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ERAMURRA SALT PROJECT

CAPE PRESTON EAST, WESTERN AUSTRALIA

GEOTECHNICAL INVESTIGATION REPORT



Leichhardt Industries

PER2020-0143AM Rev 2

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1 INTRODUCTION

CMW Geosciences Pty Ltd (CMW) was authorised by Leichhardt Industrial to conduct a geotechnical investigation of a site located at Eramurra Salt Project, Cape Preston East, Western Australia. This was authorised by a service agreement, reference CO-1001 Leichhardt & CMW Geosciences Service Agreement, dated 14 July 2021.

The scope of work proposed is addressed in the CMW proposal, reference PER2021-0143AG Rev1, dated 29 June 2021.

2 BACKGROUND

One of the main geotechnical challenges with the Eramurra solar salt project is undertaking cost-effective investigations that can characterise the very large project area, so that subsurface investigation methods can be used effectively to zone and characterise large tracts of land.

To successfully achieve this, a staged and systematically executed investigation was carried out to develop a conceptual ground model, which can be updated and modified with staged investigations (observation model) until a good level of confidence is achieved for planning and design purposes.

CMW and Leichhardt have worked towards this over the past 18 months with desk studies, terrain mapping an extensive GIS database and the Leichhardt team rationalising/optimising pond design based on information to date. The background stages and tasks leading to the ground investigation culminating in this report are briefly outlined below:

- CMW provide an Expression of Interest to Leichhardt in April 2020 to aid with the Eramurra Salt Project focussed on delivering staged and tailored ground investigations and geotechnical design services.
- Terrain evaluation mapping undertaken in August 2020 (remotely) and presented in CMW's desk top study report PER2020-0143AC Rev0 titled Geotechnical Desktop Study Report for Eramurra Salt Ponds,
- A site reconnaissance to accessible parts of the site undertaken in March 2021 by Matthew Tutton and Tristan Menzies of CMW and John Lang of Leichhardt Industrials (Leichhardt)
- A meeting in March 2021 between Leichhardt and CMW to discuss the planned scope of investigations and to present some preliminary costs estimates for non-borehole phases of the planned investigation.
- Finalised proposal submitted on 29 June 2021 to undertake a Phase 1A (Mapping) and Phase 1B (Intrusive Investigation) and accepted by way of a signed Service Agreement on 14 July 2021.
- Commencement of Phase 1A mapping phase of the investigation on 3 August 2021.
- Commencement of Phase 1B intrusive investigation on 14 August 2021.
- Phase 1B intrusive investigation works were terminated on 24 September 2021 at the instruction of Leichhardt.

3 SCOPE OF WORK UNDERTAKEN

The locations of the work undertaken are shown in Figure 1 (Figure Series) which shows an aerial photograph and proposed infrastructure in the background. They are also shown on Figure 3 (Figure Series) which show engineering geology units and proposed infrastructure as base detail.

When describing the work undertaken as part of this report reference has been made to works done within certain areas and landforms. Where italics are used in a description, reference is being made to one of the geomorphological units presented in Figure 2 (Figure Series).

A summary of the scope of the Phase 1A and Phase 1B works and the progress completed for both Phases at cessation of works on 24 September 2021 is outlined in Table 1.

Table 1 – Summary of the Scope of the Fieldwork

Phase Number	Components of Investigation	Proposed Quantities (Total/ Nr)	Completed Quantities (Total/ Nr)
1A	Field mapping of all parts of site (west of 40-mile beach road) Sampling for algal mat.	N/A	Complete
	Algal mat sampling	127	94
1B	Geophysics Survey – crystalliser pond walls and sea walls	Ground penetrating radar (crystalliser walls) – 50 km MASW survey (sea walls) – 10 km	Ground penetrating radar (crystalliser walls) – 51 km MASW survey (sea walls) – 8 km MASW (crystalliser area) 2 km
	Test Pits – Concentrator and crystalliser pond walls	245	191
	Test pits – Borrow areas A to I	68	59 (Borrow areas A to F)
	CPTu – Marshbuggy rig	100	27
	CPTu – Marooka M2 rig		38
	Surface Sample for Triaxial Permeability testing	68	68

The locations of all investigations undertaken are shown on the Figure 1 Figure Series.

Note that Figure1 is an overview of the site (small scale 1:85,000) whilst Figures 1A through to Figure 1E form a map-book for specific parts of the site at a more detailed scale (1:30,000).

4 ENGINEERING GEOLOGICAL MAPPING

Detailed engineering geological mapping to identify the presence and nature of outcropping rock was carried out in conjunction with algal map sampling between 3 and 14 August 2021 and thereafter in tandem with the progress of the test pit investigation. The objectives of the mapping investigation were as follows:

- Determine the distribution and nature of rock outcrops so that inferences about depth to rock and natural soil cover could be made, as well as the potential for seepage through exposed rock under the seawall alignment and across the floor of concentrator and crystalliser ponds in general.
- Understand the potential for shallow rock in the crystalliser pond area – this is critical in being able to design the ponds to achieve a flat floor without the need for excessive rock breaking.
- Examine creek banks where the erosion of the creek yields a good exposure of the superficial soils to derive (through mapping) information regarding the thickness, nature and variability of materials that not only underlie the ponds but could also provide important sources of borrow.
- Identification of rock type, fracture pattern and potential prospects for rip-rap and armour rock.

Field mapping was carried out using GPS/GNSS enabled tablets utilising QGIS spatial software. These observations were used together with the aerial image, published geology and the digital elevation model for the site to produce the interpretative geology maps presented as the Figure 3 Figure Series.

Field mapping was used to:

- Contribute to the geological model for the site.

- Refine the scope of subsequent investigation phases immediately ahead of the planned Phase 1B works (for instance the observed presence of shallow rock along the Pond 9 wall alignment resulted in the substitution of several planned CPTs with test pits.
- Obtain a better understanding of the potential for seepage through beach rock ledges, shallow or outcropping fractured rock etc.

4.1 Algal Mat and Acid Sulphate Soil Sampling

At the request of Leichhardt, Algal mat samples were taken during the Phase 1A mapping commencing on 4 August 2021 and continuing on an opportune basis throughout Phase 1B of the intrusive investigation. The final algal map samples were recovered on 24 September 2021.

Additionally, CMW were also requested to recover Acid Sulphate Soil (ASS) samples from the soil below the base of the algal mat sample in accordance with the instructions of Leichhardt's environmental subconsultant Land and Water Consulting (LWC).

Note that the subsequent testing, analyses, and environmental assessment of both the algal mat and ASS samples has been carried out by others and such work and results do not form part of this report.

The location of Algal Mat samples is shown on the Figure 1 and Figure 3 Figure Series.

The Chain of Custody of the ASS samples are included within Appendix K – Acid Sulfate Soils Chain of Custody.

4.2 Geophysics

During the investigation, geophysical testing by way of Multi-channel Analysis of Surface Waves (MASW) and Ground Penetrating Radar (GPR) was carried out along transects specified by CMW.

The work was carried out between 14 and 31 August 2021. The objectives of the geophysical testing were to provide enhanced subsurface information as outlined below:

- MASW profiling along proposed Sea Wall alignments in order to provide an indication of the depth to top of bedrock and of the low velocity infills of possible paleochannels or depressions in the buried rock surface. This information is useful for the purposes of assessing embankment settlement. The target depth for MASW profiles was 10m Below Ground Level (BGL).
- GPR profiling within the proposed site of the Crystalliser Ponds to map the depth to shallow bedrock (where present) to a target depth of 5 m BGL.

The geophysical investigation including the results of the MASW and GPR profiling is presented in Appendix C.

Note some of the planned alignments for geophysical traverses were locally moved to avoid the need to clear vegetation. Some planned lines were not complete due to site access and/or budget constraints.

The position of the Geophysical Lines undertaken is shown on Figure 1 and Figure 3 Figure Series.

4.3 Test pits

Test pitting was carried out between 19 August and 23 September 2021. Test pits were excavated with a rubber tyred backhoe for speed and efficiency in moving from location to location, as a cost effective, quick, and efficient way of characterising shallow ground conditions. The primary purpose of the test pits was to:

- Understand the ground conditions for the purposes of evaluating potential borrow sources, assessing shallow foundation conditions, assessing the impact of embankment subgrade type on embankment seepage and stability and to record the depth of rock (if encountered).
- Retrieve bulk disturbed samples for classification/ index testing and to assess for suitability for potential borrow.

Test pits were typically excavated to 3 m (or shallower if refusal or collapse of the sidewalls occurred or if an unacceptably slow rate of excavation took place within weathered soil profiles).

The location of completed test pits is shown on Figure 1 and Figure 3 Figure Series. Note that test pits denoted TP are generic test pits excavated to provide information on foundation conditions beneath crystalliser and concentrator walls, to assess borrow potential in the crystalliser and concentrator pond areas and to support the overall geological understanding of the site. Test pits denoted BP refer to test pits excavated in areas specifically targeted as potential borrow pit (BP) areas.

It was not part of the current scope to excavate test pits in the Inter-tidal and Supra-tidal areas as the type of backhoe mobilised could not access these areas. Excavation of test pits in these areas may form part of a future investigation phase.

4.3.1 Acid Sulphate Soil Sampling

Recovery of Acid Sulphate Soil (ASS) samples from selected test pits was undertaken in accordance with the instructions of Leichhardt's environmental subconsultant. The subsequent testing, analyses and environmental assessment of these ASS samples has been carried out by others and does not form part of this report.

4.4 Electric Friction Cone Penetrometer Tests

Electric Friction Cone Penetrometer Tests with pore pressure measurement (CPTU) were completed using the following equipment:

- Marshbuggy rig CPTu's were completed between 14 and 22 August 2021.
- Marooka M2 rig CPTu's were carried out from 14 to 18 August 2021.

The CPTu's were carried out to determine the soil profile and characterise the engineering properties of soils (especially strength and stiffness) at the nominated CPTu locations.

Note that the CPT rig is of limited use in hard ground as the cone can encounter shallow refusal on large gravel or cobbles, rock, calcrete or similar hard layers. For this reason, as part of our initial reconnaissance/ mapping carried out during Phase 1A of the investigation, original proposed CPT locations based on an initial desktop study were evaluated and where the ground was considered unsuitable for CPT testing (for example due to the presence of observed rock outcrop or boulders) then the proposed CPT location was replaced by a test pit.

Generally, CPTs were not scoped on the outwash/residual surface and gilgai area south of the *Inter-tidal and Supra-tidal flats* where shallow rock, numerous rock outcrops and gravelly clay/clayey gravel with a large gravel content was present. Some CPT testing was accomplished in limited parts of the *Alluvial Outwash/Residual Surface* south of the *Inter-tidal and Supra-tidal flats*, although generally shallow refusal occurred.

Dissipation tests were carried out predominantly in the Marshbuggy CPTs which were located in the 'softer' mangrove and intertidal mudflat areas, e.g., along the alignment of the proposed sea wall. In a dissipation test, the pressure-time dissipation characteristics of excess porewater pressures generated by pushing the cone into the ground are recorded. Analyses can then be undertaken to characterise the consolidation/compressibility characteristics of the ground

The Marshbuggy CPT rig was able to recover thin-walled piston samples (MOSTAP) samples from strata in the soft Playa/Mangrove areas along the proposed sea wall. These samples were subjected to a suite of laboratory tests including soil index tests, triaxial tests and consolidation (oedometer) tests. Limited MOSTAP and thin wall piston samples were retrieved by the Marooka M2 rig due to the harder nature of the ground this rig traversed over close to or on the *Alluvial Outwash/Residual Surface* (refer Figure 3 Figure Series) at the southern edge of the Inter- and Supra-tidal flats. CPT locations are presented on and Figure 1 (Figure Series).

4.5 Triaxial Surface Samples

Triaxial surface sampling was carried out between 13 August and 23 September 2021 at the request of Leichhardt. The samples were required for subsequent laboratory testing by others for Leichhardt's own purposes and do not form part of the analyses contained in this report. The location of the triaxial surface samples is presented on Figure 1 (Figure Series) and Figure 3 (Figure Series) are prefixed by the letters 'SST'.

Note that these samples are not to be confused with samples subjected to triaxial strength testing; the results of which are included in this report.

4.5.1 Methodology

The sampling method employed involves a stainless-steel tube being fully hammered into the topsoil and recovered containing an undisturbed soil core. To help achieve a reasonably straight drive into the soil, the tube was inserted into a guide cylinder beforehand (see Plate 1 below). The sample tube had dimensions of 100 mm (diameter) x 120mm (height) and has sharpened edges at the cutting end to limit sample disturbance.

The upper 100mm of soil was removed before taking the sample. A panoramic photographic record of the surrounding area taken for an appreciation of the environmental context in which the sample was taken. Subsequently, the steel cylinders were wetted slightly to preserve moisture content during transport, capped and sealed with duct tape prior to onward transport to Leichhardt's shipping destination.



Plate 1: Triaxial surface sample equipment

5 GEOMORPHOLOGY

The site consists of a range of geomorphological environments which are typical of the Pilbara coastline between Karratha and the Exmouth Gulf. Each of the main geomorphological unit encountered is discussed below and are useful for broad zoning of the site.

Figure 2 (Figure Series) shows our zonation of the site into Geomorphological Units. This mapping has been undertaken primarily in the office using the digital elevation model, published geology and aerial imagery to delineate units that help inform the pond embankment design (foundation conditions, distribution of borrow, trafficability etc). The mapping was 'truthed' in the field allowing the nature of each unit to be better understood and characterised. The geomorphological map units extend generally a few kilometres beyond the extents of the crystalliser and concentrator ponds.

The following Geomorphological Units were mapped, are described below and are used to practically characterise and zone the site at a macro-scale.

1. Alluvial Outwash/Residual Surface
2. Rocky hills and associated Talus
3. Inter-tidal flats
4. Supra-tidal flats
5. Islands with rock outcrops or rocky fringes
6. Former Coastal Rock Ledges
7. Beach
8. Fringing Dune
9. Deflated Dunes
10. Islands with rock outcrops or rocky fringes
11. Mangrove

5.1 Alluvial Outwash/Residual Surface

Most of the site including the entire Crystalliser Pond layout and Concentrator Ponds 3 to 14 are located on a gently dipping and generally planar land surface. This surface falls from an elevation of about 25 m AHD where it abuts a slightly steeper land surface of colluvium and talus fringing rocky hill ranges to the south. This planar land surface has mapped and called Alluvial Outwash/Residual Surface. It falls to the north at a generally consistent gradient of about 2.5 m per kilometre in the concentrator pond area west of 40-mile beach road and east of McKay Road. West of McKay Creek the gradient of this land surface is even gentler, and gradients are typically about 1.5 m per kilometre across the Crystalliser Pond area. Slide 1, Appendix B shows the typical nature of this surface.

The *Alluvial Outwash/Residual Surface* is the same land surface that has been mapped as the Horse Flats Gilgai by others. It does indeed contain extensive areas of Gilgai and associated vegetation. Site inspection and intrusive investigations reveal the superficial material underlying this landform is of mixed geological origin (transported and residual). This is because they can contain both alluvial outwash material washed down (transported) from the hill ranges to the south as well as in situ weathering products (residual soils) derived from the underlying bedrock. Across the mapped geomorphological unit are many places where rainwater erosion has removed weathered and residual materials and has exposed the underlying bedrock.

Exposure of bedrock was noted over many parts of the *Alluvial Outwash/Residual Surface* but was not noted anywhere within the Crystalliser Pond footprint. Bedrock exposure has occurred due to riverine scour in the larger creeks, especially along their lower reaches (e.g., there is extensive rock exposure in McKay Creek bed and banks) (refer Slide 2, Appendix B). Generally, the smaller creeks have not incised extensively into bedrock and their beds and banks comprise transported sands and gravel, or small cliffs (<<1 m) of exposed residual soil (red high plasticity clay). Towards the *Inter- and Supra Tidal Flat* at lower elevations on the more northerly parts of the *Alluvial Outwash/Residual Surface*

there are extensive outcrops of igneous rock (refer Slides 3-9, Appendix B). The bedrock here has been exposed due to rainwater and sheet flow eroding the overlying weathered rock and residual soil. The outcrops are generally low relief (e.g., Slide 3-5, Appendix B), sometimes only a domed surface of rock rising only 100 mm above the surrounding area is the extent of the outcrop. Sometimes the outcrops form low tors of core-stones especially when granite is the predominant rock type (refer Slide 6). Dolerite dykes are also present, and outcrop occur as shallow sub-crop, typically indicated by a discontinuous line of dolerite outcrop/boulders (refer Slides 3 and 9, Appendix B). The main areas of exposed rock have been mapped and are shown on Figure 3 (Figure Series). Note the greatest concentration of outcrop and inferred shallow rock occurs along McKay Creek and towards the northern edge of the *Alluvial Outwash/Residual Surface* especially in the vicinity of Ponds 8, 9 and 10. CMW note a correlation between areas of extensive outcrop and shallow refusal in test pits, which is to be expected.

There is extensive evidence of sheet flow across the geomorphological unit with areas where a thin veneer of sheet wash gravel can be noted usually coinciding with subtle rises (interfluvial centimetres higher than adjacent area). These areas are often characterised by the presence of a low woody scrub. The adjacent areas of slightly lower relief are commonly characterised by scattered grassland and an exposed clay surface often displaying polygonal desiccation cracks, and small collapse features (volume of feature typically 1-2 litres), colloquially referred to as crabholes. These features can form where surface water has caused erosion just below the surface allowing the surface to collapse into the hole.

Where sheet flow has concentrated and starts to form intermittent creeks, sand and gravel deposition is noted to occur across the *Alluvial Outwash/Residual Surface*. These geomorphological/geological changes across this surface have been mapped (refer Figure 3 (Figure Series)). Note sometimes the sheetwash appears to transport cobbles and gravels a short distance from areas of weathered and outcropping rock leading to deposits a short distance from the area of outcrop. An example of this is illustrated in Slide 11, Appendix B.

Test pits have indicated that soils overlying the bedrock are generally residual weathering products derived from weathering of the bedrock but also contain clasts of transport material. At the surface the alluvial material, where present, can be unweathered. It presents as a thin veneer, typical 100-200 mm of sand and gravel. However, within the clay and sandy clays occasional gravel sized clasts of material that is clearly not associated with the underlying bedrock (i.e., not a litho-relict) and must therefore be alluvial in origin although has weathered in situ to form a clay rich in situ soil similar to those residual soil derived from the underlying bedrock.

There are some areas of very thin sheet calcrete of limited spatial extent at ground level on the *Alluvial Outwash/Residual Surface*. Whilst their presence has been noted, their spatial extent has not been mapped as they are extremely hard to see, because they have no relief and are discontinuous and not very extensive.

Numerous channels incise the *Alluvial Outwash/Residual surface*. These are both minor and major, the four major ones being named on Figure 2 (Figure Series). These channels were dry at the time of this investigation, however, the depth and degree of erosion noted within the channels indicate that during periods of heavy rainfall they have a rapid flow rate.

Along the northern edge of the *Alluvial Outwash/Residual surface* is the presence of a calcarenite fringe. This has been mapped as an Engineering Geological unit, where observed (refer Figure 3 (Figure Series)) however it is part of *Alluvial Outwash/Residual surface* geomorphological unit. The nature of the calcarenite can be seen in Slides 12, 13 and 15. Its origin appears to be variable. In some places it appears to be due to eolian sand accumulation (presumably blown off the surface of the Inter-tidal flats) and containing calcium carbonate which subsequently has become cemented. This is illustrated in Slide 12, Appendix B. There also appear to be some small surface accumulation of calcrete (also refer Slide 12).

Some of the sands become cemented as a nodular calcarenite/calcirudite. The gravel sized clasts being largely comprised of cemented sand sized grains (refer Slide 13).

Geomorphologically the presence of the calcarenite is resulting in a distinct erosion pattern along the northern edge of the *Alluvial Outwash/Residual surface*. Here several short sandy creek beds occur as indentations into the *Alluvial Outwash/Residual surface* along the southern Inter-tidal flats shoreline and terminate against a low vertical cliff of calcarenite. One such feature is illustrated in Slide 15, Appendix B located close to SST037. It is apparent that rainwater is infiltrating the highly permeable calcarenite surface to the south of the cliff and emerging as spring, which in turn causes slotting and undermine the cliff (spring sapping) causing cliff retreat and enlargement of the indentation in a southerly direction. The sketch on Slide 15, Appendix B illustrates this mechanism.

Currently parts of the Pond 9 wall are founded on this material and significant seepage and erosion could be expected under parts of Pond 9, with erosion possibly resulting in subsidence of the Pond Wall without significant engineering works.

5.2 Rocky hills and associated Talus

There are rocky hills to the west, east and south of the site. The hills to the south form a watershed limiting the size of the hydrological catchments upstream of the site. Only Devils Creek drains a more extensive catchment that is not constrained by the hill to the south.

None of these hills fall within the site. Whilst there is potential to develop a quarry this option has not been further investigated at this stage as it is understood that rock armour to protect the seawall will likely be won from existing commercial quarries.

5.3 Inter-tidal flats

Inter-tidal flats refer to inter-tidal area or lagoonal area that has formed due to a prograding coastline most likely occurring during the late Pleistocene during period of fluctuating sea-level.

There is much evidence of former coastline occurring along the northern margin of the *Alluvial Outwash/Residual Surface*. This evidence includes wave cut platforms of igneous rock, beach rock, exposures of coral as well as clam shells often buried/embedded within the carbonate cemented beach rock.

Slide 21, Appendix B illustrates some of the features associated with the prograding coastline. In this Slide a former coastal barrier (red dashed line) formed by a storm beach and coastal dune allowed fine-grained sediment to accumulate between the northern margin of the *Alluvial Outwash/Residual Surface* through a process of sediment being washed in thorough creeks that formed through gaps in the coastal barrier. The same process is still occurring but this time the Inter-tidal flats are accumulating behind a contemporary coastal barrier, referred to as the Fringing Dune on Figure 2 (Figure Series) In the western part of the site the Fringing Dune becomes discontinuous, and the coastal barrier is instead formed by dense swath of Mangrove allowing a gradual accumulation of lagoonal muds to occur, brought in by the tide.

The Inter-tidal flats refer to a geomorphological unit behind the Mangrove that inundates regularly by normal tidal fluctuation. Some such areas inundate daily, other areas only fortnightly on spring highwaters, other areas even more infrequently such as during astronomical tides. Areas subject to less frequent inundation will tend to comprise stiff clays because of consolidation through drying out and desiccation. Surface desiccation can however be deceptive and softer material might be present beneath a surface crust due to more frequent inundation below the surface through a network of desiccation cracks. Slide 17, Appendix B illustrates some of the landscape's association with this unit.

5.4 Supra-tidal flats

Supra-tidal flats are similar both in nature and origin to the Inter-tidal flats. The fundamental difference is that they do not inundate as regularly and only inundate by events resulting in a higher-than-normal tides. Such events would be for instance highwaters resulting from storm-surges coinciding with high tides and resulting in 'Supra-tidal' events. The Supra-tidal flats can also be former inter-tidal flats that have become so full that a normal tidal event no longer results in inundation and as such might be older than the Inter-tidal areas. The result is generally a stiffer material, due to more desiccation and the gradual covering with wind-blown sand or colonisation with vegetation. Nonetheless the Supra-tidal flats are still extensive and are a geomorphological mappable unit. Note in the area immediately west of 40-mile beach, the lagoonal muds (now consolidated to clays) have drowned extensive rock outcrops of granite and dolerite which presumably were once rock outcrops and islets within the coastal marine environment. Such features are illustrated in Slide 18, Appendix B.

5.5 Mangrove

Mangrove forms a dense coastal barrier in the western part of the site. It also lines the major creeks and has been mapped as a geomorphological unit (refer Figure 2 (Figure Series)). Slide 19, Appendix B illustrates the typical Mangrove environment.

A number of creeks break through the Mangrove barrier, and these allow the tide to ebb and flow bring in clays and silts to form mangrove and lagoonal muds with each tide. It is also apparent that from time-to-time higher energy events result in sand entering the backwater area and mixing with the finer grained material close to the mouths of the creeks. An example of this higher energy environment can be seen in the bottom photograph on Slide 20 (Appendix B), as illustrated by the ripples, gravel veneer and presence of sand.

Slide 20 also illustrates the transition area between the Mangrove muds and Inter-tidal flats.

The presence of Mangrove creates a very low energy environment allowing very soft Mangrove muds to accumulate. Such material present significant trafficability issues and can only be traversed using amphibious vehicles.

5.6 Islands with rock outcrops or rocky fringes

These islands were once coastal barriers similar to the current Fringing Dunes. Where erosion has occurred, it has been noted that igneous rock is sometimes exposed, and such rock is inferred to be present at shallow depth beneath many of the islands. In addition, some of the dunal sand and storm beach gravel that once formed the former fringing dune/coastal barrier has cemented to form calcarenite and calcirudite which in turn has been exposed around their edges. An example of these rocky fringes is illustrated in Slide 14, Appendix B. This calcarenite and calcirudite is inferred to be present beneath parts of the islands. Test pits in the deflated dunes and sandplains to the north (which is a similar geomorphological unit) exposed highly weathered calcarenite which was generally weathered to a clay but with extensive litho-relicts of calcarenite being present to identify its origin.

5.7 Former Coastal Rock Ledges

Across parts of the Inter-tidal flats east of McKay Creek and along the western edges of some of the larger islands and along parts of northern edge of the *Alluvial Outwash/Residual Surface* unit are areas of former rock ledges. These can be seen as a planar rock surface almost at the same level as the Inter-tidal flats. The larger extents have been mapped and are shown as Beach Rock on Figure 2 (Figure Series).

Sometimes a surface of igneous rock at the same level as the lagoonal muds and can only be discerned from joint patterns and is inferred to be a wave cut platform. There are also extensive outcrops of beachrock, albeit with almost zero relief, and some coral, conglomerations of oyster shells and clam and cone shells, buried within a cemented calcareous matrix.

5.8 Beach

None of the project area is located on the beach which comprises, silty sands seaward of mangrove, rocky ledges and sand beaches.

5.9 Fringing Dune

The fringing dune rises to about 20 m, is generally aeolian in origin comprising silty sand. It is however in close association with a gravel storm beach. Storm beaches and cheniers are likely present beneath the contemporary dune. In addition, localised ledges of calcarenite and calcirudite and beach rock occur within this coastal unit (refer right hand photo in Slide 16, Appendix B).

5.10 Deflated Dunes

The deflated dune, sand plains and sandy islands is the final mapped geomorphological unit (refer Figure 2 (Figure Series)).

The unit is the subdued sandy topography present south of the more prominent contemporary fringing dune. It is a former dune system that has been deflated and also blown out to form a sand plain (e.g., to the south of the 40-mile beach campsite). As such it may be that parts of the sand plain are underlain in part by older consolidated lagoonal muds. Some of the sandy islands are also likely remnants from earlier coastal dunes and as such might rest directly on igneous bedrock or a calcareous beach rock.

6 GEOLOGY

6.1 Bedrock Geology

1:100,000 mapping as GIS layers (vector files) is available from the Geological Survey of Western Australia and has been used in this project. A layer (ArcMap feature class) called *GeologySimple_Preston_2156* shows the basement geology. This layer shows that granitic rock belonging to the Dampier Granitoid Complex (AgD) is present under the entire site, apart from the proposed jetty area (outside the scope of this report) where finer grained and metamorphosed igneous rocks are present. None of these rocks are exposed as hills but are present in creek beds and can be seen at low relief outcrops across much of the *Alluvial Outwash/Residual Surface* area and even rising as low outcrop above the level of the Inter- and Supratidal flat, especially in the area west and of and within 3 km of the 40-mile Beach Road Causeway. A report by Geopeko (Geopeko 1989) also encounters granite at shallow levels (around 0 m AHD) immediately south of the 40 mile beach foredune and at shallow levels in test pits further south along the Santos pipeline route out towards the Northwest Coastal Highway. Some of the Geopeko boreholes encountered a steep dip in the rock surface down to about -45 m AHD. This may be a palaeochannel incised into the granite bedrock. It should be noted however that is significantly deeper than the refusal levels of Cone Penetrometer Tests (inferred rockhead) undertaken in the same area (refer Section A-A' (Figure 4 Series)). At a depth of 45 m this depression or palaeochannel is considered too deep into competent bedrock geology to have been formed by one of the glacial sea level lows of the last 200,000 years and may have been incised by a far earlier event. It subsequently has had its infill of sediment removed during a late Pleistocene event and was then infilled again with late Pleistocene and Holocene sediments (as appears to be the case from the Geopeko boreholes) as the sea level rose. These sediments comprise:

- A 2-3 m drape of brown clayey quartz sand, glauconitic, gypsum bearing sandy clay (lagoonal sediments- Playa).
- Carbonaceous sand with pyritised wood, silt sand and in the base above the granite fluvial sand and
- Pebbly sand signifying the higher energy lag deposits commonly found in the bottoms of channels before low energy (fine grained) sedimentary infilling occurs.

CPT refusal occurred at a maximum depth of about -18 m AHD. This is significantly shallower than the -45 m for rockhead encountered in the Geopiko boreholes. It is possible CPTs refused on cemented

layers of cobbles and pebbles above the rock level within the deepest part of the depression or palaeochannel.

To the west of the site rock is exposed in north-south trending hill ranges and comprises:

- Kylene Formation, described as massive and amygdaloidal basalt;
- Maddina Formation, described as massive vesicular and amygdaloidal basalt; and
- AFkfd-Dacite.

To the east of the site, bedrock geology comprises mainly Mount Roe Basalt, which outcrops in the hills immediately east of Devil Creek close to the Northwest Coastal Highway.

The geological maps show several mapped dolerite dykes passing under the site and beneath the ocean, presumably mapped using geophysics. Dolerite dykes were noted to outcrop across the site. The more prominent dykes were mapped. Note dolerite dykes are noted to vary in width from about 100 mm to about 10 m (refer Slides 8 and 9, Appendix B). Dolerite outcrops are often highly eroded and often are expressed as intermittent alignment of boulders (refer Slide 3, Appendix B).

6.2 Published Surface Geology

The mapped geology is detailed and quite complex however, close inspection shows some features are approximately 50-100 m misaligned with the DEM. This simply reflects the published mapping was intended for use at 1:100,000 where 50-100 m on the ground is 0.5 to 1 mm on the map and not for use at more detailed scales. The principal units comprise:

1. Mangrove and marine muds fringing the coast but about 1 km wide in the west,
2. Shelly sand in coastal dunes and old beach deposits,
3. Coastal limestone, lime-cemented shelly sand, dune sand and beach conglomerate,
4. Silt and mud in supra-tidal and inter-tidal flats and lagoon,
5. Quartzo-feldspathic eluvial sand with quartz and rock fragments.

6.3 Project Specific Engineering Geological Mapping and Observations

CMW have made observations of the geology and engineering geology during dedicated Phase 1A mapping and during our extensive traverses across the site to travel to the extensive number of test pits and CPTs. These observations and the knowledge gained for instance from excavating a test pit near a rock outcrop of observed surface deposit is communicated through an Engineering Geological Map (refer Figure 3 (Figure Series)) and through the description of units provided below which relate surface mapping observations with those acquired through test pitting and interpretation of CPT traces and laboratory test results.

The unit description titles used here are the same as those used in the test pits and mapping field descriptions. It should be noted that not every unit listed below has surface expression and is shown on Figure 3 (Figure Series). The geological units have been grouped into the two geographical main areas where they are encountered. Unit names in *italics* below are the geomorphological units within which the geological unit is commonly encountered:

- A. Units occurring within the *Alluvial Outwash/Residual Surface* north of the low-lying hills present immediately south of the North West Coastal Highway, extending north through the crystalliser and concentrator ponds to the southern margin of the *Inter- and Supra-tidal flats*.
- B. Units occurring north of the *Alluvial Outwash/Residual Surface* within the *Playa (Inter and Supra tidal flats)* and heading north towards the coastal dunes and including the sand islands (*Fringing Dunes and Deflated Dunes, Sand Plains and Sandy Islands*) interspersed within the

Inter- and Supra-tidal Flats and areas Mangrove and associated mangrove muds both along the coastline and within tidal creeks – referred to as Coastal.

6.3.1 Geological Units – *within Alluvial Outwash/Residual Surface*

Unit	Description
1	Alluvial Sheetwash These comprise thin (typically less than 200mm) surface deposits of predominantly sand with gravel or gravelly sand with cobbles. These are the weathering products from the igneous basement materials from the hills to the south and have been washed down over the underlying Residual Soil (see Unit 2, below) with which they are almost exclusively associated with throughout the <i>Alluvial Outwash/Residual Surface</i> area. The extent of these surface deposits is shown on Figure 3 (Figure Series). During the mapping phase these sheetwash sands and gravelly sands were observed to form braided linear lenticular deposits where storm rain events had initiated overland flow. These surface features result from stormwater being unable to drain into the underlying Residual Soil and flows moving sands and gravels from upstream into these braided linear/lenticular shapes because of the sheet flow generating its own hydraulic gradient. These braided gravels were also incised by sinuous sandy channels typically less than 100 to 150mm deep and no more than 0.50 m wide. Lack of depth to the sheetwash means they have little prospectively as sources of free draining or granular fill. They will however require removal beneath embankments to prevent underdrainage/seepage. These braided channel gravels are like the sheetwash alluvial gravels but are generally found associated with the main river channels where they have broken their banks during storm events. Coarser grained gravels are present in areas of fractionally higher elevation and the with highly localised thicker (up to 200mm) over-bank deposits present around creek beds. Gravels and cobble sized clasts typically comprise quartz, granite, and dolerite fragments. <u>Geotechnical Comments</u> Lack of depth to the sheetwash means they have little prospectively as sources of free draining or granular fill. They will however require removal beneath embankments to prevent underdrainage/seepage.
2	Residual Soil Residual soils are located at the surface throughout the <i>Alluvial Outwash/Residual Surface</i> area and beneath the thin veneer of Alluvial Outwash described above with which they are associated. These soils are the result of <i>in situ</i> weathering of the underlying Dampier Granitoid Complex to such an extent that the mass structure and material texture and fabric of the rock is no longer visible, but the resulting soils remain <i>in situ</i> and have not been transported. These soils are associated with surface Gilgai features characteristic of high plasticity cohesive soils and typified by a surface expression of undulating hummocks and the formation of shallow “crab holes”. The main soil types noted at the surface and in the test pits are: • Sandy Clay, medium to high plasticity, red brown, trace (< 5%) to with (5-12%) gravel of quartz, granite and dolerite and gravel sized litho-relicts of extremely weathered granite or dolerite, stiff to very stiff • Clay with sand, medium to high plasticity, red brown with gravel sized litho-relicts of extremely weathered granite or dolerite, stiff to very stiff. Litho-relicts are <i>in situ</i> weathered clasts of the original parent rock which retain some of the original rock's texture and occasionally structure compared to the surrounding residual soil matrix.

	The upper 0.50 to 0.75m of the residual soil profile typically contained some transported alluvial clasts of granite, dolerite and quartz gravel which had weathered <i>in situ</i> within this upper part of the residual profile appears to be a secondary residual soil associated with the overlying Alluvial Sheetwash veneer. In the lower sections of test pits cobble sized lithorelicts of extremely to highly weathered granite or dolerite were observed, typically below 1.50 to 2.00 m depth, although excavatable by a backhoe.
3	Alluvium Potential Alluvial deposits were encountered in test pits within the <i>Alluvial Outwash/Residual Surface</i> area generally associated with (in the vicinity of) existing creek beds and are considered to represent former channel courses (palaeochannels). The soils typically encountered in these inferred former channels comprised: - Sandy Clay, medium to high plasticity, red brown, trace to with gravel of dolerite, stiff to very stiff; underlain by - Sandy Gravel, fine to coarse grained, with cobbles. The gravel and cobbles occasionally comprised rounded dolerite indicating an alluvial/transported origin, coupled with the absence of <i>in situ</i> litho-relicts in the overlying sandy clay. The sandy gravel was very dense with test pits typically terminating due to refusal after penetrating no more than 1.0 m into this material.
4	Granite – Extremely Weathered This unit was encountered directly beneath the Residual Soil and although the parent rock has been weathered to such an extent that it is a soil, the mass structure, texture and fabric of the parent rock can be observed. The predominant soil types comprised coarse through to fine grained clay-sand-gravel mixtures as follows: - Sandy Gravel, fine to coarse grained, trace to with clay, with cobbles. - Clayey Gravelly Sand, with cobbles - Gravelly Sandy Clay, trace cobbles. Gravel and cobbles are typically highly weathered litho-relicts of granite, occasionally becoming highly to moderately weathered, particularly in cobbles.
5	Dolerite – Extremely weathered As for Unit 4 this extremely weathered dolerite was encountered directly below the Residual Soil within test pits. <i>In situ</i> weathering of the parent rock has produced a similar range of clay-sand-gravel mixtures as noted above for Unit 4: - Sandy Gravel, fine to coarse grained, trace to with clay, with cobbles - Clayey Gravelly Sand, with cobbles - Gravelly Sandy Clay, trace cobbles The coarse litho-relict fractions comprise highly weathered dolerite, becoming highly to moderately weathered in cobble sized litho-relicts. Typically, the weathering products from the dolerite parent rock tended towards the finer components of the clay-gravel-sand fractions than the granitic weathering products, with a correspondingly higher plasticity noted generally in simple field observations. The provenance of the extremely weathered dolerite is discussed below in Unit 6 but is assumed to originate from the <i>in-situ</i> weathering of dolerite dykes that cross-cut the granite. Some dolerite dykes have been mapped (refer Figure 3 (Figure Series)). The occurrence of this unit is accordingly more restricted in extent than the granite derived weathered materials.
6	Granite – Moderately Weathered The Archaean-age Dampier Granitoid Complex is present under most of the site and is exposed in outcrops as follows: In the banks of incised creek bed channels and particularly towards the mouth of the creeks where they discharge into the Playa (<i>Inter- and Supra-tidal flats</i>).

	- At the southern margins of the Playa (<i>Inter and Supra-tidal flats</i>) sometimes as a coastal wave cut platform (shoreline surface). - As low relief, shallow outcrops across the <i>Alluvial Outwash/Residual Surface</i> area. When undertaking the engineering geological mapping and when traversing the site between test locations low relief shallow outcrops of granite ranging in extent from less than 1 m² to several 1000 m² were noted and indicate that shallow granite bedrock will underlie adjacent areas. The outcrop relief was typically less than 0.5 m and typically intermittent. The granite was typically pale coloured, moderately to slightly weathered and medium to high strength. Joint sets were noted in the granite with two dominant sets oriented north-south and northwest-southeast. The mapping study revealed that the surface of the granite is variable across the <i>Alluvial Outwash/Residual Surface</i> area as in addition to actual outcrop, discrete discontinuous areas of boulders were recorded interpreted as the surface expression of a shallow subcrop of the granite. Additionally slight increases in surface relief were noted associated with concentrations of surface gravel and cobbles also indicative of relatively shallow granite subcrop. Lusher areas of vegetation indicative of semi-permanent inundation of water/ moisture pointed towards a deeper contact between the granite subcrop and overlying <i>in situ</i> weathered soils. These observations are indicative of a highly variable and undulating granite subcrop/ buried surface beneath residual soils of variable thickness and transported alluvium across the <i>Alluvial Outwash/Residual Surface</i> area. The test pit investigation generally did not encounter the granite subcrop beneath the weathered soils apart from those pits completed close to creek beds or adjacent the low relief outcrops. The granite encountered was typically coarse grained, pale grey, highly to moderately weathered and low to medium strength. The outcrops of granite noted above in some instances contained intrusions of dolerite dykes which infilled the joint sets within the granite. The dolerite dykes ranged in size from 100mm to 15m in width (refer Slide 8, Appendix B) and several were traced for distances of up to 100 to 200m. Surface expressions of <i>in situ</i> weathering of dolerite dykes were traced within the creek beds as lines of dolerite boulders typically in a similar orientation to the joint sets noted above. The dolerite was typically dark grey coloured, moderately to slightly weathered and medium to high strength. Slides 6 to 9 (Appendix B) illustrate the nature of both granitic and doleritic rock outcrop and in Slide 8, the relationship between the two rock types. Two of the main fracture sets are 340-160° and 070-250° (refer Slide 10, Appendix B). However, another common trend particularly for dolerite dykes is 020-200° and 060-240°. The test pit investigation encountered extremely weathered dolerite soil profiles as detailed In Unit 5 and are considered to represent the weathering products of dolerite dyke subcrops and hence are of reduced lateral extent compared to the weathering products noted from the granite. Limited outcrops of gabbro, a coarse grained basic igneous rock like dolerite in composition, were also noted associated with the low relief granite outcrops and dolerite dyke intrusions. Gabbro typically formed massive low relief outcrops like the granite but of considerably reduced lateral extent.
7	Metasediment – Highly to Moderately Weathered This Unit was encountered within test pits along the western edge of the crystalliser ponds area close to the western boundary of the study area.

	The metasediment was fine grained, dark pinkish brown, highly to moderately weathered, low to medium strength. Weakly to moderately cemented gravel- to cobble-sized clasts of (meta) conglomerate was noted. The material was encountered below Residual Soil typically from around 1.00 to 1.50 m depth and recovered from the pit as a Sandy Gravel. The backhoe struggled to penetrate more than 0.50 m into this material.
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6.3.2 Units – Coastal

Unit	Description
8	Eolian Sand This Unit typically occurred immediately north and east of the of the <i>Intertidal and Supra-tidal Flats</i> along the coast behind the beach areas. These sands occurred within the study area in the following geological settings: • <i>Deflated Dunes and Sand Plains</i> (immediately north and east of the <i>Inter- and Supra- Tidal Flats</i> and extending eastwards beyond 40 Mile Beach Road). These were characterised by broad, rolling areas of low relief, almost flat in some areas. • Sandy Islands (within <i>Inter- and Supra-tidal Flats</i> and extending east beyond 40 Mile Beach Road). • <i>Fringing</i> (Coastal) <i>Dunes</i> typically up to 10 m in height and rapidly flattening out along the southern edge as these dunes merge with the <i>Deflated Dunes and Sand Plains</i> to the south (located north of the <i>Inter- and Supra-tidal Flats</i>). The Eolian Sand (more specifically a silty sand) was encountered both at the surface and excavated within test pits in the areas noted above. Typically, this material comprised: • Silty Sand, orange, brown to yellow brown, trace to with gravel; occasionally trace clay. The silty sand was up to approximately 2.0m thick in the deflated dunes and sand plains (with 1.0 to 1.5m depth being more typical) and much thinner on the sandy islands, rarely exceeding 1.0m thickness. Test Pits located on or close to the fringing dunes recorded sand to the full depth of the pit before the sidewalls collapsed at around 2.5m depth and on the <i>fringing dunes</i> were likely much deeper. The Eolian Sand is underlain by Residual Soils, extremely weathered igneous rocks and over the majority of the <i>deflated dune</i> area it overlies an extremely weathered calcarenite. CPTs undertaken along the southwestern end of the fringing coastal dunes indicate potentially multiple phases of dune depositions, associated with changes in sea level, indicated by the presence of clay bands between successive dunal systems. Gravel composition depends on the underlying geology. Granitic and doleritic gravel clasts were restricted to test pits within the sand plain at the northern margins of the Inter - and Supra-tidal Flats and in the east of some of the larger sandy islands. Clasts of calcarenite, coralline limestone and beach rock were noted beneath much of the sand plain heading north from the margins of the <i>Inter- and Supra-tidal Flats</i> towards the fringing dunes, and coralline limestone, shells and calcarenite dominated the gravel components within the fringing dunes. This observation points to this entire area being relatively recently a shallow coastal/marine environment. In this context areas have been mapped fringing the southern edge of the <i>Inter-tidal Flats</i> on the Geomorphology Maps (refer Figure 2 (Figure Series)) as Former Coastal Rock ledges. Similarly, the geology has been mapped in the same area as Beach Rock. The Beach Rock generally comprises a calcium carbonated cemented

	coarse-grained mixture of shells, coral fragments, cone, and clam shells, pieces of calcarenite and calcirudite (former beach rock) and occasional igneous gravel and cobble sized fragments and as Beach Rock
2#.	Residual Soil This is similar to Unit 2 described above for the <i>Alluvial Outwash/Residual</i> area. This unit was encountered within the Coastal area, below the Eolian Sand at the southern edge of the <i>Sand Plains</i> adjoining the northern margin of the <i>Inter- and Supra-tidal Flats</i>. However, this Unit was derived from a parent rock of either calcarenite, beach rock or coralline limestone, and is observed within the test pits beneath the majority of the <i>Deflated Dune and Sand Plain</i> extending north from the margins of the <i>Inter- and Supra-tidal Flats</i> and below the <i>Fringing Dunes</i>. Typically, this material comprised: Sandy Clay or Clayey Sand, trace to with gravel, soft to firm and firm. Residual soils derived from the calcareous deposits were observed to often display characteristic variegated pale red / yellow/ pale green colours. The gravel component comprised extremely to highly weathered litho-relicts of calcarenite or, more rarely beach rock.
4	Granite – Extremely Weathered Unit 4 as described in the <i>Alluvial Outwash/Residual</i> area was encountered within this Coastal area below the Eolian Sand at the southern edge of the sand plains adjoining the northern margin of the <i>Inter- and Supra-tidal flats</i>.
5	Dolerite – Extremely weathered Unit 5 as described in the Outwash Plain area was again encountered within this Coastal area as for Unit 4 below the Eolian Sand at the southern edge of the sand plains adjoining the northern margin of the <i>Alluvial Outwash/Residual Surface</i> and in the east of the sandy islands. This unit was generally of limited areal extent compared to the granite derived materials.
9	Calcarenite – Extremely Weathered Extremely weathered calcarenite, coralline limestone and Beach rock were encountered in test pits below the residual soil beneath the majority of the <i>Deflated Dunes and Sand Plains</i> extending north from the margins of the <i>Alluvial Outwash/Residual Surface</i> and below the <i>Fringing Dunes</i>. This unit typically comprised: - Sandy Gravel, fine to coarse grained, trace to with clay, with cobbles. - Clayey Gravelly Sand, with cobbles Gravel and cobbles are typically highly weathered litho-relicts of calcarenite or beach rock, occasionally becoming moderately weathered particularly in cobble-sized fragments.
10	Calcarenite – Highly to Moderately Weathered Noted from mapping this unit comprises calcarenite or beach rock in the following geological settings: - Former coastal rock ledges exposed at the margins of the sandy islands and along the southern margin of the <i>Inter- and Supra-tidal Flats</i> - Occasional cemented dune sands i.e., calcarenites exposed immediately to the south of the <i>Fringing Dunes</i> or around the edges of sand islands. Examples of surface exposure of calcarenite is shown in Slides 12-16, Appendix B.

	The exposed beach rock ledges comprised coarse grained, moderately weathered, medium strength rocks composed of moderately cemented clasts of coralline limestone, calcarenite and shells. The test pit investigation encountered highly to moderately weathered calcarenite typically in the <i>Sand Plain</i> areas immediately south of the <i>Fringing Dunes</i> at depths of approximately 1.5m. The calcarenite was fine to coarse grained, pale grey to pale red, highly to moderately weathered and low to medium strength with gravel sized shells and coral fragments.
11	Lagoonal Muds (Sediments) This Unit comprises the soft sediments encountered in the <i>Inter- and Supra-tidal Flats</i>. No test pits investigations were carried out in this Unit due to accessibility for plant but CPTs were carried out by the Marshbuggy along the location of the proposed sea wall in the western part of the northern margins <i>Inter-tidal flats</i> and also within the body of the <i>Inter-tidal Flats</i> where cross walls are planned and access was not prevented due to presence of Aboriginal heritage areas. Some opportunistic geological mapping was carried out via amphibious Argo vehicle at the time of sampling of the algal mats was undertaken. These sediments occurred within the following geological settings • <i>Inter-tidal flats and creeks.</i> • Within area of scattered <i>mangrove</i> • Within area of <i>Supra-tidal flats</i> Based on visual assessments completed at the surface and interpretation of the CPT tests the materials comprised: • Inter-laminated Clay, Silt, Sand and Sandy Clay, very soft to soft (CPT tests) • Inter-laminated Clay, Silt, Sand and Sandy Clay, firm to stiff, stiff to very stiff (CPT tests) • Clayey Sand and Sandy Clay (observed at the surface) Very soft to soft mud sediments are the result of sedimentation in a lagoonal setting behind a beach/dune/mangrove barrier. The muds are laminated with silts and sands. Periodic cyclonic events likely deposit thin laminae of silts and sands across wide areas. More locally around creeks and gaps in coastal dunes regular introduction of sand will occur due to strong onshore winds and high tides. In the <i>Inter-tidal flats</i> area, the firm to stiff and very stiff materials underlying near surface soft to very soft materials are thought to represent old former lagoonal sediments which have been subject to desiccation and consolidation with a corresponding increase in shear strength. In the <i>Supra-tidal Flats</i>, the near surface materials tend to be stiffer than in the <i>Inter-tidal Flats</i> and this is due to near surface desiccation that occurs during the long periods between inundation events. In this context, the elevation of the <i>Supra-tidal Flats</i> is above normal spring highwater level and inundation occurs mainly during times of astronomical high water and storm surges. It is observed that during spring tides the higher elevation <i>Inter-tidal Flats</i> become inundated from below with water saturating the soils via a system of polygonal desiccation cracks. This can result in a stiffer crust overlying softer materials leading to potential vehicle bogging and trafficability issues if a breakthrough in the stiffer crust occurs. It is presumed a similar mechanism occurs when the <i>Supra-tidal Flats</i> become inundated. During the algal mat sampling it was noted that areas closer to the sandy islands typically comprised clayey sands at the surface due to run-off and subsequent re-deposition of the sand from the islands.

7 FIELDWORK AND LABORATORY TEST RESULTS

7.1 Results of the Fieldwork

An extensive range of data was collected during the field investigation emanating from the scope of investigation, testing and sampling described in Section 3. Factual data, photographs and records emanating from this work is provided in Table 1.

Table 2 – List of Factual Data Appendices

Appendix	Contents
A	Location Summary Sheet (list of investigation locations according to location type).
B	Annotated Sie Photographs
C	Geophysical Investigation Report
D	Test Pit Logs
E	Test pit Photographs
F	Electric Friction Cone Penetrometer Tests (CPT)
G	Electric Friction Cone Penetrometer Test Location Photographs
H	Soil Sample Algal Mat and Soil Sample Triaxial Descriptions
I	Soil Sample Algal Mat Photographs
J	Soil Sample Triaxial Photographs
K	Acid Sulfate Soils Chain of Custody

Note that Appendix K also indicates where the Acid Sulfate soil samples were obtained.

7.2 Results of Laboratory Testing

The scope of laboratory testing is listed in Table 3.

Table 3 – Scope of Laboratory Testing

Test Type	Relevant Standard	Test Quantity
Particle size distribution to 75 microns	AS1289.3.6.1	86
Particle size distribution including hydrometer	AS1289.3.6.3	10
4 Point Atterberg Limit including linear shrinkage	AS1289.3.1.1 -liquid limit AS1289.3.2.1 – plastic limit AS1289.3.3.1 – plasticity index AS1289.3.4.1 – linear shrinkage	77
CaCO ₃ content	In-house method	14
Particle Density	AS1289.3.5.1	10
Emerson Class No.	AS1289.3.8.1	25
Pinhole	AS1289.8.8.3	4
Organic Content	ASTM D2974	12
Maximum dry compressive strength (MDCS)	WA140.1-2021	4
Compaction testing	AS1289.5.2.1 (Modified Compaction)	34
Permeability Test – falling head test method	AS 1289.6.7.2	7
California Bearing Ratio (CBR) – unsoaked	AS1289.6.1.1	7
California Bearing Ratio (CBR) – soaked	AS1289.6.1.1	17

Aggressivity suite – pH, Sulphate, Chloride	In-house method	7
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The results of the laboratory testing are included in various tables in Appendix L as follows:

- Table L1 – Laboratory Test Summary
- Table L2 – Oedometer Laboratory Test Summary
- Table L3 – Triaxial Laboratory Test Summary
- Table L4 – Crystalliser PSD Atterberg Summary
- Table L5 – Concentrator Pond PSD Atterberg Summary
- Table L6 – Investigated Borrow Area PSD Atterberg Summary

8 DATA ANALYSIS

8.1 Laboratory Test Data

8.1.1 Index Testing

The results of the particle size distribution tests and the Atterberg limit tests are presented in various figures listed below:

- Figure 6: PSD Chart - Residual Soil
- Figure 7: PSD Chart - Eolian Sands
- Figure 8: PSD Chart - Extremely Weathered Granite
- Figure 9: PSD Chart - Extremely Weathered Calcarenite
- Figure 10: PSD Chart - Extremely Weathered Dolerite
- Figure 11: PSD Chart - Lagoonal Deposits
- Figure 12: PSD Chart – Investigated Borrow Pit Samples

A combined plot of the Atterberg limit tests is included as Figure 13: Atterberg Limit Chart

8.1.2 Advanced Testing Suite

A suite of advanced tests including oedometer and triaxial tests were completed on two suites of samples comprising lagoonal sediment samples and paleochannel infill samples respectively.

The samples were collected in thin-walled sample tubes, sealed against moisture loss and transported to the laboratory.

A suite of index tests were also completed on each sample tube. The geological unit from which the sample was taken and the sample description in terms of AS1726:2017 *Geotechnical Site Investigations* is provided in Table 4 while the results of the index tests are provided in Table 5.

Table 4 – Sample Geological Unit and Soil Classification for Oedometer and Triaxial Test Samples

Location	Sample Depth Range (m)	Test Type	Geological Unit	Sample Description
CPT40	0.5-1.0	Triaxial and Oedometer	Lagoonal sediments	Clayey SAND (SC)
CPT46	0.5-1.0	Triaxial and Oedometer		Sandy CLAY (CL)
CPT49	2.0-2.5	Triaxial and Oedometer		Clayey SAND with gravel (CL)
CPT52	0.3-0.8	Triaxial and Oedometer		Sandy CLAY with trace gravel (CI)
CPT56	1.7-2.2	Triaxial and Oedometer		Sandy CLAY with gravel (CL)
CPT59	0.5-1.0	Triaxial and Oedometer		Sandy CLAY with trace gravel (CI)
CPT15	6-6.5	Triaxial	Paleochannel infill	Sandy CLAY (CH)
CPT17	4-4.5	Triaxial		CLAY with sand and trace gravel (CH)

Table 5 – Summary of Index Tests on Oedometer and Triaxial Tests

Location	Sample Depth Range (m)	e_o	ρ_d (t/m ³)	w_o (%)	Organic Content (%)	LL (%)	PI (%)	% Gravel	% Sand	% Fines
CPT40	0.5-1.0	0.505	1.71	24.4	3.7	28	6	0	65	35
CPT46	0.5-1.0	0.65	1.64	29.3	2.1	-	-	0	62	38
CPT49	2.0-2.5	0.566	1.7	28.9	1.6	-	-	25	51	24
CPT52	0.3-0.8	0.706	1.43	27.3	2	43	21	2	57	41
CPT56	1.7-2.2	1.037	1.32	27.9	2.4	33	14	18	37	45
CPT59	0.5-1.0	0.653	1.6	24.3	-	49	27	2	34	64
CPT15	6-6.5	0.76	1.51	25.2	2.6	86	62	0	34	66
CPT17	4-4.5	0.84	1.45	29.9	2.1	74	51	3	28	69

Where:

- e_o initial void ratio
- ρ_d initial dry density
- w_o initial water content
- LL liquid limit
- PI plasticity index

The initial void ratio, dry density and water content is from the results of the oedometer tests for sample CPT40 to CPT59 while these values were obtained from the triaxial tests for samples CPT15 and CPT17.

8.1.3 Oedometer Testing

The results of the oedometer testing were analysed in order to determine field compression curves and associated parameters. Note that the field curve is a corrected compression curve that accounts for the impact of sample disturbance and relies on establishing the pre-compression pressure (P'_c) that was determined based on a simplified method was established using the method of intersecting tangent lines described in Budhu (2011). The construction of the field curve is described in Craig (2004).

Analysed oedometer test results are presented in the following figures:

- Figure 14: Oedometer Test – CPT40/CPT46/CPT49
- Figure 15: Oedometer Test – CPT52/CPT56/CPT59
- Figure 16: Oedometer Test – Constrained Modulus

The results of the oedometer tests are summarised in Table 6.

Table 6 – Summary of Oedometer Test Results

Location	Depth Range (m)	e_o	Laboratory Curve C_c	Corrected Curve C_c	C_r	OCR	c_v (m ² /yr)	$\frac{C_c}{(1 + e_o)}$	C_α (10 ⁻³)
CPT40	0.5-1.0	0.505	0.143	0.158	0.01	4	2.3	0.105	0.5
CPT46	0.5-1.0	0.65	0.242	0.418	0.017	6	0.8	0.253	1
CPT49	2.0-2.5	0.566	0.182	0.197	0.013	2	3	0.126	0.4
CPT52	0.3-0.8	0.706	0.332	0.43	0.027	7	0.9	0.252	1.3
CPT56	1.7-2.2	1.037	0.465	0.654	0.033	2	1	0.321	1.5
CPT59	0.5-1.0	0.653	0.365	0.587	0.033	13	1.5	0.355	1

Notes: c_v and $C_c/(1+e_o)$ are reported in the stress range 25 kPa to 50 kPa.

Where:

- e_o initial void ratio
- C_c compression index
- C_r re-compression index
- C_α secondary compression index
- OCR over consolidation ratio
- c_v coefficient of consolidation

Note that while the oedometer tests included a value for the secondary compression index for each load stage, those values were found to be an order of magnitude lower than that typically quoted in the literature for soils similar to the lagoonal deposits.

A typical secondary compression index can be estimated based on $C_\alpha/C_c = 0.03$ (Carter and Bentley (1991)). Further consideration of an appropriate secondary compression index value to be adopted in design is to be assessed and investigated by Designers.

8.1.4 Triaxial Testing

The results of the triaxial testing are summarised in Table 5 while a more detailed analysis of the triaxial results are included in Appendix L.

Table 7 – Summary of Triaxial Test Results

Sample Id	Sample Depth (m)	Geological Unit	Soil Type	ϕ' (Deg)	c' (kPa)	Average Values
CPT015	6.0	Lagoonal sediments	Clayey SAND (SC)	27	21	$\phi'=27^\circ$ $c' = 40$ kPa
CPT017	4.0		Sandy CLAY(CL)	27	59	
CPTU40	0.5		Clayey SAND with gravel (CL)	39	5	$\phi'=36^\circ$ $c' = 25$ kPa
CPTU46	0.5		Sandy CLAY with trace gravel (CI)	32	41	
CPT049	2		Sandy CLAY with gravel (CL)	45	36	
CPT052	0.3		Sandy CLAY with trace gravel (CI)	28	9	
CPT056	1.7	Paleochannel infill	Sandy CLAY (CH)	35	33	
CPT059	0.5		CLAY with sand and trace gravel (CH)	34	25	

Where:

ϕ' is the effective friction angle

c' effective cohesion

A stress-path plot is included on Figure 17 for the Lagoonal sediments and Paleochannel infill respectively.

Each plotted point represents the peak p' and q' value from all of the triaxial tests completed and for each stage within each test (three stages per test).

The definition of p' and q' is as follows:

$$p' = \frac{(\sigma'_1 + \sigma'_3)}{2}$$

$$q' = \frac{(\sigma'_1 - \sigma'_3)}{2}$$

Where:

σ'_1 is the major principal effective stress at the point of failure.

σ'_3 is the minor principal effective stress at the point of failure.

8.2 Field Test Data

8.2.1 CPT Test Data

The CPT data was interpreted using the *CpeT-IT* software program (Geologismiki (2014)). The results of the interpretation are provided in Appendix O.

This post analysis of the data provides a soil classification for the various intersected strata and associated geotechnical parameters.

The definition of the terms used on these respective plots are as follows:

- I_c is the soil behaviour type index
- E_s is the soil elastic modulus – calculated for non-cohesive soils only
- D_r is the relative density
- Φ is the effective friction angle – calculated for non-cohesive soils only
- M is the constrained modulus – drained value (by definition) and calculated for all soil types
- S_u is the undrained shear strength based on $N_{kt} = 14$ (default value)

The methods used to derive each of the above parameters is described in Geologismiki (2014).

Of particular interest is the use of the soil behaviour type index (I_c) as it has been used extensively to interpret the stratigraphy at each CPT location – refer to the plots included in Appendix O. The delineations between I_c value and inferred soil type are outlined in Table 8.

Table 8 – Definition of Terms used in CPT Analysis

Soil Behaviour Type	I_c value	Colour of shading on I_c charts included in Appendix O.	Soil behaviour under imposed shear stress
Sensitive, fine grained	N/A	-	-
Organic soils – clay	> 3.6	Dark orange/brown	Undrained
Clays – silty clay to clay	2.95 – 3.6	Dark blue/purple	
Silt mixtures – clayey silt to silty clay	2.60 – 2.95	Dark green	Transitional, partially drained
Sand mixtures – silty sand to sandy silt	2.05 – 2.6	Light green/teal	Drained
Sands – clean sand to silty sand	1.31 – 2.05	Brown	
Gravelly sand to dense sand	< 1.31	Orange brown	
Very stiff sand to clayey sand	N/A	-	-
Very stiff, fine grained	N/A	-	-

8.2.2 Dissipation Test Data

The data collected during the CPT dissipation testing has been analysed using the *CpeT-IT* software program (Geologismiki (2014)). The data analyses and its results are included in Appendix N on a test-by-test basis. The results of the analyses are included in Table 9.

Table 9 – Summary of Dissipation Test Results

Location	Depth (m)	Ground Elevation (m AHD)	Test Elevation (m AHD)	Soil Unit	C _h (m ² /yr)	Equilibrium Pore Pressure (kPa)	Inferred Groundwater Elevation (m AHD)
CPTU17	18.02	4	-14.02	Clay – Paleochannel Infill	-	-	
CPTU35	2.76	1.2	-1.56	Silty Sand and Sandy Silt	-	30	1.5
CPTU36	4.05	1.5	-2.55	Clay and Silty Clay	-	-	-
CPTU37	3.82	3	-0.82	Silty Sand and Sandy Silt	-	22.5	1.5
CPTU38	2.05	1.4	-0.65	Clay and Silty Clay	78	15	0.9
CPTU39	2.19	1.4	-0.79	Clay	-	25	1.8
CPTU40	2	1.1	-0.9	Sand and Silty Sand	-	20	1.1
CPTU42	0.99	1.37	0.38	Clay and Silty Clay	1687	14	1.8
CPTU43	1.4	1	-0.4	Clay	135	6.5	0.3
CPTU44	2.1	1.4	-0.7	Lagoonal Deposit (V Soft Clay)	66	18	1.1
CPTU45	2.6	1.1	-1.5	Clay and Silty Clay	1090	19	0.4
CPTU46	1.8	0.9	-0.9	Silty Sand and Sandy Silt	415	8.8	0.0
CPTU47	1.1	1.7	0.6	Lagoonal Deposit (V Soft Clay)	193	2	1.5
CPTU48	2.7	1.9	-0.8	Clay and Silty Clay	763	16	0.3
CPTU49	1	0.9	-0.1	Clay and Silty Clay	1047	3.5	0.5
CPTU50	2.1	1.2	-0.9	Clay	73	20	-0.8
CPTU51	1.92	1.1	-0.82	Clay	452	16	-0.5
CPTU52	1.91	1.1	-0.81	Clay	168	14	-0.3
CPTU53	1.86	1.3	-0.56	Clay	144	20	-0.7
CPTU54	1.82	1.9	0.08	Clay	990	9	1.0
CPTU55	1.39	1.3	-0.09	Clay and Silty Clay	628	12	0.1
CPTU56	2.6	1.2	-1.4	Clay and Silty Clay	108	16	-0.4
CPTU57	1.16	1.3	0.14	Lagoonal Deposit (V Soft Clay)	923	8	0.5
CPTU58	2.04	1.5	-0.54	Lagoonal Deposit (V Soft Clay)	182	13	0.2
CPTU59	2.34	1.5	-0.84	Lagoonal Deposit (V Soft Clay)	-	-	
CPTU76	0.94	1.7	0.76	Silty Sand and Sandy Silt	25	0	1.7

9 GEOTECHNICAL CONSIDERATIONS

9.1 Earthworks

9.1.1 Crystalliser Ponds

9.1.1.1 Depth to Rock and Excavatability

Ground Penetrating Radar (GPR) was undertaken along traverse lines that criss-cross the Crystallisers Pond Area largely following the alignment of the proposed pond walls. The alignment of the traverse lines is shown on Figures 1 (Figure Series) and Figure 3 (Map Series) and in the Geophysical subcontractor's report titled "*a report on the Geophysical Investigation undertaken at Eramurra*" dated 7 October 2021 (Appendix C). This report concludes the GPR did not detect evidence for the presence of bedrock within the top 5 m of subsurface materials. A Multi-channel Analysis of Surface Waves (MASW) transect (Transect T 7) was also undertaken coincidental with one of the GPR traverses as a cross-check to the GPR. This Transect (results presented in Appendix C) confirmed the general absence of shallow rock (<5 m) apart from a localised zone of possible calcrete/silcrete noted between chainages 630 and 910 m along Transect 7 (refer Appendix C). This localised area of possible calcrete is shown on Figure 5.

A total of 43 test pits, TP036 to TP078, were excavated. Refer Figure 3 (Figure Series). Also refer to Appendices D and E for logs and photographs respectively. The target depth for test pits was 3 m and although some test pits were terminated early due to very slow excavation total refusal did not occur in any of the test pits and a larger machine would likely have been able to advance the excavations beyond these depths.

The test pits in all cases were terminated in either EW to HW Granite or an EW to HW metasediment which was excavated as a soil (gravel).

Figure 5 has been prepared to show the approximate depth to test pit termination level (using a backhoe) within EW to HW granite or meta-sediment. Based on the performance of the backhoe it is generally expected that larger excavation plant e.g., a 30-t excavator or D9 dozer could extend these excavation depths before encountering refusal, particularly if a ripping tine was used.

We understand that the floor of each Crystalliser Pond is required to be cut and filled to form a level surface. The height difference across a typical crystalliser pond is approximately 1.5 m. If it is assumed the upper 0.75 metres of residual soil might be stripped as borrow for embankment construction the maximum depth of cut to form the Crystalliser Pond floors would be 1.5 m (comprising upper 0.75 m cut for select fill for walls lower 0.75 m cut for general fill within the pond floor). The contours indicate the depth to highly weathered rock to be generally greater than 1.5 m and as such it is anticipated that most of the Crystalliser Ponds can be excavated using conventional earthmoving plant.

It should be noted test pits are widely spaced (at least 400 m apart) and it is possible undetected rises in the rock surface could be present. Nonetheless no surface outcrops were noted whilst traversing across the Crystalliser area or between test pits. In this respect this is quite different to other parts of the *Outwash/Residual Surface* area especially those areas underlying Concentrator Ponds 8 and 9 where surface outcrops are common.

9.1.1.2 Nature of Materials

Appendix L (Table L4) presents index laboratory test results for samples taken from between 0.3 and 2.6 m from test pits in the Crystalliser Pond Area. The materials generally classify as CLAY and Sandy CLAY with average percent fines of 51%.

The clays are generally of high plasticity, with only one medium and one low plasticity result. The mean liquid limit is 53% (i.e., high plasticity). Linear shrinkages are very high (up to 20%) and plasticity indices also high.

Overall, the test results indicate a clay that when moisture conditioned and compacted will have a very low permeability (likely $<1 \times 10^{-8}$ m/s). It will also however display a propensity to crack. The *Outwash/Residual Surface* across the Crystalliser area in this context is displaying gilgai features, namely open crack arranged in a polygonal pattern, localised crabholes where material from the surface is washed into the labyrinth of cracks below the surface and mounding where local heave occurs. Assuming the same clays are used to form the pond walls within the Crystallisers similar cracking can be expected to occur within the walls.

To manage cracking there are several options:

- 1) Blend the clay with a less plastic material. This would be very difficult to execute given the nature of the clay in the first place and there are also no nearby alliterative sources.
- 2) Build a clay core and protect the core from desiccating by shoulders formed from a less plastic or no plastic material. Again, there are few alternative material sources to build these shoulders
- 3) Design the walls wide so that desiccation of material occurs in the shoulders, but the core of the wall is protected. The desiccation potential in the core material of the walls could be reduced by either building greater height in the wall above brine levels or by protecting the clay materials by a covering of sub-base material (i.e., the core would be located beneath access and maintenance tracks).

9.2 Concentrator Ponds 3 to 14

9.2.1 General Geological and Geotechnical Conditions

These Concentrator Ponds are located almost exclusively on the *Outwash/Residual Surface*. This geomorphological unit is incised by a number of major and minor creeks, namely McKay Creek between Ponds 3 to 9 in the west and 10 to 14 in the west. This is a major creek and much of the residual weathering products from weathering of outwash materials and the underlying largely granitic rocks have been removed through erosion exposing outcrops of granite and other rock types in the floor of the creek. There are also a number of minor creeks that incise into this surface except close to the mouth of these creeks where they discharge into the into the ocean).

The majority of the Concentrator Pond area is underlain by similar materials to those underlying the Crystalliser. There are important exceptions that needs consideration and might result in a modification of the conceptual layout of the ponds rather than an engineered solution using the current layout.

Mapping has identified the presence of outcropping rock or inferred shallow rock across large tracts of the Crystalliser ponds. The actual percentage of rock outcropping is small (likely $<<5\%$) but the presence of rock as scattered extensive outcrop and inferred shallow (<1 m) subcrop has implications for the design of ponds and pond walls and their construction, and implications for availability and ease of winning construction materials. In this context, igneous rock outcrops/shallow rock subcrop is most concentrated in the area highlighted on Figure 3 (Figure Series) in the eastern part of Ponds 8 and 9.

Slides 6, 7 and 9 (Appendix B) show typical outcrops in this area of the site.

The following geotechnical considerations are noted:

- The presence of rock makes traversing this area very difficult. The rock surface would need to be ripping before rubber-tyred construction can traverse areas of rock outcrop
- Ripping would create a permeable layer allowing seepage to occur under Pond Walls unless a cut-off is formed, or the pond lined
- The presence of outcropping rock or shallow rock mean a simple push up of surficial gravelly clay material is not practical and construction materials require importation
- The presence of shallow rock reducing prospectively of the area for borrow.

A further “presence of rock” impediment also exists along the northern parts of Pond 9 and Pond 10 where sheets of calcarenite are present and will likely underlie Sections of the Pond wall and pond floors.

Under the Geomorphological Section of this report the mechanism of naturally occurring seepage, erosion/piping and spring sapping resulting in the breaking away of sheets of calcarenite was described.

Slides 12 to 16 (Appendix B) clearly illustrate the types of material present and the potential for voids, erosion and collapse. In this context refer specifically to Slides 14 and 15.

Similar to areas of igneous rock the following geotechnical considerations are noted:

- The presence of calcarenite create the potential for seepage of brine through the floor of the pond which not only results in loss of fluid but erosion and piping of the foundation material resulting in potential subsidence and sinkholes. The mechanism appears to be occurring naturally. To engineer against this the pond walls would need to be founded below the calcarenite.
- The presence of calcarenite means a simple push up of surficial gravelly clay material is not possible and construction materials require importation
- The presence of calcarenite reduces the prospect for clayey borrow in this area.

Recommendation

Whilst it is possible to engineer pond wall and lined pond floors to accommodate the shallow rock and calcarenite and voids/undercutting conditions described above, it is recommended that consideration is given to modifying the layout of Pond 7, 8, 9, and 10 (principally Pond 9) to avoid as far as practical the polygons (refer Figure 3 (Figure Series)) depicting the main calcarenite and shallow rock area

9.2.1.1 Nature of Materials

Appendix L (Table L5) presents index laboratory test results for samples taken from between 0.2 and 2.6 m from test pits in the Crystalliser Pond Area. The materials generally classify as CLAY and Sandy CLAY with average percent fines of 41%.

The clays are generally of medium to high plasticity. The mean liquid limit is 48%. Linear shrinkages are high (mean 12.9%) with results as high as 18.5%.

Overall, the test results indicate a clay that when moisture conditioned and compacted will have a very low permeability (likely $<1 \times 10^{-8}$ m/s). It will also however display a propensity to crack. The *Outwash/Residual Surface* across the Concentrator Ponds (Pond 1 and 2 excepted) in this context are displaying gilgai features, namely open crack arranged in a polygonal pattern, localised crabholes where material from the surface is washed into the labyrinth of cracks below the surface and mounding where local heave occurs. Assuming the same clays are used to form the pond walls within similar cracking can be expected to occur within the walls.

Similar to the Crystalliser Area to manage cracking there are several options:

- 1) Blend the clay with a less plastic material. This would be very difficult to execute given the nature of the clay in the first place and there are also no nearby alternative sources.
- 2) Build a clay core and protect the core from desiccating by shoulders formed from a less plastic or no plastic material. Again, there are few alternative material sources to build these shoulders
- 3) Design the walls wide so that desiccation of material occurs in the shoulders, but the core of the wall is protected. The desiccation potential in the core material of the walls could be reduced by either building greater height in the wall above brine levels or by protecting the clay materials by a covering of sub-base material (i.e., the core would be located beneath access and maintenance tracks).

9.2.2 Earthwork Methodology

9.2.2.1 Machinery Selection

Assuming areas of rock are avoided the clays are expected to be excavatable using conventional earthmoving plant. i.e., excavators, dozers and in some areas the use of motorised elevating scraper might be considered.

In all instances, following rainfall events, and particularly for several weeks following cyclonic rain the site may become un-trafficable and the high plasticity clays will tend to ball and adhere to wear parts on machinery.

Earthworks will therefore need to be programmed around the weather.

Granular material should be removed prior to winning underlying clays and gravelly clays most likely using a bulldozer from beneath the footprint of wall and from areas where clayey material is being won to form pond walls.

The choice of plant to excavate and form the walls to Ponds 3 to 14 (excluding Ponds 1 and 2) will depend on presence of shallow rock. Elevating scrapers may be practical (under the right moisture conditions) to cut, load and move clay and gravelly clay. Once conditions become wet, a scraper is likely to become bogged but also the clayey material will ball up inside the scarper bucket and elevating mechanism. A trial in the use of this machinery is recommended.

A dozer to locally push up materials is considered a practical method of working borrow. This is because generally the granular materials to be removed are between zero and 0.2 m thick and most of the clay and gravelly clay is anticipated to be exploited from within the upper 1 m of the profile.

Working around rock outcrops and in areas of shallow rock excavators may prove to be a more practical means to work spoil. Clearly where there is a significant dozer push-up distance or motor-scraper haul distance, an excavator load and dump truck haul may be necessary. It is however anticipated, assuming some modification to Ponds 7, 8, 9 and 10 to avoid shallow rock and areas of calcarenite, the majority of clayey materials for pond wall construction can be sourced locally.

9.3 Concentrator Pond 1 and 2

9.3.1 General Geological and Geotechnical Conditions

Concentrator Ponds 1 and 2 are located within mangrove mud areas. The location of seawalls within Ponds 1 and 2 is indicated on Figure 18 together with CPT test locations completed in that area.

The ground profile is characterised by very soft and soft clays at the surface underlain in turn by an inter-bedded sand and firm to stiff clay horizon. Sub-surface Section E-E' (refer Figure 4 (Figure Series) drawn in a north-south direction within a low-lying creek area illustrates the typical inter-relationship between these respective units.

The upper clay layer thickness was typically recorded as 1 m thick – refer to Figure 18 which shows the thickness of the upper clay layer encountered at each CPT location. Atterberg Limits tests were completed on two samples from this layer: CPT035 (depth of 1 m) and CPT053 (depth of 0.2 m). The recorded Liquid Limit was in the range of 39% to 45% indicating that the tests samples included clay of a medium plasticity. Our experience indicates that high plasticity clays may also present.

The maximum recorded thickness of the upper clay layer was 2.5 m at CPT047. At this location, a relatively continuous deposit of clay was encountered but a thin sandy layer was also encountered in the depth range of 0.4 m to 0.6 m (200 mm thick layer).

A plot of the undrained strength based on CPT cone resistance versus depth is shown on Figure 19 and shows that the average undrained shear strength of the upper clay at this location is about 10 kPa. This low strength is indicative of a very soft clay. The undrained shear strength profile indicates the possible presence of a desiccated crust about 1 m thick from the surface due to the higher strength measured in this depth interval.

Figure 19 also presents a plot of constrained Modulus M , versus depth based on an interpretation of the CPT data. The clays are of a low stiffness below a depth of 1 m ($M < 1$ MPa). The range of constrained modulus values recorded in the oedometer tests is superimposed on the constrained modulus plot and are applicable for vertical applied stresses of the order of 50 kPa to 100 kPa (i.e., within the range of embankment applied stresses). The range of oedometer constrained moduli values are in fair agreement with those derived from the CPT data.

The average coefficient of consolidation (c_v) recorded in the oedometer test was about 1.5 m²/year (refer Table 6). In contrast, c_h (coefficient of consolidation measured in the horizontal direction) derived from CPT dissipation test data provided much greater coefficient of consolidation values at least one order of magnitude higher. Note however that c_h and c_v are not directly comparable due to different soil permeabilities usually observed in the vertical and horizontal direction. This difference is often due to the presence of thin horizontal sand partings within the clay that provides a preferential horizontal drainage path. While such partings may have been present within the oedometer test samples, only vertical drainage can occur within that test.

The lower clay layer is stronger and stiffer compared to the upper clay layer. A 1.25 m thick lower clay layer was encountered at CPT043 that has an undrained shear strength in the range of 25 kPa to 100 kPa indicating that the clay is in the firm to stiff range. The lower clays layer is of such a strength and stiffness that it is unlikely to greatly impact the stability and settlement of pond embankments up to 3.5 m in height.

9.3.2 Short Term Embankment Stability

The presence of the upper very soft upper clay layer is detrimental to short-term embankment stability. In the short-term (i.e., during the construction period and during the primary consolidation period following it), undrained conditions within the upper clay layer prevail because excess pore pressures generated within the upper clay layer require time to dissipate.

For high-level pond concept development, the stability of embankments can be evaluated using the following relationship:

$$FOS = \frac{5.14 S_u}{Z \gamma_b}$$

Where:

- S_u is the undrained shear strength of the upper clay layer
- Z is the embankment height (m)
- γ_b is the fill unit weight (kN/m³)
- FOS is the factor of safety

This relationship assumes that the embankment is constructed on a deep deposit of clay and that failure occurs along circular slip surfaces.

By way of comparison, a slope stability analysis was completed using the program SLIDE to verify the calculated factor of safety derived from the above equation. The case analysed included a 3.5 m high embankment with a crest width of 4 m. The batter side slopes are 1(V):2(H) while an upper clay layer thickness of 2.5 m is assumed. Other input parameters were as follows:

$$S_u = 10 \text{ kPa (conservatively assessed mean value)}$$

$$\gamma_b = 18 \text{ kN/m}^3$$

The results of the analysis are shown in Plate 2 below. The analysed FOS is 0.98 versus a FOS of 0.82 calculated using the above equation (a difference of 17%).

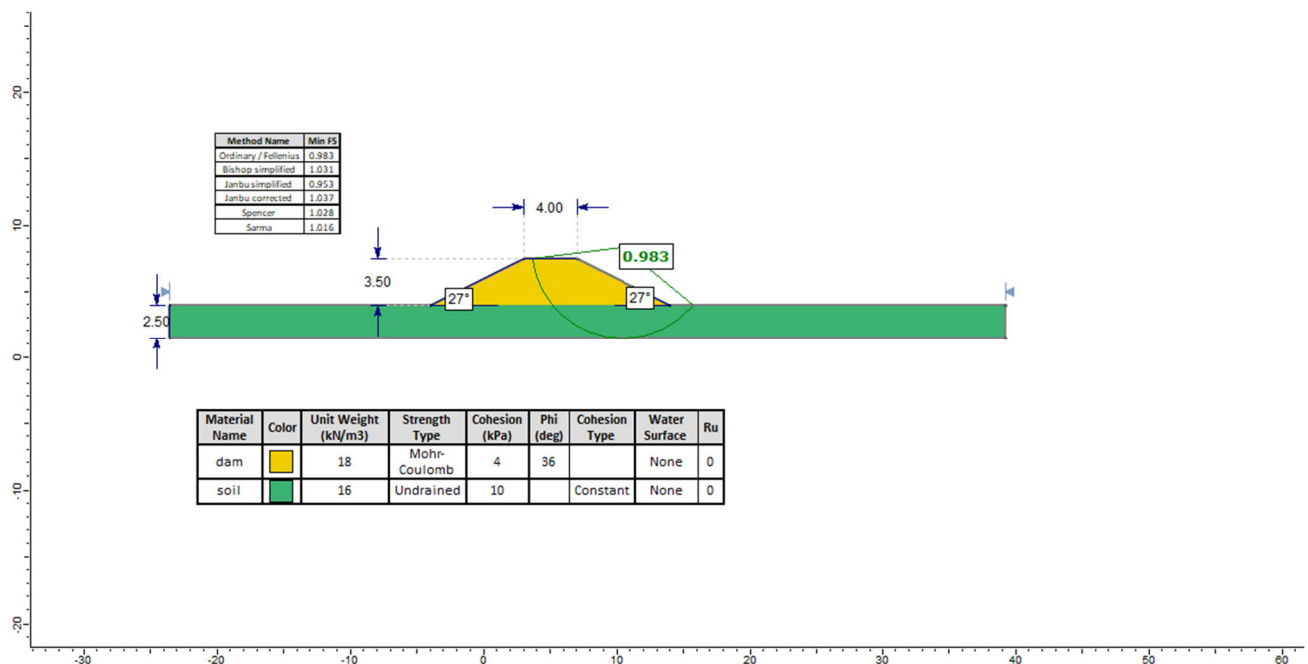


Plate 2: Short-term embankment stability analysis

Other stability criteria may also apply such as the case of clay squeezing (or extrusion) where a thin, soft clay layer exists between a hard stratum beneath, and embankment fill above. The clay is squeezed under embankment loads. It is assumed that during detailed design, embankment stability will be assessed more thoroughly taking various possible failure criteria into account such as squeezing.

For the short-term construction case, a factor of safety of about 1.1 may apply on the basis that embankments heights are generally limited to 3.5 m and that during the construction phase, the ponds are not operational. These respective conditions combined indicate a low consequence of failure allowing for a lower factor of safety compared to operational conditions. In that regard, it is also assumed that the undrained shear strength of the upper clay layer is appropriately assessed by for example adopting a conservatively assessment mean value of the undrained shear strength.

Using the above equation and input parameters, the maximum initial embankment height is about 2.4m based on the following input parameters:

$$S_u = 10 \text{ kPa (conservatively assessed mean value)}$$

$$\gamma_b = 19 \text{ kN/m}^3$$

$$FOS = 1.1$$

This embankment height is less than the required 3.5 m leaving two options to available to construct the embankment to full height:

1. The use of a staged embankment construction approach. This option would involve the placement of embankment fill to a height of approximately 2 m followed by the placement of the remainder of the embankment fill after completion of primary consolidation under the first stage.
2. The use of basal reinforcement. A layer of geogrid of sufficient strength to support the full height of the embankment would be placed on top of the upper clay before the placement of embankment fill.

The most cost-effective option is likely one involving staged construction. Even so, provision for a lighter grade of geogrid, in conjunction with a geofabric, may still be required for some areas where the upper clay layer is particularly soft to allow for the placement of the first 0.5 m thick fill layer. The placement of this geogrid/ geofabric would be on an 'as-required' basis.

If the basal reinforcement option is considered; then our experience with similar projects indicates that the use of a geogrid such as a Tensar TX160 combined with Bidim would allow for construction of the embankment to full height in one operation. However, this may prove an expensive option even after optimisation of basal reinforcement requirements (following detailed design) given the large footprint area of the embankments measuring several thousand square metres.

9.3.3 Consolidation Periods

The time required for primary consolidation of an upper clay layer 2.5 m thick would be about 10 months assuming that $C_v = 1.5 \text{ m}^2/\text{year}$ (typical value – refer Table 6) and two-way drainage. This is the notional period between lifts required for staged construction. Note however that this period is considerably less (about one to two months) based on data derived from the dissipation test data.

A pragmatic approach to dealing with the uncertainty surrounding primary consolidation periods could involve the construction of a small trial embankment in an area of thicker upper clay to verify this consolidation period.

9.3.4 Embankment Settlement

The estimated primary consolidation settlement for a 3.5m high embankment constructed on a 2.5 m thick very soft clay layer is 150 mm to 200 mm and includes a small settlement contribution from the soil layers underlying the very soft upper clay layer.

If a stage construction approach is adopted, about 150 mm of primary consolidation settlement is expected for the first stage (embankment height of 2.4 m) with an additional 25 – 50 mm of primary consolidation settlement occurring during the second stage.

Long-term creep settlements would occur after the completion of primary consolidation settlement. Estimated creep settlements of the order of 20 mm are expected over a 30-year period following a primary consolidation period of one month (shorter primary consolidation periods based on the CPT dissipation data leads to greater estimates of creep settlement). In this calculation, the upper clay layer is assumed to be 2.5 m thick while the average $C_{\alpha}/(1+e_0)$ value is assumed to be 0.003. These preliminary calculations suggest that long-term creep settlements will likely be insignificant brought about by the relatively limited thickness of the upper clay layer.

9.3.5 Long-Term Embankment Stability

In the long term, under drained conditions and considering seepage through the embankments, embankment stability is expected to be adequate due to the high drained shear strength parameters measured in the triaxial tests – refer Figure 17 – where a drained effective friction angle of over 40° is indicated. Further analysis is required to determine the actual design friction angle that may apply; but the results of the testing indicate that higher drained friction angles for the upper clay layer may apply leading in turn to more favourable conditions for embankment stability.

9.3.6 Summary

In overview, it should be possible to construct Pond 1 and 2 embankments within the mangrove mud areas as per the current project concept plans.

That said, it may be prudent to avoid this partially or all together and relocate the embankments away from the mangrove mud areas to adjacent inter-tidal areas where stiffer and stronger embankment subgrade conditions are likely to exist.

Relocating the embankments would simplify construction of Ponds 1 and 2 and could bring savings to the project schedule.

9.4 Seepage

Permeability tests on predominantly clayey materials derived from residual soils and compacted to 95% maximum modified compaction range between 2.89×10^{-8} m/s and 1.06×10^{-9} m/s. This material was tested as it is considered to be a potential pond wall building material.

Triaxial samples (SST) were taken for testing by a third party for triaxial permeability. Results from these triaxial permeability tests have not been provided to CMW for part of this assessment.

Based on our site observations we summarise qualitatively the permeability material/mass permeability of the various material likely to be encountered in the pond floors. Figure 3 (Figure Series) shows the approximate spatial extent of each unit, except for the extremely weathered granitoid and dolerite rocks which will only be encountered in about 25% of the Crystalliser Pond cut footprints.

Note that for broad estimating purposes, very low permeability is assumed to be 10^{-9} m/s, low approximately 10^{-8} m/s, moderate 10^{-6} m/s, high 10^{-5} m/s, and very high 10^{-4} m/s or greater. The values and range given being both approximate and broad.

Areas of high and very high permeability can generally be avoided (e.g. calcarenite outcrops). It is a recommendation of this report to complete in situ permeability testing on the eolian sand to assess potential for seepage through this unit as this has a relatively large spatial footprint beneath Pond 2.

Table 8 provides a further general assessment of pond floor permeabilities based on engineering geological unit.

Table 10 – Summary of Relative Permeabilities of Soils by Engineering Geological Unit

Engineering Geological Unit	Typical/ Predominant Soil/ Rock Description	Qualitative Estimate of Relative Permeability
Mangrove mud	Interlaminated clay, silt, sand	Low (vertical); low to moderate (horizontal)
Lagoonal mud	Interlaminated clay, silt, sand	Low (vertical); low to moderate (horizontal)
Eolian Sand	Silty sand	Moderate to high
Beach rock (surface outcrop)	Open textured and vuggy	Very high permeability
Residual Soil	Clay and Sandy Clay	Low to very low

Engineering Geological Unit	Typical/ Predominant Soil/ Rock Description	Qualitative Estimate of Relative Permeability
Granitoid rocks (extremely weathered) -exposed in crystalliser pond floor cuts	Sandy gravel, Clayey gravelly sand and gravelly sandy clay	Low to moderate
Doleritic dyke (extremely weathered)-exposed in crystalliser pond floor cuts	As for granitoid rocks but skewed towards finer soil mixtures	Low
Shallow/ outcropping calcarenite	Highly to moderately weathered calcarenite	High to very high
Shallow/ outcropping rock	Highly to moderately weathered granitoid/ doleritic rock	Low to moderate (along joint system)

10 MATERIAL AVAILABILITY FOR CONSTRUCTION

10.1 Clayey Borrow

Clayey borrow is generally present in the upper 1-1.5 m of the *Alluvial Outwash/Residual surface* if areas of outcropping or shallow rock or calcarenite are avoided. Comment has been made for Pond 3-14 in Section 8 above.

This material is also seen as the principal source of material to build Pond Walls in areas of Mangrove, and on the *Inter- and Supra- tidal Flats*. This is because the materials underlying Inter-tidal, Mangrove and Supra-tidal areas are wet, weak and they would be difficult to excavate, dry, condition and compact. As such various potential borrow areas were investigated through test pitting as part of the current investigations.

10.1.1 Borrow Areas

Not all planned areas for borrow were investigated due to the presence of aboriginal heritage area preventing ground penetrating activities.

10.1.1.1 Borrow Area A-D

Borrow Areas investigated includes Investigated Borrow Areas A, B, C and D north of the Inter- and supra tidal flats located on the *Deflated Dunes, Sand Plains and Sandy Islands* geomorphological unit and the Eolian Sand Engineering Geological Unit.

These borrow pits indicate mixed conditions of sandy clay and clayey sand derived from the weathering of calcarenite underlying a variable thickness (generally about 1 m) of silty sand and sand. The clayey sand and sandy clay in potential borrow areas are generally softer and wetter than those encountered on the *Alluvial Outwash/Residual surface* south of the *Inter-tidal and Supra-tidal flats*.

Whilst exploitation of clayey material in the vicinity of these potential borrow areas would involve first removing the cover of overlying sand, there are advantages of exploiting these material sources. The advantages and disadvantages are listed below:

Borrow Areas located on *Deflated Dune, Sand Plain and Sandy Islands*.

Advantages:

- More proximal to the Pond 2 seawall east of McKay Creek

- More Proximal to the Pond 2 wall across the Supratidal Flats
- Moisture content closer to that required for compaction therefore less moisture-conditioning (wetting or drying) prior to compaction compared with sources from the *Alluvial Outwash/Residual Surface*.

Disadvantages

- More variability in material properties, spatial extent and depth; therefore borrow areas will need to be investigated in detail to target area with minimal sand overburden and good material properties
- Clayey material will become progressively wetter with depth limiting exploitation
- Likelihood of encountering calcarenite rock and cobbles of calcarenite in some areas of the borrow pits

Laboratory result test summaries for these borrow areas can be found in Appendix L, Table L6. Test Pit logs and photographs are presented in Appendices D and E respectively.

10.1.1.2 Investigated Borrow Areas E and F

These potential borrow areas were targeted as potential sources of clayey material for haulage north to build the Pond 1A walls and Pond 1 and 2 seawalls. Originally a third borrow area within the western footprint of Pond 10 was proposed but could not be investigated due to it coinciding with a heritage area.

Good quality clayey borrow was encountered with descriptions typically; clay, sandy clay, and clayey sand. Fines content varies in samples tested from 18 to 71% and the fines are generally high plasticity clay (refer Appendix L, Table L6).

Potential borrow Areas E and F are considered good targets for clayey borrow. They will likely yield clay that will be water hungry and require significant addition of water to moisture condition ahead of compaction.

These borrow areas like much of the clayey soils over the *Alluvial Outwash/Residual surface* are limited in depth. The best yield is likely to come from the top 1 m of the profile. With increasing depth an extremely weathered rock profile is present and gravel and cobbles of distinctly weathered rock are present. Some of this underlying material may be useful in the works in that it would have better mechanical properties and could be used within the pond walls (e.g., use the higher fines/higher plasticity material as a core and the lower fines content extremely weathered rock as shoulder or capping materials).

If the deeper extremely weathered material was to be exploited, it is recommended an investigation be conducted using both a D9 dozer and 30 t excavator to evaluate excavatability as well as to enable sampling of deeper (harder to excavate) soil/weak rock for material assessment.

10.2 Basecourse material

No basecourse quality material¹ was noted anywhere within the site boundary nor in exploitable quantities in any of the test pits. Basecourse material potentially could be available from potential borrow pits close to and generally south of the Northwest Coastal Highway. For instance, an existing quarry/borrow pit exists north and close to the Devil Creek Camp. These off-site sources were not investigated as part of the current study.

Despite the absence of basecourse quality material there are on-site materials that potentially could be exploited for sheeting, hardstand and sub-base quality materials. The principal source is the extensive areas of calcarenite fringing the northern edge of the *Alluvial Outwash/Residual Surface* and several of the sandy islands. Slides 12, 13, 14 and Slide 15, Appendix B illustrate this.

¹ As defined by MRWA or similar road authority specifications

As can be noted from Slides 12-15, the thickness and quality of the calcarenite varies. It will be necessary to target areas based on the intended use and therefore quality required. Areas of the highest strength calcarenite might be passed by for basecourse usage but targeted for use as rip-rap. Low rock strength calcarenite can likely be excavated using a 30-40 t excavator equipment with a rock bucket and will likely break down during excavation into a mix of sand, gravel cobbles and small boulders. Track rolling, or the use of grid or pad foot roller, is expected to further break-down cobbles and boulders to sand and gravel sized clasts. With suitable moisture-conditioning and compaction in thin (150 mm) nominal layers this material is expected to perform as a sub-base or road sheeting material. It is expected that soaked CBR values greater than 60% should be achievable. However, it is recommended that samples of material are taken and crushed and compacted in a laboratory and CBR tests undertaken to confirm this expected CBR strength.

10.3 Rip-Rap

Rip rap material between nominal sizes of 200 mm to 400 mm could potentially won on site. Whilst there is outcrop of high strength igneous rock that could potentially yield both armour rock and rip-rap, the low relief of these outcrops within the site would mean the development of a hard rock quarry (which would require drill and blasting) is not likely to be economical. Armour rock will therefore likely come from off-site. Rip-rap by contrast could potentially be won from the significant areas of calcarenite fringing the *Alluvial Outwash/Residual Surface* and some of the sandy islands within the *Inter- and Supra-tidal flats* - refer Figure 3 (Figure Series) for mapped and inferred locations for calcarenite. Quality will be poor and this material would not be suitable for scour protection in high energy environments as it will break down. It may however be suitable as erosion protection in lower energy environments, for instance to protect some of the internal pond walls from wind generated waves occurring within the ponds.

10.4 Armour Rock

The dolerite, granitic and gabbro rock on site are all potentially suitable rock-types for armour rock. Prospectively will depend on the size and relative proportions of each rock armour class required. Yield depends on fracture spacing and typically only a very small proportion of the total rock extracted results in blocks suitable for the larger armour rock classes. For this reason, many quarries treat armour rock as a by-product and the bulk of the material quarried is crushed and screened to create other quarry products.

Development of a quarry on site specifically for armour rock would therefore likely result in perhaps only a 10-25% armour rock yield, and the remaining material would likely have no specific project usage. Furthermore, the outcrops on site are of low relief and are not suitable for exploitation by drill and blast quarrying techniques. This would therefore necessitate the development of quarry into one of the low hills south or east of the site and necessitate a 10-20 km haul distance to get the armour rock to placement location.

Reconnaissance of the low hills, 2 km east of the Santos Gas plant appear to be prospective with respect to armour rock. However, these hills as a site for a possible project-specific quarry have not been investigated by drilling and testing as part of the current scope, nor have any other potential quarry sites. This is because Leichhardt advised that armour rock would likely be sourced from one of several commercial quarries between the site and Dampier/Karratha.

11 FURTHER WORKS

At the time of issuing this report it is understood Stage 2 of the project east of the 40-mile beach road is to be studied and Leichhardt have requested a scope be developed for geotechnical studies in this area for bankable feasibility study purposes. At the same time Leichhardt have requested a scope be developed to infill gaps in the knowledge based on the current site investigation.

The current investigation has allowed for far greater understanding of the site, the geological and geotechnical model, material distribution and properties than existed at the time the current layout was developed.

The current study has highlighted some improvements and adjustments to the current layout to minimise the need for costly engineering works and the final scope for further geotechnical studies for the bankable feasibility study and will be dependent on any layout changes.

At this stage however the following additional investigations are recommended:

- 1) Boreholes to investigate ground conditions for the intake structure
- 2) CPTs near the intake and in areas in the western part of Pond 1 where access was previously restricted due to heritage area
- 3) Further test pitting in areas where the current scope of work was curtailed by Leichhardt (for instance in the western part of Ponds 8 and 9 and some of this scope will be dependent on potential modifications to the pond layout)
- 4) Further and more detailed borrow studies in relation to a potential borrow area in the western part of Pond 10, not previously possible due to heritage areas.
- 5) Infiltration studies where brine is placed over the deflated dunes, sand plain and sandy islands geomorphological areas (Double Ring Infiltrimeters recommended)
- 6) Use of excavator and dozer to access excavatability and prospectively of calcarenite for use as basecourse and rip rap material
- 7) Sampling of rock clasts from commercial quarries for armour rock durability tests. Drop testing of armour rock on location at commercial quarries to assess suitability of commercial sources.

12 SAFETY IN DESIGN

It is a legal requirement to consider health and safety associated with the proposed structure throughout its entire lifecycle including, construction, operation and eventual demolition. This is done during the projects' design phase by all relevant designers. As part of our current scope of work, CMW will identify and communicate geotechnical hazards that we identify and consider relevant to SiD in our reporting. CMW may need to have ongoing involvement during the full design phase to manage the SiD process with regard to geotechnical design aspects.

13 CLOSURE

The findings contained within this report are the result of limited discrete investigations conducted in accordance with normal practices and standards. To the best of our knowledge, they represent a reasonable interpretation of the general condition of the site. Under no circumstances can it be considered that these findings represent the actual state of the ground conditions away from our investigation locations.

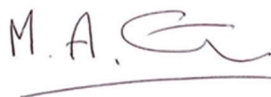
If the ground conditions encountered during construction are significantly different from those described in this report and on which the conclusions and recommendations were based, then we must be notified immediately.

This Geotechnical Investigation Report has been prepared for use by Leichhardt in relation to the Eramurra Salt Project, Cape Preston, WA in accordance with generally accepted consulting practice. No other warranty, expressed or implied, is made as to the professional advice included in this report. Use of this report by parties other than Leichhardt and their respective consultants and contractors is at their risk as it may not contain sufficient information for any other purposes.

**For and on behalf of
CMW Geosciences Pty Ltd**



Richard David
Principal Geotechnical Engineer



Matthew Tutton
Senior Principal Geotechnical Engineer

Distribution: 1 copy to Leichhardt (electronic)
Original held by CMW Geosciences Pty Ltd



14 REFERENCES

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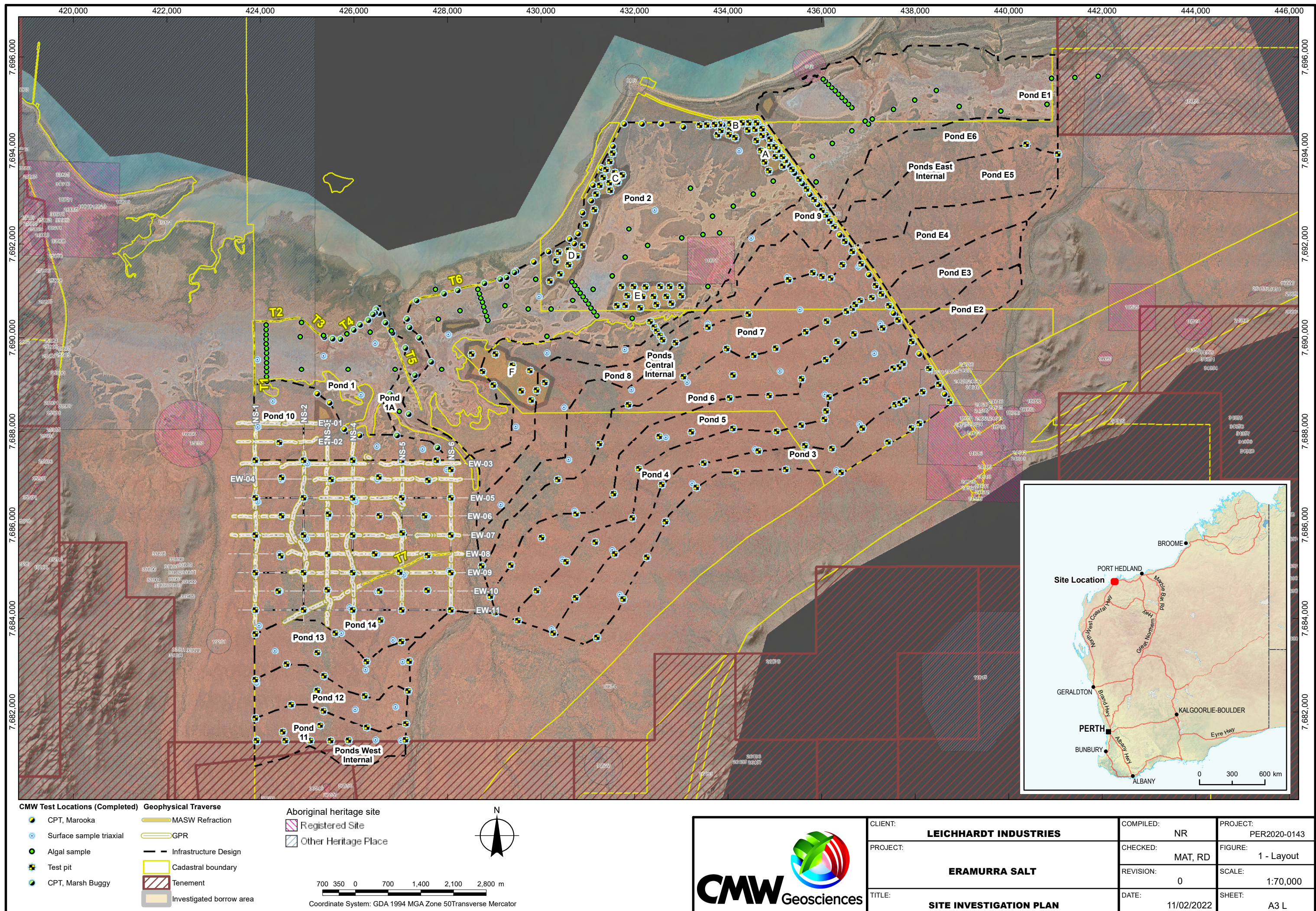
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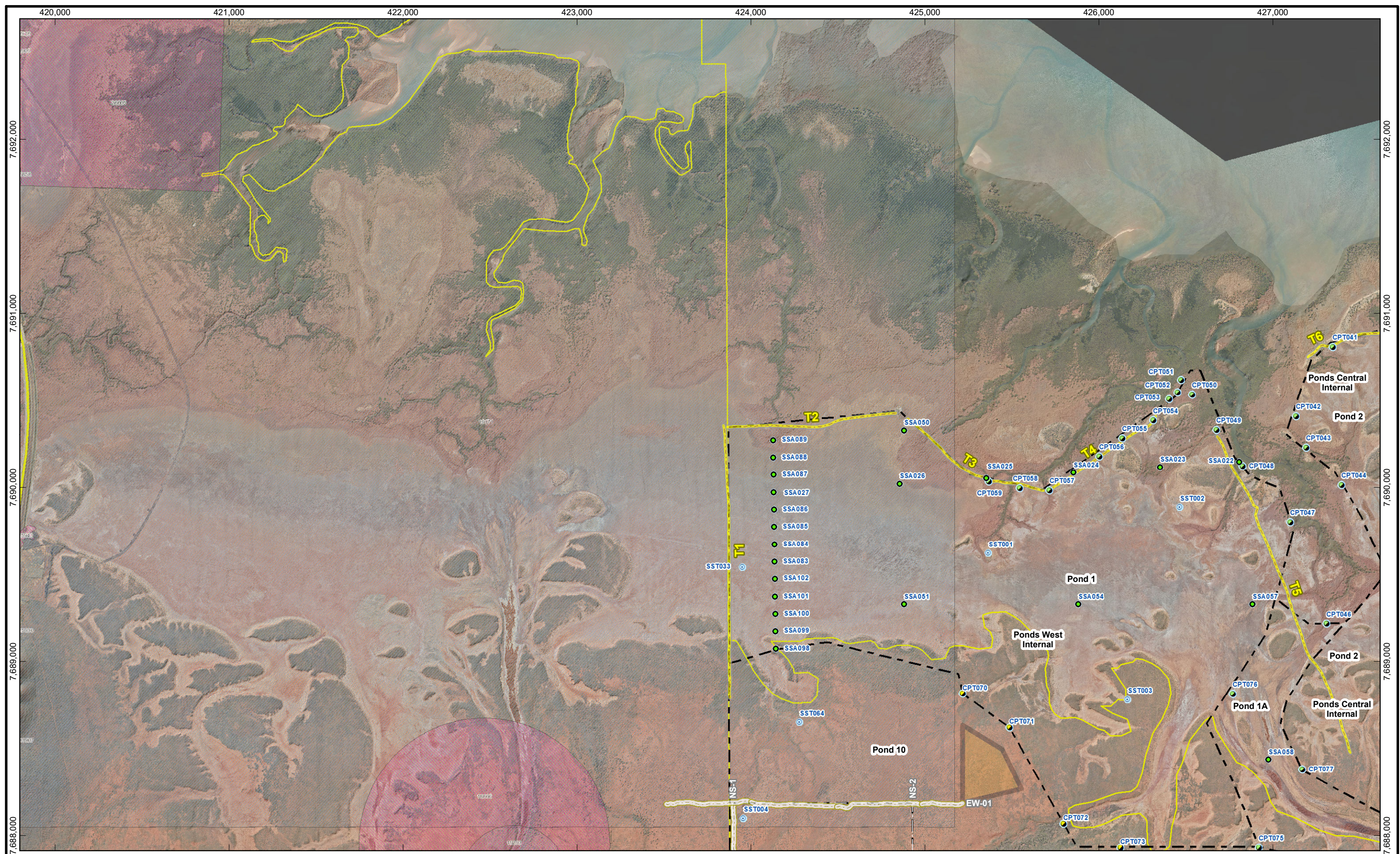
Craig, R. F. (2004). Craig's Soil Mechanics. Seventh Edition

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Figures

Figure 1: Figure Series – Site Location Plans





CMW Test Locations (Completed)

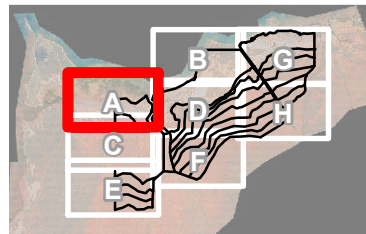
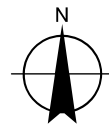
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- Surface sample triaxial
- Algal sample
- CPT, Marsh Buggy

Geophysical Traverse

-  MASW Refraction
 GPR
 Infrastructure Design
 Cadastral boundary
 Investigated borrow area

Aboriginal heritage site

-  Registered Site
 Other Heritage Place



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CPT, Marooka

Surface sample triaxial

Algal sample

Test pit

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Cadastral boundary

Investigated borrow area

Aboriginal heritage site

Registered Site

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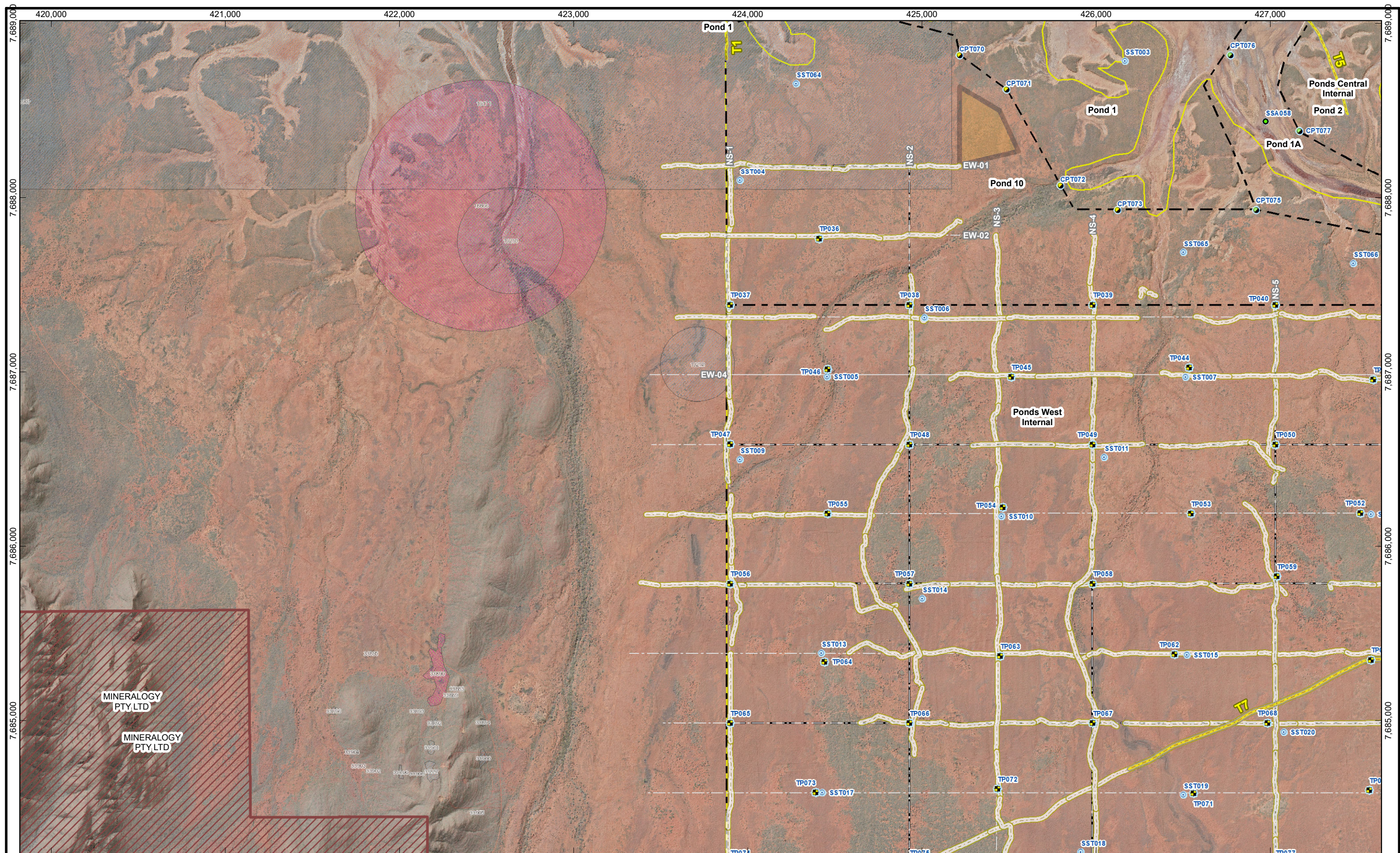
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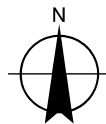
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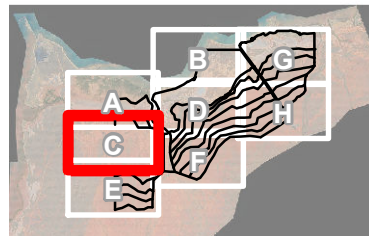
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 - Algal sample
 - Test pit
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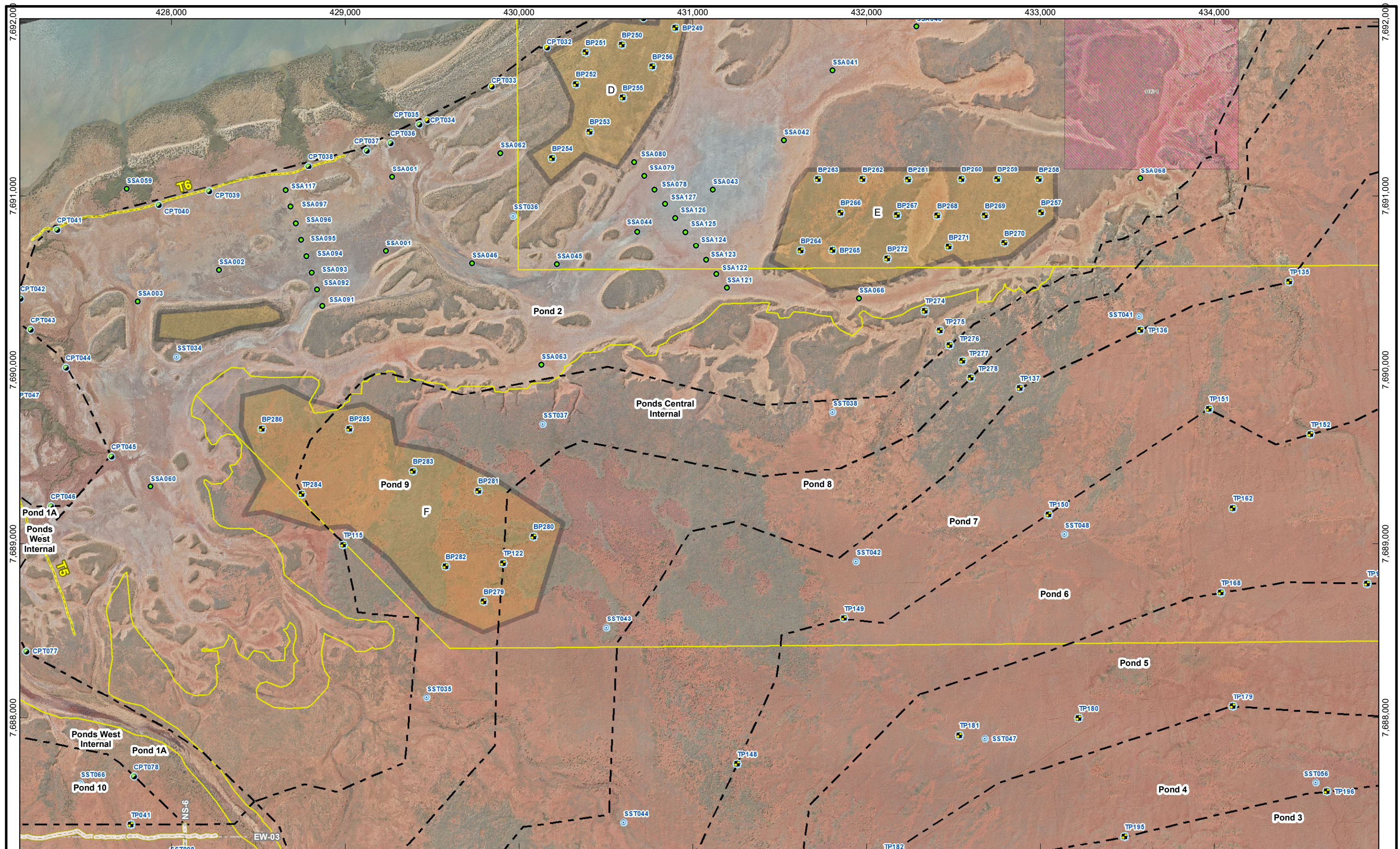


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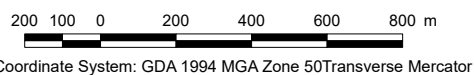
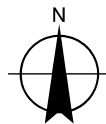


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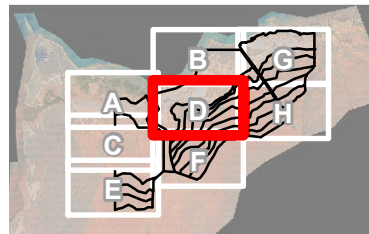


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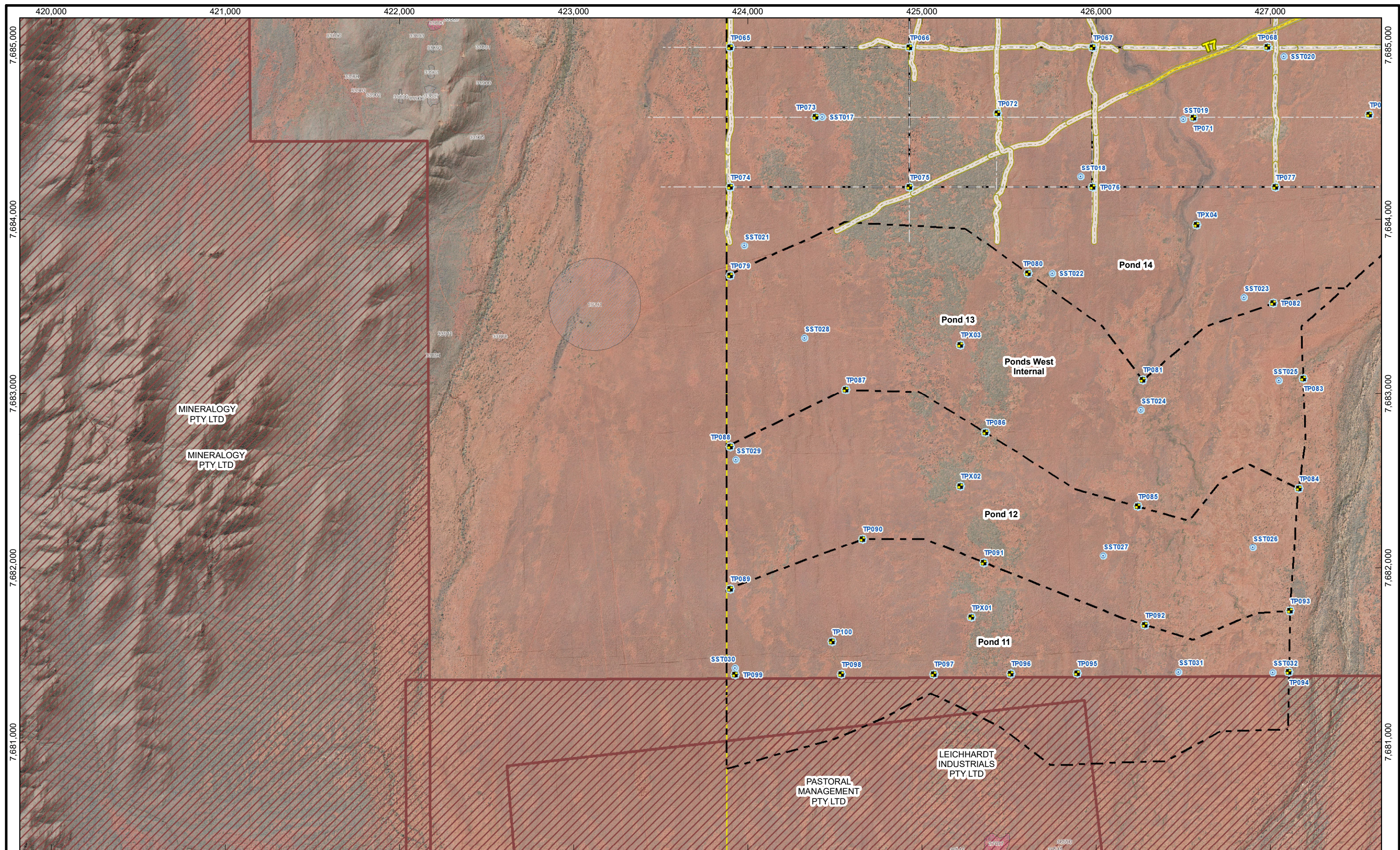
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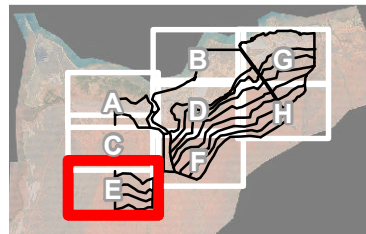
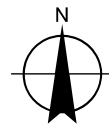


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 - Tenement

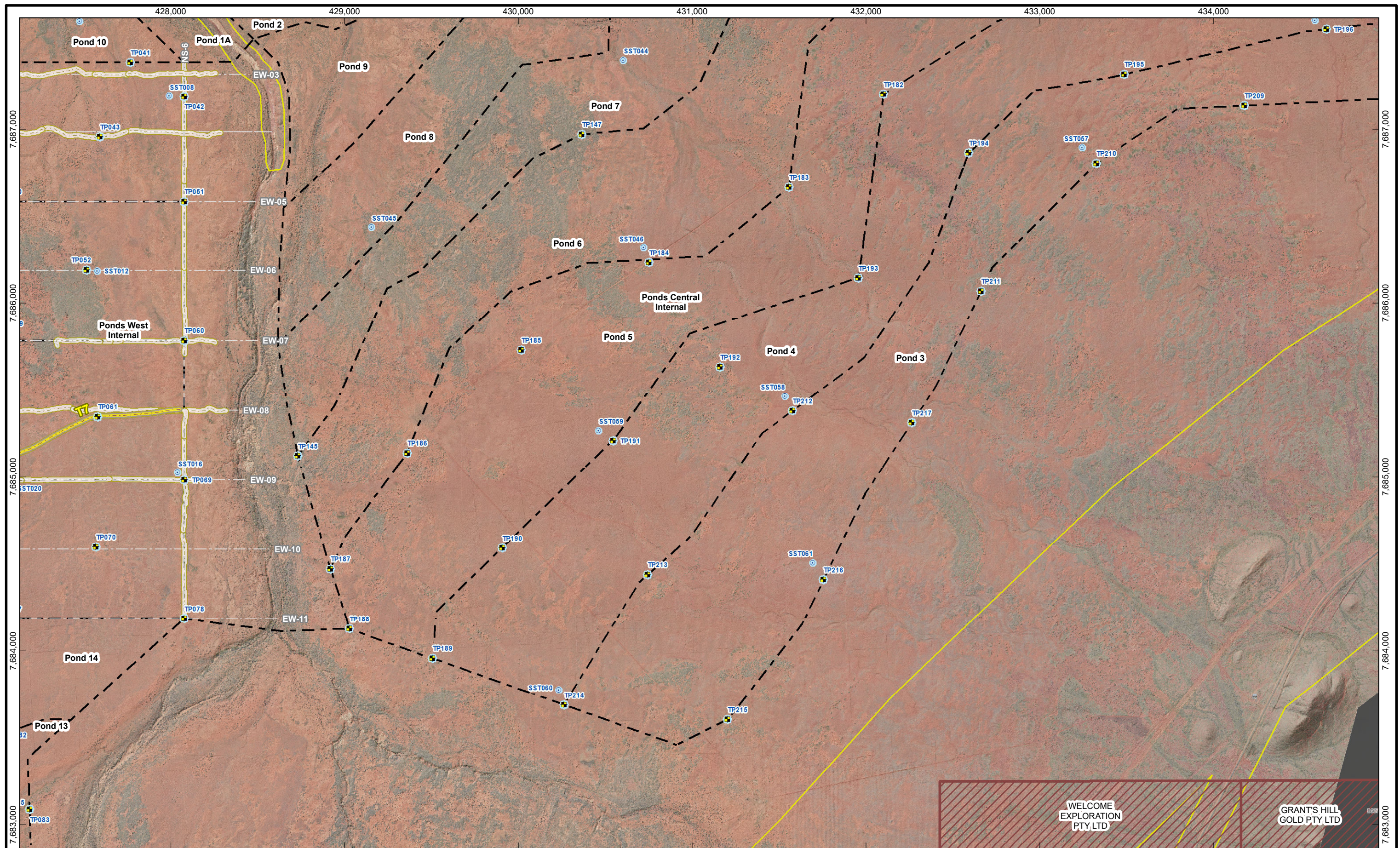
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CMW Test Locations (Completed)

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- Test pit

Geophysical Traverse

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- GPR

Infrastructure Design

- Infrastructure Design
- Cadastral boundary
- Tenement

Aboriginal heritage site

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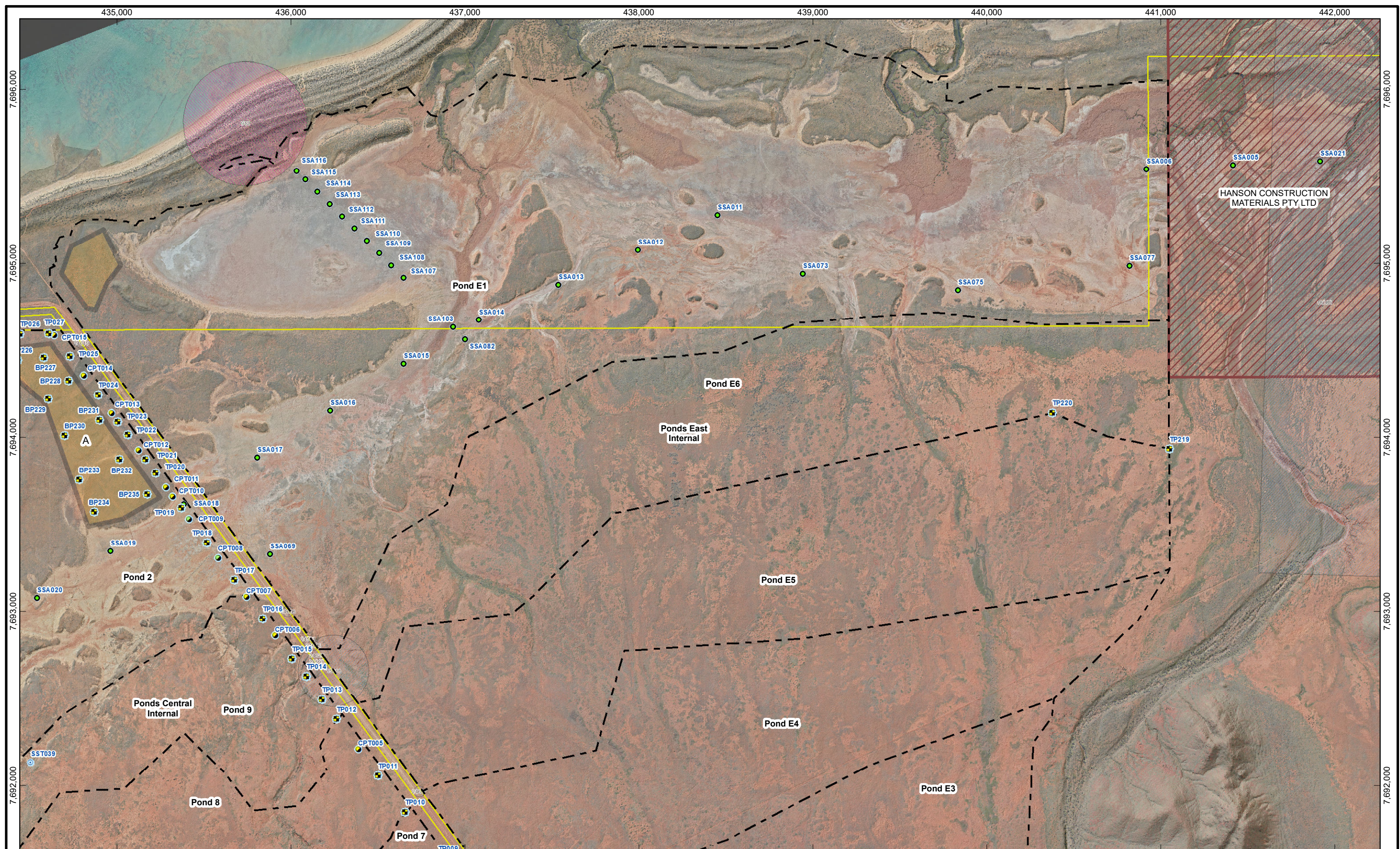
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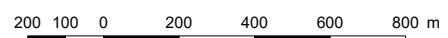
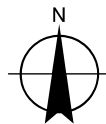
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- CPT, Marsh Buggy

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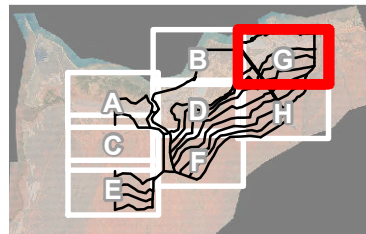
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 Investigated borrow area

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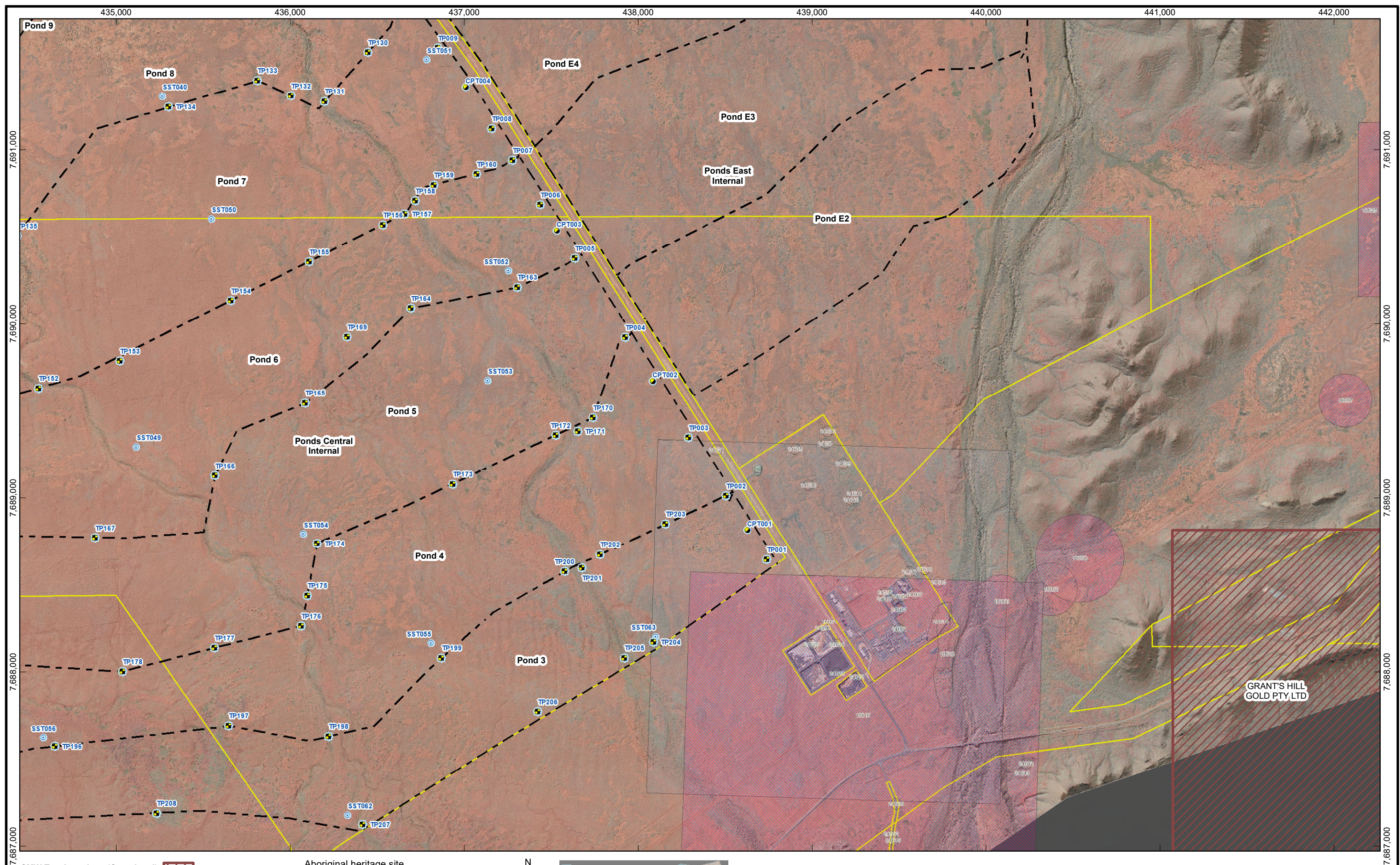
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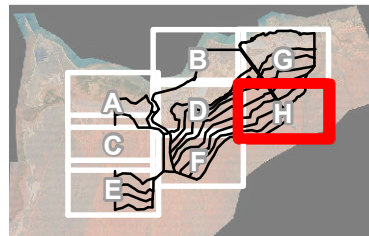
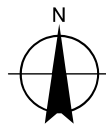


7. **CMW Test Locations (Completed)**

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-  Test pit
-  Infrastructure Design
-  Cadastral boundary

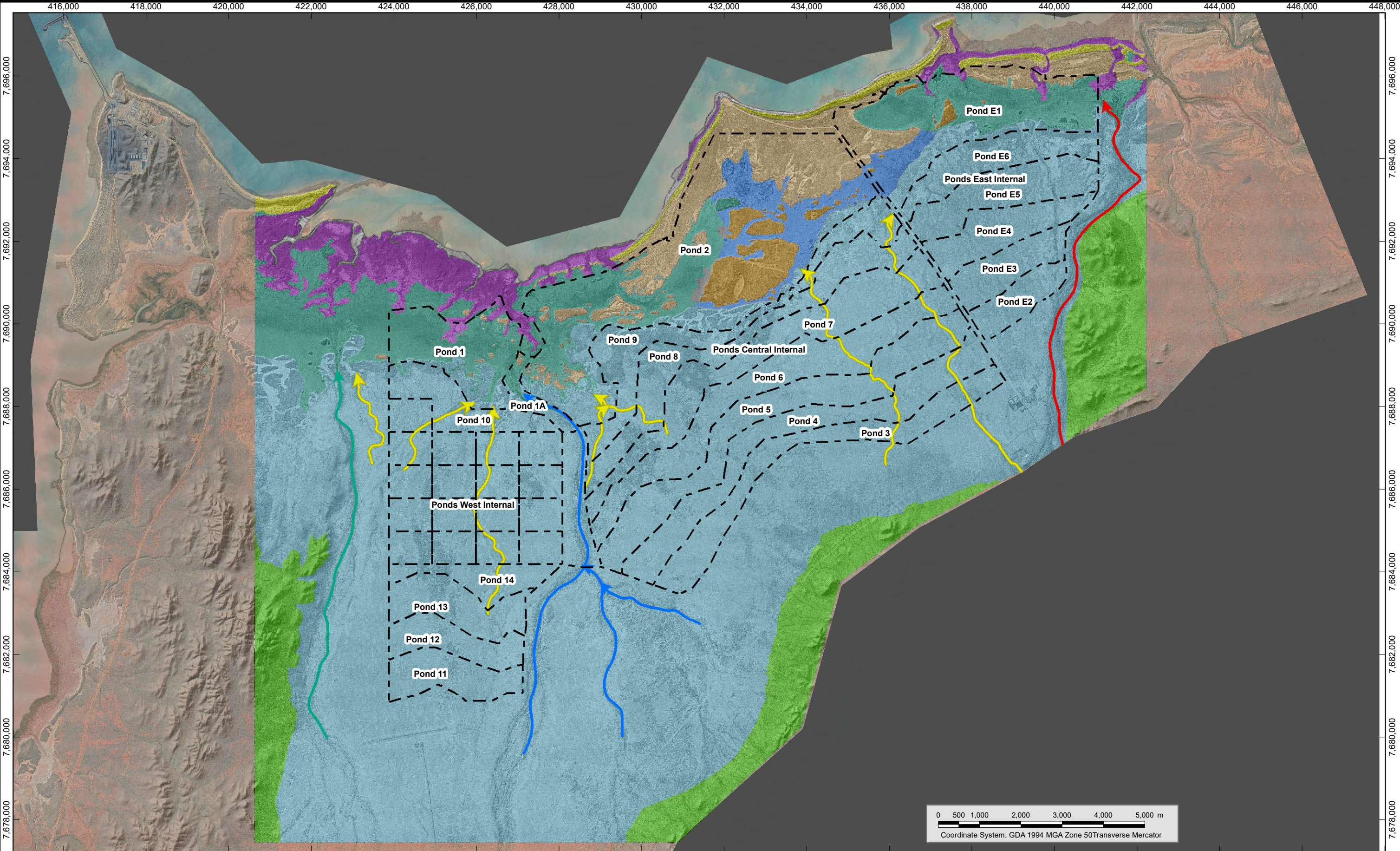
 Tenement

Aboriginal heritage site
 Registered Site
 Other Heritage Place



CLIENT:	COMPILED:	PROJECT:
LEICHHARDT INDUSTRIES	NR	PER2020-0143
PROJECT:	CHECKED:	FIGURE:
ERAMURRA SALT	MAT, RD	1H
	REVISION:	SCALE:
	0	1:20,000
TITLE:	DATE:	SHEET:
SITE INVESTIGATION PLAN	11/02/2022	A3 L

Figure 2: Figure Series – Geomorphology Maps



— — Infrastructure Design

Channels

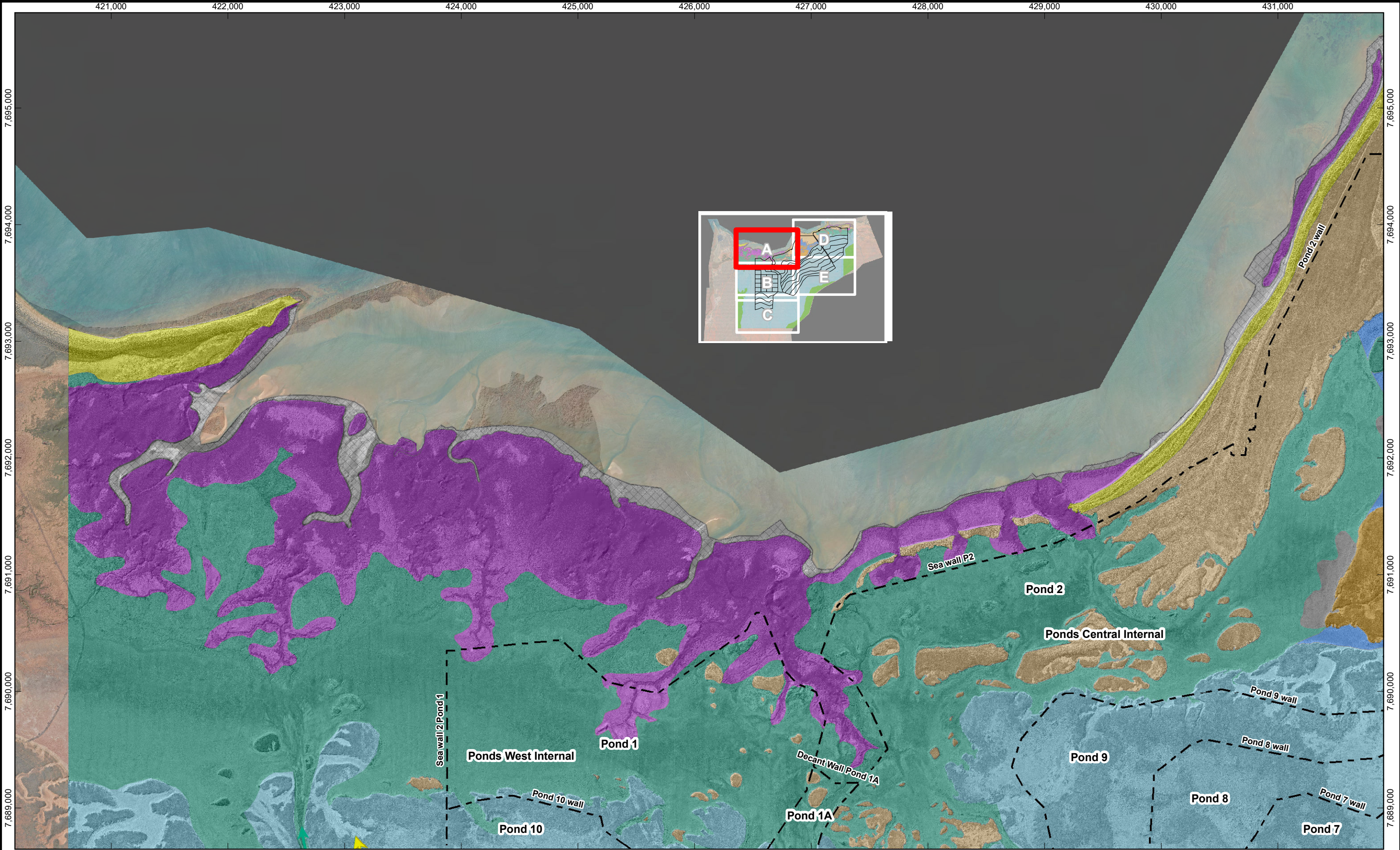
- Devils Creek Channel
- Eramurra Creek Channel
- McKay Creek Channel
- Minor Creek Channel

Geomorphology

- Beach
- Former Coastal Rock Ledges
- Deflated Dunes, Sand Plains and Sandy Islands
- Fringing Dune
- Rocky Hills and associated talus

- Intertidal Flats and Creeks
- Mangrove (dense and scattered)
- Islands with rock outcrops or rocky fringes
- Alluvial Outwash/Residual Surface with low relief rock outcrop
- Supra-Tidal Flats (with some low relief igneous rock outcrop)

CLIENT:	LEICHHARDT INDUSTRIES	COMPILED:	NR	PROJECT:	PER2020-0143
PROJECT:	ERAMURRA SALT	CHECKED:	MAT, RD	FIGURE:	2 - Layout
TITLE:	GEOMORPHOLOGY	REVISION:	0	SCALE:	1:85,000
		DATE:	11/02/2022	SHEET:	A3 L



Infrastructure Design

Channels

Eramurra Creek Channel

Minor Creek Channel

Geomorphology

Beach

Former Coastal Rock Ledges

Deflated Dunes, Sand Plains and Sandy Islands

Fringing Dune

Intertidal Flats and Creeks

Mangrove (dense and scattered)

Islands with rock outcrops or rocky fringes

Alluvial Outwash/Residual Surface with low relief rock outcrop

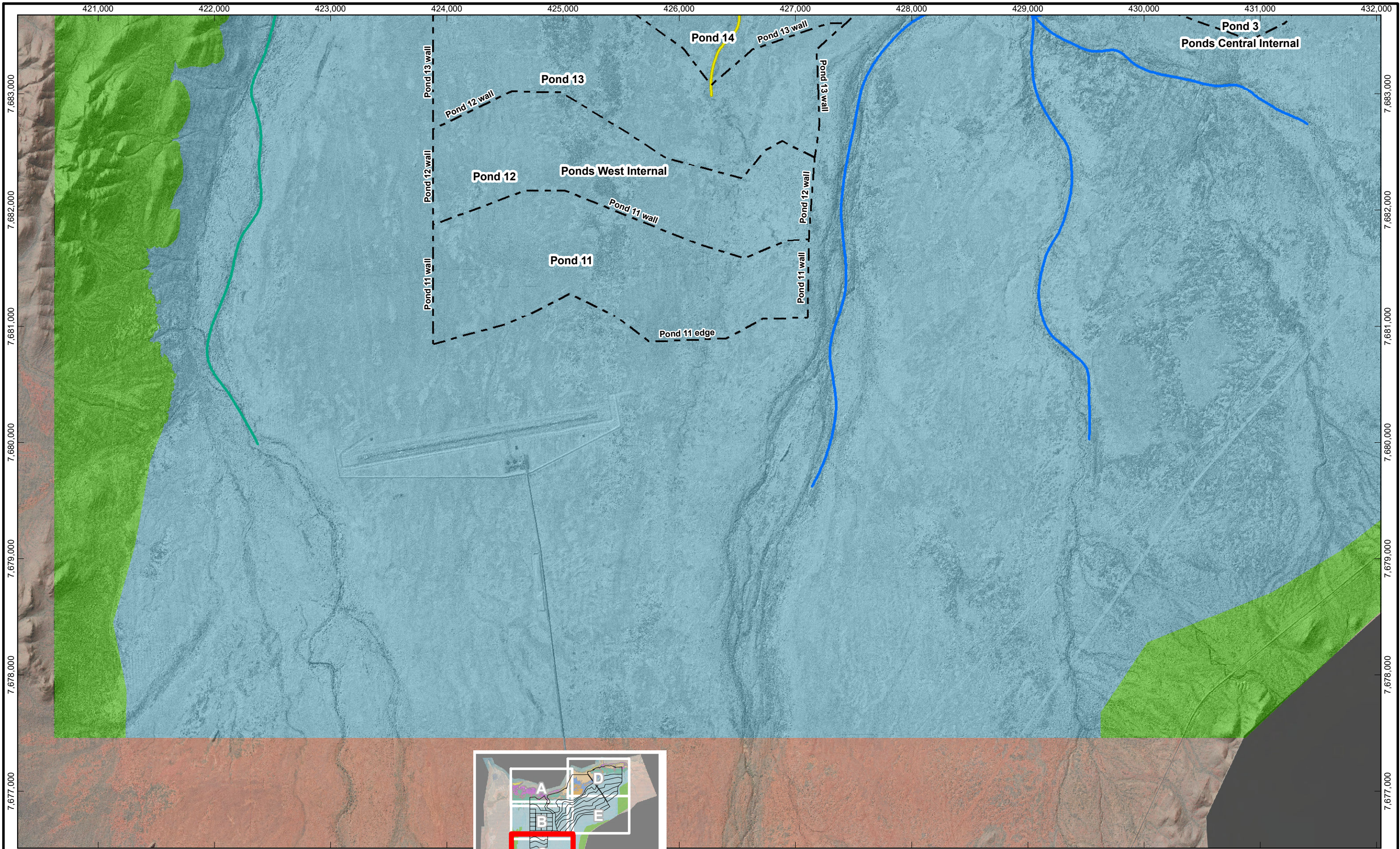
Supra-Tidal Flats (with some low relief igneous rock outcrop)

0 125 250 500 750 1,000 1,250 1,500 m

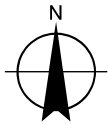
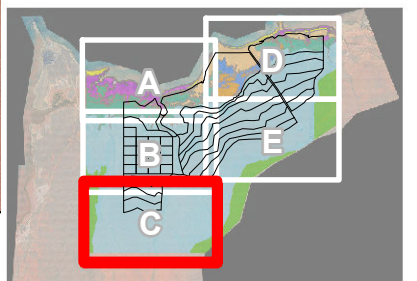
Coordinate System: GDA 1994 MGA Zone 50 Transverse Mercator

N

CMW Geosciences	CLIENT:	LEICHARDT INDUSTRIES		COMPILED:	NR	PROJECT:	PER2020-0143
	PROJECT:	ERAMURRA SALT		CHECKED:	MAT, RD	FIGURE:	2A
	TITLE:	GEOMORPHOLOGY		REVISION:	0	SCALE:	1:30,000
				DATE:	11/02/2022	SHEET:	A3 L



- Infrastructure Design
- Light blue box: Alluvial Outwash/Residual Surface with low relief rock outcrop
- Channels**
- Green arrow: Eramurra Creek Channel
 - Blue arrow: McKay Creek Channel
 - Yellow arrow: Minor Creek Channel
- Geomorphology**
- Green box: Rocky Hills and associated talus

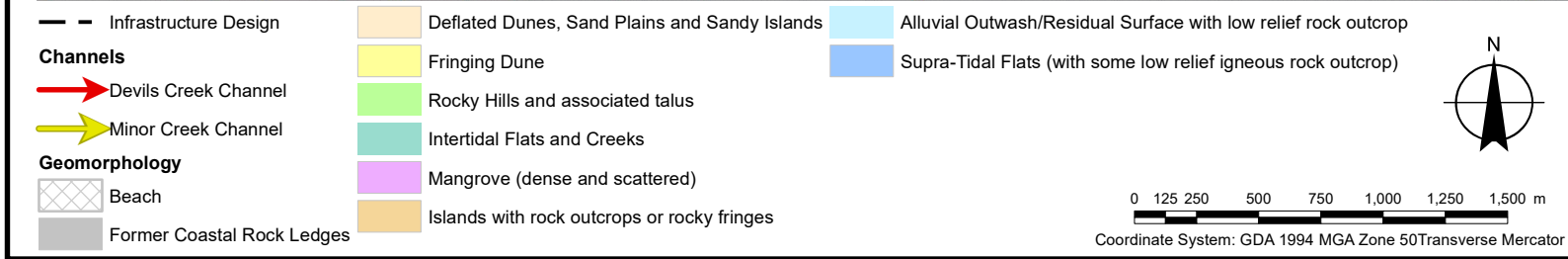
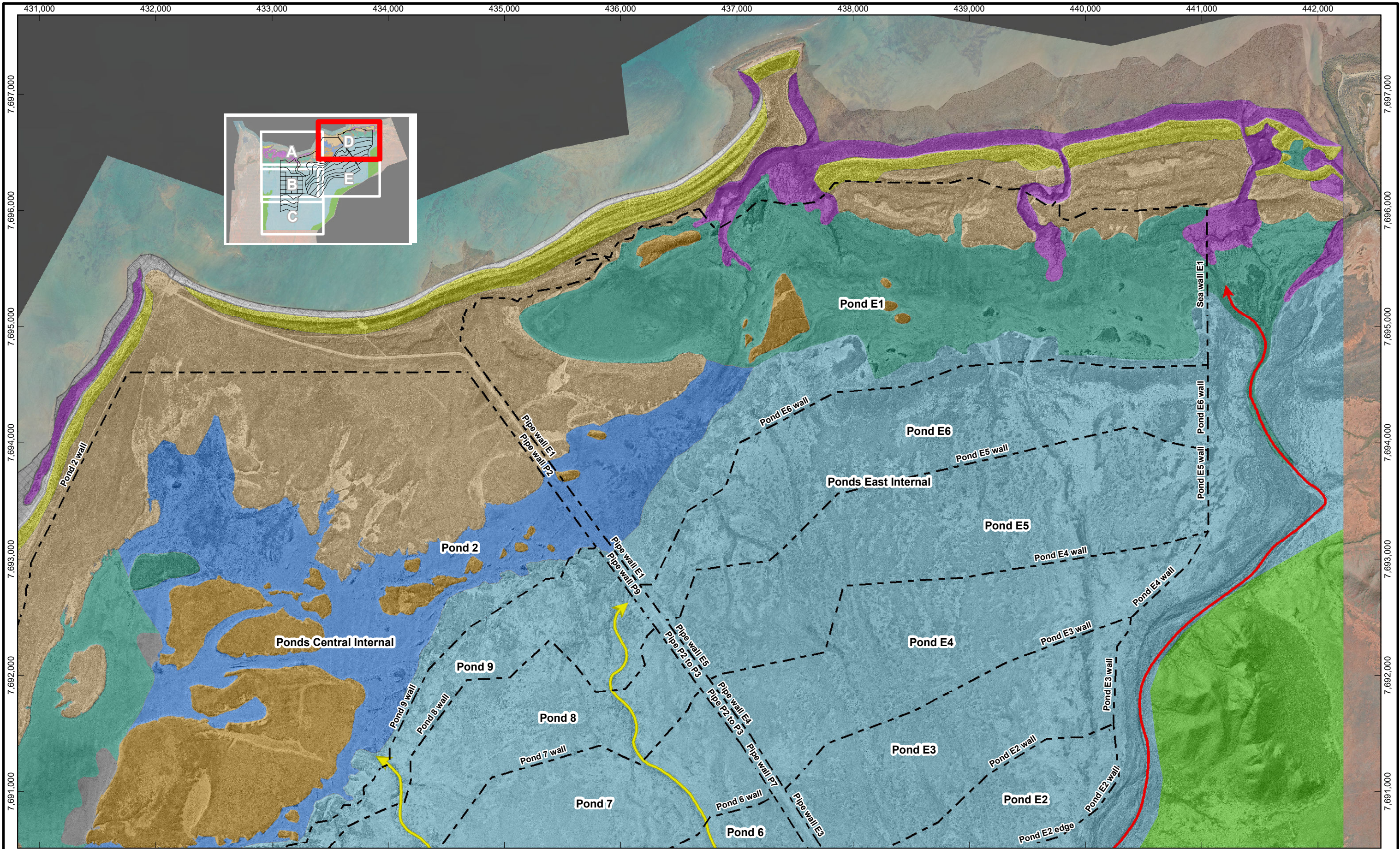


0 125 250 500 750 1,000 1,250 1,500 m

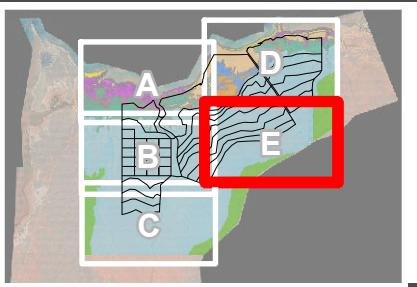
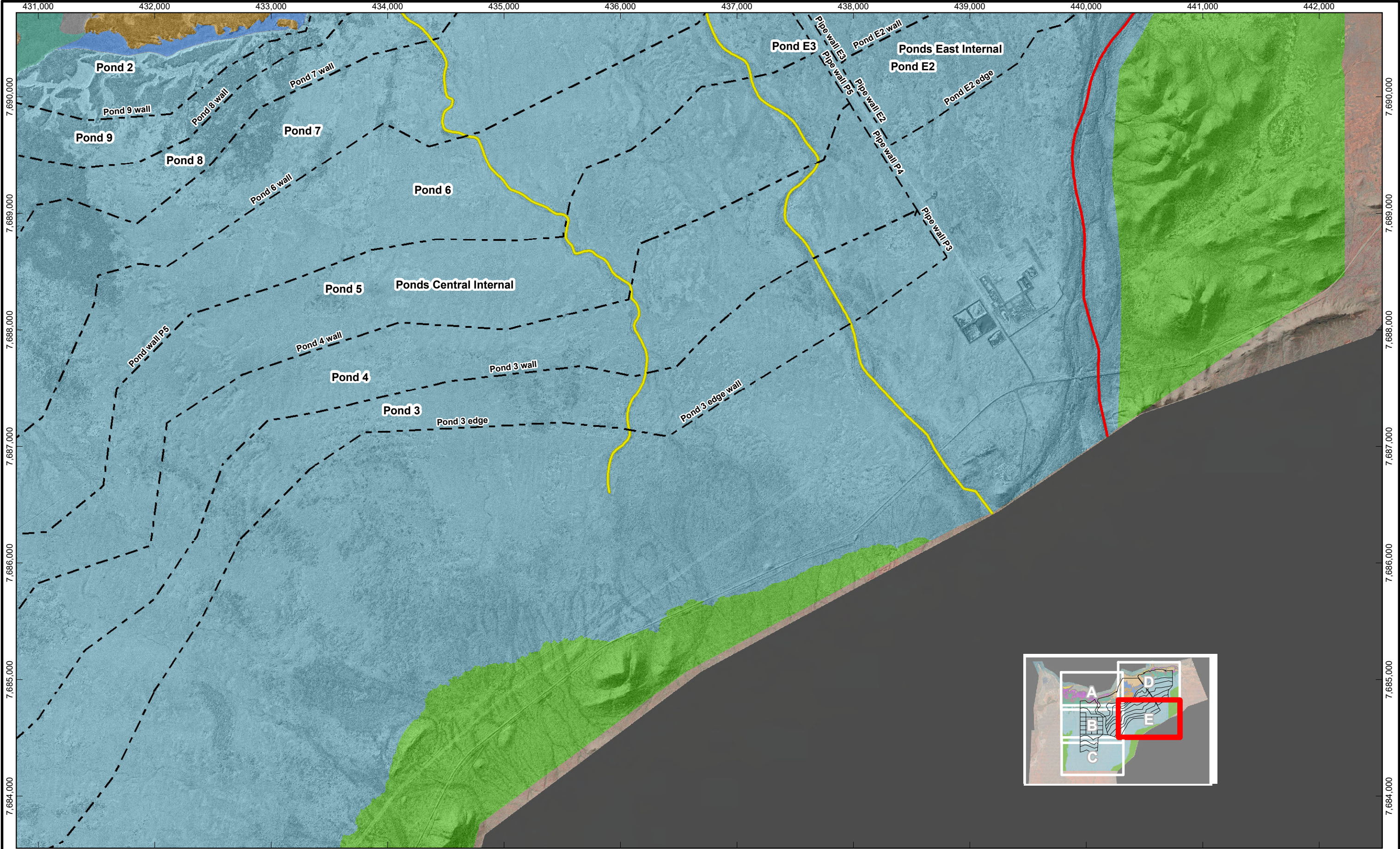
Coordinate System: GDA 1994 MGA Zone 50 Transverse Mercator



CLIENT:	LEICHHARDT INDUSTRIES		COMPILED:	NR	PROJECT:	PER2020-0143
PROJECT:	ERAMURRA SALT		CHECKED:	MAT, RD	FIGURE:	2C
TITLE:	GEOMORPHOLOGY		REVISION:	0	SCALE:	1:30,000
			DATE:	11/02/2022	SHEET:	A3 L



CLIENT:	LEICHHARDT INDUSTRIES		COMPILED:	NR	PROJECT:	PER2020-0143
PROJECT:	ERAMURRA SALT		CHECKED:	MAT, RD	FIGURE:	2D
TITLE:	GEOMORPHOLOGY		REVISION:	0	SCALE:	1:30,000
			DATE:	11/02/2022	SHEET:	A3 L



- Infrastructure Design

Channels

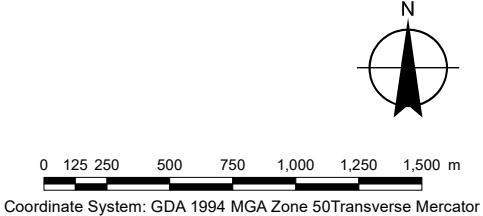
Devils Creek Channel

Minor Creek Channel

Geomorphology

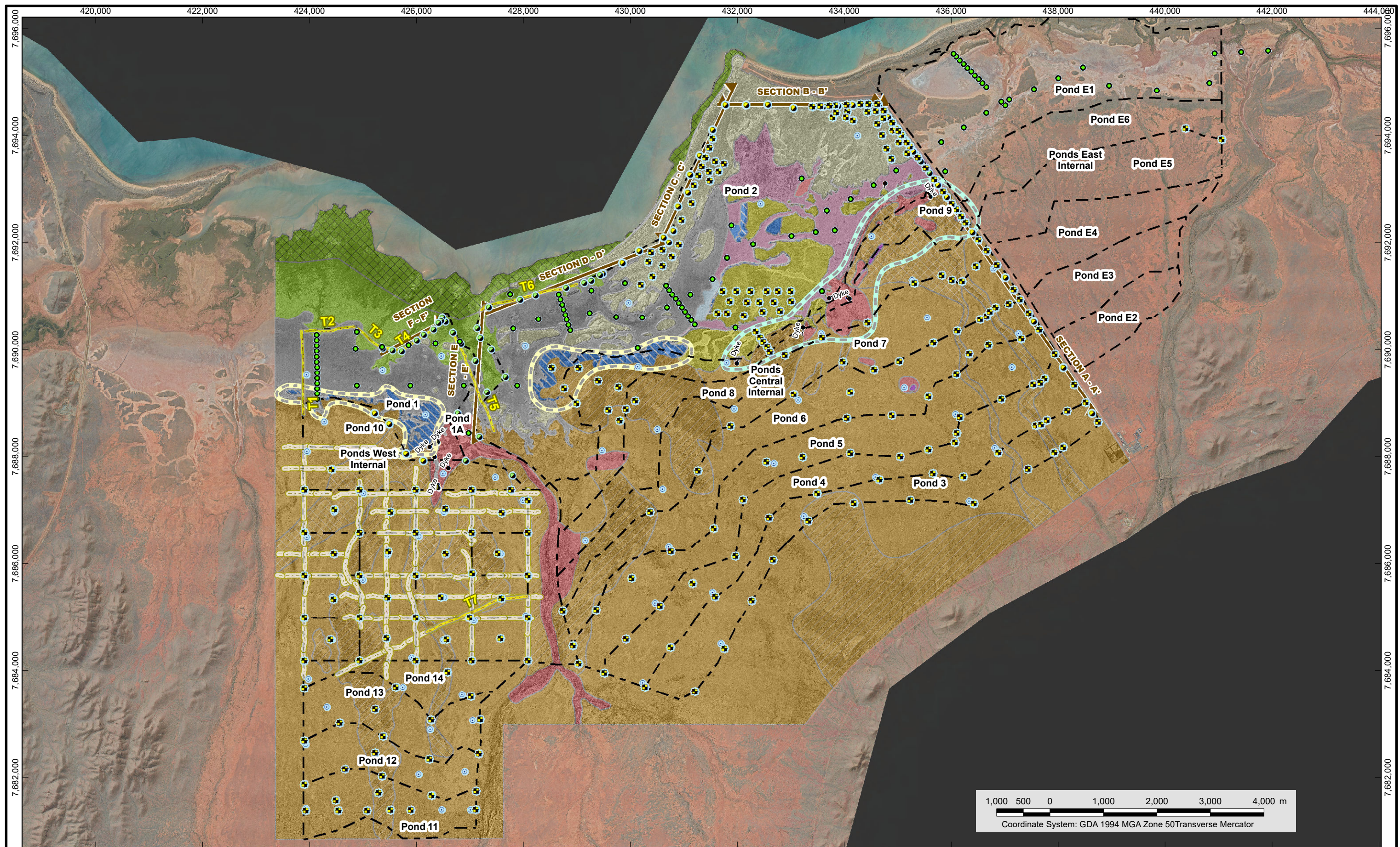
Former Coastal Rock Ledges

Deflated Dunes, Sand Plains and Sandy Islands
- Rocky Hills and associated talus
- Intertidal Flats and Creeks
- Islands with rock outcrops or rocky fringes
- Alluvial Outwash/Residual Surface with low relief rock outcrop
- Supra-Tidal Flats (with some low relief igneous rock outcrop)



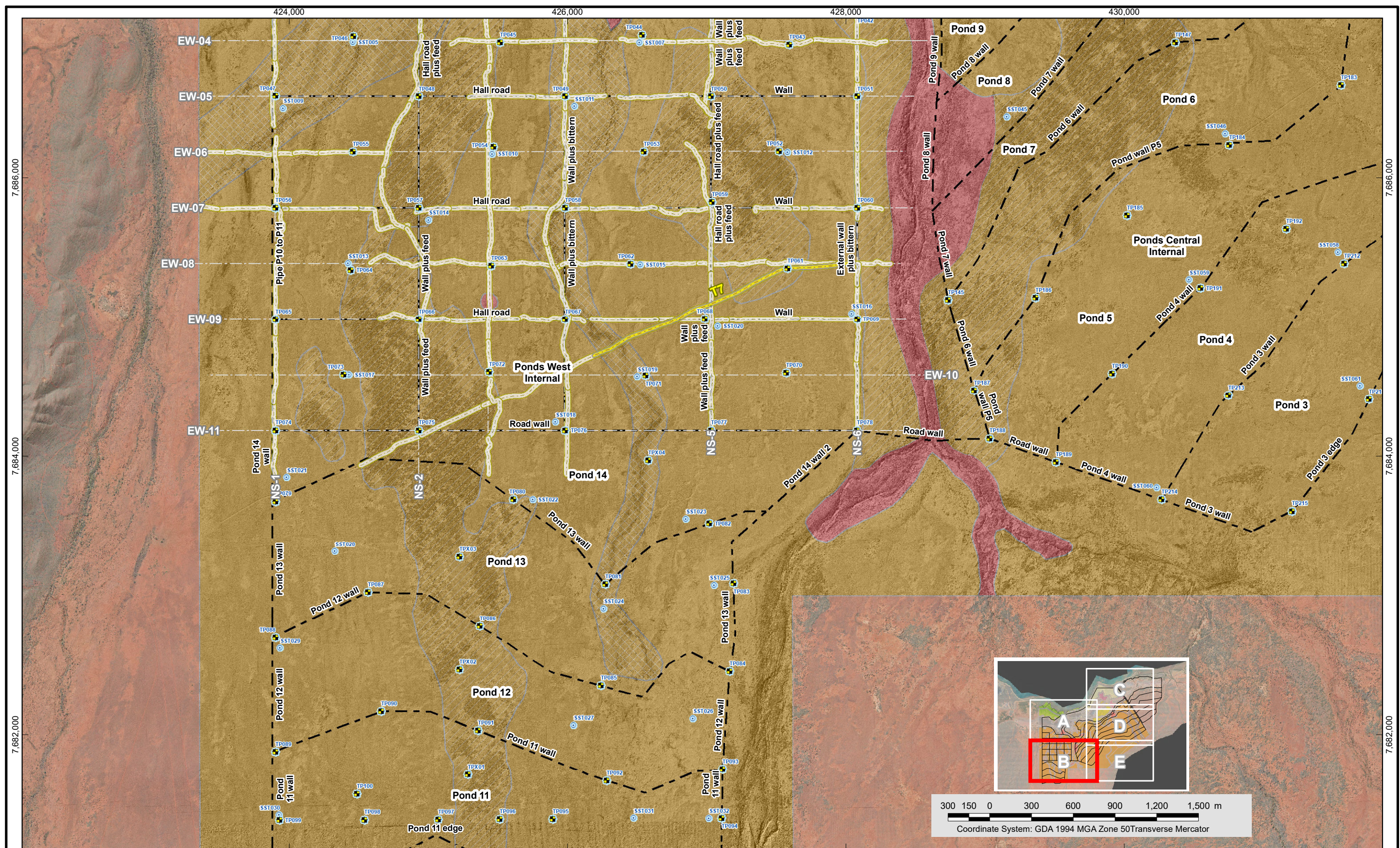
CLIENT:	LEICHHARDT INDUSTRIES		COMPILED:	NR	PROJECT:	PER2020-0143
PROJECT:	ERAMURRA SALT		CHECKED:	MAT, RD	FIGURE:	2E
TITLE:	GEOMORPHOLOGY		REVISION:	0	SCALE:	1:30,000
			DATE:	11/02/2022	SHEET:	A3 L

Figure 3: Figure Series – Engineering Geology Maps



CMW Test Locations (Completed)		Infrastructure Design		Engineering Geology		Geophysical Traverse	
● Surface sample triaxial	● Doleritic dyke	● Section Line	● Mangrove and Inter-tidal muds	● Beach rock	● Calcarenite	● MASW Refraction	● GPR
● Algal sample	● Test pit	● CPT, Marooka	● CPT, Marsh Buggy	● Mangrove mud	● Lagoonal mud	● Thin Lagoonal Mud over Igneous Rock	● Eolian sand (overlying calcarenite)
● Eolian sand (overlying calcarenite)	● Predominantly Doleritic dyke	● Shallow/outcropping calcarenite with high seepage potential	● Shallow/outcropping rock impacting borrow potential, foundation preparation and seepage under walls	● Eolian sand (overlying granitoid and mafic rocks)	● Alluvial soil (Thin veneer of sheetwash gravel over Residual soil derived from underlying rocks and also weathering of thin alluvium)	● Alluvial soils (Braided channel gravels)	● Residual soil
● Predominantly Granitoid rocks							

CLIENT:	LEICHHARDT INDUSTRIES	COMPILED:	NR	PROJECT:	PER2020-0143
PROJECT:	ERAMURRA SALT	CHECKED:	MAT, RD	FIGURE:	3 - Layout
TITLE:	ENGINEERING GEOLOGY	REVISION:	1	SCALE:	1:65,000
		DATE:	23/02/2022	SHEET:	A3 L



CMW Test Locations (Completed) — — Infrastructure Design

- Surface sample triaxial
- Test pit

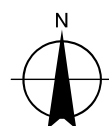
Geophysical Traverse

 MASW Refraction

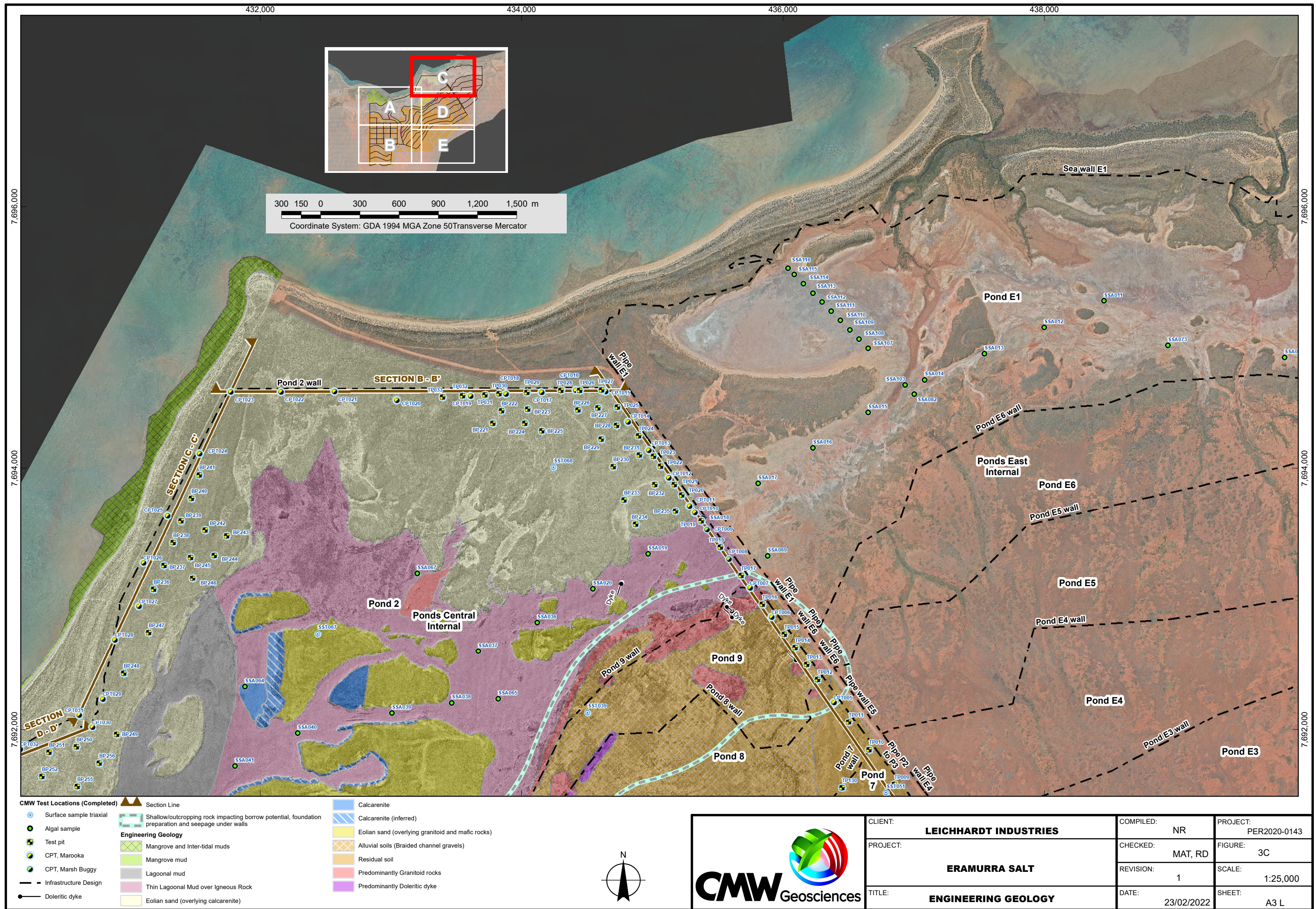
 GPR

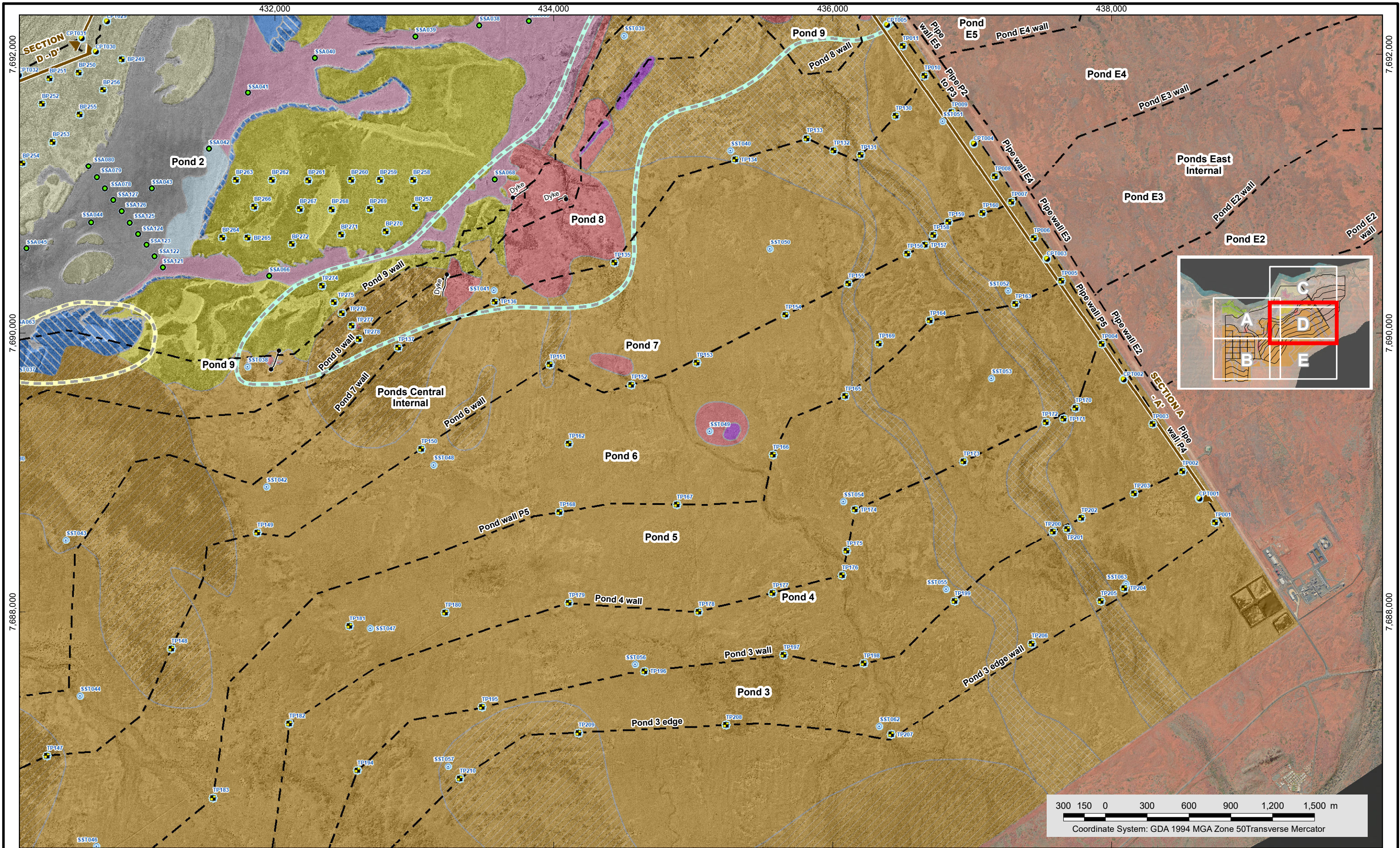
Engineering Geology

	Alluvial soil (Thin veneer of sheetwash gravel over Residual soil derived from underlying rocks and also weathering of thin alluvium)
	Alluvial soils (Braided channel gravels)
	Residual soil
	Predominantly Granitoid rocks



S	CLIENT: LEICHHARDT INDUSTRIES	COMPILED: NR	PROJECT: PER2020-0143
	PROJECT: ERAMURRA SALT	CHECKED: MAT, RD	FIGURE: 3B
		REVISION: 1	SCALE: 1:25,000
	TITLE: ENGINEERING GEOLOGY	DATE: 23/02/2022	SHEET: A3 L





CMW Test Locations (Completed)

- Surface sample triaxial
- Algal sample
- Test pit
- CPT, Marooka
- Infrastructure Design
- Doleritic dyke
- Section Line

Engineering Geology

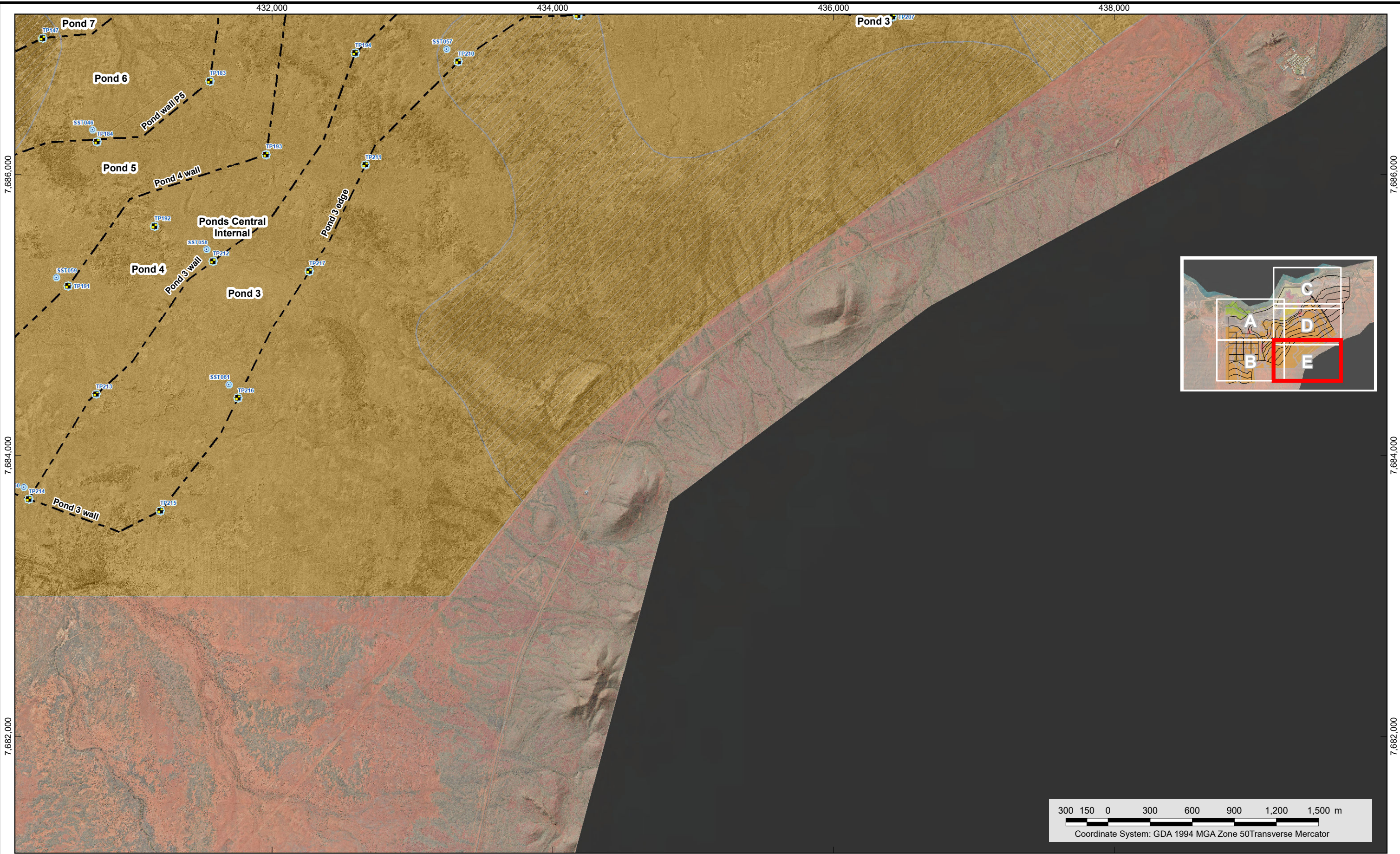
- Lagoonal mud
- Thin Lagoonal Mud over Igneous Rock
- Eolian sand (overlying calcarenite)
- Beach rock
- Calcarene

- Shallow/outcropping calcarenite with high seepage potential
- Shallow/outcropping rock impacting borrow potential, foundation preparation and seepage under walls
- Calcarene (inferred)
- Eolian sand (overlying granitoid and mafic rocks)
- Alluvial soil (Thin veneer of sheetwash gravel over Residual soil derived from underlying rocks and also weathering of thin alluvium)
- Alluvial soils (Braided channel gravels)
- Residual soil
- Predominantly Granitoid rocks
- Predominantly Doleritic dyke

300 150 0 300 600 900 1,200 1,500 m

Coordinate System: GDA 1994 MGA Zone 50 Transverse Mercator

CLIENT:	LEICHARDT INDUSTRIES	COMPILED:	NR	PROJECT:	PER2020-0143
PROJECT:	ERAMURRA SALT	CHECKED:	MAT, RD	FIGURE:	3D
TITLE:	ENGINEERING GEOLOGY	REVISION:	1	SCALE:	1:25,000
		DATE:	23/02/2022	SHEET:	A3 L



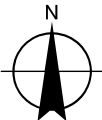
CMW Test Locations (Completed)

- Surface sample triaxial
- Test pit
- Infrastructure Design

Engineering Geology

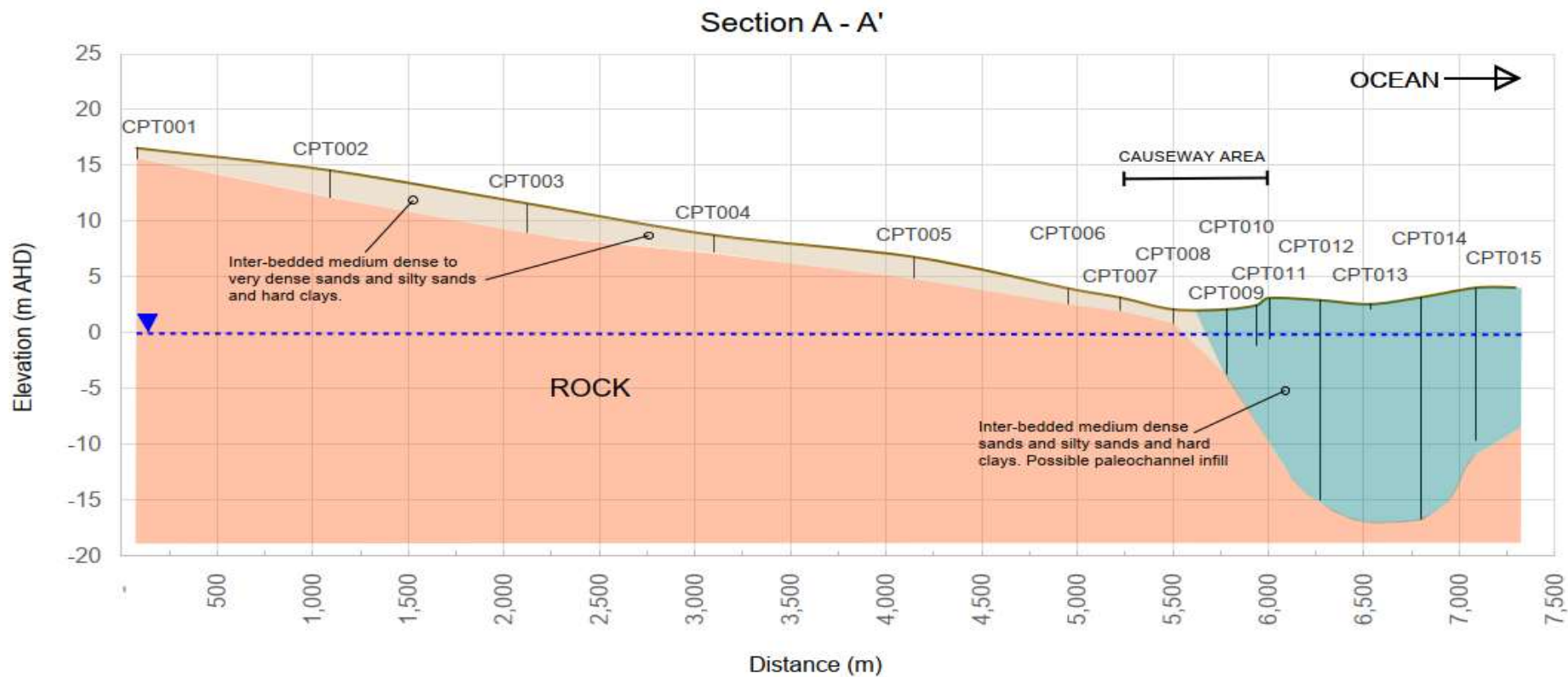
Alluvial soil (Thin veneer of sheetwash gravel over Residual soil derived from underlying rocks and also weathering of thin alluvium)

Alluvial soils (Braided channel gravels)
Residual soil



CLIENT:	LEICHHARDT INDUSTRIES		COMPILED:	NR	PROJECT:	PER2020-0143
PROJECT:	ERAMURRA SALT		CHECKED:	MAT, RD	FIGURE:	3E
TITLE:	ENGINEERING GEOLOGY		REVISION:	1	SCALE:	1:25,000
			DATE:	23/02/2022	SHEET:	A3 L

Figure 4: Figure Series – Subsurface Sections



Client:

LEICHHARDT INDUSTRIALS PTY LTD

Project:

ERAMURRA SALT PROJECT

Title:

CROSS SECTION A-A'

Project:

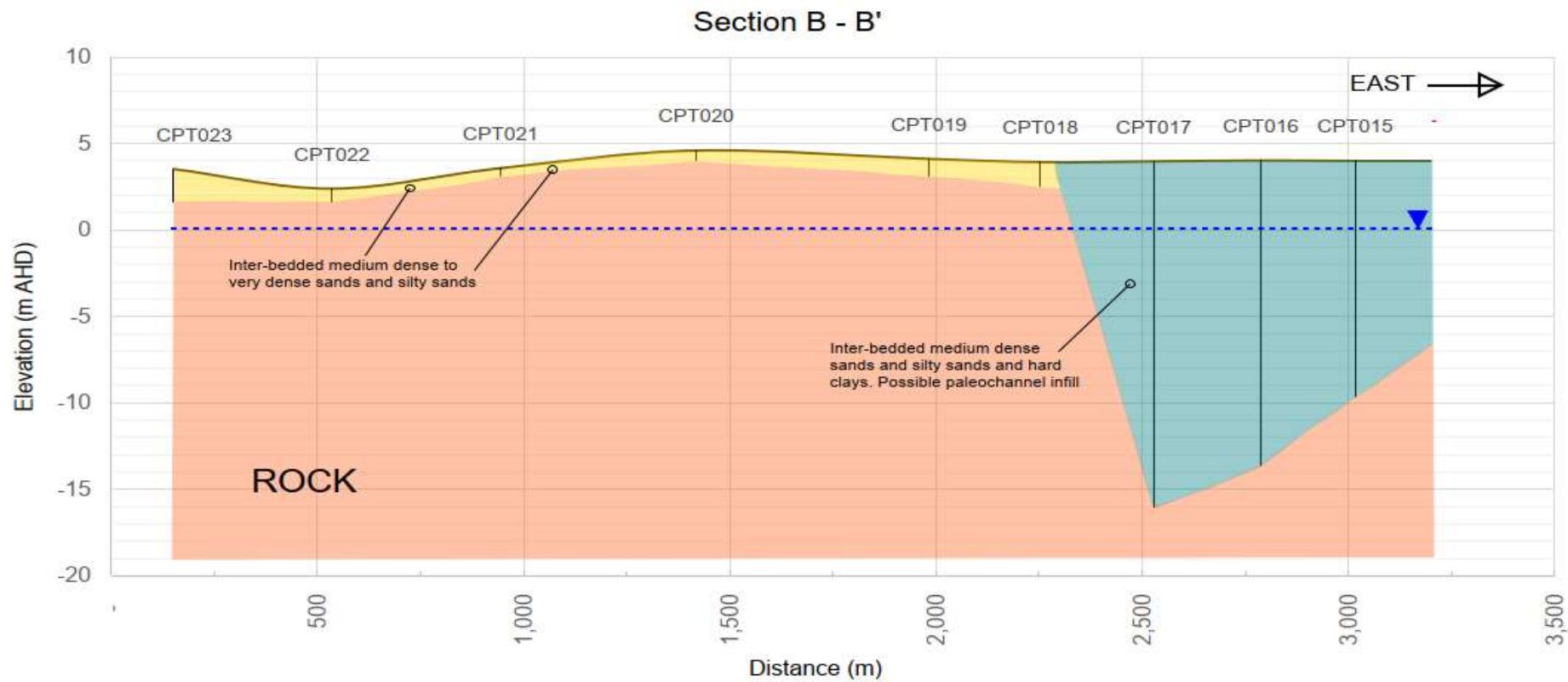
PER2020-0143

Figure:

4 - A

Date:

10/02/2022



Client:

LEIGHARDT INDUSTRIALS PTY LTD

Project:

ERAMURRA SALT PROJECT

Title:

CROSS SECTION B-B'

Project:

PER2020-0143

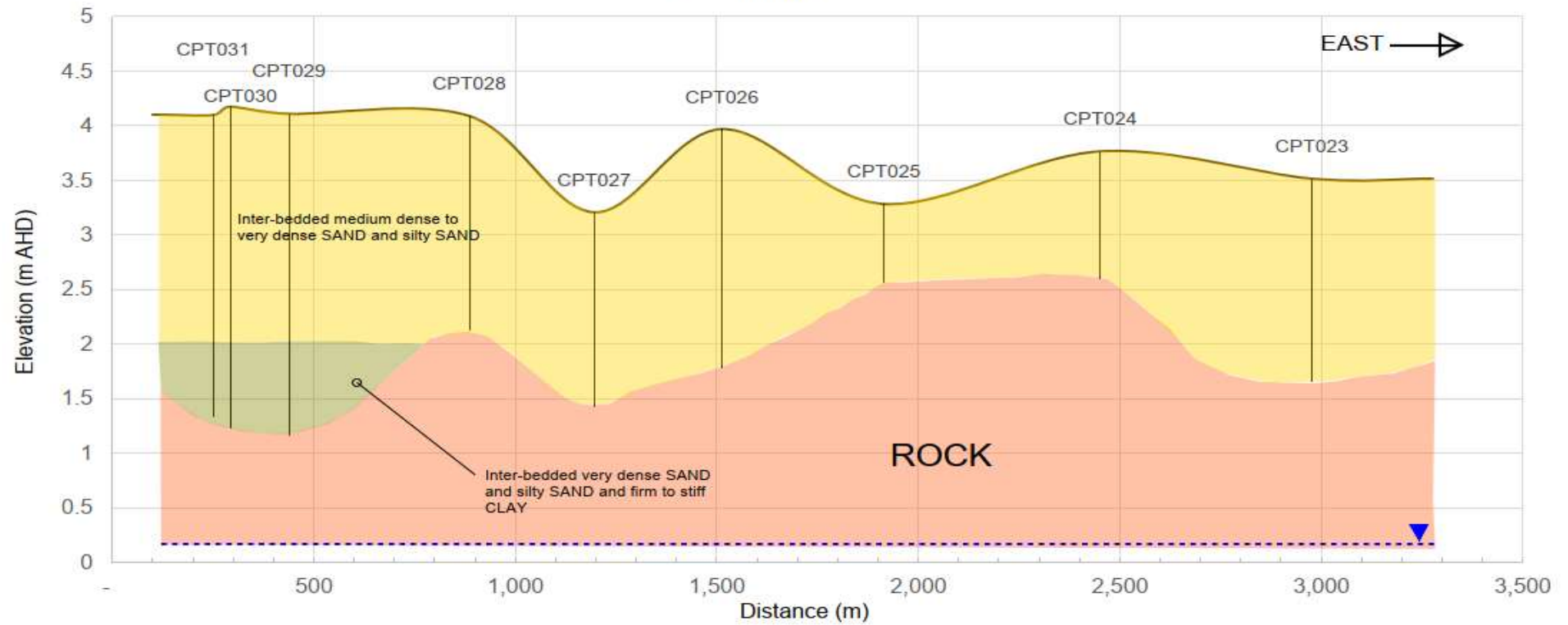
Figure:

4 - B

Date:

10/02/2022

Section C - C'



Client:

LEIGHARDT INDUSTRIALS PTY LTD

Project:

PER2020-0143

Project:

ERAMURRA SALT PROJECT

Figure:

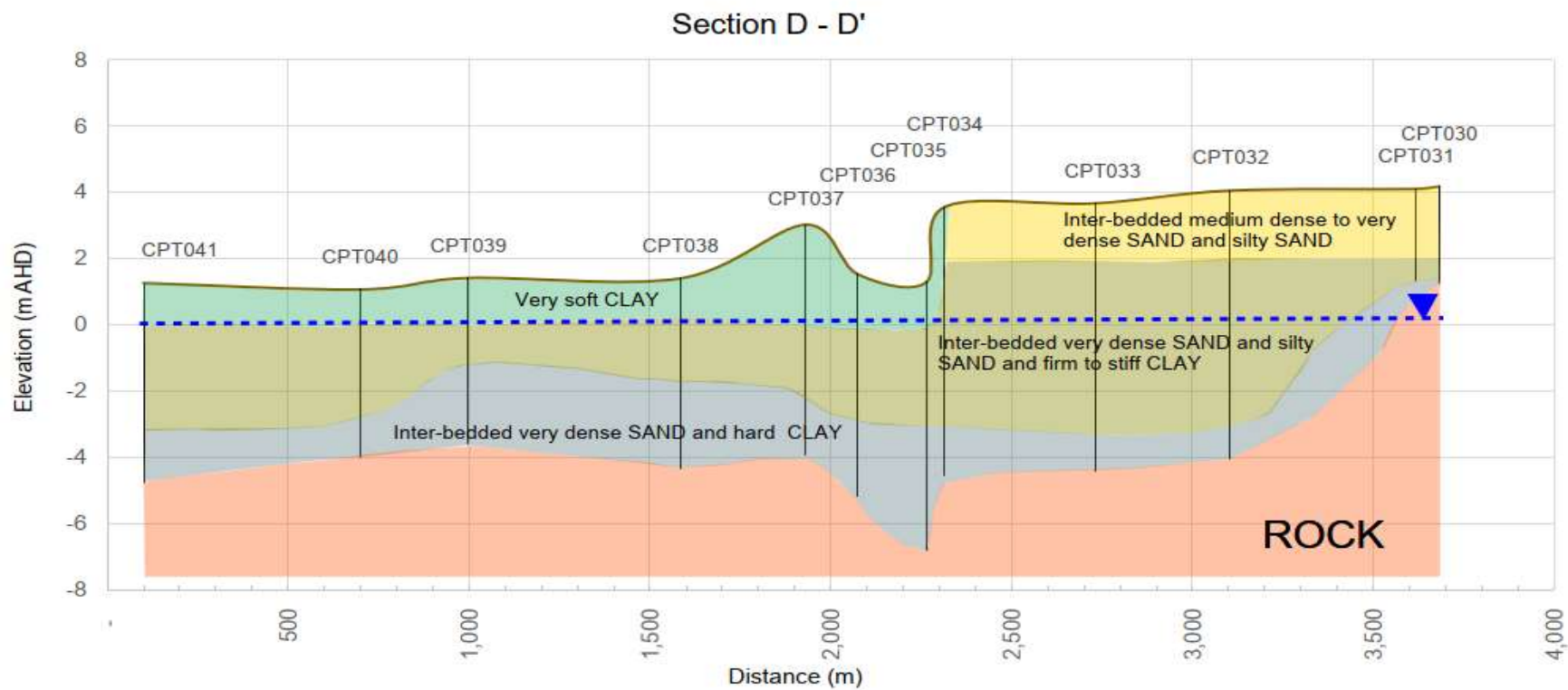
4 - C

Title:

CROSS SECTION C-C'

Date:

10/02/2022



Client:

LEIGHARDT INDUSTRIALS PTY LTD

Project:

ERAMURRA SALT PROJECT

Title:

CROSS SECTION D-D'

Project:

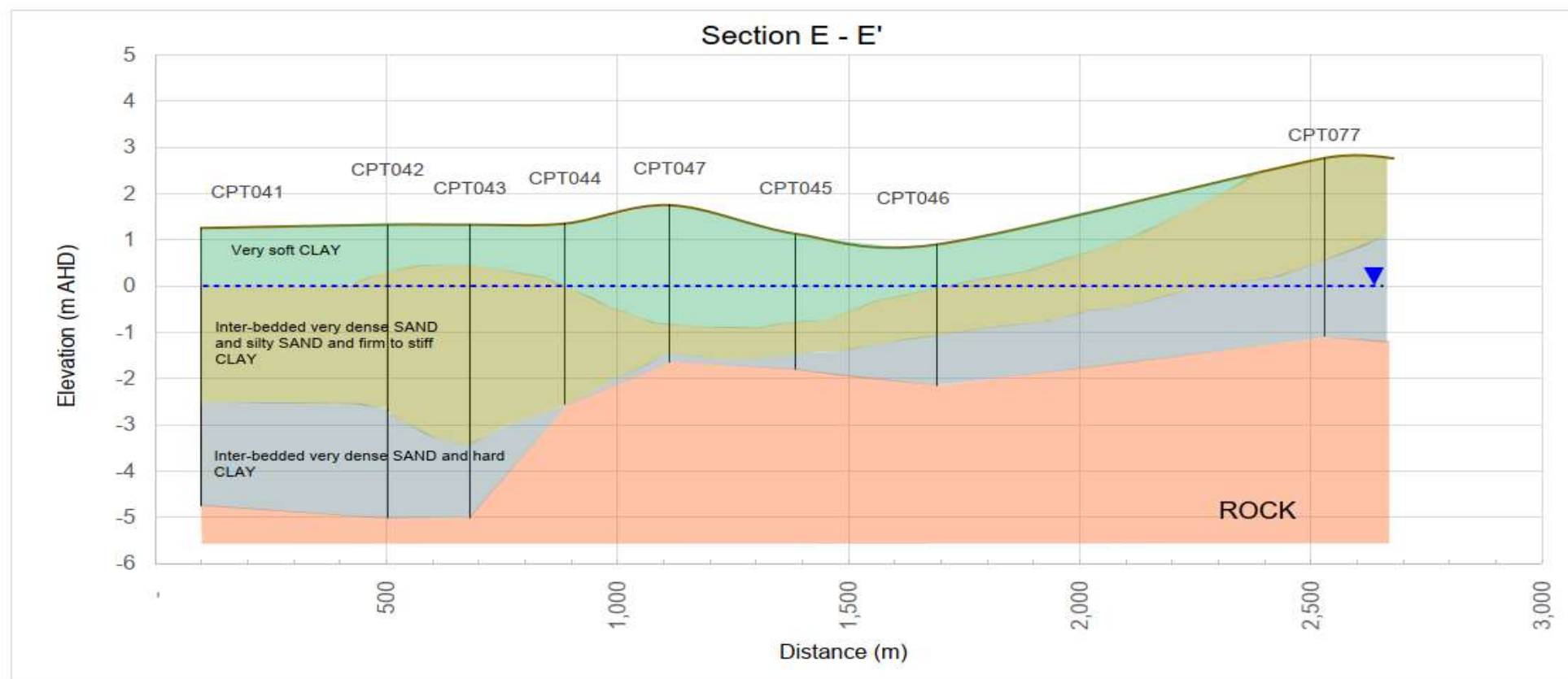
PER2020-0143

Figure:

4 - D

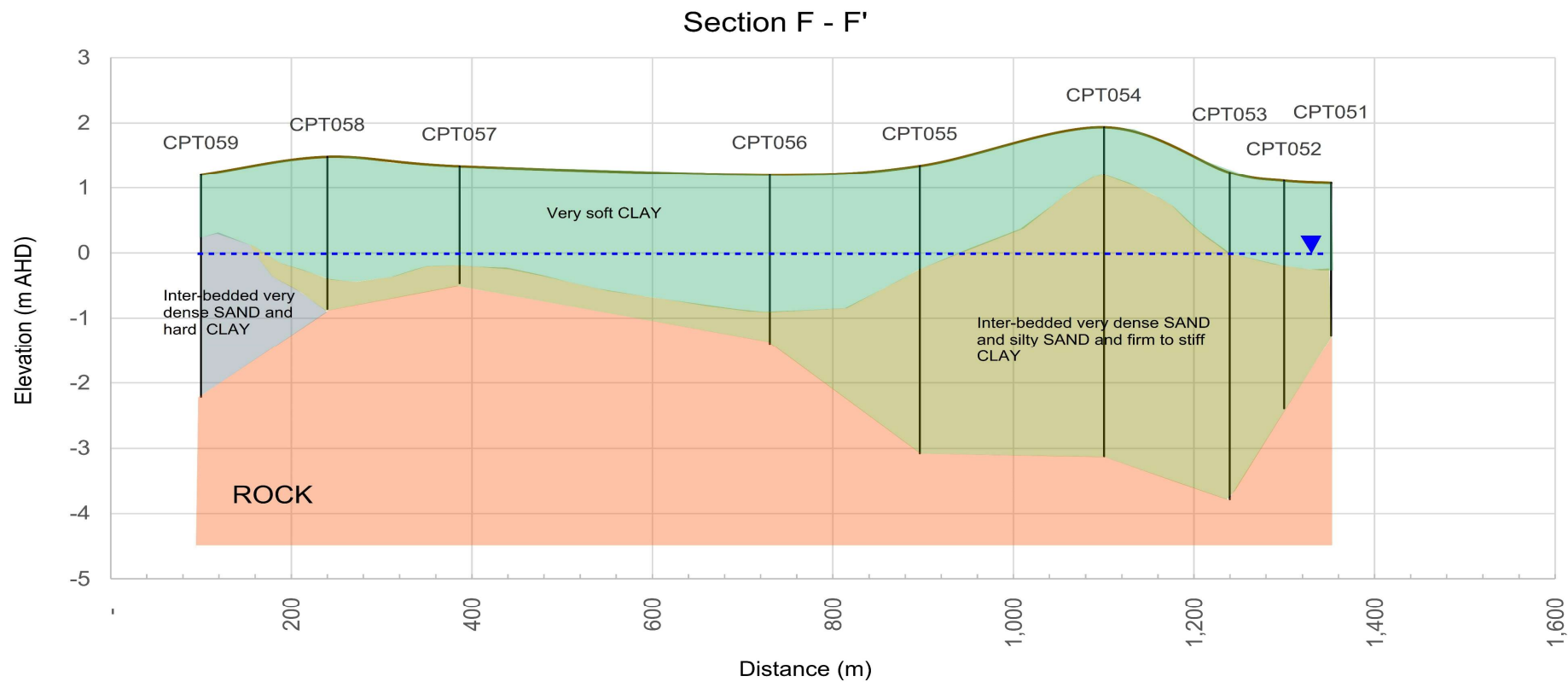
Date:

10/02/2022



Client:	LEIGHARDT INDUSTRIALS PTY LTD
Project:	ERAMURRA SALT PROJECT
Title:	CROSS SECTION E-E'

Project:	PER2020-0143
Figure:	4 - E
Date:	10/02/2022



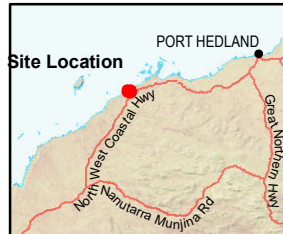
Client:	LEIGHARDT INDUSTRIALS PTY LTD	Project:	PER2020-0143
Project:	ERAMURRA SALT PROJECT	Figure:	4 - F
Title:	CROSS SECTION F-F'	Date:	10/02/2022

Figure 5 to Figure 19 (Individual Figures)



Legend

- Location ID - Termination depth used in contours Terrain surface (mAHD)
- Cone penetrometer
 - Test pit
 - Indicative depth to highly weathered rock (m)
- Terrain surface (mAHD)
- High : 13.98
 - Low : 2.852



NOTES

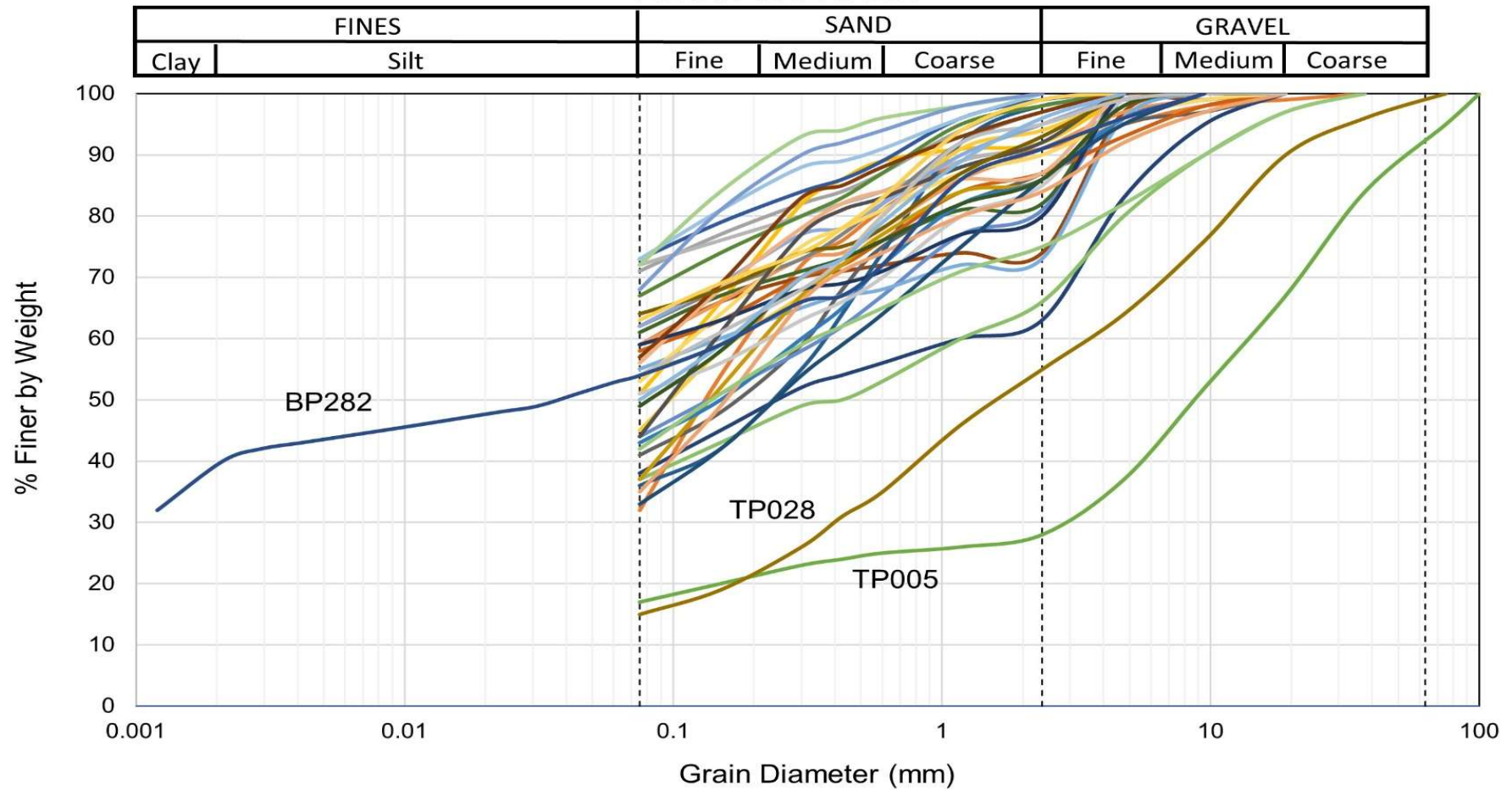
1. Contours based on test pit termination depth in HW-EW granite materials. Backhoe did not refuse at depths shown, but progress was very slow.

200 100 0 200 400 600 800 m
Coordinate System: GDA 1994 MGA Zone 50 Transverse Mercator



CLIENT:	LEICHARDT INDUSTRIES		COMPILED:	NR	PROJECT:	PER2020-0143
PROJECT:	ERAMURRA SALT		CHECKED:	MAT	FIGURE:	5
TITLE:	CRYSTALLISER AREA - APPROX WEATHERED ROCK DEPTH		REVISION:	0	SCALE:	1:17,500
			DATE:	11/02/2022	SHEET:	A3 L

PARTICLE SIZE DISTRIBUTION CHART RESIDUAL SOIL



Client:

LEICHHARDT INDUSTRIALS PTY LTD

Project:

PER2020-0143

Project:

ERAMURRA SALT PROJECT

Figure:

6

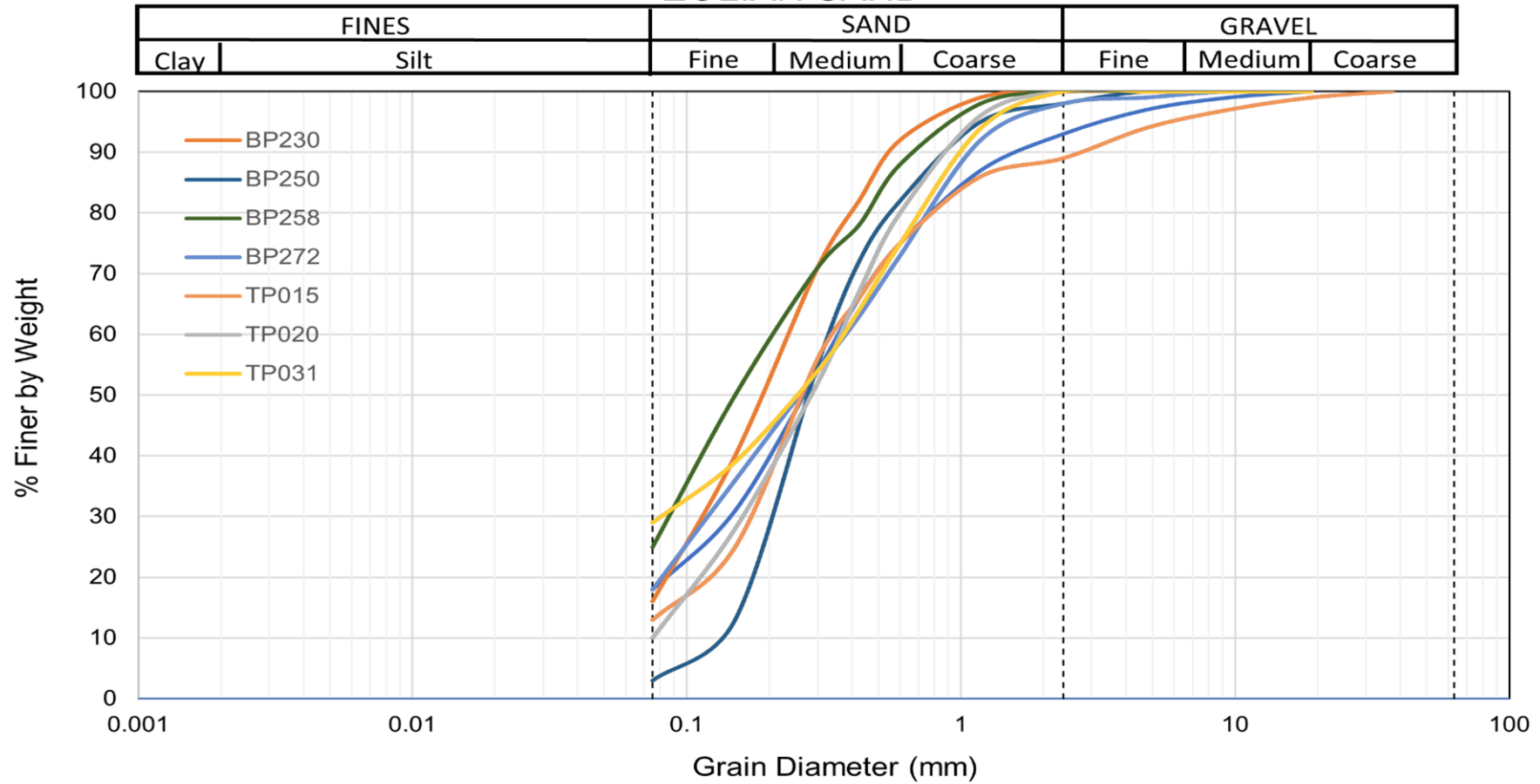
Title:

PSD CHART - RESIDUAL SOIL

Date:

10/02/2022

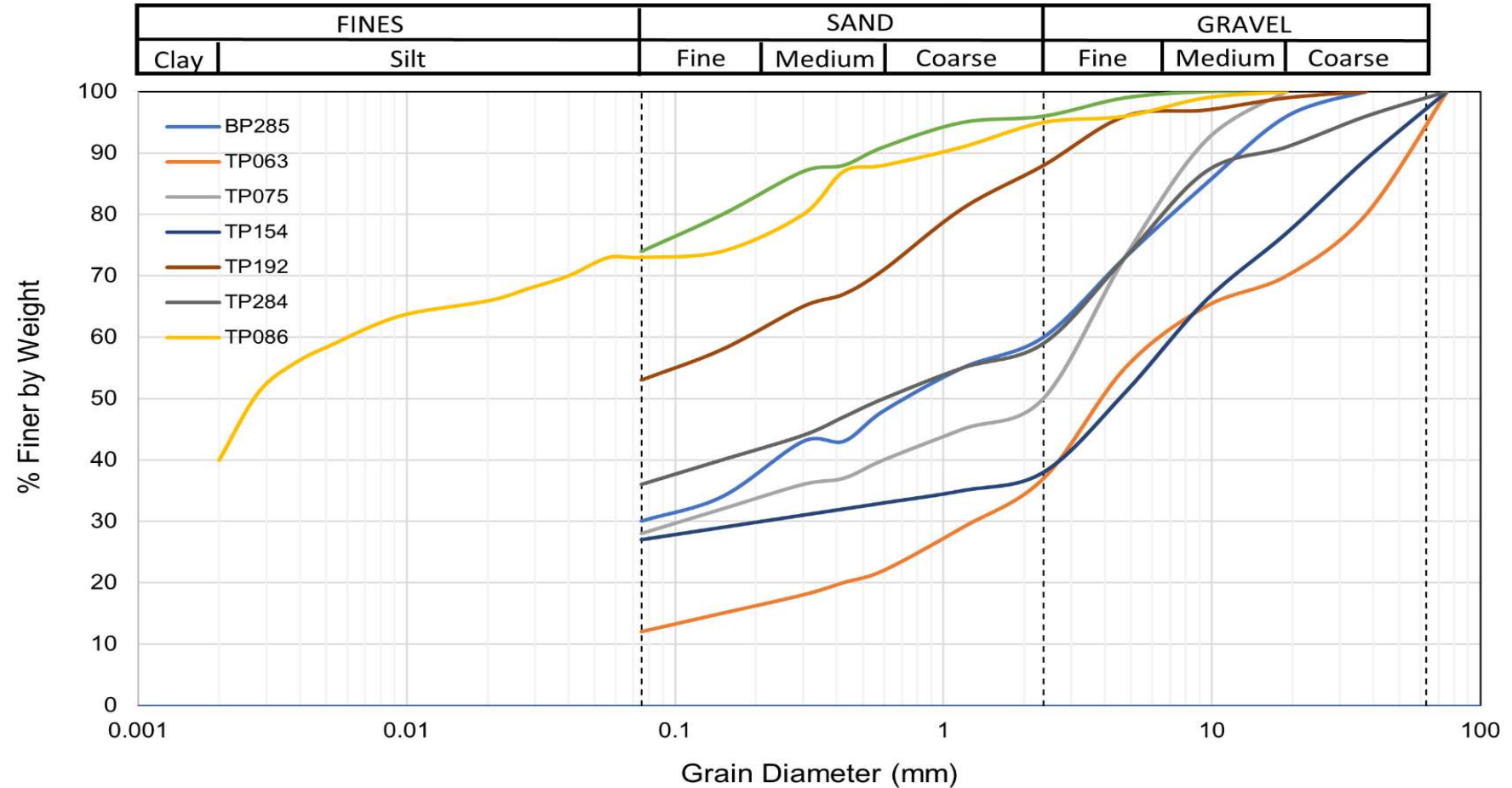
PARTICLE SIZE DISTRIBUTION CHART EOLIAN SAND



Client:	LEICHHARDT INDUSTRIALS PTY LTD
Project:	ERAMURRA SALT PROJECT
Title:	PSD CHART - EOLIAN SOIL

Project: PER2020-0143
Figure: 7
Date: 10/02/2022

PARTICLE SIZE DISTRIBUTION CHART EXTREMELY WEATHERED GRANITE



Client:

LEICHHARDT INDUSTRIALS PTY LTD

Project:

ERAMURRA SALT PROJECT

Title:

PSD CHART - EXTREMELY WEATHERED GRANITE

Project:

PER2020-0143

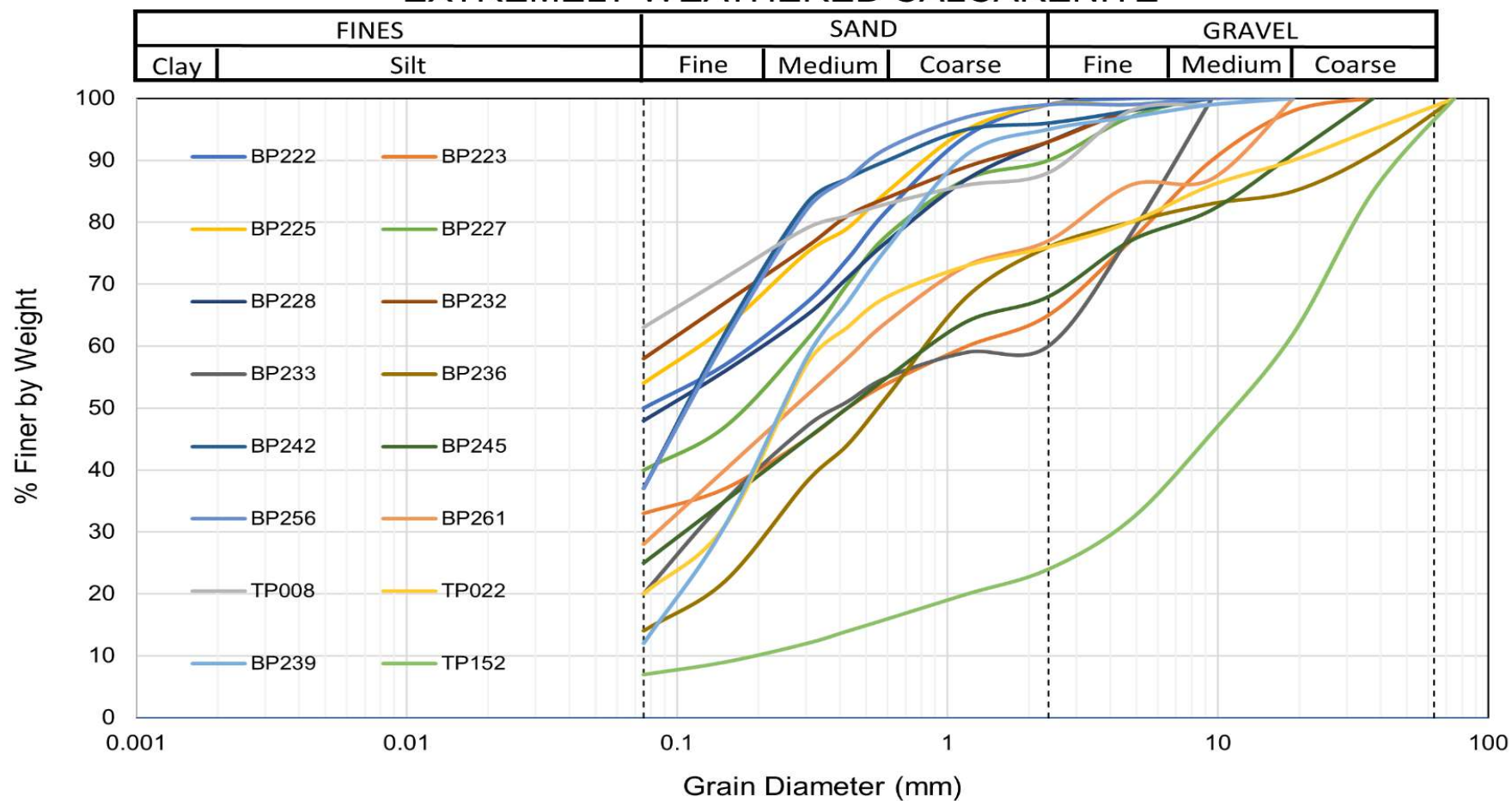
Figure:

8

Date:

10/02/2022

PARTICLE SIZE DISTRIBUTION CHART EXTREMELY WEATHERED CALCARENITE



Client:

LEICHHARDT INDUSTRIALS PTY LTD

Project:

ERAMURRA SALT PROJECT

Title:

PSD CHART - EXTREMELY WEATHERED CALCARENITE

Project:

PER2020-0143

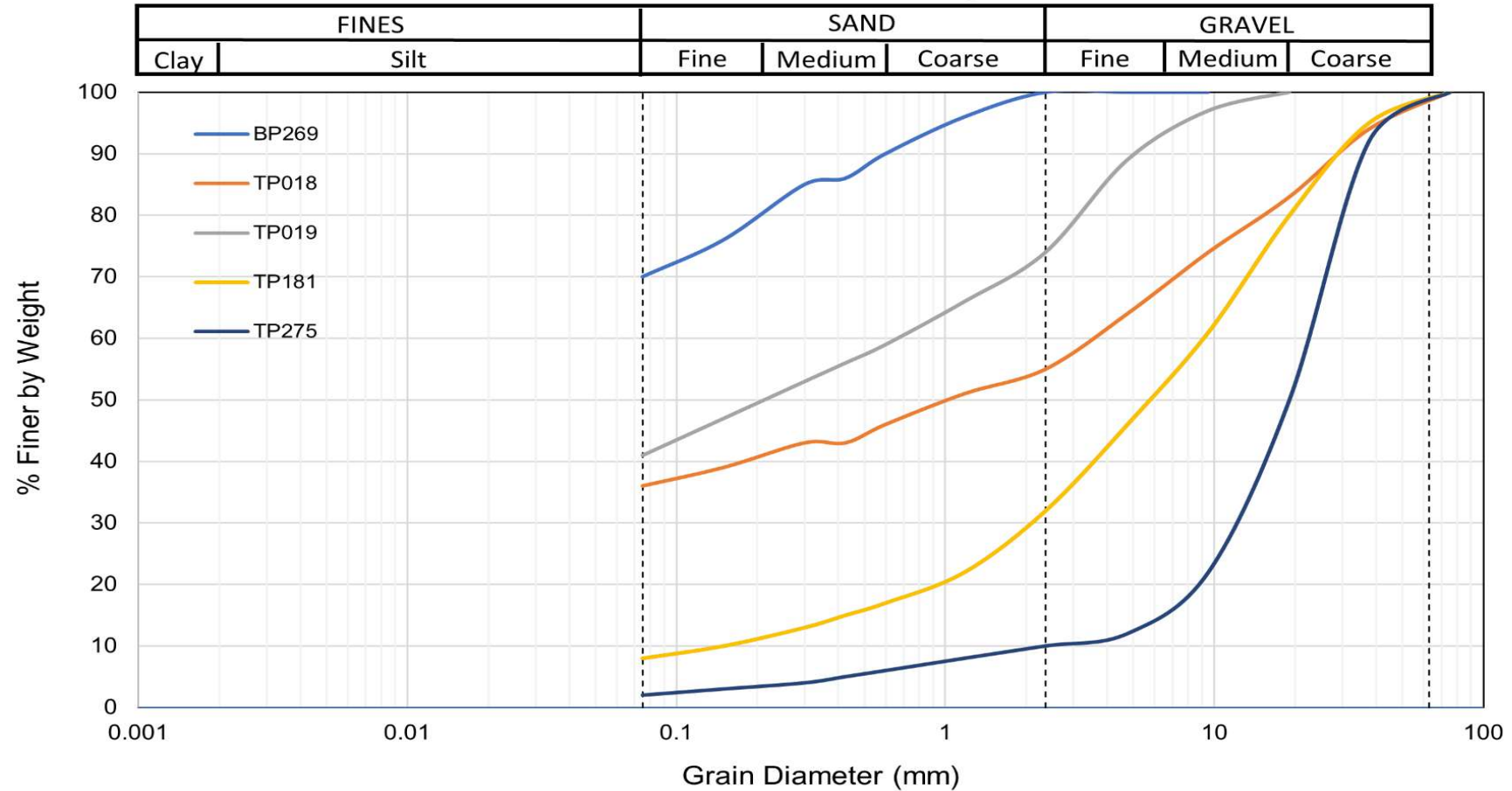
Figure:

9

Date:

10/02/2022

PARTICLE SIZE DISTRIBUTION CHART EXTREMELY WEATHERED DOLERITE



Client:

LEIGHARDT INDUSTRIALS PTY LTD

Project:

ERAMURRA SALT PROJECT

Title:

PSD CHART - EXTREMELY WEATHERED DOLERITE

Project:

PER2020-0143

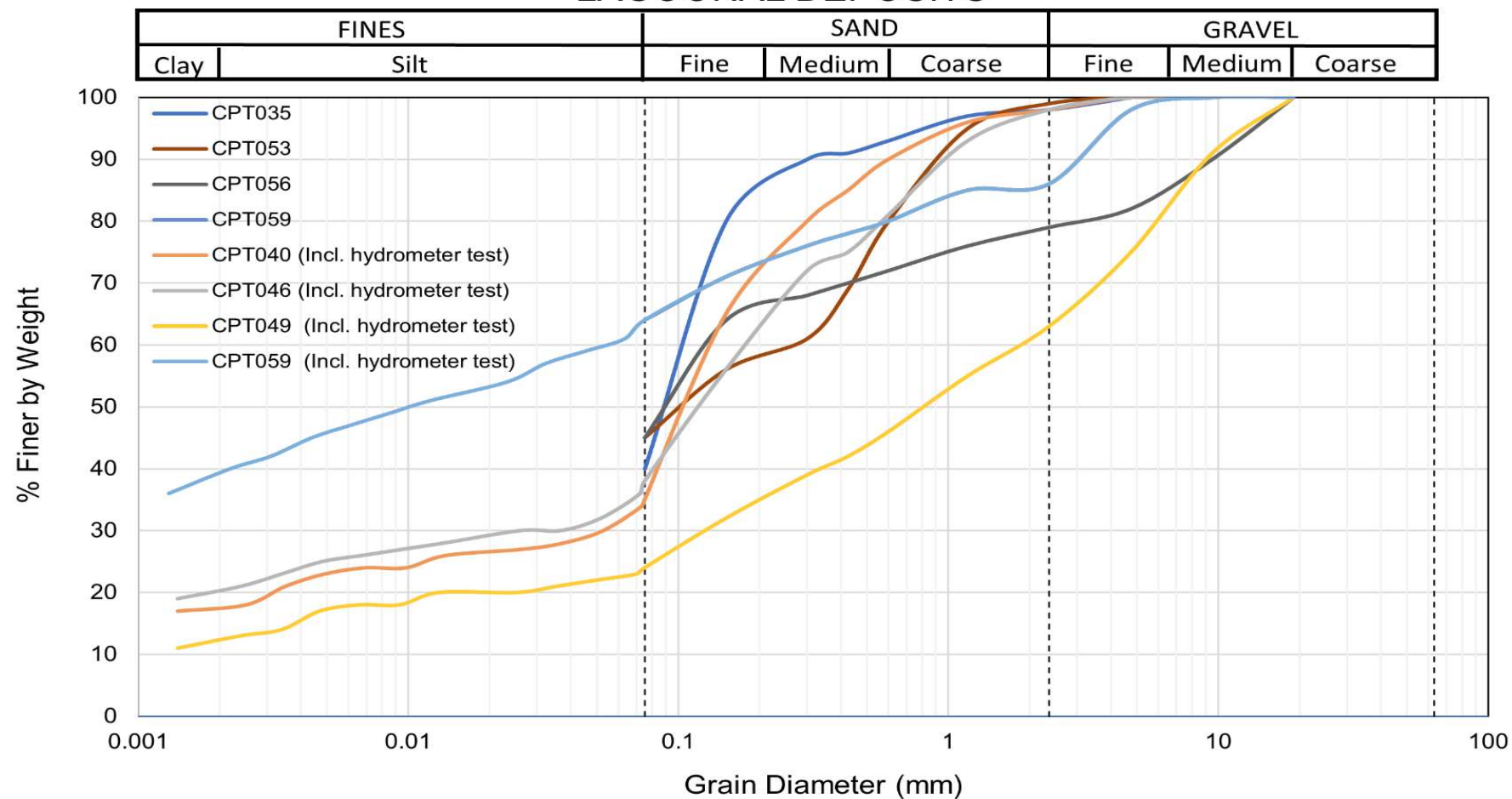
Figure:

10

Date:

10/02/2022

PARTICLE SIZE DISTRIBUTION CHART LAGOONAL DEPOSITS



Client:

LEICHHARDT INDUSTRIALS PTY LTD

Project:

ERAMURRA SALT PROJECT

Title:

PSD CHART - LAGOONAL DEPOSITS

Project:

PER2020-0143

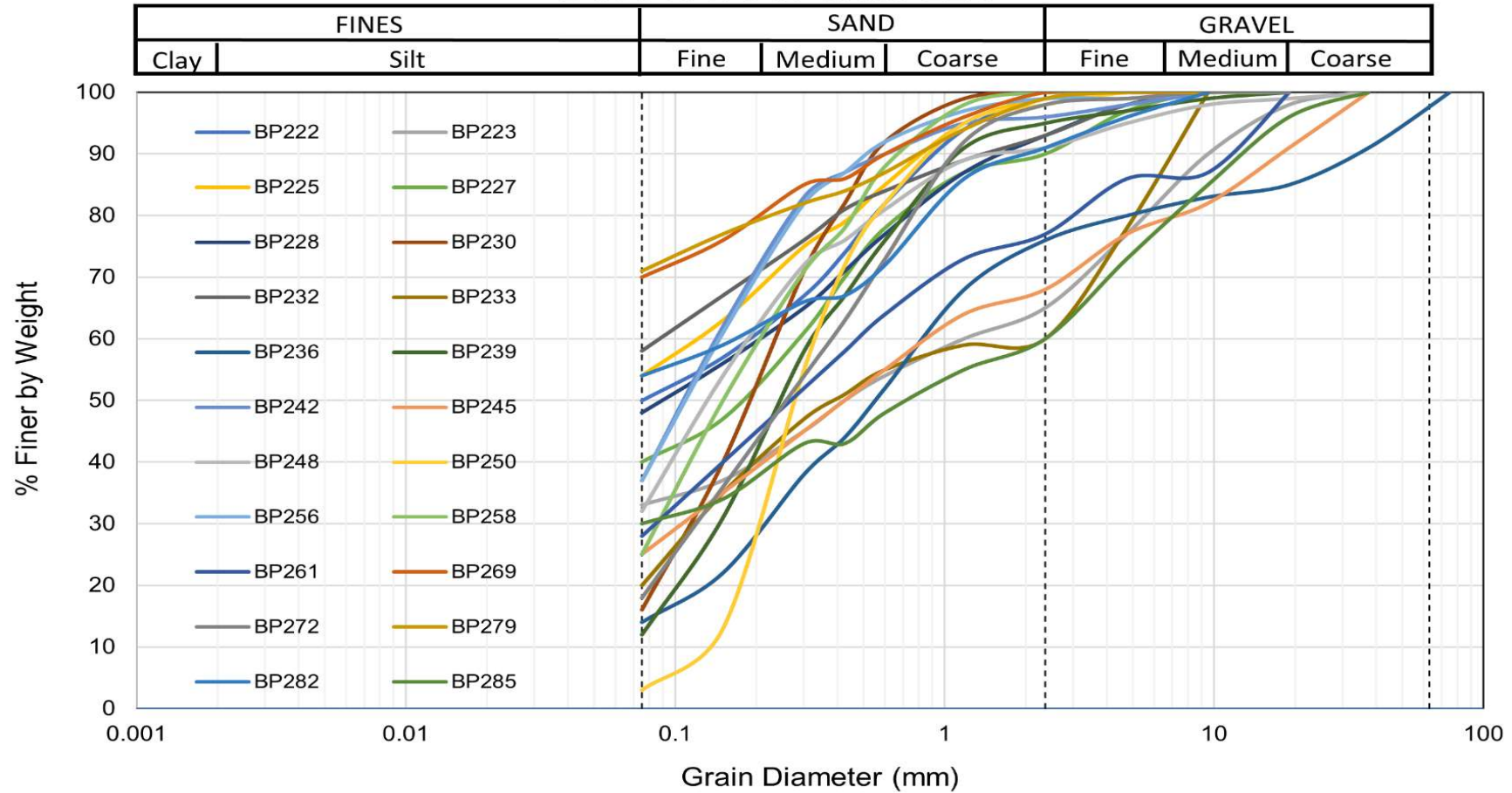
Figure:

11

Date:

10/02/2022

PARTICLE SIZE DISTRIBUTION CHART BORROW PIT SAMPLES



Client:

LEICHHARDT INDUSTRIALS PTY LTD

Project:

ERAMURRA SALT PROJECT

Title:

PSD CHART - INVESTIGATED BORROW PIT SAMPLES

Project:

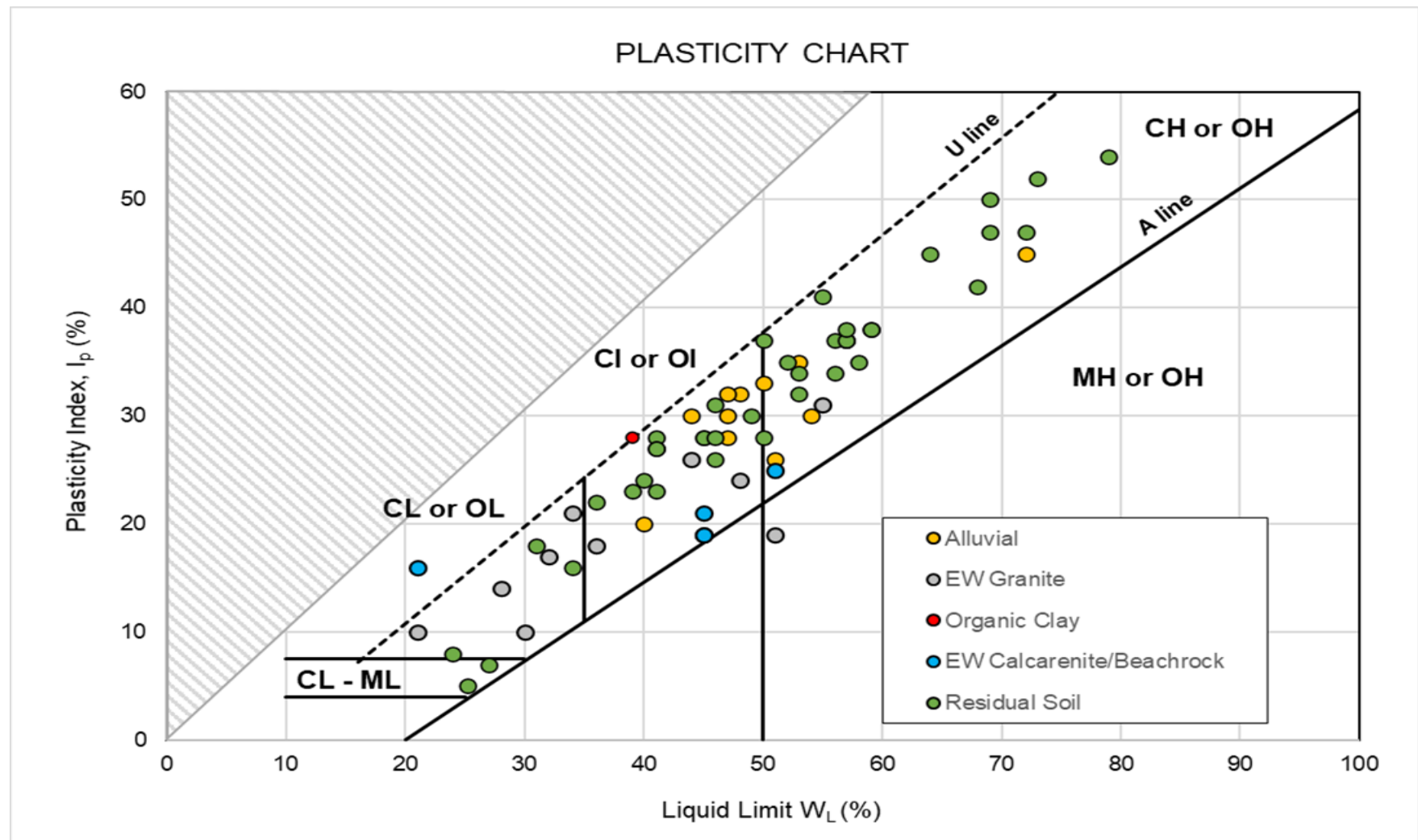
PER2020-0143

Figure:

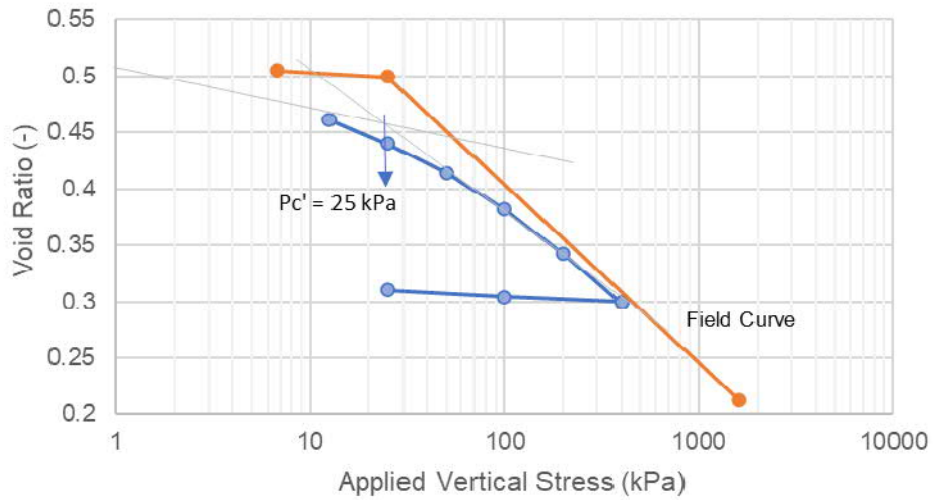
12

Date:

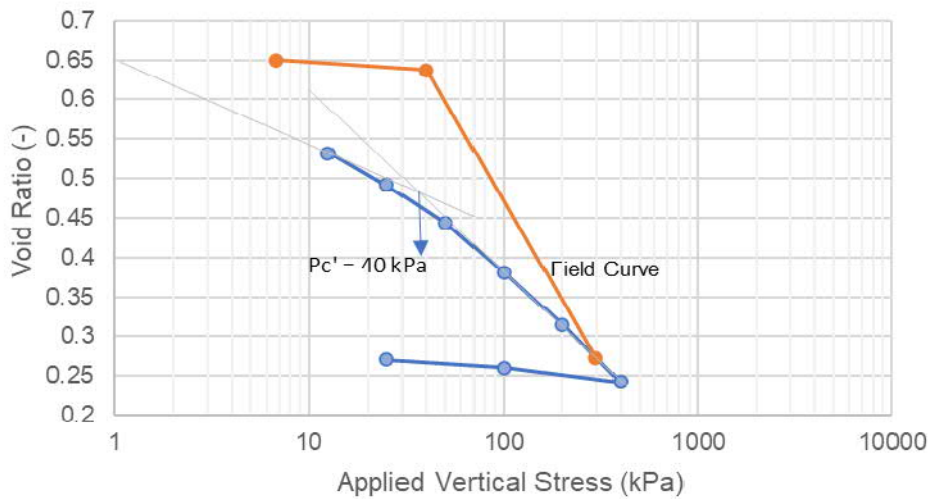
10/02/2022



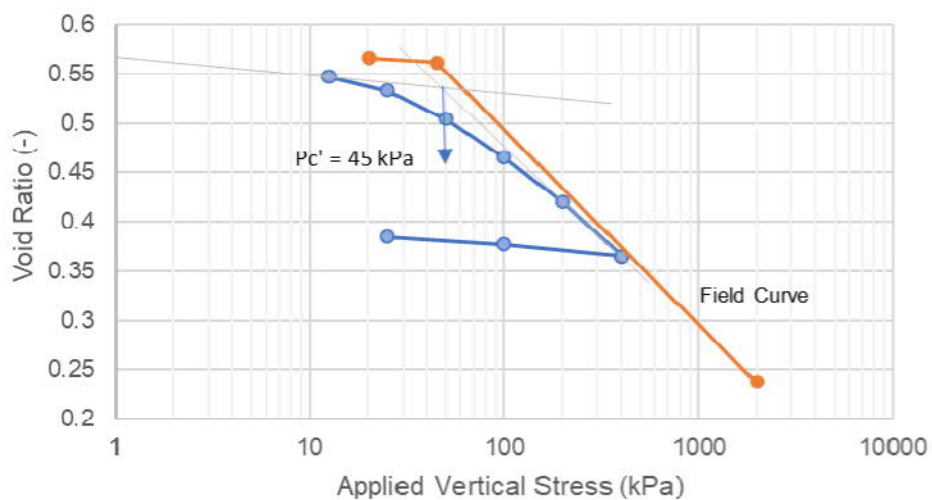
Sample Location: CPT40
Sample Depth: 0.5m to 1m



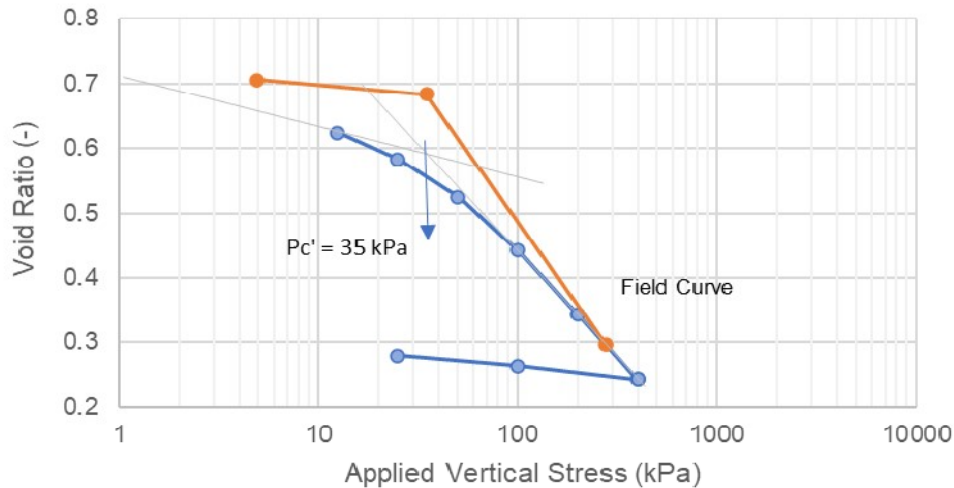
Sample Location: CPT46
Sample Depth: 0.5m to 1m



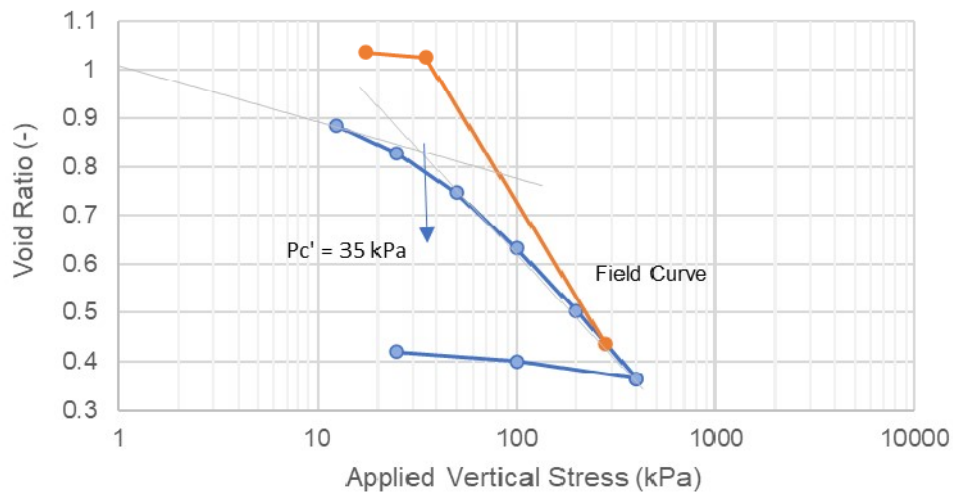
Sample Location: CPT49
Sample Depth: 2m to 2.5m



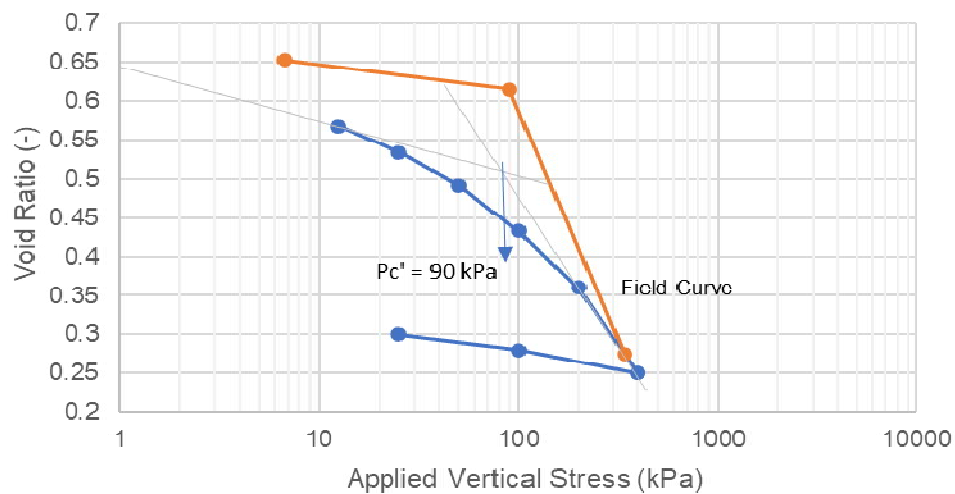
Sample Location: CPT52
Sample Depth: 0.3m to 0.8m



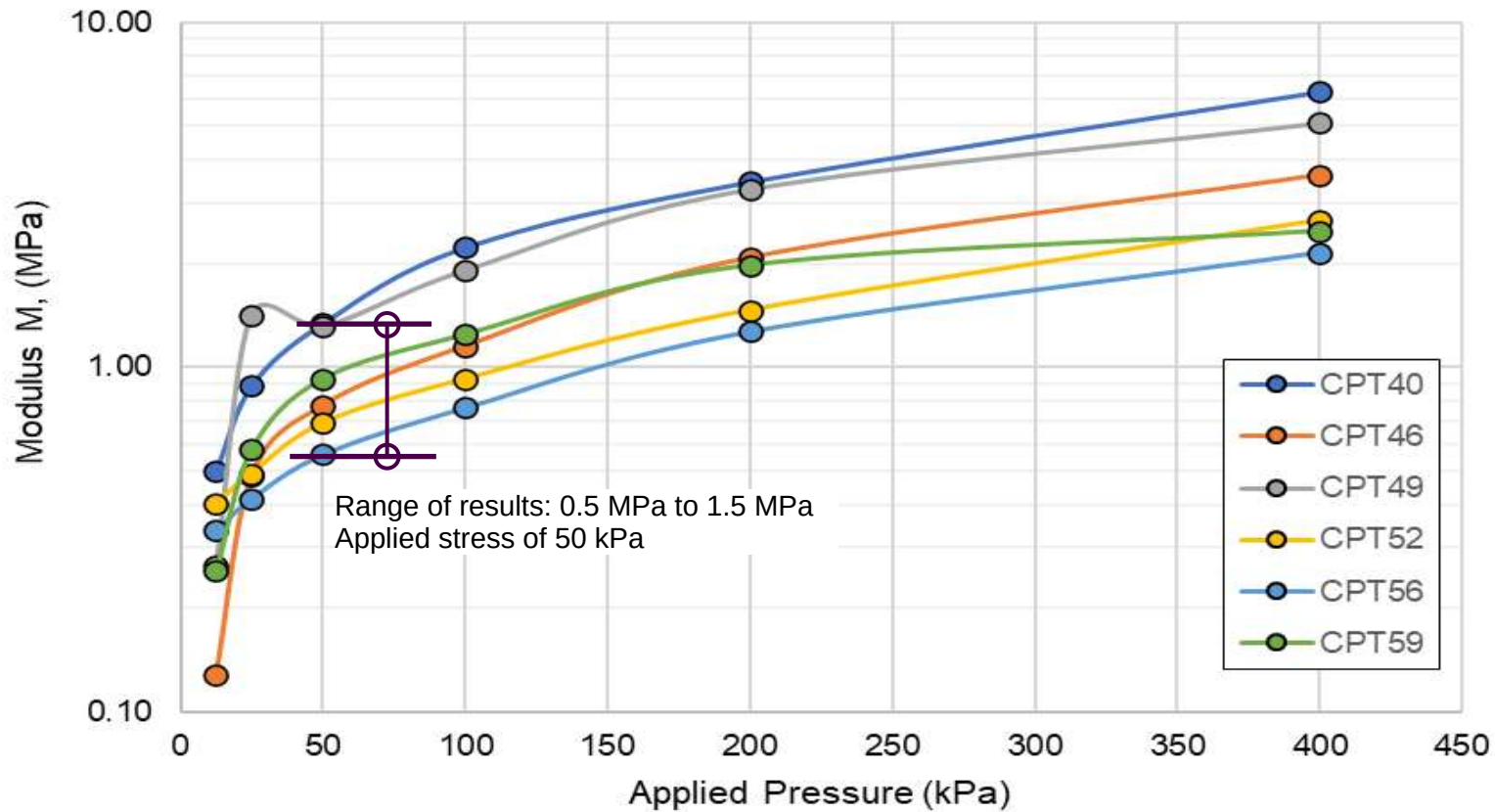
Sample Location: CPT56
Sample Depth: 1.7m to 2.2m



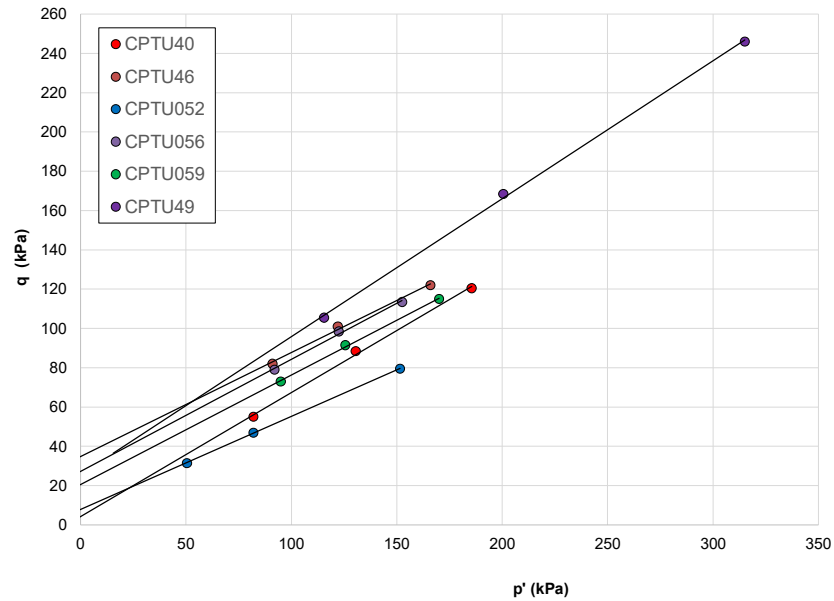
Sample Location: CPT59
Sample Depth: 0.5m to 1 m



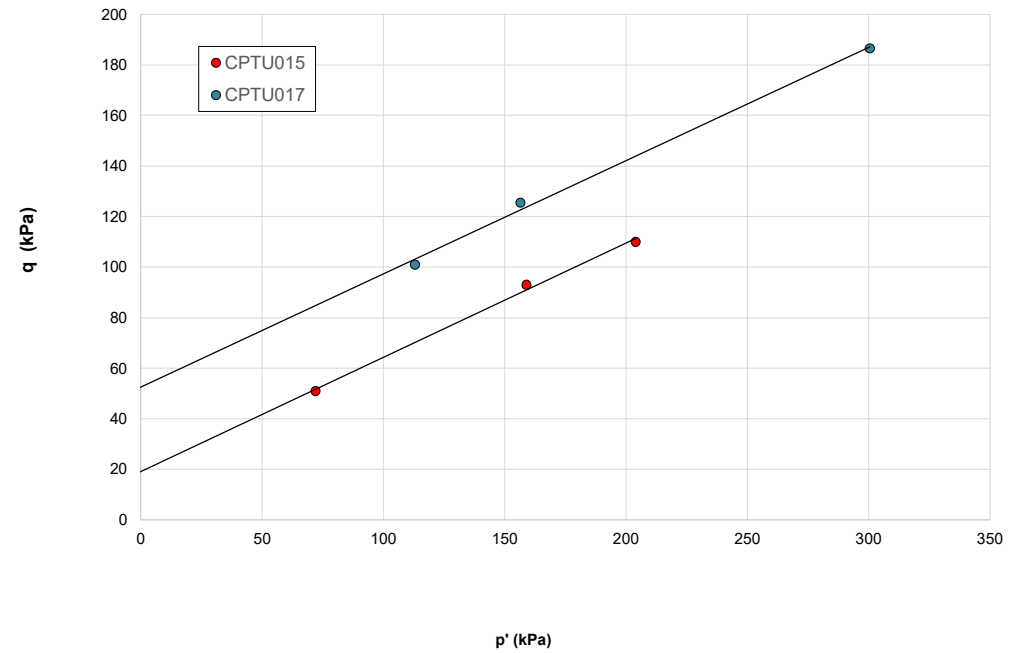
Constrained Modulus, M Oedometer Test Results



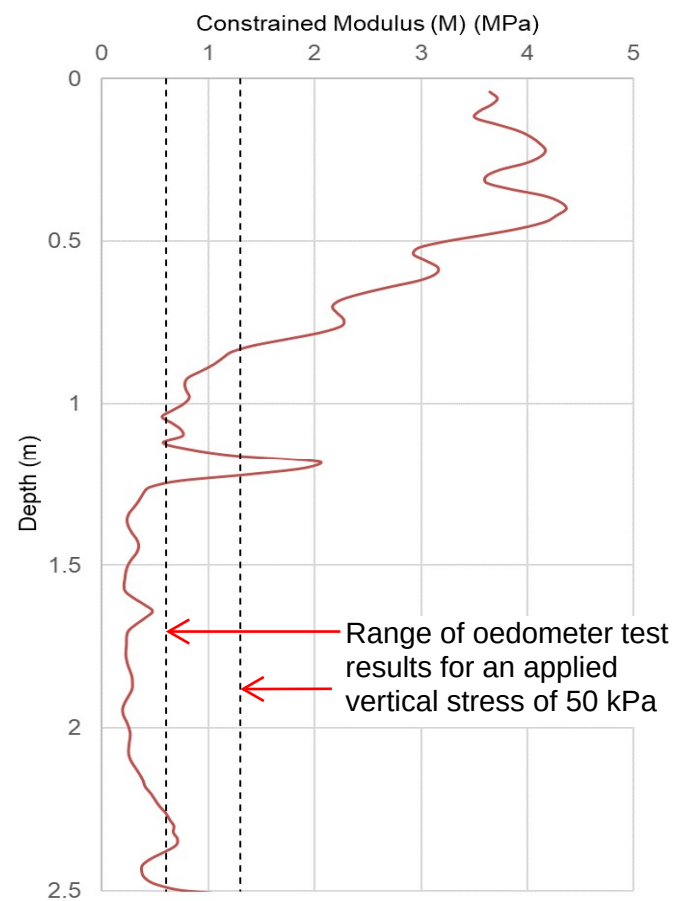
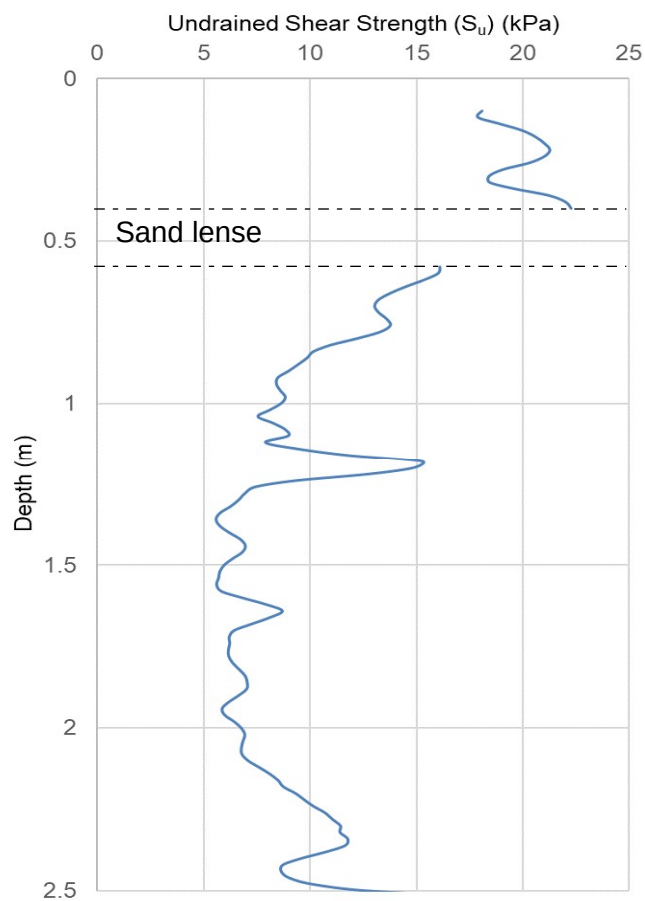
**p'-q Plot
Lagoonal Sediments**



**p'-q Plot
Paleochannel Deposits**



Client:	LIECHHART INDUSTRIALS PTY LTD	Project: PER2020-0143
Project:	ERAMURRA SALT PROJECT	Figure: 17
Title:	TRIAXIAL TEST - PEAK POINTS STRESS PATH PLOT	Date: FEBRUARY 2022



Client:

LEIGHARDT INDUSTRIALS PTY LTD

Project:

ERAMURRA SALT PROJECT

Title:

LAGOONAL SEDIMENT PROPERTIES - CPT047

Project:

PER2020-0143

Figure:

19

Date:

FEBRUARY 2022