Albion Park Rail bypass

Environmental impact statement
Technical Paper 11 – Groundwater

October 2015

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CONTENTS

FIGURES

TABLES

GLOSSARY

AHD	Australian height datum, which references a level or height to a standard base level.
Alluvium	Sediments consisting of silt, sand, clay, and gravel in varying proportions that are deposited by flowing water in marshes or valleys
Aquifer	A geological structure of formation or part thereof, permeated with water or capable of- (a) being permeated permanently or intermittently with water; and (b) transmitting water
Aquifer Interference Activity	An activity involving any of the following: (a) the penetration of an aquifer, (b) the interference with water in an aquifer, (c) the obstruction of the flow of water in an aquifer, (d) the taking of water from an aquifer in the course of carrying out mining, or any other activity prescribed by the regulations.
Aquitard	Geologic material with little hydraulic conductivity which prevent flow between aquifers. Water does not pass naturally through this layer or the rate of movement is extremely slow.
Bedrock	Solid or fractured rock usually underlying unconsolidated geologic materials; bedrock may be exposed at the land surface
bgl	Below ground level
Bore yield	The amount of water which can be extracted from a bore (either by pumping or natural artesian flow) over a specific time interval. Bore yields are usually measured in litres per second.
Confined aquifer	An aquifer holding water by a layer above it that does not allow water to pass through. Due to pressure, the water level of a well in a confined aquifer may rise above the top of the aquifer.
Contaminant	Any substance introduced to the water that makes water unfit for a given use.
Drawdown	Refers to a lowering of the surface that represents the level to which water will rise in cased bores. Natural drawdown may occur due to seasonal climatic changes. Groundwater pumping and dewatering may also result in seasonal, short term and long-term drawdown.
EEC	Endangered Ecological Communities
GDE	Groundwater Dependent Ecosystem, ecosystems which have their species composition and natural ecological processes wholly or partially determined by groundwater.
High Priority Groundwater Dependent Ecosystems	Are groundwater dependent ecosystems which are considered high priority for management actions.
Hydraulic conductivity	The term used to describe the permeability of water through a medium; a controlling factor on the rate at which water can move through a permeable medium.
Hydrostratigraphy	The structure of subsurface units on the basis of hydraulic properties (aquifer / aquitard) that have considerable lateral extent. Groundwater flow and geological characteristics are the main criteria to define the hydrostratigraphy of a hydrogeological system.

GLOSSARY

Lithology	The study of rocks. Can also be defined as the physical characteristics of a rock, including colour, composition and origin.
Perched aquifer	A saturated zone that overlies a confining layer; a perched aquifer is above the main water table and usually limited spatially.
Permeability	The property or capacity of a soil or rock for transmitting a fluid, usually water; the rate at which a fluid can move through a medium. Hydraulic conductivity is also used to discuss the same property.
Recharge area	An area in which water infiltrates and moves downward into the zone of saturation of an aquifer; area that replenishes groundwater.
Specific yield	The volume of water released from storage by an unconfined aquifer per unit surface area of aquifer per unit decline of the water table.
Stratigraphy	The classification, nomenclature, correlation, and interpretation of stratified rocks.
Unconfined aquifer	An unconfined aquifer is one that is open to receive water from the surface, and whose water table surface is free to fluctuate up and down and be influenced directly by rainfall and atmospheric pressures.
Unconsolidated alluvial aquifer	Are aquifers formed by sediment deposited by the action of flowing water in particular along river beds and floodplains, but not including lakes and seas.
Water table	The water surface in an unconfined aquifer; the level below which the pore spaces in the soil or rock are saturated with water; the upper surface of the zone of saturation.
Water table contour	A line in a groundwater map that connects points of equal groundwater elevation.

EXECUTIVE SUMMARY

This hydrogeology technical paper has been prepared to accompany the environmental impact statement for the Albion Park Rail bypass. Roads and Maritime proposes to build a 9.8 kilometre extension of the Princes Motorway between Yallah and Oak Flats to bypass the suburb of Albion Park Rail. The project has the potential to impact on groundwater flow and groundwater quality with potential consequences on groundwater users and groundwater dependent ecosystems (GDEs).

The project area consists of rocky hills and ridges to the north and south, bordered by an escarpment to the west and the foreshore of Lake Illawarra to the east. The central section comprises a floodplain of low elevation. The study area for the groundwater impact assessment is larger than the project area, as necessary to define the hydrogeological context.

The hydrogeology of the study area consists of two aquifers, a quaternary unconfined unconsolidated alluvium aquifer and a deeper unconfined to semi-confined consolidated rock aquifer. The alluvium aquifer is restricted to the location of the quaternary deposits. The thickness and hydraulic properties of this aquifer are highly variable depending on the nature and environment of the deposits. This aquifer is generally low yielding.

The consolidated rock aquifer is composed of shale, sandstone or latites and tuffs of Permian age. This aquifer is found underneath the quaternary alluvium aquifer where present. It is unconfined to semi-confined. The consolidated rock aquifer is the main source of groundwater supply for local groundwater users.

The aquifers are interpreted to support (possibly with surface water) the Macquarie Rivulet GDE (a unique GDE identified as high priority in the NSW regulation), located at the estuary of the Macquarie Rivulet on Illawarra Lake. A State Environmental Planning Policy (SEPP) 14 freshwater wetland is also present in that area.

The project includes a number of bridges, cut and fill areas and soil treatments with a potential to affect groundwater. An impact assessment has been completed with the following key findings:

- The Macquarie Rivulet estuary GDE and SEPP14 wetland would not be impacted by the project. Other groundwater dependant ecosystems such as the deep rooted vegetation from the grassy woodland ecological communities would not be impacted by the project
- Risks to groundwater are low to medium before management measures and reduced to low with management measures
- Although some dewatering due to road cuts is unavoidable on the northern section of the route, this will not impact groundwater users or GDEs.
- Impact on groundwater flow from soil treatments are not expected to impact environmental values and groundwater users
- There is a need to manage the risk of contamination to groundwater from spills and runoff water. This risk is addressed through a series of measures in the road design ranging from requirement for spill kits to water flow controls with different types of water basins and a soil and water management plan during construction.

To ensure groundwater is not affected, Roads and Maritime will be monitoring groundwater at key locations before the start of construction and following the opening of the new road.

1 INTRODUCTION

Roads and Maritime Services propose to construct a 9.8 kilometre extension of the Princes Motorway between Yallah and Oak Flats that would bypass Albion Park Rail. This hydrogeology technical paper has been prepared for Roads and Maritime to support the environmental impact statement for the project.

The project area consists of rocky hills and ridges to the north and south, bordered by an escarpment to the west and the foreshore of Lake Illawarra to the east. The central section comprises of a floodplain of low elevation (less than 10 metres AHD). The hydrogeological study area is larger than the project area, as necessary to define the hydrogeological context.

This hydrogeology technical paper addresses the risk of impact of the project on groundwater. The project includes a number of cut and fill areas, new bridges and soil treatments with potential to affect groundwater. The assessment takes into account the Secretary's Environmental Assessment Requirements and the requirements of the applicable regulations. In particular, the NSW Office of Water regulates all interactions with groundwater, groundwater quality and groundwater dependent ecosystems (GDEs). According to NSW Office of Water (2011), activities which intersect ('interfere with') an aquifer may involve:

- The extraction of groundwater that flows (or would flow) into a void to allow the activity to operate safely. This is often called dewatering, and the water extracted is often referred to as 'incidental groundwater'
- Other impacts resulting from the intersection of the aquifer, such as changes to groundwater flow paths and gradients, subsidence and cracking of river beds, river bank collapse, destruction/removal of the aquifer structure, and artificial aquifer recharge.

Based on this definition, the project can potentially interfere with aquifers and their associated environmental values.

This hydrogeology technical paper describes the groundwater settings and the environmental values potentially impacted by the project. A risk based approach is used to assess the level of impact and recommendations are provided on management and mitigation of the impact.

The following methodology was used to characterise the hydrogeological system(s) and identify, assess and manage the risk of impact to groundwater and associated environmental values:

- Establish regulatory context (Section 2)
- Define the study area (Section 3.1)
- Consultation (Section 3.2.1)
- Data sourcing, data extractions and quality checks (Section 3.2.2– 3.3)
- Groundwater system characterisation and preparation of a groundwater conceptual model (Section 4)
- Risk and impact assessment (Section 5)
- Risk management (Section 6).

2 REGULATORY CONTEXT

2.1 SECRETARY'S ENVIRONMENTAL ASSESSMENT REQUIREMENTS (SEARS)

The Secretary's Environmental Assessment Requirements (SEARs) for the project were issued on 18 March 2015. The relevant requirements to address in the Environmental Impact Statement (EIS) relating to groundwater are reproduced in Table 2-1.

Table 2-1 Groundwater SEARs

SEARs requirement	Where addressed
Hydrology, Soils and Water - including but not limited to:	
Groundwater impacts, taking into consideration impacts associated with geotechnical ground treatments, deep cuttings and fill locations	Section 5.2.2
Cumulative impacts on regional hydrology.	Section 5 and Section 5.1.3 Technical Paper 3 – Flooding and Hydrology
The assessment shall consider:	
▪ the extent of drawdown;	Section 5.2.2
▪ impacts to:	
o groundwater characteristics;	Section 5.2
o groundwater quality;	Section 5.2.3
o groundwater quantity;	Section 5.2.2
o groundwater connectivity;	Section 5.2.1
▪ discharge and recharge rates, and	Section 5.2.2
▪ implications for:	
o watercourses;	Section 5.2.4
o groundwater users;	Section 5.2.5
o groundwater dependent ecosystems, riparian areas and wetlands.	Section 5.2.4

2.2 APPLICABLE NSW POLICY AND LEGISLATION

The NSW groundwater policy framework is defined in the *NSW State Groundwater Policy Framework Document* (Department of Land and Water Conservation, 1997). This document defines the three components of the NSW groundwater policy, which are:

- Groundwater quantity management
- Groundwater quality protection
- Groundwater dependent ecosystems (GDEs).

The following sections discuss the groundwater policy and legislation applicable to the project.

Water Management Act 2000

The *Water Management* Act 2000 provides a sustainable regulatory basis for water management in NSW. The *Water Management Act 2000* manages the allocation and provision of water for the environmental health of rivers and groundwater systems, while providing licence holders with secure access to water and a system of water trading through separation of water licences from land. Apart from the exercise of basic landowner rights, which authorise use of water for domestic consumption and stock watering, the *Water Management Act* requires any taking of water to be licenced.

The main tools developed under the *Water Management Act 2000* are water sharing plans. Water sharing plans set out the rules for the sharing of water in a particular water source between water users and the environment and rules for the trading of water in a particular water source. Water sharing plans have been implemented progressively from 2000.

In some areas of NSW where the *Water Management Act 2000* is not yet fully implemented, the *Water Act* 1912 stills applies, however this does not apply to the project area.

Water Sharing Plan for the Greater Metropolitan Region Groundwater Sources

Water sharing plans in NSW are legislative tools under the *Water Management Act,* 2000, which regulates the taking, use and trade of groundwater. Water sharing plans establish rules for sharing water between the environmental needs of the river or aquifer and water users, and between different types of water use such as town supply, rural domestic supply, stock watering, industry and irrigation. The plans also provide area specific rules for the trading of water.

For the study area, the Water Sharing Plan for the Greater Metropolitan Region Groundwater Sources (NSW Office of Water, 2011) applies. The study area is located within the Southern Sydney management area. Conditions specific to this management area potentially applying to the project are:

- Granting of water access licence is possible under a controlled allocation order using unassigned water volumes. The drilling and installation of a new bore is subject to minimum distances requirements from an existing bore. This applies specifically to water supply bores and not monitoring bores
- To minimise the impact on water quality from saline interception in the shale aquifers overlying Sydney basin sandstone, the bore being used to take groundwater must be constructed with pressure cement to seal off the shale aquifer as specified by the Minister
- Minimum distances from high priority groundwater dependant ecosystems apply to the installation of a water supply bore. This restriction will not impact on the project.

Of interest to the project, the Water Sharing Plan provides a listing of GDEs of high value. In the study area only the wetland associated with the Macquarie Rivulet estuary is identified as a high value GDE.

NSW Aquifer Interference Policy under the *Water Management Act 2000*

The NSW Aquifer Interference Policy is the NSW Government policy for the licensing and assessment of aquifer interference activities (Department of Primary Industries NSW Office of Water, 2012). The policy was developed to regulate activities directly interfering with groundwater or resulting in indirect interference on a source aquifer. The NSW Aquifer Interference Policy defines an aquifer or a groundwater system as “any type of saturated geological formation that can yield anywhere from low to high volumes of water”.

The following activities potentially required for the project have a potential to trigger the Aquifer Interference Policy and the associated need for an Aquifer Interference Licence:

- The penetration of an aquifer,
- The interference with water in an aquifer, and
- The obstruction of the flow of water in an aquifer.

The identification of the risk and assessment of risk are addressed in Section 5.

NSW Groundwater Quality Protection Policy

The NSW Groundwater Quality Protection Policy (Department of Land and Water Conservation, 1998) sets the context and objectives for groundwater quality protection in NSW. Contamination of groundwater is managed by the Office of Environment and Heritage.

NSW Groundwater Dependent Ecosystems Policy

The Groundwater Dependent Ecosystems Policy (Department of Land and Water Conservation, 2002) is a component of the NSW State Groundwater Policy Framework. The GDE Policy is designed to protect valuable ecosystems which rely on groundwater for their survival. The policy aims at minimising adverse impact from water use and land activities on GDEs by:

- Maintaining, where possible, natural pattern of groundwater flow and not disrupting groundwater levels that are critical for ecosystems
- Not polluting or causing adverse changes in groundwater quality
- Rehabilitating degraded groundwater systems where practical.

Where developments are in a sensitive area, the policy requires a risk assessment be prepared. The Risk Assessment Guidelines for Groundwater Dependent Ecosystems (Kuginis et al, 2012a) provides the elements to be considered during the risk assessment. It should be noted that the policy defines a sensitive area as being an area within the zone of influence of a significant GDE. The term “significant” is interpreted to relate to the high value GDEs named in the Water Sharing Plan. For the current study area, this is the zone of influence of the Macquarie Rivulet estuary.

Freshwater wetlands: endangered ecological communities and protected freshwater wetlands

Endangered freshwater wetlands are regulated in NSW under the *Threatened Species Conservation Act 1995*. As defined by the NSW Scientific Committee (2004), Freshwater Wetlands on Coastal Floodplains of the NSW North Coast, Sydney Basin and South East Corner Bioregion is the name given to the ecological community associated with periodic or semi-permanent inundation by freshwater, although there may be minor saline influence in some wetlands. These freshwater wetlands appear to be dominated by herbaceous plants and have very few woody species (NSW Scientific Committee, 2004). They can often present ephemeral or semi-permanent standing water conditions.

Some freshwater wetlands on coastal floodplains are also protected by State Environmental Planning Policy 14, often referred as SEPP14. Section 4.8.1 provides details on groundwater dependent ecosystems and SEPP14 wetlands. In the study area, two areas are declared as SEPP14:

- Wetland associated with Lake Illawarra and located at the estuary of the Macquarie Rivulet and the estuary of Duck Creek (right bank only); and
- Wetland (feature 382) located to the west of Albion Park airport and located on Frazers Creek.

3 STUDY AREA, DATA AND CHARACTERISATION APPROACH

3.1 AREA OF STUDY

The area of study, as presented in Figure 3-1, encompasses the extent of the Albion Park plain and the start of the rising topography which is present to the North, South and West. The study area is bounded to the east by Lake Illawarra and the coast.

3.2 INFORMATION SOURCING AND LITERATURE REVIEW

3.2.1 CONSULTATION WITH THE NSW OFFICE OF WATER

The NSW Office of Water was consulted to identify potential hydrogeological technical reports and other data sources for the area. No reports were identified. However, NSW Office of Water referenced applicable regulations for the groundwater impact assessment. NSW Office of Water confirmed that no groundwater characterisation report has, to their knowledge, been previously developed over the whole study area.

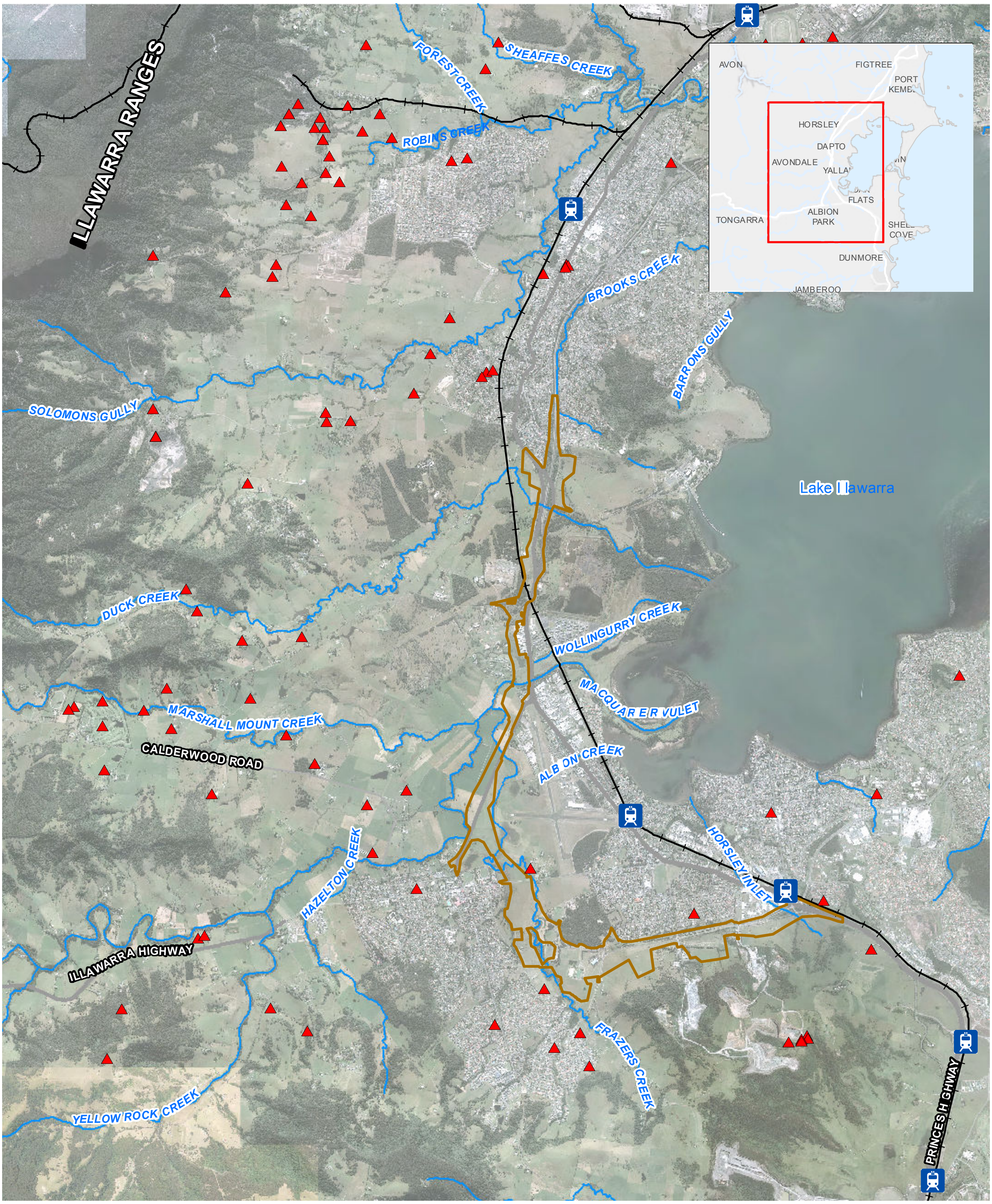
NSW Office of Water suggested the following guidelines and regulatory framework for the assessment of the project (refer Section 2.2):

- The water sharing plan relevant to the study area
- The range of NSW groundwater management policies:
  - NSW State Groundwater Policy Framework Document
  - NSW State Groundwater Quality Protection Policy
  - NSW Groundwater Dependent Ecosystems Policy
  - NSW Aquifer Interference Policy
- A series of reports developed on risk assessment to GDEs and risk assessment guidelines developed as part of the Australian Bureau of Meteorology GDE atlas and work done by the National Water Commission on GDEs (Richardson et al, 2011a, b).

The above documents or sources of exploration were each considered during the assessment.

NSW Office of Water was further consulted to discuss the preliminary outcome of the groundwater impact assessment. The groundwater impact assessment generally addressed expectations. Recommendations made included:

- Considering the management of groundwater outflows from cuts via sealing or drainage
- Considering the impacts of differential settlement of buildings resulting from groundwater drawdown in the consolidated rock near cuts
- Considering groundwater monitoring to fulfil community expectations and ensure any impacts, should they arise, are identified.



LEGEND

- Study Area Groundwater Bores
- Major Watercourses
- Site Project Boundary
- Railway

FIGURE 3-1

1:70,000 @ A4

0 355 710 1,420
Metres

FIGURE 3-1 GROUNDWATER ASSESSMENT STUDY AREA

GROUNDWATER TECHNICAL PAPER
ALBION PARK RAIL BYPASS
NSW ROADS AND MARITIME SERVICES

COORDINATE SYSTEM:
GDA 1994 MGA ZONE 56

REVISION NUMBER: 03
AUTHOR: RNB

DATE: AUGUST 7, 2015

Transport Roads & Maritime Services

Hyder Cardno JOINT VENTURE

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3.2.2 AVAILABLE DATA

A literature review was performed to identify existing information on geology, hydrogeology and groundwater dependent environmental values. A complete listing of the literature accessed can be found in Section 9. Information sourced from regulatory documents are presented in Section 2.

This section summarises the main sources of information relevant to the groundwater impact assessment.

Albion Park Rail bypass geotechnical design report (Hyder Cardno Joint Venture, 2015a)

The geotechnical design report for the project provides a description of the local geology. It grouped the Albion Park Rail bypass area into four Domains (A to D) based on topography, soils, bedrock geology and land use. These are described in Section 4.2.

Based on site investigations, previous Roads and Maritime investigations adjacent to the route and groundwater levels for a number of bores, the geotechnical report characterises groundwater levels as follows:

- Standing water levels were found between 0.2 to 6.4 metres (m) below ground level (bgl)
- The central domains (B and central parts of C) comprise low lying flood plains with groundwater typically one to two metres below ground level. In the more elevated areas of domains A and D, groundwater is typically deeper, at about three to four metres below ground level.

The geotechnical report provides some indication of potential impact to groundwater, especially when associated with cuts (excavations required for the project):

- Existing groundwater levels in the main Cut (Cut 1) located to the north of the Macquarie Rivulet are typically at least five metres above the cut floor;
- At the Oak Flats entry and East-West link entry at the southern end of the alignment (Cut 4), groundwater will be considerably higher than the proposed cut floor level, potentially resulting in groundwater discharge.

Cleary Bros (2013)

This report relates to the hydrogeology of the Cleary Bros quarry located in the southern part of the study area, directly south of the project east-west section (Figure 3-1). In accordance with the recommendations of a Surface Water and Groundwater Management/Monitoring Plan for the site (Golder Associates, 2005), Golder was commissioned by Cleary Bros in late 2012 to evaluate the Water Management Plan for their quarry located to the south of the study area.

Of interest to this study, the report included a description of the groundwater system. According to Cleary Bros (2013), Golder (2005), in a report that was not sighted as part of the preparation of this assessment, reportedly identified that the site model “comprises groundwater flow in two aquifers:

1. Perched (shallow) groundwater within the thin residual zone (soil and weathered bedrock overlying the fresh bedrock mass), and

2. The regional bedrock (deep) aquifer developed with the latite, agglomerate and sandstone sequence which is regionally dominant.”

Three groundwater monitoring stations were established prior to the quarry being developed (Cleary Bros, 2013). Two of the monitoring locations (MW1 & MW2) contain both shallow and deep monitoring wells while the third, MW3, contained only a deep well. The wells are located down gradient to the south of the quarry.

The observed water levels show significant variations and lack a detailed explanation and interpretation to be relevant to the current study. Other hydrogeological data associated with the Cleary Bros quarry and potentially of interest was not available for review for this assessment.

Doulas Partners (2010)

Douglas Partners installed ten groundwater monitoring wells in the Calderwood Valley within the study area, to the north-west of the township of Albion Park. The site is bounded by the Illawarra Highway to the south and Marshall Mount Road in the north; Macquarie Rivulet and Marshall Mount Creek run west to east across the site in the south and north, respectively.

The monitoring wells were installed within the alluvium formations. Groundwater levels during the investigation were found to be in the range of 2.5 – 4.5 metres below ground level. The shallow aquifers were interpreted to be contained in the alluvial deposits of Marshall Mount Creek and Macquarie Rivulet and were limited by the underlying bed rock, i.e. the shallow groundwater was interpreted as essentially perched on *this impermeable unit* (Douglas Partners, 2010).

The wells were constructed in the alluvial deposits between 10 and 20 metres AHD. The aquifers comprised clays and sandy clays with some gravel. The hydraulic conductivities interpreted to vary between $3x10^{-3}$ m/d and 0.3 metre per day.

NSW Office of Water risk assessment guidelines for groundwater dependent ecosystems

The NSW Office of Water (Serov et al, 2012; Williams et al, 2012; Kuginis et al, 2012b; Kuginis et al, 2012a) has developed risk assessment guidelines for GDEs. The guidelines are developed within the regulatory and licensing framework provided by the *Water Management Act 2000* and water sharing plans. The guidelines are based on a risk assessment of the GDEs ecological value and other risk factors.

The work is reported in four volumes. It includes the detailed assessment of a number of GDEs in NSW (Volume 2, Williams et al, 2012). Those seven 'pilot' GDEs are located on the North Coast and as a consequence do not provide any site specific information relevant to the study area. The NSW Office of Water has identified in Appendix 7 of Volume 4 (Kuginis et al, 2012a) of the guidelines high probability GDEs on the coastal plains of NSW located south of Sydney. Their ecological values are discussed in Appendix 9 of Volume 3 (Kuginis et al, 2012b). The groundwater source relevant to the study area is the Sydney Basin South Groundwater Source. On the maps of Appendix 7, it appears that no high value GDE is identified within the study area.

Public domain technical datasets

Table 3-1provides a list of datasets accessed to inform on groundwater characterisation and GDEs. Section 3.3 outlines the extraction and analysis of the data to assist with the characterisation of groundwater.

Table 3-1 Datasets accessed for the groundwater impact assessment

Name of dataset	Author	Relevance to the study
Pinneena Database	NSW Office of Water	NSW State groundwater bore database. The following information was sourced from the datasets: ▪ Bores in the study area ▪ Lithology information ▪ Water level information ▪ Groundwater use information
Groundwater quality data request	NSW Office of Water	Groundwater quality data was requested from the NSW Office of Water for the bores within the study area. The NSW Office of Water indicated the data quality had not been quality controlled.
BOM Groundwater Dependent Ecosystems Atlas	Australian Bureau of Meteorology	This datasets is an online visualisation tool of potential GDEs.
Wollongong 250,000 Geological Sheet, New South Wales Coastal Quaternary Geology Australia stratigraphy database	Geological Survey of NSW NSW Department of Primary Industries Geoscience Australia	Geology

3.3 SITE CHARACTERISATION DATA ANALYSIS

3.3.1 STRATIGRAPHY AND HYDROSTRATIGRAPHY

Stratigraphy and hydrostratigraphy information for the study area was sourced primarily from the NSW Office of Water Pinneena database (Section 3.2). Lithology information in the form of tabulated drilling logs was available for 88 bores. Those locations are reasonably spread over the study area, with a spatial data gap near Lake Illawarra. However, this restriction did not limit the assessment.

In addition to the above, the lithology from the bores drilled during the geotechnical assessment for the project and previous geotechnical assessments by Roads and Maritime near Oak Flats were added to the datasets and provided valuable data in the study area. Geological maps and data from the national stratigraphy database were consulted to develop the conceptual hydrogeological model for the study area.

Details of the geology and stratigraphy in the study area can be found in Section 4.2.

Details of the hydrostratigraphy in the study area can be found in Section 4.3.

3.3.2 PARAMETER ESTIMATION

Aquifer hydraulic properties for the alluvium (quaternary) formation were derived from the geotechnical report for the Calderwood Urban Development Project (Douglas Partners, 2010). Aquifer hydraulic properties for the rock (Permian) formations were estimated from a number of hydraulic tests, namely falling head tests, carried out in bores along the route. Values for bore yields from the NSW Pinneena database were also reviewed. Those data points require careful handling due to the variability and heterogeneity of sediment depositions. All estimated values were used to provide an indicative range of hydraulic conductivity only. All values were assessed against reference values.

Details of the parameters identified for application in the study area can be found in Section 4.3.

3.3.3 GROUNDWATER LEVELS AND FLOW

Groundwater levels were sourced from the Pinneena database, geotechnical reports for the project (Golder, 2015) and the geotechnical report for the Calderwood Urban Development Project (Douglas Partners, 2010). Water levels were assigned to one of the three main types of groundwater system in the study area (the alluvium aquifer system, the Permian fractured rock system or volcanics system). An estimate of ground elevation was extracted for each bore from the two metre topographic contour layer from NSW Department of Land and Property Information (LPI). The project elevation datasets (LiDAR datasets) did not cover all of the study area and were not used where they were not available. A comparison of elevations between the two datasets provided confidence that the LPI two metre contour dataset was suitable. Standing water levels were subtracted from the reference elevation and the resulting groundwater elevations in metres AHD were contoured.

For the purposes of the groundwater elevation maps, the consolidated rock aquifer was considered areally extensive while the Quaternary alluvium was limited to areas shown by Golder (2015, Figure A2). Further, there is an area with no or very few observations to the east of the project area near Lake Illawarra. Lake Illawarra is a coastal lake with connection to the sea that also receives groundwater inflow. To simulate this, groundwater elevations along the boundaries of the lake were assumed at 1.0 m AHD, slightly higher than the normal lake level that is approximately 0.3 m AHD.

Details of the groundwater levels and flow in the study area can be found in Section 4.4.

3.3.4 GROUNDWATER USE AND GROUNDWATER QUALITY

Groundwater use was sourced from the Pinneena database and from publically available information from the NSW Office of Water website.

Groundwater quality information was sought from the NSW Office of Water. The data was assessed for its content, reliability and spread over the study area.

No other groundwater quality data was identified over the study area.

Details of groundwater quality and groundwater use in the study area are provided in Sections 4.5 and 4.6 respectively.

3.3.5 GROUNDWATER DEPENDENT ECOSYSTEMS

The identification of GDEs required the review of a number of public datasets and reports. In addition to the GDEs identified on public registers, a review was completed using the ecological surveys carried out for the project. The reliance of species on water, species characteristics and species vulnerability to presence/ lack of water was further discussed with project ecologists.

It should be noted, that the large majority of GDEs listed on public registry, especially in the national datasets available from the Bureau of Meteorology have not been ground-truthed. Their identification is from desktop analysis only.

Details of GDEs in the study area are provided in Section 4.8.1.

4 GROUNDWATER SYSTEM CHARACTERISATION

4.1 REGIONAL SETTING

The project lies within the Greater Metropolitan Region groundwater area. NSW Office of Water (2011) describes the Greater Metropolitan Region groundwater sources as located on the east coast of NSW and covering an area of approximately 32,500 square kilometres, from Broken Bay in the north, to Shoalhaven Heads in the south, and Lithgow and Goulburn to the west. The Greater Metropolitan Region is bounded by the Hawkesbury River catchment to the north and west and the Shoalhaven River catchment to the south and south-west.

The Sydney Basin is further described by the NSW Office of Water (2011) as “an asymmetrical structural basin which has its centre around Fairfield and extends from Port Stephens in the north to Bateman’s Bay in the south. It has been split into six separate groundwater sources in the plan. Within this basin bore depths are variable, ranging from 20 to 200 metres with most bores less than 60 metres deep. Groundwater quality, in particular salinity in several areas, may limit its potential uses.”

The *Greater Metropolitan Region* includes the groundwater of the Illawarra and metropolitan Sydney. The 13 groundwater sources covered by the plan include the ‘Porous rock groundwater sources’ that in turn includes the Sydney Basin South Groundwater Source where the project area is located.

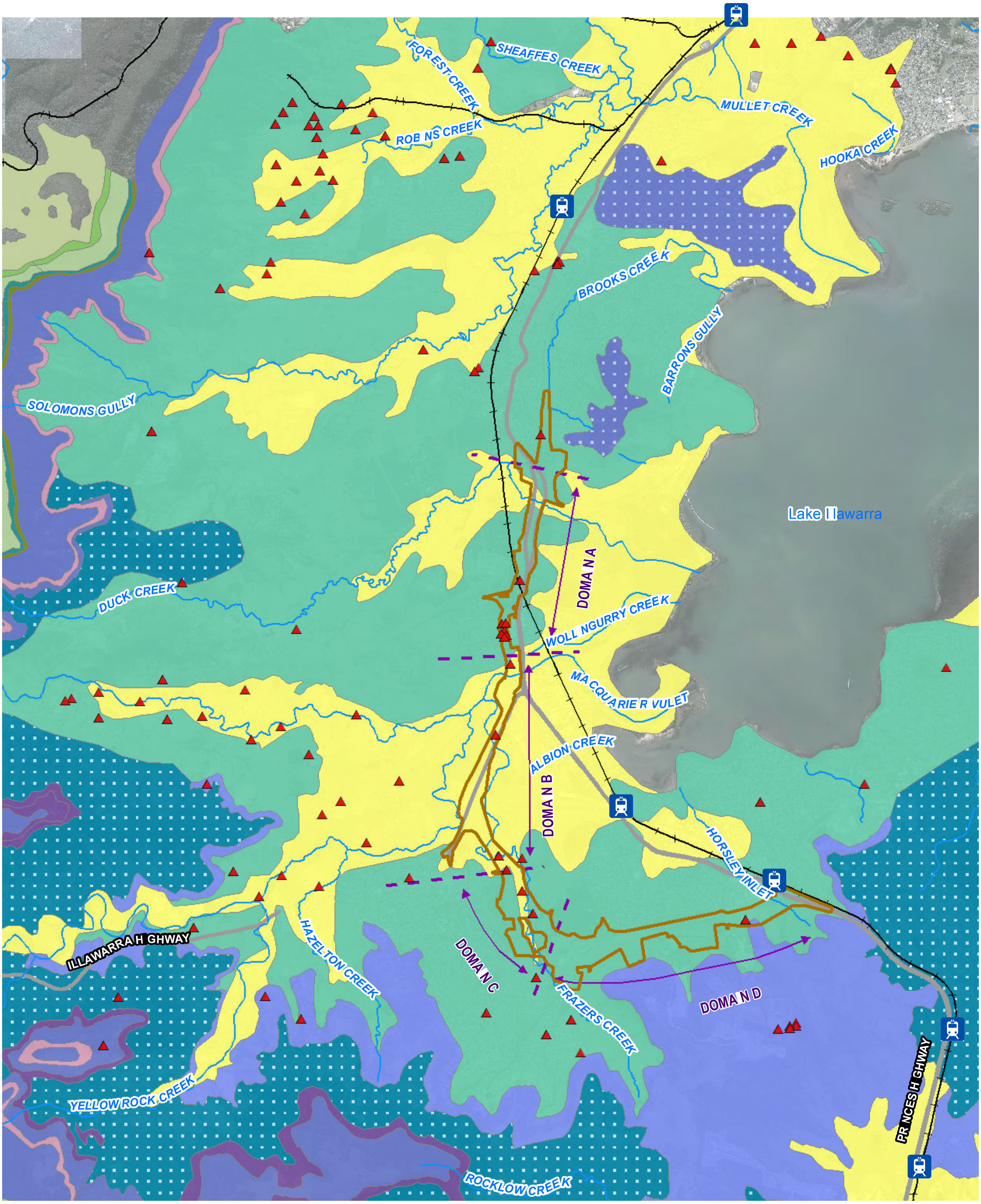
The Sydney Basin South Groundwater Source is bounded by the Illawarra Range to the north, the Turpentine Range to the south and east, and the geological boundary of the Goulburn Fractured Rock to the west. This groundwater source has a total area of just over 3,000 km^2 and bore distribution is mainly limited to the northern half of this area with national parks covering much of the southern part (NSW Office of Water, 2011). Further aspects of NSW Office of Water (2011) are discussed under the appropriate heading in this Section.

4.2 GEOLOGY

Geological information was sourced from published geological maps and reports either prepared for the project or for other projects in the study area. Additional information included lithology information sourced from the NSW Pinneena Database (State groundwater bore database) (Section 3.2).

The study area comprises of late Permian formations from the Shoalhaven Group overlaid by Quaternary alluvium in low lying areas. The late Permian formations of the Shoalhaven Group are the Berry Siltstone, overlain by the volcaniclastic sandstone, conglomerate and mudstone of the Broughton Formation. The Broughton Formation is interbedded with the Gerringong Volcanics. Of relevance to the study area is the Bumbo Latite Member, found outcropping and forming the hills to the south of the study area. The Broughton Formation is itself overlain by the red, brown, grey lithic sandstone of the Budgong Sandstone.

The surface geology is illustrated in Figure 4-1 and the full geological formations in the region (ie not just those outcropping at the surface) are described in Table 4-1.



LEGEND

- Bores Used for Lithology (Pinneena Database, Golder 2015, RMS)
- Site Project Boundary
- Golder Domains
- Railway
- Major Watercourses

Geology Unit

- Pbb, Bumbo Latite Member
- Pbk, Kiama Sandstone Member
- Pgb, Jamberoo Sandstone Member
- Pgc, Saddleback and Cambewarra Latite Members
- Pgd, Dapto Latite Member
- Pi, undifferentiated
- Pipm, Pheasants Nest Formation
- Pnc, Coal Cliff Sandstone
- Pnw, Wombarra Claystone
- Psb, Berry Siltstone
- Qa,Undifferentiated
- Rh, Hawkesbury Sandstone
- Rnc, Colo Vale Sandstone
- Rnk, Kangaloon Sandstone
- Rnz, Undifferentiated

FIGURE 4-2

1:70,000 @ A4

0 355 710 1,420
Metres

FIGURE 4-1 SURFACE GEOLOGY OF THE STUDY AREA

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Table 4-1 Geological formations of the study area

Formation	Description
Quaternary Alluvium (Qa)	Alluvium (mostly gravels, clays, silts)
Budgong Sandstone*	Red, brown, grey lithic sandstone.
Broughton Formation interbedded with the Gerringong Volcanics (Psb, Gv)	Broughton Formation: volcaniclastic sandstone, conglomerate, mudstone Gerringong Volcanics: latite, trachyte tuff with pebbly bands.
Berry Siltstone (Psb)	Sandy grey mudstone (previously defined as siltstone, shale, sandstone)

Source: Australian Stratigraphic Units Database

* The formations listed do not necessarily outcrop in the project area and therefore may not be present on Figure 4-2. However, it is also important to note that Budgong Sandstone was previously classified as part of another unit but revised stratigraphy defines it as an independent unit. Further detail is provided in Section 4.3.

It should be noted that in most bore lithological logs (Pinneena database or Golder, 2015), the latite is often identified as 'basalt'.

From the observation of the lithology, the following formation distribution can be gathered:

- On the northern part of the study area, the geology is dominated by sandstone formations found below five to ten metres of quaternary silts and clays, no siltstone is found in the logs above the sandstone. In some bores some basalt is found above the sandstone. The thickness of sandstone is found to reach 20 metres in some bores, but the bores are not deep enough to confirm the full thickness of the sandstone
- Slightly south, and reaching the northern part of the project area, the quaternary alluvium are directly underlain by shale or sandstone with some interbedded tuffs
- In the centre of the study area, corresponding to the low lying areas of the plain, the dominant geology below the alluvium are shale beds with thicknesses that can exceed 40 m. At times, those shale beds are interbedded with sandstone beds, however the shale component remains the predominant formation
- In the southern part of the study area, the alluvium, where present, are directly underlain by volcanic formations, predominantly latite.

Golder (2015) further characterises the distribution and thickness of the alluvium along the route:

- In the northern part of the project area (referred as Domain A by Golder), the area is characterised by shallow basement (volcanic sandstone to siltstone) rock with minor alluvium confined both laterally and vertically to the vicinity of surface watercourses
- Domain B, directly South of Domain A, transects on the surface the main alluvium and both the thickness (up to 15 m) and lateral extent of alluvial deposits reflect that. The alluvium was noted to coarsen with increasing depth, interpreted by Golder (2015) as the difference between Holocene (clay and sand) and Pleistocene (clay and gravel) deposits. The Macquarie Rivulet crosses the route at Domain B and alluvial deposits are interpreted by Golder (2015) as up to six metres thick at that location. South of the Macquarie Rivulet, the top elevation of the bedrock rises. In the southern portion of Domain B, gravels up to 6m thickness were noted
- In Domain C, alluvium is typically 5-15 metre thick, the underlying siltstone is extremely weathered but becomes fresh in about 5 metres deeper
- Domain D is characterised by thin localised alluvium over shallow rock interrupted by up to ten metres deep alluvium at one location (referred to as chainage 25,600 metres).

4.3 HYDROSTRATIGRAPHY

From the preceding description of geology along the route, the main hydrostratigraphic units appear to be alluvium and basement rock. Any significant thickness of alluvium is restricted to close vicinity of low lying areas and surface watercourses. Based on Golder (2015) and bore data (NSW Pinneena Database), the basement rocks are comprised of siltstone to fine sandstone, inter-fingered in places with volcanic tuffs.

To the southern part of the study area, the hydrostratigraphy is dominated by sandstone formation overlaid directly by latite or inter-fingered with latite (as in the example shown in Table 4-2, for groundwater bore GW107966 to the South West of the study area). Basalt and sandstone are the predominant rock types at GW107966 (Figure 4-2). Of specific interest, basalt, various grade sandstone, a small siltstone bed and basalt again make up the lithology of the 'consolidated rock' unit.

In the centre of the study area, the alluvium is generally underlain by siltstone with at times, minor beds of sandstone and tuffs. In the northern part, some three kilometres north-west of the north end of the project area, the alluvium is directly underlain by sandstone water supply beds, some of them with conglomerates.

Table 4-2 Lithological log for GW107966 (from the NSW Pinneena Database)

Depth from, m	Depth to, m	Description	Simplified Code (Created for this study) *
0	1	Clay Brown	Qa
1	2.5	Clay Sandy	Qa
2.5	6.5	Basalt Fractured	Gv
6.5	35.1	Basalt Fresh	Gv
35.1	35.2	Basalt Fractured	Gv
35.2	46.8	Sandstone Fine Grain, Pale, Grey	Psb
46.8	47	Siltstone	Psb
47	55.7	Sandstone, Grain Hard	Psb
55.7	61	Sandstone D/Grey	Psb
61	92	Sandstone F/Grain, Pale, Grey, Hard	Psb
92	180	Sandstone, M/Grain, Green, Grey	Psb
180	181	Sandstone Conglomerate	Psb
181	186	Basalt, Fresh, Hard	Gv

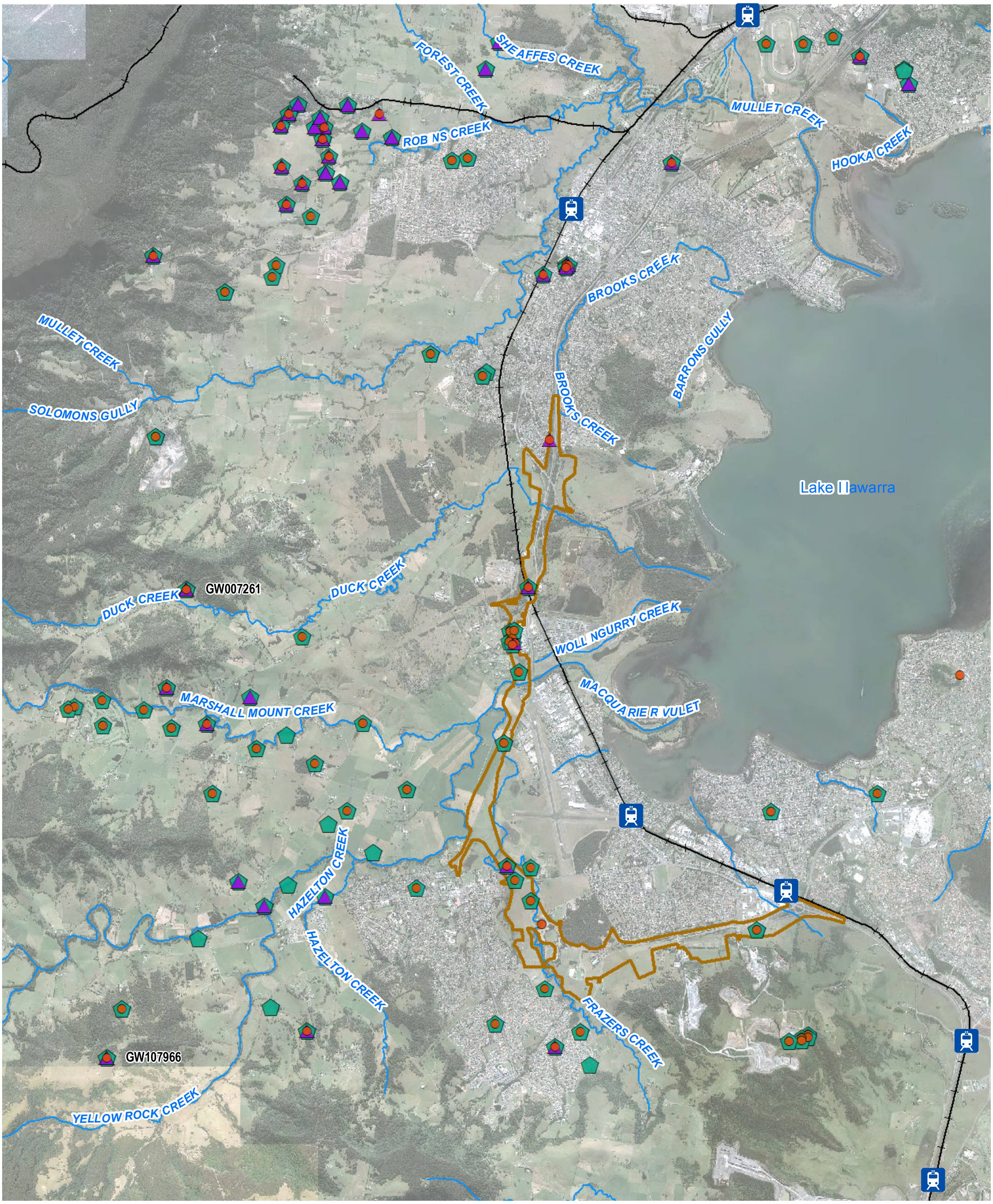
*Qa standing for Quaternary Alluvium, Psb standing for the Permian Berry siltstone but also encompassing here beds from the Broughton Formation and Budgong Sandstone as formations cannot be differentiated in between, Gv standing for beds from the Gerringong Volcanics and encompassing all Permian beds of volcanic origin.

Another, shallower example is shown in Table 4-3 for bore GW007261 (Figure 4-2). Beneath the alluvial gravels, the consolidated rock unit consist of sandstone and shale, the shale remaining the dominant unit. In other bores, the shale units indicated as "water supply" are also found described as "shale sandstone" or "shale soft water supply" alternating with "shale hard" units (GW015075 for example).

Table 4-3 Lithological Log for GW007261 from the NSW Pinneena Database)

Depth from (metres)	Depth to (metres)	Description	Simplified code (created for this study) *
0	0.61	Topsoil	Qa
0.61	0.91	Clay Yellow	Qa
0.91	5.49	Clay	Qa
5.49	16.46	Shale Black	Psb
16.46	19.2	Sandstone Grey	Psb
19.2	21.64	Shale Black Water Supply	Psb
21.64	22.25	Sandstone Grey	Psb
22.25	23.47	Shale Black	Psb
23.47	24.08	Sandstone Grey	Psb
24.08	24.69	Shale Black	Psb
24.69	25.3	Sandstone Grey	Psb
25.3	26.21	Shale Black	Psb
26.21	26.82	Sandstone Grey	Psb
26.82	27.43	Shale Black	Psb
27.43	28.04	Sandstone Grey	Psb
28.04	28.35	Shale Black	Psb
28.35	28.65	Sandstone Grey	Psb
28.65	29.57	Shale Sandy	Psb
29.57	30.18	Shale Hard	Psb

*Qa standing for Quaternary Alluvium, Psb standing for the Permian Berry siltstone but also encompassing here beds from the Broughton Formation and Budgong Sandstone as formations cannot be differentiated in between, Gv standing for beds from the Gerringong Volcanics and encompassing all Permian beds of volcanic origin.



LEGEND

Site Project Boundary
Railway
Major Watercourses

Lithology Encountered

Siltstone or Shale
Sandstone
Others

FIGURE 4-3

1:70,000 @ A4

0 355 710 1,420
Metres

FIGURE 4-2 HYDROSTRATIGRAPHY DISTRIBUTION

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Due to the varying nature of the Permian depositions and little information available for the hydraulic conductivity of the Permian strata, the fine differences in lithological description are not expected to transfer to varying hydraulic parameters in the vicinity of the project area. For these reasons, the Permian sandstone, siltstone and volcanics were "lumped" into one unit, referred to in the report as "consolidated rock". Table 4-4 indicates the adopted simplified hydrostratigraphy.

Note: The sandstone units observed in the northern part of the study area are further removed from the project area and as a consequence their hydraulic conductivity has no effect on the above assumption for the groundwater impact assessment.

Table 4-4 Study area simplified hydrostratigraphy

Rock type	Location	Geological name	Description	Aquifer/ aquitard
Alluvium	Mostly low-lying areas associated with watercourses	Quaternary alluvium	Quaternary unconsolidated sediments, nature of alluvium variable	Highly variable. Considered as an aquifer in its thickest sections.
Sandstones	Areally extensive: Interfingering with siltstone over the floodplain area Interfingering with latite to the south Consistent beds with presence of conglomerate in the North West area	Budgong Sandstone, Broughton Formation	Latite, sandstone and siltstone	Consolidated rock aquitard especially when defined as "hard shale (or siltstone) AND Aquifer where coarse or fractured
Latite	Present to the southern part of the study area, uppermost formation of the hills. Material accessed by the quarry industry. Other minor volcanic interfingering with shales and sandstone	Gerringong Volcanics		
Siltstones	Areally extensive, siltstone and shale predominant interfingering with volcanics and sandstone	Berry Siltstone		

There is little or no available information on the hydraulic conductivity of the Quaternary alluvium and the consolidated rocks in the project area. Kruseman and deRidder (1994; after Bouwer, 1978) lists a range of hydraulic parameters, including hydraulic conductivity and specific yield, reproduced in Table 4-5.

Table 4-5 Hydraulic parameters

Stratigraphy Unit	Unit	Hydraulic conductivity, m/day*	Specific yield	Bore yields as per Pinneena database
Quaternary Alluvium	Alluvial sediments	10^{-3} to 10^{2} (Textbook)	0.05 to 0.3 (Textbook)	0.126 to 2.5 L/s, median 0.631 L/s
		3×10^{-3} m/d to 0.3 m/d (Douglas Partners, 2010)	-	
Consolidated rock	Sandstone	10^{-3} to 1 (Textbook)	0.05 to 0.3 (Textbook)	0.01L/s to 11L/s, median 0.7 L/s
	Siltstone (shale)	10^{-7} (Textbook)	0 to 0.1 (Textbook)	
	Siltstone (weathered)	1.7×10^{-2} m/d to 1 m/d (slug tests - 4 bores)	Value cannot be provided due to variable levels of weathering	
	Volcanic rocks	"almost" 0 to 10^{3} (Textbook)	0 to 0.05 (0 to 0.1 if fractured) (Textbook)	

* "Textbook" refers to Kruseman and deRidder (1994)

It appears that Cleary Bros (2013), referring to Golder (2005; a report that was not sighted during this study) refers to very low hydraulic conductivities for the consolidated rocks, Cleary Bros (2013) does however not provide the range of conductivity values and therefore no data was derived from this source for this assessment.

Douglas Partners (2010) refers to the shallow (Quaternary) aquifers interpreted to be contained in the alluvial deposits and being limited by the underlying bed rock, i.e. the shallow groundwater was interpreted as essentially perched on an impermeable unit. The hydraulic conductivities for the Quaternary alluvium were interpreted as ranging between 3 10^{-3} m/d and 0.3 m/d by Douglas Partners (2010).

From the preceding discussion it appears that the sandstones will have a hydraulic conductivity towards the lower end of the range of Kruseman and deRidder (1994) while the siltstones and volcanics probably have a hydraulic conductivity largely determined by fractures. The middle of the lowest magnitude (10^{-3}) was therefore adopted for sandstones as presented in Table 4-5 being 5×10^{-3} m/day for the consolidated rocks. For the Quaternary alluvium a hydraulic conductivity of 0.5 m/day was adopted, the middle of the range presented in Table 4-5 and close to that interpreted by Douglas Partners (2010). The two orders of magnitude difference between the adopted hydraulic conductivities for the Quaternary alluvium and consolidated rocks also appears to be consistent with the statement made by Douglas Partners (2010) that groundwater was found to be perched on the top of consolidated rocks.

The Pinneena database informs on bore yields, essentially air-lift tests performed during drilling. The information is considered only "indicative". In the Quaternary alluvium, 13 bores have bore yield information. The higher value is reported for GW108326, a bore drilled through 16 metres of alluvium with coarse gravels in its lower section over eight metres. The other bore yields are reported between 0.13 to 2.5 L/s, with a median of 0.631 L/s.

In the consolidated rock, there are 103 data points with bore yield varying from 0.01 L/s to 11 L/s, with a median of median 0.7 L/s. Those 103 data points include all water inflow zones tested for yield during drilling (i.e. one bore may have a few data points). Those 103 data points are taken over 58 bores. The water inflow zones the bores have been completed in have yields varying from 0.05 to 11 L/s with a median of 1.068 L/s. The highest yielding bores are located either in weathered shale (such as GW107191, north of Lake Illawarra) or sandstone in the north western part of the study area.

4.4 GROUNDWATER LEVELS AND FLOW

As outlined in Section 3.3, a groundwater elevation map was created from data imported from the NSW (Pinneena Database) water bore data and the groundwater monitoring wells completed for the project (Golder, 2015).

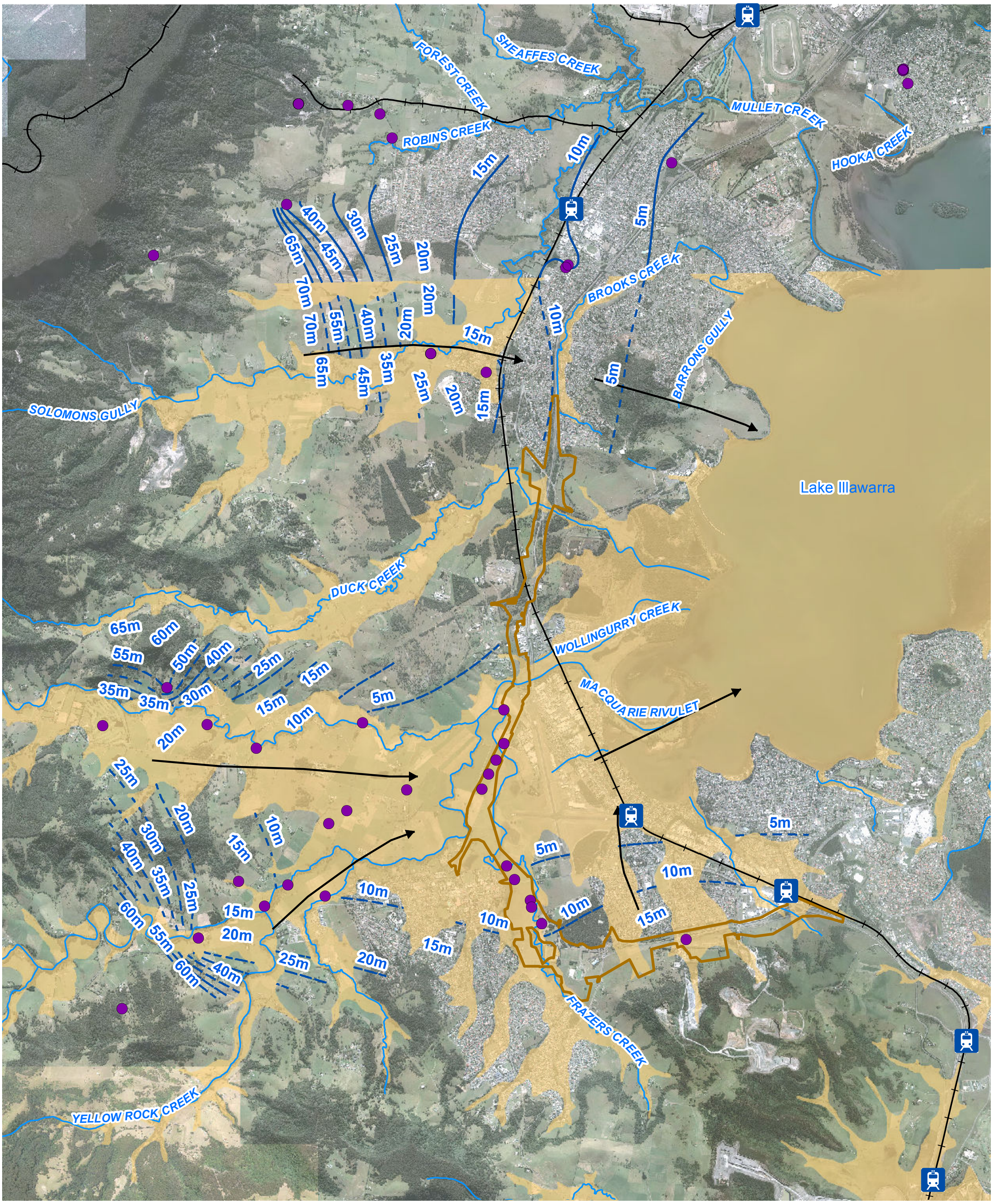
Drawing water contours using a computerised algorithm (kriging) method requires a critical review of the outcome. Surfer contouring software was used to perform the contouring using the kriging algorithm. Surfer also allows for blanking of areas as was required for generating the Quaternary alluvium contours.

Figure 4-3 shows groundwater elevation in the Quaternary Alluvium and Figure 4-4 in the consolidated rock.

4.4.1 GROUNDWATER ELEVATION IN THE QUATERNARY ALLUVIUM

Figure 4-3 indicates that groundwater flow in the Quaternary alluvium is west to east along the north and central section of the study area and north to south along the southern part of the study area. The five metre contours are dense in higher elevations and sparse in lower elevation, possibly an indication of increasing hydraulic conductivity along the flowpath, typical to alluvial sediments that are better sorted with increasing distance from their source in the west, and increasing thickness.

There may be two anomalies in the NSW Pinneena Database, GW011738 (220 m AHD groundwater elevation) and GW015076 (56 m AHD groundwater elevation). As these potentially anomalies are situated more than four kilometres to the west of the route and there are bores with much lower observations to the east of them, their effect on the groundwater elevations interpreted further west are small and were not investigated further.



LEGEND

- Groundwater Flow Directions
- Groundwater Elevation Mapping Locations
- Quaternary Alluvium Groundwater Contour
- Inferred Quaternary Alluviam Groundwater Contour
- Site Project Boundary
- Railway
- Major Watercourses
- Quaternary Geology Extent (Source information does not extend further to the North)

FIGURE 4-4

1:70,000 @ A4

0 355 710 1,420
Metres

FIGURE 4-3 INTERPRETED GROUNDWATER ELEVATION, M AHD, QUATERNARY ALLUVIUM

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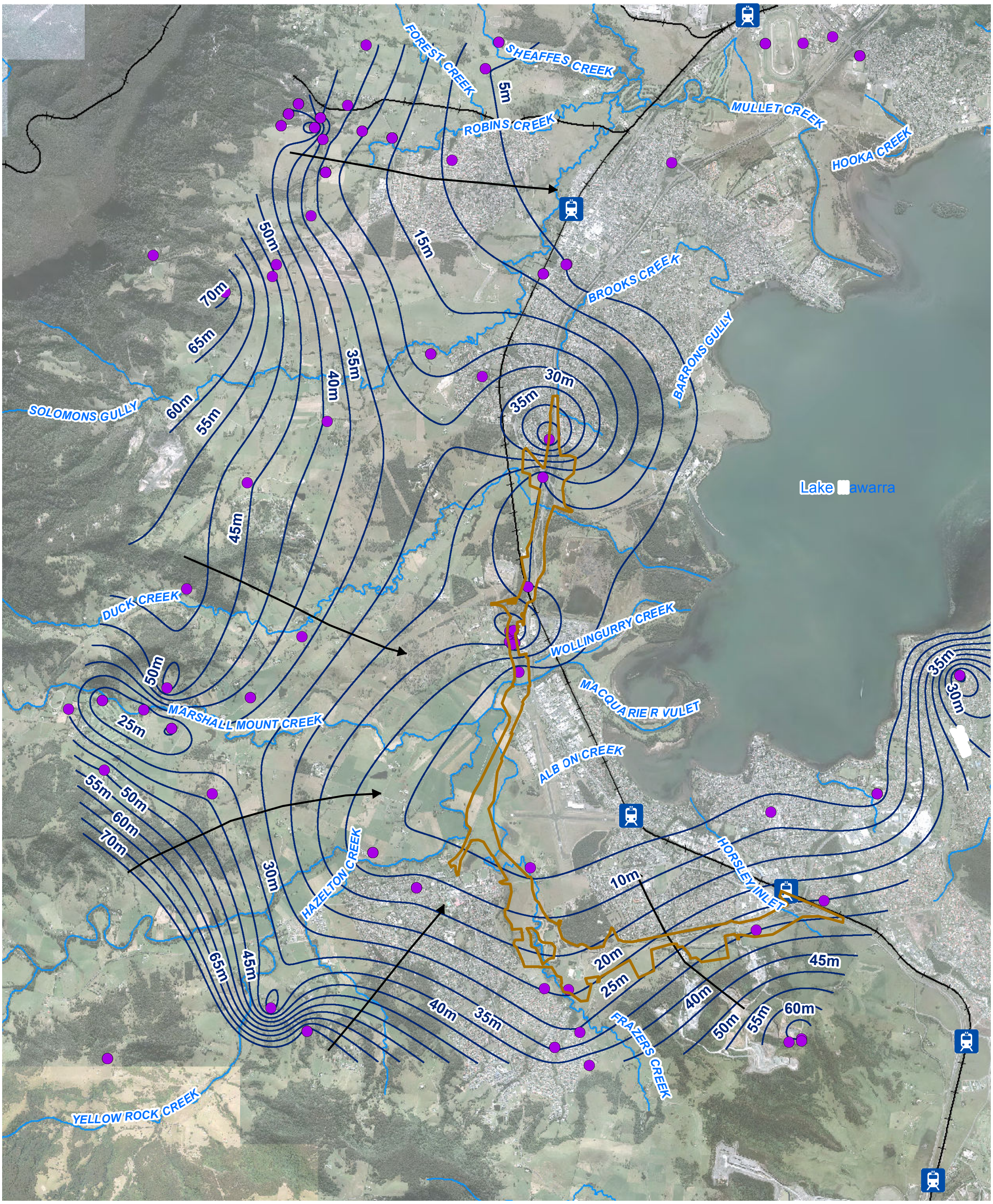
4.4.2 GROUNDWATER ELEVATION IN THE CONSOLIDATED ROCKS

Figure 4-4 indicates interpreted groundwater elevation in the consolidated rocks. The contours are consistent with the topography and groundwater elevation appears to be a subtle expression of the land surface. Groundwater flow would be west to east along the northern and central part of the study area and north to south along the south of the study area. The density of the five metres contours are much more uniform than those in the Quaternary alluvium, possibly an indication of consistent transmissivity on a scale of kilometres. On a finer scale, anomalies and variations in hydraulic conductivity are expected, as the presence / absence of fractures especially in the siltstone member would have a pivotal effect.

There may be two anomalies in the NSW Pinneena Database, such as the sink situated five kilometres to the west-south-west of the of the route with little effect on the groundwater elevations interpreted further west for the same reasons as discussed above for the Quaternary alluvium.

The anomalies (small mounds) in the northern end of the route and three kilometres further to the south (near the 15 metre contour) appear to be ‘real’ and related to topographic highs.



LEGEND

- Groundwater Elevation Mapping Locations
- Site Project Boundary
- Groundwater Flow Directions
- Consolidated Rocks Groundwater Contour
- Railway
- Major Watercourses

FIGURE 4-5

1:70,000 @ A4

0 355 710 1,420
Metres

FIGURE 4-4 INTERPRETED GROUNDWATER ELEVATION, M AHD, CONSOLIDATED ROCKS

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4.5 GROUNDWATER QUALITY

Water quality data was sought from the NSW Office of Water. Twenty bores have water quality information across the project area. Groundwater chemical characterisation in the datasets is often limited to physical parameters (pH and electrical conductivity) and major ions characterisation (calcium, magnesium, potassium, sodium, sulphate, chloride and carbonates) for most of these bores. The majority of the data was collected between the 1960's and the late 1980's. The bores with water quality data are located generally in the western part of the study area.

Although groundwater quality characteristics generally do not change so much over time, the data is to be considered as indicative only. Where required during the course of the project development, a local targeted groundwater quality sampling program and water quality characterisation would be performed (refer to Section 6).

Water quality (electrical conductivity) is observed to be fresh to brackish ranging from 270 µS/cm to 7660 µS/cm, with the fresher points located mostly at the foothills; however this does not appear to form a recurring pattern.

A review of existing and potential existing soil and groundwater contamination was undertaken as part of the EIS studies in December 2014 (refer to main EIS). The review concluded that:

- No notices of contaminated land record were identified in the project area
- Five licenced premises were identified via the Protection of the Environment Operations (PoEO) Act Public Register to potentially pose a risk of affecting land within the project area. Amongst those, only one site at Dapto (330 kV Substation at Yallah Road, Yallah, Licence 11364) may pose off-site impacts as a result of this licenced activity. The licence was not available and further conclusion could not be drawn; and
- No sites within the public registry of sites notified to the EPA for assessment under Section 60 of the *Contaminated Land Management Act 1997* would constitute a source of off-site contamination affecting the project.

There are five areas of potential concern located in the project area (refer Section 16.2.1 of the EIS), however these have not been confirmed as contaminated sites. A Phase 2 assessment would be undertaken during detailed design to confirm their status, and if confirmed as contaminated, managed in accordance with the Roads and Maritime Guidelines for the Management of Contamination (2013) to ensure no off-site migration occurs as a result of the works.

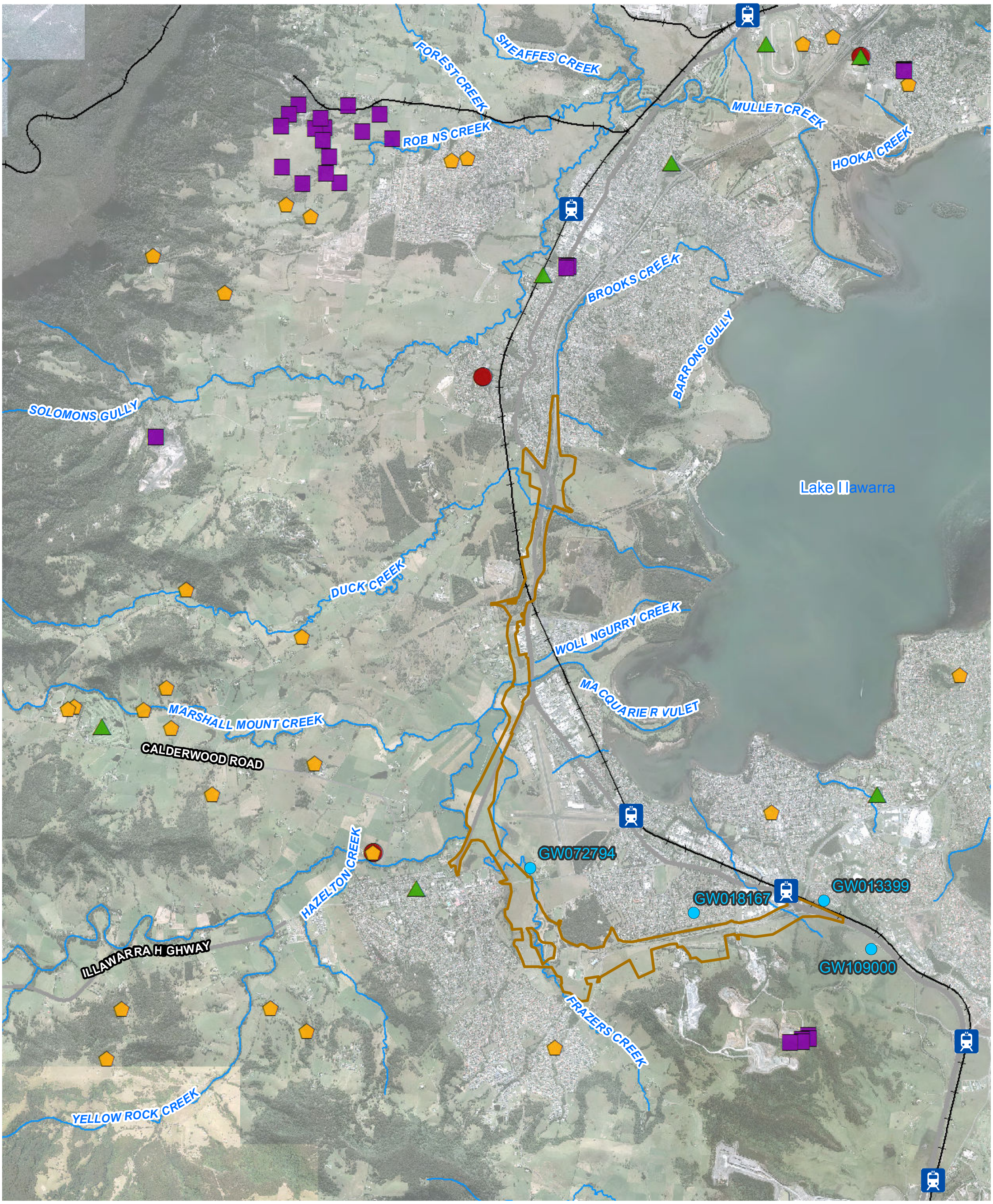
Based on these findings, it was concluded that there are no known sources of groundwater contamination in the project boundary.

4.6 GROUNDWATER USE

This section is based on information from the Pinneena database. Information on bore use is available for 66 bores (out of 104) over the study area. Groundwater bores are typically used in the area for stock, domestic use and monitoring. The monitoring bores (36 bores) are located over five properties and appear to be associated with industrial activities.

Nine bores are used for recreational purposes mostly and also industrial and irrigation purposes (see Figure 4-5). Those bores are licenced and have a defined water allocation. Groundwater allocations range from 1 to 19 ML/year (or equivalent share units). The larger groundwater allocation is for recreational purposes (e.g. irrigation of sports fields) with 19 ML/year (or equivalent share units) of groundwater allocation.

Within the licenced producing bores, 28 bores are targeting the consolidated rock formation and only two bores are targeting alluvium formations. The same pattern is observed when looking at the bore target aquifer for all the bores over the study area. This reflects the bore yield and aquifer characteristics previously described, that is, better groundwater resources are found in the fractured rock units of the consolidated formation. Groundwater usage from the alluvium is limited spatially and found where the alluvium is thick and of sandy or gravelly nature.



LEGEND

- Study Area Groundwater Bores
- Site Project Boundary
- Railway
- Major Watercourses

Groundwater Bore Use

- Industrial and Irrigation
- Monitoring Bore
- Recreation
- Stock and Domestic

FIGURE 4-6

1:70,000 @ A4

0 355 710 1,420
Metres

FIGURE 4-5 GROUNDWATER USE

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4.7 HYDROGEOLOGICAL CONCEPTUAL MODEL

All the elements of the groundwater system described in Sections 4.1 – 4.6 were assembled together in a hydrogeological conceptual model. A hydrogeological conceptual model is a representation of a groundwater system in words, figures and maps. The hydrogeological conceptual model has been used as a key tool for the assessment of the risk to groundwater from the project and the development of suitable management and mitigation measures where an impact or potential impact associated with the project has been identified.

Consistent with the limited data and information available, a simplified conceptual hydrogeological model was prepared.

The hydrogeological conceptual model describes the following:

- The aquifer(s) and aquitard(s) of the study area
- The groundwater flow (depth to water and flow direction)
- The formation hydraulic characteristics
- The groundwater recharge and discharge process, and connectivity between water bodies
- The groundwater environmental values.

The simple hydrostratigraphy consists of Quaternary alluvium (mainly associated with low lying areas and watercourses) and the laterally extensive Permian consolidated rocks (sandstones, siltstones and volcanics). Where present, the Quaternary alluvium is unconfined. The consolidated rock aquifer is either unconfined or in places semi-confined.

Recharge to groundwater occurs mainly by spatially distributed rainfall recharge. Discharge is most likely to be a combination of evaporation from shallow water tables and groundwater outflow to surface watercourses and to Lake Illawarra and the sea.

In the Illawarra area, the total average annual rainfall decreases generally from west to east. The highest rainfall occurs on the Illawarra Range south west of Jamberoo with an average annual rainfall of 2,300 millimetres. The lowest rainfall occurs at Albion Park with an average annual rainfall of 1,200 millimetres (NSW Office of Water, 2011). Rainfall recharge was calculated based on a percentage of infiltration of average annual rainfall between 1921 and 1995 over the groundwater source area (NSW Office of Water, 2011). This approach is considered precautionary by the NSW Office of Water (2011) and goes towards the determination of the volume of groundwater reserved as planned environmental water and the volume that is potentially available for extraction in each groundwater source.

The average annual rainfall recharge volumes for the Greater Metropolitan Region groundwater sources are displayed in Table 7 of NSW Office of Water (2011). For the 3035 km^2 area of the Sydney Basin South groundwater source, 6% of the average rainfall or 225 GL/year was considered as appropriate by the NSW Office of Water (2011).

The relatively high rainfall and considerable topographical relief suggest that groundwater contours can be expected to be a subdued form of the topography. Consistent with this expectation, the groundwater head map (Figure 4-4) indicates a hydraulic gradient that generally follows the topography of the land, from the high elevation in the west towards the low elevation coastal area in the east. Groundwater discharge is most likely to occur in the low lying coastal area, as evaporation from the shallow water table and locally to surface watercourses, to Lake Illawarra and to the sea.

In Section 4.3 an overview of the most likely hydraulic parameters is presented. Accordingly, the hydraulic conductivity of the alluvium is expected to be at least one magnitude higher than that of the consolidated rocks.

4.8 GROUNDWATER CONNECTIVITY

The NSW Office of Water (2011, Table 3) lists the connectivity of the porous rocks of the Sydney Basin South as follows:

- Low to moderate level of connection between surface and groundwater
- Low level of impact on instream values (since not major contributor)
- Years to decades estimated travel time between groundwater and unregulated river.

All alluvium beds in the Sydney Basin South groundwater source (NSW Office of Water, 2011) have lower levels of management and are managed as miscellaneous unmapped alluvium. This will mean that they will not have a separate extraction limit calculated and will take their share of water from the underlying groundwater source (i.e. the porous or fractured rock water source that underlies these smaller alluvial deposits).

In terms of characterising the physical level of connectivity between water bodies, there is potential for interconnectivity as follows:

- Connectivity with communities dependent on groundwater for survival, in other words GDEs
- Connectivity with surface water bodies such as rivers and lakes
- Connectivity between formations.

4.8.1 GROUNDWATER DEPENDENT ECOSYSTEMS

Groundwater dependent ecosystems (GDEs) are shown in Figure 4-6.

The NSW Office of Water (Appendix 4, 2011) lists identified high priority GDEs in the Greater Metropolitan Region for the Sydney Basin South groundwater source as follows:

- Budderoo National Park and Barren Grounds Nature Reserve Health Swamps (wetland)
- Macquarie Rivulet estuary (wetland), corresponding surface water source: Illawarra Rivers
- Minnamurra River Estuary (wetland), corresponding surface water source: Illawarra Rivers
- Ettrema and Jones Creek Karst, corresponding surface water source: Shoalhaven Rivers.

Of the above significant GDEs, the Macquarie Rivulet is the only identified GDE in the vicinity of the project area. The Macquarie Rivulet wetland is about 1.3 km east of the route (Figure 4-6). No literature has been found that describes this GDE.

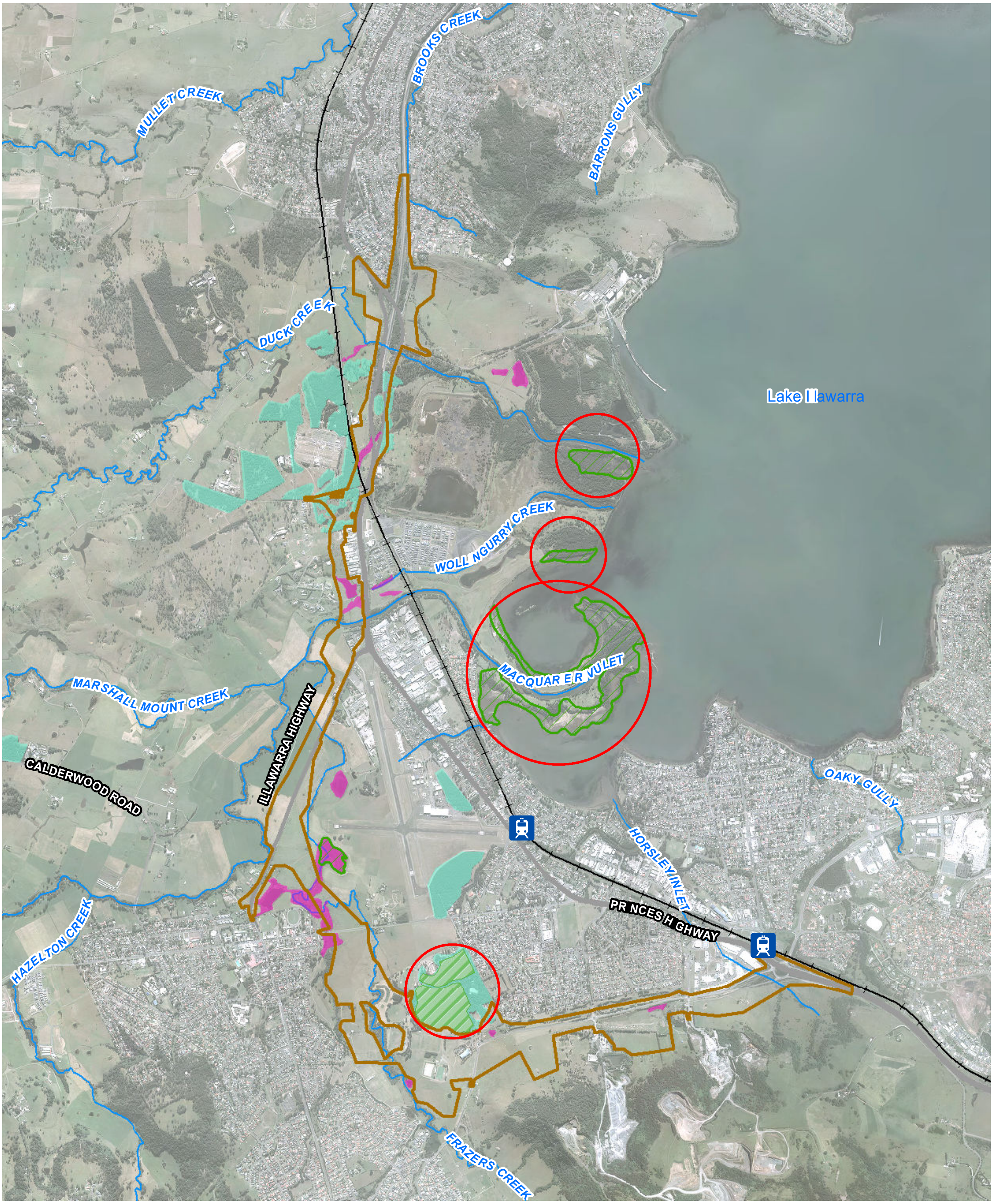
The BOM GDE Atlas lists additional GDEs reliant on subsurface groundwater consisting typically of deep rooted vegetation. A review of the location of these GDEs with aerial photography has revealed that although the areas mapped on the BOM GDE Atlas sometimes match areas mapped as Endangered Ecological Communities (EECs) (as listed under state or Commonwealth biodiversity legislation), other areas are not necessarily associated with areas of vegetation. This is not unexpected from work using solely desktop tools. As a consequence, only GDEs identified as high value by the NSW Office of Water and areas mapped as EECs under the provisions of the *Threatened Species Conservation Act*, 1995 were considered as GDEs or potential GDEs for this assessment.

The Australian groundwater-dependent ecosystems toolbox (Richardson et al, 2011a, b) prepared for the National Water Commission was consulted to review the methodology of identification of GDEs but not used further in this technical paper as it did not yield any additional information relevant to this assessment.

The Macquarie Rivulet estuary is the only recognised high value GDE in the study area. The groundwater table is expected to be similar to the lake surface level of Lake Illawarra in this location and as such would contribute to the GDE. Freshwater wetlands in the study area (Figure 4-6) are not necessarily GDEs.

The average annual rainfall is quite significant over the study area and will be a large contributor to fresh water wetland ecological communities. However, deep rooted vegetation as identified in Illawarra Lowlands Grassy Woodland Communities (Figure 4-6) would be partially relying on groundwater. This includes the area close to the route, the Croom Reserve (Figure 4-6). Other areas mapped as EECs Illawarra Grassy Woodland Communities are further north along the route and match some vegetation patches on road reserves and vegetation patches in paddocks. The management of these areas is defined in the Section 9 of the EIS.

The SEPP14 wetland located on Frazers Creek directly east of the route (Figure 4-6) only supports low level vegetation and freshwater fauna. Reliance on groundwater by this wetland is uncertain and potential impacts are discussed further in Section 5.2.4.



LEGEND

- Railway Station
- Site Project Boundary
- Major Watercourses
- Railway
- Groundwater Dependent Ecosystems
- SEPP14 Wetlands
- Croom Voluntary Conservation Area
- Illawarra Lowlands Grassy Woodland
- Freshwater Wetlands

FIGURE 4-7

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0 235 470 940
Metres

FIGURE 4-6 LOCATION OF GROUNDWATER DEPENDENT ECOSYSTEMS

GROUNDWATER TECHNICAL PAPER
ALBION PARK RAIL BYPASS
NSW ROADS AND MARITIME SERVICES

COORDINATE SYSTEM:
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DATE: AUGUST 7, 2015

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4.8.2 SURFACE WATER – GROUNDWATER INTERACTIONS

Little information is available on the connectivity between groundwater and surface water in the study area. The following information is therefore based on experience with similar groundwater systems and the general observations made by Toth (1963) under rainfall recharge in areas of significant topographic relief.

The relatively high rainfall and high topographical relief suggest that groundwater contours can be expected to be a subdued form of the topography. Consistent with this expectation, the groundwater elevation maps (Figure 4-3 and Figure 4-4) indicate hydraulic gradients that generally follow the topography of the land, from the high elevation 'regional recharge area' in the west towards the low elevation 'regional discharge area' in the east. As rainfall increases towards the west, surface waters are most likely to recharge groundwater there while groundwater is most likely to discharge to surface water in the east.

Depth to groundwater data (NSW Office Water, Pinneena Database; not shown in figures) generally show deep groundwater in the west and shallow groundwater in the east which is consistent with this interpretation. Accordingly, groundwater discharge is most likely to occur in the low lying coastal area, as evaporation from the shallow water table and locally to surface watercourses and offshore. Further, most but not all GDEs are most likely to be situated in the coastal discharge area in low lying areas next to watercourses or near the western edge of Lake Illawarra (Section 4.8.1).

4.8.3 INTRA FORMATION CONNECTIVITY

There is little data or information available for the relationship between groundwater flow in the alluvium and that in the consolidated rocks (Permian sandstones, siltstones and volcanics). The groundwater elevation maps (Figure 4-3 and Figure 4-4) are not sufficiently detailed to draw conclusions about vertical hydraulic gradients between the Quaternary alluvium and groundwater in the consolidated rock.

Based on the conceptual hydrogeology (Section 4.7) and statements in Sections 4.8.1 and 4.8.2, where the Quaternary alluvium exists, the vertical hydraulic gradients are likely downward in the west and upward in the east. Whether this gradient results in significant inter-aquifer groundwater flow or not depends on the presence/absence of intervening low hydraulic conductivity material. From the analysis of the data sourced from the NSW Office Water, Pinneena Database it appears that in most places sandstones and siltstones interfinger rather than forming distinct regional layers and therefore connectivity will vary on a local scale.

5 IMPACT ASSESSMENT

5.1 RISK IDENTIFICATION

This section on risk identification aims to identify all potential hazards that may impact groundwater and groundwater environmental values associated with the project, even if those are later found to be 'perceived' risks that are unlikely to be realised. The hazards are identified for activities both during construction and during the operational stages of the project. Only those hazards identified as representing a risk of leading to impacts on groundwater have been further assessed for impact. These are listed the end of each subsection.

The first step of the risk assessment was to identify the hazards associated with both the construction and the operation of the project on the groundwater system and associated groundwater values. This could for example, be hazards that may translate into a risk to the aquifers themselves, to groundwater users or GDEs.

To better identify the location of risks associated with the project, elements of the project potentially at risk of altering groundwater systems have been identified as hazards. Each element / hazard was then assessed independently as part of the risk assessment.

The identification process considered initially the perceived risks and discusses their legitimacy (ie does the risk have potential to be realised as an impact?) based on a comparison of the location of the element / hazard and site specific data using the hydrogeological conceptual model (Section 4.7), project design information, or environmental settings.

This process allowed for the selection of the hazards relevant to the project for which the risk analysis is to be carried out. The risk analysis considered the likelihood of a hazard occur and the level of the consequences of the impact. This risk analysis was informed by qualification or quantification of the risk as appropriate, depending on the available data.

The outcome of the process has been used to define potential impacts, and to identify appropriate management measures where required (Section 6).

5.1.1 GROUNDWATER DEWATERING

As described in Section 1, the project may potentially intersect ('interfere with'; NSW Office of Water, 2011) aquifers in the study area where it penetrates the water table. The hazards that represent a risk of groundwater depressurisation / dewatering can be summarised as follows:

- Aquifer dewatering due to pumping of groundwater for construction work purposes (e.g. water may be required for dust suppression, or some features may need to be constructed in dry conditions, requiring temporary lowering of the groundwater)
- Ongoing aquifer dewatering due to interception of groundwater at road cuts
- Initial aquifer dewatering associated with the use of wick drains to stabilise embankments.

No supply from groundwater is expected to be required during the construction phase of the project (water will be obtained from other sources). Similarly, no dewatering over a long period to enable building in dry conditions would be required during construction. The remaining risk of dewatering is associated with groundwater interception at road cuts and areas with wick drains. A definition of wick drains is given in Table 5-1.

Wick drains are an element of the road design for the areas of Fill 6 and Fill 7 (Figure 5-1). Wick drains are used to ensure soil stability in soft soils; as a consequence, they only affect the alluvium. Wick drains increase the speed of settlement by draining pore water along the road transect where they are installed. The water is expected to flow up the drains, into a horizontal drainage layer at the base of the embankment and reinfiltrate on the side of the embankments. As such, the wick drains act as a local dewatering-reinjection system and will affect groundwater levels and groundwater flows along the Fill 6 and Fill 7 road sections in the short term.

Cuts are required at several points (Figure 5-1), as follows (Hyder Cardno Joint Venture, 2015b):

- The northern domain, consisting of that section of the project from the north down to the Macquarie Rivulet requires one deep cutting and two small cuts (Figure 5-1):
  - Widening of an existing cut at the northbound entry ramp to the Princes Motorway in sandstone formation
  - A minor cut at the Yallah Interchange southbound exit ramp predominantly in siltstone bedrock
  - A deep cut, referred to as Cut 1, to the south of Yallah Road and to the north of Macquarie Rivulet. Cut 1 is 440 metres long and reaches a height of 15.2 metres, predominantly in siltstone units. There is no alluvium formation along that road section. The bottom of the cut is below the measured groundwater levels and as such is expected to impact on groundwater
- Over the central domain, consisting of the section between Macquarie Rivulet through to the Croom Regional Sporting Complex, a very minor cut is required immediately south of Macquarie Rivulet. In this area the presence of near surface soft soils are expected and therefore the design allows for partial excavation and backfill
- In the southern domain, consisting of the section between Croom Regional Sporting Complex through to Oak Flats Interchange, three cuts are required:
  - Cuts 2 and 3 along the East West Link over a distance of 500 metres. These cuts follow an existing alignment and do not require substantial work. The work for these cuts will add ‘scrapes’ into the face of the existing alignment
  - Cut for service road to the south of Oak Flats Interchange over a length of 425 metres. This cut is planned to a maximum height of 12.5 metres in siltstone and latite formations.

The impact of cuts on the groundwater system is assessed in Section 5.2.2.

LEGEND

- Site Project Boundary
- Cut
- Fill
- Cut and Fill
- Major Watercourses
- Railway

FIGURE 5-8

1:40,000 @ A4

0 205 410 820
Metres

FIGURE 5-1 LOCATION OF CUT AND FILL AREAS FOR THE ALBION PARK RAIL BYPASS

GROUNDWATER TECHNICAL PAPER
ALBION PARK RAIL BYPASS
NSW ROADS AND MARITIME SERVICES

COORDINATE SYSTEM:
GDA 1994 MGA ZONE 56

REVISION NUMBER: 02
AUTHOR: RNB

DATE: AUGUST 7, 2015

Transport Roads & Maritime Services

Hyder Cardno JOINT VENTURE

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5.1.2 POTENTIAL FOR GROUNDWATER FLOW DIVERSION

The risk of impact on groundwater flows identified with the construction of a new motorway and ongoing use of the motorway are primarily as follows:

- Risk of ongoing aquifer drainage due to interception of groundwater at road cuts
- Risk of adverse groundwater flow changes due to:
  - Soil compaction
  - Structural features below larger fill transects
  - Interception of groundwater flow at road cuts.

Figure 5-1 identifies the locations of cut and fill required for the route. The map is based on the elevation (compared to the current elevation) of the 80% concept design. Cut areas are described in detail in Section 5.1.1.

Potential for groundwater flow changes at fill areas

Fill of over 1.5 metres in height requires engineering, and possibly soft soil treatments, to ensure its stability. Soft soil treatments are defined in the Concept Design Report, 80% Concept Design Issue (Hyder Cardno Joint Venture, 2015b) and can comprise different types of treatments:

- Type E1 – Loosen and Compact
- Type E2 – Bridging Layer and Geogrid
- Type E4 – Geogrid layers
- Type E5 – Drainage Layer, Wick Drains, High Strength Geogrid and Surcharge
- Type E7.1 – Load Transfer Platform, Controlled Modulus Columns
- Type E7.2 – Load Transfer Platform, Piles.

Types E1 and E2 are standard soil treatments, soil treatments E4, E5, E7.1 and E7.2 are used to reinforce stability in areas of soft soils. Table 5-1 provides definitions of the soil treatments that have the potential to interfere with groundwater.

Table 5-1 Definition of soil treatments

Soil treatment	Definition and application specification for the project
Wick drain	Wick drains are a ground improvement technique that provides drainage paths for pore water in soft compressible soil, using prefabricated geotextile filter-wrapped plastic strips with moulded channels. The wick drains are used to accelerate the consolidation process. In the project, they will reduce the typical consolidation time from 5 years to of the order of 3 months to 6 months. The wick drains are expected to be installed at typical spacing of 1.5 m to 2.0 m in a triangular pattern in plan. The depth of installation depends on the thickness of the soft soils. The wick drains are only targeting the alluvium, they are not targeting the consolidated formation and do not require anchoring. A typical length of wick drain is expected to be of the order of 12 m on average based on the geological model over the central domain.

Soil treatment	Definition and application specification for the project
Controlled Modulus Columns and load transfer platforms	The controlled modulus columns are used to improve the soil characteristics of a compressible soil layer on a global scale and to reduce its compressibility by use of semi-rigid soil reinforcement columns. Unlike a piling solution which is designed to support the entire load of the structures on the piles, the objective of a controlled modulus columns solution is to increase the stiffness of the soil mass to globally reduce both total and differential settlements by sharing the load of the structure between the soils and the controlled modulus columns. Under uniformly loaded structures, such as embankments and slabs, a load transfer platform is designed between the top of the columns and the structure to efficiently transfer the load to the controlled modulus columns. The controlled modulus columns are placed uniquely in the alluvium. A typical length of the controlled modulus columns is expected to be of the order of 12 m to 15 m deep at 1.75 m to 2.5 m centres in a triangular pattern.
Piles and load transfer platforms	Piles are to be drilled into the solid rock. They are only to be used at certain gas pipeline crossings and at bridge structures. They are designed to support the entire load of the structure on the piles, a load transfer platform is used to distribute the load above the piles.

With respect to potential of impact on groundwater flows, only wick drains, controlled modulus columns and piles have the potential to interfere with groundwater flows. Geogrids and load transfer platforms are surface treatments positioned above existing soil level and below fill.

Wick drains, controlled modulus columns and piles are primarily found on the central domain of the project; that is between Macquarie Rivulet through to the Croom Regional Sporting Complex. Some piles are planned supporting bridges in the north of the site and to the east of Croom Reserve. In this section of the project the soil treatments are associated either with the necessity of strong soil settlement controls due to a large pipeline crossing (three crossings), or with high embankments of up to 12 metres.

The soil treatments potentially at risk of impact on groundwater are located as follows:

- There is likely to be an area of piling at the Albion Park interchange southbound exit ramp, located west of Frazers Creek, along the existing Illawarra Highway
- At the most downstream Frazers Creek crossing, due to the crossing of the Eastern Gas pipeline, the design includes wick drains and constant modulus columns
- Wick drains are planned along all of Fill 6 and Fill 7 sections (Figure 5-2), those sections south of Frazers Creek have high embankments which are designed to reach a maximum height of 11.6 metres.

Identifying potential for groundwater flow changes at cuts

Groundwater flow changes at cuts are associated with groundwater dewatering and are identified in Section 5.1.1.

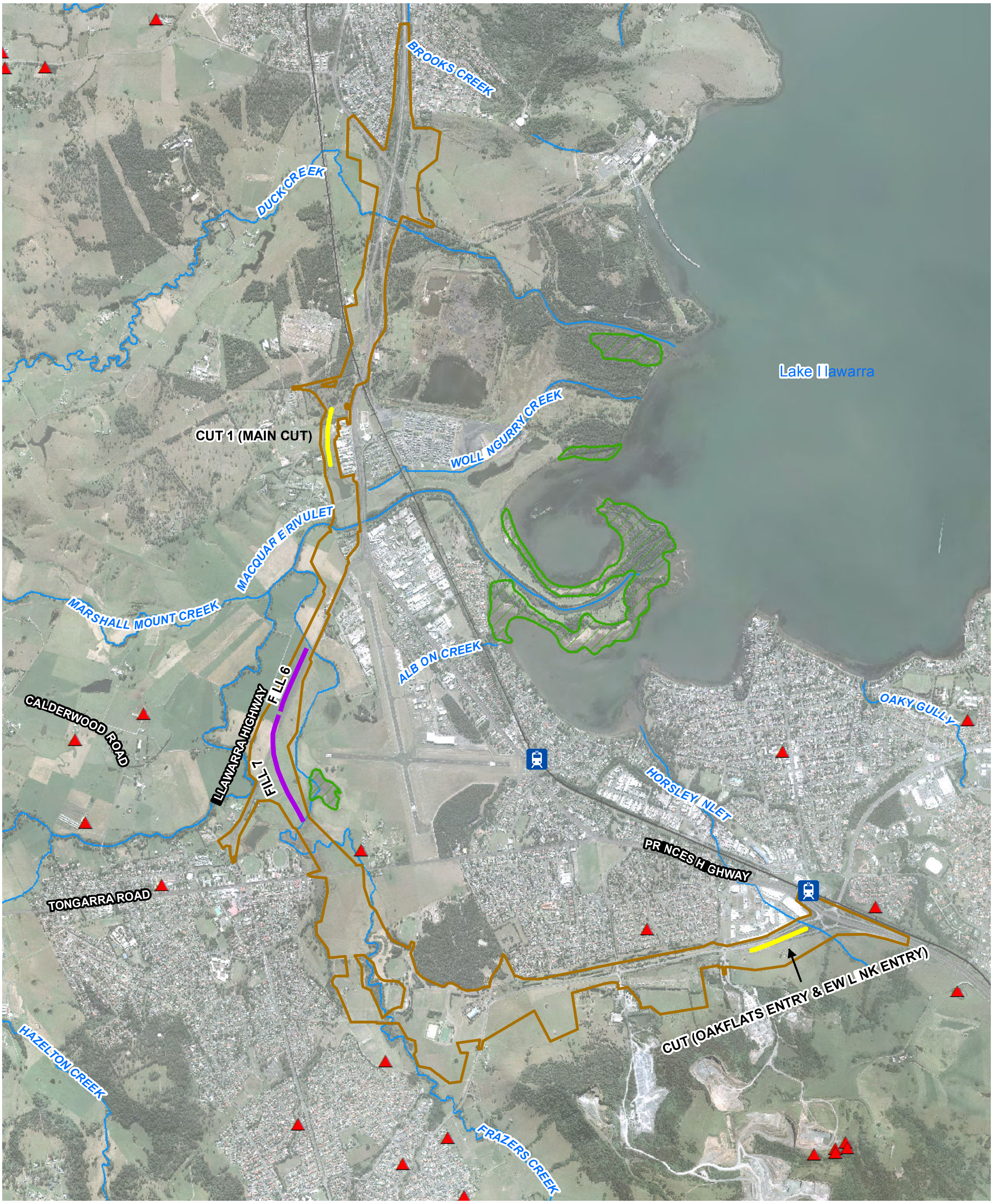
Conclusion on potential for groundwater flow changes

To summarise, the assessment of risk for potential impacts to groundwater flows have been identified as follows:

- Risk of groundwater flow diversion in the Quaternary Alluvium formation
- Settlement will occur in the Quaternary Alluvium over the road footprint in areas of fill. The settlement can be up to one metre in areas. The settlement will particularly affect areas Fill 6 and 7 (Figure 5-1). The settlement will have the effect of reducing the hydraulic conductivity of the alluvium.
- At the Albion Park Interchange Southbound Exit Ramp, the piling is likely to reduce groundwater flow and create a diversion for groundwater flow locally.

  Note: Controlled constant modulus columns are intended only for a 50 metre long section of road at the first crossing of Frazers Creek (Chainage 19,730). The risk of groundwater flow changes can be assessed with the adjoining areas of Fill 6 and 7.

There is no risk of groundwater flow changes or diversions arising from soil treatments for the consolidated rock formations. Activities resulting in groundwater flow changes in this aquifer would solely be associated with dewatering at cuts and is identified in further detail in Section 5.1.1.



LEGEND

Site Project Boundary
Cut
Fill
Private Bores
Railway
Major Watercourses
SEPP14 Wetlands

FIGURE 5-9

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0 205 410 820
Metres

FIGURE 5-2 LOCATION OF CUT AND FILL AREAS OF POTENTIAL RISK TO GROUNDWATER

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COORDINATE SYSTEM:
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5.1.3 POTENTIAL IMPACTS ON RECEIVING WATERS AND SENSITIVE RECEIVING ENVIRONMENTS

Surface water and groundwater contamination have the potential to result from the rainfall runoff and most importantly from accidental spill and release to soils and drainage system during the construction and operational phases of the project.

The project area drains to three main waterways, all of which are tributaries of Lake Illawarra:

- Duck Creek
- Macquarie Rivulet, which is fed by Marshall Mount and Frazers Creeks
- Horsley Creek.

These watercourses, including Lake Illawarra and the uppermost groundwater aquifer (alluvium system or consolidated rock system depending on locations), comprise the receiving waters for the project, and have the potential to be impacted by the project during the construction and/or operational phases.

Impact discussed here is in terms of change in water quality. Other impacts on groundwater are discussed throughout other sections of this report.

The receiving waters support a range of sensitive riparian and aquatic ecosystems that support a diverse range of flora and fauna. They may have high conservation value, be highly valued by the community, support human uses (eg fishing or aquaculture), or be susceptible to water pollution. These sensitive ecosystems are referred to as sensitive receiving environments.

Areas that may be categorised as sensitive receiving environments include:

- Protected wetlands, such as Endangered Ecological Communities, SEPP 14 (Coastal Wetlands), Wetlands of National Importance and Ramsar Wetlands
- Protected areas such as National Parks or Reserves, State Conservation Areas, Marine Parks, aquatic reserves or World Heritage Areas
- Key fish habitat areas and sensitive aquatic ecosystems (e.g. seagrass beds) identified by Fisheries NSW
- Locations important for commercial fishing or aquaculture
- Known or potential habitat for threatened aquatic species
- Recreational swimming areas
- Drinking water catchments
- Aquifers.

Sensitive receiving environments that have potential to be directly impacted by the project are the Macquarie Rivulet, Frazers Creek, Duck Creek, Horsley Inlet and the shallow and deep groundwater systems. Other sensitive receiving environments, primarily Lake Illawarra, SEPP14 areas, endangered ecological communities (EECs) and the Macquarie Rivulet estuary GDE (Section 4.8.1), would only be impacted indirectly due to changes to groundwater through migration of contamination and as such are not discussed further in this report.

Impacts on GDEs are discussed in Section 5.2.4.

5.2 IMPACT ASSESSMENT

5.2.1 GROUNDWATER FLOW CHANGES

The soil treatments described in Section 5.1.2 are most likely to influence the Quaternary alluvium by reducing its hydraulic conductivity through compaction of the sediments. There are no expected groundwater flow changes to the consolidated rock aquifer.

The two largest fill areas are Fill 6 and Fill 7, both of which have a north–south alignment (Figure 5-1). Figure 4-3 shows that in the vicinity of Fill 6 and Fill 7 groundwater flows generally from south to north in the quaternary alluvium (ie the groundwater flow is parallel to the fill sections). As a consequence, the flow will not be 'intercepted' and allowed to mound against the compacted alluvium. The changes in flow will be localised and are expected to be minimal.

As the soil treatments will not cause such changes on a regional scale but locally, any flow diversions will be minor and local.

5.2.2 DEWATERING IMPACT QUANTIFICATION

Quantifying the dewatering impact involves the use of Darcy's Law (Equation 1):

$$Q = k\ i\ b\ w = k\ (H2\text{-}h2)\ w\ /\ 2\ L \qquad (1)$$

Where:

Q is the flow [given here in cubic metres/day]

k is the hydraulic conductivity [given here in m/day]

i is the hydraulic gradient [dimensionless]

b is the saturated thickness of the aquifer [metres]

w is the width of the aquifer perpendicular to the route [metres]

H is the head above the base of the aquifer outside the interference zone of the project [metres]

h is the head above the base of the aquifer in the motorway cut drain [metres]

L is the distance to the edge of the interference zone [metres], i.e. the maximum radial distance where the motorway will affect groundwater elevations.

The Theis method (Equation 2) may be used to calculate the interference zone:

$$L = \sqrt{\frac{2.25\ Tt}{S}} \qquad (2)$$

With, L is distance to the edge of the interference zone [metres]

T=kb is the transmissivity [metres^2/day]

t is the time [days]

S is specific yield [dimensionless].

Implementation

Darcy's Law was used, as described above, with the following simplifications:

- A steady-state solution was used.
- Horizontal groundwater flow was assumed from both sides of the route in places where the water table was higher than the route elevation.
- A constant hydraulic conductivity was assumed for the Quaternary (0.5 metres per day) and the consolidated rock (0.005 metres per day) aquifers, respectively.
- 100 metres and 200 metres radii were adopted for consolidated rock, and quaternary aquifers, respectively.
- Hi, the groundwater head in the aquifer undisturbed by the project, was calculated from groundwater elevations using Golden Software Surfer software with 10 x 10 metres grid size.
- Hi, the groundwater head at the project centreline was assumed to be equal to the final route elevation.
- The 11.5 kilometre long centreline of the route was discretised to 2377 line segments with an average segment length just below 5 metres.
- The base of the consolidated rock aquifer was assumed to be at -50 metres AHD. This is because fracture density is assumed to decline with increasing depth. In other words the consolidated rock is considered impervious below -50 metres AHD due to the lack of fractures. Only 1.5 per cent of the lithology records (NSW Pinneena Database) for the project area extend below -50 metres AHD.
- For the Quaternary aquifer, the base was calculated for each line segment from bore data.
- A conservative t = 365 days between significant recharge events was adopted;
- Conservative (worse case) values were used within the expected k, b and S values yields:
  - o Alluvium k=0.5 m /d, b = 10 m, S =0.1; L =200 m
  - o Consolidated rock: k=0.005 m /d, b = 50 m, S =0.02; L =100 m
- The width of the flow, w, was determined by calculating the distance between successive points. In addition, groundwater flow was assumed to be perpendicular to each and every line segment (this assumption would likely result in overestimation of the groundwater flow). Accordingly, the total flow in a cut can be estimated from:

$$Q_i = k_i \, (H_i^2 - h_i^2) \, w_i \, / \, L \text{ if } H_i > h_i \text{ and}$$

$$Q_i = 0 \text{ if } H_i \leq h_i$$

$$Q = \sum Q_i$$

  Where Q_i refers to the flow through a section of the route, from halfway between the i-th and i-1-th to halfway between the i-th and i+1-th digitised points along the centre of the route.

H_i, the head above the base of the aquifer outside the interference zone of the project was estimated from the groundwater elevation map, the construction of which is described in Section 4.4.

The elevation from the route, h_i, was extracted along the route at 2377 locations and groundwater elevation was estimated at the same locations for both the consolidated rock and the Quaternary alluvium using Golden Software Surfer Grid/Residuals process. This process estimates the elevation of a surface (such as groundwater head) at the exact locations of the 2377 points along the route. The spatial estimator used, as described in Section 4.4, was kriging.

Results - Consolidated Rock

Figure 5-3 indicates the relationship between predicted groundwater elevation (blue) in the consolidated rocks and the existing land (grey) and the design (black) elevation of the route. In places, groundwater elevation is predicted to be above the current land elevation. These occurrences most likely reflect errors / uncertainties in the groundwater measurements and contouring process near steep changes, for example from chainage 17500 metres to 17850 metres in Figure 5-3. There is a steep change in that location in the current land profile and the much smoother predicted groundwater elevation curve is above the existing land surface, almost certainly due to uncertainties in the contouring (kriging) process and data (limited number of wells) constraints.

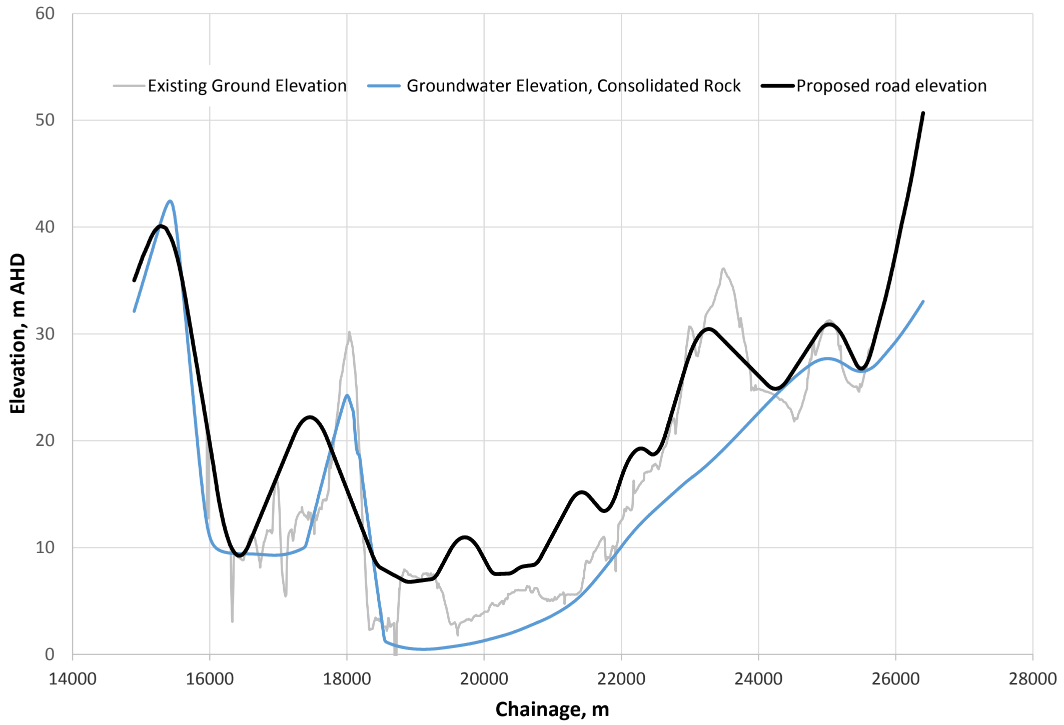

Figure 5-3 Predicted groundwater elevation (blue) in the consolidated rocks, existing land (grey) and the design (black) elevation of the route

The cumulative predicted flow along the entire length of the route is 26.9 cubic metres per day (Figure 5-5). Most of the predicted flow, namely 21 cubic metres per day, occurs at the deep cut, Cut 1 over a distance of 440 metres. A flow of 5.8 cubic metres per day is predicted at the northbound entry ramp at the Yallah interchange. A much smaller flow, namely 0.1 cubic metres per day groundwater flow is predicted at the Yallah interchange cut. These flows are all predicted to occur in the northern section of the road extension (Figure 5-5).

It is noted that the works required at the northbound entry ramp are a widening of the existing cut. The above estimation predicts an inflow of groundwater into the cutting of 5.8 cubic metres per day at the northbound entry ramp. The prediction is driven by local observation of the water level at borehole BH301 which water level sits at about 45 metres AHD, at least seven metres above the current road level. As such, it would be expected that there would already be an inflow along this section of the current road. Road and Maritime indicated that to their knowledge there is no inflow into the existing cut. However, this technical paper considers the most conservative approach and retains the estimated value of inflow at the northbound entry ramp.

Results – Quaternary Alluvium

There is no groundwater inflow predicted from the Quaternary Alluvium along the route. As Figure 5-4 indicates this is the consequence of the predicted groundwater elevation being beneath the route elevation.

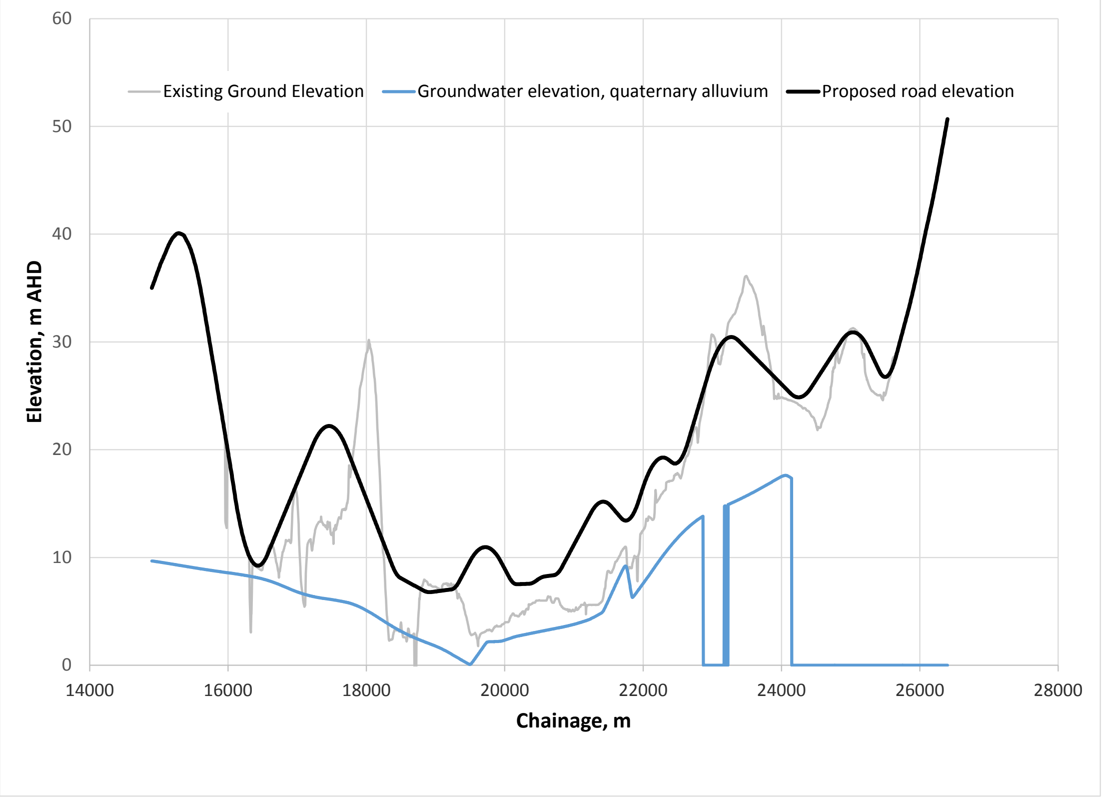

Figure 5-4 Predicted groundwater elevation (blue) in the Quaternary alluvium, existing land (grey) and the design (black) elevation of the project route

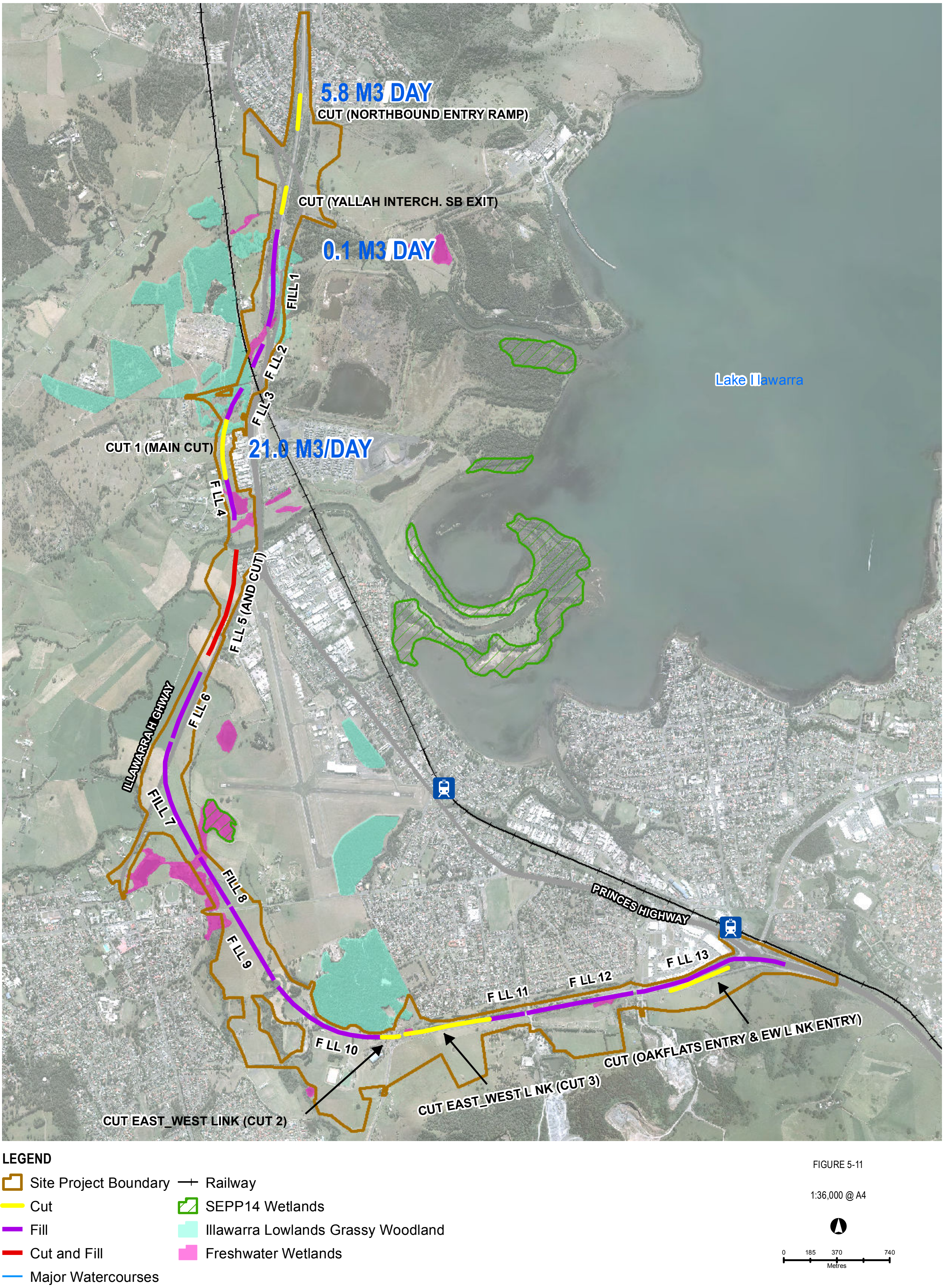

FIGURE 5-5 PREDICTED GROUNDWATER INFLOWS ALONG THE APRB, CONSOLIDATED ROCKS

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DATE: AUGUST 7, 2015

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Sensitivity of predicted flows to hydraulic conductivity

As indicated in Section 4.3, there is considerable uncertainty in the hydraulic parameters, including hydraulic conductivity and specific yield and is therefore important to note that the sensitivity of results (location and size of groundwater inflows and associated drawdown).

The location of the predicted inflows are not sensitive to hydraulic parameters at all and depend only on the hydraulic heads. Similar, the maximum drawdown along the route is not a function of the hydraulic conductivity.

The lateral propagation (decay) of the drawdown is dependent on the hydraulic parameters. The predicted groundwater inflows are sensitive to hydraulic conductivity (Equation 1: linear relationship, Equation 2: Square root) and specific yield (Equation 2: inverse square root).

It is, however, important to consider an increase in hydraulic conductivity with a corresponding increase in specific yield. For example, a magnitude of order increase, from 0.005 to 0.05 metres per day of the hydraulic conductivity, and an assumed corresponding increase in specific yield from 0.02 to 0.05 would increase L, the interference zone in Equation 2 from 100 metres to 200 metres. The combined effect of increased k and decreased L in Equation 1 would yield a five-fold increase in the predicted groundwater inflow, as opposed to a ten-fold (magnitude) increase that may have been anticipated from Equation 1 and the hydraulic conductivity alone.

Drawdown

Predicted drawdown will be restricted to a L=100 metre interference zone. At the centre trace of the route the maximum drawdown will be equal to the difference between the blue and solid black line of Figure 5-10. Predicted drawdown at the i-th point (s_i) will decay with increasing distance (r) laterally from the route:

$$s_i = H_i - \sqrt{H_i^2 - \frac{(H_i^2 - h_i^2)\,(L - r)}{L}} \quad \text{if } H_i > h_i \text{ else } 0$$

Although r is under the square root in the equation above, a linear approximation, between s_i and r is sensible given the large influence of the parameter values for H_i and h_i and the relatively small contribution of (L-r)/L.

The relationship between drawdown, chainage and lateral distance is shown in Figure 5-6. The relatively large drawdowns predicted around 18,000 metres chainage are almost certainly due to uncertainties in the contouring (kriging) process and data (limited number of wells) constraints, as discussed earlier in Section 5.2.2.

The maximum drawdown is associated with the main cut with an expected drawdown of nine metres (Figure 5-6). The drawdown diminishes steeply laterally. Notwithstanding the errors, the average drawdown where inflow is predicted at the centreline (worst case) is 1.6 metres.

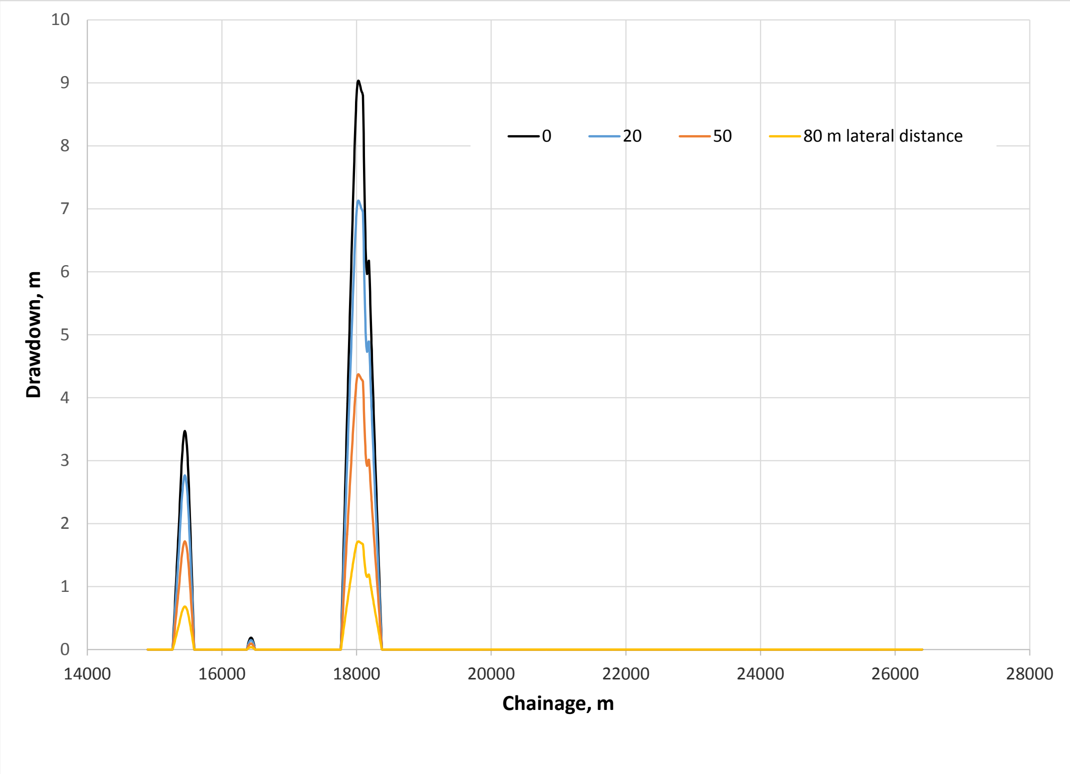

Figure 5-6 Predicted drawdown at 0, 20, 50 and 80 m lateral distance from the main carriageway

5.2.3 GROUNDWATER QUALITY

Groundwater quality impact would arise from:

- Current industrial activities within the project area; or
- Uncontrolled spills and contamination.

In relation to current industrial activities, a desktop and site inspection review of potential contamination (see Section 3.3.4) identified no known contaminated sites

In the case of uncontrolled spills, the chemical characteristics of the contaminant are most likely to be from the hydrocarbons family and as such can easily be identified from natural groundwater and surface water settings.

The design of the road allows for a number of elements and management measures to reduce the risk of impact on water quality.

The objective for water quality and longitudinal drainage design is to (Hyder Cardno Joint Venture, 2015b):

- Provide effective drainage for the road surface and enable the gutter flow width design criteria to be achieved
- Minimise the water quality impacts of the project using reasonable water quality treatment measures given the topography and constraints
- Design an integrated system to transport road and embankment surface runoff to water quality treatment and confirm feasible locations for water quality treatment with other project constraints
- Quantify the performance of the water quality design to demonstrate appropriate mitigation of water quality impact to the receiving environment.

Design and management measures are described in Section 6.1.

5.2.4 VULNERABILITY OF GROUNDWATER DEPENDENT ECOSYSTEMS, WATERCOURSES AND WETLANDS

The GDEs located in close proximity of the route are the grassy woodland community of the Croom Reserve and potentially the small SEPP14 wetland on Frazers Creek (Figure 4-6).

At both GDEs, groundwater flow direction in the alluvium aquifer is from South to North and as such will not be affected by possible reduced flow along Fill 6 and Fill 7 sections of the project.

The deeper consolidated rock aquifer is not affected by groundwater depressurisation or change to groundwater flow in the vicinity of the identified GDEs.

For the islands of grassy woodlands near chainage 16,400 metres, the predicted groundwater discharge is 0.1 cubic metres per day and drawdown in the centreline of the project area is predicted to be small (namely lower than 0.2 metres). The nearest edge of the woodlands are some 80 metres from the centreline, therefore no measurable drawdown is expected at that distance (Figure 5-6).

One freshwater wetland EEC located at chainage 18,350 metres, adjacent to Macquarie Rivulet, is in the very southern end of the deep cut, Cut 1. On closer examination, this appears to be a farm dam. The depth of the farm dam is unknown, as such the reliance on groundwater is unknown. However, as the freshwater wetland EEC lies wholly within the project area, it has been assumed as part of the biodiversity assessment that the entire EEC will be removed as part of the project. The biodiversity assessment report has established the requirement for offsets and further information can be found in the Chapter 9 of the EIS. Consequently, the evaluation of groundwater impacts on this EEC is not required.

As discussed in Sections 5.2.1 and 5.2.2, changes to groundwater levels and flows are expected to be minor and localised, and hence impacts on watercourses are expected to be negligible. The Frazers Creek adjustment is expected to result in minor, localised changes in groundwater flows and levels, and is expected to have minor, short term impacts on Frazers Creek. By extension, there are no indirect impacts on riparian areas expected for any of the watercourses, including Frazers Creek.

The Macquarie Rivulet GDE is located about 1.3 km east of the project. Impacton groundwater supplying this GDE may potentially be through drawdown impact propagation within the groundwater systems, or groundwater flow changes that affect the propagation to the Macquarie Rivulet. The impacts from groundwater flow changes and localised dewatering have been discussed earlier (Sections 5.2.1 and 5.2.2). The outcome of the impact assessment identified that groundwater flow changes would be minor and local (i.e. will not propagate 1.3 km away), and therefore no impacts on the Macquarie Rivulet GDE are anticipated. The groundwater dewatering impact would be a maximum of 2 metres at up to 80 metres distance from the carriageway. Due to the distance of the Macquarie Rivulet from the alignment, there would be no drawdown propagation impact on the GDE. The Macquarie Rivulet GDE will not be impacted by the project.

5.2.5 IMPACT ON GROUNDWATER USERS

Based on the Pinneena database, four groundwater bores are located within 500 metres of the route, GW072794, GW018167, GW13399 and GW109000 (Figure 4-5). The four bores are located in the southern section of the study area. As assessed in Table 5-2, the bores will not be affected by the project.

Table 5-2 Impact on groundwater bores

Bore number	Target aquifer	Latitude	Longitude	Bore location in respect of route	Impact discussion
GW013399	Consolidated rock aquifer	-34.5731	150.8256	170 m north of existing road, at the very southern end of the route.	No project works directly up-gradient of this location. In addition, the consolidated rock aquifer is not subject to impact in this location. As such the bore is not subject to impact.
GW018167	Unknown	-34.5742	150.8072	About 270 m north of the east-west road section. There is no impact predicted to the rock aquifer from cuts and fills in this area.	Not subject to impact.
GW072794	Consolidated rock aquifer	-34.5686	150.7844	About 250 m east of the route, north of Croom Reserve.	Groundwater flow in the consolidated rock aquifer is not impacted by the project, as such the bore is not subject to impact.
GW109000	Unknown	-34.5788	150.8320	South of road extension and up-gradient.	Not subject to impact.

5.2.6 VULNERABILITY TO DIFFERENTIAL SETTLEMENT

Dewatering in or near cuts has the potential to result in differential settlement of the surface and any buildings or features located on the area affected.

Although dewatering is inevitable at cuts, the dewatering will occur in the consolidated fractured rock aquifer rather than from the alluvium aquifer.

Differential settlement is not expected anywhere in the project area considering the relatively low dewatering required (less than 10 metre water level drop) and the fact that the drop of water level will affect the consolidated rock aquifer (which would not be subject to consolidation).

5.2.7 CONCLUSION ON IMPACT TO GROUNDWATER

The risk to aquifers and groundwater values has been assessed in the previous sections. The assessment has identified that:

- Road cuts will not impact on the alluvium aquifer
- Some dewatering will occur in the consolidated rock aquifer at three of the northern cuts. The main outflow being for Cut 1 with a predicted 21 cubic metres per day over a distance of around 440 metres. A flow of 5.8 cubic metres per day is predicted at the

northbound entry ramp (200 metres long) and 0.1 cubic metres per day groundwater flow is predicted at the Yallah interchange cut (150 metres long). Predicted drawdown would be restricted to a 100 metres zone from the highway. It is noted that the existing cut has an influence on the groundwater levels in this area. The works at the northbound entry ramp consist of a widening of the existing road, and as no flow is currently observed, it is possible that the fractured rock has a lower hydraulic conductivity than the value used for the assessment. Hence it may be that the estimate of potential draw down due to groundwater dewatering is less than the amount estimated

- Fill and soil treatments would have no impact on the consolidated rock aquifer
- Fill and soil treatments will possibly alter groundwater flow in the alluvium aquifer locally in the central section of the project, but this would be of no impact to sensitive receiving environments
- There will be no adverse impact on GDEs, including the Macquarie Rivulet GDE
- There will be no impact on groundwater users (i.e. private groundwater bores)
- There is a potential risk to groundwater quality from accidental spills during construction and operation of the road.

5.3 RISK ASSESSMENT AND IDENTIFICATION OF POTENTIAL IMPACT TO GROUNDWATER

A risk is defined by the Australian / New Zealand Standard for Risk Management (AS/NZS ISO 31000:2009) as “the chance of something happening that will have an impact on objectives”. It is measured in terms of a combination of the consequences of an event and the likelihood of an event occurring. The chosen risk rating matrix is presented in Table 5-3. Table 5-4 provides definitions for the risk matrix terms.

The potential risks and their impacts on groundwater and environmental values associated with the project were identified (Sections 5.1). The potential risks have then been evaluated (Section 5.2). This section assigns a risk rating to those evaluated risks, according to the likelihood of the risk occurring and the anticipated consequences.

Table 5-3 Risk rating matrix

		Likelihood				
		Rare	Unlikely	Possible	Likely	Almost certain
Consequence	Catastrophic	Medium	High	High	Extreme	Extreme
	Severe	Medium	Medium	High	High	Extreme
	Major	Low	Medium	Medium	High	High
	Moderate	Low	Low	Medium	Medium	High
	Minor	Low	Low	Low	Medium	Medium

Table 5-4 Definitions of risk matrix terms

Likelihood	Definition
Almost certain	Is expected to occur in most circumstances (>95% probability)
Likely	Will probably occur in most circumstances (>65%)
Possible	Might occur at some time (occurred more than 3 times in the past 10 years or is considered to have a reasonable likelihood of occurring in the next few years)
Unlikely	Could occur at some time (has occurred 2 or 3 times over 10 years)
Rare	May occur only in exceptional circumstances (has occurred or can reasonably be considered to occur only a few times in 100 years)
Consequence	**Definition**
Minor	Negligible effect to environment
Moderate	Minor effect, complaint from adjacent neighbours
Major	Localised impact, local media coverage, may trigger regulators involvement
Severe	Major impact, national media coverage, would trigger regulators involvement
Catastrophic	Massive damage, national to international media coverage, regulators involved.

The risks identified with the project prior to the implementation of any risk management measures are rated in Table 5-5. Overall the risk levels extend from low to medium.

The risk of dewatering at cuts is rated medium, mostly due to its ‘almost certain’ likelihood. The consequences were rated ‘minor’ due to the presence of the risk only to the northern portion of the project and the outcome of the impact assessment demonstrating that the risk of dewatering has no impact on groundwater users and groundwater values (GDEs) (Section 5.2). The dewatering is expected to trigger the NSW Aquifer interference Policy and the associated need for an Aquifer Interference Licence. This is discussed further in Section 6.2

Risks to GDEs and environmental sensitive areas either from groundwater flow changes due to dewatering at cuts or from groundwater flow changes due to soil treatments at fill areas is rated as medium. Although the likelihood rated low the consequences rated severe.

Risk of impact to groundwater users was rated low.

Table 5-5 Risk assessment to groundwater for the project (before risk management)

Risk	Consequence	Impact assessment outcome (Section 5.2)	Likelihood	Risk rating
Impact to GDEs and environmentally sensitive areas from groundwater flow changes due to dewatering at cuts	Major	No impact on GDEs and groundwater flow predicted from dewatering at cuts	Rare	Low
Impact to GDEs and environmentally sensitive areas from groundwater flow changes due to soil treatments at fill areas	Major	Fill 6 and 7 sections are most at risk of having an impact. Soil treatments only to affect the Quaternary Alluvium. Groundwater flow parallel to areas of soil treatment, not expected to be affected by the project	Rare	Low
Groundwater dewatering	Minor	Estimated at 27 m^3/day over three sections of a total 790 m	Almost certain	Medium
Groundwater contamination	Major	Potential impact prior to the implementation of management measures defined in the design	Unlikely	Medium
Impact to groundwater users	Major	Groundwater users not subject to impact	Rare	Low

6 MITIGATION OF IMPACTS

Risks rated low in the risk assessment (Section 5, Table 5-5) are considered insignificant and unlikely to result in any impact, and therefore do not require management and mitigation. Risks rated medium in Table 5-5 have a potential to impact groundwater and can be managed through mitigation. This section defines the environmental mitigation and management measures which have been selected to address the medium rated risks to groundwater.

Two risks are rated as medium, having potential to result in impacts on groundwater:

- Risk of groundwater contamination
- Risk of groundwater dewatering near some of the cuts.

Sections 6.1 and 6.2 provide the management measures selected to manage these risks.

Section 6.3 provides a summary discussion with regard to the potential for the project to GDEs.

Section 6.4 details the recommended approach to groundwater monitoring to confirm no impact or to trigger management action where unexpected impacts arise.

6.1 SURFACE AND GROUNDWATER QUALITY MANAGEMENT

Construction phase

Risk to surface and groundwater quality is managed through a number of measures integrated in the road design. During construction, impacts to groundwater quality will be managed through the implementation of a Soil and Water Management Plan prepared under the Construction Environmental Management Plan. The size, location and number of temporary sedimentation basins and spill containment basins to treat site runoff during construction would be confirmed during detailed design. The detailed design process would consider the site constraints (such as topography and ecology), land take, and proximity to receiving waters and / or sensitive receiving waters.

Operational phase

The operational phase of the project includes a number of water quality devices to treat stormwater runoff from the road surface. The devices include:

- Grassed swales
- Water quality basins
- Longitudinal water quality basins
- Spill containment structures.

The design of the water quality treatment strategy is described in Chapter 5 of the EIS, including the features (water quality basins and spill containment) and their indicative locations. As discussed in Chapter 5 of the EIS, the current road network provides minimal treatment of stormwater runoff from the road. Treatment is confined to grass verges and open drains that function as swales. The project water quality treatment strategy would represent an improvement over the existing condition, which would reduce the net stormwater impacts on the receiving waterbodies, including groundwater.

Areas of potential environmental concern with respect to contamination are identified in the main EIS. The risks posed by work in these areas would be evaluated and managed through a Phase 2 Assessment including:

- A review of historical information
- Targeted sampling and analysis of samples at the areas of potential environmental concern.

In the event the Phase 2 Assessment identifies any areas of contamination that are to be impacted by the project, the Construction Environmental Management Plan will include a strategy to manage these areas.

6.2 DEWATERING

Dewatering from road cuts will not impact environmental values. However, it will remove groundwater flow from the consolidated rock aquifer and as such would be classified as an activity interfering with an aquifer (triggering the NSW Aquifer Interference Policy (Department of Primary Industries NSW Office of Water, 2012) and the need for an Aquifer Interference Licence. Similarly, the temporary short term dewatering and direct reinfiltrating of the alluvium aquifer where wick drains are designed may also trigger the NSW Aquifer Interference Policy (Department of Primary Industries NSW Office of Water, 2012) and the need for an Aquifer Interference Licence.

During consultation, the Office of Water advised that, subject to interim arrangements, Roads and Maritime are exempt from the need to obtain an Aquifer Interference Licence under the provisions of the Water Management (General) Regulation 2011.

During consultation for the project, the NSW Office of Water recommended that inflow water at cuts be managed through either sealing, or drainage and re-infiltration back to the groundwater system (Section 3.2.1). The project approach is generally to adopt a combined engineering and environmental management measure and therefore the preference is not to seal cuts but to re-infiltrate water into the groundwater system down gradient of the road cuts.

6.3 MANAGEMENT OF GDES

No specific measures are required for the Macquarie Rivulet estuary GDE due to its remote location from the project. Those GDEs that are in closer proximity to the project and therefore have some risk are the small SEPP14 freshwater wetland directly east of the project and the deep rooted GDEs associated with the Illawarra Coastal Grassy Woodland EEC at Croom Reserve.

There is no predicted impact on the consolidated rock aquifer near the Croom Reserve (Section 5.2.4), and as such no impacts on the EEC are anticipated. No management measures are required for this GDE.

At the small SEPP14 freshwater wetland located on Frazers Creek, the extent to which the wetlands is reliant on groundwater is unknown at this stage. The groundwater flow in the alluvium aquifer is however not expected to be impacted by the project (Section 5.2.4). The groundwater flow in the consolidated rock formation would remain unchanged. As such no impacts on the SEPP14 wetlands are anticipated, and specific management measures are not required.

6.4 GROUNDWATER MONITORING

To demonstrate there are no adverse impacts to environmental values located close to the route, targeted groundwater monitoring will be implemented at least twelve months prior to the construction works (to establish baseline conditions) and then through the construction phase and into the operational phase. The need for monitoring should be reviewed eighteen months after the road opening, and any decision to cease monitoring would be undertaken in consultation with a suitably qualified third party expert.

Groundwater monitoring will target the following areas to confirm the conclusions of the impact assessment:

- Effects of Fill 6 and Fill 7 on the SEPP14 wetland along Frazers Creek (identified as part of this assessment to have no impact)
- Effects of dewatering at Cut 1 (the deep cut) (identified as part of this assessment to be a low risk)
- Effects of the project on groundwater level and quality supporting the Illawarra Coastal Grassy Woodland EEC at Croom Reserve (identified as part of this assessment to have no impact).

Four groundwater monitoring locations are recommended (Figure 6-1). The rationale is provided in Table 6-1. The locations are indicative and are able to be moved to accommodate for land access and other logistical matters.

Water level monitoring would be automated and measured on a daily basis. Manual water level monitoring is recommended every six months (minimum) to coincide with data download and maintenance of the automated water level loggers. Prior to construction, water quality should be monitored on a six-monthly basis to establish a baseline. The water quality should as a minimum include the analytes listed in Table 6-2

Table 6-1 Recommended groundwater monitoring

Groundwater monitoring location	Rationale	Target formation
GW01, Croom Reserve	Monitoring of potential impact to deep flow sustaining the deep rooted groundwater dependant ecosystem at Croom Reserve	Consolidated rock aquifer
GW02, south west of the SEPP14 wetland along Frazers Creek	Monitoring of potential impact from alluvium compaction at Fill 7 on alluvium aquifer flow potentially affecting the SEPP 14 wetland	Alluvium aquifer
GW03, between Fill 6 and the freshwater wetland to the south-east	Monitoring of potential impact from alluvium compaction at Fill 6 on alluvium aquifer flow potentially affecting the freshwater wetland	Alluvium aquifer
GW04, directly east of the main cut (Cut 1)	Monitoring of pressure of drawdown due to the dewatering at the main cut	Consolidated rock aquifer

Table 6-2 Groundwater monitoring suite of analytes

Analytical suite	Parameters
Physical parameters (field)	pH, electrical conductivity, temperature
Physical parameters (laboratory)	pH, electrical conductivity, temperature, total dissolved solids
Analytes (laboratory)	Major ions: sodium, potassium, calcium, magnesium, sulphate, chloride, carbonates, bicarbonates TPH (total petroleum hydrocarbons), BTEX (benzene, toluene, ethyl benzene, xylene)

LEGEND

- Site Project Boundary
- Recommended Groundwater Monitoring Bore Locations
- Cut
- Fill
- Railway
- Major Watercourses
- SEPP14 Wetlands
- Croom Voluntary Conservation Area

FIGURE 6-14

1:35,000 @ A4

0 180 360 720
Metres

FIGURE 6-1 RECOMMENDED GROUNDWATER MONITORING

GROUNDWATER TECHNICAL PAPER
ALBION PARK RAIL BYPASS
NSW ROADS AND MARITIME SERVICES

COORDINATE SYSTEM:
GDA 1994 MGA ZONE 56

REVISION NUMBER: 01
AUTHOR: RNB

DATE: AUGUST 7, 2015

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6.5 RESIDUAL RISK

After risk management for the identified impacts, the residual risk to groundwater and groundwater values associated with the project is low (Table 6-3).

Table 6-3 Residual Risk Level (After Risk Management)

Risk	Management measures	Risk rating	
		Before management	After management
Impact to GDEs and environmentally sensitive areas from groundwater flow changes due to dewatering at cuts	Groundwater monitoring	Low	Low
Impact to GDEs and environmentally sensitive areas from groundwater flow changes soil treatments at fill areas	Groundwater monitoring	Low	Low
Groundwater dewatering	Groundwater monitoring	Medium	Low
Groundwater contamination	Water quality measures included in the road design	Medium	Low
Impact to groundwater users	Not required (groundwater bores not subject to impact – refer to Section 5.2.5)	Low	Low

7 ASSESSMENT LIMITATIONS

There are some key limitations with the assessment associated with the available groundwater datasets. These are as follows:

- No regional groundwater characterisation has previously been developed for the Albion Park floodplain area and surrounding foothills
- The development of the hydrogeological conceptual model relies strongly on data from the Pinneena database. Although a quality control approach was used when using this data in the assessment, data such as bore yields cannot be readily checked. In terms of water levels, the values are spread over a number of years. As groundwater is not used as a major water supply, it was judged that the data has probably not changed considerably to affect the result of the assessment. In addition, water level data seem to fit with the more recent water level datasets, those ones being located along the route
- Nevertheless, this groundwater impact assessment has been developed using a robust approach and sufficient information was available to assess the level of risk to groundwater and groundwater environmental values.

8 CONCLUSION

The hydrogeology of the study area consists of two aquifers, a quaternary unconfined unconsolidated alluvium aquifer and a deeper unconfined to semi-confined consolidated rock aquifer. The alluvium aquifer is confined to the location of the quaternary deposits. The thickness and hydraulic properties of this aquifer are highly variable depending on the nature and environment of the deposits. This aquifer is generally low yielding.

The second aquifer is the consolidated rock aquifer composed of shale, sandstone or latites and tuffs of Permian age. This aquifer is found underneath the quaternary alluvium aquifer (where present). It is unconfined to semi-confined. The consolidated rock aquifer is the main source of groundwater supply for local groundwater users.

The perceived risks and impacts associated with the project are:

- Risk of dewatering at road cuts impacting on groundwater systems, groundwater users and groundwater dependant ecosystems
- Risk of groundwater flow changes at geotechnical soil treatment locations impacting on groundwater systems, groundwater users and groundwater dependant ecosystems
- Risk on groundwater quality impacting negatively the water resources.

The level of impact was assessed through qualification or quantification of the impact as appropriate based on the available information. Through a risk analysis exercise, the maximum level of risk before management measured was rated “medium” and associated to inflow of groundwater at cuts and potential groundwater contamination. The risk to GDEs and environmental sensitive areas has been assessed as low. The residual risk was reduced to “low” in consideration of the management measures implemented through the road design and groundwater monitoring.

To summarise:

- The impact assessment has identified that although some dewatering due to road cuts was unavoidable on the northern section of the road extension, this would not impact groundwater users or GDEs
- Similarly, impact on groundwater flow from the soil treatments are not expected to impact environmental values and groundwater users
- The aquifers are interpreted to support (possibly with surface water) the Macquarie Rivulet GDE (a unique GDE identified as high priority in the NSW regulation), located at the estuary of the Macquarie Rivulet on Illawarra Lake. A SEPP14 freshwater wetland is also identified in that area. The Macquarie Rivulet estuary GDE and SEPP14 wetland would not be impacted by the project. Other groundwater dependant ecosystems such as the deep rooted vegetation from the grassy woodland ecological communities would not be impacted by the project.
- The remaining risk to manage is the risk of contamination to groundwater from spills and runoff water. This risk is addressed through a series of measures in the road design ranging from requirement for spill kits to water flow controls with different types of water basins and a soil and water management plan during construction.

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