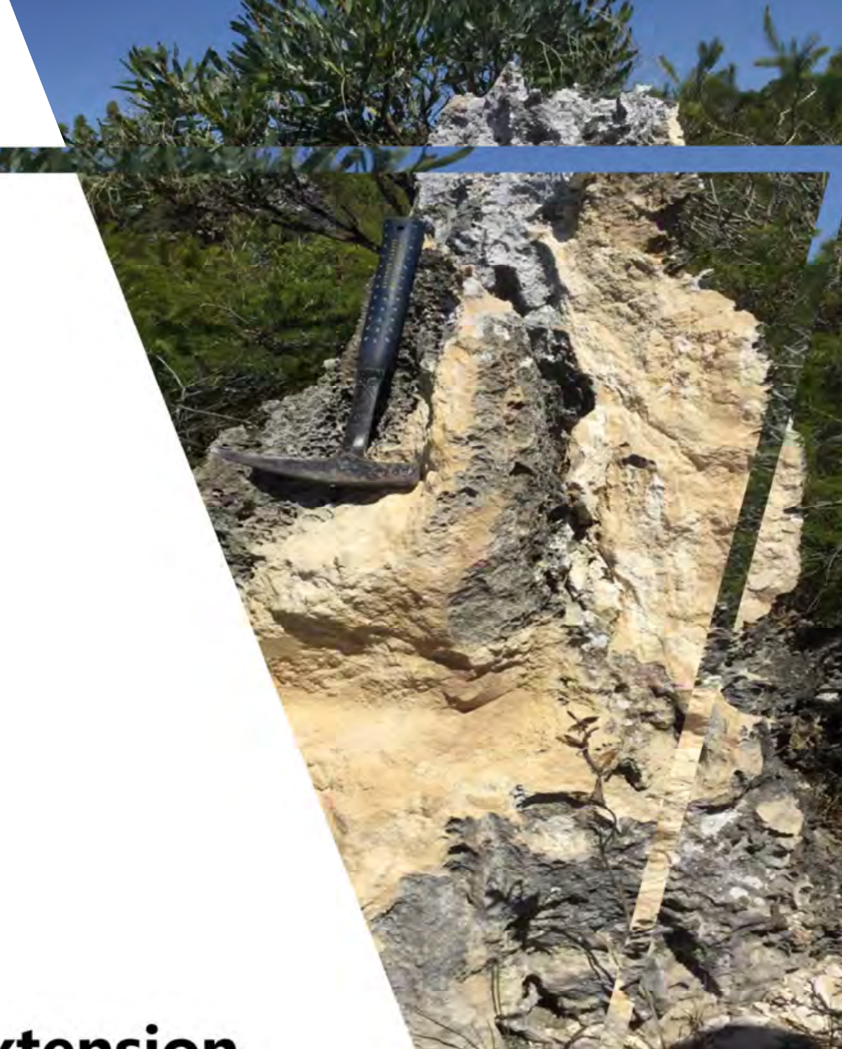

Yanchep Rail Extension

Geotechnical Investigation Report

26-July-2017

Level 4, 600 Murray St
West Perth WA 6005
Australia

301012-02366-SS-REP-0001

www.**advisian**.com

Advisian
WorleyParsons Group

Synopsis

This report presents the results of a geotechnical investigation undertaken for the Public Transport Authority (PTA) to provide a preliminary assessment of the proposed Yanchep Rail Extension (YRE).

The scope of work broadly comprised:

- Desktop study;
- Site investigation fieldwork, including (i) site inspection and mapping, (ii) Cone Penetration Testing, and (iii) borehole drilling;
- Laboratory testing; and
- Reporting, including interpretation of an engineering geological model / long-section parallel to the alignment centreline (CL).

Disclaimer

Project No: 301012-02366-SS-REP-0001 – Yanchep Rail Extension: Geotechnical Investigation Report

Rev	Description	Author	Review	Advisian Approval	Date
A	Internal Review	Michael Page Michael Page	Gavin Fisher Gavin Fisher	N/A N/A	
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Executive Summary

The principal objectives of the preliminary geotechnical investigation undertaken for the YRE project included:

- Preliminary assessment of the geological profile along the YRE alignment, principally focussing on:
  - Variability in rock-head profile / depth to rock;
  - *In situ* condition of surficial soils ('sands');
  - Identification of any unexpected, unusual or deleterious soil types; and
  - Identification of any potential for karst risk (subsurface cavities or caverns); and
- Preliminary interpretation of the geotechnical engineering implications for construction of the YRE project, principally focussing on:
  - Estimation of the approximate relative quantities of soil and rock to be excavated as part of bulk earthworks programs in areas of cut;
  - Inferred excavation conditions, including excavatability and excavation methods likely to be required in areas of cut;
  - Foundation and subgrade conditions in areas of both cut and fill; and
  - Foundation and subgrade variability at road crossing and station locations.

The following key conclusions can be interpreted from the results of the investigation:

- General geological conditions, including high levels of variability in engineering properties of rock (ranging from Very Low to Very High strength), appear to be fairly typical of what is expected in 'limestone' terrains common to the greater Perth coastal plain;
  - The interpreted engineering geology of the YRE project area has been developed into an engineering geological model, which is summarised in Table 5-1 and comprises four units;
    - Safety Bay Sand (S2);
    - Cemented Safety Bay Sand (LS4);
    - Tamala Sand (S7); and
    - Tamala Limestone (LS1);
- Rock-head profile / depth to rock is highly variable, but has been interpreted with varying levels of confidence along the majority of the YRE alignment;
  - Interpreted depth to rock is presented on the engineering geological long-section (Figures 1 to 15 in Appendix A), accompanied by a summary of the site investigation data presented in Table 7-1;
- Areas of particular risk due to karst or unexpected/deleterious soils were not explicitly identified during this investigation, although there remains potential for these geohazards to be present and continual assessment for the presence of geohazard risk should be undertaken during future investigations;

- The overall relative proportion of soil and rock in bulk earthwork excavations along the YRE alignment is estimated as 53% rock and 47% soil, noting that:
  - Relative proportions of soil and rock expected in excavations within discrete 'Engineering Divisions' along the YRE alignment are presented in Table 5-2;
  - The inferred reliability of the data associated with each 'Engineering Division' has been assessed qualitatively based on a number of factors, including the accessibility of the area for both inspection/mapping and penetrative testing, the degree to which rock levels could be inferred from outcrop or subcrop and the relative spacing of penetrative testing locations; and
  - The estimated relative proportions of soil and rock are preliminary and do not take into account variability perpendicular to the alignment, nor do they account for variations in rock strength and excavation requirements, including the presence of 'weak rock' (LS4) within areas of soil and for 'Tamala Sand' layers to be present within areas of rock; and
- The geological profile has been assessed at all station complexes and the majority of road crossing locations and is summarised in Table 5-3, along with a brief discussion of the implications for engineering with respect to bulk excavations and expected foundation and subgrade conditions. Engineering geological cross-sections at selected road crossings and station complexes, where data is available perpendicular to the YRE alignment, are presented as Figures 1 to 7 in Appendix B.

1 Introduction

This report presents the results of a geotechnical investigation undertaken for the Public Transport Authority (PTA) to provide a preliminary assessment of the proposed Yanchep Rail Extension (YRE), as outlined in PTA Consultancy Panel Quotation Request No. 160952.

The scope of work broadly comprised:

- Desktop study;
- Site investigation fieldwork, including:
  - Site inspection and mapping;
  - Cone Penetration Testing (CPT); and
  - Borehole drilling;
- Laboratory testing; and
- Reporting, including interpretation of an:
  - Engineering geological model / long-section parallel to the alignment centreline (CL).

Advisian was commissioned by the PTA to undertake the investigation on 19th January 2017 under contract number 160952.

1.1 Project Background

The YRE project comprises a proposed extension of the northern suburbs passenger railway ('Joondalup Line') from the existing Butler Station to Yanchep. The PTA requires geotechnical investigation services to assist in finalising the Stage 1A study included as part of the Project Definition Plan (PDP) for the proposed YRE project.

The proposed rail extension is approximately 15 km in length, starting at Chainage 40892 (CH40892), immediately north of the existing Butler Station, to the Buffer Stop at CH55300, immediately north of the proposed Yanchep Station. The current rail reserve corridor is nominally 40 m wide and construction will require cuts and fills up to about 15 m high and 10 m high, respectively.

The YRE project also includes proposed construction of three new stations; Alkimos, Eglinton and Yanchep Stations, and up to 19 grade-separated (rail under road) road crossings.

1.2 Purpose of This Report

The purpose of this report is to provide a preliminary assessment of the geotechnical conditions that can be expected to be encountered during construction of the proposed YRE. The information contained in this report is intended to enable the PTA to finalise the Stage 1A study of the PDP for the project, including refining the preliminary engineering designs and built-cost estimations for the project.

In consultation with the PTA, the principal objectives of this investigation were identified as:

- Preliminary assessment of the geological profile along the YRE alignment, principally focussing on:
  - Variability in rock-head profile / depth to rock;
  - *In situ* condition of surficial soils ('sands');
  - Identification of any unexpected, unusual or deleterious soil types; and
  - Identification of any potential for karst risk (subsurface cavities or caverns); and
- Preliminary interpretation of the geotechnical engineering implications for construction of the YRE project, principally focussing on:
  - Estimation of the approximate relative quantities of soil and rock to be excavated as part of bulk earthworks programs in areas of cut;
  - Inferred excavation conditions, including excavatability and excavation methods likely to be required in areas of cut;
  - Foundation and subgrade conditions in areas of both cut and fill; and
  - Foundation and subgrade variability at road crossing and station locations.

1.3 Limitations of This Investigation

The scope of this investigation is limited to a preliminary assessment of geotechnical conditions.

Fieldwork activities in particular were restricted to locations that could be readily accessed by foot, for the purpose of surface mapping, or via existing roads and non-gazetted ('off-road') tracks that did not require clearing of vegetation, for the purpose of penetrative testing by CPT or borehole drilling. As such, due to the density of vegetation and lack of tracks within some portions of the YRE alignment, access either by vehicles or on foot was not possible and assessments of these areas are therefore limited to desktop interpretations.

These limitations should be given due consideration when applying the results of this investigation to engineering design and cost estimation activities. Additional geotechnical investigations will be required for detailed design of the YRE project.

2 Desktop Study

2.1 Regional Physiography and Geology

The regional physiography and geology of the YRE project area is demonstrated on the Geological Survey of Western Australia (GSWA) 1:50,000 Environmental Geology Series map "Yanchep" (Gozzard, 1982).

The Yanchep map indicates that the natural geomorphology throughout the project area is associated with superimposed coastal dune (aeolian) systems of varying age. The relatively old and non-active Spearwood Dune system is present as a "Degraded surface of aeolian origin" and is interspersed with "Deflation plains and basins". These landforms typically have natural slopes varying between 0° and 10° throughout the project area with elevations mostly varying from around 20 m to 40 m above sea-level, reflecting a general reduction in slope and relief due to erosion and deflation ('natural settlement'). These landforms are partly overlain by a "Parabolic and nested parabolic dune complex" of the Quindalup Dunes. The younger and more recently-active Quindalup Dunes are expected to have steeper natural slopes, mostly between 10° and 20° throughout the project area, with elevations varying from around 20 m to 60 m above sea-level.

Consistent with the predominance of dune systems in shaping the landscape throughout the YRE project area, the surficial geology is expected to predominantly comprise 'sands', a significant proportion of which has been cemented to form 'limestone' rock. Conversely, some of the 'limestone' has subsequently been weathered and eroded back into 'sands'. There is also a close association between the surface distributions of the various geological units in the area with the aforementioned geomorphic divisions, such that Tamala Limestone and Tamala Sand are generally associated with the Spearwood Dune system and deflation plains, whilst the Safety Bay Sand is mostly associated with the Quindalup Dunes. Accordingly, the principal geological units expected to be encountered along the YRE alignment include:

- Limestone (LS1), light yellowish brown, fine- to coarse-grained, sub-angular to well-rounded, quartz, trace of feldspar, shell debris, variably lithified, surface kankar, of eolian origin (Tamala Limestone, Qtl); and
- Sand (S7), pale and olive yellow, medium to coarse-grained, sub-angular quartz with a trace of feldspar, of residual origin (Sand derived from weathering of Tamala Limestone, Qts), intermittently overlain by:
- Safety Bay Sand (Qhs), comprised of:
  - Calcareous Sand (S2), white, fine- to medium-grained, sub-rounded quartz and shell debris, of eolian origin; and
  - Limestone (LS4), pale yellowish brown weakly cemented, friable, medium-grained, sub-rounded, quartz and shell debris, of eolian origin.

2.1.1 Regional Geohazards

It is important to note that a subdivision of the Tamala Limestone mapped by Gozzard (1982) as LS2, which is characterised by "…abundant karstic phenomena including caves, dolines, swallows", is also present in the wider region surrounding the YRE project area. This unit poses a geohazard risk due to the potential for karstic collapse or sinkhole development, which could impact on the stability and integrity of engineered structures.

The closest mapped occurrence of LS2 to the project area is around CH49500, where the western boundary of the unit is approximately 500 m east of the alignment. Other mapped occurrences of LS2 occur approximately 1 km east of the alignment near CH45600 and approximately 1.5 km east of the alignment near CH55300.

There are no known occurrences of the LS2 unit specifically within the YRE project area, or to the west of the alignment, however, the potential for unknown occurrences of this unit in the project area should be carefully considered.

2.1.2 Local Conditions

Superimposed on the natural geology and geomorphology of the region, it should be noted that parts of the YRE project area are situated within or immediately adjacent to residential estates, as well as crossing several existing ‘gazetted’ roads. As such, it is evident that the natural ground surface in these areas has been partially modified by construction activities and that fill materials, including both controlled and uncontrolled fill, are also likely to be present.

2.2 Regional Hydrogeology

The YRE project area is located in the Perth Basin, which comprises a regional sedimentary basin up to 12 km thick with several significant aquifers. The key aquifer of interest at the site is the Superficial Aquifer, which is a shallow unconfined regional aquifer.

The Superficial Aquifer is made up of multiple geological formations, but in the vicinity of the site comprises the Safety Bay Sand and Tamala Limestone Formations. These formations are highly transmissive and have a saturated thickness of approximately 20-30m in this region (Davidson, 1995; DoW, 2016a). The groundwater flow is from the Gnangara Mound (North) towards the coast, where groundwater discharges over a saline wedge. Recharge is primarily from the infiltration of rainfall and some run-off from the Gingin Scarp (Davidson, 1995).

The water table is expected to be within a range of approximately >1 to <10 m AHD throughout the project area and groundwater quality is likely to be fresh to brackish (Davidson, 1995; DoW, 2016a).

3 Site Investigation

All site investigation activities were scoped, planned and undertaken by a Senior Engineering Geologist from Advisian. The fieldwork program was initially planned based on the results of the desktop study, followed by several different phases and activities, each of which was in turn scoped and planned based on the results of the preceding phases, so as to optimise data acquisition methods and approaches. The proposed scope and locations of testing for each phase were also discussed with PTA representatives prior to commencement, to enable client-specific requirements to be accounted for in the execution and planning of the work, as well as to assist with environmental and heritage requirements of the project.

The site investigation fieldwork components ultimately included:

- Site mapping;
- Services and utilities location;
- Cone Penetration Testing (CPT) at 111 locations; and
- Geotechnical borehole drilling at 8 locations.

A combined synopsis of all key findings resulting from the site investigation fieldwork is provided in the summary table (Table 7-1) provided in Appendix A, which is accompanied by an engineering geological long-section of the YRE alignment presented as Figures 1 to 15.

All site investigation fieldwork was undertaken in accordance with the Advisian Health, Safety and Environmental Management Plan (HSEMP) and with due care and respect for the environment and heritage values associated with the project.

3.1 Site Mapping

A thorough site inspection of the YRE project area was undertaken on 1st March 2017 and from the 7th to 9th March 2017. The inspection was undertaken by accessing the YRE alignment by vehicle where possible, utilising gazetted roads and 'off-road' tracks, followed by traversing the alignment and wider project area on foot to observe and record ('map') pertinent surficial geological features.

The YRE alignment was the primary focus of the activity, however the inspection and mapping encompassed the wider project area adjacent to the alignment, as well as nearby excavations in the form of road cuttings, drainage sumps, historical pits and various exposures related to natural or induced erosion (e.g. 'off-road' track cuttings). These observations of the wider project area and shallow subsurface features enhanced the inferences and interpolations that could be made with regard to the potential subsurface features within the YRE alignment.

The primary aims of the site inspection and mapping where to:

- Assess the potential distribution of shallow rock along the YRE alignment;
- Assess the accessibility of the site for geotechnical testing vehicles and plant; and

- Identify locations and priority areas for proposed penetrative geotechnical investigation by CPT or drilling.

The key observations and findings resulting from the site inspection and mapping, including descriptions of rock outcrop (OC) and subcrop (SC), are provided in the site investigation summary table (Table 7-1) in Appendix A and shown on Figures 1 to 15.

3.2 Service Location

A multi-layered approach was adopted for identification and avoidance of above and below ground services and utilities for the YRE geotechnical investigation.

Initially, during the site inspection the locations identified as potential targets for penetrative investigation (i.e. either CPT or borehole drilling) were visual assessed for the presence of services in the immediate vicinity. If necessary, proposed investigation locations were relocated where it was considered practical and technically feasible to do so, in order to provide adequate separation distances from identified services.

Dial-Before-You-Dig (DBYD) service plans were then acquired for all proposed investigation locations. Where it was apparent from the DBYD plans that services were present in the vicinity of the proposed locations, the locations were either (i) relocated a safe distance away from services where it was practical and technically feasible to do so, or (ii) placed on to a list of locations that required further assessment by an accredited service location contractor.

For the proposed investigation locations where working in close proximity to services was unavoidable, on-site location of buried services was subsequently undertaken by Abaxa; an accredited service location contractor. The on-site service location activities were undertaken by Abaxa on the 2nd May 2017, in the presence of the Advisian engineering geologist responsible for scoping and managing the fieldwork activities.

The on-site services location comprised an initial reconnaissance of the wider investigation areas to positively identify all known services recorded on DBYD service plans and any other services identified on site. These known services were marked on the ground surface with spray paint for temporary future reference. The proposed investigation locations were subsequently checked for buried services using both electronic and ground-penetrating-radar (GPR) equipment.

Some proposed investigation locations were modified slightly based on the location of services identified on site, or due to the presence of subsurface anomalies discovered during the service location activities. Once the investigation locations were assessed by Abaxa as being clear of buried services, the locations were marked on the ground surface with spray-paint for future reference during penetrative testing.

3.3 Cone Penetration Testing

The objectives of the CPT investigations were primarily to provide information on the depth to rock along the YRE alignment, with the additional benefit of providing information on the *in situ* geotechnical properties of the overlying soils ('sands').

Proposed locations for CPT investigations were thus determined based on the results of the site inspection and mapping, with the rationale and approach for the distribution of proposed CPTs based on:

- Providing regular and reasonably closely-spaced testing coverage of the YRE alignment, as far as was practical within the limitations of existing access roads and 'off-road' tracks (i.e. clearing was not possible);
- Focussing the majority of testing on areas of proposed cut so as to enable assessment of excavations conditions, whilst:
  - Limiting the number of tests in areas where shallow rock was evident (and thus shallow CPT refusal was expected) as rock levels could be inferred with reasonable confidence; and
  - Providing increased coverage where rock levels could not be inferred with confidence from site observations;
- Undertaking tests at the specific locations of proposed road crossings and station complexes to enable assessment of both excavation and foundation conditions; and
- Undertaking a smaller number of tests in areas of proposed fill so as to enable assessment of foundation conditions for embankments.

Cone Penetration Testing was subsequently undertaken in two phases utilising a 22 tonne Mercedes Benz 6 wheel-drive truck-mounted rig operated by CPTWest. Testing was undertaken in accordance with AS1289.6.5.1-1999 using a 10 cm^2 cone.

The first phase of CPT operations was conducted between the 3rd and 5th May 2017 and on the 9th May 2017 and comprised 90 individual CPTs. Tests undertaken during this phase were pushed to depths of at least 2 m below the proposed cut level, or until prior refusal was encountered. In areas of proposed fill, tests were pushed to depths of between 4 and 8 m below the existing ground level, depending on the expected embankment height and whether or not refusal was encountered.

The second phase of CPT operations was conducted on the 13th June 2017 and comprised 21 individual CPTs. Planning and positioning of these CPTs was undertaken after completion of the borehole drilling operations and following initial assessment of the entire site investigation dataset. The approach for positioning of CPTs undertaken during this phase was targeted to provide additional coverage at road crossing locations and at station complexes, particularly where based on the previous data the depths to rock were either (i) unknown due to 'non-refusal' of previous CPTs, or (ii) demonstrated potential for significant variability and to range both above and below the proposed cut/foundation level. All CPTs completed during this phase were pushed until refusal was encountered.

The details of the 'as-probed' CPTs undertaken for this project, including horizontal and vertical positions and completion depths, are provided in Table 3-1.

Graphical records (plots) of the CPT data as processed by CPTWest are provided in Appendix B.

The key findings resulting from the CPT investigation, including comments on the relationship with proposed engineering works for the YRE and comparison with other site investigation data are provided in the site investigation summary table (Table 7-1) in Appendix A. Summary plots of cone resistance are also shown on the engineering geological long-section of the YRE alignment presented in Appendix A as Figures 1 to 15.

Table 3-1: CPT locations, elevations and depths

CPT ID	Chainage	Coordinates (MGA94)		Test Depth (m)	Elevation (mAHD)	Base RL (mAHD)
		Easting	Northing			
CPT 01	42660	376097.85	6501002.94	6.40	39.94	33.54
CPT 02	42780	376090.17	6501121.21	2.93	39.84	36.91
CPT 03	42780	376069.89	6501117.01	1.52	39.26	37.74
CPT 04	42780	376047.02	6501112.14	1.09	38.04	36.95
CPT 05	42980	376020.65	6501312.03	6.99	40.28	33.29
CPT 06	43070	376004.54	6501399.4	4.60	38.31	33.71
CPT 06-2	43070	375975.94	6501390.74	7.06	38.85	31.79
CPT 06-3	43070	376023.99	6501400.62	7.19	38.21	31.02
CPT 07	43150	375992.68	6501480.26	7.42	36.69	29.27
CPT 08	43220	375972.92	6501546.42	7.26	37.11	29.85
CPT 08A	43280	375912.8	6501594.38	2.95	42.12	39.17
CPT 08-2	43300	375953.47	6501621.86	3.19	38.35	35.16
CPT 08-3	43190	375933.95	6501505.76	8.87	38.52	29.65
CPT 08-4	43190	376059.13	6501519.66	16.17	34.43	18.26
CPT 08-5	43290	376032.11	6501627.25	11.09	36.30	25.21
CPT 09	43360	375944.16	6501685.19	6.30	41.56	35.26

CPT ID	Chainage	Coordinates (MGA94)		Test Depth (m)	Elevation (mAHD)	Base RL (mAHD)
		Easting	Northing			
CPT 09A	43420	375950.37	6501743.47	2.62	39.12	36.50
CPT 09A(2)	43420	375950.9	6501747.22	2.63	38.98	36.35
CPT 09-2	43360	375921.81	6501680.80	3.55	41.14	37.59
CPT 09-2A	43360	375915.92	6501675.84	3.26	41.83	38.57
CPT 09-3	43360	375965.52	6501693.97	5.81	40.23	34.42
CPT 10	43500	375916.17	6501825.01	3.12	33.25	30.13
CPT 10 (2)	43500	375911.46	6501824.86	1.74	33.19	31.45
CPT 11	43580	375873.8	6501895.21	10.91	34.16	23.25
CPT 11A	43690	375877.34	6501999.89	7.48	21.48	14.0
CPT 13	44480	375698.11	6502779.63	9.16	32.86	23.70
CPT 14	44480	375714.96	6502779.89	5.86	33.53	27.67
CPT 15	44480	375734.89	6502780.8	4.28	34.68	30.40
CPT 16	44585	375696.43	6502880.64	1.85	35.44	33.59
CPT 16A	44800	375651.4	6503086.66	4.44	28.00	23.56
CPT 16B	44650	375674.8	6502946.19	2.52	32.20	29.68
CPT 17	44920	375621.25	6503211.18	0.08	31.70	31.62
CPT 17A	44870	375624.78	6503154.48	4.15	29.93	25.78
CPT 18	45140	375540.02	6503414.72	4.94	35.28	30.34
CPT 18 (2)	45140	375535.62	6503413.39	3.70	35.14	31.44
CPT 19	45330	375437.48	6503567.45	4.15	32.39	28.24
CPT 19A	45470	375349.88	6503680.11	7.51	28.21	20.70
CPT 20	45680	375174.82	6503809.46	2.18	39.80	37.62
CPT 20A	45630	375231.62	6503786.33	8.03	31.97	23.94

CPT ID	Chainage	Coordinates (MGA94)		Test Depth (m)	Elevation (mAHD)	Base RL (mAHD)
		Easting	Northing			
CPT 21	45820	375063.38	6503872.4	1.84	46.19	44.35
CPT 21 (2)	45820	375063.14	6503878.62	2.01	46.04	44.03
CPT 22	46210	374735.29	6504105.43	0.76	39.16	38.40
CPT 22A	46650	374381.44	6504355.09	4.46	25.87	21.41
CPT 24	47070	374129.64	6504695.68	2.71	41.02	38.31
CPT 25	47190	374090.02	6504803.41	1.11	46.58	45.47
CPT 25B	47360	374107.63	6504983.91	1.47	47.33	45.86
CPT 26	47520	374004.95	6505120.2	0.74	45.08	44.34
CPT 27	47770	373941.97	6505358.57	2.07	40.44	38.37
CPT 28	47870	373891.87	6505458.69	3.83	43.93	40.10
CPT 29	47980	373877.42	6505559.43	2.94	38.80	35.86
CPT 30	48120	373857.12	6505702.6	3.76	45.66	41.90
CPT 31	48230	373848.81	6505807.04	1.0	38.97	37.97
CPT 32	48370	373842.42	6505951.14	6.16	41.08	34.92
CPT 33	48480	373852.9	6506058.56	4.36	28.15	23.79
CPT 33A	48630	373893.78	6506209.81	4.22	24.59	20.37
CPT 34	48780	373893.37	6506358.82	2.16	22.52	20.36
CPT 36	48980	373892.41	6506551.01	1.63	23.52	21.89
CPT 42	51920	371814.51	6508335.21	0.57	32.85	32.28
CPT 43	52100	371711.56	6508489.83	8.25	35.49	27.24
CPT 44	52230	371649.42	6508599.18	1.74	36.23	34.49
CPT 45	52340	371584.29	6508688.02	4.32	33.30	28.98
CPT 47	52600	371452.88	6508917.03	4.30	38.08	33.78

CPT ID	Chainage	Coordinates (MGA94)		Test Depth (m)	Elevation (mAHD)	Base RL (mAHD)
		Easting	Northing			
CPT 47A	52550	371476.74	6508871.38	0.70	34.39	33.69
CPT 47A(2)	52550	371478.49	6508874.52	0.35	34.22	33.87
CPT 48	52650	371431.25	6508958.41	1.15	33.98	32.83
CPT 49	52800	371358.28	6509093.99	0.48	29.78	29.30
CPT 49 (2)	52800	371355.48	6509093.87	5.57	29.67	24.10
CPT 50	52900	371317.85	6509186.6	5.38	30.77	25.39
CPT 51	53030	371301.52	6509307.8	3.88	38.76	34.88
CPT 52	53130	371284.66	6509412.23	2.93	38.56	35.63
CPT 53	53230	371285.61	6509510.72	3.89	35.10	31.21
CPT 54	53370	371275.48	6509652.47	2.10	38.65	36.55
CPT 55	53420	371278.52	6509698.15	1.49	38.19	36.7
CPT 56	53500	371273.42	6509775.14	5.73	37.53	31.8
CPT 57	53600	371276.86	6509883.08	1.54	38.53	36.99
CPT 57A	53650	371272.18	6509927.13	0.87	39.69	38.82
CPT 58	53700	371275.22	6509981.58	1.79	36.16	34.37
CPT 59	53775	371244.14	6510053.81	7.49	44.89	37.40
CPT 59-2	53800	371288.70	6510078.05	8.98	42.34	33.36
CPT 60	53890	371267.24	6510167.66	3.41	32.86	29.45
CPT 61	54070	371237.8	6510347.33	6.24	29.75	23.51
CPT 61-2	54040	371235.77	6510315.85	9.01	29.00	19.99
CPT 62	54160	371243.66	6510443.51	4.40	30.92	26.52
CPT 63	54260	371249.64	6510537.39	12.53	38.27	25.74
CPT 63-2	54275	371250.61	6510554.76	9.67	36.34	26.67

CPT ID	Chainage	Coordinates (MGA94)		Test Depth (m)	Elevation (mAHD)	Base RL (mAHD)
		Easting	Northing			
CPT 64	54350	371259.88	6510633.62	2.08	32.41	30.33
CPT 64-2	54290	371250.12	6510568.25	5.56	34.59	29.03
CPT 64-3	54310	371251.52	6510584.38	2.92	33.09	30.17
CPT 64-3A	54310	371252.11	6510586.72	2.20	33.02	30.82
CPT 66	54500	371260.81	6510779.17	3.62	35.59	31.97
CPT 67	54610	371267.91	6510887.86	6.47	30.44	23.97
CPT 67-2	54650	371269.88	6510929.21	6.28	29.14	22.86
CPT 68	54700	371274.23	6510981.44	5.42	27.95	22.53
CPT 69	54860	371236.51	6511135.59	6.52	30.86	24.34
CPT 69A	54790	371238.82	6511066.07	5.90	31.50	25.60
CPT 69-2	54860	371251.23	6511137.75	5.17	30.46	25.29
CPT 69-3	54860	371219.16	6511134.65	4.59	31.17	26.58
CPT 70	54970	371234.52	6511251.35	6.47	28.59	22.12
CPT 70A	55180	371295.76	6511463.67	4.38	22.99	18.61
CPT 71	55300	371225.58	6511581.22	5.04	28.20	23.16
CPT 72	42490	376131.21	6500830.63	8.66	45.81	37.15
CPT 72-2	42500	376145.56	6500846.70	7.26	46.16	38.9
CPT 72-3	42480	376123.61	6500812.57	7.85	46.04	38.19
CPT 73	42350	376180.98	6500701.03	0.84	48.50	47.66
CPT 73 (2)	42350	376182.79	6500696.46	2.82	48.43	45.61
CPT 74	42240	376224.8	6500601.72	5.75	49.83	44.08
CPT 75	41840	376386.63	6500232.17	4.90	50.78	45.88
CPT 76	41560	376484.47	6499971.24	7.89	50.82	42.93

CPT ID	Chainage	Coordinates (MGA94)		Test Depth (m)	Elevation (mAHD)	Base RL (mAHD)
		Easting	Northing			
CPT 76-2	41620	376464.74	6500034.14	4.85	50.88	46.03
CPT 77	41450	376519.24	6499866.78	4.32	41.92	37.60
CPT 78	41300	376555.55	6499722.42	3.26	44.75	41.49

3.4 Geotechnical Drilling

The objectives of the geotechnical drilling investigation were primarily to provide information on the depth to rock and the engineering properties of rock at ley locations along the YRE alignment.

Proposed locations for drilling investigations were thus determined based on the results of the site inspection and mapping, supplemented by the first phase of CPT results, with the rationale and approach for prioritising the distribution of proposed boreholes based on:

- Investigating the specific locations of proposed road crossings and station complexes, where available data indicated a high potential for rock to be present above the cut/foundation level; and
- Investigating at proposed high cuttings, where available data indicated a high potential for large volumes of rock to be present within excavations.

Boreholes were thus proposed for eight key locations along the YRE alignment, including:

- Romeo Road crossing;
- Alkimos Station / Landcorp 2 road crossing;
- Landcorp 3 road crossing;
- Pipidinny Road crossing / Eglinton Station;
- Yanchep Beach Road crossing;
- Tokyu 1 road crossing;
- Yanchep Station / Tokyu 4 road crossing; and
- Proposed cutting up to 10m high near CH45820.

Geotechnical boreholes were subsequently drilled at the eight proposed locations between 11th and 12th May 2017 and from 15th to 17th May 2017 by National Geotech Pty Ltd (National Geotech) using a Geoprobe 7822DT tracked drill rig.

The details of the 'as-drilled' boreholes completed for this project, including horizontal and vertical positions and completion depths, are provided in Table 3-2.

The drilling method utilised for the investigation was predominantly HQ-3 diamond coring, with the exception of the upper few metres in two boreholes (BH-12 and BH-59), which were advanced by HQ washboring in soils before reverting to HQ-3 coring in rock. Washboring was utilised for these two boreholes in order to complete the boreholes more quickly in response to time constraints.

Standard Penetration Tests (SPTs) were undertaken in all boreholes, including at the ground surface, at 2 m below ground level (mbgl) and then at consecutive 1.5 m intervals downhole, including at the bottom of each borehole if soils were present. Where rock was encountered in boreholes, SPTs ceased to be undertaken, however, if a significant quantity of interbedded 'sands' were encountered within the rock-mass then SPTs were resumed within these intervals. The SPTs were performed by National Geotech in general accordance with AS1289.6.3.1-2004.

Geotechnical field logs of the boreholes, inclusive of SPT results, were prepared by Advisian personnel, either directly by, or under the direct guidance of the Advisian senior engineering geologist supervising the investigation. Boreholes were logged in general accordance with AS1726-2017 and with reference to Advisian logging guidelines. Geotechnical borehole logs, core photographs and Advisian logging guidelines are provided in Appendix C.

The key findings resulting from the drilling investigation, including comments on the relationship with proposed engineering works for the YRE and comparison with other site investigation data, are provided in the site investigation summary table (Table 7-1) in Appendix A. Visual representations of the boreholes are also shown on the engineering geological long-section of the YRE alignment presented in Appendix A as Figures 1 to 15.

Table 3-2: Borehole locations, elevations and depths

Borehole ID	Chainage	Coordinates (MGA94)		Drilled Depth (m)	Elevation (mAHD)	Base RL (mAHD)
		Easting	Northing			
BH-03	42780	376067	6501118	9.50	39.10	29.60
BH-09	43360	375945	6501686	14.45	41.50	27.05
BH-12	44140	375788	6502441	8.0	31.70	23.70
BH-21	45820	375064	6503892	12.50	45.50	33.0
BH-26	47520	374002	6505122	14.0	45.0	31.0
BH-47	52600	371461	6508917	14.0	38.0	24.0
BH-59	53800	371258	6510079	15.60	41.50	25.90
BH-65	54430	371256	6510708	15.50	38.0	29.50

4 Geotechnical Laboratory Testing

Geotechnical laboratory testing was undertaken on representative samples of rock core obtained from the boreholes drilled for this project. The primary objective of the testing was to provide a laboratory assessment of potential rock strength parameters and strength variability to supplement tactile assessments of rock strength logged in the field.

The samples tested were selected by an Advisian senior engineering geologist with the intent to demonstrate the range in rock strength properties that can be expected to be encountered throughout the YRE project area. However, it is important to note that variations from the range of laboratory rock strength results reported should be expected.

It is also important to note that laboratory testing of rock strength requires samples to be of sufficient size and shape to be suitable for testing. Samples that meet these requirements are generally more difficult to acquire in materials of relatively low strength. As such, there is typically some bias towards testing of materials with relatively higher strength, especially for Uniaxial Compressive Strength (UCS) testing, for which the required sample sizes are largest. Furthermore, it is also important to note that 'limestone' rocks common to the wider Perth region (i.e. Tamala Limestone) commonly exhibit post-depositional features associated with dissolution of carbonate ('solution features') that result in weakening of the rock fabric on both small and large scales. Where dissolution is present on relatively small scales, e.g. solution voids or sand pockets in rock core, the features can result in apparent failure of samples when subject to testing, even though the primary rock sample may not have been broken or fractured. Accordingly, these features can also introduce some bias in the results towards indicating materials may be of relatively lower strength than that indicated by tactile assessments during logging of core, or by inspection of outcrops or other exposures of rock-masses. The factors should be given consideration when assessing the results of laboratory testing, particularly in 'limestone' terrains such as that present throughout the YRE project area.

The following laboratory tests were performed by the NATA accredited GBTesting laboratory in Perth:

- 27 Uniaxial Compressive Strength (UCS) tests; and
- 75 Point Load Index (PLI) tests, including:
  - 53 performed in a Diametral orientation; and
  - 22 performed in an Axial orientation.

The results of the geotechnical laboratory testing are summarised in Table 4-1 and discussed further below. Copies of the geotechnical laboratory test certificates are included in Appendix D.

4.1 Uniaxial Compressive Strength

Uniaxial Compressive Strength (UCS) testing was undertaken on rock core samples to provide an indication of potential rock strength that can be compared against AS1726-2017, as presented on .

The results vary between 0.46 MPa and 23 MPa and suggest that UCS rock strengths vary from Very Low (VL) to High (H).

Samples selected were intended to cover the full range of rock strengths logged in boreholes, however, due to difficulty in meeting sample size and shape requirements for UCS testing, particularly for rock of relatively low strength, this was not always possible.

In addition, based on review of photos of UCS samples before and after testing, some samples appear to have failed though a 'plane of weakness'. This is not unusual for carbonate rocks ('limestone'), however it should be noted and some of the low UCS values should be considered with this in mind.

The range in test results suggests that UCS rock strength is predominantly Very Low (VL) to Low (L) when referenced against AS1726-2017, with only minor Medium (M) and High (H) strength materials. However, it is considered likely that relatively high strength results are under-represented in the testing dataset, possibly due to sampled materials experiencing localised failures during testing that do not accurately represent *in situ* rock-mass strength.

Furthermore, prior experience with Tamala Limestone in this region has indicated that UCS of 'caprock' can reach values as high as 50 MPa or more. Based on field observations of 'caprock' materials in the YRE project area, as well as tactile assessment of rock in boreholes drilled for this project, it is considered likely that there will be rocks present in the project area that have higher UCS values than that indicated by the specific test results reported herein.

4.1.1 Density and Moisture Content

Density and moisture content testing has been undertaken on samples selected for UCS testing as part of the standard test preparation procedure.

The density and moisture content test results are presented on laboratory test certificates in Appendix D and have been included in Table 4-1.

The bulk and dry density results range from a minimum of 1.772 tm^{-3} and 1.334 tm^{-3}, respectively, to a maximum of 2.268 tm^{-3} and 2.092 tm^{-3}, respectively. Moisture content results range from between 6.9 % and 34.9 %.

4.2 Point Load Index (PLI)

Point Load Index (PLI) testing was undertaken on rock core samples to provide an indication of potential rock strength in comparison to AS1726-2017, as presented on . The $I_{S(50)}$ results vary between 0.02 MPa and 3.96 MPa and suggest that PLI rock strengths vary from Very Low (VL) to Very High (VH).

Given that there is a reasonable number of tests plotting in all categories of PLI rock strength from Very Low (VL) to High (H) when referenced against AS1726-2017, it is considered that the PLI results may more accurately represent the range of *in situ* rock-mass strengths that could be expected throughout the YRE project area.   Furthermore, the single PLI test result suggesting the sampled material is potentially Very High (VH) strength is consistent with both logged assessments of strength as well as with regional datasets as discussed in Section 4.1. That is, it is considered likely that there will be localised occurrences of rock throughout the YRE project area that will exhibit Very High (VH) apparent rock strength.

PLI testing was undertaken in both a Diametral orientation, which is performed perpendicular to the core, as well as in an Axial orientation, which is performed parallel to the core.

PLI testing was mostly performed in a Diametral orientation, which given the boreholes were drilled with a vertical orientation, provides an assessment of strength in a sub-horizontal plane relative to the ground surface. Testing in a Diametral orientation was thus considered to be of most relevance for assessment of bulk earthworks excavation conditions utilising common digging or ripping equipment.

A lesser number of PLI tests were performed in an Axial orientation, which provides an assessment of strength in a sub-vertical plane relative to the ground surface. Testing in an Axial orientation was thus considered to be of lesser relevance for assessment of bulk earthworks excavations utilising digging or ripping equipment, but of increased relevance for excavation conditions utilising rock-breaking equipment and for assessment of foundation conditions when subject to vertical loads. As such, axial PLI tests were mainly performed on samples from deeper depths in boreholes, corresponding to elevations close to or below the proposed cut/foundation level.

A comparison plot of Diametral and Axial PLI results is presented on . The comparison plot generally indicates that Diametral and Axial PLI strengths are mostly comparable in the sampled dataset, with the majority of tests plotting within the same rock strength category or in adjacent categories. Nevertheless, differences in Diametral and Axial PLI strength are common and expected within Tamala Limestone and suggest some degree of anisotropy with regard to rock strength in the sub-horizontal and sub-vertical plane, likely related to rock fabric defects including bedding and solution features, which can reduce the apparent strength in one plane relative to the other.

4.3 UCS / PLI comparison

Overall, fewer numbers of UCS tests were undertaken in comparison to PLI tests, which is a common approach for geotechnical projects due to both the difficulty in meeting size and shape requirements for UCS testing and in order to rationalise the overall cost and duration of laboratory testing programs. For this reason, PLI tests were performed on comparable samples from adjacent depths to UCS tests so as to enable comparisons between UCS and PLI strength testing results.

The comparison between the recorded UCS values and the PLI $I_{S(50)}$ values of adjacent, comparable samples is shown on . The results indicate a very wide scatter with comparative ratios ranging mostly from about UCS = 2 x PLI to UCS = 20 x PLI.

AS1726-2017 indicates a ratio of UCS = 20 x PLI is applicable for most rock types, although a ratio of UCS = between 4 and 10 x PLI has been postulated for Tamala Limestone by Gordon (2003).

Given the wide scatter of comparative data presented in this study and the lack of a clear correlation between UCS and PLI results, it is recommended that caution should be exercised when interpreting the results of laboratory testing for application to engineering design. Furthermore, it is strongly recommended that rock strengths logged from tactile assessments made in the field should also be considered when making assessments of overall rock-mass strength, rather than relying on laboratory data in isolation.

It is also worth noting that whilst comparison and correlation between UCS and PLI data is commonly undertaken for geotechnical investigations, it must also be recognised that UCS testing provides an indication of compressive strength properties, whereas PLI testing provides an indication of tensile strength properties. These rock strength characteristics are sometimes similar, however, they are not necessarily equivalent or directly comparable.

Table 4-1: Rock Strength Laboratory Test Results Summary

Borehole ID	Depth		PLI Axial	PLI Diametral	UCS	Moisture Content	Bulk Density	Dry Density
	from (m)	to (m)	$I_{S(50)}$ (MPa)	$I_{S(50)}$ (MPa)	MPa	%	t/m^3	t/m^3
BH-03	0.88	1.0		0.02				
BH-03	2.40	2.50		0.11				
BH-03	2.50	2.75			1.5	19.1	1.988	1.669
BH-03	3.20	3.30		0.66				
BH-03	3.68	3.89			5.2	17.1	2.073	1.771
BH-03	3.89	4.0		0.25				
BH-03	4.90	5.0	0.16	0.18				
BH-03	5.0	5.20			1.6	19.3	2.058	1.725
BH-03	5.67	5.80	0.32	0.24				
BH-03	6.50	6.60	0.44	0.44				
BH-03	8.0	8.10	0.10					
BH-03	9.07	9.18	0.04					
BH-09	6.28	6.35		0.05				
BH-09	7.35	7.45		0.05				
BH-09	7.45	7.65			7.1	18.3	1.989	1.681
BH-09	8.35	8.42		0.26				
BH-09	8.85	8.95		0.23				
BH-09	9.50	9.57		0.75				
BH-09	9.60	9.80			1.3	27.7	1.772	1.387
BH-09	10.20	10.40			2.9	24.7	1.904	1.527
BH-09	10.40	10.55	0.30	0.34				
BH-09	11.90	12.0	0.58	0.31				
BH-12	4.05	4.15		1.34				
BH-12	4.66	4.75		0.22				
BH-12	5.76	5.83		0.03				
BH-12	5.83	5.94		2.52				
BH-12	7.10	7.20	0.12					
BH-12	7.20	7.30		0.07				
BH-21	2.10	2.220		0.86				
BH-21	3.0	3.12		0.47				
BH-21	3.12	3.32			2.5	19.6	2.036	1.702
BH-21	3.65	3.7.0		0.07				
BH-21	3.70	3.90			0.46	19.6	1.984	1.659
BH-21	4.55	4.63		0.19				
BH-21	4.63	4.85			0.8	18.1	2.056	1.741
BH-21	7.55	7.70		0.07				
BH-21	9.0	9.20			2.9	16.9	2.063	1.764
BH-21	9.20	9.30		0.68	1.12			
BH-21	11.12	11.30			0.94	17.7	1.889	1.605
BH-21	11.70	11.80	0.87	1.06				
BH-21	11.80	12.0			5.1	19.7	1.913	1.599
BH-26	1.07	1.15		0.20				
BH-26	1.15	1.40			3.4	14.7	2.068	1.802

Borehole ID	Depth		PLI Axial	PLI Diametral	UCS	Moisture Content	Bulk Density	Dry Density
	from (m)	to (m)	$I_{S(50)}$ (MPa)	$I_{S(50)}$ (MPa)	MPa	%	t/m^3	t/m^3
BH-26	2.0	2.08		1.04				
BH-26	10.45	10.70			6.2	6.9	2.225	2.082
BH-26	10.70	10.80	0.81	2.52				
BH-26	11.35	11.50	1.08	3.96				
BH-26	13.46	13.70			2.6	13.6	2.028	1.785
BH-26	13.7	13.83		3.02				
BH-47	4.05	4.15		2.45				
BH-47	4.15	4.35			23	8.4	2.268	2.092
BH-47	4.87	5.0		0.69				
BH-47	5.0	5.20			3.5	18.4	2.005	1.693
BH-47	6.10	6.20		0.52				
BH-47	6.20	6.28	0.39					
BH-47	7.20	7.30		0.85				
BH-47	8.25	8.35		0.35				
BH-47	8.35	8.45	0.39					
BH-47	9.75	9.86	0.04	0.11				
BH-47	10.55	10.7	0.88	0.47				
BH-47	11.10	11.30			1.1	33.5	1.782	1.335
BH-47	11.30	11.43	0.07	0.36				
BH-47	13.50	13.70			1.1	28.4	1.945	1.558
BH-47	13.70	13.85	0.53	0.20				
BH-59	5.32	5.50		0.46				
BH-59	6.60	6.70		0.31				
BH-59	7.67	7.75		0.35				
BH-59	7.75	8.0			2.6	20.3	1.932	1.607
BH-59	9.85	10.0		0.7				
BH-59	11.0	11.20			2.7	27.5	1.838	1.441
BH-59	11.20	11.30		0.82				
BH-59	13.0	13.13	0.32	0.55				
BH-59	14.72	14.80	0.22	0.20				
BH-59	14.80	15.0			0.5	34.9	1.800	1.334
BH-65	4.33	4.57			1.3	21.8	1.944	1.597
BH-65	4.57	4.66		0.08				
BH-65	5.30	5.50			2.9	21.3	1.904	1.569
BH-65	5.50	5.60		0.45				
BH-65	7.40	7.50		0.45				
BH-65	7.50	7.73			0.92	18.9	2.020	1.699
BH-65	9.0	9.15	0.24	0.16				
BH-65	13.85	14.0	0.58	1.98				
BH-65	14.0	14.20			2.2	12.8	2.109	1.899
BH-65	14.90	15.0	0.15	0.50				
Statistical Summary	*Minimum*		*0.04*	*0.02*	*0.46*	*6.9*	*1.782*	*1.334*
	Maximum		*1.08*	*3.96*	*23*	*34.9*	*2.268*	*2.092*
	Mean		*0.39*	*0.69*	*3.30*	*20.1*	*1.991*	*1.678*
	Standard deviation		*0.30*	*0.86*	*4.29*	*8.6*	*0.145*	*0.239*

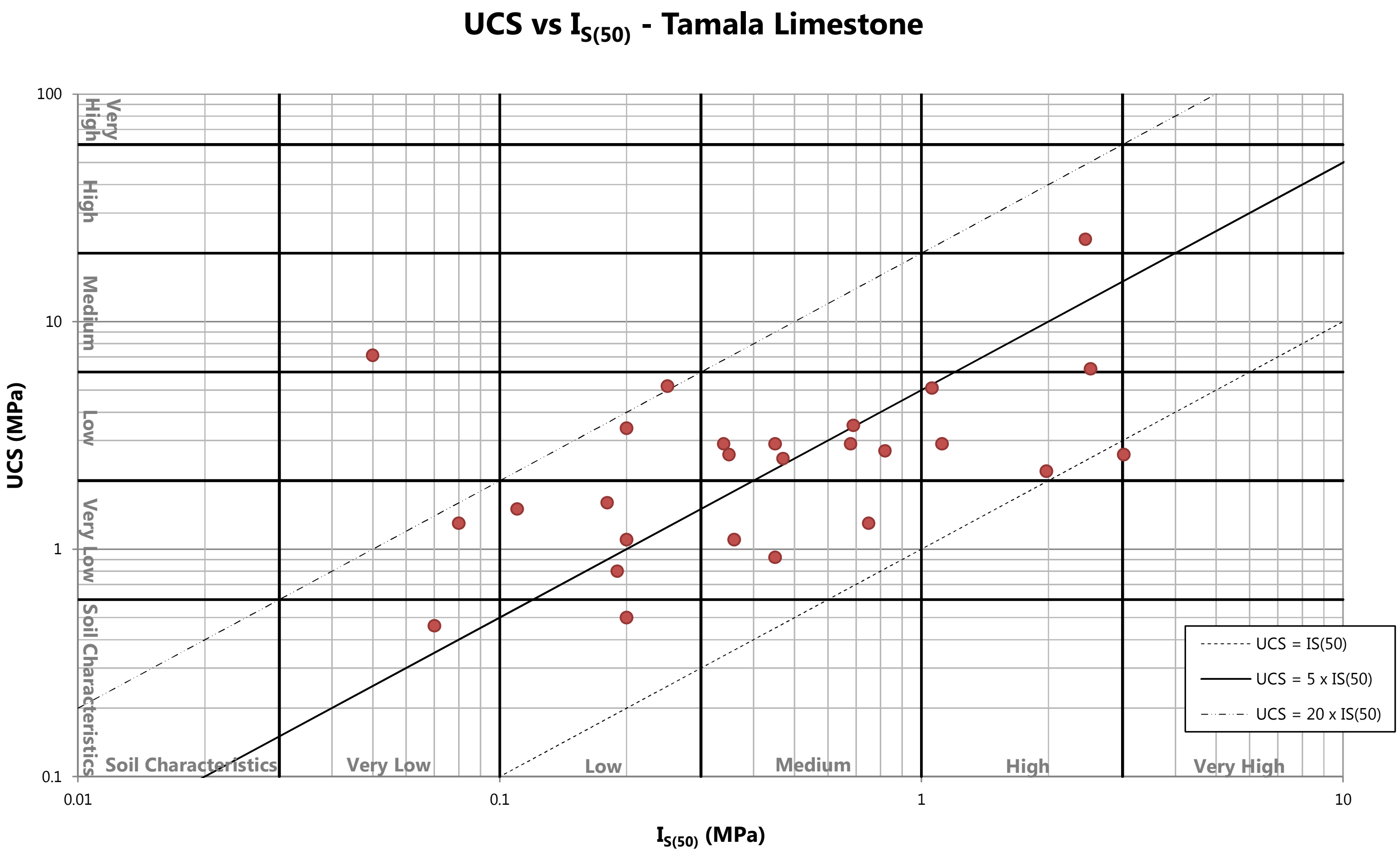


Figure 4-1: UCS and PLI test results plotted with reference to rock strengths as defined in AS1726-2017

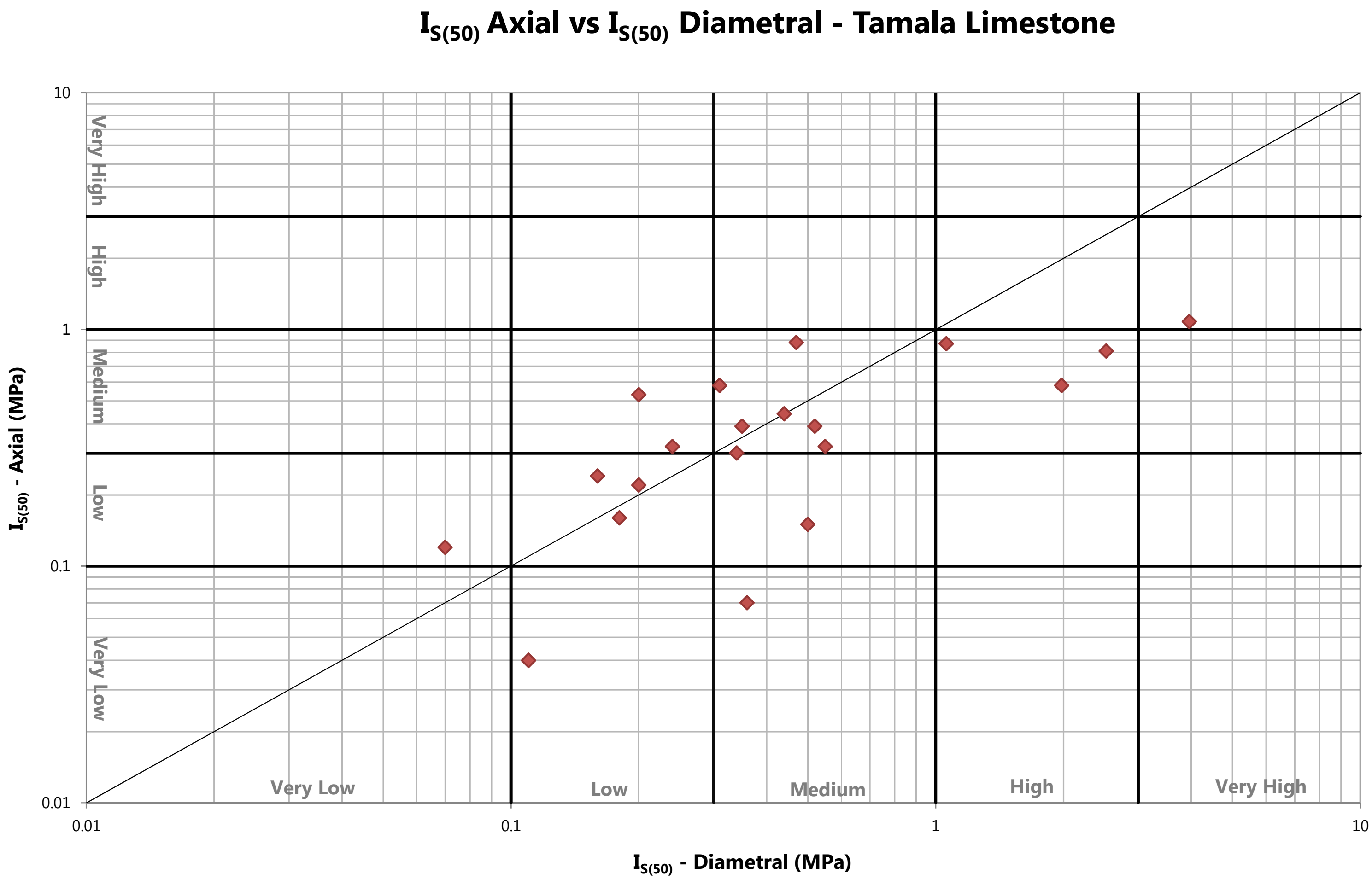


Figure 4-2: Diametral and Axial PLI test results plotted with reference to rock strengths as defined in AS1726-2017

5 Engineering Geology

The interpreted engineering geology of the YRE project area is described in the following sections. The interpretation has been developed into an engineering geological model, which is summarised in Table 5-1 and presented as a long-section on Figures 1 to 15 in Appendix A.

The development of the engineering geological model has been based on the data obtained during the geotechnical site investigation, inclusive of site mapping observations and inferences, CPT data and borehole data. The model has also been informed by reference to the regional geological conditions and as such, the naming conventions and codes utilised are in general accordance with those on published geological maps, in particular the *Yanchep* map of Gozzard (1982).

The engineering geological model developed for the YRE project area recognises four engineering geological units, namely:

- Safety Bay Sand (S2);
- Cemented Safety Bay Sand (LS4);
- Tamala Sand (S7); and
- Tamala Limestone (LS1).

A summary of the geohazards and geotechnical issues considered likely to have an impact on the project are provided in Table 5-1. Note that the geohazards and geotechnical engineering advice provided is preliminary and based on the results of the site investigation along with engineering judgement and experience of similar materials within the region.

5.1 Safety Bay Sand (S2)

The Safety Bay Sand unit comprises relatively recent wind-blown material that has accumulated naturally as part of the coastal dune system. Within the YRE project area investigated, the unit was most commonly comprised of calcareous silica sand and can generally be described as:

- Calcareous Silica SAND: fine- to medium-grained, subrounded quartz and flakey/platey to elongate shell fragments; pale brown-white; with carbonate silt in places; tending to siliceous carbonate sand in places.

In situ density of the Safety Bay Sand unit is typically very loose to medium dense.

Within the YRE project area the Safety Bay Sand unit is mostly present in regions of more pronounced relief, consistent with the presence of relatively recent sand dunes, particularly between CH42250 and CH42600, CH43500 and CH43700, CH49500 and CH51850 and north of CH53700. In the area north of CH53700 in particular, the Safety Bay Sand is often evident as layers of 'lighter-coloured' sand towards the tops of relatively narrow dune ridges, underlain by more widespread and relatively 'darker-coloured' sands associated with the Tamala Sand unit (Figure

5-1). Outcrops of Tamala Limestone 'caprock' are also often evident near the boundary between these different coloured sand bodies (Figure 5-2).

Figure 5-1: Safety Bay Sand ('lighter-coloured') forming crest of narrow dune, underlain by Tamala Sand

Figure 5-2: Tamala Limestone outcrop near the boundary (approximate position of vehicle) between Tamala Sand and overlying Safety Bay Sand, which forms the narrow dune crest in the background

5.2 Cemented Safety Bay Sand (LS4)

In localised areas the Safety Bay Sand exhibits patchy to intermittent carbonate cementation, resulting in the formation of very weakly cemented and very low strength siliceous calcarenite. These rocks commonly exhibit planar cross-bedding features (Figure 5-3) from several centimetres to several decimetres thick, typical of cemented dune sands ('aeolianites').

Cemented Safety Bay Sand was observed at a few locations in subcrop, particularly in cuttings located within the southern part of the YRE alignment between CH42250 and CH42600, and CH43500 and CH43700. The unit was also encountered at a number of locations in outcrop, particularly in the central to northern part of the alignment between CH49500 and CH51850. In outcrop, LS4 was commonly exposed on the western or north-western flanks of dunes and close to dune crests (Figure 5-4), possibly as a result of erosion of the overlying uncemented sand by prevailing westerly winds. The unit was not encountered in any boreholes, but was potentially encountered in CPTs where it was apparent that weakly cemented materials may be present in the subsurface, although in general these materials did not result in CPT refusal.

Cemented Safety Bay Sand is not expected to present any particularly high risk geohazards for the project, partly because it is expected to have limited distribution and thickness, and partly because it is not expected to be difficult to excavate as part of bulk earthworks programs. There is some risk associated with this unit in regard to foundation design, if the unit is incorrectly identified as Tamala Limestone or strengths are overestimated, which could result in overestimations of bearing capacity, however, this unit is typically at elevations higher than design cut levels.

Figure 5-3: LS4 (Cemented Safety Bay Sand) exposed as subcrop in cutting, exhibiting planar cross-bedding typical of aeolianites

Figure 5-4: LS4 (Cemented Safety Bay Sand) outcropping near dune crest, exhibiting planar cross-bedding features overprinted by small-scale solution features

5.3 Tamala Sand (S7)

The Tamala Sand unit is widespread throughout the YRE project area, occurring almost everywhere as a surficial layer of variable thickness overlying Tamala Limestone (Figure 5-8), with the exception of discrete areas where the unit is overlain by Safety Bay Sand (Figure 5-1).

The Tamala Sand mostly comprises sand derived from the weathering of Tamala Limestone, but is likely to also represent relatively older coastal dune systems that have remained uncemented over time. The primary components of Tamala Sand are thus similar to those in the underlying rock-mass and the material can generally be described as:

- (Calcareous) Silica SAND: fine- to medium-grained, subrounded to rounded, quartz; orange to pale orange-brown, pale yellow and pale grey; with shell fragments and carbonate silt in places; tending to calcareous silica sand in places.

In situ density of the Tamala Sand unit typically ranges from loose to dense.

The presence of Tamala Sand is typically represented in the landscape throughout the YRE project area by regions of relatively subdued and undulating relief.

5.4 Tamala Limestone (LS1)

The Tamala Limestone unit is present in the subsurface throughout the entire YRE project area and also outcrops at the surface in various locations. The Tamala Limestone is a carbonate rock-mass, which in the project area investigated is comprised predominantly of siliceous calcarenite, but which also includes a significant proportion of calcreted calcarenite, most commonly as a duricrust ('caprock') layer, as well as a relatively minor proportion of calcareous sandstone.

The engineering properties of Tamala Limestone encountered across the project area range widely from rock that is very well cemented and high strength, to rock that is very weakly cemented and very low strength. Variations in cementation and strength within the rock-mass are commonly associated with post-depositional processes such as cementation (including calcretisation) and dissolution/leaching ('solution').

Siliceous carbonate sand is also commonly interbedded (i.e. encountered within) the Tamala Limestone. The presence of sand often reflects wholesale leaching and dissolution of carbonate from parts of the Tamala Limestone, which has resulted in the rock-mass essentially being reduced to soil *in situ*, or can also be as a result of downward migration of overlying sands into the rock-mass and infilling open cavities or voids. In the former case, this leached material is still Tamala Limestone *sensu stricto*. However, for the purposes of this investigation, where 'interbedded sands' of significant thickness were encountered within the Tamala Limestone, these intervals have been assigned to the Tamala Sand unit, due to the commonality of engineering properties with the surficial soils.

5.4.1 Calcreted Calcarenite ('Caprock')

Calcreted calcarenite is often present at the top of the Tamala Limestone rock-mass throughout the YRE project area, where it has formed as a 'caprock' (i.e. calcareous duricrust) on the present or a former ground surface. Calcretisation of the precursor rock (mostly siliceous calcarenite) has formed at the surface by evaporative precipitation of cryptocrystalline carbonate cements out of groundwater, which on precipitation have infilled pore spaces and coated primary grains. Consequently, calcreted calcarenite is typically well cemented and of relatively high strength, with maximum UCS rock strength of 23 MPa encountered during this investigation.

The calcretisation process is also typically associated with karstic weathering of upper parts of the Tamala Limestone rock-mass, resulting in the formation of subvertical features including limestone 'pinnacles' and calcrete-lined 'solution pipes'. 'Pinnacles' were identified at numerous locations throughout the YRE project area in various forms, including as (i) outcrops protruding up to several metres above the surrounding landscape (Figure 5-5), (ii) toppled boulders on the surface likely disturbed by clearing (Figure 5-6), and (iii) buried features with or without minor surface expression (Figure 5-7). In the latter case, an example of how buried 'pinnacles' appear in the subsurface was evident from an existing excavation discovered adjacent to the YRE project area near CH42780 (Figure 5-8). This excavation provides a superb visual representation of the variability that can be expected in rock levels over relatively short distances throughout the project area, as well as the potential for large volumes of rock to be present in the subsurface even in areas where there is relatively minimal surface exposure of rock.

Minor occurrences of calcreted calcarenite were also observed at lower elevations within the Tamala Limestone rock-mass, which are likely associated with either the former ground surface or the past level of the groundwater table.

Figure 5-5: Pinnacles of Tamala Limestone outcropping above the surrounding landscape

Figure 5-6: Toppled pinnacles of Tamala Limestone in area of historical clearing

Figure 5-7: Minor surface outcrop of Tamala Limestone indicative of potential buried 'caprock' pinnacles

Figure 5-8: Buried pinnacles of Tamala Limestone with sub-vertical solution features ('solution pipes') exposed in excavation and overlain by Tamala Sand

5.4.2 Siliceous Calcarenite

Siliceous calcarenite is likely to be the predominant rock type present within the Tamala Limestone unit throughout the YRE project area. This inference is consistent with the relative proportion of this material encountered in boreholes compared to other rock types, as well as with regional studies of the Tamala Limestone. Although the most commonly encountered rock type during this site investigation was Calcreted Calcarenite, this is mostly as a result of the latter material generally being present as a 'caprock' layer at the top of the Tamala Limestone, which is therefore more likely to be represented in outcrop.

The siliceous calcarenite encountered during this investigation is comprised chiefly of fine to medium sand-sized grains of subrounded quartz and platey / flakey shell fragments bound by carbonate cements, mostly representing cemented coastal dune deposits (aeolianites). Cementation is predominantly very weak to moderately weak and rock strengths mostly very low to medium.

The siliceous calcarenite has often been subject to extensive diagenesis, which has overprinted the primary fabric and led to the formation of solution voids and bands of uncemented sandy material. Defects in the rock-mass are numerous and typically associated with solution features. Some parts of the rock-mass display patchy 'calcretisation' in association with abundant dissolution features (voids and cavities), which probably relate to alternate precipitation and dissolution associated with paleo-groundwater levels. In these cases, angular gravel to cobble-size patches are well cemented but the rock-mass as a whole is typically weakly cemented and of relatively low strength.

5.4.3 Calcareous Sandstone

Calcareous sandstone was encountered in a limited number of intervals within boreholes drilled for this project. Calcareous sandstone is comprised of similar components and exhibits similar engineering properties to siliceous calcarenite, although with a higher proportion of quartz in comparison to carbonate.

5.4.4 Siliceous Carbonate Sand

Siliceous carbonate sand also appears to comprise a significant proportion of the Tamala Limestone unit throughout the YRE project area. This material represents parts of the rock-mass in which extensive dissolution of carbonate has occurred, resulting in the weakening/breakdown of the rock-mass fabric and effective conversion into soil. The layers of siliceous carbonate sand are usually present below cemented parts of the rock-mass and are typically interbedded with siliceous calcarenite.

5.5 Geohazards

Carbonate geological terrains in general, and carbonate rock-masses such as the Tamala Limestone in particular, demonstrate inherently variable physical and chemical characteristics that result in wide ranging engineering properties. These variations in engineering properties are partly associated with the physical characteristics of the primary components of the rock-mass, such as grain size and composition of the grains, but are also greatly affected by chemical processes such as cementation (both primary and secondary), which generally increases rock strength, and dissolution (leaching), which generally decreases rock strength. As an added complexity, these processes can also occur contemporaneously, such as in the development of calcrete-lined, leached solution pipes, or can occur within the same part of a rock-mass at different times in geological history. Furthermore, strengthening of one part of the rock-mass via secondary cementation (e.g. calcretisation) is commonly accompanied by dissolution and weakening of another part of the rock-mass via leaching, in order to provide a source of carbonate cement.

The combination of these processes within the Tamala Limestone can pose significant geohazards for engineering projects, such as resulting in:

- Localised or widespread failures such as karstic collapse (e.g. sinkholes), which can jeopardise the structural integrity of the rock-mass as a whole and which can in turn jeopardise the integrity and safety of engineered structures, including risk of failure or collapse;
- Discrete parts of the rock-mass having unexpectedly high strengths, which can jeopardise engineering works such as excavations, pile-driving or horizontal boring; and
- Large differences in strength and bearing capacity over relatively short lateral distances, which can result in differential settlement, including risk of damage to foundations and structures.

These variations in rock-mass characteristics are evident within the Tamala Limestone unit throughout the YRE project area, including karstic surface weathering resulting in the formation of ‘caprock’, pinnacles and solution pipes/cavities, as well as the leaching of underlying parts of the rock-mass resulting in the presence of interbedded layers of cemented (‘calcarenite’) and uncemented (‘sand’) material. Given that leached portions of the Tamala Limestone generally occur below a relatively strong and better cemented upper portion of the rock-mass, the leached portions are more likely to be encountered within excavations in areas of relatively deeper cut along the YRE alignment. No larger scale karstic features, such as sinkholes or caverns, were identified during this investigation, however, the possibility that they exist in the subsurface should be given due consideration with respect to engineering design.

Table 5-1: Engineering Geological Model

Engineering Geological Unit	Distribution	Geology (Material Types)	Notes	Excavation Characteristics		General Suitability for Reuse as Fill	Geohazards / Geotechnical Issues	Potential Consequence	Likelihood
				Ease of Excavation	Temporary Stability				
Safety Bay Sand (S2)	Intermittent surface distribution overlying S7, particularly CH42250-42600, CH43500-43700, CH49500-51850 and north of CH53700	**Calcareous Silica SAND**: fine- to medium-grained, subrounded quartz and flakey/platey to elongate shell fragments; pale brown-white; with carbonate silt in places; tending to siliceous carbonate sand in places	Patchy distribution; mostly absent outside of noted chainages	Common (free dig); very loose to medium dense	Unstable: requires shallow batters or trench supports	Suitable for general fill; likely mostly suitable for engineered fill, with removal of any isolated organic layers	Instability of excavations, especially below groundwater table; readily erodible	Collapse of excavations	High
Cemented Safety Bay Sand (LS4)	Occurs within or underlying Safety Bay Sand	**Siliceous CALCARENITE**: very weakly to moderately weakly cemented siliceous calcarenite (cemented sand as described above):	Relatively minor occurrences; mostly very low strength	Common (free dig) to easy ripping; very dense soil to very low strength rock	Stable: open excavations temporarily stable	Mostly suitable for general fill; requires crushing and screening for use as engineered fill	Variable cementation and strength	Potential variability in bearing capacity within S2 'soil'; potential for localised layers resistant to common (free-dig) excavations	Medium
Tamala Sand (S7)	Surface distribution across the majority of the site; partly overlain by Safety Bay Sand (S2); forms 'sand zones' within Tamala Limestone (see below)	**(Calcareous) Silica SAND**: fine- to medium-grained, subrounded to rounded, quartz; orange to pale orange-brown, pale yellow and pale grey; with shell fragments and carbonate silt in places; tending to calcareous silica sand in places	Distribution within Tamala Limestone mostly unknown and likely to be highly variable	Common (free dig); loose to dense	Unstable: requires shallow batters or trench supports	Suitable for general fill; likely mostly suitable for engineered fill, with removal of any isolated organic layers	Instability of excavations, especially below groundwater table; readily erodible	Collapse of excavations	High
							Potential for loose soil zones within Tamala Limestone	Zones of low bearing capacity	
Tamala Limestone (LS1)	Underlies Tamala Sand across the entire project area, with surface outcrop in places	**Calcreted CALCARENITE**: fine-grained, pervasively cemented; brown to pale brown; massive to laminar calcrete concretions; subvertical weathering/ solution in part, lined with organics and infilled with sand; well to very well cemented	Mostly present as 'caprock'; karstic surface with pinnacles and solution pipes	Hard ripping / rock-breaking; medium to very high strength	Stable: open excavations temporarily stable	Mostly suitable for general fill; requires crushing and screening for use as engineered fill	Very High Strength rock in part	Localised very difficult excavations	High
							Variable elevation, 'pinnacles'	Rock might be encountered shallower than expected	
								Differential settlement due to variable bearing capacity (e.g. foundations straddling pinnacles)	
		Siliceous CALCARENITE: fine- to coarse-grained, platey and subangular to rounded, shell fragments and quartz; pale brown to pale yellow-white; carbonate silt in matrix; calcrete-lined solution cavities/ root casts in part; variably cemented	Mostly present under 'caprock'; interbedded with uncemented layers (sand)	Easy to hard ripping / rock-breaking; very low to high strength	Variable: stability varies with degree of cementation and defect spacing		Variable elevation, cementation and strength	Excavation conditions and temporary stability potentially highly variable	High
		Siliceous Carbonate SAND: fine- to coarse-grained, flakey/platey to elongate and subrounded, shell fragments and quartz; pale yellow-white to pale brown; with carbonate silt; trace fine to medium gravel of calcarenite; very weakly cemented in part; carbonate Silty SAND in part	Mostly underlies 'cemented' parts of rock-mass; interbedded with calcarenite	Common (free dig); medium dense to very low strength	Unstable: requires shallow batters or trench supports	Suitable for general fill; likely mostly suitable for engineered fill, may require some crushing and screening	Instability of excavations, especially below groundwater table; readily erodible	Collapse of excavations, including affecting temporary stability and bearing capacity of rock-mass	High

5.6 Engineering Geological Model Long Section

The principal objectives of this investigation, as directed by the PTA, included:

- Preliminary assessment of the geological profile along the YRE alignment, primarily focussing on the variability in rock-head profile / depth to rock; and
- Preliminary interpretation of the geotechnical engineering implications for construction of the YRE project, focussing mainly on:
  - Estimation of the approximate relative quantities of soil and rock to be excavated as part of bulk earthworks programs in areas of cut;
  - Inferred excavation conditions, including excavatability and excavation methods likely to be required in areas of cut;
  - General foundation and subgrade conditions in areas of both cut and fill; and
  - General foundation and subgrade variability at road crossing and station locations.

To address these objectives, the findings from the desktop study and the results from the various components of the geotechnical site investigation have been collated to develop an engineering geological long-section parallel to the centreline (CL) of the YRE alignment. The long-section is presented as Figures 1 to 15 in Appendix A, accompanied by a summary of the site investigation data presented in Table 7-1.

A key component of the engineering geological long-section is the interpretation of rock-head profile (depth to rock) along the YRE alignment, noting that rock nominally refers to Tamala Limestone (LS1). The interpretation of rock-head profile has been developed based on:

- The confirmed elevation of rock in the landscape from both observations and mapping of LS1 surface outcrop (or subcrop) and the depth to LS1 encountered in boreholes;
- The inferred depth to rock based on CPT refusal depths; and
- Interpolation of the rock-head profile between the locations of confirmed and inferred depths.

The general use of the term 'rock' to refer to Tamala Limestone (LS1) in regard to the engineering geological long-section is important to note, mainly because known deposits of Cemented Safety Bay Sand (LS4) were not incorporated into the interpreted rock-head profile along the YRE alignment. The rationale for this approach is that the estimated engineering properties of Cemented Safety Bay Sand generally range from soils with patchy cementation, with equivalent properties of dense to very dense sand, to Very Weakly (Vwk) cemented, Very Low (VL) strength rock (see Section 5.2). As such, with regard to bulk earthworks in particular, the LS4 unit is mostly expected to have geotechnical properties that will not present overly difficult excavation conditions. Therefore, inclusion of this unit as part of the overall estimation of rock-head profile was considered likely to present an unrealistic representation of the general difficulty of excavation conditions along the YRE alignment.

It is also important to note, however, that whilst the engineering properties of Tamala Limestone mostly range from Weakly (Wk) to Well (We) cemented, Low (L) to High (H) strength rock, some portions of the rock-mass have been extensively leached and reduced in strength to Very Weakly cemented, Very Low strength rock, or uncemented (Uc) sandy soil (see Section 5.4). The long-section and interpretation of rock-head profile along the YRE alignment does not make distinction between portions of the Tamala Limestone with different cementation and strength characteristics.

5.6.1 Limitations and Constraints

The accuracy and reliability of the engineering geological long-section and interpreted rock-head profile along the YRE alignment is subject to various limitations and constraints that should be considered when assessing the results for engineering purposes.

In particular, fieldwork activities were restricted to locations that could be readily accessed by foot for the purposes of surface mapping, or via existing roads and non-gazetted ('off-road') tracks that did not require clearing for the purposes of penetrative testing by CPT or borehole drilling. As such, the frequency of surface observations and penetrative testing is variable along the YRE alignment depending on the accessibility in different areas. In some portions of the YRE alignment, access either by vehicles or on foot was not possible at all due to the density of vegetation and the lack of existing tracks. Assessments of these areas are therefore limited to desktop interpretations.

It is also important to note that for the purposes of this investigation the depth of CPT refusal was generally inferred to correlate with the depth to rock in the subsurface. This inference is consistent with shallow refusal being encountered in areas where rock was evident in nearby outcrop or subcrop, as well as being supported by borehole data where this was available in close proximity to CPT locations. However, in practice CPT refusal can be due to either (i) high cone resistance, typically greater than 50 MPa up to a maximum of 100 MPa, or (ii) inclination of the rods.

Inclination refusal occurs in CPTs when the trajectory of the rods deviates abruptly and to an angle which is considered to present a risk of damage to the cone or rods. Rod deviation can occur where the boundary between a relatively harder and weaker material is not perpendicular to the CPT rods (e.g. a sloping rock level) or where isolated harder materials occur within weaker materials (e.g. cobbles or boulders buried within soil). In 'limestone' terrains deviations can also be due to the CPT rods encountering sub-vertical features such as buried 'pinnacles' or solution 'pipes', which can cause the rods to deflect along the contact between soil and rock.

Due to these uncertainties, where CPT refusal encountered during this investigation was due to inclination and the depth of refusal was above the proposed cut level, unless there was supporting evidence for inferring rock levels (e.g. nearby outcrop or subcrop) the CPT rig was typically relocated a short distance away (typically 1 to 3 m) and the test repeated. If refusal was experienced in the 'repeat tests' at a similar depth, either due to cone resistance or inclination, this was inferred to be indicative of the typical depth to rock in that location. In a limited number of locations where 'repeat tests' were undertaken during this investigation, refusal was encountered at a significantly deeper depth than in the original test. In these cases it was inferred that the initial refusal was likely an anomaly or outlier result, which was not representative of 'average' rock depth in that general location. As such, interpretations of rock depths in these areas have been based on the result of the 'repeat test'.

5.7 Geotechnical Engineering Implications

5.7.1 Bulk Earthworks Excavations

The approximate relative quantities of soil and rock to be excavated as part of bulk earthworks programs have been estimated based on the interpreted engineering geological long-section and are presented in Table 5-2.

The estimations have been generated from a simplified 2-dimensional model aligned parallel with the centreline of the proposed YRE and do not take into account variations in rock levels that may occur perpendicular to the YRE alignment. Furthermore, the estimations assume that the interpreted rock-head levels correlate with the upper surface of Tamala Limestone and that all materials above this level are 'soils', notwithstanding the potential presence of Cemented Safety Bay Sand within these materials (see discussion in Section 5.6).

The relative percentages of soil and rock presented in Table 5-2 are cross-referenced to several 'engineering divisions' of the YRE alignment. These divisions have been made based on the inferred reliability or 'accuracy' of the relative soil and rock quantity estimations in each division. The inferred reliability of the data associated with each 'engineering division' has been assessed qualitatively based on a number of factors, including the accessibility of the area for both inspection/mapping and penetrative testing, the degree to which rock levels could be inferred from outcrop or subcrop and the relative spacing of penetrative testing.

5.7.2 Road Crossings and Stations

The locations of proposed road crossings and station complexes were specifically targeted during the site investigation to supplement the general assessment of rock-head profile along the YRE alignment with data pertinent to preliminary foundation and subgrade assessment for these key structures.

With the exception of the Eglinton Drive crossing location, to which access was not readily practical, all other road crossings and station complexes were specifically assessed during the site mapping inspection, with the majority of the locations subsequently assessed with penetrative testing. At a few locations where surface rock outcrop was common and access for testing vehicles was restricted, penetrative testing was not undertaken and interpreted geotechnical conditions are reliant on surface mapping observations. However, at most locations a minimum of either 1 CPT or 1 borehole was performed to supplement mapping observations, with the majority of locations being assessed with multiple CPTs. Boreholes were further targeted at specific crossings and station complexes were a significant quantity of rock was expected to be present.

A summary of the site investigation data acquired at the specific locations of proposed road crossings and station complexes is presented in Table 5-3, along with a brief discussion of the implications for engineering with respect to bulk excavations and expected foundation and subgrade conditions.

Table 5-2: Relative percentages of soil and rock expected in bulk earthworks excavations along the YRE alignment

Engineering Division	Chainage		Description	Percent of Excavations		Relative Data Reliability
	from	to		Sand (%)	Rock (%)	
ED-1	41280	43660	Predominantly cut; access mostly unrestricted, either cleared or grassy low vegetation, apart from Romeo Rd area; within residential estates to CH42500, with some previous earthworks; numerous LS1 rock outcrop between CH42500 and CH43000 (Romeo Rd area), with some LS1 outcrop to CH43660; closely spaced penetrative testing throughout, supplemented by historical testing to CH42500	67	23	High
ED-2	43660	44460	Fill area to CH43920, followed by cut; limited track access with relatively dense 'woodland' vegetation; 2 penetrative tests only; no rock outcrop	67	23	Low
ED-3	44460	45860	Mostly cut with minor fill areas; mostly good to reasonable access; within residential estate to CH44950, then relatively open 'forest' and partly revegetated clearings; moderately spaced penetrative testing; sporadic LS1 rock outcrop	50	50	Medium
ED-4	45860	46860	Mostly cut; limited track access with relatively dense 'woodland' vegetation; 2 penetrative tests only; no rock outcrop	51	49	Low
ED-5	46860	49000	Almost entirely cut; mostly good to reasonable access on tracks or on foot through low scrub; widely spaced penetrative testing; abundant LS1 rock outcrop	21	79	High
ED-6	49000	51360	Mostly fill with minor cut areas in 'Bush Forever' area; poor access for vehicles (other than motorcycles), reasonable to good access on foot through low scrub or relatively open 'forest'; no penetrative testing; minor LS4 outcrop	58	42	Low
ED-7	51360	51880	Entirely cut in 'Bush Forever' area; poor access for vehicles (other than motorcycles), mostly good access on foot through relatively open 'forest'; no penetrative testing; minor LS4 and LS1 rock outcrop	40	60	Low
ED-8	51880	55300	Mostly cut with minor fill areas; access mostly unrestricted to CH53900 and partly cleared, then good access to CH55300; moderately to closely spaced penetrative testing; sporadic LS1 rock outcrop	54	46	High
Overall	*41280*	*55300*	*Combined estimate along full length of YRE alignment*	*47*	*53*	*Not Applicable*

Table 5-3: Summary of Site Investigation Data at Road Crossings and Stations and Implications for Engineering

Road Crossing / Station	Chainage	Site Investigation Data	Summary of Site Investigation Data Summary	Implications for Engineering
Santorini Promenade	41580	CPT-76, CPT-76-2; Test Pit No. 3 (Geosite, 2010)	Rock depths interpreted from CPTs and Test Pit suggest rock varies from about 1 to 2 m both above and below cut level	Predominantly soil in excavations, with potential for small to moderate quantities of rock; foundation likely to be variable with soil on southern side and rock on northern side
LWP2 - Howden Pde	42500	CPT-72, CPT-72-2, CPT-72-3; Test Pit No. 12 (Geosite, 2010)	Rock depths interpreted from CPTs and Test Pit suggest rock varies from near cut level to >2 m below cut level	Predominantly soil in excavations, with potential for small quantities of rock; foundation likely to be mostly soil with some rock
Romeo Rd	42780	CPT-02, CPT-03, CPT-04, BH-03; rock outcrop in immediate vicinity	Abundant LS1 rock outcrop (protruding 'pinnacles'); widespread shallow rock confirmed by CPTs and BH indicates rock up to 5 m above cut level	Predominantly rock in excavations; rock likely present across width and breadth of foundation
Landcorp 1	43070	CPT-06, CPT-06-2, CPT-06-3	Rock depths interpreted from CPTs suggest rock varies from about 1m above cut level to >2m below cut level	Predominantly soil in excavations, with potential for small quantities of rock; foundation likely to be variable with soil on eastern and western sides and rock in centre
Alkimos Station	43100 to 43340	CPT-07, CPT-08, CPT-08A, CPT-08-2, CPT-08-3, CPT-08-4, CPT-08-5	Rock depths interpreted from CPTs suggest rock level is highly variable, ranging from >10m below cut level in the south and east, to <5m above cut level in the north and west	Significant quantity of both soil and rock in excavations; foundation will be variable with soil in the south and east and rock in the north and west; subgrade conditions in the south-east include >10m of soil below cut level and potentially very loose in part
Landcorp 2	43360	CPT-09, CPT-09-2, CPT-09-2A, CPT-09-3; BH-09	Rock depth confirmed in BH and interpreted from CPTs indicates rock varies from around 6 to 9 m above cut level	Significant quantity of both soil and rock in excavations; rock likely present across width and breadth of foundation
Landcorp 3	44140	BH-12	Rock depth confirmed in BH indicates rock is around 2m above cut level	Likely significant quantity of both soil and rock in excavations; rock likely present across width and breadth of foundation (unconfirmed; one penetrative test only)
Alkimos Drive	44440	CPT-13, CPT-14, CPT-15 (all ~40m north of crossing location)	No data from actual crossing location; CPT data from about 40m north of crossing locations suggests rock likely to be variable but present at or near the cut level	Unknown conditions at actual crossing location; nearby data suggests excavations could be predominantly soil with small to moderate quantities of rock and foundation could be variable
Eglinton Drive	46880	Rock outcrop in immediate vicinity	Abundant LS1 rock outcrop (on surface); no penetrative data to confirm rock depths, but outcrop suggests rock likely present 6 to 9 m above cut level	Likely to be predominantly rock in excavations; rock likely present across width and breadth of foundation
Road @ CH47180	47180	CPT-25; rock outcrop nearby	Abundant LS1 rock outcrop (on surface) to north; shallow rock confirmed by CPT suggests rock is up to 13 m above cut level	Predominantly rock in excavations; rock likely present across width and breadth of foundation
Eglinton Station (incl. Road @ CH47450)	47280 to 47520	CPT-25B, CPT-26, BH-26; rock outcrop throughout	Abundant LS1 rock outcrop (on surface and minor protruding 'pinnacles'); shallow rock confirmed by CPTs and adjacent BH at Pipidinny Road indicates rock up to 12m above cut level	Predominantly rock in excavations; rock likely present across width and breadth of foundations
Pipidinny Road	47540	CPT-26, BH-26; rock outcrop in immediate vicinity	Abundant LS1 rock outcrop (on surface); widespread shallow rock confirmed by CPTs and BH indicates rock up to 11 m above cut level	Predominantly rock in excavations; rock likely present across width and breadth of foundations
Landcorp 4	48320	Rock outcrop nearby	Minor LS1 rock outcrop (on surface); shallow rock confirmed by nearby CPTs (CPT-31 and CPT-32) suggests rock is 6 to 8 m above cut level	Predominantly rock in excavations; rock likely present across width and breadth of foundations
Yanchep Beach Road	52660	CPT-47, CPT-48, BH-47; rock subcrop in vicinity	Minor LS1 rock subcrop and LS4 subcrop in track cutting to east of CPT-47/BH-47 location; rock depth confirmed in BH and interpreted from CPTs indicates rock present from around 7 m above cut level	Predominantly rock in excavations with minor surface soil on southern side; rock likely present across width and breadth of foundations

Road Crossing / Station	Chainage	Site Investigation Data	Summary of Site Investigation Data Summary	Implications for Engineering
Tokyu 1	53800	CPT-59, CPT-59-2, BH-59	Rock depth confirmed in BH and interpreted from CPTs indicates rock varies from around 6 to 11 m above cut level	Significant quantity of both soil and rock in excavations; rock likely present across width and breadth of foundation
Tokyu 2	54050	CPT-61, CPT-61-2	Rock depth interpreted from CPTs suggests rock is about 3 to 5 m below cut level	Predominantly soil in excavations; foundation likely to be mostly soil; testing restricted to western side of crossing
Tokyu 3	54260	CPT-63, CPT-63-2	Rock depth interpreted from CPTs suggests rock is at or near cut level	Predominantly soil in excavations, with potential for small quantities of rock; foundation likely to be variable soil and rock at cut level with rock in shallow subgrade
Yanchep Station	54280 to 54440	CPT-64, CPT-64-2, CPT-64-3, CPT-64-3A, BH-65; rock outcrop in area, particularly in northern part	Sporadic LS1 rock outcrop throughout (on surface), particularly in northern part of station complex; rock depth confirmed in BH and interpreted from CPTs suggests rock surface is 'pinnacled' and varies from around 3 to 12 m above cut level, with rock level rising to the north	Significant quantity of both soil and rock in excavations, but increasing to predominantly rock in the north; rock likely present across width and breadth of foundation
Tokyu 4	54450	Rock outcrop in immediate vicinity; BH-65 adjacent to south, CPT-66 adjacent to north	LS1 rock outcrop in crossing area; rock depths interpolated from adjacent BH and CPT suggests rock 8 to 10 m above cut level	Predominantly rock in excavations with minor surface soil in part; rock likely present across width and breadth of foundations
Tokyu 5	54650	CPT-67-2	Rock depth interpreted from CPT suggests rock is about 3 m below cut level	Predominantly soil in excavations; foundation likely to be mostly soil; testing restricted to eastern side of crossing
Toreopango Av	54860	CPT-69, CPT-69-2, CPT-69-3	Rock depth interpreted from CPTs suggests rock varies from about 1 m above cut level to 2 m below cut level	Predominantly soil in excavations, with potential for small quantities of rock; foundation likely to be variable soil and rock at cut level with rock in shallow subgrade

6 Conclusion and Recommendations

The principal objectives of the preliminary geotechnical investigation undertaken for the YRE project included:

- Preliminary assessment of the geological profile along the YRE alignment, principally focussing on:
  - Variability in rock-head profile / depth to rock;
  - *In situ* condition of surficial soils ('sands');
  - Identification of any unexpected, unusual or deleterious soil types; and
  - Identification of any potential for karst risk (subsurface cavities or caverns); and
- Preliminary interpretation of the geotechnical engineering implications for construction of the YRE project, principally focussing on:
  - Estimation of the approximate relative quantities of soil and rock to be excavated as part of bulk earthworks programs in areas of cut;
  - Inferred excavation conditions, including excavatability and excavation methods likely to be required in areas of cut;
  - Foundation and subgrade conditions in areas of both cut and fill; and
  - Foundation and subgrade variability at road crossing and station locations.

The following key conclusions can be interpreted from the results of the investigation:

- General geological conditions, including high levels of variability in the thickness of surficial sand (depth to rock) and in the engineering properties of rock (ranging from Very Low to Very High strength), appear to be fairly typical of what is expected in 'limestone' terrains common to the greater Perth coastal plain;
- Rock-head profile / depth to rock is highly variable, but has been interpreted with varying levels of confidence along the majority of YRE alignment;
  - The overall relative proportion of soil and rock in bulk earthwork excavations along the YRE alignment is estimated as 53% rock and 47% soil;
  - The estimated relative proportions of soil and rock are preliminary and do not take into account variability perpendicular to the alignment, nor do they account for variations in rock strength and excavation requirements, including the presence of 'weak rock' (LS4) within areas of soil and for 'Tamala Sand' layers to be present within areas of rock;
- Foundation and subgrade conditions have been assessed for all station complexes and the majority of road crossing locations;
  - Consistent with the remainder of the investigation, these assessments indicate significant variability in geotechnical conditions;
  - Foundation / cut levels are variously dominated by either soil, rock or mixed soil and rock conditions; and

- Areas of particular risk due to karst or unexpected / deleterious soils were not explicitly identified during this investigation, although there remains potential for these geohazards to be present and continual assessment for the presence of geohazard risk should be undertaken during future investigations.

Future geotechnical investigations will be required along the YRE alignment and at the locations of all key structures, to supplement the information provided in this report and to enable detailed design. It is recommended that consideration should be given to the following key aspects requiring further geotechnical investigation:

- Areas that were inaccessible during this investigation will require thorough assessment utilising a range of similar techniques to those employed in this study, noting that:
  - Provision of adequate access to enable geotechnical investigations will require clearing of vegetation from the alignment centreline in certain areas;
  - The cleared centreline should be inspected ('mapped') to assess local conditions and appropriate penetrative testing by CPT or borehole drilling undertaken to assess general geotechnical conditions;
- Key civil design aspects of the project, such as recommended earthworks batters, site preparation advice and drainage management will require additional site investigation, laboratory testing and geotechnical analyses, in particular:
  - Areas of significant cut, including both deep and long cuttings, as well as areas of significant fill, will require additional CPT and / or borehole investigations to refine the engineering geological model and provide data on geotechnical properties of materials;
  - Investigations in areas of fill should ideally penetrate to a depth equivalent to at least 2 times the width of the embankment foundation;
  - Laboratory testing of soil and rock samples should be undertaken to assess geotechnical parameters relevant to slope and foundation stability, such as friction angle, strength and bearing capacity;
  - Slope stability analyses should be undertaken using limit equilibrium or finite element software to assess temporary and permanent stability of earthworks batters for cut slopes and fill embankment slopes;
  - Foundation assessment and bearing capacity analyses should be undertaken, particularly in areas of significant fill, to estimate the short and long term settlement of embankments, including potential for differential settlement;
  - Foundation assessment should include laboratory testing relevant to interpretation of site preparation requirements needed to achieve desired foundation performance, including standard and / or modified compaction and California Bearing Ratio;
  - Site drainage requirements should be adequately assessed with a combination of *in situ* permeability testing, facilitated by installation of monitoring wells in selected boreholes, supplemented by hydrogeological analyses of groundwater transmissivity and flow paths;
- Structural and foundation design aspects for all key structures, including station complexes and road crossings ('bridges') will require specific investigations targeted at the structure locations, including:

   - Additional boreholes and CPTs to refine the engineering geological model and provide data on geotechnical properties of materials;
   - Penetrative testing depth requirements will need to be individually assessed based on the expected dimensions and loads associated with each structure, as well as the likely foundation type (i.e. shallow or piled foundation);
   - Laboratory testing of soil and rock samples should be undertaken to assess geotechnical parameters relevant to foundation design, and;
   - Geotechnical analyses will be required to provide interpretation of parameters relevant to foundation design, including bearing capacity, resistance to horizontal and uplift loads and expected settlements;
- Bulk earthworks requirements will also require further assessment to refine the estimated overall relative proportion of soil and rock to be excavated, as well as to refine and quantify the relative proportions of material representing relatively easy and relatively difficult excavation conditions. This should be achieved by:
   - Incorporating the data acquired from the aforementioned targeted investigations of key structures, areas of significant cuttings and areas that were inaccessible during the current investigation into the overall engineering geological model for the YRE alignment;
   - Targeted infill investigation in areas of the current study that demonstrate significant uncertainty in interpreted depth to rock, due to either significant variability in local rock levels or wide spacing between test locations;
   - Consideration may also be given to analysing as-constructed records of bulk earthworks excavations for portions of the existing northern suburbs railway that traverse a comparable geological terrain, in order to gauge the proportions of relatively easy and relatively difficult excavation conditions that might be expected.

It is further recommended that scoping and specification of future geotechnical investigations be undertaken in close consultation with engineering teams experienced with civil, structural and geotechnical design elements of rail construction projects, in order to optimise and prioritise the future investigations.

7 References

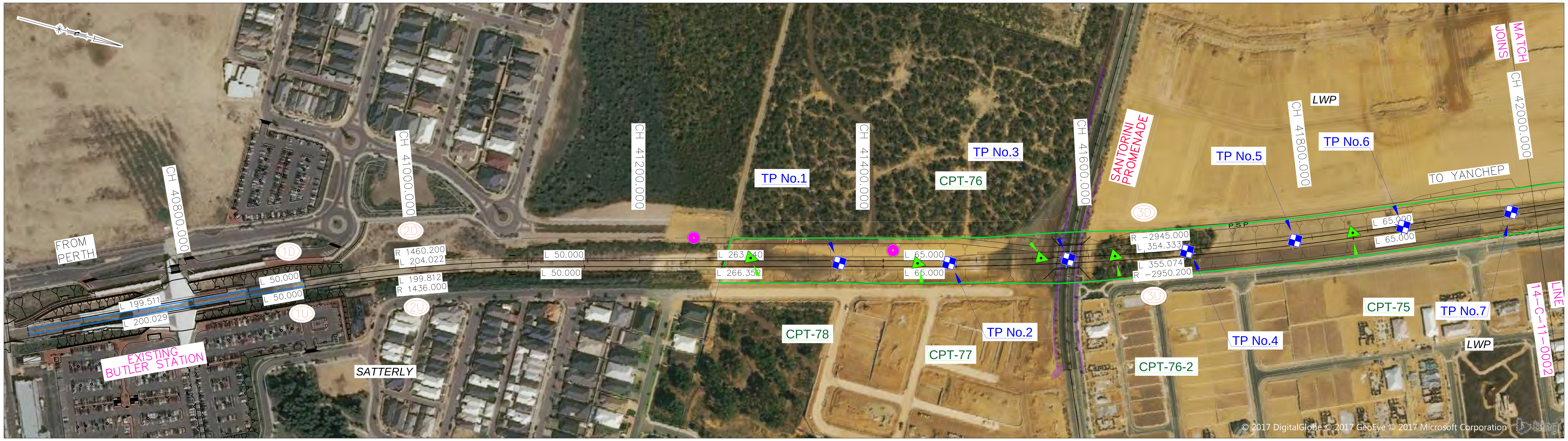
Davidson, W.A. (1995). *Hydrogeology and Groundwater Resources of the Perth Region, Western Australia.* Geological Survey of Western Australia, Bulletin 142.

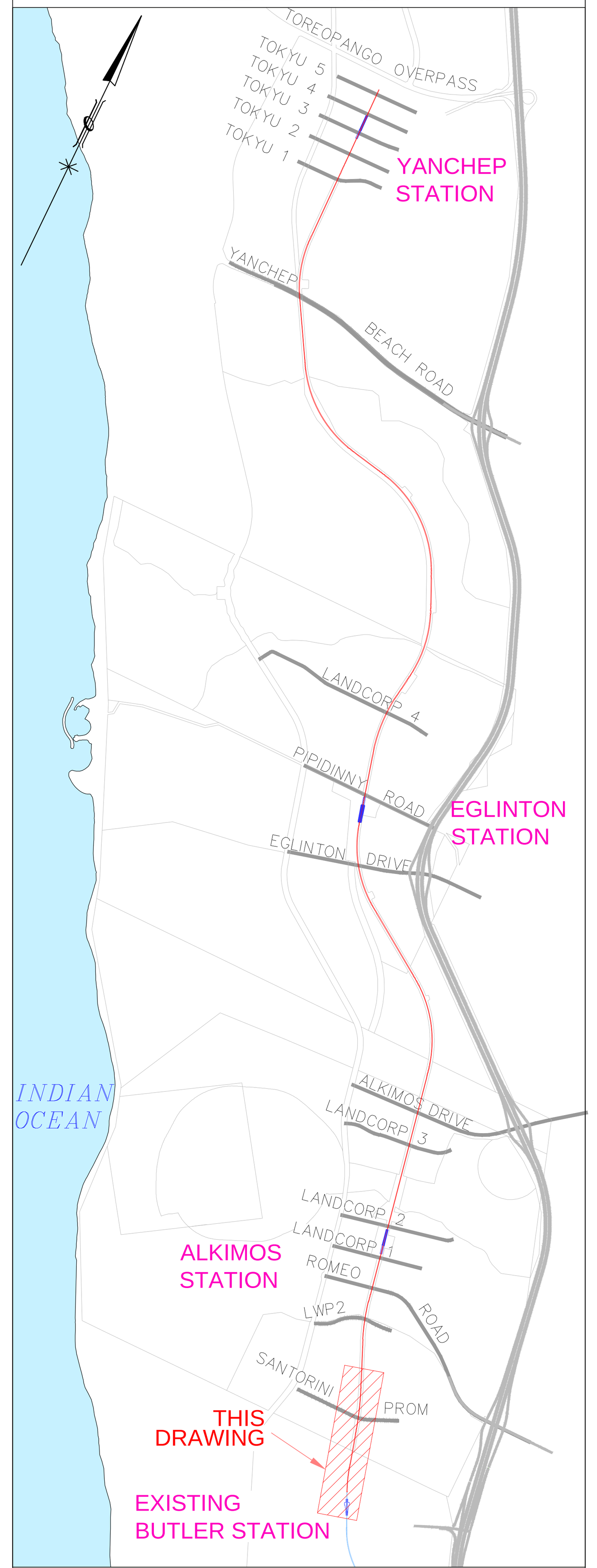
Department of Water (2016a): Perth Groundwater Atlas [website]. Available from: http://atlases.water.wa.gov.au/idelve/gwa/. Accessed 19 February 2016.

Geosite (2010), *Geotechnical Investigation, Brighton to Alkimos Railway Extension, Lot 3 Section*, Report 2009-03-AB, prepared for PTA by Geosite Pty Ltd, December 2010

Gozzard, J.R. (1982) *Yanchep Sheet 2034 IV*, Perth Metropolitan Region, Environmental Geology Series, Geological Survey of Western Australia

Appendix A Engineering Geological Long-Section





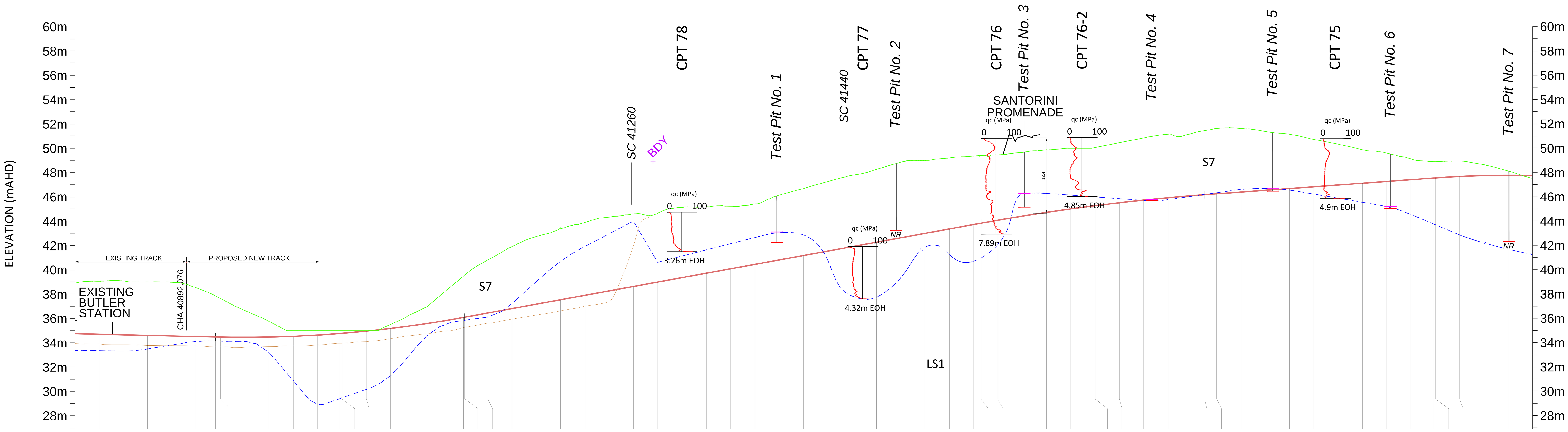
LEGEND

FEATURES (PLAN)

- PROPOSED PLATFORM
- DESIGN PASSENGER MAIN
- EXISTING PASSENGER MAIN
- PROPOSED PSP
- EXSTING RAIL RESERVE
- PROPOSED RAIL RESERVE
- DEVELOPER BOUNDARY
- LANDCORP — DEVELOPER NAME
- CADASTRE
- 2D — HORIZONTAL CURVE NUMBER

1:200 Vertical at A3

1:2000 Horizontal at A3



Datum R.L. 23m

PASSENGER DOWN MAIN THROUGH CHAINAGE	EXISTING SURVEY LEVEL	PASSENGER DOWN MAIN LOW RAIL LEVEL
40800.000	38.897	34.743
40820.000	39.061	34.697
40840.000	39.079	34.650
40860.000	38.992	34.604
40880.000	38.964	34.557
40900.000	38.521	34.511
40915.995	37.846	34.473
40920.000	37.636	34.465
40940.000	36.654	34.446
40960.000	35.752	34.468
40980.000	35.000	34.529
41000.000	35.000	34.631
41018.520	35.000	34.761
41020.000	35.000	34.772
41040.000	35.000	34.954
41060.000	35.506	35.176
41080.000	36.475	35.437
41100.000	37.809	35.739
41120.000	39.476	36.080
41121.052	39.563	36.099
41140.000	40.807	36.444
41160.000	41.913	36.807
41180.000	42.736	37.171
41200.000	43.441	37.534
41220.000	43.890	37.898
41240.000	44.328	38.262
41260.000	44.594	38.625
41280.000	44.659	38.989
41300.000	45.138	39.353
41320.000	45.172	39.716
41340.000	45.221	40.080
41360.000	45.418	40.443
41380.000	46.134	40.807
41400.000	46.678	41.171
41420.000	47.256	41.534
41440.000	47.769	41.898
41460.000	48.253	42.261
41480.000	48.851	42.625
41500.000	49.000	42.989
41520.000	49.203	43.352
41540.000	49.350	43.716
41546.019	49.390	43.825
41560.000	49.448	44.074
41580.000	49.654	44.409
41600.000	49.849	44.721
41620.000	50.000	45.008
41638.128	50.018	45.249
41640.000	50.055	45.273
41660.000	50.451	45.513
41680.000	50.844	45.730
41700.000	51.150	45.923
41720.000	51.227	46.093
41730.236	51.436	46.171
41740.000	51.626	46.242
41760.000	51.611	46.387
41780.000	51.373	46.533
41800.000	51.146	46.678
41820.000	50.722	46.824
41840.000	50.338	46.970
41860.000	49.870	47.115
41880.000	49.599	47.261
41900.000	49.122	47.407
41919.020	48.892	47.545
41920.000	48.892	47.552
41940.000	48.941	47.672
41960.000	48.638	47.745
41980.000	48.126	47.770
42000.000	47.514	47.749

NOTES

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3. ALLTRACK BALLASTED UNLESS SHOWN OTHERWISE.
4. DESIGN ALIGNMENT: 141001_AlignP_Dn_HA15

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Government of Western Australia
Public Transport Authority

0 20 40 60 80 100 200m
AT ORIGINAL PLOT SIZE

Datum: GDA94
Map Grid of Australia
Zone 50

LEGEND

- Borehole
- Cone Penetrometer Test
- Test Pit (Geosite, 2010)
- SC - Subcrop (rock) exposed in cutting
- OC - Outcrop (rock) exposed on surface
- NR No Refusal

LITHOLOGY

- Silica SAND
- Siliceous Calcarenite
- Calcreted calcarenite
- Sandstone with carbonate cement

LONG-SECTION

- Natural Surface Level
- Interpreted Rock Level

GEOLOGY

- Safety Bay Sand (S2)
- Tamala Sand (S7)
- Tamala Limestone (LS1)
- Cemented Safety Bay Sand (LS4)
- Core Loss
- Inferred Rock Level
- Design Rail Level

CPT Trace

qc (MPa) 0 100

3.26m EOH

Test Pit

Top of Limestone

Base of Pit

PUBLIC TRANSPORT AUTHORITY
YANCHEP RAIL EXTENSION
ENGINEERING GEOLOGICAL MODEL

DRG No

LONG-SECTION - SHEET 1 of 15

REV 0

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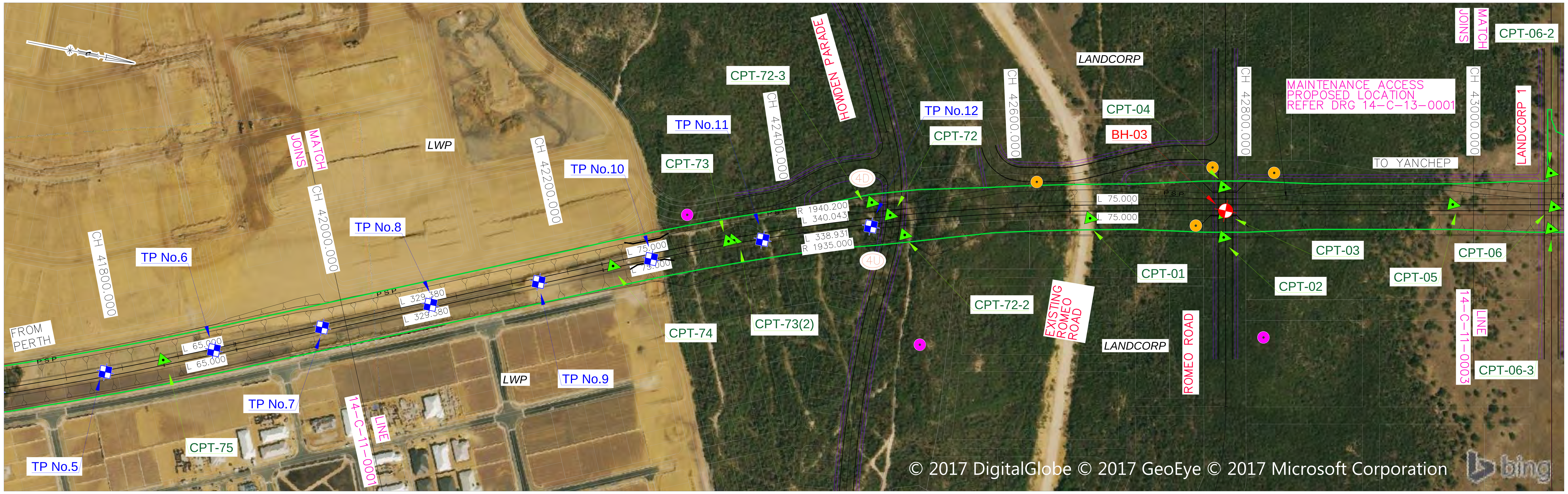

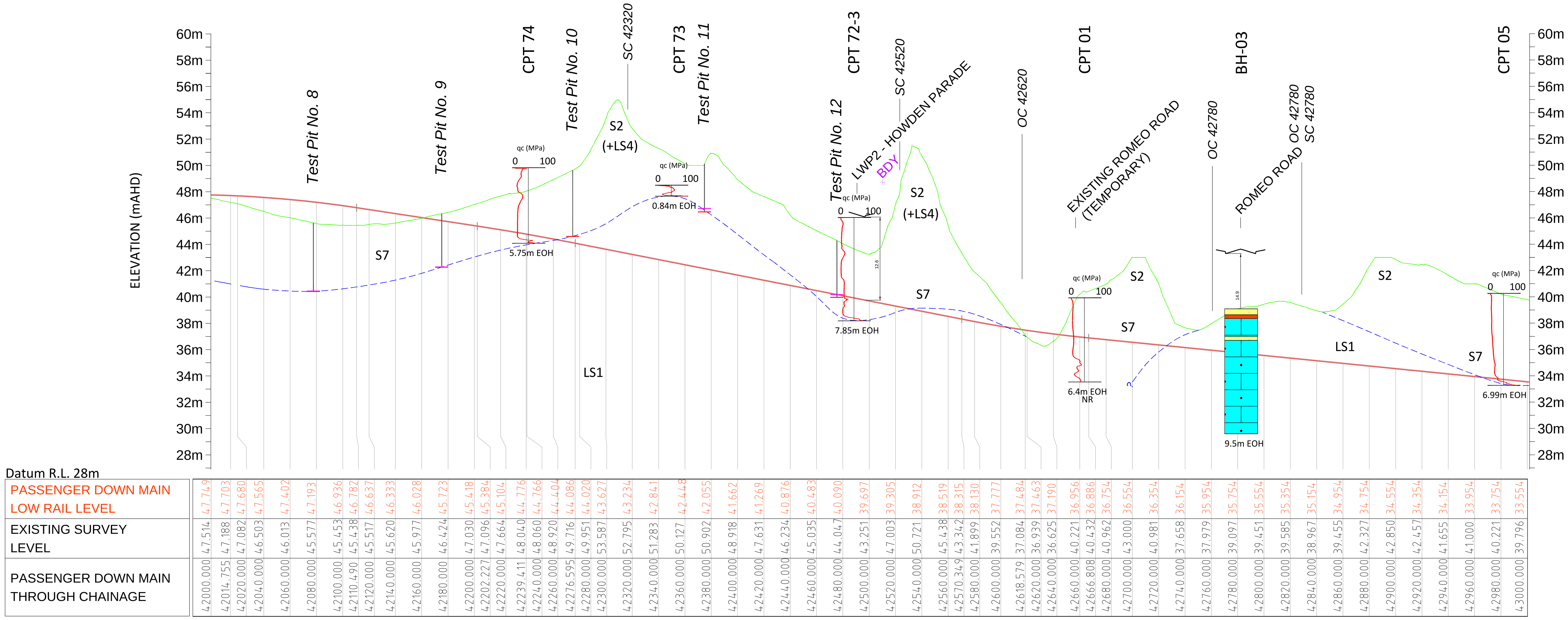

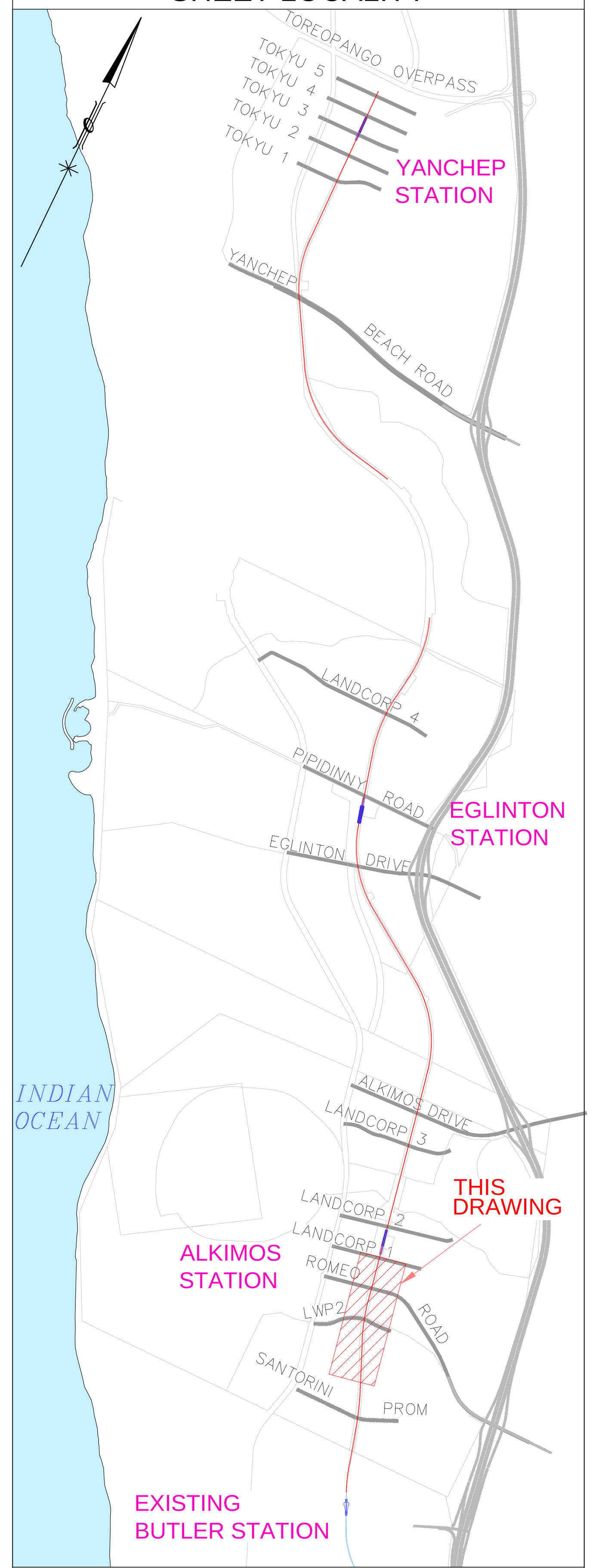

LEGEND

FEATURES (PLAN)

- PROPOSED PLATFORM
- DESIGN PASSENGER MAIN
- EXISTING PASSENGER MAIN
- PROPOSED PSP
- EXSTING RAIL RESERVE
- PROPOSED RAIL RESERVE
- DEVELOPER BOUNDARY
- LANDCORP — DEVELOPER NAME
- CADASTRE
- 2D — HORIZONTAL CURVE NUMBER

1:200 Vertical at A3
1:2000 Horizontal at A3

NOTES

1. ALL LEVELS AND DIMENSIONS ARE IN METRES UNLESS SHOWN OTHERWISE
2. THESE PLANS ARE FOR TRACK ALIGNMENT ONLY AND SHOULD BE READ IN CONJUNCTION WITH ASSOCIATED PLANS FOR ROADWORKS, CIVILWORKS, STRUCTURES, ELECTRIFICATION etc.
3. ALLTRACK BALLASTED UNLESS SHOWN OTHERWISE.
4. DESIGN ALIGNMENT: 141001_AlignP_Dn_HA15

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Government of Western Australia
Public Transport Authority

0 20 40 60 80 100 200m
AT ORIGINAL PLOT SIZE

Datum: GDA94
Map Grid of Australia
Zone 50

LEGEND

- Borehole
- Cone Penetrometer Test
- Test Pit (Geosite, 2010)
- SC - Subcrop (rock) exposed in cutting
- OC - Outcrop (rock) exposed on surface
- NR — No Refusal

LITHOLOGY

- Silica SAND
- Siliceous Calcarenite
- Calcreted calcarenite
- Sandstone with carbonate cement

LONG-SECTION

- Natural Surface Level
- Interpreted Rock Level

GEOLOGY

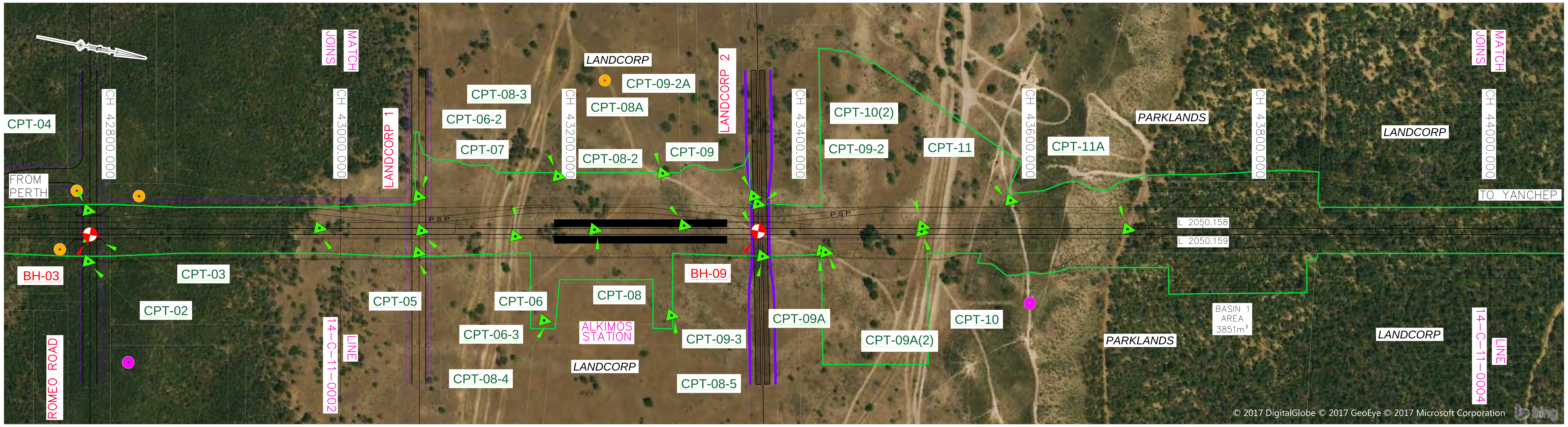
- Safety Bay Sand (S2)
- Tamala Sand (S7)
- Tamala Limestone (LS1)
- Cemented Safety Bay Sand (LS4)
- Core Loss
- Inferred Rock Level
- Design Rail Level

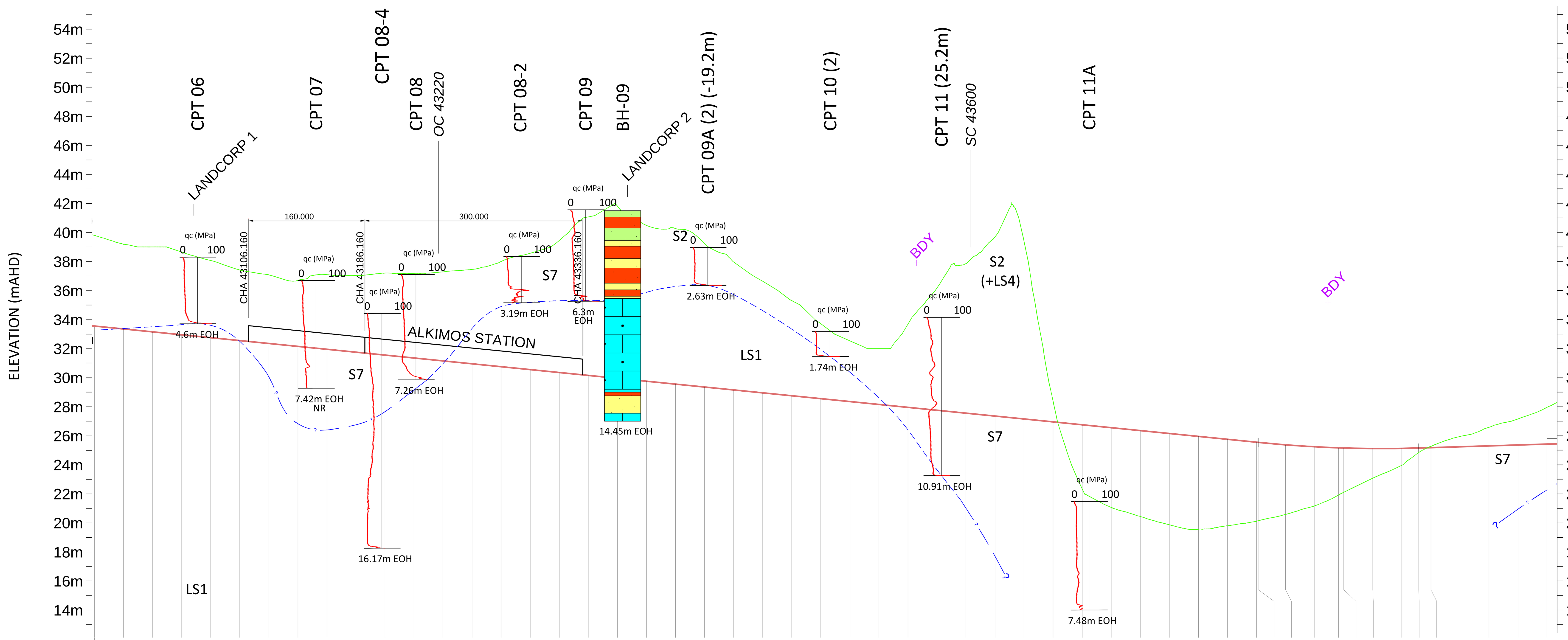
CPT Trace
qc (MPa) 0 100
3.26m EOH

Test Pit
Top of Limestone
Base of Pit

PUBLIC TRANSPORT AUTHORITY
YANCHEP RAIL EXTENSION
ENGINEERING GEOLOGICAL MODEL

DRG No
LONG-SECTION - SHEET 2 of 15
REV 0





PASSENGER DOWN MAIN THROUGH CHAINAGE	PASSENGER DOWN MAIN LOW RAIL LEVEL	EXISTING SURVEY LEVEL
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43040.000	33.154	39.000
43060.000	32.954	38.646
43080.000	32.754	38.067
43100.000	32.554	37.413
43120.000	32.354	37.073
43140.000	32.154	36.695
43160.000	31.954	37.091
43180.000	31.754	37.036
43200.000	31.554	37.199
43220.000	31.354	37.181
43240.000	31.154	37.283
43260.000	30.954	37.454
43280.000	30.754	38.003
43300.000	30.554	38.567
43320.000	30.354	39.452
43340.000	30.154	41.069
43360.000	29.954	41.807
43380.000	29.754	40.481
43400.000	29.554	40.263
43420.000	29.354	39.238
43440.000	29.154	37.966
43460.000	28.954	36.638
43480.000	28.754	35.305
43500.000	28.554	33.715
43520.000	28.354	32.537
43540.000	28.154	32.000
43560.000	27.954	33.680
43580.000	27.754	36.178
43600.000	27.554	37.844
43620.000	27.354	39.699
43640.000	27.154	39.351
43660.000	26.954	28.339
43680.000	26.754	22.338
43700.000	26.554	21.061
43720.000	26.354	20.439
43740.000	26.154	19.869
43760.000	25.954	19.561
43780.000	25.754	19.801
43800.000	25.554	20.110
43801.153	25.542	20.140
43820.000	25.375	20.581
43840.000	25.242	21.173
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43860.000	25.157	22.106
43880.000	25.119	23.079
43900.000	25.128	23.963
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43920.000	25.180	25.269
43940.000	25.241	25.948
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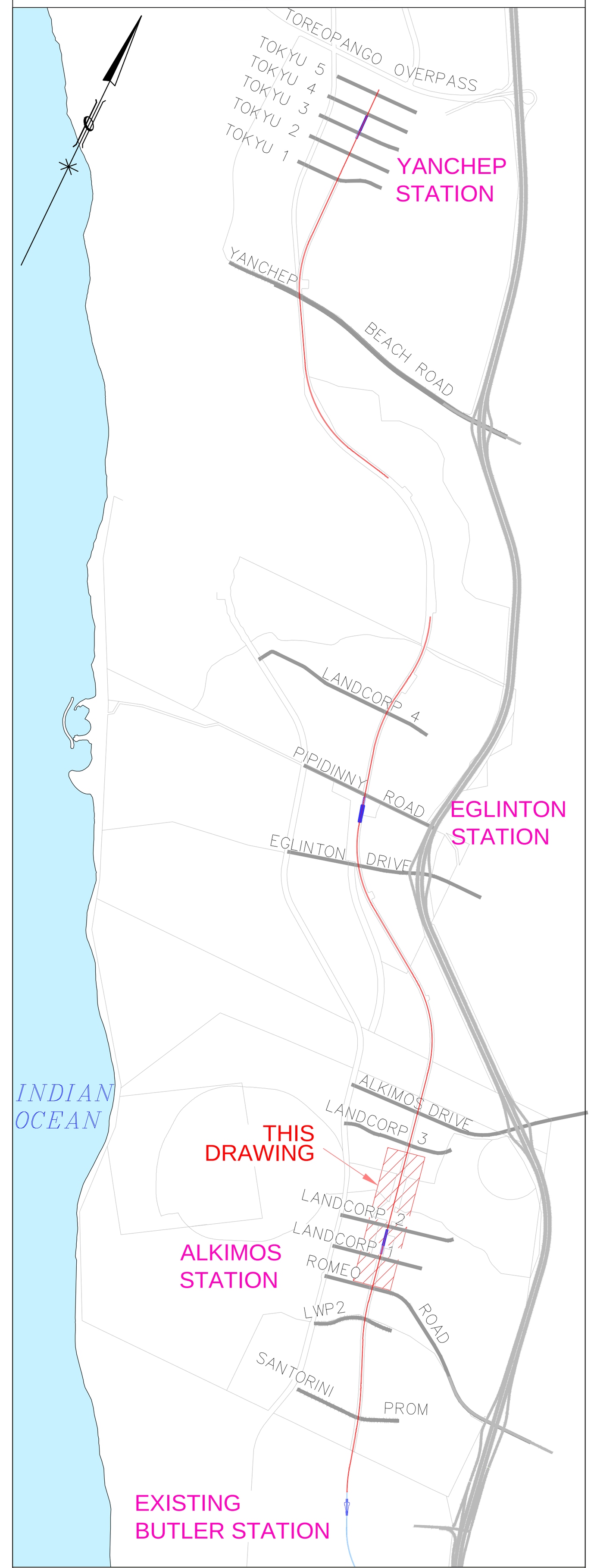

LEGEND

FEATURES (PLAN)

- PROPOSED PLATFORM
- DESIGN PASSENGER MAIN
- EXISTING PASSENGER MAIN
- PSP — PROPOSED PSP
- EXISTING RAIL RESERVE
- PROPOSED RAIL RESERVE
- DEVELOPER BOUNDARY
- LANDCORP — DEVELOPER NAME
- CADASTRE
- 2D — HORIZONTAL CURVE NUMBER

0 4 8 12
1:200 Vertical at A3
0 40 80 120
1:2000 Horizontal at A3

NOTES

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4. DESIGN ALIGNMENT: 141001_AlignP_Dn_HA15

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WorleyParsons Group

Government of Western Australia
Public Transport Authority

0 20 40 60 80 100 200m
AT ORIGINAL PLOT SIZE

Datum: GDA94
Map Grid of Australia
Zone 50

LEGEND

- Borehole
- Cone Penetrometer Test
- Test Pit (Geosite, 2010)
- SC - Subcrop (rock) exposed in cutting
- OC - Outcrop (rock) exposed on surface
- NR No Refusal

LITHOLOGY

- Silica SAND
- Siliceous Calcarenite
- Calcreted calcarenite
- Sandstone with carbonate cement

LONG-SECTION

- Natural Surface Level
- Interpreted Rock Level

GEOLOGY

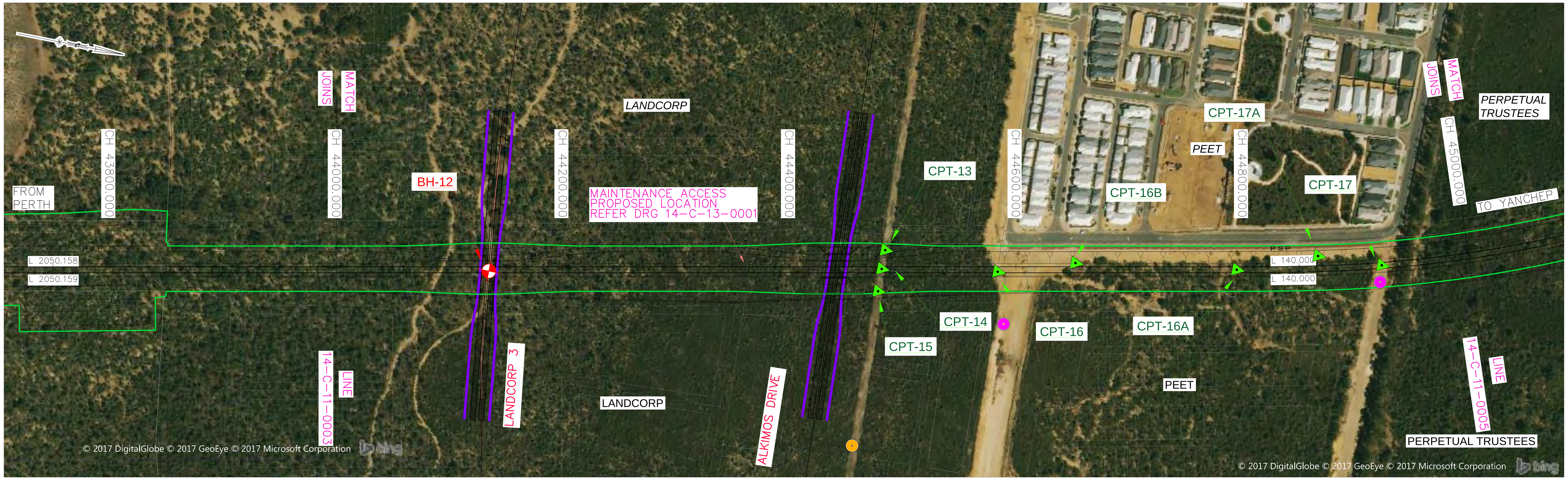
- Safety Bay Sand (S2)
- Tamala Sand (S7)
- Tamala Limestone (LS1)
- Cemented Safety Bay Sand (LS4)
- Core Loss
- Inferred Rock Level
- Design Rail Level

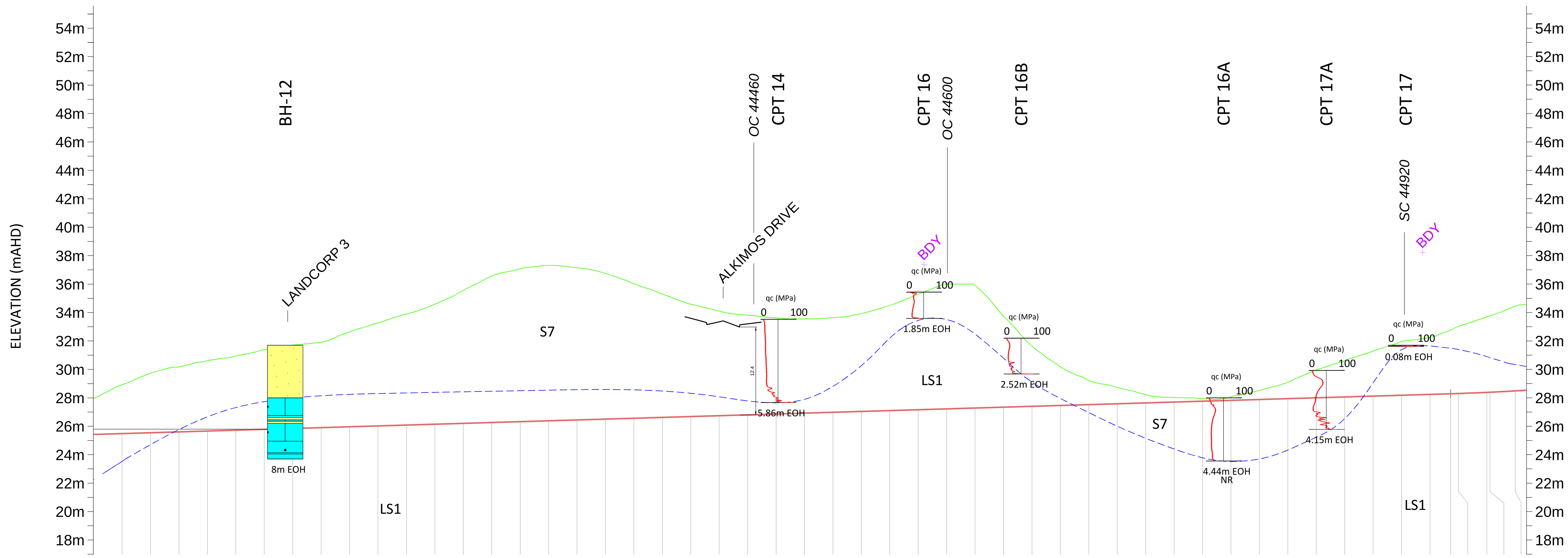
CPT Trace
qc (MPa)
0 100
3.26m EOH

Test Pit
Top of Limestone
Base of Pit

PUBLIC TRANSPORT AUTHORITY
YANCHEP RAIL EXTENSION
ENGINEERING GEOLOGICAL MODEL

DRG No
LONG-SECTION - SHEET 3 of 15
REV
0





PASSENGER DOWN MAIN THROUGH CHAINAGE	EXISTING SURVEY LEVEL	PASSENGER DOWN MAIN LOW RAIL LEVEL
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44040.000	29.723	25.541
44060.000	30.174	25.601
44080.000	30.608	25.661
44100.000	30.954	25.721
44120.000	31.384	25.781
44140.000	31.712	25.841
44160.000	31.911	25.901
44180.000	32.641	25.961
44200.000	33.273	26.022
44220.000	33.892	26.082
44240.000	34.590	26.142
44260.000	35.561	26.202
44280.000	36.568	26.262
44300.000	37.082	26.322
44320.000	37.317	26.382
44340.000	37.144	26.442
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44380.000	36.030	26.562
44400.000	35.300	26.622
44420.000	34.586	26.682
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44520.000	33.637	26.983
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44560.000	34.506	27.103
44580.000	35.292	27.163
44600.000	36.000	27.223
44620.000	35.909	27.283
44640.000	33.744	27.343
44660.000	31.643	27.403
44680.000	30.190	27.463
44700.000	29.213	27.523
44720.000	28.733	27.583
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44860.000	29.958	28.004
44880.000	30.610	28.064
44900.000	31.294	28.124
44920.000	31.955	28.184
44940.000	32.258	28.244
44954.552	32.772	28.288
44960.000	33.031	28.305
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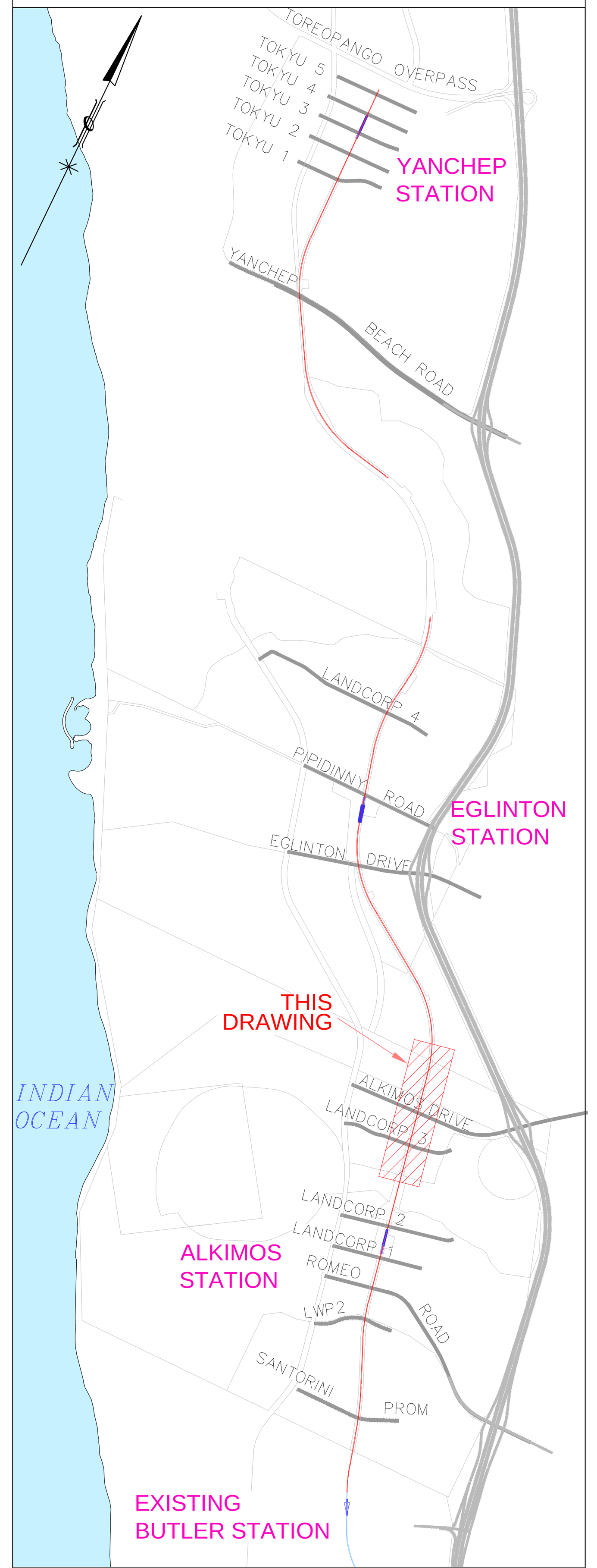
SHEET LOCALITY



LEGEND

FEATURES (PLAN)

- PROPOSED PLATFORM
- DESIGN PASSENGER MAIN
- EXISTING PASSENGER MAIN
- PROPOSED PSP
- EXISTING RAIL RESERVE
- PROPOSED RAIL RESERVE
- DEVELOPER BOUNDARY
- LANDCORP — DEVELOPER NAME
- CADASTRE
- HORIZONTAL CURVE NUMBER

1:200 Vertical at A3

1:2000 Horizontal at A3

NOTES

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4. DESIGN ALIGNMENT: 141001_AlignP_Dn_HA15

Advisian
WorleyParsons Group

Government of Western Australia
Public Transport Authority

0 20 40 60 80 100 200m
AT ORIGINAL PLOT SIZE

Datum: GDA94 Map Grid of Australia Zone 50

LEGEND

- Borehole
- Cone Penetrometer Test
- Test Pit (Geosite, 2010)
- SC - Subcrop (rock) exposed in cutting
- OC - Outcrop (rock) exposed on surface
- NR — No Refusal

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- Silica SAND
- Siliceous Calcarenite
- Calcreted calcarenite
- Sandstone with carbonate cement

LONG-SECTION

- Natural Surface Level
- Interpreted Rock Level

GEOLOGY

- Safety Bay Sand (S2)
- Tamala Sand (S7)
- Tamala Limestone (LS1)
- Cemented Safety Bay Sand (LS4)
- Core Loss
- Inferred Rock Level
- Design Rail Level

CPT Trace

qc (MPa) 0 100

3.26m EOH

Test Pit

Top of Limestone

Base of Pit

PUBLIC TRANSPORT AUTHORITY
YANCHEP RAIL EXTENSION
ENGINEERING GEOLOGICAL MODEL

DRG No

LONG-SECTION - SHEET 4 of 15

REV 0

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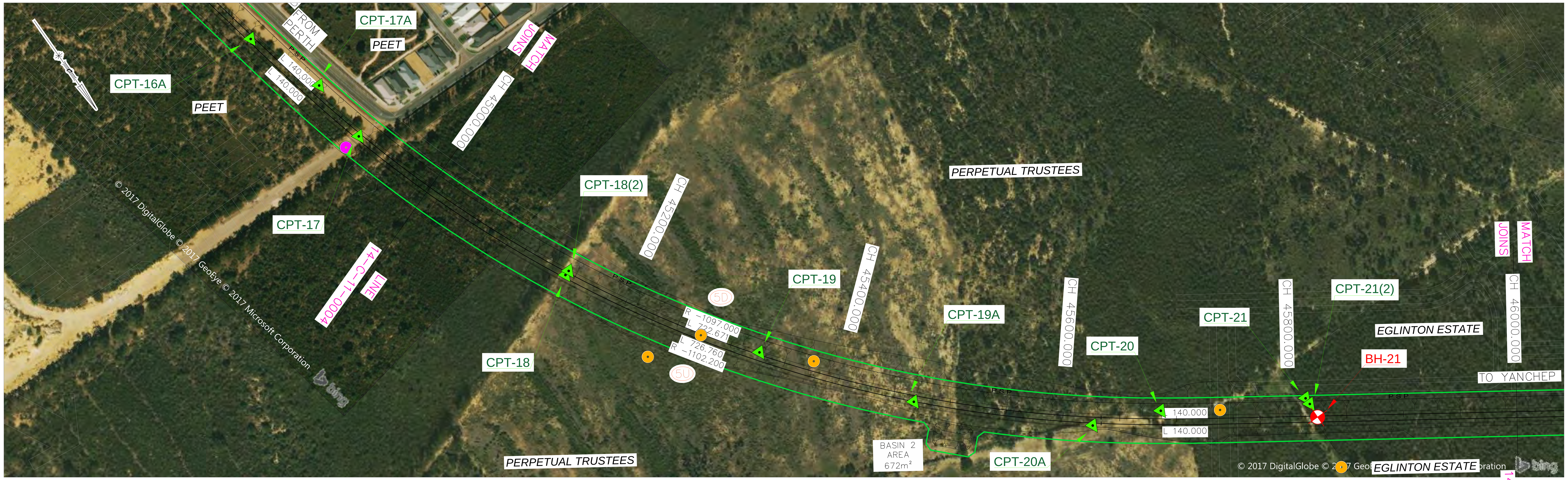

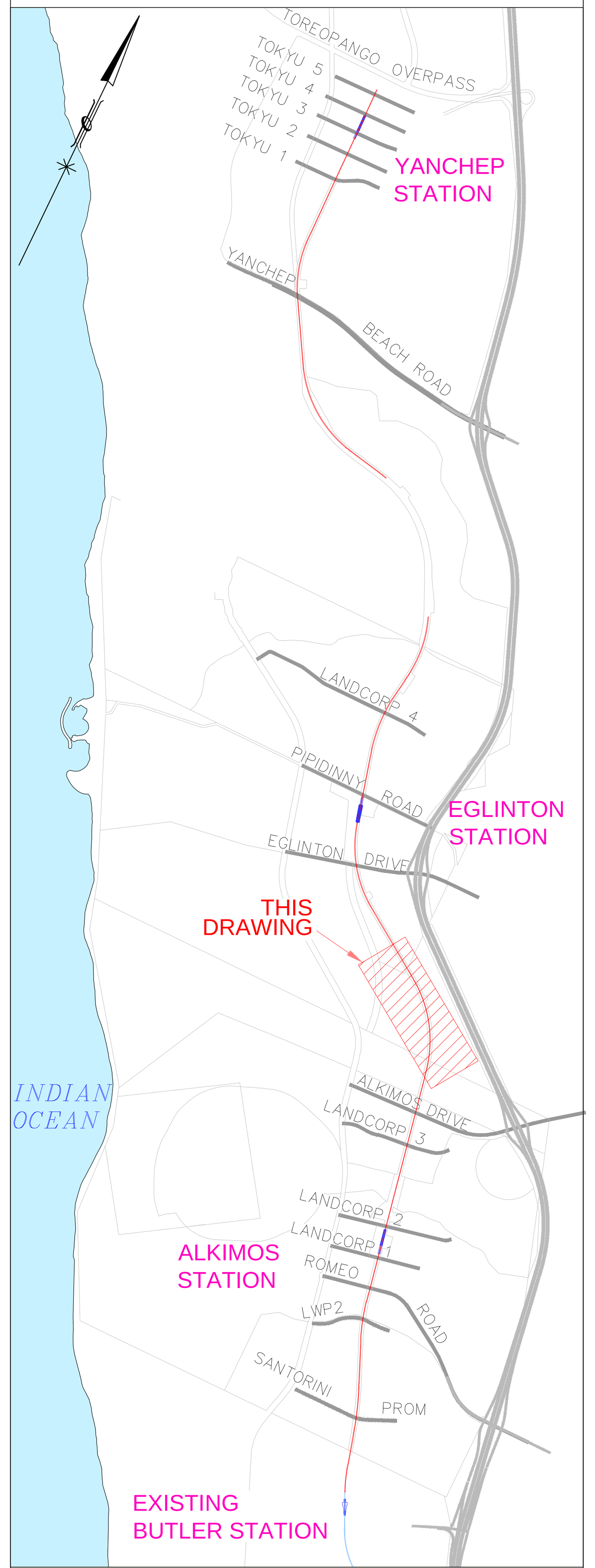

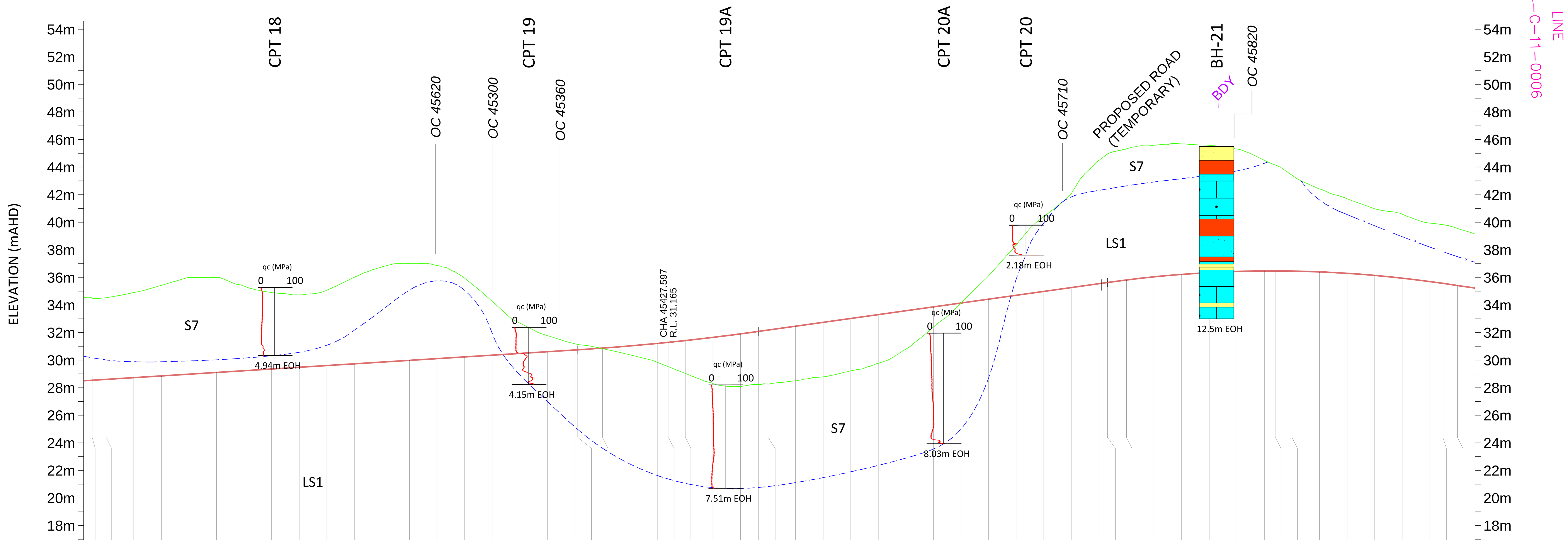

Datum R.L. 23m

PASSENGER DOWN MAIN LOW RAIL LEVEL	28.486	28.544	28.608	28.734	28.859	28.985	29.110	29.236	29.361	29.486	29.612	29.737	29.863	29.988	30.114	30.239	30.365	30.490	30.616
EXISTING SURVEY LEVEL	34.460	34.518	34.532	34.902	35.431	36.000	36.000	35.375	34.905	34.735	35.077	36.019	36.775	37.000	36.869	35.947	34.261	32.689	31.779
PASSENGER DOWN MAIN THROUGH CHAINAGE	45000.000	45009.797	45020.000	45040.000	45060.000	45080.000	45100.000	45120.000	45140.000	45160.000	45180.000	45200.000	45220.000	45240.000	45260.000	45280.000	45300.000	45320.000	45340.000

PASSENGER DOWN MAIN LOW RAIL LEVEL	30.741	30.753	30.876	31.035	31.217	31.292	31.423	31.652	31.906	32.086	32.181	32.462	32.743	33.024	33.304	33.585	33.866	34.147	34.427
EXISTING SURVEY LEVEL	31.184	31.149	30.831	30.383	29.831	29.530	29.040	28.305	28.089	28.238	28.268	28.500	28.786	29.219	29.776	30.794	32.406	34.152	36.126
PASSENGER DOWN MAIN THROUGH CHAINAGE	45360.000	45361.985	45380.000	45400.000	45420.000	45427.597	45440.000	45460.000	45480.000	45493.209	45500.000	45520.000	45540.000	45560.000	45580.000	45600.000	45620.000	45640.000	45660.000

PASSENGER DOWN MAIN LOW RAIL LEVEL	34.708	34.989	35.270	35.550	35.638	35.820	36.045	36.223	36.353	36.437	36.473	36.475	36.463	36.405	36.301	36.149	35.951	35.705	35.572	35.418
EXISTING SURVEY LEVEL	38.363	40.410	42.096	44.500	44.961	45.330	45.591	45.694	45.584	45.314	44.500	44.158	43.418	42.424	41.715	40.989	40.590	39.945	39.830	39.560
PASSENGER DOWN MAIN THROUGH CHAINAGE	45680.000	45700.000	45720.000	45740.000	45746.231	45760.000	45780.000	45800.000	45820.000	45840.000	45860.000	45867.847	45880.000	45900.000	45920.000	45940.000	45960.000	45980.000	45989.463	46000.000

LEGEND

FEATURES (PLAN)

- PROPOSED PLATFORM
- DESIGN PASSENGER MAIN
- EXISTING PASSENGER MAIN
- P S P — PROPOSED PSP
- EXSTING RAIL RESERVE
- PROPOSED RAIL RESERVE
- DEVELOPER BOUNDARY
- LANDCORP — DEVELOPER NAME
- CADASTRE
- 2D — HORIZONTAL CURVE NUMBER

0 4 8 12
1:200 Vertical at A3
0 40 80 120
1:2000 Horizontal at A3

NOTES

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Advisian
WorleyParsons Group

Government of Western Australia
Public Transport Authority

0 20 40 60 80 100 200m
AT ORIGINAL PLOT SIZE

Datum: GDA94
Map Grid of Australia
Zone 50

LEGEND

- Borehole
- Cone Penetrometer Test
- Test Pit (Geosite, 2010)
- SC - Subcrop (rock) exposed in cutting
- OC - Outcrop (rock) exposed on surface
- NR No Refusal

LITHOLOGY

- Silica SAND
- Siliceous Calcarenite
- Calcreted calcarenite
- Sandstone with carbonate cement

LONG-SECTION

- Natural Surface Level
- Interpreted Rock Level

GEOLOGY

- Safety Bay Sand (S2)
- Tamala Sand (S7)
- Tamala Limestone (LS1)
- Cemented Safety Bay Sand (LS4)
- Core Loss
- Inferred Rock Level
- Design Rail Level

CPT Trace

qc (MPa) 0 100
3.26m EOH

Test Pit

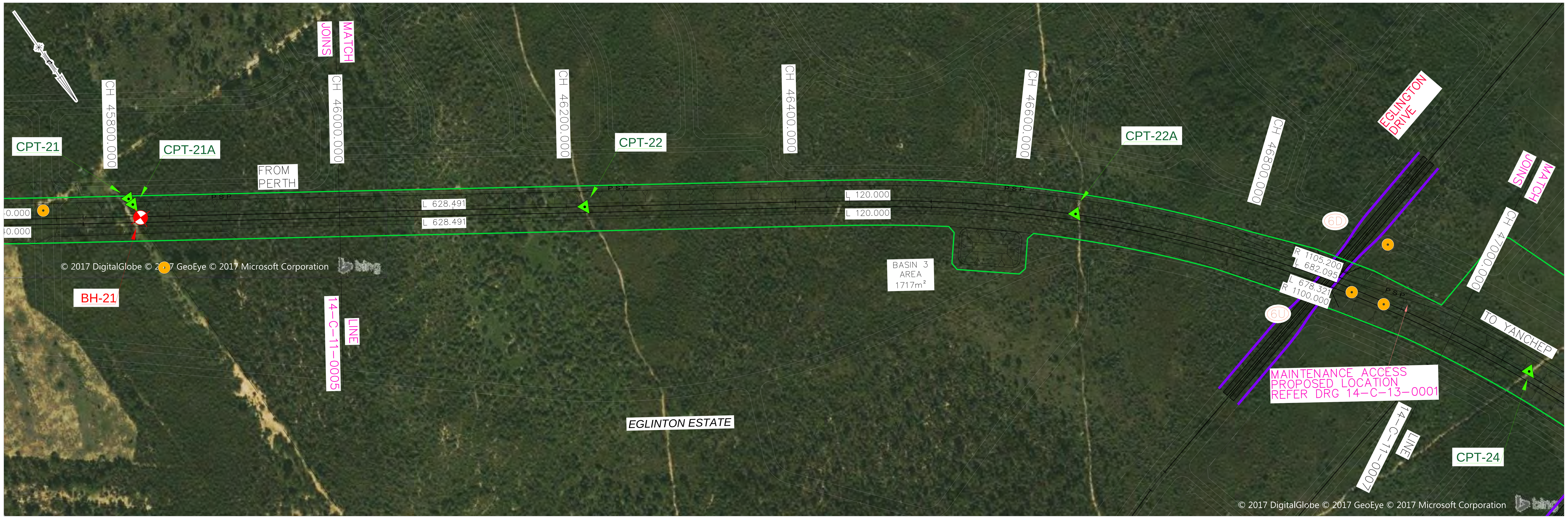
Top of Limestone
Base of Pit

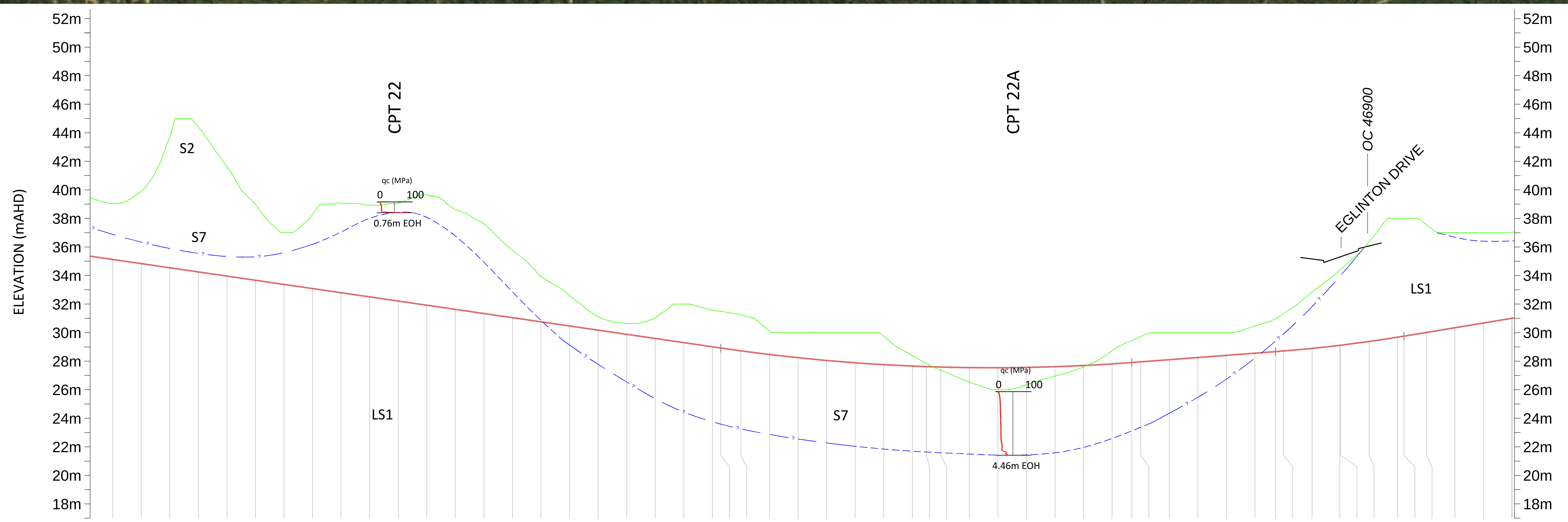
PUBLIC TRANSPORT AUTHORITY
YANCHEP RAIL EXTENSION
ENGINEERING GEOLOGICAL MODEL

DRG No

LONG-SECTION - SHEET 5 of 15

REV 0

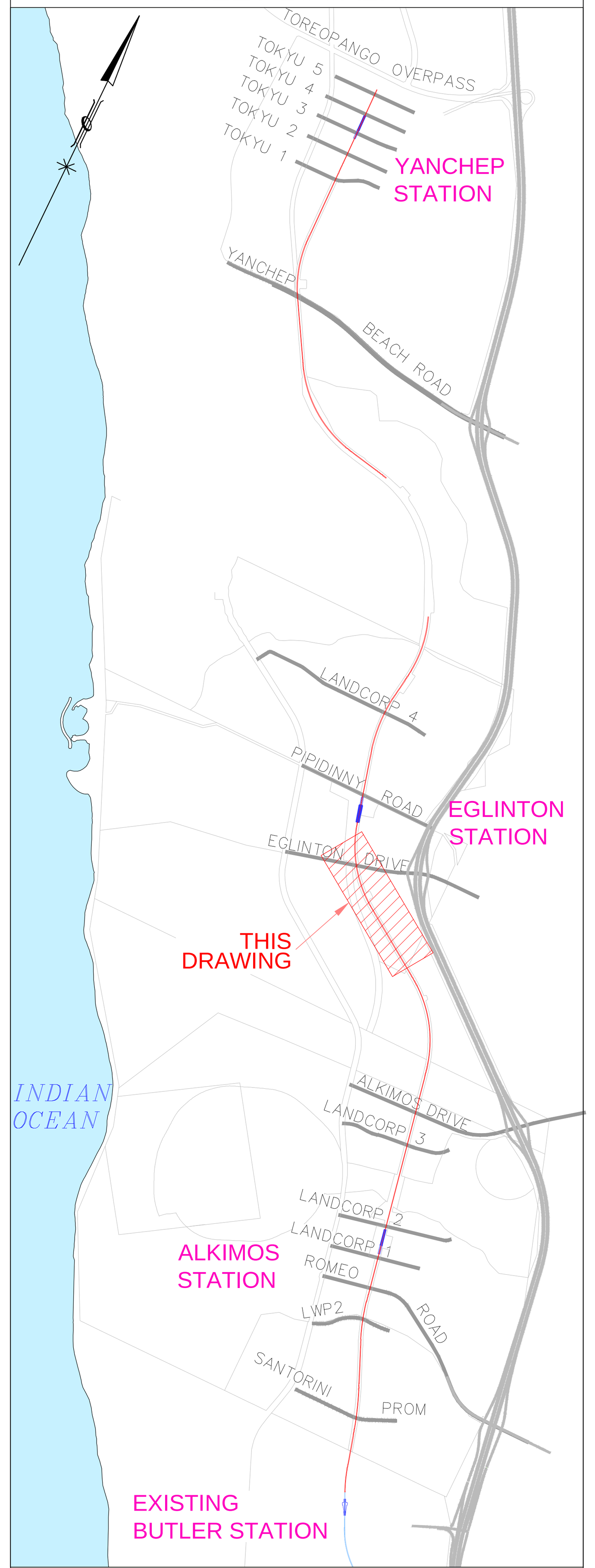




Datum R.L. 20m

PASSENGER DOWN MAIN THROUGH CHAINAGE	PASSENGER DOWN MAIN LOW RAIL LEVEL	EXISTING SURVEY LEVEL
46000.000	35.418	39.560
46020.000	35.127	39.032
46040.000	34.835	39.892
46060.000	34.544	43.731
46080.000	34.252	44.400
46100.000	33.961	41.610
46120.000	33.669	38.988
46140.000	33.378	37.000
46160.000	33.086	38.299
46180.000	32.794	39.060
46200.000	32.503	38.933
46220.000	32.211	39.088
46240.000	31.920	39.660
46260.000	31.628	38.622
46280.000	31.337	37.634
46300.000	31.045	35.766
46320.000	30.753	33.931
46340.000	30.462	32.608
46360.000	30.170	31.106
46380.000	29.879	30.642
46400.000	29.587	31.047
46420.000	29.296	32.000
46440.000	29.004	31.567
46445.901	28.918	31.487
46460.000	28.720	31.230
46480.000	28.466	30.124
46500.000	28.242	30.000
46520.000	28.049	30.000
46540.000	27.887	30.000
46560.000	27.755	29.748
46580.000	27.655	28.392
46589.819	27.617	27.835
46600.000	27.585	27.357
46620.000	27.546	26.533
46640.000	27.537	26.000
46660.000	27.560	26.349
46680.000	27.613	26.950
46700.000	27.697	27.603
46720.000	27.812	28.718
46733.737	27.908	29.436
46740.000	27.956	29.719
46760.000	28.107	30.000
46780.000	28.258	30.000
46800.000	28.410	30.000
46820.000	28.561	30.468
46834.437	28.670	30.974
46840.000	28.714	31.333
46860.000	28.896	32.846
46879.384	29.111	34.365
46880.000	29.118	34.421
46900.000	29.381	36.375
46920.000	29.683	38.000
46924.331	29.754	38.000
46940.000	30.013	37.565
46960.000	30.344	37.000
46980.000	30.675	37.000
47000.000	31.007	37.002

SHEET LOCALITY



LEGEND

FEATURES (PLAN)

- PROPOSED PLATFORM
- DESIGN PASSENGER MAIN
- EXISTING PASSENGER MAIN
- P S P — PROPOSED PSP
- EXSTING RAIL RESERVE
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0 4 8 12
1:200 Vertical at A3
0 40 80 120
1:2000 Horizontal at A3

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Advisian
WorleyParsons Group

Government of Western Australia
Public Transport Authority

0 20 40 60 80 100 200m
AT ORIGINAL PLOT SIZE

Datum: GDA94
Map Grid of Australia
Zone 50

LEGEND

- Borehole
- Cone Penetrometer Test
- Test Pit (Geosite, 2010)
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- Calcreted calcarenite
- Sandstone with carbonate cement

LONG-SECTION

- Natural Surface Level
- Interpreted Rock Level

GEOLOGY

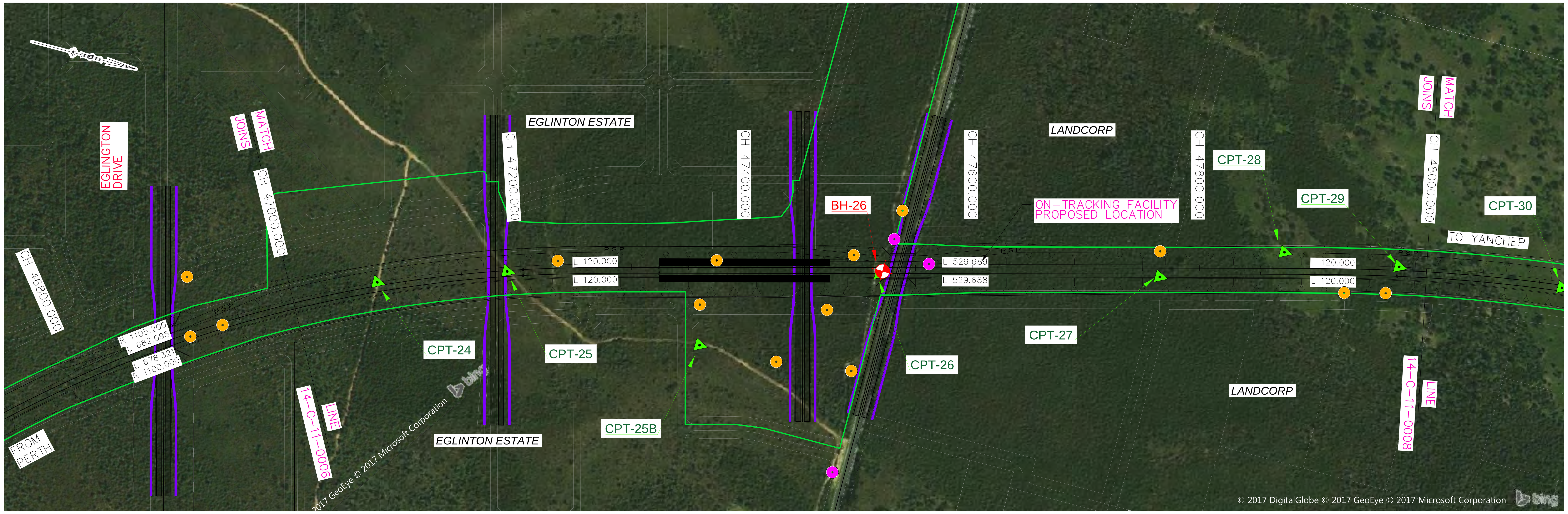
- Safety Bay Sand (S2)
- Tamala Sand (S7)
- Tamala Limestone (LS1)
- Cemented Safety Bay Sand (LS4)
- Core Loss
- Inferred Rock Level
- Design Rail Level

CPT Trace
qc (MPa)
0 100
3.26m EOH

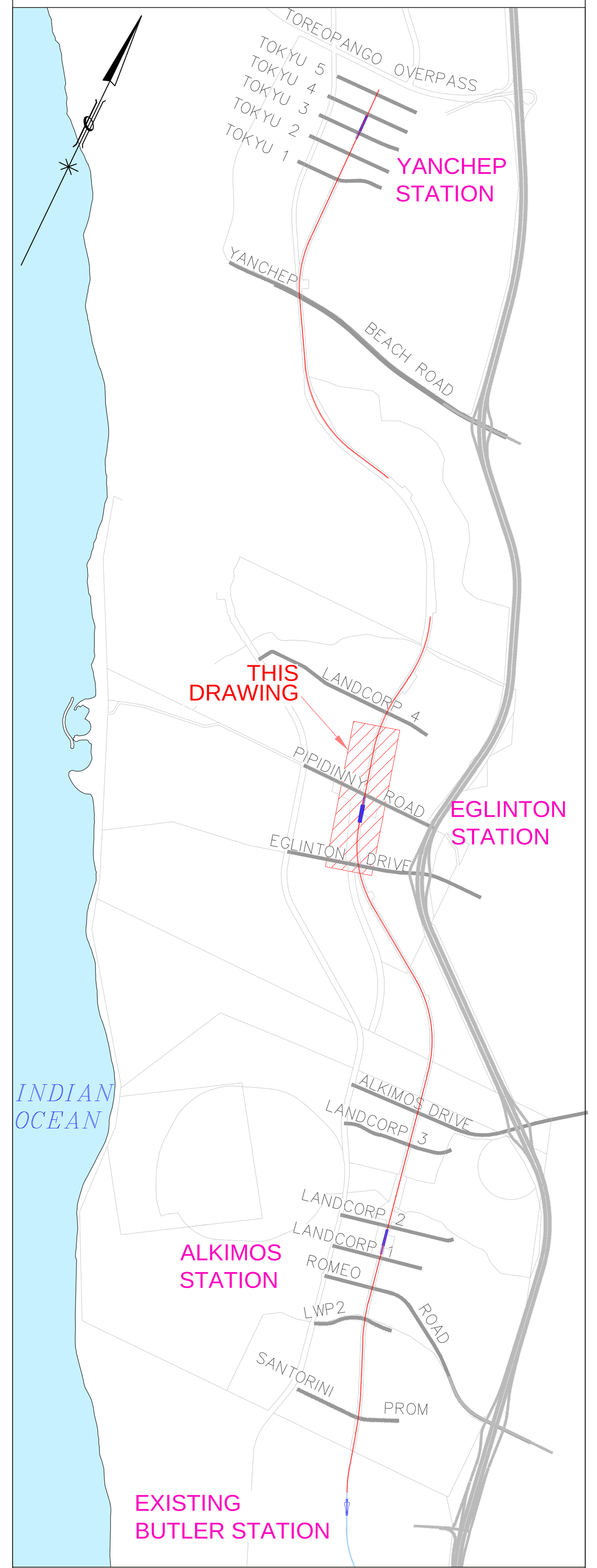
Test Pit
Top of Limestone
Base of Pit

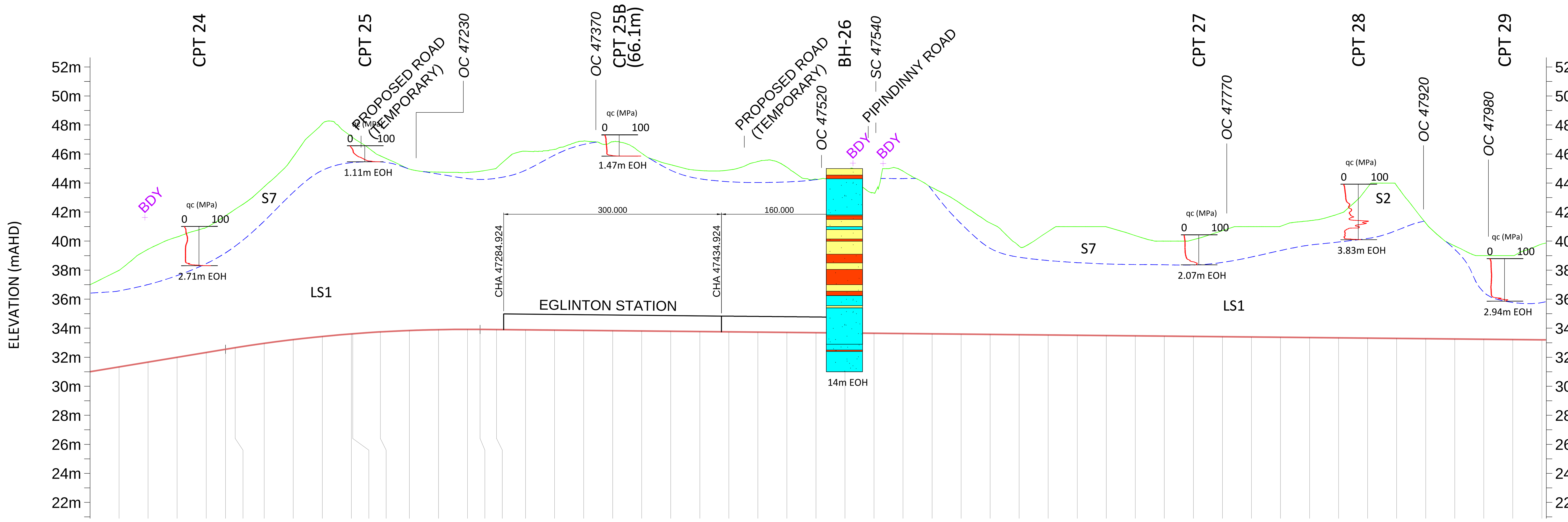
PUBLIC TRANSPORT AUTHORITY
YANCHEP RAIL EXTENSION
ENGINEERING GEOLOGICAL MODEL

DRG No
LONG-SECTION - SHEET 6 of 15
REV
0



SHEET LOCALITY





Datum R.L. 25m

PASSENGER DOWN MAIN LOW RAIL LEVEL	31.007	31.338	31.669	32.000	32.331	32.551	32.660	32.957	33.215	33.433	33.610	33.618	33.748	33.846	33.903	33.921	33.916	33.905
EXISTING SURVEY LEVEL	37.002	37.989	39.442	40.289	40.941	41.743	42.199	43.754	45.812	48.096	47.213	47.141	45.876	44.968	44.757	44.732	44.814	45.046
PASSENGER DOWN MAIN THROUGH CHAINAGE	47000.000	47020.000	47040.000	47060.000	47080.000	47093.318	47100.000	47120.000	47140.000	47160.000	47180.000	47180.969	47200.000	47220.000	47240.000	47260.000	47268.620	47280.000

PASSENGER DOWN MAIN LOW RAIL LEVEL	33.886	33.866	33.847	33.827	33.807	33.788	33.768	33.749	33.729	33.710	33.690	33.671	33.651	33.631	33.612	33.592	33.573	33.553
EXISTING SURVEY LEVEL	46.198	46.324	46.897	46.849	46.056	45.267	44.868	44.902	45.488	45.090	44.273	44.532	43.316	44.825	43.695	42.563	41.252	39.653
PASSENGER DOWN MAIN THROUGH CHAINAGE	47300.000	47320.000	47340.000	47360.000	47380.000	47400.000	47420.000	47440.000	47460.000	47480.000	47500.000	47520.000	47540.000	47560.000	47580.000	47600.000	47620.000	47640.000

PASSENGER DOWN MAIN LOW RAIL LEVEL	33.534	33.514	33.495	33.475	33.455	33.436	33.416	33.397	33.377	33.358	33.338	33.319	33.299	33.280	33.260	33.240	33.221	33.201
EXISTING SURVEY LEVEL	40.666	41.000	40.991	40.382	40.000	40.103	40.727	41.000	41.023	41.407	41.878	43.702	43.826	41.252	39.672	39.000	39.000	39.803
PASSENGER DOWN MAIN THROUGH CHAINAGE	47660.000	47680.000	47700.000	47720.000	47740.000	47760.000	47780.000	47800.000	47820.000	47840.000	47860.000	47880.000	47900.000	47920.000	47940.000	47960.000	47980.000	48000.000

LEGEND

FEATURES (PLAN)

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- EXSTING RAIL RESERVE
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0 4 8 12
1:200 Vertical at A3
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Advisian
WorleyParsons Group

Government of Western Australia
Public Transport Authority

0 20 40 60 80 100 200m
AT ORIGINAL PLOT SIZE

Datum: GDA94
Map Grid of Australia
Zone 50

LEGEND

- Borehole
- Cone Penetrometer Test
- Test Pit (Geosite, 2010)
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- Silica SAND
- Siliceous Calcarenite
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- Sandstone with carbonate cement

LONG-SECTION

- Natural Surface Level
- Interpreted Rock Level

GEOLOGY

- Safety Bay Sand (S2)
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- Tamala Limestone (LS1)
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- Core Loss
- Inferred Rock Level
- Design Rail Level

CPT Trace

qc (MPa)
0 100
3.26m EOH

Test Pit
Top of Limestone
Base of Pit

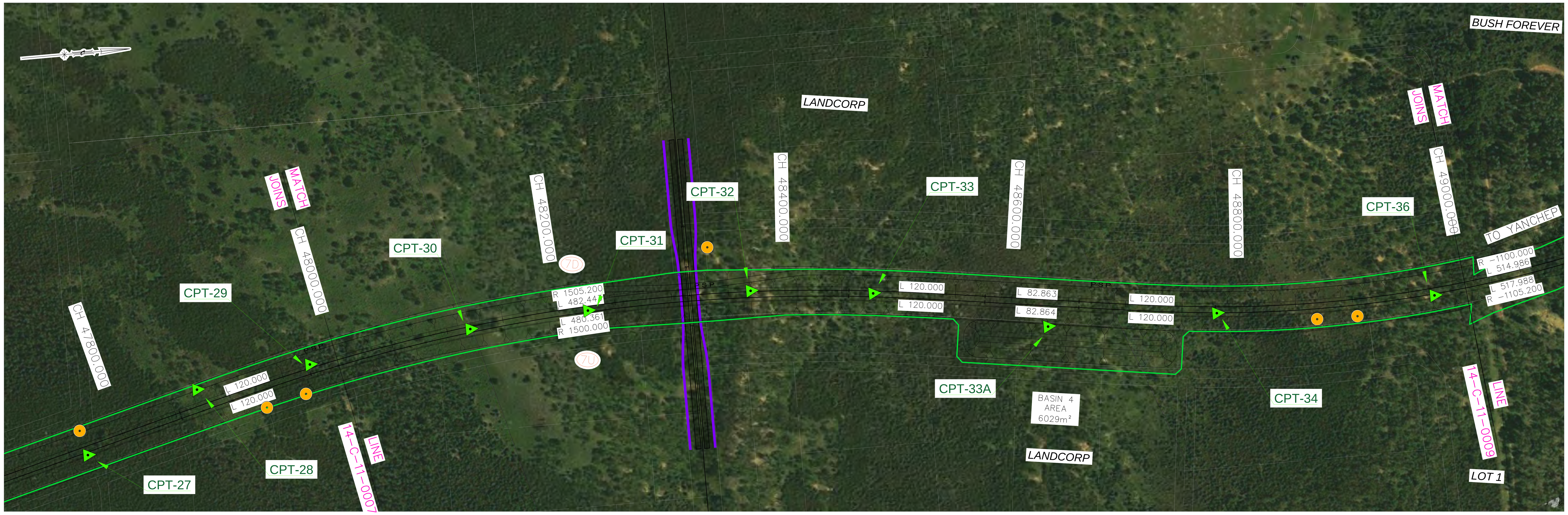
PUBLIC TRANSPORT AUTHORITY
YANCHEP RAIL EXTENSION
ENGINEERING GEOLOGICAL MODEL

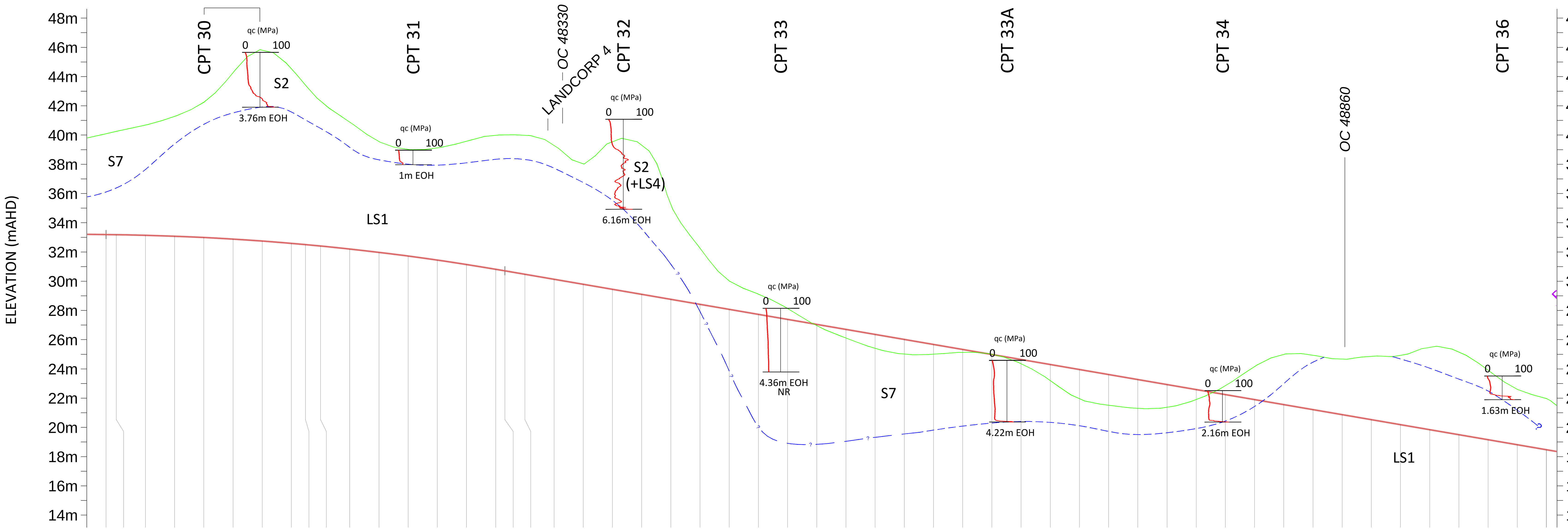
DRG No

LONG-SECTION - SHEET 7 of 15

REV
0

DATE & TIME: 07/07/2017 11:18:52 AM USER NAME: paul.rolfe LOCATION: I:\Projects\301012-02366 Butler to Yanchep Rail Extension Geotech\5_Engineering\GM-Geomatics\07CAD\FIGURES\FIGURES_ALL_R2015.dwg

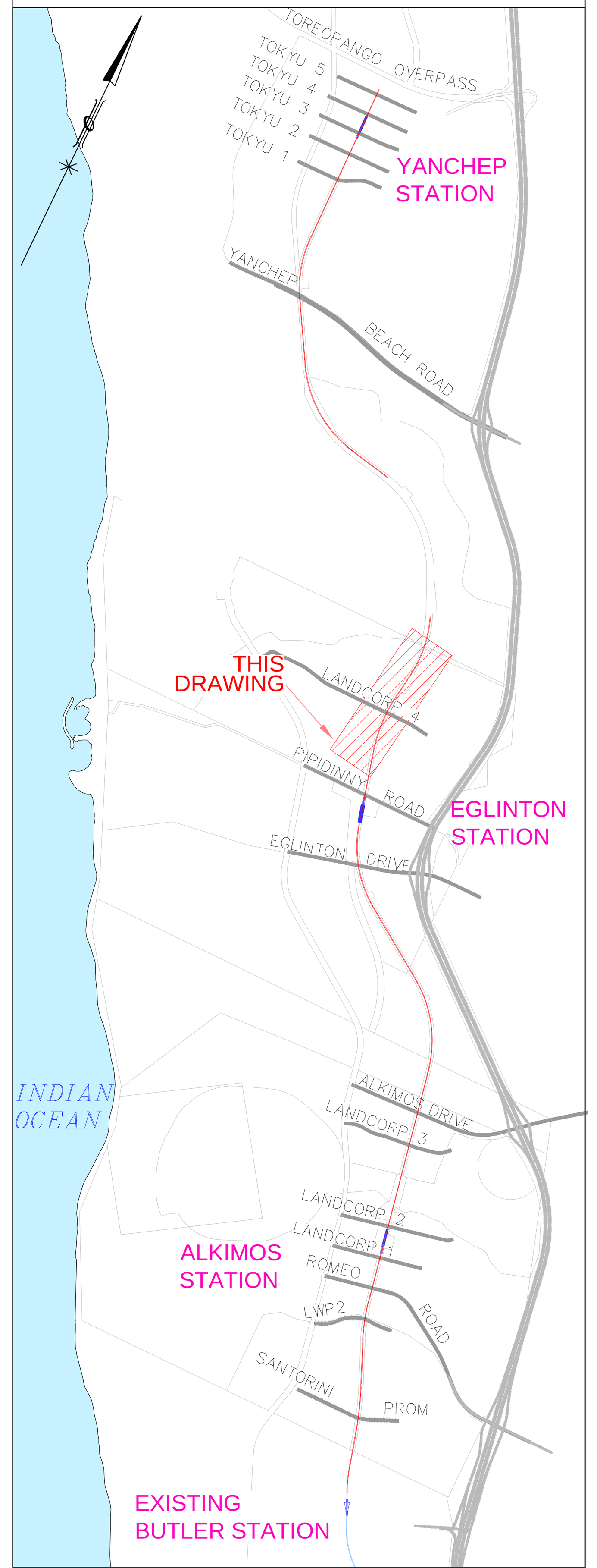




Datum R.L. 13m

PASSENGER DOWN MAIN THROUGH CHAINAGE	PASSENGER DOWN MAIN LOW RAIL LEVEL	EXISTING SURVEY LEVEL
48000.000	33.201	39.803
48013.008	33.189	40.085
48020.000	33.180	40.246
48040.000	33.141	40.676
48060.000	33.077	41.268
48080.000	32.990	42.233
48100.000	32.880	44.260
48120.000	32.745	45.851
48140.000	32.587	44.544
48149.640	32.503	43.406
48160.000	32.406	42.297
48180.000	32.200	40.884
48200.000	31.971	39.545
48220.000	31.719	39.000
48240.000	31.442	39.110
48260.000	31.142	39.567
48280.000	30.819	40.000
48286.272	30.712	40.000
48300.000	30.477	39.946
48320.000	30.134	39.324
48340.000	29.791	38.000
48360.000	29.448	39.629
48380.000	29.105	39.360
48400.000	28.762	35.201
48420.000	28.419	32.253
48440.000	28.076	30.011
48460.000	27.733	29.114
48480.000	27.390	28.134
48500.000	27.047	26.941
48520.000	26.704	26.108
48540.000	26.361	25.394
48560.000	26.019	25.000
48580.000	25.676	25.000
48600.000	25.333	25.135
48620.000	24.990	25.004
48640.000	24.647	24.356
48660.000	24.304	23.204
48680.000	23.961	21.925
48700.000	23.618	21.511
48720.000	23.275	21.290
48740.000	22.932	21.355
48760.000	22.589	21.892
48780.000	22.246	22.836
48800.000	21.903	24.162
48820.000	21.560	25.000
48840.000	21.217	24.940
48860.000	20.874	24.642
48880.000	20.531	24.879
48900.000	20.189	24.890
48920.000	19.846	25.519
48940.000	19.503	25.172
48960.000	19.160	23.910
48980.000	18.817	22.596
49000.000	18.474	21.971

SHEET LOCALITY



LEGEND

FEATURES (PLAN)

- PROPOSED PLATFORM
- DESIGN PASSENGER MAIN
- EXISTING PASSENGER MAIN
- PSP — PROPOSED PSP
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Advisian
WorleyParsons Group

Government of Western Australia
Public Transport Authority

0 20 40 60 80 100 200m
AT ORIGINAL PLOT SIZE

Datum: GDA94
Map Grid of Australia
Zone 50

LEGEND

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CPT Trace

qc (MPa)
0 100
3.26m EOH

Test Pit

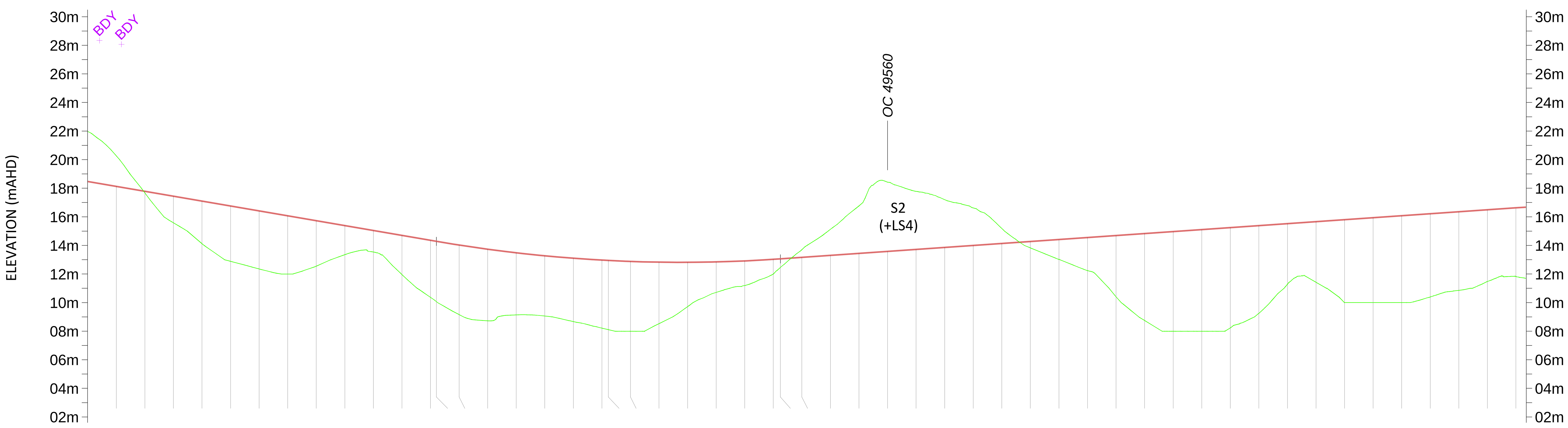
Top of Limestone
Base of Pit

PUBLIC TRANSPORT AUTHORITY
YANCHEP RAIL EXTENSION
ENGINEERING GEOLOGICAL MODEL

DRG No

LONG-SECTION - SHEET 8 of 15

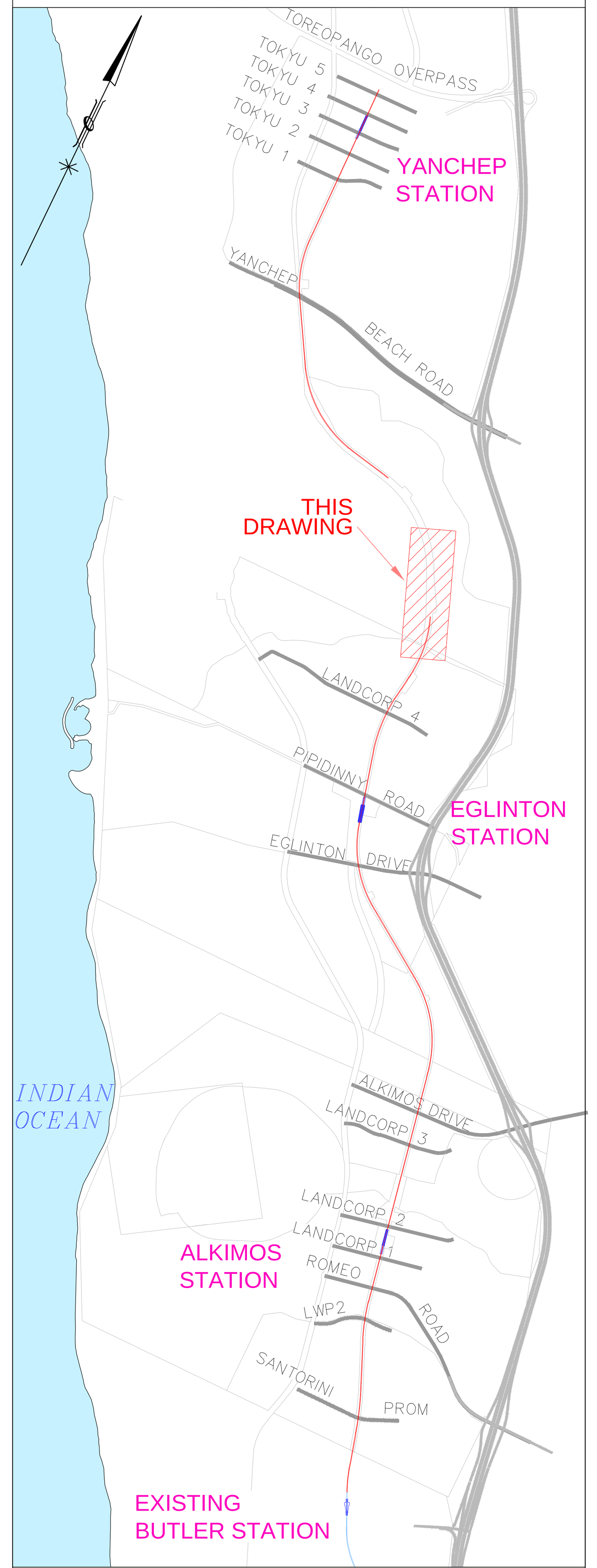
REV
0



Datum R.L. 2m

PASSENGER DOWN MAIN THROUGH CHAINAGE	PASSENGER DOWN MAIN LOW RAIL LEVEL	EXISTING SURVEY LEVEL
49000.000	18.474	21.971
49020.000	18.131	20.260
49040.000	17.788	17.674
49060.000	17.445	15.582
49080.000	17.102	14.124
49100.000	16.759	12.888
49120.000	16.416	12.354
49140.000	16.073	12.000
49160.000	15.730	12.551
49180.000	15.387	13.352
49200.000	15.044	13.540
49220.000	14.701	11.960
49240.000	14.359	10.367
49244.136	14.288	10.070
49260.000	14.028	9.164
49280.000	13.737	8.728
49300.000	13.486	9.140
49320.000	13.275	9.062
49340.000	13.103	8.673
49360.000	12.972	8.215
49364.543	12.948	8.105
49380.000	12.881	8.000
49400.000	12.830	8.529
49420.000	12.818	9.716
49440.000	12.847	10.714
49460.000	12.916	11.195
49480.000	13.025	11.996
49484.949	13.058	12.458
49500.000	13.162	13.703
49520.000	13.301	15.128
49540.000	13.440	16.766
49560.000	13.578	18.426
49580.000	13.717	17.781
49600.000	13.856	17.203
49620.000	13.994	16.623
49640.000	14.133	15.188
49660.000	14.272	13.828
49680.000	14.410	13.017
49700.000	14.549	12.239
49720.000	14.688	10.408
49740.000	14.827	8.749
49760.000	14.965	8.000
49780.000	15.104	8.000
49800.000	15.243	8.229
49820.000	15.381	9.251
49840.000	15.520	11.286
49860.000	15.659	11.422
49880.000	15.797	10.000
49900.000	15.936	10.000
49920.000	16.075	10.000
49940.000	16.213	10.394
49960.000	16.352	10.857
49980.000	16.491	11.478
50000.000	16.629	11.828

SHEET LOCALITY



LEGEND

FEATURES (PLAN)

- PROPOSED PLATFORM
- DESIGN PASSENGER MAIN
- EXISTING PASSENGER MAIN
- PROPOSED PSP
- EXSTING RAIL RESERVE
- PROPOSED RAIL RESERVE
- DEVELOPER BOUNDARY
- LANDCORP — DEVELOPER NAME
- CADASTRE
- HORIZONTAL CURVE NUMBER

0 4 8 12
1:200 Vertical at A3
0 40 80 120
1:2000 Horizontal at A3

NOTES

1. ALL LEVELS AND DIMENSIONS ARE IN METRES UNLESS SHOWN OTHERWISE
2. THESE PLANS ARE FOR TRACK ALIGNMENT ONLY AND SHOULD BE READ IN CONJUNCTION WITH ASSOCIATED PLANS FOR ROADWORKS, CIVILWORKS, STRUCTURES, ELECTRIFICATION etc.
3. ALLTRACK BALLASTED UNLESS SHOWN OTHERWISE.
4. DESIGN ALIGNMENT: 141001_AlignP_Dn_HA15

Advisian
WorleyParsons Group

Government of Western Australia
Public Transport Authority

0 20 40 60 80 100 200m
AT ORIGINAL PLOT SIZE

Datum: GDA94
Map Grid of Australia
Zone 50

LEGEND

- Borehole
- Cone Penetrometer Test
- Test Pit (Geosite, 2010)
- SC - Subcrop (rock) exposed in cutting
- OC - Outcrop (rock) exposed on surface
- NR No Refusal

LITHOLOGY

- Silica SAND
- Siliceous Calcarenite
- Calcreted calcarenite
- Sandstone with carbonate cement

LONG-SECTION

- Natural Surface Level
- Interpreted Rock Level
- Inferred Rock Level
- Design Rail Level

GEOLOGY

- Safety Bay Sand (S2)
- Tamala Sand (S7)
- Tamala Limestone (LS1)
- Cemented Safety Bay Sand (LS4)
- Core Loss

CPT Trace
qc (MPa)
0 100
3.26m EOH

Test Pit
Top of Limestone
Base of Pit

PUBLIC TRANSPORT AUTHORITY
YANCHEP RAIL EXTENSION
ENGINEERING GEOLOGICAL MODEL

DRG No
LONG-SECTION - SHEET 9 of 15
REV
0