



APPENDIX C

Limitations



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For more information, visit golder.com

Africa	+ 27 11 254 4800
Asia	+ 86 21 6258 5522
Australasia	+ 61 3 8862 3500
Europe	+ 44 1628 851851
North America	+ 1 800 275 3281
South America	+ 56 2 2616 2000

solutions@golder.com
www.golder.com

Golder Associates Pty Ltd
Building 7, Botanicca Corporate Park
570 – 588 Swan Street
Richmond, Victoria 3121
Australia
T: +61 3 8862 3500



Appendix B

Golder Associates Ground Movement Assessment EES Summary Report



14 April 2016

MELBOURNE METRO RAIL PROJECT

Ground Movement Assessment - EES Summary Report

Submitted to:
AJM Joint Venture
Level 11, 121 Exhibition Street
Melbourne, Victoria, 3000



REPORT

Report Number. 1525532-219-R-Rev1

Distribution:

1 Copy - AJM Joint Venture
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Glossary of Abbreviations and Technical Terms

AHD	Australian Height Datum
AJM JV	Aurecon Jacobs Mott MacDonald Joint Venture
CD	Concept Design
CIS	Coode Island Silt
EES	Environment Effects Statement
FEM	Finite Element Modelling
IGSR	Interpreted Geological Setting EES Summary Report
IHSR	Interpreted Hydrogeological Setting EES Summary Report
Melbourne Metro or project	The Melbourne Metro Rail Project
PTV	Public Transport Victoria
RGNMR	Regional Groundwater Numerical Modelling EES Summary Report
TBM	Tunnel Boring Machine



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Limitations



1.0 INTRODUCTION

1.1 Background

Aurecon Jacobs Mott Macdonald Joint Venture (AJM JV) has engaged Golder Associates Pty Ltd (Golder) to provide geotechnical services for the proposed Melbourne Metro Rail Project (Melbourne Metro). The services provided by Golder in 2015 and 2016 have supported the development of the Melbourne Metro 'Concept Design'.

Between 2011 and 2013, Golder was engaged by Public Transport Victoria (PTV) to provide geotechnical services to support development of route options for the project. Since completion of this work in 2013, the proposed MMRP alignment has been modified. As a result, a further stage of ground movement assessment work has been undertaken to gain an appreciation of the potential settlement effects which may be induced by the Melbourne Metro Concept Design during construction and operation of the project.

This Ground Movement Assessment Report (GMAR) provides discussion of the ground movement assessment results along the Melbourne Metro Concept Design alignment. This report considers the results of investigations and assessments summarised in the Interpreted Geological Setting Report (IGSR) and Interpreted Hydrogeological Setting EES Summary Report (IHSR), which consider all of the site investigation information that has been collected for the project up to September 2015. The relationship of this report to the other EES specialist reports is summarised in Table 1.

Table 1: Relationships between EES Specialist Reports and the supporting Golder EES Summary Reports

		EES Specialist Reports			
		Ground movement and Land Stability	Future Development Loading	Groundwater	Contaminated Land and Spoil Management
Golder EES Summary Report	Ground Movement Assessment				
	Interpreted Geological Setting				
	Interpreted Hydrogeological Setting				
	Regional Groundwater Numerical Modelling				
	Contaminated Land Assessment				

1.2 Project Description

The Melbourne Metro Concept Design comprises 7.2 m external diameter twin rail tunnels approximately 9 km long, running from Kensington to South Yarra. The proposed alignment would connect into the existing rail network near South Kensington Station, run beneath North Melbourne and Parkville, then continue south beneath Swanston Street, under the Yarra River, east of and beneath St Kilda Road, then east beneath Toorak Road and Fawkner Park. Melbourne Metro connects to the existing rail network, Caulfield Line, at South Yarra. The proposed alignment is presented in Figure 1



GROUND MOVEMENT ASSESSMENT EES SUMMARY REPORT

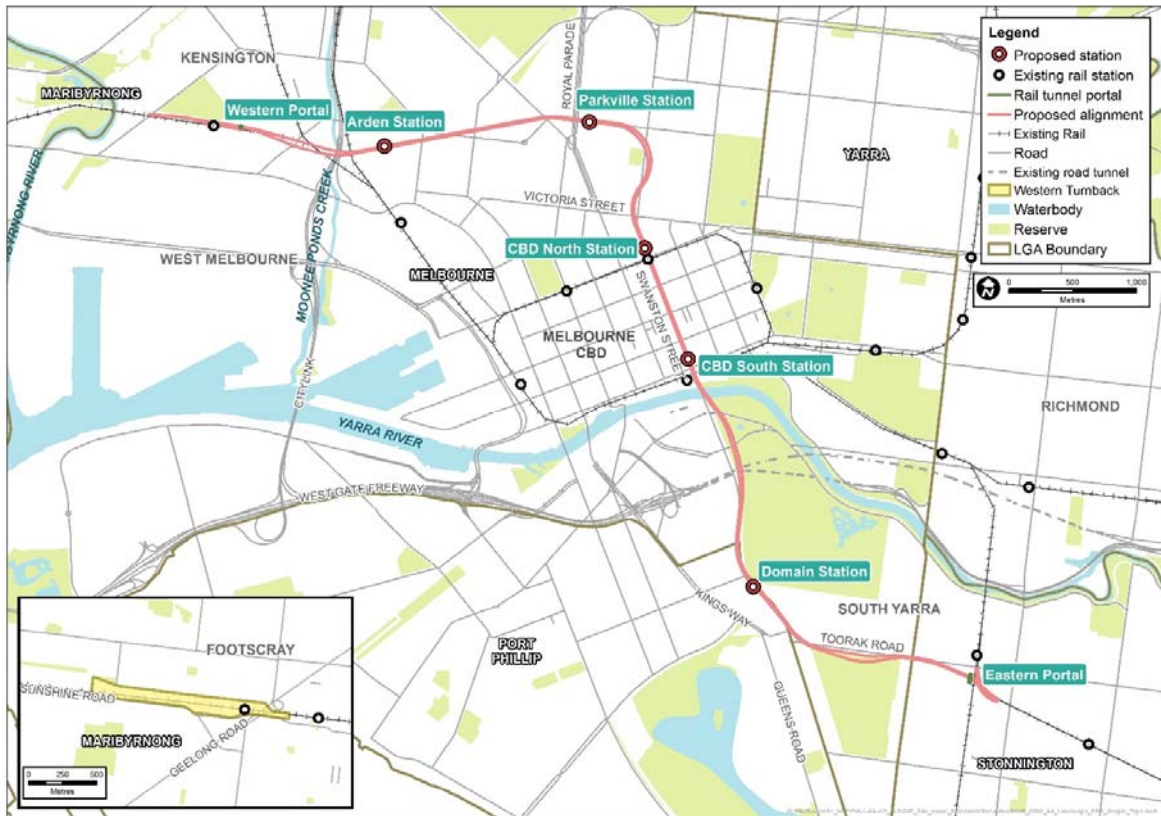


Figure 1: Melbourne Metro Alignment and Station and Portal Locations

Key aspects of the Project include:

- Portals at South Yarra and Kensington;
- Three cut and cover station excavations at Arden, Parkville and Domain;
- Two underground stations at CBD North and CBD South; and
- Ventilation shafts and cross passages along the twin tunnel alignment.

For reporting purposes, the alignment has been divided into 23 segments, based on the type of infrastructure proposed and the expected ground conditions. The segments are numbered from west towards east. Their extents are shown on the longitudinal geological section in Appendix A and a brief description presented in Table 2.



GROUND MOVEMENT ASSESSMENT EES SUMMARY REPORT

Table 2: Summary of segments adopted for reporting purposes

Segment	Precinct	Description	Key elements
1	2	Surface works and embankments	Embankment widening on potentially soft soils.
2	2	Western Portal approaches	Decline structure including retained excavation through soft soils and weak rock.
3	2	Western Portal and TBM shaft	Cut and cover excavation for TBM shaft and portal within weak rock.
4	1	TBM Tunnels	Twin bored tunnels through weak rock.
5	1	TBM Tunnels	Twin bored tunnels through dense clayey sand and sand with cross passage.
6	1	TBM Tunnels	Twin bored tunnels through soft to stiff cohesive soils, some gravel and sand.
7	3	Arden Station	Cut and cover station excavation through soft to stiff cohesive soils, some gravel and sand.
8	1	TBM Tunnels	Bored tunnels through mixed face conditions comprising dense sands, clayey sands and weak rock.
9	1	TBM Tunnels	Bored tunnels through weathered siltstone and sandstone.
10	4	Parkville Station	Cut and cover station excavation through weathered and jointed siltstone and sandstone.
11	1	TBM Tunnels	Bored tunnels through weathered to fresh siltstone and sandstone.
12	5	CBD North Station	Underground cavern excavation in weathered to fresh siltstone and sandstone with deep access shafts.
13	1	Mined Tunnels	Mined tunnels through weathered siltstone and sandstone.
14	6	CBD South Station	Underground cavern excavation in weathered to fresh siltstone and sandstone with deep access shafts. Deepening of existing City Square basement excavation.
15	1	TBM Tunnels	Bored twin tunnels through weathered siltstone and sandstone.
16	1	TBM Tunnels – Yarra Crossing	Bored tunnels through variable, mixed face conditions comprising high strength basalt rock, dense sand and soft to stiff clay.
17	1	TBM Tunnels	Bored tunnels through weathered siltstone and sandstone. Shaft at Linlithgow Avenue.
18	1	TBM Tunnels – City Link Crossing	Bored tunnels through mixed face conditions with dense sand, hard clay and weathered siltstone and sandstone. In close proximity to the existing City Link tunnels.
19	1	TBM Tunnels	Bored tunnels through weathered siltstone and sandstone.
20	7	Domain Station	Cut and cover station excavation through weathered and jointed siltstone and sandstone, dense sand and hard clay.
21	1	TBM Tunnels	Bored tunnels through weathered siltstone and sandstone. One access shaft in Fawkner Park
22	1	TBM Tunnels	Bored tunnels through mixed face conditions comprising weathered siltstone and sandstone, dense sand and hard clay.
23	8	Eastern Portal and TBM Shaft	Cut and cover shaft and decline structure in dense sand and hard clay. Widening of existing rail corridor excavations in dense sand and hard clay.

Based on discussion with AJM JV throughout the development of the Concept Design, the following provides a high level summary of the concepts for proposed Civil Infrastructure, from west to east:

- The proposed Melbourne Metro branches north off the existing Sunbury line just east of the Kensington Road Bridge and dives in a cut towards the western portal. The twin track decline structure is to be fully retained.
- A shaft is to be constructed at the western portal for use in Tunnel Boring Machines (TBM) retrieval during construction.
- The rail tunnels from western portal to Arden station are to be constructed TBM's.
- Arden station is to be constructed as a cut and cover bottom-up station box.
- The twin rail tunnels from Arden station to Parkville station are to be constructed using TBM's.



- Parkville station is to be constructed as a top down cut and cover station box.
- The twin rail tunnels from Parkville station to CBD North station are to be constructed using TBM's.
- An underground station cavern is to be constructed at CBD North station with an expected span of approximately 23 m. Four access shafts would be constructed adjacent to the cavern and underground adits and passages would be constructed between the shafts, cavern and the existing Melbourne Central Station.
- Twin tunnels would be mined between CBD North station and CBD South station.
- An underground station cavern is to be constructed at CBD South station. This would have similar dimensions to the cavern at CBD North station. Three fully supported access shafts would be constructed, one of which would involve the deepening of the existing City Square basement excavation. TBM tunnels are proposed between CBD South station and Domain station. This section of the alignment would pass beneath the Yarra River and would be bored through highly variable geological materials including very high strength rock and soft clay. The tunnels would pass beneath the existing footings of the Princes Bridge. Closed face TBM's are expected to be required through this section.
- Domain station is to be constructed as a partial top down cut and cover excavation.
- Twin TBM tunnels are proposed between Domain station and the eastern portal.
- The eastern portal consists of a ventilation / emergency egress / TBM retrieval shaft in the vicinity of Osborne Street, realignment of the existing Dandenong and Frankston Line tracks, twin track cut and cover tunnel sections including a section beneath the Sandringham Line tracks and Frankston Up track, twin track tunnel decline structure between the reconfigured Dandenong Line tracks and surface tie-in to the existing Dandenong Line.
- There are two emergency access shafts located at Linlithgow Avenue and Fawkner Park.
- There are a number of emergency egress cross-passages, including low point drainage sumps and pumping facilities.

At this stage we understand that the tunnels and stations would be designed as long term undrained underground structures.

1.3 Purpose of this Report

The purpose of this report is to provide a preliminary assessment of the potential ground movements along the Melbourne Metro Concept Design alignment that is likely to be a result of the response of the ground to the excavation process itself (i.e. station and tunnel construction) and consolidation settlement which may be triggered by groundwater depressurisation.

This report is provided in support of the Melbourne Metro Concept Design. While the results of this study are preliminary in nature, the aims of the assessment are to:

- Identify the potential mechanisms and causes of ground movement;
- Estimate potential ground movement caused by the construction works and potential consolidation settlement triggered by groundwater depressurisation; and
- Provide indicative settlement contours along the alignment based on the results of the assessment.

The findings of the ground movement assessment presented in this report would inform the development of the Melbourne Metro Concept Design, so potential adverse effects on land stability that might arise directly or indirectly from project works can be minimised or avoided. More detailed settlement assessments of



potentially effected structures, utilities and infrastructure would need be undertaken by the Contractor during detailed design prior to the start of construction.

1.4 Scope of Works

The ground movement assessment was completed in conjunction with AJM JV using a collaborative approach. A summary of the scope of work completed by Golder and AJM JV can be summarised as follows:

Development of Preliminary Assessment Inputs

- Derivation of the conceptual ground model including recommendations for the preliminary geotechnical parameters to be used in the analyses – Golder
- Estimation of the parameters to relate the surface settlement to the tunnelling techniques and ground conditions (two parameters termed face loss and trough width) – AJM JV in consultation with Golder
- Numerical modelling of interpreted ground models at selected locations conducted by Golder Associates to estimate the surface settlement profile for face loss values of 0.5 percent, 1 percent, and 1.5 percent – Golder
- Using the settlement profiles from the numerical modelling, back-calculation of the corresponding trough widths - AJM JV
- Estimation of the surface settlement profiles resulting from the excavation for open cut excavations (station boxes and cut and cover tunnels and portals) using preliminary geotechnical parameters recommended by Golder – AJM JV
- Estimation of the surface settlement profile resulting from cavern station excavations – Golder
- Hydrogeological modelling to predict groundwater drawdowns during construction and operation phases - Golder
- Estimation of primary consolidation settlement induced by drawdown of ground water, resulting from Melbourne Metro - Golder

Determination of the Potential Zone of Influence

- Combination and plotting of the excavation induced surface settlements resulting from tunnelling and open cut excavations using the software package XDisp – AJM JV
- Plotting of estimated primary consolidation settlement contours – Golder
- Review of settlement contours and determination of the potential zone of influence of the induced surface settlements – AJM JV in consultation with Golder
- First level of interpretation of settlement effects on buildings and other infrastructure (including utilities) within the potential zone of influence – AJM JV

Impact Assessment

- Review of the infrastructure and buildings for their position and type in relation to the plotted surface contours for selection for second level analyses - AJM JV
- Calculation of strains and distortion of the buildings and infrastructure using the software XDisp when subjected to the estimated settlement, with output in terms of predicted consequences described by damage categories - AJM JV
- Interpretation of the combined effects of excavation and consolidation induced settlement on buildings and other infrastructure – AJM JV



Site Specific Assessment

- Review of the infrastructure and buildings that would otherwise be selected for second level analyses, but require more specific numerical modelling because of their height or complexity - AJM JV
- Detailed two dimensional and three dimensional numerical modelling of the excavation induced settlements at selected structures – AJM JV and Golder (see Section 4.3 for list of structures assessed by each party)
- Structural engineering assessment of the buildings and infrastructure when subjected to strains and distortion determined by the numerical modelling of the surface settlements in terms of predicted damage categories - AJM JV

Other Considerations

- Review of the history and rate of the creep settlement, with interpretation the influence of Melbourne Metro on it - Golder
- Review of the addition of these effects to the settlements induced by Melbourne Metro - AJM JV

1.5 Report Limitations

Your attention is drawn to the document - “Limitations” (LEG04, RL1), which is included in Appendix F of this report. The statements presented in this document are intended to advise you of what your realistic expectations of this report should be. The document is not intended to reduce the level of responsibility accepted by Golder, but rather to ensure that all parties who may rely on this report are aware of the responsibilities each assumes in so doing.

We would be pleased to answer any questions the reader may have regarding these ‘Limitations’.



2.0 REGIONAL GEOLOGICAL AND HYDROGEOLOGICAL SETTING

2.1 Main Geological Units

The regional geology, geological history and regional structures of the broad study area are presented in detail in the IGSR. A summary of the stratigraphic units expected to be encountered along the proposed Melbourne Metro alignment is provided in Table 3 and longitudinal geological sections are provided in Appendix A.

Table 3: Main Stratigraphic Units

Geological Period	Geological Epoch	Stratigraphic Unit	Description
Quaternary	Holocene	Coode Island Silt (Q _{hi})	Soft clayey sediments with shells and organic materials, and lenses or thin layers of sandy materials
		Holocene Alluvium (Q _{ha}) ¹	Fine to medium grained alluvial sands
	Pleistocene	Jolimont Clay (Q _{pl})	Marine clay with minor silts and sands
		Newer Volcanics (Q _{vn}) (Burnley Basalt Flow)	Olivine basalt, variably weathered and fractured
		Pleistocene Alluvium (Q _{pa})	Alluvial sediments typically comprising clay, silt and sand. The proportion of each of these materials is variable, with firm to stiff silty or sandy clay being dominant material.
		Fishermens Bend Silt (Q _{pf})	Marine sediments with high contribution of continental origin materials along former shallow embayment. Clay, silt with sand size particles and occasionally sand lenses and interlayers. Proportion of sand is higher towards the base of the unit (lower Fishermens Bend Silt sub-unit, Q _{pfli}) and along former shallow embayment. Finer material encountered typically towards the top representative of deep sea depositional environment (upper Fishermens Bend Silt sub-unit, Q _{pfu}).
		Moray Street Gravels (Q _{pg})	Alluvial sediments, medium to coarse grained quartz sands with minor gravels, clay and silt.
		Fluvial Sediments (Q _{pc}) – Early Pleistocene Colluvial and Alluvial Sediments	Colluvial and alluvial sediments comprising medium to coarse sands, gravels and clays with coarse boulder and cobble typically of basalt material.
		Newer Volcanics (Q _{nvs}) – Swan Street Basalt	Olivine basalt variably weathered and fractured. Typically referred to as lower Newer Volcanics.
		Punt Road Sands (Q _{pp})	Colluvial and alluvial sediments comprising boulders and gravels of siltstone, and river gravels and sands.
Neogene	Pliocene	Brighton Group (T _{pb})	Sand, sandy clay, clayey sand, silt, clay and occasionally gravel.
Paleogene	Oligocene to Miocene	Older Volcanics (T _{vo})	Olivine and pyroxene basalt with abundant volcanic glass, variably weathered and fractured.
		Werribee Formation (T _{ew})	Fluvial quartz sand, minor gravels, silty clays and clays.
Devonian		Igneous rock (D _{gr})	Granodiorite and quartz porphyries, feldspar porphyries and lamprophyres dykes.
Silurian		Melbourne Formation (S _{ud})	Interbedded siltstone and sandstone, folded, fractured and variably weathered.

¹ In Geology of Victoria (Birch, 2003) a formal name of Batman Avenue Gravels was suggested for Holocene Alluvium. We kept the old terminology herein as the term "Alluvium" describes better the depositional environment of the unit.



It should be noted that the geological units expected along the proposed alignment are based on the information presented in the borehole reports and on the known geological history and relationships between materials. It should be noted that the only point at which the stratigraphy is known is at the borehole locations. All relationships between the geological materials as shown on the long section presented in Appendix A have been interpreted and as such there is some inherent uncertainty. One of the objectives of the proposed reference design and procurement phase investigations would be to continue to reduce these uncertainties as part of the overall risk management strategy for the project.

2.2 Preliminary Engineering Properties

Based on the geotechnical investigation results presented in the IGSR, engineering properties have been selected for the preliminary ground movement assessment. It should be noted that due to limited investigation results available along the alignment, these parameters should be considered to be preliminary and further work would be required to refine them in the future, once additional site investigation along the Melbourne Metro alignment has been completed.

The preliminary engineering properties that have been assumed for the settlement assessment are summarised in the relevant sections and appendices included in this report. To avoid confusion these are not listed here as they typically vary along the project alignment. Details are presented in Appendices B and C.

2.2.1 Summary of Soil Properties

The following are general explanations for the preliminary engineering soil properties of which have been assumed in the ground movement assessment.

- Long term material behaviour has been assumed for the purpose of the preliminary settlement analyses, and as such, linear elastic perfectly plastic Mohr-Coulomb strength parameters (Mohr-Coulomb Model) have been primarily adopted for the initial assessments. In some cases, the unloading elastic modulus has also been assumed based on the IGSR data for the relevant materials. Parametric studies were also been undertaken using a strain hardening soil model and undrained material behaviour where appropriate.
- Assumed preliminary engineering properties are intended for drained (i.e. long term) material behaviour in which stiffness and strength are defined in terms of effective stress shear strength parameters. These also aim to reflect the tunnel horizon and station depth vs. the expected stratigraphy and the presence of each unit along the project alignment. So it is clear which parameters have been adopted for each section analysed, a summary of the adopted parameters is also provided with the simplified ground profiles included in Appendix B.
- Werribee Formation is typically underlying Older Volcanics. However, this is often on the edge of alluvial channels and a lower bound for soil properties has been considered at this stage to reflect potential softening at the unit boundary.
- Brighton Group of variable thicknesses is expected along the alignment, typically from surface to depths of less than 5 m in the western end of the project and to depths of up to about 20 m around Domain and the Eastern Portal area. Values adopted at this stage are considered to be lower bound based on past project experience and in view of deep excavations and open cut works proposed within this unit.

To estimate consolidation settlement in the Coode Island Silt (CIS), the following properties of the unit were initially assessed:

- Preconsolidation pressure (or over consolidation ratio);
- Compression and re-compression indices; and
- Initial void ratio (or unit weight).

The compressibility characteristics of the CIS area can vary significantly within the study area. At a given location, the properties can also vary with depth. Published information suggests that the characteristics of



the CIS deposits are typical of normally or slightly over-consolidated materials. Review of the available CPT results suggests that the preconsolidation pressure within the deposit can also vary considerably depending on the past development/construction activities in the vicinity at a given location. For example, stockpiling of materials in a construction site, groundwater drawdown associated with past underground construction activities and deep leaky sewer or stormwater pipes can alter the preconsolidation pressure. Groundwater drawdown associated with the construction activities can also extend to considerable distances through confined aquifers along old river channels as observed during the construction of Melbourne's City Link (1997-2001).

For the assessment of consolidation settlement presented in this report, the compressibility parameters presented in Table 4 were assumed for the CIS in the areas of the Maribyrnong River, Moonee Ponds Creek and Yarra River Palaeovalleys.

Table 4: Parameters Adopted for Coode Island Silt for Consolidation Settlement Assessment

Initial Void Ratio e_0	Compression Ratio C_c	Recompression Ratio C_r
1.3	0.43	0.043

Based on the available information to date, the parameters presented in Table 4 are considered to be preliminary parameters for the study area. It is noted that the procurement phase investigation is still ongoing and further site specific data would be obtained. For future assessments, the parameters presented in Table 4 would need to be reviewed and revised once more site specific data becomes available.

For the assessment of consolidation settlement presented in this report, the preconsolidation pressure was assumed to be 10 kPa higher than the current vertical effective stress. This is considered to be prudently conservative. In particular, the CIS in the areas of Jolimont and Yarra Valleys may have higher preconsolidation pressures due to past development/construction activities. Typically an additional 10 kPa of preconsolidation pressure is observed due to seasonal groundwater fluctuations of about 1 m.

The magnitude of consolidation settlement would also depend on the thickness of the CIS deposit and the magnitude of stress changes.

The time for consolidation settlement to occur would depend on the hydraulic conductivity and available drainage paths. Our previous experience suggests that the presence of very thin sandy layers that naturally occur in alluvial depositional environments would provide shorter drainage paths and contribute to faster field consolidation compared to the rate of consolidation inferred from laboratory consolidation tests and CPT dissipation tests.

2.2.2 Summary of Rock Properties

The following are general explanations and assumptions for the preliminary geotechnical design parameters for rocks, which are based on the information provided in the IGSR.

- Based on a review of the available information, summary of preliminary engineering properties for the rock units has been presented in relevant sections and appendices of this report. The rock mass properties have primarily been differentiated based on weathering grade for the purpose of this preliminary assessment. It should be noted that these rock mass properties are also based on engineering judgment and previous experience on past projects in Melbourne.
- Assumed parameters are intended for different weathering grades varying from residual and extremely weathered material to slightly weathered and fresh as indicated in geological long sections and variability of weathering profile is expected with depth. Nevertheless, the parameters assumed for analyses are considered reasonably representative of the weathered rock mass.
- Assumed preliminary engineering properties for rock mass are intended for drained (i.e. long term) material behaviour in which stiffness and strength are defined in terms of effective stress shear strength



parameters. These also aim to reflect the tunnel horizon and station depth vs. the expected stratigraphy and the presence of each unit along the project alignment. Further studies would be required and site specific sets of parameters would be developed for detailed design stage. So it is clear which parameters have been adopted for each analysis section, a summary of the adopted parameters is also provided with the simplified ground profiles included in Appendix B.

- The Newer Volcanics unit is only expected to be encountered at the Yarra River Crossing and the assumed parameters are specific to the two flows which exist at that location.

2.3 Hydrogeological Model

2.3.1 Main Hydrostratigraphic Units and Hydraulic Properties

For the purpose of providing an overview of hydrogeological conditions, a summary of hydrogeological classification of hydrostratigraphic units expected along the proposed alignment is presented in Table 5.

Stratigraphic units that are expected to be encountered along the alignment of the proposed Melbourne Metro were deposited / formed under variable conditions, which resulted in significant variability of materials contained within each unit. Consequently, hydrogeological characteristics of the units or parts of a unit, and their roles in the groundwater flow system are often complex and highly variable.

A summary of hydrogeological characteristics of the main stratigraphic units and their roles in the groundwater flow system, as inferred from field observations and testing, is provided in Table 5.

Further details on the interpreted hydrogeological setting along the project corridor are provided in the IHSR.

Table 5: Hydrostratigraphic Units and Their Role in Groundwater Flow System

Stratigraphic Units	Hydrogeological Classification	Main Occurrence
Coode Island Silt (Q_{ni})	Aquitard, porous medium, due to presence of sand layers and lenses, horizontal hydraulic conductivity (K_h) greater than vertical (K_v).	South Melbourne, Docklands, Moonee Pond Creek Valley Holocene Alluvium Valley
Holocene Aluvium (Q_{ha})	Aquifer, confined, porous medium, high yielding.	Holocene Alluvium Valley
Jolimont Clay (Q_{pj})	Aquitard, porous medium	Localised occurrence within Jolimont Valley (Richmond, southern parts of CBD and northern parts of South Melbourne)
Newer Volcanics (Q_{vn}) – Burnley Basalt Flow	Aquifer, unconfined to semi-confined, fractured rock medium, low (where weathered) to high hydraulic conductivity (where fractured).	Jolimont Valley (Richmond, southern parts of CBD and northern parts of South Melbourne)
Pleistocene Alluvium (Q_{pa})	Aquifer where sandy, confined, porous media, potentially low to medium hydraulic conductivity and yield (limited data available) Potentially leaky aquitard where fine materials dominate unit profile.	Maribyrnong River Valley, Moonee Ponds Creek Valley
Fishermens Bend Silt clayey upper horizons – (Q_{pfu})	Aquitard (both upper and lower sub-units), porous medium, due to fissuring vertical hydraulic conductivity may be greater than horizontal	Jolimont Valley, South Melbourne, Docklands area
Fishermens Bend Silt sandy lower horizons and former shallow sea embayment areas – (Q_{pfi})	Aquifer, confined, porous medium, medium to high hydraulic conductivity, potentially medium to high yielding when in direct connection with other high yielding aquifers.	Arden Station, Jolimont Valley
Moray Street Gravels (Q_{pg})	Aquifer, confined, porous medium, high yielding	Jolimont Valley, South Melbourne



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Stratigraphic Units	Hydrogeological Classification	Main Occurrence
Fluvial Sediments (Q_{pc})	Aquifer, confined, porous media, potentially high yielding (limited data available)	Broader Moonee Ponds Creek valley, Docklands, Jolimont Valley
Newer Volcanics (Q_{vns}) – Lower Basalt Flow	Aquifer of a localised extent and low significance due to discontinuity of the unit. Confined, fractured rock medium to low hydraulic conductivity.	Jolimont Valley, South Melbourne
Punt Road Sands (Q_{pp})	Aquifer, confined, porous medium, potentially of a high hydraulic conductivity but of a low yield and significance due to limited extent and thickness.	Jolimont Valley only
Brighton Group (T_{pb})	Aquifer, unconfined, porous medium, medium yielding aquifer where sandy but aquitard where clayey.	Botanical Gardens, western CBD fringes
Older Volcanics (T_{vo})	Aquifer, confined, fractured rock medium, low (where weathered) to high hydraulic conductivity (where fractured).	South Melbourne, western CBD fringes, Port Melbourne and Kensington
Werribee Formation (T_{ew})	Aquifer, confined porous medium, zones of potentially high yielding sub-aquifer(s) (lower zone).	South Melbourne, Docklands, Port Melbourne and Kensington
Melbourne Formation (S_{ud})	Aquifer, unconfined to semi-confined, fractured rock medium.	Bedrock

Based on published literature and Golder’s past project experience, typical hydraulic characteristics of the main hydrostratigraphic units within the broader extent of the study area are summarised in Table 6.

Table 6: Main Hydrostratigraphic Units and Their Characteristics

Geological Unit	Typical Hydraulic Conductivity Ranges
Coode Island Silt	$K_h - 10^{-8}$ m/s to 10^{-7} m/s, $K_v - 10^{-9}$ m/s to 10^{-8} m/s
Holocene Aluvium	$K - 10^{-5}$ m/s to 5×10^{-4} m/s
Jolimont Clay	$K - 10^{-9}$ m/s to 10^{-8} m/s
Newer Volcanics	$K - 10^{-7}$ m/s to 10^{-4} m/s
Fishermens Bend Silt	$K_h - 10^{-9}$ m/s to 10^{-8} m/s, $K_v - 10^{-8}$ m/s
Moray Street Gravels	$K - 10^{-5}$ m/s to 5×10^{-4} m/s
Early Pleistocene sediments	$K - 10^{-5}$ m/s to 5×10^{-4} m/s
Brighton Group	$K - 10^{-7}$ m/s to 5×10^{-6} m/s
Older Volcanics	$K - 10^{-7}$ m/s to 10^{-5} m/s
Werribee Formation	$K - 10^{-8}$ m/s to 10^{-5} m/s
Igneous rock	$K - 10^{-9}$ m/s to 5×10^{-8} m/s
Melbourne Formation	$K - 10^{-7}$ m/s to 10^{-5} m/s

2.4 Preliminary Groundwater Modelling

Based on the results of preliminary hydrogeological modelling as summarised in the Regional Groundwater Numerical Modelling EES Summary Report, predictions of potential groundwater drawdowns within the Coode Island Silt (CIS) sediments have been developed for the purpose of this preliminary ground movement assessment.

The objective of this work was to assist with the development of the Melbourne Metro Concept Design by assessing the potential effects of different rail tunnel and station watertightness criteria on groundwater levels within the study area. Two classes of waterproofing were considered for this work: Haack Class 2 and



Haack Class 3, which are typically intended for road and rail tunnels (Haack, A., 1991). Permissible daily inflows for these two classes adopted for modelling are as follows:

- Haack Class 2 (HC2) – 0.05 L/m² per 100 m length; and
- Haack Class 3 (HC3) – 0.10 L/m² per 100 m length.

The preliminary groundwater numerical modelling that has been undertaken at this stage and the groundwater modelling results and drawdown predictions used for estimates of potential consolidation settlement of CIS included the following groundwater drawdown cases.

- Construction Phase – groundwater drawdowns induced by excavations up to the point where the excavations are sealed, including:
 - Construction of western portal shaft and cut and cover structure including secant pile wall and toe grouting beneath wall;
 - Construction of Arden Station including D-Wall around the station and toe grouting beneath D-Wall;
 - Construction of Parkville Station;
 - Construction of CBD North Station and mined tunnel;
 - Construction of CBD South Station; and
 - Construction of Domain Station.
- Operational Phase – post-construction (long term) groundwater drawdowns predicted for operational phase of completed stations, portals and tunnels:
 - Scenario 1: Tunnels and Parkville station sealed to Class HC3, and all other structures sealed to Class HC2; and
 - Scenario 2: as per Scenario 1 with the modification to tunnel section at the Yarra River crossing, where tunnels sealed to Class HC2.

It should be noted that at the time of writing this report, further hydrogeological modelling work and sensitivity analyses were expected to be required at the later design stage, and the results of future modelling would need to be incorporated into future consolidation settlement and ground movement assessments. Table 7 presents a summary of water tightness criteria assumed for the purposes of the groundwater modelling.

For further details on the hydrogeological modelling refer to the RGNMR dated February 2016 which presents the preliminary groundwater modelling results.



Table 7: Summary of water tightness criteria assumed for groundwater modelling of project elements

Project Element	Construction Phase	Operational Phase Scenario 1	Operational Phase Scenario 2
Western Portal	Unsealed	HC2	HC2
TBM Tunnels (not including Yarra River crossing section)	TBM	HC3	HC3
Arden Station	Unsealed	HC2	HC2
Parkville Station	Unsealed	HC3	HC3
CBD North Station	Unsealed	HC2	HC2
Mined Tunnels	Unsealed	HC3	HC3
CBD South Station	Unsealed	HC2	HC2
TBM Tunnels (Yarra River crossing section only)	TBM	HC3	HC2
Domain Station	Unsealed	HC2	HC2
Eastern Portal	Unsealed	HC2	HC2

HC – Haack Class

2.4.1 Construction Phase Drawdowns

The Version 2 Regional Model results for the construction phase scenarios indicate that groundwater levels within the Moray Street Gravel aquifer may be affected during construction of the CBD South station. In the construction phase scenario, groundwater drawdowns in the Moray Street Gravel aquifer up to 1 m were predicted just prior to sealing of the station during construction. While these levels of predicted groundwater drawdown are likely manageable from a settlement perspective, it was suggested in the RGNMR that mitigation measures such as pre-injection grouting and temporary recharge wells be included in the Melbourne Metro Concept Design as part of the groundwater management strategy for the station.

Results of the numerical modelling for the Domain station construction suggest that groundwater drawdowns within Coode Island Silt in the South Melbourne area are likely to be less than 0.1 m for the diaphragm wall construction scenario adopted for the Melbourne Metro Concept Design. Such groundwater drawdowns are unlikely to be significant from a settlement perspective, considering they are likely within the range that has been experienced historically in this area. However the results of this preliminary modelling should be checked once further site investigation results become available for this area.

Results of the Version 2 model for Arden station and the western portal indicate groundwater drawdowns beneath the Coode Island Silt of up to 1.5 m at the Arden Station and up to 2.0 m at the western portal cut and cover structure may be induced during construction based on the modelled designs. To further mitigate these potential drawdowns and the settlement they could induce, it was also suggested in the RGNMR that temporary recharge wells be included in the Melbourne Metro Concept Design for these structures as well.

2.4.2 Operation Phase Drawdowns

The Version 2 Regional Model results for the operational phase scenarios indicate that the groundwater drawdowns within the majority of the study area are likely to be less than 0.5 m during the operational phase. However, the modelling also indicates that groundwater drawdowns up to 0.6 m are possible locally at the base of the Coode Island Silt within Alexandra Gardens if the rail tunnels in this area are lined to Haack Class 3. The modelling also suggests that lining of the rail tunnel to Haack Class 2 along a 150 m section of the twin tunnels in this area would result in a slight reduction of the operation phase drawdowns to less than 0.5 m at the base of the Coode Island Silt. Based on the results of these analyses, a water tightness of Haack Class 3 was adopted for all sections of mined and TBM tunnel in the Melbourne Metro Concept Design.



3.0 METHODOLOGY

3.1 Potential Causes of Ground Movement

The causes of potential ground settlement along the proposed alignment can be associated with one or more of the following:

- Tunnel excavation induced ground movements (TBM and mined tunnels);
- Station excavation induced ground movements (cut and cover boxes and mined caverns, and associated shafts and adits);
- Open cut excavation induced ground movements (portals and shafts); and
- Ground movements due to compression/consolidation of soils induced by groundwater drawdowns.

We have assumed that the additional fill placements in the areas where CIS deposit is present (i.e. Maribyrnong River, Moonee Ponds Creek and Jolimont and Yarra Valleys) would be minimal and not more than 0.5 m. We have not assessed consolidation settlement in CIS due to additional fill placement.

We have also not carried out any detailed assessment of the potential creep settlements in the CIS deposit. The magnitude of creep settlement would mostly depend on the thickness of CIS. The overconsolidation occurred due to past construction/development activities and would also have some influence.

3.1.1 Tunnel Induced Ground Movement

In simple terms, tunnel induced ground movement occurs when actual ground loss caused by the excavation exceeds the theoretical excavation volume. Typically, the amount of ground movement observed at the ground surface can be related to the volume of ground loss experienced during tunnelling.

It is also possible for certain ground conditions and excavation methods that ground heave may occur at the surface during tunnelling. This may occur under high horizontal stress conditions or in soft soils when TBM face pressures are too high.

The magnitude of tunnel induced ground movement for a parallel twin tunnel scenario is related to the following parameters:

- Depth, size of tunnel and the centre to centre distance between the two tunnels;
- The actual ground and groundwater conditions at the tunnel level; and
- Excavation technique and tunnel support method.

3.1.2 Open Cut Excavation Induced Ground Movement

Horizontal and vertical ground displacements are typically observed adjacent to deep excavations due to relaxation of the supported or partially supported ground.

The magnitude of movement is dependent on the following parameters:

- Type and rigidity of the adopted retention system;
- The actual ground and groundwater conditions at the site;
- Construction methodology and stages adopted for the works; and
- The depth and extent of excavation in plan.

3.1.3 Ground Movement Induced by Groundwater Drawdown

Groundwater drawdown may be induced during construction due to dewatering which is typically undertaken to provide dry working areas in underground or deep excavations that extend below the groundwater table. Other reasons for groundwater drawdown could be leakage through the tunnel linings or excavation retention



systems. Groundwater drawdown or depressurisation caused by dewatering and leakage can migrate laterally over significant distances in confined aquifers.

In soft soils, increase in effective stress caused by groundwater drawdown can result in a significant settlement due to consolidation. Groundwater drawdown is not expected to induce consolidation in stiffer soils or weathered rock.

No ground movement associated with the shrinking or swelling of reactive clays, due to near surface moisture changes in the soils which could occur independently of the project, was considered in this preliminary assessment. No specific data is available at this stage; however, it should be recognised that if such soils are present (for example, basaltic clays), potential ground movement may be amplified by water level variations. The requirement for baseline settlement monitoring has therefore been incorporated into the Melbourne Metro Concept Design, so existing movement trends or patterns caused by the shrinking or swelling of reactive clays along the alignment can be identified prior to the start of construction.

3.2 Project Elements and Construction Methods

Based on the initial discussions with AJM JV at the start of the ground movement assessment, the construction methodology summarised in Table 8 for each of the project elements was assumed for the modelling.



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Table 8: Summary of construction methods assumed for Ground Movement Assessments

Segment	Approx. Chainage (m)	Project Element	Assumed Construction Method
1	94+600 to 94+940	Western Portal tie-ins	Surface works and embankment works
2	96+940 to 95+140	Western Portal approaches	Decline structure including cantilever secant pile wall retention systems with toe grouting.
3	95+140 to 95+350	Western Portal and TBM shaft	Cut and cover, secant pile retention system with toe grouting.
4	95+350 to 95+580	Twin Tunnels	TBM
5	95+580 to 95+950	Twin Tunnels	TBM
6	95+950 to 96+310	Twin Tunnels	TBM
7	96+310 to 96+580	Arden Station	Cut and cover, diaphragm wall retention system with toe grouting, ground improvement at TBM break in and breakout points.
8	96+580 to 97+050	Twin Tunnels	TBM
9	97+050 to 98+020	Twin Tunnels	TBM
10	98+020 to 98+300	Parkville Station	Cut and cover, soldier pile retention system.
11	98+300 to 99+240	Twin Tunnels	TBM
12	99+240 to 99+520	CBD North Station	Underground mined cavern with deep access shafts.
13	99+520 to 100+200	Twin Tunnels	Mined tunnels.
14	100+200 to 100+470	CBD South Station	Underground mined cavern with deep access shafts.
15	100+470 to 100+570	Twin Tunnels	TBM
16	100+570 to 100+970	Twin Tunnels (Yarra River Crossing)	TBM
17	100+970 to 101+980	Twin Tunnels	TBM
18	101+980 to 101+650	Twin Tunnels (City Link Crossing)	TBM
19	101+650 to 102+250	Twin Tunnels	TBM
20	102+250 to 102+580	Domain Station	Cut and cover station, diaphragm wall retention system.
21	102+580 to 103+880	Twin Tunnels	TBM
22	103+880 to 104+250	Twin Tunnels	TBM
23	104+250 to 104+650	Eastern Portal tie-ins and TBM Shaft	Cut and cover tunnel and decline structure, secant pile retention system

3.3 Expected Geological and Hydrogeological Conditions

Based on the available information, including the longitudinal geological sections presented in Appendix A, a number of simplified ground profiles have been developed for the purpose of this ground movement assessment.

The variable conditions expected along the alignment are reflected in the simplified ground models derived for the settlement analysis. The inferred ground profiles adopted for analysis are included in Appendix B.



GROUND MOVEMENT ASSESSMENT EES SUMMARY REPORT

A summary of geological and hydrogeological conditions expected along the proposed Melbourne Metro Concept Design alignment (by project segment) is presented in Table 9.

Table 9: Expected Ground Conditions along Melbourne Metro alignment

Segment	Inferred ground profile below existing surface level (based on GIR geological long section)	Ground conditions at excavation level	Groundwater conditions at excavation level
1	Fill overlying Coode Island Silt overlying either Quaternary Alluvial Deposits or Older Volcanics and Werribee Formation, and Melbourne Formation	Fill, Soft Soil (Fill and Q_{hi}) (open cut works only)	Above groundwater table
2	Fill overlying Coode Island Silt overlying Older Volcanics and Werribee Formation, and Melbourne Formation	Fill, Soft Soil (Fill and Q_{hi}) (open cut works only)	Near or below groundwater table
3	Fill, then Older Volcanics overlying Werribee Formation, and Melbourne Formation	Stiff Soil and Rock (residual/extremely weathered T_{vo} likely behaves like stiff soil)	Below groundwater table
4	Fill overlying Older Volcanics, then Werribee Formation, and Melbourne Formation	Stiff Soil and Rock (T_{vo} likely behave like stiff soil)	Below groundwater table
5	Fill overlying Older Volcanics or Coode Island Silt and Alluvial Deposits, then Werribee Formation overlying Melbourne Formation	Mixed ground, transition zone from Rock (T_{vo}) to Soil (T_{ew}) to Rock (S_{ud}) at tunnel invert	Below groundwater table
6	Fill at surface, then Coode Island Silt overlying Fishermens Bend Silt and Melbourne Formation	Mixed conditions, Soils (T_{ew} , Q_{pfu} and Q_{pc}) and Rock (S_{ud}) at the tunnel invert level	Below groundwater table
7	Fill at surface, Coode Island Silt overlying Alluvial Deposits and Fishermens Bend Silt, and Melbourne Formation	Soft and Stiff Soils (Q_{hi} , Q_{pa} , Q_{pfu} and Q_{pc})	Below groundwater table
8	Fill at surface, Coode Island Silt overlying Alluvial Deposits and Fishermens Bend Silt, and Melbourne Formation (tunnels near the station). Fill overlying Older Volcanics overlying Werribee Formation (further away from the station), then Melbourne Formation.	Mixed ground including Soft and Stiff Soils (Q_{hi} , Q_{pa} , Q_{pfu} , T_{vo} , T_{ew}) and Weathered Rock (S_{ud})	Station box excavation below groundwater table
9	Fill at surface, then Older Volcanics overlying Melbourne Formation, area of Pleistocene Alluvium overlying Melbourne Formation	Rock (T_{vo} , S_{ud}) at tunnel elevation	Below groundwater table
10	Fill at surface, overlying Melbourne Formation	Parkville Station (excavation in Rock (S_{ud}))	Excavation below groundwater table
11	Fill at surface, overlying Melbourne Formation	Rock (S_{ud}), generally highly weathered or less weathered at tunnel elevation	Generally below groundwater table
12	Fill at surface, overlying Melbourne Formation	CBD North Station, excavation in Weathered Rock (S_{ud})	Generally above groundwater table
13	Fill at surface, overlying Melbourne Formation with a zone of area of Pleistocene Alluvium overlying Melbourne Formation	Rock (S_{ud}), generally highly weathered or less weathered at tunnel elevation	Below groundwater table
14	Fill at surface, overlying Melbourne Formation	CBD South Station, excavation in Weathered Rock (S_{ud})	Excavation below groundwater table
15	Fill at surface, overlying Melbourne Formation or Jolimont Clay or Newer Volcanics Basalt	Rock (S_{ud} and Q_{vn}), highly weathered or less weathered, locally soil (Q_{pj})	Below groundwater table
16	Fill at surface, then Newer Volcanics Basalt (upper flow) overlying Fishermens Bend Silt, Morey Street Gravels, and Quaternary Fluvial Sediments and Newer Volcanics Basalt (lower flow), Melbourne Formation. South of the river, fill at surface, then Coode Island Silt overlying Newer Volcanics Basalt, Fishermens Bend Silt, Morey Street Gravels, and Quaternary	Mixed conditions including Soil (Q_{hi} , Q_{pfu} , Q_{pfi} , Q_{pg} , Q_{pc} , Q_{ha} and recent river deposits) and Rock (S_{ud} , Q_{vn} and Q_{vns})	Below groundwater table



Segment	Inferred ground profile below existing surface level (based on GIR geological long section)	Ground conditions at excavation level	Groundwater conditions at excavation level
	Fluvial Sediments and Newer Volcanics Basalt (lower flow), Melbourne Formation		
17	Fill at surface, overlying Melbourne Formation	Rock (S_{ud})	Partially below groundwater table
18	Fill at surface, then Brighton Group overlying Melbourne Formation	Mixed conditions including Soil (T_{pb}) and Rock (S_{ud})	Generally above groundwater table
19	Fill at surface, overlying Melbourne Formation	Rock (S_{ud})	Generally below groundwater table
20	Fill at surface, then Brighton Group overlying Melbourne Formation	Mixed conditions including Soil (T_{pb}) and Rock (S_{ud})	Station base generally below groundwater table
21	Fill at surface, then Brighton Group overlying Melbourne Formation	Mixed conditions including Soil (T_{pb}) and Rock (S_{ud})	Generally below groundwater table
22	Fill at surface, then Brighton Group overlying Melbourne Formation	Mixed conditions including Soil (T_{pb}) and Rock (S_{ud})	Generally below groundwater table
23	Fill expected at surface, overlying Brighton Group, Melbourne Formation and Devonian Granite anticipated below depth of about RL-3m AHD	Stiff Soil (open cut works only)	Partially below groundwater table

3.4 Ground Movement Assessment

The following methods and assumptions have been considered for the preliminary assessment of potential ground movements. For the purpose of this study, the methods adopted for assessment of potential ground movement are based on green-field conditions, unless indicated otherwise.

In addition to the preliminary ground movement assessments of typical TBM tunnel, mined tunnel and cavern sections, a number of selected existing buildings and structures which are located adjacent to the proposed alignment have also been considered. The purpose of this assessment was; to analyse the potential ground movements induced by the proposed excavations; to explore the potential impacts on the existing structures due to the proposed construction; and to provide information to inform the development of the Melbourne Metro Concept Design.

It should be noted that further assessments would be required to consider the ground-structure interaction to address the potential effects and impacts on the existing buildings, infrastructure and underground services.

3.4.1 Settlement due to Excavation of TBM Tunnels

Methods adopted for settlement assessment due to tunnelling are based on the principle that the ground movement would occur due to stress relief and displacement towards the opening in the ground during the excavation.

If there was no closure of the ground around the tunnel towards the opening, the theoretical volume of soil excavated would be exactly the same as the volume of the tunnel constructed. The ground does close into the opening, with the magnitude of the ground closure depending on a number of factors related to ground properties and tunnelling methods.

The ground response to tunnelling and the excess material removed over and above the theoretical excavation volume is termed 'Volume Loss' (V_L) and is defined as a percentage of theoretical excavation volume. In case of the TBM operation, it is a sum of face loss, shield loss and post-shield loss occurring during tunnel construction.

For estimates of settlement induced by the mined tunnels, a volume loss approach was also adopted for the preliminary assessment. The sources of volume loss for a mined tunnel are typically related to convergence of the face and excavation perimeter as the heading is advanced.



Empirical Analysis

Tunnelling in uniform soils and induced free ground movement expressed at the surface can be estimated by empirical models describing the transverse settlement profile at some distance behind the tunnel face. This can be derived using the idealised shape of Gaussian (bell curve) trough, with an area equal to the volume loss (V_L) parameter. This is defined as a percentage of the tunnel face area and represents both material lost at the face and the closure of the ground due to stress relief.

The ground conditions above the tunnel excavation are defined by the trough width parameter (k), which determines the width and gradient of settlement trough. The width of the transverse settlement trough is defined by the parameter ' i ', which corresponds to the standard deviation for the normal probability curve. It defines the point of maximum slope and the inflexion on the settlement trough.

This approach to settlement requires an input assumption of the ' k ', a parameter which would vary at each location along the alignment depending on geological units at that location. A typical transverse settlement profile estimated using the empirical method is presented in Figure 2.

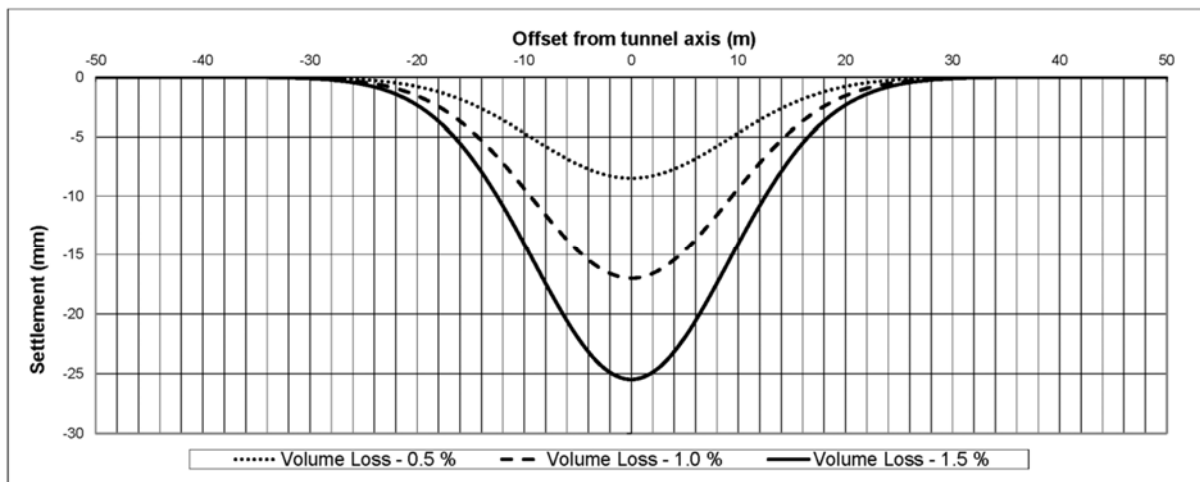


Figure 2: Typical transverse settlement profile at the surface derived for the assumed volume loss parameters

A simplified approach is typically adopted to account for twin tunnel excavation by superposition of the two settlement curves to obtain an indicative settlement profile behind the twin tunnel excavation.

It should be noted that our preliminary ground movement assessments of construction / excavation induced ground movement were primarily carried out using Finite Element (FE) numerical methods in the PLAXIS geotechnical software package. Once these analyses were complete, the results were then used by AJM JV to produce the settlement contour drawings in Appendix D, using the geotechnical software Xdisp. Xdisp automates the process of settlement contouring typically undertaken using spreadsheets and allows the results to be displayed graphically in three dimensions.

Parameters Considered for Settlement Analysis

For the purpose of the ground movement assessment, a parametric study was undertaken with sensitivity analyses considered. The approach adopted for the volume loss (V_L) and the trough width (k) parameters derivation considered the "Matrix Approach" (Chirioti et al., 2001) used for TBM tunnelling in non-uniform ground conditions. This approach is often considered at early stages of tunnelling project development, largely due to its ease of calculation and ability to obtain an early prediction fairly quickly.

Table 10 presents a summary of the volume loss parameters suggested by "Matrix Approach" which have been considered for the preliminary assessments of potential ground movement induced by TBM tunnelling. These input parameters aim at being representative of variability of overburden conditions and geological conditions expected at the tunnel face.



Table 10: Summary of volume loss parameters considered for settlement assessments

V _L parameter range (%) (k parameter range)		GEOLOGICAL CONDITION AT THE TUNNEL FACE			
		Soil-like material	Mixed conditions (soil and rock mass)	Faults and/or weathered bands	Discontinuous rock mass and weak rock
OVERBURDEN CONDITIONS	Soil-like material	0.8 – 1.0 (0.3 – 0.5)	1.0 – 1.2 (0.3 – 0.5)	0.8 – 1.0 (0.3 – 0.5)	0.5 – 0.8 (0.3 – 0.5)
	Mixed conditions (soil and rock mass)	0.5 – 0.7 (0.3 – 0.5)	0.6 – 0.8 (0.3 – 0.5)	0.5 – 0.8 (0.5 – 0.7)	< 0.5 (0.5 – 0.7)
	Faults and/or weathered bands	0.4 – 0.8 (0.3 – 0.5)	0.5 – 0.9 (0.3 – 0.5)	0.6 – 1.2 (0.3 – 0.5)	0.4 – 0.9 (0.5 – 0.7)
	Discontinuous rock mass and weak rock	0.3 – 0.5 (0.5 – 0.7)	0.4 – 0.6 (0.5 – 0.7)	< 0.4 (> 0.7)	< 0.2 (> 0.7)

It should be noted that, based on existing information, inclined weak rock zones may be present along the proposed alignment and tunnelling induced effects can be transmitted in non-vertical directions. Potential for movements in non-vertical directions have not been considered in the preliminary empirical ground movement assessments. As such, these early settlement predictions should be considered as indicative and may need to be locally supplemented by additional FE analyses once further site investigation and design development has been completed.

To provide for initial estimates and in view of the above the ranges of volume loss (V_L) and the width of settlement trough (k) parameters presented in Table 11 are recommended for the purpose of the preliminary settlement assessment and to develop settlement contours using the Xdisp software. For the FE analyses, the tunnel convergence adopted for modelling was assumed to be equal to the volume loss value.

Table 11: Parameters recommended for settlement analysis

Ground Conditions at Tunnel Face	Volume Loss – V _L (%)	Trough Width Parameter (k)
Soft Soil	0.5 – 1.5	0.3 – 0.5
Soft / Stiff Soil	0.5 – 1.5	0.3 – 0.5
Stiff Soil	0.5 – 1.0	0.3 – 0.5
Stiff Soil / Rock	0.5 – 1.0	0.5 – 0.7
Rock (>2D – twice the tunnel diameter cover or more)	0.5	0.7

Finite Element Modelling

Finite Element Modelling (FEM) of tunnel excavation was carried out using both two-dimensional (2D) and three-dimensional (3D) PLAXIS software. In particular, the FE method was adopted for analysis at locations where the empirical Gaussian method was considered less applicable due to the anticipated variable ground conditions and potential for ground heave to occur subsequently to tunnels being excavated and ground unloaded. Location specific assessments and potential for ground movement associated with ground heave have been further investigated at this stage.

Simplified ground models were established at various locations along the Melbourne Metro alignment based on the expected geological conditions, tunnel geometry and existing surface contours. Based on the conditions expected at the tunnel level and above, a range of volume loss values were adopted for settlement calculation to investigate the potential magnitude of ground movement induced by the tunnelling works.

Refer to Appendix C for details of FEM work carried out for preliminary assessment of TBM tunnels.



3.4.2 Settlement due to Excavation of Mined Tunnels and Caverns

Methods adopted for ground movement assessment due to mined tunnels and caverns excavations are based on the principle that the ground movement would occur due to stress relief and displacement towards the opening in the ground during the excavation.

Finite Element Modelling

Following are assumptions adopted for the purpose of the preliminary ground movement assessment and 2D PLAXIS analyses specific to mined underground openings.

- The preliminary assessment of potential ground movement induced by mined tunnel excavations has been carried out using 2D PLAXIS to assess the effects of staged construction proposed for the mined tunnels and CBD North and CBD South Station caverns. In the models tunnel excavations were simulated by using a staged approach, where the three-dimensional arching effects were modelled using the *β-method*. The idea is that the initial stress p_k acting around the location where the tunnel is constructed is split into two stages where $(1-\beta) p_k$ stress is applied to the unsupported opening followed by a stage where βp_k is applied to the supported crown and walls. This allows for some convergence of the tunnel prior to installation of support and for preliminary analyses it was assumed that 50% ground relaxation occurs prior to support being installed. It was assumed that staged excavation would have an initial effect on inducing ground movement. The rock support (rock bolts and shotcrete lining) was then introduced in a second stage to restrain the ground movements until equilibrium between the soil stress field and the support elements was achieved.
- In models of mined tunnels and caverns, variations of principal horizontal in situ stresses have been considered in Melbourne Formation (MF) a range of K_0 (Major (σ_{h1}) or Minor (σ_{h2})) have been adopted for sensitivity analyses. The actual in situ stresses would vary depending on depth, in situ stress history and orientation of existing and new structures that is being considered.
- It is assumed that the use of robust pre-support in combination with ground improvement measures ahead of excavations would be required for mined tunnels and caverns where poor ground is encountered along the alignment. This would likely comprise the use of spiles and/or canopy tubes installed ahead of the excavation face, with grouting as a form of ground improvement if needed, and application of fairly thick layer of shotcrete and lattice girders as primary support. It was assumed that the pre-support and ground improvement measures would be designed to keep the effective volume loss due to mined tunnel excavations below 0.5%, to limit the potential surface settlement above mined tunnel.

Further details of our preliminary ground movement assessment carried out for mined tunnels and caverns at selected locations along the proposed alignment are presented in Appendix C.

3.4.3 Settlement due to Open Cut Excavation

The ground response to deep excavation in soil and/or rock would largely depend on the construction method, excavation sequence and wall support systems. For the purpose of the ground movement assessment it was assumed that the concept design of wall support system would be capable of providing sufficient lateral restraint to minimise inward wall deflections.

As the excavation progresses, the lateral pressures imposed by the ground on the up-side of the wall would induce wall deflections into the excavation. This would result in vertical and lateral displacements of the ground adjacent to the retaining wall. In principle, the magnitude and extent of this ground movement is a function of the retention system type, the adopted construction methodology and the properties of the soil and/or rock materials.

It should be noted that this preliminary ground movement assessment is based on what is termed “green-field” conditions, because the influence of existing structures or excavations on ground movement predictions are not considered in the analyses. This assumption is typically made for preliminary screening levels assessments and is considered appropriate for the preliminary assessment which has been completed for the Melbourne Metro Concept Design. Further assessments of the ground movement would be required



once further site investigation and design development has been completed. In particular this work should focus on critical sections where the topography, complex interface with existing structures and/or foundation/ basement conditions are not suited to the assumed simplified green-field methods of analysis.

Based on the available conceptual design details the following retention system types have been considered for the proposed stations boxes, shafts and portal structures.

- Western Portal – decline structure on the portal approach with secant pile walls.
- Arden station – diaphragm walls around perimeter of the station box, with temporary propping installed as excavation advances and ground improvement as necessary.
- Parkville station – soldier piles with shotcrete infill panels were considered for the retention system, with top-down approach including construction of roof slab and installation of temporary propping as required. Internal reinforced concrete wall, water retaining, cast in situ after excavation is complete.
- CBD North station – soldier piles with shotcrete infill panels were considered for the retention system of deep shafts, top-down approach including construction of roof slab and installation of temporary propping as required. Internal reinforced concrete wall, water retaining, cast in situ after excavation is complete.
- CBD South station – diaphragm walls were considered for the deep shaft retention system, top-down approach including construction of roof slab and installation of temporary propping as required.
- Domain station – diaphragm walls around perimeter of the station box, with top-down approach and temporary propping installed as excavation advances.
- Eastern Portal – decline structure on the portal approach with secant pile walls, assumed to be laterally restrained.

Empirical Analysis

For preliminary assessments of ground movement due to open cut excavation, an empirical method proposed by Clough & O’Rourke (1990) has been considered for verification of the settlement contours and to initially assess the ground movement profiles adjacent to deep excavations. This method provides formulas relating to the maximum ground settlement (δ_{vm}) to the maximum horizontal wall deformation (δ_{hm}), which is assessed based on the total excavation depth (H_e) and type of material supported by the wall retention system. The following equation has been used to estimate the maximum horizontal deformation at the top of excavation.

$$\delta_{hm} = (0.2 - 0.5\%) H_e$$

For the preliminary analysis, a simplified approach based on the relationship between the maximum vertical and horizontal ground movement was considered. The ratios recommended by Ou (2006) depend on the soil conditions behind the wall and the values presented in Table 12 were considered for this study.

Table 12: Summary of vertical to horizontal ratios typically adopted for different soil conditions

Assumed Soil Condition	Vertical movement (δ_{vm}) / Horizontal movement (δ_{hm})
Sands	0.50
Clays	0.75
Soft Soils	1.00

Finite Element Modelling

The finite element modelling for the western portal, Arden station, Parkville station, CBD North and CBD South station shafts, Domain station and the Eastern Portal was completed by AJM JV. 2D PLAXIS software was used by AJM JV to model ground structure interaction and settlement at the surface. The assessed ground movements were then used by AJM JV to develop the excavation induced settlement contours around these structures, as shown on the settlement contour drawings in Appendix D.



3.4.4 Consolidation Settlement due to Groundwater Drawdown

It should be recognised that if not carefully controlled, groundwater drawdown may induce significant ground settlements due to consolidation of the soft soils (primarily Coode Island Silt) which lie within the project's zone of influence.

The preliminary groundwater modelling results, summarised in the Regional Groundwater Numerical Model EES Summary Report (RGNMR), indicated that the proposed Melbourne Metro tunnels and stations may have potential impact on the surrounding groundwater system.

The impact on the surrounding groundwater system, once long term steady state conditions have been established, is not considered significant and expected to be limited to a relatively small area based on the regional groundwater modelling results. This assumes all of the project elements are adequately sealed to restrict groundwater inflows to maximum allowable levels. If the actual hydraulic conductivities are greater than those assumed, then the anticipated drawdowns within these soils could also be greater than currently predicted.

The results of numerical modelling indicated potential groundwater drawdowns at the base of the Coode Island Silt (CIS) for different Melbourne Metro scenarios were simulated under transient and steady state conditions. Based on the results of this initial hydrogeological assessment, the following predictions of groundwater drawdowns at the base of the Coode Island Silt have been estimated:

- Western portal and Arden station – groundwater drawdown of up to about 2.0 m at the end of construction phase;
- CBD south station – groundwater drawdown between about 0.5 m to 1.0 m at the end of construction phase;
- Domain station – groundwater drawdown of less than about 0.5 m at the end of construction phase; and
- CBD South station and Yarra River crossing – groundwater drawdown of less than about 0.5 m for the operational phase.

It should be noted that the Coode Island Silt in these areas may have been partly drained in the past, so the actual settlement triggered by construction and operation of the project could be less than predicted for the estimated drawdowns. In addition to anecdotal evidence of settlement occurring due to groundwater drawdown associated with leaking sewers in these areas, there have been historic drawdown events such as those associated with the Melbourne Arts Centre construction, and City Link construction, which effected the Coode Island Silt in the Yarra River palaeovalley. Where this has occurred in areas which may be influenced by Melbourne Metro construction activities, this past history may mitigate against the settlements which would occur as the soil may have experience similar changes in effective stress previously. However due to the lack of specific details associated with these events, such potentially beneficial effects cannot be readily assessed or relied upon for the purposes of this assessment.

The risk of drawdown due to leakage through the tunnel segmental lining or the secondary lining systems for the portals and stations may also result in lowering of the groundwater table or depressurisation of confined aquifers in the vicinity of the alignment. Reductions in groundwater pressure, which are caused by such inflows, would result in an increase in the effective stress and a time dependent reduction in volume (consolidation) of the soil. This would result in settlement observed at the ground surface.

The magnitude of settlement expected along the proposed Melbourne Metro alignment would depend on the following:

- The existing state of groundwater pressure and levels prior to construction;
- The extent of groundwater drawdown due to leakage into the tunnels and stations;
- The properties of the soils and compressibility of the soil layer;
- The thickness of the saturated soil layer that is dewatered;



- The time the groundwater remains drawn down or the aquifer depressurised;
- The extent and rate of groundwater recovery; and
- The rate of any secondary compression which is already occurring.

Potential ground movement associated with shrink and swell behaviour of moisture sensitive soils may be amplified by water level variations during and post-construction and further assessment should also be considered in a subsequent detailed design study.

Settlement due to Consolidation of Coode Island Silt

The Coode Island Silt is typically a soft to firm normally or slightly over-consolidated clay with lenses of sand, which underlies parts of Melbourne. It is recognised that consolidation settlement may occur due to groundwater drawdown where the proposed Melbourne Metro alignment crosses in Maribyrnong River, Moonee Ponds Creek and Yarra River paleochannels. In these areas substantial thicknesses of this unit are expected, which would be prone to consolidation if depressurised.

The estimates of primary consolidation settlements presented in this report were based on one-dimensional consolidation theory and were assessed using the following formula:

$$S = \int_0^h \frac{1}{1 + e_0} \left(C_r \log \frac{P_c}{P_o} + C_c \log \frac{P_f}{P_c} \right) dh$$

where S is the settlement, C_r is the re-compression index, C_c is the compression index, e_0 is the initial void ratio, P_o , P_c and P_f are the initial, pre-consolidation and final vertical effective stresses and h is the CIS thickness.

We have also assumed that the estimated drawdown at the base of CIS from the hydrogeological modelling is applicable over the full thickness of the CIS. This is considered to be a prudently conservative assumption, as there could be some natural recharging occurring in the upper part of CIS due to infiltration.

It should be noted that consolidation settlement of soils due to groundwater drawdown is time dependent. The time that the groundwater pressure remains reduced would influence the percentage of the total primary consolidation settlement that occurs. Based on our past experience, we would expect that about 50% of the primary consolidation settlement to occur in about 6 months and about 95% of the primary consolidation settlement to occur in about 3 years in CIS deposits greater than 10 m thick. In the areas, where the CIS thickness is less than 5 m, the rate of settlement is expected to be faster.

For the assessment of consolidation settlement presented in this report, we have assumed that most of the primary consolidation settlements due to groundwater drawdowns during construction would occur within the construction period (i.e. by the end of construction). This assumption is considered to be prudently conservative.

The following assumptions were also made in estimating the consolidation settlement:

- Existing ground surface level typically at about RL 3.0 m AHD in the areas likely to be affected.
- Top of Coode Island Silt typically at about RL 0.0 m AHD and is overlain by about 3 m of fill or other natural materials.
- Coode Island Silt deposit thickness between about 2.0 and 22.0 m.
- The parameters presented in Table 4 have been adopted for the preliminary settlement assessment.
- Initial groundwater table assumed at RL 0.0 m AHD.



- Pre-consolidation pressure of 10 kPa higher than the current vertical effective stress to account for past groundwater level fluctuations and ageing.
- The groundwater drawdown estimated at the base of the CIS is applicable for the full thickness of CIS.

As discussed previously, the groundwater drawdowns estimated for the construction phase are larger than those estimated for the operation phase. Hence, most of the primary consolidation settlement due to groundwater drawdown is expected to occur during construction. Once the structures are sealed/lined, the groundwater levels would recover, but most of the consolidation settlement occurred during the construction phase would be permanent. There would be some rebound movements in the CIS due to groundwater recovery after the end of construction, but they are not expected to be significant.

Figure 3 present estimates of consolidation settlements in CIS deposits of various thicknesses due to groundwater drawdowns of 0.5 m, 1.5 m and 2.5 m over an extended period of time.

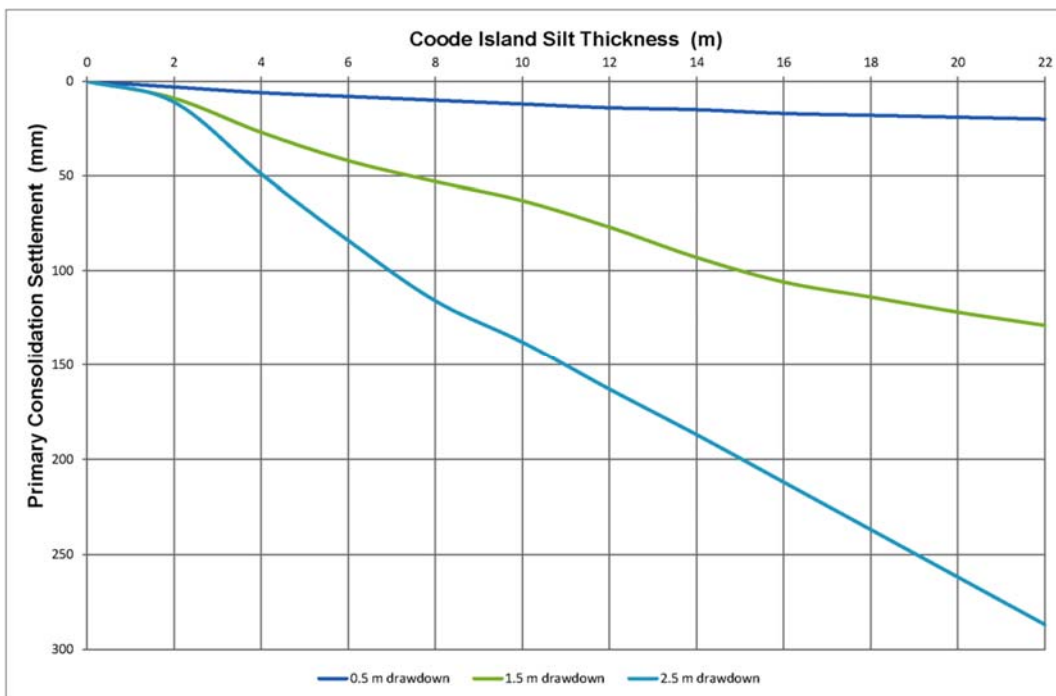


Figure 3: Estimated consolidation settlements due to groundwater drawdown in CIS

Contours of calculated primary consolidation settlements in the areas of CIS due to groundwater drawdowns are presented in the drawings included in Appendix E. These contours were based on consolidation settlements estimated based on the estimated drawdowns and the CIS thicknesses at selected grids of locations in the areas of concern. The calculated consolidation settlements in CIS near the CBD South and Domain stations are generally less than 10 mm. The calculated consolidation settlements in CIS near the areas of western portal and Arden station are up to about 50 mm and 100 mm, respectively. These settlements would need to be further refined once more geotechnical information and the results of further hydrogeological sensitivity analyses become available.

The available records and published data (Srithar, 2010) indicate areas, within and/or near the proposed Melbourne Metro corridor, which are locally underlain by over 20 m of Coode Island Silt have settled in excess of 1000 mm over the past 100 years. Some of this settlement is possibly related to primary consolidation initiated by surcharge loading and/or groundwater drawdown, but some also is probably associated with secondary compression or background creep which may be ongoing over the design life of the structure.



It is possible that the difference between the actual preconsolidation pressure and the current effective stress in the CIS, (which was assumed to be 10 kPa for our assessment) can be greater than the expected stress increase caused by the drawdown. If this is the case, then the consolidation settlement in the CIS would be mostly re-compression settlements and considerably less than those shown on the drawings in Appendix E.

3.4.5 Long Term Background Settlement (Creep)

In normally consolidation or slightly-overconsolidated clays creep settlement can occur. Based on laboratory tests and classical soil mechanics theory, the rate of creep settlement is expected to be linear on a log time scale. That is, the rate of creep would gradually decrease with time. However, historical measurements of creep settlements in CIS deposits in Melbourne over the last century suggest an apparent linear trend on a real time scale. It is possible that construction activities in the past century may have caused small settlements, even if in some cases the activities might not have been in close vicinity of the proposed MMRP corridor. Examples of typical long term background settlement rates based on observations within the South Melbourne area are presented in 'Settlement Characteristics of Coode Island Silt' (Srithar, 2010).

It is considered that reasonable estimates of settlement due to historic fill surcharge can only be made by assessment of historical data. Based on the available data and previous project experience, the creep estimates presented in Table 13 should be considered in the long term settlement assessment.

Table 13: Creep settlement within Coode Island Silt

Thickness of Coode Island Silt	Expected Creep Settlement Rates
Less than 5 m	< 2 mm per year
5 – 10 m	2 - 5 mm per year
10 – 15 m	5 - 10 mm per year
15 m or more	> 10 mm per year

The values presented in Table 13 are intended to provide indicative rates of background creep for consideration for the design of structures in areas of CIS. However, for Melbourne Metro it is considered prudent that an attempt should also be made to measure relevant background creep, which would also provide a baseline for contractual purposes. It is currently proposed to install a network of surface settlement points within each of these areas to confirm these assumed rates.

It should be noted that this creep settlement is the natural background settlement that is expected to occur regardless if the project is constructed or not. This should be considered as a settlement in addition to any other cause of ground movement.

We reiterate that the estimates of consolidation settlements presented in this report are for the expected groundwater drawdown levels related to Melbourne Metro construction and operation only. Predictions of additional displacement due to long term regional creep of these soils have not been provided at this stage and it should be based on baseline monitoring data in the Study Area. A typical example of combined consolidation settlement (assumed to be 100 mm occurring due to drawdown) and creep settlement (assumed to be 5 mm/year) over a period of 30 years is shown in Figure 4.

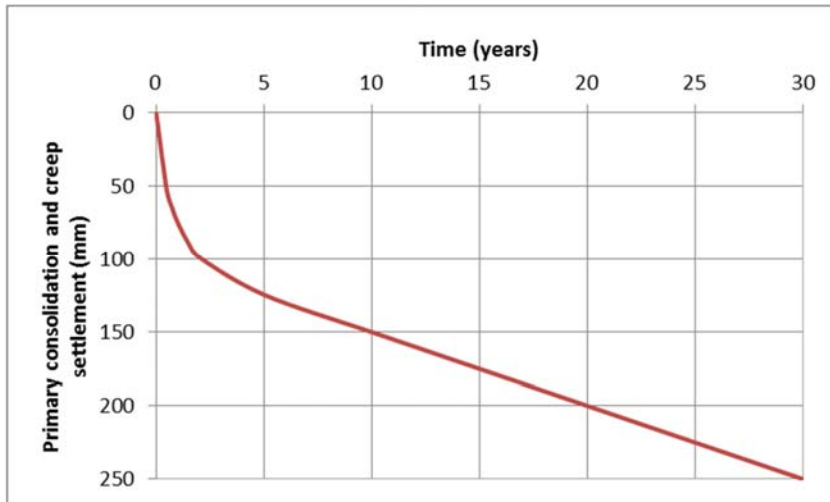


Figure 4: Example consolidation and creep settlement in CIS over 30 years

The creep settlement can also result in differential settlement within the footprints of existing structures. The differential settlement due to creep could be up to 30% of the total creep settlement over a 20 m distance.



4.0 SUMMARY OF RESULTS OF PRELIMINARY ASSESSMENTS

It should be noted that, due to the preliminary stage of design development when the settlement assessment was completed, the calculated settlement values are approximate and based on a number of prudently conservative assumptions, including simplified ground profiles and preliminary design geotechnical parameters adopted for the purpose of this assessment.

The effects of portals, tunnels and station boxes and cavern excavations and groundwater drawdown induced ground movements for the Melbourne Metro Concept Design are presented as indicative settlement contour plots derived from the analysis methods outlined in Section 3.0.

The preliminary predictions of the ground movement due to open cut, portal, tunnel, shaft and cavern excavations are incorporated in the settlement contours provided in Appendix D. The predictions of potential settlements reported in Appendix D are considered to be reasonable initial estimates based on past deep excavation and tunnelling experience in Melbourne; however further analyses would be required to refine them going forward as the project develops.

The preliminary predictions of consolidation settlement presented in Appendix E take account of the results of the preliminary regional groundwater numerical modelling and are based on the predictions of potential groundwater drawdowns for construction and operational phases of selected elements of the project. The assumptions made for the groundwater modelling with respect to construction methodology, sequencing and timing are summarised in the RGNMR.

It is assumed the construction activities would manage groundwater inflows such that the drawdowns would not be greater than those shown on the drawings. It should be noted that, in the event that higher drawdowns beneath the Coode Island Silt are induced during construction, larger settlements than those currently predicted would occur.

The following is a summary of results of ground movement assessment for the Melbourne Metro alignment presented for each segment from west to east of the project.

4.1 Excavation Induced Settlement

4.1.1 Tunnels and Caverns Induced Settlement

The purpose of this ground movement assessment carried out for tunnels and caverns at selected locations along the proposed alignment was to assess the potential ground movements induced by underground excavations; to explore the potential impacts on the existing buildings and infrastructure due to construction of tunnels and caverns and to provide information to inform development of the Melbourne Metro Concept Design.

The tunnelling and cavern excavation related settlements estimated at the nominated locations are summarised in Appendix C. These estimates are based on the results of the two-dimensional finite element methods of analysis. These green-field estimates are representation of maximum settlements expected at the existing ground level unless noted otherwise.

4.1.2 Open Cut Works Induced Settlement

The ground movements and potential impacts of construction of the proposed station boxes, deep shafts and portal structures have been analysed and assessed by AJM JV, and used along with tunnel and cavern induced settlement calculated by Golder, to produce the settlement contours provided in Appendix D (see Section 1.4 for further details of the scope split between AJM JV and Golder).

4.2 Groundwater Drawdown Induced Consolidation Settlement

4.2.1 Construction Phase

Estimates of the potential groundwater drawdowns were considered in this preliminary ground movement assessment for sections along the Melbourne Metro alignment (i.e. western portal, Arden station, CBD South station and Yarra River tunnel crossing, and Domain station) susceptible to consolidation settlement.



The results of the preliminary assessment of potential consolidation settlement due to the groundwater drawdowns estimated at the end of construction within the Melbourne Metro corridor indicate that consolidation settlements in the order of 50 to 100 mm may occur. This is likely to be observed in the areas where Coode Island Silt sediments of significant thicknesses are present and the groundwater drawdown is up to 2.0 m, which is expected at western portal and Arden station area.

It should be noted that in addition to the modelled tunnels and stations construction induced groundwater drawdowns, construction of other Melbourne Metro elements can also induce consolidation settlement within compressible soils subject to groundwater depressurisation. This may include deep shafts and tunnel cross passages excavated within or close to the palaeovalleys which have not been included in the groundwater modelling at this stage.

Combined and overlapping groundwater drawdowns from portals, stations, tunnels, cross passages and shafts have not been modelled at this stage, and as such, cumulative effects of groundwater induced consolidation settlements could not be considered. The effects of such cumulative impacts would be additive to pre-existing influences beyond the control of Melbourne Metro. However, providing appropriate mitigation measures are implemented during construction, groundwater drawdowns within the areas of compressible soils are not expected to be significantly greater than drawdowns already predicted for the stations and portal structures. Further modelling work would be required to investigate the cumulative effects of various elements along the Melbourne Metro alignment and the properties and extent of any potentially high permeability units (e.g. Early Pleistocene Colluvial and Alluvial Sediments).

The results of the CD stage ground movements of groundwater induced consolidation settlement are presented on the consolidation settlement contour drawings provided in Appendix E.

4.2.2 Operational Phase

Based on the results of the groundwater modelling of operational stage, which assumed post-construction (sealed stations, tunnels, etc.) conditions, recovery of groundwater drawdown is expected and the estimated long term groundwater drawdowns are expected to be less than groundwater drawdowns due to Melbourne Metro construction. It is therefore expected that the overall consolidation settlement within CIS should not be greater than that induced by the groundwater drawdown due to construction.

Ongoing hydrogeological modelling would refine the anticipated construction and long term drawdowns, and consolidation settlement estimates would need to be refined accordingly.

4.3 Ground Movement Assessment for Selected Structures

A limited number of more detailed assessments of ground movements were completed on a selection of existing potentially settlement sensitive structures along the Melbourne Metro Concept Design alignment by both AJM JV and Golder. FE modelling of tunnel and cavern excavations was carried out by Golder using 2D and 3D PLAXIS software. This approach was adopted to develop a better understanding of the potential ground structure interaction issues and to gain a more detailed understanding of the potential ground movements in the vicinity of the existing structures.

The existing structures assessed by AJM JV and Golder were as follows:

Ground movement assessments completed by AJM JV

- Western portal retrieval shaft and decline;
- Existing West Melbourne Terminal Station raked piles;
- Existing CityLink viaduct foundations;
- Arden station;
- Existing Grattan Street tunnel with Victorian Comprehensive Cancer Centre and Royal Women's Hospital retaining walls;



- Parkville station;
- CBD North station;
- CBD South station;
- Linlithgow emergency access shaft;
- Existing CityLink crossing;
- Domain station;
- Fawkner shaft;
- Eastern portal retrieval shaft and decline; and
- Eastern portal cutting widening and stabilisation.

Ground movement assessments completed by Golder

- Selected approved developments;
- City Loop;
- Manchester Unity Building;
- Telstra Tunnel;
- St Paul's Cathedral;
- Princes Bridge; and
- Alexandra Avenue Underpass.

4.4 Summary of Key Findings

It is understood that the settlement contour plans and results presented in this report would be used by AJM JV to assess the potential for damage to existing buildings, infrastructure and underground services along the alignment. It should be noted that the settlement results within this report are preliminary and should only be used to support the development of Melbourne Metro Concept Design.

It is recognised that the presence of existing buildings and underground services, existing basement structures and deep foundations would likely have an effect on the predicted ground movements. However, for the purposes of this study, ground movements have been calculated for a 'greenfield' site.

For the purpose of this preliminary ground movement assessment, a range of volume loss due to TBM tunnelling of 0.5 % to 1.0 % has been adopted for the settlement calculations and settlement contour plans. However, if difficult tunnelling conditions are encountered during construction and in particular in sections of mixed and/or weak ground and on the contacts of geological boundaries, volume losses greater than 1.0 % and even 1.5 % may be experienced. This may lead to an extent of tunnelling induced settlement greater than currently presented in the settlement contour drawings.

To fully appreciate the magnitude of potential settlements due to the construction of Melbourne Metro, cumulative effects of excavation induced settlements and groundwater drawdown induced consolidation settlements need to be considered and potential impacts of both be assessed accordingly. The combined effects can be estimated by adding the predictions of settlements presented on:

- Excavation induced settlement contours included in Appendix D; and
- Groundwater drawdown induced settlement contours included in Appendix E.



The potential ground movements have been assessed using a combination of semi-empirical and simplified analytical methods, and finite element analyses at selected sections through the alignment. A number of comparisons of the results obtained, using FE and empirical methods, have been undertaken at complex geological setting locations to calibrate the results and check if methods adopted for settlement assessment are adequate. If such checks are not undertaken, the potential settlement impacts could either be over or underestimated, which in turn could have implications for the project risk assessment.

Notwithstanding these limitations, the analytical and modelling work completed for this assessment are considered adequate to provide a preliminary indication of potential ground movement and potential impacts of the proposed Melbourne Metro alignment on existing buildings, infrastructure and services.

The results of this preliminary settlement assessment indicate that settlements at the surface due to tunnel and station excavations can be summarised as follows:

- Tunnels
 - A maximum settlement of up to 60 mm is predicted at sections underlain by soft soils.
 - Where the ground conditions comprise mostly fill and residual/alluvial soil, estimated ground settlements typically range between about 10 mm and 40 mm.
 - Less than about 5 mm for deep tunnels to a maximum of about 20 mm in shallower sections in weathered rock.
 - The potential zone of influence along the proposed Melbourne Metro alignment, which is the defined as the distance to the 5 mm settlement contour, varies between a maximum of 80 m around the section between the western portal and Arden station and a maximum of about 50 m between Alexandra Avenue and City Link tunnels area.
- Stations
 - Estimated ground settlements due to the station box excavations vary significantly across the site, with the largest predicted ground settlement of about 40 mm occurring at the Arden station area, adjacent to the excavation.
 - A maximum settlement and horizontal displacement of less than about 20 mm was predicted at the critical section within the weathered rock at the Parkville station area, adjacent to the excavation.
 - The potential zone of influence around the proposed Melbourne Metro stations excavations, which is the defined as the distance to the 5 mm ground movement contour, is predicted to range typically between about 20 m and 30 m.
- Consolidation settlement of the Coode Island Silt due to groundwater drawdown was estimated to be typically less than about 10 mm, except in the areas of western portal near Maribyrnong River and Arden station near the Moonee Ponds Creek. Consolidation settlements up to 50 mm and 100 mm were estimated in the areas of western portal and Arden Station, respectively. The higher settlements are confined to areas of higher predicted drawdowns close to the Melbourne Metro alignment, where CIS is thicker. The contours of estimated consolidation settlement are shown on drawings presented in Appendix F and should be considered in addition to ground loss resulting settlement contours to obtain the combined values of the two predictions.

It should be noted that, at locations where substantial thickness (greater than 5 m) of CIS exists, there is a potential for ongoing creep settlement which currently has not been taken into consideration. Creep settlement has not been assessed and is not included in the settlement contours shown on the drawings in Appendix E. It should be noted that creep settlement is a natural background settlement that would occur regardless of whether Melbourne Metro is constructed or not.

The potential influence of any long term background creep which is currently occurring would be assessed once a settlement monitoring network has been installed and background baseline settlement rates



established. Based on the local experience and the records of long term CIS background consolidation available in the Melbourne area, the values of creep rates presented in Table 13 may be considered for the purposes of the development of the Melbourne Metro Concept Design. These are suggested to inform the EES and therefore should only be considered as indicative. The creep settlement can also result in differential settlements within the footprints of existing structures. The differential settlement due to creep could be up to 30% of the total creep settlement over a 20 m distance.

The significance of these predicted settlements, including ongoing creep movement, with respect to potential impacts on existing buildings and infrastructure along the Melbourne Metro Concept Design alignment is discussed in the AJM JV Ground Movement Impact Assessment (AJM JV, 2016).

5.0 ASSESSMENT LIMITATIONS

The key assumptions adopted for the ground movement assessment and the subsequent results of the settlement analyses presented within this report should be considered preliminary and are provided to support the development of the Melbourne Metro Concept Design. The limitations associated with this modelling and assessment work are as follows:

- The ground movement assessment is based on limited site investigation data and would need to be updated once the results of the ongoing investigation become available. Further project-specific geotechnical investigations would be required to support the detailed design works.
- Simplified ground models have been developed and considered for this ground movement assessment. It should be noted that variability in ground conditions is expected and should ground conditions be worse than those assumed, the extent and magnitude of the actual settlement could be greater than predicted.
- Limited sensitivity analyses were undertaken to assess potential impacts of a range of geotechnical parameters. The characteristic design parameters adopted for geological units for the modelling were based on the IGSR and Golder's previous experience with similar materials. It should be noted that variability of engineering properties of the anticipated soil and rock materials along the proposed alignment is expected and should be considered for future sensitivity analyses.
- This ground movement assessment is based on green-field conditions. Limited assessments of ground movements and potential impacts on the existing structures along the Melbourne Metro alignment have been carried out at this stage. Further assessment of the ground movements using more complex numerical models would be required at critical sections where the topography, complex interface with the existing structures and/or foundations/basement conditions are not suited to the assumed simplified green-field methods of analysis.
- The available limited information about the existing buildings, structures and underground services, present along the proposed Melbourne Metro alignment, is currently considered insufficient to undertake detailed ground movement assessments. Further project-specific site investigations would be required to support detailed assessment of potential impacts of the project on the existing structures.
- Simplified temporary support designs and construction staging have been adopted for the preliminary ground movement assessments. Because of these simplifications, the estimated ground movement and potential adverse effect on the existing structures induced by the station and tunnel excavations may not be representative of the worst credible condition and should be considered preliminary only.
- Assessment regarding the potential ground movement induced by aquifer depressurisation related to temporary and permanent dewatering works is based on the preliminary drawdown predictions contained within the Regional Groundwater Numerical Modelling Report. Further sensitivity analyses and an assessment of potential combined drawdown effects would need to be completed as part of the next phase of groundwater modelling work to refine the current drawdown estimates and associated settlement predictions. Based on the groundwater modelling work completed for the Melbourne Metro



Concept Design, Golder do not consider that such combined effects would materially change the results of this ground movement assessment, given all of the drawdown mitigation strategies suggested in the Regional Groundwater Numerical Modelling Report have been adopted in the concept design.

- Ongoing settlement associated with the background creep settlement of Coode Island Silt sediments is not included in the preliminary settlement predictions. Baseline settlement monitoring should therefore be undertaken prior to the start of construction to establish existing background creep rates, so these can be distinguished from project induced settlement during construction.
- No ground movement associated with the shrinking or swelling of reactive clays was considered in this preliminary assessment. Again baseline settlement monitoring should be undertaken prior to the start of construction to establish any existing patterns of shrinking and swelling of near surface soils along the alignment, so these can be distinguished from project induced settlement during construction.

Overall, notwithstanding these limitations, the analytical and modelling work completed for this assessment are considered adequate to provide a preliminary indication of the ground movements which may be associated with the Melbourne Metro Concept Design based on Golder's past project experience.



6.0 REFERENCES

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Report Signature Page

GOLDER ASSOCIATES PTY LTD

A handwritten signature in blue ink, appearing to read 'S Barrett', with a wavy line underneath.

Stephen Barrett
Principal

SK/SVLB-STG-DLG/sk

A.B.N. 64 006 107 857

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APPENDIX A

Geological Long Sections

MELBOURNE METRO RAIL PROJECT GEOLOGICAL LONG SECTION

LEGEND

- PROPOSED STATION EXTENT IN PLAN
- CONTROL LINE PROPOSED WESTBOUND RAIL TUNNEL
- CONTROL LINE PROPOSED EASTBOUND RAIL TUNNEL
- INDICATIVE RAIL INFRASTRUCTURE
- ALTERNATIVE CONTROL LINE
- INDICATIVE PROPOSED RAIL TUNNEL PLATFORM (SECTION)
- INDICATIVE EXISTING INFRASTRUCTURE (SECTION)
- INFERRED GROUND WATER LEVEL (SECTION)

LEGEND INVESTIGATION LOCATIONS

- REFERENCE DESIGN BOREHOLE
- Measured Depth
- Measured Groundwater Level
- Screening

NOTES

- THESE NOTES APPLY TO ALL PROJECT DRAWINGS IN THE SET UNLESS NOTED OTHERWISE.
- ALL LEVELS ARE IN METRES TO AHD.
- ALL CO-ORDINATES ARE IN METRES TO MGA-55.
- INFERRED GROUNDWATER LEVEL BASED ON MEASUREMENTS TAKEN IN MELBOURNE METRO BOREHOLES BETWEEN AUGUST AND DECEMBER 2015.
- GEOLOGICAL UNITS SHOWN ARE SIMPLIFIED AND MATERIAL COMPOSITION AND STRENGTH CAN VARY CONSIDERABLY WITHIN GEOLOGICAL UNIT.
- BOUNDARIES BETWEEN GEOLOGICAL UNITS ARE INFERRED ONLY AND SUBJECT TO CHANGE AS FURTHER SUBSURFACE INFORMATION BECOMES AVAILABLE.
- AERIAL PHOTOGRAPH HAS 50% TRANSPARENCY APPLIED.
- EXISTING STRUCTURES ARE INDICATIVE ONLY.

REFERENCES

- TUNNEL ALIGNMENT BASED ON PROPOSED RAIL ALIGNMENT (REVISION 2.3) SOURCED FROM AJM JV, FILE <MMR-AJM-PWAA-M2-DD-D08000-TRACK.DWG> AND <MMR-AJM-PWAA-M2-DD-D08000-PROF.DWG>, RECEIVED BY GOLDER ASSOCIATES 28-10-2015.
- TUNNEL INFRASTRUCTURE SOURCED FROM AJM-JV FILE <MMR-AJM-PWAA-M2-CS-D05000-TNNL-STR.dwg>, RECEIVED BY GOLDER 16-11-2015.
- STATION EXTENTS (REVISION 3.3) SOURCED FROM AJM JV, DWG FILE <MMR-AJM-PM2-M2-DD-D05000_STN_EXTENT.dwg>, RECEIVED BY GOLDER ASSOCIATES 16-11-2015.
- AERIAL PHOTOGRAPH DATE OF CAPTURE OCTOBER 2014, IMAGE RESOLUTION 10 cm, SOURCED FROM PUBLIC TRANSPORT VICTORIA.
- TOPOGRAPHY, ROADS AND RAIL DATA SOURCED FROM VICMAP 2013.

LEGEND STRATIGRAPHY

- @ra Recent Silt
- Fill Fill
- Qhi Coode Island Silt
- Qha Holocene Alluvium
- Qpj Jolimont Clay
- Qvn Newer Volcanics
- Qpa Pleistocene Alluvium
- Qpfu Fishermens Bend Silt (Upper)
- Qpfl Fishermens Bend Silt (Lower)
- Qpg Moray Street Gravels
- Qpc Early Pleistocene Colluvial and Alluvial Sediments
- Qvns Newer Volcanics Swan St Basalt
- Qpp Punt Rd Sands
- Tpb Brighton Group
- Tvo Older Volcanics
- RS - EW (Residual to Extremely Weathered)
- HW - FR (Highly Weathered to Fresh)
- Tew Werribee Formation
- Dgr Devonian Granite
- Sud - Melbourne Formation, Siltstone / Sandstone
- RS - EW (Residual to Extremely Weathered)
- HW - MW (Highly to Moderately Weathered)
- SW - FR (Slightly Weathered to Fresh)

LEGEND HISTORICAL INVESTIGATION LOCATIONS

- MELBOURNE METRO BOREHOLES
- GOLDER BOREHOLE
- GOLDER CONE PENETRATION TEST
- GOLDER PROBE HOLE
- AURECON STAGE 1 BOREHOLE
- DESKTOP AUDIT BOREHOLES
- DESKTOP AUDIT BOREHOLE - STAGE 1
- GOLDER ASSOCIATES FILES
- REGIONAL RAIL LINK
- FEDERATION SQUARE
- CITY LINK
- MURL
- WESTERN BYPASS

LEGEND RELIABILITY

QUALITY AND QUANTITY OF DATA	GEOLOGICAL COMPLEXITY				
	Very Complex	Complex	Intermediate	Simple	Very Simple
Very Poor	Very Low	Very Low	Low	Low	Moderate
Poor	Very Low	Low	Low	Moderate	High
Fair	Low	Moderate	Moderate	High	High
Good	Moderate	Moderate	High	High	Very High
Very Good	High	High	Very High	Very High	Very High

GROUND MODEL RELIABILITY

Very low (VL)	Available information insufficient given the geological complexity to develop a basic conceptual model. Indicative only, should not be relied upon.
Low (L)	Available information sufficient given the geological complexity to develop a basic conceptual ground model. Insufficient to develop an observational model.
Moderate (M)	Sufficient information given the geological complexity to develop an observational model. Significant uncertainty requiring further investigation or risk management.
High (H)	Sufficient information given the geological complexity to develop an observational ground model. Some uncertainty requiring further investigation or risk management.
Very High (VH)	Able to develop detailed observational ground model. Sufficient information given the geological complexity to identify ground related uncertainty.

FIGURE LIST MMR-AJM-PWAA-DR-NN-500450

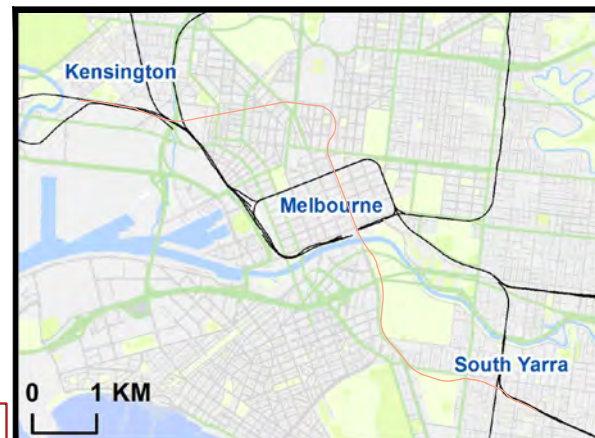
- SHEET 1 KEY MAP, LEGEND AND NOTES
- SHEET 2 TO 18 GEOLOGICAL LONG SECTION
- SHEET 19 TO 35 GEOLOGICAL LONG SECTION - RELIABILITY

KEY MAP



Note:
Surface works are not shown

NOT FOR CONSTRUCTION



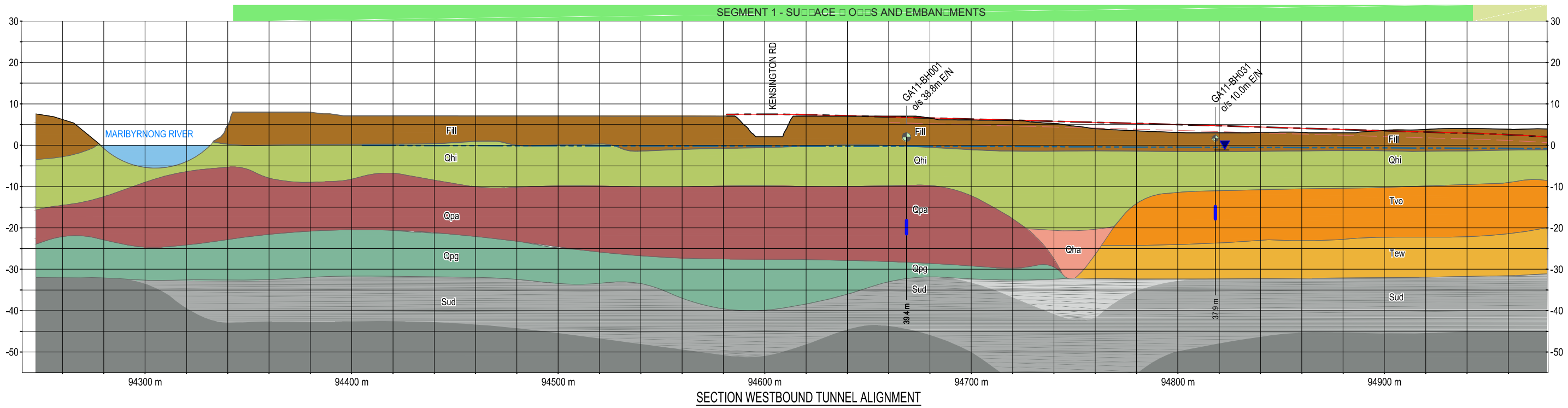
Melbourne Metro Rail Project

Title GEOLOGICAL LONG SECTION		SHEET 1 OF 35	
Drawing Number MMR-AJM-PWAA-DR-NN-500450		Revision P1.1	
Drawn By GOLDER	Approved By SLVB	Date 23-03-2016	Map Size A3





PLAN VIEW



SECTION WESTBOUND TUNNEL ALIGNMENT

NOTES

1. REFER FIGURE MMR-AJM-PWAA-DR-NN-500450, SHEET 1 OF 35 FOR NOTES AND LEGEND.
2. ALL LEVELS ARE IN METRES TO AHD.
3. ALL COORDINATES ARE IN METRES TO MGA-Z55
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Title: GEOLOGICAL LONG SECTION SHEET 2 OF 35

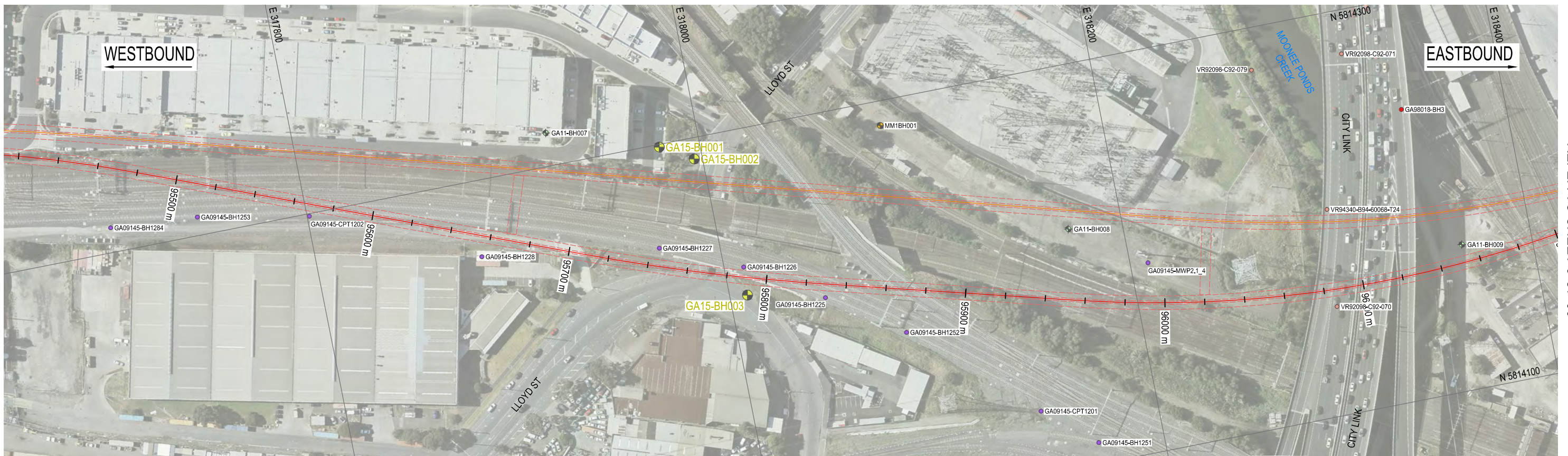
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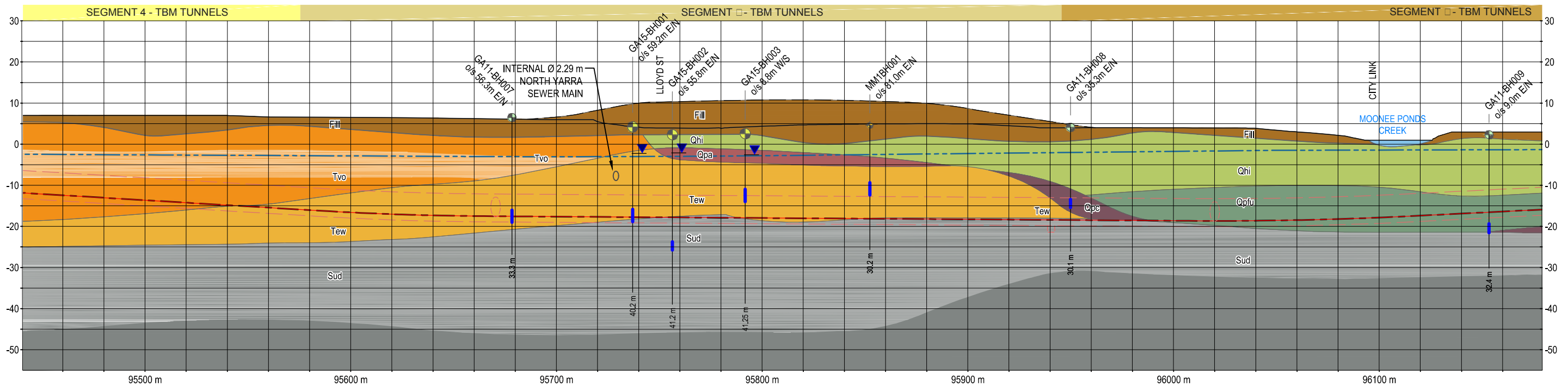


REFER TO SHEET 3 OF 35

REFER TO SHEET 5 OF 35



PLAN VIEW



SECTION WESTBOUND TUNNEL ALIGNMENT

NOTES

1. REFER FIGURE MMR-AJM-PWAA-DR-NN-500450, SHEET 1 OF 35 FOR NOTES AND LEGEND.
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Melbourne Metro Rail Project

Title: GEOLOGICAL LONG SECTION SHEET 4 OF 35

Drawing Number: MMR-AJM-PWAA-DR-NN-500450 Revision: P1.1

Drawn By: GOLDER Approved By: SLVB Date: 23-03-2016 Map Size: A3

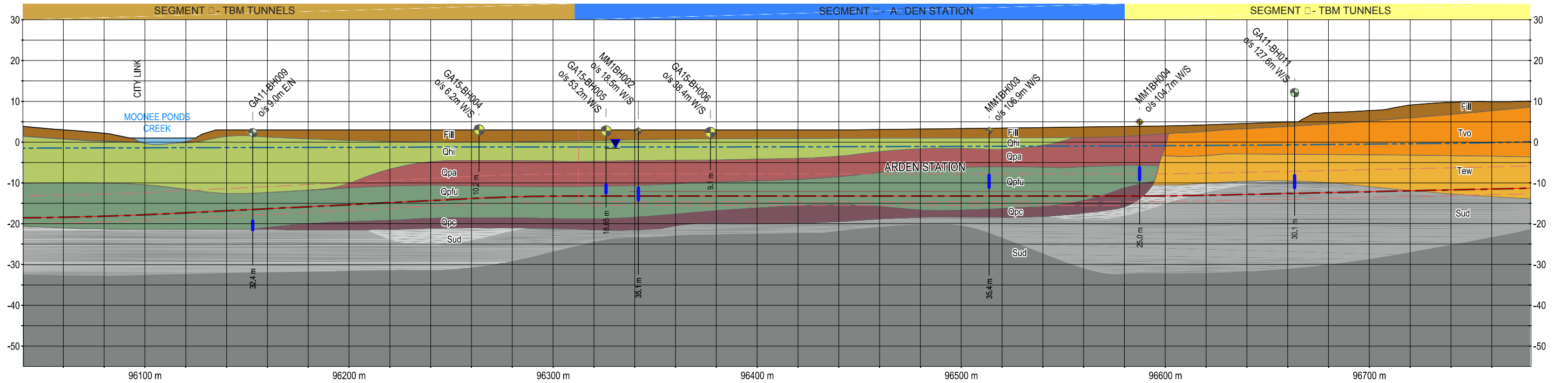


REFER TO SHEET 4 OF 35

REFER TO SHEET 6 OF 35



PLAN VIEW



SECTION WESTBOUND TUNNEL ALIGNMENT

NOTES

1. REFER FIGURE MMR-AJM-PWAA-DR-NN-500450, SHEET 1 OF 35 FOR NOTES AND LEGEND.
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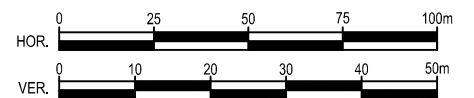


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Title: GEOLOGICAL LONG SECTION SHEET 5 OF 35

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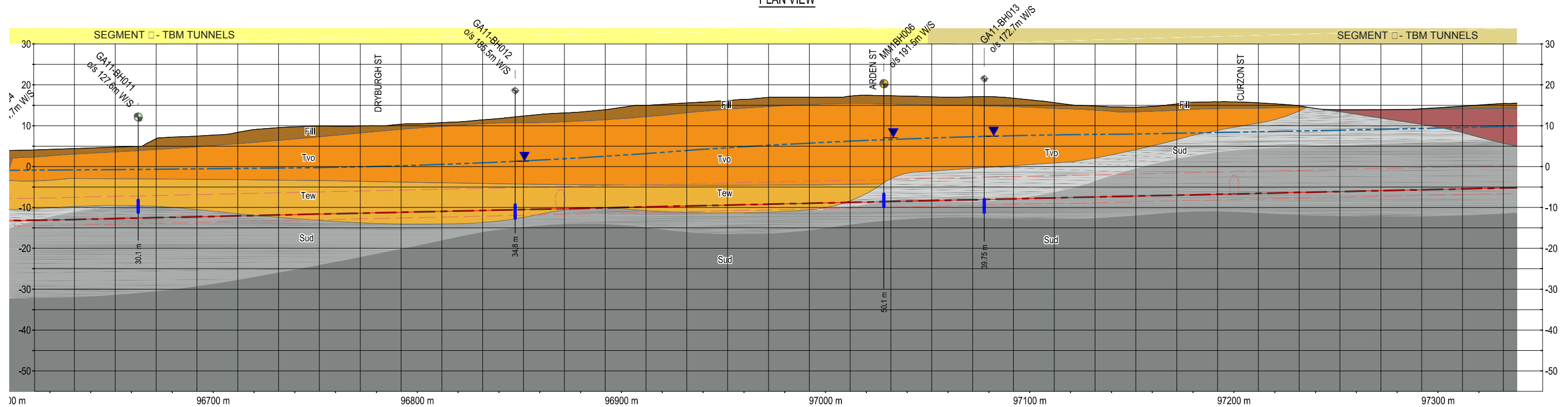


REFER TO SHEET 5 OF 35

REFER TO SHEET 7 OF 35



PLAN VIEW



SECTION WESTBOUND TUNNEL ALIGNMENT

NOTES

1. REFER FIGURE MMR-AJM-PWAA-DR-NN-500450, SHEET 1 OF 35 FOR NOTES AND LEGEND.
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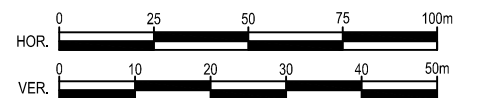


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Title: GEOLOGICAL LONG SECTION SHEET 6 OF 35

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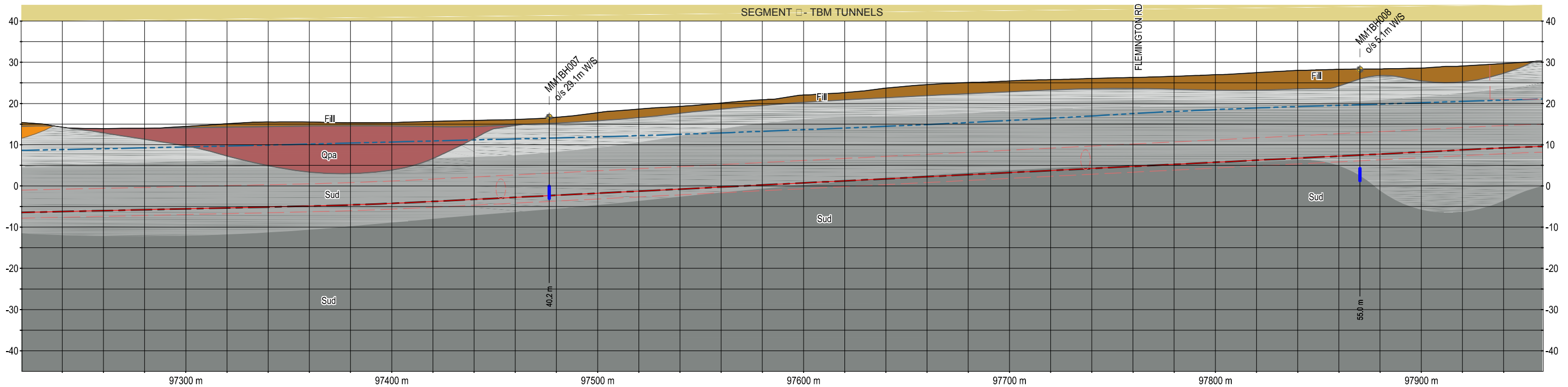


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REFER TO SHEET 8 OF 35



PLAN VIEW



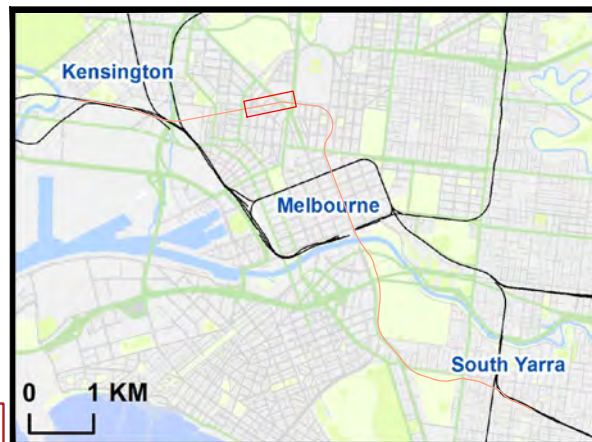
SECTION WESTBOUND TUNNEL ALIGNMENT

NOTES

1. REFER FIGURE MMR-AJM-PWAA-DR-NN-500450, SHEET 1 OF 35 FOR NOTES AND LEGEND.
2. ALL LEVELS ARE IN METRES TO AHD.
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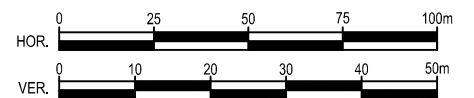


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Title: GEOLOGICAL LONG SECTION SHEET 7 OF 35

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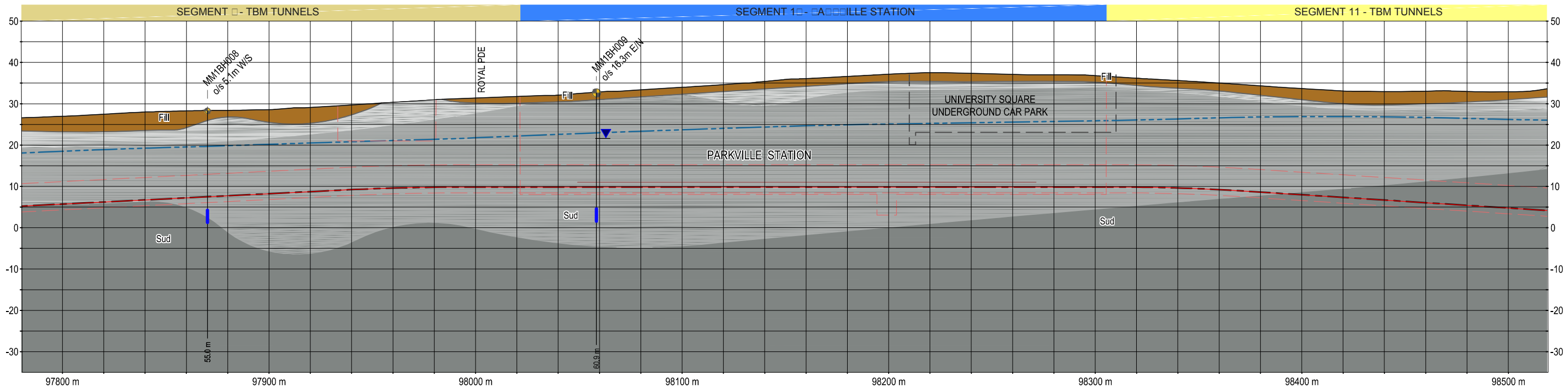


REFER TO SHEET 7 OF 35

REFER TO SHEET 9 OF 35



PLAN VIEW



SECTION WESTBOUND TUNNEL ALIGNMENT

NOTES

1. REFER FIGURE MMR-AJM-PWAA-DR-NN-500450, SHEET 1 OF 35 FOR NOTES AND LEGEND.
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Melbourne Metro Rail Project

Title: GEOLOGICAL LONG SECTION SHEET 8 OF 35

Drawing Number: MMR-AJM-PWAA-DR-NN-500450 Revision: P1.1

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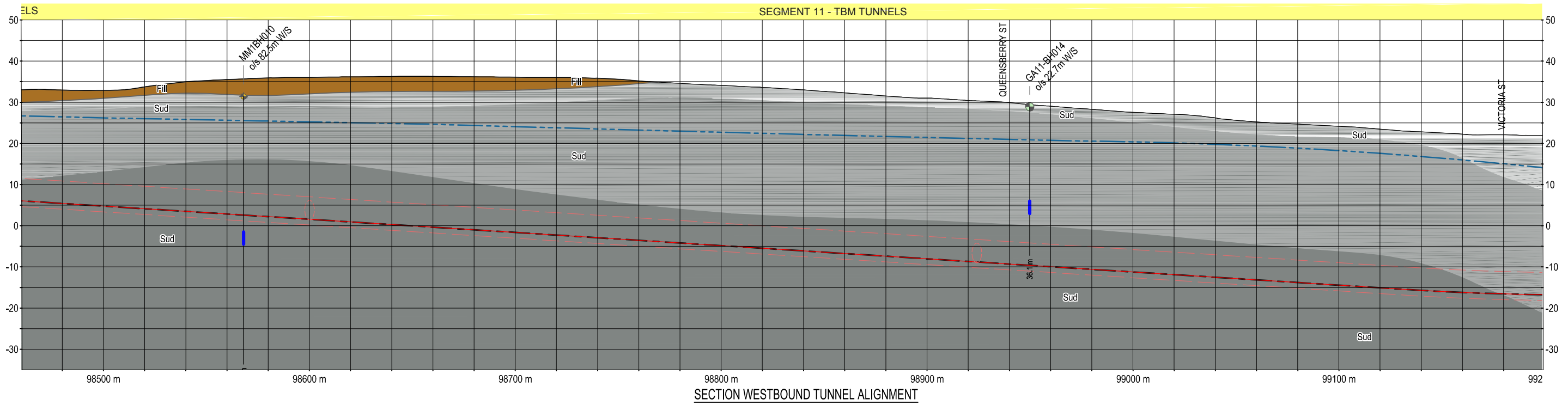


REFER TO SHEET 8 OF 35

REFER TO SHEET 10 OF 35



PLAN VIEW



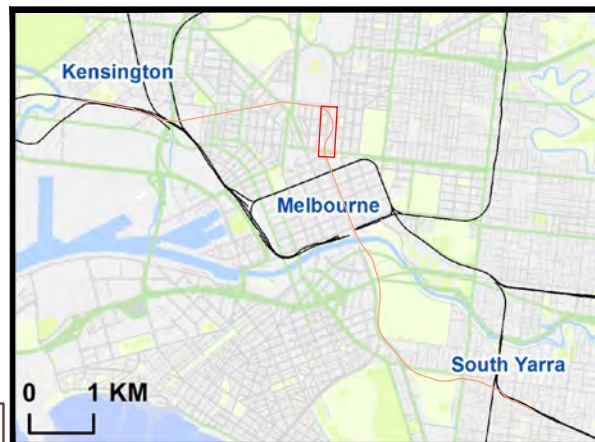
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NOTES

1. REFER FIGURE MMR-AJM-PWAA-DR-NN-500450, SHEET 1 OF 35 FOR NOTES AND LEGEND.
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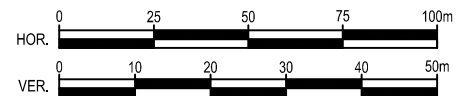


Melbourne Metro Rail Project

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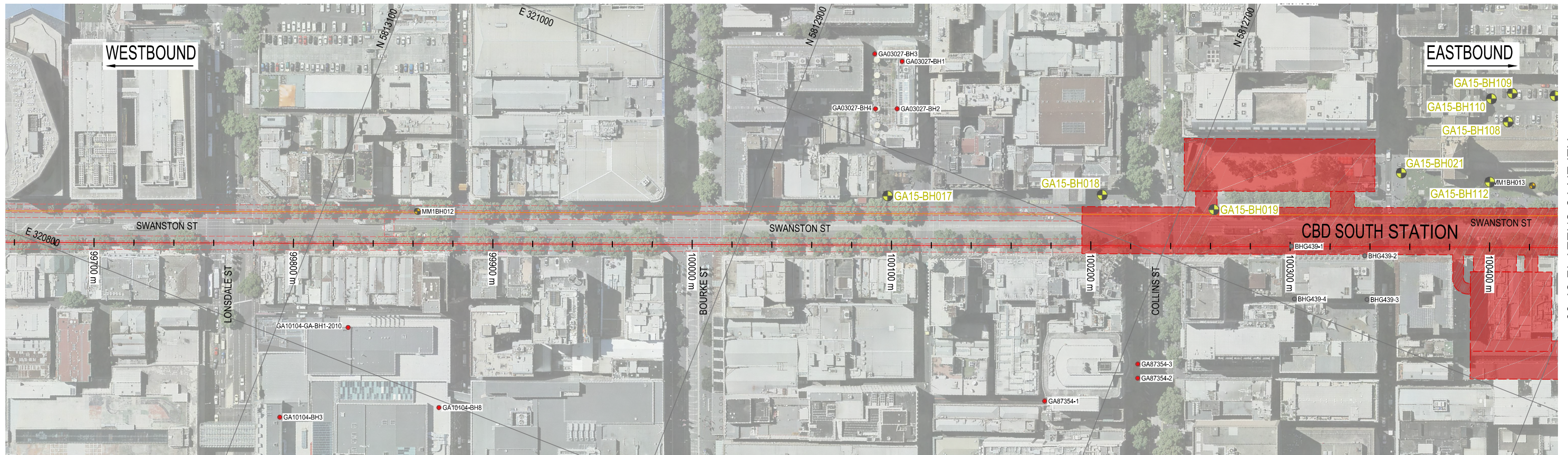
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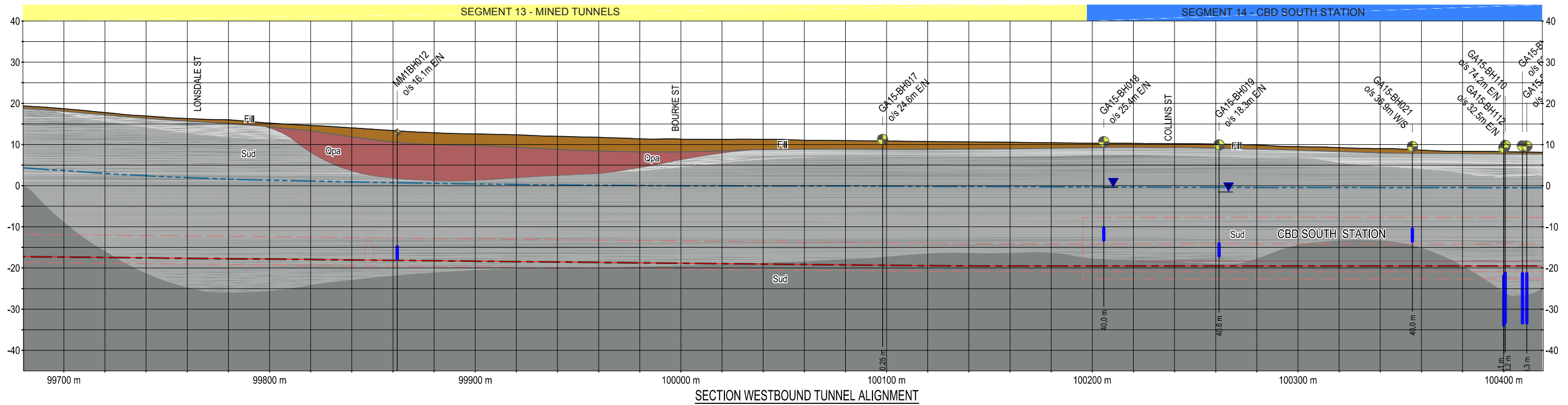


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REFER TO SHEET 12 OF 35



PLAN VIEW



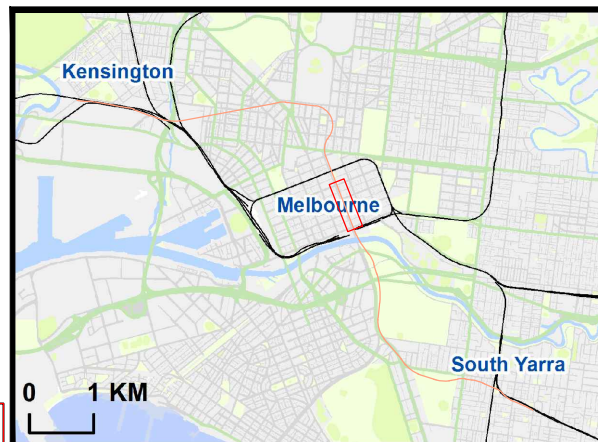
SECTION WESTBOUND TUNNEL ALIGNMENT

NOTES

1. REFER FIGURE MMR-AJM-PWAA-DR-NN-500450, SHEET 1 OF 35 FOR NOTES AND LEGEND.
2. ALL LEVELS ARE IN METRES TO AHD.
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Note:
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Title: GEOLOGICAL LONG SECTION SHEET 11 OF 35

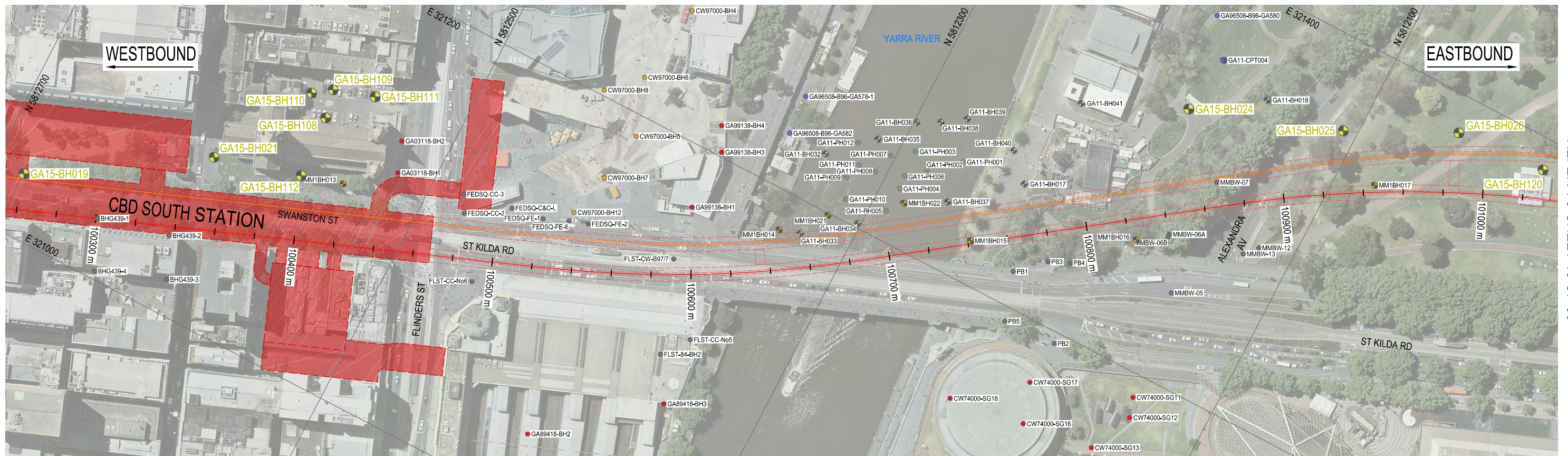
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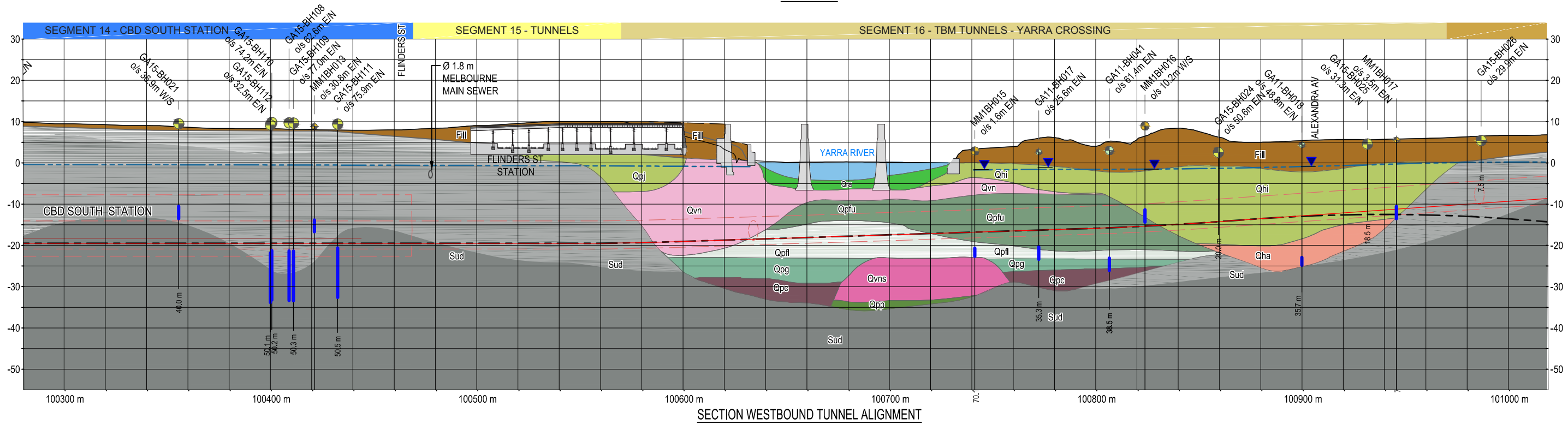


REFER TO SHEET 11 OF 35

REFER TO SHEET 13 OF 35



PLAN VIEW



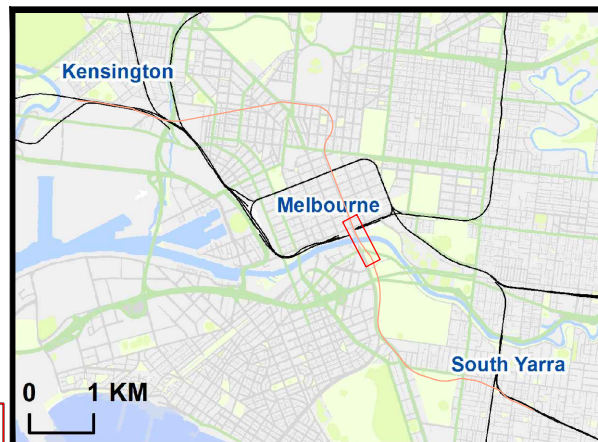
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NOTES

1. REFER FIGURE MMR-AJM-PWAA-DR-NN-500450, SHEET 1 OF 35 FOR NOTES AND LEGEND.
2. ALL LEVELS ARE IN METRES TO AHD.
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Note:
Surface works are not shown

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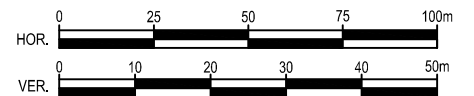


Melbourne Metro Rail Project

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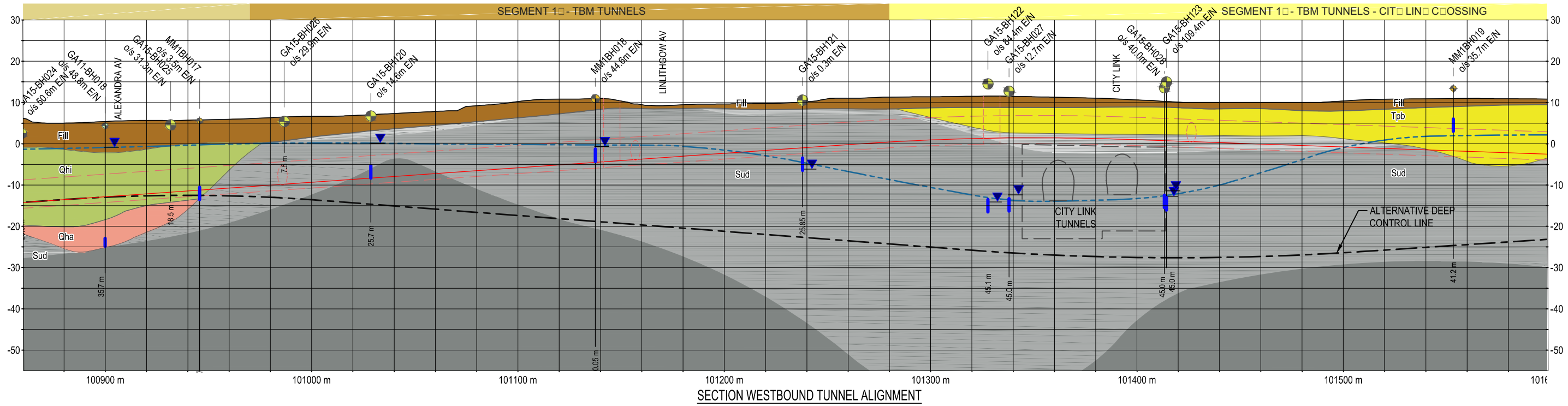


REFER TO SHEET 12 OF 35

REFER TO SHEET 14 OF 35



PLAN VIEW



SECTION WESTBOUND TUNNEL ALIGNMENT

NOTES

1. REFER FIGURE MMR-AJM-PWAA-DR-NN-500450, SHEET 1 OF 35 FOR NOTES AND LEGEND.
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Note:
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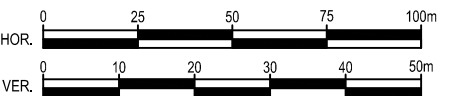


Melbourne Metro Rail Project

Title: GEOLOGICAL LONG SECTION SHEET 13 OF 35

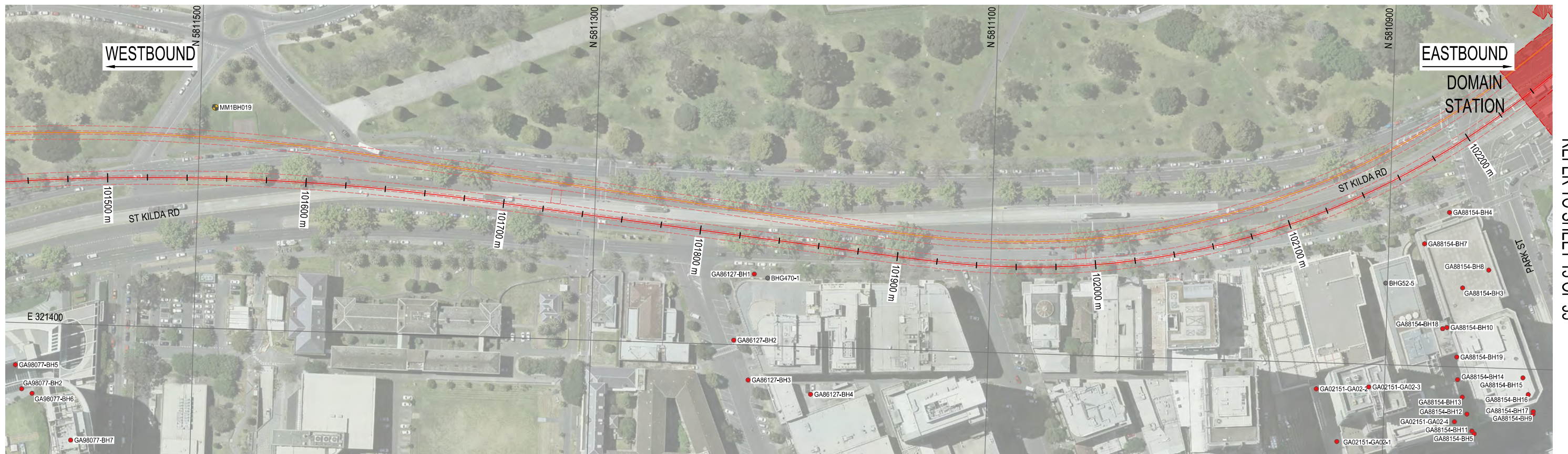
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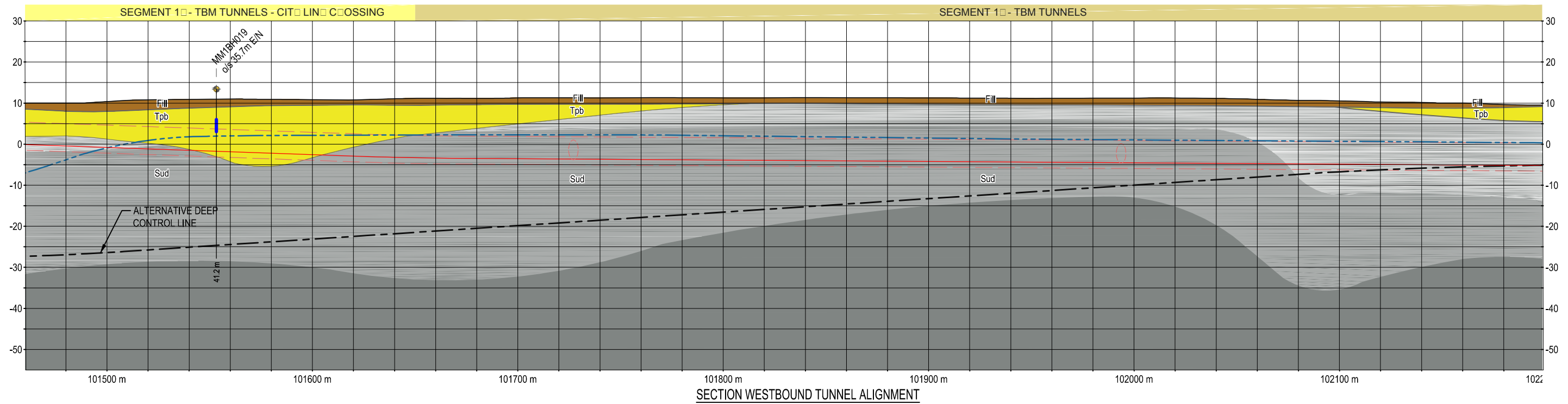


REFER TO SHEET 13 OF 35

REFER TO SHEET 15 OF 35



PLAN VIEW



SECTION WESTBOUND TUNNEL ALIGNMENT

NOTES

1. REFER FIGURE MMR-AJM-PWAA-DR-NN-500450, SHEET 1 OF 35 FOR NOTES AND LEGEND.
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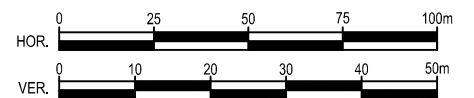


Melbourne Metro Rail Project

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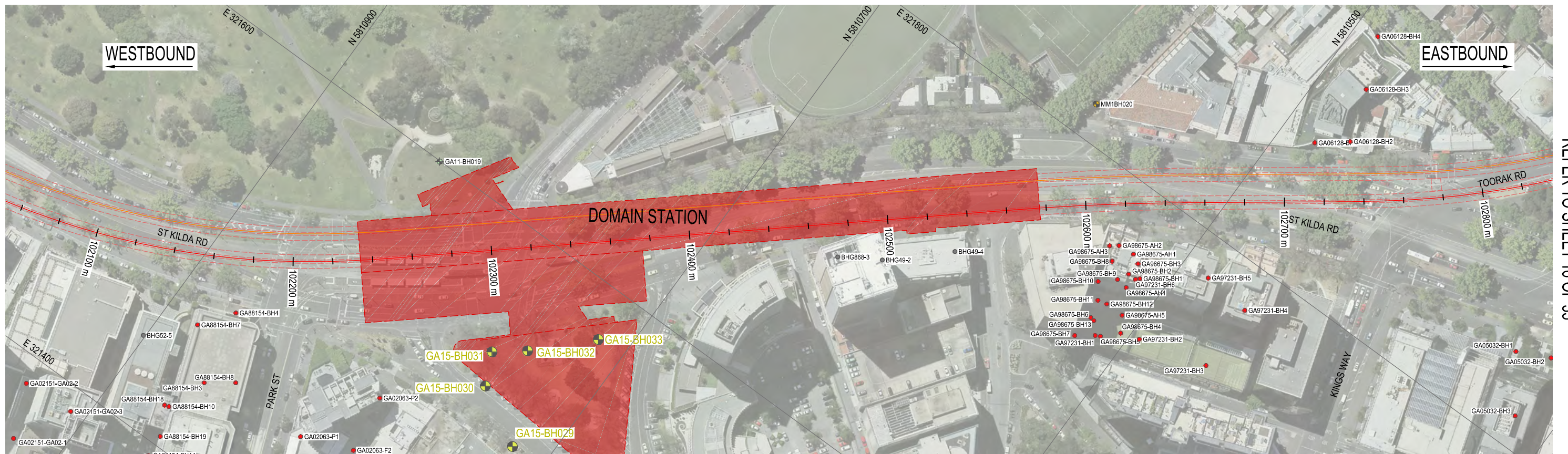
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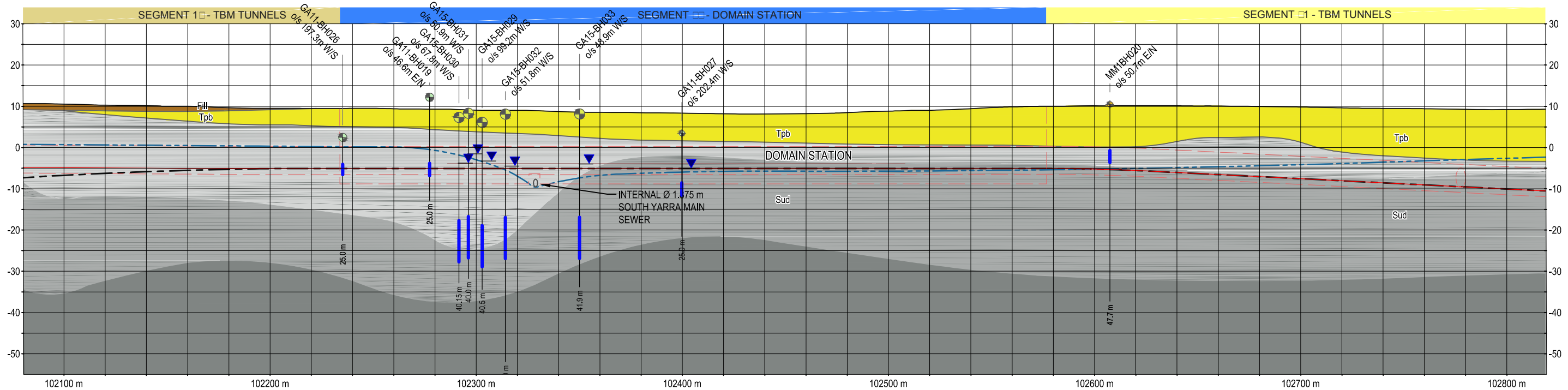


REFER TO SHEET 14 OF 35

REFER TO SHEET 16 OF 35



PLAN VIEW



SECTION WESTBOUND TUNNEL ALIGNMENT

NOTES

1. REFER FIGURE MMR-AJM-PWAA-DR-NN-500450, SHEET 1 OF 35 FOR NOTES AND LEGEND.
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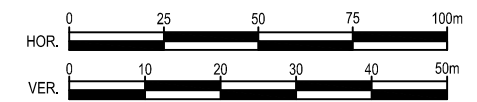


MELBOURNE METRO RAIL AUTHORITY

ajm **JACOBS**
Mott MacDonald
Joint Venture GRIMSHAW

Melbourne Metro Rail Project

Title GEOLOGICAL LONG SECTION		SHEET 15 OF 35	
Drawing Number MMR-AJM-PWAA-DR-NN-500450		Revision P1.1	
Drawn By GOLDER	Approved By SLVB	Date 23-03-2016	Map Size A3

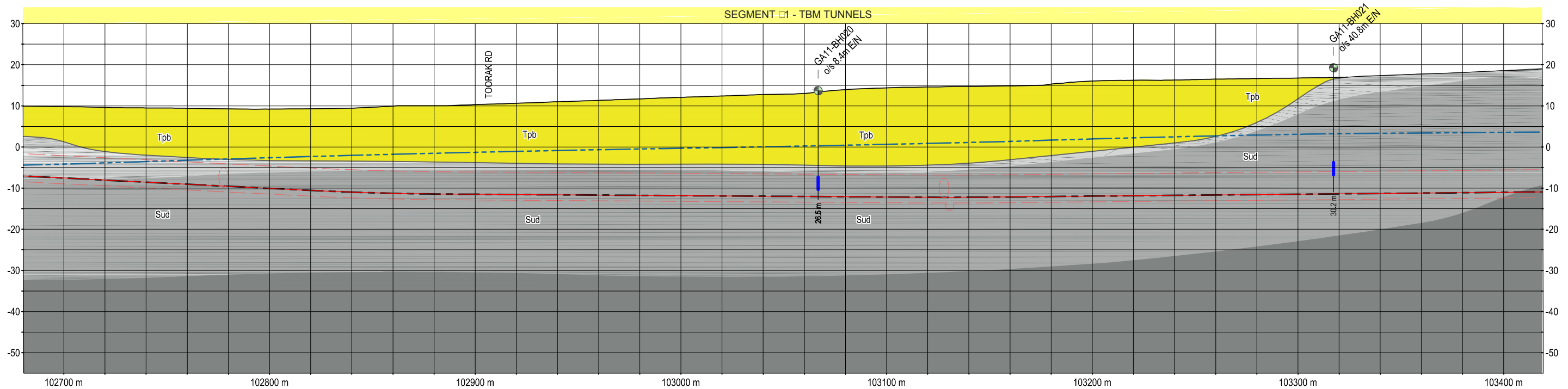


REFER TO SHEET 15 OF 35

REFER TO SHEET 17 OF 35



PLAN VIEW



SECTION WESTBOUND TUNNEL ALIGNMENT

NOTES

1. REFER FIGURE MMR-AJM-PWAA-DR-NN-500450, SHEET 1 OF 35 FOR NOTES AND LEGEND.
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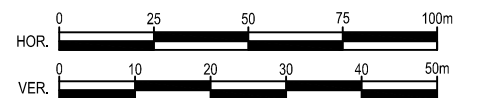


Melbourne Metro Rail Project

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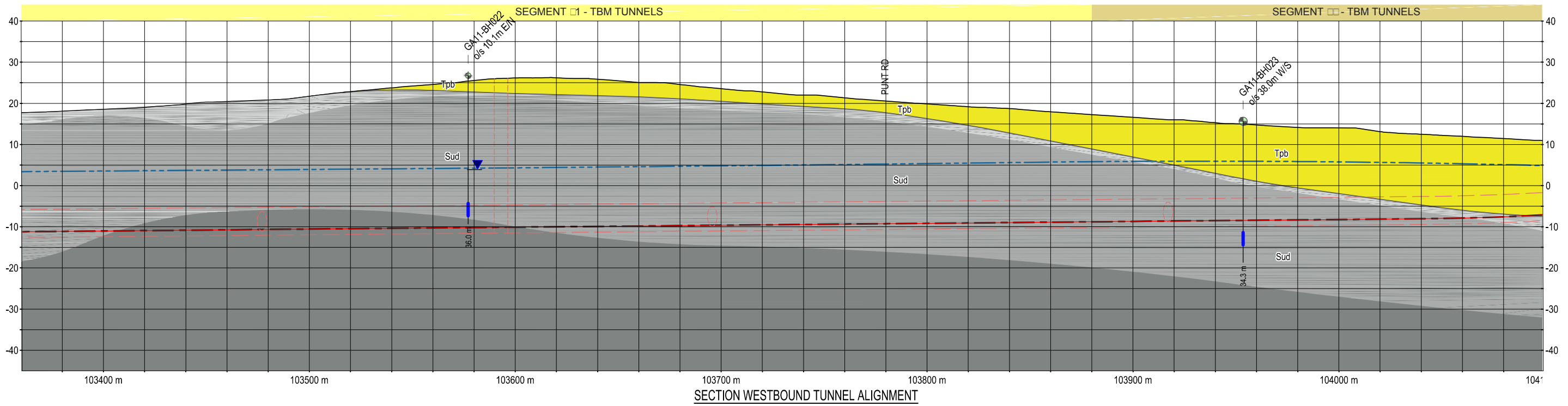


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PLAN VIEW



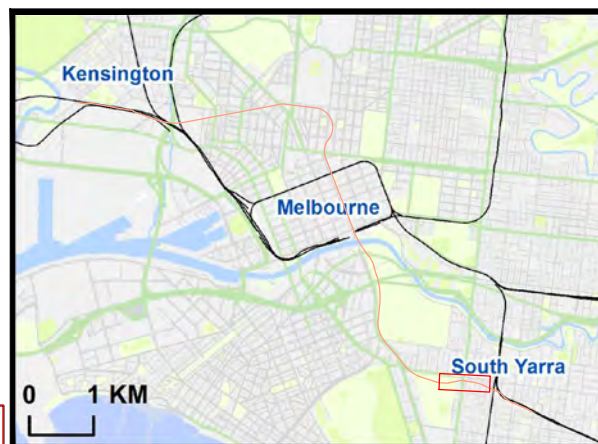
SECTION WESTBOUND TUNNEL ALIGNMENT

NOTES

1. REFER FIGURE MMR-AJM-PWAA-DR-NN-500450, SHEET 1 OF 35 FOR NOTES AND LEGEND.
2. ALL LEVELS ARE IN METRES TO AHD.
3. ALL COORDINATES ARE IN METRES TO MGA-Z55
4. INTERPRETED SUBSURFACE CONDITIONS SHOWN ON LONG SECTION TO BE USED FOR EES PURPOSES ONLY.

Note:
Surface works are not shown

NOT FOR CONSTRUCTION

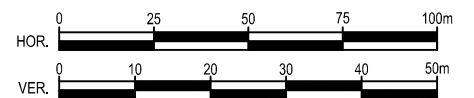


Melbourne Metro Rail Project

Title: GEOLOGICAL LONG SECTION SHEET 17 OF 35

Drawing Number: MMR-AJM-PWAA-DR-NN-500450 Revision: P1.1

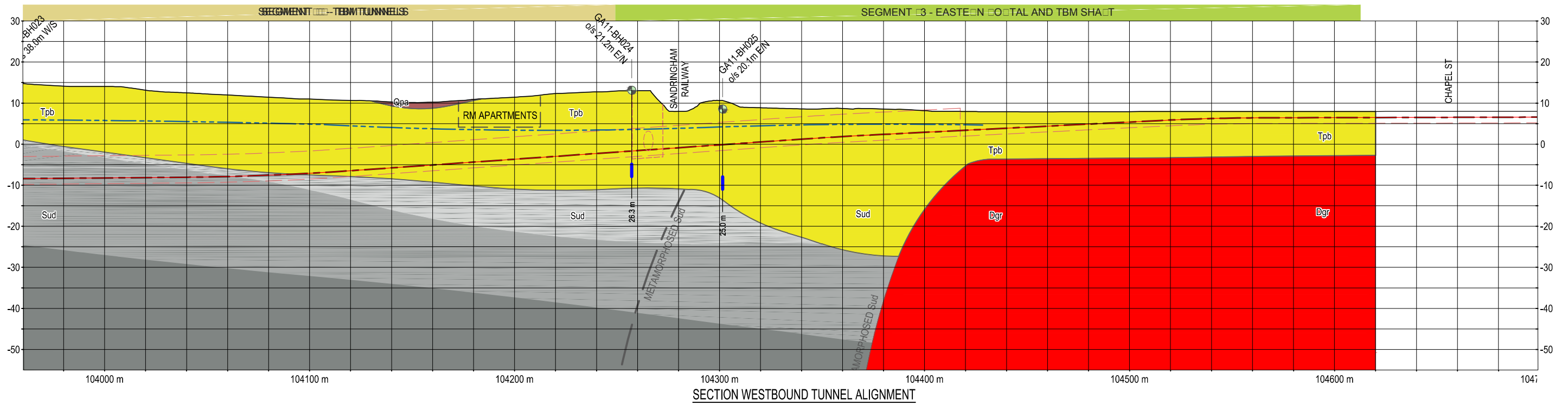
Drawn By: GOLDER Approved By: SLVB Date: 23-03-2016 Map Size: A3



REFER TO SHEET 17 OF 35



PLAN VIEW



SECTION WESTBOUND TUNNEL ALIGNMENT

NOTES

1. REFER FIGURE MMR-AJM-PWAA-DR-NN-500450, SHEET 1 OF 35 FOR NOTES AND LEGEND.
2. ALL LEVELS ARE IN METRES TO AHD.
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4. INTERPRETED SUBSURFACE CONDITIONS SHOWN ON LONG SECTION TO BE USED FOR EES PURPOSES ONLY.

Note:
Surface works are not shown

NOT FOR CONSTRUCTION



Melbourne Metro Rail Project

Title: GEOLOGICAL LONG SECTION SHEET 18 OF 35

Drawing Number: MMR-AJM-PWAA-DR-NN-500450 Revision: P1.1

Drawn By: GOLDER Approved By: SLVB Date: 23-03-2016 Map Size: A3

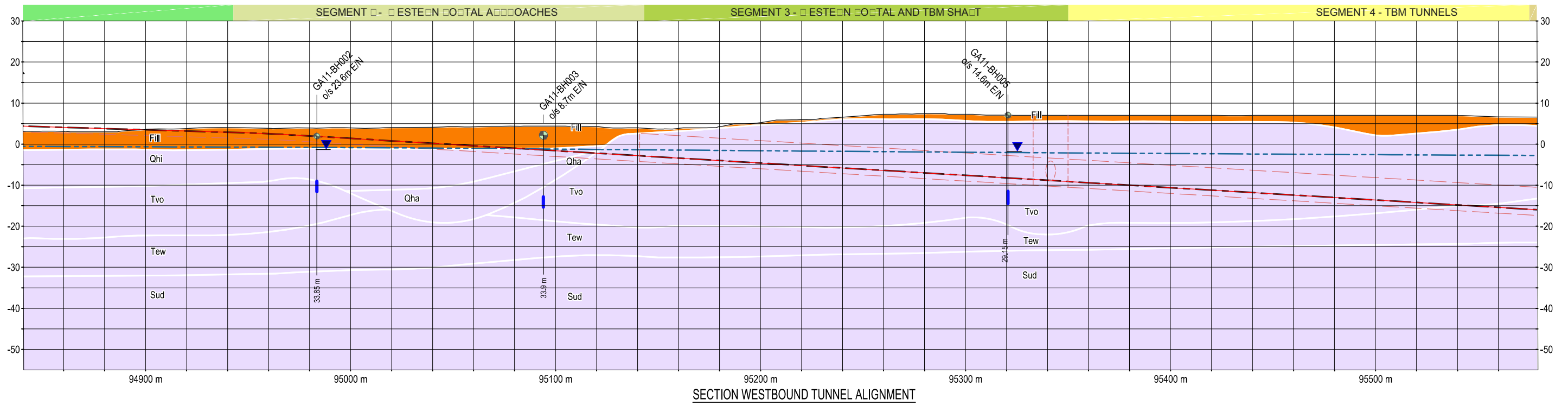


REFER TO SHEET 19 OF 35

REFER TO SHEET 21 OF 35



PLAN VIEW



SECTION WESTBOUND TUNNEL ALIGNMENT

NOTES

1. REFER FIGURE MMR-AJM-PWAA-DR-NN-500450, SHEET 1 OF 35 FOR NOTES AND LEGEND.
2. ALL LEVELS ARE IN METRES TO AHD.
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4. INTERPRETED SUBSURFACE CONDITIONS SHOWN ON LONG SECTION TO BE USED FOR EES PURPOSES ONLY.

Note:
Surface works are not shown

NOT FOR CONSTRUCTION



Melbourne Metro Rail Project

Title: GEO. SECTION - RELIABILITY SHEET 20 OF 35

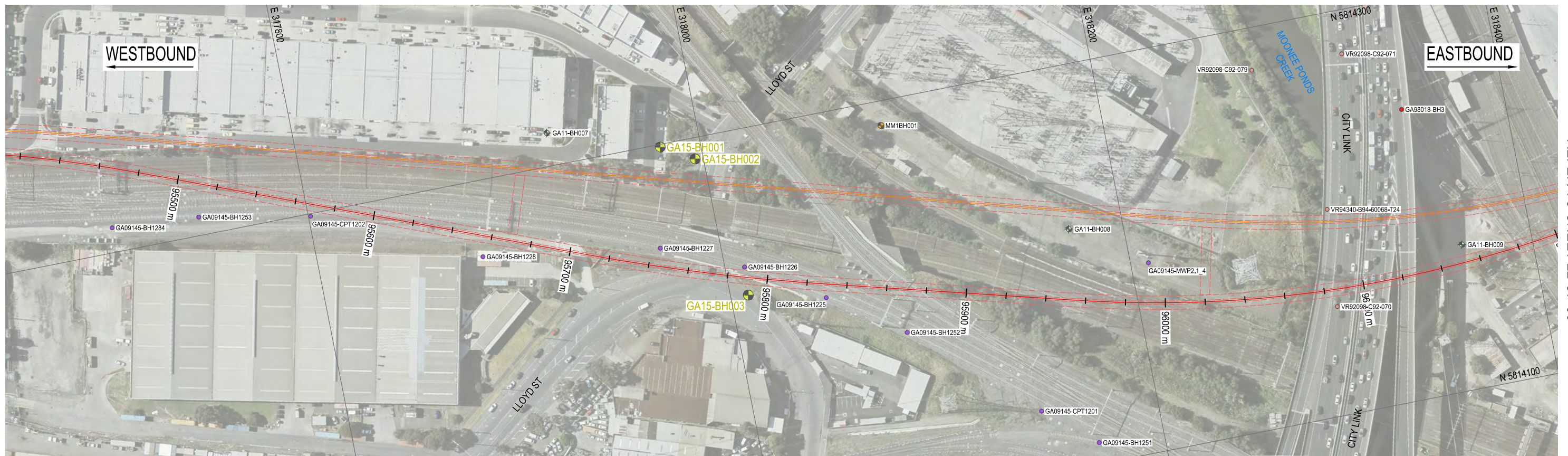
Drawing Number: MMR-AJM-PWAA-DR-NN-500450 Revision: P1.1

Drawn By: GOLDER Approved By: SLVB Date: 23-03-2016 Map Size: A3

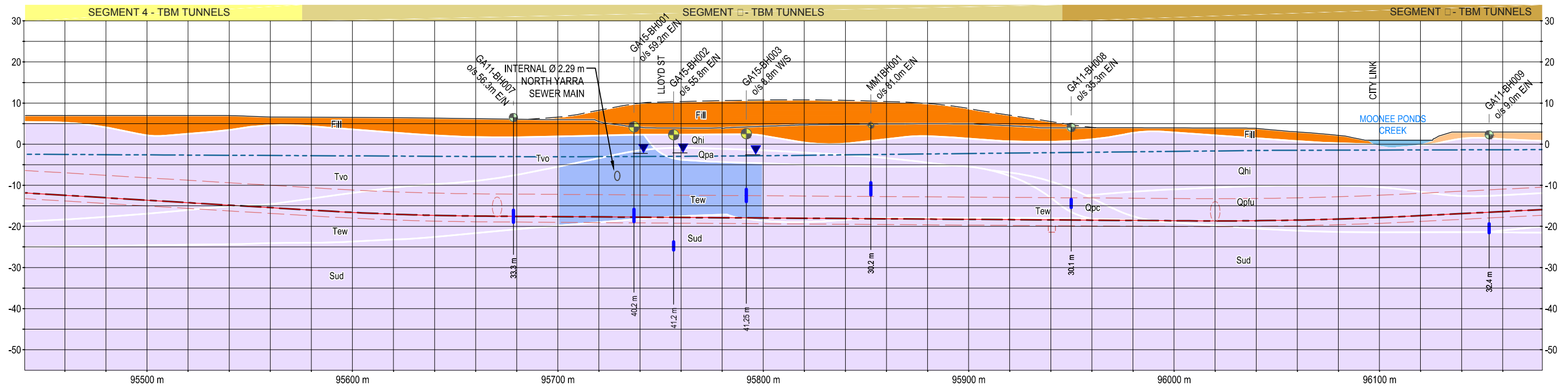


REFER TO SHEET 20 OF 35

REFER TO SHEET 22 OF 35



PLAN VIEW



SECTION WESTBOUND TUNNEL ALIGNMENT

NOTES

1. REFER FIGURE MMR-AJM-PWAA-DR-NN-500450, SHEET 1 OF 35 FOR NOTES AND LEGEND.
2. ALL LEVELS ARE IN METRES TO AHD.
3. ALL COORDINATES ARE IN METRES TO MGA-Z55
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Note:
Surface works are not shown

NOT FOR CONSTRUCTION



Melbourne Metro Rail Project

Title: GEO. SECTION - RELIABILITY SHEET 21 OF 35

Drawing Number: MMR-AJM-PWAA-DR-NN-500450 Revision: P1.1

Drawn By: GOLDER Approved By: SLVB Date: 23-03-2016 Map Size: A3

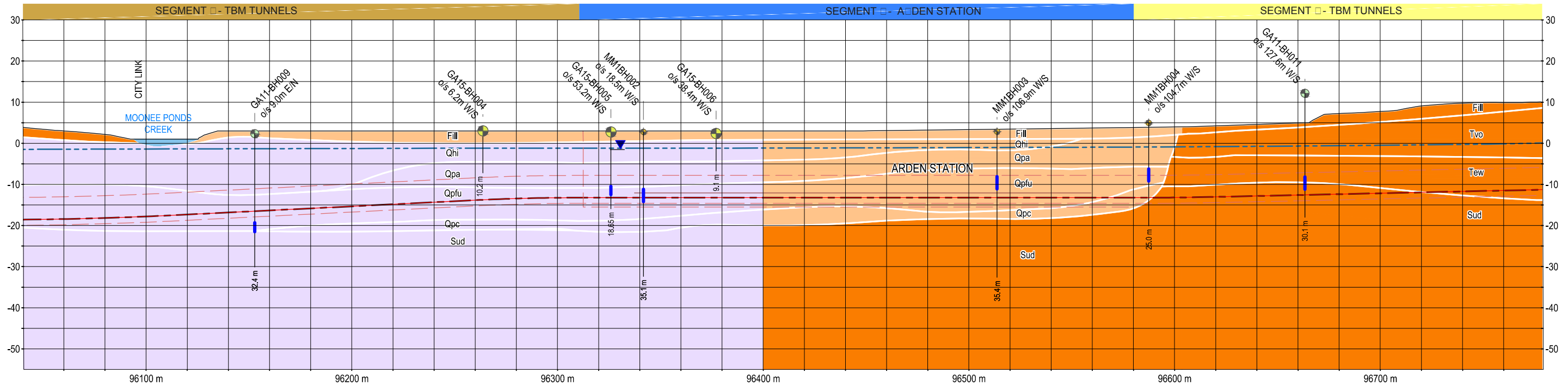


REFER TO SHEET 21 OF 35

REFER TO SHEET 23 OF 35



PLAN VIEW



SECTION WESTBOUND TUNNEL ALIGNMENT

NOTES

1. REFER FIGURE MMR-AJM-PWAA-DR-NN-500450, SHEET 1 OF 35 FOR NOTES AND LEGEND.
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4. INTERPRETED SUBSURFACE CONDITIONS SHOWN ON LONG SECTION TO BE USED FOR EES PURPOSES ONLY.

Note:
Surface works are not shown

NOT FOR CONSTRUCTION

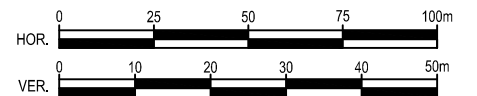


Melbourne Metro Rail Project

Title: GEO. SECTION - RELIABILITY SHEET 22 OF 35

Drawing Number: MMR-AJM-PWAA-DR-NN-500450 Revision: P1.1

Drawn By: GOLDER Approved By: SLVB Date: 23-03-2016 Map Size: A3

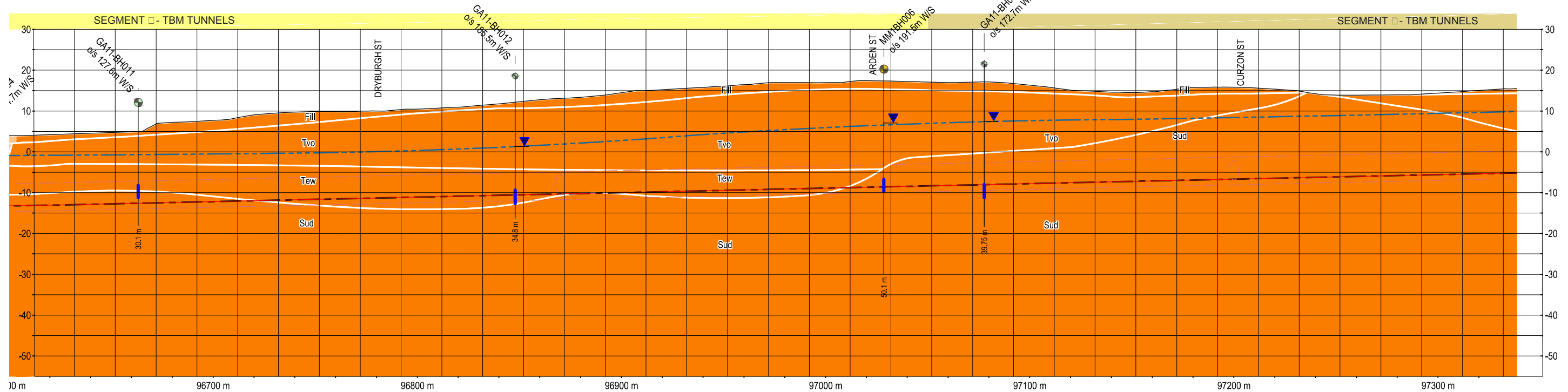


REFER TO SHEET 22 OF 35

REFER TO SHEET 24 OF 35



PLAN VIEW



SECTION WESTBOUND TUNNEL ALIGNMENT

NOTES

1. REFER FIGURE MMR-AJM-PWAA-DR-NN-500450, SHEET 1 OF 35 FOR NOTES AND LEGEND.
2. ALL LEVELS ARE IN METRES TO AHD.
3. ALL COORDINATES ARE IN METRES TO MGA-Z55
4. INTERPRETED SUBSURFACE CONDITIONS SHOWN ON LONG SECTION TO BE USED FOR EES PURPOSES ONLY.

Note:
Surface works are not shown

NOT FOR CONSTRUCTION

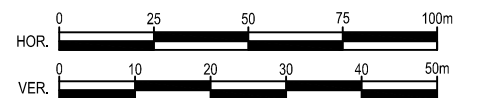


Melbourne Metro Rail Project

Title: GEO. SECTION - RELIABILITY SHEET 23 OF 35

Drawing Number: MMR-AJM-PWAA-DR-NN-500450 Revision: P1.1

Drawn By: GOLDER Approved By: SLVB Date: 23-03-2016 Map Size: A3

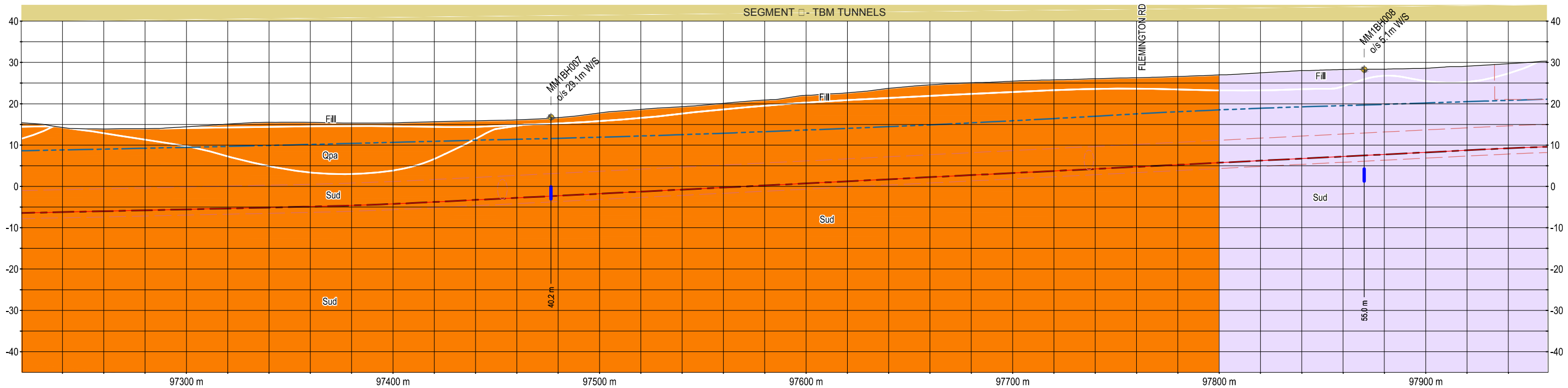


REFER TO SHEET 23 OF 35

REFER TO SHEET 25 OF 35



PLAN VIEW



SECTION WESTBOUND TUNNEL ALIGNMENT

NOTES

1. REFER FIGURE MMR-AJM-PWAA-DR-NN-500450, SHEET 1 OF 35 FOR NOTES AND LEGEND.
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NOT FOR CONSTRUCTION

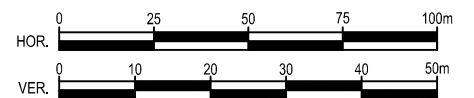


Melbourne Metro Rail Project

Title: GEO. SECTION - RELIABILITY SHEET 24 OF 35

Drawing Number: MMR-AJM-PWAA-DR-NN-500450 Revision: P1.1

Drawn By: GOLDER Approved By: SLVB Date: 23-03-2016 Map Size: A3

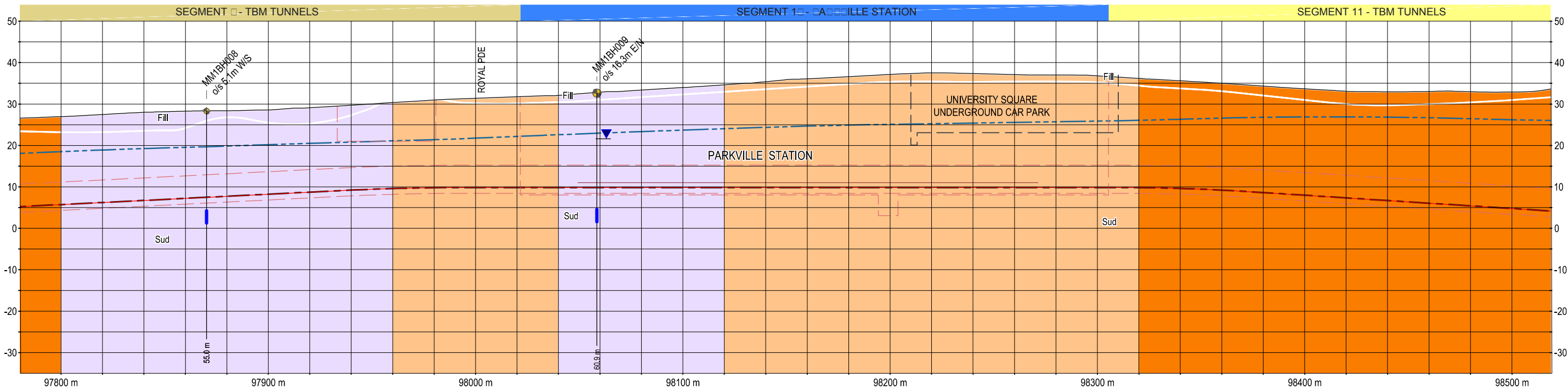


REFER TO SHEET 24 OF 35

REFER TO SHEET 26 OF 35



PLAN VIEW



SECTION WESTBOUND TUNNEL ALIGNMENT

NOTES

1. REFER FIGURE MMR-AJM-PWAA-DR-NN-500450, SHEET 1 OF 35 FOR NOTES AND LEGEND.
2. ALL LEVELS ARE IN METRES TO AHD.
3. ALL COORDINATES ARE IN METRES TO MGA-Z55
4. INTERPRETED SUBSURFACE CONDITIONS SHOWN ON LONG SECTION TO BE USED FOR EES PURPOSES ONLY.

Note:
Surface works are not shown

NOT FOR CONSTRUCTION

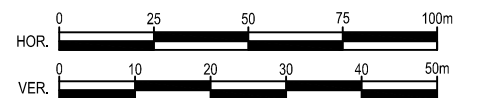


Melbourne Metro Rail Project

Title: GEO. SECTION - RELIABILITY SHEET 25 OF 35

Drawing Number: MMR-AJM-PWAA-DR-NN-500450 Revision: P1.1

Drawn By: GOLDER Approved By: SLVB Date: 23-03-2016 Map Size: A3

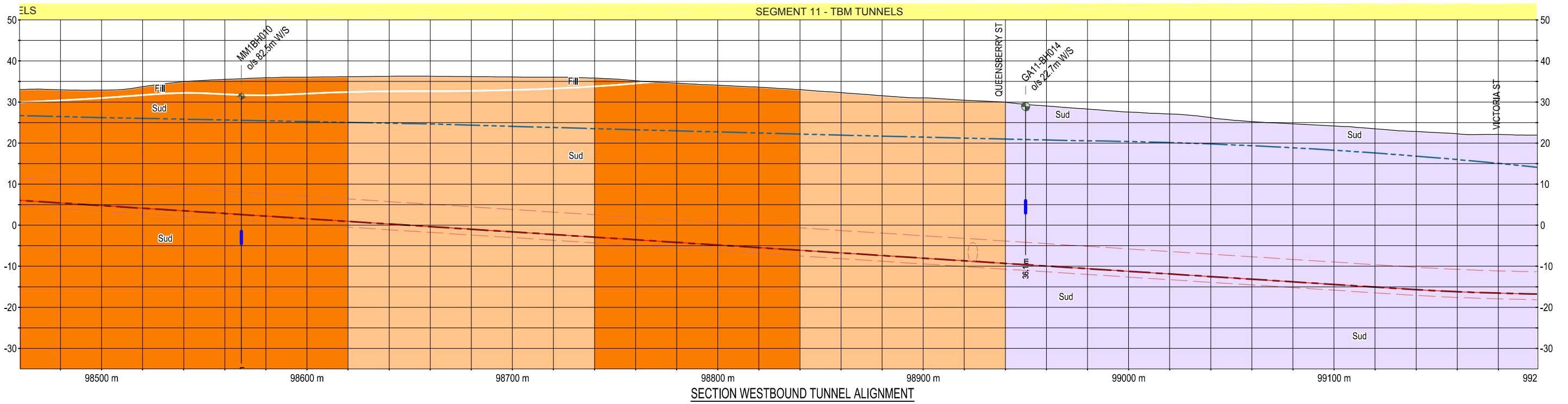


REFER TO SHEET 25 OF 35

REFER TO SHEET 27 OF 35



PLAN VIEW



SECTION WESTBOUND TUNNEL ALIGNMENT

NOTES

1. REFER FIGURE MMR-AJM-PWAA-DR-NN-500450, SHEET 1 OF 35 FOR NOTES AND LEGEND.
2. ALL LEVELS ARE IN METRES TO AHD.
3. ALL COORDINATES ARE IN METRES TO MGA-Z55
4. INTERPRETED SUBSURFACE CONDITIONS SHOWN ON LONG SECTION TO BE USED FOR EES PURPOSES ONLY.

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Surface works are not shown

NOT FOR CONSTRUCTION

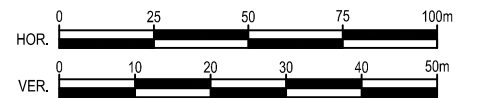


Melbourne Metro Rail Project

Title: GEO. SECTION - RELIABILITY SHEET 26 OF 35

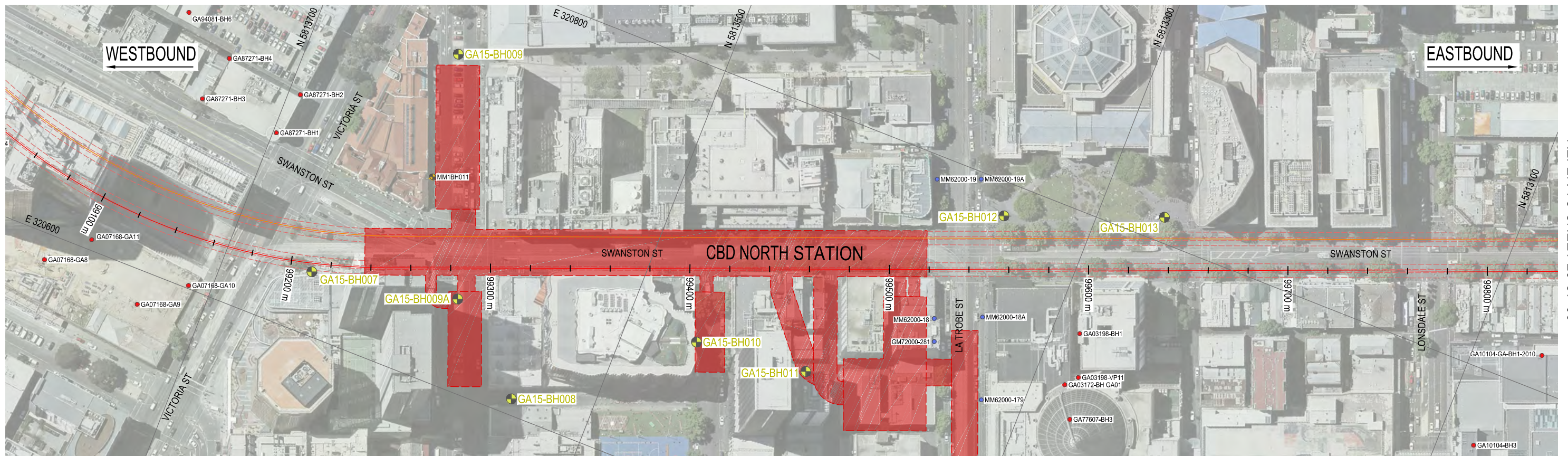
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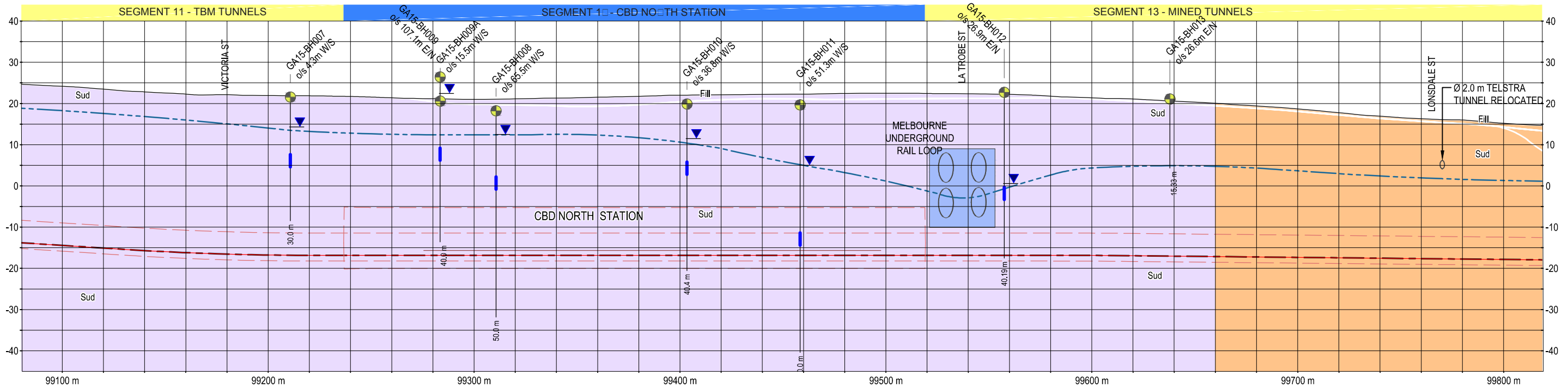


REFER TO SHEET 26 OF 35

REFER TO SHEET 28 OF 35



PLAN VIEW



SECTION WESTBOUND TUNNEL ALIGNMENT

NOTES

1. REFER FIGURE MMR-AJM-PWAA-DR-NN-500450, SHEET 1 OF 35 FOR NOTES AND LEGEND.
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4. INTERPRETED SUBSURFACE CONDITIONS SHOWN ON LONG SECTION TO BE USED FOR EES PURPOSES ONLY.

Note:
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NOT FOR CONSTRUCTION

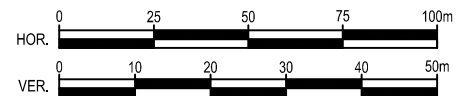


Melbourne Metro Rail Project

Title: GEO. SECTION - RELIABILITY SHEET 27 OF 35

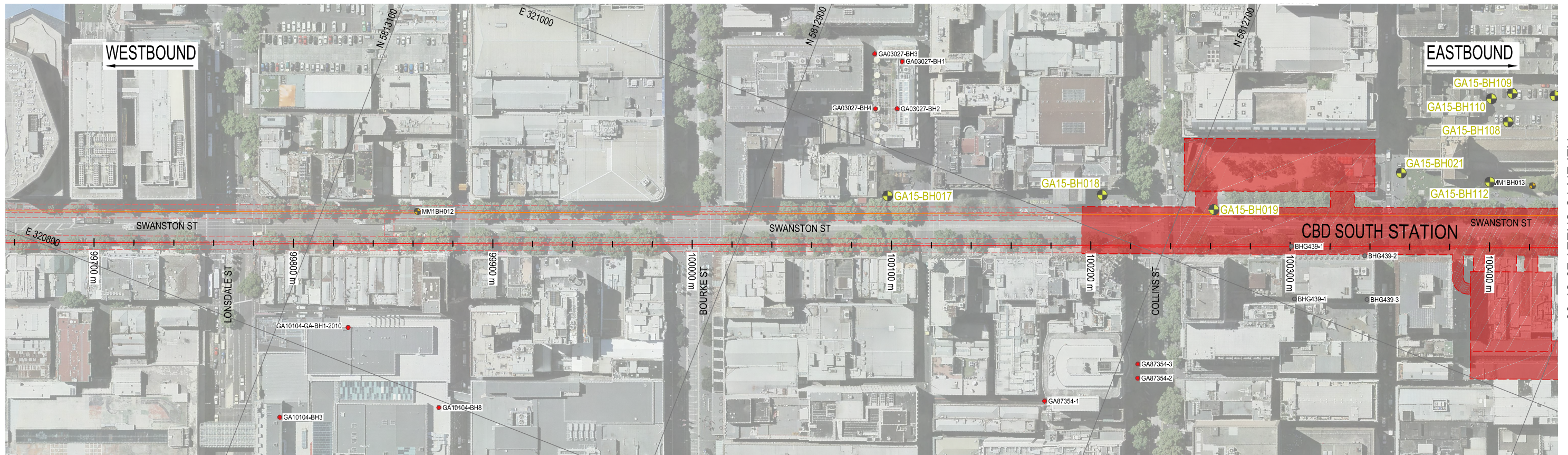
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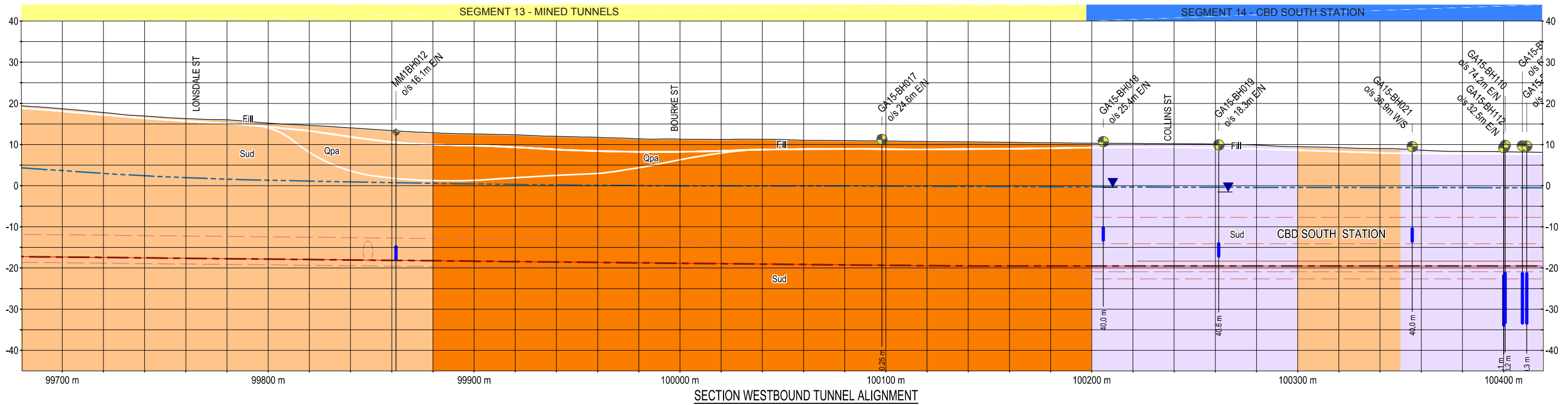


REFER TO SHEET 27 OF 35

REFER TO SHEET 29 OF 35



PLAN VIEW



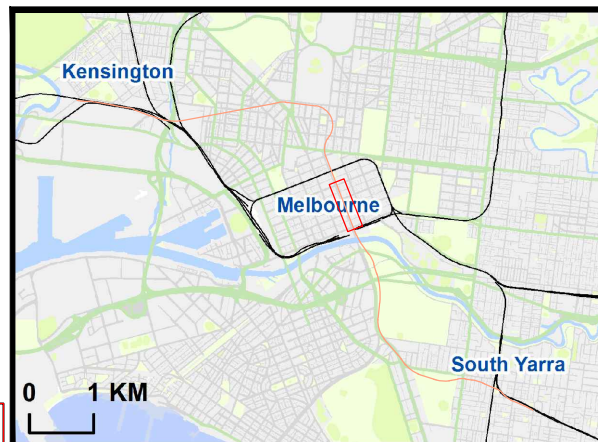
SECTION WESTBOUND TUNNEL ALIGNMENT

NOTES

1. REFER FIGURE MMR-AJM-PWAA-DR-NN-500450, SHEET 1 OF 35 FOR NOTES AND LEGEND.
2. ALL LEVELS ARE IN METRES TO AHD.
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4. INTERPRETED SUBSURFACE CONDITIONS SHOWN ON LONG SECTION TO BE USED FOR EES PURPOSES ONLY.

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Surface works are not shown

NOT FOR CONSTRUCTION



Melbourne Metro Rail Project

Title: GEO. SECTION - RELIABILITY SHEET 28 OF 35

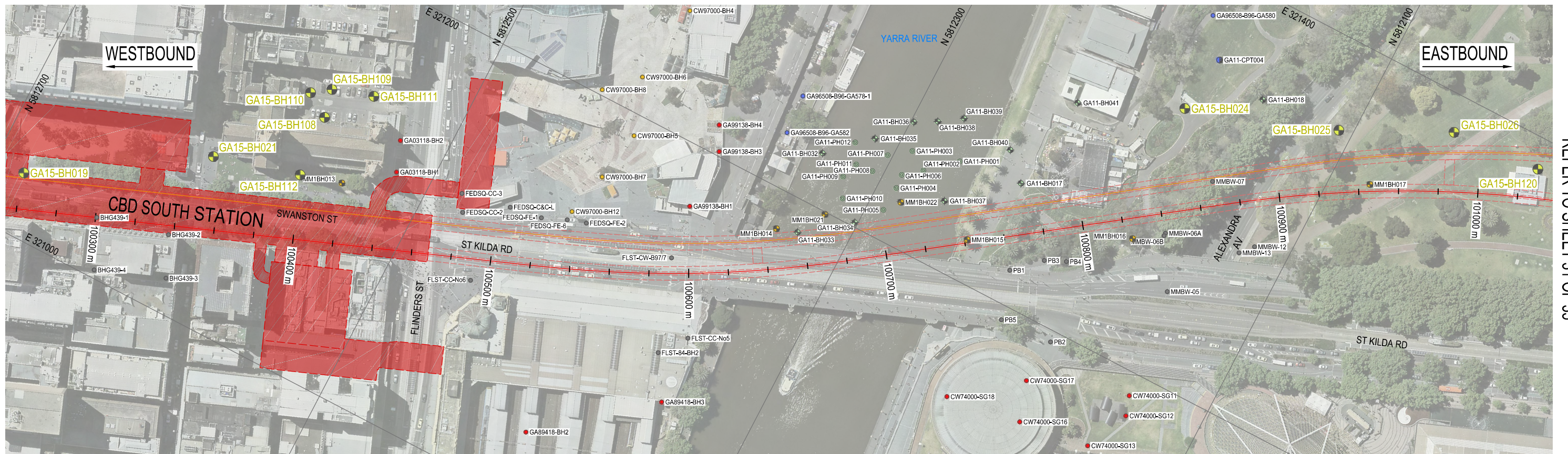
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Drawn By: GOLDER Approved By: SLVB Date: 23-03-2016 Map Size: A3

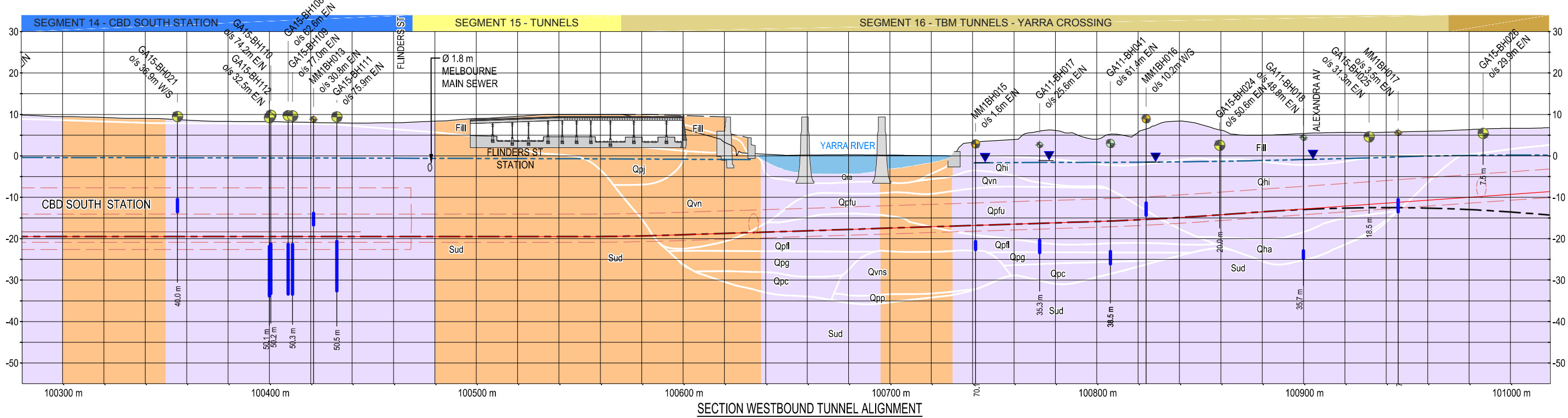


REFER TO SHEET 28 OF 35

REFER TO SHEET 31 OF 35



PLAN VIEW



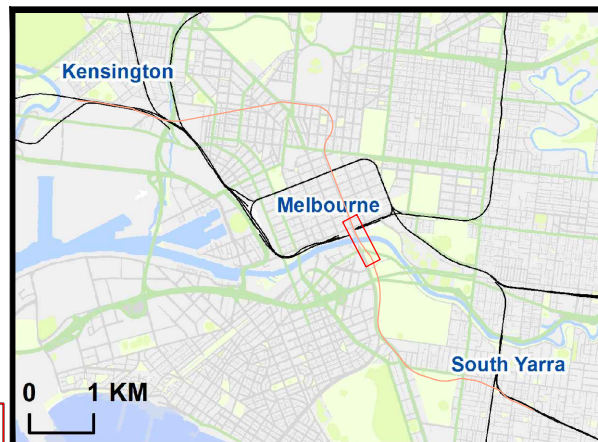
SECTION WESTBOUND TUNNEL ALIGNMENT

NOTES

1. REFER FIGURE MMR-AJM-PWAA-DR-NN-500450, SHEET 1 OF 35 FOR NOTES AND LEGEND.
2. ALL LEVELS ARE IN METRES TO AHD.
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4. INTERPRETED SUBSURFACE CONDITIONS SHOWN ON LONG SECTION TO BE USED FOR EES PURPOSES ONLY.

Note:
Surface works are not shown

NOT FOR CONSTRUCTION

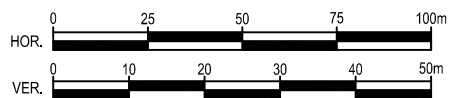


Melbourne Metro Rail Project

Title: GEO. SECTION - RELIABILITY SHEET 29 OF 35

Drawing Number: MMR-AJM-PWAA-DR-NN-500450 Revision: P1.1

Drawn By: GOLDER Approved By: SLVB Date: 23-03-2016 Map Size: A3

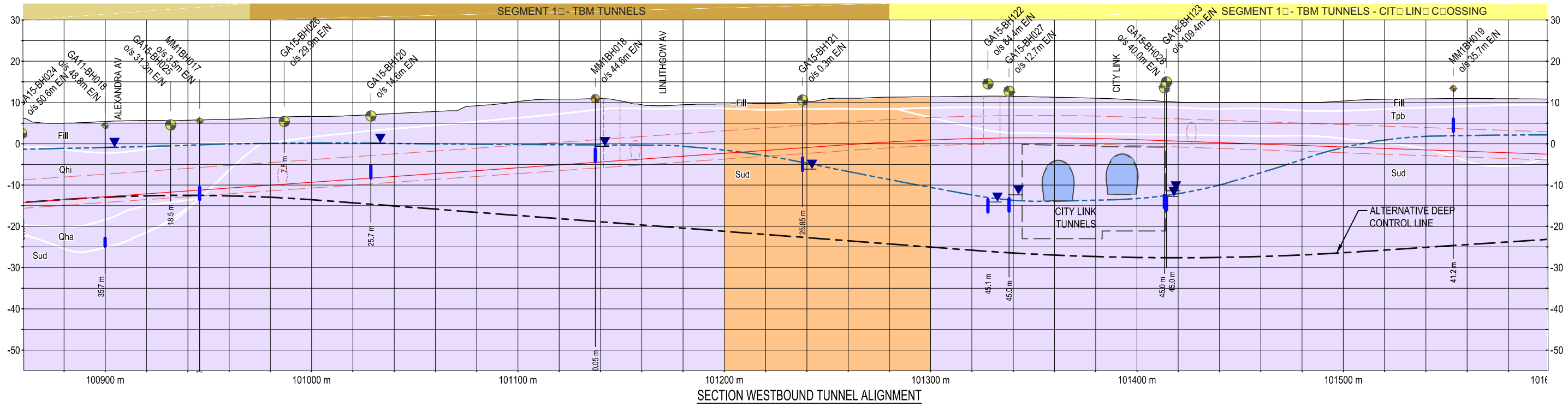


REFER TO SHEET 29 OF 35

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PLAN VIEW



SECTION WESTBOUND TUNNEL ALIGNMENT

NOTES

1. REFER FIGURE MMR-AJM-PWAA-DR-NN-500450, SHEET 1 OF 35 FOR NOTES AND LEGEND.
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NOT FOR CONSTRUCTION

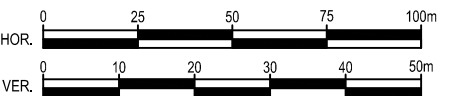


Melbourne Metro Rail Project

Title: GEO. SECTION - RELIABILITY SHEET 30 OF 35

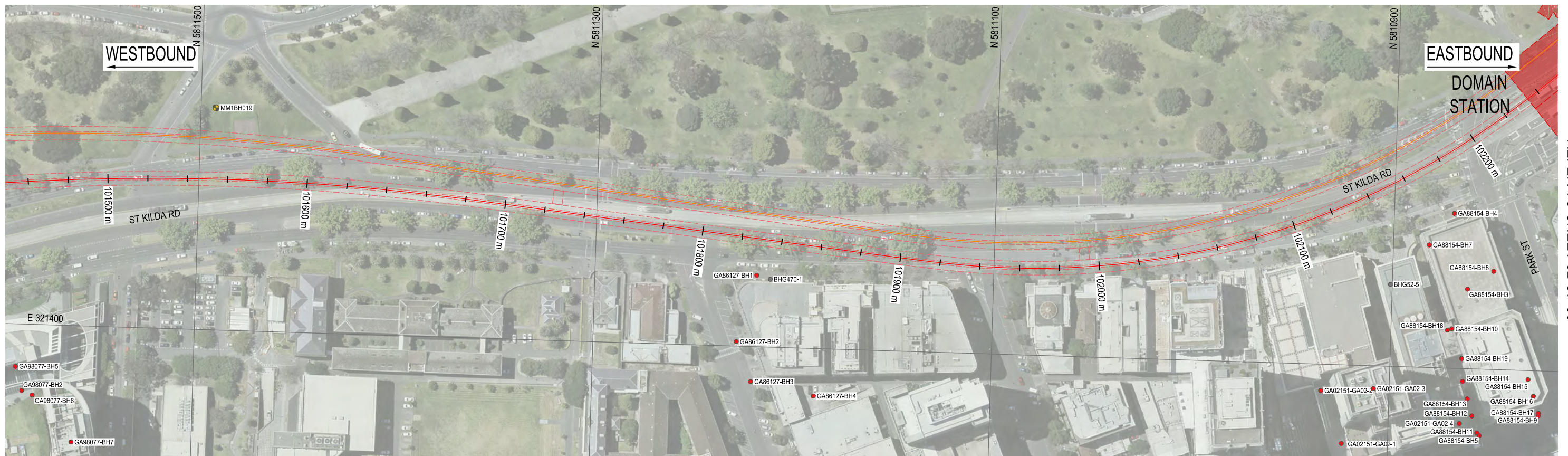
Drawing Number: MMR-AJM-PWAA-DR-NN-500450 Revision: P1.1

Drawn By: GOLDER Approved By: SLVB Date: 23-03-2016 Map Size: A3

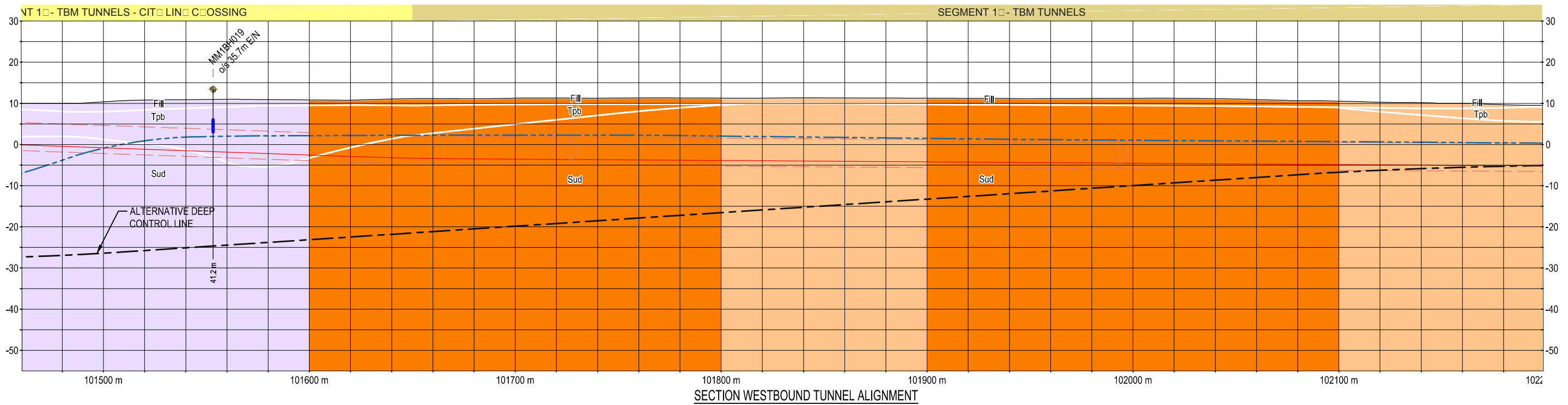


REFER TO SHEET 30 OF 35

REFER TO SHEET 32 OF 35



PLAN VIEW



SECTION WESTBOUND TUNNEL ALIGNMENT

NOTES

1. REFER FIGURE MMR-AJM-PWAA-DR-NN-500450, SHEET 1 OF 35 FOR NOTES AND LEGEND.
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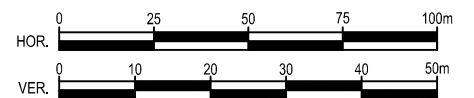


Melbourne Metro Rail Project

Title: GEO. SECTION - RELIABILITY SHEET 31 OF 35

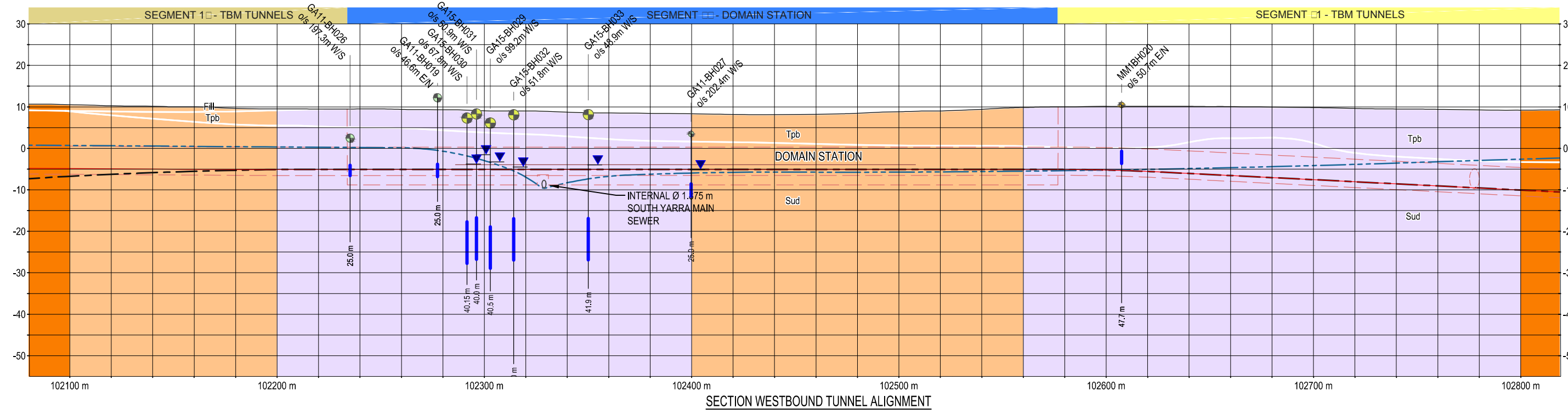
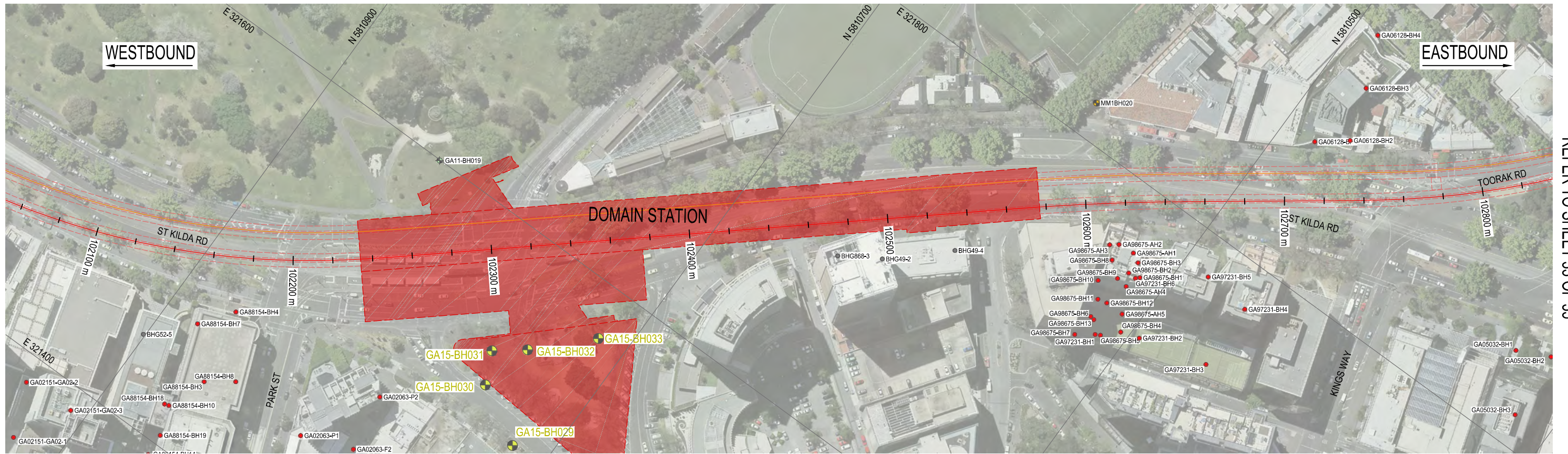
Drawing Number: MMR-AJM-PWAA-DR-NN-500450 Revision: P1.1

Drawn By: GOLDER Approved By: SLVB Date: 23-03-2016 Map Size: A3



REFER TO SHEET 31 OF 35

REFER TO SHEET 33 OF 35



NOTES

- 1. REFER FIGURE MMR-AJM-PWAA-DR-NN-500450, SHEET 1 OF 35 FOR NOTES AND LEGEND.
- 2. ALL LEVELS ARE IN METRES TO AHD.
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NOT FOR CONSTRUCTION



Melbourne Metro Rail Project

Title: GEO. SECTION - RELIABILITY SHEET 32 OF 35

Drawing Number: MMR-AJM-PWAA-DR-NN-500450 Revision: P1.1

Drawn By: GOLDER Approved By: SLVB Date: 23-03-2016 Map Size: A3

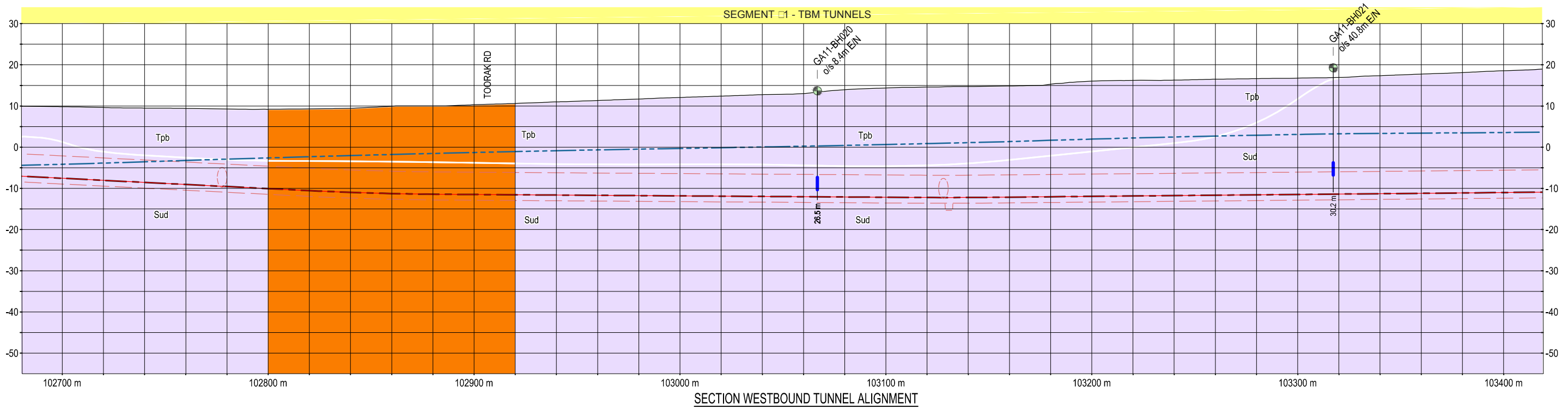


REFER TO SHEET 32 OF 35

REFER TO SHEET 34 OF 35



PLAN VIEW



SECTION WESTBOUND TUNNEL ALIGNMENT

NOTES

1. REFER FIGURE MMR-AJM-PWAA-DR-NN-500450, SHEET 1 OF 35 FOR NOTES AND LEGEND.
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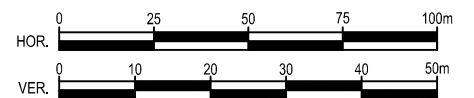


Melbourne Metro Rail Project

Title: GEO. SECTION - RELIABILITY SHEET 33 OF 35

Drawing Number: MMR-AJM-PWAA-DR-NN-500450 Revision: P1.1

Drawn By: GOLDER Approved By: SLVB Date: 23-03-2016 Map Size: A3

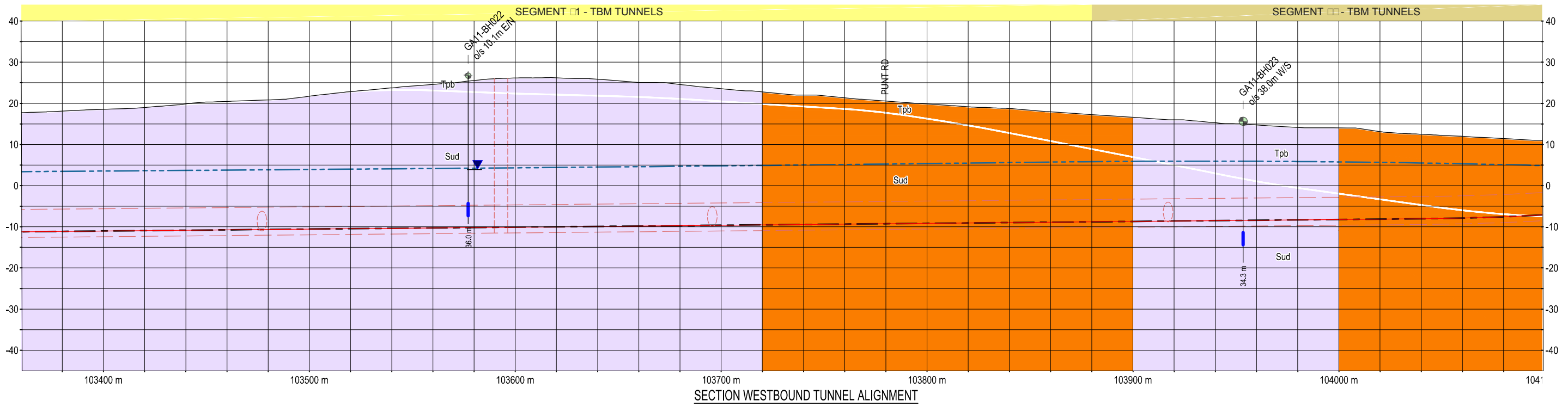


REFER TO SHEET 33 OF 35

REFER TO SHEET 35 OF 35



PLAN VIEW



SECTION WESTBOUND TUNNEL ALIGNMENT

NOTES

1. REFER FIGURE MMR-AJM-PWAA-DR-NN-500450, SHEET 1 OF 35 FOR NOTES AND LEGEND.
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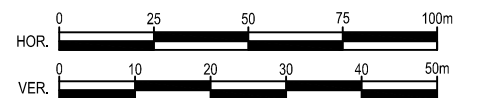


Melbourne Metro Rail Project

Title: GEO. SECTION - RELIABILITY SHEET 34 OF 35

Drawing Number: MMR-AJM-PWAA-DR-NN-500450 Revision: P1.1

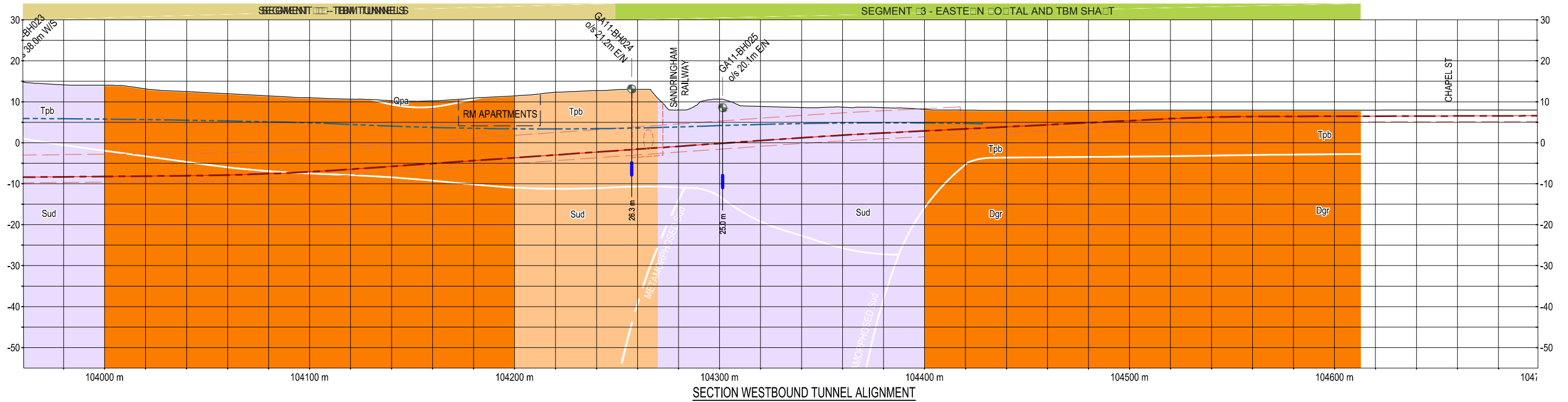
Drawn By: GOLDER Approved By: SLVB Date: 23-03-2016 Map Size: A3



REFER TO SHEET 34 OF 35



PLAN VIEW



SECTION WESTBOUND TUNNEL ALIGNMENT

NOTES

1. REFER FIGURE MMR-AJM-PWAA-DR-NN-500450, SHEET 1 OF 35 FOR NOTES AND LEGEND.
2. ALL LEVELS ARE IN METRES TO AHD.
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Melbourne Metro Rail Project

Title: GEO. SECTION - RELIABILITY SHEET 35 OF 35

Drawing Number: MMR-AJM-PWAA-DR-NN-500450 Revision: P1.1

Drawn By: GOLDER Approved By: SLVB Date: 23-03-2016 Map Size: A3

