walker

TOONDAH HARBOUR

CHAPTER 10

GROUNDWATER

saunders havill group

10. Groundwater

10.1. Introduction

The Groundwater technical studies were completed by Australasian Groundwater and Environmental Consultants Pty Ltd (AGE) and are included as Appendix 2-H. Details of the key personnel involved in the study are provided in Appendix 1-F.

10.1.1 Scope of Study

Specific requirements for the groundwater assessment to address the EPBC Act EIS Guidelines and other legislative requirements include:

a) Collect, present and summarise relevant hydrogeological data to produce a hydrogeological conceptual model for the Project footprint;
b) Identify potential groundwater impact risks using interpretation on the outcomes of the conceptual model;
c) Assess excavation dewatering and containment wall on groundwater levels;
d) Discussion of impacts related to the historical landfill, groundwater users and mapped groundwater dependant ecosystems (GDEs);
e) Discussion of mitigation measures to minimise the risk of impacts to groundwater;
f) Overview of monitoring plan including location and parameters to be monitored.

10.1.2 Activities that May Result in Impacts

Groundwater could be impacted through a number of Project activities. These include:

- Reclamation and maritime construction works:
  - Installation of permanent and temporary sheet piling for the bund walls which result in changes to groundwater interaction between terrestrial areas and Moreton Bay;
  - Dewatering of the bunded area;
  - Reclamation which will replace previous intertidal mudflat and mangrove habitats with a landform above tidal limits potentially changing existing groundwater interaction with Moreton Bay;
  - Potential for spills of fuel and other chemicals creating areas of contamination that may enter the groundwater system.

- Dredging:
  - Removal of sub-tidal and intertidal areas through expansion and deepening of the existing Fison Channel and turning basin potentially changing existing groundwater interaction with Moreton Bay;
  - Potential for spills of fuel and other chemicals creating areas of contamination that may enter the groundwater system.

- Building and civil works (onshore and within the reclamation):
  - Disturbance of potentially contaminated materials within the Project footprint including historical landfill areas under sections of GJ Walter Park;
  - Potential for spills of fuel and other chemicals creating areas of contamination that may enter the groundwater system

10.2. Assessment Methodology

Desktop and field investigations were conducted to characterise the groundwater regime at Toondah Harbour. These investigations included:

- Desktop assessment comprising:
  - A detailed review of available relevant studies in the Project footprint;
  - Publicly available environmental data and maps;
  - A review of Queensland Department of Resources (DoR) groundwater database records to assist in understanding regional groundwater regime and identify groundwater users; and
- Site investigations at Toondah Harbour to obtain hydrogeological data to provide a detailed characterisation of the groundwater regime in the Project footprint and vicinity which included:
  - Conducting groundwater exploration drilling within identified aquifer bearing units to assess yields and saturated thickness;
  - Constructing monitoring bores for water level and water quality measurement;
  - Collecting groundwater data from completed bores.

Data was collated from the desktop studies and site assessments to develop a conceptual understanding of the hydrogeology. This section provides an overview of the methods of investigation to collect data for this groundwater study.

10.2.1 Desktop Methods

A review was undertaken to collect relevant data from the DoR groundwater database and previous studies in the area with comparable geological and environmental settings to support the development of the hydrogeological regime. Desktop review and data collation was completed for the following sources within a 3 km radius from the Project footprint:

- Rainfall data (BOM, 2021);
- Tidal levels;
- Drainage and catchment mapping;
- State geological maps;
- Groundwater dependent ecosystems; and
- Registered groundwater bores, which includes:
  - Location;
  - Groundwater levels;
  - Bore construction details;
  - Stratigraphic logs.

Previous site-specific investigation reports commissioned at Toondah Harbour were also reviewed. Relevant geological and hydrogeological information from these studies was then used to inform the conceptual understanding of the groundwater regime as discussed in this section.

10.2.2 Field Methods

In April 2020, nine investigation boreholes were drilled and completed as groundwater monitoring bores within the inland portion of the PDA (Figure 10-1) under the direction of AGE to support hydrogeological conceptualisation of the Project footprint. The bores were installed within Quaternary sediments and the underlying Petrie Formation (basalt) with a focus on providing paired, nested sites that monitor and compare the deeper and shallower formations within the same location. This approach allows for comparison and determination of water quality and groundwater flow direction in the vertical direction in addition to flows in the horizontal flow direction. This design of the monitoring bore network is a key component to the conceptualisation of flow and groundwater discharge discussed in later sections.

Geological descriptions, barometric measurements, groundwater data and in-situ downhole hydraulic (permeability) testing data were collected from the initial construction and ongoing monitoring of these bores. Five groundwater quality sampling events have occurred between April 2020 and December 2021.

In-situ measurements of pH, electrical conductivity, redox and dissolved oxygen were taken during groundwater sampling. Redox and dissolved oxygen were analysed only during the December 2021 sampling event. The groundwater samples were analysed at NATA certified Laboratory for an extensive suite of parameters. The parameters can be divided into the following groups; standard laboratory parameters (electrical conductivity, pH, alkalinity), major ions (sodium, magnesium, potassium, calcium, carbonate, bicarbonate, chloride, sulfate), total and dissolved metals (19 parameters), nutrients, BTEX, phenolic compounds, polynuclear aromatic hydrocarbons (PAH), total petroleum hydrocarbons (TPH) and total recoverable hydrocarbons (TRH). Nutrients were analysed only during the December 2021 sampling event.

A fieldwork report providing results of the investigations is provided as an attachment to Appendix 2-H. Bore location, drilling and construction details of the installed monitoring bores are summarised in Table 10-1.

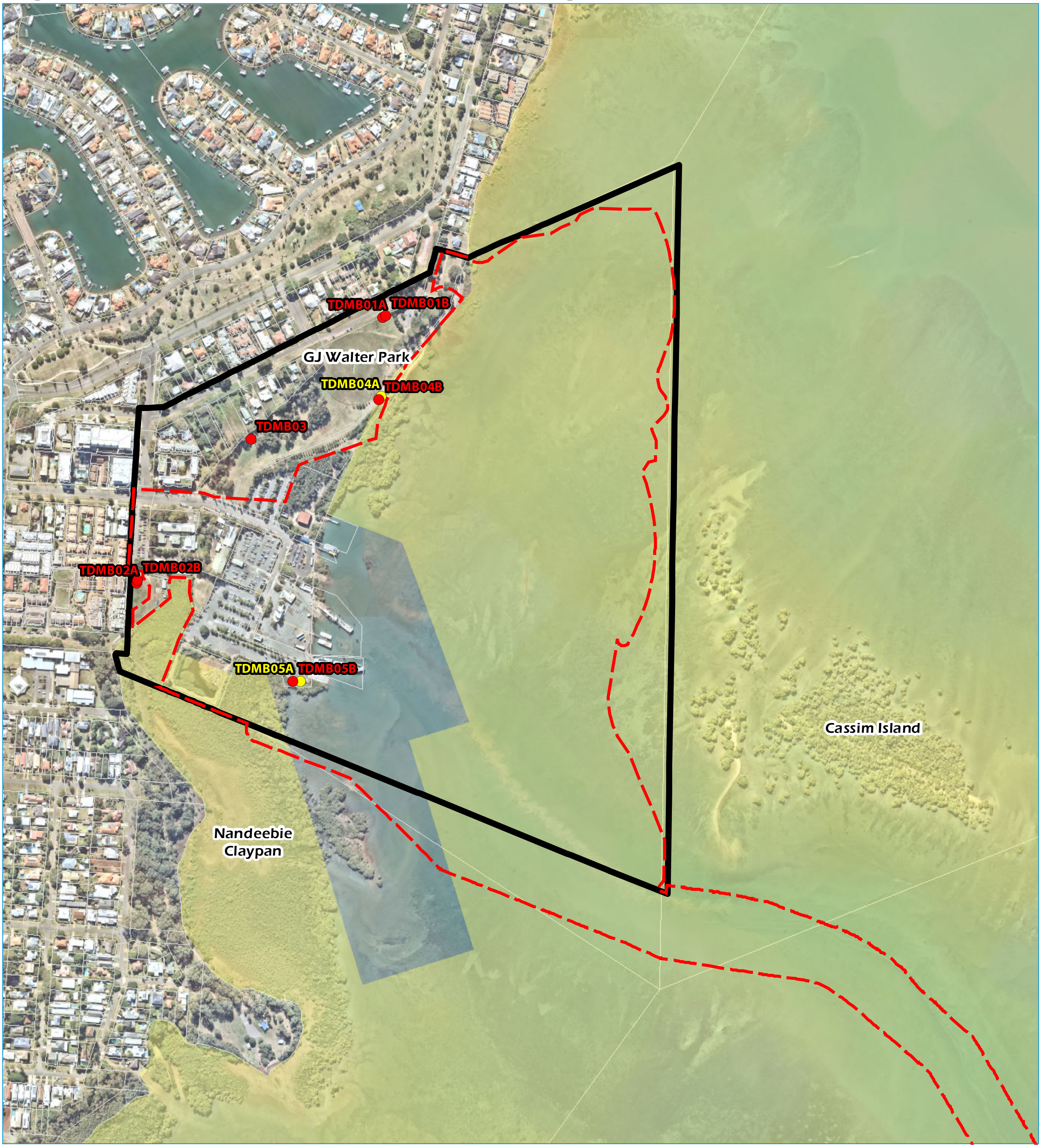
Table 10-1: Groundwater Monitoring Bore Details.

Bore ID	Date drilled	Easting (m E) GDA94	Northing (m N) GDA94	Surveyed well cap elevation (mAHD)	Drilled depth (mbgl)	Screen interval (mbgl)	Screened geology
TDMB01A	43899	528184	6955485	2.26	8	3-6	Basalt (weathered)
TDMB01B	43898	528189	6955488	2.3	25	22-25	Basalt (fresh rock)
TDMB02A	43904	527792	6955061	2.99	6	1-4	Basalt (weathered)
TDMB02B	43904	527793	6955066	3.01	15	7.2-10.2	Basalt (weathered)
TDMB03	43896	527974	6955291	1.95	10.1	7-10	Basalt (weathered)
TDMB04A	43896	528181	6955359	1.57	10	2-5	Quaternary sediments (sand/clay)
TDMB04B	43897	528178	6955354	1.63	15	10-13	Basalt (weathered)
TDMB05A	43906	528053	6954905	2.1	8	1-4	Quaternary sediments (fine sand/ sandy clay)
TDMB05B	43905	528041	6954905	2.12	20	13-16	Basalt (weathered)

10.2.3 Excavation Dewatering Investigation

An assessment has been undertaken as part of this groundwater assessment to evaluate the impacts of excavation dewatering on groundwater levels on the landward side of the excavation containment (sheet piling) wall. A two-dimensional (2D) groundwater numerical model using GeoStudio SeepW software was used to simulate groundwater flow behaviour and determine the extent of groundwater drawdown or alternately mounding upslope from the sheet piling wall within GJ Walter Park during and post excavation. The model was also used to determine flux through the sheet piling wall.

Figure 10 -1: Groundwater Monitoring Bore Locations



Toondah Harbour EIS

Legend

- Toondah Harbour PDA
- Qld DCDB
- Moreton Bay Ramsar site
- Project area/footprint

Groundwater Monitoring Locations

- Petrie formation
- Quaternary sediments

0 100 200 300 400 m

GDA 1994 MGA zone 56 Scale (A4): 1:8,600

10.3. Existing Values – Conceptual Groundwater Model

A conceptual groundwater model is a simplified representation of the natural groundwater system and shows the hydrogeological framework and water input and outputs processes. This section discusses components of the conceptual hydrogeological model such as aquifers units, groundwater levels, flow direction, hydraulic properties, recharge and discharge processes, water quality and groundwater use. The description of the conceptual model is based on the interpretation of groundwater data from field investigations and relevant historical studies for the Project.

Cross sections of the conceptual hydrogeological model of the existing environment have been developed for the Project footprint. The conceptual model is mainly based on the results of the field investigation and desktop studies completed for the Project. A summary of information assessed to develop the conceptual model is provided below.

10.3.1 Geology

The major geological units in the Project footprint are delineated on the Beenleigh 1:100,000 geology sheet. These are, from youngest to oldest:

- Quaternary aged terrestrial and marine sediments consisting of unconsolidated muds, marine clays, silts, sands and gravel;
- Tertiary aged Petrie Formation comprising primarily weathered olivine basalt in Project footprint; and
- Triassic aged Woogaroo subgroup, consisting of sedimentary sandstone, siltstone and conglomerates.

The regional surface geology depicting these units is provided in Section 2.1.4 of the EIS.

10.3.2 Hydrostratigraphic Units

The geological units are grouped into the following hydrostratigraphic units based on their ability to store and transmit groundwater:

- Quaternary sediments deposits which can be sub-categorised as follows:
  - Low energy coastal marine and intertidal sediments predominantly comprising fine grained sediments of low permeability generally forming aquitards;
  - Terrestrial clays, silts and sands of variable permeability with sands providing localised minor thin aquifer lenses; and
- Tertiary basalts comprising:
  - Upper weathered layer of moderate to high permeability which store and transmit water within weathered fracture networks or contact zone between basalt flow layers and within vesicular layers;
  - Underlying fresh rock of low permeability and lower storage, except permeability maybe enhanced along discrete fracture networks.

Underlying Triassic metasediments of the Woogaroo Group contain significant aquifer systems within porous sandstone units which are separated by low permeable siltstone and claystone units.

The main aquifer close to surface which has the potential to be impacted by Project activities is the Tertiary basalts of the Petrie Formation. The Woogaroo Group aquifer units are unlikely to be impacted due to their depth of over 50 m below ground level.

In general, Quaternary terrestrial sediments are slightly more permeable that the underlying weathered Petrie Formation due to larger proportion of sands.

10.3.3 Groundwater Levels and Flow Directions

Conceptual model sections have been developed across the Project footprint to present the relationship of groundwater levels and flow direction for the hydrostratigraphic units. The location of conceptual cross-sections are provided in plan view in Figure 10-2 and the cross-sections are presented in Figure 10-3 and Figure 10-4. The water levels and geological information has been informed primarily by the recent field groundwater investigations and historical geotechnical assessments. Bores labelled with a prefix of TDMB were investigated by AGE. Bores with a prefix of 'BH' were investigated by Structerre (2014) while bores with a prefix of 'RO' were investigation by DTMR (2013). The cross sections are described below:

- 'A-A' intersects the nested monitoring bores TDMB02A/B and TDMB05A/B from the western boundary of the Toondah Harbour PDA towards the coast and extends across the southern reclamation area within the PDA; and
- 'B-B' intersects monitoring bores TDMB03 and the nested monitoring bores TDMB04A/B from the western boundary of the PDA towards the coast and extends across the northern reclamation area within the PDA.

10.3.3.1 *Quaternary Sediments*

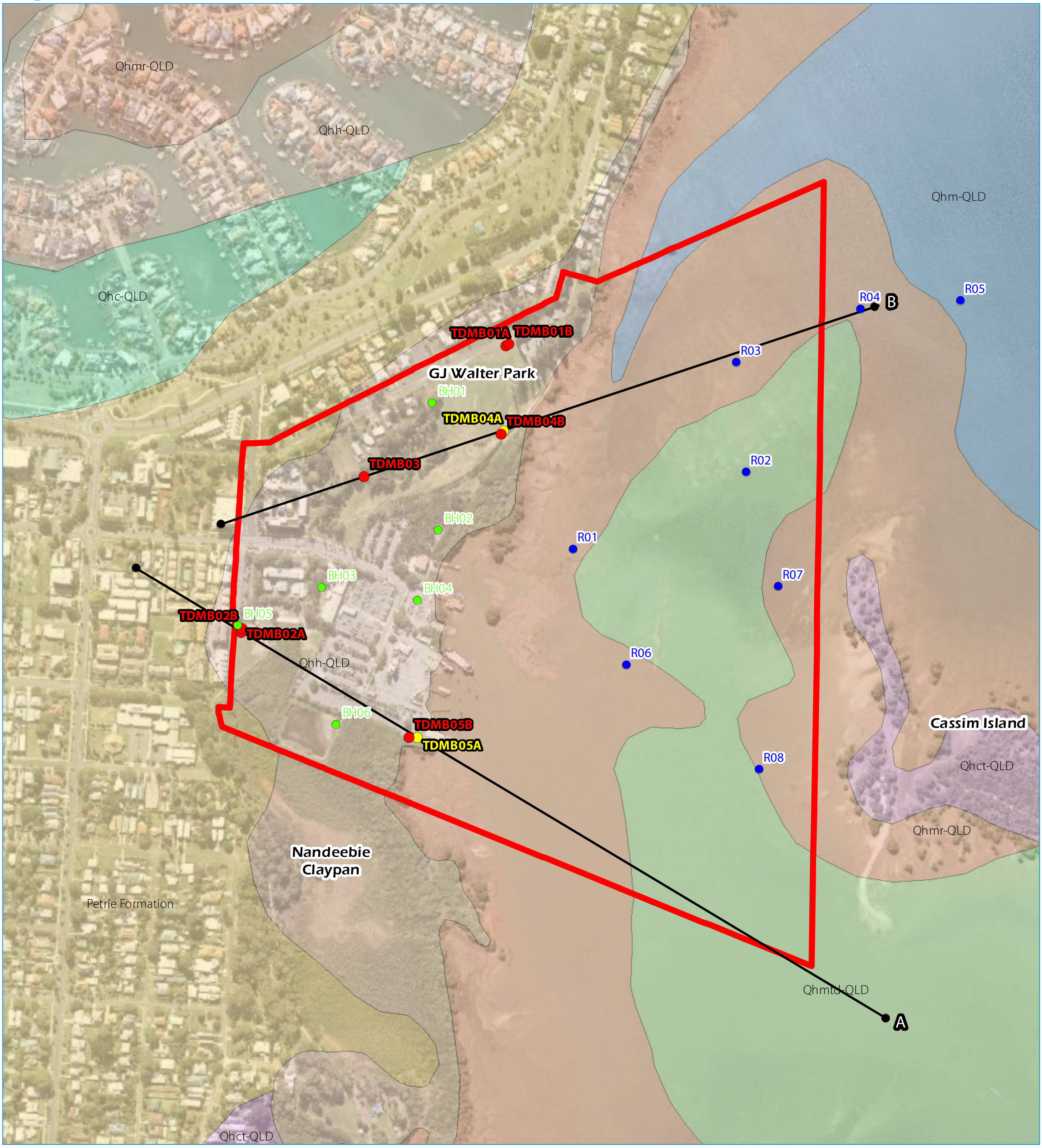
Groundwater levels have been measured in bores TDMB04A and TDMB05A, which are both screened in the Quaternary sediments. Groundwater level contours have not been generated due to limited occurrence of terrestrial Quaternary sediments within and surrounding the PDA. Given the limited extent and thickness of the Quaternary sediments, groundwater saturation in the Quaternary will gradually decrease inland in GJ Walter Park, and in this case, the underlying Petrie formation will host the water table. During site investigations, the bores TDMB02 and TDMB03 (located further inland) were drilled and screened towards the edge of the mapped Quaternary sediments. Both bores had limited to no saturated thickness in the Quaternary at the time of drilling and were therefore screened in the underlying Petrie formation.

Groundwater levels have been measured by automated loggers within TDMB04A and TDMB05A from April 2020 to early December 2021. Groundwater levels in these bores are greater than 0.7 m AHD which is higher than mean sea level (MSL) of 0.04 m AHD, and so the flow direction is toward the coast as shown on Figure 10-3 and Figure 10-4.

The water level fluctuations of the Quaternary sediments show influences from tidal changes, barometric changes and rainfall recharge. The relationships of these influences with groundwater levels are summarised below:

- Groundwater levels show sinusoidal fluctuations (repetitive waves) which strongly correlate with rising and falling tides at Toondah Harbour. Normalised water levels from TDMB04A and TDMB05A in the Quaternary sediments may show fluctuations generally ranging from 0.5 to 0.7 m in amplitude. The bore TDMB05A shows a stronger response to the tidal effects, and this is likely due to its closer proximity to the coast compared to TDMB04A.
- Depth to groundwater in the Quaternary sediments is typically shallow ranging from 0.5 to 1.0 mbgl. Due to the shallow depths, the water levels are also affected by changes in barometric pressure. Over the period of 24 April 2020 to 2 December 2021, barometric pressure differed by about 0.28 m. A gradual reduction of barometric pressure in a low atmospheric pressure environment allows water levels to rise and allow stronger tidal effects. Conversely, high-pressure systems result in higher barometric pressure, lower groundwater levels and depressed tidal effects.
- Groundwater levels generally show a short-term increase following high rainfall events. Bore TDMB04A shows short term increase in groundwater level of up to approximately 0.8 m, while response from TDMB05A in most cases is subdued. Bore TDMB04A is located in clean sands in GJ Walter Park while TDMB05A is located adjacent a bituminous hardpan (boat ramp) which restricts rainfall recharge and is also adjacent mangroves on the south side, which restrict groundwater movement from recharge areas in elevated topography to the west.

Figure 10-2: Groundwater Conceptual Model Cross Section Locations



Toondah Harbour EIS

Legend

Toondah Harbour PDA (Project Area)

Cross-section line

Groundwater Monitoring Locations

Petrie formation

Quaternary sediments

Council geotech inverstigation boreholes (2013)

Stability investigation boreholes

Beenleigh surface geology

Petrie Formation/b (Tpb)

Qhc-QLD (Qhc)

Qhct-QLD (Qhct)

Qhh-QLD (Qhh)

Qhm-QLD (Qhm)

Qhmr-QLD (Qhmr)

Qhmtd-QLD (Qhmtd)

N 0 100 200 300 400 m

GDA 1994 MGA zone 56 Scale (A4): 1:8,000

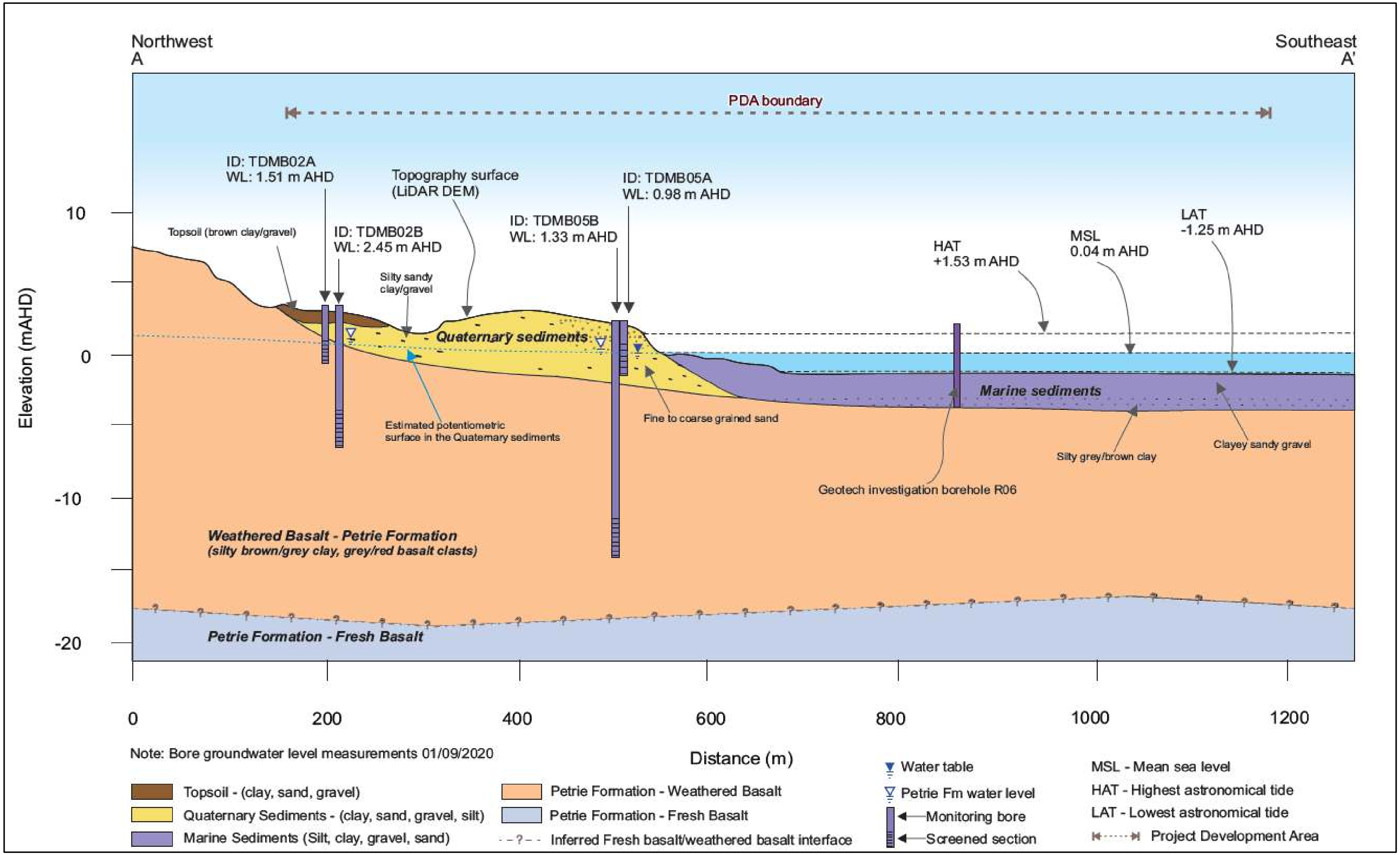


Figure 10-3: Groundwater Conceptual Northwest – Southeast Hydrogeological Cross-section A-A.

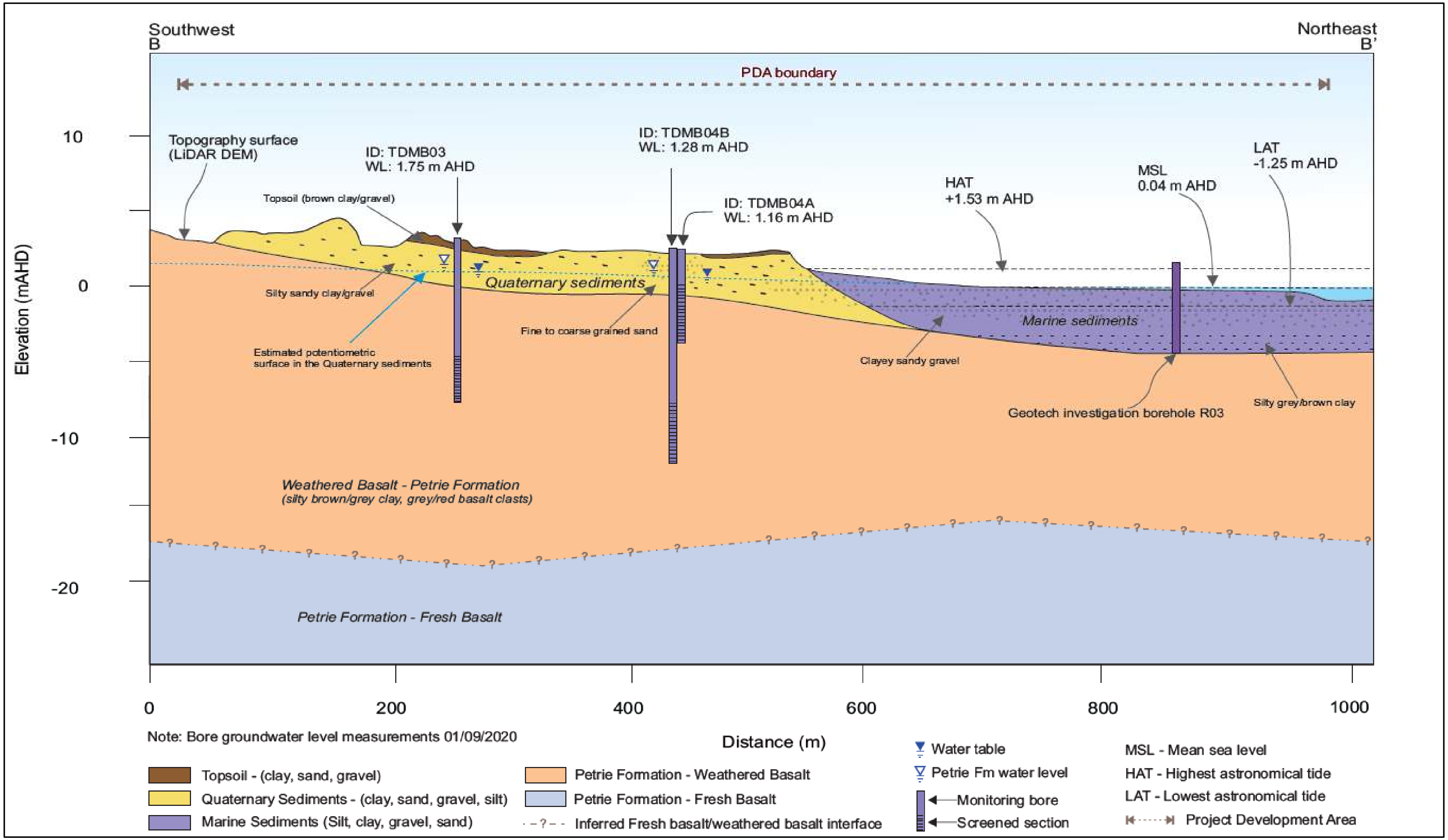


Figure 10-4: Groundwater Conceptual Southwest – Northeast Hydrogeological Cross-section B-B.

10.3.3.2 *Petrie Formation*

Groundwater levels have been measured in bores TDMB01A, TDMB01B, TDMB02A, TDMB02B, TDMB03, TDMB04B and TDMB05B screened in the Petrie Formation (refer to Figure 10-1). The groundwater elevation interpolated from groundwater level data measured from bores on 1 September 2020 is presented on Figure 10-5 and indicate the flow within the Petrie Formation is toward the coast.

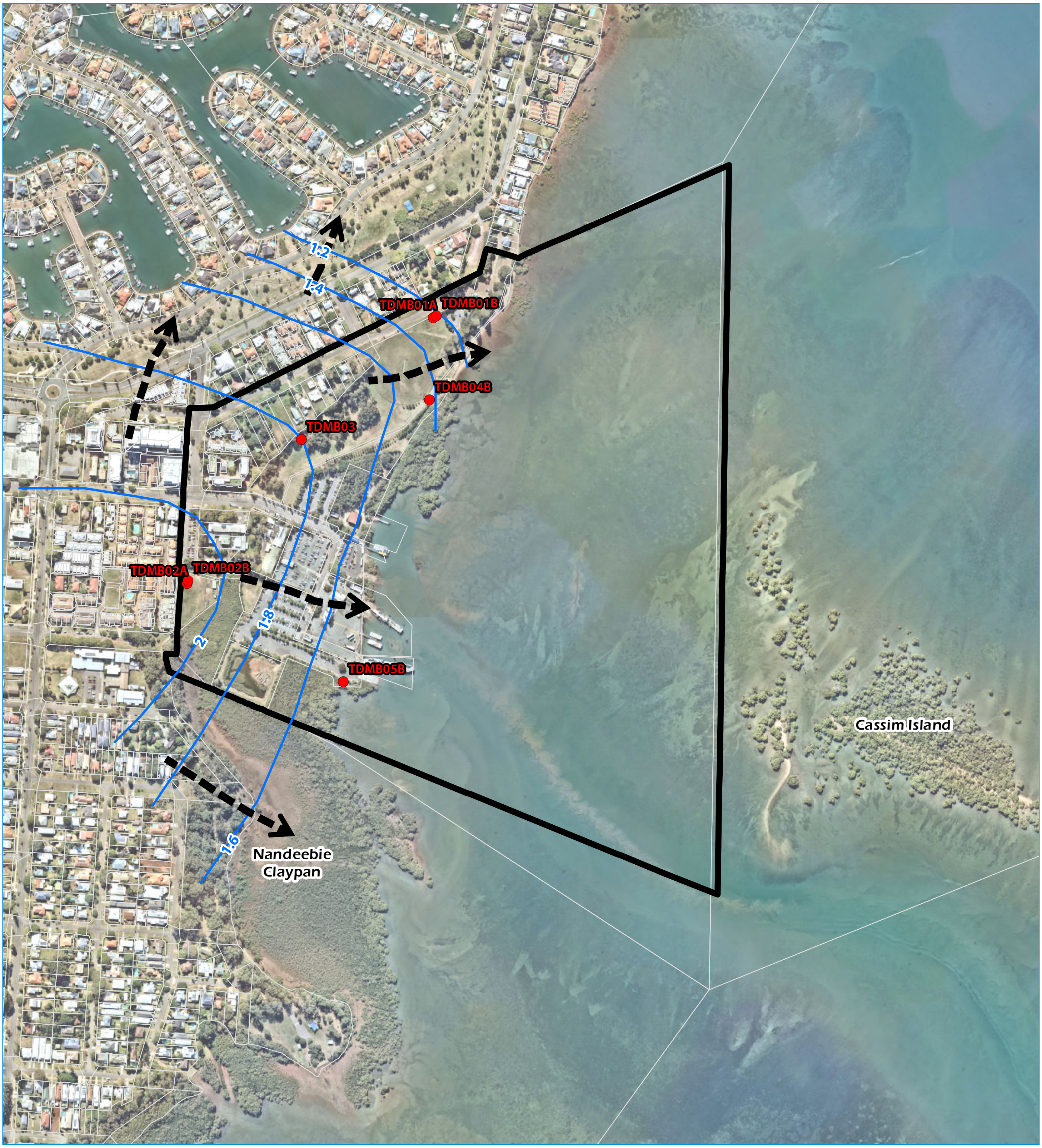
The measured groundwater levels from each bore are presented on Figure 10-6 in conjunction with rainfall data from nearby BOM station 040770 (Ormiston College). The basalt bores show a rise in groundwater levels following successive high rainfall events with the most pronounced response occurring during the March to April 2021 rainfall events. The response to rainfall recharge is variable and can be quite rapid (TDMB01A, TDMB02A and TDMB02B) with a rise of up to a couple of metres, as evident in TDMB02B, or more subdued as evident in TDMB04B, TDMB05B. The rapid rise in water level in bore TDMB02B is followed by a rapid decline following some rainfall events indicating effective drainage and likely limited storage within fracture systems. Bore TDMB02 provided the highest site test result of hydraulic conductivity when considering all Petrie Formation monitoring bores and this is reflected in rapid water level response from rainfall events.

Sinusoidal water level fluctuations reflect the influence of tidal effects of the ocean, but to varying degrees between the bores. TDMB05B is the closest monitoring point to the sea and therefore groundwater exhibits the largest tidal fluctuation (up to 0.8 m). The magnitude of the fluctuations in other bores are smaller owing to the relatively slower rate at which groundwater pressure propagates back inland through the ground.

The bores TDMB01A, TDMB01B and TDMB04B, located in weathered basalt are located close to Moreton Bay (approximately 100 m distance), and show a similar magnitude of tidal fluctuation. Bore TDMB01B shows a dampened effect of tidal oscillation, and this is due to the bore being screened deeper (22 to 25 m bgl) in the fresh basalt, exhibiting a buffering of tidal pressure. Bores TDMB1A and TDMB4B are screened within the top 6 m from the surface and are therefore more susceptible to showing the effects of tidal pressure.

The dampened tidal fluctuation in bores is likely due to the thick marine Quaternary sediments immediately within the adjacent coast buffering the propagation of tidal pressures into the inland groundwater system. In contrast, TDMB5A (Quaternary sediments) and TDMB5B (Petrie Formation) both show larger tidal influence. This is likely due to propagation of tidal pressures within thinner Quaternary marine sediments within the dredged channel for Toondah Harbour.

Figure 10-5: Groundwater level contours in the Petrie Formation



Toondah Harbour EIS

Legend

Toondah Harbour PDA

Qld DCDB

Groundwater level contour (mAHD)

Groundwater flow direction

Groundwater Monitoring Locations

Petrie formation

TOONDAH HARBOUR

walker

N

0 100 200 300 400 m

GDA 1994 MGA zone 56

Scale (A4): 1:8,600

Layer Source: © State of Queensland Datasets (Department of Resources 2022), Aerial (Nearmap 2020)

DATE 12/04/2022 FILE REF. 9858 E Figure 10 5 Groundwater level contours Petrie Formation B

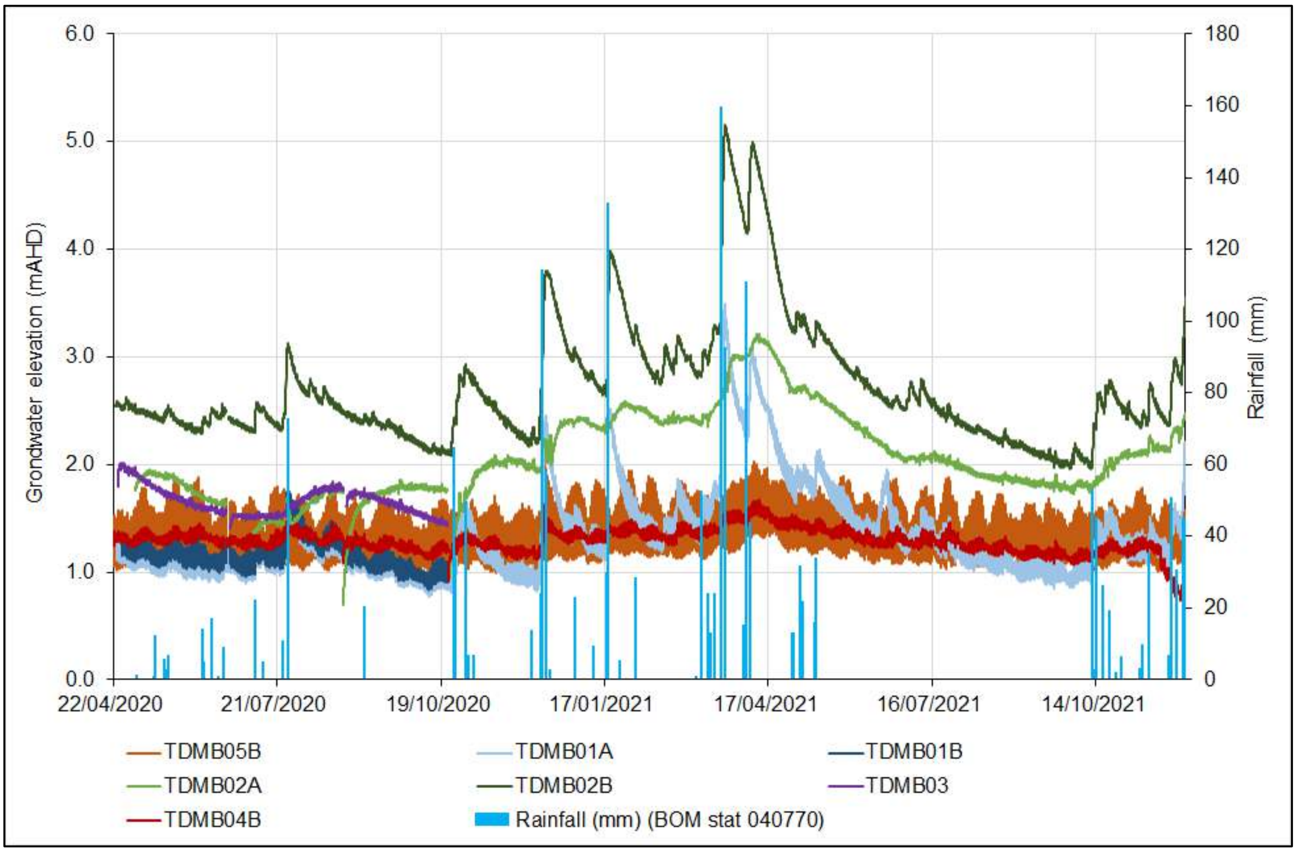


Figure 10-6: Petrie Formation Water Level Data.

10.3.3.3 *Vertical Head Gradient*

The nested groundwater monitoring bores have been constructed to assess upward or downward groundwater flow directions between the Quaternary sediments and Petrie Formation, and within the Petrie Formation. The nested monitoring bores TDMB04A/B and TDMB05A/B monitor water levels between the shallow Quaternary sediments and underlying Petrie Formation, while nested bores TDMB01A/B and TDMB02A/B monitor water levels within the Petrie Formation.

Table 10-2 shows the average groundwater levels observed in each monitoring bore for each nested location and the resulting difference in water levels between the bores at the nested sites. Average groundwater levels from the nested monitoring bores consistently show higher water pressure in the lower screened intervals compared to their shallower counterparts. This suggests that groundwater pressure in the Petrie Formation is higher (and becomes increasingly higher) at depth due to increasing confinement by lower permeability residual bedrock clay or massive fresh bedrock zones. TDMB03 does not have a nested monitoring counterpart having consistently intersected only extremely weathered basalt up to a depth of 10 m. The average groundwater level in the bore is 1.68 m AHD.

Table 10-2: Average Vertical Head Gradient across Nested Groundwater Monitoring Sites.

Nested site	Average groundwater level from shallower bore (A) (mAHD)	Average groundwater level from deeper bore (B) (mAHD)	Upward head gradient (m)
TDMB01A/B	1.09	1.14	0.05
TDMB02A/B	2.08	2.72	0.64
TDMB04A/B	1.19	1.29	0.10
TDMB05A/B	0.99	1.32	0.33

10.3.4 Groundwater Quality

Groundwater salinity profiles at the land–sea interface are illustrated along the conceptual hydrogeological section lines A – A′ and B – B′ in Figure 10-7 and Figure 10-8, respectively. The groundwater salinity data is derived from the field groundwater investigations on 24 June 2020 and shows halocline development. The salinity profile B – B′ in Figure 10-8 shows increasing saline conditions at depth in the deeper Petrie Formation basalt and the development of a saltwater wedge beneath the shore. The development of a saltwater wedge is not so evident in salinity section profile A – A′ (Figure 10-7) and this is due to the section line not located perpendicular to the coastline with a tidal inlet located adjacent and south of TDM02A/2B and TDM05A/05B which has influenced shallow bore salinities. The monitoring bores TDMB04A and TDMB05A in the Quaternary sediments have average salinities of 29,782 µS/cm to 44,532 µS/cm respectively, which is close to seawater salinity level of 52,000 µS/cm and indicates mingling of sea water in these bores. A detailed discussion of groundwater salinity is included in Appendix 2-H.

10.3.4.1 *Baseline Groundwater Chemistry*

A Piper diagram showing the major ion composition of groundwater at the Project footprint is presented in Figure 10-9. Groundwater in both the Petrie Formation and Quaternary terrestrial sediments are predominantly sodium, chloride and sulfate type. The groundwater systems are hydraulically connected to the ocean and the high sodium, chloride and sulfate are directly related to this hydraulic connection.

The preliminary environmental investigation by Golder (2013) identified TPH (C10 – C36 fraction) and traces of nickel and zinc in a single snapshot sampling of leachate from the landfill. The TPH concentration was at low levels of 420 ug/L and the nickel and zinc concentrations were below ANZECC 2000 guidelines 95% species protection for marine waters. Traces of copper, zinc, arsenic, and nickel, and TPH were also found in surface water samples. Golder (2013) mentioned that low levels of these compounds are common within stormwater drainage and may not necessarily be coming from landfill onsite, although it was identified that further periodical monitoring was required to supplement the results.

Groundwater sampling from the monitoring bore network has been conducted to investigate temporal changes in baseline water quality in the Quaternary sediments and Petrie Formation. Five groundwater sampling events have been conducted at the Project site. Four sampling events occurred in 2020 (April, June, August, and October) and a fifth sampling event occurred as part of the updated groundwater assessment in December 2021. In situ measurements of pH, electrical conductivity, redox and dissolved oxygen were taken during sampling. Redox and dissolved oxygen were analysed only during the December 2021 sampling. The laboratory reports and field sampling sheets are provided in Appendix 2-D.

The summary statistics of the sampled water quality parameters are presented in Appendix 2-H and compared against WQOs outlined by Australian and New Zealand Environment and Conservation Council (ANZECC) Water Quality Guidelines (ANZG, 2018). The WQO is a numerical concentration limit to be measured and reported back on and have been derived for this Project from the Redland Creeks Environmental Values and Water Quality Objectives (2010). The WQO refers to the ANZG (2018) guidelines for the highest level of protection for 99% of aquatic species. The sampled water quality parameters are also compared to NEPM for assessment of site contamination due to historic landfill in GJ Walter Park. These are the groundwater investigation levels (GILs) assigned for fresh water (Table 1C in NEPM 2011).

The Environmental Protection (Water and Wetland Biodiversity) Policy 2019 lists the EVs for groundwaters for the Redland Creeks Plan area to be relevant for aquatic ecosystems, irrigation, farm supply, stock water and drinking water. Toondah Harbour is a smaller area within the Redland Creeks Plan. Features of note in the PDA include the existing ferry terminals, GJ Walter Park, car parking, private dwellings, and a trade college all which have access to urban water supply utilities.

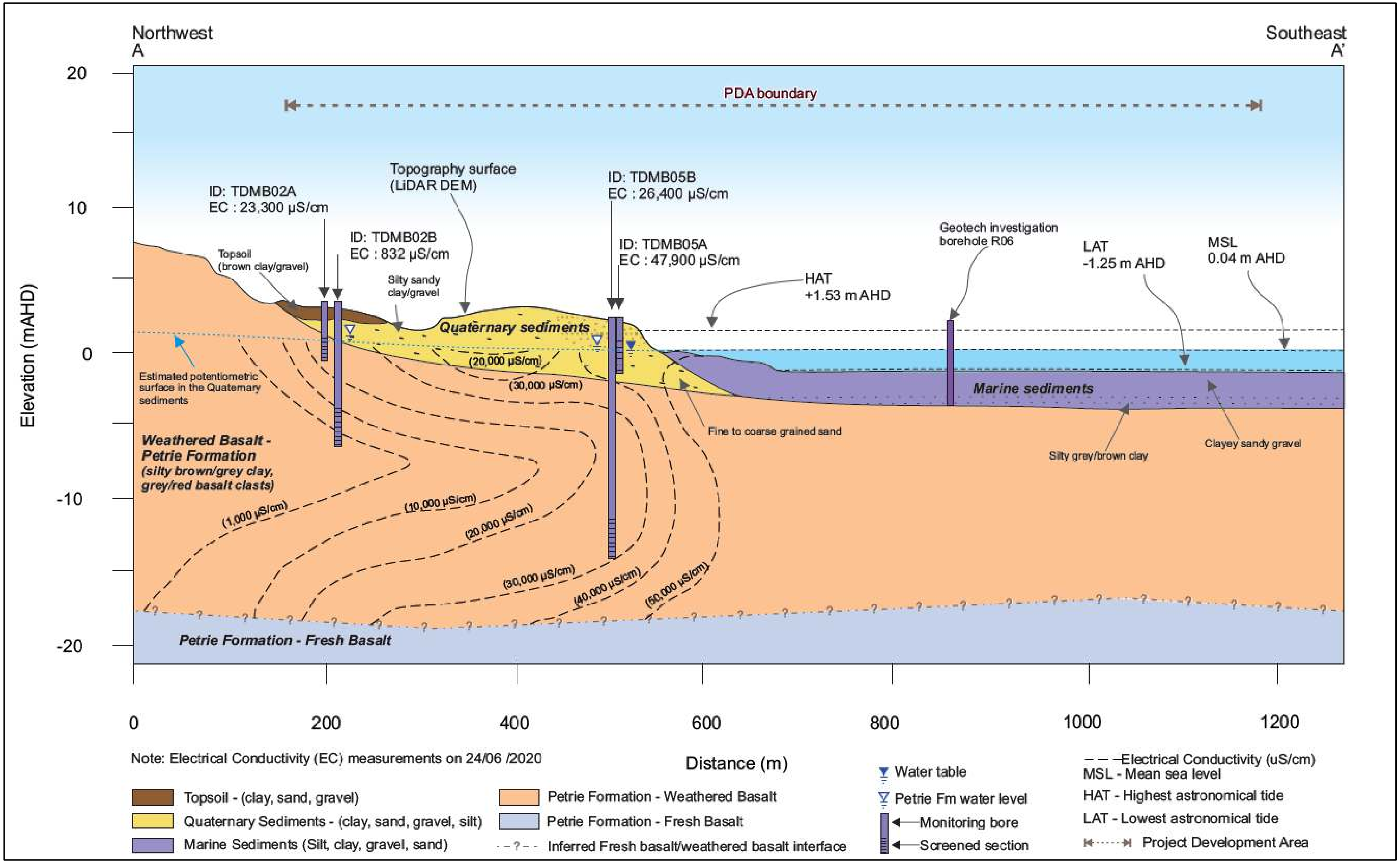


Figure 10-7: Groundwater Conceptual Northwest – Southeast Hydrogeological Cross-section A-A with Halocline.

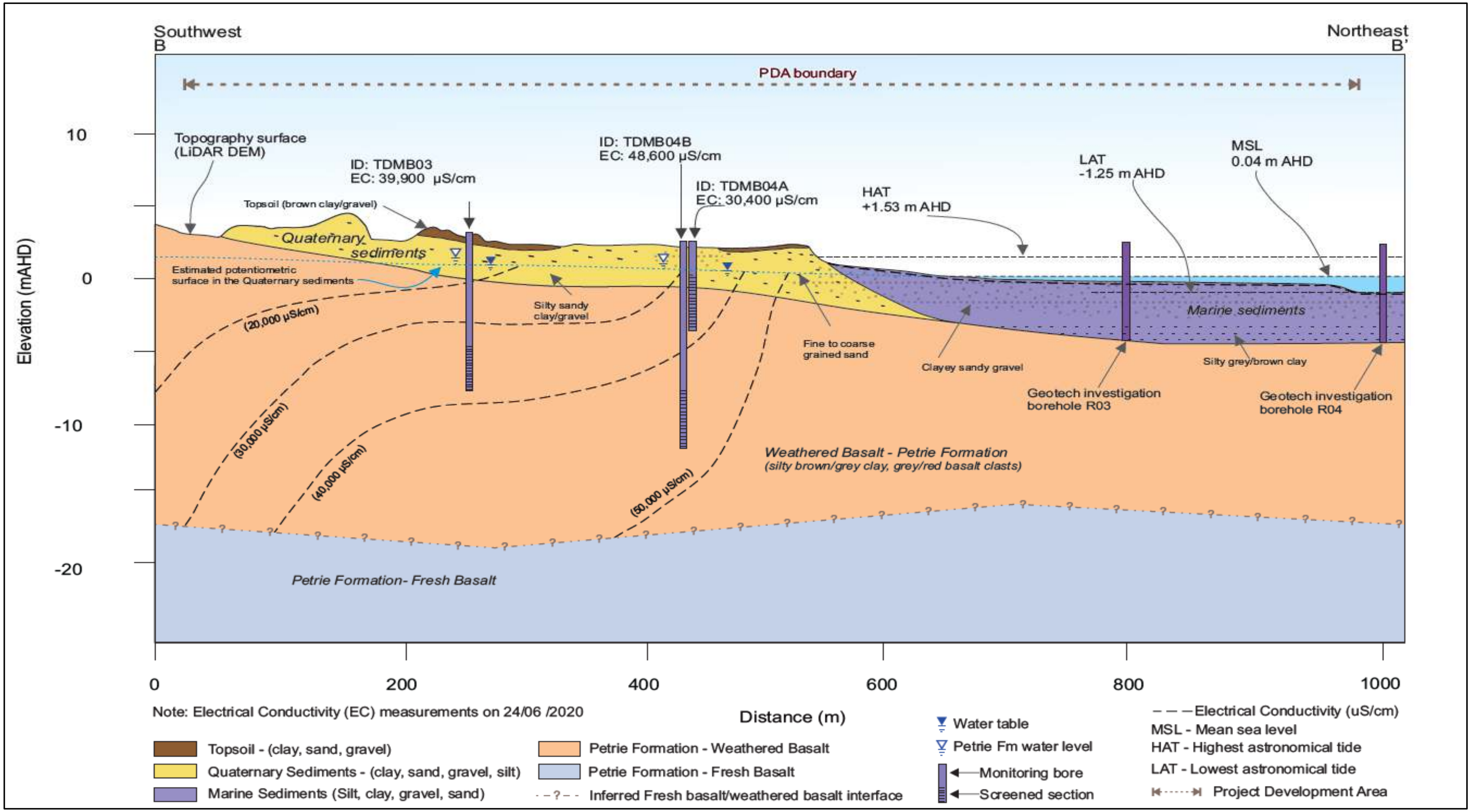


Figure 10-8: Groundwater Conceptual Southwest – Northeast Hydrogeological Cross-section B-B with Halocline.

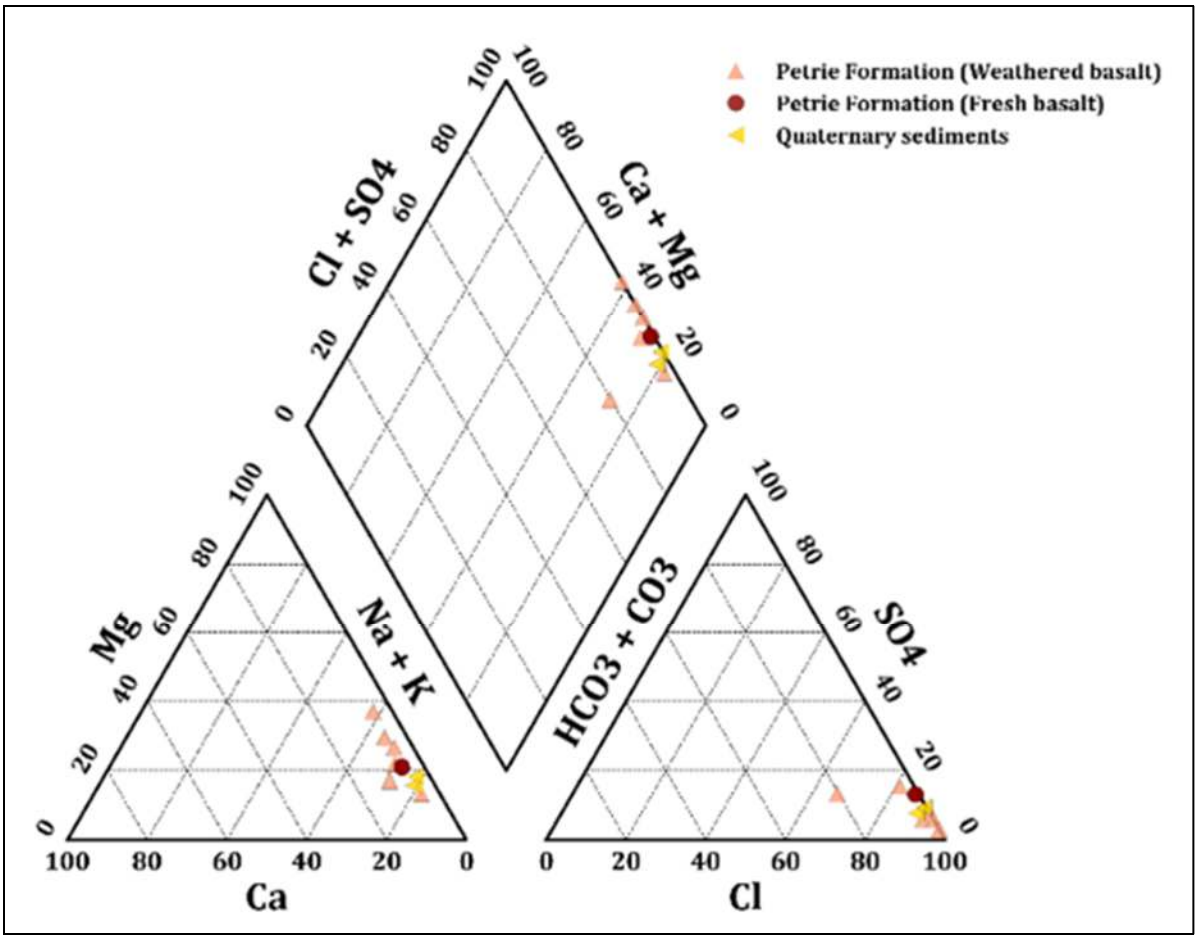


Figure 10-9: Major Ion Composition of Groundwater in Hydrostratigraphic Units.

No registered bores are located within the Toondah Harbour PDA, therefore groundwater is not considered to be in use for irrigation, farm supply, stock water or drinking water. The major EV for groundwater in the PDA is therefore considered to be aquatic ecosystems. The EPP policy (2019) for Redland Creeks recommends that the highest level of protection should be provided for underground aquatic ecosystems, given their high conservation value.

Ongoing monitoring of groundwater quality will be undertaken prior to the commencement of construction to collate a more robust baseline dataset which will be used to set threshold criteria for ongoing monitoring during construction. The baseline water quality dataset will include at least eight sampling events (including the five already undertaken) prior to the commencement of any site works.

In general, water quality data sampled from the terrestrial Quaternary sediments already exceed WQOs (ANZG 2018 water quality guidelines) for ammonia, aluminium, arsenic, boron, iron, nickel, and zinc. Water quality data in the Petrie Formation have similarly high values for the same parameters in addition to copper and manganese. Exceedances in ammonia occur in bores TMB01A/1B and TMDB2B located near the western boundary of GJ Walter Park. This assessment is broadly in line with findings from previous studies. The source of these trace metals has been suggested to be combination of weathering of near-shore basalts and anthropogenic inputs from built up areas (Morelli and Gasparon, 2019). Sediments in the Moreton Bay marine environment exhibit concentration levels naturally elevated in iron, nickel, mercury, lead, zinc and occasionally cadmium, arsenic and chromium according to a study by Cox and Preda (2005). The Golder (2013) environmental investigation in GJ Walter Park found traces of elevated metals within shallow groundwater (zinc and nickel) and surface water (copper, zinc, arsenic and nickel) with the source potentially from the old landfill or alternately from urban runoff.

The exceedances mean that the existing groundwater qualities partially do not meet the criteria for WQOs for protection of 99% of aquatic species.

The water quality data sampled from the terrestrial Quaternary sediments also exceed the fresh water GILs within Table 1C of the NEPM (assessment of site contamination) for aluminium, boron, nickel, copper, and zinc. In this instance boron and zinc typically show exceedance while aluminium, nickel, and copper show occasional marginal exceedance. The Petrie Formation have greater exceedance of these parameters in addition there are exceedances for ammonia, cadmium, chromium IV, lead, selenium, and arsenic.

There are traces of hydrocarbons within monitoring bore TMDB02A screened in the Petrie Formation during the first sampling event following drilling and installation of the bore in April 2021 predominantly comprising TPH/TRH of the mid to heavier fractions with total concentrations up to 500 µg/L. The total concentrations reduce to 140 µg/L in the June 2021 sampling event and is below limits of reporting (<100 µg/L) for successive August 2021, October 2021, and December 2022 sampling events. This indicates the occurrence of the hydrocarbons is likely to be from the drilling process as the hydrocarbons have broken down over time. Hydrocarbons were not detected in any of the other monitoring bores.

There was no detection of phenolic compounds or polynuclear aromatic compounds within the groundwater from all sampling events.

10.3.5 Groundwater Surface Water Seawater Interaction

Groundwater in the Quaternary sediments is predominantly saline and is more representative of seawater salinities due to mixing with seawater (52,000 µS/cm) as opposed to fresh rainfall recharge. Hydrographs Bores TDMB04A and TDMB05A respectively are often below the HAT level of 1.53 m AHD, indicating the hydraulic gradient would reverse and seawater would flow toward the bores during high tides.

Recharge into the Petrie Formation is primarily sourced from rainfall and possibly urban infiltration. This is particularly evident from typically fresh to brackish water observed within TDMB2B (839 µS/cm) at the western edge of the Toondah Harbour PDA and fresh to brackish groundwater salinity data from historical data in registered bores west of the Project footprint.

The horizontal and vertical groundwater flow direction in Petrie Formation shows that lateral groundwater flow is towards the coast and also vertical contribution moving upwards. This indicates that groundwater from the Petrie Formation discharges into the shallow marine environment at Toondah Harbour. Stewart *et al*. (2015) have also similarly concluded significant submarine groundwater discharge into Moreton Bay. The volume of groundwater discharge was estimated to be 18 times greater than the annual inputs from all major rivers draining into the bay. The study identified significant areas of groundwater discharge near the southern islands and mangroves in the vicinity of the Project footprint.

Groundwater field investigations for the Project show progressive increase of saline groundwater in the Petrie Formation towards the coast. Figure 10-7 and Figure 10-8 illustrate the salinity profile and halocline (salinity contour) of groundwater for the southern cross section A-A’ and B-B’ respectively. Both the cross sections show lower groundwater salinity in bores towards the inland (TDMB2A, TDMB3) while bores close to the coast, TDMB4B and TDMB5B, have higher groundwater salinity. The progressive increase in groundwater salinity reflects increasing contribution of seawater mixing into Petrie Formation with the development of a saltwater wedge. Groundwater salinity in the Petrie Formation is expected to increase to about sea water concentration at 52,000 µS/cm beneath the ocean floor.

10.3.6 Groundwater Users

10.3.6.1 *Registered Bores*

A search of the DoR groundwater database returned 71 existing registered bores located within an approximate 3 km radius of the Project footprint. Their locations are shown on Figure 10-10. Bores within a 3 km radius limit are shown to approximate the locations of potential water users within the Cleveland catchment boundary. Details of the registered bores, which include bore location and distance from the PDA, year of construction, depth of accessed aquifer, extraction yield, water level and quality, are provided in Appendix 2-H.

No existing registered bores were found within the PDA, but five registered water supply bores within 1 km of the PDA potentially extract groundwater from the weathered basalts of the Petrie Formation.

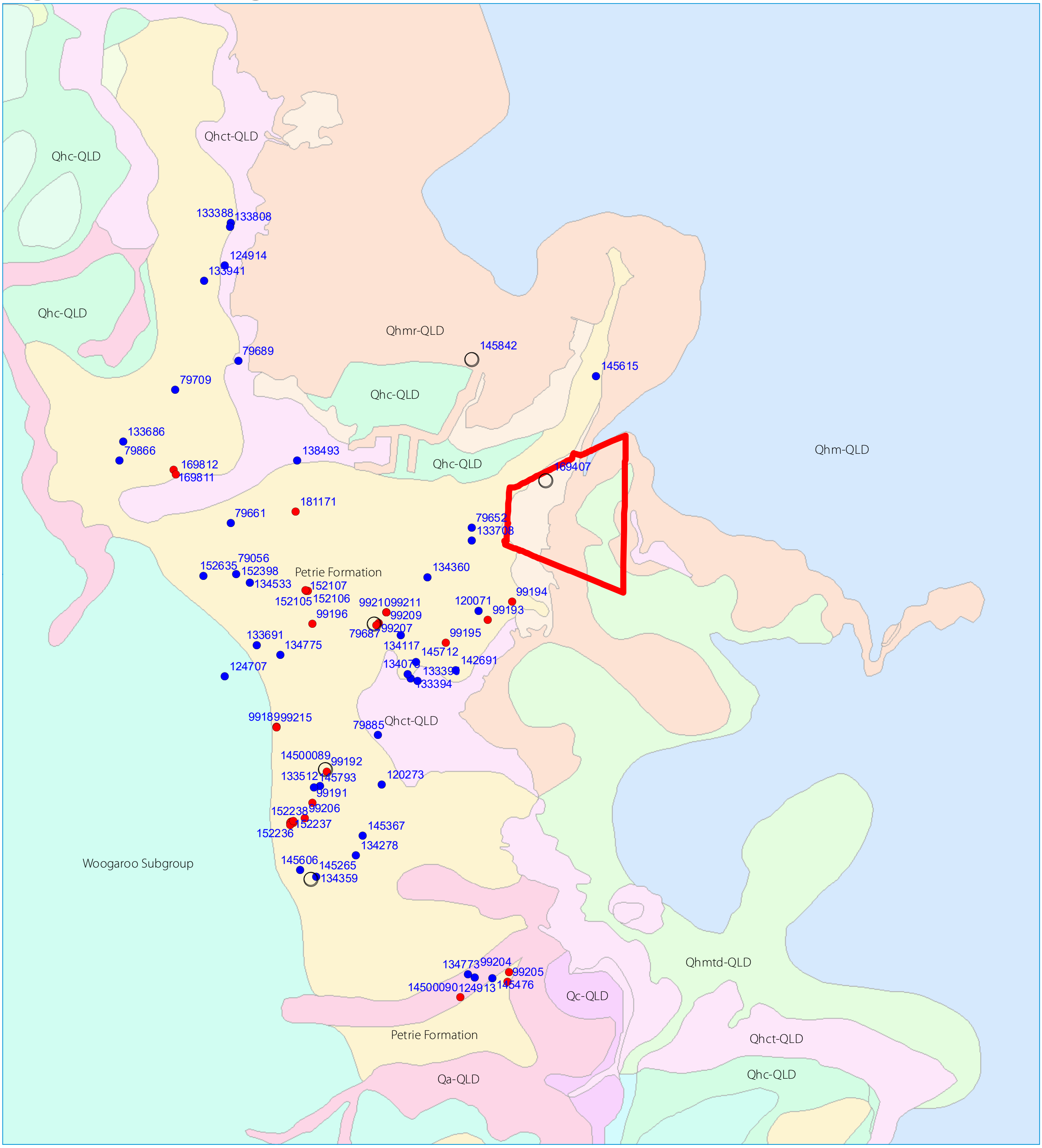
Further afield, registered bores within the Cleveland catchment are used for private water supply (55%) or monitoring purposes (42%), with a small proportion (3%) of bores with no specific purpose recorded. Due to the availability of urban water supply facilities in the area, it is likely that most of the water supply bores are not actively used anymore.

Many of the bores are screened in the basalts of the Petrie Formation (40%), with a smaller portion within the Quaternary sediments (14%). The remaining registered bores (46%) do not have information on the stratigraphic formation screened.

Some bores (152000 series) are registered as monitoring bores for fuel stations within the urban Cleveland area. Lithology from these bores were recorded as clay dominated Quaternary sediment. However, detailed geological mapping (1:100k Beenleigh geology) indicated that these bores are likely to be screened in the Petrie Formation. Weathering of basalts into clays may contribute to the difficulty in discriminating strata belonging to the Petrie Formation compared to overlying Quaternary clays.

Groundwater monitoring was last undertaken by the DoR between 1988 and 1993 from bores 14500082, 14500089 and 14500090 southwest of the Project footprint. Some of these monitoring bores have since been abandoned or destroyed and monitoring from the remaining bores has ceased since 1993.

Figure 10-10: Registered Groundwater Bore Locations



Legend

Toondah Harbour PDA

Qld DCDB

Registered Bores

- Abandoned and Destroyed
- Existing - Monitoring
- Existing - Water Supply

Beenleigh surface geology

- Petrie Formation/b (Tpb)
- Qa-QLD (Qa)
- Qc-QLD (Qc)
- Qha-QLD (Qha)
- Qhc-QLD (Qhc)
- Qhct-QLD (Qhct)
- Qhh-QLD (Qhh)
- Qhm-QLD (Qhm)
- Qhmr-QLD (Qhmr)
- Qhmtd-QLD (Qhmtd)
- Woogaroo Subgroup (RJbw)

Toondah Harbour EIS

N

0 250 500 750 1,000 m

GDA 1994 MGA zone 56

Scale (A4): 1:40,000

TOONDAH HARBOUR

walker

10.3.6.2 *Groundwater Dependent Ecosystems*

The Moreton Bay Ramsar Site (MBRS) is a major wetland complex, extending approximately 110 km from Bribie Island in the north to the Gold Coast Seaway to the south. GDEs occurrence for the MBRS have been previously described by BMT WBM (2009) and the other studies that inform the Ramsar Information Sheet (2019). However, groundwater dependency of GDEs within the MBRS is only relevant within the near shore environment and areas adjacent to the Project footprint, namely the Nandeebie Claypan and Cassim Island.

As previously discussed, the study by Stewart et. al. (2015) suggests significant submarine groundwater discharge into Moreton Bay. However, Dennison and Abal (1999) previously noted that groundwater does not constitute a major flow or nutrient contributor into Moreton Bay and, as such, is likely to have minimal impact on wetland functions. The groundwater salinity profile shows the salinity in the Quaternary sediments is approximately 47,900 µS/cm at TDMB05A directly adjacent to the Nandeebie Claypan. Based on this observation, the claypan vegetation is unlikely to be dependent on inland freshwater discharge. Vegetation is dominated by grey mangroves (*Avicennia marina*) and other mangrove species which only grow in saline conditions. Similarly, Cassim Island, which is submerged by tidal conditions and supports mangroves is likely to have high salinity in the sediments and vegetation not dependent on fresh submarine discharge.

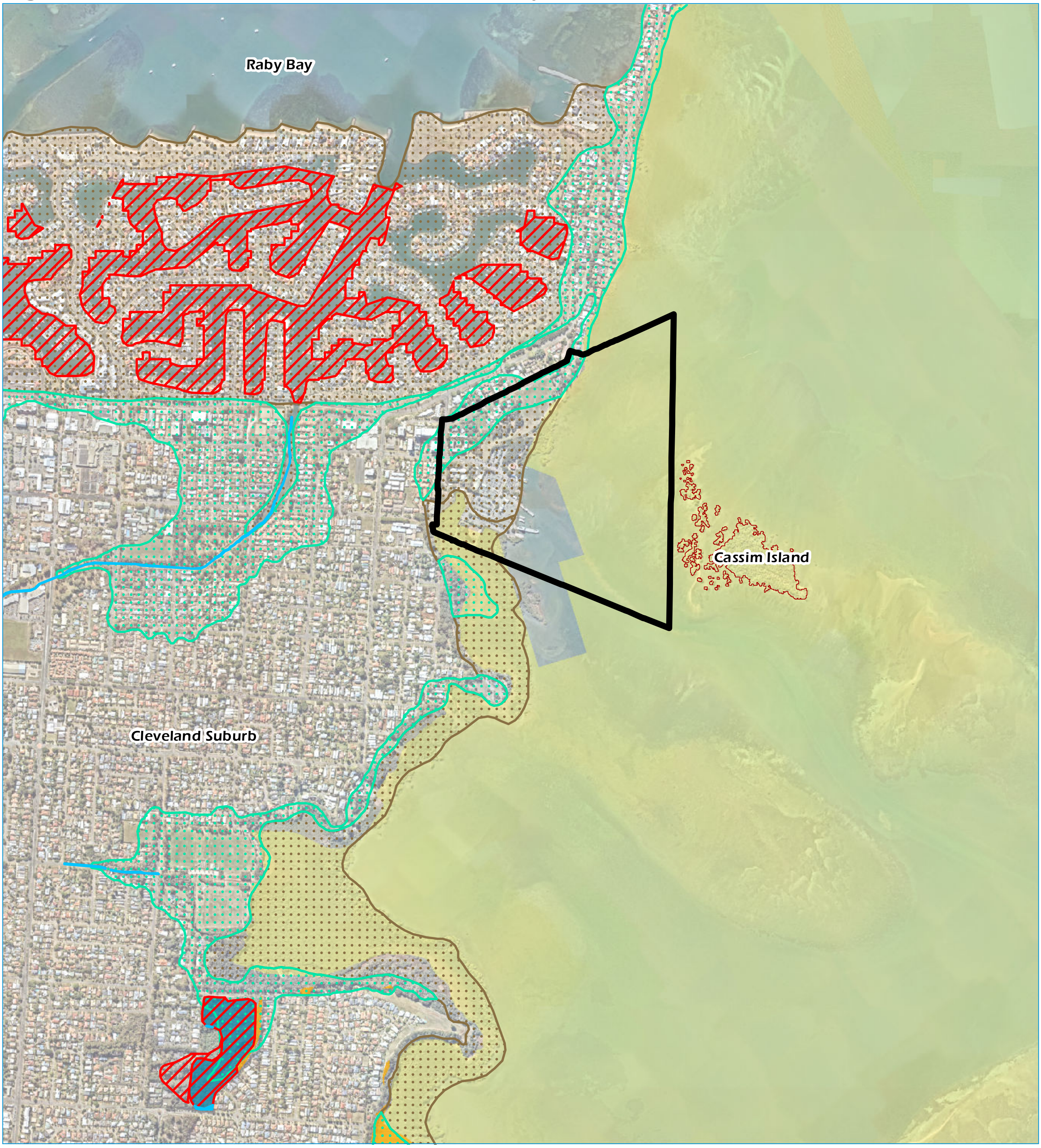
GDEs within 3 km inland of the Project footprint have also been reviewed using the Queensland GDE Atlas developed by the DoR (Figure 10-11). The areas of mapped (but not confirmed on ground) potential GDEs identified within 3 km of the Project footprint are:

- High potential GDE:
    - Waterway canals of Raby Bay associated with local water table directly north of the Project footprint;
    - Estuarine wetlands with riparian vegetation approximately 2 km west of the Project footprint;
    - Estuarine wetlands with riparian vegetation approximately 2 km southwest of the Project footprint;
- Moderate potential GDE:
    - Mangroves associated with the Petrie Formation, along the coast south of Henry Ziegenfusz Park, Cleveland;
    - Riparian vegetation associated with an unnamed watercourse approximate 3 km south of the Project footprint;
    - Riparian vegetation associated with the water table of the Petrie Formation along Hilliards Creek, approximately 3 km west of the Project footprint;
- Low potential GDE:
    - Riparian vegetation associated with the water table of the Petrie Formation along Ross Creek, approximately 2.5 km west of the Project footprint.

The GDE closest and most relevant to the Project footprint is within the waterway canals of Raby Bay north of the Project footprint. The canal is highly modified with significant urban drainage and motorised marine traffic and therefore is unlikely to have high environmental values. Due to its physical connection and proximity to the sea, the water in the canal is influenced by tidal effects and also potentially receives fresher submarine groundwater discharge from the underlying Petrie Formation. Due to the development of a saline wedge extending beneath the shore from sea water intruding into the underlying formations, the groundwater discharge is likely to be saline from mixing prior to reaching the surface.

In summary, identified GDEs are highly unlikely to be influenced by Project activities as they are located more than 2 km from the Project footprint. Mangrove ecosystems in the intertidal areas or sea grass flats near the Project footprint are not dependent on fresh submarine water as a saltwater wedge intrudes beneath the shore as demonstrated by salinities in shallow project monitoring bores in the Project footprint.

Figure 10-11: Groundwater Dependent Ecosystems Near Toondah Harbour



Toondah Harbour EIS

Legend

- Toondah Harbour PDA
- Moreton Bay Ramsar site

Aquatic

- Moderate potential GDE - from regional studies
- High potential GDE - from regional studies

Terrestrial

- High potential GDE - from regional studies
- Moderate potential GDE - from regional studies

Acid Sulfate Soils

- Low probability of ASS
- ASS present in soil profile, type and depth to ASS not defined

N

0 100 200 300 400 m

GDA 1994 MGA zone 56

Scale (A4): 1:20,000

TOONDAH HARBOUR

walker

10.3.7 Summary of Conceptual Model

A hydrogeological conceptual cross section diagram showing the interaction of groundwater and seawater within the hydrostratigraphic units for the Project footprint is presented in Figure 10-12. The hydrogeological model is discussed here as a framework to describe the potential groundwater interaction by Project activities with the groundwater receptors within the existing environment.

The main hydrostratigraphic units relevant to the Project footprint are Quaternary sediments consisting of Anthropocene materials such as fill and fine sediments in the marine harbour and the underlying weathered basalts of Petrie Formation. The Petrie Formation forms the regional aquifer system due to its extensive occurrence as outcrop over much of the Cleveland catchment. The top of the Petrie Formation basalt is weathered and has enhanced storage capacity and permeability compared to underlying fresh basalt rock. The weathered zone is approximately 15 m thick but is expected to be variable. Nearer to the coast, shallow marine deposition of unconsolidated sediments during the Quaternary period resulted in thin deposits of sand, silts and marine clays being deposited on the top of the weathered basalts.

In general, the permeability of Quaternary sediments is higher than the Petrie Formation due to the greater proportion of sands. In contrast, the upper weathered and residual soils of the Petrie Formation largely consist of clays and is relatively less permeable. The permeability in the Petrie Formation increases with depth in the weathered zone due to less proportion of clay in the residual rock matrix (i.e., becomes less weathered at depth). Freshwater recharge into the regional aquifer occurs mostly inland through a combination of rainfall and urban seepage into the water table within the weathered Petrie Formation. Downward leakage of groundwater flow is constrained by deeper, unweathered low permeability basalt of Petrie Formation. As a result, groundwater flow is predominantly lateral from areas of higher elevation towards the coast, where it eventually discharges into the overlying Quaternary sediments and marine environments of Moreton Bay.

Groundwater levels in the Quaternary sediments indicate flow is toward the coast but may reverse near to the coastline during high tides causing mixing of fresh water and seawater. Groundwater levels in the Petrie Formation recorded from monitoring bores near the coast is generally higher than the base of the Quaternary sediments and mean sea levels. This suggests that the Petrie Formation discharges into the overlying Quaternary sediments and the marine environment. The maximum groundwater level fluctuation within the Project footprint recorded to date is 0.83 m. Fluctuations are a result of daily tidal effects and changes in barometric pressure during changes in the local climate system. The fluctuation in groundwater levels result in constant flux between groundwater and seawater over time and have resulted in a 'mixing zone' where groundwater salinity becomes more saline and progressively reflect seawater quality towards the coast.

Current groundwater quality shows concentrations of arsenic, aluminium, copper, boron, iron, manganese, nickel and zinc above the Redland Creeks EVs and WQOs for protection of 99% of aquatic ecosystems. Comparison of the current water quality results with the previous study by Golder in 2013 suggests that some of these elevated concentrations are related to the rehabilitated landfill underneath GJ Walter Park. Sediments in Moreton Bay marine environment also exhibit concentration levels naturally elevated in Ni, Hg, Pb, Zn and occasionally Cd, As and Cr (Cox and Preda, 2005). Future monitoring will seek to at least maintain existing water quality within and surrounding the Project footprint during construction and ongoing use of the site.

No existing registered bores have been found within the PDA, but five registered water supply bores within 1 km of the Project footprint potentially extract groundwater from the weathered basalts of the Petrie Formation. Other potential groundwater users are the Raby Bay canal, Nandeebie Claypan and Cassim Island which are located within the MBRS adjacent to the Project footprint. The groundwater investigation suggests that the fresher groundwater zone currently starts approximately 300 m inland and therefore the freshwater discharge and requirement by these wetlands are unlikely.

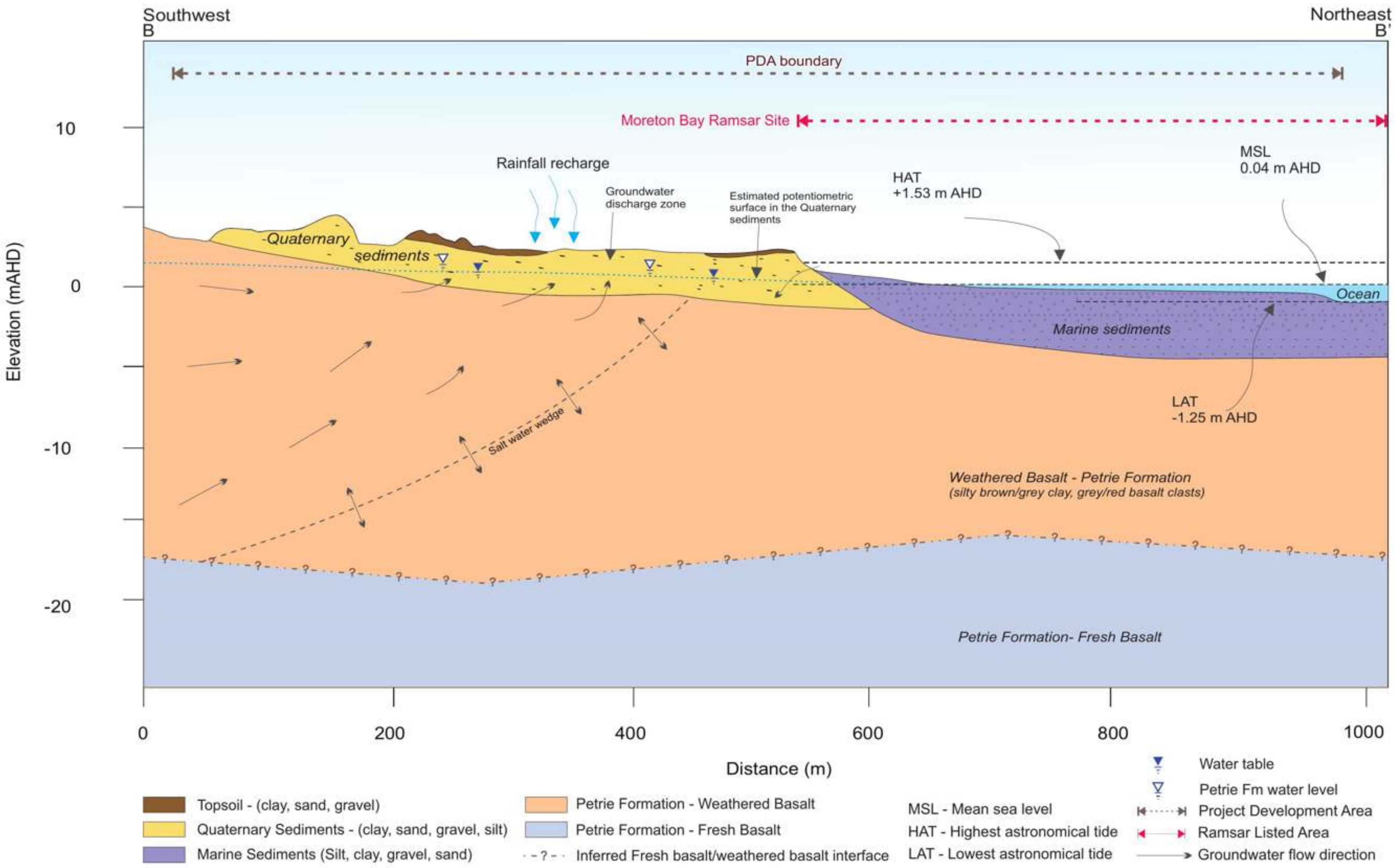


Figure 10-12: Summary Conceptual Model - Southeast Hydrogeological Cross-section B – B'.

10.4. Potential Impacts

Works associated with the Project have the potential to impact on groundwater resources which may then indirectly impact MNES. This assessment addresses impacts as they relate to different work types. The key work types for the Project where there are potential groundwater impacts include:

- Dredging;
- Reclamation;
- Sheet pile installation;
- Dewatering; and
- Removal of mangroves.

Given the Project has a low likelihood of resulting in changes to groundwater resources, the assessment has generally been carried out using qualitative methods, including interpretation of data collected onsite and the hydrogeological conceptual model. The exception is a quantitative assessment of construction dewatering influence on the western side of the sheet piling containment wall.

10.4.1 Dredging

Dredging is planned to remove up to 530,000 m^3 of sediments to widen the turning basin and deepen the existing Fison Channel. The dredge area has a small overlap with mapped PASS. Sediment analysis indicated PASS is present in some the sediments to be dredged (frc environmental, 2019). Some trace metals were also present however they have been found throughout Moreton Bay at concentrations that exceed sediment quality guidelines. In particular, Ni, Hg, Pb, Zn and occasionally Cd, As and Cr (Cox & and Preda, 2005). The source of these trace metals has been suggested to be a combination of weathering of near-shore basalts and anthropogenic inputs from built up areas (Morelli & Gasparon, 2019). Assessment of potential impacts to groundwater from dredging activities are presented in Table 10-3. In general, while sediments to be dredged contain PASS and low levels of potential contaminants in some locations, potential for these to impacts groundwater are very low.

Table 10-3: Dredging Impacts to Groundwater.

EIS Requirements	Impact to Groundwater
Changes in porosity and permeability	Local aquifers are not intersected by dredging activities therefore there is no potential for impact.
Extent of groundwater resource impacted	Local to intertidal zone at Quaternary marine and terrestrial contact within the PDA. Dredging is planned within the existing marine and intertidal zone.
Groundwater resource depletion or recharge	The removal of marine sediments via dredging could potentially increase localised connectivity between seawater and the underlying aquifer hosted in either Petrie Formation or Quaternary sediments. Where the seawater height is higher than the groundwater hydraulic head, localised seawater recharge could occur into groundwater, resulting in increased groundwater salinity. However, groundwater directly adjacent to the coast is already saline so further salinity increase is expected to be negligible.
Potential to contaminate groundwater resources	Increased connectivity between seawater and inland groundwater, resulting in additional mixing locally near the dredging interface.

EIS Requirements	Impact to Groundwater
	Disturbed dredged zones may mobilise metals in water associated with PASS sediments. However, impacts are expected to be limited due to dilution by seawater and only occur at high tide ranges where seawater recharges groundwater due to seawater level above groundwater level. Changes in metal concentrations are likely to be constrained to the dredging interface within the low-permeability clay-rich marine sediments which typically occur at Toondah Harbour.

10.4.2 Reclamation

Reclamation will involve the relocation of the dredged material and external materials to create the built-up hardstand areas. These areas will be compacted, and parts eventually resurfaced.

The reclaimed dredge material contains PASS and may also contain elevated concentrations of trace metals. Sediment analysis of Toondah Harbour marine sediments within the planned dredging zone found that 95% UCL of all metals and metalloids were below the NAGD screening level in the proposed dredge area (refer to Section 7.3.1). This means that the concentration of metals and metalloids in the sediment in the proposed dredge area is not of concern, therefore the potential for impacts are negligible. Assessment of potential impacts to groundwater from reclamation activities are presented in Table 10-4.

Table 10-4: Reclamation Impacts to Groundwater.

EIS Requirements	Impact to Groundwater
Changes in porosity and permeability	Reclamation should not change the formation permeability of either the Tertiary or Quaternary formations.
Extent of groundwater resource impacted	Reclaimed areas within the Project footprint will initially create elevated platforms to receive direct rainfall recharge; however, compaction and surfacing will limit infiltration.
Groundwater resource depletion or recharge	As above
Potential to contaminate groundwater resources	Reclamation areas where dredged material will be placed marginally overlap the existing land. Where this occurs materials will potentially be a source of groundwater contamination from the generation of ASS if not managed and treated properly.

10.4.3 Perimeter Containment Wall and Dewatering for Excavation

A perimeter containment bund will extend around the reclaimed area to a depth of -5 m AHD to allow dry excavation without direct sea water or groundwater ingress. The containment bund is proposed to comprise an interlocking sheet piling cut-off wall, vibrated into place, within a rock revetment bund at a level above HAT. The containment bund between the existing shoreline and reclaimed area will extend into low-permeability materials (clays) and only be temporary to minimise the ingress of groundwater flowing into the reclamation during construction. Sheet piling in this area would be removed following Project site establishment to allow unimpeded groundwater flows during ongoing use of the development. The extent of the sheet piling containment wall is described in section 2.4.2 of the EIS.

The depth to the Petrie Formation is shallow in the northern extent of the Project footprint (the formation was encountered at 3 m BGL in TDMB01A), whereas weathered basalt is encountered at over 6 m on the southern edge of the Project footprint (TDMB05B).

Details on the model simulation and sensitivity analysis of the containment wall and excavation dewatering, and the modelled results are included in Appendix 2-H. The modelled results show drawdown of water levels occurs west (landward) of the sheet piling wall during construction while temporary sheet piling is positioned at the interface between the reclamation and existing land. As the excavation is to - 0.5 m AHD and the water table near the sheet piling wall is less than 1 m AHD, the maximum predicted drawdown that can occur near the sheet piling wall is 1.5 m. The rate of drawdown is initially rapid and then the rate decreases towards the completion of the northern reclamation works. Schematic Figure 10-13 presents the predicted groundwater levels at the completion of northern reclamation works for typical material hydraulic conductivities. The greatest drawdown of groundwater level occurs adjacent the sheet piling wall and gradually decreases with increasing distance landward (west) of the containment wall. Groundwater level drawdown at its extremity is predicted to extend about 430 m from the sheet piling wall, but at this distance it is miniscule at < 0.05 m.

Groundwater flow seeps beneath the sheet piling wall through the weathered basaltic clays with some minor seepage through the sheet piling. The potential for groundwater mounding behind the sheet piling wall does not occur in the model simulations during construction. This is due to slow lateral groundwater movement from a combination of a low hydraulic gradient and low hydraulic conductivity of geological materials. The linear velocity of groundwater movement towards the sea within GJ Walter Park is estimated at approximately 5 x 10-7 m/s (0.04 m/d). Mounding would occur if the substrata comprised a coarser grained matrix with higher hydraulic conductivity, as this would allow greater movement of water to be channelled downslope to bank up against the sheet piling wall anchored in low-permeability clay-rich substrata.

Early in the construction phase, drawdown extending landward of the sheet piling wall will induce a slightly steeper hydraulic gradient east towards the sea due to the predicted drawdown. As the natural groundwater flow is towards the sea, there will not be a regional change in flow direction, although there may be slight changes on a localised scale depending on scheduled excavation works. Groundwater flow will predominantly flow under the sheet piling wall at a slow rate through the clay-rich layers of low permeability. There will also be some very localised flow around the northern and southern ends of the sheet piling wall into the marine environment.

During later stages of construction when the earthworks in the reclaimed area are raised to the level of the residential subdivision, the magnitude and extent of drawdown declines over time. With the removal of the sheet piling wall at the completion of reclamation works, the groundwater level reverts back to close to pre-construction levels. Schematic Figure 10-14 presents the predicted recovery of groundwater levels at the completion of the northern reclamation works, when reclaimed land is raised to 3 m, and also after Project completion for the typical case.

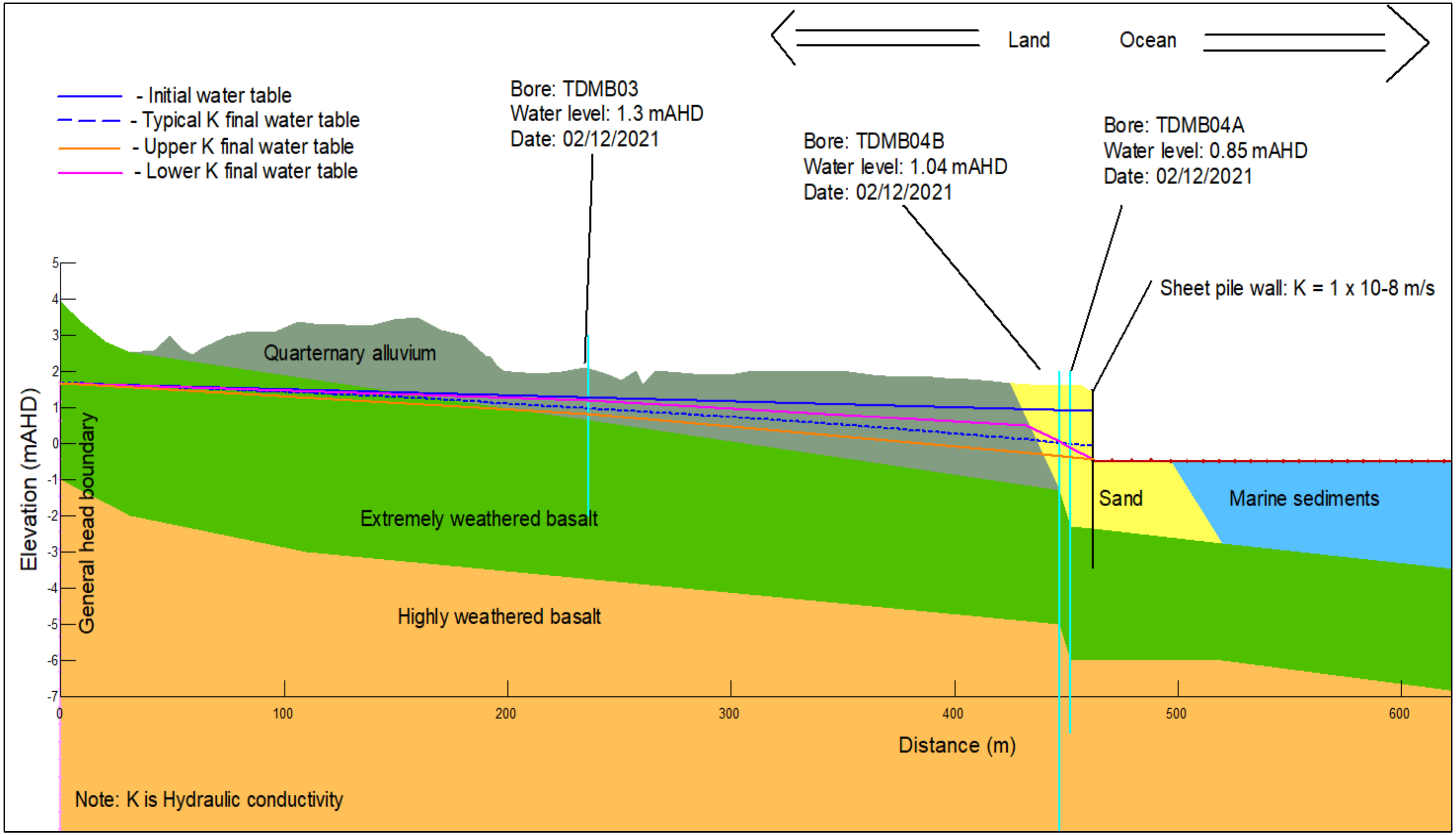


Figure 10-13: Modelled prediction of groundwater levels – Temporary Sheet Piling Installed

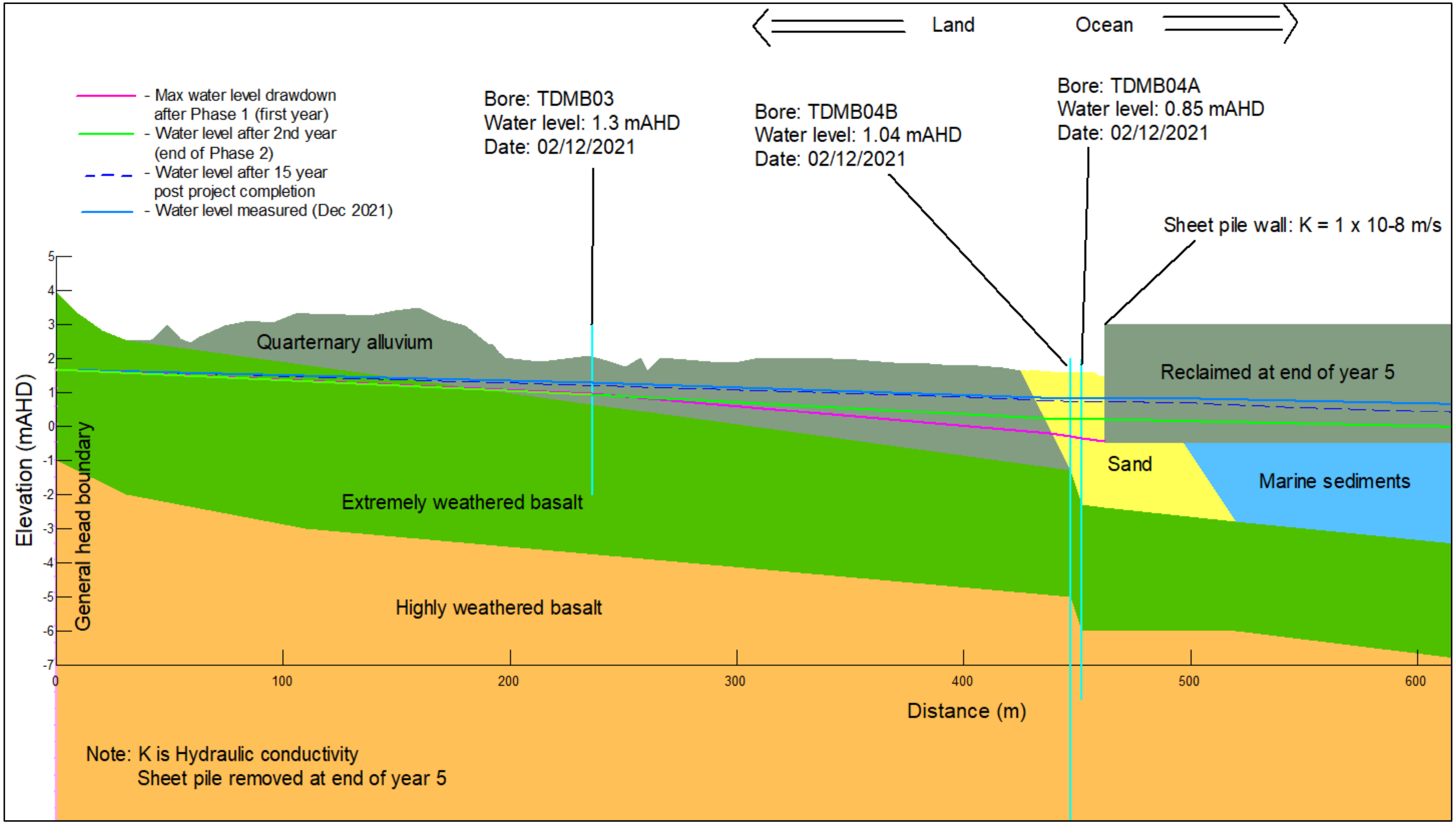


Figure 10-14: Modelled prediction of groundwater levels – Temporary Sheet Piling Removed

Drawdown of water levels on the landward side of the sheet piling wall during construction dewatering is not significant and is a temporal condition. Levels will recover following land reclamation on the Project footprint. The drawdown is not predicted to be greater than 1.5 m in close proximity to the sheet piling wall and reduces in magnitude landward to the west in vicinity of GJ Walter Park. According to Golder (2013) there is potential ASS fill and sediments in GJ Walter Park. The ASS fill and sediments which occur beneath the water table may be exposed to oxidation from temporal dewatering which may lead to generation of acidic conditions in the groundwater and mobilisation of metals. Also, potential leachate from the historic landfill may be mobilised. Proposed groundwater monitoring during construction will identify any changes to acidity (or any other contaminant) within the aquifer and remediation could be carried out I response to any changes. This may include removing the potentially contaminated fill material from GJ Walter Park and disposing in an appropriate facility offsite.

The groundwater will flow under hydraulic gradient beneath the sheet piling wall at a very slow rate with some seepage through the containment wall into the reclaimed area. Water that collects in the reclaimed area will be treated prior to reuse or disposal. Localised groundwater flow around the sheet piling wall to the north will be minor and diluted by mixing with marine waters such that the pH is restored, and contaminants are diluted to below risk levels. With recovery of groundwater levels following construction, the dewatered soil horizon will become saturated, and soils will not produce acid forming conditions and preconstruction groundwater conditions will be restored.

Drawdown is relatively minor and will not cause a significant change in substrata porosity leading to potential subsidence. Root zones for grass and trees in GJ Walter Park would be above the water table during typical conditions, therefore are not dependant on the water table for water.

Potential impacts to groundwater from the sheet piling activities are summarised in Table 10-5.

Table 10-5: Sheet Piling Containment Wall Impacts to Groundwater.

EIS Requirements	Impact to Groundwater
Changes in porosity and permeability	The bund wall creates a low permeability zone within the Quaternary or weathered Tertiary basalt.
Extent of groundwater resource impacted	Groundwater drawdown is expected to occur locally within the Project footprint behind the containment wall typically extending between 400 to 450 m west of the sheet piling wall during reclamation excavation. Potential groundwater level decline greater than 1 m is unlikely to occur greater than 50 m from sheet piling wall.
Groundwater resource depletion or recharge	Temporary sheet piling will partially limit lateral groundwater throughflow with water level drawdown induced on the landward side during excavation. This will induce a temporary minor depletion of groundwater resource within sediments behind the sheet piling wall. No existing water supply bores are within proximity of the predicted drawdown. The drawdown of water levels will recover during reclamation on the seaward side of the wall and continue to recover once the sheet piling is removed. The groundwater sheet piling wall will not obstruct recharge in the terrestrial sediments.
Potential to contaminate groundwater resources	Sheet piling is not expected to directly contaminate groundwater.

Dewatering of groundwater within the reclamation areas will be required to support land compaction and dry excavation access. Excavation in proposed residential zones is to a depth of approximately -0.5 m AHD to create drying and treatment platforms for reclaimed land materials. Excavation in the marina precinct and internal waterways is to -4.25 m AHD. Monitoring bore logs interpret the top of the weathered basalt of the Petrie Formation to range between 1.6 m AHD (TDMB01A) at the northern end of the Project footprint down to -4 m AHD (TDMB05B) at the southern end. Dewatering for excavation is therefore anticipated to extend to a depth within the top part of the weathered basalt.

Dewatering for excavation will cause some drawdown of groundwater levels west of the sheet piling wall during Project construction. Draw down will be minor and water levels will recover when active dewatering ceases and placement of fill occurs. Recovery is expected to be quicker following removal of temporal sheet piling.

Assessment of potential impacts to groundwater from dewatering for excavation activities are presented in Table 10-6.

Table 10-6: Dewatering Impacts to Groundwater.

EIS requirements	Impact to groundwater
Changes in porosity and permeability	Dewatering will have negligible impact on the bulk porosity/ permeability of Quaternary sediments and Petrie Formation (weathered) aquifer as water level drawdown is predicted to be less than 1.5 m.
Extent of groundwater resource impacted	The extent is anticipated to be minimal, temporal, and localised to: ▪ west of sheet piling wall; and ▪ underneath the reclaimed areas, as groundwater availability is primarily controlled by replenishment from seawater. Groundwater levels are predicted to be drawn down by up to 1.5 m close to sheet piling during excavation dewatering, which will reduce in magnitude towards the west away from the excavation. The groundwater flow will only have minor localised changes in flow direction as a result of dewatering and will continue to flow from land to sea as occurred prior to Project construction. A detailed analysis will be undertaken in conjunction with the dewatering strategy prior to the construction phase.
Groundwater resource depletion or recharge	Where groundwater in the Petrie Formation is intersected, groundwater dewatering will be required down to the anticipated dry excavation level of -0.5 m AHD for residential areas and -4.25 m AHD for internal waterways and the marina basin.
Potential to contaminate groundwater resources	Dewatering could potentially mobilise contaminants from the following sources: ▪ Old landfill leachate near GJ Walter Park; and ▪ Mapped terrestrial PASS, where dewatered and oxidised

10.4.4 Clearing of Mangroves

Clearing of mangroves is proposed in the southwestern part of the Project footprint to extend the existing ferry car park. The area designated for the new ferry terminal is situated almost exclusively on mapped ASS. Clearing of mangroves is not expected to affect groundwater levels, availability and quality as the groundwater system is predominantly controlled by tidal recharge near the coast.

10.5. Adaptive Management and Monitoring Measures

Where an activity is anticipated to have an impact on groundwater, mitigation measures to reduce severity of impacts and measures for detection and management of potential impacts are proposed in Table 10-7. Monitoring criteria and trigger values will be developed and implemented in accordance with "Using monitoring data to assess groundwater quality and potential environmental impacts" (Department of Science, Information Technology, and Innovation 2017).

Table 10-7: Groundwater Management Measures

Potential Impacts	Mitigation Measure	Desired outcomes and effectiveness
Dredging and removal of marine sediments facilitating direct mixing of seawater and groundwater	None proposed as only limited and localised changes to groundwater quality, which is currently already dominated by seawater.	Not applicable
Dewatering: lowering the groundwater table for access by other users/ potential GDEs	▪ Use of (temporary) sheet piling to minimise propagation of drawdown from excavation dewatering. Removal of temporary sheet piling will facilitate recovery of groundwater levels to near pre-construction levels. ▪ Ongoing monitoring to characterise groundwater levels within the Project footprint prior and during construction. ▪ Further assessment during the construction stage to predict extent of drawdown due to the Project and inform adaptive management program.	▪ No impacts on marine or terrestrial environments outside of the Project footprint as a result of groundwater drawdown or other changes that may result from the Project. ▪ Modelling has shown changes to the groundwater regime are expected to be localised and temporary, therefore management measures will be highly effective.
Dewatering: changing hydraulic gradients between aquifers/seawater to facilitate mixing	▪ Ongoing monitoring to characterise baseline groundwater level and quality within the Project footprint. ▪ Develop water level and quality 'trigger' levels to inform monitoring criteria and groundwater management during development.	▪ No impacts on marine or terrestrial environments outside of the Project footprint as a result of groundwater drawdown or other changes that may result from the Project. ▪ Modelling has shown changes to the groundwater regime are expected to be localised and temporary, therefore management measures will be highly effective.
Dewatering: inducing contaminant mobilisation from buried landfill	▪ Ongoing monitoring to characterise baseline groundwater level and quality within the Project footprint. ▪ Develop water level and quality 'trigger' levels to inform monitoring criteria and groundwater management during development. ▪ If further investigation identifies significant risk of contamination, evaluate cost benefit of source removal prior to construction or post-construction groundwater treatment options.	▪ No impacts on marine or terrestrial environments outside of the Project footprint as a result of groundwater drawdown or other changes that may result from the Project. ▪ Modelling has shown changes to the groundwater regime are expected to be localised and temporary, therefore management measures will be highly effective.

Potential Impacts	Mitigation Measure	Desired outcomes and effectiveness
Reclaimed dredged sediments as potential source of contamination to groundwater	▪ Installation of (temporary) sheet piling wall to restrict groundwater flow to the west. ▪ Construction of new groundwater monitoring bores within reclaimed platform. ▪ Complete additional baseline monitoring prior to construction to characterise baseline groundwater level and quality within the Project footprint. ▪ Develop water level and quality 'trigger' levels to inform monitoring criteria and groundwater management during development. ▪ Dredged PASS will be treated onsite using lime prior to oxidation occurring.	▪ No impacts on marine or terrestrial environments outside of the Project footprint as a result of groundwater drawdown or other changes that may result from the Project. ▪ Modelling has shown changes to the groundwater regime are expected to be localised and temporary, therefore management measures will be highly effective.
Disturbance of ASS – potentially acidifying groundwater and mobilising metals	▪ Monitoring groundwater quality for changes at TDMB02A, TDMB02B, TDMB05A, TDMB05B. ▪ Construct and monitor new monitoring bores in the reclaimed platform.	▪ No impacts on marine or terrestrial environments outside of the Project footprint as a result of groundwater drawdown or other changes that may result from the Project. ▪ Modelling has shown changes to the groundwater regime are expected to be localised and temporary, therefore management measures will be highly effective.
Sheet piling restricting groundwater throughflow	▪ Analysis of groundwater levels at monitoring bores to detect change in groundwater levels over time. Sheet piling being only a temporary measure on landward side of reclamation and removal after Project completion.	▪ No impacts on marine or terrestrial environments outside of the Project footprint as a result of groundwater drawdown or other changes that may result from the Project. ▪ Modelling has shown changes to the groundwater regime are expected to be localised and temporary, therefore management measures will be highly effective.

10.5.1 Draft Groundwater Monitoring Plan

The EVs for the receiving environment have been described for Toondah Harbour based on the EPP(Water) for Redland Bay (Department of Environment and Resource Management, 2010). The project WQOs will be defined, and trigger levels will be developed using the DSITI (2017) guidelines, following further baseline data collection and analysis prior to commencing construction. Ongoing baseline monitoring for water level and quality has been undertaken in the existing monitoring bore network (Figure 10-1) over a bi-monthly period since April 2020. A further eight baseline monitoring rounds are expected to be undertaken.

The proposed strategy for monitoring impacts set out in Table 10-8 has been designed to assess changes that may occur as result of the key impacts summarised in Section 10.4. The potential for impacts from the activities will be monitored with the groundwater bore network currently constructed for the Project assessment. The following monitoring objectives have been identified based on the key impacts:

- Objective A: Baseline groundwater levels and water quality around the Project and the MBRS;
- Objective B: lowering the groundwater table for other users/GDEs;
- Objective C: changes to hydraulic gradients between aquifers/seawater to facilitate mixing;
- Objective D: point sources of contamination from the existing landfill;
- Objective E: contamination from reclaimed platform material;
- Objective F: acidifying groundwater and contaminant mobilisation due to disturbed PASS; and
- Objective G: groundwater drawdown (mounding) behind containment wall.

Table 10-8: Analysis Strategy for Project Groundwater Monitoring.

Bore ID	Eastings (z56 m E)	Northings (z56 m S)	Screened geology and logged constituents (weathered products)	Monitoring objective
TDMB01A	528184	6955485	Basalt (weathered)	A, B, C, E, F, G
TDMB01B	528189	6955488	Basalt (fresh rock)	A, B, C, E, F, G
TDMB02A	527792	6955061	Basalt (weathered)	A, B, C, F, G
TDMB02B	527793	6955066	Basalt (weathered)	A, B, C, F, G
TDMB03	527974	6955291	Basalt (weathered)	A, B, C, F, G
TDMB04A	528181	6955359	Quaternary sediments (sand/clay)	A, C, D, F, G
TDMB04B	528178	6955354	Basalt (weathered)	A, C, D, F, G
TDMB05A	528053	6954905	Quaternary sediments (fine sand – sandy clay)	A, B, C, F
TDMB05B	528041	6954905	Basalt (weathered)	A, B, C, F

The parameters to be monitored are provided in Table 10-9. The suite of parameters has been selected primarily to monitor possible changes in metal concentrations from land disturbance and dredging activities, as well as organic and volatile compounds to assess against machinery or anthropogenic contaminants. Water levels and general parameters will also be monitored to assess general changes in the groundwater system, such as the changes in freshwater seawater interface and flow directions. Once sufficient monitoring data have been collected, a statistical analysis (minimum, maximum, median, mean 5th to 95th percentile, etc) of the baseline dataset will be conducted. The results will be used to understand the natural groundwater variations within the Toondah Harbour PDA to assist in development of trigger values using the DSITI (2017) guidelines. The derived trigger values will be adopted during the construction period as an allowable upper or lower concentration limit prior to triggering management actions or further groundwater investigations.

Existing water quality guideline values (ANZG 2018) and NEPM (2011) will be utilised for site assessment until such time as appropriate site-specific triggers are developed.

Table 10-9: Groundwater Analysis Suite Description.

Analysis	Description
GP (General parameters)	pH, DO, Temp, EC, TDS, major cations, and anions (Na^+, Ca^{2+}, K^+, Mg^{2+}, Cl^-, SO_4^{2-}, HCO_3^-, CO_3^{2-}) Alkalinity.
Br	Bromide (using HPLC method).
Organic and volatile compounds	BTEX, phenolic compounds, polynuclear aromatic hydrocarbons (PAH), total petroleum hydrocarbons (TPH) and total recoverable hydrocarbons (TRH).
Metals	Arsenic, cadmium, chromium, copper, lead, manganese, mercury, nickel, zinc, aluminium, antimony, barium, beryllium, boron, calcium, cobalt, iron, magnesium, molybdenum, potassium, selenium, silver, strontium, thallium, tin, vanadium.
Nutrients	Ammonia, nitrite, nitrate, total kjeldahl nitrogen, total phosphorus
Other parameters	Fluoride
SWLS	Standing water level data: Time-series groundwater levels. Corrected for barometric pressure effects.

10.6. Residual Risk of Impact

A risk assessment has been carried out for key activities where an impact to groundwater is anticipated (Table 10-10). This risk assessment considers the risk posed before and after application of proposed mitigation measures following the methodology outlined in Section 6.1 of the EIS. The risk assessment determined that the risk of significant impact was low after application of mitigation measures.

Table 10-10: Groundwater Risk Assessment of Key Activities.

Activity	Initial risk assessment					Mitigated risk assessment				
	Scale	**Duration**	**Impact**	**Likelihood**	**Risk**	**Scale**	**Duration**	**Impact**	**Likelihood**	**Residual risk**
Dredging	Local	Medium	Medium	Possible	**Medium**	Local	Medium	Medium	Not likely	**Low**
Dewatering: lowering the groundwater table for other users/GDEs	Local	Medium	Medium	Possible	**Medium**	Local	Medium	Medium	Not likely	**Low**
Dewatering: changing hydraulic gradients between aquifers/ seawater to facilitate mixing	Local	Medium	Medium	Possible	**Medium**	Local	Medium	Medium	Not likely	**Low**
Dewatering: inducing contaminant mobilisation from buried landfill	Local	Medium	Medium	Possible	**Medium**	Local	Medium	Medium	Not likely	**Low**
Sheet piling	Local	Medium	Medium	Possible	**Medium**	Local	Medium	Medium	Not likely	**Low**
Reclaimed sediments	Local	Long	High	Possible	**High**	Local	Medium	Medium	Not likely	**Low**