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SKM aurecon

CRR JOINT VENTURE

Cross River Rail

Environmental Impact Statement

Technical Report No. 4 – Groundwater assessment

July 2011

Cross River Rail

TECHNICAL REPORT NO. 4
GROUNDWATER ASSESSMENT

JULY 2011

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Appendix A – Risk Assessment

Executive summary

The groundwater assessment was undertaken in two stages – the first aimed at characterising the existing hydrogeological environment in the study area whilst the purpose of the second stage was to quantify the potential impacts to groundwater that may arise as a result of the Project proceeding.

Two conceptual hydrogeological models have been formulated based on the available data for the anticipated hydrogeological conditions within the study area. Model 1, the fractured rock aquifer shows that groundwater is principally stored and transmitted in the fractures, joints and other discontinuities within the rock mass. Aquifer properties are typically highly variable and available data indicates that permeability is generally low. Groundwater recharge occurs from infiltration of rainfall in rock outcrop areas and in some areas from overlying Alluvial Aquifers. Groundwater is expected to discharge in topographically low areas and it is anticipated that groundwater generally flows towards the Rivers and Creeks within the study area. Groundwater discharge in some areas can also occur to adjacent alluvial aquifers. The fractured rock aquifer is anticipated to occur over the majority of the study area. Model 2, the alluvial aquifer is classified as a porous media aquifer where groundwater occurs within the voids between individual grain particles. Aquifer properties are variable depending on the nature of the sediments. The permeability and storage capacity of this aquifer is expected to be significantly larger than the Fractured Rock Aquifers. Groundwater is often hydraulically connected to the surface water systems. The alluvial sediments are recharged by infiltrating rainfall and in some areas via through-flow from the adjacent Fractured Rock Aquifers. Groundwater is expected to discharge down valley and into the creeks and rivers of the study area. Given that the majority of the drainage lines are tidal, both recharge and discharge processes are expected to occur in the aquifer based on the relative differences in water levels between surface water and groundwater systems. This aquifer is expected to occur within the immediate vicinity of the Brisbane River and other associated tributaries and along nearby drainage lines. The two hydrogeological models developed may occur individually or in combination with each other.

The conceptual understanding of groundwater occurrence and processes form the basis for the formulation of a three dimensional finite difference groundwater model that has been developed in order to provide predictive assessments as part of the impact assessment phase of the program. The model is aimed at quantifying the following potential impacts:

- drawdown emanating from the tunnel inflows leading to depressed groundwater levels at the locations of existing groundwater users or groundwater dependent ecosystems
- drawdown in groundwater levels in areas of acid sulfate soils
- reduced flows to streams and rivers
- increased flux of saline water from the Brisbane River into the aquifer and potentially into the tunnel itself.

The best estimate of groundwater inflow into the tunnel is <1 L/second. Identified potential risks to groundwater as a result of groundwater inflow into the tunnel include:

- falling groundwater levels associated with potential dewatering
- changes in groundwater quality (groundwater salinity)
- contamination of groundwater
- acidification of groundwater.

Mitigation measures have been recommended to minimise impacts to groundwater users and groundwater dependent ecosystems as a result of the above identified risks. The review of the existing hydrogeological environment of the study area and the accompanying impact assessment of the proposed tunnel has identified a range of hydrogeological issues/gaps that will require further consideration. This may be achieved by way of further investigations and assessment, implementing appropriate management options or a combination of the two.

1 Introduction

The Department of Transport and Main Roads (TMR) is proposing a new Cross River Rail (CRR) north-south rail track (the Project), approximately 19 km in length and extending from Salisbury to Wooloowin. Whilst the detailed feasibility study is currently underway, it is anticipated that the Project will consist of a new tunnel (or tunnels) under the Brisbane River and four new underground train stations.

The SKM – Aurecon Cross River Rail Joint Venture was commissioned by the Department to prepare an Environmental Impact Statement (EIS) for the Project. The EIS is being undertaken in two stages – the first is aimed at characterising the existing environment in the study area whilst the purpose of the second stage is to quantify the potential environmental impacts that may arise as a result of the Project proceeding.

This report describes the hydrogeological setting in the study area under existing (pre-construction) conditions. The conceptual understanding of groundwater occurrence and processes form the basis for the formulation of a numerical groundwater model that has been developed in order to provide predictive assessments as part of the impact assessment phase of the program.

1.1 Methodology

This assessment will be undertaken by referencing available groundwater related data, previous tunnelling work conducted within the Brisbane area, geotechnical drilling undertaken as part of the Project and data obtained through a review of the Queensland Department of Environment and Resource Management (DERM) reports and records. A review of the existing available groundwater information relevant to the study corridor includes the following sources:

- the Department of Natural Resources and Water (DNRW) groundwater facility (GWDB) and licensing databases 2010
- preliminary groundwater and geotechnical investigations undertaken for the Project, including
  - hydrogeology and groundwater issues report prepared by Australian Groundwater Environmental Consultants (AGE) for TMR
  - preliminary draft geotechnical investigations undertaken by AECOM
  - Phase 2 Geotechnical Investigation undertaken by Golder Associates
- groundwater and geotechnical investigations undertaken for other projects within or near to the study corridor, including
  - Boggo Road Busway near Dutton Park and Woolloongabba (Douglas and Partners 2007)
  - Inner Northern Busway (INB HUB Alliance 2005)
  - S1 Sewer Tunnel (Brisbane City Council)
  - North South Bypass Tunnel (also known as Clem7) and Airport Link Tunnel projects (taken from AGE 2009)
  - Northern Link Project (SKM-CW JV, 2009)
  - Eastern Busway Project (SKM, 2009)
- various geotechnical and contaminated land assessments undertaken (or commissioned) in the locality by BCC City Design
- available geotechnical data from QTMR archives and BCC archives
- published Geographical Information System (GIS) datasets, including digital terrain model, topography, geology and aerial photography
- Queensland Geological Survey's published 1:100,000 Brisbane geology map sheet.

A three dimensional finite difference groundwater model was developed to assess potential impacts of the long term inflow of groundwater to the tunnel. The groundwater model was based on the conceptual hydrogeological model developed as part of the existing environment section. This is discussed in **Section 5**.

1.2 Study corridor/area

This assessment extends beyond the study corridor identified in the Terms of Reference. This is referred to in this report as the study area. The study area includes that area within the study corridor plus an additional 5 km buffer zone.

1.3 Terms of Reference

This assessment is based on the requirements as identified in the Terms of Reference for this Project.

Existing Environment

The EIS should describe the quality, quantity and significance of groundwater in the study corridor and adjacent areas, together with groundwater use that may be affected by the project. The description of the existing environment for hydrogeology resources that may be affected by the project and the possible significance of the project to groundwater depletion or recharge, or potential saltwater intrusion of existing aquifers should be made in the context of environmental values as defined in such documents as the Environmental Protection (Water) Policy 2009 [EPP (Water)].

This section should provide a description of groundwater resources in the study corridor and adjacent areas in terms of:

- *geology/ stratigraphy*
- *aquifer type—such as confined, unconfined*
- *depth to and thickness of the aquifer*
- *depth to water level and seasonal changes in levels*
- *groundwater flow directions (defined from water level contours)*
- *interaction with surface water*
- *possible sources of recharge*
- *basic water quality of the aquifer*
- *potential exposure to pollution*
- *groundwater resources proposed to be used by the project (if applicable), including a description of the quality, quantity, usage rate and required location of those resources.*

The groundwater assessment should be consistent with relevant guidelines for the assessment of acid sulfate soils, including spatial and temporal monitoring to accurately characterise baseline groundwater characteristics within or near the study corridor.

Impact Assessment

This section should include an assessment of the potential for environmental impact caused by the project to local groundwater resources, including the potential for groundwater induced salinity.

It should define and describe the objectives and practical measures for protecting or enhancing water resource environmental values, how nominated quantitative standards and indicators may be achieved, and how the achievement of the objectives will be monitored, audited and managed. Matters to be addressed should include:

- *groundwater resources proposed to be used by the project (if applicable), including a description of the quality, quantity, usage rate health standards[1] and required location of those resources.*
- *potential impacts on the flow and the quality of groundwater from all phases of the project, including possible alteration of porosity and permeability of any land disturbance*
- *an assessment of all likely impacts on groundwater depletion or recharge regimes*
- *the extent of the potential area within which groundwater resources are likely to be affected, including the presence of tunnels and the availability of groundwater downstream*
- *the potential impacts of the project on groundwater dependent ecosystems and vegetation, and measures to prevent, mitigate and remediate such impacts*
- *an assessment of the potential to contaminate ground water resources and measures to prevent, mitigate and/or remediate such contamination (with cross-reference to land contamination section 3.2.2 where appropriate)*
- *the cumulative impacts of dewatering or other groundwater impacts during construction and operation[2], including the potential for localised ground subsidence associated with any groundwater depletion caused by the project.*

Monitoring programs, which will assess the effectiveness of management strategies for protecting groundwater resources during the construction and operation of the project and how these strategies are incorporated into appropriate sections of the EMP must be described.

[1] QH 41.4
[2] DERM 47.23

2 Description of existing environment

This chapter outlines the conceptual understanding of groundwater occurrence and associated hydrogeological processes which are likely to operate within the investigation area and surrounds.

2.1 Geological summary

The regional geological setting of the Project is based on the Queensland Geological Survey's published 1:100,000 Brisbane sheet and Geotechnical Investigations currently being undertaken for the Project by AECOM (2010) (refer to **Chapter 7 Topography, Geology, Geomorphology and Soils** for a detailed description of the geological setting and stratigraphy).

The geological sequence in the vicinity of the route consists of (from oldest/deepest to youngest/shallowest):

- Neranleigh-Fernvale Beds (Dcf) – Devonian/Carboniferous (c. 290-370 Million of years old (Ma)), contemporaneous with the Bunya Phyllite (DCy), the Neranleigh-Fernvale Beds are the basement rocks of the study corridor. They consist of a sequence of metamorphosed sedimentary rocks including meta-greywacke, argillite, phyllite, arenite, meta-basalt
- Brisbane Tuff (Rif) –Triassic (c. 220-240Ma). Welded tuff associated with a widespread pulse of intrusive activity. The tuff is a product of pyroclastic flows infilling valleys/basins in the pre-eruption terrain
- Aspley Formation (Rip) – late-Triassic/early-Jurassic age (c.180-220Ma). This unit consists of sandstones; claystones/shale; and conglomerates. The evidence would suggest that these rocks are the products of sediments deposited in basins/river flood-plains. The nature of some of the deposits encountered during the construction of the Clem7 Tunnel would suggest a wide range of depositional environments, from debris-flows in narrow incised channels cut-down into Brisbane Tuff (see above); to low-energy basin deposits
- The Tingalpa Formation (Rin) is Triassic in Age and consists of sandstone, siltstone, shale, and thin coal seams. The Tingalpa Formation is younger and overlies the Aspley Formation
- The Woogaroo Sub-Group (RJbw) is Early Jurassic to Late Triassic in Age. This Formation contains sedimentary rocks consisting of coarse sandstone and conglomerates and a few beds of fine grained siltstones and shales
- Alluvium – two broad categories of alluvial deposit are apparent from a review of the borehole logs recovered to date: i) what has been inferred as a younger deposit, typically soft to firm clays/loose to medium-dense sands; and ii) a stiffer/denser unit that has been inferred as being older. The first unit is expected to conform to that identified on the published 1:100000-scale mapping as 'Qhe' – deposits along estuarine channels and banks, of Holocene age. The second unit is expected to conform to units identified as 'Qha/2' (seasonal river terrace) or 'Qa' (Quaternary alluvium, <2Ma) and is inferred as being more competent either through age or setting
- Fill – the nature, consistency, depth and extent varies greatly along the study corridor. Significant depths are apparent where intensive development/re-shaping of landforms has taken place, such as at pre-development drainage lines where extensive valley infill has occurred[3] (AECOM 2010).

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[3] Particular depths of fill of this nature are expected at the Woolloongabba Go-Print site and along Albert Street.

Forming part of the stratigraphy of the area is the unconformity between the Brisbane Tuff and the underlying NFB (AECOM, 2010). The various expressions of the unconformity include:

- zones of clay and brecciated rock
- sharp, slickensided, mylonitic contact
- tuffaceous claystones and shales.

2.2 Aquifers

2.2.1 Overview

A review of the available geological data indicates that the hydrogeological regime of the study area comprises two broad aquifer types (from oldest/deepest to youngest/shallowest):

- fractured rock (secondary porosity) aquifer systems comprising Neranleigh-Fernvale Beds, Brisbane Tuff, Aspley and Tingalpa Formations, Woogaroo Sub-Group
- alluvial (primary porosity) aquifer systems overlying bedrock aquifers.

Reference should be made to **Chapter 7 Topography, Geology, Geomorphology and Soils** for the spatial distribution of the geological units. In fractured rock aquifers, groundwater is typically stored in geological structural features such as fractures, joints, bedding planes and cavities of the formation. The availability of water in these systems is largely dependent of the nature (size, geometry, hydraulics) of the fractures and their degree of interconnection.

Groundwater in primary porosity systems exists within pores between grains of the sedimentary rock. The porosity of a unit, and hence availability of water, will be influence by the grain size, size sorting, grain shape and fabric of the original sediment.

In some cases, a layer of low-permeability material (eg clay) may exist as a lens above the main water table. Recharging water moving downward through the higher permeability unsaturated zone may accumulate on top of these lenses to form an aquifer that is perched above the main water table, giving this aquifer its name (ie perched aquifer). Perched aquifers are hydraulically disconnected from the underlying water table aquifer system and, as such, are usually unaffected by processes that impact on the underlying aquifer.

Whilst the specific thicknesses of aquifers are unknown, the hydrogeological characteristics of the various aquifers within the study area are described below.

2.2.2 Neranleigh-Fernvale Beds

The Neranleigh-Fernvale Beds (NFB) is one of the oldest bedrock units of the Brisbane area and is exposed over much of the area between Brisbane and the Gold Coast. Within the study area, the NFB outcrops to the north near the Brisbane city and Spring Hill areas, and southeast near Woolloongabba area, of the Brisbane River. Groundwater occurrence in the NFB is typically limited to secondary porosity associated with localised zones of structural deformation. Fractures can occur at depths down to more than 60 m mostly close to drainage lines. Due to the complex variety of rock types, groundwater characteristics vary considerably (Swann, 1997). Groundwater yields in the NFB are generally low and can range from 0 to 1.0 L/second (Swann, 1997).

The bulk permeability of the NFB is likely to vary both spatially and with depth as a function of geology and structural integrity. **Table 2-1** provides a summary of aquifer properties for the NFB based on the review of other projects undertaken within or near to the study corridor.

Table 2-1 Aquifer Properties for the NFB

Aquifer Parameters	S1 Sewer Tunnel		Airport Link		NSBT		Northern Link		Eastern Busway	
	Count	Mean	Count	Mean	Count	Mean	Count	Mean	Count	Mean
Permeability/ Hydraulic Conductivity	50	5.3 Lugeons	13	<1 Lugeons	71	2.1 Lugeons	-	0.04 m/day	10	0.14 m/day
Transmissivity	-	-	-	-	-	-	-	-	5	0.78 m^2/day
Storage	-	-	-	-	-	-	-	-	5	0.009

Source: S1 Sewer Tunnel, Airport Link EIS, NSBT EIS, Northern Link EIS, Eastern Busway

In general, the rocks of the NFB can be described as an aquifer of very low to low permeability with isolated areas of higher permeability (AGE, 2009). Based on the available data, permeability for the NFB ranged from 0 m/day to 5.9 x 10^{-1} m/day (0 to 69 Lugeons[4]). This is indicative of very low to extremely high permeability. The average permeability for the NFB based on the above data is 1.23 x 10^{-1} m/day. A review of the available data, however shows that the majority of the data reports permeability of <8.64 x 10^{-3} m/day which is indicative of low permeability. Higher permeability results are likely to be attributable to tests undertaken in isolated areas of higher permeability.

A summary of hydraulic conductivities obtained from geotechnical investigations undertaken for the NSBT and S1 Sewer is shown **Table 2-2**.

Table 2-2 Summary of Packer Test Results for NFB (NSBT and S1 Sewer Investigations)

Calculated Effective Hydraulic Conductivity (m/second)	Comments	Percentage of Packer Tests
0	Impermeable rock	21 %
1x10-9 to 9x10-9	Relatively tight/low inflow	36 %
1x10-8 to 9x10-8		
1x10-7 to 9x10-7	Typical joint conditions/ medium inflow	29 %
1x10-6 to 9x10-6	Typical joint conditions/ significant inflow	14 %
1x10-5 to 9x10-5	Structural disturbance/ high inflow	0 %

Source: AGE 2009

Approximately 14% of tests undertaken indicate potential for significant inflow. It is considered that these tests are associated with areas of localised fracturing rather than being indicative of broad areas of high permeability (AGE, 2009).

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[4] One Lugeon is approximately equivalent to a mass permeability of 1 x 10^{-7} m/second (8.64 x 10^{-3}m/day). Lugeon Values can generally be evaluated as:

Lugeon Value	Permeability
<1	Low
1 to 5	Moderate
5 to 20	High
20 to 50	Very High
>50	Extremely High

Transmissivity and storage values were obtained from pumping tests undertaken in the NFB for the Eastern Busway project. Based on this data, the average transmissivity and storage value for the NFB is 0.78 m^2/day and 0.009 respectively (Eastern Busway, 2009).

A summary of hydraulic conductivities obtained from geotechnical investigations undertaken for the Cross River Rail Project is shown **Table 2-3**. The results of the packer testing provide a range of hydraulic conductivity values similar to those presented for previous studies.

Table 2-3 Summary of Packer Test Results for NFB (Cross River Rail Investigation)

Borehole	Top Packer Test Section (m, bgl)	Bottom Packer Test Section (m, bgl)	Estimated Hydraulic Conductivity (m/second)	Aquifer
CRR201	13	19	7.40E-06	Neranleigh-Fernvale
CRR201	19	26.33	3.60E-05	Neranleigh-Fernvale
CRR202	23	29	0	Neranleigh-Fernvale
CRR202	29	35	0	Neranleigh-Fernvale
CRR203	37	44	1.50E-10	Neranleigh-Fernvale
CRR204	34	40	9.70E-10	Brisbane Tuff /Neranleigh-Fernvale
CRR205	25.5	31.5	0	Brisbane Tuff /Neranleigh-Fernvale

Source: Golder December 2010

A summary of all hydraulic conductivity estimates for the NFB are provided in **Table 2-4**. The summary of hydraulic conductivities for the NFB indicates a significant range of hydraulic conductivities (2 orders of magnitude) plus/minus one standard deviation of the mean. The range in values is reflective of experiences on previous tunnelling projects within the NFB whereby inflow rates can vary significantly spatially.

Table 2-4 Summary of Hydraulic Conductivities for NFB

	Log(k)	k (m/second)	k (m/day)
Count	68		
Mean	-6.65	2.3E-07	0.020
Standard Deviation	1.00		
Median (50th percentile)		1.8E-07	0.015
Upper Bound (+1std dev)	-5.65	2.3E-06	0.195
Lower Bound (-1std dev)	-7.64	2.3E-08	0.002

The degree of confinement or un-confinement of the NFB is likely to vary given the discontinuous nature of zones of structural deformation. It is anticipated that future hydrogeological investigations as part of the detailed design phase will aim to characterise the hydraulic interactions/ connectivity of overlying and underlying units with the NFB.

2.2.3 Brisbane Tuff

The Brisbane Tuff outcrops near Fortitude Valley and Bowen Hills in the northern section of the study area and between Brisbane River and Park Road in the south. Groundwater within the Brisbane Tuff is contained within fractures and joints but aquifers are not widespread (Swann, 1997). The Brisbane Tuff is considered to have reasonable groundwater supplies (EHA, 2006). Groundwater yields from this unit range from 0.1 to 1.5 L/second. A review has been undertaken of nearby information and this is summarised in **Table 2-5** below.

Table 2-5 Aquifer Properties for the Brisbane Tuff

Aquifer Parameters	S1 Sewer Tunnel		Airport Link		NSBT		Eastern Busway	
	Count	Mean	Count	Mean	Count	Mean	Count	Mean
Permeability/ Hydraulic Conductivity	21	23.2 Lugeons	14	<1 Lugeons	55	22.7 Lugeons	1	0.12 m/day

Source: S1 Sewer Tunnel, Airport Link EIS, NSBT EIS, Eastern Busway

Data from previous investigations indicates variable permeable nature of the rock, with packer test results ranging from negligible water loss to instances where water losses were so great that no test could be completed (AGE, 2009). The average results range from <8.6 x 10^{-3} m/day to 0.2 m/day, which is indicative of very low to high permeability.

A summary of hydraulic conductivities obtained from geotechnical investigations undertaken for the Cross River Rail Project is shown **Table 2-6**.

Table 2-6 Summary of Packer Test Results for Brisbane Tuff (Cross River Rail Investigations)

Borehole	Top Packer Test Section (m, bgl)	Bottom Packer Test Section (m, bgl)	Estimated Hydraulic Conductivity (m/s)	Aquifer
CRR204	26	34	3.20E-07	Brisbane Tuff
CRR204	34	40	9.70E-10	Brisbane Tuff /Neranleigh-Fernvale
CRR205	25.5	31.5	0	Brisbane Tuff /Neranleigh-Fernvale
CRR205	31.5	37.5	0.00E+00	Brisbane Tuff
CRR210	30.3	36.37	2.90E-09	Brisbane Tuff /siltstone

Source: Golder December 2010

A summary of all hydraulic conductivity estimates for the Brisbane Tuff are provided in **Table 2-7**. The summary of hydraulic conductivities for the Brisbane Tuff indicates a significant range of hydraulic conductivities (2 orders of magnitude) plus/minus one standard deviation of the mean. The range in values is reflective of experiences on previous tunnelling projects within the Brisbane Tuff whereby inflow rates can vary significantly spatially. These results are consistent with the results presented for the NFB (**Table 2-4**).

Table 2-7 Summary of Hydraulic Conductivities for Brisbane Tuff

	Log(k)	k (m/second)	k (m/day)
Count	83		
Mean	-6.71	2.0E-07	0.017
Standard Deviation	1.14		
Median (50th percentile)		1.0E-07	0.009
Upper Bound (+1std dev)	-5.57	2.7E-06	0.235
Lower Bound (-1std dev)	-7.85	1.4E-08	0.001

Future hydrogeological investigations will aim to further characterise the hydraulic interactions/ connectivity of overlying and underlying units with the Brisbane Tuff as part of detailed design.

2.2.4 Aspley and Tingalpa Formation

The Aspley and Tingalpa Formations have a similar geological and depositional history and will be considered as one in this assessment. Within the vicinity of the study area, the Aspley Formation outcrops in the north near Albion station and to the south of the Brisbane River near Yeronga and Fairfield stations. The Tingalpa Formation outcrops to the south of Brisbane River near Moorooka, Yeerongpilly and Fairfield stations. A review has been undertaken of nearby information and this is summarised in **Table 2-8**.

Table 2-8 Aquifer Properties for the Aspley and Tingalpa Formation

Aquifer Parameters	Airport Link		NSBT	
	Count	Mean	Count	Mean
Permeability	17	<1 Lugeons	1	3.3 Lugeons

Source: Airport Link EIS, NSBT EIS

Data for Airport Link and NSBT indicate that average results range from <8.34×10^{-3} m/day to 2.85×10^{-2} m/day. This is indicative of low to moderate permeability. The primary porosity of the Aspley and Tingalpa Formations is considered to be essentially zero and the permeability of the rock will be governed by the number of fractures and the degree to which fracture zones are interconnected.

A summary of hydraulic conductivities obtained from geotechnical investigations undertaken for the Project is shown **Table 2-9**.

Table 2-9 Summary of Packer Test Results for Aspley and Tingalpa Formation (Cross River Rail Investigations)

Borehole	Top Packer Test Section (m, bgl)	Bottom Packer Test Section (m, bgl)	Estimated Hydraulic Conductivity (m/s)	Aquifer
CRR206	15	21	3.10E-06	Aspley and Tingalpa Formation
CRR207	22	32	3.30E-08	Aspley and Tingalpa Formation
CRR207	32	44	2.50E-08	Aspley and Tingalpa Formation
CRR208	20.4	26.4	1.70E-06	Aspley and Tingalpa Formation
CRR208	26.4	32.6	1.20E-08	Aspley and Tingalpa Formation
CRR209	13	19	7.00E-07	Aspley and Tingalpa Formation
CRR209	19	25	0	Aspley and Tingalpa Formation

Source: Golder December 2010

A summary of all hydraulic conductivity estimates for the Aspley and Tingalpa Formation are provided in **Table 2-10**. The summary of hydraulic conductivities for the Aspley and Tingalpa Formation indicates a significant range of hydraulic conductivities (2 orders of magnitude) plus/minus one standard deviation of the mean. The range in values is reflective of experiences on previous tunnelling projects within the Aspley and Tingalpa Formation whereby inflow rates can vary significantly spatially. These results are consistent with the results presented for the Brisbane Tuff and NFB (**Table 2-4**).

Table 2-10 Summary of Hydraulic Conductivities for Aspley and Tingalpa Formation

	Log(k)	k (m/second)	k (m/day)
Count	26		
Mean	-6.73	1.9E-07	0.016
Standard Deviation	0.85		
Median (50th percentile)		2.9E-08	0.003
Upper Bound (+1std dev)	-5.88	1.3E-06	0.114
Lower Bound (-1std dev)	-7.59	2.6E-08	0.002

It should also be noted that the median of the dataset, including zero values, is close to the lower bound estimate based upon the mean of the log values and the standard deviation. This skewness of the data is a result of the significant proportion of zero values (35%) in the dataset, which are not included in the log statistical estimates.

Future hydrogeological investigations will aim to further characterise the hydraulic interactions/ connectivity of overlying and underlying units with the Aspley and Tingalpa Formations during detailed design.

2.2.5 Woogaroo Sub-Group

Geological mapping shows that this formation outcrops in the southern section of the study area near Moorooka, Rocklea and Salisbury areas. The Woogaroo Sub-Group consists of porous sandstones with both primary intergranular permeability and fracture permeability (EHA, 2006). Supply in this aquifer ranges from 0.1 to 1.5 L/second (Swann, 1997). Larger yielding supplies are generally encountered where both secondary fracture and primary permeability exist. The Woogaroo Sub-Group represents a relatively heterogeneous system of aquifers in terms of both hydraulics and hydrochemistry (EHA, 2006). The better supplies from this formation have been shown to be restricted to the southern fringe area of Brisbane (in areas towards Logan City).

It is anticipated that the majority of the construction work for the Project will be surface works in this area and will not be below the water table. Based on this, the Woogaroo Sub-Group is not considered in detail.

2.2.6 Quaternary Alluvium

The Quaternary Alluvium (<2 million years old) is the youngest unit in the study area and comprises sediments associated with watercourses. The four main areas of alluvium have been identified as the Brisbane River, Norman Creek, Yorks Hollow Creek and Enoggera Creek (AGE, 2009). Groundwater potential in the alluvial aquifers is inherently related to their depositional characteristics and parent material. Groundwater in the alluvial aquifers is expected to be in direct hydraulic connection with the adjacent rivers and creeks within the study area.

Along the Brisbane River and its floodplain (and in the major tributaries and some lesser tributaries), the alluvium consists of both older (Pleistocene age) and younger (Holocene age) deposits. The Pleistocene deposits, commonly referred to as "old" or "older" alluvium, are typically river, and sometimes estuarine, deposits and overlie the bedrock. The older alluvium generally consists of medium dense to dense sands and gravels and over-consolidated stiff to very stiff clays. In the main Brisbane River channel, gravel horizons are often found immediately above the bedrock. The Holocene or "recent" alluvium often overlies the older sequence, having been deposited under estuarine conditions in the periods of higher sea level since the last Ice Age. Typically these deposits consist of normally to slightly over-consolidated silts and clays, often with organics and shells, and loose to medium dense sands and sometimes gravels. Aquifers of the Brisbane River will largely be unconsolidated alluvium (semi-consolidated material is known) containing varying proportions of porous and permeable sands and gravels (EHA, 2006).

Locally, moderate groundwater yields may exist, however, the low overall storage within these systems limits long term sustainable yields. In general, these alluvial sediments form unconfined and perched aquifers overlying less permeable basement rocks with groundwater occurrence primarily a function of matrix porosity.

A review has been undertaken of nearby information and this is summarised in **Table 2-11** below.

Table 2-11 Aquifer Properties for the Quaternary Alluvium

Aquifer Parameters	S1 Sewer Tunnel		Inner Northern Busway		Eastern Busway	
	Count	Mean	Count	Mean	Count	Mean
Hydraulic Conductivity	-	10^{-4} m/second	1	2.88 x 10-6 m/second	6	0.15 m/day
Transmissivity	-	8.6 m^2/day	-	-	4	1.3 m^2/day
Storage	-	0.003	-	-	2	0.0165

Source: S1 Sewer Tunnel, INB EIS, Eastern Busway

Data from investigations undertaken for previous projects (ie S1 Sewer, INB, EB) indicates that average hydraulic conductivity data for the alluvium ranges from 0.15 m/day to 86.4 m/day. This is indicative of high to extremely high permeability. Transmissivity, based on the above averages, in the alluvium ranges from 1.3 m^2/day to 8.6 m^2/day. Average storage characteristics for the alluvium ranges from 0.003 to 0.0165.

A summary of all hydraulic conductivity estimates for the Alluvium are provided in **Table 2-12**. The summary of hydraulic conductivities for the Alluvium indicates a significant range of hydraulic conductivities (2 orders of magnitude) plus/minus one standard deviation of the mean. The range in values is lower than what would be expected for typical alluvial systems. It is noted the dataset population is limited and this may only be reflective of a small area.

Table 2-12 Summary of Hydraulic Conductivities for Aspley and Tingalpa Formation

	Log(k)	k (m/second)	k (m/day)
Count	6		
Mean	-6.36	4.4E-07	0.038
Standard Deviation	0.85		
Median (50th percentile)		1.7E-07	0.015
Upper Bound (+1std dev)	-5.50	3.1E-06	0.270
Lower Bound (-1std dev)	-7.21	6.1E-08	0.005

It is anticipated that future hydrogeological investigations will aim to further characterise the hydraulic interactions/ connectivity of adjacent and underlying units with the Quaternary Alluvium.

2.2.7 Fill material

Anthropogenic fill materials occur throughout the study area and are predominantly associated with areas of urban development. The nature, consistency, depth and extent will vary greatly across the site. Significant depths are apparent where intensive development/re-shaping of landforms has taken place, such as at pre-development drainage lines where extensive valley infill has occurred (AECOM, 2010). Particular depths of fill of this nature are expected at the Woolloongabba Go-Print site; and along Albert Street (AECOM, 2010). Previous assessments within the investigation area have identified moderately transmissive and localised perched aquifer systems in these materials. Field investigations will be required to confirm the presence and significance of these aquifers within the study corridor. The hydrogeological characteristics of these deposits are dependent upon composition, source and degree of compaction. Accordingly, the occurrence of perched aquifers within the fill deposits is likely to vary significantly. These perched aquifers are limited in aerial extent and ephemeral in nature (occurring for a short period immediately after a recharge event) and consequently have not been considered further.

2.3 Groundwater recharge and discharge

Recharge to the alluvial aquifers is controlled by climate and geology. Direct vertical recharge in the alluvial aquifer is likely to occur from rainfall or overland surface water flows. The primary source of recharge is considered to be via in-stream recharge, ie recharge that occurs within stream channels during periods of stream flow. Given that the majority of the streams and rivers in the study area such as Norman Creek, Breakfast Creek, Oxley Creek and Brisbane Rive are tidal, both recharge and discharge processes are likely to occur within the alluvial aquifer (if in hydraulic connection) based on the tidal cycles. Discharge may also occur via evapotranspiration and infiltration to underlying aquifers. It should be noted that the study area is located in an urban environment. Based on the high area of paved surfaces it is likely that evapotranspiration contributes only a small component to the total discharge from the aquifer. Specific areas where evapotranspiration are occurring area unknown.

The fractured rock aquifers may be hydraulically connected with the overlying alluvial aquifer. Recharge in this aquifer may occur from infiltration from rainfall in rock outcrop areas, or from overlying alluvial aquifer if in hydraulic connection. Discharge is expected to occur as seeps along the base of slopes or by through-flow to the alluvial aquifer where they are in hydraulic connection. Specific areas where this is occurring is unknown.

In an urban environment there is significant potential for additional recharge from water mains, shallow stormwater drains and sewage pipes. Leakage from such services can provide an additional source of localised recharge to adjacent aquifers. Within the Brisbane CBD area, basement dewatering occurs. This is to some extent an additional source of discharge for the surrounding aquifers. Specific areas where this is occurring is unknown.

2.4 Groundwater users

A search was undertaken for this assessment of the DERM groundwater database to identify existing registered groundwater facilities within the vicinity of the study area. Groundwater facilities encompass water bores, wells, groundwater interception trenches and other infrastructure constructed to allow extraction of groundwater. A total of 402 registered groundwater facilities were identified within a 5 km radius of the study corridor of which 331 have been identified as existing and 71 as abandoned and destroyed facilities. A search of water entitlement data was undertaken from the Water Management System (WMS) to identify volumetric allocations applied to individual bores. Results indicated that none of the groundwater facilities identified below have volumetric allocation limits applied to them. The spatial distribution of the groundwater facilities is shown in **Figure 2-1**.

Thirty-five existing groundwater facilities were identified within a 1 km radius of the study corridor. A summary of these is provided in **Table 2-13**.

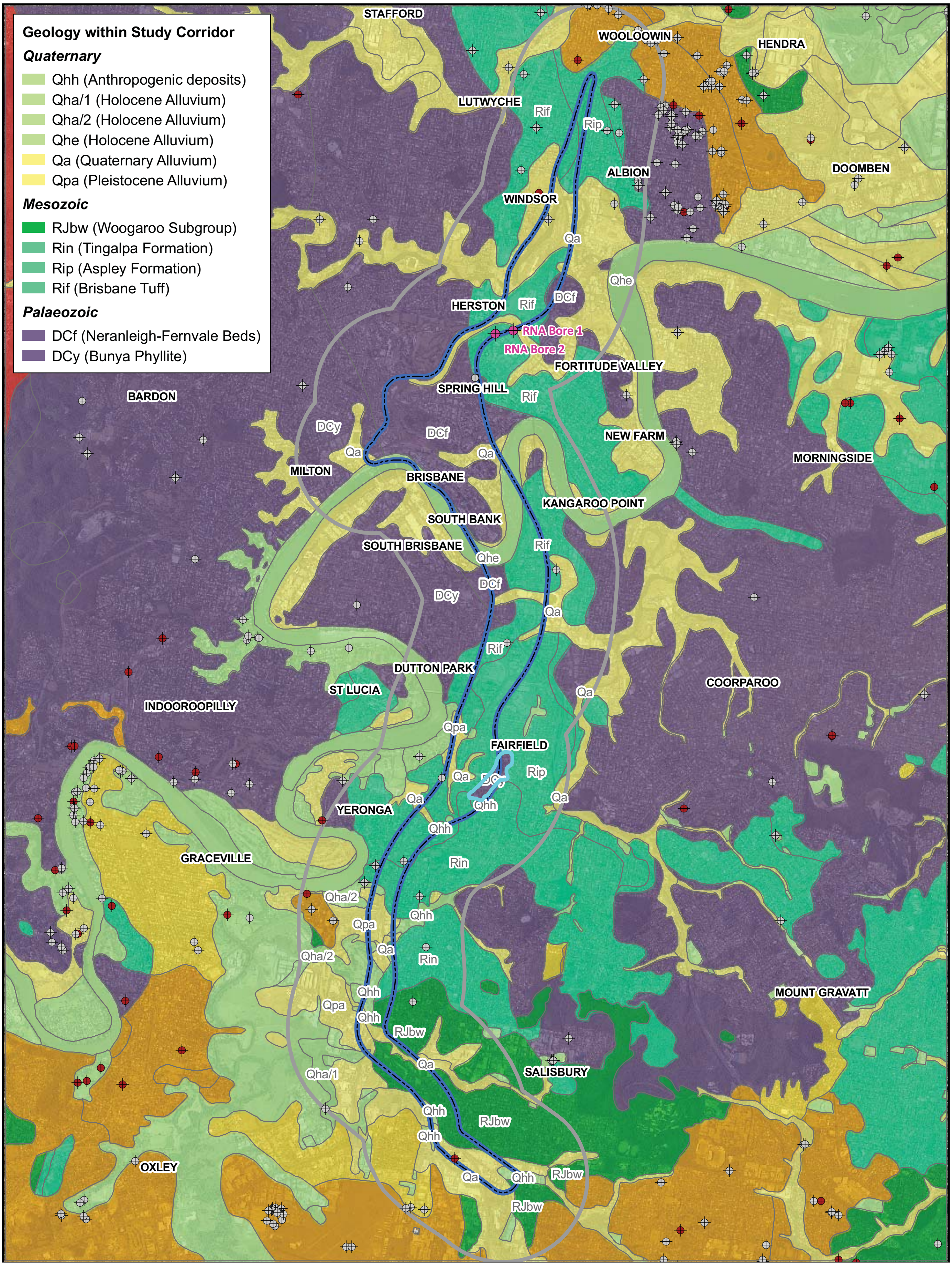
Table 2-13 Groundwater Facilities within a 1 km radius of the study corridor

Section of study corridor	Number of bores	Range of Total Depth of Bore	Geology	Range of Yield
North section	17	8 to 80 m	Aspley Formation, Alluvium, Neranleigh- Fernvale Beds	0.06 to 1.88
Central section	5	12 to 36 m	Aspley Formation, Brisbane Tuff, Alluvium, Neranleigh-Fernvale Beds	0.03 to 0.38
Southern section	13	5.1 to 48	Aspley/ Tingalpa Formation, Alluvium, Woogaroo Sub-group	0.05 to 4.4

Source: DERM 2010

In addition to the above identified bores, some bores within the Brisbane Tuff have been utilised for irrigation purposes for a long period of time, such as the Brisbane Exhibition Ground and Perry Park extraction bores (EHA, 2006). One historical bore constructed within the Neranleigh–Fernvale Beds was recorded in the Fortitude Valley supplying a commercial laundry at approximately 2 L/second (EHA, 1006).

Groundwater use on-site (dust suppression etc.) has not been identified during construction for the Project.



LEGEND

- Study Corridor
- Study Area
- Existing Groundwater Bores
- Extraction Bores
- Abandoned and Destroyed Groundwater Bores

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Figure 2-1

Existing Groundwater Users within a 5km radius of the Study Corridor

0 0.5 1 1.5 2 2.5 km

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2.5 Groundwater levels

Boreholes were drilled at Dutton Park as part of the initial Project geotechnical investigations (Round 1). Three groundwater monitoring bores were installed as part of these investigations. Details of these bores are provided in **Table 2-14**.

Table 2-14 Groundwater Bore Details

Borehole No.	Location	Total Depth of Bore (m)	Lithology Summary
CRR101	Near alignment; in street; Cornwall Street	30	Tuff, Breccia, Sandstone
CRR102	East of existing corridor; End of Cope Street	20	Fill, Sandstone, Conglomerate, Siltstone
CRR103	West of existing corridor; Nobel Street	20	Fill, Tuff, Sandstone, Breccia, Siltstone

Source: AECOM 2010

Additional boreholes were installed as part of the Phase 2 Geotechnical Investigations (Golder, 2010). Details of these bores are provided in **Table 2-15**.

Table 2-15 Phase 2 Groundwater Bore Details

Bore	Easting	Northing	Top Screen (m, AHD)	Bottom Screen (m, AHD)	SWL (m, bgl)	SWL (m, AHD)	Aquifer(s)
CRR201	502129	6961818	5.4	-22.2	7.46	5.24	Neranleigh-Fernvale
CRR202	502732	6961305	22.5mbgl	45mbgl			Neranleigh-Fernvale
CRR203	502763	6961178	24.5mbgl	44.55mbgl			Neranleigh-Fernvale
CRR204	503036	6960985	-16.1	-45.7	4.3	-0.29	Neranleigh-Fernvale
CRR205	502841	6961116	-9.8	-39			Neranleigh-Fernvale
CRR207	503413	6960804	-10.05	-47.05			Brisbane Tuff
CRR208	503296	6959926	-0.85	-27.55			Brisbane Tuff /Neranleigh-Fernvale
CRR209	503264	6959897	3.73	-22.17			Brisbane Tuff /Neranleigh-Fernvale
CRR210	502960	6958824	24.44	-6.76	10.15	23.09	Brisbane Tuff
CRR211	502416	6957252	-15.66	-36.86			Aspley and Tingalpa Formation
CRR212	501997	6956616	-4.38	-31.58			Aspley and Tingalpa Formation
CRR213	501820	6956414	3.1	-24.7			Aspley and Tingalpa Formation
CRR214	501624	6956103	6.57	-15.33			Aspley and Tingalpa Formation
CRR215	501491	6955728	11.67	-1.43			Aspley and Tingalpa Formation
CRR216	502827	6958586	25.13	2.33			Aspley and Tingalpa Formation

Bore	Easting	Northing	Top Screen (m, AHD)	Bottom Screen (m, AHD)	SWL (m, bgl)	SWL (m, AHD)	Aquifer(s)
CRR217	501525	6955903	8.04	-6.86			Aspley and Tingalpa Formation
CRR218	503284	6959923	0.11	-29.17			Brisbane Tuff /Siltstone
CRR219	502119	6961821	3.71	-27.09	7.22	5.69	Siltstone

Source: Golder, 2010

Broad trends in groundwater levels for the hydrogeological units can be inferred from the results of other geotechnical and groundwater drilling undertaken for previous projects. Groundwater levels in the study area are variable and are a subdued reflection of topography, except in areas where the water table has been impacted by existing infrastructure (basement dewatering). A summary of groundwater levels from previous investigations is provided in **Table 2-16**.

Table 2-16 Groundwater Levels within the study area

Project	Approximate location within/from Study Corridor	Year	Bore Completion Details	Groundwater Level (mBGL*) Range (from – to)
North South Bypass Tunnel (Clem 7)	500 m east of study corridor. Intersects study corridor around Herston and Woolloongabba.	2004	Alluvium	1.02 – 5.33
			Brisbane Tuff	0.25 – 24.5
			Neranleigh–Fernvale Beds	4.01
			Open tidal hole	2.93 – 6.13
Northern Link	Intersects western portion of study corridor near Milton. Less than 1 km from Roma Street Station.	2008	Alluvium	0.52 – 1.80
			Bunya Phyllite	0 – 20.70
			Neranleigh–Fernvale Beds	5.8 – 20.7
Airport Link	500 m North West of study corridor from Herston through to Wooloowin. Intersects study corridor at Herston.	2006	Alluvium	1.66 – 8.22
			Brisbane Tuff	-0.03 – 10.94
			Tingalpa Formation	1.59 – 9.81
			Aspley Formation	5.33
			Neranleigh–Fernvale Beds	10.93
Inner Northern Busway	Intersects study corridor in Brisbane City from Queen Street to Roma Street.	2000	Alluvium	2.8 – 6.5
			Bunya Phyllite	13.5
			Neranleigh–Fernvale Beds	13.1
Eastern Busway	Less than 1.5 km east of study corridor from Woolloongabba.	2009	Alluvium	1.07 – 3.55
			Neranleigh–Fernvale Beds	-0.065 – 3.54
			Brisbane Tuff	2.82

Project	Approximate location within/from Study Corridor	Year	Bore Completion Details	Groundwater Level (mBGL*) Range (from – to)
Boggo Road Busway	Intersects Study corridor near Dutton Park.	2007	Aspley Formation	7.9
			Brisbane Tuff	12.2 – 18.6

Source: NSBT EIS, Northern Link EIS, Airport Link EIS, INB EIS, Eastern Busway and Boggo Road Busway

*Note: *mBGL - metres Below Ground Level*

A cross-section has been developed from the compiled information showing the water table profile along the study corridor in relation to topography. This cross-section is shown in **Figure 2-2**.

Based on the available data, groundwater levels in the alluvial aquifer range from 0.52 to 8.22 mBGL. Groundwater levels in the Aspley and Tingalpa Formations range from 1.59 to 9.81 mBGL. The groundwater levels in the Brisbane Tuff ranges from -0.03 to 24.5 mBGL. Groundwater levels in the Neranleigh-Fernvale Beds vary from -0.06 to 20.7 mBGL. The Bunya Phyllite groundwater levels range from 0 to 20.7 m BGL. Groundwater levels in the alluvium and bedrock along or close to the Brisbane River will most likely be at river level and will be influenced by tidal fluctuations, while groundwater levels in the CBD are controlled by artificially modified recharge, leakage and the level of the Brisbane River (AGE, 2009). It is considered that groundwater levels within the CBD have been temporarily or permanently lowered as a result of site construction and dewatering of basements. A review was undertaken as part of the Project Geotechnical Investigations, of the current/past practice with respect to CBD basement construction. This identified:

- Basements that are draining groundwater – no reported/obvious signs of distress[5] - therefore recharge (presumably from the river) is sufficient to maintain fixed heads in the vicinity of any pockets of soft-compressible soils; or that basements that are draining groundwater are not the vicinity of any pockets of soft-compressible soils
- Rock at/near rockhead is an effective permeability barrier (AECOM, 2010).

Given the lack of long term groundwater level monitoring data available for this Project, seasonal trends in groundwater levels is unknown.

[5] This statement needs to be tested/confirmed.

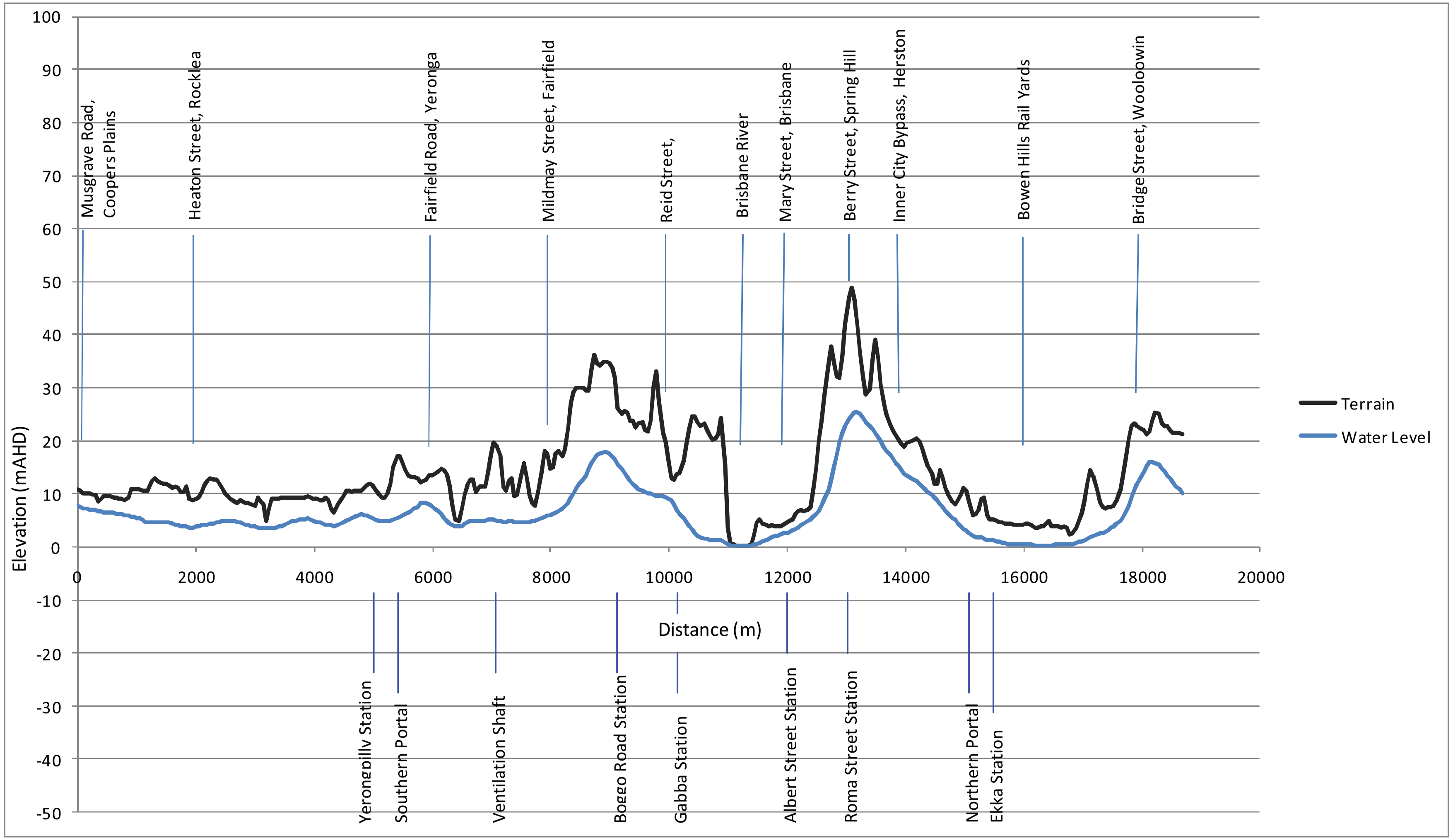

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Figure 2-2

Water Table Profile along Study Area: Long-Section

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The available hydrogeological data has been compiled to provide a preliminary indication of depth to water table for the study area using derived secondary variables from a Digital Terrain Model (DTM)[6].

A number of modelled surfaces were compiled and then calibrated against the available bore data. The underlying hypothesis was that in unconfined aquifers flowing under topographic gradients, the water table would be a smoothed and subdued reflection of topography (Desbarats et. al., 2001). That is, the water table would be proportionally deeper under locally higher topographic features. The modelled surface that best reflected the bore data is presented in **Figure 2-3**.

Areas of shallow water tables in the study area are considered to be critical as there is greater potential for the Project to impact on shallow groundwater. Critical areas are considered to be those with water tables shallower than 5 m as is indicated by pink shading on the figure. Based on this figure, a shallow groundwater table (less than 5 m) is generally encountered along and in association with drainage lines.

2.6 Groundwater flow

A groundwater elevation contour map has been developed based on the available groundwater data collated from Projects located within or near to the study corridor and relevant groundwater databases.

In general, groundwater flows from areas of higher water table elevation, down-gradient towards the river, creeks and drainage channels which are discharge zones (AGE, 2009). **Figure 2-4** provides an indication of groundwater flow direction. It should be noted that the boundaries between different colour shading represent groundwater elevation contours. This figure indicates that regional groundwater flow is towards the Brisbane River.

At a catchment scale, alluvial groundwater flows down valleys in the same direction as stream flow. It is anticipated that similar flow processes occur in the Project area. Given the heterogeneous nature of the alluvial aquifer sediments and the variability in annual and seasonal recharge, the rate of this down valley flow is expected to be spatially and temporally non-uniform. Flows are likely to be constrained to higher permeability pathways where sands and gravels are present, rather than through the entire cross sectional area of alluvium.

There is limited data and information on the interactions of groundwater between the alluvial aquifers and adjacent and underlying fractured rock. It is expected that on the alluvium margins, lateral groundwater flow to alluvial aquifers from adjacent fractured rock aquifers is likely, particularly near drainage lines. The magnitude and direction of leakage to/from the alluvial aquifer is unknown.

The groundwater monitoring program to be undertaken will provide site specific hydrogeological data to characterise groundwater flow at drained locations including station sites, Fairfield shaft and tunnel portals.

[6] Field investigations will provide site specific data against which it can be more broadly calibrated.

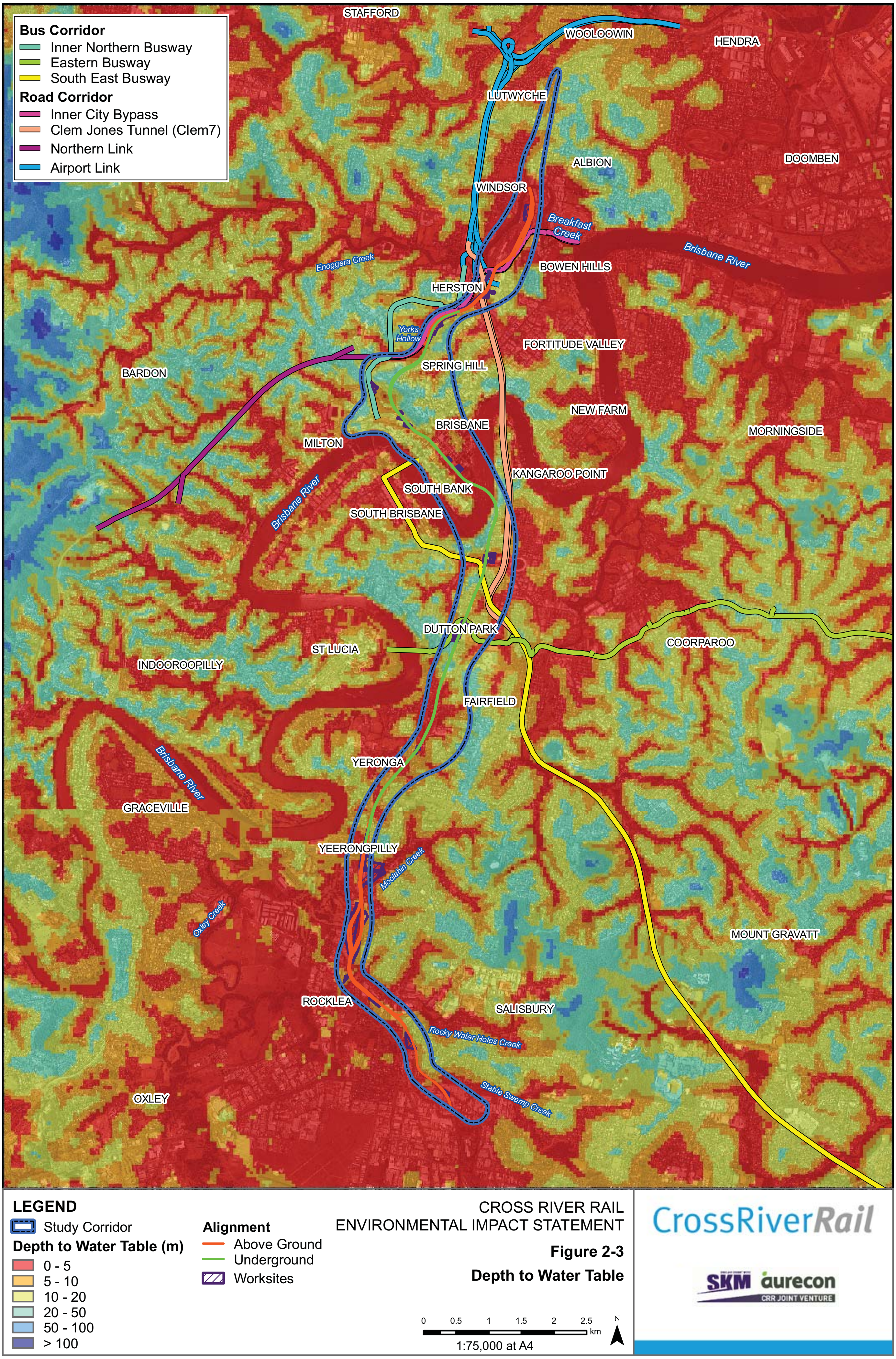

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Figure 2-3

Depth to Water Table

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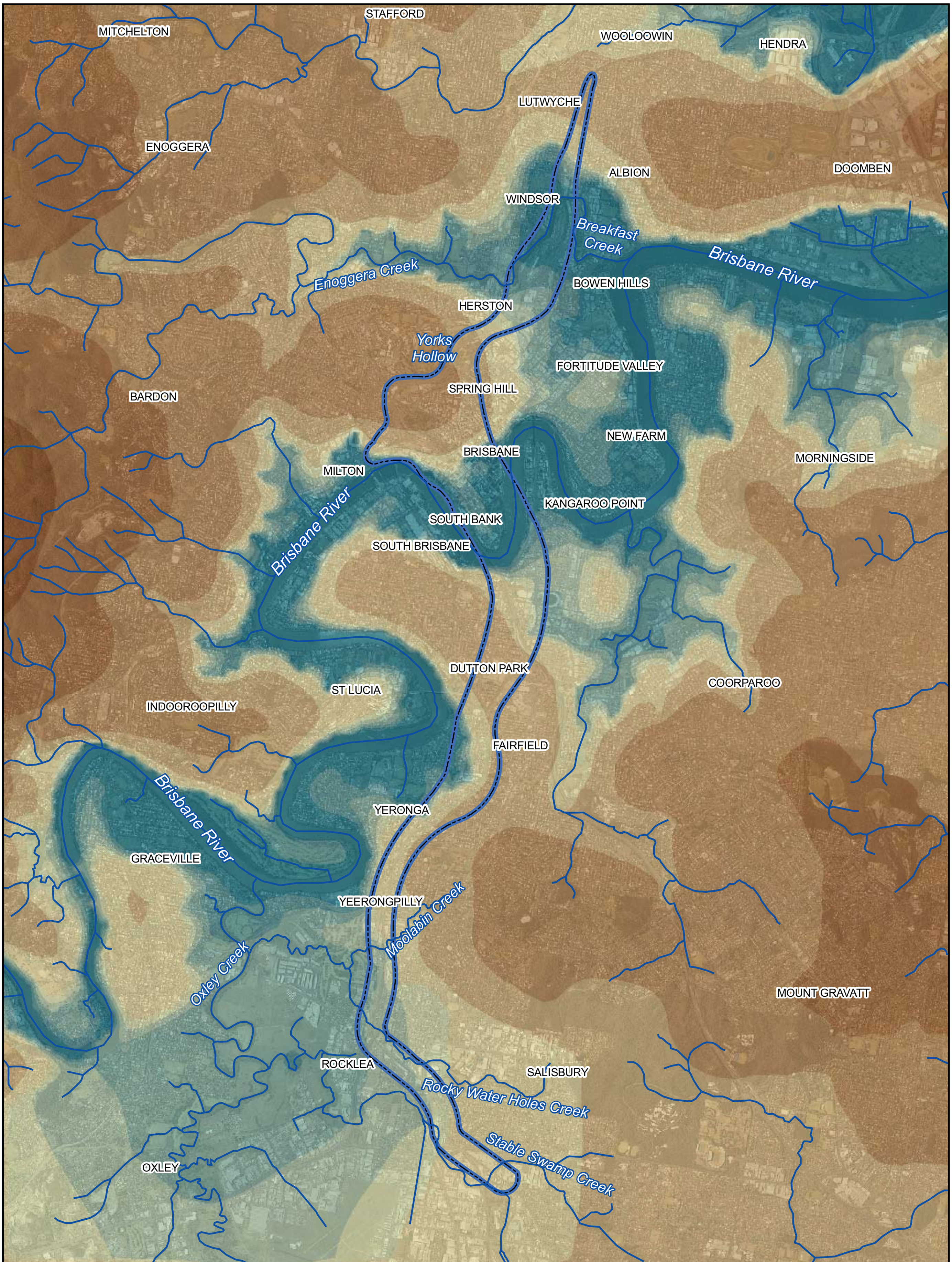

LEGEND

Study Corridor

Water Table Elevation m (AHD)

- 0 - 1
- 1 -2
- 2 - 3
- 3 - 4
- 4 - 5
- 5 - 10
- 10 - 20
- 20 - 50
- 50 - 100
- > 100

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Figure 2-4

Water Table Elevation

0 0.5 1 1.5 2 2.5 km

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2.7 Surface water – groundwater interaction

The dominant hydrological feature in the study area is the Brisbane River. Three major waterway catchments exist on either side of the Brisbane River which are the Oxley Creek Catchment, Norman Creek Catchment and the Breakfast/Enoggera Creek Catchment. Within the study area, these rivers and creeks have been identified as being tidal in nature. Drainage from the tunnel corridor is either direct to the Brisbane River or into the main waterways catchment which ultimately drains to the Brisbane River (AGE, 2009). The main catchments in the study area include:

- a sub-catchment of Norman Creek on the southern side of the river which drains the entire suburb of Woolloongabba and most of East Brisbane. The axis of the sub-catchment is Logan Road, which corresponds to the now infilled Kingfisher Creek. The study corridor intersects the upper parts of this sub-catchment
- Yorks Hollow on the northern side of the river which drains the southern extents of Kelvin Grove and which forms the corridor of the Inner City Bypass
- the catchment associated with Enoggera Creek also on the northern side of the river. The study corridor intersects the lower parts of this catchment which comprises the northern Brisbane Suburbs of Spring Hill, Herston, Bowen Hills, Windsor and Albion
- the catchment of Oxley Creek is located on the southern side of the river. Water from the catchment flows through Beaudesert Shire, Logan and Brisbane Cities and parts of Ipswich City. The study corridor is closest to two main tributaries of Oxley Creek which are Moolabin Creek and Rocky Waterholes Creek.

Surface water – groundwater connectivity may occur at the creeks and rivers associated with the catchments. The term ‘connectivity’ refers to the physical hydraulic connection between groundwater in an aquifer and surface water in a river (Evans, 2007). This is influenced by depth to water table and the hydraulic conductivity of the aquifer and stream bed sediments. A review of available data (refer to **Section 1.1**) shows that shallow groundwater monitoring bores within the vicinity of the Brisbane River have been identified as displaying groundwater level fluctuations consistent with tidal levels. This suggests that the shallow aquifers are in hydraulic connection with the River.

The groundwater monitoring program to be undertaken will provide site specific hydrogeological data to characterise surface water - groundwater interaction at underground construction sites.

2.8 Groundwater quality

Water quality data obtained for boreholes located within the vicinity of the study corridor is available from existing groundwater facilities recorded in the DERM groundwater database and from the Eastern Busway and NSBT projects. A review of groundwater quality results from other projects within the general Brisbane area has also been undertaken for comparison, and results presented in **Table 2-17**.

Table 2-17 Groundwater Quality data for the study area

Aquifer	No. of Monitoring Bores	pH (range)	Total Dissolved Solids mg/L (range)
Airport Link			
Alluvial	6	5.89 – 7.90	540 – 3819
Brisbane Tuff	5	4.34 – 7.14	293 – 1717
Neranleigh-Fernvale Beds	1	6.49 – 7.98	334 – 368
Tingalpa Formation	4	5.91 – 7.89	161 - 1042
S1 Sewer Tunnel			
Neranleigh-Fernvale Beds	1	6.7	3540

Aquifer	No. of Monitoring Bores	pH (range)	Total Dissolved Solids mg/L (range)
NSBT			
Alluvium	4	5.4 – 6.8	570 – 3200
Brisbane Tuff	4	6.4 – 6.9	860 – 3200
Neranleigh-Fernvale Beds	2	6.7 – 7.3	15000 – 22000
Northern Link			
Alluvium	-	6.52 – 7.27	1494 – 2508
Bunya Phyllite	-	4.6 – 7.7	300 – 5000
Neranleigh-Fernvale Beds	-	6.7	300 – 30000
Eastern Busway			
Alluvium	3	6.79 – 8.03	1762 – 6821
Brisbane Tuff	1	6.18	1983
Neranleigh-Fernvale Beds	3	5.87 – 7.07	2909 – 7732
DERM Groundwater Database			
Not Specified	17	4.5 – 8.4	33 – 9896

Source: DERM 2010

A groundwater salinity map has been developed based on existing available data and Groundwater Database records (refer **Figure 2-5**).

In general, the quality of groundwater within the NFB is spatially variable and considered poor, with TDS values ranging from 300 (fresh) to 30,000 (saline) mg/L. Groundwater in the NFB vary from acidic to neutral (pH 5.87 to 7.98) conditions.

The Brisbane Tuff ranges from pH of 4.34 to 7.14 which is indicative of acidic to neutral conditions. Groundwater quality varies from fresh to brackish with TDS of 293 to 3,200 mg/L.

Groundwater within the alluvial aquifer is fresh to brackish, with recorded TDS ranging from 540 – 6,821 mg/L. The pH of groundwater in this aquifer ranges from acidic to slightly alkaline (pH 5.4 and 8.03). Groundwater quality in the alluvial aquifers is variable and will be dependent on the proximity of creeks or rivers and associated tidal influences, including saline intrusion.

Groundwater quality monitoring was collated by AGE (2009) from the NSBT and Airport Link projects (refer to **Table 2-18)**. AGE (2009) suggest that there will be a marked difference in water quality along the study corridor, as the Project intersects a variety of geological units and passes under the Brisbane River (AGE, 2009).

The groundwater quality results indicate that groundwater quality in the fractured rock will generally be of poor quality that is unsuitable for drinking water. In the older, highly urbanised areas, nutrient levels can also be expected to be high due to the application of fertilisers on gardens.

Groundwater quality in the alluvial areas is variable and depends on the proximity of the creek to tidal influence and hence saline intrusion.

In summary, groundwater quality is generally a function of lithology, recharge and groundwater flow within the aquifer unit and proximity to saline or fresh surface water bodies such as the Brisbane River (AGE, 2009). The groundwater monitoring program to be undertaken will provide site specific hydrogeological data to characterise groundwater quality in areas disturbed by tunnelling or other subsurface works.

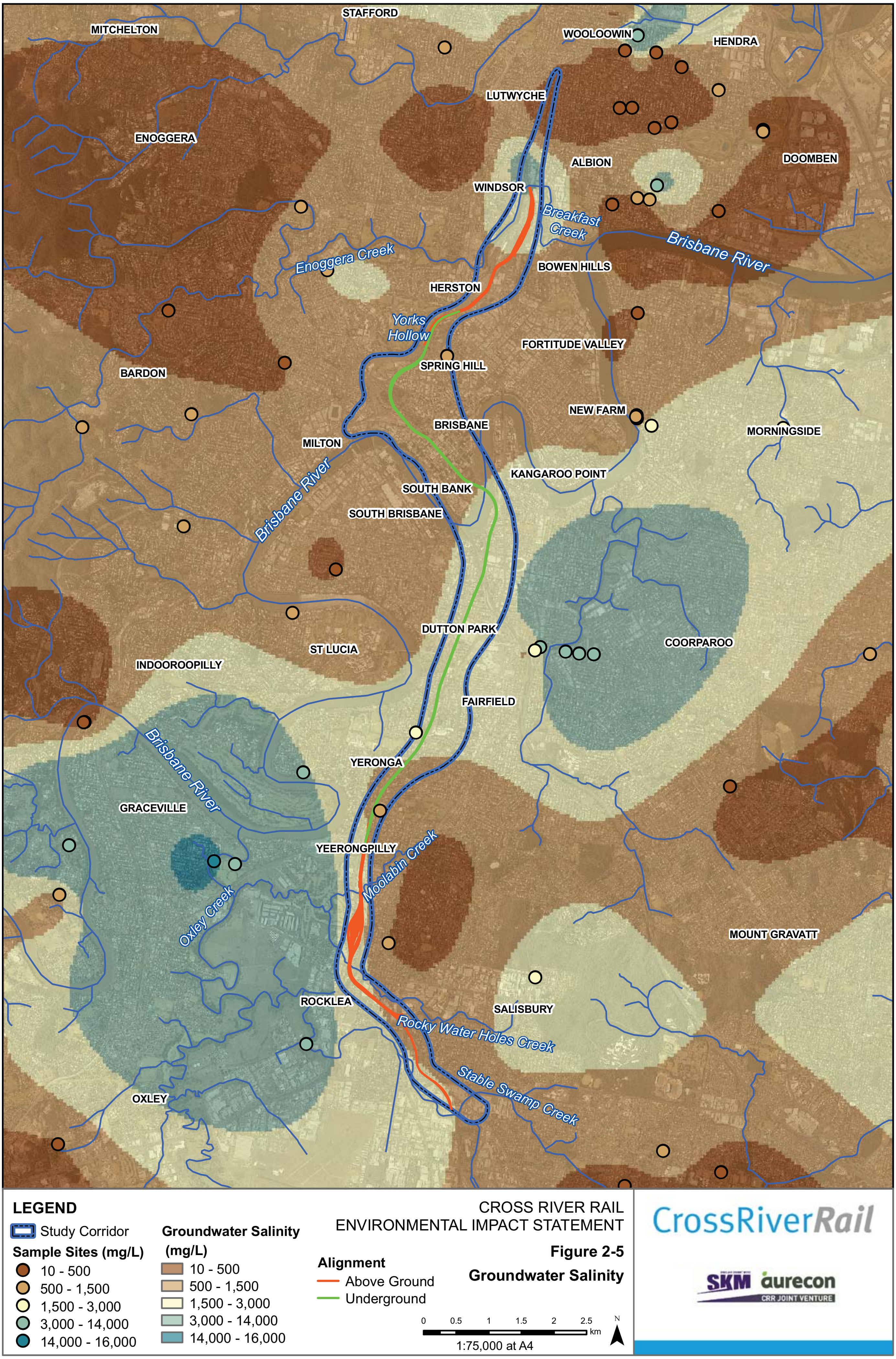

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Figure 2-5
Groundwater Salinity

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Table 2-18 NSBT and Airport Link Groundwater Quality Monitoring Results (extracted from AGE, 2009).

Borehole	Units	NST01S	NST02S	NST03S	NST03D	NST04	NST13	NST28	NST32	NST35S	NST35D	APL01	APL02
Sample Date		-	-	-	-	-	-	-	-	-	-	26/10/05	26/10/05
Aquifer		-	-	-	-	-	-	-	-	-	-	NFB	Tuff
pH	-	6.8	5.4	6.5	7.3	6.7	6.8	6.8	6.9	6.6	6.4	6.5	7.3
Conductivity @ 25C	µS/cm	5000	2600	890	35000	24000	5000	4100	1300	1600	2200	610	6400
Total Dissolved Solids	mg/L	3200	1700	570	22000	15000	3200	2600	860	1000	1400	354	3820
Calcium	mg/L	32	5.6	39	280	690	210	98	71	110	43	8.7	90
Magnesium	mg/L	51	20	16	790	590	88	58	27	52	44	6.5	170
Sodium	mg/L	930	500	130	6600	3700	640	650	170	130	320	120	1000
Potassium	mg/L	9.4	4.1	4.2	310	88	17	15	9.8	13	7.7	5.9	13
Chloride	mg/L	1400	770	93	13000	8500	1200	1100	270	280	590	130	2200
Sulphur as SO_4	mg/L	130	150	100	1600	770	250	78	38	240	88	28	240
Total Alkalinity as $CaCO_3$	mg/L	370	23	210	280	350	300	370	230	100	160	100	360
Bicarbonate Alkalinity as $CaCO_3$	mg/L	370	23	210	270	350	300	370	230	100	160	100	360
Carbonate Alkalinity as $CaCO_3$	mg/L	<1.0	<1.0	<1.0	1	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	1.0
Ammonia N	mg/L	0.067	0.066	0.081	4.5	2.5	0.18	0.12	<0.06	0.26	1.4	<0.004	0.016
Nitrate+Nitrite as N	mg/L	<0.02	<0.02	<0.02	<0.02	<0.02	0.04	<0.02	<0.02	0.16	<0.02		
Ortho Phosphorous as P	mg/L	0.17	0.15	0.16	0.14	0.14	0.15	0.15	0.15	0.15	0.15	0.27	0.044
Aluminium	mg/L	0.035	0.039	0.032	0.041	0.086	0.06	0.072	0.046	0.039	0.07	0.039	0.027
Arsenic	mg/L	<0.005	<0.005	<0.005	0.011	0.021	0.009	0.015	0.02	<0.005	<0.005	<0.005	<0.005

Borehole	Units	NST01S	NST02S	NST03S	NST03D	NST04	NST13	NST28	NST32	NST35S	NST35D	APL01	APL02
Barium	mg/L	0.091	0.15	0.036	0.095	0.064	0.067	0.089	0.04	0.11	0.17	0.052	0.14
Cadmium	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.001
Chromium	mg/L	<0.001	<0.001	<0.001	0.001	0.002	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.001
Copper	mg/L	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	0.037	0.031
Iron	mg/L	0.007	0.054	0.029	0.55	4.5	2.3	2.4	1.5	1.9	24	0.13	0.038
Manganese	mg/L	0.22	0.05	0.18	1.8	1.7	0.83	0.35	0.33	0.36	0.99	0.29	0.14
Nickel	mg/L	0.003	0.004	0.005	0.009	0.005	0.005	0.005	0.008	0.005	0.004	0.005	0.006
Lead	mg/L	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Zinc	mg/L	0.086	0.079	0.012	0.006	0.061	0.041	0.022	0.051	0.013	0.075	0.18	0.26
Mercury	µg/L	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
TPH	µg/L	350	-	100	500	360	-	100	1400	-	-	ND	ND
LSI	-	-	-	-	-	-	-	-	-	-	-	-2.2	0.2
Aggressivity to Concrete	-	-	-	-	-	-	-	-	-	-	-	Very Strong	Depositing
Aggressivity to Steel	-	-	-	-	-	-	-	-	-	-	-	Low	Medium

Source: AGE (2009)

2.8.1 Groundwater contamination

An assessment of the Environmental Management Register (EMR) and the Contaminated Land Register (CLR) was undertaken as part of this EIS and is *Technical Report No.2 – Contaminated Land*. The objectives of this assessment were to:

- provide a description of land parcels located within the study corridor that are listed on the EMR/CLR
- identify land parcels which are not included on the EMR/CLR (based on past or current land uses) but which have the potential to cause soil and/or groundwater contamination.

The assessment undertaken was based on the introductory steps of a preliminary site investigation (PSI), as per the Draft Guidelines. These steps are intended to broadly identify whether there is a potential risk of a historical or existing land use to have occurred with the potential to cause contamination. The assessment included the study corridor and a surrounding 1 km buffer area located outside the study corridor to account for potential groundwater drawdown. Reference should be made to the Contaminated Land technical report for locations of identified contaminated sites and high risk areas.

The contaminated site investigation identified the presence of a number of sites within the study area with an existing or historical land use with the potential to cause land contamination. High risk areas within the study area summarised in the **Table 2-19** below.

Table 2-19 Higher risk EMR listed land parcels within the Study Corridor

Notifiable Activity	EMR* listed properties	SMP** managed properties
Chemical manufacture or formulation	1	-
Coal fired power station	4	-
Hazardous contaminant	84	1
Landfill	50	-
Petroleum product or oil storage	198	5
Railway yards	86	3
Service stations	13	-
Total	**432**	**9**

Notes:
**Environmental Management Register*
***Site Management Plan*

It is highly likely that groundwater is also contaminated within the vicinity of identified contaminated sites in the study area (refer to **Chapter 8 Contaminated Land**). Due to the point source nature of the contaminants, it would be extremely difficult to identify the location of all potential contaminant plumes. In addition, hydrocarbon and nutrient contaminants have been identified in Norman Creek, Brisbane River and Breakfast Creek which can be drawn into the tunnel.

Areas of groundwater contamination, particularly of petroleum hydrocarbons are likely to be located in the rockmass along the study corridor (AGE, 2009).

2.8.2 Acid Sulfate Soils (potential – groundwater acidification)

The occurrence of Actual Acid Sulfate Soils (ASS) and Potential Acid Sulfate Soils (PASS) is reported in the Geology and Soils technical report. In general, Holocene alluvial deposits, which were deposited in estuarine conditions, are often associated with acid sulfate potential. Typically the Holocene alluvium occurs below a relative level of +5 m AHD.

ASS is present within the study area, including along Breakfast/ Enoggera Creek, Norman Creek, Oxley Creek and Brisbane River. Based on the Queensland Acid Sulfate Soil Technical Manual (DERM, 2004), harmful substances can be transferred from the site of acid generation by surface water and/or groundwater. The mixing of acid deposits with surface water or groundwater results in the formation of acidic waters. The disturbance of ASS can result in a significant degradation of the aquatic environment and poses both short and long term risks to riverine, estuarine and near-shore marine biota.

It is likely that potential groundwater acidification can occur from dewatering operations along Breakfast/ Enoggera Creek, Norman Creek, Oxley Creek and Brisbane River. Given the existing land use and highly developed nature of the study area, groundwater acidification is likely to have occurred to some extent. It is also likely that ASS in some areas has already been excavated and in-filled with fill (clean) material for new developments and hence no longer exists.

2.9 Groundwater Dependent Ecosystems

Groundwater Dependant Ecosystems (GDEs) are ecosystems which have their species composition and their natural ecological processes determined by groundwater (ANZECC, 2000). Six broad functional groups of GDEs have been classified: terrestrial vegetation, river base flow systems, estuarine and near shore marine, aquifer and cave systems and wetlands (Clifton and Evans, 2001) (Hatton and Evans, 1998). Groundwater dependant ecosystems function (ie health) is generally defined by four groundwater parameters: flux, level, pressure and quality, with dependence being a function of one or all of these factors.

Reference should be made to **Chapter 11 Nature Conservation** which provides an overview of the sensitive terrestrial and aquatic ecosystems within the study area. A review of this report indicates that:

- during dry seasons, terrestrial vegetation (particularly large remnant trees) may be dependent on groundwater where the water table is close to the surface
- the groundwater dependence of riparian remnant trees (principally Forest red gums) adjacent to Breakfast Creek/ Enoggera Creek (where there is shallow water tables) is difficult to determine due to tidal influences
- shallow water tables occur to the north of Brisbane River near the Brisbane CBD and City Botanic Gardens. The main species that may be influenced by groundwater are large remnant Forest red gums
- wetlands at Yorks Hollow, City Botanic Gardens and Roma Street Parklands are all constructed and appear to be perched well above the water table
- the mangrove forests along Breakfast Creek/Enoggera Creek and the Brisbane River may be GDEs, however the degree of freshwater dependency is generally unknown for such systems.

The greatest potential for groundwater dependency is likely to be within shallow alluvial sequences associated with drainage lines. In these areas the water table is likely to be permanently shallow and above the maximum rooting depth of established vegetation. Given that the drainage lines within the study area are saline to brackish and tidal in nature, it is anticipated that groundwater in these areas are also to some extent, brackish to saline. Groundwater levels in these areas are likely to be tidally influenced and the water table is likely to fluctuate accordingly. Based on this it is considered that the level of groundwater dependency in these areas is likely to be relatively low (opportunistic at best) with only salt tolerant species potentially utilising groundwater in these saturated zone. Given the local climatic conditions and drainage characteristics of these areas it is considered that surface water runoff and infiltrated rainfall represents the primary source of flux required to satisfy plant water requirements.

Established vegetation on residual soil or imported fill within park areas may also potentially utilise groundwater opportunistically during dry periods, however, the potential level of dependency is likely to be even less than for vegetation in the vicinity of drainage lines, as shallow groundwater in non-alluvial sequences is likely to represent interface drainage which persists only following rainfall events.

2.10 Environmental values

The *Environmental Protection (Water) Policy 2009* aims to protect all Queensland waters by:

- identifying environmental values and management goals for Queensland waters
- stating water quality guidelines and water quality objectives to enhance or protect the environmental values
- providing a framework for making consistent, equitable and informed decisions about Queensland waters
- monitoring and reporting on the condition of Queensland waters.

Section 6 of the policy defines environmental values as:

Environmental values to be enhanced or protected

(1) The environmental values of waters to be enhanced or protected under this policy are—

(a) for water mentioned in schedule 1, column 1—the environmental values stated in the document opposite

the water in schedule 1, column 2; or

(b) for other water—the environmental values stated in subsection (2).

The water defined in Schedule 1, Column 1 of the policy relevant to this Project refers to:

- Brisbane River, including all tributaries of the Brisbane River estuary other than Oxley Creek (Basin No. 143)
- Brisbane Creeks – Bramble Bay, including Bald Hills, Cabbage Tree, Downfall, Kedron Brook, Nudgee and Nundah creeks (Basin No. 142)
- Oxley Creek, including all tributaries of the creek (Basin No. 143).

The above plans apply to fresh, estuarine surface water and groundwaters draining the catchment. The Environmental Values included in these plans include Aquatic Ecosystems, Drinking Water, Irrigation, Stock Water and Farm Supply. It is considered that Stock Water and Farm Supply are not relevant to the Study Corridor and consequently have not been assessed. The relevant Environmental Values for groundwater as outlined in the above mentioned plans are discussed in more detail as follows.

2.10.1 Aquatic ecosystems

Groundwater quality within the investigation area is likely to be 'non pristine' due to the level of anthropogenic development within the area and associated recharge zones. Furthermore, the area has been significantly disturbed as a result of surface development. Given the saline to brackish nature of groundwater which is influenced by the tidal creeks and rivers within the study area, any aquatic ecosystems that may exist within the study area are considered to be salt tolerant. Based on this, groundwater quality as a function of aquatic ecosystem health is considered negligible.

2.10.2 Drinking water

Comparison of the groundwater quality to the Australian Drinking water guidelines indicates that the groundwater within the alluvium and basement rocks is generally unsuitable for potable use, primarily due to elevated salinity levels. Opportunities for groundwater extraction and use are also considered negligible due to the low yields associated with the primary hydrostratigraphic units.

2.10.3 Irrigation

Based on the available water quality data, groundwater sourced from the Bunya Phyllite, Neranleigh-Fernvale beds and Alluvium (in some areas) is considered to be too saline for general irrigation use as outlined in the Australian and New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand (ANZECC, 2000) water quality guidelines. The suitability of groundwater for irrigation purposes will depend on a number of case-specific factors which include:

- soil type and structure (Exchangeable Sodium Percentage (ESP)
- vegetation species
- irrigation application methods
- ionic composition of water (sodium adsorption ratio (SAR)) and residual alkalinity hazard.

3 Conceptual hydrogeological models

Two conceptual hydrogeological models have been formulated for the anticipated hydrogeological conditions within the study area. This is based on a summary of all the data presented in **Section 2**. The hydrogeological models may occur individually or in combination with each other. Review of these models is required following field investigations to confirm their significance and refine the assumptions made.

3.1 Model 1: Fractured Rock Aquifer

3.1.1 Description

The conceptual hydrogeological model for the Fractured Rock Aquifer has been schematically represented in **Figure 3-1**.

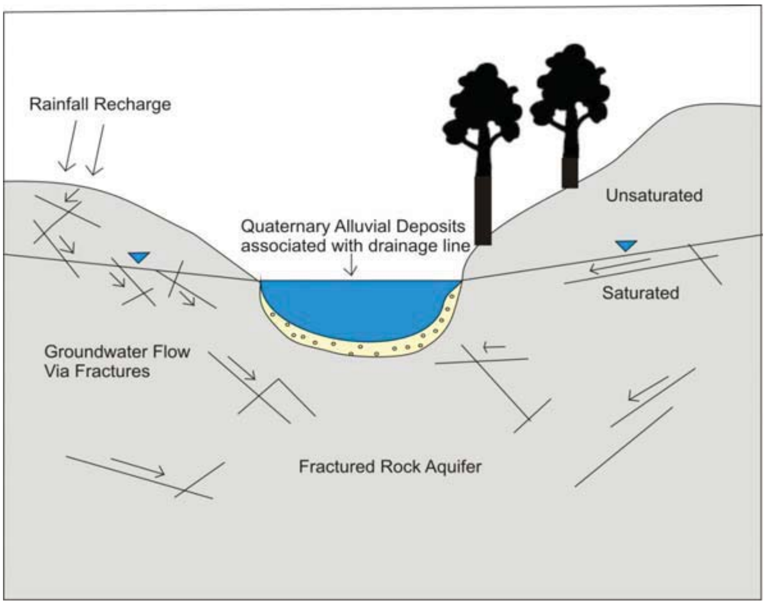


Figure 3-1 Model 1 Fractured Rock Aquifer

This model shows that groundwater is principally stored and transmitted in the fractures, joints and other discontinuities within the rock mass. The volume of groundwater contained within the fractured rock aquifer and the ability of the aquifer to transmit water is largely a function of the degree of fracturing and extent of interconnection of the fracture systems. Aquifer properties are typically highly variable and available data indicates that permeability is generally low. Groundwater recharge occurs from infiltration of rainfall in rock outcrop areas and in some areas from overlying Alluvial Aquifers. Groundwater is expected to discharge in topographically low areas and it is anticipated that groundwater generally flows towards the Rivers and Creeks within the study area. Groundwater discharge in some areas can also occur to adjacent alluvial aquifers.

3.1.2 Type localities

The Fractured Rock Aquifer is expected to occur over the majority of the study area.

3.1.3 Possible implications

Rail corridor traversing such hydrogeological conditions may encounter:

- unsaturated conditions in excavations along the steeper topographic areas where water tables are expected to be deep
- wet conditions in tunnel and sub-surface excavations where fractures are saturated
- variable seepage rates into excavations depending on the size and degree of interconnection of the fracture systems. Dewatering may yield high initial flow rates, which decline as fracture storage is depleted.
- brackish to saline or potentially contaminated groundwater conditions may be encountered.

3.2 Model 2: Alluvial Aquifer

3.2.1 Description

This model has been developed for those areas where extensive areas of saturated Quaternary sediments overlie the Fractured Rock Aquifers. The conceptual hydrogeological model has been schematically represented in **Figure 3-2**.

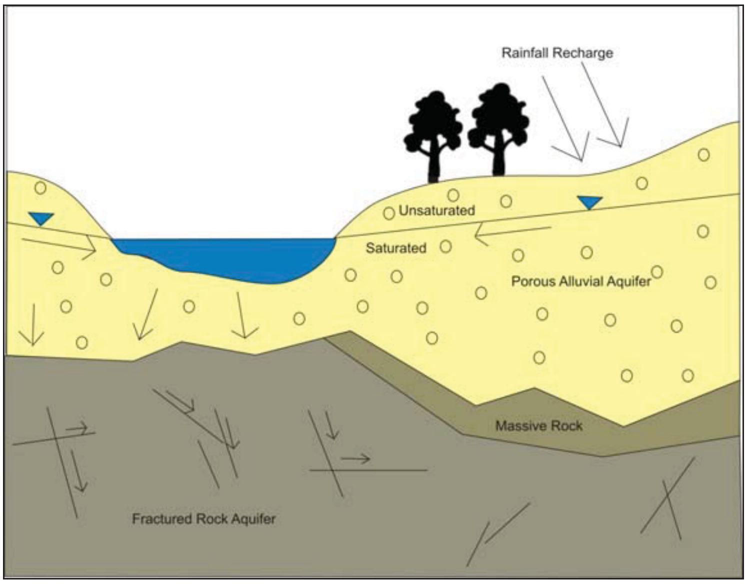


Figure 3-2 Model 2 Alluvial Aquifer

The alluvial aquifer is classified as a porous media aquifer where groundwater occurs within the voids between individual grain particles. The volume of groundwater stored within the aquifer and the ability of the aquifer to transmit groundwater are largely a function of the particle size of the material comprising the aquifer and the saturated thickness of the sediments. Aquifer properties are variable depending on the nature of the sediments. The permeability and storage capacity of this aquifer is expected to be significantly larger than the Fractured Rock Aquifers. Groundwater is often hydraulically connected to the surface water systems. The alluvial sediments are recharged by infiltrating rainfall and in some areas via through-flow from the adjacent Fractured Rock Aquifers. Groundwater is expected to discharge down valley and into the creeks and rivers of the study area. Given that the majority of the drainage lines are tidal, both recharge and discharge processes are expected to occur in the aquifer based on the relative differences in water levels between surface water and groundwater systems.

3.2.2 Type localities

This aquifer is expected to occur within the immediate vicinity of the Brisbane River and other associated tributaries and along nearby drainage lines.

3.2.3 Possible implications

Rail corridor traversing such hydrogeological conditions may encounter:

- unconsolidated ground conditions
- a greater likelihood of intersection water tables (relative to Model 1)
- intersecting brackish to saline or potentially contaminated groundwater conditions
- high construction inflows requiring a greater dewatering effort.

4 Tunnel reference design

Groundwater modelling undertaken as part of the impact assessment is based on the Reference Project. A summary of the proposed groundwater drainage provisions in the tunnel design is outlined in **Table 4-1**.

Table 4-1 Summary of proposed groundwater drainage provisions (Source: AECOM, 2010)

Element	Groundwater Drainage
Yeerongpilly Portal	Dive structures at portal trough – drained; cut and cover approach tunnels immediately north of portal – undrained
Yeerongpilly – Boggo Road tunnels	Undrained –segmental linings with gaskets; undrained cross-passages
Southern Ventilation Shaft	Undrained in soil –base of shaft in rock – drained
Boggo Road Station	Drained
Boggo Road – Gabba Station tunnels	Undrained –segmental linings with gaskets; undrained cross-passages
Gabba Station	Undrained section for cut and cover elements protruding above rock (station sited in paleochannel) - base of box and cavern elements drained (ie openings in rock drained)
Woolloongabba – Albert Street station tunnels	Undrained –segmental linings with gaskets; undrained cross-passages
Albert Street station	Undrained section for cut and cover elements protruding above rock – base of boxes and cavern elements drained
Albert Street – Roma St tunnels	Undrained –segmental linings with gaskets; undrained cross-passages
Roma Street Station	Drained (southern shaft/central shaft may require groundwater cut-off to rock depending on profile)
Roma Street – North Portal tunnels	Undrained –segmental linings with gaskets; undrained cross-passages; mined tunnels immediately south of portal/dive structure – drained
Northern Portal	May require groundwater cut-off to rock depending on site (near paleochannel) - openings in rock drained

It is understood that the following provisions will be made during construction:

- TBM driven tunnels will be lined with pre-cast segmental concrete linings. Gaskets will be included wherever these linings are used to create a waterproof lining
- the cross-passages linking the TBM driven tunnels will be undrained
- all tunnel sections will be constructed by TBM, and will as a consequence be undrained
- only station locations will be drained in the rock and undrained in the alluvium.

The tunnel reference design, based on the above information, is considered to be adequate in terms of assessing environmental impacts.

4.1 Groundwater use by the Project

Supply of water is anticipated to be sourced off-site. It is, however, anticipated that some off-site sourcing can be offset against groundwater recovered from the excavation on-site. No active dewatering or groundwater pumping will be undertaken to source water for construction purposes. Groundwater recovered on-site will be treated prior to discharge.

5 Groundwater modelling

Groundwater modelling was undertaken for the construction and operational phase of the Project. The construction phase was simulated only for excavation areas and did not the tunnelling. Tunnelling was no simulated based on advice from the design team that the method of construction using the tunnel boring machine will result in inflows that are no greater than those expected during normal tunnel operation.

5.1 Groundwater modelling set up

A three dimensional finite difference groundwater model was developed to assess potential impacts of the long term inflow of groundwater to the drained sections of the tunnel. The model is aimed at quantifying the following potential impacts:

- drawdown emanating from the tunnel inflows and leading to depressed groundwater levels at the locations of existing groundwater users or GDEs
- drawdown in groundwater levels in areas of ASS
- reduced flows to streams and rivers
- increased flux of saline water from the Brisbane River into the aquifer and potentially into the tunnel itself.

5.1.1 Modelling strategy

The model has been formulated in the MODFLOW 2000 numerical simulation code using the Visual Modflow 4.3 graphical user interface. The MODFLOW 2000 code is a finite difference simulation code that is the industry standard groundwater modelling software programme.

The model aims to represent the flow of groundwater into the drained segments of tunnel. Where the tunnel is drained it is assumed that groundwater levels will be forced to the tunnel/station/shaft invert level. This may lead to the water table falling to the invert level or alternatively groundwater may become perched over an unsaturated zone that forms around the tunnel. In either case the inflows to the tunnel will lead to localised depression of groundwater levels centred on the tunnel alignment. Where the tunnel is designated to be un-drained it is assumed that a liner will be installed around the tunnel to prevent any inflow of water into the tunnel. In this case the model assumes no inflow and no associated impacts caused by the absence of inflows.

Modelling has assumed that the tunnelling will not induce significant inflows of groundwater to the tunnel as the tunnel boring machine will effectively control and eliminate such inflows.

The model incorporates a rectangular finite difference grid of 100 m squares. This choice of grid size is effectively limited by the numerical effort required to solve for more refined grids and by the need to maintain manageable model run times. Because the spatial discretisation of the model exceeds the proposed tunnel dimensions special care has been taken to moderate or control tunnel inflows to avoid over-estimation of the impacts. This was achieved by the formulation of more detailed two dimensional finite element models that represent the tunnel at its true size and by using the outcomes of these detailed models to tune the inflows to the larger three dimensional whole-of-tunnel model.

5.1.2 Model design

A. **Whole-of-Tunnel Model**. A large three dimensional finite difference model was formulated to cover the entire length of tunnel with additional area around the tunnel to ensure that all potential impacts are observed within the model domain. The model domain is 15 km in the east-west direction and 22 km in the north-south direction. The model has been discretised into a grid of elements that are 100 m square. The model domain is shown in **Figure 5-1**.

The base of the model has been defined as -50 m AHD and the model layer structure was chosen in a manner that provides for vertical flow components to the tunnel inflows. In general insufficient geological information is available to be able to assign variable geology with depth in the model domain and accordingly the surface geology, except for the alluvium, is assumed to extend to full model depth. Pockets of alluvium identified in the surface geology are assumed to be a maximum of 10 m thick. The geological units included in the model are shown in **Figure 5-2**. The model layer structure shown on a model cross section through the Brisbane River is shown in **Figure 5-3**.

The Brisbane River is represented in the model as MODFLOW river cells that allow water to enter or exit groundwater from or to the River depending on the gradients obtained from the estimated groundwater levels at the river and the specified river elevation (0 m AHD). Other drainage features in the area are represented in the model as MODFLOW drain cells that only allow water to flow out of groundwater when calculated groundwater levels exceed specified drain levels (as obtained from the digital elevation model of the ground surface).

The tunnel itself is represented in the model as a MODFLOW drain boundary condition where water flows out of the model when calculated groundwater levels exceed the tunnel invert level. The rate at which water is removed from the model through the drain cells is moderated by a conductance term that adds a flow resistance to the tunnel inflow. The conductance term was used to control tunnel inflows so that they are consistent with those estimated from the two dimensional finite element models described below. This *"calibration"* of tunnel inflows is required to account for the fact that the model cells are much larger than the actual tunnel dimension and as such the assumption that groundwater levels in the entire model cell fall to tunnel invert level would substantially overestimate inflows to the tunnel.

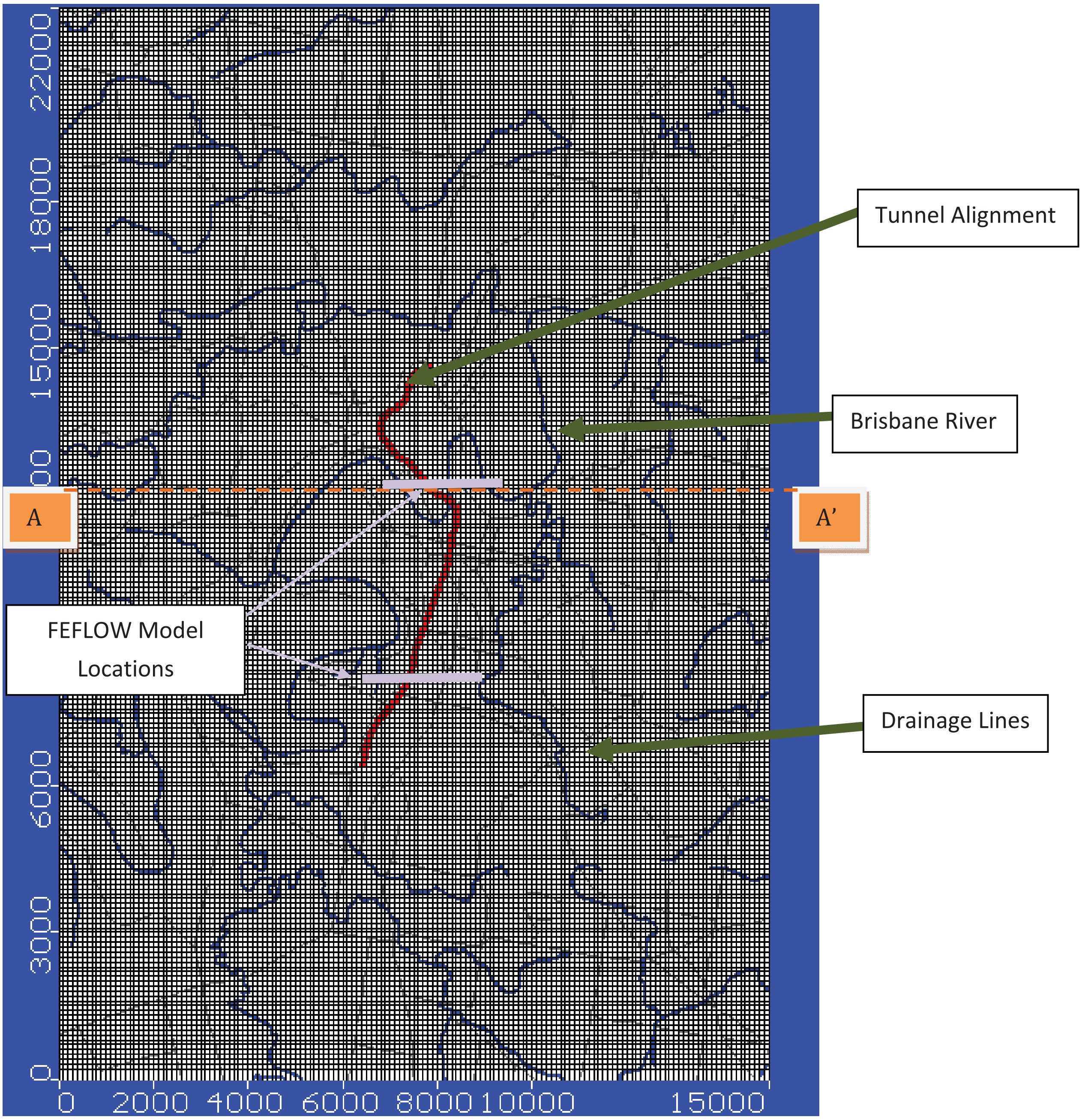


Figure 5-1 Model Domain and Grid

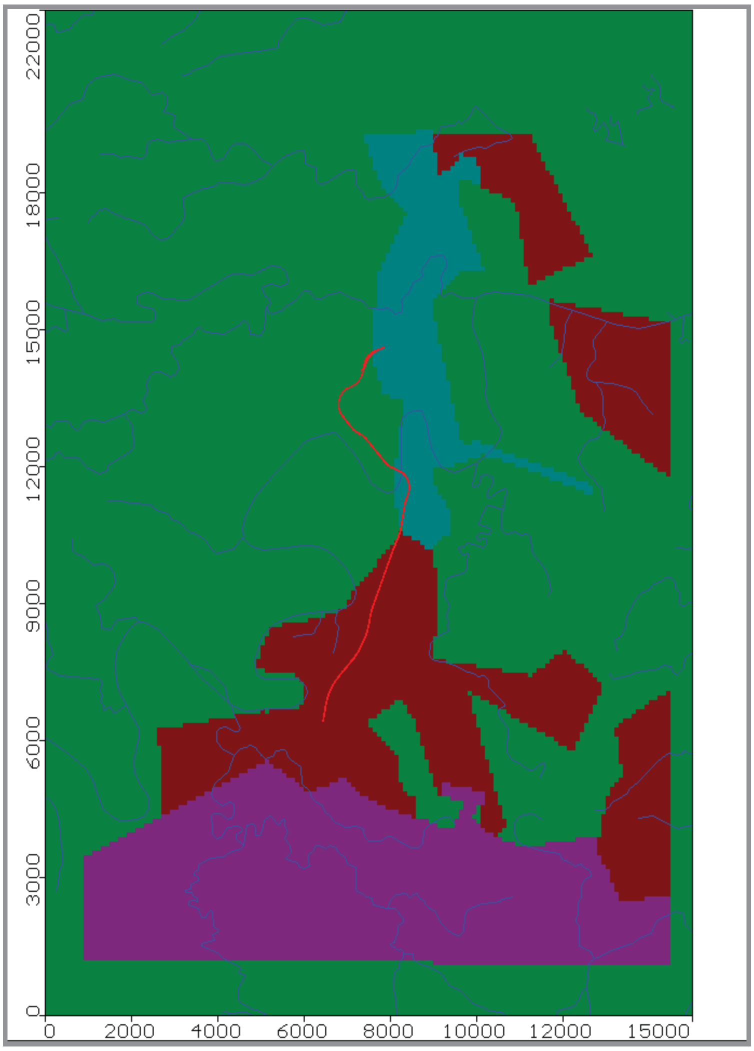


Figure 5-2 Geological Units included in the Model

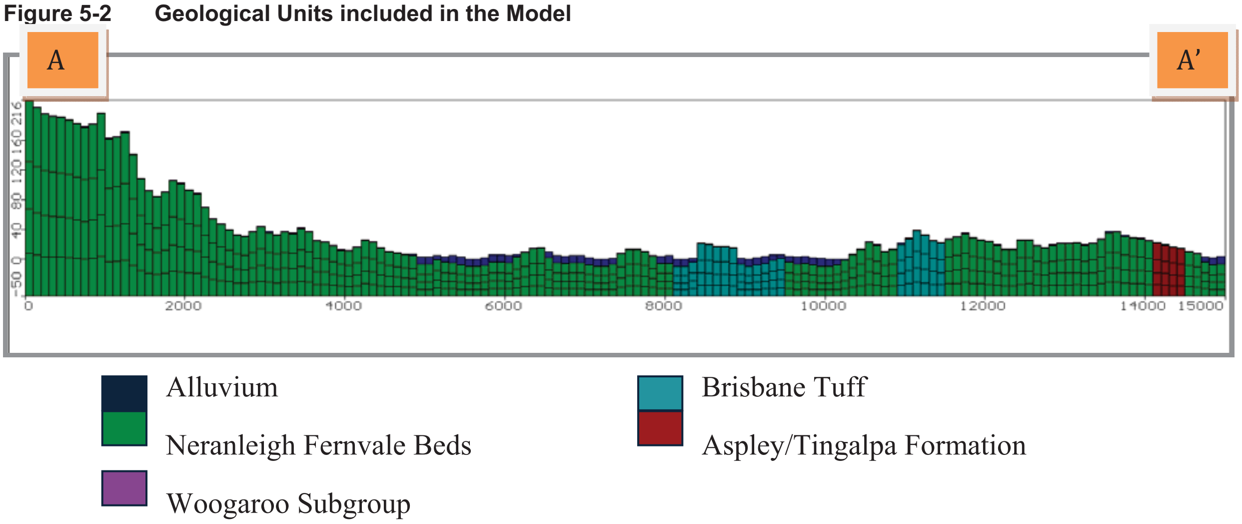


Figure 5-3 Model Grid on Cross Section AA'

B. **Two Dimensional Finite Element Models**. Two detailed tunnel cross section models were developed in the FEFLOW Finite Element simulation code. The objective of these detailed models is to provide estimates of inflow to the tunnel in which the tunnel is represented in its true dimensions. The model results were then up-scaled to estimate the corresponding inflow to a 100 m square grid cell as used in the three dimensional whole-of-tunnel model. The locations of the two cross section models (shown in **Figure 5-1**) were chosen to include representative hydrogeological units (Neranleigh Fernvale Beds near Albert St Station and the Aspley/Tingalpa Formation between Fairfield and Yeronga) included in the three dimensional model. The models were formulated with a finite element grid in which a refined mesh is included in the vicinity of the tunnel with coarser cells elsewhere. Both sections are 2 km in length and are centred on the tunnel alignment.

The tunnel is represented as a volume of constant head cells in which the head is specified at tunnel invert level. The models were run for thirty days in transient mode and the inflows to the tunnel estimated as a time series. Results from these models were then up-scaled to represent results for a 100 m length of tunnel (as appropriate for the 100 m grid cells of the three dimensional whole-of-tunnel model) and used as calibration targets for the three dimensional model as described above.

The finite element grids used for the cross section models are shown schematically in **Figure 5-4** and **Figure 5-5**.

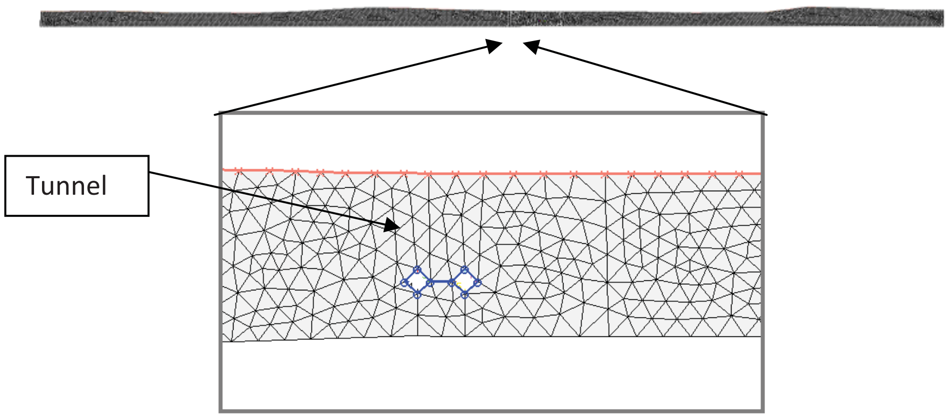


Figure 5-4 FEFLOW model mesh for the Model near Albert St Station

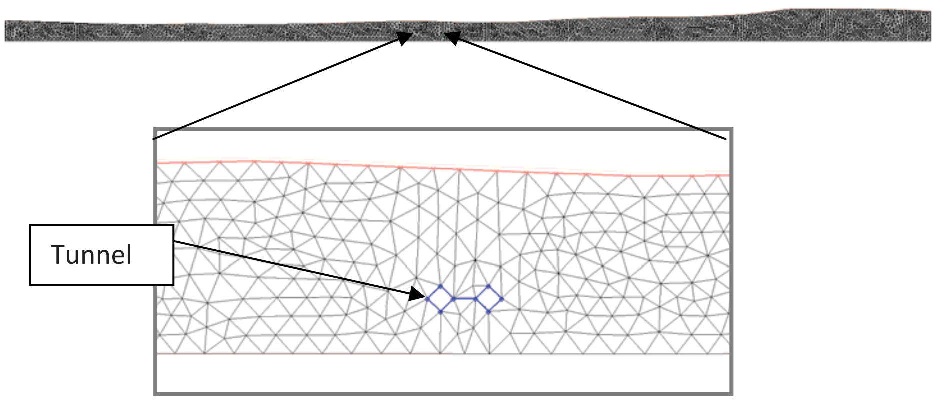


Figure 5-5 FEFLOW model mesh for the Model between Fairfield and Yeronga

5.1.3 Modelling approach

Owing to a lack of site specific hydrogeologic information that can be used to calibrate the model, a modelling approach has been adopted that uses information gained from recently completed tunnelling projects elsewhere in Brisbane to supplement the data collected thus far for the Cross River Rail Project. Model calibration has been possible by matching model predicted groundwater levels to the potentiometric surface profile in **Figure 2-2** that has been generated from observed groundwater levels at discharge sites with additional constraints associated with ground surface topography.

The whole of dataset, inclusive of information gained from other projects, provides a good level of confidence in the range of expected hydraulic conductivities within each of the geologic units. Therefore, it was chosen to use the automated parameter estimation PEST (*Watermark Numerical Computing, 2005)* to help optimise the calibration to the model to the measured and synthesised profile along the Project corridor.

5.1.4 Model parameters

The range in hydrogeological parameters included in the calibration process are summarised in **Table 5-1**. The extent of the range made available for the optimisation is a direct reflection of the level of information available for each parameter.

Table 5-1 Hydrogeological Parameters Used in Models

Parameter	Initial Value	Minimum	Maximum	Adopted
Alluvium (k_h) (m/d)	1	0.001	10	3.6
Alluvium (k_v) (m/d)	1	$1x10^{-6}$	1	0.35
Neranleigh Fernvale (k_h) (m/d)	0.003	0.0001	1	0.001
Neranleigh Fernvale (k_v) (m/d)	0.003	$1x10^{-6}$	1	0.009
Brisbane Tuff (k_h) (m/d)	0.014	0.001	1	0.0045
Brisbane Tuff (k_v) (m/d)	0.014	$1x10^{-6}$	1	0.041
Aspley/Tingalpa (k_h) (m/d)	0.025	0.001	1	0.0024
Aspley/Tingalpa (k_v) (m/d)	0.025	$1x10^{-6}$	1	0.06
Woogaroo (k_h) (m/d)	0.05	0.001	1	0.25
Woogaroo (k_v) (m/d)	0.05	$1x10^{-6}$	1	0.16
Specific Storage (S_s) (1/m)				$5x10^{-6}$*
Specific Yield (S_y)				0.05*
Recharge (mm/yr)	0.5	0.001**	50**	1.27

Notes:
**Storage values not optimised as calibration was steady state only.*
***Minimum and maximum values are multipliers of the initial value.*

5.1.5 Model calibration

The matching of target head values with simulated heads was suitably obtained as a result of the optimisation procedure. A graphical representation of target heads versus simulated heads is presented **Figure 5-6**. Statistical analyses of the residuals (ie difference between simulated and observed measurements) are provided in **Table 5-2**.

Table 5-2 Statistical Summary of Calibration Residuals

Statistic	Result
Mean (m)	0.058
Standard Error (m)	0.1
Median (m)	-0.035
Standard Deviation (m)	1.94
Sample Variance	3.75
Kurtosis	2.29
Skewness	-0.056
Range (m)	17.98
Minimum (m)	-9.46
Maximum (m)	8.52
Sum (m)	22.16
Count	379
Confidence Level (95.0%) (m)	0.20
Correlation	0.94
Normalised RMS	7.54%

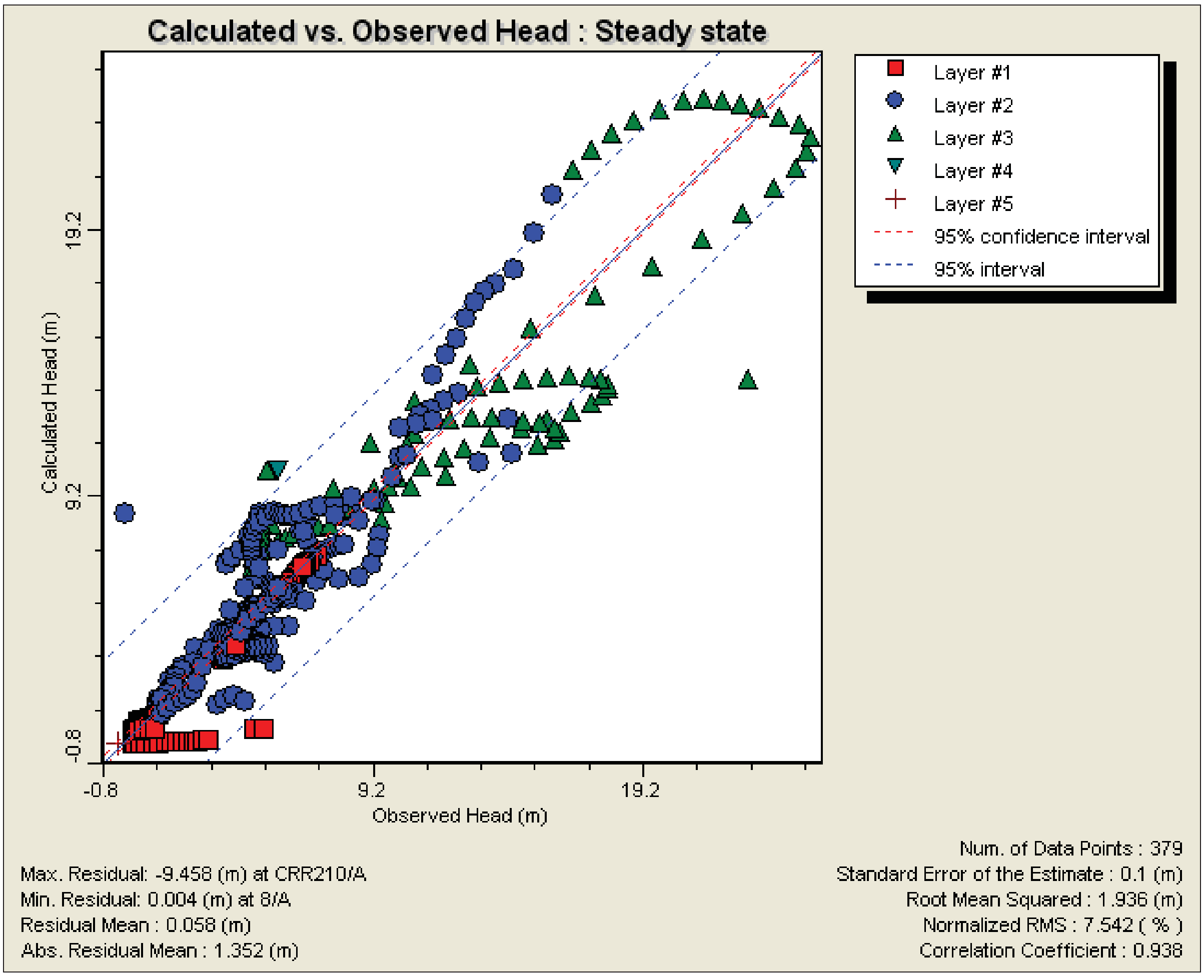


Figure 5-6 Simulated vs Target Heads

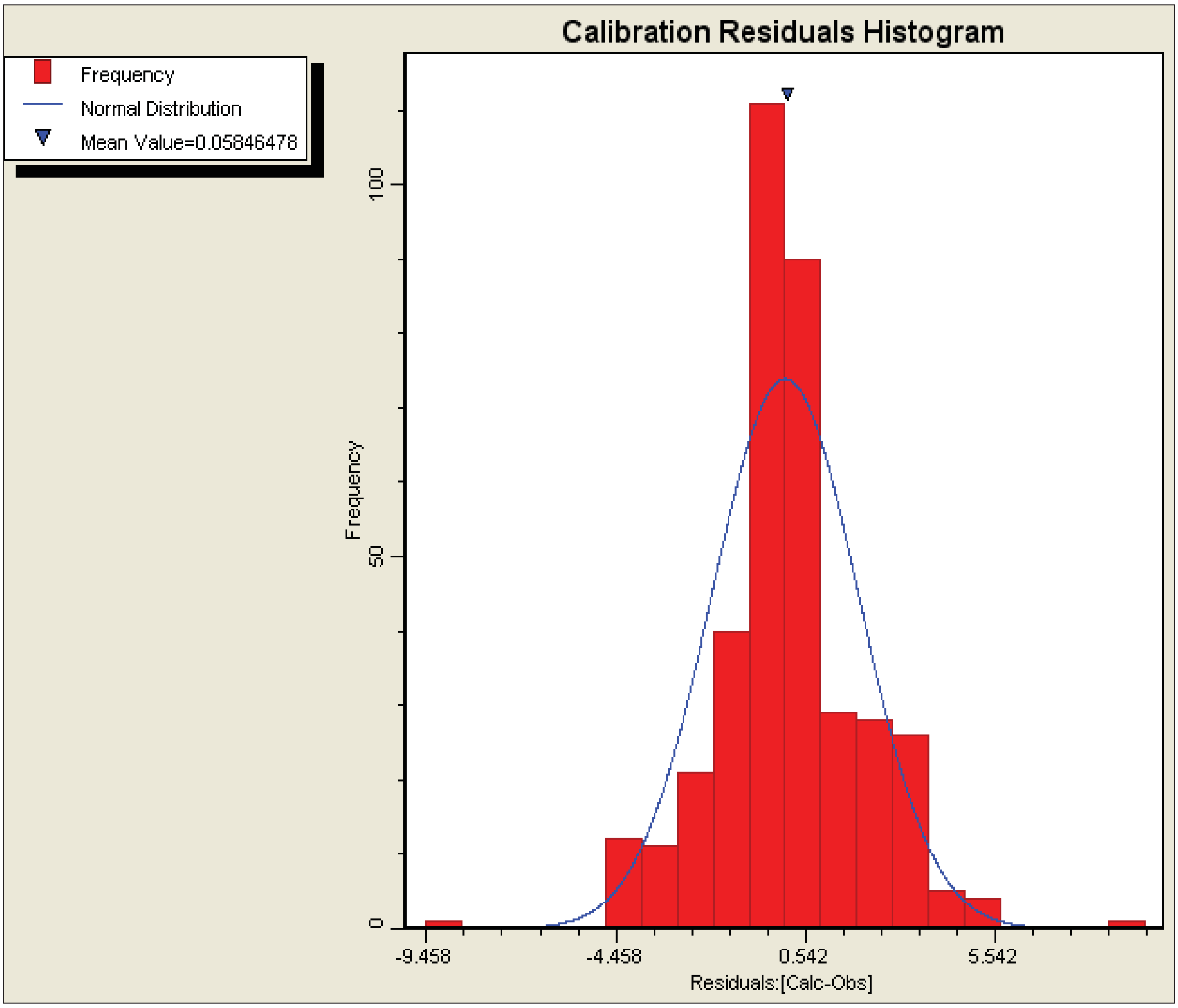


Figure 5-7 Simulated vs Target Heads

A histogram of the residuals is presented in **Figure 5-7**, to provide an assessment of the distribution of errors. Ideally residual errors will be normally distributed around the mean. As indicated, the residual error are a good reflection of the normal distribution and as such do not indicate systematic errors within the model.

The calibrated model potentiometric surface is presented in **Figure 5-8**.

Based upon the statistical and graphic calibration analyses and the confidence in parameters used, the model was considered suitably calibrated for the Project objectives and the predictive simulations.

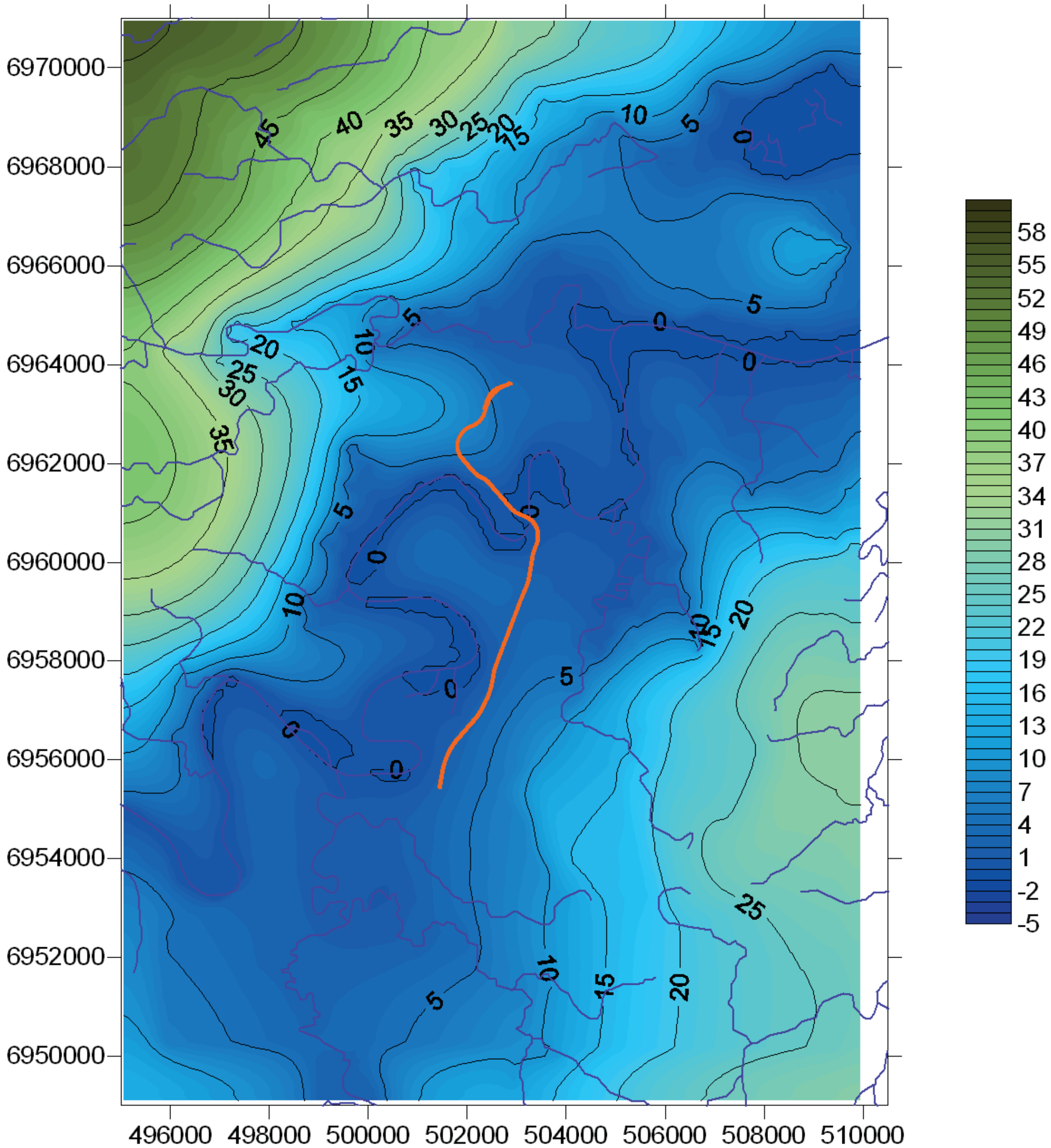


Figure 5-8 **Simulated Potentiometric Surface (m AHD)**

5.2 Groundwater model predictions

During the construction phase of the Project, construction inflow will be dependent upon the number, permeability and position of individual fractures intersected. It is emphasised that there is a possibility of intersecting highly fractured zones during construction which could lead to short term periods of high groundwater inflow rates. It has been advised that any groundwater inflows during construction will be managed using engineering solutions (ie waterproof lining, specified grouting criteria etc.). Based on this, impacts resulting from groundwater inflows into the tunnel during construction are considered to be less than that expected during the operational phase of the Project. Given the likely staged approach to construction and short timeframe of the construction period, impacts are expected to be short term.

5.2.1 Tunnel groundwater Inflow

The groundwater models have been set up to provide an estimate of groundwater inflow into the drained tunnel areas. Predictions of inflow into tunnel areas is provided in **Figure 5-9** below. The early time results for tunnel inflows are variable as excavations progress at different stages and rates. The larger rates are associated with the intial dewatering of the rock, while the lower and smoother portions of the curve are more representative of the long-term inflow rates.

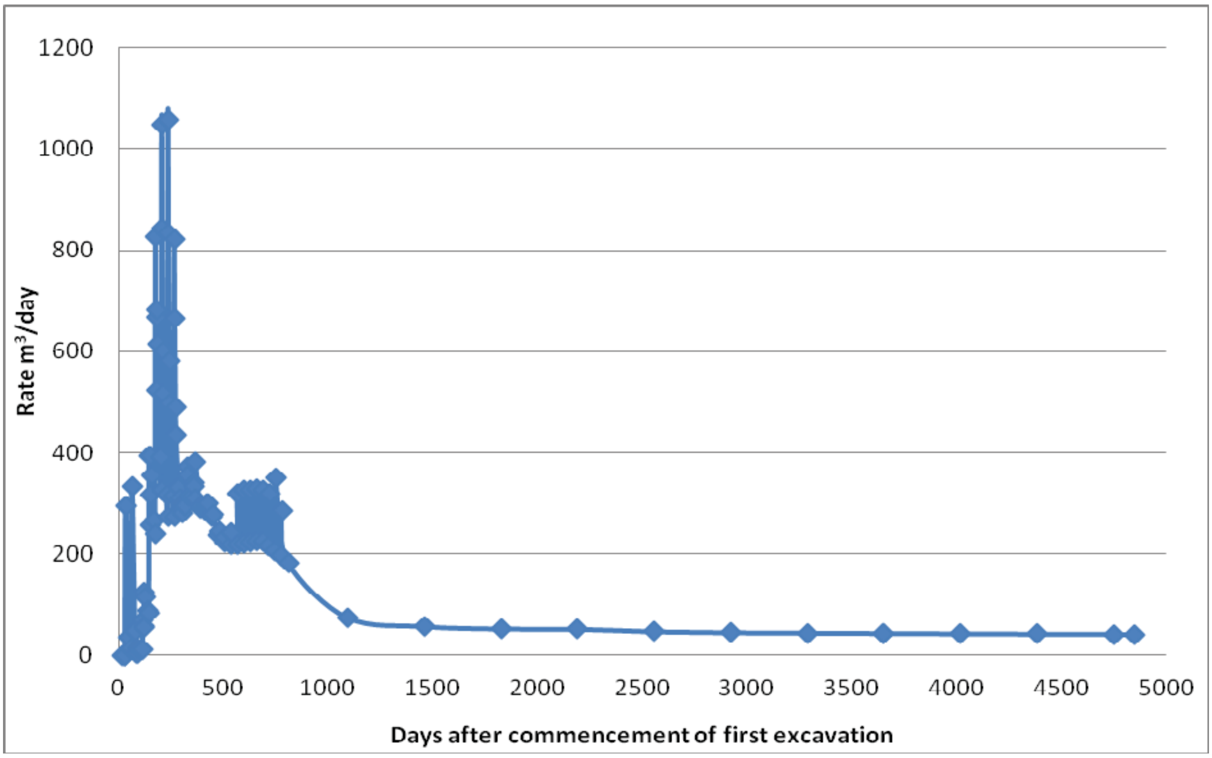


Figure 5-9 Modelled tunnel drain inflows

Based on the above figure, the rate of groundwater inflow into drained sections of the tunnel is shown to decrease over time. The average long-term groundwater inflows for all permanently drained sections of the tunnel approximately 50 m^3/day (0.6 L/s), indicating for all intent and purposes a dry structure.

5.2.2 Groundwater flow

For the operational phase of the Project, groundwater heads have been predicted for 3650 days after the last excavation (4849.5 days). The modelled groundwater heads at 3650 days post construction is shown in **Figure 5-10.**

As expected, the potentiometric surfaces indicate a falling hydraulic gradient towards the Brisbane River during steady state. A review of modelled groundwater heads at 3650 days following construction show that there has been little change in groundwater flow over time. Shallow groundwater ranging from 0 to 5 m exists along the tunnel alignment. Groundwater flow is towards the Brisbane River. No real change to the regional groundwater flow regime is noted.

Locally in drained tunnel areas, steep vertical downward hydraulic gradients are predicted to develop between in the fractured rock aquifer in the proximity to the tunnel. Leakage of groundwater from the alluvial aquifer to the fractured rock aquifer and ultimately to the tunnel itself may result.

River leakage predictions

Drainage of groundwater into the tunnel may cause leakage of water from Brisbane River into the groundwater system and then potentially into the tunnel. Drawdown associated with nearby drained sections (underground stations) of the tunnel is predicted to alter the hydraulic gradient and flow regime of groundwater resulting in potential discharge of saline water into these sections of the tunnel. The groundwater model was set up to simulate river fluxes over time for the Brisbane River within the model domain. **Figure 5-11** provides an overview of the change in predicted river leakage. Modelled 'river leakage out' represents the rate of groundwater flowing into the river (ie baseflow). Modelled 'river leakage in' represents the amount of river water recharging into the groundwater system. Based upon the model results, changes in baseflow and/or increases in leakage from the Brisbane River are expected to be minimal and below detection levels.

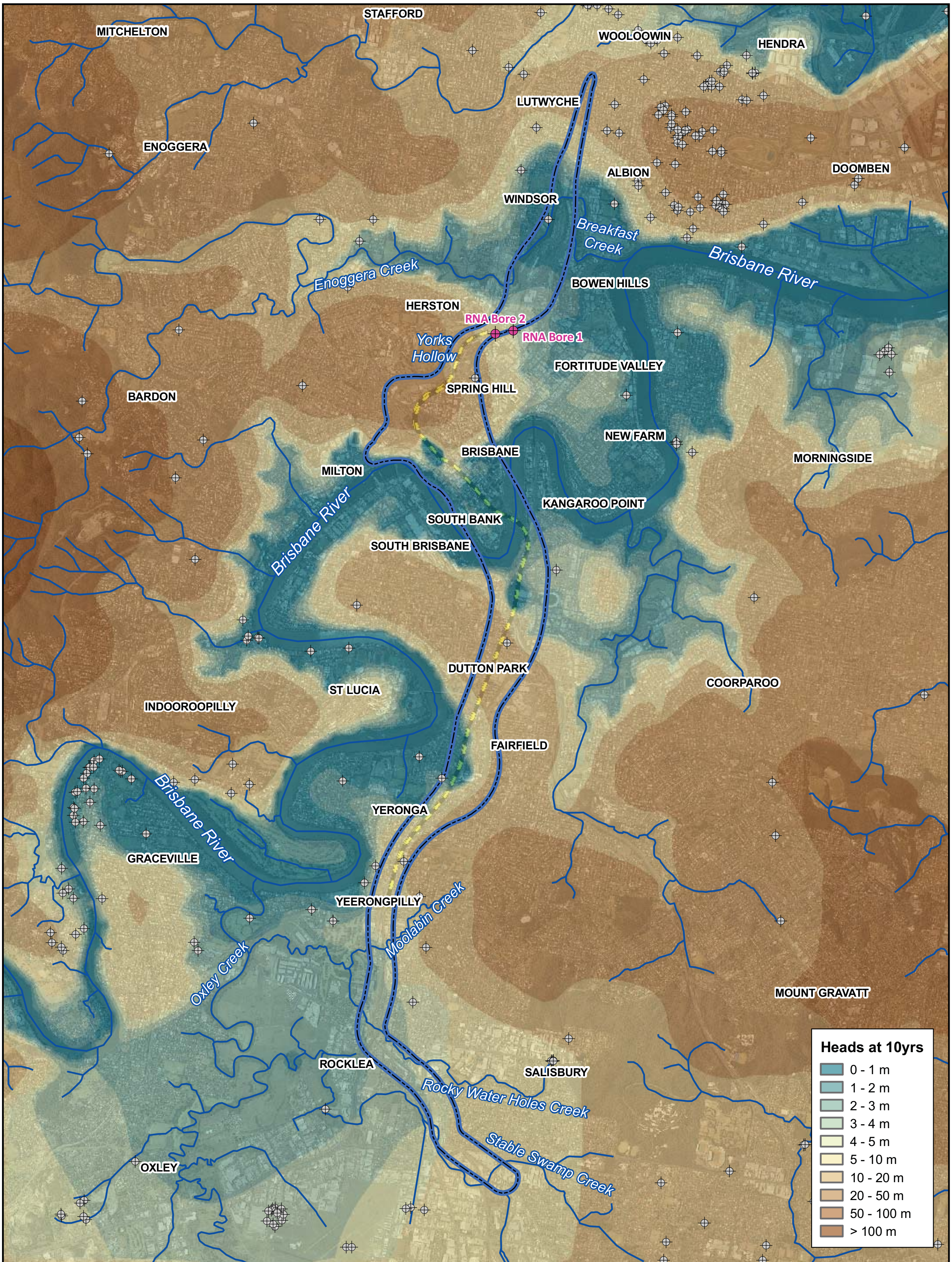
Evapotranspiration (ET)

Groundwater drainage from the tunnel has the potential to impact on groundwater discharge in the form of ET. ET is where groundwater is lost through the combined effects of evaporation from the ground surface and transpiration from the vegetation. A review of the modelled predictions of the change in ET indicates less than 0.1% reduction in ET rates.

Storage

The changes in groundwater storage can make up a substantial portion of a mass balance. Changes in storage relate to the loss and gain of groundwater due to the rise and fall of groundwater levels respectively. Operation of the tunnel results in a decline in groundwater levels and hence changes in storage associated with that decline appear in the model mass balance. An average rate of change in storage during construction is estimated to be 300 m^3/day; while post-construction the average drops to 48 m^3/day.

Changes to river leakage, stream leakage and ET as a result of the Project are considered to be small in comparison to changes to storage.



LEGEND

- Study Corridor
- Tunnel Alignment
- Existing Groundwater Bores
- Extraction Bores
- Watercourse

CROSS RIVER RAIL
ENVIRONMENTAL IMPACT STATEMENT

Figure 5-10

Modelled Heads at time 3650 days (10 years)

0 0.5 1 1.5 2 2.5 km

1:75,000 at A4

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CrossRiverRail

SKM aurecon CRR JOINT VENTURE

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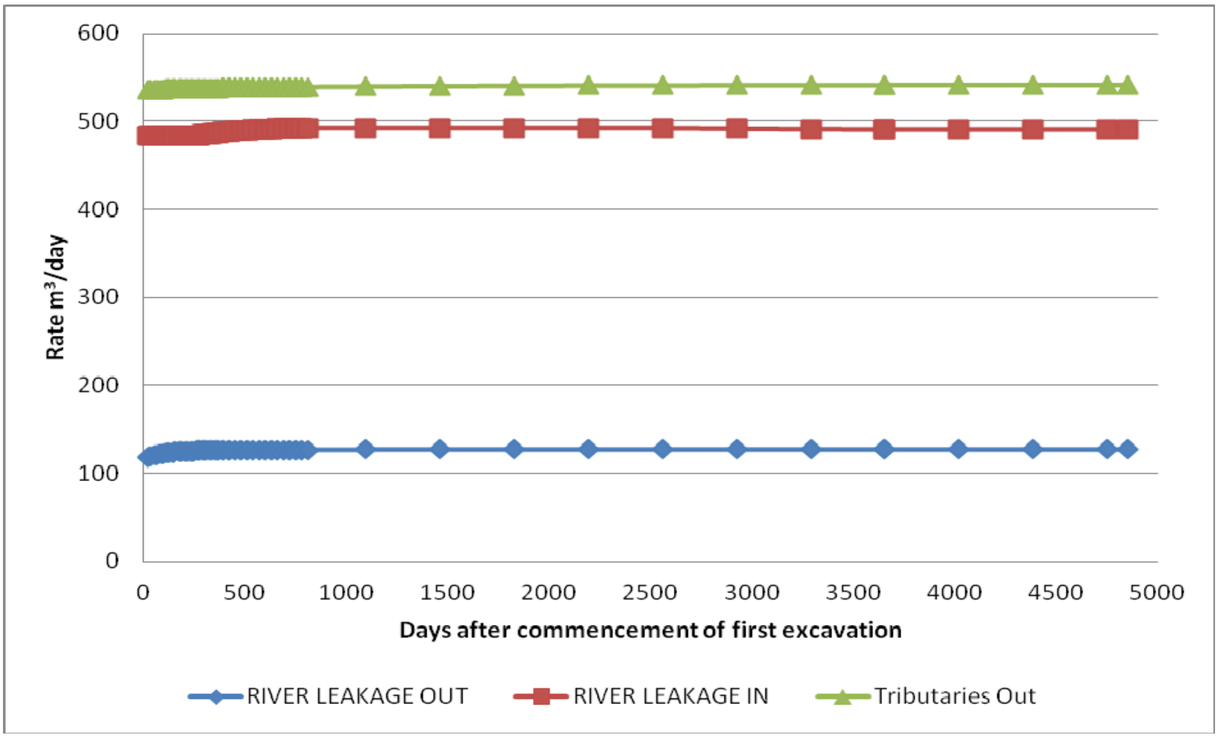

Figure 5-11 Modelled River Leakage

5.2.3 Groundwater drawdown

Groundwater level drawdown has been predicted for 1 year, 5 years and 10 years following tunnel construction and is shown in **Figure 5-12, Figure 5-13** and **Figure 5-14** respectively. Groundwater level drawdown occurs around the drained sections of the tunnel and the station locations. Groundwater modelling results show that groundwater drawdown will occur under areas of alluvium. There is a possibility that shallow alluvial aquifers may exist in these areas. Groundwater drawdown in the underlying rock to drained portions of the tunnel may impact upon groundwater in the shallow alluvial systems.

Settlement resulting from tunnel excavation/construction activities may arise due to:

- elastic ground settlements caused by the excavation of the tunnel
- consolidation settlements caused by dewatering of porous rock formations or compressible soil layers that are hydraulically connected to groundwater drawn down into the tunnel excavations.

A preliminary review of the settlement effects of construction, based on preliminary finite element analyses, empirical relationships between shaft and tunnel depths, ground conditions and with allowances for initial disturbance due to excavation/pile installation is provided in **Chapter 7 Topography, Geology, Geomorphology and Soils**. Higher risk locations include Lower Albert Street station, Woolloongabba station and Boggo Road station.

To minimise the risk associated with settlement, it is important to adhere to suitable engineering practices and ensure that effective management and monitoring methods are implemented and reviewed from the onset of construction. Appropriate mitigation measures would be identified and implemented during the detailed design process. All buildings and structures within the areas where surface settlements and possible damage are predicted, such as Albert Street, would have a building condition survey completed. Surveys and other displacement monitoring would be used to monitor the effects of settlement, if any. Potential impacts and mitigation measures for settlement is discussed in more detail in **Chapter 7 Topography, Geology, Geomorphology and Soils**.

The predicted drawdown for the tunnel sections to the south of the Brisbane River is discussed below. The refinement of drawdown gradation is limited by the coarseness of the model (100 m x 100 m). As such the additional, more refined modelling would occur during the detailed design works to further characterise and assess drawdown propagation based upon site knowledge.

Gabba Station

Groundwater drawdown occurs around the Gabba Station. Groundwater drawdown of 1 to 5 m extends approximately 200 m from the tunnel following 1 year of tunnel operation and increases up to 350 m from the tunnel following 10 years of tunnel operation.

Groundwater drawdown of 5 to 10 m extends approximately 50 m from the tunnel following the first year of tunnel operation. Following 10 years of tunnel operation, the extent of groundwater drawdown increases up to 200 m from the tunnel. Localised areas of 10 to 20 m drawdown within the immediate vicinity of the Gabba Station are predicted following 5 years of tunnel operation.

Fairfield to Southern Portal

Groundwater drawdown within this portion of the tunnel exists along the tunnel alignment between Yeronga and Yeerongpilly. Groundwater drawdown of 1 to 5 m extends approximately 300 m from the tunnel following the first year of tunnel operation. Following 10 years of tunnel operation, groundwater drawdown extends up to 1.5 km from the tunnel.

Groundwater drawdown of greater than 5 m occurs locally within the vicinity of the tunnel. Following the first year of tunnel operation, the extent of groundwater drawdown is approximately 100 m from the tunnel. The extent of groundwater drawdown following 5 years of tunnel operation is approximately 300 m and increases up to 1 km following 10 years of tunnel operation.

Localised drawdown exists at the Fairfield Ventilation Shaft. Groundwater drawdown of 1 to 5 m extends up to 75 m following the first year of tunnel operation. Following the fifth year of tunnel operation groundwater drawdown of 1 to 5 m extends up to 100m. Following 10 years of tunnel operation, groundwater drawdown of 1 to 5 m extends up to approximately 125 m from the shaft. Groundwater drawdown of greater than 5 m occurs locally within the immediate vicinity of the shaft.

Groundwater users

Groundwater observation bores were added into the groundwater model based on the known groundwater extraction bores at RNA showgrounds (RNA Bore 1 and RNA Bore 2). As indicated in the drawdown figures (**Figure 5-12**, **Figure 5-13** and **Figure 5-14**), no discernable drawdown is estimated to occur at these bore locations.

Groundwater contamination

As the extent of the groundwater drawdown cone extends as a consequence of discharge to the tunnel, the potential area in which existing contaminants may potentially be intersected becomes progressively larger. It is important to note that the capture zone is not totally dependent on the drawdown cone. Groundwater may be flowing towards the tunnel alignment regardless of drawdown so would ultimately be captured by the tunnel.

Drawdown has been overlain onto high risk contaminated land areas based on input from **Chapter 8 Contaminated Land**, which is shown in **Figure 5-15**. This figure shows that potentially contaminated land parcels exist within the capture zone of the potential groundwater level drawdown cone resulting from the operation of the tunnel. Whilst the tunnel is constructed in the rock, based on the conceptual hydrogeological model, recharge may occur to the rock from overlying or adjacent alluvium. Based on this, any mobile groundwater contaminants within this capture zone may be expected to ultimately discharge to the proposed tunnel.

LEGEND

- Study Corridor
- Tunnel Alignment
- Existing Groundwater Bores
- Extraction Bores
- Watercourse

CROSS RIVER RAIL
ENVIRONMENTAL IMPACT STATEMENT

Figure 5-12

Modelled Drawdown at 300 days (1 year)

0 0.5 1 1.5 2 2.5 km

1:75,000 at A4

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CRR JOINT VENTURE

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LEGEND

- Study Corridor
- Tunnel Alignment
- Existing Groundwater Bores
- Extraction Bores
- Watercourse

CROSS RIVER RAIL
ENVIRONMENTAL IMPACT STATEMENT

Figure 5-13

Modelled Drawdown at 1800 days (5 years)

0 0.5 1 1.5 2 2.5 km

1:75,000 at A4

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LEGEND

Study Corridor
Tunnel Alignment
Existing Groundwater Bores
Extraction Bores
Watercourse

CROSS RIVER RAIL
ENVIRONMENTAL IMPACT STATEMENT

Figure 5-14

Modelled Drawdown at 3650 days (10 years)

0 0.5 1 1.5 2 2.5 km

1:75,000 at A4

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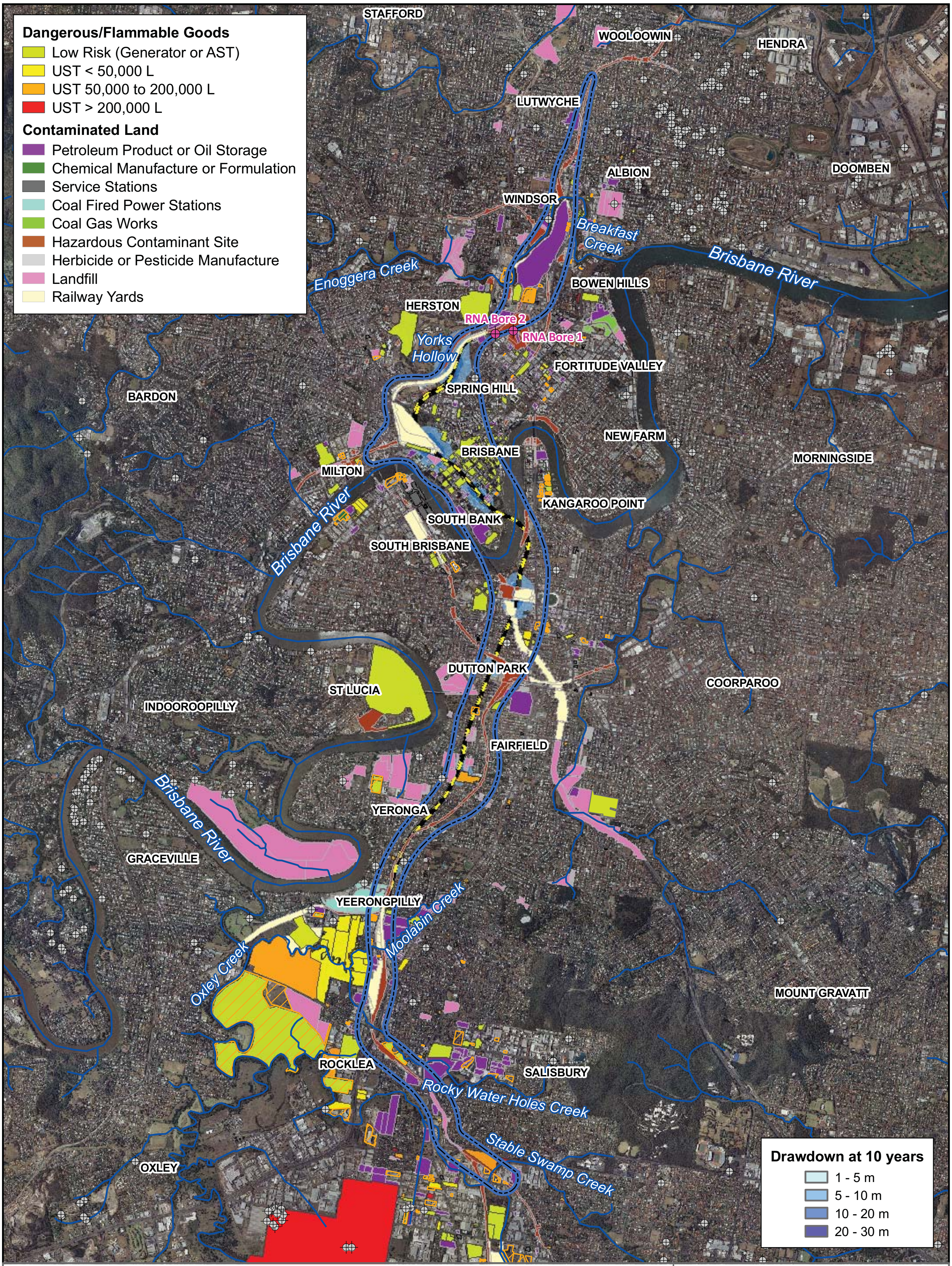

LEGEND

- Study Corridor
- Tunnel Alignment
- Existing Groundwater Bores
- Extraction Bores
- Watercourse
- EMR Low Risk Properties

CROSS RIVER RAIL
ENVIRONMENTAL IMPACT STATEMENT

Figure 5-15

Potential Groundwater Contamination

0 0.5 1 1.5 2 2.5 km

1:75,000 at A4

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SKM aurecon
CRR JOINT VENTURE

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Contaminant travel times will be dependent on the contaminant itself, the distance from the tunnel and the magnitude of the hydraulic gradient towards the tunnels. Particle tracking was simulated as part of groundwater modelling to provide an estimate of contaminant travel times at various locations of the tunnel. A review of modelled pathlines indicates that travel times for potential mobile contaminants range from 1.2 m/year to 7.3 m/year.

On the basis that groundwater inflow to the drained sections of the tunnel is expected to be low, in the order of <1 L/sec, contaminant fluxes would also be correspondingly low. Further discussion on potential impacts and mitigation measures associated with contaminants in groundwater is provided in **Chapter 8 Contaminated Land**.

Potential for land disturbance

Land disturbance as a result of the Project construction will largely be limited to the open trough structures and cut and cover or top down construction areas (Station locations). High rainfall events that coincide with the presence of open cut and cover areas or open troughs may temporarily flood workings and lead to a short period of localised increase in recharge to the aquifer system. In this instance the impacts would be considered minor, localised and of short duration.

Preliminary geotechnical investigations undertaken to date suggest that there is negligible to moderate potential for settlement at each of the station locations except for Albert Street. Drawdown settlement at Albert Street may be higher due to the geological complexities in this area. The reference design has accounted for this by proposing groundwater cut off to rock in all station locations. With this construction methodology, all surface sediments (and alluvium) will be undrained. This is in line with the majority of the basements in the study area.

As discussed in **Section 2.8.2**, it is likely that potential groundwater acidification can occur as a result of dewatering. Areas where potential ASS may exist include Breakfast/ Enoggera Creek, Norman Creek, Oxley Creek and Brisbane River. Given the existing land use and highly developed nature of the study area, groundwater acidification is likely to have occurred to some extent. It is also likely that ASS in some areas has already been excavated and in-filled with fill (clean) material for new developments and hence no longer exists. Nonetheless, the extent of groundwater drawdown will not reach Breakfast/Enoggera Creek, Norman Creek or Oxley Creek. Hence the potential to lower groundwater levels in these areas and expose potential acidic soils is considered negligible. Consequently, the potential to drawdown acidic groundwater is considered negligible in these areas. The extent of drawdown does however extend out to the Brisbane River in some areas. There is potential for groundwater acidification to occur in these areas if ASS materials exist.

Groundwater Dependent Ecosystems

The existence of potential GDEs in the study area is discussed in **Section 2.9**. In general, it is considered that the level of groundwater dependency in the area is likely to be relatively low with terrestrial vegetation, river baseflow systems and aquifer systems potentially utilising groundwater in the saturated zone only during drought conditions where surface water flux is uncommon. **Figure 5-16** provides an overview of the predicted drawdown at 10 years and areas of potential GDE's. Based on this Figure, the following conclusions can be drawn:

- The extent of drawdown (> 1 m) does not reach the Enoggera Creek and is not predicted to impact on potential GDEs associated with Enoggera Creek.
- Whilst the extent of drawdown (> 1m) extends over a small area of the City Botanic Gardens (towards Alice St), the extent of drawdown (> 1 m) is not expected to reach potential GDEs located on the banks of Brisbane River north west of Queensland University of Technology. Hence, impacts to these GDEs are not anticipated.
- Groundwater drawdown (> 1 m) associated with the Gabba Station is predicted to extend over a small area of the banks of Brisbane River towards Kangaroo Point.

- The extent of groundwater drawdown (> 1 m) does not reach the potential GDEs identified through Kookaburra Park near Rocklea, hence impacts to these GDEs are not anticipated.

Groundwater drawdown may impact on GDEs identified within the City Botanic Gardens and Brisbane River areas (as noted above). In addition to this, groundwater modelling indicates that drainage from the tunnel may reduce groundwater discharge in the form of ET. Reduction in evapotranspiration may limit the water availability for vegetation. However, a review of the modelling predictions of the change in evapotranspiration indicates less than a 0.1% reduction in potential evapotranspiration rates. Therefore, the risk of impact(s) is small.

The main species that may be influenced by groundwater are the large remnant Forest red gums. The Brisbane River is saline and tidal in nature. It is anticipated that shallow aquifers within the vicinity of the Brisbane River are also to some extent, brackish to saline. Groundwater levels in these areas are likely to be tidally influenced and the water table is likely to fluctuate accordingly. It is difficult to determine what, if any, influence groundwater plays in the survival of the little remaining remnant trees. It is considered however that the level of groundwater dependency in these areas is likely to be relatively low (opportunistic at best) with only salt tolerant species potentially utilising groundwater in these saturated zone.

LEGEND

- Study Corridor
- Tunnel Alignment
- Existing Groundwater Bores
- Extraction Bores
- Watercourse
- Groundwater Dependent Ecosystem

CROSS RIVER RAIL
ENVIRONMENTAL IMPACT STATEMENT

Figure 5-16

Potential Impacts to Groundwater Dependent Ecosystems

0 0.5 1 1.5 2 2.5 km

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6 Potential groundwater impacts and mitigation assessment

6.1 Groundwater risk assessment

An assessment of risks to groundwater from the Project was undertaken. The objective of the risk assessment was to evaluate groundwater-related risks from the Project; specifically to:

- identify activities that have the potential to impact groundwater
- provide an indication of groundwater risk and vulnerability from operational activities
- prioritise high-risk activities and identify field investigations that might be required to further evaluate specific risks
- define management activities that could be progressively implemented to minimise or mitigate risks to groundwater.

6.1.1 Methodology

A list of potential risks was derived from an assessment of the Reference Design. Following this, each potential risk was evaluated in terms of (i) the probability that the risk might occur and (ii) the consequence to groundwater of the risk eventuating. The outcome of this process was the classification of each identified potential risk into one of the following:

- Extremely high
- High
- Medium
- Low.

Identified potential risks to groundwater included:

- falling groundwater levels associated with potential dewatering
- changes in groundwater quality
- contamination of groundwater
- acidification of groundwater.

The completed risk assessment, including definitions of “probability” and “consequence”, the scoring criteria adopted in the evaluation and descriptions of the rankings are presented in **Appendix A**. The outcome of the risk assessment, including descriptions of the potential risks, the derived risk rankings and mitigation measures, are presented below.

6.1.2 Falling groundwater levels associated with potential dewatering

Overall Risk: Low

Issue: Dewatering activities associated with the tunnel may lower groundwater levels.

Based on the current tunnel reference design, portions of the tunnel and station locations are forecast to be drained in the rock. This indicates that dewatering in these drained sections of the tunnel will be required. Dewatering has the potential to result in groundwater drawdown. As a result, groundwater drawdown has the potential to reduce water availability to neighbouring groundwater users (RNA Bore 1 and RNA Bore 2) and potential GDEs.

Based on results from groundwater modelling, groundwater drawdown in RNA Bore 1 and RNA Bore 2 is considered to be nil and should have a negligible impact on pumping rates. Drawdown may however impact on any unregistered groundwater users within the zone of drawdown.

The extent of groundwater drawdown (> 1 m) is not predicted to extend to the majority of the locations where GDEs may be present. Groundwater drawdown may however occur within small areas of the City Botanic Gardens (towards Alice St) and along the banks of Brisbane River near Kangaroo Point. A slight decline (<0.1%) in groundwater discharge as ET is noted however this is considered to be very small. It is difficult to determine what, if any, influence groundwater plays in the survival of the little remaining remnant trees. It is considered however that the level of groundwater dependency in these areas is likely to be relatively low (opportunistic at best) with only salt tolerant species potentially utilising groundwater in these saturated zone.

Mitigation: A groundwater monitoring program should be put in place to establish baseline groundwater conditions. Groundwater monitoring is discussed in **Section 6.2**. Deviations from seasonal baseline water levels will be assessed and if necessary, mitigation options formulated. It is envisaged that mitigation of any impacts will be depended upon the location of the increased drawdown. Strategies may range from 'do nothing', to an assessment of the extent of the impact and the establishment of mitigation measures such as surface irrigation networks to maintain root zone moisture content levels.

Further study is required to determine the level of groundwater dependency (if any) of the ecosystems identified within the zone of drawdown. It should also be noted that the groundwater model is sensitive to initial groundwater levels and the conductance value that was applied to the Brisbane River. Further hydrogeological investigation should be undertaken (including estimating river conductance) to refine the model accordingly to provide a better representation of groundwater drawdown. If impacts to GDEs are anticipated, then alternative water sources should be sought to sustain plant water requirements in these areas. An irrigation system sourcing mains water may be put in place.

6.1.3 Changes in groundwater quality

Overall Risk: Low

Issue: Dewatering associated with the tunnel may change groundwater quality

The existing beneficial use of groundwater within the study area is considered to be low. Existing groundwater quality in the study area is variable and can be brackish to saline in quality.

Drainage of groundwater into the tunnel may cause approximately 48 m^3/day of saline water from the Brisbane River (EC >20,000µS/cm) to migrate into the aquifer and subsequently into the tunnel. River leakage accounts for only 7% of total groundwater inflow based on a review of the mass balance. This is considered to be low to moderate. In addition to this, the mean daily flow in the Brisbane River is approximately 2300 ML/day. A reduction in flow of 48 m^3/day ie water loss from the river to the groundwater system is considered to be minor (0.001% of daily flow in the Brisbane River). A reduction in groundwater storage accounts for the majority of groundwater inflow.

There is likely to be a brackish groundwater zone that exists adjacent to the Brisbane River. As a result of drainage of groundwater into the tunnel, over time, there is a potential for movement of this brackish zone inland towards the tunnel.

Discharge of saline water to the tunnel has the potential to impact upon the integrity of the tunnel by the corrosion of concrete drains or potential precipitation (scaling) of calcium carbonate contributing to the clogging of concrete drainage systems. Impacts may also occur to the tunnel disposal system being used depending on where groundwater inflows are being discharged and the level of treatment being adopted.

Mitigation: A groundwater monitoring program should be put in place to establish baseline groundwater conditions. Groundwater monitoring is discussed in more detail in **Section 6.2**. It is noted that groundwater quality within the study area is variable and can be brackish to saline in nature. Based on this, it is considered important to characterise the quality of groundwater (beneficial use) within the zone of drawdown to better quantify impacts.

6.1.4 Contamination of groundwater

Overall Risk: Low

Issue: Dewatering associated with the tunnel may result in the migration of contaminated groundwater into the tunnel and/or into areas where groundwater is not contaminated.

The contaminated sites investigation identified the presence of a number of sites with an existing or historical land use with the potential to cause land contamination. It is considered that groundwater is likely to be contaminated in these areas. Any mobile groundwater contaminants within the study area may ultimately discharge to the proposed tunnel. A review of modelled pathlines indicates that travel times for potential mobile contaminants range from 1.2 m/year to 7.3 m/year.

On the basis that groundwater inflow to the tunnels is expected to be low, in the order of <1 L/sec, contaminant fluxes would also be correspondingly low. Further discussion on potential impacts and mitigation measures associated with contaminants in groundwater is provided in **Chapter 8 Contaminated Land**.

Mitigation: A groundwater monitoring program should be put in place to establish baseline groundwater conditions ie characterising existing groundwater contamination in the study corridor. Groundwater monitoring is discussed in **Section 6.2**.

Given the urban setting of the Project and the occurrence of existing basement dewatering and construction sites, it is difficult to ascertain the root cause of groundwater contaminant migration. Nonetheless, a number of mitigation measures are available with reference to the potential for the construction and operation of the tunnel to induce groundwater contamination towards or through adjacent previously uncontaminated sites. Remedial activities or contaminant management strategies may be considered if subsequent investigations at the potentially impacted sites indicate the presence of mobile contaminants within the groundwater system. In the areas where contamination has been already detected, further investigations should be carried out to assess the scale of the contamination.

It is understood that groundwater entering the tunnel will be treated prior to disposal and accordingly, construction of the tunnel will serve to intercept and treat any contaminated groundwater that would otherwise discharge to surface water systems. Treatment systems will need to be designed to handle the type of contaminants that may discharge into the tunnel. In general, therefore, the capturing of contaminated groundwater could have a positive impact on the aquifer and surface water systems.

6.1.5 Acidification of groundwater

Overall Risk: Low

Issue: Dewatering associated with the tunnel may result in groundwater acidification where PASS or ASS is present.

The extent of groundwater drawdown is predicted to extend out to the Brisbane River in some areas. There is the potential to expose potential acidic soils as a result of drawdown in these areas. This may result in the oxidation of PASS. Consequently, the formation of acidic conditions in these areas may result in the acidification of groundwater. Dewatering has the potential to drawdown acidic groundwater into the tunnel within these areas. Acidic groundwater has the potential to impact on concrete and steel structures as well as dissolve metals (eg Fe, As, Mn) from mineral such as sulphides ie create a contaminant plume. There is also potential for acidic groundwater to discharge into the Brisbane River. Groundwater acidification has the potential to impact on the beneficial use of groundwater to unregistered groundwater users and potential GDEs.

Mitigation: A groundwater monitoring program would be put in place to establish baseline groundwater conditions. Groundwater monitoring is discussed in **Section 6.2**.

Further quantification and characterization should be undertaken in drawdown zones within the vicinity of the Brisbane River where areas of PASS or ASS is considered to exist. Once the occurrence of these sites has been confirmed, remediation measures should be put in place to manage the PASS or ASS prior to construction of the tunnel. In the event that any ASS are encountered and disturbed during tunnel excavations, management plans should be put in place to contain these soils.

6.2 Groundwater monitoring program

A network of monitoring bores has been established as part of the Geotechnical Investigations for this Project. A review should be undertaken of available bore construction records and target aquifers to determine the suitability of the monitoring bores installed during the Geotechnical Investigations. There may be a requirement to install additional bores for future investigations. The groundwater monitoring network based on existing bores is summarised in **Table 6-1**.

Table 6-1 Recommended Groundwater Monitoring Network based on Existing Bores

Borehole	Location
CRR101	Cornwall St, Fairfield
CRR102	Cope St, Annerley
CRR201	Roma St
CRR204	Botanic Gardens (River Bank)
CRR207	Kangaroo Point Cliffs (River Bank Park)
CRR208	Land Reserve between Vulture St off-ramp and Vulture St
CRR209	GoPrint Site
CRR210	Boggo Road Busway/ Ecosciences Precinct
CRR211	Land Reserve at corner of Brogham St and Fairfield Rd
CRR212	Land Reserve between Fairfield Rd and Park Rd (North of Ovendean St)
CRR213	Yeronga Park and Ride
CRR214	Car park at the end of Christensen St (Corner of Christensen and Lake St)
CRR216	Boggo Road Busway/ Ecosciences Precinct
CRR217	Railway end of School Road Yeronga
RNA Bore 1	RNA Showgrounds*
RNA Bore 2	RNA Showgrounds*

Note:
**Monitoring of RNA Bores should continue as part of RNA Operations*

Groundwater monitoring prior to the construction phase of the Project should be undertaken in the groundwater monitoring network to establish baseline groundwater conditions. The baseline groundwater data will serve as guideline levels to enable identification of any impacts during the construction and operational phases of the Project. In the event a 'groundwater feature' (eg areas of high groundwater flow/yield) is identified along the Project alignment, detailed groundwater monitoring would be undertaken to characterise the feature and identify potential impacts to the environment. Management measures should be further developed accordingly.

Groundwater monitoring should be undertaken to monitor changes in groundwater levels and quality during construction and operation phases of the Project.

Groundwater levels monitored should be referenced to both m AHD and m BGL. Automated groundwater level data recorders are suggested to be used for groundwater level monitoring. The recommended groundwater quality monitoring should include analysis of parameters identified in **Table 6-2**.

Table 6-2 Groundwater Quality Monitoring Recommendations

Field Chemistry Parameters	Laboratory Chemistry Parameters
pH, Temperature, Electrical Conductivity and Total Dissolved Solids	Ammonia as N, Nitrite, Nitrate, Total Nitrogen as N, Total Phosphorous as P, Arsenic, Cadmium, Chromium, Copper, Nickel, Lead, Zinc, Mercury, Major Cations (Calcium, Magnesium, Sodium and Potassium), Major Anions (Chloride, Sulfate and Alkalinity), Iron, Aluminium, Silver, Antimony, Molybdenum, Selenium, TPH and BTEX

Groundwater level monitoring should be undertaken on a monthly basis for six to twelve months prior to the commencement of the construction phase of the Project. Groundwater quality monitoring should be undertaken on a quarterly basis for six to twelve months prior to the commencement of the construction phase of the Project. During the construction phase of the Project, groundwater level and quality monitoring should be undertaken on a quarterly basis. Groundwater level and quality monitoring should be undertaken 6 monthly during the operational phase of the Project. An annual review of the collected data should be undertaken to identify any impacts and whether ongoing monitoring is required. If any groundwater level or quality deviations from seasonal baseline data are observed, the nature of the impact can be assessed and mitigation measures implemented if necessary. Reference should be made to *Technical Report No. 2 – Contaminated Land,* for management measures proposed in the event of groundwater contamination.

7 Recommendations for further study

The review of the existing hydrogeological environment of the study area and the accompanying impact assessment of the proposed tunnel has identified a range of hydrogeological issues that will require further consideration. This may be achieved by way of further investigations and assessment, implementing appropriate management options or a combination of the two.

It is emphasised that the hydrogeological assessment completed to date has been undertaken by adopting a very broad range of assumptions. A key requirement of the groundwater assessment was the results of the geotechnical investigations. The geotechnical investigations for this Project included:

- installation of groundwater bores
- aquifer pumping tests
- packer permeability tests
- falling head tests
- groundwater levels
- groundwater quality monitoring.

In the absence of the more detailed information, the conceptual and numerical model is based on a relatively small dataset of localised data, so there is a moderate risk that the outcomes of the model could change on a localised basis. However for the objectives of this study, the data available, site specific and databases for other projects, the modelling conducted herein is suitable. More detailed studies will be performed as part of the detailed design phase of the Project which will be able to utilise more site specific field investigations.

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Appendix A – Risk Assessment

Hazard	Cause(s)	Impact(s) without Controls	Groundwater			Comments	Impact(s) after Standard Controls	Groundwater			Action Plan	Person	Assessment
			Con	Prob	HRI			Con	Prob	HRI			
Falling Groundwater Levels	Tunnel Dewatering	Reduction in groundwater availability in neighbouring groundwater extraction bores and GDEs	3	D	10	Groundwater monitoring should be undertaken to establish baseline conditions to adequately assess impacts	Source alternative water supply, deepen existing bores or lower pumps in existing bores to maintain irrigation supply	1	E	20	Groundwater Monitoring Plan	SKM	Adequate
Changes in Groundwater Quality	Tunnel Dewatering	Drainage causes leakage of saline water from Brisbane River into groundwater system and potentially the tunnel. This may impact the beneficial use of the aquifer to groundwater users, GDEs and may impact on tunnel integrity	2	D	14	Groundwater monitoring should be undertaken to establish baseline conditions to adequately assess impacts	Source alternative water supply	1	E	20	Groundwater Monitoring Plan	SKM	Adequate
Groundwater Contamination	Tunnel Dewatering	Drawdown may alter groundwater flow regimes and may cause movement of potentially contaminated water	3	C	6	Groundwater monitoring should be undertaken to establish baseline conditions to adequately assess impacts	Specific remeidation plans put in place once groundwater contaminant and contaminant plume characterised. Treatment of contaminated groundwater inflow into tunnel may be required.	2	E	17	Groundwater Monitoring Plan	SKM	Adequate
Groundwater Acidification	Tunnel Dewatering	Drawdown may expose potentially acidic soils (if they exist) resulting in potental for groundwater acidification in that area	1	D	19	Groundwater monitoring and further characterisation/quantification of the existance of ASS in these areas	Remediation of Potential Acid Sulphate Soils site prior to construction	2	E	17	Groundwater Monitoring Plan	SKM	Adequate

Risk Scoring Criteria

1 Consequence

	Environmental Impact
4	Catastrophic: Significant long term damage to the environment and would be extremely difficult to rectify
3	Critical: Significant short term damage to the environment which would be difficult to rectify.
2	Major: Short term damage to the environment which would be readily rectifiable.
1	Minor: Short term damage to the environment requiring no rectification activities.

2 Probability

	Description	Individual item
A	Frequent	Likely to occur Regularly
B	Probable	Will occur several times in the life of the item.
C	Occasional	Unlikely, but can be reasonably expected to occur in the life of the item.
D	Remote	Unlikely, but possible to occur in the life of the item.
E	Improbable	So unlikely, it may not be experienced.

Risk Ranking Matrix

Hazard / Risk Index (HRI)	Catastrophic 4	Critical 3	Major 2	Minor 1
Frequent A	1	3	7	13
Probable B	2	5	9	16
Occasional C	4	6	11	18
Remote D	8	10	14	19
Improbable E	12	15	17	20

HRI	Risk Level	Risk Acceptability	Acceptability Definitions
1 to 5	Extremely High	Intolerable	The impact would normally be immediately discontinued except in extreme circumstances. The decision to continue impact would almost certainly be made at senior levels, with as much risk management rigour as practicable, unless dire operational needs precluded doing so.
6 to 9	High	Unacceptable	The impact would normally be discontinued as soon as is reasonably practicable. Continued impact would only be considered in exceptional circumstances, and the decision to do so would normally be made at senior levels, after due consideration of the cost versus benefit.
10 to 17	Medium	Acceptable (with continuous review)	The impact is acceptable provided it has been appropriately assessed, has been mitigated to 'As Low As Reasonably Practicable' (ALARP), and is subject to continuous review to ensure the risk does not increase and/or the context does not change. It would be appropriate that measures to achieve long term further reduction to the risk are considered.
18 to 20	Low	Acceptable (with periodic review)	The impact is acceptable, but must be reviewed periodically to ensure the risk does not increase and/or the context does not change.

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CRR JOINT VENTURE