected during the drilling program.

# 2.2 Monitoring Bore Designs

Monitoring bore locations were selected in collaboration with Leichhardt, O2 Marine and LWC and have been designed to target select EV locations over the Project area. During the selection process, consideration was made to previous groundwater drilling results in the Project area (LWC, 2022) to inform the approximate target depths of each monitoring bore. Monitoring bores were generally split between shallow and deep bores to investigate respectively (i) the presence and depth of shallow groundwater over the Project area, and (ii) the depth of sedimentary cover and potential for a deeper aquifer, or a continuous aquifer, within the basement. The following provides a summary of the key design details for the shallow and deep bores:

#### Shallow bores:

- DN 50 mm CL12 or greater uPVC casing screened with a minimum 3 m of 1 mm aperture slotted casing targeting the saturated interval of the aquifer above basement.
- A hydraulic seal installed above the screened and cement grouted to surface to prevent surface water ingress to the bore.
- Target EVs thought to be reliant upon the shallow groundwater to meet their environmental water requirement (EWR).

#### Deep bores:

- DN 50 mm CL12 or greater uPVC casing screened with a minimum 3 m of 1 mm aperture slotted casing targeting the upper interval of basement.
- A hydraulic seal installed above the basement to isolate the sedimentary layers from the basement as much as possible.
- Designed primarily to investigate basement depth and potential for a deeper aquifer system. Although
  not specifically designed to target EVs, deep bores may provide an indication on groundwater interaction
  between aquifers (if this occurs) or the continuity of an aquifer which may provide useful for
  understanding how the Project might affect the groundwater system.

All monitoring bores have been designed to be constructed with a lockable steel collar and concrete plinth, dimensions at the driller's discretion. A schematic of the monitoring bores is presented in Figure 2-1.



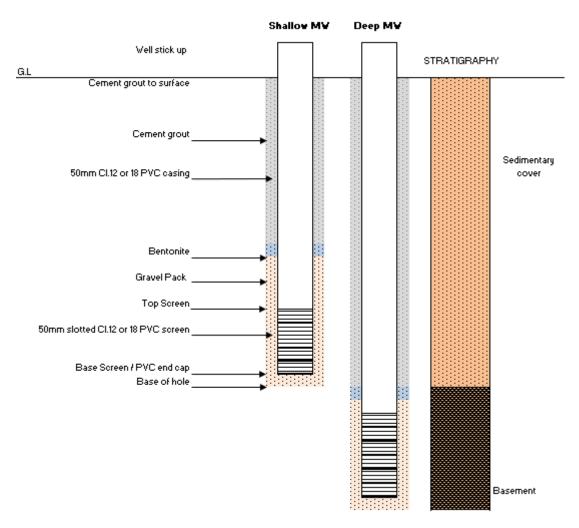


Figure 2-1 Nominal monitoring bore design



# 2.3 Drilling and Construction

Drilling and construction of monitoring bores involved the following:

- Collaring at 9" diameter and installation of DN 175 mm temporary PVC surface casing, dependent on ground conditions.
- RAB drilling at 5" diameter to target drill depths.
- Installation of DN 50 mm PN12 uPVC casing within each monitoring bore, with 1 mm factory slotted screens
  installed within nominated target formations, and gravel packed using 3 mm gravel to at least 1 m above the
  top of screens.
- Installation of a 1 to 2 m bentonite seal above the gravel pack. Bentonite was left for an hour to hydrate to ensure the bentonite pellets had activated prior to grouting.
- Grouting the hole annulus with a 5% bentonite/cement mix.
- Installation of a protective stainless-steel collar to approximately 1 m above ground level, surrounded by a concrete plinth measuring 0.4 m (L) x 0.4 m (W) x 0.2 m (D).
- Airlift development at final depth if yield is sufficient until the discharge water was clear and free of sediment, with measurement of yield and physio-chemical water quality parameters.

During drilling, chip samples were laid out in one metre intervals for geological logging (photographs presented in Appendix A). A CDM Smith hydrogeologist logged the samples and recorded hydrogeological information such as water strikes, airlift yields and water quality. Composite logs of the monitoring bores are presented in Appendix B.

A summary of the monitoring bore drilling and construction is presented in Table 2-1 while a summary of the drilling observations is provided in Table 2-2. An example photograph showing MB39d and MB34s is provided in Figure 2-2.



Table 2-1 Monitoring Bores Drilling and Construction Summary

Bore ID	Coordinates [1] GDA2020 Z50	Elevation (mAHD) [2]	Drilled Depth (mbgl) <sup>[2]</sup>	Target/screened geology	Screened interval (mbgl) <sup>[3]</sup>	Gravel pack (mbgl)	Bentonite seal (mbgl) <sup>[3]</sup>	Stick up (m)	Depth to water (m btoc) [3]
MB21s	0440329 E 7691543 N	11.65	24	Devils Pools (shallow groundwater)	17 - 23	16 - 23	15 - 16	0.99	8.08
MB21d	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
MB26d	0432867 E 7694530 N	4.35	36	Potential paleochannel	19 - 25	18 - 25	16 - 18	1.2	4.95
MB33s	0427265 E 7682331 N	16.73	20	Eucalypts (shallow groundwater)	14 - 20	13 - 20	12 - 13	0.9	6.66
MB34s	0427608 E 7682312 N	17.03	20	Eucalypts (shallow groundwater)	17 - 20	16 - 20	15 - 16	0.75	6.43
MB33d	0427261 E 7682320 N	16.86	60	Basement (deeper groundwater)	54 - 60	53 - 60	52 - 53	0.99	23.09
MB35s	0428313 E 7686043 N	6.96	15	Eucalypts (shallow groundwater)	12 - 15	11 - 15	10 - 11	1.00	5.09
MB35d	0428356 E 7686032 N	10.92	42	Basement (deeper groundwater)	N/A	N/A	N/A	N/A	N/A
MB36s	0428649 E 7685974 N	9.88	20	Eucalypts (shallow groundwater)	N/A	N/A	N/A	N/A	N/A
MB37d	0427028 E 7684363 N	12.55	42	Basement (deeper groundwater)	36 - 42	35 - 42	34 - 35	1.07	7.39
MB38d	0433931 E 7685886 N	23.37	49.6	Basement (deeper groundwater)	43.6 - 49.6	42.6 - 49.6	40.6 - 42.6	1.06	17.77
MB39d	0435086 E 7688672 N	12.31	27	Basement (deeper groundwater)	21 - 27	19 - 27	18 - 19	1.08	8.58

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Bore ID	Coordinates [1] GDA2020 Z50	Elevation (mAHD) <sup>[2]</sup>	Drilled Depth (mbgl) <sup>[2]</sup>	Target/screened geology	Screened interval (mbgl) <sup>[3]</sup>	Gravel pack (mbgl)	Bentonite seal (mbgl) <sup>[3]</sup>	Stick up (m)	Depth to water (m btoc) <sup>[3]</sup>
MB40d	0437922 E 7692766 N	8.15	60	Basement (deeper groundwater)	57 - 60	56 - 60	54 - 56	0.89	6.41

- Notes: 1. Coordinates collected by Murray and Associated Pty Ltd by a registered surveyor using a Trimble R10 GNSS with horizontal accuracy of +/- 15 mm and vertical accuracy of +/- 25 mm
  - 2. Metres above height datum (AusGeoidO9). Elevations collected using a Trimble R10 GNSS from ground level
  - 3. Metres below top of casing



Table 2-2 Drilling observation summary

Bore ID	Observations
MB21s	Drilling intercepted water at around 10 m after which water (~1.5-3 L/s) was observed each time the drill string was raised to flush the hole. Loose formation encountered from 10 m through to 15 m caused hole stability issues. Dolerite was encountered from approximately 16 m which slowed the rate of penetration.
	Drilling was ceased after water returns led to a blowout at the collar. The bore was installed and screened in the shallow groundwater within the dolerite.
MB21d	This hole was not drilled due to time constraints.
MB26d	Drilling intercepted water at around 10 m after which hypersaline water (~5L/s at >160 mS/cm) was observed each time the drill string was raised to flush the hole. A dense black clay layer was encountered at 15 – 19 m with loose wet sands beneath. Hole stability issues were encountered at 36 m within a gravelly sand unit. Drilling, therefore, ceased and the casing screen was installed in the sandstone underlying the black clay layer (19 – 25 m) in the highly saline aquifer.
MB33s	Drilling intercepted water at around 12 m after which water (~0.2L/s) was observed each time the drill string was raised to flush the hole. Easy drilling occurred through the shallow subsurface dominated by sandy gravels with weathered quartz gravels intercepted at 12 m and granodiorite basement encountered from around 16m.
	Drilling ceased at 20 m after the collar blew out due to excessive water down the hole. The bore was installed and screened within the contact of the gravel and granodiorite basement.
MB33d	Drilling initially commenced in December 2023 at MB33d with water intercepted at 12 m. Water yields (<0.1L/s) and unstable ground conditions led to a blowout within the hole at around 18m which prevented drilling from continuing. The hole was grouted to surface to improve hole stability.
	Drilling resumed in January 2024 with no water intercepted. Competent granodiorite basement was encountered at around 20 m and remained unchanged to target depth (60 m). Minimal to no water was observed in the bedrock.
MB34s	Drilling intercepted water at around 10 m with minimal amounts of water noted each time the drill string was raised to flush the hole (<50 L). Easy drilling conditions were noted through the weathered rock and clayey gravel which extended to depth at 20 m. No issues were noted during drilling.
MB35s	Drilling intercepted water at around 13 m after which water (~1 L/s) was observed each time the drill string was raised to flush the hole. Drilling continued to 15 m with no issues noted, and casing screen installed within clayey sand at the base of the hole.
MB35d	Drilling initially commenced in December 2023 at MB35d with water intercepted at 13 m. Water returns (~1 L/s) and unstable ground conditions led to a blowout within the hole at around 33 m which prevented drilling from continuing. The hole was grouted to surface to improve hole stability.  Drilling resumed in January 2024 and water was intercepted at 6 m with little to no grout found in chip returns. Drilling continued to 33 m with several hole blockages noted. A rock roller bit was used to clear the hole and run surface casing down to 15 m to assist with reducing water returns. Sample returns were minimal for much of the drilling due to swelling clays clogging the drill string. The hole was abandoned at 42 m and grouted to surface due to swelling clays, hole stability and flooding of the drill pad with water returns leading to unsafe operating conditions.
MB36s	No water was intercepted during drilling of MB36s. Competent granodiorite basement was encountered at around 2 m and remained unchanged to target depth (20 m).  At the end of hole, a plug was inserted, and the hole backfilled to prevent injury to fauna.



Bore ID	Observations
MB37d	Drilling intercepted water at around 36 m with minimal amounts of water (<0.1 L/s) noted each time the drill string was raised to flush the hole. Dry gravely clays were observed within the first 30 metres and proved easy to drill. Competent granodiorite basement was encountered at 33 m and corresponded with the first water cut at 36 m. Bore screen was installed beneath the first water cut within the granodiorite basement. No issues were encountered during drilling or installation of the bore.
MB38d	Drilling intercepted water at around 21 m after which water (<0.1 L/s) was observed each time the drill string was raised to flush the hole. Water and muds were required to flush the hole and alleviate blockages caused by clay material downhole. Hole stability issues occurred (24 m) due to silty clays which required further flushing and mud injection to stabilise the hole. Fine silts and clays caused further blockages to the air hose and cyclone leading to the hole collapsing between rod changes and rod pulls. Due to the persistent difficult drilling conditions and risk of further hole collapse and rod entrapment, drilling was ceased at 49.6 m and the bore installed and screened within the sandy gravels at the base of the hole.
	Ground conditions caused what was initially thought to be a cave in at (33 m), however the PVC casing and gravel pack were able to be installed below this point.
MB39d	Drilling intercepted water at around 12 m after which water (<0.1 L/s) was observed each time the drill string was raised to flush the hole. Gravelly sand and sandy gravel were logged in the shallow subsurface which transitioned to weathered granodiorite basement at around 12m. Competent basement rock was encountered at 15 m and drilling was ceased shortly after at 27 m. The bore screen was installed within the basement at the bottom of the hole. No issues were encountered during drilling or installation of the bore.
MB40d	Drilling intercepted water at around 12 m after water (<0.1 L/s) was observed each time the drill string was raised to flush the hole. Sandy/gravelly clays were encountered within the upper 4 m of the subsurface coarsening to sand and gravels to around 10 m. Wet clays led to a blockage in the sample hose at (12 m), otherwise drilling continued to 60 m with no issues observed. Varying degrees of weathered granodiorite basement were noted between 10 and 60 m.
	Recent groundwater gauging and sampling from this bore by LWC identified a bend in the casing at 10 m. This was not observed during drilling, installation and development.







Figure 2-2 Example of MB39d (left) and MB34s (right) completion



# 2.4 Monitoring Bore Development

Following drilling and construction, each monitoring bore was developed using inducted air via a polyline to remove remnant drilling fluids and fines (sand/silt/clay) from the screened interval. Bore development is necessary to maximise the inward flow of groundwater ensuring later hydraulic testing and groundwater sampling best represent the aquifer. Monitoring bores were developed by moving the polyline up and down within the screened interval and a combination of sustained and surging flow. Development continued until discharging water observed a low turbidity or stabilised physico-chemical parameters.

During development groundwater samples were collected and tested for physico-chemical parameters (electrical conductivity (EC), pH and temperature) using a YSI water quality meter. Yield measurements were collected using a bucket test, where the time to fill a bucket of a known volume is measured. Field water quality measurements taken from each of the monitoring bores are presented in Table 2-3.

A number of bores (MB33d, MB34s, MB38d, MB39d and MB40d) were unable to be fully developed due to low or absence of yields. Purging within these bores, to flush muds and drilling fluids, was completed with the poly air-line until yields were no longer sustained. Note, monitoring bore MB33d is possibly dry with no water observed upon returning to drill the bore in January 2024 and being screened within the basement. This monitoring bore received flushes at an attempt to clean muds.

**Table 2-3 Field Water Quality Measurements** 

Bore ID	Airlift yield (L/s) <sup>[1]</sup>	EC (mS/cm)	рН	Temperature (°C)	Comments
MB21s	~0.6	N/A	N/A	N/A	Yield not sustained, slight turbidity, no odour.  Fast development.
MB26d	1.5-2	150.8	7.4	29.6	Sustained yield, no turbidity, no odour. Fast development.
MB33s	~0.2	2.1	8.05	31	Average sustained yield, slight turbidity, no odour. Slow development.
MB33d	<0.1	-	-	-	Little to no water present following grouting of hole to improve hole stability, bubbles from drilling foam, not enough for a sample.
MB34s	<0.1	-	-	-	Low yield not sustained, fines present, turbid, no odour.
MB35s	~1	N/A	N/A	N/A	Sustained yield, no turbidity, no fines, no odour.  Fast development.
MB37d	<0.1	2.3	8.9	32.3	Low yield not sustained, no fines, no turbidity, no odour. Slow development.
MB38d	<0.1	-	-	-	Low yield not sustained, lots of drilling foam, high turbidity, no samples obtained due to foam, odour present.
MB39d	<0.1	0.03	8.7	29.4	High yield not sustained, no fines present, high turbidity, no odour.
MB40d	<0.1	-	-	-	Odour present, low yield not sustained, minimal fines.

Notes:

<sup>1.</sup> Estimated during development

<sup>&#</sup>x27;-' denotes sample not collected due to minimal yields with excessive muds present during final airlift development

<sup>&#</sup>x27;N/A' - denotes samples that were not collected due to YSI water quality meter not being available



# **Section 3 Site Hydrogeological Conceptualisation**

Data collected from the recent drilling program have been used to update the Project's hydrogeological conceptualisation, illustrated in Figure 3-1 and Figure 3-2 in northeast-southwest and northwest-southeast cross sections respectively. Figure 3-2 has been revised from the original interpretation by CDM Smith (2023) to include holes drilled during the current program, while Figure 3-1 presents an additional cross section orientation (northeast-southwest). The following describes key updates to the conceptual model:

- Surficial deposits for most of the Project area consist of alluvial outwash, residual soil and weathered basement. Given the common source rock, it is difficult to distinguish between units, and the boundaries between the cover units remain poorly defined.
- The current round of drilling confirms the variability of the depth to bedrock, which ranges from zero (i.e. outcropping in creeks and east of MB21s) to > 48 m (the depth of the deepest well that did not encounter competent rock MB38d). The updated conceptualisation identifies areas where basement depth changes rapidly across a short distance. This includes MB35d and MB36s, which are separated by 300 m laterally but have cover depths of >42 m and 3 m respectively. Without structural information, it is unclear whether this basement topography is controlled by faulting or folding.
- Some uncertainty exists as to whether MB21s intersects a dolerite dyke or basalt. Geological mapping completed over the Project area suggests a basalt layer surrounds the area adjacent to this well on the eastern side of Devil's Creek.
- Drilling to date indicates the groundwater system is confined with water typically encountered between between 8 – 36 m predominantly within the elluvium and upper weathered basement and a potentiometric surface that lies within the shallow sedimentary cover sequence, except where basement approaches the surface or outcrops.
- The difference in water levels between and MB33s and MB33d, suggest there could be downward movement of groundwater (recharge) occurring deeper into the basement HSU. At this stage, it is considered the elluvial system at the top of the basement is acting as a single aquifer. It is possible that there may be a deeper groundwater system, although this is yet to be verified through drilling.
- Given the depth groundwater has been encountered near the surface water drainages across the Project area (i.e. between 8 and 13 m), it is possible the terrestrial vegetation are groundwater dependent.



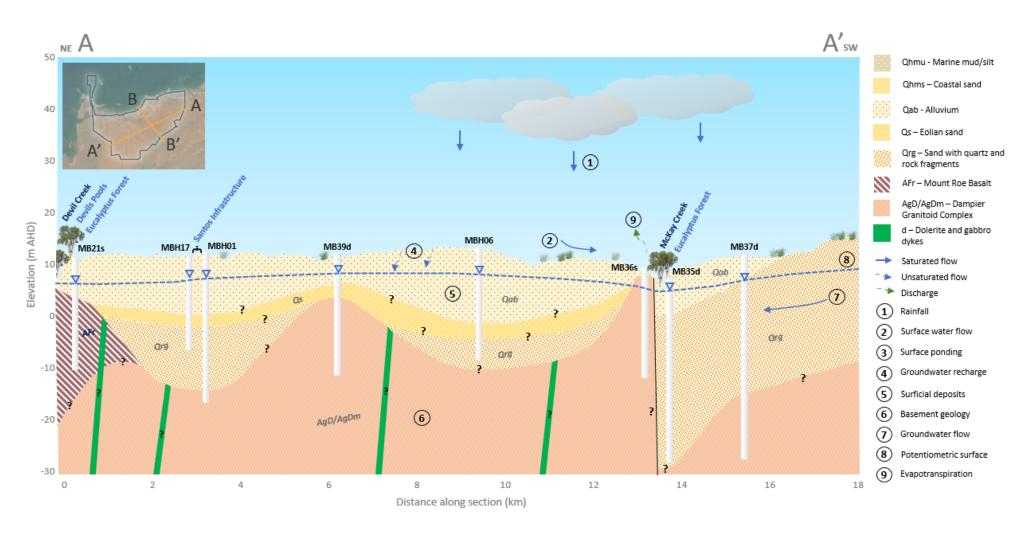


Figure 3-1 Conceptual hydrogeological model (NE-SW)



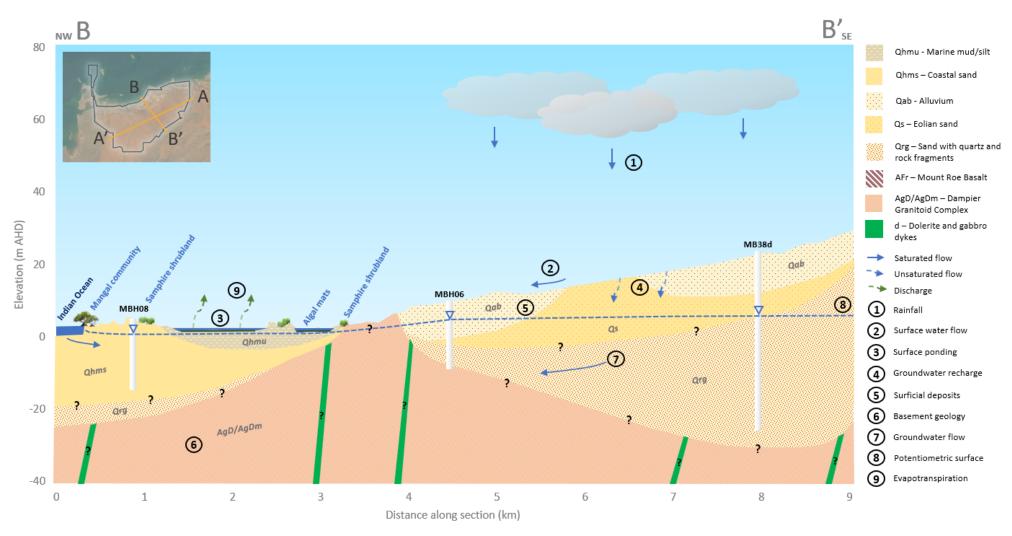


Figure 3-2 Conceptual hydrogeological model (NW-SE)

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# **Section 4 Recommendations and Further Work**

The following works are recommended to be completed before the end of 2024:

- Complete aquifer testing, (i.e. slug tests) at each monitoring bore to determine hydraulic properties of the installed hydrostratigraphic units (HSUs).
- Return to MB35d, re-drill and install monitoring bore casing. The hole currently is cemented from 42 m to surface and experienced swelling clays and difficulty with hole stabilisation during drilling. Installation of this well will provide a second nested site which will assist in investigating any potential deeper aquifers within the basement
- Return to MB21 and drill a deep bore (60 m) to investigate the change in groundwater quality with depth and the potential occurrence of a deeper groundwater system. A proposed drill location is presented in Figure 4-1. The collar has been offset from a potential dyke or basalt layer intersected by MB21s with the aim to intersect diorite basement. MB21d will likely require a larger sump to manage groundwater yields during drilling.
- Complete drilling of the remaining non-priority groundwater bores. It is recommended the remaining deep
  monitoring bores be completed using RAB drilling techniques while track mounted rigs are recommended for
  the shallow coastal bores located within the tidal zone to avoid risks associated with site access.
- Update the site conceptualisation using further drilling results to obtain a clearer understanding of the spatial variability of groundwater heads and HSU thicknesses.

The following work is recommended for consideration to further the environmental studies and approvals for the Project:

Consider completing a combination of vegetation surveys and remote sensing to assist in further
understanding the water use patterns, rooting depths and water sources of eucalypt species. These surveys
can help understand the baseline conditions of these EVs as well as the changes to vegetation health with
respect to weather patterns over time.



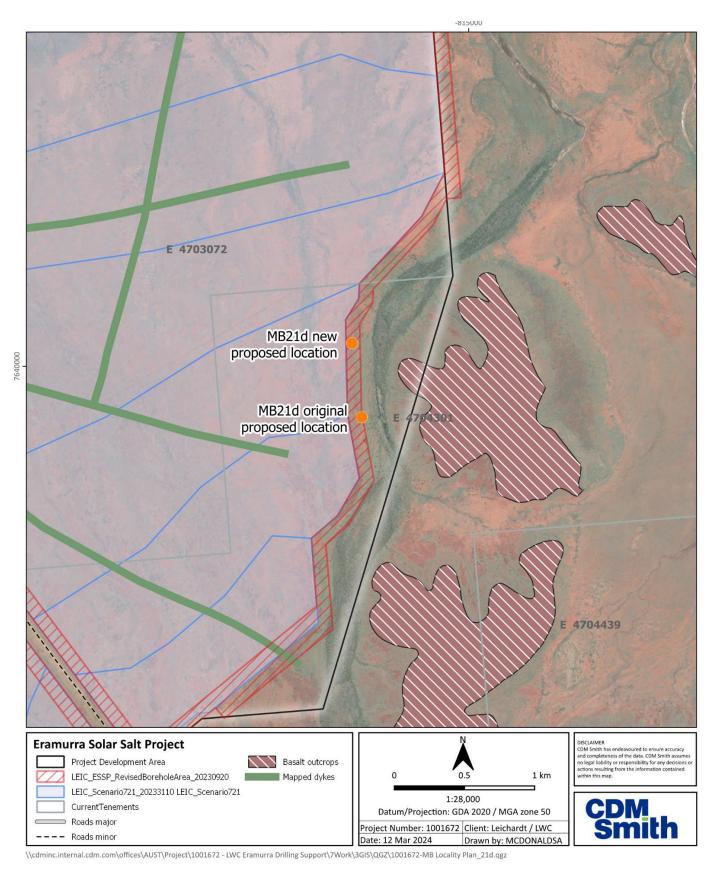


Figure 4-1 Proposed MB21d location

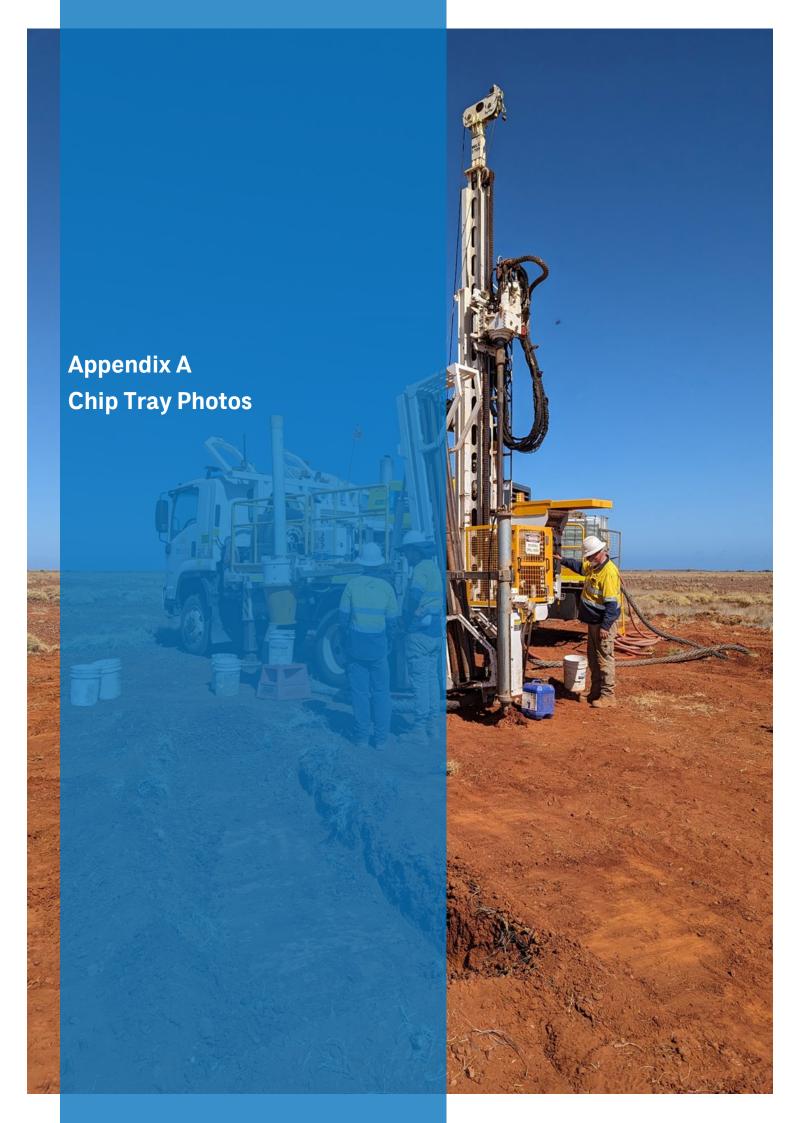
22



# **Section 5 References**

Land & Water Consulting, 2022. December 2021 Groundwater Well Installation and Monitoring Event. Prepared for Leichhardt Salt Pty Ltd.

National Uniform Drillers Licensing Committee (NUDLC), 2020. *Minimum construction requirements for water bores in Australia*, Fourth edition.





### A.1 MB21S



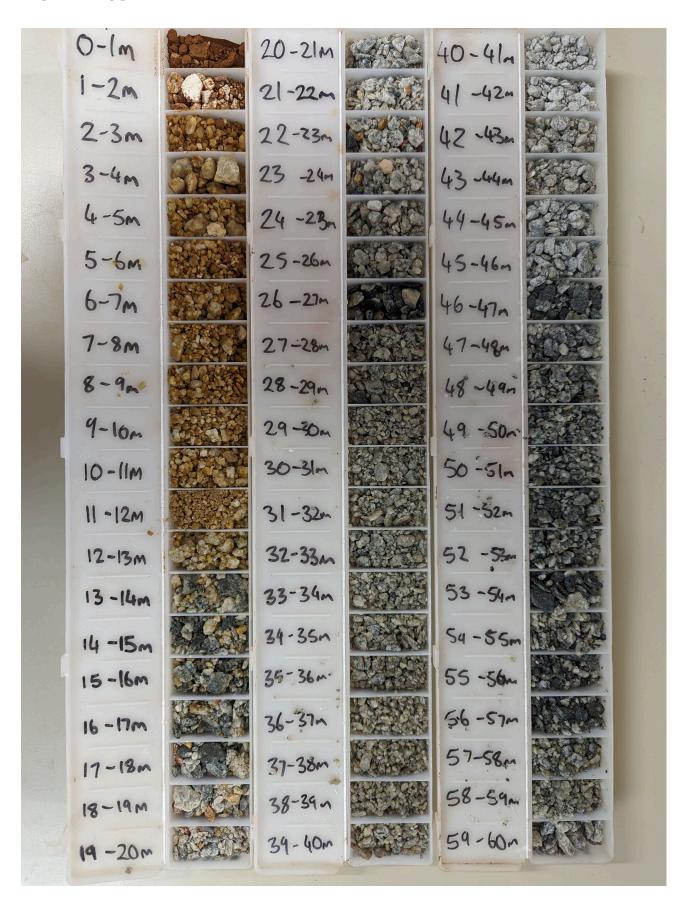


### A.2 MB26D





## A.3 MB33D





# A.4 MB33S





# A.5 MB34S





## A.6 MB35D





# A.7 MB35S





# A.8 MB36S





### A.9 MB37D





# A.10 MB38D





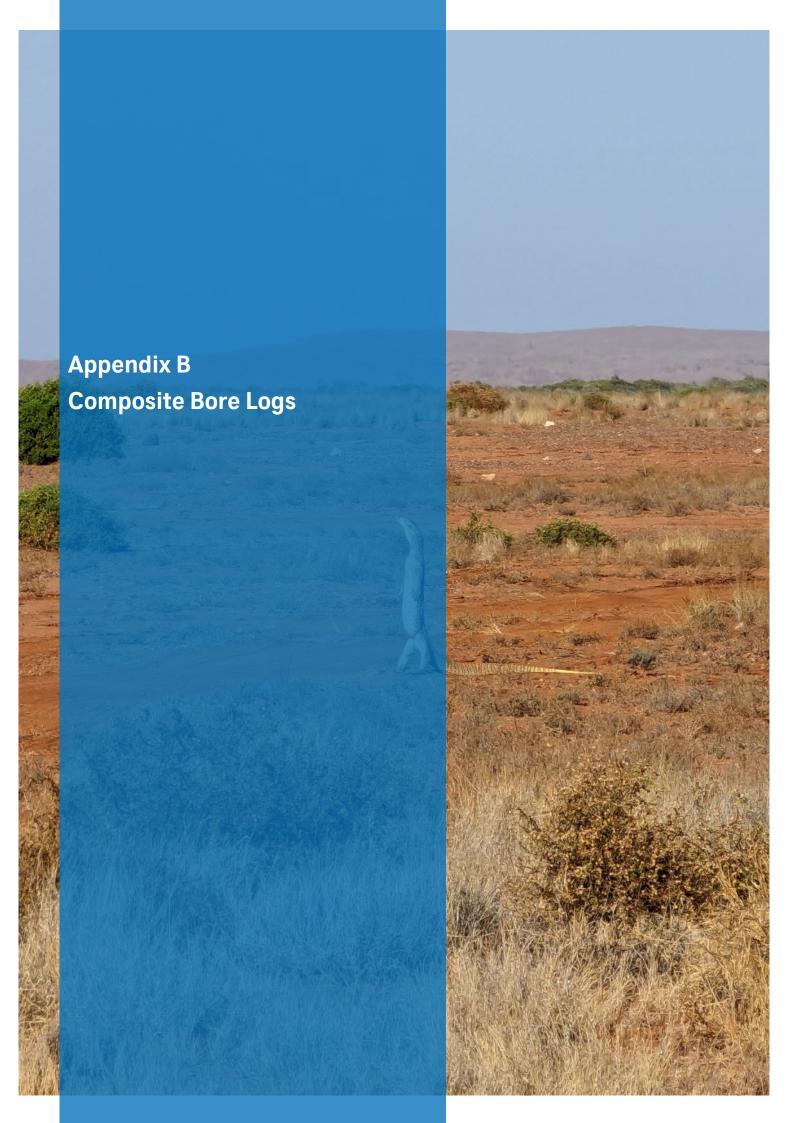
# A.11 MB39D





# A.12 MB40D







## WELL COMPLETION LOG

#### **BOREHOLE / WELL NUMBER: MB21S**

Project Number: 1001672

Project Name: Eramurra Solar Salt Project

Location: Pilbara, WA

Client: Land and Water Consulting (WA) Pty Ltd

Date Started: 1/12/2023

Date Finished: 1/12/2023

**Drilling Contractor:** Soil Mechanics

Driller: Andrew Garden

**Drilling Method:** Air Hammer **Total Depth (m bgl):** 24 **Hole Diameter (inches):** 5 **Easting:** 440329 **Northing:** 7691543

Surface Elevation (m AHD): 11.7

Static Water Level
Depth (m btoc): 8.08
Date: 19/02/2024

			Da	te Finished: 1/12/2023								
D	RILLING IN	FO.		GEOLOGICAL DESCRIPTION		I				RECORDS / CONST	RUCTION INFO.	
Drilling Method	Bit Log (Inches)	Depth (m)	Lithology	Description	Water Cut (m bgl)	Airlift Yield (L/s)	EC (mS/cm)	pH (pH units)	Temperature (°C;	Field Comments	Well Construction	Well Description
	Bit Log (Inches)		dio Caa Lithology			Airlift Yield (L/s)	EC (mS/cm)	(St) Hd (bH nuits)	Temperature (°C)			Well Description  Stick up: 0.89m  0-15m Bentonite/cement grout  0-17m DN50mm PN12 uPVC casing  15-16m Bentonite Seal  16-23m 3mm Gravel Pack  17-23m DN50mm PN12 uPVC 1mm slotted screen
		22 -								Airlift during development: 0.6 L/s, yield not sustained, slight turbidity, no odour.		slotted screen  23-24 Backfill material

Qhm = Marine mud and silt on supratidal to intertidal flats, Qhms = Aeolian reworked coastal sand in beach deposits, Qpmb = Coastal limestone, dune sand, beach conglomerate, lime-cemented shelly sand, Qaa = Alluvium, sands, gravels, clay and silt, Qab = Alluvial floodplain sand, silt and clay with gilgai surfaces, Qrg = Quartzofeldspathic eluvial sand derived from underlying granitoid rock, Czaa = consolidated alluvial sand, silt and clay, d/o = Undifferentiated tertiary volcanics, AgD = Undivided Dampier Granitoid Complex

Logged By: RA Checked By: JPK

Notes:



#### WELL COMPLETION LOG

#### **BOREHOLE / WELL NUMBER: MB26D**

Project Number: 1001672

Project Name: Eramurra Solar Salt Project

Location: Pilbara, WA

Client: Land and Water Consulting (WA) Pty Ltd

**Date Started:** 11/12/2023 **Date Finished:** 12/12/2023

**Drilling Contractor:** Soil Mechanics

Driller: Andrew Garden

Drilling Method: Air Hammer Total Depth (m bgl): 36 Hole Diameter (inches): 5 **Easting:** 432867 **Northing:** 7694530

Surface Elevation (m AHD): 4.35

Static Water Level
Depth (m btoc): 4.95
Date: 19/02/2024

	DRILLING INFO.		Da	te Finished: 12/12/2023								
DRIL		<b>O</b> .		GEOLOGICAL DESCRIPTION						RECORDS / CONST	RUCTION INFO.	
Drilling Method	Bit Log (Inches)	Depth (m)	Lithology	Description	Water Cut (m bgl)	Airlift Yield (L/s)	EC (mS/cm)	pH (pH units)	Temperature (°C)	Field Comments	Well Construction	Well Description
Air Hammer Drilling	Bit Log	2	Ohm Ohms Copmb	Gravelly clay, red/brown, highly weathered, dry, firm, red/white fine to very coarse gravel Gravelly clay, red, 20% medium to coarse gravel, calcareous rock 5-10%  Gravelly clay, yellow/white clay, 10% medium to coarse gravel, quartz, calcareous rock present  Clayey gravel, white/yellow, medium to coarse gravel, calcareous rock present, 5-10% clay  Clayey gravel, yellow, medium to coarse gravel, fine clay, dense, moist  Clay, black/brown, dense moist clay, high plasticity  Sand, yellow, fine to medium, very wet		Airlift Y	EC (m)	нд) нд		Water yields increasing with depth	Well Construction	Well Description  Stick up: 0.98m  0-16m Bentonite/cement grout  0-19m DN50mm PN12 uPVC casing  16-18m Bentonite Seal  18-25m 3mm Gravel Pack
		20	S <b>u</b> HO	Gravelly sand, yellow/white, fine sand, very wet, 5% white gravel		~5		7.07	29.4 29.9 29.9 27.8	~5 L/s (visual estimate), highly saline  Development results: No fines present, clear, minimal developing needed, Airlift: 1.6 L/s, EC: 150.8 mS/cm, pH: 7.47, Temp: 29.6 °C		19-25m DN50mm PN12 uPVC 1mm slotted screen

Notes: Ohm = Marine mud and silt on supratidal to intertidal flats, Ohms = Aeolian reworked coastal sand in beach deposits,

Opmb = Coastal limestone, dune sand, beach conglomerate, lime-cemented shelly sand, Qaa = Alluvium, sands, gravels, clay and silt,

Qab = Alluvial floodplain sand, silt and clay with gilgai surfaces, Org = Quartzofeldspathic eluvial sand derived from underlying granitoid rock,

Czaa = consolidated alluvial sand, silt and clay, d/o = Undifferentiated tertiary volcanics, AgD = Undivided Dampier Granitoid Complex



### WELL COMPLETION LOG

#### **BOREHOLE / WELL NUMBER: MB33D**

Project Number: 1001672

Project Name: Eramurra Solar Salt Project

Location: Pilbara, WA

Client: Land and Water Consulting (WA) Pty Ltd

**Date Started:** 7/12/2023 **Date Finished:** 11/01/2024

**Drilling Contractor:** Soil Mechanics

**Driller:** Andrew Garden

Drilling Method: Air Hammer Total Depth (m bgl): 60 Hole Diameter (inches): 5 **Easting:** 427261 **Northing:** 7682320

Surface Elevation (m AHD): 16.9

Static Water Level
Depth (m btoc): 23.09
Date: 19/02/2024

DRIL	LING INF	О.		GEOLOGICAL DESCRIPTION					FIELD	RECORDS / CONST	RUCTION INFO.	
Drilling Method	Bit Log (Inches)	Depth (m)	Lithology	Description	Water Cut (m bgl)	Airlift Yield (L/s)	EC (mS/cm)	pH (pH units)	Temperatue (°C)	Field Comments	Well Construction	Well Description
Air Hammer	ı	12		Gravelly clay, red/brown, fine to very coarse gravel, highly weathered, firm, dry Sandy gravel, yellow/clear/white, medium to very coarse gravel, 10% fine to medium sand  Granodiorite, white/yellow/blue, phaneritic, weathered, hard, wet  Granodiorite and granitic gneiss, white/blue/mottled, phaneritic, dry	12	<0.1	1.44	7.94	32 31.7	Drilling Dec 2023, airlift <0.1L/s, unstable ground led to blow out at 18m, drilling abandoned and grouted to surface. Jan 2024, return to hole, drill TD minimal to no water intercepted, install well.  Minimal water present, excessive foam, air too disruptive and a very low recharge rate, no fines present, Airlift: <0.1 L/s during development		0-52m Bentonite/cement grout  0-54m DN50mm PN12 uPVC casing  52-53m Bentonite Seal 53-60m 3mm Gravel Pack  54-60m DN50mm PN12 uPVC 1mm slotted screen

Notes: Qhm = Marine mud and silt on supratidal to intertidal flats, Qhms = Aeolian reworked coastal sand in beach deposits,
Qpmb = Coastal limestone, dune sand, beach conglomerate, lime-cemented shelly sand, Qaa = Alluvium, sands, gravels, clay and silt,
Qab = Alluvial floodplain sand, silt and clay with gilgai surfaces, Qrg = Quartzofeldspathic eluvial sand derived from underlying granitoid rock,
Czaa = consolidated alluvial sand, silt and clay, d/o = Undifferentiated tertiary volcanics, AgD = Undivided Dampier Granitoid Complex



Project Number: 1001672

Project Name: Eramurra Solar Salt Project

Location: Pilbara, WA

Client: Land and Water Consulting (WA) Pty Ltd

**WELL COMPLETION LOG** 

Date Started: 7/12/2023 Date Finished: 7/12/2023

**Drilling Contractor:** Soil Mechanics

Driller: Andrew Garden Drilling Method: Air Hammer Total Depth (m bgl): 20 Hole Diameter (inches): 5

Northing: 7682331 **Easting:** 427265

Surface Elevation (m AHD): 16.7

Static Water Level Depth (m btoc): 6.66 Date: 19/02/2024

**BOREHOLE / WELL NUMBER: MB33S** 

DRIL	LING INF	O.		GEOLOGICAL DESCRIPTION					FIELD	RECORDS / CONST	RUCTION INFO.	
						(s/		_				
Drilling Method	Bit Log (Inches)	Depth (m)	Lithology		Water Cut (m bgl)	Airlift Yield (L/s)	EC (mS/cm)	pH (pH units)	Temperature (°C)	5		
	ā	۵		Description	35	₹	Ш	<u>q</u>	<u>a</u>	Field Comments	Well Construction	Well Description
		2 -	Oaa	Gravelly Clay. red/brown, fine to medium gravel, highly weathered, dry, firm  Sandy gravel, yellow/clear/white, medium to very coarse gravel, 10% fine to medium sand								Stick up: 0.81m
		6 -									<u></u>	0-12m Bentonite/cement grout
Air Hammer	ß	10 —										0-14m DN50mm PN12 uPVC casing
		12		Gravel, white/yellow/blue, medium to very coarse gravel, granite lithics, weathered, hard, wet	12	~0.2	1.11	7.86	32.5	~0.2 L/s airlift visual estimate		12-13m Bentonite Seal
		16 -		Granodiorite/Diorite, blue, fractured, 10-15% quartz, some chips heavily weathered			0.91	7.72	31.5			13-20m 3mm Gravel Pack
		18	AgD				1.5	7.82	29.9	Development results: Water initially black/brown, with odour, some fines. Steady yield. Airlift: 0.16 L/s, EC: 2.147 mS/cm, pH: 8.05, Temp: 31		14-20m DN50mm PN12 uPVC 1mm slotted screen
		22								°C		

Notes: Qhm = Marine mud and silt on supratidal to intertidal flats, Qhms = Aeolian reworked coastal sand in beach deposits, Opmb = Coastal limestone, dune sand, beach conglomerate, lime-comented shelly sand, Qaa = Alluvium, sands, gravels, clay and silt, Qab = Alluvial floodplain sand, silt and clay with gilgai surfaces, Qrg = Quartzofeldspathic eluvial sand derived from underlying granitoid rock, Czaa = consolidated alluvial sand, silt and clay, d/o = Undifferentiated tertiary volcanics, AgD = Undivided Dampier Granitoid Complex



#### WELL COMPLETION LOG

#### **BOREHOLE / WELL NUMBER: MB34S**

Project Number: 1001672

Project Name: Eramurra Solar Salt Project

Location: Pilbara, WA

Client: Land and Water Consulting (WA) Pty Ltd

Date Started: 6/12/2023

Date Finished: 6/12/2023

**Drilling Contractor:** Soil Mechanics

Driller: Andrew Garden

**Drilling Method:** Air Hammer **Total Depth (m bgl):** 20 **Hole Diameter (inches):** 5

**Easting:** 427608 **Northing:** 7682312

Surface Elevation (m AHD): 17

Static Water Level
Depth (m btoc): 6.43
Date: 19/02/2024

DDII	LING INF	:n		GEOLOGICAL DESCRIPTION					EIEI F	O RECORDS / CONST	DUCTION INFO	
Drilling Method	Bit Log (Inches)		Jy.	GEOLOGICAE DESCRIPTION	Cut	Airlift Yield (L/s)	3/cm)	units)	Temperature (°C)	, RECORDS / CONST	ROCTION INFO.	
Drilling	Bit Log	Depth (m)	Lithology	Description	Water Cut (m bgl)	Airlift Y	EC (mS/cm)	pH (pH units)	Temper	Field Comments	Well Construction	Well Description
Air Hammer Air Hammer	ى	9 11 13 11 12 11 12 11 13 11 15 11 16 11 17 18 11 18 18		Gravelly clay, red/brown, fine to medium gravel, highly weathered, dry, firm  Sandy rock, yellow/white, dry, weathered, quartz, very hard  Clayey gravel, yellow/white, medium to coarse gravel, 5% yellow clay, quartz, damp to moist		Airlift >	EC (m.	-d) Hd	Tempe	Too little water for a sample  Development notes: Very low recharge rate,	Well Construction	O-15m Bentonite/cement grout  15-16m Bentonite Seal 16-20m 3mm Gravel Pack
		19 -								too low to acquire adequate sample		slotted screen

Notes: Qhm = Marine mud and silt on supratidal to intertidal flats, Qhms = Aeolian reworked coastal sand in beach deposits,
Qpmb = Coastal limestone, dune sand, beach conglomerate, lime-cemented shelly sand, Qaa = Alluvium, sands, gravels, clay and silt,
Qab = Alluvial floodplain sand, silt and clay with gilgai surfaces, Qrg = Quartzofeldspathic eluvial sand derived from underlying granitoid rock,
Czaa = consolidated alluvial sand, silt and clay, d/o = Undifferentiated tertiary volcanics, AgD = Undivided Dampier Granitoid Complex



CDM Smith Australia Pty Ltd Unit 1, Level 2, 87 Colin Street West Perth WA 6005

#### WELL COMPLETION LOG

**BOREHOLE / WELL NUMBER: MB35D** 

Project Number: 1001672

Project Name: Eramurra Solar Salt Project

Location: Pilbara, WA

Client: Land and Water Consulting (WA) Pty Ltd

**Date Started:** 10/12/2023 **Date Finished:** 13/01/2024

**Drilling Contractor:** Soil Mechanics

Driller: Andrew Garden

**Drilling Method:** Air Hammer **Total Depth (m bgl):** 42 **Hole Diameter (inches):** 5

**Easting:** 428356 **Northing:** 7686032

Surface Elevation (m AHD): 10.9 Static Water Level

Depth (m btoc):

Date:

DRIL	ORILLING INFO.			GEOLOGICAL DESCRIPTION					FIELD	RECORDS / CONST	RUCTION INFO.	
Drilling Method	Bit Log (Inches)	Depth (m)	Lithology	Description	Water Cut (m bgl)	Airlift Yield (L/s)	EC (mS/cm)	pH (pH units)	Temperature (°C)	Field Comments	Well Construction	Well Description
Blade bit Air Hammer	D.	2 - 4 - 10 - 11 - 12 - 11 - 12 - 11 - 12 - 11 - 12 - 11 - 12 - 11 - 12 - 11 - 12 - 11 - 12 - 11 - 12 - 11 - 12 - 11 - 12 - 11 - 12 - 11 - 12 - 11 - 12 - 11 - 12 - 11 - 12 - 11 - 12 - 12 - 11 - 12		Clayey gravel, white/red, fine to coarse gravel, white clay  Clayey sand, white/red, fine to coarse sand, medium plasticity, white clay, quartz  Clayey sand, red, fine to coarse sand, medium plasticity, white clay, quartz  Clayey sand, yellow, fine to coarse sand, medium plasticity, white clay, quartz  Clayey gravel, white/red, medium to coarse gravel, dense Gravelly clay, white, dense firm dry clay, medium to coarse quartz  Clayey gravel, white, firm dense clay, moist, low to medium plasticity	13	~1	2.11		32.2	Hole abandoned at 42m due to swelling clays and hole instability, poor seals, ~ 1 L/s produced while drilling. Hole grouted to surface, concrete monument install.		0-42m Bentonite/cement grout

Notes: Qhm = Marine mud and silt on supratidal to intertidal flats, Qhms = Aeolian reworked coastal sand in beach deposits,
Qpmb = Coastal limestone, dune sand, beach conglomerate, lime-cemented shelly sand, Qaa = Alluvium, sands, gravels, clay and silt,
Qab = Alluvial floodplain sand, silt and clay with gilgai surfaces, Qrg = Quartzofeldspathic eluvial sand derived from underlying granitoid rock,
Czaa = consolidated alluvial sand, silt and clay, d/o = Undifferentiated tertiary volcanics, AgD = Undivided Dampier Granitoid Complex



#### WELL COMPLETION LOG

#### **BOREHOLE / WELL NUMBER: MB35S**

Project Number: 1001672

Project Name: Eramurra Solar Salt Project

Location: Pilbara, WA

Client: Land and Water Consulting (WA) Pty Ltd

**Date Started:** 10/12/2023 **Date Finished:** 10/12/2023

**Drilling Contractor:** Soil Mechanics

Driller: Andrew Garden

Drilling Method: Air Hammer Total Depth (m bgl): 15 Hole Diameter (inches): 5 **Easting:** 428313 **Northing:** 7686043

Surface Elevation (m AHD): 6.96 Static Water Level

Depth (m btoc): 5.09 Date: 19/02/2024

			Da	te Finished: 10/12/2023								
DRIL	LING INF	О.		GEOLOGICAL DESCRIPTION						RECORDS / CONST	RUCTION INFO.	
Drilling Method	Bit Log (Inches)	Depth (m)	Lithology	Description	Water Cut (m bgl)	Airlift Yield (L/s)	EC (mS/cm)	pH (pH units)	Temperature (°C)	Field Comments	Well Construction	Well Description
Air Hammer Air Hammer Drilling	5       Bit Log	10		Clayey sand, red, fine to coarse sand, medium plasticity white clay, quartz  Clayey sand, yellow, fine to coarse sand, medium plasticity white clay, quartz	Water (m bgl)	Airlift	EC (#	d) Hd	Tempe	No samples due to missing quality meter  Development comments: No odour at development, no fines present after development started, colour		O-10m Bentonite/cement grout  10-11m Bentonite Seal  11-15m 3mm Gravel Pack
		13			13	~1				disappeared after 5 minutes, airlift: ~1 L/s		12-15m DN50mm PN12 uPVC 1mm slotted screen

Notes: Ohm = Marine mud and silt on supratidal to intertidal flats, Ohms = Aeolian reworked coastal sand in beach deposits,
Qpmb = Coastal limestone, dune sand, beach conglomerate, lime-cemented shelly sand, Qaa = Alluvium, sands, gravels, clay and silt,
Qab = Alluvial floodplain sand, silt and clay with gilgai surfaces, Qrg = Quartzofeldspathic eluvial sand derived from underlying granitoid rock,
Czaa = consolidated alluvial sand, silt and clay, d/o = Undifferentiated tertiary volcanics, AgD = Undivided Dampier Granitoid Complex



### WELL COMPLETION LOG

#### **BOREHOLE / WELL NUMBER: MB36S**

Project Number: 1001672

Project Name: Eramurra Solar Salt Project

Location: Pilbara, WA

Client: Land and Water Consulting (WA) Pty Ltd

**Date Started:** 5/12/2023 **Date Finished:** 6/12/2023

**Drilling Contractor:** Soil Mechanics

Driller: Andrew Garden

**Drilling Method:** Air Hammer **Total Depth (m bgl):** 20 **Hole Diameter (inches):** 5

**Easting:** 428668 **Northing:** 7685975

Surface Elevation (m AHD): 9.88

Static Water Level
Depth (m btoc):

Date:

DRIL	LING INF	О.		GEOLOGICAL DESCRIPTION					FIELD	RECORDS / CONST	RUCTION INFO.	
Drilling Method	Bit Log (Inches)	Depth (m)	Lithology	Description	Water Cut (m bgl)	Airlift Yield (L/s)	EC (mS/cm)	pH (pH units)	Temperature (°C)	Field Comments	Well Construction	Well Description
Air Hammer	5	1		Gravelly Clay, red/brown, fine to medium gravel, highly weathered, dry, firm  Granite, white/grey, very hard, very dense, dry, fractured						No water observed during drilling		Drilled to 20m, dry, plastic cap installed at 2m with backfill on top

Notes: Qhm = Marine mud and silt on supratidal to intertidal flats, Qhms = Aeolian reworked coastal sand in beach deposits,
Qpmb = Coastal limestone, dune sand, beach conglomerate, lime-cemented shelly sand, Qaa = Alluvium, sands, gravels, clay and silt,
Qab = Alluvial floodplain sand, silt and clay with gilgai surfaces, Qrg = Quartzofeldspathic eluvial sand derived from underlying granitoid rock,
Czaa = consolidated alluvial sand, silt and clay, d/o = Undifferentiated tertiary volcanics, AgD = Undivided Dampier Granitoid Complex



#### WELL COMPLETION LOG

#### **BOREHOLE / WELL NUMBER: MB37D**

Project Number: 1001672

Project Name: Eramurra Solar Salt Project

Location: Pilbara, WA

Client: Land and Water Consulting (WA) Pty Ltd

**Date Started:** 10/01/2024 **Date Finished:** 10/01/2024

**Drilling Contractor:** Soil Mechanics

Driller: Andrew Garden

Drilling Method: Air Hammer Total Depth (m bgl): 42 Hole Diameter (inches): 5 **Easting:** 427028 **Northing:** 7684363

Surface Elevation (m AHD): 12.6

Static Water Level
Depth (m btoc): 7.39
Date: 19/02/2024

			Da	te Finished: 10/01/2024								
	LING INF	О.		GEOLOGICAL DESCRIPTION	-					RECORDS / CONST	RUCTION INFO.	
Drilling Method	Bit Log (Inches)	Depth (m)	Lithology	Description	Water Cut (m bgl)	Airlift Yield (L/s)	EC (mS/cm)	pH (pH units)	Temperature (°C)	Field Comments	Well Construction	Well Description
Air Hammer	ıo	20 - 32 - 332 - 332 - 334 - 34	AgD O O O O O O O O O O O O O O O O O O O	Gravelly clay, red/brown, highly weathered, dry, firm, red/white fine to very coarse gravel Gravelly clay, red/white clay, 20% medium to coarse gravel Clayey gravel, red/white dry clay, medium to coarse white/clear gravel  Gravelly clay, grey/white clay, 5-10% medium to coarse white/clear gravel, heavily leached  Gravelly clay, grey/white clay, medium to coarse white/clear gravel, heavily leached  Gravelly clay, grey/white clay, medium to coarse white/clear gravel  Gravelly clay, grey/white clay, medium to coarse white/clear gravel  Clayey gravel, blue/grey clay, medium to very coarse gravel, quartz  Diorite, blue/white hard firm rock, moist	36	<0.1	0.88		34 31.6	Development notes: no fines present, clear, very low recharge, EC values appear incorrect, development ceased after minimal yield. Airlift: <0.1 L/s, EC: 2.331 mS/cm, pH: 8.9, Temp: 32.3 °C		O-34m Bentonite/cement grout  O-36m DN50mm PN12 uPVC casing  34-35m Bentonite Seal  35-42m 3mm Gravel Pack 36-42m DN50mm PN12 uPVC 1mm slotted screen

Notes: Ohm = Marine mud and silt on supratidal to intertidal flats, Ohms = Aeolian reworked coastal sand in beach deposits,
Qpmb = Coastal limestone, dune sand, beach conglomerate, lime-cemented shelly sand, Qaa = Alluvium, sands, gravels, clay and silt,
Qab = Alluvial floodplain sand, silt and clay with gilgai surfaces, Qrg = Quartzofeldspathic eluvial sand derived from underlying granitoid rock,
Czaa = consolidated alluvial sand, silt and clay, d/o = Undifferentiated tertiary volcanics, AgD = Undivided Dampier Granitoid Complex



#### WELL COMPLETION LOG

#### **BOREHOLE / WELL NUMBER: MB38D**

Project Number: 1001672

Project Name: Eramurra Solar Salt Project

Location: Pilbara, WA

Client: Land and Water Consulting (WA) Pty Ltd

**Date Started:** 3/12/2023 **Date Finished:** 4/12/2023

**Drilling Contractor:** Soil Mechanics

Driller: Andrew Garden

Drilling Method: Air Hammer Total Depth (m bgl): 48 Hole Diameter (inches): 5 **Easting:** 433931 **Northing:** 7685886

Surface Elevation (m AHD): 23.4

Static Water Level
Depth (m btoc): 17.77
Date: 19/02/2024

			Da	te Finished: 4/12/2023								
DRI	ILLING INF	О.		GEOLOGICAL DESCRIPTION						RECORDS / CONST	RUCTION INFO.	
Drilling Method	Bit Log (Inches)	Depth (m)	Lithology	Description	Water Cut (m bgl)	Airlift Yield (L/s)	EC (mS/cm)	pH (pH units)	Temperature (°C)	Field Comments	Well Construction	Well Description
Air Hammer Air Hammer Drilling Method	Bit Log (Inches)	12 - 16 - 20 -	Czaa'or Org?	Gravelly clay, red/brown, highly weathered, dry, firm, fine to medium gravel  Sandy gravel, red/yellow, fine to medium gravel, fine sand, friable  Sandy gravel, yellow/white, fine to med sand, dense, dry, 5% med gravel  Sandy clay, yellow/brown low plasticity clay, highly wetahered, moist, fine sand  Clayey sand, yellow fine sand, 5-10% grey clay  Sandy gravel, yellow/brown medium to coarse gravel, dense, firm, fine sand	24		4.52	7.79	29.3	Water and muds used to flush clay blockages downhole, mud injection at 24m to increase hole stability, hole collapses between rod changes due to silts/clays  During development: very low recharge rate, discoloured water, some drill foam present, due to excessive foam, a sample	Well Construction	O-40.6m Bentonite/cement grout  O-43.6m DN50mm PN12 uPVC casing  40.6-42.6m Bentonite Seal 42.6-49.6m 3mm Gravel
		48 -					2.37	7.81	32.2	was not taken due to mud interference, no fines present, turbidity high due to air being very disruptive, airlift <0.1 L/s		Pack 43.6-49.6m DN50mm PN12 uPVC 1mm slotted screen

Notes: Ohm = Marine mud and silt on supratidal to intertidal flats, Ohms = Aeolian reworked coastal sand in beach deposits,
Qpmb = Coastal limestone, dune sand, beach conglomerate, lime-cemented shelly sand, Qaa = Alluvium, sands, gravels, clay and silt,
Qab = Alluvial floodplain sand, silt and clay with gilgai surfaces, Qrg = Quartzofeldspathic eluvial sand derived from underlying granitoid rock,
Czaa = consolidated alluvial sand, silt and clay, d/o = Undifferentiated tertiary volcanics, AgD = Undivided Dampier Granitoid Complex



## WELL COMPLETION LOG

#### **BOREHOLE / WELL NUMBER: MB39D**

Project Number: 1001672

Project Name: Eramurra Solar Salt Project

Location: Pilbara, WA

Client: Land and Water Consulting (WA) Pty Ltd

**Date Started:** 5/12/2023 **Date Finished:** 5/12/2023

**Drilling Contractor:** Soil Mechanics

Driller: Andrew Garden

**Drilling Method:** Air Hammer **Total Depth (m bgl):** 27 **Hole Diameter (inches):** 5

**Easting:** 435086 **Northing:** 7688672

Surface Elevation (m AHD): 12.3

Static Water Level
Depth (m btoc): 8.58
Date: 19/02/2024

	DRILLING INFO.			te Finished: 5/12/2023								
DRI		О.		GEOLOGICAL DESCRIPTION						RECORDS / CONST	RUCTION INFO.	
Drilling Method	Bit Log (Inches)	Depth (m)	Lithology	Description	Water Cut (m bgl)	Airlift Yield (L/s)	EC (mS/cm)	pH (pH units)	Temperature (°C)	Field Comments	Well Construction	Well Description
Air Hammer Drilli	Bit I	10 - 112 - 114 - 1	Agu Cab Lithe	Gravelly clay, red/brown, fine to medium gravel, highly weathered, dry, firm  Gravelly sand, white/yellow, med to coarse gravel, fine to coarse sand, dry, loose  Sandy gravel, yellow/white, fine to medium sand, medium to very coarse gravel 10-20%  Diorite, yellow/brown/blue, weathered, wet, quartz rich  Diorite, blue, some weathered rock fragments	Te/M	< 0.1.0 > Airlif	1.29	8.06	34.5	During development: lots of foam, low recharge/yield, muds not cleared and air was not able to clean out well properly, requiling or slow pump. Airlift: <0.1 L/s, Cc, 0.0.3 m, Cm, pH: 8.6 m, Cm, pH: 8.7 m, Cm, pH: 8.8 m, Cm, pH: 8.9 m, pH: 8.9 m	Well Construction	O-18m Bentonite/cement grout  0-21m DN50mm PN12 uPVC casing  18-19m Bentonite Seal  19-27m 3mm Gravel Pack  21-27m DN50mm PN12 uPVC 1mm slotted screen
		28										

Notes: Ohm = Marine mud and silt on supratidal to intertidal flats, Ohms = Aeolian reworked coastal sand in beach deposits,
Qpmb = Coastal limestone, dune sand, beach conglomerate, lime-cemented shelly sand, Qaa = Alluvium, sands, gravels, clay and silt,
Qab = Alluvial floodplain sand, silt and clay with gilgai surfaces, Qrg = Quartzofeldspathic eluvial sand derived from underlying granitoid rock,
Czaa = consolidated alluvial sand, silt and clay, d/o = Undifferentiated tertiary volcanics, AgD = Undivided Dampier Granitoid Complex



WELL COMPLETION LOG

#### **BOREHOLE / WELL NUMBER: MB40D**

Project Number: 1001672

Project Name: Eramurra Solar Salt Project

Location: Pilbara, WA

Client: Land and Water Consulting (WA) Pty Ltd

Date Started: 2/12/2023

Date Finished: 2/12/2023

**Drilling Contractor:** Soil Mechanics

Driller: Andrew Garden

**Drilling Method:** Air Hammer **Total Depth (m bgl):** 60 **Hole Diameter (inches):** 5 Easting: 437922 Northing: 7692766 Surface Elevation (m AHD): 8.15

Static Water Level
Depth (m btoc): 6.41
Date: 19/02/2024

	DRILLING INFO.			te Finished: 2/12/2023								
DRIL	1	О.		GEOLOGICAL DESCRIPTION		ı				RECORDS / CONST	RUCTION INFO.	
Drilling Method	Bit Log (Inches)	Depth (m)	Lithology	Description	Water Cut (m bgl)	Airlift Yield (L/s)	EC (mS/cm)	pH (pH units)	Temperature (°C)	Field Comments	Well Construction	Well Description
Air Hammer Air Hammer	Bit Log	12 - 16 - 1 20 - 1 32 - 1 36 -	AgD	Gravelly clay, red/brown, highly weathered, dry, firm, fine to medium gravel Clayey gravel, red, medium to very coarse gravel, weathered, dry  Clayey gravel, white/red clay, low plasticity, med to coarse blue/yellow gravel Gravel, yellow/clear gravel, white clay, highly weathered  Gravel, white/yellow with black mottle quartz, loose, moist/wet, large fragments  Sandy gravel, sand fine, loose, wet, white  Sandy gravel, blue/white/yellow med to very coarse gravel. Fine to medium sand, loose Gravelly sand, white/blue fine sand, 10% med to coarse gravel, loose  Sandy gravel, wet, med to very coarse quartz, loose  Gravelly sand, white/blue fine sand, med to coarse gravel, loose	12	< 0.1	1.4 2.46 2.39 2.04 2.17 2.26 N/A 2.27 2.52 2.47 2.52	8.12 8.21 8.23 8.16 8.12 N/A 8.17 8.19	31.1 31.7 32 31.5 31.6 31.3 N/A 30.9 32.2 31.6 31.4	Rods getting stuck  Drilling fluids used for hole stabilisation  Low but consistent yields during drilling, <0.1 L/s  Development notes: Foul odour, grey/white colour, no fines present, very low recharge rate, filled with water and	Well Construction	Stick up: 0.81m  0-54m Bentonite/cement grout  0-57m DN50mm PN12 uPVC casing  54-56m Bentonite Seal 56-60m 3mm
		60					2.48	8.2 8.25	31.5	purged to remove muds. Airlift: 0.04 L/s, EC: 3.19mS/cm, pH: 8.83, Temp: 28.2 °C		Gravel Pack 57-60m DN50mm PN12 uPVC 1mm slotted screen

Notes: Ohm = Marine mud and silt on supratidal to intertidal flats, Ohms = Aeolian reworked coastal sand in beach deposits,
Qpmb = Coastal limestone, dune sand, beach conglomerate, lime-cemented shelly sand, Qaa = Alluvium, sands, gravels, clay and silt,
Qab = Alluvial floodplain sand, silt and clay with gilgai surfaces, Qrg = Quartzofeldspathic eluvial sand derived from underlying granitoid rock,
Czaa = consolidated alluvial sand, silt and clay, d/o = Undifferentiated tertiary volcanics, AgD = Undivided Dampier Granitoid Complex