13 Precinct 7: Domain Station

13.1 Project Components

The Domain station precinct is located from 40 m north of the junction of St Kilda Road and Park Street to the junction of St Kilda Road and Toorak Road. The precinct extends to Kings Way in the west and 70 m into the Shine of Remembrance parklands to the east. This section describes the components and construction activities that could result in the impacts to existing conditions in this precinct, based on the Concept Design and the assumptions stated in Section 4.7 of this report. Where the risk of impact is predicted to be medium, high or very high, mitigation measures would be applied during construction and operation to reduce impacts to a low risk.

13.1.1 Infrastructure

The station box is located from CH102+240 and is 325 m long, between 22 and 60 m wide (excluding the western entrance) and 19 m deep. Three station entrances are proposed: one to the east into the Shrine Parklands; one to the west into the triangular park located on the corner of Albert Road and St Kilda Road; and one entrance to the Domain tram interchange in the centre of Street Kilda Road.

13.1.2 Construction

The proposed construction technique for this station is a mixture of bottom up and top down cut and cover, depending on the sensitivity of the land use (i.e. whether the land needs to be reinstated quickly such as in the road). Bottom up cut and cover is where the station box is fully excavated and built up from the base slab. Top down cut and cover involves constructing the permanent retaining structure from the surface and excavating far enough to install the permanent roof before excavating beneath the roof. This method allows for surface reinstatement whilst the excavation is completed beneath the roof slab.

Due to the geological conditions at this location, it is assumed that diaphragm walls would be used as the retaining structures for this station. Diaphragm walls are constructed in panels using specialised equipment to cut a narrow trench to the appropriate depth. This trench would be kept open using bentonite slurry whilst a reinforcement cage is installed and concrete is pumped into the trench. The diaphragm wall would be embedded 5 m below the base of the excavation into the Melbourne Formation. This method is likely to result in very little groundwater inflow, which would be largely restricted to the base of the excavation.

Other construction works in this precinct that may change the groundwater environment include the relocation of the South Yarra Main Sewer. The construction and potential groundwater impacts associated with this work is discussed in Section 16. Early works on stormwater drains are also planned, but these are above groundwater level.

13.1.3 Operation

During operation, the Concept Design assumes that all underground structures in this precinct would be tanked to a tightness classification of Haack 2.

13.2 Existing Conditions

13.2.1 Hydrostratigraphy

The expected geology (Figure 13-1) across this precinct is Melbourne Formation in the tunnels and lower half of the station box (CH102+150 to CH102+750) and Brighton Group in the upper half of the station box. The Brighton Group within this precinct is unsaturated and the watertable occurs in the Melbourne Formation

(Figure 13-1). The Geology of Melbourne map (GSV, 1967) indicates that a syncline exists within the Melbourne Formation at the north-eastern edge of this precinct, striking north-east- south-west. The tunnels cross this feature at approximately CH102+200. The rock around this feature may exhibit more fracturing and therefore, higher hydraulic conductivities. Testing shows that the Brighton Group has a low potential to generate acidity. Deep fresh to slightly weathered Melbourne Formation rock, typically present at depths greater than 24 m, has moderate to high potential to generate acidity. Shallow highly weathered to extremely weathered Melbourne Formation is typically non-acid forming and hence low risk.

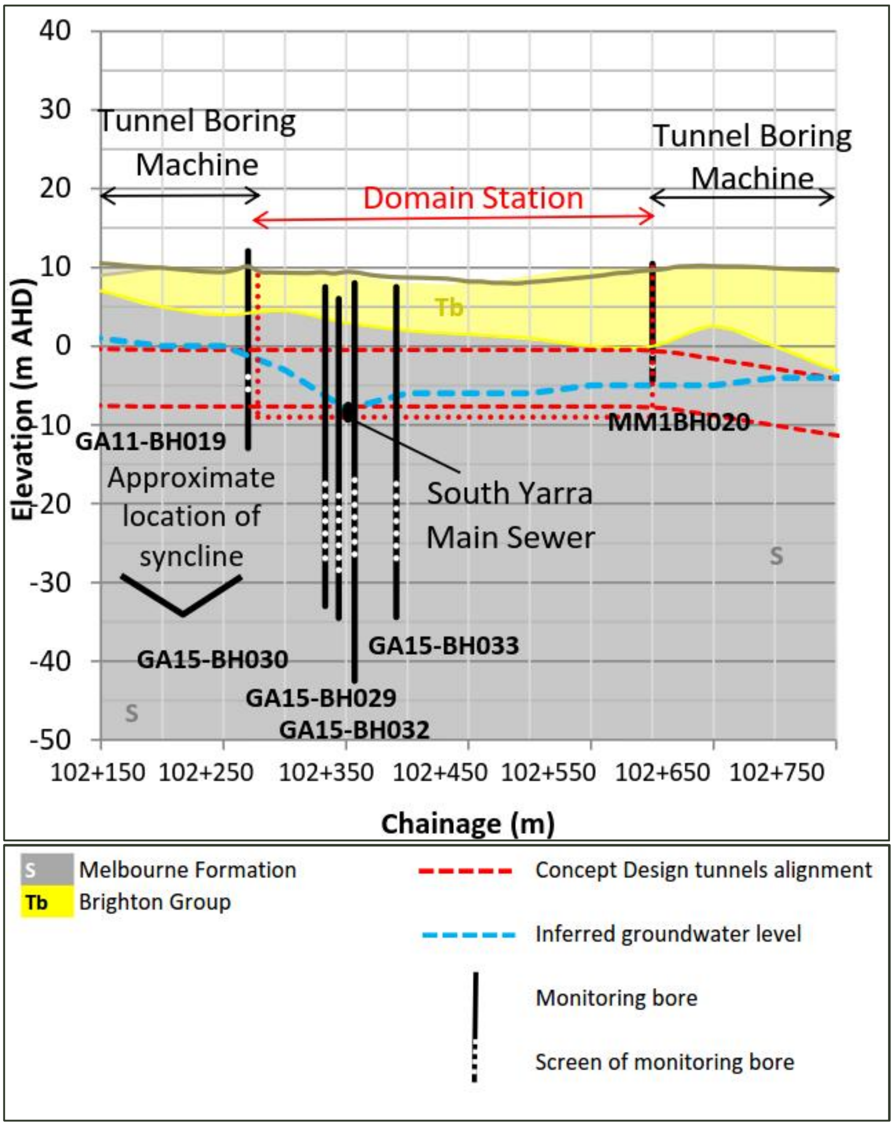


Figure 13-1: Conceptual site model for the Domain station precinct

There are eight monitoring bores relevant to this area; six within the station precinct (MM1BH020, GA11-BH019, GA11-BH027, GA15-BH029, GA15-BH030, GA15-BH032, GA15-BH033) and one 50 m to the west (GA11-BH026). Three of these bores have undergone hydraulic testing and results are shown in Appendix D of this report. The three bores tested are all screened within the Melbourne Formation and the hydraulic conductivity measured in these bores varies by two orders of magnitude, with the highest occurring in MM1-BH020 (5.8×10^{-6} m/sec). The other tests recorded similar values of between 3.0×10^{-8} and 3.7×10^{-8} m/sec.

13.2.2 Groundwater Levels

There are eight groundwater monitoring bores in this precinct and groundwater levels have been monitored at least once at each. Survey data was not available for the four newest bores (GA15 series), so the elevation was assumed to be the same as land surface. The groundwater levels monitored in the bores and the bore hydrographs and included in Appendix D of this report.

Seasonal variations were relatively large (0.45m) in bore GA11-BH027 when compared to the wider Study Area. The year to year variations in general are small with the exception of GA11-BH019 which shows a rise in levels between March 2012 and June 2012 of 2.43 m. In comparison to other groundwater levels in the precinct, the June 2012 reading appears anomalous.

The bores in this precinct record groundwater levels below 0 m AHD (with the exception of the one anomalous point above 0 m AHD). These low levels are likely to be due to the presence of the South Yarra Main Sewer which crosses the alignment at CH102+330 and runs along Domain Road and Albert Road. The base of the sewer is approximately -10 m AHD where it crosses the alignment and the diameter of the sewer is almost 3 m. The sewer is over 100 years old and likely to be of brick and concrete construction. Therefore, the capacity of the sewer to prevent groundwater ingress is almost certainly compromised and in this area it appears to be acting as a drain (as indicated by the depressed groundwater levels).

Under natural conditions, groundwater levels in this area would be expected to be above sea level, given the distance from Port Phillip Bay (more than 3.5 km). Groundwater flow would be to the south-west, towards the low lying Albert Park Lake (a former swamp). The South Yarra Main Sewer runs along the northern edge of Albert Park Lake and it is possible that there is some water loss from the lake to the sewer. As the sewer appears to be acting as a major groundwater drain in the area, its replacement may cause groundwater levels in the east of this precinct to rise by up to 5 m.

The depth to groundwater in this precinct ranges between approximately 7 m to 12.5 m below ground level. The shallowest groundwater levels are in the north-west of the precinct.

13.2.3 Groundwater Quality

Regional salinity mapping shows that groundwater in this area is fresh (< 3,500 mg/L TDS) to brackish (<13,000 mg/L TDS). Groundwater of this salinity is within Segment B to C of the SEPP (GoV), which means the following beneficial uses must be protected:

- Maintenance of ecosystems: groundwater discharging to surface water ecosystems must not alter ecosystem health
- Potable mineral water supply (there are no areas of mineral waters in the vicinity of the project and therefore this Beneficial Use is not considered further)
- Irrigation
- Stock watering
- Industrial water use
- Primary contact recreation (e.g. swimming)
- Buildings and structures (groundwater contamination must not cause corrosion)

Due to high salinity, the groundwater is not suitable for use as drinking water.

Four monitoring bores in this precinct have been sampled and record a wide range of TDS concentrations. The TDS concentrations at GA11-BH026 and GA11-BH027 suggest a local source of fresh water recharge such as leaking water infrastructure or irrigation.

GA11-BH026 records the lowest TDS concentration and is screened within the Brighton Group. GA11-019 records a TDS concentration at the upper end of the range measured over the entire alignment for the Melbourne Formation. GA11-BH027 and MM1BH020 record below average TDS concentrations for this formation. Full groundwater quality analysis results are included in Appendix D of this report.

Organic compounds can be an indication of anthropogenic contamination, and were detected in the following bores:

- MM1BH020 (Melbourne Formation) – TPH fraction C_{10}-C_{36} (0.09 mg/L)

The concentrations of TPH fractions detected are below relevant guideline values (refer to Appendix E of this report) and are therefore not considered to be of concern. Storm water runoff from large road intersections may be the cause of the low level organic contamination at this location (i.e. oil spills transported from road through runoff and infiltration into groundwater). The bore is screened within the watertable aquifer.

There is one site within 1 km of Domain station that has been identified as a GQRUZ (Figure 13-2). These are sites where groundwater contamination restricts certain uses of the groundwater, as shown in Table 13-1. Volatile contaminants are present in these GQRUZs. Drawdown associated with inflows at the station may change hydraulic gradients in the area, causing migration of these contaminants towards the station.

Table 13-1 Contaminants and restricted uses for GQRUZ within 1 km of Domain station

Reference	Main groundwater contaminants	Restricted / excluded uses of groundwater
CARMS 68727-1. Golder Associates Pty Ltd, 2011. Environmental Audit report (53X) - 63-75 Coventry Street, South Melbourne.	Cadmium, lead, nickel, zinc, PAHs, MAH, Chlorinated Ethenes.	Potable water supply. Agriculture, parks and gardens. Stock watering. Industrial water use Primary contact recreation.

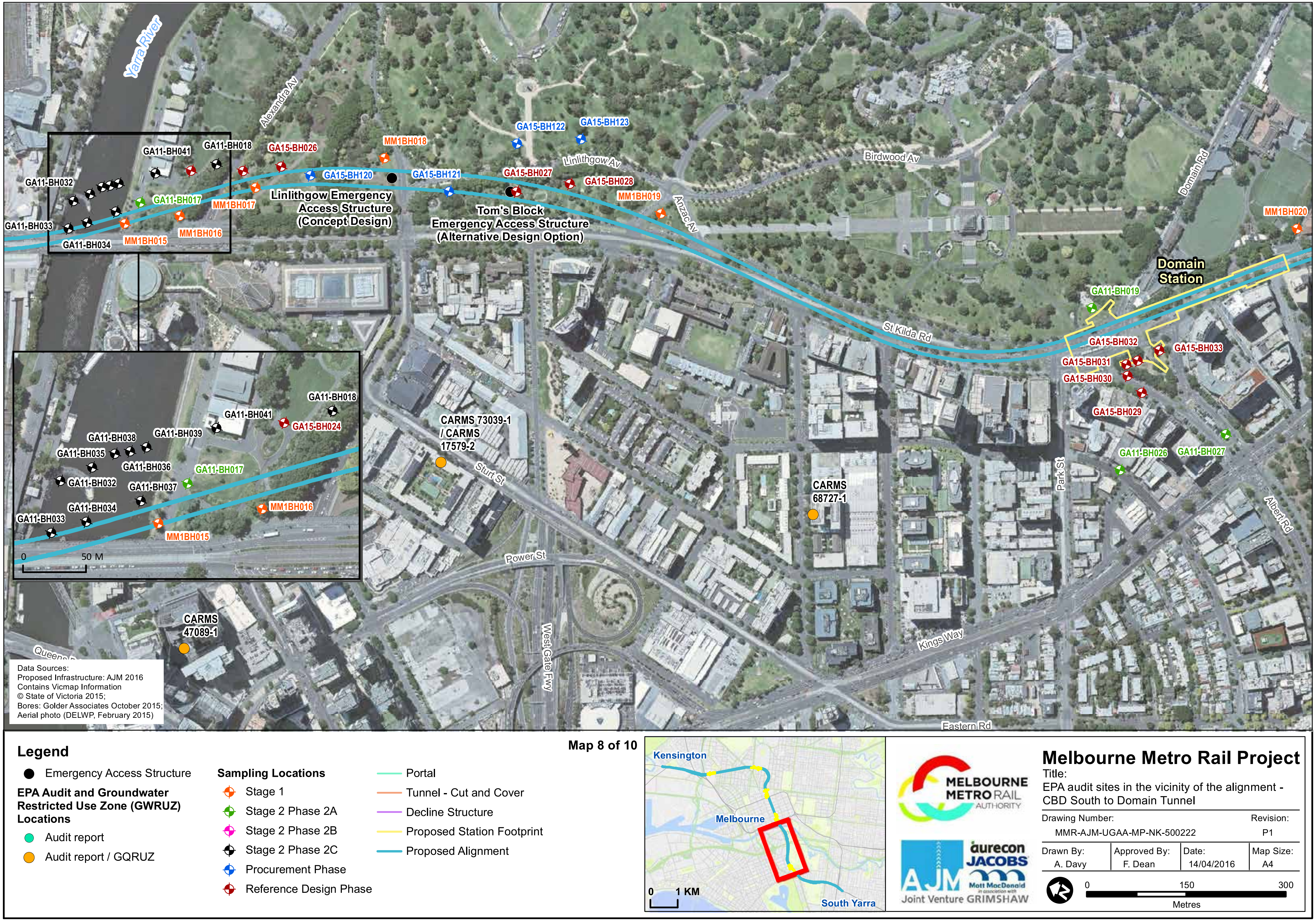
The design of any structures needs to take into account the potential aggressive groundwater conditions in accordance with AS 2159-2009. A durability assessment that reviews the potential for corrosion of Melbourne Metro structures is contained in the Contaminated Land and Waste Management impact assessment (Technical Appendix Q *Contaminated Land and Spoil Management*).

13.2.4 Groundwater Use

There are no active stock and/or domestic bores within 1 km of this precinct. A domestic bore (WRK990820) is mapped as being approximately 1.1 km east of the station, however a site inspection undertaken for Melbourne Metro in July 2015 and discussion with the property owner suggest that this bore was never installed. Outcomes of the site inspections are summarised in Appendix D of this report. Discussions with Southern Rural Water confirmed that this bore is not used and can be excluded from further consideration in the EES.

13.2.5 Groundwater-Surface Water Interaction

The nearest surface water feature to the Domain station precinct is Albert Park Lake, approximately 600 m to the south-west. As discussed above, under natural conditions it is expected that groundwater would flow towards this low lying feature. However, the presence of the South Yarra Main Sewer is likely to be diverting some flow to the north of the lake. Any interaction between the lake and groundwater at the northern end (near Domain station) is likely to be from the lake to the groundwater.



Melbourne Metro Rail Project			
Title: EPA audit sites in the vicinity of the alignment - CBD South to Domain Tunnel			
Drawing Number: MMR-AJM-UGAA-MP-NK-500222			Revision: P1
Drawn By: A. Davy	Approved By: F. Dean	Date: 14/04/2016	Map Size: A4

0 150 300 Metres

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Figure 13-2 GQRUZs within 1 km of Domain station

13.2.6 Groundwater Dependent Vegetation

Trees along the alignment were reviewed in the arboriculture impact assessments (Technical Appendix R and S *Arboriculture*) and are considered not to be groundwater dependent. Outside the project boundary, there are large trees in the vicinity of the station that were not assessed in the arboriculture impact assessment. The trees along St Kilda Road are elms and plane trees, which have very shallow (<1.5 m) root systems. These trees would be utilising water from the unsaturated zone rather than groundwater in this area.

Other trees outside the project boundary, for example in the Royal Botanic Gardens and Albert Park, also have the potential to access groundwater, particularly where the watertable is shallow such as around Albert Park Lake. There is no information on the type of these trees and their water requirements, and therefore the groundwater dependence of these trees cannot be assessed. Where deep-rooted tree species exist in this area, there is a greater potential for groundwater use, and hence, a greater sensitivity to impacts from drawdown. These deep rooted trees should be identified and irrigated through the period of drawdown.

13.3 Potential Issues

As identified in the risk assessment (Table 6-1), the potential issues associated with the Concept Design are identified in Table 13-2. These are the potential receptors for which impacts must be specifically assessed during the impact assessment in the following sections.

Table 13-2 Potential issues associated with the Concept Design

Concept Design	Issue	Risk #
Domain station	Inflows may occur through the base of the station box during construction. This could result in groundwater drawdown, which may affect nearby groundwater users, surface water bodies, and vegetation. Potential impacts of drawdown in this area include: • Potential increased flow from Albert Park Lake to groundwater • Impacts on large trees that may be using groundwater in Albert Park • Migration of existing contaminants to third party properties. One GQRUZ exists in the area, and low level anthropogenic contamination has been identified in the vicinity of the station. Migration may impact beneficial uses of groundwater at third party properties and/or cause vapour intrusion to underground structures • Potential acid generation from exposure of the Melbourne Formation. There are no active groundwater bores within 1 km of Domain station.	GW010 GW015 GW020 GW023 GW032 GW034

13.4 Impact Assessment

Potential impacts of Melbourne Metro construction and operation on the values associated with groundwater are evaluated in accordance with the assessment criteria outlined in Section 2. The potential impacts outlined in this section are based on the design components specified in the Concept Design and the assumptions stated in Section 4.7 in this report. In cases where an impact with moderate, major or severe consequences has been predicted, additional mitigation measures are recommended to reduce the risk of impact.

13.4.1 Construction

Construction of the Domain station would be by either top down or bottom up excavation with diaphragm walls used as retaining structures. Diaphragm walls prevent groundwater inflows from the sides of the station box, but inflows may still occur through the base of the structure. The impacts of drawdown associated with groundwater inflows through the base of the station excavation have been assessed.

Inflow volumes and associated drawdown of groundwater levels were modelled using a regional groundwater model in FEFLOW. The method and accompanying inputs and assumptions of the numerical modelling are detailed in Golder Associates (2016b, Appendix H), which is included as Appendix H of this report.

13.4.1.1 Groundwater Drawdown Estimate

At the end of construction, the drawdown cone extending from the station is predicted to be roughly elliptical with the long axis along the length of the station (north-west to south-east) and extending several hundred metres from the station. The shape of the drawdown cone is affected by the South Yarra Main Sewer which has been modelled as recharging the groundwater (fixed head boundary).

13.4.1.2 Potential Impacts

There are no groundwater dependent assets within this area of drawdown, and therefore impacts are not expected to occur (Figure 13-3). If there is any change in construction technique or detailed design that may cause greater inflows, potential drawdown impacts should be assessed for:

- Albert Park Lake (**Risk #GW010**)
- Potential groundwater dependent vegetation in Albert Park and the parkland adjacent to the station (**Risk #GW020)**
- Potential acid generation from exposure of the Melbourne Formation (**Risk #GW034**).

The GQRUZ is approximately 500 m north of Domain station and is outside the area of predicted drawdown. It therefore does not present a risk of impacting beneficial uses on neighbouring properties. The Brighton Group is unsaturated at this location and hence is not a PASS risk. The station is mainly excavated through extremely weathered Melbourne Formation and in part through highly weathered to moderately weathered Melbourne Formation. Hence the risk of PASS is considered low. This is supported by testing to date which indicates the absence of PASS at the level of the station cavern (Golder 2016a, Appendix G).

13.4.2 Operation

Domain station would be tanked for operation and therefore long term inflows are expected to be minor. The inflow rate is determined by the construction of the tanking and the aim for Domain station in the Concept Design is Haack Tightness Class 2, which limits daily inflow to 0.05 L/m^2 per 100 m length. Drawdown of groundwater levels as a result of these inflows during operation were modelled using a regional groundwater model in FEFLOW. The method and accompanying inputs and assumptions of the numerical modelling are detailed in Golder Associates (2016b), which is included as Appendix H of this report.

13.4.2.1 Potential Impacts

The estimated groundwater drawdown as a result of the minor inflows to the station is predicted to be less than 0.2 m immediately above the station at steady state. This minimal drawdown means that no impacts on groundwater dependent values are anticipated at Domain station during operation. If there is any change in construction technique or detailed design that may cause greater inflows, potential drawdown impacts should be assessed for the following potential receptors:

- Albert Park Lake (**Risk #GW010**)
- Potential groundwater dependent vegetation in Albert Park and the Royal Botanic Gardens (**Risk #GW015)**
- Potential acid generation from exposure of the Melbourne Formation (**Risk #GW034**).

13.5 Environmental Performance Requirements

Since the minimal drawdown predicted means the risk of impacts to groundwater dependent values is low, no specific Environmental Performance Requirements have been recommended for this station precinct. However the project-wide Environmental Performance Requirements of developing a detailed design phase model and a Groundwater Management Plan to assess and manage impacts associated with the detailed design still apply.

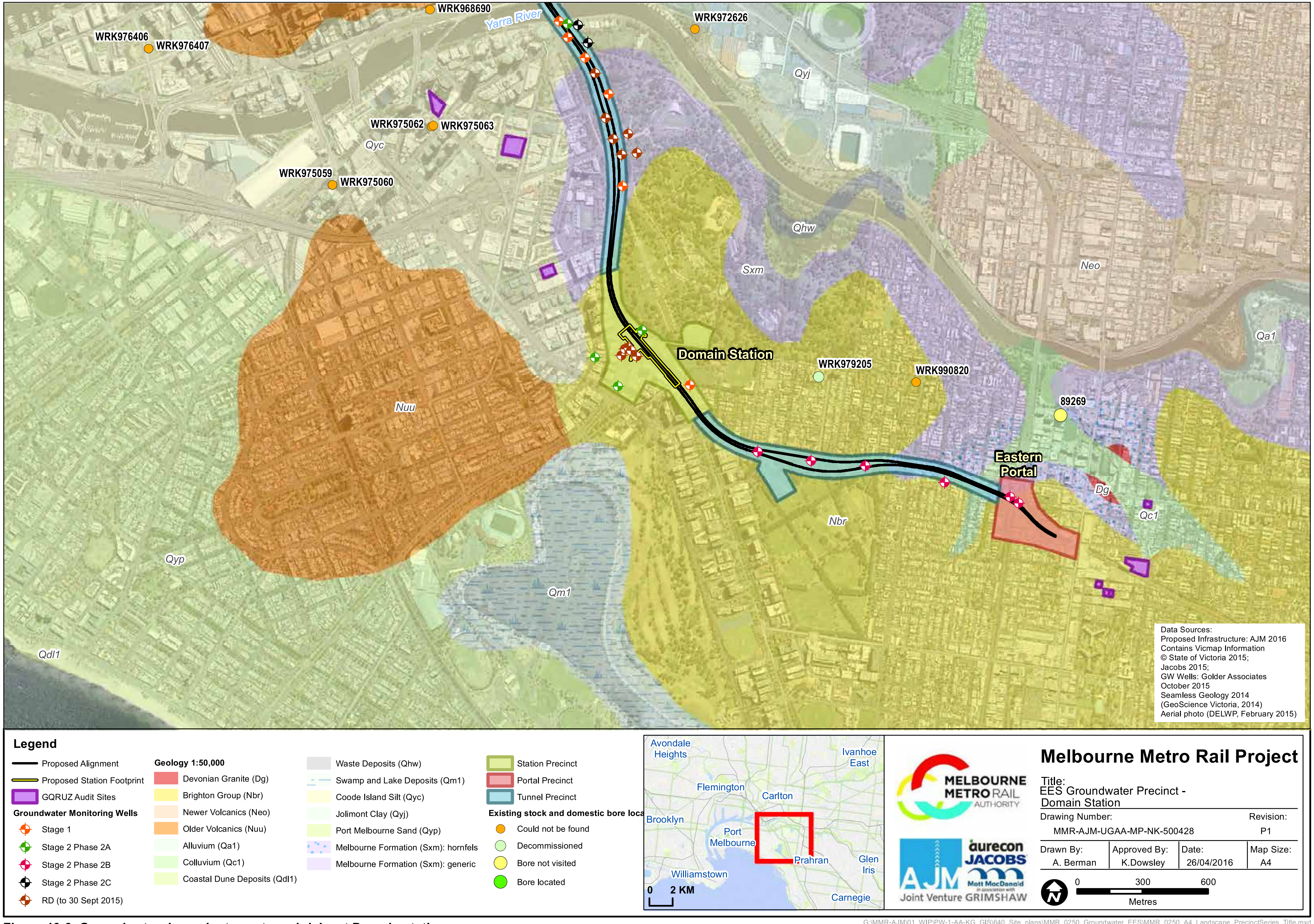

Figure 13-3 Groundwater dependent assets and risks at Domain station

14 Precinct 8: Eastern Portal (South Yarra)

14.1 Project Components

The eastern portal is located from approximately 40 metres west of Orborne Street in the west to Chapel Street in the east and from Toorak Road in the north to Arthur Street in the south. This section describes the components and construction activities that could result in the impacts to existing conditions in this precinct, based on the Concept Design and the assumptions stated in Section 4.7. Where the risk of impact is predicted to be medium, high or very high, mitigation measures would be applied during construction and operation to reduce the level of risk to low.

14.1.1 Infrastructure

The tunnel would be constructed using a TBM driven to CH104+250 where the TBM box is located (CH104+250 to CH104+280). From here the tunnels are cut and cover to CH104+420. The decline structure is between CH104+420 and CH104+550. The TBM box is likely to be approximately 30 m long by 60 m wide and up to 17 m below the existing ground level. Cross passage 23 is located within the TBM retrieval box.

14.1.2 Construction

During construction of the decline structure, it would be expected that open cut/embankment methods would be used. Once the decline structure is more than 6 m deep, a cut and cover tunnel would be constructed to the TBM retrieval shaft. Earth retaining structures may be used where geological conditions or space constraints dictate. These are likely to be in the form of piles constructed prior to excavation. Where underground components of the eastern portal are below the watertable, it is assumed that these components are drained during construction. This means that below the watertable, groundwater would seep into the excavation and need to be pumped out from a sump in the excavation.

14.1.3 Operation

During operation it is planned that all underground structures in this precinct would be tanked to a tightness classification of Haack 3.

14.2 Existing Conditions

14.2.1 Hydrostratigraphy

The expected geology across this precinct is Melbourne Formation (CH104+040 to CH102+280) and Brighton Group (CH104+120 to CH104+600) – refer to Figure 14-1. The Melbourne Formation may have undergone slight metamorphism in the area due to a large Devonian granite intrusion in the eastern part of this Precinct. It is unlikely that the tunnels would intersect any metamorphosed rocks, but dykes may exist around the intrusion. Depending on the weathering state of the dykes, they may act as a barrier to groundwater flow (if weathered to clay) or a conduit for flow (if heavily fractured). Dykes in the area are normally conceptualised as barriers to groundwater flow.

The Brighton Group has a low potential to generate acidity. Deep, fresh to slightly weathered Melbourne Formation rock, typically present at depths greater than 24 m, has moderate to high potential to generate acidity. Shallow highly weathered to extremely weathered Melbourne Formation is typically non-acid forming and hence low risk.

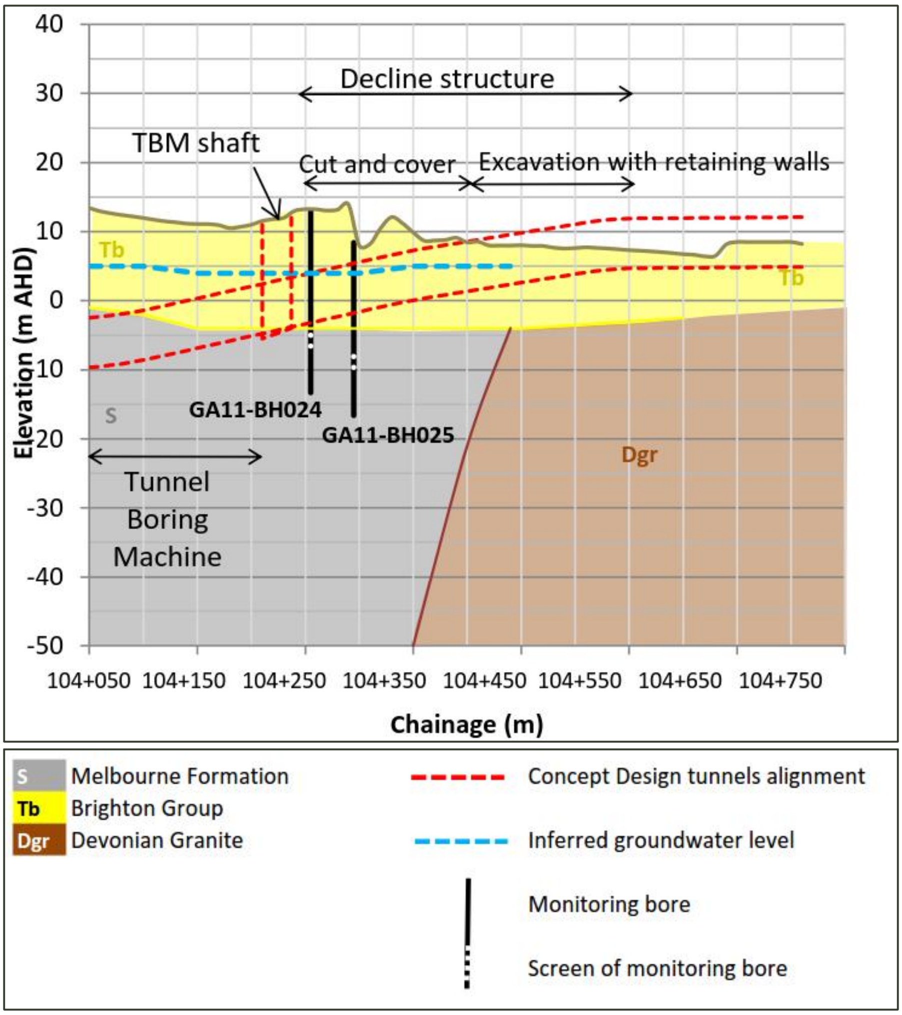

Figure 14-1: Conceptual site model for the eastern portal

There are two groundwater monitoring bores screened within the Melbourne Formation in this precinct, and one has undergone hydraulic testing (GA11-BH024). No bores in this precinct are screened within the Brighton Group. The hydraulic conductivity measured in the bore in this precinct is 4.8×10^{-8} m/sec, which is two orders of magnitude lower than the average hydraulic conductivity measured in the Melbourne Formation for this project (2.7×10^{-6} m/sec). The bore is screened towards the top of the Melbourne Formation and may be in a part of the rock which is more weathered and clayey. The presence of the granite intrusion also suggests that the Melbourne Formation may have undergone some metamorphosis that has reduced hydraulic conductivity.

14.2.2 Groundwater Levels

There are two groundwater monitoring bores in this precinct and groundwater levels have been monitored once at each bore in January 2013. The groundwater levels monitored in the bores and the bore hydrographs are included in Appendix D of this report.

Even though the bores are less than 50 m apart and screened at similar depths (in the Melbourne Formation) they show a difference in groundwater elevation of 1.33 m. The difference in water levels may reflect a monitoring error or the influence of a drain or sewer on one of the bores.

Under natural conditions, groundwater flows in the precinct would be to the west towards Port Phillip Bay or to the north-west towards the Yarra River. However, a sewer main located to the north and east of the precinct may be acting as a groundwater drain and diverting flow in a more northerly or easterly direction.

The depth to groundwater in this precinct is shallow and ranges between approximately 5 m below ground level to 8 m below ground level.

14.2.3 Groundwater Quality

Both monitoring bores in this precinct have been sampled and record TDS concentrations at around the average of results over the entire alignment for the Melbourne Formation (5,640 mg/L). The groundwater salinity in this precinct is above the range given by regional watertable mapping, which designates this area as 500 to 3,500 mg/L TDS. The regional mapping shows salinity for the watertable only, and deeper confined aquifers are typically more saline.

Groundwater of this salinity is within Segment A1 to B of the SEPP (GoV), which means the following beneficial uses must be protected:

- Maintenance of ecosystems: groundwater discharging to surface water ecosystems must not alter ecosystem health
- Potable water supply (acceptable)
- Irrigation
- Potable mineral water (no mineral water is expected in this area and this Beneficial Use is not considered further)
- Stock watering
- Industrial water use
- Primary contact recreation (e.g. swimming)
- Buildings and structures (groundwater contamination must not cause corrosion).

Groundwater quality analysis at the eastern portal did not include hydrocarbon analysis, or other analytes indicative of anthropogenic contamination. This area has a history of industrial landuse and widespread low-level contamination of soil and groundwater is expected.

The nitrate concentration at GA11-BH024 is high. High nitrate concentrations in urban environments are most likely due to leaking sewer or drainage infrastructure.

Seven GQRUZs are located within a 1km radius of the eastern portal (Figure 14-2). These are sites where groundwater contamination restricts certain uses of the groundwater, as shown in Table 14-1. Volatile contaminants are present in these GQRUZs. Drawdown associated with inflows at the portal may change hydraulic gradients in the area, causing movement of these contaminants towards the portal.

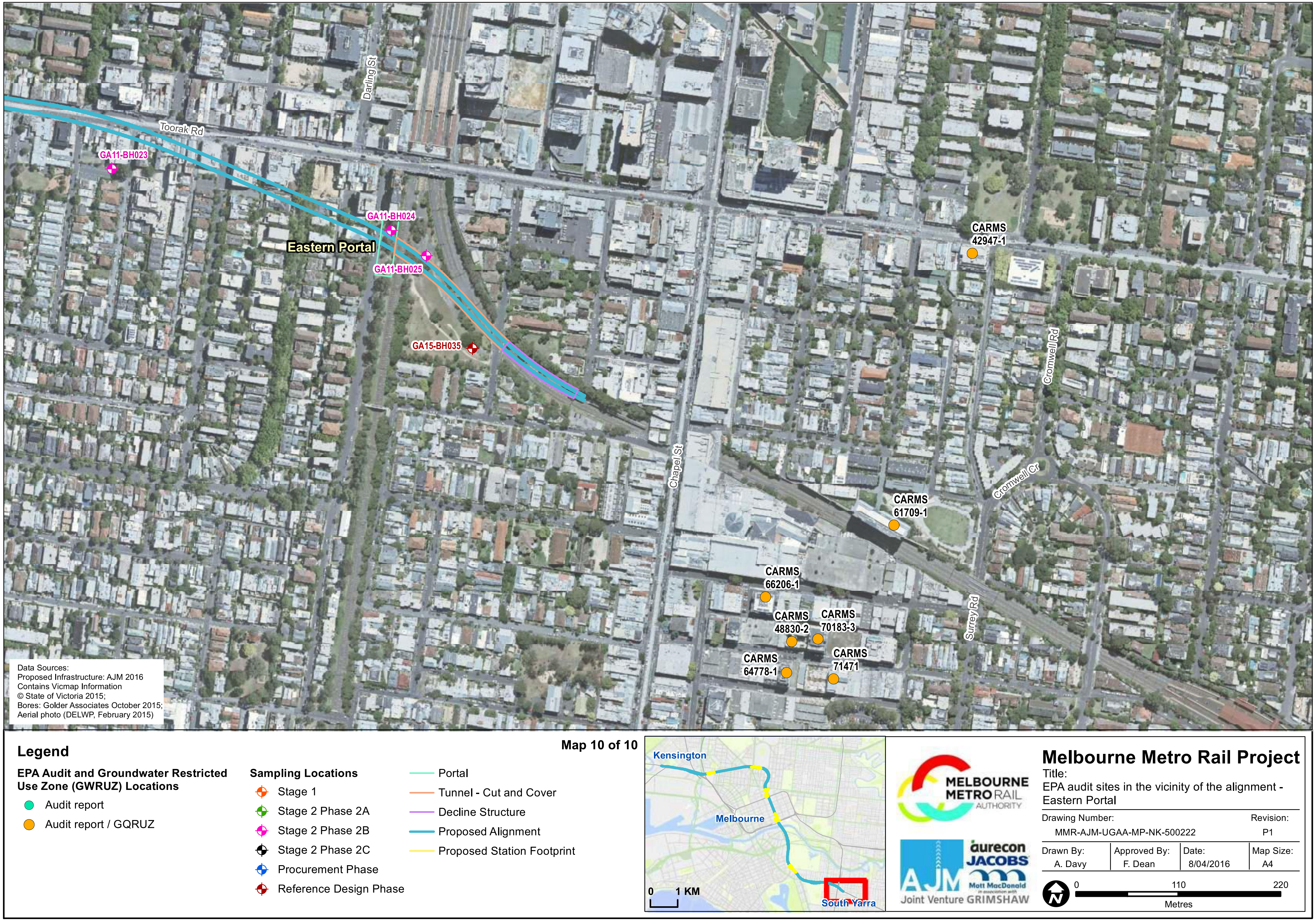

Figure 14-2 GQRUZs within 1 km of the eastern portal

Table 14-1 Contaminants and restricted uses for GQRUZs within 1 km of the eastern portal

Reference	Main groundwater contaminants	Restricted / excluded uses of groundwater
CARMS 42947-1. Golder Associates Pty Ltd, 2002. Environmental Audit report (53X) - 332-336 Toorak Road, South Yarra.	PAHs, TCE, PCE, Nickel, Zinc.	Drinking water Livestock water supply Irrigation Recreational (e.g. contact) Industrial
CARMS 61709-1. LanePiper, 2008. Environmental Audit report (53X) - Surrey Road depot 67-73 Surrey Road, South Yarra.	Arsenic, manganese, nickel, zinc, nitrate (as N), naphthalene, phenanthrene, anthracene, fluoranthrene, benzene, toluene, ethylbezene, xylene, cyanide, fluoride, tetrachloroethene, phenol.	Drinking water Livestock water supply Irrigation Recreational (e.g. contact)
CARMS 66206-1. Peter J Ramsay & Associates Pty Ltd, 2011. Environmental Audit report (53X) - 20-24 Garden Street, South Yarra.	boron, copper, selenium, zinc, aluminium, iron, lead, manganese, ammonia, toluene, ethylbenzene, xylenes, naphthalene, benzene, LNAPL.	Drinking water Livestock water supply Irrigation Recreational (e.g. contact) Industrial
CARMS 48830-2. Coffey Geosciences Pty Ltd, 2004. Environmental Audit report (53X) - 19-23 Wilson Street, South Yarra.	aluminium, iron, manganese, sodium, chloride, benzene, toluene, ethylbenzene, xylenes, phenol, naphthalene, sulfate, acetone, 1,3 Dichloropropene, LNAPL.	Drinking water Livestock water supply Irrigation Recreational (e.g. contact)
CARMS 70183-3. Environmental Auditor Pty Ltd, 2013. Environmental Audit report (53X) - 25-29 Wilson Street, South Yarra.	Zinc and Benzene.	Drinking water Livestock water supply Irrigation
CARMS 64778-1. Peter J Ramsay & Associates Pty Ltd, 2010. Environmental Audit report (53X) - 26-28 Wilson Street, South Yarra.	benzene, toluene, ethylbenzene, xylene, arsenic, zinc, 1,1-dichloroethene, 1,1-dicholoethane, 2,4-dimethylphenol, TPHs, LNAPL.	Drinking water Livestock water supply Irrigation Recreational (e.g. contact) Industrial
CARMS 71471-1. Golder Associates Pty Ltd, 2014. Environmental Audit report (53X) - 42 Wilson Street, South Yarra.	Ammonia (as N), nitrate, chloride, cis-1,2-dichloroethene, 1,2-trichloroethane, trichloroethene, vinyl chloride, copper, zinc.	Drinking water Livestock water supply Irrigation Recreational (e.g. contact) Industrial

The design of any structures needs to take into account the potential aggressive groundwater conditions in accordance with AS 2159-2009. A durability assessment that reviews the potential for corrosion of Melbourne Metro structures is contained in the contaminated land and spoil management impact assessment (Technical Appendix Q *Contaminated Land and Spoil Management*).

14.2.4 Groundwater Use

There are two registered groundwater bores within 1 km of the eastern portal:

- A stock and domestic bore is located approximately 375 m to the north (89269). It was not found during a site inspection undertaken for Melbourne Metro in July 2015. It is likely that the bore was destroyed during construction of buidlings in 2012
- A domestic bore (WRK990820) approximately 750 m north-west of the portal, however a site inspection and discussion with the property owner suggest that this bore was never installed.

Outcomes of the site inspections are summarised in Appendix D of this report. Discussions with Southern Rural Water confirmed that these bores probably do not exist and are not used. On this basis, it was agreed they can be excluded from further consideration in the EES.

14.2.5 Groundwater-surface Water Interaction

The nearest surface water feature to the eastern portal is the Yarra River, located approximately 550 m to the north. Groundwater-surface water interaction in the Yarra River is limited, as shown during the CityLink project construction, which resulted in rapid drawdown beneath and beyond the Yarra River, indicating that connection between the river and underlying sediments is weak (Golder 2016a, p30). This may be due to low permeability sediments in the riverbed.

14.2.6 Groundwater Dependent Vegetation

Trees along the alignment were reviewed in the arboriculture impact assessments (Technical Appendix R and S *Arboriculture*) and most trees are considered not to be groundwater dependent. However one mature *Eucalyptus cladocalyx* (#13) in the northern part of South Yarra Siding Reserve may have sinker roots that extend to the watertable and is therefore potentially groundwater dependent (Technical Appendix S *Arboriculture*).

Large trees outside the project boundary were not assessed in the arboriculture impact assessments (Technical Appendix R and S *Arboriculture*), but where groundwater is shallow such as around the Yarra River there is the potential for them to be using groundwater. Where deep-rooted tree species exist in this area, there is a greater potential for groundwater use, and hence, a greater sensitivity to impacts from drawdown.

14.3 Potential Issues

As identified in the risk assessment (Table 6-1), the potential issues associated with the Concept Design are identified in the Table 14-2. These are the potential receptors for which impacts must be specifically assessed during the impact assessment in the following sections.

Table 14-2 Potential issues associated with the Concept Design

Concept Design	Issue	Risk #
Dive structure, cut and cover tunnels and TBM Shaft in the rail reserve between Osbourne Street and the existing Sandringham line	Groundwater levels in the area could be up to approximately 5 m AHD, which would mean groundwater would have to be lowered by approximately 11.5 m to keep the excavation dry during construction. This could result in groundwater drawdown which may affect nearby groundwater users, vegetation, and surface water bodies. Potential receptors are:	
	• Large trees that may use shallow groundwater along the Yarra River and one large tree in South Yarra siding reserve	GW015, GW021
	• Migration of existing contaminants to third party properties. Seven GQRUZs exist in the area, and other plumes of anthropogenic	GW023

Concept Design	Issue	Risk #
	contamination may exist (although not identified in project sampling), given the intensive development in the area. Migration may impact beneficial uses of groundwater at third party properties and/or cause vapour intrusion to underground structures	GW033
	• Potential acid generation from exposure of the Melbourne Formation.	GW034
	The Yarra River is expected to have limited interaction with groundwater, and therefore drawdown impacts are considered unlikely and are not assessed. Vegetation away from the river is not expected to be dependent on groundwater, so impacts are not considered further. There are no active stock and domestic groundwater bores within 1 km of the eastern portal.	

14.4 Impact Assessment

Potential impacts of Melbourne Metro construction and operation on the values associated with groundwater are evaluated in accordance with the assessment criteria outlined in Section 2. The potential impacts outlined in this section are based on the design components specified in the Concept Design and the assumptions stated in Section 4.7 in this report. In cases where a medium, high or very high risk of impact has been predicted, additional mitigation measures are recommended to reduce the risk of impact.

14.4.1 Construction

It is assumed that all infrastructure at the eastern portal would be drained during construction, including the decline structure, the cut and cover tunnels, and the TBM retrieval shaft. Where these structures are below the watertable groundwater inflows would occur, resulting in drawdown around the portal.

Groundwater levels are approximately 4.6 m AHD at the eastern portal, and the base of the TBM shaft is at approximately -6 m AHD. Therefore, approximately 11.6 m of groundwater drawdown would be required to keep the excavation dry during construction. Inflow volumes and associated drawdown of groundwater levels were estimated using an analytical approach that is described in Appendix F of this report.

14.4.1.1 Groundwater Drawdown Estimate

At the end of construction, the unmitigated drawdown cone at the eastern portal is predicted to propagate out from the TBM shaft in a circular shape for several hundred metres. Results of the analytical modelling are shown in Appendix F of this report. Groundwater dependent values within this area of drawdown may be impacted by reduced groundwater availability as a result of deeper groundwater levels.

14.4.1.2 Potential Impacts

Groundwater dependent assets within the area of drawdown are susceptible to impacts. As a result of the predicted unmitigated drawdown at the eastern portal, potential environmental, economic and social receptors of changes in groundwater levels, flow or quality include (Figure 14-3):

- One mature *Eucalyptus cladocalyx* (#13) in South Yarra Siding Reserve that may be groundwater dependent (**Risk #GW21**)
- Third parties with properties close to possible contaminant plumes. There are no GQRUZs within the predicted area of drawdown. However the industrial land use of the area suggests that contaminant plumes may be present which may migrate if drawdown occurs (**Risk #GW033**).

There are no registered groundwater users within the predicted area of drawdown around this portal precinct. Similarly, the surface water bodies and vegetation within the area of drawdown are not expected to be dependent on groundwater, so impacts are not considered further.

The risk of PASS activation due to groundwater drawdown at and away from the eastern portal is considered low given the low risk form the Brighton Group and the shallow extent of excavations into the Melbourne Formation.

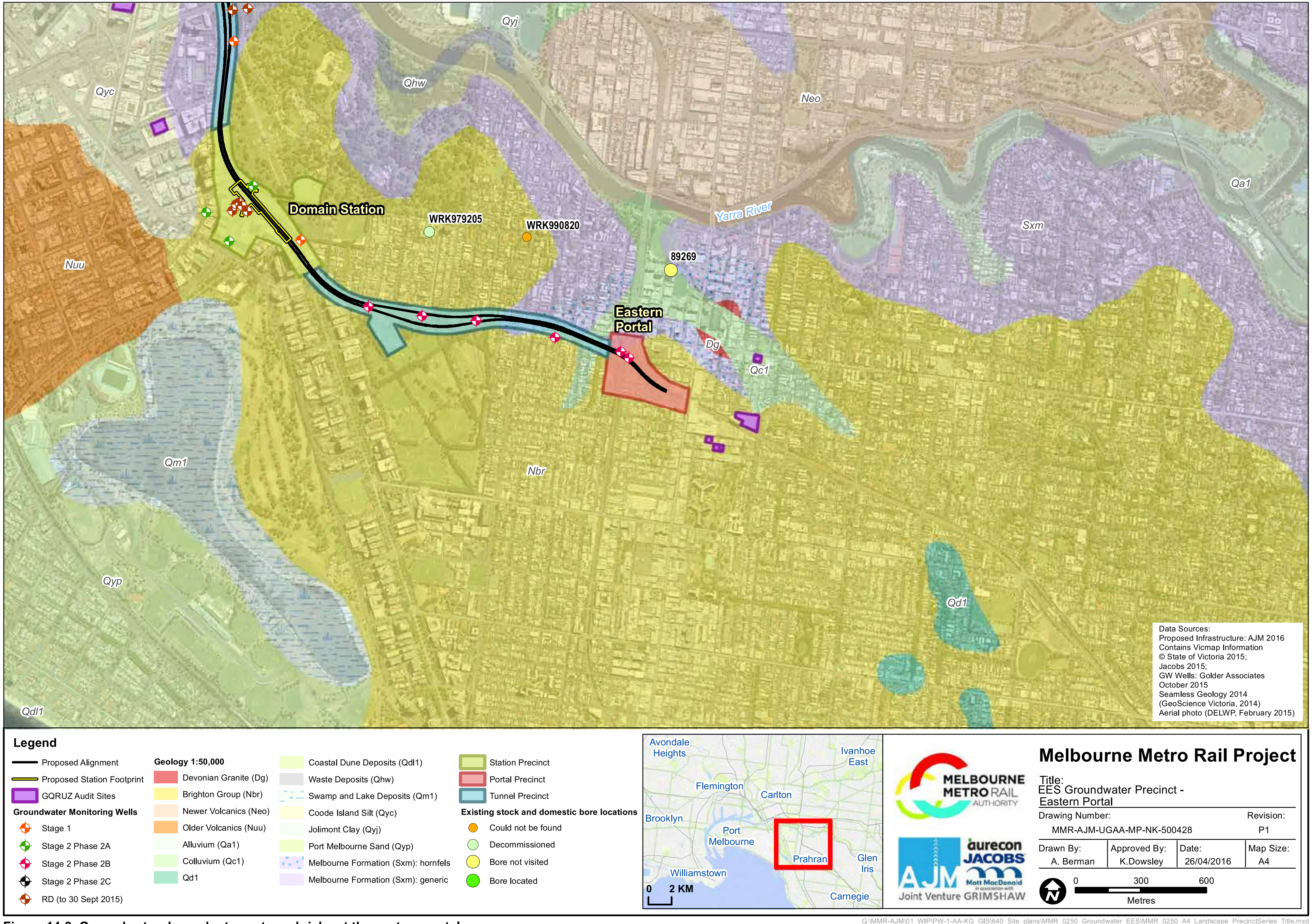

Figure 14-3 Groundwater dependent assets and risks at the eastern portal

14.4.1.2.1 Impacts on Vegetation

Most trees within the area of drawdown are shallow rooted or in areas where the watertable is deep, and as such, are not considered to be groundwater dependent. However one deep-rooted tree (*Eucalyptus cladocalyx* #13) in South Yarra Siding Reserve is in an area where groundwater is approximately 5 m deep and therefore it may have sinker roots that access the groundwater.

The water within the 5 m of unsaturated soil above the watertable would provide a water source for most of the year, however the tree may rely on groundwater in dry periods when the soil water has been consumed. The tree should therefore be irrigated through the period of drawdown. This measure is expected to fully mitigate any potential impacts on trees caused by groundwater drawdown.

14.4.1.2.2 Contaminant Migration to Third Party Properties

The predicted drawdown cone does not intersect any areas of known contamination. However, there are likely to be areas with contaminated groundwater given the industrial land uses in the past.

If contamination migrates to previously uncontaminated areas, beneficial uses of groundwater at third party properties may be precluded. Beneficial uses that need to be protected are:

- Irrigation
- Drinking water (acceptable)
- Stock watering
- Industrial water use
- Primary contact recreation (e.g. swimming)
- Buildings and structures (groundwater contamination must not cause corrosion).

Maintenance of ecosystems is not protected because there are no ecosystems that are reliant on groundwater in this precinct.

Due to the uncertainty around the presence of contaminated groundwater within the predicted area of impact, there is considered to be a moderate risk of migration of contaminants and associated vapour migration in the area of drawdown. Mitigation and monitoring would be implemented to reduce this risk to low.

14.4.2 Operation

The eastern portal would be tanked for operation and therefore, long-term inflows are expected to be minor. The inflow rate is determined by the construction of the tanking and the aim for all underground structures for this project is Haack Tightness Class 3, which limits inflow to 0.1 L/m^2 per day per 100 m length. Drawdown of groundwater levels as a result of these inflows during operation were modelled using a regional groundwater model in FEFLOW. The method and accompanying inputs and assumptions of the numerical modelling are detailed in Golder Associates (2016b, Appendix H of this report).

14.4.2.1 Groundwater Drawdown Estimate

The estimated groundwater drawdown as a result of these minor inflows to the eastern portal is minimal. At steady state, the maximum drawdown immediately above the portal is predicted to be less than 0.5 m. The 0.2 m drawdown contour is elliptical and extends to the north and south of the portal for several hundred metres.

14.4.2.2 Potential Impacts

Minimal drawdown would be expected at the eastern portal precinct during operation since it is assumed inflows are largely prevented by constructing the portal to a Haack 3 tightness classification. Therefore, no impacts on groundwater dependent values are anticipated during operation. If there is any change in construction technique or detailed design that may cause greater inflows, potential drawdown impacts should be assessed for:

- Third parties with properties close to possible contaminant plumes (**Risk #GW023**).

No groundwater dependent surface water bodies or vegetation are expected to exist in this portal precinct. There are no active groundwater bores within 1 km of the portal.

14.5 Environmental Performance Requirements

Table 14-3 provides the recommended Environmental Performance Requirements and proposed mitigation measures for the precinct. In addition to the precinct specific Environmental Performance Requirements below, the project-wide Environmental Performance Requirements of developing a detailed design phase model and a Groundwater Management Plan to assess and manage impacts associated with the detailed design also apply.

Table 14-3 Environmental Performance Requirements for precinct

Asset / value	Impact	Environmental Performance Requirements	Proposed mitigation measures	Risk no.
Large trees that may access groundwater	Construction: possible during dry periods due to shallow watertable and presence of deep-rooted tree (Eucalyptus Cladcalyx #13). Operation: none.	Develop and implement a Groundwater Management Plan (GMP) detailing groundwater management approaches to address the predicted impacts to groundwater dependent values during construction. The GMP must be based on the detailed design phase groundwater model, and should include the following details: • Identifying and if necessary, specifying mitigation measures to protect groundwater dependent vegetation during periods of drawdown.	Deep-rooted tree species in areas of shallow groundwater should be irrigated throughout the period of drawdown.	GW021
		Develop and implement a groundwater monitoring plan as part of the GMP that details sufficient monitoring of drawdown to verify that no significant impacts occur from potential: • Reduction in access to groundwater for trees.		

Asset / value	Impact	Environmental Performance Requirements	Proposed mitigation measures	Risk no.
Beneficial uses of groundwater at third party properties	Construction: moderate risk of migration of groundwater contaminants based on past landuse and expected presence of contaminants within the predicted area of impact. Beneficial uses that need to be protected are: • Irrigation • Drinking water (acceptable) • Stock watering • Industrial water use • Primary contact recreation • Buildings and structures. • Operation: none	Develop and implement a GMP detailing groundwater management approaches to address the predicted impacts to groundwater dependent values during construction. The GMP must be based on the detailed design phase groundwater model, and should include the following details: • An approach identified in consultation with the EPA so that contaminant migration causes no significant impacts on beneficial uses and vapour intrusion into underground structures, and establish appropriate monitoring networks to confirm effectiveness of approach. Develop and implement a groundwater monitoring plan as part of the GMP that details sufficient monitoring of drawdown to verify that no significant impacts occur from potential: • Contaminant migration on the beneficial uses of groundwater at third party properties caused by drawdown and vapour intrusion to underground structures.	Likely to involve further investigation and/or mitigation measures, for example: • Site specific risk assessment of contaminant location and concentrations • Use of injection or discharge bores to prevent contaminant migration • Minimisation of drawdown through construction techniques such as grouting of the structure.	GW033

15 Precinct 9: Western Turnback

15.1 Project Components

This section describes the components and construction activities that could result in impacts to existing conditions in the Western Turnback precinct.

Operations of the new Metro Melbourne would include turning back some trains early on the Sunbury line to run back towards the CBD to optimise the efficient service of Melbourne Metro corridor. The Concept Design for the western turnback is West Footscray, with a third platform and track at West Footscray station, and modifications to the existing concourse.

15.1.1 Infrastructure

The infrastructure for the western turnback at West Footscray station includes a new railway track and modification to the existing concourse. All works would be above ground and therefore there is no infrastructure that would interact with groundwater.

15.1.2 Construction

All construction works would be above ground and there would be no interaction with groundwater.

15.1.3 Operation

The operational running of the western turnback would not interact with groundwater.

15.2 Existing Conditions

No intrusive investigations have been completed in this precinct to date for the project. The following information is from desk top sources:

- The surface geology at West Footscray station consists of Newer Volcanics aquifer
- The depth to groundwater ranges from less than 5 m to 10 m below ground level
- The groundwater salinity is 1,000 mg/l to 7,000 mg/L
- There is one stock and domestic use bore (WRK988542) within 1 km of the site located 600 m to the north-west of the site. This bore was drilled in 2008 to a total depth of 17.70 m
- The site is 1.9 km west of the Maribyrnong River.

15.3 Potential Issues

There are no potential issues associated with the Concept Design as all works are above ground and would not intersect the groundwater.

15.4 Impact Assessment

All works and infrastructure associated with the Concept Design are above ground and would not intersect the groundwater. Therefore no impacts are expected.

15.5 Environmental Performance Requirements

No specific Environmental Performance Requirements have been recommended for this precinct since groundwater impacts are not expected. However, the project-wide Environmental Performance Requirements of developing a detailed design phase model and a groundwater management plan still apply to manage potential changes to the detailed design that may have groundwater implications.

16 Early Works

16.1 Project Components

16.1.1 Infrastructure

A number of early works are required prior to the commencement of the main construction works. The early works all comprise modifications, temporary works, relocations or new works associated with existing utilities and services as follows:

- Electrical
- Sewer
- Gas
- Water
- Stormwater
- Communications
- Tram works.

All these works are associated with the stations and the portals. The only works of relevance to groundwater are the beneath-ground works, which intersect the watertable. It is anticipated that the only early works with the potential to impact groundwater would be:

- North Yarra Main Sewer: no work is currently proposed on the sewer, however if it is found to be unstable, some strengthening of the sewer may be required. There are unlikely to be groundwater implications and this work has not been assessed any further
- South Yarra Main Sewer: it is planned to replace the sewer in the vicinity of Domain station. Works would include installation of:
  - Four new manholes, at Domain Road, on St Kilda Road north of the Domain station, on St Kilda Road south of Domain station, and where the new sewer joins the existing sewer on Albert Road
  - GRP sewer (1905 mm diameter) from the new manhole on Domain Road, under Melbourne Grammar to St Kilda Road, under Domain station, and joining to the South Yarra Main on Albert Road
  - Decommissioning of the existing sewer between the new manholes on Domain Road and Albert Road, probably by plugging the ends.

Three structures associated with CBD North and CBD South stations which would impact groundwater are also included in the early works package. The groundwater impacts associated with these structures have been assessed together with the other structures in the station precincts and are reported in the relevant station precinct sections of this report. The structures to be constructed as part of the early works program are:

- The Franklin Street East shaft, to the east of CBD North cavern
- The A'Beckett Street shaft, which is west of the CBD North cavern
- The demolition of the car park beneath City Square, east of CBD South station.

These excavations are part of the CBD North and CBD South precincts, and impacts of drawdown are discussed in Sections 11.4 and 12.4. The inclusion of these works in the early works package does not change the modelled drawdown and predicted impacts associated with excavation of the shafts. It is important to note that the shafts at CBD North would be excavated to below the watertable during the early works program and as such, there may be groundwater inflows that require disposal. The Groundwater Disposal Strategy (discussed in Section 17), must therefore be in place for the early works program.

16.1.2 Construction

Construction of the relocated South Yarra Main Sewer would likely be by pipe jacking from the new manholes. It is expected that each manhole would need to be dewatered, and that works would take six to 12 months. Domain station would be built over (or potentially around) the replaced sewer. The sewer obvert would be at approximately 5.9 m AHD.

16.1.3 Operation

It is assumed that manholes would be tanked so that groundwater ingress would not occur during operation.

16.2 Existing Conditions

The existing conditions for early works at the South Yarra Main Sewer are the same as for Domain station, as described in Section 13.2 and so not repeated here.

16.3 Potential Issues

The potential issues associated with the Concept Design are identified in Table 16-1.

Table 16-1 Potential issues associated with the Concept Design

Concept Design	Issue	Risk #
South Yarra Main Sewer relocation and replacement works – Domain station	Dewatering of manholes during construction may lower groundwater levels for six to 12 months.	GW059
South Yarra Main Sewer relocation and replacement works – Domain station	Relocation and replacement of a section of old sewer with impervious GRP sewer may cause some local recovery of groundwater levels.	GW059

16.4 Benefits and Opportunities

Table 16-2 provides the benefits and opportunities associated with this part of the Concept Design.

Table 16-2 Benefits and opportunities associated with the Concept Design

Concept Design	Benefits	Opportunities
South Yarra Main Sewer relocation and replacement works – Domain station	Replacement would decrease the volume of regional groundwater ingress to the sewer.	None
South Yarra Main Sewer relocation and replacement works – Domain station.	Recovery of groundwater levels in the vicinity of the replaced sewer section.	None

16.5 Impact Assessment

Potential impacts of Melbourne Metro construction and operation on the values associated with groundwater are evaluated in accordance with the assessment criteria outlined in Section 2. The potential impacts outlined in this section are based on the design components specified in the Concept Design and the assumptions stated in Section 4.7 of this report. In cases where an impact with moderate, major or severe consequence has been predicted, additional mitigation measures are recommended to reduce the risk of impact.

Natural groundwater levels are expected to be at least 0 m AHD at the Domain station, but the South Yarra Main Sewer is causing groundwater levels to be depressed to around -4 to 5 m AHD. If the entire sewer was to be replaced with impervious material, groundwater ingress would stop and groundwater levels in the area could be expected to rise. However, since only a small section of sewer would be replaced, any rise in groundwater levels would be local, and the sewer to the east and west of the new section would continue to drain groundwater and lower groundwater levels. A rise in groundwater level of around 5 m (to 0 m AHD) above the sewer is used as the basis for this impact assessment, as this is considered to be the maximum possible increase in groundwater level. In reality, the increase is likely to be less, as it would be offset by increased leakage into the existing old sections of sewer.

16.5.1 Groundwater Impacts on Sewer

Higher groundwater levels as a result of replacing a section of the sewer would increase hydraulic gradients and cause increased groundwater inflow to existing leaky structures. This is likely to increase groundwater inflow to the sections of sewer to the east and west that are not being replaced, but with no net increase in total inflows. Since inflows are offset, the change in groundwater levels over the length of the replaced section of sewer would be minor. Also there are no groundwater dependent values in this area. Risk of impct is therefore very low.

16.5.2 Inflows to Domain Station and Tunnels

The modest rise in groundwater levels that is likely to be associated with the sewer replacement has the potential to cause greater inflows into drained structures. This is unlikely to be a concern for construction and operation of tunnels in the area, as the tunnels would be tanked during both construction and operation. Inflows would therefore be controlled by the construction and design techniques, and would not be dependent on groundwater gradients.

For the construction of Domain station, a cut and cover technique with diaphragm retaining walls is assumed in the Concept Design. This technique prevents groundwater inflow from the sides of the excavation, and since it would be embedded in low permeability Melbourne Formation, flow through the base of the station would also be minor. Higher groundwater levels as a result of sewer replacement are unlikely to cause a significant increase in flows through the station floor during construction.

16.5.3 Groundwater Users

There are no licensed groundwater users within 1 km of the sewer. Impacts from rising groundwater levels are not expected to occur outside this radius. Groundwater users are therefore not expected to be impacted.

16.5.4 Groundwater Dependent Ecosystems

The northern part of Albert Park Lake is not currently considered to be a GDE, however higher groundwater levels as a result of sewer replacement may result in groundwater discharge to the lake. Groundwater gradients between the lake and groundwater would be relatively flat (even with a 5 m rise in groundwater level) and the volume of groundwater discharge can be expected to be small. Although a water quality differential may exist between the lake and groundwater, the expected small discharge volumes mean any water quality impacts on the lake are unlikely.

The risk of elevated groundwater levels intersecting tree roots depends on the type of tree. Elms and plane trees on St Kilda Road have shallow root systems (less than ~1.5m deep) and therefore the anticipated rise in groundwater levels would still be several metres below the tree roots. No waterlogging or salinity impacts on these trees are expected as a result of the sewer works.

16.5.5 Groundwater Contaminant Migration

No groundwater contaminants above guideline values have been detected in sampling around Domain station. The one GQRUZ within 1 km of the precinct is far enough away that impacts from sewer replacement would not occur. The risk of contaminant migration impacting beneficial uses of neighbouring third party properties is therefore low.

16.6 Environmental Performance Requirements

No specific Environmental Performance Requirements have been recommended for early works, since groundwater impacts are not expected for works on the sewers. Groundwater impacts associated with early works on shafts at CBD North and CBD South stations are covered by precinct specific Environmental Performance Requirements in Sections 11.5 and 12.5. The project-wide Environmental Performance Requirements of developing a detailed design phase model and a Groundwater Management plan still apply to manage potential changes to the detailed design of early works that may have groundwater implications.

17 Groundwater Inflow and Disposal Options

Analysis has been undertaken to assess the anticipated volumes of groundwater that would flow into excavations (shafts, stations, portals, tunnels) during the construction phase of the project. Even without further mitigation measures applied, the predicted total groundwater inflows as reported in this impact assessment are considered relatively small and would readily be managed during the construction phase.

A preliminary Groundwater Disposal Strategy has been prepared to assess potential options for disposal of this groundwater (Appendix I). It is anticipated that the mitigated average inflow across all project infrastructure sites would be around 2 - 3 L/s, reaching a peak inflow of 6 – 7 L/s at the height of construction. This estimate of groundwater inflow has been undertaken for the construction methodology and staging developed for the Concept Design, which has assumed design features that reduce inflow to construction areas (as described in Section 4.5.1). The predicted inflow estimates would be revised for the final design and construction staging adopted by the contractors. Note that the Groundwater Disposal Strategy must be in place for the beginning of the early works at CBD North station, where excavations below the watertable could result in groundwater inflows that require disposal.

As for any major construction project, there are a number of options that can be considered for disposal of the extracted groundwater. These options include groundwater re-injection, re-use by third parties (industrial or irrigation), on-site uses, discharge to waterways, disposal to a certified waste disposal facility or treatment such as reverse osmosis to lower groundwater salinity and hence, open up other disposal options. These options have all been evaluated for Melbourne Metro. However, until the volume of inflows to construction areas is confirmed during the detailed design phase, the management options have not been finalised. At this stage, due to the limited construction timeframes, elevated salinity of the groundwater and the sporadic availability of groundwater for other uses (e.g. re-use on-site), disposal to sewer is the option being further investigated. Aquifer conditions and the number of bores required make re-injection to the aquifer from which the groundwater originates unfeasible. Discharge to waterways would only be considered if discharge to sewer cannot be achieved and to deal with emergency discharge situations in storm events, with the required regulatory approvals.

An important issue for disposal to sewer is the salt concentration in the groundwater. The total dissolved solids (TDS) concentrations measured in bores along the alignment varies from less than 1,500 to greater than 40,000 mg/L. Combining the spatial distribution of groundwater salinity and estimated groundwater inflows would allow salt loads for each location to be calculated. Salt load criteria form part of trade waste agreements for discharge to sewer. As salt loads are expected to be above normal trade waste criteria, further assessment and discussion with regulators and water authorities is required.

Given the short-term nature and low estimated volumes of the groundwater discharge, it would be expected that agreement with regulators can be reached regarding the salt load. Further assessment of the timing and amount of groundwater discharge during the construction phase of the project would provide a more realistic indication of the salt load distribution across the project and over the period of construction. Some structures would only receive groundwater inflows for relatively short periods of time as measures such as grouting would be implemented to significantly reduce inflow, hence the peak and average salt loads across the project would vary and be significantly lower than the sum of salt loads for the whole project. Aside from salt loads, provided the groundwater is subject to basic pre-treatment for removal of coarse suspended solids and hydrocarbons, the groundwater is suitable for discharge to sewer. Other treatment options for the removal of contaminants may be required. Pre-treatment options for reducing the salt load prior to discharge to sewer are also being investigated.

In the unlikely event that disposal of groundwater to sewer during construction is not possible or practical, then discharge to stormwater is an option that could be pursued because the groundwater is generally of similar quality to the receiving waterways, although it varies in quality across the alignment. This would require further environmental assessment and the necessary approvals obtained from the EPA and Melbourne Water. If a stormwater disposal option was pursued, a contingency sewer discharge would be required to deal with groundwater contamination that cannot be isolated from the main groundwater discharge stream, and cannot be treated with the proposed pre-treatment system.

There are some constituents above background river water quality and if the stormwater option was to be pursued further, groundwater would need to be treated to achieve background water quality conditions and comply with the SEPP. To enable appropriate treatment to be designed, a detailed analysis of the quality and variability of inflows over time would be required for each precinct to allow comparison with background river water quality and SEPP guidelines. A risk assessment to further examine potential risks to receiving waters would be required to determine an appropriate mixing zone and to assess the level of treatment prior to discharge to ensure that the mixing zone is of an appropriate/acceptable size. Freshwater flow in the Yarra River suggests rapid dilution and only a small mixing zone is likely to be required to achieve background concentrations. This detailed comparative analysis of water quality would be completed by the contractor only if disposal to stormwater became necessary,

During the long-term operation of Melbourne Metro, all the structures would be tanked and hence, the groundwater inflow would be very small, in the order of 0.3 L/s for the whole alignment. As with the construction inflows, it is anticipated that this very small inflow would be disposed to sewer. In the unlikely event that detailed design suggests otherwise, then any environmental impacts of alternative disposal methods would need to be assessed.

17.1 Environmental Performance Requirements

Table 17-1 provides the recommended Environmental Performance Requirements and proposed mitigation measures for the disposal of groundwater during construction and operation. In addition to the precinct specific Environmental Performance Requirements below, the project-wide Environmental Performance Requirements of developing a detailed design phase model and a Groundwater Management Plan to assess and manage impacts associated with the detailed design also apply.

Table 17-1 Environmental Performance Requirements for groundwater disposal

Asset / value	Impact	Environmental Performance Requirements	Proposed mitigation measures	Risk no.
Recipient of groundwater disposal (sewer or surface waters)	Construction and operation: potential for unexpected groundwater contamination to result in release of groundwater that is not treated to agreed levels.	Develop and implement a Groundwater Management Plan (GMP) detailing groundwater management approaches to address the predicted impacts to groundwater dependent values during construction. The GMP must be based on the detailed design phase groundwater model, and should include the following details: • Approach to collection, treatment and disposal of groundwater collected during construction in accordance with the MMRA Groundwater Disposal Strategy. Use the Groundwater Disposal Strategy and Groundwater Management Plan to obtain a Trade Waste Agreement with the relevant Water Retailers for groundwater disposal.	Develop a groundwater disposal strategy that confirms disposal option, contingency measures and emergency response plan if unexpected groundwater contamination is encountered and requires disposal.	GW055 GW056

18 Environmental Performance Requirements

This section provides a comprehensive list of the Environmental Performance Requirements identified as a result of this risk and impact assessment. Table 18-1 provides the Environmental Performance Requirements which apply across the project and the mitigation measures which may be implemented to achieve the Environmental Performance Requirement, linked to the draft EES evaluation objective.

The impact assessment is based on the significant amount of investigation and analysis undertaken to date, and this is considered sufficient and appropriate as the basis for this EES assessment. The impact assessment has also identified a program of further studies and analysis that would need to be undertaken in the detailed design phase, in particular to address knowledge gaps identified in the impact assessment in order to satisfy the Environmental Performance Requirements. These further studies are summarised below for ease of reference and can be divided into two groups:

Field work and investigations:

- Further investigation into permeability of the Melbourne Formation and connection with the Yarra River palaeovalley. This would include further analysis of the existing data from the St. Pauls Cathedral pumping test, slug tests and packer tests, and potentially additional aquifer testing. A longer term pumping test (30 days) should be considered to further test the response of palaeovalley sediments to groundwater drawdown in the area of the CBD South Station
- Groundwater bores in areas of shallow watertables near trees with deep root systems to determine the groundwater dependence of the trees
- Assessment of CBD North contaminant plume and potential impacts of contaminant migration on neighbouring properties
- Groundwater bores that monitor groundwater quality at the watertable in areas where contamination is expected and where significant drawdown is predicted.

Design and modelling:

- Further modelling of injection schemes for western portal, Arden station and CBD South station, to confirm bore locations and the number of bores required, bore depths, and injection rates
- Additional drawdown modelling and scenarios, based on the detailed design of structures and the construction timing and features. Specifically, the scenarios that would be modelled by the design phase model include:
  - The detailed design specification of all stations, tunnels, shafts, cross passages and portals
  - Cumulative drawdown during construction
  - A sensitivity/uncertainty analysis for drawdown predictions, in particular in relation to hydraulic conductivity, and transient mass balance
  - Stochastic modelling of CBD South station to include sensitivity testing and transient mass balance calibration. The possible range in hydraulic properties (hydraulic conductivity and specific storage) and boundary conditions should be assessed to identify the likely impacts and probability of occurrence
  - Effectiveness of the recommended mitigation measures, specifically grouting and temporary injection bores for western portal, CBD South station and Arden station
  - Scenarios where some stations that are currently modelled as Haack 2 are modelled as Haack 3
  - Numerical modelling of shafts, Parkville station and the eastern portal.

The additional modelling would be required during the detailed design phase so that various design alternatives are able to be assessed.

Table 18-1 Environmental Performance Requirements

Draft EES evaluation objective	Impact	Environmental Performance Requirements	Proposed mitigation measure	Precinct	Timing	Risk no.
Hydrology, water quality and waste management – To protect waterways and waterway function and surface water and groundwater quality in accordance with statutory objectives, to identify and prevent potential adverse environmental effects resulting from the disturbance of contaminated or acid-forming material and to manage excavation spoil and other waste in accordance with relevant best practice principles	Detailed design does not adopt design features that minimise groundwater drawdown.	Design the tunnel and underground structures so that they minimise groundwater drawdown during construction and operation to minimise impacts on groundwater dependent values, ground movement and contamination plume migration.	Adopt design features such as used in the Concept Design to minimise groundwater inflows. This should include: • TBM tunnel construction • Diaphragm wall station construction at Domain and Arden station • Secant pile wall construction at the western portal • Tanking to Haack criteria of 2 or 3.	All	Design	All
	Alterations to design features of tunnels, stations, shafts and portals proposed during detailed design result in different levels of impact than the design features specified in the Concept Design.	Develop a groundwater model for the detailed design phase to predict impacts associated with any changes to construction techniques or operational design features proposed during detailed design, and reconfirm that the Environmental Performance Requirements and mitigation measures are sufficient to mitigate impacts from changes in groundwater levels, flow and quality. Undertake monitoring during construction to ensure that predictions are accurate and mitigation measures are appropriate.	Groundwater model should: • Incorporate all new data • Predict impacts associated with detailed design and proposed construction timing • Assess cumulative impacts for construction and operation • Model uncertainty • Enable detailed design of mitigation measures (grouting approaches, injection borefield configuration and operation) to mitigate predicted impacts.	All	Design	All
	Details of groundwater management, disposal, mitigation measures and monitoring are not	Develop and implement a Groundwater Management Plan (GMP) detailing groundwater management approaches to address the predicted impacts to		All	Construction and operation	All

Draft EES evaluation objective	Impact	Environmental Performance Requirements	Proposed mitigation measure	Precinct	Timing	Risk no.
	appropriate or acceptable to the relevant authorities, delaying project start or resulting in unexpected groundwater impacts for which no contingency has been planned.	groundwater dependent values during construction. The GMP must be based on the detailed design phase groundwater model, and should include the following details: • Approach to collection, treatment and disposal of groundwater collected during construction in accordance with the MMRA Groundwater Disposal Strategy • Identifying and if necessary, specifying mitigation measures to protect groundwater dependent vegetation during periods of drawdown • An approach identified in consultation with the EPA so that contaminant migration causes no significant impacts on beneficial uses and vapour intrusion into underground structures, and establish appropriate monitoring networks to confirm effectiveness of approach • Methods for minimising drawdown in areas of known PASS and establishing appropriate monitoring networks to confirm effectiveness of approach • Methods for minimising drawdown at any existing recharge bores, and establishing appropriate monitoring networks to confirm effectiveness of mitigation • Groundwater drawdown trigger levels for groundwater dependant values at which additional mitigation measures				

Draft EES evaluation objective	Impact	Environmental Performance Requirements	Proposed mitigation measure	Precinct	Timing	Risk no.
		must be adopted • Design, operation and management of groundwater injection borefields • Contingency measures for if impacts occur at existing active groundwater bores and surface water bodies • Contingency measures should unexpected groundwater conditions be encountered. The Groundwater Management Plan must satisfy the EPA and relevant water authorities that groundwater dependent values would be protected. The groundwater management plan should also address MMRA's sustainability requirements where appropriate.				
	Moderate risk of impact on third party properties based on land use and expected presence of contaminants within predicted area of impact. Beneficial uses that need to be protected are specified in each precinct chapter of this report.	Develop and implement a Groundwater Management Plan (GMP) detailing groundwater management approaches to address the predicted impacts to groundwater dependent values during construction. The GMP must be based on the detailed design phase groundwater model, and should include the following details: • An approach identified in consultation with the EPA so that contaminant migration causes no significant impacts on beneficial uses and vapour intrusion into underground structures, and establish appropriate monitoring networks to confirm effectiveness of approach.	Likely to involve further investigation and/or mitigation measures, for example: • Site specific risk assessment of contaminant location and concentrations • Use of injection or discharge bores to prevent contaminant migration • Minimisation of drawdown through construction techniques such as construction using a TBM or grouting of the tunnels.	Precinct 1: Tunnels between CBD North and CBD South stations Precinct 1: Tunnels between Domain station and eastern portal (shaft construction) Precinct 2:	Construction	GW025 GW027 GW028 GW033

Draft EES evaluation objective	Impact	Environmental Performance Requirements	Proposed mitigation measure	Precinct	Timing	Risk no.
		Develop and implement a groundwater monitoring plan as part of the GMP that details sufficient monitoring of drawdown to verify that no significant impacts occur from potential: • Contaminant migration on the beneficial uses of groundwater at third party properties caused by drawdown.		Western Portal Precinct 3: Arden station Precinct 8: Eastern Portal		
	Moderate risk of impact on Beneficial Uses of groundwater within predicted area of impact. Beneficial uses that need to be protected are specified in each precinct chapter of this report.	Develop and implement a GMP detailing groundwater management approaches to address the predicted impacts to groundwater dependent values during construction. The GMP must be based on the detailed design phase groundwater model, and should include the following details: • Methods for minimising drawdown in areas of known PASS and establishing appropriate monitoring networks to confirm effectiveness of approach. Develop and implement a groundwater monitoring plan as part of the GMP that details sufficient monitoring of drawdown to verify that no significant impacts occur from potential: • Contaminant migration on the beneficial uses of groundwater at third party properties caused by drawdown.	Testing of rock cores to assess site specific risk of PASS. Prevent acidification of groundwater by minimizing drawdown in the area through: • Use of injection or discharge bores to prevent contaminant migration • Construction techniques such as construction using a TBM or grouting of the tunnels.	Precinct 1: Tunnels between CBD North and CBD South stations Precinct 3: Arden station	Construction	GW038 GW039
	Large trees that may access groundwater: Uncertain due to lack of knowledge of tree species and their water requirements for large	Develop and implement a Groundwater Management Plan (GMP) detailing groundwater management approaches to address the predicted impacts to groundwater dependent values during construction. The GMP must be based on	Deep-rooted tree species in areas of shallow groundwater should be identified and their dependence on groundwater should be assessed. If found to be groundwater dependent, the trees within the area of drawdown should be irrigated	Precinct 1: Tunnels between CBD South and Domain stations	Construction	GW017 GW019

Draft EES evaluation objective	Impact	Environmental Performance Requirements	Proposed mitigation measure	Precinct	Timing	Risk no.
	trees outside the project boundary, but possible since trees are within drawdown extent.	the detailed design phase groundwater model, and should include the following details: • Identifying and if necessary, specifying mitigation measures to protect groundwater dependent vegetation during periods of drawdown. Develop and implement a groundwater monitoring plan as part of the GMP that details sufficient monitoring of drawdown to verify that no significant impacts occur from potential: • Reduction in access to groundwater for trees.	throughout the period of drawdown.	(Linlithgow shaft alternative design option) Precinct 6: CBD South station		
	Some drawdown predicted at CityLink recharge bores.	Develop and implement a GMP detailing groundwater management approaches to address the predicted impacts to groundwater dependent values during construction. The GMP must be based on the detailed design phase groundwater model, and should include the following details: • Methods for minimising drawdown at any existing recharge bores, and establishing appropriate monitoring networks to confirm effectiveness of mitigation. Develop and implement a groundwater monitoring plan as part of the GMP that details sufficient monitoring of drawdown to verify that no significant impacts occur from potential: • Change in groundwater levels in any existing recharge bores that may be	Mitigation measures would include grouting, and temporary injection bores located in the Yarra River palaeovalley.	Precinct 1: Tunnels between CBD South and Domain stations (Linlithgow shaft alternative design option) Precinct 6: CBD South station	Construction	GW045 GW046

Draft EES evaluation objective	Impact	Environmental Performance Requirements	Proposed mitigation measure	Precinct	Timing	Risk no.
		present in the area around the project.				
	Low risk of impact on third party properties based on presence of GQRUZs within predicted area of impact. Beneficial uses that need to be protected are buildings and structures.	Develop and implement a Groundwater Management Plan (GMP) detailing groundwater management approaches to address the predicted impacts to groundwater dependent values during construction. The GMP must be based on the detailed design phase groundwater model, and should include the following details: • An approach identified in consultation with the EPA so that contaminant migration causes no significant impacts on beneficial uses and vapour intrusion into underground structures, and establish appropriate monitoring networks to confirm effectiveness of approach.	Likely to involve further investigation and/or mitigation measures, for example: • Site specific risk assessment of contaminant location and concentrations • Use of injection or discharge bores to prevent contaminant migration • Minimisation of drawdown through construction techniques such as grouting of the station cavern.	Precinct 4: Parkville station	Construction and operation	GW029
		Develop and implement a groundwater monitoring plan as part of the GMP that details sufficient monitoring of drawdown to verify that no significant impacts occur from potential: • Contaminant migration on the beneficial uses of groundwater at third party properties caused by drawdown and vapour intrusion to underground structures.				
	High risk of impact on third party properties based on presence of GQRUZs and anthropogenic	Develop and implement a Groundwater Management Plan (GMP) detailing groundwater management approaches to address the predicted impacts to groundwater dependent values during	Likely to involve further investigation and/or mitigation measures, for example: • Site specific risk assessment of	Precinct 5: CBD North station	Construction	GW030

Draft EES evaluation objective	Impact	Environmental Performance Requirements	Proposed mitigation measure	Precinct	Timing	Risk no.
	contamination within predicted area of impact. Beneficial uses that need to be protected are: • Irrigation • Stock watering • Industrial water use • Primary contact recreation • Buildings and structures. Moderate risk of vapour migration impacts to underground structures.	construction. The GMP must be based on the detailed design phase groundwater model, and should include the following details: • An approach identified in consultation with the EPA so that contaminant migration causes no significant impacts on beneficial uses and vapour intrusion into underground structures, and establish appropriate monitoring networks to confirm effectiveness of approach.	contaminant location and concentrations • Use of injection or discharge bores to prevent contaminant migration • Minimisation of drawdown through construction techniques such as grouting of the station cavern.			
		Develop and implement a groundwater monitoring plan as part of the GMP that details sufficient monitoring of drawdown to verify that no significant impacts occur from potential: • Contaminant migration on the beneficial uses of groundwater at third party properties caused by drawdown and vapour intrusion to underground structures.				
	Large trees that may access groundwater: Possible during dry periods due to shallow watertable and presence of deep-rooted tree (Eucalyptus Cladcalyx #13).	Develop and implement a Groundwater Management Plan (GMP) detailing groundwater management approaches to address the predicted impacts to groundwater dependent values during construction. The GMP must be based on the detailed design phase groundwater model, and should include the following details: • Identifying and if necessary, specifying mitigation measures to protect groundwater dependent vegetation during periods of drawdown.	Deep-rooted tree species in areas of shallow groundwater should be irrigated throughout the period of drawdown.	Precinct 8: Eastern Portal	Construction	GW021

Draft EES evaluation objective	Impact	Environmental Performance Requirements	Proposed mitigation measure	Precinct	Timing	Risk no.
		Develop and implement a groundwater monitoring plan as part of the GMP that details sufficient monitoring of drawdown to verify that no significant impacts occur from potential: • Reduction in access to groundwater for trees.				
	Potential for unexpected groundwater contamination to result in release of groundwater that is not treated to agreed levels.	Develop and implement a Groundwater Management Plan (GMP) detailing groundwater management approaches to address the predicted impacts to groundwater dependent values during construction. The GMP must be based on the detailed design phase groundwater model, and should include the following details: • Approach to collection, treatment and disposal of groundwater collected during construction in accordance with the MMRA Groundwater Disposal Strategy Use the Groundwater Disposal Strategy and Groundwater Management Plan to obtain a Trade Waste Agreement with the relevant Water Retailers for groundwater disposal.	Develop a groundwater disposal strategy that confirms disposal option, contingency measures and emergency response plan if unexpected groundwater contamination is encountered and requires disposal.	All	Construction and operation	GW055 GW056

19 Conclusion

This report documents the outcomes of an assessment of the impacts to groundwater from activities associated with construction and operation of the Melbourne Metro.

The focus for the assessment is the risk of groundwater drawdown around Melbourne Metro structures causing impacts on existing bore users, asset owners and other third parties, vegetation that may use groundwater, and surface water features such as rivers, creeks and lakes.

Groundwater drawdown also affects settlement and migration of existing contaminated groundwater. Settlement and contaminant migration are also assessed in Technical Appendix P *Ground Movement and Land Stability* and Technical Appendix Q *Contaminated Land and Spoil Management*, but this groundwater impact assessment identifies mitigation measures that are commonly used in construction, in addition to the Concept Design features that minimise groundwater inflows, that could be used to manage these impacts and achieve the Environmental Performance Requirements.

19.1 Relevant EES objectives

The following draft EES evaluation objectives and assessment criteria are relevant to this assessment.

Draft EES evaluation objectives	Assessment criteria
Hydrology, water quality and waste management: To protect waterways and waterway function and surface water and groundwater quality in accordance with statutory objectives, to identify and prevent potential adverse environmental effects resulting from the disturbance of contaminated or acid-forming material and to manage excavation spoil and other waste in accordance with relevant best practice principles.	Criteria: Manage extraction of groundwater to avoid consequential impacts on natural (e.g. streamflows and GDEs) and built environment (subsidence, recharge wells and other groundwater bores) resulting from groundwater drawdown. • Indicator: Stream flow – changes in streamflow as a result of the project are predicted to be within range of natural intra and inter-seasonal variability • Indicator: GDEs (vegetation) – if impacts cannot be easily managed (e.g. via watering), the magnitude and rate of change of groundwater drawdown predicted to be within range of natural intra and inter-seasonal variability • Indicator: Subsidence – settlement predicted to be within tolerance of relevant infrastructure (addressed in Technical Appendix P *Ground Movement and Land Stability*) • Indicator: CityLink recharge wells - no discernible change predicted in groundwater levels (near infrastructure of concern) compared to baseline / background levels • Indicator: Other bores - decline in groundwater levels is predicted to be less than 10 per cent of available drawdown (unless compensation can be easily implemented).
	Criteria: Manage extraction of groundwater to avoid consequential impacts on the natural environment resulting from groundwater disposal. • Indicator: Groundwater disposal must result in no detectable impact on river/creek water quality, i.e. within background and SEPP guidelines.
	Criteria: Manage extraction of groundwater to avoid consequential impacts of moving known groundwater contamination to third party receptors. • Indicator: No reduction in beneficial uses of groundwater at third party properties as a result of contaminant migration in

Draft EES evaluation objectives	Assessment criteria
	accordance with SEPP (GoV) • Indicator: No human contact at third party properties with contaminant levels over relevant guideline values.

The project is consistent with the draft EES evaluation objective as all potential impacts on groundwater dependent values and assets, associated with predicted groundwater drawdown around Melbourne Metro structures, would be mitigated to reduce the majority of risks to either low or very low.

19.2 Impact Assessment Summary

This assessment addresses the specified EES Scoping Requirements and specifically evaluates potential impacts to groundwater dependent assets from activities associated with construction and operation of the Melbourne Metro, based on the assessment criteria.

This report has identified and assessed:

- The predicted groundwater drawdown for project infrastructure, based on a combination of numerical and analytical modelling, as well as additional mitigation measures that would further reduce or manage groundwater drawdown (noting that the implications of groundwater drawdown for settlement are addressed in Technical Appendix P *Ground Movement and Land Stability*)
- The potential impacts associated with groundwater drawdown, which include:
  - Lowering the watertable and reducing access to groundwater for bore owners and dependent vegetation
  - Changing the water balance of surface water bodies such as rivers, creeks and lakes
  - Changing gradients and causing existing contaminant plumes to migrate and preclude the beneficial uses of groundwater
  - Changing groundwater gradients and causing existing volatile contaminant plumes to migrate and come into contact with underground structures where vapour intrusion may occur
- The potential for Melbourne Metro structures to block aquifer flow and cause a groundwater 'damming' effect that increases groundwater levels upstream, and decreases groundwater levels downstream of the structure
- The predicted groundwater inflow into project infrastructure during construction and operation, preferred disposal option and alternative disposal options including further regulator oversight.

The results of the impact assessment in reference to the draft EES objectives and indicators are summarised below, and the required mitigation measures are outlined.

Indicator: Streamflow – changes in streamflow as a result of the project are predicted to be within range of natural intra and inter-seasonal variability.

Most of the surface water bodies within the project boundary, such as the Yarra River, Moonee Ponds Creek and Maribyrnong River, are not considered to be groundwater dependent, and therefore the risk that drawdown alters the water balance of these features is low. The impact assessment indicates that drawdown would not affect these surface water bodies. Some potentially groundwater dependent water bodies were identified (the lake in the Royal Botanic Gardens and the southern part of Albert Park Lake), but these are outside the area of predicted drawdown and would therefore not be impacted.

Indicator: GDEs (vegetation) – if impacts cannot be easily managed (e.g. via watering), the magnitude and rate of change of groundwater drawdown predicted to be within range of natural intra and inter-seasonal variability.

There is a low risk that some large trees may have less access to groundwater as a result of Melbourne Metro. Other than potentially one tree in the Eastern Portal precinct, trees within the project boundary are not considered to be groundwater dependent (Technical Appendices R and S *Arboriculture*). Trees outside the project boundary have not been assessed but deep-rooted trees in areas of shallow groundwater, such as around the Yarra River, the lake in the Royal Botanic Gardens and Albert Park Lake, are considered potentially groundwater dependent. Deep-rooted tree species should be identified and their dependence on groundwater should be assessed. If found to be groundwater dependent, the trees within the area of drawdown should be irrigated throughout the period of drawdown to mitigate potential impacts on tree health. An Environmental Performance Requirement has been recommended to require this investigation and action.

Indicator: Subsidence – settlement predicted to be within tolerance of relevant infrastructure (addressed in Technical Appendix P Ground Movement and Land Stability).

Predicted groundwater drawdown during construction of the western portal, Arden station and CBD South station, suggests there is a risk of ground settlement in these areas through depressurisation of Coode Island Silts. The relationship between groundwater drawdown and land settlement is discussed in Technical Appendix P *Ground Movement and Land Stability*. Temporary injection borefields have been planned to mitigate drawdown in these areas and manage the risk of settlement. These borefields would be designed so that groundwater levels can be quickly increased if drawdown occurred, in order to not exceed allowable settlement levels at each location. Environmental Performance Requirements have been recommended to require modelling based upon the detailed design, development of a Groundwater Management Plan and monitoring during construction.

Indicator: CityLink recharge wells - no discernible change predicted in groundwater levels (near infrastructure of concern) compared to baseline / background levels.

The unmitigated impact assessment (based on the Concept Design) predicted potential drawdown at CityLink recharge wells as a result of construction of CBD South station and the Linlithgow emergency access shaft. Drawdown at the recharge bores was predicted to be less than 1 m. Drawdown may affect the injection rates that need to be achieved by the CityLink injection bores in order to maintain groundwater pressure in the overlying Coode Island Silt. Environmental Performmace Requirements and mitigation measures have been identified to ensure that the detailed design would achieve acceptable drawdown at CityLink recharge bores. These mitigation measures include a temporary injection borefield in the Yarra palaeovalley and grouting of CBD South station cavern and Linlithgow emergency access shaft during construction.

Indicator: Other bores - decline in groundwater levels is predicted to be less than 10 per cent of available drawdown (unless compensation can be easily implemented).

There are no existing groundwater bores within the predicted area of drawdown. The risk to existing groundwater users is therefore very low to low.

Indicator: No reduction in beneficial uses of groundwater at third party properties as a result of contaminant migration in accordance with SEPP (GoV); and, no human contact at third party properties with contaminant levels over relevant guideline values.

Where drawdown is predicted at an area of known contamination, an initial medium or high risk has been assigned because there is the potential for migration of this contamination to neighbouring properties, where it may reduce the potential uses of groundwater at those properties. For the majority of locations, mitigation measures can reduce these risks to low, with the exception of plume migration near CBD North station, which has a residual risk of medium. The Environmental Performance Requirement require further analysis to provide more information on impacts and receptors from possible migration of this contaminant plume and to inform mitigation measures in more detail through the Groundwater Management Plan. These mitigation measures would aim to prevent the contamination from further migrating outside the boundary of the contaminated property, and would also therefore prevent human contact with these contaminants. Where there is considered to be a risk of contaminant migration due to past land uses but there is no information on the extent or types of contamination, a medium risk of migration has been assigned to reflect uncertainty. The use of mitigation measures would also reduce these risks to low. Monitoring during construction would be required as set out in the recommended Environmental Performance Requirements to confirm that drawdown remains within predicted limits and that the mitigation measures are effective.

Indicator: Groundwater disposal must result in no detectable impact on river/creek water quality, i.e. within background and SEPP guidelines.

Disposal to sewer is the option being considered for the groundwater extracted during construction and operation of Melbourne Metro. Peak volumes requiring disposal are estimated to be 6 – 7 L/sec at the height of construction from all Project infrastructure, and associated salt loads have been estimated. Given the short term nature and low estimated volumes of the groundwater discharge, it would be expected that agreement with regulators can be reached regarding the salt load. This option would not require any groundwater to be disposed to rivers or creeks and would therefore satisfy the EES indicator.

In the unlikely event that disposal of groundwater to sewer during construction is not possible or practical then discharge to stormwater may be an option that could be pursued with the relevant regulatory approvals. If a stormwater disposal option was pursued, pre-disposal treatment would be required to achieve background water quality conditions and comply with the SEPP. In addition, a contingency sewer discharge would be required to deal with areas of groundwater contamination that cannot be isolated from the main groundwater discharge stream, and cannot be treated with the proposed pre-treatment system. A risk assessment to further examine potential risks to receiving waters would also be required to determine an appropriate mixing zone and to assess the level of treatment prior to discharge to ensure that the mixing zone is of an appropriate/acceptable size. This would require further environmental assessment and the necessary approvals obtained from regulatory authorities.

This report has also recommended Environmental Performance Requirements to minimise impacts and on this basis the majority of residual risks to groundwater identified for the Melbourne Metro are considered 'very low' or 'low'. These must be complied with during construction and operation of Melbourne Metro. A series of mitigation measures have been identified which would achieve the Environmental Performance Requirements. These measures are expected to include grouting of the tunnels and caverns at CBD North and CBD South stations and at the Linlithgow Avenue emergency access shaft, and temporary injection bores to maintain groundwater levels at CBD South station, Arden station and the western portal. These bores would allow injection of water in order to maintain the groundwater levels, acting as a mechanism that can quickly remedy falling groundwater levels, if they occur. In combination, these measures would reduce inflows and/or drawdown so that impacts from construction are minimal. Effective grouting together with injection bores are reliable and proven measures for preventing impacts to groundwater dependent values. The drawdown and mitigation measures required for construction are temporary, as after construction structures would be tanked, which largely prevents inflows. Therefore, groundwater levels would recover after construction. During operation, long term drawdown would be less than 1 m around each structure. The risk of aquifer damming as a result of Melbourne Metro structures creating a barrier to groundwater flow has been assessed and deemed to be low. Groundwater quality can deteriorate where groundwater drawdown exposes PASS rock or sediments, however with implementation of the mitigation measures to reduce drawdown, the risk of groundwater acidification due to PASS activiation is low.

Further works would be required during the detailed design phase and construction to inform the predictive modelling to confirm the predicted drawdown levels, effectiveness of proposed mitigation measures and the associated impacts on groundwater dependent assets. These works include additional modelling of drawdown based on the detailed design, preparation and implementation of a Groundwater Management Plan and groundwater disposal strategy, and groundwater monitoring during construction to provide further assurance that drawdown behaves as expected and that mitigation measures are effective.

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Appendices

Appendix A Description of relevant legislation

Legislation, policy, standards and guideline requirements considered in the assessment of groundwater contamination and hydrogeological assessment are listed below.

A.1 Legislation and Policy

A.1.1 Commonwealth

Commonwealth legislation relevant to the assessment of groundwater contamination includes the following:

1) Commonwealth *National Environment Protection Council Act 1994* (Commonwealth, 1994) (the NEPC Act) - The National Environment Protection Council (NEPC) is established under the NEPC Act, and complementary State and Territory legislation. The NEPC has two primary functions: to make National Environment Protection Measures (NEPMs); and to assess and report on the implementation and effectiveness of NEPMs in participating jurisdictions. NEPMs are a special set of national objectives designed to assist in protecting or managing particular aspects of the environment

2) National Environment Protection Council (1999) National Environment Protection (Assessment of Site Contamination) Measure, Amendment Measure 2013 (No. 1) (the NEPM) – The goal of the NEPM is to establish a nationally consistent approach to the assessment of site contamination to ensure sound environmental management practices by the community including all stakeholders, to provide adequate protection of human health and the environment, where site contamination has occurred. The NEPM, including the associated Health Investigation Levels and NEPM Ecological Investigation Levels and approaches to assessment of land contamination is given effect in Victoria by the State Environmental Protection Policy (Prevention and Management of Contamination of Land).

A.1.2 Victorian

A.1.2.1 Overview

The *Water Act 1989* and the *Environment Protection Act 1970* provide the primary framework for the management of groundwater in Victoria. Subordinate legislation under the Environment Protection Act includes the various State Environmental Protection Policies, which designate specific quality objectives and requirements for protection of the land, surface water, groundwater and air environments (and noise) respectively. Waste management requirements are specified by EPA Victoria in guidance forming part of the industrial waste resources guidelines.

Victorian requirements, standards and guidelines relevant to the assessment of groundwater contamination, hydrogeological assessment and ground movement include the following, and are discussed in the sections below:

1) *Water Act 1989*

2) *Planning and Environment Act 1987*

3) *Environment Protection Act 1970*

4) State Environment Protection Policies (SEPP's) relevant to groundwater contamination including:

   - State Environment Protection Policy (Groundwaters of Victoria) (1997) (SEPP (GoV)) (State Govt. of Vic. (1997))
   - State Environment Protection Policy (Waters of Victoria) (2003) (SEPP (WoV)), including relevant Schedules which for the MM location would include:
     - Variation of the State Environmental Protection Policy (Waters of Victoria) – Insertion of Schedule F7: Waters of the Yarra Catchment (1999) as varied by the SEPP (WoV) (State Govt. of Vic. (1999).

A.1.3 Water Act 1989

The *Water Act 1989* provides the framework for allocating surface water and groundwater throughout Victoria. It details the Crown's entitlements to water and private entitlements to water from all rivers, streams and groundwater systems in Victoria, and establishes the mechanisms for managing Victoria's water resources. It also establishes the rights of the applicable Water Corporation (Melbourne Water) to control activities to protect the Yarra River in accordance with the State Environment Protection Policy (Waters of Victoria). Sections 67 and 72 of the *Water Act 1989* detail the requirement that apply to the Victorian Government for the issue of a license to construct or renew a groundwater bore; the licensing system is administered by the rural water authorities (Southern Rural Water in southern Victoria).

A.1.4 Planning and Environment Act 1987

The *Planning and Environment Act 1987* does not contain specific requirements associated with groundwater management and its contribution to ground movement and subsidence but Section 60 of the *Planning and Environment Act 1987*, implies a general responsibility of planning authorities to consider the following:

1) any significant effects which the responsible authority considers the use or development may have on the environment
2) any significant effects which the responsible authority considers the environment may have on the use or development
3) any significant social and economic effects of the use or development for which a planning application is made.

A.1.5 Environment Protection Act 1970

The EP Act provides a legal framework to protect the environment in the State of Victoria, including in relation to noise emissions and the air, surface water, groundwater and land. The EP Act establishes the powers, duties and functions of the Environmental Protection Authority (EPA), which include the administration of the Act and any regulations and orders made pursuant to it, recommending State Environment Protection Policies (SEPPs) and Industrial Waste Management Policies to the Governor in Council, issuing works approvals, licences, permits, pollution abatement notices and implementing National Environment Protection Measures (NEPMs).

The Act embodies the basic philosophy of preventing pollution and environmental damage by setting environmental quality objectives and establishing programs to meet them. Key aims of the Act include sustainable use and holistic management of the environment, ensuring consultative processes are adopted so that community input is a key driver of environment protection goals and programs and encouraging a co-operative approach to environment protection.

The EP Act provides for SEPPs to be declared as subordinate legislation, to establish policies and controls to reduce and manage environmental pollution. The SEPPs establish the 'beneficial uses' and values that are to be protected in different segments of the environment, and provide a framework under which beneficial uses are identified and protected.

'Beneficial use' is described in the EP Act as a *use of the environment or any element or segment of the environment which is conducive to public benefit, welfare, safety, health or aesthetic enjoyment and which requires protection from the effects of waste discharges, emissions or deposits or of the emission of noise.*

A.1.5.1 State Environment Protection Policies (SEPPs)

A.1.5.1.1 Groundwater

The State Environment Protection Policy Groundwaters of Victoria (SEPP (GoV)) categorises the groundwater environment into segments based on background groundwater salinity. Beneficial uses of groundwater required to be protected, and quality objectives protective of each beneficial use are designated for each groundwater segment. Protected beneficial uses include Maintenance of Ecosystems; Potable Water Supply; Potable Mineral Water Supply; Agriculture, Parks and Gardens; Stock Watering; Industrial Use; Primary Contact Recreation; and Buildings and Structures.

The SEPP (GoV) designates objectives for protection of groundwater beneficial uses, and references other policies / frameworks to support interpretation of selected beneficial uses, including:

1) SEPP (Waters of Victoria (WoV)) – used to identify objectives for protection of the groundwater beneficial use, maintenance of ecosystems

2) Australian Standard 2159-2009 'Piling-Design and Installation' (AS2159) – used to identify objectives for protection of the groundwater beneficial use, Buildings and Structures. AS2159-2009 includes exposure conditions for sulfates (expressed as SO3), chlorides, and pH to provide a suitable basis for consideration of soil and groundwater conditions with respect to protection of buildings and structures

3) Australian Food Standards Code (1987) – Standard 08 Mineral Water – used to identify objectives for protection of the groundwater beneficial use, potable mineral water supply

4) ANZECC Water Quality Guidelines for Fresh and Marine Waters (1992) – used to identify objectives for the protection of the other groundwater beneficial uses. Guidance documents that post-date the ANZECC 1992 guidance are also recognised as being based on more recent research in respect to toxicity of chemicals and receptor exposure parameters, including the:

   - Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC/ARMCANZ (2000)
   - Australian Drinking Water Guidelines (NHMRC/NRMMC (2011)), National Water Quality Management Strategy
   - Guidelines for Managing Risks in Recreational Water (NHMRC 2008).

A.1.5.1.2 Surface Waters

SEPP (WoV)) (State Govt. of Vic. (2003)) (inclusive of all associated schedules and variations) sets a framework for the protection of the beneficial uses and environmental values of Victoria's fresh and marine water environments. The SEPP (WoV) designates water quality indicators and objectives for protection of those beneficial uses and values for various Segments of the surface water environment. The SEPP (WoV) identifies a separate schedule that applies to the Yarra Catchment; Schedule F7 – Waters of the Yarra Catchment (State Govt. of Vic. (1999)).

A.1.6 Groundwater Management

The project is located in the East Port Phillip Bay Groundwater Catchment.

The project does not extend into any Groundwater Management Areas (GMA). The nearest GMAs are the Moorabbin GMA, which is 2 km to the south of the southern leg of the alignment, and the Cut Paw Paw GMA, which is 1.5 km south-west of the western most point of the alignment (to the west of the Maribyrnong River).

Groundwater in the area is managed by Southern Rural Water. Licences must be obtained from Southern Rural Water prior to dewatering or recharging through bores commencing. Further consultation with Southern Rural Water would be required to assess whether a licence is required as currently there are no plans to actively (i.e. using dewatering bores) dewater the project. Dewatering is only expected to occur within excavations (e.g. sumps) and minor inflows to tunnels. Only minimal inflows to tunnels are expected to occur due to tunnels construction techniques, principally, the TBM method to be adopted for the majority of Melbourne Metro Tunnels. Licences are also required for recharge bores, which may be used for the project.

Licence applications are set on a volumetric basis, with higher volumes requiring more rigorous assessment. The licences are divided into Tiers, with Tier 1 requiring minimal hydrogeological assessment and Tier 3 requiring more detailed hydrogeological assessment. In addition, some uses are automatically required to provide more detailed assessments. Tier 2 uses include road construction and dewatering of construction work sites and Tier 3 uses include quarrying and dewatering of sites.

Initial consultation with Southern Rural Water indicates that they see the Melbourne Metro as a Tier 3 application. Tier 3 applications must have a hydrogeological assessment which includes:

1) Description of the conceptual hydrogeology of the site including:
   - Potentiometric mapping
   - Identification of private bore users, surface water features and GDEs within 5 km
   - Summary of nearby State Observation Bore Network bores
   - Recharge and discharge mechanisms.
2) Site testing including:
   - A step test with at least three steps
   - A constant rates test of seven days' minimum duration
   - A recovery test of at least seven days' duration
   - All tests with at least one observation well in same aquifer and other aquifers if practical
   - Monitoring of surface waters if appropriate.
3) Details of proposed scheme
4) Prediction of drawdown impacts
5) Groundwater quality risk assessment.

A.2 Standards and Guidelines

A.2.1 National Standards and Guidelines

National Standards and Guidelines relevant to the hydrogeological assessment include:

1) Minimum Construction Requirements for Water Bores in Australia (NUDLC, 2012)
2) Australian groundwater modelling guidelines - Waterlines Report Series No. 82, June 2012 (Sinclair Knight Merz (SKM) and National Centre for Groundwater Research and Training)
3) Australian Standard AS2368 - 1990 Test pumping of water wells.

A.2.2 Victorian Guidelines

Victorian guidelines relevant to environmental sampling and hydrogeological assessment include:

1) Groundwater Sampling Guidelines, EPA Victoria Publication 669 (2000)

2) Sampling and Analysis of Waters, Wastewaters, Soils and Wastes Publication, EPA Victoria Publication IWRG701 (June 2009)

3) Hydrogeological assessment (groundwater quality) guidelines, EPA Victoria Publication 668 (September 2006).

EPA Victoria has also published guidance on EPA's implementation of groundwater contamination management by declaration of Groundwater Quality Restricted Use Zones (GQRUZs):

1) Groundwater Attenuation Zones, EPA Victoria Publication 841 (2002a)

2) Groundwater Quality Restricted Use Zone, EPA Victoria Publication 862 (2002b).

A.2.3 Other Guidance Specific to Hydrogeological Assessments

Other guidance specific to hydrogeological assessment is presented in the sections below.

A.2.3.1 Bore Construction

The National Uniform Drillers Licensing Committee publication Minimum Construction Requirements for Water Bores in Australia (NUDLC, 2012) is the third edition, and updates the document of the same name (Edition 2) published by Land and Water Biodiversity Committee in 2003.

The document outlines the minimum requirements for constructing, repairing, and decommissioning water bores in Australia, with the aims (amongst other) to protect groundwater resources from contamination, deterioration and uncontrolled flow associated with poorly constructed bores.

The third edition separates the requirements into mandatory requirements, and recommendations for good industry practice. Mandatory requirements are enforceable by regulators for the protection of the groundwater resource. Good Industry Practices are methods and techniques recommended to:

1) help satisfy mandatory requirements

2) provide efficient and cost-effective water bores

3) ensure the long-term efficiency and operation of the water bore.

A.2.3.2 Groundwater Modelling Guidelines

1) Australian groundwater modelling guidelines - Waterlines Report Series No. 82, June 2012 (Sinclair Knight Merz and National Centre for Groundwater Research and Training).

An overview of the guidelines is presented below, as provided in the guidelines document.

The Australian groundwater modelling guidelines are intended as a reference document for groundwater modellers, project proponents (and model reviewers), regulators, community stakeholders and model software developers who may be involved in the process of developing a model and/or modelling studies. The objective of the guidelines is to promote a consistent and sound approach to the development of groundwater flow and solute transport models in Australia that is underpinned by a progression through a series of interdependent stages with frequent feedback loops to earlier stages: planning; conceptualisation; model design and construction; model calibration; predictive scenarios; and model reporting.

The guidelines suggest that the model review process should be undertaken in a staged approach, with separate reviews taking place after each reporting milestone (i.e. after conceptualisation and design, after calibration and sensitivity and at completion). Three levels of review are suggested: a model appraisal by a non-technical audience to evaluate model results; a peer review by experienced hydrogeologists and modellers for an in-depth review of the model and results; and a post-audit, a critical re-examination of the model when new data is available or the model objectives change.

The guidelines include a detailed description of solute transport modelling where the solute of interest is non-reactive, and for problems relating only to groundwater flow and storage.

A.2.3.3 Groundwater Dependent Ecosystems

Groundwater dependent ecosystems (GDEs) are communities of plants, animals and other organisms whose extent and life processes are dependent on groundwater, such as wetlands, ecosystems in streams fed by groundwater; forests and terrestrial vegetation and springs.

Mapping conducted for the Atlas of GDEs in Victoria (http://www.bom.gov.au/water/groundwater/gde/map.shtml) suggests potential GDEs associated with the Yarra River floodplain and aquatic and riparian ecosystems associated with Moonee Ponds Creek.

Maintenance of groundwater quality and levels within natural background levels would be sufficient to maintain potential GDEs within the project study area.

A.2.3.4 Acid Sulfate Soils

Acid sulfate soil (ASS) is the term commonly given to soil and sediment that contains iron sulfides (commonly iron pyrite), or the products of sulfide oxidation. Potential acid sulfate soils (PASS) contain iron sulfides which are stable in an un-oxidised state (such as below the watertable). If left undisturbed and covered with water, sulfidic materials pose little threat of acidification. However, when sulfidic material is exposed to the air, the sulfides react with oxygen to form sulfuric acid and without adequate buffering capacity, the soils may become sulfuric, i.e., the soils attain a pH less than 4. These oxidising soils are commonly referred to as actual acid sulfate soils (AASS). When these sulfuric materials are subsequently covered with water (or leaching occurs through rainfall recharge), significant amounts of acidity can be released into the water.

Hazards associated with acid sulfate soil include:

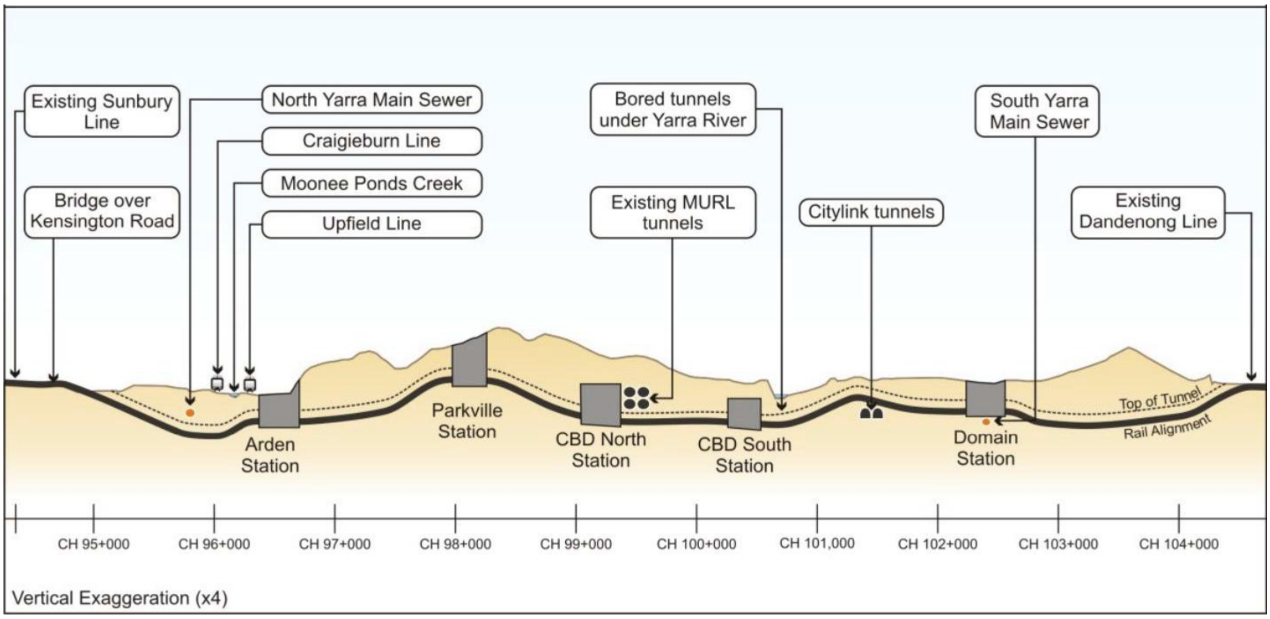
1) discharge of acidified groundwater to receiving surface water bodies
2) mobilisation from soils of metals, metalloids and non-metals, including iron and aluminium to receiving surface water bodies
3) decrease in oxygen in the water column when mono-sulfidic materials are mobilised into the water column
4) production of noxious or malodorous gases.

EPA Publication 655.1 'Acid Sulfate Soil and Rock' (EPA 655) is the primary Victorian guideline relevant to the assessment and management of acid sulfate soil. The Victorian Best Practice Guidelines for Assessing and Managing Coastal Acid Sulfate Soils (DSE, 2010) is another key guideline.

Appendix B Peer Review Report

Melbourne Metro Rail Project Independent Review of Groundwater Impact Assessment

Prepared for:	Melbourne Metro Rail Authority (through Herbert Smith Freehills)	21 April 2016



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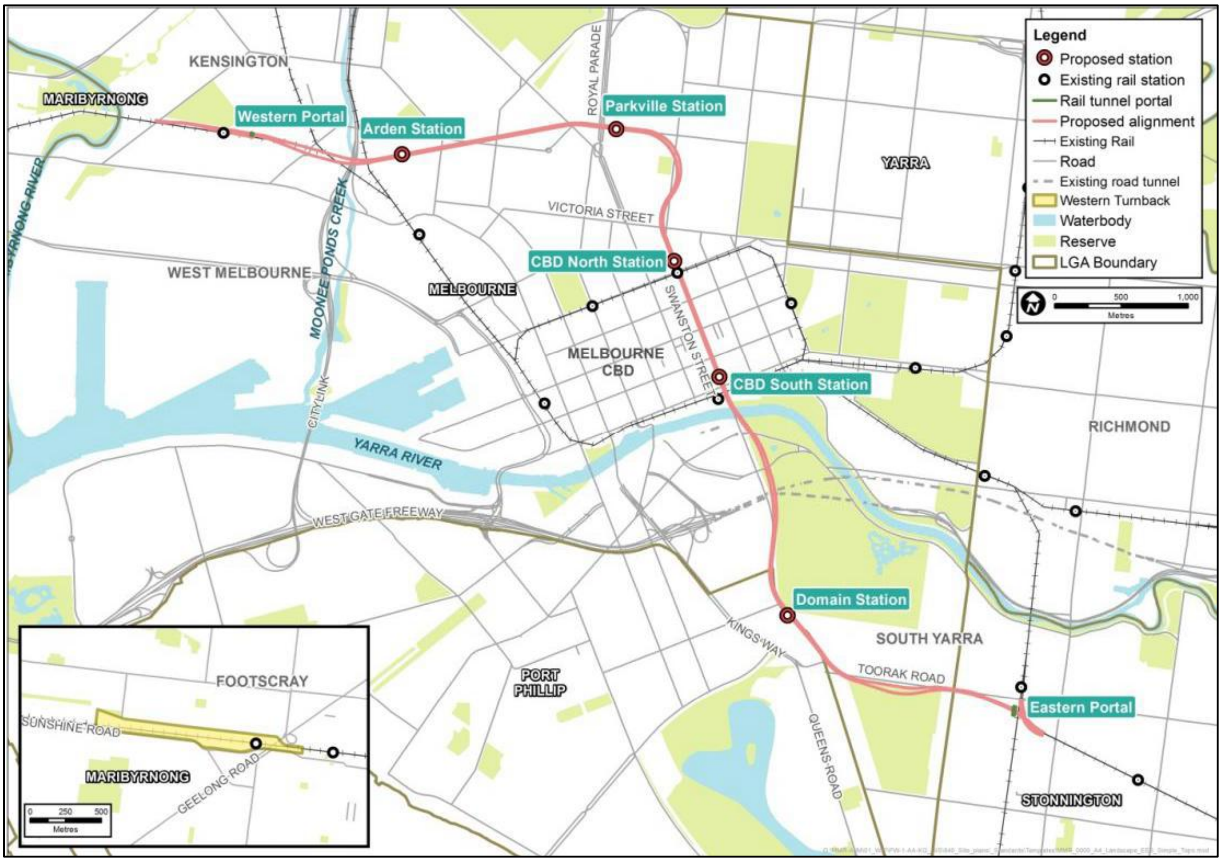
THIS REPORT SHOULD BE CITED/ATTRIBUTED AS:

Middlemis, H. (2016). Melbourne Metro Rail Project Independent Review of Groundwater Impact Assessment. Prepared by Hydrogeologic for Melbourne Metro Rail Authority (through Herbert Smith Freehills). 21 April 2016.

1. Introduction

The Melbourne Metro Rail Project (MMRP or Melbourne Metro) involves the construction of twin nine-kilometre rail tunnels from Kensington in the west to South Yarra in the south east, and five new railway stations (Figure 1).

Figure 1 - Melbourne Metro Rail Project tunnel alignment and stations (AJM 2016)



This report presents the findings of an independent review of the Groundwater Impact Assessment (GIA) component of the Environmental Effects Statement (EES) for the Melbourne Metro. The GIA is also referred to as the EES Technical Appendix O.

The review was undertaken at the request of Herbert Smith Freehills (HSF), acting as legal counsel to the Melbourne Metro Rail Authority (MMRA).

The independent review was undertaken in several short campaigns over the period from December 2015 to April 2016 and involved consideration of various draft reports on the Groundwater Impact Assessment studies undertaken by the Aurecon Jacobs Mott McDonald (AJM) Joint Venture, and the specialist modelling consultant Golder Associates. The reviewer also held two brief and informal telephone and email discussions with Dr Rick Evans (Principal Hydrogeologist, Jacobs) on technical matters identified during the independent review process.

2. Evidentiary Basis, Review Scope and Criteria

This independent review considered the assumptions, methodology and assessment of hydrogeological drawdown impacts relating to the Melbourne Metro, as outlined in the GIA. The EES Scoping Requirements (Government of Victoria, 2015) and the Project Description for EES Specialists (MMRP, 2015) set the context for this review, and the main evidentiary basis comprises the Groundwater Impact Assessment (the *EES Technical Appendix O*; AJM, 2016):

> *Aurecon Jacobs Mott McDonald Joint Venture (2016). Melbourne Metro Rail Project Groundwater Impact Assessment. Prepared for Melbourne Metro Rail Authority. Dated 20 April 2016. Revision D1. AJM References MMR-AJM-PWAA-RP-NN-00826 and CMS332569.*

Related Golder Associates reports on numerical modelling studies were considered during the independent review process (Appendices G and H of the EES Technical Appendix O - see references for details).

This independent review did not consider two related EES Technical Appendices that provide detailed discussion on two key risk areas:

- groundwater contamination risks are addressed in Technical Appendix Q *Contaminated Land and Spoil Management*, including the risk of contaminated groundwater ingress to the proposed tunnels and stations
- land settlement due to groundwater drawdown is discussed in Technical Appendix P *Ground Movement and Land Stability*.

This independent review was completed as a detailed "fatal flaws" analysis of the assumptions, scope, methodology and assessment criteria applied in the Groundwater Impact Assessment report (AJM, 2016). While this review does not consider or address all risks, and it was not possible to evaluate in detail the entire range of hydrogeological data and modelling, this independent review provides comments on:

- whether the EES Scoping Requirements have been adequately addressed, and
- whether any further issues should be included in the scope of the Detailed Design investigations being undertaken by the technical advisers to the MMRA and/or its selected contractors.

The Australian Groundwater Modelling Guidelines issued by the National Water Commission (Barnett et al., 2012), were used as the main criteria to review the impact assessment analytical/modelling methods, and the underpinning hydrogeological investigations and data. Other criteria included the Murray Darling Basin Commission Groundwater Flow Modelling Guideline (Middlemis et al, 2001), which was the foundation for the 2012 guideline. The Groundwater Impact Assessment lists the Victorian EPA (2006) Hydrogeological Assessment (Groundwater Quality) Guidelines, Bulletin No. 668, as a key policy document (AJM, 2016, Table 3-1). Bulletin 668 (EPA, 2006) itself lists the 2001 MDBC modelling guideline as a key reference, and there is substantive consistency between all these documents, including the notable focus on hydrogeological conceptualisation.

This independent review was conducted by Hugh Middlemis, an independent hydrogeology and modelling specialist with more than 25 years' experience in this field, including developing models for several projects across Victoria. Hugh is principal author of the MDBA groundwater modelling guideline (Middlemis et al, 2001) and was awarded a Churchill Fellowship in 2004 to benchmark groundwater modelling against international best practice. Hugh has been appointed to independent review roles by many Australian government agencies, and has made expert witness submissions to the Victorian Civil and Administrative Tribunal and Planning Panels Victoria. Hugh has not undertaken any work on the Melbourne Metro, and there is no conflict of interest in relation to this review task.

3. Independent Review Synopsis

The purpose of the Groundwater Impact Assessment is to identify the risks and assess the potential hydrogeological impacts of the Melbourne Metro. The GIA report confirmed the focus of their hydrogeological investigations in these valid terms: "*The primary way that construction and operation of Melbourne Metro may change groundwater levels and flow is when groundwater inflow to the structures causes lower groundwater levels in the surrounding aquifer*."

This independent review endorses the Groundwater Impact Assessment methodology at this Concept Design stage and concurs with the findings that most potential impacts are ‘low’ or ‘very low’ (in terms of initial risk), mainly because “*the Concept Design features and assumed construction techniques incorporate features that prevent large groundwater inflows, and therefore minimise groundwater drawdown and associated impacts on groundwater dependent values*.”

In particular, the tanking of all structures that are below the water table is designed to achieve a high level of water tightness and thus very small inflows and related drawdowns during operation (post-construction), while there is also a low potential for regional groundwater flow barrier impacts (“aquifer damming”).

The Groundwater Impact Assessment report (AJM, 2016) correctly identified notable risk factors during construction phase, however, including (but not limited to):

- drawdown impacts on the compressible Coode Island Silt (CIS) which may cause settlement; notable areas where there is a risk of impact on high value built and natural environment assets include the Yarra Valley crossing and nearby South Melbourne, and also the Moonee Creek area between the Arden station and Western Portal areas
- potential movement of groundwater contaminant plumes near the CBD North station that may affect beneficial uses of groundwater by third parties, and/or potential for vapour intrusion to existing underground structures.

Where the Groundwater Impact Assessment identified higher risks such as those above, suitable Environmental Performance Requirements (EPRs) and mitigation measures (e.g. grouting and temporary injection bores to control drawdown) have been identified in the GIA report to reduce the initial risk to a lower residual risk ranking. This is entirely consistent with the EES Scoping Requirements.

Achieving low impact risk during all phases of the project will obviously require further investigation and assessment during the Detailed Design stage of the project, along with consultation with the EPA and other agencies, and development and implementation of a groundwater management plan (a key element of the EPRs). The Groundwater Impact Assessment report is commendable in making this very clear.

In summary, it is my professional opinion that:

- the hydrogeological investigations and groundwater modelling methodologies applied in the Groundwater Impact Assessment are largely consistent with best practice in the context of the Melbourne Metro Concept Design stage
- a Class 1 groundwater model confidence level classification (Barnett et al, 2012) has been achieved (with elements of Class 2), meaning that the numerical and analytical modelling methodology is suitable for Concept Design impact prediction purposes.

This independent review finds that the Melbourne Metro Groundwater Impact Assessment report (AJM, 2016) adequately addresses the EES Scoping Requirements at this Concept Design stage. The recommendations made for further field investigations and modelling studies to be undertaken at the Detailed Design stage are warranted and appropriate, as are the Environmental Performance Requirements and Groundwater Management Plan recommendations.

4. Groundwater Modelling Methodology Compliance

Table 1 presents a summary of these review findings in terms of the modelling guidelines compliance checklist criteria (Barnett et al, 2012). The focus of these best practice criteria on hydrogeological conceptualisation is notably consistent with requirements of the Victorian EPA (2006) Hydrogeological Assessment (Groundwater Quality) Guidelines, Bulletin No 668, a key policy document in the GIA report (AJM 2016, Table 3-1).

Table 1 - Groundwater Model Compliance Checklist: 10-point essential summary

Question	Yes/No	Melbourne Metro models Concept Design stage
1. Are the model objectives and model confidence level classification clearly stated?	Yes	3D regional model to evaluate groundwater impacts and risks during construction and operation. Class 1 model achieved (elements of Class 2). Model methods suitable for Concept Design impact prediction purposes. EPRs are appropriate.
2. Are the objectives satisfied?	Yes	Adequate for Concept Design stage and for most operational (long term) impacts. Where certain knowledge gaps remain (transient model calibration, prediction of cumulative impacts during construction, uncertainty assessment), these are scoped to be addressed during the Detailed Design stage.
3. Is the conceptual model consistent with objectives and confidence level classification?	Yes	The model concepts/methodology are consistent with best practice, including use of analytical and numerical methods. This review finds that a Class 1 model confidence level is achieved at this stage, with elements of Class 2, and this should be improved to Class 2 overall at the Detailed Design stage by addressing the identified/acknowledged gaps.
4. Is the conceptual model based on all available data, presented clearly and reviewed by an appropriate reviewer?	Yes	A multi-disciplinary team has clearly been involved in the extensive investigations undertaken over many years to develop the conceptual model, including inputs from infrastructure project experience nearby. EPRs appropriate.
5. Does the model design conform to best practice?	Yes	No fatal flaws relating to the model design have been identified during this review. Further refinements will no doubt be made during the Detailed Design stage.
6. Is the model calibration satisfactory?	Yes	The numerical model design, software, extent, boundaries, cell size, parameters and steady state calibration are largely consistent with best practice. EPRs are appropriate
7. Are the calibrated parameter values and estimated fluxes plausible?	Yes	Report could be improved with technical justification on specific storage and compressibility factors, but otherwise acceptable. Fluxes and drawdowns are plausible and analytical model results are consistent with numerical model.
8. Do the model predictions conform to best practice?	Yes (for Concept Design stage)	• Yes, for Concept Design operations phase numerical model, and also analytical model results. • No (strictly) due to steady state calibration but transient predictions, no cumulative construction impacts and no uncertainty evaluation; but adequate for Concept Design. • The model refinements during Detailed Design should address transient calibration, cumulative impacts and uncertainty analysis, to confirm the model is a sound tool for predictions, as specified in the appropriate EPRs.
9. Is the uncertainty associated with the predictions reported?	Yes/No	There are statements in the report that the analytical model drawdown predictions are "*assumed to be accurate to the nearest 1m*". Similarly, the numerical model is stated to be "*adequate for a preliminary assessment of the potential groundwater impacts*". However, best practice numerical model uncertainty analysis is an acknowledged gap at this Concept Design stage, and recommended further work during the Detailed Design stage is warranted. EPRs are appropriate.
10. Is the model fit for purpose?	Yes (for Concept Design stage)	Numerical model steady state calibration and subsequent transient predictions, combined with analytical model assessments in some areas, is a methodology that is fit for impact assessments at this Concept Design stage. Further work is warranted during the Detailed Design stage (e.g. transient calibration, cumulative impacts and comprehensive uncertainty assessments). EPRs are appropriate.

5. Discussion of Identified Review Issues

Given the review aim to identify weaknesses to help guide future Detailed Design tasks, this review process tends to focus on negative aspects. However, it is acknowledged that almost all elements of the impact assessment process have been very well executed in this case.

5.1 GIA Report Documentation Issues

The Groundwater Impact Assessment report (EES Technical Appendix O) is a substantial document (500+ pages). It is well structured, generally well written and the graphics are of good quality. It is largely sufficient as a standalone document, although it does rely upon extensive prior studies.

Certain issues with the documentation have been identified during this review, which could be criticised, although pedantic issues such as those listed below are not necessarily material to the soundness of the technical impact assessments as such. The Groundwater Impact Assessment report could be improved with attention to the following (but is basically adequate as it stands):

- Improve the consistency between the AJM reports and the Golder Associates reports that together form the EES Technical Appendix O:
  - resolve the confusion relating to the Segment term (Salinity Segments or Alignment Segments?), and preferably align the report usage of the terms Precincts, Segments and Zones;
  - clarify tunnel diameter details (6.3 or 7.2 m? internal or external diameter?);
  - resolve inconsistencies in the stratigraphic unit tables within Golder Associates reports (Appendix G, Hydrogeological Setting, Table 3; and Appendix H, Numerical Modelling, Table 2) and also between those tables and the AJM report (Appendix D, Table D-1) in terms of: Holocene/Pleistocene epochs, the inclusion of Pleistocene Alluvium and Punt Road Sands units, and the Fishermans Bend Silt character (upper=aquitard; lower=aquifer);
- Present the analytical model equations and summarise the inflow and drawdown results in the Groundwater Impact Assessment report, Appendix F; analytical equations and results were presented in previous draft GIA reports and best practice model guidelines do recommend full documentation, using appendices for technical details if required;
- Provide a technical justification as to why the predicted drawdown from the CBD structures is truncated at the northern boundary of the Yarra Valley (e.g. Golder Associates Appendix H, Numerical Modelling, Figure 20 and 22); this is important because there is a substantial thickness of compressible Coode Island Silt within the valley and yet the truncation of drawdown is not adequately explained (but it could be related the value of specific storage adopted – see next section);
- Golder Associates Appendix G Numerical Modelling: Appendix A parameter plots - the legend appears to be not consistent with the parameter values shown; suggest using numbers to identify parameter values or zone numbers rather than simple colour flood plots (i.e. improve the plots to be consistent with the best practice guidelines (Barnett et al, 2012)). There is also a potential issue regarding the confined aquifer storage parameter used in the Golder numerical modelling (see next section), but it cannot be ascertained at this time whether it is material to the hydrogeological assessment without a detailed discussion with the Golder modeller(s). As a minimum, it should be considered during the Detailed Design stage, and the EPRs make appropriate provisions.

5.2 AQUIFER SPECIFIC STORAGE (SS) PARAMETER

This independent review finds that a high value of aquifer specific storage parameter (Ss value of order of 10^{-4} m^{-1}) that has been applied in the numerical groundwater model could be justified for compressible lithological units (e.g. Coode Island Silt). However, the moderately high Ss value (order of 10^{-5} m^{-1}) applied to many fractured rock units (e.g. Melbourne Formation) has not been adequately justified. Discussion here is warranted to help guide future investigations during the Detailed Design stage.

Table 10 of the Golder Associates Numerical Modelling report (Appendix H of the EES Technical Appendix O; Golder, 2016b) lists values for the aquifer specific storage (Ss) parameter in the range of 10^{-4} to 10^{-5} m^{-1}. Values of this order are too high for most aquifers but may be acceptable for clays and silts, provided there is compressibility data to justify it. However, in this case, the Golder reports provide adequate justification for this value only in relation to the higher permeability parts of the Melbourne Formation. Equally importantly, the Golder reports do not explore the related uncertainties (e.g. the parameter value may be involved in currently predicted truncation of drawdown at the northern boundary of the Yarra Valley).

Adequate justification is provided for the Ss value applied to the higher permeability zones of the Melbourne Formation (fractured rock siltstones & sandstones). The Ss value in this case is based on some testing information, and it is indeed realistic at 4×10^{-6} m^{-1}. However, the Ss value of 10^{-5} m^{-1} that has been applied to the less permeable zones of the Melbourne Formation unit, and to the Newer and Older Volcanics units, is a high value and arguably not physically realistic for these relatively non-compressible units.

The implication for a high Ss value is to increase the confined storage (S) value (S = Ss*b, where b is the aquifer or layer thickness, typically 5 m in this case, but 10-15 m for the Melbourne Formation siltstones) that is used in the groundwater hydraulic equations. That in turn decreases the aquifer diffusivity (D) value that governs drawdown extent/development (D=T/S, where T=transmissivity, noting that T=K*b, where K=hydraulic conductivity; see Table 10 of Golder (2016b) for values).

A lower D value (e.g. due to a high Ss value) reduces the extent of drawdown and increases the time taken for drawdown impacts to be conveyed through the confined aquifer. However, a higher D value (e.g. due to a lower Ss value) would increase the extent of drawdown and decrease the time taken for drawdown impacts to be conveyed through the confined aquifer. In simple terms, a high Ss value can result in a decreased diffusivity and thus reduced impact predictions, and may well be justified for a compressible (clay) unit (e.g. Coode Island Silt). However, a more realistic (lower) Ss value (order of 10^{-6} m^{-1}) for most other aquifer units would tend to increase the predicted impacts.

It is notable that the tunnel alignment runs mostly through the Melbourne Formation, and it is respectfully suggested that a justifiable/conservative approach would be to apply the site-specific Ss value of 4×10^{-6} m^{-1} to the other fractured rock units in place of the existing unrealistic value of 10^{-5} m^{-1}. However, even if this change were invoked, it is possible that it may have no material effect on the impact predictions, as there are other complex hydrogeological processes in play, and the implications outlined above are not always as straight forward as the effects described in principle. Noteworthy among these is that the unconfined specific yield parameter (Sy) should dominate aquifer drainage responses, and this review finds that the Sy parameter values applied in the numerical modelling are indeed physically realistic (in the range 0.03-0.15). The implication is that, even if the Ss parameters are refined as suggested, it may be that Sy parameter dominates the drainage effects and the distribution of drawdown. However, making the refinement would address a potential (but not necessarily material) weakness in the methodology.

Sensitivity and uncertainty testing would be needed to confirm whether or not the issues outlined above may be manifest in this case, and the Environmental Performance Requirements are commendable in requiring such evaluations during Detailed Design.

6. Conclusions and Recommendations

The Groundwater Impact Assessment report (AJM, 2016) provides comprehensive details on the groundwater-related impacts for the Concept Design elements of the Melbourne Metro Rail Project. It is consistent the with EES draft evaluation objectives in that it identifies and assesses potential impacts and mitigation measures, it considers Environmental Performance Requirements (including the requirement for a Groundwater Management Plan) and it provides appropriate detail on the further work that is required during the Detailed Design stage.

The Groundwater Impact Assessment does not quantify cumulative impacts during construction (this gap is acknowledged in the GIA report), nor indeed the effect of the additional potential mitigation measures identified for application during construction. There has been a reasonable attempt to quantify the cumulative impacts during the operational (post-construction) phase, via the steady state numerical model prediction assuming fully tanked structures.

This independent review endorses the Groundwater Impact Assessment methodology at this Concept Design stage and concurs with the findings that most potential impacts are 'low' or 'very low'. The mainly low risk result is not unexpected given "*the Concept Design features and assumed construction techniques incorporate features that prevent large groundwater inflows, and therefore minimise groundwater drawdown and associated impacts on groundwater dependent values.*" Where the Groundwater Impact Assessment identified some higher risks, suitable Environmental Performance Requirements and mitigation measures (e.g. grouting and temporary injection bores to control drawdown) have been identified (but not yet evaluated in detail) to reduce the initial risk to a lower residual risk ranking. This is entirely consistent with the EES Scoping Requirements.

The recommendations of the Groundwater Impact Assessment report for further investigations during the Detailed Design stage are commendable, including:

- hydrogeological field investigations (e.g. long term pumping tests and monitoring)
- numerical groundwater modelling, including transient model calibration, and subsequent application to predict the cumulative impacts of Detailed Design elements, to test and optimise risk treatments and mitigation measures (e.g. grouting and recharge wells) and to evaluate uncertainties (e.g. specific storage)
- Groundwater Management Plan preparation to meet the Environmental Performance Requirements.

7. References

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Appendix C Groundwater monitoring bores

Table C-1 Groundwater monitoring bores drilled for the Melbourne Metro project

Stage /Phase	Bore ID	Easting	Northing	Depth (mbgl)	Screened interval (mbgl) Top of screen (mbgl)	Screened interval (mbgl) Bottom of screen (mbgl)	Screened unit
Stage 1	MM1BH001	318091	5814288	17.43	13.93	16.93	Quaternary Fluvial Sediments
	MM1BH002	318555	5814176	17.44	13.94	16.94	Quaternary Fluvial Sediments
	MM1BH003	318740	5814121	14.4	10.9	13.9	Quaternary Fluvial Sediments
	MM1BH004	318812	5814136	14.85	11.35	14.35	Older Volcanics
	MM1BH006	319262	5814132	30.5	27	30	Melbourne Formation
	MM1BH007	319673	5814374	21.57	17.07	20.07	Melbourne Formation
	MM1BH008	320056	5814444	27.9	24.4	27.4	Melbourne Formation
	MM1BH009	320245	5814444	31.52	28.02	31.02	Melbourne Formation
	MM1BH010	320634	5814219	36.89	33.39	36.39	Melbourne Formation
	MM1BH012	320883	5813057	31.71	28.21	31.21	Melbourne Formation
	MM1BH013	321000	5812330	27.66	24.16	27.16	Melbourne Formation
	MM1BH015	321220	5812247	25.6	23.5	25.5	Moray Street Gravels
	MM1BH016	321255	5812175	23.79	20.29	23.29	Fishermans Bend Silt
	MM1BH017	321347	5812077	20.36	16.36	19.36	Coode Island Silt
	MM1BH018	321370	5811740	15.67	12.17	15.17	Melbourne Formation
	MM1BH019	321430	5811290	11	7.5	10.5	Brighton Group
	MM1BH020	321730	5810390	14.83	11.33	14.33	Melbourne Formation
Stage 2 Phase 2A	GA11-BH002	317239	5814459	33.85	11	13.5	Older Volcanics
	GA11-BH003	317345	5814426	33.85	15	17.5	Older Volcanics
	GA11-BH005	317570	5814392	29.15	18.5	21.5	Older Volcanics
	GA11-BH007	317295	5814317	33.3	22.5	25.5	Werribee Formation
	GA11-BH008	318173	5814219	30.1	17.5	19.5	Quaternary Fluvial Sediments
	GA11-BH017	321258	5812236	35.3	23	26	Moray Street Gravels
	GA11-BH019	321600	5810832	25	16	19	Melbourne Formation
	GA11-BH026	321384	5810709	25	6.5	9	Brighton Group
	GA11-BH027	321490	5810577	25	12	15	Melbourne Formation
Stage 2 Phase 2B	GA11-BH020	322128	5810277	26.45	21	24	Melbourne Formation
	GA11-BH021	322373	5810235	30.15	23	26	Melbourne Formation
	GA11-BH022	322621	5810214	36	31	34	Melbourne Formation

Stage /Phase	Bore ID	Easting	Northing	Depth (mbgl)	Screened interval (mbgl)		Screened unit
					Top of screen (mbgl)	Bottom of screen (mbgl)	
	GA11-BH023	322983	5810137	35	27	30	Melbourne Formation
	GA11-BH024	323284	5810070	26.3	18	21	Melbourne Formation
	GA11-BH025	323321	5810043	25	16.5	19.5	Melbourne Formation
Stage 2 Phase 2C	GA11-BH001	316926	5814510	39.4	20.2	23.4	Moray Street Gravels
	GA11-BH009	318356	5814176	32.4	21.6	23.6	Quaternary Fluvial Sediments
	GA11-BH011	318891	5814128	30.1	20.3	23.3	Melbourne/Werribee Formation
	GA11-BH012	319083	5814105	34.8	27.9	31.2	Not listed
	GA11-BH013	319307	5814159	39.75	29.5	32.7	Melbourne Formation
	GA11-BH014	320661	5813919	36.1	22.9	25.9	Melbourne Formation
	GA11-BH018	321352	5812148	35.7	27.3	29.2	Holocene Alluvium
	GA11-BH031	317073	5814472	37.9	16.5	19.5	Older Volcanics
	GA11-BH041	321307	5812230	38.5	26.05	29.05	Moray Street Gravels
RD (to 30 Sept 2015)	GA15-BH001	317979.8	5814299	40.2	20	23	Werribee Formation
	GA15-BH002	317995.8	5814289	41.2	26	28	Silurian
	GA15-BH003	318008.8	5814217	41.25	13.5	16.5	Fluvial Sediments
	GA15-BH005	318546.1	5814139	18.65	13.2	15.2	Sands at the base of Coode Island Silt
	GA15-BH007	320630.6	5813656	30	14	17	Silurian
	GA15-BH008	320608.8	5813543	50	16	19	Silurian
	GA15-BH009	320758.9	5813628	40	17.2	20.2	Silurian
	GA15-BH010	320668.3	5813464	40.4	14	17	Silurian
	GA15-BH011	320676.8	5813404	50	31	34	Silurian
	GA15-BH012	320783.6	5813343	40.19	23	26	Silurian
	GA15-BH018	321017.2	5812739	40	19	23	Silurian
	GA15-BH019	321030.9	5812684	40.6	24	27	Silurian
	GA15-BH021	321082.4	5812603	40	21	24	Silurian
	GA15-BH027	321467.9	5811709	45	26	29	Silurian
	GA15-BH028	321506.5	5811637	34	26	29	Silurian
	GA15-BH029	321505.2	5810718	40.5	25	35	Silurian
	GA15-BH030	321522	5810747	40.5	25	35	Silurian
	GA15-BH031	321537.2	5810754	40	25	35	Silurian

Stage /Phase	Bore ID	Easting	Northing	Depth (mbgl)	Screened interval (mbgl)		Screened unit
					Top of screen (mbgl)	Bottom of screen (mbgl)	
	GA15-BH032	321551	5810741	50.5	25	35	Silurian
	GA15-BH033	321574.3	5810715	41.9	25	35	Silurian
	GA15-BH108	321125.5	5812564	50.25	31	43	Silurian
	GA15-BH109	321138	5812567	50.3	31	43	Silurian
	GA15-BH110	321133.5	5812575	50.2	31	43	Silurian
	GA15-BH111	321146.6	5812545	50.5	30	42	Silurian
	GA15-BH112	321094.3	5812560	50.1	31	43	Silurian
	GA15-BH120	321384.9	5812009	25.7	12	15	Silurian
	GA15-BH121	321433.3	5811804	25.85	14	17	Silurian
	GA15-BH122	321536.3	5811733	40	28	31	Silurian
	GA15-BH123	321575.6	5811644	45	28	31	Silurian

Easting and northing GDA94 MGA Zone 55

Appendix D Geology and hydrogeology

D.1 Main Geological and Hydrostratigraphic Units

The main geological units in the study area, their occurrence, description and hydrogeological classification are described in the table below. While the alignment of the tunnels does not necessarily intersect all of these geological formations, they may still be hydraulically connected to the tunnels and are therefore important when considering inflows and drawdown.

Table D-1 Main geological and hydrostratigraphic units and their characteristics (from Golder 2016a, Appendix G)

Geological period	Geological epoch	Unit	Description	Hydrogeological classification	Occurrence (precincts)
Quatrnary	Holocene / Pleistocene	Coode Island Silt (Qc)	Soft clayey sediments with shells and organic materials and lenses or thin layers of sandy material.	Aquitard, porous medium, due to presence of sand layers and lenses, horizontal hydraulic conductivity (Kh) greater than vertical (Kv).	Western portal precinct, Arden station precinct, Tunnels precinct (CBD South station to Domain station).
	Pleistocene	Holocene Alluvium (Qha)	Fine to medium grained alluvial sands.	Aquifer, confined, porous medium, high yielding. *Holocene Aquifer.*	Tunnels precinct (CBD South station to Domain station).
		Jolimont Clay (Qj)	Marine clay with minor silts and sands.	Aquitard, porous medium.	Tunnels precinct (CBD South station to Domain station).
		Newer Volcanics (Qnv) (Burnley Basalt Flow)	Olivine basalt, variably weathered and fractured.	Aquifer, unconfined to semi confined, fractured rock medium, low (where weathered) to high (where fractured) hydraulic conductivity. *Basalt Aquifer.*	Tunnels precinct (CBD South station to Domain station).
		Fishermans Bend Silt (Qf)	Clay and silt with some sands. Typically, proportion of sand is higher towards the base of the unit (lower Fishermans Bend Silt sub-unit), with clayey material encountered towards the top (Upper Fishermans Bend Silt sub-unit).	Aquitard (both upper and lower sub-units), porous medium, due to fissuring vertical hydraulic conductivity may be greater than horizontal.	Western portal precinct, Arden station precinct, Tunnels precinct (CBD South station to Domain station).
		Moray Street Gravels (Qm)	Medium to coarse grained quartz sands with minor gravels, clay and silt.	Aquifer, confined, porous medium, high yielding.	Western portal precinct, Tunnels precinct (CBD South station to Domain station).

Geological period	Geological epoch	Unit	Description	Hydrogeological classification	Occurrence (precincts)
		Fluvial Sediments (Qac)	Medium to coarse sands, gravels and clays with coarse inclusions of boulder and cobble size.	Aquifer, confined, porous medium, potentially high yielding (limited data available).	Western portal precinct, Arden station precinct, Tunnels precinct (CBD South station to Domain station).
		Newer Volcanics (Qlv) (Lower Flow)	Olivine basalt variably weathered and fractured. Typically referred to as lower Newer Volcanics.	Aquifer of localised extent and low significance due to discontinuity of the unit (Golder, 2016a, Appendix G). Confined, fractured rock medium, medium to low hydraulic conductivity.	Tunnels precinct (CBD South station to Domain station).
Neogene	Pliocene	Brighton Group (Tb)	Sand, sandy clay, clayey sand, silt, clay and occasionally gravel.	Aquifer, unconfined, porous medium, medium-yielding aquifer where sandy but aquitard where clayey.	Tunnels precinct (Arden station to Parkville station, CBD South to Domain station, Domain station to eastern portal), Domain station precinct, eastern portal precinct.
Paleogene	Oligocene to Miocene	Older Volcanics (Tov)	Olivine and pyroxene basalt with abundant volcanic glass, variably weathered and fractured.	Aquifer, confined, fractured rock medium, low (where weathered) to high (where fractured) hydraulic conductivity.	Western portal precinct, Arden station precinct, Tunnels precinct (western portal to Arden station, Arden station to Parkville station.)
		Werribee Formation (Tw)	Fluvial quartz sand, minor gravels, silty clays and clays.	Aquifer, confined, porous medium, zones of potentially high yielding sub-aquifer(s) (lower zone).	Western portal precinct, Arden station precinct, Tunnels precinct (western portal to Arden station, Arden station to Parkville station).
Devonian		Igneous rock (Dgr)	Granodiorite and quartz porphyries, feldspar porphyries and lamprophyres dykes.	Likely to be local barriers to flow given past experience of weathering.	Eastern portal precinct.
Silurian		Melbourne Formation (S)	Interbedded siltstone and sandstone, folded, fractured and variably weathered.	Aquifer, unconfined to semi confined, fractured rock medium. *Silurian Aquifer*.	All precincts and sectors.

D.2 Hydrostratigraphy of Each Precinct

D.2.1 Hydrostratigraphy of Precinct 1 Tunnels: Western Port to Arden Station

Table D-2 Hydrogeological units expected to be encountered in the section of tunnels between the western portal and Arden station

Geological unit	Chainage	Construction type	Hydrogeological classification and horizontal hydraulic conductivity (Kh)
Coode Island Silt	CH96+100 to CH96+220	TBM	Aquitard – no hydraulic testing undertaken in the western portal precinct, but slug tests in other areas give hydraulic conductivities of: • 6.6 x 10^{-5} m/sec at Arden station precinct (GA15-BH005) • 2.0 x 10^{-7} m/sec near the Yarra River (MM1BH017).
Pleistocene Alluvium	CH96+200 to CH96+230	TBM	This is a newly identified unit, which was previously mapped as Coode Island Silt. There is no information currently available on its hydraulic conductivity.
Fishermans Bend Silt	CH95+960 to CH96+230	TBM	Aquitard – hydraulic testing undertaken in this area gave a hydraulic conductivity value of 1.3 x 10^{-5} m/sec which is considered to be high for this unit. The hydraulic conductivity encountered is likely to depend on the proportion of sand in the unit.
Quaternary Fluvial Sediments	CH95+940 to CH95+980	TBM	Aquifer, porous media, confined by Coode Island Silt in this area – hydraulic testing in bores in this area 100 m apart gave results an order of magnitude apart (6.9 x 10^{-6} – 8.6 x 10^{-5} m/sec).
Older Volcanics	CH95+350 to CH95+610	TBM	Aquifer, fractured rock, confined to semi confined by Coode Island Silt and weathering profile within Older Volcanics. Hydraulic testing in neighbouring precinct (western portal) gave range of hydraulic conductivity of 6.1 x 10^{-7} to 2.8 x 10^{-6} m/sec.
Werribee Formation	CH95+560 to CH95+960	TBM	Aquifer, porous media, confined by weathered Older Volcanics. Hydraulic testing of one bore in this unit in this area resulted in hydraulic conductivity of 8.8 x 10^{-7} m/sec.
Melbourne Formation	CH95+740 to CH96+000	TBM	Aquifer, fractured rock, confined in this area by overlying Quaternary and Tertiary sediments. Hydraulic testing undertaken in one bore in this unit resulted in a hydraulic conductivity of 8.7 x 10^{-6} m/sec, which is at the higher end of the range of hydraulic conductivity measured in this formation along the alignment. Hydraulic conductivity is likely to vary considerably depending on degree of fracturing and weathering. Presence of structural features (faults and fold axes) is unknown.

D.2.2 Hydrostratigraphy of Precinct 1 Tunnels: Arden Station to Parkville Station

Table D-3 Groundwater levels monitored in the tunnels area between Arden and Parkville Stations

Bore ID	Formation monitored[1]	Water level (m AHD)[2]					
		Jun/Jul 2010	Aug 2010	Jul 2011	Jun 2012	Jul 2013	Sep 2015
MM1BH006	S (SC-UC)	5.91	5.94	6.92	7.19	-	7.07
GA11-BH013	S (SC-UC)	-	-	-	-	7.88	7.47
MM1BH007	S (SC-UC)	10.79	10.74	11.74	-	-	
GA11-BH012	S (SC-UC)						1.32

Notes:

1. UC = unconfined conditions, SC = semi confined conditions
2. Corrected for bore inclination and density effects

D.2.3 Hydrostratigraphy of Precinct 1 Tunnels: Parkville Station to CBD North Station

Table D-4 Geological units expected to be encountered in the tunnels area from Parkville to CBD North stations

Geological unit	Chainage	Construction type	Hydrogeological classification and horizontal hydraulic conductivity (Kh)
Melbourne Formation	CH98+330 to CH99+190	TBM	Aquifer, fractured rock, unconfined to semi-confined in this precinct by weathering profile and overlying fill in some places. Hydraulic testing undertaken in this unit gave a hydraulic conductivity range of 5.2×10^{-7} to 9.5×10^{-7} m/sec. The Geology of Melbourne map (GSV, 1967) indicates that the Melbourne Formation across this area is dipping towards the south-east and there are no major fold or fault structures mapped in this area.

D.2.4 Hydrostratigraphy of Precinct 1 Tunnels: CBD North Station to CBD South Station

Table D-5 Hydrogeological units expected to be encountered in the tunnels area between CBD North station and CBD South station

Geological unit	Chainage	Construction type	Hydrogeological classification and horizontal hydraulic conductivity (Kh)
Melbourne Formation	CH99+650 to CH100+120	Mined tunnels (road header)	Aquifer, fractured rock. Hydraulic testing on one bore in the area, screened in this unit produced a hydraulic conductivity of 1.1 x 10^{-6} m/sec. The Geology of Melbourne map (GSV, 1967) indicates that a syncline exists within the Melbourne Formation in this area at approximately CH99+700, striking north-east to south-west. The rock around this feature may exhibit more fracturing and therefore higher hydraulic conductivities.

D.2.5 Hydrostratigraphy of Precinct 1 Tunnels: CBD South Station to Domain Station

Table D-6 Hydrogeological units expected to be encountered in the tunnels area between CBD South and Domain stations

Geological unit	Chainage	Construction type	Hydrogeological classification and horizontal hydraulic conductivity (Kh)
Newer Volcanics (Burnley Basalt Flow)	CH100+580 to CH100+650	TBM	Aquifer, fractured rock, unconfined to semi confined by Coode Island Silt and Fill. No hydraulic testing undertaken and a large range of hydraulic conductivity values are possible (5 x 10^{-9} to 1 x 10^{-4} m/sec).
Coode Island Silt	CH100+820 to CH100+960	TBM	Aquitard – hydraulic testing undertaken in this precinct gave a hydraulic conductivity range of 4.5 x 10^{-8} to 2.0 x 10^{-7} m/sec.
Fishermans Bend Silt	CH100+640 to CH100+830	TBM	Aquitard – hydraulic testing undertaken in this precinct gave hydraulic conductivity of 2.9 x 10^{-7} m/sec (considered to be high for this unit). In this precinct the Fishermans Bend Silt is divided into two units, the lower permeability upper unit and the higher permeability lower unit – construction is likely to be restricted to the upper unit.
Brighton Group	CH101+300 to CH101+640	TBM	Aquifer, porous media, unconfined and only the lower parts are likely to be saturated. Hydraulic testing of one bore in this unit in this precinct resulted in hydraulic conductivity of 2.9 x 10^{-7} m/sec.
Melbourne Formation	CH100+560 to CH100+590 and CH100+950 to CH102+150	TBM	Aquifer, fractured rock, confined in this precinct by overlying Quaternary sediments in the north but likely to be unconfined in the south of the precinct. Hydraulic testing of five bores in this unit (and in this precinct) produced a range of hydraulic conductivity from 1.7 x 10^{-10} to 4.7 x 10^{-8} m/sec, which is very low for this unit. The average hydraulic conductivity for the

Geological unit	Chainage	Construction type	Hydrogeological classification and horizontal hydraulic conductivity (Kh)
			Melbourne Formation is 2.7 x 10^{-6} m/sec. There are two anticline structures and one syncline structure in the Melbourne Formation in this precinct according to the Melbourne geology map (GSV, 1967). The anticlines cross the alignment at CH100+660 and CH101+800 and the syncline at CH100+950. The Melbourne Warp is a major geological structure that cuts through Melbourne on a south-east to north-west direction, and is thought to enhance permeability in the Melbourne Formation in this area.

D.2.6 Hydrostratigraphy of Precinct 1 Tunnels: Domain Station to Eastern Portal

Table D-7 Hydrogeological units expected to be encountered in the tunnels area from Domain station to eastern portal

Geological unit	Chainage	Construction type	Hydrogeological classification and horizontal hydraulic conductivity (Kh)
Melbourne Formation	CH102+750 to CH104+060	TBM	Aquifer, fractured rock, confined in part in this precinct by overlying Quaternary and Tertiary sediments. One bore screened in this formation in this precinct produced a hydraulic conductivity of 2.2 x 10^{-5} m/sec which is an order of magnitude higher than the average for the Melbourne Formation testing across the Study Area of 2.7 x 10^{-6} m/sec. The Geology of Melbourne map (GSV, 1967) indicates that a syncline and an anticline exist within the Melbourne Formation across this area, both striking north-east south-west. The tunnels cross these features at approximately CH102+800 (anticline) and CH103+980 (syncline). The rock around these features may exhibit more fracturing and therefore higher hydraulic conductivities.

D.2.7 Hydrostratigraphy of Precinct 2: Western Portal

Table D-8 Hydrogeological units expected to be encountered in the western portal

Geological unit	Chainage	Construction type	Hydrogeological classification and horizontal hydraulic conductivity (Kh)
Fill	CH94+900 to CH95+140	Decline structure (open cut and cut and cover)	No information on permeability – above watertable.
Coode Island Silt	Potentially CH95+060 to CH95+090	Decline structure (potentially open cut and cover)	Aquitard – no hydraulic testing undertaken in the western portal precinct, but slug tests in other areas give hydraulic conductivities of: 6.6 x 10^{-5} m/sec at Arden station precinct (GA15-BH005) 2.0 x 10^{-7} m/sec near the Yarra River (MM1BH017).
Older Volcanics	CH95+090 to CH95+350	Decline structure (open cut and cut	Aquifer, fractured rock, confined to semi confined by Coode Island Silt, fill and weathering profile within Older

Geological unit	Chainage	Construction type	Hydrogeological classification and horizontal hydraulic conductivity (Kh)
		and cover), TBM retrieval shaft	Volcanics. Hydraulic testing in this precinct gave range of hydraulic conductivity values of 6.1 x 10^{-7} to 2.8 x 10^{-6} m/sec.

D.2.8 Hydrostratigraphy of Precinct 3: Arden Station

Table D-9 Hydrogeological units expected to be encountered in the Arden station precinct

Geological unit	Chainage	Construction type	Hydrogeological classification and horizontal hydraulic conductivity (Kh)
Coode Island Silt	CH96+230 to CH96+590	TBM and station box (cut and cover, diaphragm wall retaining structure).	Aquitard – hydraulic testing undertaken in this unit gave horizontal hydraulic conductivity results of • 6.6 x 10^{-5} m/sec at Arden station precinct (GA15-BH005) • 2.0 x 10^{-7} m/sec near the Yarra River (MM1BH017).
Fishermans Bend Silt	CH96+230 to CH96+570	TBM and station box (cut and cover, diaphragm wall retaining structure).	Pleistocene Alluvium.
Quaternary Fluvial Sediments	CH96+420 to CH96+590	Station box (cut and cover, diaphragm wall retaining structure).	Aquifer, porous media, confined by Coode Island Silt and Fishermans Bend Silt in this area – hydraulic testing in bores in other precincts in two bores gave a range of 6.9 x 10^{-6} to 8.6 x 10^{-5} m/sec.
Werribee Formation	CH96+570 to CH96+760	TBM (cut and cover, diaphragm wall retaining structure).	Aquifer, porous media, confined by weathered Older Volcanics. Hydraulic testing in this unit in this precinct resulted in hydraulic conductivity of 6.4 x 10^{-5} m/sec and 1.6 x 10^{-4} (both in MM1BH004) which is considered to be high for this unit but not outside the expected range.
Melbourne Formation	CH96+570 to CH96+760	TBM and station box (cut and cover, diaphragm wall retaining structure.)	Aquifer, fractured rock, confined in this precinct by overlying Quaternary and Tertiary sediments. No bores screened in this formation in this precinct but hydraulic conductivity likely to vary considerably depending on degree of fracturing and weathering. Likely to be a syncline in the west of this precinct and an anticline in the east of the precinct based on the Melbourne Geology Map (GSV, 1967).

Hydrogeological units expected to be encountered in precincts 4 to 9 are discussed within each section. Slug test results for these precincts are covered in Table C-10 below

D.3 Hydraulic conductivity

Single bore hydraulic tests (slug tests) have been undertaken in a number of bores along the alignment:

1) During Stage 1: slug tests were undertaken in 17 bores (15 bores falling and rising head tests, 2 bores falling head tests)

2) During Stage 2, Phase 1: nine of the wells previously tested during stage 1 were retested in 2011 (4 bores falling and rising head tests, 4 bores falling head tests, one bore unsuccessful)

3) During Stage 2, Phase 2a: slug were undertaken in 9 bores in (2 bores falling and rising head tests, 4 bores falling head tests, 2 bores rising head tests, one bore unsuccessful)

4) During Stage 2, Phase 2b: slug were undertaken in 2 bores (1 bore falling and rising head test, 1 bore falling head test)

5) During Stage 2, Phase 2c: slug were undertaken in 4 bores (3 bores falling and rising head tests, 1 bore rising head test).

6) Concept Design – undertaken by Golder Associates (June to September 2015) – included drilling and installation of 29 groundwater monitoring bores, hydraulic testing (17 bores) and groundwater sampling (18 bores).

7) The estimated hydraulic conductivity from each test is shown in Table C-10.

Table D-10 Results of slug tests along Melbourne Metro alignment

Precinct / sector	Stage / phase of works	Bore ID	Aquifer	Estimated hydraulic conductivity (m/sec)		
				Falling head test	Rising head test	Adopted value*
Western portal	2, 2a	GA11-BH002	Tov	-	2.8E-06	2.8E-06
	2, 2a	GA11-BH003	Tov	-	1.4E-06	1.4E-06
	2, 2a	GA11-BH005	Tov	6.1E-07	-	6.1E-07
	2, 2a	GA11-BH007	Tw	2.2E-04	-	2.2E-04
Western portal to Arden station	1	MM1BH001	Qac	5.8E-06	8.1E-06	6.9E-06
	2, 2a	GA11-BH008	Qac	7.1E-05	1.0E-04	8.6E-05
	2, 2c	GA11-BH009	Qac	1.4E-05	1.1E-05	1.3E-05
	RD	GA15-BH001	Tw	6.6E-07	1.1E-06	8.8E-07
	RD	GA15-BH002	S	9.5E-06	7.9E-06	8.7E-06
	RD	GA15-BH003	Qac	4.8E-05	5.8E-05	5.3E-05
Arden station	1	MM1BH002	Qac	3.5E-07	1.2E-07	2.3E-07
	1	MM1BH003	Qac	5.2E-05	1.1E-05	3.1E-05
	1	MM1BH003	Qac	1.4E-04	8.0E-05	1.1E-04
	1	MM1BH004	Tov	1.5E-05	1.7E-05	1.6E-05
	1	MM1BH004	Tov	1.6E-04	-	1.6E-04
	RD	GA15-BH005	Qc	7.4E-05	5.8E-05	6.6E-05
Arden station to Parkville station	1	MM1BH006	S	3.5E-08	9.3E-08	6.4E-08
	1	MM1BH006	S	3.0E-08	-	3.0E-08
	2, 2c	GA11-BH013	S	3.5E-06	3.5E-06	3.5E-06
	1	MM1BH007	S	5.8E-07	4.6E-07	5.2E-07
Parkville station	1	MM1BH008	S	2.3E-07	1.2E-08	1.2E-07
	1	MM1BH009	S	5.8E-07	5.8E-07	5.8E-07
Parkville station to CBD North station	1	MM1BH010	S	5.8E-07	4.6E-07	5.2E-07
	1	MM1BH010	S	8.0E-07	1.1E-06	9.5E-07
CBD North station	RD	GA15-BH007	S	1.1E-06	4.6E-06	2.9E-06
	RD	GA15-BH008	S	4.0E-08	-	4.0E-08

Precinct / sector	Stage / phase of works	Bore ID	Aquifer	Estimated hydraulic conductivity (m/sec)		
				Falling head test	Rising head test	Adopted value*
	RD	GA15-BH009	S	6.1E-08	-	6.1E-08
	RD	GA15-BH010	S	3.3E-08	-	3.3E-08
	RD	GA15-BH012	S	2.9E-07	1.4E-07	2.2E-07
CBD North station to CBD South station	1	MM1BH012	S	1.2E-06	1.0E-06	1.1E-06
CBD South station	1	MM1BH013	S	1.2E-06	1.2E-06	1.2E-06
	1	MM1BH013	S	7.6E-06	8.0E-06	7.8E-06
	RD	GA15-BH018	S	2.3E-07	-	2.3E-07
	RD	GA15-BH019	S	2.0E-08	-	2.0E-08
	RD	GA15-BH021	S	6.4E-08	-	6.4E-08
	RD	GA15-BH112	S	1.1E-06	1.1E-06	1.1E-06
CBD South station to Domain station	1	MM1BH015	Qm	2.1E-04	2.5E-04	2.3E-04
	1	MM1BH015	Qm	6.2E-05	5.8E-05	6.0E-05
	2, 2a	GA11-BH017	Qm	5.7E-05	7.6E-05	6.7E-05
	2, 2c	GA11-BH041	Qm	-	2.7E-04	2.7E-04
	1	MM1BH016	Qf	4.6E-07	1.2E-07	2.9E-07
	2, 2c	GA11-BH018	Qha	1.7E-06	2.0E-06	1.9E-06
	1	MM1BH017	Qc	1.0E-07	4.6E-07	2.8E-07
	1	MM1BH017	Qc	4.5E-08	-	4.5E-08
	1	MM1BH018	S	4.6E-09	-	4.6E-09
	1	MM1BH018	S	-	-	
	1	MM1BH019	Tb	3.5E-07	-	3.5E-07
	RD	GA15-BH027	S	4.3E-08	-	4.3E-08
	RD	GA15-BH028	S	1.0E-09	-	1.0E-09
	RD	GA15-BH122	S	1.7E-10	-	1.7E-10
	RD	GA15-BH123	S	4.7E-08	-	4.7E-08
Domain station	2, 2a	GA11-BH019	S	4.1E-08	-	4.1E-08
	2, 2a	GA11-BH026	Tb	-	-	
	2, 2a	GA11-BH027	S	3.7E-08	-	3.7E-08
	1	MM1BH020	S	5.8E-06	4.6E-07	3.1E-06
	1	MM1BH020	S	3.0E-08	-	3.0E-08
Domain station to Eastern portal	2, 2b	GA11-BH023	S	2.1E-05	2.2E-05	2.2E-05
Eastern portal	2, 2b	GA11-BH024	S	4.8E-08	-	4.8E-08

Notes: *Adopted value is the average of rising and falling head tests undertaken in the bore

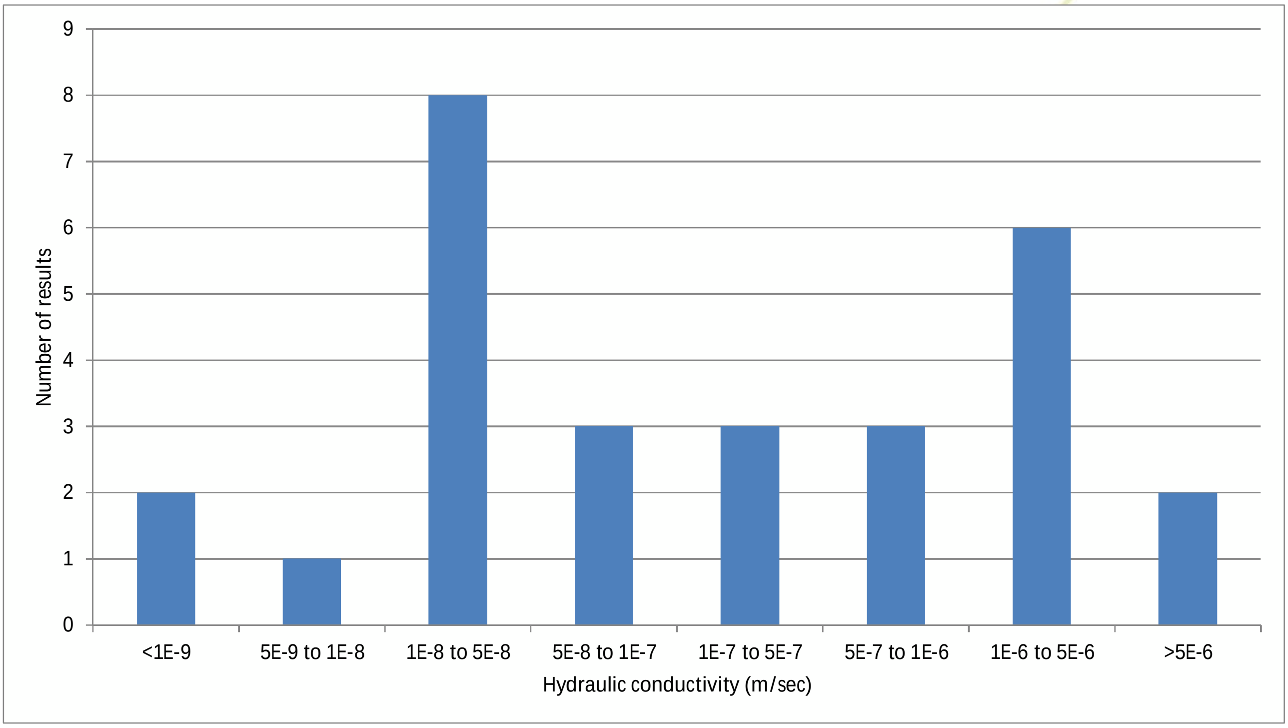

Figure D-1 Distribution of hydraulic conductivity results from slug tests in the Melbourne Formation for the Melbourne Metro

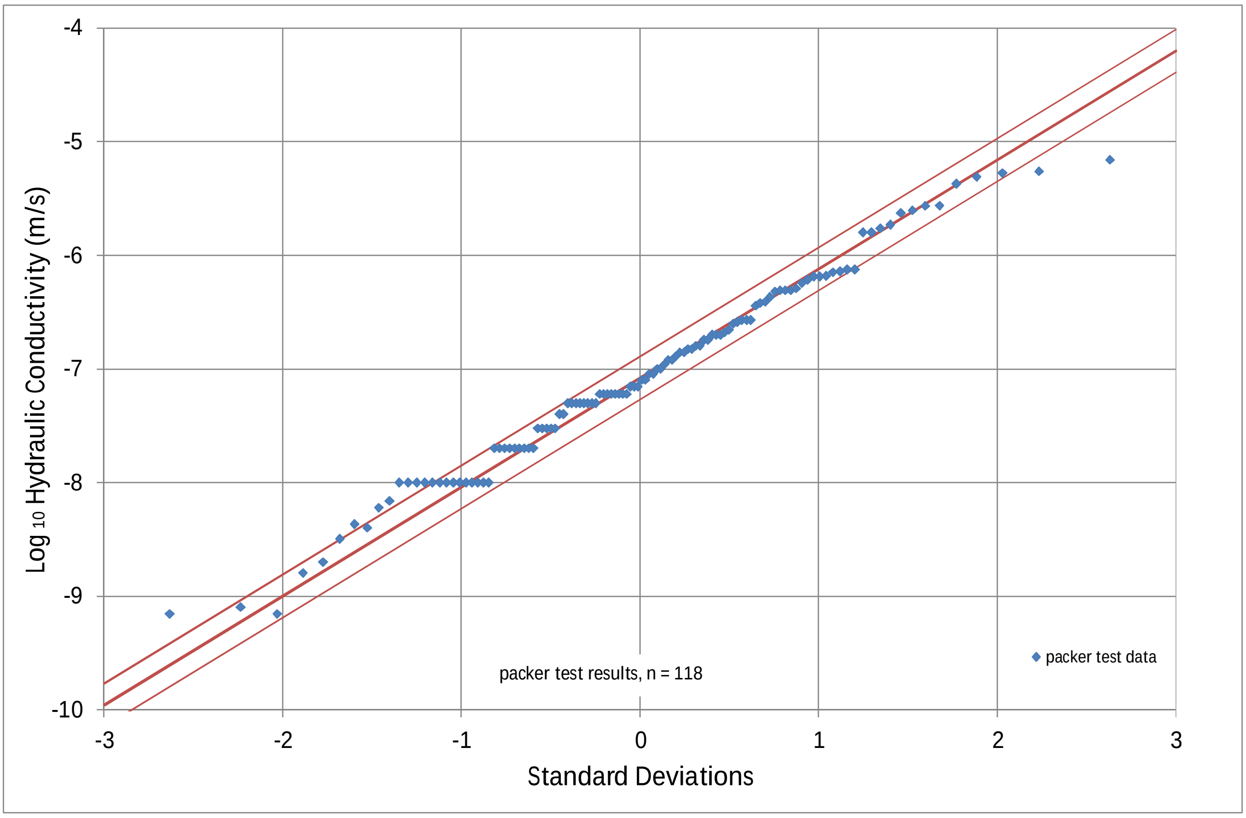

Figure D-2 Raymer Plot of hydraulic conductivity results derived from packer tests in the Melbourne Formation for the Melbourne Metro

D.4 Storativity and Specific Storage

As no pumping tests have been undertaken during the Melbourne Metro investigations (to date) no site specific estimate of storativity for any formation is available. During the Stage 1 preliminary groundwater investigations undertaken by Aurecon et al. (2010b), estimates were listed for some units based on previous studies as discussed below.

Melbourne Formation (Value adopted in Stage 1 analytical modelling 0.01 (unitless), value adopted in Golder regional modelling 0.15 (Golder 2016b, Appendix H)): For the majority of the area where this unit is unconfined, the storativity (or specific yield) is unlikely to be less than 0.01 and the Department of Water Resources (1992) indicates a storativity of less than 0.05. Nearby pumping tests (24 hour tests in the Kings Domain) resulted in much lower storativity of 4×10^{-4} and 3×10^{-4} (RWC, 1992), which are considered very low for an unconfined aquifer. These low storativity results are thought to be due to the short duration of these tests and the effects of delayed yield. Longer pumping tests undertaken for the Northern Sewerage Project (SKM, 2005) resulted in storativity results of 0.007 and 0.02 from a 3.8 day test and a 1.8 day test respectively. These are indicative of unconfined conditions in low porosity bedrock.

Brighton Group (Value adopted in Stage 1 analytical modelling 0.05, value adopted in Golder regional modelling 0.08 (Golder 2016b, Appendix H)): A pumping test conducted for the Northern Sewerage Project (SKM, 2005) resulted in an estimate of storativity for this unit of 1.5×10^{-1} although this was in an area of high hydraulic conductivity for this unit. The lower hydraulic conductivity material more common in the Study Area would have a lower (effective) porosity and hence a lower storativity.

Moray Street Gravels (Value adopted in Stage 1 analytical modelling 0.0005, value adopted in Golder regional modelling 0.1 (Golder 2016b, Appendix H)): A 38-hour pumping test undertaken in the Moray Street Gravels at Swan Street (HydroTechnology, 1994) and a 48-hour pumping test adjacent to the Westgate Bridge (SKM, 2004) resulted in storativity values of 1.5×10^{-4} and 2.4×10^{-5} respectively, which are close to the minimum value expected based on the estimated thickness and assuming a fully confined aquifer. A higher value was adopted for the Stage 1 works because the Moray Street Gravels was modelled as a semi confined, not fully confined, aquifer (and hence a higher storativity would be expected). A 5 day pumping test undertaken in the Moray Street Gravels for the Westlink project (SKM, 2010) resulted in an estimate of storativity of 1.2×10^{-4} which is near to the value adopted for the Stage 1 calculations.

Coode Island Silt (Value adopted in Stage 1 analytical modelling 0.005 m^{-1} for specific storage – multiply by saturated thickness to get storativity, value adopted in Golder regional modelling 0.15 (Golder 2016b, Appendix H)): The storativity for the Coode Island Silt has not been measured in pumping tests. A specific storage value of 5×10^{-3} m^{-1} was derived from laboratory testing in Ervine et al. (2006b). As the unit acts unconfined in the Study Area, the storativity would be expected to be dependent on the volume of water that would drain from the pore spaces under the influence of gravity alone (thought to be 0.001 to 0.01 (Aurecon et al., 2010a)). However, due to the high compressibility of this unit, the release of water (e.g. into an excavation) may cause consolidation, decreasing the volume of the unit. As a result, the storativity would be greater than that expected if water was only released through gravity drainage.

D.5 Groundwater Levels and Variability

Table D-11 Summary of groundwater level monitoring undertaken across the Study Area

Precinct / sector	Bore ID	Aquifer [1]	No. occasions monitored	Date range of monitoring	Groundwater elevation (m AHD) [2] Min. to max. value (range)
Western portal	GA11-BH001	Qm (C)	1	Jul-13	-0.43
	GA11-BH031	Tov (C)	2	Jul-13 to Sep-15	-1.18 to -1.00 (0.18m)
	GA11-BH002	Tov (C)	3	Mar-12 to Sep-15	-1.32 to -0.88 (0.44m)
	GA11-BH003	Tov (C)	2	Mar-12 to Jun-12	-1.58 to -1.46 (0.12m)
	GA11-BH005	Tov (SC-C)	2	Mar-12 to Jun-12	-1.58 to -1.55 (0.03m)
	GA11-BH007*	Tw (C)	6	Mar-12 to May-14	-2.12 to -1.76 (0.36m)
Tunnels Western portal to Arden	MM1BH001	Qac (C)	2	Jul-10 to Jun-12	-2.28 to -2.02 (0.26m)
	GA11-BH008	Qac (C)	2	Mar-12 to Jun-12	-1.53 to -1.48 (0.05m)
	GA15-BH002	S	1	Sep-15	-2.11
	GA15-BH003	Qac	1	Sep-15	-2.54
Arden station	GA11-BH009*	Qf (C)	5	Jul-13 to May-14	-1.73 to -1.34 (0.39m)
	MM1BH002	Qf (C)	4	Jul-10 to Jun-12	-1.75 to -1.38 (0.37m)
	MM1BH003	Qf (C)	4	Jul-10 to Jun-12	-1.26 to -0.78 (0.48m)
	MM1BH004	Tw (SC-C)	3	Jul-10 to Jun-12	-1.28 to -0.87 (0.41m)
	GA11-BH011*	S (SC-C)	5	Jul-13 to Jun-14	-1.09 to -0.79 (0.3m)
Tunnels Arden to Parkville station	MM1BH006	S (SC-UC)	5	Jul-10 to Sep-15	5.91 to 7.19 (1.28m)
	GA11-BH013	S (SC-UC)	2	Jul-13 to Sep-15	7.47 to 7.88 (0.41m)
	MM1BH007	S (SC-UC)	3	Jul-10 to Jul-11	10.74 to 11.74 (1.00m)
	GA11-BH012	S	1	Sep-15	1.32
Parkville station	MM1BH008	S (SC-UC)	3	Jul-10 to Jun-12	18.23 to 20.84 (2.61m)
	MM1BH009*	S (SC-UC)	8	Jul-10 to Sep-15	21.04 to 24.13 (3.09m)
Tunnels Parkville to CBD North station	MM1BH010	S (SC-UC)	3	Jul-10 to Jun-12	21.78 to 22.28 (0.50m)
	GA11-BH014	S (SC-UC)	1	Jul-13	19.51
CBD North station	GA15-BH007	S	1	Sep-15	14.28
	GA15-BH010	S	1	Sep-15	11.46
	GA15-BH012	S	1	Sep-15	0.57
Tunnels CBD North to CBD South station	MM1BH012	S (SC-UC)	4	Jul-10 to Jun-12	-0.33 to 0.32 (0.65m)

Precinct / sector	Bore ID	Aquifer [1]	No. occasions monitored	Date range of monitoring	Groundwater elevation (m AHD) [2] Min. to max. value (range)
CBD South station	MM1BH013	S (SC-UC)	2	Jul-10 to Jul-11	-0.02 to 1.06 (1.08m)
	GA15-BH018	S	1	Sep-15	-0.44
	GA15-BH019	S	1	Sep-15	-1.52
Tunnels CBD South to Domain	MM1BH015*	Qm (C)	9	Jul-10 to Sep-15	-2.01 to -1.52 (0.49m)
	GA11-BH017*	Qm (C)	6	Mar-12 to May-14	-1.31 to -0.96 (0.35m)
	GA11-BH041	Qm (C)	1	Jul-13	-0.82
	MM1BH016*	Qf (C)	9	Jul-10 to Sep-15	-2.06 to -1.33 (0.73m)
	GA11-BH018*	Qha (C)	6	Jul-13 to Sep-15	-1.03 to -0.65 (0.38m)
	MM1BH017	Qc (SC-UC)	4	Jul-10 to Jun-12	-1.29 to 0.21 (1.50m)
	MM1BH018*	S (SC-UC)	7	Jul-10 to Sep-15	-2.68 to -0.04 (2.72m)
	MM1BH019	Tb (UC)	4	Jul-10 to Jun-12	2.59 to 4.27 (1.68m)
	GA15-BH027	S	1	Sep-15	-12.44
	GA15-BH021	S	1	Sep-15	-6.15
Domain station	GA11-BH019	S (SC-UC)	2	Mar-12 to Jun-12	-0.59 to 1.84 (2.43m)
	GA11-BH026	Tb (UC)	2	Mar-12 to Jun-12	-3.60 to -3.51 (0.09m)
	GA11-BH027*	S (UC)	7	Mar-12 to Sep-15	-5.10 to -4.44 (0.66m)
	MM1BH020	S (UC)	3	Jul-10 to Jul-11	-1.48 to -1.27 (0.21m)
Tunnels Domain to Eastern portal	GA11-BH020	S (UC)	1	Jan-13	-1.62
	GA11-BH021	S (SC-UC)	1	Jan-13	3.37
	GA11-BH022*	S (SC-UC)	6	Jan-13 to Sep-15	3.88 to 4.29 (0.41m)
	GA11-BH023	S (SC-UC)	1	Jan-13	6.22
Eastern portal	GA11-BH024	S (SC-UC)	1	Jan-13	3.29
	GA11-BH025	S (SC-UC)	1	Jan-13	4.62

Notes:

1. UC = unconfined conditions, SC = semi confined conditions, C = confined conditions
2. Corrected for bore inclination and density effects
3. Bore marked with an asterisks are where loggers were installed

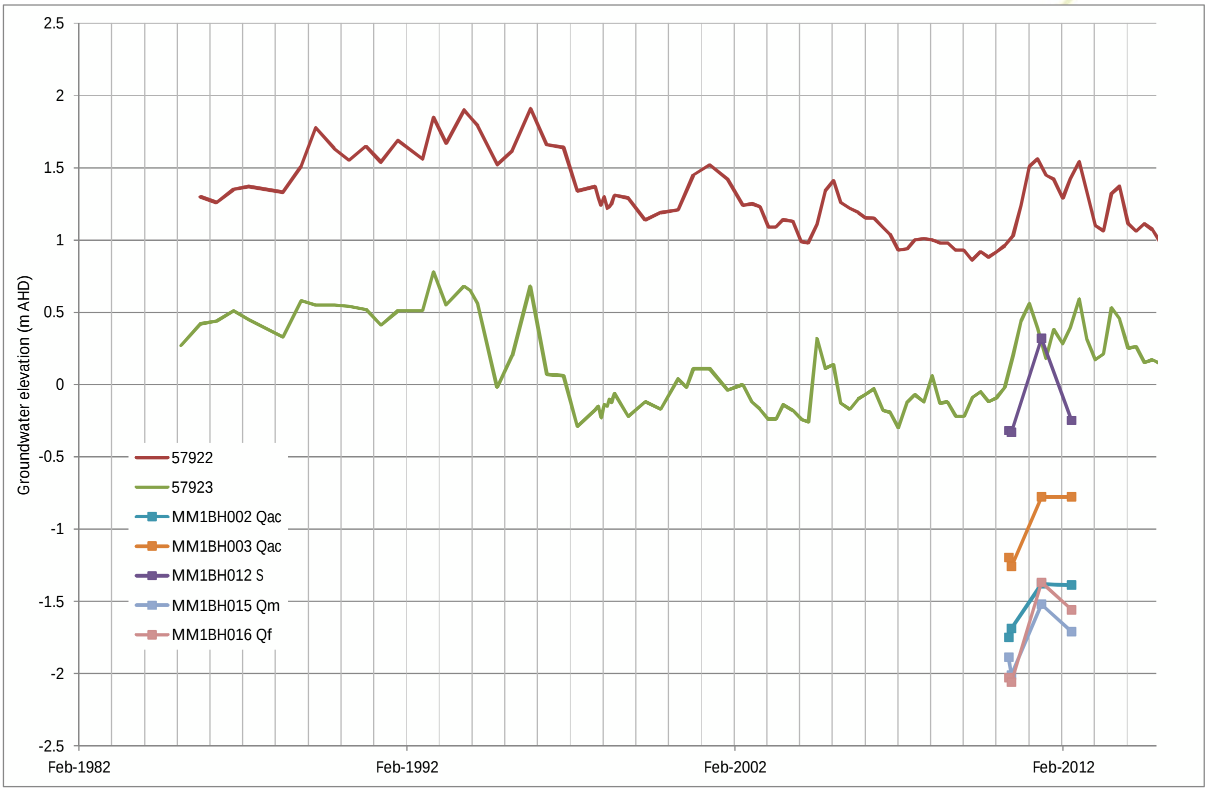

Figure D-3 Hydrographs for SOBN bores 57922 and 57923 and on alignment bores

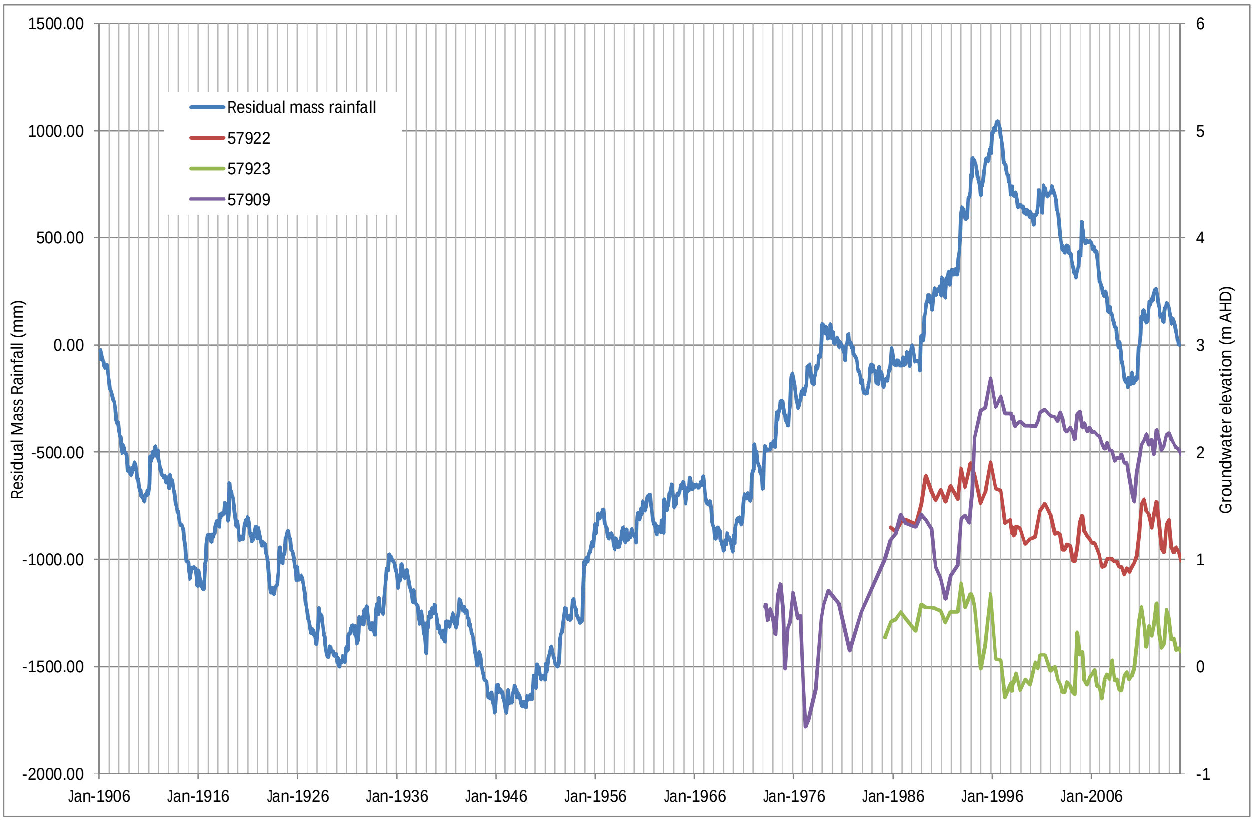

Figure D-4: Residual mass rainfall plot and groundwater hydrographs for SOBN bores

D.5.1 Groundwater Levels Monitored in Precinct 1 Tunnels (Between the Western Portal and Arden Station)

Table D-12 Groundwater levels monitored in the area of tunnels between the western portal and Arden station

Bore ID	Formation monitored[1]	Water level (m AHD)[2]				
		Jun/Jul 2010	Mar 2012	Jun 2012	Jul 2013	Sep 2015
MM1BH001	Qac (C)	-2.28	-	-2.02	-	-
GA11-BH008	Qac (C)	-	-1.53	-1.48	-	-
GA11-BH009	Qf (C)	-	-	-	-1.54	
GA-15-BH002	S					-2.11
GA-15-BH003	Qac (C)					-2.54

Notes:

1. C = confined conditions
2. Corrected for bore inclination and density effects

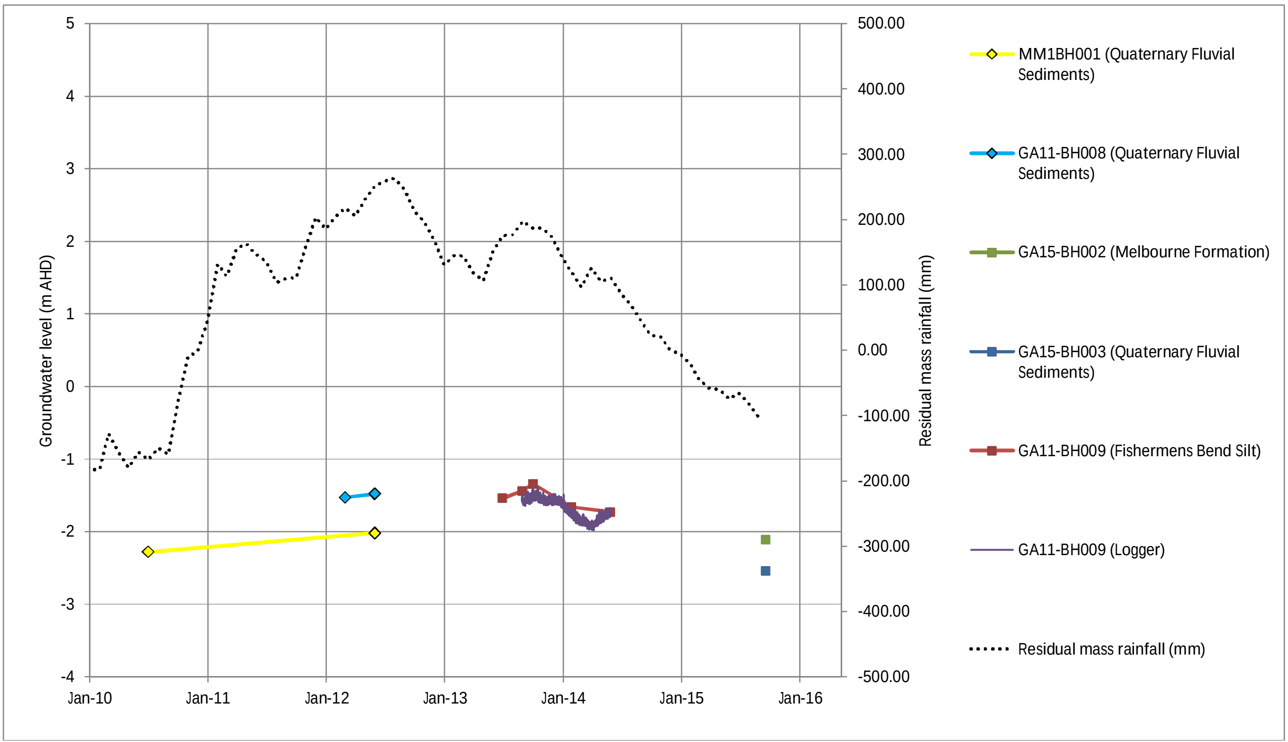

Figure D-5: Bore hydrographs for the area of tunnels between the western portal and Arden station

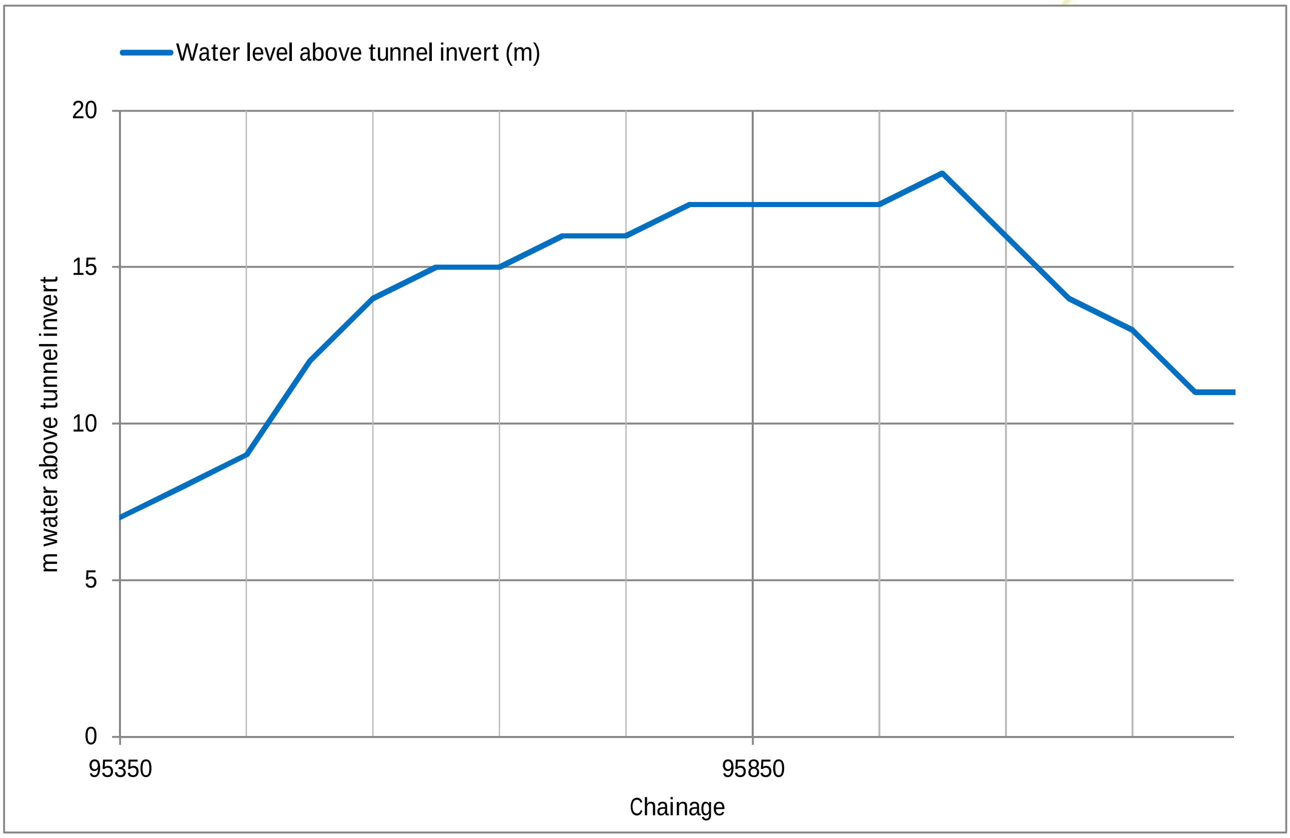

Figure D-6: Approximate height of groundwater above the base of the tunnels in the area of tunnels between the western portal and Arden station based on long section (Golder Associates, 2016a, Appendix G)

D.5.2 Groundwater Levels Monitored in Precinct 1 Tunnels (Between Arden Station and Parkville Station)

Table D-13 Groundwater levels monitored in the tunnels area between Arden and Parkville Stations

Bore ID	Formation monitored[1]	Water level (m AHD)[2]					
		Jun/Jul 2010	Aug 2010	Jul 2011	Jun 2012	Jul 2013	Sep 2015
MM1BH006	S (SC-UC)	5.91	5.94	6.92	7.19	-	7.07
GA11-BH013	S (SC-UC)	-	-	-	-	7.88	7.47
MM1BH007	S (SC-UC)	10.79	10.74	11.74	-	-	
GA11-BH012	S (SC-UC)						1.32

Notes:

1. UC = unconfined conditions, SC = semi confined conditions
2. Corrected for bore inclination and density effects

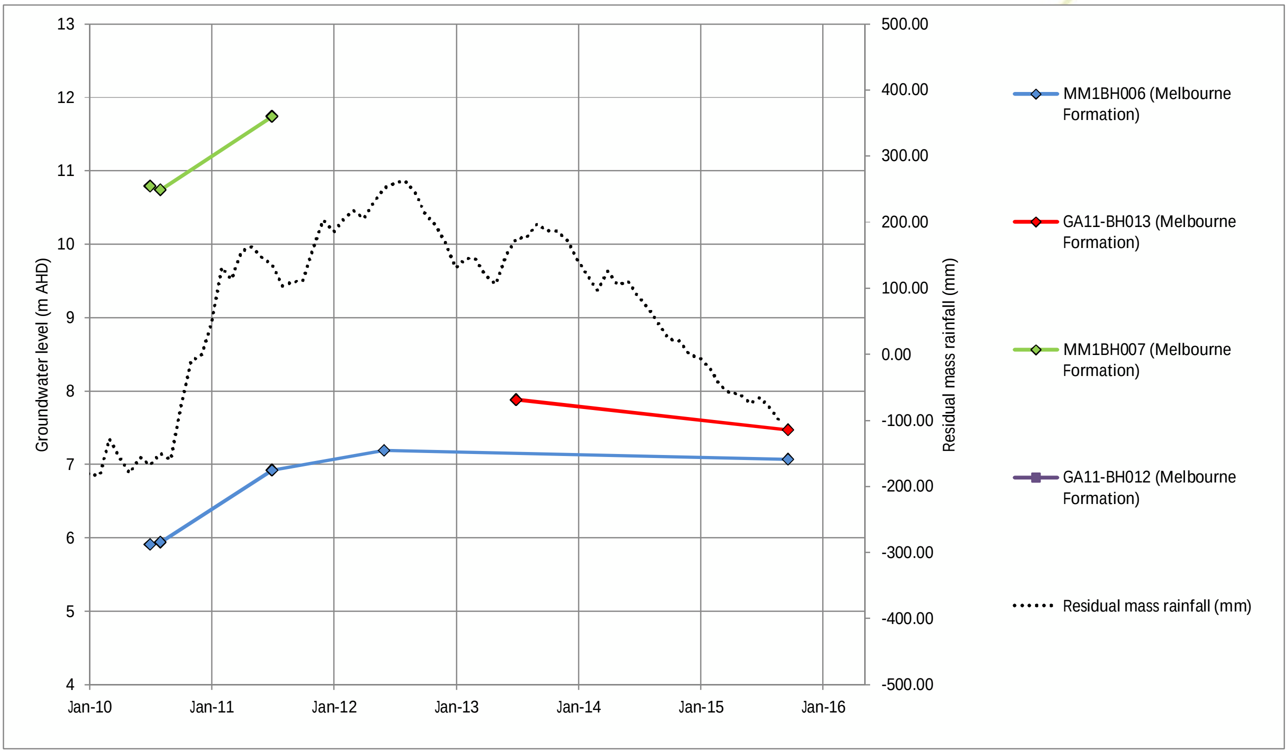

Figure D-7: Bore hydrographs for the tunnels area between the Arden and Parkville stations

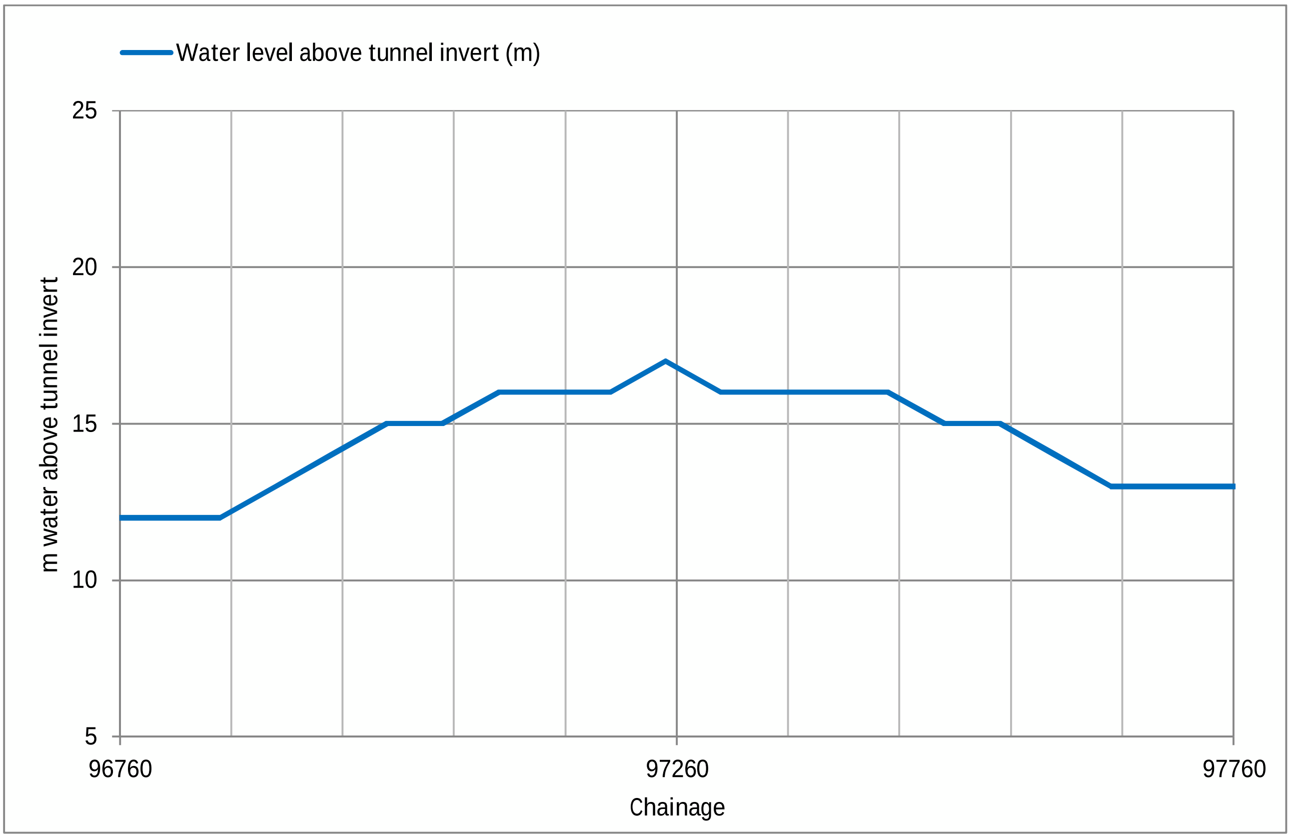

Figure D-8: Approximate height of groundwater above the base of the tunnels in the tunnels area between the Arden and Parkville stations based on long section (Golder Associates, 2016a, Appendix G)

D.5.3 Groundwater levels monitored in Precinct 1 Tunnels (between Parkville Station and CBD North Station)

Table D-14 Groundwater levels monitored in the tunnels area between Parkville and CBD North stations

Bore ID	Formation monitored[1]	Water level (m AHD)[2]			
		Jun/Jul 2010	Aug 2010	Jun 2012	Jul 2013
MM1BH010	S (SC-UC)	21.83	21.78	22.28	-
GA11-BH014	S (SC-UC)	-	-	-	19.51

Notes:

1. UC = unconfined conditions, SC = semi confined conditions
2. Corrected for bore inclination and density effects

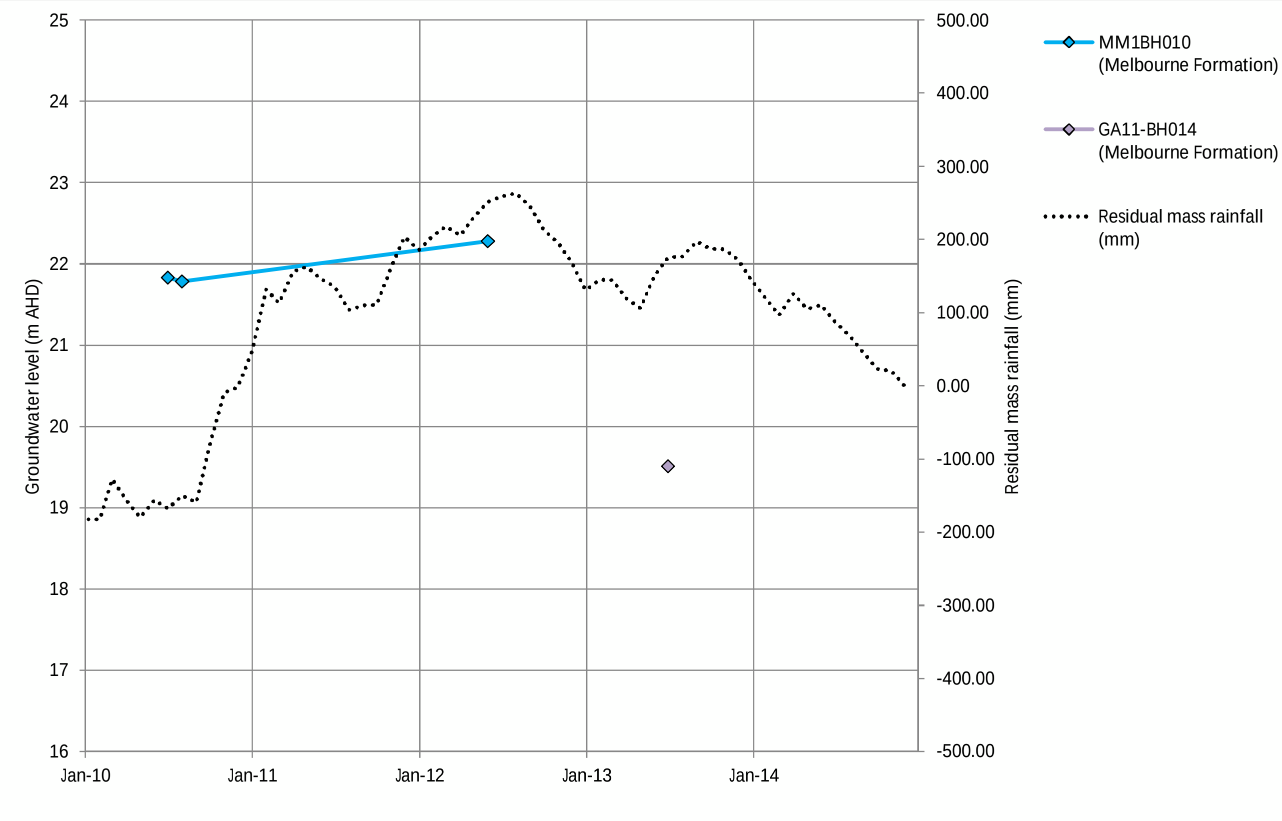

Figure D-9 Bore hydrographs for the tunnels area between Parkville station and CBD North station

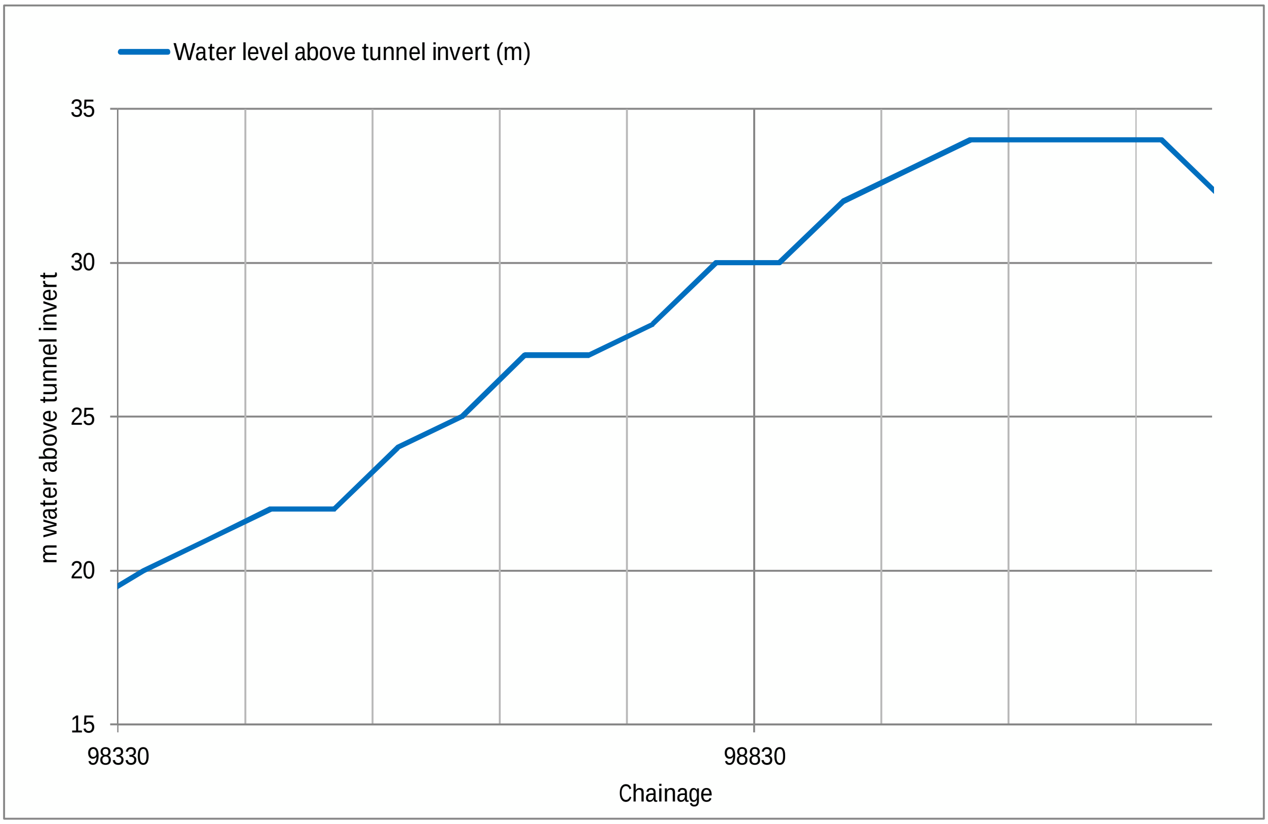

Figure D-10 Approximate height of groundwater above the base of the tunnels in the tunnels area between Parkville and CBD North stations based on long section (Golder Associates, 2016a, Appendix G)

D.5.4 Groundwater levels monitored in Precinct 1 Tunnels (between CBD North Station and CBD South Station)

Table D-15 Groundwater levels monitored in the tunnels area between CBD North and CBD South stations

Bore ID	Formation monitored[1]	Water level (m AHD)[2]			
		Jun/Jul 2010	Aug 2010	Jul 2011	Jun 2012
MM1BH012	S (SC-UC)	-0.32	-0.33	0.32	-0.25

Notes:

1. UC = unconfined conditions, SC = semi confined conditions
2. Corrected for bore inclination and density effects

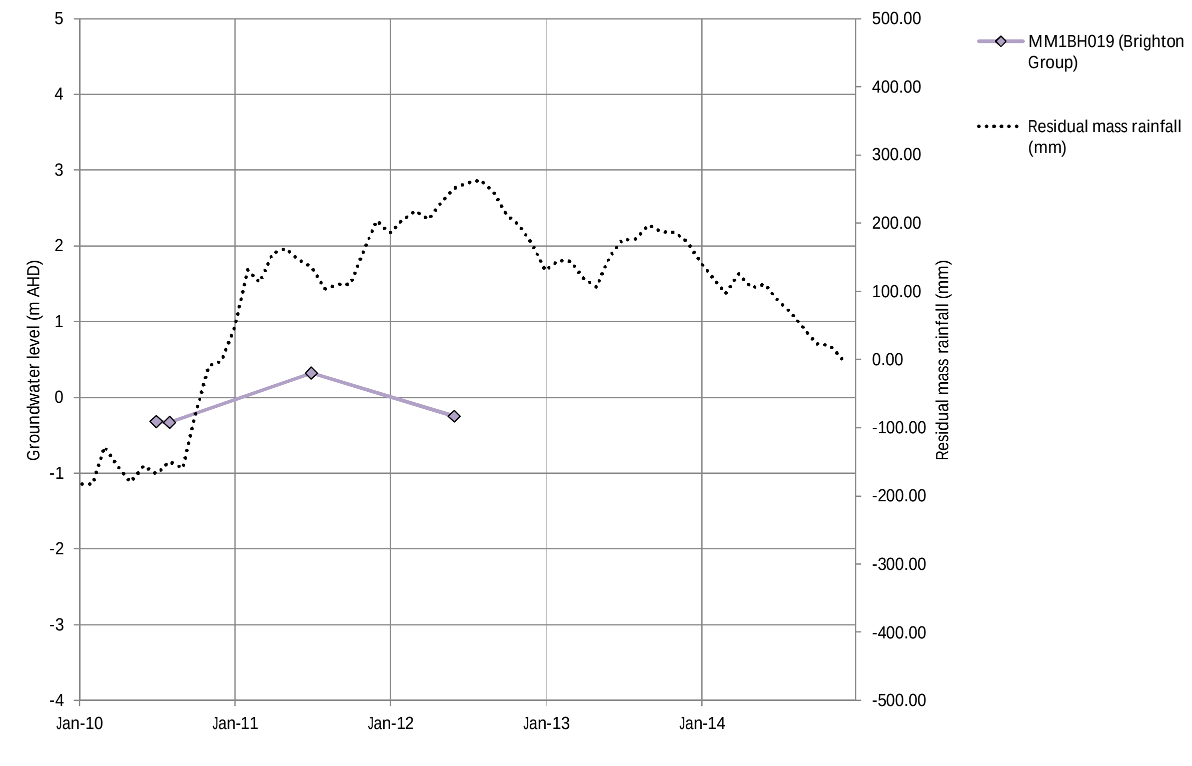

Figure D-11: Bore hydrographs for the tunnels area between CBD North and CBD South stations

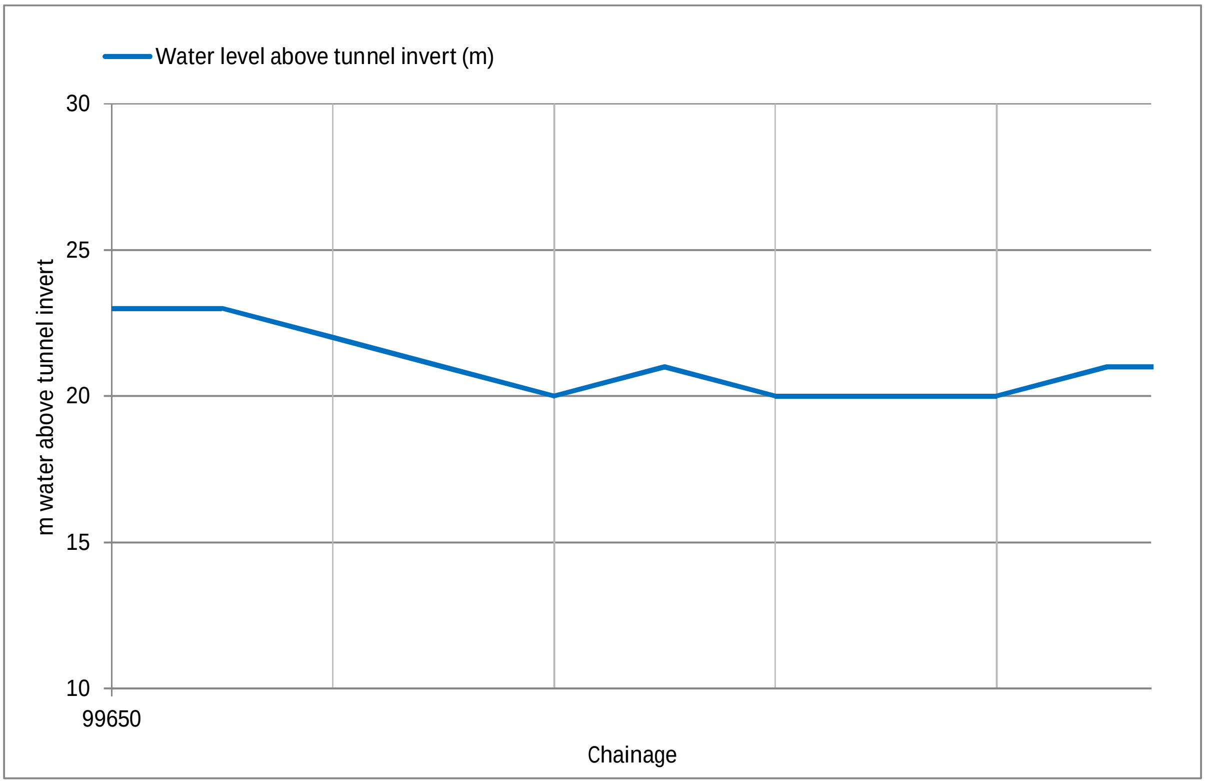

Figure D-12: Approximate height of groundwater above the base of the tunnels in the tunnels area between CBD North and CBD South stations based on long section (Golder Associates, 2016a, Appendix G)

D.5.5 Groundwater levels monitored in Precinct 1 Tunnels (between CBD South Station and Domain Station)

Table D-16 Groundwater levels monitored in the tunnels area between CBD South and Domain stations

Bore ID	Formation monitored[1]	Water level (m AHD)[2]										
		Jun/ Jul 2010	Aug 2010	Jul 2011	Mar 2012	Jun 2012	Jul 2013	Aug 2013	Oct 2013	Jan 2014	May 2014	Sep 2015
MM1BH015	Qm (C)	-1.89	-2.01	-1.52	-	-1.71	-	-1.59	-1.55	-1.69	-1.69	-1.62
GA11-BH017	Qm (C)	-	-	-	-0.96	-1.16	-	-1.2	-1.15	-1.31	-1.29	
GA11-BH041	Qm (C)	-	-	-	-	-	-0.82					
MM1BH016	Qf (C)	-2.03	-2.06	-1.37	-	-1.56	-	-1.36	-1.33	-1.48	-1.44	-1.52
GA11-BH018	Qha (C)	-	-	-	-	-	-0.83	-0.65	-0.77	-0.91	-1.03	-0.83
MM1BH017	Qc (SC-UC)	-1.29	-1.27	-0.12	-	0.21	-					
MM1BH018	S (SC-UC)	-2.68	-1.43	-1.06	-	-0.45	-	-0.21	0.04			-0.66
MM1BH019	Tb (UC)	2.59	3.07	4.27	-	3.31	-					
GA15-BH027	S (SC-UC)											-12.44
GA15-BH121	S (SC-UC)											-6.15

Notes:

1. SC = semi confined conditions, C = confined conditions, UC = unconfined conditions
2. Corrected for bore inclination and density effects

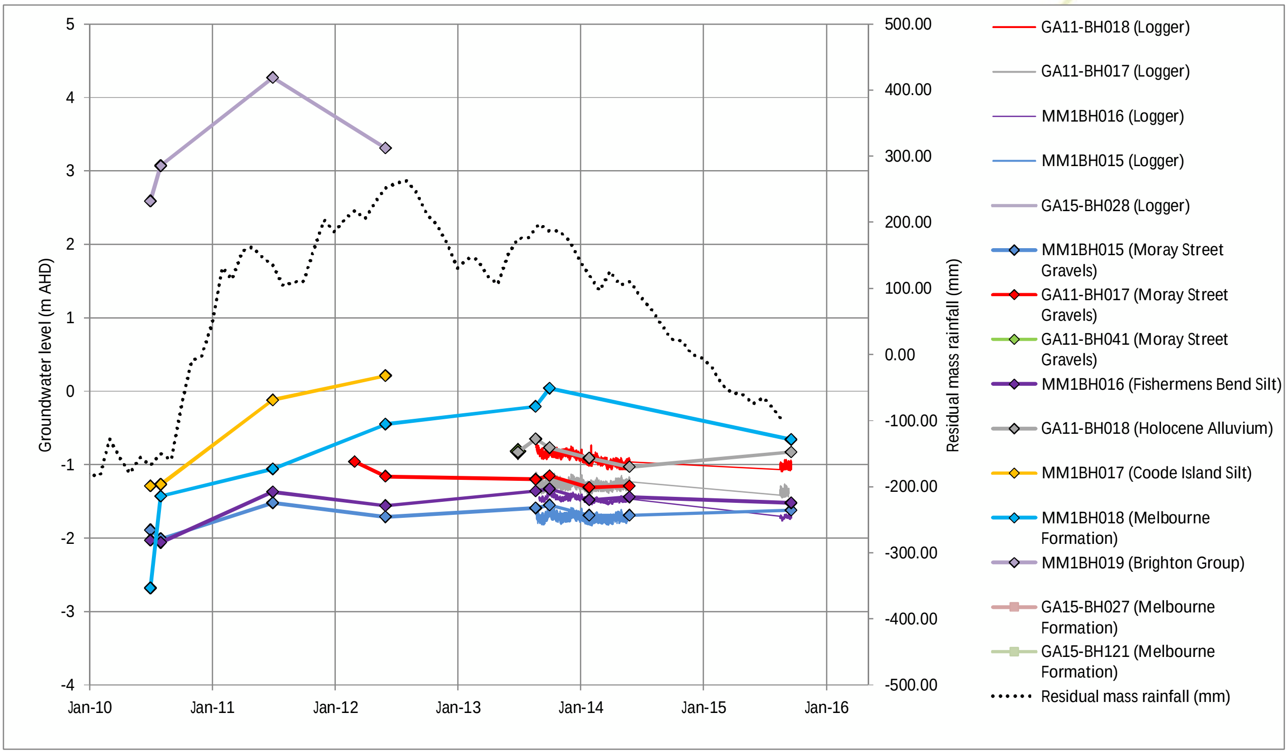

Figure D-13: Bore hydrographs for the tunnels area between CBD South and Domain stations

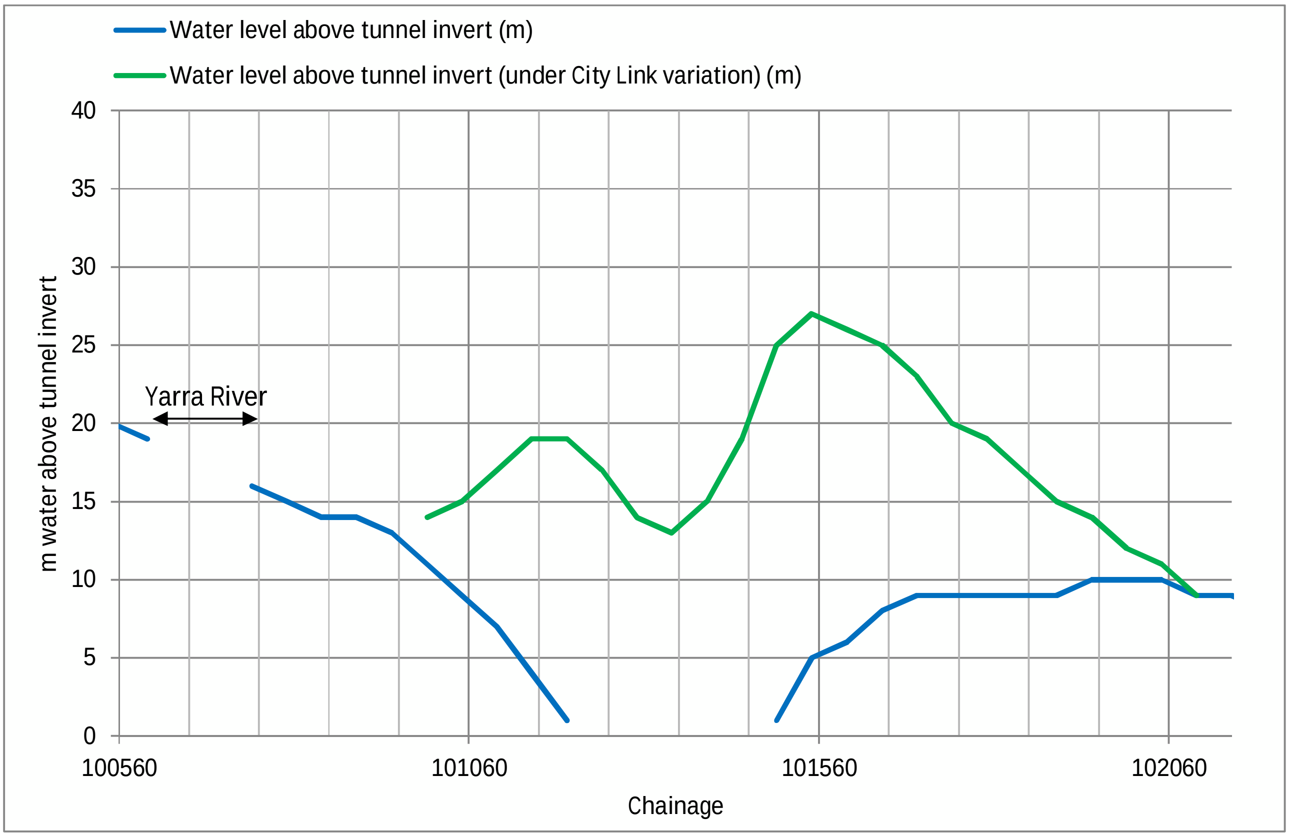

Figure D-14: Approximate height of groundwater above the base of the tunnel in the tunnel area between CBD South and Domain stations based on long section (Golder Associates, 2016a, Appendix G) including the below CityLink alternative design option

D.5.6 Groundwater Levels Monitored in Precinct 1 Tunnels (Between Domain Station and the Eastern Portal)

Table D-17 Groundwater levels monitored in the tunnels area between Domain station and the eastern portal

Bore ID	Formation monitored[1]	Water level (m AHD)[2]					
		Jan 2013	Aug 2013	Oct 2013	Jan 2014	May 2014	Sep 2015
GA11-BH020	S (UC)	-1.62	-	-	-	-	-
GA11-BH021	S (SC-UC)	3.37	-	-	-	-	-
GA11-BH022	S (SC-UC)	4.29	4.21	4.20	4.17	4.11	3.88
GA11-BH023	S (SC-UC)	6.22	-	-	-	-	-

Notes:

1. UC = unconfined conditions, SC = semi confined conditions
2. Corrected for bore inclination and density effects

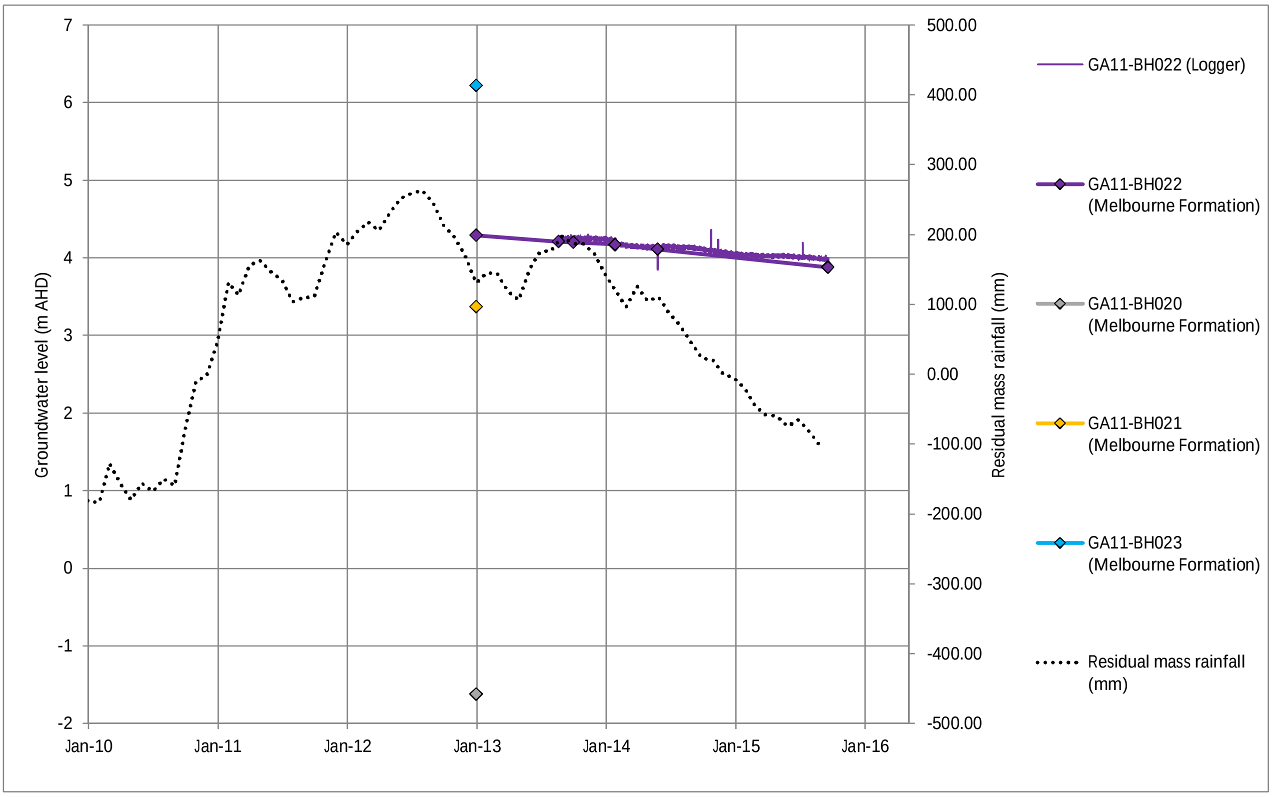

Figure D-15: Bore hydrographs for the tunnels area between Domain station and the eastern portal

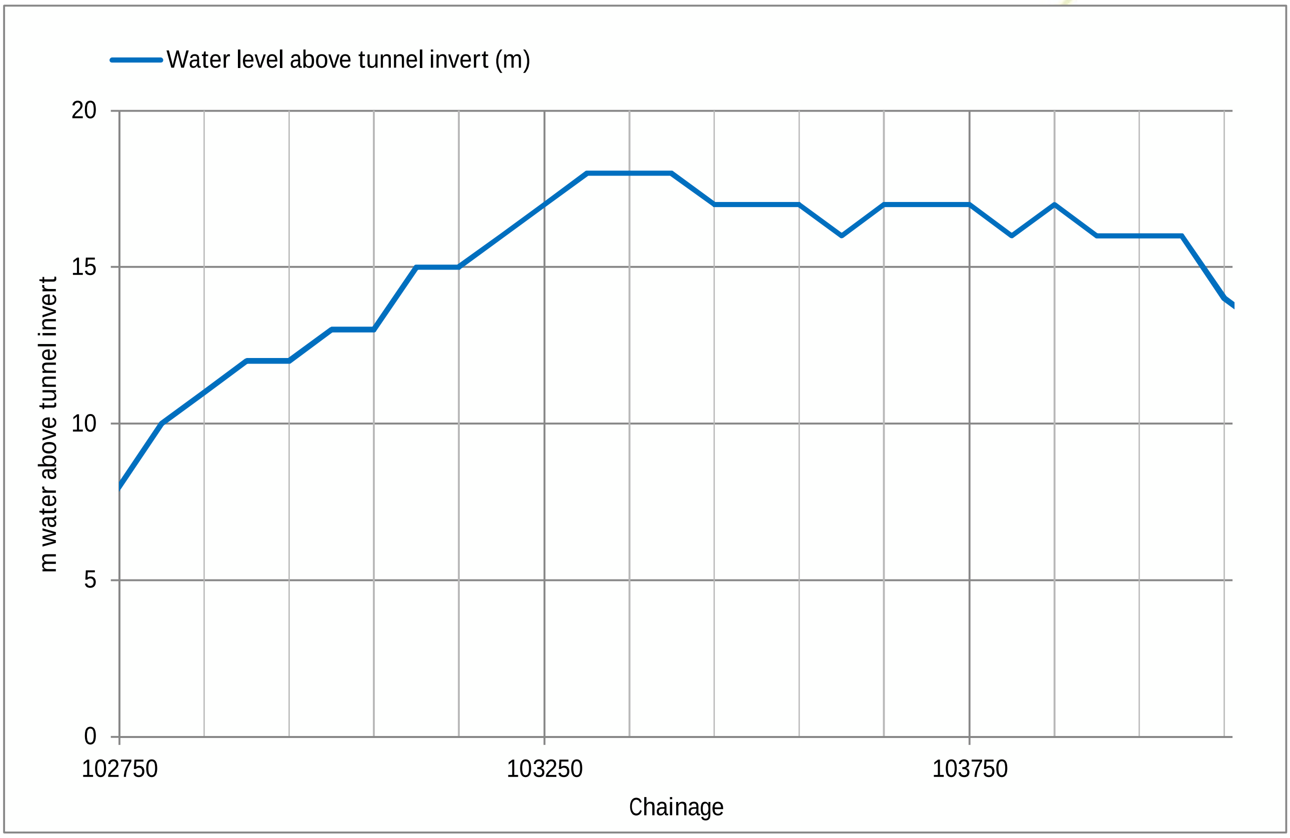

Figure D-16: Approximate height of groundwater above the base of the tunnels in the tunnels area between Domain station and the eastern portal based on long section (Golder Associates, 2016a, Appendix G)

D.5.7 Groundwater Levels Monitored in Precinct 2 Western Portal (Kensington)

Table D-18 Groundwater levels monitored at the western portal

Bore ID	Formation monitored[1]	Water level (m AHD)[2]								
		Jun/ Jul 2010	Mar 2012	Jun 2012	Jul 2013	Aug 2013	Oct 2013	Jan 2014	May 2014	Sept 2015
GA11-BH001	Qm (C)	-	-	-	-0.43	-	-	-	-	-
GA11-BH031	Tov (C)	-	-	-	-1.00	-	-	-	-	-1.18
GA11-BH002	Tov (C)	-	-0.99	-0.88	-	-	-	-	-	-1.32
GA11-BH003	Tov (C)	-	-1.58	-1.46	-	-	-	-	-	-
GA11-BH005	Tov (SC-C)	-	-1.58	-1.55	-	-	-	-	-	-
GA11-BH007	*Tw (C)*	-	*-1.80*	*-1.76*	-	*-1.84*	*-1.85*	*-2.05*	*-2.12*	-

Notes:

1. SC = semi confined conditions, C = confined conditions
2. Corrected for bore inclination and density effects

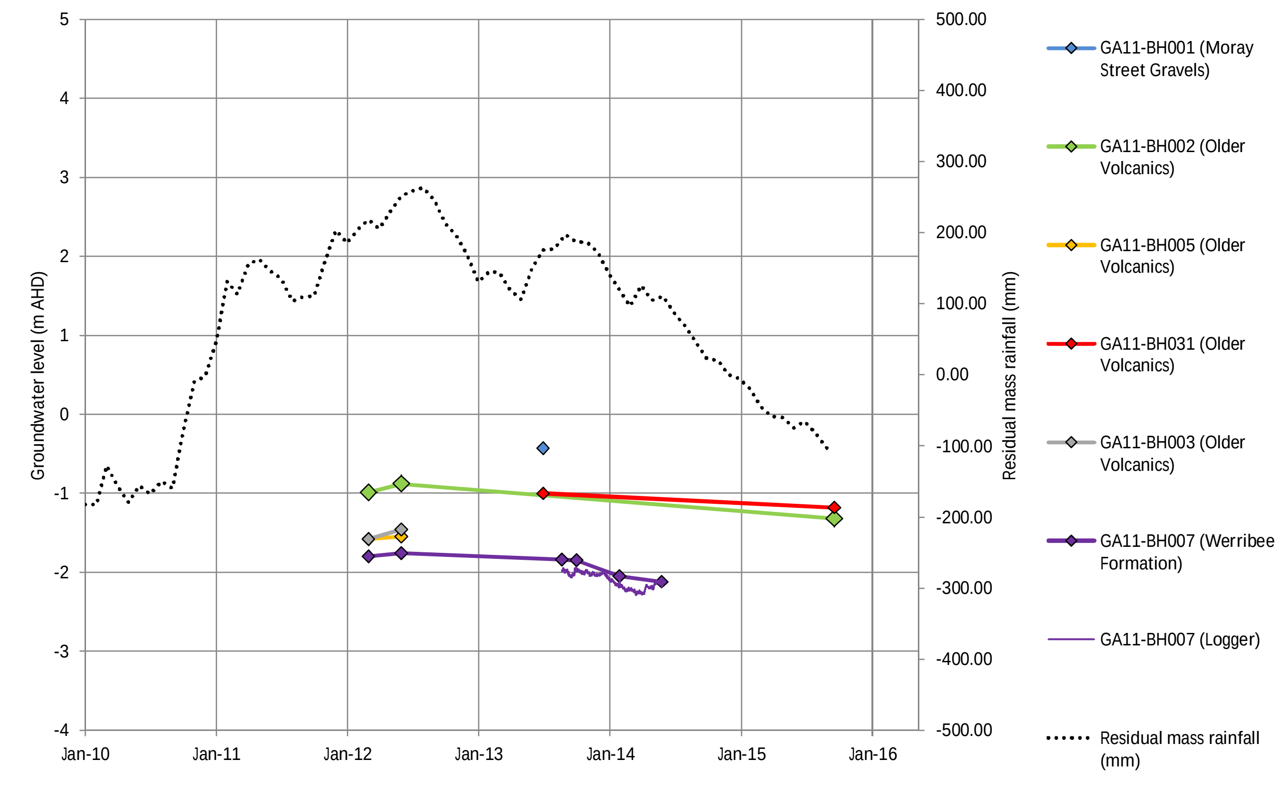

Figure D-17: Bore hydrographs for the western portal

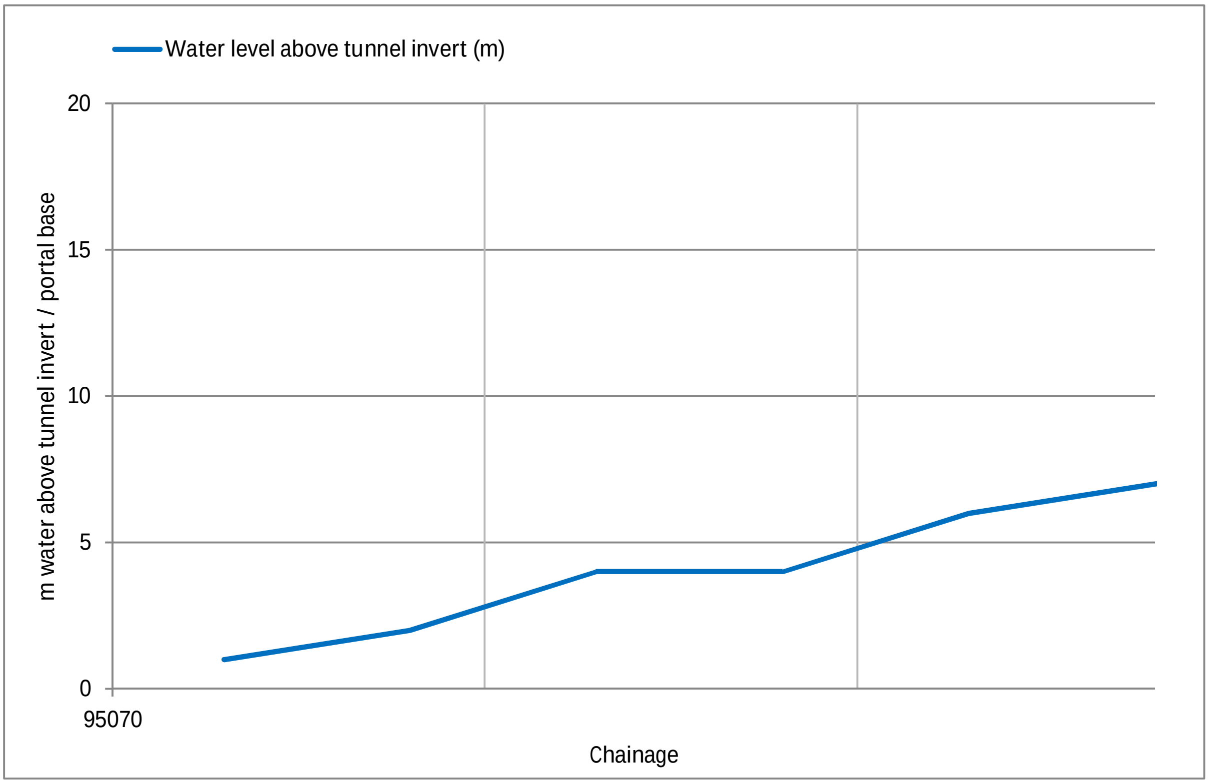

Figure D-18: Approximate height of groundwater above the base of the tunnels and station floor (including deep engineering boxes) in the western portal precinct based on long section (Golder Associates, 2016a, Appendix G).

D.5.8 Groundwater Levels Monitored in Precinct 3 Arden Station

Table D-19 Groundwater levels monitored in the Arden station precinct

Bore ID	Formation monitored[1]	Water level (m AHD)[2] Jun/ Jul 2010	Aug 2010	Jul 2011	Jun 2012	Jul 2013	Aug 2013	Sept 2013	Oct 2013	Jan/ Feb 2014	May/ Jun 2014
GA11-BH009	Qf (C)	-	-	-	-	-1.54	-1.44	-	-1.34	-1.66	-1.73
MM1BH002	Qf (C)	-1.75	-1.69	-1.38	-1.39	-					
MM1BH003	Qf (C)	-1.20	-1.26	-0.78	-0.78	-					
MM1BH004	Tw (SC-C)	-1.28	-	-0.87	-0.87	-					
GA11-BH011	S (SC-C)	-	-	-	-	-1.00		-0.91	-0.79	-1.09	-1.01

Notes:

1. SC = semi confined conditions, C = confined conditions
2. Corrected for bore inclination and density effects

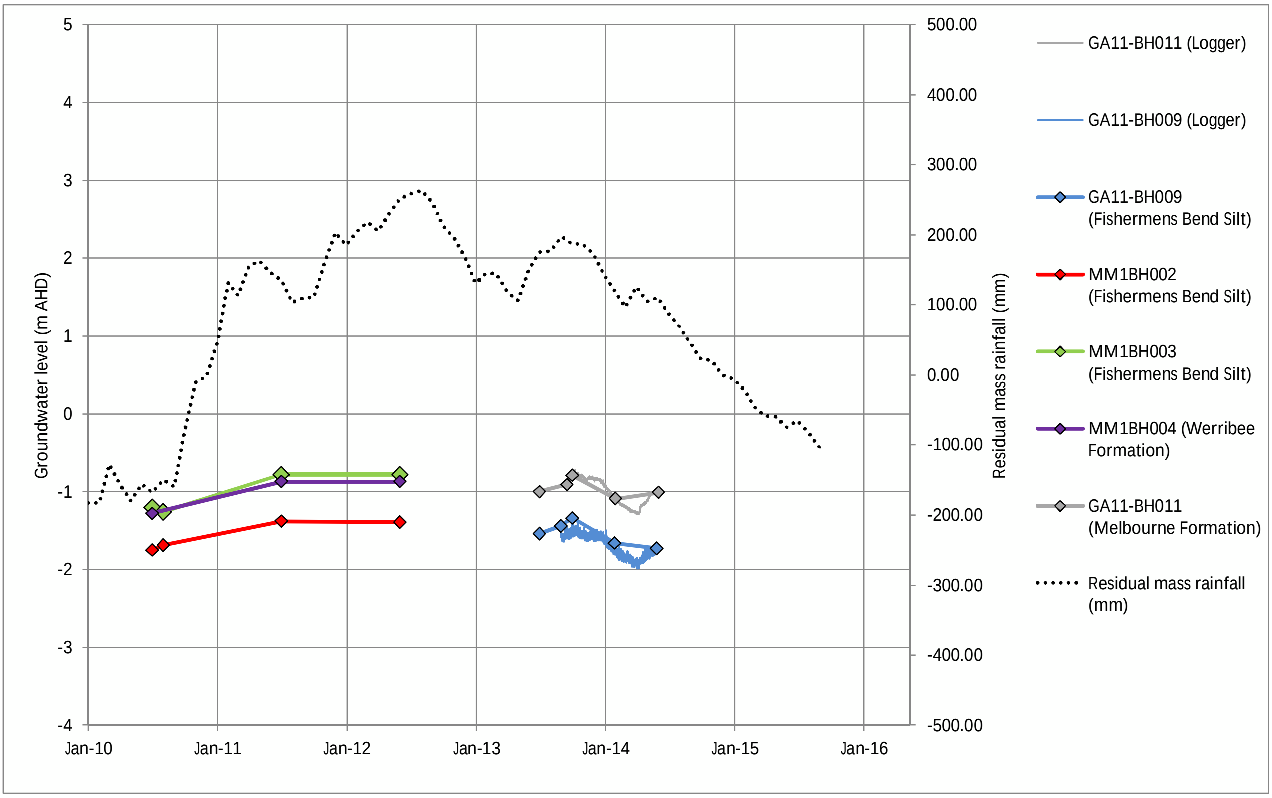

Figure D-19: Bore hydrographs for the Arden station precinct

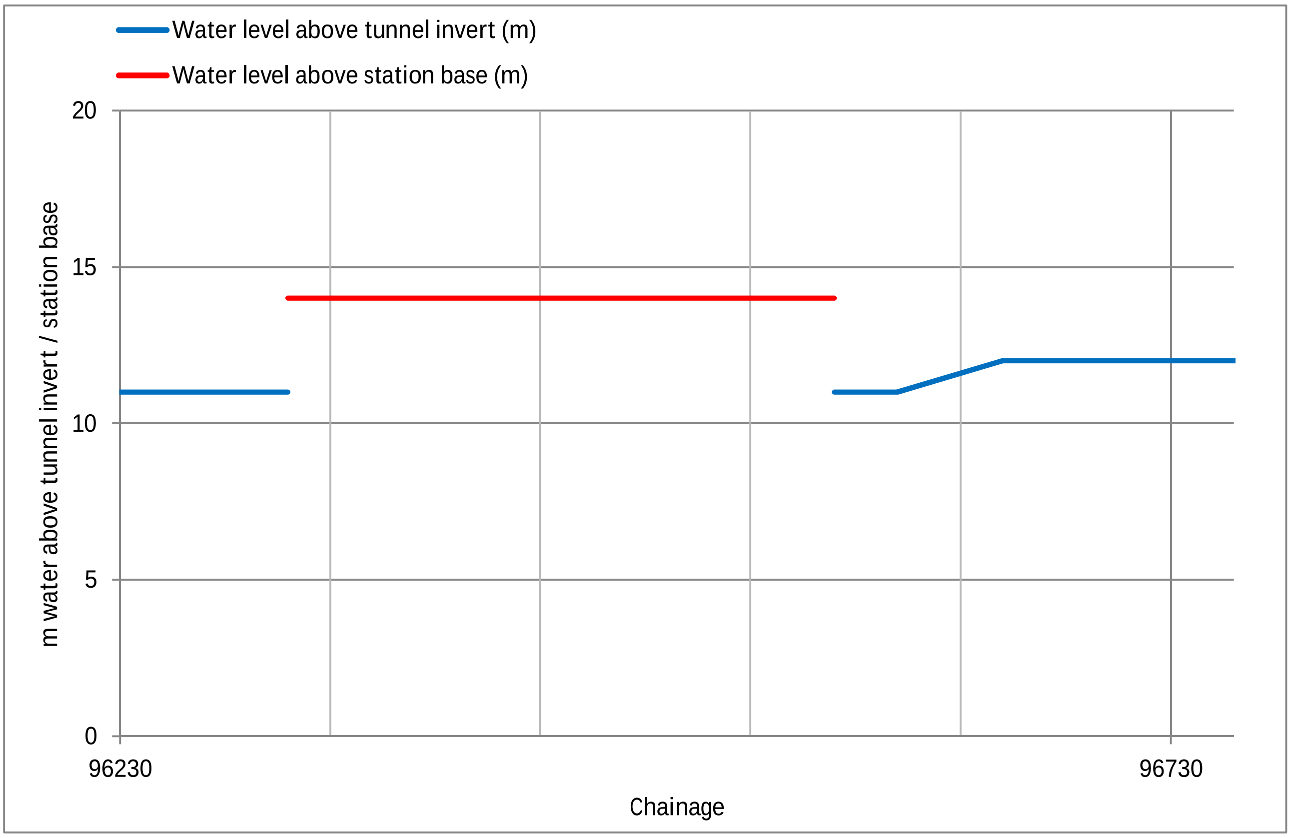

Figure D-20: Approximate height of groundwater above the base of the tunnels and station floor (including deep engineering boxes) in Arden station precinct based on long section (Golder Associates, 2016a, Appendix G).

D.5.9 Groundwater levels monitored in Precinct 4 Parkville Station

Table D-20 Groundwater levels monitored in Parkville station precinct

Bore ID	Formation monitored[1]	Water level (m AHD)[2]							
		Jun/Jul 2010	Jul 2011	Jun 2012	Aug 2013	Oct 2013	Jan 2014	May 2014	Sept 2015
MM1BH008	S (SC-UC)	20.29	20.84	18.23	-	-	-	-	-
MM1BH009	S (SC-UC)	23.87	24.09	24.13	21.4	21.38	21.16	21.04	21.59

Notes:

1. UC = unconfined conditions, SC = semi confined conditions
2. Corrected for bore inclination and density effects

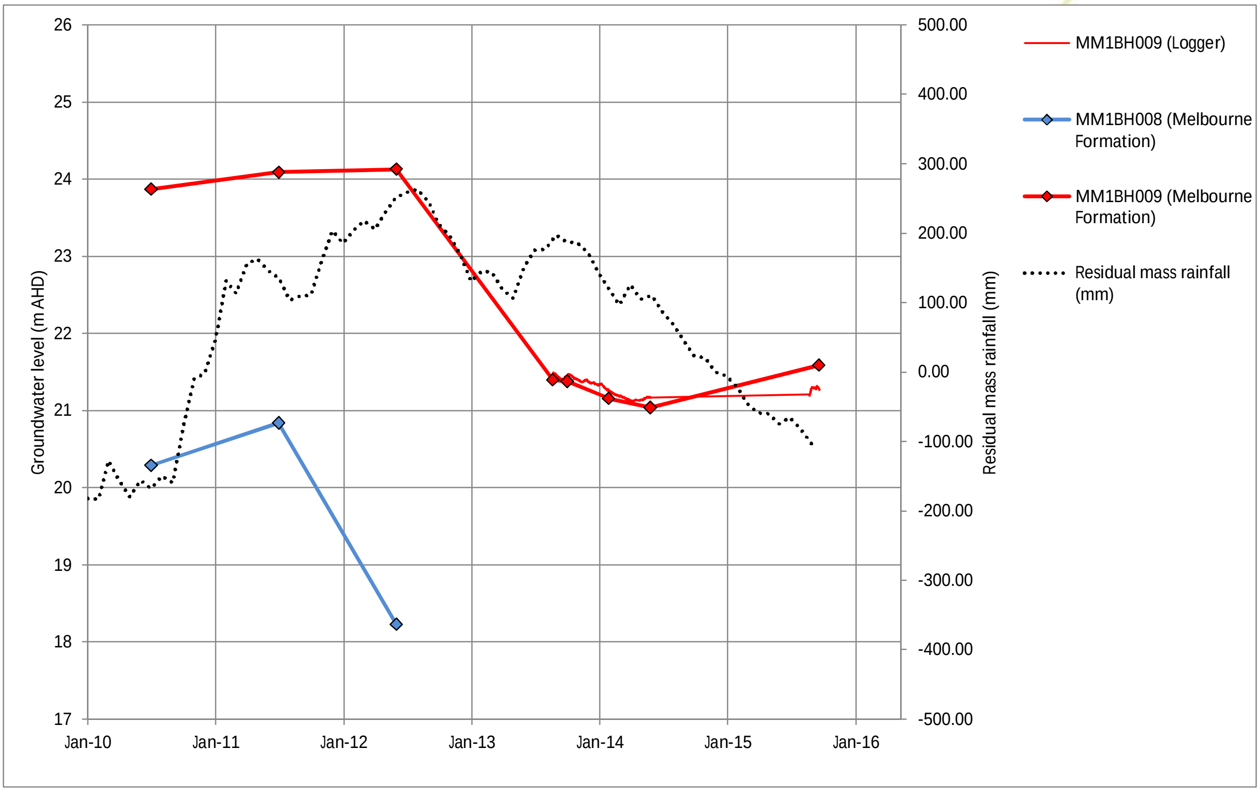

Figure D-21: Bore hydrographs for the Parkville station precinct

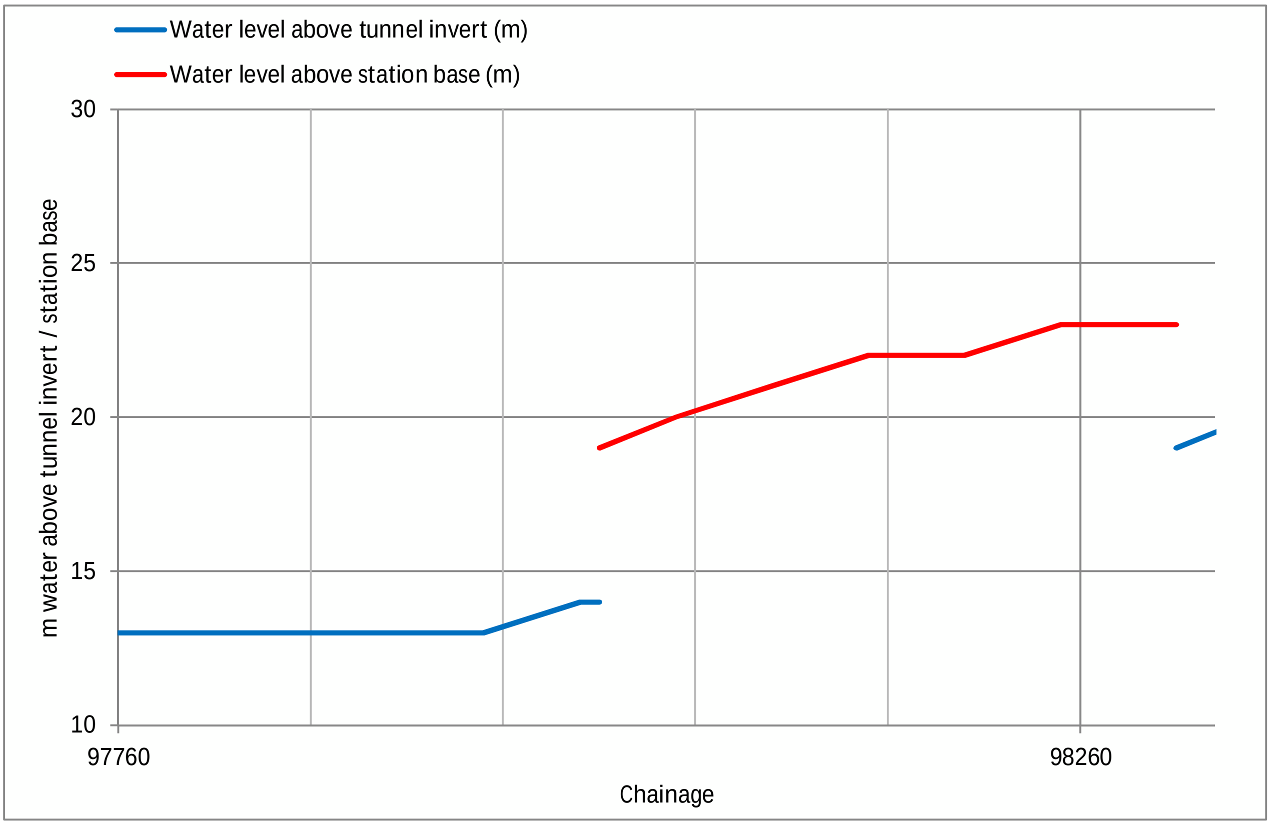

Figure D-22: Approximate height of groundwater above the base of the tunnels in Parkville station precinct based on long section (Golder Associates, 2016a, Appendix G)

D.5.10 Groundwater Levels Monitored in Precinct 5 CBD North Station

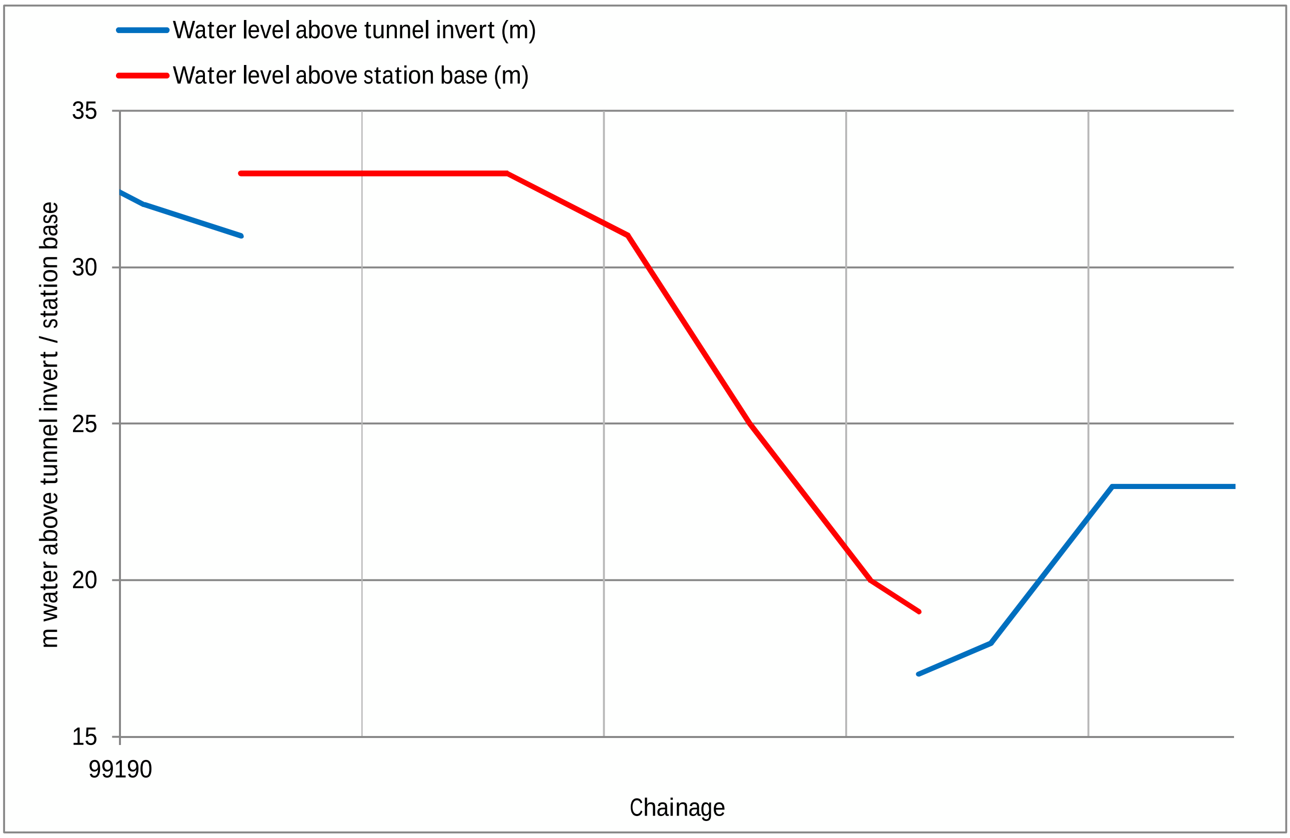

Figure D-23: Approximate height of groundwater above the base of the tunnels and station floor in CBD North station precinct based on long section (Golder Associates, 2016a, Appendix G)

D.5.11 Groundwater levels monitored in Precinct 6 CBD South Station

Table D-22 Groundwater levels monitored in CBD South station precinct

Bore ID	Formation monitored1	Water level (m AHD)2		
		Jun/Jul 2010	Jul 2011	Sept 2015
MM1BH013	S (SC-UC)	-0.02	1.06	-
GA15-BH018	S (SC-UC)	-	-	-0.44
GA15-BH019	S (SC-UC)	-	-	-1.52

Notes:

1. UC = unconfined conditions, SC = semi confined conditions
2. Corrected for bore inclination and density effects

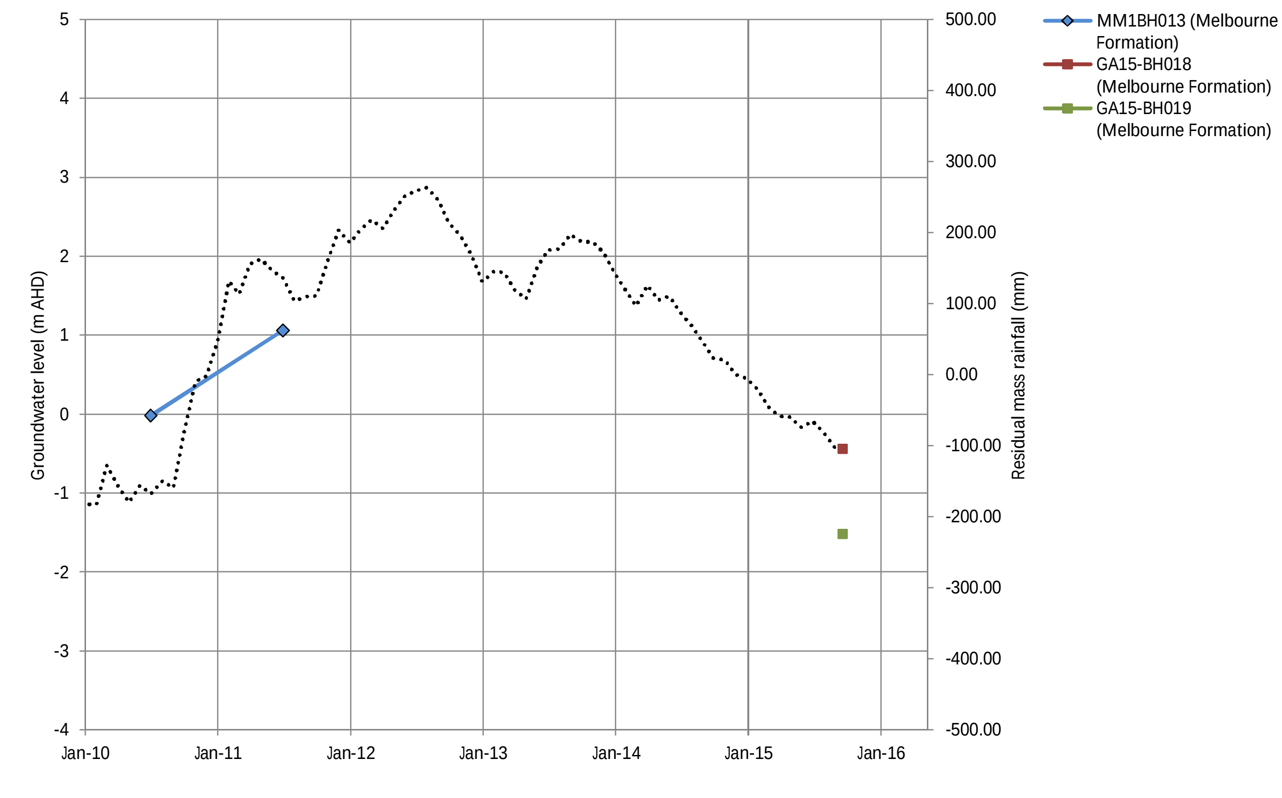

Figure D-24: Bore hydrographs for CBD South station precinct

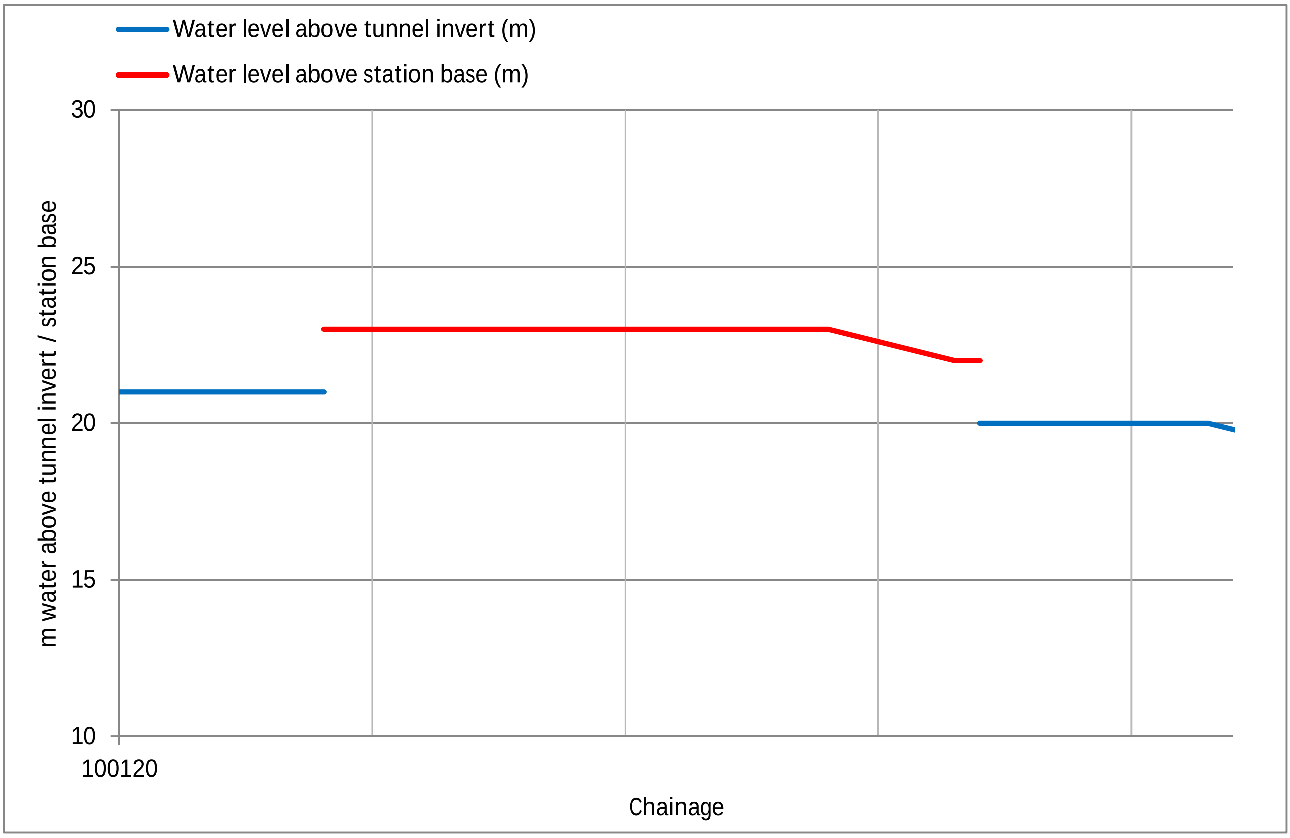

Figure D-25: Approximate height of groundwater above the base of the tunnels and station floor in CBD South station precinct based on long section (Golder Associates, 2016a, Appendix G)

D.5.12 Groundwater Levels Monitored in Precinct 7 Domain Station

Table D-23 Groundwater levels monitored in Domain station precinct

Bore ID	Formation monitored[1]	Water level (m AHD)[2]									
		Jun/Jul 2010	Aug 2010	Jul 2011	Mar 2012	Jun 2012	Aug 2013	Oct 2013	Jan 2014	May 2014	Sept 2015
GA11-BH019	S (SC-UC)	-	-	-	-0.59	1.84	-	-	-	-	-
GA11-BH026	Tb (UC)	-	-	-	-3.51	-3.60	-	-	-	-	-
GA11-BH027[3]	S (UC)	-	-	-	-4.93	-4.95	-4.57	-4.44	-4.85	-4.95	-5.1
MM1BH020	S (UC)	-1.32	-1.48	-1.27	-	-	-	-	-	-	-
GA15-BH029[4]	S (UC)	-	-	-	-	-	-	-	-	-	0.4
GA15-BH030[4]	S (UC)	-	-	-	-	-	-	-	-	-	-1.6
GA15-BH032[4]	S (UC)	-	-	-	-	-	-	-	-	-	-3.0
GA15-BH033[4]	S (UC)	-	-	-	-	-	-	-	-	-	-3.2

Notes:

1. UC = unconfined conditions, SC = semi confined conditions
2. Corrected for bore inclination and density effects
3. Level logger also installed between August 2013 and May 2014
4. Top of bore casing is assumed to be at groundwater surface (bore not yet surveyed), and water level may be affected by nearby well development

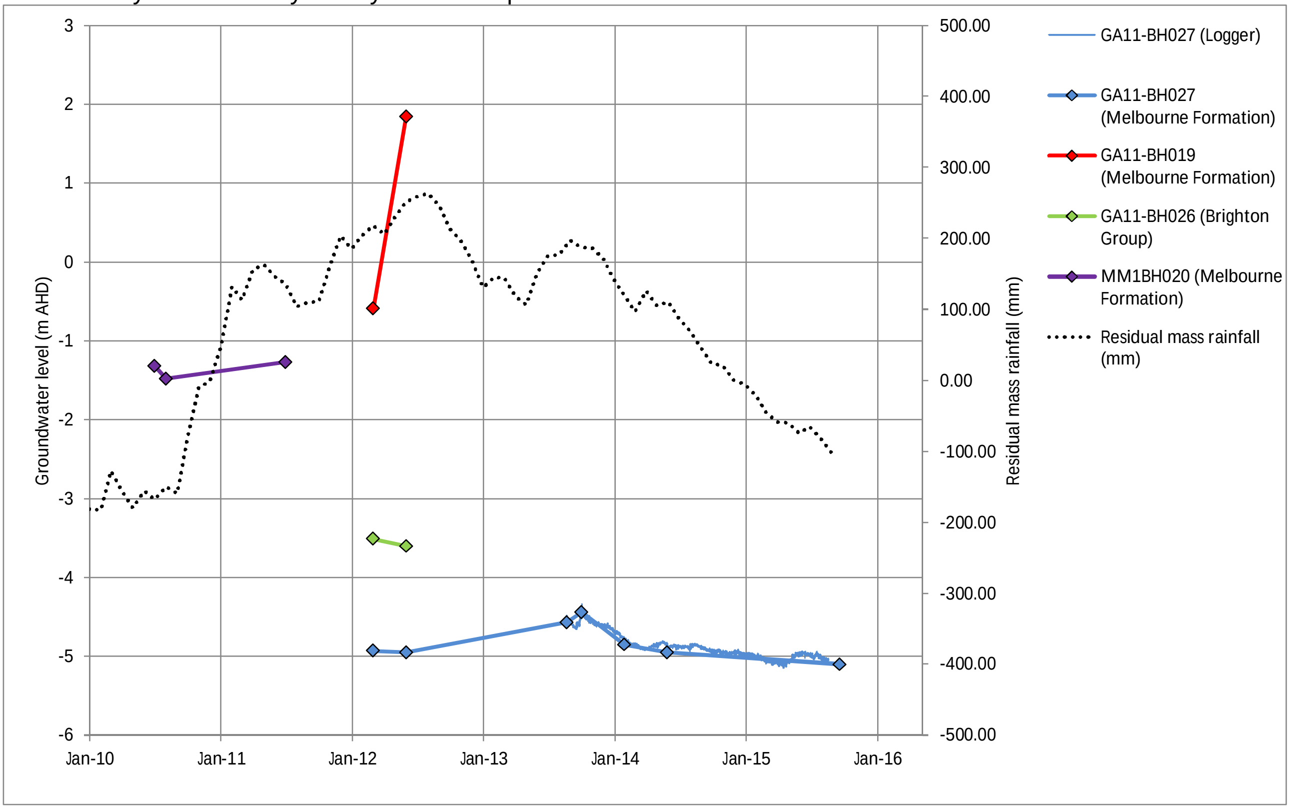

Figure D-26: Bore hydrographs for the Domain station precinct

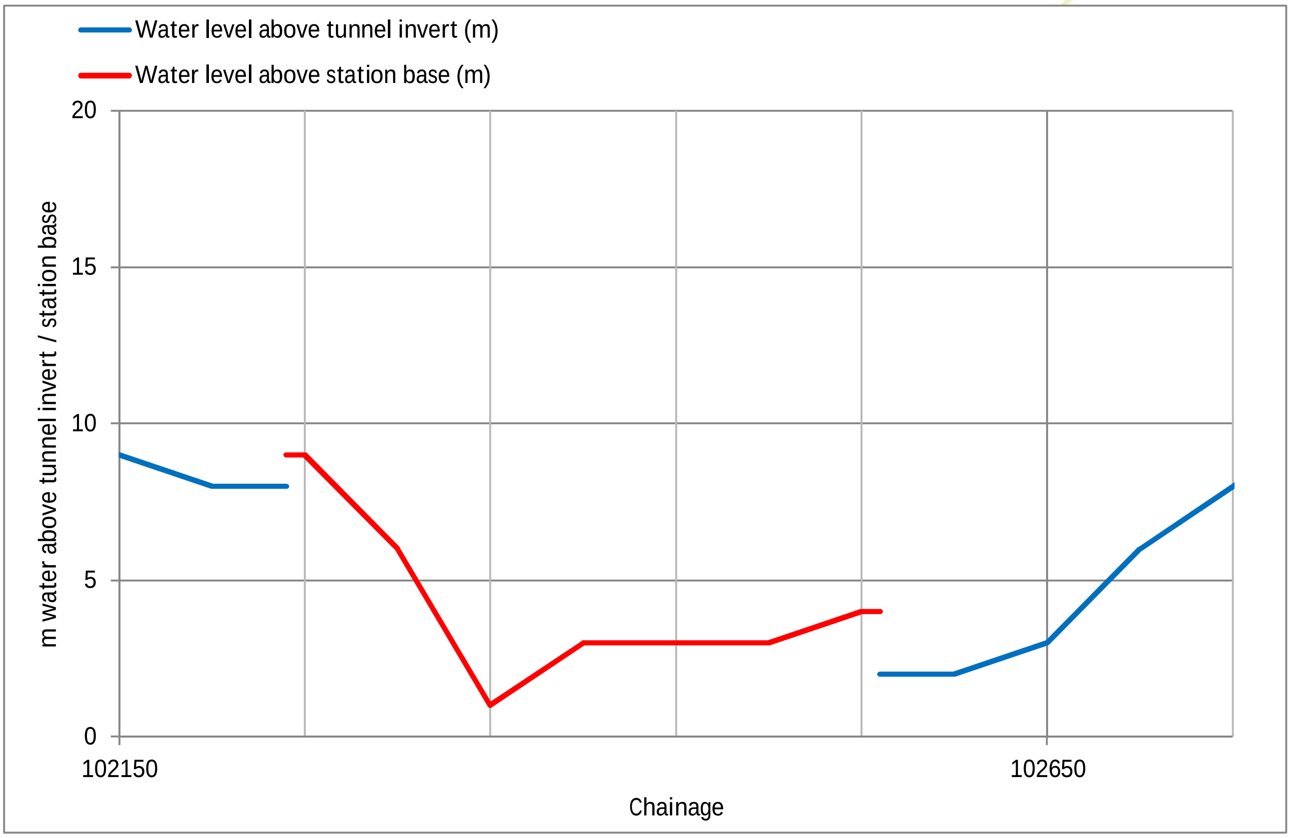

Figure D-27: Approximate height of groundwater above the base of the tunnels and station floor at Domain station precinct based on long section (Golder Associates, 2016a, Appendix G)

D.5.13 Groundwater Levels Monitored in Precinct 8 Eastern Portal

Table D-24 Groundwater levels monitored in the eastern portal precinct

Bore ID	Formation monitored[1]	Screen depth (mBGL)	Water level (m AHD)[2] Jan 2013
GA11-BH024	S (SC-UC)	18 - 21	3.29
GA11-BH025	S (SC-UC)	16.5 – 19.5	4.62

Notes:

1. UC = unconfined conditions, SC = semi confined conditions
2. Corrected for bore inclination and density effects

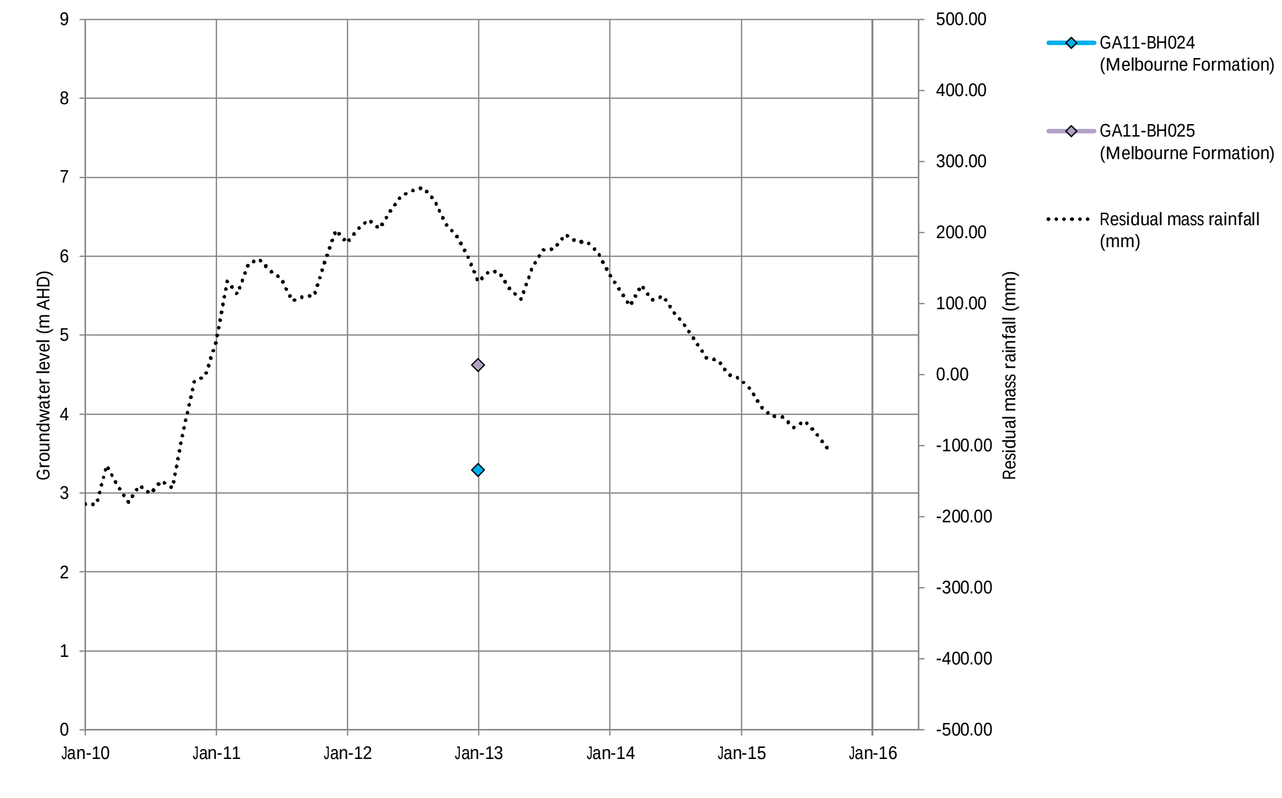

Figure D-28: Bore hydrographs for the eastern portal

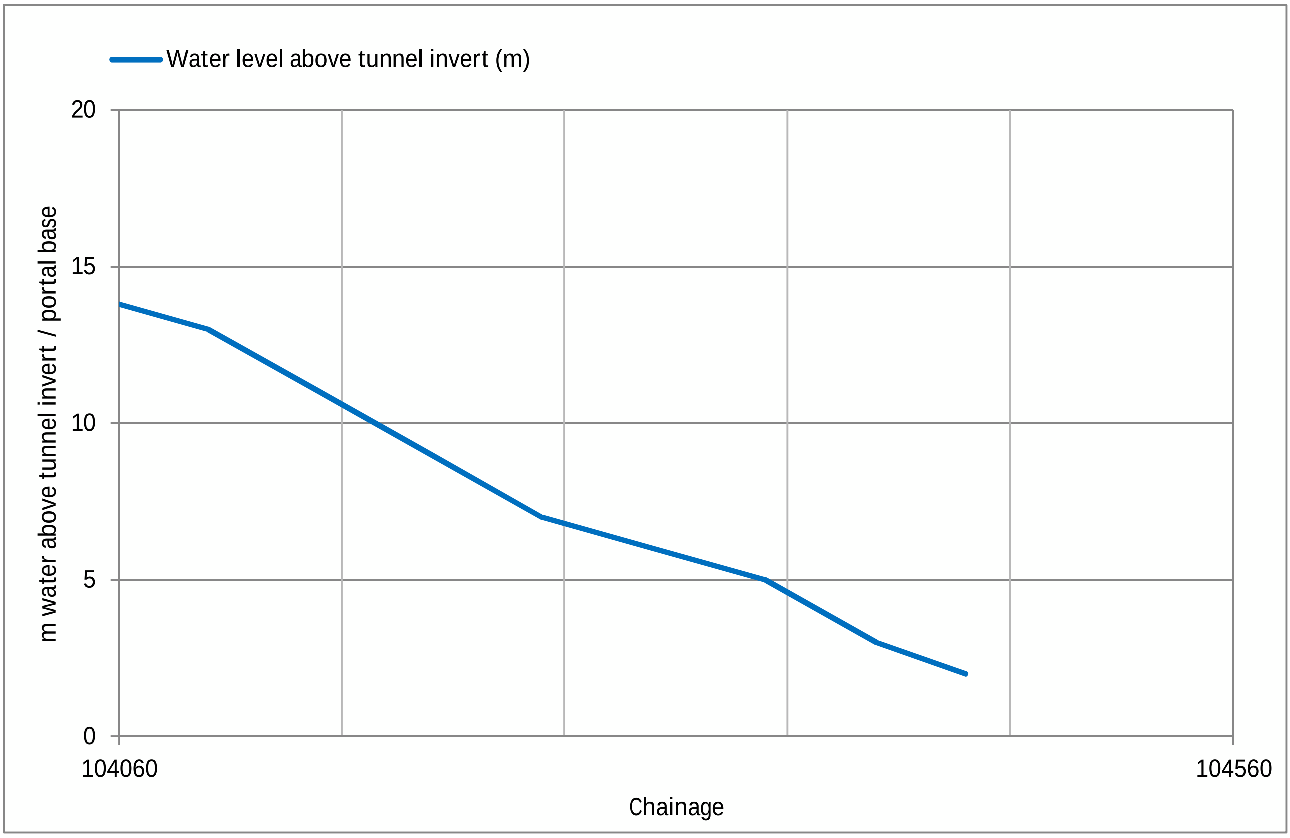

Figure D-29: Approximate height of groundwater above the base of the tunnels in the eastern portal based on long section (Golder Associates, 2016a, Appendix G)

D.6 Groundwater Quality

Table D-25 Flow at which salt load is exceeded based on measured TDS

TDS value (mg/L)	Flow rate at which salt load would exceed limit of 200 kg/day	
	L/s	m3/day
1,300 (minimum)	1.8	155
38,000 (maximum)	0.06	5
9,915 (average)	0.23	20

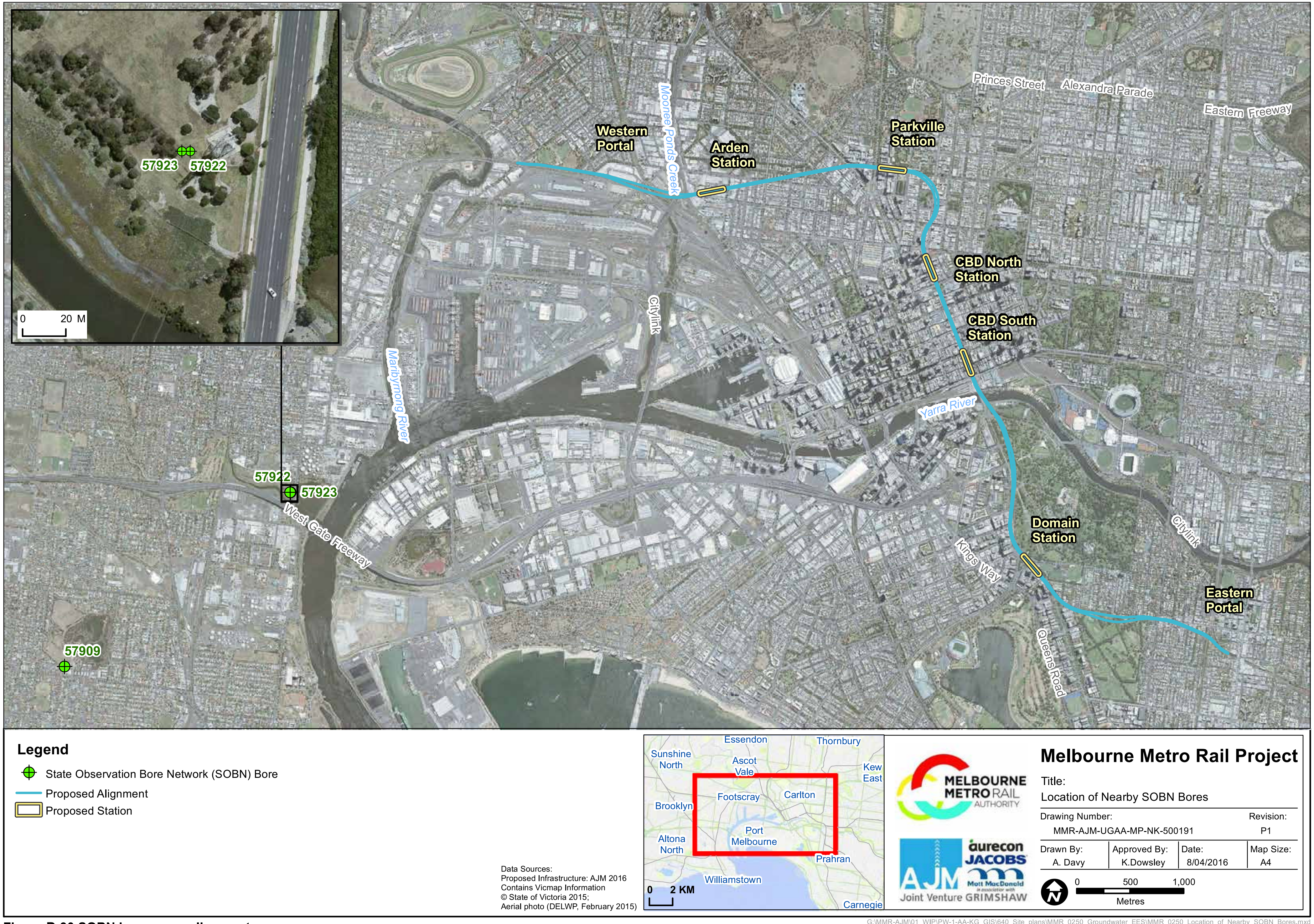

Figure D-30 SOBN bores near alignment

D.7 Existing groundwater Use Bores

Table D-26 Summary of private groundwater bores within groundwater model boundary and outcomes of site inspection and discussion with Southern Rural Water.

Bore ID	Use	Date drilled	Depth (m)	Screen details	Location	Bore located during site inspection?	Findings of investigation	Suggested action
89269	Stock and domestic	1/12/1979	36.5	125 mm OD PVC, 30 to 36 m	500m north of eastern portal	No	Visited site and spoke to building manager. The building management had no knowledge of a groundwater bore located onsite. The car park and several service corridors were subsequently investigated but no bores were located. An investigation into the construction of the building resulted in a comment from building manager Hamish that construction finished in 2012, whilst the bore was completed in 1979, suggesting destruction during construction.	Eliminate from EES *Bore does not appear to exist. No groundwater use on site.*
WRK962001	Stock and domestic	9/05/2003	9.5	60 mm OD (50 mm ID) PVC (SC), 3.5 to 9.5 m	<100m south of tunnels between Arden and Parkville stations	No	Visited site and spoke to property manager and property architect. Neither was aware of a groundwater bore on the site. After checking records they recalled a geotechnical bore was drilled on the site but this was not installed as a groundwater bore.	Eliminate from EES *Bore does not appear to exist. No groundwater use on site.*
WRK968523	Stock and domestic	29/04/2005	11.7	60 mm OD PVC, 2.7 to 11.7 m	2km east of tunnels between CBD South and Domain stations	-	Site not visited	Continue to consider within EES
WRK965942	Stock and domestic	8/02/2005	10.4	115 mm OD PVC, 3 to 10 m	1km north of Arden station	-	Unable to engage with tenants of this property and site could not be visited.	Continue to consider within EES
WRK968690	Stock and domestic	18/02/2005	10.2	60 mm OD PVC, 4.2 to 10.2 m	500m west of CBD South	No	Visited site (public land) but unable to locate bore. Coordinates place it just to the south of Flinders Street near	Eliminate from EES *Bore not stock and*

Bore ID	Use	Date drilled	Depth (m)	Screen details	Location	Bore located during site inspection?	Findings of investigation	Suggested action
					station		the junction with Queen Street – not on a private property and therefore unlikely to be used as a stock and domestic bore.	*domestic use – not likely to be groundwater use given diameter.*
WRK972626	Stock and domestic	17/04/2007	34	108 mm OD SS, 28 to 34 m	500m east of tunnels between CBD South and Domain stations	No	Visited site (public land) but unable to locate bore. Coordinates place it just to the west of Batman Avenue – not on a private property and therefore unlikely to be used as a stock and domestic bore.	Continue to consider within EES *Although not likely to be stock and domestic use the construction of this bore suggests groundwater use of some sort*
WRK975059	Stock and domestic	5/09/2006	4	60 mm OD PVC C18, 1 to 4 m	1.25km west of tunnels between CBD South and Domain stations	No	Visited site and spoke to the building concierge who was unaware of any groundwater bores on the site.	Eliminate from EES *Bores not stock and domestic use – not likely to be groundwater use given diameter.*
WRK975060	Stock and domestic	5/09/2006	4	60 mm OD PVC C18, 1 to 4 m				
WRK975062	Stock and domestic	8/09/2006	4.5	60 mm OD PVC C18, 1.5 to 4.5 m	750m west of tunnels between CBD South and Domain stations	No	Visited site and spoke to the building concierge who was unaware of any groundwater bores on the site. The building was constructed in 2010, six years after the bore was drilled, suggesting that the bore has been destroyed.	Eliminate from EES *Bores do not appear to exist. No groundwater use on site.*
WRK975063	Stock and domestic	14/09/2006	4.5	60 mm OD PVC C18, 1.5 to 4.5 m				
WRK976406	Stock and domestic	4/12/2006	5	61 mm OD PVC, 2 to 5 m	1.75km west of CBD South station	No – but four observation bores were located	Visited site (public land) and located four 50 mm groundwater bores which appeared to be observation bores. These bores are not on a private property and therefore unlikely to be used as stock and domestic bores.	Eliminate from EES *Bores not stock and domestic use – not likely to be groundwater use given diameter.*
WRK976407	Stock and domestic	4/12/2006	5	61 mm OD PVC, 2 to 5 m				

Bore ID	Use	Date drilled	Depth (m)	Screen details	Location	Bore located during site inspection?	Findings of investigation	Suggested action
WRK979557	Stock and domestic	14/06/2007	79	110 mm OD PVC, 72 to 78 m	700m south of western portal	Yes – two bores located	Visited site (Melbourne Market) and spoke to site operation manager. The manager was aware that several groundwater bores were installed on site but he did not know the location of the bores. A site worker who had worked at the site for over 20 years was able to assist in finding the bores: • The first bore was located adjacent to the Melbourne market centre way in the northern-most stall row. This bore was covered with a heavy concrete gatic cover • The second bore was located adjacent to the Melbourne market site operations shed to the west of the market stalls. The heavy concrete gatic cover had been destroyed due to vehicle movement. The fragments were removed by the electrician with a crowbar to reveal a 100mm bore which was in good structural condition and adequately sealed from surface water intrusion. The Site Operations manager stated that neither of the bores were utilised as a water resource due to the very poor quality of the groundwater in specific reference to the salinity	Continue to consider within EES
WRK979561	Stock and domestic	25/06/2007	66	110 mm OD PVC, 60 to 66 m				
WRK979562	Stock and domestic	25/06/2007	66	110 mm OD PVC, 60 to 66 m				
WRK981452	Stock and domestic	15/04/2007	16.1	33 mm OD PVC, 3.8 to 15.8	150m north of Parkville station	No	Visited site and spoke to the facilities manager who was unaware of any bore installed on the site.	Eliminate from EES *Bores do not appear to exist. No groundwater use on site.*
WRK981453	Stock and domestic	15/04/2007	16.1	33 mm OD PVC, 3.8 to 15.8				
WRK990820	Domestic	27/06/2009	105	150 mm OD	300 m north of	No	Visited site and spoke to property	Eliminate from EES

Bore ID	Use	Date drilled	Depth (m)	Screen details	Location	Bore located during site inspection?	Findings of investigation	Suggested action
				(100 mm ID) PVC (SC) 67 to 79 m 100mm open hole 85 to 105 m	tunnels between Domain station and the eastern portal		owner. He stated that an explorative groundwater investigation was undertaken in the southern region of the property but did not intersect groundwater with a total borehole depth of ~30 m subsequently the hole was backfilled	*Bores do not appear to exist. No groundwater use on site.*
WRK989150	Groundwater	22/07/2009	20	63 mm OD PVC, 9 to 20 m	1km east of tunnels between Parkville and CBD North stations	-	Did not visit	Continue to consider within EES
WRK989690	Groundwater	26/03/2009	4	60 mm OD PVC, 1.7 to 3.7 m	1.25km north of Arden station	No	The site was not visited as there is an ongoing environmental audit remediation project (including groundwater remediation) at the site. Spoke to the Environmental Auditor who stated that he was unable to locate the bore but that its use as a stock and domestic borehole is most probably precluded due to groundwater contamination.	Continue to consider within EES

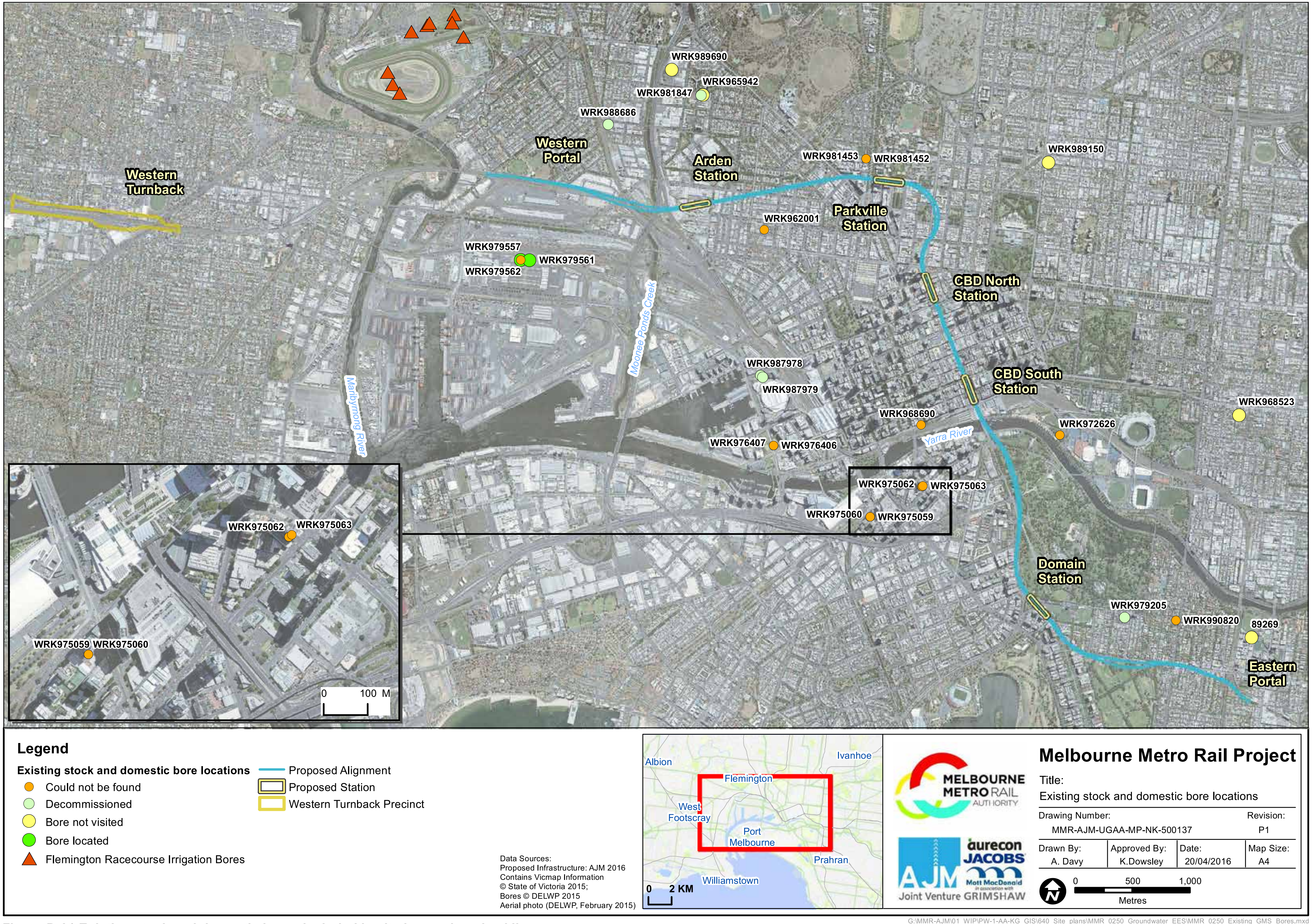

Figure D-31 Existing stock and domestic bores included in site inspection checklist

Appendix E Groundwater quality analysis results

Summary of groundwater quality results

Precinct	Well ID	Aquifer monitored	Date	Dissolved Oxygen (Field)	Dissolved Oxygen (Field) (Filtered)	Electrolytic Conductivity (Field)	pH (Field)	Redox Potential (Field)	Temp (Field)	Electrical Conductivity @ 25°C	pH (Lab)	Total Dissolved Solids @180°C	Sodium (Filtered)	Potassium (Filtered)	Calcium (Filtered)	Magnesium (Filtered)	Chloride	Sulphate (as SO4)	Bicarbonate Alkalinity (as CaCO3)	Carbonate Alkalinity (as CaCO3)	Total Alkalinity (as CaCO3)	Nitrate (as N)	Nitrite (as N)	Nitrogen (Total Oxidised)	Ammonia (as N)	Total Kjeldahl Nitrogen (as N)	Nitrogen (Total)	Bromide	Cyanide (total)	Fluoride	Total Phosphorus (as P)	Sulphide	Sulphur (Total Oxidised as SO4)	Biological Oxygen Demand	Total Organic Carbon	Hardness (as CaCO3)	Arsenic (Filtered)	Barium (Filtered)	Boron (Filtered)	Bromine (Filtered)	Cadmium (Filtered)	Chromium (Filtered)	Cobalt (Filtered)
				Field Parameters									Inorganics and ions																														
Units				mg/L	mg/L	uS/cm	pH_Units	mV	oC	uS/cm	pH_Units	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
LOR										1	0.01	5	1	1	1	1	1	1	1	1	1	0.01	0.01	0.01	0.01	0.1	0.1	0.01	0.004	0.1	0.01	0.1	1	2	1	1	0.001	0.001	0.05	0.1	0.0001	0.001	0.001
Stage 1 LOR											0.1	5	0.1	1	0.1	0.1	0.5	0.5	10	10	20	0.5	0.5			1	0.5	0.5	0.005	0.5	0.1	0.5			1	0.01	0.005	0.005	0.005		0.0002	0.005	0.005
Drinking water (health/asethetic)							6.5-8.5				6.5-8.5	-/600	-/180			0.5/0.1	-/250	500/250				50 (as NO3)/-	3 (as NO2)/-		-/0.5 (as NH3)				0.08/-	1.5/-							0.01/-	2/-	4/-		0.002/-	0.05 (as CrVI)/-	
Recreational							6.5-8.5				6.5-8.5	1000	300				400	400							0.01				0.100								0.05	1	1		0.005	0.05	
Irrigation (Long/Short)													<460				<700																				0.1/2		0.5/-		0.01/0.05	0.1/1	0.05/0.1
Vapour intrusion residential - HSL B (assume <4/8+m in SAND)																																											
Vapour intrusion commercial industrial - HSL D (assume <4m/8+m in SAND)																																											
City West Water & South East Water Discharge Criteria									38		6-10														50	500			10	30		1	100	4000			1	150	25	5	2	10	10
Western Portal	GA11-BH001	Moray Street Gravels	9/07/2013							39,800	6.93	29,800	7140	160	416	967	13500	1630	457	<1	457	0.02	<0.01	0.02	23.7	24.5		48.8			0.13					5020							
Western Portal	GA11-BH031	Older Volcanics	8/07/2013							12,600	7.29	7630	2540	79	67	144	2650	2150	1100	<1	1100	<0.01	<0.01	<0.01	0.06	<0.1		12.2			0.34					760							
Western Portal	GA11-BH002	Older Volcanics	21/02/2012		0.82	7040	7.48	-52	16.9	8370	7.64	5000	1640	70	42	82	835	2320	1100	<1	1100	<0.01	<0.01	<0.01	0.75	1.7		8.38	0.013	0.6	0.11				70	442	0.004	0.083	4.89		<0.0001	<0.001	0.003
Western Portal	GA11-BH003	Older Volcanics	22/02/2012		0.2	3590	7.81	-176	17.1	4060	7.94	2160	870	22	6	12	590	517	757	<1	757	0.03	<0.01	0.03	0.29	0.5		2.23			0.49				27	64							
Western Portal	GA11-BH005	Older Volcanics	21/02/2012		0.98	11,550	7.36	131	18	13,200	7.59	7920	2390	33	146	282	4310	897	445	<1	445	8.02	0.17	8.19	0.06	0.1		15.1	<0.004	0.2	0.09				4	1520	<0.001	0.088	0.36		<0.0001	0.008	0.003
Western Portal	GA11-BH007	Werribee Formation	21/02/2012		0.96	43,940	6.78	-93	17.6	48,900	6.93	37,200	8760	209	698	1490	18000	2340	754	<1	754	0.02	<0.01	0.02	6.3	7.5		63.9	<0.004	0.2	0.53				13	7880	<0.001	0.193	1.58		<0.0001	<0.001	0.054
Tunnel (WP-AS)	MM1-BH001	Quaternary Fluvial Sediments	2/07/2010								7.30	28000	23	3.8	23	8.9	14000	1000	800	<20	800	<0.1	<0.2	<0.5		19	19	50		<0.5	0.1	<0.1	<0.005		<5	94	0.052	0.21	1.2		0.0005	<0.05	0.041
Tunnel (WP-AS)	MM1-BH001	Quaternary Fluvial Sediments	2/07/2010								7.50	28000	23	4.1	24	9.8	13000	1000	840	<20	840	<0.1	<0.2	<0.5		20	20	48		<0.5	0.2	<0.1	<0.005		<5	100	0.051	0.21	1.1		0.0004	<0.05	0.04
Tunnel (WP-AS)	GA15-BH001	Werribee Formation	3/07/2015		1.96	44,490	6.09	11	17.9	55,600	6.51	44,200	10,700	217	693	1720	19900	2720	763	<1	763	0.01	<0.01	0.01	11.5	12.2	12.2	105	<0.004	0.3	0.06				7	8810	0.002	0.278	1.8		<0.0002	<0.002	0.107
Tunnel (WP-AS)	GA15-BH002	Melbourne Formation	6/07/2015		2.17	28,781	5.31	-5	18.5	37,600	5.68	25,300	6290	127	622	1130	12600	1490	226	<1	226	0.01	<0.01	0.01	1.13	1.3	1.3			0.3	0.09				2	6210	0.012	0.047	0.65	24.8	<0.0002	<0.002	0.006
Tunnel (WP-AS)	GA15-BH003	Quaternary Fluvial Sediments	6/07/2015		1.89	37,473	6.21	-98	17.7	46,800	6.60	31,500	7750	137	583	1420	16400	1070	899	<1	899	<0.01	<0.01	<0.01	21	20.8	20.8		<0.004	0.4	0.1				5	7300	0.002	0.204	1.28	35.5	<0.0002	<0.002	0.102
Tunnel (WP-AS)	GA11-BH008	Quaternary Fluvial Sediments	24/02/2012		0.57	44,240	7.16	-125	17.7	51,300	7.07	38,000	8440	185	510	1360	18400	698	1100	<1	1100	<0.01	<0.01	<0.01	49.4	49.9		71.6			2.13				37	6870							
Tunnel (WP-AS)	GA11-BH009	Fishermans Bend Silt	30/08/2013							38,200	6.83	22,600	6070	128	530	1210	13200	1390	710	<1	710	0.01	<0.01	0.01	15.4	17.5		46.3	<0.004	0.6	0.1					6310	<0.001	0.042	0.5		0.0002	<0.001	0.008
Arden Station	MM1-BH002	Fishermans Bend Silt	8/07/2010								7.30	8600	1700	41	350	480	3800	470	430	<20	430	<0.1	<0.2	<0.5		<1	<2	9		<0.5	<0.1	<0.1	0.011		<5	2800	0.013	0.19	0.58		<0.0002	0.008	0.016
Arden Station	MM1-BH003	Fishermans Bend Silt	6/07/2010								7.50	8600	2200	42	180	390	3100	900	800	<20	790	5.8	15	21		<1	21	11		<5	<0.1	<0.1	<0.005		15	2100	0.013	0.043	1.1		<0.0002	<0.005	0.008
Arden Station	MM1-BH004	Werribee Formation	7/07/2010								8.00	3000	840	19	35	64	860	340	650	<20	650	6.6	<0.2	6.6		<1	6.6	2.2		0.7	<0.1	<0.1	0.011		12	350	<0.005	0.052	1.1		0.0004	0.013	<0.005
Arden Station	GA15-BH005	Coode Island Silt	7/08/2015		0.33	31,753	6.57	75	18.7	38,900	7.43	24,900	5830	130	498	938	11900	2420	668	<1	668	0.02	<0.01	0.02	7.06	7.3	7.3		<0.004	0.3	0.11				7	5110	0.002	0.127	0.94	47.6	0.0002	<0.001	0.03
Arden Station	GA11-BH011	Melbourne Formation	23/07/2013							9500	7.70	5740	1750	23	98	234	2600	600	506	<1	506	21	2.29	23.3	0.03	<0.1		8.92	<0.004	1	0.27					1210	0.003	0.066	0.4		<0.0001	0.003	0.004
Tunnel (AS-PS)	MM1-BH006	Melbourne Formation	12/07/2010								7.40	10000	2900	35	180	440	440	950	340	<20	340	5.6	<0.2	5.6		1	6.6	18			<0.1	<0.1			<5	2200							
Tunnel (AS-PS)	MM1-BH007	Melbourne Formation	12/07/2010								7.60	6700	2300	22	56	240	3000	380	840	<20	840	9.8	<0.2	9.8		<1	9.8	10		0.7	<0.1	<0.1	<0.005		<5	1100	0.009	0.029	0.42		<0.0002	0.009	<0.005
Tunnel (AS-PS)	GA11-BH013	Melbourne Formation	23/07/2013							7190	7.49	4400	1460	13	40	108	1820	383	422	<1	422	8.62	1.68	10.3	0.36	0.4		6.12			0.06					545							
Parkville Station	MM1-BH008	Melbourne Formation	13/07/2010								6.50	8800	2500	43	69	300	3900	550	830	<20	830	0.6	<5	<5		<1	<2	12			<0.1	<0.1			<5	1400							
Parkville Station	MM1-BH009	Melbourne Formation	14/07/2010								7.10	12000	3500	33	99	390	4900	500	930	<20	930	1.3	<0.2	1.3		<1	<2	13			0.5	<0.1			22	1900							
Tunnel (PS-CN)	MM1-BH010	Melbourne Formation	9/07/2010								7.50	4400	1700	17	35	90	1500	280	1000	<20	1000	8.1	<0.2	8.1		<1	8.1	5.8		1.1	<0.1	<0.1	<0.005		31	460	0.007	0.014	0.53		<0.0002	0.007	<0.005
Tunnel (PS-CN)	MM1-BH010	Melbourne Formation	9/07/2010								6.95	5100	1380	20	37	90	1620	339	1060	<1	1060			12.5		0.2	12.7	4.69		1.5	0.05	0.1	<0.004		3	464	<0.001				<0.0001	<0.001	0.001
Tunnel (PS-CN)	GA11-BH014	Melbourne Formation	25/07/2013							6890	7.31	4270	1320	27	20	64	1540	335	618	<1	618	26.3	0.73	27	0.05	<0.1		4.72	<0.004	1.5	0.05					313	0.001	0.085	0.17		<0.0001	<0.001	0.002
CBD North	GA15-BH007	Melbourne Formation	7/07/2015		0.78	2942	6.76	96	18.2	3750	6.79	2280	715	14	31	4	759	222	565	<1	565	0.01	0.71	0.72	0.06	0.4	1.1		<0.004	2.6	0.03				96	94	0.004	0.061	0.33	2.7	<0.0001	0.016	<0.001
CBD North	GA15-BH008	Melbourne Formation	31/08/2015		3	7131	7.08	23	16.7	6850	7.93	4710	1700	19	34	83	2130	450	829	<1	829	3.63	0.06	3.69	0.05	0.1	3.8		<0.004	1.1	0.03				4	427	0.003	0.134	0.28	8.2	<0.0001	0.008	<0.001
CBD North	GA15-BH009	Melbourne Formation	3/08/2015		3.31	6671	6.8	101	18.4	8050	7.01	4400	1420	19	21	68	1880	353	769	<1	769	14.5	0.7	15.2	0.14	0.2	15.4		<0.004	1.3	0.04				4	332	0.002	0.038	0.33	6.5	<0.0001	0.001	0.006
CBD North	GA15-BH010	Melbourne Formation	7/07/2015		3.87	4987	5.93	188	17.2	6710	6.32	3620	1190	11	12	37	1370	411	708	<1	708	7.49	0.09	7.58	0.12	0.4	8		-	1.7	0.03				5	182	0.001	0.106	0.41	5.2	<0.0001	0.001	0.003
CBD North	GA15-BH011	Melbourne Formation	15/10/2015		0.6	10,684	5.86	158	19.5	13,100	6.13	6960	2560	36	45	162	3790	413	2100	<1	2100	0.03	<0.01	0.03	0.08	<0.1	<0.1		<0.004	0.7	0.02				6	779	0.002	0.061	0.21	11.3	<0.0001	<0.001	0.003
CBD North	GA15-BH012	Melbourne Formation	27/08/2015		5.75	1906	7.74	12	17.1	2380	7.73	1410	483	7	2	6	363	121	569	<1	569	1.17	<0.01	1.17	0.04	0.4	1.6		<0.004	5.3	0.21				4	30	0.002	0.026	0.57	1.7	<0.0001	0.003	<0.001
Tunnel (CN-CS)	MM1-BH012	Melbourne Formation	27/07/2010								7.20	5100	1800	25	28	87	2000	280	690	<20	690	4.8	<0.2	4.8		5.9	11	5.6		<0.5	<0.1	<0.1	0.01		17	430	0.006	0.031	0.2		<0.0002	<0.005	<0.005
CBD South	MM1-BH013	Melbourne Formation	26/07/2010								7.90	2400	1100	15	29	40	760	170	720	<20	720	0.1	<0.2	<0.5		<1	<2	2.1		0.8		<0.1	0.01		280	240	<0.005	0.31	0.16		<0.0002	0.007	<0.005
CBD South	GA15-BH018	Melbourne Formation	31/07/2015		1.11	2625	7.01	180	15.4	3500	7.17	2030	646	11	9	12	710	185	574	<1	574	6.23	0.41	6.64	0.11	1.1	7.7			2.8	0.08				3	72	0.002	0.009	0.21	2	<0.0001	0.002	<0.001
CBD South	GA15-BH019	Melbourne Formation	8/07/2015		3.37	3760	5.93	436	16.5	4960	5.91	2810	913	12	9	15	1070	288	735	<1	735	4	0.17	4.17	0.09	0.3	4.5			2.4	0.04				5	84	0.002	0.194	0.21	3	<0.0001	<0.001	<0.001
CBD South	GA15-BH021	Melbourne Formation	31/07/2015		1.15	1838	6.86	104	19.4	2470	6.99	1450	457	8	6	5	473	138	404	<1	404	5.68	0.23	5.91	0.34	0.7	6.6		<0.004	7.4	0.43	<0.1	139	3	2	36	0.003	0.235	0.28	1.3	<0.0001	0.002	<0.001
CBD South	GA15-BH110	Melbourne Formation	4/08/2015		0.54	4307	7.19	67	17.4	5430	7.30	3250	992	18	24	48	1150	304	663	<1	663	0.12	<0.01	0.12	0.08	0.3	0.4		<0.004	1.8	0.08	<0.1	269	3	2	258	0.002	0.048	0.12	3.4	<0.0001	<0.001	0.003
CBD South	GA15-BH110	Melbourne Formation	2/09/2015							8090	7.19	4280	1610	13	10	67	1820	399	849	<1	849	1.97	0.02	1.99	0.02	0.2	2.2		<0.004	0.2	0.03				2	301	0.001	0.007	0.16	<0.1	<0.0001	<0.001	<0.001
CBD South	GA15-BH110	Melbourne Formation	7/09/2015							9890	7.15	5300	1820	22	28	113	2620	498	822	<1	822	2.25	0.02	2.27	0.07	0.1	2.4		<0.004	1.1	0.02				2	535	0.001	0.006	0.16	8.3	<0.0001	<0.001	<0.001
CBD South	GA15-BH112	Melbourne Formation	28/08/2015		2.06	5935	6.34	-13	17.3	4350	6.72	3000	966	14	10	37	1160	305	713	<1	713	0.01	<0.01	0.01	0.04	<0.1	<0.1		<0.004	2	0.04				3	177	0.005	0.037	0.16	3.9	<0.0001	<0.001	0.001
Tunnel (CS-DS)	MM1-BH015	Moray Street Gravels	29/06/2010								7.20	16000	4600	47	200	680	7200	550	700	< 20	700	< 0.1	< 5	<5		<1	< 5	24			<0.1	<0.1			<5	3300							
Tunnel (CS-DS)	MM1-BH016	Fishermans Bend Silt	30/07/2010								7.30	10000	4000	75	180	450	5500	390	960	<20	960	<0.1	<5	<5		21	21	19		<0.5	2.6	<0.1	<0.005		17	2300	0.018	0.78	0.59		<0.0002	0.017	0.006

Summary of groundwater quality results

Precinct	Well ID	Aquifer monitored	Date	Metals										Other				Microbial Analyses				Monocyclic Aromatic Hydrocarbons							Total Recoverable Hydrocarbons									
				Copper (Filtered)	Iron (Filtered)	Lead (Filtered)	Manganese (Filtered)	Molybdenum (Filtered)	Nickel (Filtered)	Selenium (Filtered)	Silver (Filtered)	Tin (Filtered)	Zinc (Filtered)	Carbon Dioxide	CO2 (Free)	Formaldehyde	Residual Chlorine	Escherichia coli (Colilert)	Sulphate Reducing Bacteria Population Estimate	Sulphate-reducing bacteria (MPN/100mL)	Sulphate-reducing bacteria (ORG/100mL)	Benzene	Toluene	Ethylbenzene	Xylenes (m & p)	Xylene (o)	Xylenes (Sum of total) (Lab Reported)	Total BTEX	TRH C6 - C9 Fraction	TRH C10 - C14 Fraction	TRH C15 - C28 Fraction	TRH C29 - C36 Fraction	TRH+C10 - C36 (Sum of total) (Lab Reported)	TRH+C10 - C40 (Sum of total) (Lab Reported)	TRH C6 - C10 Fraction F1	TRH C6 - C10 Fraction Less BTEX F1	TRH >C10 - C16 Fraction F2	TRH >C10 - C16 Fraction Less Naphthalene F2
Units				mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	orgs/mL	pac/mL	MPN/100 mL	ORG/100 mL	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
LOR				0.001	0.05	0.001	0.001	0.001	0.001	0.01	0.001	0.001	0.005	1	1	0.1	0.02	0.001	1	2	300	0.001	0.002	0.002	0.002	0.002	0.002	0.001	0.02	0.05	0.1	0.05	0.05	0.1	0.02	0.02	0.1	0.1
Stage 1 LOR				0.005		0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	20							0																	
Drinking water (health/asethetic)				2/1	-/0.3	0.01/-	0.5/0.1	0.05/-	0.02/-	0.01/-	0.1/-		-/3			0.5/-		100				0.001/-	0.8/0.025	0.3/0.003			0.6/0.2						0.09	0.09		15		
Recreational				1	0.3	0.05	0.1		0.1	0.01	0.05		5									0.01											0.9	0.9		15		
Irrigation (Long/Short)				0.2/5	0.2/10	2/5	0.2/10	0.01/0.05	0.2/2	0.02/0.05			2/5																				0.18	0.18		15		
Vapour intrusion residential - HSL B (assume <4/8+m in SAND)																						0.8/0.9	NL/NL	NL/NL			NL/NL									1/1		1/1
Vapour intrusion commercial industrial - HSL D (assume <4m/8+m in SAND)																						5/5	NL/NL	NL/NL			NL/NL									6/7		NL/NL
City West Water & South East Water Discharge Criteria				10	100	10	10	10	10	0.001	5	10	10			200						1	2	2	0.001	0.001	2	0.001	1	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Western Portal	GA11-BH001	Moray Street Gravels	9/07/2013		6.38		4.44							510	107						>110,000																	
Western Portal	GA11-BH031	Older Volcanics	8/07/2013		0.86		0.911							1080	113						>110,000																	
Western Portal	GA11-BH002	Older Volcanics	21/02/2012	0.011	0.42	<0.001	0.637	0.011	0.033	<0.01	<0.001	<0.001	0.029		50					>11,000		<0.001	<0.003	<0.002	<0.002	<0.002	<0.002	<0.001	<0.02	<0.05	0.33	0.08	0.41	0.37	<0.02	<0.02	<0.1	
Western Portal	GA11-BH003	Older Volcanics	22/02/2012		0.46		0.165								17					>110,000																		
Western Portal	GA11-BH005	Older Volcanics	21/02/2012	0.008	<0.05	<0.001	0.147	0.013	0.024	0.01	<0.01	<0.001	0.021		23					1500		<0.001	<0.002	<0.002	<0.002	<0.002	<0.002	<0.001	<0.02	<0.05	<0.1	<0.05	<0.05	<0.1	<0.02	<0.02	<0.1	
Western Portal	GA11-BH007	Werribee Formation	21/02/2012	0.009	16.7	<0.001	10.2	0.009	0.059	<0.01	<0.01	<0.001	0.018		177					>11,000		<0.001	<0.003	<0.002	<0.002	<0.002	<0.002	<0.001	<0.02	<0.05	0.22	<0.05	0.22	0.18	<0.02	<0.02	<0.1	
Tunnel (WP-AS)	MM1-BH001	Quaternary Fluvial Sediments	2/07/2010	0.013	0.1	<0.005	8	<0.005	0.05	0.24	<0.005	<0.005	0.061		80							<0.001	<0.002	<0.002	<0.002	<0.002	<0.002	<0.001	<0.02	<0.05	<0.1	<0.05	<0.05	<0.1	<0.02	<0.02	<0.1	<0.1
Tunnel (WP-AS)	MM1-BH001	Quaternary Fluvial Sediments	2/07/2010	0.013	0.5	<0.005	8.4	<0.005	0.049	0.26	<0.005	<0.005	0.059		53							<0.001	<0.002	<0.002	<0.002	<0.002	<0.002	<0.001	<0.02	<0.05	<0.1	<0.05	<0.05	<0.1	<0.02	<0.02	<0.1	<0.1
Tunnel (WP-AS)	GA15-BH001	Werribee Formation	3/07/2015	0.007	9.48	<0.002	18	0.002	0.043	<0.02	0.003	<0.002	0.04		472				27,000			<0.001	<0.002	<0.002	<0.002	<0.002	<0.002	<0.001	<0.02	<0.05	<0.1	<0.05	<0.05	<0.1	<0.02	<0.02	<0.1	<0.1
Tunnel (WP-AS)	GA15-BH002	Melbourne Formation	6/07/2015	0.002	3.87	<0.002	0.154		0.024	<0.02			0.1		944				>1100																			
Tunnel (WP-AS)	GA15-BH003	Quaternary Fluvial Sediments	6/07/2015	<0.002	3.92	<0.002	4.3	0.002	0.039	<0.02	<0.002	<0.002	0.034		452				75			<0.001	<0.002	<0.002	<0.002	<0.002	<0.002	<0.001	<0.02	<0.05	<0.1	<0.05	<0.05	<0.1	<0.02	<0.02	<0.1	<0.1
Tunnel (WP-AS)	GA11-BH008	Quaternary Fluvial Sediments	24/02/2012		22.9		1.92								187					>110,000																		
Tunnel (WP-AS)	GA11-BH009	Fishermans Bend Silt	30/08/2013	0.005	<0.05	<0.001	2.9	0.003	0.009	<0.01	<0.001	<0.001	0.01	835	210						15,000	<0.001	<0.002	<0.002	<0.002	<0.002	<0.002	<0.001	<0.02	<0.05	<0.1	<0.05	<0.05	<0.1	0.02	0.02	<0.1	
Arden Station	MM1-BH002	Fishermans Bend Silt	8/07/2010	<0.005	0.9	<0.005	2.9	<0.005	0.025	0.067	<0.005	<0.005	0.022		43			11				<0.001	<0.002	<0.002	<0.002	0.003	<0.002	<0.001	<0.02	0.1	0.5	<0.05	<0.05	<0.1	<0.02	<0.02	<0.1	<0.1
Arden Station	MM1-BH003	Fishermans Bend Silt	6/07/2010	<0.005	<0.1	<0.005	0.93	<0.005	0.011	0.088	<0.005	<0.005	0.024		51			4.6				<0.001	<0.002	<0.002	<0.002	<0.002	<0.002	<0.001	<0.02	<0.05	<0.1	<0.05	<0.05	<0.1	<0.02	<0.02	<0.1	<0.1
Arden Station	MM1-BH004	Werribee Formation	7/07/2010	<0.005	0.3	<0.005	0.83	0.009	0.015	0.02	<0.005	<0.005	0.02		<20			11				<0.001	<0.002	<0.002	<0.002	<0.002	<0.002	<0.001	<0.02	<0.05	<0.1	<0.05	<0.05	<0.1	<0.02	<0.02	<0.1	<0.1
Arden Station	GA15-BH005	Coode Island Silt	7/08/2015	0.025	0.07	<0.001	5.8	0.003	0.053	<0.01	<0.001	<0.001	0.041		343				500,000			<0.001	<0.002	<0.002	<0.002	<0.002	<0.002	<0.001	<0.02	<0.05	<0.1	<0.05	<0.05	<0.1	<0.02	<0.02	<0.1	<0.1
Arden Station	GA11-BH011	Melbourne Formation	23/07/2013	0.006	<0.05	0.002	0.758	0.009	0.018	0.02	<0.001	<0.001	0.043	465	20						900	<0.001	<0.002	<0.002	<0.002	<0.002	<0.002	<0.001	<0.02	<0.08	<0.1	<0.05	<0.05	<0.1	<0.02	<0.02	<0.1	
Tunnel (AS-PS)	MM1-BH006	Melbourne Formation	12/07/2010		0.2										27			1																				
Tunnel (AS-PS)	MM1-BH007	Melbourne Formation	12/07/2010	0.01	2.8	<0.005	0.15	<0.005	0.006	0.052	<0.005	<0.005	0.037		42			2				<0.001	<0.002	<0.002	<0.002	<0.002	<0.002	<0.001	<0.02	<0.05	<0.1	<0.05	<0.05	<0.1	<0.02	<0.02	<0.1	<0.1
Tunnel (AS-PS)	GA11-BH013	Melbourne Formation	23/07/2013		<0.05		0.342							399	27						24,000																	
Parkville Station	MM1-BH008	Melbourne Formation	13/07/2010		0.6										530			>11																				
Parkville Station	MM1-BH009	Melbourne Formation	14/07/2010		1										150			>11																				
Tunnel (PS-CN)	MM1-BH010	Melbourne Formation	9/07/2010	<0.005	2.2	<0.005	0.22	<0.005	0.012	0.04	<0.005	<0.005	0.05		66			2				<0.001	<0.002	<0.002	<0.002	<0.002	<0.002	<0.001	<0.02	<0.05	<0.1	<0.05	<0.05	<0.1	<0.02	<0.02	<0.1	<0.1
Tunnel (PS-CN)	MM1-BH010	Melbourne Formation	9/07/2010	0.002	1.89	<0.001	0.174	0.001	0.019	<0.01	<0.010	<0.001	0.029		237			2.4				<0.001	<0.002	<0.002	<0.002	<0.002	<0.002	<0.001	<0.02	<0.05	<0.1	<0.05	<0.05	<0.1	<0.02	<0.02	<0.1	<0.1
Tunnel (PS-CN)	GA11-BH014	Melbourne Formation	25/07/2013	0.004	0.23	0.005	0.254	0.018	0.004	<0.01	<0.001	<0.001	0.027	604	60						110,000	<0.001	<0.002	<0.002	<0.002	<0.002	<0.002	<0.001	<0.02	<0.05	<0.1	<0.05	<0.05	<0.1	<0.02	<0.02	<0.1	
CBD North	GA15-BH007	Melbourne Formation	7/07/2015	0.004	<0.05	<0.001	0.035	0.015	0.013	<0.01	0.002	<0.001	0.052		318				6000			<0.001	0.004	<0.002	<0.002	<0.002	<0.002	0.004	<0.02	0.08	0.56	<0.05	0.64	0.66	<0.02	<0.02	0.11	0.11
CBD North	GA15-BH008	Melbourne Formation	31/08/2015	0.005	<0.05	<0.001	0.021	0.002	0.017	<0.01	<0.001	<0.001	0.05		55				5,000,000			<0.001	<0.002	<0.002	<0.002	<0.002	<0.002	<0.001	<0.02	<0.05	<0.1	<0.05	<0.05	<0.1	<0.02	<0.02	<0.1	<0.1
CBD North	GA15-BH009	Melbourne Formation	3/08/2015	0.008	0.08	<0.001	0.209	0.004	0.037	<0.01	<0.001	<0.001	0.048		150				120,000			<0.001	<0.002	<0.002	<0.002	<0.002	<0.002	<0.001	<0.02	<0.05	<0.1	<0.05	<0.05	<0.1	<0.02	<0.02	<0.1	<0.1
CBD North	GA15-BH010	Melbourne Formation	7/07/2015	0.015	<0.05	0.003	0.22		0.145	<0.01			0.237		1230				6000																			
CBD North	GA15-BH011	Melbourne Formation	15/10/2015	0.022	0.38	0.001	0.241	0.004	0.024	<0.01	<0.001	<0.001	0.096		3110				27,000			<0.001	<0.002	<0.002	<0.002	<0.002	<0.002	<0.001	<0.02	<0.05	<0.1	<0.05	<0.05	<0.1	<0.02	<0.02	<0.1	<0.1
CBD North	GA15-BH012	Melbourne Formation	27/08/2015	0.004	<0.05	0.001	0.016	0.002	0.009	<0.01		<0.001	0.019		14				120,000			<0.001	<0.002	<0.002	<0.002	<0.002	<0.002	<0.001	<0.02	<0.05	<0.1	<0.05	<0.05	<0.1	<0.02	<0.02	<0.1	<0.1
Tunnel (CN-CS)	MM1-BH012	Melbourne Formation	27/07/2010	<0.005	0.9	<0.005	0.24	<0.005	0.1	0.37	<0.005	<0.005	0.036		87			incubating				<0.001	0.002	<0.002	<0.002	<0.002	<0.002	<0.001	<0.02	<0.05	<0.1	<0.05	<0.05	<0.1	<0.02	<0.02	<0.1	<0.1
CBD South	MM1-BH013	Melbourne Formation	26/07/2010	0.008	4.6	<0.005	0.16	<0.005	0.027	0.01	<0.005	<0.005	0.045		<20			2				<0.001	<0.002	<0.002	<0.002	<0.002	<0.002	<0.001	<0.02	<0.05	<0.1	<0.05	<0.05	<0.1	<0.02	<0.02	<0.1	<0.1
CBD South	GA15-BH018	Melbourne Formation	31/07/2015	0.002	<0.05	<0.001	0.039		0.049	<0.01			0.02		78				120,000																			
CBD South	GA15-BH019	Melbourne Formation	8/07/2015	0.023	0.09	0.004	0.533		0.11	<0.01			0.341		1810				320																			
CBD South	GA15-BH021	Melbourne Formation	31/07/2015	0.002	<0.05	<0.001	0.046	0.005	0.039	<0.01	0.001	<0.001	0.018		83	0.2	0.06	0	120,000			<0.001	<0.002	<0.002	<0.002	<0.002	<0.002	<0.001	<0.02	<0.05	1.02	0.57	1.59	1.74	<0.02	<0.02	<0.1	<0.1
CBD South	GA15-BH110	Melbourne Formation	4/08/2015	0.001	<0.05	<0.001	0.16	0.004	0.02	<0.01	0.002	<0.001	0.023		66	<0.1	0.06	0	120,000			<0.001	<0.002	<0.002	<0.002	<0.002	<0.002	<0.001	<0.02	<0.05	<0.1	<0.05	<0.05	<0.1	<0.02	<0.02	<0.1	<0.1
CBD South	GA15-BH110	Melbourne Formation	2/09/2015	<0.001	0.21	<0.001	0.077	<0.001	0.001	<0.01		<0.001	0.009		110				500,000			<0.001	<0.002	<0.002	<0.002	<0.002	<0.002	<0.001	<0.02	<0.05	<0.1	<0.05	<0.05	<0.1	<0.02	<0.02	<0.1	<0.1
CBD South	GA15-BH110	Melbourne Formation	7/09/2015	0.001	0.17	<0.001	0.078	<0.001	0.002	<0.01	<0.001	<0.001	0.005		116				500,000			<0.001	<0.002	<0.002	<0.002	<0.002	<0.002	<0.001	<0.02	<0.05	<0.1	<0.05	<0.05	<0.1	<0.02	<0.02	<0.1	<0.1
CBD South	GA15-BH112	Melbourne Formation	28/08/2015	0.002	0.25	<0.001	0.102	0.006	0.009	<0.01	<0.001	<0.001	0.021		272				500,000			<0.001	<0.002	<0.002	<0.002	<0.002	<0.002	<0.001	<0.02	<0.05	<0.1	<0.05	<0.05	<0.1	<0.02	<0.02	<0.1	<0.1
Tunnel (CS-DS)	MM1-BH015	Moray Street Gravels	29/06/2010		2.3										88																							
Tunnel (CS-DS)	MM1-BH016	Fishermans Bend Silt	30/07/2010	<0.005	74	<0.005	0.73	0.029	0.008	0.089	<0.005	<0.005	0.033		96							<0.001	<0.002	<0.002	<0.002	<0.002	<0.002	<0.001	<0.02	<0.05	<0.1	<0.05	<0.05	<0.1	<0.02	<0.02	<0.1	<0.1

Summary of groundwater quality results

Precinct	Well ID	Aquifer monitored	Date			Halogenated Compounds					Phenols	Ethers
				TRH >C16 - C34 Fraction F3	TRH >C34 - C40 Fraction F4	1,1-Dichloroethane	1,1-Dichloroethene	cis-1,2-Dichloroethene	Chloroform	Tetrachloroethene	Phenol	Methyl Ethyl Ketone
Units				mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
LOR				0.1	0.1	0.005	0.005	0.005	0.005	0.005	0.001	0.05
Stage 1 LOR												
Drinking water (health/asethetic)							0.03/-	0.06/-				
Recreational							0.0003	0.01		0.01	0.002	
Irrigation (Long/Short)												
Vapour intrusion residential - HSL B (assume <4/8+m in SAND)												
Vapour intrusion commercial industrial - HSL D (assume <4m/8+m in SAND)												
City West Water & South East Water Discharge Criteria				0.001	0.001	5	0.001	0.001	1	1	0.001	
Western Portal	GA11-BH001	Moray Street Gravels	9/07/2013									
Western Portal	GA11-BH031	Older Volcanics	8/07/2013									
Western Portal	GA11-BH002	Older Volcanics	21/02/2012	0.37	<0.1	<0.005	<0.005	<0.005	<0.005	<0.005	<0.001	<0.05
Western Portal	GA11-BH003	Older Volcanics	22/02/2012									
Western Portal	GA11-BH005	Older Volcanics	21/02/2012	<0.1	<0.1	<0.005	<0.005	<0.005	<0.005	<0.005	<0.001	<0.05
Western Portal	GA11-BH007	Werribee Formation	21/02/2012	0.18	<0.1	<0.005	<0.005	<0.005	<0.005	<0.005	<0.001	<0.05
Tunnel (WP-AS)	MM1-BH001	Quaternary Fluvial Sediments	2/07/2010	<0.1	<0.1	<0.005	<0.005	<0.005	<0.005	<0.005	<0.001	
Tunnel (WP-AS)	MM1-BH001	Quaternary Fluvial Sediments	2/07/2010	<0.1	<0.1	<0.005	<0.005	<0.005	<0.005	<0.005	<0.001	
Tunnel (WP-AS)	GA15-BH001	Werribee Formation	3/07/2015	<0.1	<0.1	<0.005	<0.005	<0.005	<0.005	<0.005	<0.001	0.15
Tunnel (WP-AS)	GA15-BH002	Melbourne Formation	6/07/2015									
Tunnel (WP-AS)	GA15-BH003	Quaternary Fluvial Sediments	6/07/2015	<0.1	<0.1	<0.005	<0.005	<0.005	<0.005	<0.005	<0.001	0.19
Tunnel (WP-AS)	GA11-BH008	Quaternary Fluvial Sediments	24/02/2012									
Tunnel (WP-AS)	GA11-BH009	Fishermans Bend Silt	30/08/2013	<0.1	<0.1	<0.005	<0.005	<0.005	<0.005	<0.005	<0.001	0.3
Arden Station	MM1-BH002	Fishermans Bend Silt	8/07/2010	<0.1	<0.1	<0.005	<0.005	<0.005	<0.005	<0.005	<0.001	
Arden Station	MM1-BH003	Fishermans Bend Silt	6/07/2010	<0.1	<0.1	<0.005	<0.005	<0.005	<0.005	<0.005	<0.001	
Arden Station	MM1-BH004	Werribee Formation	7/07/2010	<0.1	<0.1	<0.005	<0.005	<0.005	<0.005	<0.005	<0.001	
Arden Station	GA15-BH005	Coode Island Silt	7/08/2015	<0.1	<0.1	<0.005	<0.005	<0.005	<0.005	<0.005	<0.001	<0.05
Arden Station	GA11-BH011	Melbourne Formation	23/07/2013	<0.1	<0.1	<0.005	<0.005	<0.005	<0.005	<0.005	<0.001	<0.05
Tunnel (AS-PS)	MM1-BH006	Melbourne Formation	12/07/2010									
Tunnel (AS-PS)	MM1-BH007	Melbourne Formation	12/07/2010	<0.1	<0.1	<0.005	<0.005	<0.005	<0.005	<0.005	<0.001	
Tunnel (AS-PS)	GA11-BH013	Melbourne Formation	23/07/2013									
Parkville Station	MM1-BH008	Melbourne Formation	13/07/2010									
Parkville Station	MM1-BH009	Melbourne Formation	14/07/2010									
Tunnel (PS-CN)	MM1-BH010	Melbourne Formation	9/07/2010	<0.1	<0.1	0.013	0.084	<0.005	<0.005	<0.005	<0.001	
Tunnel (PS-CN)	MM1-BH010	Melbourne Formation	9/07/2010	<0.1	<0.1	0.016	0.071	<0.005	<0.005	<0.005	<0.001	
Tunnel (PS-CN)	GA11-BH014	Melbourne Formation	25/07/2013	<0.1	<0.1	<0.005	<0.005	0.007	<0.005	0.012	<0.001	<0.05
CBD North	GA15-BH007	Melbourne Formation	7/07/2015	0.55	<0.1	<0.005	<0.005	<0.005	0.01	<0.005	0.0017	<0.05
CBD North	GA15-BH008	Melbourne Formation	31/08/2015	<0.1	<0.1	<0.005	<0.005	<0.005	<0.005	<0.005	<0.001	<0.05
CBD North	GA15-BH009	Melbourne Formation	3/08/2015	<0.1	<0.1	<0.005	<0.005	<0.005	<0.005	<0.005	<0.001	<0.05
CBD North	GA15-BH010	Melbourne Formation	7/07/2015									
CBD North	GA15-BH011	Melbourne Formation	15/10/2015	<0.1	<0.1	<0.005	<0.005	<0.005	<0.005	<0.005	<0.001	<0.05
CBD North	GA15-BH012	Melbourne Formation	27/08/2015	<0.1	<0.1	<0.005	<0.005	<0.005	<0.005	<0.005	<0.001	<0.05
Tunnel (CN-CS)	MM1-BH012	Melbourne Formation	27/07/2010	<0.1	<0.1	<0.005	<0.005	<0.005	<0.005	<0.005	<0.001	
CBD South	MM1-BH013	Melbourne Formation	26/07/2010	<0.1	<0.1	<0.005	<0.005	<0.005	<0.005	<0.005	<0.001	
CBD South	GA15-BH018	Melbourne Formation	31/07/2015									
CBD South	GA15-BH019	Melbourne Formation	8/07/2015									
CBD South	GA15-BH021	Melbourne Formation	31/07/2015	1.5	0.24	<0.005	<0.005	<0.005	<0.005	<0.005	<0.002	<0.05
CBD South	GA15-BH110	Melbourne Formation	4/08/2015	<0.1	<0.1	<0.005	<0.005	<0.005	<0.005	<0.005	<0.002	<0.05
CBD South	GA15-BH110	Melbourne Formation	2/09/2015	<0.1	<0.1	<0.005	<0.005	<0.005	<0.005	<0.005	<0.001	<0.05
CBD South	GA15-BH110	Melbourne Formation	7/09/2015	<0.1	<0.1	<0.005	<0.005	<0.005	<0.005	<0.005	<0.001	<0.05
CBD South	GA15-BH112	Melbourne Formation	28/08/2015	<0.1	<0.1	<0.005	<0.005	<0.005	<0.005	<0.005	<0.001	<0.05
Tunnel (CS-DS)	MM1-BH015	Moray Street Gravels	29/06/2010									
Tunnel (CS-DS)	MM1-BH016	Fishermans Bend Silt	30/07/2010	<0.1	<0.1	<0.005	<0.005	<0.005	<0.005	<0.005	<0.001	

Summary of groundwater quality results

Field Parameters

Precinct	Well ID	Aquifer monitored	Date	Dissolved Oxygen (Field)	Dissolved Oxygen (Field) (Filtered)	Electrolytic Conductivity (Field)	pH (Field)	Redox Potential (Field)	Temp (Field)	Electrical Conductivity @ 25°C	pH (Lab)	Total Dissolved Solids @180°C
Units				mg/L	mg/L	uS/cm	pH_Units	mV	oC	uS/cm	pH_Units	mg/L
LOR										1	0.01	5
Stage 1 LOR											0.1	5
Drinking water (health/asethetic)							6.5-8.5				6.5-8.5	-/600
Recreational							6.5-8.5				6.5-8.5	1000
Irrigation (Long/Short)												
Vapour intrusion residential - HSL B (assume <4/8+m in SAND)												
Vapour intrusion commercial industrial - HSL D (assume <4m/8+m in SAND)												
City West Water & South East Water Discharge Criteria									38		6-10	
Tunnel (CS-DS)	MM1-BH017	Coode Island Silt	29/06/2010								6.80	8100
Tunnel (CS-DS)	MM1-BH018	Melbourne Formation	5/07/2010								9.10	1300
Tunnel (CS-DS)	GA11-BH017	Moray Street Gravels	22/02/2012		1.27	38,040	6.82	76	19	38,800	6.77	25,000
Tunnel (CS-DS)	GA11-BH018	Holocene Alluvium	8/07/2013							26,400	6.84	17,500
Tunnel (CS-DS)	GA11-BH041	Moray Street Gravels	23/07/2013							45,700	6.92	27,400
Tunnel (CS-DS)	GA15-BH120	Melbourne Formation	6/07/2015		3.6	2288	5.88	312	15.1	3130	6.09	1790
Tunnel (CS-DS)	GA15-BH121	Melbourne Formation	20/08/2015		2.56	1120	7	105	14.2	1430	7.29	8380
Tunnel (CS-DS)	GA15-BH027	Melbourne Formation	20/08/2015		6.29	9249	6.92	147	16.3	9950	6.99	6650
Tunnel (CS-DS)	GA15-BH028	Melbourne Formation	19/08/2015		7.44	7086	6.76	152	17.7	7670	6.52	4810
Domain Station	MM1-BH020	Melbourne Formation	5/07/2010								7.90	4200
Domain Station	GA11-BH019	Melbourne Formation	23/02/2012		3.74	15,940	7.03	126	17.9	17,000	7.08	10,100
Domain Station	GA15-BH029	Melbourne Formation	6/10/2015							11,200	6.41	6500
Domain Station	GA15-BH031	Melbourne Formation	28/09/2015							14,800	6.17	7470
Domain Station	GA15-BH033	Melbourne Formation	7/10/2015							11,600	5.80	6360
Domain Station	GA11-BH026	Brighton Group	23/02/2012		0.7	1930	7.47	19	18.5	2160	7.67	1520
Domain Station	GA11-BH027	Melbourne Formation	22/02/2012		1.18	3380	6.89	-50	20	3080	7.02	1660
Tunnel (DS-EP)	GA11-BH020	Melbourne Formation	18/01/2013		1.27	9750	6.09	49	18.5	11,000	6.35	6220
Tunnel (DS-EP)	GA11-BH021	Melbourne Formation	18/01/2013		1.31	1990	6.82	46	18.2	2310	6.32	1380
Tunnel (DS-EP)	GA11-BH022	Melbourne Formation	18/01/2013		0.93	10,570	6	-3	19.7	11,900	6.30	7000
Tunnel (DS-EP)	GA11-BH023	Melbourne Formation	17/01/2013		1.05	7970	5.74	-41	18.7			
Eastern Portal	GA11-BH024	Melbourne Formation	17/01/2013		3.07	8050	5.78	125	19.2			
Eastern Portal	GA11-BH025	Melbourne Formation	17/01/2013		3.58	8700	5.12	237	18.7			

Inorganics and ions

Precinct	Well ID	Sodium (Filtered)	Potassium (Filtered)	Calcium (Filtered)	Magnesium (Filtered)	Chloride	Sulphate (as SO4)	Bicarbonate Alkalinity (as CaCO3)	Carbonate Alkalinity (as CaCO3)	Total Alkalinity (as CaCO3)	Nitrate (as N)	Nitrite (as N)	Nitrogen (Total Oxidised)	Ammonia (as N)	Total Kjeldahl Nitrogen (as N)	Nitrogen (Total)
Units		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
LOR		1	1	1	1	1	1	1	1	1	0.01	0.01	0.01	0.01	0.1	0.1
Stage 1 LOR		0.1	1	0.1	0.1	0.5	0.5	10	10	20	0.5	0.5			1	0.5
Drinking water (health/asethetic)		-/180			0.5/0.1	-/250	500/250				50 (as NO3)/-	3 (as NO2)/-		-/0.5 (as NH3)		
Recreational		300				400	400							0.01		
Irrigation (Long/Short)		<460				<700										
Vapour intrusion residential - HSL B (assume <4/8+m in SAND)																
Vapour intrusion commercial industrial - HSL D (assume <4m/8+m in SAND)																
City West Water & South East Water Discharge Criteria														50	500	
Tunnel (CS-DS)	MM1-BH017	2700	84	170	290	3100	88	1600	< 20	1600	< 0.1	< 5	<5		82	82
Tunnel (CS-DS)	MM1-BH018	130	5.7	16	11	390	360	140	85	230	0.9	<0.2	0.9		<1	<2
Tunnel (CS-DS)	GA11-BH017	7750	171	409	1180	14400	1430	819	<1	819	0.03	<0.01	0.03	59	67.9	
Tunnel (CS-DS)	GA11-BH018	4250	131	145	597	8750	200	1630	<1	1630	<0.01	<0.01	<0.01	171	180	
Tunnel (CS-DS)	GA11-BH041	7930	163	399	1180	16000	1980	399	<1	399	0.04	<0.01	0.04	40.7	52.3	
Tunnel (CS-DS)	GA15-BH120	639	20	11	12	380	241	806	<1	806	8.69	0.41	9.1	0.17	1	10.1
Tunnel (CS-DS)	GA15-BH121	264	4	2	1	143	185	362	<1	362	0.26	0.03	0.29	0.26	3	3.3
Tunnel (CS-DS)	GA15-BH027	2090	38	39	149	3300	447	680	<1	680	1.7	0.05	1.75	0.14	0.4	2.2
Tunnel (CS-DS)	GA15-BH028	1620	26	38	72	2410	386	362	<1	362	0.37	0.05	0.42	0.07	0.7	1.1
Domain Station	MM1-BH020	1200	25	71	83	1500	260	290	<20	290	0.3	<0.2	<0.5		<1	<2
Domain Station	GA11-BH019	3160	46	121	328	5750	392	756	<1	756	0.71	0.05	0.76	0.01	0.5	
Domain Station	GA15-BH029	1780	34	81	224	3730	233	229	<1	229	0.02	<0.01	0.02	0.06	1.3	1.3
Domain Station	GA15-BH031	2240	40	136	335	4510	376	497	<1	497	0.38	0.08	0.46	0.07	0.1	0.6
Domain Station	GA15-BH033	1810	33	82	246	3950	230	178	<1	178	0.02	<0.01	0.02	0.11	0.1	0.1
Domain Station	GA11-BH026	460	6	7	9	273	180	507	<1	507	6.91	0.22	7.13	0.25	1	
Domain Station	GA11-BH027	493	18	40	57	860	111	159	<1	159	0.14	0.1	0.24	0.54	1.1	
Tunnel (DS-EP)	GA11-BH020	1940	38	85	295	3780	402	300	<1	300	0.1	0.02	0.12	0.07	0.2	
Tunnel (DS-EP)	GA11-BH021	448	13	4	17	428	141	375	<1	375	11.2	0.42	11.6	0.1	1.3	
Tunnel (DS-EP)	GA11-BH022	1910	24	77	384	4110	443	94	<1	94	<0.01	<0.01	<0.01	<0.01	<0.1	
Tunnel (DS-EP)	GA11-BH023															
Eastern Portal	GA11-BH024															
Eastern Portal	GA11-BH025															

Precinct	Well ID	Bromide	Cyanide (total)	Fluoride	Total Phosphorus (as P)	Sulphide	Sulphur (Total Oxidised as SO4)	Biological Oxygen Demand	Total Organic Carbon	Hardness (as CaCO3)	Arsenic (Filtered)	Barium (Filtered)	Boron (Filtered)	Bromine (Filtered)	Cadmium (Filtered)	Chromium (Filtered)	Cobalt (Filtered)
Units		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
LOR		0.01	0.004	0.1	0.01	0.1	1	2	1	1	0.001	0.001	0.05	0.1	0.0001	0.001	0.001
Stage 1 LOR		0.5	0.005	0.5	0.1	0.5			1	0.01	0.005	0.005	0.005		0.0002	0.005	0.005
Drinking water (health/asethetic)			0.08/-	1.5/-							0.01/-	2/-	4/-		0.002/-	0.05 (as CrVI)/-	
Recreational			0.100								0.05	1	1		0.005	0.05	
Irrigation (Long/Short)											0.1/2		0.5/-		0.01/0.05	0.1/1	0.05/0.1
Vapour intrusion residential - HSL B (assume <4/8+m in SAND)																	
Vapour intrusion commercial industrial - HSL D (assume <4m/8+m in SAND)																	
City West Water & South East Water Discharge Criteria			10	30		1	100	4000			1	150	25	5	2	10	10
Tunnel (CS-DS)	MM1-BH017	9.8			2.6	< 0.1			17	1600							
Tunnel (CS-DS)	MM1-BH018	0.8				<0.1			140	83							
Tunnel (CS-DS)	GA11-BH017	49.6			0.2				12	5880							
Tunnel (CS-DS)	GA11-BH018	29.5	<0.004	0.3	1.65					2820	0.015	2.57	0.53		0.0006	<0.001	0.002
Tunnel (CS-DS)	GA11-BH041	58.1	<0.004	0.4	0.65					5860	0.001	0.167	0.84		<0.0001	<0.001	0.005
Tunnel (CS-DS)	GA15-BH120			5.8	0.34				4	77	0.003	0.04	0.25	0.8	<0.0001	<0.001	<0.001
Tunnel (CS-DS)	GA15-BH121			3.5	3.74				17	<10	0.013	0.033	0.18	0.5	<0.0001	0.003	0.001
Tunnel (CS-DS)	GA15-BH027			1.8	0.08				4	711	0.001	0.29	0.18	11.6	0.0002	0.004	0.002
Tunnel (CS-DS)	GA15-BH028			1	0.11				7	391	0.001	0.551	0.15	8.3	0.0004	<0.001	0.002
Domain Station	MM1-BH020	3.7		0.8	0.2	<0.1	<0.005		5.1	520	0.008	0.032	0.14		<0.0002	0.014	<0.005
Domain Station	GA11-BH019	13.7	0.004	0.9	0.07				18	1650	0.002	0.152	<0.05		0.0001	0.004	0.001
Domain Station	GA15-BH029		<0.004	0.4	<0.01				8	1120	0.002	0.218	0.14	11.3	0.0002	<0.001	0.006
Domain Station	GA15-BH031		<0.004	0.3	0.04				3	1720	<0.001	0.105	0.11	13.8	0.0002	0.001	0.017
Domain Station	GA15-BH033			0.2	0.05				<1	1220	0.002	0.096	0.13	11.8	0.0004	0.002	<0.001
Domain Station	GA11-BH026	1.32	0.004	1.8	0.18				7	54	0.001	0.081	0.3		<0.0001	<0.001	<0.001
Domain Station	GA11-BH027	2.58			0.02				4	335							
Tunnel (DS-EP)	GA11-BH020	8.87			<0.01				5	1430							
Tunnel (DS-EP)	GA11-BH021	0.988			<0.01				6	80							
Tunnel (DS-EP)	GA11-BH022	9.5	<0.004	0.6	0.04				5	1770	0.008	0.171	0.05		<0.0001	<0.001	0.075
Tunnel (DS-EP)	GA11-BH023																
Eastern Portal	GA11-BH024																
Eastern Portal	GA11-BH025																

For TPH health criteria: WHO (2005). Petroleum Products in Drinking Water. Background Document for Development of WHO Guidelines for Drinking Water

For TPH irrigation criteria: NZ Ministry of environment, 2011. Giuidelines for assessing and managing petroleum hydrocarbon sites in New Zealand (revised 2011) Module 5 - tier 1 groundwater acceptance criteria

NEPC 2013. The National Environment Protection (Assessment of Site Contamination) Amendment Measure 2013 (No. 1) Amendment of the National Environment Protection (Assessment of Site Contamination) Measure 1999 - Guideline on Investigation Levels for Soil and Groundwater (B1)

For TPH Ecosystem protection: CRGWQOB - California Environmental Protection Agency, San Francisco Bay Regional Water Quality Control Board Environmental Screening Levels from http://www.waterboards.ca.gov/sanfranciscobay/water_issues/programs/esl.shtml (accessed 25/3/14)

Summary of groundwater quality results

Precinct	Well ID	Aquifer monitored	Date	Metals										Other				Microbial Analyses				Monocyclic Aromatic Hydrocarbons							Total Recoverable Hydrocarbons									
				Copper (Filtered)	Iron (Filtered)	Lead (Filtered)	Manganese (Filtered)	Molybdenum (Filtered)	Nickel (Filtered)	Selenium (Filtered)	Silver (Filtered)	Tin (Filtered)	Zinc (Filtered)	Carbon Dioxide	CO2 (Free)	Formaldehyde	Residual Chlorine	Escherichia coli (Colilert)	Sulphate Reducing Bacteria Population Estimate	Sulphate-reducing bacteria (MPN/100mL)	Sulphate-reducing bacteria (ORG/100mL)	Benzene	Toluene	Ethylbenzene	Xylenes (m & p)	Xylene (o)	Xylenes (Sum of total) (Lab Reported)	Total BTEX	TRH C6 - C9 Fraction	TRH C10 - C14 Fraction	TRH C15 - C28 Fraction	TRH C29 - C36 Fraction	TRH+C10 - C36 (Sum of total) (Lab Reported)	TRH+C10 - C40 (Sum of total) (Lab Reported)	TRH C6 - C10 Fraction F1	TRH C6 - C10 Fraction Less BTEX F1	TRH >C10 - C16 Fraction F2	TRH >C10 - C16 Fraction Less Naphthalene F2
Units				mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	orgs/mL	pac/mL	MPN/100 mL	ORG/100 mL	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
LOR				0.001	0.05	0.001	0.001	0.001	0.001	0.01	0.001	0.001	0.005	1	1	0.1	0.02	0.001	1	2	300	0.001	0.002	0.002	0.002	0.002	0.002	0.001	0.02	0.05	0.1	0.05	0.05	0.1	0.02	0.02	0.1	0.1
Stage 1 LOR				0.005		0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	20							0																	
Drinking water (health/asethetic)				2/1	-/0.3	0.01/-	0.5/0.1	0.05/-	0.02/-	0.01/-	0.1/-		-/3			0.5/-		100				0.001/-	0.8/0.025	0.3/0.003			0.6/0.02						0.09	0.09		15		
Recreational				1	0.3	0.05	0.1		0.1	0.01	0.05		5									0.01											0.9	0.9		15		
Irrigation (Long/Short)				0.2/5	0.2/10	2/5	0.2/10	0.01/0.05	0.2/2	0.02/0.05			2/5																				0.18	0.18		15		
Vapour intrusion residential - HSL B (assume <4/8+m in SAND)																						0.8/0.9	NL/NL	NL/NL			NL/NL									1/1		1/1
Vapour intrusion commercial industrial - HSL D (assume <4m/8+m in SAND)																						5/5	NL/NL	NL/NL			NL/NL									6/7		NL/NL
City West Water & South East Water Discharge Criteria				10	100	10	10	10	10	0.001	5	10	10			200						1	2	2	0.001	0.001	2	0.001	1	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Tunnel (CS-DS)	MM1-BH017	Coode Island Silt	29/06/2010		10										510																							
Tunnel (CS-DS)	MM1-BH018	Melbourne Formation	5/07/2010												<20																							
Tunnel (CS-DS)	GA11-BH017	Moray Street Gravels	22/02/2012		0.08		1.14								278					1500																		
Tunnel (CS-DS)	GA11-BH018	Holocene Alluvium	8/07/2013	0.005	21	<0.001	0.131	0.005	0.033	<0.01	<0.001	<0.001	0.024	1900	471						>110,000	<0.001	<0.002	<0.002	<0.002	<0.002	<0.002	<0.001	<0.02	<0.05	<0.1	<0.05	<0.05	<0.1	<0.02	<0.02	<0.1	
Tunnel (CS-DS)	GA11-BH041	Moray Street Gravels	23/07/2013	0.005	8.36	<0.001	1.51	0.009	0.013	<0.01	<0.001	0.001	0.034	447	96						4300	<0.001	<0.002	<0.002	<0.002	<0.002	<0.002	<0.001	<0.02	0.48	0.66	<0.05	1.14	1.09	<0.02	<0.02	1.09	
Tunnel (CS-DS)	GA15-BH120	Melbourne Formation	6/07/2015	0.005	<0.05	<0.001	0.108		0.068	<0.01			0.168		1310				9																			
Tunnel (CS-DS)	GA15-BH121	Melbourne Formation	20/08/2015	0.012	0.84	0.002	0.016		0.007	<0.01			0.022		37				150																			
Tunnel (CS-DS)	GA15-BH027	Melbourne Formation	20/08/2015	0.015	<0.05	<0.001	0.17		0.008	<0.01			0.065		139				27,000																			
Tunnel (CS-DS)	GA15-BH028	Melbourne Formation	19/08/2015	0.018	<0.05	<0.001	0.285		0.013	<0.01			0.113		219				6000																			
Domain Station	MM1-BH020	Melbourne Formation	5/07/2010	<0.005	11	<0.005	0.29	0.016	0.01	0.039	<0.005	<0.005	0.022		<20			>11				<0.001	<0.002	<0.002	<0.002	<0.002	<0.002	<0.001	<0.02	0.07	0.2	<0.05	<0.05	<0.1	<0.02	<0.02	<0.1	<0.1
Domain Station	GA11-BH019	Melbourne Formation	23/02/2012	0.01	<0.05	<0.001	0.066	0.011	0.027	0.03	<0.01	<0.001	0.038		126					24,000		<0.001	<0.002	<0.002	<0.002	<0.002	<0.002	<0.001	<0.02	<0.05	<0.1	<0.05	<0.05	<0.1	<0.02	<0.02	<0.1	
Domain Station	GA15-BH029	Melbourne Formation	6/10/2015	0.011	0.96	0.002	0.238	0.006	0.036	<0.01	<0.001	<0.001	0.144		178				500,000			<0.001	<0.002	<0.002	<0.002	<0.002	<0.002	<0.001	<0.02	0.06	<0.1	<0.05	0.06	<0.1	<0.02	<0.02	<0.1	<0.1
Domain Station	GA15-BH031	Melbourne Formation	28/09/2015	0.042	<0.05	<0.001	0.257	<0.001	0.119	<0.01	<0.001	<0.001	0.095		1140							<0.001	<0.002	<0.002	<0.002	<0.002	<0.002	<0.001	<0.02	<0.05	<0.1	<0.05	<0.05	<0.1	<0.02	<0.02	<0.1	<0.1
Domain Station	GA15-BH033	Melbourne Formation	7/10/2015	0.012	4.11	0.001	0.144		0.075	0.01			0.14		564				500,000																			
Domain Station	GA11-BH026	Brighton Group	23/02/2012	0.004	0.08	<0.001	0.119	0.016	0.007	<0.01	<0.001	<0.001	0.03		22					>110,000		<0.001	<0.002	<0.002	<0.002	<0.002	<0.002	<0.001	<0.02	<0.05	<0.1	<0.05	<0.05	<0.1	<0.02	<0.02	<0.1	
Domain Station	GA11-BH027	Melbourne Formation	22/02/2012		2.53		0.437								30					46,000																		
Tunnel (DS-EP)	GA11-BH020	Melbourne Formation	18/01/2013		8.54		0.623								268						>110,000																	
Tunnel (DS-EP)	GA11-BH021	Melbourne Formation	18/01/2013		0.16		0.134								359						>110,000																	
Tunnel (DS-EP)	GA11-BH022	Melbourne Formation	18/01/2013	0.006	37	<0.001	7.16	0.005	0.105	<0.01	<0.001	<0.001	0.276		94						>110,000	0.002	<0.002	<0.002	<0.002	<0.002	<0.002	0.002	<0.02	<0.05	<0.1	<0.05	<0.05	<0.1	<0.02	<0.02	<0.1	
Tunnel (DS-EP)	GA11-BH023	Melbourne Formation	17/01/2013																																			
Eastern Portal	GA11-BH024	Melbourne Formation	17/01/2013																																			
Eastern Portal	GA11-BH025	Melbourne Formation	17/01/2013																																			

For TPH health criteria: WHO (2005). Petroleum Products in Drinking Water. Backgro
For TPH irrigation criteria: NZ Ministry of environment, 2011. Giuidelines for assessir
NEPC 2013. The National Environment Protection (Assessment of Site Contaminatior
For TPH Ecosystem protection: CRGWQOB - California Environmental Protection Age

Summary of groundwater quality results

Precinct	Well ID	Aquifer monitored	Date	TRH >C16 - C34 Fraction F3	TRH >C34 - C40 Fraction F4	Halogenated Compounds: 1,1-Dichloroethane	Halogenated Compounds: 1,1-Dichloroethene	Halogenated Compounds: cis-1,2-Dichloroethene	Halogenated Compounds: Chloroform	Halogenated Compounds: Tetrachloroethene	Phenols: Phenol	Ethers: Methyl Ethyl Ketone
Units				mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
LOR				0.1	0.1	0.005	0.005	0.005	0.005	0.005	0.001	0.05
Stage 1 LOR												
Drinking water (health/asethetic)							0.03/-	0.06/-				
Recreational							0.0003	0.01		0.01	0.002	
Irrigation (Long/Short)												
Vapour intrusion residential - HSL B (assume <4/8+m in SAND)												
Vapour intrusion commercial industrial - HSL D (assume <4m/8+m in SAND)												
City West Water & South East Water Discharge Criteria				0.001	0.001	5	0.001	0.001	1	1	0.001	
Tunnel (CS-DS)	MM1-BH017	Coode Island Silt	29/06/2010									
Tunnel (CS-DS)	MM1-BH018	Melbourne Formation	5/07/2010									
Tunnel (CS-DS)	GA11-BH017	Moray Street Gravels	22/02/2012		-							
Tunnel (CS-DS)	GA11-BH018	Holocene Alluvium	8/07/2013	<0.1	<0.1	<0.005	<0.005	<0.005	<0.005	<0.005	<0.001	<0.05
Tunnel (CS-DS)	GA11-BH041	Moray Street Gravels	23/07/2013	<0.1	<0.1	<0.005	<0.005	<0.005	<0.005	<0.005	<0.001	<0.05
Tunnel (CS-DS)	GA15-BH120	Melbourne Formation	6/07/2015									
Tunnel (CS-DS)	GA15-BH121	Melbourne Formation	20/08/2015									
Tunnel (CS-DS)	GA15-BH027	Melbourne Formation	20/08/2015									
Tunnel (CS-DS)	GA15-BH028	Melbourne Formation	19/08/2015									
Domain Station	MM1-BH020	Melbourne Formation	5/07/2010	<0.1	<0.1	<0.005	<0.005	<0.005	<0.005	<0.005	<0.001	
Domain Station	GA11-BH019	Melbourne Formation	23/02/2012	<0.1	<0.1	<0.005	<0.005	<0.005	<0.005	<0.005	<0.001	<0.05
Domain Station	GA15-BH029	Melbourne Formation	6/10/2015	<0.1	<0.1	<0.005	<0.005	<0.005	<0.005	<0.005	<0.001	<0.05
Domain Station	GA15-BH031	Melbourne Formation	28/09/2015	<0.1	<0.1	<0.005	<0.005	<0.005	<0.005	<0.005	<0.001	<0.05
Domain Station	GA15-BH033	Melbourne Formation	7/10/2015									
Domain Station	GA11-BH026	Brighton Group	23/02/2012	<0.1	<0.1	<0.005	<0.005	<0.005	0.006	<0.005	<0.001	<0.05
Domain Station	GA11-BH027	Melbourne Formation	22/02/2012									
Tunnel (DS-EP)	GA11-BH020	Melbourne Formation	18/01/2013									
Tunnel (DS-EP)	GA11-BH021	Melbourne Formation	18/01/2013									
Tunnel (DS-EP)	GA11-BH022	Melbourne Formation	18/01/2013	<0.1	<0.1	<0.005	<0.005	<0.005	<0.005	<0.005	<0.001	0.15
Tunnel (DS-EP)	GA11-BH023	Melbourne Formation	17/01/2013									
Eastern Portal	GA11-BH024	Melbourne Formation	17/01/2013									
Eastern Portal	GA11-BH025	Melbourne Formation	17/01/2013									

For TPH health criteria: WHO (2005). Petroleum Products in Drinking Water. Backgro
For TPH irrigation criteria: NZ Ministry of environment, 2011. Giuidelines for assessir
NEPC 2013. The National Environment Protection (Assessment of Site Contaminatior
For TPH Ecosystem protection: CRGWQOB - California Environmental Protection Age

Appendix F Impact analysis methodology – analytical methods and results

All of the analytical techniques used in this assessment assume a simplified hydrogeological model which in some cases may not fully capture the hydrogeological complexity of the site or the interaction of the groundwater regime and associated infrastructure. Nevertheless, the results provide an estimate that is considered accurate to within an order of magnitude which can be used to assess potential impacts on groundwater receptors. Common assumptions for the methods used include the homogenous, isotropic, uniform thickness and infinite nature of the aquifer.

F.1 Theis (1935) Drawdown method

The Theis (1935) solution to transient groundwater flow is generally used to calculate drawdown in response to rates of groundwater pumping, and as such is commonly used in pumping test analysis. It can also be used to calculate pumping rates required to achieve a specified amount of drawdown. As well as the above mentioned aquifer assumptions, the method assumes a non-leaky, confined aquifer and flow to a fully penetrating pumping well discharging at a constant rate.

The Theis equation is for a confined system, however the difference between the Theis confined and unconfined response is negligible over the periods of time considered in this assessment.

F.1.1 Construction Drawdowns and Inflows

For construction related effects, the Theis solution is used in this assessment to simulate groundwater flow into an excavation (station boxes or shafts) by modelling a line of closely spaced pumping bores set up along the edges of the excavation. Simulated observation bores were set up within the excavation as shown in Figure F-1. Inflow rates were then varied though an iterative method to achieve the required drawdown at the monitoring bores. Simulated observation bores were set up at a number of distances away from the excavation to assess the propagation of drawdown away from the excavation.

The target drawdown was to achieve a zero groundwater head above the base of the excavation (in the observation bores in the centre of the excavation). In practice, drainage to 1 or 2 m below the excavation would be required during construction. This difference is accounted for in the way the drainage is simulated, with higher drawdown required in the pumping bores in order for the target drawdown to be reached at the observation bores.

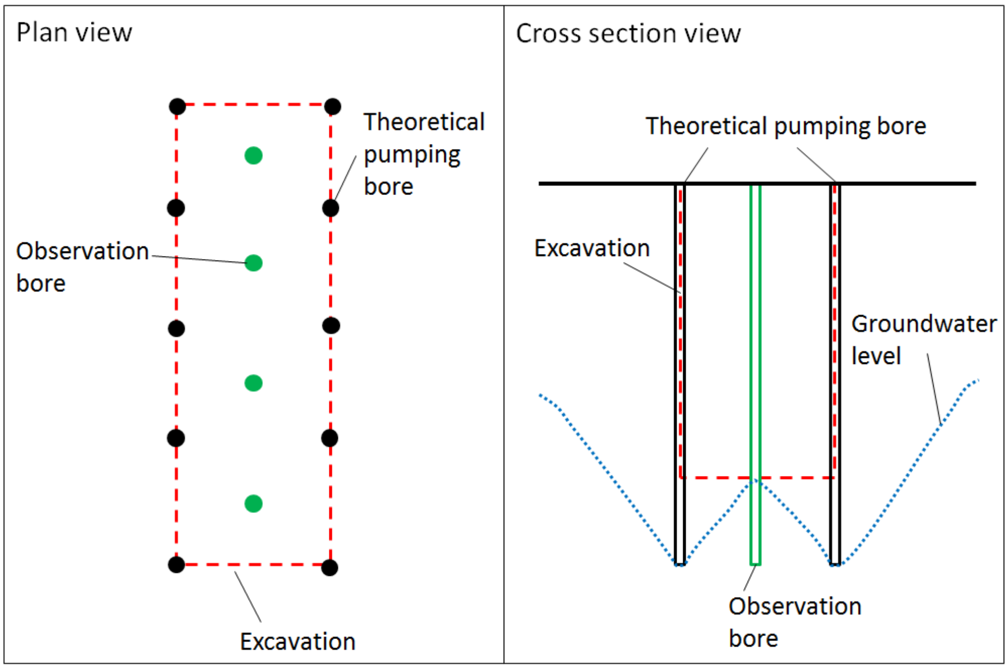

Figure F-1 Plan view and cross sectional view of Theis drawdown method using simulated pumping bores and observation bores

The total amount of time that the excavations are required to be drained consists of two periods: excavation and tanking (i.e. sealing of the excavation to minimise groundwater inflow). The target drawdown (i.e. groundwater level to the base of the excavation) is simulated to be at the end of the excavation period. This method only allows for one inflow rate in each bore and therefore there is a period of time between the end of excavation and when the structure is fully tanked where inflows and drawdown would be somewhat overestimated. In reality, inflow rates are likely to be lower and therefore drawdown away from the structure would be less during this time period and therefore the results presented for the full time period (i.e. up to full tanking) are conservative. In addition, inflows would decrease during the period of tanking due to progressive tanking during this time period. However, given that inflows and drawdown change most rapidly early in the dewatering process (with change continuing to reduce over time), this effect is not considered to unduly impact on the results. The drawdown somewhere between that simulated at full excavation and the drawdown at full tanking is likely to be more representative of the maximum drawdown. It is noted that this effect gives rise to some modelled drawdowns during the tanking phase that exceed the depth of the excavation. This is clearly not possible and is an artefact of the modelling process.

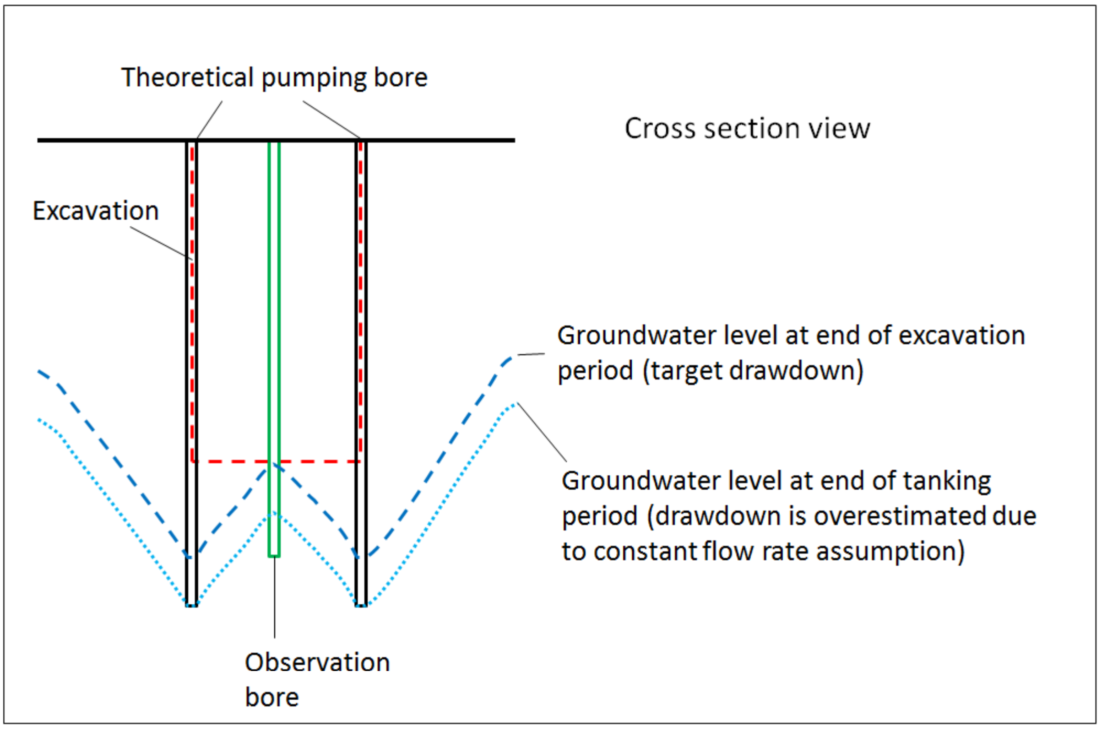

Figure F-2 Cross sectional view of Theis drawdown method showing difference between drawdown at end of excavation and end of tanking (overestimation due to constant flow rate assumption)

F.1.2 Method Assumptions and Limitations

At locations along the alignment where a multi-layer aquifer/aquitard system exists (e.g. in the palaeovalleys of Moonee Ponds Creek and the Yarra River), this analysis has assumed a vertically connected system. This means that although dewatering occurs in a unit below the watertable, the impacts have been assumed to occur in the watertable. In reality, the vertical connectivity between deeper aquifers and the watertable would be limited where a lower permeability unit lies between the dewatered interval and the watertable unit. In these cases the drawdown impact would not be fully transferred to the watertable (i.e. 1 m of depressurisation in the lower unit would not equal 1 m of drawdown in the watertable). In practice, two processes operate. The vertical transmission of pressure (as described above) and the difference in the storage values between confined and unconfined units. Both processes normally operate to produce a significantly smaller response in the unconfined unit when depressurisation of the confined unit occurs. Therefore, assuming full drawdown occurs at the watertable is a worst case, conservative approach. It is also noted that at some locations (depending on the construction technique and the geology) that depressurisation of a confined or semi-confined system could be transmitted to an unconfined system due to the long periods of time over which dewatering occurs.

In a confined system, the lateral effects of depressurisation/drawdown would spread more widely than in an unconfined system – however, because in this analysis a continuous lateral extent of the dewatered unit away from the excavation is assumed and because the method adopts the time to final tanking of the structure for determining the extent of the drawdown cone, in most cases it is unlikely that the extent of drawdown has been underestimated in this analysis.

The simple analytical methods used in this analysis assume that the dewatered geological formation is of infinite lateral extent and therefore, that the drawdown propagates evenly away from the dewatered structure (station, shafts etc). Where drawdown impacts are confined to a relatively small area within the one geological unit, these assumptions are reasonable. However, where drawdown is expected to occur beyond that unit, or within a unit that has expected anisotropic properties, the model would not accurately represent the spread of drawdown. In some cases, the method is conservative in that this effect would lead to an over-prediction of drawdown, and in others it could lead to an under-prediction of drawdown. The implications of this assumption are discussed within this report for each precinct.

F.2 Armstrong (1996) Excavation Inflows Method

A method for estimating groundwater inflows into excavated pits was also used to assess the inflows and drawdowns at the portals, drained stations and shafts. This method is presented in Armstrong (1996) and is a modification of the Dupuit-Forcheimer discharge formula. As well as the general assumption listed above of a homogenous, isotropic aquifer of infinite extent, assumptions for this equation include that flow is horizontal and velocity is constant over the saturated thickness. The equation is based on flow in an unconfined aquifer. This method assumes a constant drawdown rather than a constant rate of discharge (unlike the Theis solution) and therefore the effects of overestimated drawdown between excavation and full tanking do not apply for this method.

The Dupuit–Forchheimer assumption requires that the watertable be relatively flat and that the groundwater be hydrostatic (i.e. equipotential lines are vertical). The Dupuit assumptions therefore do not take into account the curvilinear nature of the flow on the radial plane. Flow components in the vertical direction, as well as the variation of the horizontal velocity in the vertical plane are neglected. However, the solution yields reasonably accurate results if the radius (extent of drawdown away from the dewatered excavation) is sufficiently large so that the curvilinear effects are negligible.

F.2.1 Method Assumptions and Limitations

For this method only radial flow is considered. The non-circular pits are converted to equivalent circular pits by converting the base of the pit (area) to a circle of the same area.

As for the Theis method above, the simple analytical method used in this analysis assumes that the dewatered geological formation is of infinite lateral extent and therefore that the drawdown propagates evenly away from the dewatered structure (station, shafts etc). The implications of this assumption are discussed within the report for each precinct.

F.3 Selection of Input Parameters

Both analytical methods require inputs of hydraulic conductivity and groundwater level above the base of the excavation (i.e. required drawdown). The methods also require information relating to aquifer storage parameters, aquifer saturated thickness, excavation dimensions and construction timing details.

F.3.1 Hydraulic Conductivity

The hydraulic conductivity of the formation/s within and above an excavation is the most influential hydrogeological parameter in terms of inflows and groundwater drawdown. Section 5.1.1 describes the hydraulic testing undertaken for the project and provides ranges of hydraulic conductivity estimated from this testing per formation as well as a description of results from previous assessments. The basis for assigning hydraulic conductivity in different geological formations for the analytical analysis is described in the following sections.

As hydraulic conductivity is so influential to the results of the analysis, two scenarios for each location have been analysed; a best estimate hydraulic conductivity scenario and a conservative (higher) hydraulic conductivity scenario. The best estimate hydraulic conductivity is generally based on data collected for the project via aquifer tests such as slug tests and packer tests. Values derived from literature and/or previous experience are also used where the field test data is limited or considered unrepresentative.

F.3.1.1 Melbourne Formation

The Melbourne Formation is the most significant unit for the hydrogeological assessment, because four of the five stations and most of the tunnels reside within this formation. For this reason, the majority of hydraulic conductivity testing within the Project has focussed on this unit. The hydraulic conductivity (horizontal) of the Melbourne Formation has been measured for the Project using slug tests, packer tests and pumping tests. Hydraulic conductivity estimates from slug tests in 28 bores and 118 packer tests in 20 bores were available for the impact assessment. In addition, the preliminary estimates of transmissivity from one pumping test were available and are discussed later in this section. The Melbourne Formation is the primary unit for the analytical analysis of station and shafts for which analytical analysis has been undertaken.

F.3.1.1.1 Packer and slug test results

The range and median results of the packer and slug tests in the Melbourne Formation are shown below in Table E-1. The results show that the median hydraulic conductivity of the two data sets (packer tests and slug tests) is very similar, at slightly less than 0.01 m/day (1 x 10-7 m/sec). If however instead of taking the median of all packer tests (n = 118), the average hydraulic conductivity of packer tests for each bore is determined, the median of that data set (n=20) is 0.02 m/day (2 x 10-7 m/sec). This is considered to be more a reflection of the averaging process, rather than an indication that the packer tests systematically return a higher value than the slug tests.

Table F-1 Results of hydraulic testing in the Melbourne Formation across the Study Area

Test (no.)	Range of hydraulic conductivity values (m/day)	Median hydraulic conductivity (m/day)
Slug tests (28 bores)	1.4×10^{-4} to 1.9 *(2×10^{-9} to 2×10^{-5} m/sec)*	0.008 *(9×10^{-8} m/sec)*
Packer tests (average per bore) (20 bores, 118 tests in total)	0.002 to 0.2 *(2×10^{-8} to 2×10^{-6} m/sec)*	0.007 *(8×10^{-8} m/sec)*

F.3.1.1.2 Pumping Test Results

The preliminary estimate of hydraulic conductivity from the pumping test at CBD South (adjacent to St Paul's Cathedral) is 0.2 m/day (2×10^{-6} m/sec). This is significantly higher than the median values estimated from slug testing and packer testing in the Melbourne Formation across the alignment. There are two main reasons that could account for this difference:

1) The scale effect of hydraulic conductivity measurement - It is well documented in the literature that an increased scale of measurement typically results in an increase in estimate of hydraulic conductivity. This is mostly attributed to the concept that testing a greater volume of aquifer (such as in a pumping test compared to a slug test) means that more macro scale features that are more likely to result in higher hydraulic conductivity values (such as fractures or higher permeability layers) are captured by the larger scale test. Conversely, they are more likely missed in small-scale tests that rely on a vertical bore intercepting such features.

2) Local differences at the CBD South site – The second possible reason for the difference is that there could be local differences in permeability at the CBD South site compared to the remainder of the alignment. The observation bores used to estimate the hydraulic conductivity from the pumping test were also packer tested which allows a comparison with results from the whole alignment. The median of all packer tests (n = 118) is 0.0065 m/day (8×10^{-8} m/sec). The median of packer tests at/near the St Pauls pumping test site (n = 50) is 0.02 m/day (2×10^{-7} m/sec). The median of packer tests excluding the St Pauls pumping test site (n = 68) is 0.0043 m/day (5×10^{-7} m/sec). Hence it can be seen that the St Pauls site has a permeability that is approximately 5 times higher than the permeability of the remainder of the alignment (based on this sample set). Therefore there does appear to be a significant difference between the CBD South station site and the remainder of the alignment.

The median value from the packer tests at St Pauls (0.02 m/day, 2×10^{-7} m/sec) is around 10 times lower than the result from the pumping test. Hence, not only does there appear to be a significant difference between the CBD South site and the remainder of the alignment, but these results indicate that there is a substantial difference between the larger rock mass permeability measured in a pumping test compared to the smaller scale permeability measured in the packer tests. In fact these results suggest an order of magnitude difference between the packer and pumping tests. This has important implications when considering a representative value of hydraulic conductivity for use in a model (analytical or numerical), and this is discussed further in the section below.

F.3.1.1.3 Selecting Appropriate Values of Hydraulic Conductivity for Analytical Modelling of the Melbourne Formation

As described above, the hydraulic conductivity from the pumping test at CBD South was around ten times higher than the median hydraulic conductivity of the packer tests at the same site. Based on this comparison (and on the body of literature documenting the scale effect of hydraulic conductivity measurement), a value for the alignment wide assessment should be a higher value than that derived from packer tests and slug tests. Adopting the same ratio observed at CBD South, an appropriate hydraulic conductivity to apply in modelling of the alignment is 0.05 m/day (*6* $\times 10^{-7}$ *m/sec)*. This is a number ten times higher than the median for packer tests excluding CBD South. The value is about five times higher than the median for slug tests excluding CBD South.

F.3.1.2 Brighton Group

One hydraulic conductivity test in the Brighton Group has been undertaken in this Project (up to Concept Design). This slug test was undertaken 1 km to the north of the Domain station and yielded a hydraulic conductivity of 0.03 m/day. This is considered reasonably low for the Brighton Group although is within the range of previous experience provided in the Golder (2016b, Appendix H) modelling report. Based on this range, and along with previous Jacobs experience in the Brighton Group, for this analysis a horizontal hydraulic conductivity of 0.1 m/day (1×10^{-6} m/sec) was selected.

F.3.1.3 Combined Transmissivity

For the emergency intervention shafts between tunnels, the TBM launch shaft in Fawkner Park and the eastern portal, the excavation spanned both the Melbourne Formation and the Brighton Group. As only one value can be entered for hydraulic conductivity, the combined transmissivity of the units was calculated (using hydraulic conductivity and saturated thickness of each unit at each location) and then divided by the total saturated thickness to produce a representative hydraulic conductivity.

F.3.2 Other Hydrogeological Parameters and Inputs

The other hydrogeological parameters and inputs were selected based on the following:

1) **Required drawdown:** The difference between the base of the excavation (m AHD) and the maximum measured groundwater level in the precinct. The analytical solutions have been used to assess drawdown during construction (assumed to occur over approximately the next 5 years) and therefore measured maximum groundwater levels (i.e. over the last 3 to 5 years) rather than calculated design groundwater levels have been used (e.g. no allowance for long term above average recharge or climate change have been taken into account in this drawdown number). The elevation of the base of drained structures (shafts and Parkville station) has been taken from technical drawings supplied in the Concept Design or the assumptions stated in Section 4.7

2) **Aquifer storage parameters:** For transient analytical assessments (such as Theis drawdown and Armstrong inflows), an estimate of storativity/specific yield is required. In the absence of any project specific estimates of storage parameters (usually derived from pumping tests with observation bores), values from previous assessments have been used. For the Melbourne Formation a value of 0.01 (unitless) was adopted and for the Brighton Group a value of 0.1 was adopted. The Brighton Group value used for this assessment is very similar to the value used in the Golder modelling but the Melbourne Formation value used is much lower than the Golder modelling (Golder 2016b, Appendix H). The value used in this assessment is considered more likely to be accurate based on our previous experience from pumping tests in this unit. The value for the Melbourne Formation represents an unconfined storage value. While overlying weathered layers can create semi-confined conditions in this unit, over the long periods of time that dewatering is assumed to occur in this assessment it is considered more likely to behave as an unconfined system. Compared to hydraulic conductivity, the results are not highly sensitive to this value

3) **Aquifer saturated thickness:** The effective saturated thickness for these assessments is the proportion of the aquifer that may contribute to flow. A value twice the required drawdown has been used for the construction drawdown cases

4) **Excavation dimensions:** The dimensions of the station boxes and shafts have been measured from technical drawings supplied in the Concept Design

5) **Construction timings:** The aspects of the construction timing that are relevant to this assessment are the length of time to fully excavate a structure (shaft, portal, cavern or station box) and the subsequent time taken to fully tank the structure. As described above, for the purposes of this assessment, the time up to full tanking of the structure has been used as the period of assumed drainage in this analysis. The design team has provided provisional construction schedules for this assessment.

F.4 Results

F.4.1 Tunnels between CBD South station and Domain station: Emergency access shafts

F.4.1.1 Concept Design

F.4.1.1.1 Construction

The shaft just north of Linlithgow Avenue is predominantly within the unsaturated zone. The tunnels at this location are below the watertable, but assuming the tunnel is constructed first and then the emergency access shaft is installed above the tunnel, dewatering would not be required and therefore no drawdown of groundwater levels would occur.

F.4.1.2 Alternative Design Option

F.4.1.2.1 Construction

The alternative design option for the emergency access intervention shaft is located at Tom's Block. This structure is located above the watertable and therefore dewatering would not be required and no drawdown of groundwater levels would occur.

The alternative design option below CityLink means that the Linlithgow Avenue emergency access shaft would be required to go deeper to reach the deeper tunnel alignment. The deeper shaft would extend below the watertable and therefore would need to be drained during construction.

Groundwater levels at the Linlithgow emergency access shaft are approximately 0 m AHD and the base of the shaft is at -20 m AHD. Therefore approximately 20 m of groundwater drawdown would be required to keep the excavation dry during shaft construction.

Method

Two analytical methods were used to estimate groundwater drawdown away from the emergency access shaft, and groundwater inflows into the structures during construction:

1. The Theis drawdown method (Theis, 1935) and
2. The Armstrong pit inflows method (Armstrong, 2001).

This method allows modelling of drawdown in a single, homogeneous and isotropic aquifer and is therefore an over simplification of the actual system but can be used to give an indication of possible drawdown ranges. The results indicate the order of magnitude of inflows and drawdown, which can be used to assess impacts to groundwater-dependent values for the EES. Results are interpreted as accurate to within 1 m for the impact assessment.

To account for variation in estimates of hydraulic conductivity in the Melbourne Formation, a best estimate of hydraulic conductivity and a conservative case (higher hydraulic conductivity) have been analysed. Input parameters for the analysis are shown in Table F-2.

Table F-2 Input parameters for analytical analysis of inflows and potential drawdown for the Emergency Access Shaft

Parameter	Value	Reasoning
Hydraulic conductivity	Best estimate: 0.05 m/day *(6E-7 m/sec)* Conservative: 0.2 m/day *(2E-6 m/sec)*	The best estimate is the adjusted median for slug tests and packer tests undertaken for this project in this unit. The conservative value is from the results of a pumping test undertaken near CBD South in what is thought to be a highly permeable area of the Melbourne Formation.
Storativity	0.01	From previous experience in this unit as documented in Section 5.1.2.
Height of water above base of shaft	20 m	RL of base of shaft assumed to be -20 m AHD. Groundwater in this area is approximately 0 m AHD.
Saturated thickness of aquifer	40 m	Thickness of aquifer that may be influenced – assumed to be double the required drawdown.
Structure dimensions	8 m by 8 m	Estimated from design drawings (MMRA Project Description version 5, October 2015).

Parameter	Value	Reasoning
Construction timings	12 months to full length of tunnel and a further 6 months to seal walls	Estimated from design team (pers. comm. J. Wilcox, 14 Oct 2015).

Results

The Theis drawdown analysis indicates an average total inflow of 0.7 L/s (best estimate) to 2.4 L/s (conservative case) over the construction period. The solution only allows for one inflow rate throughout construction. This would result in an over prediction of inflows and drawdowns in the twelve months between full excavation (when target drawdown is achieved) and tanking. The Armstrong method, which gives variable rates over time, indicates inflows of between 0.2 and 0.4 L/s (best estimate) to 0.5 and 1.2 L/s (conservative) over the construction period.

The drawdown predicted by the two models is shown below in Table F-3. The maximum distance of influence is assumed to be the extent of the 1 m drawdown cone.

Table F-3 Predicted drawdown (m) at the emergency access shaft at Linlithgow Avenue (under CityLink alignment) using the Theis and Armstrong analytical methods

		Theis drawdown method results				Armstrong inflows method results			
		Best estimate		Conservative case		Best estimate		Conservative case	
		360	540	360	540	360	540	360	540
Maximum estimated drawdown (m) at distance (1)	10 m	16	17	16	17	15	16	17	18
	20 m	13	14	14	15	12	13	15	16
	50 m	9	10	11	12	5	6	10	12
	100 m	6	7	8	9	4	5	5	6
	150 m	5	6	7	8	3	4	4	5
	250 m	3	3	5	6	1	2	2	3
	500 m	<1	1	2	3	<1	<1	<1	1
Maximum radius of influence (drawdown <1 m) (m)		420	520	800	980	270	330	500	610

(1) Drawdown was estimated in a number of directions away from the structure and the "maximum estimated drawdown" shows the drawdown in the direction that produced the highest drawdown. In this case drawdown was equidistant in all directions

Due to the uncertainty associated with this method, the drawdown results are interpreted as accurate to within 1 m for the impact assessment.

The simple analytical methods used in this analysis assume that drawdown propagates evenly away from the point of dewatering (i.e. the shafts). However in reality, the heterogeneous nature of the geology would cause drawdown to radiate out from the shafts unevenly. In particular, if drawdown intersects the palaeovalley sediments of the Yarra River, 170 m to the north, it may spread further or be limited, depending on the nature of the sediments. If higher permeability sediments are encountered the drawdown may propagate further. If lower permeability sediments are encountered this may limit the extent of drawdown, although drawdown within the extent may be higher. The palaeovalley sediments are likely to prevent drawdown spreading to the north of the Yarra River.

The effect of the palaeovalley deposits on drawdown cannot be predicted using the Theis and Armstrong analytical methods, and the discussion of potential impacts below therefore does not recognise this influence.

F.4.2 Tunnels between Domain station and eastern portal: Emergency access shafts

F.4.2.1 Concept Design

F.4.2.1.1 Construction

There are two shafts located within this section of tunnel:

1. A TBM launch shaft is located in the northwest corner of Fawkner Park
2. An emergency access shaft is located in the northeast corner of Fawkner Park

It is assumed these shafts would be drained during construction where they would be below the water table.

Groundwater levels at the TBM launch shaft are approximately 1 m AHD and the base of the shaft is at -14 m AHD. Therefore approximately 15 m of groundwater drawdown would be required to keep the excavation dry during shaft construction.

Method

Two analytical methods were used to estimate groundwater drawdown away from the TBM launch shaft and emergency access shaft, and groundwater inflows into these structures during construction:

1. The Theis drawdown method (Theis, 1935)
2. The Armstrong pit inflows method (Armstrong, 2001).

This method allows modelling of drawdown in a single, homogeneous and isotropic aquifer and is therefore an over simplification of the actual system but can be used to give an indication of possible drawdown ranges. The results indicate the order of magnitude of inflows and drawdown, which can be used to assess impacts to groundwater-dependent values for the EES. Results are interpreted as accurate to within 1 m for the impact assessment.

To account for variation in estimates of hydraulic conductivity in the units present, a best estimate of hydraulic conductivity and a conservative case (higher hydraulic conductivity) have been analysed. Input parameters for the analysis are shown in Table F-4 and Table F-5.

Table F-4 Input parameters for analytical analysis of inflows and potential drawdown for the TBM launch shaft

Parameter	Value	Reasoning
Hydraulic conductivity	*Melbourne Formation* Best estimate: 0.05 m/day *(6E-7 m/sec)* Conservative: 0.23 m/day *(1E-6 m/sec)* *Brighton Group:* Best estimate: 0.1 m/day *(1E-6 m/sec)* Conservative: 0.5 m/day *(6E-6 m/sec)*	*Melbourne Formation* The best estimate is the adjusted median for slug tests and packer tests undertaken for this project in this unit. The conservative value is from the results of a pumping test undertaken near CBD South in what is thought to be a highly permeable area of the Melbourne Formation. *Brighton Group* Based on previous experience in this unit and range of values of Golder previous experience (Golder, 2016a, Appendix G) Total transmissivity calculated by summing transmissivity of each unit (hydraulic conductivity multiplied by saturated thickness)
Storativity	*Melbourne Formation:* 0.01 *Brighton Group:* 0.1 *Combined:* 0.055	From previous experience in this unit, as documented in Section 5.1.2. Combined unit is weighted by thickness of each formation.
Height of water above base TBM launch shaft	15 m	RL of base of TBM launch shaft assumed to be -14 m AHD. Groundwater in this area is approximately 1 m AHD
Saturated thickness of aquifer	*Total:* 30 m *Melbourne Formation:* 25 m *Brighton Group:* 5 m	Thickness of aquifer that may be influenced – assumed to be double the required drawdown at the TBM shaft.
Structure dimensions	20 m by 28 m	Estimated from design drawings (MMRA Project Description version 5, October 2015)
Construction timings	12 months to full length of tunnel and a further 6 months to seal walls	Estimated from design team (pers. comm. J. Wilcox, 14 Oct 2015)

Table F-5 Input parameters for analytical analysis of inflows and potential drawdown for the emergency access shaft

Parameter	Value	Reasoning
Hydraulic conductivity	Best estimate: 0.05 m/day *(6E-7 m/sec)* Conservative: 0.2 m/day *(2E-6 m/sec)*	The best estimate is the adjusted median for slug tests and packer tests undertaken for this project in this unit. The conservative value is from the results of a pumping test undertaken near CBD South in what is thought to be a highly permeable area of the Melbourne Formation.
Storativity	0.01	From previous experience in this unit, as documented in Section 5.1.2.
Height of water above base of shaft	17 m	RL of base of shaft assumed to be -13 m AHD. Groundwater in this area is approximately 4 m AHD
Saturated thickness of aquifer	34 m	Thickness of aquifer that may be influenced – assumed to be double the required drawdown.

Parameter	Value	Reasoning
Structure dimensions	8 m by 8 m	Estimated from Concept Design drawings
Construction timings	12 months to full length of tunnel and a further 6 months to seal walls	Estimated from design team (pers. comm. J. Wilcox, 14 Oct 2015)

Results

TBM Launch Shaft in north west of Fawkner Park

The Theis drawdown analysis indicates an average total inflow of 0.7 L/s (best estimate) to 2.5 L/s (conservative case) over the construction period. The solution only allows for one inflow rate throughout construction. This would result in an over prediction of inflows and drawdowns in the twelve months between full excavation (when target drawdown is achieved) and tanking. The Armstrong method, which gives variable rates over time, indicates inflows of between 0.1 and 0.9 L/s (best estimate) to 0.6 and 2.2 L/s (conservative) over the construction period.

The drawdown predicted by the two models is shown below in Table F-6. The maximum distance of influence is assumed to be the extent of the 1 m drawdown cone.

Table F-6 Predicted drawdown (m) at the TBM launch shaft in Fawkner Park using the Theis and Armstrong analytical methods

		Theis drawdown method result				Armstrong inflows method results			
		Best estimate		Conservative case		Best estimate		Conservative case	
		360	540	360	540	360	540	360	540
Maximum estimated drawdown (m) at distance [(1)]	10 m	13	14	13	14	10	11	12	13
	20 m	11	12	12	12	6	7	10	10
	50 m	7	8	8	9	4	4	5	5
	100 m	4	5	6	7	2	2	4	4
	150 m	2	3	4	5	<1	1	2	3
	250 m	<1	1	2	3	<1	<1	1	1
	500 m	<1	<1	<1	<1	<1	<1	<1	<1
Maximum radius of influence (drawdown <1 m) (m)		210	255	400	490	140	170	260	310

(1) Drawdown was estimated in a number of directions away from the structure and the "maximum estimated drawdown" shows the drawdown in the direction that produced the highest drawdown. In this case drawdown was equidistant in all directions

Emergency Access Shaft in north east of Fawkner Park

The Theis drawdown analysis indicates an average total inflow of 0.5 L/s (best estimate) to 1.7 L/s (conservative case) over the construction period. The solution only allows for one inflow rate throughout construction. This would result in an over prediction of inflows and drawdowns in the twelve months between full excavation (when target drawdown is achieved) and tanking. The Armstrong method, which gives variable rates over time, indicates inflows of between 0.1 and 0.3 L/s (best estimate) to 0.4 and 0.9 L/s (conservative) over the construction period.

The drawdown predicted by the two models is shown below in Table F-7. The maximum distance of influence is assumed to be the extent of the 1 m drawdown cone.

Table F-7 Predicted drawdown (m) at the Intervention Shaft in Fawkner Park using the Theis and Armstrong analytical methods

		Theis drawdown method results				Armstrong inflows method results			
		Best estimate		Conservative case		Best estimate		Conservative case	
		360	540	360	540	360	540	360	540
Maximum estimated drawdown (m) at distance [(1)]	10 m	13	14	14	15	13	14	15	15
	20 m	11	12	12	13	10	11	13	13
	50 m	8	9	9	10	4	5	8	9
	100 m	5	6	7	8	3	3	4	4
	150 m	4	5	6	6	2	2	3	3
	250 m	2	3	4	5	<1	1	2	2
	500 m	<1	<1	2	2	<1	<1	<1	1
Maximum radius of influence (drawdown <1 m) (m)		370	450	690	840	240	290	440	530

[(1)] Drawdown was estimated in a number of directions away from the structure and the "maximum estimated drawdown" shows the drawdown in the direction that produced the highest drawdown. In this case drawdown was equidistant in all directions

The simple analytical methods used in this analysis assume that drawdown propagates evenly away from the point of dewatering (i.e. the shafts). However in reality, the heterogeneous nature of the geology would cause drawdown to radiate out from the shafts unevenly. In particular, if drawdown intersects the palaeovalley sediments of the Yarra River to the north, it may spread further or be limited, depending on the nature of the sediments. If higher permeability sediments are encountered the drawdown may propagate further. If lower permeability sediments are encountered this may limit the extent of drawdown, although drawdown within the extent may be higher. The palaeovalley sediments are likely to prevent drawdown spreading to the north of the Yarra River.

Another change in geology that may impact the shape of the drawdown cone from the TBM launch shaft is the presence of Coode Island Silt at Albert Park Lake. These lower permeability sediments are likely to limit the extent of drawdown in this direction (i.e. acting as a barrier boundary), although this may result in slightly higher drawdown within the drawdown extent.

The effect of the palaeovalley and Coode Island Silt deposits on drawdown cannot be predicted using the Theis and Armstrong analytical methods, and the discussion of potential impacts below therefore does not recognise this influence.

F.4.2.1.2 Alternative Design Option

A potential alternative design option is for the emergency access shaft to be located in the northwest corner of Fawkner Park (at the TBM launch/retrieval shaft site). The predicted impacts for this alternative design option are the same as the the TBM launch/retrieval shaft, as discussed above.

F.4.3 Parkville station

F.4.3.1 Construction

It is assumed that Parkville station would be drained during construction. Where the station infrastructure is below the watertable groundwater inflows would occur, resulting in drawdown around the station.

Maximum measured groundwater levels are approximately 24.1 m AHD at Parkville station, and the base of the station is at approximately 8.1 m AHD. Therefore approximately 16 m of groundwater drawdown would be required to keep the excavation dry during construction.

F.4.3.1.1 Method

Two methods were used to estimate groundwater drawdown away from the station box, and groundwater inflows into the station box during construction:

3. The Theis drawdown method (Theis, 1935) and
4. The Armstrong pit inflows method (Armstrong, 2001) (see Section F.2).

Since there is significant variation and uncertainty associated with hydraulic conductivity values in the Melbourne Formation, a best estimate of hydraulic conductivity and a conservative case (higher hydraulic conductivity) have been analysed. Input parameters for the analysis are shown in Table F-8.

Table F-8 Input parameters for analytical analysis of inflows and potential drawdown

Parameter	Value	Reasoning
Hydraulic conductivity	Best estimate: 0.05 m/day *(6E-7 m/sec)* Conservative: 0.2 m/day *(2E-6 m/sec)*	See Section 5.1.1. The best estimate is the adjusted median for slug tests and packer tests undertaken for this project in this unit. The conservative value is from the results of a pumping test undertaken near CBD South in what is thought to be a highly permeable area of the Melbourne Formation.
Storativity	0.01	From previous experience in this unit, as documented in Section 5.1.2.
Height of water above station base	16 m	RL of station base assumed to be 8.1 m AHD. Maximum measured groundwater levels in this precinct = 24.1 m AHD. This is a conservative level considering the drop in groundwater levels that has occurred since the construction of the nearby VCCC drained basement and the fact that groundwater levels in this precinct drop from east to west.
Saturated thickness of aquifer	32 m	Thickness of aquifer that may be influenced – assumed to be double the required drawdown.
Structure dimensions	250 m by 25 m	Estimated from design drawings (MMRA Project Description version 5, October 2015).
Construction timings	12 months to excavate to full depth and a further 6 months to seal walls and base	Estimated from design team (pers. comm. J. Wilcox, 14 Oct 2015).

F.4.3.1.2 Results

The Theis drawdown analysis indicates an average total inflow of 1 L/s (best estimate hydraulic conductivity) to 4 L/s (conservative case hydraulic conductivity) over the construction period. The solution allows for only one inflow rate throughout construction. This would result in an over prediction of inflows and drawdowns in the six months between full excavation (when target drawdown is achieved) and tanking. The Armstrong method, which gives variable rates over time, indicates inflows of between 0.2 and 1.3 L/s (best estimate) to 0.7 and 3.3 L/s (conservative) over the construction period.

The predicted extent of drawdown around the excavation at two time intervals (360 days and 540 days) over the construction period is shown in Table F-9.

Table F-9 Predicted drawdown at Parkville station using the Theis and Armstrong analytical methods

		Theis drawdown method results				Armstrong inflows method results			
		Best estimate		Conservative case		Best estimate		Conservative case	
		360 days	540 days	360 days	540 days	360 days	540 days	360 days	540 days
Maximum estimated drawdown (m) at distance (1)	10 m	17	19	16	17	13	14	15	15
	50 m	15	17	14	15	7	7	10	11
	100 m	12	14	12	13	4	5	6	6
	250 m	5	7	7	9	1	2	3	4
	500 m	1	2	4	5	<1	<1	1	2
	1000 m	<1	<1	<1	1	<1	<1	<1	<1
Maximum radius of influence (drawdown <1 m) (m)		480	590	930	1140	270	330	550	660

(1) Drawdown was estimated in a number of directions away from the structure and the "maximum estimated drawdown" shows the drawdown in the direction that produced the highest drawdown. In this case that direction is perpendicular to the structure (to the north and south)

The simple analytical methods used in this analysis assume that drawdown propagates evenly away from the point of dewatering (i.e. the station excavation). However in reality, the heterogeneous nature of the geology would cause drawdown to radiate out from the station unevenly. The geology within the extent of drawdown at Parkville is entirely Melbourne Formation and therefore, there are no changes in geology that may impact the shape of the drawdown cone. However, heterogeneity within the Melbourne Formation would impact the shape of the cone. Features such as faults and fissure would provide conduits for flow whereas dykes and clay layers would prevent the propagation of drawdown.

The effect of the heterogeneity of the Melbourne Formation on drawdown cannot be predicted using the Theis and Armstrong analytical methods, and the discussion of potential impacts below therefore does not recognise this influence.

The Armstrong equation suggests a smaller drawdown extent around the station, however because of the uncertainty associated with the methods, results are considered to be consistent as they are within an order of magnitude. Results are interpreted as accurate to within 1 m for the impact assessment. To be conservative, the Theis results are used in the impact assessment. The drawdown associated with construction would be short-term, and groundwater levels would recover after the structures have been tanked.

F.4.4 Eastern Portal

F.4.4.1 Construction

It is assumed that all infrastructure at the Eastern Portal would be drained during construction, including the decline structure, the cut and cover tunnel, and the TBM retrieval shaft. Where these structures are below the watertable groundwater inflows would occur, resulting in drawdown around the portal.

Groundwater levels are approximately 4.6 m AHD at the Eastern Portal, and the base of the TBM shaft is at approximately -6 m AHD. Therefore, approximately 11.6 m of groundwater drawdown would be required to keep the excavation dry during construction.

F.4.4.1.1 Method

Two analytical methods were used to estimate groundwater drawdown away from the TBM retrieval shaft and decline structure, and groundwater inflows into these structures during construction:

5. The Theis drawdown method (Theis, 1935) and
6. The Armstrong pit inflows method (Armstrong, 2001) (see Section F.2).

Instead the results indicate the order of magnitude of inflows and drawdown, which have been used to assess impacts to groundwater-dependent values for the EES.

Since there is significant variation and uncertainty associated with hydraulic conductivity values in the Melbourne Formation, a best estimate of hydraulic conductivity and a conservative case (higher hydraulic conductivity) have been analysed. Input parameters for the analysis are shown in Table F-10.

Table F-10 Input parameters for analytical analysis of inflows and potential drawdown

Parameter	Value	Reasoning
Hydraulic conductivity	*Melbourne Formation* Best estimate: 0.05 m/day *(6E-7 m/sec)* Conservative: 0.2 m/day *(1E-6 m/sec)* *Brighton Group:* Best estimate: 0.1 m/day *(1E-6 m/sec)* Conservative: 0.5 m/day *(6E-6 m/sec)*	See Section 5.1 and Appendix D. *Melbourne Formation* The best estimate is the adjusted median for slug tests and packer tests undertaken for this project in this unit. The conservative value is from the results of a pumping test undertaken near CBD South in what is thought to be a highly permeable area of the Melbourne Formation. *Brighton Group* Based on previous experience in this unit and range of values of Golder previous experience (Golder, 2016a, Appendix G) Total transmissivity calculated by summing transmissivity of each unit (hydraulic conductivity multiplied by saturated thickness)
Storativity	*Melbourne Formation:* 0.01 *Brighton Group:* 0.1 *Combined:* 0.055	From previous experience in this unit, as documented in Section 5.1.2. Combined unit is weighted by thickness of each formation
Height of water above TBM retrieval shaft (deepest part of structure)	0 m to 10.6 m	RL of TBM retrieval shaft base assumed to be -6 m AHD. At the eastern end of the decline structure the structure is above ground level (and hence 0 m drawdown required). Maximum measured groundwater levels in this precinct = 4.6 m AHD

Parameter	Value	Reasoning
Saturated thickness of aquifer	*Total:* 21 m *Melbourne Formation:* 10.5 *Brighton Group:* 10.5	Thickness of aquifer that may be influenced – assumed to be double the required drawdown at the TBM shaft.
Structure dimensions	30 m by 60 m (TBM retrieval box) 210 m (length of decline structure below the watertable)	Estimated from design drawings (MMRA Project Description version 3, September 2015)
Construction timings	12 months to excavate to full depth and a further 6 months to seal walls and base	Estimated from design team (pers. comm. J. Wilcox, 20 Oct 2015)

F.4.4.1.2 Results

The Theis drawdown analysis indicates an inflow of 0.5 L/s (best estimate hydraulic conductivity) to 1.7 L/s (conservative case hydraulic conductivity) over the construction period. The solution only allows for only one inflow rate throughout construction. This would result in an over prediction of inflows and drawdowns in the six months between full excavation (when target drawdown is achieved) and tanking. The Armstrong method, which gives variable rates over time, indicates inflows of between 0.1 and 0.5 L/s (best estimate) to 0.4 and 1.5 L/s (conservative) over the construction period.

The drawdown and predicted maximum distance of drawdown around the excavation at two time intervals (360 days and 540 days) over the construction period is shown in Table F-11.

Table F-11 Predicted drawdown at the Eastern Portal using the Theis and Armstrong analytical methods

		Theis drawdown method results				Armstrong method method results			
		Best estimate		Conservative case		Best estimate		Conservative case	
		360 days	540 days	360 days	540 days	360 days	540 days	360 days	540 days
Maximum estimated drawdown (m) at distance [(1)]	10 m	10	11	10	11	9	9	9	10
	50 m	7	8	8	9	4	4	6	7
	100 m	5	6	6	7	2	3	3	4
	250 m	2	3	4	4	<1	1	2	2
	500 m	<1	<1	2	2	<1	<1	<1	1
	1000 m	<1	<1	<1	<1	<1	<1	<1	<1
Maximum distance of influence (drawdown <1 m) (m)		350	430	670	830	210	250	410	480

[(1)] Drawdown was estimated in a number of directions away from the structure and the "maximum estimated drawdown" shows the drawdown in the direction that produced the highest drawdown. In this case that direction is to the west away from the TBM retrieval shaft

The simple analytical methods used in this analysis assume that drawdown propagates evenly away from the point of dewatering (i.e. the decline structure and TBM launch shaft). However in reality, the heterogeneous nature of the geology would cause drawdown to radiate out from the portal unevenly. In particular, if drawdown intersects the palaeovalley sediments of the Yarra River, it may spread further or be limited, depending on the nature of the sediments encountered. If higher permeability sediments are encountered the drawdown may propagate further to the east and west along the palaeovalley and given the limited spatial extent of the palaeovalley, drawdown can be greater within these sediments compared to the uniform geology case. If lower permeability sediments are encountered, this may limit the extent of drawdown, although drawdown within the extent may be higher. The palaeovalley sediments are likely to prevent drawdown spreading to the north of the Yarra River.

The effect of the palaeovalley on drawdown cannot be predicted using the Theis and Armstrong analytical methods, and the discussion of potential impacts below therefore does not recognise this influence. Numerical modelling in preparation by Golder would more accurately assess the influence of the palaeovalley sediments on drawdown that arises as a result of dewatering at the Eastern Portal.

The Armstrong equation suggests a smaller drawdown extent around the portal, however because of the uncertainty associated with the methods, results are considered to be consistent. Results are interpreted as accurate to within 1 m for the impact assessment. To be conservative, the Theis results are used in the impact assessment. The drawdown associated with construction would be short-term, and groundwater levels would recover after the structures have been tanked.

Appendix G Golder Associates Pty Ltd, Melbourne Metro Rail Project Concept Design – Interpreted Hydrogeological Setting – EES Summary Report

14 April 2016

MELBOURNE METRO RAIL PROJECT

Interpreted Hydrogeological Setting - EES Summary Report

Submitted to:
AJM Joint Venture
121 Exhibition Street
Melbourne, Vic, 3000

REPORT

Report Number. 1525532-220-R-Rev1

Distribution:

1 Copy - AJM Joint Venture
1 Copy - Golder Associates Pty. Ltd.

Golder Associates

Glossary of Abbreviations, Nomenclature and Technical Terms

AHD	Australian Height Datum
ASS	Acid Sulfate Soils
ASR	Acid Sulfate Rock
bgl	Below Ground Level
CBD	Central Business District
CUB	Carlton United Brewery
3D	Three – Dimensional
EES	Environment Effects Statement
EMP	Environmental Management Plan
EPA	Environmental Protection Agency
GQRUZ	Groundwater Quality Restricted Use Zone
IBE	Ion Balance Error
LOR	Limit of Reporting
K	Hydraulic Conductivity
Kx	Horizontal Hydraulic Conductivity in x-direction
Ky	Horizontal Hydraulic Conductivity in y-direction
Kz	Vertical Hydraulic Conductivity
MURL	Melbourne Underground Rail Loop (City Loop)
Melbourne Metro	The Melbourne Metro Rail Project
PASS	Potential Acid Sulfate Soil
QA/QC	Quality Assurance/Quality Control
SEPP	State Environment Protection Policy
SRB	Sulphate Reducing Bacteria
TBM	Tunnel Boring Machine
TDS	Total Dissolved Solids
TRH	Total Recoverable Hydrocarbon
TWA	Trade Waste Agreement

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1.0 INTRODUCTION

1.1 Overview

Aurecon Jacobs Mott Macdonald Joint Venture (AJM JV) has engaged Golder Associates Pty Ltd (Golder) to provide hydrogeological services for the proposed Melbourne Metro Rail Project (Melbourne Metro). The services provided by Golder in 2015 and 2016 are to support the development of the Environment Effects Statement (EES) for the Melbourne Metro ‘Concept Design’.

The Melbourne Metro Concept Design comprises approximately 9 km of rail tunnels running from Kensington to South Yarra, including five new stations. 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 EES summary report describes the interpreted hydrogeological setting for the Melbourne Metro Concept Design. This report should be read in conjunction with the Interpreted Geological Setting EES Summary Report and Contaminated Land EES Summary Report, which describe the geological setting, and existing and historical land uses in the vicinity of Melbourne Metro.

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 Background

Between 2011 and 2013, Golder was engaged by Public Transport Victoria to provide geotechnical, hydrogeological and environmental services to support development of route options for the project. This report builds upon this initial work and provides an update of the hydrogeological site setting and groundwater conditions within a broader area of the Melbourne Metro Concept Design alignment based on the site investigation work which has been collected for the project up to September 2015.

1.3 Aims of Report

The aims of this EES summary report are as follows:

- To provide a description of the interpreted hydrogeological setting of the study area and an assessment of the hydraulic properties of main aquifers that are expected to be encountered along the proposed Melbourne Metro alignment.
- Outline the inferred conceptual groundwater flow system and provide an assessment of potential long term groundwater levels.
- Provide an assessment of the groundwater quality and potential issues that may arise with respect to groundwater movement, groundwater inflow into the stations and tunnels and the effects of groundwater quality on the durability of materials used for construction.

This work has also been used to inform the regional groundwater modelling completed by Golder and the subsequent Groundwater Impact Assessment completed by AJM JV for the EES.

1.4 Limitations

Your attention is drawn to the document – "Limitations", which is included in APPENDIX G 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.

2.0 PROJECT DESCRIPTION

For the purpose of this report the broad corridor around the proposed Melbourne Metro Concept Design alignment between South Kensington station in Kensington and Toorak Road in South Yarra is referred to as the "study area". This incorporates the project area which has been defined by the project boundaries in the EES. The location of the proposed Melbourne Metro alignment, rail stations and the general study area are shown in Drawing 1.

Based on the Concept Design documentation, Melbourne Metro would include the construction of two tunnels and associated structures including portals, shafts and excavations for station boxes and underground caverns as summarised below:

- Tunnel portals at South Yarra and Kensington.
- Three cut and cover station excavations at Arden, Parkville and Domain.
- Two underground cavern station excavations at CBD North and CBD South.
- A number of ventilation shafts and cross passages.

Based on the type of infrastructure proposed and the anticipated ground conditions, the alignment has been divided into 23 segments to facilitate geotechnical and contaminant soil data presentation and discussions. The segments are numbered from west towards east. Their extents are shown on the longitudinal geological section in APPENDIX A. However, for the purpose of groundwater flow and groundwater quality data discussions, the study area has been divided in four main zones taking into considerations the tunnel and station invert levels relevant to the current water table, localised groundwater flow and quality conditions, and hydrostratigraphic units in which the tunnels and associated structures would be constructed. These zones and corresponding alignment segments are listed in Table 2 and their extents are shown in Figure 1.

Table 2: Hydrogeological Zones

Hydrogeological Zone	Alignment Segments	Area
Western Zone	1 to 9	Western Portal, Western Portal to Arden Station, Arden Station, Arden Station to Parkville Station
Central Zone	10 to 15	Parkville Station, Parkville Station to CBD North Station, CBD North Station, CBD North Station to CBD South Station, CBD South Station
Yarra Crossing	16	Yarra River and Alexandra Gardens
Eastern Zone	17 to 23	Alexandra Gardens to Domain Station, Domain Station, Domain Station to Eastern Portal, Eastern Portal

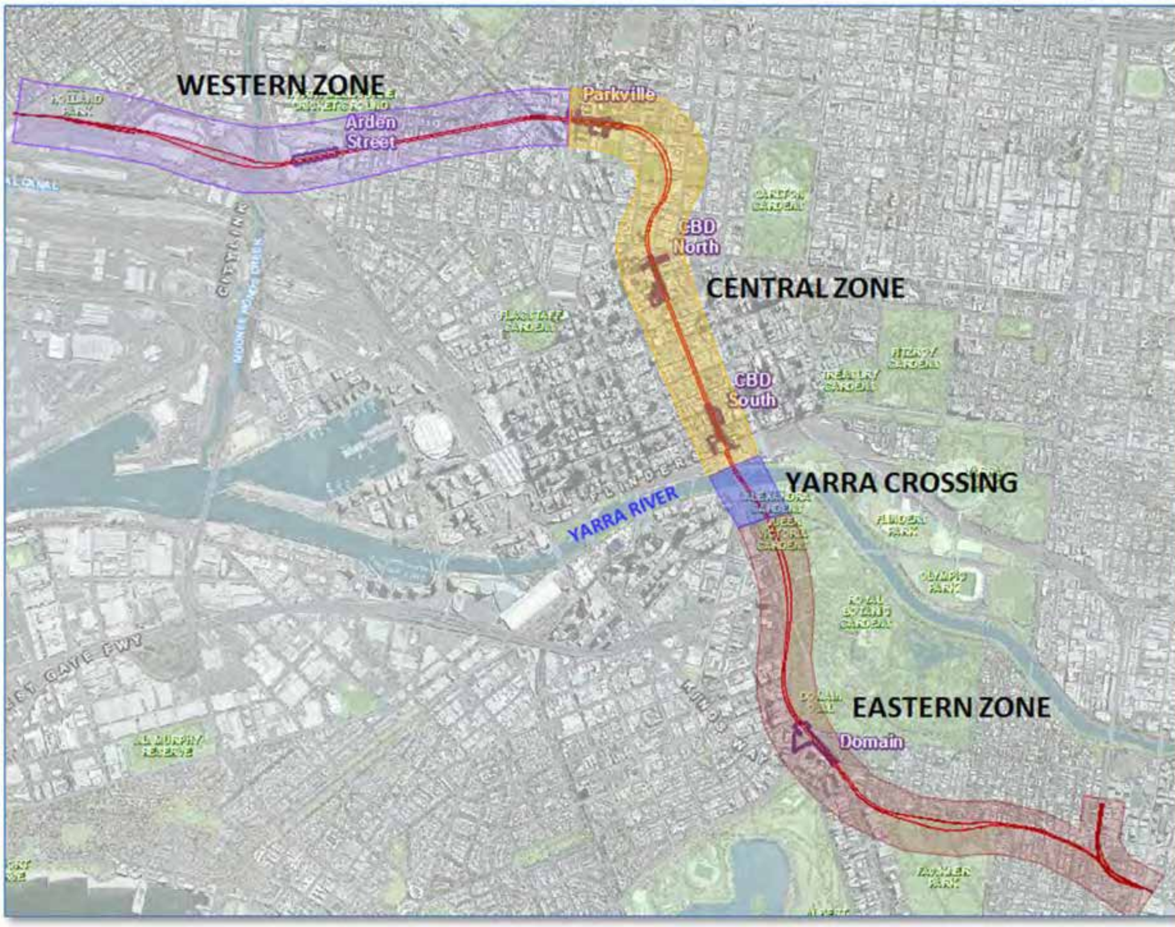

Figure 1: Extent of Hydrogeological Zones

3.0 GEOLOGICAL AND HYDROGEOLOGICAL SETTING

3.1 Main geological units

The regional geology, geological history and regional structures of the broad study area are presented in the Interpreted Geological Setting – EES Summary Report. A summary of the stratigraphic units expected to be encountered along the proposed Melbourne Metro alignment is provided in Table 3. A geological plan showing the interpreted surficial geology of the study area is provided in Drawing 2, while a geological long section showing the interpreted geological setting along tunnel alignment is 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
	Pleistocene	Holocene Alluvium (Q_{ha})[1]	Fine to medium grained alluvial sands
		Jolimont Clay (Q_{pj})	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_{pfl}) 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_{vns}) – Swan Street Basalt	Olivine basalt variably weathered and fractured. Typically referred to as lower Newer Volcanics.
		Punt 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_{ov})	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.

[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.

Geological Period	Geological Epoch	Stratigraphic Unit	Description
Silurian		Melbourne Formation (S_{ud})	Interbedded siltstone and sandstone, folded, fractured and variably weathered.

A 3D geological model was developed for the study area based on review of geological data available for the broader area. This included third party information made available to the project and Golder's past project experience within the study area. An outline of the conceptual geological model is summarised below:

- The Silurian age sediments of the Melbourne Formation form the bedrock for the younger formations except where Devonian granodiorites are present.
- The Silurian bedrock has been shaped by tectonic and erosion processes through geological time with following main events having the most prominent effect on the basement topography:
  - development of the Port Phillip Sedimentary Basin during the early Paleogene period
  - development of the Jolimont Valley during the early Quaternary period (early Pleistocene) and Holocene Alluvium Valley during the late Quaternary (late Pleistocene) by ancestral Yarra River[2]. (Drawing 2)
  - development of the Moonee Ponds Creek Valley during the early Quaternary period (early Pleistocene) (Drawing 2).
- The Port Phillip Sedimentary Basin and younger erosional valleys were filled by sequences of:
  - marine, fluvial and swamp sediments that were deposited during successive episodes of sea transgressions and regressions resulting in significant variability of materials often deposited within the same stratigraphic unit
  - volcanic rock from the lava flows that infilled palaeo-valleys developed during low sea level periods.
- Deposition of gravelly and sandy sediments occurred within the main river valleys (Jolimont Valley, Moonee Ponds Creek Valley).
- The most recent Coode Island Silt sediments were deposited within the Maribyrnong River, Moonee Ponds Creek and Yarra River valleys. The sediments have not been drained and therefore remain normally to slightly overconsolidated.

3.2 Main Hydrostratigraphic Units

Stratigraphic units that are expected to be encountered along the proposed Melbourne Metro Concept Design alignment 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 groundwater flow system are often complex and highly variable. A summary of hydrogeological characteristics of main stratigraphic unit and their roles in the groundwater flow system, as inferred from field observations and testing, is provided in Table 4.

[2] Holocene Alluvial Valley, in general, coincide with the current Yarra River valley within the Burnley and Richmond area

Table 4: Stratigraphic Units and Their Role in Groundwater Flow System

Stratigraphic Unit	Hydrogeological Classification	Main Occurrence
Coode Island Silt (Q_{hi})	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, Mooney 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_{pfl})	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
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}) – Swan Street Basalt	Aquifer of a localised extent and low significance due to discontinuity of the unit (Golder, 2015d). Confined, fractured rock medium to low hydraulic conductivity.	Jolimont Valley, South Melbourne
Punt 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, low to medium yielding, fractured rock medium.	Bedrock

By definition, hydrostratigraphic units are hydraulically continuous, scale independent and mappable units that could be defined on the bases of their hydraulic property. A hydrostratigraphic unit may include a formation, part of formation or a group of formations.

Some of the stratigraphic units that are inferred to have a similar role in the groundwater flow system such as Moray Street Gravels and early Pleistocene Fluvial sediments are indicated to be vertically continuous and potential acting as a single entity with respect to the groundwater flow, i.e. a single hydraulic entity. In contrast significant vertical and horizontal variation has been indicated within some units such as Fishermens Bend Silt. This suggests that different parts of a single unit may have a different role in the groundwater system, i.e., parts of stratigraphic unit being different hydraulic entity. Delineation of the main hydrostratigraphic units within a study area, therefore, has been a key element for understanding of the groundwater flow system.

The key hydrostratigraphic units of relevance to potential impacts of the MMRP on the groundwater system are listed in Table 5:

Table 5: Key Hydrostratigraphic Units of Relevance

Hydrostratigrapic Name	Stratigraphic Units	Comment
Aquifers		
Silurian Aquifer	Melbourne Formation (S_{ud})	Basement aquifer, low to medium yielding
Werribee Formation Aquifer	Werribee Formation (T_{ew})	Aquifer of interest predominantly within the Western Zone, medium to high yielding
Older Volcanics Aquifer	Older Volcanics (T_{vo})	Aquifer of interest in the Western Zone, medium yielding
Moray Street Gravels Aquifer	Fluvial Sediments (Q_{pc}), Moray Street Gravels (Q_{pg}), lower horizons of lower Fishermens Bend Silt sub-unit (Q_{pfl})	Aquifer of interest within Yarra Crossing Zone, high yielding
Early Pleistocene Aquifer	Fluvial Sediments (Q_{pc}), upper Fishermens Bend Silt (Q_{pfu}) deposited within shallow sea embayment	Aquifer of interest in the Western Zone (Segment 7 in particular), medium to highly yielding
Late Pleistocene Aquifer	Pleistocene Alluvium (Q_{pa})	Aquifer of interest in the Western Zone, medium yielding
Holocene Aquifer	Holocene Aluvium (Q_{ha})	Aquifer of interest within Yarra Crossing Zone, high yielding
Basalt Aquifer	Newer Volcanics (Q_{vn}) – Burnley Basalt Flow	Aquifer of interest in the Yarra Crossing Zone, medium yielding
Aquitards		
Fishermens Bend Silt	Upper Fishermens Bend Silt clayey horizons (Q_{pfu})	Unit of interest in western part of Segment 6 (Western Zone) and Yarra Crossing Zone
Coode Island Silt	Coode Island Silt (Q_{hi})	Unit of interest in Western Zone and Yarra Crossing Zone, highly compressible sediments

Note: for segments refer to geological cross sections in APPENDIX A.

4.0 FIELD HYDROGEOLOGICAL INVESTIGATION

The groundwater investigations undertaken to support development of the Concept Design and EES included:

- Installation of 27 monitoring wells and two pumping wells (GA15 series).
- Groundwater level gauging of these groundwater wells, accessible and functional Melbourne Metro groundwater wells installed during development of the business case between 2011 and 2013 (MM1 and GA11 series) and selected CityLink monitoring wells.
- Groundwater sampling of GA15 series groundwater wells and analytical testing for a range of parameters.
- Deployment of 15 groundwater data-loggers in selected groundwater monitoring wells.
- Hydraulic testing in selected open boreholes and groundwater wells. This included Lugeon testing in open boreholes, single bore aquifer tests (slug tests) in groundwater wells and a pumping test at St Paul's Cathedral car park.

Results of the Concept Design stage investigations were presented in Golder 2005g.

These investigations supplemented field investigations that were undertaken between 2011 and 2013, which resulted in:

- Installation of 42 monitoring wells (MM1 and GA11 series) of which, a total of 7 monitoring wells have subsequently been lost.
- Groundwater level gauging on a number of occasions and groundwater sampling of these monitoring wells including analytical testing for a range of parameters.
- Deployment of data loggers in 11 groundwater monitoring wells.
- Undertaking single bore aquifer tests (slug tests) in 32 groundwater monitoring wells and Lugeon testing in 20 open boreholes.

The locations of the groundwater monitoring wells are shown in Drawing 3. A summary of GA15 series wells construction details and aquifers monitored by the wells are included in Table 6. Construction details and the current status of all of Melbourne Metro monitoring wells are summarised in Table R1 at the back of the report.

Table 6: GA15-series Wells Construction Details

Well ID	Top of Filter Pack (m bgl)	Top of Well Screen (m bgl)	Base of Well Screen (m bgl)	Aquifer Monitored
GA15-BH001	19.0	20.0	23.0	Werribee Formation
GA15-BH002	25.5	26.0	28.0	Silurian
GA15-BH003	12.5	13.5	16.5	Werribee Formation
GA15-BH005	12.7	13.2	15.2	Early Pleistocene
GA15-BH007	13.0	14.0	17	Silurian
GA15-BH008	15.0	16.0	19	Silurian
GA15-BH009	16.2	17.2	20.2	Silurian
GA15-BH010	13.0	14.0	17.0	Silurian
GA15-BH011	30.0	31.0	34.0	Silurian
GA15-BH012	22.0	23.0	26.0	Silurian
GA15-BH018	20.0	19.0	23.0	Silurian
GA15-BH019	23.0	24.0	27.0	Silurian

Well ID	Top of Filter Pack (m bgl)	Top of Well Screen (m bgl)	Base of Well Screen (m bgl)	Aquifer Monitored
GA15-BH021	20.0	21.0	24.0	Silurian
GA15-BH027	24.0	26.0	29.0	Silurian
GA15-BH028	25.0	26.0	29.0	Silurian
GA15-BH029	23.0	25.0	35.0	Silurian
GA15-BH030	23.0	25.0	35.0	Silurian
GA15-BH031	23.0	25.0	35.0	Silurian
GA15-BH032	23.0	25.0	35.0	Silurian
GA15-BH033	23.0	25.0	35.0	Silurian
GA15-BH108	30.0	31.0	43.0	Silurian
GA15-BH109	30.0	31.0	43.0	Silurian
GA15-BH110	25.0	31.0	43.0	Silurian
GA15-BH111	29.0	30.0	42.0	Silurian
GA15-BH112	30.0	31.0	43.0	Silurian
GA15-BH120	11.0	12.0	15.0	Silurian
GA15-BH121	13.0	14.0	17.0	Silurian
GA15-BH122	27.0	28.0	31.0	Silurian
GA15-BH123	27.0	28.0	31.0	Silurian

Note: m bgl = metres below ground level.

5.0 HYDRAULIC PROPERTIES OF MAIN HYDROSTRATIGRAPHIC UNITS

5.1 Overview of Hydraulic Testing

For the purpose of characterisation of hydraulic properties of the main hydrostratigraphic units within the study area, hydraulic testing was carried out at a number of locations. This included packer tests (Lugeon tests) in open boreholes and hydraulic testing in the completed groundwater wells. When completing the interpretation results from the following tests were taken into consideration:

- slug tests in a total of 47 wells
- packer test at a total of 130 intervals
- one pumping test undertaken at St Paul's Cathedral car park.

The majority of these tests were undertaken within the Silurian rock aquifer, where many of the deep tunnel and station excavations would be located. Additionally, based on previous investigations of the aquifer, it is known that its hydraulic properties can vary significantly between locations.

5.2 Silurian Aquifer

5.2.1 Packer Tests

During the Concept Design site investigation, packer tests were undertaken in 20 open boreholes with a total of 130 intervals tested. Results from only 118 test intervals conducted in 17 open boreholes were considered for the interpretation. The locations of these boreholes and the number of intervals tested in each of the borehole are shown in Figure 2. The remaining 12 test results were inferred to be unreliable due to equipment failure or water by-passes within highly fractured rock zones.

The test intervals and results of interpretation are listed in Table C1 included in APPENDIX C. Results from 2011 investigation are also listed in Table C1. Values of 0 Lu ("no flow") were reported for more than 50% of total results. As this testing was not undertaken by Golder, it was not clear whether this large percentage of "no flow" results was due to low permeability of the formation of faulty equipment. To avoid biased interpretation towards these low values, these results were omitted from the discussion below but are include in Table C1 for informative purposes.

A summary of hydraulic conductivity ranges calculated based on the results obtained from packer tests is provided in Table 7. The test results have been sorted by test interval depth (m below ground surface) and the geometric mean, arithmetic mean and median values have been calculated for each depth interval. This included results from all 112 test intervals including "no flow" and "less than x Lu" tests along with testing interval depths (below ground surface), geometric mean, arithmetic mean and median values.

A correlation factor of 1 Lugeon equal to 1.0×10^{-7} m/s was used for the calculation of the hydraulic conductivity values based results obtained from the Lugeon tests.

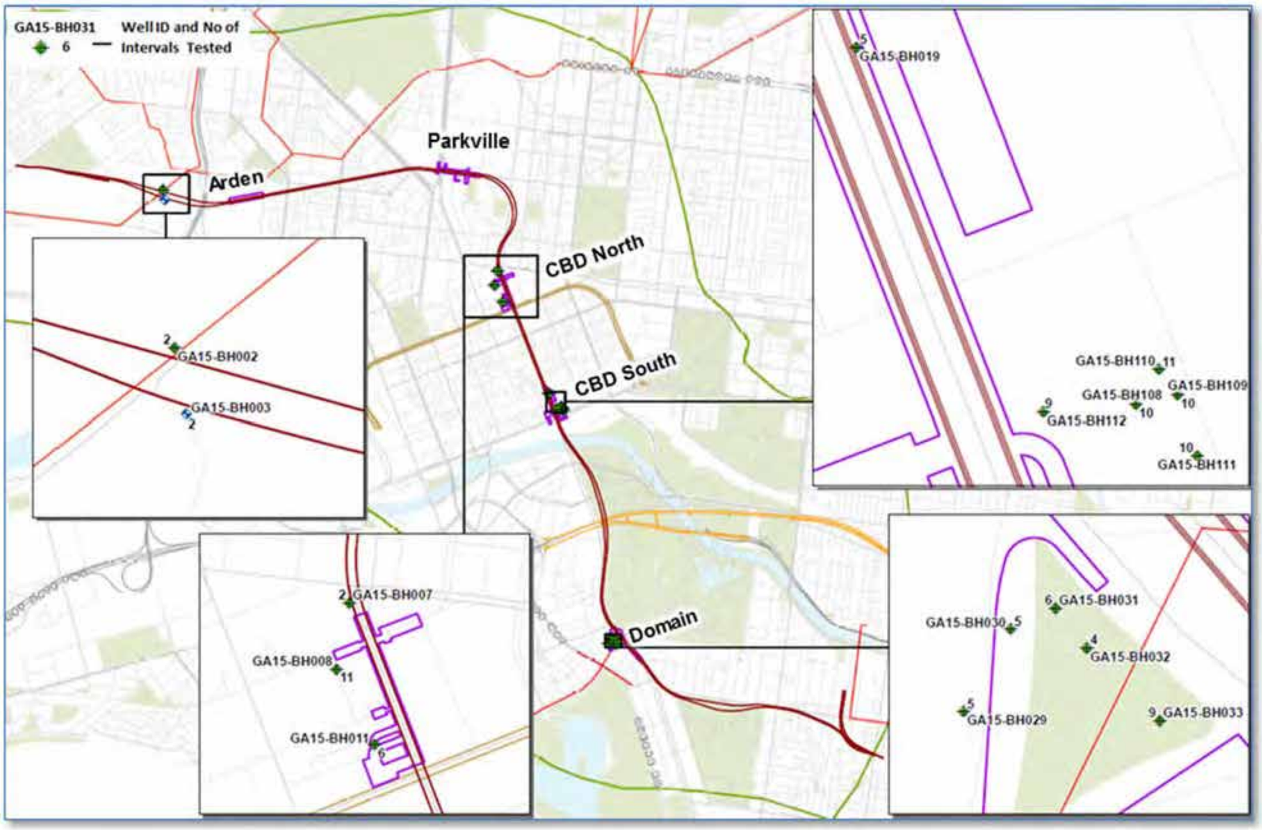

Figure 2: Packer Test Locations

Table 7: Summary of Silurian Aquifer Packer Testing Results

Test interval	Number of Data Points	Hydraulic Conductivity (m/s)				
From – to (mbgl)		Minimum	Maximum	Geometric Mean	Arithmetic Mean	Median
10-20	18	*1.0×10^{-10}*	7.2×10^{-7}	2.8×10^{-8}	1.3×10^{-7}	5.0×10^{-8}
20-30	50	*1.0×10^{-10}*	5.3×10^{-6}	2.5×10^{-8}	4.2×10^{-7}	5.0×10^{-8}
30-40	30	*1.0×10^{-10}*	5.5×10^{-6}	1.1×10^{-7}	7.8×10^{-7}	2.4×10^{-7}
40-50	14	1.0×10^{-8}	6.9×10^{-6}	2.9×10^{-7}	9.4×10^{-7}	2.8×10^{-7}
10-50	**112**	**1.0×10^{-10}**	**6.9×10^{-6}**	**5.2×10^{-8}**	**5.3×10^{-7}**	**9.0×10^{-8}**

Italic – relates to “no flow” results

The geometric means are typically used to generalise averages for a set of data covering a large value range. In such cases, geometric means are considered to be more applicable for an assessment of bulk hydraulic conductivities of a hydrostratigraphic unit. Raymer’s analysis technique (Raymer 2001, 2005), which is based on the assumption that the packer test data is log-normal distributed, was also used to estimate likely ranges of the bulk hydraulic conductivities of the rock and the reliability of the calculated Lugeon values. The results of analyses, which considered all 112 test intervals are shown in Figure 3.

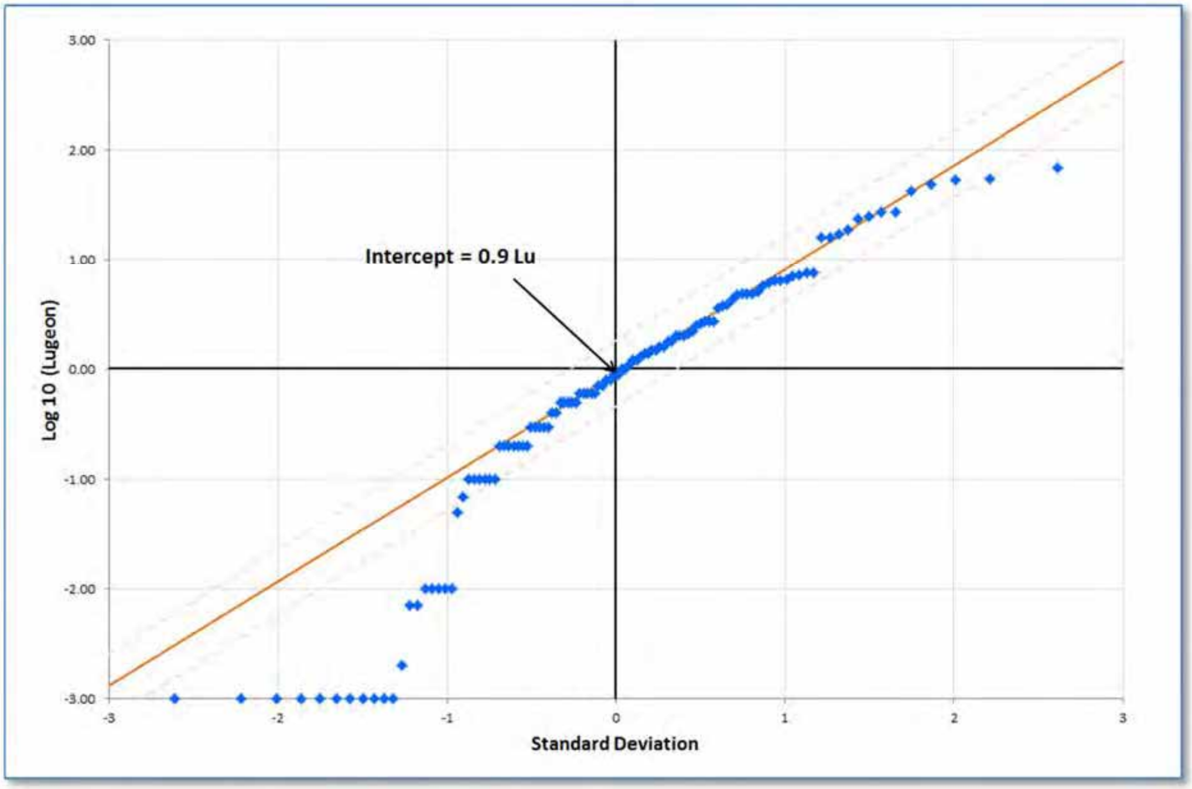

Figure 3: Raymer Analyses of All Packer Test Results

The results from the Raymer analysis indicates a median value for the data set of about 0.9 Lu, which equates to 9.0 x 10^{-8} m/s based on the Lu to K correlation factor adopted for the packer tests. This median value is equivalent to the calculated median value listed in Table 7. The log-normal distribution line was fitted relatively well to the values which fall in the range between Log Lugeon value of -0.5 and 1.5 (3.2 x 10^{-8} m/s and 3.2 x 10^{-6} m/s). The points on the right and left sides of this range show a consistent falling way from the fitted line. This is particularly prominent with the points to the left of the fitted range, suggesting inaccuracy in these results. These points are predominantly associated with the "no-flow" and "less than x Lu" tests and potentially outside of the reasonable accuracy of the equipment used for the flow measurements. Points to the right of the fitted line may be associated with some individual features that do not fit log-normal relationship, but could also be associated with unaccounted-pressure losses during the testing.

Results of packer testing indicate a broad correlation between hydraulic conductivity of the rock and depth of the testing interval as shown in Figure 4. This hypothesis is supported by the mean and median values calculated for 10 m-increment intervals in Table 7.

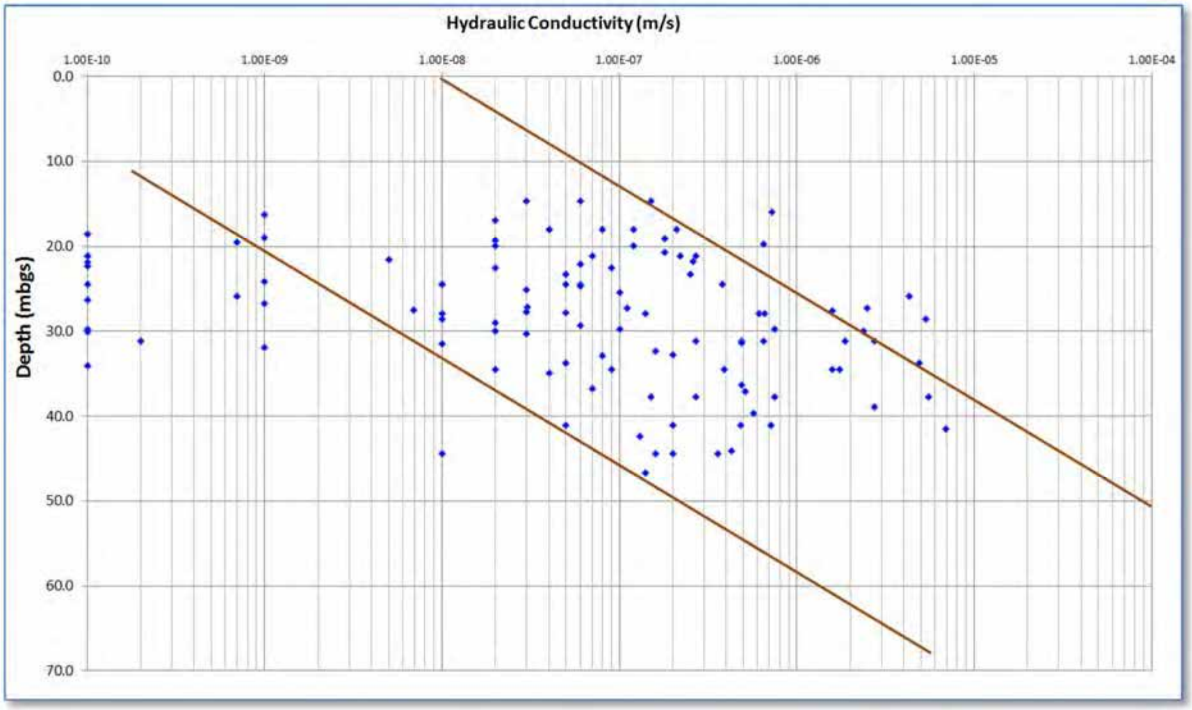

Figure 4: Lugeon Based Hydraulic Conductivity versus Depth

In addition of indicating a broad increase in the hydraulic conductivities with depth, Figure 4 shows that data points associated with the hydraulic conductivities less than 1 x 10^{-8} m/s (left side from fitted range in Figure 3) are typically related to the rock zoned above 30 mbgl. This zone corresponds largely to shallow extremely to highly weathered rock. This is also supported by the Raymer analysis plots shown in Figure 5. A median hydraulic conductivity of 4 x 10^{-8} m/s is indicated by the fitted line for the shallower rock zone (test intervals 10-25 mbgl), while a median value of 1.5 x 10^{-7} m/s is indicated for the deeper rock zone (test intervals 25-50 mbgl). However, it should be noted that the deeper rock zone data set is significantly larger than the shallower rock zone data set, which may bias the results. Additionally, data from the shallower rock zone show higher divergences from the log-normal distribution than the data from the deeper aquifer zone.

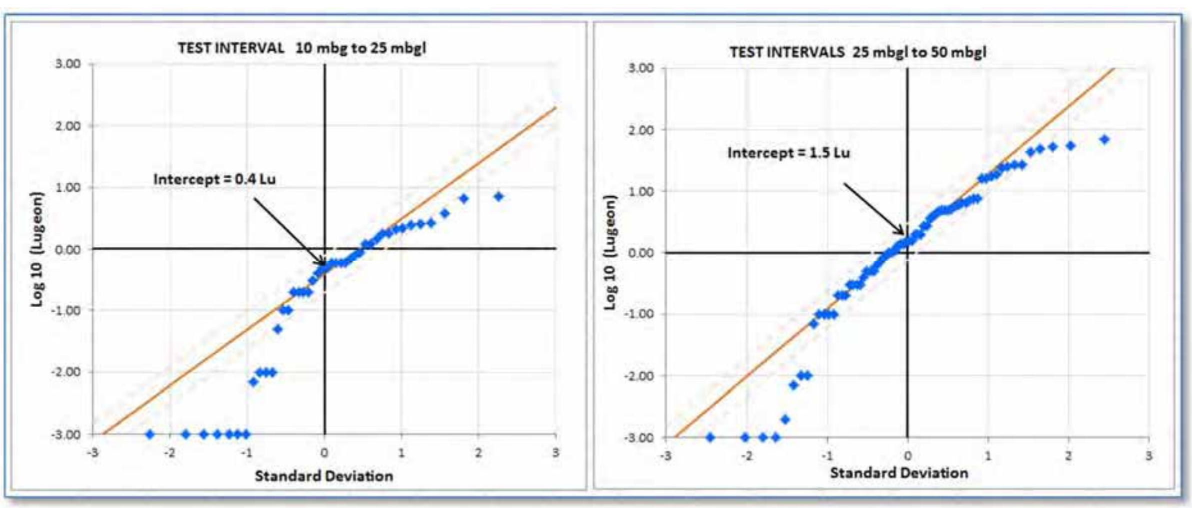

Figure 5: Raymer Analysis for Test Results from Shallow and Deep Rock Zones

To assess variability of data with respect to spatial distribution, an assessment of the results obtained from the boreholes located around CBD North station, CBD South station and Domain station was undertaken. The results of testing around the CBD South station are shown in Figure 6, and Domain station and CBD North station in Figure 7[3]. Results of the assessment indicate significant differences in the packer test results at these three locations confirming a spatial variability in hydraulic properties of the rock. Results obtained at the boreholes located in the area of CBD South and CBD North stations confirm that a broad increase in the hydraulic conductivity of the rock below depth of about 25-30 mbgl occurs in comparison to the shallower testing intervals. However, this was not confirmed with the hydraulic testing at Domain station. It is also interesting to note that the vertical distribution of high hydraulic conductivities observed in the pumping test well at CBD South (GA15-BH110) was not observed to a similar extent in the adjacent observation wells. This suggests the open discontinuities observed in the pumping well may be part of a relatively narrow sub-vertical fracture zone rather than a much wider feature.

Overall, the results of the packer testing undertaken within the Silurian aquifer indicate a wide range of the hydraulic conductivities for the rock. This is to be expected for a fractured rock aquifer with the rock conditions ranging from extremely to slightly weathered. A slight increase in the hydraulic conductivities of the rock with depth is also indicated, with an average hydraulic conductivity within the 10-30 mbgl depth interval in the order of 10^{-8} m/s, and within 30-60 mbgl depth interval in the order of 10^{-7} m/s. This suggests that two sub-aquifer zones (shallow and deeper) may exist within the Silurian aquifer at some locations.

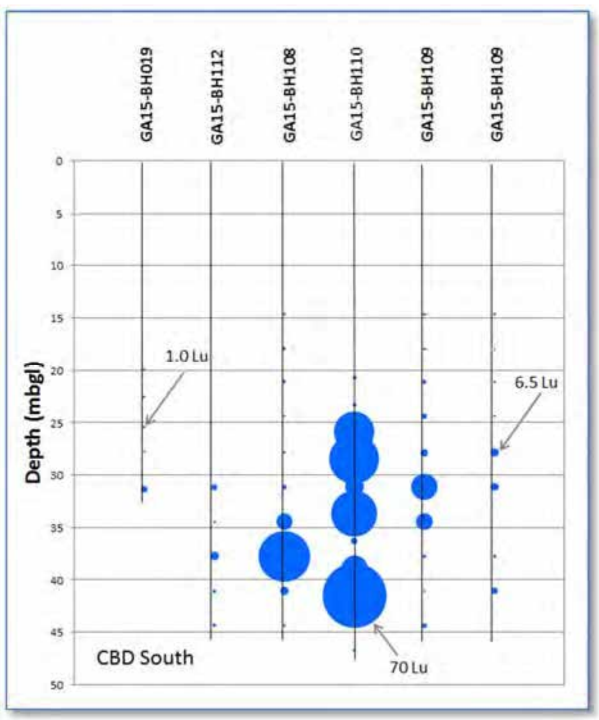

Figure 6: Packer Test Results at CBD South Station Boreholes

[3] Note different scale of bubbles at the CBD South Station graph compared to CBD North and Domain Station graphs.

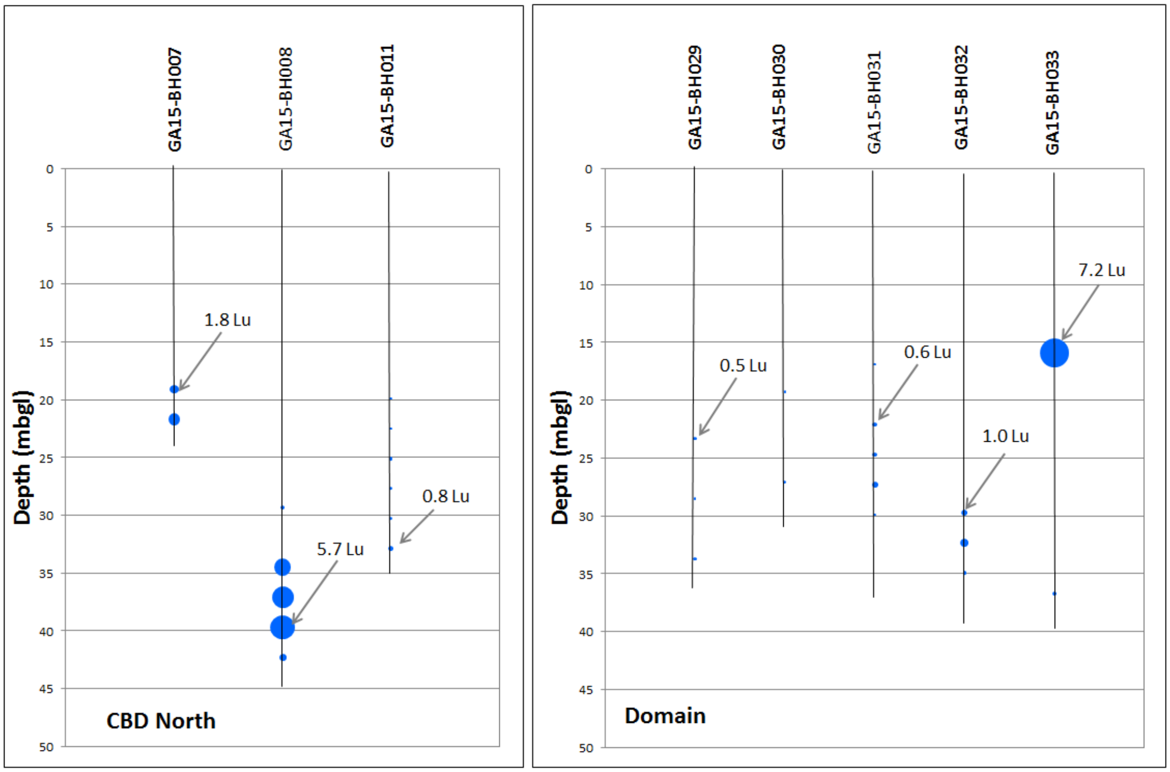

Figure 7: Packer Test Results at CBD North and Domain Stations Boreholes

5.2.2 Slug Tests

A single-bore aquifer test using a solid slug (slug test) was carried out in total of 29 Silurian aquifer wells. Results from total of 27 tests resulted sufficient to undertake interpretation as summarised in Table 8.

Table 8: Summary of Slug Test Results, Silurian Aquifer

Test interval	Number of Data Points	Hydraulic Conductivity (m/s)				
From – to (mbgl)		Minimum	Maximum	Geometric Mean	Arithmetic Mean	Median
10-20	10	5.0×10^{-9}	2.8×10^{-6}	6.7×10^{-8}	3.9×10^{-7}	4.0×10^{-8}
20-30	14	1.7×10^{-10}	2.2×10^{-5}	1.4×10^{-7}	2.5×10^{-6}	2.2×10^{-7}
30-40	3	4.0×10^{-7}	3.5×10^{-6}	2.2×10^{-7}	1.7×10^{-6}	1.6×10^{-6}
10-40	**27**	**1.7×10^{-10}**	**2.2×10^{-5}**	**1.4×10^{-7}**	**1.6×10^{-6}**	**4.8×10^{-6}**

Similar to the packer tests, the results of the slug tests indicated a broad range of hydraulic conductivities for the Silurian aquifer. However, the mean values calculated from all of the slug tests are generally about half to one order of magnitude higher than those calculated from the packer tests. An increase in the hydraulic conductivities of the rock with depth is also suggested by the slug testing results. However, it should be noted that the slug test data set is significantly smaller than the packer test data set and in particular with respect to deeper zones of the rock.

5.2.3 Pumping Test at St Paul's Cathedral

Test Setting and Observation

A long term pumping test was undertaken at St Paul's Cathedral car park during the August 2015 to September 2015 period. A total of five groundwater wells were installed to facilitate the test. One extraction well, GA15-BH110 and three monitoring wells (GA15-BH108, GA15-BH109, GA15-BH111) were installed at the St Paul's Cathedral car park and one monitoring well (GA15-BH112) was installed at the nature strip between Swan Street and the Cathedral. The locations of these wells are shown in Drawing 4 and in Figure 8 below. Distance of the monitoring wells from the pumping well are summarised in Table 9.

Table 9: Monitoring Well Distance from the Pumping Wells

Well ID	Distance from Pumping Well GA15-BH110 (m)	Direction
GA15-BH109	11	South-east
GA15-BH108	14	West
GA15-BH111	32	South-east
GA15-BH112	42	West
GA15-BH021	59	North-west
GA15-BH019	150	North-west
GA11-BH017	360	South-east

St Paul's Cathedral wells were completed with a long well screen, generally at a depth interval 28-42 m bgl (from about RL -34 m AHD to RL -20 m AHD). The interval of well screen was selected based on results of the packer tests undertaken in these boreholes. As shown in Figure 4, hydraulic conductivities of the rock within this deeper zone were indicated to be significantly higher than within the shallow zone above.

Continuous groundwater level monitoring commenced on 29 August 2015 (2 days prior to trial) and ceased on 12 October 2015 (about 4 weeks after pumping stopped). The data-loggers were installed in all four monitoring wells and the pumping well. The data-loggers were set to record groundwater pressures at a one-minute interval. Additionally, groundwater levels were monitored manually in the wells GA15-BH019 and GA15-BH021 located to the north of the Cathedral. Pressure data collected at the monitoring well GA11-BH017 as a part of the long term level monitoring was also utilised for the assessment of the test effect on the groundwater levels in the Moray Street Gravels aquifer.

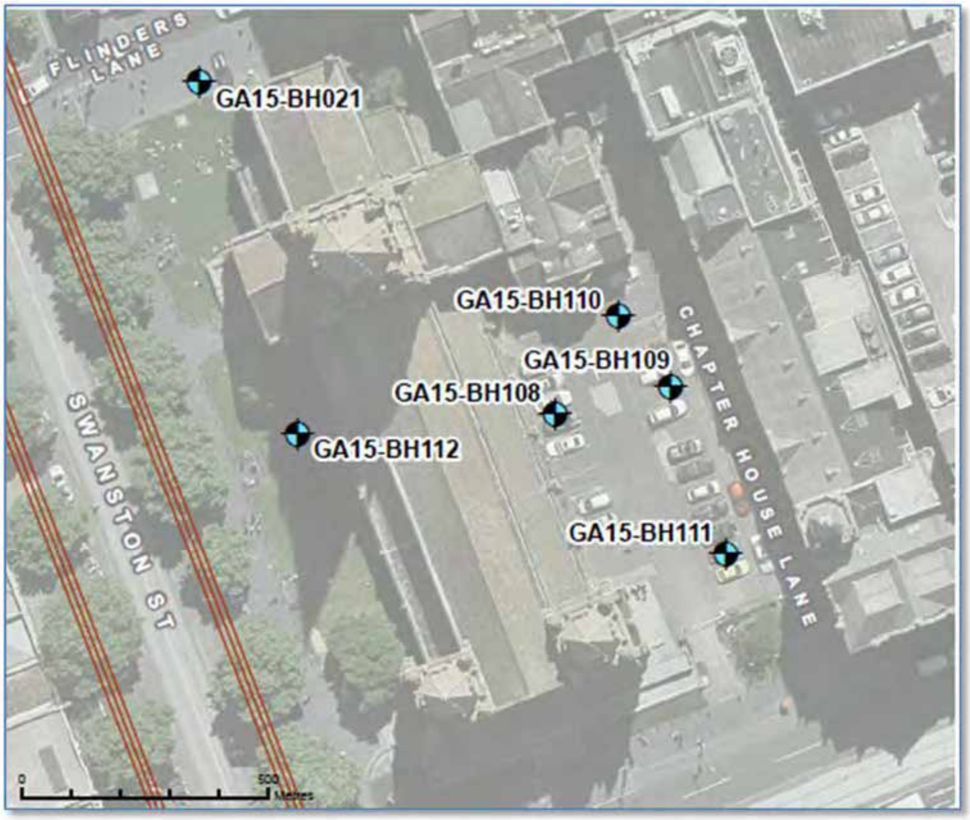

Figure 8: Location of the St Paul's Cathedral Pumping Test Wells

The pumping test commenced on 31 August 2015 and ceased on 9 September 2015. A step test was undertaken on 31 August 2015. The step test included groundwater extraction at three different rates (i.e., steps) starting from lower to higher extraction rates. The extraction rates, duration of each of the steps and groundwater drawdowns in the monitoring wells at the end of each step are summarised in Table 10. No monitoring of the groundwater levels in distant wells was carried out during the step test.

Table 10: Step Test Pumping Rates

	Average Extraction Rate (L/s)	Duration (min)	Groundwater Drawdown (m) at the End of Step				
			GA15-BH110	GA15-BH108	GA15-BH109	GA15-BH111	GA15-BH112
Step 1	0.50	95	6.3	2.0	1.9	0.7	1.0
Step 2	0.80	130	14.8	3.7	3.5	1.6	2.0
Step 3	1.00	152	20.2	4.9	4.7	2.4	2.8

The groundwater levels were allowed to recover overnight. Continuous rate pumping test (main test) commenced on 1 September 2015 at 12:00 pm, although no full recovery of the water levels occurred. Based on the recovery rate, it was judged that a considerably longer time would be required for the full recovery and it was decide to continue with the test. The luck of groundwater recovery was one of consideration when analytic methods for the data interpretation were selected.

The extraction rates through the main test phase were kept as constant as practical. The extraction rates ranged between 0.88 L/s and 1.10 L/s, with an average flow rate of about 0.97 L/s. A slight adjustment to the pumping rate were made during the test to prevent groundwater within the pumping well decreasing below the pump intake as this would result in pump to stop. A graph showing changes in the groundwater extraction rates during the main test is included in Figure 5.

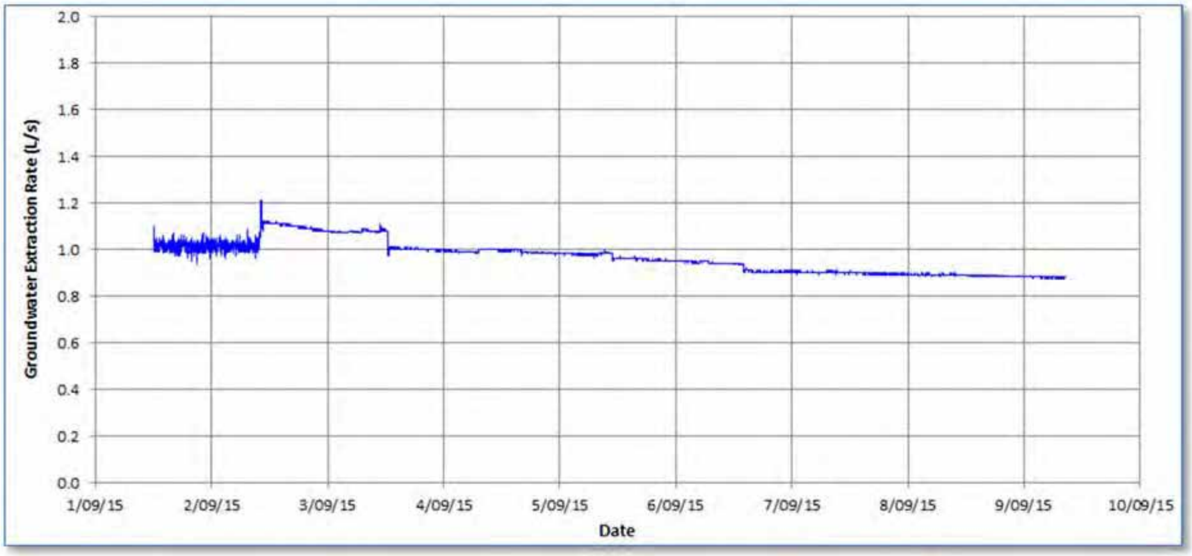

Figure 9: Groundwater Extraction Rates during the Main Test

Measurable groundwater drawdowns were indicated in wells GA15-BH108, GA15-BH109, GA15-BH111, GA15-BH112 and GA15-BH021. No measurable drawdowns were indicated GA11-BH017. Groundwater changes observed in GA15-BH019 were variable during the monitoring and no clear indication of the groundwater response to the pumping test could be made. Changes in the groundwater levels observed in monitoring wells GA15-BH108 to GA15-BH112 are shown in Figure 10 and changes in the groundwater levels in GA15-BH019 and GA15-BH021 are shown in Figure 11.

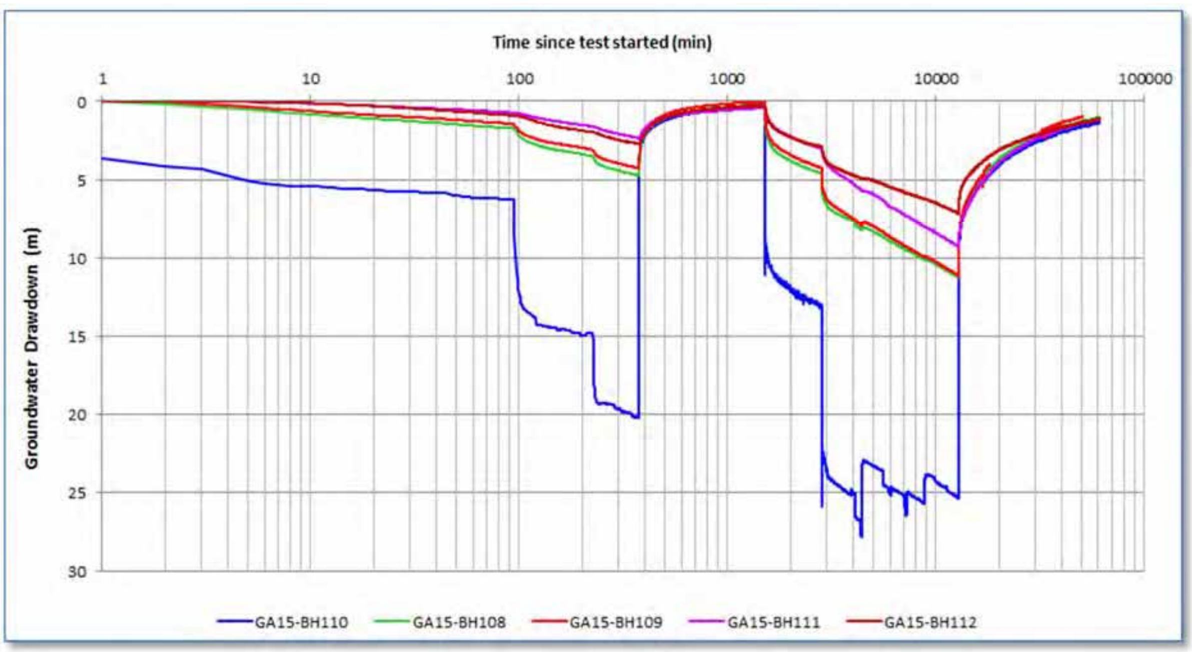

Figure 10: Groundwater Drawdowns in Wells GA15-BH108 to GA15-BH112

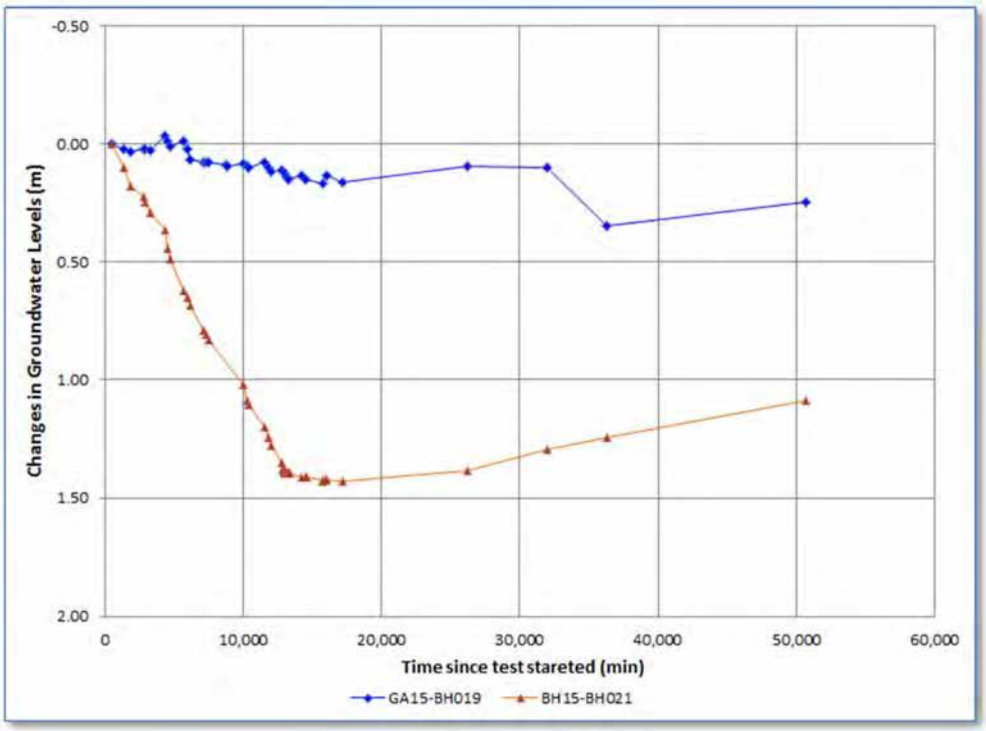

Figure 11: Groundwater Level Changes in Wells GA15-BH019 and GA15-BH021

Results Interpretation

Groundwater drawdowns at the end of pumping test (just prior to turning the pump off) are shown in Figure 12. Observations in monitoring wells GA15-BH108, GA15-BH109, GA15-BH111 and GA15-BH112 indicate distribution of the drawdown to be generally radial around the pumping well, i.e., no preferential direction of the drawdown propagation was indicated. The groundwater drawdown in GA15-BH021 was indicated to be significantly lower than expected for a radial distribution considering the distance of this well from the pumping well. This is also illustrated in Figure C1 (APPENDIX C) by the drawdown versus distance method, which was used for an initial and broad assessment of the aquifer hydraulic conductivity.

The well GA15-BH021 is a shallow well installed within the weathered Silurian rock zone (screen interval 19-22 m bgl) as shown in APPENDIX A, Sheet 12. This suggests that the deeper rock zone may not be well connected with the shallow rock zone and that confined groundwater conditions may prevail within the deeper aquifer zone.

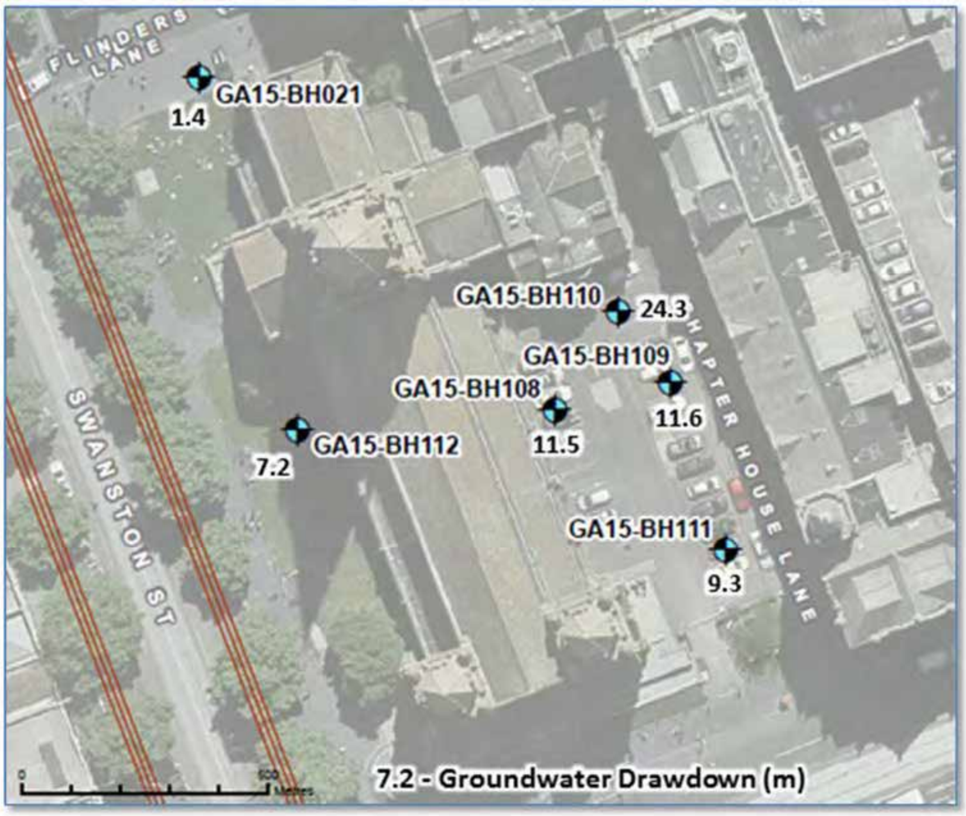

Figure 12: Groundwater Drawdown at the End of Pumping Test

Initial data interpretation was undertaken using the Theis's (1935) method to assess whether the aquifer zone tested behaves as an idealised, isotropic and indefinite extent aquifer. As shown in Figure 13 two stages with respect to fitting Theis's type curves are indicated:

- An initial stage that includes step test and the early time (first day) of the main test.
- A long term stage that includes main test following the first day of testing, and groundwater recovery period.

The groundwater drawdowns observed during the initial stage fitted relatively well to the Theis's type curves (Figure 13). However, the groundwater drawdowns observed during the long term stage diverged from the Theis's type curves with a rate of divergence generally increasing with the time.

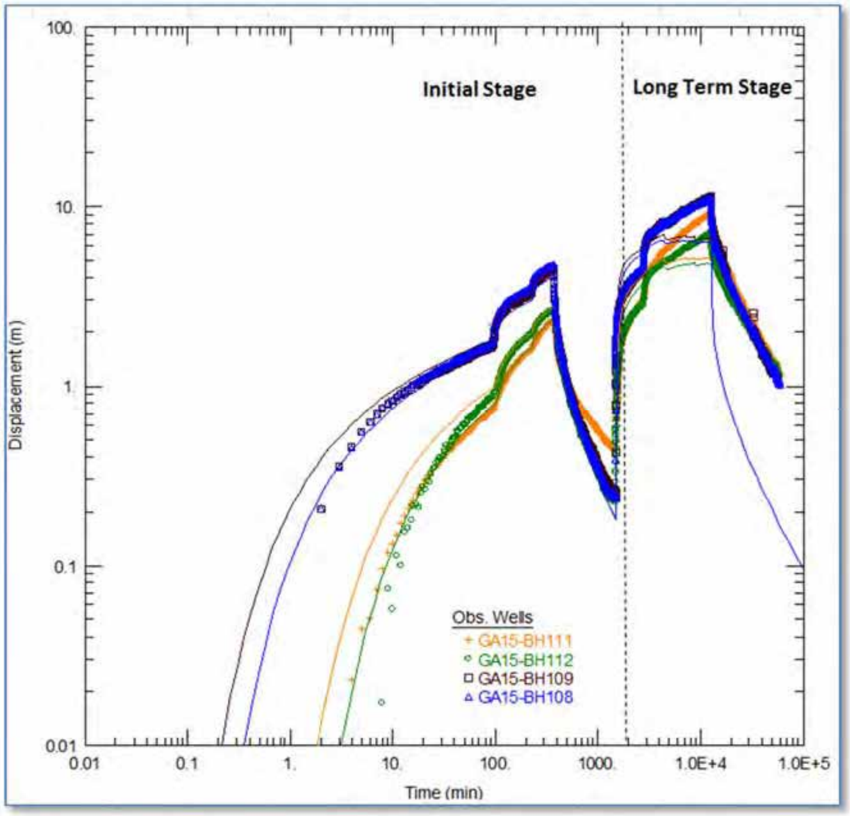

Figure 13: Drawdown Data versus Theis's Type Curves

This behaviour suggests that the aquifer properties in the near vicinity of the pumping and monitoring wells are likely to be generally uniform. However, it appears that this uniformity diminishes as the large area of the aquifer start to response to the test. This suggested that the localised pumping test zone may have been bounded by lower permeability aquifer zones.

The following two methods, which allows for bounded aquifer interpretation, therefore, were used for the data analyses:

- ***The Type Curve Analysis Method – the Moench method*** *(Moench, 1985)*. This method uses a type curve solution for a pumping/recovery test in a leaky aquifer. Case 3 configuration was adopted, which assumes the pumped confined aquifer is overlain by an infinite constant-head plane source and is underlain by an infinite no-flow boundary plane source.
- ***The Type Curve Analysis Method – the Dougherty-Babu Method*** *(Dougherty-Babu, 1984).* This method uses a type curve solution for a pumping/recovery test in a confined aquifer.

Both type curve analysis methods assumed a no flow boundaries at a distance from the pumping well. The best fit to monitoring data was achieved by placing two parallel "no flow" boundaries at each side of the pumping well, as illustrated in Figure 14. The distance of these boundaries from the pumping well were derived by best fit of the data to type curves.

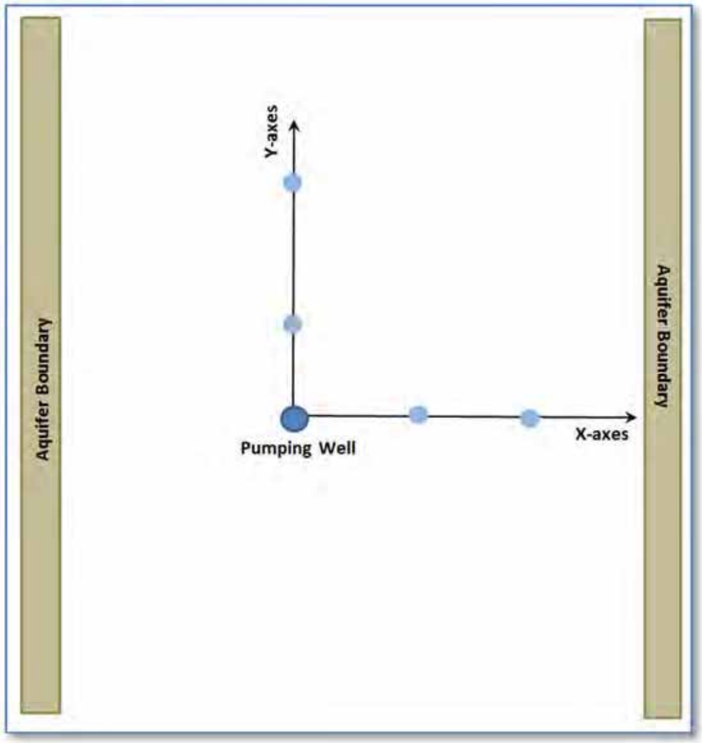

Figure 14: Schematic Presentation of Aquifer Boundaries as per Analitical Model

The results from the interpretations are summarised in Table 11 and shown in Figures C2 to C7 provided in APPENDIX C. An aquifer thickness of 23 m was assumed for the calculation of hydraulic conductivity values. This was based on the thickness of higher permeability deep rock zone indicated by the packer tests within the proposed CBD South station (Figure 5) and observation during the drilling (water loss intervals, rock weathering and fracturing intervals).

Table 11: Summary of Pumping Test Results

Wells Used in Interpretation	T (m^2/s)	K (m/s)	K (m/day)	Storativity	Interpretation Solution	Boundary at Distance (m)
All monitoring wells	5.50E-05	2.39E-06	0.21	5.5E-05	Drawdown vs Distance	N/A
All monitoring wells	1.01E-04	4.39E-06	0.38	1.1E-04	Moench Case 3	400
GA15-BH111, GA15-BH112	1.04E-04	4.52E-06	0.39	6.0E-05	Moench Case 3	400
GA15-BH108, GA15-BH109	1.01E-04	4.39E-06	0.38	1.1E-04	Moench Case 3	400
Average Combined Wells	**9.03E-05**	**3.92E-06**	**0.34**	**8.4E-05**		
GA15-BH108	9.63E-05	4.19E-06	0.36	1.2E-04	Moench Case 3	200
GA15-BH108	1.01E-04	4.39E-06	0.38	6.3E-05	Dougherty-Babu	400

Wells Used in Interpretation	T (m^2/s)	K (m/s)	K (m/day)	Storativity	Interpretation Solution	Boundary at Distance (m)
GA15-BH109	1.10E-04	4.78E-06	0.41	4.9E-05	Moench Case 3	400
GA15-BH109	9.90E-05	4.30E-06	0.37	5.9E-05	Dougherty-Babu	400
GA15-BH111	7.07E-05	3.07E-06	0.27	1.2E-04	Moench Case 3	250
GA15-BH111	6.75E-05	2.93E-06	0.25	2.5E-04	Dougherty-Babu	100
GA15-BH112	4.00E-05	1.74E-06	0.15	2.3E-05	Moench Case 3	400
GA15-BH112	1.17E-04	5.09E-06	0.44	7.7E-05	Dougherty-Babu	100
Average Individual Wells	**8.77E-05**	**3.81E-06**	**0.33**	**9.5E-05**		

Note: T = Transmissivity, K = Hydraulic conductivity (based on 23 m aquifer thickness),

Moench Case 3 = Moench (1985) solution for a pumping test in a leaky aquifer

Dougherty-Babu = Dougherty-Babu (1984) solution for a pumping test in a confined aquifer

Overall, the results from the St Paul's Cathedral pumping test indicate an average hydraulic conductivity for the Silurian aquifer affected by the test of about 4 x 10^{-6} m/s (0.35 m/day) and storativity value in the order of 9 x 10^{-5} (specific storage of about 4 x 10^{-6} m^{-1} for a 23 m thick aquifer).

They also suggest that lower zones of the Silurian aquifer may act as a distinctive sub-aquifer. Based on the groundwater levels response to the pumping test, this lower sub-aquifer zone is indicated to behave as a confined aquifer with a groundwater leakage from an upper lower permeability zone. Although the pumping well is located about 150 m away from the Yarra River and about 190 m from the Moray Street Gravels aquifer, no effect of these features has been suggested by observed groundwater response to the pumping (i.e. no recharge boundary effects were observed). On the contrary the test data indicates that aquifer zone tested may have been bounded by a lower permeability features at a distance between 250 m to 400 m away from the pumping well as indicated by the curve fitting interpretative work described above.

The pumping test results indicate a specific storage of the lower sub-aquifer zone to be about 4 x 10^{-6} m^{-1}, which is to be expected for a slightly weathered rock aquifer.

5.3 Other Aquifers

A summary of hydraulic conductivity ranges based on the slug test results for the other aquifers along with log-averages is provided in Table 12. The summary is based on results obtained through all phases of investigation from 2011 through to September 2015.

Table 12: Summary of Other Aquifer Testing Results

Hydrostratigraphic Unit	Hydraulic Conductivity (m/s)			Number of Data Points
	Range		Geometric Mean	
	Minimum	Maximum		
Coode Island Silt	4.5×10^{-8}	4.5×10^{-8}	-	1
Holocene aquifer	2.0×10^{-6}	2.0×10^{-6}	-	1
Early Pleistocene aquifer	2.5×10^{-7}	8.5×10^{-5}	1.9×10^{-5}	6
Moray Street Gravels aquifer	2.0×10^{-5}	2.7×10^{-4}	7.1×10^{-4}	3
Older Volcanics aquifer	6.0×10^{-7}	3.0×10^{-6}	1.4×10^{-6}	3
Werribee Formation aquifer	5.3×10^{-5}	2.0×10^{-4}	8.6×10^{-5}	4

The results from the slug testing indicate hydraulic conductivities of the Early Pleistocene, Moray Street Gravels and Werribee Formation aquifers to be, generally, within similar ranges, from low 10^{-5}'s m/s to high 10^{-4}'s m/s. Hydraulic conductivities of the Older Volcanics aquifer are indicated, in general, to be at least one order of magnitude lower. No slug test was undertaken within the Late Pleistocene aquifer and only one test was conducted within each of the Holocene aquifer and Coode Island Silt. Additionally, there is no groundwater well installed in the Newer Volcanics aquifer.

6.0 GROUNDWATER LEVELS AND FLOW SYSTEM

6.1 Groundwater Levels

The groundwater levels observed in the monitoring wells from April 2015 to November 2015 are listed in Table R2 (attached at the end of the report text), with the levels from the August 2015 to November 2015 monitoring period (more recent) summarised in Table 13. The groundwater elevations were calculated based on the measured depth to water, taking into consideration the borehole inclination. The groundwater elevations were corrected to fresh water head to account for the density effect[4] based on the laboratory reported dissolved solids (TDS) concentrations reported for the laboratory testing data or inferred TDS for the wells where analytical data was not available. Total dissolved solids (TDS) concentrations and density values for each well used for density effect calculation, including calculation equation are listed in Table R2.

Table 13: Summary of Most Recent Groundwater Levels Recorded in Monitoring Wells in 2015

Borehole ID	Hydrostratigraphic Unit Monitored	Date of Measurements	Corrected Groundwater Level (m AHD)(1)
MM1BH006	Werribee Formation aquifer	23-Sep-15	7.07
MM1BH009	Silurian aquifer	28-Oct-15	21.53
MM1BH015	Moray Street Graves aquifer	23-Sep-15	-1.62
MM1BH016	Fishermens Band Silt/Coode Island Silt	29-Oct-15	-1.49
MM1BH018	Silurian aquifer	23-Sep-15	-0.66
GA11-BH002	Older Volcanics aquifer	23-Sep-15	-1.32
GA11-BH005	Older Volcanics aquifer	29-Oct-15	-1.89
GA11-BH012	Werribee Formation aquifer	23-Sep-15	1.32
GA11-BH013	Silurian aquifer	23-Sep-15	7.47
GA11-BH017	Moray Street Graves aquifer	21-Aug-15	-1.15
GA11-BH018	Holocene aquifer	29-Oct-15	-0.81
GA11-BH022	Silurian aquifer	29-Oct-15	3.96
GA11-BH027	Silurian aquifer	28-Oct-15	-5.17
GA11-BH031	Older Volcanics aquifer	23-Sep-15	-1.18
GA15-BH001	Werribee Formation aquifer	30-Oct-15	-2.32
GA15-BH002	Silurian aquifer	30-Oct-15	-2.15
GA15-BH003	Werribee Formation aquifer	23-Sep-15	-2.54
GA15-BH005	Early Pleistocene aquifer	28-Oct-15	-1.74
GA15-BH007	Silurian aquifer	28-Oct-15	14.25
GA15-BH008	Silurian aquifer	23-Sep-15	12.46
GA15-BH009	Silurian aquifer	15-Oct-15	22.44
GA15-BH010	Silurian aquifer	23-Sep-15	11.46
GA15-BH011	Silurian aquifer	23-Sep-15	5.01
GA15-BH012	Silurian aquifer	29-Oct-15	0.51
GA15-BH018	Silurian aquifer	23-Sep-15	-0.44
GA15-BH019	Silurian aquifer	23-Sep-15	-1.52

[4] The following equation was used to correct static water level measurement for density effect:

$$h_f * \rho_f = h_m * \rho_m$$: where

h_m is measured water column in the well, ρ_m is density of groundwater based on measured total dissolved solids (TDS), h_f is equivalent fresh water column in the, well and ρ_f is fresh water density (1.0 g/cm^3 was adopted for calculation).

Borehole ID	Hydrostratigraphic Unit Monitored	Date of Measurements	Corrected Groundwater Level (m AHD)[(1)]
GA15-BH021	Silurian aquifer	31-Aug-15	-0.15
GA15-BH027	Silurian aquifer	28-Oct-15	-12.33
GA15-BH028	Silurian aquifer	28-Oct-15	-12.71
GA15-BH029	Silurian aquifer	6-Oct-15	-3.26
GA15-BH030	Silurian aquifer	5-Oct-15	-3.63
GA15-BH031	Silurian aquifer	6-Oct-15	-1.48
GA15-BH032	Silurian aquifer	5-Oct-15	-4.09
GA15-BH033	Silurian aquifer	7-Oct-15	-3.98
GA15-BH108	Silurian aquifer	30-Aug-15	0.14
GA15-BH109	Silurian aquifer	30-Aug-15	0.12
GA15-BH110	Silurian aquifer	30-Aug-15	-0.20
GA15-BH111	Silurian aquifer	27-Aug-15	0.27
GA15-BH112	Silurian aquifer	30-Aug-15	0.16
GA15-BH120	Silurian aquifer	6-Jul-15	0.17
GA15-BH121	Silurian aquifer	23-Sep-15	-6.15
GA15-BH122	Silurian aquifer	23-Sep-15	-14.10
GA15-BH123	Silurian aquifer	23-Sep-15	-11.39

Notes: [(1)] groundwater elevation corrected for water density and well inclination;
m AHD – metres Australian Height Datum.

The majority of the monitoring wells were installed to monitor deeper zones within the hydrostratigraphic units in order to provide an indication of the initial groundwater pressures and potential pressure changes in the vicinity of the proposed Concept Design tunnels and stations. The water levels observed in the majority of the well are, therefore, representative of the piezometric levels. Only a few wells have been constructed across the water table (water table wells) or close to the water table (for purpose of this report termed "phreatic" wells). The aquifer head conditions inferred to be monitored by each of the monitoring well are summarised in Table R2 attached at the end of the report.

Groundwater levels below sea level (RL 0 m AHD) were observed in a number of monitoring wells located in a broader area of the North Yarra Main Sewer (Kensington and North Melbourne area), CityLink tunnels (South Melbourne, Royal Botanic Gardens), Melbourne Underground Rail Link (City Loop) (close to the proposed CBD North Station) and the South Yarra Main Sewer (South Melbourne) as shown in Drawing 4.

6.2 Long Term Groundwater Levels

A total of 15 non-vented data-loggers with pressure sensors along with four baro-loggers were deployed as part of the 2015 investigations to assess the long term changes in the groundwater levels across the study area.

Deployment and data-logger download has been gradual, starting from 22 August 2015 subject to access. By 14 September 2015, all data-loggers and baro-loggers were deployed.

The groundwater levels (expressed in metres Australian Height Datum, AHD) were calculated from the pressure data recorded by data-loggers. The calculation included:

- Compensation of row data for the barometric pressure data[5] to obtain water pressures.

[5] Non-vented data-loggers record total pressure, which is a sum of the water head pressure and the barometric pressure.

- Correction of the water pressure data for the barometric efficiency that was affecting each of the wells[6].
- Correction of the water pressure for well inclination (where applicable).
- Correlation of the water pressure to the elevation of data-logger sensor to obtain groundwater levels in m AHD.
- Correction of the groundwater elevation for the density effect based on the measured TDS concentrations and temperature of groundwater.

The changes in groundwater levels recorded in the monitoring wells since deployment of data-loggers, which were corrected for barometric efficiency (as described above), are provided in APPENDIX B (Figure1B to 14B) along with manual measurements undertaken during the same monitoring period. Additional levels were recorded in some of the wells in 2013 to 2014, which are also provided in APPENDIX B.

A summary of the maximum water level variation in each well, the barometric coefficient used to correct the levels for the barometric efficiency and monitoring period are provided in Table 14 along with the aquifer monitored. The data-logger deployed in well GA15-BH002 has been retrieved from the well and is currently being repaired. Hence, the results from this data-logger are not presented in this document.

Table 14: Summary of Long Term Changes in Groundwater Levels

Well ID	Aquifer Monitored	Barometric Coefficient	Monitoring Period	Water Level Variation (Monitoring Period) (m)
GA11-BH005	Older Volcanics	0.40	1 September 2015 – 29 October 2015	0.20
GA11-BH017	Moray Street Gravels	0.50	*23 August 2013 – 29 May 2014* 21 August 2015 – 2 December 2015	0.30
GA11-BH018	Holocene	0.45	*23 August 2013 – 29 May 2014* 1 September 2015 – 1 December 2015	0.45
GA11-BH022	Silurian – Deep zone	0.35	22 August 2013 – 1 December 2015	0.30
GA11-BH027	Silurian – Shallow zone	0.30	22 August 2013 – 1 December 2015	0.90
GA15-BH001	Werribee Formation	0.50	6 October 2015 – 1 December 2015	0.15
GA15-BH005	Early Pleistocene	0.25	14 September 2015 – 28 October 2015	0.30
GA15-BH007	Silurian – Shallow zone	0.20	2 September 2015 – 1 December 2015	0.10
GA15-BH009	Silurian – Shallow zone	0.60	4 September 2015 – 18 November 2015	0.30
GA15-BH012	Silurian – Shallow zone	0.45	2 September 2015 – 1 December 2015	0.15
GA15-BH027	Silurian – Deep zone	0.35	1 September 2015 – 1 December 2015	0.15
GA15-BH028	Silurian – Deep zone	0.20	1 September 2015 – 1 December 2015	0.10

[6] Barometric pressure fluctuations can have an impact on the groundwater measured within a monitoring well depending on the aquifer conditions, i.e., a rise in the pressure resulting in a decrease of the groundwater levels in the well and versus wise. To be able to assess the true groundwater levels within the aquifer, the groundwater levels measured in a well have to be corrected for these influences (i.e., barometric efficiency). A barometric coefficient, which is expressed as the ratio of well water change to barometric pressure change, calculated for each well based on observed data, has been used to correct the raw data for barometric influences.

Well ID	Aquifer Monitored	Barometric Coefficient	Monitoring Period	Water Level Variation (Monitoring Period) (m)
MM1-BH009	Silurian – Shallow zone	0.15	23 August 2013 – 29 May 2014 25 August 2015 – 1 December 2015	0.40
MM1-BH016	Fishermens Bend Silt/Coode Island Silt	0.35	2 September 2013 – 29 May 2014 1 September 2015 – 1 December 2015	0.25

The greatest variation in groundwater levels over the monitoring period were recorded in the Silurian - Shallow aquifer well GA11-BH027 located in vicinity of Albert Road, South Melbourne near Albert Park. The lowest variation was recorded in the Silurian (deep aquifer zone) well GA15-BH028 located in Queen Victoria Gardens. The monitoring period for GA11-BH027 was considerably longer than GA15-BH028, which is likely to have increased the water level variation.

6.3 Conceptual Groundwater Flow System

A number of different hydrostratigraphic units have been recognised within the study area (Table 5). Throughout the majority of the study area, the Silurian age Melbourne Formation is a primary aquifer with the water table occurring within this aquifer unit (Figures 1-A to 18-A, APPENDIX A). A number of aquifers and aquitards, however, coexist within the within the Maribyrnong River, Moonee Ponds Creek and Yarra River palaeovalleys. This has resulted in a complex relationship between the aquifers and within individual aquifers subzones. Groundwater head conditions range from confined to unconfined with influences of man-made structures and processes on the groundwater pressures adding to complexity of the system.

Groundwater levels within the study area were gauged in a number of the monitoring wells, which were constructed to monitor various hydrostratigraphic units. The latest groundwater level data are presented in Drawing 4.

An interpretation of the conceptual groundwater flow model and direction of the flow across the study area has been undertaken to assist with the recalibration of the regional numerical groundwater model. The interpretation was based on the average groundwater levels measured in the Melbourne Metro monitoring wells during the 2013 through 2015 monitoring period and the average groundwater levels observed in the CityLink monitoring wells over the 2014 to 2015 period. Although these groundwater levels have not always been taken at the same time or within the same time period, they were considered adequate for a broad assessment of the regional groundwater flow conditions. This is supported by the long term groundwater data level monitoring that indicates a relatively narrow range of the water level variations (Table 14) within the study area over the past two to three years. The groundwater level contours and directions of the groundwater flow across the study area inferred from this assessment are shown in Drawing 5.

The key points of the conceptual groundwater flow model are summarised below.

- The highest groundwater levels have been observed within the broader Parkville area, East Melbourne area. The recharge to groundwater is considered to be the predominant process within these high topographic areas, where the Silurian aquifer occurs as the upper unit.
- The lowest groundwater levels are indicated to occur in the low lying areas and around man-made structures.
- The following man-made structures are inferred to have significant effects on groundwater levels within the study area:
    - CityLink tunnels – the groundwater levels in the main aquifers (Silurian, Moray Street Gravels, Basalt and Holocene aquifers) within the influences of the CityLink tunnels were observed to be below sea level, typically below RL -0.8 m AHD.

The groundwater levels below RL -10 m AHD have been observed in monitoring wells GA15-BH27, GA15-BH028, GA15-BH122 and GA15-BH123 located where the Melbourne Metro alignment crosses the existing CityLink tunnels to the east of St Kilda Road (Figure 13-A, APPENDIX A). All these wells have been installed to monitor groundwater head conditions at or immediately below the water table.

- City Loop tunnels – relatively steep groundwater head gradients towards City Loop tunnels have been indicated in the vicinity of the proposed CBD North station. A hydraulic head gradient of about 0.1 m/m is indicated by the wells GA15-BH010 and GA15-BH011 located north of City Loop tunnels in this area. As shown in Figure 10-A, APPENDIX A these wells have been constructed to monitor different aquifer horizons and therefore may not be representative of true horizontal head gradients. Currently there are no nested wells monitoring different aquifer horizons at the same location to assess potential vertical head gradients within this part of the study area and the hydraulic relationship between deep and shallow horizons of the Silurian aquifer. Further assessment of the vertical head gradients within this area would assist with better understanding of potential impacts of CBD North station and the mined tunnels on the groundwater flow system within this area.
- Deep Building Basements – the groundwater levels within the CBD, around City Square, were observed to be below sea level (RL -0.44 m AHD in GA15-BH018, RL -1.52 m AHD in GA15-BH009 and RL – 1.45 m AHD in GA15-BH021). This is inferred to be due to groundwater drainage into nearby deep basement(s), potentially City Square car park.
- Various sewer mains – the low groundwater levels measured in monitoring wells in Kensington and North Melbourne area (approximately between RL -2.5 m AHD and RL -0.8 m AHD, Drawing 4) are inferred to be due to impacts from the North Yarra Main Sewer, while the low groundwater levels in South Melbourne, adjacent to the proposed Domain Station (approximately between RL -5.2 m AHD and RL -1.5 m AHD, Drawing 4) are inferred to be result of impacts from the South Yarra Main Sewer. Lower groundwater levels within eastern extent of the study area may also indicate influence by the Prahran Sewer Main.

- The Maribyrnong River, Moonee Ponds Creek and the Yarra River are the main water courses within the study area. Under undisturbed groundwater conditions (i.e., no impacts from man-made structures) it is expected that these rivers are the main discharge zones for shallow groundwater. Groundwater levels below the river's water levels were observed in a number of the monitoring wells adjacent to these water courses. This suggests that currently these water courses are not acting as points of discharge in these parts of the study area. In addition, these differences in water levels as well as observations obtained during construction of the CityLink tunnels[7], suggest a relatively weak connectivity between the rivers and the groundwater system, potentially due to presence of low permeability riverbed sediments. This suggests that the water courses also not likely to be significant groundwater recharge features in these parts of the study area.

Overall, the groundwater flow across the study area is inferred to occur from the higher elevation in the broader Parkville, Richmond and Botanical Gardens areas towards CityLoop, CityLink tunnels, Yarra River and Moonee Ponds Creek. Additionally, deep basements within the CBD and South Melbourne area are known to have affected the local groundwater levels and flow patterns, as well as the Prahran Sewer Main located close at the eastern end of the study area.

[7] The groundwater drawdowns in the Silurian and Basalt aquifer transmitted quickly under and beyond the river away from the tunnel excavation.

6.4 Concept Design Groundwater Levels

Estimates of maximum groundwater levels are required to support development of acceptance criteria related to a structure being able to perform its intended function. This is based on estimation of the loads (including groundwater pressures) to which a structure would be subject over the design life. For purpose of this report, these estimates are related to the maximum groundwater levels that could potentially occur and persist for a period of time over design life of the project, which for Melbourne Metro is 100 years and are referred to as "design groundwater levels.

The design groundwater levels discussed below are considered to be the Service Limit State (SLS) levels (return period of 100 years as defined in AS5100.2 Table 5.4). For the purpose of developing the Concept Design, the Ultimate Limit State (ULS) levels should be taken as equivalent to the ground surface elevations along the alignment (return period of 1000 years in AS5100.2 Table 5.4).

Factors considered in the determination of design groundwater levels include:

- Seasonal variations.
- Inter-seasonal variations: decade-scale changes in water levels due to variations in rainfall.
- Long-term climate change.
- Groundwater level rises due to flooding from surface water bodies.
- Potential changes due to anthropogenic influences, including basement dewatering and changes to sewers.

Seasonal and inter-seasonal variations were assessed using available long-term groundwater level data from state monitoring network wells and long-term rainfall records, as shown in Figure 15 and Figure 16 below. The long term rainfall data was plotted as cumulative deviation from the monthly mean (CDFM) to enable better correlation between rainfall and groundwater levels. The monitoring wells included in the assessment are located within a broad area of the Melbourne Metro alignment and with the exception of Silurian aquifer well B97-GW03 not within the same aquifer units expected to be encountered along the alignment. However, the groundwater response in these wells was considered adequate to provide an indication of potential changes in the groundwater levels within the study area. This was supported by groundwater levels in monitoring well B97-GW03 that was installed in Richmond for the CityLink project monitoring purposes and which shows a similar trend in the groundwater levels as the Brighton Group and Newer Volcanics monitoring wells located further away from the study area. A long term climate fluctuation in groundwater levels between 2.5 m and 3.0 m has been indicated based on the long term observations in the monitoring well 80245 and 97007. Based on this a total potential rise of 3.0 m was adopted for the calculation of Concept Design SLS groundwater levels, which are summarised in Table 15.

Figure 15: Long Term Groundwater Levels in Brighton Group and Silurian Aquifer Wells vs Rainfall

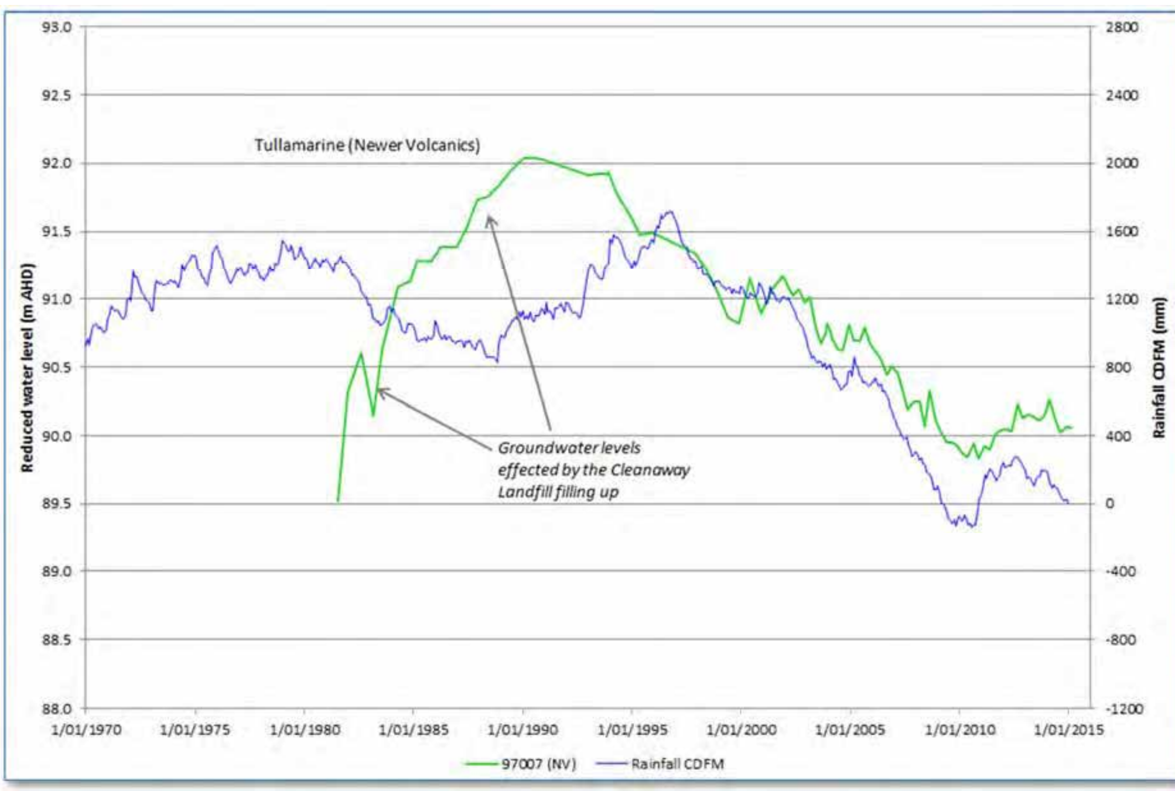

Figure 16: Long Term Groundwater Levels in Newer Volcanics Monitoring Well vs Rainfall

The regional groundwater numerical model was used to assess potential groundwater rises due to long term sea level rise, high flood events and repairs to existing sewers and the City Loop. This model is calibrated to average groundwater levels observed in Melbourne Metro monitoring wells during the year 2014 and early 2015 as well as data available for the CityLink project. The CityLink data included 2014 to early 2015 monitoring records for groundwater monitoring wells and recharge wells, and groundwater seepages rates into the tunnels.

Likely variations due to climate change were assessed only by consideration of a sea level rise of up to RL 0.98 m AHD over the project life, which were estimated by AJM JV.

Flooding influences were based on the assumed 1 in 100 year flood levels, as provided by AJM JV:

- RL 2.1 m AHD for the Yarra River in the CBD area
- RL 3.7 m AHD for Moonee Ponds Creek south of Arden Street
- RL 2.65 m AHD for the Maribyrnong River upstream of the Melbourne Metro alignment.

The resulting groundwater rises are summarised in Table 15, with the recommended SLS design levels provided in the far right hand column of the table.

For the purpose of this assessment the project structures including tunnels, stations, portals, shafts and cross passages simulated in the model were assumed to be tanked (sealed) structures over the project life. Should any of the structure be constructed as permanently drained, the design groundwater levels would then correspond to design groundwater dewatering levels for that structure.

Table 15: Concept Design SLS Groundwater Levels

	Surface Level (m AHD)	Initial[(1)] groundwater levels used for the assessment (m AHD)	Rise in Groundwater Level (m)			Adopted Long Term Rise (m)			Recommended SLS Groundwater Levels (m AHD), based on current levels from steady state regional numerical model and total rise
			Sewers repaired and MURL self-sealed	High sea level, sewers and MURL non-draining	High sea level, flood event, sewers and MURL non-draining	High sea level, sewers and MURL non-draining	Long term climate fluctuation	Total potential rise	
Western Portal - west end	3.56	0.51	0.9	1.9	1.9	1.9	3.0	4.9	3.6
Western Portal - east end	4.60	0.25	1.3	2.2	2.3	2.3	3.0	5.3	4.6
Western Portal Shaft	6.84	-0.09	1.9	2.8	3.1	3.1	3.0	6.1	6.0
Lloyd St	4.08	-1.84	3.1	3.9	4.4	4.4	3.0	7.4	4.1
Arden Station - west end	2.95	-0.85	2.4	3.3	3.3	3.3	3.0	6.3	3.0
Arden Station - east end	3.02	0.92	3.4	1.6	1.6	1.6	3.0	4.6	3.0
Abbotsford St	19.10	5.72	3.3	3.7	3.9	3.9	3.0	6.9	12.6
Arden St	20.13	13.59	0.6	0.7	0.8	0.8	3.0	3.8	17.4
Parkville Station - west end	27.82	22.76	0.5	0.6	0.7	0.7	3.0	3.7	26.5
Parkville Station - east end	34.67	24.56	1.4	1.4	1.5	1.5	3.0	4.5	29.1
MM1BH10	30.60	23.37	3.0	3.0	3.0	3.0	3.0	6.0	29.4
CBD North Station - north end	21.55	11.16	8.6	8.6	8.6	8.6	3.0	11.6	21.6
CBD North Station - south end	21.41	2.69	13.8	13.8	13.8	13.8	3.0	16.8	19.5
MM1BH12	13.07	4.58	8.2	8.3	8.3	8.3	3.0	11.3	13.1
CBD South Station - north end	10.29	3.84	4.3	4.4	4.4	4.4	3.0	7.4	10.3
CBD South Station - south end	8.24	0.81	1.7	1.9	1.9	1.9	3.0	4.9	5.7
Linilithgow Avenue Shaft	10.50	-2.55	0.2	0.3	0.4	0.4	3.0	3.4	0.8
CityLink Crossing	11.56	-9.74	0.1	0.2	0.2	0.2	3.0	3.2	-6.5
Dorcas St	10.90	0.84	3.5	3.7	3.7	3.7	3.0	6.7	7.5
Domain Station - north end	9.34	-1.17	7.5	7.6	7.7	7.7	3.0	10.7	9.3

	Surface Level (m AHD)	Initial[1] groundwater levels used for the assessment (m AHD)	Rise in Groundwater Level (m)			Adopted Long Term Rise (m)			Recommended SLS Groundwater Levels (m AHD), based on current levels from steady state regional numerical model and total rise
			Sewers repaired and MURL self-sealed	High sea level, sewers and MURL non-draining	High sea level, flood event, sewers and MURL non-draining	High sea level, sewers and MURL non-draining	Long term climate fluctuation	Total potential rise	
Domain Station - south end	9.67	-2.36	9.3	9.4	9.5	9.5	3.0	12.5	9.7
Toorak Rd	18.68	3.45	5.0	5.1	5.2	5.2	3.0	8.2	11.7
Fawkner Park Shaft	10.88	-1.88	9.4	9.4	9.5	9.5	3.0	12.5	10.6
Punt Rd	20.52	6.18	1.7	1.8	1.9	1.9	3.0	4.9	11.1
Eastern Portal Shaft	11.50	5.79	1.7	1.8	1.9	1.9	3.0	4.9	10.7
Eastern Portal - west end	9.34	5.71	1.7	1.8	1.9	1.9	3.0	4.9	9.3
Eastern Portal - east end	9.56	5.97	1.6	1.6	1.7	1.7	3.0	4.7	9.6

(1) Initial groundwater levels used for calculation were based on the groundwater levels generated by the regional groundwater model

Highlighted in green shading – groundwater levels at the ground surface levels, i.e. does not take in consideration potential ponding of water at the surface.

7.0 GROUNDWATER QUALITY

7.1 Introduction

This section provides a summary of the groundwater quality assessment along the Melbourne Metro Concept Design alignment and the possible implications of the groundwater quality on:

- the human health risk to Melbourne Metro workers and users posed by groundwater contamination associated with current and historical land uses within the Melbourne Metro area
- the groundwater disposal options relating to the Melbourne Metro construction and operation
- the potential impact of groundwater on the durability of structures.

The section is presented into two parts. The first part provides a discussion on the broad groundwater quality in each of the aquifer units tested along the Melbourne Metro alignment (Section 7.2). The second part provides an understanding of the possible implications of the groundwater quality on the above matters (Section 7.3).

7.2 Groundwater Quality Discussion

7.2.1 General

This section is based on a consolidated data set resulting from the Concept Design and the previous phases of work. The data were collected from a total of 45 wells monitoring the various aquifer units along the Melbourne Metro Concept Design alignment.

The dataset is provided in APPENDIX E. Details of the analytical suites for the Concept Design are provided in APPENDIX D. Concentrations of key inorganic are illustrated on Drawing 6 while concentrations of key contaminants are illustrated on Drawing 7. Drawing 8 illustrates the distribution of TDS along the alignment.

The ion balance error for the major ion data was calculated for the groundwater samples collected. The major ion results that had an ion balance error inside the ±10 % range were plotted on a Piper diagram (Figure 17) in order to establish an understanding of the chemical signature of groundwater. Further discussion on the chemical signature in each of the aquifer units is provided in the following sections.

Sulphate reducing bacteria (SRB) results were reported using three different units including predicted active cells per millilitre (pac/mL), most probable number per 100 millilitres (MPN/100mL) and organism per 100 millilitres (org/100mL). To facilitate comparison, all SRB results were presented as org/100mL. The results in org/100mL and MPN/100mL are interchangeable. Although the multiplication of the pac/mL results by a factor of 100 does not provide strictly equivalent results in org/100mL, the magnitude of the results is comparable, which is acceptable for the purpose of this document.

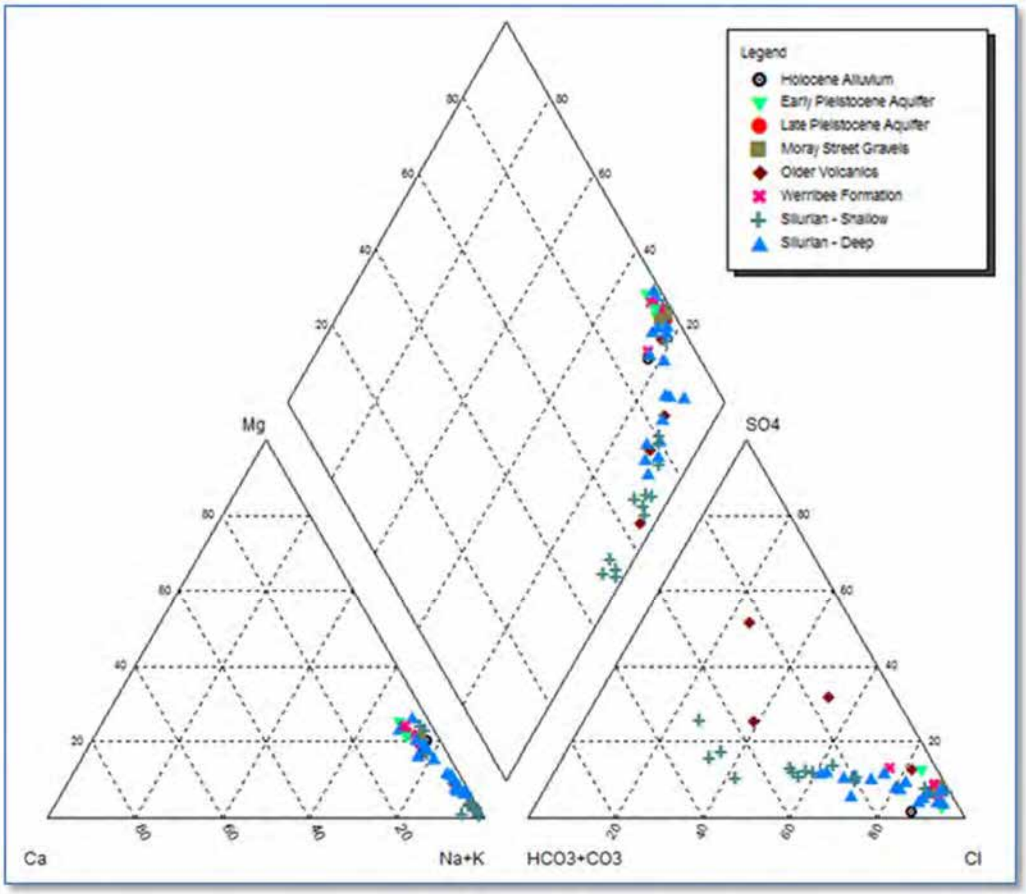

Figure 17: Piper Diagram

7.2.2 Holocene Aquifer

There is one well monitoring the Holocene Aquifer, located in the vicinity of the Yarra Crossing. There were no organics detected above the LOR in this well.

The pH value of groundwater from this well is slightly acidic (6.5 pH unit). The redox conditions are indicated to be reducing (-113 mV).

The TDS concentration in this well is 17,500 mg/L (Drawing 6), which is indicative of saline conditions. The TDS concentrations correspond to the highest background salinity levels (Segment D) defined by the State Environment Protection Policy (SEPP) for Groundwaters of Victoria (Groundwater SEPP) (GoV, 1997).

Groundwater is indicated to be of Na/Cl type (Figure 17), with sodium being the most dominant cation (over 30 % of the total ion composition) and chloride being the most dominant anion (over 45 % of the total ion composition).

Chloride concentration in groundwater from this well is 8,750 mg/L (Drawing 6). The sulphate (as SO_4) concentration is 200 mg/L to 1,980 mg/L while the SRB results exceed 110,000 org/100mL.

The ammonia (as N) concentration is 171 mg/L while the nitrate (as N) concentration is below the limit of reporting (LOR) of 0.01 mg/L. The presence of ammonia and the absence of nitrate is supported by the reducing conditions (-113 mV).

Metal concentrations in the Holocene Aquifer well are below 0.1 mg/L, with the exception of barium (2.57 mg/L), boron (0.53 mg/L), iron (21 mg/L) and manganese (0.131 mg/L). These metals are redox sensitive and their occurrence in higher concentrations is also supported by the low redox conditions.

7.2.3 Early Pleistocene Aquifer

There are three wells monitoring the Early Pleistocene Aquifer. There were no organics detected above the LOR in the wells monitoring these units.

Groundwater quality results for key field and inorganic parameters for these other units are summarised in Table 16 while concentration of key metals are summarised in Table 17.

Table 16: Early Pleistocene Aquifer - Summary of Inorganics

Parameters	GA11-BH008	GA11-BH009	GA15-BH005
pH (pH unit)	7.2	6.6	6.6
Redox (mV)	-124.5	25.4	75.2
TDS (mg/L)	38,000	22,600	24,900
IBE (%)	-4.05	-2.66	-5.33
Water Type	Na-Mg/Cl	Na-Mg/Cl	Na-Mg/Cl
Sulphate (as SO_4) (mg/L)	698	1,390	2,420
Chloride (mg/L)	18,400	13,200	11,900
Ammonia (as N) (mg/L)	49.4	15.4	7.06
Nitrate (as N) (mg/L)	<0.01	0.01	0.02
SRB (org/100mL)	>110,000	15,000	*5,000,000*

Notes to Table: IBE – Ion Balance Error

Underlined – results expressed as MPN/100mL in laboratory report

Italic – results expressed as org/mL in laboratory report

The pH of groundwater from the Early Pleistocene Aquifer is indicated to be near-neutral, ranging from 6.6 pH units to 7.2 pH units. The redox values reflect a range of conditions, from reducing conditions (less than 100 mV) to more oxidising conditions (over 50 mV).

TDS concentrations generally exceed 20,000 mg/L (Drawing 6), which corresponds to the highest background salinity levels (Segment D) according to the Groundwater SEPP (GoV, 1997).

The groundwater type follows a similar trend to that of TDS. Groundwater is indicated to generally be of Na-Mg/Cl type (sodium-magnesium/chloride) (Figure 17). Sodium is the most dominant cation (contributing to more than 30 % of the total ion composition) and magnesium is the second dominant cation (contributing to about 10% of the total ion composition). Chloride is the most dominant anion (contributing to over 45 % of the total ion composition). The chloride concentrations range from 11,900 mg/L to 18,400 mg/L.

The sulphate (as SO_4) concentrations are more variable, ranging from 698 mg/L in well GA11-BH008 to 2,420 mg/L in well GA15-BH005 (Drawing 6). The SRB results range from 15,000 org/100mL in excess of 110,000 org/100mL.

Concentrations of ammonia (as N) range from 7.06 mg/L to 49.4 mg/L while the nitrate (as N) concentrations are low, not exceeding 0.02 mg/L. The higher ammonia (as N) concentrations coincide with the lower redox conditions.

Table 17: Early Pleistocene - Summary of Key Metals

Parameters	GA11-BH008	GA11-BH009	GA15-BH005
Boron (mg/L)	NT	0.5	0.94
Iron (mg/L)	22.9	<0.05	0.07
Manganese (mg/L)	1.92	2.9	5.8

Notes to Table: NT – Not Tested

Metal concentrations in the other units are below 0.5 mg/L, with the exception of boron, iron and manganese (Table 17). Higher concentrations of these metals (in particular iron) tend to coincide with stronger reducing conditions (well GA11-BH008) (Drawing 7).

7.2.4 Late Pleistocene Aquifer

There is one well monitoring the Late Pleistocene Aquifer, located in the Western Zone (Western Portal). There were no organics detected above the LOR in this well.

The pH value of groundwater from this well is slightly alkaline (8.4 pH unit). The redox conditions are indicated to be reducing (-108 mV).

The TDS concentration in this well is 29,800 mg/L (Drawing 6), which is indicative of saline conditions. The TDS concentrations correspond to the highest background salinity levels (Segment D according to the groundwater SEPP) (GoV, 1997).

Groundwater is indicated to be of Na/Cl type (Figure 17), with sodium being the most dominant cation (over 35 % of the total ion composition) and chloride being the most dominant anion (over 45 % of the total ion composition).

Chloride concentration in groundwater from this well is 13,500 mg/L (Drawing 6). The sulphate (as SO_4) concentration is 1,630 mg/L to 1,980 mg/L while the SRB results exceed 110,000 org/100mL.

The ammonia (as N) concentration is 23.7 mg/L while the nitrate (as N) concentration is 0.02 mg/L. The presence of ammonia and the absence of nitrate is supported by the reducing conditions (-108 mV).

The concentration of iron is 6.38 mg/L while the manganese concentration is 4.44 mg/L. The low redox conditions in this well supports the higher concentrations in these metals.

7.2.5 Moray Street Gravels

Groundwater quality results for key field and inorganic parameters for the Moray Street Gravels are summarised in Table 18. The two wells monitoring this unit are located in the vicinity of the Yarra Crossing.

Table 18: Moray Street Gravels - Summary of Inorganics

Parameters	GA11-BH017	GA11-BH041
pH (pH unit)	6.8	7.0
Redox (mV)	75.7	-47.4
TDS (mg/L)	25,000	27,400
IBE (%)	1.15	-3.25
Water Type	Na-Mg/Cl	Na-Mg/Cl
Sulphate (as SO_4) (mg/L)	1,430	1,980
Chloride (mg/L)	14,400	16,000
Ammonia (as N)	59	40.7
Nitrate (as N)	0.03	0.04
SRB (org/100mL)	1,500	4,300

Notes to Table: IBE – Ion Balance Error, Underlined – results expressed as MPN/100mL in laboratory report

The pH values of groundwater from wells monitoring the Moray Street Gravels indicate slightly acidic to neutral conditions, ranging from 6.8 pH units to 7.0 pH units. With the exception of well GA11-BH017, Redox values in the unit are indicated to vary, from about -50 mV (reducing conditions) to about 75 mV (oxidising conditions).

TDS concentrations exceed 20,000 mg/L (Drawing 8), which is indicative of saline conditions. The TDS concentrations correspond to the highest background salinity levels (Segment D) (GoV, 1997).

Groundwater is indicated to be of Na-Mg/Cl type (Figure 17), with sodium being the most dominant cation (over 30 % of the total ion composition), magnesium being the second dominant cation (about 10 % of the total ion composition) and chloride being the most dominant anion (over 45 % of the total ion composition). Chloride concentrations range from 14,400 mg/l to 16,000 mg/L.

Sulphate (as SO_4) concentrations range from 1,430 mg/L to 1,980 mg/L (Drawing 6) while the SRB results range from 1,500 org/100mL to 4,300 org/100mL.

Ammonia (as N) concentrations range from 40.7 mg/L to 59 mg/L while nitrate (as N) concentrations are less than 0.05 mg/L.

Metal concentrations are generally below 0.1 mg/L with the exception of boron, iron and manganese. Boron concentrations up to 0.84 mg/L, iron concentrations up to 8.36 mg/L and manganese concentrations up to 1.51 mg/L are indicated.

Total recoverable hydrocarbons (TRH) were detected in groundwater from well GA11-BH041 (Yarra Crossing). The results are dominated by the TRH (C_{10}-C_{14}) fraction (0.48 mg/L) and the TRH (C_{15}-C_{28}) fraction (0.66 mg/L). No other organic parameters tested in groundwater from wells monitoring the Moray Street Gravels were above their LOR.

7.2.6 Older Volcanics

Groundwater quality results for key field and inorganic parameters for the Older Volcanics are summarised in Table 19. The four wells monitoring this unit are located in the Western Zone.

Table 19: Older Volcanics - Summary of Inorganics

Parameters	GA11-BH002	GA11-BH003	GA11-BH005	GA11-BH031
pH (pH unit)	7.5	7.8	7.3	7.0
Redox (mV)	-52	-175.7	131	-122
TDS (mg/L)	5,000	2,160	7,920	7,630
IBE (%)	-6.76	-3.45	-5.11	-5.16
Water Type	Na/SO_4-Cl-HCO_3	Na/Cl-HCO_3-SO_4	Na/Cl	Na/Cl-SO_4
Sulphate (as SO_4) (mg/L)	2,320	517	897	2,150
Chloride (mg/L)	835	590	4,310	2,650
Ammonia (as N)	0.75	0.29	0.06	0.06
Nitrate (as N)	<0.01	0.03	8.02	<0.01
SRB (org/100mL)	>11,000	>110,000	1,500	>110,000

Notes to Table: IBE – Ion Balance Error

Underlined – results expressed as MPN/100mL in laboratory report

The pH in groundwater from the Older Volcanics indicates neutral conditions, with the pH being around 7 pH units. With the exception of well GA11-BH005 (redox value of 131 mV), the redox values in the unit tend to indicate reducing conditions, below -50 mV.

TDS concentrations in the Older Volcanics were lower to that of the Fluvial Sediments and Moray Street Gravels, ranging from 2,160 mg/L to 7,920 mg/L (Drawing 8). The distribution in TDS indicates that the background groundwater quality of the groundwater in the Older Volcanics is typical of Segment C according to the Groundwater SEPP (GoV, 1997).

The groundwater type in the Older Volcanics is indicated to be variable, mainly due to variations in the contribution of chloride, sulphate, and to a lesser extent, bicarbonate (Figure 17). Sodium is the most dominant cation in the Older Volcanics, contributing to over 35 % of the total ion composition. The contribution of chloride ranges from about 20 % (GA11-BH003) to over 40 % (GA11-BH005) of the total ion composition. Where the contribution of chloride is lower, an increase of the contribution of sulphate (up to about 27 % of the total composition in GA11-BH002), and to a lesser extent, bicarbonate (up to about 18 % of the total ion composition in GA11-BH003) is indicated.

The chloride concentrations range from 590 mg/L to 4,310 mg/L while the sulphate (as SO_4) concentrations range from 517 mg/L to 2,320 mg/L (Drawing 6). The SRB results range from 1,500 org/100mL to in excess of 110,000 org/100mL.

Ammonia (as N) concentrations lower than 1 mg/L while the nitrate (as N) concentrations are less than 0.03 mg/L, with the exception of well GA11-BH005. In this well, a nitrate (as N) concentration of 8.02 mg/L is indicated.

Metal concentrations are below 0.1 mg/L with the exception of boron, iron and manganese. The concentrations of these metals, however, do not exceed 1 mg/L with the exception of boron in GA11-BH002 (4.89 mg/L).

TRH were detected in groundwater from well GA11-BH002. The results are dominated by the heavier TRH (C_{15}-C_{28}) fraction (0.33 mg/L) and the TRH (C_{29}-C_{36}) fraction (0.08 mg/L). No other organic parameters tested in groundwater from wells monitoring the Older Volcanics were above their respective LOR.

7.2.7 Werribee Formation

Groundwater quality results for key field and inorganic parameters for the Werribee Formation are summarised in Table 20. The four wells monitoring this unit are located in the Western Zone.

Table 20: Werribee Formation - Summary of Inorganics

Parameters	GA11-BH007	GA11-BH011	GA15-BH001	GA15-BH003
pH (pH unit)	6.8	7.7	6.1	6.2
Redox (mV)	-93.2	199.4	11	-98.2
TDS (mg/L)	37,200	5,740	44,200	31,500
IBE (%)	-2.50	1.67	1.10	-1.55
Water Type	Na-Mg/Cl	Na/Cl	Na-Mg/Cl	Na-Mg/Cl
Sulphate (as SO_4) (mg/L)	2,340	600	2,720	1,070
Chloride (mg/L)	18,000	2,600	19,900	16,400
Ammonia (as N) (mg/L)	6.3	0.03	11.5	21.0
Nitrate (as N) (mg/L)	0.02	21	0.01	<0.01
SRB (org/100mL)	>11,000	900	*2,700,000*	15,000

Notes to Table: IBE – Ion Balance Error
Underlined – results expressed as MPN/100mL in laboratory report
Italic – results expressed as org/mL in laboratory report

The data generally indicate that the chemical signature of groundwater from well GA11-BH011 differ to that from wells GA11-BH007, GA15-BH001 and GA15-BH003. Well GA11-BH011 is screened partially within sandy gravels of the Werribee Formation and partially within clayey sands of the residual siltstone of the Silurian Aquifer. This may affect the chemical signature of this well.

The pH of groundwater in wells GA11-BH007, GA15-BH001 and GA15-BH003 is slightly acidic (6.1 pH units to 6.8 pH units) while the redox values tend to be low (11 mV to -93.2 mV). In well GA11-BH011, the pH is 7.7 pH units while the redox value is markedly positive, close to 200 mV.

TDS concentrations in wells GA11-BH007, GA15-BH001 and GA15-BH003 exceed 30,000 mg/L (Drawing 8), which is indicative of saline conditions. The TDS concentrations corresponds to the highest background salinity levels (Segment D) defined by the Groundwater SEPP (GoV, 1997). TDS concentration in well GA11-BH011 is considerably lower (less than 6,000 mg/L), which is indicative of fresher conditions.

Although groundwater from the four wells is indicated to be of Na-Mg/Cl type (sodium-magnesium/chloride), the contribution of chloride is slightly more pronounced in wells GA11-BH007 and GA15-BH001 (over 40 % of the total ion composition) (Figure 17). The contribution of chloride in groundwater from well GA11-BH011 is in the order of 35 % of the total ion composition. The contribution of sodium, which is the most dominant cation, is comparable in the three wells (in the order of 35 % of the total ion composition). Manganese is the second most dominant cation, contributing to about 10 % of the total ion composition.

The chloride concentrations are over 15,000 mg/L in wells GA11-BH007, GA15-BH001 and GA15-BH003 while the chloride concentration in well GA11-BH001 is about 2,600 mg/L (Drawing 5). Sulphate (as SO_4) and SRB results follows a similar pattern. Higher sulphate (as SO_4) concentrations (above 2,000 mg/L) and higher SRB results (over 11,000 org/100mL) are indicated in wells GA11-BH007, GA15-BH001 and GA15-BH003. A lower concentration in sulphate (as SO_4) (600 mg/L) and a lower SRB result (900 org/100mL) are indicated in well GA11-BH011.

Ammonia (as N) concentrations are higher in wells GA11-BH007, GA15-BH001 and GA15-BH003 (from 6.3 mg/L to 21 mg/L) while the nitrate (as N) concentrations in these wells is marginally above the LOR of 0.01 mg/L. Ammonia (as N) concentration is lower in well GA11-BH011 (0.03 mg/L) while the nitrate (as N) concentration is higher (21 mg/L). This is supported by the redox values, oxidising in GA11-BH011 and broadly reducing in wells GA11-BH007, GA15-BH001 and GA15-BH003.

Metal concentrations are below 0.5 mg/L with the exception of boron, iron and manganese. Higher concentrations of boron (up to 1.8 mg/L), iron (up to 16.7 mg/L) and manganese (up to 18 mg/L) are indicated in in wells GA11-BH007, GA15-BH001 and GA15-BH003 (Drawing 6). The concentrations of these metals in GA11-BH011 are lower, not exceeding 1 mg/L.

The heavier TRH (C_{15}-C_{28}) fraction (0.22 mg/L) was detected in groundwater from well GA11-BH007. The other TRH factions were below the LOR (ranging from 0.02 mg/L to 0.05 mg/L). The other organic parameters tested in groundwater from wells in the Werribee Formation were below their respective LOR.

7.2.8 Silurian

7.2.8.1 Water Type and Inorganics

TDS results and an assessment of the water type of the Silurian Aquifer is summarised in Table 21 while groundwater quality results for other key field and inorganic parameters are summarised in Table 22. A distinction was made between shallow wells installed in the vicinity of the water table and deep wells representative of the deeper zone of the Silurian aquifer. The wells monitoring the Silurian aquifer are distributed in the different geographical zones along the Melbourne Metro alignment.

Table 21: Silurian - Summary of TDS and Water Types

Aquifer Zone	Well ID	Location	TDS	Water Type	IBE
Shallow	GA15-BH007	Central Zone	2,280	Na/Cl-HCO_3	-5.69
	GA15-BH008	Central Zone	4,710	Na/Cl	-1.98
	GA15-BH009	Central Zone	4,400	Na/Cl-HCO_3	-5.43
	GA15-BH010	Central Zone	3,620	Na/Cl-HCO_3	-5.28
	GA15-BH012	Central Zone	1,410	Na/HCO_3-Cl	-5.30
	GA15-BH018	Central Zone	2,030	Na/Cl-HCO_3	-9.12
	GA15-BH019	Central Zone	2,810	-	**-10.19**
	GA15-BH021	Central Zone	1,450	Na/Cl-HCO_3	-8.54
	GA11-BH019	Eastern Zone	10,100	Na/Cl	-3.91
	GA11-BH026	Eastern Zone	1,520	Na/HCO_3-Cl	-1.88
	GA11-BH027	Eastern Zone	1,660	Na/Cl	-2.00
	GA15-BH120	Eastern Zone	1,790	Na/HCO_3-Cl	-4.12
	GA15-BH121	Eastern Zone	8,380	-	**-12.41**
Deep	GA11-BH013	Western Zone	4,400	Na/Cl	4.43
	GA15-BH002	Western Zone	25,300	Na-Mg/Cl	1.19
	GA11-BH014	Central Zone	4,270	Na/Cl	4.43
	GA15-BH011	Central Zone	6,690	Na/Cl-HCO_3	-7.96
	GA15-BH110	Central Zone	3,250	Na/Cl-HCO_3	-3.27
	GA15-BH112	Central Zone	3,000	Na/Cl-HCO_3	-7.47
	GA11-BH020	Eastern Zone	6,220	Na-Mg/Cl	-3.07
	GA11-BH021	Eastern Zone	1,380	Na/Cl-HCO_3	-4.22
	GA11-BH022	Eastern Zone	7,000	Na-Mg/Cl	-3.24
	GA11-BH023	Eastern Zone	5,200	Na/Cl	-4.82
	GA11-BH024	Eastern Zone	5,000	Na-Mg/Cl	-6.85
	GA11-BH025	Eastern Zone	5,680	Na-Mg/Cl	-4.56
	GA15-BH027	Eastern Zone	6,650	Na/Cl	-4.52
	GA15-BH028	Eastern Zone	4,810	Na/Cl	-2.69
	GA15-BH029	Eastern Zone	6,500	Na/Cl	-6.48
	GA15-BH031	Eastern Zone	7,470	Na/Cl	-4.43
	GA15-BH033	Eastern Zone	6,360	Na/Cl	-7.12

Notes to Table: IBE – Ion Balance Error

IBE> ±10% - Water Type not assessed

The wells representative of the shallow zone of the Silurian aquifer are located in the Central Zone and the Western Zone (Drawing 8). The TDS concentrations in these wells generally range from less than 2,000 mg/L to about 4,500 mg/L, representative of brackish conditions. Two wells of the Eastern Zone (GA11-BH019 and GA15-BH121) have higher TDS concentrations (exceeding 8,000 mg/L), representative of more saline conditions.

The typical water type that represents the shallow zone is indicated to be of Na/Cl type (sodium/chloride) and Na/Cl-HCO_3 (sodium/chloride-bicarbonate) (Figure 17). Sodium is the most dominant cation, contributing to over 40 % of the total ion composition. Chloride is the most dominant anion, contributing to about 30 % and more of the total contribution. Enrichment in bicarbonate is indicated in the shallow zone, with this anion contributing from about 10 % to 20 % of the total ion composition. The increased contribution in bicarbonate typically coincides with lower TDS concentrations, possibly indicating the influence from surficial infiltration into the groundwater system.

The TDS concentrations in wells representing the deep zone of the Silurian aquifer are higher, typically ranging from about 3,000 mg/L to 7,000 mg/L (Drawing 8). The exceptions to this are well GA11-BH021 (1,380 mg/L) and well GA15-BH002 (25,300 mg/L).

Two main water types dominate the chemical signature in the deep zone, these types being Na/Cl (sodium/chloride) and Na-Mg/Cl (sodium-magnesium/chloride) (Figure 17). For these two types, sodium is the most dominant cation contributing to about 40 % to 45 % of the total ion composition. Magnesium tends to be the second most dominant anion, with its contribution representing from about 5 % to 12 % of the total ion composition. Chloride is the most dominant anion, with its contribution ranging from about 25 % GA11-BH021) to about 45 % (GA15-BH002) of the total ion composition. Occasionally, an increased contribution of bicarbonate is indicated, not exceeding 15 % of the total ion composition.

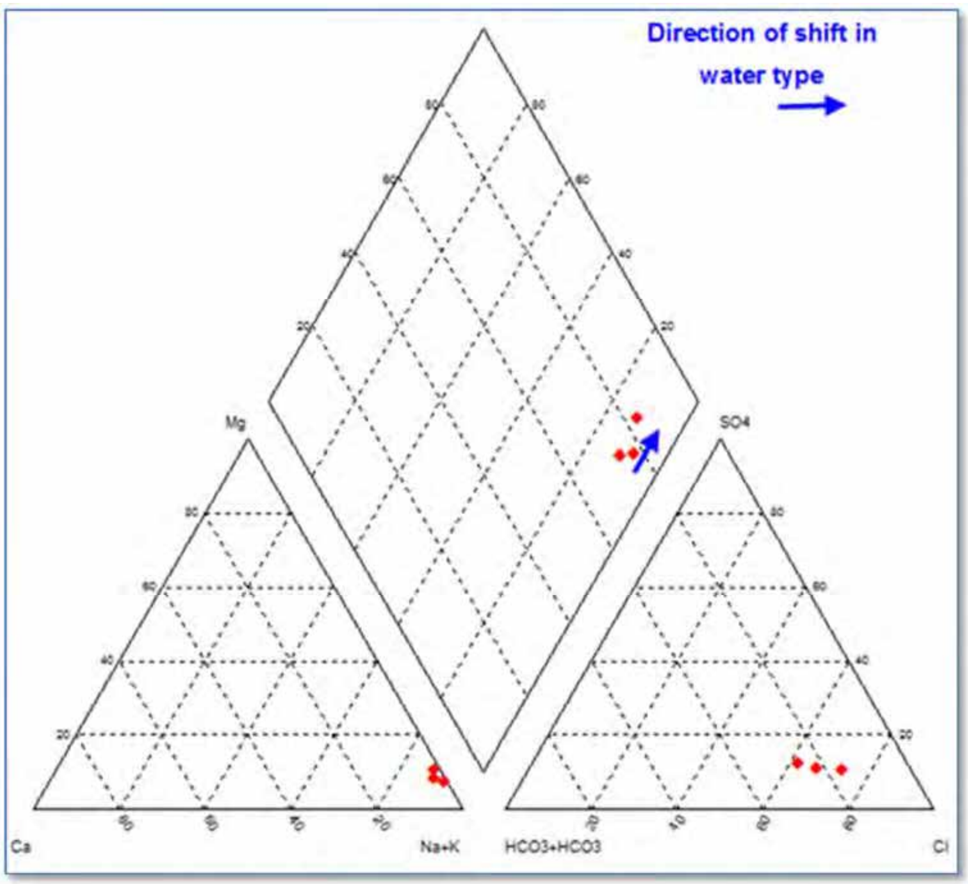

Figure 18: Changes in Water Type During Pumping Test

During the pumping test undertaken in well GA15-BH110, a gradual shift in the water type was indicated (Figure 18). At the start of pumping, the water type in this well was Na/Cl-HCO_3, with a contribution in bicarbonate representing about 13 % of the total ion composition. At the end of the pumping test period, the water type in this well was Na/Cl, with the contribution of bicarbonate having decreased to less than 9 %.

Table 22: Silurian - Summary of Inorganics

Parameter	Silurian - Shallow		Silurian - Deep	
	Lower end of range	Upper end of range	Lower end of range	Upper end of range
pH (pH unit)	5.9 (GA15-BH120)	7.7 (GA15-BH012)	5.1 (GA11-BH025)	7.7 (GA11-BH013)
Redox (mV)	-49.8 (GA11-BH027)	435.5 (GA15-BH019)	-78.6 (GA15-BH033)	237.2 (GA11-BH025)
Sulphate (as SO_4) (mg/L)	111 (GA11-BH027)	450 (GA15-BH008)	141 (GA11-BH021)	1,490 (GA15-BH002)
Chloride (mg/L)	143 (GA15-BH121)	5,750 (GA11-BH019)	428 (GA11-BH021)	12,600 (GA15-BH002)
Ammonia (as N) (mg/L)	0.01 (GA11-BH019)	0.54 (GA11-BH027)	<0.01 (GA11-BH022)	1.13 (GA15-BH002)
Nitrate (as N) (mg/L)	0.01 (GA15-BH007)	14.5 (GA15-BH009)	0.01 (GA15-BH002, GA15-BH112)	26.3 (GA11-BH014)
SRB (org/100mL)	900 (GA15-BH120)	500,000,000 (GA15-BH008)	24,000 (GA11-BH013)	50,000,000 (various)

The range in pH of groundwater in wells monitoring the Silurian aquifer is broader than the other aquifer units (from about 5 pH units to slightly less than 8 pH units), indicating variability between slightly acidic and slightly alkaline conditions. The redox values are also indicative of a broad range of conditions, from reducing (less than -50 mV) to oxidising conditions (above 200 mV), reflecting the local influences.

Sulphate (as SO_4) concentrations are lower in the shallow zone, ranging from about 100 mg/L to less than 500 mg/L (Drawing 6). In the deep zone, sulphate (as SO_4) concentrations tend to be higher ranging from about 150 mg/L to about 1,500 mg/L. The SRB results also reflect the variability in local conditions. The variability in SRB results is more pronounced in the shallow zone, with results ranging from 900 org/100mL to over several millions of org/100mL. This likely reflects the variability associated with the conditions near the water table. The range in SRB results for the deep zone is narrower, ranging from 24,000 org/100mL to 50,000,000 org/100mL.

Chloride concentrations broadly follow the spatial trend in TDS concentrations (Drawing 6). Chloride concentrations in the shallow zone of the Silurian Aquifer are lower than in the deep zone, ranging from 143 mg/L to 5,750 mg/L. The chloride concentrations in the deep zone are higher, ranging from about 400 mg/L to over 10,000 mg/L.

Nitrogen species concentrations also reflect the variability in local conditions. Nitrate (as N) concentrations are variable, ranging less than the LOR of 0.01 mg/l to locally over 10 mg/L. Ammonia (as N) concentrations tend to be lower than in other units such as Moray Street Gravels, infrequently exceeding 1 mg/L.

7.2.8.2 Metals and Organics

Metal concentrations are below 0.5 mg/L with the exception of boron, iron and manganese. A summary of the typical concentration ranges for these metals in provided in Table 23.

Table 23: Silurian - Typical Concentrations Ranges for Boron, Iron and Manganese

Metal	Shallow Zone	Deep Zone
Boron (mg/L)	0.009 – 0.3	0.1 – 0.2
Iron (mg/L)	<0.05 – 0.84	0.2 - 10
Manganese (mg/L)	0.02 – 0.119	0.1 – 0.5

The concentrations of boron, iron and manganese in the shallow zone are generally low (less than 1 mg/L), likely reflecting the more oxidising conditions near the water table. The exception to this is well GA11-BH027 that has an iron concentration 2.53 mg/L (Drawing 7), however, this well has also a negative redox value of about -50 mV. The concentrations of boron, iron and manganese in the deep zone tend to be slightly higher, albeit not to the extent indicated in more reducing aquifer units such as Moray Street Gravels or the Werribee Formation.

Organic chemicals were detected in five wells monitoring the Silurian Aquifer (Drawing 7). The results are summarised in Table 24.

Table 24: Silurian - Summary of Organics

Parameters	GA11-BH014 (Central Zone)	GA15-BH007 (Central Zone)	GA15-BH021 (Central Zone)	GA15-BH029 (Eastern Zone)	GA11-BH022 (Eastern Zone)
Aquifer Zone	**Deep**	**Shallow**	**Shallow**	**Deep**	**Deep**
TRH (C_6-C_9)	<0.02	<0.02	<0.02	<0.02	<0.02
TRH (C_{10}-C_{14})	<0.05	0.08	<0.05	0.06	<0.05
TRH (C_{15}-C_{28})	<0.1	0.56	1.02	<0.1	<0.1
TRH (C_{29}-C_{36})	<0.05	<0.05	0.57	<0.05	<0.05
Benzene	<0.001	<0.001	<0.001	<0.001	0.002
Toluene	<0.002	0.004	<0.002	<0.002	<0.002
Total Xylene	<0.002	<0.002	<0.002	<0.002	0.01
Phenol	<0.001	0.0017	<0.002	<0.002	<0.001
Tetrachloroethene	0.012	<0.005	<0.005	<0.005	<0.005
Cis-1,2-Dichloroethene	0.007	<0.005	<0.005	<0.005	<0.005
Chloroform	<0.005	0.01	<0.005	<0.005	<0.005

TRH was detected in shallow zone wells GA15-BH007 and GA15-BH021 and deep zone well GA15-BH029. The TRH concentrations are dominated by the heavier TRH (C_{15}-C_{28}) fraction, with concentration ranging from 0.56 mg/L to 1.02 mg/L. The TRH (C_{29}-C_{36}) fraction was detected in well GA15-BH021 (0.57 mg/L). The other TRH fractions were below the LOR with the exception of the TRH (C_{10}-C_{14}) fraction in wells GA15-BH007 and GA15-BH029, which was slightly above the LOR (0.06 mg/L to 0.08 mg/L).

The following was detected in the individual wells:

- Deep zone well GA11-BH014 (Central Zone): Tetrachloroethene was detected at a concentration of 0.012 mg/L while its biodegradation product, cis-1,2-dichlorethene was detected at a concentration of 0.007 mg/L.
- Shallow zone well GA15-BH007 (Central Zone): Toluene was detected at 0.004 mg/L, phenol was detected at 0.0017 mg/L and chloroform was detected at 0.01 mg/L.
- Deep zone well GA11-BH022 (Eastern Zone): Benzene was detected at a concentration of 0.002 mg/L while a total xylene concentration 0f 0.01 mg/L was detected.

7.3 Groundwater Quality Implications

7.3.1 Contamination

7.3.1.1 Summary of Potential Sources of Groundwater Contamination

A review of the existing and historical land uses in the vicinity of Melbourne Metro was undertaken as described in the Contaminated Land Assessment EES Summary Report. This report included an evaluation of identified potential sources of contamination, the potential contaminants that may be associated with these sources and provides a relative ranking for each item with respect to potential contamination. The ranking is not intended to infer severity or extent of impact or risk to workers or users of Melbourne Metro; rather, it is intended to indicate the potential for the contamination issues that may exist at the identified source, to adversely impact groundwater that might interact with Melbourne Metro during construction or operation.

The ranking is defined as follows:

- **Low:** Unlikely to present a potential contamination issue.
- **Medium:** Possibly presents a potential contamination issue that may need further consideration.
- **High**: Increased potential to presents a contamination issue that may need further consideration and investigation.

Table 25 summarises the potential sources of groundwater contamination in the vicinity of the proposed stations that were ranked as having a medium to high implications for Melbourne Metro. For groundwater, the highest ranking between the on-site and the off-site assessment area was adopted. The potential sources of groundwater contamination along the tunnels linking the proposed stations that were ranked as medium to high are summarised in Table 26.

Table 25: Summary of Potential Sourced of Groundwater Contamination, Proposed Station Areas

Zone	Area	Summary of historical activities and potential sources of contamination	Potential Contaminant	Rating
Western Zone	Arden Station	The eastern portion of the proposed station area is within the footprint of Print works, which has the potential for high solvent use. The area is also part of a larger property, which included activities such as store yards, underground storage tank and other chemical storage. A gas holder was present approximately 300 m north of the station.	Metals, nutrients, creosote, cyanide, aliphatic and aromatic hydrocarbons, volatile organic compounds, phenols and solvents	High
Central Zone	Parkville Station	A service station and motor garage was historically present approximately 50 metres south of the proposed station. Industries east of the station area included electroplating and leather manufacture.	Metals, aliphatic and aromatic hydrocarbons, volatile organic compounds and solvents	Medium
	CBD North Station	North west of the proposed station has historically been part of the Carlton United Brewery (CUB). Impacts to groundwater, including fuels and chlorinated solvents have been reported in this area.	Chlorinated solvents, aliphatic and aromatic hydrocarbons	High
	CBD South	Dry cleaning or dying services, printing offices and leather manufacturers are listed within or immediately adjacent to the proposed station area.	Metals, aliphatic and aromatic hydrocarbons, phenols and solvents	Medium
Eastern Zone	Domain Station	A tramway engine house was located on the corner of Bromby Street and St Kilda Road. The tramway engine house may have housed boilers and stored oils and greases.	Metals, aliphatic and aromatic hydrocarbons and solvents	Medium
	Eastern Portal	A high density of dry cleaners, service stations and motor garages has been present within the surrounding area. Several groundwater quality restriction use zones (GQRUZ) are present approximately 250 m southeast of the portal, including non-aqueous phase liquid impacts to groundwater.	Metals, aliphatic and aromatic hydrocarbons and solvents	High

The key proposed stations where groundwater contamination issues have the potential to affect the proposed MMRP construction and operation include:

- **Arden Station:** The eastern portion of the proposed station area is within the footprint of Print works, which has the potential for high solvent use.
- **CBD North:** The CUB has been historically northwest of the proposed station with impacts to groundwater (including chlorinated solvents) reported. The site has been subject to an Environmental Audit (Ramsey, 2015) which reported concentrations of trichloroethene up to 480 mg/L in the source impact area.
- **Eastern Portal:** A high density of dry cleaners, service stations and motor garages has been present within the surrounding area. Several GQRUZs are present approximately 250 m southeast of the portal, including non-aqueous phase liquid impacts to groundwater.

While a sealed wall system would be used at Arden station to limit the effect of the station on groundwater levels and flow directions during construction, it is intended to construct CBD North station and the eastern portal as drained structures during construction, which would locally affect groundwater level and flow directions until they are sealed.

Table 26: Summary of Potential Sources of groundwater Contamination, Tunnel Sections

Zone	Area	Summary of historical activities and potential sources of contamination	Potential Contaminant	Rating
Western Zone	Arden to Parkville	The alignment is shown to go beneath a current and a former service station. Melbourne Gas Works was historically present, north of the alignment area. Presence of light non-aqueous phase liquid and metal impacts in groundwater at 35 Arden Street.	Metals, nutrients, creosote, cyanide, aliphatic and aromatic hydrocarbons, volatile organic compounds, phenols and solvents	High
Central Zone	Parkville to CBD North	A number of dry cleaners, service stations including a service station along Swanston street with GQRUZ as well as a leather manufacturer are located in the close vicinity of the tunnel alignment.	Metals, aliphatic and aromatic hydrocarbons, and solvents	High
	CBD North to CBD South	Various commercial and industrial properties including a printing office as well as dry cleaning or dying services	Metals, aliphatic and aromatic hydrocarbons and solvents	Medium
Eastern Zone	Domain to Eastern Portal	Several historic service stations, motor garages at least 7 historical businesses listed as dry cleaners /dyers.	Metals, aliphatic and aromatic hydrocarbons and solvents	High

The following key tunnel sections where groundwater contamination issues have the potential to affect the proposed Melbourne Metro construction and operation include:

- **Arden to Parkville:** The alignment is shown to go beneath a current and a former service station. Melbourne Gas Works was historically present, north of the alignment area.
- **Parkville to CBD North:** Dry cleaners, service stations and a leather manufacturer are located in the close vicinity of the tunnel alignment.
- **Domain to Eastern Portal:** Several historic service stations, motor garages at least 7 historical businesses listed as dry cleaners /dyers.

The tunnel sections in these areas are intended to be constructed using tunnel boring machines (TBM's) and gasketted precast segmental linings and therefore would effectively be sealed during construction and operation stages. This should limit the effect of the tunnels on groundwater levels and flow direction.

The purpose of the following sections is to evaluate the implications of the site history information with respect to current groundwater monitoring data set and the potential for impacts associated with migration of contaminated groundwater during the construction and operation phases of the project

7.3.1.2 Groundwater Contamination Data Review

The groundwater quality results were compared against the Australian Drinking Water Guidelines (NHMRC and NRMMC, 2011). The criteria from these guidelines are considered to be protective of workers and users who might incidentally come into contact with groundwater via ingestion. The criteria are considered conservative for the likely exposure scenarios posed to the workers and users of the MMRP. Where measured concentrations are observed to be below these criteria, the risks to human health are deemed to be acceptably low. Exceedence of the criteria does not imply that the risk is unacceptable; rather that further consideration of the risk is required.

There are a number of chemicals of interest that were detected and that are not covered by the Australian Drinking Water Guidelines. Therefore, for the purposes of this review, the groundwater concentrations for these chemicals have been assessed against the United States Environment Protection Agency (USEPA) *Regional Screening Levels for Chemical Contaminants at Superfund Sites* for tap water (USEPA, 2015).

The criteria adopted for inorganics and metals (with the exception of mercury) in this assessment have been adjusted by a factor of ten as standard drinking water guidelines are based upon the water consumption of 2 L per day, while incidental ingestion is likely to be more comparable to volume consumed during recreational activities in accordance with the guidance provided by NHMRC (2008). Criteria for mercury and other organics were not adjusted as these chemicals have the potential to be absorbed through the skin.

The results of the screening are provided in APPENDIX E. The following are possible broad contamination issues inherent to urban environment that involve the whole Melbourne Metro alignment:

- The anthropogenic activities identified in the review are likely to have contributed to the elevated concentrations of ammonia (as N) that were detected, especially in the Arden Station area (up to 49.5 mg/L in Early Pleistocene Aquifer well GA11-BH008) and potentially in the Yarra Crossing area (up to 171 mg/L in Holocene Aquifer well GA11-BH018).

  However, at this concentration, ammonia is more likely to pose an aesthetic issue (odours) or risk to ecosystems (via discharge into surface water course) than risk through the incidental pathways of exposure anticipated for the Melbourne Metro Concept Design. Further to this, the neutral to slightly acidic nature of the pH indicates that the volatile (un-ionized) fraction of ammonia (NH_3) is unlikely to exceed 1 % of the measured concentration, which would reduce the aesthetic issue.

- Although nitrite (as N), iron and manganese concentrations were occasionally above criteria, it is expected that the most likely incidental pathway of exposure is via seepage along the underground structures (e.g. tunnel wall). In such a scenario, the presence of oxygen at the seepage face is likely to result in precipitation of the metals or oxidation of nitrite. Hence, these criteria exceedences are not considered likely to pose a risk under the anticipated scenario.

- Although there are no criteria for TRH, the TRH results were either dominated by the heavier C_{15}-C_{28} fraction (Moray Street Gravels well GA11-BH014, Older Volcanics well GA11-BH002, Silurian well GA15-BH021) or else the only fraction detected (0.06 mg/L for C10-C14) was marginally above the LOR of 0.05 mg/L in Silurian well GA15-BH029. This supports that the TRH impacts were limited, typically dominated by the low mobility fraction (i.e. heavier fraction) and hence, unlikely to pose a contamination issue.

The following groundwater quality results are more likely to be indicative of localised contamination associated with the potential sources of contamination identified in Table 25 (Drawing 6):

- **Western Zone:** With the exception of ammonia and TRH, the parameters tested did not indicate occurrence of groundwater contamination that could be related to the potential sources of contamination identified in the review (Table 25). The parameters tested were below their respective LOR.

- **Central Zone (*Parkville to CBD North Tunnel Section*):** Tetrachloroethene and its biodegradation product cis-1,2-dichloroethene were detected above their LOR in well GA11-BH014 (0.012 mg/L and 0.007 mg/L, respectively). These contaminants are likely to be indicative of the dry-cleaning activities[8] that have been identified in the review (Table 25). The well is about 15 m below the water table, monitoring the deeper zone of the Silurian Aquifer. Although the concentrations are below (0.036 mg/L for cis-1,2-dichloroethene) or slightly above (0.011 mg/L for tetrachloroethene) criteria, higher concentrations may occur near the water table or in the vicinity. Further to this, the contamination in this well is not likely to be associated with the CUB brewery given that the well is upgradient of the site (Drawing 4) and the chemical signature is different i.e. the CUB impact is dominated by trichloroethene (Ramsey, 2015).

[8] Nearby identified dry-cleaning activities include (1) north of GA11-BH014 – 605 Swanston St, Carlton and (2) east of GA11-BH014, 157 Queensberry St, North Melbourne (Golder, 2015).

- **Central Zone (CBD North):** Concentrations of toluene (0.004 mg/L), phenol (0.0017 mg/L) and chloroform (0.01 mg/L) were detected in Silurian well GA15-BH007 near the CBD North Station. The toluene and phenol concentrations are below the criteria (0.8 mg/L and 5.8 mg/L, respectively). Chloroform is above the considered criteria of 0.00022 mg/L. However, the relatively low level of chloroform combined with the absence of other chlorinated solvents in the sample support the need for confirmatory sampling prior to considering further evaluation. No other chlorinated solvents, possibly relating to the impact from the CUB brewery (i.e. trichloroethene) were detected.

- **Eastern Zone:** Benzene and total xylene were detected at a concentration of 0.002 mg/L and 0.01 mg/L in Silurian well GA11-BH022. Benzene in this well is marginally above criteria (0.001 mg/L). Although this likely relates to the industrial activities in the Eastern Zone, the low concentration and the conservative nature of the screening support that this is not likely to pose an issue to the MMRP.

Benzene, toluene, total xylene, tetrachloroethene, cis-1,2-dichloroethene, chloroform and ammonia (as N) are volatile compounds that can volatilise from groundwater to pose indoor air risk. A partitioning calculation based on USEPA (2012) guidance was undertaken to assess a conservative hypothetical indoor air concentrations using the following formula:

$$C_v = C_g H' \cdot CF$$

$$\textit{where:}$$

$$C_v = soil\ gas\ concentrations\ at\ the\ source\ (mg/m^3)$$

$$C_g = groundwater\ concentration\ (mg/L)$$

$$H' = Henry's\ Law\ Constant\ (dimensionless)$$

$$CF = conversion\ factor\ (1000L/m^3)$$

The hypothetical indoor air concentrations were all below the USEPA *Regional Screening Levels* for residential indoor air (USEPA, 2015), supporting that these low levels of volatile organic compounds are unlikely to result in risk to indoor air. The hypothetical indoor air concentrations for ammonia were derived by estimating the fraction of the volatile (un-ionized) ammonia (NH3) based on the Canadian Water Quality Guidelines (CWQG, 2010).

In the long term, prolonged groundwater pumping may mobilise groundwater plumes from other historic sources resulting in an increase of concentrations of a number of the above contaminants. The potential for this to occur and its implications should be considered when the numerical groundwater flow model is available.

7.3.1.3 Summary of Contamination Issues

The review of existing and historical land uses (Section 7.3.1.1) combined with the contamination data (Section 7.3.1.2) indicate that the following issues may have implications to the MMRP construction or operation:

- **Arden Station:** The tanked (sealed) station design is anticipated to limit the effect of the station on groundwater level and flow and hence there is likely to be minimal effect on the movement of contaminated groundwater that may exist in the area of the station. However, the eastern portion of the station is within the footprint of a Print works, which has the potential for high solvent use and hence, groundwater contamination impact.

- **CBD North Station:** The proposed station is intended to be drained during construction, which would affect groundwater level and flow. The site history review identified the presence of chlorinated solvent impacted groundwater on the CUB site (dominated by trichloroethene) which is located west of the proposed station (Ramsey, 2015). The portion of the tunnel immediately adjacent to the station is indicated to come within 30 m to 50 m of the identified source area on the CUB site. The available information indicates that this chlorinated solvent plume is quite narrow and heading in a south south-westerly direction. The current MMRP monitoring well network has not identified impacted groundwater that is indicative of this contamination. However, given the proximity of the impacted groundwater on the CUB site, further evaluation of this issue is required to assess the potential for movement of this impacted toward the station during construction and operation of Melbourne Metro.

- **Eastern Portal:** Possible sources of groundwater impacts (i.e. GQRUZs approximately 250 m southeast of the portal) were identified from the site history review and low levels of benzene and total xylene were detected in wells along the alignment. The portal is intended to be drained during construction with invert level at its deepest end (western end) being about 5 m below groundwater level (Figure 18-A, APPENDIX A). The portal rises to the east. Hence, the potential for influence on these sources and identified groundwater impacts is likely to be low. Further investigation, therefore, may not be required providing the numerical modelling results support this outcome.

Low levels of contaminants indicative of dry-cleaning activities (tetrachloroethene and its biodegradation product cis-1,2-dichloroethene) have been detected in well GA11-BH014 along the Parkville to CBD North tunnel section. Although the well is about 15 m below the water table, higher concentrations may occur in the shallow saturated zone. However, this tunnel section is intended to be tanked (sealed) (i.e. effect on groundwater flow anticipated to be limited), which supports that the potential influence from this contamination is likely to be low. Further investigation, therefore, may not be required providing the numerical modelling results support this outcome.

7.3.2 Disposal

Typically the most common disposal options for groundwater are groundwater discharge to sewer and discharge to surface water.

7.3.2.1 Discharge to Sewer

The disposal option for groundwater entering Melbourne Metro considered for the Concept Design involves a single point of discharge to sewer. Consideration is also given to long-term operation of the tunnel i.e. following attainment of steady-state groundwater flow conditions.

Groundwater disposal to sewer is dependent upon the requirements of the relevant Water Authority under which a Trade Waste Agreement (TWA) is issued. The groundwater quality data for the Concept Design were screened against the TWA criteria from the two Water Authorities relevant to the MMRP (City West Water and South East Water). The results of the screening are presented in APPENDIX F.

Salt Load

One of the main limiting factors for groundwater disposal to sewer is the total salt load expressed in kg/day. Guidelines from the two relevant Water Authorities specify a maximum salt load of 200 kg/day.

An estimate of the weighted average of the TDS along Melbourne Metro has been developed to support an initial assessment of the bulk groundwater inflow that may not be exceeded in order to keep the daily salt load under 200 kg (Table 27). The weighting factors were derived for each segment of Melbourne Metro based on the ratio between the length of the segment and the total length of tunnel planned to be constructed under the water table. Segments 1 and 2 were excluded while only half of the length of Segment 23 was considered as these portions of the MMRP are planned to be above the water table.

An average TDS value was derived for segments where TDS data were not available based on TDS values from adjacent segments relating to their relevant aquifer unit. Along Segment 16, although the tunnel is not planned to be constructed in the Moray Street Gravels and the Holocene Alluvium, it is expected that the long-term operation of the tunnel would draw groundwater from these units, which typically have higher TDS concentrations.

Table 27: Average TDS Concentrations along Segments of Melbourne Metro

Segment No	Key Relevant Aquifer Unit	Average TDS* (mg/L)	Approximate Segment Length (m)	Segment Length to MMRP Length under Water Table (%)
3	Older Volcanics	7,900	210	2
4	Older Volcanics	7,900	230	2
5	Werribee Formation	37,600	370	4
6	Early Pleistocene	30,300	360	4
7	Early Pleistocene	24,900	280	3
8	Silurian/Werribee Formation	5,100	470	5
9	Silurian	3,300	970	10
10	Silurian	3,300	280	3
11	Silurian	3,300	940	10
12	Silurian	4,900	280	3
13	Silurian	1,400	680	7
14	Silurian	3,200	260	3
15	Silurian	3,200	100	1
16	Moray Street Gravels/Holocene Alluvium**	23,300	400	4
17	Silurian	5,100	310	3
18	Silurian	5,700	370	4
19	Silurian	6,100	590	6
20	Silurian	6,400	340	4
21	Silurian	4,900	1,300	14
22	Silurian	5,300	370	4
23	Silurian	5,300	190	2
		Total	**9,300**	**100**

Notes to Table: *Rounded to nearest hundred

**Although units not planned to be intercepted in this segment, they would likely impact long-term operation.

Underlined – No data available in this segment, data derived from adjacent segment.

Based on the weighting derived in Table 27 and the TDS distribution along the Melbourne Metro alignment, a weighted average TDS concentration of 8,200 mg/L was derived. Based on this value, the maximum groundwater inflow rate that may not be exceeded to keep the salt load to less than 200 kg/day is estimated to be about 24 m^3/day. Temporary variations from the 200 kg/day salt load criteria may be negotiated with Water Authorities allowing increased TDS discharge. We are aware that TDS mass load limit of up to 3,400 kg/day have been permitted for construction purposes for period of around12 months.

Other TWA Criteria

Exceedences of the other TWA criteria are summarised in Table 28 along with an understanding of their possible implications or need for further action.

Table 28: Summary of Other TWA Criteria Exceedences

Parameters	Criteria	Nature of Exceedences	Possible Implications or Further action
pH (pH unit)	Outside the 6 – 10 range	Only three wells with pH marginally below the range (no less than 5.7). Two of these wells do not intercept the aquifer units in which the tunnel/stations are to be constructed.	Unlikely to result in material implications.
Oxidised Sulphur (as S) (mg/L)	100	The sulphate (as SO_4) data were converted to oxidised sulphur (as S) in order to enable comparison to the line with the TWA criterion requirement[9]. The data indicate that there are exceedances of the TWA criterion across the majority of the alignment.	Require further discussion with relevant Water Authorities.
Ammonia (as N) (mg/L)	50	Although ammonia (as N) is above TWA criteria in two wells, these wells monitor aquifer units (i.e. Holocene Alluvium, Moray Street Gravels) that are not planned to host the tunnel/stations.	Unlikely to result in material implications.
Bromine (mg/L)	5	Recurrent exceedences of bromine concentrations by a factor of 5 to 10.	Require further discussion with relevant Water Authorities.
Manganese (mg/L)	10	Localised exceedence of manganese in two wells of the Werribee Formation in the Eastern Zone	Unlikely to result in material implications, however, contribution of the Werribee Formation to be checked when numerical model available.

Oxidised sulphur and bromine are indicated to generally exceed the TWA criteria. The implications of these exceedances require further discussion with the relevant Water Authorities.

Although pH and ammonia (as N) are locally above TWA criteria, the localised nature of these exceedances is likely to be masked (i.e. diluted) by the bulk groundwater inflow during the long-term operation of the tunnel. The TWA manganese criterion of 10 mg/L is exceeded in two wells monitoring in the Werribee Formation in the Eastern Zone. The contribution of the Werribee Formation to the groundwater inflow may need to be checked when the numerical groundwater flow model is available to confirm that the manganese contribution from this part is likely to be diluted by the groundwater inflow during the long-term operation.

Further to this, selenium, TRH fractions including C_{10}-C_{14}, C_{15}-C_{28} and C_{29}-C_{36}, phenol and cis-1,2-dichloroethene were occasionally above the catch-all TWA criteria of 1 µg/L. However, the localised nature of these exceedences and the relatively low concentrations support that the contribution from these parameters in the bulk groundwater inflow during the long-term operation of the tunnel should be limited.

7.3.2.2 Discharge to Surface Water

Discharge of groundwater to surface water is an alternative option for disposal that would require regulatory approval. High TDS concentrations and potentially elevated concentrations in ammonia (Moray Street Gravels aquifer, Holocene aquifer, Early Pleistocene aquifer and Werribee Formation aquifer), nitrate (predominantly in some Silurian aquifer wells) and metals may be limiting factors for this disposal option. However, there is a potential to dispose of groundwater to the lower zone of the Yarra River that are more brackish than the upper zones due to tidal influence. This may require treatment to reduce ammonia, nitrate and metal concentrations.

7.3.3 Structural Durability Issues

The groundwater chemical composition can impact on the durability of materials used for construction of underground structures and groundwater drainage system. The main implications include aggressivity and

[9] Use of sulphate data provides a lower bound estimate of the oxidised sulphur in the groundwater sample. There is the potential for sulphur to be present in other forms including sulphide. Only two samples have been analysed directly for oxidised sulphur as part of the analytical program and those results are comparable to that derived from the results for sulphate in those wells.

corrosion of groundwater when in contact with various construction materials, as well as potential for clogging of drainage systems that may be installed within the permanent structures.

Table 29 summarises key parameters that may have implications on the durability of the structures and drainage system. The implications of acid sulphate soil and rock are not considered in this document. The locations where such materials may be present are discussed in the Contaminated Land Assessment EES Summary Report.

Table 29: Key Groundwater Parameters Potentially Affecting Material Durability

Parameters	Nature of Implication	Nature of Occurrence along MMRP	Need for Further Consideration
pH	Agressivity/ Corrosion	Typically near-neutral, in the 6-8 range	Unlikely
TDS	Corrosion	Elevated TDS values, weighted average TDS of 8,200 mg/L (see previous section)	Likely
Sulphate (as SO_4)	Agressivity/ Corrosion	Elevated sulphate concentrations, from 1,000 mg/L to about 2,500 mg/L, mainly in the Moray Street Gravels, Early Pleistocene, Older Volcanics, Werribee Formation.	Likely
SRB	Microbiologically influenced corrosion	Presence of SRB bacteria (over 1,000,000 org/100mL) combined with possible presence of reducing conditions in units such as Moray Street Gravels, Older Volcanics and Werribee Formation.	Likely
Chloride	Agressivity/ Corrosion	Chloride concentrations over 10,000 mg/L in units such as Moray Street Gravels, Werribee Formation.	Likely
Nitrate, nitrite	Corrosion	Generally low level of nitrate and nitrite, typically not above 1 mg/L	Unlikely
Alkalinity and Carbonic Acid	Agressivity/ Corrosion, Clogging	Occasional higher total alkalinity concentrations (over 1,000 mg/L) in Holocene Alluvium, Early Pleistocene, Older Volcanics and one deep Silurian well. These occurrences typically coincide with higher carbon dioxide (including free CO_2).	Likely
Redox Sensitive Metals	Clogging	Iron concentrations over 10 mg/L and manganese concentrations over 5 mg/L units such as Holocene Alluvium, Early Pleistocene, Werribee Formation, and Silurian.	Likely
Magnesium	Aggressivity	High concentrations in magnesium over 1,000 mg/L in Early Pleistocene, Moray Street Gravels and Werribee Formation.	Likely
Organics	Solvation and deterioration of plastic components	Occasional impacts in organics generally do not exceed 0.1 mg/L.	Unlikely[1]

__Notes to Table:__ [1]Does not consider possible increase in concentrations over time as a result of groundwater inflow into structures

The potential for elevated concentrations in TDS, sulphate, chloride, alkalinity, redox sensitive metals, as well as higher levels of SRB bacteria, need to be taken into consideration in the concept design's durability assessment.

Additionally, the groundwater quality may change as in-situ conditions are altered by activities associated with construction. This could potentially lead to formation of ionic states and deposition/precipitation of solids from groundwater. The long-term drawdowns resulting from groundwater inflow may result in similar issues.

8.0 SUMMARY

The Melbourne Metro Concept Design comprises 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, south 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 2015 groundwater investigation phase was undertaken to support the development of the Concept Design and EES for the project. Results obtained during this phase of the investigation were used to update the hydrogeological site setting and further assess groundwater level conditions across the study area, as well as provide an assessment of the groundwater quality and associated potential issues. This work has also been used to inform the regional groundwater modelling completed by Golder and the subsequent Groundwater Impact Assessment completed by AJM JV for the EES

To facilitate the interpretation of the investigation results in this report, the following zones were established:

- **Western Zone** (Alignment segments 1 to 9) from the western portal to Parkville station, inclusive.
- **Central Zone** (Alignment segments 10 to 15) from beyond Parkville station to CBD South station, inclusive.
- **Yarra Crossing** (Alignment segment 16) including the Yarra River and Alexandra Gardens.
- **Eastern Zone** (Alignment segments 17 to 23) from beyond Alexandra Gardens to the eastern portal.

Based on the 2015 site investigations as well as the results of previous phase of investigations the following hydrostratigraphic units were recognised as the key units of relevance to Melbourne Metro

- **Coode Island Silt**, which is inferred to act as a leaky aquitard. A unit of interest within Western Zone and Yarra Crossing.
- **Newer Volcanics** (Burnley Flow) fractured rock aquifer which is an aquifer of interest in the Yarra Crossing zone. The aquifer is inferred to be of medium to high hydraulic conductivity.
- **Holocene** aquifer which comprises sediments of the Holocene Alluvium. This is an aquifer of interest within the Yarra Crossing and is inferred to be of a high hydraulic conductivity.
- **Late Pleistocene** aquifer which comprises Pleistocene Alluvial sediments. This is an aquifer of interest within the Western Zone and is inferred to be of a relatively low hydraulic conductivity.
- **Early Pleistocene** aquifer which comprises Fluvial sediments, upper Fishermens Bend Silt sediments. Based on the slug test results an average hydraulic conductivity of about 7.1×10^{-4} m/s is indicated. This is an aquifer of interest within the Western Zone.
- **Moray Street Gravels** aquifer which comprises Fluvial sediments, Moray Street Gravels and lower Fishermens Bend Silt sediments deposited within shallow sea embayment. Based on the slug test results an average hydraulic conductivity of about 1.9×10^{-5} m/s is indicated. This is an aquifer of interest within the Yarra Crossing zone.
- **Older Volcanics** fractured rock aquifer which is an aquifer of interest in the Western Zone. Based on the slug test results an average hydraulic conductivity of about 1.4×10^{-7} m/s is indicated.
- **Werribee Formation** aquifer which comprises sediments of the Werribee Formation. Based on the slug test results an average hydraulic conductivity of about 8.6×10^{-5} m/s is indicated. This is an aquifer of interest within the Western Zone.
- **Silurian fractured rock** aquifer that is the primary aquifer within majority of the study area. Based on the hydraulic testing an average hydraulic conductivity of about 1.0×10^{-7} m/s is indicated, with locally higher hydraulic conductivity of about 5.0×10^{-6} m/s. Two sub-aquifer zones shallow and deep are suggested by the aquifer response to the pumping test at the St Pauls' Cathedral.

The groundwater levels are influenced within the study area by seepage into the following man-made structures:

- CityLink tunnels
- City Loop tunnels
- Deep building basements within the CBD
- Various sewer mains such as North Yarra Main Sewer, South Yarra Main Sewer and Prahran Sewer Main.

The groundwater flow across the study area is inferred to occur from the higher elevations in the broader Parkville and Richmond areas towards City Loop, CityLink tunnels, Yarra River and Moonee Ponds Creek.

The possible groundwater contamination issues that may have implications to Melbourne Metro construction and subsequent operations include:

- **Arden Station:** Although the effect of the station on movement of contaminated groundwater is likely to be minimal, the eastern portion is within the footprint of a Print works. The high solvent usage associated with this activity has the potential to have resulted in groundwater contamination impact.
- **CBD North Station:** The portion of the tunnels immediately adjacent to the station is indicated to come within 30 m to 50 m of the identified contaminant source area of chlorinated solvents on the CUB site. Further evaluation is required to assess the potential for movement of this impact toward the station as a result of groundwater drawdown and drainage during construction.
- There are low levels of contamination detected along the Parkville to CBD North tunnel section as well as tunnel sections near the eastern portal. Based on the proposed Melbourne Metro Concept Design, the potential influence from these sections of Melbourne Metro to affect contaminant migration in these areas is likely to be low. Further investigation may not be required providing the numerical modelling results support this outcome.

The main disposal option for groundwater entering Melbourne Metro involves a single point of discharge to sewer. Such an option is dependent upon the requirements of the relevant Water Authority under which a TWA is issued. A review of the data indicated that the following parameters may result in limiting factors to the disposal of groundwater to sewer:

- TWA requirements specify that the total salt load is not to exceed 200 kg/day. An estimate of the weighted average TDS concentration of 8,200 mg/L along the Melbourne Metro Concept Design alignment supported that the maximum groundwater inflow rate should not exceed 24 m^3/day in order to keep the salt load below this requirement. However, temporary variations from the the 200 kg/day salt load criteria may be negotiated allowing increased TDS discharge.
- Other possible limiting factors for groundwater disposal include oxidised sulphur (as S) and bromine. Their concentrations are indicated to generally exceed the TWA criteria, which require the need for further discussion with the relevant Water Authorities.

The following parameters may have implications on the durability of the structures and drainage system and need to be further assessed as a part of the Concept Design durability assessment: TDS, sulphate, SRB, chloride, alkalinity, carbonic acid, redox sensitive metals (e.g. boron, iron, manganese) and magnesium.

9.0 REFERENCES

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