Northern Link

TECHNICAL REPORT 4

GROUNDWATER

- June 2008

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1. Introduction

In 2005, Brisbane City Council completed a prefeasibility study into TransApex – a plan to enhance cross-city travel in Brisbane through the creation of a motorway standard ring road around the Central Business District. The TransApex prefeasibility study identified and investigated five links that would connect existing motorways and major arterials. It concluded that the proposed Northern Link (NL) would provide an important and viable inner-western bypass of Brisbane's Central Business District and inner western suburbs. Specifically, the Link would connect the Western Freeway at Toowong in the west with the Inner City Bypass at Kelvin Grove in the north.

The proposed NL tunnel is a road tunnel that is approximately 5 kilometers in length and connects the Western Freeway (near the Toowong roundabout) with the Inner City Bypass (ICB) (at Kelvin Grove). Tunnel connections are located in the Toowong precinct (at Fredrick Street/Milton Road) and at Kelvin Grove (at Kelvin Grove Road). A locality plan of the NL Project corridor is presented in **Figure 1**.

Construction of the Project has the potential to impact the hydrogeological regime of the area in that groundwater levels may be permanently lowered from their existing levels in areas where the Project tunnel is untanked (i.e. unlined). The lowering of the groundwater levels may lead to settlement in areas of compressive soils, mobilisation of contaminated groundwater towards the tunnel, and reduction in available water for groundwater dependent ecosystems. Groundwater flowing into the tunnel will also need to be pumped with potential environmental impacts dependent upon the groundwater quality and disposal method.

The Sinclair Knight Merz – Connell Wagner Joint Venture was commissioned by Brisbane City Council (BCC) to prepare an Environmental Impact Statement (EIS) for the proposed NL Tunnel Project. The EIS is being undertaken in two stages – the first is aimed at characterising the existing environment in the vicinity of the project investigation 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 addresses the hydrogeological component of these two stages by describing the hydrogeological setting in the NL project area under existing (pre-construction) conditions, together with the potential environmental impacts that may emerge as a consequence of disturbing the hydrogeological regime during tunnel construction and operation.

The report was prepared primarily using data and information recovered as part of independent assessments undertaken within the project area together with the findings of the NL subsurface Geotechnical Investigation Program being undertaken by BCC City Design. The conceptual understanding of groundwater occurrence and processes described in this report form the basis of predictive assessments undertaken as part of the impact assessment phase of the program. It is emphasised that the hydrogeological assessment completed to date has been undertaken by assuming a very broad range of assumptions. The results of the Stage 1 and 2 Geotechnical Investigations whilst valuable in constructing a conceptual hydrogeological model, are limited with respect to the provision of a representative range of hydraulic parameters for application to the numerical modelling assessment. The Stage 3 Geotechnical Investigation (currently ongoing) will be reviewed and referenced to the current hydrogeological model and will be utilised for future hydrogeological analysis and interpretation.

2. Terms of Reference

The Terms of Reference (ToR) for the NL Road Tunnel Project Environment Impact Statement (EIS) were finalised by the Queensland Co-ordinator General in April 2008. Section 5.2 of the ToR relates to groundwater issues and is described as follows:

Description of Existing Environment (Section 5.2.1)

The EIS should review the significance of groundwater in the study corridor and adjacent areas, together with groundwater use that may be affected by the project. The depth and extent of groundwater and flow direction should be identified where possible. All groundwater facilities and resources within the influence of the project should be identified and recorded, with details such as drilling logs, groundwater levels and yields provided.

The review of the significance of groundwater in the study corridor should also include an analysis of the extent of any aquifer with which the project may interfere or from which water may be removed.

The groundwater assessment should take into account the potential to intercept acid sulphate soils, and the findings of the survey for contaminated land sites within or near the study corridor.

The environmental values of the groundwater should be described in terms of:

- *values identified in the Environmental Protection (Water) Policy 1997;*
- *sustainability, including both quality and quantity;*
- *physical integrity, fluvial processes and morphology of groundwater resources; and*
- *the reliability of recharge areas for the groundwater.*

Potential Impacts and Mitigation Measuring (Section 5.2.2)

The EIS is to include an assessment of the potential for environmental impacts to be caused by the project's effect on any existing groundwater regime.

The impact assessment should consider the impacts of the project on groundwater resources; define the extent of the potential area within which groundwater resources are likely to be affected, and the significance of the project to groundwater depletion or recharge. The assessment should take into account the potential impact of the project on any affected groundwater regime including possible alteration of porosity or permeability of any land disturbed. The assessment of these potential impacts should specify any conditions for taking of groundwater. The assessment should also identify any groundwater-dependent ecosystems that may be impacted and the nature of any such impact. Proposed groundwater monitor regimes and any proposed mitigation methods, including the make-up of any reduction in supply from groundwater resources, should be described.

Potential for draw-down of known and potentially contaminated groundwater should be investigated and, if relevant, the identification of measures to manage significant contaminant migration to adjacent and previously uncontaminated sites should be carried out.

This report serves to address Sections 5.2.1 and 5.2.2 of the EIS ToR by providing the description of the existing hydrogeological environment, an assessment of the potential impacts and provision of appropriate mitigation measures. These requirements will be addressed by referencing available groundwater related data, previous tunnelling work conducted within the Brisbane area, geotechnical drilling undertaken as part of the NL Project and data obtained through a review of the Queensland Department of Natural Resources and Water (DNRW) reports and records.

3. Available Information

The following data sources have been considered as part of the hydrogeological assessment:

- The Department of Natural Resources and Water (DNRW) groundwater facility (GWDB) and licensing databases.
- Data reviewed and recovered by Australian Groundwater Environmental Consultants (AGE) for the North South Bypass and Airport Link Tunnel projects.
- Water supply and hydrogeological investigations undertaken by Environmental Hydrology Associates (EHA) at the Botanical Gardens.
- Various geotechnical and contaminated land assessments undertaken (or commissioned) in the locality by BCC City Design.
- Published Geographical Information System (GIS) datasets (topography, geology and aerial photography).
- Field observations and data recovered by SKM.
- Rainfall and evaporation data published by the Bureau of Meteorology (BOM).

The current assessment relied predominantly upon existing data and reports recovered during independent studies, together with the findings of the ongoing subsurface geotechnical and hydrogeological investigation program being conducted by BCC City Design for the NL Tunnel Project.

A discussion is provided below of a number of the key data sources. The results of all the relevant previous investigations have been incorporated into the development of the conceptual hydrogeological model along the length of the proposed tunnel alignment.

Groundwater Database Records (DNRW)

A review of the DNRW groundwater database (GWDB) was undertaken to assess the location and characteristics of registered groundwater facilities within and near the investigation area. The groundwater database contains details of registered bores drilled and constructed by licensed drillers, as is required under the Queensland Water Act (2000). Where recorded, the database includes records of lithological, bore construction, water quality, and hydraulic testing undertaken following construction.

An initial search of the GWDB within a 10 kilometres radius of the investigation area identified 21 registered groundwater facilities. Most of these facilities were located at the periphery of the search area (several kilometres away from the investigation area). Within a smaller radius of 5 kilometres, 12 registered facilities were identified.

A separate review of the DNRW licensing database was undertaken to investigate whether registered bores in the vicinity of the study corridor had established groundwater allocation entitlements. In general, DNRW only impose allocation limits where groundwater extraction or disturbance is undertaken for non-stock and domestic purposes within a designated Groundwater Management Unit (GMU) under a Water Resources Plan. The project area and surrounds are not located within a GMU and there were no bores with allocation entitlements identified as part of this study.

Inner City Bypass Geotechnical Investigation (BCC City Design, 1999)

City Design Geotechnical and Environmental Engineering Group conducted a geotechnical investigation as part of the Inner City Bypass (ICB) project. The study was designed to acquire data and information to assist with the preliminary project design with a particular focus on the Kelvin Grove Road area (the north-western extent of the investigation area). The report included details of the local geology, associated geotechnical properties and groundwater occurrence and levels within the Neranleigh-Fernvale Beds.

Relief Drainage Geotechnical Investigations (BCC City Design, 2000, 2001 and 2002)

City Design has undertaken a series of subsurface investigations within and near the study corridor. Information acquired as part of these investigations includes test pitting records, geological and geotechnical borehole logging, hydrochemistry and other details of groundwater occurrence.

Toowong Bus Depot Contamination Assessment (BCC City Design, 2002)

City Design conducted a contaminated land and groundwater assessment for fuel line leakage at the Toowong Bus Depot (Miskin Street, Toowong) in 2002.

NSBT EIS (Australasian Groundwater & Environment Consultants, 2004)

In October 2004, Australasian Groundwater & Environment (AGE) reported on findings from a study to assess potential hydrogeological impacts in response to construction of the North-South Bypass Tunnel (NSBT). During their investigation AGE (2004) completed a review of available hydrogeologic data, developed a conceptual hydrogeologic model and utilised a numerical groundwater flow model to quantify potential impacts.

Key modelling outcomes from their study were:

- The modelled long term inflow rate for the tunnel is approximately 5L/s.
- Drawdown occurs predominantly in the untanked (unlined) road header sections of the tunnel, though drawdown is also evident at areas where the cross passages are unlined;
- Groundwater level drawdown is greatest at the deeper parts of the tunnel, that is, at the northern point of the Kangaroo Point peninsula.
- A quasi-steady-state drawdown condition is achieved within 5 years of construction of the tunnel. Development of the drawdown depression along the tunnel axis subsequent to this time is very slow.
- The drawdown, as defined by the 1 metre drawdown contour extends at most approximately 1 kilometre from the tunnel alignment. This extent is apparent in three

directions: through East Brisbane, to the west of the tunnel towards Highgate Hill and at the northern end of the tunnel towards Spring Hill.

- Groundwater within the area of influence of the tunnel will not be “depleted”, rather the water level will be lowered and the degree of recharge enhanced. The increased potential for recharge will slightly reduce volumes of rainfall runoff from impacted areas, however, due to the low volumes this is considered inconsequential.
- Land disturbance, as a result of the tunnel construction, will be limited to the portal and vent shaft areas. These areas are above the water table and as such, impacts on any groundwater regime are expected to be minor.
- The untanked portions of the tunnel (below the water table) will always act as a groundwater sink, and will draw water with the groundwater capture zone towards the tunnel.

NL Preliminary (Stage 1) Geotechnical Investigations (BCC City Design, 2004)

City Design undertook a preliminary geotechnical investigation (later referred to as Stage 1) along an initial proposed NL alignment to characterise geological and geotechnical conditions and assist in guiding the implementation of future subsurface investigations. The report also incorporated drilling results from the Hale Street Bridge and the rail corridor tunnel option assessment program. In total seven boreholes were drilled along the current alignment including several others along another route under consideration at the time. Borehole locations included in the City Design (2004) assessment are presented in **Figure 2**.

Airport Link EIS (Australasian Groundwater & Environment Consultants, 2006)

AGE was commissioned by the SKM – Connell Wagner Joint Venture to undertake hydrogeological investigations for the Airport Link (AL) EIS assessment. During this investigation AGE conducted a series of field and desktop hydrogeological assessments (in conjunction with the geotechnical assessments) to define the hydrogeological regime in the respective project areas.

As the NL project will encounter similar geological (and potentially, hydrogeological) conditions to the AL and NSBT projects a subset of the AGE (2004, 2006) data was employed to assist with characterisation of the NL investigation area.

Key model outcomes from their study were:

- Due to a very low permeable hardrock, the drawdown for the north-south driven tunnels continues to extend over the following decades.
- The modelled long-term seepage inflow rate for the tunnel was estimated to be approximately 8 L/s.
- Water level drawdown occurs predominantly at the untanked (unlined) road header sections, cut and cover tunnels and at the deeper transition structures.

- Water level drawdown as a result of the Project is aligned about the Project axis and is greatest at the deeper parts of the Project, that is, at the north-south bound driven tunnels, where a drawdown of up to 45 metres is predicted.
- For the hardrock aquifers, a quasi-steady- state drawdown condition is achieved within 20 years of construction of the Project.
- No inflow (seepage) is derived from the Brisbane River or Breakfast/Enoggera Creek. Hence, the long-term groundwater inflow to the tunnel is met mainly by infiltration of rainfall over the remainder of the area.

Mt Coot-tha Botanic Gardens, Toowong Dam Investigation (City Design, 2006)

A new retention basin is proposed in the eastern corner of the Mt Coot-tha Botanic Gardens, Toowong, adjacent to the city end of the Western Freeway. It is proposed that an earth embankment dam be constructed across the stream and that flows from a second, subparallel, drainage excavation to the south also be piped to the basin. Deepening of the basin area, for the purposes of increasing its storage capacity is also being considered.

Groundwater conditions at the site were investigated by excavating seven test pits. Four were located along the centre line of the proposed embankment and three at the upstream end of the proposed basin.

Botanical Gardens Hydrogeological Assessment (Environmental Hydrology Associates, 2007)

Environmental Hydrology Associates (EHA) undertook a hydrogeological investigation within the Botanical Gardens seeking groundwater for irrigation of the Botanic Gardens. This investigation was an adjunct to the Brisbane Aquifers Project which represents a broad scale investigation being undertaken on behalf of BCC to identify groundwater resources within the Brisbane Metropolitan area.

As part of the assessment three pilot boreholes were constructed into the Bunya Phyllite at the eastern extent of the Botanical Gardens. One of the installed boreholes produced groundwater yields sufficient for long-term irrigation purposes (approximately 3 L/s) and was subsequently completed as a production bore to a total depth of 70 metres. The water bearing interval encountered during drilling corresponded to a heavily fractured schistose zone. Groundwater encountered during drilling was slightly brackish and some purification was deemed necessary prior to irrigation use.

Following the completion of bore installation a 36 hour constant rate pumping test was undertaken to determine the hydraulic properties of the aquifer and changes in groundwater quality over time.

Mt Coot-tha Stormwater Harvesting – Planning Report (City Design, September 2007)

The planning report presents the planning framework for implementation of the *Water for today and tomorrow strategy* for the proposed 18 Megalitre stormwater harvesting facility at Mt Coo-tha

Botanic Gardens. The proposed water supply is demonstrated to be cost effective, local, reliable and a low energy source of water for the Gardens.

NL Stage 2 Geotechnical Investigations (BCC City Design, 2008)

As part of the Northern Link Feasibility Design, Major Infrastructure Projects Office commissioned City Design to undertake a second stage geotechnical investigation. The Stage 2 investigation carried out between October 2007 and February 2008 consisted of 25 boreholes (designated NL2-01 to NL2-25) as illustrated in **Figure 3**.

The borehole testing consisted of Standard Penetration Testing (SPT's) of the soil horizons, and water pressure testing (Packer Testing) and RAAX Imagery in the rock horizons in nominated boreholes. Standpipes were installed in fourteen of the boreholes. Finally, laboratory testing for the investigation consisted of the following tests: Unconfined Compressive Strengths (UCS) on selected rock core samples and Point Load Index testing (Is(50)) of rock core.

NL Stage 3 Geotechnical Investigations (BCC City Design, 2008 ongoing)

Results from the Stage 3 geotechnical investigation (Report not available at completion of EIS) will contribute to findings from an ongoing geotechnical programme. Ongoing programmes will provide an opportunity to acquire site specific hydrogeological data from across the Northern Link Project area. From a hydrogeological perspective, particular tasks of Stage 3 will include:

- further definition of the extent of Quaternary age alluvium and competent rock in the trough zones and transitions from cut and cover to driven tunnel at each end of the tunnel;
- characterisation of a possibly faulted interface (the Normanby Fault) of unknown orientation between geological formations at the northern end of the route;
- drilling infill boreholes for rock characterisation between some of the broadly spaced Stage 1 and Stage 2 boreholes;
- investigation of a zone of major lineament intersections in the Fernberg Road – Ellena Street area with regard to rock fracturing and groundwater;
- installation of downhole groundwater monitoring facilities in selected boreholes;
- investigation and characterisation of groundwater conditions in the Quaternary alluvium in the cut and cover zone at the western end of the tunnel; and
- performing lugeon packer tests through nominated zones within specified boreholes.

The boreholes constituting the Stage 3 investigation program are illustrated in **Figure 4**.

4. 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. It should be noted that the geological setting of the investigation area reported elsewhere in this EIS describes the framework upon which this conceptualisation is based.

4.1 Physiography

Drainage and Topography

The NL Project area is situated in the inner western suburbs of Brisbane and includes the suburbs of Toowong, Auchenflower, Milton, Paddington, Red Hill, Kelvin Grove and Herston (**Figure 5**).

The topography of the Northern Link study corridor is characterised by a series of steep ridges and spurs dissected by linear valleys. Maximum ground surface elevations within the corridor range from approximately 70 metres above Australian Height Datum (m AHD) near the intersection of Musgrave Road and Kelvin Grove Road (outside of the eastern NL tunnel area) and 50 m AHD near the Frederick Street – Birdwood Terrace intersection (within the western NL tunnel area). The proposed portal locations of the NL tunnel are at elevations of approximately 20 m AHD at the Toowong portal and 25 m AHD at the Herston portal (at Kelvin Grove Road, near the Inner City Bypass).

From the proposed NL tunnel, ground surfaces rise toward the west and northwest and fall toward the east and southeast (i.e. along the Brisbane River). The topography across the NL Project area is presented in **Figure 5**.

The NL Project area is within the Lower Brisbane River Catchment that hosts a number of surface water tributaries (i.e. Bellbowrie, Breakfast, Bulimba, Cubberla and Enoggera Creeks). Within the immediate vicinity of the NL Project area, most surface waters are drained via Toowong Creek (south of and in separate catchment from the western portals) and Enoggera Creek (north of the eastern portals).

Within the Brisbane River Catchment, the proposed NL tunnel straddles two smaller subcatchment areas. These subcatchment areas are drained by a number of small creeks that empty into the Brisbane River (**Figure 6**). The subcatchment areas are informally referred to as the:

- Brisbane subcatchment (includes most of the mainline NL tunnel); and
- Enoggera Creek subcatchment (includes the eastern most extent of the NL tunnel).

Rainfall

The Brisbane area is characterised by a sub-tropical climate. Rainfall can be received in any month; however, there is a predominance of rainfall throughout the summer months. The mean annual rainfall in proximity to the site is approximately 1,090 mm/annum (Toowong Bowls Club, rainfall gauge # 040245).

Geomorphology

Geomorphology within the NL Project area is dominated by the Mt Coot-tha massif toward the west. Mt Coot-tha owes its elevation to the intrusion of the Late Triassic Enoggera Granite. This intrusion has been uncovered by erosion at the northern end of Mt Coot-tha where the granite has been quarried at The Gap and at Keperra. Although it is not evident at the southern part of Mt Coot-tha, the granite lies very close to ground surface as evidenced by hornfels at the Mt Coot-tha Quarry.

The Mt Coot-tha granite was formed when the country rock was heated from the molten granite cauldron before it was cooled and crystallised. The application of excessive heat resulted in the hardening of rock above the granite intrusion. This contributed to the Mt Coot-tha massif being more resistant to weathering, and thus it has retained its elevation since formation. Over many eons, weathering has resulted in the development of a (generally) radial drainage system whereby less resistant rocks were weathered and transported to downstream locations and ultimately into the Brisbane River.

Soils within the various subcatchments are largely derived from the geologic unit, the Bunya Phyllite. Exposed road cuttings demonstrate that most soils are very thin. The thinness of these soils is likely to be a response to water erosion where soils have been removed and transported from higher to lower elevations.

Within low landscape areas are significant deposits of alluvium. The alluvium is mapped along the Brisbane River as well as within the subcatchment valleys. Within the NL Project corridor, the largest accumulation of alluvium lies within the vicinity of the Brisbane Botanic Gardens; near the Toowong portal. Recent drill results (City Design, 2008b) indicate that recent clayey soils and alluvium deposits are up to approximately 10 metres thick.

4.2 Soils

Quaternary alluvial sediments that reside adjacent to the Brisbane River were deposited in response to a sequence of events that includes the lowering of sea levels, erosional downcutting by the Brisbane River (and its tributaries) and the subsequent rise of sea levels. During the period of rising sea levels, alluvium was deposited in the flooded erosional channels. Available information shows that virtually all alluvial deposits consist of undifferentiated gravel, sand, silt, mud and clay; without indicating whether they were laid down under marine or freshwater conditions. The extent of alluvial sediments within the tributary drainages of the Brisbane River is shown on Figure 8.

Figure 7 illustrates the distribution of the different soil types within the project corridor.

Based on extensive geomorphological research, Cranfield et al. (1976) considered that along the southeastern Queensland coastline the present sea level is approximately 3 metres below the highest known sea level. It therefore appears that extensive sediments located in the valley of Moggill Creek (at Brookfield) and the valley of Cedar Creek (at Ferny Grove and Upper Kedron) were deposited as braided stream deposits in a non-marine environment at elevations exceeding those of early marine influences.

Alluvium located within the small subcatchment drainage areas of the NL Project area were likely to have been deposited in response to rainfall erosional events and the redistribution of surface soils from the hilly terrain of the Bunya Phyllite. The potential for Acid Sulphate Soils (ASS) to occur within these Quaternary age alluvium deposits is assessed as relatively low (DNR map (2002) of ASS distribution).

The area of alluvium that resides within the vicinity of Cribb Street, Suncorp Stadium and Given Terrace should be considered to be anthropogenic fill that was probably derived from freshwater (at least until 1859) marshy sediments. The area of the Frederick Street/Dean Street/Miskin Street intersection is at elevations exceeding 10 m AHD. In consideration of this elevation, these soils lie above previous marine influences and are not considered to be potentially harbouring ASS.

4.3 Groundwater Occurrence

Groundwater occurrence within the project area is associated with the following hydrostratigraphic units:

- The Bunya Phyllite
- The Neranleigh Fernvale Beds
- Unconsolidated terrestrial alluvial/colluvial sediments derived from weathering and erosion of elevated Bunya Phyllite and lower terrace alluvial sequences associated with the Brisbane River.

The geological setting in proximity to the tunnel corridor is presented in **Figure 8**. Each unit is described in detail below.

Bunya Phyllite

The Devonian–Carboniferous age Bunya Phyllite underlies a significant proportion of the investigation area and forms much of the relief in the study corridor. The outcrop zone trends in a north-northwest direction and contacts the Neranleigh-Fernvale Beds on both sides. The Bunya Phyllite is inferred to be comprised of regionally metamorphosed (greenschist phase) and locally fractured metasediments which specifically include fine to medium grained quartz-sericite-chlorite phyllites (City Design, 2004; EHA, 2006).

The generally accepted view concerning the stratigraphic relationship between the two rock formations is that the Bunya Phyllite is folded in a broad antiformal structure with an axis near Mt Coot-tha and that there are thrust faults or steep normal faults along the boundaries with the apparently younger overlying Neranleigh-Fernvale Beds. These boundary faults are referred to as the Normanby Fault in the Red Hill – Kelvin Grove area and the Kenmore Fault in the west.

The Bunya Phyllite possesses negligible primary porosity with groundwater occurrence limited to zones of secondary porosity associated with localised structural defects. Relatively ‘clean’ fractures encountered at depth have the highest groundwater potential. However these are typically not interconnected or regionally extensive. At shallower depths within the profile, preferential weathering is typically associated with structural defects and results in the production of clayey gouge materials which infill joints and fractures in saprolitic horizons (EHA, 2005).

Groundwater within the Bunya Phyllite is likely to be semi-confined or confined due to the laterally and vertically discontinuous nature of zones of structural deformation. During the initial geotechnical drilling program artesian conditions were encountered at depths of 20 metres below ground level near the Botanical Gardens. Standing water levels at this location following equilibration were reported at 1.3 maGL[1].

Neraneligh-Fernvale Beds

The Devonian-Carboniferous age Neranleigh-Fernvale Beds underlie the north-eastern portion of the investigation area and are predominantly comprised of metasediments and metavolcanics which have been tightly folded and steeply inclined (City Design, 2004). These beds are comprised of fine to medium grained metamorphosed marine sediments (greywacke, chert, shale and quartzite) with occasional marine volcanics (andesites and tuffs) and brecciated zones; (City Design, 2004; Swann, 1997). Slightly to highly weathered zones are typically associated with outcrops and the palaeosurface of the Neranleigh-Fernvale Beds. These zones are generally overlain by medium to heavy residual clays.

Groundwater occurrence within the Neranleigh-Fernvale beds is typically limited to secondary porosity associated with localised zones of structural deformation. City Design (2004) described defects within this unit as being of foliation parting, infill seams, weathered seams, shear zones and crushed seams.

The bulk permeability of the Neranleigh-Fernvale beds is likely to vary both spatially and with depth as a function of geology and structural integrity. Packer (Lugeon) testing undertaken by AGE (2004, 2006) suggests that the in-situ hydraulic conductivity of this formation is low with hydraulic conductivities typically in the order of $<10^{-9}$ to 10^{-6} m/s.

4.3.1 Alluvium

Minor surficial deposits of Quaternary alluvium are present near the portals at each end of the tunnel. These sedimentary sequences are typically associated with topographical depressions in the bedrock surface (representing deeply incised stream channels) which have infilled with alluvium and colluvium derived predominantly from weathering and erosion of the Bunya Phyllite. These shallow sedimentary deposits comprise heterogeneous sequences of intercalated sandy and gravely clays, silts and sandy gravels.

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

[1] maGL = metres above ground level.

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. These Holocene deposits, which were deposited in estuarine conditions, are often associated with acid sulphate potential. Typically the Holocene alluvium occurs below a relative level of +5 m AHD.

Groundwater potential in the alluvial aquifers is inherently related to their depositional characteristics and parent material. 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.

No direct field measurements were conducted for the alluvial deposits in the Airport Link investigations (AGE, 2004). This study assumed various hydraulic parameters for the alluvium based on lithological descriptions and the results of initial computer simulation runs. For the recent alluvium, covering mostly the Kedron Brook and Enoggera Creek areas in proximity to the proposed Airport Link tunnel, a value of 2.7 m/day (3.16×10^{-5} m/s) was estimated while for the more clayey older alluvium this value was reduced to 0.75 m/day (8.67×10^{-6} m/s). Tidal deposits along the western border of the model were assumed to possess a similar low hydraulic conductivity.

4.3.2 Fill Material

Anthropogenic fill materials occur throughout the study area and are predominantly associated with areas of urban development. Previous assessments within the investigation area have identified moderately transmissive and localised perched aquifer systems in these materials. The hydrogeological characteristics of these deposits are dependent upon composition, source and degree of compaction. Accordingly, the deposits are likely to vary significantly.

4.4 Groundwater Levels

Broad trends in groundwater levels for the hydrogeological units can be inferred from results recovered during the various geotechnical and groundwater drilling programs undertaken. These are summarised in the following section.

4.4.1 Fractured Rock Aquifers

Depth to groundwater within the basement rocks varies spatially across the study area but is generally between 3 and 10 metres below ground level (mbgl) within the Bunya Phyllite and Neranleigh-Fernvale beds, respectively (**Table 1**). Locally, artesian heads have been observed within the Bunya Phyllite (M1C-A) with the potentiometric surface (groundwater level) being recorded above the natural surface. Depths to watertable of greater than 10 metres have been recorded at localities of elevated topography (i.e. at NL2-06 and NL2-13; **Table 1**).

No long term hydrographs exhibiting changes in groundwater level over time were available for the basement rock aquifers. Groundwater levels are however likely to respond rapidly to rainfall recharge downslope of topographically elevated areas and where deep drainage from water supply infrastructure (i.e. mains, stormwater) and drainage lines occurs. Groundwater recharge is likely to be influenced by permeability, fracture connectivity and is, in most instances, probably slow and tortuous.

- **Table 1 Groundwater Level Recorded in the Fractured Basement Rocks (between 2000 and 2008)**

Borehole	Rock Unit	Water Level Depth (mbGL)	Water Level Elevation (MAHD)	Data Source
BH7	Weathered Bunya Phyllite	3.90	0.10	City Design, 2000
MW2(d)	Weathered Bunya Phyllite	4.88	13.44	City Design, 2002
MW5	Weathered Bunya Phyllite	3.25	14.21	City Design, 2002
MW9	Weathered Bunya Phyllite	4.34	14.66	City Design, 2002
MW13	Weathered Bunya Phyllite	4.51	11.02	City Design, 2002
MW6	Residual Soil (Bunya Phyllite)	6.11	12.66	City Design, 2002
MW3D	Residual Soil (Bunya Phyllite)	5.96	12.53	City Design, 2002
EW-1	Bunya Phyllite	5.00	7.00	City Design, 2004
M1C-A	Buyan Phyllite	-1.30		EHA, 2007
NL2-01	Bunya Phyllite	0.00	22.67	City Design, 2008b
NL2-02	Bunya Phyllite	6.43	19.35	City Design, 2008b
NL2-03	Bunya Phyllite	12.49	16.91	City Design, 2008b
NL2-06	Spilite	20.70	43.23	City Design, 2008b
NL2-09	Spilite	6.70	34.66	City Design, 2008b
NL2-10	Alluvium / Neranleigh-Fernvale Beds	5.80	28.89	City Design, 2008b
NL2-12	Bunya Phyllite	6.09	19.98	City Design, 2008b
NL2-13	Bunya Phyllite	13.36	42.98	City Design, 2008b
NL2-15	Bunya Phyllite	9.16	5.82	City Design, 2008b
NL2-19D	Bunya Phyllite	-0.55	21.49	City Design, 2008b

4.4.2 Alluvial Aquifers

Groundwater levels recovered from bores and test pits constructed in alluvium are relatively shallow ranging from 0.5 to 5.8 mbgl (**Table 2**). Groundwater recharge to these areas is likely to be relatively rapid following rainfall events and is expected to gradually decline following cessation due to evapotranspiration.

- **Table 2 Groundwater Levels Recorded in Alluvial Sediments (between 1999 and 2008)**

Borehole	Rock Unit	Water Level Depth (mbGL)	Water Level Elevation (MAHD)	Data Source
IC7	Alluvium	2.60	8.00	City Design, 1999
IC8	Alluvium	4.50	13.80	City Design, 1999
IC9	Alluvium	3.20	15.80	City Design, 1999
IC11	Alluvium	3.00	19.30	City Design, 1999

Borehole	Rock Unit	Water Level Depth (mbGL)	Water Level Elevation (MAHD)	Data Source
IC12	Alluvium	3.00	7.40	City Design, 1999
BW24	Alluvium	3.20	19.20	City Design, 1999
BW28	Alluvium	2.40	24.40	City Design, 1999
BH1	Alluvium overlying Bunya Phyllite	2.40	0.60	City Design, 2000
BH4	Alluvium	2.10	0.60	City Design, 2000
BH5	Alluvium	2.10	0.40	City Design, 2000
BH6	Alluvium	2.00	0.50	City Design, 2000
NLM1	Alluvium overlying Bunya Phyllite	2.00	0.10	City Design, 2004
NLR2	Alluvium overlying Bunya Phyllite	1.50	1.20	City Design, 2004
NLR4	Alluvium overlying Bunya Phyllite	2.50	0.30	City Design, 2004
NL3	Alluvium overlying Bunya Phyllite	3.00	0.40	City Design, 2004
MW4S	Alluvium/Residual soil	5.84	12.52	City Design, 2006
MW12	Alluvium overlying Bunya Phyllite	3.74	10.60	City Design, 2006
MW13S	Alluvium overlying Bunya Phyllite	3.47	12.02	City Design, 2006
MW14	Alluvium overlying Bunya Phyllite	4.25	12.32	City Design, 2006
NL2-17	Alluvium	1.45	20.75	City Design, 2008b
NL2-19S	Alluvium	1.25	19.70	City Design, 2008b
NL2-22	Alluvium	1.80	20.76	City Design, 2008b
NL2-23	Alluvium	0.52	20.34	City Design, 2008b

4.5 Groundwater Movement

As the network of monitoring bores installed as part of the various investigations is not well distributed spatially it is difficult to define groundwater potentiometry and movement. It is expected that in general groundwater levels represent a subdued reflection of topography with flow being from topographically elevated areas to valley sequences.

Groundwater movement within the basement rocks would occur predominantly along structural defects (faults, fractures, joints and foliation) with the rate of flow being governed primarily by the frequency, length and aperture, connectivity and orientation (longitudinal, transverse or oblique) of fractures and joints (Cook, 2003). Within the surficial alluvium groundwater movement would occur as a function of gravity drainage within intergranular pore space.

4.6 Hydraulic Parameters

Aquifer parameters acquired from the various investigations are presented to provide indicative values for bedrock and alluvial aquifer hydraulic conductivity in the vicinity of the proposed tunnel.

4.6.1 Fractured Rock Aquifers

Fractured rock aquifers are influenced by the structural characteristics of the rock. Detailed information on the variability of vertical and horizontal hydraulic conductivities within the investigation area was not able to be estimated with the available dataset. To describe the likely hydraulic properties of the rock units within the study area a number of general observations have been made from previous and ongoing geotechnical and water supply investigations (AGE, 2004 & 2006 & 2008b).

Bunya Phyllite

Hydraulic parameters for the Bunya Phyllite are inferred from the pumping test performed at the Botanical Gardens as part of the Brisbane Aquifer Project (EHA, 2006). The pumping test was performed as a single-bore test to derive a specific capacitance and not as a 'traditional' pumping test. The average transmissivity value determined for the Bunya Phyllite was 9.5m^2/d (EHA, 2006). The major permeability zone at 56 to 64 metres bGL, indicates a representative (localised) hydraulic conductivity of approximately 1.2 m/day.

Hydraulic characteristics of the Bunya Phyllite do however vary over short distances. For example, a pilot bore drilled approximately 20 metres from the production bore produced very low groundwater yields in the order of 0.1 L/s at a depth of 180 mbGL.

Packer (Lugeon) testing was undertaken in proximity to NL as part of the Stage 2 Geotechnical Investigation (City Design, 2008b). Packer testing is a geotechnical engineering method used to provide an indication of the transmissivity or permeability of the rock. Testing involves the isolation of a length of the drill hole (usually in the order of 6 metres) and the injection of water at different pressures. Results are recorded in lugeon units which relate to the number of litres lost to the formation per minute per metre length of test section at an effective pressure of 1,000 kPa. One lugeon equates to a mass permeability of 10^{-7} m/s.

A total of twelve packer tests were completed during the Stage 2 investigations. Of the twelve tests, one was carried out in highly weathered phyllites and was abandoned due to excessive water loss. Seven tests were conducted in the fresh phyllite and returned Lugeon values of zero, being representative of very low permeability. The four remaining tests were undertaken in a variety of weathered bedrock including fresh and slightly weathered phyllites (i.e. Greywacke), returning Lugeon values of between 0.4 and 7.2.

The results of the packer testing are presented in **Table 3**.

- **Table 3 Packer Test Results - Stage 2 Geotechnical Drilling Program (City Design, 2008b)**

Bore Number	Test Section Depth (m below surface)	Lugeon Value (litres loss / m / min @ 1000 kPa)	Permeability (m/d)	Test Section Rock Types
NL2 - 02	15.00 – 22.00	Test aborted due to excess water loss	n/a	Fr Hornfels / SW-Fr Phyllite
NL2 - 03	12.0 – 20.16	1.5	0.013	SW – FR Phyllite
NL2 - 05	19.20 – 26.65	0.0	< 0.009	Fr Phyllite
NL2 - 05	25.50 – 32.36	0.0	< 0.009	Fr Phyllite
NL2 - 06	28.2 – 35.73	0.4	0.004	Fr Spilite
NL2 - 06	34.2 – 41.73	7.2	0.060	Fr Spilite

Bore Number	Test Section Depth (m below surface)	Lugeon Value (litres loss / m / min @ 1000 kPa)	Permeability (m/d)	Test Section Rock Types
NL2- 10	15.00 – 22.56	6.2	0.050	Fr Greywacke
NL2- 10	21.00 – 28.65	Test abandoned due to leakage past packer	n/a	Fr Greywacke
NL2 - 12	28.00 – 35.58	0.0	< 0.009	Fr Phyllite
NL2 - 12	34.50 – 41.59	0.0	< 0.009	Fr Phyllite
NL2 - 12	40.50 – 47.64	0.0	< 0.009	Fr Phyllite
NL2 - 15	34.30 – 41.69	0.0	< 0.009	Fr Phyllite
NL2 - 15	40.50 – 46.91	0.0	< 0.009	Fr Phyllite

Neranleigh-Fernvale Beds

While no drilling or hydraulic testing has been performed for the Neranleigh-Fernvale beds as part of the Northern Link project, results from previous geotechnical investigations (City Design, 2008a, 2008b) have been used to provide indicative values of hydraulic parameters for this unit. Results from these tests indicate that the rocks have an approximate permeability ranging between negligible (i.e. 8.6×10^{-5} m/day) to 0.1 m/day, with an average of 0.04 m/day.

4.6.2 Alluvial Aquifers

No hydraulic testing has been undertaken within the alluvial sequences in the investigation area. However, observation from test pitting investigations at the eastern extremity of the botanical gardens (in close proximity to the Botanical Gardens production bore) indicates the gravely sediments within this area are relatively transmissive units (Chris Thorley, *pers. comm*.).

4.6.3 Inter-Aquifer Leakage

Limited monitoring data are available to define the relationship between alluvium along the proposed alignment and the underlying fractured basement rocks. Conceptually, it can be inferred from available data that vertical leakage from the overlying alluvium to the basement rock aquifer occurs but is typically limited by the low permeability of the underlying unit. This assumption is based on the limited extent of alluvium along the proposed tunnel alignment and low *in situ* permeability of the basement rocks.

In contrast, upward seepage from the basement rocks into overlying alluvium may occur based on the observation that heads within the Bunya Phyllite are at least locally artesian. This upward flow results from recharge entering the basement aquifers at locations which are at greater elevations than the measured heads and/or the storage of groundwater under pressure.

4.7 Facility Survey

A facility survey was undertaken using the DNRW GWDB to identify existing groundwater users in the vicinity of the proposed alignment and their current status. The search identified twelve registered groundwater bores within 5 kilometres of the investigation area as illustrated in **Figure 9**, with the exception of bore 133390 at Alderley which is outside the map area.

Five of these facilities were classified as “abandoned and destroyed” probably due to insufficient groundwater yields and/or quality being encountered during exploratory drilling. For the remaining bores the facility information was limited to spatial location, basic lithological data and in some instances, electrical conductivity (salinity) data. No detailed water quality, hydraulic testing or groundwater yield data were available for any of the registered groundwater bores.

The absence of groundwater facilities in the investigation area is not surprising given that the Neranleigh-Fernvale Beds and Bunya Phyllite are typically associated with very poor groundwater prospects. Swann (1997) suggests that groundwater occurrence within the Neranleigh-Fernvale Beds is limited to zones of structural deformation associated with low lying drainage lines which are typically recharged by surface water flow. Similarly, EHA (2006) describe groundwater prospects in the Bunya Phyllite as being extremely poor with high salinities and low yields typically limiting potential usage. However, there are localised exceptions where yields suitable for stock and domestic purposes have been encountered. The spatial distribution of these areas is at present understood to be limited and poorly characterised. Based on available data it is considered that groundwater occurrence for domestic or commercial purposes in the vicinity of the investigation area are largely opportunistic.

The status and details of each identified facility located within 5 kilometres of the investigation area is presented in **Table 4**. The production bore installed in the Botanical Gardens (MC1-A) has also been included in the table as it is a known production facility (albeit one that does not yet appear on the register).

No existing facilities were identified within the investigation area and only two bores were located within 500 metres (MC1-A and 134569). As discussed MC1-A is to be utilised to supply groundwater for desalination and subsequent irrigation at the Botanical Gardens. The current usage of bore 134569 is unknown and no further details are held with the DNRW Water Accounting and Management Services.

Table 4 Registered Groundwater Facilities within the NL Investigation Area

Facility Number	Facilities Status	Bore Details	Lot	Plan	Field Location
79231	Existing	No drilled data Depth	201	RP20204	101 Alexandra St Bardon
124312	Existing	Drilled: 27/01/05 Depth: 7m	2	RP116686	14 Josling St Toowong
124313	Existing	Drilled: 28/01/05 Depth: 10.5m	1	RP71381	3 Gaily Rd Taringa
133390	Abandoned and destroyed	Drilled: 02/05/06 Depth: 42.4m	26	RP71658	233 Yarmont Rd, Alderley
133735	Abandoned and destroyed	Drilled: 08/03/06 Depth: 6m	5	SP146655	36 Gilgandra st Indooroopilly
133853	Abandoned and destroyed	Drilled: 23/06/06, Depth: 6m EC: 3850µS/cm	47	RP23406	47 Dennis St, Indooroopilly
134034	Existing	Drilled: 23/08/06 Depth: 48m EC: 2050µS/cm	20	RP113595	39 Glencairn Ave, Indooroopilly
134365	Abandoned and destroyed	Drilled: 12/10/06 Depth: 42m	3	RP54441	20 Harrys Rd, Taringa
134379	Existing	Drilled: 02/11/06 Depth: 42m EC: 2000µS/cm	17	RP106213	41 Cadiz St, Indooroopilly
134488	Abandoned and destroyed	Drilled: 27/11/06 Depth: 46m	18	RP106213	37 Cadiz St, Indooroopilly
134497	Existing	Drilled: 01/11/06 Depth: 30m EC: 1800µS/cm	21	RP70506	162 Harts Rd, Indooroopilly
134569	Existing	Drilled: 17/11/06 Depth: 44m	18	RP20541	44 Harwood St, Bardon
MC1-A (unregistered)	Existing	Irrigation Production Bore Drilled: 01/12/06 Depth: 70m	6	RP18899	Mt Coot-tha Botanical Gardens

4.8 Groundwater Quality

4.8.1 General

Available groundwater quality data were compared with established guidelines (ANZECC, 2000) to assess the suitability of groundwater for use. The guidelines considered were:

- Water quality objectives to protect environmental values specified in the Environmental Protection (Water) Policy Environmental Values and Water Quality Objectives for Brisbane River Estuary Bain No. 143 (2007).
- Australian and New Zealand Guidelines for Fresh and Marine Water Quality (October, 2000), prepared by the Australian and New Zealand Environment and Conservation

Council (ANZECC) and the Agriculture and Resource Management Council of Australian and New Zealand, (ARMCANZ).

- "Australian Drinking Water Guidelines", National Health and Medical Research Council/ Agricultural and Resource Management Council of Australia and New Zealand, 2004.

In general, quality of groundwater within the Bunya Phyllite is spatially variable and considered poor with total dissolved solids (TDS) concentrations ranging from fresh (300 mg/L) to brackish (5,000 mg/L). Similar trends were noted in the Neranleigh-Fernvale beds with TDS values ranging from 300 to 30,000 mg/L (AGE, 2006). For reference purposes the Australian Drinking water guidelines recommends TDS values of between 500 mg/L and 1,000 mg/L for potable use.

Groundwater within the localised alluvial aquifer located down-gradient of the Botanical Gardens is brackish with recorded TDS ranging from 1,494 – 2,508 mg/L. The pH of groundwater at this location ranged from slightly acidic to neutral (pH 6.52 and 7.27).

Water quality data obtained for boreholes located in the vicinity of the proposed tunnel are from existing groundwater facilities recorded in the DNRW groundwater database. An overview of the groundwater quality data recorded for these bores is presented in **Table 5**. The concentration of most analytes reported is below the relevant water quality criteria specified in ANZECC (2000). Exceptions include:

- Total Dissolved Solid concentrations were elevated for all bores (excepting 79231), with concentrations above the aesthetic value specified in the drinking water guidelines. Based on salinity alone groundwater from these sites would only be suitable for irrigation of highly salt tolerant vegetation species.
- Elevated sulphate concentrations were observed in two bores installed in the alluvium downslope of the Botanical Gardens (BG01 and BG02). In both instances the sulphate concentration exceeded health and aesthetic drinking water guideline limits.
- The concentration of iron in bore BG01 was above both the irrigation value of 0.2 mg/L and the aesthetic drinking water value of 0.3 mg/L.
- Sodium and chloride concentrations in seven bores (MC1-A, MW2D, MW9, BG01, BG02, BG03 and BG04) exceeded aesthetic and drinking water guideline values (180 mg/L and 250 mg/L, respectively). When considered with reference to irrigation guidelines the groundwater quality values are suitable for moderately tolerant to tolerant crop species.
- Aluminium and manganese values recorded for BCC 136 were slightly elevated when compared to the aesthetic value specified in the drinking water guideline. Barium concentrations were above drinking water guidelines health values of 0.7 mg/L. Manganese values for bores installed down-gradient of the Botanical Gardens (BG01, BG02, BG03 and BG04) displayed manganese concentrations above both the health and aesthetic drinking water values.

Table 5 Water Quality Values and Relevant Guidelines

Analytes	Irrigation* Water Quality Objectives	Livestock Water Quality Objective	Drinking Water		MC1-A (Bunya Phyllite)	79231 (Bunya Phyllite)	BCC136 (Neranleigh-Fernvale)	MW2D (Bunya Phyllite)	MW3D (Bunya Phyllite)	MW5 (Bunya Phyllite)	MW6 (Bunya Phyllite)	MW9 (Bunya Phyllite)	BG04 (Bunya Phyllite)	BG01 (Alluvium)	BG02 (Alluvium)	BG03 (Alluvium)
			Health	Aesthetic												
Sampling Date					21/12/06	31/10/90	16/11/1994	16/08/01	16/08/01	16/08/01	16/08/01	16/08/01	16/11/07	16/11/07	16/11/07	16/11/07
Physico – chemical Parameters																
pH (pH unit)	6 – 8.5	-	-	6.5 – 8.5	6.9	7.7	6.7	7.0	6.7	4.6	6.6	6.4	7.23	6.52	7.14	7.23
Conductivity (µS/cm)	Varies on crop Sensitivity and soil	-	-	-	2,900	49	5,900	2,600	1,000	1,200	2,000	1,100	3,110	2,490	2,530	4,180
Total Dissolved Solids (mg/l)	Varies on crop Sensitivity and soil	Beef <4000 Dairy- <2500 Sheep <5000 Horses <4000 Pigs < 4000 Poultry <2000	-	500	1,900	33.48	3,540	1,560+	600+	720+	1,200+	660+	1,866*	1,494*	1,518*	2,508*
Total Alkalinity as $CaCO_3$ (mg/l)	-	-	-	-	460	21	420	-	-	-	-	-	381	93	301	592
Major Ions (mg/l)																
Calcium (mg/l)	-	<1000	-	-	100	4.6	110	52	43	1.2	8.6	66	193	177	149	243
Magnesium (mg/l)	-	-	-	-	42	0.8	76	79	26	7.2	20	38	120	106	106	284
Sodium (mg/l)	-	-	-	180	480	5	-	380	88	100	350	110	476	342	357	605
Potassium (mg/l)	-	-	-	-	4	0.2	9.6	7.2	5.7	4.1	8.1	6.7	13	12	10	17
Carbonate as $CaCO_3$ (mg/l)	-	-	-	-	<1.0	0.1	-	180	150	<1	68	170	<1	<1	<1	<
Bicarbonate as $CaCO_3$ (mg/l)	-	-	-	-	460	25.5	-	180	150	<1	68	170	381	93	301	592
Sulphate (mg/l)	-	<1000	500	250	<0.1	3.6	240	84	91	14	57	160	98	748	293	144
Chloride (mg/l)	-	-	-	250	560	2		720	160	180	530	190	1,480	738	935	1,240
Total Nitrate As N (mg/l)	-	<400	50	-	0.030	0.5	-	-	-	-	-	-	0.038	<0.010	0.024	0.010
Ammonia as N	-	-	C	0.5	0.002	-	-	-	-	-	-	-	<0.010	0.110	<0.010	<0.010
Total Phosphorus (mg/l)	0.8-12	-	-	-	-	-	-	-	-	-	-	-	0.04	0.42	2.28	0.06

Analytes	Irrigation* Water Quality Objectives	Livestock Water Quality Objective	Drinking Water		MC1-A (Bunya Phyllite)	79231 (Bunya Phyllite)	BCC136 (Neranleigh-Fernvale)	MW2D (Bunya Phyllite)	MW3D (Bunya Phyllite)	MW5 (Bunya Phyllite)	MW6 (Bunya Phyllite)	MW9 (Bunya Phyllite)	BG04 (Bunya Phyllite)	BG01 (Alluvium)	BG02 (Alluvium)	BG03 (Alluvium)
			Health	Aesthetic												
Metals																
Aluminium (mg/l)	5	5	c	0.2	-	-	-	-	-	-	-	-	<0.01	<0.01	<0.01	0.01
Arsenic (mg/l)	-	-	-	-	-	-	1	<0.005	-	-	-	-	0.006	0.003	0.001	0.002
Barium (mg/l)	-	-	0.7	-	-	-	2.9	-	-	-	-	-	-	-	-	-
Cadmium (mg/l)	0.01	0.01	0.002	-	-	-	<0.01	<0.001	-	-	-	-	<0.0001	0.0001	<0.0001	<0.0001
Chromium (mg/l)	0.1	1	0.05	-	-	-	<0.01	0.001	-	-	-	-	<0.001	<0.001	<0.001	<0.001
Copper (mg/l)	0.2	Sheep – 0.4 Cattle – 1 Pigs – 5 Poultry - 5	2	1	-	-	<0.01	0.010	-	-	-	-	<0.001	0.002	0.003	0.001
Iron (mg/l)	0.2	-	c	0.3	1.7	-	1.5	-	-	-	-	-	0.19	1.36	<0.05	0.07
Manganese (mg/l)	0.2	-	0.5	0.1	0.29	-	2.5	-	-	-	-	-	0.748	2.41	0.644	0.675
Nickel (mg/l)	0.2	1	0.02	-	-	-	<0.02	0.006	-	-	-	-	0.006	0.004	0.001	0.011
Zinc (mg/l)	-	20	c	3	-	-	0.035	0.083	-	-	-	-	0.010	0.022	0.006	0.020
Faecal Coliform	<10 cfu	-	-	-	<1	-	-	-	-	-	-	-	-	-	-	-
E. Coli	-	-	-	-	<1	-	-	-	-	-	-	-	-	-	-	-
TPH																
C_6-C_9	-	-	-	-	-	-	-	<0.020	<0.020	<0.020	<0.020	<0.020	-	-	-	-
C_{10}-C_{14}	-	-	-	-	-	-	-	<0.050	<0.050	0.065	0.152	<0.050	-	-	-	-
C_{15}-C_{28}	-	-	-	-	-	-	-	<0.100	<0.100	0.171	0.120	<0.100	-	-	-	-
C_{29}-C_{36}	-	-	-	-	-	-	-	<0.050	<0.050	<0.050	<0.050	<0.050	-	-	-	-

*Long term values were used as they are more conservative.

c – Insufficient data to set a guideline value based on health considerations.

+ TDS calculated from EC using conversion of 0.6.

4.8.2 Hydrofacies

A comparison of the major ion chemistry for groundwater recovered from the Bunya Phyllite and alluvium down-gradient of the Botanical Gardens was assessed using a Piper-Trilinear diagram. This plot allows for the comparison and discrimination between different water types (hydrofacies) and is presented as **Figure 10**. Since groundwater quality evolves through water-rock interaction, the concentration of individual ionic species is generally different to that found in surface waters and rainfall. Plots can also be used to demonstrate mixing of water from different sources.

Observations indicate that the groundwater type within the Bunya Phyllite is highly variable, with limited similarities observed between samples. This variation may indicate different degrees of water rock interactions due to residence time of groundwater, weathering processes and recharge inputs. Groundwater sampled from the alluvium down-gradient of the botanical gardens plotted in relatively close proximity on **Figure 10** which suggests that the groundwater within this unit shares a common origin and has a relatively short *in situ* residence time.

4.8.3 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 described in further detail elsewhere in the EIS). The objectives of this assessment were to:

- provide a description of land parcels located within the Study Corridor Boundary that are listed on the EMR/CLR and;
- 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.

This assessment included a desk-top review of potentially contaminated land parcels as well as a targeted drive-by-survey of land parcels that may not be listed on the EMR/CLR but which have (or previously had) a commercial/industrial land use. The assessment included the Study Corridor Boundary and a surrounding 1,000 metre buffer area located outside the Study Corridor Boundary to account for potential groundwater drawdown.

For reference, the EMR listed land parcels are illustrated in **Figure 11**, **Figure 12** and **Figure 13** for the Northern Link study area.

Properties Listed on the EMR/CLR

Three hundred and seventy-eight (378) land parcels were identified with Notifiable Activities within the Project Study Area. Twenty-eight (28) land parcels were identified within or on the boundary of the Study Corridor Boundary, twenty-two (22) were high risk and six (6) were low. Three hundred and fifty (350) land parcels were identified within or on the boundary of the theoretical Groundwater Drawdown Area (GDA), two hundred and ninety one (291) were high risk and eighty-seven (87) were low.

No land parcels were listed on the CLR.

Sixty-one (61) land parcels were listed on the EMR, subject to a Site Management Plan (SMP). All 61 properties were located within or on the boundary of the GDA. No properties were located within or on the boundary of the Study Corridor Boundary.

Properties with the Potential for Groundwater Contamination

A historical aerial photograph review was undertaken to identify potentially contaminated land parcels which may have had a Notifiable Activity that were not identified on the EMR/CLR database. Nine (9) land parcels were identified as having/had a potentially Notifiable Activity. A further three (3) additional sites were identified during the drive-by survey and six (6) sites were identified during the NSBT EIS (SKM 2004) historical aerial photo review.

Additional public information was also reviewed in order to identify areas of potential contamination. These included the:

- assessment of unexploded Ordinates (UXO) potential;
- BCC run landfill information;
- City Design Report on the Toowong Bus Depot;
- review of contaminated land information from QR; and a
- drive by survey of the Project Study Area.

The potential for UXO contamination does not exist within or near the Project Study Area.

QR and the EPA acknowledge that past land use may have resulted in soil and/or groundwater contamination within railway land in Queensland. Several large areas of QR land fall within the Project Study Area however QR identified only the Mayne Railway Yards as having a contamination concern due to the presence of hydrocarbon contamination in soil and groundwater at the site.

The Toowong Cemetery is listed for the Notifiable Activity “Petroleum Product or Oil Storage”. Although the cemetery itself is not a Notifiable Activity, potential soil and/or groundwater contamination may be present in heavy metals from lead lined coffins, and arsenic and formaldehyde from embalming solutions.

A known diesel leakage has been documented at the Toowong Bus Depot (City Design, 2002). City Design (2002) determined that the contamination had not impacted, to any significant degree, the underlying natural soil, rock and/or the associated aquifer system. In their conclusions, City Design (2002) recommended that hydrocarbon contamination may exist at a location adjacent to the bus depot and park and ride areas and that adequate management plans must be prepared and implemented prior to commencement of any underground works.

In summary, there is potential for contaminated land (soils) to be disturbed at the Toowong Connection and the Kelvin Grove Connection during construction of the Project. This disturbance is likely to occur at identified EMR listed land parcels. Concentrations of EMR listed land parcels are located within and around the Study Corridor at the Toowong Connection and the Kelvin Grove Connection.

4.9 Acid Sulphate Soils

Discussion of the potential occurrence of acid sulphate soils (ASS) is presented elsewhere in the EIS. There is no evidence to suggest marine sediments or processes have occurred within the investigation area and as such the potential for ASS materials to be encountered is negligible, particularly given the topographical elevation of most of the study corridor.

4.10 Groundwater Dependant 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 as 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 (i.e. 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.

A review of Queensland EPA (2006) regional ecosystem mapping identified that limited areas of remnant vegetation remain within the investigation area. As such, the only vegetation that may potentially be reliant upon groundwater is likely to have been established post European settlement and following clearing.

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. This excludes grass species which represent the predominant cover in most topographically depressed areas visually assessed as part of this study. It is considered that the level of groundwater dependency in these areas is likely to be relatively low (opportunistic at best) with species potentially utilising groundwater in the saturated zone only during drought conditions where surface water flux is uncommon. 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. The exception to this may be the wetland present in the southern portion of Mt Coot-tha Botanical Gardens. The wetland, despite being largely dry at present, is likely to rely upon a combination of both groundwater and surface water flow.

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.

4.11 Environmental Values

The Environmental Protection (Water) Policy (1997) aims to protect Queensland's environments by providing a framework to:

a) *Identify environmental values for Queensland waters.*

b) *Decide and state water quality guidelines and objectives to enhance or protect the environmental values.*

c) *Make consistent and equitable decisions about Queensland waters that promote efficient use of resources and best practice environmental management.*

d) *Involve the community through consultation and education, and promoting community responsibility.*

The values identified in the Environmental Protection (Water) policy under Section 7 include:

- *The "environmental values" of waters to be enhanced or protected under this policy include:*
  a) *For a water in schedule 1, column 1 - for the Project area incorporates the Brisbane River environmental values and water quality objectives Basin No 143. This document applies to fresh and estuarine surface water and ground waters draining the catchment as indicated in plan WQ1431.*
- *The environmental values (EVs) for groundwater outlined in this document relate to:*

Aquatic Ecosystems

Drinking Water

Irrigation

Stock water

Farm Supply

4.11.1 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. It is therefore considered unlikely that baseflow systems[2] exist within the general area and as such, the potential for aquatic ecosystems to be associated with the study corridor is considered negligible.

4.11.2 Drinking Water

Comparison of the groundwater quality to the Water Quality Objectives outlined in the Brisbane River environmental values and the Australian Drinking water guidelines (**Section 4.8**) 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] Systems where groundwater discharge to riverine or marine environments could potentially support aquatic ecosystems

4.11.3 Irrigation

Based on the available water quality data, groundwater sourced from the Bunya Phyllite and Neranleigh-Fernvale beds is considered to be too saline for general irrigation use. Desalination, as is proposed at the Botanical Gardens is not considered an appropriate corrective action to render groundwater suitable for irrigation and it is considered that the intent of the EPP (Water) relates to groundwater as it occurs naturally. Nonetheless, 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.

4.11.4 Stock Water

Comparison of groundwater quality with the stock water quality objectives has identified that the water may be suitable for stock water use. However, the salinity restricts the type of species that may be suitable. Furthermore, the low reported yields are unlikely to provide sufficient groundwater for stock use (which is probably incompatible with the existing land use).

4.11.5 Farm Use

Groundwater for farm use according to the Brisbane River Water Quality Objectives needs to comply with values defined in ANZECC (2000). As for other uses, the high salinity of groundwater (and existing land use in the area) is likely to restrict the suitability of groundwater for 'general' farm use.

5. Impact Assessment

5.1 Groundwater Modelling

5.1.1 Model Objectives and Conceptual Model

The primary objective of this hydrogeologic assessment is to assess the groundwater level drawdown impacts in response to the construction and operation of the NL tunnels. On the basis of the Existing Environment review, the following conclusions are made with respect to the conceptual hydrogeological model of the tunnel corridor:

- The NL Project area is characterised by a series of steep ridges and spurs dissected by linear valleys.
- Ground surface elevations rise toward the west and northwest and fall toward the east and southeast (i.e. towards the Brisbane River).
- Across the NL Tunnel corridor, ground surface elevations range between 20 m AHD and 70 m AHD.
- The Project area is within the Lower Brisbane River Catchment area which hosts a number of surface water tributaries that drain into the Brisbane River.
- Within the immediate vicinity of the NL Project area most surface waters are drained by Toowong Creek (at the western extremity south of the Western Freeway and Toowong portals), by a series of small largely channelised streams entering the Brisbane River between Toowong and Hale Street and Enoggera Creek (north of the Herston portal).
- The footprint of the NL Tunnel straddles two subcatchment areas; a subcatchment of the larger Brisbane River Catchment and the eastern most extent of the Enoggera Creek subcatchment.
- The NL Project area is characterised by a sub-tropical climate with a mean annual rainfall of 1,091 mm.
- The geology of the NL corridor includes two major rock formations (Bunya Phyllite and the Neranleigh Fernvale Beds) and several isolated deposits of Quaternary alluvium.
- With the exception of a relatively shallow weathered zone, the Bunya Phyllite and Neranleigh Fernvale Beds have very low permeability, by comparison to the Quaternary alluvium.
- Within the footprint of the NL tunnel, one Quaternary deposit is located at the upper end of a channel at Mt Cootha Road and a second is located in a wider channel near Baroona Road.
- Outside localised fractures and/or joints, significant faults and/or fault zones have not been identified within the NL Project area.
- Two broad aquifer types exist within the NL Project corridor; the unconfined Quaternary alluvial aquifers (that reside along the bottoms of local creek valleys and which extend to the Brisbane River) and the semi-confined to confined fractured

bedrock aquifer systems that comprise the Bunya Phyllite and the Neranleigh-Fernvale Bed geologic units.

- Groundwater within each of the aquifer systems ultimately reach the Brisbane River.
- Groundwater within the NL Project area is characterised by variable and slightly brackish quality within the Quaternary alluvium and fresh to brackish within the Bunya Phyllite and Neranleigh Fernvale Beds.
- A number of documented contaminated sites and potentially contaminated sites exist within the vicinity of the NL Project area.
- There is no evidence to suggest that potentially producing acid sulphate soils exist within the vicinity of the proposed NL tunnel corridor.

5.1.2 Modelling Strategy

A computer based numerical model provides a powerful tool that may be used to predict groundwater flows within complex and temporally varying environments. The modelling process includes application of a technique for simulating groundwater flows using a system of mathematical equations based on Darcy's Law. Darcy’s Law can be applied to simulate groundwater flow within porous and fractured aquifer systems. The process requires definition of the aquifers with respect to geometry, hydraulic properties and regional groundwater processes.

A calibrated steady state numerical model may be used to simulate complex hydrogeological conditions by introducing variations in hydraulic conductivity and/or annual recharge. The accuracy of model predictions depends upon the knowledge of the input parameters that may have an impact on the groundwater flow regime, both in the area of interest as well as at more distant locations. The numerical model also facilitates a sensitivity analysis, which provides a means of identifying the dominant parameters and mechanisms of a groundwater flow system.

The principal application of the numerical model was to simulate the dewatering impact of the proposed NL tunnel on the existing groundwater flow regime. Predictive numerical modelling was carried out to assess groundwater inflow volumes and to estimate local variations in drawdown as a consequence of groundwater inflows into the NL tunnel.

Groundwater flow modelling was undertaken using the finite difference numerical model MODFLOW, developed by the United States Geological Survey. The operating interface that was used with MODFLOW was VISUAL MODFLOW (version 4.2).

The MODFLOW numerical code is the most widely used code for groundwater flow modelling and is regarded as an industry standard. MODFLOW represents the groundwater flow system in a quasi-3D fashion. In the formulation, groundwater is assumed to flow horizontally within model layers and vertically between layers. From an operational perspective, this means that horizontal flow within a model layer is governed by, amongst other factors, the value of horizontal hydraulic conductivity whilst vertical flow between layers is related to the magnitude of the harmonic mean of the vertical hydraulic conductivity of the two model layers.

MODFLOW generally works well in most groundwater environments, however the model code is prone to instabilities within specific model locations where: (i) large contrasts in hydraulic conductivity may exist between geologic units; (ii) large elevation variations may exist between the model layers and (iii) the model cells may become dry during the computer simulations.

MODFLOW is also incapable of modelling discrete fractures or fracture networks. The modelling of fractures or fracture networks requires much more sophisticated modelling software packages as well as detailed spatial information concerning the fractures.

Despite the above limitations, groundwater data are generally sparse and as such, it is unreasonable to expect a groundwater modelling software code to incorporate a level of complexity beyond that of the available data.

During this investigation, groundwater modelling was undertaken to develop and calibrate the groundwater flow model to a steady state condition. Following completion of the steady state calibration, the model was used to simulate transient groundwater flows into the NL tunnel.

5.1.3 Model Design

The extent of the model domain was based upon the locations of natural topographic catchment divides and the locations of surface water drainage courses. The model domain includes a sub-region of the (larger) Brisbane River surface water catchment, the Toowong Creek subcatchment, the Ithaca Creek subcatchment and the lower southeast portion of the Enoggera Creek subcatchment.

The northern boundary of the model domain is represented by Enoggera Creek and the eastern boundary is represented by the Brisbane River. The southern and western boundaries are represented by the Toowong Creek and Ithaca Creek subcatchment boundaries, respectively. The model domain is illustrated in **Figure 14**.

Three hydrostratigraphic units were inputted into the numerical computer model. The shallowest hydrostratigraphic unit (Layer 1) represents both the Quaternary alluvium and weathered (fractured) Bunya Phyllite and/or Neranleigh Fernvale sediments. Layer 2 represents the Bunya Phyllite/Neranleigh Fernvale sediments and Layer 3 represents deeper hardrock Bunya Phyllite/Neranleigh Fernvale units.

The numerical computer model was arranged so that determination of the model layers, whether confined or unconfined, was made by the MODFLOW model. The MODFLOW model made this determination based on the elevation head within the model layer, relative to the bottom elevation of the model cells.

The model consists of a finite difference grid that consists of 159 rows and 169 columns. The model grid was oriented 39.38° north of east to correspond with the assumed principal (horizontal) direction of groundwater flow.

The model cells ranged from 32 metres × 13 metres within the near vicinity of the two western and two eastern tunnel portals, 57 metres × 17 metres along the tunnel alignment and from 113 metres

× 80 metres at the outer edges of the model domain. The base of the model was set at -80 m AHD which is approximately 50 metres below the deepest point of the tunnel (referenced as –28.175 m AHD).

The model boundaries used to develop the groundwater flow model were based on the locations of selected subcatchment boundaries and surface watercourses. The topographic highs (**Figure 15**) were assumed to be groundwater divides and as such were designated as "no-flow" boundaries. "No-flow" boundaries are boundary conditions whereby no water is permitted to leave or enter the model domain.

The Brisbane River and Enoggera Creek were represented as "specified head" (i.e. constant head) boundaries. The Brisbane River was assigned a specified head of 0.1 metres AHD and Enoggera Creek was assigned a gradational falling constant head of between 3 metres AHD and 0.1 metres AHD. The gradational falling head fell along Enoggera Creek toward the Brisbane River.

Along the Brisbane River, constant head cells were set in each of the three model layers. The assignment of constant head cells in each model layer was made to reflect the regional significance of this hydrogeologic boundary. By contrast, constant head cells along Enoggera Creek were set only for the first model layer. Boundary conditions along both the Brisbane River and Enoggera Creek represent an infinite source of water and these conditions represent a valid assumption.

The NL tunnel is represented by a number of drainage cells. These drainage cells allow the removal of groundwater from the model via drain-type sinks. The rate of inflow to each of the model drain cells, and hence its removal from the system, is governed by the specified drainage elevation of the MODFLOW drainage cells, the drain hydraulic conductance, the hydraulic parameters of the nearby model cells, and the water level in the surrounding cells.

The MODFLOW drainage cells cease removing groundwater from the model only when the groundwater level in the cell falls below the pre-set drainage level. The drainage cells remain active throughout the model simulations and function only when groundwater levels rise to the drainage level.

Drainage cells were applied along each of the twin tunnels. The drainage level was set equal to the invert level of the NL tunnel. On the basis that diaphragm walls are planned for the cut and cover sections of the tunnel where alluvial material will be intersected no drainage cells were applied at these locations in Layer 1. The diaphragm walls will limit the volume of groundwater inflow to these sections of the tunnel.

5.1.4 Model Calibration and Hydraulic Parameters

Layer 1 of the model domain was divided into two hydraulic conductivity zones to represent the Quaternary alluvium sediments and the Weathered Bunya Phyllite/Neranleigh-Fernvale Beds. Due to limited hydraulic information, a distinction between the Weathered Bunya Phyllite and the Weathered Neranleigh-Fernvale Beds was not made within the numerical computer model.

The boundaries of Quaternary alluvium sediments were based on available data derived from both geologic and soils maps. The thickness of Layer 1 was based upon the observed thickness of

Quaternary alluvium sediments located within the vicinity of the Western Tunnel portal. Across the model domain, the thickness of Layer 1 ranged between approximately 4 and 7 metres.

The thickness of Layer 2 was based upon the depth of the Bunya Phyllite sediments located within the vicinity of the Western Tunnel portal. Across the model domain, the thickness of Layer 2 ranged between approximately 50 metres and 70 metres.

The maximum depth of the numerical model was set at an elevation of -80 m AHD. The thickness of Layer 3 was similar to that of Layer 2 and ranged between 45 and 60 metres.

The hydraulic conductivity for each of sediment types and hydrostratigraphic units were selected according to available data derived from packer tests, pump tests, particle size distributions and previous numerical modelling calibration results. Analysis of the data provided a range of hydraulic conductivity values for the various sediment types **Table 6**.

Table 6 Range of Measured Hydraulic Parameters

Geologic Unit	Upper Range (m/day)	Lower Range (m/day)	Specific Yield
Holocene age alluvium	3.00	8.64×10^{-3}	0.05
Pleistocene age alluvium	0.75	8.64×10^{-6}	N/a
Weathered Bunya Phyllite	1.55	N/a	N/a
Bunya Phyllite	6.2×10^{-2}	3.5×10^{-6}	N/a
Neranleigh/Fernvale Beds	0.04	2.59×10^{-3}	0.02

A steady state calibration was developed by inputting hydraulic conductivity values based on the lower range of estimated values for each of the sediment types and geologic units. During model calibration these values were gradually re-adjusted to provide an acceptable comparison of observed and computer simulated groundwater levels in proximity to the tunnel alignment.

A uniform drainable porosity, or specific yield, of 5% was assumed for the Layer 1 sediments and 2% for the Layer 2 and 3 sediments. The specific storage for Layers 1, 2 and 3 was assumed to be 5×10^{-6}. The calibrated steady state hydraulic conductivity values are presented in **Table 7**.

Table 7 Calibrated Hydraulic Conductivity Values

Geologic Unit	Model Layer	Hydraulic Conductivity (KxKyKz) m/day
Alluvium	Layer 1	2.00
Weathered Bunya Phyllite and Neranleigh-Fernvale Beds	Layer 1	0.32
Moderately fractured Bunya Phyllite and Neranleigh-Fernvale Beds	Layer 2	0.01
Poorly Fractured Bunya Phyllite and Neranleigh-Fernvale Beds	Layer 3	0.01

5.1.5 Recharge Estimates

Three groundwater recharge areas were represented within the model domain. The first groundwater recharge area includes most of the model domain area and represents heavily urbanised land. The second recharge area encompasses most of the Mt Coot-tha area and represents a natural or non-urbanised environment. The third area is also urbanised but coincides with elevated land.

Aquifer recharge was estimated using SKM's Soil Moisture Water Balance Model (SMWBM) – a rainfall runoff model that uses a soil moisture accounting approach – calibrated to observed stream flow data. The model simulates hydrological processes and of particular relevance to this project, sub-surface drainage and the resulting percolation to groundwater storages. Further details of model operation and parameters are supplied in the **Appendix**.

Input Data

Daily rainfall data for Toowong Bowls Club were acquired for the period 1904 – 2001 from the Bureau of Meteorology as well as mean monthly potential evaporation for the Brisbane Aero Rainfall Station.

Daily average river flow data for Mogill River at Misty Morn and Upper Brookfield were sourced from Natural Resources – Water (NRW). Details of the flow records as well as rainfall and evaporation data are provided in **Table 8**.

- **Table 8 Summary of Available Rainfall, Evaporation and Stream Flow Data**

Data Type	Location	Duration	Details
Rainfall	Toowong Bowls Club	1904 – 2001	Daily totals
Evaporation	Brisbane Aero	1929 – 2000	Mean monthly totals
Stream Flow	Mogill River at Misty Morn	1972 – 1981	Daily average data; Catchment area = 21 km^2
	Mogill River at Brookfield	1976 – 2001	Daily average data; Catchment area = 61 km^2

Model Calibration

The SMWBM was calibrated to the Mogill River at Misty Morn daily flow record. This record was chosen on the basis of its larger catchment area and more representative flow regime. A flow duration curve of the observed and simulated flows for this time is illustrated in **Figure 16**. The figure demonstrates that the model is capable of simulating the catchment runoff processes, replicating observed flow data to an acceptable level of accuracy. For recharge estimation, the calibration focuses on the low flow events (i.e. those flow that occur less than 10% of the time), as these are driven almost entirely by groundwater storage.

A summary of the simulated water balance partitioning is provided in **Table 9**.

Table 9 Modelled Water Balance Partitioning

Water Balance Component	Proportion of Mean Annual Rainfall (%)	
	Natural Catchment	Urbanised Zone
Interception Loss	18.0	12.0
Soil Evaporation	53.7	39.3
Surface Runoff	26.9	48.0
Groundwater Percolation	1.8	1.4
TOTAL	100.4	100.7

Note: Mean annual rainfall at the site is 1,091 mm.

Recharge Estimation

Groundwater recharge for the natural catchment is estimated based on the long-term average of the groundwater percolation component of the model output. This is estimated to be on average 5.46×10^{-5} m/d (20 mm/annum), which amounts to 1.8% of average rainfall.

Recharge was estimated for the urban zone following modification of the model parameters to reflect a higher impervious portion of the catchment and a lower canopy interception capacity. Recharge for the urban zone is estimated to be on average 4.32×10^{-5} m/d (16 mm/year), which amounts to 1.4% of average rainfall.

Details of the model parameters for both natural and urban catchments are provided in the **Appendix**.

During the steady state model calibration process these rainfall recharge estimates were adjusted downwards to 12 mm per year for the natural model and 10 mm per year for the urban model area, whilst the high land was calibrated with a recharge of 60mm/year.

The 60mm annual recharge zone on high ground was introduced in an attempt to improve model calibration with the groundwater level recorded at bore NL2-06. Prior to introducing this higher recharge zone the model was under predicting piezometric levels at this bore, which is located underneath a ridge line in the terrain. The use of higher recharge rates contributes to a more conservative representation of drainage rates as a consequence of the higher groundwater head gradients in the vicinity of the tunnel. At this stage, application of this higher recharge zone cannot be confirmed with reference to observed land use or surface conditions. This model input should be the focus of revision subsequent to obtaining more observations of hydrogeological properties and piezometric levels of the aquifers in the study area. The recorded groundwater level in bore NL2-06 should also be confirmed in the event that the level is erroneously high due to poor bore construction / development, monitoring inaccuracies, the presence of a perched watertable, etc.

5.1.6 Model Calibration and Sensitivity

The computer model was calibrated to a steady state condition by closely matching the recorded groundwater levels at a number of standpipe monitoring bores (screened within the alluvium and Bunya Phyllite units). Groundwater levels were recorded in both mid February and mid March 2008.

A summary of these data is provided below in **Table 10**.

Table 10 Comparison of the Recorded and Calibrated Groundwater Levels

Well	Easting	Northing	Recording Date	Recorded Groundwater Elevation (m AHD)	Calibrated Steady State Groundwater Elevations (m AHD)	Range of Residual Differences (m)	Screened Geologic Unit
NL2-01	47934	157865	14-Feb-08	22.67	24.61	1.94	Bunya Phyllite
NL2-01	47934	157865	11-Mar-08	25.90	24.61	-1.29	Bunya Phyllite
NL2-02	48099	157916	13-Mar-08	19.35	22.61	3.26	Bunya Phyllite
NL2-06	51145	160257	13-Mar-08	43.23	29.88	-13.35	Spilite
NL2-12	48630	158316	13-Mar-08	19.98	20.46	0.48	Bunya Phyllite
NL2-15	49547	159283	13-Mar-08	5.82	7.67	1.85	Bunya Phyllite
NL2-17	47997	157890	14-Feb-08	20.75	22.68	1.93	Alluvium
NL2-17	47997	157890	11-Mar-08	20.90	22.68	1.78	Alluvium
NL2-19D	48050	157910	14-Feb-08	21.49	22.97	1.48	W. Bunya Phyllite
NL2-19D	48050	157910	11-Mar-08	21.70	22.97	1.27	W. Bunya Phyllite
NL2-19S	48049	157910	14-Feb-08	19.70	22.44	2.74	Alluvium
NL2-19S	48049	157910	11-Mar-08	19.90	22.44	2.54	Alluvium
NL2-22	47974	157941	14-Feb-08	20.76	24.09	3.33	Alluvium
NL2-22	47974	157941	11-Mar-08	20.90	24.09	3.19	Alluvium
NL2-23	48026	157965	14-Feb-08	20.34	23.76	3.42	Alluvium
NL2-23	48026	157965	11-Mar-08	20.50	23.76	3.26	Alluvium

The steady state calibration exhibits a reasonably close correlation between the calibrated and recorded groundwater levels. Residual head differences were largely less than 3 metre and ranged between values of -1.3 metres and +3.4 metres, with the exception of observation bore NL2-06 where the residual is -13.4 metres. Despite elevating the modelled recharge in this area the residual head difference continued to remain above 10 metres. This issue was explored in the preceding section.

5.1.7 Model Predictions

The calibrated potentiometric surface of Layer 1 (alluvium and weathered material) and Layer 2 (fractured rock) are depicted in **Figure 17** and **Figure 18**, respectively. As expected, the pre-construction potentiometric surfaces represented indicate a falling hydraulic gradient towards the Brisbane River.

The water table intersects Layer 1 of the model where the water table is shallowest; otherwise the water table intersects Layer 2 of the model (fractured rock). The water table intersects Layer 1 of the model in areas that typically coincide with the occurrence of alluvium however there are significant areas of weathered rock in Layer 1 that are also intersected by the water table. These areas usually surround the alluvium material.

The predicted groundwater level drawdown as a consequence of tunnel construction and operation is illustrated for Layer 1 and Layer 2 at one year post-construction in **Figure 19** and **Figure 21**, respectively. **Figure 20** represents a detailed illustration of the groundwater level drawdown within Layer 1 at one year post-construction.

In general, one year following the construction of the NL tunnel, the groundwater level within the alluvium and weathered material (Layer 1) can be expected to decline by up to 5 metres. The greatest drawdown is predicted to occur within the alluvium located in proximity to Fernberg Road (at the mid-point of the tunnel alignment), although as discussed below this is likely to be an over-estimate. A steep groundwater level drawdown cone is expected to develop in the fractured rock aquifer (Layer 2) and is approximately 100 metres in width either side of the tunnel alignment following one year of construction. It is noted that the groundwater level drawdown within Layer 1 is a consequence of the potential for the vertical movement of groundwater as steep vertical gradients develop between the alluvium / weathered material and the fractured rock aquifer.

The predicted groundwater level drawdown as a consequence of tunnel construction and operation is illustrated for the alluvial / weathered material (Layer 1) and fractured rock aquifers (Layer 2) at quasi steady state conditions (inferred to be fifty years post-construction)[3] in **Figure 22** and **Figure 24**, respectively. **Figure 23** represents a detailed illustration of the groundwater level drawdown within Layer 1 at fifty years post-construction. **Figure 25** represents the potentiometric surface of Layer 2 at fifty years post-construction.

As indicated in these figures the model predicts that the alluvium / weathered material in proximity to the tunnel will dry out as a consequence of the steep vertical drawdowns between Layer 1 and Layer 2. This prediction is likely to be an *overestimate of the groundwater level drawdown in the alluvium aquifer* as the model assumes the absence of a confining layer between the two layers. A level of confinement is expected (as evidenced by the artesian and upward hydraulic gradient recorded in NL2-19D), hence, the alluvium / weathered material is unlikely to dry out completely; rather a perched shallow aquifer may be derived, interrupting the direct hydraulic connection between the two aquifers.

It is expected that quasi-steady state conditions will be reached in the aquifers following a period of between 10 and 20 years post-construction. At this time, the groundwater level within the fractured rock aquifer is drawn down to the invert level of the tunnel and a steep lateral hydraulic gradient will occur with a width of approximately 800 metres either side of the tunnel. The drawdown is

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[3] The modelling exhibited quasi-steady state conditions following a period of 10-20 years. Quasi steady state is a near approximation of steady state (or dynamic equilibrium) and is achieved in the model when the lateral extent and depth of the groundwater level drawdown essentially remains constant having reached a near state of equilibrium. A conservative approach has been adopted by illustrating quasi steady state in the model output following a period of 50 years post tunnel construction.

aligned about the Project axis and is greatest at the deeper parts of the Project, (at the mid-point of the tunnel) where a drawdown of up to 45 metres is predicted in the fractured rock aquifer.

The modelling results indicated that the gradient of the potentiometric surface in the fractured rock aquifer is likely to remain towards the river due to a zone of slightly elevated groundwater between the tunnel and the Brisbane River (**Figure 25**). The accuracy of the model is such however, that a definitive conclusion regarding the post-construction hydraulic gradient between the tunnel and the river cannot be made. The implication of the potential migration of saline water towards the NL tunnel is discussed in further detail in **Section 5.5**.

5.2 Groundwater Depletion or Recharge

The results of the modelling discussed in the previous sections can be used to quantify any groundwater depletion and recharge as a consequence of the construction and operation of the tunnel. The following impacts to the groundwater and recharge regime may occur:

- Total long-term groundwater inflow to the tunnel is likely to be in the order of 4 L/s. The long-term groundwater inflow rate was validated with the Heuer method as described in the **Appendix**. 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 bursts of high groundwater inflow rates. Following input of the Stage 3 groundwater level data, the numerical groundwater flow model will be re-calibrated and used to further assess the estimate of seepage inflow into the Northern Link tunnel. Notably, the current prediction of long-term inflows in the order of 4 L/s along the length of the tunnel is considered reasonable and compare well with those predicted for the Airport Link tunnel (8 L/s) and the North South Bypass Tunnel (5 L/s).
- Quasi-steady state conditions may be reached following a period of between 10 to 20 years post-construction.
- Steep vertical downward hydraulic gradients will develop between the alluvial aquifer and the fractured rock aquifer in proximity to the tunnel. Leakage of groundwater from the alluvial aquifer to the fractured rock aquifer and ultimately to the tunnel itself may result. As discussed above, the alluvial aquifer is unlikely to dry out completely; rather a perched shallow aquifer is likely to be derived, interrupting the direct hydraulic connection between the two aquifers.
- Groundwater levels within the weathered Bunya Phyllite/Neranleigh Fernvale Beds will be permanently lowered to depths of tens of metres below the bottom of the alluvium sediments. The drawdown cone is expected to extend up to 800 metres either side of the tunnel corridor.
- Surface water inflow from the Brisbane River is unlikely to occur as a consequence of groundwater drawdown during construction and operation of the tunnel (refer to **Section 5.5**). This conclusion will require further verification in subsequent hydrogeological investigations.

5.3 Impacts of Land Disturbance

Land disturbance as a result of the Project construction will largely be limited to the open trough structures and cut and cover tunnels. 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.

With regards to potential settlement issues *as a result of groundwater decline*, the rocks along most of the tunnel alignment are very strong and competent. The rocks have been subject to high compaction forces and are highly over-consolidated. For this reason, settlement due to groundwater level lowering, along almost the entire tunnel route will be effectively negligible. The only possible exceptions are the occurrences of alluvium in proximity to the western portal cut and cover section and at the central section of the tunnel (close to Fernberg Road).

With reference to the western portal cut and cover section, the alluvium at this location consists of up to 2 metres of compressible silty clays with SPT values between 1 and 9. The drained tunnel could potentially dewater this material and small absolute and differential settlement may occur. It is currently understood that there are no sensitive structures at this location and hence a small level of settlement is not expected to contribute to significant impacts. It is acknowledged however that construction of a pedestrian / bicycle bridge over the Western Freeway is planned for this year (and hence will be in operation prior to NL construction commencing). The potential for settlement to occur at this location should be given further consideration during the detailed design phase.

With reference to the central section of the tunnel (close to Fernberg Road) groundwater level drawdowns within the alluvial sediments are predicted by the numerical model. As discussed earlier however, the alluvium material is unlikely to dry out completely as the model assumes the absence of a confining layer between this unit and the underlying fractured rock aquifer. A level of confinement is expected (as evidenced by the artesian and upward hydraulic gradient recorded in NL2-19D), hence, the alluvium / weathered material is unlikely to dry out completely; rather a perched shallow aquifer may be derived, interrupting the direct hydraulic connection between the two aquifers.

An assessment of the bore logs in the vicinity of Fernberg Rd (NL-3 and NL-4) indicates a varying thickness of alluvium from 2 to 6 metres. These medium to high plasticity CI silty clays have a recorded SPT value of between 8 and 9. The water table depth is not currently known. If it assumed that the silty clays are completed dried out (and as stated above this is likely to be an overestimation) a maximum settlement between 15 to 25 mm may be possible. The rapidly varying thickness of the alluvium suggests that this could induce significant differential settlements. Accordingly, it is recommended that the nature of the confining layer between the fractured rock and alluvium aquifers be reviewedin light of the Stage 3 Geotechnical Investigation results. The analysis should inform the potential for groundwater level drawdown in the alluvium material (as a consequence of construction and operation of the tunnel) and in turn, the implications for settlement at this location.

5.4 Potential Impact to Groundwater Dependent Ecosystems

The existence of Groundwater Dependent Ecosystems in proximity to the study corridor was discussed in **Section 4.10**. In general, it is considered that the level of groundwater dependency in the area is likely to be relatively low with terrestrial vegetation, river base flow systems and aquifer systems potentially utilising groundwater in the saturated zone only during drought conditions where surface water flux is uncommon. The exception to this may be the wetland present in the southern portion of Mt Coot-tha Botanical Gardens. The wetland, despite being largely dry at present is likely to rely upon a combination of both groundwater and surface water flow.

It is understood that the current design allows for the construction of diaphragm walls through the alluvial channel at the western portal cut and cover structures. Conceptually, as groundwater flow is towards the Brisbane River, there is potential for groundwater to bank up behind the north western diaphragm wall. The preclusion of groundwater throughflow may in turn contribute to a groundwater level decline on the downgradient (south eastern) side of the diaphragm wall.

The alteration of the groundwater regime in this area may have the potential to impact on the wetlands present in the southern portion of Mt Coot-tha Botanical Gardens. The potential reduction of groundwater throughflow may preclude an important water source to the ecosystems present in the wetlands. It is also acknowledged that the construction of the proposed storage dam to the north will intercept a significant source of surface water run-off that would otherwise discharge to the wetlands. The combined reduction in groundwater throughflow and surface water flow has the potential to impact upon the possible Groundwater Dependent Ecosystems present in the wetlands.

With reference to the impact of the diaphragm walls within the alluvial channel at the western portal cut and cover structures, the preliminary numerical modelling indicates only a minor alteration to the groundwater throughflow regime. In fact any alteration to the groundwater throughflow is largely insignificant relative to the potential impact on the alluvial aquifer by way of induced downwards leakage to the fractured rock. That is, the impact of the downwards vertical movement of groundwater dominates over the alteration to lateral groundwater throughflow as a consequence of the diaphragm walls. The dominance of vertical flow over lateral groundwater flow is a function of the assumption in the model of no confining layer between the alluvium and fractured rock aquifer.

Clearly, the implication for the wetlands will depend upon (amongst other factors) the nature of the confining unit between the alluvium and the fractured rock aquifer. If a high degree of confinement exists there is a potential for the groundwater to bank up behind the north western diaphragm wall, impeding flow to the wetlands. The obstruction to lateral groundwater flow could simply be managed by constructing a gravel drain over the diaphragm walls to intercept rising groundwater levels and in turn discharging this component of flow to the downgradient wetlands.

If there is a low level of confinement between the alluvium and the fractured rock aquifer (as assumed in the numerical model), the groundwater in the alluvium will leak downwards to the fractured rock to be subsequently intercepted by the tunnel drainage system. This component of groundwater flow that would otherwise discharge to the wetlands will be intercepted by the tunnel. Undertaking a water balance of the wetland to determine its reliance on groundwater flow will aid in clarifying whether the loss of this lateral groundwater flow component to the tunnel will have significant implications for the heath of this system.

Lastly, groundwater level drawdown within the alluvium in the central section of the tunnel (close to Fernberg Road) may have the potential to impact upon any Groundwater Dependent Ecosystems present at this location.

As discussed in **Section 5.3**, the level of groundwater level drawdown will principally be dictated by the nature of the confining unit between the alluvium and the fractured rock aquifer. The level of confinement at the western and central sections of the tunnel should be further examined upon analysis of the Stage 3 Geotechnical Investigation results. The analysis should inform the potential for groundwater level drawdown in the alluvium material (as a consequence of construction and operation of the tunnel) at these locations and in turn, the implications for any Groundwater Dependent Ecosystems present.

5.5 Impact on Groundwater Quality and Contamination

As the extent of the groundwater drawdown cone extends as a consequence of discharge to the tunnel, the potential area in which contaminants may potentially be impacted becomes progressively larger.

An outcome of the modelling exercise demonstrates that a range of Environmental Management Register (EMR) listed land parcels (**Figure 11**, **Figure 12** and **Figure 13**) exist within the capture zone of the potential groundwater level drawdown cone (**Figure 22** and **Figure 24**) resulting from the construction and operation of the tunnel. Any mobile groundwater contaminants within this capture zone may be expected to ultimately discharge to the proposed tunnel. Contaminant travel times will be dependent upon the contaminant itself, the distance from the tunnel and the magnitude of the hydraulic gradient towards the tunnels. On the basis that groundwater inflows to the tunnel are expected to be low (in the order of 4 L/s), contaminant fluxes will also be correspondingly low.

An important issue for consideration is the potential migration of contaminated groundwater towards or through adjacent previously uncontaminated sites as a consequence of the altered hydraulic gradient. The current water table depths in both the alluvium and fractured rock may well be within typical root zone depths (< 8 metres in depth) of overlying vegetation. The groundwater level will however become deeper as the tunnel is constructed and in turn, the potential environmental impact of any migrating contamination will be considerably reduced.

Furthermore, the potential impact of migrating contamination may warrant further attention if a contaminant plume migrates towards a formerly non-contaminated zone in which groundwater extraction and usage occurs.

A separate issue to the potential for contaminant migration is the inducement of saline water from the Brisbane River into the aquifer and subsequently to the tunnel as a consequence of groundwater drawdown during construction and operation of the tunnel and reversal of the hydraulic gradient between the aquifer and adjacent river system. 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.

The numerical modelling undertaken does indicate that the drawdown cone is unlikely to intercept the Brisbane River in the long term (**Section 5.1.7** and **Figure 25**). The prospect of saline water migrating and discharging to the tunnel (and presenting corrosion or clogging issues) is therefore considered improbable. Furthermore, in the event that a marginal reversal of the hydraulic gradient does occur, the saline water would not be expected to intercept the tunnel for well over 200 years.[4]

It is emphasised however, that the accuracy of the model is such that a definitive conclusion regarding the post-construction hydraulic gradient between the tunnel and the river cannot be made. Additionally, if an interconnected shear zone / fault is present between the Brisbane River and the tunnel, preferential flow may occur to the extent that saline water is intercepted by the tunnel within a relatively short time frame (i.e.< 100 years). Findings from the Stage 3 Geotechnical Investigation will provide additional information regarding risks of these potential impacts.

5.6 Potential for Acid Sulphate Soils

As discussed in Section 4.9 the potential for ASS materials to be encountered is considered negligible. In the event that any sulphate soils are encountered and disturbed during excavations management plans should be put in place to contain these soils.

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[4] The velocity of the saline water was calculated as follows:

$$\text{Pore water velocity } (v) = \frac{\text{Groundwater Flow Rate } (Q)}{\text{Volumetric Water Content } (\theta)}$$

Assumptions: Q = 0.0001 m^3/day and θ = 0.01

6. Management Options & Recommendations for Further Study

The review of the existing hydrogeological environment of the Project Corridor 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. The results of the Stage 1 and 2 field investigations whilst valuable in constructing a conceptual hydrogeological model, is limited with respect to the provision of a representative range of hydraulic parameters for application to the numerical modelling assessment. Analysis of the results from the Stage 3 Geotechnical Investigation will add a level of confidence to the assumptions concerning the hydrogeologic environment represented in the model. It is recommended (as detailed below) that the assessment described in this report be revised in accordance with the field data derived.

The following recommendations concern further refinements to the current assessment and possible management options available to address the issues identified:

- The permeability of the fractured rock in the Project Corridor, represented by the Bunya Phyllite and Neranleigh-Fernvale Beds, has the potential to be highly variable. This heterogeneity is not reflected in the numerical modelling analysis. While an “average” hydraulic conductivity for the two units was applied in the model, investigations to date (Environmental Hydrology Associates, 2007) indicate the upper limit of hydraulic conductivity may be substantially higher (in localised areas) than that represented. It is emphasised however that there is a possibility of intersecting highly fractured zones during construction which could lead to short term bursts of high groundwater inflow rates in excess to 4 L/s.

  The results of the Stage 3 Geotechnical Investigations will provide a greater level of confidence concerning the “average” hydraulic conductivity of the fractured rock. Possible zones of highly fractured (permeable) material may similarly be identified in the investigations. Slug tests of the alluvial material in the proximity of the Western Freeway cut and cover tunnels have been carried out as part of the Stage 3 Geotechnical Investigations.

  Together these results should be used to refine the hydraulic permeability estimates of the fractured rock and alluvial units as applied in the numerical model. Furthermore, if the results permit, it may be possible to represent a level of heterogeneity of both units in the model. Together these refined model inputs will provide an added level of confidence to the estimated tunnel inflows, the extent of the drawdown cone and any associated impacts.
- Inherent in the calibrated model was a level of uncertainty concerning the recharge rates adopted and the anomalously high groundwater levels recorded for a number of bores situated in the east of the study area. The results of the Stage 3 Geotechnical Investigation,

(in particular, the groundwater level monitoring and additional drilling) provides an opportunity to verify the elevated groundwater levels and if necessary, to conceptualise the local scale process giving rise to the anomalous readings. In turn, the results of the field investigations can be reflected in the model calibration and scenarios assessed.

- As discussed in the previous chapter, a proposed storage dam is planned for the south east corner of the Mt Coot-tha Botanical Gardens. If constructed, this dam has the potential to leak and represent an "infinite" source of water for discharge to the drained tunnel. Depending on the level of dam leakage, sustained and increased inflows to the tunnel may result.

- It is proposed that various scenarios be modelled to represent the inflow impact of variable levels of dam leakage. The scenarios should incorporate the range of representative hydraulic conductivities determined from the Stage 3 Geotechnical Investigations described above.

- The section of tunnel that is cut and cover and passes through the alluvium at the south western end of the tunnel is over 200 metres in length. The MODFLOW model constructed in this study incorporates grid cells that range in side length from 30 to 70 metres. The MODFLOW layer thickness of the fractured rock unit through which the tunnel passes is typically 50 metres. This discretisation is relatively course compared to the length and size of the cut and cover tunnel section. Furthermore, the boundary conditions represented by MODFLOW do not support a detailed investigation of the complex groundwater flow processes in this area. It is therefore recommended that consideration be afforded to undertaking a more detailed model of this area. The modelling could be conducted utilising a FEFLOW slice model. FEFLOW is a software package that utilises a finite element numerical approach. Finite elements allow the user to define problem geometry using a variable size triangular mesh, making geometry representation more flexible. This detailed modelling approach will assist in determining the potential effect to the downgradient wetland present (in the southern portion of Mt Coot-tha Botanical Gardens) together with any impacts to the Groundwater Dependent Ecosystems present.
Prior to undertaking additional modelling, the nature of the confining unit between the fractured rock aquifer and the alluvium should be determined by evaluating the results of the Stage 3 Geotechnical Investigation. Accurate representation of the confining unit in the model is paramount to understanding the implications of the tunnel development on the downgradient wetland and Groundwater Dependent Ecosystems present and the appropriate management options.

- The groundwater level drawdown within the alluvium in the central section of the tunnel (close to Fernberg Road) may have the potential to impact upon any Groundwater Dependent Ecosystems present at this location. As for the western tunnel end, the level of confinement between the fractured rock aquifer and the alluvium should be further examined upon analysis of the Stage 3 Geotechnical Investigation results. The analysis should inform the potential for groundwater level drawdown in the alluvium material (as a consequence of construction and operation of the tunnel) and in turn, the implications for any Groundwater Dependent Ecosystems present at this location.

- 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 Northern Link tunnel will serve to intercept and treat any contaminated groundwater that would otherwise discharge to surface water systems. In general, therefore, the capturing of contaminated groundwater will have a positive impact on the aquifer and surface water systems.
- The risk of saline water from the Brisbane River discharging to the tunnel (and possibly contributing to corrosion or clogging impacts to the concrete drains) is very small. The results of the Stage 3 Geotechnical Investigation will provide more evidence concerning the risks of such impacts occurring (for example, as a consequence of intersecting a shear zone or fault). It is recommended that the risk of these impacts be further evaluated upon completion of the investigative program.
- Settlement due to groundwater level lowering along almost the entire tunnel route will be effectively negligible. The only possible exceptions are the occurrences of alluvium in proximity to the western portal cut and cover section and at the central section of the tunnel (close to Fernberg Road). Small levels of settlement may be possible in these areas and it is recommended that the nature of the confining unit between the fractured rock and alluvium (which will dictate the level of groundwater level drawdown) be further examined upon analysis of the Stage 3 Geotechnical Investigation results. The implications for potential settlement may require further consideration during the detailed design phase.
- A suitable network of monitoring bores has been established during the first, second and third stage Geotechnical Investigations. It is recommended that groundwater bores constructed in both the alluvial and fractured rock aquifer be regularly monitored for groundwater level in order to provide baseline data to monitor any future impacts associated with tunnel construction and operation. If any groundwater level deviations from seasonal baseline water levels are observed, the nature of the impact can be assessed and mitigation measures implemented if necessary.

[NOTE ADDED PRIOR TO RELEASE OF EIS]

The groundwater modelling was undertaken on the basis of an early tunnel design in which the entire tunnel was to be constructed as drained ie with the expectation that groundwater would enter the tunnel and provision would be made for its capture and removal.

However, review of the tunnel design in light of the issues raised in this report with respect to the tunnels' effect on the groundwater regime of the cut and cover sections at the Western Freeway connection adjacent to the Botanic Gardens necessitated redesign. The reference design in the EIS now includes an undrained section of tunnel through the alluvium in this area. This change in design removes the potential for blocking groundwater flow beneath the Western Freeway and also largely removes the potential for settlement effects in the same area.

The implications of this change in design have been incorporated into Chapter 7 – Hydrology in Volume 1 of this EIS. However, this Technical Report has not been so changed as it provides the original groundwater modelling and interpreted impacts that lead to the change in tunnel design and provides a good example of how the environmental impact assessment is incorporated into project design.

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Appendix

Estimation of Groundwater Recharge with Soil Moisture Water Balance Modelling

The Soil Moisture Water Balance Model (SMWBM) is a deterministic lumped parameter model originally developed by Pitman (1976) to simulate river flows in South Africa. Modification of these algorithms and additional algorithms developed now permit soil moisture accounting and assessment of the various components of the catchment water balance. In this study the SMWBM is employed as a pre-conditioner for assigning groundwater recharge to the MODFLOW model.

Soil moisture accounting on a daily basis model ensures that antecedent soil moisture conditions are considered in a realistic manner. The model utilises daily rainfall and mean-monthly evaporation data to calculate soil moisture conditions and rainfall percolation to the aquifer. The model incorporates parameters that characterise the catchment in terms of:

- interception storage;
- evaporation losses;
- soil moisture storage capacity;
- soil infiltration characteristics;
- surface ponding and subsequent drainage and open water evaporation;
- soil moisture percolation dynamics;
- surface runoff (quickflow);
- stream baseflows (groundwater contribution); and
- parameters that govern the recession and/or attenuation of groundwater and surface water flow components, respectively.

The fundamental operation of the model is as follows:

- Daily rainfall is disaggregated into hourly intervals when a rain day occurs to allow refined accounting of soil infiltration and evaporation losses. Rainfall received must first fill a nominal interception storage (PI – see below) before reaching the soil zone, where the net rainfall is assessed as part of the runoff/infiltration calculation.

- Water that penetrates the soil fills a nominal soil moisture storage zone (ST). This zone is subject to evapotranspiration via root uptake and direct evaporation (R) according to the mean monthly evaporation rate and current soil moisture deficits. The soil moisture zone provides a source of water for deeper percolation to the underlying aquifer, which is governed by the parameters FT and POW.

- If disaggregated hourly rainfall is of greater intensity than the calculated hourly infiltration rate (ZMAX, ZMIN) surface runoff occurs. Surface runoff is also governed by two other factors, which are the prevailing soil moisture deficit and the proportion of impervious portions of the catchment directly linked to drainage pathways (AI).

- Rainfall of sufficient intensity and duration to fill the soil moisture storage results in excess rainfall that is allocated to either surface runoff or groundwater percolation depending on the soakage and slope characteristics of the catchment (DIV).
- Finally, the model produces daily summaries of the various components of the catchment water balance and calculates the combined surface runoff/percolation to groundwater to form a total catchment runoff discharge.

Model Parameters

The most significant parameters used in the soil moisture accounting model are described below.

ST: Maximum soil moisture capacity
The parameter ST is of major importance in that it is the most significant factor governing the ability of the catchment to regulate runoff for a given rainfall event. The higher the value of ST potentially the greater the amount of rainfall absorbed during wet periods, and results in more sustained baseflow during dry periods.

The depth of the ST zone basically prescribes an active zone above the water table (vadose zone) within which plant root uptake can occur. Depending on the vegetative and lithological characteristics of the catchment, this may coincide with the soil zone or may be deeper (i.e. forests and in sands).

SL: Soil moisture storage capacity below which percolation ceases
There is a definable soil moisture state below which percolation ceases due to soil moisture retention. For practical purposes this has been assigned zero.

ZMAX & ZMIN: Maximum and minimum soil infiltration rate
ZMAX and ZMIN are nominal maximum and minimum infiltration rates in mm/hr used by the model to calculate the actual infiltration rate ZACT. ZMAX and ZMIN regulate the volume of water entering soil moisture storage and the resulting surface runoff. ZMIN is usually assigned zero. ZMAX is usually assigned the saturated infiltration rate from field testing. ZACT may be greater than ZMAX at the start of a rainfall event. ZACT is usually nearest to ZMAX when soil moisture is nearing maximum capacity.

FT: Percolation rate from soil moisture storage at full capacity
Together with POW, FT (mm/day) controls the rate of percolation to the underlying aquifer system from the soil moisture storage zone. FT is the maximum rate of percolation through the soil zone.

POW: Power of the soil moisture-percolation equation
The parameter POW determines the rate at which percolation diminishes as the soil moisture content is decreased. POW therefore has significant effect on the seasonal distribution and reliability of percolation, as well as the total yield from a catchment.

AI: Impervious portion of catchment

This parameter represents the proportion of impervious zones of the catchment directly linked to drainage pathways (AI).

R: Evaporation-soil moisture relationship

Together with the soil moisture storage parameters ST and SL, R governs the evaporative process within the model. The rate of evapotranspiration is estimated using a linear relationship relating evaporation to the soil moisture status of the soil. As the soil moisture capacity approaches full, evaporation occurs at a near maximum rate based on the mean monthly pan evaporation rate, and as the soil moisture capacity decreases, evaporation decreases linearly according to the predefined function.

Table 11 summarises the parameter values applied for the simulation.

- **Table 11 Model Input Parameters**

Parameter	Primary Model Parameters					Secondary Model Parameters									
	Area	ST	FT	Z_{max}	PI	AI	Z_{min}	R	DIV	TL	GL	LAG	O_{obs}	POW	SL
Units	km^2	mm	mm/d	mm/h	mm	%	mm/h		%	d	d	d	m^3/day		mm
Mogill at Misty Morn	61	80	0.5	10	2	0.1	0	10	0	1	3	0.5	3,000	2.6	0
Urban Zone	N/A	80	0.5	10	1	0.5	0	10	0	1	3	0.5	3,000	2.6	0

Note: Bold text indicates modified values for urbanised zone.

Validation of the Groundwater Inflow Rate Using the Heuer Method

Heuer's method (Heuer, 1995) is a semi-empirical method used to validate the model's prediction of steady-state groundwater inflow to the tunnel. This method uses the equation derived in Goodman et al., (1965) for steady-state inflow into a horizontal drain under the condition of a constant head boundary. In turn the Goodman equation was adapted from the Theim equation for steady-state, radial inflow into wells (Lohman, 1972). Heuer applies an empirical factor of 0.125 to the Goodman equation based on observations in various rock tunnels. Goodman's equation, with Heuer's reduction factor is:

$$Q_L = 0.125 \frac{2\pi KH}{\ln \frac{R_0}{r}}$$

where:

Q_L is the inflow rate per unit length of tunnel (m^3/day/m)

K is the hydraulic conductivity of the ground (0.01 m/day)

H is the head of water above the tunnel (30 metres)

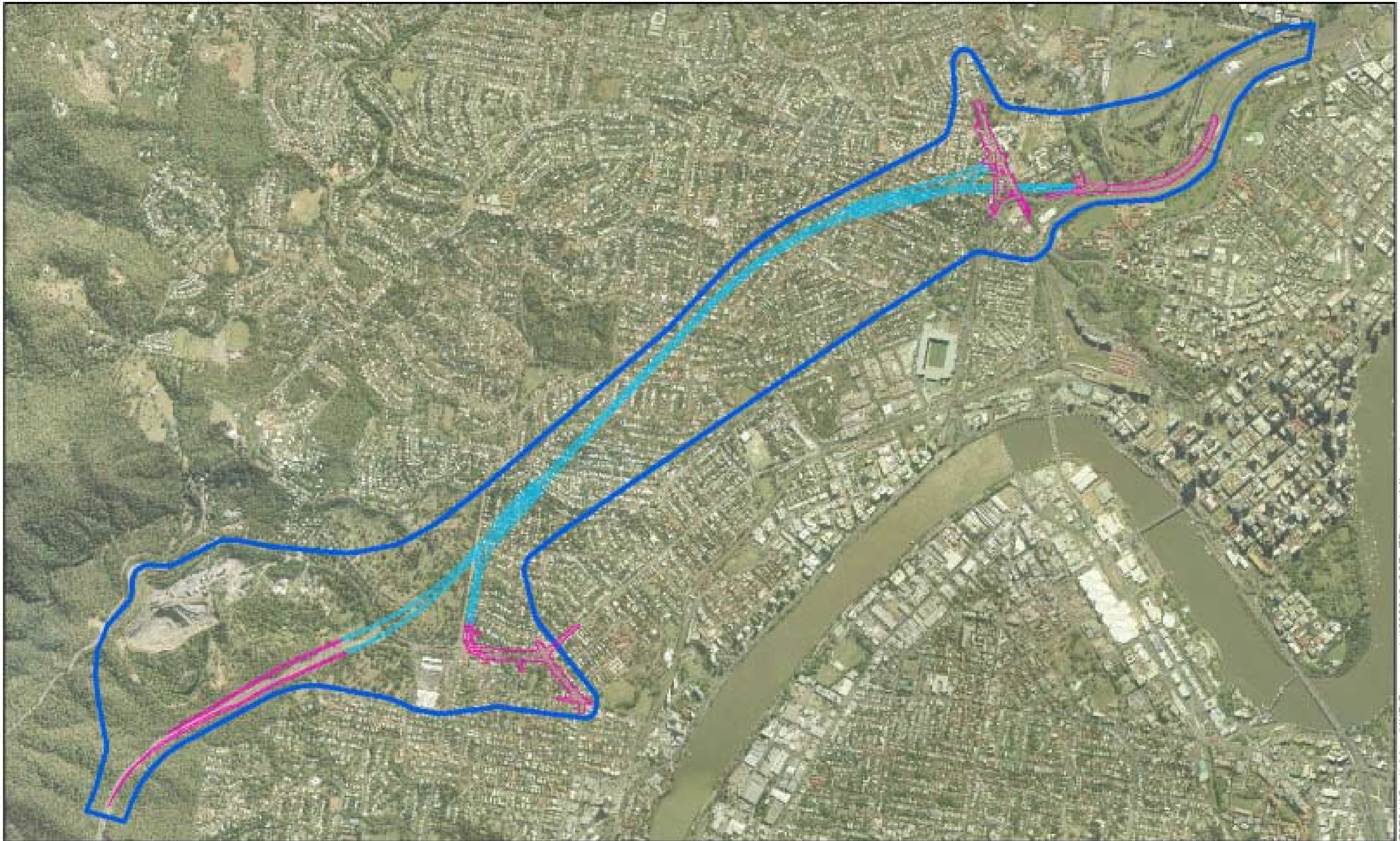
R_0 is the radius of influence, distance to which piezometric head is influenced by the tunnel (800 metres)

r is the radius of the tunnel (15 metres)

0.125 is Heuer's reduction factor

Assuming the above input parameters and a tunnel length of 5,000 metres, Q_L is derived at 3.42 L/sec.

Figures



LEGEND

Study Area Corridor

Proposed Alignment

Surface Work

Tunnel Underground

0 500 1,000

metres

Scale 1:25,000 (A4)

N

NORTHERN LINK
ENVIRONMENTAL IMPACT STATEMENT

Figure 1

Project Corridor

Northern Link

SKM Connell Wagner
JOINT VENTURE

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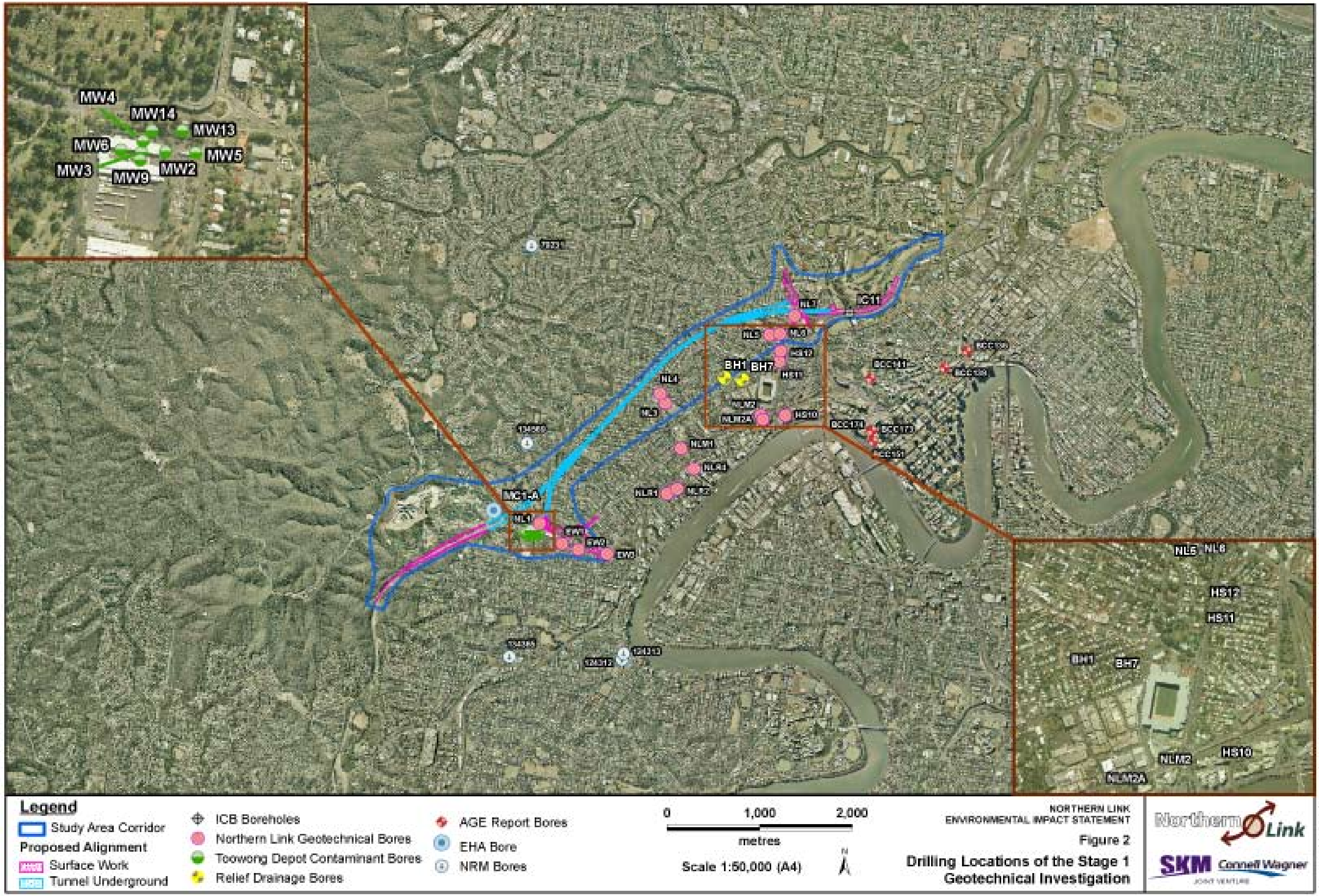
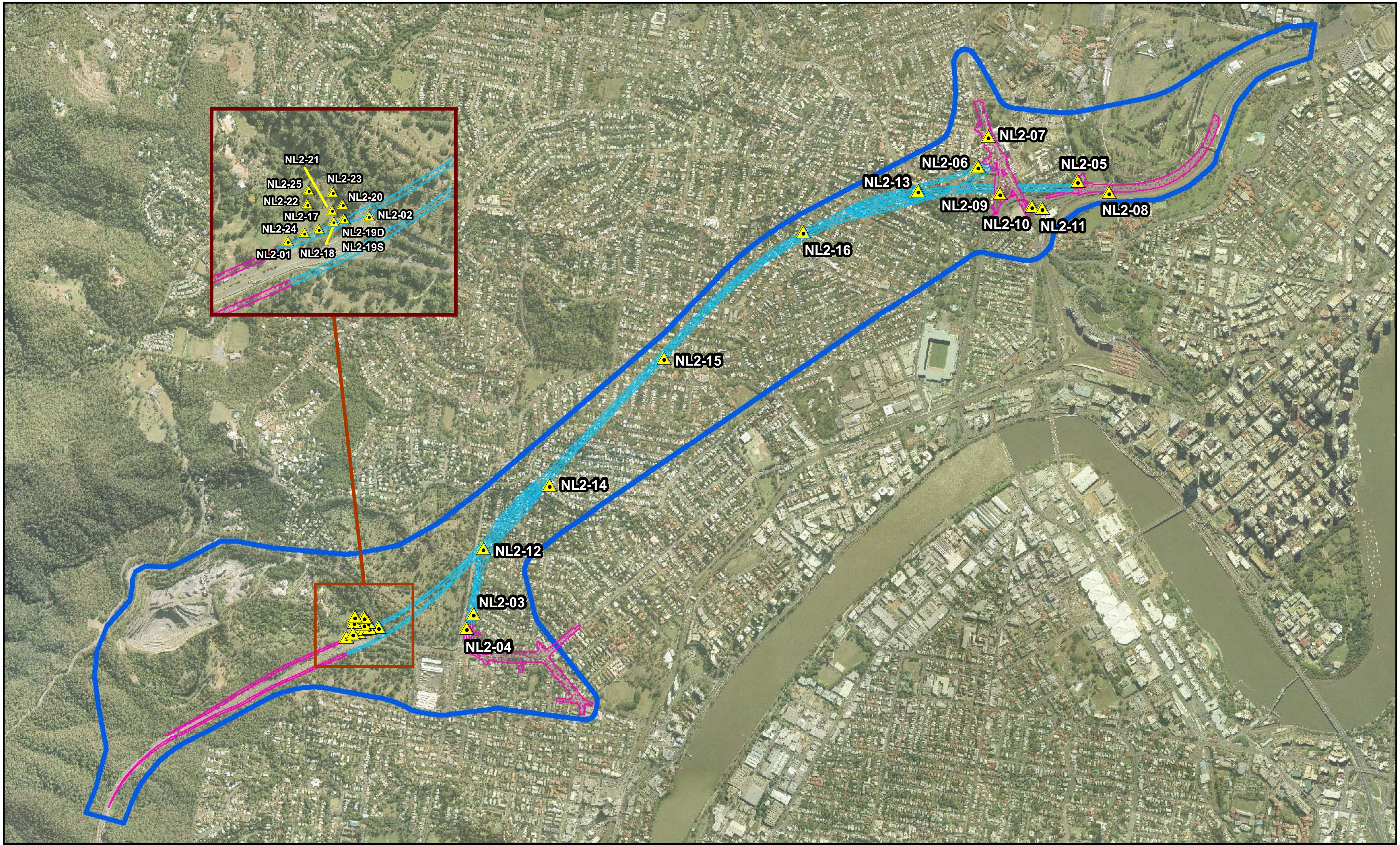


NORTHERN LINK
ENVIRONMENTAL IMPACT STATEMENT

Figure 2

Drilling Locations of the Stage 1 Geotechnical Investigation



Legend

- Study Area Corridor
- Stage2 Investigation Boreholes (2008)

Proposed Alignment

- Surface Work
- Tunnel Underground

0 500 1,000
metres
Scale 1:25,000 (A4)
N

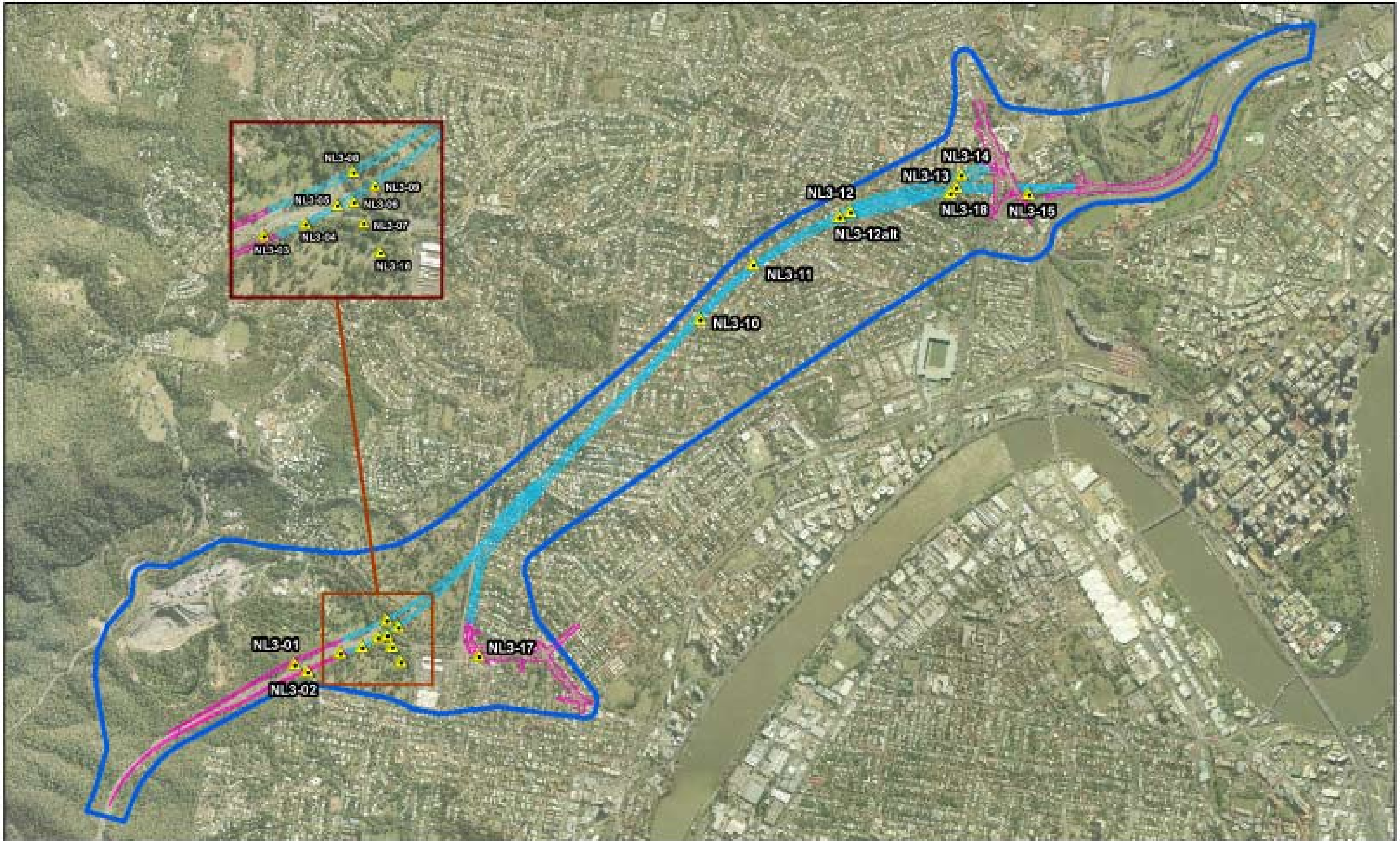
NORTHERN LINK
ENVIRONMENTAL IMPACT STATEMENT

Figure 3

Drilling Locations of the Stage 2 Geotechnical Investigation

Northern Link
SKM Connell Wagner
JOINT VENTURE

I:\QENV\Projects\QE07311\Spatial\Arc_MXD\Hydrogeology\LarryLuba_Report\080816_LL_Fig3_Stage2_Investigation_Bores.mxd



Legend

- Study Area Corridor
- Stage 3 Investigation Boreholes

Proposed Alignment

- Surface Work
- Tunnel Underground

0 500 1,000
metres
Scale 1:25,000 (A4)

N

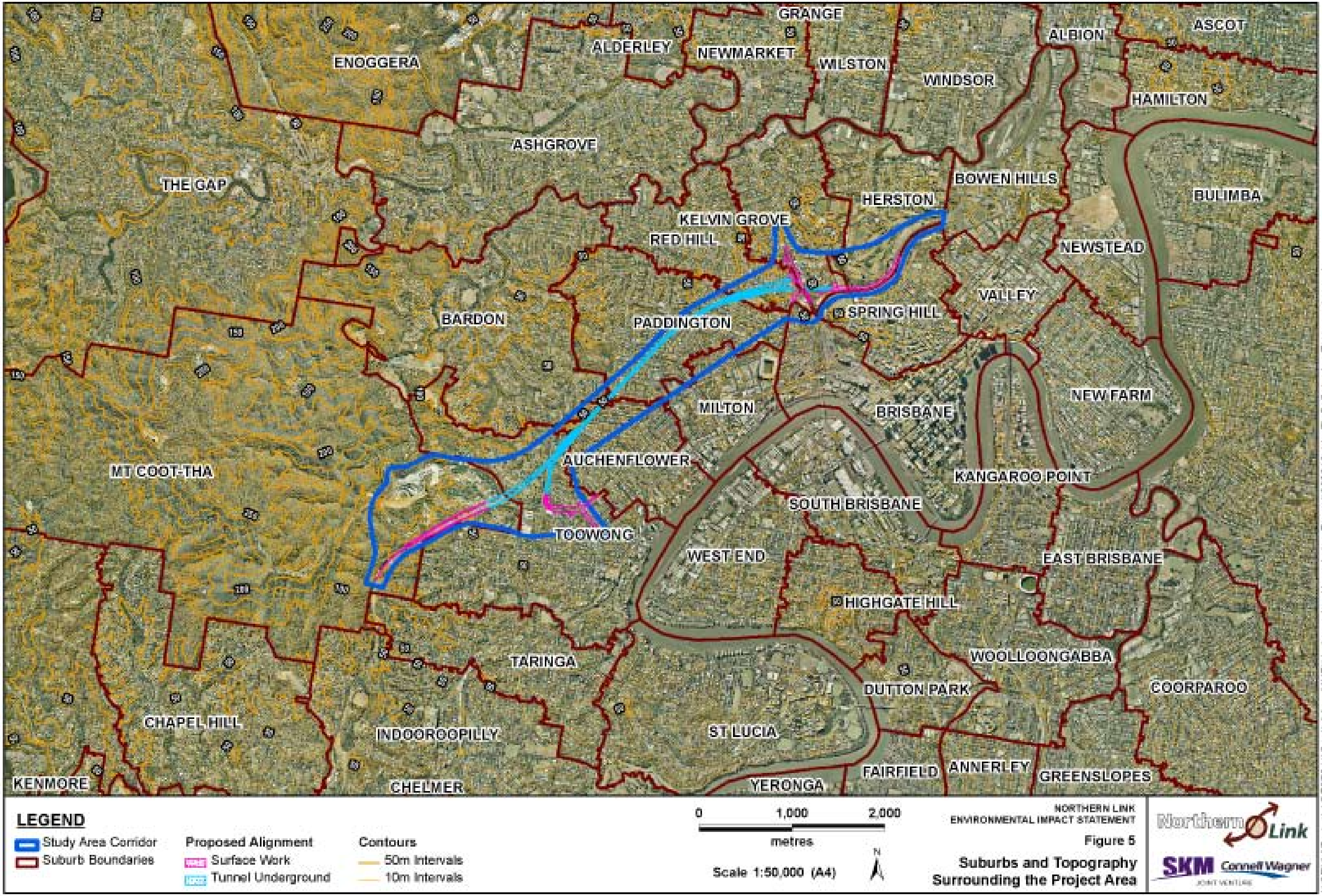
NORTHERN LINK
ENVIRONMENTAL IMPACT STATEMENT

Figure 4

Drilling Locations of the Stage 3 Geotechnical Investigation

Northern Link

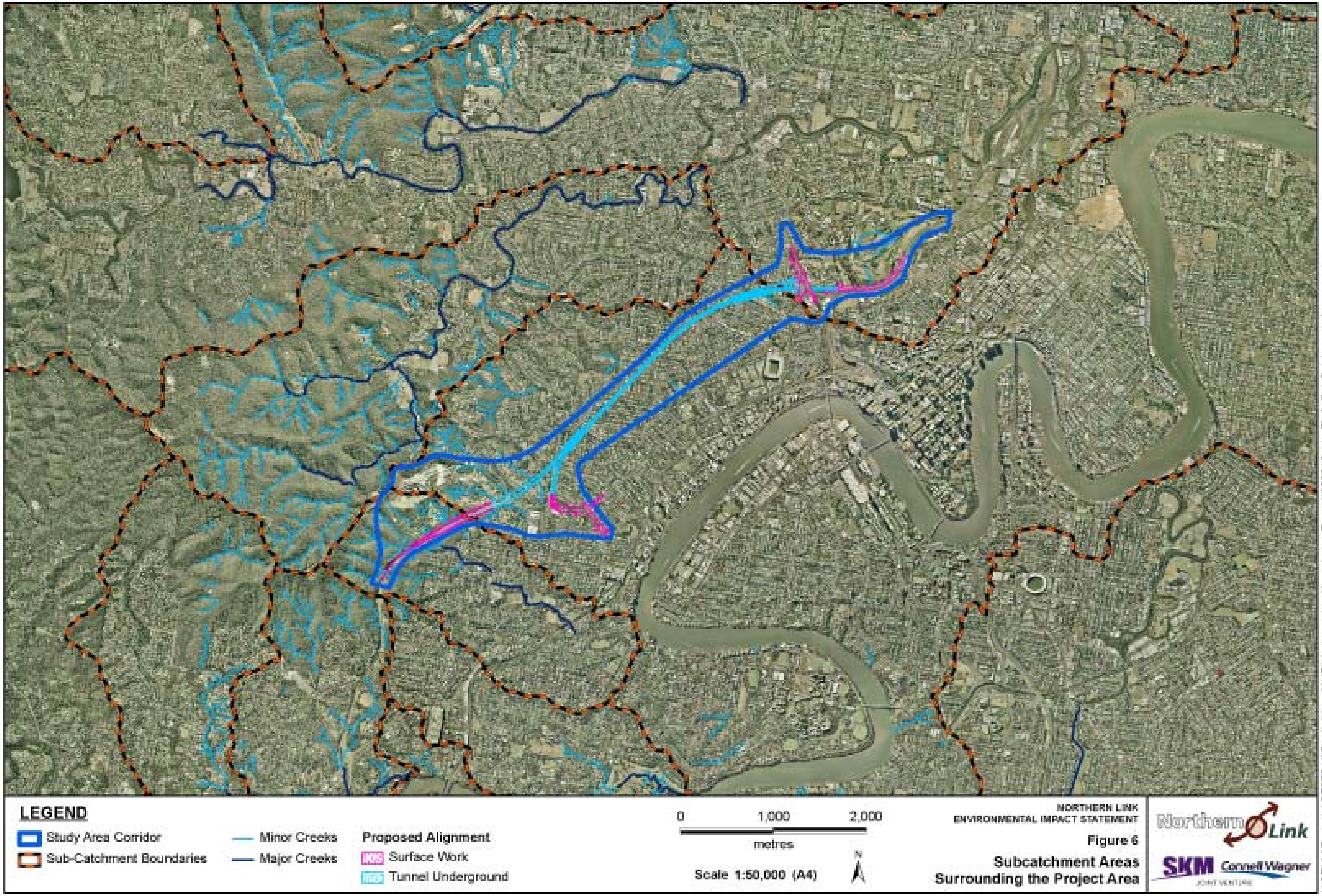
SKM Connell Wagner
JOINT VENTURE

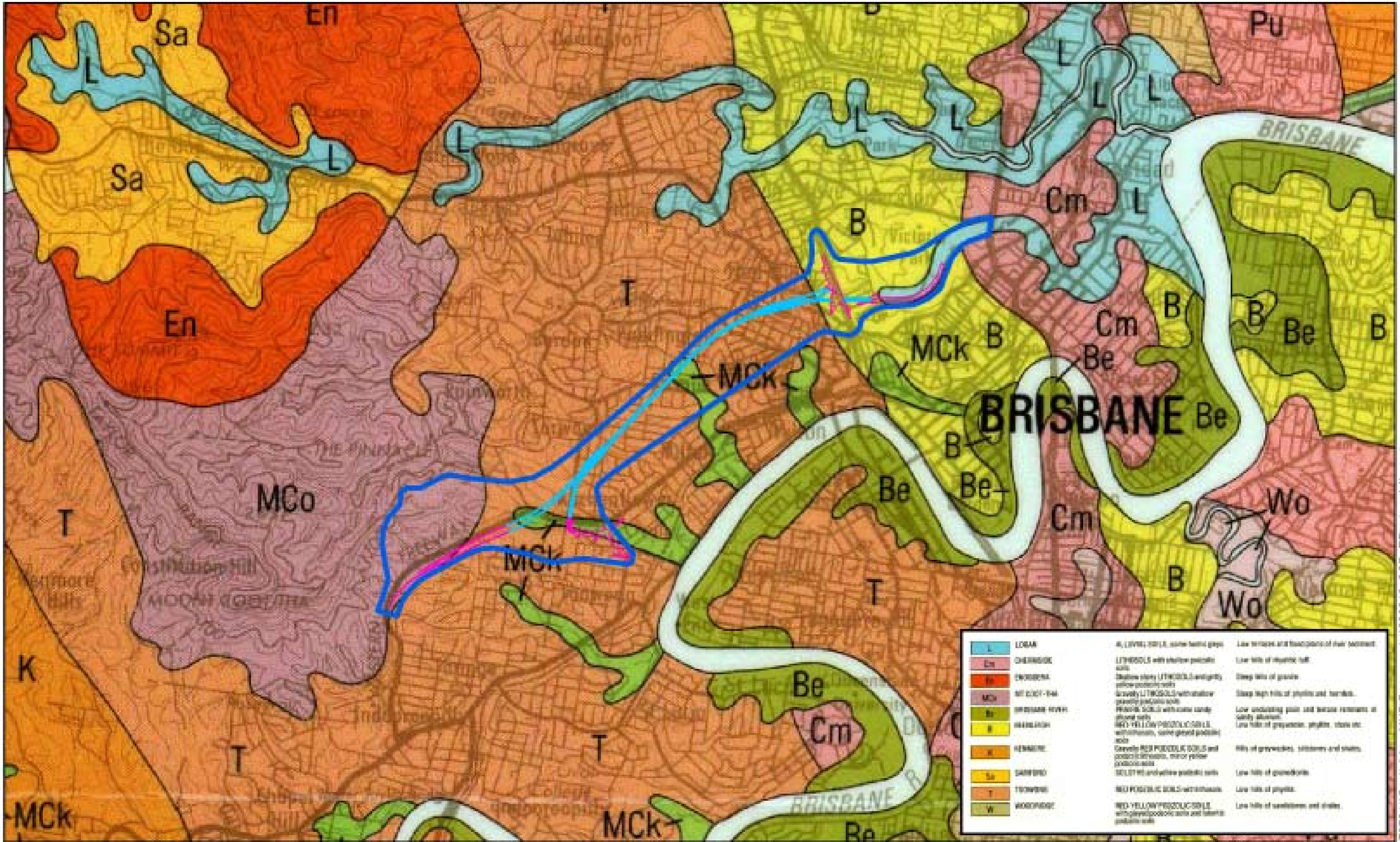


NORTHERN LINK
ENVIRONMENTAL IMPACT STATEMENT

Figure 5

Suburbs and Topography Surrounding the Project Area


LEGEND
Study Area Corridor
Sub-Catchment Boundaries
Minor Creeks
Major Creeks
Proposed Alignment
Surface Work
Tunnel Underground
0
1,000
2,000
metres
Scale 1:50,000 (A4)
N
NORTHERN LINK
ENVIRONMENTAL IMPACT STATEMENT
Figure 6
Subcatchment Areas
Surrounding the Project Area
Northern Link
SKM
Connell Wagner
JOINT VENTURE



LEGEND

Study Area Corridor

Proposed Alignment

Surface Work

Tunnel Underground

0 1,000 2,000

metres

Scale 1:50,000 (A4)

N

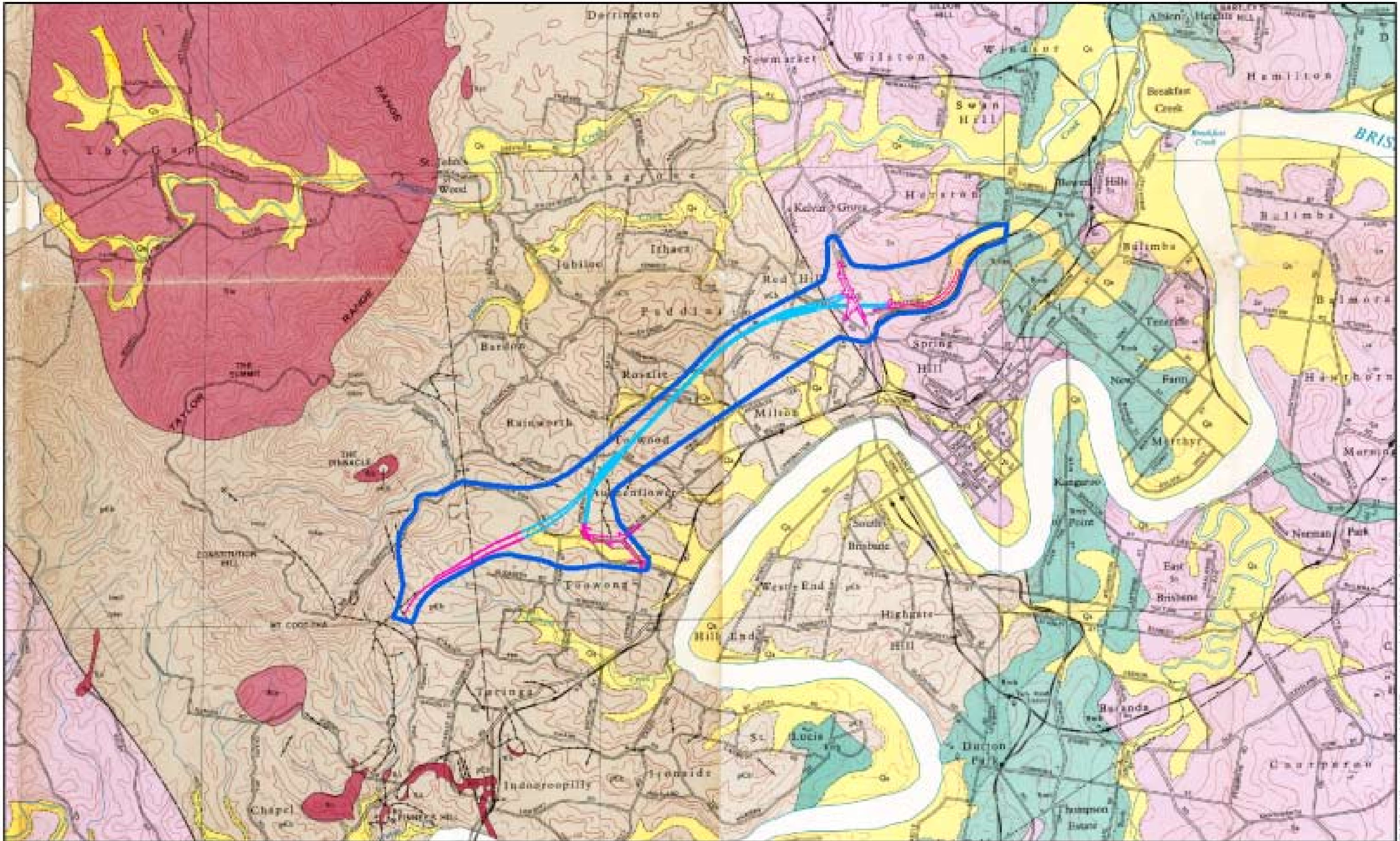
NORTHERN LINK
ENVIRONMENTAL IMPACT STATEMENT

Figure 7

Soil Types

Northern Link

SKM Connell Wagner
JOINT VENTURE



LEGEND

Study Area Corridor

Proposed Alignment

- Surface Work
- Tunnel Underground

Geological Seetings

- Alluvium
- Brisbane Tuff
- Enoggera Granite
- Neranleigh Fernvale
- Bunya phyllite

0 1,000 2,000
metres

Scale 1:50,000 (A4)

N

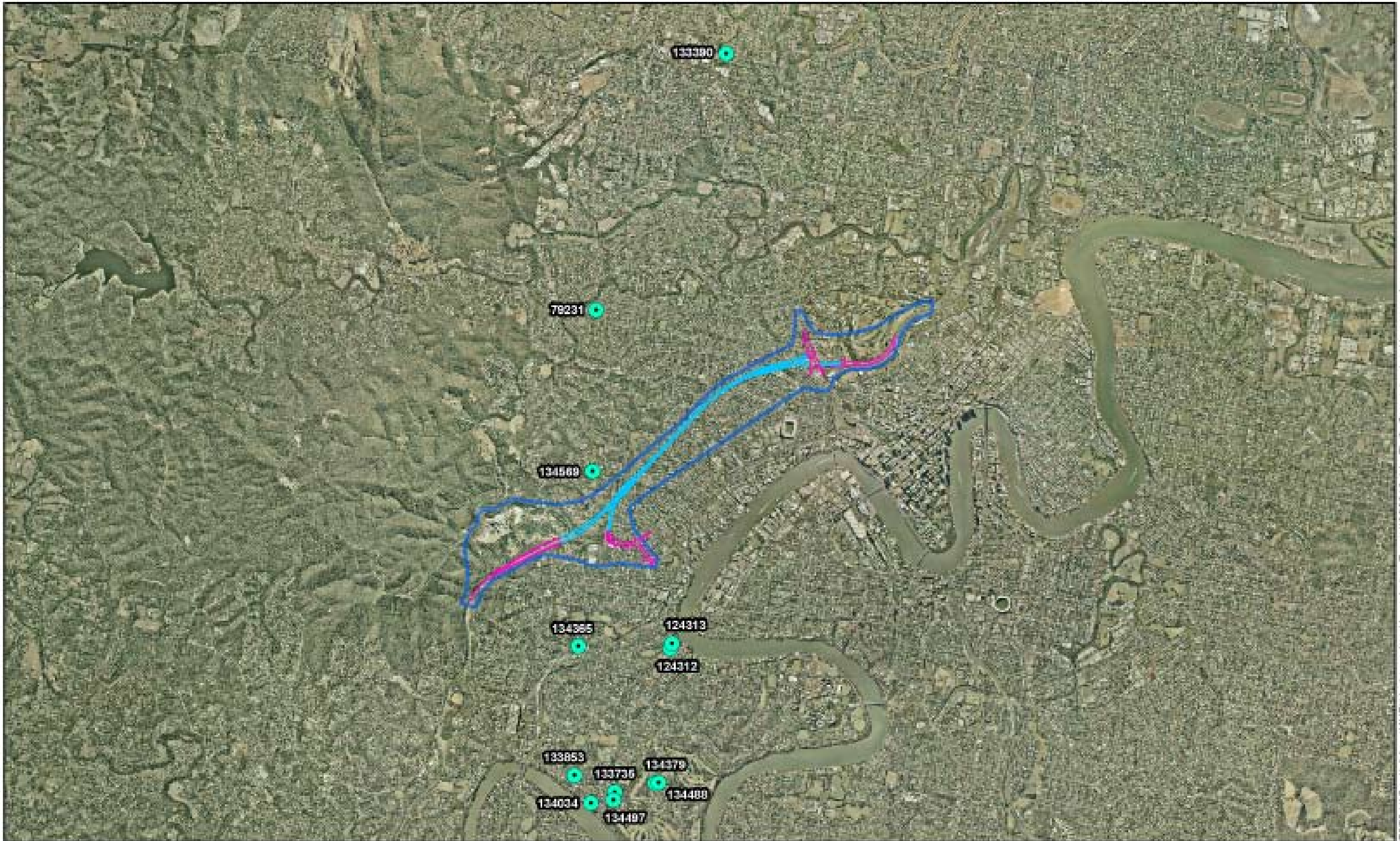
NORTHERN LINK
ENVIRONMENTAL IMPACT STATEMENT

Figure 8

Geology

Northern Link

SKM Connell Wagner
JOINT VENTURE



LEGEND

Study Area Corridor

Groundwater Users

Proposed Alignment

Surface Work

Tunnel Underground

0 1,500 3,000

metres

Scale 1:65,000 (A4)

N

NORTHERN LINK
ENVIRONMENTAL IMPACT STATEMENT

Figure 9

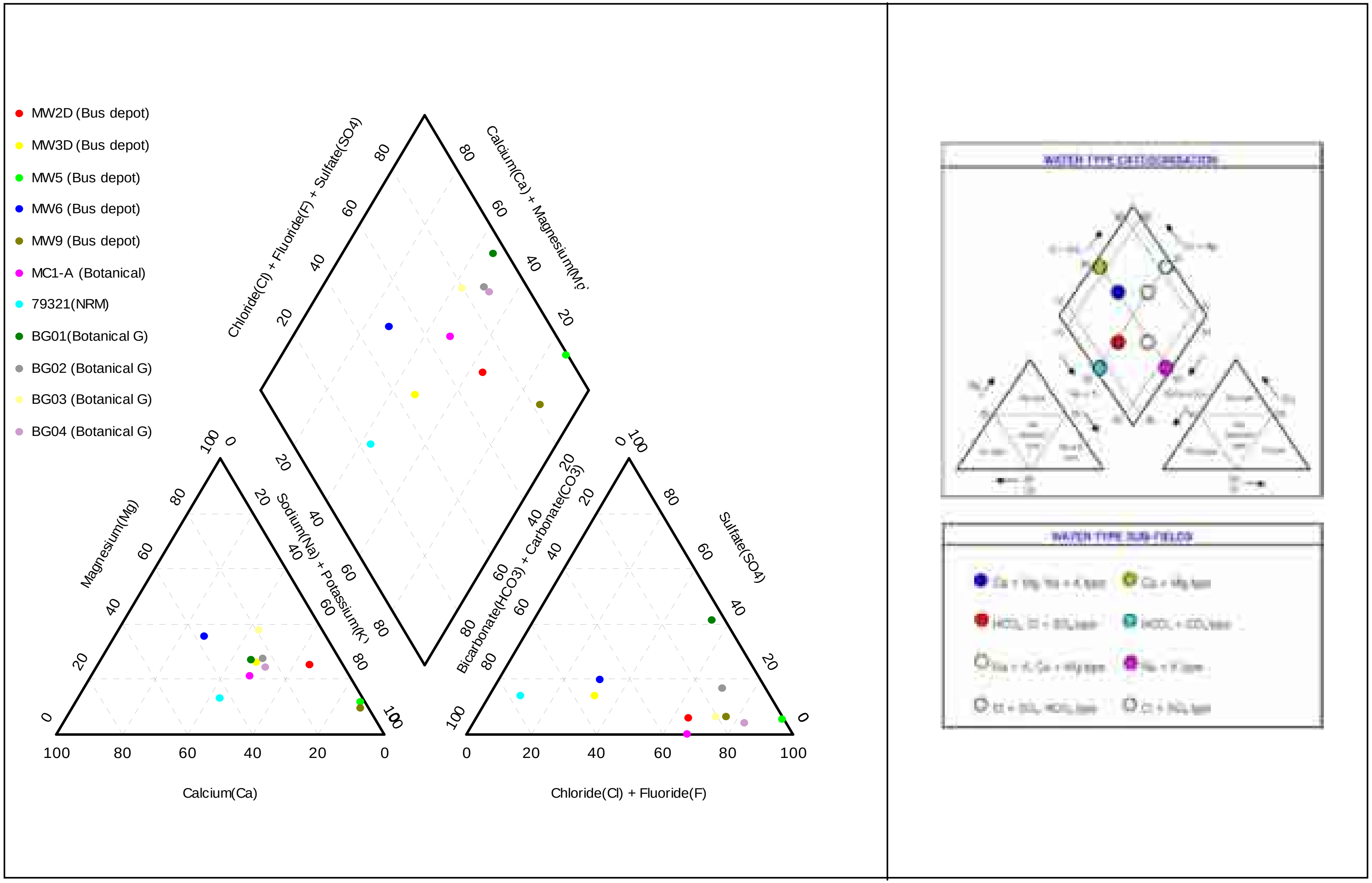
Groundwater Users in Proximity to the Northern Link Tunnel

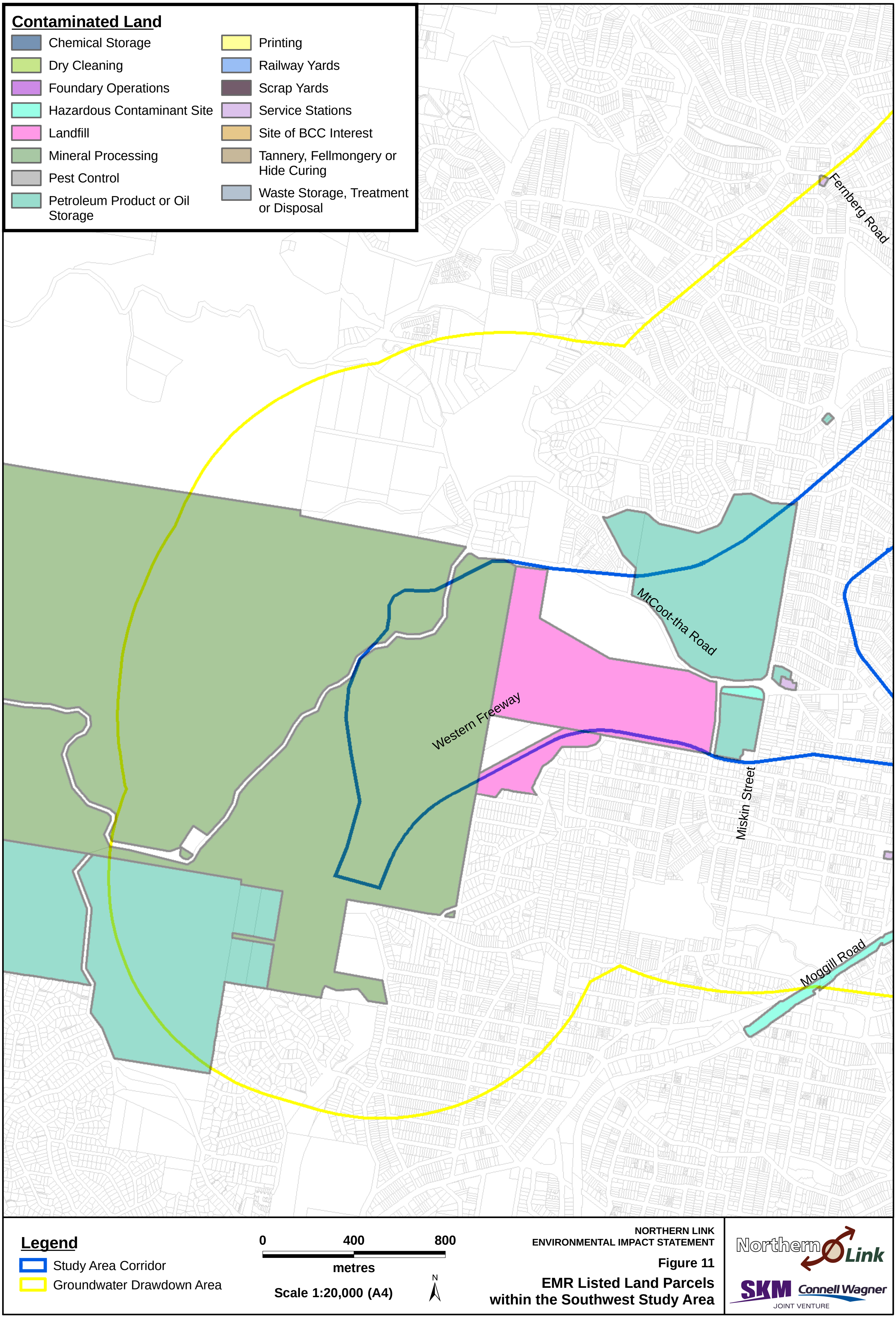
Northern Link

SKM Connell Wagner
JOINT VENTURE

I:\SENV\Projects\QE07311\Spatial\Arc_MXD\Hydrogeology\LarryLutes_Report\080816_LL_Fig9_Groundwater_Users.mxd

Figure 10 Piper Trilinear Diagram for Groundwater



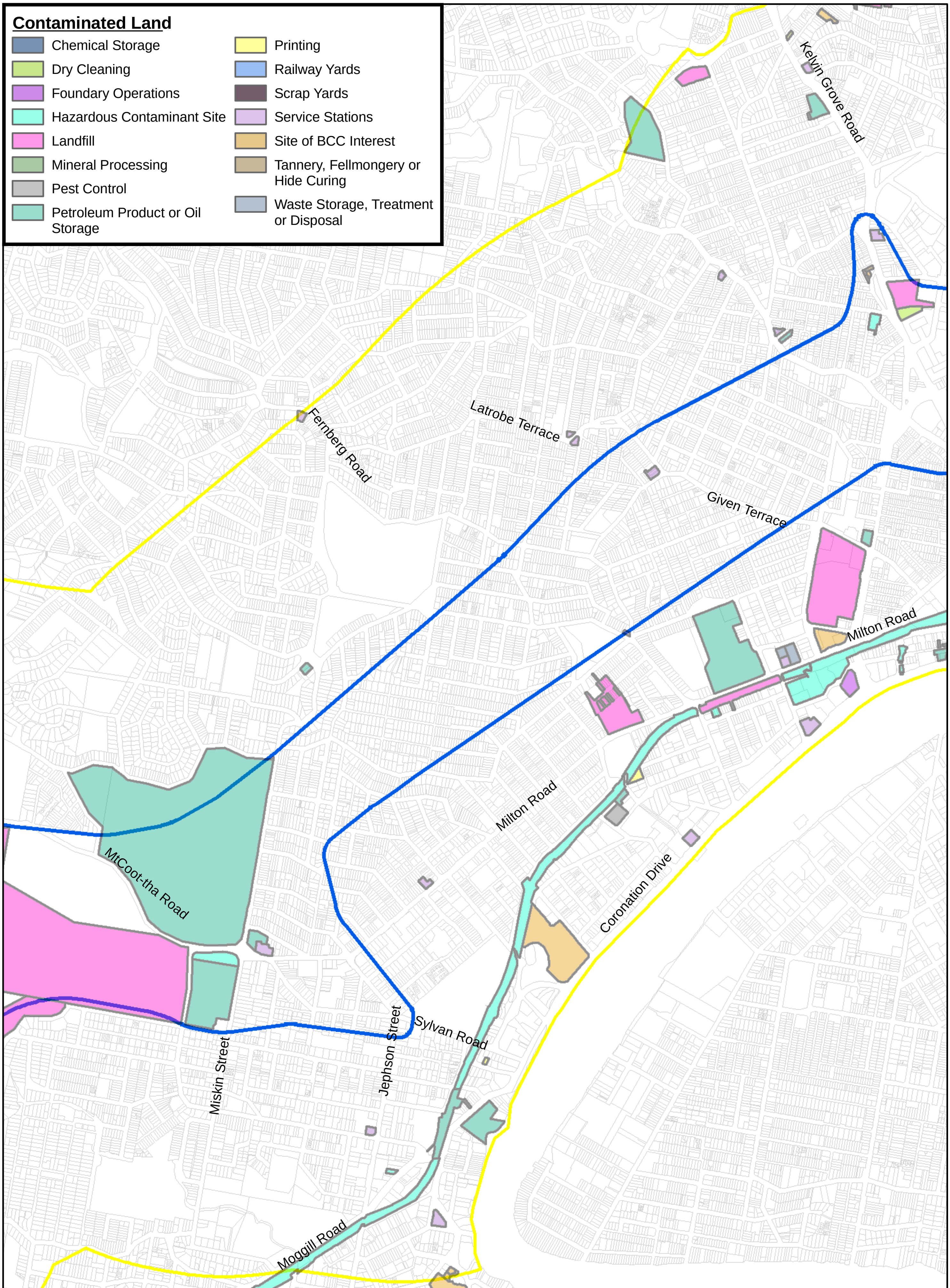


NORTHERN LINK
ENVIRONMENTAL IMPACT STATEMENT

Figure 11
EMR Listed Land Parcels within the Southwest Study Area

Northern Link
SKM Connell Wagner
JOINT VENTURE

I:\QENV\Projects\QE07311\Spatial\Arc_MXD\Hydrogeology\LarryLuba_Report\080816_LL_Fig11-13_EMR_Listed_Properties_StudyArea.mxd



Legend

Study Area Corridor

Groundwater Drawdown Area

0 400 800

metres

Scale 1:20,000 (A4)

N

NORTHERN LINK
ENVIRONMENTAL IMPACT STATEMENT

Figure 12

EMR Listed Land Parcels within the Southwest Study Area

Northern Link

SKM Connell Wagner JOINT VENTURE

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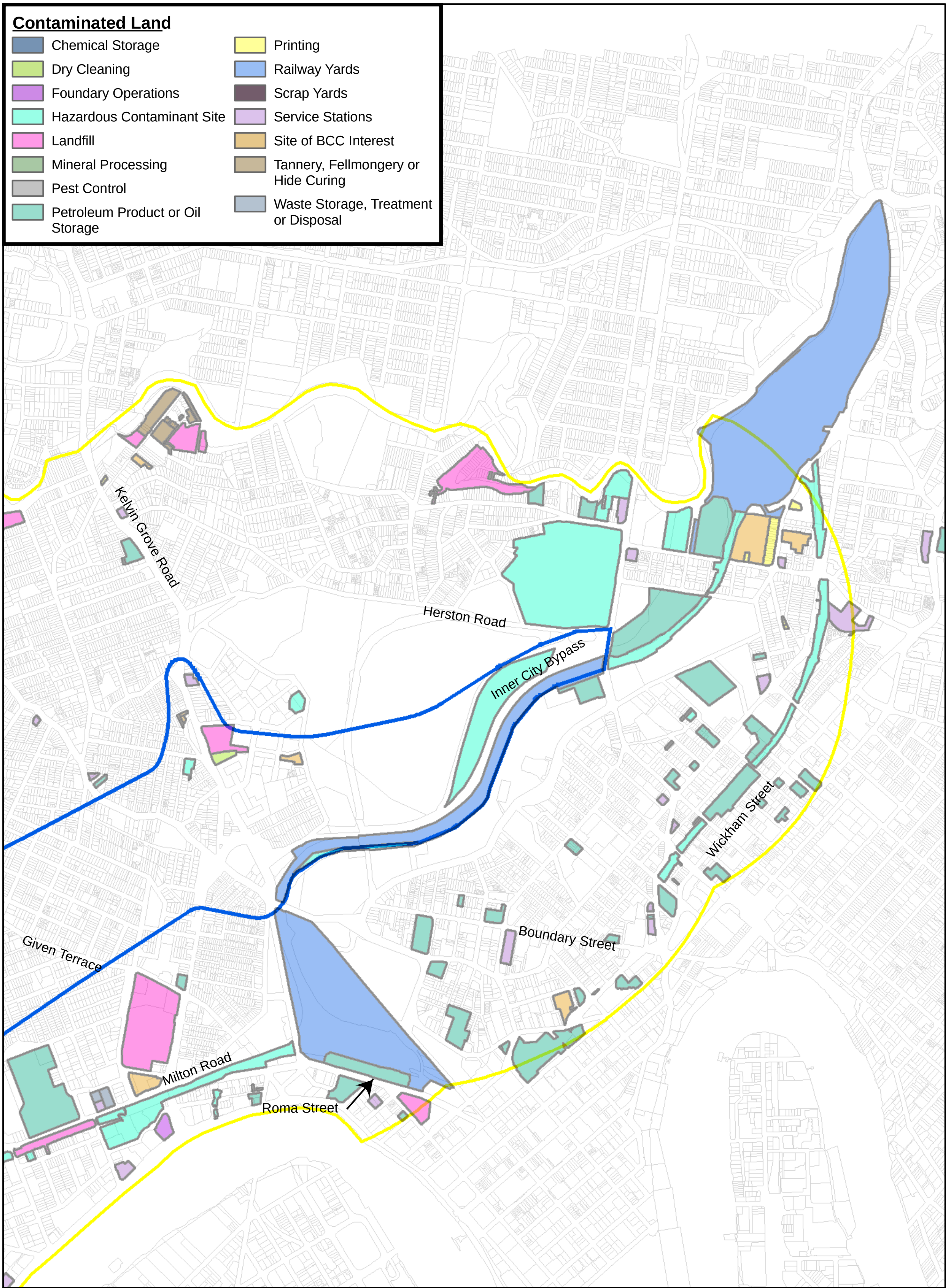


Legend

Study Area Corridor

Groundwater Drawdown Area

0 400 800

metres

Scale 1:20,000 (A4)

N

NORTHERN LINK
ENVIRONMENTAL IMPACT STATEMENT

Figure 13

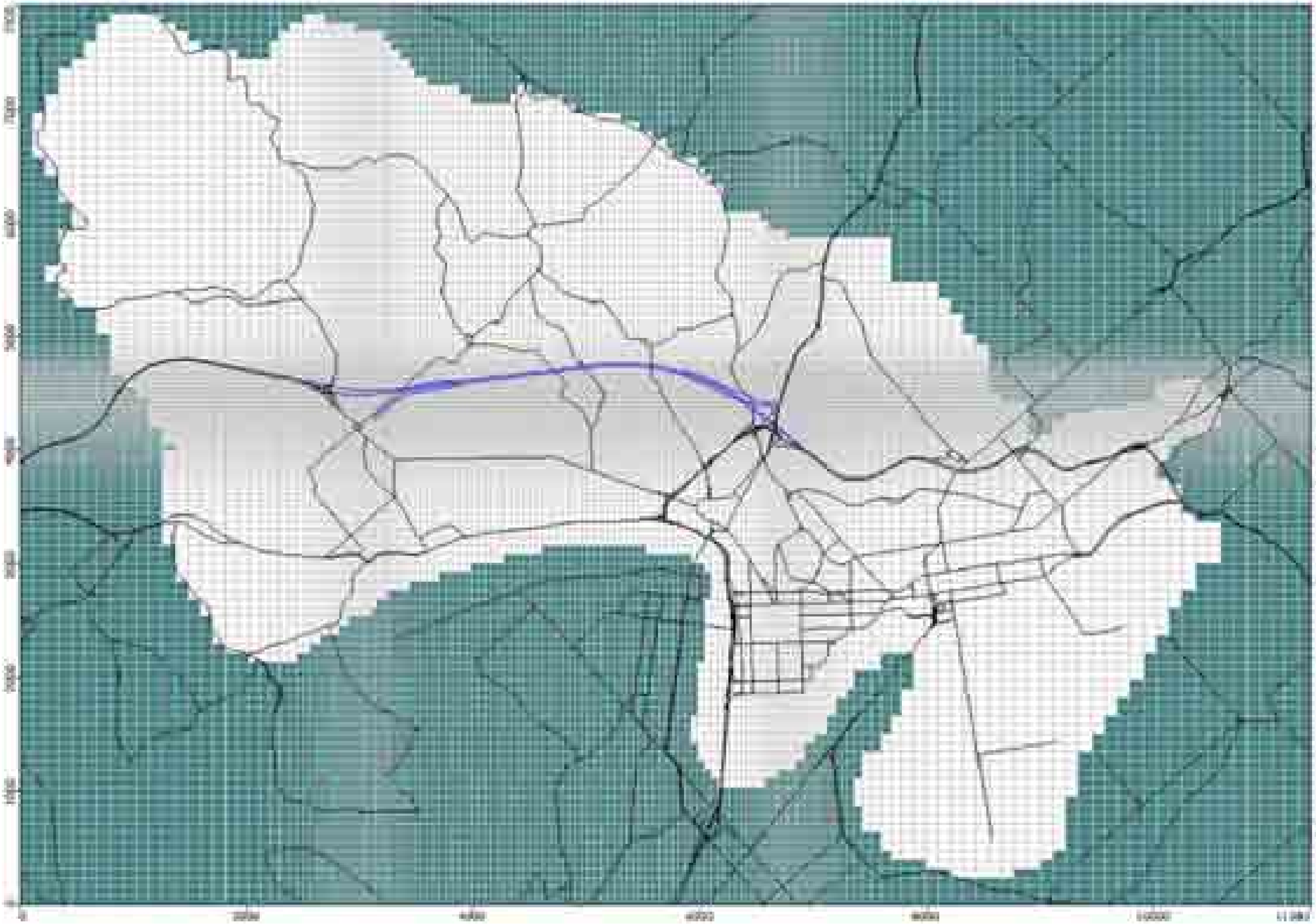
EMR Listed Land Parcels within the Southwest Study Area

Northern Link

SKM Connell Wagner JOINT VENTURE

I:\QENV\Projects\QE07311\Spatial\Arc_MXD\Hydrogeology\LarryLuba_Report\080816_LL_Fig11-13_EMR_Listed_Properties_StudyArea.mxd

- **Figure 14 Model Domain**



- **Figure 15 Topography Represented in the Model**

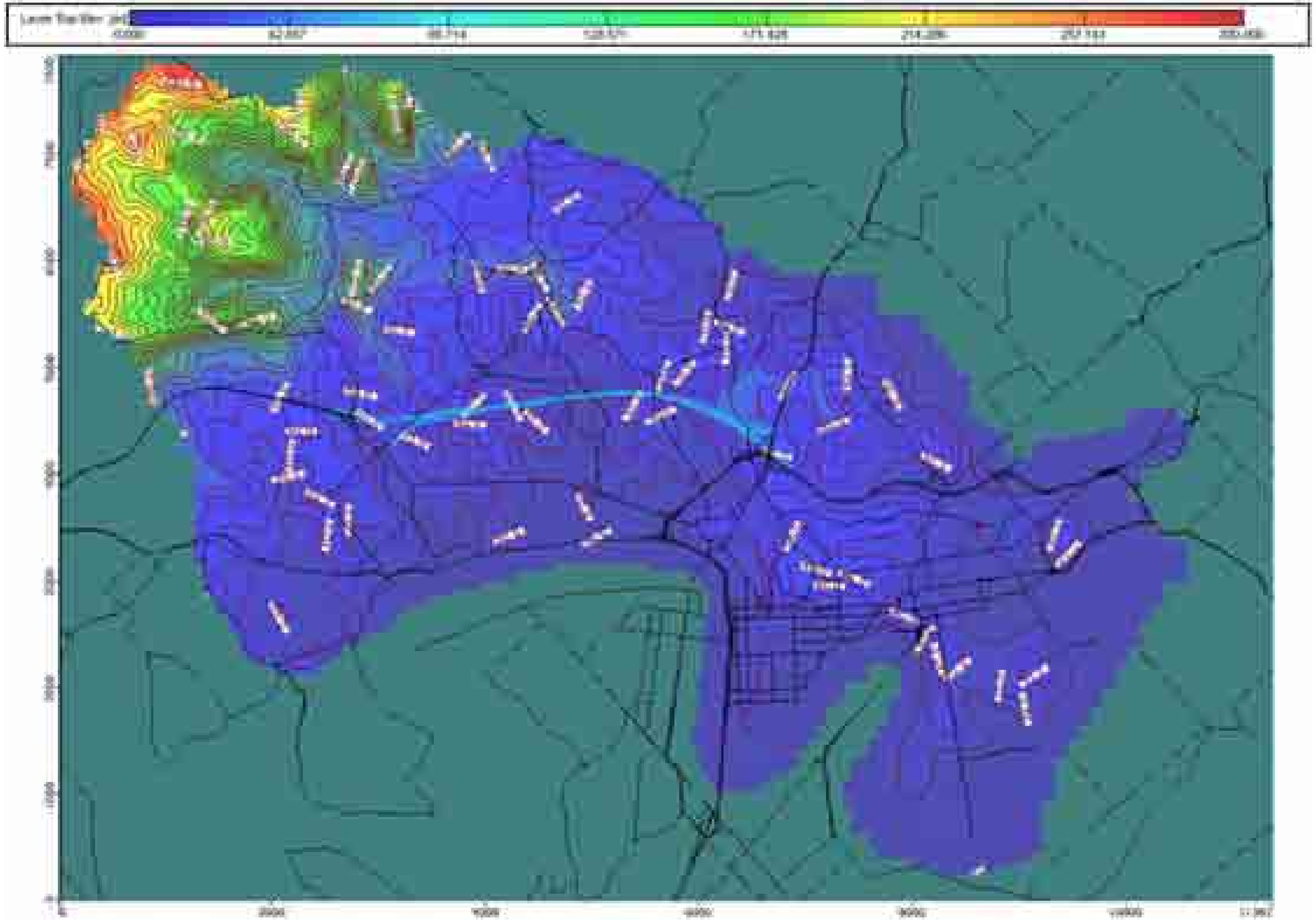


Figure 16 Flow Duration Curve of Observed and Simulated Stream Flow - Mogill River

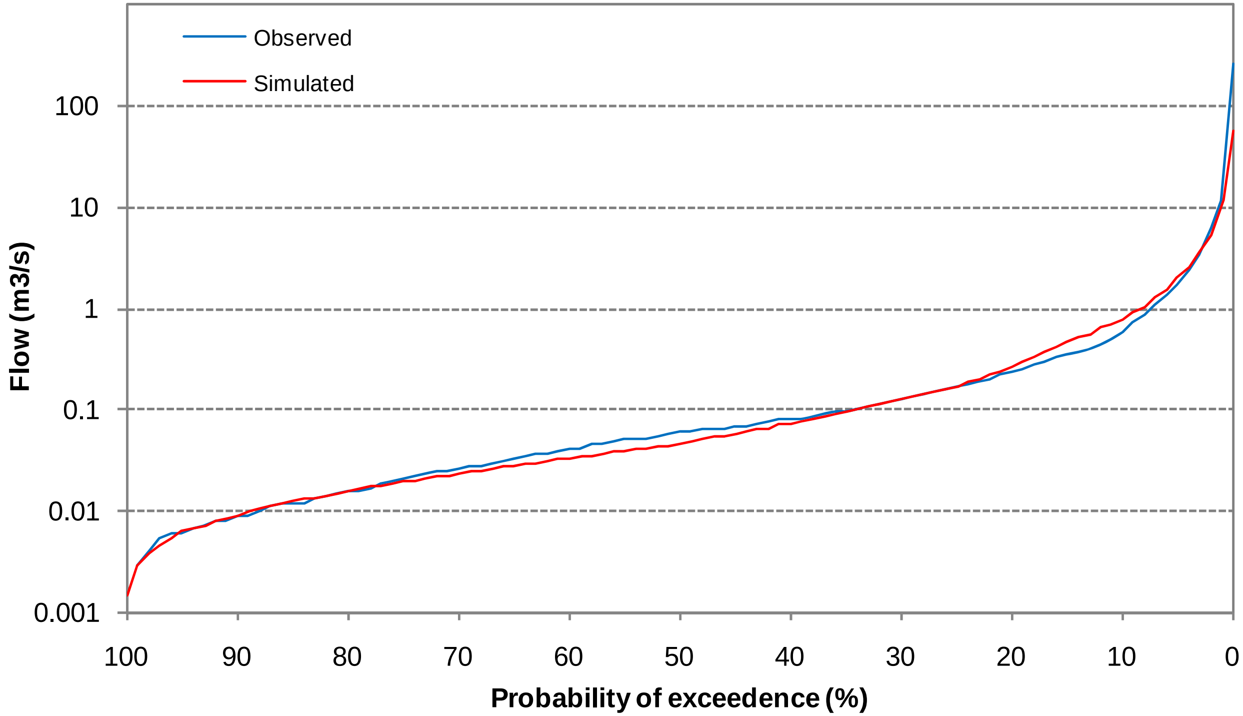
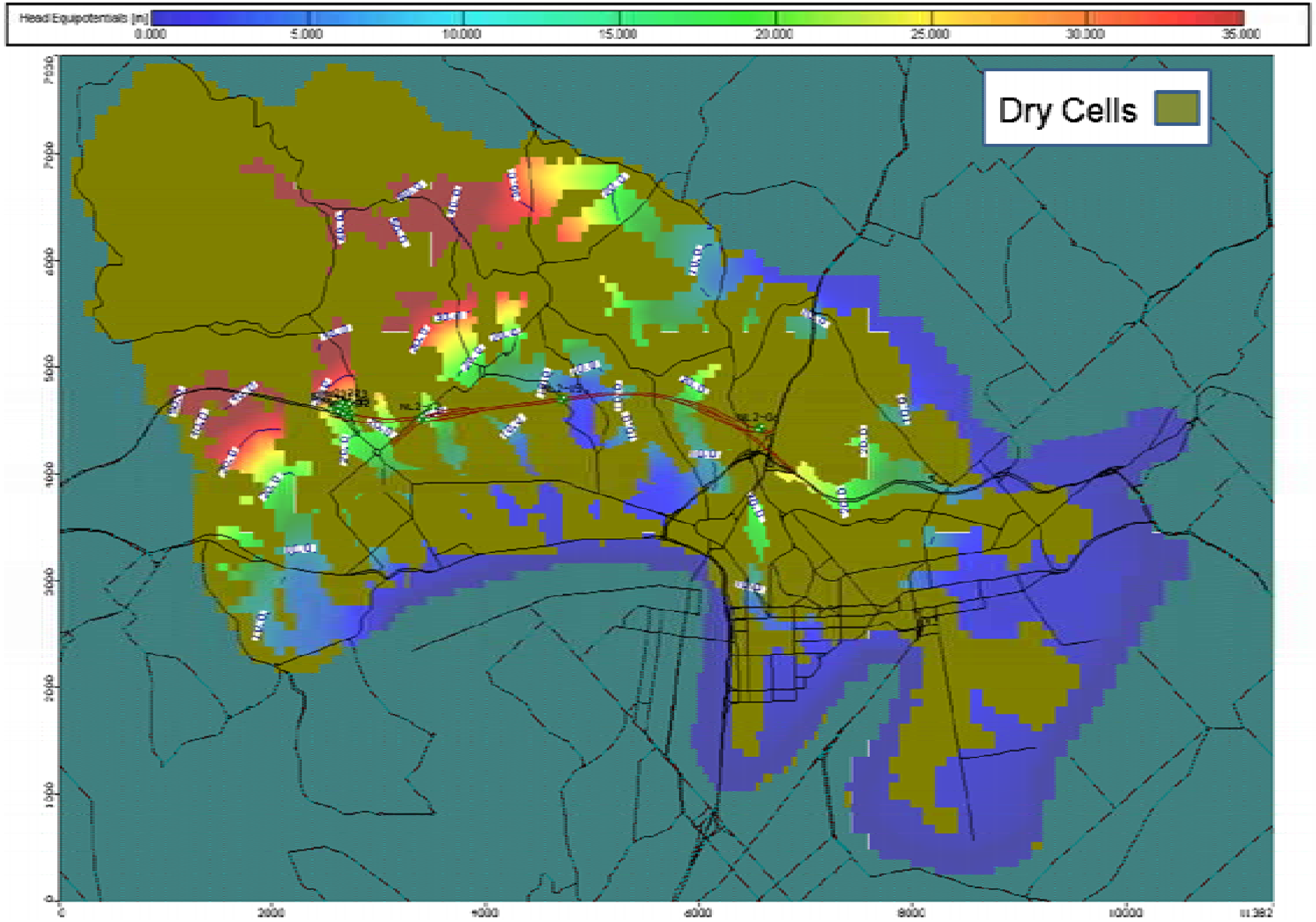
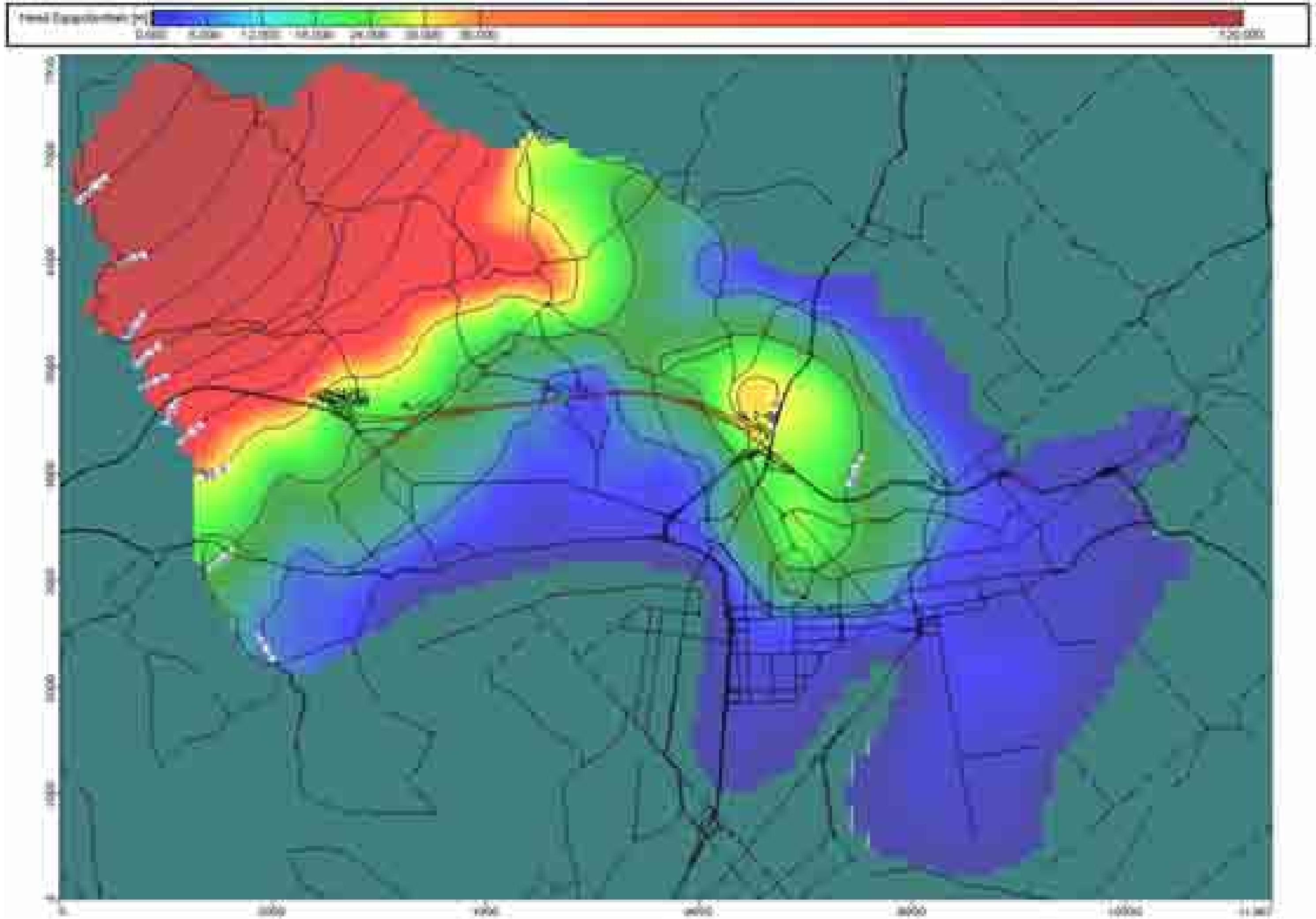


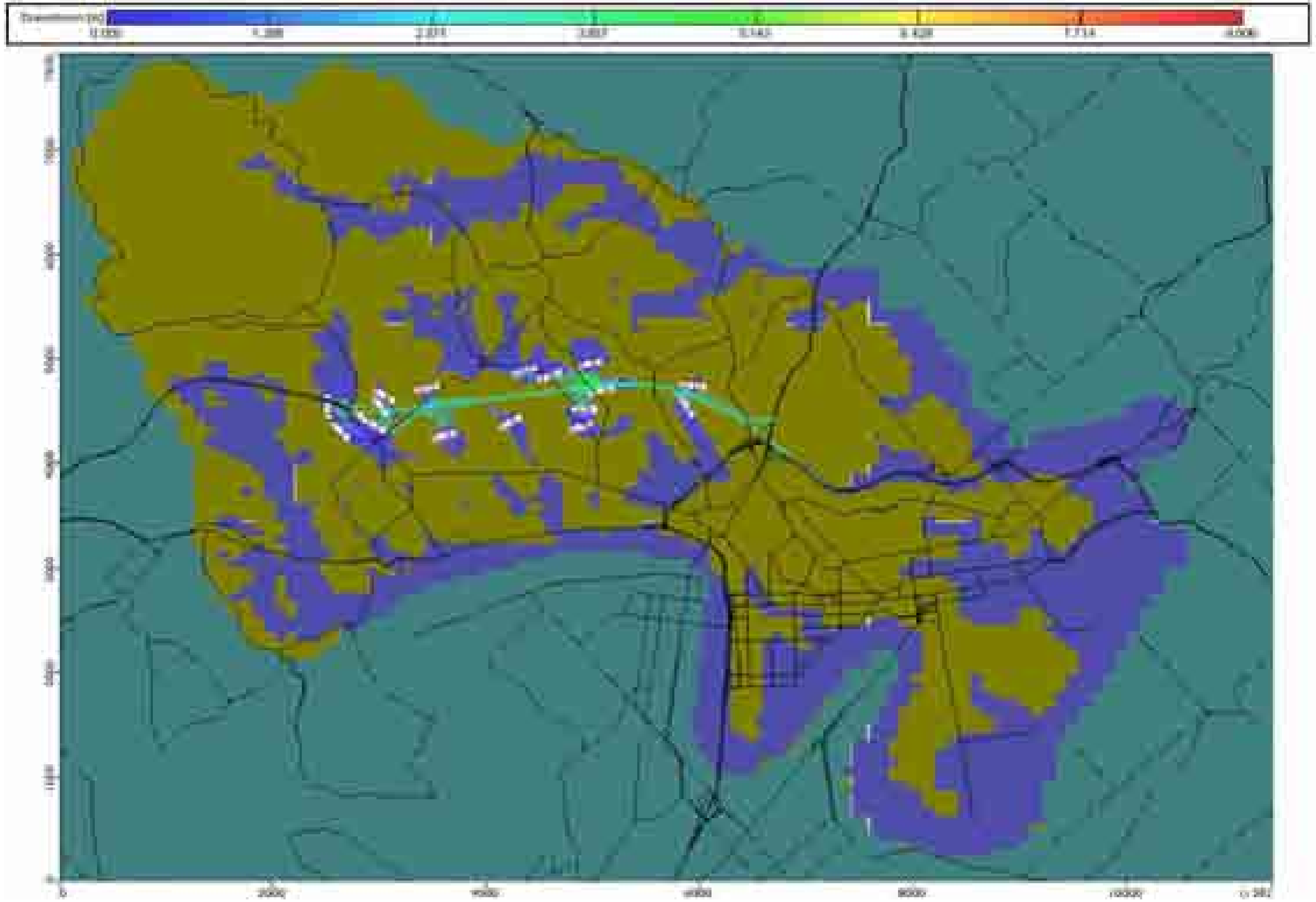
Figure 17 Modelled Groundwater Levels Pre-Construction – Layer 1



▪ Figure 18 Modelled Groundwater Levels Pre-Construction – Layer 2



- **Figure 19 Modelled Groundwater Level Drawdown Post Construction (1 Year) – Layer 1**



- **Figure 20 Modelled Groundwater Level Drawdown Post Construction (1 Year) – Layer 1 (Detailed Illustration)**

■ **Figure 21 Modelled Groundwater Level Drawdown Post Construction (1 Year) – Layer 2**

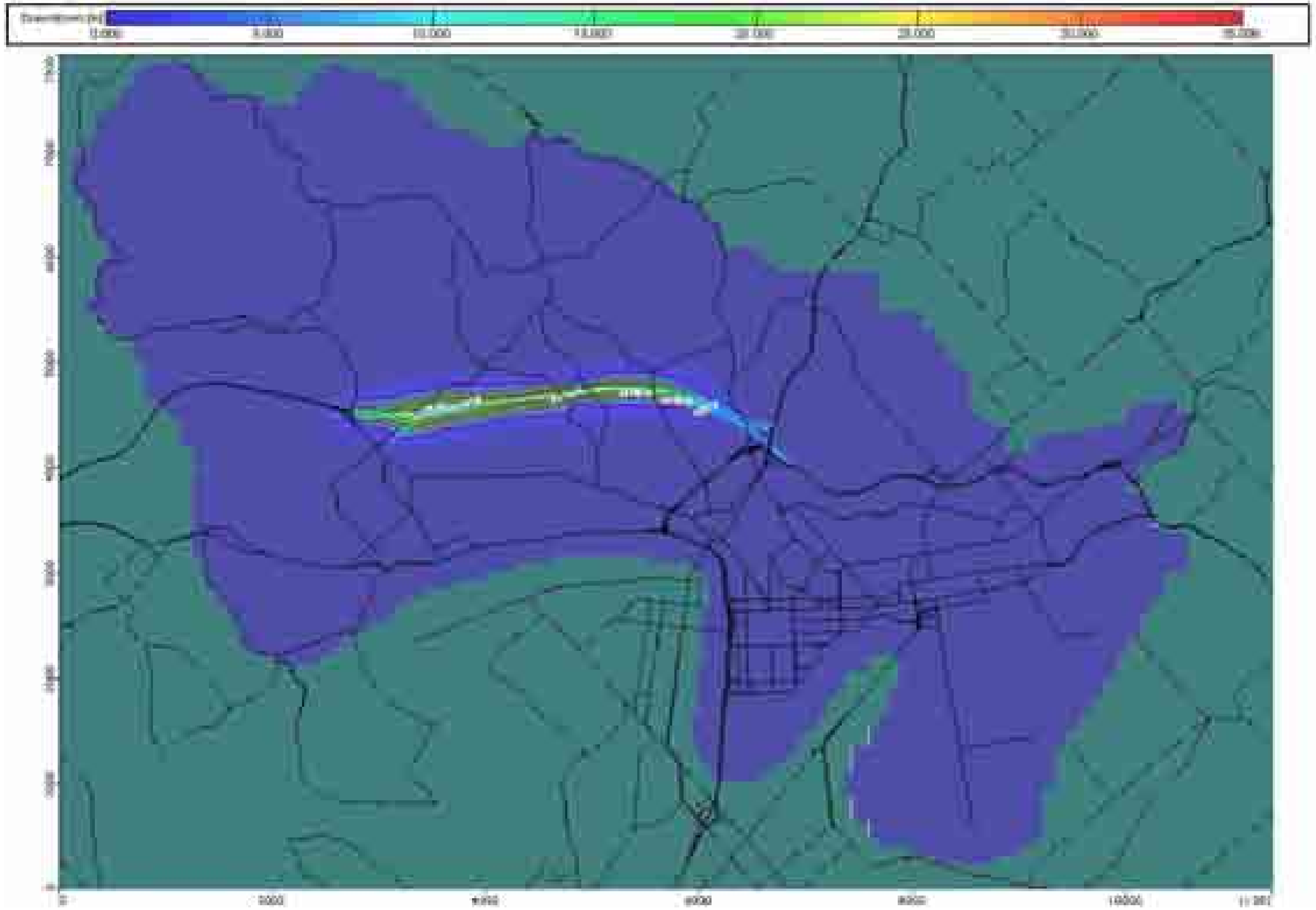
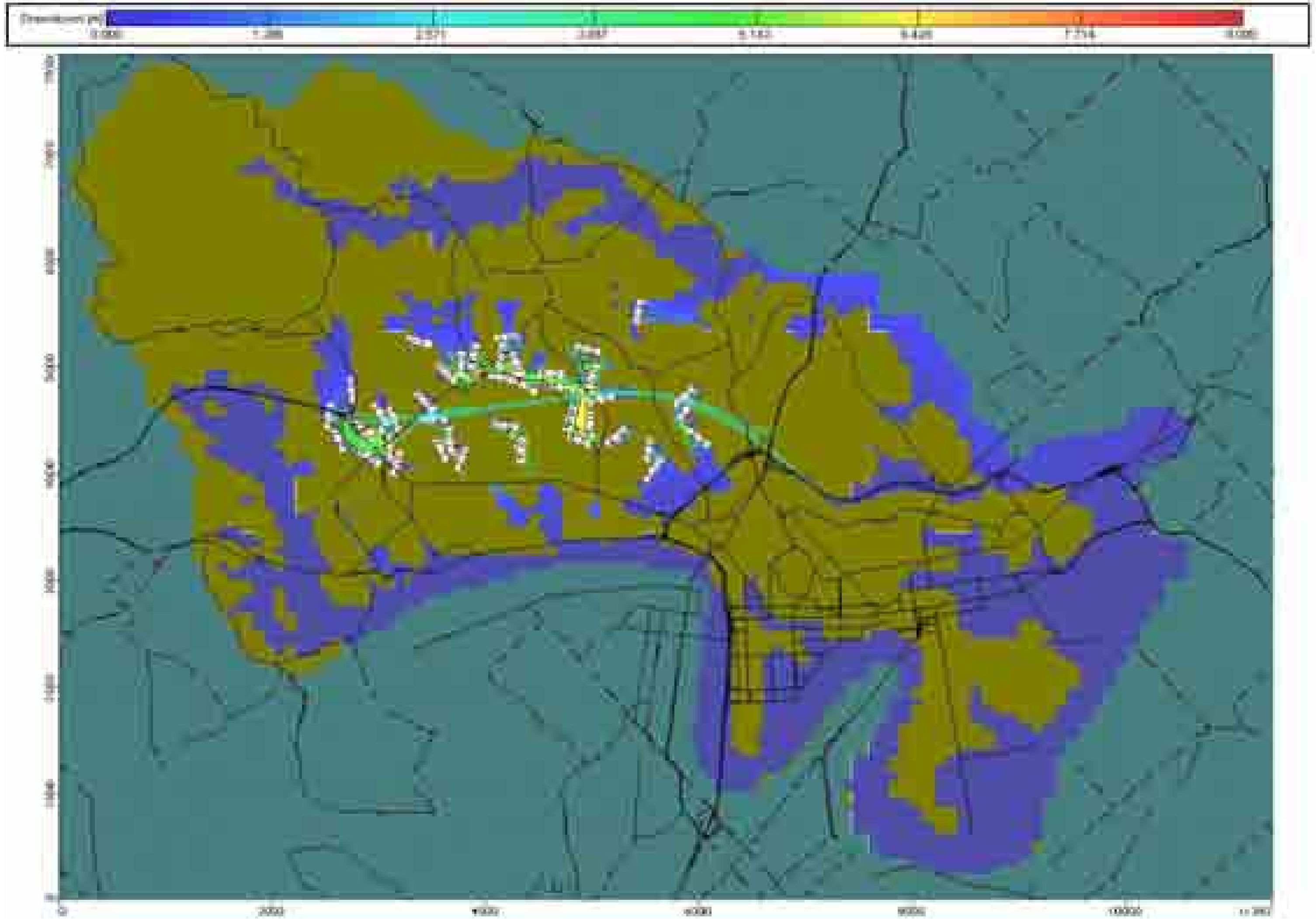
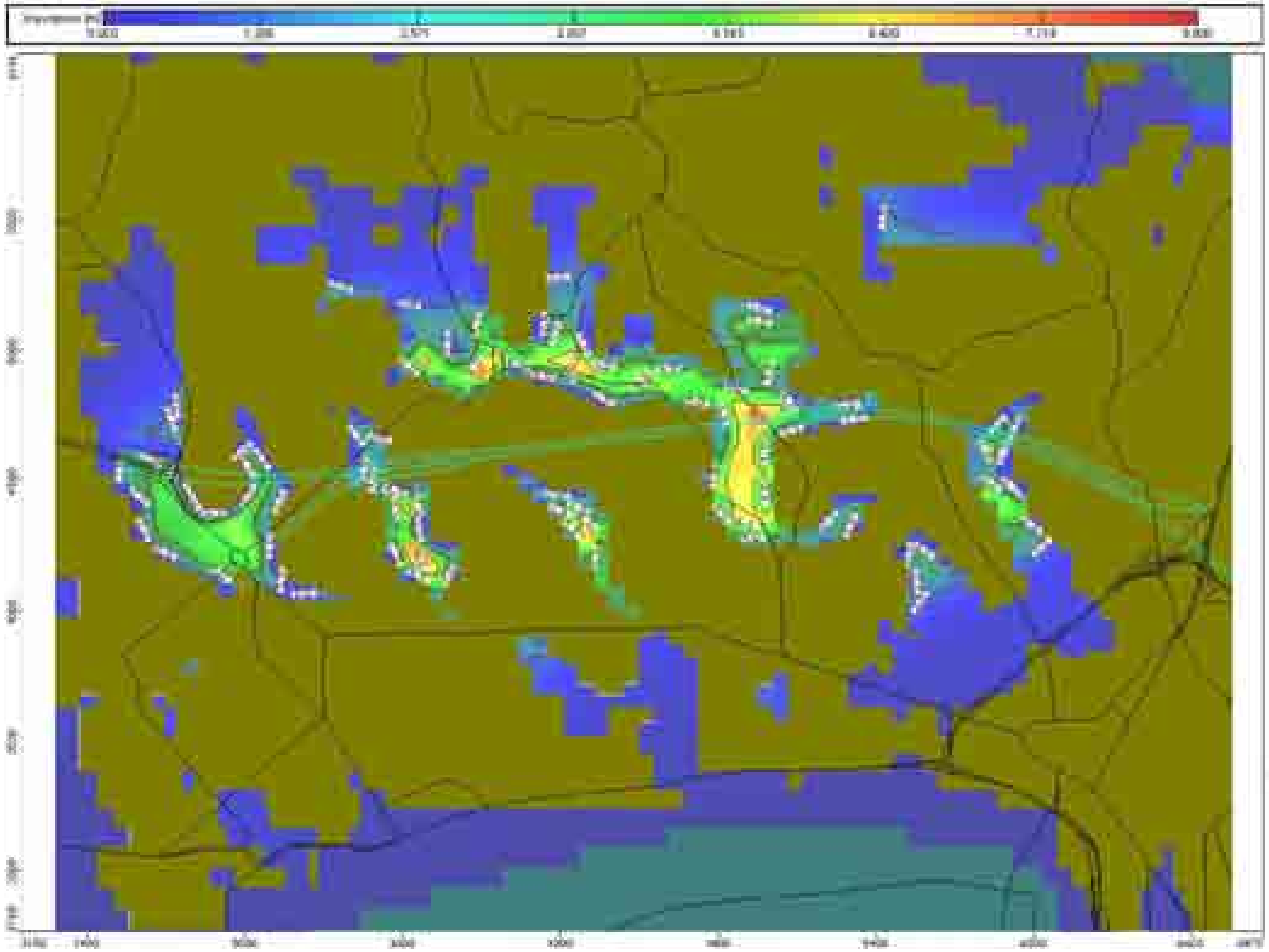


Figure 22 Modelled Groundwater Level Drawdown Post Construction (50 Years) – Layer 1



- **Figure 23 Modelled Groundwater Level Drawdown Post Construction (50 Years) – Layer 1 (Detailed Illustration)**



- **Figure 24 Modelled Groundwater Level Drawdown Post Construction (50 Years) – Layer 2**

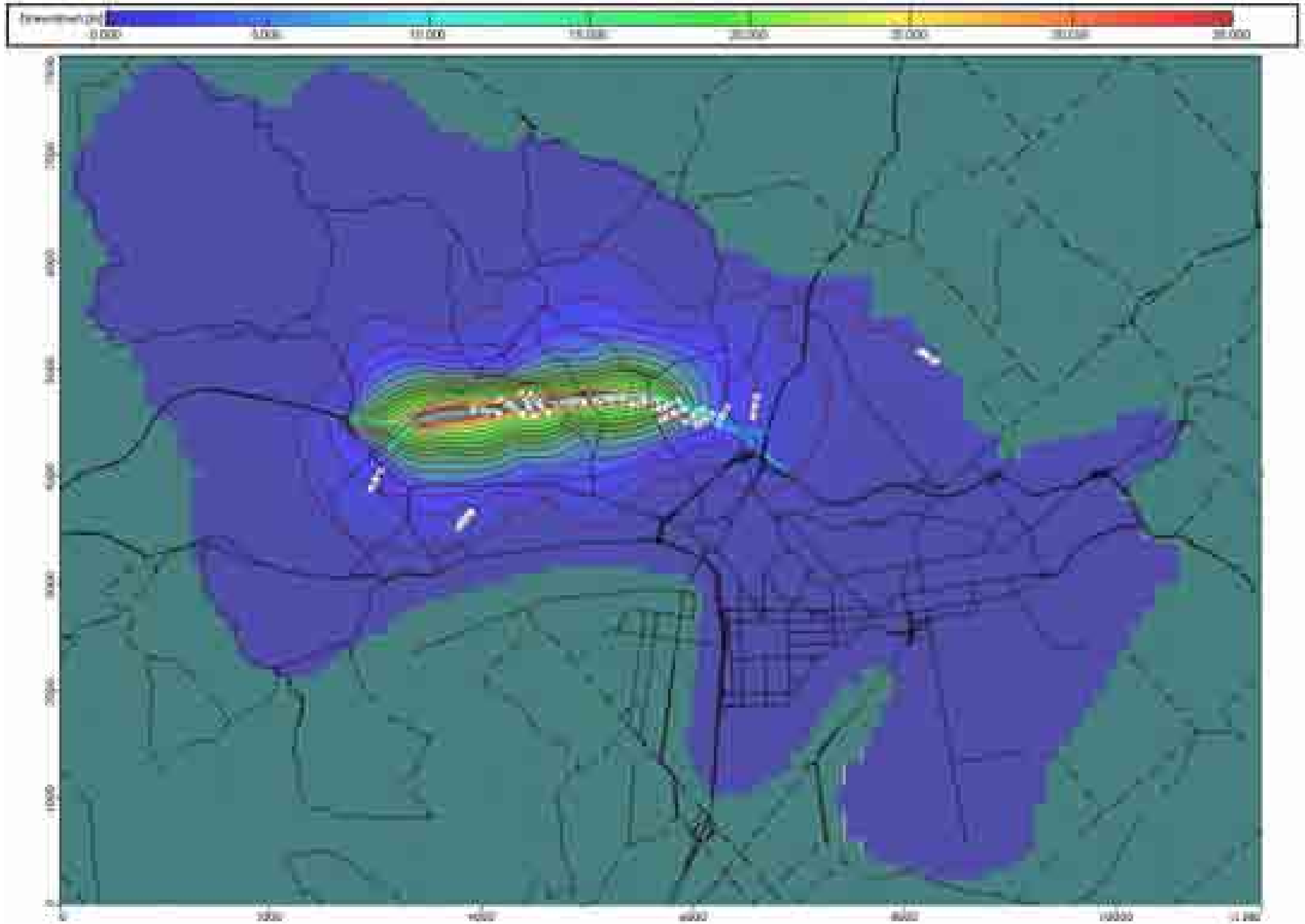


Figure 25 Modelled Potentiometric Surface Post Construction (50 Years) – Layer 2