K+S Salt Australia Ltd

Ashburton Solar Salt Project

Hydrogeological Investigation

June 2021

Executive Summary

K+S Salt Australia Pty Ltd (K+S) appointed GHD Pty Ltd (GHD) to undertake hydrogeological, geotechnical and acid sulfate soil (ASS) investigations for Phase 2 of the Ashburton Solar Salt Project.

The proposed salt facility is planned to operate with a salt export capacity of 4.7 million tonnes per annum of salt, harvested from the progressive evaporation of seawater in a series of concentration and crystalliser ponds. The proposed salt facility will also include a wash plant, stockyard and reclaim conveyor system and a marine jetty export facility.

The project area is situated on the coastal plain approximately 40 km south west of Onslow, Western Australia. Landward of coastal dunes and mangrove intertidal areas, is a large expanse of largely supratidal salt flats (the Onslow Plain). The salt concentration pond footprint is proposed to be located on thesupratidal salt flats. Elevated mainland remnants (loosely termed 'islands') are scattered across the salt flats. The site operations compound (including washplant, stockyard, reclaim, and administrative buildings) is proposed to be located on a mainland remnant island within the salt flats.

Hydrogeological Field Investigations

The site investigation was directed towards obtaining information about the hydrogeological conditions to inform numerical groundwater modelling required for the project's environmental impact assessment and permitting submissions to the Environmental Protection Agency (EPA). The initial and main part of the site investigation was carried out between 28th October 2019 and 31st March 2020, and was complemented by supplementary fieldwork between 30th August and 4th September 2020:. This comprised:

- Fifteen hydrogeological / geotechnical boreholes drilled with hollow stem auger and diamond coring techniques;
- Installation of shallow and deep groundwater monitoring bores;
- Installation of pumping test bores adjacent to selected boreholes;
- Twelve double-ring infiltrometer tests across the concentration pond and crystalliser pond footprints;
- Short-term pumping tests in two locations (the third locations had to be abandoned due to flooding);
- Measurements of water levels (including installation of loggers in three locations) and collection of groundwater samples; and
- Additional fieldwork between 30th August 2020 and 4th September to perform additional infiltrometer tests, collect water level logger data, measure groundwater levels, perform electrical conductivity (EC) profiling, collect another set of groundwater samples and install additional loggers for long-term precision monitoring.

Hydrogeological Conceptualisation

The site investigation results and review of existing information were used to develop a hydrogeological conceptual model. The key features of hydrogeological conceptualisation are as follows:

- The project footprint covers a coastal area which has been emerging from previous sea inundation for the last 5000 years. The mostly flat area with ground elevations around 1 to 2 m AHD contains mainland remnant 'islands, up to 16 m AHD. To the east of the project area exists an elevated dune landscape (16 to 19 mAHD) with interspersed claypans. The water levels in the salt flats (when inundated) are shallow (less than a metre) subjecting groundwater to evaporation effects.

- The hydrogeology is characterised by the presence of hypersaline groundwater beneath the supratidal flats. It is thought to have formed over time from the combined actions of:
  - Seawater submersion;
  - Evaporitic concentration of salts supplied periodically by tidal inundation and storm surge; and
  - Contribution from the regional throughflow from east to west.

This has created a dense hypersaline waterbody underneath the flats which affects incoming shallow groundwater flows from inland areas.

The project, in particular its evaporation pond complex, will increase recharge and salt load to groundwater underneath the ponds which will be redistributed in the groundwater radially from the pond footprint.

Numerical Modelling

A numerical groundwater flow and transport model was developed to assist in an assessment of likely environmental impacts associated with the project development. The 3D numerical model was developed in 'MODFLOW-USG Transport' software, with density-driven flow functionality to account for density effects of hypersaline groundwater present at the site. The model with proposed confidence Class 1 has been developed in alignment with the Australian Groundwater Modelling Guidelines (Barnett et al., 2012).

The model reproduces the key hydrogeological processes of the subregional groundwater discharge system through the coastal plain that characterises the project area, both in terms of:

- Overall observed spatial trends in groundwater levels; and
- Groundwater salinity through simulation of the effects of sea level regression over the last 2,500 years.

The predicted groundwater seepage rates post-development are in line with previous predictions (PFS, Arcadis 2008a) and are controlled by density differences between water in the ponds and the underlying dense hypersaline groundwater.

Groundwater Change Assessment (Water Levels, Salinity)

The calibrated numerical model was used to provide quantified estimates of groundwater regime change due to construction and operation of ponds and to inform impact assessment on environmental receptors, in particular mangroves and algal mats. The changes are estimated using conservative assumptions including the permeability of the pond floor, which was assumed to remain unaltered through the 50-year project operation, providing conservative estimates of seepage and associated effects on groundwater.

The project is predicted to promote groundwater recharge (over the footprint of ponds) and accompanying salt loading. It will create a local groundwater mound and will have an effect on groundwater flow directions and groundwater quality. Initial mounding will result from direct vertical infiltration into the thin unsaturated zone and horizontal redistribution within the thin surficial aquifer. Water logging is assessed to be minor since seepage will be intercepted by high evaporation affecting the shallow groundwater system.

The ponds will generally refresh groundwater underneath the ponds but will create a halo of increased groundwater salinity around the perimeter of the pond complex.

Impact Assessment

The results of this assessment have been provided to AECOM, the project's marine and intertidal consultants, in order to predict potential impacts on mangroves and algal mats located to the west of the proposed ponds.

Recommendations are made towards continuing and extending groundwater level and EC monitoring, including two lines of shallow monitoring bores to the west of Ponds 1 and 2.

This report is subject to, and must be read in conjunction with, the limitations set out in section 1.4.2 and the assumptions and qualifications contained throughout the Report.

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1. Introduction

1.1 Background

K+S Salt Australia (K+S) is the Australian entity of the international resources company K+S Group. K+S have appointed GHD Pty Ltd (GHD) to undertake hydrogeological, geotechnical and acid sulfate soil (ASS) investigations for Phase 2 of the Ashburton Solar Salt project. The proposed Ashburton Solar Salt project is situated within the coastal region approximately 40 km south west of the town of Onslow, Western Australia (hereon in referred to as ‘the site’) (Map 1).

GHD previously completed a desktop study which included a hydrogeological overview (GHD, 2019). The report presented the existing knowledge about the site hydrogeology and likely hydrogeological issues that could have an effect on the proposed development and also provided recommendations for proposed field investigations.

The fieldwork component of the hydrogeological, geotechnical and ASS site investigation for Phase 2 of the Ashburton Solar Salt project was completed in April 2020. The drilling of boreholes and geotechnical testing was completed on 31st March 2020. Further fieldwork was undertaken between 30th August and 4th September 2020 to perform infiltrometer tests and gather additional groundwater data for the hydrogeological modelling.

The investigation was undertaken in accordance with GHD’s proposal to K+S dated 13th September 2019. This report presents the hydrogeological data obtained from the site investigation conducted between 28th October 2019 and 31st March 2020, and 30th August 2020 to 4th September 2020, hydrogeological conceptualisation based on the existing knowledge, and numerical groundwater flow and salinity modelling to inform the environmental impact assessment.

1.2 Proposed Development

The facility is planned to operate with a target salt export capacity of 4.7 million tonnes per annum of salt, harvested from the progressive evaporation of seawater in a series of concentration and crystalliser ponds. It is anticipated that the proposed salt facility will comprise the following:

- Seawater intake pump station and channel to the salt ponds;
- Salt concentration and crystalliser ponds;
- Salt stockyard and reclaim conveyor system;
- Salt wash plant, bitterns discharge infrastructure and drainage diversions;
- A jetty to transport salt to an offshore anchorage for ocean going vessels; and
- Non-process infrastructure (NPI) including stores, workshops and access road network.

The proposed development layout is shown on Map 2.

1.3 Purpose of This Report

The information provided in this report is intended to provide sufficient hydrogeological information to conduct an environmental impact assessment on potential hydrogeological receptors.

This report provides descriptions of the intersected ground and groundwater conditions and includes an assessment of potential post-development hydrogeological impacts.

1.4 Scope

The scope of work for the hydrogeological investigation includes the following components:

- Establishment of a groundwater monitoring network at 15 locations, with 2 installation depths at 10 locations, equipped with 50 mm diameter casing;
- Drilling and construction of up to three test bores with diameter of 100 mm;
- Installation of transducers in a selection of bores (provision was made up to 10 bores);
- Aquifer testing (pumping tests) at up to three locations, slug testing of each monitoring bore using a groundwater level transducer, and subsequent analysis of aquifer testing using Aqtesolv software;
- Groundwater sampling and laboratory analysis (total metals (Fe, Al) / dissolved metals (Al, As, Cr, Cd, Fe, Mn, Ni, Se, Zn), pH, C, sulfate, chloride, total alkalinity, sodium, ammonia, TDS, total nitrogen, total phosphorus, filterable reactive phosphorous and silica);
- Hydrogeological conceptualisation based on hydrogeological investigations, outcomes of the existing surface water modelling and other relevant information sources, in accordance with the Australian Groundwater Modelling Guidelines (Barnett et al., 2012) and relevant DWER requirements. The hydrogeological conceptual model includes sections on the selection of the hydrostratigraphic units (aquifers, aquitards), hydraulic properties (hydraulic conductivity, storativity, porosity, transport properties), boundary conditions, recharge and discharge processes, surface water groundwater interaction, groundwater salinity and quality, key environmental receptors and area's water and mass balance;
- Development and calibration of a numerical groundwater model to simulate the key hydrogeological processes of the project area and its surrounding environment. The model is required to simulate the potential for seepage from the salt ponds to migrate and impact on the receiving environment. The final scope of the modelling was adjusted following review of the site data and consultation with K+S to agree modelling-specific aims, including discussions with the third party peer reviewer to ensure that they were aware of and agree with the purposes and limitations of the modelling required;
- A groundwater assessment report following completion of the modelling phase and considering the DWER guidance document "Hydrogeological reporting associated with a groundwater well licence" (Operational Policy 5.12, DWER, 2009), consistent with an H3 level of assessment reporting. This guidance provides a standard framework for reporting;
- Recommended groundwater monitoring including locations, frequency and monitoring suite (i.e. water levels and water quality suites); and
- On-going liaison and regular meetings with third party reviewer, to ensure compliance with conceptual and numerical model requirements.

1.5 Limitations

This report has been prepared by GHD for K+S and may only be used and relied on by K+S for the purpose agreed between GHD and the K+S.

GHD otherwise disclaims responsibility to any person other than K+S arising in connection with this report. GHD also excludes implied warranties and conditions, to the extent legally permissible.

The services undertaken by GHD in connection with preparing this report were limited to those specifically detailed in the report and are subject to the scope limitations set out in the report.

The opinions, conclusions and any recommendations in this report are based on conditions encountered and information reviewed at the date of preparation of the report. GHD has no responsibility or obligation to update this report to account for events or changes occurring subsequent to the date that the report was prepared.

The opinions, conclusions and any recommendations in this report are based on assumptions made by GHD described in this report. GHD disclaims liability arising from any of the assumptions being incorrect.

GHD has prepared this report on the basis of information provided by K+S and others who provided information to GHD (including Government authorities), which GHD has not independently verified or checked beyond the agreed scope of work. GHD does not accept liability in connection with such unverified information, including errors and omissions in the report which were caused by errors or omissions in that information.

The opinions, conclusions and any recommendations in this report are based on information obtained from, and testing undertaken at or in connection with, specific sample points. Site conditions at other parts of the site may be different from the site conditions found at the specific sample points.

Investigations undertaken in respect of this report are constrained by the particular site conditions. As a result, not all relevant site features and conditions may have been identified in this report.

Site conditions (including the presence of hazardous substances and/or site contamination) may change after the date of this report. GHD does not accept responsibility arising from, or in connection with, any change to the site conditions. GHD is also not responsible for updating this report if the site conditions change.

1.6 Overview of Approach

The following approach has been followed:

- Desktop review of available background information (previously summarised in GHD, 2019);
- Investigation fieldwork to establish an understanding of the shallow aquifer system, its geological profile, groundwater levels, groundwater flow directions, aquifer hydraulic properties and shallow groundwater quality (including salinity);
- Assessment of baseline groundwater conditions and development of a hydrogeological conceptual model including:
    - Identification of groundwater domain relevant for the project;
    - Identification of key aquifer units and characterisation of their hydraulic properties;
    - Characterisation of key climatic factors and hydrological processes (recharge, evapotranspiration, tidal flooding, surface runoff) that lead to current groundwater conditions including salinity at a regional scale; and
    - Derivation of a likely groundwater and mass (salinity) balance for site's current conditions.
- Development of a regional groundwater flow and transport (salinity) model to confirm the hydrogeological conceptualisation and to provide a framework for post-develoment groundwater level and salinity change estimation. This included:

- Development and calibration of a regional groundwater flow and transport model with density-driven flow capability to reproduce current conditions;
- Identification of sensitive parameters for model predictive purposes;
- Simulation of the project operation over the life of the project with the calibrated regional model;
- Estimation of seepage and salinity contribution from evaporation ponds over the life of the project;
- Provision of modelling outputs to enable impact assessment (by another consultant) of potential groundwater changes induced by the project which are relevant to the functioning of mangrove communities and algal mats; and

- Development of recommendations for ongoing groundwater monitoring.

2. Project Description

2.1 Site Identification

The project area of the proposed Ashburton Salt Project (the project) is located approximately 40 km south west of the town of Onslow, Western Australia (see Map 1 and Map 2). This area contains various significant physiographic features including coastal dunes, tidal creeks lined with mangroves, intertidal/supratidal flats, undulating sand plains, clay pans and the marine environment.

2.2 Mining Tenements

A search of the Department of Mines, Industry Regulation and Safety (DMIRS) MINEDEX and Materials Titles Online systems was completed in July 2020. The search indicates that at the time of the search K+S held exploration status on five mining tenements..

A summary of mining tenement details is presented in Table 2.1 and the tenements are presented on Map 1.

Table 2.1 Mining Tenement Overview

Tenement identifier	Date received	Commencement	Expiry	Area (ha)
E 08/1395	03/06/2003	15/06/2004	14/06/2020	22,231
E 08/1396	03/06/2003	15/06/2004	14/06/2020	10,807
E 08/1399	03/06/2003	15/06/2004	14/06/2020	8,576
E 08/1421	15/10/2003	15/06/2004	14/06/2020	7,306
E 08/2840	27/04/2016	25/01/2018	24/01/2023	13,985

2.3 Zoning

According to the Department of Planning Lands and Heritage, the site is located on land parcels zoned as *'Rural'*, '*Tidal inundation special control area'* and '*Conservation, recreation and nature landscape'* (DPLH 2020).

2.4 Current Land Use

2.4.1 Onsite Land Use

The project area is situated on a region of intertidal/supratidal flats, with remnant islands and isolated sand dunes. The project area is currently on pastoral land associated with the Urala and Koodarrie Stations. The project area is predominately absent of any development, with the exception of an area in the northeast portion of the site that is shared land between the Proposal and the Australian Gas Infrastructure Group (AGIG) Tubridigi Gas Plant.

According to spatial information provided by AGIG, a single gas production well appears to be located within the Proposal Development Envelope, along with various access tracks and other minor gas plant support infrastructure.

2.4.2 Surrounding Land Use

The AGIG Tubridgi Gas Plant is located approximately 2.5 km north-east of the site (Map 1). The Tubridgi Gas Plant facilitates gas storage and delivery to the Dampier to Bunbury Natural Gas Pipeline (DBNGP). A further 13 km north-east of the project area is the Macedon Domestic Gas Plant operated by BHP Group Limited and beyond is the Wheatstone Liquefied Natural Gas (LNG) Plant operated by Chevron Australia Pty Ltd.

The project area is also located 25 km south-west of the Onslow Salt project. The Onslow Salt project is an active solar salt mining operation with an estimated production of 2.5 million tonnes per annum. Similar to the salt manufacturing process outlined in the Proposal's Pre-Feasibility Study (Arcadis 2018a), the Onslow Salt project pumps seawater from Beadon Creek to concentration ponds, before passing material through a variety of handling methods and infrastructure to process the salt for conveyor loading onto ships from a jetty.

A review of available aerial imagery and online data indicates that no coastal or offshore development has occurred proximal to the project area.

2.5 K+S Ashburton Solar Salt Project

The proposed project is planned to operate with a salt export capacity of 4.7 million tonnes per annum, harvested from the progressive evaporation of seawater in a series of concentration and crystalliser ponds. It is anticipated that the proposed salt facility will comprise the following infrastructure and/ or components:

- Seawater intake pump station and channel to the salt ponds;
- Salt concentration ponds (concentration ponds) ;
- Salt crystalliser ponds (crystalliser ponds) ;
- Brine pond and brine transfer structures including bitterns discharge infrastructure (channel, dilution pond, pipeline and diffuser);
- Salt wash plant;
- Salt stockyard and reclaim conveyor system;
- Non-process infrastructure (NPI) including administration buildings, stores (including fuel stores), workshops, laydowns areas and internal access road network;
- A dedicated jetty and loading platform to facilitate the transport of salt to an offshore anchorage for ocean going vessels;
- Dredging of a small berthing pocket and onshore dredge disposal area;
- Drainage diversions; and
- Borrow pit areas for construction materials.

2.6 Project Infrastructure and Operation Period

2.6.1 Overview

The proposed project has been described in the pre-feasibility study design report and pre-feasibility study basis of design prepared by Arcadis (2018a and 2018b). For brevity, the description below is limited to salt concentration and crystaliser ponds which are the key project components expected to influence groundwater once constructed and operational.

For information on other infrastructure elements reference should be made to Arcadis (2018a and 2018b).

2.6.2 Salt Concentration Ponds

The proposed salt concentations ponds are predominately sited on supratidal flats as shown on Map 1 and Map 4. The supratidal flats are typically between approximately RL 0.6 m AHD and RL 1.3 m AHD. The elevations of the mainland remnant islands (which will be tied into pond embankments) are up to 16 mAHD, whilst the dunes to the east of the supratidal flats rise up to approximately 19 m AHD.

2.6.3 Crystalliser Ponds

The crystaliser ponds are proposed to be located immediately north of the concentration ponds (Map 1) and consist of 12 cells separated by internal embankments. Both the internal and external embankments are proposed to tie into the mainland remnant islands.

The crystalliser pond operations involve developing a salt pavement at the bottom of each cell to protect harvestable salt from the below mudflats. Salt is then precipitated upon the salt pavement and harvested every 12 months, with one cell harvested each month to facilitate year-round export.

3. Literature Review

3.1 Geological Mapping

Two publicly available map sheets provide relevant geological information on the study area, to inform the hydrogeological assessment:

- Yanrey – Ningaloo 1:250,000 Geological Map Sheet SF50-9 with explanatory notes, GSWA, 1980; and
- Onslow 1:250,000 Geological Map Sheet SF50-5 with explanatory notes, GSWA, 1982.

3.2 DWER WIN Database Search

The WIN database operated and maintained by DWER confirmed there are no groundwater records in the vicinity of the project area.

3.3 Previous Solar Salt Investigations

Straits Salt Pty Ltd (Straits) previously proposed to develop the Yannarie Salt Project, with a production capacity of 10 million tonne per annum (Mtpa) on the eastern side of Exmouth Gulf, Western Australia, the northern part of which would have included the southern extent of the proposed Ashburton Salt project area. This Yannarie Salt Project would have extended some 50 km southwest of the Ashburton Salt project area and consequently would have had a much broader footprint. In 2009, Straits announced it would not proceed with the project after the EPA recommended it not be approved and the Minister for Environment subsequently directed the EPA to re-assess the proposal (EnviroWorks, 2016).

Straits previous geotechnical and hydrogeological investigations included a census of 72 sites (bores, windmills, tanks, clay pans), and an infill drilling program at seven locations (predominantly in dune fields), supplemented in 2007 by 12 locations; installation of loggers at 12 locations and collection of water samples from 41 locations. These indicated the presence of shallow groundwater, within a thin low permeability aquifer, which was found to be highly saline (DC Blandford and Associates, 2006; Parsons Brinckerhoff, 2005; 2008a).

In accordance with DC Blandford (2006) the area was divided into distinct geomorphic types: tidal flats, salt flats, dune fields and outwash plains, each with their own hydrogeological characteristics. Groundwater levels varied in only two logged locations (1 to 3 m), which were situated in the salt flats, while the rest of the evaluated sites (all within the dune fields and tidal flats) had stable water levels within the reported September to November 2004 period. The study confirmed the distinct concentration gradient in groundwater salinity, ranging from hypersaline beneath salt flats (average 150 g/L), to saline inland east of the landward edge of the flats (13 to 35 g/L) to brackish (2 to 13 g/L) further inland.

After field investigations Parsons Brinckerhoff undertook modelling of the effect of the construction of the concentration and crystalliser ponds upon groundwater within the underlying shallow aquifer to understand the potential impact upon the coastal mangroves, and if necessary, to manage it (Parsons Brinckerhoff, 2008b). Their cross-sectional SEEP/W model predicted increased input to groundwater from the ponds and the rise of groundwater levels outside the pond footprint, but only within approximately 17 to 22 m from the seaward pond perimeter. Beyond that, the predicted changes were found to be negligible. The model used design permeability of 0.35 m/d for terrestrial deposits (and three orders of magnitude lower for marine deposits). The study did not include modelling or discussion of groundwater salinities and their impact on groundwater flows and/or environmental receptors.

3.4 Wheatstone Project

Chevron Australia Pty Ltd proposed to construct and operate a multi-train liquefied natural gas (LNG) plant and domestic gas plant, referred to as Wheatstone Project at Ashburton North, to the north of the proposed Ashburton Salt project area. Chevron engaged URS (2010) to characterise hydrogeology of that area. The filed program included drilling, testing and sampling of 69 groundwater monitoring bores and 28 drive piezometers. The investigation confirmed that this area is underlain by a shallow groundwater level and is a predominantly groundwater discharge zone. The shallow groundwater appeared to be accumulating salt and was generally hypersaline (156 to 200 g/L), with fresher groundwater in dunes sands (20 to 200 g/L). The impacts of the project were described as increased recharge, change of water table elevations, groundwater flow directions and groundwater quality.

As part of this assessment a groundwater flow model was developed to predict seepage from the project infrastructure. The model was used to predict the extent of mounding from loadings of seawater into a dredge material placement area, and a predicted seepage of approximately 2,200 kL/d.

The simulated seepages were sufficiently low since they were predicted to be intercepted by evaporation and did not cause surface water flows on the ground surface. Since the model simulated only groundwater flows the salinity changes in groundwater were not modelled or explicitly assessed.

3.5 Surface Water, Tidal Inundation and Flood Assessments

Water Technology (2021) carried out a suite of surface and marine water studies to improve understanding of potential environmental impacts of the proposed Ashburton Salt Project. The studies aim to define the baseline hydrological and tidal flow conditions, describe key hydrological and nutrient processes, assess impacts and propose mitigation measures and inform engineering design of the site infrastructure.

The reports characterise the existing conditions of the site, catchment and downstream sensitive receptor areas. Floodplain hydraulics were assessed using a MIKE21FM GPU 2D flexible mesh hydraulic model, which was calibrated to historic flood data available for Ashburton River and also to the largest known cyclone event (Cyclone Vance in 1999). The model was used to simulate a range of design flood events and describe flood behaviour. The DHI Flow model was used to simulate tidal inundation and predict project related changes to tidal inundation extent, depth and frequency.

The relevant results of Water Technology modelling (including pre-development tidal inundation and modelled post-development tidal inunation changes) (Water Technology, 2021) have been considered and incorporated into this study.

4. Physical Environment

4.1 Climate

4.1.1 Rainfall

The climate of the Project area is semi-arid to arid, with influences of both tropical maritime air from the Indian Ocean, and continental air from the interior (GSWA, 1982). Rainfall data from the nearest Bureau of Meteorology monitoring stations is presented in Figure 4-1 for annual and monthly rainfall.

The annual data highlights the variability in total rainfall data, with a range of less than 50 mm/yr to up to over 600 mm/yr. The average annual rainfall for Urala Station (period from 1977 to 2019) is 267 mm. The longer term average, albeit from an incomplete dataset from Onslow, is 313 mm, possibly indicates evidence of a drying climate in more recent years. Bimodal pattern is typical for the rainfall in this region, observed with the primary peak occurring from January to March, and the second peak in May and June (Figure 4-2).

The large range in annual rainfall is largely influenced by cyclonic events occurring during the hotter summer months. Due to the significant impact on rainfall of local cyclones, the monthly rainfall averages also show a large degree of variability. During these events, discharge from the surface drainage lines causes flooding of the salt flats and is usually accompanied by storm tide inundation.

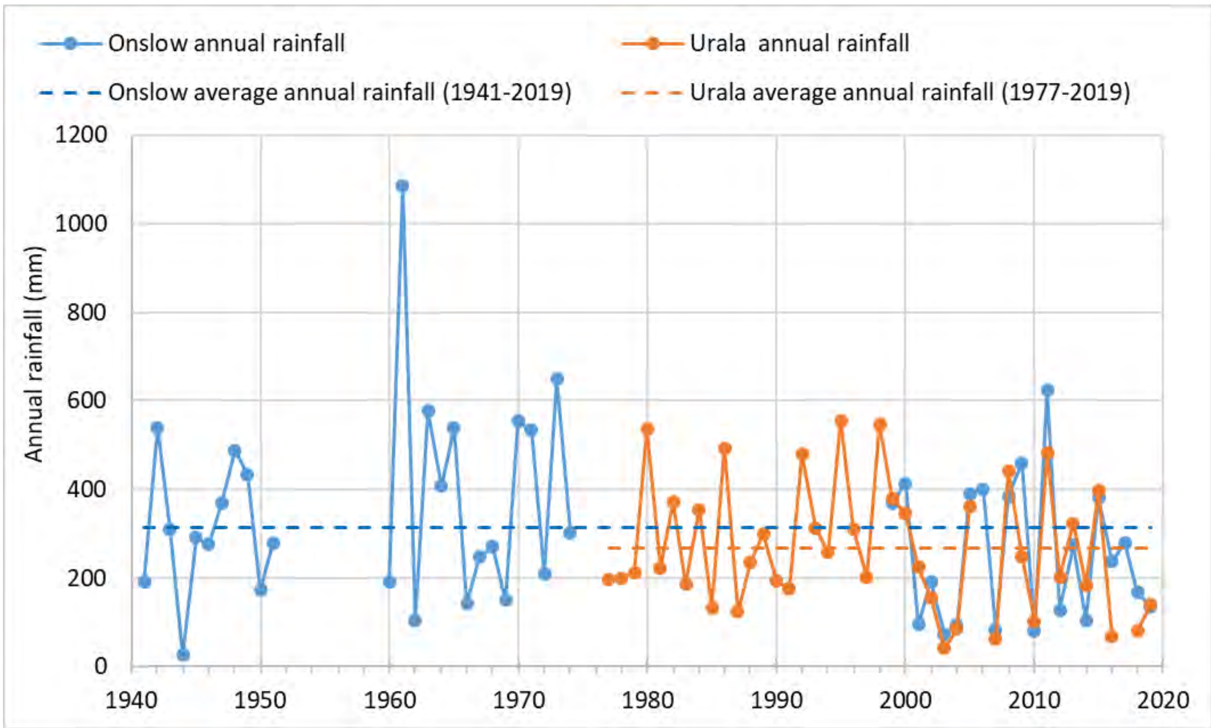


Figure 4-1 Annual rainfall data: BOM stations Onslow Airport (5017) and Urala Station (5078)

Cyclones typically occur from mid-December to April, peaking in February and March. The most intense cyclone at Australian coast, cyclone Vance, was recorded in 1999, with maximum wind speed of 267 km/hr (at Learmonth Airport). Cyclones can produce substantial storm surges near the coastline. The peak of a cyclone storm surge generally lasts for a few hours.

4.1.2 Evaporation

The area experiences high evaporation rates which greatly exceed rainfall. Evaporation is highest during summer months and lower in the winter months. The evaporation rate is approximately equal to rainfall only during June (Urala Station) and slightly higher than rainfall in March and May. Evaporation rates are an order of magnitude greater during the August to December period (Figure 4-2).

Evaporation data from Dampier (the nearest site with available long term data) highlight the hotter summer period when monthly evaporation generally exceeds 300 mm between October to April (Figure 4-2). Mean annual evaporation exceeds 3 m and significantly exceeds the annual average rainfall.

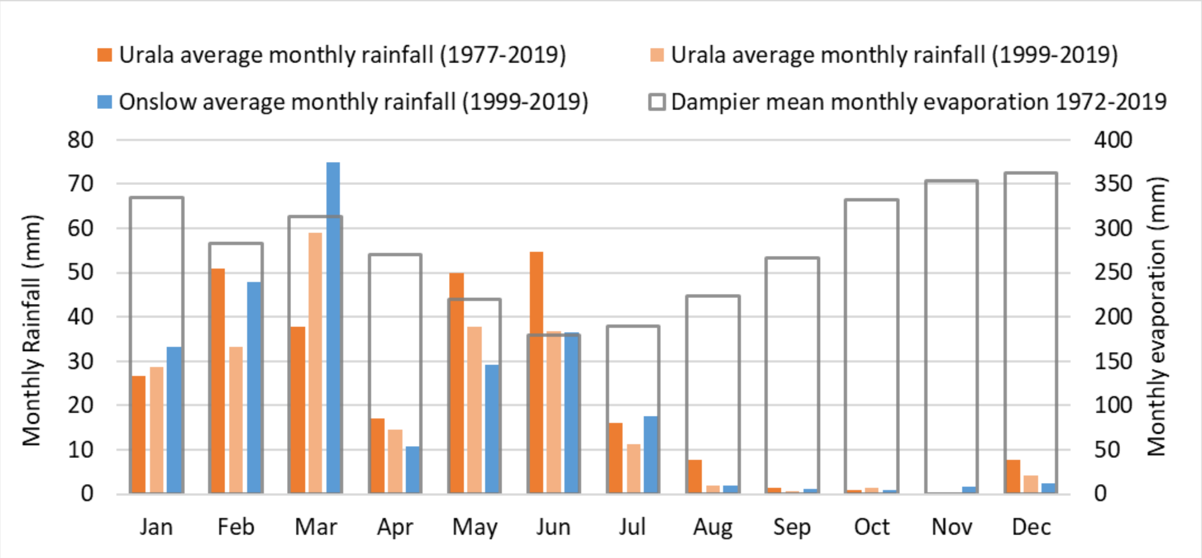


Figure 4-2 Monthly Rainfall, Onslow Airport (5017) and Urala Station (5078), and Evaporation Data (Dampier (5061))

4.2 Geomorphology and Ground Elevations

The project area is situated on the coastal plain approximately 40 km south west of Onslow, Western Australia (Map 3). The coastal plain is relatively featureless in terms of significant topographic features. Coastal dunes run parallel to the shoreline particularly north from Urala Creek South to Tubridgi Point, and east of Locker Point stretching east beyond the proposed jetty and bitterns discharge channel (Map 3).

The three geomorphic types or landforms present in the area from west to east (or inland to sea) are shown in Map 3 (Parsons Brinckerhoff, 2005).

- **Tidal flats and mangrove swamps** include the coastal fringe of beach systems, sand sheets and limestone outcrops. These are intersected by tidal creeks with a strong mangrove presence;
- **Salt flats (Onslow Salt Plain)**, a low relief feature typically inundated during high tide or storm events with embedded terrestrial sand islands. This floodplain is elevated just above or at the reach of regular tides, but becomes inundated during spring tides and storm surges; and
- **Dune field (Carnarvon Dune Field)**, aeolian sands processed by winds into sand dune ridges up to 25 m high. Clay pans are present in the inter-dunal areas.

The proposed salt concentration ponds have a footprint on the salt flats of almost 100 km^2, covering an area approximately 15 km north to south, and 10 km east to west.

The salt flats are up to 10 km wide and extend the full length of the eastern coast of the Exmouth Gulf. The elevation of the salt flats, as recorded by project LIDAR data, is generally around 0.6 to 1.3 m AHD, with the lower elevation areas being in the eastern portion of the salt flats. The salt flats are generally supratidal and become inundated during the highest spring tides (during March and April) and storm surges. The mangrove and adjacent mudflats closer to the shore are intertidal.

For clarity purposes the tidal regime distinguishes the following zones:

- The supratidal zone is above high tide and is inundated only during the highest spring tides (in March and Apri) or during storms. This zone forms the dominant landscape in the project area also referred to as salt flats. The proposed salt concentration and crystalliser ponds are situated in this zone;
- The zone between mean high tide and mean low tide is the intertidal zone. It is inundated twice daily during high tide and exposed twice daily during low tide. Mangrove vegetation is typically associated with this zone; and
- The subtidal zone is below mean low tide (at the shore) and is rarely, if ever, exposed (i.e. always inundated).

Isolated, round-shaped remnant mainland fragments or ‘islands’ up to 2 km diameter occur scattered across the supratidal salt flats, the tops of which can extend up to approximately 16 m above the surrounding salt flats. These represent remnants of the mainland dune system which still exists to the east of the supratidal salt flats. The footprint of the concentration and crystalliser ponds is proposed to be located on the supratidal salt flats, with pond embankments tying into the mainland remannt islands.

West of the project area are coastal dunes which extend almost 2 km inland from Tubridgi Point (Map 3), and approximately 500 m inland at the proposed jetty location.

To the east of the salt flats, the terrain gives way to the mainland sand dune / claypan area dominated by longitudinal sand dunes (the Carnarvon Dunefield). Claypans are exposed in the relatively low-lying areas (swales) between the dunes.

4.3 Soils

The soils within the project area are heterogeneous, reflecting (DC Blandford and Assoc, 2005):

- Periods of erosion and deposition;
- Development and deposition of Aeolian sheet sand and dune system;
- Periods of fluvial reworking of sediments;
- Marine transgression and regression; and
- Development of a fringing coastal dune system.

A detailed soil description is provided in the geotechnical report (GHD, 2020).

4.4 Ephemeral Creeks

Various minor drainage lines run off the Carnarvon Dunefield area and drain westward on to the supratidal flats and the project footprint. The largest of these is Chinty Creek, which drains on to the flats just east of the proposed crystalliser ponds (Map 5). There are various weir features along Chinty Creek that may limit flow onto the flats. During field investigations, no flow was observed in the creek.

4.5 Coastal Inundation

Sea elevations which affect the tidal regime of the tidal flats are driven by the variations in climate (long-term), astronomical tides and ocean currents (Water Technology, 2021). The following tidal processes are affecting water levels on the shoreline of the project area:

- Astronomical tides;
- Barometric water level changes;
- Wind direction and speed;
- Storm surge;
- Long-term sea-level changes; and
- Tsunamis.

Tidal information obtained from the technical studies for the Wheatstone Project (URS, 2019) reported Highest Astronomical Tide (HAT) on the Onslow coast of 1.55 m AHD and Lowest Astronomical Tide (LAT) is -1.42 m AHD.

Water Technology (2018) suggest a spring tide change of approximately 2.2 m. They also installed water level loggers to generate tidal planes for the project. The spring tide range for Urala Creek North is 1.6 m with accuracy specified around ± 0.2 m.

Water Technology (2021) found there is a seasonal variation tidal inundation with a ±0.2 m variation from the lowest month in August to the highest month in March. This seasonal variation is the reason the supratidal salt flats are inundated by the highest spring tides in March and April, but not by spring tides for the remainder of the year (Water Technology, 2021).

During the field investigations (described in Section 7.3), a high spring tide event on the 11 April 2020 resulted in the part of the supratidal zone area including areas within the project footprint being tidally inundated (Figure 4-3).

With reference to the available LIDAR data, the flood waters reached an elevation of 1.2 m AHD.

Looking west from B10

Looking east with B5 in centre of photo (shallow, deep and 100 mm test bore).

Figure 4-3 Tidal Inundation on Site Observed on 11 April 2020

5. Hydrogeological Setting

5.1 Geological Setting

The Geological Survey of Western Australia produced 1:250,000 geological maps for the area (Onslow and Yanrey-Ningaloo Sheets). The project area is based on the Palaeozoic to recent Northern Carnarvon Basin and has a thick sedimentary infill with siliclastic deltaic marine sediments (of Triassic age) overlain by the carbonate-rich sedimentary successions of Cretaceous to Cainozoic age.

The pre-Quaternary geological structure of the project area is considered to be of little consequence to the project since the project infrastructure will interact only with shallow Quaternary sediments. The surface geology map is provided in Map 5. The Quaternary sedimentary cover has a substantial clay content, especially at its base. The characteristics of the Quaternary cover are strongly influenced by their position in the geomorphic landscape. Detailed geological description of Quaternary deposits occurring within the project area is available in GHD (2021a and 2021b).

5.2 Shallow Groundwater Environment

Saturated coastal sediments form minor unconfined aquifers of alluvial origin within the project area (combined with marine transgression and regression). These superficial formations are typically less than 30 m thick.

The local groundwater regime (and in particular groundwater salinity) of these shallow alluvial aquifers is highly influenced by their geomorphology. The two geomorphic types considered to be of importance to shallow hydrogeology of the project area include:

- Salt flats (the supratidal zone) and to some degree tidal creeks of intertidal zone; and
- Dune fields at the fringe between the ocean and tidal flats and dune fields landward from tidal flats.

Each of these geomorphic types are described below.

Salt Flats

The salt flats of Onslow Plain are a supratidal-affected groundwater environment developed through slow sediment accumulation. The surface elevations of this supratidal environment vary between 1.1 m and 2.0 m AHD with very low relief. The plain forms a thin unconcolidated aquifer comprising sand, silt and clays, of a relatively low permeability due to the abundant clay or silt fraction typical of low energy environments.

Depth to groundwater in this unit is shallow and varies between 0.2 and 1 m below ground level. Various evaporitic minerals form through precipitation of hypersaline groundwater and include gypsum, anhydrite, halite and carbonates and form visible salt crust at the surface.

Dune Fields

Groundwater in the dune fields is generally found at greater depths, between 4 and 8 m. The dunes form ridges which can be over 20 m high. The dune fields have a greater proportion of sand fraction and hence typically higher permeability.

Claypans are commonly developed in inter-dunal areas which usually centre around thin calcrete lenses and have their own micro hydrogeological regime.

5.3 Groundwater Levels

Groundwater levels vary from a few centimetres below ground level in the salt flats to 4 m to 8 m in the mainland dune fields to the east. Locally the groundwater flow gradients are flat due to the two main factors:

- Strong evaporation from the flats which forces discharge from the groundwater system. This results in substantial removal of groundwater from the inflowing groundwater from the east and a water table controlled by evaporation. Net recharge is likely zero since all recharge is effectively removed by evaporation; and
- The higher permeability of mainland remnant islands and sand dunes also results in flatter flow gradients. Following rainfall events any mounding of groundwater beneath the mainland remant islands is quickly removed radially from the centre of the mound and the water table equilibrates to its pre-recharge level.

5.4 Groundwater Flow Directions

Groundwater flow directions are generally from inland to the coast, i.e from south-east to north-west. The salt flats, which act as a large evaporation basin, intercept the groundwater flow from the upgradient mainland dune field to the east. Intercepted groundwater is lost to evaporation. Groundwater gradients in the salt flat area are flat, almost unmeasurable, resulting in almost stagnant groundwater kept in this state by evaporation effects.

It is possible that during some conditions groundwater flows are reversed from the ocean to the centre of the flats (such as high tide events).

Due to the high salinity of groundwater underneath the salt flats, groundwater flows are also affected by density differences. The hypersaline character of groundwater underneath the salt flats has led to development of a fresher saltwater edge on both the seaward and inland sides of the salt flat strip.

The zone of hypersaline groundwater underneath the salt flat parallel to the coast forces upward flow of inflowing groundwater from the mainland dune fields to the east.

As groundwater daylights along the edges of the hypersaline groundwater body beneath the salt flat, it is exposed to evaporation which results in on-going increasing salinisation.

5.5 Surface Water Groundwater Interaction

The local tidal environment, including supratidal and intertidal flats has been formed by interaction of the on-going tidal action, flooding from occasional surface runoff, rainfall, evaporation and groundwater discharge.

There are no major rivers within the project area, that would bring significant runoff from upgradient catchments to the coast and spread over the intertidal area. Chinty Creek is not considered a major river, although it would provide rainfall related inflows into the project area. Both major rivers, Ashburton and Yannarie, are distant from the project area and have no direct impact on groundwater or surface water processes.

Water Technology (2021) identified in their flood assessment, two drainage pathways (including Chinty Creek and an un-named overland flow path further south) that can bring surface runoff to the intertidal system after major rainfall events including breakout inflow from Ashburton River (inflow branching off the main river course).

Tidal action is considered to have a more frequent influence on the salt flats than surface runoff from rainfall events, with the highest spring tides causing inundation of the salt flats twice per year in March and April.

The majority of surface water (either from tidal or runoff flooding) in the salt flats is lost to evaporation, increasing the salt contents in the surficial sediments and the underlying groundwater. They are remobilised and redistributed by subsequent flooding leading to spread of salts and development of hypersaline groundwater. Tidal inundation also provides an opportunity for salt export in the water that leaves previously inundated areas. This process is reflected in the salinity of water recorded in the tidal creeks and nearshore area which is higher than average seawater, with salinity in nearshore waters ranging from 38 to 41 mg/L and salinity in Urala Creek South ranging from 40 to 50 mg/L (Water Technology, 2021).

In addition, the density-driven groundwater flow effects in combination with surface water sources result in the following:

- Gradual vertical downward movement of dense groundwater as it is displaced by less dense surface water sources;
- Occasional or temporary development of a thin layer of fresher groundwater in response to rainfall or tidal flooding of less saline water. In the mainland remant sand islands embedded in the tidal flats this could lead to locally fresher lenses of groundwater floating on top of the hypersaline water body (similar to fresh groundwater lenses in ocean islands) prevented from high evaporative salinisation by greater topographic elevations of these features and subsequently localised greater depth to groundwater; and
- More permanent presence (compared to salt flats) of less saline groundwater at the water table beneath tidal creeks due to more frequent tidal inundation (tidal flushing twice a day) resulting in a thin surface layer of less saline groundwater.

5.6 Groundwater Salinity

Geomorphology of the coastal area and interaction of tidal flooding, surface runoff, groundwater flow and evaporation has resulted in the salinity pattern observed in the project area (the hydraulic causes of which are described in the previous section). Due the high evaporitic action, sodium-chloride type salinity dominates the groundwater.

Essentially a strip pattern (or zonation) of salinity has developed along the coast as follows:

- The salt flats host hypersaline groundwater in a strip parallel to the coast. The salinities in this zone vary between 150 to 300 g/L. The hypersaline groundwater forms a dense water body, potentially distorting incoming fresher groundwater flow from inland locations;
- The coastal dunes and mangrove swamps between the ocean and salt flats form a transition zone. This transition zone is influenced by seawater salinity, fresh groundwater recharge from rainfall unaffected by evaporation in elevated dunes and the potential hypersaline wedge extending seaward from the salt flat zone. This area has a range of salinities between 20 and 100 g/L. Beneath tidal creeks a shallow thin layer of groundwater is expected to be of similar salinity to the marine water which is flushing the tidal creeks twice daily; and
- The mainland dune system to the east, rising landward from the salt flats is also a transition zone. It contains comparatively fresher, but potentially still saline or brackish groundwater originating from the upgradient dune fields further inland. Based on a previous regional study (Parsons Brinckerhoff, 2005) in a similar environment to the south of the project area, this transition zone is interpreted to have a range of salinities from brackish (about 5 to 6 g/L) to hypersaline near the contact with the salt flats.

This conceptual salinity zonation is depicted in Map 8.

6. Groundwater Use

6.1 Licensed and Unlicensed Abstraction

There are no licensed groundwater abstractions within the project area or in its immediate vicinity. This is likely the result of groundwater's little beneficial use due to its excessive salinity and the general lack of suitability for human/animal consumption or irrigation.

Unlicensed groundwater withdrawals for stock watering purposes occur further east and north from the project area, where groundwater quality achieves brackish levels or where freshwater lenses sporadically occur (e.g. associated with infrequent stream recharge along Ashburton River, north of the site).

6.2 Groundwater Dependent Ecosystems

The project area is located within the Exmouth Gulf East Wetland (WA007) which is listed in the Directory of Important Wetlands in Australia (EnviroWorks 2016). The Directory describes the significance of the wetland as "*An outstanding example of tidal wetland systems of low coast of northwest Australia, with well-developed tidal creeks, extensive mangrove swamps and broad saline coastal flats.* This wetland is tidal in nature and not considered to be groundwater dependent.

The dependency of existing vegetation communities on groundwater is best described as facultative due to the generally hypersaline groundwater that is not tolerable by most vegetation communities. Of greatest interest are the mangrove communities which line the tidal creeks in the intertidal zone between the ocean and the Onslow Salt Plain.

Mangroves receive tidal watering by ocean water twice a day for their shallow root system. They are known to tolerate groundwater that does not exceed salinity of approximately 90 g/L (AECOM, 2021).

The Onslow Salt Plain also hosts algal mats which are understood to be surface water (tide) dependent and do not rely on underlying groundwater (AECOM, 2021).

Due to the hypersaline character of the salt flats vegetation is non-existent. Mainland remnant sand islands within the salt flats host vegetation communities and these could potentially make use of relatively thinner (and temporary) groundwater lenses that may occur at the top of the saturated profile after rainfall.

7. Hydrogeological Investigations

7.1 Overview

Field investigations were completed to support geotechnical and hydrogeological assessment. The field investigations included borehole drilling, monitoring bore construction, test pitting, hand augering, acid sulfate soil sampling, aquifer testing and groundwater quality sampling. The following sections provide a summary of groundwater site investigation aspects.

The investigation locations and the investigation scope was also consulted with the third party peer reviewer.

7.2 Hydrogeological Drilling

7.2.1 Overview

Locations for proposed groundwater monitoring bores were selected prior to the field investigation based on assessment of existing data and consideration of the proposed project footprint and site infrastructure. In accordance with the agreed scope, a total of 15 locations were chosen for investigation. It should be noted that where possible, bores were located just outside of the proposed pond and embankment footprint, thus allowing the bores to be continued to be used during operations.

In general, the bore locations were chosen to represent the following areas:

- Upgradient of the project site, and representing background conditions: These include the coastal dune locations (BH03), site infrastructure (BH02), potential creek inflow (BH04) and general upgradient area further south (BH13);
- Downgradient: West of proposed ponds and representing potential downgradient areas most likely to detect potential seepage impacts once the site is operational. Example locations include BH14, BH12, BH11. The proposed location at BH06 could not be completed due to access limitations (ground too soft for drill rig access); and
- Areas within the proposed project area, including mainland remnant 'island' locations: This includes the footprint of the crystalliser ponds (BH05), mainland remnant island locations and 'near-island' locations at BH01, BH07, BH08, BH09 and BH10.

Location BH06 could not be accessed due to soft clays in the area west of the crystalliser ponds and therefore a total of 14 locations (out of original 15 planned) were drilled.

7.2.2 Monitoring Bore Installation

Of the 14 selected and accessible locations, nine were completed (Map 6) as paired sites with two monitoring bores constructed to represent the shallow and deep groundwater horizons or units. At three of these locations (BH05, BH07 and BH10) a third bore was constructed using 100 mm diameter casing to facilitate aquifer testing of the site (see Section 7.2.3).

Bores were drilled to a maximum target depth of 20 m using a Jacro 350 drill rig mounted on a mangrove buggy. The majority of the boreholes were advanced to their full depth using PQ sized diamond coring techniques. A coring methodology was selected in order to recover samples that were required for the geotechnical and geochemical investigation (including Acid Sulfate Soils). Each of these bores was initially drilled to 5 m depth with water, then to target depth using biodegradable drilling fluids.

Four of the boreholes (i.e. BH02, BH03, BH09 and BH10), and the majority of the shallow bore sites, were advanced from surface using hollow stem augering techniques aided with water.

One of these four boreholes, BH10, switched over to PQ diamond coring techniques from 14 m depth due to hard augering conditions. Bore coordinates, ground surface levels and termination depths are summarised in Table 7.1. Bore logs are presented in Appendix A.

Fifty millimetre internal diameter PVC casing was installed in each monitoring bore, with a slotted interval selected as specified based on interpretation of the lithology and potential aquifer units. The slotted interval ranged between 1 and 6 m in the monitoring bores. The bottom depths of the screens varied between 3.0 m and 18.25 m. The top of the installations at all monitoring bore locations are protected with an above-ground monument cover. The installations were developed by airlifting until the recovered water was clear.

The monitoring bore coordinates, ground surface levels, screen depths and dipped groundwater depths are summarised in Table 7.1. The installation details of each bore are shown on the relevant bore logs in Appendix B.

7.2.3 Test Bore Installation

Three test bores (BH05B, BH07B and BH10B) were installed adjacent to selected monitoring bore locations (BH05, BH07 and BH10) for aquifer testing. The test bores comprise a 100 mm internal diameter PVC pipe installed to a general depth equivalent to the base of the flow zone identified in the corresponding ‘deep’ monitoring bores. The top of the installation is protected with an above-ground monument cover. The installation was developed by airlifting until the recovered water was clear.

The test bore coordinates, inferred ground surface level, collar height, pipe height, screened zone and dipped groundwater depths are summarised in Table 7.1. The installation details of the test bores are shown on the bore logs presented in Appendix A.

7.3 Aquifer Testing

7.3.1 Depth to Groundwater

Measurements of depth to groundwater from the Project area are available as spot measurements. Measurements over a 13 day period for two bores and continuous logger measurements in two bores over 6 months are also available.

The depth to groundwater was measured prior to commencement of the slug tests. The tests were completed following a period of at least 5 days after final bore development (completed by airlifting). In addition to groundwater bores, the depth to groundwater was also recorded during the excavation of geotechnical test pits and the drilling of hand augers.

The depth to groundwater records are included in the bore summary in Table 7.1.

Table 7.1 Bore Installation Summary

ID	Type	Easting	Northing	Ground level (m AHD	Depth to top of screen (m)	Depth to bottom of screen (m)	Depth to water (m)	Water level (mAHD)
BH01	Single bore: water table (shallow)	269,885	7,581,709	7.08	2	8	Dry	0
BH02S	Pair: shallow bore	272,594	7,585,015	1.72	5	8	3.64	-1.92
BH02D	Pair: deep bore	272,594	7,585,017	1.72	12.2	18.2	3.66	-1.94
BH03S	Pair: shallow bore	267,802	7,587,158	2.51	2	5	1.42	1.09
BH03D	Pair: deep bore	267,804	7,587,156	2.51	11	14	1.56	0.95
BH04	Single bore: water table (shallow)	272,867	7,580,738	3.45	3.4	8.4	2.96	0.49
BH05S	Pair: shallow bore	266,677	7,578,586	0.71	1	2	0.28*	0.43
BH05D	Pair: deep bore	266,676	7,578,586	0.71	12	15	2.25*	-1.54
BH05 TB	Test bore for BH05	266,677	7,578,582	0.71	5	15	-	-
BH07S	Pair: shallow bore	262,937	7,573,342	1.58	1.8	7.8	0.88	0.7
BH07D	Pair: deep bore	262,937	7,573,341	1.58	10.6	13.6	0.94	0.64
BH07 TB	Test bore for BH07	262,938	7,573,343	1.58	2.4	8.4	-	-
BH08	Single bore: water table (shallow)	263,027	7,573,315	5.42	5.6	10.1	4.58	0.84
BH09S	Pair: shallow bore	268,022	7,572,205	3.37	0.5	3	2.27	1.1

ID	Type	Easting	Northing	Ground level (m AHD	Depth to top of screen (m)	Depth to bottom of screen (m)	Depth to water (m)	Water level (mAHD)
BH09D	Pair: deep bore	268,022	7,572,207	3.37	6	9	2.32	1.05
BH10S	Pair: shallow bore	266,487	7,572,274	0.90	2	5	0.36	0.54
BH10D	Pair: deep bore	266,489	7,572,272	0.90	8.5	11.5	0.34	0.56
BH10 TB	Test bore for BH10	266,490	7,572,272	0.90	4.4	14.4	-	-
BH11S	Pair: shallow bore	260,262	7,569,713	1.21	1.5	4.5	0.41	0.8
BH11D	Pair: deep bore	260,262	7,569,712	1.21	6	9	0.42	0.79
BH12	Single bore: water table (shallow)	261,195	7,565,603	9.94	4	10	7.43	2.51
BH13	Single bore: water table (shallow)	271,733	7,563,998	6.88	3	6	2.31*	4.57
BH14S	Pair: shallow bore	259,882	7,565,533	0.96	3	6	0.23	0.73
BH14D	Pair: deep bore	259,892	7,565,531	0.96	11	14	0.16	0.8
BH15S	Pair: shallow bore	265,135	7,565,584	1.49	2	5	0.66	0.83
BH15D	Pair: deep bore	265,135	7,565,582	1.49	9	12	0.76	0.73

‘ - measurement taken prior to slug testing in April 2020. All remaining measurements taken from September 2020 monitoring event*

The groundwater level data, converted from depth to water records from the field program is presented in Map 7 for both shallow and deep installations. Key observations from these measurements are as follows:

- For paired monitoring bore sites (bores sites with two different screen intervals), there is generally a downward gradient between the screened intervals. This is apparent for five out of the nine paired sites, with no significant vertical gradients at the remaining four paired sites. The water level difference (density uncorrected) is generally around 0.1 m at each of the five sites;
- Groundwater levels were manually recorded over a 13 day period on two paired monitoring bore sites at BH02 and BH03. BH02 is around 1.5 km from the intertidal flats, and 4 km from the coast. BH03 is within the coastal dunes, around 0.9 km from the coastal high tide line (to the west). The measurements, taken at various times of the day, indicate stable groundwater levels at BH02, with measured levels in the paired bores varying by less than 0.02 m over the monitoring period. At BH03 there did appear to be some variation in levels over time, particularly in the deeper screened bore. This varied by around 0.1 m, whilst the shallow bore varied by only by 0.03 m. The groundwater level changes were compared to tidal data, but no clear relationship could be determined with comparison to the semi-diurnal tidal cycle;
- Logger data from two bores (BH02 and BH04) recorded water levels from April to September 2020. The logger in BH07S was found to be non-functional. The groundwater levels show a seasonal maximum at the end of June. The overall range is however small and it does not exceed 0.1 m. There is a clear response to a rainfall event that occurred in May 2020 (18 mm) which amounted to a short-term groundwater level rise of 4 cm in both bores. Tidal influence as measured in Urala Creek South has little effect on measured groundwater levels in these two bores;
- Within the area of the supratidal salt flats, depth to groundwater is consistently shallow, less than 0.4 m in all sites tested. Two locations within the supratidal salt flat area recorded groundwater levels at or slightly above the natural ground surface (BH05 and BH14). Measurements at these locations were taken during the tidal inundation event following a king tide; and
- Water levels measured in mainland remnant island locations indicates slight mounding.

Groundwater levels plotted in Map 7 are used to make inferences on groundwater flow directions and gradients. The flow gradient in the salt flats is approximately 0.0001, with a slightly increased gradient from the adjacent mainland dune fields.

The groundwater system in this area is a highly saline one with TDS concentrations exceeding that of seawater by up to 5 to 6 times. Density influences the measured groundwater level which can be converted into an equivalent freshwater head. These effects and their influences on water level measurements were reviewed e.g. by Post, Kooi and Simmons (2007) who also provided guidance on evaluation of the magnitude of these effects.

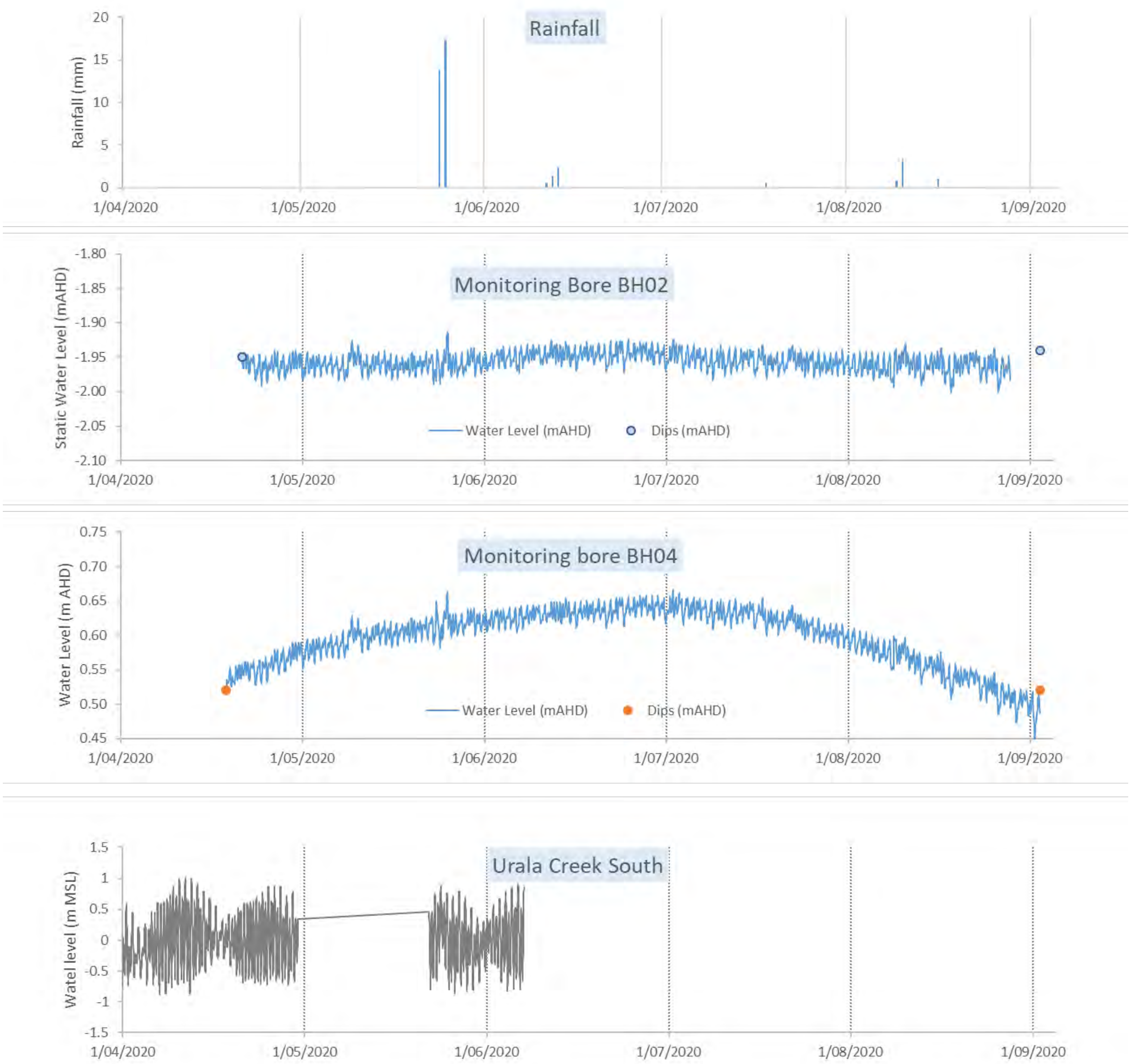


Figure 7-1 Rainfall, Groundwater Level (BH02 and BH04), and Urala Creek South Level Data

Groundwater salinity and the associated density effects in the area are expected to be heterogeneous spatially and subject to frequent changes due to the tidal inundation and rainfall related inundation regime experienced over the project area (at least within the near surface zone).

For evaluation of density effects, freshwater equivalent heads were calculated (Table 7.2) using the methods in Post, Kooi and Simmons (2007) and in Kuniansky (2018). The reference elevation for this calculation was set at -12 m AHD, an approximate mid-point of the unconfined aquifer. In theory, this needs to be set at a mid-point of the freshwater part of the aquifer system, however there is no freshwater in the project area (other than potential thin lenses in dunes or islands). Despite this, the calculations are still considered useful in indicating the trends in pressure differences between the deeper and shallower part of the unconfined aquifer.

The pressure differences between the shallow and deeper part of the aquifer do not appear large, a few centimetres in the majority of locations. They do consistently indicate higher equivalent heads in deeper sections as would be expected in the net groundwater discharge area. More notable equivalent head differences are apparent at BH07, BH09 and BH15 locations. Due to similarity of salinities, the equivalent heads of deeper and shallower section appear to be equal at BH14.

Table 7.2 Equivalent Freshwater Head Estimates

BoreID	Ground level (m AHD)	Screen Base Elevation (m AHD)	TDS (mg/L)	Density	SWL (m AHD)	Freshwater Equivalent Head (m AHD)
BH02D	1.72	-16.48	69,561	1050	-1.98	-1.48
BH02S	1.72	-6.28	61,780	1044	-1.90	-1.45
BH03D	2.51	-11.49	37,381	1027	0.71	1.05
BH03S	2.51	-2.49	20,500	1015	0.79	0.98
BH04	3.45	-4.95	107,752	1077	1.72	2.78
BH05D	0.71	-14.29	219,252	1157	0.82	2.83
BH05S	0.71	-1.29	211,338	1151	0.83	2.77
BH07D	1.58	-12.02	213,767	1153	0.66	2.59
BH07S	1.58	-6.22	183,765	1131	0.68	2.34
BH08	5.42	-4.68	163,300	1117	0.87	2.37
BH09D	3.37	-5.63	173,576	1124	1.08	2.70
BH09S	3.37	0.37	78,435	1056	1.10	1.83
BH10D	0.90	-10.60	250,859	1179	0.55	2.80
BH10S	0.90	-4.10	247,473	1177	0.54	2.76
BH11D	1.21	-7.79	268,825	1192	0.72	3.16
BH11S	1.21	-3.29	257,457	1184	0.82	3.18
BH12	9.94	-0.06	94,597	1068	2.51	3.49
BH13	6.88	0.88	61,185	1044	2.99	3.65
BH14D	0.96	-13.04	234,822	1168	0.84	2.99
BH14S	0.96	-5.04	236,114	1169	0.83	2.99
BH15D	1.49	-10.51	204,351	1146	0.70	2.55
BH15S	1.49	-3.51	147,379	1105	0.81	2.16

7.3.2 Aquifer Testing

Three sites were selected for installation of 100 mm diameter bores for the completion of aquifer (pumping) tests. These were at sites BH05, BH07 and BH10, which were selected due to their locations within the general footprint of the ponds, review of the lithologies from their adjacent monitoring bores, and logistical constraints at the time of installation. Due to access limitations caused by flooding, the pumping test equipment could not be moved to BH05 so this site was not tested (see Figure 4-3 in Section 4).

Pumping tests were analysed using Aqtesolv software. Aqtesolv outputs are presented in Appendix B.

Pumping Test on BH07

An initial calibration test was completed on BH07 TB (test bore). The test demonstrated that only limited drawdown was occurring at the maximum pumping rate for the electric submersible pump. Following recovery of groundwater levels in the test bore, a constant rate test (CRT) was commenced at a rate of 0.7 L/s. The CRT was undertaken for a period of 11.4 hours. During the CRT and subsequent recovery, groundwater levels were recorded with manual dip and data-loggers (transducers) in the pumping bore, and the adjacent monitoring bores BH07D, BH07S and BH08.

Table 7.3 provides a summary of the pumping test data including the calculated hydraulic parameters.

Table 7.3 Pumping Test Summary, BH07

Bore	Details	Interpretation
BH07 TB	Test bore. Screened 5 to 15 m. Constant rate of 0.7 L/s completed for 11.4 hrs Maximum drawdown of 1.47 m	Moench model (aquifer response is considered to be unconfined, also indicated by the shape of the derivative curves): Transmissivity of 20 to 23 m^2/day, hydraulic conductivity of 1.5 to 1.7 m/d (based on aquifer thickness of 13.5 m) Specific yield 0.05; specific storage $3.7x10^{-5}$ m^{-1} Parameter differences between shallow and deeper sections (lower T, higher Sy in the deeper section) of the unconfined surficial aquifer. Skin effect present in the pumping bore and accounted for in the calculation.
BH07S	Shallow monitoring bore, 1.2 m from BH07 TB. Screened 1.7 to 7.5 m. Maximum drawdown of 0.77 m	
BH07D	Deeper monitoring bore, 2.4 m from BH07 TB. Screened 11.5 to 13.5 m. Maximum drawdown of 0.55 m	
BH08	Shallow monitoring bore, 93 m from BH07 TB. Screened 5.6 to 10.1 m. No recorded drawdown.	Beyond the radius of influence at the rates and durations applied.

Pumping Test on BH10

An initial calibration test was completed on BH10 TB (test bore). The tests demonstrated that only limited drawdown was occurring at the maximum pumping rate for the electric submersible pump. Following recovery of groundwater levels in the test bore, a constant rate test (CRT) was commenced at rate of 0.7 L/s. The CRT was undertaken for a period of 24 hours. During the CRT and subsequent recovery groundwater levels were recorded with manual dip and data-loggers (transducers) in the pumping bore and the adjacent monitoring bores BH10D and BH10S.

At approximately 575 minutes into the CRT a recovery in groundwater levels is noted. This coincides with a king-tide that caused the supratidal flats to become inundated, flooding the area of the test bores. During this inundation, the pumping test was unsupervised (pumping occurring overnight). The test area was still inundated at the cessation of the test and its subsequent recovery. The inundation data resulted in between 0.1 m (BH10 TB and BH10S) and 0.16 m (BH10D) recovery during the CRT.

Table 7.4 provides a summary of the pumping test data including the calculated aquifer parameters.

Table 7.4 Summary of Pumping Test in PBH10

Bore	Details	Interpretation
BH10 TB	Test bore. Screened 4.4 to 14.4 m. Constant rate test of 0.7 L/s completed for 24 hrs Maximum drawdown of 3.6 m Approximate 0.1 m recovery during site flooding.	Moench model (aquifer response is considered to be unconfined, also indicated by the shape of the derivative curve): Transmissivity of 23 m^2/day, hydraulic conductivity of 1.5 m/day (based on aquifer thickness of 15 m) Specific yield of 0.06, specific storage $3.5x10^{-5}$ m^{-1} Skin effect present in the pumping bore and accounted for in the calculation.
BH10S	Shallow monitoring bore, 3.9 m from BH10 TB. Screened 2 to 5 m. Maximum drawdown of 0.77 m Approximate 0.1 m recovery during site flooding.	
BH10D	Deep monitoring bore, 1.6 m from BH10 TB. Screened 8.5 to 11.5 m. Maximum drawdown of 1.46 m Approximate 0.16 m recovery during site flooding.	

7.3.3 Slug Tests

Slug tests provide indicative values for hydraulic conductivity. Because the test is influenced only by the immediate surroundings of the test bore (and also the gravelpack or other construction details) their value as indicator of aquifer permeability cannot be compared to data obtained from good quality pumping test. In this context, the value of slug test data is as a means of inter-site comparison of spatial variability in hydraulic conductivity. Storage estimates (where obtained from analysis) from slug tests are not considered reliable.

Slug tests were completed on all monitoring bores with the exception of BH01. BH01 only had a limited head of water and was deemed not suitable for the rising head slug test method.

Slug tests were completed using a rising head method whereby a ‘slug’ of water is quickly removed from the bore’s water column using a plastic one litre bailer, causing an initial drop in water levels and subsequent groundwater level recovery. Groundwater levels were recorded using a data logger set to record levels every 1 second.

A summary of the slug tests is provided below as Table 7.5. Aqtesolv analyses of the slug test data are provided in Appendix B.

The slug test estimates indicate a wide range of hydraulic conductivity values, between 0.004 and 20 m/d. The median and geometric mean of this dataset are 2.5 m/d and 1.03 m/d respectively, which are consistent with the values obtained from pumping tests (1.5 to 1.7 m/d).

Table 7.5 Summary of Slug Tests

ID	Screened lithology	Screened Unit	Model unit*	K value (m/d)	K value comment
BH02S	Clayey SAND	Czp (Qs?)	Unit 2a	1.3	KGS model, good fit.
BH02D	Sandy CLAY/Clayey SAND	Czp	Unit 2b	2.8	KGS model. BR also good fit with K of 1 m/d
BH03S	SAND/Silty SAND	Qs	Unit 1	20	KGS model, average fit.
BH03D	Clayey SAND/Sandy CLAY/SAND	Czp/Qsed	Unit 2a	3.4	KGS model, average fit.
BH04	Sandy CLAY/CLAY	Czp/Qsed	Unit 2a	0.04	KGS model, good fit.
BH05S	CLAY/Clayey GRAVEL	Qt	Unit 1	3.1	KGS model, good fit.
BH05D	Calcareous CLAYSTONE	Qsed	Unit 2b	0.8	KGS model, good fit.
BH07S	Carbonate silty SAND	Qt	Unit 1	2.7	KGS model, average fit
BH07D	Sandy CLAY/Sandy gravely CLAY	Qsed	Unit 2a	5.3	KGS Model, good fit
BH08	Carbonate silty SAND\Carbonate clayey SAND	Qe	Unit 1	4.7	KGS model, good fit.
BH09S	SAND/Sandy CLAY	Qe/Czp	Unit 2a	0.2	KGS model, good fit.
BH09D	Sandy CLAY	Qzp	Unit 2a	7.9	KGS model ok fit.
BH11S	Clayey gravelly SAND, Sandy CLAY	Qt	Unit 1	2.3	KGS model, average fit.
BH11D	Sandy CLAY/Sandy CLAY	Qsed	Unit 2b	0.1	KGS model, good fit.
BH12	Carbonate SAND, Silty SAND	Qe	Unit 1	3.7	KGS model. Bouwer-Rice model also good fit with K of 3.96 m/d
BH13	Sandy CLAY, Silty SAND	Czp	Unit 2a	0.16	KGS model, good fit.
BH14S	Silty SAND/Gravelly SAND	Qt	Unit 1	4.9	KGS model, good fit.
BH14D	SANDSTONE/CLAY	Qsed	Unit 2b	0.004	BR model, good fit
BH15S	Sandy CLAY	Qt	Unit 2a	0.3	KGS, average fit.
BH15D	SANDSTONE	Czp	Unit 2b	0.8	KGS, poor fit.

7.4 Infiltration Testing

GHD carried out ring infiltrometer testing of the surface soils as part of geotechnical investigations for estimation of potential seepage rates. The details of testing and evaluation of results are reported in GHD (2020b) and included both freshwater and seawater as infiltration medium.

The result summary compiled from GHD (2020b) is provided in Table 7.6. Since seawater will be imported into the pond area only the results with seawater as an infiltrating medium are summarised.

The minimum inferred infiltration rates recorded for each test were twice to 4.5 times higher with freshwater compared to seawater; and maximum inferred infiltration rates for each test were 1.6 times to 9 times higher with freshwater compared to seawater. Consequently, as testing progressed, the use of seawater became the preferred approach.

Table 7.6 Summary of Infiltration Testing Results

Environment	Number of Tests (Seawater/Freshwater)	Average K (m/d)	Minimum K (m/d)	Maximum K (m/d)
Concentration Ponds	4/5	0.43	0.27	0.60
Evaporation Ponds	12/15	0.18	0.004	0.95

Additional tests were done at sites in the supratidal salt flats (two sites), mainland remnant islands (two sites) and mainland (two sites) areas, all of them with freshwater as the infiltrating medium. The highest infiltration rate (using freshwater) was recorded in the mainland remnant islands (4.3 to 14.7 m/d), while infiltration rates of the supratidal salt flats (outside of the project footprint) and the mainland varied between 0.86 to 2.3 m/d.

7.5 Groundwater Sampling

Following completion of each of the slug tests, a groundwater sample was taken and submitted to MGT Eurofins for laboratory analysis in April 2020. The samples were obtained using a bailer lowered approximately 1 m below the top of the water table

The second sampling run was completed in September 2020. During this sampling run, groundwater samples were generally bailed out from the water table for the shallow bores (carrying bore name suffix “S”). Samples were also bailed out from the deep bores (suffixed with “D”), 0.5 to 1 m from the bottom of the screen.

7.6 Water Quality Laboratory Results

7.6.1 General

Groundwater samples were analysed for a general suite to provide baseline data on groundwater quality. The tabulated groundwater results are presented in Appendix C. The TDS values for the bores (from September sampling run) are presented in Map 8, with the paired sites (deep and shallow screens) highlighted.

7.6.2 TDS and EC

- EC and TDS dry were found to be unreliable indicators of groundwater salinity, especially in hypersaline samples. In general, the correlation between EC and TDS for samples with salinity exceeding 150 g/L TDS (sum of dissolved ions as opposed to TDS dry) is unreliable beyond that salinity threshold. TDS as sum of dissolved ions is therefore adopted as the more reliable indicator of salinity;
- TDS is well correlated with chloride concentrations – chloride can be used as surrogate TDS indicator (Cl = 0.17 x TDS; R^2 = 0.99);
- All the bores showed saline or hypersaline groundwater conditions. EC values ranged between 20 g/L (BH03S) to 306 g/L (BH14D, but only 234 g/L during September run). Largest salinities observed during the September sampling run were detected in BH10D and BH11D (251 and 269 g/L respectively);
- The least saline groundwater was measured in both the shallow and deep bores at BH03, where the shallow bore was slightly less saline than the deep bore (20 and 30 g/L the shallow and deep bore, respectively). The location of BH03 in an area of elevated dunes, and some distance from the supratidal flats, may suggest that there is the possibility of a fresher water lens at this location;

- The next lowest salinity was measured in BH13 (61 g/L). BH13 is the furthest inland located bore, indicating that background salinities are still high, suggesting only minor freshening from recharge. This is supported by the hypersaline groundwater also found at BH04 (105 g/L), located immediately adjacent to Chinty Creek. The hypersaline water here suggests (current) insufficient capacity and availability of fresh water from this creek line to refresh groundwater (it was dry at the time of sampling);
- All the bores located within the supratidal salt flats showed hypersaline conditions. The average of these bores (BH05, BH07, BH08, BH10, BH11, BH14 and BH15) is 215 g/L, compared to an average of 78 g/L for the bores located either within mainland renmant islands or located off the flats (BH02, BH03, BH04, BH09, BH12 and BH13); and
- All paired sites show a slight stratification of groundwater quality between deep and shallow bores, with higher salinities found in the deeper screened bores.

7.6.3 Analytical Results

The laboratory reports are presented as Appendix C. The following sections provide a summary of the analytical results.

Inorganic constituents

Inorganic groundwater chemistry results are summarised below:

- pH results reported for groundwater indicate that groundwater across the site is relatively neutral. pH values ranged from 6.7 to 7.7 pH units, with the minimum pH reported at BH10S/D and maximum value reported at BH03S/D. pH values did not demonstrate significant variability between screen depths, with all shallow and deep paired wells displaying pH variance <0.2, with the exception of 0.5 difference between BH02S and BH02D. Spatially, pH values appeared to increase towards the peripheries of the site, with the lowest pH values returned for the central evaporation pond area;
- Alkalinity (total as $CaCO_3$) concentrations were generally consistent across the site with a minimum concentration of 77 mg/L, maximum of 690 mg/L and average of 162 mg/L. Two comparatively high results were returned at locations BH12 (690 mg/L) and BH09S (510 mg/L). Spatially, negligible variability is seen in alkalinity results, with the exception of the two high results being confined to mainland remnant islands within the evaporation pond area;
- Chloride concentrations are the dominant contributor to groundwater salinity. They vary from 11 g/L in BH03S to 190 g/L in BH14D. The highest values, consistent with TDS, are found in the salt flats;
- Sulfate concentrations demonstrated variability across the site with a minimum concentration of 1,700 mg/L (BH03S), maximum of 18,000 mg/L (BH07S – this value was only 8470 mg/L in September sampling run) and average of 7,978 mg/L. Comparatively high sulfate concentrations were reported for groundwater samples within the south-western study area, while lower concentrations were reported further inland and in the northern portion of the site; and
- Silica concentrations show some variability across the site with a minimum concentration of 9 mg/L (BH14S), maximum of 82 mg/L (BH15S) and average of 24 mg/L. Comparatively high silica concentrations were reported towards the southern portion of the site and generally confined to monitoring wells on or proximal to remnant islands.

Nutrients

Nitrogen species are represented as ammonia N and nitrate N:

- Ammonia concentrations are generally consistent across the site with a minimum concentration of 0.02 mg/L (BH03D), maximum of 6 mg/L (BH12) and average of 0.89 mg/L. Four exceedances of the *ANZG Freshwater 95% Guideline* assessment criteria were reported with comparatively high results returned for BH05D (5.2 mg/L) and BH12 (6 mg/L); and
- Nitrate concentrations are on average generally low, with 52% samples below the detection limit. Largest concentrations, detected during the September sampling run, were obtained from BH15S and BH15D (8.2 and 8.8 mg/L as N) and BH08 (5.7 mg/L as N).

Metals and Metalloids

Metals groundwater chemistry results are summarised below:

- Aluminium (total) concentrations were reported above the *ANZG Freshwater 95% Guideline* (0.055 mg/L) at all locations, with the exception of BH10 and BH15D. Limited variability was seen in aluminium (total) across the site, however a comparatively high result of 200 mg/L was reported at BH09S;
- The aluminium (filtered) results were below laboratory limits of reporting (LOR) for all locations except for five locations which showed *ANZG Freshwater 95% Guideline* exceedances;
- Iron (total) concentrations were above the *ANZG Freshwater 95% Guideline* (0.055 mg/L) at all locations, with the exception of BH10 and BH15D. Limited variability was seen in iron (total) across the site, however a comparatively high result of 490 mg/L was reported at BH09S; and
- The iron (filtered) results were generally below laboratory limits of reporting (LOR) and only one location (BH14D) showed a guideline exceedance.

8. Hydrogeological Conceptualisation

8.1 Introduction

This section outlines the hydrogeological conceptualisation. It discusses the conceptual groundwater model, based on review of hydrogeological, geological, climatic, hydrological, topographical and water quality information obtained during the literature review and from field investigations. This conceptualisation is mainly focused on the tidal surface / groundwater system and key processes affecting the shallow groundwater regime and salinity, underlying the majority of the proposed project.

The conceptual model presented in this section is based on the current understanding of the shallow hydrogeological system and outlines the key processes deemed important for developing the numerical groundwater model. Estimates of main fluxes and mass balances are provided as part of this conceptualisation, to inform model parameters and to provide a physical basis for examining the validity of key assumptions and the system conceptualisation (highlighting key uncertainties where appropriate).

The hydrogeological conceptual model captures a number of hydrogeological and hydrological processes, which include rainfall recharge, evaporation, horizontal and vertical flows in the aquifer and potential effects of density-driven groundwater flow due to the broadly hypersaline character of the modelled aquifer system.

8.2 Conceptual Model Domain

Delineation of a discrete area is necessary to estimate fluxes and mass balance within the groundwater system. While it is preferable to align model boundaries with physical boundaries, this is not always practical in regional scale studies due to model scale constraints. Consequently, some of the model boundaries are hydraulic, in a sense that they follow either regional flow lines or equipotential contours, designed to preserve hydrogeological processes in the area of focus without undue influences.

The conceptual model domain chosen for this project includes both physical and hydraulic (artificial) boundaries. The area of the conceptual model domain covers 1,010 km^2. The western boundary is defined by the Indian Ocean which forms a fixed head boundary and is set to mean sea level. The domain's northern and southern boundaries are defined as parallel to major groundwater flow directions. They are characterised as hydraulic boundaries and assume no major groundwater flow across them. The eastern boundary represents a component of groundwater lateral flow into the model domain and is set to a fixed head boundary, allowing water to enter or leave the domain at a set water level. Based on evaluation of regional data and groundwater level measured in bore BH13, this boundary is currently assumed to be 3 m AHD. There are no water level measurements available along this boundary and therefore a higher groundwater level is also possible, although 3 m AHD conforms with the regional groundwater contours presented in Parson Brinkerhoff (2008a).

Groundwater salinity is also constrained within the model domain. The two model boundaries that allow flow into or out of the model domain also provide mass flux boundaries. In the case of the western boundary, the Indian Ocean, groundwater salinity is assumed at 35 g/L (although the near-shore salinity is affected by export of salts from inland); while the eastern boundary of the model provides an inflow of brackish groundwater which is assumed vary between 6 to 20 g/L. The closest monitoring bore west of that boundary with observed groundwater salinity, BH13, recorded TDS of 61 g/L, however this bore is situated within a small groundwater discharge area subject to evapoconcentration effects and hence may not be a good example of inland groundwater salinity. Moving inland and considering findings in Parsons Brinkerhoff (2008a) at a similar distance from the ocean and in the same geomorphic unit, groundwater salinity is assumed to decrease.

8.3 Hydrostratigraphic Units

The Quaternary formations are of most interest to this assessment since they are considered hydraulically insulated from the underlying geological units due to increasing clay content with depth. Therefore, groundwater processes within the deeper underlying units are considered to have no material influence on the shallow groundwater processes and are excluded from the conceptualisation.

A simplified hydrostratigraphic unit (HSU) definition of the shallowest sediments was developed, taking into account the recent field investigation and literature data. Simplification is necessary in hydrogeological assessments, although it is recognised that the physical environment is naturally heterogeneous due to cycles of depositions, tidal reworking and occasional inland-originated flooding following large rainfall events which contribute to the complex nature of textural patterns observed in the area.

A summary of the hydrostratigraphic units is provided in Table 8.1.

Table 8.1 Interpreted Hydrostratigraphic Units

Hydrostratigraphic unit	Unit description	Spatial occurrence
Unit 1: Upper sands	Sand rich unit present at surface. Generally shallow (less than 5 m) but can offer increased thickness in those areas of mainland remnant islands i.e. Qe mapped unit, and in dunal areas. Can be up to 12 m in depth (for example at BH01 and BH12). Can include coastal dunes and local calcarenite. Includes some more clay/silty units that form the upper sequence of the supratidal flats (for example Qt mapped units). Within the area of the supratidal flats, the water table generally occurs in this unit, i.e. it can be unsaturated and saturated.	Present throughout the supratidal and intertidal flats area, i.e. underlying all the proposed concentration ponds. Present as more sand dominant terrain in dunal areas. Present as a thin veneer in some areas outside of the flats.
Unit 2a: Upper Clays	Unit consistently underlying Unit 1. Comprised of more clay rich sediments. Can also include some clayey sands. Consistent with Czp mapped unit. Up to 20 m in depth (for example BH01 and BH12), but generally grades into underlying Unit 2b at around 10-15m. Within the area of the supratidal flats, this unit is generally saturated, with the water table being present in Unit 1 above. Outside of the flats, the water table can be present in this unit (i.e. Unit 1 either absent or unit 1 is unsaturated). It is expected that this unit would be largely unconfined although some local confinement may occur in areas clay dominance	Can occur at surface in the east of the project area. Present throughout the Project footprint under varying thickness of Unit 1.
Unit 2b: Lower Clays (indurated)	Typically cemented to partly cemented clays present at depth and underlying Unit 2a. Broadly consistent with logged unit Qsed	Present throughout the Project footprint under varying thickness of Unit 2a.

Hydrostratigraphic unit	Unit description	Spatial occurrence
	This unit is fully saturated and possibly partly confined by the overlying clay rich Unit 2a.	

Excluding surface mapping, the only interpretation of the superficial formations available in the public domain was previously completed by Parsons Brinckerhoff (2008a). Their interpretation was limited to 2D cross-sections at a conceptual level in the Yannarie River area approximately 50 km south of the project area.

In the absence of any 3D representations of the project area subsurface geology, a simplified 3D hydrostratigraphical unit (HSU) model was developed for the K+S hydrogeological assessment using Leapfrog Geo, a workflow-based 3D geological modelling tool. The model was developed through importing the bore and test pit data, with lithological descriptions categorised as one of the three simplified hydrostratigraphic units outlined in Table 8.1. In addition, various control points were included to enable realistic interpretation of surface geology.

The simple 3D Leapfrog model is shown in Figure 8-1, represented as relatively flat-layered contemporary environment with clay content progressively increasing with depth. It also contains mainland remnant islands in the supratidal surface which are represented by Unit 1.

Figure 8-1 also includes locations of the long sections through the study area. The cross sections highlight how the model honours the interpreted hydrostratigraphic units. Some of the bores included in the sections are slightly off the cross section alignment, thus they may appear unaligned with the topography and model geometry.

The 3D block model and surfaces generated in Leapfrog are conceptual representations of shallow (exclusively Quaternary) lithology. Local-scale heterogeneity within each HSU is not fully accounted for within the model.

The purpose of the 3D model was to capture the regional scale variability with enough accuracy to inform the development of a regional scale numerical model.

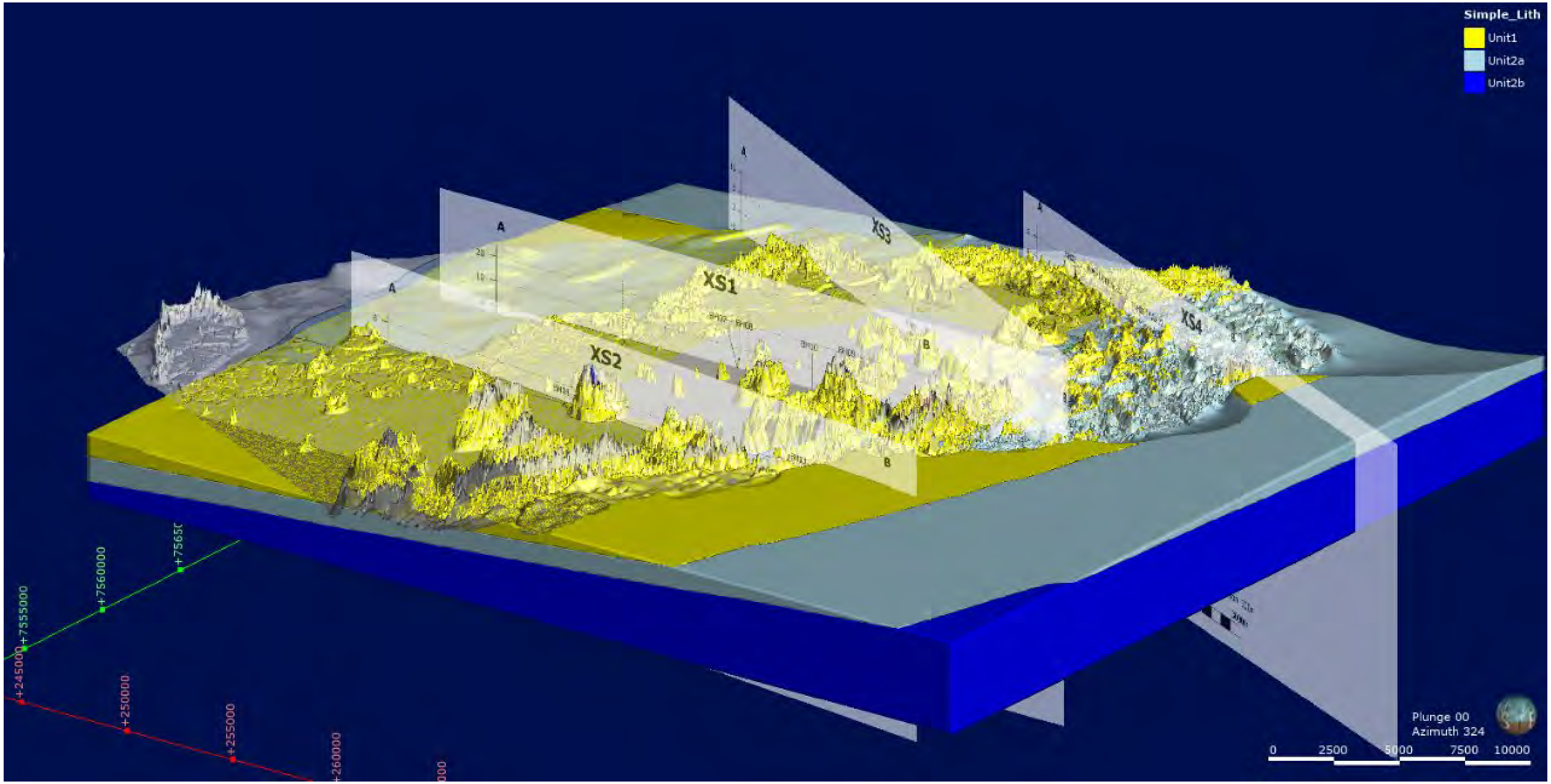


Figure 8-1 3D Leapfrog HSU Model, Looking WNW, with Long Section Locations

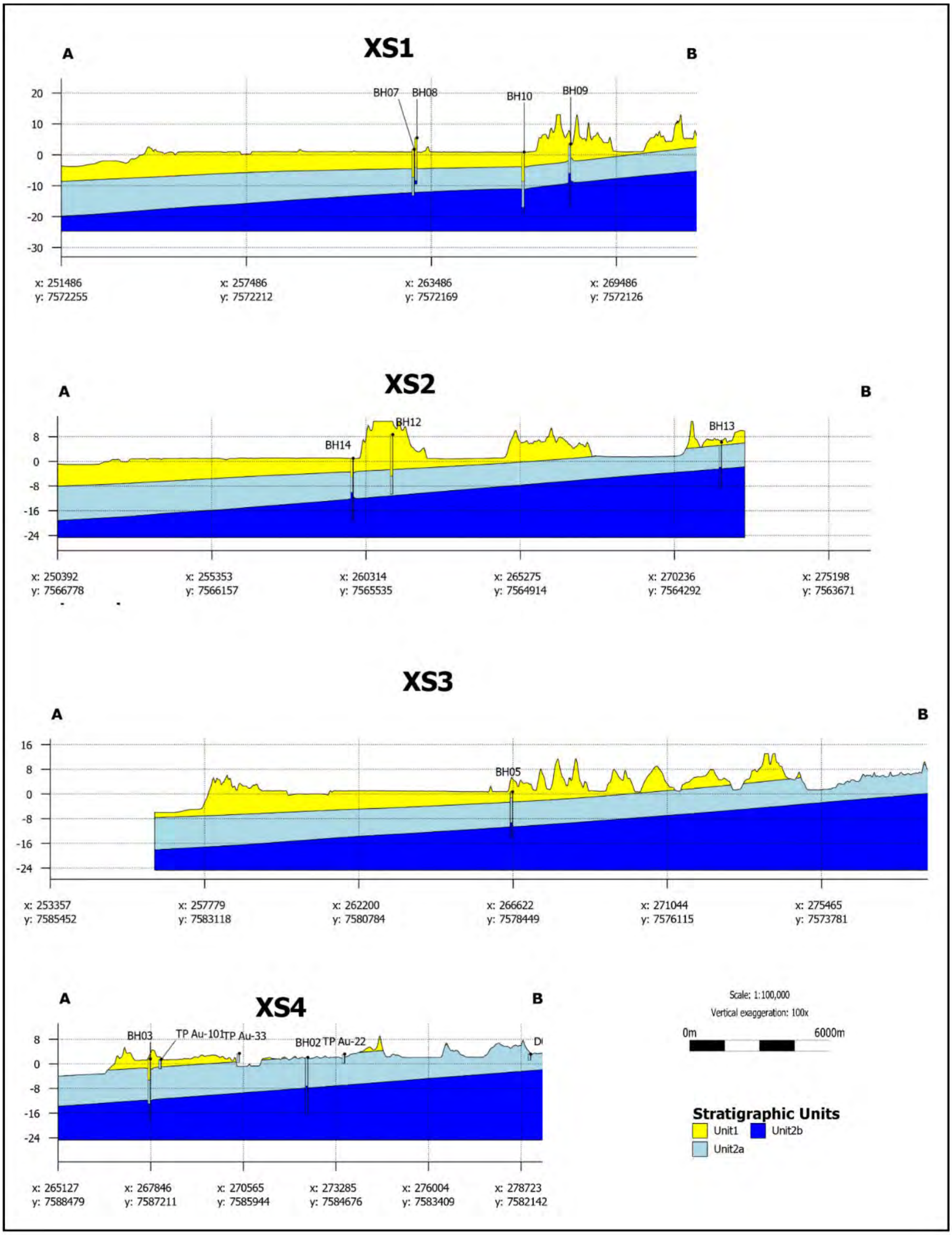


Figure 8-2: HSUs Representation along Sections XS1 to XS4

8.4 Hydraulic Parameters

Each of the three HSUs delineated within the conceptual model domain is a surrogate for aquifer material with distinct hydrogeological properties. Based on the review of testing results from the site, and published values from adjacent projects, estimates of hydrogeological properties are summarised in Table 8.2.

Table 8.2 Ranges of Hydraulic Conductivity, Specific Yield and Specific Storage Values for Respective HSUs

HSU	Kh (m/d)	Kz factor	Sy	Ss (m^{-1})
Unit 1	0.2 to 9.5	0.05 to 1	0.05 to 0.2	$1x10^{-6}$ to $5x10^{-5}$
Unit 2a	0.01 to 6.4	0.01 to 1	0.02 to 0.1	$1x10^{-6}$ to $5x10^{-5}$
Unit 2b	0.6 to 4.6	0.01 to 1	0.02 to 0.1	$1x10^{-6}$ to $5x10^{-5}$

Kz factor is a multiplier applied to Kh (horizontal hydraulic conductivity)

The ranges of hydraulic conductivity were obtained from on-site testing. Based on extensive double ring infiltrometer testing, the vertical hydraulic conductivity (Kz) value for Unit 1 is considered to range from 0.1 to 0.3 m/d, with an average of 0.2 m/d. Storage values reflect typical values for unconsolidated sediments (for example, based on the work undertaken by Rau et al. (1998) and confirmed by the available pumping tests.

An important parameter for estimating the mass of salt in the subsurface environment and the transport of dissolved phase salt in groundwater is the effective porosity. While lithological materials such as clay are known to have high total porosity, the specific yield, representing the drainable portion of porosity, can be very low due to the mineralogical structure of clay e.g. typically less than 5% (Johnson, 1966). Similarly, the portion of porosity through which groundwater can flow (effective porosity) is typically smaller than the total porosity but larger than the drainable porosity.

McWorter and Sunada (1977) provides an expected range of effective porosity for different lithological materials, with an average of around 30% for fine to medium sand and 6% for clay. More recent studies undertaken by Payne et al (2008) suggests that the effective porosity should be replaced by a much smaller “mobile porosity” to describe the transport of solutes in groundwater based on the findings of tracer studies. For most lithological materials, this was estimated to range from 2 to 10%. The subsequent work by Kulkarni et al (2020), based on the analysis of 141 bore logs, suggests that the average mobile porosity is around 11%, which is less than the typical effective porosity of around 25% often quoted in the literature but slightly higher than the 10% upper limit presented by Payne et al (2008).

For the purpose of this assessment, an effective porosity of 10% is considered appropriate. This is consistent with the average of Kulkarni et al (2020) and is much less than the total porosity for the lithologies encountered at the site (but greater than their expected specific yield). In the context of the transport of salt and the assessment of potential impact on down gradient receptors, an effective porosity of 10% is considered realistic and sufficiently conservative given an upper bound estimate of 20% is considered plausible locally, particularly within Unit 1 where sand is more abundant.

8.5 Hydrogeological Processes

8.5.1 Effect of Holocene Sea-Level History on the Groundwater Regime

Lewis et al. (2013) indicates that the mean sea level off the coast of Australia peaked at around 2 m above the current level (roughly 9,000 to 5,000 years ago) and the sea level has been trending down at a rate of roughly 0.3 m per 100 years since. This was caused by developing climate patterns following the last glacial maximum that occurred approximately 18,000 years ago, which represent the most extreme dry conditions.

Figure 8-3 provides the estimated sea level in Western Australia, showing a steady decline over the last 7,000 years. This means the majority of the current project area was permanently inundated for several thousand years and became exposed over relatively recent time (geologically speaking) as the sea level declined towards the current level.

A schematic representation of the difference in the position of the coastline over the conceptual model domain based on the present day topography and assuming a 2 m higher mean sea level in the past is presented in Figure 8-4.

The mean sea level trend indicates that the aquifers over much of the project area were submerged in the past, resulting in groundwater salinity approximately equal to that of seawater roughly 5,000 years ago. Over the period of 5,000 years the sea level fell and the water table gradually dropped to re-equilibrate with the new sea level, with groundwater discharging offshore and via evapotranspiration. The salts supplied by periodic tidal inundation/storm surge and throughflow slowly accumulated in the low-lying inundation area/supratidal flats, resulting in the formation of hypersaline groundwater that exists today.

Rainfall derived recharge over the broader area has mobilised salts previously accumulated in the unsaturated zone and partly flushed them out over the period of the regressing sea level, with rainfall recharge having a net freshening effect. The salinity of groundwater in bores outside of the tidal inundation zone, in more elevated areas with less intense evapotranspiration, ranges from 21 to 40 g/L, indicating either very little salinisation, or local freshening of groundwater by recharge along the coastal dunes.

Prior to sea level regression, the salinity of upgradient groundwater may have been higher than that of seawater due to tidal inundation/storm surge and evapotranspiration (the same processes resulting in the present day salinisation of groundwater down gradient). This is an important consideration because the initial aquifer salinity influences the assumed rate of accumulation of salts and the dilution effect of rainfall recharge/aquifer throughflow.

Figure 8-4 provides a schematic representation of hydrogeological processes of the Holocene past and present and conceptual development of a groundwater regime that led to currently experienced salinity patterns in groundwater in the area.

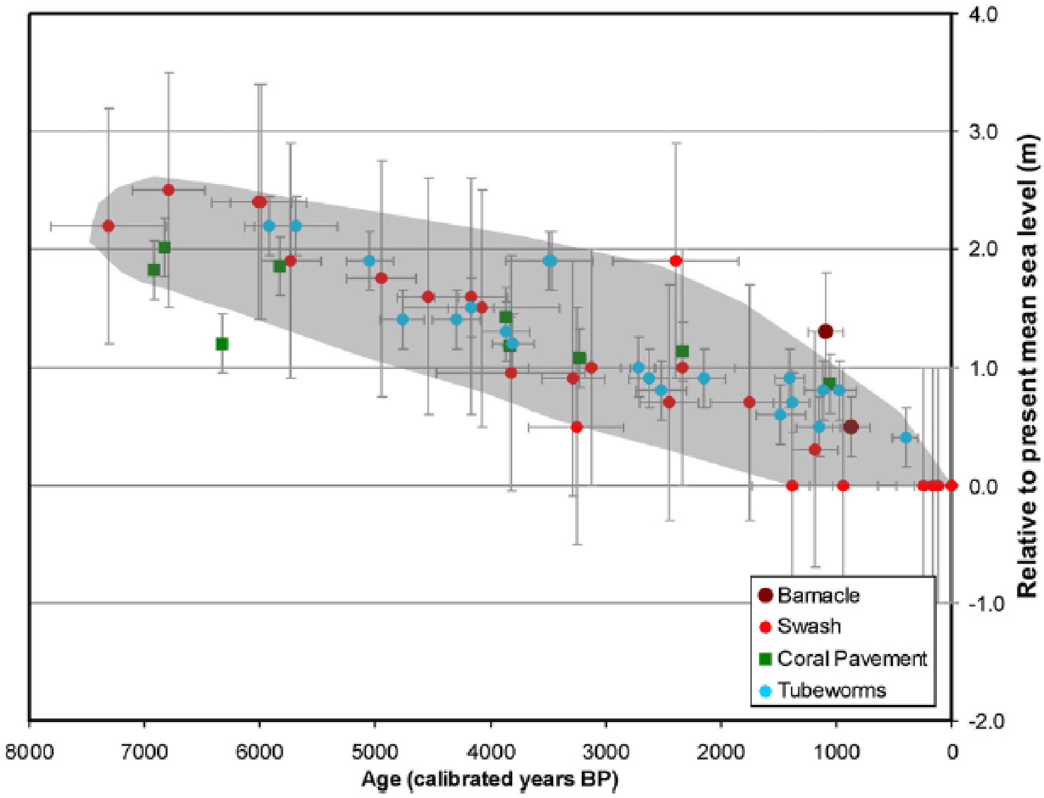


Figure 8-3 Sea Level over past 7,000 Years in Western Australia (after Lewis et al., 2013)

DC Blandford and Associates (2005) discuss the role of the present surface forms and the complex hydrological relationships related to the on-going development of the Ashburton River palaeo-super delta, which has the surface area of approximately 700 km^2. Ongoing sediment deposition on the super-delta has resulted in the development of a number of palaeodrainage lines. Of the three main ones, the important one for the project area is a northwest-flowing palaeodrainage line which approximately bisected the super-delta to the north-west of the alluvial plain and discharged in the vicinity of the current Chinty Creek (map 5).

With the onset of aridity (about 25,000 years ago) came the development of the Carnarvon Dunefield and finally, during and following the already discussed small marine transgression, the extensive salt flats of the Onslow Salt Plain were formed which contain hypersaline groundwater today. The development of the salt flat resulted from tidal action, wave action and cyclonic storm surge (and possibly from the role of prehistoric tsunamis, with some evidence available at Learmonth, DC Blandford and Associates, 2005).

In summary, the current groundwater regime of the project area can be characterised by the net discharge of groundwater flowing into the project area from the east, with the presence of hypersaline groundwater beneath the supratidal flats. The Holocene history suggests that hypersaline groundwater formed gradually over time from combined actions of:

- Seawater submersion;
- Evaporitic concentration of salts supplied periodically by tidal inundation and storm surge (after accounting for any loss due to tidal flushing); and
- Contribution from the regional through-flow from east to west.

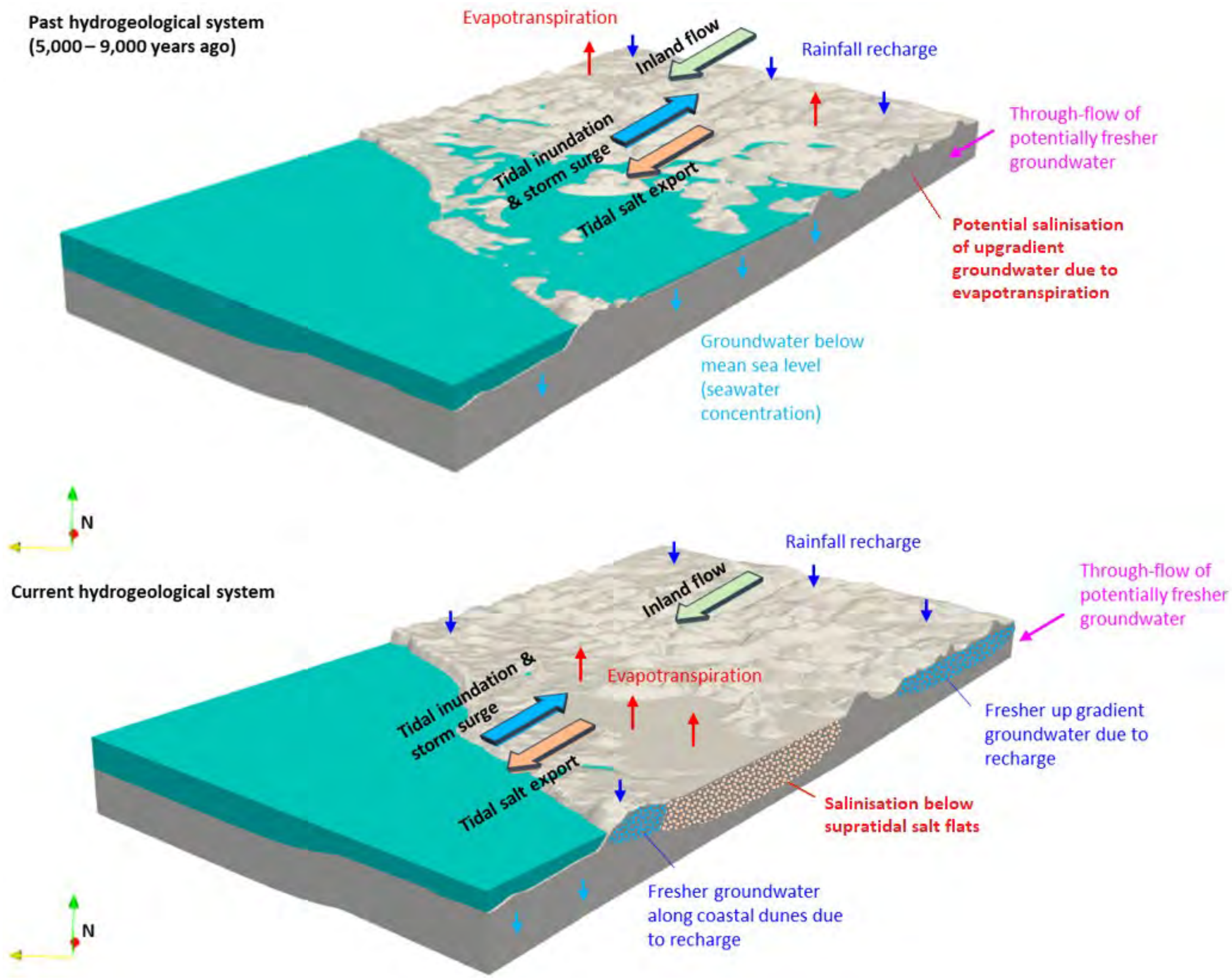


Figure 8-4 Key Hydrogeological Processes Occurring through Holocene Period to Recent

8.5.2 Groundwater Recharge

Recharge to the shallow groundwater system generally represents the proportion of rainfall that reaches the water table and contributes to the water balance of the aquifers. It is a complex process that depends on several factors that include rainfall intensity, frequency and duration as well as land use, topography, groundwater depth and unsaturated zone conditions.

In view of these factors, the following characteristics of the project area provide indications of recharge dynamics:

- Relatively shallow depth to groundwater of less than a metre in the salt flats, increasing to several metres in dune fields;
- Soil and unsaturated zone conditions that permit rainfall, if in sufficient quantity, to reach the water table quickly;
- Uneven rainfall intensity and frequency;
- Sparse vegetation cover; and
- High evaporation and evapotranspiration.

A combination of high evaporation rate and shallow groundwater suggests that net recharge (the portion that reaches groundwater and contributes to its water balance) is likely to occur only in topographically elevated areas over dune fields and mainland remnant sand islands. Any rainfall or surface runoff contribution from rainfall on the salt flats is likely to be removed quickly by evaporation and evapotranspiration, resulting in no net increase in groundwater quantity.

In this sense, groundwater recharge in the salt flat area can be thought of as a short-term diluting factor but with quantities relevant to groundwater flow only material in the mainland dune field to the east and mainland remnant islands. Even in these areas of net recharge, the water level logger data indicated an immediate and short-term groundwater response to a rainfall event before the water levels returned to the pre-rainfall levels.

In the supratidal zone of the salt flats, incoming seawater during extreme spring tides (which occur in March and April) and occasionally from storm surges, can also be conceptualised as a form of groundwater recharge that fills up the thin unsaturated zone quickly. Due to evaporation action, this component of recharge has an important role in supplying salts to the supratidal flats, contributing to the ongoing development of hypersaline groundwater. Part of the salinity mass present at the ground surface or in the near surface portion of the aquifer can be also exported by outgoing tide. The tidal flushing process is described further in Section 8.5.5.

8.5.3 Horizontal Groundwater Flow

Horizontal throughflow represents the component of groundwater that enters the project area laterally from the upgradient areas to the east. It is driven by the groundwater flow (hydraulic) gradients, which are controlled by recharge and discharge processes. It is conceptualised that:

- There is a net inflow (convergence of flow lines) from topographically elevated areas (zone of net recharge) to the low-lying area of salt flats (zone of net discharge). This contribution from the inland areas can be estimated using the groundwater flow gradient calculated between the most upgradient monitoring bore BH13 (approximately 3 m AHD) and the salt flat area that is approximately 4,500 m downgradient (approximately 0.7 m AHD). This is equal to a groundwater flow gradient of around 0.0005, or 0.5 m head loss for every kilometre along the flowpath;
- Groundwater within the area of salt flats is essentially stagnant, with extremely low groundwater flow gradients due to net evaporation. The groundwater flow gradients (and

directions) vary periodically in response to tidal inundation, storm surge and flow of flood waters from inland, but only for short periods of time; and

- Hypersaline groundwater beneath salt flats forms a wedge, creating a salinity/density barrier against less saline groundwater from further upgradient.

It follows that most of the horizontal groundwater flow component entering the project area discharges in the salt flats, which acts as a local groundwater sink. It is therefore possible that only a small portion of the shallow (Quaternary) horizontal groundwater flow from the upgradient areas ultimately reaches the ocean boundary.

The presence of dense, hypersaline groundwater underlying the salt flats creates a density barrier, forcing fresher groundwater from upgradient areas (dune fields to the east) to flow up along the hypersaline wedge and discharge at surface along the edge of salt flats.

8.5.4 Evaporation and Evapotranspiration

Evaporation and evapotranspiration from groundwater can occur via three major mechanisms:

- Direct evaporation from groundwater in areas of tidal inundation or where the water table emerges at or is close to surface. This includes parts of the salt flats and fringing inland areas where shallow groundwater is forced up along the hypersaline wedge;
- Evaporation from within the unsaturated zone, where the unsaturated zone is typically less than a metre thick (typically 0.2 to 0.4 m during field investigations in 2020) in parts of the salt flats;
- Transpiration by deep-rooted terrestrial vegetation, extracting groundwater from within the saturated zone (and often from the capillary fringe above the water table via negative suction pressure). This may occur in dune field areas and sand islands where vegetation cover is developed and groundwater is potentially accessed to meet some or all of its water requirements;
- In dune fields, both seaward and landward of the salt flats, the water table is deeper and likely to be below the extinction depth of evaporation (depth below which evaporation becomes zero); and
- The evaporation rates in the project area are high (mean annual evaporation is over 3 m) and evaporation and evapotranspiration are considered the major discharge components of the groundwater flow balance. Evaporation rates are also influenced by salinity, with studies typically indicating a decrease in evaporation from water bodies is associated with an increase in their salinity (Levy, 2012).

8.5.5 Groundwater Salinity

The conceptualisation of salinity development has been discussed in previous sections, associated with the Holocene sea level transgression and groundwater discharge via evapotranspiration that resulted in dense hypersaline groundwater underneath the salt flats.

The measured salinities in the salt flats are in the order of 220 to 260 g/L in shallow groundwater, with salinities reducing to around 80 to 90 g/L towards the dune fields and sand islands. Outside of the salt flats, salinities reduce to between 20 to 70 g/L over areas of net recharge (Map 8).

Hypersalinity leads to groundwater reaching solubility limits with respect to dissolved ions, resulting in the precipitation of salts from the groundwater system and formation of salt crusts on ground surface (refer to Section 8.5.5 for more discussion). Saturation indices calculated from samples collected in September 2020 using the hydrochemical software PHREEQC2 indicate oversaturation with respect to gypsum, anhydrite, calcite and dolomite and levels close to saturation with respect to halite for samples within the salt flats. This is consistent with the presence of natural salt crusts that are observed across the site and are easily identifiable from aerial imagery.

8.5.6 Tidal Flushing and its Effect on Present Day Salinity

Supratidal Zone

The supratidal zone (salt flats) is characterised by infrequent tidal inundations, intense evaporation and salt crust on the surface. Salt is transported into the supratidal zone by tidal water during extreme spring tides (March and April), which recharges groundwater and temporarily raises the water table to the surface. A sustained period of evaporation following the tide results in the salinity of pore water increasing, leading to the precipitation of salt at the surface when the solubility limit is reached. As the water table subsides, some of the salts are retained in the soil pores, leading to the formation of a salt crust.

The formation of salt crusts in supratidal zones has been attributed to a combination of shallow water table and sustained evaporation in various studies (Shen et al, 2018). Historically, salts in less frequently inundated areas may have also accumulated from the throughflow of saline groundwater that became trapped by evaporation in the low-lying supratidal zone. Numerical simulations have demonstrated that shallow water table can result in an upward transport of salt within the unsaturated zone via capillary fringe (negative pore pressure) under the condition of high evaporation (Geng et al, 2016, Zhang et al, 2014, Shen et al, 2018). This can lead to the precipitation of salt from shallow groundwater via upward flow.

Salt Export through Tidal Action

As the salt flats and algal mats are inundated, some of the salt crystallised at the surface, is dissolved and transported away as the tide recedes. Data from other similar sites have identified large increases in the salinity of receding tidal water following spring (high) tides (Paling 1986, Ridd et al, 1988). Field observations during the April 2020 spring high tide also confirmed that water remains ponded at the surface (and groundwater levels elevated) for some time after the tide receded. This suggests that some of the salts accumulated from prior tidal inundations is exported during the subsequent tidal inundation, while the remnant water and elevated water table results in further precipitation of salt (replacing some of the salts flushed away).

The presence of salt crusts and hypersaline groundwater beneath the supratidal zone means there would have been a long period of net import of salt to the system i.e. more salt added to the system than taken away for salt to accumulate in a sufficient quantity to result in the conditions observed today. Over time, as the salt crust and hypersaline groundwater developed, the export of salt via tidal flushing is likely to have become an increasingly larger component of the salt mass balance in the supratidal zone.

Estimating the net export of salt under the current condition is not straightforward. Paling (1986) indicates that at King Bay, Dampier Salt, the tidal water entered the tidal flats at a salinity of 40 g/L and left at 60 g/L, indicating an increase in the salinity of tidal water by 20 g/L. Ridd et al (1988) provides a more detailed analysis of salinity changes following the first summer spring tide in the salt flats of north-east Australia, equating to around 90 g of salt exported per m^2 of salt flats.

To put this into context, if the algal mat area is considered on its own, the potential salt exported from the hydrogeological domain could be as much as 4.6 million kg per tidal inundation (for a mapped algal matarea of around 51 km^2, AECOM 2021). The typical submersion frequency of the algal mats area is 1% to 3% (AECOM, 2021), which would equate to around one tidal flushing per month or potential salt export of 55 million kg annually from the study domain.

Paling (1986) noted that the salinity of groundwater beneath algal mats in a similar environment remained consistent throughout successive tidal cycles, indicating poor connectivity with groundwater. This is consistent with the presence of mud flat clays, which are relatively impermeable due to the absence of crab holes or other bioturbation. The implication is that, while large quantities of salt can be flushed out from the algal mats and salt flats by infrequent tides, salts from the underlying groundwater system may not be removed at a rate high enough to cause notable changes to its salinity over the short term.

This suggests that salt flushed via the dissolution of surface salt crystals is partly replenished by the evaporation of remnant water and shallow water table recharged by tidal water, with very little changes to the groundwater salinity. In this sense, the salinity of groundwater in the supratidal zone can be considered to be in a quasi-steady state condition, with groundwater salinity typically ranging from 100 to 200 g/L below algal mats (Paling, 1986, Gulf Holdings, 1990).

Intertidal Zone Occupied by Mangroves

The mangrove occupied intertidal zone is frequently inundated by tidal water, which flushes salts accumulated by evapotranspiration and maintains less saline groundwater at the watertable. The presence of mangrove habitats in the intertidal zone is a strong indicator of regular flushing, as the salinity in the soil and groundwater must be maintained at concentrations suitable for mangrove survival. The data from similar mangroves habitats indicate shallow groundwater salinity ranging from around 40 to 55 g/L on the coastal side to around 70 to 90 g/L in the more landward section (AECOM, 2021, Gulf Holdings, 1990).

The mangroves and adjacent mudflats are located in areas with a high density of crab holes and other bioturbation that serve as conduits for tidal water to mix with shallow groundwater. This means the relatively low ground elevation of the mangrove and adjacent mudflat zone combined with the enhanced connectivity via crab holes and high frequency of flushing maintains the shallow groundwater salinity in the 40 to 90 g/L range by regular and effective tidal flushing.

The modelled submersion frequency curve indicates that the mangroves are inundated from around 50% of the time at the lower elevation end (on the coastal side) to around 5% of time at the higher elevation end on the landward side (Water Technology, 2021). Mangrove roots tap into the top 0.1 to 0.2 m of the watertable and thereforeare sensitive to the salinity of shallow groundwater within the top 0.1 to 0.2 m (AECOM, 2021), which is typically less saline due to the frequent tidal flushing.

The amount of salt exported from the mangrove area is difficult to estimate and is likely to be relatively small compared to the flushing of the algal mats and salt flats due to the higher frequency of inundation, resulting in a limited opportunity for salt to accumulate in the soils and groundwater.

8.6 Conceptual Water and Salt Balance

To place sensible constraints on the key components of the groundwater mass balance (recharge and discharge estimates), simple mass balance calculations of salt and groundwater fluxes have been considered.

For the calculation of mass balance, a hydrogeological timeframe of 2,500 years has been chosen. This corresponds to a period when the mean sea level was approximately 1 m above the current level (Figure 8-3) and the majority of the present day supratidal salt flatswere still below sea level (see Figure 5). It is considered a sensible starting point for estimating the progressive accumulation of salts as the mean sea level gradually receded and exposed the inundation area to evapotranspiration and periodic tidal inundation.

The source of salt in the supratidal flats is likely to be from infrequent tidal inundation and storm surge primarily, with a part contribution from aquifer throughflow and, to a lesser degree, rainfall recharge (carrying salts from within the unsaturated zone). Estimating the relative contributions of different salt and flow components is charged with uncertainty at a conceptual level because the past hydrogeological processes over a very long response time can only be inferred.

For example, it is not known whether groundwater upgradient of the project was indeed more saline in the past and became fresher over time as the sea level receded, resulting in varying contributions to salt accumulation. Similarly, rainfall recharge may have initially leached salts in the soil but become increasingly freshening over time.

In light of these limitations, each component of the conceptual salt and flow mass balance is considered individually, using a range of potential parameter values and assumptions, to demonstrate their plausible range and, most importantly, to place sensible bounds for guiding the subsequent model calibration efforts.

The conceptual mass balance calculations indicate the following:

- The rate of loading of salt by tidal inundation depends on the assumed initial and current groundwater salinity beneath the inundation area and effective porosity (storage) of the aquifers. For the purpose of mass balance calculations, the inundation area has been defined based on the mean high tide of 1 m above mean sea level and the source of salt is assumed to be entirely due to tidal inundation/storm surge (with a typical seawater concentration of 35 g/L, which when moved inland has been indicated to rise up to 41 g/L). For effective porosity ranging from 0.1 to 0.2 (based on the expected range of values for clayey sand/sandy clay) and present day salinity of 200 to 300 g/L, the incremental increase in salt mass over 2,500 years (salt load) equates to average seawater inundation/loading rates of 6 to 18 mm/year. Note that these refer to the potential rates of net import of salt into the area of hypersaline groundwater, after accounting for any losses due to tidal flushing i.e. surplus salt added to the groundwater system;
- The estimated inundation rates are towards the lower end of the potential infiltration rate inferred from a 0.5 m increase in groundwater level observed during a spring tide event in April 2020. For example, a specific yield of 5% would imply 20 mm infiltration to produce a 0.5 m increase in groundwater level after a single tidal event. However, this is based on observations at a single location and the net annual infiltration is expected to vary depending on the extent of each tidal event and antecedent effects from prior tidal events, which are currently not well understood (including any periodic flushing of salts that may be associated with large but infrequent inland flooding events). The mass balance calculations seek to estimate the average net inundation/loading rates over a very long timeframe that would result in the observed groundwater salinity for the whole inundation area;
- The flat hydraulic gradient observed across the project area implies low aquifer throughflow and rainfall-derived recharge and in this case is also indicative of the terminal stage of groundwater flow and associated salt mass. Based on the range of hydraulic gradients (from 3 to up to 6 m head difference between the inundation zone and upgradient head boundary at various points) and weighted arithmetic mean hydraulic conductivity of 2 to 3 m/d from field testing, the aquifer throughflow in the project area is estimated to range from around 660 m^3/d to 3,740 m^3/d (0.24 to 1.36 GL/yr). If groundwater were assumed to completely terminate in the inundation (discharge) area, the throughflow would equate to discharge rates of 1.4 to 7.7 mm/year (per unit inundation area) for the lower and upper estimates of throughflow respectively. The

recharge rate required to maintain the gentle hydraulic gradient would be equally small, in the order of a few mm per year;

- Another method of constraining regional recharge would be to assume that the salts accumulated in the inundation area are supplied primarily by throughflow and derive recharge from the volumes of throughflow required to accumulate the estimated salt load. For example, assuming in-flowing groundwater salinity of 35 g/L, recharge required over the conceptual model domain (onshore area outside the inundation area), would be 1.4 and 8 mm/year for the lower and upper estimate of salt loads, respectively. In reality, the salts are more likely to derive primarily from tidal inundation/storm surge and there is evidence of slight freshening of groundwater due to recharge; however, this simple calculation is useful for placing a sensible upper bound on long-term average regional recharge, which is unlikely to be more than several millimetres per year;
- The Bureau of Meteorology long-term average actual and potential evapotranspiration are approximately 300 and 1,600 mm/year, respectively. During tidal inundation, when the supply of surface water is large, evapotranspiration is likely to be towards the upper end of this range. Although the evapotranspiration, inundation/loading and recharge rates are poorly constrained, the mass balance calculations indicate that net inflow (inundation and recharge) is likely to be far below the potential rate of evapotranspiration. The groundwater system is therefore conceptualised as a net discharge system, consistent with the accumulation of salts required to produce hypersaline groundwater; and
- Over time, evaporation rate in the inundation area is likely to have reduced due to the salinisation and formation of salt crust. Studies undertaken in other similar environments have identified reductions in evaporation with salinity. An assessment undertaken by Morton Salt (2019) suggests around 22% reduction in pan evaporation can be expected over salt ponds. The relationship between evaporation ratio and specific gravity presented in Levy (2012) indicates a similar reduction in evaporation for average total dissolved solids (TDS) of 200 g/L, although for TDS of up to 400 g/L evaporation over salt flats could be as much as 40% less. A similar reduction in evapotranspiration is considered possible over the highly saline inundation area.

The water and salt balance from tidal inundation derived for the conceptual domain is presented in Table 8.3. The calculations are intended to provide indicative rates of net import of salt to the groundwater system based on the potential mass of salt accumulated in the aquifers, after accounting for losses due to tidal flushing.

Table 8.3: Salt Load Calculation from Tidal Inundation

Parameter	Lower	Upper
Inundation area (m^2)	176,920,000	176,920,000
Effective porosity (%)	10	20
Effective pore water volume (m^3)	512,534,769	1,025,069,537
Initial concentration (g/L)	35	35
Initial salt mass (kg)	17,938,716,900	35,877,433,799
Existing TDS (g/L)	200	300
Salt load (increase in salt mass) (kg)	84,568,236,812	271,643,427,337
Inundation water concentration (g/L)	35	35
Inundation volume (m^3)	2,416,235,337	7,761,240,781
Hydrogeological timeframe (years)	2,500	2,500
Inundation/ loading rate (mm/year)	6	26

Note: Effective pore water volume represents the volume of groundwater in hydraulically connected pore spaces. Salt load is the amount of salt accumulated in the pore volume under the inundation zone over the assumed timeframe.

Inundation volume is the volume of seawater required for the estimated salt load, from which the inundation/loading rate can be calculated per unit inundation area (inundation volume/inundation area/2,500 years)

The water and salt balance does not include the mass of salt held in the salt crust on the surface or in the soil pores, which cannot be readily estimated and is influenced by the highly uncertain tidal flushing process (in terms of the mass of salt exported).

The water balance for the model area that assumes quasi-steady state conditions is estimated as shown in Table 8.4.

This water balance assumes recharge and lateral inflow from inland areas as inflow components. The recharge for inundated areas also includes the combined effect of tidal inundation.

The major outflow components are evaporation and lateral outflow. The evaporation term cannot be readily constrained, i.e its potential capacity is larger than the sum of estimated inflows.

Table 8.4 Conceptual Water Balance

Component/Process	Rate (m^3/d)	Rate (GL/yr)	Comments
Recharge (inundation)	2,908	1.06	Represents combined effects of inundation and occasional inland runoff (6 mm/yr
Recharge (outside of inundation)	3,480	1.27	Diffuse recharge in dunes etc (2 mm/yr)
Lateral inflow from inland areas	664	0.24	Based on K=2 m/d; hydraulic gradient 0.00032
Subtotal (inflows)	**7,052**	**2.57**	
Lateral outflow	-1,723	-0.63	Based on K=2 m/d, hydraulic gradient 0.00083
Evaporation	-5,326	-1.94	Limited only by inflow (it can be an order of magnitude larger). Due to general lack of transpiring vegetation it is assumed to occur only where water table is at or close to surface in salt flats
Subtotal (outflows)	**-7,052**	**-2.57**	

Within the model domain, the total water-carrying capacity of the shallow aquifer system is estimated at 2,355 GL, assuming a porosity value of 0.1. Based on consideration of average concentrations for inundated and non-inundated areas (at approximately 150 and 10 g/L respectively), the shallow aquifer is estimated to contain 188 GT (gigatonne) of salt.

Tidal action and regular inundation are expected to export some of the salts from the inundated areas. This is difficult to quantify given the uncertainty of how much tidal imported water would eventually leave the inundated area. Salt crust has developed at the surface of the inundated areas. It is partly dissolved by the incoming tide and the mobilised salts are exported with the outgoing tide. The salt inventory at the surface of the inundated areas is however also replenished by evaporation from remnant ponding water that stays behind the outgoing tide.

(1) Tidal inundation net salt load

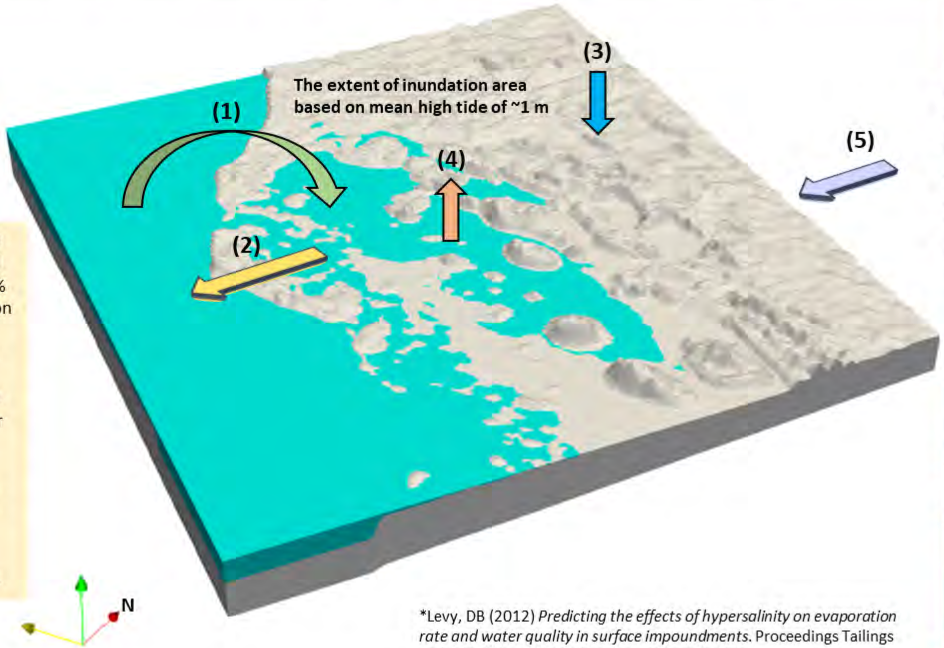
Parameter	Lower	Upper
Inundation area (m2)	176,920,000	176,920,000
Effective porosity (%)	**10**	**20**
Effective pore water volume (m3)	512,534,769	1,025,069,537
Initial Concentration (kg/m3)	35	35
Initial salt mass (kg)	17,938,716,900	35,877,433,799
Existing TDS (kg/m3)	**200**	**300**
Salt load (increase in salt mass) (kg)	84,568,236,812	271,643,427,337
Inundation water concentration (kg/m3)	35	35
Inundation volume (m3)	2,416,235,337	7,761,240,781
Hydrogeological timeframe (years)	2,500	2,500
Net inundation/ loading rate (mm/year)	**6**	**18**

Estimates of potential net salt loading rates in the inundation area have been derived based on simple mass balance calculations, assuming an initial concentration of 35 kg/m3. The calculations assume the source of additional salt is entirely from tidal inundation/storm surge (after accounting for loss due to tidal flushing). The estimates of the loading rate are sensitive to the assumed timeframe, effective porosity and representative existing concentrations, which vary from around 80 – 400 kg/m3, with an average of 200 kg/m3 (and 300 kg/m3 chosen as a representative upper estimate). Although the calculations are simplified, the range of loading rate (expressed per unit area) is considered within the plausible range of recharge and is far below the potential range of evapotranspiration. This is consistent with the inundation area acting as a zone of net discharge, resulting in the accumulation of salt over time.

Note: effective pore water volume represents the volume of groundwater in hydraulically connected pore spaces. Salt load is the amount of salt accumulated in the pore volume under the inundation zone over the assumed timeframe. Inundation volume is the volume of seawater required for the estimated salt load, from which the inundation/loading rate can be calculated per unit inundation area for seawater salinity of 35 kg/m3 (inundation volume/inundation area/2,500 years).

(2) Tidal flushing

Assuming a salt export rate of 90 g/m2 per inundation and around 12 inundations per year (~1 to 3% inundation), as much as 55 million kg of salt could be exported per year by tidal flushing of the algal mats area (primarily from the dissolution of salt crust). The salt that accumulates in groundwater is after accounting for this loss. Salt is also flushed out of the mangroves area although this is expected to be small due to the high frequency of flushing that maintains the groundwater salinity fresher at 40 – 90 kg/m3.



*Levy, DB (2012) *Predicting the effects of hypersalinity on evaporation rate and water quality in surface impoundments*. Proceedings Tailings and Mine Waste 2012, Keystone, Colorado, USA.

(3) Rainfall recharge

In a quasi-steady state system, hydraulic gradient is controlled by the ratio of recharge to hydraulic conductivity and topographical constraints imposed by evapotranspiration. Given the gentle hydraulic gradient and only slightly fresher groundwater observed in regional bores (compared to seawater), the natural rate of rainfall recharge would be expected to be generally low. This is supported by low estimated aquifer through-flow and therefore low recharge required to maintain the gentle hydraulic gradient.

(4) Evapotranspiration

The BoM long term average areal actual and potential evapotranspiration is around 300 and 1,600 mm/year, respectively. The daily evapotranspiration calculated at Learmonth Airport is much higher (around 2,800 mm/year in 2019). During periods of tidal inundation/storm surge, when the supply of surface water is plentiful, the evapotranspiration rate would be towards the upper end of this range.

Over time, effective evapotranspiration in the inundation area is likely to have reduced due to the salinisation and formation of salt crust. An assessment undertaken by Morton Salt suggests around 22% reduction in pan evaporation over salt ponds. This is broadly consistent with the evaporation ratio presented by Levy (2012)* for TDS of 200 kg/m3, although for TDS of up to 400 kg/m3 evaporation over salt flats could be as much as 40% less. A similar reduction in evapotranspiration is considered likely over the highly saline inundation area.

(5) Aquifer through-flow

Parameter	Lower	Upper
Hydraulic gradient	0.00032	0.0012
Saturated thickness (m)	29	29
Aquifer width (m)	35,800	35,800
Hydraulic conductivity (m/d)	**2**	**3**
Through-flow (m3/d)	**664**	**3,738**
Normalised discharge (mm/year)	1.4	7.7

Aquifer through-flow has been estimated based on average saturated thickness and a range of plausible hydraulic gradients (based on a range of upgradient heads and flow distance) and hydraulic conductivity from field testing.

Note: normalised discharge refers to through-flow normalised against the tidal inundation area. It represents the discharge rates required if all groundwater were to terminate in the inundation area and also provides an indication of recharge rate required to maintain the hydraulic gradient. The normalised discharge rates are low, consistent with the gentle hydraulic gradient, and are far below the potential rate of evapotranspiration.

These images show inundation due to a spring tide event in April 2020, resulting in the majority of the inundation area flooded (as shown in the block diagram)

Figure 8-5 Key Conceptual Water and Salt Balance Components

8.7 Project-Anticipated Changes to Baseline Conditions

Due to the nature of solar salt production, the proposed footprint of the project is relatively large and centred on the salt flat area. The inundation of salt concentration ponds with seawater will progressively increase their salinity from approximately 40 g/L in Pond 1 to 270 g/L in Pond 8 and will directly affect groundwater underneath the ponds.

The anticipated effects associated with the pond operation are as follows:

- Ponds will be elevated above the existing water table, providing an additional source of water to the groundwater system via downward seepage that may result in spatially limited groundwater mounding;
- Due to the limited unsaturated zone thickness, groundwater may express to the surface and cause waterlogging. Due to high evaporation rates and shallow groundwater, this effect is likely to be limited only to the immediate vicinity of the ponds.
- Density-driven effects are likely to influence how water seeps from the ponds and redistributes in the subsurface. Where the pond salinity is close to that of seawater, denser, more saline groundwater underneath the ponds could limit the seepage of less dense pond water. Conversely, where the pond salinity exceeds that of underlying groundwater (likely to occur in Ponds 7 and 8), the seepage rates may increase due to the density differences;
- Import of fresher seawater and subsequent seepage has the potential to decrease the groundwater salinity under the largest ponds (Ponds 1 and 2);
- Evaporation at the fringes of the ponds may create a high salinity interface between groundwater underneath the ponds and fringing areas of the ponds. This would be expected to be most pronounced where the salinity in the fringing area is increased by the displacement of hypersaline groundwater from underneath the ponds and the trapping of salts by evaporation. If the groundwater salinity exceeds solubility, and this occurs in areas of shallow water table, salts may precipitate at ground surface, leading to the formation of salt crust; and
- Pond floors may silt up during their operational life and/or develop salt crusts, which could reduce the rate of seepage of pond water over time. The extent to which this occurs is difficult to estimate.

Other project features that have the potential to interfere with groundwater include borrow pits, located adjacent to Ponds 4, 5, 6 and 7. The lowering of existing ground surface at these pits could result in a condition of very shallow water table, potentially leading to discharge of groundwater via evapotranspiration and an increase in groundwater salinity from the accumulation of salts.

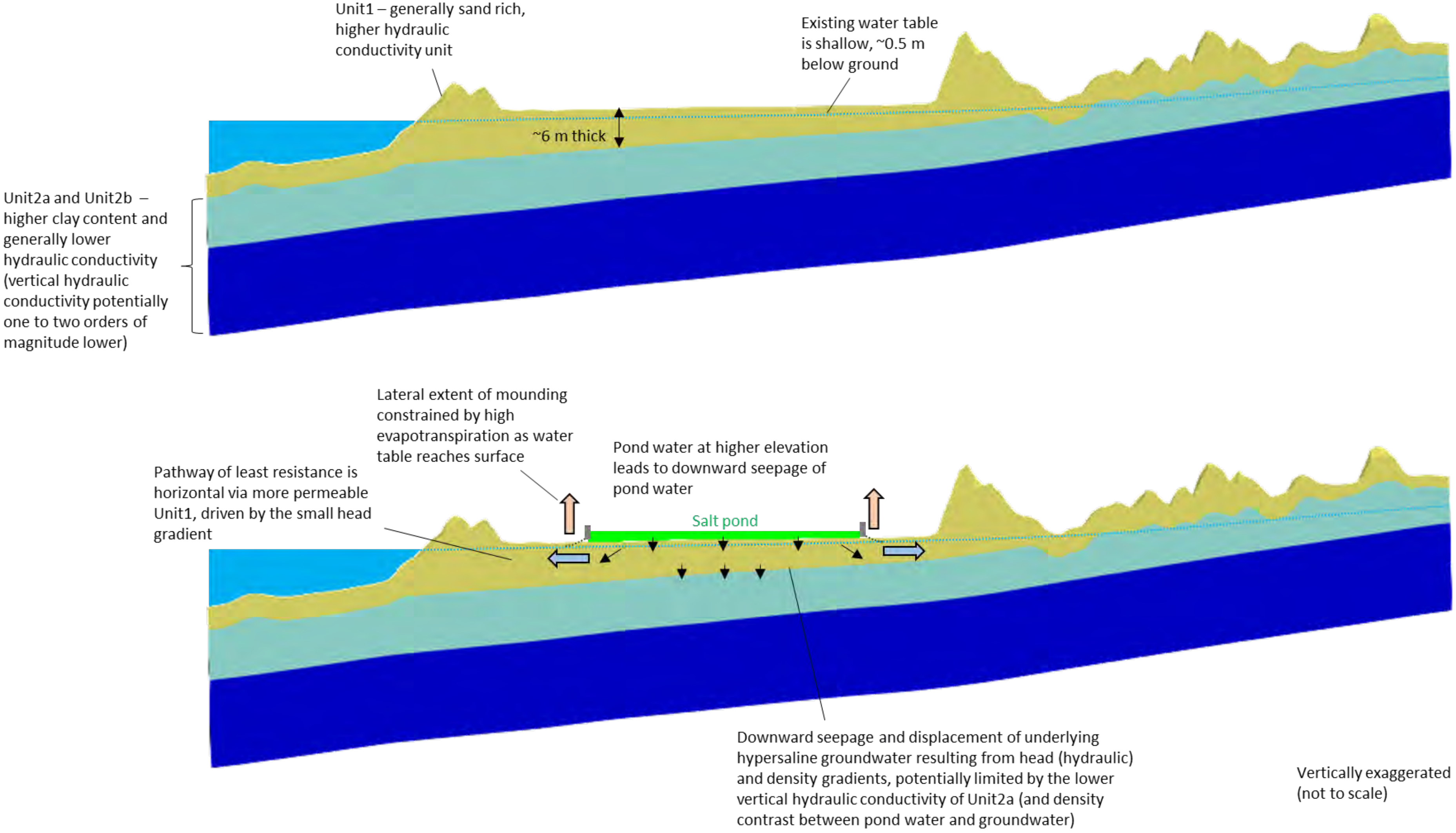


Figure 8-6 Anticipated Project-Induced Changes

9. Numerical Groundwater Flow and Transport Model

9.1 Modelling Context

9.1.1 Modelling Objectives

The Ashburton Solar Salt project will involve the construction of salt concentration ponds and crystalliser ponds, which will concentrate and evaporate seawater in order to harvest salt. As the ponds would be elevated above the existing water table, they will act as a source of water to the underlying aquifer for the duration of the project. K+S have indicated that pond permeability decreases over time as silt and biological matter build up on the pond floors, however as a conservative assumption a reduction in permeability over the project life has not been simulated. In recognition of limited data a sensitivity analysis has been undertaken to examine the possible effect of reduced permeability (hydraulic conductivity) of the pond floor, specifically the magnitude of reduction required before it results in a material difference to the groundwater seepage rate.

Surface water from the ponds will seep vertically through the thin unsaturated zone, which would raise the water table beneath the footprint of the ponds. This will create hydraulic head differences with the surrounding water table, resulting in the horizontal movement of groundwater.

Due to the shallow natural water table, the mounding has the potential to cause waterlogging at the surface which will be maintained by the ponds during their operational phase. As the concentration of salts in some of the ponds increases, the seepage of water could lead to possible salinisation of groundwater where the salinity of pond water is greater than that of the underlying groundwater. Conversely, where pond salinity is lower than that of the underlying groundwater this could lead to its relative freshening.

To the west of the proposed ponds lies communities of mangroves and algal mats. These ecosystems are sensitive to changes in the water table, in particular wetting and drying cycles, and changes in salinity. This means seepage of pond water has the potential to affect the health of these adjacent ecosystems, due to the potential alteration to the natural wetting and drying cycles (prolonged mounding of the water table) and salinity.

The purpose of the numerical modelling is to quantify the potential project-induced changes to groundwater levels, fluxes and salinity to assist with the assessment of groundwater impacts and risks, particularly to sensitive ecological receptors. To meet this intended model use, the modelling is required to:

- Simulate groundwater flow and solute (salinity) transport processes, accounting for the influence of density, at a regional scale commensurate with the large spatial extent of the salt ponds (approximately 87 km^2);
- Simulate the existing hydrogeological conditions, including the distribution of hydraulic heads and salinity, flow directions and components of water and solute balance, informed by the findings of field investigations and hydrogeological conceptualisation; and
- Quantify the magnitude, extent and duration of project-induced changes to groundwater levels and salinity, at a level of accuracy appropriate for the scale and complexity of the model, and for assisting with the assessment of impacts on sensitive ecological receptors i.e. salinity changes in the order of 10 to 15 g/L at the location of ecosystems, consistent with the typical range of salinity tolerance.

9.1.2 Modelling Approach

Staged Approach

Groundwater modelling described in this report has been undertaken in a staged manner, consistent with the recommendations of the Australian Groundwater Modelling guidelines (Barnett et al., 2012). The hydrogeological conceptualisation that underpins the development of the numerical model is described in the preceding section, followed by descriptions of Model Design and Construction (Section 9.2), Calibration (Section 9.3), Prediction (Section 9.4) and Uncertainty Analysis (Section 9.5).

Target Confidence Level

The Australian Groundwater Modelling Guideline (Barnett et al., 2012) recommend setting out a target confidence level at the start of the modelling process. While the actual confidence level achieved is not known until the outcomes of predictions are considered within the context of model calibration performance and data, the target confidence level provides a useful point of reference for setting out the modelling expectations.

As outlined in the guidelines, groundwater modelling is an iterative process with feedback expected between conceptualisation and numerical modelling. Insights obtained during numerical modelling may identify areas of deficiencies in the conceptual model or gaps in data. Aspects of conceptualisations that have been revised or enhanced through numerical groundwater modelling are highlighted in this section of the report.

According to the guidelines, the confidence in a model's ability to simulate potential future effects depends primarily on whether or not:

- Future stresses to be predicted by the model are similar to those of the past;
- Predictions are required for a period of time similar to that of historical observations;
- Available data sufficiently characterises hydrological features of most relevance to model predictions; and
- The model is capable of simulating the key hydrological processes and can be calibrated to available data.

As outlined in the hydrogeological conceptual model, the existing hydrogeological conditions are likely to have evolved over a very long period (~2,500 years or more), responding to hydrological and salinity changes such as receding sea level, salt loads from tidal inundation/storm surge, flushing/dilution from periodic inland flow and rainfall recharge and evapotranspiration.

Historical data is not available to enable these complex processes to be simulated in detail with confidence, nor is it feasible to do so from a practical point of view, using a regional scale density coupled flow and transport groundwater model. Instead, the focus of the modelling (or more appropriately, this model's calibration) is to simulate the net effect of these processes that would produce hydraulic heads and salinity that are consistent with those observed, at the end of a realistic simulation period.

The implication is that, although a long simulation time is required to replicate the existing conditions, the period of available historical observations used to inform the past behaviour remains small compared to the period of predictive simulation. Similarly, the future hydraulic stresses imposed by seepage from the ponds, in terms of the magnitude, extent and duration, would be large compared to those observed to date (such as localised drawdown imposed during pumping tests).

In this context, the target confidence level of one is considered appropriate, which is common for projects in remote areas with no long-term site specific data. This does not limit the usefulness of the model, the purpose of which is to quantify potential project-induced changes and evaluate associated uncertainty that cannot be readily reduced through calibration to existing data.

Through appropriate model design and calibration efforts, elements of higher confidence levels can also be achieved, including acceptable calibration, small mass balance errors and numerically robust results.

9.2 Model Design and Construction

9.2.1 Modelling Software

An unstructured grid version of the industry standard MODFLOW code called USG-Transport Version 1.5.0 (Panday, 2020) has been selected for this study.

This is based on the United States Geological Survey's MODFLOW-USG code (Panday et al., 2013), with several enhanced capabilities. Features of USG-Transport that are particularly suited to addressing the modelling needs and objectives include:

- The capability to simulate density-dependent flow and transport using the Block-Centered Transport (BCT) and Density-Dependent Flow (DDF) packages. The BCT package solves the transport equation following the flow equation for each time step, requiring only one model to simulate both the flow and transport processes. The DDF package also includes the hydraulic head formulation that precludes the need to undertake conversion to and from equivalent freshwater heads, which avoids complexities arising due to non-linearities and boundary conditions (Panday, 2018, Langevine et al., 2020). The hydraulic head formulation employed by the DDF package has been benchmarked by Langevine et al.(2020);
- Efficient local mesh refinement around features of interest within a regional model domain while retaining larger cells elsewhere, minimising model size (total cell count) and run times without compromising resolution in critical areas. The model layers can also 'pinch out' where hydrostratigraphic units (HSUs) are not present and cells are not required throughout the model domain (if this is necessary), reducing the total cell counts and improving numerical stability. This has flow-on benefits to the modern requirements of modelling projects such as a run-intensive calibration and uncertainty analysis;
- Robust handling of desaturation and resaturation of model cells for tracking the water table across multiple model layers, based on the Upstream Weighting scheme of MODFLOW-NWT (Niswonger et al., 2011). In this case, all model layers are of the upstream weighting type;
- Extraction of local water balance, such as in and out of group of cells associated with particular boundary conditions, which can be implemented using utilities such as USGBUD2SMP (Doherty, 2016c); and
- Interface with the parameter estimation and uncertainty analysis code PEST, including a suite of utilities for facilitating pre- and post-processing of model files (irrespective of whether PEST is used or not).

The unstructured mesh of the USG-Transport model has been generated using GMS 10.4.4 and model input files have been prepared using a combination of GMS, Groundwater Vistas v7 and a range of in-house and third-party utilities.

9.2.2 Model Domain and Grid

The model domain fully encloses the proposed outline of the salt concentration ponds and crystalliser ponds and extends to the west to include the adjacent sensitive ecological receptors. The western boundary of the model includes the coastline, extending around 5 km offshore to enable discharge of groundwater from seafloor and to simulate salinity in the offshore area, including a hypersaline wedge that exists between more saline, denser groundwater and fresher seawater.

The eastern boundary extends nearly 9 km upgradient of the salt ponds, representing the upgradient boundary of regional flow. The domain is rotated 35 degrees clockwise to align the model grid to the interpreted regional groundwater flow direction, with the northern and southern boundaries aligned parallel to the expected directions of regional flow. The domain has a total area of 1,011 km^2.

The model grid is discretised using 200 m by 200 m square cells, which are progressively refined in critical areas using a technique known as quadtree refinement. An area of refinement is defined around the salt ponds and over mainland remnant sand islands and mapped extents of mangroves using 100 m by 100 m cells. The grid is further refined to 50 m by 50 m cells along the perimeter of the ponds and crystallisers, including an area adjacent to the western boundary of the salt ponds where it is closest to the down gradient receptors.

Because of the low hydraulic gradient across the model domain, with very little gradient across the supratidal flats, the maximum cell length of 200 m satisfies the minimum grid Peclet number (less than 1) required for minimising numerical dispersion i.e. the range of plausible groundwater flow velocity is low and the transport problem is not advection dominated. Similarly, the maximum time step size required to satisfy the Courant number is large, equal to several thousand days, and is not a limiting factor for the long simulation period. The grid refinement further increases numerical accuracy in critical areas and allows the boundary of salt ponds to be more accurately simulated.

Map 9 shows the model grid, along with key project features. The model top is derived from the project LIDAR data and, where LIDAR is absent, SRTM data (corrected for the discrepancy with the LIDAR elevation). The offshore area has been defined using the bathymetry data provided by Water Technology (2021). There are 43,394 active cells per layer.

A cross-section (2D) sub-model was also developed to examine processes of tidal watering that are not suited to the regional discretisation described above and require a localised focus and increased vertical discretisation. Further details on this model are provided in Section 9.6.

9.2.3 Model Layers

The model layers have been derived from the Leapfrog geological model, which was developed based on the geotechnical and hydrogeological drilling data. This ensures that the current geological interpretations are consistently represented in the numerical groundwater model. As per the hydrogeological conceptual model, the hydrogeological units have been grouped into three hydrostratigraphic units (HSUs).

The initial three-layer configuration has been refined by splitting each HSU into additional model layers to increase numerical accuracy in the vertical direction and to better track the vertical density-driven movement of salts, whilst balancing the need to ensure sensible cell counts and model run time. There are 8 model layers in total, resulting in 347,152 active model cells. Table 9.1 summarises the model layer configuration. Figure 9-1 shows an east to west cross-section across the centre of the groundwater model, showing the relationship between model layers and HSUs. Note that model layers 1 and 2 include Unit 2a where Unit 1 is absent/pinched out. The base elevation of each HSU is presented in Map 10 to Map 12.

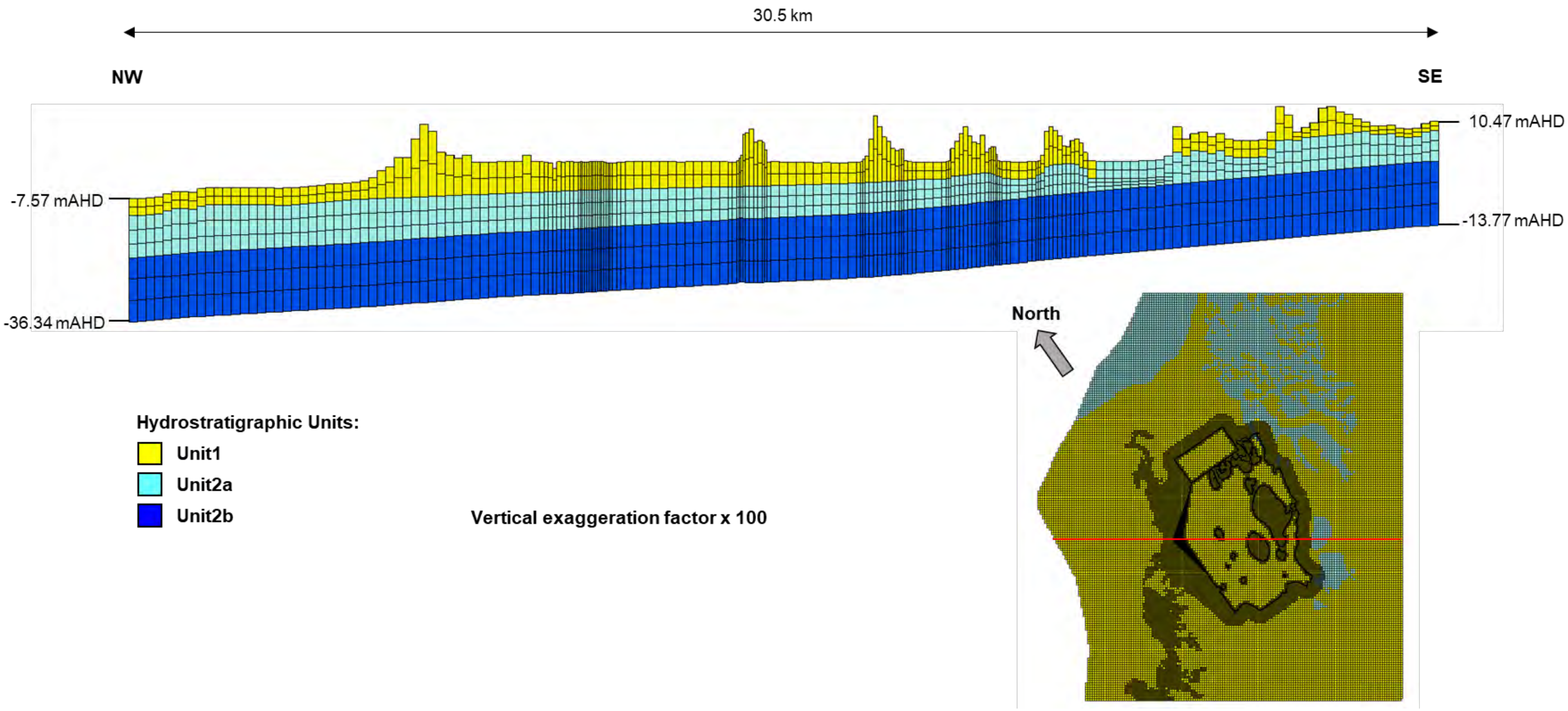


Figure 9-1 Example Model Section

Table 9.1 Model Layer Configuration

Model Layer	HSU	Cells	Layer Type	Average Thickness (m)
1	Unit 1/Unit 2a	43,394	4 - USG Upstream Water K+S	2.6
2	Unit 1/Unit 2a	43,394	4 - USG Upstream Water K+S	2.6
3	Unit 2a	43,394	4 - USG Upstream Water K+S	2.5
4	Unit 2a	43,394	4 - USG Upstream Water K+S	2.5
5	Unit 2a	43,394	4 - USG Upstream Water K+S	2.5
6	Unit 2b	43,394	4 - USG Upstream Water K+S	5
7	Unit 2b	43,394	4 - USG Upstream Water K+S	5
8	Unit 2b	43,394	4 - USG Upstream Water K+S	5

9.2.4 Model Boundary Conditions

Constant Head

A constant head boundary condition is prescribed to model layer 1 over the offshore area, with a head value of 0 mAHD based on mean sea level and a concentration of 35 g/L, representing typical salinity of seawater. This applies to offshore cells, it is acknowledged that when seawater moves inland through the tidal action, its salinity increases to around 40 g/L.

A constant head boundary condition is also prescribed along the eastern boundary (Map 13) to allow a component of flow into or out of the model, representing aquifer throughflow. A head value of 3 m AHD is prescribed based on the groundwater level measure in the up gradient bore BH13 and regional groundwater contours from Parsons Brinckerhoff (2009).

A concentration of 6 g/L is assigned to represent the background concentration. Both the head and concentration of this eastern boundary were allowed to vary during calibration to verify the expected low sensitivity of model outputs to this boundary condition.

USG-Transport's River (RIV)

USG-Transport's River (RIV) modelling package is a head-dependent flux boundary condition that allows fluxes to be exchanged vertically between the aquifer and surface water features based on the vertical differences in head and conductance (resistance to flow). The RIV cells are prescribed along parts of the channels that are permanently inundated by seawater, with a time-constant RIV stage equal to mean sea level of 0 mAHD (Map 13). A concentration of 35 g/L, approximately equal to seawater salinity, is assigned to these RIV cells (which can be larger by several g/L when transported inland). However, the actual groundwater salinity beneath the creek cells is more strongly influenced by the much greater salinity from the adjacent areas and EVT in the vicinity, to the point that the difference of a few g/L assigned to the RIV cells makes no difference to the salinity below.

The RIV cells are also used to simulate the seepage of seawater and associated effect on groundwater levels observed during pumping test at bore PBH10, which is further discussed as part of model calibration in Section 9.3. Additionally, the RIV cells are used to simulate the interaction between the salt ponds and groundwater as part of predictive modelling, discussed further in Section 9.4.

For all RIV cells, the conductance term has been accurately calculated to account for different cell surface areas within the unstructured model grid.

USG-Transport's Well (WEL) and Connected Linear Network (CLN)

USG-Transport's Well (WEL) modelling package is used to simulate the extraction of groundwater from bores PBH07 and PBH10 during constant rate pumping tests. As each pumping bore is screened across both Unit 1 and Unit 2a, the Connected Linear Network (CLN) package is also used to accurately distribute pumping to appropriate model layers based on the length of well screen intersecting each layer. The combined used of the WEL and CLN packages produces results similar to MODFLOW's Multi-Node Well (MNW2) package.

USG-Transport's Recharge

USG-Transport's Recharge modelling package is used in this model to simulate the following two processes:

1. Influx of surface water from rainfall that maintains the water table and regional groundwater flow, such as rainfall-recharge and periodic inland flow/flooding; and
2. Tidal inundation and storm surge, as a mechanism of supplying salts to the groundwater system, resulting in the formation of hypersaline groundwater in low-lying areas over a very long hydrological response time.

The following four recharge zones have been delineated to simulate these two processes:

- **Zone 1** defined over the supratidal flats, based on the approximate extent of tidal inundation zone delineated using 1 mAHD contour. This zone is used to simulate the average effect of tidal inundation/storm surge that would have occurred over a very long period of time, supplying salts over a low-lying area where hypersaline groundwater exists today. While the zone is intended to account for the long-term average effect, the extent delineated in the model is broadly consistent with the large area that was observed to be inundated during field work in April 2020. The recharge rate and concentration would be equal to the net salt load, after accounting for any dilution due to rainfall-recharge and periodic inland flows (flooding). This means the recharge concentration would be close to that of seawater or lower;
- **Zone 2** over the area outside of the supratidal flats, representing the long-term average rainfall recharge;
- **Zone 3** over the offshore area, where the constant head boundary condition is prescribed and recharge is set to zero; and
- **Zone 4** over the coastal sand dunes, where rainfall recharge is potentially higher/fresher as evidenced by fresher groundwater and higher hydraulic conductivity derived from slug testing at BH03S/03D.

Map 14 presents the spatial distribution of recharge zones. Recharge rates and concentrations prescribed to the calibrated model are discussed as part of model calibration (Section 9.3). Recharge is assigned to the uppermost active nodes, using USG-Transport's recharge option 3

Evapotranspiration

Evapotranspiration is assigned to the top layer using USG-Transport's Evapotranspiration (EVT) modelling package to simulate discharge of groundwater that occurs near surface. The EVT package requires specification of EVT surface (model top), EVT rate and EVT extinction depth (depth within the aquifer where the EVT reduces to zero).

The following four EVT zones have been delineated (Map 15):

- Zone 1 over the supratidal flats, as per recharge, to account for potential reduction in EVT due to the presence of salt crust and hypersaline groundwater within the tidal inundation zone;
- Zone 2 over the area outside of the supratidal flats, representing the long term average EVT;
- Zone 3 over the offshore area, where EVT is set to zero; and
- Zone 4 along low-lying areas where the existing ground surface is locally below sea level. Within this zone, the EVT extinction depth is reduced to prevent unrealistically low hydraulic heads from developing within the model. Otherwise the EVT rate is the same as Zone 2 (background).

The EVT package is configured to allow salts to accumulate within the model, to simulate evaporitic concentration in low-lying areas that results in hypersaline groundwater. The EVT rate and extinction depth assigned to each zone are discussed further as part of model calibration (Section 9.3). The EVT package is also used to simulate evapotranspiration from the floor of borrow pits under the project condition, which is discussed further in the predictive modelling section.

Salt Removal Process from Flats Simulated with Zero-Order Decay in Water

USG-Transport's zero-order decay capability has been activated locally in the mapped areas of mangroves to simulate the average effect of high frequency tidal flushing processes that is known to remove salt from the upper part of the aquifer and maintains shallow groundwater fresher. As high frequency tidal flushing cannot be readily simulated in a regional model with long simulation times, zero-order decay provides a practical means of exporting salt from the groundwater model and simulate a realistic range of shallow groundwater salinity in the mangrove areas. The term "zero-order" means the "decay term" is maintained constant over time so that an average rate of export of salt by tidal flushing can be simulated.

The zero-order decay coefficients are assigned to Layer 1 in the mangroves area and locally in the algal mat areas (in the northern area, where the elevation is lower and tidal inundation is expected to be more frequent than other algal mat areas). The zero-order decay rates have been adjusted iteratively during calibration to achieve sensible shallow groundwater salinity in the areas of mangroves (and locally in the algal mats areas), which are discussed further in the calibration section.

9.2.5 Parameterisation

Parameterisation involves making choices about how the spatial distribution of aquifer properties will be represented in the model (Barnett et al., 2012). Models with the smallest number of parameters possible are described as parsimonious, whereas models with a large number of spatially varying parameters are described as highly parameterised.

In modelling studies, a balance is sought between parsimony and complexity (highly parameterised spatial variability) that is consistent with the objective of modelling, the physical system of interest and supporting data.

In this study, the model has been parameterised on an HSU basis; however, hydraulic conductivities have been varied spatially via interpolation of parameter values assigned to strategically positioned points (Map 16) called 'pilot points' (Doherty, 2003). For this model, the pilot points are positioned at the location of bores where estimates of horizontal hydraulic conductivity are available from field testing.

By assigning narrow parameter ranges centred on field-derived values, the horizontal hydraulic conductivity for each aquifer is allowed to vary within sensible bounds during calibration without significantly altering the spatial variability identified through field testing. The vertical hydraulic conductivities are calculated from horizontal hydraulic conductivities, using a model-wide factor for each HSU.

Specific yield and specific storage are assigned a constant value to each HSU, applying the principle of parsimony where appropriate and introducing complexity (spatial variability) as necessary to simulate the physical system of interest in a manner consistent with the data available. Effective porosity of each HSU is calculated from specific yield using a multiplier, ensuring that specific yield (drainable porosity) is no greater than effective porosity.

Model parameterisation is discussed further as part of model calibration in Section 9.3.

9.3 Model Calibration

9.3.1 Calibration Objective

Model calibration is a process by which model parameter values are altered within realistic bounds until the model outputs fit historical measurements, such that the model can be accepted as a reasonable representation of the physical system of interest (Barnett et al. 2012).

The quality of model calibration is often assessed against a predefined value of goodness of fit between simulated and observed values. However, there is a number of other criteria that can be used to assess whether the model is fit for purpose, for example, the model's ability to appropriately simulate key hydrogeological processes that are of most relevance to predictions of interest, and that the model outputs are numerically sound.

The hydrogeological modelling of the proposed Ashburton Salt Project is complex because of the need to account for the effects of hydraulic heads, concentration and density at a regional scale and a unique set of challenges that are associated with solving coupled density flow and transport problems. Additionally, the existing hypersaline groundwater beneath the footprint of the project is likely to have developed over several thousand years, necessitating a long simulation time to replicate the gradual development of groundwater conditions that exist today.

The objective of model calibration is therefore to simulate the distribution of hydraulic heads and salinity (and the effects of density) that are broadly consistent with those observed at the site, using plausible ranges of model parameters and a long simulation period of several thousand years to account for the evolution of hydrogeological system.

The set of model parameters used to calibrate the model must also be able to replicate transient response to pumping, based on the pumping rates and drawdown recorded during two pumping tests completed at the site. To achieve this objective, the following two model types were developed:

- Regional scale density coupled flow and transport model with quasi-steady state boundary conditions to replicate the evolution of the hydrogeological system towards the conditions observed today; and
- Local scale flow model at each pumping test site (PBH07 and PBH10) to simulate the short term response to pumping observed in closely spaced observation bores. The local scale models are used as the spacing between the bores is only a few metres and it is not practical to introduce sufficient refinement into the regional scale model to simulate such localised effect. Each local scale model is effectively a cut out from the regional model (over a small area approximately equal to two 200 m cells), with a consistent layer thicknesses and parameters to the regional model. Cells in the local scale model range in size from 8 m to 0.125 m locally near the pumping and observation bores.

The regional scale density coupled flow and transport calibration has been undertaken in two stages totally a 3,500 year timeframe: (1) an initial 2,500-year run to simulate the evolution of the hydrogeological system towards the existing condition, starting with a uniform initial salinity from which dense hypersaline groundwater is gradually developed beneath supratidal flats, and (2) a subsequent 1000-year run incorporating the zero-order decay coefficients to simulate the more recent tidal flushing effects and stabilisation of salinity in the near coastal areas towards a quasi-steady state condition.

While there is some uncertainty with the total 3,500-year timeframe, what is critical from the modelling point of view is the recognition that the natural hydrogeological response time is very large compared to the period of predictive simulations required to assess the impacts of the project (the project life of 50 years).

It follows that a model that is capable of approximating the existing quasi-steady state condition after some 3,500 years would provide a sensible basis for examining the incremental impacts of the project and associated uncertainty that would occur over a much shorter period.

Both the 2,500-year and 1000-year flow and transport simulations have been undertaken using 10 stress periods of 250 years and 100-years in duration, respectively. Testing has shown that the maximum time step size of no greater than 110 days is required for each stress period to keep the flow and solute mass balance errors small (and the model outputs mathematically sound). Additionally, version 1.5 of USG-Transport offers a practical solution for handling errors in solute transport calculations that can arise from local flow mass balance errors (as detailed in Panday et al, 2017). This option has been used to further minimise errors in the transport solution.

USG-Transport's auto time stepping capability has been used to efficiently adjust the number and size of time steps within the specified minimum and maximum thresholds, resulting in around 840 time steps per stress period. The local scale flow model simulation periods are based on the duration of pumping tests, lasting 1 and 2 days for pumping tests at PBH07 and PBH10 respectively.

9.3.2 Calibration Approach

Calibration Workflow

The model calibration has been undertaken using a combination of manual and automated methods. The automated calibration has been undertaken rigorously using PEST_HP (Doherty, 2017) in a highly parallelised computing environment, with several iterations undertaken to thoroughly examine the effect of model parameters and parameter combinations on model outputs.

Figure 9-2 presents the automated calibration workflow. It involves running the regional (2,500-year) and local scale models in parallel, with the latter used to ensure that the model parameters are consistent with drawdown observed during pumping tests. The benefits of incorporating pumping test data into the calibration workflow include:

- More realistic estimates of specific yield and specific storage, especially where drawdown is observed in different aquifers, compared to storage coefficients derived from conventional aquifer test analyses (typically a lumped storage coefficient representing mixed unconfined and confined response);
- More realistic accounting of leakage across different aquifers and response to pumping in different aquifers/depths; and
- Consistency in model parameterisation, ensuring that the parameters can adequately replicate both the drawdown response due to pumping and distribution of heads and

salinity, while enabling the parameters to vary during calibration and be incorporated into sensitivity analysis (as opposed to fixing these prior to calibration based on analytical solutions derived from a simplified set of assumptions).

The automated calibration process has utilised a number of PEST utilities to facilitate pre- and post-processing efforts including:

- PAR2PAR (Doherty, 2016b) that converts one model parameter into another, when multipliers (ratios) are calibrated e.g. converting specific yield into effective porosity;
- PLPROC (Doherty, 2016d) that undertakes spatial interpolation of horizontal hydraulic conductivities from pilot points to the model grid; and.
- USGMOD2OBS (Doherty, 2016c) that extracts computed hydraulic heads, salinity and drawdown at the time and location of observations.

In addition to the PEST utilities, an in-house utility has been used to convert horizontal hydraulic conductivities into vertical hydraulic conductivities from the calibrated vertical hydraulic conductivity factor (the ratio of horizontal to vertical hydraulic conductivities). A single batch file has been prepared to run PEST and associated utilities in a sequential order and to process model outputs.

Following the automated calibration, the concentration and heads computed by the regional model at the end of the 2,500-year conditioning run were extracted and supplied to the 1000-year run as initial conditions. The zero-order decay coefficients have been adjusted manually to bring shallow groundwater concentration (salinity) to within the expected 40 to 90 g/L range in the mangrove areas, as the system tends towards a quasi-steady state condition.

This means the concentration of groundwater in the mangrove areas reduces more rapidly at the start of the 1000-year run and stabilises (effectively unchanged) towards the end of the 1000-year run as the system reaches quasi-steady. The concentrations and heads computed at the end of the 1000-year run are compared against the salinity and heads measured in the bores (refer below) to ensure sensible calibration.

Calibration Targets

The model calibration targets include:

- Measurements of hydraulic heads from 22 monitoring bores collected in April 2020;
- Salinity estimated from electric conductivity and major ion concentrations from 22 monitoring bores, based on data collected in April 2020; and
- Drawdown measured at four monitoring bores during constant rate pumping tests undertaken on pumping bores PBH07 and PBH10. Total pumping rates were included as calibration targets to minimise the potential for modelled pumping rates to fall below the actual pumping rates as USG-Transport's autoflow correction adjusts the pumping rates i.e. to ensure sufficient transmissivity in the model to sustain the actual pumping rates.

Following calibration, the model outputs were further verified against additional hydraulic heads and salinity data collected from 18 monitoring bores in September 2020.

Calibration Parameters

Table 9.2 summarises the calibration parameters, including their initial (pre-calibration) estimate and the minimum and maximum range allowed during calibration. The majority of parameters are estimated on a HSU basis, following the principle of parsimony where appropriate. The exception is hydraulic conductivity, where spatial variability is introduced to reflect the spatial variability identified in slug test and pumping test data, broadly consistent with lithological variations.

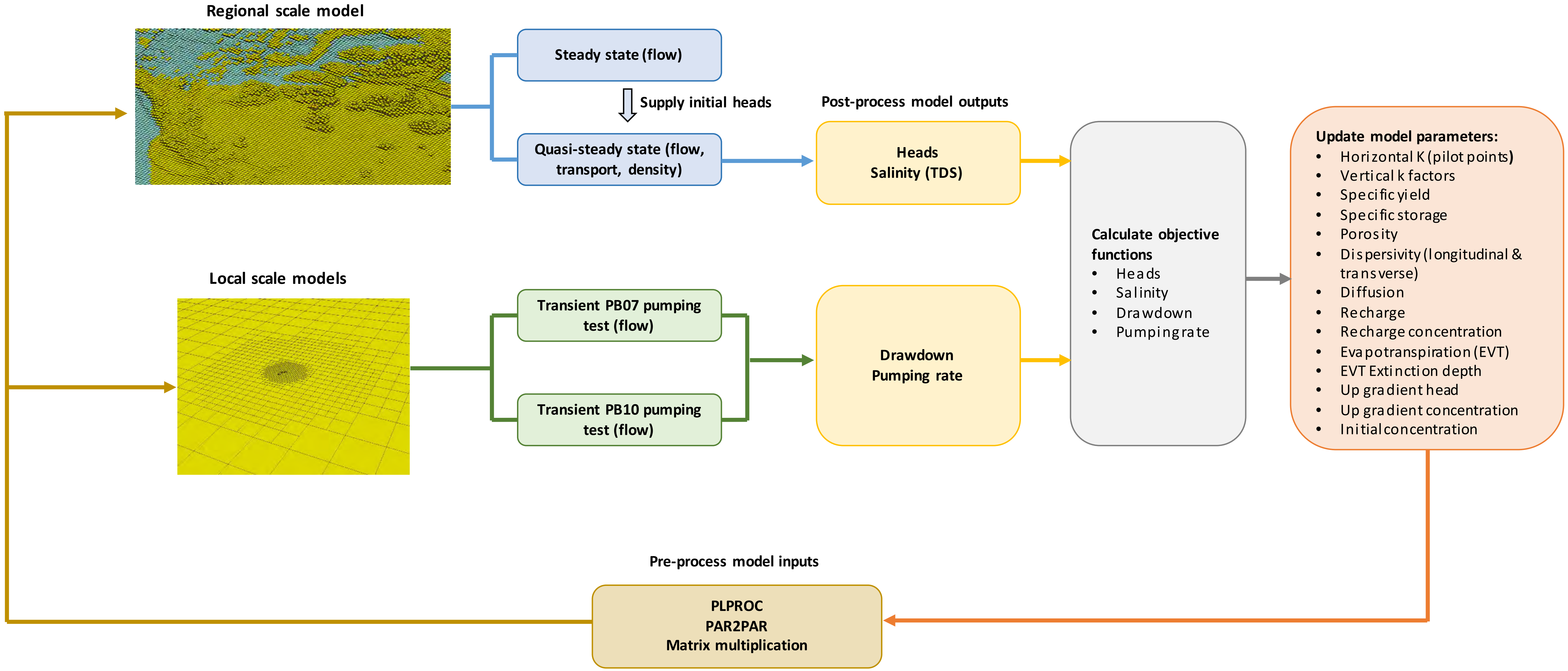


Figure 9-2 Automated Calibration Workflow

The number of adjustable pilot points (Map 16) used to define spatial variability is kept as small as possible, to maintain hydraulic conductivity distribution consistent with the density of available data and to minimise risks of overfitting the data (Barnett et al., 2012) or introducing spurious heterogeneity.

A total of 10, 11, and 4 adjustable pilot points are used for Unit 1, Unit 2a and Unit 2b respectively (Map 16). Regional hydraulic conductivity outside the area of field data is estimated using one adjustable pilot point, with several pilot points tied to this adjustable pilot point to constrain the interpolation and ensure uniform regional hydraulic conductivity.

Prior information is included, using the hydraulic conductivity estimates derived from the analysis of field data as preferred parameter values. A pilot point covariance matrix is also used to account for spatial interdependence of each pilot point to surrounding pilot points within the same HSU. PEST_HP is then run in the regularisation mode to minimise parameter variability unless deemed necessary during calibration.

Several model parameters have been calibrated as a ratio (multiplier) to another parameter. These include:

- EVT over Zone 1 (supratidal flats), where the presence of hypersaline groundwater and salt crust is expected to reduce EVT compared to that occurring in the background (Zone 2). Parameter “EVT2” represents the EVT rate in Zone 2 while “EVTfac” is a factor the converts EVT2 into EVT rate assigned to Zone 1. This reduction factor is allowed to vary from 0.7 to 0.9 during calibration, based on the relationship between evaporation and specific gravity (calculated from salinity of groundwater at the site) from Levy (2012);
- Effective porosity, which is calculated from the specific yield value of each unit. The parameters Nfac1, Nfac2 and Nfac3 are multipliers that convert specific yield into effective porosity of Unit 1, Unit 2a and Unit 2b respectively. The use of multipliers ensure that that specific yield does not exceed effective porosity as they are adjusted during calibration;
- Vertical hydraulic conductivity, which is calculated from horizontal hydraulic conductivity using multipliers Kz1fac, Kz2fac and Kz3fac for Unit 1, Unit 2a and Unit 2b respectively. This ensures that spatial differences in vertical hydraulic conductivity are consistent with (related to) those of horizontal hydraulic conductivity. An upper bound limit of 1 is used for these multipliers so the horizontal hydraulic conductivities are not exceeded by the vertical hydraulic conductivities; and
- Transverse dispersivity, which is calculated from longitudinal dispersivity using a factor DTfac, ensuring that transverse dispersivity is equal to or less than longitudinal dispersivity.

The local scale models used to simulate the pumping tests are parameterised using the same parameters adopted in the regional scale model at the location of each pumping test site. For example, pilot points kx1p3 and kx2p4 are located at pumping test site PBH07 and are used to assign horizontal hydraulic conductivity of Unit 1 and Unit 2a of the local scale model.

The DDF package of USG-Transport requires the specification of freshwater density, standard solution concentration (maximum concentration) and standard solution (maximum) density. This information is used to derive a simple linear relationship between concentration and density, similar to the linear equation of state used in SEAWAT (Langevin et al., 2003). For this project, the maximum concentration of 400 g/L has been assumed based on the expected range of salinity and the typically solubility limit of salts.

9.3.3 Calibration Performance

Calibration performance is assessed by goodness of fit between the observed and modelled groundwater heads and concentrations (salinities) while employing relevant groundwater and surface water interacting processes, along with plausible and defensible ranges of parameters.

The modelled hydraulic heads and salinity at the end of the 1,000-year quasi-steady state simulation are compared against the observed hydraulic heads and salinity and summarised in Table 9.3. Scatter plots of the same dataset are also shown in Figure 9-3. The mean sum of residuals (MSR) for hydraulic heads is around 0.28 m. This means the modelled heads are generally accurate to within 0.3 m, with the exception of anomalous water levels measured in bores BH02S/2D.

The MSR for salinity is around 30 g/L and the quality of calibration achieved (in terms of the goodness of fit) is generally in line with that typically expected for a regional scale density coupled flow and transport model. For example, the model is well capable of simulating fresher groundwater in areas outside of supratidal flats (e.g. BH02S/02D and BH03S/03D) and higher salinity in groundwater within the supratidal flats (e.g. BH05S/05D, BH05S/05D), consistent with the expected and observed distribution of salinity.

The model underestimates salinity at upgradient bore BH13, although this is due to the presence of a narrow channel and associated salinisation by evapotranspiration which cannot be captured at the resolution of the model without introducing more refinement. This does not have a material impact on the simulated salinity in the area of salt ponds, which is the focus of modelling.

While a statistical measure of goodness of fit between simulated and observed values provides a useful indication of the quality of model calibration, the performance of model calibration can also be assessed qualitatively based on a number of key attributes and whether or not they are consistent with the current hydrogeological conceptualisation. These are summarised as follows:

- Map 17 shows the simulated groundwater contours and depth to groundwater contours. The contours have been generated using the uppermost active cells in the model and are approximately equal to the surface of water table. The groundwater contours indicate an overall flow direction to the northwest and very low hydraulic gradient across the supratidal flats, consistent with the conceptualisation;
- Map 18 presents computed salinity concentrations. Figure 9-4 compares the simulated groundwater salinity against the aerial imagery, showing a high degree of consistency between the visually visible spatial extent of salt crust and hypersaline groundwater simulated by the model. The vegetated areas shown in the aerial imagery are also broadly consistent with the areas of fresher groundwater simulated by the model outside the supratidal flats. In the mapped area of mangroves, the simulated salinity generally ranges from 40 to 90 g/L, which is considered to be within the salinity tolerance of mangroves in these environments (AECOM, pers. comm). Salinity towards the upper end of this range is simulated by the model along narrow channels, where the mangroves form a narrow strip and very localised salinity variations cannot be accurately captured in the regional scale model. In general, fresher salinity is simulated closer to the coast and channels, where tidal flushing is more frequent, and higher salinity is simulated on the landward side;
- Figure 9-5 shows the simulated salinity on east-west cross-sections across the model domain, where the spatial differences in salinity and associated density effects can be seen. These include the presence of a hypersaline wedge that extends below fresher (less dense) groundwater along coastal dunes and locally below seafloor, effectively

forming an inverted seawater – groundwater interface. Also shown on the cross-sections are local fresher groundwater lenses simulated over sand islands, where groundwater is maintained fresher by rainfall-recharge and limited evapotranspiration (due to greater groundwater depth). These features are analogous to freshwater lenses that develop over denser groundwater in ocean island settings and demonstrate that the model is correctly accounting for the effect of density differences; and

- Figure 9-6 compares the time series of modelled and observed drawdown at the location of observation bores used during constant rate pumping tests at pumping bores PBH07 and PBH10. The figure indicates that drawdown is reasonably replicated in both the shallow (Unit 1) and deep (Unit 2a) observation bores at each site. At PBH10, the effect of seepage from tidal inundation and the flattening of drawdown trend are simulated using the RIV boundary condition. A RIV stage of 1 m AHD is used based on the peak tidal level at the time of inundation, which is broadly consistent with the pooling of water observed in the field. The RIV bed (salt crust) thickness is assumed to be 0.1 m and hydraulic conductivity is assumed to be 0.2 m/d (based on the average vertical hydraulic conductivity from infiltration testing). Figure 9-6 shows the modelled drawdown with and without leakage (RIV cells) to demonstrate the incremental effect of tidal inundation, which is appropriately simulated.

Table 9.2 Model Parameters

Parameter	Parameter ID	HSU/Zone	Initial	Min	Max	Unit	Comment
Horizontal hydraulic conductivity	kx1p1 - kx1p10	Unit 1	0.2 – 9.5	0.2	9.5	m/d	Spatially variable (pilot points), with the initial, min and max based on field testing. Regional (control) pilot point is assigned an initial value equal to the average of field derived value for each HSU. The min and max range assigned to each pilot point is narrower than the full range for all pilot points shown in this table.
	kx2p1 - kx2p11	Unit 2a	0.01 – 6.4	0.01	6.4	m/d	
	kx3p3 - kx3p4	Unit 2b	0.6 – 4.6	0.1	4.6	m/d	
Vertical hydraulic conductivity (factor)	kzfac1	Unit 1	0.1	0.05	1	-	Parameterised as a model-wide factor of horizontal hydraulic conductivity with a maximum of 1 (Kz no greater than Kx)
	kzfac2	Unit 2a	0.1	0.01	1	-	
	kzfac3	Unit 2b	0.1	0.01	1	-	
Specific yield	sy1	Unit 1	0.08	0.05	0.2	-	Based on a typical range of values for the lithologies (Johnson, 1967). Lower Sy for Unit2 reflects the higher clay content
	sy2	Unit 2a	0.05	0.02	0.1	-	
	sy3	Unit 2b	0.05	0.02	0.1	-	
Specific storage	ss1	Unit 1	0.00001	0.000001	0.00005	1/m	A recent publication by Rau et al.(2018) suggests a plausible upper threshold of Ss of confined aquifers to be 1.3 x 10^{-5} m^{-1}. A slightly higher upper threshold of $5x10^{-5}$ m^{-1} is chosen based on other publications (e.g. Younger, 1993) and experience at other similar sites.
	ss2	Unit 2a	0.00001	0.000001	0.00005	1/m	
	ss3	Unit 2b	0.00001	0.000001	0.00005	1/m	
Porosity factor	Nfac1	Unit 1	1.25	1.2	3	-	Calculated as a factor of specific yield such that effective porosity remains greater than specific yield and in line with values reported in the literature e.g. around 0.1, based on Payne et al (2008) and Kulkarni et al (2020).
	Nfac2	Unit 2a	2	1.1	4	-	
	Nfac3	Unit 2b	2	1.1	6	-	
Longitudinal dispersivity	DL	Uniform	20	10	200	m	Initial value based on 10% of the characteristic length (in this case, 200 m cell length). The maximum is limited by the cell length.
Transverse dispersivity factor	DTfac	Uniform	0.1	0.05	1	-	Parameterised as a model-wide factor of longitudinal dispersivity with an initial value of 10% and a maximum of 100% i.e. DL ≥ DT
Molecular diffusion	DIF	Uniform	0.00173	0.00086	0.0259	m^2/d	Typical range of value based on literature ($1x10^{-6}$ to 3 x 10^{-5} cm^2/s)
Recharge rate	rch1	Inundation	0.0000411	0.0000219	0.00011	m/d	A range of 8 to 40 mm/year based on mass balance calculations, with a slightly wider range to account for parameter combinations and bounds
	rch2	Regional	0.00000548	0.00000274	0.0000218	m/d	A range of 1 to 8 mm/year based on through-flow calculations
	rch3	Offshore	0	-	-	m/d	Fixed (non-adjustable) at zero recharge over the coastal boundary representing open sea
	rch4	Coastal dune	0.00000548	0.00000274	0.0000218	m/d	A range of 1 to 8 mm/year based on through-flow calculations
Recharge concentration	rchcon1	Inundation	35	25	35	g/L	Constrained at seawater concentration (35,000 mg/L), allowing for a lower value to reflect rainfall contribution (dilution due to rainfall recharge and inland flood waters)
	rchcon2	Regional	0.1	0.1	1	g/L	Expected to be generally fresh, with a range of 100 to 1000 mg/L to account for mobilisation of salts in the unsaturated zone
	rchcon3	Offshore	0	-	-	g/L	Fixed (non-adjustable) at zero over the coastal boundary (no recharge) representing open sea
	rchcon4	Coastal dune	0.1	0.1	1	g/L	Expected to be generally fresh, with a range of 100 to 1000 mg/L to account for mobilisation of salts in the unsaturated zone
Evapotranspiration rate	evt2	Regional	0.00493	0.00438	0.00548	m/d	Min based on BoM's long term average areal potential EVT (1600 mm/year), with a higher value allowed (up to 2000 mm/yr) to reflect potential very high EVT at ground surface
	evtfac	Inundation	0.78	0.7	0.9	-	Parameterised as a factor of regional evapotranspiration to account for expected reduction over the salinised inundation area. The bounds based on evaporation ratio for the range of salinity (e.g. Levy, 2012).
	evt3	Offshore	0	-	-	-	Fixed (non-adjustable) at zero over the coastal boundary (no EVT) representing open sea
Extinction depth	exdp1	Inundation	0.5	0.3	2	m	A range based on expected effective depth of evapotranspiration, accounting for decrease with depth and inaccuracies of cell top
	exdp2	Regional	0.5	0.3	2	m	
	exdp3	Coast	0	0	0	m	Fixed at zero over the coastal boundary (no evapotranspiration)
	exdp4	Low points	0.1	0.05	0.2	m	Smaller extinction depth where existing ground level is below mean sea level, to prevent unrealistically low heads

Parameter	Parameter ID	HSU/Zone	Initial	Min	Max	Unit	Comment
Upgradient head	chd1	Unit 2a & Unit 2b	3	3	6	m	Up gradient head boundary condition, included as an adjustable parameter to examine the sensitivity of model outputs to boundary condition
Upgradient concentration	cnchd1	Unit 2a & Unit 2b	35	25	80	g/L	As per above, with a range that allows through-flow to be either slightly fresher or slightly more saline due to the uncertainty of up gradient salinity
Initial concentration	icon	Uniform	35	35	130	g/L	Expected to be seawater concentration, with higher concentration allowed to account for potential salinisation from prior inundation and evapotranspiration

9.3.4 Calibrated Parameters

The calibrated model parameters are presented graphically in Figure 9-7 and Figure 9-8, which compares the calibrated parameter values against their initial estimate and upper and lower parameter bounds allowed during calibration. The calibrated parameter values are also labelled on the figure. The figure indicates the following:

- The calibrated horizontal hydraulic conductivity values for Unit 2a and Unit 2b are generally similar to their initial estimates based on slug testing and pumping tests. For Unit 1, some of the pilot points are calibrated towards the lower end of the range although on average hydraulic conductivity is around 3 m/d, which is similar to the average of around 4 m/d from slug testing. For Unit 2a and Unit 2b the model-wide average calibrated horizontal hydraulic conductivity is 2 and 0.7 m/d respectively, again similar to their averages from slug testing. At the location of pumping tests, pilot points in Unit 2a (kx2p4, kx2p6) have varied little from the initial estimates derived from the analysis of the test data using standard analytical methods. The spatial variability in hydraulic conductivity is shown in Map19;
- For Unit 1, the calibrated vertical hydraulic conductivity factor of 0.13 results in an average vertical hydraulic conductivity of around 0.4 m/d over the entire model domain and around 0.2 m/d over the footprint of the proposed salt ponds (Map 20) consistent with the average vertical hydraulic conductivity estimated from the infiltration tests; and
- The calibrated specific yield (0.02 to 0.05) is generally towards the lower end of the range for each unit (<0.1). This is considered plausible given the abundance of clay and the range of values reported in the literature for similar lithologies. The calibrated effective porosity is 0.1 for all units, which is considered appropriate based on recent studies on “mobile porosity” (Payne et al., 2008, Kulkarni et al., 2020) and sufficiently conservative for the purpose modelling the potential project-induced effects on groundwater salinity.

Table 9.3 Observed and Modelled Heads

Bore ID	Modelled	Observed Apr 2020	Observed Sept 2020	Residual
BH02S	1.25	-1.91	-1.90	3.15 to 3.16
BH02D	1.13	-1.99	-1.98	3.11 to 3.12
BH03S	0.64	0.79		-0.12
BH03D	0.61	0.69	0.71	-0.10 to -0.08
BH04	1.03	0.53	1.72	-0.69 to 0.5
BH05S	0.40	0.83		-0.43
BH05D	0.35	0.82		-0.47
BH07S	0.70	0.73	0.68	-0.03 to 0.02
BH07D	0.67	0.70	0.66	-0.03 to 0.01
BH08	0.74	0.89	0.87	-0.15 to -0.13
BH09S	1.56	1.15	1.10	0.41 to 0.46
BH09D	1.50	1.04	1.08	0.42 to 0.46
BH10S	0.56	0.86	0.54	-0.3 to 0.02
BH10D	0.52	0.86	0.55	-0.34 to -0.03

Bore ID	Modelled	Observed Apr 2020	Observed Sept 2020	Residual
BH11S	0.79	1.19	0.82	-0.4 to -0.03
BH11D	0.78	1.20	0.72	-0.42 to 0.06
BH12	1.63	2.39	2.51	-0.76 to -0.88
BH13	3.18	2.99		0.19
BH14S	0.64	1.22	0.83	-0.58 to -0.19
BH14D	0.49	1.23	0.84	-0.74 to -0.35
BH15S	0.93	0.94	0.81	-0.01 to 0.12
BH15D	0.80	0.82	0.70	-0.02 to 0.10

Table 9.4 Observed and Modelled Salinity

BoreID	Modelled	Observed Apr 2020	Observed Sept 2020	Residual
BH02S	77	61		16
BH02D	90	81	70	9 to 20
BH03S	40	20	20	20
BH03D	46	33	37	9 to 13
BH04	126	105	108	17 to 21
BH05S	243	211		22
BH05D	226	219		7
BH07S	189	176	184	5 to 13
BH07D	195	201	214	-19 to -6
BH08	184	133	163	11 to 51
BH09S	101	86	78	15 to 23
BH09D	117	149	174	-57 to -32
BH10S	251	286	247	-35 to 4
BH10D	248	264	251	-16 to -3
BH11S	173	215	257	-84 to -42
BH11D	178	216	269	-91 to-38
BH12	126	95	95	31
BH13	0.21	61		-60
BH14S	198	263	236	-38 to -65
BH14D	212	306	235	-94 to -23
BH15S	193	157	147	
BH15D	221	247	204	

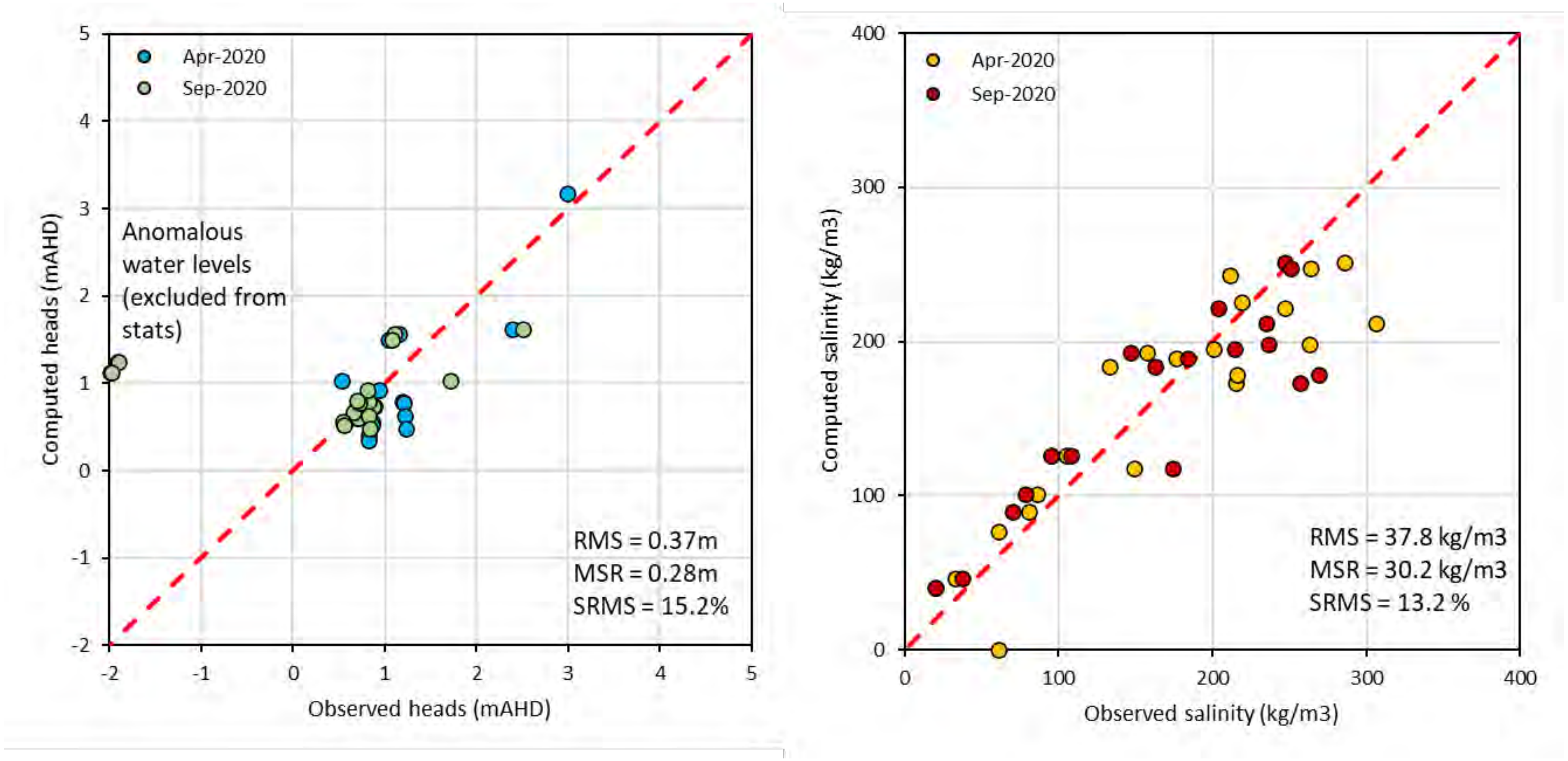


Figure 9-3 Calibration Performance Scatter Plots

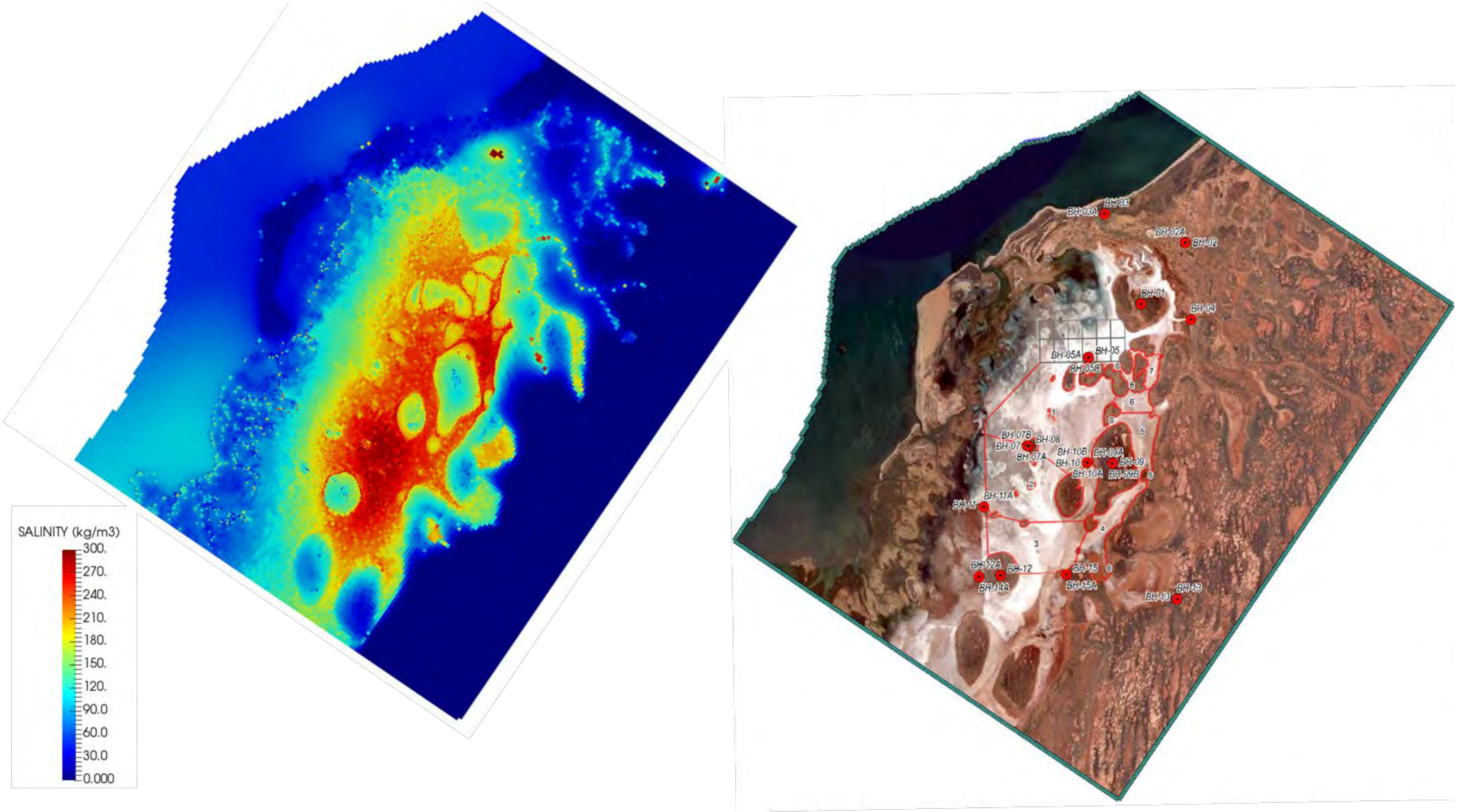


Figure 9-4 Simulated Groundwater Salinity Patterns Compared against Aerial Imagery

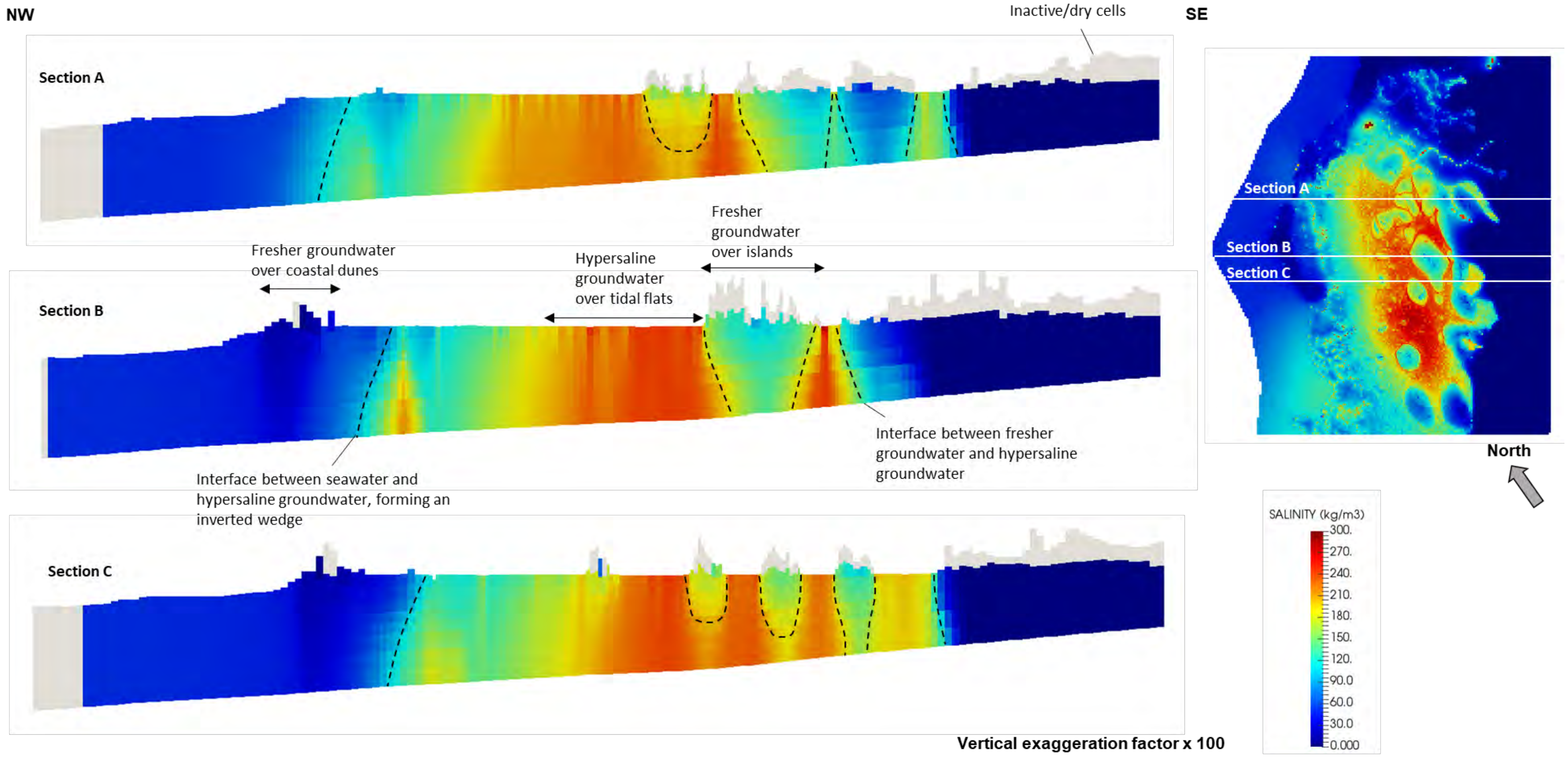


Figure 9-5 Simulated Salinity in Selected Cross-Sections

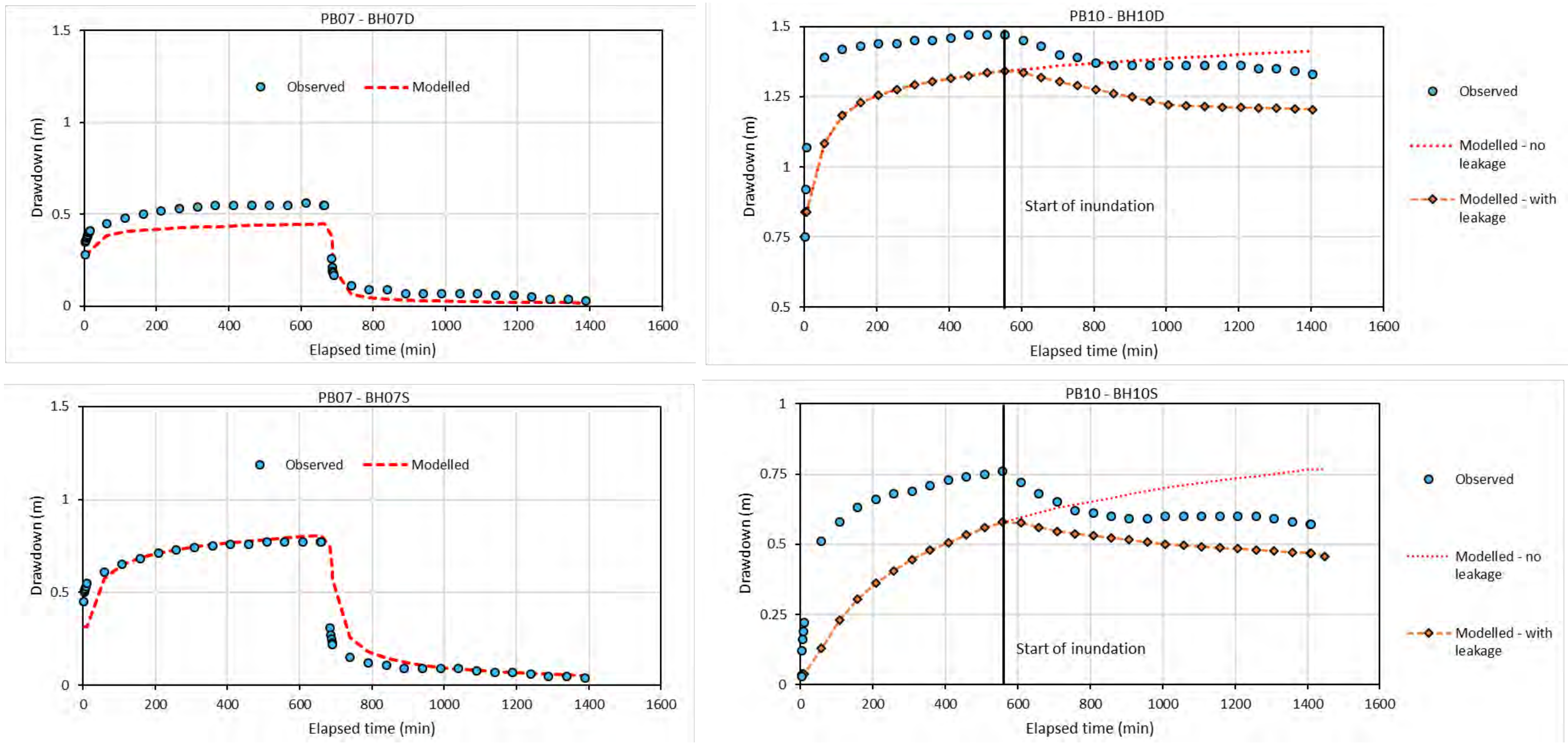


Figure 9-6 Simulated and Observed Drawdown (Pumping Tests)

- The salinity of recharge over the supratidal flats (rchcon1) has a calibrated value of 25 g/L, which is lower than the seawater salinity to account for dilution due to fresh rainfall recharge and periodic inland flooding (sheet flow). The salinity of rainfall recharge outside the supratidal flats/tidal inundation area is assumed to be fresh, with a salinity of around 0.1 g/L. The calibrated recharge rates are 8 mm/year over the supratidal flats and coastal sand dunes and 1.2 mm/year elsewhere (background recharge);
- The calibrated evapotranspiration rate is around 1,600 mm/year, equal to the Bureau of Meteorology's long term average areal potential evapotranspiration rate. A higher evapotranspiration rate is also possible, although this would not have a material effect on model outputs as evapotranspiration is already much larger than recharge. The calibrated evapotranspiration rate over supratidal flats is 1,120 mm/year, to reflect lower evapotranspiration rate expected in the area of hypersaline groundwater. The calibrated EVT extinction depths are around 0.3 m, reducing to 0.1 m in isolated areas where the model top is below mean sea level (Zone 4); and
- The calibrated zero-order decay coefficients range from 0.0008 to 0.04 g/L/d, which have been adjusted manually until the salinity simulated in the areas of tidal flushing/mangroves reached the 40 to 90 g/L range expected.

9.3.5 Parameter Sensitivity

During each optimisation iteration, PEST calculates composite parameter sensitivity (also commonly referred to as scaled composite sensitivity) from Jacobian matrix (a matrix of derivative of model output at the time and location of observation to each parameter). The composite parameter sensitivity provides useful indications of the sensitivity of all observations used in calibration to each model parameter, especially when it is combined with the knowledge gained from running the model many times during calibration. The composite parameter sensitivity is summarised graphically in Figure 9-9 for the final optimisation iteration.

The parameter sensitivity and model calibration efforts indicate elevated sensitivity to:

- Recharge and recharge concentration over Zone 1 (rch1 and rchcon1), which is expected as these parameters represent the mechanism by which salts are supplied to the supratidal flats/inundation zone that gives rise to the formation of hypersaline groundwater;
- Pilot points kx2p4 and kx2p6. As discussed in the previous section, these represent the hydraulic conductivity of Unit 2a at the location of pumping tests which is strongly constrained by the drawdown response observed during pumping tests. Similarly, there is high sensitivity to pilot point kx1p6, representing the hydraulic conductivity of Unit 1 at PBH10;
- kzfac2 and kzfac3, representing the vertical hydraulic conductivity of Unit 2a and Unit 2b that influences the density-driven transport of salts and hence the distribution of salinity, including vertical differences in salinity as measured at several nested monitoring sites; and
- EVT extinction depths (exdp1 and exdp2), which places constraints on the water table elevation in low-lying areas and allow salts to accumulate in the area of hypersaline groundwater.

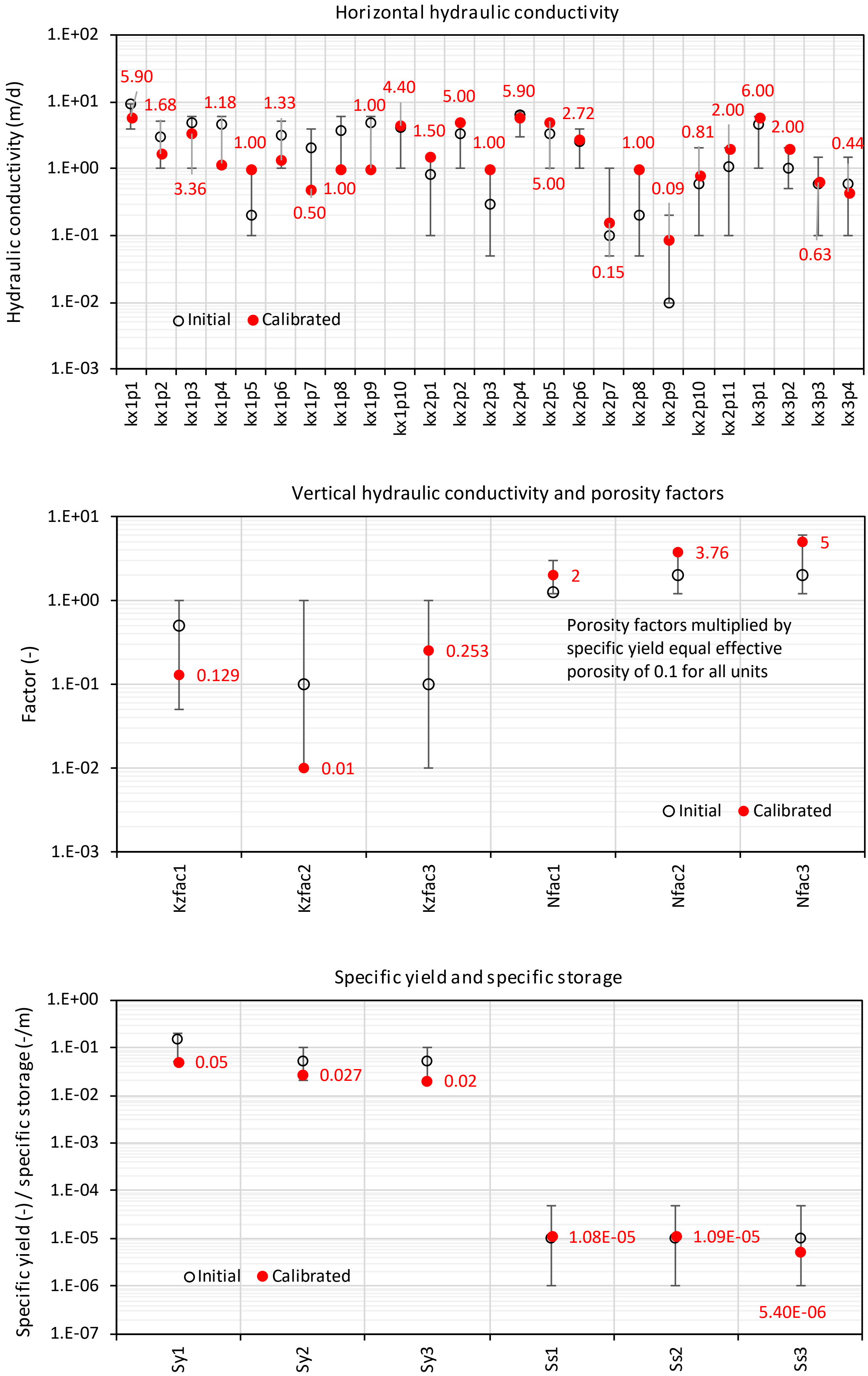


Figure 9-7 Calibrated Model Parameters

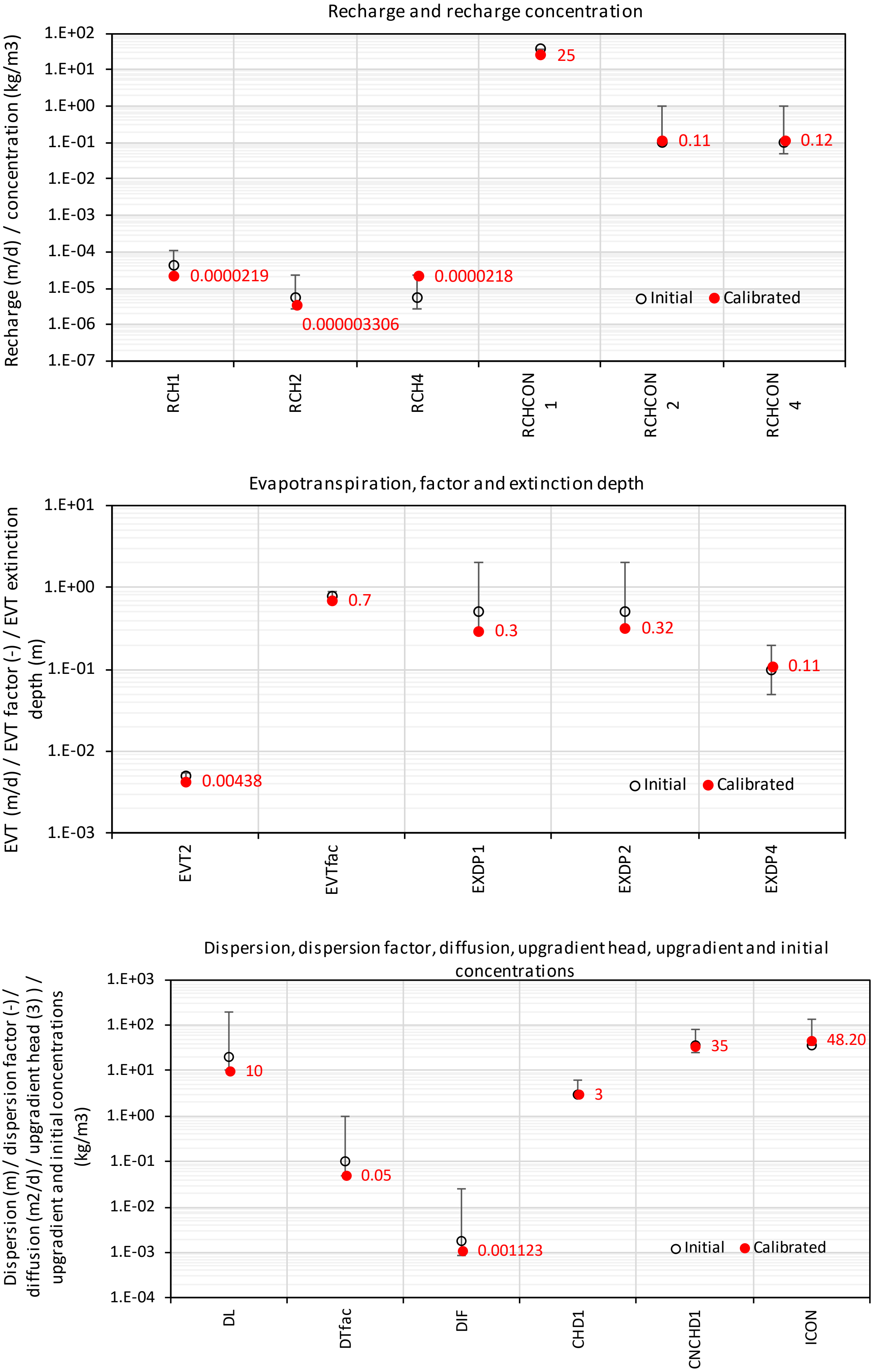


Figure 9-8 Calibrated Model Parameters, Continued

The model shows moderate sensitivity to specific yield in Layer 1 and Layer 3 and consequently porosity which influences the rate of migration of salts.

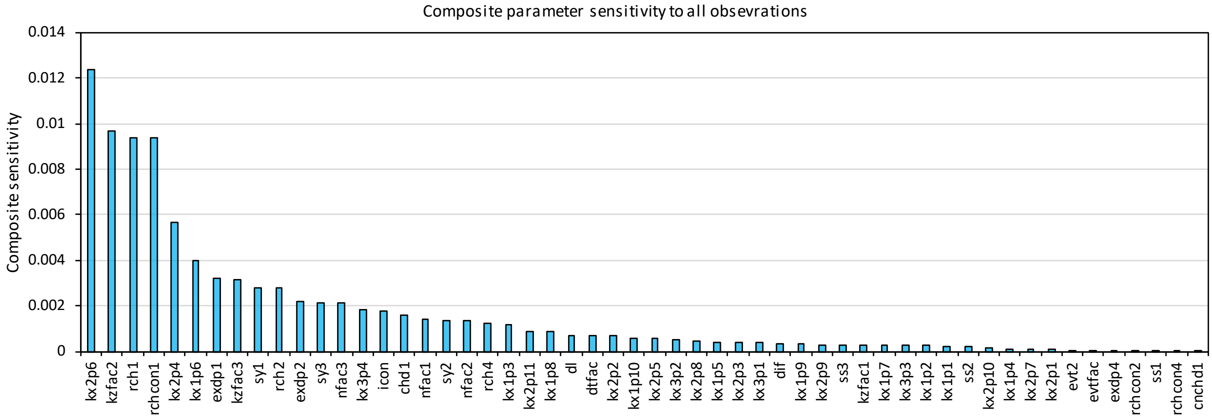


Figure 9-9 Composite Parameter Sensitivity of Final Optimisation Iteration

9.3.6 Volumetric Water and Solute Mass Balance

Table 9.5 and Table 9.6 summarise the flow and solute mass balance from the 1,000-year quasi-steady state simulation, respectively. The DDF package of USG-Transport computes a term known as “Density Storage” in the flow mass balance. This is because the hydraulic-head formulation employed by the DDF package separates total flow into constant density flow component and density dependent correction component (Langevine et al., 2020). This allows the effect of density variations to be compartmentalised and easily added to any flow models where the constant density flow component is already computed.

The mass decay component in the solute mass balance represents the component of solute concentration lost by the zero-order decay term used to simulate the average effect of tidal flushing on shallow groundwater salinity. The solute mass balance also includes a component that handles errors in solute transport calculations arising from local flow mass balance errors (as detailed in Panday et al, 2017). This is a small component of the solute mass balance.

The mass balance error for each time step of the 1000-year flow and transport simulations is less than 0.05% on average. The cumulative mass balance error is 0.03% and 0.05% for the flow and transport simulations, respectively. A very small number of time steps recorded larger mass balance errors in the prior 2,500-year conditioning run, due to the changes in concentration from the initial condition; however, these equate to <0.3% of the time steps (23 out of 8430 time steps) and are likely to be numerical anomalies.

The flow balance figures (final times steps in Table 9.5) are consistent with the conceptual flow balance figures presented in Section 8.6.

The calculated salt mass in the numerical model at the end of calibration period equates to 197 GT which is relatively close to the conceptual estimate of 188 GT.

Table 9.5 Calibration Flow Balance (1000-year run)

Component	Transient Cumulative		Transient Average		Final Time Step	
	In (GL)*	Out (GL)*	In (m^3/d)	Out (m^3/d)	In (m^3/d)	Out (m^3/d)
Storage	0.42	0.55	1.15	1.53	0.41	1.57
Density storage	13.68	4.09	37.51	11.23	27.64	6.57
Constant head	273.21	657.71	748.49	1801.95	785.41	1785.57
River	42.99	187.23	117.79	512.95	129.32	531.75
Recharge	2439.55	0	6683.69	0	6683.69	0
EVT	0	1918.92	0	5257.3	0	5299.18
Total	2769.85	2768.5	7588.63	7584.96	7626.47	7624.64

**GL – gigalitre*

Table 9.6 Calibration Transport Mass Balance (1000-year run)

Component	Transient Cumulative		Transient Average		Final Time Step	
	In (MT)**	Out (MT)	In (T/d)***	Out (T/d)	In (T/d)	Out (T/d)
Mass storage	17.29	5.44	47.42	14.95	29.69	7.47
Mass decay	0	24.79	0	67.93	0	67.9
Transport flow mass balance error	0.3	0.3	0.83	0.83	0.23	0.3
Constant head mass flux	7.4	16.9	20.28	46.31	22	43.36
River mass flux	1.5	13.56	4.12	37.15	4.53	31.88
Recharge mass flux	34.48	0	94.46	0	94.46	0
*EVT mass flux	0	0	0	0	0	0
Total	60.98	61	167.12	167.17	150.91	150.91

**Zero EVT mass flux confirms that EVT is not removing solute from the model; ** MT – million tonnes; ***T/d – tonne per day*

9.4 Predictive Modelling

9.4.1 Predictive Scenario

The construction of salt ponds of different salinity, density and static water levels will result in changes to the exiting groundwater conditions. The nature of interaction between the salt ponds and groundwater will be complex due to hydraulic, salinity (concentration) and density effects which vary over time.

In order to clearly understand this interaction and the processes that contribute to potential incremental impacts, the predictive modelling scenario has been formulated based on a number of simplified assumptions. These assumptions are also necessary to ensure confidence in model's ability to appropriately simulate the complex density-dependent flow and transport processes, when changes are induced by the project.

The assumptions for the predictive scenario are as follows:

- All eight salt concentration ponds are assumed to become active at the start of the simulation and remain active for the proposed project duration of 50 years;
- The static water level and salinity of each of the salt pond water are based on the Pre-Feasibility Design (Arcadis, 2018) and are summarised in Table 9.7;
- Each salt pond is simulated using RIV cells with RIV stage and salinity as per Table 9.7;
- The RIV bed is assumed have a salt crust thickness of 0.1 m with hydraulic conductivity of 0.2 m/d, based on the average from infiltration tests undertaken in the area of salt ponds. The top of RIV bed is assumed to be 1 mAHD based on the average current surface elevation over the footprint of the salt ponds. Map 21 shows the RIV cells assigned to Layer 1 of the model;.
- The influence of climate (recharge and evapotranspiration) is time-constant, representing approximately an average long term condition as per the calibration. Similarly, the effect of high frequency tidal inundation is approximated using time-constant recharge. This means any changes simulated by the model relative to the current (initial) condition are due to the presence of salt ponds, allowing their incremental impacts to be clearly identified;
- There will be no on-going seepage from the crystallisers due to the presence of thick salt crust and intermittent filling of the crystallisers;
- Hydraulic conductivity along the base of salt ponds, as represented by the RIV bed material, is constant (0.2 m/d). Experience in other salt pond operations suggests that the base of salt ponds often becomes less permeable over time due to the formation and thickening of salt crust and siltation. As these effects are site-specific and not known in advance, the predictive scenario conservatively assumes no changes to the hydraulic conductivity along the base of the salt ponds. The implication of this assumption is examined further as part of uncertainty analysis; and
- The potential discharge of groundwater from the floor of borrow pits and associated groundwater salinity changes are simulated using the EVT package with the EVT surface set equal to the estimated floor elevation of each borrow pit (Map 21). Table 9.8 summarises the floor elevation of the borrow pits used in the predictive model, assuming that the ground surface will be lowered to elevations approximately equal to those of the surrounding salt flats. The EVT rates are set to zero over the salt ponds, which are simulated using RIV cells.

The initial heads and concentrations for the predictive model are derived from the calibrated heads and salinity simulated at the end of the 1000-year quasi-steady state simulation. The incremental effects of the project have been quantified by running two model simulations, with and without the salt ponds and borrow pits, and calculating the difference between the two model outputs.

Table 9.7 Modelled Salt Concentration Pond Levels and Salinity

Pond	Static Water Level (m AHD)	Salinity (g/L)
1	2.3	40
2	2.1	58
3	1.9	81
4	2.25	109
5	2.15	141
6	2.05	180
7	1.95	223
8	1.85	274

Table 9.8 Borrow Pit Elevations

Borrow Pit	Floor elevation (m AHD)	Location
1	0.8	East of Pond 7
2	0.8	East of Pond 6
3	2	East of Pond 5
4	1	East of Pond 4

9.4.2 Predicted Seepage Rates

Figure 9-10 compares the predicted seepage rates for each pond against the seepage rates assumed in the Pre-Feasibility Study (Arcadis, 2018). The predicted seepage rates are presented for the first year, when the seepage rates are higher, and as averages for the 50-year operation.

The purpose of this comparison is to simply demonstrate that the seepage rates predicted by the model are consistent with those originally estimated in the PFS and are in line with those typically assumed for projects of this kind.

Where there are differences, these are likely due to the density driven interaction between pond water and groundwater which is simulated in more detail in the groundwater model.

Figure 9-11 highlights the importance of density differences between the pond water and groundwater in the prediction of seepage rates. The figure compares the average modelled salinity of groundwater beneath each pond against the salinity of pond water. Also shown in the figure are the predicted seepage rate per unit area of each pond in Year 1 of the operation.

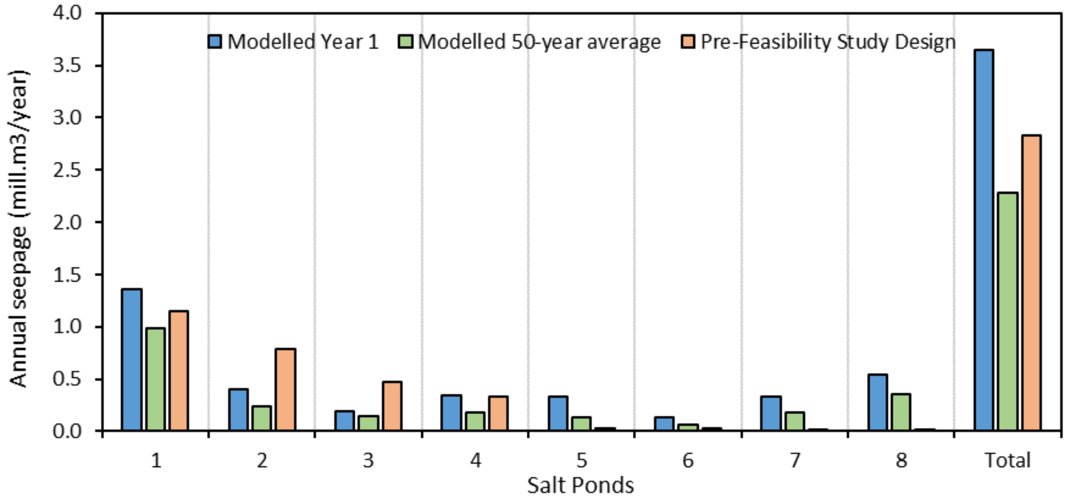


Figure 9-10 Predicted Seepage Rates and PFS Design Seepage Rates

As the salinity of pond water exceeds that of groundwater (Ponds 7 and 8), the seepage rate per unit area increases markedly due to greater density of pond water. In reality, higher salinity in these ponds may lead to the development of salt crust over time that eventually reduces the seepage rate; however, the density effect is likely to remain important in the initial stages of operation.

Figure 9-12 shows changes in predicted seepage rates over time, using Pond 1 (freshest) and Pond 8 (most saline) as examples. The seepage rates reduce over time, eventually reaching quasi-steady state. This reduction in seepage rates is most likely to be the result of changes in the salinity and density of groundwater over time, which is discussed further in Section 9.4.4.

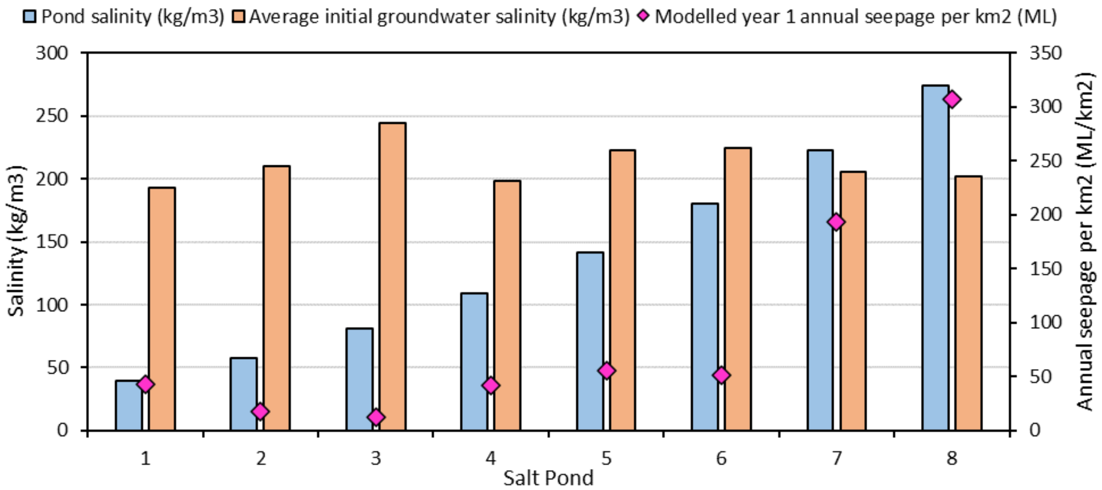
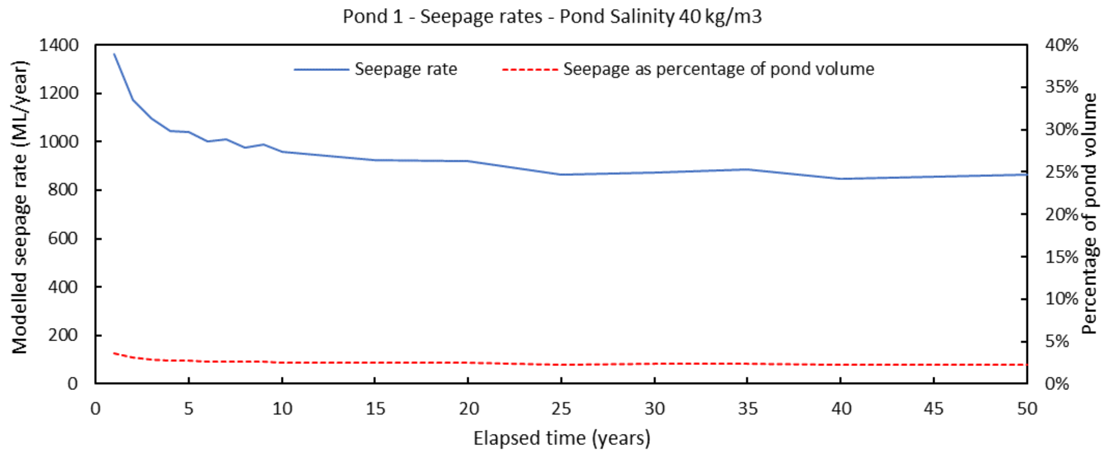


Figure 9-11 Effect of Salinity and Density Differences on Predicted Seepage Rates



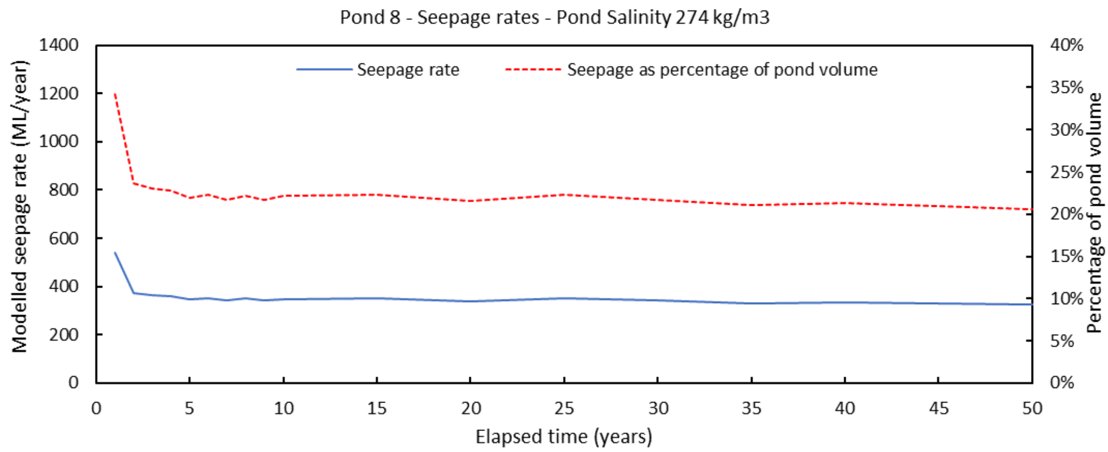


Figure 9-12 Predicted Changes in Seepage Rate over Time

9.4.3 Predicted Changes in Groundwater Levels

The water table beneath the footprint of salt ponds is shallow, typically around 0.3 to 0.5 m below surface. When the salt ponds are filled, the water table quickly equilibrates with the pond water level (within a matter of a few days). The spatial extent of waterlogging depends to a large degree on the depth to groundwater and effect of evapotranspiration.

In the low-lying area between the mangroves and the western boundary of Ponds 1 and 2, there is a limited unsaturated zone, and the water table becomes intercepted by evapotranspiration. As the rate of evaporation is greater than the rate of seepage of pond water, the extent of potential waterlogging is constrained to a narrow area immediately adjacent to the pond boundary (outside of where the embankment would be, based on where the modelled water table is either at or slightly above ground surface, refer to Map 26 for depictions of that water logging).

In more elevated areas, such as the mainland remnant sand islands, the water table can rise to a greater elevation before evapotranspiration becomes effective. This means the water table in elevated areas adjacent to some parts of the salt ponds increases over time. This effect can be seen in the upgradient areas in Map 22, which shows the predicted increase in groundwater levels after 10 and 50 years of operation.

Map 22 reveals a small area west of Pond 1 where the ground surface is slightly elevated and the groundwater level is predicted to increase by around 0.2 m before evaporation becomes effective. The depth to groundwater remains at around 0.3 m in this area, constrained by evaporation.

In some areas down gradient of the salt ponds, the modelling shows an initial increase in groundwater level followed by a gentle reduction. This explains some of the differences between the contours of groundwater level change after 10 and 50 years, where the extent of change appears smaller after 50 years and is most likely to be related to the initial displacement of pore water associated with salinity and density effects, which are discussed in Section 9.4.4.

To the east of salt ponds, the model simulates a lowering of groundwater level at the borrow pits where the pit floor penetrates the water table or where the water table reaches close to ground surface and becomes intercepted by evapotranspiration. This drawdown of the water table (generally less than 0.5 m) is due to the locally elevated groundwater level simulated beneath sand dunes and ridges to the east of the project where the water table is currently less constrained by evapotranspiration.

9.4.4 Predicted Changes in Groundwater Salinity

The predicted changes in groundwater salinity are discussed with reference to Map 23, Map 24 and Map 25 and cross-sections shown in Figure 9-13 and Figure 9-14.

Groundwater salinity simulated under the existing condition is compared with the salinity predicted after 10 and 50 years of project operation. There will be a general decrease (freshening) in salinity underneath the salt ponds and an increase in salinity along the area adjacent to the salt ponds. The processes leading to these changes in salinity are more clearly illustrated in northwest-southeast cross sections shown in Figure 9-13.

Where the salt ponds are filled with fresher water than groundwater, seepage of pond water results in a gradual freshening of groundwater below. Where the difference in salinity between groundwater and pond water is smaller, this freshening effect occurs more quickly due to smaller density gradients (e.g. in the western part of Pond 1, in the fringing area of the hypersaline zone).

The seepage of fresher pond water also displaces more saline existing groundwater, which becomes intercepted (trapped) by evapotranspiration in the low-lying area immediately adjacent to the salt ponds. Over time, salts from existing hypersaline groundwater as well as those carried by seepage water accumulate in the area outside the salt ponds, resulting in the formation of more saline and denser groundwater.

The combination of freshening of groundwater beneath the salt ponds and salinisation in the adjacent area results in the formation of a wedge/interface along the boundary of salt ponds, with a fresher groundwater lens forming in the middle. The salinity and density contrasts along this wedge are likely to be the primary cause of the reduction in seepage rate shown in Figure 9-12. As the salinity increases along the perimeter of the salt ponds, the salts (salinity front) migrate into the surrounding area under the hydraulic, salinity and density gradients.

In areas adjacent to Pond 7 and 8, where water in the salt ponds is more saline than groundwater, large quantities of salts quickly accumulate in the adjacent area. This forms a dense, hypersaline plume which migrates down and outward under the hydraulic, salinity and density gradients, as shown in Figure 9-14. It is important to note that the model assumes no changes to the permeability of the base of these hypersaline salt ponds and this suggests that the predicted salinity effects shown in Figure 9-14 are likely to be over-predicted and conservative.

The processes described above mean the changes in the salinity are largely due to the displacement of existing hypersaline groundwater out from underneath the salt ponds and into the surrounding area. While there is some uncertainty in the rate of change of salinity, the important finding of the modelling is the identification of the potential for changes in salinity to occur in the area of down gradient receptors within the 50-year operation of the project.

The model also simulates an increase in salinity below the borrow pits where the salts accumulate in shallow groundwater due to evapotranspiration from the floor of the pits. This effect is particularly pronounced at Borrow Pits 1 and 2, which may partly be due to the salts derived from the seepage of more saline pond water in the adjacent Ponds 6 and 7 (as well as the salt in existing hypersaline groundwater). This results in a localised wedge forming below these borrow pits due to the density contrast against the adjacent fresher groundwater (for example, below the sand dunes to the east as shown in Figure 9-14).

The density coupled flow and transport model does not simulate more complex hydrochemical reactions, such as the precipitation of salts once the salinity of groundwater reaches solubility limit[1]. As a result, the salts can theoretically continue to accumulate within the groundwater model, simulating salinity greater than the solubility limit. This occurs only in localised areas adjacent to Ponds 7 and 8 and along the floor of Borrow Pits 1 and 2 (where the salts are trapped by EVT) and has no effect on the predicted changes in salinity in critical areas adjacent to Ponds 1 and 2. The density effect is also constrained at the maximum salinity of 400 g/L.

Map 24 and Map 25 show the predicted increases in the average salinity of Unit 1 (top aquifer) at the end of Year 10 and Year 50, to demonstrate the potential magnitude and extent of the incremental effect of the project. The salinity changes are derived from the uppermost active (saturated) layer, which generally corresponds to layer 1. In the area downgradient of the salt ponds, the thickness of this layer is typically around 2 to 2.5 m, meaning that the salinity changes predicted by the model represent the potential average salinity changes of the top 3 m of the aquifer (or at the mid-point of the layer, roughly 1 to 1.25 m below surface).

Areas potentially susceptible to the development of a surface salt crust have been estimated based on the locations where the modelled groundwater salinity is greater than solubility (assumed to be 350 g/L) and where the depth to groundwater is within 0.3 m of ground surface (within the modelled depth of evapotranspiration, where salts could be transported upwards via evaporation). The areas of potential salt crust formation are indicated in Map 27. The model locally simulates salinity greater than 350 g/L beneath the crystallisers; however, salt crust is not indicated in the map as the base of crystallisers will be effectively impermeable due to the formation crystallised salt.

[1] Version 1.7 of USG-Transport, released in March 2021, now allows solutes to precipitate out of water phase once the solubility limit is reached. This capability is unlikely to change the outcome of the modelling, given the salinity in excess of 400 g/L is only simulated in localised areas where salts are trapped by EVT and allowed to accumulate over time.

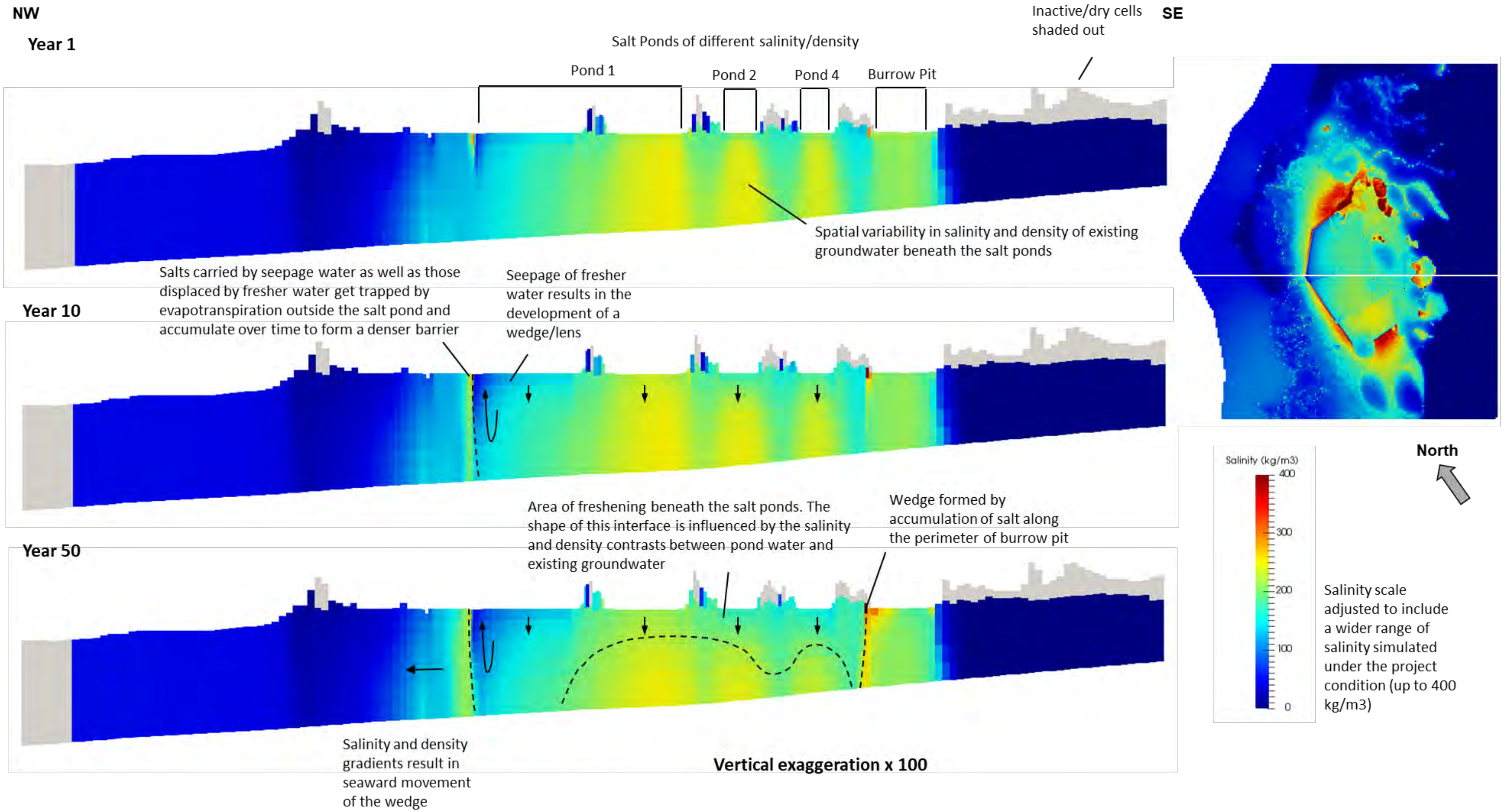


Figure 9-13 Predicted Salinity Profile across Pond 1

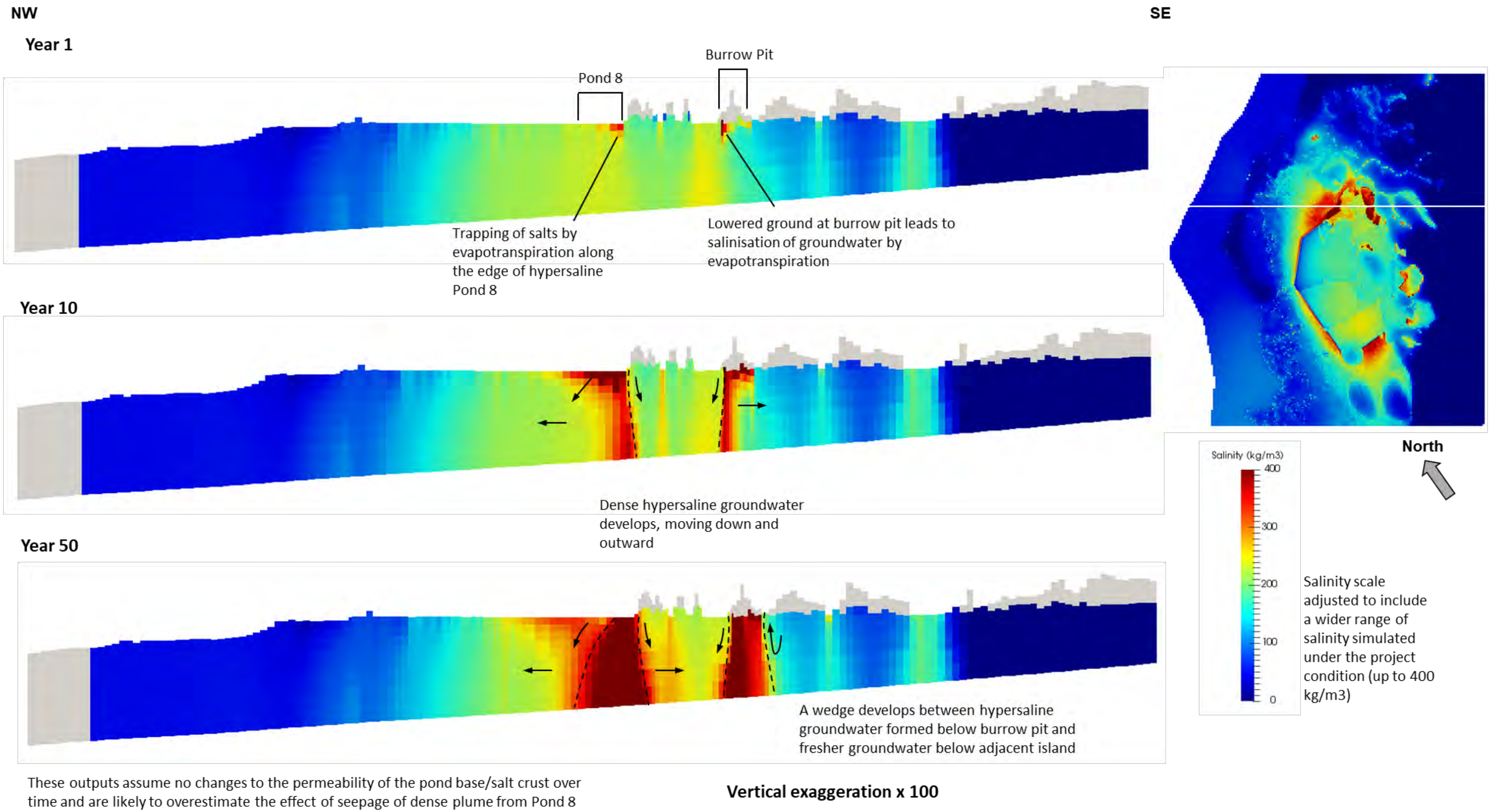


Figure 9-14 Predicted Salinity Profile across Pond 8

9.4.5 Timeseries of Predicted Groundwater Level and Salinity Changes

Predicted changes in groundwater levels and salinity of Unit 1 (top aquifer) at several downgradient locations are presented as time series (hydrographs) (Figure 9-15) to illustrate the rate at which the potential project-induced changes may occur.

The time series plots at these locations show a gradual increase in the average salinity of Unit 1 due to the displacement of hypersaline groundwater and a stabilisation of groundwater level following the initial increase due to seepage of pond water. The hydrographs provide indications of the potential timing and magnitude of groundwater level and salinity changes at different distances away from the edge of the ponds, based on conservative conditions adopted in the model.

9.5 Uncertainty Analysis

9.5.1 Approach

Hydrogeological systems are complex natural systems with properties which cannot be measured at all spatial and temporal scales. Hydrogeological processes that have occurred in the past, and those that may occur in the future, can only be inferred from a finite number of measurements. Simplifications are therefore necessary in groundwater modelling and uncertainty is inherent in all model predictions.

In groundwater modelling, uncertainty in model parameters can lead to the problem of model non-uniqueness or non-identifiability (Barnett et al., 2012). This is when the behaviour of the groundwater system being modelled depends on a particular combination of parameters rather than a single parameter in isolation. Because model parameters are uncertain, with a plausible range of values, different combinations of parameter values could result in more than one plausible realisation of the same model.

This section explores the potential effect of model uncertainty in two ways:

- Linear analysis of predictive uncertainty to examine the effects of parameter uncertainty; and
- Subjective sensitivity analysis to examine the effect of potential changes in the permeability of the base of salt ponds, which cannot be assessed with prior knowledge or through calibration.

9.5.2 Linear Analysis of Predictive Uncertainty

Method

The method of uncertainty analysis adopted in this study is based on the linear analysis of post-calibration predictive uncertainty. In linear analysis, only the knowledge of measurement or structural error informed by model to measurement misfit and the sensitivity of model outputs to model parameters are required.

While there are limitations associated with the assumed model linearity, the linear analysis provides efficient means of computing uncertainty in the predictions of interest. This is well suited to models with long run time, such as the density coupled flow and transport model developed for this project. Both the Australian Groundwater Modelling guidelines (Barnett et al, 2012) and recently published uncertainty information guidelines by the Independent Expert Scientific Committee (Middlemis and Peeters, 2018) recommend linear analysis as one of the methods for quantifying uncertainty in groundwater model predictions.

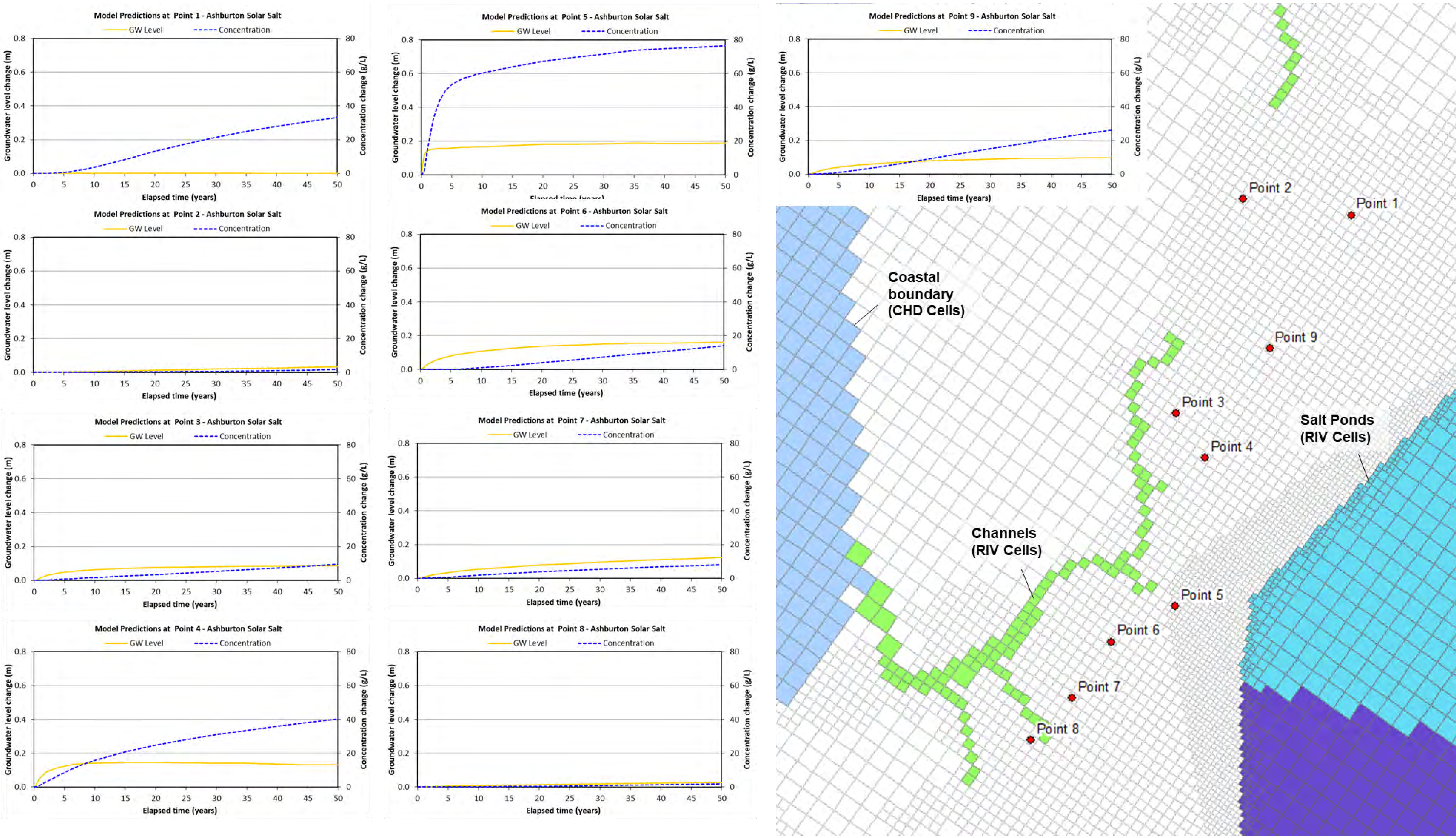


Figure 9-15 Timeseries of Predicted Groundwater Level and Salinity Changes at Selected Downgradient Locations

The linear analysis of predictive uncertainty has been completed based on the following key steps:

- Calculation of the Jacobian sensitivity matrix of calibration as well as prediction observations with respect to each adjustable model parameter. The Jacobian matrix from the automated calibration has been expanded to include additional parameters such as the zero-order decay coefficients (previously manually adjusted) and bed conductance of the salt pond RIV cells. A total of 60 adjustable parameters are used for the linear analysis. The prediction observations include modelled seepage rate from each of the eight salt ponds and change in concentration (salinity) and groundwater level calculated at the key downgradient locations shown in Figure 9-15;
- Calculation of the posterior (post-calibration) parameter covariance matrix from the Jacobian sensitivity matrix using the PEST utility PREDUNC7. The unique feature of PEST and associated utilities is the inclusion of a quantitative expression of parameter simplification errors in uncertainty forecast for highly parameterised models. The parameter simplification errors arise from the need to translate the heterogeneity of the complex physical system into a numerical model. This is achieved by supplying PREDUNC7 with a prior (pre-calibration) parameter covariance matrix based on the plausible upper and lower parameter bounds used in model calibration (within which the true parameter values can be expected to exist); and
- Linear propagation of uncertainty using the posterior covariance matrix and the Jacobian sensitivity matrix of the prediction observations.

Results of linear analysis

Figure 9-17 presents the results of the linear analysis of the modelled seepage rates, using the average modelled seepage rate of each pond over the 50-year operation. The marker indicates the modelled seepage rates using the calibrated parameters. The seepage rates are in million cubic metres per year, to be consistent with the rates shown in Figure 9-10. The error bars represent the 90% confidence interval of the modelled seepage rates, calculated between the 5^{th} and 95^{th} quantile.

The length of each error bar provides an indication of the level of uncertainty associated with the modelled seepage rate. For example, the largest uncertainty is associated with Pond 1 seepage due to its large surface area (interacting with a larger area of the model) and least saline pond water (sensitive to density differences). There is also larger uncertainty associated with the modelled seepage rates from Ponds 2, 5, 7 and 8 compared to Ponds 3, 4 and 6. The upper limit of the error bars represents the 95^{th} percentile seepage rate, indicating that the long term average seepage rate for each salt pond is unlikely to be greater than the threshold represented by this upper limit.

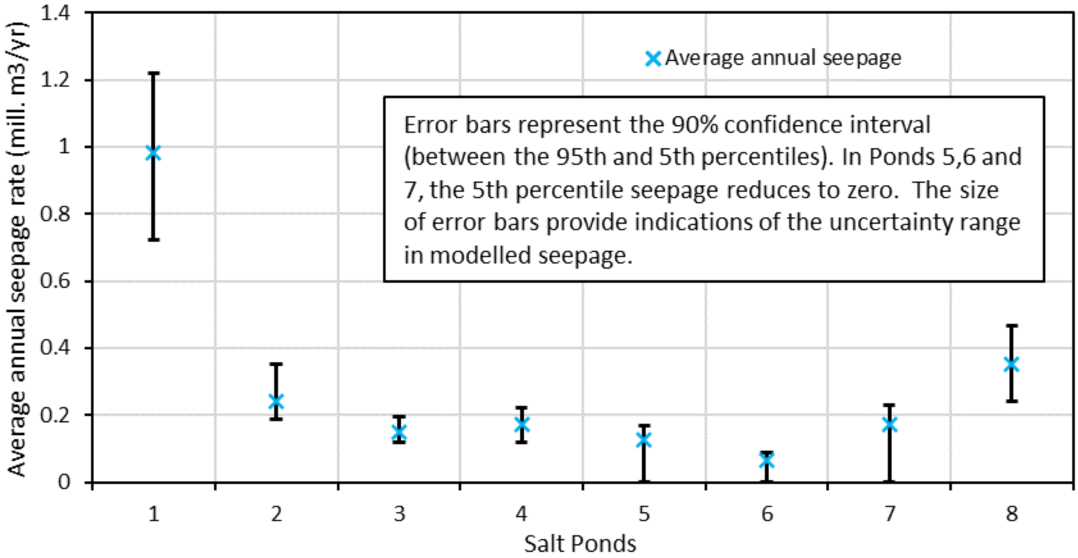


Figure 9-16 Linear Analysis of Seepage Rates

Figure 9-17 and Figure 9-18 show the time series of modelled changes in groundwater levels and salinity at several locations downgradient of the salt ponds, respectively. Also indicated in each hydrograph is the 90% confidence interval of the modelled changes. For the groundwater level change, the uncertainty range is generally small (less than 0.15 m). For the salinity change, the uncertainty range is generally around 20 g/L or less. The largest uncertainty is associated with the locations closest to the edge of Pond 1 (Points 4 and 5), which is expected as these locations are closest to the salinity/density front migrating from the salt ponds where the salinity is changing most rapidly.

Data Worth Considerations

Groundwater data, like other environmental data, has worth in proportion to its ability to reduce uncertainty inherent in model predictions. The quantification of uncertainty through linear analysis, as presented in the previous sections, also allows quantification of data worth and associated reduction in model uncertainty. This supplementary information from the linear analysis can be extracted using the PREDUNC suite of PEST utilities.

Information derived from PREDUNC utilities, such as the relative contributions of model parameters and observations to predictive uncertainty, can be useful for identifying which parameters and observations are most critical for reducing uncertainty associated with the predictions of interest. The information also provides a quantitative basis for confirming the conceptualisation of the expected project outcomes and the interpretation of model results presented in Section 9.4

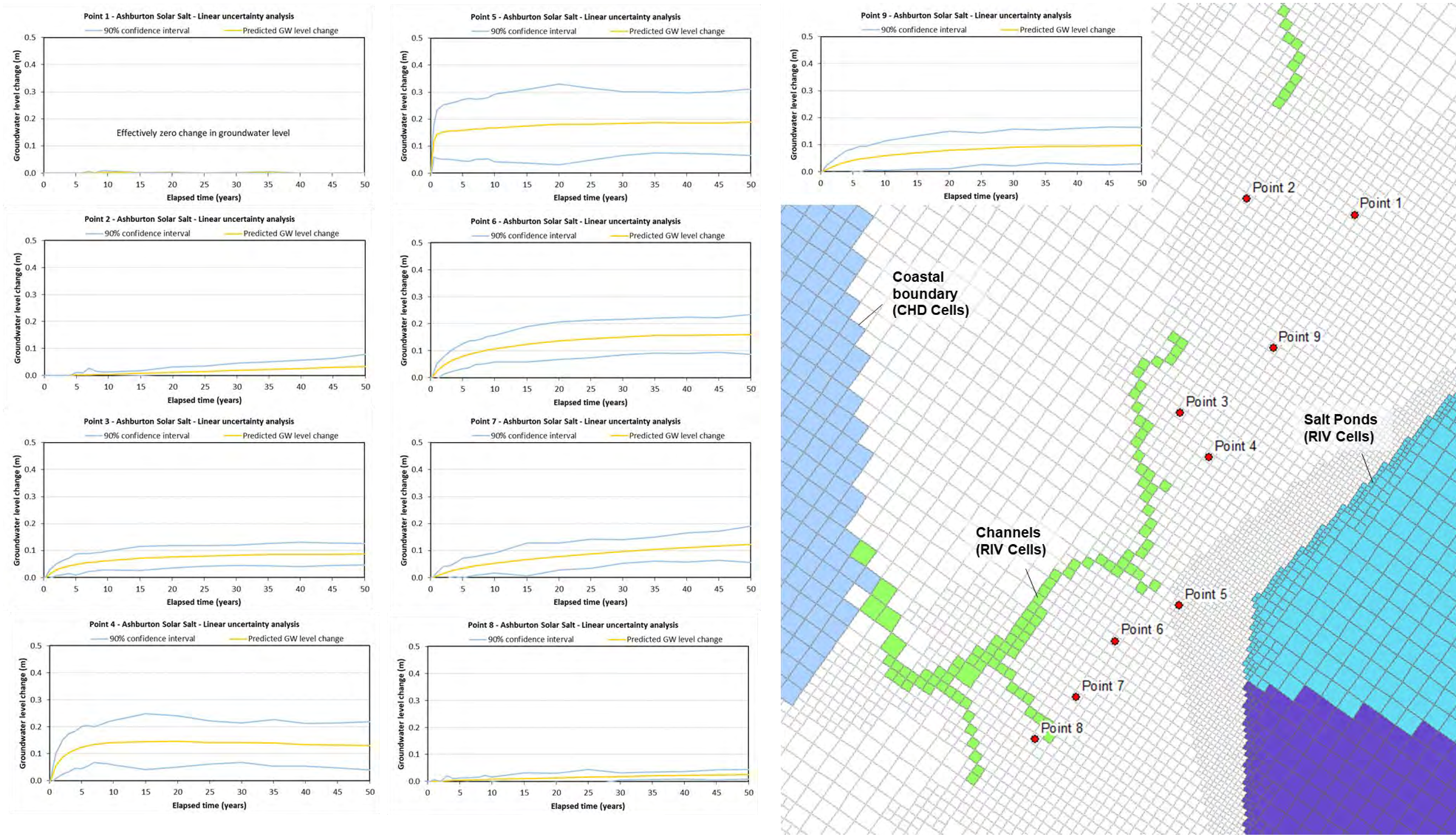


Figure 9-17 Linear Analysis of Groundwater Level Change at Selected Downgradient Locations

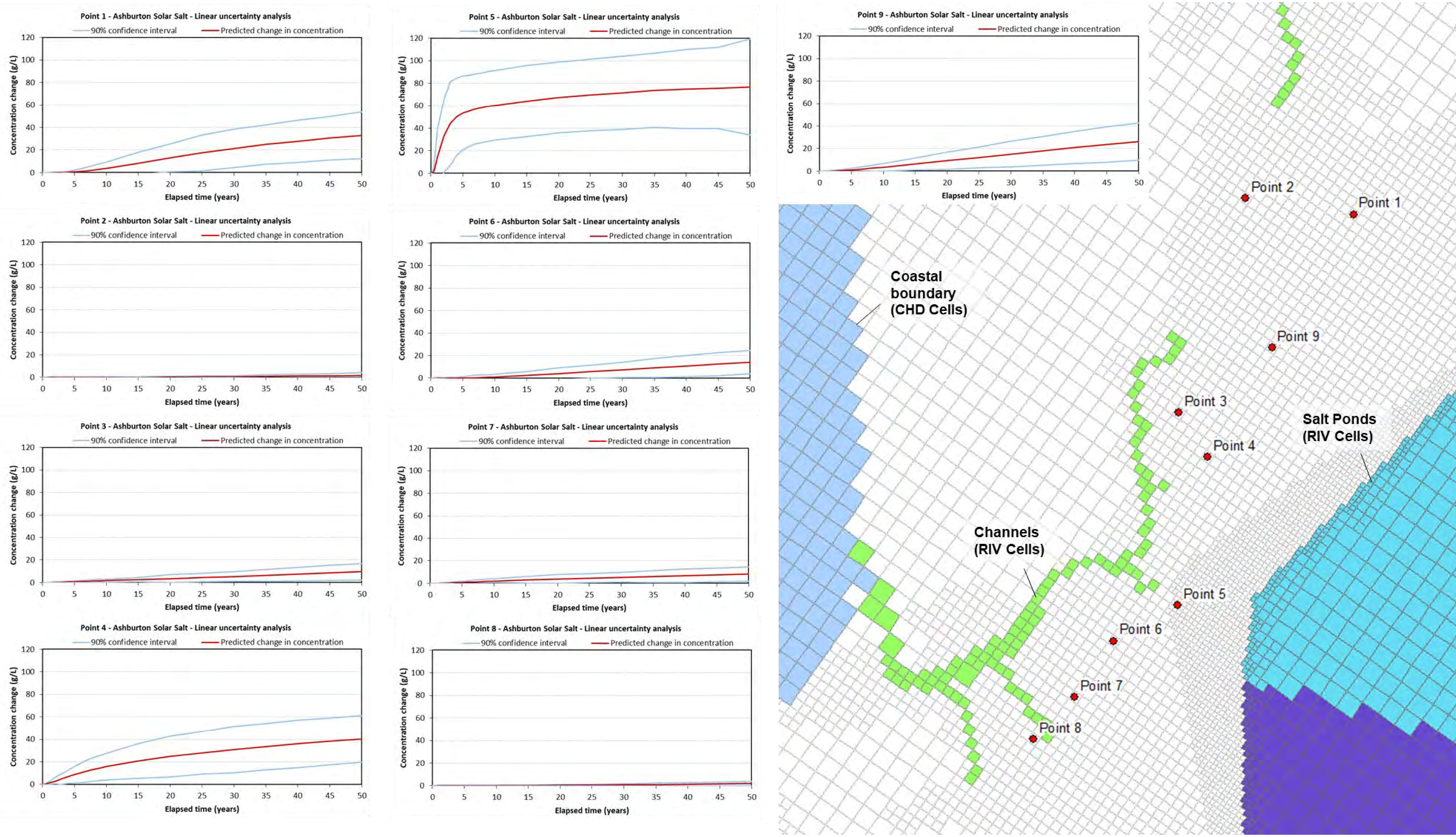


Figure 9-18 Linear Analysis of Groundwater Salinity Change at Selected Downgradient Locations

To demonstrate this process, the PREDUNC utilities have been run for the following key predictions of interest:

- Seepage rate from Pond 1, which is most critical for influencing the salinity and groundwater level changes at downgradient locations; and
- Change in groundwater level and concentration downgradient of Pond 1 (Point 5 in Figure 9-17 and Figure 9-18, closest to the pond).

Figure 9-19 shows the contribution of each model parameter type to predictive uncertainty. The figure includes both the pre-calibration and post-calibration predictive uncertainty variance (a measure of the degree of uncertainty) for each parameter type, normalised against the total pre-calibration uncertainty variance.

The parameter types with the largest normalised uncertainty variance have the largest contribution to uncertainty associated with each prediction of interest. Figure 9-19 indicates that recharge, evapotranspiration and horizontal and vertical hydraulic conductivities generally have the largest uncertainty contributions. This is not surprising, based on the current conceptualisation of the system behaviour and their sensitivities discussed in Section 9.3.5.

The reduction in post-calibration uncertainty (relative to the pre-calibration) indicates the degree to which the prediction uncertainty has been reduced through the formal calibration procedure implemented in Section 9.3. For example, a large uncertainty reduction associated with recharge and evapotranspiration is consistent with the importance of these processes in controlling the salt mass balance and distribution of groundwater salinity, which are ultimately critical for understanding the rate of seepage and changes in shallow groundwater salinity downgradient (Point 5 in Figure 9-19). Given the large reduction in uncertainty achieved through calibration, additional data collection efforts to improve estimates of these parameters may not lead to a significant reduction in uncertainty associated with the current model.

In contrast, a further data collection effort to improve the knowledge of hydraulic conductivity and, to a lesser degree, specific yield (also linked to effective porosity) and dispersivity, could assist in further reducing the uncertainty associated with the prediction of seepage and downgradient salinity changes. Again, this is not surprising, as hydraulic conductivities are known to vary by one to two orders of magnitude, which have a large influence on estimating the rate of groundwater flow and solute transport.

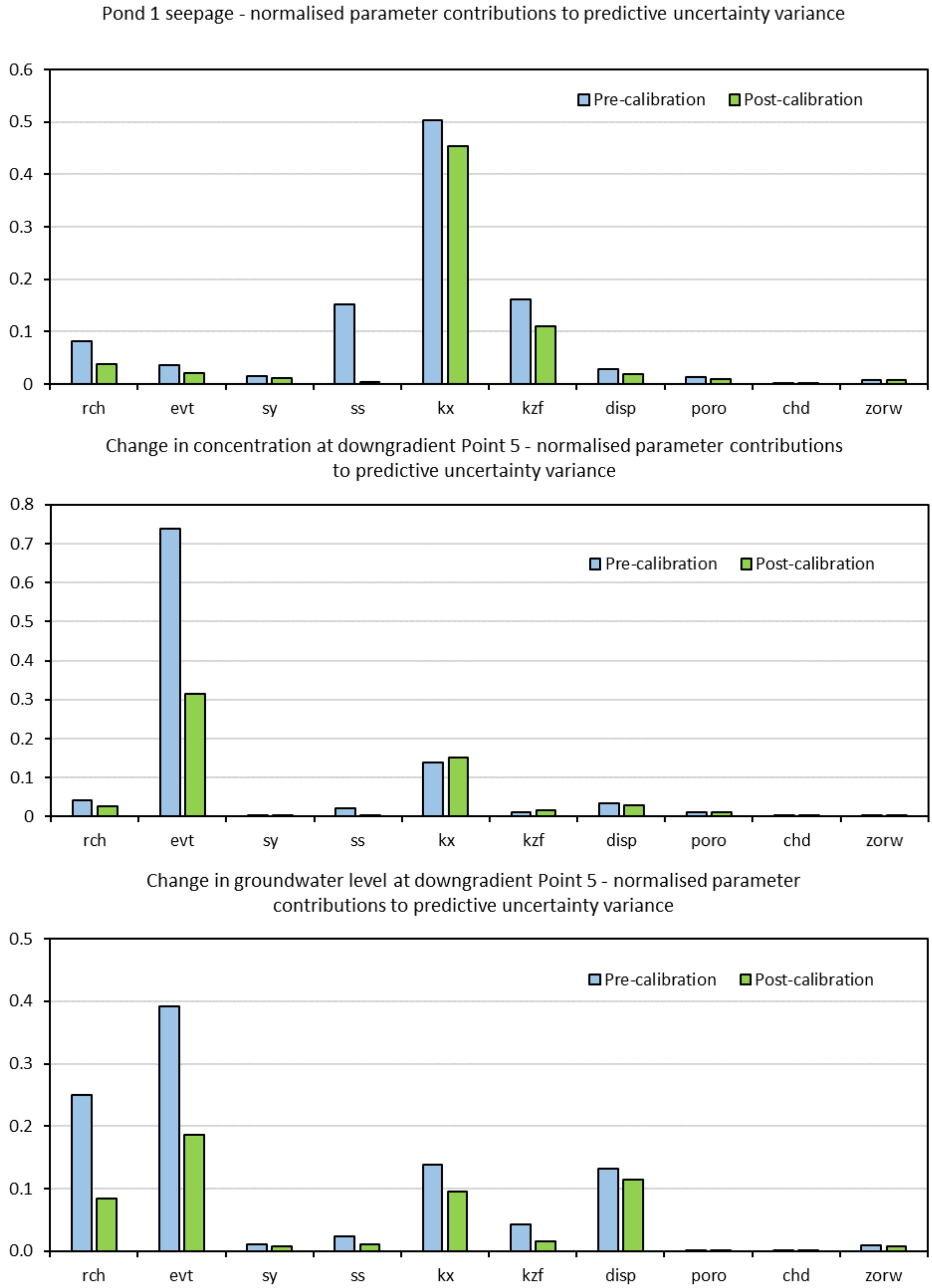
The linear analysis can also provide indications of the observation data worth by calculating the relative change in predictive uncertainty variance when each observation type is added or removed. For this project, the three observation types considered are groundwater level (head), salinity and drawdown (from two pumping tests).

Figure 9-20 compares the relative change in uncertainty for the predictions of interest. The first bar chart indicates the relative increase in predictive uncertainty variance that arises when each observation type is omitted sequentially, i.e. the predictions become more uncertain as the information contained in the observation type is removed.

The second bar chart in Figure 9-20 indicates the relative fall in predictive uncertainty when the observation types are sequentially added, i.e. the predictions become less uncertain as the information contained in the observation types is added. Hence the size of the bars in both charts provides indications of the worth of the observation types in reducing uncertainty associated with each prediction of interest.

It can be seen in Figure 9-20 that the largest change in predictive uncertainty associated with the downgradient salinity changes is due to the salinity and head observations. Interestingly, drawdown observations have the largest change in the predictive uncertainty of Pond 1 seepage. This is likely be due to the fact that the two pumping tests used to estimate hydraulic conductivity and storage coefficients are located within Pond 1, hence the drawdown observations have a greater influence on the parameters that affect the seepage rate at this location. Undertaking the same analysis on Pond 3 seepage confirms that the head and salinity observations result in greater changes to predictive uncertainty than drawdown, as the pumping test sites are some distance away.

It should be noted that the data worth, as shown in Figure 9-20, has been limited to the data currently available.



rch = recharge, evt = evt rate and extinction depth, sy = specific yield, ss = specific storage, kx = horizontal hydraulic conductivity, kzf = vertical hydraulic conductivity factor, disp = hydrodynamic dispersion, poro = porosity, chd = constant head boundary, zorw = zero-order decay constant

Figure 9-19 Parameter Contributions to Predictive Uncertainty

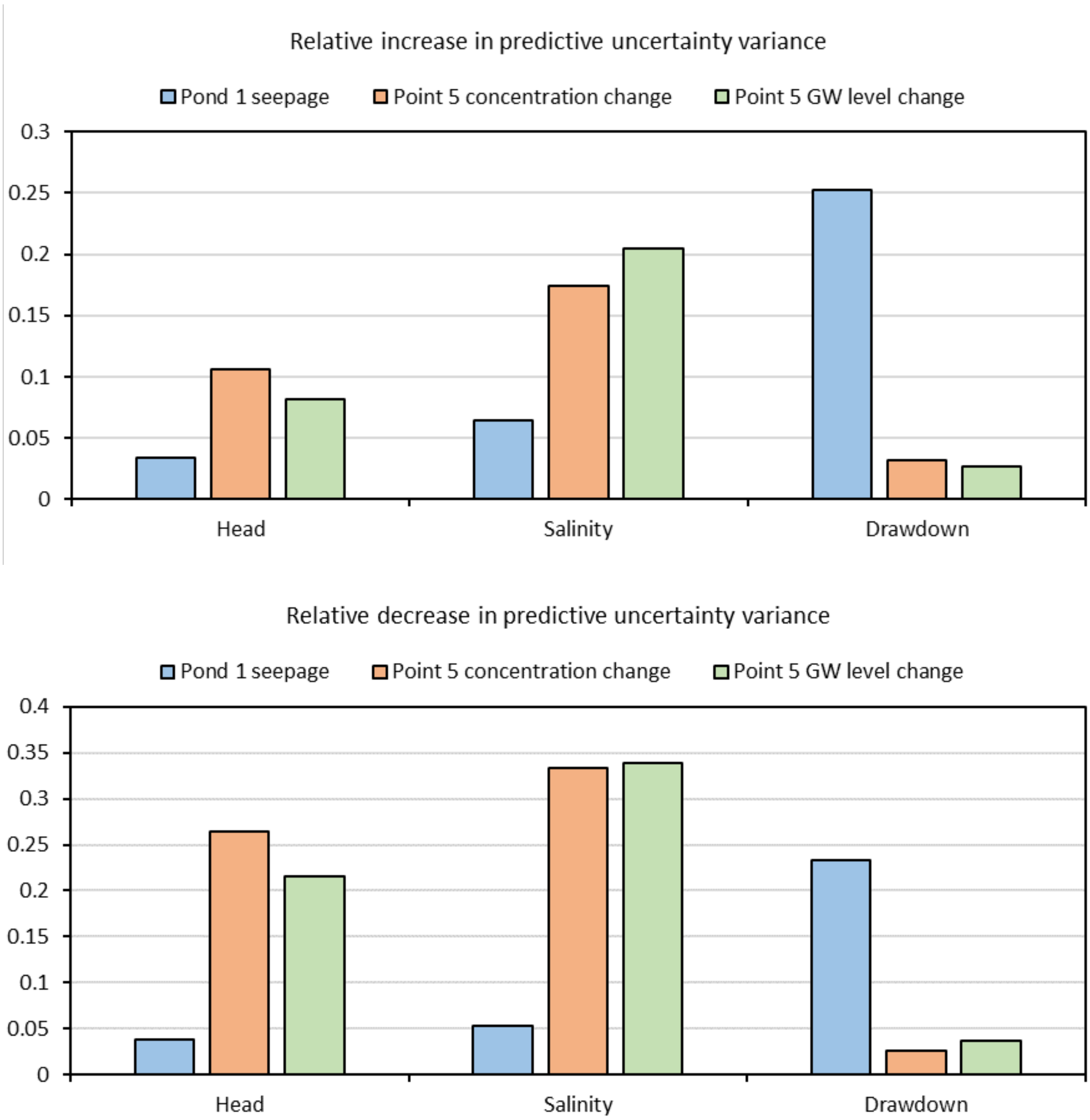


Figure 9-20 Relative Post-Calibration Predictive Uncertainty Variance

9.5.3 Subjective Sensitivity Analysis

As highlighted in Section 9.4.1, experience at other operations suggests that the permeability of the base of salt ponds typically reduces over time. To examine this effect, the hydraulic conductivity of the RIV cells of each salt pond has been linearly reduced during the 50-year simulation period using a simple relationship shown in Figure 9-21.

Figure 9-22 compares the predicted seepage rates for Pond 1 and 8 with and without this reduction in the salt pond hydraulic conductivity. The sensitivity analysis indicates that a reduction in seepage rate occurs when the hydraulic conductivity of the RIV cells becomes less than 0.001 m/d, with a significant reduction in seepage occurring when the hydraulic conductivity becomes less than 0.0001 m/d (around year 30). The implication is that the hydraulic conductivity of the base of the salt ponds would need to become as low as at least 0.0001 m/d to make a material difference to the impacts predicted assuming a constant (unchanged) hydraulic conductivity.

Additionally, this reduction would need to occur within the first few years of the operation to mitigate the displacement of the existing hypersaline groundwater and resulting salinisation of the surrounding area. This may be plausible at hypersaline salt ponds (Pond 7 and 8) but less likely at fresher salt ponds, depending on the effect of siltation and biological processes.

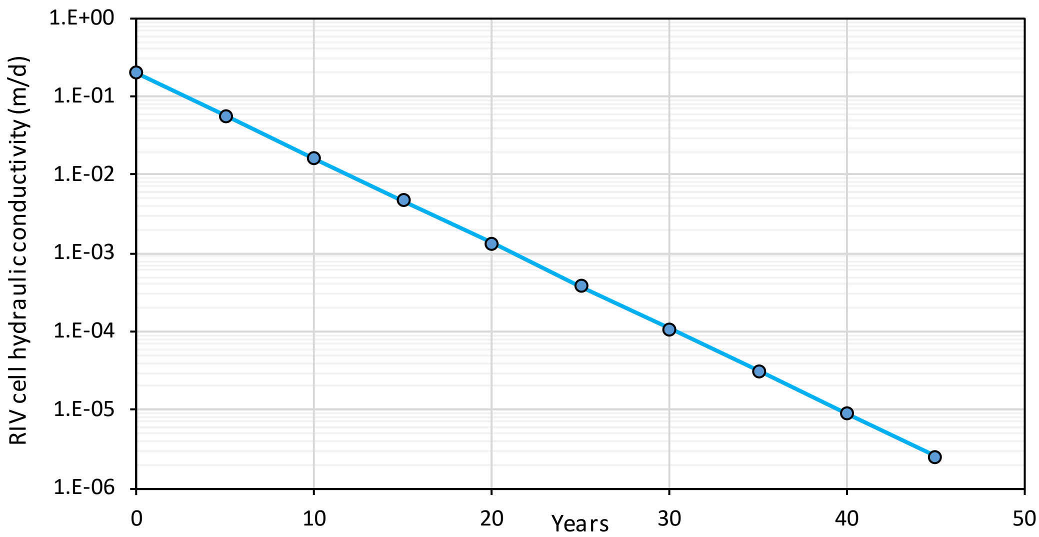


Figure 9-21 Reduction in Salt Pond Hydraulic Conductivity

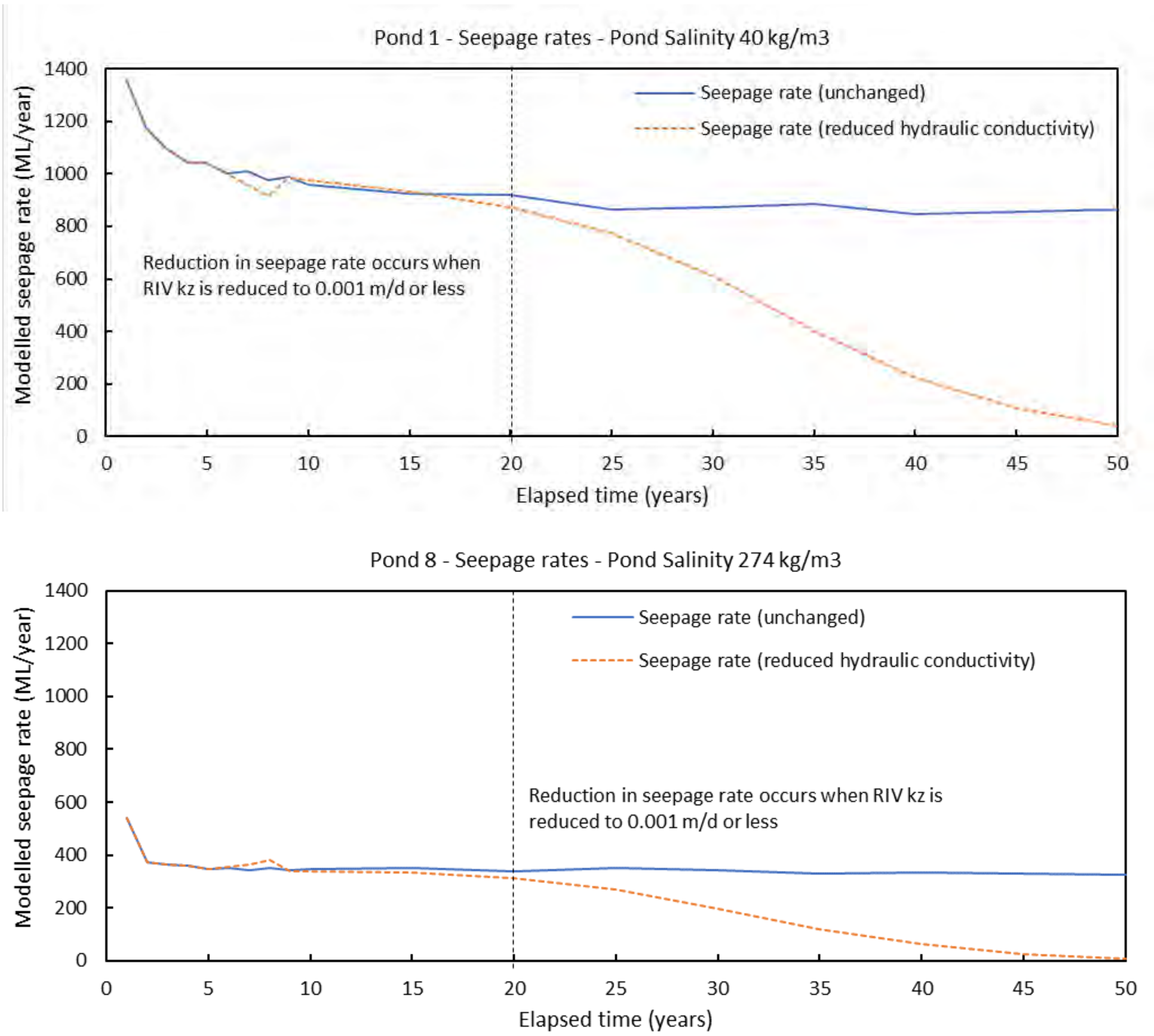


Figure 9-22 Effect of Salt Pond Hydraulic Conductivity on Seepage Rates

Siltation of Ponds 1 and possibly 2 may be enhanced by imported turbidity (suspended solids) from seawater, the majority of which have the potential to settle at the base of Pond 1. The magnitude of siltation from suspended solids is difficult to predict, however this may be a reasonable process to occur in Pond 1 and potentially less in Pond 2. Similarly biological processes such as formation of algae growth on pond floors could reduce permeability.

A high-level estimation of the magnitude of potential siltation is based on consideration of suspended solids load from imported seawater. The project assumes approximately 250 GL of seawater imported annually into the pond system. The typical range of suspended solids in seawater is between 0 to 10 mg/L, which represents a potential annual load of up to 2,500 tonnes.

If, for example, 50% of that suspended solids load settle as sediments at the base of Pond 1 it would represent on average 33 g/m^2 in year 1, and 330 g/m^2 and 1,650 g/m^2 in years 10 and 50, respectively, while excluding any additional atmospheric deposition. Crystalisation of salts (halite) would not occur in Ponds 1 and 2 but there is the potential for precipitation of carbonates (calcite, dolomite). This indicates that a relatively thin layer of unknown (but generally low) permeability may form at the base of Pond 1. This has not been included in the predictions provided in the previous sections and only the sensitivity is described in this section. Similarly it is difficult to predict biological processes such as algae growth which may affect permeability.

9.6 Targeted Modelling of Shallow (Near Surface) Groundwater Salinity

9.6.1 Overview

Communities of mangroves in low-lying areas near tidally inundated channels are supported by regular tidal flushing that maintains the soils and shallow groundwater fresher at around 40 to 90 g/L salinity. Although the regional scale modelling described in the preceding sections accounts for the average effect of tidal flushing (through the use of zero-order decay coefficients), there is insufficient resolution in the vertical direction to simulate the potential local salinity stratification in the very top part of the shallow aquifer. The regional model predicts salinity at approximately 1.25 m below the water table, which is below the zone that mangroves tap into (which is 0.1 to 0.2 m below the water table).

The salinity in the top 0.1 to 0.2 m of the water table tapped by the mangrove roots is likely to remain fresher than the average salinity simulated in the top layer of the regional model, which is an important implication for the assessment of project-induced salinity changes on the health of mangroves.

Targeted high resolution modelling was undertaken to examine the potential degree of salinity stratification within the very top part of the aquifer and how this may change in response to the range of salinity changes predicted by the regional scale model. The targeted modelling is not based on rigorous calibration to site specific data and is therefore intended as “proof-of-concept” modelling to demonstrate the potential significance of this highly localised tidal flushing effect within tidal creeks.

9.6.2 Model Design

The submersion frequency curve prepared by Water Technology (2021) indicates that the mangroves are generally found at elevations ranging from 0 to 0.6 mAHD, with a submersion frequency of around 30% at an average elevation of 0.3 mAHD. For the purpose of this assessment, the mangroves are assumed to be submerged, on average, one third of the day and exposed to net evaporation two thirds of the day.

A proof-of-concept 2D cross-sectional model has been developed in USG-Transport to examine the tidal flushing effect over a relatively narrow inundation width of 20 m. This is based on the width of mangroves mapped adjacent to narrow channels (for example, on the landward side of the channel closest to Pond 1). The 2D model has a total width of 200 m, with 1 m by 1 m cells and the 20 m wide inundation zone located in the middle.

The model top is set at 0.3 mAHD, based on the average inundation elevation, and the model bottom is at -31 mAHD, corresponding to the average bottom elevation of Unit2b over the mapped mangroves area. The model bottom has been extended down to the natural hydrostratigraphic base to minimise the bottom boundary effect on the development of a fresher lens in the upper part of the model.

There are 30 layers in the model. The top 13 layers are 0.1 m in thickness, providing the vertical resolution necessary for simulating the salinity stratification in the top 1.3 m. The layer thickness is gradually increased to the bottom of Unit 1. Figure 9-23 shows the model layers and elevation of each hydrostratigraphic unit.

The constant head (CHD) boundary condition is prescribed along the lateral boundaries, with a value equal to 0 mAHD (equating to a natural depth to groundwater of 0.3 m). The flushing effect is simulated using the River (RIV) boundary condition, similar to the way the tidal inundation effect has been simulated in the local scale pumping test model (Section 9.3.4). The RIV cells are assigned to layer 1, over the 20 m wide inundation area in the middle, with a RIV stage of 0.3 mAHD and RIV bed bottom of 0.2 mAHD. The RIV cells are activated during tidal inundation and deactivated during inter-tidal periods.

Evapotranspiration (EVT) is assigned to layer 1, with the EVT extinction depth set at 0.3 m below model top. The EVT rate is set to zero when and where the RIV cells are active and re-assigned when the RIV cells are inactive to simulate evaporative loss of tidally inundated water.

As tidal flushing results in the water table reaching ground surface (effectively providing an abundant source of water at ground surface), the EVT rate is set equal to the typical evaporation rate of 3 m/year. The EVT cells are also configured with ETFACTOR set to 1, which allows salt added by tidal flushing to be removed by EVT. This is intended to account for the flushing/export of salts from the soils, which would take place as the salts are accumulated in the soils via evapotranspiration and then are transported away by the subsequent tidal inundation.

The model parameters for each unit are based on the average calibrated parameters from the regional model in the mangrove areas. The exception is the top three layers, where higher hydraulic conductivities, specific yield and effective porosity are assigned to account for the enhanced connection with tidal water due to a large number of crab-holes that are commonly present within the mangroves root zone. Table 9.9 summarises the parameters assigned to each unit.

Table 9.9 Local Model Parameters

HSU	Layers	Kh (m/d)	Kv (m/d)	Sy	Ss (m^{-1})	Eff.Poro (-)
Unit1	1 – 3	10	10	0.1	1.08×10^{-5}	0.2
Unit1	4 - 22	3	0.3	0.05	1.08×10^{-5}	0.1
Unit2a	23 - 25	1.55	0.0155	0.0267	1.09×10^{-5}	0.1
Unit2b	26 - 30	0.47	0.12	0.02	5.4×10^{-6}	0.1

Kh – horizontal hydraulic conductivity, Kv – vertical hydraulic conductivity, Sy – specific yield, Ss – specific storage, Eff.Poro – effective porosity

The tidal flushing effect is simulated by repeatedly switching the RIV cells on and off, alternating with the EVT rate varying from zero to 3 m/year (note the EVT rate remains at 3 m/year throughout the simulation outside of the 20 m wide inundation area where the RIV cells are assigned). Each tidal cycle consists of one stress period with the RIV cells on (0.3 days) and one stress period with the RIV cells off and EVT at 3 m/year (0.7 days). The concentration of 35 g/L is prescribed to the RIV cells and the tidal flushing effect has been simulated with different initial groundwater salinities ranging from 100 to 200 g/L to assess how the salinity stratification develops under different groundwater salinity conditions (note the concentrations of CHD cells are adjusted for each initial groundwater salinity).

The model has been run until the salinity in the top part of the aquifer stabilises, reaching a quasi-steady state condition in response to flushing. A total of 240 stress periods are used to simulate 120 flushing cycles to attain a quasi-steady state condition.

The model uses the BCT and DDF packages of USG-Transport, consistent with the application of these packages to the regional scale model for simulating the salinity (concentration) and density effects.

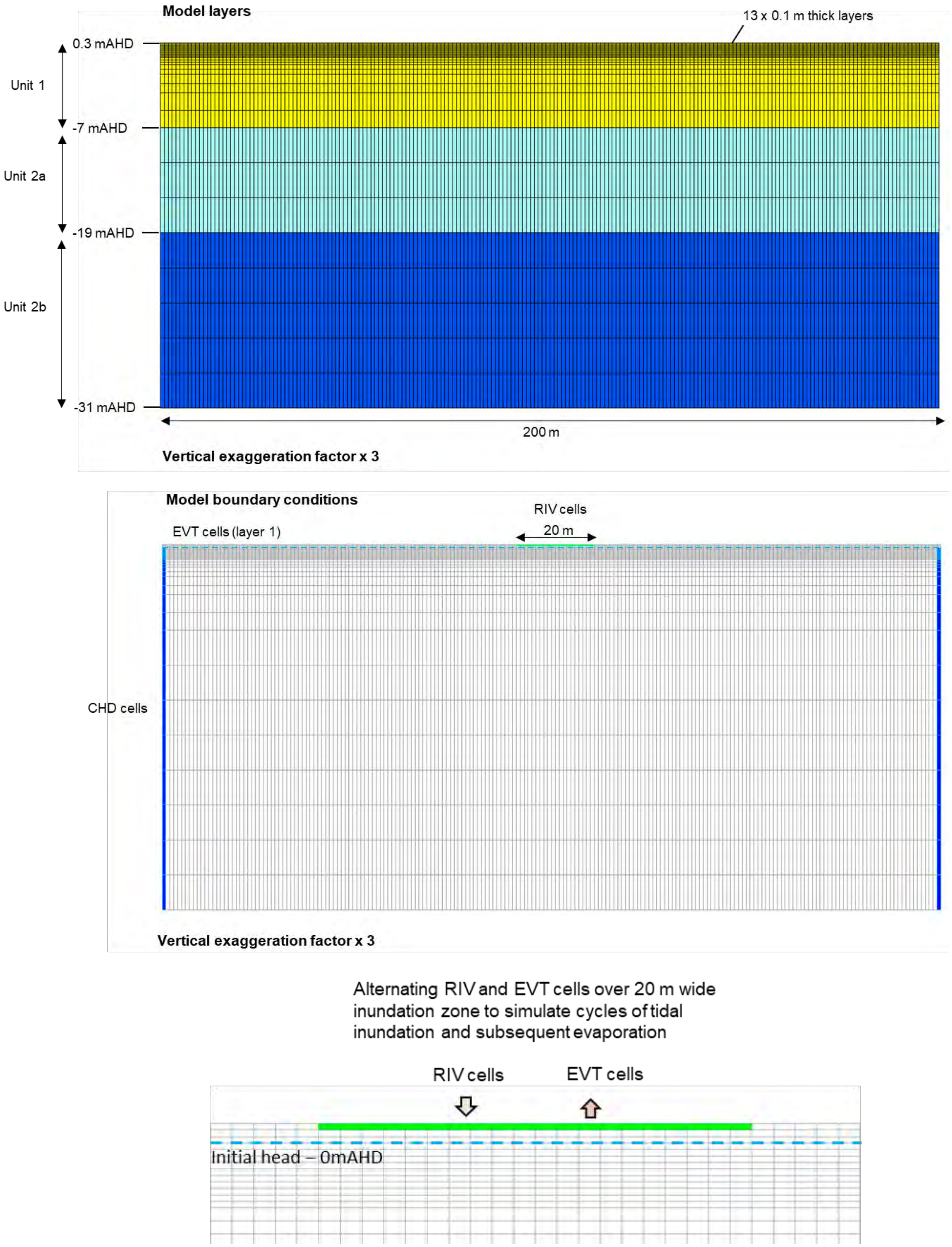


Figure 9-23 Local Model Design

9.6.3 Results

Figure 9-24 shows the simulated salinity within the top 0.2 m of the water table (at around 0.2 m below the static/initial water level of 0 mAHD) for the initial groundwater salinity ranging from 100 to 200 g/L over time. The figure shows that the salinity will stabilise relatively quickly, after only around 80 flushing cycles. The trends shown in Figure 9-24 are also similar to the stabilisation of salinity simulated in the regional model when the zero-order decay coefficients are applied, meaning that the latter approach, while simplistic, can adequately mimic the effect of high frequency flushing.

Figure 9-25 shows the development of a fresher water lens in the upper part of the aquifer for the initial groundwater salinity of 100 and 200 g/L. For the groundwater salinity of 100 g/L, the tidal flushing results in a simulated salinity of 40 g/L within the top 0.2 m of the water table. This corresponds to the lower end of the typical salinity range of 40 to 90 g/L in the mangroves area and can be considered approximately representative of the existing condition. For every 20 g/L increase in groundwater salinity, there is a corresponding increase in the salinity in the top 0.2 m of the water table albeit by a much lower amount due to the tidal flushing effect.

This relationship is shown graphically in Figure 9-25 (top right chart), which compares the simulated salinity in the top 0.2 m (Y-axis) against the initial groundwater salinity (X-axis). Assuming that the salinity of 40 g/L in the top 0.2 m is approximately equal to the existing condition, this relationship can also be presented graphically as changes in salinity (bottom right chart). For example, an increase in groundwater salinity by 80 g/L (change from 100 to 180 g/L) could result in the salinity in the top 0.2 m increasing by 15 g/L (change from 40 to 55 g/L).

Given the simplified nature of modelling, care is needed when interpreting these results. The purpose of the modelling described in this section is to demonstrate the likely occurrence of salinity stratification within the very top part of the aquifer due to tidal flushing and that the changes in groundwater salinity predicted over the broader area by the regional model (at approximately 1.25 m below water table) is unlikely to lead to the same salinity changes in the top 0.2 m of the water table tapped by the mangrove roots.

These results should be reviewed in conjunction with the findings from the regional scale modelling and practical knowledge gained from other similar sites to make an informed assessment of potential groundwater salinity impacts on receptors that are sensitive to this very top part of the aquifer.

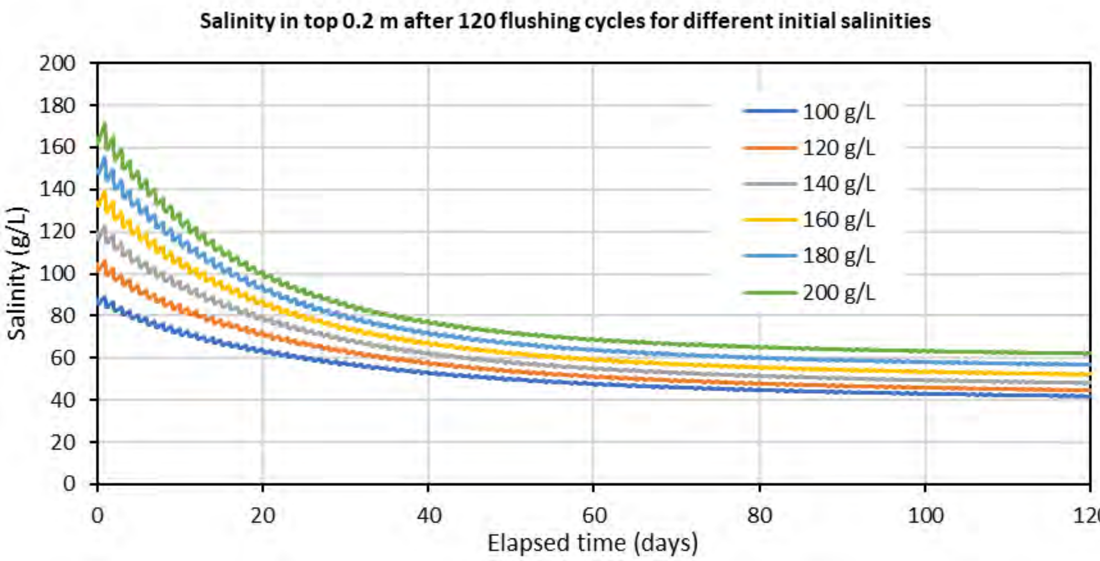


Figure 9-24 Simulated Shallow Groundwater Salinity over Successive Tidal Flushing Cycles

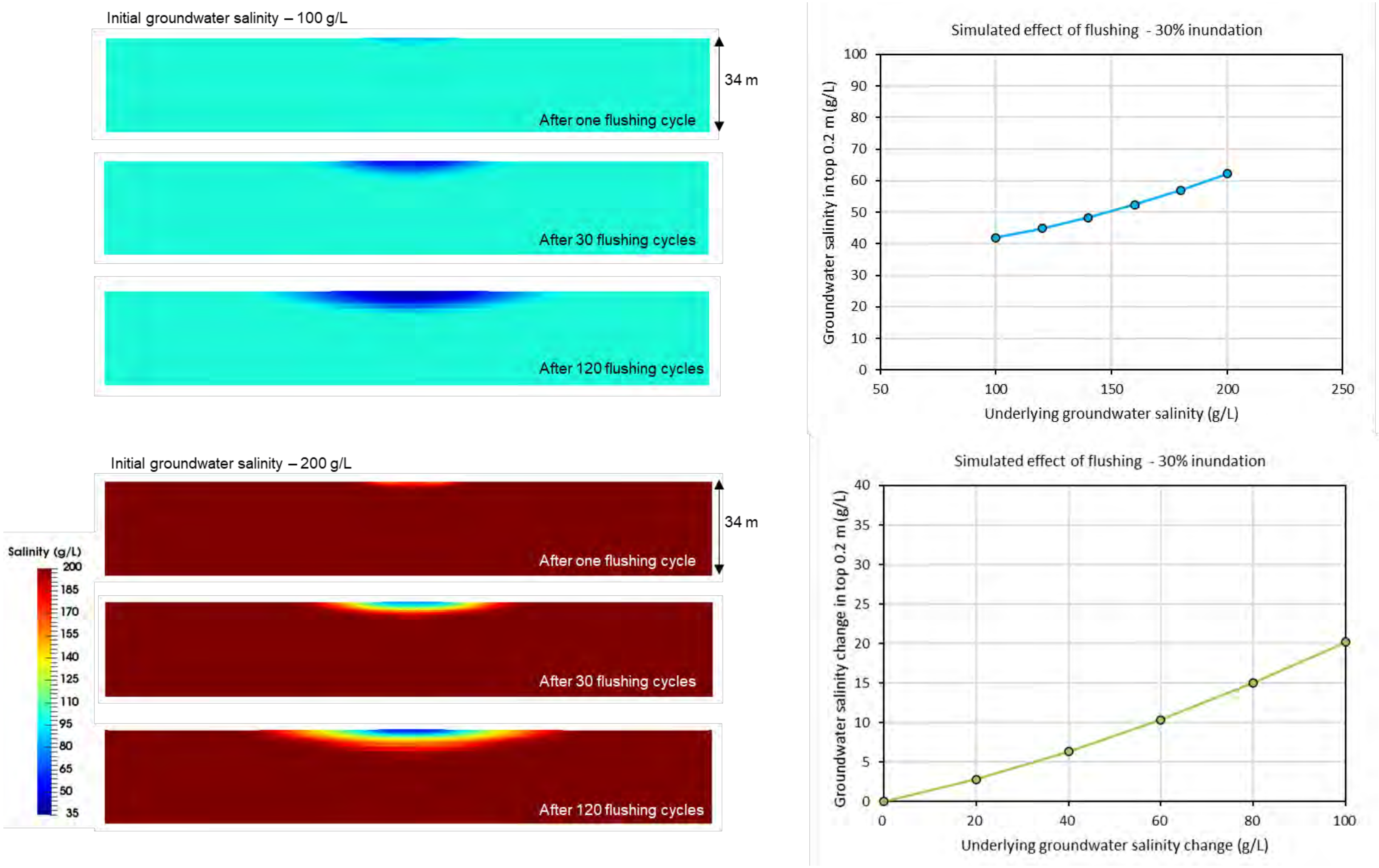


Figure 9-25 Simulated Changes in Groundwater Salinity Due to Tidal Flushing

9.7 Numerical Model Limitations

Numerical groundwater models are a mathematical representation of complex real world systems. The physical domain of interest, comprising layers of rocks and sediments, is discretised into a number of cells and parameters that control the movement of groundwater and solutes through these layers are prescribed to each cell.

The governing groundwater flow and transport equations are solved by the code to compute hydraulic head, concentrations and fluxes into and out of each cell. This mathematical representation of a natural physical system, using a finite number of cells, is a necessary simplification that is inherent in all numerical modelling, the degree of which is influenced by factors including the availability of data, scale of the model, intended model use and computational demand of modelling techniques.

The groundwater model described in this report is of regional scale, consistent with the scale of the project, with a level of detail commensurate with the intended model use and available data. It is not designed to simulate groundwater flow and transport processes at all spatial scales, which is neither necessary to inform the potential regional scale impacts of the project nor possible with the data currently available. It is possible that there is very localised variability in salinity and density in the near surface environment, for example within the rooting depth of mangroves where a thin fresher water lens of potentially several tens of centimetres may be maintained by high frequency tidal inundations. A localised, high resolution “proof of concept” model has been undertaken to examine the potential salinity stratification in the very top part of the aquifer and how this could be impacted by the broader groundwater salinity changes.

The uncertainty associated with the model non-uniqueness has been explored using linear analysis, with a subjective sensitivity analysis undertaken to examine the effect of hydraulic conductivity changes along the base of salt ponds.

10. Discussion

10.1 Introduction

Construction and operation of evaporation (salt) ponds will locally change groundwater flow and salinity regime, promote increased groundwater recharge and alter spatial salinity patterns.

The methodology of the impact assessment focuses on project induced changes from the interpreted baseline groundwater level and salinity. The infrastructure examined is the complex of eight evaporation ponds, the single largest structure to be operated by the project, and the one with the dominant effect on groundwater.

Changes from the baseline environment have been examined through the use of robustly calibrated numerical groundwater flow and transport modelling with density-driven flow functionality. Conservative assumptions have been made, where appropriate, to derive a conservative understanding of potential project induced impacts.

A local scale model has also been produced, simulating the effect of tidal flushing within tidal creeks on surface groundwater salinity.

10.2 Water Logging Assessment

The predictive modelling indicates a limited occurrence of water logging due to seepage of water from Ponds 1 to 8 (Map 26). Water logging originates as mounding from initial filling of the ponds through vertical infiltration and quick saturation of a thin unsaturated zone (typically less than 0.5 m). Filling of the ponds thus promotes both vertical and horizontal flow within the shallow groundwater.

Modelling also shows that seepage rates, and consequently water logging is reduced due to the density of the underlying groundwater body. Water logging is predicted to be generally limited to the immediate vicinity of the pond perimeter.

Groundwater level in the islands surrounding or abutting the ponds will increase with the filling the ponds.

10.3 Salinity Change Assessment

10.3.1 Groundwater Salinity Change

Water imported into the ponds will provide an additional source of salinity which would increase the salinity load to groundwater. Imported water of seawater salinity concentration would also dilute the underlying hypersaline groundwater which is 5 to 7 times more concentrated than seawater.

The net effect would be a general freshening of groundwater underneath the ponds and increase in salinity on the outer fringes of the ponds and beneath the mainland remnant sand islands within the salt concentration pond footprint.

The salinity front in the shallow groundwater would propagate radially away from the ponds. Predictive simulations indicate that additional groundwater salinisation would occur west of the pond complex.

These salinity changes should be considered within the context of conservative assumptions incorporated in the modelling. The predicted salinity changes do not account for potential siltation or biological processes or sal crust development at the base of ponds which may in time decrease seepage and salt loading. While this is likely to happen, the magnitude of this effect is difficult to estimate in advance due to the highly site specific nature of this process.

Therefore, salt loading from the pond complex may be smaller than predicted. This would also affect the extent, concentrations and timing of groundwater salinity increases occurring radially from the ponds, which are potentially overestimated by the modelling.

10.3.2 Salt Crust Development Outside of Ponds

Strong evaporation effects on water seeping from the ponds and daylighting at or close to the surface will result in development of salt crust, similar to the existing crust cover in the salt flats. Development of additional crusts due to the Project was estimated by the numerical model in areas where predicted salinity exceeds 350 g/L (i.e. likely to exceed solubility limits for minerals such as halite or gypsum). Modelling indicated that these areas are limited to the immediate vicinity of the project perimeter (Map 27).

The crust is predicted to develop along the western boundary of Pond 2 and 3 and partly Pond 1. A larger area of salt crust is predicted to develop along the southern perimeter of Pond 3, up to 800 m from the boundary. The affected area will be approximately 1.4 km^2. The near-perimeter areas along Ponds 6, 7 and 8 and the nearby borrow pits are also likely to experience development of salt crusts. The model does not indicate large-scale development of salt crusts around or within mainland remnant islands.

10.3.3 Mangrove Considerations

The regional scale predictive simulations provide salinity concentration estimates for each model cell and this means the model discretisation used (regionally appropriate cell sizes and model layering) can prevent the prediction of subtle localised variations that may otherwise be expected at a detailed local scale. For example, the modelled concentrations are averaged over the thickness each model layer. In the area downgradient of the salt ponds, the thickness of this layer is typically around 2 to 2.5 m, meaning that the salinity changes predicted by the model represent the potential average salinity changes of the top 3 m of the aquifer (or at the mid-point of the layer, roughly 1 to 1.25 m below surface).

Mangroves rely on a relatively shallow depth of watering,tapping into the top 0.1 to 0.2 m below the water table (AECOM, 2021) which is subject to frequent inundation of seawater (tidal flushing approximately twice a day). Due to the lower seawater density and frequent inundation, there is fresher groundwater within the upper part of the stratigraphic profile in areas subject to regular tidal inundation.

This suggests that, while overall groundwater salinisation may be possible, the mechanism of freshening of the top 0.5 m will remain in place as long as tidal action remains in place. This mechanism was also confirmed by specific modelling of tidal creek action in mangrove areas as presented in Section 10.3.2. Given that mangroves have shallow root systems, they will not be exposed to the level of average salinity changes predicted by the model.

10.3.4 Algal Mat Considerations

The numerical modelling of groundwater level and salinity change indicates the spatially limited potential for shallow groundwater salinity to increase in the areas where the algal mats occur.

The algal mats are poorly connected to the underlying groundwater system and are more dependent on surface water that comes through inundation (in particular infrequent tidal inundations). The predicted groundwater salinity increases may not directly result in material changes to the salinity at ground surface (which is already affected by salt crust development). The quality of surface water is most likely to be maintained by infrequent tidal inundation and partial export of surficial salt.

Given that algal mats are not connected to the groundwater, they will not be exposed to the level of average salinity changes predicted by the model.

10.3.5 Information for Impact Assessment

The outputs of the modelling undertaken by this study have been provided to AECOM the marine and intertidal consultants for the project, in order to enable the assessment of potential impacts to mangroves and algal mats.

10.4 Recommendations

10.4.1 Monitoring

It is recommended that two lines (transects) of monitoring bores to the west of Ponds 1 and 2 are used to monitor and quantify potential impacts of the project.

The first line of additional shallow monitoring bores (2 to 3 m deep) should be installed in the salt flats between the ponds and mangrove communities. It is suggested that a line of approximately six monitoring bores be installed 400 m from the perimeter of Ponds 1 and 2.

The second line of monitoring shall include shallow monitoring bores (2 m deep) to monitor groundwater levels and salinity indicator(s) within first 2 m of the saturated profile. Loggers for water levels and EC should be installed within the zone of the water table fluctuation.

The data should be downloaded at least every six months. At a time of logger download it is recommended that groundwater samples are collected for chloride analysis (chloride is well correlated with TDS and suitable as surrogate for salinity indicator).

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- Marine, Coastal and Surface Water Existing Environment
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- Marine and Coastal Assessment and Modelling
- Nutrient Pathways Assessment and Modelling

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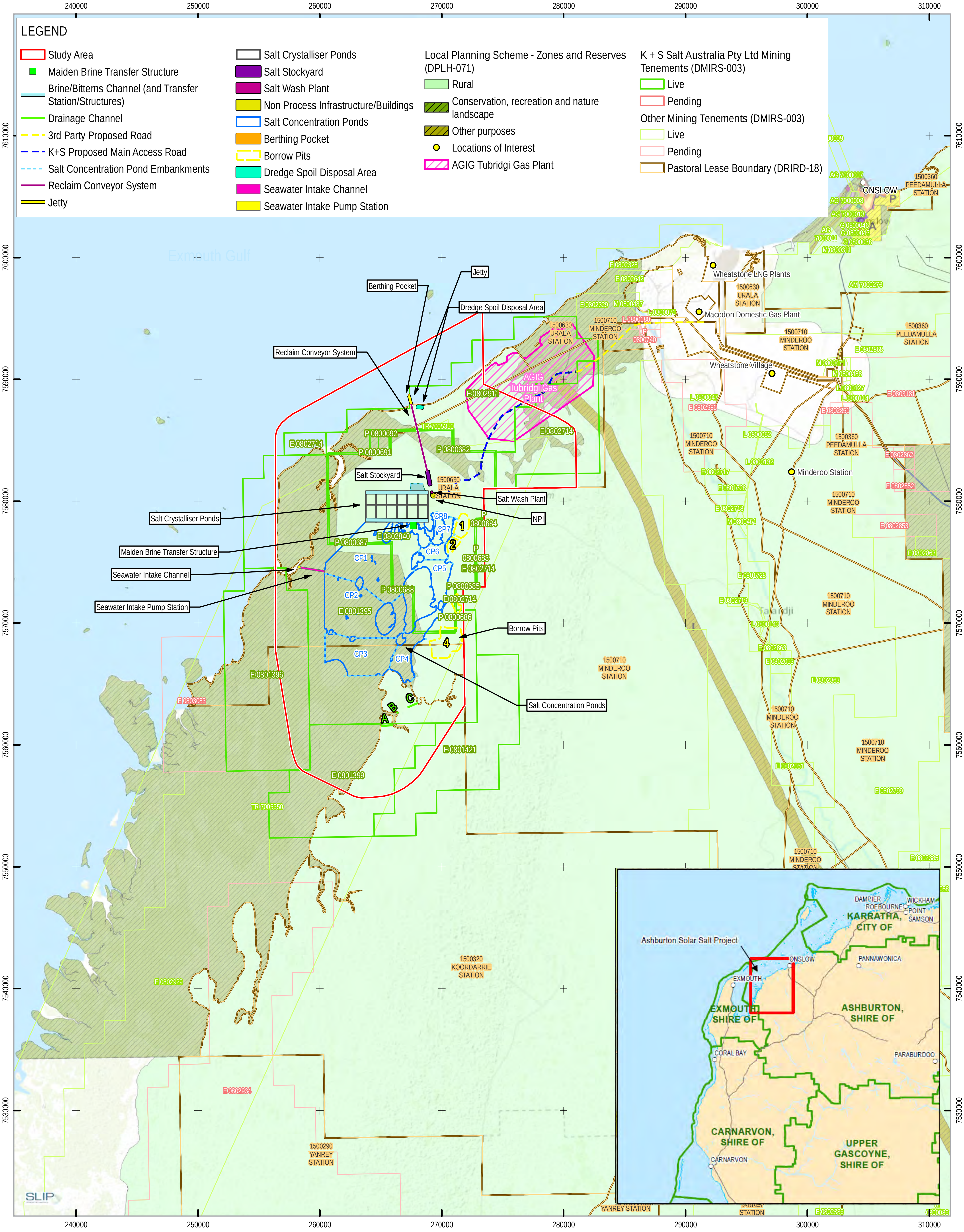
Maps



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0 2 4 6

Kilometres

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 50

N

GHD

K + S Salt Australia Pty Ltd
Ashburton Solar Salt Project
Phase 2 Site Investigation

Project No. 12516706
Revision No. 0
Date 03 Jun 2021

Proposal Location and Land Use

MAP 1

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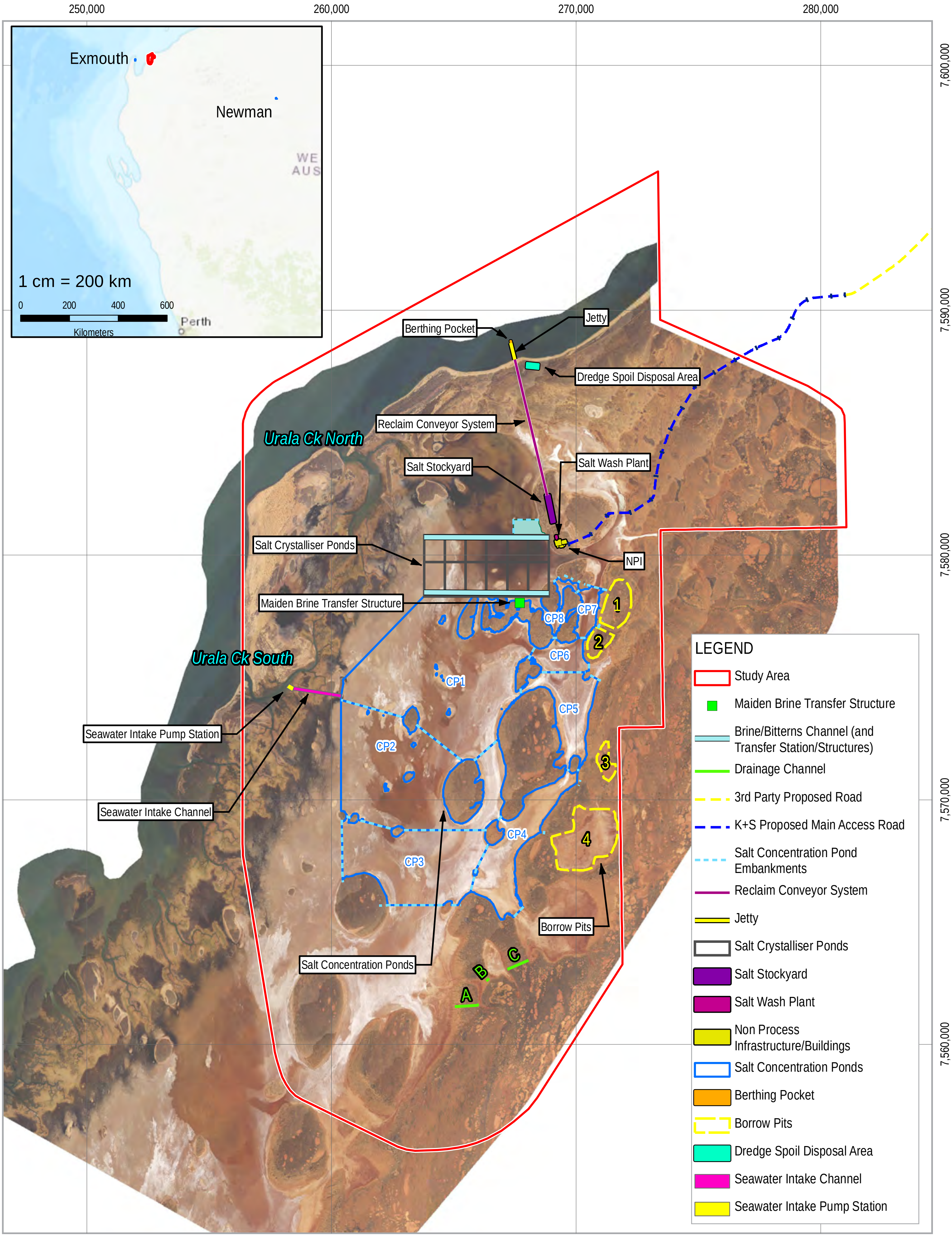

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Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 50

N

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Ashburton Solar Salt Project
Phase 2 Site Investigation

Project Location

Project No. 12516706
Revision No. 0
Date 03 Jun 2021

MAP 2

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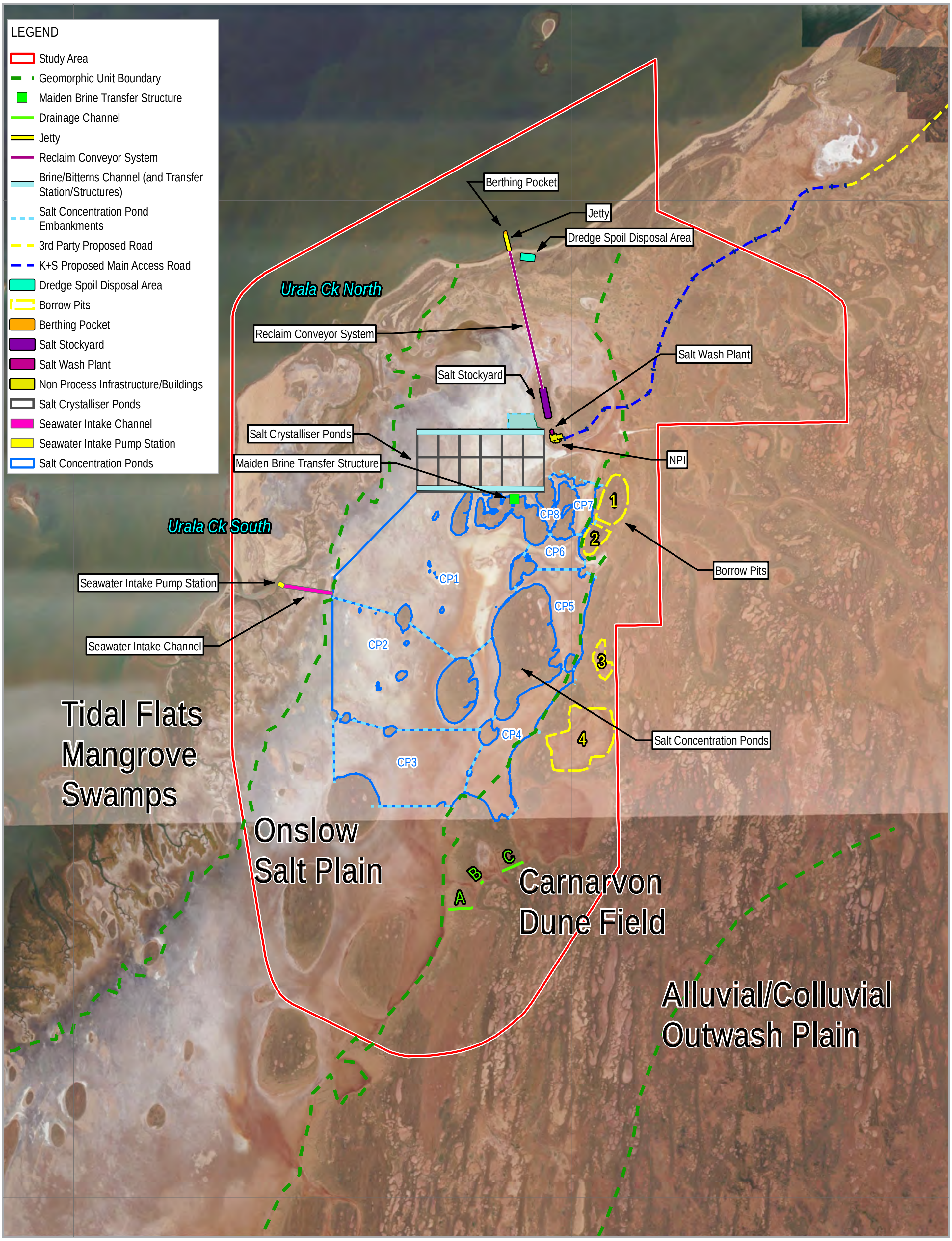
Data source: Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), (c) OpenStreetMap contributors, and the GIS User Community. Created by: htaniza



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Kilometers

Map Projection: Transverse Mercator
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Grid: GDA 1994 MGA Zone 50

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Ashburton Solar Salt Project
Phase 2 Site Investigation

Project No. 12516706
Revision No. 0
Date 03 Jun 2021

Geomorphic Units

MAP 3

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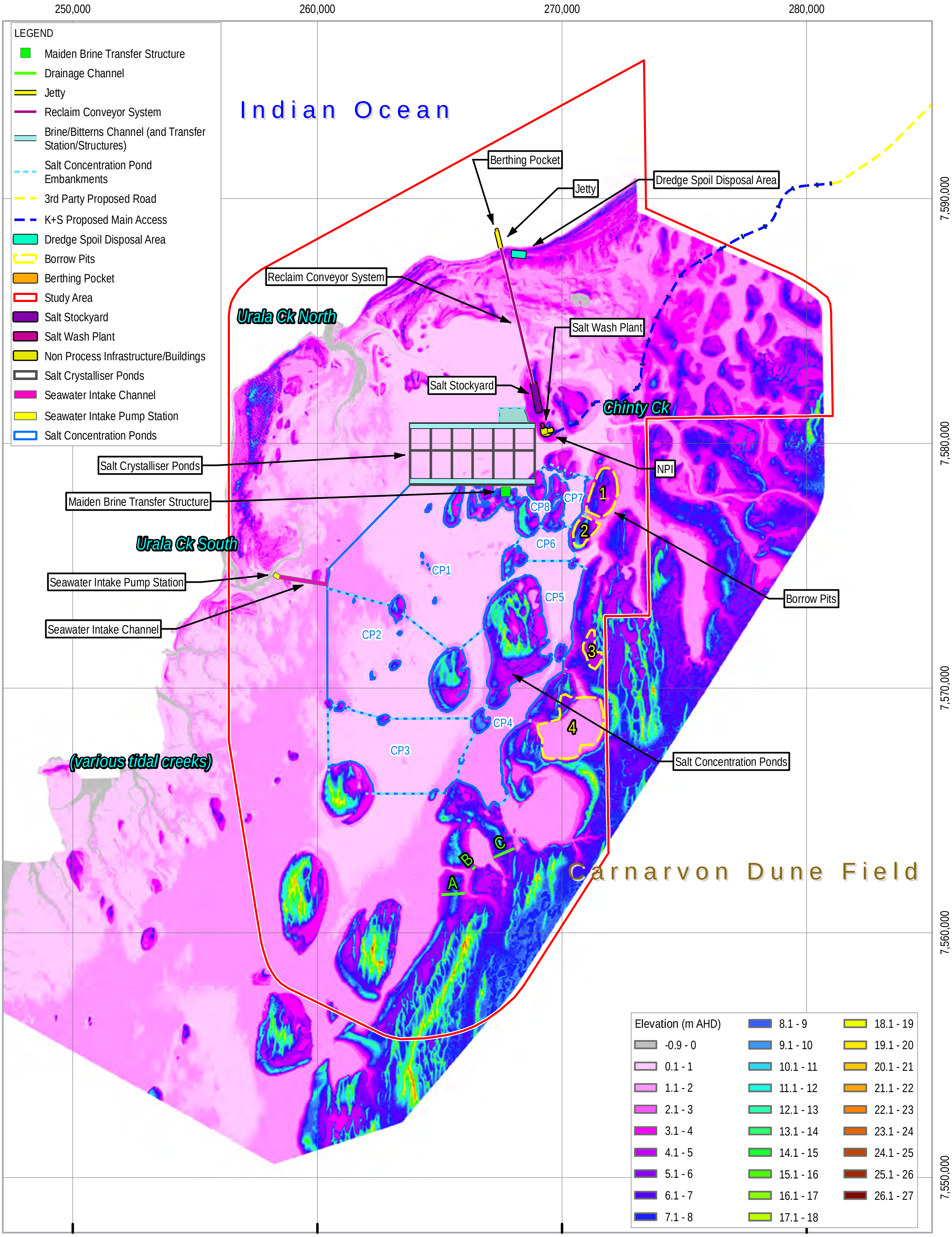

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Kilometers

Map Projection: Transverse Mercator
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Grid: GDA 1994 MGA Zone 50

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Ashburton Solar Salt Project
Phase 2 Site Investigation

Project No. 12516706
Revision No. 0
Date 08 Jun 2021

Ground Elevation (LiDAR)

MAP 4

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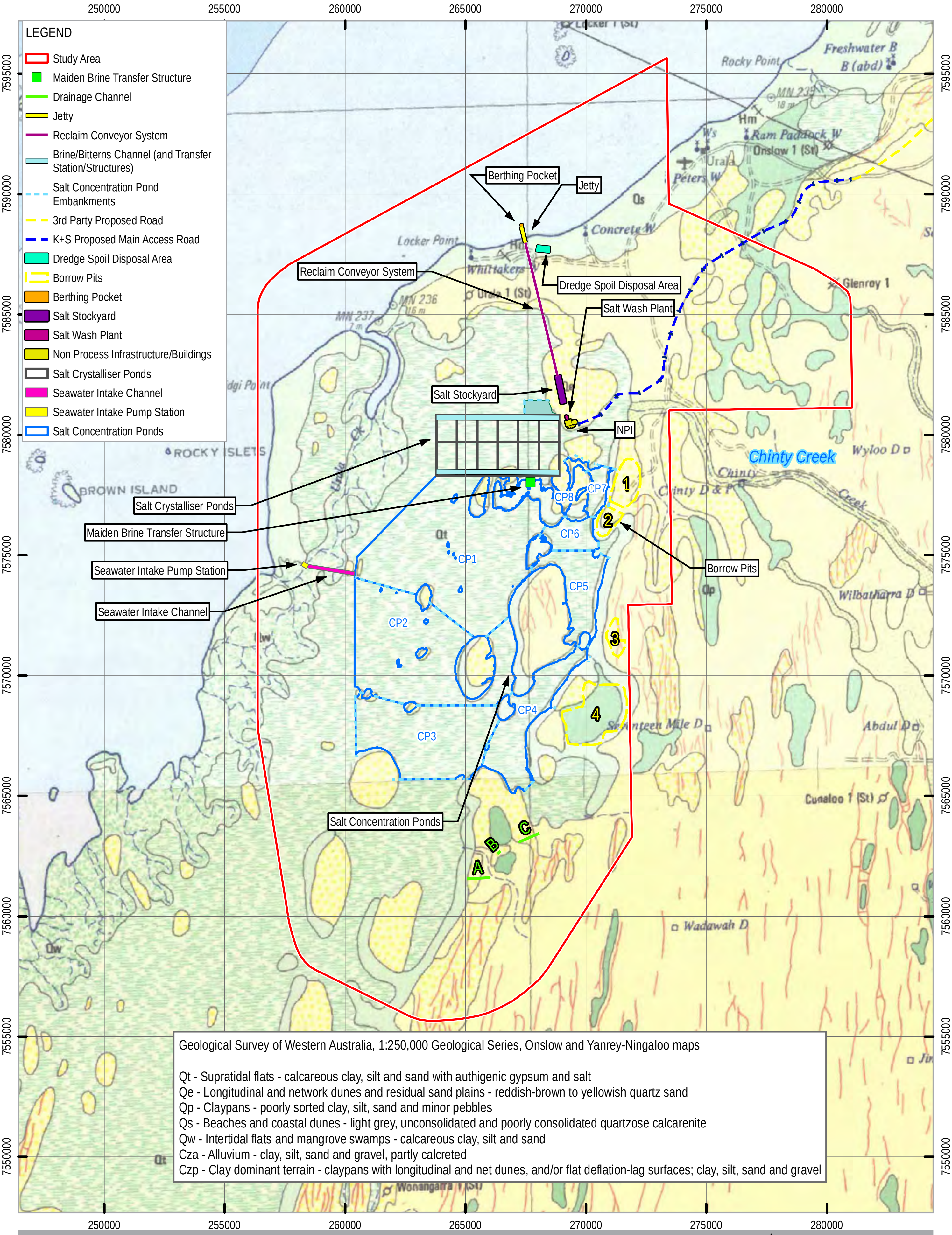

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Kilometers

Map Projection: Transverse Mercator
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Grid: GDA 1994 MGA Zone 50

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Ashburton Solar Salt Project
Phase 2 Site Investigation

Surface Geology

Project No. 12516706
Revision No. 0
Date 04 Jun 2021

MAP 5

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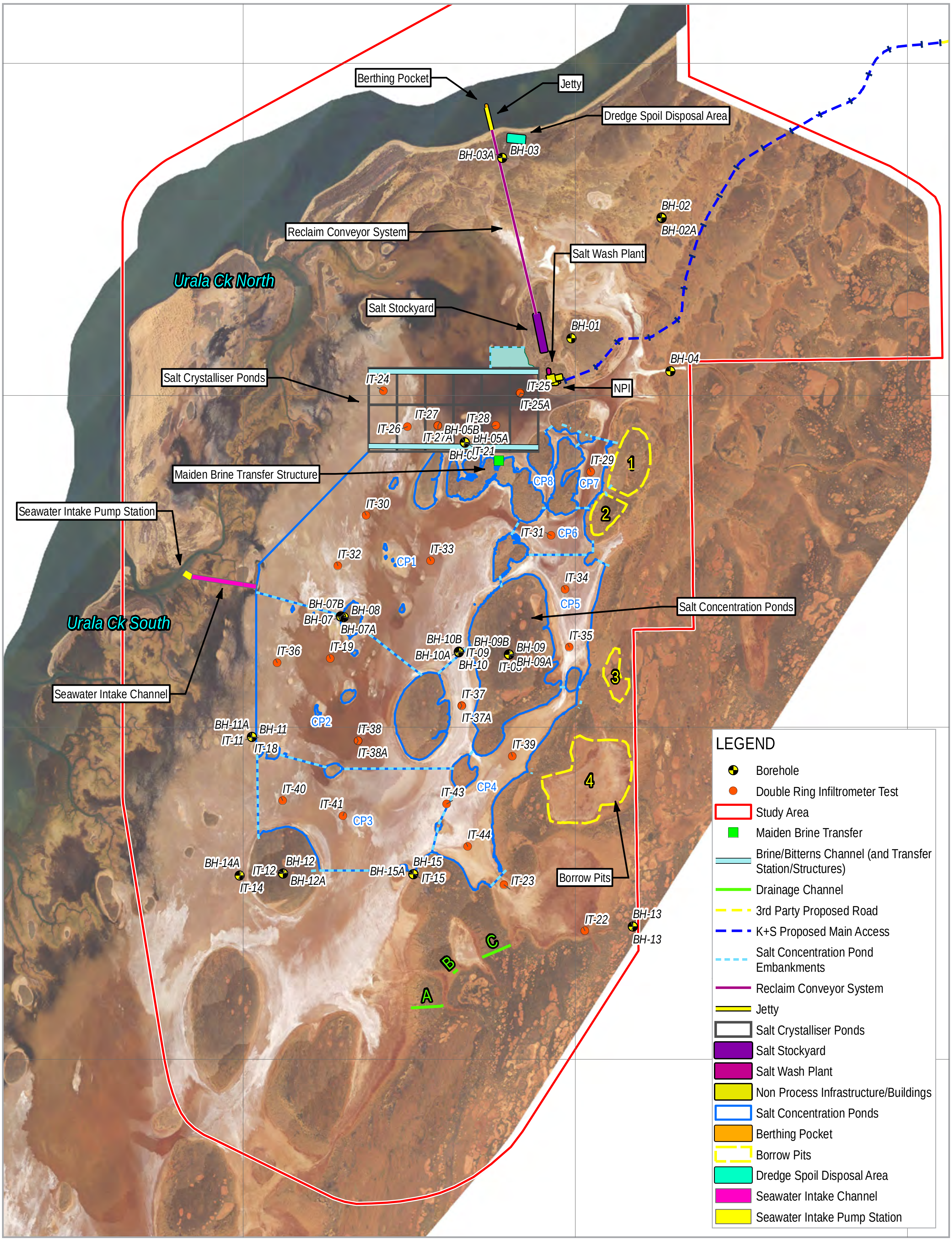

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Kilometers

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Map Projection: Transverse Mercator
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Grid: GDA 1994 MGA Zone 50

GHD

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Ashburton Solar Salt Project
Phase 2 Site Investigation

Project No. 12516706
Revision No. 0
Date 08 Jun 2021

Field Investigation Locations

MAP 6

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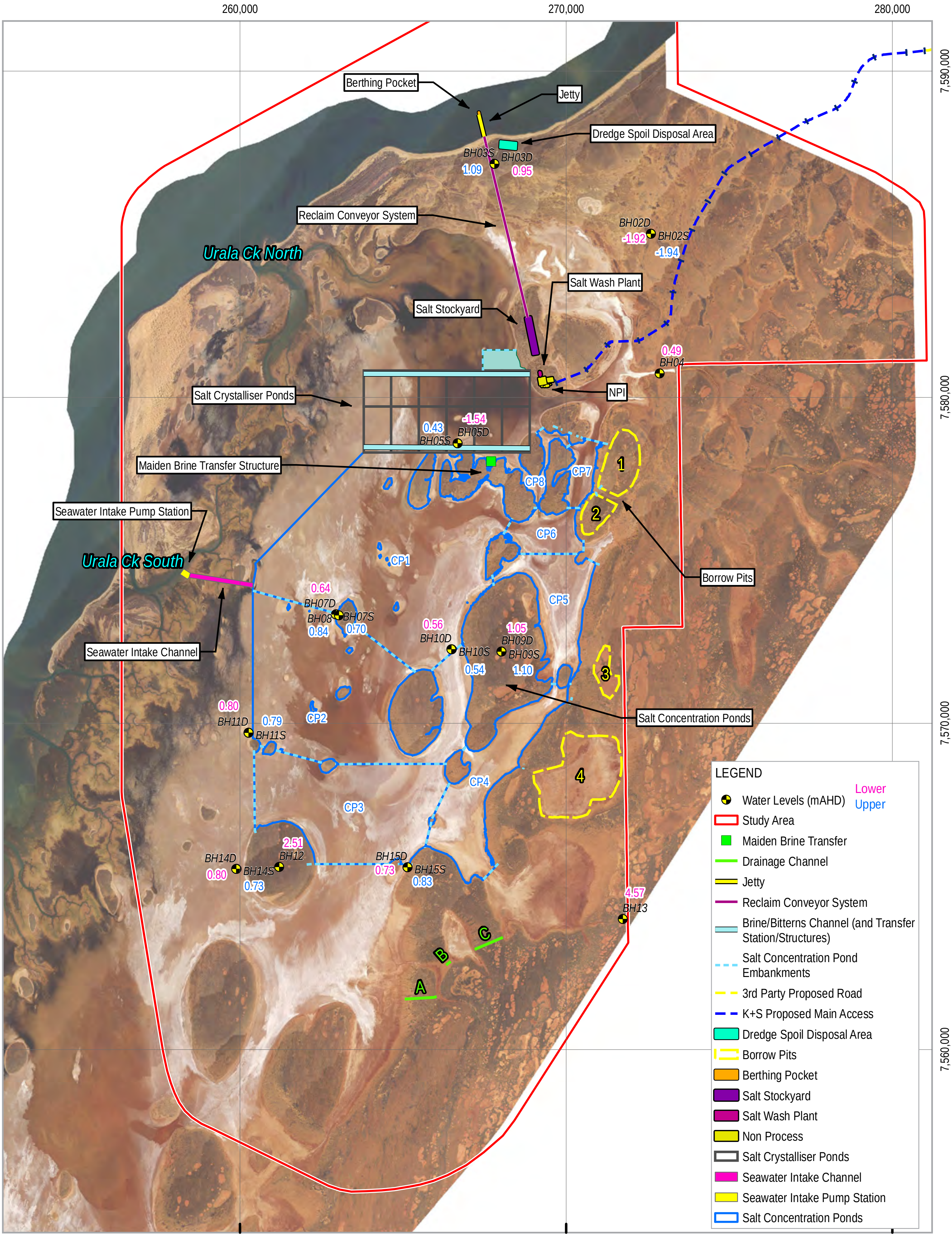

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Kilometers

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Grid: GDA 1994 MGA Zone 50

GHD

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Ashburton Solar Salt Project
Phase 2 Site Investigation

Project No. 12516706
Revision No. 0
Date 08 Jun 2021

Measured Groundwater Levels

MAP 7

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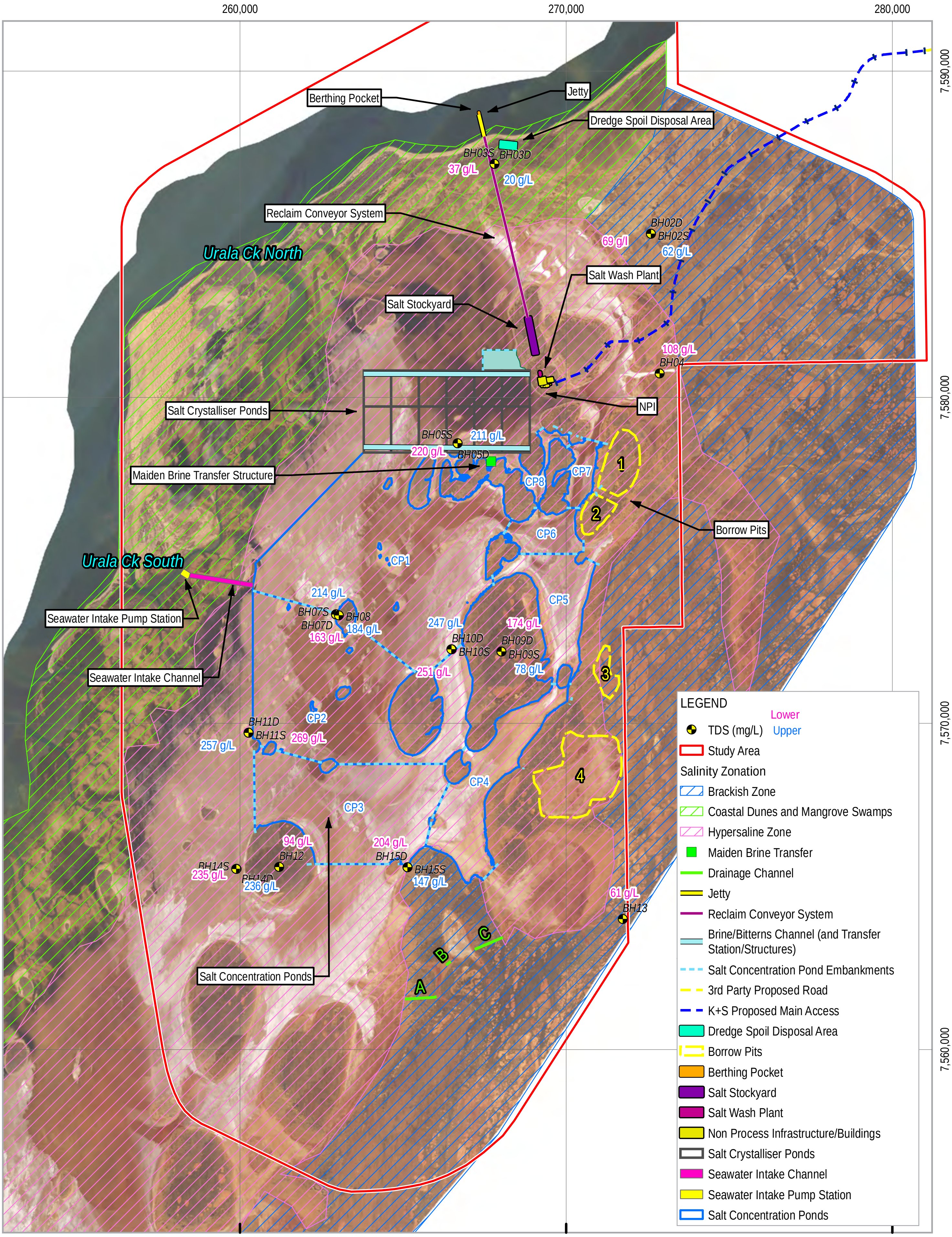

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Kilometers

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N

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Ashburton Solar Salt Project
Phase 2 Site Investigation

Measured Total Dissolved Solids and Conceptual Salinity Zonation

Project No. 12516706
Revision No. 0
Date 04 Jun 2021

MAP 8

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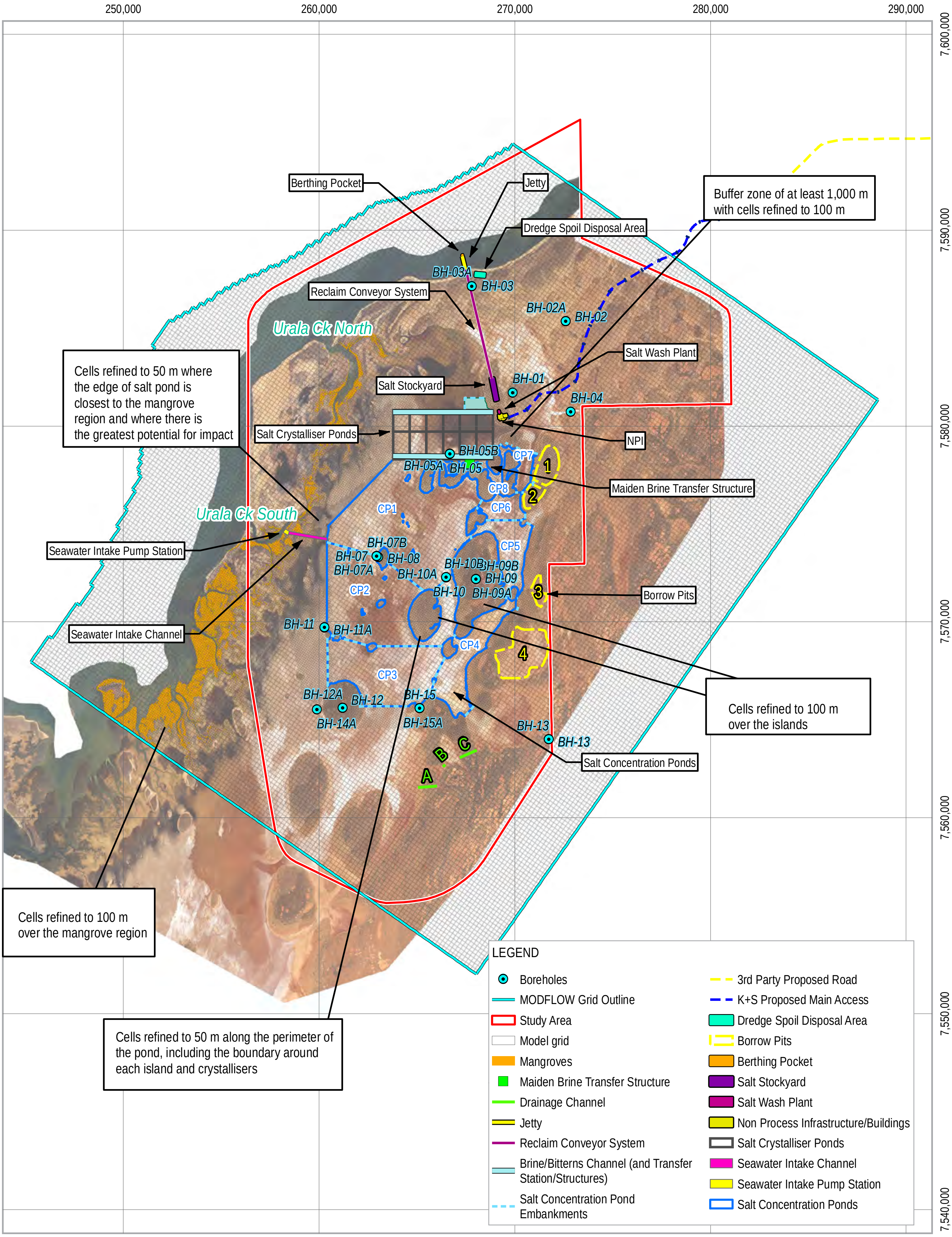

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Kilometers

Map Projection: Transverse Mercator
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Grid: GDA 1994 MGA Zone 50

N

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Ashburton Solar Salt Project
Phase 2 Site Investigation

Project No. 12516706
Revision No. 0
Date 08 Jun 2021

Numerical Model Grid

MAP 9

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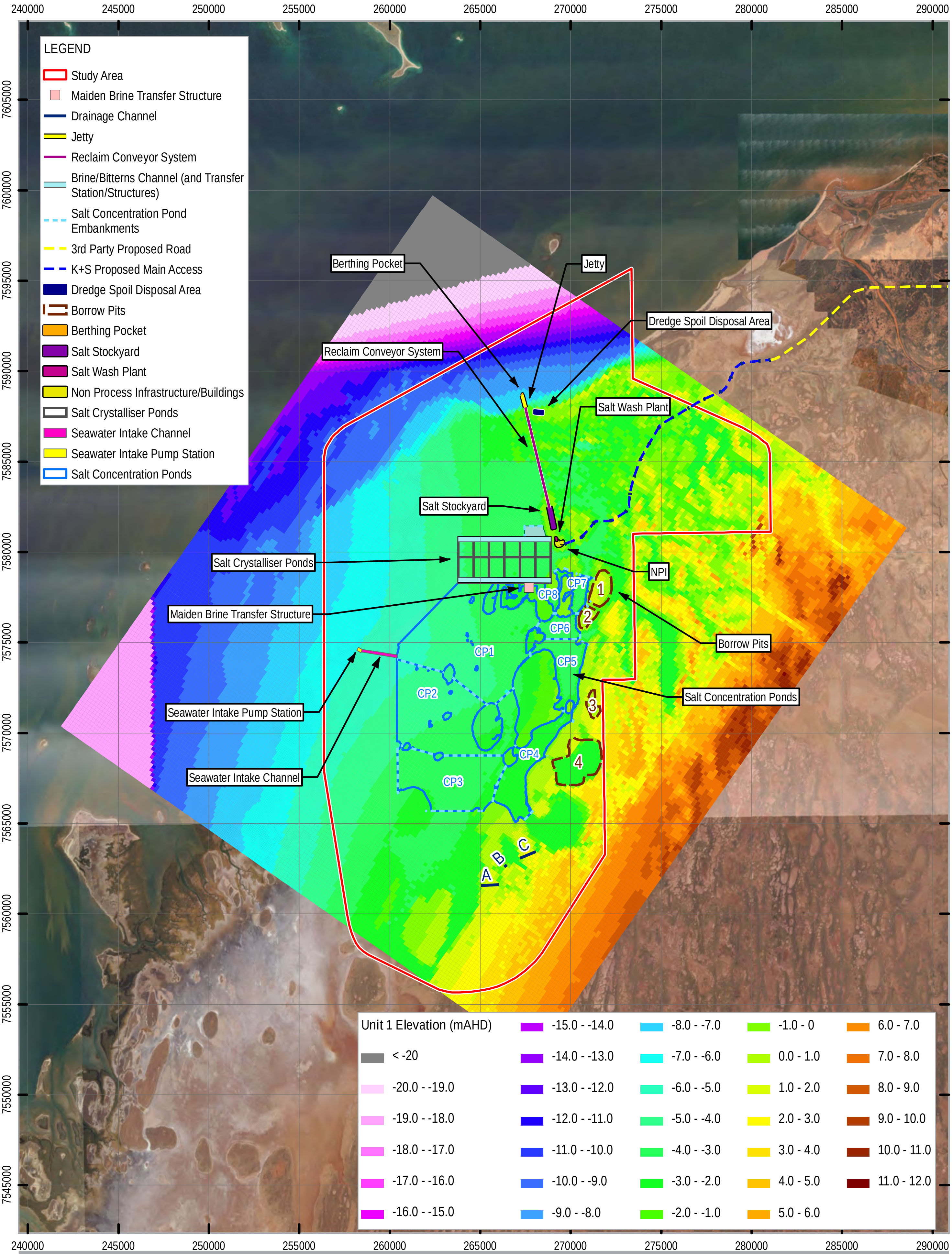

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Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
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N

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Ashburton Solar Salt Project
Phase 2 Site Investigation

Project No. 12516706
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Date 08 Jun 2021

Model Layer Elevations - Unit 1

MAP 10

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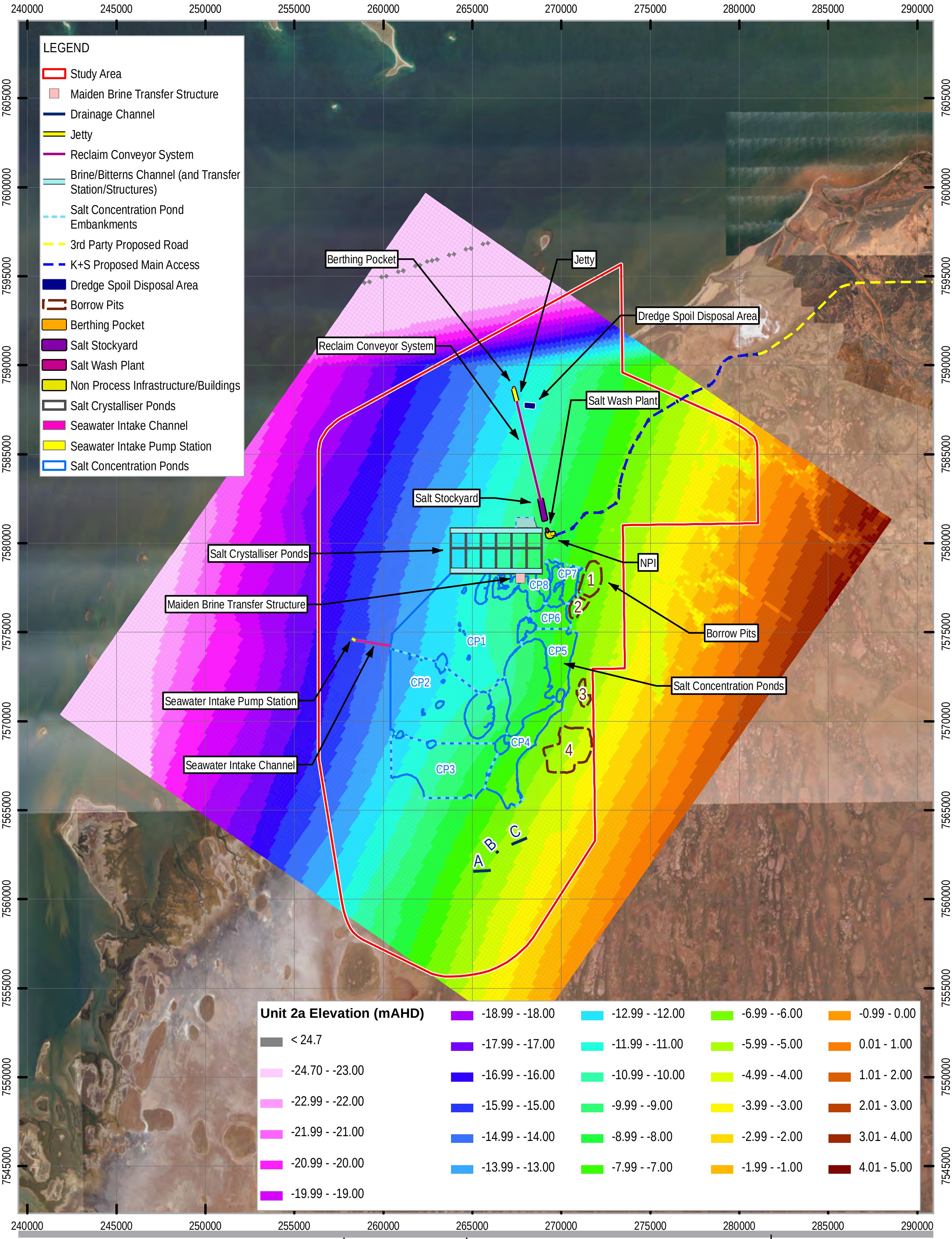

Paper Size ISO A4

0 2 4 6 8

Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 50

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Ashburton Solar Salt Project
Phase 2 Site Investigation

Model Elevation - Unit 2a - Upper Clays

Project No. 12516706
Revision No. 0
Date 04 Jun 2021

MAP 11

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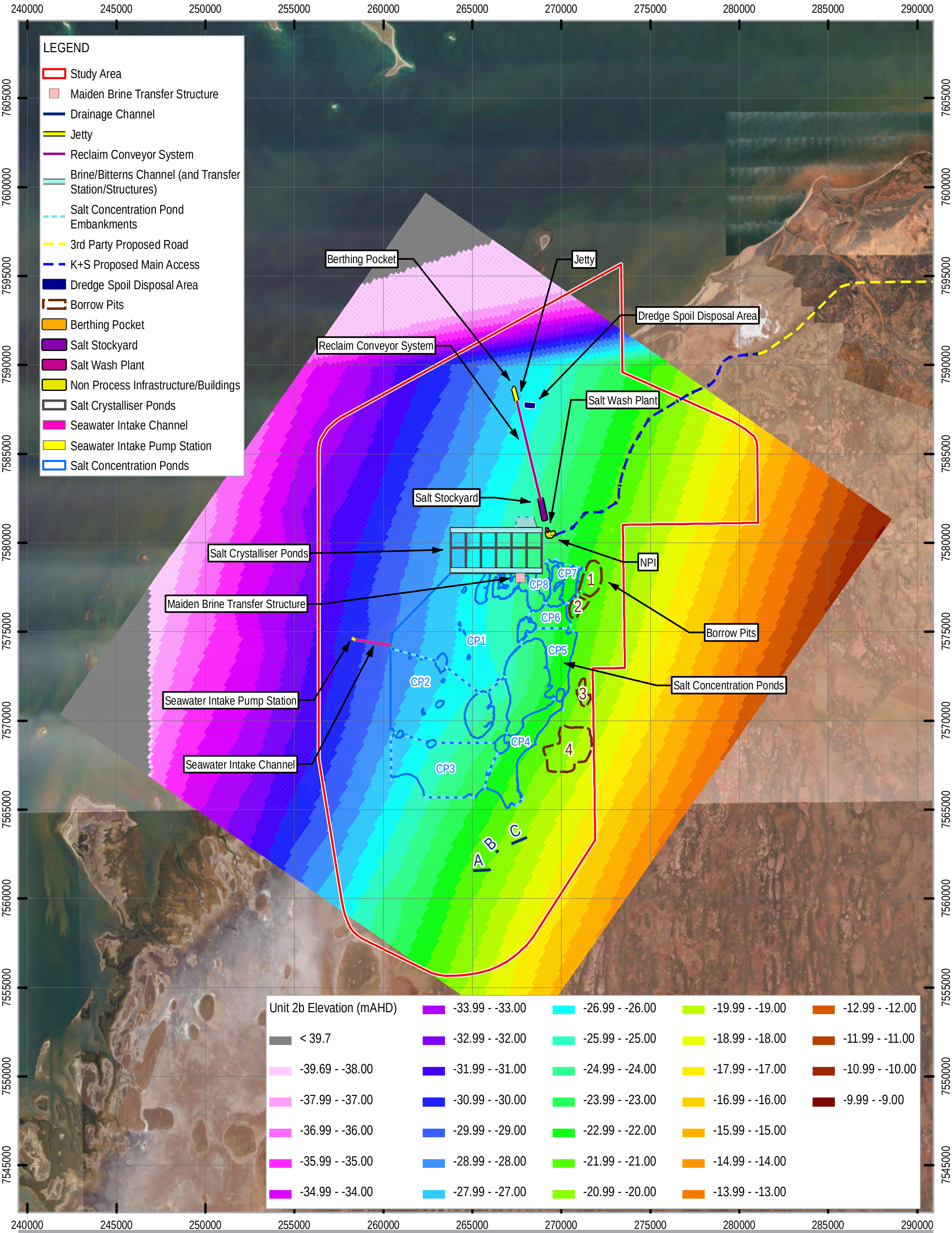

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Kilometers

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Horizontal Datum: GDA 1994
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Ashburton Solar Salt Project
Phase 2 Site Investigation

Model Elevation - Unit 2b - Lower Clays

Project No. 12516706
Revision No. 0
Date 04 Jun 2021

MAP 12

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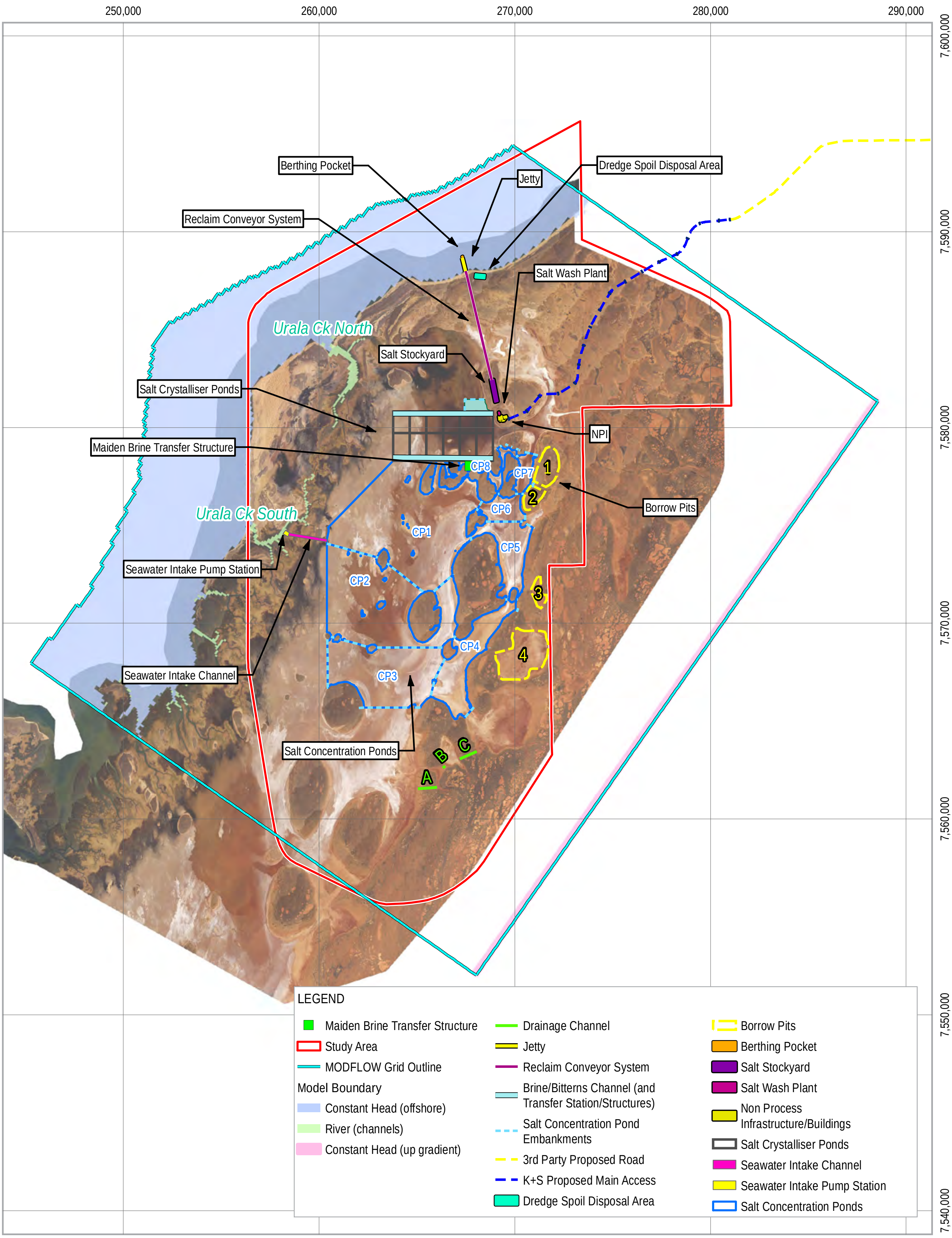

Paper Size ISO A4

0 2.5 5 7.5

Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 50

N

GHD

K + S Salt Australia Pty Ltd
Ashburton Solar Salt Project
Phase 2 Site Investigation

Project No. 12516706
Revision No. 0
Date 03 Jun 2021

Model Boundary Conditions

MAP 13

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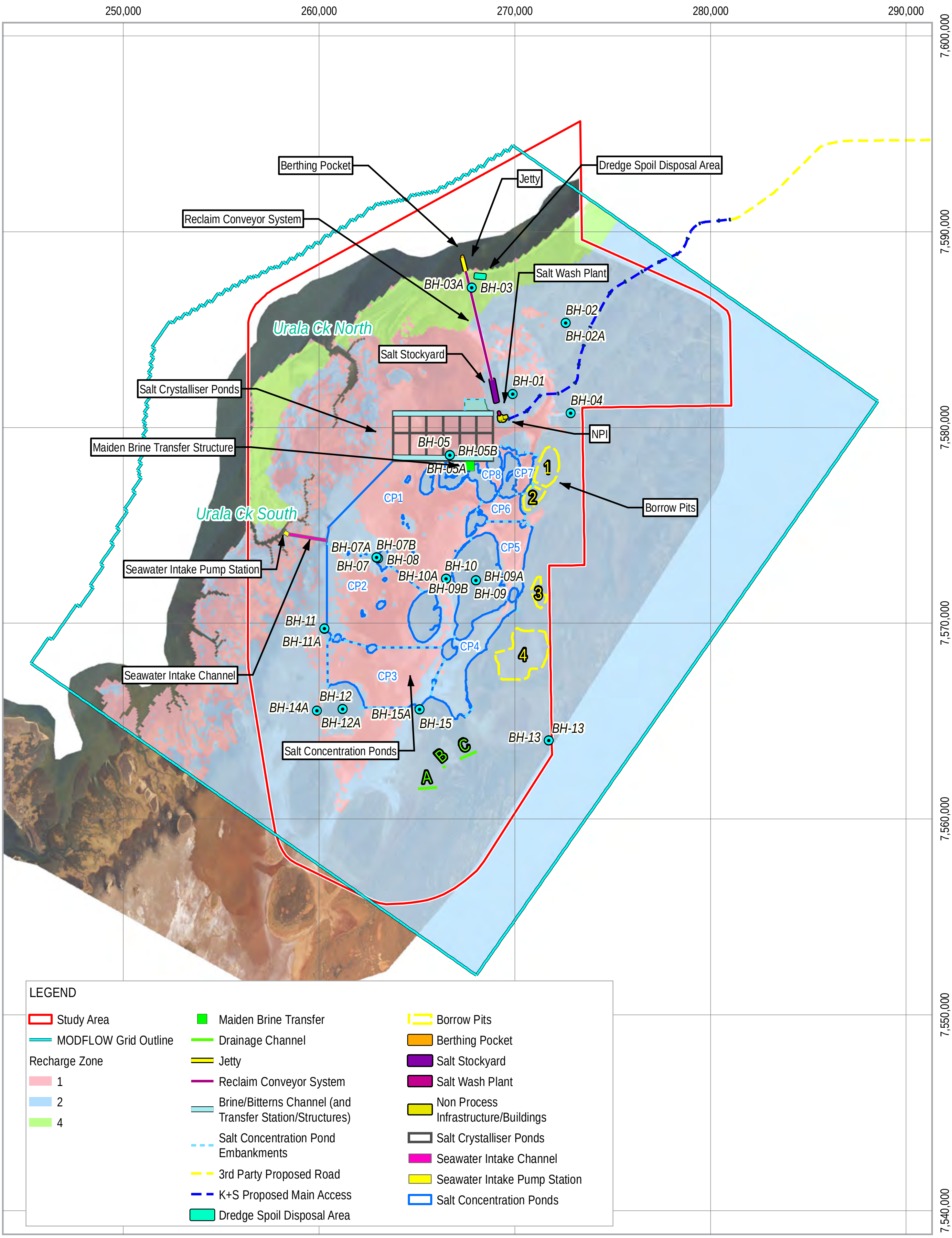
Data source: GHD - Project Components. . Created by: htaniza



Paper Size ISO A4

0 2.5 5 7.5

Kilometers

N

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 50

GHD

K + S Salt Australia Pty Ltd
Ashburton Solar Salt Project
Phase 2 Site Investigation

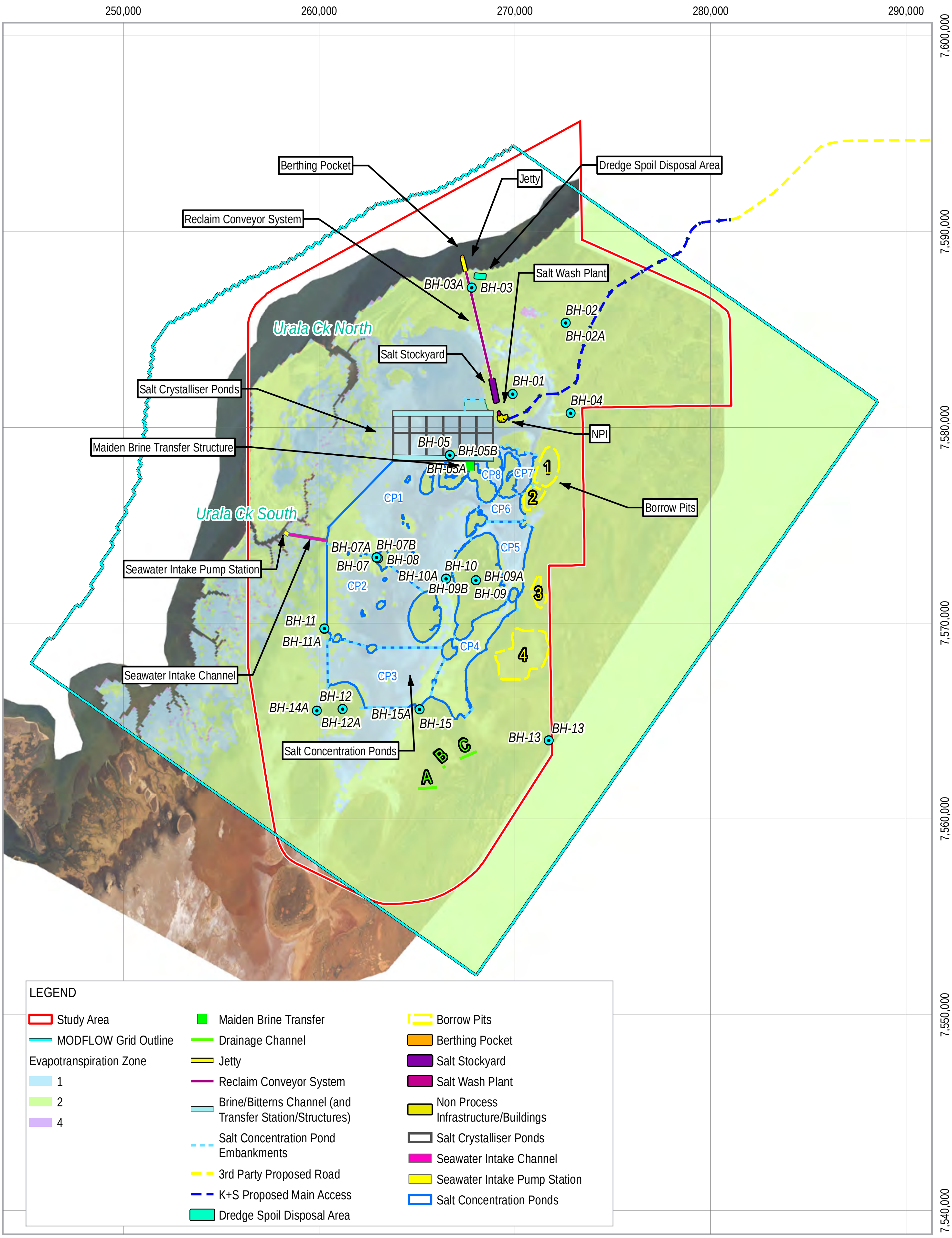
Groundwater Recharge Zones

Project No. 12516706
Revision No. 0
Date 04 Jun 2021

MAP 14

G:\61\12516706\GIS\Maps\Working\A4P Groundwater Maps\Map14_RechargeZones_A4P_Rev0.mxd
Print date: 04 Jun 2021 - 14:57

Data source: GHD - Project Components. . Created by: htaniza



Paper Size ISO A4

0 2.5 5 7.5

Kilometers

N

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 50

GHD

K + S Salt Australia Pty Ltd
Ashburton Solar Salt Project
Phase 2 Site Investigation

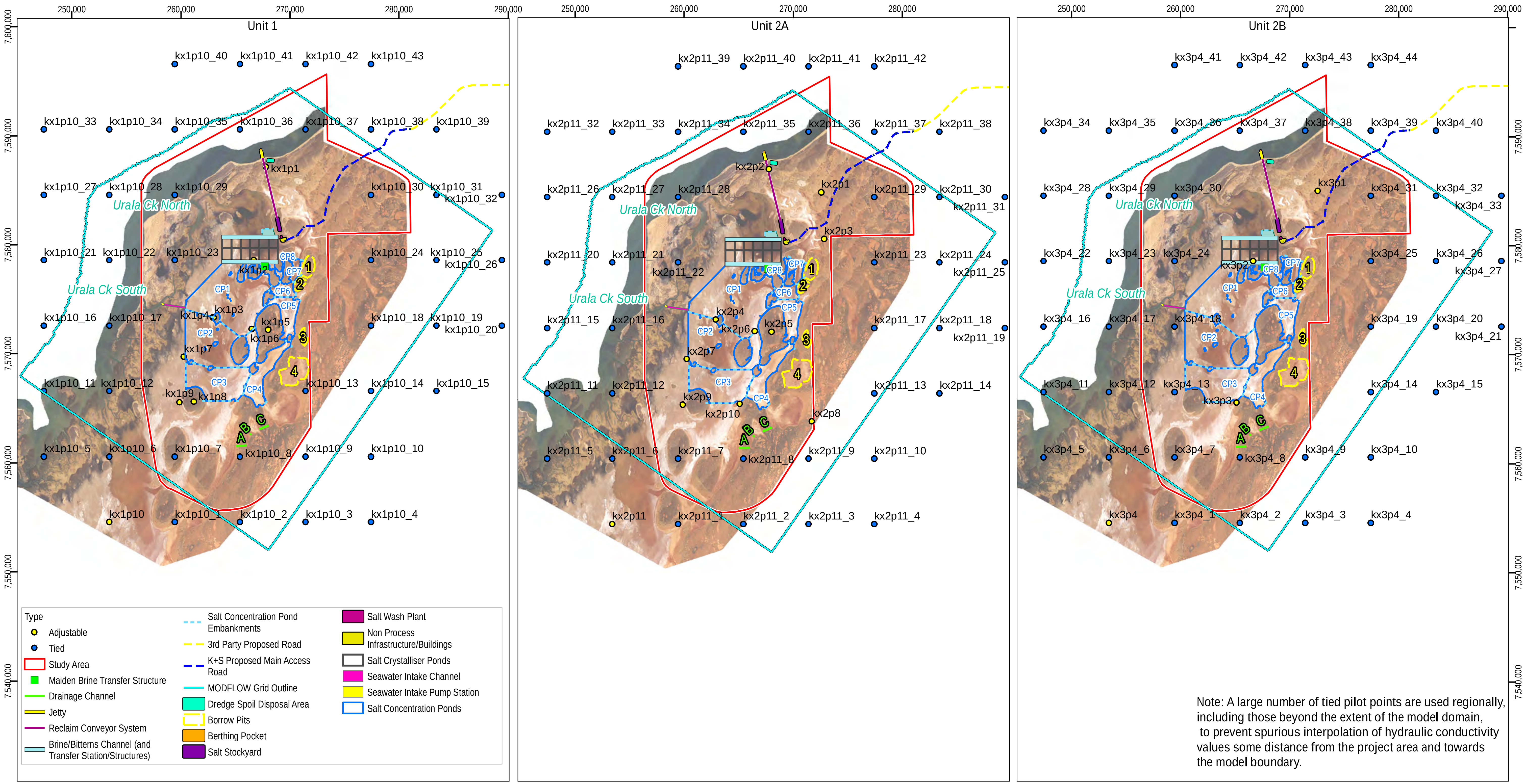
Project No. 12516706
Revision No. 0
Date 04 Jun 2021

Evapotranspiration Zones

MAP 15

G:\61\12516706\GIS\Maps\Working\A4P Groundwater Maps\Map15_EvapotranspirationZones_A4P_Rev2.mxd
Print date: 04 Jun 2021 - 14:51

Data source: GHD - Project Components. . Created by: htaniza



Paper Size ISO A3

0 3.5 7 10.5

Kilometers

N

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 50

GHD

K + S Australia Pty Ltd
Ashburton Solar Salt Project
Phase 2 Site Investigations

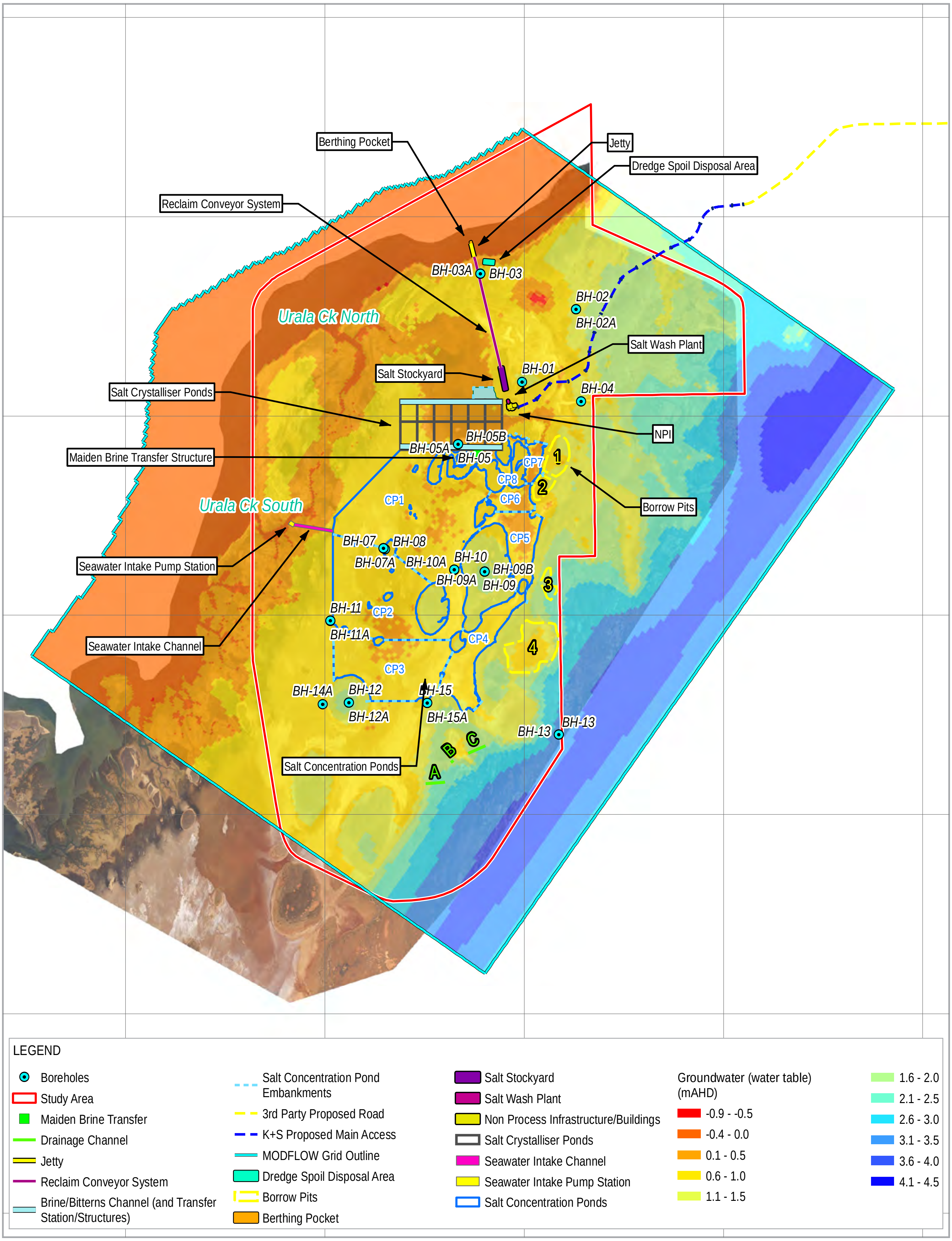
Pilot Point
Spatial Distribution

Project No. 12516706
Revision No. 0
Date 04 Jun 2021

MAP 16

G:\61\12516706\GIS\Maps\Working\A4P Groundwater Maps\Map16_PilotPoints_A3L.mxd
Print date: 04 Jun 2021 - 16:07

Data source: GHD - Project Components . Created by: htaniza



Paper Size ISO A4

0 2.5 5 7.5

Kilometers

N

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 50

GHD

K + S Salt Australia Pty Ltd
Ashburton Solar Salt Project
Phase 2 Site Investigation

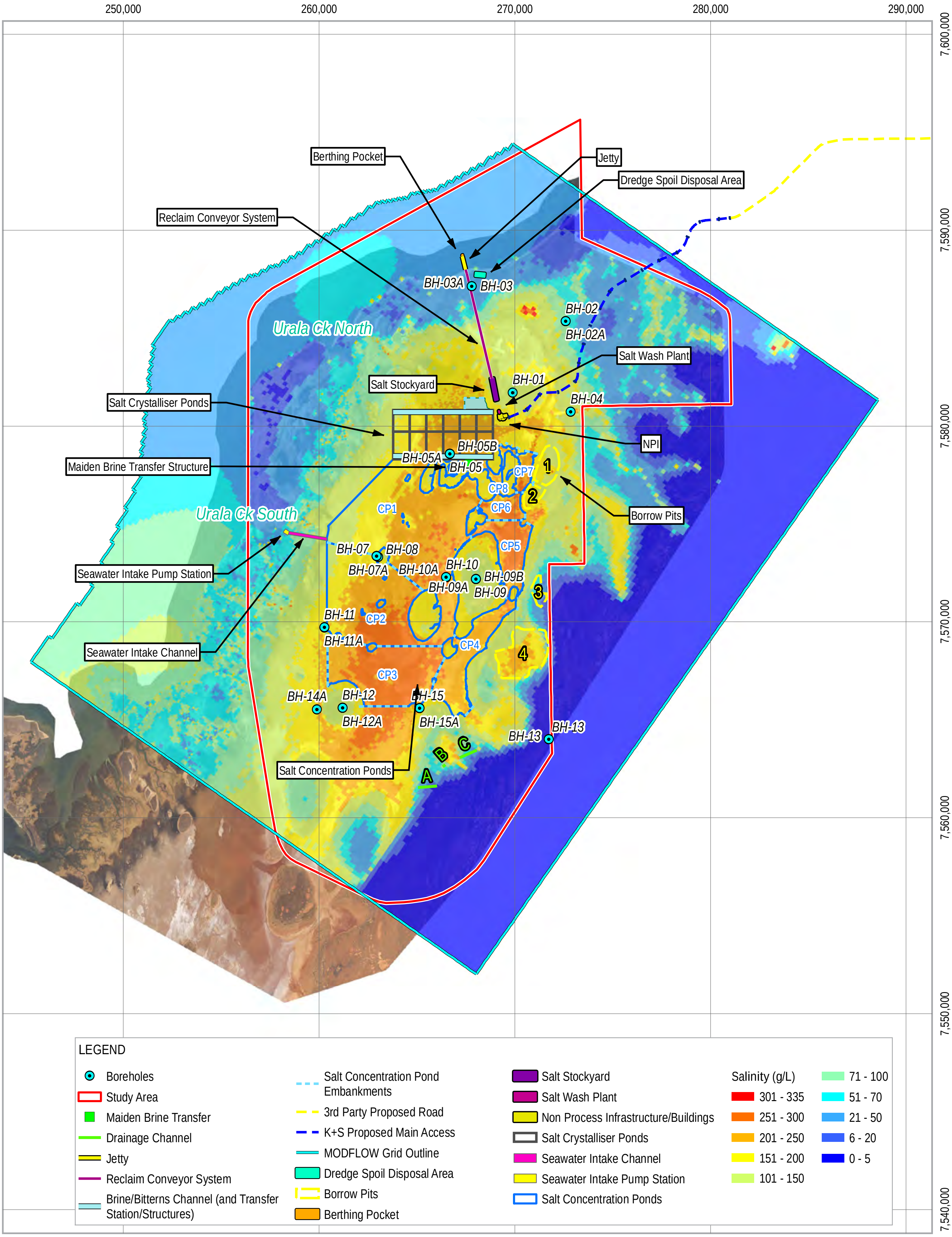
Project No. 12516706
Revision No. 0
Date 04 Jun 2021

Current Groundwater Levels

MAP 17

G:\61\12516706\GIS\Maps\Working\A4P Groundwater Maps\Map14_CurrentWaterLevels_A4P_Rev0.mxd
Print date: 04 Jun 2021 - 08:58

Data source: GHD - Project Components . Created by: htaniza



Paper Size ISO A4

0 2.5 5 7.5

Kilometers

N

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 50

GHD

K + S Salt Australia Pty Ltd
Ashburton Solar Salt Project
Phase 2 Site Investigation

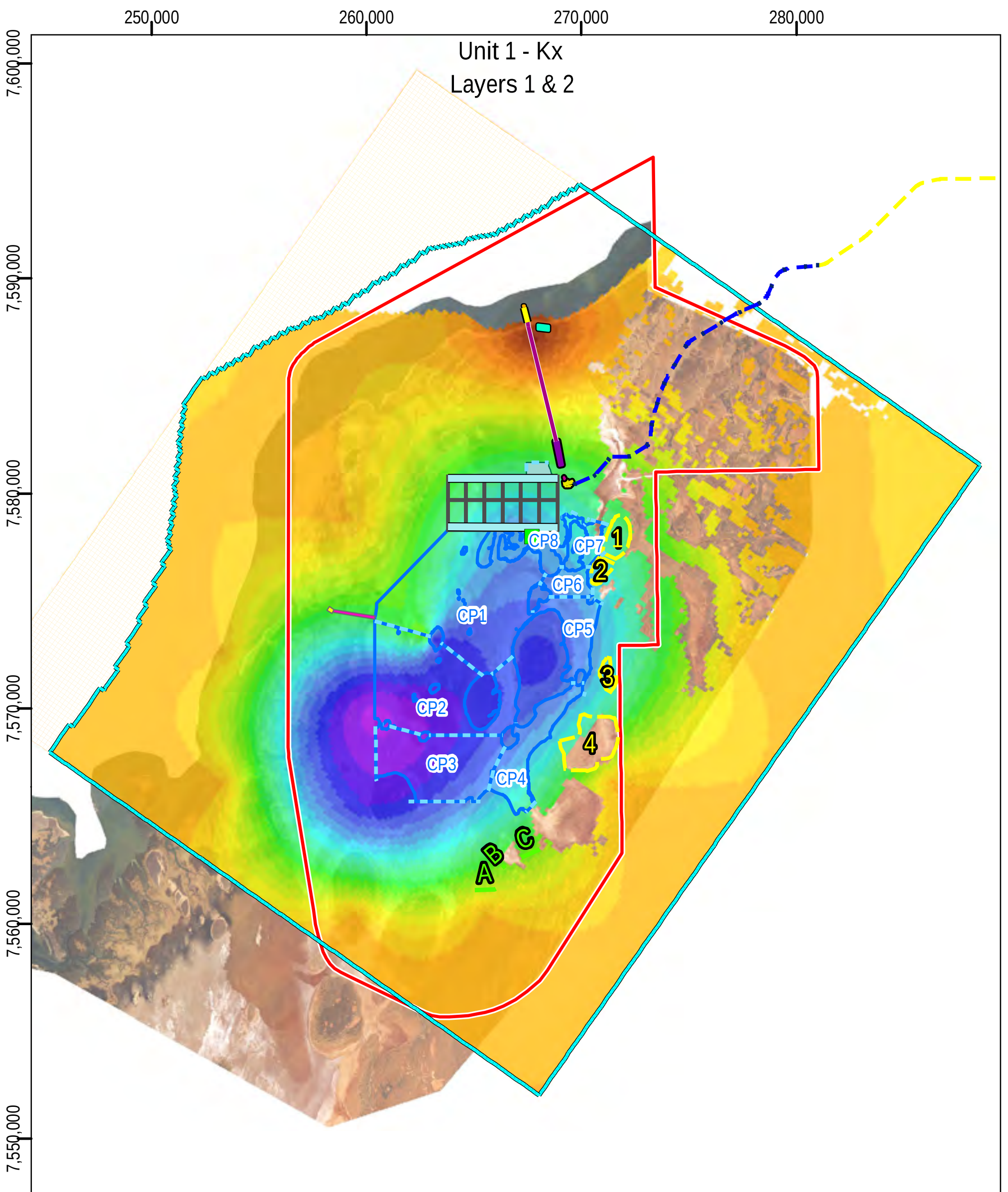
Project No. 12516706
Revision No. 0
Date 08 Jun 2021

Current Groundwater Salinity

MAP 18

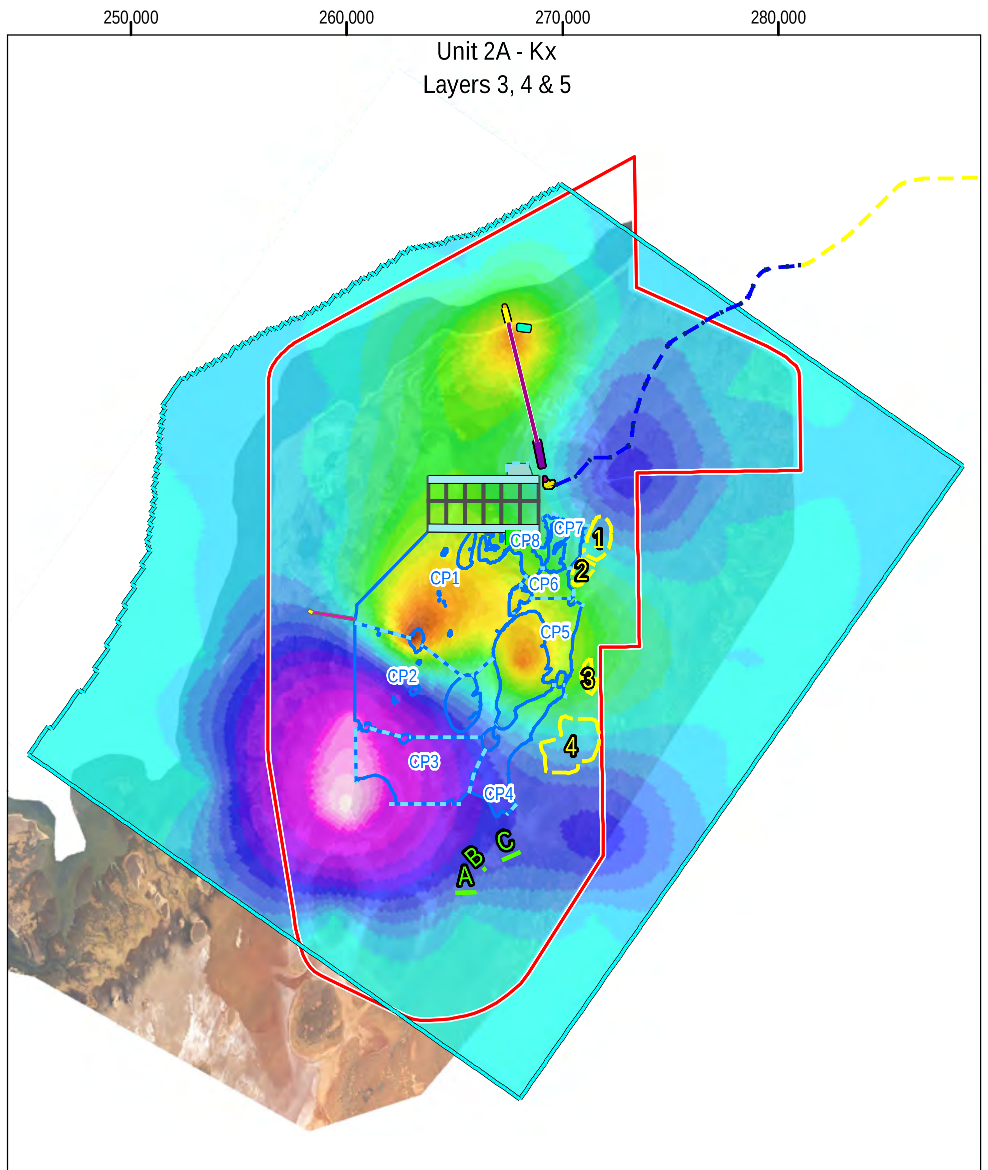
G:\61\12516706\GIS\Maps\Working\A4P Groundwater Maps\Map20_CurrentSalinity_A4P_Rev2.mxd
Print date: 08 Jun 2021 - 11:24

Data source: GHD - Project Components . Created by: htaniza



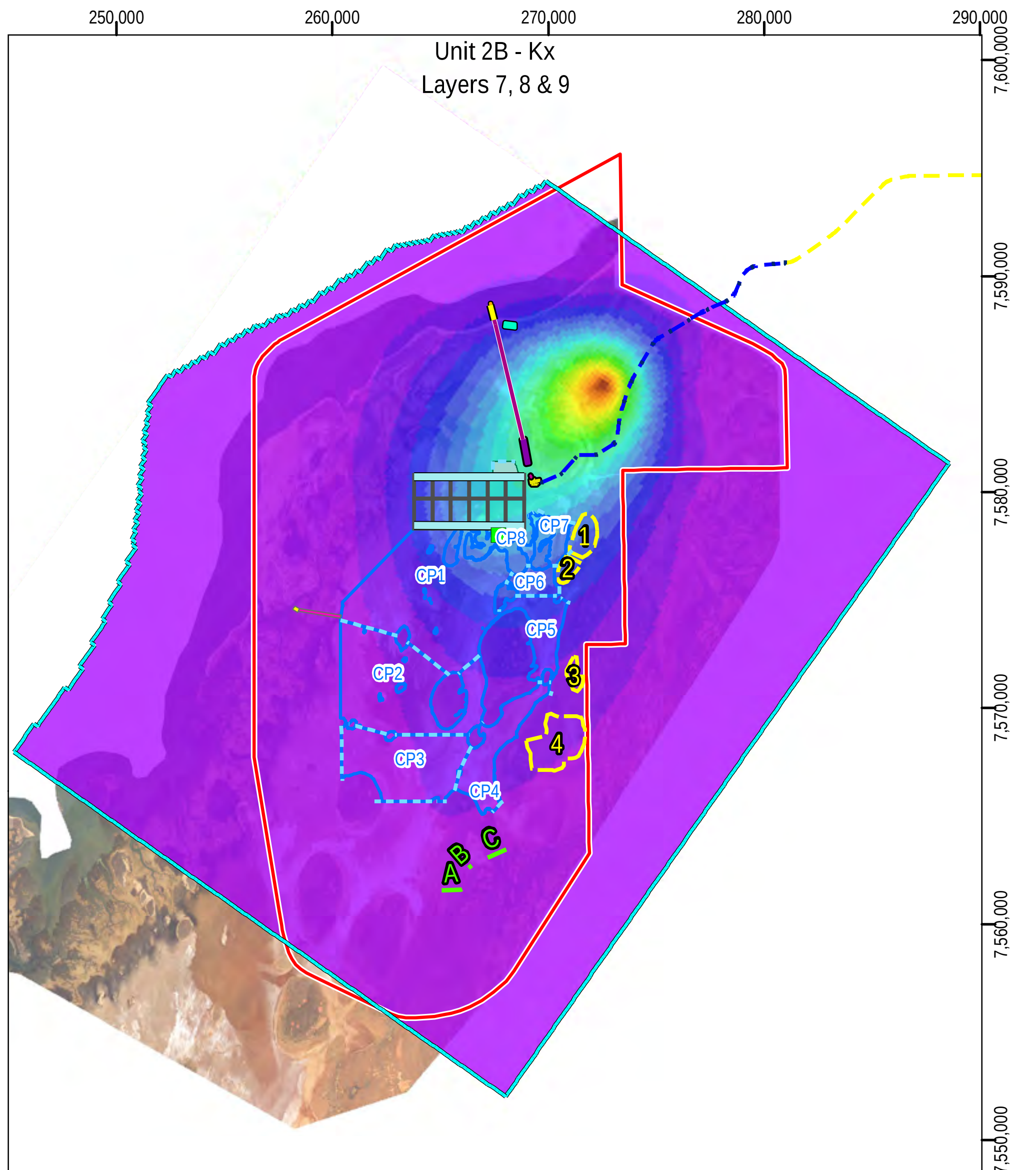
Unit 1 (Kx) (m/d)

- < 0.1
- 0.10 - 0.12
- 0.12 - 0.14
- 0.14 - 0.16
- 0.16 - 0.18
- 0.18 - 0.2
- 0.20 - 0.4
- 0.40 - 0.6
- 0.60 - 0.8
- 0.80 - 1
- 1.0 - 1.2
- 1.2 - 1.4
- 1.4 - 1.6
- 1.6 - 1.8
- 1.8 - 2
- 2.0 - 2.2
- 2.2 - 2.4
- 2.4 - 2.6
- 2.6 - 2.8
- 2.8 - 3
- 3.0 - 3.2
- 3.2 - 3.4
- 3.4 - 3.6
- 3.6 - 3.8
- 3.8 - 4
- 4.0 - 4.2
- 4.2 - 4.4
- 4.4 - 4.6
- 4.6 - 4.8
- 4.8 - 5
- 5.0 - 5.2
- 5.2 - 5.4
- 5.4 - 5.6
- 5.6 - 5.8
- 5.8 - 6



Unit 2a (Kx) (m/d)

- < 0.1
- 0.10 - 0.12
- 0.12 - 0.14
- 0.14 - 0.16
- 0.16 - 0.18
- 0.18 - 0.2
- 0.20 - 0.4
- 0.40 - 0.6
- 0.60 - 0.8
- 0.80 - 1
- 1.0 - 1.2
- 1.2 - 1.4
- 1.4 - 1.6
- 1.6 - 1.8
- 1.8 - 2
- 2.0 - 2.2
- 2.2 - 2.4
- 2.4 - 2.6
- 2.6 - 2.8
- 2.8 - 3
- 3.0 - 3.2
- 3.2 - 3.4
- 3.4 - 3.6
- 3.6 - 3.8
- 3.8 - 4
- 4.0 - 4.2
- 4.2 - 4.4
- 4.4 - 4.6
- 4.6 - 4.8
- 4.8 - 5
- 5.0 - 5.2
- 5.2 - 5.4
- 5.4 - 5.6
- 5.6 - 5.8
- 5.8 - 6



Unit 2b (Kx) (m/d)

- < 0.1
- 0.10 - 0.12
- 0.12 - 0.14
- 0.14 - 0.16
- 0.16 - 0.18
- 0.18 - 0.2
- 0.20 - 0.4
- 0.40 - 0.6
- 0.60 - 0.8
- 0.80 - 1
- 1.0 - 1.2
- 1.2 - 1.4
- 1.4 - 1.6
- 1.6 - 1.8
- 1.8 - 2
- 2.0 - 2.2
- 2.2 - 2.4
- 2.4 - 2.6
- 2.6 - 2.8
- 2.8 - 3
- 3.0 - 3.2
- 3.2 - 3.4
- 3.4 - 3.6
- 3.6 - 3.8
- 3.8 - 4
- 4.0 - 4.2
- 4.2 - 4.4
- 4.4 - 4.6
- 4.6 - 4.8
- 4.8 - 5
- 5.0 - 5.2
- 5.2 - 5.4
- 5.4 - 5.6
- 5.6 - 5.8
- 5.8 - 6

Legend

- Study Area
- Maiden Brine Transfer Structure
- Drainage Channel
- Jetty
- Reclaim Conveyor System
- Brine/Bitterns Channel (and Transfer Station/Structures)
- Salt Concentration Pond Embankments
- 3rd Party Proposed Road
- K+S Proposed Main Access Road
- MODFLOW Grid Outline
- Dredge Spoil Disposal Area
- Borrow Pits
- Berthing Pocket
- Salt Stockyard
- Salt Wash Plant
- Non Process Infrastructure/Buildings
- Salt Crystalliser Ponds
- Seawater Intake Channel
- Seawater Intake Pump Station
- Salt Concentration Ponds

Paper Size ISO A3

0 3.5 7 10.5

Kilometers

N

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 50

GHD

K + S Australia Pty Ltd
Ashburton Solar Salt Project
Phase 2 Site Investigations

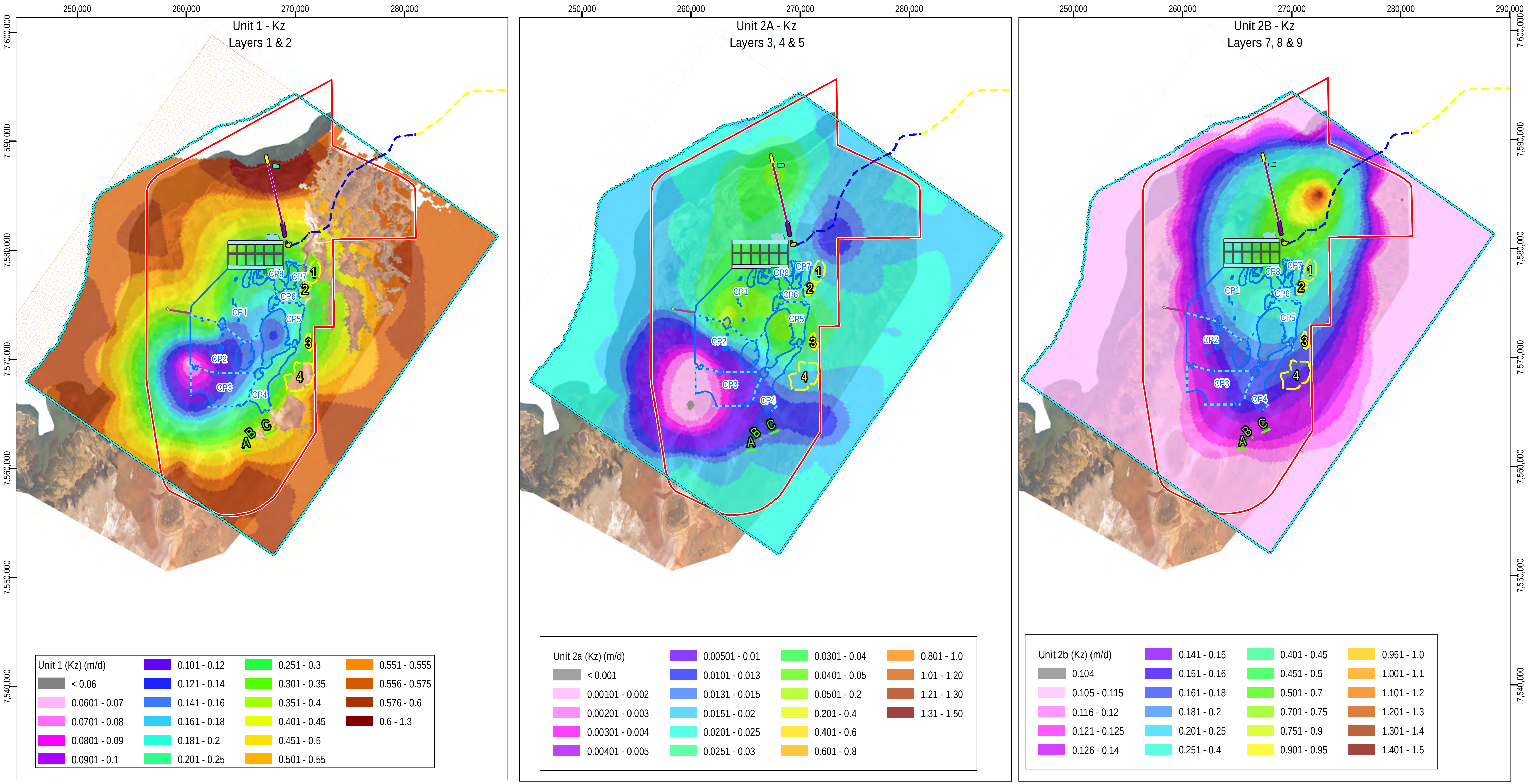
Project No. 12516706
Revision No. 0
Date 23 Jun 2021

Calibrated Hydraulic Conductivity Spatial Distribution

MAP 19

G:\61\12516706\GIS\Maps\Working\A4P Groundwater Maps\Map19_LateralHydraulicConductivity_A3L_Rev0.mxd
Print date: 23 Jun 2021 - 11:07

Data source: GHD - Project Components . Created by: kaadams



Legend

- Study Area
- Maiden Brine Transfer Structure
- Drainage Channel
- Jetty
- Reclaim Conveyor System
- Brine/Bitterns Channel (and Transfer Station/Structures)
- Salt Concentration Pond Embankments
- 3rd Party Proposed Road
- K+S Proposed Main Access Road
- MODFLOW Grid Outline
- Dredge Spoil Disposal Area
- Borrow Pits
- Berthing Pocket
- Salt Stockyard
- Salt Wash Plant
- Non Process Infrastructure/Buildings
- Salt Crystalliser Ponds
- Seawater Intake Channel
- Seawater Intake Pump Station
- Salt Concentration Ponds

Paper Size ISO A3

0 3.5 7 10.5

Kilometers

N

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 50

GHD

K + S Australia Pty Ltd
Ashburton Solar Salt Project
Phase 2 Site Investigations

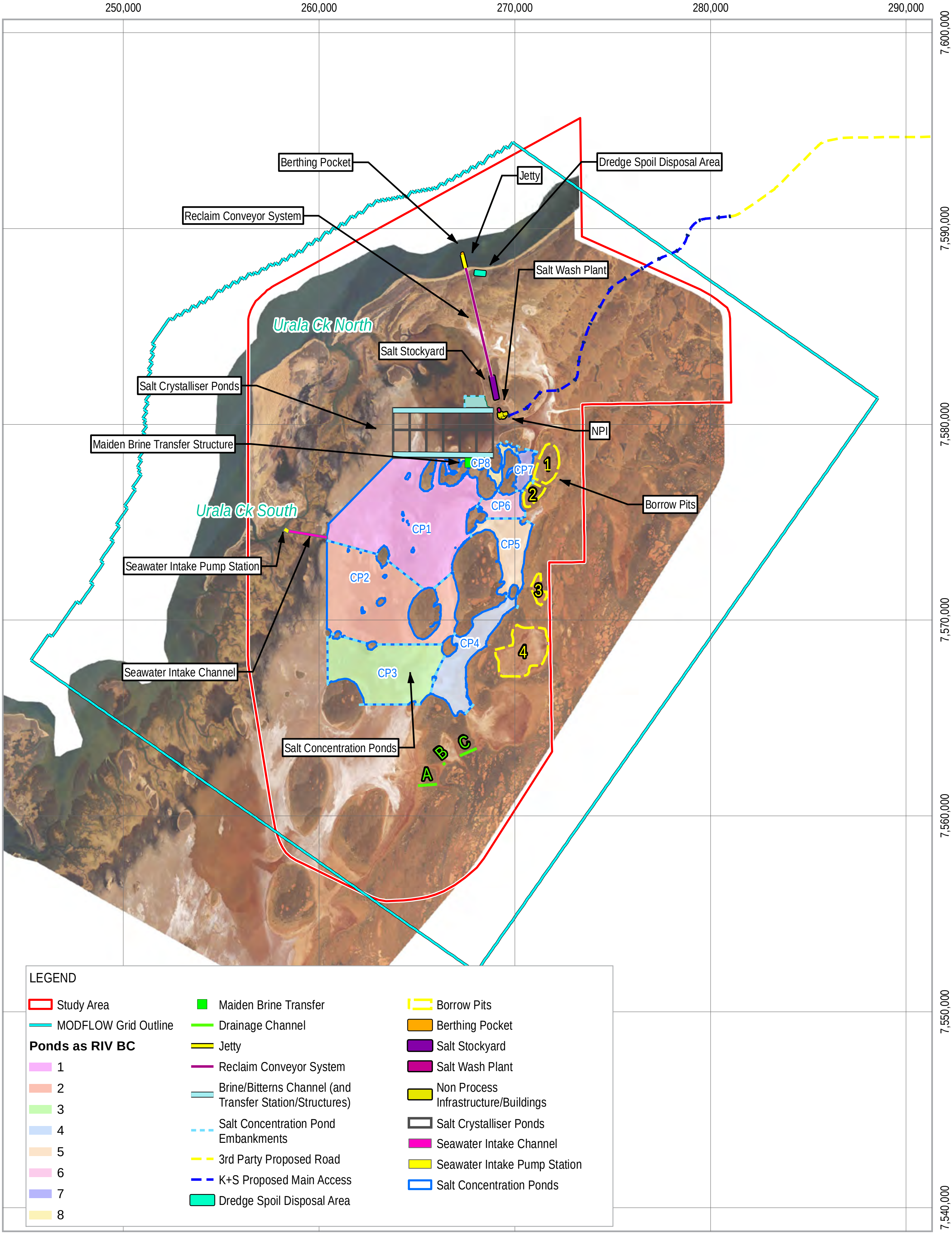
Calibrated Hydraulic Conductivity Spatial Distribution

Project No. 12516706
Revision No. 0
Date 23 Jun 2021

MAP 20

G:\61\12516706\GIS\Maps\Working\A4P Groundwater Maps\Map20_VerticalHydraulicConductivity_A3L_Rev0.mxd
Print date: 23 Jun 2021 - 11:11

Data source: GHD - Project Components . Created by: kaadams



Paper Size ISO A4

0 2.5 5 7.5

Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 50

N

K + S Salt Australia Pty Ltd
Ashburton Solar Salt Project
Phase 2 Site Investigation

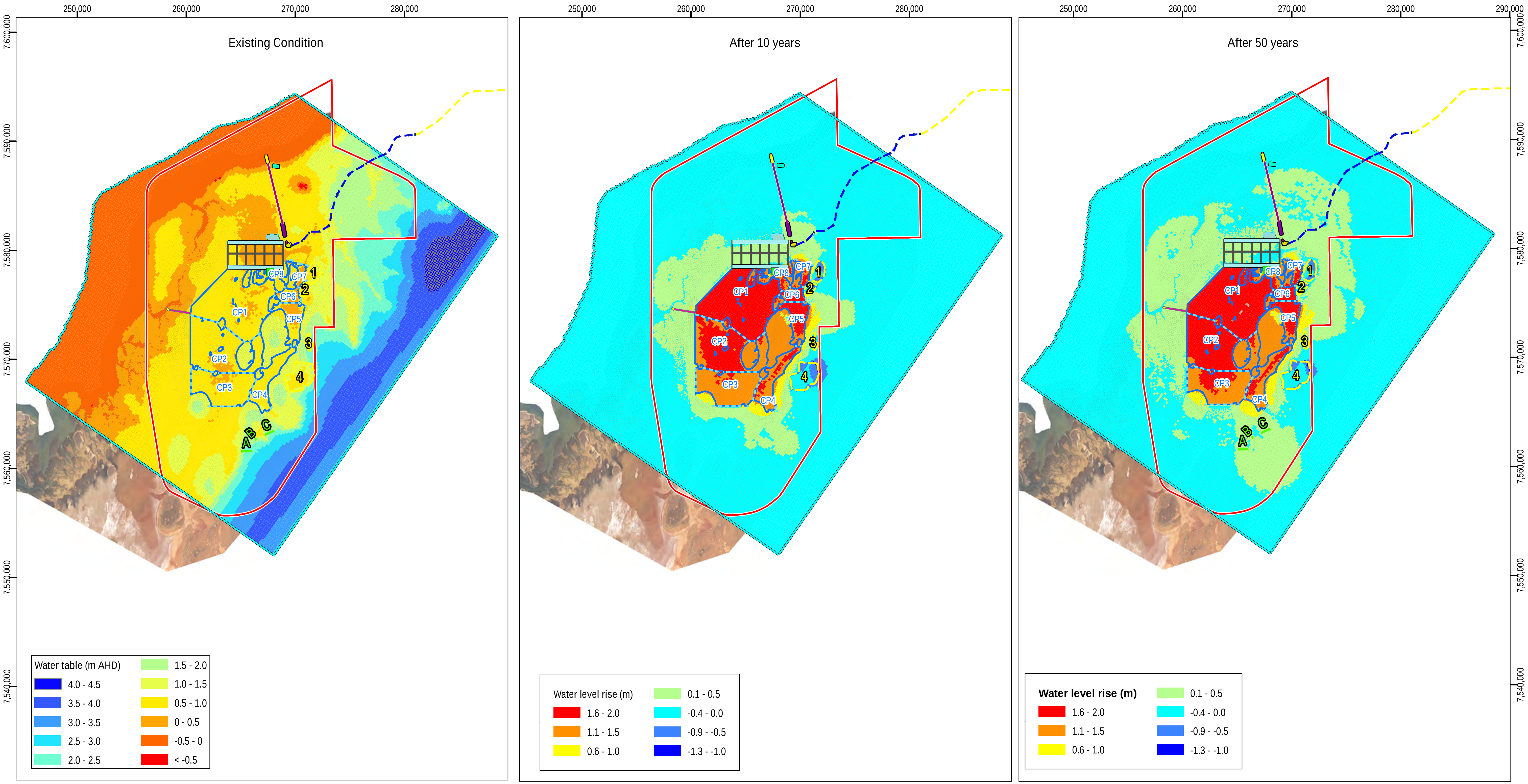
Representation of Ponds as RIV Boundary Condition

Project No. 12516706
Revision No. 0
Date 04 Jun 2021

MAP 21

G:\61\12516706\GIS\Maps\Working\A4P Groundwater Maps\Map21_RIVBCs_Pred_A4P_Rev2.mxd
Print date: 04 Jun 2021 - 11:00

Data source: GHD - Project Components. . Created by: htaniza



Legend

- Study Area
- Maiden Brine Transfer Structure
- Jetty
- Reclaim Conveyor System
- Brine/Bitterns Channel (and Transfer Station/Structures)
- Salt Concentration Pond Embankments
- 3rd Party Proposed Road
- K+S Proposed Main Access
- MODFLOW Grid Outline
- Dredge Spoil Disposal Area
- Borrow Pits
- Berthing Pocket
- Salt Stockyard
- Salt Wash Plant
- Non Process Infrastructure/Buildings
- Salt Crystalliser Ponds
- Seawater Intake Channel
- Seawater Intake Pump Station
- Salt Concentration Ponds

Paper Size ISO A3

0 3.5 7 10.5

Kilometers

N

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 50

GHD

K + S Australia Pty Ltd
Ashburton Solar Salt Project
Phase 2 Site Investigations

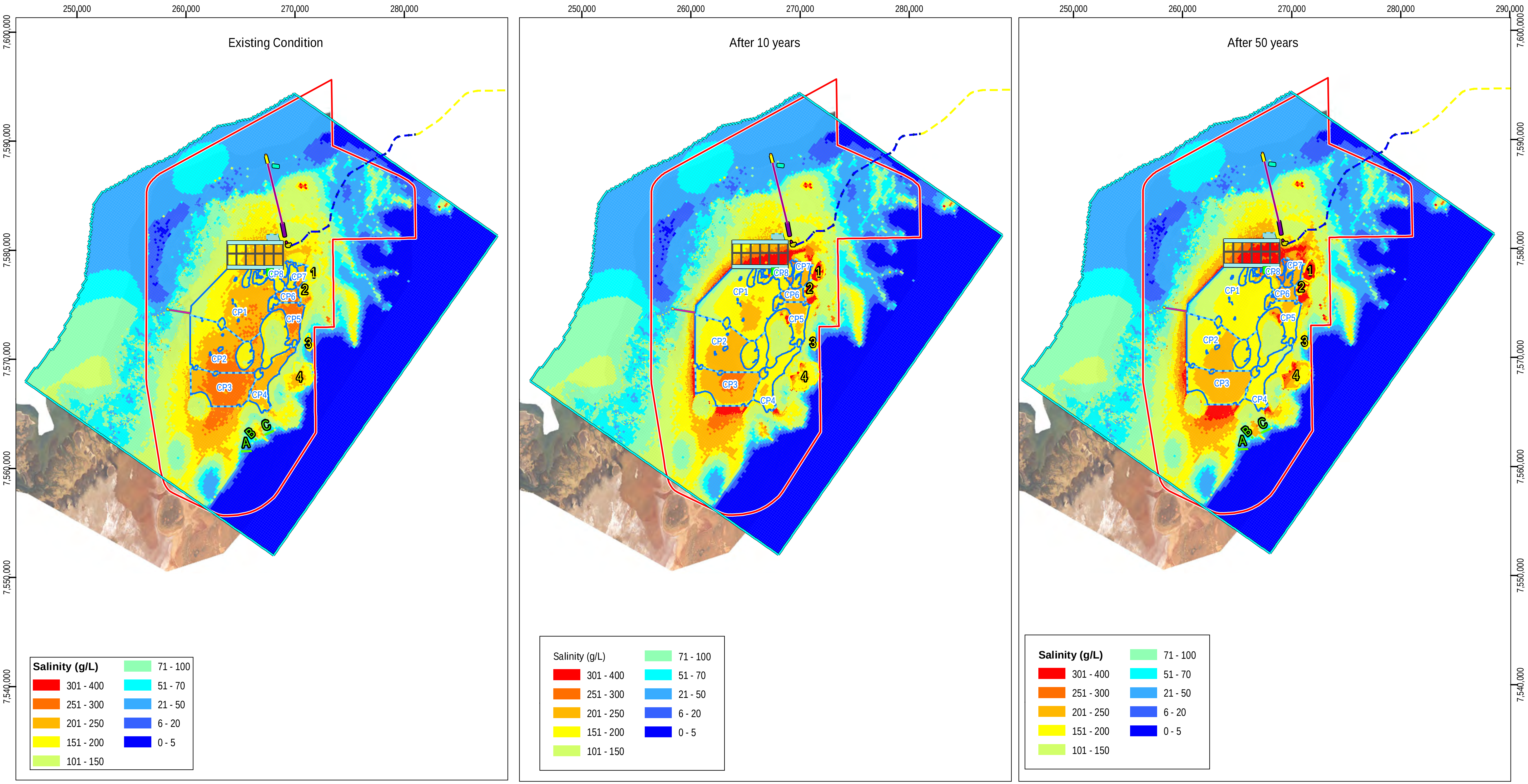
Predicted Change in Groundwater Level

Project No. 12516706
Revision No. 0
Date 23 Jun 2021

MAP 22

G:\61\12516706\GIS\Maps\Working\A4P Groundwater Maps\Map22_PredictedGWrise_A3L_Rev2.mxd
Print date: 23 Jun 2021 - 11:12

Data source: GHD - Project Components . Created by: kaadams



Legend

- Study Area
- Maiden Brine Transfer Structure
- Jetty
- Reclaim Conveyor System
- Brine/Bitterns Channel (and Transfer Station/Structures)
- Salt Concentration Pond Embankments
- 3rd Party Proposed Road
- K+S Proposed Main Access Road
- MODFLOW Grid Outline
- Dredge Spoil Disposal Area
- Borrow Pits
- Berthing Pocket
- Salt Stockyard
- Salt Wash Plant
- Non Process Infrastructure/Buildings
- Salt Crystalliser Ponds
- Seawater Intake Channel
- Seawater Intake Pump Station
- Salt Concentration Ponds

Paper Size ISO A3

0 3.5 7 10.5

Kilometers

N

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 50

GHD

K + S Australia Pty Ltd
Ashburton Solar Salt Project
Phase 2 Site Investigations

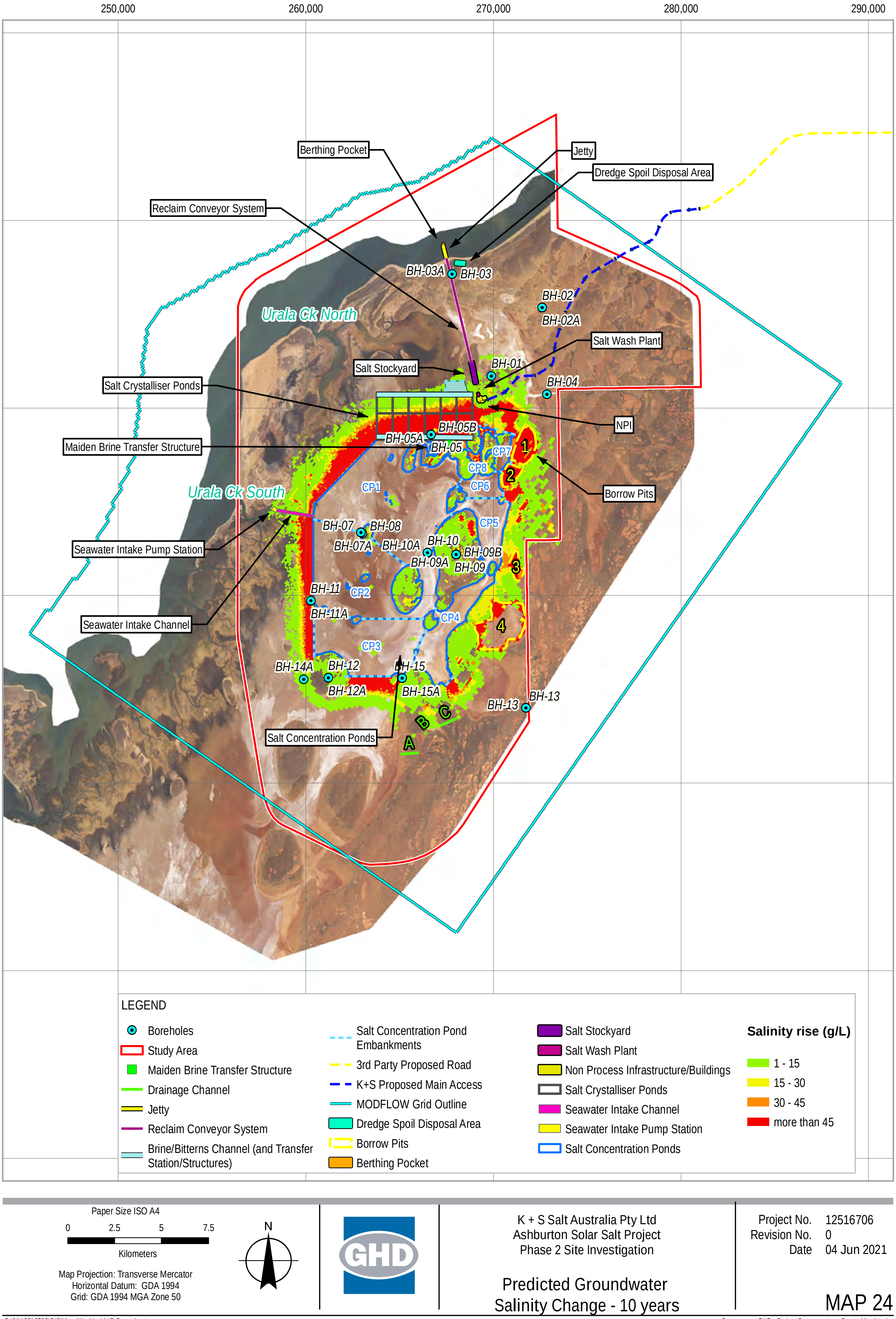
Predicted Groundwater Salinity

Project No. 12516706
Revision No. 0
Date 23 Jun 2021

MAP 23

G:\61\12516706\GIS\Maps\Working\A4P Groundwater Maps\Map23_PredictedSalinityEffects_A3L_Rev2.mxd
Print date: 23 Jun 2021 - 11:13

Data source: GHD - Project Components . Created by: kaadams



Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 50

K + S Salt Australia Pty Ltd
Ashburton Solar Salt Project
Phase 2 Site Investigation

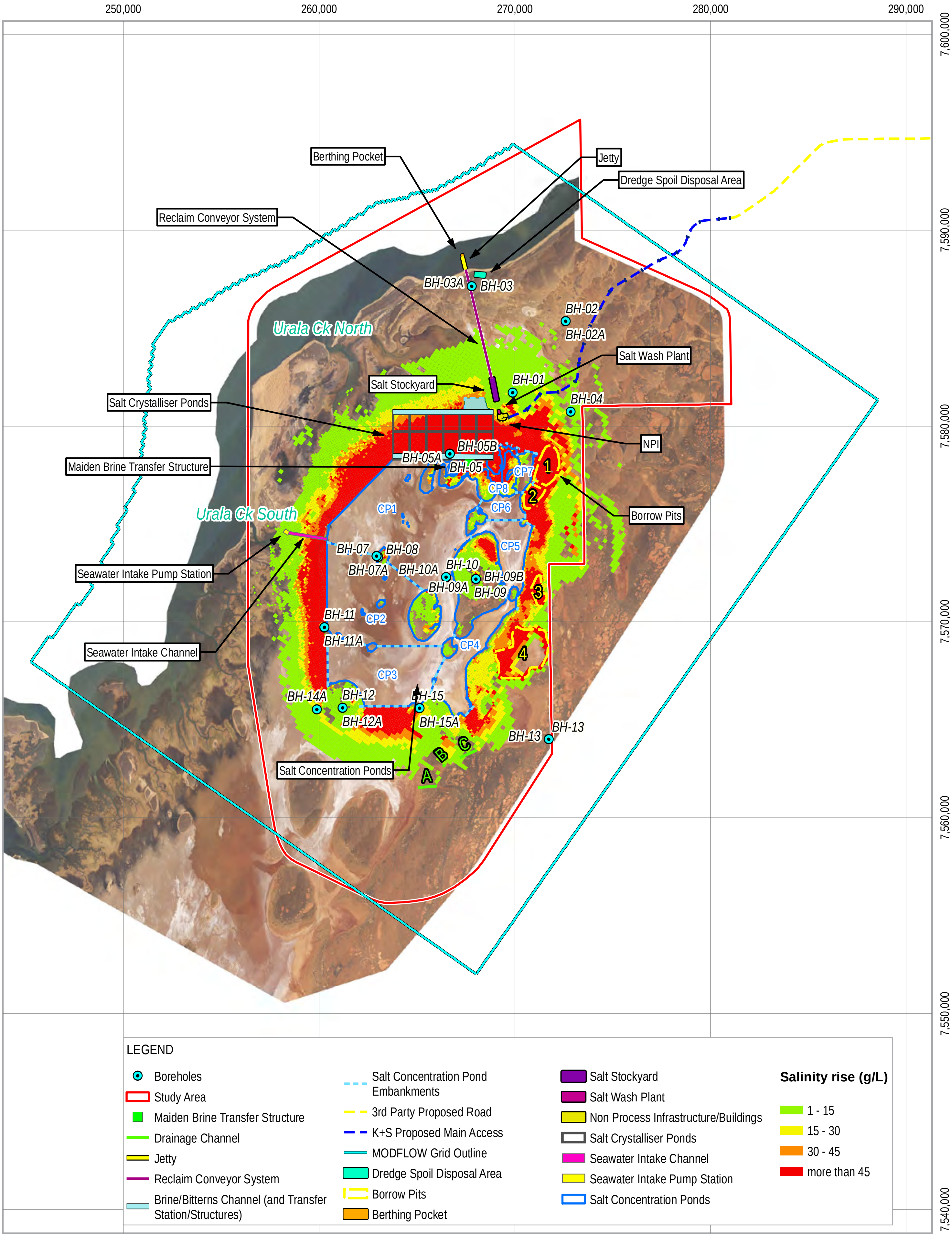
Predicted Groundwater Salinity Change - 10 years

Project No. 12516706
Revision No. 0
Date 04 Jun 2021

MAP 24

G:\61\12516706\GIS\Maps\Working\A4P Groundwater Maps\Map24_SalinityChange10yr_A4P_Rev2.mxd
Print date: 04 Jun 2021 - 12:05

Data source: GHD - Project Components . Created by: htaniza



Paper Size ISO A4

0 2.5 5 7.5

Kilometers

N

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 50

K + S Salt Australia Pty Ltd
Ashburton Solar Salt Project
Phase 2 Site Investigation

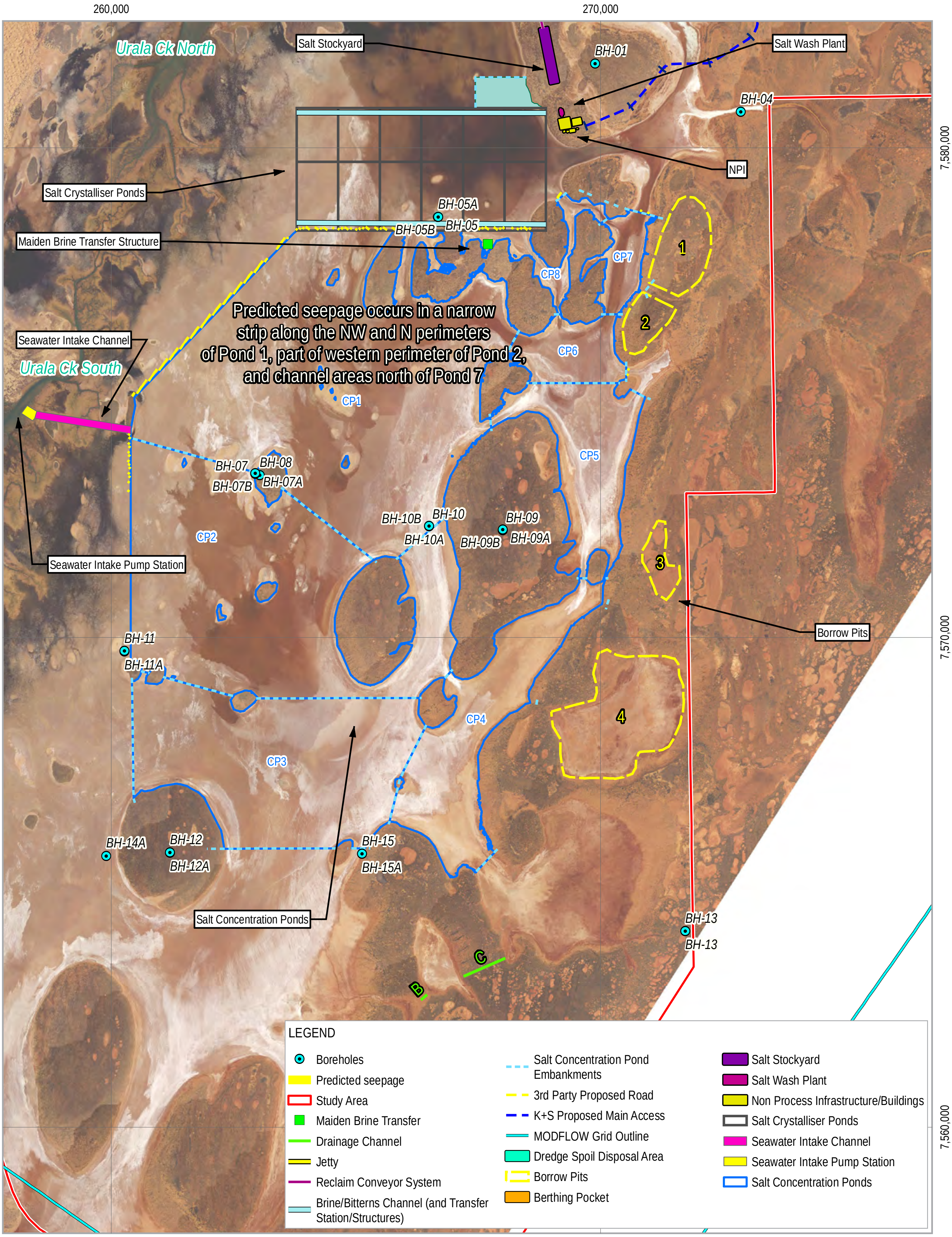
Predicted Groundwater Salinity Change - 50 years

Project No. 12516706
Revision No. 0
Date 04 Jun 2021

MAP 25

G:\61\12516706\GIS\Maps\Working\A4P Groundwater Maps\Map25_SalinityChange50yr_A4P_Rev2.mxd
Print date: 04 Jun 2021 - 13:38

Data source: GHD - Project Components . Created by: htaniza



Paper Size ISO A4

0 1 2 3

Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 50

N

K + S Salt Australia Pty Ltd
Ashburton Solar Salt Project
Phase 2 Site Investigation

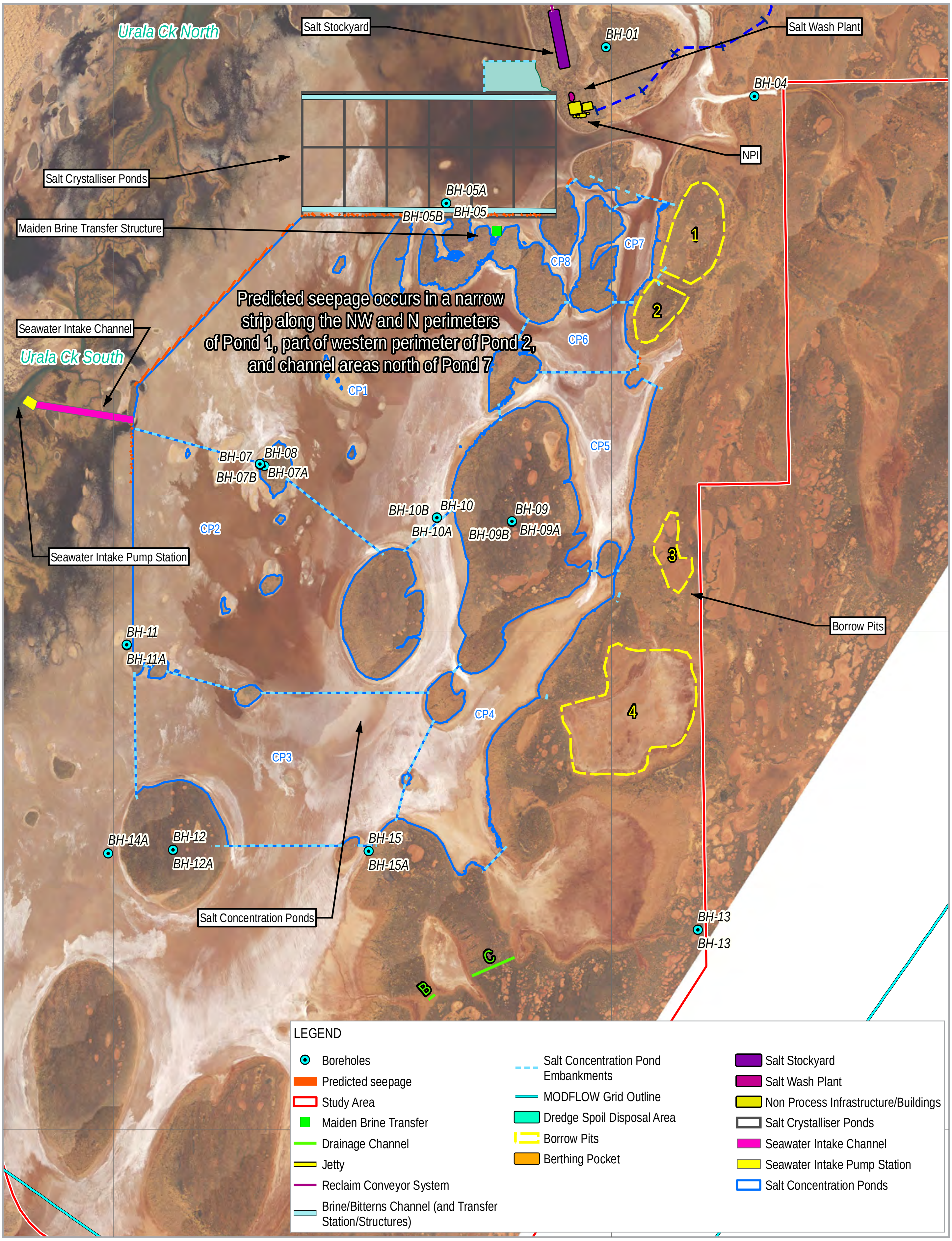
Project No. 12516706
Revision No. 0
Date 08 Jun 2021

Predicted Seepage Areas

MAP 26

G:\61\12516706\GIS\Maps\Working\A4P Groundwater Maps\Map26_Seep_A4P_Rev2.mxd
Print date: 08 Jun 2021 - 11:42

Data source: GHD - Project Components . Created by: htaniza



Paper Size ISO A4

0 1 2 3

Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 50

N

GHD

K + S Salt Australia Pty Ltd
Ashburton Solar Salt Project
Phase 2 Site Investigation

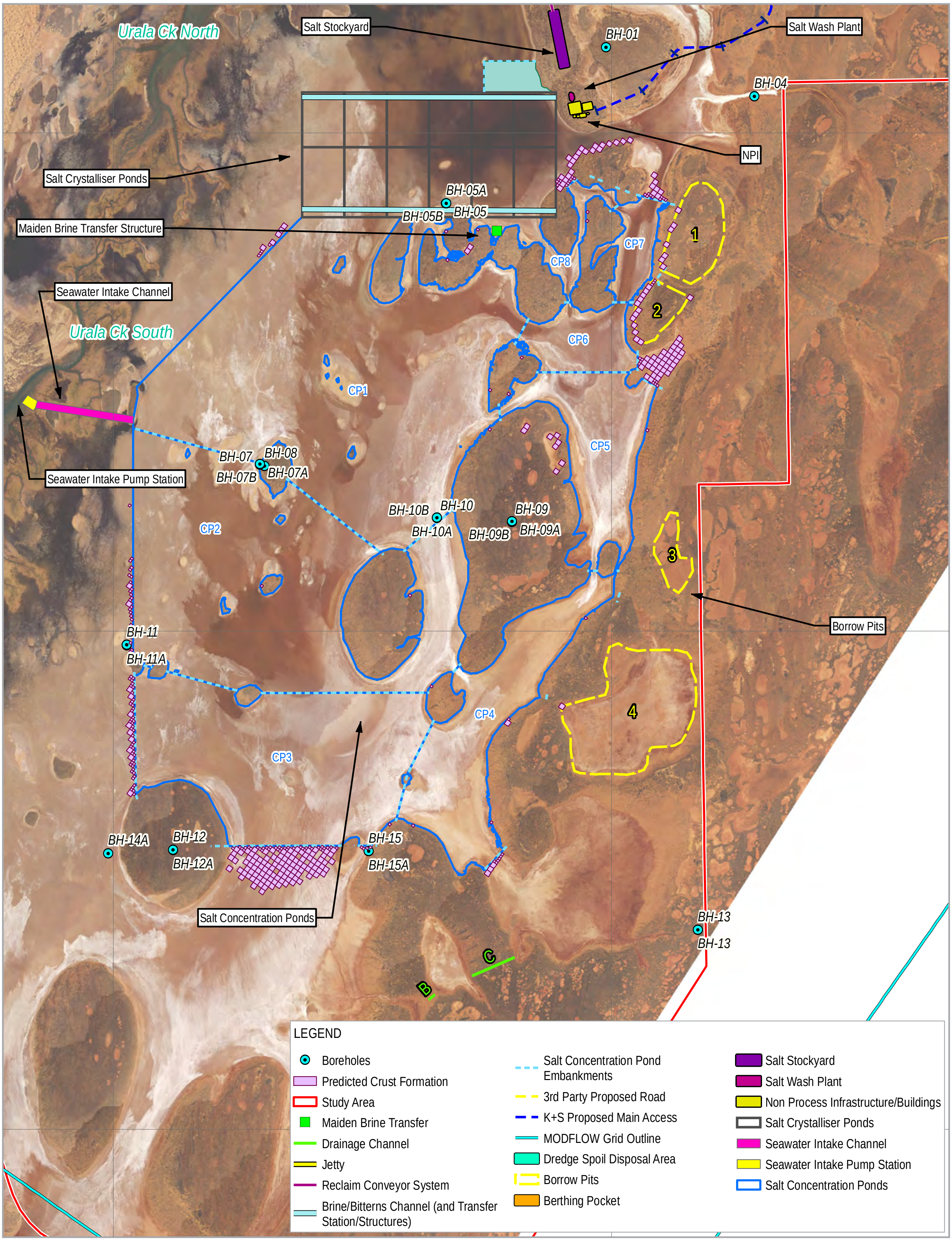
Predicted Seepage Areas

Project No. 12516706
Revision No. 0
Date 09 Jun 2021

MAP 26

G:\61\12516706\GIS\Maps\Working\A4P Groundwater Maps\Map26_Seep_A4P_Rev2.mxd
Print date: 09 Jun 2021 - 13:10

Data source: GHD - Project Components . Created by: htaniza



Paper Size ISO A4

0 1 2 3

Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 50

N

GHD

K + S Salt Australia Pty Ltd
Ashburton Solar Salt Project
Phase 2 Site Investigation

Project No. 12516706
Revision No. 0
Date 08 Jun 2021

Predicted Salt Crust Areas

MAP 27

G:\61\12516706\GIS\Maps\Working\A4P Groundwater Maps\Map27_Crust_A4P_Rev2.mxd
Print date: 08 Jun 2021 - 11:42

Data source: GHD - Project Components . Created by: htaniza

Appendices

Appendix A – Bore Logs

BOREHOLE LOG

HYDROGEOLOGICAL-GROUNDWATER

MONITORING WELL BH01

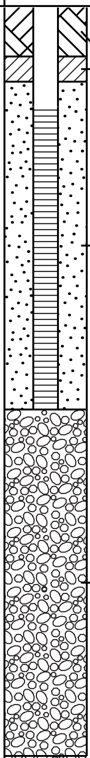
Client K+S Salt	**Drill Co.** J&S Drilling	**Easting, Northing** 269887, 7581719
Project Geotechnical, Groundwater and ASS Investigation	**Rig Type** Jacro 350 Mangrove Buggy	**Grid Ref** GDA94_MGA_zone_50
Project No. 12516706	**Drill Method** PQ core	**Elevation** 7.2
Site Tubridgi	**Total Depth (m)** 19.87	**TOC Elevation (m)** -
Location Tubridgi, Onslow 6710 WA	**Casing Diameter (mm)** 50	**Logged By** SG
Date Drilled 24/03/2020 - 30/03/2020	**Stickup (m)** 0.5	**Checked By** DO/PB
Casing 50 mm Class 18 PVC	**Screen** Class 18 PVC 2-8m	**Surface Completion** Monument cover

Depth (m): 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24

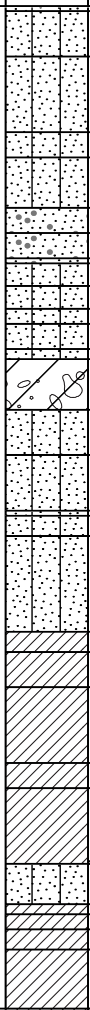
Drilling Method: PQ Coring

Water

Well Details:



Graphic Log:



LITHOLOGICAL DESCRIPTION Soil Type (Classification Group Symbol); Particle Size; Colour; Secondary / Minor Components.
Topsoil - Carbonate Silty SAND. Fine grained, sub-round to sub-angular; red-brown; non-plastic fines; with organics., D, L
Core loss: 0.1 to 1.0 m. Inferred as Silty SAND
Carbonate Silty SAND. Fine to medium grained, angular, inferred salt; red-brown; non-plastic fines, trace broken shells, fine grained sand sized., MD
Core loss: 2.5 to 3.0 m. Inferred as Silty Sand.
Carbonate Silty SAND. Fine to medium grained, sub-rounded to sub-angular, inferred quartz; red-brown; non-plastic fines, trace broken shells, fine grained sand sized., D-M
Core loss: 4.0 to 4.5 m
Carbonate SAND. Fine to coarse grained, sub-rounded to sub-angular, inferred quartz; red-brown; trace silt., M, MD
Carbonate SAND. Fine to coarse grained, sub-rounded to sub-angular, inferred quartz; red-brown; trace silt., M, MD
Carbonate Silty SAND. Fine to medium grained; red-brown; non-plastic fines.
Core loss: 5.55 to 6.0 m
Carbonate SAND. Fine to coarse grained, sub-round to sub-angular, quartz; red-brown; trace silt; trace fine shell gravel., W, L
Carbonate Sandy CLAY. Low to medium plasticity; red-brown; sand is fine to medium grained.. 6.7 m: with Carbonate Silty SAND inclusions, pale orange., W, St
Core loss: 6.8 to 7.0 m
Carbonate Clayey Sandy GRAVEL. Fine to coarse grained; sub-angular to angular; pale orange; sand is red-brown, fine to medium grained; clay is low plasticity., M, MD
Carbonate Silty Gravelly SAND. Fine to medium grained, sub-angular, inferred salt; red-brown; gravel is fine to coarse grained, sub-angular, of limestion; non-plastic fines.. 8.3-8.5 m: increased gravel content.
Silty SAND. Fine to medium grained, sub-angular, inferred salt; red-brown; non-plastic fines; trace gravel of limestone.. From 9.9 m: with gravel, fine to coarse grained, sub-angular of limestone; trace cobbles of limestone., L
Silty SAND. Fine to medium grained, sub-angular, inferred salt; red-brown; non-plastic fines; trace gravel of limestone.. From 9.9 m: with gravel, fine to coarse grained, sub-angular of limestone; trace cobbles of limestone., M, MD
Silty Sandy GRAVEL. Fine to medium grained, sub-angular to angular, limestone; pale orange gravel; red-brown sand fines; fine to medium grained angular salt sand; non-plastic fines.
Carbonate Silty Gravelly SAND. Fine to medium grained, angular, salt; red-brown; gravel is pale orange, fine to coarse grained, sub-angular of limestone; non-plastic fines.
Sandy CLAY. Low plasticity fines; red-brown; sand is fine to medium grained; angular, salt., W, VSt
Core loss: 12.8 to 13.5 m
Sandy CLAY. Low plasticity fines; red-brown; sand is fine to medium grained; angular, salt; trace gravel, fine grained, sub-angular of limestone., W, H
Sandy CLAY. Medium plasticity; red-brown; sand is fine to medium grained, angular, salt., W, H
Carbonate Sandy CLAY. Low plasticity; red-brown; sand is fine to medium grained, angular.
16.95 to 17.0 m: with gravel, fine grained, sub-rounded of haematite.
Silty SAND. Fine to medium grained, angular, salt; red-brown; non-plastic fines; trace gravel, fine to medium grained, sub-rounded of haematite., D-M, VD

DRILLING OBSERVATIONS

Inferred geolgical unit: Qe (0-13.5m)

Inferred geolgical unit: Qsed (13.5-19.87m)

Elevation (m): 7, 6, 5, 4, 3, 2, 1, 0, -1, -2, -3, -4, -5, -6, -7, -8, -9, -10, -11, -12, -13, -14, -15, -16, -17

Notes

This log is not intended for geotechnical purposes.

Drilling Abbreviations	Moisture Abbreviations	Consistency Abbreviations	
AH-Air Hammer, AR-Air Rotary, BE-Bucket Excavation, CC-Concrete Coring, DC-Diamond Core, FH-Foam Hammer, HA-Hand Auger, HE-Hand Excavation (shovel), HFA-Hollow Flight Auger, MR-Mud Rotary, NDD-Non Destructive Drilling, PT-Pushtube, SD-Sonic Drilling, SFA-Solid Flight Auger, SS-Split Spoon, WB-Wash Bore, WS-Window Sampler	D-Dry, SM-Slightly Moist, M-Moist, VM-Very Moist, W-Wet, S-Saturated	**Granular Soils** VL-Very Loose, L-Loose, MD-Medium Dense, D-Dense,VD - Very Dense	**Cohesive Soils** VS-Very Soft, S-Soft, F-Firm, ST-Stiff, VST-Very Stiff, H-Hard

BOREHOLE LOG

HYDROGEOLOGICAL-GROUNDWATER

MONITORING WELL BH02D

Client K+S Salt	**Drill Co.** J&S Drilling	**Easting, Northing** 272595, 7585346
Project Geotechnical, Groundwater and ASS Investigation	**Rig Type** Jacro 350 Mangrove Buggy	**Grid Ref** GDA94_MGA_zone_50
Project No. 12516706	**Drill Method** PQ core	**Elevation** 2.1
Site Tubridgi	**Total Depth (m)** 18.74	**TOC Elevation (m)** -
Location Tubridgi, Onslow 6710 WA	**Casing Diameter (mm)** 50	**Logged By** DO
Date Drilled 30/10/2019 - 01/11/2019	**Stickup (m)** 0.5	**Checked By** DO/PB

Casing 50 mm Class 18 PVC | **Screen** Class 18 PVC 12.2-18.2m | **Surface Completion** Monument cover

Depth (m)	Drilling Method	Water	Well Details	Graphic Log	LITHOLOGICAL DESCRIPTION Soil Type (Classification Group Symbol); Particle Size; Colour; Secondary / Minor Components.	DRILLING OBSERVATIONS	Elevation (m)
	Solid Auge				Sandy CLAY. High plasticity; brown; sand is fine grained sub-rounded; trace gravel, fine to medium grained, sub-angular (iron cemented?)., W, VSt	Inferred geolgical unit: Czp (0-15.8m)	2
1					Core loss: 0.5 to 0.85m. Inferred as above		1
2					Sandy CLAY. Medium plasticity; brown; sand is fine grained, sub-rounded; high dry strength.		0
3			Bentonite & grout mix Depth: 0.0 - 7.6		Carbonate Sandy CLAY. High plasticity; brown; sand is fine to medium grained, sub-rounded of carbonate; with gravel, fine to coarse-grained, sub-angular to sub-rounded calcrete.		-1
4		∇			Carbonate Clayey SAND. Fine to medium grained; sub-rounded to sub-angular; pale brown; low plasticity fines; trace gravel, fine to medium grained, sub-angular to sub-rounded of calcrete; uncemented., W, L-MD		-2
5					Clayey Gravelly SAND. Fine to medium grained, sub-rounded to sub-angular; pale brown; low plasticity fines; gravel, fine to coarse grained, sub-rounded to rounded of calcrete; uncemented.		-3
6					Clayey SAND. Fine to medium grained, sub-rounded to sub-angular; brown; low plasticity fines; trace gravel, (locally with) fine to medium, sub-rounded of calcrete; uncemented.		-4
7					Core loss: 4.7 to 5.0m. Inferred as below, L		-5
8					Clayey SAND. Fine to medium grained, sub-rounded to sub-angular sand; brown; medium plasticity clay; trace gravel, fine grained, sub-rounded to rounded of calcrete; uncemented., W, L		-6
9			Bentonite Depth: 7.6 - 11.		From 6.5m, gravel becomed sub-angular to sub-rounded., M-W, MD		-7
10					From 8.0m, gravel becomes sub-rounded., D		-8
11					Between 8.65 and 8.75m: brown, mottled white (CaCO3 mottling); low to medium plasticity fines.		-9
12					Sandy CLAY. Medium plasticity; brown; sand is fine grained, sub-rounded to sub-angular; trace gravel, fine to medium grained, sub-angular of calcrete., W, H		-10
13					Sandy CLAY. Medium plasticity; brown; sand is fine grained, sub-rounded to sub-angular., W, H		-11
14			Gravel Depth: 11. - 18.		Core loss: 10.65 to 11.0m		-12
15					Sandy CLAY. High plasticity; brown; sand is fine grained, sub-rounded to sub-angular; trace gravel, white, fine to medium grained, sub-angular of calcrete.		-13
16					Clayey SAND. Fine to medium grained; brown; low plasticity., W, VD	Inferred geolgical unit: Qsed (15.8-18.74m)	-14
17					Core loss: 12.0 to 12.5m. Inferred as above		-15
18					Sandy CLAY. High plasticity; brown; sand is fine grained, sub-angular to sub-rounded., W, H		-16
19					Clayey SAND. Fine to meduim grained, sub-angular to rounded; brown, stained pale grey; trace gravel, (locally with) fine to medium grained, sub-angular of calcrete; uncemented., W, VD		-17
20					Sandy CLAY. Medium to high plasticity; brown; sand is fine to medium grained, sub-angular to sub-rounded; trace gravel, (locally with) fine to medium grained, sub-angular of calcrete., W, H		-18
21					Core loss: 14.5 to 14.75m: Inferred as below., W		-19
22					Clayey SAND. Fine to medium grained, sub-angular to rounded; brown; medium plasticity fines; trace gravel, fine to medium grained, sub-angular to sub-rounded of calcrete; uncemented., VD		-20
23					Core loss: 15.25 to 15.5m Inferred as above		-21
					Clayey SAND. As above.		
24					Sandy CLAY. High plasticity; brown; sand is fine grained, sub-rounded; trace gravel, fine grained, sub-angular of calcrete and sandstone., W, H		-22
					Clayey SAND. Fine to medium grained, sub-angular to sub-rounded; brown;		

Notes

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Drilling Abbreviations	Moisture Abbreviations	Consistency Abbreviations	
AH-Air Hammer, AR-Air Rotary, BE-Bucket Excavation, CC-Concrete Coring, DC-Diamond Core, FH-Foam Hammer, HA-Hand Auger, HE-Hand Excavation (shovel), HFA-Hollow Flight Auger, MR-Mud Rotary, NDD-Non Destructive Drilling, PT-Pushtube, SD-Sonic Drilling, SFA-Solid Flight Auger, SS-Split Spoon, WB-Wash Bore, WS-Window Sampler	D-Dry, SM-Slightly Moist, M-Moist, VM-Very Moist, W-Wet, S-Saturated	**Granular Soils** VL-Very Loose, L-Loose, MD-Medium Dense, D-Dense,VD - Very Dense	**Cohesive Soils** VS-Very Soft, S-Soft, F-Firm, ST-Stiff, VST-Very Stiff, H-Hard

BOREHOLE LOG

HYDROGEOLOGICAL-GROUNDWATER

MONITORING WELL BH02S

Client K+S Salt	**Drill Co.** J&S Drilling	**Easting, Northing** 272595, 7585351
Project Geotechnical, Groundwater and ASS Investigation	**Rig Type** Jacro 350 Mangrove Buggy	**Grid Ref** GDA94_MGA_zone_50
Project No. 12516706	**Drill Method** Auger	**Elevation** 2.2
Site Tubridgi	**Total Depth (m)** 8.00	**TOC Elevation (m)** -
Location Tubridgi, Onslow 6710 WA	**Casing Diameter (mm)** 50	**Logged By** DO
Date Drilled 02/11/2019 - 02/11/2019	**Stickup (m)** 0.5	**Checked By** DO/PB
Casing 50 mm Class 18 PVC	**Screen** Class 18 PVC 5-8m	**Surface Completion** Monument cover

Depth (m)	Drilling Method	Water	Well Details	LITHOLOGICAL DESCRIPTION Soil Type (Classification Group Symbol); Particle Size; Colour; Secondary / Minor Components.	DRILLING OBSERVATIONS	Elevation (m)
0.0 – 0.5	Solid Auge		Backfill Depth: 0.0 - 2.7	Sandy CLAY. High plasticity; brown; sand is fine grained sub-rounded; trace gravel, fine to medium grained, sub-angular (iron cemented?)., W, VSt		2
0.5 – 0.85				Core loss: 0.5 to 0.85m. Inferred as above		1.5
0.85 – 1.7				Sandy CLAY. Medium plasticity; brown; sand is fine grained, sub-rounded; high dry strength.		1
1.7 – 2.55				Carbonate Sandy CLAY. High plasticity; brown; sand is fine to medium grained, sub-rounded of carbonate; with gravel, fine to coarse-grained, sub-angular to sub-rounded calcrete.		0.5, 0
2.55 – 3.5			Bentonite Depth: 2.7 - 4.1	Carbonate Clayey SAND. Fine to medium grained; sub-rounded to sub-angular; pale brown; low plasticity fines; trace gravel, fine to medium grained, sub-angular to sub-rounded of calcrete; uncemented., W, L-MD		-0.5, -1
3.5 – 4.1				Clayey Gravelly SAND. Fine to medium grained, sub-rounded to sub-angular; pale brown; low plasticity fines; gravel, fine to coarse grained, sub-rounded to rounded of calcrete; uncemented.		-1.5
4.1 – 4.7		▽ (approx. 4.3)	Gravel Depth: 4.1 - 8.0	Clayey SAND. Fine to medium grained, sub-rounded to sub-angular; brown; low plasticity fines; trace gravel, (locally with) fine to medium, sub-rounded of calcrete; uncemented.		-2
4.7 – 5.0				Core loss: 4.7 to 5.0m. Inferred as below, L		-2.5
5.0 – 6.5				Clayey SAND. Fine to medium grained, sub-rounded to sub-angular sand; brown; medium plasticity clay; trace gravel, fine grained, sub-rounded to rounded of calcrete; uncemented., W, L		-3, -3.5, -4
6.5 – 8.0				From 6.5m, gravel becomed sub-angular to sub-rounded., M-W, MD		-4.5, -5, -5.5
8.0				Termination Depth at: 8.00 m. Target depth.		-6

Notes

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Drilling Abbreviations	Moisture Abbreviations	Consistency Abbreviations	
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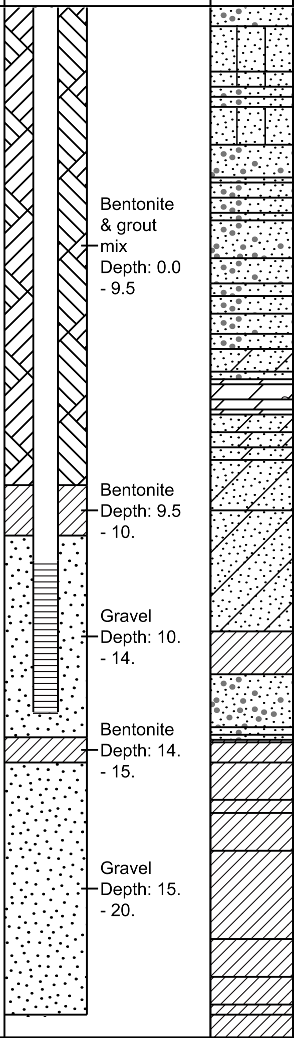
BOREHOLE LOG

HYDROGEOLOGICAL-GROUNDWATER

MONITORING WELL BH03D

Client K+S Salt	**Drill Co.** J&S Drilling	**Easting, Northing** 267805, 7587157
Project Geotechnical, Groundwater and ASS Investigation	**Rig Type** Jacro 350 Mangrove Buggy	**Grid Ref** GDA94_MGA_zone_50
Project No. 12516706	**Drill Method** PQ core	**Elevation** 1.6
Site Tubridgi	**Total Depth (m)** 20.45	**TOC Elevation (m)** -
Location Tubridgi, Onslow 6710 WA	**Casing Diameter (mm)** 50	**Logged By** DO
Date Drilled 03/11/2019 - 04/11/2019	**Stickup (m)** 0.5	**Checked By** DO/PB
Casing 50 mm Class 18 PVC	**Screen** Class 18 PVC 11-14m	**Surface Completion** Monument cover

Depth (m)	Drilling Method	Water	Well Details	Graphic Log	LITHOLOGICAL DESCRIPTION Soil Type (Classification Group Symbol); Particle Size; Colour; Secondary / Minor Components.	DRILLING OBSERVATIONS	Elevation (m)
1–24	Solid Auge	▽ (approx. 2.4)					1 to -23

LITHOLOGICAL DESCRIPTION	DRILLING OBSERVATIONS
SAND. Fine to medium grained, sub-angular to sub-rounded; brown; with fines; with plant root fibres to 0.1m depth; uncemented., D, VL	Inferred geolgical unit: Qs (0-6.8m)
Carbonate Silty SAND. Fine grained, sub-angular to sub-rounded of carbonate and quartz; brown; non-plastic fines; trace gravel, angular of claystone (?); uncemented.	
Silty SAND. Fine to medium grained, sub-rounded to sub-angular of quartz; grey mottled orange; low plasticity fines; uncemented., M, MD	
SAND. Fine to medium grained, sub-rounded of quartz; grey; with fines., W	
Core loss: 1.8 to 2.0m Inferred as above	
Silty SAND. Fine to medium grained, sub-angular to sub-rounded; grey; low plasticity fines; trace coral and shell fragments (up to 25mm).	
SAND. Fine to medium grained, sub-angular to sub-rounded of quartz; grey; trace coral and shell fragments (up to 10mm); trace fines; uncemented., L	
Core loss: 3.4 to 3.5 m Inferred as above	
Inferred as SAND below.	Inferred geolgical unit: Czp (6.8-12.4m)
SAND. Fine to medium grained, sub-angular to sub-rounded of quartz; grey; trace fines; trace coral and shell fragments (up to 20mm).	
From 4.1m, becoming with coral and shell fragments.	
Core loss: 4.25 to 5.0 m	
SAND. Fine to medium grained, sub-angular to sub-rounded of quartz; grey; with shell and coral fragments (up to 10mm); uncemented., W, VL	
Core loss: 5.5 to 5.75 m Inferred as above	
SAND. Fine to medium grained, sub-angular to sub-rounded of quartz; grey; with shell and coral fragments (up to 10mm); uncemented.	
Core loss: 6.1 to 6.5 m Inferred as above	
SAND. Fine to medium grained, sub-angular to sub-rounded of quartz; grey; trace fines; trace shell fragments (up to 10mm); uncemented., L	Inferred geolgical unit: Qsed (12.4-20.45m)
Carbonate Clayey SAND. Fine to medium grained, sub-angular to sub-rounded of carbonate and quartz; brown; low plasticity fines; trace gravel, fine to medium grained, sub-angular to sub-rounded of calcrete.	
Carbonate SAND. Fine to medium grained, sub-angular to sub-rounded of carbonate and quartz; brown; with fines; trace gravel, fine to medium grained, sub-angular of calcrete., MD	
Carbonate Clayey Sandy GRAVEL. Fine to coarse grained, sub-angular to sub-rounded of calcrete, claystone and shell fragments; brown; sand is fine to medium grained, sub-angular to sub-rounded of carbonate; low plasticity fines.	
From 7.5 to 7.6 m: Silty SAND	
Core loss: 7.8 to 8.0 m	
Carbonate Clayey Sandy GRAVEL. As above	
Carbonate Clayey SAND. Fine to medium grained, sub-angular to sub-rounded of carbonate; brown; low plasticity fines; trace gravel, fine to medium grained, sub-angular to sub-rounded of calcrete., M-W	
Core loss: 8.45 to 8.75m Inferred as above	
Carbonate Clayey SAND. Fine to medium grained, sub-angular to sub-rounded; brown; low plasticity fines; trace gravel, fine grained, sub-angular to sub-rounded of calcrete and claystone.	
From 9.0 m: Clayey SAND	
Clayey SAND. Fine to medium grained, sub-angular to sub-rounded; brown; low plasticity fines; trace gravel, fine grained, sub-rounded to sub-angular of calcrete., M-W, MD	
Sandy CLAY. Medium plasticity; brown; sand is fine grained, sub-angular to	

Notes

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BOREHOLE LOG

HYDROGEOLOGICAL-GROUNDWATER

MONITORING WELL BH03S

Client K+S Salt	**Drill Co.** J&S Drilling	**Easting, Northing** 267803, 7587157
Project Geotechnical, Groundwater and ASS Investigation	**Rig Type** Jacro 350 Mangrove Buggy	**Grid Ref** GDA94_MGA_zone_50
Project No. 12516706	**Drill Method** Auger	**Elevation** 1.5
Site Tubridgi	**Total Depth (m)** 5.00	**TOC Elevation (m)** -
Location Tubridgi, Onslow 6710 WA	**Casing Diameter (mm)** 50	**Logged By** DO
Date Drilled 04/11/2019 - 05/11/2019	**Stickup (m)** 0.5	**Checked By** DO/PB
Casing 50 mm Class 18 PVC	**Screen** Class 18 PVC 2-5m	**Surface Completion** Monument cover

Depth (m)	Drilling Method	Water	Well Details	Graphic Log	LITHOLOGICAL DESCRIPTION Soil Type (Classification Group Symbol); Particle Size; Colour; Secondary / Minor Components.	DRILLING OBSERVATIONS	Elevation (m)
0.0	Solid Auge		& grout mix Depth: 0.0 - 0.5		SAND. Fine to medium grained, sub-angular to sub-rounded; brown; with fines; with plant root fibres to 0.1m depth; uncemented., D, VL		
0.5			Bentonite Depth: 0.5 - 1.5		Carbonate Silty SAND. Fine grained, sub-angular to sub-rounded of carbonate and quartz; brown; non-plastic fines; trace gravel, angular of claystone (?); uncemented.		1
1							0.5
1.5			Gravel Depth: 1.5 - 5.0		Silty SAND. Fine to medium grained, sub-rounded to sub-angular of quartz; grey mottled orange; low plasticity fines; uncemented., M, MD		0
					SAND. Fine to medium grained, sub-rounded of quartz; grey; with fines., W		
					Core loss: 1.8 to 2.0m Inferred as above		
2					Silty SAND. Fine to medium grained, sub-angular to sub-rounded; grey; low plasticity fines; trace coral and shell fragments (up to 25mm).		-0.5
2.5		▽					-1
3					SAND. Fine to medium grained, sub-angular to sub-rounded of quartz; grey; trace coral and shell fragments (up to 10mm); trace fines; uncemented., L		-1.5
3.5					Core loss: 3.4 to 3.5 m Inferred as above		-2
					Inferred as SAND below.		
4					SAND. Fine to medium grained, sub-angular to sub-rounded of quartz; grey; trace fines; trace coral and shell fragments (up to 20mm).		-2.5
					From 4.1m, becoming with coral and shell fragments.		
4.5					Core loss: 4.25 to 5.0 m		-3
5					Termination Depth at: 5.00 m. Target depth.		-3.5
5.5							-4
6							-4.5
6.5							-5
7							-5.5
7.5							-6
8							-6.5
8.5							-7
9							-7.5
9.5							-8

Notes

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BOREHOLE LOG

HYDROGEOLOGICAL-GROUNDWATER

MONITORING WELL BH04

Client K+S Salt	**Drill Co.** J&S Drilling	**Easting, Northing** 272867, 7580738
Project Geotechnical, Groundwater and ASS Investigation	**Rig Type** Jacro 350 Mangrove Buggy	**Grid Ref** GDA94_MGA_zone_50
Project No. 12516706	**Drill Method** PQ core	**Elevation** 3.4
Site Tubridgi	**Total Depth (m)** 15.00	**TOC Elevation (m)** -
Location Tubridgi, Onslow 6710 WA	**Casing Diameter (mm)** 50	**Logged By** SD
Date Drilled 30/03/2020 - 31/03/2020	**Stickup (m)** 0.5	**Checked By** DO/PB
Casing 50 mm Class 18 PVC	**Screen** Class 18 PVC 3.4-8.4m	**Surface Completion** Monument cover

Depth (m)	Drilling Method	Water	Well Details	Graphic Log	LITHOLOGICAL DESCRIPTION Soil Type (Classification Group Symbol); Particle Size; Colour; Secondary / Minor Components.	DRILLING OBSERVATIONS	Elevation (m)
	PQ Coring		Concrete Depth: 0.0 - 0.2		Silty CLAY. Medium plasticity; brown; with sand, fine to coarse grained; calcerous., W, S	Inferred geolgical unit: Czp (0-6m)	3
1			Bentonite Depth: 0.2 - 2.2		1.0 to 1.5 m, locally becoming Sandy Silty CLAY.		2
2					From 1.5 m, loss of silt, clay is high plasticity.		1
3					Clayey GRAVEL. Fine grained; sub-rounded; of gypsum; brown; clay is high plasticity; with sand, fine to medium grained gypsum; calcerous., M, MD		0
4		▽			Sandy CLAY. High plasticity; brown; sand, fine to medium grained, sub-angular to sub-rounded, of gypsum and quartz; trace gravel, sub-rounded of gypsum; calcerous., W, F-St		-1
5			Gravel Depth: 2.2 - 8.2		From 3.5 m, becoming non-calcareous., St-VSt		-2
6					From 4.5 m, loss of gravel., VSt		-3
					Sandy CLAY. High plasticity; brown; sand, fine to medium grained, sub-angular to sub-rounded, of quartz; trace gravel, sub-rounded of gypsum; trace gravel, fine grained, sub-rounded; calcerous., W, VSt	Inferred geolgical unit: Qsed (6-15m)	
7					CLAY. High plasticity; brown; with sand, fine grained; with local calcerous cementation as nodules up to 30 mm., H		-4
8			Bentonite Depth: 8.2 - 9.0		From 7.0 m, trace local cemented nodules up to 150 mm., W		-5
9					From 7.5 m, addition of trace gravel, fine grained, black, sub-rounded, of claystone, and crystalline of gypsum.		-6
10					Calcareous CLAYSTONE. High plasticity; W-PL; brown; massive; with sand, fine to coarse grained, sub-angular to sub-rounded, of quartz and claystone, and coarse grained crystalline of gypsum; trace chart gravel (as below); local calcareous cementation nodules (as below); moist.		-7
11					From 9.8 m, becoming dry.		-8
12			Backfill Depth: 9.0 - 15.		Calcareous CLAYSTONE. High plasticity; W-PL; brown; massive; with sand, fine to coarse grained, sub-angular to sub-rounded, of quartz and claystone, and coarse grained crystalline of gypsum; trace gravel, medium grained (20 mm), rounded of chert; local ca		-9
13					From 10.1 m, sand is fine to medium grained.		-10
14					From 11.5 m, increase in size of calcareous nodules up to 350 mm.		-11
15					CORE LOSS 11.78 to 12.0 m Inferred as above		-12
16					Calcareous CLAYSTONE. High plasticity; W-PL; brown; massive; with sand, fine to coarse grained, sub-angular to sub-rounded, of quartz and claystone, and coarse grained crystalline of gypsum; local calcareous cementation as angular nodules, up to 15 mm; dry.		-13
17					From 12.57 m, Increase in sand content to Sandy CLAYSTONE.		-14
18					CORE LOSS 13.13 to 13.5 m Inferred as above		-15
19					Calcareous Sandy CLAYSTONE. High plasticity; W-PL; brown; massive; with sand, fine to coarse grained, sub-angular to sub-rounded, of quartz and claystone, and coarse grained crystalline of gypsum; local calcareous cementation as angular nodules, up to 15 mm; dry.		-16
20					Termination Depth at: 15.00 m. Target depth.		-17
21							-18
22							-19
23							-20
24							-21

Notes

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Client K+S Salt	**Drill Co.** J&S Drilling	**Easting, Northing** 266675, 7578586
Project Geotechnical, Groundwater and ASS Investigation	**Rig Type** Jacro 350 Mangrove Buggy	**Grid Ref** GDA94_MGA_zone_50
Project No. 12516706	**Drill Method** Auger	**Elevation** 0.7
Site Tubridgi	**Total Depth (m)** 15.00	**TOC Elevation (m)** -
Location Tubridgi, Onslow 6710 WA	**Casing Diameter (mm)** 50	**Logged By** SD
Date Drilled 14/01/2020 - 17/01/2020	**Stickup (m)** 0.5	**Checked By** DO/PB
Casing 50 mm Class 18 PVC	**Screen** Class 18 PVC 12-15m	**Surface Completion** Monument cover

Depth (m)	Drilling Method	Water	Well Details	Graphic Log	LITHOLOGICAL DESCRIPTION Soil Type (Classification Group Symbol); Particle Size; Colour; Secondary / Minor Components.	DRILLING OBSERVATIONS	Elevation (m)
0–6.5	Solid Auge	▽ (~2 m)	Grout Depth: 0.0 - 10.		Crust. Halite crystals up to 40 mm; white mottled brown; trace fines, non-plastic., D, S	Inferred geolgical unit: Qt (0-2m)	0
					CLAY. High plasticity; pale grey; trace sand is fine to medium grained, sub-angular, of quartz; non-calcareous.. 0.22-0.28 m: becoming grey-brown; with sand, fine to coarse-grained; with gravel, fine to medium; of angular gypsum crystals; uncemented., W	Inferred geolgical unit: Qsed (2-15m)	
					0.28-0.5 m: CORE LOSS		
					Clayey GRAVEL. Fine to medium grained, angular, of quartz; brown; clay is high plasticity, W>PL; with sand, fine to coarse-grained, angular, of gymsum and calcite; uncemented., W, L		
					0.77-1.0 m: CORE LOSS		
					Clayey GRAVEL. As above.		
					Sandy CLAY. High plasticity; brown; sand is fine to medium-grained, sub-rounded, of quartz; calcareous., W, F		
					At 3.0 m: loss of sand., W, F - St		
					At 4.0 m: becoming slightly calcareous.		
					4.12-4.5 m: CORE LOSS. Infered as above.		
6.5–15	PQ Coring				Sandy CLAY. High plasticity; brown; sand is fine to medium-grained, sub-rounded, of quartz; calcareous., St-VSt		
					From 6.1 m: with trace amounts of gravel, fine grained, angular, platy, of gypsum.		
					From 6.5 m: with trace amounts of sand; coarse-grained, angular, platy, of gypsum.		
					6.8-7.0 m: bivalve shells, non-intact, up to 41x55 mm in size.		
					At 7.0 m: non-calcareous., W		
					At 7.5 m: loss of gravel. Sand is fine to medium-grained.		
					At 8.7 m: gain of trace local cementation of calcite, ~30% area, moderately cemented.		
			Bentonite Depth: 10. - 11.		Calcareous CLAYSTONE. Brown; massively bedded; with 40% fine to medium grained sand, of quartz and salt (?) ; moderately well cemented; calcite veins, typically vertical, 20-30mm long, 5-20mm wide, <20% of area; moist.		
			Gravel Depth: 11. - 15.		At 11.95 m: 3 mm thick lamination, undulating, of crystalline gypsum.		
					At 12.21, 12.28, 12.42, 12.45, 12.69, 12.77, 13.25, 13.61, 14.28, 14.45 and 14.55 m: 1 mm thick laminations of gypsum, undulating, discontinuous, subhorizontal.		
					SANDSTONE. Fine to medium grained, angular, of quartz and iron oxides, brown; massively bedded; non-calcareous; moist.		
					Termination Depth at: 15.00 m. Target depth.		

Depth scale (m): 1–24. Elevation scale (m): 0 to -24.

Notes

This log is not intended for geotechnical purposes.

Drilling Abbreviations	Moisture Abbreviations	Consistency Abbreviations	
AH-Air Hammer, AR-Air Rotary, BE-Bucket Excavation, CC-Concrete Coring, DC-Diamond Core, FH-Foam Hammer, HA-Hand Auger, HE-Hand Excavation (shovel), HFA-Hollow Flight Auger, MR-Mud Rotary, NDD-Non Destructive Drilling, PT-Pushtube, SD-Sonic Drilling, SFA-Solid Flight Auger, SS-Split Spoon, WB-Wash Bore, WS-Window Sampler	D-Dry, SM-Slightly Moist, M-Moist, VM-Very Moist, W-Wet, S-Saturated	**Granular Soils** VL-Very Loose, L-Loose, MD-Medium Dense, D-Dense,VD - Very Dense	**Cohesive Soils** VS-Very Soft, S-Soft, F-Firm, ST-Stiff, VST-Very Stiff, H-Hard

BOREHOLE LOG

HYDROGEOLOGICAL-GROUNDWATER

MONITORING WELL BH05S

Client K+S Salt	**Drill Co.** J&S Drilling	**Easting, Northing** 266675, 7578587
Project Geotechnical, Groundwater and ASS Investigation	**Rig Type** Jacro 350 Mangrove Buggy	**Grid Ref** GDA94_MGA_zone_50
Project No. 12516706	**Drill Method** PQ core	**Elevation** 0.7
Site Tubridgi	**Total Depth (m)** 5.00	**TOC Elevation (m)** -
Location Tubridgi, Onslow 6710 WA	**Casing Diameter (mm)** 50	**Logged By** SD
Date Drilled 14/01/2020 - 17/01/2020	**Stickup (m)** 0.5	**Checked By** DO/PB
Casing 50 mm Class 18 PVC	**Screen** Class 18 PVC 1-2m	**Surface Completion** Monument cover

Depth (m)	Drilling Method	Water	Well Details	Graphic Log	LITHOLOGICAL DESCRIPTION Soil Type (Classification Group Symbol); Particle Size; Colour; Secondary / Minor Components.	DRILLING OBSERVATIONS	Elevation (m)
0	PQ Coring	∇	Bentonite Depth: 0.0 - 0.5		Crust. Halite crystals up to 40 mm; white mottled brown; trace fines, non-plastic., D, S		0.5
					CLAY. High plasticity; pale grey; trace sand is fine to medium grained, sub-angular, of quartz; non-calcareous.. 0.22-0.28 m: becoming grey-brown; with sand, fine to coarse-grained; with gravel, fine to medium; of angular gypsum crystals; uncemented., W		0
0.5			Gravel Depth: 0.5 - 2.0		0.28-0.5 m: CORE LOSS		-0.5
1					Clayey GRAVEL. Fine to medium grained, angular, of quartz; brown; clay is high plasticity, W>PL; with sand, fine to coarse-grained, angular, of gymsum and calcite; uncemented., W, L		-1
1.5					0.77-1.0 m: CORE LOSS		
					Clayey GRAVEL. As above.		-1.5
2			Bentonite Depth: 2.0 - 5.0		Sandy CLAY. High plasticity; brown; sand is fine to medium-grained, sub-rounded, of quartz; calcareous., W, F		-2
3					At 3.0 m: loss of sand., W, F - St		-2.5
4					At 4.0 m: becoming slightly calcareous.		-3.5
					4.12-4.5 m: CORE LOSS. Infered as above.		
4.5					Sandy CLAY. High plasticity; brown; sand is fine to medium-grained, sub-rounded, of quartz; calcareous., St-VSt		-4
5					Termination Depth at: 5.00 m. Target depth.		-4.5

Depth scale: 0.5, 1, 1.5, 2, 2.5, 3, 3.5, 4, 4.5, 5, 5.5, 6, 6.5, 7, 7.5, 8, 8.5, 9, 9.5

Elevation scale: 0.5, 0, -0.5, -1, -1.5, -2, -2.5, -3, -3.5, -4, -4.5, -5, -5.5, -6, -6.5, -7, -7.5, -8, -8.5, -9

Notes

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Drilling Abbreviations	Moisture Abbreviations	Consistency Abbreviations	
AH-Air Hammer, AR-Air Rotary, BE-Bucket Excavation, CC-Concrete Coring, DC-Diamond Core, FH-Foam Hammer, HA-Hand Auger, HE-Hand Excavation (shovel), HFA-Hollow Flight Auger, MR-Mud Rotary, NDD-Non Destructive Drilling, PT-Pushtube, SD-Sonic Drilling, SFA-Solid Flight Auger, SS-Split Spoon, WB-Wash Bore, WS-Window Sampler	D-Dry, SM-Slightly Moist, M-Moist, VM-Very Moist, W-Wet, S-Saturated	**Granular Soils** VL-Very Loose, L-Loose, MD-Medium Dense, D-Dense,VD - Very Dense	**Cohesive Soils** VS-Very Soft, S-Soft, F-Firm, ST-Stiff, VST-Very Stiff, H-Hard

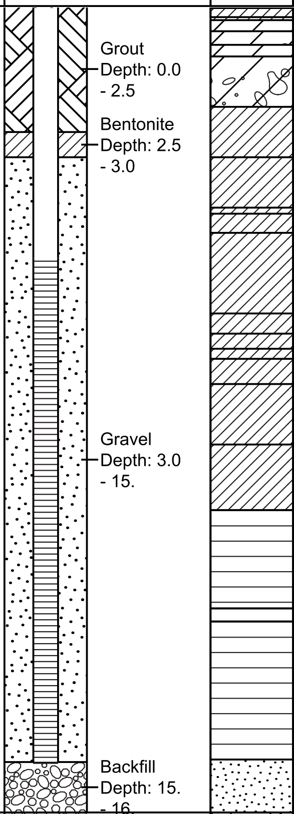
BOREHOLE LOG

HYDROGEOLOGICAL-GROUNDWATER

MONITORING WELL BH05 TB

Client K+S Salt	**Drill Co.** J&S Drilling	**Easting, Northing** 266676, 7578588
Project Geotechnical, Groundwater and ASS Investigation	**Rig Type** Jacro 350 Mangrove Buggy	**Grid Ref** GDA94_MGA_zone_50
Project No. 12516706	**Drill Method** Auger	**Elevation** 0.7
Site Tubridgi	**Total Depth (m)** 16.00	**TOC Elevation (m)** -
Location Tubridgi, Onslow 6710 WA	**Casing Diameter (mm)** 100	**Logged By** SD
Date Drilled 22/03/2020 - 22/03/2020	**Stickup (m)** 0.5	**Checked By** DO/PB
Casing 100 mm Class 12 PVC	**Screen** Class 18 PVC 5-15m	**Surface Completion** Monument cover

Depth (m)	Drilling Method	Water	Well Details	Graphic Log	LITHOLOGICAL DESCRIPTION Soil Type (Classification Group Symbol); Particle Size; Colour; Secondary / Minor Components.	DRILLING OBSERVATIONS	Elevation (m)
0–16	Wash Borin	▽	Grout Depth: 0.0 - 2.5; Bentonite Depth: 2.5 - 3.0; Gravel Depth: 3.0 - 15.; Backfill Depth: 15. - 16.				



Lithological description:

- Crust. Halite crystals up to 40 mm; white mottled brown; trace fines, non-plastic., D, S
- CLAY. High plasticity; pale grey; trace sand is fine to medium grained, sub-angular, of quartz; non-calcareous.. 0.22-0.28 m: becoming grey-brown; with sand, fine to coarse-grained; with gravel, fine to medium; of angular gypsum crystals; uncemented., W
- 0.28-0.5 m: CORE LOSS
- Clayey GRAVEL. Fine to medium grained, angular, of quartz; brown; clay is high plasticity, W>PL; with sand, fine to coarse-grained, angular, of gymsum and calcite; uncemented., W, L
- 0.77-1.0 m: CORE LOSS
- Clayey GRAVEL. As above.
- Sandy CLAY. High plasticity; brown; sand is fine to medium-grained, sub-rounded, of quartz; calcareous., W, F
- At 3.0 m: loss of sand., W, F - St
- At 4.0 m: becoming slightly calcareous.
- 4.12-4.5 m: CORE LOSS. Infered as above.
- Sandy CLAY. High plasticity; brown; sand is fine to medium-grained, sub-rounded, of quartz; calcareous., St-VSt
- From 6.1 m: with trace amounts of gravel, fine grained, angular, platy, of gypsum.
- From 6.5 m: with trace amounts of sand; coarse-grained, angular, platy, of gypsum.
- 6.8-7.0 m: bivalve shells, non-intact, up to 41x55 mm in size.
- At 7.0 m: non-calcareous., W
- At 7.5 m: loss of gravel. Sand is fine to medium-grained.
- At 8.7 m: gain of trace local cementation of calcite, ~30% area, moderately cemented.
- Calcareous CLAYSTONE. Brown; massively bedded; with 40% fine to medium grained sand, of quartz and salt (?) ; moderately well cemented; calcite veins, typically vertical, 20-30mm long, 5-20mm wide, <20% of area; moist.
- At 11.95 m: 3 mm thick lamination, undulating, of crystalline gypsum.
- At 12.21, 12.28, 12.42, 12.45, 12.69, 12.77, 13.25, 13.61, 14.28, 14.45 and 14.55 m: 1 mm thick laminations of gypsum, undulating, discontinuous, subhorizontal.
- SANDSTONE. Fine to medium grained, angular, of quartz and iron oxides, brown; massively bedded; non-calcareous; moist.

Termination Depth at: 16.00 m. Target depth.

Depth scale (m): 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24

Elevation scale (m): 0, -1, -2, -3, -4, -5, -6, -7, -8, -9, -10, -11, -12, -13, -14, -15, -16, -17, -18, -19, -20, -21, -22, -23, -24

Notes

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Drilling Abbreviations	Moisture Abbreviations	Consistency Abbreviations	
AH-Air Hammer, AR-Air Rotary, BE-Bucket Excavation, CC-Concrete Coring, DC-Diamond Core, FH-Foam Hammer, HA-Hand Auger, HE-Hand Excavation (shovel), HFA-Hollow Flight Auger, MR-Mud Rotary, NDD-Non Destructive Drilling, PT-Pushtube, SD-Sonic Drilling, SFA-Solid Flight Auger, SS-Split Spoon, WB-Wash Bore, WS-Window Sampler	D-Dry, SM-Slightly Moist, M-Moist, VM-Very Moist, W-Wet, S-Saturated	**Granular Soils** VL-Very Loose, L-Loose, MD-Medium Dense, D-Dense,VD - Very Dense	**Cohesive Soils** VS-Very Soft, S-Soft, F-Firm, ST-Stiff, VST-Very Stiff, H-Hard

BOREHOLE LOG

HYDROGEOLOGICAL-GROUNDWATER

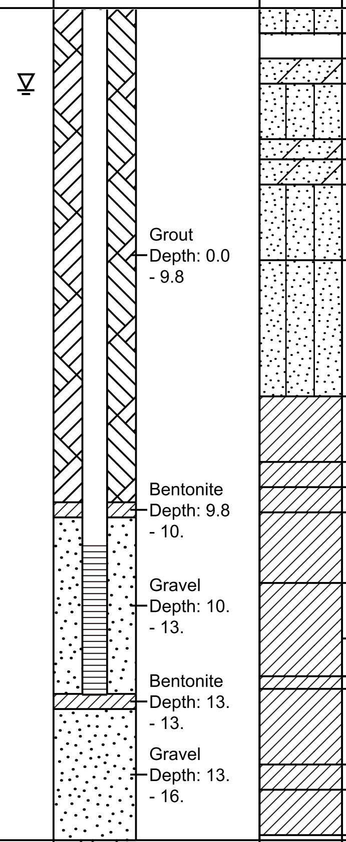
MONITORING WELL BH07D

Client K+S Salt	**Drill Co.** J&S Drilling	**Easting, Northing** 262938, 7573345
Project Geotechnical, Groundwater and ASS Investigation	**Rig Type** Jacro 350 Mangrove Buggy	**Grid Ref** GDA94_MGA_zone_50
Project No. 12516706	**Drill Method** PQ core	**Elevation** 1.8
Site Tubridgi	**Total Depth (m)** 16.50	**TOC Elevation (m)** -
Location Tubridgi, Onslow 6710 WA	**Casing Diameter (mm)** 50	**Logged By** SG
Date Drilled 11/03/2020 - 14/03/2020	**Stickup (m)** 0.5	**Checked By** DO/PB
Casing 50 mm Class 18 PVC	**Screen** Class 18 PVC 10.6-13.6m	**Surface Completion** Monument cover

Depth (m) | Drilling Method | Water | Well Details | Graphic Log | LITHOLOGICAL DESCRIPTION Soil Type (Classification Group Symbol); Particle Size; Colour; Secondary / Minor Components. | DRILLING OBSERVATIONS | Elevation (m)

Depth (m): 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24

Drilling Method: PQ



Lithological Description

- Carbonate Silty SAND. Fine to coarse grained, sub-rounded to sub-angular, of quartz; pale brown; silt is non-plastic; trace clay; trace gravel, fine grained, angular of gypsum and shells., D, L
- From 0.5 m: With medium grained gravel sized shell fragments., M
- Carbonate Clayey SAND. Fine to coarse grained, sub-rounded to sub-angular, of quartz; pale brown; non-plastic to low plasticity fines; with gravel and sand sized shell fragments., MD-L
- Carbonate Silty Gravelly SAND. Fine to coarse grained, sub-rounded to sub-angular, of quartz; pale brown; gravel is fine to medium grained, angular, of calcarenite (weakly cemented); silt is non-plastic; with gravel sized shells., W, MD
- Carbonate Clayey/Silty SAND. Fine to medium grained, of carbonate; pale brown; clay/silt is low plasticity, red/brown; trace sand, coarse grained, of shell fragments; with gravel, of calcarenite (weakly cemented)., M
- Clayey SAND. Fine to medium grained; red-brown; clay is low plastic; calcareous.
- Carbonate Silty SAND. Fine to medium grained; red-brown; silt is non-plastic; with gravel, fine to medium grained, of calcarenite (weakly to moderately cemented).
- Carbonate Silty SAND. Fine to medium grained; red-brown; silt is non-plastic; with gravel, fine to medium grained, of calcarenite (weakly to moderately cemented); trace gravel, fine grained of non-intact shells., M, MD
- Carbonate Sandy CLAY. Medium plasticity; red-brown; sand is fine to medium grained.. At 7.7m: 2mm thick layer of shells, W, VSt-H
- Sandy CLAY. High plasticity; red-brown; sand is fine to medium grained; calcareous., VSt
- Sandy CLAY. Low to medium plasticity; red-brown; sand is fine to medium grained; with gravel; fine to medium grained, sub-rounded to sub-angular, weakly cemented gravel; calcareous., W, H
- Sandy CLAY. Low to medium plasticity; red-brown; sand is fine to medium grained; with gravel; fine to medium grained, sub-rounded to sub-angular, weakly cemented gravel; calcareous., W, H
- 12.5 to 13.0 m: Gravel is fine to medium grained, sub-rounded of quartz.
- Coreloss: 13.25 to 13.5 m., -
- Sandy Gravelly CLAY. Low plasticity; red-brown; sand is fine to medium grained, sub-angular, gravel is fine grained, black, weakly cemented., W
- Sandy Gravelly CLAY. Low plasticity; red-brown; sand is fine to medium grained, sub-angular; gravel is fine grained, sub-angular, black, weakly cemented.
- From 15.5 m: Becoming red-brown with minor pale grey mottling.
- Coreloss: 16.4 to 16.5 m., -

Termination Depth at: 16.50 m. Target depth.

Drilling Observations

- Inferred geolgical unit: Qt (0-7.7m)
- Inferred geolgical unit: Qsed (7.7-16.5m)

Elevation (m): 1, 0, -1, -2, -3, -4, -5, -6, -7, -8, -9, -10, -11, -12, -13, -14, -15, -16, -17, -18, -19, -20, -21, -22, -23

Notes

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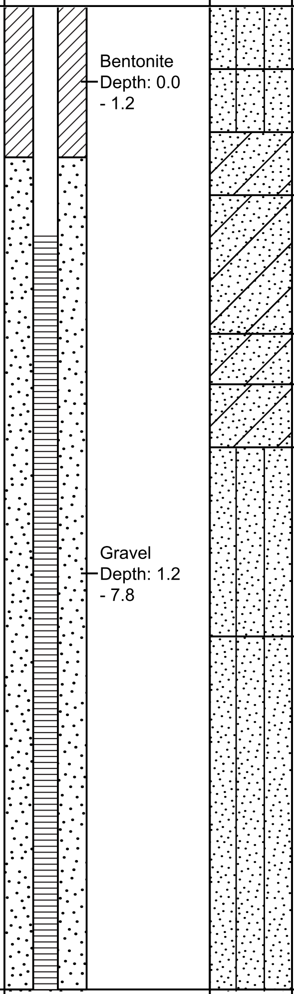
Drilling Abbreviations	Moisture Abbreviations	Consistency Abbreviations	
AH-Air Hammer, AR-Air Rotary, BE-Bucket Excavation, CC-Concrete Coring, DC-Diamond Core, FH-Foam Hammer, HA-Hand Auger, HE-Hand Excavation (shovel), HFA-Hollow Flight Auger, MR-Mud Rotary, NDD-Non Destructive Drilling, PT-Pushtube, SD-Sonic Drilling, SFA-Solid Flight Auger, SS-Split Spoon, WB-Wash Bore, WS-Window Sampler	D-Dry, SM-Slightly Moist, M-Moist, VM-Very Moist, W-Wet, S-Saturated	**Granular Soils** VL-Very Loose, L-Loose, MD-Medium Dense, D-Dense,VD - Very Dense	**Cohesive Soils** VS-Very Soft, S-Soft, F-Firm, ST-Stiff, VST-Very Stiff, H-Hard

Client K+S Salt	**Drill Co.** J&S Drilling	**Easting, Northing** 262938, 7573346
Project Geotechnical, Groundwater and ASS Investigation	**Rig Type** Jacro 350 Mangrove Buggy	**Grid Ref** GDA94_MGA_zone_50
Project No. 12516706	**Drill Method** Auger	**Elevation** 1.8
Site Tubridgi	**Total Depth (m)** 7.80	**TOC Elevation (m)** -
Location Tubridgi, Onslow 6710 WA	**Casing Diameter (mm)** 50	**Logged By** SG
Date Drilled 14/03/2020 - 14/03/2020	**Stickup (m)** 0.5	**Checked By** DO/PB
Casing 50 mm Class 18 PVC	**Screen** Class 18 PVC 1.8-7.8m	**Surface Completion** Monument cover



Depth (m)	Drilling Method	Water	Well Details	LITHOLOGICAL DESCRIPTION Soil Type (Classification Group Symbol); Particle Size; Colour; Secondary / Minor Components.	DRILLING OBSERVATIONS	Elevation (m)
0.0–0.5	Solid Auge		Bentonite Depth: 0.0 - 1.2	Carbonate Silty SAND. Fine to coarse grained, sub-rounded to sub-angular, of quartz; pale brown; silt is non-plastic; trace clay; trace gravel, fine grained, angular of gypsum and shells., D, L		1.5
0.5				From 0.5 m: With medium grained gravel sized shell fragments., M		1
1				Carbonate Clayey SAND. Fine to coarse grained, sub-rounded to sub-angular, of quartz; pale brown; non-plastic to low plasticity fines; with gravel and sand sized shell fragments., MD-L		0.5
1.5		▽		Carbonate Silty Gravelly SAND. Fine to coarse grained, sub-rounded to sub-angular, of quartz; pale brown; gravel is fine to medium grained, angular, of calcarenite (weakly cemented); silt is non-plastic; with gravel sized shells., W, MD		0
2.5				Carbonate Clayey/Silty SAND. Fine to medium grained, of carbonate; pale brown; clay/silt is low plasticity, red/brown; trace sand, coarse grained, of shell fragments; with gravel, of calcarenite (weakly cemented)., M		-1
3				Clayey SAND. Fine to medium grained; red-brown; clay is low plastic; calcareous.		-1.5
3.5			Gravel Depth: 1.2 - 7.8	Carbonate Silty SAND. Fine to medium grained; red-brown; silt is non-plastic; with gravel, fine to medium grained, of calcarenite (weakly to moderately cemented).		-2
5				Carbonate Silty SAND. Fine to medium grained; red-brown; silt is non-plastic; with gravel, fine to medium grained, of calcarenite (weakly to moderately cemented); trace gravel, fine grained of non-intact shells., M, MD		-3.5
7.8				Termination Depth at: 7.80 m. Target depth.		-6

Notes

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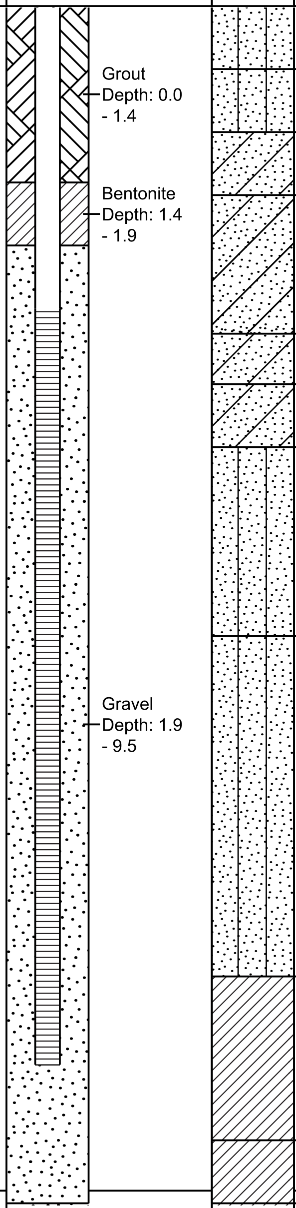
Drilling Abbreviations	Moisture Abbreviations	Consistency Abbreviations	
AH-Air Hammer, AR-Air Rotary, BE-Bucket Excavation, CC-Concrete Coring, DC-Diamond Core, FH-Foam Hammer, HA-Hand Auger, HE-Hand Excavation (shovel), HFA-Hollow Flight Auger, MR-Mud Rotary, NDD-Non Destructive Drilling, PT-Pushtube, SD-Sonic Drilling, SFA-Solid Flight Auger, SS-Split Spoon, WB-Wash Bore, WS-Window Sampler	D-Dry, SM-Slightly Moist, M-Moist, VM-Very Moist, W-Wet, S-Saturated	**Granular Soils** VL-Very Loose, L-Loose, MD-Medium Dense, D-Dense,VD - Very Dense	**Cohesive Soils** VS-Very Soft, S-Soft, F-Firm, ST-Stiff, VST-Very Stiff, H-Hard

Client K+S Salt	**Drill Co.** J&S Drilling	**Easting, Northing** 262938, 7573347
Project Geotechnical, Groundwater and ASS Investigation	**Rig Type** Jacro 350 Mangrove Buggy	**Grid Ref** GDA94_MGA_zone_50
Project No. 12516706	**Drill Method** Auger	**Elevation** 1.8
Site Tubridgi	**Total Depth (m)** 9.40	**TOC Elevation (m)** -
Location Tubridgi, Onslow 6710 WA	**Casing Diameter (mm)** 100	**Logged By** SG
Date Drilled 15/03/2020 - 15/03/2020	**Stickup (m)** 0.5	**Checked By** DO/PB
Casing 100 mm Class 12 PVC	**Screen** Class 18 PVC 2.4-8.4m	**Surface Completion** Monument cover

Drilling Method: Wash Borin



Depth (m)	LITHOLOGICAL DESCRIPTION Soil Type (Classification Group Symbol); Particle Size; Colour; Secondary / Minor Components.	Elevation (m)
0.0 – 0.5	Carbonate Silty SAND. Fine to coarse grained, sub-rounded to sub-angular, of quartz; pale brown; silt is non-plastic; trace clay; trace gravel, fine grained, angular of gypsum and shells., D, L	1.8 – 1.3
0.5 – 1.0	From 0.5 m: With medium grained gravel sized shell fragments., M	1.3 – 0.8
1.0 – 1.5	Carbonate Clayey SAND. Fine to coarse grained, sub-rounded to sub-angular, of quartz; pale brown; non-plastic to low plasticity fines; with gravel and sand sized shell fragments., MD-L	0.8 – 0.3
1.5 – 2.6	Carbonate Silty Gravelly SAND. Fine to coarse grained, sub-rounded to sub-angular, of quartz; pale brown; gravel is fine to medium grained, angular, of calcarenite (weakly cemented); silt is non-plastic; with gravel sized shells., W, MD	0.3 – -0.8
2.6 – 3.0	Carbonate Clayey/Silty SAND. Fine to medium grained, of carbonate; pale brown; clay/silt is low plasticity, red/brown; trace sand, coarse grained, of shell fragments; with gravel, of calcarenite (weakly cemented)., M	-0.8 – -1.2
3.0 – 3.5	Clayey SAND. Fine to medium grained; red-brown; clay is low plastic; calcareous.	-1.2 – -1.7
3.5 – 5.0	Carbonate Silty SAND. Fine to medium grained; red-brown; silt is non-plastic; with gravel, fine to medium grained, of calcarenite (weakly to moderately cemented).	-1.7 – -3.2
5.0 – 7.7	Carbonate Silty SAND. Fine to medium grained; red-brown; silt is non-plastic; with gravel, fine to medium grained, of calcarenite (weakly to moderately cemented); trace gravel, fine grained of non-intact shells., M, MD	-3.2 – -5.9
7.7 – 9.0	Carbonate Sandy CLAY. Medium plasticity; red-brown; sand is fine to medium grained.. At 7.7m: 2mm thick layer of shells, W, VSt-H	-5.9 – -7.2
9.0 – 9.4	Sandy CLAY. High plasticity; red-brown; sand is fine to medium grained; calcareous., VSt	-7.2 – -7.6
9.4	~~Termination Depth at: 9.40 m. Target depth.~~	

Notes

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Drilling Abbreviations	Moisture Abbreviations	Consistency Abbreviations	
AH-Air Hammer, AR-Air Rotary, BE-Bucket Excavation, CC-Concrete Coring, DC-Diamond Core, FH-Foam Hammer, HA-Hand Auger, HE-Hand Excavation (shovel), HFA-Hollow Flight Auger, MR-Mud Rotary, NDD-Non Destructive Drilling, PT-Pushtube, SD-Sonic Drilling, SFA-Solid Flight Auger, SS-Split Spoon, WB-Wash Bore, WS-Window Sampler	D-Dry, SM-Slightly Moist, M-Moist, VM-Very Moist, W-Wet, S-Saturated	**Granular Soils** VL-Very Loose, L-Loose, MD-Medium Dense, D-Dense,VD - Very Dense	**Cohesive Soils** VS-Very Soft, S-Soft, F-Firm, ST-Stiff, VST-Very Stiff, H-Hard

BOREHOLE LOG

HYDROGEOLOGICAL-GROUNDWATER

MONITORING WELL BH08

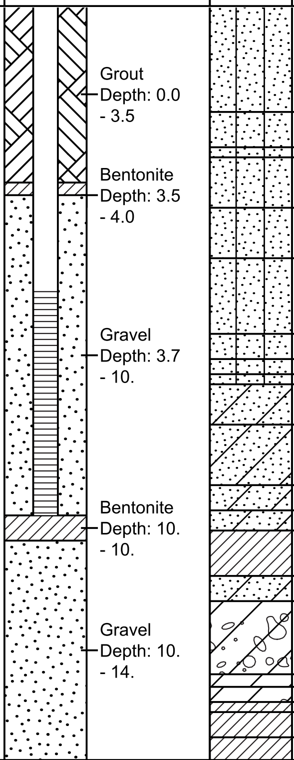
Client K+S Salt	**Drill Co.** J&S Drilling	**Easting, Northing** 263029, 7573316
Project Geotechnical, Groundwater and ASS Investigation	**Rig Type** Jacro 350 Mangrove Buggy	**Grid Ref** GDA94_MGA_zone_50
Project No. 12516706	**Drill Method** PQ core	**Elevation** 5.5
Site Tubridgi	**Total Depth (m)** 14.95	**TOC Elevation (m)** -
Location Tubridgi, Onslow 6710 WA	**Casing Diameter (mm)** 50	**Logged By** SG
Date Drilled 15/03/2020 - 17/03/2020	**Stickup (m)** 0.5	**Checked By** DO/PB
Casing 50 mm Class 18 PVC	**Screen** Class 18 PVC 5.6-10.1m	**Surface Completion** Monument cover

Depth (m) | Drilling Method | Water | Well Details | Graphic Log | **LITHOLOGICAL DESCRIPTION** Soil Type (Classification Group Symbol); Particle Size; Colour; Secondary / Minor Components. | **DRILLING OBSERVATIONS** | Elevation (m)

Depth (m): 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24

Elevation (m): 5, 4, 3, 2, 1, 0, -1, -2, -3, -4, -5, -6, -7, -8, -9, -10, -11, -12, -13, -14, -15, -16, -17, -18, -19

Drilling Method: PQ



Lithological Description

- Carbonate Silty SAND. Fine to medium grained, of carbonate; pale orange-brown; silt is non-plastic., M, VL
- From 2.1 m: Becoming gravelly, fine to medium grained, sub-angular of calcrete (weakly CaCo3 cemented calcarenite).
- Core loss: 2.8 to 3.0 m.
- Carbonate Silty SAND. Fine to medium grained, of carbonate; pale orange-brown; silt is non-plastic., M, L-MD
- From 4.0 m: With fine to medium gravel sized shells.
- Carbonate Silty SAND. Fine to medium grained, of carbonate; pale orange-brown; silt is non-plastic; with gravel, fine to coarse grained, sub-angular of calcrete (weakly CaCO3 cemented calcarenite)., M, L-MD
- Core loss: 6.5 to 7.0 m Inferred as Silty SAND
- Carbonate Silty SAND. Fine to medium grained, of carbonate; pale orange-brown; silt is non-plastic; with gravel, fine to coarse grained, sub-angular of calcrete (weakly CaCO3 cemented calcarenite)., M, MD
- From 7.3 m: Becoming red/brown with thin white bands.
- Carbonate Clayey SAND. Fine to medium grained, of carbonate; red-brown; clay has low plasticity; trace gravel, fine grained.
- From 8.3m: Loss of gravel.
- From 9.5 m: Increasing sand content.
- Carbonate Clayey SAND. Fine to medium grained, of carbonate; red-brown; clay has low plasticity.
- Sandy CLAY. Low plasticity; red-brown; sand is fine to medium grained, of carbonate., W, H
- Carbonate Clayer SAND. Fine to medium grained, of carbonate; red-brown; clay is non-plastic; weakly cemented., D-M, D
- Clayey Sandy GRAVEL. Fine to coarse grained, rounded, mixed lithology of quartz, Banded Iron Formation & chert; sand is fine to medium grained; clay has low plasticity., M
- Core loss: 13.25 to 13.5 m, -
- Sandy GRAVEL. Fine to medium grained, rounded mixed lithology, sand is medium to coarse grained (red-brown-black to white gravel) with fines., M, VD
- Sandy CLAY. Low to medium plasticity; red-brown; sand is fine to medium grained., W, H
- Core loss: 14.0 to 14.5 m Inferred as Sandy CLAY.
- Sandy CLAY. Medium plasticity; red/brown; sand is fine to medium grained; with gravel, fine grained, sub-rounded., W

Termination Depth at: 14.95 m. Target depth.

Drilling Observations

- Inferred geolgical unit: Qe (0-10.4m)
- Inferred geolgical unit: Qsed (10.4-14.95m)

Notes

This log is not intended for geotechnical purposes.

Drilling Abbreviations	Moisture Abbreviations	Consistency Abbreviations	
AH-Air Hammer, AR-Air Rotary, BE-Bucket Excavation, CC-Concrete Coring, DC-Diamond Core, FH-Foam Hammer, HA-Hand Auger, HE-Hand Excavation (shovel), HFA-Hollow Flight Auger, MR-Mud Rotary, NDD-Non Destructive Drilling, PT-Pushtube, SD-Sonic Drilling, SFA-Solid Flight Auger, SS-Split Spoon, WB-Wash Bore, WS-Window Sampler	D-Dry, SM-Slightly Moist, M-Moist, VM-Very Moist, W-Wet, S-Saturated	**Granular Soils** VL-Very Loose, L-Loose, MD-Medium Dense, D-Dense,VD - Very Dense	**Cohesive Soils** VS-Very Soft, S-Soft, F-Firm, ST-Stiff, VST-Very Stiff, H-Hard

BOREHOLE LOG

HYDROGEOLOGICAL-GROUNDWATER

MONITORING WELL BH09D

Client K+S Salt	**Drill Co.** J&S Drilling	**Easting, Northing** 268003, 7572193
Project Geotechnical, Groundwater and ASS Investigation	**Rig Type** Jacro 350 Mangrove Buggy	**Grid Ref** GDA94_MGA_zone_50
Project No. 12516706	**Drill Method** PQ core	**Elevation** 3.5
Site Tubridgi	**Total Depth (m)** 20.25	**TOC Elevation (m)** -
Location Tubridgi, Onslow 6710 WA	**Casing Diameter (mm)** 50	**Logged By** SD/DO
Date Drilled 20/01/2020 - 23/01/2020	**Stickup (m)** 0.5	**Checked By** DO/PB

Casing 50 mm Class 18 PVC	**Screen** Class 18 PVC 6-9m	**Surface Completion** Monument cover

Depth (m)	Drilling Method	Water	Well Details	LITHOLOGICAL DESCRIPTION Soil Type (Classification Group Symbol); Particle Size; Colour; Secondary / Minor Components.	DRILLING OBSERVATIONS	Elevation (m)
	Solid Auge			SAND. Fine to medium grained, sub-angular to sub-rounded, of quartz; red-brown; with clay, non-plastic; calcareous; very weakly cemented. At 0.75 m, nodules up to 10 mm, moderately cemented., D, L	Inferred geolgical unit: Qe (0-0.8m)	3
1			Grout Depth: 0.0 - 3.5	Sandy CLAY. High plasticity; brown; sand is fine to medium-grained, sub-angular to sub-rounded, of quartz; trace gravel, fine grained, sub-angular of calcrete; Calcareous., W, S-F	Inferred geolgical unit: Czp (0.8-9.45m)	2
2				1.0-1.5 m: CORE LOSS Inferred as above.		1
3		▽		Sandy CLAY. High plasticity; brown; sand is fine to medium-grained, sub-angular to sub-rounded, of quartz; trace gravel, fine grained, sub-angular of calcrete; moderately cemented Calcareous., VS		0
4			Bentonite Depth: 3.5 - 5.0	2.0 m, becoming CLAY with sand., S-F		-1
5				2.25 m, loss of gravel, only slight calcareous reaction.		-2
6				3.0 m, becoming Sandy CLAY.		-3
7			Gravel Depth: 5.0 - 9.0	4.0-4.5 m: CORE LOSS Inferred as above.		-4
8				Sandy CLAY, as above.		-5
9				Sandy CLAY. High plasticity; brown; sand is fine to medium-grained, sub-angular to sub-rounded, of quartz; trace gravel, fine grained, sub-angular of calcrete; moderately cemented; calcareous., W		-6
10				6.45-6.75 m: CORE LOSS Inferred as above.	Inferred geolgical unit: Qsed (9.45-20.25m)	-7
11				Sandy CLAY. High plasticity; brown; sand is fine to medium-grained, sub-angular to sub-rounded, of quartz; trace gravel, fine grained, sub-angular of calcrete; moderately cemented; calcareous.		-8
12				7.0 m, non-calcareous., W		-9
13				7.4-7.5 m, trace gravel, medium grained, rounded, of quartz., W, St		-10
14				7.5 m, becoming CLAY with Sand., W, F		-11
15				8.0-8.1 m, calcareous, trace gravel, fine grained of calcrete; moderately cemented.		-12
16				8.9 m, becoming CLAY; trace sand.		-13
17				Sandy CLAY. Medium plasticity; brown; sand is fine to medium-grained, sub-angular to sub-rounded., W		-14
18				10.5 m: fines becoming medium to high plasticity.		-15
19				Clayey SAND. Fine to medium grained, sub-angular to sub-rounded; brown; low plasticity fines; non-calcareous; uncemented., M-W, D		-16
20				12.15-12.5 m: CORE LOSS Inferred as above.		-17
21				Clayey SAND. Fine to medium grained, sub-angular to sub-rounded; brown; low plasticity fines; non-calcareous; uncemented.		-18
22				13.0 m: fines becoming medium plasticity.		-19
23				13.2 m: with gravel, coarse grained, sub-rounded of calcrete.		-20
24				SAND. Fine to medium grained, sub-angular to sub-rounded; brown; with clay, non-plastic; non-calcareous; uncemented., W		-21
				13.8-14.0 m: CORE LOSS Inferred as above.		
				SAND. Fine to medium grained, sub-angular to sub-rounded; brown; with clay, non-plastic; trace gravel, fine to coarse grained, sub-angular of calcrete; uncemented., VD		
				14.55-14.75 m: CORE LOSS		
				SAND, as above.		
				Clayey SAND. Fine to medium grained, sub-angular to sub-rounded; brown; low to medium plasticity fines; trace gravel, fine to coarse grained, sub-angular of calcrete., W, VD		
				15.35-15.5 m: CORE LOSS		
				Clayey SAND. Fine to medium grained, sub-angular to sub-rounded; brown; low to medium plasticity fines; trace gravel, fine to coarse grained		

Notes

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Drilling Abbreviations	Moisture Abbreviations	Consistency Abbreviations	
AH-Air Hammer, AR-Air Rotary, BE-Bucket Excavation, CC-Concrete Coring, DC-Diamond Core, FH-Foam Hammer, HA-Hand Auger, HE-Hand Excavation (shovel), HFA-Hollow Flight Auger, MR-Mud Rotary, NDD-Non Destructive Drilling, PT-Pushtube, SD-Sonic Drilling, SFA-Solid Flight Auger, SS-Split Spoon, WB-Wash Bore, WS-Window Sampler	D-Dry, SM-Slightly Moist, M-Moist, VM-Very Moist, W-Wet, S-Saturated	**Granular Soils** VL-Very Loose, L-Loose, MD-Medium Dense, D-Dense,VD - Very Dense	**Cohesive Soils** VS-Very Soft, S-Soft, F-Firm, ST-Stiff, VST-Very Stiff, H-Hard

BOREHOLE LOG

HYDROGEOLOGICAL-GROUNDWATER

MONITORING WELL BH09S

Client K+S Salt	**Drill Co.** J&S Drilling	**Easting, Northing** 268003, 7572197
Project Geotechnical, Groundwater and ASS Investigation	**Rig Type** Jacro 350 Mangrove Buggy	**Grid Ref** GDA94_MGA_zone_50
Project No. 12516706	**Drill Method** Auger	**Elevation** 3.5
Site Tubridgi	**Total Depth (m)** 5.00	**TOC Elevation (m)** -
Location Tubridgi, Onslow 6710 WA	**Casing Diameter (mm)** 50	**Logged By** DO
Date Drilled 23/01/2020 - 23/01/2020	**Stickup (m)** 0.5	**Checked By** DO/PB
Casing 50 mm Class 18 PVC	**Screen** Class 18 PVC 0.5-5m	**Surface Completion** Monument cover

Depth (m)	Drilling Method	Water	Well Details	LITHOLOGICAL DESCRIPTION Soil Type (Classification Group Symbol); Particle Size; Colour; Secondary / Minor Components.	DRILLING OBSERVATIONS	Elevation (m)
0.0	Solid Auge		Bentonite Depth: 0.0 - 0.2	SAND. Fine to medium grained, sub-angular to sub-rounded, of quartz; red-brown; with clay, non-plastic; calcareous; very weakly cemented. At 0.75 m, nodules up to 10 mm, moderately cemented., D, L		
0.5						3
1				Sandy CLAY. High plasticity; brown; sand is fine to medium-grained, sub-angular to sub-rounded, of quartz; trace gravel, fine grained, sub-angular of calcrete; Calcareous., W, S-F		2.5
1.5				1.0-1.5 m: CORE LOSS Inferred as above.		2
				Sandy CLAY. High plasticity; brown; sand is fine to medium-grained, sub-angular to sub-rounded, of quartz; trace gravel, fine grained, sub-angular of calcrete; moderately cemented Calcareous., VS		
2				2.0 m, becoming CLAY with sand., S-F		1.5
2.5			Gravel Depth: 0.2 - 5.0	2.25 m, loss of gravel, only slight calcareous reaction., W, St		1
3		▽		3.0 m, becoming Sandy CLAY.		0.5
3.5						0
4				4.0-4.5 m: CORE LOSS Inferred as above.		-0.5
4.5				Sandy CLAY, as above.		-1
5				Termination Depth at: 5.00 m. Target depth.		-1.5
5.5						-2
6						-2.5
6.5						-3
7						-3.5
7.5						-4
8						-4.5
8.5						-5
9						-5.5
9.5						-6

Notes

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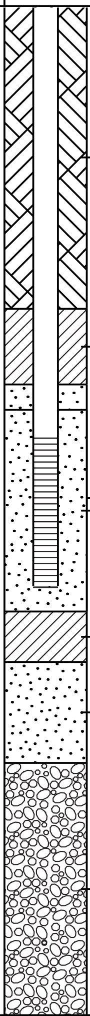
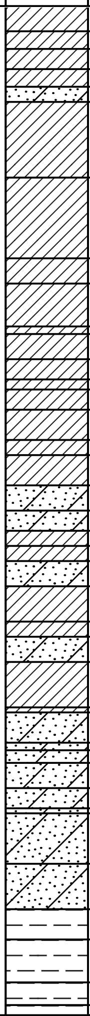
Drilling Abbreviations	Moisture Abbreviations	Consistency Abbreviations	
AH-Air Hammer, AR-Air Rotary, BE-Bucket Excavation, CC-Concrete Coring, DC-Diamond Core, FH-Foam Hammer, HA-Hand Auger, HE-Hand Excavation (shovel), HFA-Hollow Flight Auger, MR-Mud Rotary, NDD-Non Destructive Drilling, PT-Pushtube, SD-Sonic Drilling, SFA-Solid Flight Auger, SS-Split Spoon, WB-Wash Bore, WS-Window Sampler	D-Dry, SM-Slightly Moist, M-Moist, VM-Very Moist, W-Wet, S-Saturated	**Granular Soils** VL-Very Loose, L-Loose, MD-Medium Dense, D-Dense,VD - Very Dense	**Cohesive Soils** VS-Very Soft, S-Soft, F-Firm, ST-Stiff, VST-Very Stiff, H-Hard

Client K+S Salt	**Drill Co.** J&S Drilling	**Easting, Northing** 266494, 7572270
Project Geotechnical, Groundwater and ASS Investigation	**Rig Type** Jacro 350 Mangrove Buggy	**Grid Ref** GDA94_MGA_zone_50
Project No. 12516706	**Drill Method** PQ core	**Elevation** 0.9
Site Tubridgi	**Total Depth (m)** 20.00	**TOC Elevation (m)** -
Location Tubridgi, Onslow 6710 WA	**Casing Diameter (mm)** 50	**Logged By** DO
Date Drilled 25/01/2020 - 29/01/2020	**Stickup (m)** 0.5	**Checked By** DO/PB
Casing 50 mm Class 18 PVC	**Screen** Class 18 PVC 8.5-11.5m	**Surface Completion** Monument cover

Depth (m)	Drilling Method	Water	Well Details	Graphic Log	LITHOLOGICAL DESCRIPTION Soil Type (Classification Group Symbol); Particle Size; Colour; Secondary / Minor Components.	DRILLING OBSERVATIONS	Elevation (m)
1	Solid Auge	⊻	 Bentonite & grout mix Depth: 0.0 - 6.0		Sandy CLAY. Medium plasticity; brown; sand is fine to medium grained, sub-angular to sub-rounded of quartz and some carbonate; trace gravel, fine to medium grained, sub-angular to sub-rounded of calcrete; moderately well cemented; Calcareous.	Inferred geolgical unit: Qt (0-1.9m)	0
2					From 0.5 m, Sandy CLAY.	Inferred geolgical unit: Qsed (1.9-17.9m)	-1
					0.85-1.25 m: CORE LOSS, W		
3					Sandy CLAY. Medium plasticity; brown; sand is fine to medium grained, sub-angular to sub-rounded; trace gravel pale brown, fine to medium grained, sub-angular to sub-rounded of calcrete.		-2
4					Clayey SAND. Fine to medium grained, sub-angular to sub-rounded; brown; clay has low plasticity; non-calcareous; uncemented.		-3
5					Sandy CLAY. Medium plasticity; brown; sand is fine to medium grained, sub-angular to sub-rounded of quartz; trace gravel, pale brown, fine to medium grained, sub-angular to sub-rounded of calcrete.		-4
6			Bentonite Depth: 6.0 - 7.5		From 3.4 m, trace gravel, becoming grey, fine to coarse grained, angular, tabular of quartz (?)., W		-5
7					Sandy CLAY. Medium plasticity; brown; sand is fine grained, sub-angular to sub-rounded; trace gravel, pale brown, fine to medium grained, sub-angular to sub-rounded of calcrete., M, VD		-6
8					CLAY. High plasticity; brown; with sand, fine to medium grained; trace gravel, fine to coarse grained, sub-angular to sub-rounded of calcrete.		-7
9			Gravel Depth: 7.5 - 12. Gravel Depth: 8.0 - 12.		6.35-6.5 m: CORE LOSS, M-W, VD		-8
10					CLAY. High plasticity; brown; with sand, fine to medium grained; trace gravel, fine to coarse grained, sub-angular to sub-rounded of calcrete., W, H		-9
11					From 7.0 m, trace fine to medium grained sand., M, VD		-10
12			Bentonite Depth: 12. - 13.		From 7.4 to 7.6 m: Sandy CLAY bed.		-11
					7.7-8.0 m: CORE LOSS, W, H		
13			Gravel Depth: 13. - 15.		CLAY. High plasticity; brown; with sand, fine grained; trace gravel, pale grey and pale brown, fine to coarse grained, sub-angular to sub-rounded of calcrete., M-W, VD		-12
14	PQ Coring				From 8.75 m, grading to Sandy CLAY.		-13
15					8.9-9.5 m: CORE LOSS, W, H		-14
16			Hole collapse Depth: 15. - 20.		Clayey SAND. Fine to medium grained, sub-angular to sub-rounded; brown; low plasticity fines; trace gravel, fine to medium grained, sub-angular to sub-rounded of calcrete., M-W, VD		-15
17					Clayey SAND. Fine to medium-grained, sub-angular to sub-rounded; brown; low to medium plasticity fines; trace gravel, fine to medium grained, sub-angular to sub-rounded of calcrete, well-cemented.		-16
18					Sandy CLAY. Medium plasticity; brown; sand is fine to medium grained; trace gravel, pale brown, fine to medium grained, sub-angular to sub-rounded of calcrete, well-cemented.	Inferred geolgical unit: Qsed (17.9-20m)	-17
19					10.7-11.0 m: CORE LOSS		-18
20					Clayey SAND. Fine to medium grained; brown; sub-angular to sub-rounded; clay has low to medium plasticity; with gravel, pale brown and pale grey, fine to coarse grained, sub-angular to sub-rounded of calcrete., M-W, VD		-19
21					Sandy CLAY. Medium to high plasticity; brown; sand is fine to medium grained; trace gravel, pale grey, fine to medium grained, sub-angular to sub-rounded of quartz and calcrete.		-20
22					12.2-12.5 m: CORE LOSS. Inferred as below		-21
23					Clayey SAND. Fine to medium grained, sub-angular to sub-rounded; brown, locally mottled pale grey; clay has low plasticity; trace gravel, fine to medium grained, sub-rounded of quartz.		-22
24					Sandy CLAY (locally Clayey SAND). Medium plasticity; brown; sand is fine to		-23
							-24

Notes

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Drilling Abbreviations	Moisture Abbreviations	Consistency Abbreviations	
AH-Air Hammer, AR-Air Rotary, BE-Bucket Excavation, CC-Concrete Coring, DC-Diamond Core, FH-Foam Hammer, HA-Hand Auger, HE-Hand Excavation (shovel), HFA-Hollow Flight Auger, MR-Mud Rotary, NDD-Non Destructive Drilling, PT-Pushtube, SD-Sonic Drilling, SFA-Solid Flight Auger, SS-Split Spoon, WB-Wash Bore, WS-Window Sampler	D-Dry, SM-Slightly Moist, M-Moist, VM-Very Moist, W-Wet, S-Saturated	**Granular Soils** VL-Very Loose, L-Loose, MD-Medium Dense, D-Dense,VD - Very Dense	**Cohesive Soils** VS-Very Soft, S-Soft, F-Firm, ST-Stiff, VST-Very Stiff, H-Hard

BOREHOLE LOG

HYDROGEOLOGICAL-GROUNDWATER

MONITORING WELL BH10S

Client K+S Salt	**Drill Co.** J&S Drilling	**Easting, Northing** 266494, 7572272
Project Geotechnical, Groundwater and ASS Investigation	**Rig Type** Jacro 350 Mangrove Buggy	**Grid Ref** GDA94_MGA_zone_50
Project No. 12516706	**Drill Method** Auger	**Elevation** 0.9
Site Tubridgi	**Total Depth (m)** 5.00	**TOC Elevation (m)** -
Location Tubridgi, Onslow 6710 WA	**Casing Diameter (mm)** 50	**Logged By** DO
Date Drilled 25/01/2020 - 29/01/2020	**Stickup (m)** 0.5	**Checked By** DO/PB
Casing 50 mm Class 18 PVC	**Screen** Class 18 PVC 1.5-4.5m	**Surface Completion** Monument cover

Depth (m)	Drilling Method	Water	Well Details	LITHOLOGICAL DESCRIPTION Soil Type (Classification Group Symbol); Particle Size; Colour; Secondary / Minor Components.	DRILLING OBSERVATIONS	Elevation (m)
0.0–0.5	Solid Auge		Bentonite Depth: 0.0 - 1.0	Sandy CLAY. Medium plasticity; brown; sand is fine to medium grained, sub-angular to sub-rounded of quartz and some carbonate; trace gravel, fine to medium grained, sub-angular to sub-rounded of calcrete; moderately well cemented; Calcareous.		0.5
0.5				From 0.5 m, Sandy CLAY.		0
0.85–1.25		▽ (~1.0)		0.85-1.25 m: CORE LOSS		
1.25			Gravel Depth: 1.0 - 5.0	Sandy CLAY. Medium plasticity; brown; sand is fine to medium grained, sub-angular to sub-rounded; trace gravel pale brown, fine to medium grained, sub-angular to sub-rounded of calcrete., M-W, MD		-0.5
~1.6				Clayey SAND. Fine to medium grained, sub-angular to sub-rounded; brown; clay has low plasticity; non-calcareous; uncemented., W, VSt		-1
~1.9				Sandy CLAY. Medium plasticity; brown; sand is fine to medium grained, sub-angular to sub-rounded of quartz; trace gravel, pale brown, fine to medium grained, sub-angular to sub-rounded of calcrete.		-1.5 / -2
3.4				From 3.4 m, trace gravel, becoming grey, fine to coarse grained, angular, tabular of quartz (?)., H		-2.5 / -3 / -3.5 / -4
5.0				Termination Depth at: 5.00 m. Target depth.		-4

Notes

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BOREHOLE LOG

HYDROGEOLOGICAL-GROUNDWATER

MONITORING WELL BH10 TB

Client K+S Salt	**Drill Co.** J&S Drilling	**Easting, Northing** 266494, 7572273
Project Geotechnical, Groundwater and ASS Investigation	**Rig Type** Jacro 350 Mangrove Buggy	**Grid Ref** GDA94_MGA_zone_50
Project No. 12516706	**Drill Method** Auger	**Elevation** 0.9
Site Tubridgi	**Total Depth (m)** 17.00	**TOC Elevation (m)** -
Location Tubridgi, Onslow 6710 WA	**Casing Diameter (mm)** 100	**Logged By** SD
Date Drilled 19/03/2020 - 20/03/2020	**Stickup (m)** 0.5	**Checked By** DO/PB

Casing 100 mm Class 12 PVC	**Screen** Class 18 PVC 4.4-14.4m	**Surface Completion** Monument cover

Drilling Method: Wash Borin

Well Details:
- Grout Depth: 0.0 - 2.5
- Bentonite Depth: 2.5 - 3.0
- Gravel Depth: 3.0 - 14.
- Backfill Depth: 14. - 17.

Depth (m) scale: 1–24; Elevation (m) scale: 0 to -24

LITHOLOGICAL DESCRIPTION Soil Type (Classification Group Symbol); Particle Size; Colour; Secondary / Minor Components.
Sandy CLAY. Medium plasticity; brown; sand is fine to medium grained, sub-angular to sub-rounded of quartz and some carbonate; trace gravel, fine to medium grained, sub-angular to sub-rounded of calcrete; moderately well cemented; Calcareous.
From 0.5 m, Sandy CLAY.
0.85-1.25 m: CORE LOSS, W
Sandy CLAY. Medium plasticity; brown; sand is fine to medium grained, sub-angular to sub-rounded; trace gravel pale brown, fine to medium grained, sub-angular to sub-rounded of calcrete.
Clayey SAND. Fine to medium grained, sub-angular to sub-rounded; brown; clay has low plasticity; non-calcareous; uncemented.
Sandy CLAY. Medium plasticity; brown; sand is fine to medium grained, sub-angular to sub-rounded of quartz; trace gravel, pale brown, fine to medium grained, sub-angular to sub-rounded of calcrete.
From 3.4 m, trace gravel, becoming grey, fine to coarse grained, angular, tabular of quartz (?)., W
Sandy CLAY. Medium plasticity; brown; sand is fine grained, sub-angular to sub-rounded; trace gravel, pale brown, fine to medium grained, sub-angular to sub-rounded of calcrete., M, VD
CLAY. High plasticity; brown; with sand, fine to medium grained; trace gravel, fine to coarse grained, sub-angular to sub-rounded of calcrete.
6.35-6.5 m: CORE LOSS, M-W, VD
CLAY. High plasticity; brown; with sand, fine to medium grained; trace gravel, fine to coarse grained, sub-angular to sub-rounded of calcrete., W, H
From 7.0 m, trace fine to medium grained sand., M, VD
From 7.4 to 7.6 m: Sandy CLAY bed.
7.7-8.0 m: CORE LOSS, W, H
CLAY. High plasticity; brown; with sand, fine grained; trace gravel, pale grey and pale brown, fine to coarse grained, sub-angular to sub-rounded of calcrete., M-W, VD
From 8.75 m, grading to Sandy CLAY.
8.9-9.5 m: CORE LOSS, W, H
Clayey SAND. Fine to medium grained, sub-angular to sub-rounded; brown; low plasticity fines; trace gravel, fine to medium grained, sub-angular to sub-rounded of calcrete., M-W, VD
Clayey SAND. Fine to medium-grained, sub-angular to sub-rounded; brown; low to medium plasticity fines; trace gravel, fine to medium grained, sub-angular to sub-rounded of calcrete, well-cemented.
Sandy CLAY. Medium plasticity; brown; sand is fine to medium grained; trace gravel, pale brown, fine to medium grained, sub-angular to sub-rounded of calcrete, well-cemented.
10.7-11.0 m: CORE LOSS
Clayey SAND. Fine to medium grained; brown; sub-angular to sub-rounded; clay has low to medium plasticity; with gravel, pale brown and pale grey, fine to coarse grained, sub-angular to sub-rounded of calcrete., M-W, VD
Sandy CLAY. Medium to high plasticity; brown; sand is fine to medium grained; trace gravel, pale grey, fine to medium grained, sub-angular to sub-rounded of quartz and calcrete.
12.2-12.5 m: CORE LOSS. Inferred as below
Clayey SAND. Fine to medium grained, sub-angular to sub-rounded; brown, locally mottled pale grey; clay has low plasticity; trace gravel, fine to medium grained, sub-rounded of quartz.
Sandy CLAY (locally Clayey SAND). Medium plasticity; brown; sand is fine to

Notes

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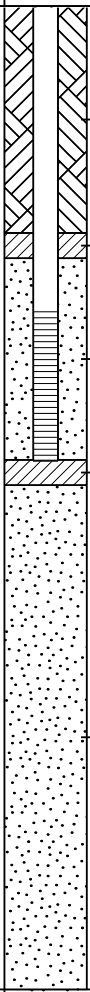
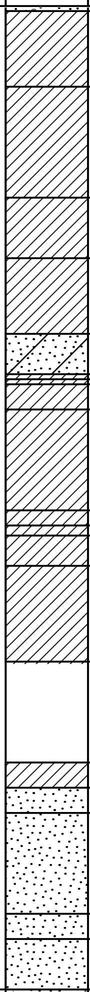
Drilling Abbreviations	Moisture Abbreviations	Consistency Abbreviations	
AH-Air Hammer, AR-Air Rotary, BE-Bucket Excavation, CC-Concrete Coring, DC-Diamond Core, FH-Foam Hammer, HA-Hand Auger, HE-Hand Excavation (shovel), HFA-Hollow Flight Auger, MR-Mud Rotary, NDD-Non Destructive Drilling, PT-Pushtube, SD-Sonic Drilling, SFA-Solid Flight Auger, SS-Split Spoon, WB-Wash Bore, WS-Window Sampler	D-Dry, SM-Slightly Moist, M-Moist, VM-Very Moist, W-Wet, S-Saturated	**Granular Soils** VL-Very Loose, L-Loose, MD-Medium Dense, D-Dense,VD - Very Dense	**Cohesive Soils** VS-Very Soft, S-Soft, F-Firm, ST-Stiff, VST-Very Stiff, H-Hard

BOREHOLE LOG

HYDROGEOLOGICAL-GROUNDWATER

MONITORING WELL BH11D

Client K+S Salt	**Drill Co.** J&S Drilling	**Easting, Northing** 260260, 7569715
Project Geotechnical, Groundwater and ASS Investigation	**Rig Type** Jacro 350 Mangrove Buggy	**Grid Ref** GDA94_MGA_zone_50
Project No. 12516706	**Drill Method** PQ core	**Elevation** 1.2
Site Tubridgi	**Total Depth (m)** 19.50	**TOC Elevation (m)** -
Location Tubridgi, Onslow 6710 WA	**Casing Diameter (mm)** 50	**Logged By** DO
Date Drilled 07/03/2020 - 08/03/2020	**Stickup (m)** 0.5	**Checked By** DO/PB
Casing 50 mm Class 18 PVC	**Screen** Class 18 PVC 6-9m	**Surface Completion** Monument cover

Depth (m)	Drilling Method	Water	Well Details	Graphic Log	LITHOLOGICAL DESCRIPTION Soil Type (Classification Group Symbol); Particle Size; Colour; Secondary / Minor Components.	DRILLING OBSERVATIONS	Elevation (m)
0–24 (scale: 1, 2, 3 … 24)	PQ Coring	▽ (at approx. 1 m)			SAND. Fine to medium grained, sub-angular to sub-rounded of quartz; pale brown; with silt.	Inferred geolgical unit: Qt (0-3.8m)	1, 0, -1 … -23
					Sandy CLAY (borderline Clayey SAND). Medium plasticity; brown; sand is fine to medium grained, sub-angular to sub-rounded of quartz; trace fine to medium grained, sub-rounded of calcrete (moderately to well CaCO3 cemented sandstone).		
					Clayey Gravelly SAND. Fine to coarse grained, sub-angular to sub-rounded of carbonate and quartz; pale brown; gravel is fine to coarse grained, sub-angular to sub-rounded of calcrete (well CaCO3 cemented sandstone); trace fines; trace shell fragments (gravel sized).	Inferred geolgical unit: Qsed (3.8-19.5m)	
					Sandy CLAY. Medium plasticity; brown; sand is fine to medium grained, sub-angular to sub-rounded of quartz; trace gravel, fine to coarse grained, sub-rounded to rounded of calcrete (well CaCO3 cemented sandstone).		
					Sandy CLAY. Medium to high plasticity; brown, locally mottled grey; sand is fine grained of quartz; trace gravel, fine to medium grained, sub-angular to sub-rounded, of black iron cemented claystone and calcrete.		
					Clayey SAND. Fine to medium grained, sub-angular to sub-rounded of quartz; brown; low plasticity fines; trace gravel, fine to medium grained, sub-angular to rounded of gypsum, iron cemented and calcrete.		
					Sandy CLAY as below.		
					7.4 m to 7.5 m: CORE LOSS. Inferred as below.		
					Sandy CLAY. Medium to high plasticity; brown; sand is fine grained of quartz; trace gravel, fine to medium grained, of gypsum, black iron cemented claystone and calcrete.		
					From 8.0 m, clay, with fine grained sand; trace gravel, fine to medium grained, sub-angular to sub-rounded of gypsum claystone, iron cemented and calcrete.		
					CLAY. Medium to high plasticity; brown; with sand, fine grained; trace gravel, fine to medium grained, sub-angular to sub-rounded of calcrete, iron cemented, claystone and quartz.		
					10.3 m to 10.5 m: CORE LOSS. Inferred as below.		
					CLAY. Medium to high plasticity; brown; with sand, fine grained; trace gravel, fine to medium grained, sub-angular to sub-rounded of calcrete, iron cemented, claystone and quartz., M, L		
					Sandy CLAY. Medium plasticity; brown; sand is fine to medium grained, sub-angular to sub-rounded of quartz; with gravel, fine to medium grained, sub-angular to rounded of calcrete, iron cemented and claystone., W, F		
					MUDSTONE. Fine grained; Brown, locally mottled grey; trace fine to coarse grained, sub-angular to sub-rounded of calcrete and iron cemented nodules. Borderline soil strength., W, MD		
					Sandy CLAY. Medium to high plasticity; brown, locally mottled grey; sand is fine to medium grained of quartz, W>PL., W, H		
					SANDSTONE. Fine to medium grained; brown, locally mottled grey.		
					From 16.0 m, locally stained white.		
					From 18.0 m, with white/pale grey (non-CaCO3) cemented clay veins / localised mottling., D, MD		
					From 18.5 m, trace gravel, fine grained, rounded, dark brown.		
					Termination Depth at: 19.50 m. Target depth.		

Notes

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Drilling Abbreviations	Moisture Abbreviations	Consistency Abbreviations	
AH-Air Hammer, AR-Air Rotary, BE-Bucket Excavation, CC-Concrete Coring, DC-Diamond Core, FH-Foam Hammer, HA-Hand Auger, HE-Hand Excavation (shovel), HFA-Hollow Flight Auger, MR-Mud Rotary, NDD-Non Destructive Drilling, PT-Pushtube, SD-Sonic Drilling, SFA-Solid Flight Auger, SS-Split Spoon, WB-Wash Bore, WS-Window Sampler	D-Dry, SM-Slightly Moist, M-Moist, VM-Very Moist, W-Wet, S-Saturated	**Granular Soils** VL-Very Loose, L-Loose, MD-Medium Dense, D-Dense,VD - Very Dense	**Cohesive Soils** VS-Very Soft, S-Soft, F-Firm, ST-Stiff, VST-Very Stiff, H-Hard

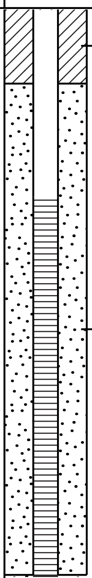
BOREHOLE LOG

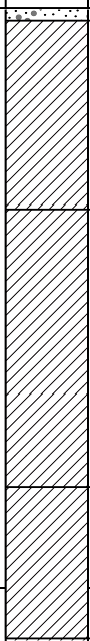
HYDROGEOLOGICAL-GROUNDWATER

MONITORING WELL BH11S

Client K+S Salt	**Drill Co.** J&S Drilling	**Easting, Northing** 260263, 7569718
Project Geotechnical, Groundwater and ASS Investigation	**Rig Type** Jacro 350 Mangrove Buggy	**Grid Ref** GDA94_MGA_zone_50
Project No. 12516706	**Drill Method** Auger	**Elevation** 1.2
Site Tubridgi	**Total Depth (m)** 4.60	**TOC Elevation (m)** -
Location Tubridgi, Onslow 6710 WA	**Casing Diameter (mm)** 50	**Logged By** DO
Date Drilled 09/03/2020 - 10/03/2020	**Stickup (m)** 0.5	**Checked By** DO/PB
Casing 50 mm Class 18 PVC	**Screen** Class 18 PVC 1.5-4.5m	**Surface Completion** Monument cover

Depth (m)	Drilling Method	Water	Well Details	Graphic Log	LITHOLOGICAL DESCRIPTION Soil Type (Classification Group Symbol); Particle Size; Colour; Secondary / Minor Components.	DRILLING OBSERVATIONS	Elevation (m)
0.0	PQ Coring		Bentonite Depth: 0.0 - 0.6		SAND. Fine to medium grained, sub-angular to sub-rounded of quartz; pale brown; with silt., M		1
0.5					Sandy CLAY (borderline Clayey SAND). Medium plasticity; brown; sand is fine to medium grained, sub-angular to sub-rounded of quartz; trace fine to medium grained, sub-rounded of calcrete (moderately to well CaCO3 cemented sandstone).		0.5
1							0
1.5					Clayey Gravelly SAND. Fine to coarse grained, sub-angular to sub-rounded of carbonate and quartz; pale brown; gravel is fine to coarse grained, sub-angular to sub-rounded of calcrete (well CaCO3 cemented sandstone); trace fines; trace shell fragments (gravel sized).		-0.5
2							-1
2.5			Gravel Depth: 0.6 - 4.5				-1.5
3							-2
3.5							-2.5
4					Sandy CLAY. Medium plasticity; brown; sand is fine to medium grained, sub-angular to sub-rounded of quartz; trace gravel, fine to coarse grained, sub-rounded to rounded of calcrete (well CaCO3 cemented sandstone)., W, L		-3
4.5					Termination Depth at: 4.60 m. Target depth.		-3.5
5							-4
5.5							-4.5
6							-5
6.5							-5.5
7							-6
7.5							-6.5
8							-7
8.5							-7.5
9							-8
9.5							-8.5





Notes

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Drilling Abbreviations	Moisture Abbreviations	Consistency Abbreviations	
AH-Air Hammer, AR-Air Rotary, BE-Bucket Excavation, CC-Concrete Coring, DC-Diamond Core, FH-Foam Hammer, HA-Hand Auger, HE-Hand Excavation (shovel), HFA-Hollow Flight Auger, MR-Mud Rotary, NDD-Non Destructive Drilling, PT-Pushtube, SD-Sonic Drilling, SFA-Solid Flight Auger, SS-Split Spoon, WB-Wash Bore, WS-Window Sampler	D-Dry, SM-Slightly Moist, M-Moist, VM-Very Moist, W-Wet, S-Saturated	**Granular Soils** VL-Very Loose, L-Loose, MD-Medium Dense, D-Dense,VD - Very Dense	**Cohesive Soils** VS-Very Soft, S-Soft, F-Firm, ST-Stiff, VST-Very Stiff, H-Hard

BOREHOLE LOG

HYDROGEOLOGICAL-GROUNDWATER

MONITORING WELL BH12

Client K+S Salt	**Drill Co.** J&S Drilling	**Easting, Northing** 260263, 7569718
Project Geotechnical, Groundwater and ASS Investigation	**Rig Type** Jacro 350 Mangrove Buggy	**Grid Ref** GDA94_MGA_zone_50
Project No. 12516706	**Drill Method** PQ core	**Elevation** 8.7
Site Tubridgi	**Total Depth (m)** 19.25	**TOC Elevation (m)** -
Location Tubridgi, Onslow 6710 WA	**Casing Diameter (mm)** 50	**Logged By** DO
Date Drilled 14/02/2020 - 28/02/2020	**Stickup (m)** 0.5	**Checked By** DO/PB
Casing 50 mm Class 18 PVC	**Screen** Class 18 PVC 4-10m	**Surface Completion** Monument cover

Drilling Method: PQ Coring

Water: groundwater level symbol at approx. 8 m

Well Details

- Backfill Depth: 0.0 - 2.5
- Bentonite Depth: 2.5 - 3.0
- Gravel Depth: 3.0 - 10.
- Bentonite Depth: 10. - 10.
- Hole collapse Depth: 10. - 19.

Depth (m): 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24

Elevation (m): 8, 7, 6, 5, 4, 3, 2, 1, 0, -1, -2, -3, -4, -5, -6, -7, -8, -9, -10, -11, -12, -13, -14, -15, -16

LITHOLOGICAL DESCRIPTION
Soil Type (Classification Group Symbol); Particle Size; Colour; Secondary / Minor Components.

- Topsoil - Silty SAND. Fine to medium grained; red-brown; silt is non-plastic; non-calcareous., W, L
- Silty SAND. Fine to medium grained; red-brown; silt is non-plastic; non-calcareous; uncemented.
- 0.45 m to 1.2 m: CORE LOSS. Inferred as above.
- Silty SAND. Fine to medium grained; red-brown; silt is non-plastic; non-calcareous; uncemented., MD
- 1.95 m to 3.0 m: CORE LOSS. Inferred as below.
- Silty SAND. Fine to medium grained; red-brown; silt is non-plastic; non-calcareous; uncemented., M-W, MD
- 3.45 m to 4.0 m: CORELOSS. Inferred as below.
- Silty SAND. As above., W, VSt
- Carbonate SAND (borderline Silty SAND). Fine to medium grained, sub-angular to sub-rounded of carbonate; brown; with silt; trace gravel, fine to medium grained, sub-rounded to rounded calcrete (weakly to moderately, CaCO3 cemented sandstone).
- Carbonate Gravelly SAND. Fine to medium grained, sub-angular to sub-rounded of carbonate; brown; gravel is fine to medium grained, sub-angular to sub-rounded of calcrete (weakly to strongly CaCO3 cemented sandstone); with silt, non-plastic.
- 5.9 m to 6.0 m: CORE LOSS., W, VSt
- Carbonate Silty SAND (borderline SAND). Fine to medium grained, sub-angular to sub-rounded of carbonate; brown; non-plastic fines; with gravel, fine to medium grained, sub-angular to sub-rounded of concrete (moderately to strongly CaCO3 cemented sandstone). 6.45 m to 6.75 m: Gravelly Silty SAND., W, VD
- Silty SAND. Fine to medium grained, sub-angular to sub-rounded of quartz and carbonate; brown; silt is non-plastic to low plasticity; trace shell fragments, gravel sized, fine grained; calcareous.
- From 8.1 m, trace gravel, fine to medium grained, sub-angular to sub-rounded of sandstone and calcrete (moderately to strongly CaCO3 cemented sandstone).
- Silty SAND. Fine to medium grained, sub-angular to sub-rounded of quartz; brown; silt has low plasticity., W, H
- From 11.8 m, trace gravel, black, fine to coarse grained, sub-rounded of claystone; and trace gravel, fine to medium grained, sub-rounded to rounded of quartz and gypsum.
- Sandy CLAY. Medium plasticity; brown; sand is fine grained, sub-angular to sub-rounded of quartz; trace gravel, black, fine to medium grained, sub-rounded of claystone.
- Between 14.15 m and 14.3 m, bed of sand, with silt., -, -
- From 14.3 m, increasing clay content., W, VSt
- Sandy CLAY. High plasticity; brown; sand is fine grained, sub-angular to sub-rounded of quartz; trace gravel, black, fine to medium grained, sub-rounded of claystone; with dry clasts of sandy clay.
- Silty Gravelly SAND. Fine to medium grained, sub-angular to sub-rounded of quartz; brown; silt has low to medium plasticity; gravel is fine to coarse grained, sub-rounded to rounded of claystone and quartz., M, MD
- 16.74 m to 18.0 m: CORE LOSS.. Recoved as gravel, medium to coarse grained, sub-rounded to rounded of quartz and claystone. Inferred as above.
- Silty Gravelly SAND. As above.
- Gravelly CLAY. Medium plasticity; brown; gravel is fine to medium grained, sub-angular to sub-rounded of quartz and calcrete (strongly CaCO3 cemented Sandstone)., W, H

DRILLING OBSERVATIONS

- Inferred geolgical unit: Qe (0-16.5m)
- Inferred geolgical unit: Qsed (16.5-19.25m)

Notes

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Drilling Abbreviations	Moisture Abbreviations	Consistency Abbreviations	
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BOREHOLE LOG

HYDROGEOLOGICAL-GROUNDWATER

MONITORING WELL BH13

Client K+S Salt	**Drill Co.** J&S Drilling	**Easting, Northing** 271735, 7563998
Project Geotechnical, Groundwater and ASS Investigation	**Rig Type** Jacro 350 Mangrove Buggy	**Grid Ref** GDA94_MGA_zone_50
Project No. 12516706	**Drill Method** PQ core	**Elevation** 6.2
Site Tubridgi	**Total Depth (m)** 16.50	**TOC Elevation (m)** -
Location Tubridgi, Onslow 6710 WA	**Casing Diameter (mm)** 50	**Logged By** SG
Date Drilled 10/02/2020 - 11/02/2020	**Stickup (m)** 0.5	**Checked By** DO/PB

Casing 50 mm Class 18 PVC	**Screen** Class 18 PVC 3-6m	**Surface Completion** Monument cover

Drilling Method: PQ

Water: groundwater level symbol at approx. 2.2 m

Well Details:
- Backfill Clay Depth: 0.0 - 0.5
- Bentonite Depth: 0.5 - 2.0
- Gravel Depth: 2.0 - 6.0
- Bentonite Depth: 6.0 - 6.5
- Gravel Depth: 6.5 - 16.

LITHOLOGICAL DESCRIPTION Soil Type (Classification Group Symbol); Particle Size; Colour; Secondary / Minor Components.
0.0 to 0.65 m: CORE LOSS.. Inferred as SILT.
Sandy SILT. Low plasticity; red-brown with minor black mottling; sand is fine to medium grained; weakly cemented.
Sandy CLAY. Low plasticity; red-brown; sand is fine to medium grained; non-calcareous., -, -
Silty SAND. Fine to medium grained; red-brown; silt is non-plastic; calcareous.
4.2 to 4.5 m: CORE LOSS.
Silty SAND. Fine to medium grained; red-brown; silt is non-plastic; calcareous.
Sandy CLAY. Low plasticity; red-brown; sand is fine to medium grained.. 5.7m: with gravel, coarse grained of concrete (weakly to strongly CaCO3 cemented claystone)
From 5.7 m: With gravel, coarse grained of calcrete (weakly to strongly CaCO3 cemented claystone).
CLAY. Medium plasticity; red-brown; with sand, fine to medium grained; with gravel, of weakly CaCO3 cemented claystone.
Carbonate Gravelly Sandy CLAY. Low plasticity clay; red-brown; sand is fine to medium grained; angular, of quartz, weakly cemented; gravel is fine to coarse grained, of calcarenite (weakly to moderately cemented).
Carbonate Sandy CLAY. Medium plasticity; red-brown mottled white; sand is fine grained, angular of quartz; with gravel of calcarenite (weakly cemented).
Sandy Clayey GRAVEL. Medium to coarse grained; sub-angular; of weakly to moderately cemeted calcarenite; red-brown mottled white; clay has low plasticity; sand is fine to medium grained.
Calcareous Silty SANDSTONE. Fine grained; red-brown mottled white; locally calcarenite., M-W, VL/S
9.5 to 10.15 m: Zones of very weakly cemented material with no rock strength., VL
Calcareous Silty SANDSTONE. Fine grained; red-brown mottled white; locally calcarenite.
10.15 to 10.5 m: CORE LOSS., MD
Calcareous Silty SANDSTONE. Fine grained; red-brown mottled white; locally calcarenite; with mica sand.
From 11.8 m: Trace gravel, coarse grained, rounded, of quartz.
Sandy Clayey GRAVEL. Fine to coarse grained; rounded; of mixed lithology including quartz and Banded Iron Formation; clay has low plasticity; sand is fine to medium grained., W, MD
Carbonate Sandy CLAY. Medium to high plasticity; red-brown mottled pale grey; sand is fine to coarse grained; trace gravel and cobbles of calcrete (with CaCO3 cemented of claystone); moist; with calcareous veins, 1 mm thick. From 15.0 m: Increasing sand content., W, H

Termination Depth at: 16.50 m. Target depth.

DRILLING OBSERVATIONS
- Inferred geolgical unit: Czp (0-8.1m)
- Inferred geolgical unit: Qsed (8.1-16.5m)

Depth (m)	Elevation (m)
0	6
1	5
2	4
3	3
4	2
5	1
6	0
7	-1
8	-2
9	-3
10	-4
11	-5
12	-6
13	-7
14	-8
15	-9
16	-10
17	-11
18	-12
19	-13
20	-14
21	-15
22	-16
23	-17
24	-18

Notes

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Drilling Abbreviations	Moisture Abbreviations	Consistency Abbreviations	
AH-Air Hammer, AR-Air Rotary, BE-Bucket Excavation, CC-Concrete Coring, DC-Diamond Core, FH-Foam Hammer, HA-Hand Auger, HE-Hand Excavation (shovel), HFA-Hollow Flight Auger, MR-Mud Rotary, NDD-Non Destructive Drilling, PT-Pushtube, SD-Sonic Drilling, SFA-Solid Flight Auger, SS-Split Spoon, WB-Wash Bore, WS-Window Sampler	D-Dry, SM-Slightly Moist, M-Moist, VM-Very Moist, W-Wet, S-Saturated	**Granular Soils** VL-Very Loose, L-Loose, MD-Medium Dense, D-Dense,VD - Very Dense	**Cohesive Soils** VS-Very Soft, S-Soft, F-Firm, ST-Stiff, VST-Very Stiff, H-Hard

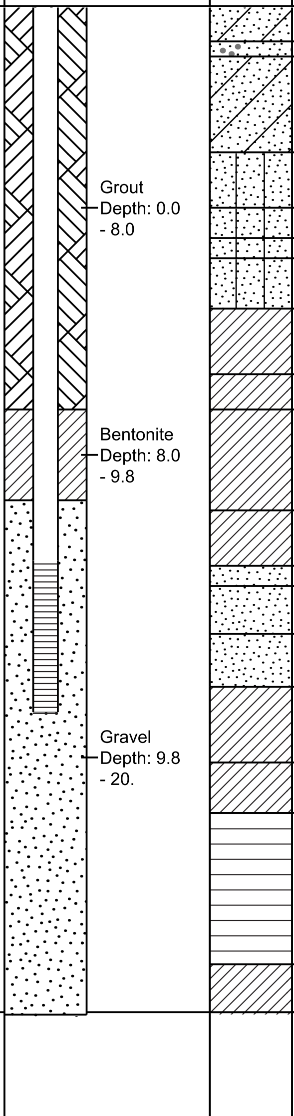
BOREHOLE LOG

HYDROGEOLOGICAL-GROUNDWATER

MONITORING WELL BH14D

Client K+S Salt	**Drill Co.** J&S Drilling	**Easting, Northing** 259892, 7565531
Project Geotechnical, Groundwater and ASS Investigation	**Rig Type** Jacro 350 Mangrove Buggy	**Grid Ref** GDA94_MGA_zone_50
Project No. 12516706	**Drill Method** Auger	**Elevation** 1
Site Tubridgi	**Total Depth (m)** 19.95	**TOC Elevation (m)** -
Location Tubridgi, Onslow 6710 WA	**Casing Diameter (mm)** 50	**Logged By** DO
Date Drilled 01/03/2020 - 03/03/2020	**Stickup (m)** 0.5	**Checked By** DO/PB
Casing 50 mm Class 18 PVC	**Screen** Class 18 PVC 11-14m	**Surface Completion** Monument cover

Depth (m) | **Drilling Method**: PQ Coring | **Water** | **Well Details** | **Graphic Log** | **LITHOLOGICAL DESCRIPTION** Soil Type (Classification Group Symbol); Particle Size; Colour; Secondary / Minor Components. | **DRILLING OBSERVATIONS** | **Elevation (m)**



Lithological Description

- Clayey SAND (borderline Sandy CLAY). Fine to medium grained, sub-angular to sub-rounded of quartz; brown; clay has low to medium plasticity.
- SAND. Fine to medium grained, sub-angular to sub-rounded of quartz; brown; with silt., W, H
- Clayey SAND. Fine to medium grained, sub-angular to sub-rounded of quartz; grey-brown; clay has low to medium plasticity.
- Silty SAND. Fine to medium grained, sub-angular to sub-rounded of quartz; grey-brown; silt has low plasticity; trace gravel, pale brown, fine to medium grained, sub-angular to sub-rounded of calcrete (weakly to strongly CaCO3 cemented sandstone).
- From 4.0 m, sand/silty sand, of quartz and some carbonate sand.
- Gravelly Clayey SAND. Fine to medium grained, sub-angular to sub-rounded of quartz; brown; clay and gravel as below.
- Gravelly Clayey SAND. Fine to medium grained, sub-angular to sub-rounded quartz; brown; clay has low plasticity; gravel is fine to medium grained, sub-angular (clasts of clayey sand/sandy clay and trace calcrete).
- CLAY. High plasticity; brown; trace fine grained sand; trace gravel, fine to medium grained, sub-angular of calcrete (strongly CaCO3 cemented sandstone).
- Sandy CLAY. Medium to high plasticity; brown, locally stained pale grey; sand is fine grained; with gravel, fine to medium grained, sub-angular to sub-rounded of calcrete and sandstone (strongly CaCO3 cemented sandstone).
- From 8.0 m, brown, locally stained pale grey and locally spotted black (iron).
- Sandy CLAY. Medium to high plasticity; brown, locally stained pale grey and locally spotted black (iron); sand is fine grained; with gravel, fine to medium grained, sub-angular to sub-rounded of calcrete and sandstone (strongly CaCO3 cemented sandstone)., M-W, VL/S
- SANDSTONE. Fine to medium grained; brown, stained pale grey, locally stained white (CaCO3) and black (iron); locally CaCO3 cemented., VL
- From 11.5 m to 11.55 m, well iron cemented band.
- From 12.25 m, brown, loss of CaCO3 cementation; addition of trace gravel, fine grained, black, rounded, of claystone., MD
- CLAY. Medium to high plasticity; brown, stained pale grey; with fine grained sand; with gravel, fine to medium grained, sub-angular to sub-rounded, of white gypsum, black iron cemented and pale grey mudstone.
- CLAY. Medium to high plasticity; brown, stained pale grey; with fine grained sand; with gravel, fine to medium grained, sub-angular to sub-rounded, of white gypsum, black iron cemented and pale grey mudstone.
- MUDSTONE. Fine grained; brown, stained pale grey, locally iron stained orange and red; trace gravel, fine to coarse grained, black iron cemented and white gypsum., W, MD
- CLAY. Medium to high plasticity; brown, stained grey; with fine grained sand; with gravel, fine to medium grained, sub-angular to sub-rounded, of mudstone and some black iron cemented and white calcrete.

Termination Depth at: 19.95 m. Target depth.

Drilling Observations

- Inferred geolgical unit: Qt (0-6m)
- Inferred geolgical unit: Qsed (6-19.95m)

Depth (m)	Elevation (m)
1	0
2	-1
3	-2
4	-3
5	-4
6	-5
7	-6
8	-7
9	-8
10	-9
11	-10
12	-11
13	-12
14	-13
15	-14
16	-15
17	-16
18	-17
19	-18
20	-19
21	-20
22	-21
23	-22
24	-23

Notes

This log is not intended for geotechnical purposes.

Drilling Abbreviations	Moisture Abbreviations	Consistency Abbreviations	
AH-Air Hammer, AR-Air Rotary, BE-Bucket Excavation, CC-Concrete Coring, DC-Diamond Core, FH-Foam Hammer, HA-Hand Auger, HE-Hand Excavation (shovel), HFA-Hollow Flight Auger, MR-Mud Rotary, NDD-Non Destructive Drilling, PT-Pushtube, SD-Sonic Drilling, SFA-Solid Flight Auger, SS-Split Spoon, WB-Wash Bore, WS-Window Sampler	D-Dry, SM-Slightly Moist, M-Moist, VM-Very Moist, W-Wet, S-Saturated	**Granular Soils** VL-Very Loose, L-Loose, MD-Medium Dense, D-Dense,VD - Very Dense	**Cohesive Soils** VS-Very Soft, S-Soft, F-Firm, ST-Stiff, VST-Very Stiff, H-Hard

BOREHOLE LOG

HYDROGEOLOGICAL-GROUNDWATER

MONITORING WELL BH14S

Client K+S Salt	**Drill Co.** J&S Drilling	**Easting, Northing** 259892, 7565533
Project Geotechnical, Groundwater and ASS Investigation	**Rig Type** Jacro 350 Mangrove Buggy	**Grid Ref** GDA94_MGA_zone_50
Project No. 12516706	**Drill Method** PQ core	**Elevation** 1
Site Tubridgi	**Total Depth (m)** 6.00	**TOC Elevation (m)** -
Location Tubridgi, Onslow 6710 WA	**Casing Diameter (mm)** 50	**Logged By** DO
Date Drilled 04/03/2020 - 04/03/2020	**Stickup (m)** 0.5	**Checked By** DO/PB
Casing 50 mm Class 18 PVC	**Screen** Class 18 PVC 3-6m	**Surface Completion** Monument cover

Depth (m)	Drilling Method	Water	Well Details	LITHOLOGICAL DESCRIPTION Soil Type (Classification Group Symbol); Particle Size; Colour; Secondary / Minor Components.	DRILLING OBSERVATIONS	Elevation (m)
0.0 – 0.7	PQ Coring			Clayey SAND (borderline Sandy CLAY). Fine to medium grained, sub-angular to sub-rounded of quartz; brown; clay has low to medium plasticity., W, St		0.5
0.7 – 1.0		▽ (water level, approx. 0.8 m)	Bentonite Depth: 0.0 - 2.0	SAND. Fine to medium grained, sub-angular to sub-rounded of quartz; brown; with silt.		0
1.0 – 2.9				Clayey SAND. Fine to medium grained, sub-angular to sub-rounded of quartz; grey-brown; clay has low to medium plasticity.		-0.5 to -1.5
2.9 – 4.0				Silty SAND. Fine to medium grained, sub-angular to sub-rounded of quartz; grey-brown; silt has low plasticity; trace gravel, pale brown, fine to medium grained, sub-angular to sub-rounded of calcrete (weakly to strongly CaCO3 cemented sandstone).		-2 to -2.5
4.0 – 4.6			Gravel Depth: 2.0 - 6.0	From 4.0 m, sand/silty sand, of quartz and some carbonate sand., W, H		-3 to -3.5
4.6 – 5.0				Gravelly Clayey SAND. Fine to medium grained, sub-angular to sub-rounded of quartz; brown; clay and gravel as below., W		-4
5.0 – 6.0				Gravelly Clayey SAND. Fine to medium grained, sub-angular to sub-rounded quartz; brown; clay has low plasticity; gravel is fine to medium grained, sub-angular (clasts of clayey sand/sandy clay and trace calcrete).		-4.5 to -5
6.0				Termination Depth at: 6.00 m. Target depth.		-5

Notes

This log is not intended for geotechnical purposes.

Drilling Abbreviations	Moisture Abbreviations	Consistency Abbreviations	
AH-Air Hammer, AR-Air Rotary, BE-Bucket Excavation, CC-Concrete Coring, DC-Diamond Core, FH-Foam Hammer, HA-Hand Auger, HE-Hand Excavation (shovel), HFA-Hollow Flight Auger, MR-Mud Rotary, NDD-Non Destructive Drilling, PT-Pushtube, SD-Sonic Drilling, SFA-Solid Flight Auger, SS-Split Spoon, WB-Wash Bore, WS-Window Sampler	D-Dry, SM-Slightly Moist, M-Moist, VM-Very Moist, W-Wet, S-Saturated	**Granular Soils** VL-Very Loose, L-Loose, MD-Medium Dense, D-Dense,VD - Very Dense	**Cohesive Soils** VS-Very Soft, S-Soft, F-Firm, ST-Stiff, VST-Very Stiff, H-Hard

BOREHOLE LOG

HYDROGEOLOGICAL-GROUNDWATER

MONITORING WELL BH15D

Client K+S Salt	**Drill Co.** J&S Drilling	**Easting, Northing** 265126, 7565578
Project Geotechnical, Groundwater and ASS Investigation	**Rig Type** Jacro 350 Mangrove Buggy	**Grid Ref** GDA94_MGA_zone_50
Project No. 12516706	**Drill Method** PQ core	**Elevation** 1.6
Site Tubridgi	**Total Depth (m)** 20.00	**TOC Elevation (m)** -
Location Tubridgi, Onslow 6710 WA	**Casing Diameter (mm)** 50	**Logged By** DO
Date Drilled 31/01/2020 - 02/02/2020	**Stickup (m)** 0.5	**Checked By** DO/PB
Casing 50 mm Class 18 PVC	**Screen** Class 18 PVC 9-12m	**Surface Completion** Monument cover

Drilling Method: Solid Auge (0-5 m); PQ Coring (5-20 m)

Well Details:
- Grout Depth: 0.0 - 6.5
- Bentonite Depth: 6.5 - 8.0
- Gravel Depth: 8.0 - 12.
- Bentonite Depth: 12. - 12.
- Backfill Depth: 12. - 20.

LITHOLOGICAL DESCRIPTION Soil Type (Classification Group Symbol); Particle Size; Colour; Secondary / Minor Components.	DRILLING OBSERVATIONS
Silty SAND (borderline SAND). Fine to medium grained, sub-angular to sub-rounded; brown; silt is non-plastic., W	Inferred geolgical unit: Qe (0-1.2m)
Sandy CLAY / CLAY. Medium to high plasticity; brown; sand is fine to medium grained, sub-angular to sub-rounded; trace gravel, fine to medium grained, sub-angular of calcrete.	Inferred geolgical unit: Czp (1.2-8.4m)
Sandy CLAY. Medium plasticity; brown; sand is fine to medium grained, sub-angular to sub-rounded; trace gravel, fine to medium grained, sub-angular to sub-rounded of calcrete.	
Between 3.05 and 3.1 m, weakly CaCO3 cemented.	
Between 3.4 and 3.5 m, weakly CaCO3 cemented.	
From 3.5 m, trace gravel, fine to medium grained, angular, elongated, of gypsum .	
At 4.23 m, 20 mm of halite.	
4.7 to 5.0 m: CORE LOSS. Inferred as below.	
Sandy CLAY. Medium plasticity; brown; sand is fine to medium grained, sub-angular to sub-rounded; trace gravel, black, fine to medium grained, angular, gypsum and claystone.	
Between 5.5 and 5.8 m, becoming high plasticity CLAY; with sand.	
From 7.0 m, becoming medium to high plasticity; brown stained pale grey-brown, spotted black; with gravel, fine to coarse grained, angular to sub-angular of calcrete and laminated gypsum; locally weakly CaCO3 cemented.	
SANDSTONE. Fine to medium grained; brown patched pale grey and pale brown, locally spotted black; trace gravel, fine to coarse grained, angular, of gypsum. Borderline soil strength.	Inferred geolgical unit: Qsed (8.4-20m)
SANDSTONE. Fine to medium grained; brown patched pale grey and pale brown, locally spotted black; trace gravel, fine to coarse grained, angular, of gypsum; trace thin (<5 mm) gypsum seams, with occasional thin clayey sand layers (<0.3 m). Borderline soil strength to 14.1 m.	
11.0 to 11.3 m, Clayey SAND., D, MD	
From 11.6 m, loss of gypsum seams, becoming brown patched pale grey and pale brown., W, St	
12.55 to 12.75 m, Clayey SAND.	
13.30 to 13.35 m, Clayey SAND.	
SANDSTONE. Fine to medium grained; brown patched pale grey and pale brown.	
15.80 m, 20 mm thick Clayey SAND layer., W, H	
From 17.5 m, brown streaked pale brown and locally spotted black., W	
From 19.3 m, trace gravel, dark grey, fine to medium grained, sub-rounded of claystone.	
Termination Depth at: 20.00 m. Target depth.	

Notes

This log is not intended for geotechnical purposes.

Drilling Abbreviations	Moisture Abbreviations	Consistency Abbreviations	
AH-Air Hammer, AR-Air Rotary, BE-Bucket Excavation, CC-Concrete Coring, DC-Diamond Core, FH-Foam Hammer, HA-Hand Auger, HE-Hand Excavation (shovel), HFA-Hollow Flight Auger, MR-Mud Rotary, NDD-Non Destructive Drilling, PT-Pushtube, SD-Sonic Drilling, SFA-Solid Flight Auger, SS-Split Spoon, WB-Wash Bore, WS-Window Sampler	D-Dry, SM-Slightly Moist, M-Moist, VM-Very Moist, W-Wet, S-Saturated	**Granular Soils** VL-Very Loose, L-Loose, MD-Medium Dense, D-Dense,VD - Very Dense	**Cohesive Soils** VS-Very Soft, S-Soft, F-Firm, ST-Stiff, VST-Very Stiff, H-Hard

BOREHOLE LOG

HYDROGEOLOGICAL-GROUNDWATER

MONITORING WELL BH15S

Client K+S Salt	**Drill Co.** J&S Drilling	**Easting, Northing** 265126, 7565580
Project Geotechnical, Groundwater and ASS Investigation	**Rig Type** Jacro 350 Mangrove Buggy	**Grid Ref** GDA94_MGA_zone_50
Project No. 12516706	**Drill Method** Auger	**Elevation** 1.6
Site Tubridgi	**Total Depth (m)** 5.00	**TOC Elevation (m)** -
Location Tubridgi, Onslow 6710 WA	**Casing Diameter (mm)** 50	**Logged By** DO
Date Drilled 31/01/2020 - 02/02/2020	**Stickup (m)** 0.5	**Checked By** DO/PB
Casing 50 mm Class 18 PVC	**Screen** Class 18 PVC 2-5m	**Surface Completion** Monument cover

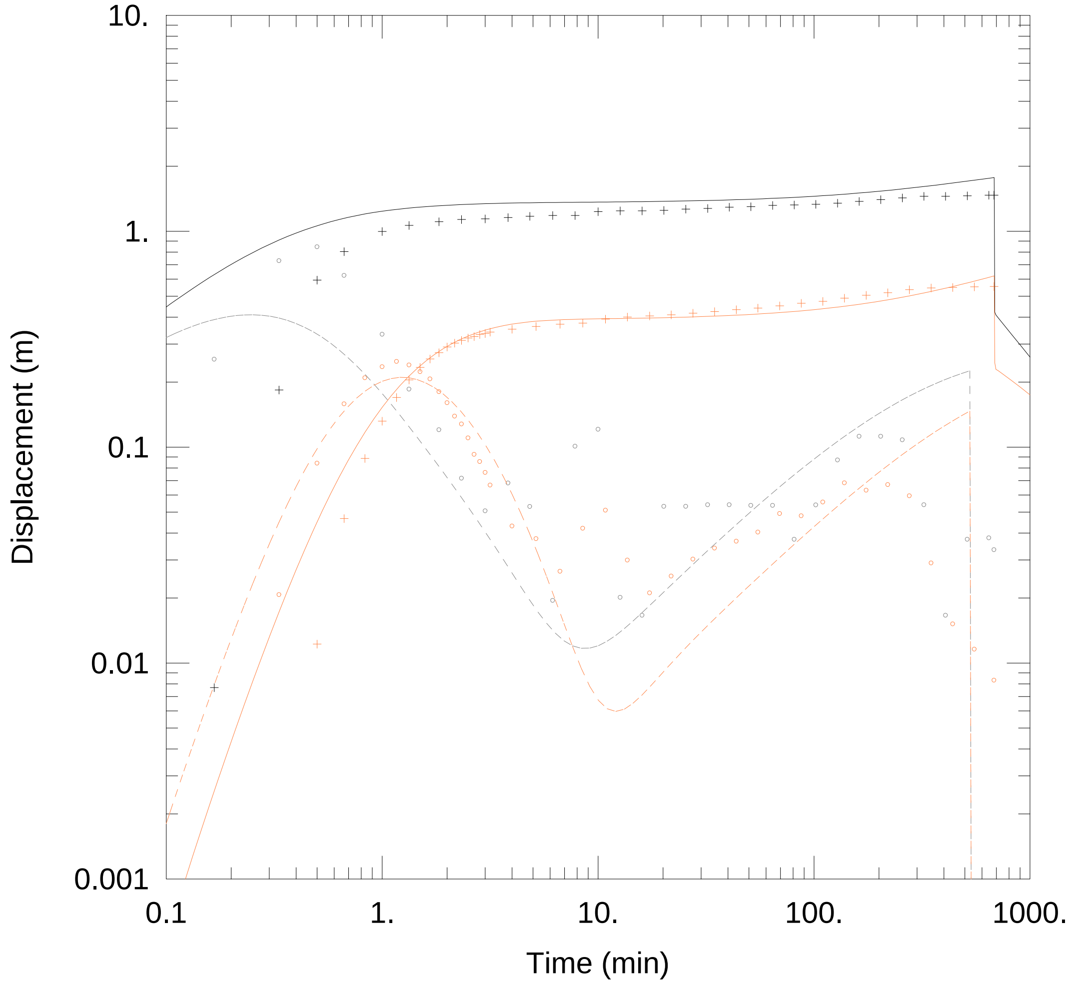
Depth (m)	Drilling Method	Water	Well Details	LITHOLOGICAL DESCRIPTION Soil Type (Classification Group Symbol); Particle Size; Colour; Secondary / Minor Components.	DRILLING OBSERVATIONS	Elevation (m)
0.0	PQ Coring		Bentonite Depth: 0.0 - 1.0	Silty SAND (borderline SAND). Fine to medium grained, sub-angular to sub-rounded; brown; silt is non-plastic.		1.5
1.2		Water level (▽)	Gravel Depth: 1.0 - 5.0	Sandy CLAY / CLAY. Medium to high plasticity; brown; sand is fine to medium grained, sub-angular to sub-rounded; trace gravel, fine to medium grained, sub-angular of calcrete.		
2.8				Sandy CLAY. Medium plasticity; brown; sand is fine to medium grained, sub-angular to sub-rounded; trace gravel, fine to medium grained, sub-angular to sub-rounded of calcrete.		
3.05				Between 3.05 and 3.1 m, weakly CaCO3 cemented.		
3.4				Between 3.4 and 3.5 m, weakly CaCO3 cemented.		
3.5				From 3.5 m, trace gravel, fine to medium grained, angular, elongated, of gypsum .		
4.23				At 4.23 m, 20 mm of halite.		
4.7				4.7 to 5.0 m: CORE LOSS. Inferred as below.		
5.0				Termination Depth at: 5.00 m. Target depth.		-3.5

Notes

This log is not intended for geotechnical purposes.

Drilling Abbreviations	Moisture Abbreviations	Consistency Abbreviations	
AH-Air Hammer, AR-Air Rotary, BE-Bucket Excavation, CC-Concrete Coring, DC-Diamond Core, FH-Foam Hammer, HA-Hand Auger, HE-Hand Excavation (shovel), HFA-Hollow Flight Auger, MR-Mud Rotary, NDD-Non Destructive Drilling, PT-Pushtube, SD-Sonic Drilling, SFA-Solid Flight Auger, SS-Split Spoon, WB-Wash Bore, WS-Window Sampler	D-Dry, SM-Slightly Moist, M-Moist, VM-Very Moist, W-Wet, S-Saturated	**Granular Soils** VL-Very Loose, L-Loose, MD-Medium Dense, D-Dense,VD - Very Dense	**Cohesive Soils** VS-Very Soft, S-Soft, F-Firm, ST-Stiff, VST-Very Stiff, H-Hard

Appendix B – Aquifer Testing, Aqtesolv Plots



WELL TEST ANALYSIS

Data Set: G:\61\12516706\Tech\Hydrogeo\Pump test analysis\B07\PB07 MBs MSnoR D.aqt
Date: 04/16/21 Time: 16:34:36

PROJECT INFORMATION

Company: GHD
Client: K+S
Project: 12516706
Location: Onslow
Test Well: BH07
Test Date: 18/04/2020

AQUIFER DATA

Saturated Thickness: 13.5 m Anisotropy Ratio (Kz/Kr): 0.5444

WELL DATA

Pumping Wells

Well Name	X (m)	Y (m)
PB BH07	0	0

Observation Wells

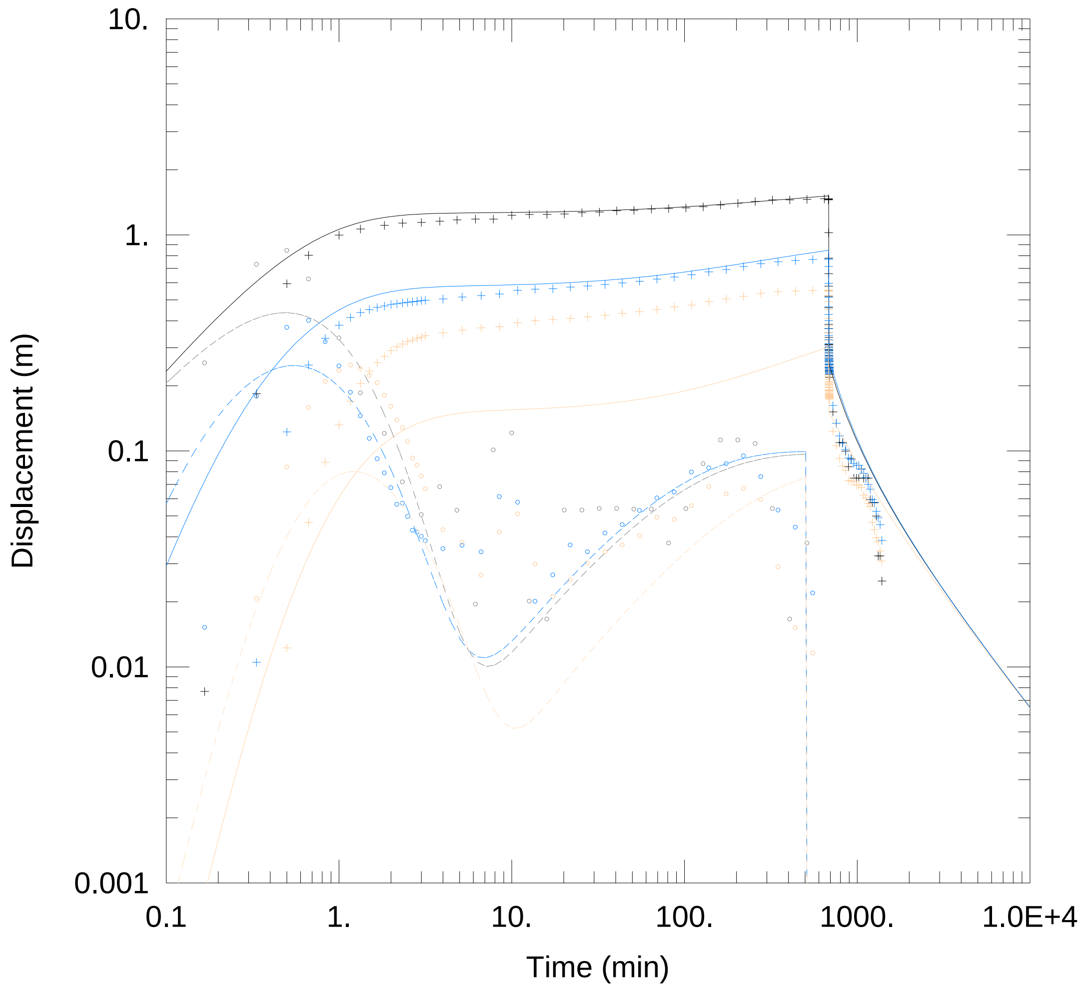
Well Name	X (m)	Y (m)
+ PB BH07	0	0
+ BH07D	2.5	0

SOLUTION

Aquifer Model: Unconfined Solution Method: Moench

T = 19.59 m^2/day
Sy = 0.04725
Sw = -4.385
r(c) = 0.0448 m

S = 0.0001923
Kz/Kr = 0.5444
r(w) = 0.02613 m
alpha = 0.309 min^{-1}



WELL TEST ANALYSIS

Data Set: G:\61\12516706\Tech\Hydrogeo\Pump test analysis\B07\PB07 MBs MSnoR S.aqt
Date: 04/16/21 Time: 13:54:05

PROJECT INFORMATION

Company: GHD
Client: K+S
Project: 12516706
Location: Onslow
Test Well: BH07
Test Date: 18/04/2020

AQUIFER DATA

Saturated Thickness: 13.5 m Anisotropy Ratio (Kz/Kr): 0.5081

WELL DATA

Pumping Wells

Well Name	X (m)	Y (m)
PB BH07	0	0

Observation Wells

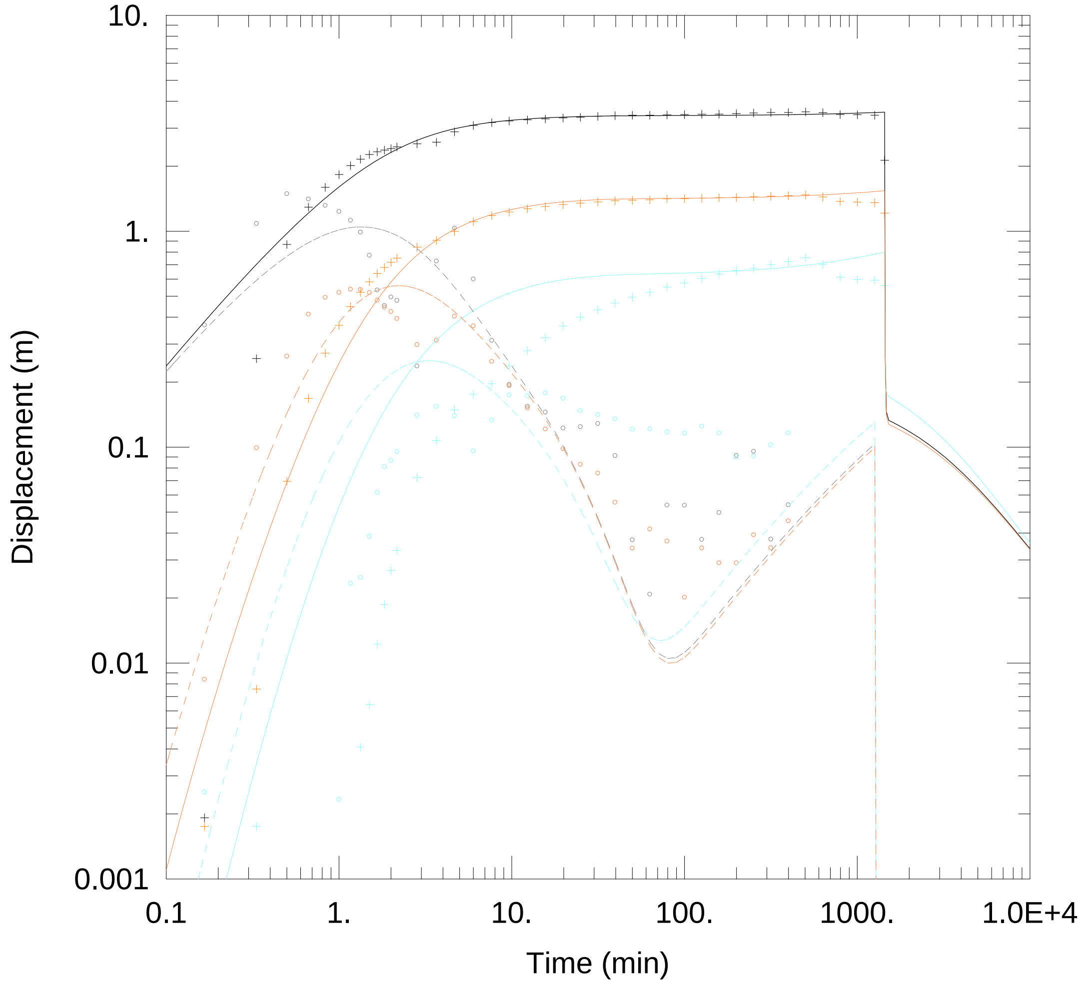
Well Name	X (m)	Y (m)
+ PB BH07	0	0
+ BH07S	1.2	0
+ BH07D	2.5	0

SOLUTION

Aquifer Model: Unconfined Solution Method: Moench

T = 56.51 m^2/day
Sy = 0.05073
Sw = -1.91
r(c) = 0.07265 m

S = 0.0005322
Kz/Kr = 0.5081
r(w) = 0.03215 m
alpha = 1.949E+4 min^{-1}



PB10 CRT

Data Set: G:\61\12516706\Tech\Hydrogeo\Pump test analysis\B10\BH10 CRT MS noR.aqt
Date: 04/16/21 Time: 13:14:49

PROJECT INFORMATION

Company: GHD
Client: K+S
Project: 12516706
Location: Onslow
Test Well: BH10
Test Date: 11/04/2020

AQUIFER DATA

Saturated Thickness: 15. m Anisotropy Ratio (Kz/Kr): 0.4571

WELL DATA

Pumping Wells

Well Name	X (m)	Y (m)
PB10	0	0

Observation Wells

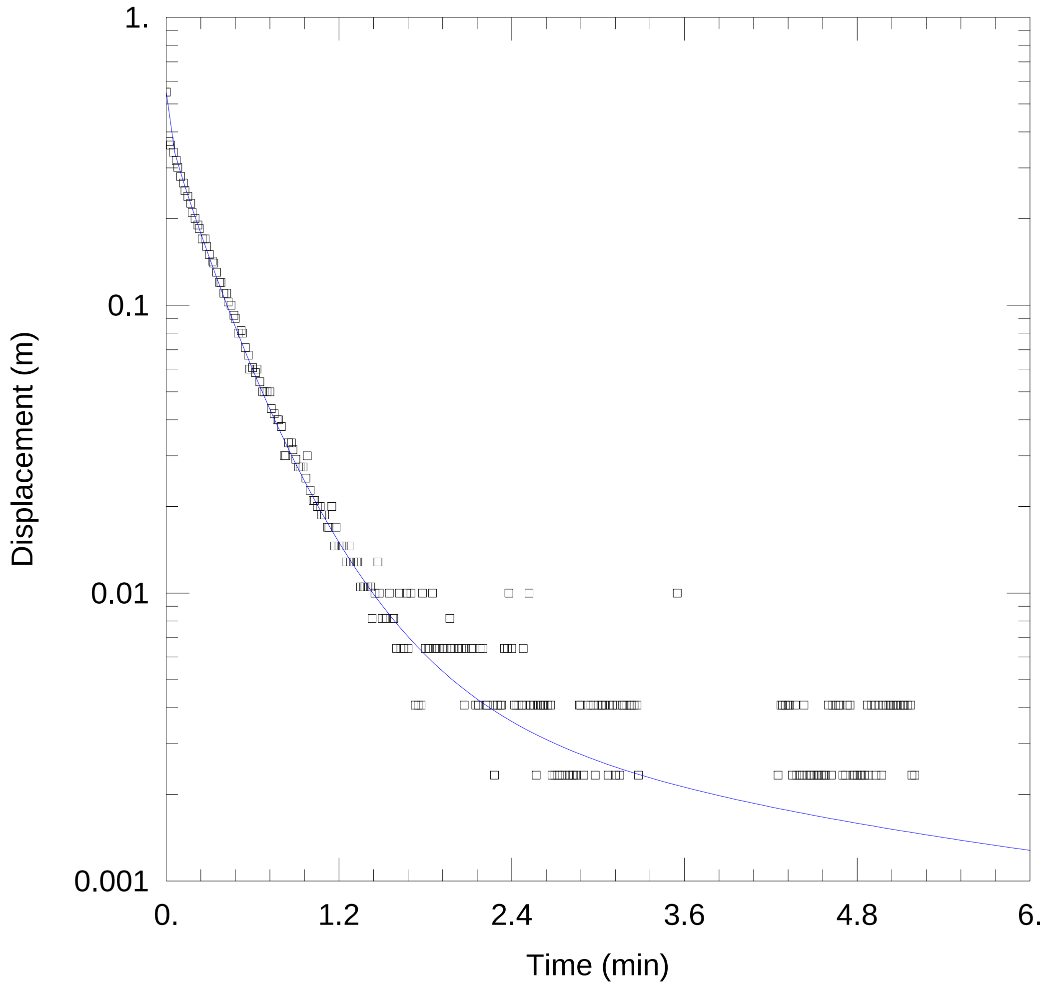
Well Name	X (m)	Y (m)
+ PB10	0	0
+ BH10S	3.6	0
+ B10D	2.2	0

SOLUTION

Aquifer Model: Unconfined Solution Method: Moench

T = 22.58 m^2/day
Sy = 0.05716
Sw = -0.45
r(c) = 0.075 m

S = 0.0005248
Kz/Kr = 0.4571
r(w) = 0.05 m
alpha = 0.001 min^{-1}



SLUG TEST

Data Set: G:\61\12516706\Tech\Hydrogeo\Geotech\Slug tests\aqtesolve\BH02D_kgs.aqt
Date: 04/22/21 Time: 16:47:29

PROJECT INFORMATION

Company: GHD
Client: K+S
Project: 12516706
Location: Onslow
Test Well: BH02D
Test Date: 11/04/2020

AQUIFER DATA

Saturated Thickness: 13.75 m

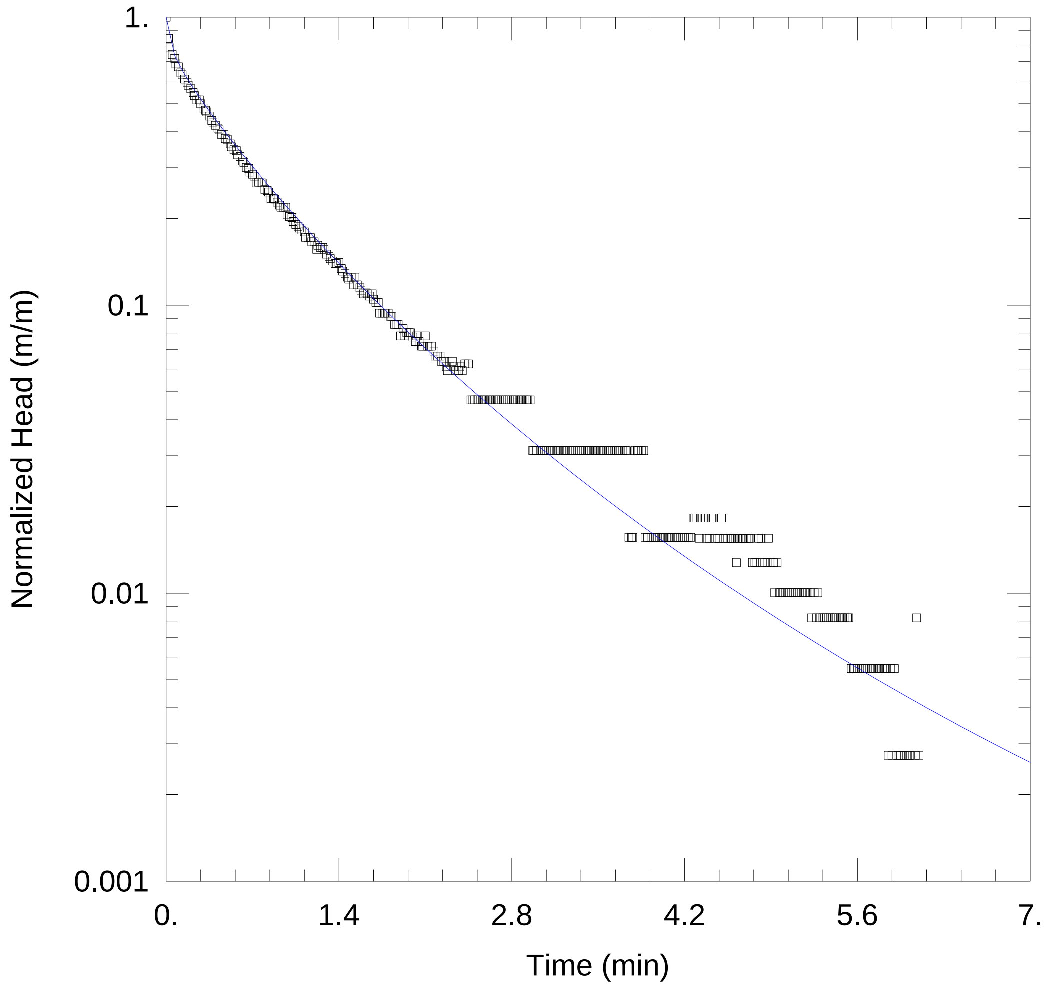
WELL DATA (BH02D)

Initial Displacement: 0.55 m
Total Well Penetration Depth: 13.75 m
Casing Radius: 0.025 m
Well Skin Radius: 0.09 m
Static Water Column Height: 13.75 m
Screen Length: 6. m
Well Radius: 0.048 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: KGS Model w/skin

Kr = 2.793 m/day
Kz/Kr = 0.5957
Ss' = 0.02103 m^{-1}
Ss = 0.0542 m^{-1}
Kr' = 0.2313 m/day
Kz/Kr' = 0.7586



SLUG TEST

Data Set: G:\61\12516706\Tech\Hydrogeo\Geotech\Slug tests\aqtesolve\BH02S_kgs.aqt
Date: 04/22/21 Time: 16:58:15

PROJECT INFORMATION

Company: GHD
Client: K+S
Project: 12516706
Location: Onslow
Test Well: BH02S
Test Date: 11/04/2020

AQUIFER DATA

Saturated Thickness: 13.75 m

WELL DATA (BH02S)

Initial Displacement: 0.64 m
Total Well Penetration Depth: 3.625 m
Casing Radius: 0.025 m
Well Skin Radius: 0.09 m

Static Water Column Height: 3.625 m
Screen Length: 3. m
Well Radius: 0.048 m

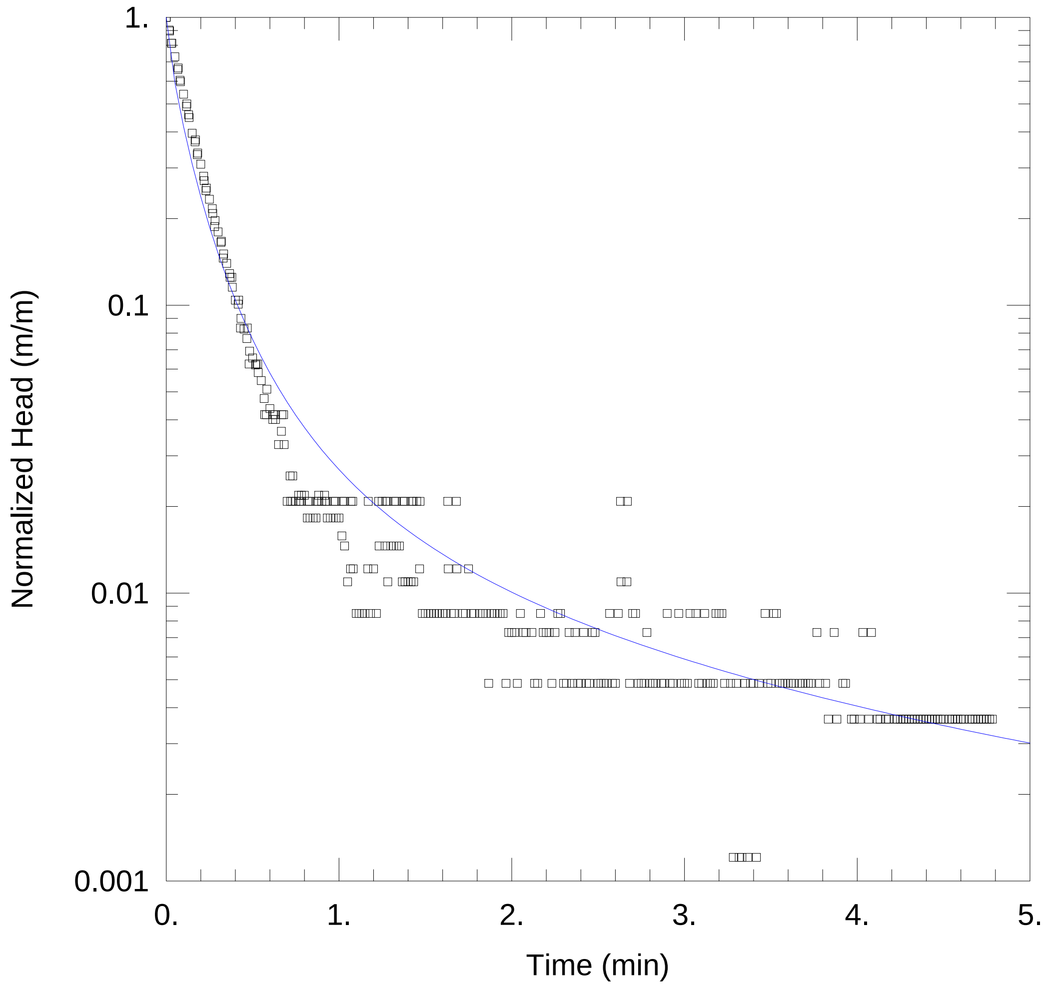
SOLUTION

Aquifer Model: Unconfined

Solution Method: KGS Model w/skin

Kr = 1.28 m/day
Kz/Kr = 0.3548
Ss' = 0.01585 m^{-1}

Ss = 0.0003688 m^{-1}
Kr' = 0.3393 m/day
Kz/Kr' = 0.2884



SLUG TEST

Data Set: G:\61\12516706\Tech\Hydrogeo\Geotech\Slug tests\aqtesolve\BH03D_kgs.aqt
Date: 04/21/21 Time: 16:52:30

PROJECT INFORMATION

Company: GHD
Client: K+S
Project: 12516706
Location: Onslow
Test Well: BH03D
Test Date: 13/04/2020

AQUIFER DATA

Saturated Thickness: 11.43 m

WELL DATA (BH03D)

Initial Displacement: 0.48 m
Total Well Penetration Depth: 11.43 m
Casing Radius: 0.025 m

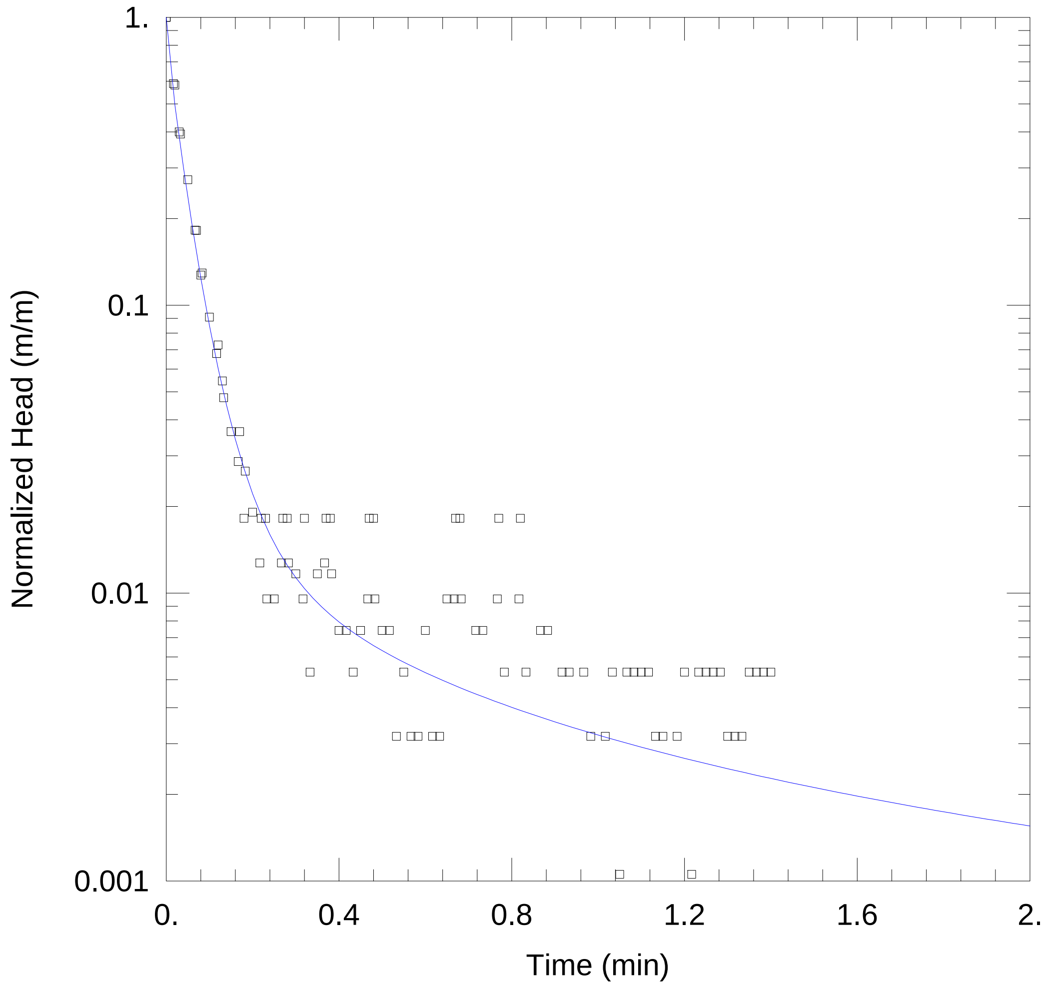
Static Water Column Height: 11.43 m
Screen Length: 3. m
Well Radius: 0.048 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: KGS Model

Kr = 3.435 m/day
Kz/Kr = 0.3199

Ss = 0.0009146 m^{-1}



SLUG TEST

Data Set: G:\61\12516706\Tech\Hydrogeo\Geotech\Slug tests\aqtesolve\BH03S_kgs.aqt
Date: 04/22/21 Time: 17:07:49

PROJECT INFORMATION

Company: GHD
Client: K+S
Project: 12516706
Location: Onslow
Test Well: BH03S
Test Date: 13/04/2020

AQUIFER DATA

Saturated Thickness: 11.43 m

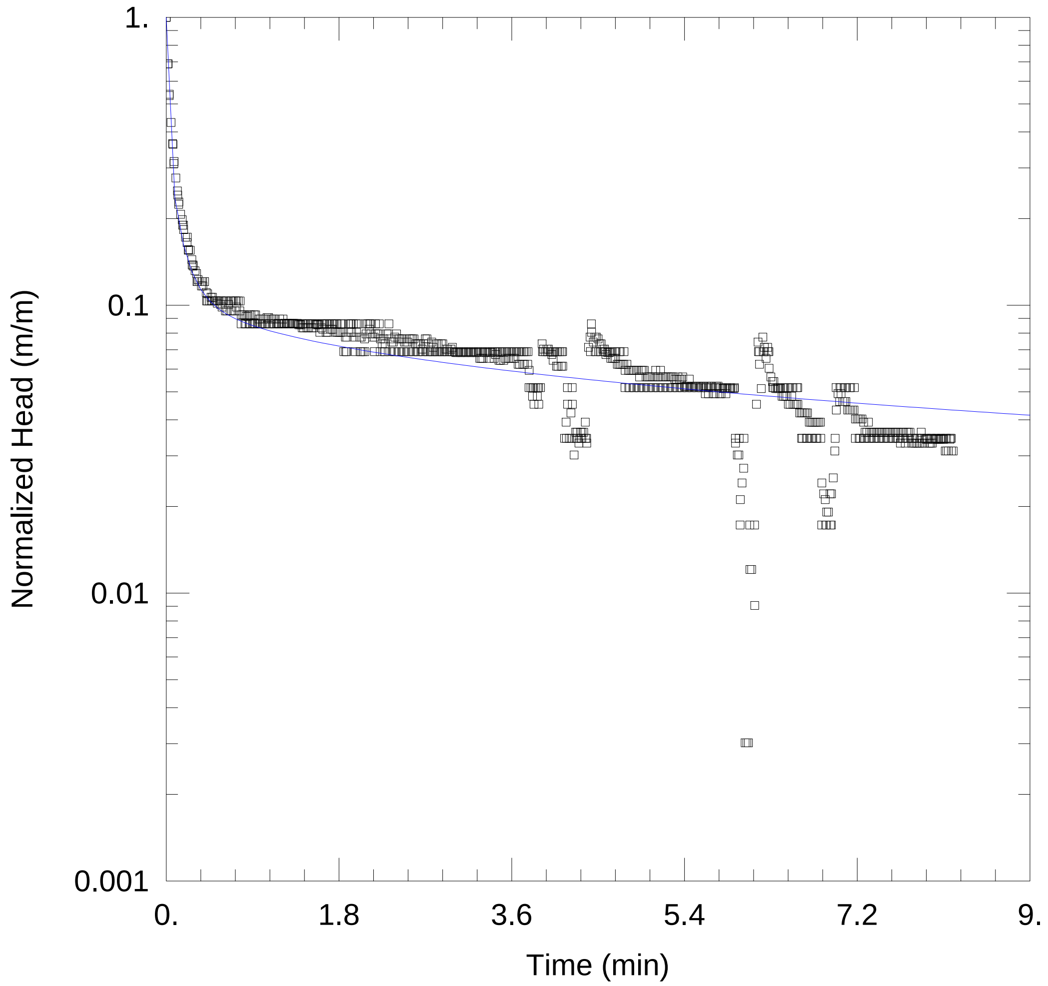
WELL DATA (BH03S)

Initial Displacement: 0.55 m
Total Well Penetration Depth: 3. m
Casing Radius: 0.025 m
Well Skin Radius: 0.09 m
Static Water Column Height: 2.525 m
Screen Length: 3. m
Well Radius: 0.048 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: KGS Model w/skin

Kr = 20. m/day
Kz/Kr = 0.5012
Ss' = 0.02239 m^{-1}
Ss = 0.2 m^{-1}
Kr' = 3.133 m/day
Kz/Kr' = 0.3548



SLUG TEST

Data Set: G:\61\12516706\Tech\Hydrogeo\Geotech\Slug tests\aqtesolve\BH04_kgs.aqt
Date: 04/22/21 Time: 17:15:08

PROJECT INFORMATION

Company: GHD
Client: K+S
Project: 12516706
Location: Onslow
Test Well: BH04
Test Date: 14/04/2020

AQUIFER DATA

Saturated Thickness: 4.76 m

WELL DATA (BH04)

Initial Displacement: 0.58 m
Total Well Penetration Depth: 5. m
Casing Radius: 0.025 m
Well Skin Radius: 0.09 m

Static Water Column Height: 4.76 m
Screen Length: 5. m
Well Radius: 0.048 m

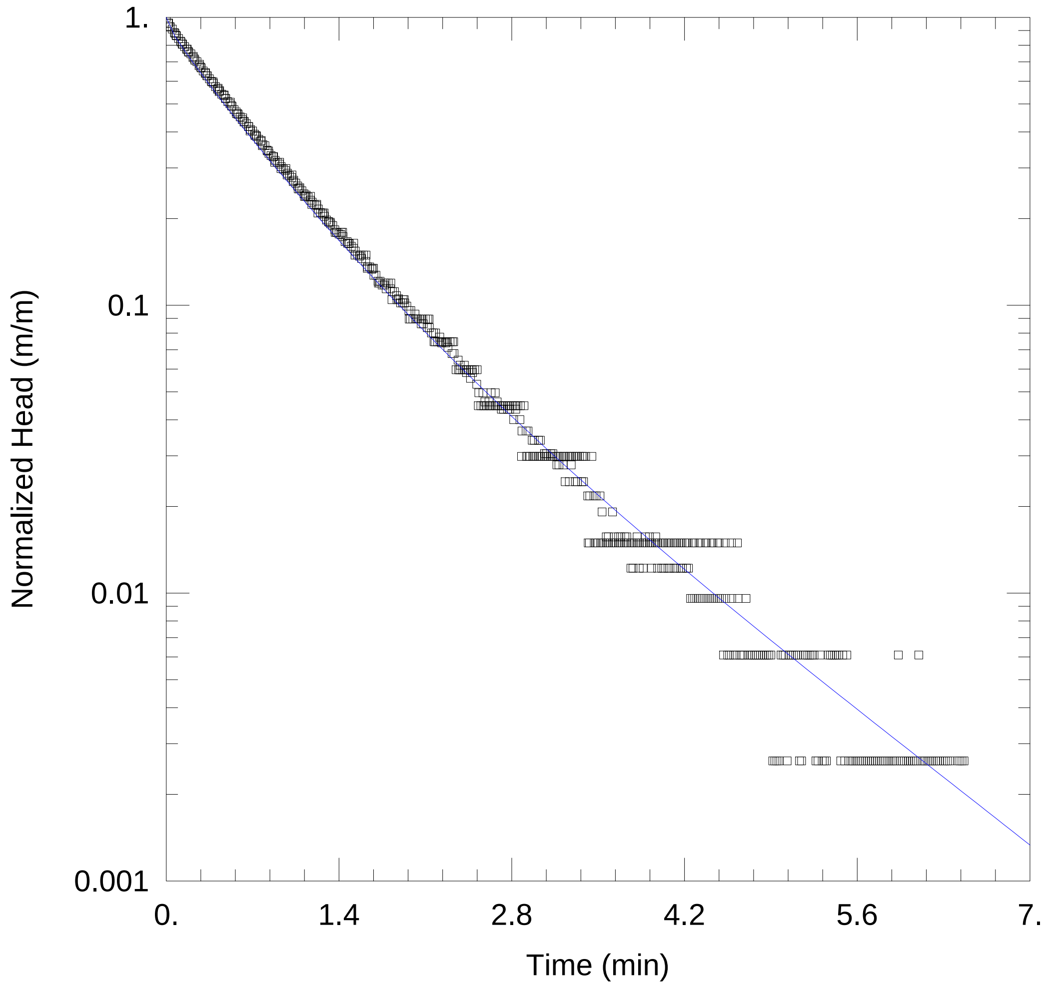
SOLUTION

Aquifer Model: Unconfined

Solution Method: KGS Model w/skin

Kr = 0.04376 m/day
Kz/Kr = 0.5012
Ss' = 0.1878 m^{-1}

Ss = 0.1588 m^{-1}
Kr' = 0.557 m/day
Kz/Kr' = 0.1549



SLUG TEST

Data Set: G:\61\12516706\Tech\Hydrogeo\Geotech\Slug tests\aqtesolve\BH05D_kgs.aqt
Date: 04/22/21 Time: 17:18:23

PROJECT INFORMATION

Company: GHD
Client: K+S
Project: 12516706
Location: Onslow
Test Well: BH05D
Test Date: 19/04/2020

AQUIFER DATA

Saturated Thickness: 14.39 m

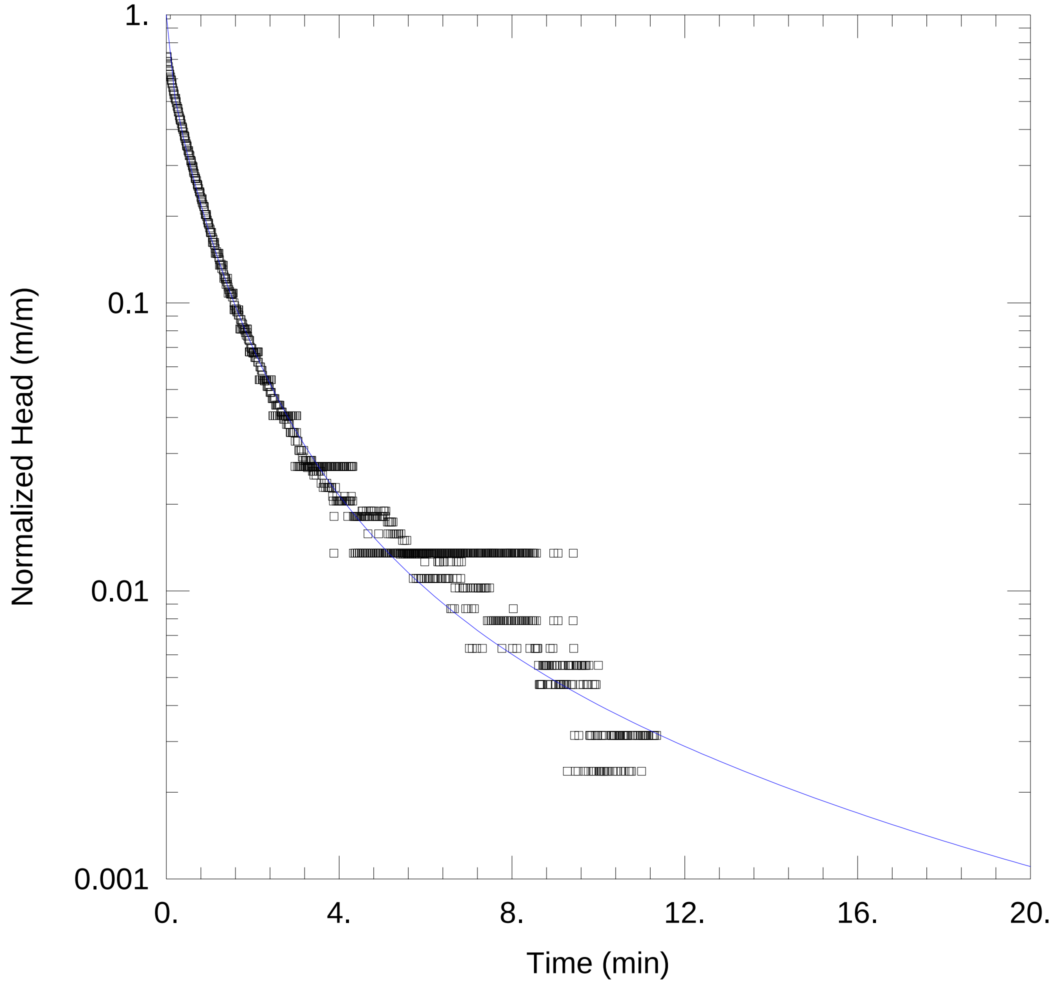
WELL DATA (BH05D)

Initial Displacement: 0.67 m
Total Well Penetration Depth: 14.39 m
Casing Radius: 0.025 m
Well Skin Radius: 0.09 m
Static Water Column Height: 13.39 m
Screen Length: 3. m
Well Radius: 0.048 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: KGS Model w/skin

Kr = 0.7579 m/day
Kz/Kr = 1.
Ss' = 0.0009246 m^{-1}
Ss = 2.077E-5 m^{-1}
Kr' = 2.64 m/day
Kz/Kr' = 0.3915



SLUG TEST

Data Set: G:\61\12516706\Tech\Hydrogeo\Geotech\Slug tests\aqtesolve\BH05S_kgs.aqt
Date: 04/21/21 Time: 17:00:28

PROJECT INFORMATION

Company: GHD
Client: K+S
Project: 12516706
Location: Onslow
Test Well: BH05S
Test Date: 19/04/2020

AQUIFER DATA

Saturated Thickness: 14.39 m

WELL DATA (BH05S)

Initial Displacement: 0.74 m
Total Well Penetration Depth: 1.4 m
Casing Radius: 0.025 m
Well Skin Radius: 0.09 m

Static Water Column Height: 1.4 m
Screen Length: 1. m
Well Radius: 0.048 m

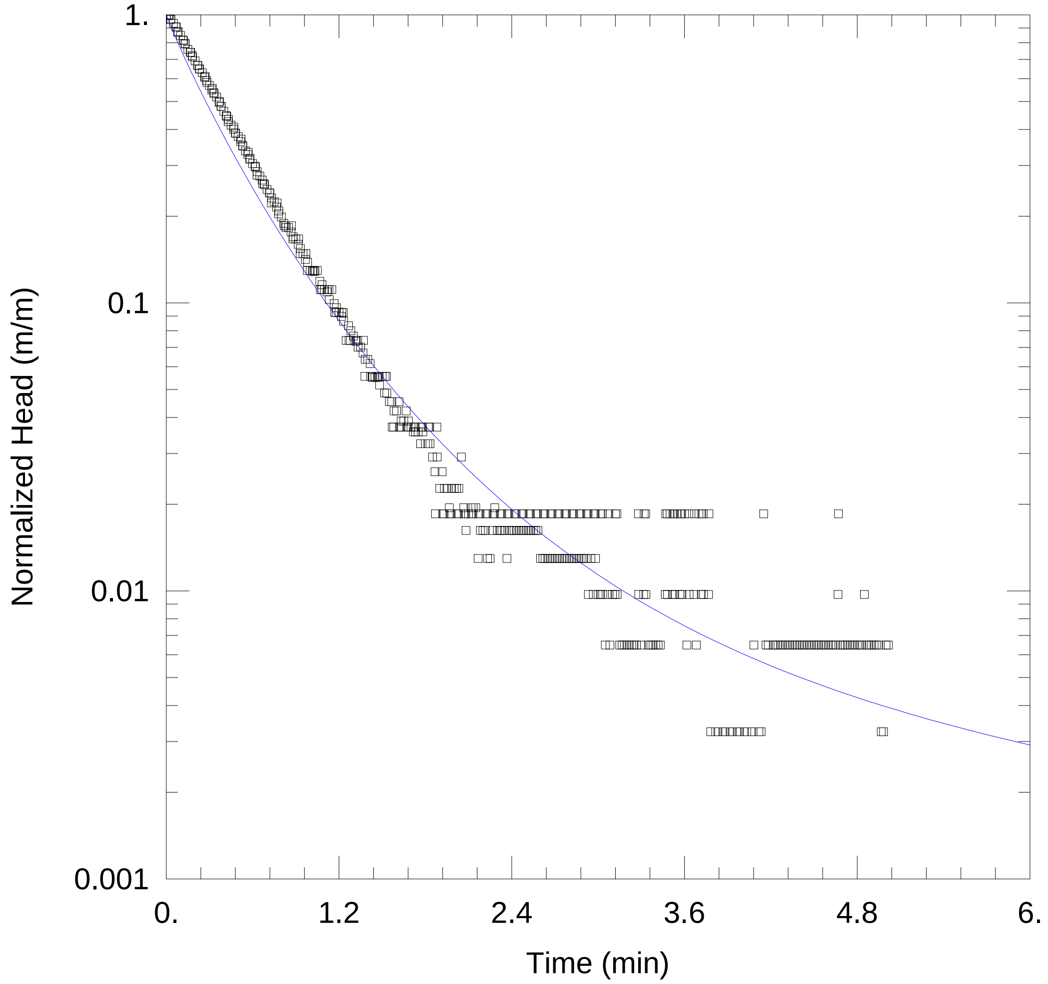
SOLUTION

Aquifer Model: Unconfined

Kr = 3.124 m/day
Kz/Kr = 0.4519
Ss' = 0.09591 m^{-1}

Solution Method: KGS Model w/skin

Ss = 0.03449 m^{-1}
Kr' = 0.8654 m/day
Kz/Kr' = 0.001



SLUG TEST

Data Set: G:\61\12516706\Tech\Hydrogeo\Geotech\Slug tests\aqtesolve\BH07D_kgs.aqt
Date: 04/21/21 Time: 17:04:25

PROJECT INFORMATION

Company: GHD
Client: K+S
Project: 12516706
Location: Onslow
Test Well: BH07D
Test Date: 17/04/2020

AQUIFER DATA

Saturated Thickness: 12.02 m

WELL DATA (BH07D)

Initial Displacement: 0.54 m
Total Well Penetration Depth: 10.02 m
Casing Radius: 0.025 m
Well Skin Radius: 0.09 m

Static Water Column Height: 12.02 m
Screen Length: 1. m
Well Radius: 0.048 m

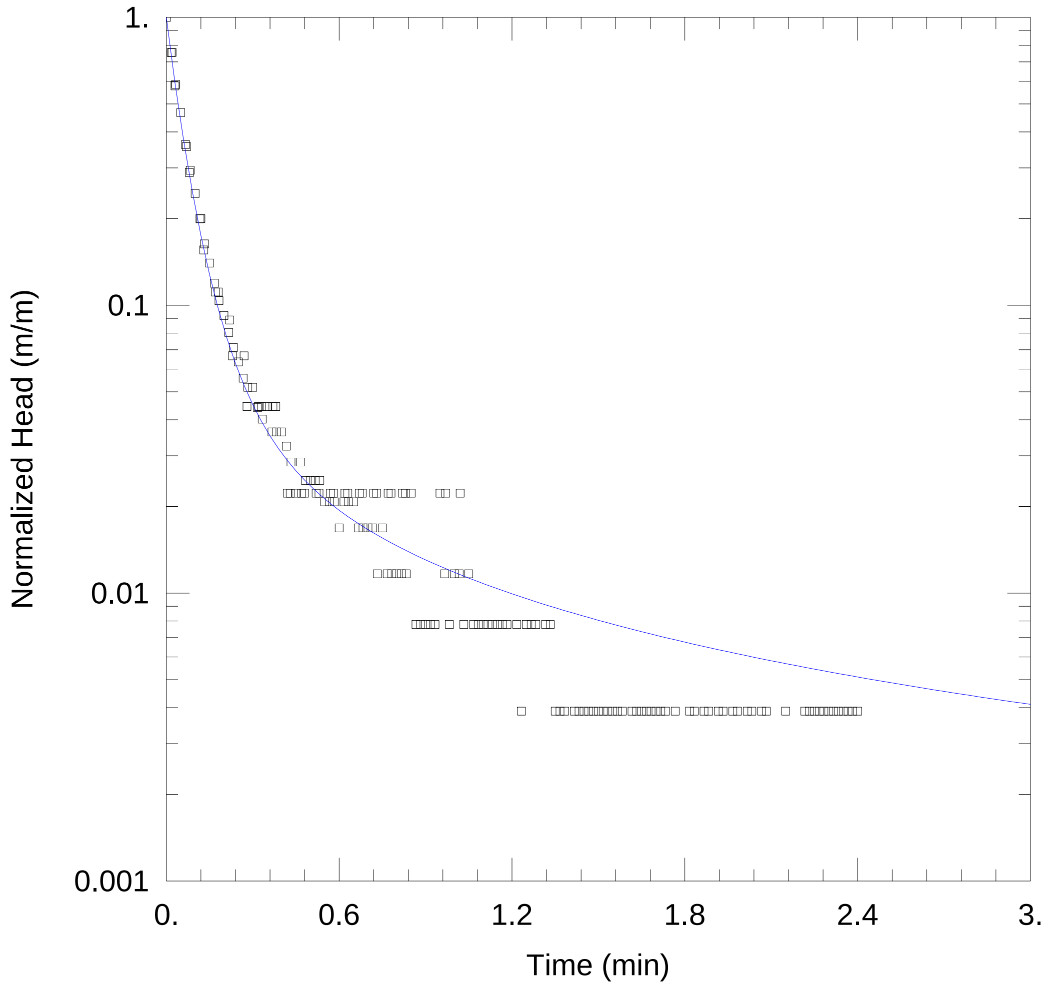
SOLUTION

Aquifer Model: Unconfined

Kr = 5.311 m/day
Kz/Kr = 0.5957
Ss' = 1.413E-6 m^{-1}

Solution Method: KGS Model w/skin

Ss = 0.0232 m^{-1}
Kr' = 0.9163 m/day
Kz/Kr' = 0.4654



SLUG TEST

Data Set: G:\61\12516706\Tech\Hydrogeo\Geotech\Slug tests\aqtesolve\BH07S_kgs.aqt
Date: 04/21/21 Time: 17:07:25

PROJECT INFORMATION

Company: GHD
Client: K+S
Project: 12516706
Location: Onslow
Test Well: BH07S
Test Date: 17/04/2020

AQUIFER DATA

Saturated Thickness: 12.02 m

WELL DATA (BH07S)

Initial Displacement: 0.45 m
Total Well Penetration Depth: 6.295 m
Casing Radius: 0.025 m
Well Skin Radius: 0.09 m

Static Water Column Height: 6.295 m
Screen Length: 6. m
Well Radius: 0.048 m

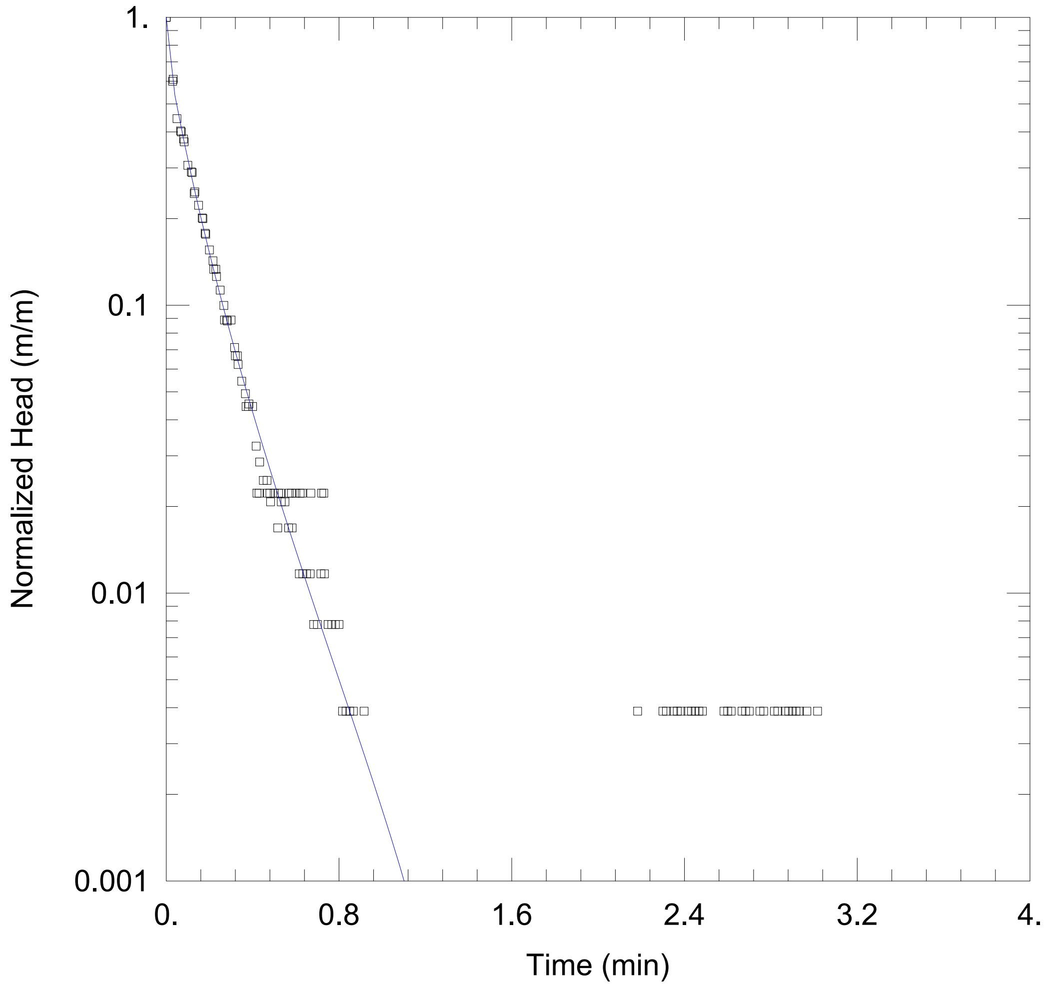
SOLUTION

Aquifer Model: Unconfined

Solution Method: KGS Model w/skin

Kr = 2.736 m/day
Kz/Kr = 0.4217
Ss' = 1.259E-5 m^{-1}

Ss = 0.05635 m^{-1}
Kr' = 0.9401 m/day
Kz/Kr' = 0.309



SLUG TEST

Data Set: C:\...\BH08_kgs.aqt
Date: 05/07/20
Time: 09:02:17

PROJECT INFORMATION

Company: GHD
Client: K+S
Project: 12516706
Location: Onslow
Test Well: BH08
Test Date: 19/04/2020

AQUIFER DATA

Saturated Thickness: 8.48 m

WELL DATA (BH8)

Initial Displacement: 0.45 m
Total Well Penetration Depth: 8.48 m
Casing Radius: 0.025 m
Well Skin Radius: 0.09 m

Static Water Column Height: 8.48 m
Screen Length: 4.5 m
Well Radius: 0.048 m

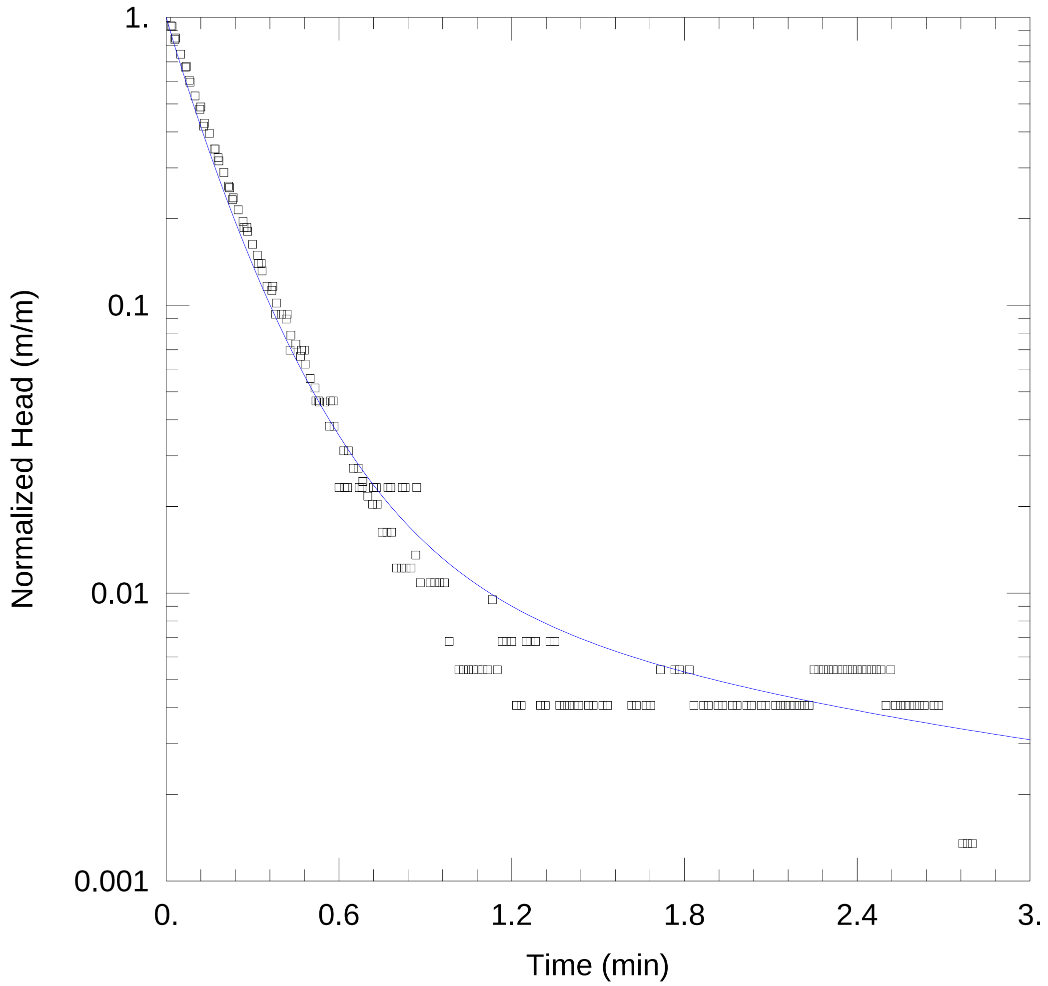
SOLUTION

Aquifer Model: Unconfined

Solution Method: KGS Model w/skin

Kr = 4.675 m/day
Kz/Kr = 1.
Ss' = 0.006183 m^{-1}

Ss = 3.822E-5 m^{-1}
Kr' = 4.221 m/day
Kz/Kr' = 0.001



SLUG TEST

Data Set: G:\61\12516706\Tech\Hydrogeo\Geotech\Slug tests\aqtesolve\BH09D_kgs.aqt
Date: 04/21/21 Time: 17:11:37

PROJECT INFORMATION

Company: GHD
Client: K+S
Project: 12516706
Location: Onslow
Test Well: BH09D
Test Date: 12/04/2020

AQUIFER DATA

Saturated Thickness: 5.95 m

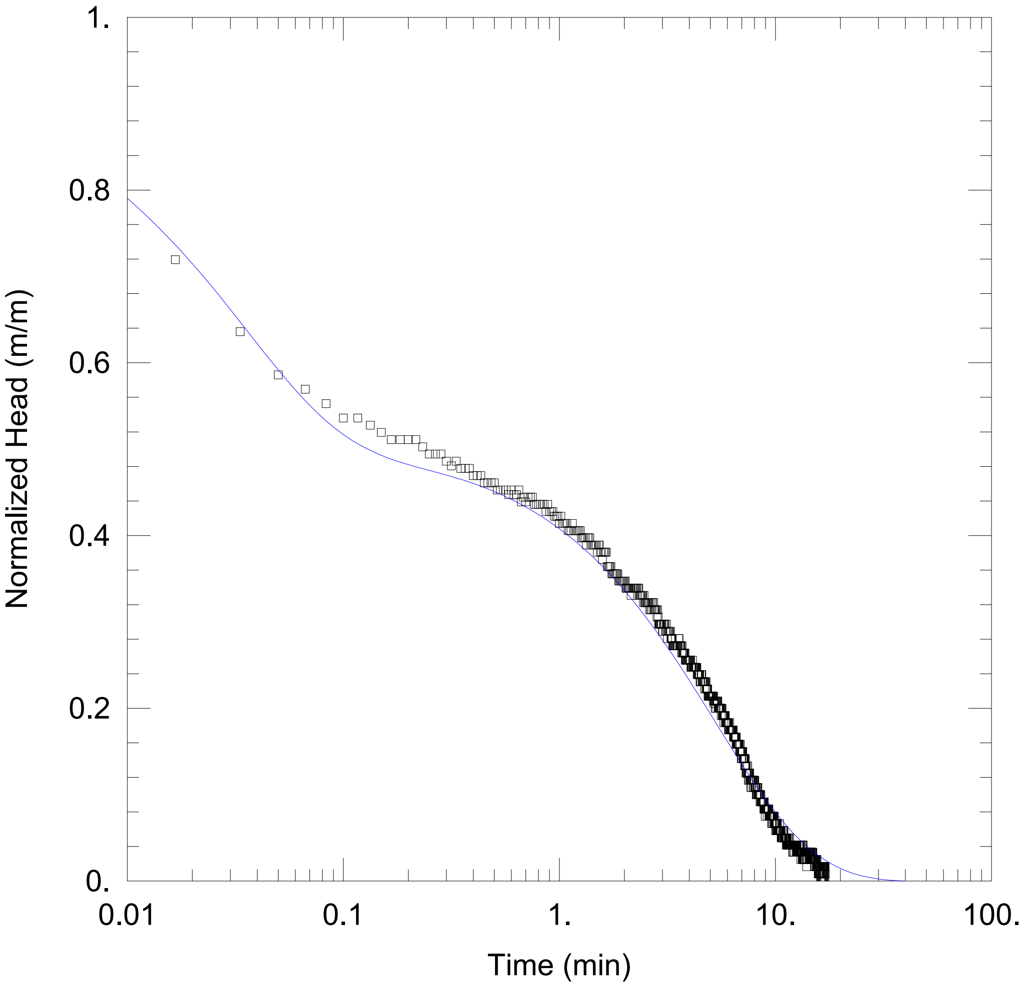
WELL DATA (BH09D)

Initial Displacement: 0.43 m
Total Well Penetration Depth: 5.95 m
Casing Radius: 0.025 m
Well Skin Radius: 0.09 m
Static Water Column Height: 5.95 m
Screen Length: 3. m
Well Radius: 0.048 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: KGS Model w/skin

Kr = 7.87 m/day
Kz/Kr = 0.5957
Ss' = 1.778E-7 m^{-1}
Ss = 0.02517 m^{-1}
Kr' = 0.7991 m/day
Kz/Kr' = 0.3199



SLUG TEST

Data Set: C:\...\BH09S_kgs.aqt
Date: 04/28/20
Time: 14:18:20

PROJECT INFORMATION

Company: GHD
Client: K+S
Project: 12516706
Location: Onslow
Test Well: BH09S
Test Date: 12/04/2020

AQUIFER DATA

Saturated Thickness: 5.95 m

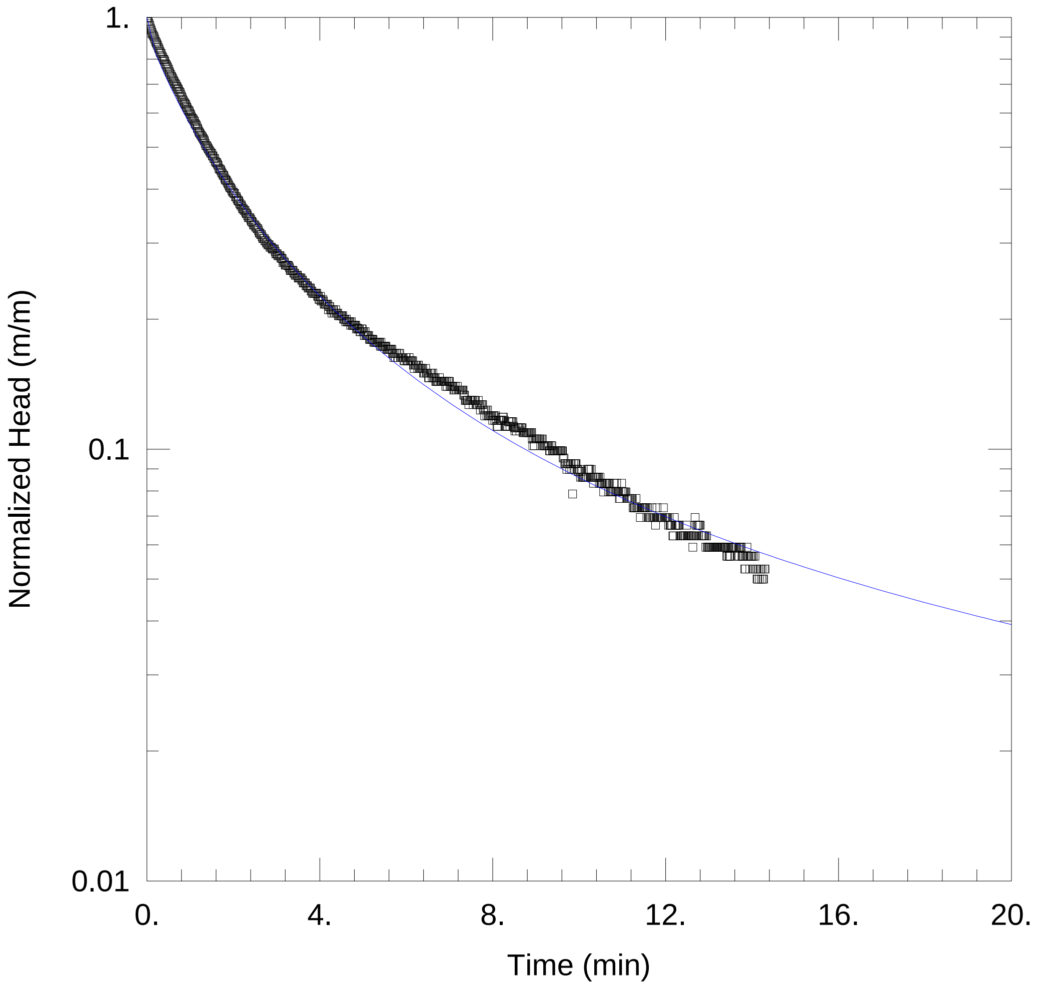
WELL DATA (BH09S)

Initial Displacement: 0.21 m
Total Well Penetration Depth: 2.5 m
Casing Radius: 0.025 m
Well Skin Radius: 0.09 m
Static Water Column Height: 0.06 m
Screen Length: 2.5 m
Well Radius: 0.048 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: KGS Model w/skin

Kr = 0.1707 m/day
Kz/Kr = 1.
Ss' = 0.04436 m^{-1}
Ss = 4.687E-11 m^{-1}
Kr' = 0.8798 m/day
Kz/Kr' = 0.001



SLUG TEST

Data Set: G:\61\12516706\Tech\Hydrogeo\Geotech\Slug tests\aqtesolve\BH11d_kgs.aqt
Date: 04/22/21 Time: 17:25:29

PROJECT INFORMATION

Company: GHD
Client: K+S
Project: 12516706
Location: Onslow
Test Well: BH11D
Test Date: 16/04/2020

AQUIFER DATA

Saturated Thickness: 8.24 m

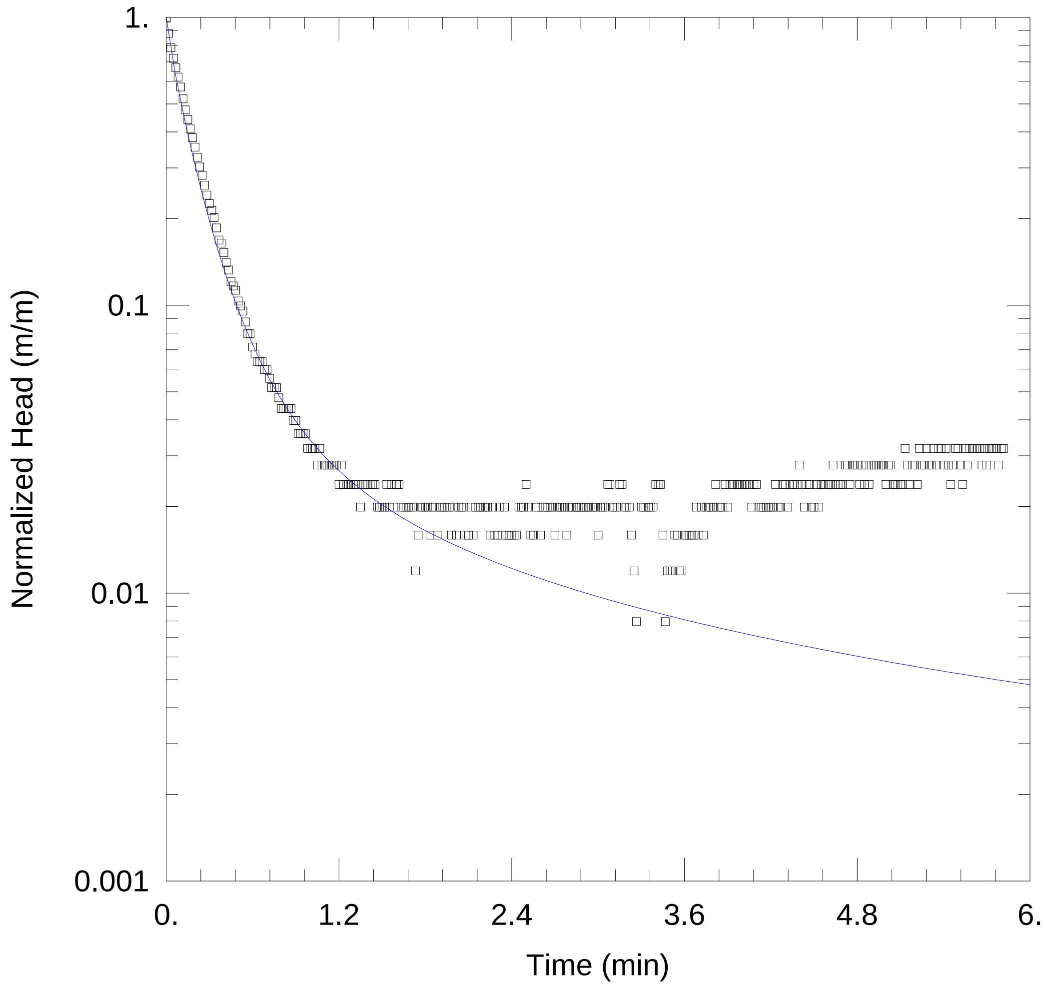
WELL DATA (BH11D)

Initial Displacement: 0.63 m
Total Well Penetration Depth: 8.24 m
Casing Radius: 0.025 m
Well Skin Radius: 0.09 m
Static Water Column Height: 8.24 m
Screen Length: 3. m
Well Radius: 0.048 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: KGS Model w/skin

Kr = 0.09995 m/day
Kz/Kr = 0.4519
Ss' = 0.00966 m^{-1}
Ss = 0.03342 m^{-1}
Kr' = 0.06642 m/day
Kz/Kr' = 1.



SLUG TEST

Data Set: G:\61\12516706\Tech\Hydrogeo\Geotech\Slug tests\aqtesolve\BH11S_kgs.aqt
Date: 04/22/21 Time: 17:31:57

PROJECT INFORMATION

Company: GHD
Client: K+S
Project: 12516706
Location: Onslow
Test Well: BH11S
Test Date: 16/04/2020

AQUIFER DATA

Saturated Thickness: 8.24 m

WELL DATA (BH11S)

Initial Displacement: 0.44 m
Total Well Penetration Depth: 3.74 m
Casing Radius: 0.025 m
Well Skin Radius: 0.09 m

Static Water Column Height: 3.74 m
Screen Length: 3. m
Well Radius: 0.048 m

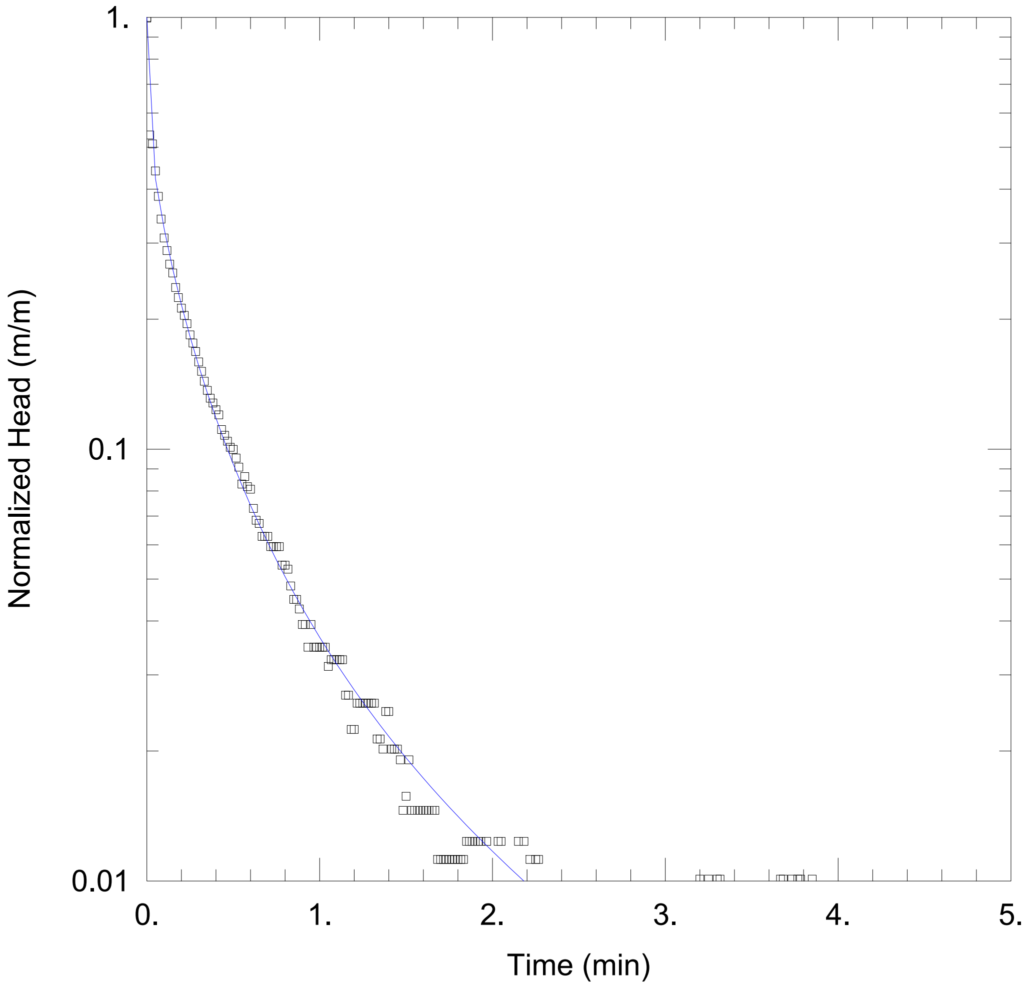
SOLUTION

Aquifer Model: Unconfined

Kr = 2.303 m/day
Kz/Kr = 0.5012
Ss' = 0.007079 m^{-1}

Solution Method: KGS Model w/skin

Ss = 0.08511 m^{-1}
Kr' = 0.6996 m/day
Kz/Kr' = 0.3802



SLUG TEST

Data Set: C:\...\BH12_kgs.aqt
Date: 04/28/20 Time: 15:21:23

PROJECT INFORMATION

Company: GHD
Client: K+S
Project: 12516706
Location: Onslow
Test Well: BH12
Test Date: 16/04/2020

AQUIFER DATA

Saturated Thickness: 1.82 m

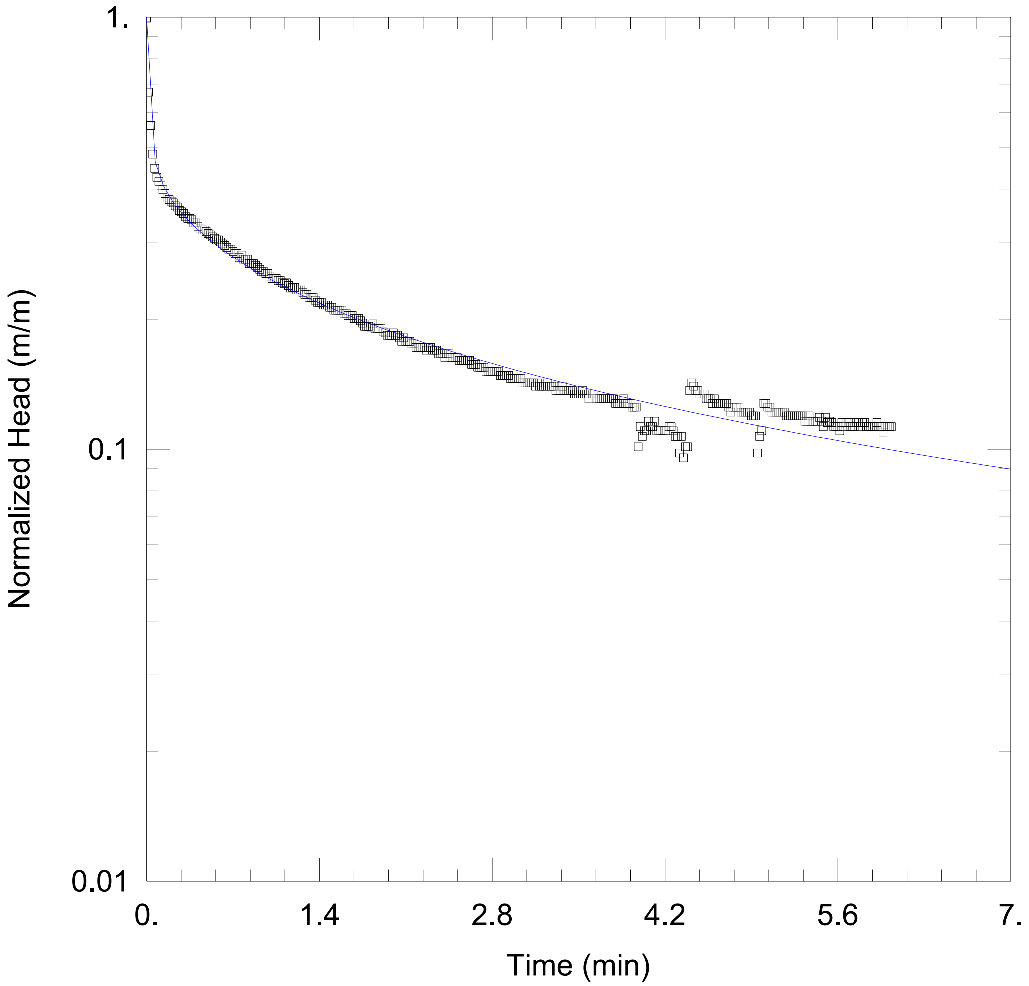
WELL DATA (BH12)

Initial Displacement: 0.52 m
Total Well Penetration Depth: 6. m
Casing Radius: 0.025 m
Well Skin Radius: 0.09 m
Static Water Column Height: 0.52 m
Screen Length: 6. m
Well Radius: 0.048 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: KGS Model w/skin

Kr = 3.706 m/day
Kz/Kr = 1.
Ss' = 0.03962 m^{-1}
Ss = 0.006528 m^{-1}
Kr' = 7.631 m/day
Kz/Kr' = 0.001



SLUG TEST

Data Set: C:\...\BH13_kgs.aqt
Date: 04/28/20
Time: 15:24:55

PROJECT INFORMATION

Company: GHD
Client: K+S
Project: 12516706
Location: Onslow
Test Well: BH13
Test Date: 16/04/2020

AQUIFER DATA

Saturated Thickness: 1.42 m

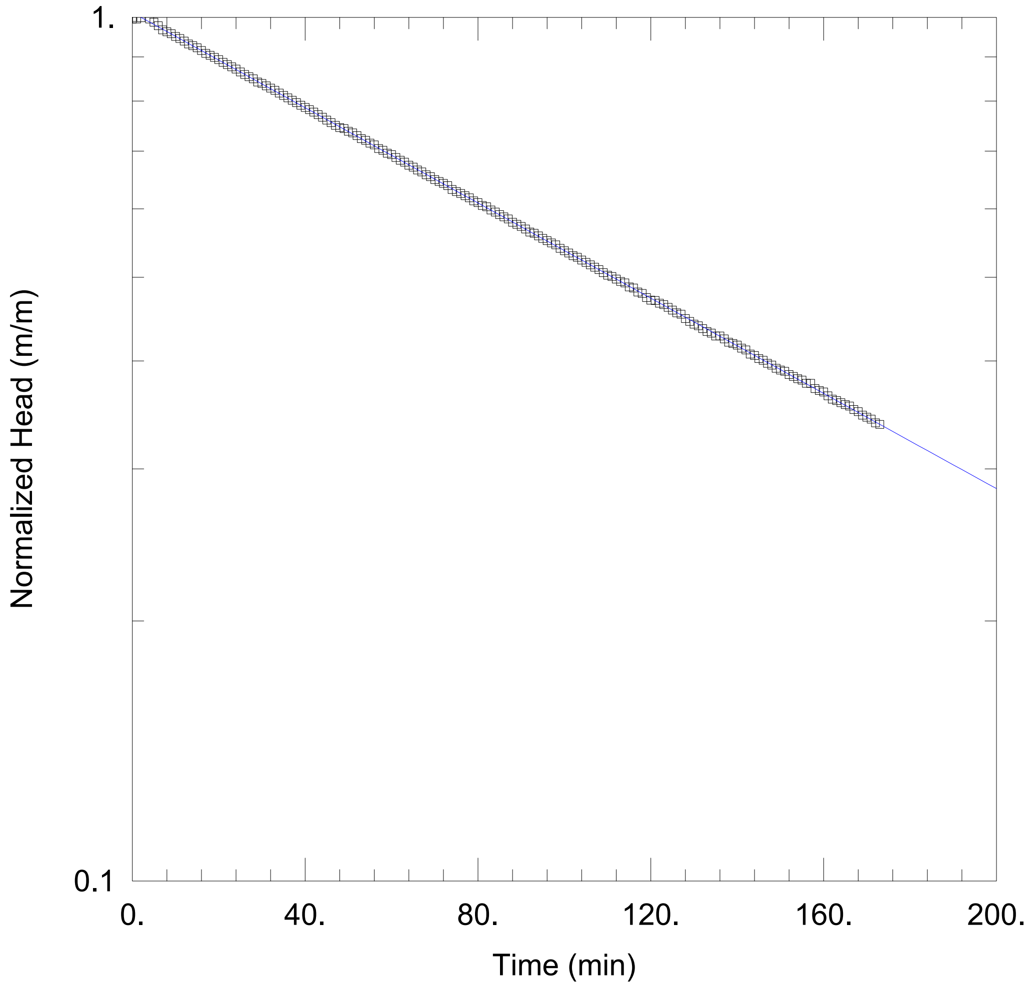
WELL DATA (BH13)

Initial Displacement: 0.71 m
Total Well Penetration Depth: 3. m
Casing Radius: 0.025 m
Well Skin Radius: 0.09 m
Static Water Column Height: 1.42 m
Screen Length: 3. m
Well Radius: 0.048 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: KGS Model w/skin

Kr = 0.1566 m/day
Kz/Kr = 1.
Ss' = 0.07726 m^{-1}
Ss = 0.1059 m^{-1}
Kr' = 3.142 m/day
Kz/Kr' = 0.001



SLUG TEST

Data Set: C:\...\BH14D_br.aqt
Date: 04/28/20
Time: 15:31:12

PROJECT INFORMATION

Company: GHD
Client: K+S
Project: 12516706
Location: Onslow
Test Well: BH14D
Test Date: 16/04/2020

AQUIFER DATA

Saturated Thickness: 13.51 m
Anisotropy Ratio (Kz/Kr): 1.

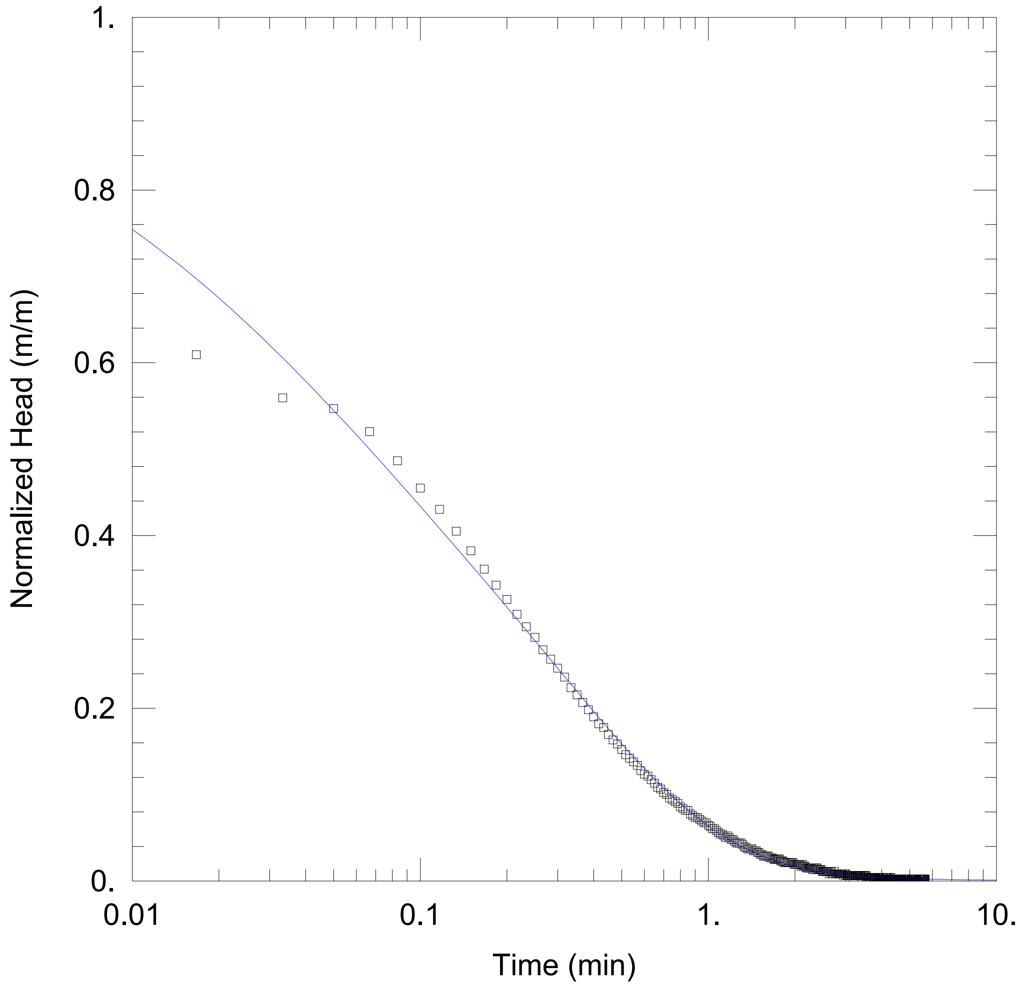
WELL DATA (BH14D)

Initial Displacement: 1.24 m
Total Well Penetration Depth: 13.51 m
Casing Radius: 0.025 m
Static Water Column Height: 13.51 m
Screen Length: 3. m
Well Radius: 0.048 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice

K = 0.003898 m/day
y0 = 1.256 m



SLUG TEST

Data Set: C:\...\BH14S_kgs.aqt
Date: 04/28/20 Time: 15:37:49

PROJECT INFORMATION

Company: GHD
Client: K+S
Project: 12516706
Location: Onslow
Test Well: BH14S
Test Date: 16/04/2020

AQUIFER DATA

Saturated Thickness: 13.51 m

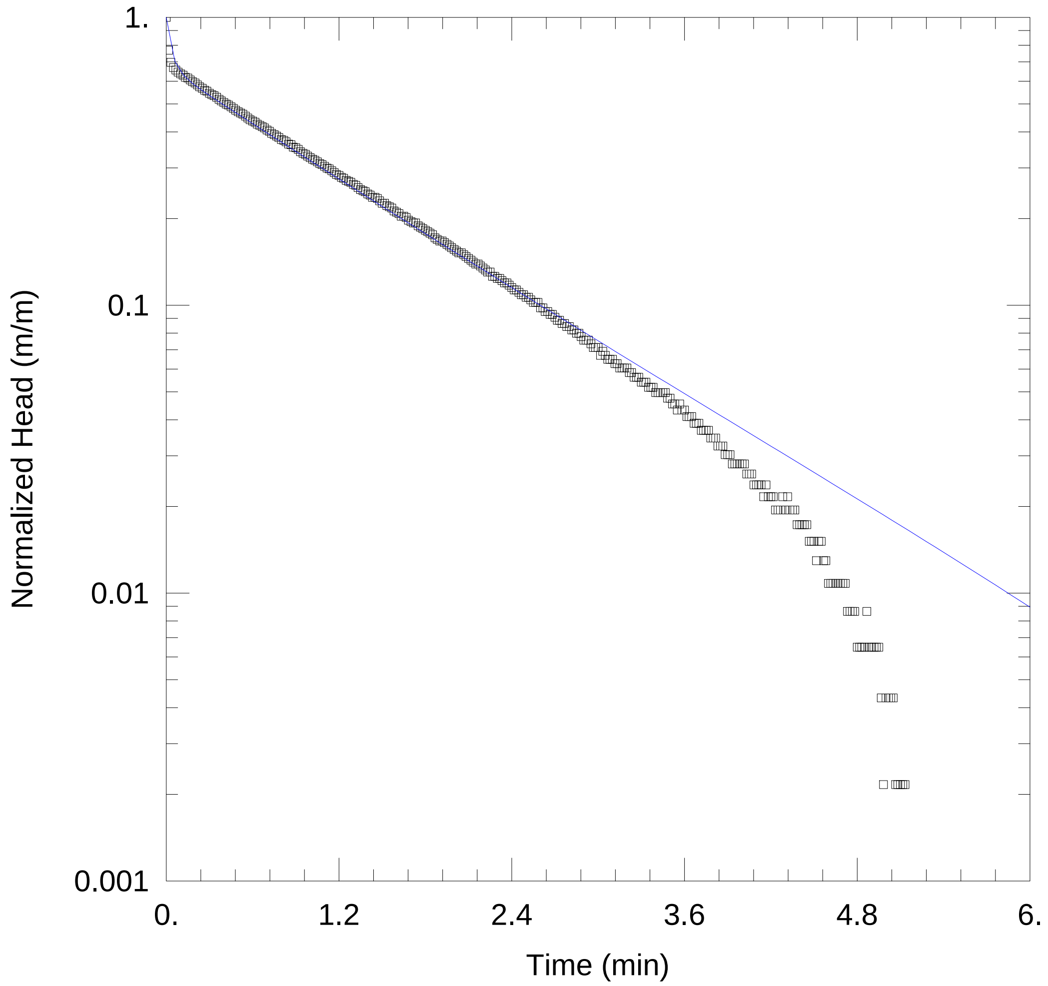
WELL DATA (BH14S)

Initial Displacement: 0.85 m
Total Well Penetration Depth: 5.505 m
Casing Radius: 0.025 m
Well Skin Radius: 0.09 m
Static Water Column Height: 5.505 m
Screen Length: 3. m
Well Radius: 0.048 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: KGS Model w/skin

Kr = 4.888 m/day
Kz/Kr = 1.
Ss' = 0.09022 m^{-1}
Ss = 0.01611 m^{-1}
Kr' = 0.4864 m/day
Kz/Kr' = 0.8056



SLUG TEST

Data Set: G:\61\12516706\Tech\Hydrogeo\Geotech\Slug tests\aqtesolve\BH15D_kgs.aqt
Date: 04/23/21 Time: 09:44:12

PROJECT INFORMATION

Company: GHD
Client: K+S
Project: 12516706
Location: Onslow
Test Well: BH14S
Test Date: 9/04/2020

AQUIFER DATA

Saturated Thickness: 10.58 m

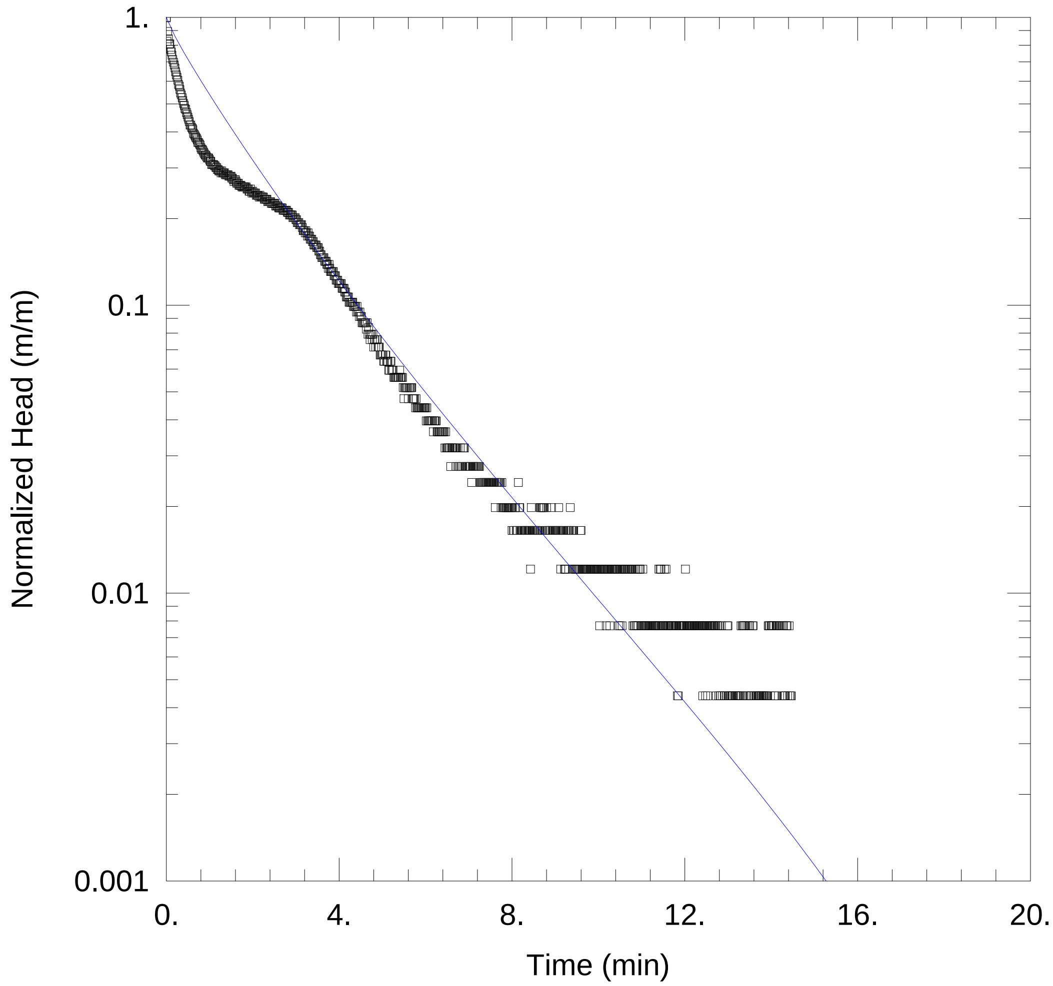
WELL DATA (BH15D)

Initial Displacement: 0.81 m
Total Well Penetration Depth: 10.58 m
Casing Radius: 0.025 m
Well Skin Radius: 0.09 m
Static Water Column Height: 10.58 m
Screen Length: 3. m
Well Radius: 0.048 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: KGS Model w/skin

Kr = 0.8092 m/day
Kz/Kr = 1.
Ss' = 0.02226 m^{-1}
Ss = 1.525E-7 m^{-1}
Kr' = 0.408 m/day
Kz/Kr' = 0.001



SLUG TEST

Data Set: G:\61\12516706\Tech\Hydrogeo\Geotech\Slug tests\aqtesolve\BH15s_kgs.aqt
Date: 04/23/21 Time: 09:35:54

PROJECT INFORMATION

Company: GHD
Client: K+S
Project: 12516706
Location: Onslow
Test Well: BH15S
Test Date: 9/04/2020

AQUIFER DATA

Saturated Thickness: 10.58 m

WELL DATA (BH15S)

Initial Displacement: 0.53 m
Total Well Penetration Depth: 3.69 m
Casing Radius: 0.025 m
Well Skin Radius: 0.09 m
Static Water Column Height: 0.53 m
Screen Length: 3. m
Well Radius: 0.048 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: KGS Model w/skin

Kr = 0.3444 m/day
Kz/Kr = 0.537
Ss' = 2.803E-5 m^{-1}
Ss = 9.834E-5 m^{-1}
Kr' = 0.2045 m/day
Kz/Kr' = 0.3548

Appendix C – Groundwater Quality Data

Location	Field_ID	Sampled Date	EC	TDS (dry)	TDS (sum)	pH (Lab)	Ca	Mg	K	Na	Cl	SO4	F	Alkalinity (as CaCO3)	SiO2	Cations Total	Anions Total	Ionic Balance
			µS/cm	mg/L	mg/L		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	meq/L	meq/L	%
EQL			1	10	10	0	1	1	1	0.5	1	5	0.1	1	0.5	0.01	0.01	0.01
ANZG (2018) - Marine water - 95% level of species protection																		
DER 2014 Non-potable Use (NPUG)											250	1,000	15					
BH02D	BH02D	13/04/2020	92,000	68,000	80,595	6.9	-	-	-	22,000	43,000	8500	-	140	20	-	-	-
		1/09/2020	98,900	-	69,559	7.34	1130	2710	1470	22700.00	34,400	7020	1.6	129	-	1300	1120	7.64
BH02S	BH02S	13/04/2020	81,000	67,000		7.4	-	-	-	18,000	30,000	8400	-	200	43	-	-	-
		1/09/2020	85,700	-	61,779	7.39	1060	2710	1180	19,400	29,100	8200	1.2	129	-	1150	994	7.26
BH03D	BH03D	13/04/2020	44,000	33,000	33,131	7.7	-	-	-	10,000	18,000	2800	-	160	17	-	-	-
		1/09/2020	54,800	-	37,379	7.59	631	1500	662	12,100	19,500	2780	1.5	206	-	698	612	6.57
BH03S	BH03S	13/04/2020	33,000	21,000	20,361	7.7	-	-	-	5900	11,000	1700	-	250	16	-	-	-
		1/09/2020	31,400	-	20,498	7.71	334	763	418	5890	11,300	1520	1.9	273	-	346	356	1.35
BH04	BH04	13/04/2020	110,000	400,000	104,956	7.2	-	-	-	29,000	59,000	7800	-	89	16	-	-	-
		1/09/2020	133,000	-	107,751	7.15	1470	4240	2000	33,700	58,600	7640	0.6	101	-	1940	1810	3.34
BH05D	BH05D	13/04/2020	170,000	180,000	219,252	7	-	-	-	57,000	130,000	9800	-	220	11	-	-	-
BH05S	BH05S	13/04/2020	160,000	240,000	211,338	7	-	-	-	72,000	120,000	11,000	-	170	15	-	-	-
BH07	BH07	13/04/2020	150,000	190,000	172,536	7.1	-	-	-	57,000	100,000	7200	-	150	15	-	-	-
BH07D	BH07D	13/04/2020	160,000	240,000	201,207	7.1	-	-	-	51,000	120,000	8600	-	160	11	-	-	-
		1/09/2020	217,000	-	213,766	6.85	1040	8650	3890	74,500	116,000	9560	0.6	126	-	4100	3470	8.32
BH07S	BH07 Shallow *	1/09/2020	202,000	-	183,762	6.99	1450	6840	2910	61,600	103,000	7850	3.2	112	-	3390	3070	4.92
	BH07S	13/04/2020	160,000	140,000	175,759	6.9	-	-	-	41,000	96,000	18,000	-	160	18	-	-	-
	BH07S Deep *	1/09/2020	220,000	-	222,099	6.84	1170	8540	3820	77,000	123,000	8470	1.3	99	-	4210	3650	7.13
BH08	BH08	13/04/2020	140,000	230,000	133,430	7.2	-	-	-	43,000	76,000	7300	-	110	21	-	-	-
		1/09/2020	182,000	-	163,296	7.07	1480	6210	2680	55,800	89,400	7600	3.6	126	-	3080	2680	6.91
BH09D	BH09D	13/04/2020	130,000	150,000	149,347	7.1	-	-	-	30,000	93,000	4100	-	86	24	-	-	-
		1/09/2020	199,000	-	173,572	6.84	2350	8340	2070	53,500	103,000	4240	3.5	72	-	3180	3000	3.05
BH09S	BH09S	13/04/2020	99,000	86,000	86,325	7.1	-	-	-	23,000	51,000	3500	-	510	37	-	-	-
		1/09/2020	113,000	-	78,431	7.27	2220	3980	1120	24,800	42,800	3430	4.4	81	-	1540	1280	9.39
BH10	BH10	13/04/2020	170,000	300,000	264,436	6.7	-	-	-	94,000	150,000	13,000	-	160	11	-	-	-
BH10D	BH10D	1/09/2020	222,000	-	250,858	6.72	752	11,400	4400	83,900	139,000	11,300	1	106	-	4740	4160	6.51
BH10S	BH10S	13/04/2020	150,000	280,000	286,285	6.7	-	-	-	77,000	170,000	12,000	-	160	12	-	-	-
		1/09/2020	224,000	-	247,472	6.73	779	11,300	4520	84,200	136,000	10,500	0.8	173	-	4750	4060	7.82
BH11D	BH11D	13/04/2020	150,000	200,000	215,682	7.3	-	-	-	49,000	130,000	9200	-	120	9.4	-	-	-
		1/09/2020	224,000	-	268,824	6.68	733	12,100	5290	96,300	142,000	12,300	1	101	-	5360	4260	11.4
BH11S	BH11S	13/04/2020	150,000	200,000	215,454	7.2	-	-	-	45,000	130,000	10,000	-	150	48	-	-	-
		1/09/2020	224,000	-	257,456	6.76	662	11,400	4900	89,600	138,000	12,800	0.8	94	-	4990	4160	9.1
BH12	BH12	13/04/2020	100,000	220,000	95,348	7.3	-	-	-	29,000	56,000	3200	-	690	61	-	-	-
		1/09/2020	126,000	-	94,596	7.11	908	3410	1320	31,200	53,800	3630	1	328	-	1720	1600	3.53
BH13	BH13	13/04/2020	67,000	40,000	61,185	7.2	-	-	-	12,000	37,000	2700	-	290	31	-	-	-
BH14D	BH14D	13/04/2020	170,000	130,000	306,467	6.7	-	-	-	55,000	190,000	11,000	-	150	15	-	-	-
		1/09/2020	221,000	-	234,822	6.78	898	9710	4010	81,800	128,000	10,300	<0.5	104	-	4500	3830	8.13
BH14S	BH14S	13/04/2020	160,000	260,000	262,600	6.9	-	-	-	53,000	160,000	11,000	-	140	8.5	-	-	-
		1/09/2020	221,000	-	236,113	6.76	942	9360	4050	81,800	130,000	9860	0.9	101	-	4480	3870	7.24
BH15	BH15S Deep *	1/09/2020	182,000	-	158,895	7.04	2320	6390	2220	54,500	87,700	5690	<0.5	75	-	3070	2590	8.39
	BH15S Shallow *	1/09/2020	174,000	-	147,378	7.09	2100	5600	1760	48,000	84,400	5450	0.5	68	-	2700	2500	3.91
BH15D	BH15D	13/04/2020	94,000	220,000	246,524	7	-	-	-	68,000	150,000	6000	-	110	16	-	-	-
		1/09/2020	219,000	-	204,351	6.71	1750	8330	3030	70,200	116,000	4970	<0.5	71	-	3900	3380	7.24
BH15S	BH15S	13/04/2020	150,000	130,000	157,302	7	-	-	-	35,000	95,000	6700	-	77	82	-	-	-

Location	Field_ID	Sampled Date	NOx-N	NH4-N	NO3-N	NO2-N	N	P reactive	P	Al	Al (filt)	As (filt)	Cd (filt)	Cr (filt)	Fe	Fe (filt)	Mn (filt)	Ni (filt)	Se (filt)	Zn (filt	SI Anhydrite	SI Gypsum	SI Halite	SI Sylvite	SI Calcite	SI Dolomite	pCO2(g)
			mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L							
EQL			0.01	0.01	0.01	0.01	0.2	0.01	0.01	0.05	0.05	0.001	0.0002	0.001	0.05	0.05	0.005	0.001	0.001	0.005							
ANZG (2018) - Marine water - 95% level of species protection				0.91									0.0055	0.0044				0.07		0.015							
DER 2014 Non-potable Use (NPUG)				0.411	113	9.13				0.2	0.2	0.1	0.02		0.3		5	0.2	0.1	3							
BH02D	BH02D	13/04/2020	-	0.26	-	-	1	<0.01	0.06	1.6	<0.1	<0.01	<0.002	<0.01	3.5	<0.1	0.026	<0.01	<0.01	<0.05	-0.34	-0.08	-1.92	-2.76	0.50	1.74	-2.38
		1/09/2020	<0.05	-	<0.05	<0.01	-	-	-	-	-	-	-	-	-	-	-	-	-	-							
BH02S	BH02S	13/04/2020	-	0.09	-	-	0.4	0.02	0.06	8	0.13	<0.01	<0.002	<0.01	22	0.18	0.082	<0.01	<0.01	<0.05	-0.29	-0.02	-2.07	-2.93	0.49	1.75	-2.42
		1/09/2020	<0.05	-	<0.05	<0.01	-	-	-	-	-	-	-	-	-	-	-	-	-	-							
BH03D	BH03D	13/04/2020	-	0.02	-	-	1.1	0.01	0.03	0.96	<0.5	<0.01	<0.002	<0.01	1.9	<0.5	1.2	<0.01	<0.01	<0.05	-0.78	-0.49	-2.45	-3.34	0.75	2.21	-2.37
		1/09/2020	<0.05	-	<0.05	<0.01	-	-	-	-	-	-	-	-	-	-	-	-	-	-							
BH03S	BH03S	13/04/2020	-	0.19	-	-	0.5	<0.01	0.16	2	<0.5	<0.01	<0.002	<0.01	11	<0.5	0.13	<0.01	<0.01	<0.05	-1.08	-0.78	-2.98	-3.74	0.82	2.33	-2.32
		1/09/2020	<0.05	-	<0.05	<0.01	-	-	-	-	-	-	-	-	-	-	-	-	-	-							
BH04	BH04	13/04/2020	-	0.04	-	-	3.9	<0.01	0.12	11	<0.5	<0.01	<0.002	0.024	29	<0.5	<0.05	<0.01	<0.01	<0.05	-0.24	0.00	-1.44	-2.35	0.42	1.70	-2.33
		1/09/2020	1.04	-	0.98	0.06	-	-	-	-	-	-	-	-	-	-	-	-	-	-							
BH05D	BH05D	13/04/2020	-	5.2	-	-	4	0.01	0.09	1.5	<0.5	<0.01	<0.002	<0.01	2.9	<0.5	6.1	0.013	<0.01	0.09	0.59	0.69	-0.47	-1.38	1.58	4.17	-2.05
BH05S	BH05S	13/04/2020	-	2	-	-	2	<0.01	0.11	6.7	<0.5	<0.01	<0.002	<0.01	22	0.13	2.9	<0.01	<0.01	0.062	0.18	0.32	-0.50	-1.89	1.00	2.98	-2.04
BH07	BH07	13/04/2020	-	0.05	-	-	3.2	<0.01	0.12	1.6	0.11	<0.01	<0.002	<0.01	2.4	0.13	0.23	<0.01	<0.01	<0.05							
BH07D	BH07D	13/04/2020	-	0.3	-	-	0.7	<0.01	0.17	2.6	<0.5	<0.01	<0.002	<0.01	5.3	<0.5	3.8	<0.01	<0.01	0.061	-0.04	0.06	-0.38	-1.52	0.51	2.38	-2.18
		1/09/2020	<0.05	-	<0.05	<0.01	-	-	-	-	-	-	-	-	-	-	-	-	-	-							
BH07S	BH07 Shallow *	1/09/2020	1.5	-	1.5	<0.01	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-0.11	0.05	-0.71	-1.81	0.62	2.37	-2.22
	BH07S	13/04/2020	-	0.23	-	-	1.1	<0.01	0.14	3.3	<0.5	<0.01	<0.002	<0.01	5.7	<0.5	0.39	<0.01	<0.01	0.025							
	BH07S Deep *	1/09/2020	<0.05	-	<0.05	<0.01	-	-	-	-	-	-	-	-	-	-	-	-	-	-							
BH08	BH08	13/04/2020	-	0.65	-	-	2.6	<0.01	0.11	2.9	0.1	<0.01	<0.002	<0.01	5.4	0.25	0.97	0.04	<0.01	0.057	-0.17	0.00	-0.88	-1.96	0.66	2.38	-2.22
		1/09/2020	5.7	-	5.67	0.03	-	-	-	-	-	-	-	-	-	-	-	-	-	-							
BH09D	BH09D	13/04/2020	-	0.35	-	-	1.9	0.01	0.05	9.2	<0.1	<0.01	0.0023	<0.01	21	<0.1	0.68	<0.01	<0.01	<0.05	-0.17	0.01	-0.78	-1.96	0.52	2.03	-2.24
		1/09/2020	0.32	-	0.2	0.12	-	-	-	-	-	-	-	-	-	-	-	-	-	-							
BH09S	BH09S	13/04/2020	-	0.12	-	-	2.7	<0.01	0.05	200	<0.1	<0.01	0.0009	0.021	490	<0.1	0.007	<0.01	0.009	<0.05	-0.40	-0.13	-1.75	-2.75	0.56	1.74	-2.53
		1/09/2020	1.84	-	1.8	0.04	-	-	-	-	-	-	-	-	-	-	-	-	-	-							
BH10	BH10	13/04/2020	-	2.3	-	-	1.7	<0.01	0.09	<0.5	<0.5	<0.01	0.0021	<0.01	<0.05	0.07	3.6	<0.01	<0.01	<0.05							
BH10D	BH10D	1/09/2020	0.58	-	0.4	0.18	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.01	0.08	-0.15	-1.31	0.35	2.45	-2.11
BH10S	BH10S	13/04/2020	-	0.76	-	-	0.8	<0.01	0.04	0.65	<0.1	<0.01	0.0031	<0.01	1.2	<0.1	16	0.021	0.004	0.1	-0.03	0.04	-0.17	-1.32	0.58	2.86	-1.90
		1/09/2020	0.61	-	0.28	0.33	-	-	-	-	-	-	-	-	-	-	-	-	-	-							
BH11D	BH11D	13/04/2020	-	0.53	-	-	1	0.02	0.08	1	<0.1	<0.01	0.0024	<0.01	2.1	<0.1	2.9	0.026	<0.01	0.18	0.07	0.11	0.02	-1.15	0.32	2.44	-2.15
		1/09/2020	<0.05	-	<0.05	<0.01	-	-	-	-	-	-	-	-	-	-	-	-	-	-							
BH11S	BH11S	13/04/2020	-	0.07	-	-	5.4	<0.01	0.11	4.3	0.12	<0.01	0.0022	<0.01	9.5	0.13	6.4	0.029	<0.01	0.14	-0.01	0.06	-0.09	-1.24	0.26	2.33	-2.24
		1/09/2020	<0.05	-	<0.05	<0.01	-	-	-	-	-	-	-	-	-	-	-	-	-	-							
BH12	BH12	13/04/2020	-	6	-	-	6	<0.01	0.11	9	<0.5	<0.01	<0.002	<0.01	53	<0.5	8.1	0.017	<0.01	<0.05	-0.75	-0.47	-1.53	-2.55	0.66	2.25	-1.78
		1/09/2020	<0.05	-	<0.05	<0.02	-	-	-	-	-	-	-	-	-	-	-	-	-	-							
BH13	BH13	13/04/2020	-	0.89	-	-	1.2	<0.01	0.1	3.6	<0.5	<0.01	<0.002	<0.01	25	<0.5	41	0.054	<0.01	<0.05	-0.53	-0.27	-2.16	-2.57	1.00	2.83	-1.88
BH14D	BH14D	13/04/2020	-	0.14	-	-	0.4	<0.01	0.03	0.99	<0.5	<0.01	<0.002	<0.01	1.9	1.4	5.2	0.011	<0.01	0.057	-0.05	0.05	-0.27	-1.43	0.39	2.33	-2.14
		1/09/2020	<0.05	-	<0.05	<0.01	-	-	-	-	-	-	-	-	-	-	-	-	-	-							
BH14S	BH14S	13/04/2020	-	0.26	-	-	0.6	<0.01	0.07	0.92	0.17	<0.01	0.0033	<0.01	8.5	0.28	2.1	0.013	<0.01	0.13	-0.03	0.07	-0.26	-1.42	0.40	2.31	-2.12
		1/09/2020	<0.05	-	<0.05	<0.01	-	-	-	-	-	-	-	-	-	-	-	-	-	-							
BH15	BH15S Deep *	1/09/2020	8.88	-	8.83	0.05	-	-	-	-	-	-	-	-	-	-	-	-	-	-							
	BH15S Shallow *	1/09/2020	8.25	-	8.2	0.05	-	-	-	-	-	-	-	-	-	-	-	-	-	-							
BH15D	BH15D	13/04/2020	-	<0.1	-	-	6.7	<0.01	0.06	<0.1	<0.1	<0.01	0.0067	<0.01	<0.1	<0.1	1.1	0.013	0.011	0.093	-0.18	-0.01	-0.50	-1.65	0.34	1.82	-2.17
		1/09/2020	6.94	-	6.89	0.05	-	-	-	-	-	-	-	-	-	-	-	-	-	-							
BH15S	BH15S	13/04/2020	-	0.04	-	-	11	0.02	0.15	11	<0.1	<0.01	0.004	0.12	28	<0.1	0.21	0.013	0.015	<0.05	-0.21	0.03	-1.01	-2.16	0.50	1.84	-2.50

*Note: * sampled at upper and lower portions of the well; "filt" means filtered; "SI" saturation index calculated by PHREEQC using Pitzer database*

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https://projectsportal.ghd.com/sites/pp18_05/kssaltphase2investig/ProjectDocs/HydroGeo/12516706-REP-2-Hydrogeoluguical Investigation Report.docx

Document Status

Revision	Author	Reviewer		Approved for Issue		
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