DESIGN PACKAGE REPORT

Hydrogeology Report

Project:	The New M5 Design and Construct
Contract Number:	15.7105.1373
Document Number:	M5N-GOL-DRT-100-200-GT-1526-0

Document Approval

Rev.	Date	Prepared by	Reviewed by	Approved by	Remarks
0	2/5/2017				

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1 Introduction

The WestConnex Stage 2 New M5 (WCX2) Project Corridor is located towards the south of the Sydney CBD. The western extent of the WCX2 Project Corridor integrates with the existing M5 motorway near King Georges Road extending east along the general alignment of the existing M5 East motorway. The new works integrate with existing works above ground through Kingsgrove, then extend east as tunnels under Earlwood, Bardwell Park, Bardwell Valley and Arncliffe. The Project Corridor then extends northeast under the Cooks River and Tempe before emerging at the Eastern Portal at St Peters.

1.1 Description of Report

The primary purpose of this Hydrogeology Report is to demonstrate that the WCX2 twin tunnel and associated underground structures are designed and can be constructed to comply with project and approval requirements relating to groundwater capture, drawdown and quality.

Key underground structures of the WXC2 project considered in the Hydrogeology Report include:

- Drained twin tunnels with each tunnel tube of about 17 metres (m) width for sections of the tunnels containing two lanes, and the tunnel crown at 8 m above the road level.
- The Western Portal along the existing M5 East motorway that is located near King Georges Road, and the eastern portal at St Peters that would be located within the Alexandria Landfill area.
- Cross passages that are generally located approximately every 120 m along the mainline tunnel alignments.
- Two (2) caverns, the crown of which is 12 m above the design level (transitions to around 8 m which is the height of the mainline tunnels) and a maximum cavern width of above 28 m.
- A construction decline connecting to the westbound mainline tunnel at Arncliffe, excavated as a sheetpile supported trough structure followed by a mined tunnel.
- Two (2) vent shafts (diameter to be confirmed) and five (5) access shafts with footprints of 14 m by 8 m, 12 and 20 m diameters, excavated to crown of tunnel.
- Smoke / vent extraction tunnels interconnecting a shaft with the twin tunnel.

The following design items have not been covered in this report:

- Landfill closure works;
- Demolition works;
- Temporary works; and
- Environmental management plans.

1.2 Not used

1.3 Not used

1.4 Definitions and Abbreviations

The key technical terms and abbreviations used through this report are defined in Table 1 and Table 2, respectively.

Table 1: Definitions

Term	Description
The Contractor	CPB Dragados Samsung Joint Venture
Project Company	WCX M5 Pty Limited
Golder	Golder Associates Pty Ltd
Project Corridor	For the purposes of this design report, the Project Corridor is defined by the alignment of the project with a buffer of one kilometer.

Table 2: Abbreviations

Abbreviation	Description
AHD	Australian Height Datum
AJJV	Aurecon Jacobs Joint Venture
bgl	Below ground level
BoM	Australian Bureau of Meteorology
BSGS	Botany Sands Groundwater Source
BSMZ1	Botany Sand Management Zone 1
BSCM2	Botany Sand Management Zone 2
CDS	CPB Dragados Samsung Joint Venture
CH	Chainage
CoA	Conditions of Approval
DCD	Developed Concept Design
CRD	Cumulative Rainfall Deficit
EB	Eastbound
EIS	Environmental Impact Statement
FD	Final design
GBR	Groundwater Baseline Report
GDR	Geotechnical Data Report
GSSA	Groundwater and Soil Salinity Assessment
IFC	Issued for Construction
K	Hydraulic conductivity
K_h	Horizontal hydraulic conductivity
K_v	Vertical hydraulic conductivity

Abbreviation	Description
km	Kilometre
m	Metre
LRU	Local Roads Upgrade
Lugeon	Unit of permability, 1 Lugeon is equivalent to 1×10^{-7} m/s
M5E	M5 East
MGA	Map Grid of Australia
mm	Millimeters
m/s	Metres per second
NGIS	National Geographic Information System
O&M	Operations & Maintenance
SCBGS	Sydney Central Basin Groundwater Source
S_s	Specific storage
S_y	Specific yield
SDD	Substantial Detailed Design
SPI	St Peters Interchange
STP	Sewage Treatment Plant
SWOOS	South Western Suburbs Ocean Outfall Sewer
SWSOOS	South Western Suburbs Ocean Outfall Sewer
SWTC	Scope of Work and Technical Criteria
WCX2	WestConnex Stage 2 The New M5
WSP	Water Sharing Plan

2 Design Development

2.1 Design Criteria

The design criteria for tunnel inflow limits of groundwater and the requirement to protect groundwater resources are outlined in Appendices B.3, E.5 and E.9 of the SWTC and the Clause B26 and B27 of the Conditions of Approval (CoA) dated April 2016. A summary of the conditions is provided in Table 3.

It is noted that the SWTC and B26 provide conflicting inflow limits to the tunnels and the underground structures. This is discussed further in Section 4.3, with reference to the predicted inflow rates.

Table 3: Groundwater specific design criteria and conditions that apply to the WCX2 Project

Document	Clause	Conditions	Addressed in this report
SWTC – Appendix E.9	Water Act 1912, S105, S112, S116D, S121A	*Obligation: Obtain a licence where interference with groundwater is likely to occur. Note that a licence is required if groundwater is to be used for any purpose. Inclusion in EMS/action required: Note that this Act is being progressively repealed by the Water Management Act 2000 and does not apply to areas of the state where water sharing plans are in place.* *Groundwater and surface water within and near the project are covered by the following Water Sharing Plans:* *Groundwater Metropolitan Region Groundwater Sources and the Greater Metropolitan Region Unregulated River Water Sources*	
SWTC – Appendix E.5	T320	*1.1.Application and Scope* *Groundwater Control shall include all work necessary to control groundwater, in order to:* *…* *(d) Limit volumes of water to be collected, channelled and conveyed to pump stations in the tunnels, such that the drainage design capacity is not exceeded.* *(e) Limit effects on natural waterways above the tunnels due to groundwater drawdown.* *3.4 Limiting Impacts on Groundwater Drawdown* *The Superintendent shall use all relevant information gathered before and during construction to determine methods necessary to limit the impact of groundwater drawdown so as to prevent or mitigate significant adverse effects on the natural or made environment.*	*Section 3.1.2* *Section 3.1.3*
SWTC – Appendix B.3		*1.3.1 Groundwater Limits* *a) The Project Company's Work and O&M Work must cause no groundwater contamination.* *b) Permanent dewatering is not permitted, except for dewatering that naturally occurs as a result of accommodating the groundwater ingress limits identified in this section and which has no adverse environmental impact.* *c) The Project Company must ensure that the maximum allowable groundwater ingress into any tunnel (including tunnel approaches and exits and ventilation tunnels) must not exceed;* *…* *ii) For Drained tunnels;* *A. 1 litre per second per kilometre of tunnel.* *iii) For Equipment and Plant Rooms* *A. 0.01 litres per square metre per day.*	*Section 3.1.2*

Document	Clause	Conditions	Addressed in this report
		Any groundwater introduced to the tunnel by associated underground structures, including but not limited to shafts, adits, emergency egress passages (and cross passages), vehicle cross passages and plant and equipment rooms must be considered as part of the tunnels total groundwater ingress. *…* *g) Notwithstanding compliance with the SWTC and the Environmental Documents, the effect of the Project Company's Work on the groundwater regime must be limited such that there is minimal adverse effect on the natural environment or existing infrastructure.*	*Section 3.1.2*
CoA (April 2016)	B26	*The Proponent must take all feasible and reasonable measures to limit operational groundwater inflows into each tunnel to no greater than one litre per second across any given kilometre.*	*Section 3.1.2*
CoA (April 2016)	B27	*The Proponent must undertake further modelling of groundwater drawdown, tunnel inflows and saline water migration prior to finalising the design of the tunnel and undertaking any works that would impact on groundwater flows or levels.* *The modelling must be undertaken in consultation with DPI (Water) and include the results of at least 12 months of current baseline groundwater monitoring data.* *The results of the modelling must be documented in a Groundwater Modelling Report.* *The Groundwater Modelling Report must be finalised in accordance with the Australian Groundwater Modelling Guidelines (National Water Commission, 2012) and prepared in consultation with DPI (Water).* *The Groundwater Modelling Report must include, but not be limited to:* *(a) justification for layer choice;* *(b) specification of matrix hydraulic and storage parameters for each layer;* *(c) statistical evaluation of the model's calibration;* *(d) details of the groundwater monitoring data inputs (levels and quality);* *(e) details of the proposed groundwater model update and validation as additional data is collected'* *(Ð assessment of impacts of groundwater drawdown, taking into consideration the NSW Aquifer Interference Policy (DPI, 2012), including potential impacts on licensed bores and groundwater dependent ecosystems;* *(g) a comparison of the results with the modelling results detailed in the document referred to in condition A2(b); and* *(h) documentation of any additional measures that would be implemented to manage and/or mitigate groundwater impacts not previously identified or identified but at a smaller scale.* *A copy of the Groundwater Modelling Report must be submitted to the Secretary prior to finalising the tunnel design.* *The Groundwater Modelling Report must include details of consultation with DPI (Water).* *The groundwater model must be updated once 24 months of groundwater monitoring data are available and the results of the modelling provided to the Secretary and DPI (Water) in an updated Groundwater Modelling Report.*	*This report* *Section 2.3* *Sections 2.2.6 and 2.3.4* *Sections 2.2.13 and 2.3.4* *Sections 2.3.4 and 2.3.5, Annexure O* *Sections 2.2.10, 2.2.11, 2.2.14 and 2.2.15, Annexures F, G, H and M* *Section 4.6* *Sections 3.1.3* *Sections 3.1.2 and 3.1.3* *Sections 3.1.2 and 3.1.3* *Section 4.6*

2.2 Design Inputs

The following sections provide a summary of geological and hydrogeological information for the general Project Corridor and for the domain of the hydrogeological model. The Project alignment and key locations are illustrated in Figure 2.1.

2.2.1 Climate

According to the Australian Bureau of Meteorology (BoM, 2006), the Sydney area generally experiences a temperate climate with warm summers and cold winters. The average annual temperature is approximately 22 degree Celsius with temperatures ranging from 9 degrees Celsius (lowest daily) in winter to 46 degrees Celsius (highest daily) in summer. Current BoM rainfall gauges that have been reviewed near the groundwater model boundary are located at the following weather stations:

- Bankstown Airport AWS (Station Number 066137, 9.6 km northwest of Kingsgrove);
- Marrickville Golf Course (Station Number 066036, 3.7 km west of St Peters);
- Peakhurst Golf Club (Station Number 066148, 4.0 km southwest of Kingsgrove);
- Sans Souci – Public School (Station Number 066058, 6.2 km south-southwest of Arncliffe);
- Strathfield Golf Club (Station Number 066070, 6.2 km northwest of Kingsgrove); and
- Sydney Airport AMO (Station Number 066037, 3.0 km south of St Peters).

A comparison of annual rainfall at each station is shown in Figure 2.2 and summarised in Table 4. The weather stations have mean annual rainfalls between 1014.4 millimetres (mm) and 1256.8 mm, with rainfall decreasing inland west of Botany Bay (Figure 2.3).

LEGEND

- WCX2 Alignment
- Waterline

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CLIENT
CPB DRAGADOS SAMSUNG JV

PROJECT
WESTCONNEX STAGE 2 NEW M5 MOTORWAY

0	500	1,000	1,500	2,000	2,500	3,000	3,500	4,000

METRES

REFERENCE SCALE: 1:50,000 (at A3)

PROJECTION: GDA 1994 MGA Zone 56

TITLE
OVERVIEW OF PROJECT ALIGNMENT AND KEY LOCATIONS

CPB CONTRACTORS | DRAGADOS | SAMSUNG C&T
WestConnex Stage 2 M5
Golder Associates

YYYY-MM-DD	2016-10-28
PREPARED	HSG
DESIGN	HSG
REVIEW	--
APPROVED	

PROJECT No.	CONTROL	Rev.	FIGURE
1524285	001	A	2.1

Path: J:\Hyd\2015\Sydney\WCX Brisbane Working Folder\GIS\Project\Hydrogeological Design Maps\Figure 2_1 Project Corridor Overview.mxd

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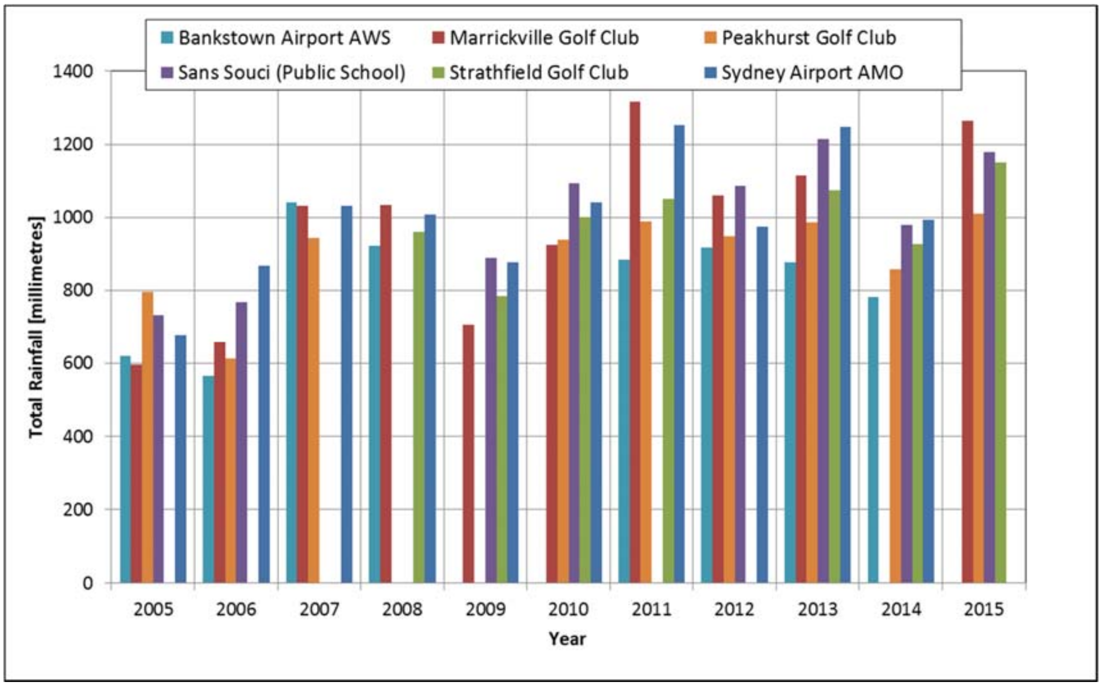


Figure 2.2: Historical total annual rainfall data between 2005 and 2015. Source: Bureau of Meteorology (2016).

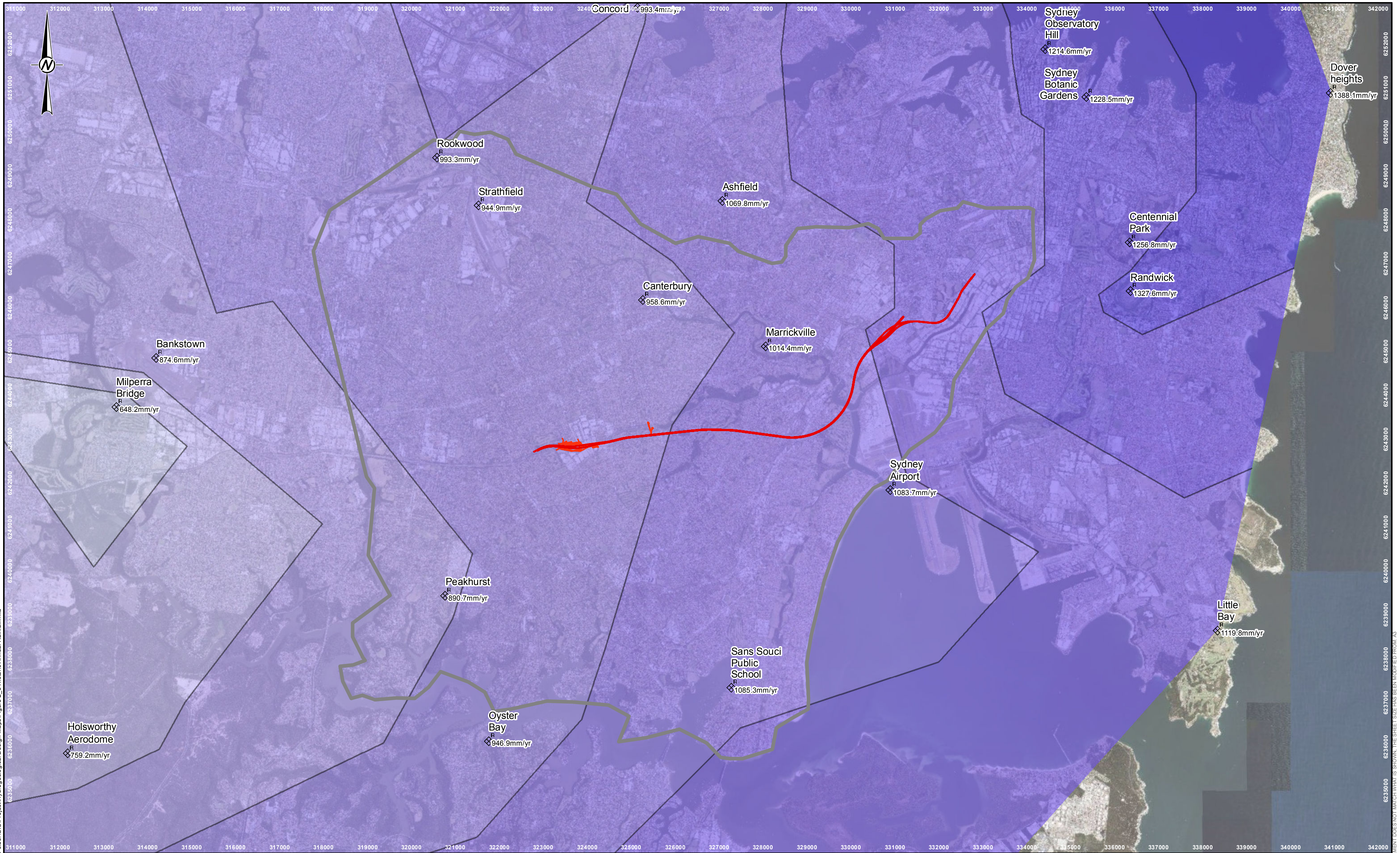
Table 4: Annual total rainfall data (mm) between 2005 and 2015. Source: Bureau of Meteorology (2016).

Station	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Bankstown Airport AWS	621	567	1040	921	null	null	885	917	877	782	null
Marrickville Golf Club	596	658	1032	1033	705	925	1317	1060	1115	null	1265
Peakhurst Golf Club	795	613	943	null	null	938	988	948	986	859	1009
Sans Souci – Public School	731	767	null	null	888	1093	null	1085	1215	979	1179
Strathfield Golf Club	null	null	null	961	785	1000	1051	null	1074	927	1151
Sydney Airport AMO	678	867	1032	1009	877	1040	1251	973	1248	993	null

Note: Total annual rainfalls are not shown for years with recording gap and in these cases a "null" is assigned to the record year instead of a value.

Mean monthly rainfall data for all six stations is shown in Figure 2.4 and summarised in Table 5.

Seasonal changes are a factor in the distribution of annual rainfall at the stations, with the five wettest months of the year (February to June inclusive) account around 50% of total annual rainfall. Over the remaining seasons, the rainfall is spread more evenly with minimum totals generally being recorded during the month of September.



LEGEND

Weather Station (946.9 mm/yr)

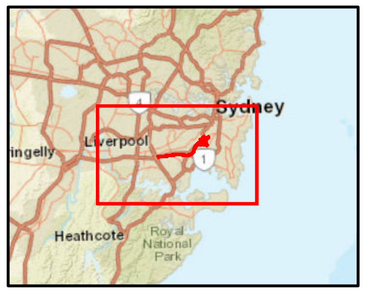
Groundwater Model Boundary

WCX2 Alignment

Average Annual Rainfall (mm)

1500 - 1600	1000 - 1100
1400 - 1500	900 - 1000
1300 - 1400	800 - 900
1200 - 1300	700 - 800
1100 - 1200	600 - 700

Service Layer Credits: © Land and Property Information 2015



CLIENT
CPB DRAGADOS SAMSUNG JV

PROJECT
WESTCONNEX STAGE 2 NEW M5 MOTORWAY

0 1,000 2,000 3,000 4,000 5,000 METRES

REFERENCE SCALE: 1:80,000 (at A3)

PROJECTION: GDA 1994 MGA Zone 56

TITLE
AVERAGE ANNUAL RAINFALL IN THE PROJECT CORRIDOR AND THE SYDNEY AREA

YYYY-MM-DD	2016-10-28
PREPARED	HSG
DESIGN	HSG
REVIEW	--
APPROVED	

PROJECT No.	CONTROL	Rev.	FIGURE
1524285	001	A	2.3

Path: J:\Hyd\2015\Sydney\WCX Brisbane Working Folder\GIS\Project\Hydrogeological Design Maps\Figure 2_3 Historic Annual Rainfall.mxd

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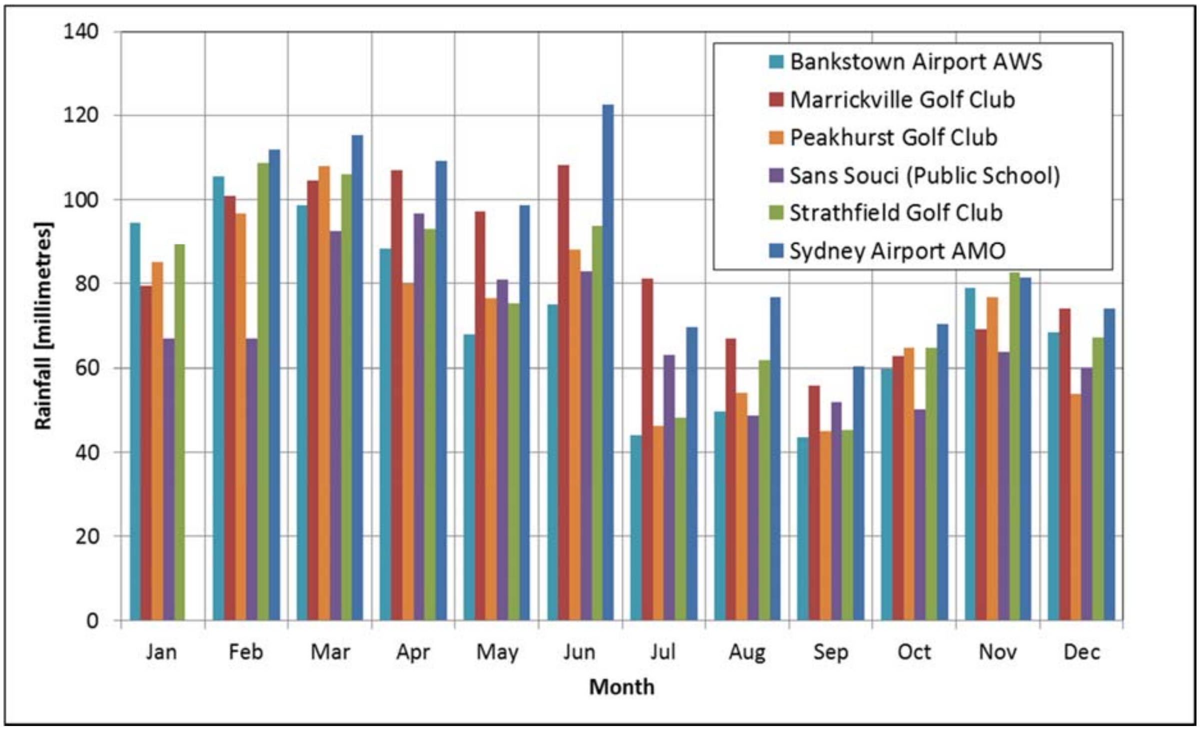


Figure 2.4: Long-term mean monthly rainfall rates between 2005 and 2015. Source: Bureau of Meteorology (2016).

Table 5: Long-term mean monthly rainfall rates (mm) between 2005 and 2015. Source: Bureau of Meteorology (2016).

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Bankstown Airport AWS	94.4	105.6	98.7	88.4	68	75	44.1	49.8	43.6	59.8	79	68.3
Marrickville Golf Club	79.4	100.8	104.7	107.1	97.1	108.2	81.3	67	55.9	62.8	69.2	74
Peakhurst Golf Club	85.3	96.7	108.0	79.9	76.5	88.1	46.3	54.2	45.0	64.7	76.7	53.9
Sans Souci – Public School	67	67	92.5	96.6	81	83	63	48.6	51.8	50.1	63.8	60
Strathfield Golf Club	89.2	108.8	106.1	93	75.2	93.7	48.2	61.8	45.3	64.6	82.6	67.2
Sydney Airport AMO	94.0	111.9	115.4	109.3	98.6	122.5	69.6	76.8	60.3	70.3	81.5	74

Note: BoM Station Bankstown Airport AWS, No. 066137, period of records from 1968 to 2015; BoM Station Marrickville Golf Course, No. 066036, period of records from 1904 to 2015; BoM Station Peakhurst Golf Club, No. 066147, period of records from 1969 to 2015; BoM Station Sans Souci Public School, No. 066058, period of records from 1899 to 2015; BoM Station Strathfield Golf Club, No.066070, period of records from 1952 to 2015; BoM Station Sydney Airport AMO, No. 066037, period of records from 1929 to 2015;

Annual rainfall records were used to calculate rainfall residuals and the Cumulative Rainfall Deficit (CRD), for the Sydney Airport Station (Figure 2.5). The CRD shows the long-term trends in rainfall patterns. A rising trend in slope in the CRD plot indicates periods of above average rainfall, whilst a declining slope indicates periods when rainfall is below average. CRD and groundwater level data are generally well correlated, with groundwater levels expected to rise during periods of rising CRD (regional scale groundwater recharge) while those recorded during periods of declining CRD expected to decline (drought conditions). The CRD graph shows a trend with a negative gradient after the start of 1999 up to the end of 2010, indicating the area had below-average rainfall during this period. Since the beginning of 2011 the graph shows relatively stable CRD, indicating average rainfall conditions.

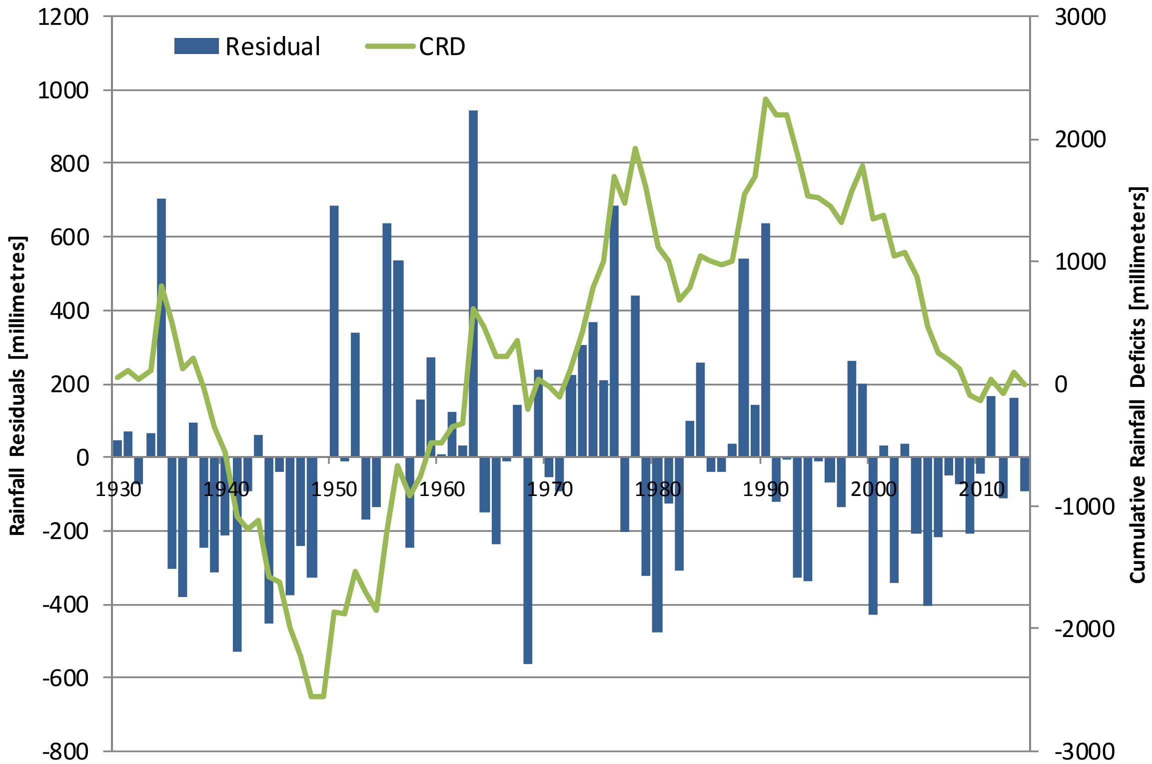


Figure 2.5: Annual residual rainfall and cumulative residual deficit (cumulative deviation from average) for BoM Sydney Airport station, record period between 1930 and 2014.

Evaporation climate data has been obtained for the Sydney Airport from the BoM database. This data indicates a mean annual evapotranspiration between 1729 mm and 2006 mm between 2005 and 2015 reported in Table 6. Evaporation typically exceeds average annual rainfall except in May where evaporation and rainfall are roughly equal and in June when rainfall exceeds evaporation as reported in Table 7 and shown on Figure 2.6.

Table 6: Annual total evaporation data (mm) between 2005 and 2015. Source: Bureau of Meteorology (2016).

Station	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Sydney Airport AMO	1846	1802	1830	1729	1977	1791	1827	1830	2006	1913	1854

Note: Total monthly evaporation are not shown for years with recording gap and in these cases a “null” is assigned to the record year instead of a value.

Table 7: Long-term mean monthly evaporation rates (mm) between 2005 and 2015. Source: Bureau of Meteorology (2016).

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Sydney Airport AMO	231.5	179.6	180.7	128.4	99.5	77.4	83.7	123.6	150.6	194.2	198.4	228.1

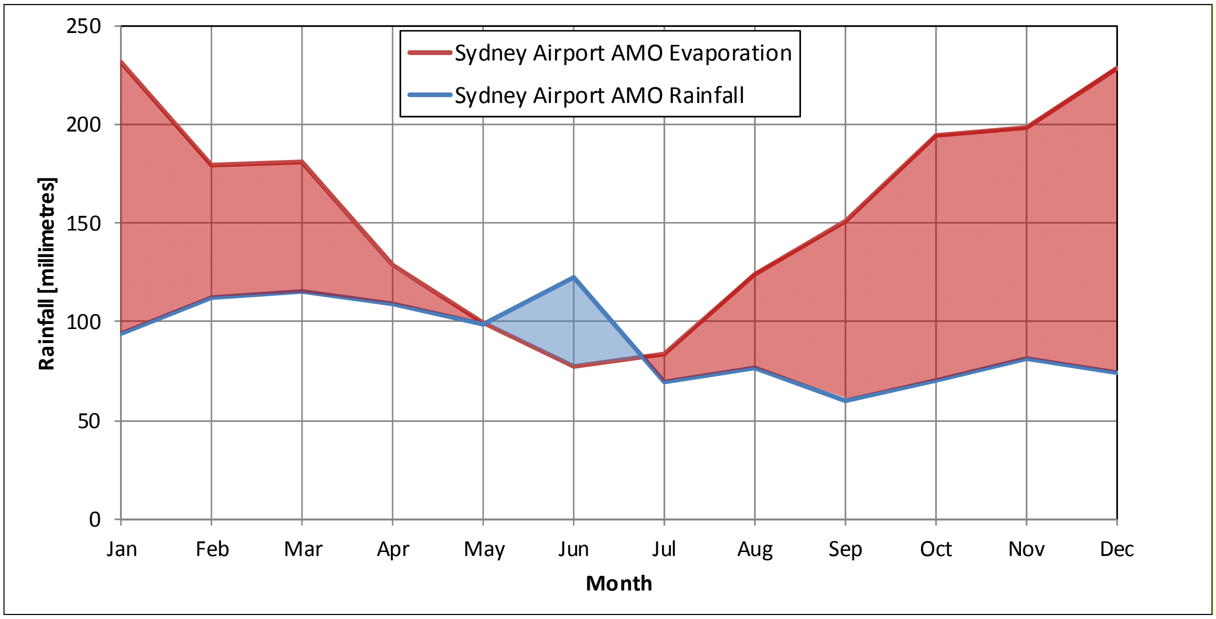


Figure 2.6: Average monthly evaporation and rainfall for BoM Sydney Airport station, record period between 2005 and 2015. Red area: evaporation surplus, blue area: rainfall surplus.

2.2.2 Topography

The topography in the project area is illustrated in Figure 2.7 based on LIDAR information at 5 m elevation contours.

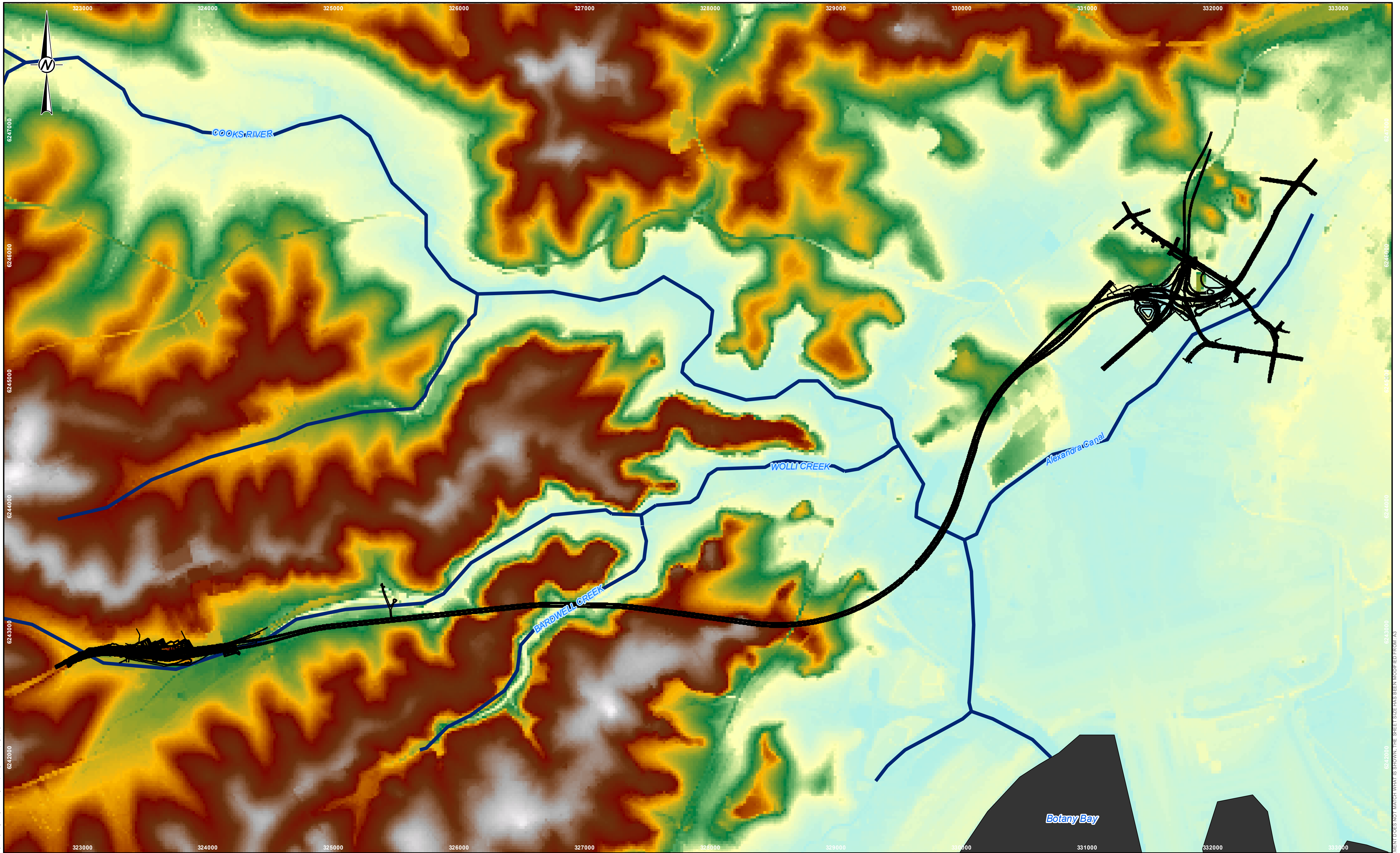
The topography of the area within the model boundary and the Project Corridor is undulating and comprised of a series of elevated ridges and relatively low lying broad valleys with gently inclined slopes. Locally steeper slopes with undulating to rolling rises and low hills occur in the middle, and toward the eastern end of the Project Corridor. The topography within the model boundary varies from approximately 0 m Australian Height Datum (AHD) to the south-east at Botany Bay to over 72 m AHD to the south-west.

2.2.3 Land Use

The Project Corridor is situated to the south of the Sydney CBD within a developed urban area to the north-west of the Sydney Airport. Along the existing M5 East Motorway, the current surface development is largely low density residential with some open parkland and leisure facilities. To the northeast from Cooks River toward St Peters and also around Kingsgrove the current land use and surface development along the Project Corridor is largely commercial and industrial with some low and medium-density residential housing above the Project Corridor. The Sydney Kingsford Smith Airport is located outside the Project Corridor to the south of Alexandra Canal and to the east of Cooks River. Land use classifications throughout the model domain are reported in Figure 2.8.

Existing major infrastructure within and adjacent to the Project Corridor includes:

- M5 East twin tunnels, along the western portion of the Project Corridor;
- New Southern Rail tunnel which crosses the Project Corridor northwest of the Sydney Airport;
- Surface railway lines for the Eastern Suburbs & Illawarra Line and the Airport, Inner West & South Line which run parallel to, and cross the tunnel alignment;
- Sewer mains follow existing rail lines and the Cooks River, converging near Wolli Creek/Turrella and direct waste water toward the Sewage Treatment Plant (STP) at Malabar; and
- The South Western Suburbs Ocean Outfall Sewer (SWSOOS, or SWOOS) which is a twin tunnel/culvert sewer crossing the Project Corridor near the Cooks River.



LEGEND

Waterline

WCX2 Alignment

Elevation (m AHD)

High : 60

Low : 0

Note: mAHD refers to metres Australian Height Datum

CLIENT
LEIGHTON DRAGADOS SAMSUNG JV

PROJECT
WEST CONNEX STAGE 2

0 500 1,000 1,500 2,000
METRES

PROJECTION: GDA 1994 MGA Zone 56

REFERENCE SCALE: 1:28,000 (at A3)

TITLE
TOPOGRAPHY ALONG PROJECT CORRIDOR

YYYY-MM-DD	2016-04-20
PREPARED	HSG
DESIGN	HSG
REVIEW	--
APPROVED	

PROJECT No.	CONTROL	Rev.	FIGURE
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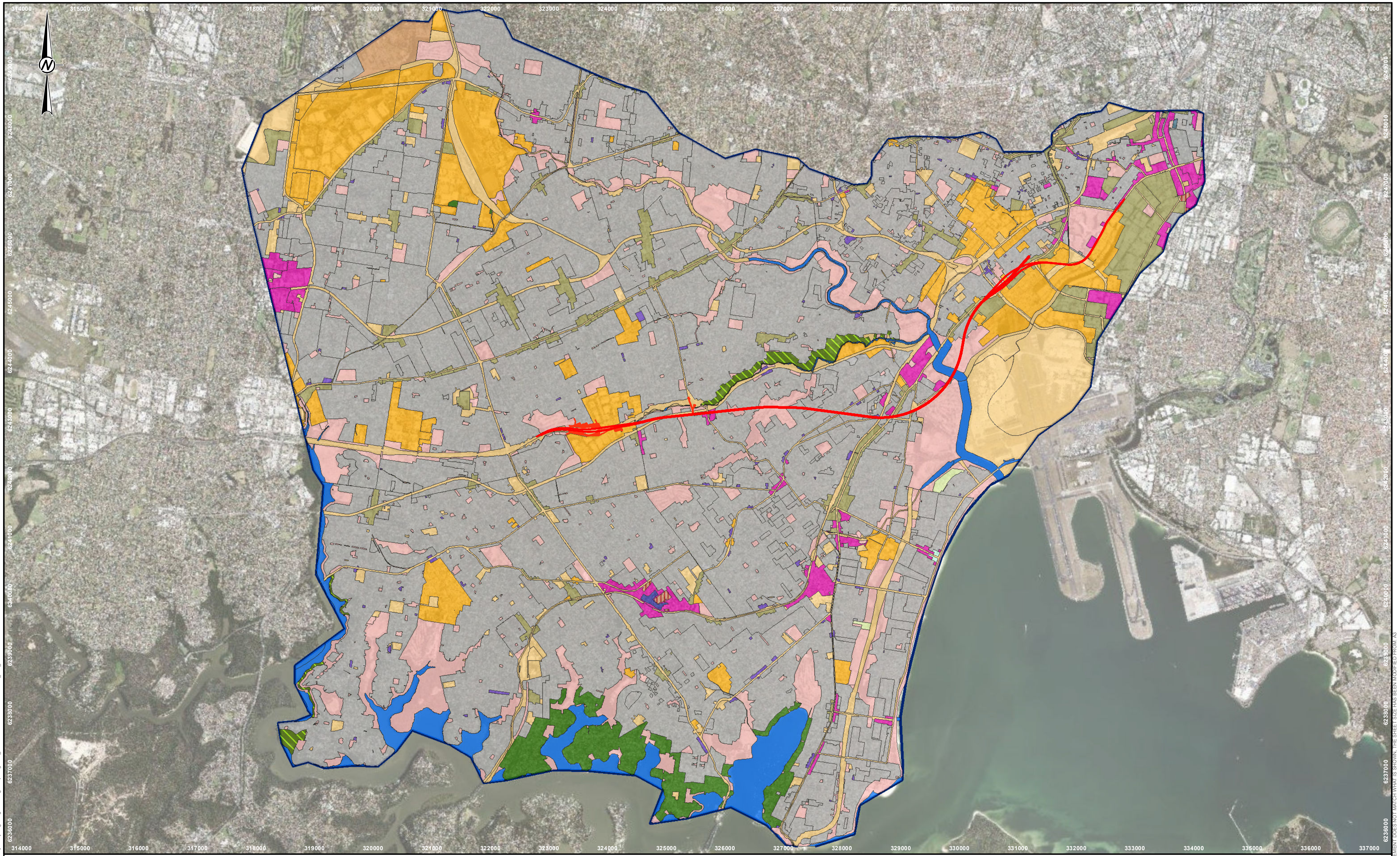

LEGEND

- Proposed Design
- Groundwater Model Outline

Land Use Classification

- Business
- Commercial Core
- Deferred Matter
- Environmental Conservation and Living
- Industrial
- Residential
- Infrastructure
- Mixed Use
- National Parks and Nature Reserves
- Waterways
- Neighbourhood Centre
- Primary Production Small Lots
- Recreation
- Cemetery
- Special Purposes Zone - Comminity
- Sydney LEP (GSTC 2) 2013
- Sydney LEP (GSTC 2) 2013 & CoS PSO
- Sydney LEP (GSTC 2) 2013 & SS LEP 114
- Sydney LEP (GSTC) 2013
- Tourist

CLIENT
LEIGHTON DRAGADOS SAMSUNG JV

PROJECT
WEST CONNEX STAGE 2

Reference(s):
NSW Department of Planning and Environment, 2006, Standard Instrument Local Environmental Plan (LEP)-Land Use Zoning (LZN), NSW Government, accessed March 2016.

0 1,000 2,000 3,000 4,000 5,000
METRES

PROJECTION: GDA 1994 MGA Zone 56 REFERENCE SCALE: 1:60,000 (at A3)

TITLE
HISTORICAL LAND USE ZONATION ACROSS THE MODEL DOMAIN

WestConnex STAGE 2 M5

YYYY-MM-DD	2016-10-28
PREPARED	HSG
DESIGN	HSG
REVIEW	--
APPROVED	

PROJECT No.	CONTROL	Rev.	FIGURE
1524285	001	A	**2.8**

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Path: J:\Hyd\2015\Sydney\WCX Brisbane Working Folder\GIS\Project\Hydrogeological Design Maps\Figure 2.8 Land Use Within Model Domain_Rev_C.mxd

2.2.4 Surface Water

The main catchments within the model boundary are the Cook's River, Parramatta River and Georges River catchments. The Project Corridor is located within the Cooks River catchment in south western Sydney, discharging to the Botany Bay at Mascot. The landscape and natural behaviour of the catchment have been impacted heavily by urbanisation and has little remaining natural bushland. Due to the development of impervious surface in urban areas, increased volumes of surface run off are anticipated.

The main surface water features in the corridor include the Cooks River and its tributaries, the Marsh Street and Eve Street wetlands and the Landing Lights Wetlands at Arncliffe. The following six waterways are in close proximity to the Project Corridor:

- Cooks River;
- Wolli Creek;
- Bardwell Creek;
- Alexandra Canal, which includes Shea's Creek;
- Eastern Channel; and
- Eve Street Wetlands.

Alexandra Canal (including Shea's Creek), part of the Eastern Channel (due to connectivity with the Cooks River) and the Cooks River are tidally influenced watercourses. Tidal influences in the Cooks River extend up to 10 kilometres (km) upstream. Tidal limits within Wolli Creek are reported to be at the confluence of Wolli Creek and Bardwell Creek (CRCAoC 1999).

An overview map of the Project Corridor and the surrounding area, including waterways with associated tributaries and sub-catchments are shown on Figure 2.9. This figure also illustrates locations where the natural waterways have been modified or remain natural, unmodified, which will impact surface water recharge to groundwater environments. Areas where the creek is lined with concrete or lined with sheet piles will reduced surface water connectivity to groundwater. Where the creek remains unmodified in its natural state, recharge to and/or discharge from groundwater over these section of the channel are inferred to remain un-impeded and will reflect natural conditions. For example, according to CRA (2014), Wolli Creek is lined with concrete from Bexley to Kingsgrove and is anticipated to have reduced recharge along this reach; whereas downstream from Bexley to the Cooks River, Wolli Creek is un-modified and surface water/groundwater interchange will reflect natural conditions. Discharge from the creeks and groundwater in the creeks/channels are controlled by topography and will flow under natural conditions to local waterways and the Botany Bay.

In accordance with the ANZECC Water Quality Guidelines (ANZECC, 2000) the Cooks River would be classified as a highly disturbed ecosystem. AECOM (2015a) states that "*the Cooks River catchment is regarded as one of the most polluted urban river catchments in Australia*".

LEGEND

- WCX2 Alignment
- Waterway
- Piped System
- Concrete Lined Channel
- Natural Creek
- Sheet Pile Lined Channel
- Sewer Main Network
- Cooks River Catchment
- Subcatchment Area

Service Layer Credits: © Land and Property Information 2015

CLIENT
CPB DRAGADOS SAMSUNG JV

PROJECT
WESTCONNEX STAGE 2 NEW M5 MOTORWAY

Reference(s):
Information regarding piped systems, concrete and sheet pile lined channels and natural creeks were digitized from CRA, 2014.

0 500 1,000 1,500 2,000 2,500 METRES

PROJECTION: GDA 1994 MGA Zone 56 REFERENCE SCALE: 1:50,000 (at A3)

TITLE
COOKS RIVER CATCHMENT AND WATERWAYS IN THE PROJECT CORRIDOR AND THE SYDNEY AREA

YYYY-MM-DD	2016-10-28
PREPARED	HSG
DESIGN	HSG
REVIEW	--
APPROVED	

PROJECT No.	CONTROL	Rev.	FIGURE
1524285	001	A	2.9

Path: J:\Hyd\2015\Sydney\WCX Brisbane Working Folder\GIS\Project\Hydrogeological Design Maps\Figure 2_9 Cooks River Catchment and Waterways.mxd

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2.2.5 Regional Geology

The project is located within the Sydney Basin. The bedrock geology along the tunnel alignment is comprised primarily of Ashfield Shale and the underlying Hawkesbury Sandstone. Regional geology including regional geological features (both faulting and dykes) is presented in Figure 2.10. Refer to the Geotechnical Interpretive Report (MSN-GOL-TER-100-200-GT-1505) for details.

The stratigraphic relationship between the geological units encountered within the model domain and the Project Corridor are summarised in Table 8.

Table 8: Regional stratigraphy

Age	Stratigraphic Unit		Description
Quaternary	Anthropogenic Fill		Waste, emplaced material and engineered fill
Quaternary	Botany Sand Beds		Holocene aeolian sand and clay
	Undifferentiated estuarine and alluvial sediments		Holocene and Pleistocene age interbedded sands and clays with discontinuous, "inter-fingered" lenses of sand and clay.
	Marine sediments		Pleistocene age primarily clayey sediments with intermittent sand lenses
Jurassic	Volcanic Intrusion		Dykes
Mid-Triassic	Wianamatta Group	Ashfield Shale	Mulgoa Laminite Regentville Siltstone Kellyville Laminite Rouse Hill Siltstone
Mid-Triassic	Mittagong Formation		Mittagong A – Fine grained sandstone Mittagong B – Inter-bedded sandstone / siltstone
Mid-Triassic	Hawkesbury Sandstone		Massive Facies Cross-Bed Facies Siltstone Facies

The Triassic age Hawkesbury Sandstone forms a basement for the younger units within the Project Corridor. The Hawkesbury Sandstone is typically comprised of fine to coarse grained quartz sandstone with very minor shale and laminite lenses. The shale interbeds can form a barrier to vertical groundwater movement. Hawkesbury Sandstone is exposed near the surface and commonly occurs as cliff lines and outcrop along water courses. Hawkesbury Sandstone underlies the topographic lows associated with the Wolli Creek and Cooks River infilled channels. Elsewhere, it is generally separated from the Ashfield Shale units by a band of interbedded sandstone and siltstone known as the Mittagong Formation.

The Ashfield Shale capping has a pervasive mantle of residual clay soil as part of the transitional weathering profile above the bedrock. Colluvial soils are likely to occur on the slopes to the Wolli Creek and Cooks River.

Quaternary alluvial and estuarine sediments within the project area are associated with current and ancient water courses. In the Sydney area, deep incised palaeochannels were formed during the Pleistocene and were carved into the Hawkesbury Sandstone.

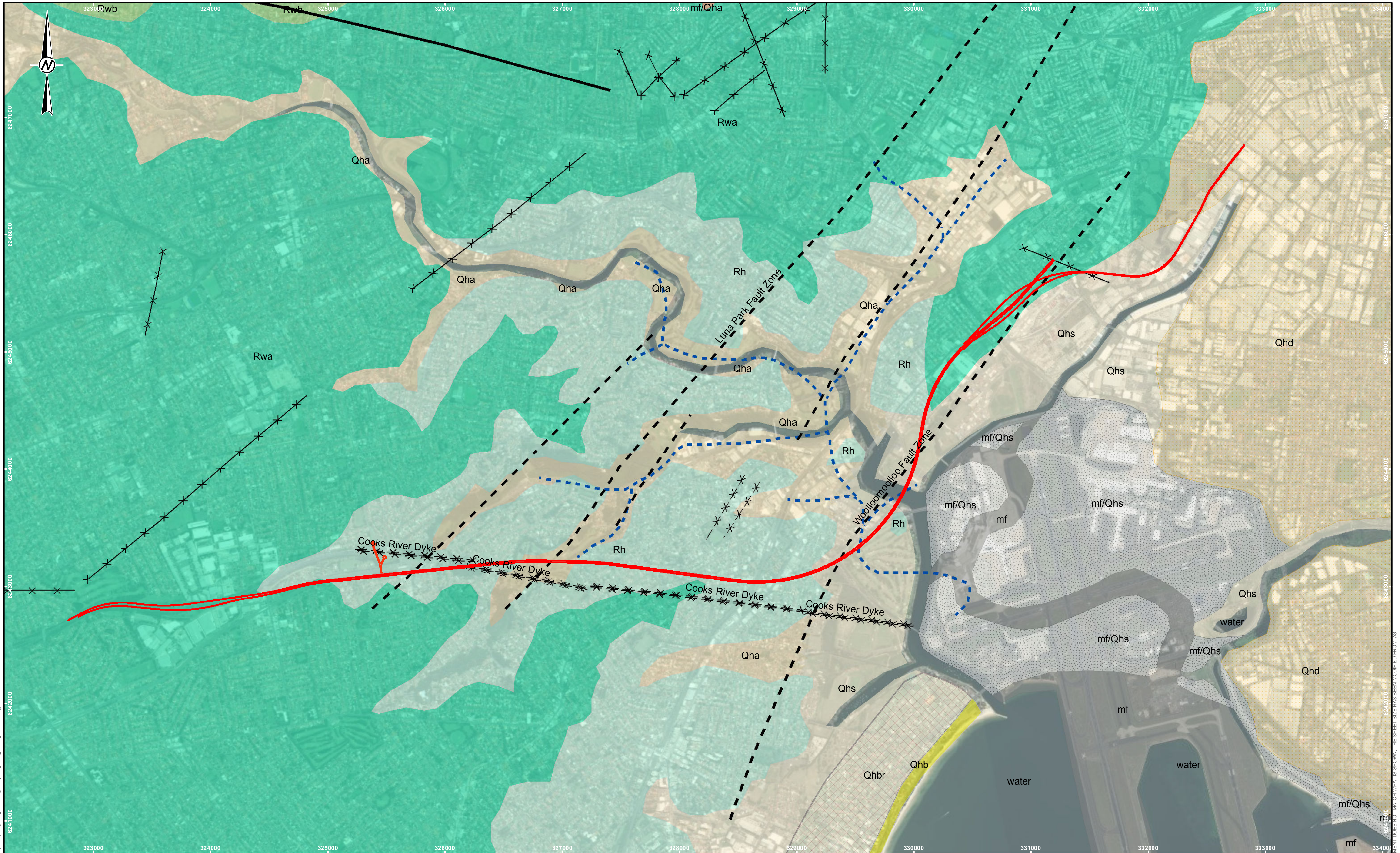
Sediments infilling the palaeochannels comprise Pleistocene and Holocene age unconsolidated alluvium, estuarine and marine deposits up to about 50 meters thick, thickening towards the Botany Basin. The channels form part of the Cooks River drainage system, draining to the southeast corner of the project into Botany Bay. Palaeochannels are illustrated on Figure 2.10.

Palaeochannel sediments are comprised of silty and peaty sands, silts and clays with common shell layers. The lithological profile is complex reflecting changes in the depositional environment associated with the infilling of channels and swamps during sea level fluctuations and flooding events. The fine and coarse grained sediments are “inter-fingered” through the profile with finer grained sediments being more abundant than the coarser grained sediments.

Sediments occur at the base of localised drainage paths along the infilled channels and palaeo-shorelines; such as the Holocene shoreline parallel to Alexandra Canal (formerly known as Sheas Creek, McNally and Branagan, 1998). The thickness of the deposits are expected to increase toward Wolli Creek and Cooks River as the infilled channels approach the outlet into Botany Bay. The deepest alluvial sediments in the corridor are anticipated along a buried palaeochannel near Kogarah Golf Course where they are about 40 m deep. The deeper sediments within this paeleochannel are interpreted to be of Pleistocene age.

In the east of the model domain (in the area of the airport for example), a layer of Pleistocene age, predominantly clayey sediments with intermittent sand lenses (interpreted to have been deposited in a marine environment) are present at the base of the alluvial/marine sediments, overlying rock.

Aeolian sands (Botany Sands) were deposited in a sub-aerial dune and beach sand environment along the Holocene shoreline. The unit is generally comprised of uniformly graded (well-sorted), clean, poorly cemented, fine to medium grained quartz sand. Lenses of peat and organic clay occur within this unit. The thickness of the Botany Sand Beds is variable and range between 0 to 30 m with an average of 15 m within the Botany Basin (Hatley, 2004).



LEGEND

- WCX2 Alignment

Structure Type

- Fault Location (inferred)
- Dyke Location (inferred)
- Dyke Location (observed)
- Fold Location (observed)
- Palaeochannel Location (inferred)

Sydney 1:100,000 Geology

- Man made fill (mf)
- fill/Qha (mf/Qha)
- fill/Qhs (mg/Qhs)
- Qha - Quartz sand, silt and clay
- Qhs - Peat, sandy peat and mud
- Qhd - Marine sand
- Qhbr - Quartz sand, minor shell content
- Qhb - Coarse quartz sand
- Rwb - Bringelly Shale
- Rwa - Ashfield Shale
- Rh - Hawkesbury sandstone

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PROJECT
WEST CONNEX STAGE 2

Reference(s):
Herbert C., 1983, Sydney 1:100 000 Geological Sheet 9130, 1st edition.
Geological Survey of New South Wales, Sydney

0 500 1,000 1,500 2,000 2,500 METRES

PROJECTION: GDA 1994 MGA Zone 56 REFERENCE SCALE: 1:30,000 (at A3)

TITLE
REGIONAL GEOLOGY OF THE PROJECT CORRIDOR AND THE SURROUNDING AREA

YYYY-MM-DD	2016-10-28
PREPARED	HSG
DESIGN	HSG
REVIEW	--
APPROVED	

PROJECT No.	CONTROL	Rev.	FIGURE
1524285	001	A	2.10

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2.2.6 Hydrostratigraphic Units and Conceptual Model

The stratigraphy has been divided into the following hydrostratigraphic units within the Project Corridor (in order of increasing age):

- Anthropogenic Fill (landfill, reclaimed land, urban engineered material);
- Botany Sands (Aeolian Holocene sand and clay);
- Quaternary sediments (undifferentiated estuarine, alluvial and marine Holocene and Pleistocene sediments);
- Ashfield Shale and Mittagong Formation;
- Hawkesbury Sandstone.

Regional and local geological structures such as palaeochannels, dykes, faults and jointing will influence groundwater flow within these hydrostratigraphic units.

Anthropogenic Fill

In general, a thin layer of fill is commonly encountered in urban areas and is associated with modifications to the topography, landscaping and pavement construction. Such filling will generally decrease infiltration rates and recharge to aquifers.

Areas of thicker filling are expected towards the Alexandra Canal and landfill sites along the Project Corridor north of Cooks River. These include closed landfill sites rehabilitated to parkland (Sydney Park, Camdenville, Tempe, near the Kogarah Golf Course and Kingsgrove), and the Alexandria Landfill at St Peters. Leachate from these current and former landfills has likely impacted on groundwater quality in the area.

Botany Sands and Quaternary Sediments

Quaternary sediments occur predominantly within the eastern parts of the Project Corridor and along valleys of current and ancient water courses. Overall, the current drainage pattern coincides with the inferred palaeodrainage system that has generally followed structural trends. Three major units have been recognised within the Quaternary age sediments based on depositional environment. These are:

- Botany Sands (aeolian sand) within the eastern part of the project area near the proposed St Peters Interchange;
- Alluvial and estuarine Holocene and Pleistocene age sediments deposited along valleys of current, ancient water courses and palaeo-shorelines.
- Pleistocene age marine sediments deposited to the east of the Project Corridor.

Hydrogeological characteristics of the units within the Project Corridor as inferred from their lithological description are summarised in Table 9.

Table 9: Hydrogeological characteristics of Quaternary age sediments

Unit	Depositional environment	Lithology	Hydrogeological Characteristic
Botany Sands	Aeolian Sands	Various sands with podsols	Aquifer (Botany Sand Beds), unconfined porous medium, moderate to high yielding
Quaternary sediments	Fluvial and shallow water	Interlayered and inter-fingered various sands, clays and silts with minor peats	Generally aquifer, unconfined porous medium, low to moderately yielding. Clayey layers could provide localised barrier to the flow
Quaternary sediments	Swamps, shallow water	Peat, sandy peat and mud	Generally aquitard
Quaternary sediments	Coastal, shallow marine	Sand with minor sands, silts	Aquifer unconfined porous medium, moderate to high yielding
Quaternary sediments	Marine	Predominantly clay with intermittent sand lenses	Aquitard

The Botany Sands are a shallow, unconfined aeolian sand aquifer with a high hydraulic conductivity. The Botany Sand Beds aquifer contains water of varying quality due to recharge, proximity to seawater, presence of peaty sediments, proximity to wetlands and contamination from various sources.

Infilled palaeochannels may contain up to 40 m of infilled alluvial and estuarine sediments. As noted above, paleochannel sediments are comprised of silty and peaty sands, silts and clays deposited in changing depositional environments associated with the infilling of channels and swamps during sea level fluctuations and flooding events. The fine and coarse grained sediments are “inter-fingered” through the profile with finer grained sediments being more abundant than the coarser grained sediments. The palaeochannel infill sediments will generally represent a low to moderately yielding aquifer with clayey layers representing localised barriers to flow. Groundwater quality in these sediments, particularly towards the east, may be impacted by high dissolved solids, and contamination from various sources.

Hydraulic connectivity of the Quaternary sediments with underlying bedrock formations is generally expected to be relatively high, except towards the east where more extensive clayey layers associated with Pleistocene age marine sediments will create an aquitard at the base of the sediments. Along the alignment of palaeochannels, connectivity between the rock and the Quaternary sediments may be enhanced as a result of the development of stress relieved bedding and joints predominantly within the upper approximately 15 m of the bedrock.

Ashfield Shale and Mittagong Formation

The Ashfield Shale formation is considered to be a low yielding fractured rock aquifer. The unit contains water which may be discharged in small volumes based on the low storage of shale and is dependent on fracture connectivity. The Ashfield Shale has a very low primary porosity and weathers to clay which may infill fractures or inhibit recharge to fracture networks.

The Mittagong Formation has been conceptualised within the Ashfield Shale unit as they exhibit similar hydraulic properties and both are not understood to contain significant amounts of groundwater except in fracture networks.

Hawkesbury Sandstone

The Hawkesbury Sandstone is considered to be the primary regional aquifer within the project area and is a partially confined, dual porosity rock aquifer with variable hydraulic conductivity. The majority of the groundwater flow is via open bedding partings and vertical or sub-vertical features such as joints, shear zones and dykes; however, the primary porosity contributes significantly to the ability of the sandstone to store and release groundwater.

The Hawkesbury Sandstone aquifer is typically fully saturated where covered by younger shale/soil units, unless affected by dewatering associated with drainage into man-made structures such as tunnels, shafts and deep excavations. Where the unit is not covered by younger units the water table occurs within the Hawkesbury Sandstone.

Aquifer parameters within the Hawkesbury Sandstone exhibit a high degree of anisotropy of varying orientation, due to the variability and thickness of each facies and the development of joints and bedding partings providing preferential flow pathways for groundwater.

Hydrogeological Impact of Geological Structures

Groundwater flow in the Hawkesbury Sandstone and Ashfield Shale will be influenced by faults and dykes. Locations of faults and dykes are discussed in the Geotechnical Interpretive Report (MSN-GOL-TER-100-200-GT-1505).

Faults are generally expected to act as conduits for groundwater flow. Dykes can potentially increase or inhibit groundwater flow depending on the degree of weathering and the degree of fracturing induced during dyke emplacement, however experience in the Sydney Basin generally appears to indicate that dykes limit groundwater flow in the direction transverse to the dyke, with likely enhanced flow parallel to the dyke within a fractured halo immediately adjacent to the dyke.

At Bexley, near the western portal to the existing, drained tunnel for the M5 East Motorway, a difference in groundwater level is observed across a dyke which is interpreted to result from the dyke acting as a barrier to flow. Groundwater levels to the north of the dyke close to the tunnel were generally around RL -4.5 m AHD over a monitoring period from November 2014 to February 2016, compared with a groundwater level of around RL 5.5 m AHD to the south of the dyke. The lower groundwater level to the north of the dyke is interpreted to be associated with drainage to the tunnel.

Regional Groundwater Flow

Groundwater flow is influenced by topography and palaeochannels. Regional flow direction generally reflects topographic trends. Locally, the tunnel alignment may alter groundwater flow direction by causing groundwater within the zone of drawdown to flow toward the tunnel.

Groundwater flow within the Hawkesbury Sandstone and the Ashfield Shale is interpreted to be predominantly within open and connected bedding partings, joints and fractures. The majority of the hydraulic conductivity and flow to the tunnels is therefore associated with secondary porosity. Generally, the vertical hydraulic conductivity (K_v), perpendicular to bedding planes, is much lower than the horizontal hydraulic conductivity (K_h), parallel to bedding planes. Therefore, the dominant groundwater flow is assumed to be in a sub-horizontal direction. The Quaternary sediments are anticipated to experience a horizontally dominated flow regime due to the presence of interbedded clay and sand units.

Shallow groundwater in the Botany Sand Beds aquifer will follow topography toward palaeochannels and flow into the Botany Bay as outlined in Hatley (2004) and reported by Bish et al. (2000). Figure 2.11 outlines groundwater flow directions in the Botany Sand Beds aquifer referenced by Hatley (2004). Regional groundwater flow from the east in the Botany Sand Beds aquifer is towards the Alexandra Canal. This suggests that there will be little impact in the regional groundwater flow regime in the Botany Sand Beds aquifer east of the Project Corridor. The regional groundwater flow direction from west toward Botany Bay will remain unchanged, with continued partial interception of groundwater at SPI.

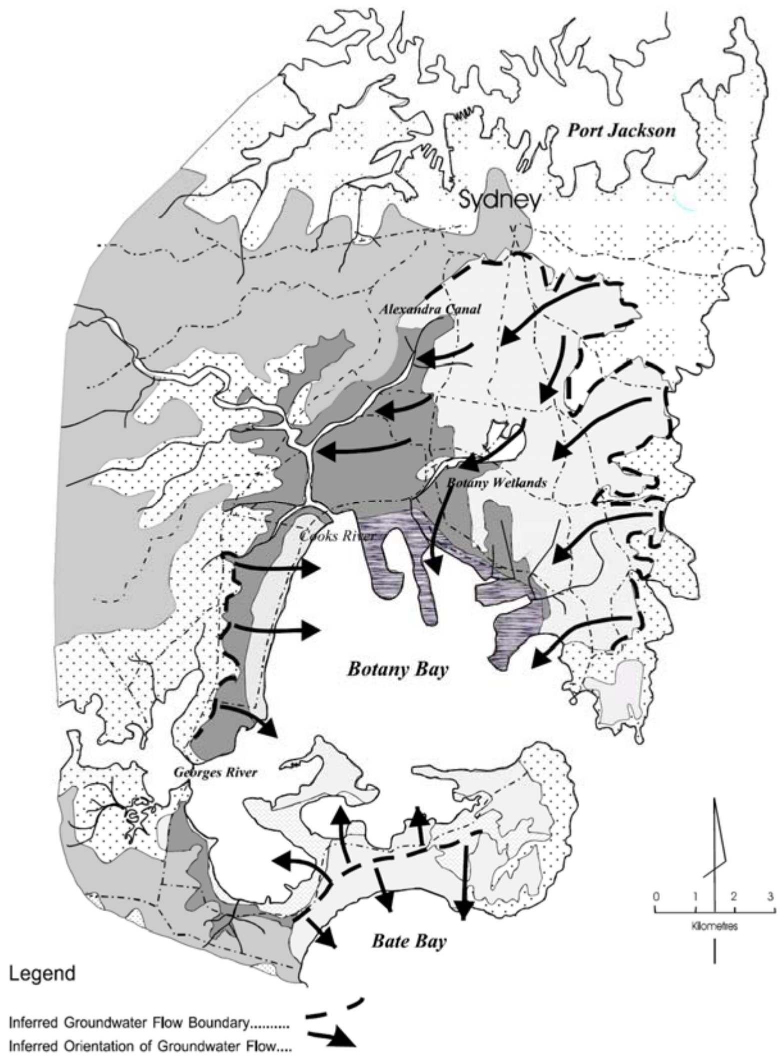


Figure 2.11: Inferred groundwater flow directions in the Botany Sand Beds aquifer unit of the Botany Basin as reported by Hatley (2004) citing Bish et al. (2000) and McKibbin and Russell (2002).

2.2.7 Regulated Groundwater Sources

The Water Sharing Plan Greater Metropolitan Region Groundwater Sources (WSP) divides the Greater Metropolitan Region of the east coast of NSW into 13 groundwater sources. Within the Project Corridor, two groundwater sources are encountered which include the Botany Sands Groundwater Source (BSGS) and the Sydney Central Basin Groundwater Source (SCBGS), as shown in Figure 2.12

The BSGS consists of aeolian sand deposits (Botany Sands) which is a high yielding aquifer. In 2003, the NSW government placed an embargo on the northern section of the aquifer due to the depletion of available clean water which was followed by a ban on domestic bores in 2006, and subsequently by a commercial ban of water extraction in 2007 (Office of Water, 2011). The BSGS has been divided into two zones; Botany Sand Management Zone 1 (BSMZ1) and BSMZ2. BSMZ1 covers the embargoed area of 2003 and BSMZ2 covers the embargoed area of 2007. The Project Corridor lies within the BSMZ1 and BSMZ2 embargo zones from SPI to the Kogarah Golf Course and to the west before entering the SCBGS. Within the BSMZ, a license must be held to interfere with an aquifer which includes the extraction of groundwater (de-watering), causing changes to a groundwater flow path or gradient, subsidence of river beds, alteration to an aquifer and artificial aquifer recharge (Office of Water, 2011). The aquifers in areas such as the Alexandria Landfill where the Botany Sand Beds and Quaternary sediments are in direct contact with landfill material and palaeochannel sediments near the Kogarah Golf Course are regulated.

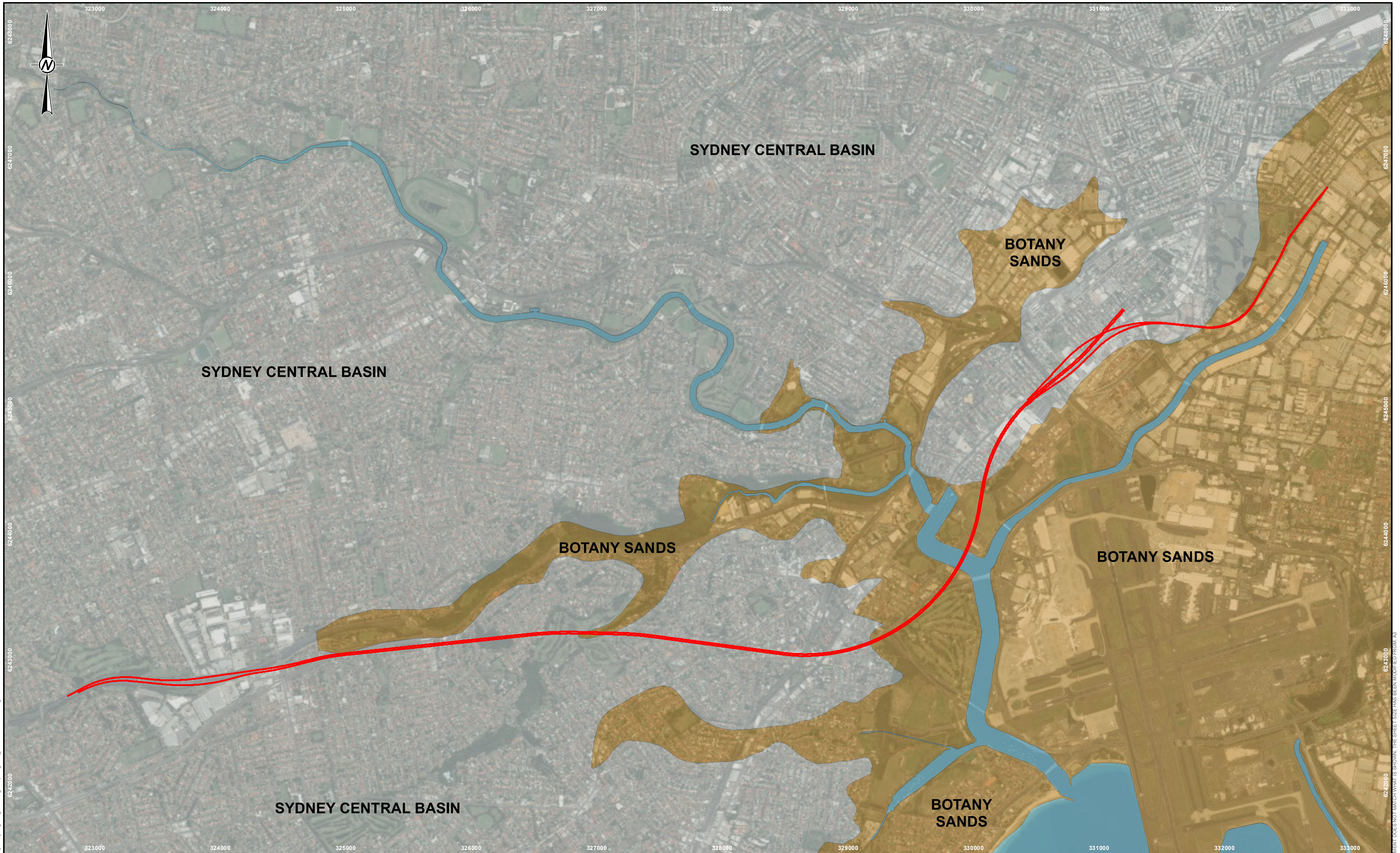
The WSP classifies the SCBGS as a porous rock groundwater source. The Ashfield Shale and Hawkesbury Sandstone are the dominant aquifers within the SCBGS and underlying the majority of the Project Corridor.

2.2.8 Registered Groundwater Bores

There are 98 registered groundwater bores within the Project Corridor. Five bores are registered as industrial and 17 are for domestic water supply. There are also 13 bores registered for monitoring purposes.

The NSW Office of Water groundwater database indicates that within the Project Corridor, approximately half of the registered bores are used for supply or irrigation; the majority of which are within the top 10 m within the Botany Sands Beds aquifer and the Quaternary sediment aquifer associated with Wolli Creek alluvium and Cooks River alluvium.

NGIS registered boreholes within 1 km of the tunnel alignment are summarised in Annexure E.



LEGEND

WCX2 Alignment

GW Mangement Zone

Botany Sandbeds

Sydney Central Basin

Water

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PROJECT
WEST CONNEX STAGE 2

REFERENCE(S):
Water Sharing Plan for the Greater Metropolitan Region Groundwater Sources, NSW Government, 2011.

0 500 1,000 1,500 2,000
METRES

PROJECTION: GDA 1994 MGA Zone 56 REFERENCE SCALE: 1:28,003 (at A3)

TITLE
WATER SHARING PLAN GROUNDWATER MANAGEMENT ZONES WITHIN THE PROJECT CORRIDOR AND SURROUNDING AREA

YYYY-MM-DD	2016-10-28
PREPARED	HSG
DESIGN	HSG
REVIEW	--
APPROVED	

PROJECT No.	CONTROL	Rev.	FIGURE
1524285	001	A	2.12

2.2.9 Groundwater Monitoring

Locations at which groundwater level information is available are illustrated in Figure 2.13, Figure 2.13.1, Figure 2.13.2 and Figure 2.13.3. Groundwater level observations for these locations, and the timing of the observations, are summarised in Table F1 of Annexure F. Monitoring comprises mainly conventional monitoring bores, and there are also some vibrating wire piezometers which have been grouted in place in the Arncliffe area.

Information on groundwater levels covers the period from 1993 to the present time as indicated in Table F1. Consequently, some of the measurements are from the period prior to construction of the M5 East Motorway. Continuous data logging records are available for 32 monitoring bores, for which groundwater levels were monitored at a two hour recording interval in the period from November 2014 to February 2016. The majority of these bores are installed in Hawkesbury Sandstone, with 10% of bores in Ashfield Shale and one bore in the shallow alluvium. Hydrographs for water levels in these monitoring bores are included in Annexure G.

Monitoring of groundwater levels using the network of vibrating wire piezometers located in the Arncliffe area was undertaken from mid-February to mid-March and during the month of July, as part of monitoring of two pumping tests carried out in this area (refer to Section 2.2.13).

Pre-construction baseline groundwater monitoring has been conducted in 43 wells along the Project Corridor to monitor shallow and deep groundwater level trends. Results of the pre-construction baseline groundwater monitoring are reported in the Groundwater Baseline Report (M5N-GOL-TER-100-200-GT-1510).

2.2.10 Groundwater Levels

Measured groundwater levels across the tunnel alignment range from 31.3 mAHD to -17.39 mAHD, and are influenced by the topography and presence of geological structural features. Groundwater heads in the Hawkesbury Sandstone follow the topography with depth to groundwater greater in elevated areas compared to low lying areas. This is observed in the Kingsgrove and Bardwell Park area, with flow from the north and south towards Wolli Creek. Artesian conditions have been noted in the Kingsgrove area in bores LDS-BH-1025A and LDS-BH1064 installed in Hawkesbury Sandstone, with a groundwater level slightly (0.03 m and 1.1 m) above the ground surface elevation.

The lowest groundwater levels are observed in the vicinity of Alexandria Landfill, where groundwater levels have been impacted by pumping from the leachate sump in the landfill.

To the south of the Kogarah Golf Course, bores WCX-BH-063 and WCX-BH-214 (Hawkesbury Sandstone) indicate groundwater responses which are related to pumping (Annexure G, Figures G10 and G32) , with short-term water level fluctuations of around 3 m and 1.5 m respectively. It is interpreted that these bores are influenced by groundwater extraction from a bore south of Kogarah Golf Course. WCX-BH-214 is located at approximately 700 m distance from the bore. Extraction rates are not known.

In the Cooks River area, all groundwater bores in Hawkesbury Sandstone have potentiometric heads in the range from 1 to 3 m below ground level (bgl). Artesian conditions were observed with vibrating wire piezometers LDS1054 and LDS1055, for the piezometers screened in rock in these nested piezometers. Potentiometric head observations in LDS1054 ranged from 0.5 to 1.5 mAHD between March and June 2016. During the same time, piezometric heads in LDS1055 ranged between 0 and 1.4 m AHD. The groundwater levels in alluvium in this area are at around 1 m bgl.

Bores and vibrating wire piezometers close to the river indicate good hydraulic connection between the Hawkesbury Sandstone and the river. Significant hydraulic response to tidal fluctuations was observed at relatively large distances from Cooks River. For example, a clear tidal response is observed at LDS-BH-2033, which is located at approximately 400 m from the river, with a time lag of approximately 2 hours between the tidal peak and the peak response in a vibrating wire piezometer screened in the Hawkesbury Sandstone at a depth of 57.7 m. The response to tidal fluctuations is consistently less in the alluvium than in the rock, which is to be expected because of the higher storage capacity in the alluvium. It appears that no tidal response is evident at LDS-BH-2007B which is located approximately 600 m from the river, although a small degree of response may be present and is being masked by barometric pressure variations. A more detailed assessment of tidal interactions is presented in Annexure H.

Groundwater levels as low as approximately RL -5.5 m AHD in the Hawkesbury Sandstone have been observed along the alignment of the existing M5 East Motorway tunnel between Bexley and Arncliffe, reflecting the long-term drainage of this tunnel. While drawdown in the Hawkesbury Sandstone are evident along the alignment of the M5 East tunnels, there is evidence that drawdown is limited in the overlying unconsolidated materials at Bexley and Turrella along the alignment of this tunnel.

A perched groundwater system is interpreted to be present at the location of the proposed northern shaft at Bexley. In this area, monitoring bore WCX-BH084 (screened at approximately RL -20 m in the Hawkesbury Sandstone) indicates a groundwater level of approximately RL -4.5 m AHD, which is interpreted to be impacted by drainage of the M5 East tunnels. Groundwater levels measured in nearby shallow, augered boreholes indicate groundwater levels of around RL 10.5 m AHD to RL 11.0 m AHD, indicating a separate perched groundwater system that is not affected by the lowering of groundwater levels in the underlying rock.

At Turrella, groundwater levels measured in shallow boreholes do not indicate an impact as a result of drainage of the M5 East ventilation tunnel which extends from the road tunnels north to a vent shaft adjacent to Wolli Creek at Turrella. Results of groundwater monitoring in 1999 (prior to excavation of the ventilation tunnel) and monitoring in early 2015 are summarised in Table 10. Although the invert of the ventilation tunnel is located at approximately 40 m below the original groundwater levels, a drawdown of approximately 4 m is evident in a sand layer immediately overlaying the sandstone, and an immediately adjacent shallow alluvial monitoring well shows no evidence of drawdown.

Table 10: Groundwater Levels at Turrella monitoring Wells

Monitoring Well	Distance from vent tunnel**	Screened Interval	Groundwater level Sep1999	Groundwater level Feb 2015	Drawdown
BH249*	85 m approx.	Screened in clayey sand RL 0.9 m AHD to RL -3.1 m AHD	RL 2.25 m AHD	RL 2.17 m AHD	0.08 m
BH250	85 m approx.	Screened in sand RL -24.7 m AHD to RL -30.7 m AHD	RL 1.76 m AHD	RL -2.45 m AHD	4.41 m
BH251	30 m approx.	Screened in sandstone RL -5.7 m AHD to RL -23.8 m AHD	RL 2.36 m AHD	RL 1.04 m AHD	1.32 m

*Located adjacent to BH250
**Vent tunnel invert at RL -37 m approx.

LEGEND

Screened Formation

- Fill
- Fill and Quaternary Sediments
- Fill and Ashfield Shale
- Fill and Hawkesbury Sandstone
- Quaternary Sediments
- Quaternary Sediments and Ashfield Shale
- Quaternary Sediments and Hawkesbury sandstone
- Ashfield Shale
- Ashfield Shale and Hawkesbury Sandstone
- Hawkesbury Sandstone
- Other
- Screened Formation Unknown
- Pending Completion
- WCX2 Alignment
- Main Roads
- Waterbodies

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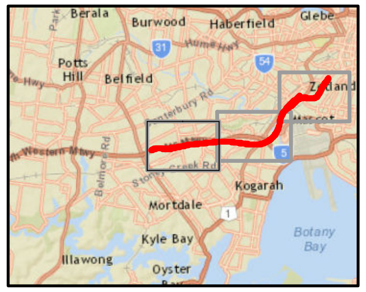

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Reference(s):
Bureau of Meteorology (2016), National Groundwater Information System (NGIS), http://www.bom.gov.au/water/groundwater/ngis/ last accessed 29 March 2016.

0 250 500
METRES

PROJECTION: GDA 1994 MGA Zone 56 REFERENCE SCALE: 1:10,000 (at A3)

TITLE
GROUNDWATER MONITORING AND OBSERVATION BORE LOCATIONS

YYYY-MM-DD	2016-10-28
PREPARED	HSG
DESIGN	HSG
REVIEW	--
APPROVED	

PROJECT No.	CONTROL	Rev.	FIGURE
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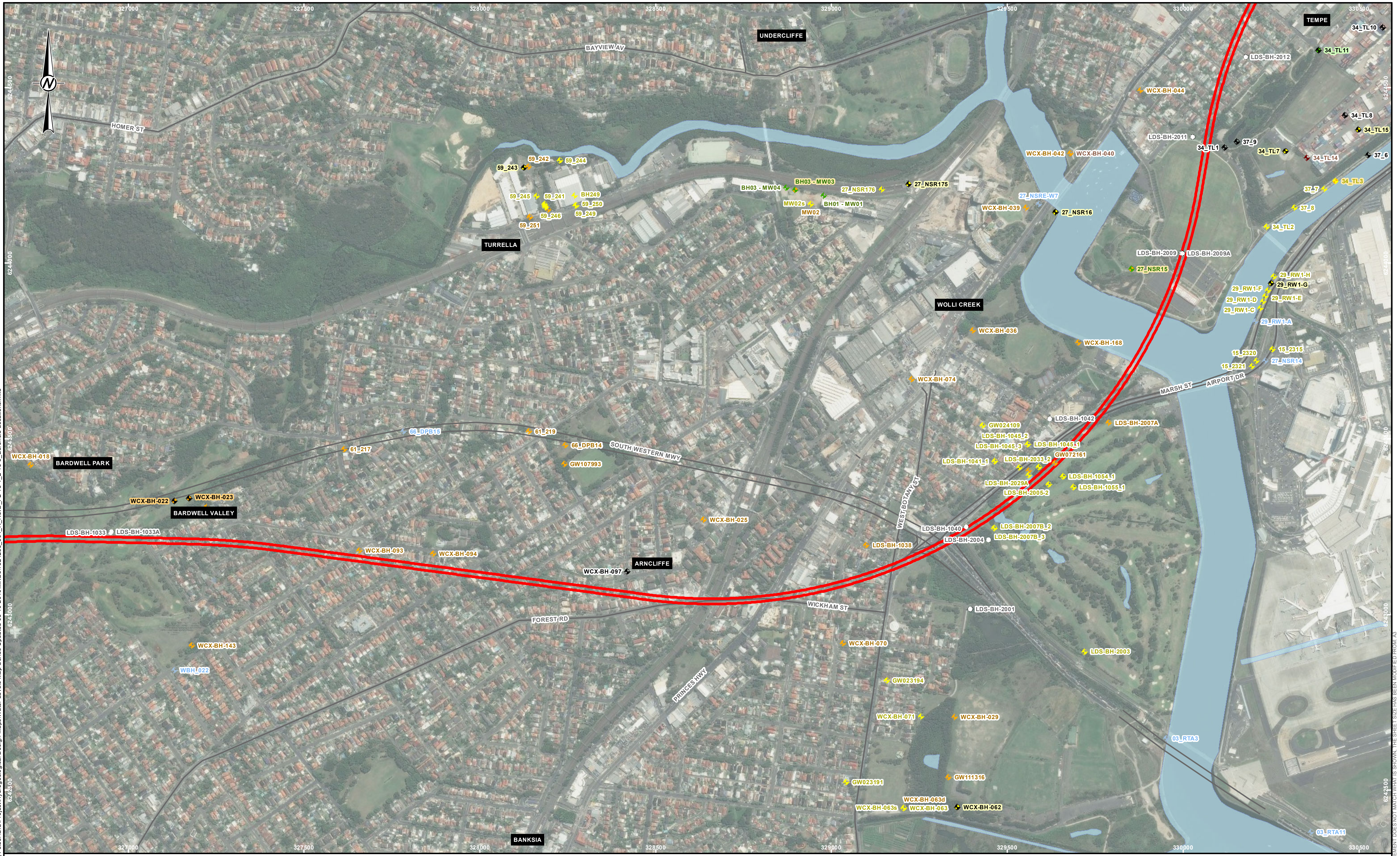

LEGEND

Screened Formation

- Fill
- Fill and Quaternary Sediments
- Fill and Ashfield Shale
- Fill and Hawkesbury Sandstone
- Quaternary Sediments
- Quaternary Sediments and Ashfield Shale
- Quaternary Sediments and Hawkesbury sandstone
- Ashfield Shale
- Ashfield Shale and Hawkesbury Sandstone
- Hawkesbury Sandstone
- Other
- Screened Formation Unknown
- Pending Completion
- WCX2 Alignment
- Main Roads
- Waterbodies

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Reference(s):
Bureau of Meteorology (2016), National Groundwater Information System (NGIS), http://www.bom.gov.au/water/groundwater/ngis/ last accessed 29 March 2016.

0 250 500
METRES

PROJECTION: GDA 1994 MGA Zone 56 REFERENCE SCALE: 1:10,000 (at A3)

TITLE
GROUNDWATER MONITORING AND OBSERVATION BORE LOCATIONS

WestConnex Stage 2 M5

YYYY-MM-DD	2016-10-28
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PROJECT No.	CONTROL	Rev.	FIGURE
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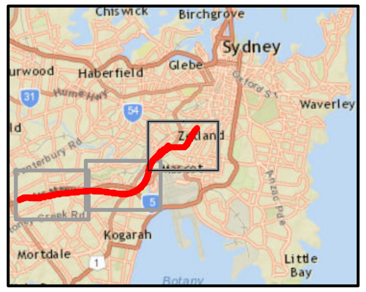
25mm

LEGEND

Screened Formation

- Fill
- Fill and Quaternary Sediments
- Fill and Ashfield Shale
- Fill and Hawkesbury Sandstone
- Quaternary Sediments
- Quaternary Sediments and Ashfield Shale
- Quaternary Sediments and Hawkesbury sandstone
- Ashfield Shale
- Ashfield Shale and Hawkesbury Sandstone
- Hawkesbury Sandstone
- Other
- Screened Formation Unknown
- Pending Completion
- WCX2 Alignment
- Main Roads
- Waterbodies



Localities, Main Roads, Waterbodies: Copyright MapInfo Australia Pty Ltd 2004; Copyright PSMA Australia Ltd 2004.
Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

CLIENT
CPB DRAGADOS SAMSUNG JV

PROJECT
WEST CONNEX STAGE 2

Reference(s):
Bureau of Meteorology (2016), National Groundwater Information System (NGIS), http://www.bom.gov.au/water/groundwater/ngis/ last accessed 29 March 2016.

0 250 500
METRES

PROJECTION: GDA 1994 MGA Zone 56 REFERENCE SCALE: 1:10,000 (at A3)

TITLE
GROUNDWATER MONITORING AND OBSERVATION BORE LOCATIONS

YYYY-MM-DD	2016-10-28
PREPARED	HSG
DESIGN	HSG
REVIEW	--
APPROVED	

PROJECT No.	CONTROL	Rev.	FIGURE
1524285	001	A	2.13.3

Path: J:\Hyd\2015\Sydney\WCX Brisbane Working Folder\GIS\Project\Hydrogeological Design Maps\Water Levels Map Series Updated 05-10-2016\MXDs\1524285_001_R_RevB_F2-13-1_2-13-3_Borehole Locations.mxd

IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: A3

25mm

2.2.11 Correlation between Ground Surface Level and Depth to Groundwater

Correlations between ground surface elevation and the depth to the water table were generated from available groundwater data for each hydrostratigraphic units within the model domain, as presented in Figure 2.14. These correlations have been used to assist with the development of additional, estimated groundwater levels as calibration targets in areas where no monitoring data is available. The use of these correlations to assist with model calibration is discussed in more detail in Section 2.3.4.

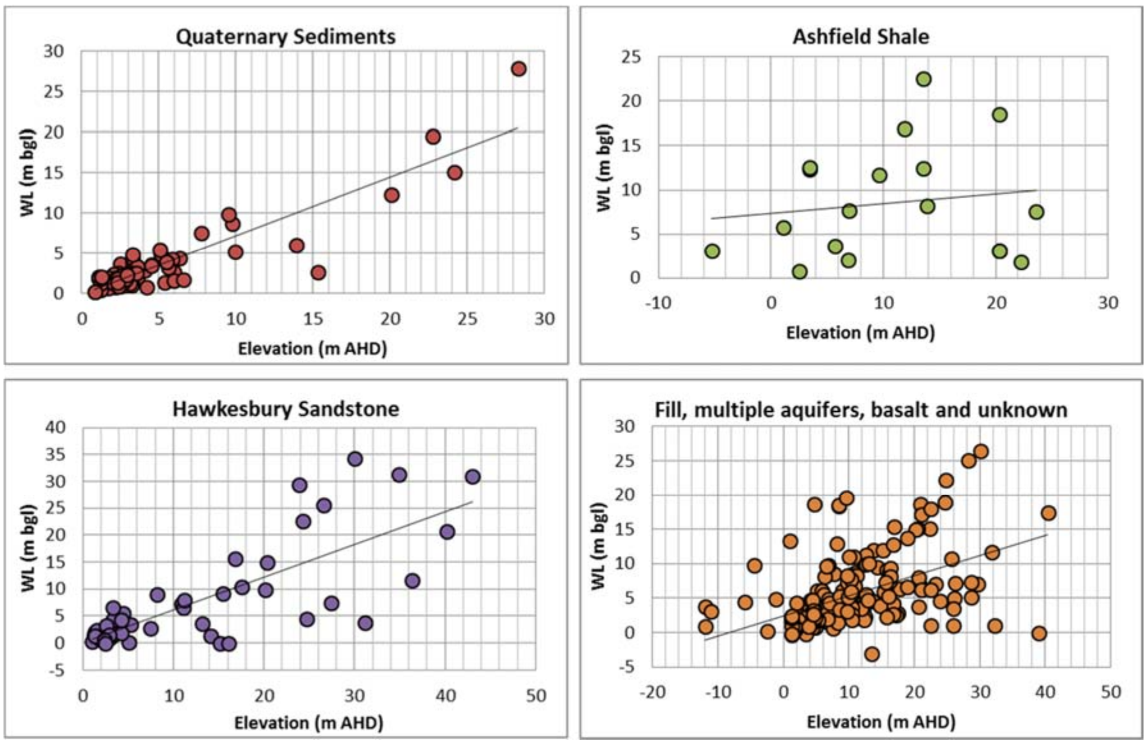


Figure 2.14: Correlation between depth to groundwater and ground surface elevation

2.2.12 Groundwater Recharge and Discharge

In an urban environment like Sydney, recharge of groundwater is controlled by a range of processes which are in part different from aquifer systems underlying areas with agriculture or low intensity land use. Surface infiltration is greatly reduced because a large portion of surface area is virtually impervious. Therefore, most rainfall becomes runoff, which is diverted to a storm water drainage system. However, reductions in direct infiltration can be counterbalanced by reductions in evapotranspiration, and by leakage from stormwater, water distribution and sewerage systems. Large volumes of water are imported into Sydney for supply, distributed through underground pipes, and collected again in sewers or septic tanks. For example, the Cooks River catchment imports over 40 000 mega-Litres per year (ML/year) of dam water for water supply purposes (CRA, 2014). The leaks from these pipe networks provide substantial recharge. Leaks from sewers and storm water drains will also provide recharge to surficial aquifers.

Figure 2.15 and Figure 2.16 present the main groundwater recharge sources and pathways within the model domain. The complexity of recharge mechanisms and pathways of a city like Sydney and scarcity of data lead to high uncertainties in quantifying urban recharge.

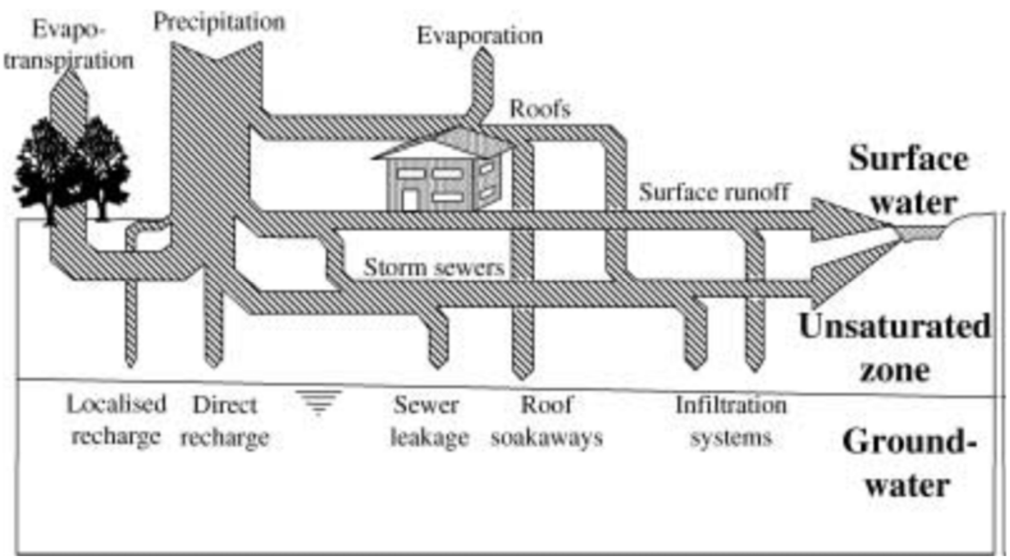


Figure 2.15: Groundwater recharge sources and pathways: pathways for precipitation to recharge groundwater in urban Areas (Lerner, 2002)

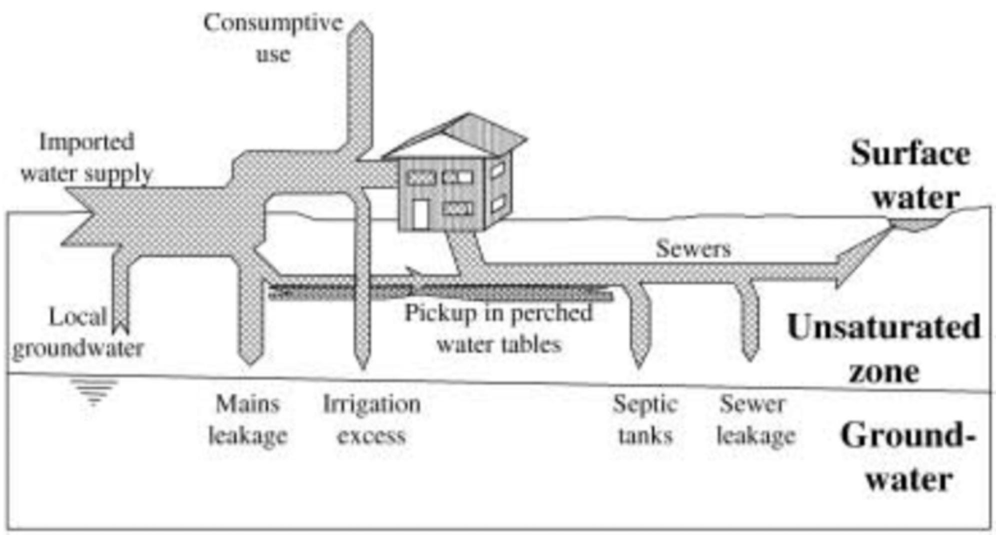


Figure 2.16: Groundwater recharge sources and pathways: routes for water supply and sewage to recharge urban groundwater (Lerner, 2002)

Recharge to the aquifers in open areas is predominantly from rainfall. The rate of the recharge varies greatly over the Project Corridor depending on hydraulic conductivities of exposed unit, topography relief and nature of surface cover.

Recharge to the Hawkesbury Sandstone from rainfall occurs in areas where the unit is extensively exposed and fractured. Where overlain by the Ashfield Shale, recharge to the Hawkesbury Sandstone is inferred to be significantly reduced due to lower vertical conductivity of the Ashfield Shale and the generally clayey weathering profile developed above the fresh Ashfield Shale. Recharge to the sandstone aquifer is further reduced within the areas of topography relief and moderate slopes where the runoff is likely to dominate.

Recharge to the Ashfield Shale will occur in areas where Ashfield Shale is fractured and extensively exposed, and where the Ashfield Shale is hydraulically connected to the unconsolidated Quaternary sediments or fill material. Recharge to the Ashfield Shale is inferred to be reduced due to weathering of the Ashfield Shale to a clayey residual soil which impedes infiltration of rainfall and runoff.

An assessment of groundwater response to rainfall is provided in Annexure I.

Groundwater discharge from the Quaternary age units occurs directly to surficial water bodies or through infiltration to underlying aquifers, in addition to localised groundwater extraction. Groundwater discharge from the Hawkesbury Sandstone aquifer occurs indirectly through these sediments. Groundwater discharge from the Ashfield Shale is inferred to occur typically through following processes:

- down-flow into Hawkesbury Sandstone;
- up-flow or cross-flow to Quaternary sediments;
- surface seepage along break of the slopes;
- along daylighting geological structures; and
- along the interface between Hawkesbury Sandstone and Ashfield Shale.

Groundwater abstraction and disposal from landfills and reclaimed land is understood to occur from the Alexandria Landfill and Sydney Park (a former landfill). It is understood that there is no active extraction at the historical Tempe landfill. There is a cut-off wall installed along the eastern perimeter of this site to approximately 9 m depth and about 1 m above the water level in the Alexandra Canal. A drainage system is understood to operate to the west of the wall (i.e. on the site of the former landfill). Water from the Tempe drainage system is collected and treated before discharge. It is unclear how other historical landfills manage their groundwater.

Alexandria Landfill is not a lined landfill and therefore, waste material is in direct contact with the underlying Ashfield Shale and adjacent Quaternary sediments. It is understood that groundwater interception is taking place from the Quaternary unit to reduce leachate in the landfill. However, the drainage pits will be decommissioned during closure and a vertical barrier wall will be installed to significantly reduce groundwater interactions with the Quaternary sediments.

Groundwater discharge to unlined tunnels will also impact on the groundwater system. Published experience from the projects within similar hydrogeological conditions as expected for the current project suggests that inflow into drained tunnels is typically low and generally in the order of 1 litre per second per kilometre (L/s/km) of tunnel.

Higher inflows, in the order of 3 to 20 L/s; however, have been reported over small distances associated with localised features such as faults, shear zones, dykes and enhanced jointing below paleo-valleys (stress relief joints). These higher inflows have been experienced typically over short durations and reduce significantly over time.

The longer term groundwater inflows reported for several of Sydney's tunnels are summarised in Table 11 along with indications of the higher inflow observed during construction.

Table 11: Reported long term tunnel inflows in the Sydney area (Golder 2015a).

Tunnel	Length (km)	Type	Inflow (L/s/km of tunnel)	Reporting period	Comment
Northside Storage Tunnel	20	Sewage Storage	0.90	In 2005	Higher below Middle Harbor (8 L/s), required chemical grouting
Lane Cove	3.6	Twin 3-lane road	0.58	Average over 2011	1.7 L/s/km average between Dec 2001 and mid-2004
M5 East	3.8	Twin 2-lane road	0.75-0.9	Average over 2011	Short duration localised inflows up to 23 L/s
Epping to Chatswood railway line (ECRL)	13	Twin rail	0.9	Average over 2011	Higher inflows 3 L/s

*New Southern Railway reported tunnel inflow of 1.7 L/s/lm at July 1997 (Merrick, 1998)[6]

2.2.13 Hydrogeological Characteristics

Results of Packer Testing

Results from 309 water pressure tests (WPT's; also referred to as "packer" or Lugeon tests) have been collated from site investigations in the WCX2 Project Corridor. Data from a large number of tests carried out for other projects is also available. Table 12 presents the breakdown of number of tests conducted in each formation.

Interpretation of packer test results has been based on adopting a hydraulic conductivity of $1x10^{-7}$ m/s as equivalent to a packer test measurement of 1 Lugeon.

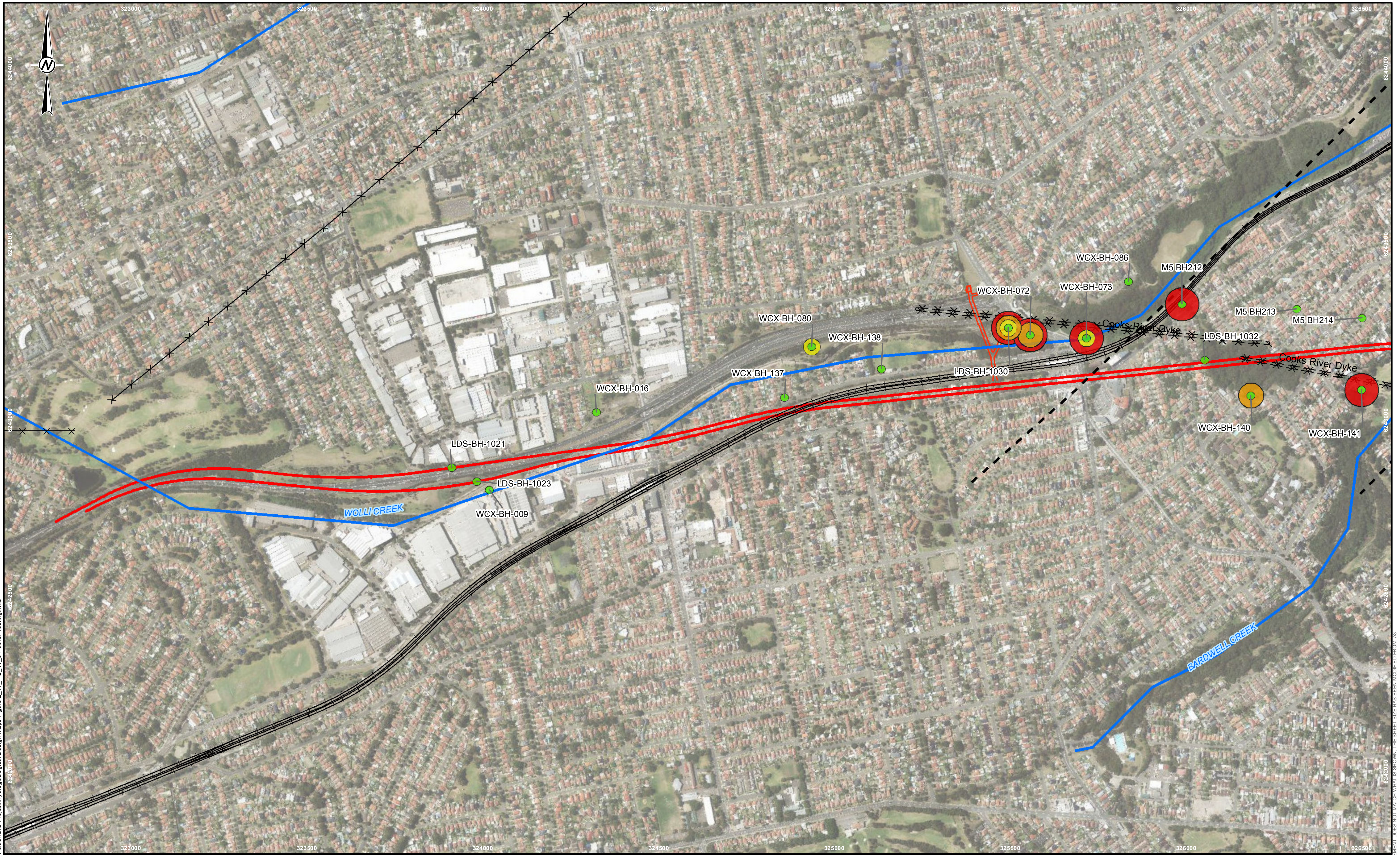
Table 12: Water pressure tests from the regional database and the Project Corridor

Unit Tested	Regional Boreholes Tested	Regional Water Pressure Tests	WCX Boreholes Tested	WCX2 Water Pressure Tests
Ashfield Shale	156	390	3	6
Mittagong Formation	62	85	9	10
Hawkesbury Sandstone	363	1096	77	288
Dyke (Basalt)	2	5	2	5

Note: Regional statistics include WCX2 data.

Regional experience has indicated that the permeability of the Ashfield Shale and Hawkesbury Sandstone units potentially reduces with increasing depth of cover. There are, however, zones at variable depth in both units where higher permeability zones are present, which are often associated with low cover beneath creeks and palaeochannels, or areas with structures such as joints, faults and shear zones.

The distribution of results from packer tests conducted within the Project Corridor is presented in Figure 2.17.1, Figure 2.17.2 and Figure 2.17.3. It should be noted that in the representation in these figures, multiple tests with a similar range of Lugeon values will not be represented as the data points will overlie one another. It can be seen from these figures that higher Lugeon values are often, but not always, associated with regional structures.



Path: J:\Hyd\2015\Sydney\WCX Brisbane Working Folder\GIS\Project\Hydrogeological Design Maps\Figure 2_17_1-2_17_3 Packer Testing.mxd

LEGEND

Lugeons

25-100
5-25
1-5
< 1

Rail - Surface

Structure Type

Fault Location (inferred)

Dyke Location (inferred)

Fold Location (observed)

WCX2 Alignment

Note: Multiple tests have been conducted at each location and there may be more than one test corresponding to each Lugeon range.

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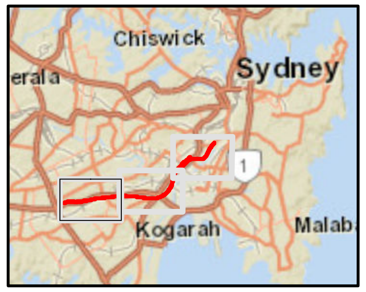


CLIENT
CPB DRAGADOS SAMSUNG JV

PROJECT
WESTCONNEX STAGE 2 NEW M5 MOTORWAY

0 100 200 300 400 500
METRES

REFERENCE SCALE: 1:10,000 (at A3)
PROJECTION: GDA 1994 MGA Zone 56

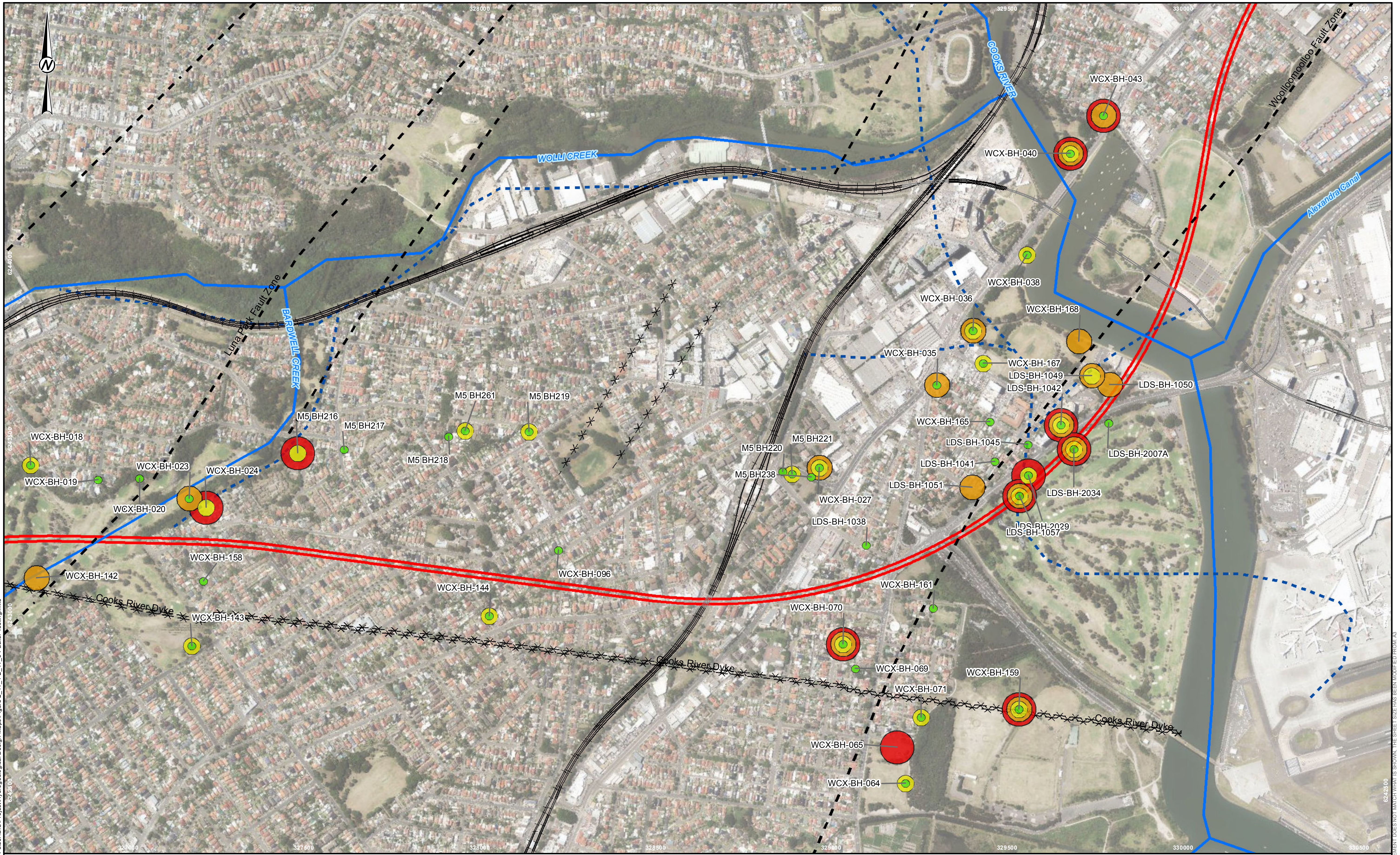
TITLE
PACKER TESTING RESULTS

YYYY-MM-DD	2016-10-28
PREPARED	HSG
DESIGN	HSG
REVIEW	--
APPROVED	

PROJECT No.	CONTROL	Rev.	FIGURE
1524285	001	A	2.17.1

IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: A3

25mm



LEGEND

Lugeons

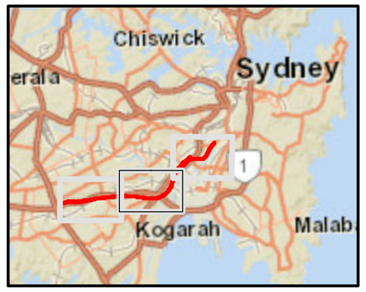
- 25-100
- 5-25
- 1-5
- < 1
- Rail - Surface
- Rail - Tunnel

Structure Type

- Fault Location (inferred)
- Dyke Location (inferred)
- Fold Location (observed)
- Palaeochannel Location (inferred)
- WCX2 Alignment

Note: Multiple tests have been conducted at each location and there may be more than one test corresponding to each Lugeon range.

Service Layer Credits: © Land and Property Information 2015



CLIENT
CPB DRAGADOS SAMSUNG JV

PROJECT
WESTCONNEX STAGE 2 NEW M5 MOTORWAY

0 100 200 300 400 500 METRES

REFERENCE SCALE: 1:10,000 (at A3)
PROJECTION: GDA 1994 MGA Zone 56

TITLE
PACKER TESTING RESULTS

YYYY-MM-DD	2016-10-28
PREPARED	HSG
DESIGN	HSG
REVIEW	--
APPROVED	

PROJECT No.	CONTROL	Rev.	FIGURE
1524285	001	A	2.17.2

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IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: A3

LEGEND

Lugeons

- 25-100
- 5-25
- 1-5
- < 1

Rail - Surface

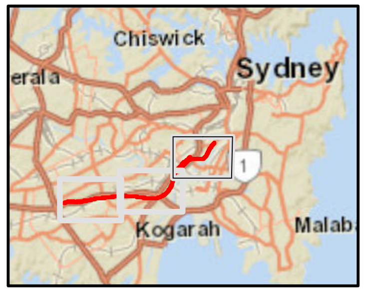
Rail - Tunnel

Structure Type

- Fault Location (inferred)
- Dyke Location (inferred)
- Fold Location (observed)
- Palaeochannel Location (inferred)
- WCX2 Alignment

Note: Multiple tests have been conducted at each location and there may be more than one test corresponding to each Lugeon range.

Service Layer Credits: © Land and Property Information 2015



CLIENT
CPB DRAGADOS SAMSUNG JV

PROJECT
WESTCONNEX STAGE 2 NEW M5 MOTORWAY

0 100 200 300 400 500 METRES

REFERENCE SCALE: 1:10,000 (at A3)
PROJECTION: GDA 1994 MGA Zone 56

TITLE
PACKER TESTING RESULTS

YYYY-MM-DD	2016-10-28
PREPARED	HSG
DESIGN	HSG
REVIEW	--
APPROVED	

PROJECT No.	CONTROL	Rev.	FIGURE
1524285	001	A	2.17.3

Path: J:\Hyd\2015\Sydney\WCX Brisbane Working Folder\GIS\Project\Hydrogeological Design Maps\Figure 2_17_1-2_17_3 Packer Testing.mxd

IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: A3

It can be seen from Figure 2.17.2 that there are a number of high Lugeon values measured immediately to the south of Cooks River at Arncliffe. These high test results are associated with sub-vertical fracture zones and zones of sub-horizontal shearing. At locations other than Arncliffe, high inflows associated with higher permeability faults and associated shear zones would be expected to persist for only relatively short periods of time, because of the limited storage of these features and lack of connectivity to an ongoing source of water. At Arncliffe, however, in the absence of measures such as grouting to reduce permeability, sustained high inflows to the tunnels in this area are likely to occur because of the presence of overlying saturated alluvium that is hydraulically well connected to both the Cooks River and the underlying rock.

Results from packer testing conducted at Arncliffe are summarised and compared to other test results in Figures 2.18 and 2.19. The following points are noted about these results:

- There is not a clear trend of changing permeability with depth for the results from Arncliffe and elsewhere in the WestConnex Stage 2 corridor.

- Overall, the results of packer testing at Arncliffe are similar to testing carried out in the remainder of the WestConnex Stage 2 corridor, and apart from the higher results at depth which also appear to be present throughout the remainder of the corridor, they are similar to test results from the broader region.

- At Arncliffe, the median permeability for features with a permeability of less than around 15 uL appears to be slightly higher than in the remainder of the WestConnex Stage 2 corridor. Features with permeability in this range are likely to include bedding and joints. The apparently higher permeability on average for these features in the Arncliffe area could be interpreted to be the result of faulting in this area, as illustrated in Figure 2.20.

- For both the results at Arncliffe, and results throughout the Westconnex Stage 2 corridor, there is evidence of a higher frequency of results in the range of approximately 15 uL to 40 uL. This is interpreted to be associated with narrow vertical faults and shear zones along bedding (related to the faulting), such as the zone of horizontal shearing, and the 2 m sub-vertical fault zone in the area of the tunnels as shown in Figure 2.21. Although the highest frequency of results is in the range of 15 uL to 40 uL, higher results of up to greater than 100 uL are also interpreted to be associated with these features.

- Higher permeability features with permeability of >100 uL are present regionally and throughout the WestConnex Stage 2 corridor, as well as at Arncliffe. These are interpreted to be associated with thicker zones of faulting.

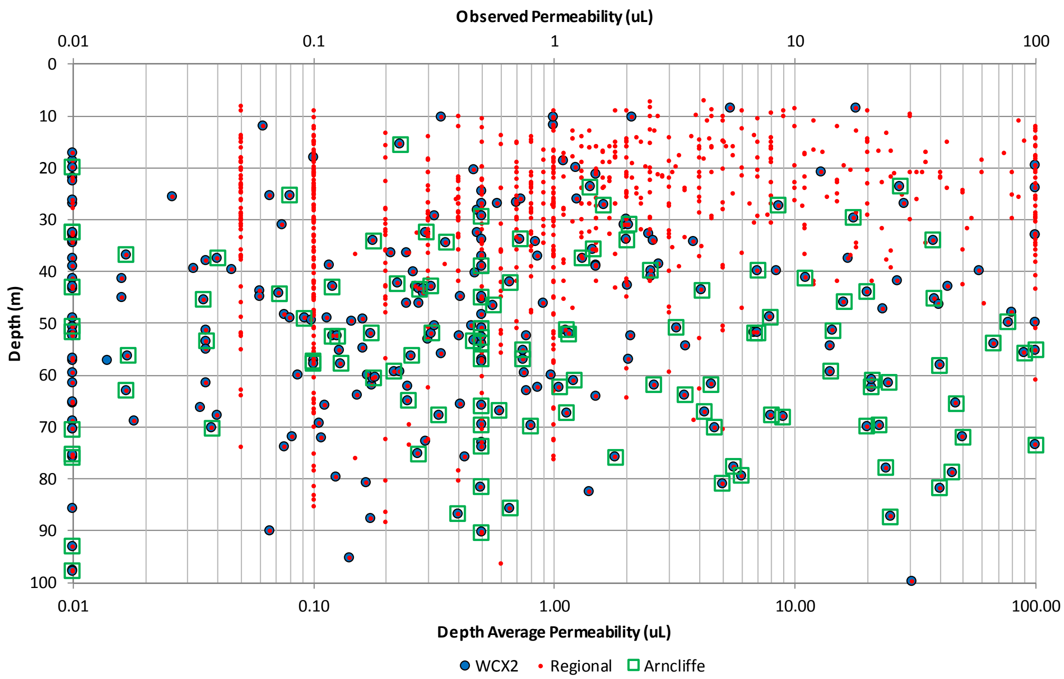


Figure 2.18: Results of packer testing in Hawkesbury Sandstone

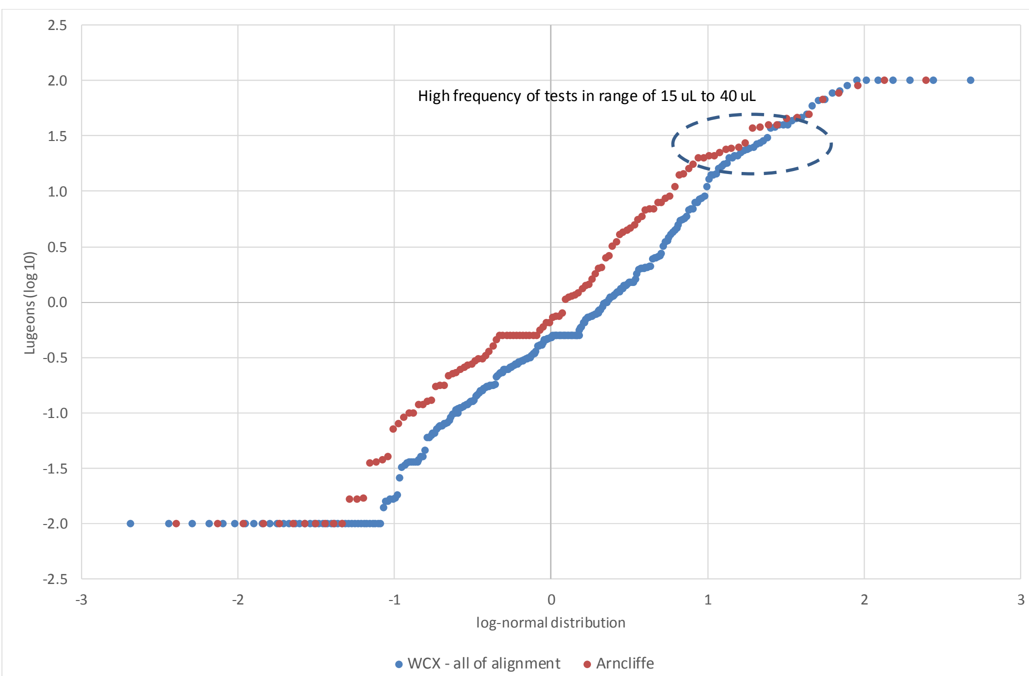
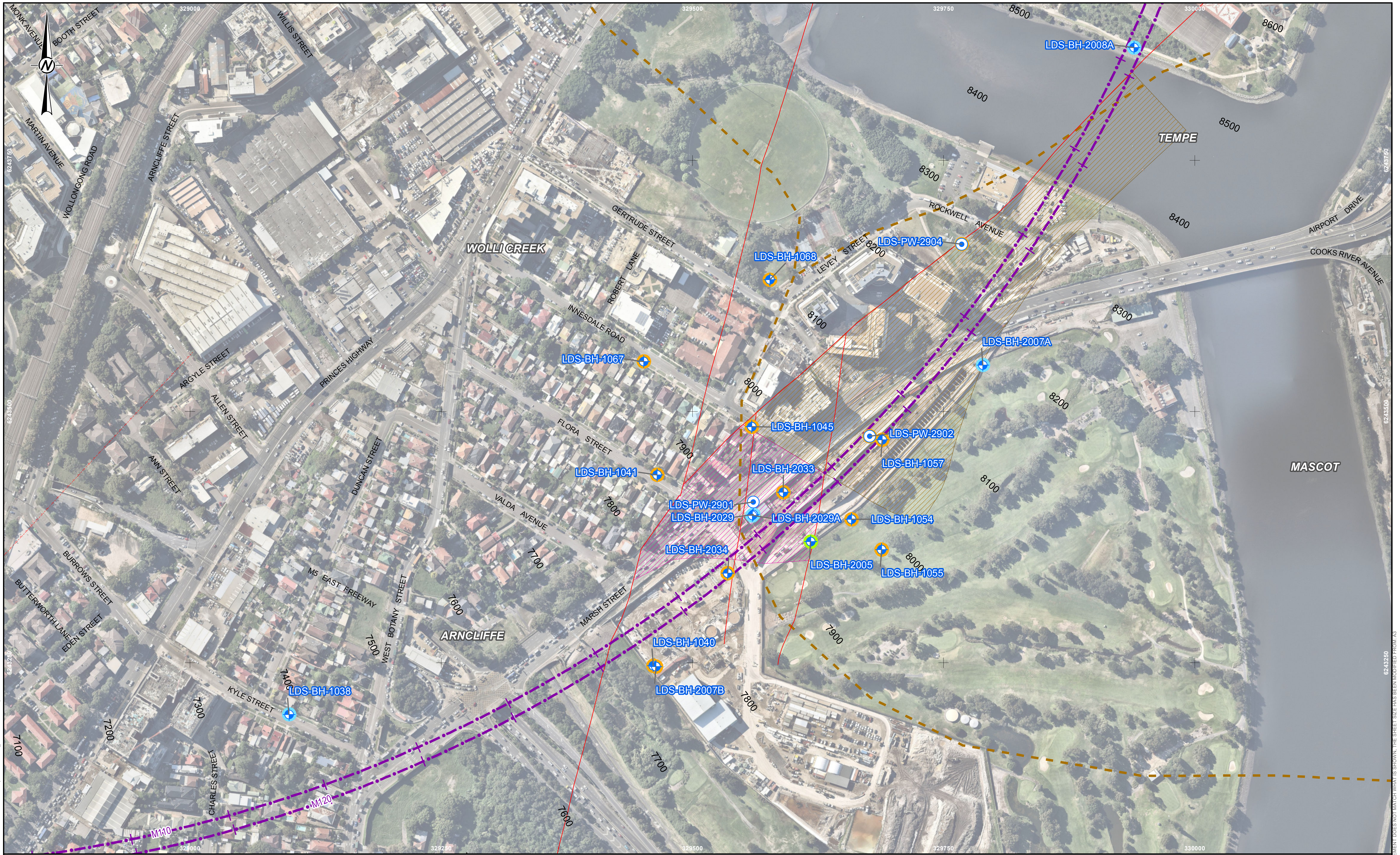


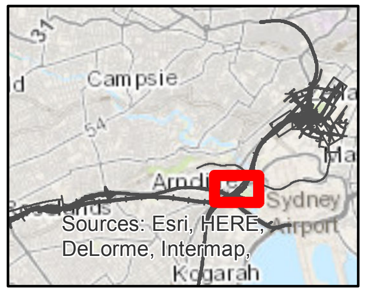
Figure 2.19: Results of packer testing in Hawkesbury Sandstone



LEGEND

Installation		Complete	
MW		Borehole	
VWP		Pump Well	
VWP+MW		Fault	
		Fault (Inferred)	

- Palaeochannel Axis
- Sub-horizontal shear zone RL -54 m to RL-59 m AHD
- Sub-horizontal shear zone RL -70 m AHD



CLIENT
CPB DRAGADOS SAMSUNG JV

PROJECT
WESTCONNEX STAGE 2 NEW M5 MOTORWAY

0 40 80 120 160 200
METRES

REFERENCE SCALE: 1:3,500 (at A3)
PROJECTION: GDA 1994 MGA Zone 56

TITLE
ARNCLIFFE SHAFT ZONES OF HIGHER PERMEABILITY
M5N-GOL-DRT-100-200-GT-1525

CPB CONTRACTORS | DRAGADOS | SAMSUNG C&T | WestConnex Stage 2 M5 | Golder Associates

YYYY-MM-DD	2017-05-01
PREPARED	JEC
DESIGN	LBM
REVIEW	-
APPROVED	

PROJECT No. 1524285 | Rev. A | FIGURE **2.20**

IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: A3

Path: J:\geo\2016\1658093_LeightonWCX2_Design&CPS_Syd\7.0 Technical Data\7.04 GIS\Project\2017-03-31_ArncliffePermeabilityZones.mxd

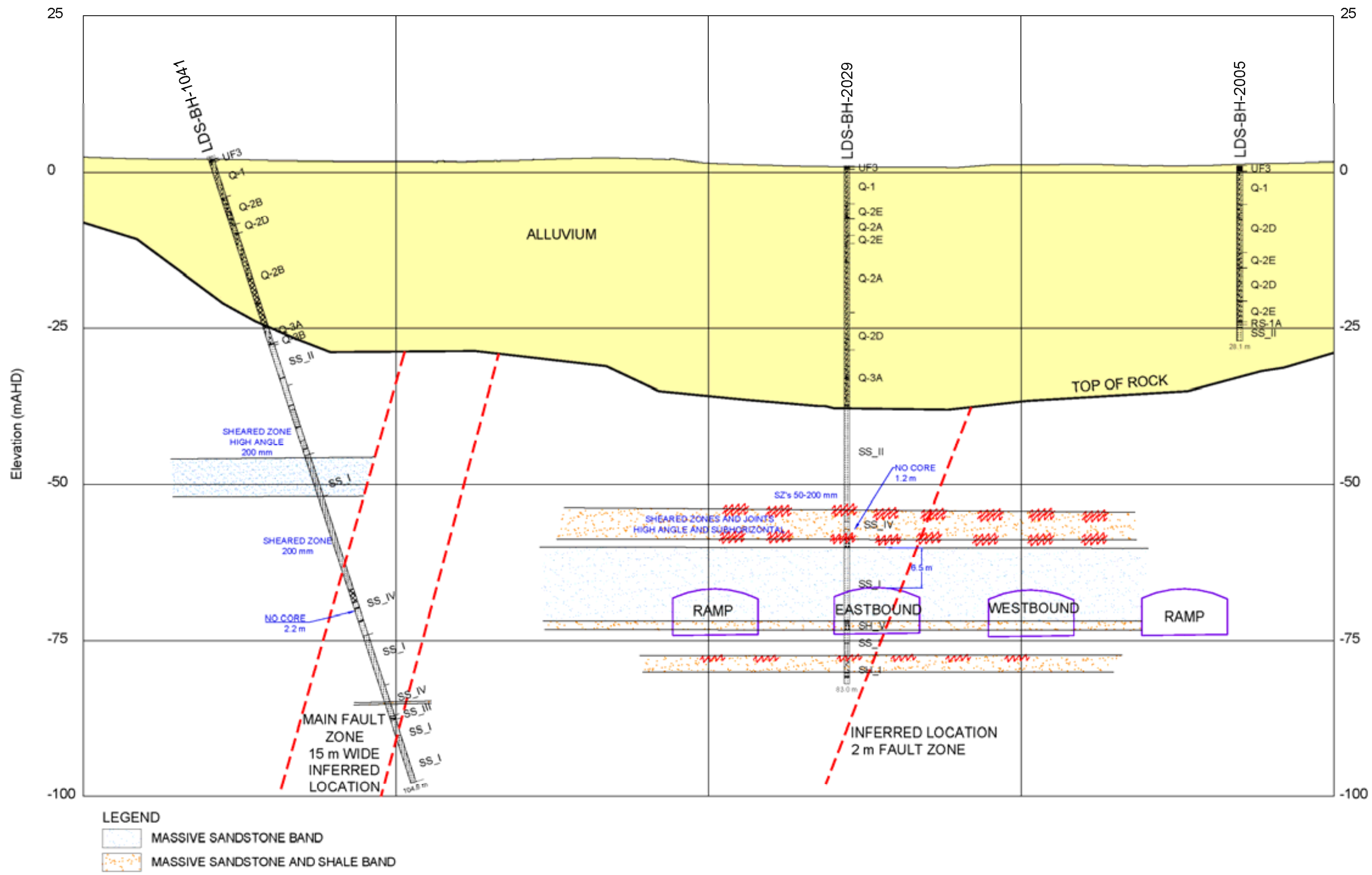


Figure 2.21: Zones of higher permeability associated with faulting at Arncliffe

Results of Pumping Tests at Arncliffe

Two pumping tests were carried out at Arncliffe to assess the hydraulic conductivity of the Hawkesbury Sandstone at a larger scale than the scale of individual packer tests, and to assess the degree of connectivity between the Hawkesbury Sandstone and the overlying alluvium. Details of these two pumping tests are summarised below.

March 2016 Pumping Test – Pumping Well LDS-PW-2901

A pumping test was carried out in March 2016, which comprised pumping from a single well (LDS-PW-2901) for a period of 4.5 days.

Pumping well LDS-PW-2901 comprises a 150 mm diameter cased section through the alluvium, and a 140 mm diameter open-hole section in the Hawkesbury Sandstone below the base of the alluvium. The final depth for the well was 61.5mbgl. Water bearing fractures were intersected in the borehole between 51 m and 60 m depth below ground level, with airlift yields from the well of approximately 2.5 L/s. Packer test results in an adjacent borehole at similar depths indicated Lugeon values of 70 uL and 100 uL. It is interpreted that the higher permeability features intersected between 51 m depth and 60 m depth are associated with the zone of sub-horizontal shearing at RL -54 m to RL -59 m indicated in Figure 2.20 and Figure 2.21.

The pumping test was carried out at a constant rate of 2 L/s, for a period of 4.5 days in early March 2016. Further details regarding the setup of the pumping test and monitoring network, and the results of the testing are described in Annexure J.

Key aspects of the observed responses to the pumping test are:

- The rate of increase in drawdown in the pumping well decreased between 10 and 20 minutes after the commencement of the test.
- Drawdown propagated rapidly in the Hawkesbury Sandstone. As an example, a measurable response was observed within 500 minutes at a distance of approximately 265 m from the pumping well, at monitoring well LDS-BH-2007A.
- A clear response is evident in the alluvium at distances of up to 190 m from the pumping well (i.e. in LDS-BH-2007A). No measurable response was observed at a distance of approximately 540 m in LDS-BH-2003.

The reduction in the rate of drawdown in the pumping well between 10 and 20 minutes after the commencement of the test is interpreted to be, at least in part, a result of the effects of leakage from the overlying alluvium.

Analysis of the pumping test results using the Barker and Black (1983) solution for dual porosity fractured rock aquifers indicates a large scale hydraulic conductivity for fracture network intersected by the 20 m long open-hole section of the pumping well of between $3x10^{-6}$ m/s to $1x10^{-5}$ m/s, with 6 of the 9 monitoring well locations indicating a hydraulic conductivity in the range of $3x10^{-6}$ m/s to $6 x10^{-6}$ m/s, and the remaining 3 wells indicating a hydraulic conductivity in the range of $9x10^{-6}$ m/s to $1x10^{-5}$ m/s.

July 2016 Pumping Test – Pumping Wells LDS-PW-2902 and LDS-PW-2904

A second pumping test was carried out in July 2016, which comprised pumping from two wells (LDS-PW-2902 and LDS-PW-2904) over a period 15 days. Over this time, there were periods of pumping from each well independently, and periods of concurrent pumping from both wells.

Pumping well LDS-PW-2902 comprised:

- a 143.8 mm OD diameter flush joint steel casing which is pressure grouted into the Hawkesbury Sandstone between the top of rock which was encountered at approximately 18.5 mbgs, and the toe of the casing at 33 mbgs.
- A 123 mm diameter open hole in the Hawkesbury Sandstone from 33 mbgs to 80 mbgs.

A fractured zone was intersected at approximately 43-44 mbgs and produced 2.5-3 litres per second (L/s) during airlifting. The airlift yield remained reasonably constant below this depth. No other significant water bearing intersections were encountered.

Pumping well LDS-PW-2904 comprised:

- a 158.5 mm OD diameter flush joint steel casing progressed to 52mbgs. Top of rock was encountered at approximately 38mbgs.
- 125 mm diameter PVC casing pressure grouted within the steel casing
- A 123 mm diameter open hole in the Hawkesbury Sandstone from 52 mbgs to 92 mbgs.

A significant fracture zone was intersected at approximately 83 mbgs and produced and estimated 13-14 L/s during airlifting. No significant water bearing intersections were encountered above this depth.

Pumping well LDS-PW-2902 was pumped at a rate of 2 L/s for approximately 12 days from 12:35 pm on 15 July 2016 to 12:20 pm on 27 July. Test pumping for LDS-PW-2904 was intermittent due to generator failure issues throughout testing. Test pumping commenced at 3:10 pm on 21 July 2016 and was terminated at 5:29 pm on 29 July 2016. The well was pumped at a rate of 6 L/s during periods of pumping. Two main periods of pumping occurred: from 3:10 pm on 21 July 2016 to 1:00 pm on 23 July 206; and from 2:00 pm on 25 July 2016 to 5:30 pm on 29 July2016.

Further details regarding the setup of the pumping test and monitoring network, and the results of the testing are described in Annexure K.

Key aspects of the observed responses to the pumping test are as follows:

- Drawdowns of up to 16 m were observed at monitoring locations in the Hawkesbury Sandstone, in response to combined pumping from PW2902 and PW2904. Very rapid responses to changes in pumping were observed at some monitoring locations, and somewhat slower responses were observed at other locations. This difference is interpreted to relate to the proximity of the vibrating wire piezometer sensors to higher permeability features.

- Drawdowns of up to approximately 4 m developed in the alluvium, at locations of up to 195 m from the pumping wells. It is noted that at some locations in close proximity to LDS-PW-2902, relatively little drawdown was observed in the alluvium, compared to the drawdown in the underlying Hawkesbury Sandstone. The response in the alluvium appears to be relatively variable, which is interpreted to reflect the variability of interbedding of sands and clays within the alluvium.

- Settlement of up to 10 mm may have resulted from the drawdowns associated with the pumping test. Rebound of settlements after the termination of pumping was observed at some locations.

The magnitude of response observed at monitoring locations in the alluvium in both pumping tests within a relatively short period of time indicates a high degree of hydraulic connection between the Hawkesbury Sandstone and the alluvium. This is consistent with the stratigraphy encountered in recent investigations in the area, which indicates that the alluvium comprises interbedded sands and clays with discontinuous, “inter-fingered” lenses of sand and clay, without a continuous low permeability clayey unit at the base of the alluvium as is present further to the east.

Review of Data from other Sources

Annexure L contains a review of hydraulic parameters from sources other than testing carried out for the WestConnex Stage 2 project, including test results for hydrostratigraphic units that have not been tested in testing to date on this project.

2.2.14 Groundwater Chemistry

There are 125 groundwater monitoring bores containing water chemistry parameters reported in the NSW groundwater database, reviewed documents and site investigations for the project. Water quality data is summarised in Annexure M.

Of the 125 bores, 29 contain a complete set of cation and anion analytical records; 2 of which are in the fill, 9 in Quaternary sediments, 7 in the Ashfield Shale, 13 in the Hawkesbury Sandstone and 1 in dyke material (basalt). Based on available data, the monitoring locations are categorised into four different groundwater types within the monitored formations as shown in Table 13. A Piper diagram was generated to determine hydrogeochemical classification of each formation tested and is shown in Figure 2.22. The milliequivalents percentage of major cations and anions are shown by separate ternary plots to the lower left and right of the diagram. The apexes of the cation plot are calcium, magnesium and sodium plus potassium cations. The apexes of the anion plot are sulfate, chloride and carbonate plus hydrogen carbonate anions. The two ternary plots are then projected onto the central diamond field, which provides the overall character of the water.

Table 13: Groundwater type based on water quality results

Formation Tested	Number of Locations	Groundwater Type
Fill	2	Sodium/Potassium and Chloride
Quaternary sediments	9	Sodium/Potassium and Chloride
Ashfield Shale	7	Sodium/Potassium and Chloride
Hawkesbury Sandstone	13	Calcium/Sodium/Potassium/Chloride and Sulfate
Basalt	1	Calcium/Sodium/Potassium/Chloride and Sulfate

Note: Subject to change with results from on-going CDS investigations

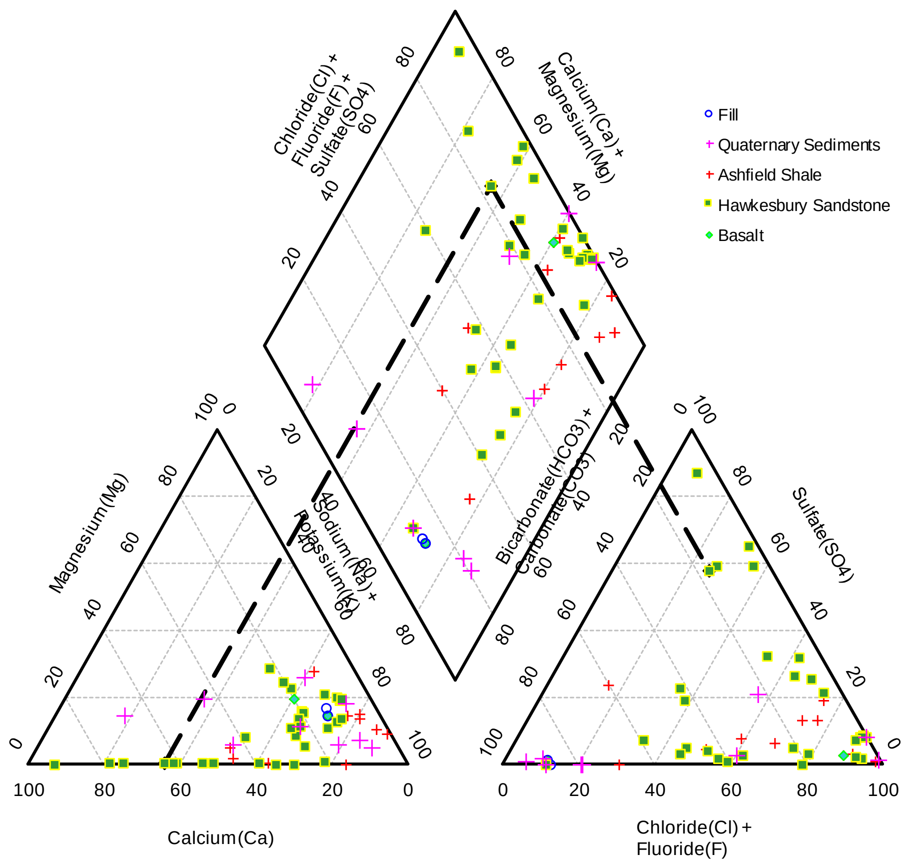


Figure 2.22: Piper diagram of hydrostratigraphic units.

2.2.15 Groundwater Contamination

A number of landfills are present to the north of the Cooks River, in the southern part of Arncliffe at Bardwell and Kingsgrove. The landfills have generally been developed within former brick pits and contain leachate of variable quality. Depressurisation of the groundwater table due to tunnel construction is considered likely to result in movement of the waste impacted groundwater towards the tunnel and potentially to result in the contaminated groundwater entering the tunnel.

Two groundwater sampling rounds were undertaken during 2015 for selected bores located along the tunnel alignment, in March and November 2015. During the first round in March, 12 bores were sampled and during the second monitoring round in November, 19 bores were sampled. Another two sampling rounds were conducted between April and August 2016, using additional monitoring bores that had been installed for establishing baseline groundwater conditions. In total 22 bores were sampled during the third round of monitoring and 26 bores for the fourth event. Samples collected were analysed for major ions, metals and nutrients (ammonia, nitrogen and phosphorus). A summary of analytical results for the first two sampling rounds is attached in Annexure M. Results of the third and fourth sampling rounds are reported in M5N-GOL-TER-100-200-GT-1510.

The laboratory results were assessed considering the ANZECC (2000) guidelines for 95% protection of marine species given that groundwater ultimately discharges into the ocean. Where the bore location is close to the creek and at a distance from the ocean (i.e. WCX-BH-018) the relevant guidelines for 95% protection of freshwater species were used. In addition, the risk to tunnel inflows was also considered in this section.

In general, sampling in March 2015 indicated that majority of metals, nutrients and hydrocarbons were below detection limit and below the ANZECC (2000) guidelines. Copper and chromium exceeded ANZECC (2000) guidelines in bores WCX-BH-018 (Cr 0.07 mg/L), WCX-BH-084 (Cu 0.005 mg/L) and WCX-BH-143 (Cr 0.12 mg/L and Cu 0.006 mg/L). Nickel was found to exceed guidelines in one bore WCX-BH-204 (0.021 mg/L). The likely reason for low metal concentrations is generally elevated pH in most bores and typically alkaline conditions.

Although total petroleum hydrocarbons (TPH) comprise many different compounds and are not a direct indicator of risk to environment, generally the light fraction was detected above the detection limit in WCX-BH-039, WCX-BH-084, WCX-BH-168 and WCX-BH-153. None of the aromated hydrocarbons were above the ANZECC (2000) guidelines.

Nutrients were typically low, with no exceedance for nitrate, however ammonia was found above guidelines in WCX-BH-039 (1.31 mg/L), WCX-BH-036 (1.74 mg/L) and WCX-BH-204 (1.96 mg/L) located close to Cooks River and WCX-BH-084 (1.24 mg/L).

The sampling event in November 2015 indicated different and mainly elevated levels of nutrients and metals. Total nitrogen (TN) and total phosphorus (TP) concentration exceeded ANZECC (2000) guidelines in most groundwater bores, in particular WCX-BH-24 (7mg/L , 0.62 mg/L), WCX-BH-029 (TN 7.7 mg/L), WCX-BH-063A (47.1 mg/L, 1.1 mg/L), WCX-BH-115 ((5.2mg/L, 0.7mg/L) and WCX-BH-122 (9.3 mg/L, 1.1 mg/L). Ammonia concentration was also high and above the ANZECC (2000) guidelines in these bores. Most of these bores are located close to green areas, industrial zones and landfills, which is to be expected since the source of nitrogen, ammonia and phosphorus is related to anthropogenic sources (waste production, fertilisers, septic systems and industrial discharge).

In addition to high nutrient content, the levels of zinc and copper were also elevated and above the ANZECC (2000) guidelines. This is mainly observed in WCX-BH-024 (Zn 0.038 mg/L), WCX-BH39, WCX-BH-063 and WCX-BH-063A, WCX-BH-072, WCX-BH-109 (Zn 0.042 mg/L) and WCX-BH-115.

Copper concentrations were exceeded in WCX-BH-109 (0.004 mg/L), WCX-BH-115 (0.011 mg/L), and WCX-BH-153 (0.006 mg/L). Chromium levels were exceeded in one bore only WCX-BH-153 (0.006 mg/L). High concentrations of these metals point to the industrial source, in particular given that elevated copper is found in the Tempe and St Peters area only.

Iron and manganese concentration in groundwater do not generally exceed 10 mg/L and 2 mg/L, however the 95% trigger level protection of ecospecies (ANZECC(2000)) for manganese is 0.9 mg/L. Iron and manganese levels were generally low in the March 2015 sampling event, with the exception of WCX-BH-168 near Cooks River (12.8 mg/L Fe and 0.9 mg/L Mn) and WCX-BH-143 in the Bardwell Park (6.85 mg/L Fe and 0.1 mg/L Mn). Monitoring round undertaken in September 2015 reported one manganese exceedance of 1.9 mg /L in WCX-BH 152s near Cooks River, and elevated concentration in WCX-BH122 (1.36 mg/L) in St Peters area. Iron concentrations are elevated in WCX-BH24, WCX-BH36, WCX-BH63A, WCX-BH122, WCX-BH152S and WCX-BH152D, with a maximum being 261 mg/L in WCX-BH152S.

Groundwater quality sampling in the Arncliffe area was undertaken in selected bores (LDS-BH-2005 – alluvium, LDS-BH-2029-Hawkesbury Sandstone, LDS-BH-2029A-alluvium and PW2901–Hawkesbury Sandstone) prior to and during the pumping test in February and March 2016. The results of the analysis are provided in Annexure M. The samples were analysed for major ions, heavy metals, nutrients and selected but comprehensive suite of organic contaminants. The results indicate that within the Arncliffe area groundwater quality is extremely saline (up to 430000 µS/cm), has elevated total phosphorus, nitrogen (up to 0.11 mg/L and 4.1 mg/L) and ammonia (up to 2.1 mg/L) above the ANZECC (2000) guidelines for 95% protection of marine and freshwater species. Most hydrocarbon components are below detection limits, and none are above the ANZECC (2000) guidelines. Out of eleven tested heavy metals in groundwater, only manganese and zinc were above the ANZECC (2000) guidelines in all bores with a max of 3.8 mg/L and 0.08 mg/L, respectively. Chromium and nickel are just above the guidelines (0.002 mg/L and 0.004 mg/L) in LDS-BH-2029 deep and shallow bore and PW2901, respectively. Although iron does not have trigger levels identified based on the ANZECC (2000) guidelines, the concentration found in groundwater at Arncliffe is very high up to 340 mg/L.

The results of the April 2016 groundwater sampling identified 12 bores having concentrations of phenol, BTEX, PAH, TRA and PHC above detection limits. One sample (WCX-BH72) contained xylene at a concentration of 0.8 µg/L.

ANZECC (2000) guideline values for 95% protection of marine species was exceeded for ammonia in 14 samples with one sample result (LDS-BH-3047) exceeding 30000 µg/L. The same sample returned methane concentration of 1712 µg/L.

Six samples (WCX-BH-122, LDS-BH3046, LDS-BH3047, LDS-BH3047A, LDS-BH3057 and LDS-BH3057A) returned concentrations in cobalt and zinc that exceeded ANZECC (2000) guideline values for 95% protection of marine species. All six bores are within close proximity to the Alexandria Landfill and Sydney Park.

Groundwater exceeding nutrient, TPH, manganese and iron concentration is generally found in a number of bores within the Arncliffe and Cooks River area. Groundwater bores in the vicinity of the eastern portal at St Peters and Tempe have in general elevated nutrient (total nitrogen and total phosphorus) and zinc and copper concentrations and higher likelihood of contaminated groundwater inflows due to presence of other old landfill areas. However, inflows in this part of the tunnel will be relatively low given the low permeability of shale and siltstone, and as a result of leachate control systems at some of the landfills lowering the groundwater table within the landfill.

Water quality parameter records for the 18 month monitoring show variations in some of the parameters. These variations may be due to naturally occurring attenuation processes which may vary seasonally or in response to rainfall events.

Risks of groundwater contamination to durability of the tunnels and surface works are addressed elsewhere. Water treatment of construction waste water and treatment of long-term groundwater inflows to the tunnels is reported elsewhere.

2.3 Method of Analysis

Assessment of groundwater impacts as a result of tunnel drainage has been made using numerical groundwater models. The models have been developed in accordance with protocols outlined in the Australian Groundwater Modelling Guidelines (Barnett et al., 2012). A regional scale model has been developed for the assessment of overall tunnel inflows along the entire project alignment, and groundwater drawdowns across the area potentially impacted by the project. A local scale model centred on the area of the Arncliffe tunnels and cavern has also been developed to allow a more accurate representation of the highly permeable geological structures that have been identified in this area as part of more recent site investigations, and to allow a more accurate representation of the drawdown in alluvial sediments overlying the tunnel alignment in this area.

Details of the conceptual models are provided in Section 2.3.3. Setup and development of the regional and local scale models are outlined in the Section 2.3.4 and Section 2.3.5, respectively. The construction sequence considered for predictive modelling is discussed in Section 2.3.6.

2.3.1 Justifications for Developing Additional Groundwater Models

CDM Smith (2015) developed a regional scale three-dimensional groundwater flow model which was used as part of the assessments carried out for the EIS for the project, as reported in AECOM 2015b. This model was developed with the MODFLOW-USG code and based on limited geological and hydrogeological information that was available at the time of model development.

New groundwater models were developed for the current assessment of groundwater impacts to allow for the following refinements to be made to the modelling in order to more accurately assess potential groundwater impacts:

- Inclusion of an updated geological model for the project corridor and beyond, based on geotechnical and hydrogeological investigations carried out subsequent to the EIS. This geological model has additional detail regarding boundaries between geological units (e.g. the boundary between the Hawkesbury Sandstone and the Ashfield Shale or the alluvial sediments), greater refinement of the geological units within the alluvial sediments overlying rock, and significant additional detail regarding the location and depth of paleochannels and faults/shear zones in the vicinity of the Arncliffe tunnels and cavern. The small drawdown predicted by the CDM Smith model for the Arncliffe area and Cooks River tunnel crossing suggest that the omission of these highly transmissive structures in the model has resulted in the optimistic groundwater drawdown and tunnel inflow estimates reported in CDM Smith (2015).

- Refinements to model boundary conditions to more realistically represent the groundwater - surface water interaction along the Alexandra Canal, Cooks River, Wolli and Bardwell Creeks, and to allow for spatially variable recharge. CDM Smith simulated net groundwater recharge through the upper model surface using a single, constant recharge rate applied across the entire upper model domain surface. The models that have been developed for the current assessment allow for spatial variation in recharge rates depending on soil characteristics and land use. These changes in boundary conditions were necessary to more accurately estimate drawdown in the soil materials overlying rock, which are required to inform the settlement analysis and the design of mitigation measures to ensure compliance with CoA.

- Inclusion of the now proposed alignments of tunnels, caverns, and other underground structures (e.g. cross-passages and vent tunnels/shafts), and other underground structures such as the existing M5 East tunnels which have the potential to impact on groundwater. Groundwater drainage by ventilation tunnels and shafts from the surface to the main tunnels and cross passages between the tunnels and between the SPI ramps were excluded from the CDM Smith model. Mesh refinement at the particular locations of these features was required to allow for them to be explicitly included in the modelling.

- Modelling of the progressive excavation of underground structures, to allow an assessment of the development of inflows over time.

2.3.2 Confidence Level Classification of the Groundwater Models

The model development took into consideration both the Murray Darling Basin Commission Groundwater Flow Modelling Guideline (MDBC, 2001) and the Australian Groundwater Modelling Guidelines (NWC, 2012).

The NWC 2012 guideline builds on the 2001 MDBC guideline and has the concept of "model confidence level", which is defined using a number of modelling criteria. These criteria relate to data availability, design, calibration and performance (predictions). A summary of model confidence class characteristics, taken from NWC 2012, is provided in Table 14.

Table 14: Groundwater model confidence level classification

Class	Data	Calibration	Prediction	Indicators
1	Not much. Sparse. No metered usage. Remote climate data.	Not possible. Large error statistic. Inadequate data spread. Targets incompatible with model purpose.	Timeframe >> calibration Long stress periods. Transient prediction but steady-state calibration. Bad verification.	Timeframe > 10x Stresses > 5x Mass balance > 1% (or single 5%) Properties <> field measurements Bad discretisation. No review.
2	Some. Poor coverage. Some usage info Baseflow estimates	Partial performance. Long-term trends wrong Short time record. Weak seasonal replication. No use of targets compatible with model purpose	Timeframe > calibration Long stress periods. New stresses not in calibration. Poor verification.	Timeframe 3-10x Stresses 2-5x Mass balance < 1% (or single 5%) Some properties <> field measurements. Some key coarse discretisation, Review by hydrogeologist
3	Lots. Good aquifer geometry. Good usage info. K measurements. High-resolution DEM	Good performance statistics, Long-term trends replicated. Seasonal fluctuation reproduced, Present day data targets, head and flux targets.	Timeframe ~ calibration. Similar stress periods. Similar stresses to those in calibration. Steady-state prediction consistent with steady state calibration. Good verification	Timeframe <3x Stresses <2x Mass balance < 0.5% Properties ~ field measurements. Some key coarse discretisation. Review by modeller.

A large amount of test data, a detailed geological ground model and 18 month of groundwater monitoring records with a good coverage within the Project Corridor were available for the groundwater models development. Data coverage outside of the Project Corridor is poor due to the nature of the linear project. Key parameters of the calibration performance statistics are good, with calibration performed to steady state and short-term transient conditions. Mass balance error is better than 0.5% and calibrated model parameter values are well within the range of values estimated by hydraulic tests conducted at locations within the Project Corridor and the wider Sydney region.

The predictions of the models are currently not validated and the time frame of prediction exceeds the period for which calibration data are available. For these reasons, the regional and local scale models described in the following sections are considered to have an upper Level 2 confidence level classification.

A peer review of the groundwater models was completed by the independent consultant, Dr Noel Merrick / HydroSimulations, based on an earlier version of this report. The peer review report is attached in Annexure Q. The reviewer concluded that:

"The primary predictive numerical groundwater model for the Project is judged to be fit for purpose, where the purpose is for estimation of likely tunnel inflows, mitigation by grouting of permeable geological structures, and evaluation of drawdown impacts."

and further:

"The conceptual model has taken into account at least 12 months of current baseline groundwater monitoring data, as required. The numerical model has focused on steady state calibration and short-term transient calibration, both of which have good performance.

In terms of the Terms of Reference:

1. *The design inputs and seepage modelling methodology are considered appropriate.*
2. *Compliance with the requirements of the BCoA Sections B26 and B27 has been achieved.*
3. *The groundwater modelling report has been undertaken in accordance with the Australian Groundwater Modelling Guidelines (National Water Commission, 2012).*
4. *Given the substantial monitoring record already available, the reviewer is of the opinion that there is no need for any supplementary investigations. The packer testing is more than sufficient to characterise the Hawkesbury Sandstone, and the 7-day pumping test at Kogarah Golf Club is sufficient to characterise the alluvium and the interactions between the alluvium and sandstone[1]. There is no need for additional groundwater modelling, as adequate sensitivity analysis has been done to indicate the uncertainty in tunnel inflows, and sufficient exploration of mitigation options has demonstrated the practicality of a grouting solution to the higher inflows expected when a tunnel intersects a geological structure."*

2.3.3 Conceptual Model used for Groundwater Model Development

Most of the elements of the conceptual hydrogeological model used as the basis for development of the numerical model are presented in the foregoing sections. These sections describe the conceptual model at the larger scale for the existing conditions without the changes to the system that will occur as a result of the tunnel construction for this project. More detailed conceptual models for certain local components of the groundwater system under the conditions as they will be modified by the project are described in the following sections.

[1] Note that the review was carried out at a time before the second pumping test.

Conceptual section for Kingsgrove

The Kingsgrove portal will be constructed as a cut and cover with vertical pile walls installed into the top of competent rock as well as cut and cover sections. The area is conceptualised to contain abundant heterogeneous fill in the surficial area with a dominant lithology of low permeability Quaternary sediment and residual soil below the fill. Water levels at this location are anticipated to be below the fill in the Quaternary sediment and residual soil; however, perched systems may exist due to the heterogeneity of the fill material. Water flow may be experienced from the fill material after recharge events. The Hawkesbury Sandstone is a semi-confined unit at this location and experiences a potentiometric groundwater level above the ground level (artesian conditions – LDS-BH-1025A and LDS-BH1064). Recharge and discharge in Kingsgrove is anticipated from Wolli Creek, irrigation, sewer, storm water and water mains leakage in addition to natural processes.

The conceptualisation for the Kingsgrove area is illustrated in Figure 2.23.

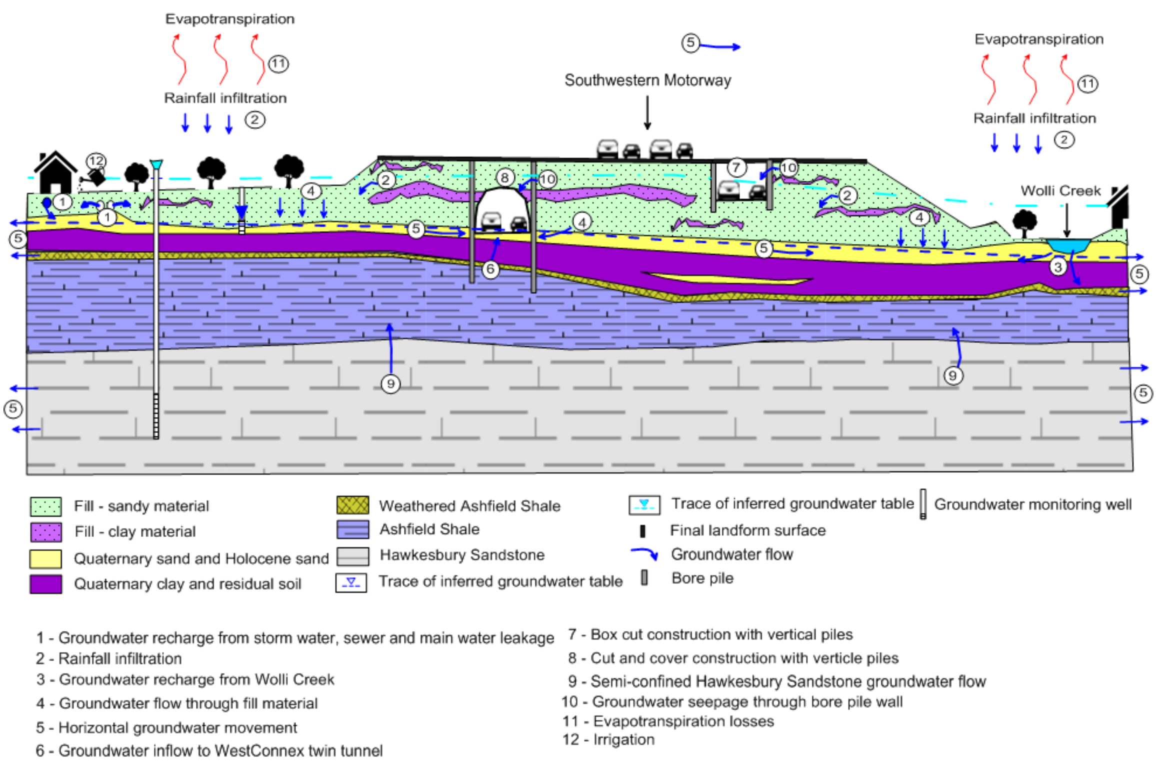


Figure 2.23: Conceptual cross-section for Kingsgrove at Chainage 1800

Conceptual section for the Bexley ventilation

The Bexley construction and ventilation shaft will be constructed to the same depth as the WCX2 twin tunnels. The construction shaft will decommissioned upon the completion of work. The area is conceptualised to contain shallow fill and Quaternary sediments underlain by the Hawkesbury Sandstone. Water levels at this location are anticipated to be variable based on M5 drainage affecting the water levels to the north of the Bexley Dyke. Groundwater levels to the north of the dyke are decreased compared to groundwater levels to the south of the dyke where the M5 tunnel will be constructed. The Hawkesbury Sandstone is a semi-confined unit at this location and experiences a potentiometric groundwater level below the ground level within the Hawkesbury Sandstone (sub-artesian conditions). Recharge and discharge in Bexley area is anticipated from Wolli Creek, irrigation, sewer, storm water and water main leakage and drainage by the rail systems in addition to natural processes.

The conceptualisation for the Bexley area is illustrated in Figure 2.24.

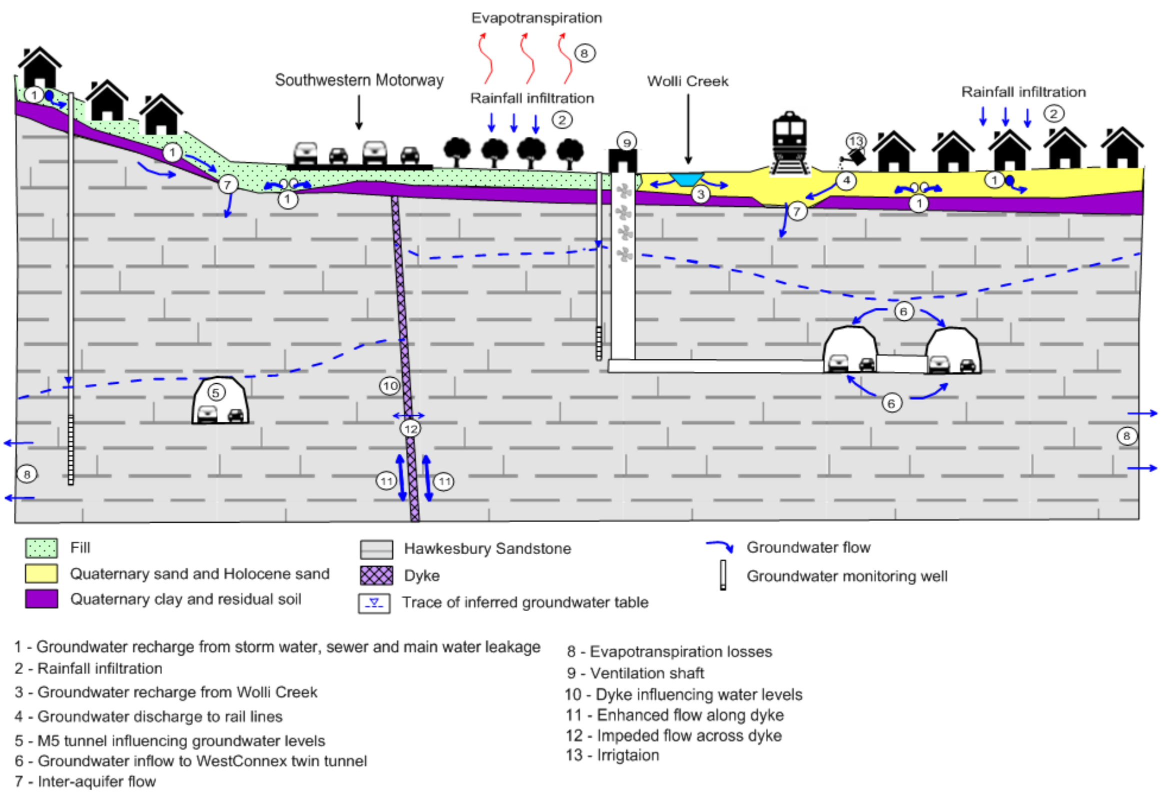


Figure 2.24: Conceptual cross-section for the Bexley construction and ventilation shafts

Conceptual section for Arncliffe and the Cooks River

The Arncliffe and Cooks River crossing will be constructed within the Hawkesbury Sandstone and may intersect the Woolloomooloo Fault and various fracture networks associated with the palaeochannel at the KGC. The area is conceptualised to contain Quaternary sediments underlain by the Hawkesbury Sandstone which has been scoured into and eroded by palaeochannels. Water levels at this location are anticipated to be related to sea level. Groundwater flow is anticipated to occur preferentially along the Woolloomooloo Fault and through stress-relief fractures associated with the palaeochannel which may enhance groundwater inflow to the tunnel. The Hawkesbury Sandstone is a semi-confined unit at this location and experiences a potentiometric groundwater level below the ground level within the Hawkesbury Sandstone (sub-artesian conditions). Recharge and discharge in Arncliffe and Cooks River area is anticipated from the Cooks River, irrigation, water main, sewer and storm water leakage in addition to natural processes.

The conceptualisation for the Arncliffe and Cooks River area is illustrated in Figure 2.25.

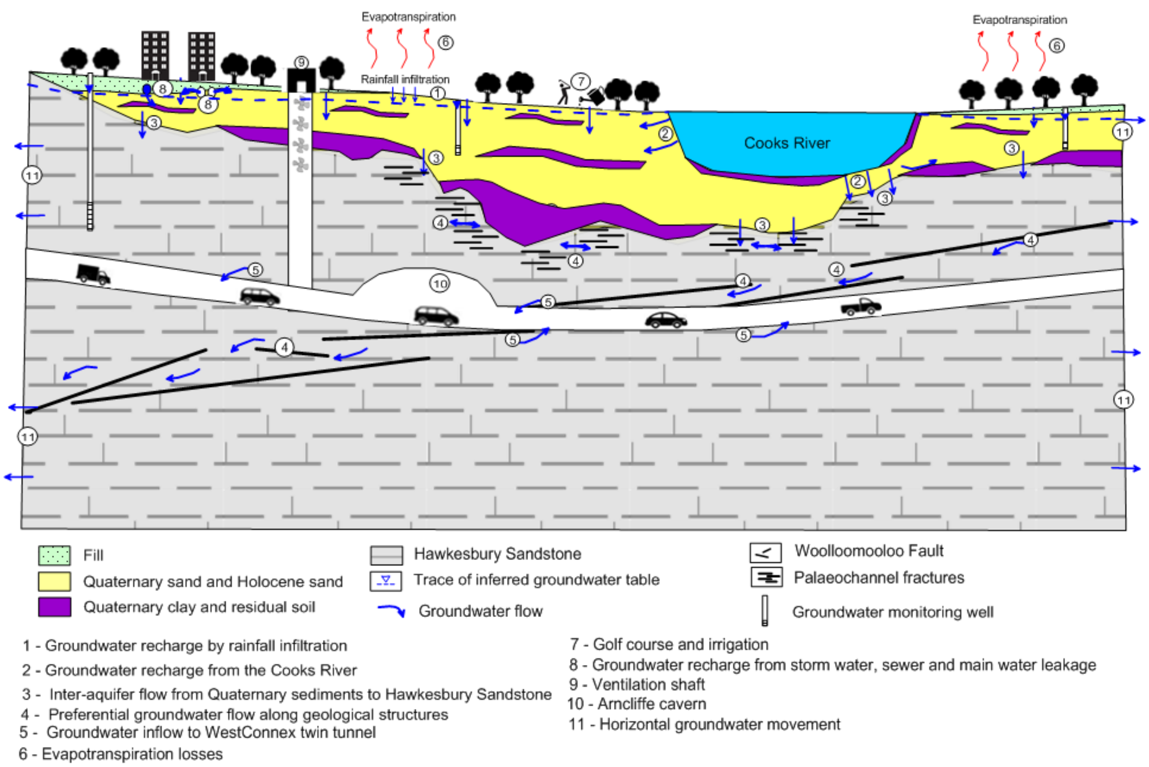
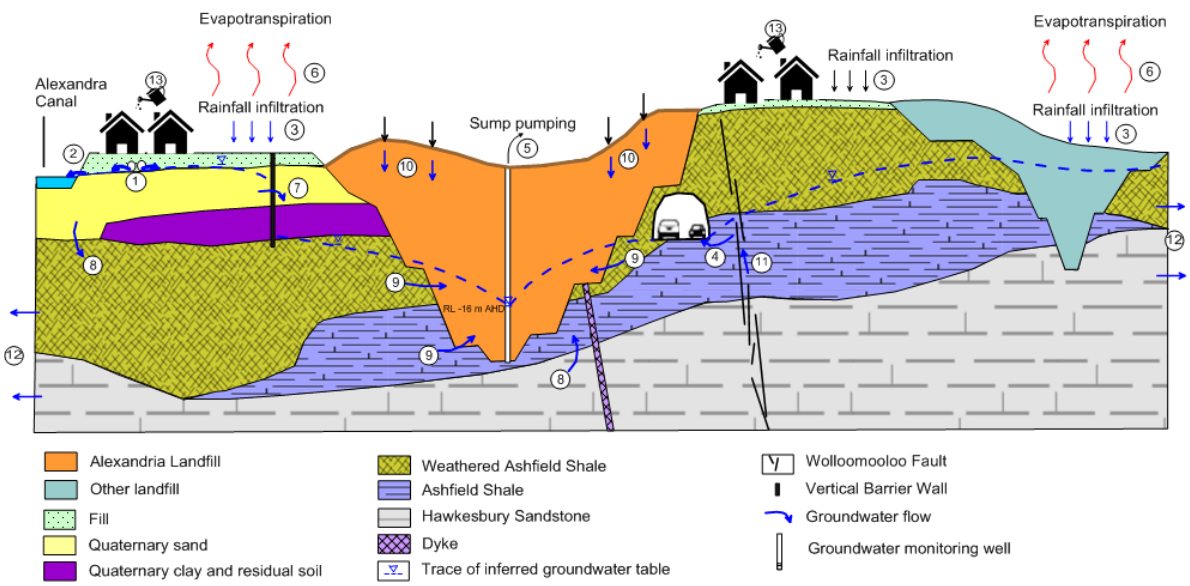


Figure 2.25: Conceptual long-section for Arncliffe and the Cooks River

Conceptual section for SPI

A portal will be constructed at SPI at the Alexandria Landfill. The area is conceptualised to contain fill material, Quaternary sediments, Botany Sands, weathered and unweathered Ashfield Shale and the Hawkesbury Sandstone. The St Peters dyke may affect groundwater levels in the area; however, its location is not known. Additionally, there is an inferred fault identified as the St Peters Fault which may act as a preferential pathway for groundwater flow. Water levels at this location are anticipated to be related to sea level in the Quaternary sediments and Botany Sands; this units is actively drained at the landfill which influences the groundwater level. A Vertical Barrier (VB) Wall will be installed into the Ashfield Shale to restrict water flow from the Quaternary sediment aquifer and the Botany Sand Beds aquifer. Water levels in the Ashfield Shale and Hawkesbury Sandstone are semi-confined and experience a potentiometric groundwater level below the ground level (sub-artesian conditions). Recharge and discharge in SPI area is anticipated from the Alexandra Canal, storm water and water mains, drainage by the Sydney Park and Alexandria Landfills and seepage into the landfill along structures in addition to natural processes.

The conceptualisation for the SPI area is illustrated in Figure 2.26.



1 - Groundwater recharge from storm water, sewer and main water leakage
2 - Groundwater discharge to Alexandra Canal
3 - Groundwater recharge by rainfall infiltration
4 - Groundwater inflow to M5 twin tunnel
5 - Leachate pumping from sump
6 - Evapotranspiration losses
7 - Groundwater seepage through Vertical Barrier Wall
8 - Inter aquifer flow
9 - Groundwater seepage to landfill
10 - Seepage through landfill cap
11 - Preferential groundwater flow along geological structures
12 - Horizontal groundwater movement
13 - Irrigation

Figure 2.26: Conceptual cross-section for SPI

2.3.4 Numerical Groundwater Model – Regional Scale Model

A 3D steady-state and transient numerical hydrogeological model has been developed (WCX2 groundwater model). Numerical modelling enables quantification of groundwater conditions and the rates of groundwater seepage to the shafts, adits and twin tunnels during construction and during operation for assessing if inflows are in compliance with CoA and SWTC.

Model Assumptions

The following key assumptions have been made for the development of the WCX2 groundwater model:

- The rock mass hydraulic conductivity of the Hawkesbury Sandstone, Mittagong Formation and Ashfield Shale can be approximated by the hydraulic conductivity of a homogeneous equivalent porous media.

- Flow of groundwater in the bedrock is assumed to mainly follow along open bedding partings and to a lesser extent along sub-vertical joints. This anisotropy in the flow is accounted for by adopting separate hydraulic conductivity values for horizontal and vertical flow within each homogeneous hydrogeological unit (vertical hydraulic conductivity may be locally enhanced along major geological structures).

- Average horizontal hydraulic conductivity estimates for the Hawkesbury Sandstone and Ashfield Shale – Mittagong Formation units assume log-normal distribution of water pressure test results. Our estimate assumes the average horizontal hydraulic conductivity estimate is representative for a rock mass volume.

- The Hawkesbury Sandstone aquifer is bounded at depth by an impervious layer.

- Recharge to the water table from above applies uniformly across 22 recharge regions (although recharge varies with the spatially varying soil and rock conditions above the water table and the enhanced recharge along drainage lines during storm events).

- For steady state modelling, recharge was assumed to be constant across all 22 recharge regions. For transient simulation, a time varying recharge term was applied to the 22 recharge areas to simulate seasonal changes in total recharge.

- All underground works are drained. Any impediment to tunnel inflow caused by temporary or permanent structures and support is not included in the model if not otherwise stated.

- The only drained underground structures within the modelling domain are the M5 East Motorway and the proposed WCX2. Impact of groundwater drainage due to deep sewer and stormwater infrastructure, drained building foundations or deep cuts along infrastructure lines is not included in the model.

Model Code Selection

The 3D finite difference modelling package MODFLOW, developed by the United States Geological Survey (USGS), was selected for the assessment. Modelling was performed using the Groundwater Vistas graphical user interface version 6.83 (ESI, 2016). Existing groundwater conditions, model calibration was conducted with the MODFLOW 2000 NWT (Harbaugh et al 1992) using the Groundwater Vistas Interface source code and PEST software (Doherty, 1994), an automated model parameter estimation package.

Selection of the model software and code for this assignment was based on:

- Ability to simulate three-dimension flow in a heterogeneous setting
- Reliable accounting of model water budget
- Globally recognised and industry standard software package and codes
- Flexibility to allow revision as and when new data becomes available.

Model Domain

The model domain is defined based on the tunnel alignment and is 15.5 km long in a north south direction and 18.2 km in the east west direction and covers an area of approximately 150 km2 incorporating several catchment areas. The spatial area in which groundwater movement was simulated by the numerical groundwater model is shown in Figure 2.27 and has been chosen using boundaries that:

- Encompass an area sufficiently large enough to include potential effects of the project;
- Are sufficiently distant from the project as to not influence the effects of the project; and
- Align with known (or justifiably inferable) groundwater behaviour (levels and/or flows).

The model was developed firstly on a structured grid for steady-state calibration purposes (using MODFLOW 2005-NWT) with cell sizes varying from 320 m at the outer reaches of the model domain down to 40 m in the Project Corridor. After steady-state calibration was achieved, MODFLOW-USG was used with quadtree grid refinement applied along the tunnel alignment to give a minimum cell size of 10m, a resolution that allows the shafts, adits and twin road tunnels to be modelled distinctly. This refined grid has been used for predictive simulation and is discussed in more detail in later sections.

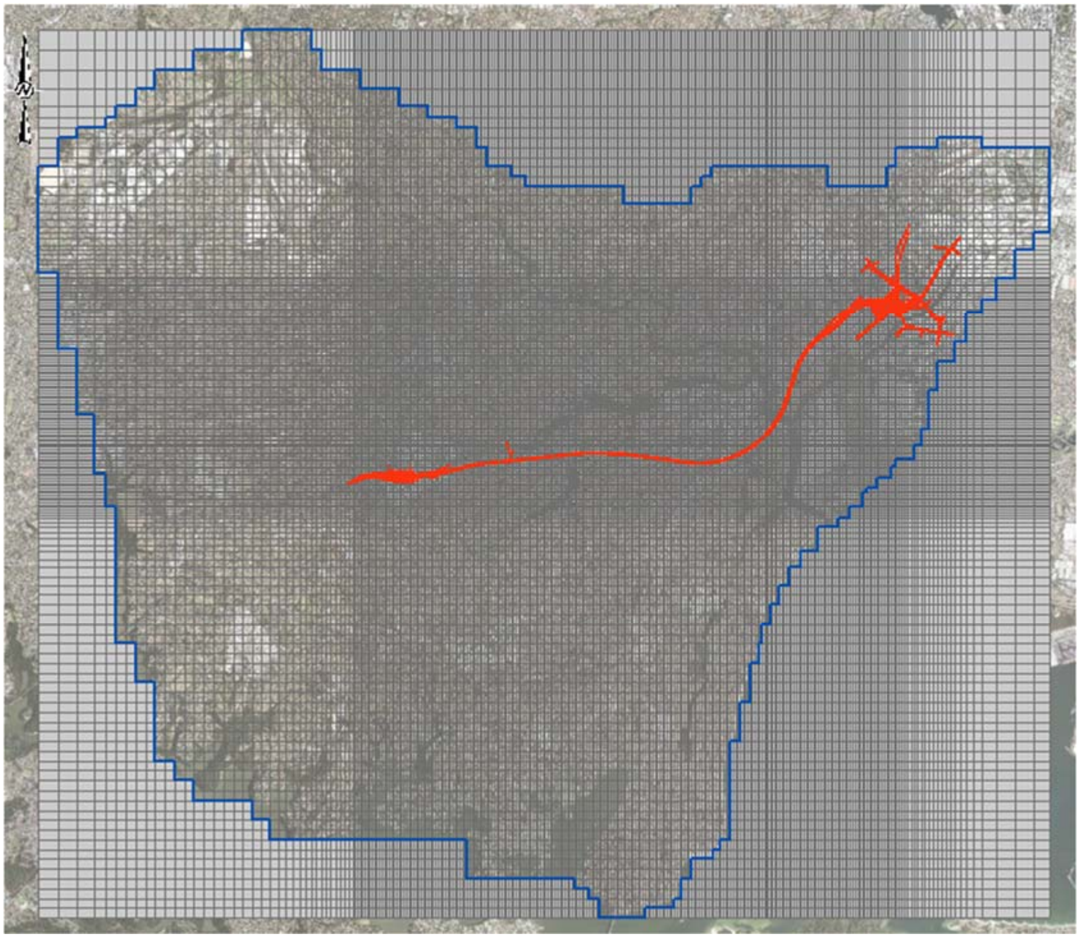


Figure 2.27: Model Domain and grid layout of base case model

Model layers

The model was constructed with 12 layers of varying thickness, which have been defined according to the hydrostratigraphic units (HSU) presented in Section 2.3.3.

Table 15 summarises the numerical model layers and assigned layer thicknesses.

The choice of layering for the models was based on a consideration of the following:

- the need for the model to represent steep vertical hydraulic gradients in the short term in the immediate vicinity of the tunnels
- the need to represent multiple material types within the alluvial sediments overlying rock
- the need to represent sub-horizontal structural features within the rock in the Arncliffe area
- the potential for improvements to representation of surface water-groundwater interaction by refining the layers to which the boundary conditions associated with surface water bodies is applied
- improvements to model predictions by more accurate representation of the vertical extent of the underground works (in particular, the alignment and height of the main tunnels)
- model grid requirements to accurately represent the progressive excavation of tunnels and shafts during construction
- maintaining reasonable vertical-to-horizontal aspect ratios in the model grid
- accurate representation of the construction details (screen depths) of the monitoring bores, thus allowing for a more reasonable comparison of simulation results to observed values at corresponding depths during calibration.

Where units are not present across an entire model layer, the hydraulic properties of the underlying HSU was applied. The layer thickness was then significantly reduced in places where units pinch out.

The upper surface of the model (i.e. the upper surface of Layer 1) represents the surface topography, with elevation values derived using the site DEM. The base of the numerical model was extended to an elevation of -200 mAHD to mitigate the effect that shallow structured models can have on impeding prediction of deeper groundwater flow regimes.

The Hawkesbury Sandstone, in which the majority of the excavation occurs, has been vertically discretised into several layers.

Table 15: Hydrogeological Model Layer Definitions

Model Layer	Hydrostratigraphic Unit (HSU)	Thickness (m)
1	Anthropogenic Fill	0.7 to 34
2	Botany Sand	0.1 to 9.5
3	Residual Soils	0.4 to 33.5
4	Quaternary Sediments	0.4 to 32
5	Mittagong Formation / Ashfield Shale	0.4 to 27
6	Ashfield Shale / Weathered Hawkesbury Sandstone	0.4 to 67
7-11	Hawkesbury Sandstone	8.5 to 23
12	Hawkesbury Sandstone	94 to 151

Boundary conditions

Boundary conditions included in the model are shown in Figure 2.28. A description of each boundary condition is provided in the following. The conditions at the model boundaries are of either the prescribed head or prescribed flow type.

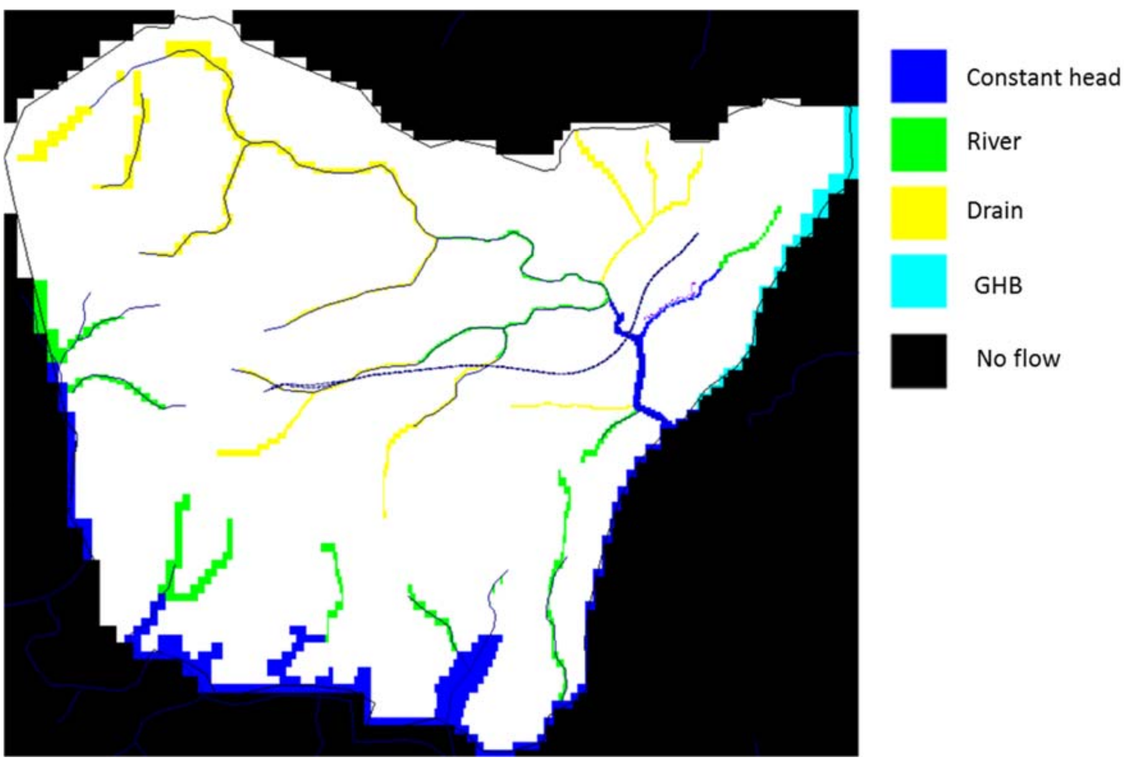


Figure 2.28: MODFLOW model boundaries

The base of the model was assumed to be of low permeability relative to the overlying overburden, and was assigned as a no flow (zero flux) boundary.

The northern and north-western boundaries follow the topographical highs of the Cooks River catchment boundary. It is assumed that no-flow conditions are present along these boundaries.

A General Head boundary has been applied to the boundary which extends to the north-east from the point where Cooks River discharges into Botany Bay.

Constant head boundary conditions were assigned along the south-eastern, southern and south-western boundaries of the model to represent Botany Bay, the downstream reaches of the Georges River, Cooks River and Alexandra Canal. The CHB in these locations were assigned zero metres AHD. The CHB were assigned to all model layers along rivers where it was only assigned in model Layer 1.

Major creeks and rivers were simulated in the model domain using MODFLOW River boundaries (upstream of the reaches described above for which constant head boundaries were used). The river boundary conditions allow both for the introduction or removal of water in the model based on relative groundwater elevation. River boundaries assigned to model layer 1 include:

- Alexandra Canal.
- Upstream reaches of Georges River (natural creek)
- Cooks River upstream of the confluence with Wolli Creek, to the point where the river bed is above RL 2 m AHD.

The elevation of the River boundaries representing these features matched topography. Conductance of the river cells varied across the model domain and was calculated based on the interpreted hydraulic conductivity of the underlying material, and the cell dimensions.

Drain boundaries (which allow water to exit the model if the water table rises to the ground surface elevation) were applied to the non-tidal sections of the creeks, with conductance rates adjusted according to channel lining (Figure 2.9).

A drain boundary was also used to represent the M5 East Motorway, a fully drained twin-tunnel running east – west parallel to the WCX2 twin-tunnel alignment west of the Cooks River. As part of the calibration process, analyses were carried out with the regional groundwater model to assess the conductance value to be assigned for drains representing tunnels in the Hawkesbury Sandstone, using the observed inflow rates and drawdown associated with the M5 East tunnel as the basis for assessing the required value of conductance such that calculated inflows and drawdown are consistent with observed values. More detail on these analyses is provided in Annexure N.

Drainage boundaries and their assigned parameters values are listed in the Table 16.

Table 16: Drainage Boundary assignment

CHB	Layers	Representation	Head Elevation (m)
River Drain	1 - 4	Major upstream of Cooks River (where riverbed is higher than 2m)	River bed level
M5 Tunnel	7 - 8	the existing M5 tunnel drain	Bottom of Tunnel
Drain in Alexandria Fill; Cooks River	2	the existing landfill drain collector	Fishbone Drain Level

The rate of drainage into the M5 East tunnel has been assumed to be 0.75 to 0.95 L/s/km of tunnel, the average inflow per single tunnel since the M5 East Motorway opened in December 2001 (Tammetta and Hewitt, 2004).

Recharge and evapotranspiration was applied across 24 zone based on catchments with recharge rates and maximum evapotranspiration optimised through calibration. Figure 2.29 and Table 17 provide details of the spatial distribution of recharge used in the calibrated model. Recharge rates applied across the 24 sub catchments are considered representative for current climate and are supported by long-term average climate data presented in Section 2.2.1. Nominal evapotranspiration rates were applied in combination with a shallow (1-2 m) extinction depth in some zones to bring maximum measured groundwater levels to below the ground surface in all model cells. Maximum evapotranspiration rates of up to 40 mm/year were applied in the model. Across most recharge areas the computed water table falls below the extinction depth and thus evapotranspiration is not active.

The recharge in these areas thus represents the net deep drainage below the zone which is affected by infiltration during and after rainfall, and by evapotranspiration in intervening dry periods. In only a few locations across areas with low lying ground is evapotranspiration activated where the predicted water table is within the defined extinction depth. This will modify the recharge rate in these areas, and will act to reduce the net overall recharge rate. In some areas a net evapotranspiration is applied.

Table 17: Calibrated Model Recharge rates

Catchment ID	Sub Catchment Name	Recharge value (mm/yr)	Recharge rate (% of rainfall)
1	Alexandria Landfill	133.2	12.23%
2	Marrickville Sydenham	6.2	0.57%
3	Alexandra Canal	12.6	1.16%
4	Marrickville Sydenham	5.8	0.53%
5	Lower Cooks River	16.4	1.51%
6	Muddy Creek	8.9	0.81%
7	Oatley Bay	24.6	2.26%
8	Bardwell Creek	17.4	1.60%
9	Middle Wolli Creek	5.9	0.54%
10	Arncliffe	20.6	1.89%
11	Upper Wolli Creek	28.5	2.61%
12	Lower Cooks River	6.7	0.62%
13	Central Cooks River	9.3	0.86%
14	Cup and Saucer Creek	15.5	1.42%
15	Lower Wolli Creek	7.5	0.69%
16	Lime Kiln	1.5	0.14%
17	Salt Pan Creek	4.9	0.45%
18	Coxs Creek	15.0	1.37%
19	Upper Cooks River	19.4	1.78%
20	Landfills	16.9	1.55%
21	West Botany	11.8	1.09%
22	Barton park	52.0	4.78%
23	Middle Cooks River	54.8	5.03%
24	Lower Cooks River	34.2	3.14%

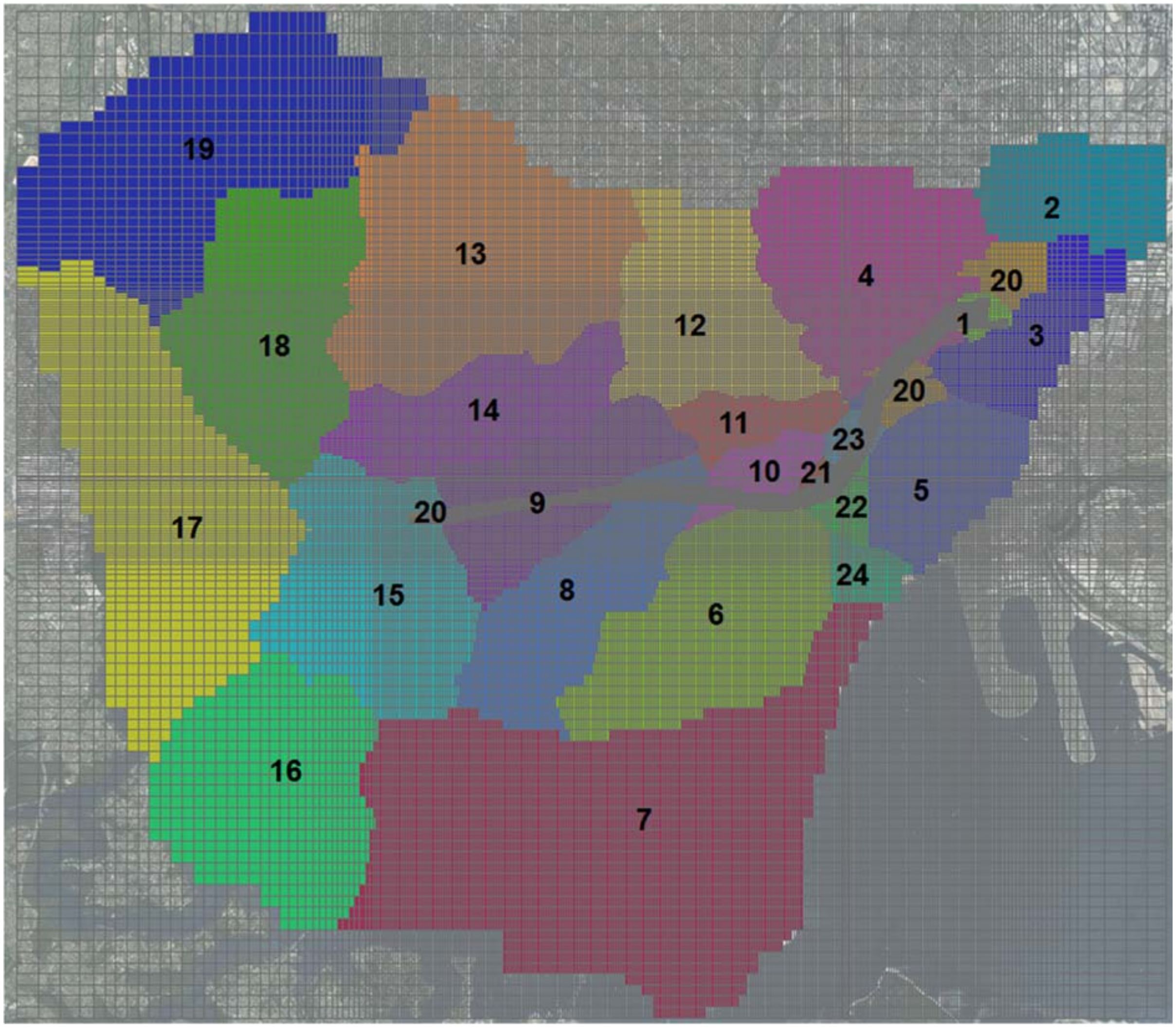


Figure 2. 29: Model Recharge and Evapotranspiration boundary distribution and catchments (for catchment names refer to Table 17)

Hydraulic Parameters

Pre-calibration input parameters were assigned from the results of field testing (water pressure and pumping testing) undertaken along the tunnel alignment as part of the WCX2 investigations and review of other available data (Section 2.3.13).

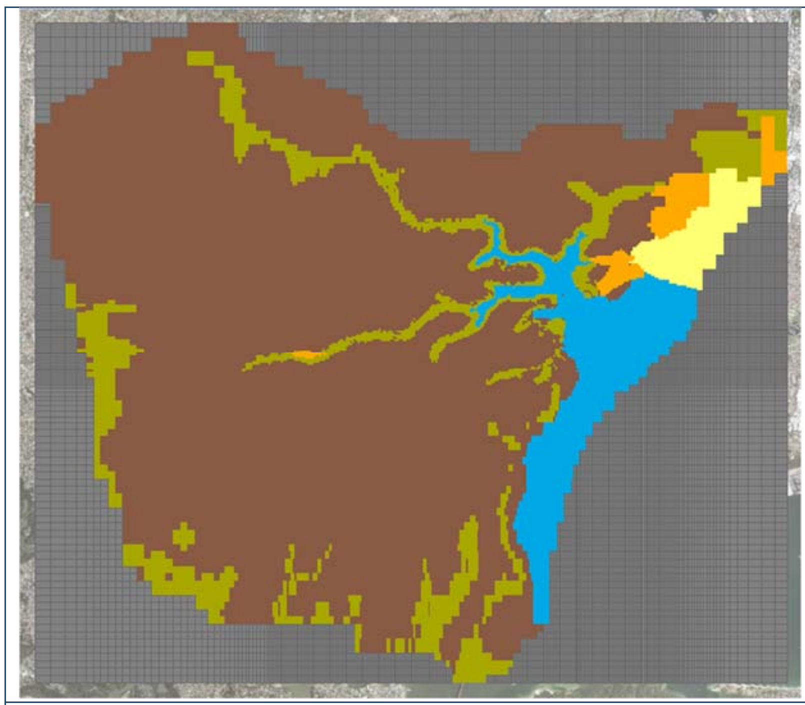
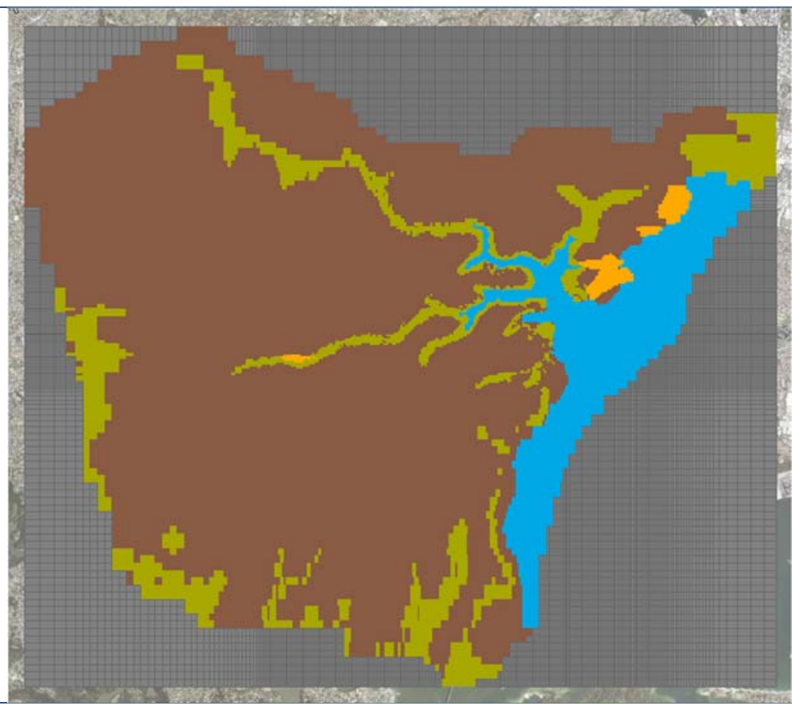
Model parameters were optimised from initial input values during calibration, with final parameters presented in Table 18. The distribution of material properties in Layers 1 to 11 is presented in Figure 2.30.

Structures represented in the model as different material zones include the Bexley, St Peters and Cooks River Dykes; and the Woolloomooloo and Luna Park Faults. The sub-vertical faults and the sub-horizontal shear zones that are present at Arncliffe in the vicinity of the change in direction of the Woolloomooloo Fault (refer to Figure 2.20) are represented in the model as an equivalent block of higher permeability material (i.e. the Arncliffe fault zone material in Figure 2.30).

No storage parameters were assigned in the model as it was initially run in steady state mode only.

Table 18: Steady state calibrated hydraulic parameters

Material	K_h (m/d)	K_v (m/d)
Landfill	5.56	5.56
Botany Sand Beds	0.8640	0.0173
Holocene alluvial sediments	0.432	0.00864
Pleistocene alluvial sediments	0.72	0.014
Pleistocene marine sediments	0.0025	0.0003
Residual	0.720	0.0014
Ashfield Shale	0.0008	0.0001
Hawkesbury Sandstone	0.01	0.001
Bexley Dyke	0.55/0.001	0.01
Woolloomooloo Fault	0.61	0.27
Arncliffe Fault Zone	0.60	0.30
Luna Park Fault	0.288	0.0576
West Fault	0.864	0.864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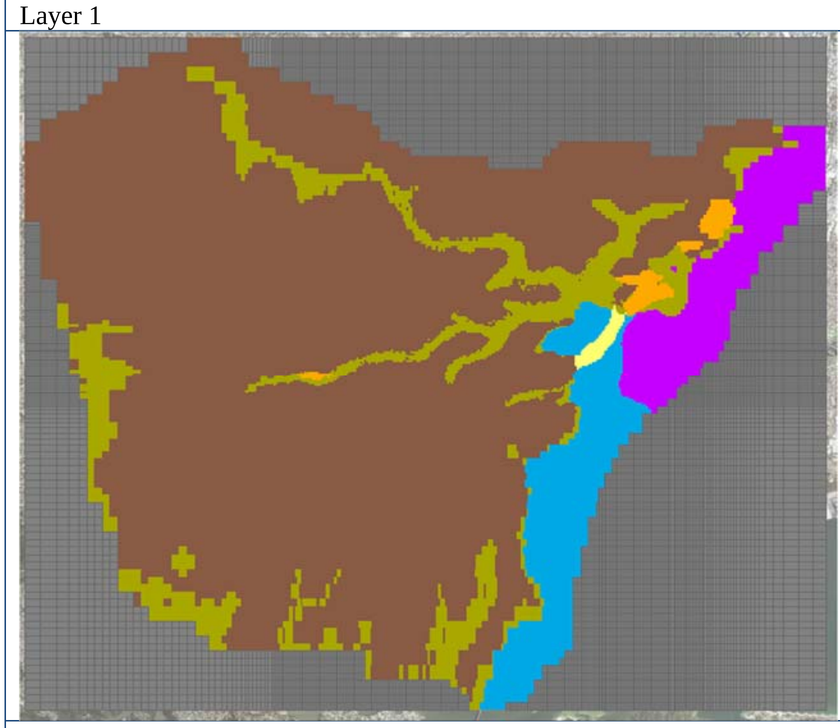
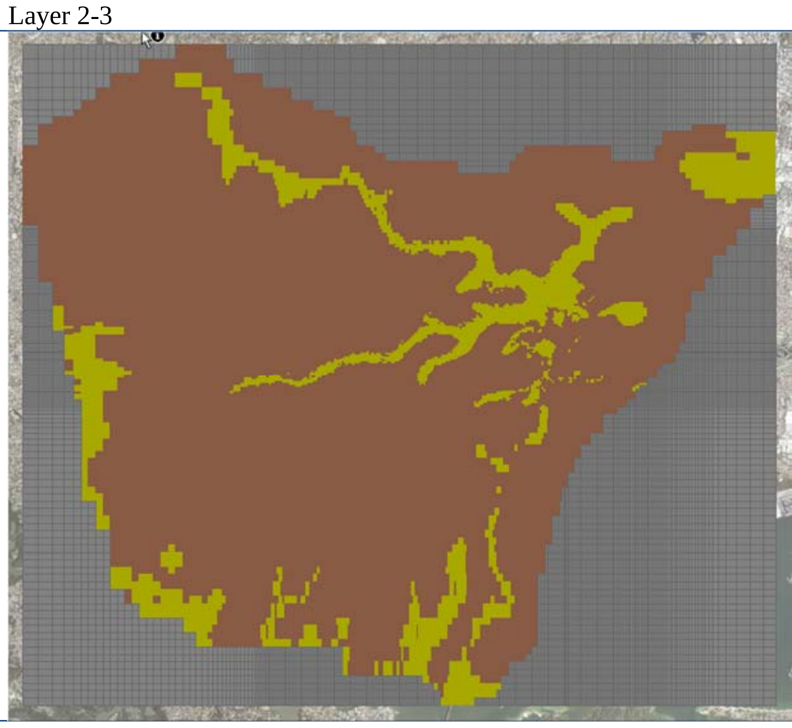
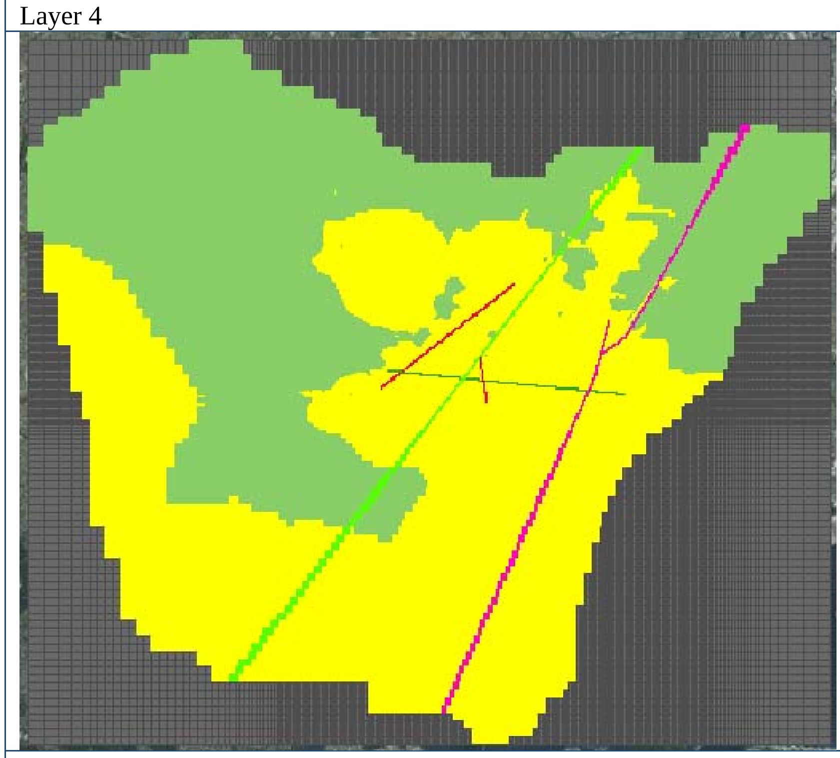
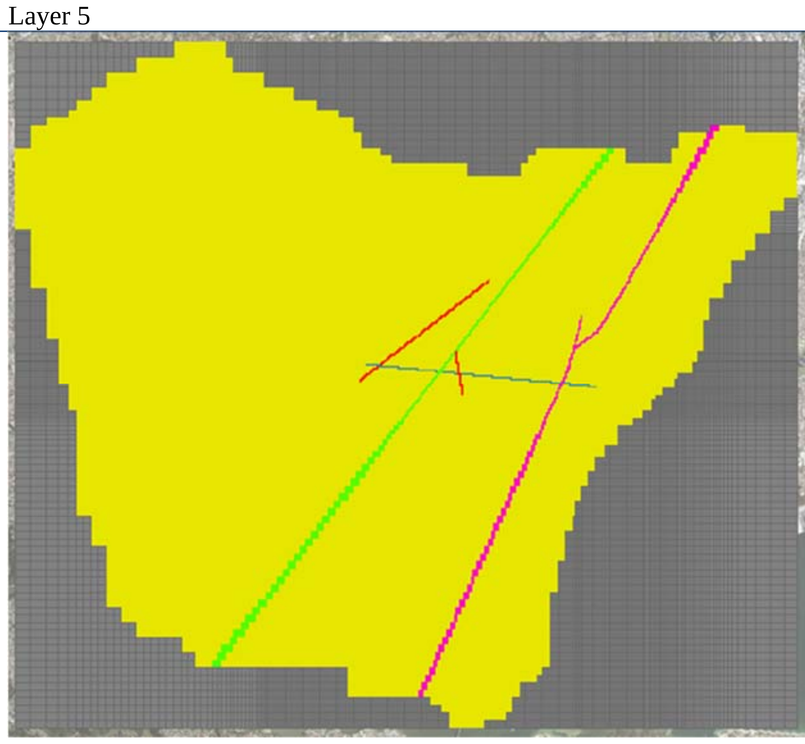
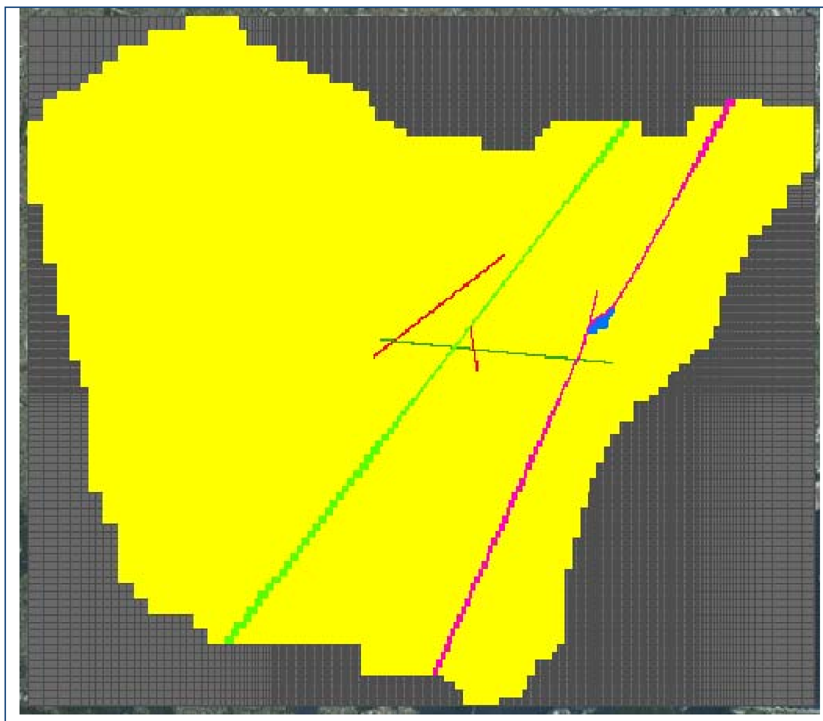
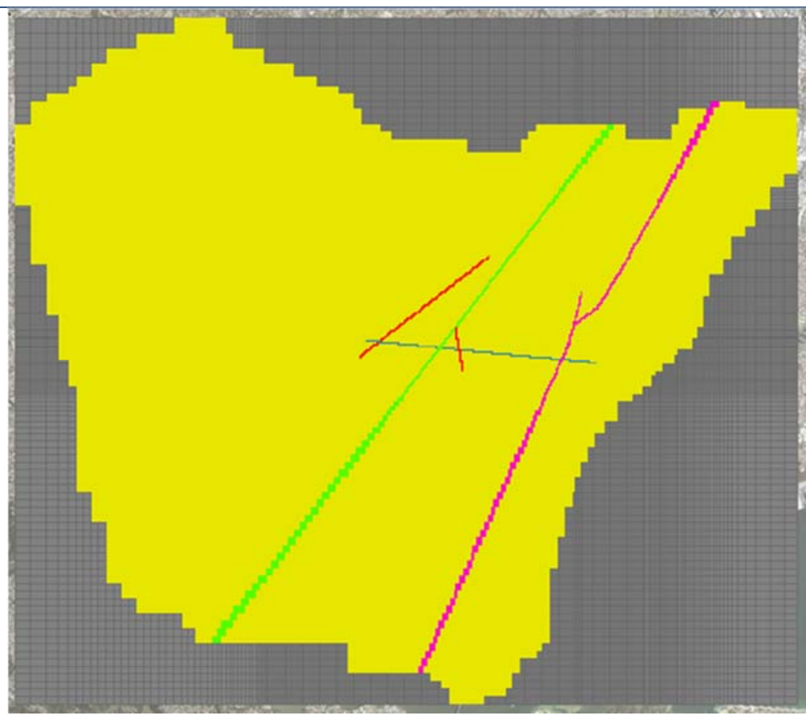
	
Layer 4	Layer 5
	
Layer 6	Layer 7



Layer 8



Layer 9-12

Figure 2.30: Material parameterisation

Model Calibration

The WCX2 groundwater model was calibrated to time averaged groundwater level observations of 132 monitoring and observation bores located mostly along the alignment. Out of the 132 bores:

- 44 are screened in Hawkesbury Sandstone;
- 6 are screened in Ashfield Shale;
- 60 are screened in unconsolidated Quaternary sediment deposits;
- 6 are screened in in residual soil and weathered shale; and
- 16 are screened in landfills.

The median of all available level observations (data collected between 2000 and 2016) for each location was computed and were used as targets for calibration. A summary table with information on bore elevation, screened formation and statistic parameters for groundwater levels are provided in Annexure F. Location and screened formation of groundwater monitoring bores with water level data used for model calibration are shown in Figures 2.13.1 to 2.13.3.

A quality control review of the data was performed prior to use. Data from bores for which date of monitoring, screen and lithology details were available were assigned a weight factor of 1. Those bores with only screen depth or date of monitoring available were weighted by a factor of 0.5. Data with neither screen depth nor date of monitoring were assigned a weight factor of 0.25. Monitoring records of 13 bores located along the current M5 East preceding the completion of the M5 Motorway tunnel in 1999 were excluded from the calibration data set. Although the timing of groundwater levels measurements varied between individual locations, the final calibration dataset was suitable for the scale of the model and the study objectives.

In model domain areas with sparse observations groundwater levels at 36 locations (Figure 2.13) were derived using the correlations of Section 2.2.11 between groundwater elevation and ground surface elevation for various hydrostratigraphic units. The derived groundwater level information at these points were weighted by a factor 0.5 and used along with the mean of groundwater level observations of the 136 monitoring and observation bores for steady state groundwater model calibration.

Calibration was performed by adjusting recharge rates, maximum evapotranspiration rates, evapotranspiration extinction depth, hydraulic conductivity and (river, creek and M5 tunnel) drainage conductance until an accepted fit between model predicted and observation data was achieved. Published M5 East tunnel inflow rates (Tammetta and Hewitt, 2004) and Alexandria Landfill leachate inflow rates from previous water balance modelling (IGGC 2004, IGGC 2011) were utilised for model calibration. Other boundary conditions remained constant as part of the calibration process. Parameters derived from the calibration of a local scale model centred on the Arncliffe area to the results of the pumping test carried out at the Kogarah Golf Course also informed parameters for the regional scale model (refer to Section 2.3.5).

Calibration was initially undertaken manually using trial and error adjustments. In order to better determine the dependence of hydraulic parameters and boundary conditions and their sensitivities further calibration was performed using utilities in PEST (Watermark Computing, 2016). This approach was preferred to manual calibration alone due to the large amount of observation data and the need to optimise several parameters simultaneously.

Sensitivity analyses for the following parameters were carried out using utilities in PEST:

- horizontal and vertical hydraulic conductivity;
- recharge rates; and
- maximum evapotranspiration rates.

Analyses were also carried out with the regional groundwater model to assess the sensitivity of model response to the value of the conductance value to be assigned for drains representing tunnels in the Hawkesbury Sandstone. Based on the results of analyses with varying values assigned for the tunnel drain conductance, a preferred value of conductance was chosen based on matching response to the observed inflow rates and drawdown associated with the existing M5 East tunnel.

Results of sensitivity analyses and assessment of drain conductance are summarised in Annexure N.

Steady State Calibration Results

The performance of model calibration is evaluated through both qualitative indicators verified against the conceptual model, and on the basis of statistical indicators.

Calibration statistics are presented in Table 19 with a plot of the observed versus predicted heads shown in Figure 2.31.

Table 19: Calibration Performance Statistics

Statistics	Value	Units
Number of head calibration targets	168	-
RMS	2.07	m
SRMS	4.01	%
Minimum Residuals	-5.20	m
Maximum Residuals	3.23	m
Coefficient of determination R^2 for linear regression between computed and observed heads	0.98	-

The following aspects were considered in the assessment of the quality of the calibration to observation data:

- The model predicted head distribution matched that developed from site investigation data with general groundwater movement within the Hawkesbury Sandstone towards the Botany Bay, except along the M5 East motorway tunnel with flows towards the drained tunnel.

- Groundwater inflows at the Alexandria Landfill were within the same order of magnitude as previous water balance assessments.

- Groundwater inflows to the existing M5 East twin tunnel were similar to published values.

The model supports the presence of the Bexley Dyke with a reduced permeability across the dyke and increased permeability along the dyke. Furthermore, two zones with increased permeability were supported by the model along inferred geological structures and satisfactory calibration of the model to water level records at boreholes WCX-BH-084, WCX-BH-137, WCX-BH-022 and WCX-BH-23 were obtained with these zones included in the model. The structures approximately intersected the tunnel alignment at Chainage 3300 m and 4900 m.

Final material properties adopted for the calibrated model are summarised in Table 18. Recharge rates for 24 recharge zones of the calibrated model range between 1.5 and 133 mm/year.

It should be noted that the adopted horizontal hydraulic conductivity values for the Ashfield Shale hydrostratigraphic unit are four to five times less than the geometric mean value derived from test data but are well within the range of test values between 7×10^{-7} and 8×10^{-9} m/s.

Horizontal hydraulic conductivity of the Hawkesbury Sandstone of the calibrated model is 1.2×10^{-7} m/s, which is slightly above the geometric mean (4.2×10^{-8} m/s) and median (5×10^{-8} m/s) values derived from WCX2 water pressure test results, but close to geometric mean and median of test results for the region.

Hydraulic conductivity of the Quaternary sediments ranges between approximately 1×10^{-4} m/s and 1×10^{-9} m/s depending on the composition of the sediments and calibrated hydraulic conductivity values are well within this range.

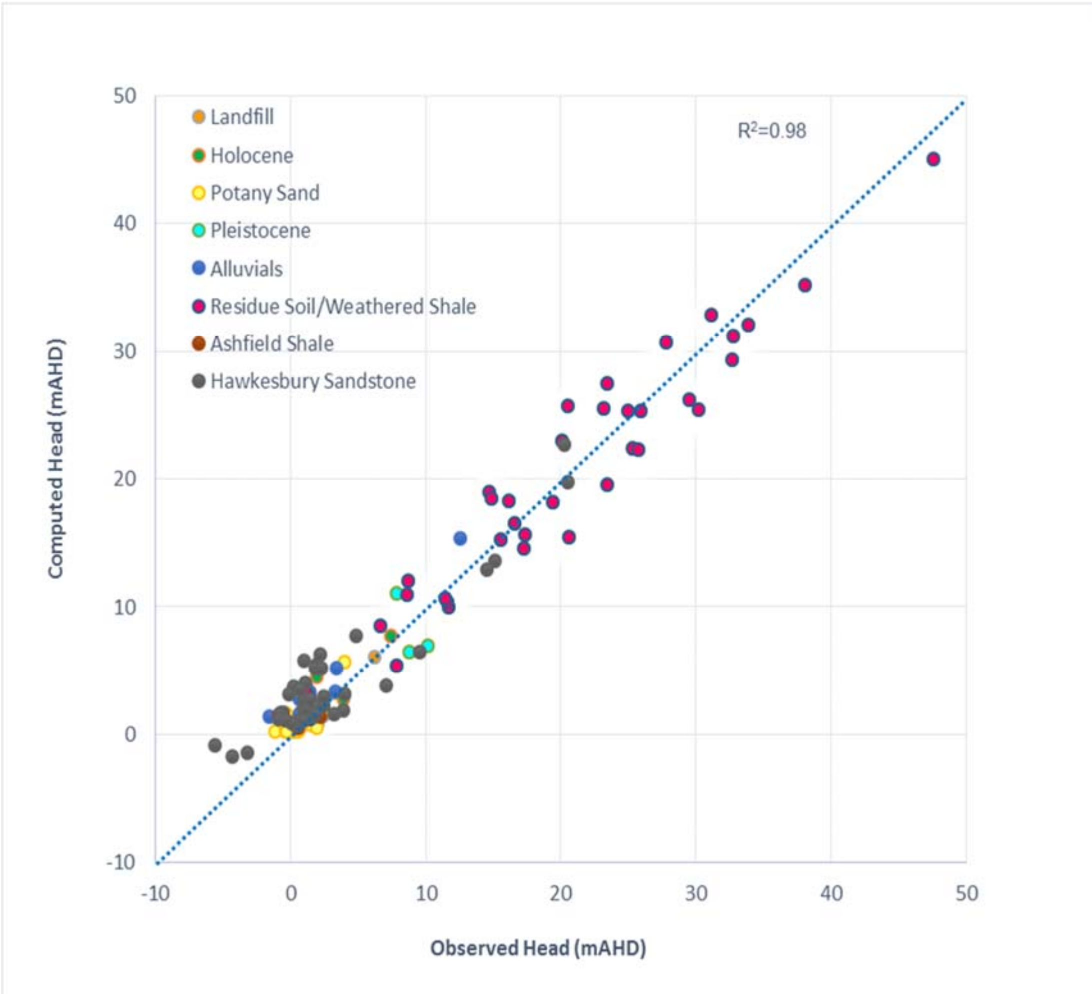


Figure 2.31: Observed versus predicted heads from steady state model calibration

Barnett et al. (2012), present guidelines regarding the confidence of predictive simulations using groundwater models. The level of confidence of groundwater model predictions depends on available data (spatial and temporal) used for model construction and the data and method used for model calibration. The model developed here is considered to have a Level 2 confidence level classification.

Water Balance

The overall steady state water balance for the calibrated model is summarised in Table 20. The water balance error is less than 1% and is within acceptance criteria typically considered for steady state groundwater flow models (MDBC, 2001).

Table 20: Steady State Water Budget

Component	Flow In		Flow Out	
	m^3/day	Percentage	m^3/day	Percentage
Recharge (rainfall)	5105	99.1%	NA	NA
Evapotranspiration	NA	NA	326	6.3%
Constant Head Boundaries	0	0	1535	29.8%
Cooks River Head Boundaries	0	0	347	6.7%
River Drain Cells	NA	NA	1641	31.9%
Existing M5 Drain Cells	NA	NA	419	8.1%
Landfill Drain Cells	NA	NA	170	3.3%
River Boundaries	39	0.8%	692	13.4%
General Head Boundaries	6	0.1%	20	0.4%
TOTAL	5150	100%	5150	100%
Percent Discrepancy	0%			

NA – Not applicable

Based on the water balance results, statistical outputs and consistency with previous model estimates; the calibrated model is considered to be suitable for the intended predictive simulations.

Predicted Groundwater Regime within the Project Corridor

The potentiometric surface computed with the calibrated model for the Hawkesbury Sandstone (Layer 8) is illustrated in Figure 2.32, and the computed phreatic surface for the unconsolidated Quaternary sediments (Layer 2) is illustrated in Figure 2.33. Groundwater flow directions were derived for both layers and plotted as arrows in direction of the flow on Figures 2.32 and 2.33.

A high is apparent in the potentiometric surface of the groundwater in the Hawkesbury Sandstone to the west of the Kingsgrove interchange. Elevations of the potentiometric surface are typically between 26 m AHD and 28 m AHD in this area. Potentiometric surface elevations decline to the east and southeast toward Cooks River and the Botany Bay. A depression in the potentiometric surface is apparent along the existing M5 East with head elevations below sea level. Groundwater head gradients in the Hawkesbury Sandstone typically range between 1:100 and 1:200 along the WCX2 tunnel alignment. Steeper gradients of 1:70 are observed along the existing M5 East. Groundwater in the Hawkesbury Sandstone is generally flowing toward the Cooks River and the Botany Bay with flow directed locally towards the existing M5 East at Bardwell and Arncliffe.

Phreatic surface elevations are at their highest in the Cooks River alluvium upstream of Elliot Reserve with elevation of 10 m AHD computed at Elliot Reserve. Groundwater levels continuously decline further downstream and eventually are between 1 and 2 m AHD at the Kogarah Golf Course.

Similarly, groundwater levels in the Wolli Creek and Bardwell Valley alluvial deposits are at their highest in the upstream reaches and decline towards the confluence with Cooks River at Waterworth Park. However, observations in monitoring bores suggest that alluvial sediments in the upper Wolli Creek are dry most of the year and may only develop a water table during wet seasons.

A steep depression in the phreatic surface is apparent at the St Peters Landfill. This depression is due to continuous drainage of the landfill waste and dewatering of the Botany Sand Beds aquifer located to the southeast of the landfill.

Direction of groundwater flow in the alluvial deposits upstream of Cooks River, the Cooks River palaeochannel deposits and in the Wolli Creek alluvial sediments generally follows the surface water flow. Groundwater gradients typically range between 1:500 and 1:800.

The flow directions and groundwater levels predicted by the model are consistent with the conceptual model described above.

LEGEND

- Elevation Contours (mAHD) (Layer 8) Pre WCX2 Tunnel
- Groundwater Model Outline
- WCX2 Alignment
- Groundwater Flow Direction

Structure Type

- Fault Location (inferred)
- Dyke Location (inferred)
- Palaeochannel Location (inferred)
- Dyke Location (observed)
- Fold Location (observed)

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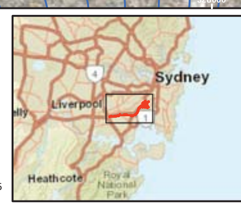

CLIENT
CPB DRAGADOS SAMSUNG JV

PROJECT
WEST CONNEX STAGE 2

Reference(s):
Herbert C., 1983, Sydney 1:100 000 Geological Sheet 9130, 1st edition.
Geological Survey of New South Wales, Sydney

0 500 1,000 1,500 2,000
METRES

PROJECTION: GDA 1994 MGA Zone 56 REFERENCE SCALE: 1:30,000 (at A3)

POTENTIOMETRIC SURFACE CONTOURS AND HORIZONTAL COMPONENT OF GROUNDWATER FLOW DIRECTIONS – HAWKESBURY SANDSTONE

YYYY-MM-DD	2016-10-13
PREPARED	HSG
DESIGN	HSG
REVIEW	--
APPROVED	

PROJECT No.	CONTROL	Rev.	FIGURE
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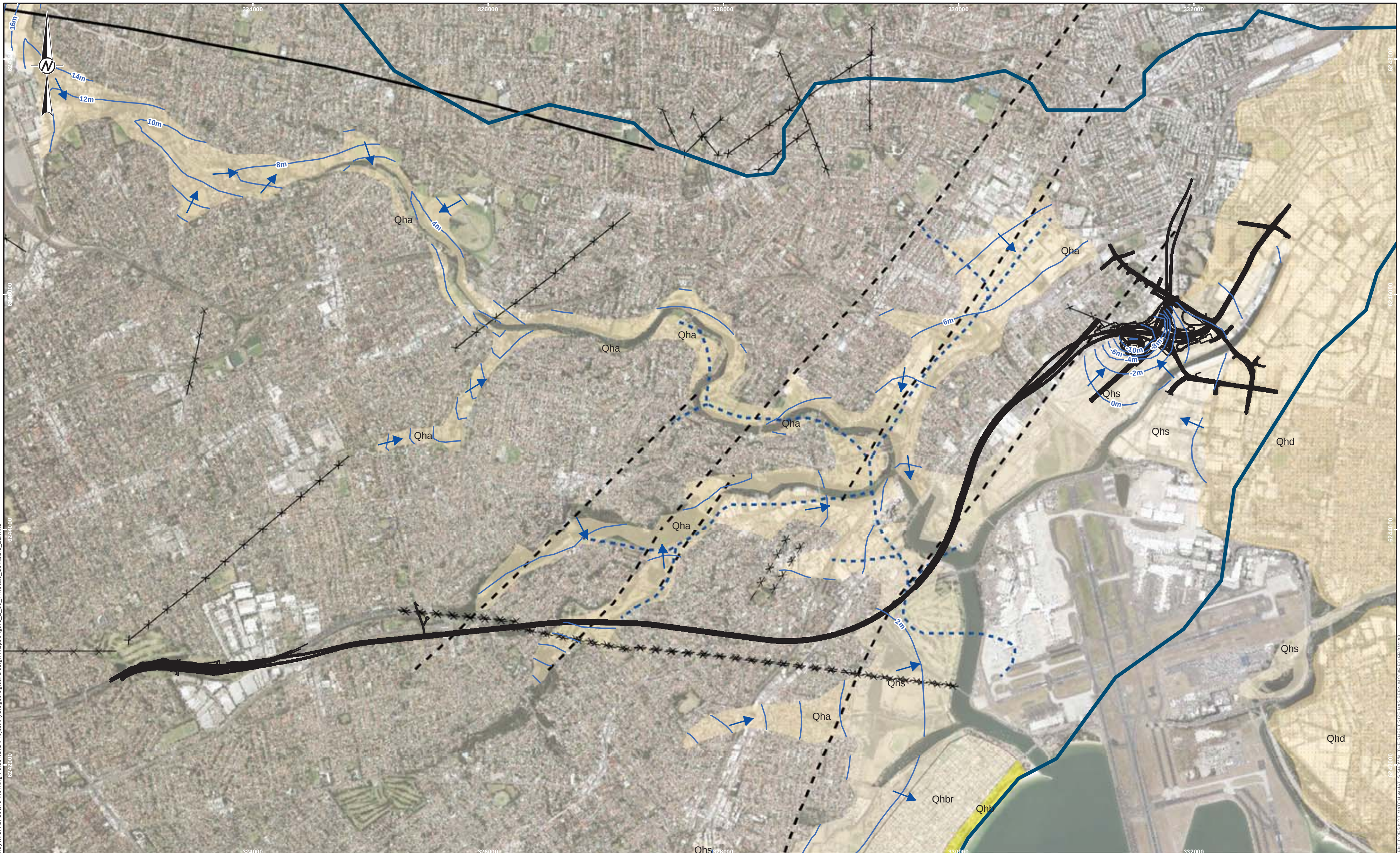
IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: A3



LEGEND

- Elevation Contours (mAHD) (Layer 2) Pre WCX2 Tunnel
- Groundwater Model Outline
- WCX2 Alignment
- Groundwater Flow Direction

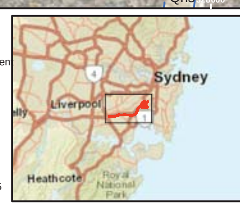
Structure Type

- Fault Location (inferred)
- Dyke Location (inferred)
- Palaeochannel Location (inferred)
- Dyke Location (observed)
- Fold Location (observed)

Sydney 1:100,000 Geology

- Qha - Quartz sand, silt and clay
- Qhs - Peat, sandy peat and mud
- Qhd - Marine sand
- Qhbr - Quartz sand, minor shell content
- Qhb - Coarse quartz sand

Service Layer Credits: © Land and Property Information 2015



CLIENT
CPB DRAGADOS SAMSUNG JV

PROJECT
WEST CONNEX STAGE 2

Reference(s):
Herbert C., 1983, Sydney 1:100 000 Geological Sheet 9130, 1st edition.
Geological Survey of New South Wales, Sydney

0 500 1,000 1,500 2,000
METRES

PROJECTION: GDA 1994 MGA Zone 56 REFERENCE SCALE: 1:30,000 (at A3)

PHREATIC SURFACE CONTOURS AND HORIZONTAL COMPONENT OF GROUNDWATER FLOW DIRECTIONS – UNCONSOLIDATED QUATERNARY SEDIMENTS

YYYY-MM-DD	2016-10-13
PREPARED	HSG
DESIGN	HSG
REVIEW	--
APPROVED	

PROJECT No.	CONTROL	Rev.	FIGURE
1524285	001	A	2.33

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2.3.5 Numerical Groundwater Model – Local Scale Model

Based on the calibrated regional groundwater model a telescoped model of the Arncliffe area was developed to allow for finer grid resolution around the proposed tunnels and cavern at Arncliffe. Finer grid resolution in this area provides the following benefits:

- More detail can be included in the model to better reflect the geological structures that are present in this area. The sub-horizontal shear zones and sub-vertical faults illustrated in Figures 2.20 and 2.21 are represented explicitly in the model. A higher permeability zone in the Hawkesbury Sandstone immediately below the base of the paleochannels in this area has also been included in the model.

- Sufficient detail can be included in the local scale model to allow it to be calibrated to the results of the Arncliffe pumping tests, while keeping computational time within manageable bounds.

- The local scale model can be used to more accurately assess flow and drawdown around Arncliffe because of the more accurate representation of the geological structure, and because there is sufficient horizontal and vertical discretisation in the model to allow accurate representation of the steep vertical gradients in this area.

The extent of the local scale model and model grid refinement is illustrated in Figure 2.34. Horizontal grid size were reduced and ranged between 5 m and 40 m. The number of layers were increased from 12 to 21 allowing more detailed modelling of vertical layering of palaeochannel sediments and more accurate modelling of screen interval depth of pumping test observation bores. MODFLOW General Head boundary conditions were applied to the local scale model boundary. Groundwater heads at the boundary were adopted from the regional groundwater model and the conductance parameter of the General Head boundary was altered until groundwater gradients at the boundary of the local scale model matched gradients of the regional model.

Summary information regarding model parameterisation and calibration to the results of the second pumping test are included in Annexure O. Model parameters determined through calibration to the second pumping test are summarised in Table 21. The results presented in Annexure O indicate that the model predictions closely match the observed drawdowns at a range of monitoring locations in the alluvium and Hawkesbury Sandstone.

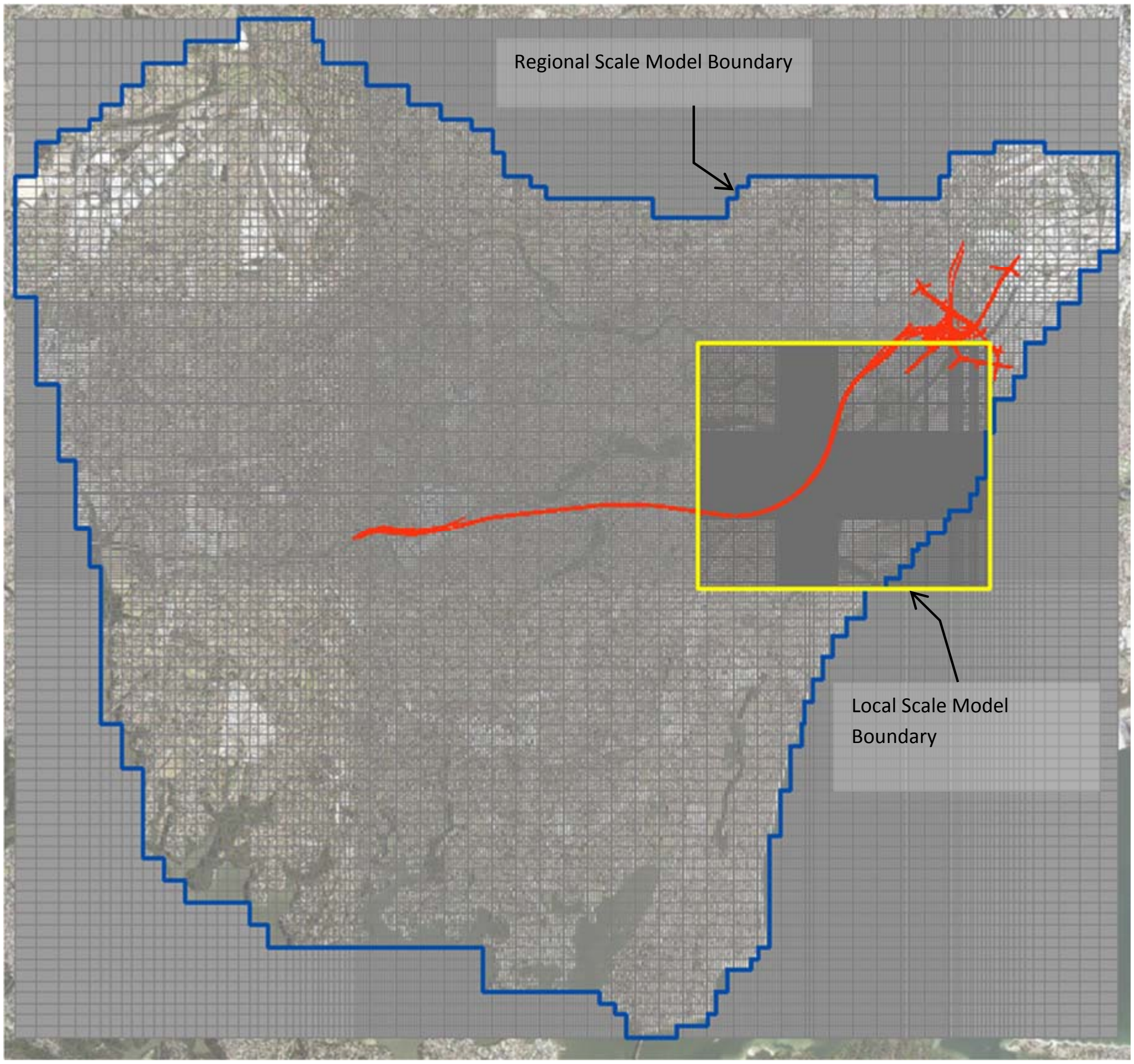


Figure 2.34: Extent and grid refinement of local scale model

Table 21: Transient calibrated hydraulic parameters from local model

Material	K_h (m/d)	K_v (m/d)	Ss (-)	Sy (-)
Landfill	5.56	5.56	2×10^{-05}	0.2
Botany Sand Beds	0.86	0.017	2×10^{-04}	0.2
Holocene alluvial sediments	0.43	0.0086	1×10^{-04}	0.2
Pleistocene alluvial sediments	0.72	0.014	3×10^{-04}	0.2
Pleistocene marine sediments	0.0025	0.0003	1×10^{-04}	0.15
Residual	0.72	0.0014	1×10^{-05}	0.2
Ashfield Shale	0.0008	0.0001	1×10^{-05}	0.01
Hawkesbury Sandstone	0.009	0.0009	2×10^{-06}	0.01
Bexley Dyke	0.55/0.001	0.01	1×10^{-05}	0.01
Woolloomooloo Fault	0.61	0.27	1×10^{-05}	0.05
Arncliffe Fault Zone	0.60	0.30	5×10^{-06}	0.05
Luna Park Fault	0.29	0.058	1×10^{-05}	0.05
West Fault	0.86	0.86	-	-
Arncliffe Shear Zone (-38mRL)	0.29	0.058	2×10^{-06}	0.02
Arncliffe Shear Zone (-54mRL)	0.60	0.30	2×10^{-06}	0.02
Arncliffe Shear Zone (-70mRL)	0.433	0.0866	2×10^{-06}	0.02
Massive Hawkesbury Sandstone	0.0035	0.0009	3×10^{-06}	0.01
Hawkesbury Sandstone at Palaeochannel	0.288	0.0576	2×10^{-06}	0.01

2.3.6 Construction Sequence Considered for Predictive Modelling

The excavation schedule of the shafts, adits and twin tunnels follows the time-chainage programme of the Project. Shafts, adits, cross passages and tunnels have been represented using drain cells, with drain elevation levels set to the invert levels corresponding to the underground structure. Drain cells are successively activated in accordance with the excavation schedule. For simulating shaft excavation drain cells at the shaft locations were activated in successive model layers as shaft excavation progressed to the depth of the next layer. Adits were similarly represented using drain cells, which were activated at the completion of shaft excavation.

2.4 Not used

2.5 Design software

The design software and version used or that will be used in this design submission are listed in Table 22.

Table 22: Design software

Software	Version
ArcGIS	10.2.1
Groundwater Vistas (MODFLOW Interface)	6.83 Build 3
MODFLOW (groundwater simulation)	MODFLOW 2005 MODFLOW USG
PEST (Parameter Estimation)	13.6
QGIS	2.8.2
Surfer (Golden Software)	9.11.947
USGS GW Chart	1.29.0.0

2.6 Not used

3 Design Outcomes

3.1 Design Details

3.1.1 Predictive Simulations

As discussed in Section 2.3.4 and 2.3.5 an acceptable level of calibration was achieved for the purpose of the hydrogeological design model. The calibrated regional scale and local scale models were used for predictive simulation to assess potential drawdown and inflows to the tunnel, for the case where hydraulic conducitivty in the vicinity of the tunnels has not been modified by grouting. The local scale model was also used for predictive simulations for a a range of cases representing different scenarios involving grouting of higher permeability geological structures in the Arncliffe area to reduce inflows to the tunnel and associated groundwater drawdown in the unconsolidated sediments. Further detail on these grouting scenarios is provided below.

Predictive Simulations with Regional Scale Model

In order to effectively simulate transient impacts of tunnel drainage during construction and operation of the tunnel, simulations were carried out with the regional scale model in which the advance with time of the tunnel and the other associated underground structures was explicitly represented. The duration of the tunnel excavation (approximately 23 months from the beginning of shaft excavation to completion of the twin tunnels) was broken down into a number of stress period of approximatly one month in length. Each stress period was further discretised into 5 time steps to achieve convergence of the modeling results throughout the simulation of tunnel excavation. The lengths of tunnels excavated in each of the stress period was determined from the excavation schedule. After completion of the simulation of tunnel construction, the length of stress periods were increased to a final stress period length of 365 days which was adopted for the reminder of the 100 year simulation period. After 100 years changes in computed heads were sufficiently small to assume that groundwater conditions have reached steady state.

For the predictive simulations, quadtree refinement was applied to the model grid for the regional scale model along the tunnel (H2 option) alignment to produce a minimum cell size of 10 m x 10 m. This resolution allows the shafts, adits, twin road tunnels and cross-passages to be modelled distinctly (incorporating approximately 4000 model cells). This refined grid is shown in Figure 3.1.

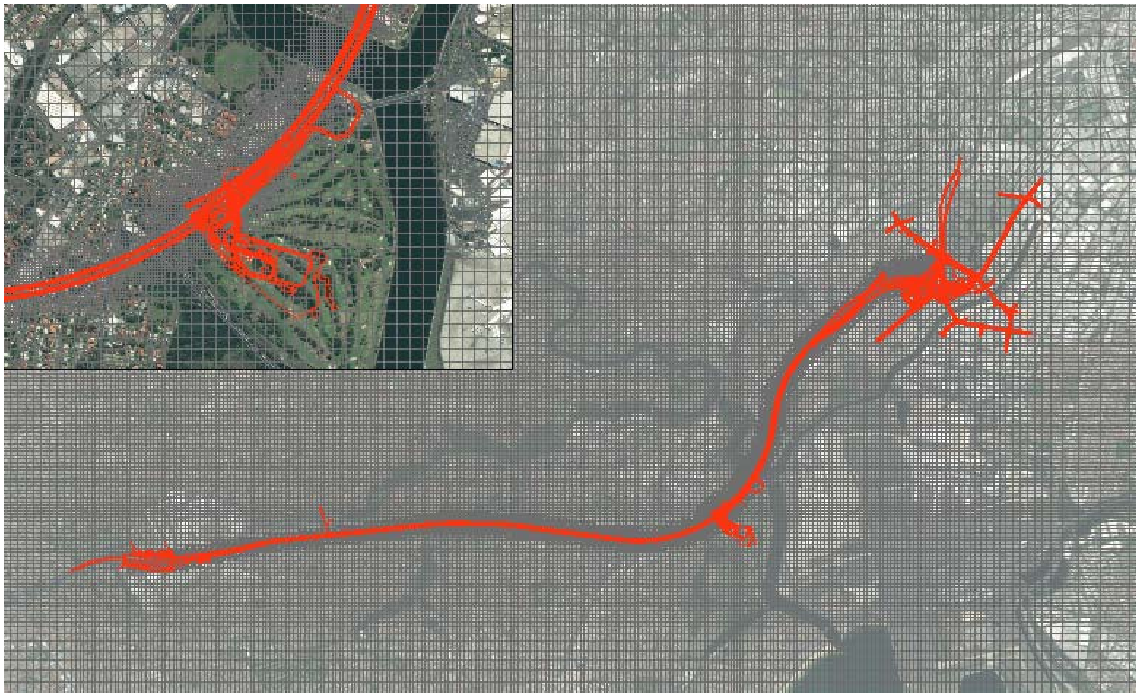


Figure 3.1: Numerical Model Grid Quadtree Refinement

The tunnel and the associated underground structures were simulated as a drainage boundary using MODFLOW's drain package. The elevation assigned to the MODFLOW drain cells was that of the tunnel invert. Drain conductance values were based on values derived for the M5 East Motorway from steady state calibration of the regional model, modified to make allowance for variations in the MODFLOW cell size between the steady state calibration model and the predictive model with grid refinement, and to account for variations in hydraulic conductivity of the rock intersected by the tunnel.

Predictive Simulations with the Local Scale Model

Predictive simulations with the local scale model were limited to steady state simulations to assess long-term drawdown and inflow rates.

A range of grouting scenarios were simulated to test the effectiveness of grouting measures in controlling groundwater inflow to the tunnel through permeable structures. Simulations were carried out for a case with no grouting to reduce the hydraulic conductivity of high permeability features (the so-called Base Case), and for four cases with different degrees of permeability reduction through grouting.

For all of these cases, reductions in permeability are applied to the following elements which are explicitly included in the local-scale model:

- the sub-horizontal shear zones in the vicinity of the change in the direction of the Woolloomooloo Fault. Reductions in permeability throughout these zones were applied below the proposed footprint of surface grouting. In other locations where the tunnel alignment intersects these shear zones, a reduction in permeability was applied within a 10 m radius of the tunnel perimeter, to represent impacts from in-tunnel grouting.
- Sub-vertical faults, where these features cross the tunnel alignment and within the footprint of the proposed footprint of surface grouting. At these crossing points, it was assumed that in-tunnel grouting would reduce permeability within a 10 m radius of the tunnel perimeter.

The following values of hydraulic conductivity were applied in grouted rock for the various grouting cases:

- Base Case – hydraulic conductivity values for Hawkesbury Sandstone unchanged from the values determined through model calibration.
- Case 1 – hydraulic conductivity values for grouted Hawkesbury Sandstone reduced to 5×10^{-7} m/s within the areas noted above, and where the value of hydraulic conductivity determined through calibration is greater than this value.
- Case 2 - hydraulic conductivity values for grouted Hawkesbury Sandstone reduced to 3×10^{-7} m/s within the areas noted above, and where the value of hydraulic conductivity determined through calibration is greater than this value.
- Case 3 - hydraulic conductivity values for grouted Hawkesbury Sandstone reduced to 1×10^{-7} m/s within the areas noted above, and where the value of hydraulic conductivity determined through calibration is greater than this value.
- Case 4 - hydraulic conductivity values for grouted Hawkesbury Sandstone reduced to 1×10^{-8} m/s within the areas noted above, and where the value of hydraulic conductivity determined through calibration is greater than this value. It is noted that in practical terms, it may not be possible to achieve a reduction in permeability to 1×10^{-8} m/s over large areas.

Results of the simulations described above are reported in Sections 3.1.2 and 3.1.3.

3.1.2 Groundwater Inflow Summary

Base Case Inflows

Estimates of inflows to selected eastbound and westbound tunnel sections and underground structures are reported in Table 23 and Table 24. Results are presented for the long term -steady state condition as total inflows for selected chainage intervals. Inflow estimates for the chainage interval between Ch 7000 and Ch 9000 are derived from the local scale model, whereas the remainder of the results presented in Table 23 and Table 24 are derived from the regional scale model.

The estimated average inflow rate over the full length of the tunnels for the Base Case is slightly in excess of 1 L/s/km of tunnel at steady state. While the average over the total length of tunnel is calculated to be close to 1 L/s/km of tunnel, some sections of tunnel are calculated to have inflows that will exceed 1 L/s/km of tunnel locally. This is particularly the case in the Arncliffe area where the tunnels/cavern are in close proximity to or intersect high permeability structures. It is noted that numerical modelling results for the Base Case suggest that approximately 60 % of the predicted tunnels inflow in the Arncliffe area are from tidal waters of the Cooks River and Alexandra Canal. Surface water is therefore replenishing the saline groundwater in the Arncliffe area thus reducing the impacts of tunnel drainage onto groundwater levels in the unconsolidated Quaternary paleaochannel sediments. Similar findings were reported in AECOM (2015b).

In order to control inflow rates in the tunnel in the Arncliffe area, a program of surface grouting and in-tunnel grouting will be implemented, as described in Section 3.1.1. Inflow estimates for the four grouting scenarios described in Section 3.1.1 are presented Table 23 and Table 24, and are discussed in more detail below in relation to the impacts of grouting on inflows in the Arncliffe area specifically. Case 2 (which represents grouting of permeable features to achieve a hydraulic conductivity of 3 $x10^{-7}$ m/s in the grouted areas) is predicted to achieve an average inflow rate of less than 1 L/s/km of tunnel for both westbound and eastbound tunnels. It is noted that in-tunnel grouting will be applied at Arncliffe in addition to the surface grouting if required to limit inflows as far as feasible and reasonable to below the CoA requirement.

Additional in-tunnel grouting to control localised inflows where higher permeability features are intersected has not been considered in the modelling, and will further reduce total inflows.

Estimates of long-term groundwater inflow reported in AECOM (2015b) for the eastbound and westbound tunnels were 0.63 L/s and 0.67 L/s per average kilometer length of tunnel, which is somewhat less than the inflow estimates provided in Table 23 and Table 24. It is considered that this difference is attributable to the fact that the CDM Smith model used a vertical hydraulic conductivity parameter value for the Hawkesbury Sandstone five times less than used for the regional and local scale models and did not include high permeability structural features in the Bexley, Arncliffe and St Peters area, the presence of which has become apparent during ground investigations conducted by CDM subsequent to the modelling carried out for AECOM (2015b).

Table 23: Computed inflows to the WCX2 eastbound tunnel and underground structures from regional scale and local scale models for the Base Case scenario (no grouting of fault structures at Arncliffe) and four grouting design scenarios

Underground Structure*	Length [m]	Inflow estimate - steady state [L/s/km]%				
		Base Case	Case 1	Case 2	Case 3	Case 4
Cut and Cover Kingsgrove Interchange	285	0.1	0.1	0.1	0.1	0.1
Kingsgrove northern smoke/vent shaft and tunnel	59	0.3	0.3	0.3	0.3	0.3
Eastbound tunnel west of Bexley	1693	0.6	0.6	0.6	0.6	0.6
Bexley smoke / vent extraction shaft and tunnels	129	0.3	0.3	0.3	0.3	0.3
Eastbound tunnel between Bexley and Arncliffe	3448	0.6	0.6	0.6	0.6	0.6
Eastbound tunnel, Arncliffe Cavern and Southern Connector, Cooks River crossing#	2141	3.0	2.3	1.9	1.0	0.5
Eastbound tunnel east of Cooks River	837	0.9	0.9	0.9	0.9	0.9
SPI cavern and stub tunnel beyond the cavern	1042	1.2	1.2	1.2	1.2	1.2
SPI Northern Exit Ramp including Cut and Cover Structure	1405	0.7	0.7	0.7	0.7	0.7
SPI Vent Tunnel	428	0.1	0.1	0.1	0.1	0.1
Average inflow per tunnel (eastbound)^ L/s/km of tunnel		**1.1**	**1.0**	**0.9**	**0.7**	**0.7**

Notes: * Excluding temporary works where not otherwise stated. Includes cross passages, and includes ventilation structures at Arncliffe.
^ L/s/km is an average rate calculated from total computed inflow to the nominated length of tunnel, divided by the total length of underground structures of that section.
# Includes inflows derived from local scale model for part of this interval.
% Values rounded to one decimal place accuracy.

Table 24: Computed inflows to the WCX2 westbound tunnel and underground structures from regional scale and local scale models for the Base Case scenario (no grouting of fault structures at Arncliffe) and four grouting design scenarios

Underground Structure*	**Approximate Chainage [m]**	**Length [m]**	**Inflow estimate - steady state [L/s/km]%**				
			Base Case	**Case 1**	**Case 2**	**Case 3**	**Case 4**
Cut and Cover Kingsgrove Interchange	1865 -2180	315	0.0	0.0	0.0	0.0	0.0
Kingsgrove southern smoke/vent shaft and tunnel		18	0.6	0.6	0.6	0.6	0.6
Westbound tunnel west of Bexley	2180 -3700	1599	0.5	0.5	0.5	0.5	0.5
Westbound tunnel between Bexley and Arncliffe	3700-7000	3448	0.5	0.5	0.5	0.5	0.5
Westbound tunnel, Arncliffe Cavern and Southern Connector, Cooks River crossing#	7000-9000	2153	3.2	2.3	2.0	1.1	0.5
Westbound tunnel east of Cooks River	9000-9800	837	0.9	0.9	0.9	0.9	0.9
SPI cavern, and stub tunnel beyond the cavern	9800-10800	1042	1.2	1.2	1.2	1.2	1.2
SPI Northern Entry Ramp including Cut and Cover Structure	0-1171	1367	0.5	0.5	0.5	0.5	0.5
Average inflow per tunnel (westbound)^ L/s/km of tunnel			**1.1**	**1.0**	**0.9**	**0.7**	**0.7**

Notes: * Excluding temporary works where not otherwise stated. Includes cross passages, and includes ventilation structures at Arncliffe.
^ L/s/km is an average rate calculated from total computed inflow to the nominated length of tunnel, divided by the total length of underground structures of that section.
# Includes inflows derived from local scale model for part of this interval.
% Values rounded to one decimal place accuracy.

It is recognised that inflow rates will reduce over time after initial tunnel excavation, for potentially a range of reasons. Transient changes in flow rate occur as water is released from storage in the aquifer. The extent to which this occurs relates to the compressibility of aquifer materials, and to the porosity in areas where aquifer desaturation occurs. The release of water from storage and its impact on transient changes in inflow rates has been assessed using the regional scale model, in which the progressive excavation of the tunnel has also been represented. The calculated differences in inflow rates between the first day of operation inflow rates, and the long-term steady state inflow rates are summarised in Table 25 for the eastbound tunnel. It can be seen that there is very little predicted reduction in inflow beyond the first day of operation. This relatively limited reduction is expected based on the relatively low compressibility of aquifer materials through most of the model domain.

Notwithstanding the model predictions, we understand that empirical evidence from other tunnels in Sydney indicates that significantly greater reductions in inflow rate are observed to occur over the long-term, of the order of a 2 to 3 times reduction from the inflow rates at opening (Pells, personal communication, 10 November 2016). It is interpreted that these transient changes are not caused by the mechanisms that are represented in the model (i.e. storage in aquifer materials), but may be caused by mechanisms such as clogging of fractures by precipitation of iron-based minerals. It is therefore expected that inflow rates could drop below the steady state values that have been predicted by modelling, as a result of mechanisms such as clogging of fractures.

Predicted inflows for local scale model for various grouting cases

As noted in Section 3.1.1, simulations have been carried out with the local scale model for 4 cases in which the permeability of high permeability structural features has been selectively reduced in the Arncliffe area, to represent the effects of different grouting intensity/effectiveness.

Computed inflows at steady state for the base case and four grouting design scenarios are provided in Table 26. It can be seen that overall inflow rates in this area could potentially be significantly reduced by grouting.

Table 25: Computed inflows to the WCX2 eastbound tunnel and underground structures from regional scale model for the Base Case scenario (no grouting of fault structures at Arncliffe) at first day of operation and steady state.

Underground Structure*	Approximate Chainage [m]	Length [m]	Inflow estimate – Regional Model [L/s/km]%	
			At first day of operation	Steady state
Cut and Cover Kingsgrove Interchange	1795-2080	285	0.1	0.1
Kingsgrove northern smoke/vent shaft and tunnel		59	0.3	0.3
Eastbound tunnel west of Bexley	2080-3700	1693	0.6	0.6
Bexley smoke / vent extraction shaft and tunnels		129	0.4	0.3
Eastbound tunnel between Bexley and Arncliffe	3700-7000	3448	0.6	0.6
Eastbound tunnel, Arncliffe Cavern and Southern Connector, Cooks River crossing	7000-9000	2141	2.4	2.4$
Eastbound tunnel east of Cooks River	9000-9800	837	1.0	0.9
SPI cavern and stub tunnel beyond the cavern	9800-10800	1042	1.3	1.2
SPI Northern Exit Ramp including Cut and Cover Structure	0-1171	1405	0.8	0.7
SPI Vent Tunnel		428	0.1	0.1
Average inflow per tunnel (eastbound)^ L/s/km of tunnel			**1.0**	**1.0$**

Notes: * Excluding temporary works where not otherwise stated. Includes cross passages.

^ L/s/km is an average rate calculated from total computed inflow to the nominated length of tunnel, divided by the length of underground structures of that section.

$ Value differ slightly to Table 24 due to differences in the details to which geological structures were represented in the local scale and regional scale models. Table 24 includes results from both the regional scale model and the local model for this interval, whereas this table includes results only from the regional scale model.

% Values rounded to one decimal place accuracy.

Table 26: Computed inflows to the WCX2 twin tunnel and underground structures from local scale model for the Base Case and Grouting scenarios (grouting of fault structures at Arncliffe)

Underground Structure*	Approximate Chainage [m]	Length [m]	Inflow Estimates at Steady State – Local Scale Model [L/s/km]%				
			Base Case	Case 1	Case 2	Case 3	Case 4
Eastbound tunnels and associated underground structures							
Eastbound tunnel west of Arncliffe cavern	7000-7800	838	0.9	0.8	0.6	0.4	0.3
Arncliffe cavern and Southern Connector	7800-8100	366	6.7	4.0	3.2	1.6	0.4
Eastbound tunnel, Cooks River crossing	8100-9000	937	3.4	3.1	2.6	1.2	0.8
Average inflow per tunnel (eastbound)^ L/s/km of tunnel			3.0	2.3	1.9	1.0	0.5
Westbound tunnels and associated underground structures							
Westbound tunnel west of Arncliffe cavern	7000-7800	838	1.0	0.8	0.6	0.7	0.3
Arncliffe Cavern and Southern Connector	7800-8100	378	5.8	3.8	3.1	1.5	0.4
Westbound tunnel, Cooks River crossing	8100-9000	937	4.0	3.1	2.6	1.2	0.8
Average inflow per tunnel (westbound)^ L/s/km of tunnel			3.2	2.3	2.0	1.1	0.5

Notes:

Refer to Section 3.1.1 for definition of grouting cases

* Excluding temporary works where not otherwise stated. Includes cross passages, and includes ventilation structures at Arncliffe.

^ L/s/km is an average rate calculated from total computed inflow to the nominated length of tunnel, divided by the length of underground structures of that section

% Values rounded to one decimal place accuracy

Figure 3.2 illustrates tunnel inflows to the mainline tunnels only, expressed as a moving average inflow rate per kilometer (i.e. as litres per second across any given kilometer). (Clause B26 of the CoA requires that all feasible and reasonable measures are taken to limit operational groundwater inflows into each tunnel to no greater than one litre per second across any given kilometre.) The results presented in Figure 3.2 indicate that inflow rates are likely to be less than 1L/s/any given km for the majority of the length of tunnels, without the need for any measures to limit inflows. Average L/s/km inflow rates are estimated to slightly exceed 1 L/s/km at approximately Ch 9800. Probing will be carried out in this area, and in-tunnel grouting will potentially be carried out if required to limit inflows where feasible and reasonable to below the CoA requirement.

The most significant potential for inflow rates to exceed 1 L/s/km will be in the area of the Arncliffe cavern. As previously discussed, and as illustrated in Figure 3.2, groundwater modelling results indicate the potential for grouting to significantly reduce inflow rates. Case 3 grouting (i.e. grouting to $1x10^{-7}$ m/s) achieves a significant reduction in inflow and is deemed practically achievable. This grouting case is therefore targeted for limiting groundwater inflows at the Arncliffe area. It is noted from Figure 3.2 that there is relatively little difference between the calculated average inflow rate for Case 3 grouting and Case 4 grouting (i.e. grouting to $1x10^{-8}$ m/s). There is, however, a significant difference between the cost and time requirements to achieve the degree of permeability reduction that is implied by Case 3 and Case 4 model simulations. It is not considered to be feasible or reasonable to require that grouting reduce the permeability of permeable features to $1x10^{-8}$ m/s.

Further discussion of inflow rates and their significance in terms of impacts that may result from tunnel inflow is provided in Section 4.3

In Figure 3.2, the average inflow rate reported at each chainage is the average inflow rate for the 1 km of tunnel beyond that point. Average inflow rates for the last 1 km tunnel length are not plotted due to the averaging interval being less than 1 km at a distance of less than 1 km to the tunnel end point.

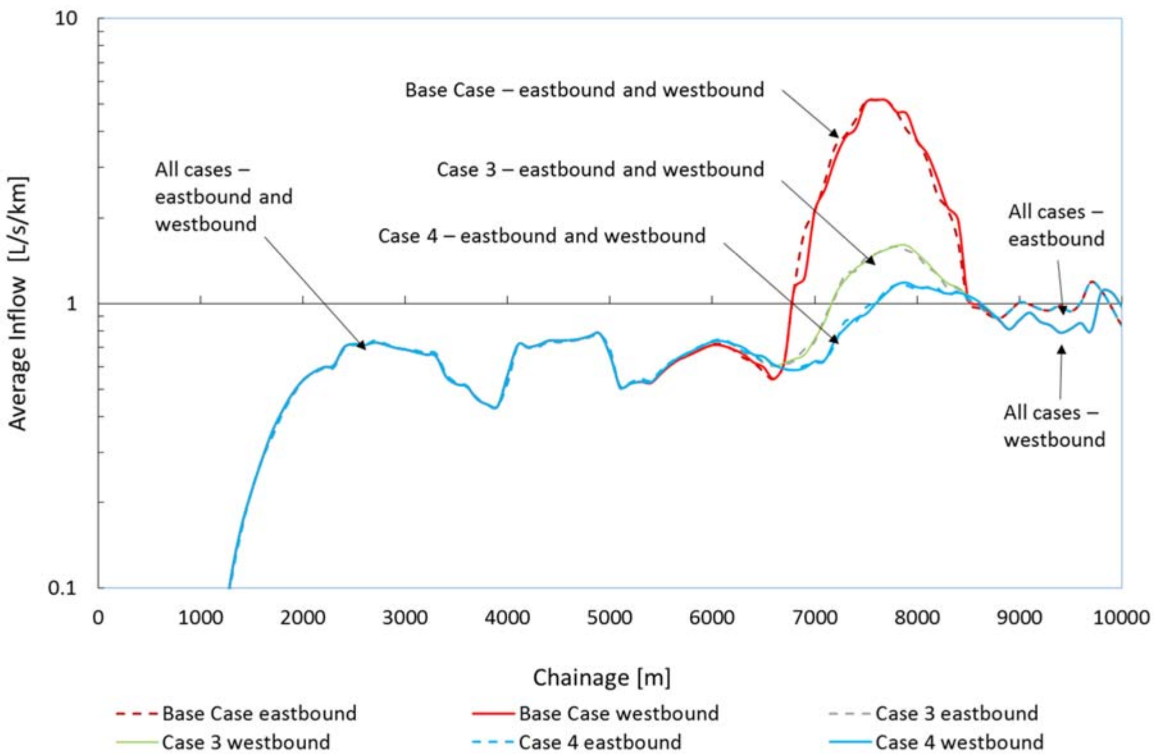


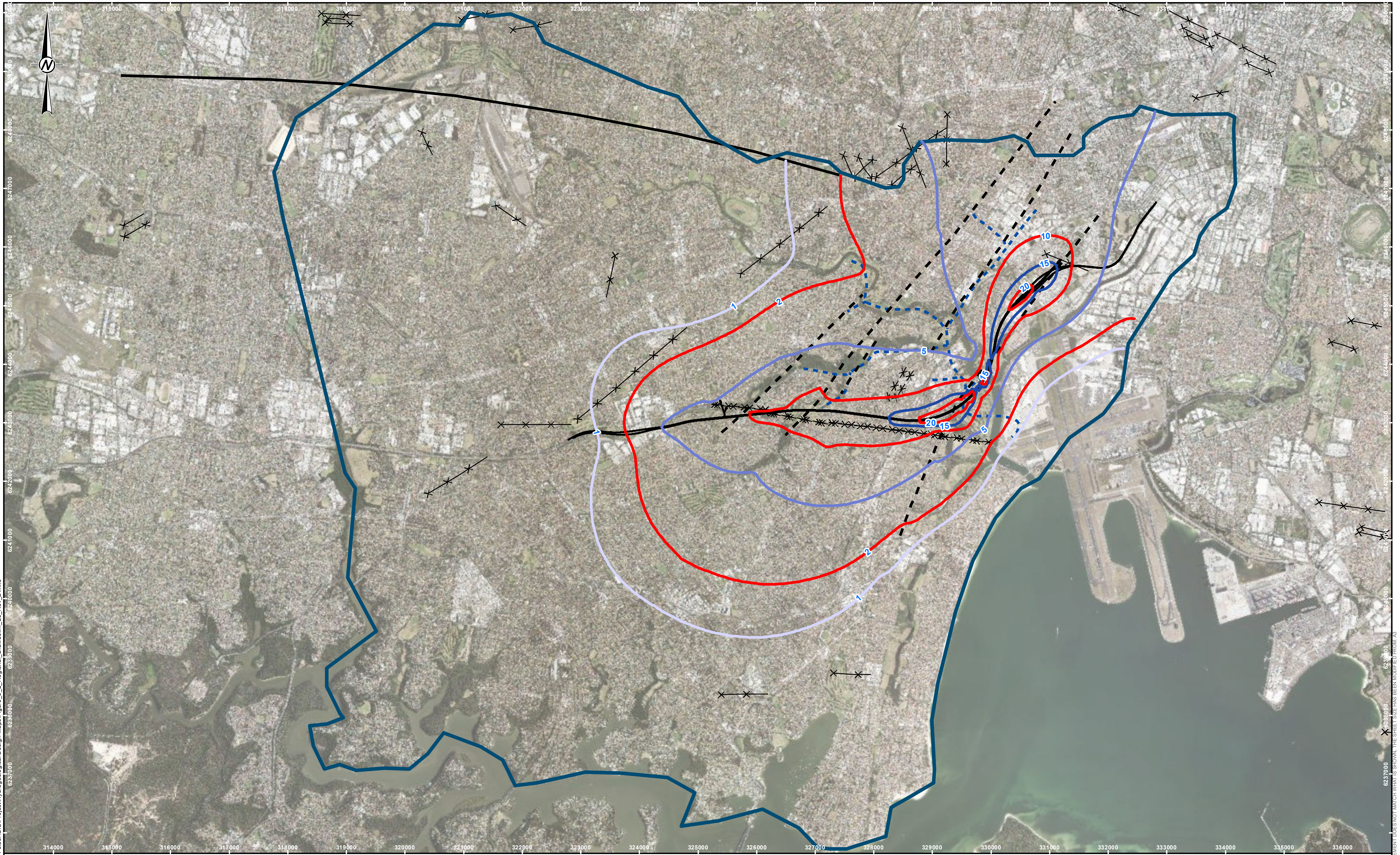
Figure 3. 2: Inflow to mainline tunnels only expressed as a moving average inflow rate per kilometer of mainline tunnel (excluding cross passages, ramps and ventilation tunnels).

3.1.3 Groundwater Drawdown

Base Case Drawdown (i.e. no grouting)

Figure 3.3 illustrates the calculated drawdown in the Hawkesbury Sandstone, calculated using the regional scale model. Maximum drawdowns between 38 to 49 m were calculated, with these maxima occurring to the south-west of Arncliffe, and to the north of Cooks River. Note that these calculated drawdowns indicate the potential for reduction in deeper groundwater levels. The model does not allow for the representation of the potential development of perched shallow groundwater systems isolated from the deeper, lowered groundwater level. In the most extreme case, the impacts of drainage in the underlying Hawkesbury Sandstone as a result of tunnel drainage may lower the groundwater level below the base of overlying unconsolidated sediments. However, as is evidenced at Bexley and Turrella (refer to Section 2.2.10), shallow groundwater systems do not show evidence of impacts from drainage to the M5 East tunnel.

As discussed previously, the alluvial/estuarine sediments overlying rock at Arncliffe show evidence of close hydraulic connection with the underlying Hawkesbury Sandstone, indicating the potential for tunnel drainage in this area to cause a lowering of groundwater levels in the unconsolidated sediments in this area. Drawdowns in the upper layers in this area have been estimated using the local scale model, which has been calibrated to the results of the second pumping test at Arncliffe, and which is more suited than the regional scale model to assess drawdowns in the immediate vicinity of the tunnel because of the finer horizontal and vertical discretisation in this model. Drawdowns in model layers 2 and 6 (corresponding to the shallow and deep unconsolidated Quaternary sediments respectively) are illustrated in Figure 3.4.1. A maximum drawdown in the shallow sediments of approximately 16 m was estimated in the vicinity of the intersection of the Woolloomooloo Fault and the tunnel alignment. Relatively significant vertical hydraulic gradients (resulting in increasing drawdown with depth) are predicted in the immediate vicinity of the tunnel, which is evident in the differences in drawdown contours between Layers 2 and 6 in Figure 3.4.1, and the profiles of drawdown as a function of elevation in Figure 3.4.6. Profiles of computed drawdown as a function of elevation for the area underlying the Sydney Airport are plotted in Figure 3.4.7. From this figure it is evident that drawdown of the groundwater table is within the range of tidal groundwater levels variation that can be expected for an area underlain by sand and close to a tidal water body (e.g. Cooks River).



LEGEND

Groundwater Drawdown in Metres

- 1
- 2
- 5
- 10
- 15
- 20

- Groundwater Model Outline
- WCX2 Alignment
- m9a0_m9b0_ramp_controls
- M110_route
- M120_route

Structure Type

- Fault Location (inferred)
- Dyke Location (inferred)
- Palaeochannel Location (inferred)
- Dyke Location (observed)
- Fold Location (observed)

Service Layer Credits: © Land and Property Information 2015

CLIENT
CPB DRAGADOS SAMSUNG JV

PROJECT
WEST CONNEX STAGE 2

Reference(s):
Herbert C., 1983, Sydney 1:100 000 Geological Sheet 9130, 1st edition.
Geological Survey of New South Wales, Sydney

0 1,000 2,000 3,000 4,000 5,000
METRES

PROJECTION: GDA 1994 MGA Zone 56 REFERENCE SCALE: 1:60,000 (at A3)

TITLE
DRAWDOWN IN MODEL LAYER 8 (HAWKESBURY SANDSTONE) FROM REGIONAL MODEL

CPB CONTRACTORS DRAGADOS SAMSUNG SAMSUNG C&T
WestConnex Stage 2 M5
Golder Associates

YYYY-MM-DD	2016-10-28
PREPARED	HSG
DESIGN	HSG
REVIEW	--
APPROVED	

PROJECT No.	CONTROL	Rev.	FIGURE
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Path: J:\Hyd\2015\Sydney\WCX Brisbane Working Folder\GIS\Project\Hydrogeological Design Maps\Figure_3_2_Regional_Drawdown_L8_Rev_B.mxd

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25mm

AECOM (2015b) predicted significantly smaller groundwater drawdowns in the Arncliffe area than is predicted by the current modelling, which is also likely to be attributable to the absence of high permeability structural features in the Arncliffe area in the modelling carried out for the AECOM report.

Drawdown reductions for various grouting designs

Contours of groundwater drawdown at steady state in model layers 2 and 6 (corresponding to the shallow and deep unconsolidated Quaternary sediments respectively) are illustrated in Figures 3.4.2 to 3.4.5 for the 4 grouting cases considered. The impacts of grouting on drawdown are also illustrated in profiles of drawdown as a function of elevation in Figure 3.4.6 and Figure 3.4.7. Iron precipitation in open fractures due to changes in the groundwater chemistry induced by the tunnel drainage may inhibit groundwater flow towards the tunnels and therefore, has the potential of reducing the impact of tunnel drainage on groundwater levels similar to grouting.

Estimates of groundwater level impacts at groundwater dependent ecosystems (GDEs) and registered bores

The New South Wales (NSW) Aquifer Interference Policy (released in 2012 by the NSW Office of Water, Department of Primary Industries) applies to all aquifer interference activities both during and after an activity. Aquifer interference includes

- The penetration of an aquifer
- The interference with water in an aquifer
- The taking of water from an aquifer
- The taking of water from an aquifer in the course of carrying out an activity prescribed by the regulations, and
- The disposal of water taken from an aquifer in the course of carrying out an activity prescribed by the regulations.

The policy stipulates that impacts and water taken following the completion of an activity need to be planned for and managed. Minimal impact considerations for aquifer interference activities specify a less than or equal to 10% cumulative variation in the water table within 40 m of any high priority GDE or culturally significant site listed in the schedule of the relevant water sharing plan, allowing for typical climatic “post-water sharing plan” variations; and a maximum of a 2 m decline cumulatively at any water supply work.

A number of wetlands and GDEs located within or adjacent to the Project Corridor have been identified in AECOM (2015c). Groundwater level impacts were reassessed based on the results of the numerical, regional and local scale groundwater modelling undertaken as part of the detailed design. Figure 3.5 and Figure 3.6 show the location of GDEs and wetlands obtained from the GDE Atlas (Bureau of Meteorology) overlain with drawdown contours for groundwater in the Hawkesbury Sandstone and unconsolidated.

Quaternary sediments respectively, from the Base Case model. Modelling results support the assessment outcomes reported in AECOM (2015b) for:

- Landing Lights Wetland, Eve Street Wetland and Marsh Street Wetland. The three wetlands are located in unconsolidated Quaternary sediments, and groundwater table drawdown is estimated to range between 1 m to 6 m when steady state has been reached. However, perched groundwater is likely to develop in these low lying areas above shallow organic rich soils. Furthermore, the vegetation in these wetlands is not considered to be associated with a dependence on groundwater (AECOM 2015c, Chapter 21).

- Groundwater drawdown in the unconsolidated Quaternary sediments underlying the Tempe Wetlands located close to Alexandra Canal are estimated to be less than 2 m. The canal is tidal and associated with tidal flows along the Cooks River (AECOM 2015c) and the wetland vegetation is not considered to be associated with a dependence on groundwater (AECOM 2015c, Chapter 21).

- Groundwater drawdown in the Hawkesbury Sandstone beneath Wolli Creek and Bardwell Creek and the estuarine fringe forest and mangrove forest between Wolli Creek and Wolli Creek Railway Station are estimated to be between 12 m and 15 m. However, groundwater drawdown in the alluvium underlying these GDEs is expected to be very limited and are unlikely to impact any GDEs that may be present. This is supported by groundwater levels measured at Turrella in shallow boreholes which do not indicate an impact as a result of drainage of the M5 East ventilation tunnel which extends from the road tunnels north to a vent shaft adjacent to Wolli Creek at Turrella (Section 2.2.10). Groundwater in the unconsolidated Quaternary sediments will be monitored and reported in accordance with the CoA.

- About 3.5 hectares of Coastal Sandstone Ridgetop Woodland within Stotts Reserve, Bexley North was identified and assessed in AECOM (2015c) as having a moderate to high potential to be dependent on groundwater. The reserve is located above the tunnel alignment on Colluvial soils overlying Hawkesbury Sandstone. Modelling results suggest that groundwater drawdown in the Hawkesbury Sandstone at this location could be in excess of 15 metres. A perched groundwater system may develop in the weathered rock fringe sufficient to support growth of trees that are partially dependent on groundwater. Trees could show signs of stress in prolonged dry periods. However the vegetation should recover following sufficient rainfall (AECOM 2015b). Groundwater at the Scotts Reserve will be monitored and reported in accordance with the CoA.

A review of NSW DPI (Water) groundwater database within and adjacent to the Project Corridor identified 98 registered users of which 24 are used for water supply and irrigation and 13 are monitoring bores. The usage of the remainder of the bores is unknown. In CDMSmith (2015) an additional 11 registered groundwater bores are listed that could not been found in the groundwater database. One of the bores is reported to be for commercial and industrial use whereas the purpose of the other 10 bores is unknown.

Figure 3.7 and Figure 3.8 shows the registered water supply bores located within a zone of computed drawdown exceeding 2 m in the Hawkesbury Sandstone and in the unconsolidated Quaternary sediments, respectively (for predicted drawdowns from the regional model).

In the event that groundwater users are impacted by the project by a permanent decline in groundwater levels in operational bores in excess of two metres, provisions will be made to 'make good' the supply by restoring the water supply to pre-development levels. The measures taken would be made in consultation with the affected licence holder. Measures could include, deepening the bore, providing a new bore, lowering the pump or providing an alternative water supply.

Minimal impact considerations for the aquifers within the WCX2 corridor and adjacent areas, in accordance with the NSW Aquifer Interference Policy (NSW OoW, 2012) are summarised in Table 27, Table 28 and Table 29.

Table 27: Minimal Impact Considerations for a "Less Productive Fractured Rock Aquifer"

Minimal Impact Considerations	Response
Water Table – Level 1 **Less than or equal to 10 per c**ent cumulative variation in the **water table, allowing for typical climatic "p**ost water sharing **plan" variations, 40 metres from any:** **(a) high priority groundwater dependent ecosystem; or** **(b) high priority culturally** significant site listed in the **schedule of the relevant water sharing plan, or** **A maximum of a two metre decline cumulatively at any water supply work.**	There are no high priority groundwater dependent ecosystems listed under Appendix 4 of the Greater Metropolitan Region Groundwater Sources Water Sharing Plan that are within the Hawkesbury Sandstone or Ashfield Shale. No culturally significant sites within the Greater Metropolitan Regional Groundwater Water Sharing Plan were reported in the EIS (AECOM 2015b). Locations of water supply bores with drawdown estimated to be more than two meters due to tunnel drainage are shown on Figure 3.6.
Water Table – Level 2 **If more than 10% cumulativ**e variation in the water table, **allowing for typical cli**matic "post water sharing plan" **variations, 40m from any:** **(a) high priority groundwater dependent ecosystem; or** **(b) high priority culturally significant site;** **listed in the schedule of the relevant water sharing plan, if appropriate studies demonstrate** to the Minister's satisfaction **that the variation will not prevent** the long-term viability of the **dependent ecosystem or significant site.** **If more than a two metre de**cline cumulatively at any water **supply work then make good provisions should apply.**	As above
Water Pressure – Level 1 **A cumulative pressure head decline of not more than a two metre decline, at any water supply work.**	The groundwater modelling has included the cumulative impacts of the existing M5 East Motorway tunnel. Shallow drained foundations and other shallow drained structures are not expected to have wide ranging impacts on regional groundwater levels and therefore, were excluded from the model. In the event that groundwater users are impacted by the project by a permanent decline in groundwater levels in operational water supply bores in excess of two metres, provisions will be made to 'make good' the supply by restoring the water supply to pre-development levels. The measures taken would be made in consultation with the affected licence holder. Measures could

	include, deepening the bore, providing a new bore, lowering the pump or providing an alternative water supply.
Water Pressure – Level 2 **If the predicted pressure head decline is greater than requirement 1 above, then appropriate studies are required to demonstrate to the Minister's satisfaction that the decline will not prevent the long term viability of the affected water supply works unless make good provisions apply.**	As above
Water Quality – Level 1 **Any change in the groundwater quality should not lower the beneficial use category of the groundwater source beyond 40m from the activity.**	The beneficial use category of groundwater is not expected to be changed beyond 40 metres of the tunnel.
Water Quality – Level 2 **If condition 1 is not met then appropriate studies will need to demonstrate to the Minister's satisfaction that the change in groundwater quality will not prevent the long-term viability of the dependent ecosystem, significant site or affected water supply works.**	It is expected that Level 1 condition will be met

Table 28: Minimal Impact Considerations for a "Highly Productive Coastal Aquifer"

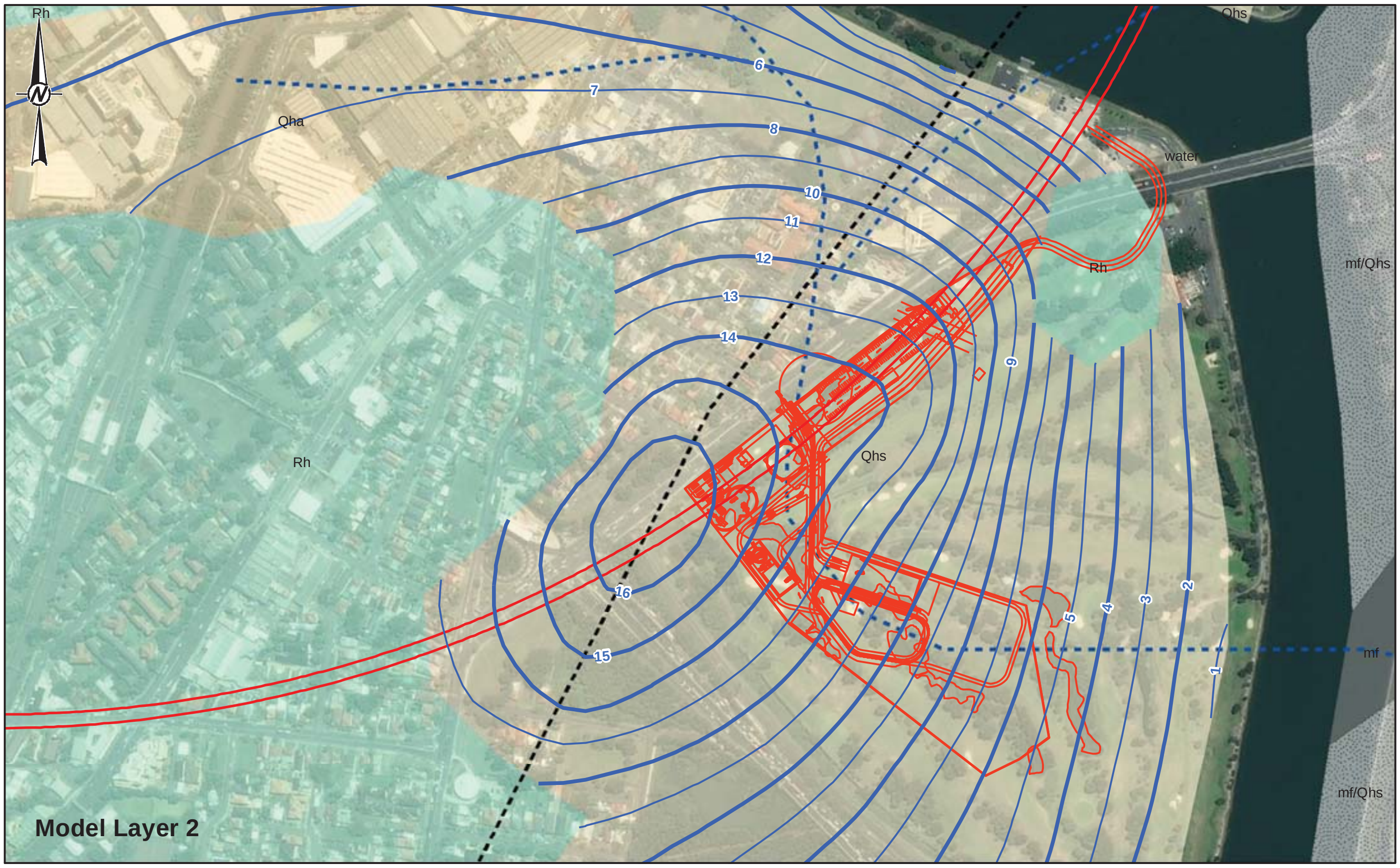
Minimal Impact Considerations	Response
Water Table – Level 1 **Less than or equal to 10 per cent cumulative variation in the water table, allowing for typical climatic "post water sharing plan" variations, 40 metres from any:** **(a) high priority groundwater dependent ecosystem; or** **(b) high priority culturally significant site listed in the** **schedule of the relevant water sharing plan, or** **A maximum of a two metre decline cumulatively at any water supply work.**	The tunnel is not intersecting the Botany Sand beds aquifer. A barrier wall immediately east and south of the Alexandria Landfill is designed to impede any inflow from the Botany Sand Beds aquifer into the leachate drainage system of the landfill. Any wells within the Core SPI area abstracting groundwater from the Botany Sand Beds aquifer will be decommissioned. Therefore no direct incidental water take by the project from the Botany Sand Beds aquifer is anticipated. No culturally significant sites within the Greater Metropolitan Regional Groundwater Water Sharing Plan were reported in the EIS (AECOM 2015b). In the event that groundwater users are impacted by the project by a permanent decline in groundwater levels in operational water supply bores in excess of two metres, provisions will be made to 'make good' the supply by restoring the water supply to pre-development levels. The measures taken would be made in consultation with the affected licence holder. Measures could include, deepening the bore, providing a new bore, lowering the pump or providing an alternative water supply.
Water Table – Level 2	It is expected that cumulative water table variation will be less than or equal to 10 per cent away from the

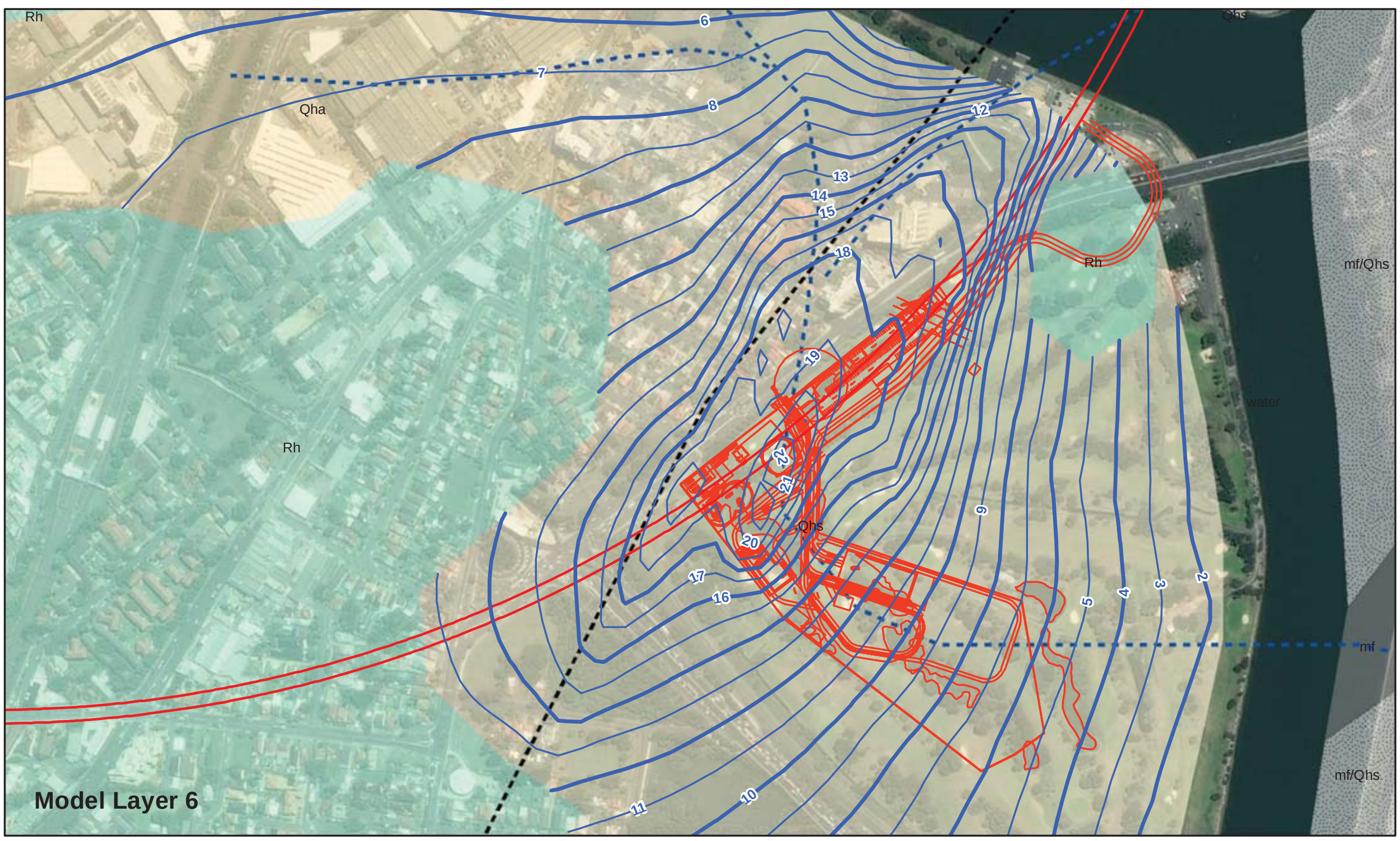
If more than 10% cumulative variation in the water table, allowing for typical climatic "post water sharing plan" variations, 40m from any: **(a) high priority groundwater dependent ecosystem; or** **(b) high priority culturally significant site;** **listed in the schedule of the relevant water sharing plan, if appropriate studies demonstrate to the Minister's satisfaction that the variation will not prevent the long-term viability of the dependent ecosystem or significant site.** **If more than a two metre decline cumulatively at any water supply work then make good provisions should apply.**	• Botany Wetland • Lachlan Swamps and • Towra Point Estuarine Wetlands These are listed as high priority groundwater dependent ecosystems under Appendix 4 of the Greater Metropolitan Region Groundwater Sources Water Sharing Plan.
Water Pressure – Level 1 **A cumulative pressure head decline of not more than a two metre decline, at any water supply work.**	No direct incidental water take by the project from the Botany Sand Beds aquifer is anticipated. Groundwater monitoring is in place to closely monitor cumulative pressure head decline in the Botany Sand Beds aquifer at the Alexandria Landfill.
Water Pressure – Level 2 **If the predicted pressure head decline is greater than requirement 1 above, then appropriate studies are required to demonstrate to the Minister's satisfaction that the decline will not prevent the long term viability of the affected water supply works unless make good provisions apply.**	In the unlikely event that groundwater users are impacted by the project by a permanent decline in groundwater levels in operational water supply bores in excess of two metres, provisions will be made to 'make good' the supply by restoring the water supply to pre-development levels. The measures taken would be made in consultation with the affected licence holder. Measures could include, deepening the bore, providing a new bore, lowering the pump or providing an alternative water supply.
Water Quality – Level 1 **Any change in the groundwater quality should not lower the beneficial use category of the groundwater source beyond 40m from the activity.**	No direct incidental water take by the project from the Botany Sand Beds aquifer is anticipated. Therefore tunnel drainage and drainage by the leachate drainage system of the Alexandria landfill is not expected to lower the current beneficial use category of the Botany Sand Beds aquifer.
Water Quality – Level 2 **If condition 1 is not met then appropriate studies will need to demonstrate to the Minister's satisfaction that the change in groundwater quality will not prevent the long-term viability of the dependent ecosystem, significant site or affected water supply works.**	It is expected that Level 1 condition will be met

Table 29: Minimal Impact Considerations for an "Alluvial Water Source"

Minimal Impact Considerations	Response
Water Table – Level 1 **Less than or equal to 10 per cent cumulative variation in the water table, allowing for typical climatic "post water sharing plan" variations, 40 metres from any:** **(a) high priority groundwater dependent ecosystem; or** **(b) high priority culturally significant site listed in the** **schedule of the relevant water sharing plan, or** **A maximum of a two metre decline cumulatively at any water supply work.**	Landing Lights Wetland, Eve Street Wetland and Marsh Street Wetland are located in unconsolidated Quaternary sediments, and groundwater table drawdown is estimated to range between 1 m to 6 m when steady state has been reached. However, perched groundwater is likely to develop in these low lying areas above shallow organic rich soils. Furthermore, the vegetation in these wetlands is not considered to be associated with a dependence on groundwater (AECOM 2015c, Chapter 21) Groundwater drawdown in the alluvium underlying the GDEs at Wolli Creek and Bardwell Creek is expected to be very limited and are unlikely to impact any GDEs that may be present. Groundwater in the unconsolidated Quaternary sediments will be monitored and reported in accordance with the CoA. No culturally significant sites within the Greater Metropolitan Regional Groundwater Water Sharing Plan were reported in the EIS (AECOM 2015b). In the event that users of an alluvial water source are impacted by the project by a permanent decline in groundwater levels in operational water supply bores in excess of two metres, provisions will be made to 'make good' the supply by restoring the water supply to pre-development levels. The measures taken would be made in consultation with the affected licence holder. Measures could include, deepening the bore, providing a new bore, lowering the pump or providing an alternative water supply.
Water Table – Level 2 **If more than 10% cumulative variation in the water table, allowing for typical climatic "post water sharing plan" variations, 40m from any:** **(a) high priority groundwater dependent ecosystem; or** **(b) high priority culturally significant site;** **listed in the schedule of the relevant water sharing plan, if appropriate studies demonstrate to the Minister's satisfaction that the variation will not prevent the long-term viability of the dependent ecosystem or significant site.** **If more than a two metre decline cumulatively at any water supply work then make good provisions should apply.**	It is expected that Level 1 condition will be met. Otherwise, provisions will be made to 'make good' for the lost water supply by restoring the water supply to pre-development levels. The measures taken would be made in consultation with the affected licence holder. Measures could include, deepening the bore, providing a new bore, lowering the pump or providing an alternative water supply.
Water Pressure – Level 1	Groundwater monitoring is in place to closely monitor cumulative pressure head decline in alluvium at Wolli Creek and Arncliffe.

A cumulative pressure head decline of not more than 40% of the "post-water sharing plan" pressure head above the base of the water source to a maximum of a 2 m decline, at any water supply work.	In the event that users of an alluvial water source are impacted by the project by a permanent decline in groundwater levels in operational water supply bores in excess of two metres, provisions will be made to 'make good' the supply by restoring the water supply to pre-development levels. The measures taken would be made in consultation with the affected licence holder. Measures could include, deepening the bore, providing a new bore, lowering the pump or providing an alternative water supply.
Water Pressure – Level 2 **If the predicted pressure head decline is greater than requirement 1. above, then appropriate studies are required to demonstrate to the Minister's satisfaction that the decline will not prevent the long-term viability of the affected water supply works unless make good provisions apply.**	As above
Water Quality – Level 1 a) **Any change in the groundwater quality should not lower the beneficial use category of the groundwater source beyond 40 m from the activity.** b) No increase of more than 1% per activity in long-term average salinity in a highly connected surface water source at the nearest point to the activity.	Tunnel drainage is not expected to lower the current beneficial use category of the alluvial groundwater source at Arncliffe and Wolli Creek beyond 40 m from the activity. Salinity of groundwater collected in the tunnel pump sumps and discharge to the Cooks River is expected to be well below current salinity levels of the river.
Water Quality – Level 2 **If condition 1 is not met then appropriate studies will need to demonstrate to the Minister's satisfaction that the change in groundwater quality will not prevent the long-term viability of the dependent ecosystem, significant site or affected water supply works.**	It is expected that Level 1 condition will be met





LEGEND

- Drawdown Contours (m)
- WCX2 Alignment and Surface Works

Structure Type

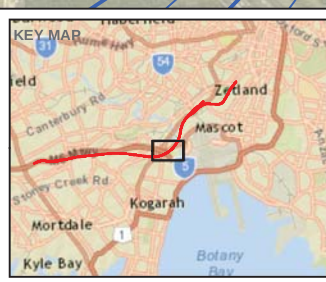
- Dyke location (inferred)
- Fault location (inferred)
- Palaeochannel (inferred)
- Dyke location (observed)
- Fold location (inferred)

Sydney 1:100,000 Geology

- Man made fill (mf)
- fill/Qhs (mg/Qhs)
- Qha - Quartz sand, silt and clay
- Qhs - Peat, sandy peat and mud
- Rh - Hawkesbury sandstone

Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

KEY MAP



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PROJECTION: GDA 1994 MGA Zone 56
REFERENCE SCALE: 1:5,500 (at A3)
DATE: 28/10/2016

Reference(s):
Herbert C., 1983, Sydney 1:100 000 Geological Sheet 9130, 1st edition. Geological Survey of New South Wales, Sydney

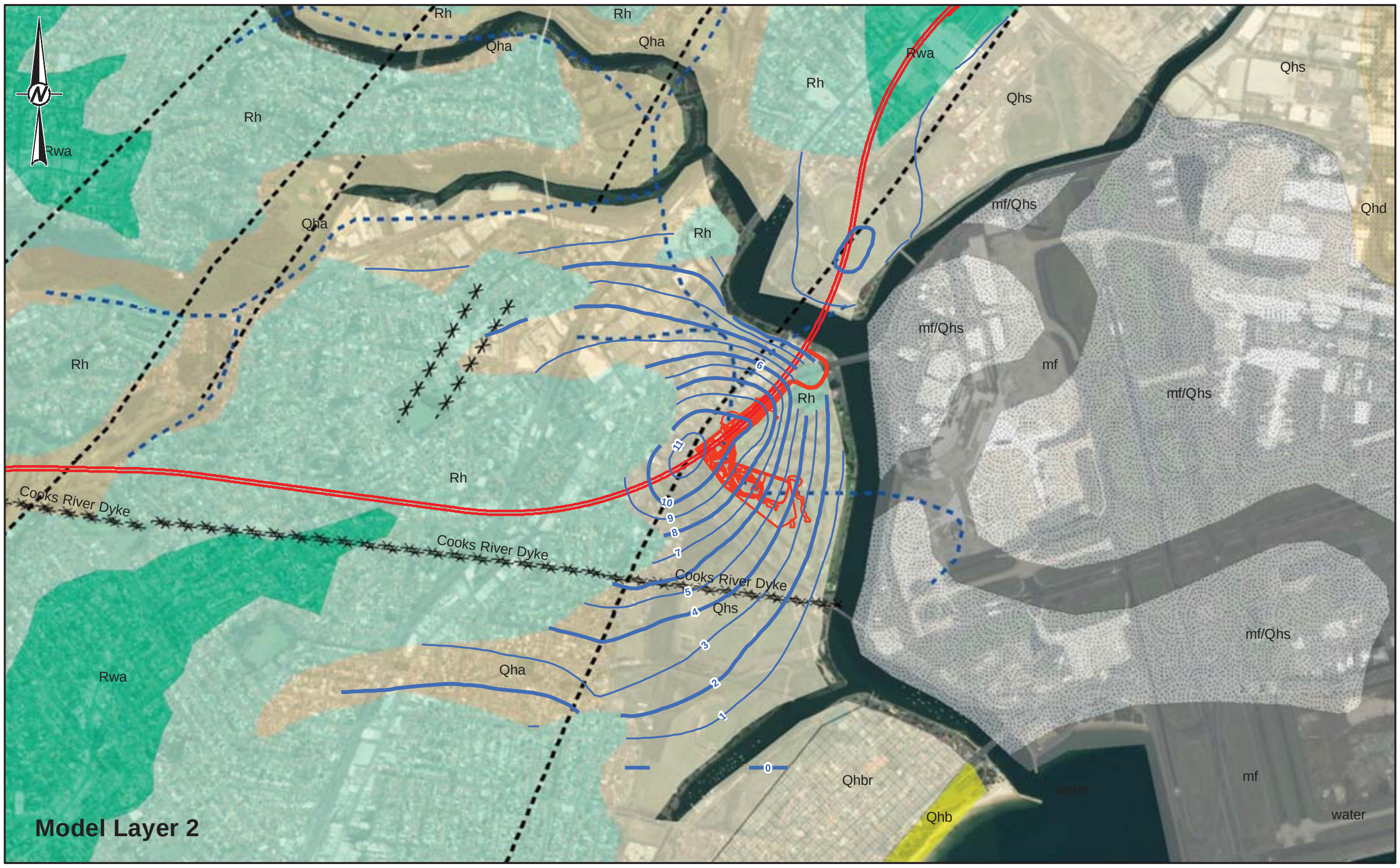
TITLE
CONTOURS OF DRAWDOWN IN UNCONSOLIDATED QUATERNARY SEDIMENTS - BASE CASE

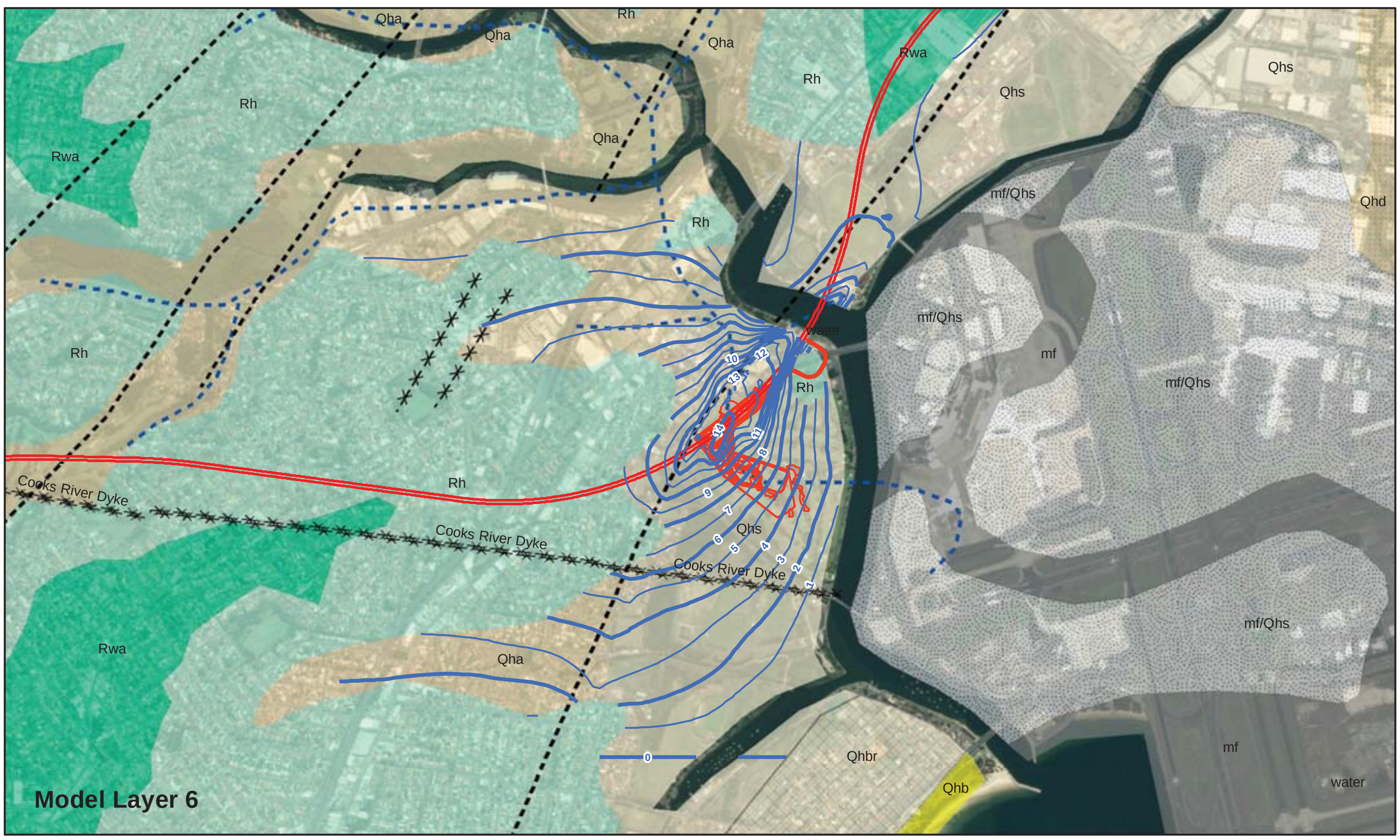
CLIENT
CPB DRAGADOS SAMSUNG JV

PROJECT
WEST CONNEX STAGE 2

PROJECT No.	CONTROL	Rev.	FIGURE
1524285	001	B	**3.4.1**

PATH: J:\Hyd\2015\Sydney\WCX Brisbane Working Folder\GIS\Project\Groundwater Drawdown Maps 15-08-2016\MXD\1524285_001_RevB_BaseCase_Drawdown_L2_L6.mxd





LEGEND

- Drawdown Contours (m)
- WCX2 Alignment and Surface Works

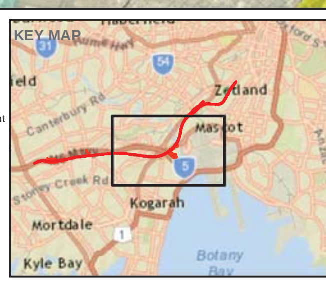
Structure Type

- Dyke location (inferred)
- Fault location (inferred)
- Palaeochannel (inferred)
- Dyke location (observed)
- Fold location (inferred)

Sydney 1:100,000 Geology

- Man made fill (mf)
- fill/Qhs (mg/Qhs)
- Qha - Quartz sand, silt and clay
- Qhs - Peat, sandy peat and mud
- Qhd - Marine sand
- Qhbr - Quartz sand, minor shell content
- Qhb - Coarse quartz sand
- Rwa - Ashfield Shale
- Rh - Hawkesbury sandstone

Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community



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PROJECTION: GDA 1994 MGA Zone 56
REFERENCE SCALE: 1:20,000 (at A3)
DATE: 28/10/2016

Reference(s):
Herbert C., 1983, Sydney 1:100 000 Geological Sheet 9130, 1st edition. Geological Survey of New South Wales, Sydney

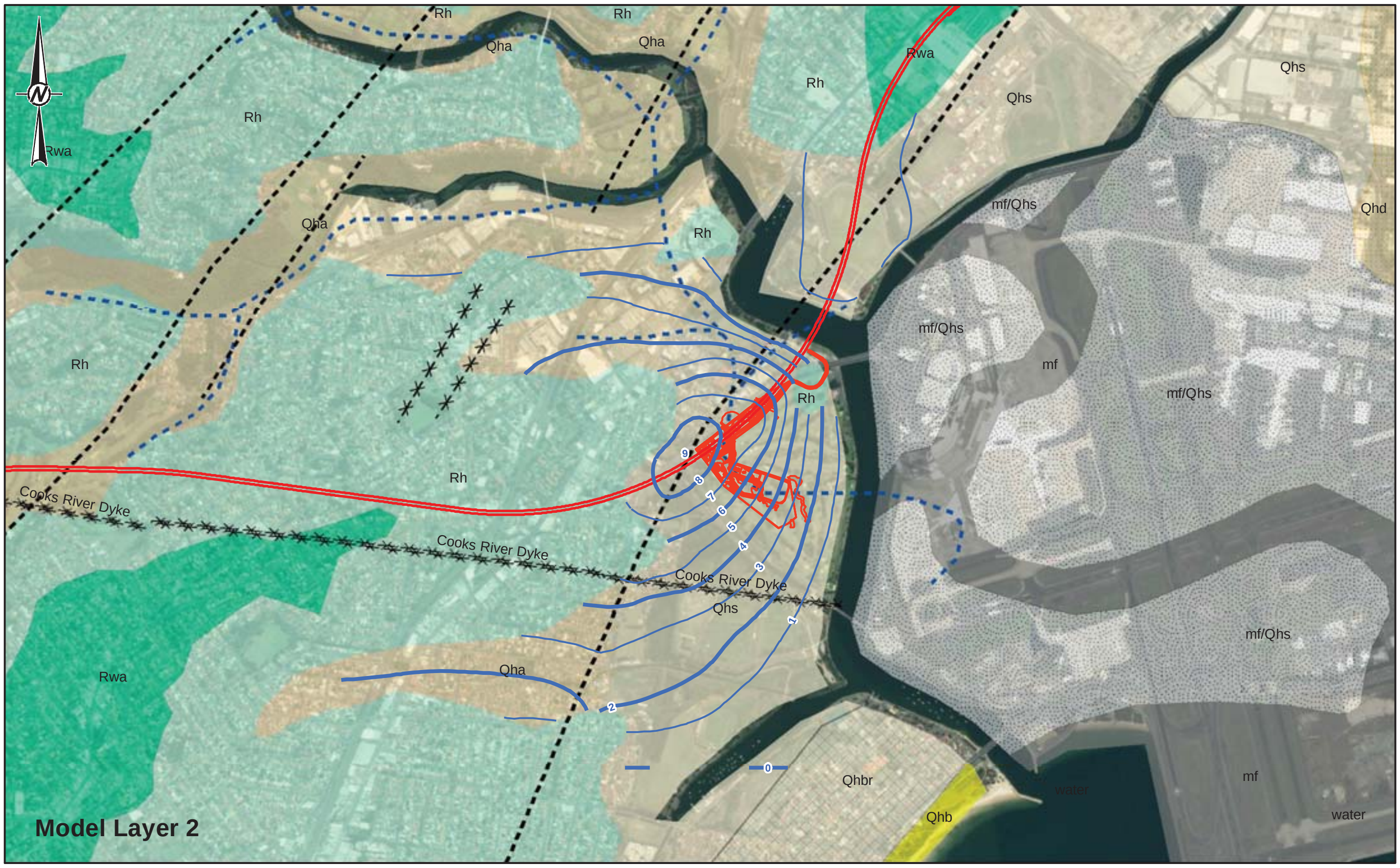
TITLE
CONTOURS OF DRAWDOWN IN UNCONSOLIDATED QUATERNARY SEDIMENTS - CASE 1 GROUTING

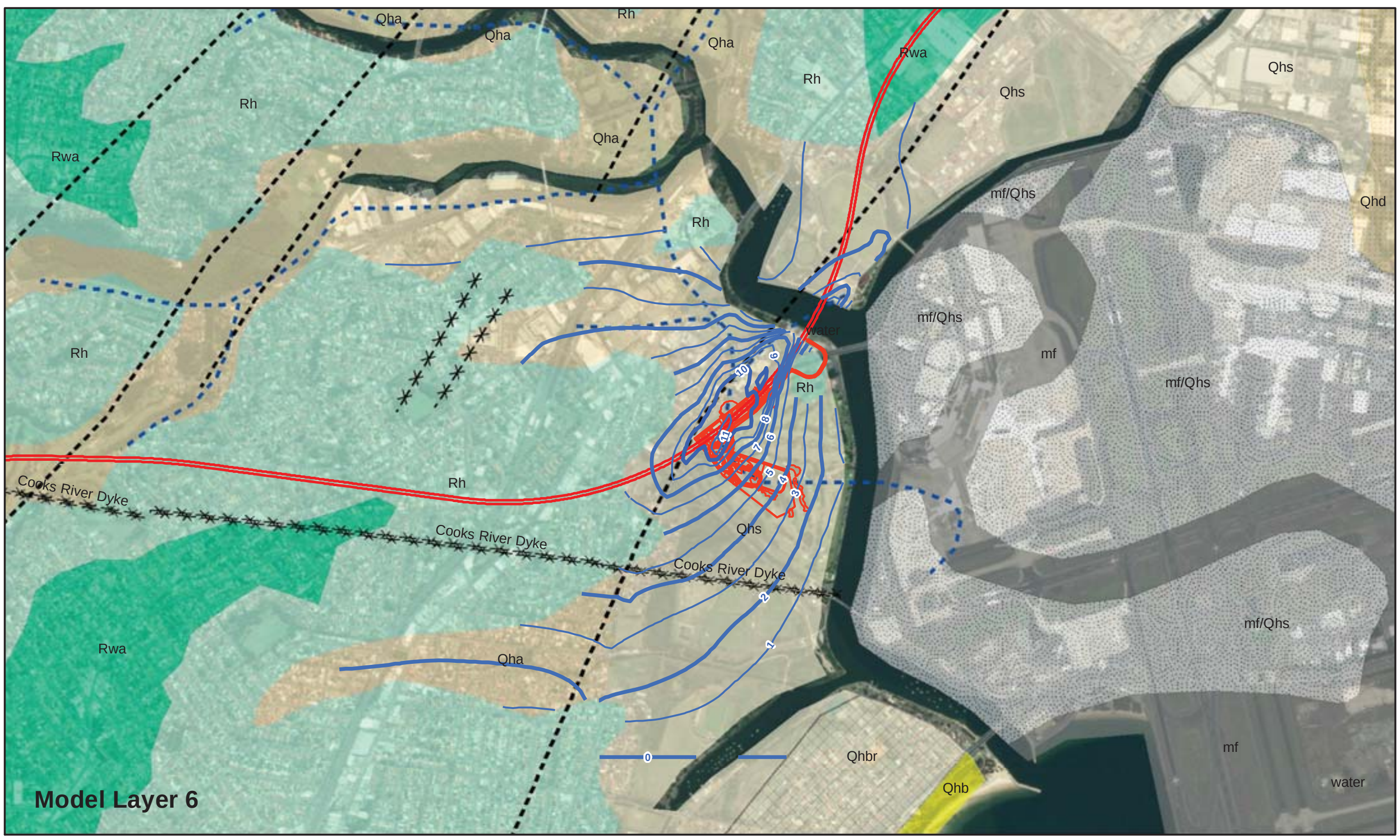
CLIENT
CPB DRAGADOS SAMSUNG JV

PROJECT
WEST CONNEX STAGE 2

PROJECT No.	CONTROL	Rev.	FIGURE
1524285	001	C	**3.4.2**

PATH: J:\Hyd\2015\Sydney\WCX Brisbane Working Folder\GIS\Project\Groundwater Drawdown Maps 15-08-2016\MXD\1524285_001_RevC_Case1_Drawdown_L2_L6.mxd





LEGEND

- Drawdown Contours (m)
- WCX2 Alignment and Surface Works

Structure Type

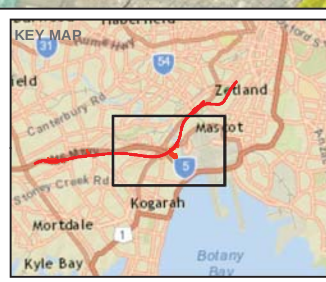
- Dyke location (inferred)
- Fault location (inferred)
- Palaeochannel (inferred)
- Dyke location (observed)
- Fold location (inferred)

Sydney 1:100,000 Geology

- Man made fill (mf)
- fill/Qhs (mg/Qhs)
- Qha - Quartz sand, silt and clay
- Qhs - Peat, sandy peat and mud
- Qhd - Marine sand
- Qhbr - Quartz sand, minor shell content
- Qhb - Coarse quartz sand
- Rwa - Ashfield Shale
- Rh - Hawkesbury sandstone

Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

KEY MAP



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PROJECTION: GDA 1994 MGA Zone 56
REFERENCE SCALE: 1:20,000 (at A3)
DATE: 28/10/2016

Reference(s):
Herbert C., 1983, Sydney 1:100 000 Geological Sheet 9130, 1st edition. Geological Survey of New South Wales, Sydney

TITLE
CONTOURS OF DRAWDOWN IN UNCONSOLIDATED QUATERNARY SEDIMENTS - CASE 2 GROUTING

CLIENT
CPB DRAGADOS SAMSUNG JV

PROJECT
WEST CONNEX STAGE 2

PROJECT No.	CONTROL	Rev.	FIGURE
1524285	001	C	3.4.3

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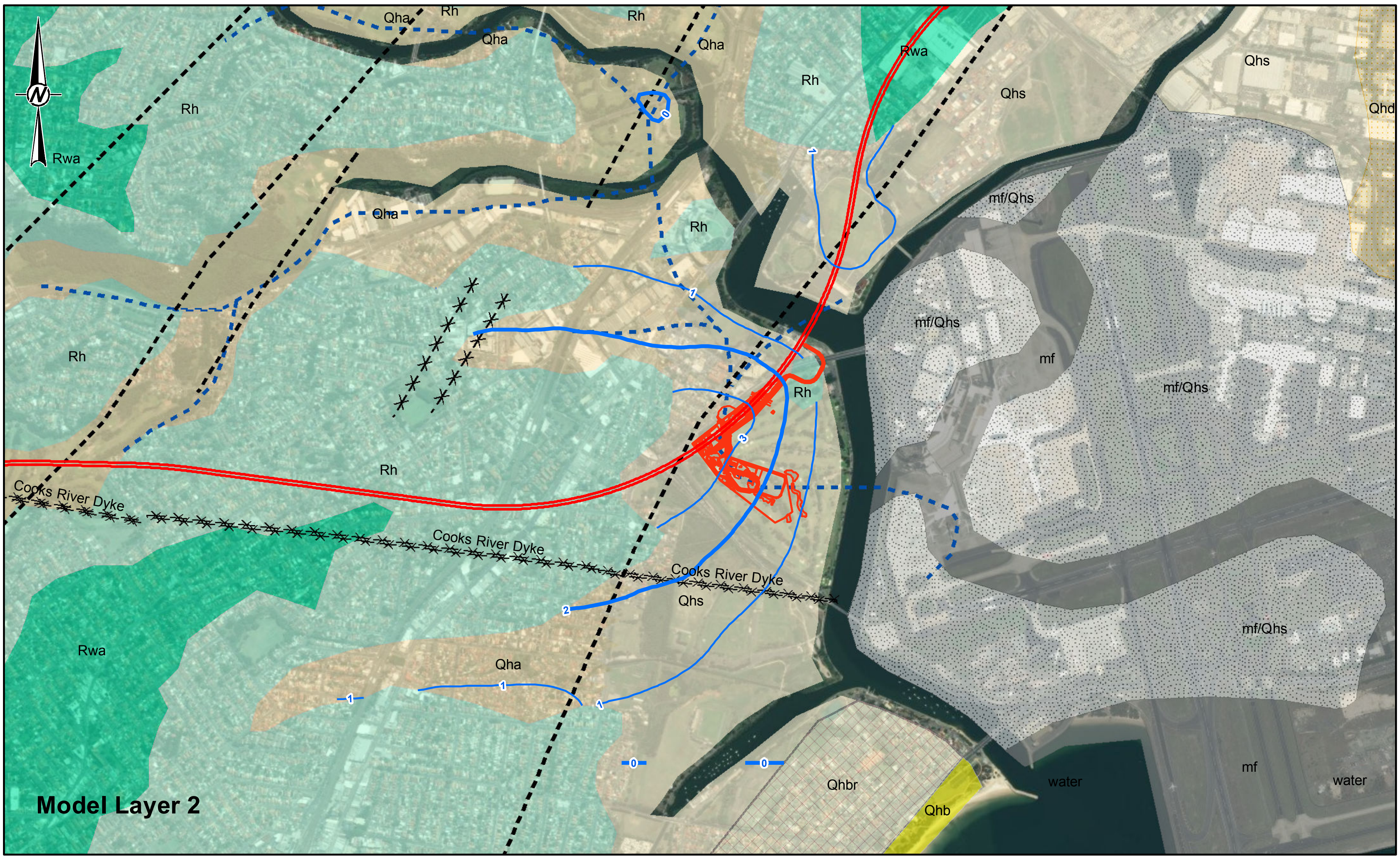
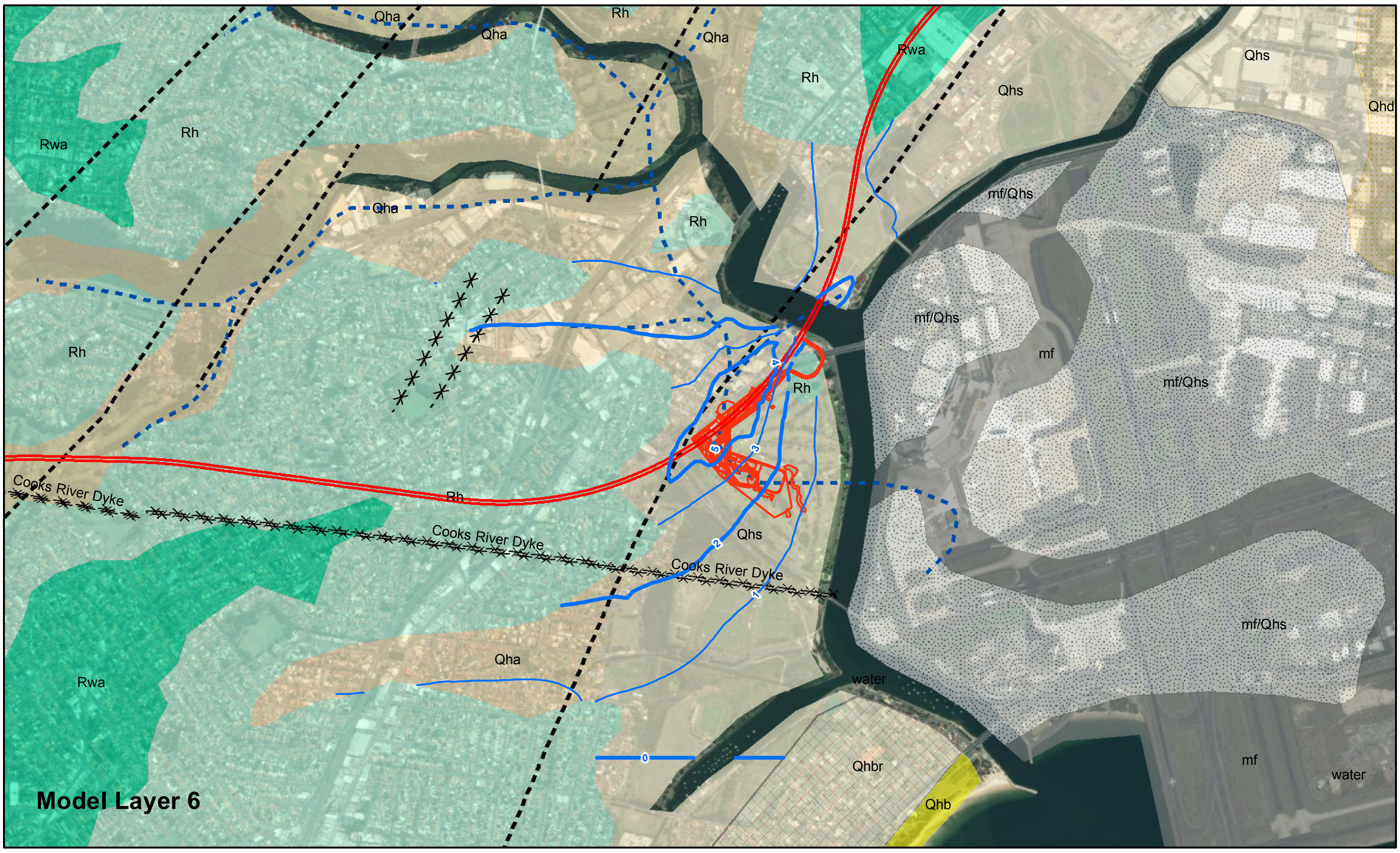




LEGEND

- Drawdown Contours (m)
- WCX2 Alignment and Surface Works

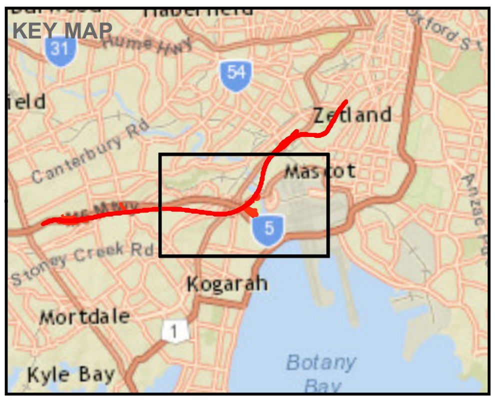
Structure Type

- Dyke location (inferred)
- Fault location (inferred)
- Palaeochannel (inferred)
- Dyke location (observed)
- Fold location (inferred)

Sydney 1:100,000 Geology

- Man made fill (mf)
- fill/Qhs (mg/Qhs)
- Qha - Quartz sand, silt and clay
- Qhs - Peat, sandy peat and mud
- Qhd - Marine sand
- Qhbr - Quartz sand, minor shell content
- Qhb - Coarse quartz sand
- Rwa - Ashfield Shale
- Rh - Hawkesbury sandstone

Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community



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PROJECTION: GDA 1994 MGA Zone 56
REFERENCE SCALE: 1:20,000 (at A3)
DATE: 28/10/2016

Reference(s):
Herbert C., 1983, Sydney 1:100 000 Geological Sheet 9130, 1st edition. Geological Survey of New South Wales, Sydney

TITLE
CONTOURS OF DRAWDOWN IN UNCONSOLIDATED QUATERNARY SEDIMENTS - CASE 3 GROUTING

CLIENT
CPB DRAGADOS SAMSUNG JV

PROJECT
WEST CONNEX STAGE 2

PROJECT No.	CONTROL	Rev.	FIGURE
1524285	001	C	**3.4.4**

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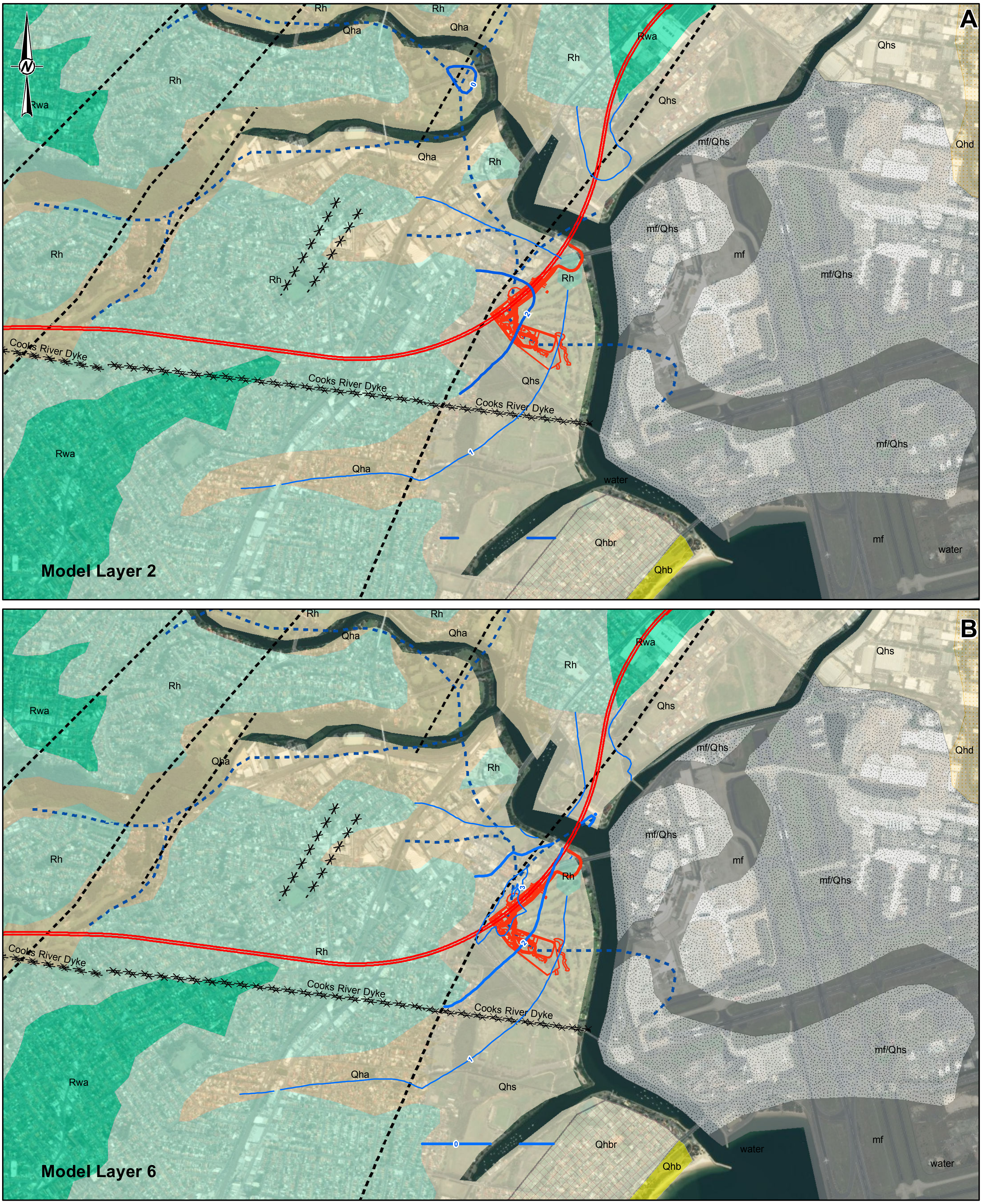


LEGEND

- Drawdown Contours (m)
- WCX2 Alignment and Surface Works

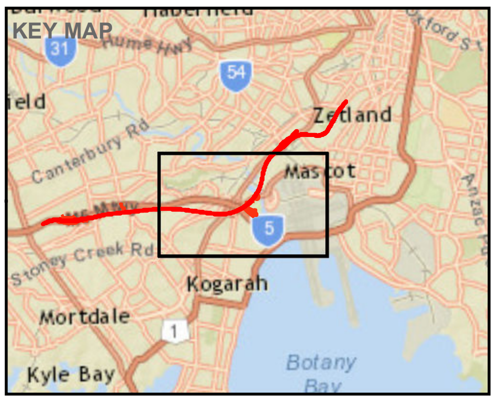
Structure Type

- Dyke location (inferred)
- Fault location (inferred)
- Palaeochannel (inferred)
- Dyke location (observed)
- Fold location (inferred)

Sydney 1:100,000 Geology

- Man made fill (mf)
- fill/Qhs (mg/Qhs)
- Qha - Quartz sand, silt and clay
- Qhs - Peat, sandy peat and mud
- Qhd - Marine sand
- Qhbr - Quartz sand, minor shell content
- Qhb - Coarse quartz sand
- Rwa - Ashfield Shale
- Rh - Hawkesbury sandstone

Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community



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Metres

PROJECTION: GDA 1994 MGA Zone 56
REFERENCE SCALE: 1:20,000 (at A3)
DATE: 28/10/2016

Reference(s):
Herbert C., 1983, Sydney 1:100 000 Geological Sheet 9130, 1st edition. Geological Survey of New South Wales, Sydney

TITLE
CONTOURS OF DRAWDOWN IN UNCONSOLIDATED QUATERNARY SEDIMENTS - CASE 4 GROUTING

CLIENT
CPB DRAGADOS SAMSUNG JV

PROJECT
WEST CONNEX STAGE 2

PROJECT No.	CONTROL	Rev.	FIGURE
1524285	001	C	3.4.5

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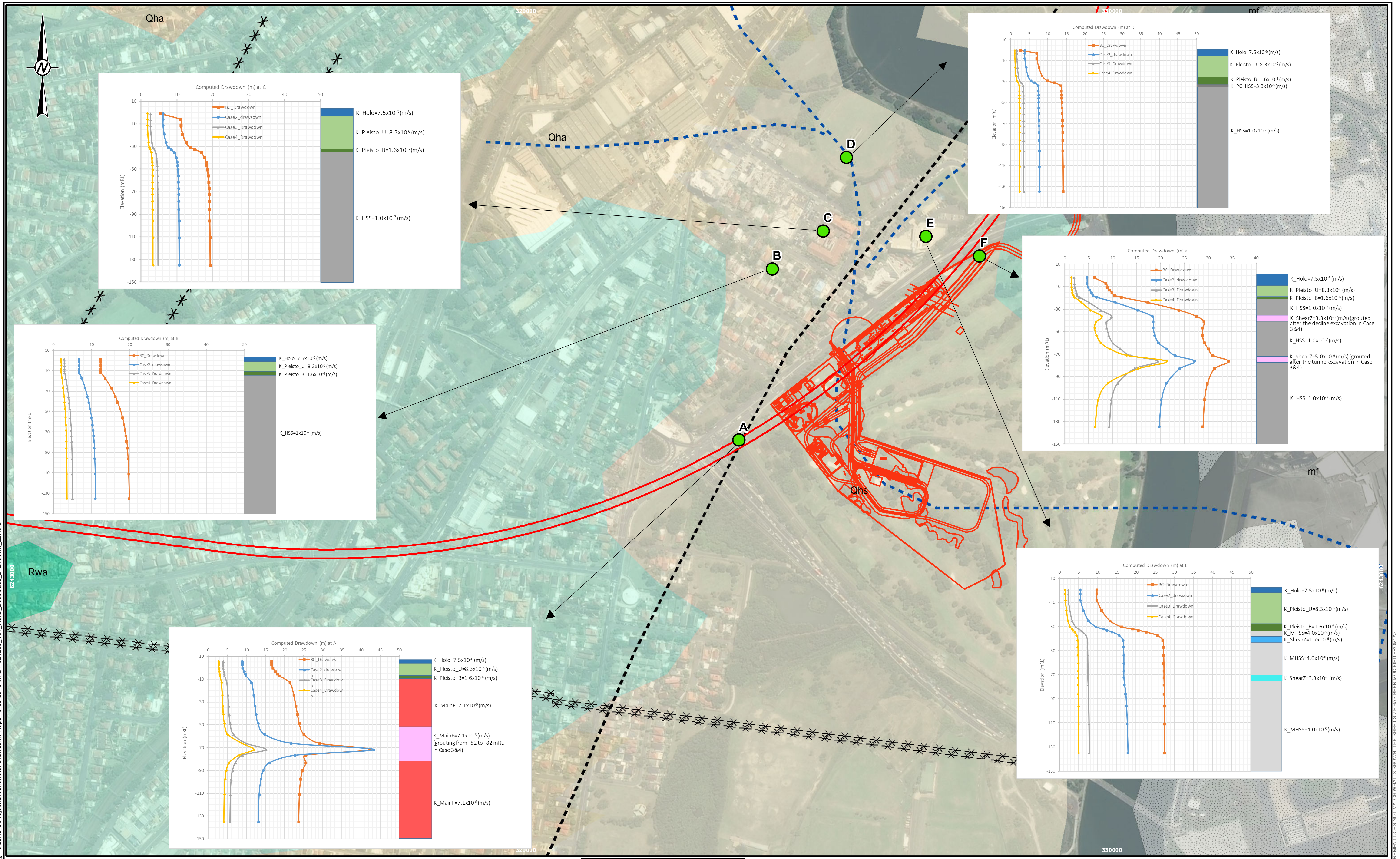


LEGEND

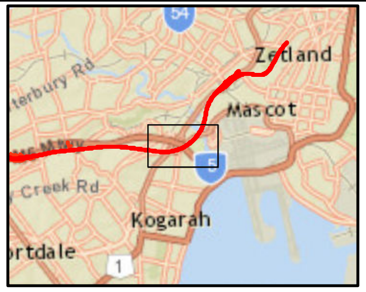
- Points of Interest

Structure Type

- Dyke location (inferred)
- Fault location (inferred)
- Palaeochannel (inferred)

Sydney 1:100,000 Geology

- Man made fill (mf)
- fill/Qhs (mg/Qhs)
- Qha - Quartz sand, silt and clay
- Qhs - Peat, sandy peat and mud
- Rwa - Ashfield Shale
- Rh - Hawkesbury sandstone



CLIENT
CPB DRAGADOS SAMSUNG JV

PROJECT
WEST CONNEX STAGE 2

Reference(s):
Herbert C., 1983, Sydney 1:100 000 Geological Sheet 9130, 1st edition. Geological Survey of New South Wales, Sydney

0 100 200 300 400 METRES

REFERENCE SCALE: 1:6,000 (at A3)

PROJECTION: GDA 1994 MGA Zone 56

TITLE
PROFILE OF DRAWDOWN WITH DEPTH AT ARNCLIFFE - BASE CASE AND GROUTING SCENARIOS

CPB CONTRACTORS | DRAGADOS | SAMSUNG C&T | WestConnex Stage 2 M5 | Golder Associates

YYYY-MM-DD	2016-10-28
PREPARED	HSG
DESIGN	HSG
REVIEW	--
APPROVED	

PROJECT No.	CONTROL	Rev.	FIGURE
1524285	001	B	3.4.6

Path: J:\Hyd\2015\Sydney\WCX Brisbane Working Folder\GIS\Project\Groundwater Drawdown Maps 15-08-2016\MXD\1524285_001_RevB_BaseCase_Drawdown_L2.mxd

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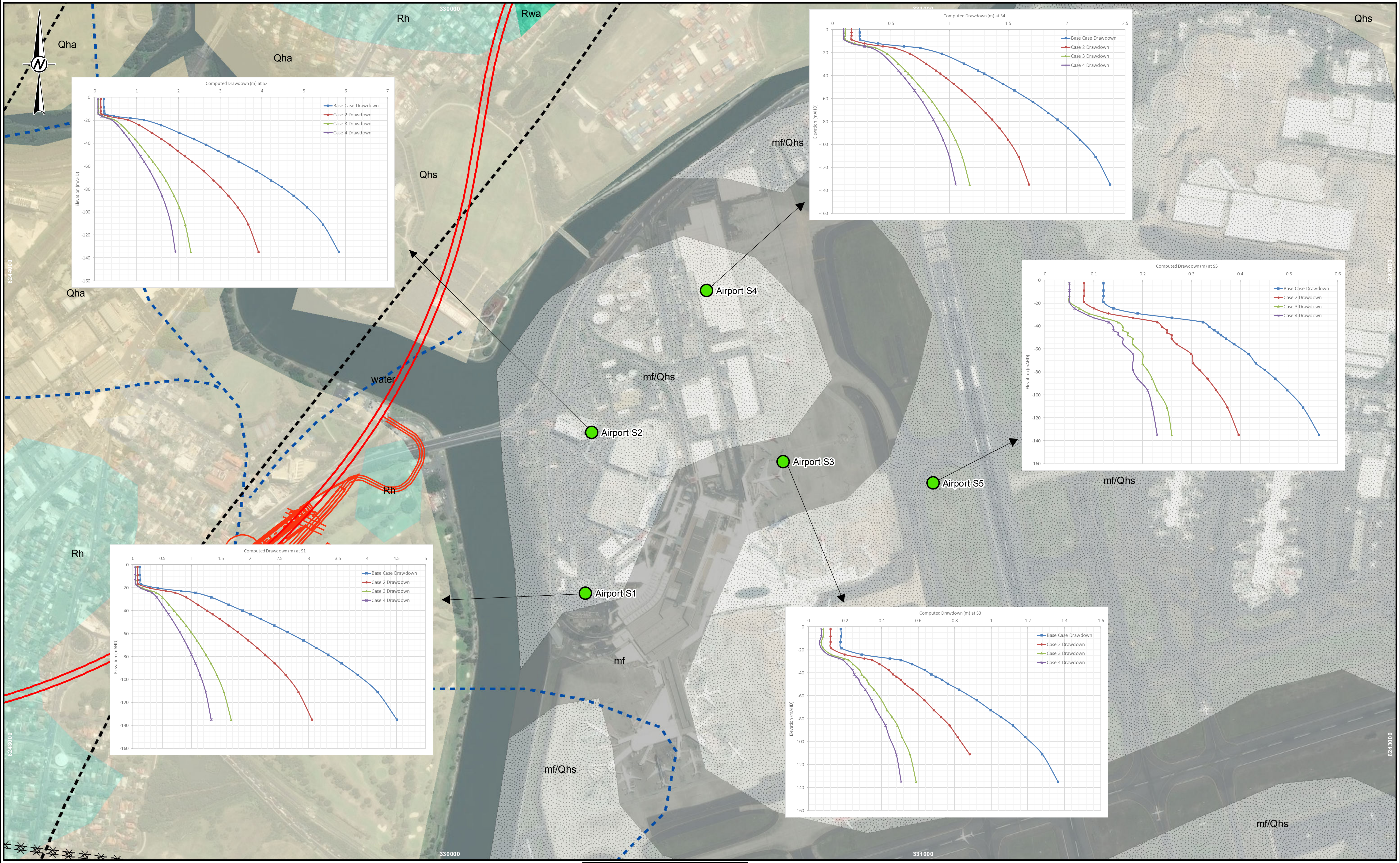


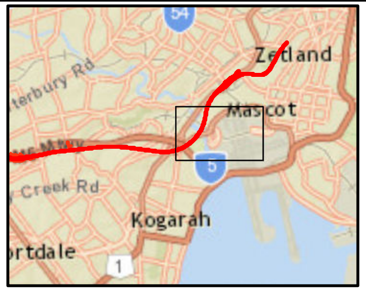
LEGEND

Structure Type

- Fault location (inferred)
- Palaeochannel (inferred)

Sydney 1:100,000 Geology

- Man made fill (mf)
- fill/Qhs (mg/Qhs)
- Qha - Quartz sand, silt and clay
- Qhs - Peat, sandy peat and mud
- Rwa - Ashfield Shale
- Rh - Hawkesbury sandstone



Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

CLIENT
CPB DRAGADOS SAMSUNG JV

PROJECT
WEST CONNEX STAGE 2

Reference(s):
Herbert C., 1983, Sydney 1:100 000 Geological Sheet 9130, 1st edition. Geological Survey of New South Wales, Sydney

0 100 200 300 400 METRES

REFERENCE SCALE: 1:7,500 (at A3)
PROJECTION: GDA 1994 MGA Zone 56

TITLE
PROFILE OF DRAWDOWN WITH DEPTH AT THE SYDNEY AIRPORT - BASE CASE AND GROUTING SCENARIOS

YYYY-MM-DD	2016-10-28
PREPARED	HSG
DESIGN	HSG
REVIEW	--
APPROVED	

PROJECT No.	CONTROL	Rev.	FIGURE
1524285	001	A	3.4.7

Path: J:\Hyd\2015\Sydney\WCX Brisbane Working Folder\GIS\Project\Airport Map\MXDs\1524285_001_RevA_Airport_Drawdown.mxd

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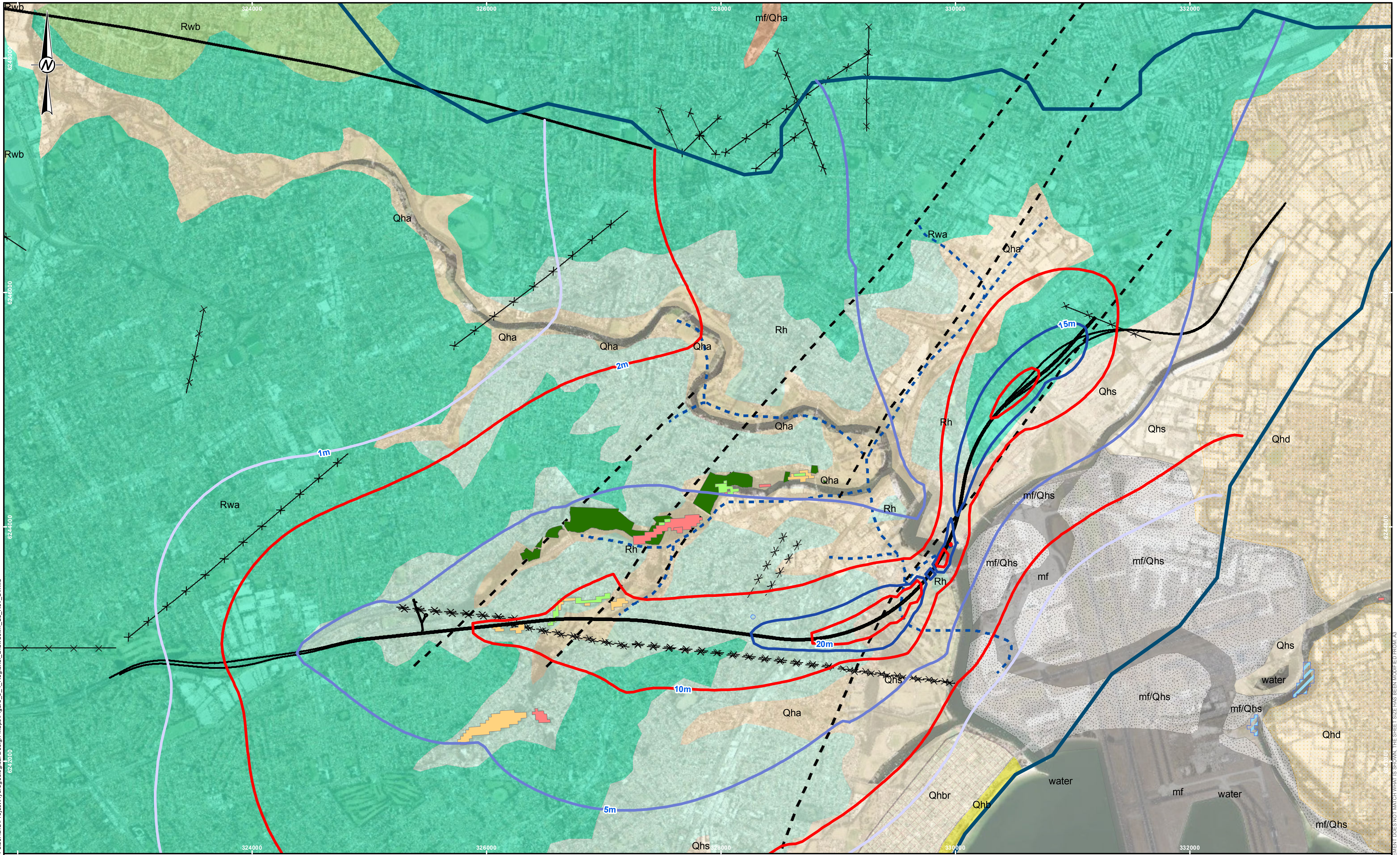


LEGEND

Groundwater Drawdown in Metres
- 1
- 2
- 5
- 10
- 15
- 20

Groundwater Model Outline
WCX2 Alignment

Structure Type
- Fault Location (inferred)
- Dyke Location (inferred)
- Palaeochannel Location (inferred)
- Dyke Location (observed)
- Fold Location (observed)

Sydney 1:100,000 Geology
- Man made fill (mf)
- fill/Qha (mf/Qha)
- fill/Qhs (mg/Qhs)
- Qha - Quartz sand, silt and clay
- Qhs - Peat, sandy peat and mud
- Qhd - Marine sand
- Qhbr - Quartz sand, minor shell content
- Qhb - Coarse quartz sand
- Rwb - Bringelly Shale
- Rwa - Ashfield Shale
- Rh - Hawkesbury sandstone

Significant Wetlands

Potential for Groundwater Ecosystem Interaction
- Low potential
- Moderate potential
- High potential

CAPAD Protected Area (2014)
- Regional Park

Service Layer Credits: © Land and Property Information 2015

Path: J:\Hyd\2015\Sydney\WCX Brisbane Working Folder\GIS\Project\Hydrogeological Design Maps\Figure_3_4_Regional_Drawdown_L8_Rev_C.mxd

CLIENT
CPB DRAGADOS SAMSUNG JV

PROJECT
WEST CONNEX STAGE 2

Reference(s):
Herbert C., 1983, Sydney 1:100 000 Geological Sheet 9130, 1st edition.
Geological Survey of New South Wales, Sydney

0 500 1,000 1,500 2,000 METRES

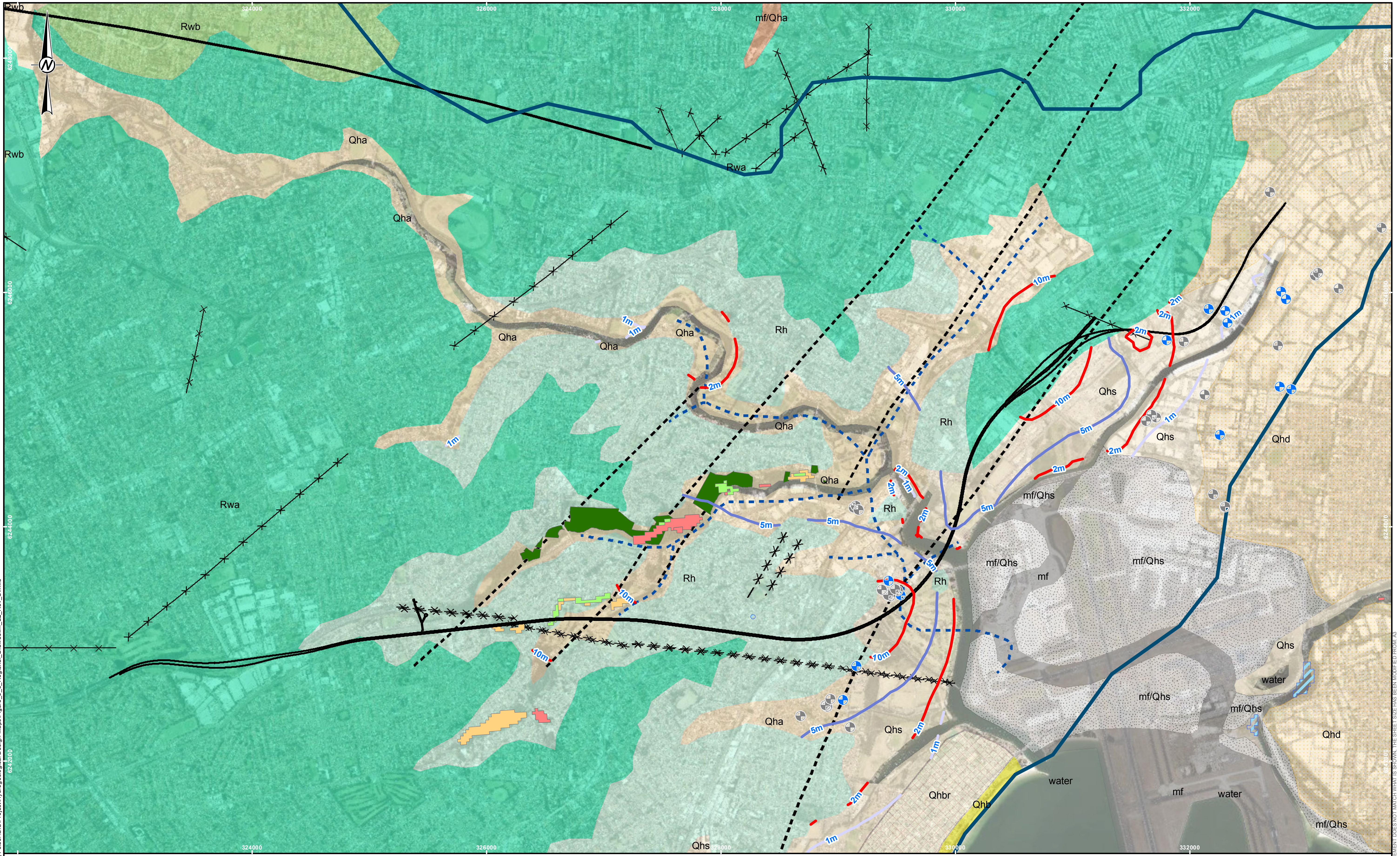
PROJECTION: GDA 1994 MGA Zone 56 REFERENCE SCALE: 1:30,000 (at A3)

TITLE
IMPACTS ON POTENTIOMETRIC LEVELS IN THE HAWKESBURY SANDSTONE (MODEL LAYER 8) AT GDES

YYYY-MM-DD	2016-10-28
PREPARED	HSG
DESIGN	HSG
REVIEW	--
APPROVED	

PROJECT No.	CONTROL	Rev.	FIGURE
1524285	001	C	3.5

IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM A3



LEGEND

Registered Bore
Screened Formation:
Quaternary Sediments
Unknown

Groundwater Drawdown in Metres
1
2
5
10

Groundwater Model Outline
WCX2 Alignment

Structure Type
Dyke location (inferred)
Fault location (inferred)
Palaeochannel Location (inferred)
Dyke Location (observed)
Fold Location (observed)

Sydney 1:100,000 Geology
Man made fill (mf)
fill/Qha (mf/Qha)
fill/Qhs (mg/Qhs)
Qha - Quartz sand, silt and clay
Qhs - Peat, sandy peat and mud
Qhd - Marine sand
Qhbr - Quartz sand, minor shell content
Qhb - Coarse quartz sand
Rwb - Bringelly Shale
Rwa - Ashfield Shale
Rh - Hawkesbury sandstone

Significant Wetlands

Potential for Groundwater Ecosystem Interaction
Low potential
Moderate potential
High potential

CAPAD Protected Area (2014)
Regional Park

Service Layer Credits: © Land and Property Information 2015

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CPB DRAGADOS SAMSUNG JV

PROJECT
WEST CONNEX STAGE 2

Reference(s):
Herbert C., 1983, Sydney 1:100 000 Geological Sheet 9130, 1st edition.
Geological Survey of New South Wales, Sydney

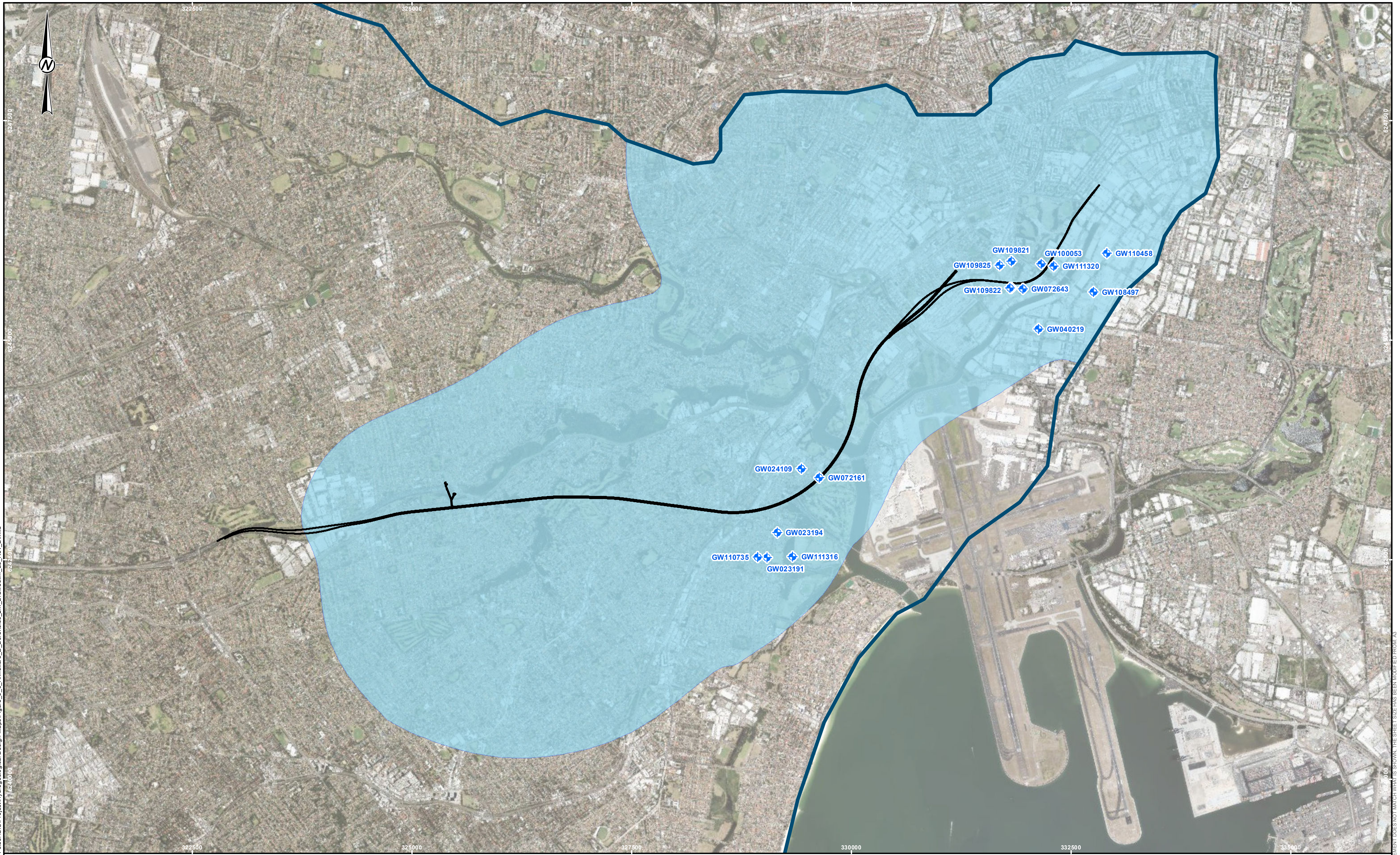
0 500 1,000 1,500 2,000
METRES

PROJECTION: GDA 1994 MGA Zone 56
REFERENCE SCALE: 1:30,000 (at A3)

TITLE
IMPACTS ON WATER TABLE LEVELS IN UNCONSOLIDATED QUATERNARY SEDIMENTS (MODEL LAYER 2) AT GDES

YYYY-MM-DD	2016-10-28
PREPARED	HSG
DESIGN	HSG
REVIEW	--
APPROVED	

PROJECT No.	CONTROL	Rev.	FIGURE
1524285	001	C	3.6



LEGEND

- Registered Water Supply Bores
- Groundwater Model Outline
- WCX2 Alignment
- Drawdown Contour (Layer 8) 2m

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CLIENT
CPB DRAGADOS SAMSUNG JV

PROJECT
WEST CONNEX STAGE 2

Reference(s):
Herbert C., 1983, Sydney 1:100 000 Geological Sheet 9130, 1st edition.
Geological Survey of New South Wales, Sydney

0 500 1,000 1,500 2,000 2,500
METRES

PROJECTION: GDA 1994 MGA Zone 56 REFERENCE SCALE: 1:40,000 (at A3)

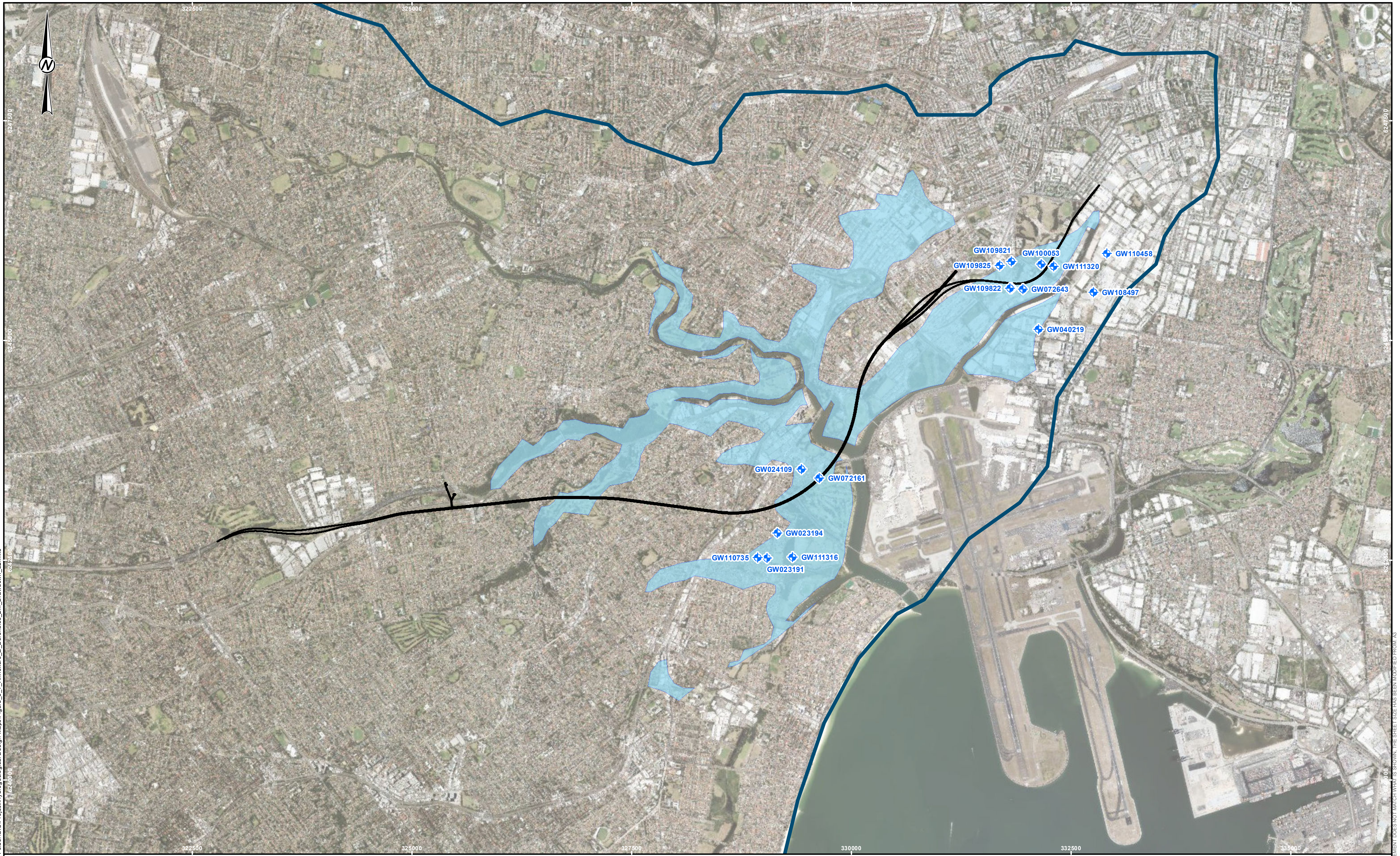
REGISTERED WATER SUPPLY BORES WITHIN A ZONE OF POTENTIAL GROUNDWATER DECLINE EXCEEDING 2 M IN HAWKESBURY SANDSTONE

YYYY-MM-DD	2016-10-28
PREPARED	HSG
DESIGN	HSG
REVIEW	--
APPROVED	

PROJECT No.	CONTROL	Rev.	FIGURE
1524285	001	B	3.7

Path: J:\Hyd\2015\Sydney\WCX Brisbane Working Folder\GIS\Project\Hydrogeological Design Maps\Figure_3_6_Annexure_E_Boreholes_2m_Drawdown_L8_Rev_B.mxd

IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM A3



LEGEND

- Annexure E
- Groundwater Model Outline
- WCX2 Alignment
- Drawdown Contour (Layer 8) 2m

Service Layer Credits: © Land and Property Information 2015

CLIENT
CPB DRAGADOS SAMSUNG JV

PROJECT
WEST CONNEX STAGE 2

Reference(s):
Herbert C., 1983, Sydney 1:100 000 Geological Sheet 9130, 1st edition.
Geological Survey of New South Wales, Sydney

0 500 1,000 1,500 2,000 2,500
METRES

PROJECTION: GDA 1994 MGA Zone 56 REFERENCE SCALE: 1:40,000 (at A3)

REGISTERED WATER SUPPLY BORES WITHIN A ZONE OF POTENTIAL GROUNDWATER DECLINE EXCEEDING 2 M IN UNCONSOLIDATED QUATERNARY SEDIMENTS

YYYY-MM-DD	2016-10-28
PREPARED	HSG
DESIGN	HSG
REVIEW	--
APPROVED	

PROJECT No.	CONTROL	Rev.	FIGURE
1524285	001	A	3.8

Path: J:\Hyd\2015\Sydney\WCX Brisbane Working Folder\GIS\Project\Hydrogeological Design Maps\Figure_3_7_Annexure_E_Boreholes_2m_Drawdown_L2.mxd

IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: A3

25mm

3.1.4 Inflow Groundwater Quality

Water quality for the water collected in tunnel groundwater drainage systems will be influenced by the background groundwater quality, the quality of groundwater that has been impacted by contaminated sites, and water quality in surface water bodies where there is a close connection between the surface water and the tunnel, such as at Arncliffe.

Background quality of groundwater in an urban environment like those found within the Project Corridor is impacted by diffuse contamination sources such as: sewer and stormwater leakage; fertiliser and pesticides applied within residential areas; copper and nickel from vehicle brake pads and lead, nitrogen oxides and hydrocarbons from vehicle exhaust fumes. These diffuse sources are likely to cause groundwater to have background concentration of ammonia, nitrate, lead, copper and nickel well above zero.

Furthermore, leakage from underground fuel storage (e.g. petrol stations), manufacturing areas and landfill sites can cause localised groundwater contamination with the extent of the contaminated groundwater (contamination plume) depending among others on the type of contaminants, soil and rock characteristics, groundwater flow and the history of contaminant release from the source.

The locations of known contaminated sites along the Project Corridor are illustrated in Figures 3.9.1 to 3.9.3. Groundwater quality for groundwater likely to be impacted by landfill leachate, fuel tank leakage and contaminated soils has been derived from groundwater quality results for monitoring bores located within 200 m of identified contaminated sites.

Water quality parameter values of groundwater inflow to 500 m long twin tunnel sections has been estimated based on water quality measurements for this project, and other published data sources located within a 2 km wide corridor of each of the 500 m tunnel sections. The 50% percentile and the maximum value for each tunnel section are summarised in Table P1 (Annexure P).

Quality of groundwater inflow to the tunnel sumps will be affected by the proportions of water derived from the various sources along the tunnel alignment discussed above. To assess the long-term quality of groundwater inflow to the tunnel sumps at Arncliffe concentrations reported in Table O1 were weighted based on the estimated volumes of twin-tunnel inflow of each 500 m section, as determined from the groundwater models, resulting in a mass flux for each groundwater compound and 500 m twin-tunnel section. The quality of groundwater received by the sumps is then estimated by the total of all mass fluxes divided by the total flow of groundwater to the sumps.

A significant proportion of the total tunnel inflow is interpreted to be derived from outflow from the Cooks River and Alexandra Canal in the Arncliffe area. Elevated levels of trace metals found in the Cooks River and Alexandria Canal river bed sediments (Albani 2011, URS 2003) are limited to a relative thin layer of contemporary sediment deposits separated from the tunnel by a several decameter thick palaechannel fill. Trace metals have been found (URS 2005) largely fixated in the sediment as highly insoluble sulfides or bi-sulfides. Changes to chemical conditions (pH and Eh) that could cause a release of trace metals from the river bed sediment due to the tunnel eventually draining water from the Cooks River and Alexandria Canal is very unlikely due to the relative small volumes of long-term tunnel drainage (less than 10 L/s) compared to the large volume flow of tidal waters in the Cooks River and Alexandria Canal. For this assessment it was assumed that contaminants in river bed sediments of the Cooks River and Alexandra canal are not mobilised due to tunnel drainage. Estimated water quality parameters for water to be collected in the two sumps at Arncliffe are provided in Table P2 (Annexure P).

The results of two water samples taken from the existing M5 East tunnels are also reported in Table P2. Water is pumped from the main sump of the existing tunnels to a treatment plant at Turella. Estimated water quality parameters reported as "Expected" in Table P2 for the WCX2 tunnel section from the Western Portal to the sump at Cooks River are in good agreement with the various Total Petroleum Hydrocarbon fractions and dissolved metals reported for the existing M5 tunnels, with the exception of dissolved iron, manganese, arsenic, chromium, copper, and nickel. The estimated concentrations of arsenic, chromium, copper and nickel are close to detection limit and the deviation between the estimates and the observed concentrations of the M5 sump water samples are within the predictive accuracy of the method used to derive the estimates. Zink concentrations are well above detection limits for both the estimated value and the analysis results for the existing M5 sump water samples. Zinc concentrations observed in the existing M5 sump water are within the range of concentrations estimated for WCX2 tunnels.

Estimates of dissolved iron and manganese concentrations for the WXC2 tunnels are 4 to 10 time higher compared to the concentrations reported for the water samples from the existing M5 sump. The very high iron and manganese concentrations of groundwater discharged during the two pumping tests conducted at Arncliffe suggest that groundwater inflow to the tunnels at Arncliffe will generally have high iron and manganese concentrations and consequently, will result in higher concentrations of dissolved iron and manganese in the sump water of the WCX2 tunnels when compared to the existing M5 sump water. Other causes for the differences in dissolved iron and manganese concentrations could be the precipitation of iron oxide-hydroxides in the drainage and the sump of the existing M5 reducing the concentration of the dissolved iron and manganese relative to that in the influent groundwater. Similar processes are expected to occur in the drainage system of the WCX2 tunnels but have not been accounted for in the estimates of iron and manganese concentrations listed in Table P2.

Estimated electric conductivity values for the WCX2 Western Portal to Cooks River section are approximately three times larger than the electric conductivity values reported for the existing M5 sump water. Much higher values are expected for the WCX2 due to the very saline groundwater seepage to the tunnels in the Arncliffe area, contributing significantly to the electric conductivity of the sump water.

Estimated total nitrogen for the WCX2 Western Portal to Cooks River section and total nitrogen concentrations reported for the sump water samples of the existing M5 are very similar. However, ammonia concentrations of groundwater seepage into the WCX2 tunnels are expected to be higher when compared to the ammonia concentrations reported for the sump water of the existing M5. Ammonia in groundwater seepage to the tunnel is expected to partially oxidise during the passage from the tunnel wall through the tunnel drainage which may in part account for the difference between the observed ammonia concentrations in the M5 sump water samples and the estimates of ammonia in the groundwater inflow to the WCX2 tunnels. Furthermore, seepage from contaminated sites (e.g. Kingsgrove and Bardwell) located at or directly above the WCX2 tunnel alignment are expected to contribute additional ammonia to the tunnel inflow.

Results of the Alexandria Landfill Phase 2 Environmental Site Assessment found elevated concentration of

- up to 404 mg/L ammonia in the waste fill
- up to 7.8 mg/L ammonia in the unconsolidated Quaternary sediment deposits to the immediate south of the landfill
- up to 15.9 mg/L total recoverable hydrocarbons (TRH) in the waste fill
- TRH concentrations in groundwater samples taken from unconsolidated Quaternary sediment deposits were below detection limit of the analysis method.
- Up to 70.5 % methane gas in landfill gas monitoring wells with highest concentrations inferred to occur at Bradshaw Mountain and south of the landfill drainage sump.

For the area of the cut and cover structure concentration of ammonia and TRH in groundwater occurring within the bedrock was inferred to range between >1 to 100 mg/L and < 2 mg/L, respectively. Based on interpolation of sparsely distributed methane gas observations methane gas was inferred to reach up to 20% of the pore gas volume in the area of the cut and cover structure. Therefore, groundwater inflow to the cut and cover structure has the potential of elevated concentration in ammonia and TRH.

LEGEND

Groundwater Quality Observation Location

Interpreted Formation

- Quaternary Sediments
- Ashfield Shale
- Ashfield Shale and Hawkesbury Sandstone
- Hawkesbury Sandstone
- Formation Unknown
- Other

Groundwater Drawdown in Metres

Drawdown in Model Layer 8 (Hawkesbury Sandstone) from Regional Scale Model

- 1 m
- 5 m
- 10 m

- Groundwater Model Boundary
- WCX2 Alignment

Categorisation of Potential Contamination Source Sites - Extent

- Low
- Medium
- High
- Additional Site Identified During Design Investigation

Service Layer Credits: © Land and Property Information 2015

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PROJECT
WEST CONNEX STAGE 2

0 250 500 750 1,000 1,250 1,500
METRES

REFERENCE SCALE: 1:20,000 (at A3)
PROJECTION: GDA 1994 MGA Zone 56

TITLE
POTENTIAL SOURCES OF GROUNDWATER CONTAMINATION

DRAGADOS SAMSUNG SAMSUNG C&T
WestConnex STAGE 2 M5
Golder Associates

YYYY-MM-DD	2016-10-28
PREPARED	HSG
DESIGN	HSG
REVIEW	--
APPROVED	--

PROJECT No.	CONTROL	Rev.	FIGURE
1524285	001	B	3.9.1

IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM A3
25mm
0

LEGEND

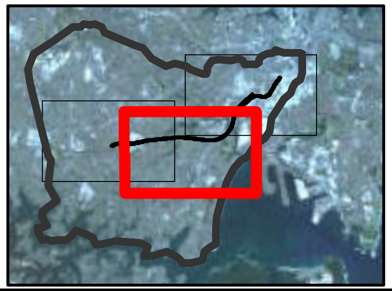
Groundwater Quality Observation Location
Interpreted Formation
- Quaternary Sediments
- Ashfield Shale and Hawkesbury Sandstone
- Hawkesbury Sandstone
- Formation Unknown
- Other

Groundwater Drawdown in Metres
Drawdown in Model Layer 8 (Hawkesbury Sandstone) from Regional Scale Model
- 1 m
- 5 m
- 10 m

- Groundwater Model Boundary
- WCX2 Alignment

Categorisation of Potential Contamination Source Sites - Extent
- Low
- Medium
- High
- Additional Site Identified During Design Investigation

Service Layer Credits: © Land and Property Information 2015



CLIENT
LEIGHTON DRAGADOS SAMSUNG JV

PROJECT
WEST CONNEX STAGE 2

0 250 500 750 1,000 1,250 1,500
METRES

REFERENCE SCALE: 1:20,000 (at A3)
PROJECTION: GDA 1994 MGA Zone 56

TITLE
POTENTIAL SOURCES OF GROUNDWATER CONTAMINATION

WestConnex STAGE 2 M5

YYYY-MM-DD	2016-10-28
PREPARED	HSG
DESIGN	HSG
REVIEW	--
APPROVED	--

PROJECT No.	CONTROL	Rev.	FIGURE
1524285	001	B	3.9.2

IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: A3

25mm 0

LEGEND

Groundwater Quality Observation Location

Interpreted Formation

- Hawkesbury Sandstone
- Formation Unknown

Groundwater Drawdown in Metres

Drawdown in Model Layer 8 (Hawkesbury Sandstone) from Regional Scale Model

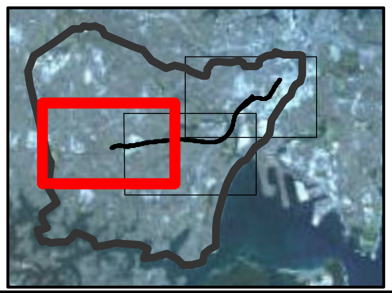
- 1 m
- 5 m
- 10 m

- Groundwater Model Boundary
- WCX2 Alignment

Categorisation of Potential Contamination Source Sites - Extent

- Low
- Medium
- High
- Additional Site Identified During Design Investigation

Service Layer Credits: © Land and Property Information 2015



CLIENT
LEIGHTON DRAGADOS SAMSUNG JV

PROJECT
WEST CONNEX STAGE 2

0 250 500 750 1,000 1,250 1,500
METRES

REFERENCE SCALE: 1:20,000 (at A3)
PROJECTION: GDA 1994 MGA Zone 56

TITLE
POTENTIAL SOURCES OF GROUNDWATER CONTAMINATION

WestConnex STAGE 2 M5

YYYY-MM-DD	2016-10-28
PREPARED	HSG
DESIGN	HSG
REVIEW	--
APPROVED	--

PROJECT No.	CONTROL	Rev.	FIGURE
1524285	001	B	**3.9.3**

3.1.5 Sensitivity Analysis

The regional and local scale models were tested for sensitivity of inflow estimates to changes in the following model parameters and boundary conditions:

- The hydraulic conductivity of the Pleistocene sediments in the base of Palaeochannel sediments (local scale model only);
- Hydraulic conductivity of the massive Hawkesbury Sandstone between discrete high permeability fault and shear zone features (local scale model only)
- Arncliffe fault and shear zone hydraulic conductivity (local scale model only) ;
- Recharge (local and regional scale model);
- The hydraulic conductivity of the sediments in the Wolli and Bardwell Creek valleys (regional scale model only); and
- The boundary condition along the northern boundary of the model (regional scale model only).

The first three of these parameters were considered to have the potential to significantly impact on the calculated inflow in the Arncliffe area (i.e. the area likely to have the highest localised inflow rates), and the assessment of sensitivity to these parameters was thus carried out using the local scale model. The sensitivity of calculated inflows to applied recharge rates was assessed using both the local scale and the regional scale model. The sensitivity analysis to assess the impact of the northern boundary condition and the hydraulic conductivity of the sediments in the Wolli and Bardwell Creek valleys was carried out in response to review comments on earlier revisions of this report.

Sensitivity of computed inflow to parameter variations were tested with the local scale model for both the ungrouted case (i.e. the so-called Base Case) and for the Case 3 grouting scenario. As discussed above, for Case 3 the hydraulic conductivity of discrete high permeability features that were included in the model to represent sub-vertical faults and sub-horizontal shear zones was reduced to 1×10^{-7} m/s within the proposed footprint of surface grouting, and to a radial distance of 10 m from underground structures where they intersect these features in the model. Calculated sensitivity of calculated inflows along the total lengths of tunnels that are included in the local scale model are summarised in Table 30 and Table 31 for the Base Case and for Case 3 respectively.

Tunnel inflow computed with the local scale model for the Base Case show the highest degree of sensitivity to changes in the hydraulic conductivity of the Pleistocene sediments in the base of the palaeochannel and of the fault/shear zones. A well-defined range of hydraulic conductivity values for the fault zones have been established by extensive testing (2 pumping tests and a large number of water pressure tests) and the uncertainty it is considered unlikely that the values for these parameters would vary over 2 orders of magnitude as has been considered in the sensitivity analysis. Similarly, the calibration of the local scale model to the pumping tests was relatively sensitive to the value adopted for the hydraulic conductivity of the Pleistocene sediments and it is considered unlikely that it may vary over the full range considered in the sensitivity analysis.

The computed tunnel inflow is moderately sensitive to changes in the hydraulic conductivity of the massive Hawkesbury Sandstone that is bounded in the model by the sub-vertical faults in the Arncliffe area.

The calibration of the local scale model to the second pumping test was found to be somewhat sensitive to the properties adopted for this zone, and this parameter value is considered to be less constrained by the calibration than others.

Results presented in Table 30 indicate that the calculated inflows are less sensitive to the hydraulic conductivity of the Pleistocene sediments and the fault/shear zones for the situation where significant engineering modifications are implemented to reduce the hydraulic conductivity of highly permeable features in the vicinity of the underground structures at Arncliffe. In this case, the inflow is governed mostly by the hydraulic conductivity of the grouted zone in the immediate vicinity the underground structures, rather than that of the in-situ materials at a greater distance from these structures.

Constant recharge values assigned to the recharge zones of the local and regional scale models are based on experience within the Sydney region and actual recharge values may vary significantly across seasons and due to variability in the recharge and discharge mechanisms influenced by land use, built up areas, and seepage losses to storm water drainage and drained underground structures. Estimates of parameter values for recharge are less certain than for other parameters such as hydraulic conductivity which have been constrained by in-situ testing. However, sensitivity analysis results with both local scale and regional scale models demonstrate that tunnel inflow estimates are not sensitive to the recharge parameter and therefore, predictive estimates of the tunnel inflows are not impacted by this uncertainty.

Table 32 summarises percentage changes in steady state total inflow computed using the regional scale model due to changes in recharge or the northern boundary conditions and hydraulic conductivity of the sediments in the Wolli and Bardwell Creek valleys. The conditions at the northern boundary of the regional scale model is less well defined compared to other boundaries of the model, with the potential that the existing groundwater divide along this boundary may move to the north as a result of the drainage created by the proposed tunnels for this project. Simulation results for the regional model with this boundary defined as a no-flow boundary indicate that drawdown in the Hawkesbury Sandstone unit may extend to this boundary. Sensitivity of the calculated tunnel inflow rates to this boundary condition was tested by changing the "no-flow" boundary to a general head boundary with a head of 10 m at a distance of 1 km from the northern boundary. Inflows computed for both cases differ by less than 0.1%, demonstrating that tunnel inflows are insensitive to the choice of boundary condition.

Sensitivity of the regional model to changes of the hydraulic conductivity of the sediments along Wolli and Bardwell Creeks is also summarised in Table 32. Tunnel inflow increased by approximately 2.7% for an increase by one order of magnitude of the hydraulic conductivity of the sediments, and decreased by approximately 1.2% for a reduction by one order of magnitude.

Table 30: Range of computed inflows to the WCX2 twin-tunnel and underground structures for a range of values for selected parameters for the Base Case scenario - local scale model.

Uncertainty Analysis Results – Local Scale Model / Base Case		
Hydraulic Conductivity of Pleistocene Sediment Deposits		
	Increased by an order of magnitude	Decreased by an order of magnitude
Tunnel Inflow	35.0 % increase	26.0 % decrease
Hydraulic Conductivity of Massive Hawkesbury		
	Increased by an order of magnitude	Decreased by an order of magnitude
Tunnel Inflow	10.8 % increase	6.5 % decrease
Hydraulic Conductivity of Arncliffe Shear Fault Zone and Major and Minor Faults (Combined)		
	Increased by an order of magnitude	Decreased by an order of magnitude
Tunnel Inflow	29.3 % increase	28.8 % decrease
Recharge Rate		
Each Recharge Zone	50% increased	50% decreased
Tunnel Inflow	1.0 % increase	1.0 % decrease

Table 31: Range of computed inflows to the WCX2 twin-tunnel and underground structures for a range of values for selected parameters for the Case 3 scenario - local scale model.

Uncertainty Analysis Results – Local Scale Model / Design Case 3		
Hydraulic Conductivity of Pleistocene Sediment Deposits		
	Increased by an order of magnitude	Decreased by an order of magnitude
Tunnel Inflow	4.4 % increase	7.0 % decrease
Hydraulic Conductivity of Massive Hawkesbury		
	Increased by an order of magnitude	Decreased by an order of magnitude
	12.6 % increase	13.1 % decrease
Hydraulic Conductivity of Arncliffe Shear Fault Zone and Major and Minor Faults (Combined)		
	Increased by an order of magnitude	Decreased by an order of magnitude
	1.1 % increase	1.2 % decrease
Recharge Rate		
Each Recharge Zone	50% increased	50% decreased
Tunnel Inflow	4.1% increase	5.6% decrease

Table 32: Range of computed inflows to the WCX2 twin-tunnel and underground structures for a range of values for selected parameters and boundary conditions - regional scale model.

Uncertainty Analysis Results – Regional Model		
Recharge Rate		
Each Recharge Zone	50% increased	50% decreased
Tunnel Inflow	5.61% increase	3.9% decrease
Hydraulic Conductivity of Sediments in Wolli and Bardwell Creek Valley		
	Increased by an order of magnitude	Decreased by an order of magnitude
Tunnel Inflow	2.7% increase	1.2% decrease
Northern Boundary Condition		
Northern boundary condition changed from a no-flow boundary, to a general head boundary with a head of 10 m at a distance of 1 km from the northern boundary		
Tunnel inflow	0.09% increase	

3.1.6 Long term impact of climatic change

The long term impact of climatic change have been considered in the development of this assessment through the review of appropriate and relevant literature.

CSIRO has undertaken a comprehensive assessment of the impact of climate change on groundwater resources in Australia and specifically the climate sensitivity of groundwater recharge (CSIRO 2010). The key conclusion of this study was that the range of climate projections across the study sites highlights the uncertainty in making projections of recharge under a future climate. The study projected a slight decrease (2% to 7%) in groundwater recharge for a study site closest to Sydney (200 km). A joint climate study undertaken by various research institutions for the Sydney region concluded that the number of wet days in the Sydney region is likely to change very little in the next 50 years. The same study projected rainfall amount to decrease slightly by two percent (NSW Office of Water 2010).

The outcome of these studies suggest that long term effect of climate change will not likely cause groundwater recharge to increase and therefore, will not adversely affect tunnel inflows. As such, no specific adjustment to this assessment has been necessary to account for the predicted effects.

3.1.7 Not used

3.2 Not used

3.3 Not used

4 Design Considerations

4.1 Not used

4.2 Not used

4.3 Compliance

CoA B26 requires the Proponent to "take all feasible and reasonable measures to limit operational groundwater inflows into each tunnel to no greater than one litre per second across any given kilometre" (Table 33).

The predicted long-term inflow rate during tunnel operation, in the absence of any measures to reduce permeability of high permeability features intersected by the tunnel, is close to the SWTC limit of 1 L/s/km of tunnel, calculated as an average across the full length of tunnel. It is noted, however, that the B26 limit of 1 L/s across any given kilometre is predicted to be exceeded in certain small portions of the alignment (Arncliffe area, SPI cavern and stub tunnels), as discussed in Section 3.1.2.

The average inflow rate calculated across the full length of tunnel is an important consideration in terms of requirements for collection of inflow at sumps, and ongoing requirements for treatment and disposal of inflows. Only nominal treatment of the higher permeability zones at Arncliffe and a small section at SPI would be required to reduce whole-of-tunnel average inflow rates to less than 1 L/s/km (refer to Table 23 and Table 24. With grouting of water making geological structures to $1x10^{-7}$ m/s a significant reduction in inflow is deemed practically achievable and therefore, this ground treatment is targeted for limiting groundwater inflows at the Arncliffe and SPI areas.

In addition to the ongoing costs of treatment and disposal of tunnel inflows, groundwater inflow to tunnels has the potential to impact on groundwater levels, which may lead to depressurisation and consolidation of compressible sediments, and may lead to adverse environmental outcomes. It is these impacts that are the most important consideration, rather than somewhat arbitrary limits on overall average or locally averaged inflow rates.

Because of the presence of compressible alluvium at Arncliffe in the same area as high permeability structures that will intersect proposed tunnels, a significant grouting program comprising surface and in-tunnel grouting is proposed to limit inflow rates with the purpose of limiting depressurisation/consolidation settlements. Groundwater model and consolidation settlement model results presented elsewhere indicate that acceptably low settlements are predicted for the case where grouting is undertaken to reduce the permeability of high permeability features to $1x10^{-7}$ m/s (Case 3). As discussed in Section 3.1.3, adverse environmental impacts are not expected for the magnitude and extent of drawdown that is predicted for this grouting scenario.

It is not considered to be feasible or reasonable to require that grouting reduce the permeability of high permeability features to below $1x10^{-7}$ m/s. Although local average inflow rates are predicted to marginally exceed 1 L/s/km in the Arncliffe area for grouting to this level, the predicted impacts on groundwater are within acceptable criteria.

Table 33: SWTC and CoA B26 clauses regarding tunnel inflow limits

Document	Clause	Conditions
SWTC – Appendix B.3		*1.3.1 Groundwater Limits* *a) The Project Company's Work and O&M Work must cause no groundwater contamination.* *b) Permanent dewatering is not permitted, except for dewatering that naturally occurs as a result of accommodating the groundwater ingress limits identified in this section and which has no adverse environmental impact.* *c) The Project Company must ensure that the maximum allowable groundwater ingress into any tunnel (including tunnel approaches and exits and ventilation tunnels) must not exceed;* *…* *ii) For Drained tunnels;* *A. 1 litre per second per kilometre of tunnel.* *iii) For Equipment and Plant Rooms* *A. 0.01 litres per square metre per day.* *Any groundwater introduced to the tunnel by associated underground structures, including but not limited to shafts, adits, emergency egress passages (and cross passages), vehicle cross passages and plant and equipment rooms must be considered as part of the tunnels total groundwater ingress.* *…* *g) Notwithstanding compliance with the SWTC and the Environmental Documents, the effect of the Project Company's Work on the groundwater regime must be limited such that there is minimal adverse effect on the natural environment or existing infrastructure.*
CoA	B26	*The Proponent must take all feasible and reasonable measures to limit operational groundwater inflows into each tunnel to no greater than one litre per second across any given kilometre.*

4.4 Not used

4.5 Not used

4.6 Predicted Effects & Monitoring

The Hydrogeological design report was developed to demonstrate the effects CDS JVO&M works have on existing groundwater conditions, local environment, or, on the performance of any infrastructure, in accordance with Clause 3.14 of the SWTC.

Table 34 includes a summary of key potential effects relating to groundwater interactions with the proposed works, and control measures to address related risks.

A monitoring procedure and action plan will be developed in accordance with Section 3.14 of the SWTC to confirm that Accepted Effects are not exceeded in accordance with the SWTC requirement. Relevant controls including trigger, action and response plans are included in the Water Quality Plan & Monitoring Program.

The groundwater model will be updated once 24 months of groundwater monitoring data are available and the results of the modelling will be provided to the Secretary and DPI (Water) in an updated Groundwater Modelling Report. The model update will include a validation process of the predictive simulation results based on the actual drawdown and inflow during the construction works. The updated Groundwater Modelling Report will include a summary of validation method, criteria used and the outcome of the validation process. The model will be re-calibrated should the model predictions do not meet the validation criteria and revised predictive inflows and drawdowns will then be provided.

Table 34: Summary of potential groundwater effects and risk control measures

Potential Groundwater Effects	Risk Control Measures
Elevated inflow through inferred fault zones at Bexley	Probe drilling and in-tunnel grouting of encountered structures where needed.
High groundwater inflows when excavating into fault structures at Arncliffe	Surface grouting, probe drilling and in-tunnel grouting of encountered structures where needed.
Excessive inflow of groundwater from unconsolidated Quaternary sediments into Arncliffe construction decline	Sheet pile support footed into Hawkesbury Sandstone or low conductive clay layers, temporary dewatering using wells along the perimeter of the excavation.
Excessive inflow of groundwater from unconsolidated Quaternary sediments into Arncliffe construction and ventilation shafts	Secant pile wall design with piles founded in the Hawkesbury Sandstone.
Drawdown in groundwater levels leading to consolidation settlements	Monitoring of settlement during construction, surface grouting, probe drilling and in-tunnel grouting of encountered structures where needed, ongoing settlement monitoring.
Long-term groundwater inflow to tunnels higher than permitted	Surface grouting, probe drilling and in-tunnel grouting of encountered structures where needed, backfill and sealing of temporary works adits and shafts, monitoring of inflow during excavation, updating of hydrogeological model during construction to re-assess likely long-term inflows.
Elevated concentration of ammonia in groundwater inflow to the tunnels	Baseline groundwater monitoring program to establish groundwater quality for design of groundwater treatment and disposal, ongoing monitoring of groundwater quality.
Hydraulic connection between landfill sites (e.g. Kingsgrove, Bardwell, Tempe) and the tunnels through geological structures with permeability higher than expected	Monitoring of inflow water quality during excavation, probe drilling and in-tunnel grouting of encountered structures where needed.
High iron and manganese concentrations in groundwater inflow to tunnels with the potential of causing drainage to clog.	Drainage designed to suit chemistry of groundwater tunnel inflow, grouting zones of seepage with high iron and manganese concentrations.
Long-term migration of high salinity groundwater from Botany Bay through regional geological structures into the tunnels	Durability assessment allows for higher salinity of groundwater in the Hawkesbury Sandstone than currently observed, probe drilling and in-tunnel grouting of encountered structures to reduce inflows through regional structures if encountered.

5 Not used

6 References

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Annexure A – Not Used

Annexure B – Not Used

Annexure C – Not Used

Annexure D – Not Used

Annexure E – Registered Groundwater Bores

State Bore ID	Easting	Northing	Purpose	Water Table Elevation (m AHD)	Bore Depth (m bgl)	Elevation (m AHD)	Status	Drilled Date
GW013331	332765	6245200	Industrial	7.9-14.8 (saturated material)	14.9	11.09	USE	1/08/1954
GW015954	332868	6245171	ND	ND	20.1	11.05	USE	1/05/1957
GW023191	329041	6242525	Water Supply - Domestic	1.2	3.7	4.62	UNK	1800-01-01
GW023194	329156	6242811	Water Supply - Domestic	3.3	4.9	11.12	UNK	1/11/1965
GW024062	328680	6242384	ND	ND	3.7	5.8	UNK	1800-01-01
GW024109	329430	6243538	Water Supply - Domestic	2.1	2.1	3.29	UNK	1/03/1966
GW024673	323244	6243332	Water Supply - Domestic	Not Available	4.3	53.07	USE	1/04/1942
GW027248	332260	6244792	Industrial	2.4	4.9	8.38	UNK	1/11/1965
GW027664	329535	6243417	Industrial	0.7	6.1	2.47	UNK	1/06/1966
GW040219	332128	6245128	Water Supply - Domestic	Not Available	0	3.9	USE	1800-01-01
GW072161	329636	6243437	Water Supply - Domestic	14	90.5	3.76	UNK	24/02/1994
GW072643	331951	6245584	Water Supply - Domestic	Not Available	12	4.6	UNK	25/09/1996
GW100053	332163	6245867	Water Supply - Domestic	1	7	6.69	UNK	20/04/1994
GW100209	329946	6243253	Industrial	Not Available	108	4.07	ABN	16/04/1993
GW101350	332201	6244281	ND	ND	5.9	7.87	UNK	22/11/1995
GW101351	332200	6244281	ND	ND	5.05	7.87	UNK	22/11/1995
GW101352	332200	6244281	ND	ND	5.7	7.87	UNK	22/11/1995
GW101353	332201	6244281	ND	ND	6	7.87	UNK	22/11/1995
GW101354	332200	6244281	ND	ND	6	7.87	UNK	22/11/1995
GW101355	332200	6244281	ND	ND	6	7.87	UNK	22/11/1995
GW101356	332201	6244281	ND	ND	5.6	7.87	UNK	22/11/1995
GW101357	332200	6244281	ND	ND	5.9	7.87	UNK	22/11/1995
GW101358	332200	6244281	ND	ND	6	7.87	UNK	22/11/1995

State Bore ID	Easting	Northing	Purpose	Water Table Elevation (m AHD)	Bore Depth (m bgl)	Elevation (m AHD)	Status	Drilled Date
GW101359	332200	6244281	ND	ND	6	7.87	UNK	22/11/1995
GW101360	332200	6244281	ND	ND	6	7.87	UNK	22/11/1995
GW101361	332200	6244281	ND	ND	4.3	7.87	UNK	22/11/1995
GW101362	332200	6244281	ND	ND	5.9	7.87	UNK	22/11/1995
GW102160	332302	6244172	ND	ND	5	8.18	FUN	7/01/1999
GW102162	332302	6244172	ND	ND	5	8.18	FUN	7/01/1999
GW102164	332302	6244172	ND	ND	5	8.18	FUN	7/01/1999
GW102165	332302	6244172	ND	ND	5	8.18	FUN	7/01/1999
GW102168	332302	6244172	ND	ND	5	8.18	FUN	7/01/1999
GW102169	332302	6244172	ND	ND	4.5	8.18	FUN	7/01/1999
GW102171	332303	6244172	ND	ND	6	8.18	FUN	7/01/1999
GW102172	332302	6244172	ND	ND	4.5	8.18	FUN	6/01/1999
GW102173	332302	6244172	ND	ND	4.5	8.18	FUN	6/01/1999
GW102176	332302	6244172	ND	ND	4.5	8.18	FUN	6/01/1999
GW102178	332303	6244173	ND	ND	4.4	8.18	FUN	22/03/1999
GW102184	332302	6244173	ND	ND	4.2	8.18	FUN	18/03/1999
GW102185	332302	6244172	ND	ND	4.2	8.18	FUN	18/03/1999
GW102186	332302	6244172	ND	ND	4.2	8.18	FUN	22/03/1999
GW102187	332302	6244172	ND	ND	4.2	8.18	FUN	22/03/1999
GW102188	332302	6244172	ND	ND	4	8.18	FUN	22/03/1999
GW102189	332303	6244172	ND	ND	4	8.18	FUN	22/03/1999
GW102190	332303	6244172	ND	ND	4	8.18	FUN	18/03/1999
GW102191	332302	6244172	ND	ND	4	8.18	FUN	18/03/1999
GW102192	332303	6244172	ND	ND	4	8.18	FUN	19/03/1999
GW102193	332302	6244173	ND	ND	3.9	8.18	FUN	22/03/1999
GW102194	332302	6244172	ND	ND	3.7	8.18	FUN	22/03/1999
GW102195	332302	6244172	ND	ND	3.6	8.18	FUN	22/03/1999
GW102196	332302	6244172	ND	ND	3.6	8.18	FUN	22/03/1999
GW102197	332303	6244172	ND	ND	3.6	8.18	FUN	22/03/1999
GW102198	332302	6244172	ND	ND	3.5	8.18	FUN	22/03/1999

State Bore ID	Easting	Northing	Purpose	Water Table Elevation (m AHD)	Bore Depth (m bgl)	Elevation (m AHD)	Status	Drilled Date
GW102199	332302	6244172	ND	ND	3.5	8.18	FUN	22/03/1999
GW102200	332302	6244172	ND	ND	3.5	8.18	FUN	19/03/1999
GW102201	332302	6244172	ND	ND	3.5	8.18	FUN	18/03/1999
GW102203	332302	6244172	ND	ND	3.5	8.18	FUN	18/03/1999
GW102204	332303	6244172	ND	ND	3.3	8.18	FUN	22/03/1999
GW102205	332303	6244172	ND	ND	3.3	8.18	FUN	22/03/1999
GW104448	331715	6244936	Domestic	Not Available	0	4.65	USE	25/11/2002
GW104449	331677	6244959	Monitoring	Not Available	0	4.72	USE	1/01/2002
GW104450	331630	6244904	Monitoring	Not Available	0	4.92	USE	1/01/2002
GW105527	333069	6246148	ND	ND	5	12.2	UNK	15/12/2000
GW105528	333273	6246037	ND	ND	5	14.4	UNK	2/12/1993
GW105529	333097	6246168	ND	ND	5	12.27	UNK	7/02/2001
GW106046	333636	6246554	ND	ND	0	15.89	UNK	7/06/2005
GW106830	323792	6242387	Monitoring	Not Available	7	24.67	UNK	15/01/2005
GW107993	328242	6243424	Monitoring	1.95	13.6	23.72	UNK	14/09/2006
GW108295	328907	6242466	Monitoring	Not Available	8	3.53	USE	1/11/2006
GW108406	329510	6243455	Monitoring	Not Available	8	3.34	UNK	28/11/2006
GW108439	328893	6242478	Monitoring	Not Available	8	3.82	UNK	5/01/2007
GW108497	332753	6245547	Water Supply - Domestic	Not Available	0	9.24	UNK	16/01/2008
GW108588	329440	6243429	Other-Test Bore	Not Available	8	2.94	UNK	3/02/2007
GW108870	329102	6242290	ND	ND	0	4.54	UNK	12/05/2008
GW109191	325255	6243188	Industrial	93	186	16.5	UNK	8/08/2008
GW109821	331819	6245899	Water Supply - Domestic	14.5	35	10.61	UNK	3/04/1997
GW109822	331806	6245594	Water Supply - Domestic	3	10.45	2.89	UNK	4/04/1997
GW109823	331819	6245594	Water Supply - Domestic	12.5	29	3.74	UNK	23/10/2000
GW109824	331393	6245635	Recreation	4.51	20.7	4.27	UNK	5/04/2005
GW109825	331689	6245853	Water Supply - Domestic	14.9	22	10.4	UNK	10/02/2005

State Bore ID	Easting	Northing	Purpose	Water Table Elevation (m AHD)	Bore Depth (m bgl)	Elevation (m AHD)	Status	Drilled Date
GW109958	327033	6242227	ND	ND	5.2	55.09	UNK	12/04/2007
GW109959	327028	6242217	ND	ND	5.9	54.48	UNK	13/04/2007
GW109960	327018	6242245	ND	ND	8	54.91	UNK	13/04/2007
GW109961	327025	6242240	ND	ND	5.8	55.09	UNK	12/04/2007
GW109963	329446	6243406	Other	Not Available	8	3.1	UNK	28/11/2006
GW109964	329426	6243419	Monitoring	Not Available	8	2.94	UNK	28/11/2006
GW109965	329489	6243467	Monitoring	Not Available	8	3.56	UNK	28/11/2006
GW109966	329373	6243465	Monitoring	Not Available	3	4.59	UNK	17/03/2009
GW110456	332781	6246011	Monitoring	2.3	3.6	7.66	UNK	1/05/2009
GW110457	332822	6245945	Monitoring	1.7	3.6	10.25	UNK	1/05/2009
GW110458	332909	6245992	Water Supply - Domestic	2.3	2.8	11.11	UNK	1/05/2009
GW110735	328935	6242529	Water Supply - Domestic	Not Available	0	4.35	UNK	1/01/2006
GW111164	332686	6246860	ND	ND	8	11.62	UNK	22/10/2010
GW111316	329333	6242538	Water Supply - Domestic	4	162	4.62	UNK	1/03/2010
GW111320	332305	6245845	Water Supply - Domestic	2.52	5.2	6.05	UNK	9/01/2007
GW111321	332322	6245742	Monitoring	2.64	5	5.29	UNK	9/01/2007
GW111344	329132	6244166	ND	ND	4	2.95	UNK	29/09/2010
GW111345	329154	6244179	ND	ND	4	3.12	UNK	29/09/2010
GW111346	329177	6244147	ND	ND	4.5	3.82	UNK	29/09/2010

Note: ND=No Data

Annexure F – Summary of Groundwater Levels

Bore ID	Easting (m)	Northing (m)	Elevation (mAHD)	Screened Formation	Groundwater Level (m AHD)			Monitoring Period	
					Max	Min	Median	From	To
27_NSR11	332223	6243802	4.30	Fill			2.40	Sep-94	
27_NSR5	333391	6246536	12.70	Fill			7.45	Aug-94	
34_2(Coffey1991)	330566	6245076	13.53	Fill			16.65	Aug-91	
34_TL1	330119	6244330	2.32	Fill			1.32	Mar-03	
34_TL10	330569	6244671	12.18	Fill			1.78	Mar-03	
34_TL12	330543	6244952	10.54	Fill			2.39	Mar-03	
34_TL13	330629	6244993	10.95	Fill			2.35	Mar-03	
34_TL21	330484	6244762	12.32	Fill			2.42	Mar-03	
34_TL8	330461	6244421	13.77	Fill			1.87	Mar-03	
34_TL9	330609	6244574	12.67	Fill			1.37	Mar-03	
37_1	330624	6244534	11.25	Fill			6.25	Sep-98	
37_2	330847	6244739	3.13	Fill			1.73	Sep-98	
37_4	330778	6244473	2.29	Fill			1.39	Sep-98	
37_5	330644	6244405	2.29	Fill			1.79	Sep-98	
37_6	330526	6244308	2.5	Fill			2.00	Sep-98	
37_9	330153	6244346	1.88	Fill			0.88	Sep-98	
BH14	331381	6246371	4.50	Fill			3.71	Mar-12	
BH358	331910	6245704	4.90	Fill			1.90	Jan-15	
BH361	331824	6245781	8.15	Fill			5.35	Jan-15	
BH367	331769	6245583	7.03	Fill			4.13	Feb-15	
MW304	331448	6245723	-4.50	Fill			-14.20	Dec-14	
MW305	331645	6245686	4.72	Fill			-13.98	Dec-14	
MW306	331719	6245728	8.40	Fill			-9.92	Feb-15	

Bore ID	Easting (m)	Northing (m)	Elevation (mAHD)	Screened Formation	Groundwater Level (m AHD)			Monitoring Period	
					Max	Min	Median	From	To
MW307	331642	6245805	8.42	Fill			-10.10	May-15	
MW308	331795	6245863	9.55	Fill			-9.98	Feb-15	
MW311	331824	6245780	8.1	Fill			-4.75	Feb-15	
MW313	331438	6245568	-5.89	Fill			-10.26	Feb-15	
MW314	331509	6245605	-11.95	Fill			-12.85	Feb-15	
WCX_BH_009	324018	6242801	17.52	Fill			14.70	Sep-14	
WCX_BH_045	331481	6245642	-11.99	Fill			-15.80	Sep-14	
WCX_BH_047	331502	6245524	-1.22	Fill			-6.00	Sep-14	
WCX_BH_048	331389	6245720	0.96	Fill			-12.40	Sep-14	
WCX_BH_050	331543	6245626	-11.09	Fill			-14.10	Sep-14	
WCX_BH_052	331621	6245738	-2.43	Fill			-2.60	Sep-14	
WCX_BH_056	331809	6245809	8.16	Fill			5.40	Oct-14	
WCX_BH_057	331820	6245676	7.65	Fill			-0.90	Sep-14	
WCX_BH_058	331867	6245668	6.25	Fill			-1.90	Sep-14	
WCX_BH_059	331932	6245727	3.70	Fill			0.20	Sep-14	
WCX_BH_097	328420	6243123	32.25	Fill			31.30	Oct-14	
27_ARL4	332436	6244969	5.5	Fill and Quaternary Sediments			3.90	May-93	
27_NSR16	329638	6244146	2.80	Fill and Quaternary Sediments			0.70	Sep-95	
27_NSR175	329219	6244225	2.94	Fill and Quaternary Sediments			1.71	May-96	
29_RW1-G	330251	6243944	1.52	Fill and Quaternary Sediments			0.02	Aug-99	
34_1(Coffey1991)	330581	6245016	12.67	Fill and Quaternary Sediments			11.88	Aug-91	
34_TL15	330498	6244380	13.71	Fill and Quaternary Sediments			1.41	Mar-03	
34_TL7	330292	6244320	13.76	Fill and Quaternary Sediments			1.86	Mar-03	

Bore ID	Easting (m)	Northing (m)	Elevation (mAHD)	Screened Formation	Groundwater Level (m AHD)			Monitoring Period	
					Max	Min	Median	From	To
59_243	328126	6244273	3.02	Fill and Quaternary Sediments			1.72	Sep-99	
69_38	332003	6245568	4.60	Fill and Quaternary Sediments			1.00	Aug-07	
BH29	331319	6246468	4.28	Fill and Quaternary Sediments			3.58	Mar-12	
BH353	331833	6245895	9.10	Fill and Quaternary Sediments			6.60	Jan-15	
WCX_BH_062	329358	6242452		Fill and Quaternary Sediments			1.30	Oct-14	
34_TL11	330386	6244607	10.48	Fill and Ashfield Shale			2.18	Mar-03	
WCX_BH_022	327131	6243324		Fill and Hawkesbury Sandstone			2.18	Nov-14	
WCX_BH_023	327173	6243331		Fill and Hawkesbury Sandstone			0.97	Oct-14	
34_TL14	330353	6244300	16.88	Fill/Quaternary Sediments and Hawkesbury Sandstone			1.48	Mar-03	
15_2315	330255	6243756	2.34	Quaternary Sediments			0.14	Jan-98	
15_2320	330209	6243722	2.45	Quaternary Sediments			-0.15	Jan-98	
15_2321	330196	6243707	2.52	Quaternary Sediments			-1.18	Jan-98	
27_NSR176	329143	6244210	2.68	Quaternary Sediments			1.28	May-96	
27_NSR6	332743	6245741	5.40	Quaternary Sediments			4.00	Sep-94	
27_NSR7	332491	6245326	6	Quaternary Sediments			3.30	Sep-94	
29_RW1-C	330221	6243872	2.36	Quaternary Sediments			-0.14	Aug-99	
29_RW1-D	330228	6243892	2.06	Quaternary Sediments			-0.34	Aug-99	
29_RW1-E	330235	6243907	2.12	Quaternary Sediments			0.37	Aug-99	
29_RW1-F	330242	6243923	1.87	Quaternary Sediments			0.57	Aug-99	
29_RW1-H	330259	6243963	1.69	Quaternary Sediments			-0.31	Aug-99	
29_RW4-C	331419	6244535	3.54	Quaternary Sediments			0.44	Sep-99	
29_RW5-A	332144	6244246	6.38	Quaternary Sediments			1.98	Sep-99	
29_RW5-B	332140	6244222	5.89	Quaternary Sediments			1.59	Sep-99	

Bore ID	Easting (m)	Northing (m)	Elevation (mAHD)	Screened Formation	Groundwater Level (m AHD)			Monitoring Period	
					Max	Min	Median	From	To
29_RW5-C	332136	6244186	5.63	Quaternary Sediments			2.43	Sep-99	
34_TL16	330631	6244428	9.79	Quaternary Sediments			1.09	Mar-03	
34_TL2	330238	6244104	3.06	Quaternary Sediments			0.51	Mar-03	
34_TL5	330865	6244481	1.83	Quaternary Sediments			0.53	Mar-03	
37_7	330402	6244212	2.50	Quaternary Sediments			1.60	Sep-98	
37_8	330317	6244158	2.71	Quaternary Sediments			1.91	Sep-98	
59_241	328184	6244168	3.63	Quaternary Sediments			1.71	Sep-99	
59_244	328227	6244293	2.78	Quaternary Sediments			1.06	Sep-99	
59_245	328161	6244191	3.22	Quaternary Sediments			2.00	Sep-99	
59_246	328187	6244159	3.22	Quaternary Sediments			2.19	Sep-99	
59_247	328186	6244163	3.10	Quaternary Sediments			2.05	Sep-99	
59_249	328272	6244165	2.87	Quaternary Sediments			2.25	Sep-99	
59_250	328274	6244165	2.79	Quaternary Sediments			1.76	Sep-99	
69_30	330936	6244991	2.90	Quaternary Sediments			1.55	Aug-07	
69_34	331521	6245409	2.20	Quaternary Sediments			1.10	Aug-07	
69_40	332049	6245725	2.20	Quaternary Sediments			1.20	Jul-07	
BH201	332805	6246273	2.50	Quaternary Sediments			1.00	Feb-13	
BH201A	328744	6239918	2.50	Quaternary Sediments			1.00	Feb-13	
BH203	332735	6246135	2.26	Quaternary Sediments			0.26	Feb-13	
BH205	332688	6246032	2.60	Quaternary Sediments			1.00	Feb-13	
BH249	328270	6244192	2.87	Quaternary Sediments	2.25	0.08	1.17	Sep-99	Feb-15
BH30	328142	6244132	2.23	Quaternary Sediments			1.44	Mar-12	
BH31	331398	6246472	4.23	Quaternary Sediments			3.44	Mar-12	

Bore ID	Easting (m)	Northing (m)	Elevation (mAHD)	Screened Formation	Groundwater Level (m AHD)			Monitoring Period	
					Max	Min	Median	From	To
GA08	332425	6246226	4.86	Quaternary Sediments	2.47	1.78	2.24	Jul-14	Dec-14
GW013331	332767	6245196		Quaternary Sediments	14.80	7.9	11.35		
GW015954	332869	6245176		Quaternary Sediments	19.20	6.7	12.95		
GW023191	329042	6242523		Quaternary Sediments			1.20		
GW023194	329157	6242813		Quaternary Sediments			3.30		
GW024109	329431	6243539		Quaternary Sediments			2.10		
GW027248	332257	6244788		Quaternary Sediments			2.40		
GW027664	329535	6243419		Quaternary Sediments			0.70		
GW075063	328406	6238157	1.73	Quaternary Sediments			1.00	Jun-01	
GW100053	332164	6245862		Quaternary Sediments			1.00		
GW109822	331806	6245594	2.89	Quaternary Sediments			3.00	Apr-97	
GW110456	332781	6246011	7.66	Quaternary Sediments			2.30		
GW110457	332822	6245945	10.25	Quaternary Sediments			1.70		
GW111320	332305	6245845	6.05	Quaternary Sediments			2.52		
GW111321	332322	6245742	5.29	Quaternary Sediments			2.64		

Bore ID	Easting	Northing	Elevation (m AHD)	Screen Interval		Screened Formation	Groundwater Level (m AHD)			Monitoring Period	
				Top (m AHD)	Bottom (m AHD)		Max	Min	Median	From	To
LDS-BH-1019	323844	6242879	23.68	23.0	16.4	Alluvium	20.27	19.75	19.86	21-Jul-16	09-Aug-16
LDS-BH-1021	323910	6242865	23.97	-4.0	-10.0	Hawkesbury Sandstone	17.48	17.38	17.39	07-Jun-16	10-Aug-16
LDS-BH-1025A[1]	324230	6242852	16.07	-1.9	-7.9	Hawkesbury Sandstone	16.10	16.05	16.08	29-Feb-16	10-Aug-16
LDS-BH-1026	324448	6242973	16.45	-17.4	-23.4	Hawkesbury Sandstone	16.07	15.65	15.96	22-Mar-16	10-Aug-16
LDS-BH-1027	324475	6242852	20.17	13.2	10.2	Hawkesbury Sandstone	15.57	15.30	15.30	17-Mar-16	10-Aug-16
LDS-BH-1030	325494	6243263	12.05	-9.2	-15.2	Hawkesbury Sandstone	5.75	5.67	5.71	23-Mar-16	11-May-16
LDS-BH-1031	325760	6243091	13.89	-24.1	-30.1	Hawkesbury Sandstone	5.31	4.87	5.04	17-Mar-16	10-Aug-16
LDS-BH-1032[2]	326053	6243172	18.97	-8.2		Hawkesbury Sandstone	13.54	13.36	13.48	28-Jul-16	10-Aug-16
				-35.5			15.23	15.18	15.21	28-Jul-16	10-Aug-16
LDS-BH-1033B	326949	6243221	12.57	-1.4	-7.4	Hawkesbury Sandstone	7.06	6.36	6.79	28-May-16	10-Aug-16
				-12.4			6.50	6.34	6.35	19-Jul-16	10-Aug-16
LDS-BH-1038	329099	6243198	15.15	-49.8	-58.8	Hawkesbury Sandstone	-0.07	-0.47	-0.30	24-Mar-16	29-Jun-16
LDS-BH-1041[3]	329465	6243437	1.93	-12.2		Alluvium	-0.21	-1.04	-0.42	12-Feb-16	29-Jun-16
				-20.7		Alluvium	-0.34	-1.51	-0.57	12-Feb-16	29-Jun-16
				-25.3		Alluvium	-0.45	-1.83	-0.66	12-Feb-16	29-Jun-16
				-59.5		Hawkesbury Sandstone	-0.46	-1.25	-0.54	12-Feb-16	29-Jun-16
LDS-BH-1044[4]	325714	6243233	15.56	6.6	5.1	Alluvium	DRY	DRY	DRY	08-Feb-16	09-Aug-16
LDS-BH-1066[1]	326526	6242873	12.59	-17.8	-23.8	Hawkesbury Sandstone	12.59	12.59	12.59	18-Aug-16	26-Aug-16
LDS-BH-2001	329361	6243035	2.21	0.2	-2.8	Alluvium	2.11	1.70	1.95	15-Apr-16	10-Aug-16
LDS-BH-2003	329720	6242895	2.41	-3.6	-6.6	Alluvium	0.99	0.69	0.84	18-Feb-16	09-Aug-16
LDS-BH-2005[5]	329618	6243371	1.10	-11.4		Alluvium	-0.60	-0.93	-0.81	09-Feb-16	01-Mar-16
				-15.9		Alluvium	-0.86	-1.05	-0.97	09-Feb-16	01-Mar-16
				-21.9		Alluvium	-0.75	-0.92	-0.84	09-Feb-16	01-Mar-16
				-25.9	-26.9	Hawkesbury Sandstone	-0.13	-1.36	-0.43	09-Feb-16	28-Jun-16
LDS-BH-2007A[6]	329789	6243546	1.02	-41.0	-53.0	Hawkesbury Sandstone	0.21	0.07	0.15	06-Feb-16	18-Feb-16

Bore ID	Easting	Northing	Elevation (m AHD)	Screen Interval		Screened Formation	Groundwater Level (m AHD)			Monitoring Period	
				Top (m AHD)	Bottom (m AHD)		Max	Min	Median	From	To
LDS-BH-2008A	329940	6243862	1.79	-42.2	-48.2	Hawkesbury Sandstone	-2.25	-3.57	-3.13	04-Aug-16	10-Aug-16
LDS-BH-2011A	330075	6244315	2.22	-27.8	-39.8	Hawkesbury Sandstone	1.16	0.99	1.01	26-Jul-16	10-Aug-16
LDS-BH-2011B	330075	6244316	2.19	-0.8	-2.8	Alluvium	1.27	1.16	1.20	26-Jul-16	10-Aug-16
LDS-BH-2015	330178	6244781	15.80	-21.2	-30.2	Hawkesbury Sandstone	7.50	7.36	7.44	15-Jul-16	10-Aug-16
LDS-BH-2018	330616	6245122	12.67	0.2	-5.8	Hawkesbury Sandstone	5.02	4.68	4.94	02-Jun-16	10-Aug-16
LDS-BH-2019	330714	6245309	9.88	-16.1	-28.1	Hawkesbury Sandstone	4.73	4.20	4.36	12-May-16	09-Aug-16
LDS-BH-2029[6]	329560	6243397	1.04	-44.0	-59.0	Hawkesbury Sandstone	-0.39	-0.43	-0.42	09-Feb-16	01-Mar-16
LDS-BH-2029A[6]	329561	6243398	1.02	-19.5	-28.5	Alluvium	-0.17	-0.44	-0.37	09-Feb-16	01-Mar-16
LDS-BH-3045	331602	6245451	2.83	1.3	-1.7	Botany Sands Aquifer	1.14	0.88	1.02	02-Jun-16	23-Aug-16
LDS-BH-3045A	331603	6245450	2.83	-13.2	-16.2	Ashfield Shale	-1.36	-1.56	-1.43	02-Jun-16	23-Aug-16
LDS-BH-3046	331841	6245571	4.06	-1.9	-3.9	Botany Sands Aquifer	1.76	1.07	1.48	01-Apr-16	23-Aug-16
LDS-BH-3046A	331842	6245571	3.89	-8.2	-23.2	Ashfield Shale	-6.22	-6.96	-6.37	01-Apr-16	23-Aug-16
LDS-BH-3047	332046	6245639	5.79	-1.2	-7.2	Botany Sands Aquifer	2.21	1.80	2.01	01-Apr-16	23-Aug-16
LDS-BH-3047A	332046	6245640	5.81	-12.2	-21.2	Ashfield Shale	1.78	1.49	1.62	30-Mar-16	23-Aug-16
LDS-BH-3082[7]	331437	6245751				Botany Sands Aquifer					
LDS-BH-3097[7]	331822	6245596				Botany Sands Aquifer					
LDS-BH-5007	331811	6245941	12.15	-2.8	-11.8	Ashfield Shale	-2.08	-2.15	-2.11	05-Aug-16	11-Aug-16
LDS-BH-5022	332211	6245657	2.76	0.8	-5.2	Botany Sands Aquifer	1.33	1.08	1.10	12-May-16	11-Aug-16
WCX-BH006	323555	6242880	24.71	2.7	-0.3	Hawkesbury Sandstone	20.38	20.04	20.18	11-Feb-16	10-Aug-16
WCX-BH018	326717	6243422	34.84	-16.2	-19.2	Hawkesbury Sandstone	14.54	12.08	13.31	11-Feb-16	12-Aug-16
WCX-BH024	327222	6243306	8.17	-17.9	-20.9	Hawkesbury Sandstone	-0.65	-1.14	-0.91	11-Feb-16	12-Aug-16
WCX-BH039	329553	6244158	3.32	-45.7	-48.7	Hawkesbury Sandstone	-0.78	-1.18	-0.97	11-Feb-16	09-Aug-16
WCX-BH072	325561	6243243	7.47	-20.4	-23.4	Hawkesbury Sandstone	5.28	4.84	4.90	11-Feb-16	09-Aug-16
WCX-BH088	326182	6243434	16.78	-24.2	-27.2	Hawkesbury Sandstone	1.44	1.34	1.39	11-Feb-16	12-Aug-16
WCX-BH093	327657	6243183	36.39	-11.1	-14.1	Hawkesbury Sandstone	27.57	24.55	25.08	11-Feb-16	10-Aug-16
WCX-BH094	327867	6243174	31.17	-22.8	-25.8	Hawkesbury Sandstone	29.34	27.31	27.53	11-Feb-16	10-Aug-16

Bore ID	Easting	Northing	Elevation (m AHD)	Screen Interval		Screened Formation	Groundwater Level (m AHD)			Monitoring Period	
				Top (m AHD)	Bottom (m AHD)		Max	Min	Median	From	To
WCX-BH103	330431	6245201	11.10	-36.9	-39.9	Hawkesbury Sandstone	5.00	4.62	4.95	11-Feb-16	09-Aug-16
WCX-BH109	331220	6245632	6.91	-26.1	-29.1	Ashfield Shale	-0.49	-0.97	-0.62	12-Feb-16	11-Aug-16
WCX-BH122	332030	6245873	5.72	-9.2	-12.2	Ashfield Shale	2.26	2.02	2.13	12-Feb-16	23-Aug-16
WCX-BH137	324858	6243065	15.15	-38.9	-41.9	Hawkesbury Sandstone	14.99	14.97	14.98	11-Feb-16	08-Jun-16
WCX-BH153	330468	6244766	11.24	-34.8	-37.8	Hawkesbury Sandstone	3.28	3.03	3.16	12-Feb-16	12-Aug-16
WCX-BH157	331518	6245766	16.82	-15.2	-18.2	Regentville Siltstone	-12.16	-12.60	-12.19	12-Feb-16	12-Aug-16
WCX-BH168	329702	6243775	1.36	-46.6	-49.6	Hawkesbury Sandstone	0.14	-0.31	-0.09	12-Feb-16	06-May-16

Notes:

1) Artesian conditions, groundwater levels not representative of static conditions.

2) Inclined borehole with a total of two fully grouted vibrating wire piezometers installed at an angle of 72˚ at the respective elevations indicated.

3) Inclined borehole with a total of four fully grouted vibrating wire piezometers installed at an angle of 70˚ at the respective elevations indicated.

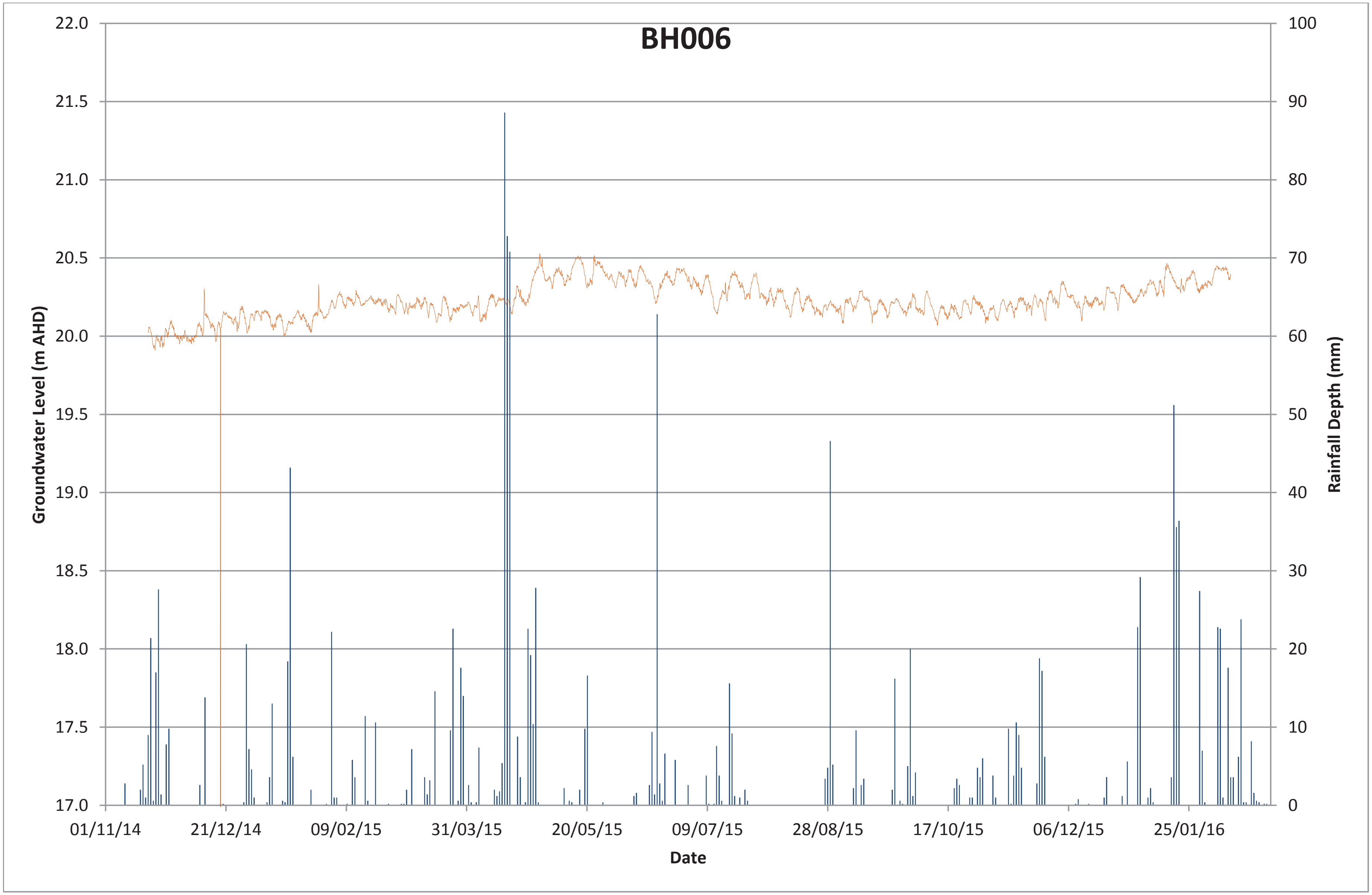
4) Monitoring well observed to be destroyed on August 9th, 2016.

5) Borehole was completed with three fully grouted vibrating wire piezometers and one monitoring well.

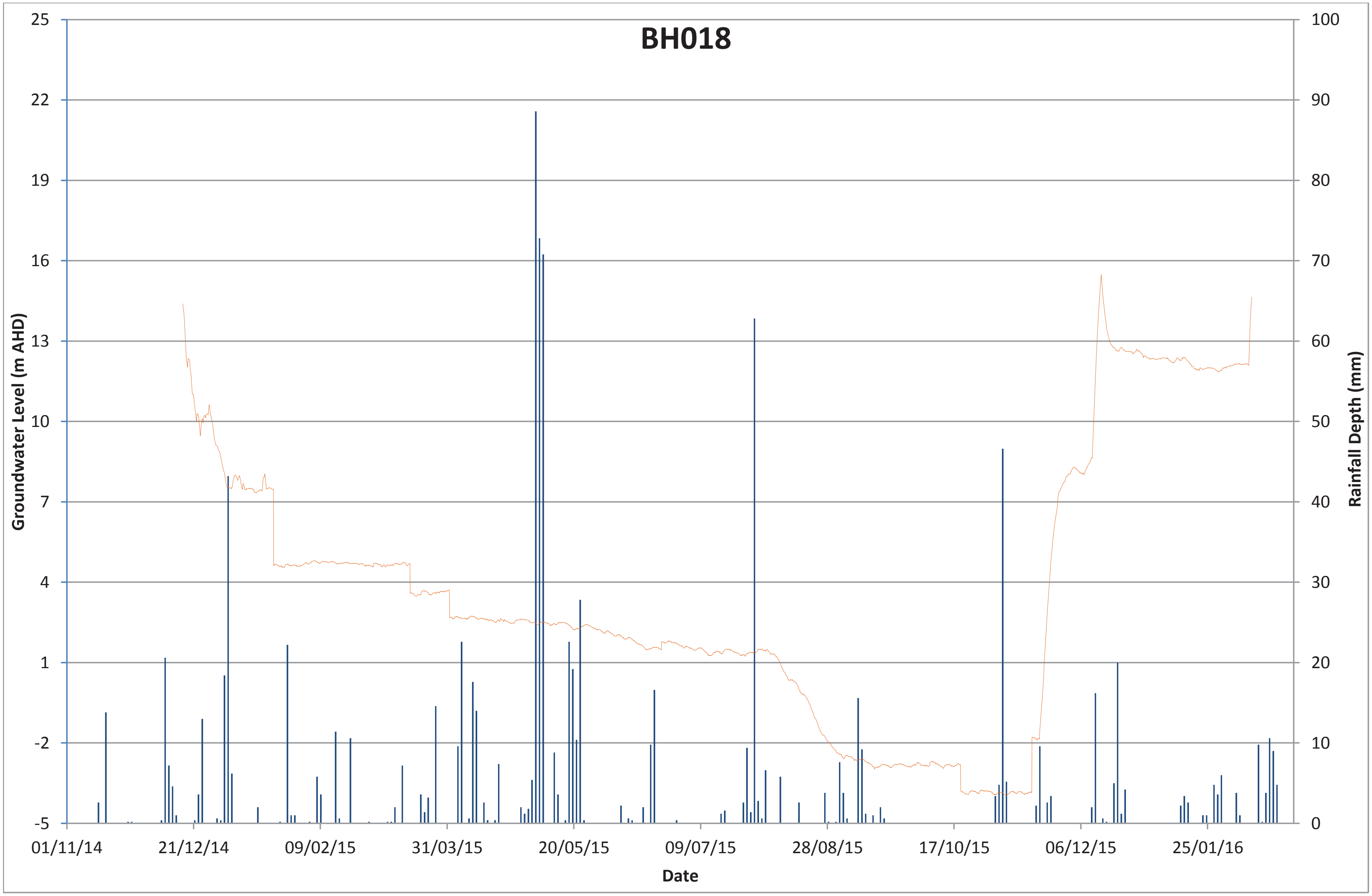
6) Monitoring well is no longer accessible due to construction related activities for the widening of Marsh Road.

7) Monitoring well to be installed.

Annexure G – Hydrographs WestConnex Wells



BH006
Groundwater Level (m AHD)
Rainfall Depth (mm)
Date
22.0
21.5
21.0
20.5
20.0
19.5
19.0
18.5
18.0
17.5
17.0
100
90
80
70
60
50
40
30
20
10
0
01/11/14
21/12/14
09/02/15
31/03/15
20/05/15
09/07/15
28/08/15
17/10/15
06/12/15
25/01/16



BH018
Groundwater Level (m AHD)
Rainfall Depth (mm)
Date
25
22
19
16
13
10
7
4
1
-2
-5
100
90
80
70
60
50
40
30
20
10
0
01/11/14
21/12/14
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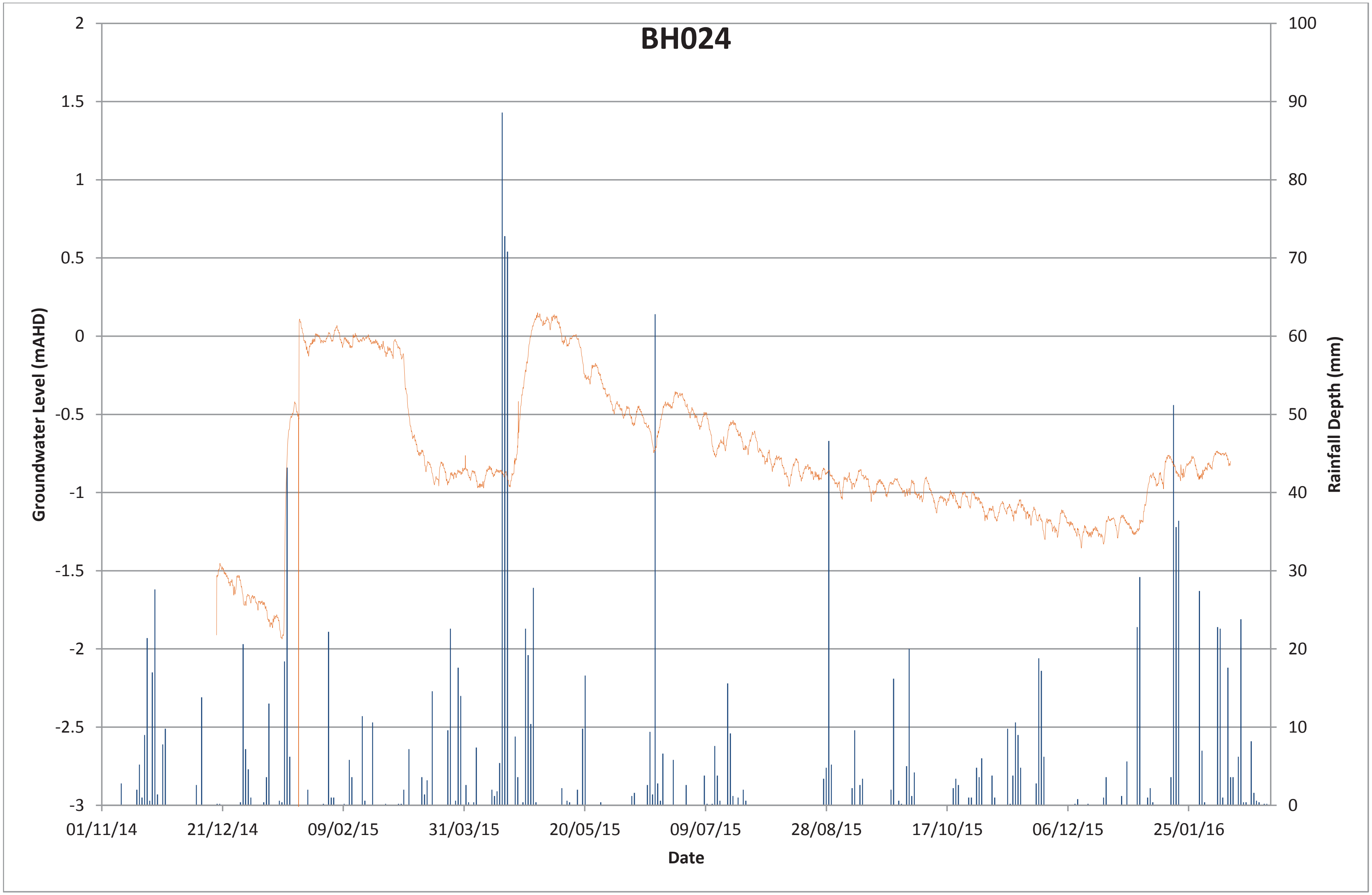
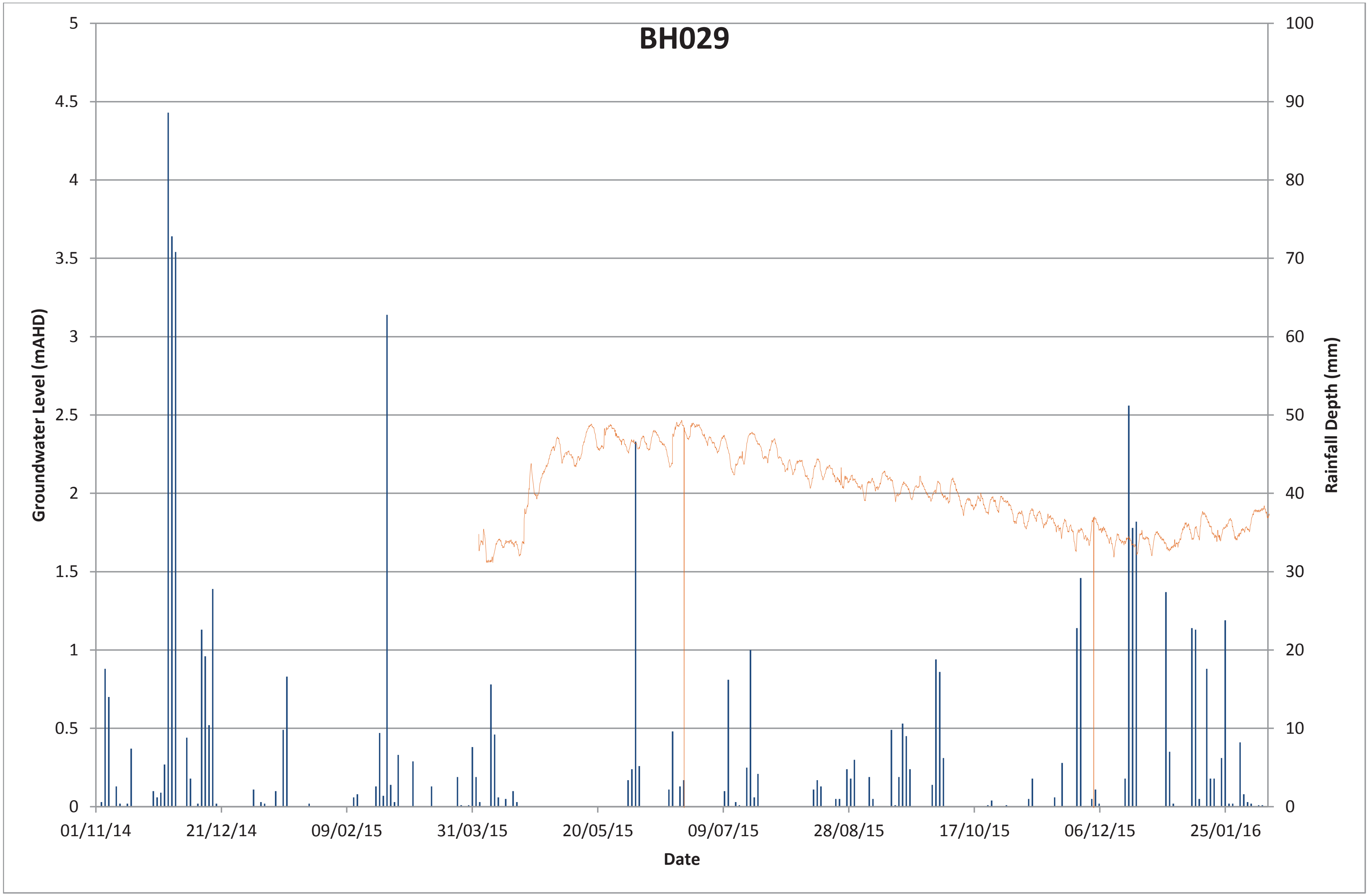
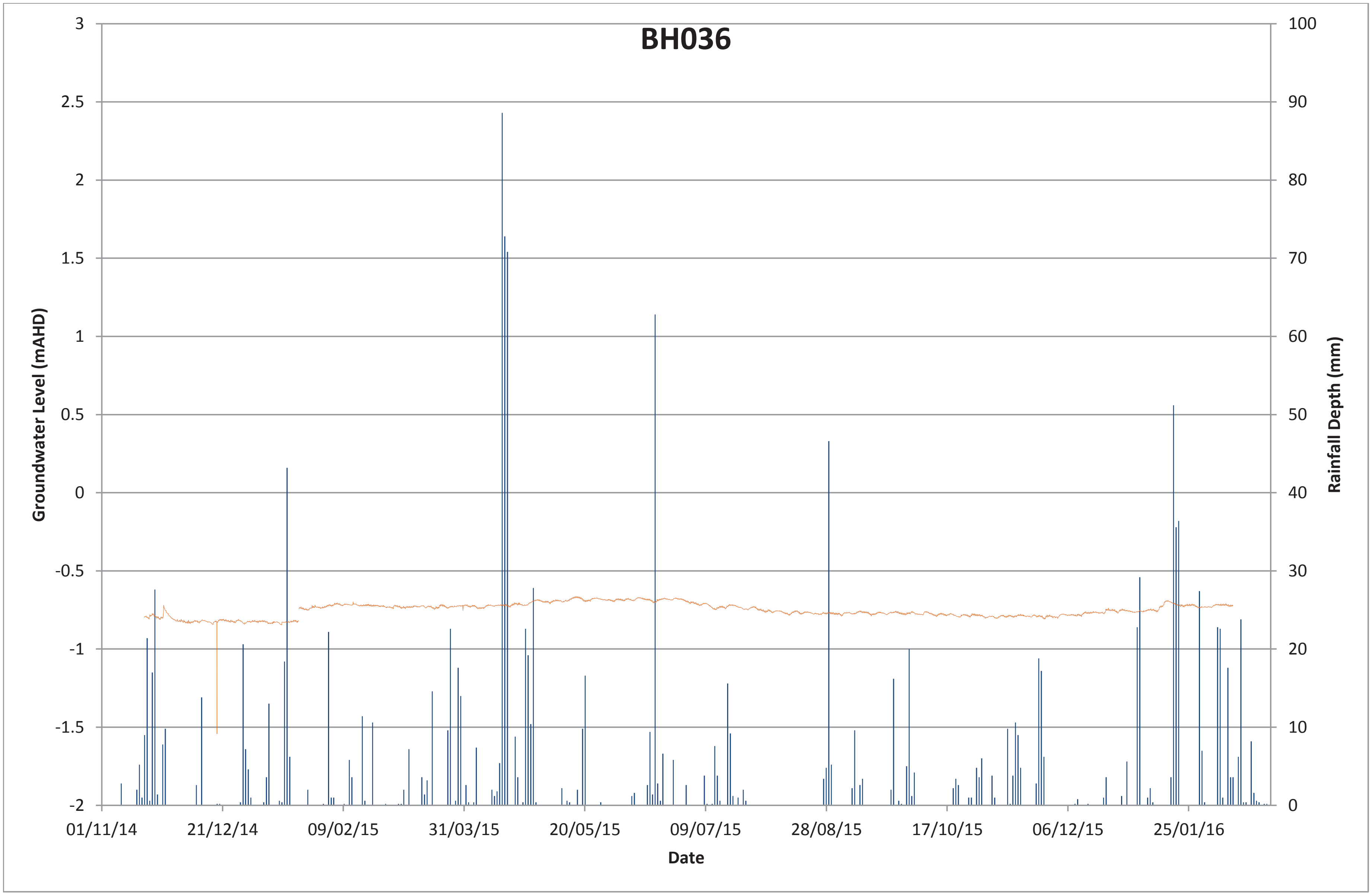
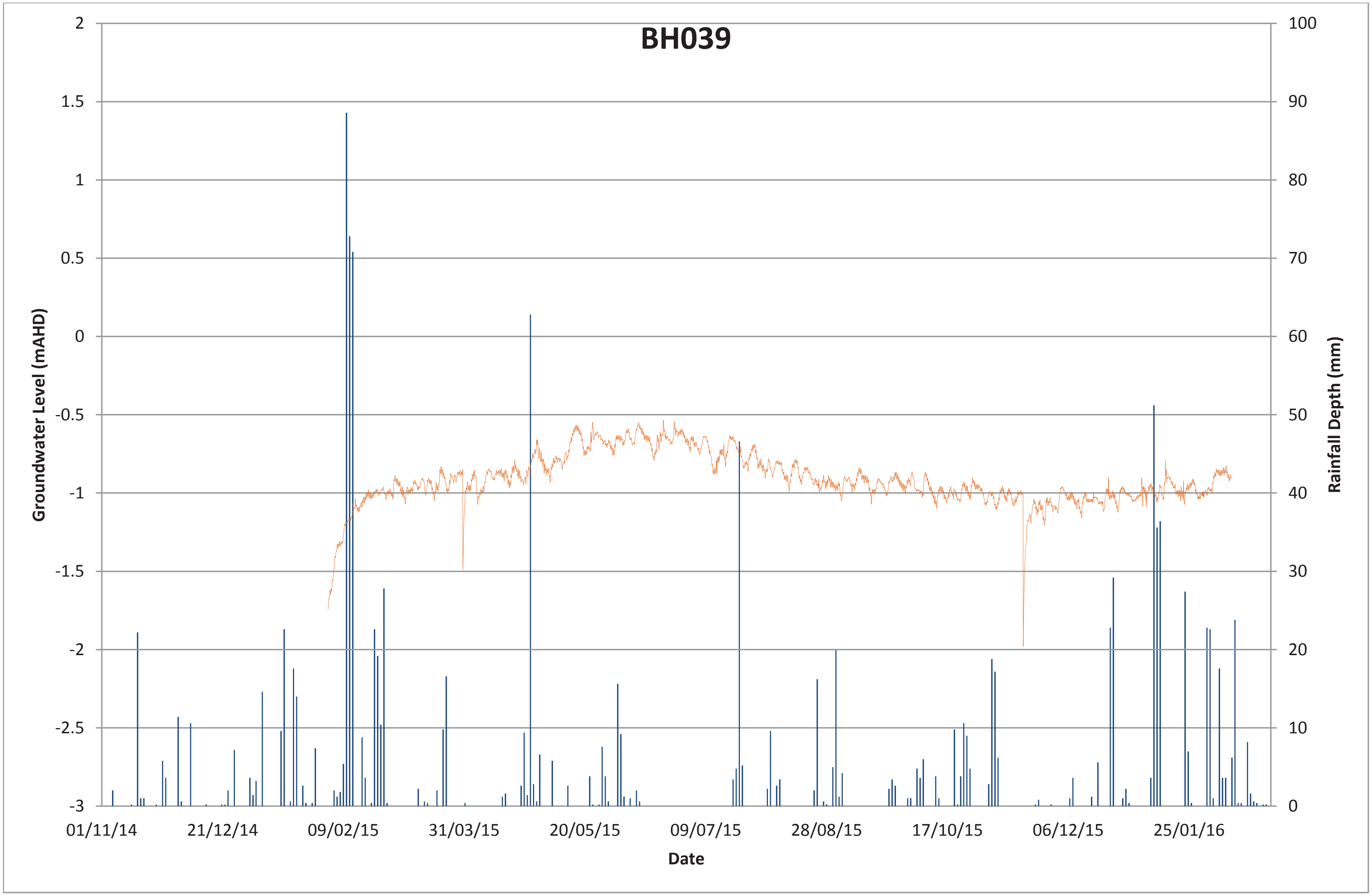
06/12/15
25/01/16

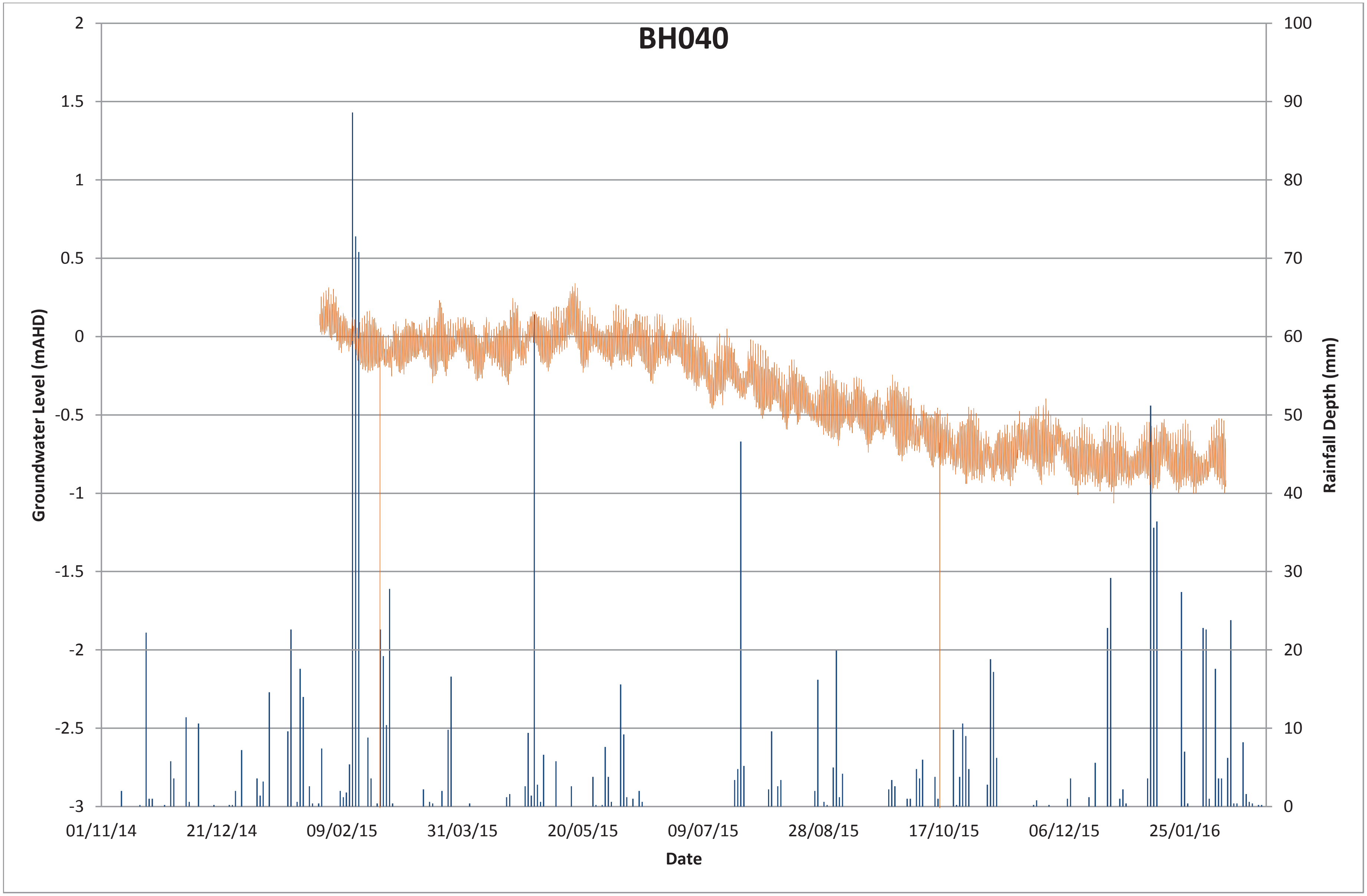


BH024
Groundwater Level (mAHD)
Rainfall Depth (mm)
Date
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
-3
100
90
80
70
60
50
40
30
20
10
0
01/11/14
21/12/14
09/02/15
31/03/15
20/05/15
09/07/15
28/08/15
17/10/15
06/12/15
25/01/16

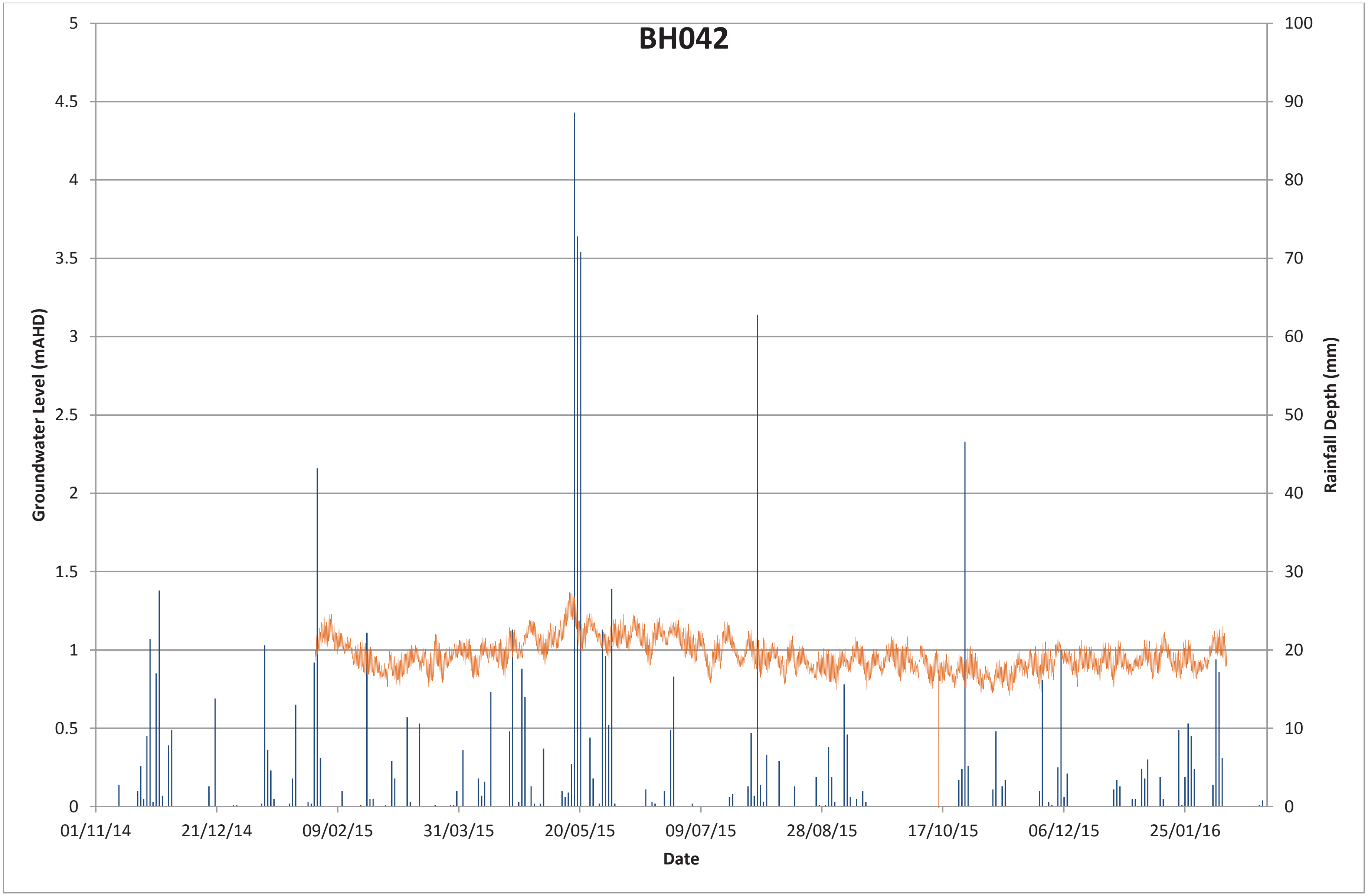

BH029
Groundwater Level (mAHD)
Rainfall Depth (mm)
Date
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
100
90
80
70
60
50
40
30
20
10
0
01/11/14
21/12/14
09/02/15
31/03/15
20/05/15
09/07/15
28/08/15
17/10/15
06/12/15
25/01/16


BH036
Groundwater Level (mAHD)
Rainfall Depth (mm)
Date
3
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
100
90
80
70
60
50
40
30
20
10
0
01/11/14
21/12/14
09/02/15
31/03/15
20/05/15
09/07/15
28/08/15
17/10/15
06/12/15
25/01/16

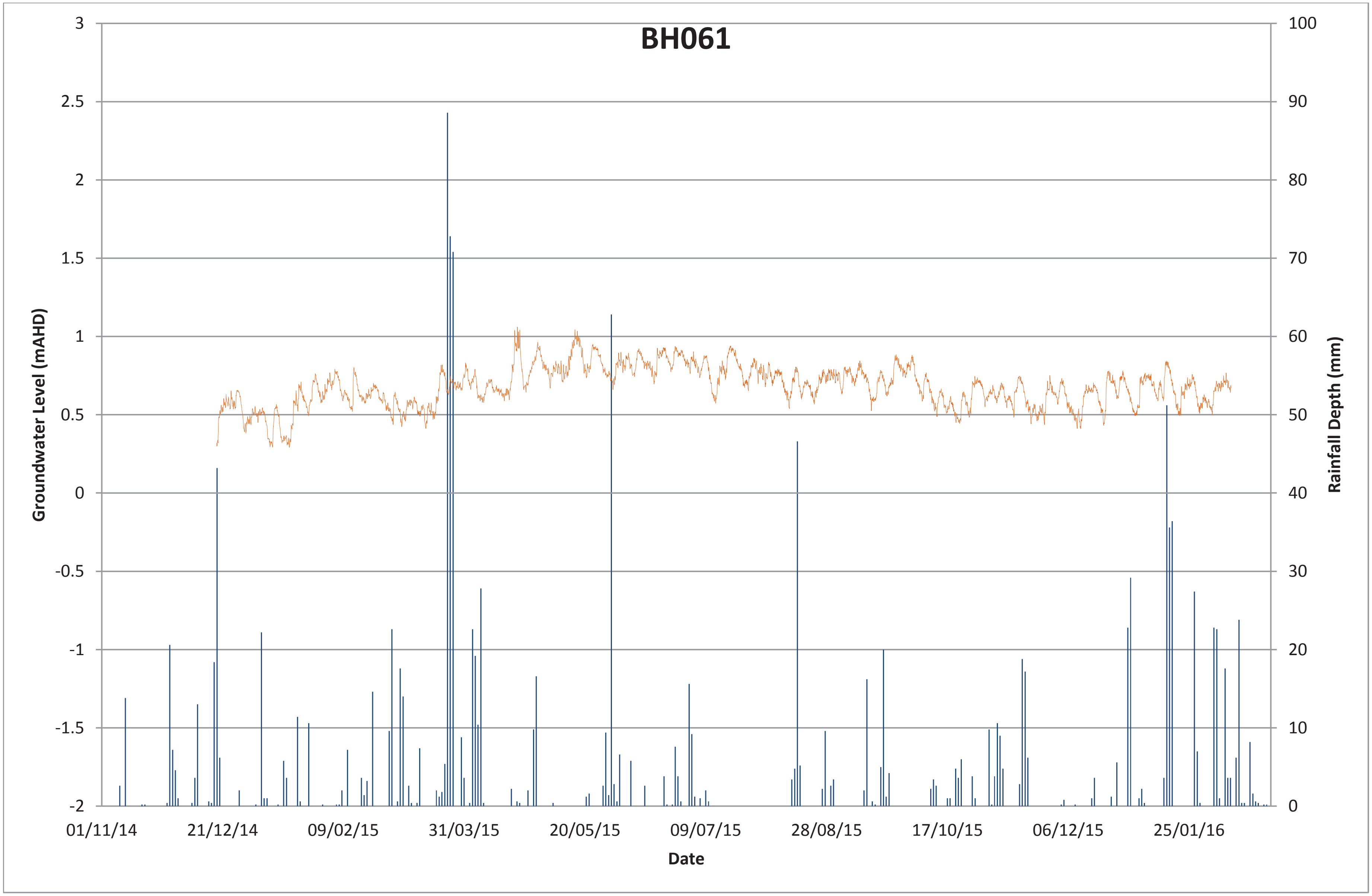

BH039
Groundwater Level (mAHD)
Rainfall Depth (mm)
Date
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
-3
100
90
80
70
60
50
40
30
20
10
0
01/11/14
21/12/14
09/02/15
31/03/15
20/05/15
09/07/15
28/08/15
17/10/15
06/12/15
25/01/16

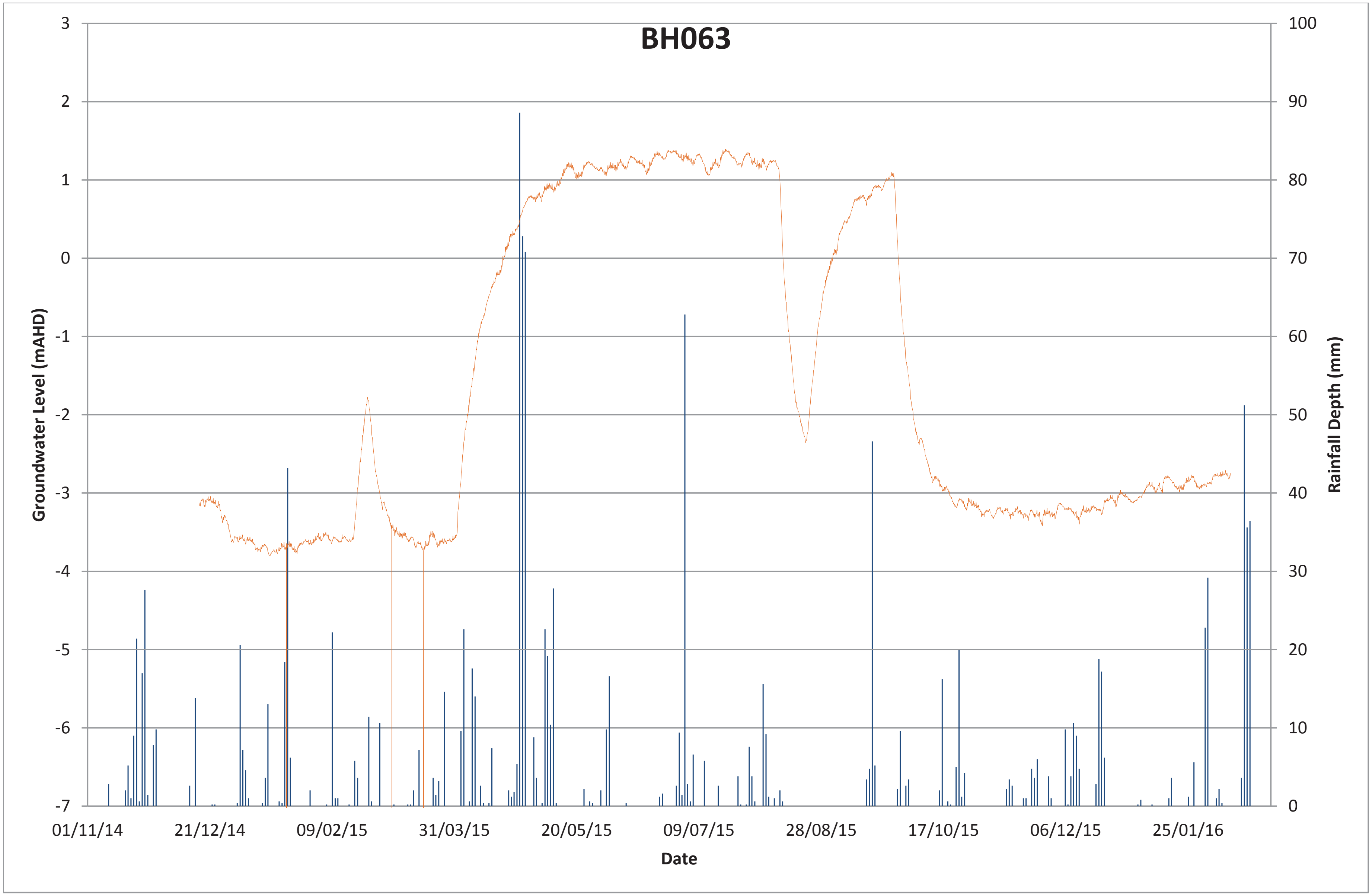


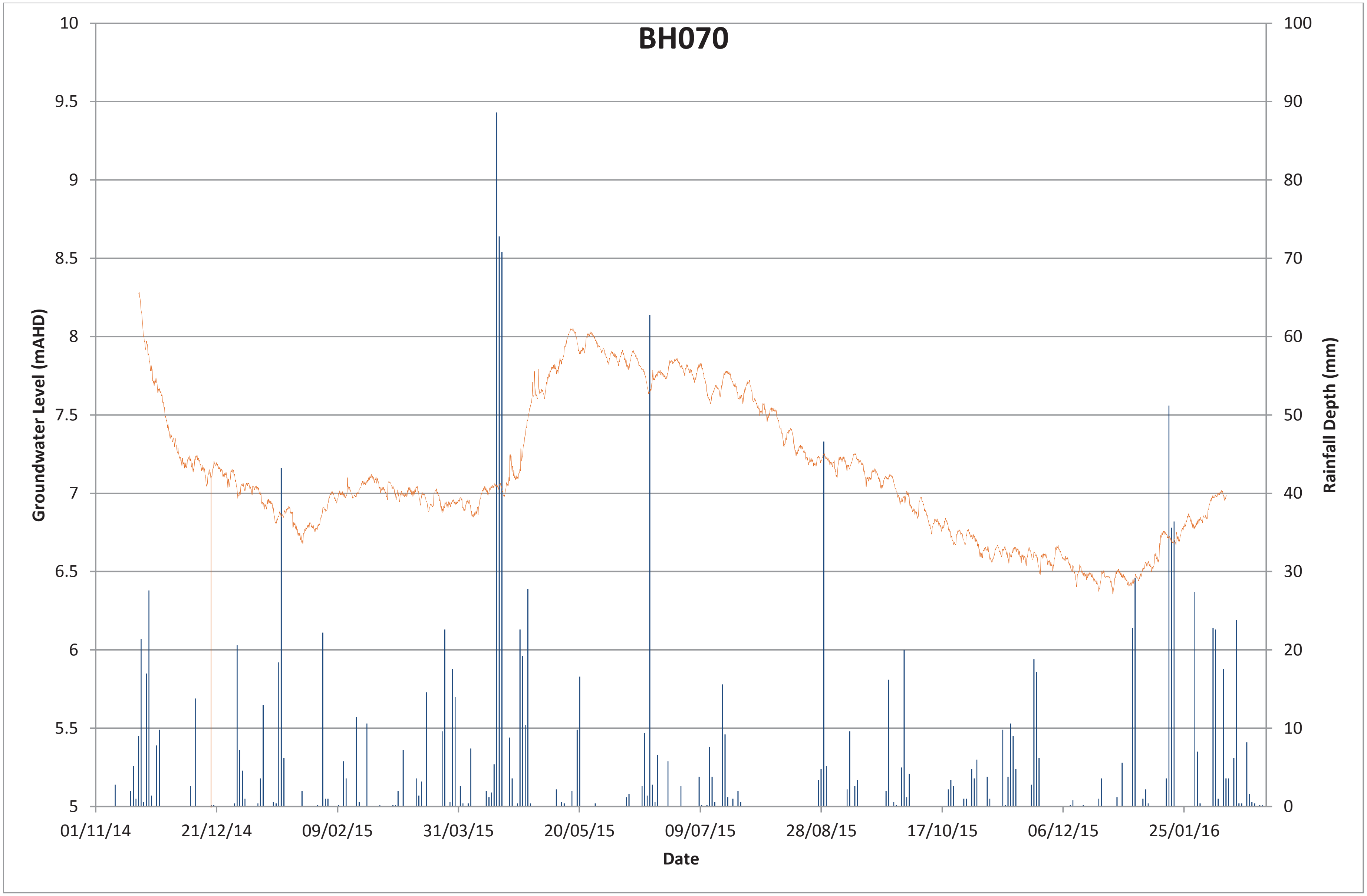
BH040
Groundwater Level (mAHD)
Rainfall Depth (mm)
Date
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
-3
100
90
80
70
60
50
40
30
20
10
0
01/11/14
21/12/14
09/02/15
31/03/15
20/05/15
09/07/15
28/08/15
17/10/15
06/12/15
25/01/16

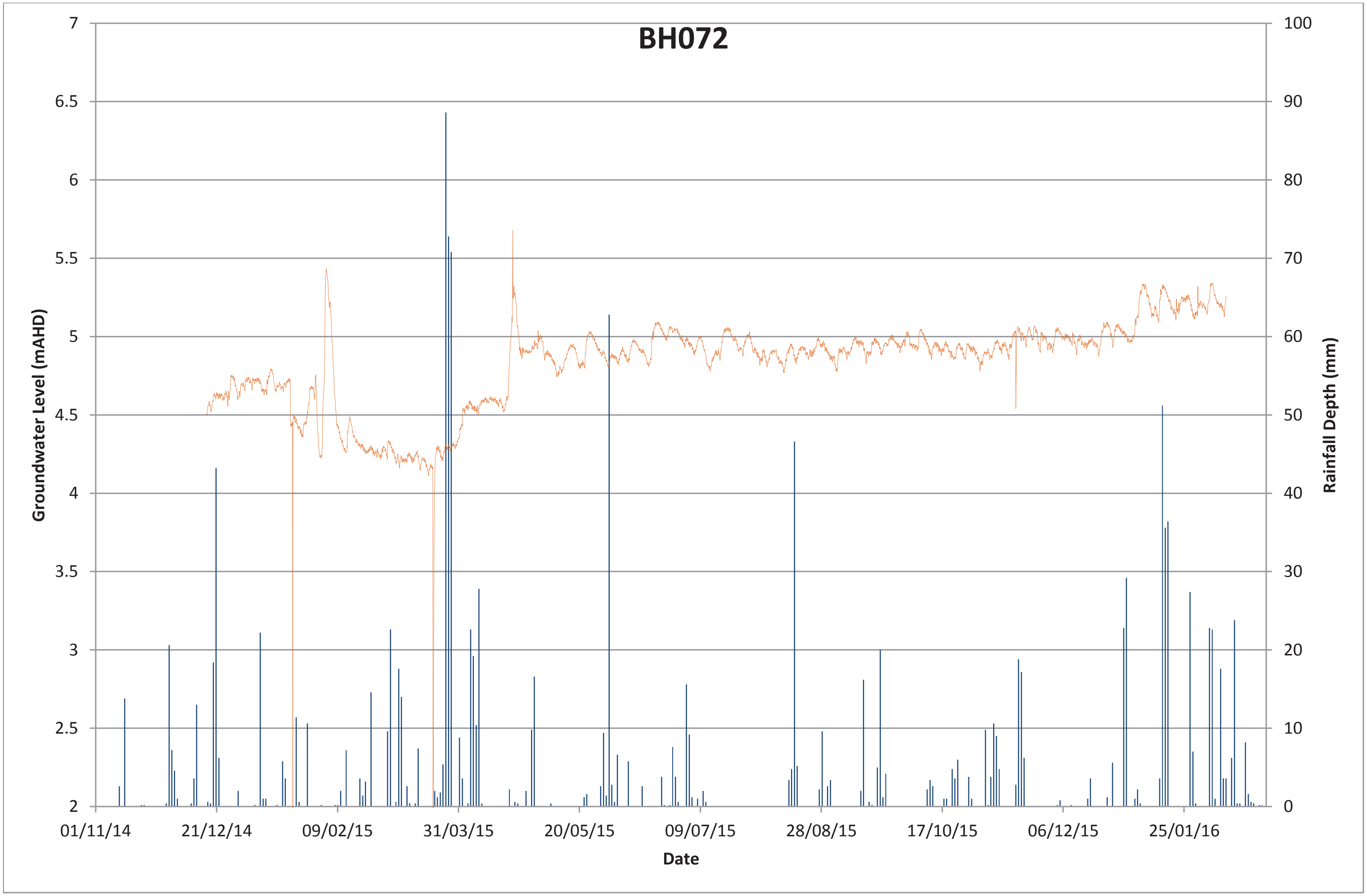


BH042
Groundwater Level (mAHD)
Rainfall Depth (mm)
Date
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
0
10
20
30
40
50
60
70
80
90
100
01/11/14
21/12/14
09/02/15
31/03/15
20/05/15
09/07/15
28/08/15
17/10/15
06/12/15
25/01/16

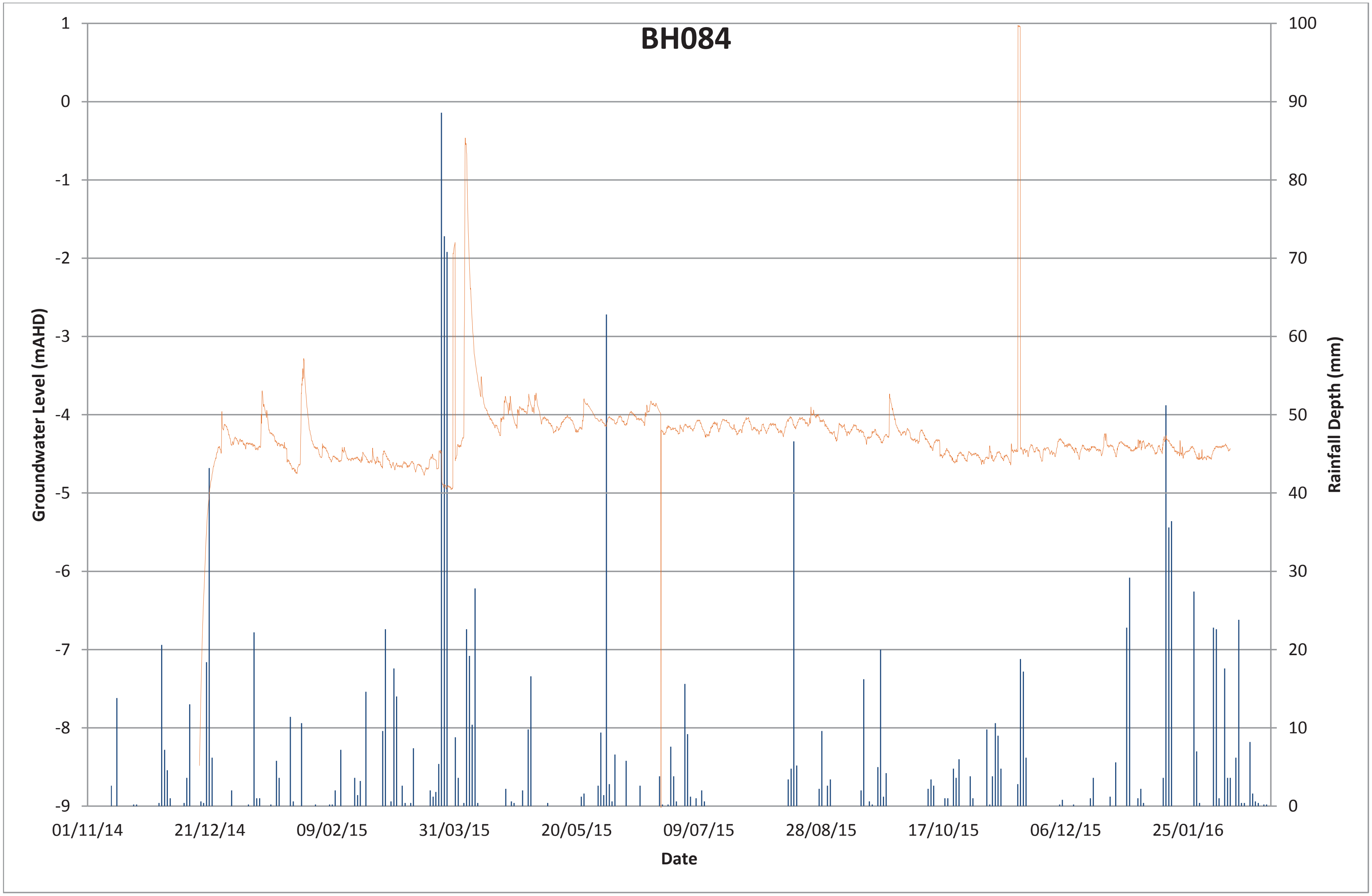

BH061
Groundwater Level (mAHD)
Rainfall Depth (mm)
Date
3
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
100
90
80
70
60
50
40
30
20
10
0
01/11/14
21/12/14
09/02/15
31/03/15
20/05/15
09/07/15
28/08/15
17/10/15
06/12/15
25/01/16

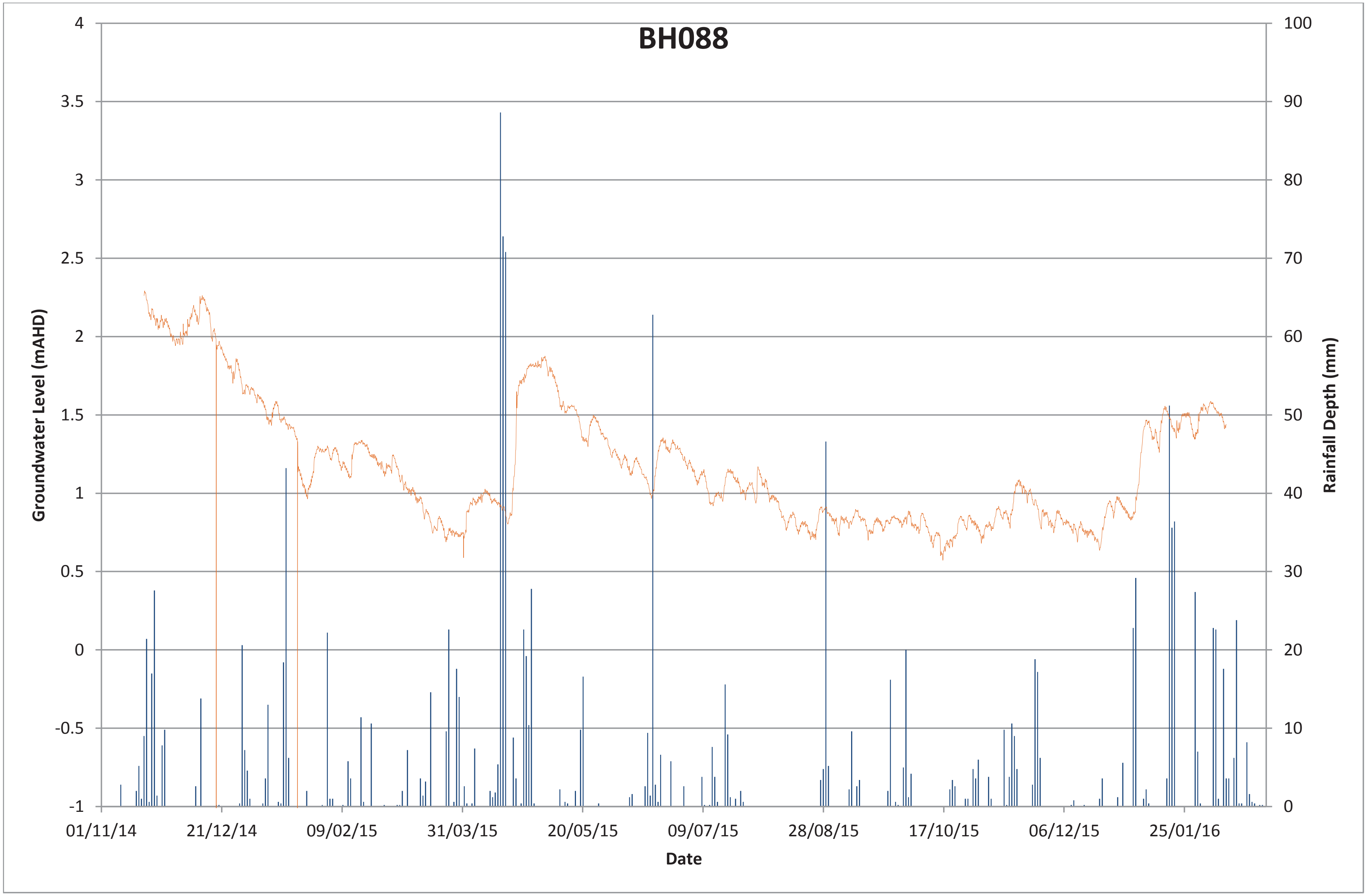

BH063
Groundwater Level (mAHD)
Rainfall Depth (mm)
3
2
1
0
-1
-2
-3
-4
-5
-6
-7
100
90
80
70
60
50
40
30
20
10
0
01/11/14
21/12/14
09/02/15
31/03/15
20/05/15
09/07/15
28/08/15
17/10/15
06/12/15
25/01/16
Date


BH070
Groundwater Level (mAHD)
Rainfall Depth (mm)
Date
10
9.5
9
8.5
8
7.5
7
6.5
6
5.5
5
100
90
80
70
60
50
40
30
20
10
0
01/11/14
21/12/14
09/02/15
31/03/15
20/05/15
09/07/15
28/08/15
17/10/15
06/12/15
25/01/16

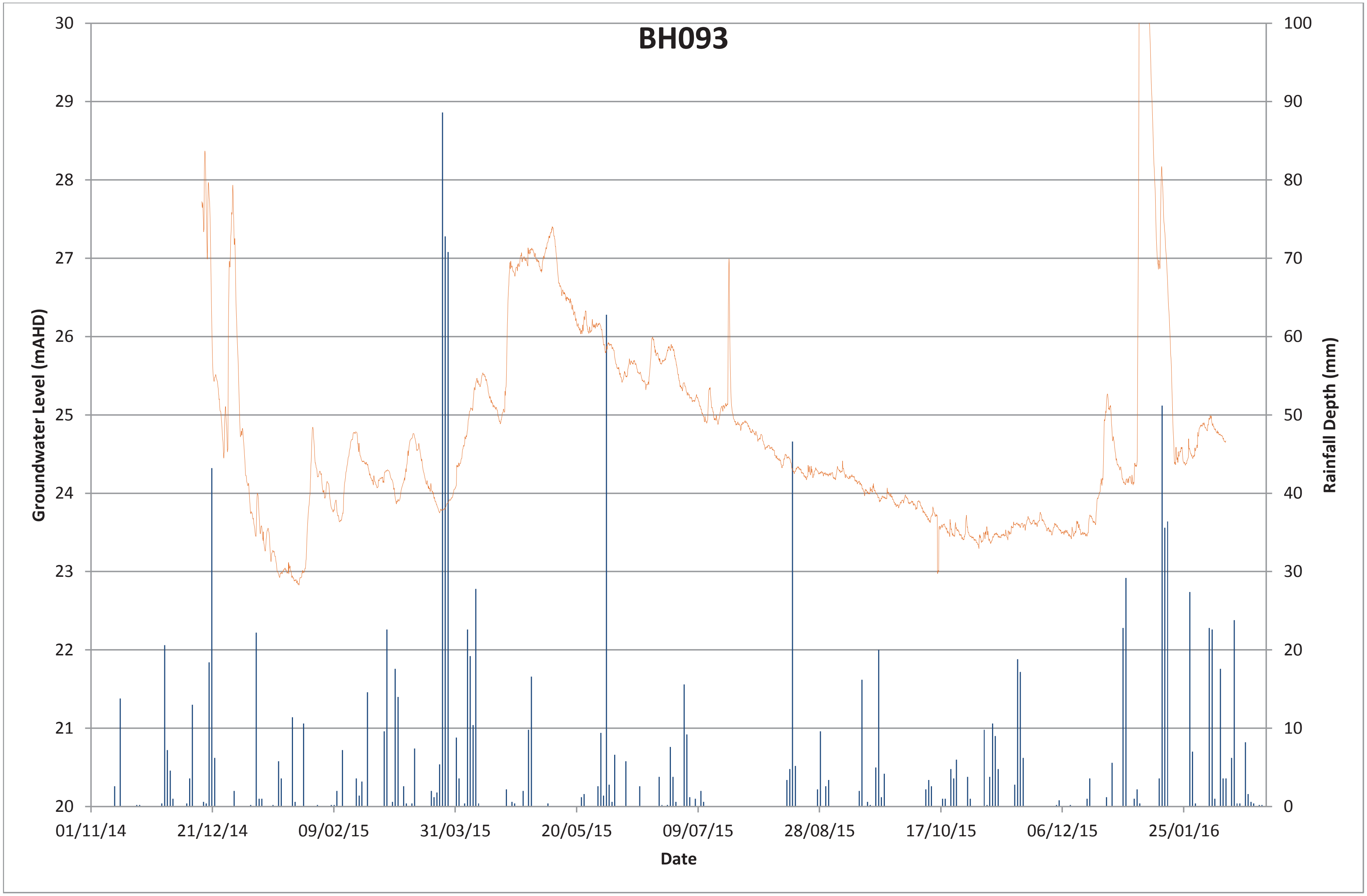


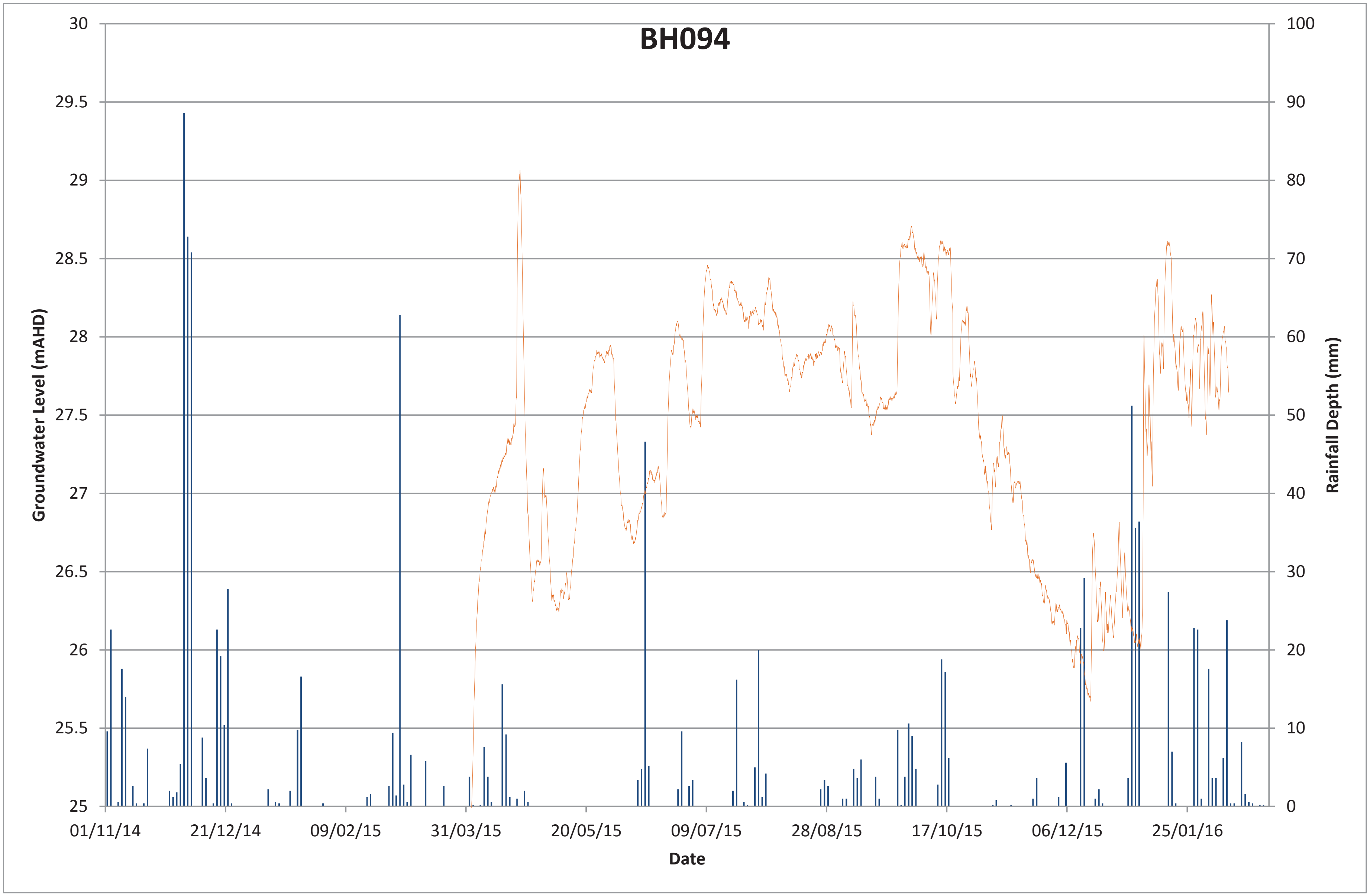
BH072
Groundwater Level (mAHD)
Rainfall Depth (mm)
Date
7
6.5
6
5.5
5
4.5
4
3.5
3
2.5
2
100
90
80
70
60
50
40
30
20
10
0
01/11/14
21/12/14
09/02/15
31/03/15
20/05/15
09/07/15
28/08/15
17/10/15
06/12/15
25/01/16

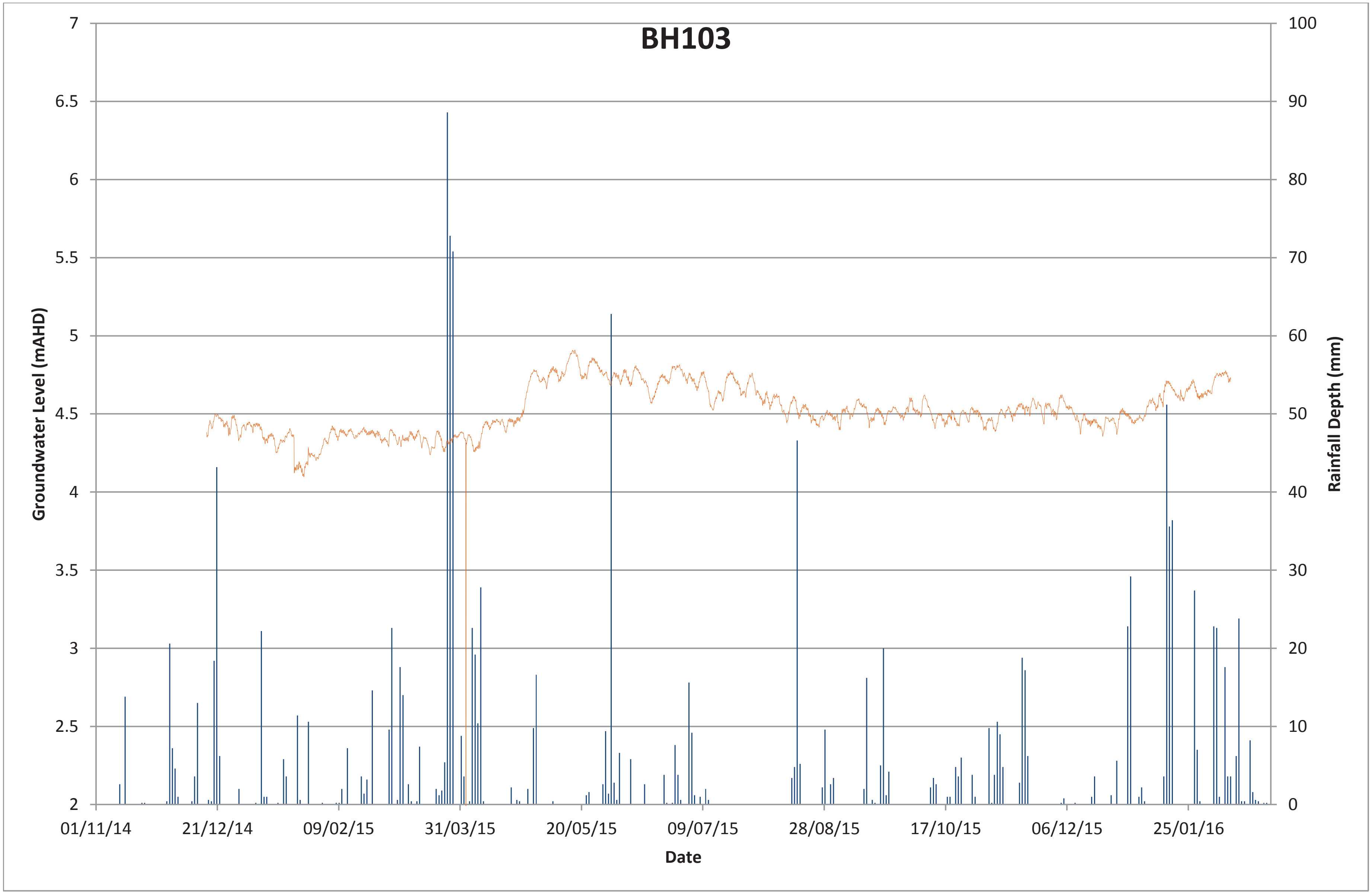

BH084
Groundwater Level (mAHD)
Rainfall Depth (mm)
1
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
100
90
80
70
60
50
40
30
20
10
0
01/11/14
21/12/14
09/02/15
31/03/15
20/05/15
09/07/15
28/08/15
17/10/15
06/12/15
25/01/16
Date

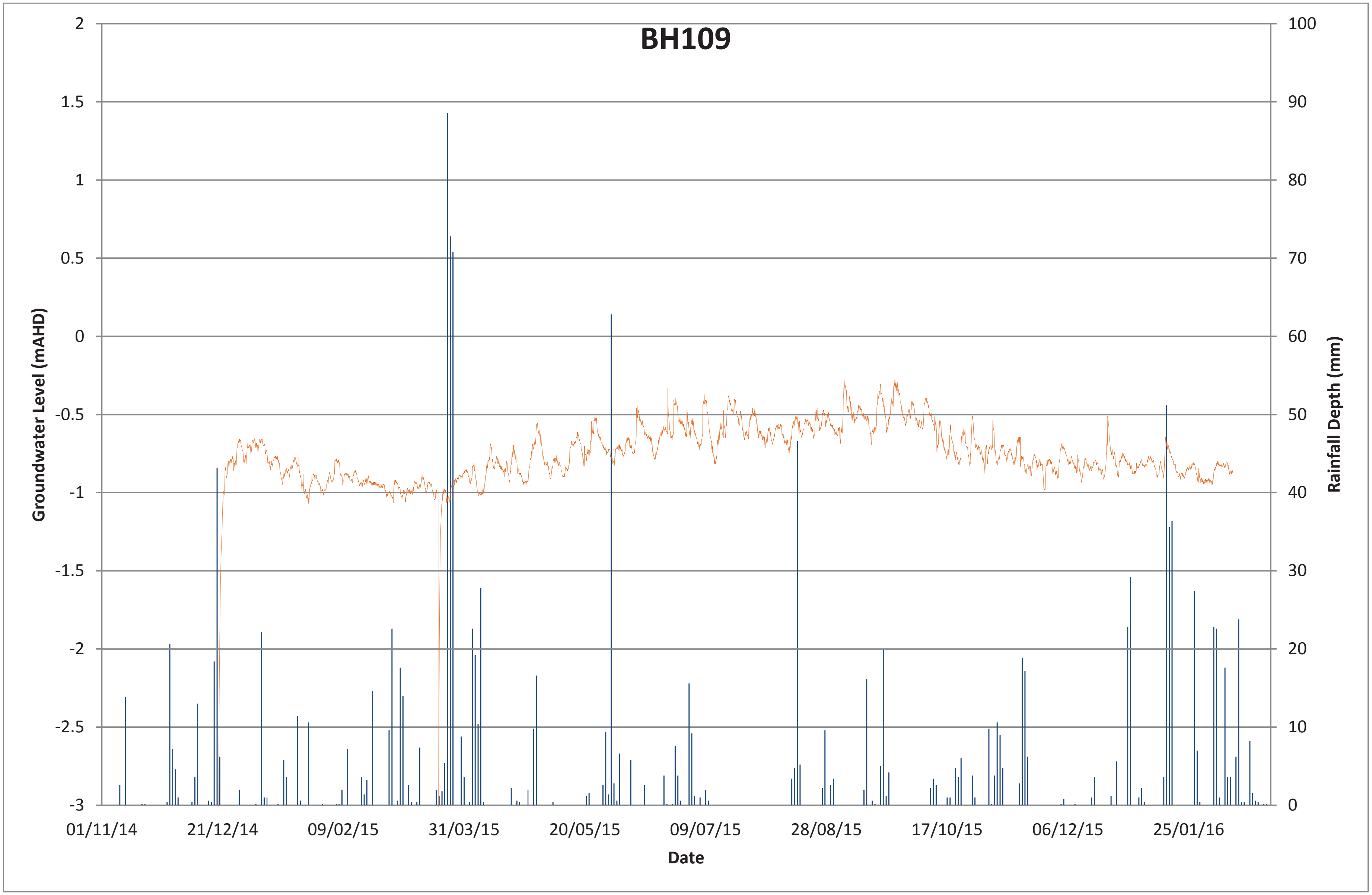


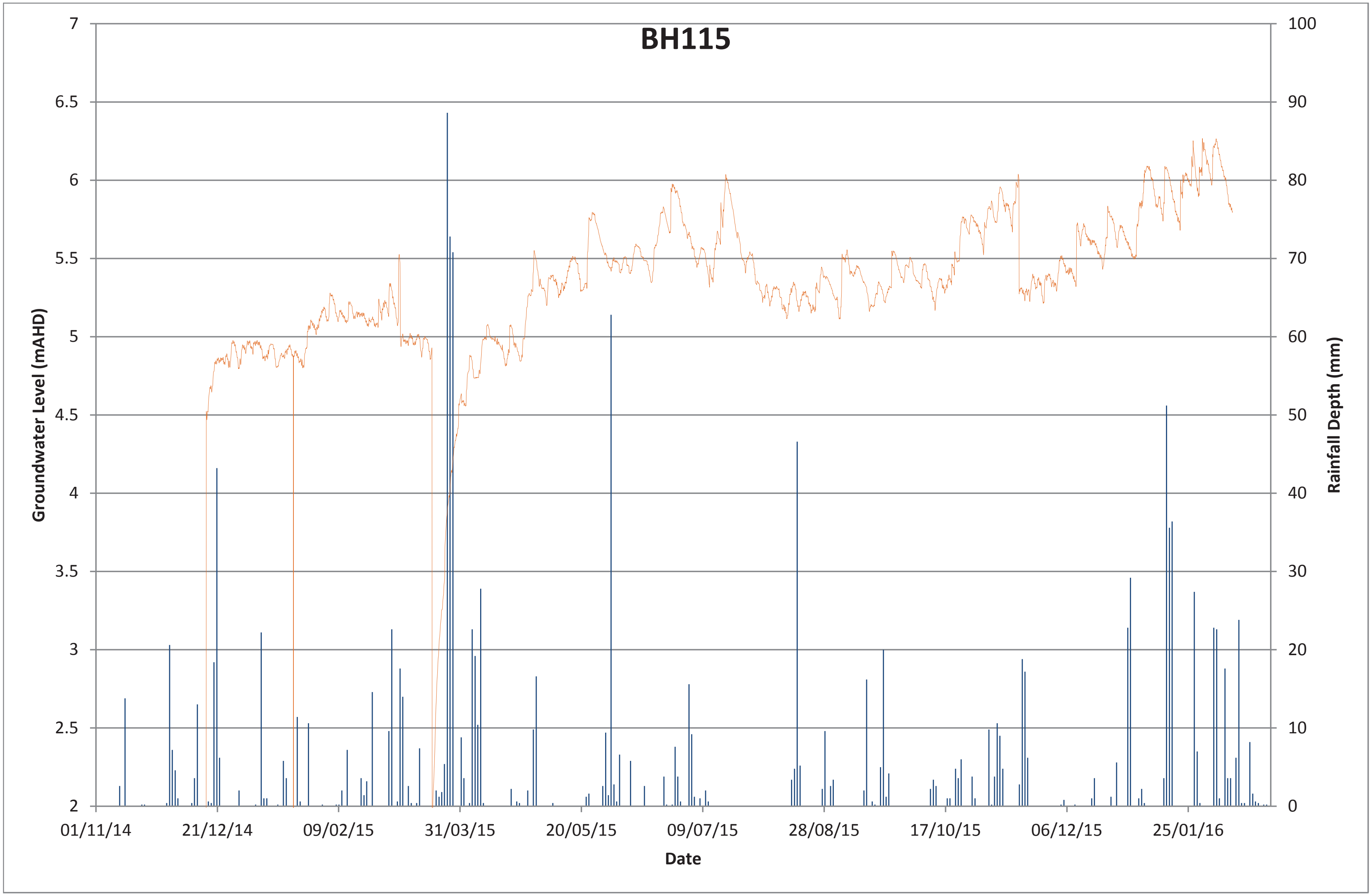
BH088
Groundwater Level (mAHD)
Rainfall Depth (mm)
Date
4
3.5
3
2.5
2
1.5
1
0.5
0
-0.5
-1
100
90
80
70
60
50
40
30
20
10
0
01/11/14
21/12/14
09/02/15
31/03/15
20/05/15
09/07/15
28/08/15
17/10/15
06/12/15
25/01/16


BH093
Groundwater Level (mAHD)
Rainfall Depth (mm)
Date
30
29
28
27
26
25
24
23
22
21
20
100
90
80
70
60
50
40
30
20
10
0
01/11/14
21/12/14
09/02/15
31/03/15
20/05/15
09/07/15
28/08/15
17/10/15
06/12/15
25/01/16

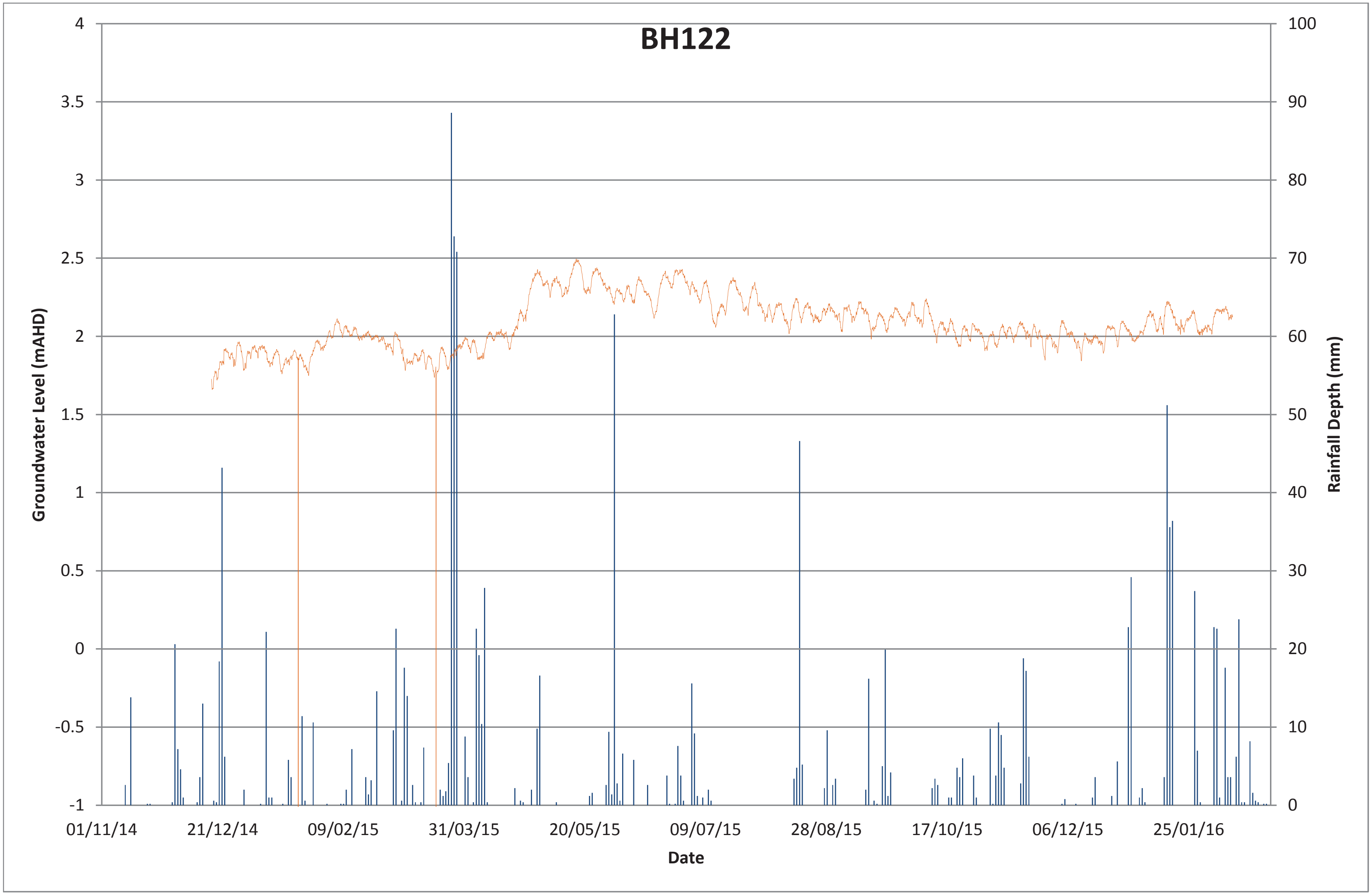

BH094
Groundwater Level (mAHD)
30
29.5
29
28.5
28
27.5
27
26.5
26
25.5
25
Rainfall Depth (mm)
100
90
80
70
60
50
40
30
20
10
0
01/11/14
21/12/14
09/02/15
31/03/15
20/05/15
09/07/15
28/08/15
17/10/15
06/12/15
25/01/16
Date

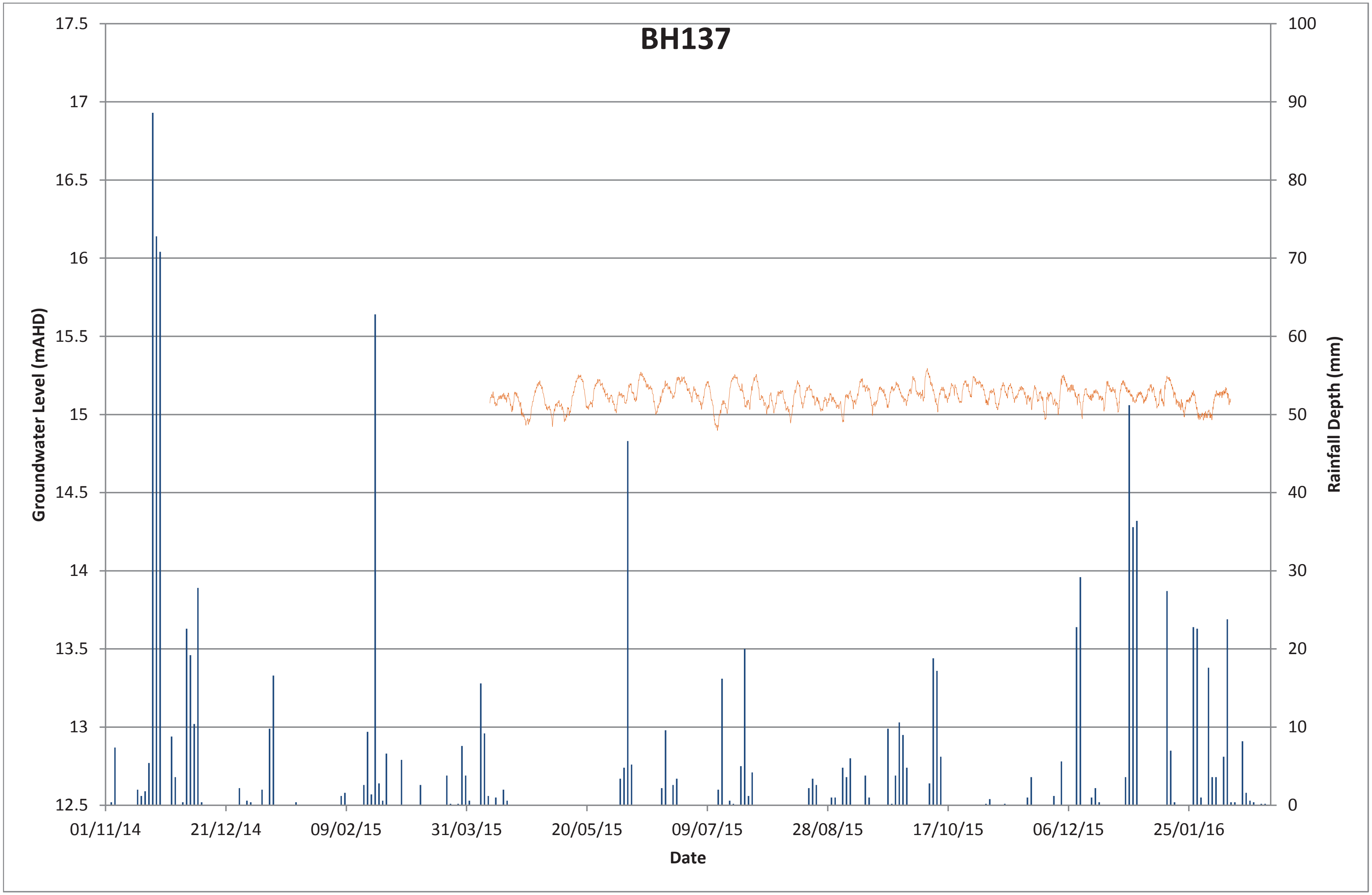

BH103
Groundwater Level (mAHD)
Rainfall Depth (mm)
Date
7
6.5
6
5.5
5
4.5
4
3.5
3
2.5
2
100
90
80
70
60
50
40
30
20
10
0
01/11/14
21/12/14
09/02/15
31/03/15
20/05/15
09/07/15
28/08/15
17/10/15
06/12/15
25/01/16

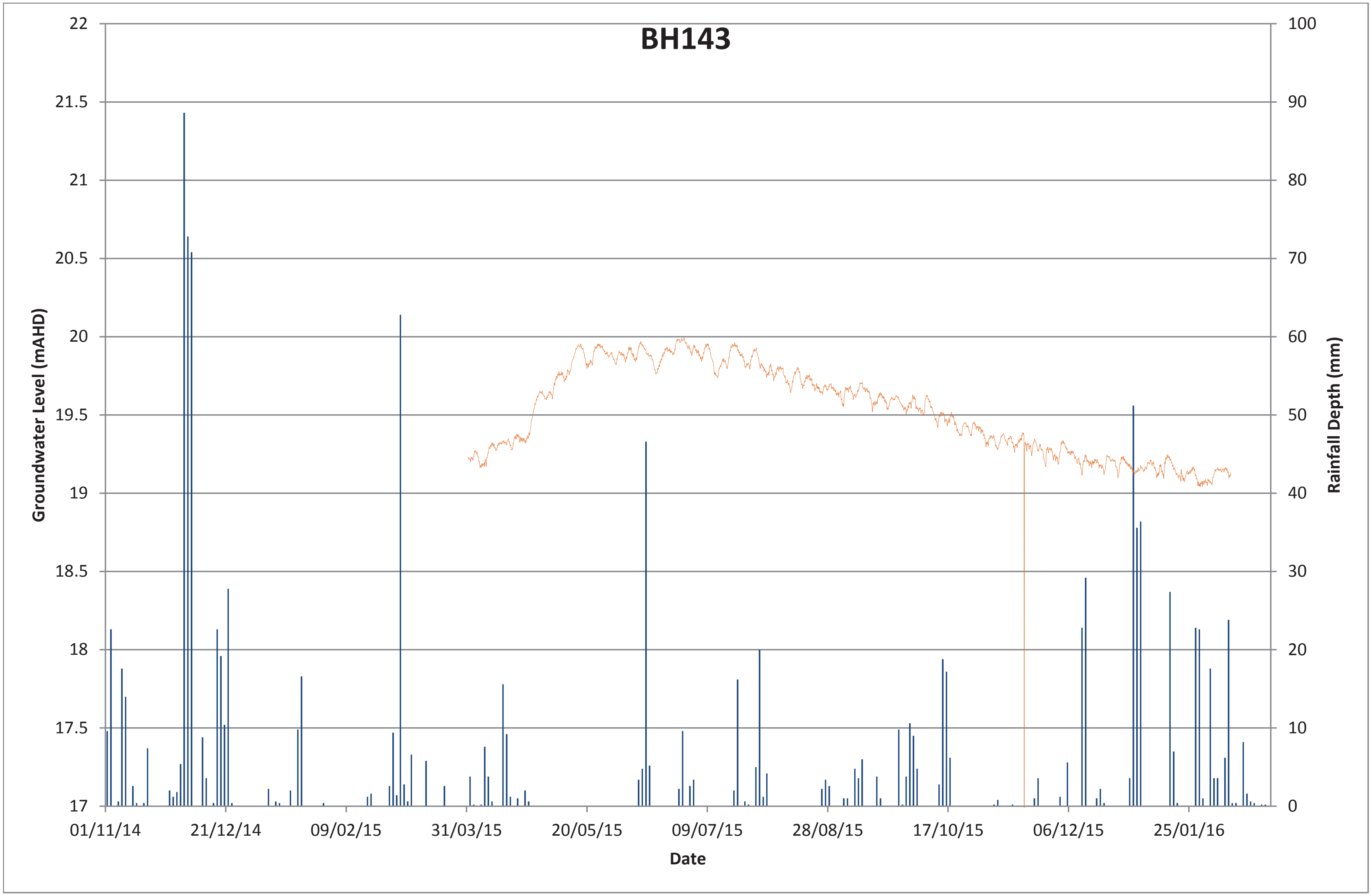

BH109
Groundwater Level (mAHD)
Rainfall Depth (mm)
Date
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
-3
100
90
80
70
60
50
40
30
20
10
0
01/11/14
21/12/14
09/02/15
31/03/15
20/05/15
09/07/15
28/08/15
17/10/15
06/12/15
25/01/16

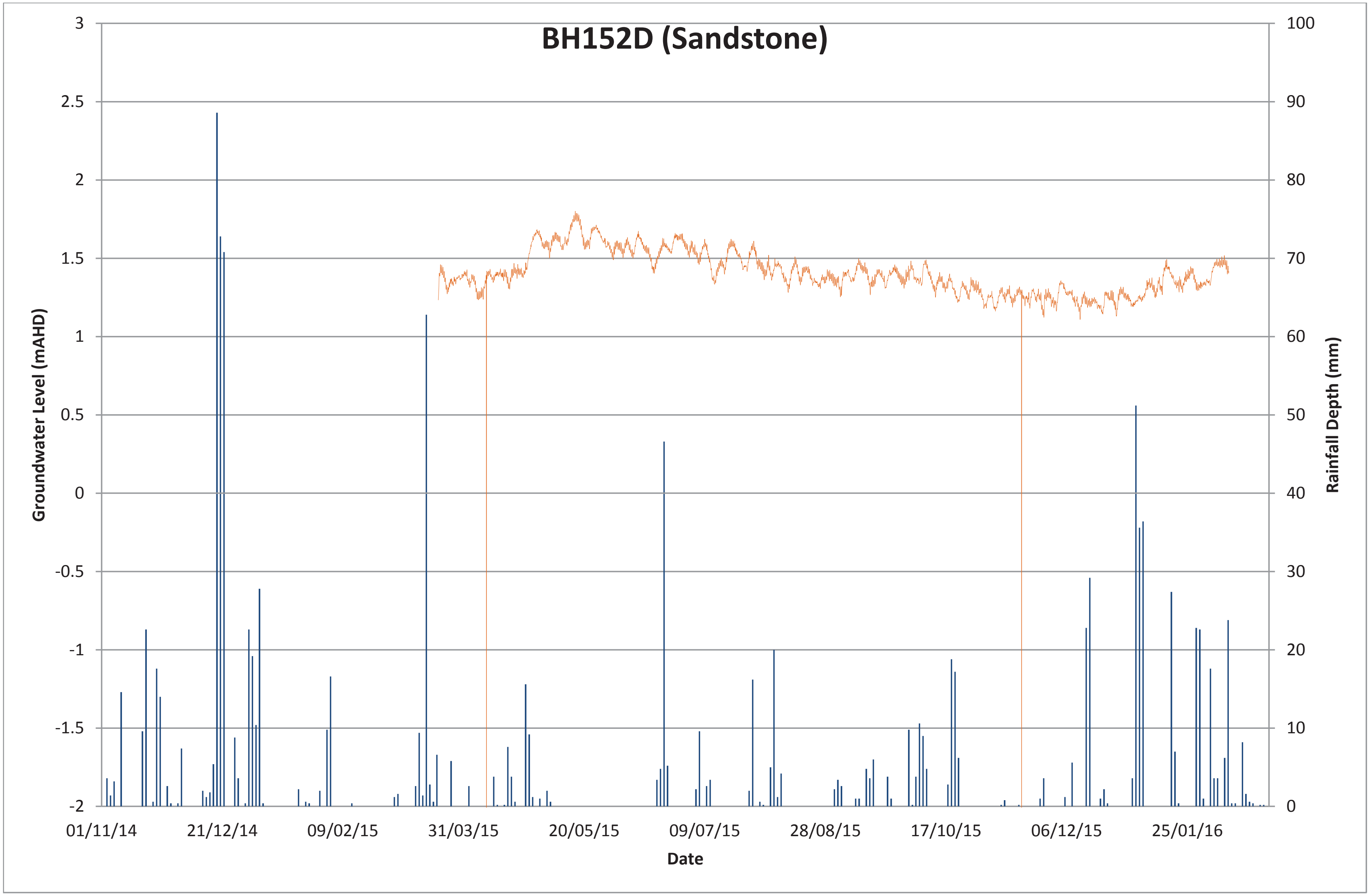


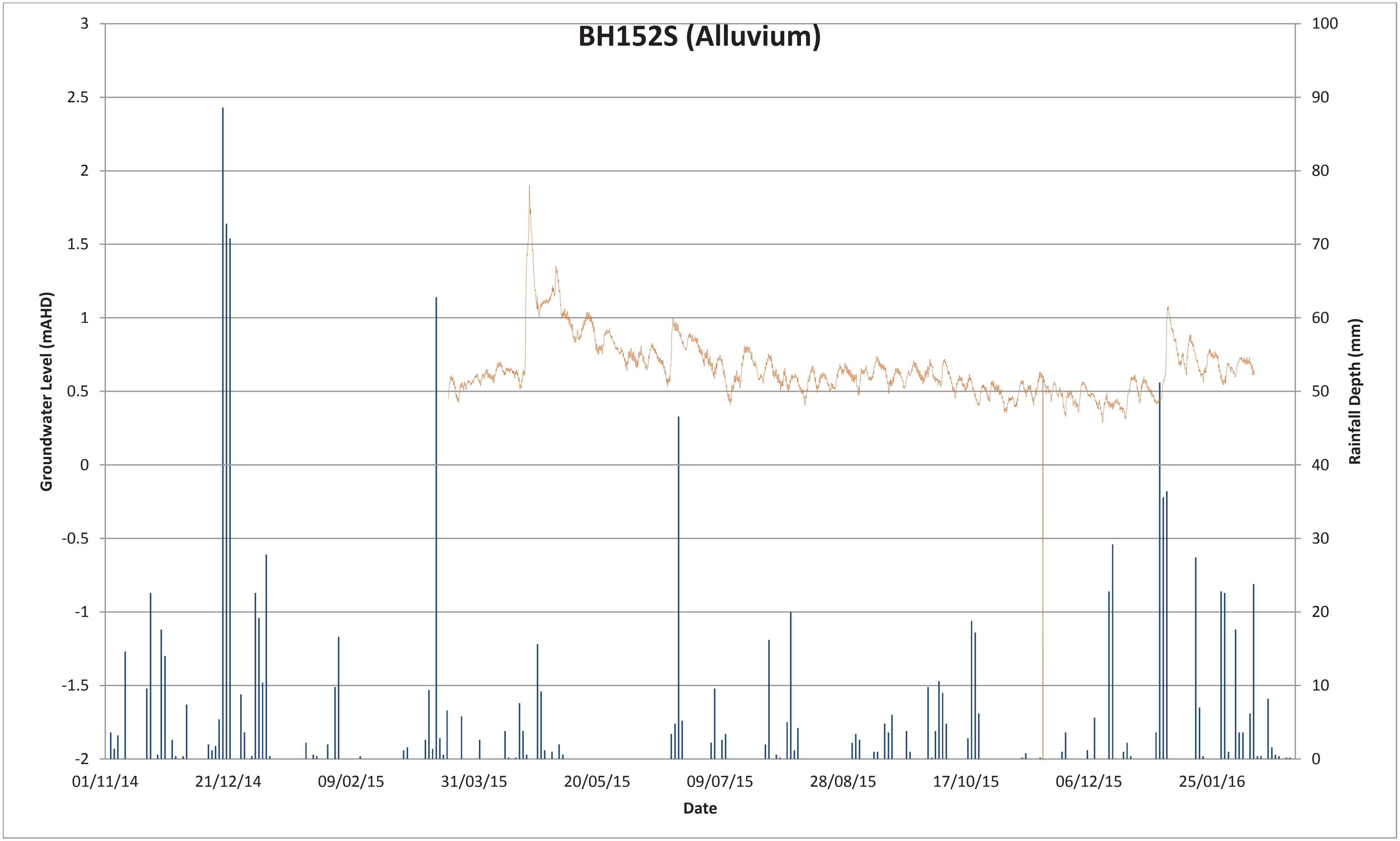
BH115
Groundwater Level (mAHD)
Rainfall Depth (mm)
Date
7
6.5
6
5.5
5
4.5
4
3.5
3
2.5
2
100
90
80
70
60
50
40
30
20
10
0
01/11/14
21/12/14
09/02/15
31/03/15
20/05/15
09/07/15
28/08/15
17/10/15
06/12/15
25/01/16


BH122
Groundwater Level (mAHD)
Rainfall Depth (mm)
Date
4
3.5
3
2.5
2
1.5
1
0.5
0
-0.5
-1
100
90
80
70
60
50
40
30
20
10
0
01/11/14
21/12/14
09/02/15
31/03/15
20/05/15
09/07/15
28/08/15
17/10/15
06/12/15
25/01/16

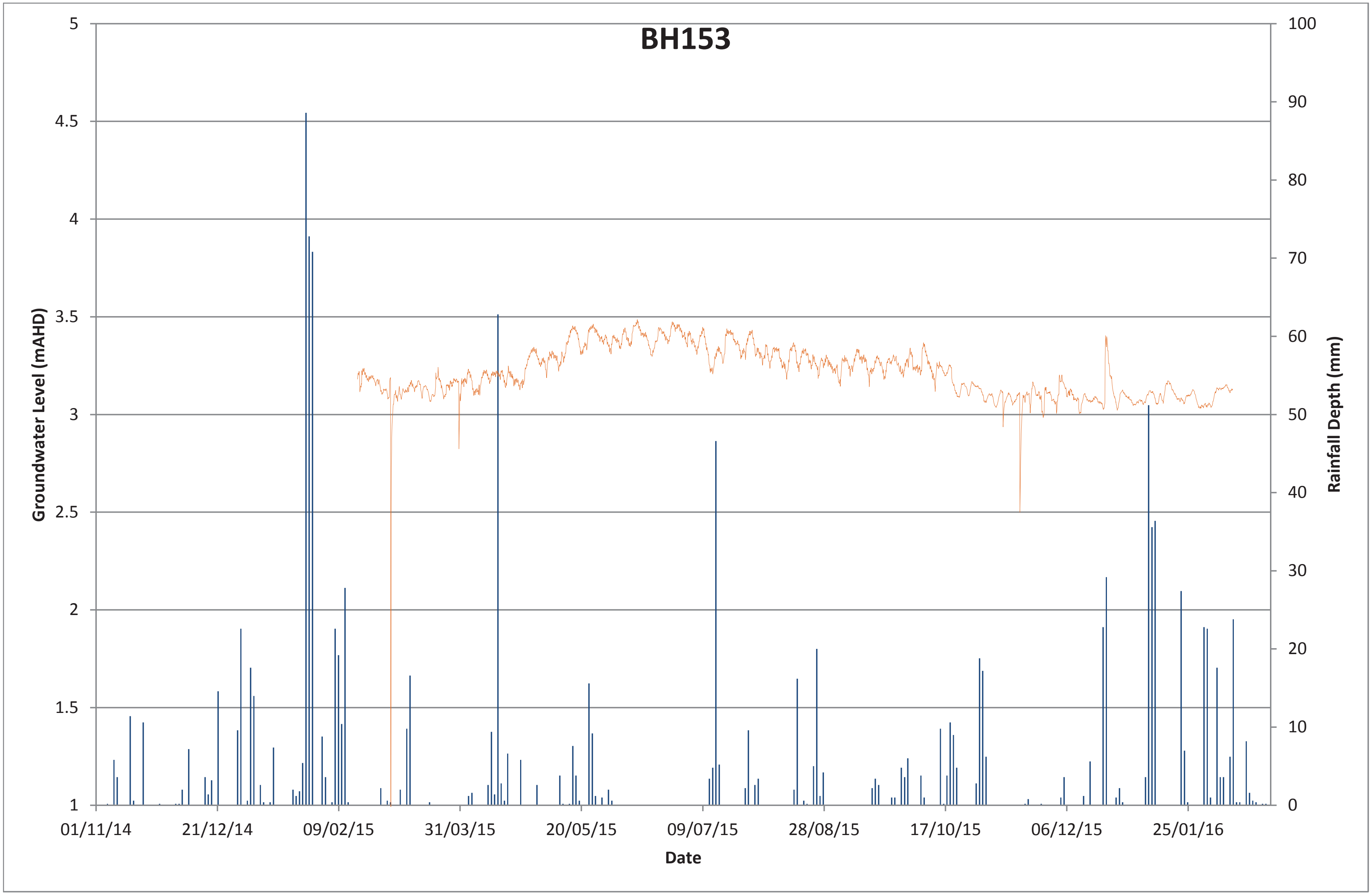

BH137
Groundwater Level (mAHD)
Rainfall Depth (mm)
Date
17.5
17
16.5
16
15.5
15
14.5
14
13.5
13
12.5
100
90
80
70
60
50
40
30
20
10
0
01/11/14
21/12/14
09/02/15
31/03/15
20/05/15
09/07/15
28/08/15
17/10/15
06/12/15
25/01/16

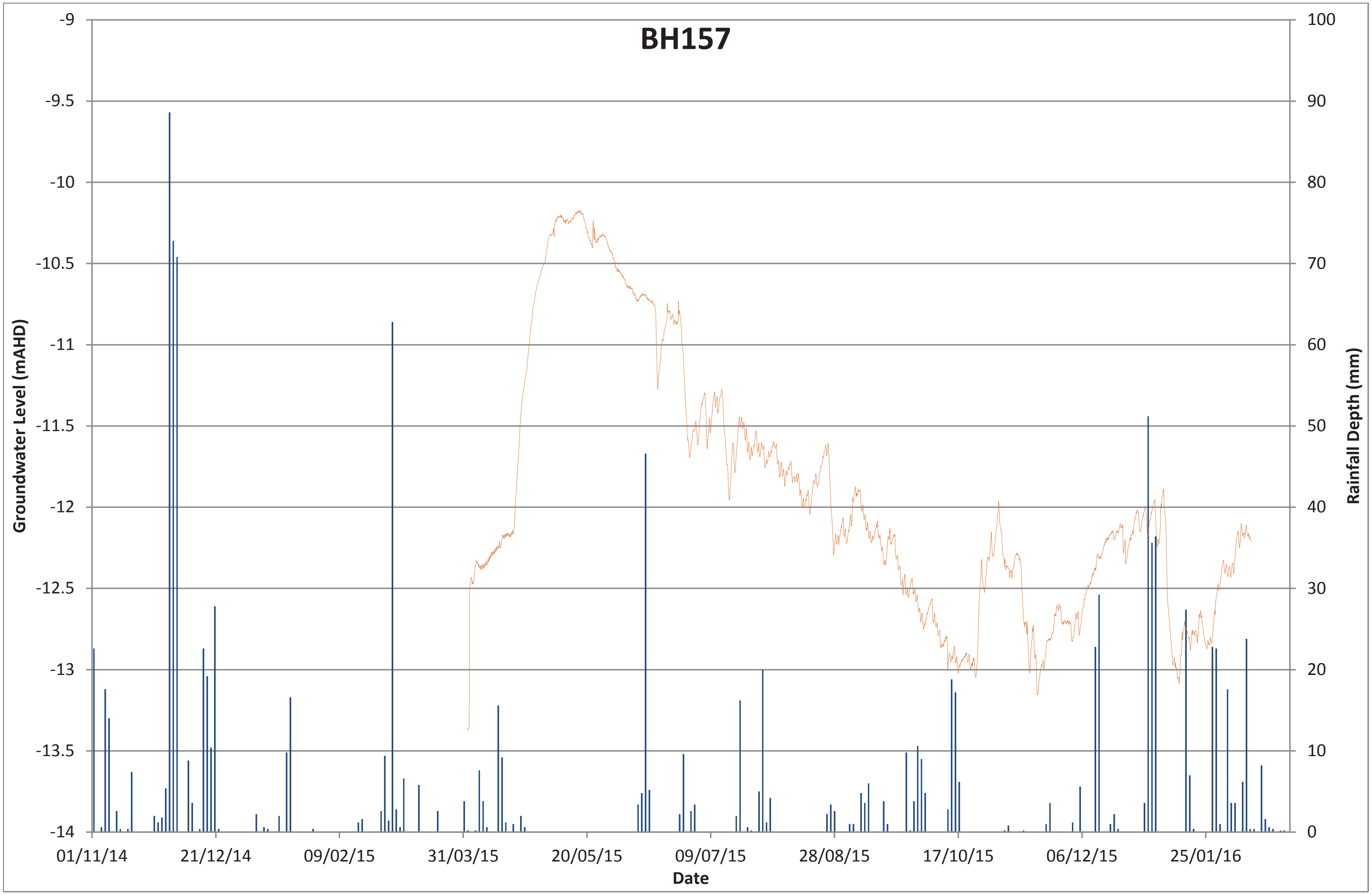

BH143
Groundwater Level (mAHD)
Rainfall Depth (mm)
Date
22
21.5
21
20.5
20
19.5
19
18.5
18
17.5
17
100
90
80
70
60
50
40
30
20
10
0
01/11/14
21/12/14
09/02/15
31/03/15
20/05/15
09/07/15
28/08/15
17/10/15
06/12/15
25/01/16


BH152D (Sandstone)
Groundwater Level (mAHD)
Rainfall Depth (mm)
Date
3
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
100
90
80
70
60
50
40
30
20
10
0
01/11/14
21/12/14
09/02/15
31/03/15
20/05/15
09/07/15
28/08/15
17/10/15
06/12/15
25/01/16

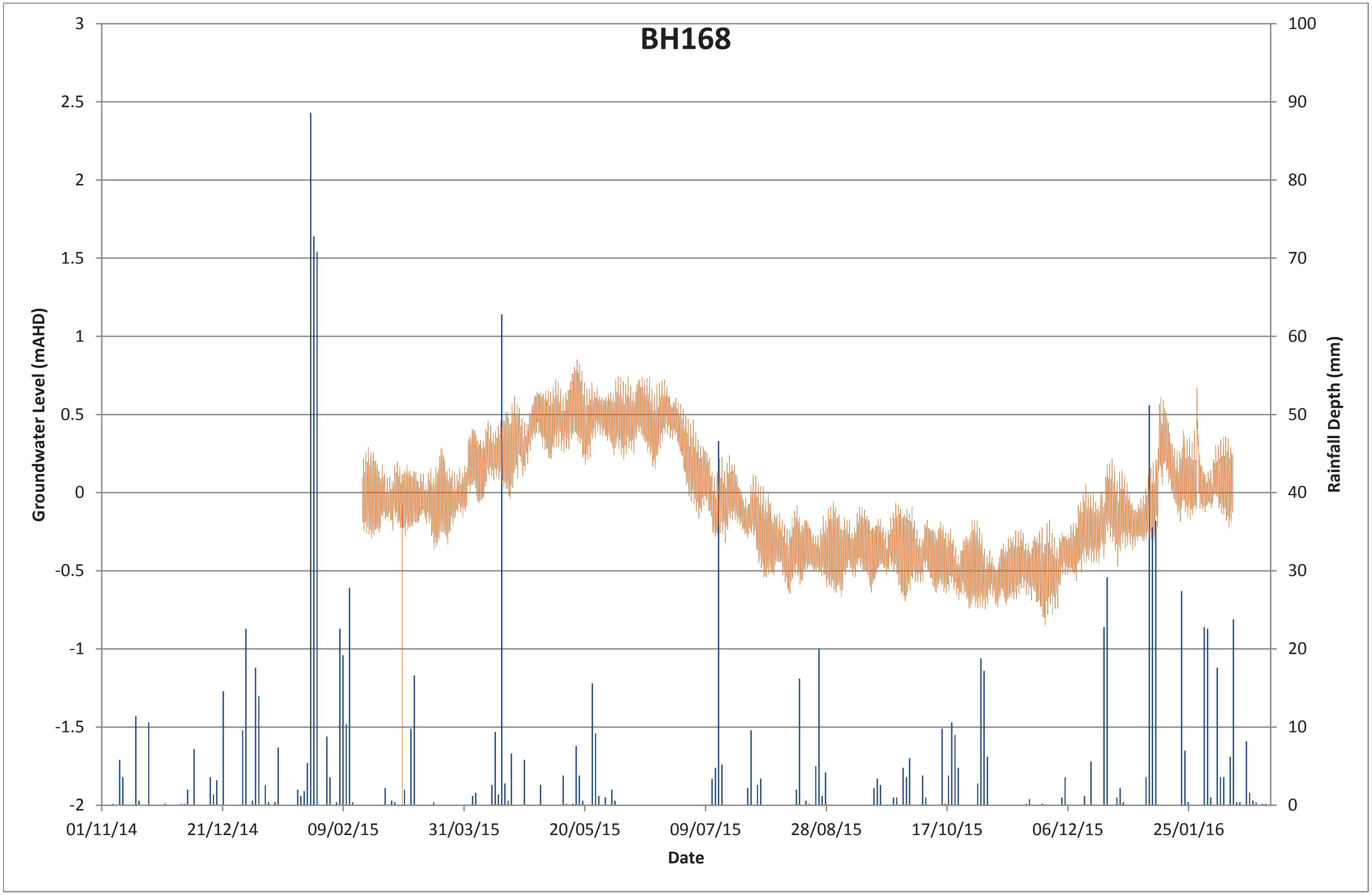


BH152S (Alluvium)
Groundwater Level (mAHD)
Rainfall Depth (mm)
Date
3
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
100
90
80
70
60
50
40
30
20
10
0
01/11/14
21/12/14
09/02/15
31/03/15
20/05/15
09/07/15
28/08/15
17/10/15
06/12/15
25/01/16

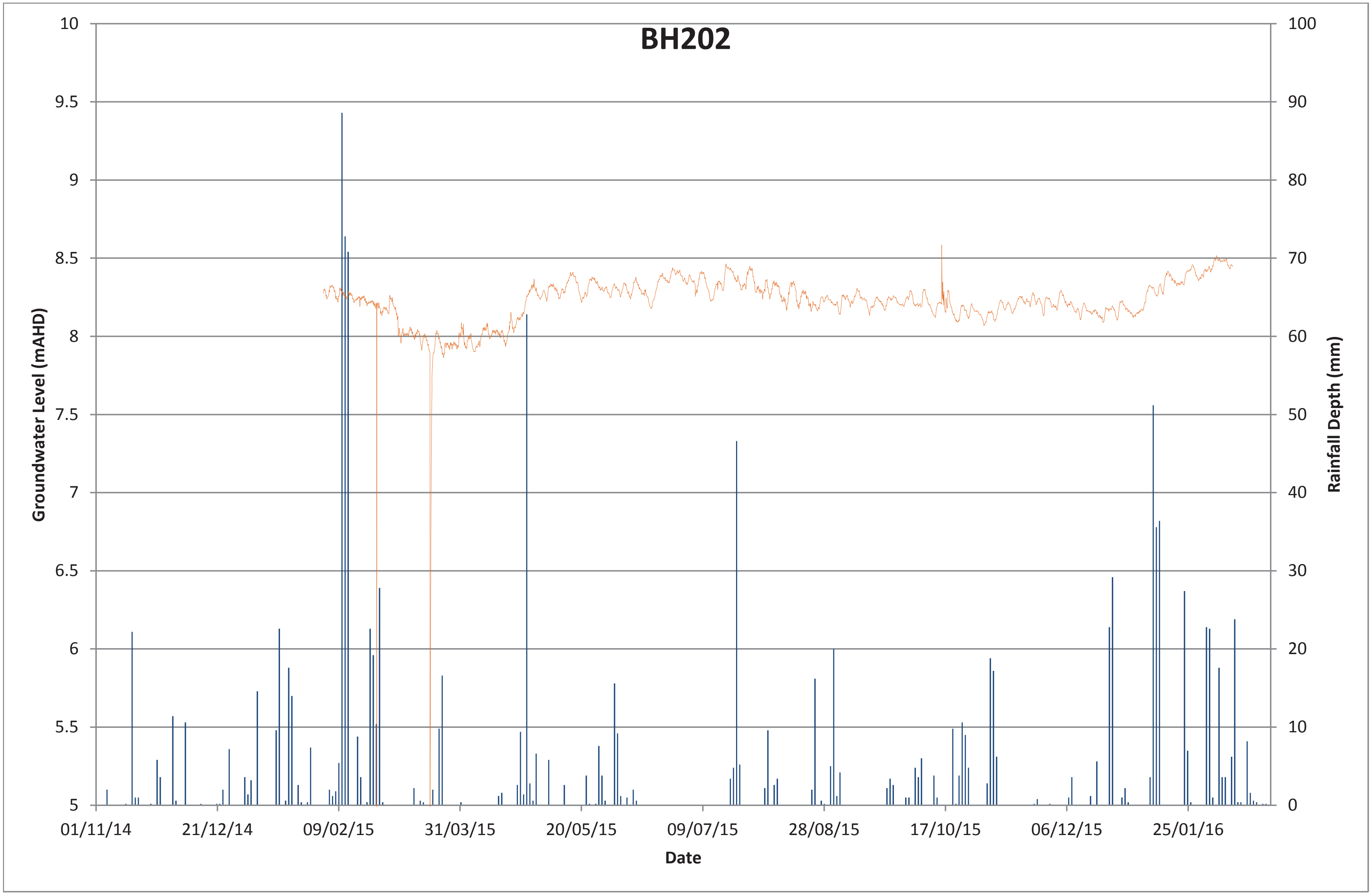

BH153
Groundwater Level (mAHD)
Rainfall Depth (mm)
Date
5
4.5
4
3.5
3
2.5
2
1.5
1
100
90
80
70
60
50
40
30
20
10
0
01/11/14
21/12/14
09/02/15
31/03/15
20/05/15
09/07/15
28/08/15
17/10/15
06/12/15
25/01/16

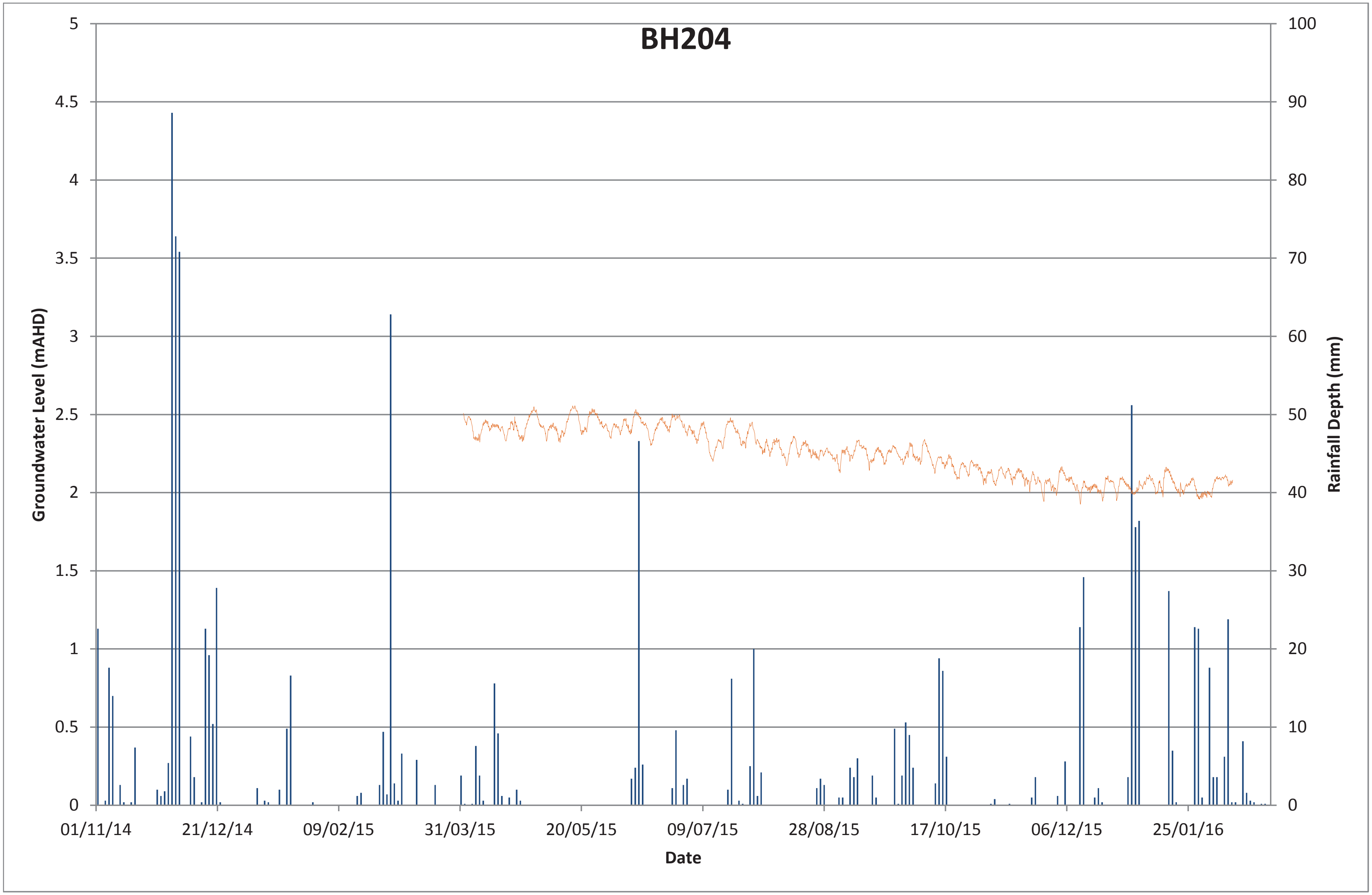


BH157
Groundwater Level (mAHD)
-9
-9.5
-10
-10.5
-11
-11.5
-12
-12.5
-13
-13.5
-14
Rainfall Depth (mm)
100
90
80
70
60
50
40
30
20
10
0
01/11/14
21/12/14
09/02/15
31/03/15
20/05/15
09/07/15
28/08/15
17/10/15
06/12/15
25/01/16
Date

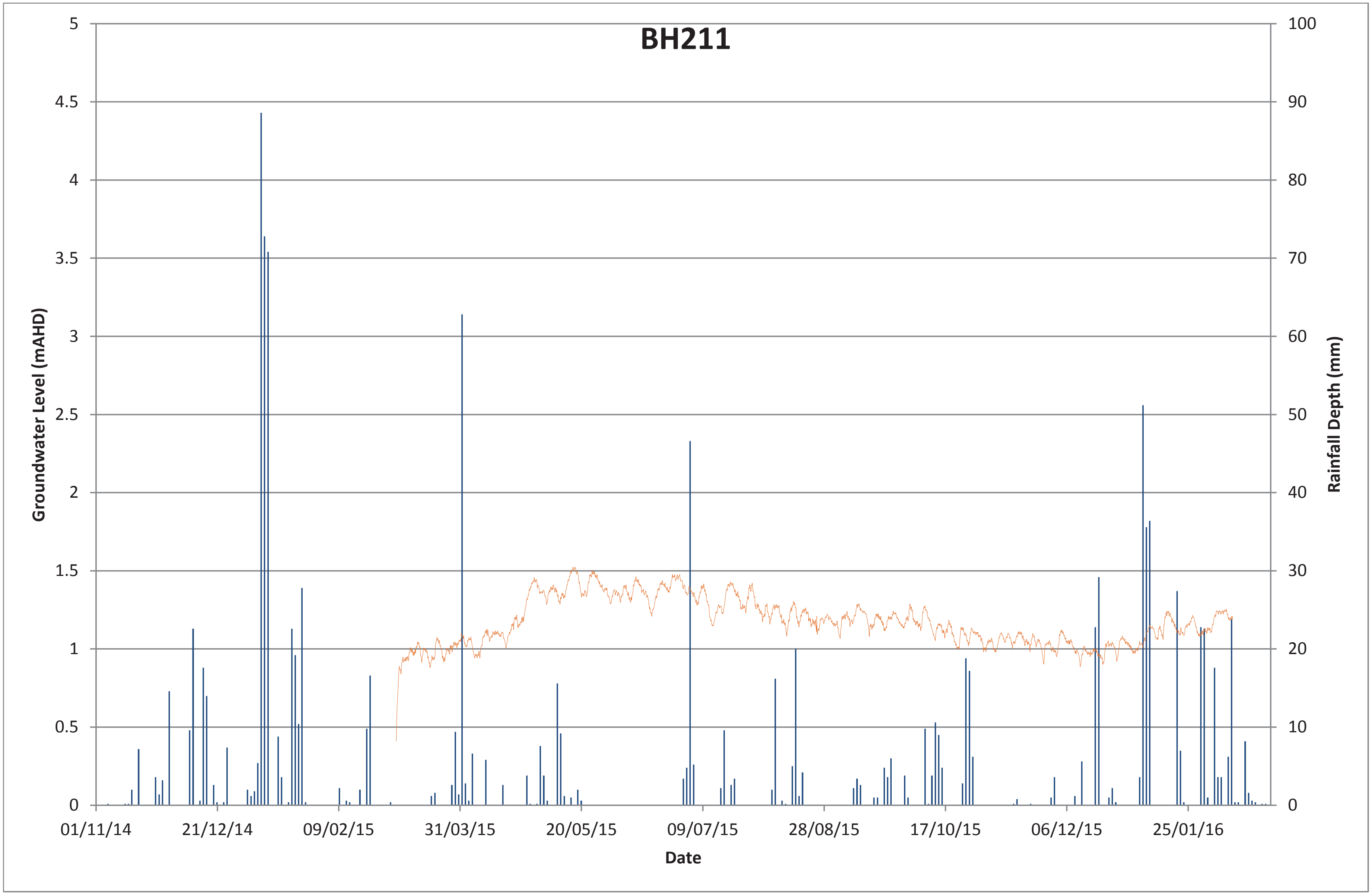


BH168
Groundwater Level (mAHD)
Rainfall Depth (mm)
Date
3
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
100
90
80
70
60
50
40
30
20
10
0
01/11/14
21/12/14
09/02/15
31/03/15
20/05/15
09/07/15
28/08/15
17/10/15
06/12/15
25/01/16


BH202
Groundwater Level (mAHD)
Rainfall Depth (mm)
Date
10
9.5
9
8.5
8
7.5
7
6.5
6
5.5
5
100
90
80
70
60
50
40
30
20
10
0
01/11/14
21/12/14
09/02/15
31/03/15
20/05/15
09/07/15
28/08/15
17/10/15
06/12/15
25/01/16



BH204
Groundwater Level (mAHD)
Rainfall Depth (mm)
Date
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
0
10
20
30
40
50
60
70
80
90
100
01/11/14
21/12/14
09/02/15
31/03/15
20/05/15
09/07/15
28/08/15
17/10/15
06/12/15
25/01/16


BH211
Groundwater Level (mAHD)
Rainfall Depth (mm)
Date
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
100
90
80
70
60
50
40
30
20
10
0
01/11/14
21/12/14
09/02/15
31/03/15
20/05/15
09/07/15
28/08/15
17/10/15
06/12/15
25/01/16

Annexure H – Assessment of Tidal Influence

Tidal influence

Tidal data was obtained from BoM (2016) for maximum and minimum tides for January and February 2016. This data was compared to groundwater response in the bores where tidal fluctuation was observed. The effect of tidal changes results in pressure loading effects in the confined aquifers where the transmission of pressure is usually instantaneous. With the distance from the coast the pressure fluctuations will be reduced in amplitude from the ocean tides.

The impact of tides has been observed in most bores located near the watercourses along the tunnel alignment. The strongest response to tides is observed in two bores next to Cooks River WCX--BH--040 and WCX--BH--042 installed in Hawkesbury Sandstone (although WCX-BH-042 was reported as being installed in Basalt, this is likely to be an error in data input) and one close to Wolli Creek installed in Hawkesbury Sandstone (WCX--BH--168). These bores show consistently strong fluctuations in the range from 0.14m to 0.5 m, compared to other bores where fluctuations are below 0.1 m, and generally in the 0.02 to 0.04 m range. For comparison the range of tidal fluctuations is up to around 1.3m. Piezometer pair WCX-BH-152a installed in alluvium and WCX-BH-152s in Hawkesbury sandstone close to the Cooks River show similar range of response to tidal fluctuations (0.05m) with response only slightly damped in WCX-BH-152a. WCX-BH-088 located about 3 km inland from Cooks River but close to Wolli Creek and installed in Hawkesbury sandstone also shows similar response to tidal fluctuations (0.045m). Similarity in response between the alluvium and sandstone in the vicinity of Cooks River points to similar storage properties of both hydraulic units.

Tidal efficiency was estimated by simple comparison of change in groundwater head fluctuation to change in tidal fluctuation. Based on the groundwater head response to tides, the tidal efficiency was estimated in the range from 0.09 (WCXBH40 and WCXBH042) to 0.28 (WCXBH0168). Tidal efficiency for other bores with minor groundwater head fluctuation is 0.006 to 0.007, and is a reflection of distance from the creeks or other tidal water bodies.

VWPs installed within the Arncliffe area allowed the estimation of influence of ocean tides on groundwater heads at several depths where the sensors are installed. LDS-BH-2033 located less than 400 m west of the coast has sensors installed in shallow and deep alluvium and Hawkesbury sandstone. Hawkesbury Sandstone is confined with head about 0.2 m above alluvium. Hydrograph superimposed by tides shows that all sensors respond to tide with a shift in phase observed in all units. The amplitude of response is 0.1 m for Hawkesbury sandstone and less than 0.04 m in alluvium. Smaller amplitude of tidal response in alluvium is due to higher specific storage of this hydrostratigraphic unit.

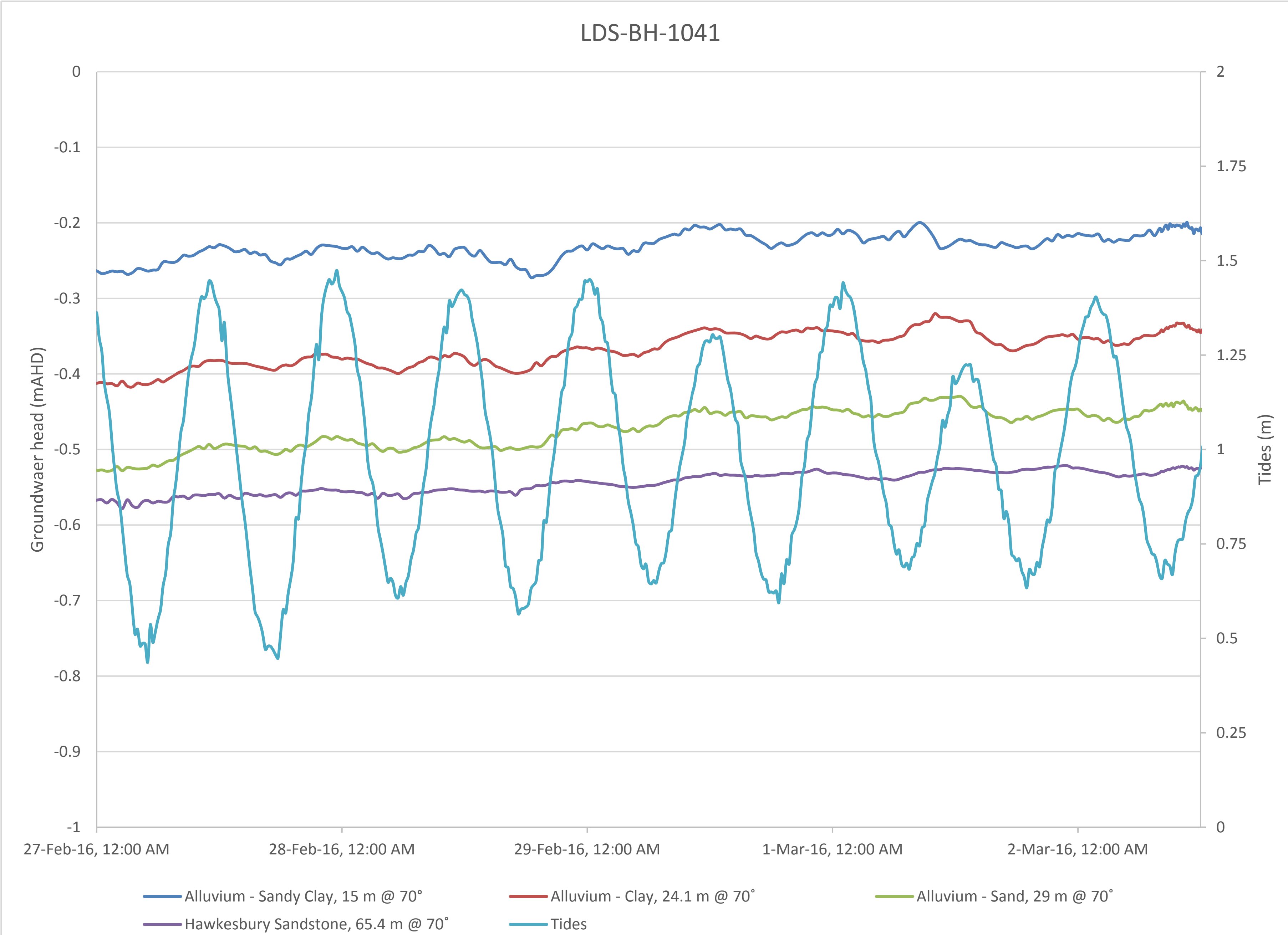
LDS-BH-2007B located about 650 m west of the coast indicates deep alluvium is confined with head about 0.25m above the shallow alluvium. The hydrograph for the four sensors at this location (two in alluvium and two in sandstone) indicates good hydraulic connection between the units. Barometric pressure influence on heads overshadows the tidal influence, however tidal influence is observed with a shift in phase. The maximum tidal amplitude in groundwater data is less than 0.02 m. LDS-BH2007A is about 150 m from the coast (installed in alluvium) with its hydrograph influenced by tides and resulting groundwater fluctuations around 0.05 m.

LDS-BH-1054 is located about 370 m west of the coast is equipped with four sensors; two in alluvium and two in sandstone. Hawkesbury Sandstone is pressurised, with vertical head gradient in upper sandstone about 0.5 m that of alluvium, and lower sandstone with 2m head above the alluvium. Instantaneous groundwater response to tides is observed in all units, however barometric pressure and other noise can be seen in the hydrographs of the upper three units.

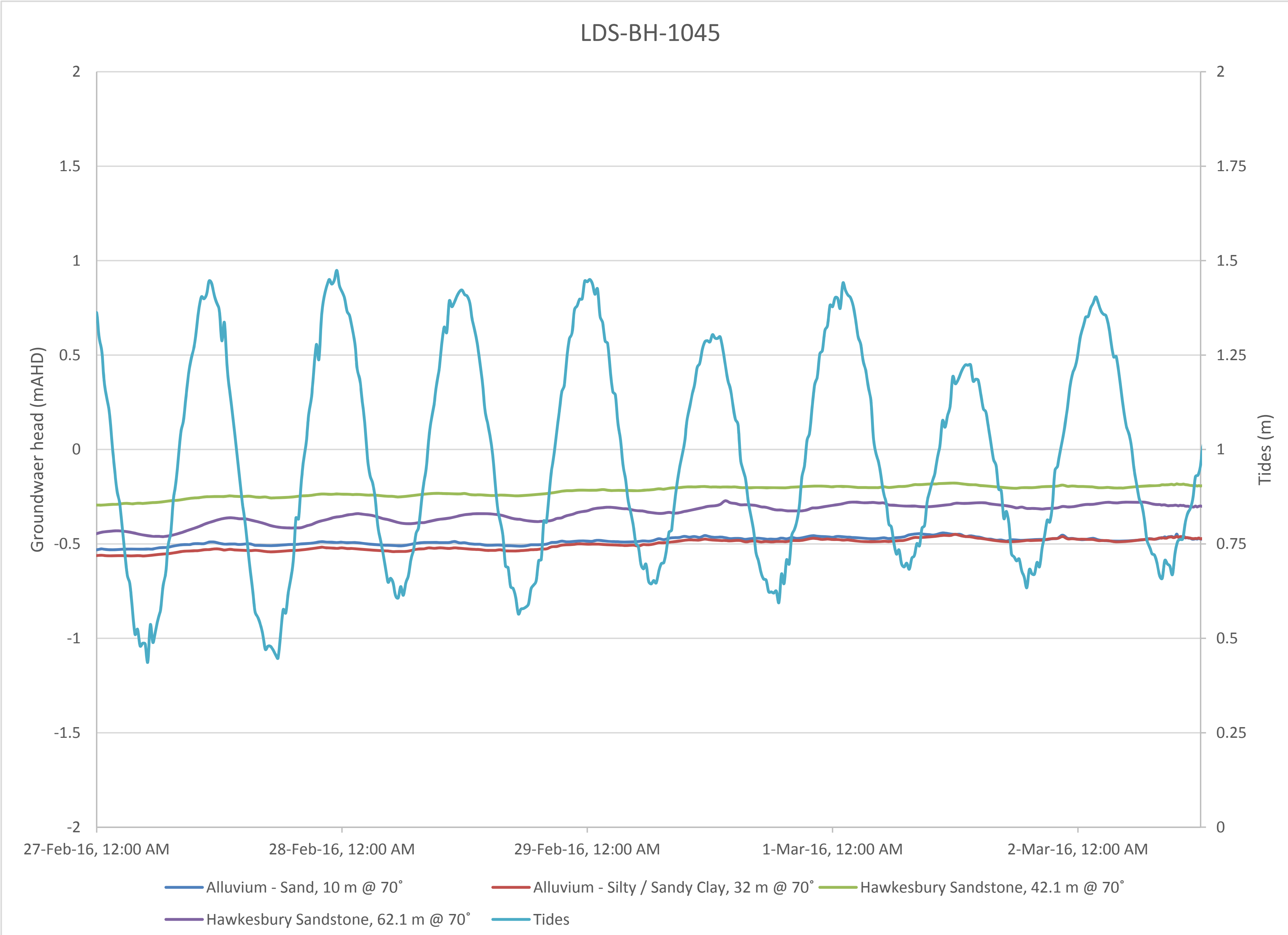
LDS-BH-1045 located about 350 m west of the coast has two sensors in alluvium and two in sandstone. Deep alluvium is pressurised with head about 0.5 m above shallow alluvium. Sandstone is confined with piezometric head about 0.8 m above shallow alluvium. Response to tide is instantaneous in lower sandstone with about 0.1m amplitude. In other units the response is opposite to tides with a rise in groundwater head when the tides are low. This is possibly due to either shift in phase or other atmospheric influences.

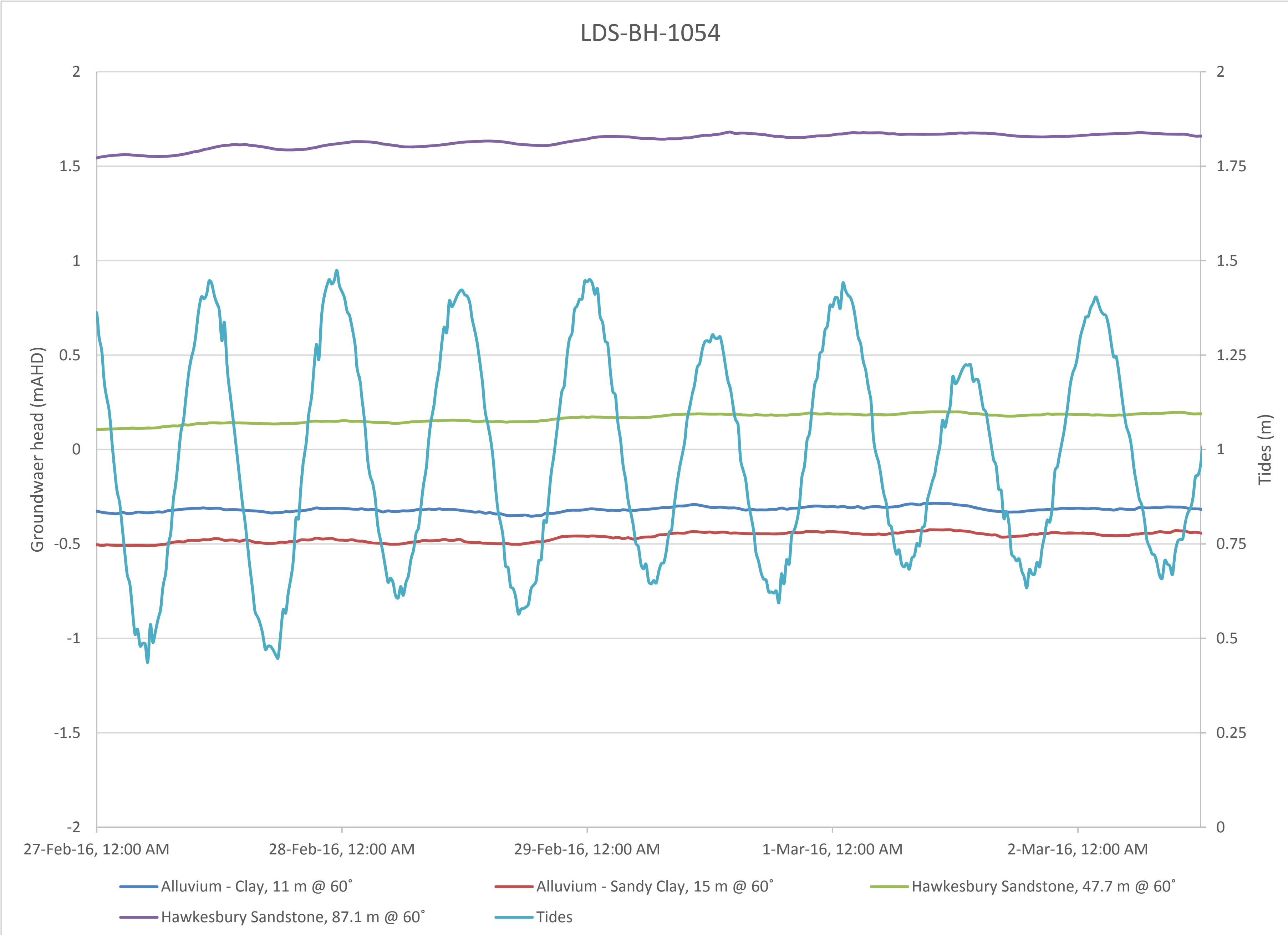
LDS-BH-1041 located about 400 m inland has three sensors in alluvium and one in sandstone. The hydrograph superimposed with tides shows the groundwater response is minor in the deepest unit. Although the response in hydrostratigraphic units is representative of semi-diurnal tidal behaviour, the response is not uniform, showing corresponding changes at the start of the observed time interval and opposite response at the later time. It is likely that atmospheric changes are the result of impact on heads at a later time.

At LDS-BH-2005 is located about 350 m inland, the response to tidal influence is evident in all three hydrographs for alluvium. A shift in phase is noted, this probably being the result of distance from the coast.

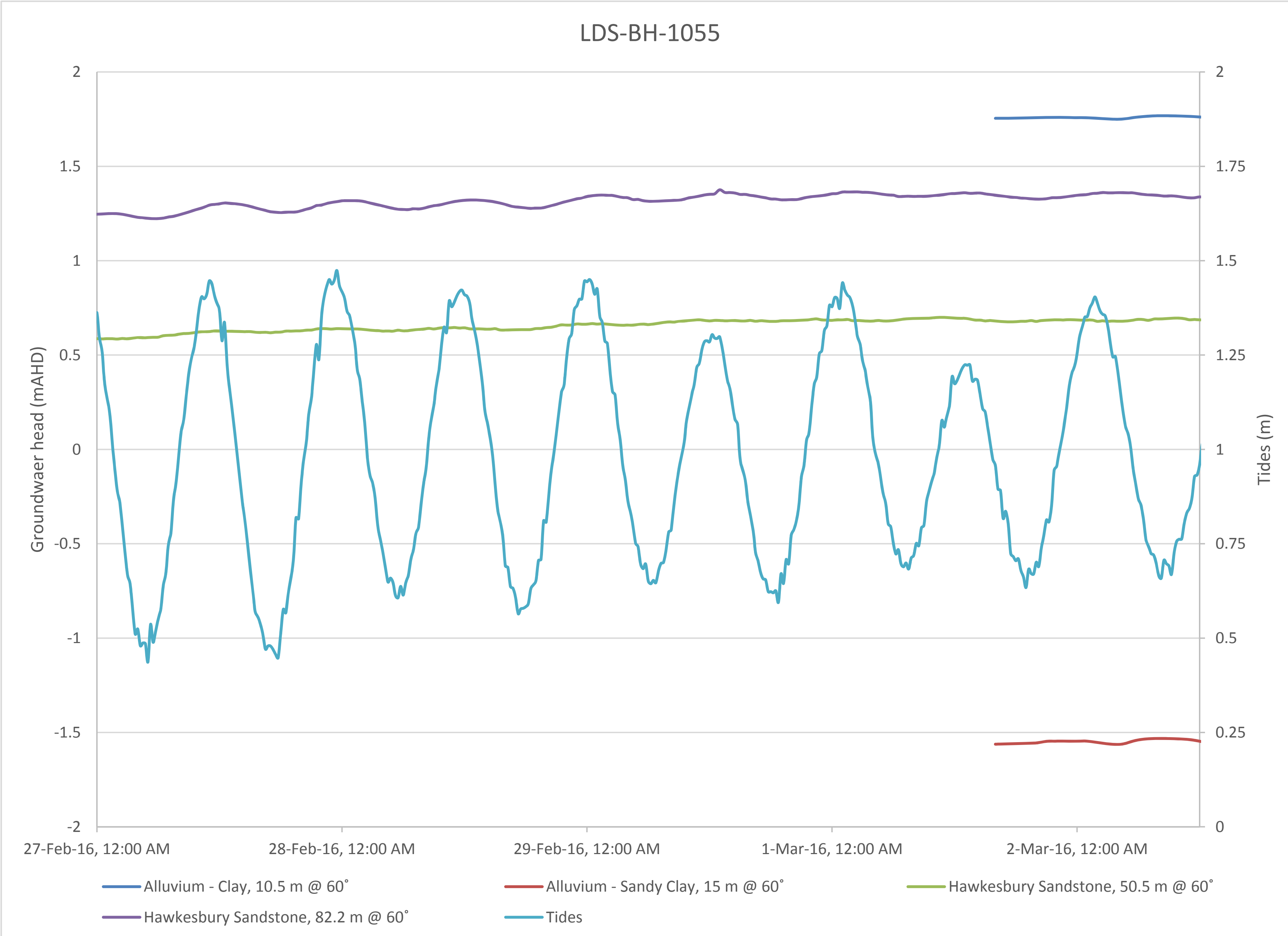


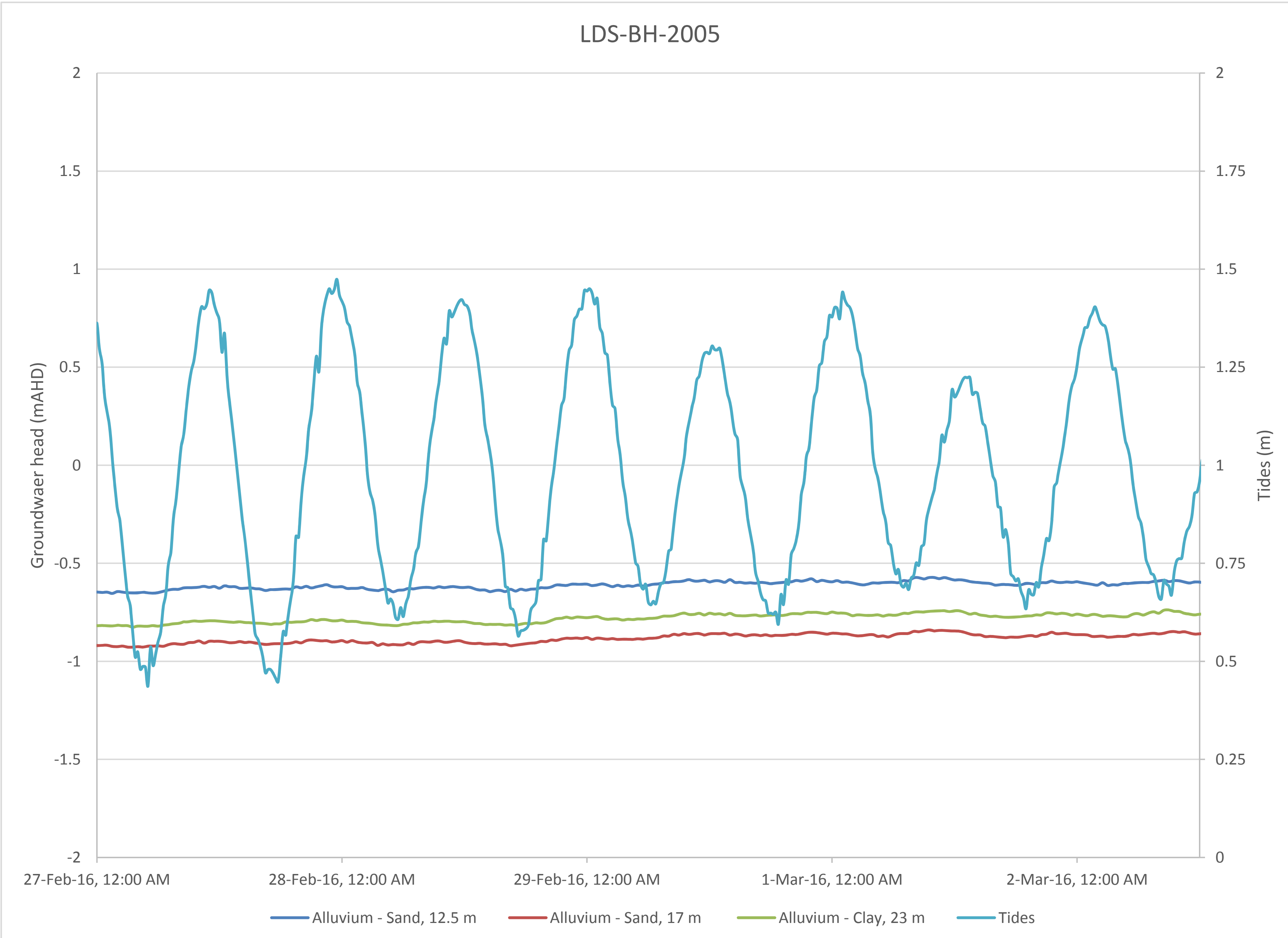
LDS-BH-1041
Groundwaer head (mAHD)
Tides (m)
0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.7
-0.8
-0.9
-1
2
1.75
1.5
1.25
1
0.75
0.5
0.25
0
27-Feb-16, 12:00 AM
28-Feb-16, 12:00 AM
29-Feb-16, 12:00 AM
1-Mar-16, 12:00 AM
2-Mar-16, 12:00 AM
Alluvium - Sandy Clay, 15 m @ 70°
Alluvium - Clay, 24.1 m @ 70˚
Alluvium - Sand, 29 m @ 70˚
Hawkesbury Sandstone, 65.4 m @ 70˚
Tides


LDS-BH-1045
Groundwaer head (mAHD)
Tides (m)
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
2
1.75
1.5
1.25
1
0.75
0.5
0.25
0
27-Feb-16, 12:00 AM
28-Feb-16, 12:00 AM
29-Feb-16, 12:00 AM
1-Mar-16, 12:00 AM
2-Mar-16, 12:00 AM
Alluvium - Sand, 10 m @ 70˚
Alluvium - Silty / Sandy Clay, 32 m @ 70˚
Hawkesbury Sandstone, 42.1 m @ 70˚
Hawkesbury Sandstone, 62.1 m @ 70˚
Tides

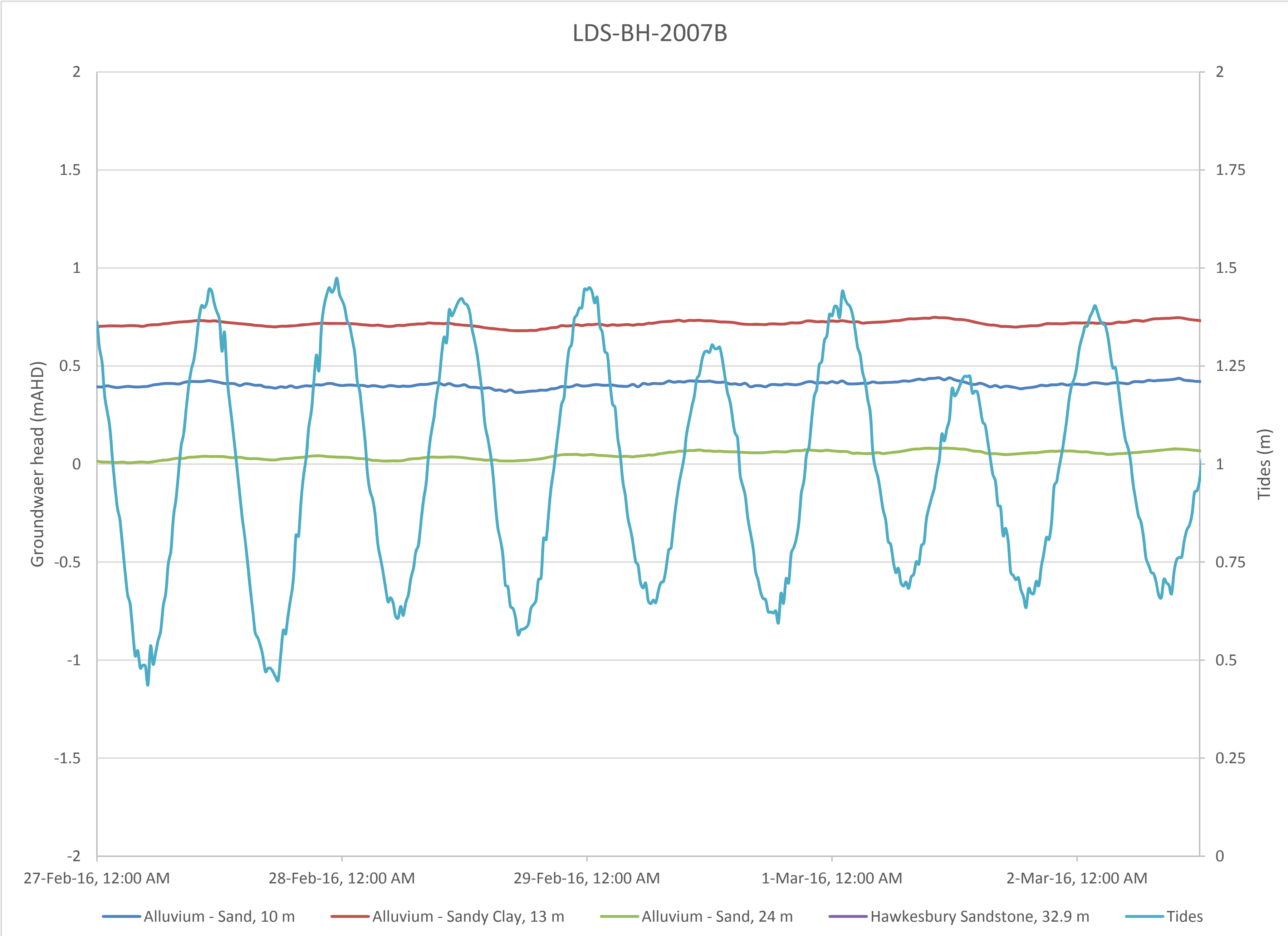


LDS-BH-1054
Groundwaer head (mAHD)
Tides (m)
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
2
1.75
1.5
1.25
1
0.75
0.5
0.25
0
27-Feb-16, 12:00 AM
28-Feb-16, 12:00 AM
29-Feb-16, 12:00 AM
1-Mar-16, 12:00 AM
2-Mar-16, 12:00 AM
Alluvium - Clay, 11 m @ 60˚
Alluvium - Sandy Clay, 15 m @ 60˚
Hawkesbury Sandstone, 47.7 m @ 60˚
Hawkesbury Sandstone, 87.1 m @ 60˚
Tides

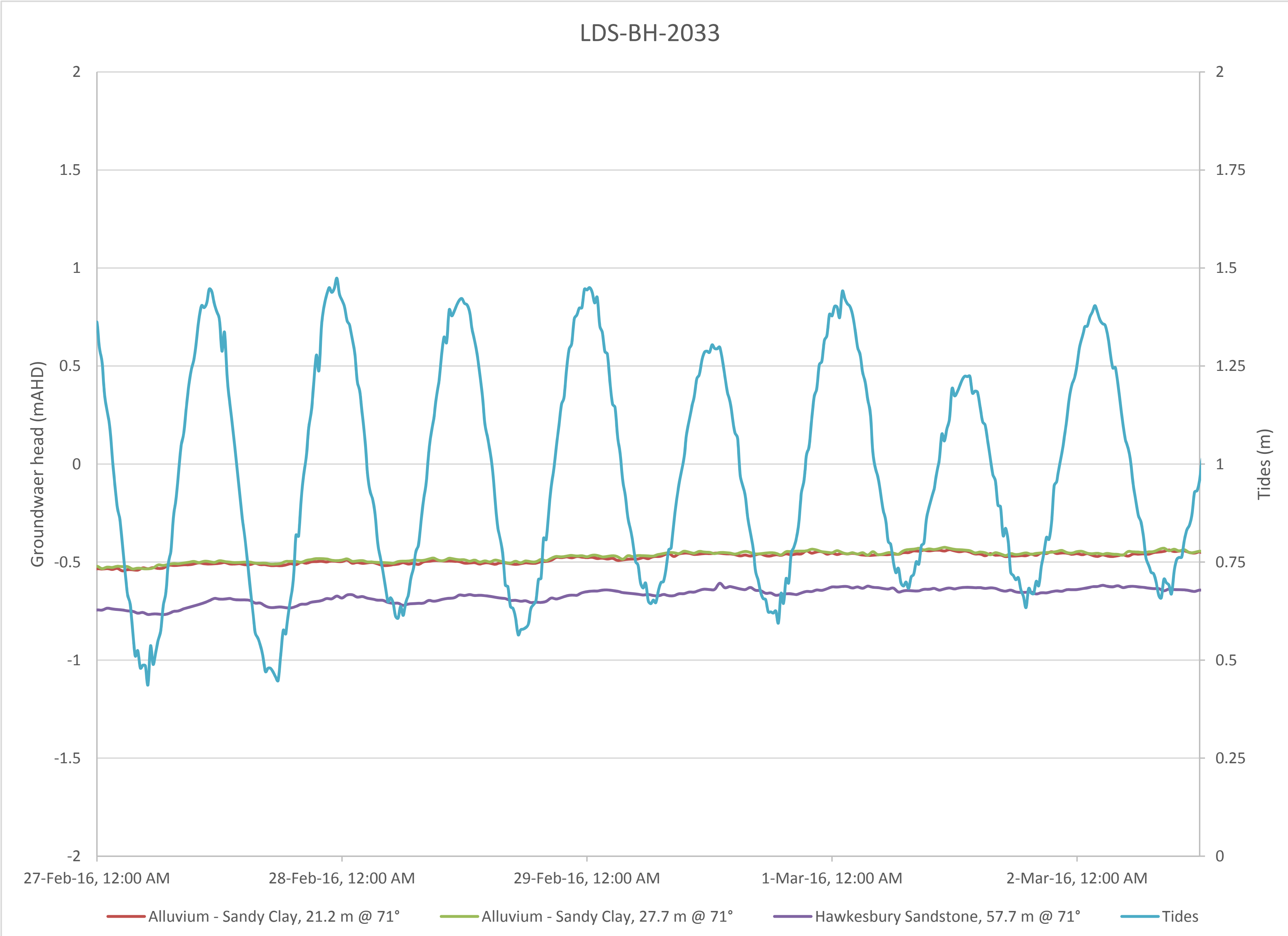

LDS-BH-1055
Groundwaer head (mAHD)
Tides (m)
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
2
1.75
1.5
1.25
1
0.75
0.5
0.25
0
27-Feb-16, 12:00 AM
28-Feb-16, 12:00 AM
29-Feb-16, 12:00 AM
1-Mar-16, 12:00 AM
2-Mar-16, 12:00 AM
Alluvium - Clay, 10.5 m @ 60˚
Alluvium - Sandy Clay, 15 m @ 60˚
Hawkesbury Sandstone, 50.5 m @ 60˚
Hawkesbury Sandstone, 82.2 m @ 60˚
Tides



LDS-BH-2005
Groundwaer head (mAHD)
Tides (m)
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
2
1.75
1.5
1.25
1
0.75
0.5
0.25
0
27-Feb-16, 12:00 AM
28-Feb-16, 12:00 AM
29-Feb-16, 12:00 AM
1-Mar-16, 12:00 AM
2-Mar-16, 12:00 AM
Alluvium - Sand, 12.5 m
Alluvium - Sand, 17 m
Alluvium - Clay, 23 m
Tides



LDS-BH-2007B
Groundwaer head (mAHD)
Tides (m)
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
2
1.75
1.5
1.25
1
0.75
0.5
0.25
0
27-Feb-16, 12:00 AM
28-Feb-16, 12:00 AM
29-Feb-16, 12:00 AM
1-Mar-16, 12:00 AM
2-Mar-16, 12:00 AM
Alluvium - Sand, 10 m
Alluvium - Sandy Clay, 13 m
Alluvium - Sand, 24 m
Hawkesbury Sandstone, 32.9 m
Tides



LDS-BH-2033
Groundwaer head (mAHD)
Tides (m)
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
2
1.75
1.5
1.25
1
0.75
0.5
0.25
0
27-Feb-16, 12:00 AM
28-Feb-16, 12:00 AM
29-Feb-16, 12:00 AM
1-Mar-16, 12:00 AM
2-Mar-16, 12:00 AM
Alluvium - Sandy Clay, 21.2 m @ 71°
Alluvium - Sandy Clay, 27.7 m @ 71°
Hawkesbury Sandstone, 57.7 m @ 71°
Tides

Annexure I – Assessment of recharge from rainfall response

Groundwater Recharge and Discharge

The impact rainfall on groundwater levels has been assessed based on one year of data from bores installed along the tunnel alignment (AECOM, 2015e). Hydrographs for these bores are included in Annexure G.

The groundwater levels in the vicinity of the shafts at Bexley are available from longer term measurements at monitoring bores WCX-BH-072 and WCX-BH-084. Both bores are screened in the Hawkesbury Sandstone at approximately RL -20 m AHD and located on south and north of the Cooks River dyke (extending through the Kingsgrove and southern part of Arncliffe area), respectively. There is about 8m head difference between the two hydrographs however they show similar groundwater response following long term periods without significant recharge. These periods are characterised by limited groundwater discharge on both sides of the dyke, possibly resulting from Wolli Creek recharge in particular in WCX-BH-072.

Bores installed in Hawkesbury sandstone at Kingsgrove and Bexley area generally respond quickly to rainfall recharge. This likely reflects the degree of fracturing of outcropping sandstone in this area. In some of the bores located close to Wolli Creek (WCX-BH-137, WCX-BH-088), the creek appears to be hydraulically connected with sandstone.

Within the Arncliffe and Cooks River area, the bores are mostly installed in Hawkesbury sandstone. These bores respond quickly to recharge events followed by slow dissipation of groundwater during lower rainfall periods. Close to Cooks River several bores indicate connectivity with Cooks River with limited groundwater discharge (WCX-BH40, WCX-BH42 and WCX-BH168).

Unusual groundwater fluctuation in the WCX-BH-063 (installed in Hawkesbury sandstone and located about 800m west of Cooks River) and drawdown of over 3m in August 2015 is not observed in the nearby WCX-BH61s (alluvium). However a similar response is observed in WCX-BH214 further south (close to Muddy Creek) in Hawkesbury sandstone. This reflects the absence of connection between the Hawkesbury sandstone and alluvium at this location and the absence of influence from the northeast-southwest extending fault zone.

In the Tempe and St Peter’s area the bores (AECOM, 2015e) are generally installed in shale or siltstone. These bores therefore typically show a delayed response to recharge and slow natural decline in potentiometric heads following the absence of rainfall events. A number of bores in this area (WCX-BH-115, WCX-BH-157), are influenced by other unknown recharge and discharge sources, unrelated to rainfall recharge. Hydrographs for paired piezometers WCX-BH-152 (alluvium and Hawkesbury sandstone) located close to Cooks River indicate good connectivity between the Hawkesbury sandstone and alluvium, with similar recharge-discharge events observed in both units.

Observations regarding groundwater response to rainfall at particular bores are summarised below.

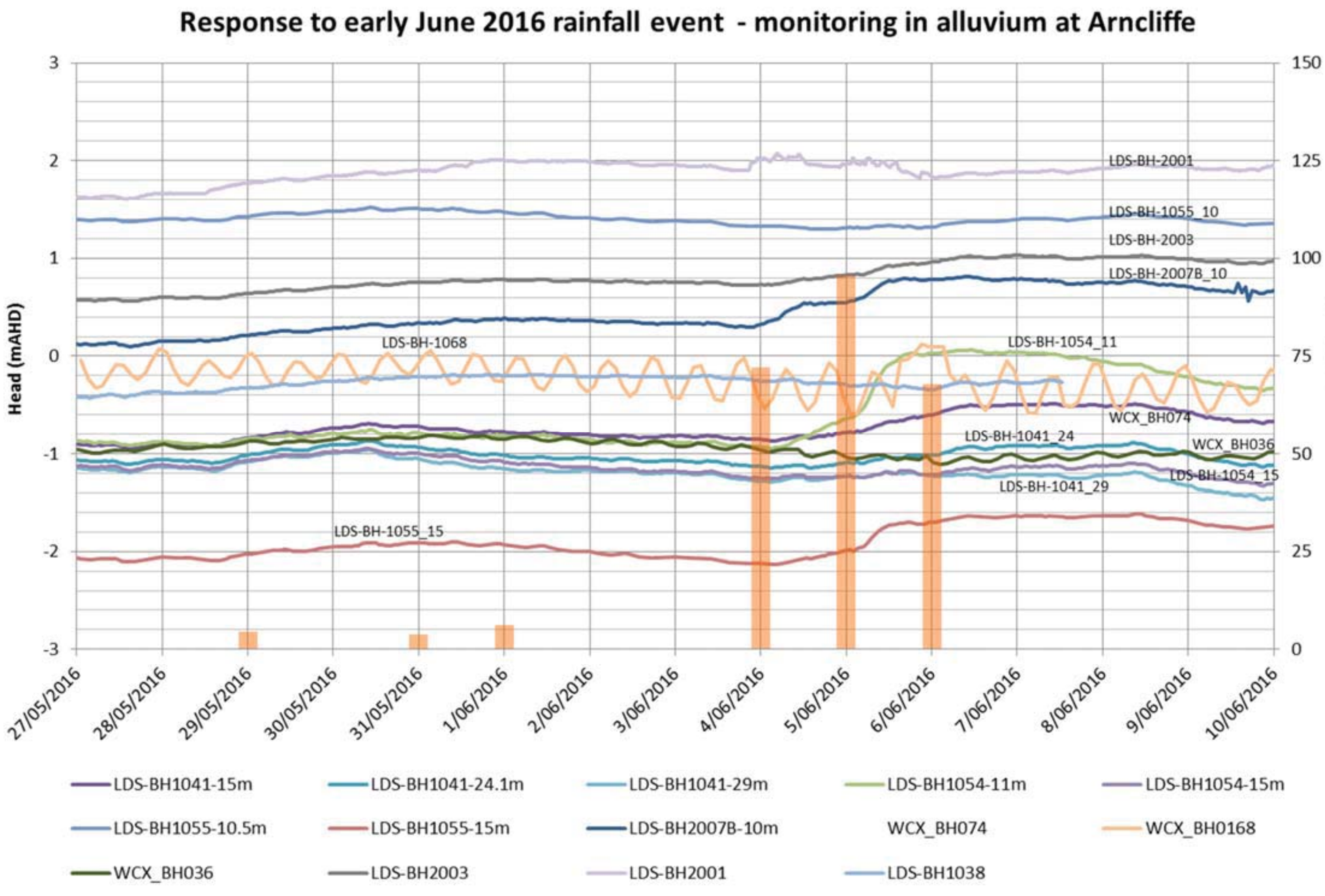
Table 1 - Summary of groundwater response to recharge and discharge

Borehole	Lithology	Screened interval	Comments
Kingsgrove and Bexley Western Areas			
WCX-BH-006	Hawkesbury Sandstone	22-25	Long term rainfall trend, but no direct response from rainfall, some other influences and delayed response on occasions.
WCX-BH-137	Hawkesbury Sandstone	54-57	Delayed response to recharge, no natural discharge possible recharge from Wolli creek
WCX-BH-036	Hawkesbury Sandstone	60-63	Delayed response to rainfall and quick natural groundwater dissipation.
WCX-BH-072	Hawkesbury Sandstone	28-31	Quick recharge response, no natural decline following absence of rain, possible recharge from Wolli Creek.
WCX-BH-084	Hawkesbury Sandstone	47.5-50.5	Quick recharge response but not consistent, slow discharge probably resulting from recharge from other sources.
WCX-BH-088	Hawkesbury Sandstone	41-44	Bore responds well to rainfall recharge, slow natural groundwater recession following the absence of rain, possible recharge from Wolli Creek.
WCX-BH-018	Hawkesbury Sandstone	51-54	Fluctuations not related to rainfall, change under other influences, possibly incorrect datalogger reading.
WCX-BH-024	Hawkesbury Sandstone	26-29	Quick response to recharge, relatively quick dissipation of water levels in the absence of rainfall.
WCX-BH-143	Hawkesbury Sandstone	82-85	Delayed possibly diffuse response to rainfall, very slow natural dissipation.
WCX-BH-093	Hawkesbury Sandstone	47-50	Significant (up to 5 m fluctuations), rainfall recharge quick but inconsistent, additional sources of recharge and discharge, slow natural discharge.
WCX-BH-094	Hawkesbury Sandstone	54-57	Around 2m head fluctuations, recharge and discharge events not directly related to rainfall, but possibly due to other sources.
WCX-BH-211	Hawkesbury Sandstone	45-48	Delayed response to recharge, natural slow groundwater

			dissipation with potential recharge and connectivity with the Muddy Creek.
WCX-BH-213	Hawkesbury Sandstone	29-32	Delay in rainfall response to recharge, slow natural dissipation.
Arncliffe and Cooks River			
WCX-BH-029	Hawkesbury Sandstone	33-36	Quick response to rainfall, natural slow dissipation of groundwater, similar response in WCX-BH143 located further west close to dyke, slow decline in pressure heads probably influenced by Cooks River dyke.
WCX-BH-039	Hawkesbury Sandstone	49-52	Delayed response to rainfall and natural groundwater recession, potential connectivity with Cooks River.
WCX-BH-070	Hawkesbury Sandstone	35-38	Delayed response to rainfall, natural groundwater discharge.
WCX-BH-063	Botany Sands	5.0-8.0	Fluctuations of up to 4m, not related to rainfall or tides, quick recharge and recovery, similar response in WCX-BH214 further south.
WCX-BH214	Hawkesbury Sandstone	32-35	Fluctuations of up to 2.5m, not related to rainfall or tides, quick recharge and recovery, similar response in WCX-BH063.
WCX-BH-040	Reported as basalt? Likely sandstone	65-68	Long term rainfall response, overshadowed by tidal influence, near Cooks River 0.5m tidal fluctuation.
WCX-BH-042	Hawkesbury Sandstone	45.5-48.5	Minor groundwater fluctuation, limited recharge response, discharge regulated by Cooks River, tidal with 0.3m fluctuation in levels.
WCX-BH-061s	Quaternary		Immediate response to recharge, discharge likely to be regulated by surface water Muddy Creek and Cooks River.
WCX-BH-168	Hawkesbury Sandstone	48-51	Responding to recharge and natural groundwater dissipation, recharge, 0.5m tidal fluctuations

Tempe to St Peters			
WCX-BH-103	Hawkesbury Sandstone	48-51	Delayed rainfall recharge response, natural slow groundwater dissipation.
WCX-BH-109	Rouse Hill Siltstone	33-36	Overall long term response to recharge, delayed response to significant recharge events, masked by barometric fluctuations.
WCX-BH-115	Ashfield Shale	29.5-32.5	Delayed response to rainfall, other recharge and discharge sources, limited natural groundwater discharge due to presence of an additional recharge source.
WCX-BH-122	Ashfield Shale	15-18	Delayed rainfall recharge response, natural groundwater dissipation.
WCX-BH-152d	Hawkesbury Sandstone	48-51	Hydraulically connected to alluvium, confined and head above that of alluvium, delayed response to recharge.
WCX-BH-152s	Alluvium	18-21	Immediate groundwater response to rainfall and relatively quick discharge.
WCX-BH-153	Hawkesbury Sandstone	46-49	Delayed rainfall response, natural groundwater dissipation following lower recharge period, potential recharge source maintaining high groundwater levels after October 2015.
WCX-BH-157	Regentville Siltstone	32-35	A number of individual recharge and discharge events not related to rainfall, where response is related to rainfall it is delayed.

Monitoring results for vibrating wire piezometers and monitoring bores grouted/screened in alluvium close to the alignment in the vicinity of Cooks River Arncliffe are shown below, for the period immediately prior to and following a large rainfall event over three days from 4 June to 6 June 2016. A total of 235 mm of rainfall was recorded over this period. It is noted that the response to rainfall is quite variable between locations, even taking into consideration the different depths at which the vibrating wire piezometers and monitoring bores are grouted/screened. At some locations vibrating wire piezometers screened at 10-11 m depth, responses of up to approximately 0.5 m are observed, with response to the rainfall event commencing on the first day of rainfall. At other locations, vibrating wire piezometers at a similar depth illustrate a smaller response with a more significant delay. The difference in response likely reflects differences in hydraulic conductivity and/or storage characteristics at different locations in the alluvium.



Note - locations LDS-BH-2001, LDS-BH2003, LDS-BH-2005, WCX-BH036, WCX-BH068 and WCX-BH074 are standpipes, whereas other locations are vibrating wire piezometers.

Annexure J –Pumping Test Summary

Pumping Well LDS – PW-2901

1.0 TEST PUMPING CONFIGURATION

Wells and monitoring instrumentation were installed for the test pumping at KGC utilising geotechnical boreholes or purpose drilled holes. The testing network presented in Figure 1 and summarised in Appendix A includes:

- 1 test pumping well (LDS-PW-2901)
- 5 Standpipe monitoring wells
- 7 nested VWP installation (24 instruments)
- 1 tidal monitoring point in the Cooks River.

Additional information on the installations is provided in the following sections.

1.1 Pumping Well LDS-PW-2901

Drilling the pumping well LDS-PW-2901 commenced on 11 February 2016 and was completed on 26 February 2016. The pumping well is located adjacent to borehole LDS-BH-2029. A 216 mm diameter borehole was drilled through the alluvial material (0 – 38mbgl) using mud rotary drilling with bentonite-polymer drilling fluids. The mud-rotary hole was drilled a further 1.5m depth into the top of the sandstone bedrock. The alluvium was cased off with 150 mm diameter (156mm internal diameter) steel casing which was hammered into the sandstone to a depth of 39.55 mbgl. With the steel casing in place, the hole was advanced into the sandstone using a down-hole air hammer to drill a 140 mm diameter borehole. The final depth for the well was 61.5mbgl. The sandstone section of the borehole was left unsupported (no casing).

Water bearing fractures were intersected in the borehole from between 51 mbgl and 60 mbgl with airlift yields from the well of approximately 2.5 L/s.

At the completion of drilling, wireline acoustic and optical tele-viewers were run in the hole. At the completion of testing and once the pump has been removed from the well, a heat-pulse vertical flow meter was also run in the hole.

1.2 Groundwater level monitoring

Baseline groundwater level monitoring and drawdown response during testing have been collected by manual dipping and automatic systems (data logging). Standpipe piezometers were equipped with pressure transducer data loggers (PTDLs).

The recording frequency of data loggers was adjusted as required to align with data capture requirements (i.e. background recording versus high temporal resolution during the test pumping). Data was downloaded periodically during and after well pumping.

1.3 Pump installation and flow control

A 3-phase Grundfos SP14-11 electro-submersible pump was installed in LDS-PW-2901. The pump intake was set at approximately 44mbgl. The rising main from the pump is a 63mm PN12 HDPE. Two small diameter (25 mm) HDPE tubes were installed with the rising main and power cable to allow installation of a PTDL, manual monitoring of groundwater levels and for the installation of low water level sensors (pump protection). The pump is connected to a mains power supply via an electrical distribution board on the Marsh Street boundary.

Pumping rates were regulated using a flow control manifold with four flow control valves (FCV) in parallel. The FCV's have fixed flowrates of 0.5, 0.75, 1.0 and 2.1 L/s respectively. By opening different valve combinations flow rates between 0.5 to 4.3L/s could be achieved. Flow rates during testing were monitored using a flow meter (totaliser).

1.4 Groundwater discharge

Groundwater was discharged to the adjacent stormwater system on Marsh Street under a Rockdale Council Permit. The permit required the discharge pH to be >6.5.

1.4.1 pH Dosing

Groundwater pH measured during monitoring well development indicated pH values less than the pH discharge criteria (i.e. field measured pH was less than 6.5). An in line pH dosing unit was installed to raise pH automatically by injection of sodium hydroxide solution.

2.0 HYDRAULIC TESTING

The following pumping tests were carried out in LDS-PW-2901:

- Step rate test (SRT) carried out on 3 March 2016; the test comprised 6 steps at flow rates of 1.0, 1.4, 1.8, 2.0, 2.3 and 2.6 L/s. Each step was 1 hour with the exception of the final step (5 minutes).
- A 26 hour constant rate test (CRT) commenced at 10:10AM on 4 March and was terminated on 5 March at 12:10PM, due to a blockage in the stormwater system that was being used for discharge. The test was carried out at a pumping rate of 2.2 L/s based on the results of the SRT.
- A 4.5 Day (6605 minute) CRT commenced at 09:25AM on 11 March and was terminated on 15 March at around 23:30PM. The test terminated because of a malfunction of the sensors used to protect the pump from running dry. The test was carried out at a pumping rate of 2.0 L/s based on the drawdown observed in the pumping well in the 26 hour CRT. At the end of testing, groundwater level recovery was monitored. Hydrographs of drawdown at the various locations in the monitoring network are provided in Appendix B. Note that at this point in time, the responses in vibrating wire piezometers have not been corrected for barometric pressure variations.

3.0 TESTING TO ASSESS WATER QUALITY

Groundwater samples for laboratory analysis and field parameters collected during hydraulic testing are summarised in Table 1. Groundwater samples and field water quality parameters collected included:

- during monitoring well development for LDS-2029; LDS-BH-2029A and LDS-BH-2005 and prior to test pumping;
- during the first day of the 26 hour test including sampling from upstream and downstream from the pH dosing unit; and
- during the 4.5 day test including sampling from upstream and downstream from the pH dosing unit.

Table 1: Summary of groundwater quality testing and sampling

Event	Field Parameters	Laboratory sample
Monitoring well development	pH, EC, TDS, Redox, Temp	LDS-2029; LDS-2029A; 2005 Samples
Pumping well airlifting	pH, EC, TDS, Redox, Temp	1 Sample
SRT	pH, EC, TDS, Redox, Temp (upstream and downstream of pH dosing unit)	Not sampled
26hr CRT	pH, EC, TDS, Redox, Temp, Turbidity (NTU) (upstream and downstream of pH dosing unit)	1 Sample at 4 hours
4.5 day CRT	pH, EC, TDS, Redox, Temp, Turbidity (upstream and downstream of pH dosing unit)	2 Samples (at 5 hours and 2.25 days)

Water quality parameters from field testing and laboratory analyses are tabulated in Appendix C.

LEGEND

Completed

- Borehole
- Pump Well
- CPT

Installation

- MW
- VWP
- VWP+MW

CLIENT
LEIGHTON DRAGADOS SAMSUNG JV

PROJECT
WEST CONNEX STAGE 2

0 40 80 120 160 200
METRES

REFERENCE SCALE: 1:4,000 (at A3)
PROJECTION: GDA 1994 MGA Zone 56

TITLE
EXISTING AND PROPOSED SITE INVESTIGATION PUMP TEST LAYOUT

WestConnex STAGE 2 M5

YYYY-MM-DD	2016-03-21
PREPARED	ICD
DESIGN	CMC
REVIEW	CMC
APPROVED	

PROJECT No.	Rev.	FIGURE
1524285	0	1

IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM A3

APPENDIX A
Monitoring Network Summary

Monitoring point ID	Installation Type	Monitored Interval (mRL)*	Formation	Distance to pumping well (m)	Max. Drawdown 4.5 day test (m)
LDS-PW-2901	Test pumping well	39.6 – 61.5	Hawkesbury Sandstone - Fractured	-	26.98
LDS-BH-2003	Standpipe Piezometer	-2.6 to -7.6	Alluvial - Sand	539	No drawdown recorded
LDS-BH-2005	VWP - Grouted	-11.4	Alluvial - Sand	68.8	0.58
	VWP - Grouted	-15.9	Alluvial - Sand		0.59
	VWP - Grouted	-21.9	Alluvial - Clay		0.81
	Standpipe Piezometer	-24.9 to -26.9	Hawkesbury Sandstone - massive		1.26
LDS-BH-2007A	Standpipe Piezometer	-39.0 to -56.0	Hawkesbury Sandstone	266	1.71
LDS-BH-2007B	VWP - Grouted	-8.77	Alluvial - Sand	188.3	0.11
	VWP - Grouted	-11.77	Alluvial - sandy clay		0.11
	VWP - Grouted	-22.77	Alluvial - Sand		0.8
	VWP - Grouted	-31.67	Hawkesbury Sandstone		1.78
LDS-BH-2029	Standpipe Piezometer	-42.0 to -62.0	Hawkesbury Sandstone - Fractured	10.5	6.38
LDS-BH-2029A	Standpipe Piezometer	-17.5 to -31.5	Alluvial - Sand	11.5	1.67
LDS-BH-2033 (inclined)	VWP - Grouted	-18.62	Alluvial - Sandy Clay	26.9	1.58
	VWP - Grouted	-24.73	Alluvial - Sandy Clay	25.3	1.58
	VWP - Grouted	-52.92	Hawkesbury Sandstone - Core loss zone, Fractured?	19.4	6.71
LDS-BH-1041 (inclined)	VWP - Grouted	-12.17	Alluvial - Sandy Clay	94.3	0.52
	VWP - Grouted	-20.72	Alluvial - Clay	91.3	0.91

	VWP - Grouted	-25.32	Alluvial - Sand	89.7	1.6
	VWP - Grouted	-59.53	Hawkesbury Sandstone	77.7	3.48
LDS-BH-1045	VWP - Grouted	-7.32	Alluvial - Sand	74.8	.046
(inclined)	VWP - Grouted	-27.99	Alluvial - Silty-sandy Clay	70.7	1.64
	VWP - Grouted	-37.48	Hawkesbury Sandstone - Core Loss zone, Fractured?	69.0	2.57
	VWP - Grouted	-56.27	Hawkesbury Sandstone - Joint	66.1	6.01
LDS-BH-1054	VWP - Grouted	-8.31	Alluvial - Clay	96.3	0.17
(inclined)	VWP - Grouted	-11.77	Alluvial - Sandy Clay	95.1	0.74
	VWP - Grouted	-40.09	Hawkesbury Sandstone - Fractured	86.8	2.99
	VWP - Grouted	-74.21	Hawkesbury Sandstone - Fractured	80.1	5.54
LDS-BH-1055	VWP - Grouted	-7.83	Alluvial - Clay	131.9	0.36
(inclined)	VWP - Grouted	-11.73	Alluvial - Sandy Clay	130.2	0.06
	VWP - Grouted	-42.47	Hawkesbury Sandstone - sheared	117.1	2.96
	VWP - Grouted	-69.93	Hawkesbury Sandstone - Fractured	106.5	6.11
Marsh Street Bridge	Conduit in Open Water	-	Cooks River – Tidal Monitoring	NA	NA
*	For monitoring wells, the monitoring interval includes screen and filter pack interval.				

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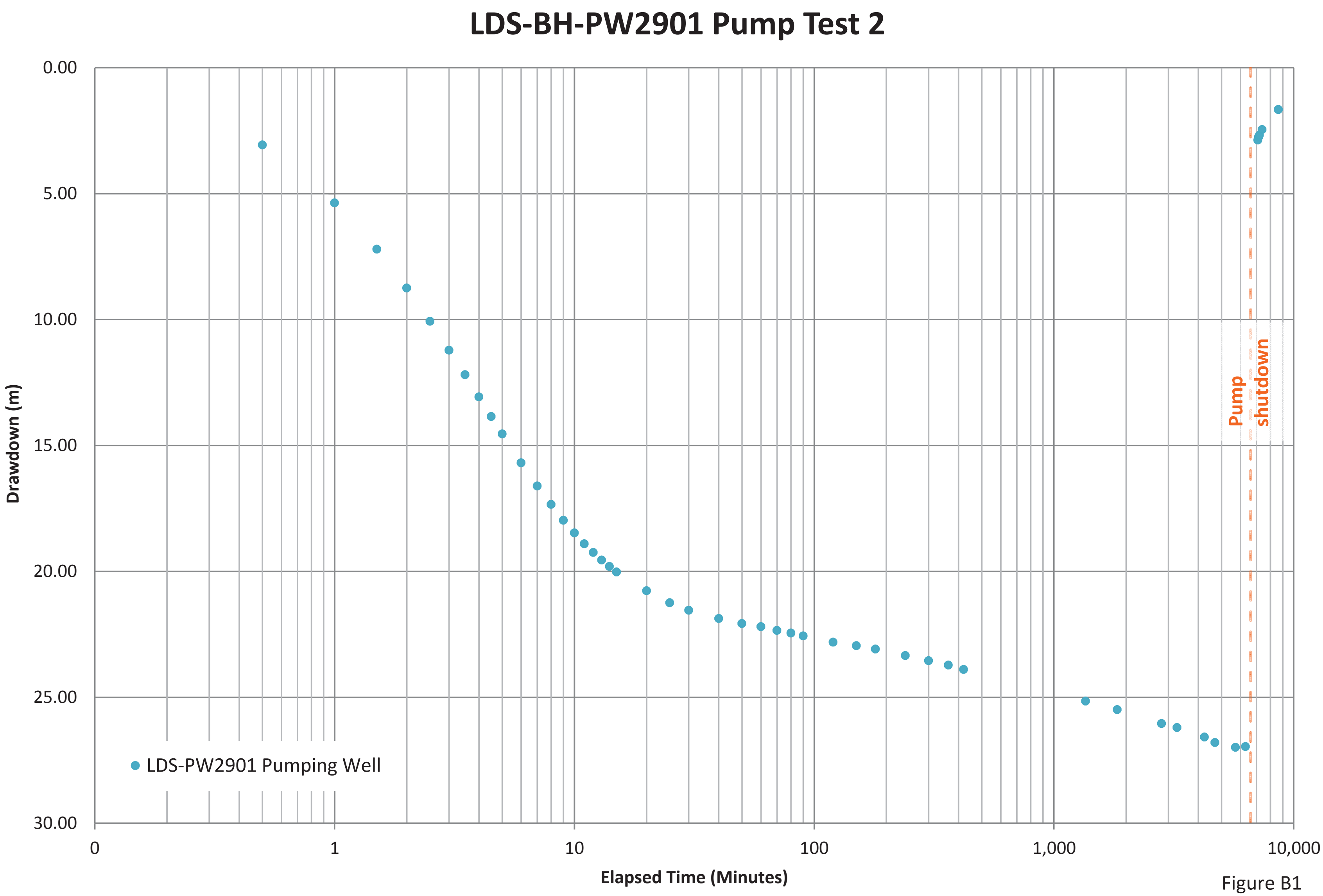
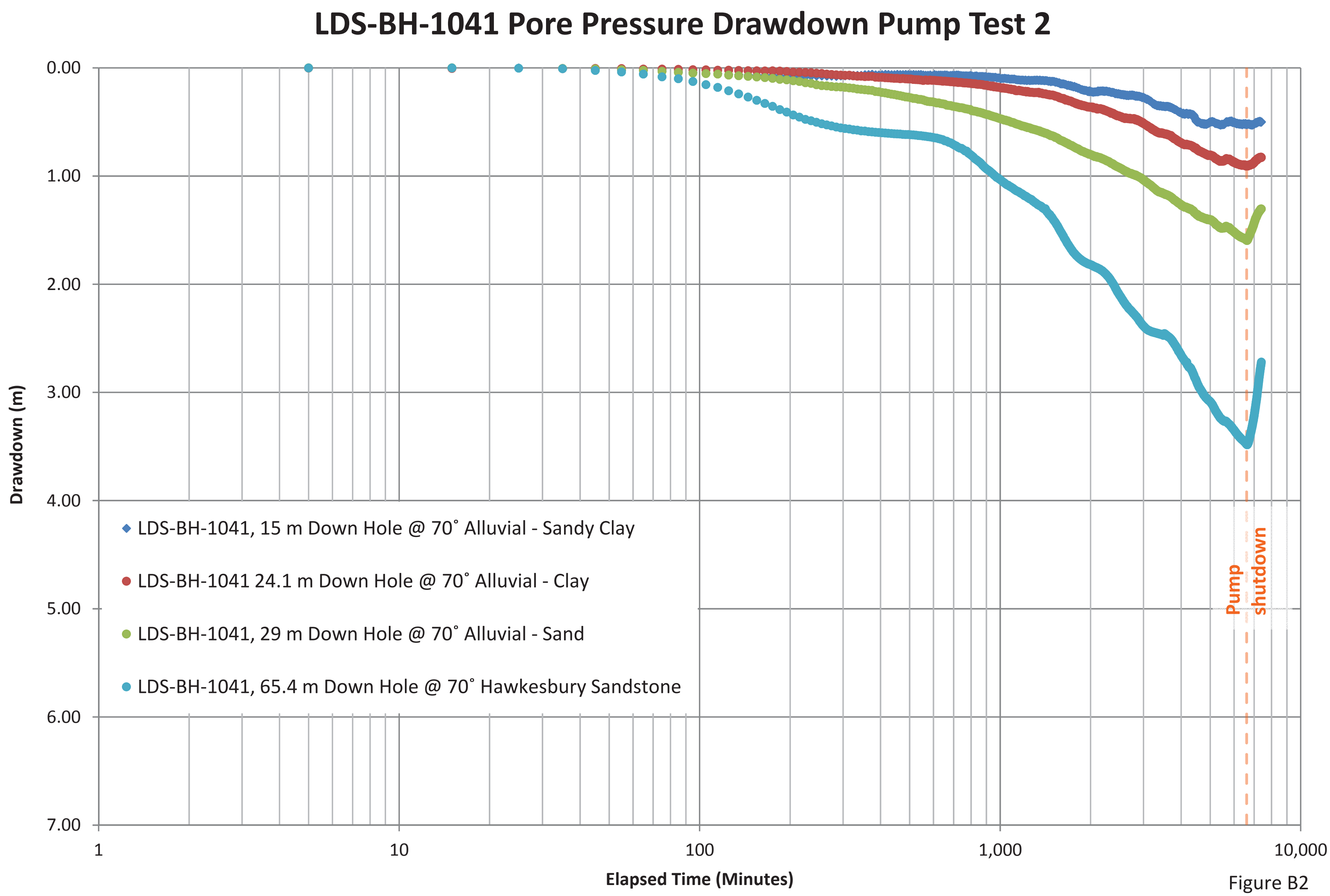
APPENDIX B

4.5 day Constant Rate Test Hydrographs



LDS-BH-PW2901 Pump Test 2
Drawdown (m)
0.00
5.00
10.00
15.00
20.00
25.00
30.00
0
1
10
100
1,000
10,000
Elapsed Time (Minutes)
Pump shutdown
LDS-PW2901 Pumping Well

Figure B1



LDS-BH-1041 Pore Pressure Drawdown Pump Test 2
Drawdown (m)
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
1
10
100
1,000
10,000
Elapsed Time (Minutes)
LDS-BH-1041, 15 m Down Hole @ 70˚ Alluvial - Sandy Clay
LDS-BH-1041 24.1 m Down Hole @ 70˚ Alluvial - Clay
LDS-BH-1041, 29 m Down Hole @ 70˚ Alluvial - Sand
LDS-BH-1041, 65.4 m Down Hole @ 70˚ Hawkesbury Sandstone
Pump shutdown

Figure B2

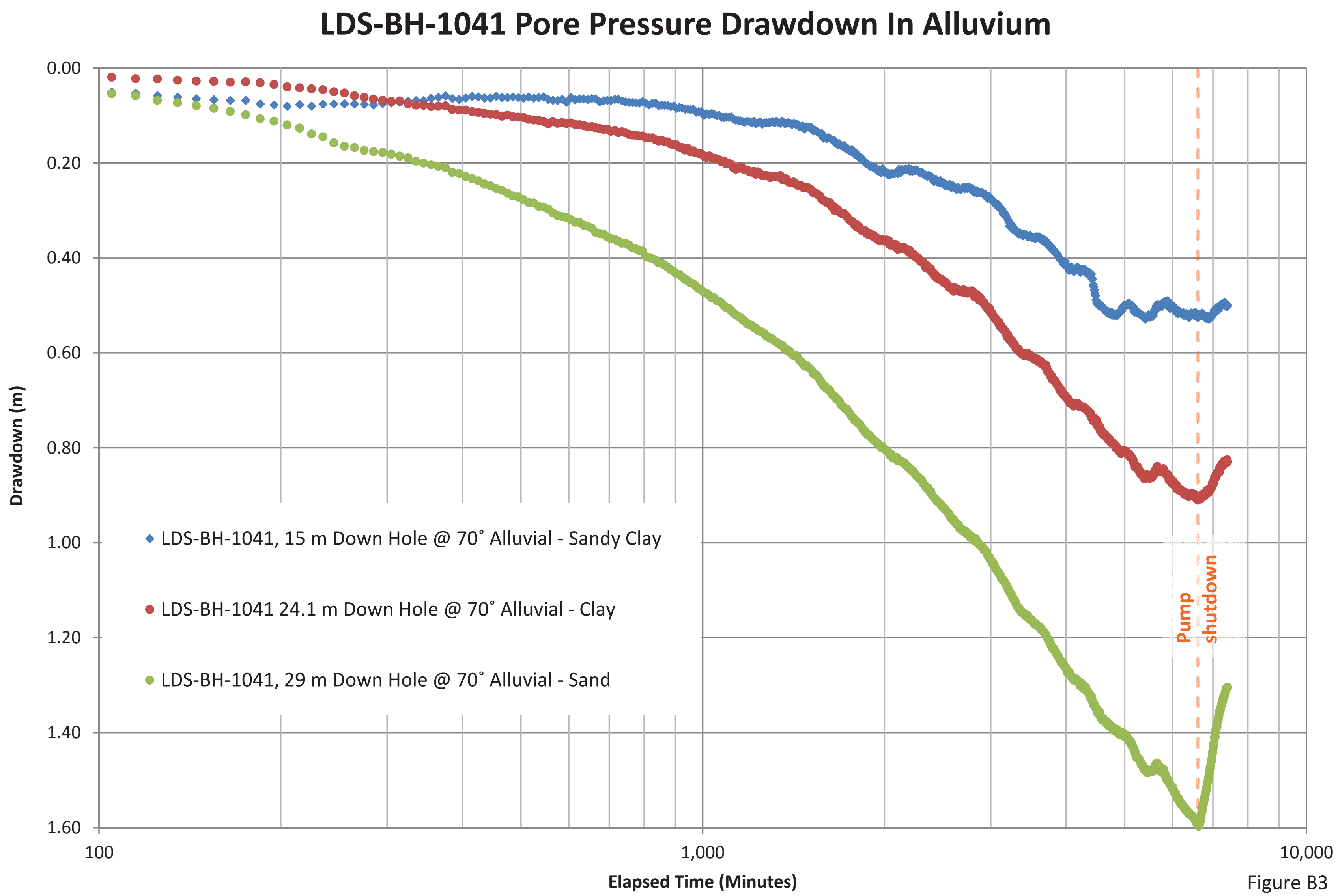
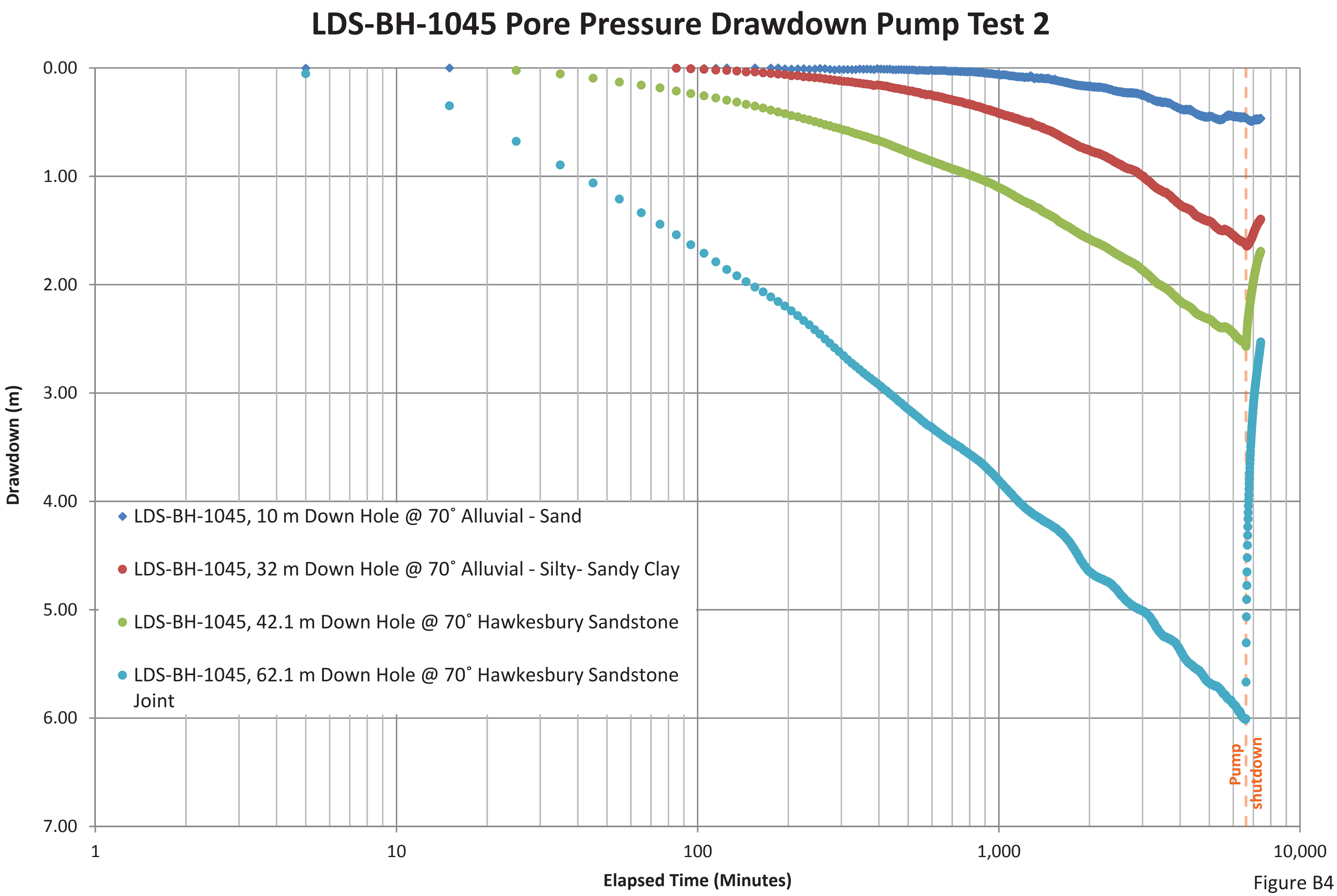

LDS-BH-1041 Pore Pressure Drawdown In Alluvium
Drawdown (m)
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
1.60
100
1,000
10,000
Elapsed Time (Minutes)
LDS-BH-1041, 15 m Down Hole @ 70˚ Alluvial - Sandy Clay
LDS-BH-1041 24.1 m Down Hole @ 70˚ Alluvial - Clay
LDS-BH-1041, 29 m Down Hole @ 70˚ Alluvial - Sand
Pump shutdown

Figure B3



LDS-BH-1045 Pore Pressure Drawdown Pump Test 2
Drawdown (m)
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
1
10
100
1,000
10,000
Elapsed Time (Minutes)
LDS-BH-1045, 10 m Down Hole @ 70˚ Alluvial - Sand
LDS-BH-1045, 32 m Down Hole @ 70˚ Alluvial - Silty- Sandy Clay
LDS-BH-1045, 42.1 m Down Hole @ 70˚ Hawkesbury Sandstone
LDS-BH-1045, 62.1 m Down Hole @ 70˚ Hawkesbury Sandstone Joint
Pump shutdown

Figure B4

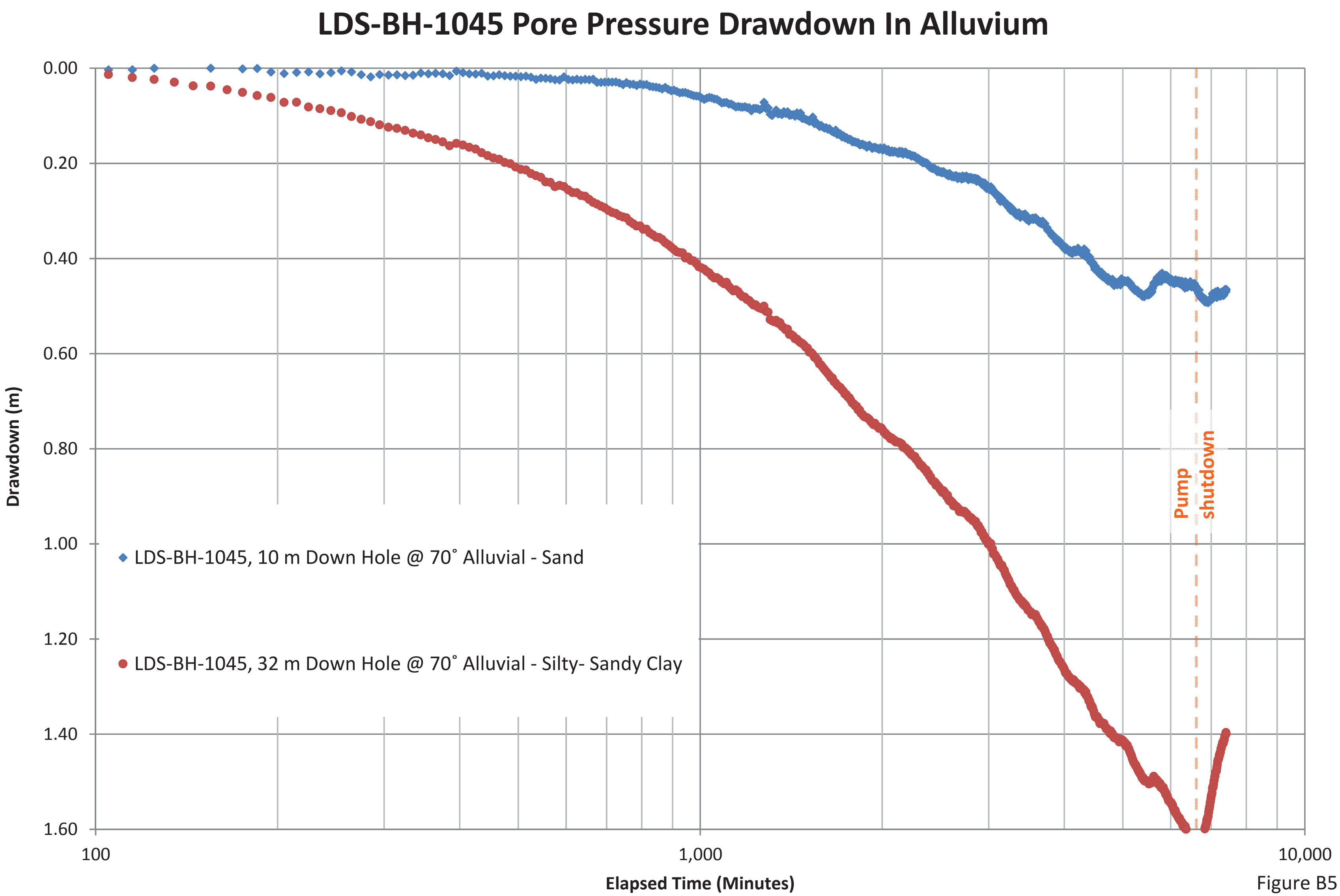
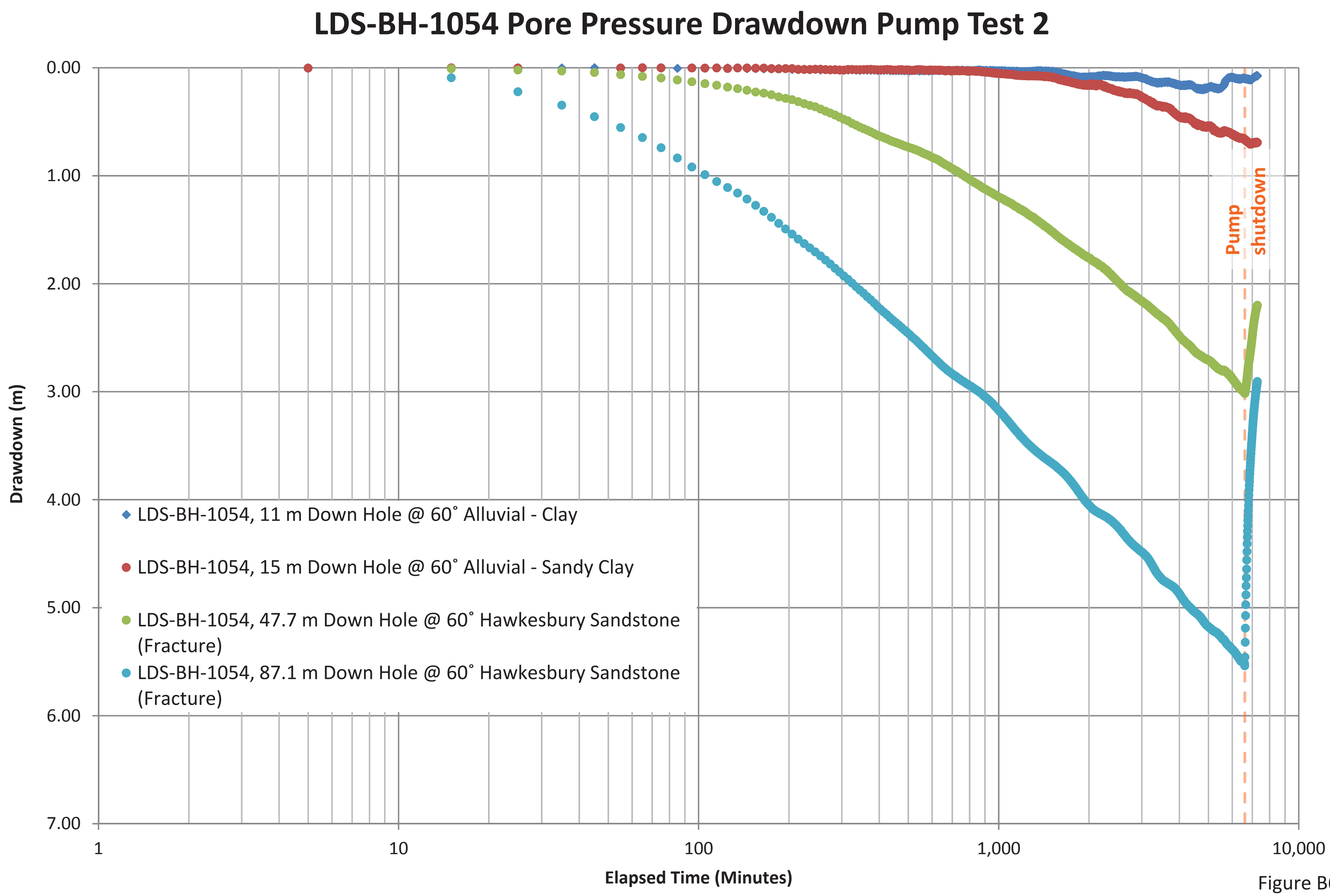
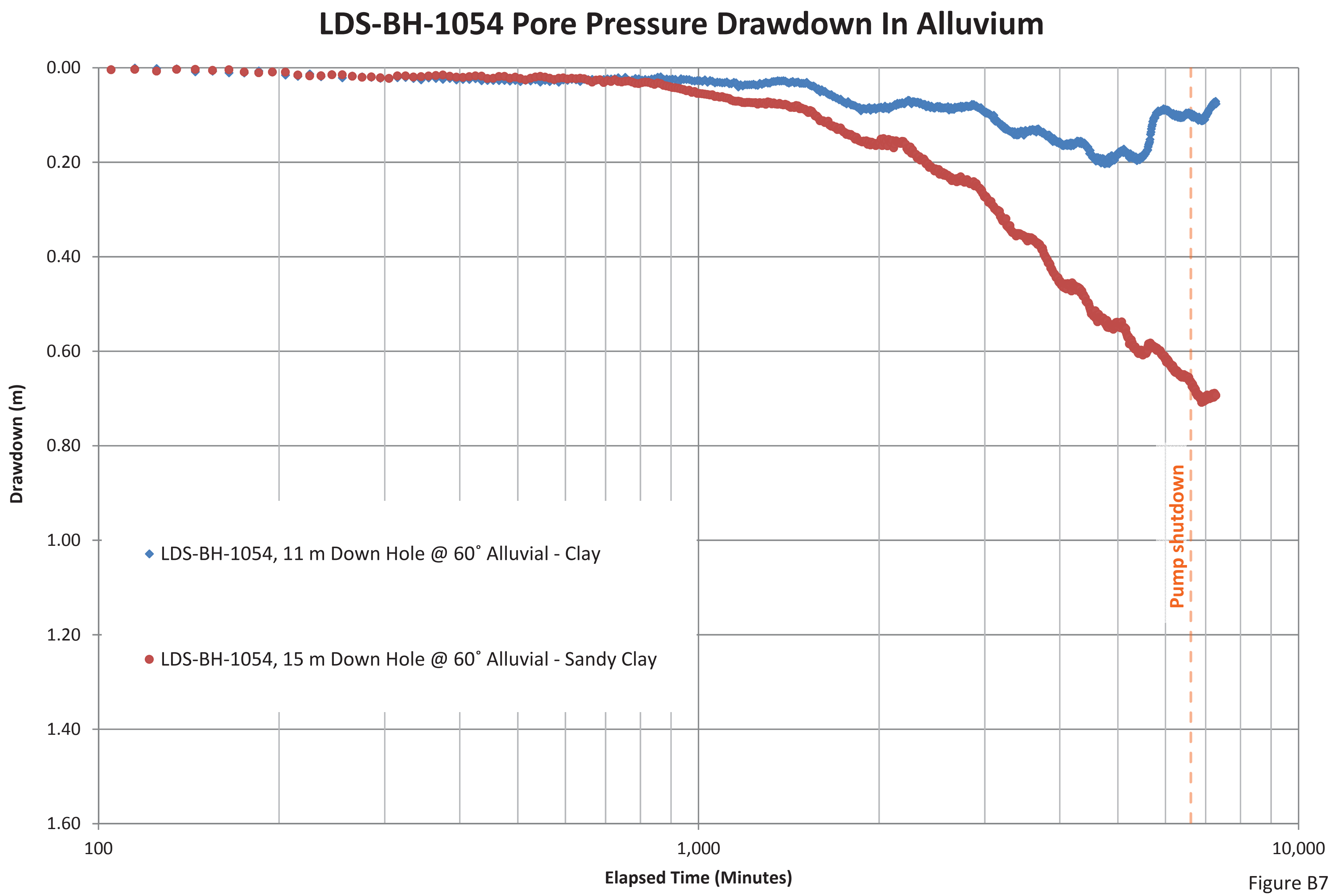

LDS-BH-1045 Pore Pressure Drawdown In Alluvium
Drawdown (m)
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
1.60
100
1,000
10,000
Elapsed Time (Minutes)
LDS-BH-1045, 10 m Down Hole @ 70˚ Alluvial - Sand
LDS-BH-1045, 32 m Down Hole @ 70˚ Alluvial - Silty- Sandy Clay
Pump shutdown

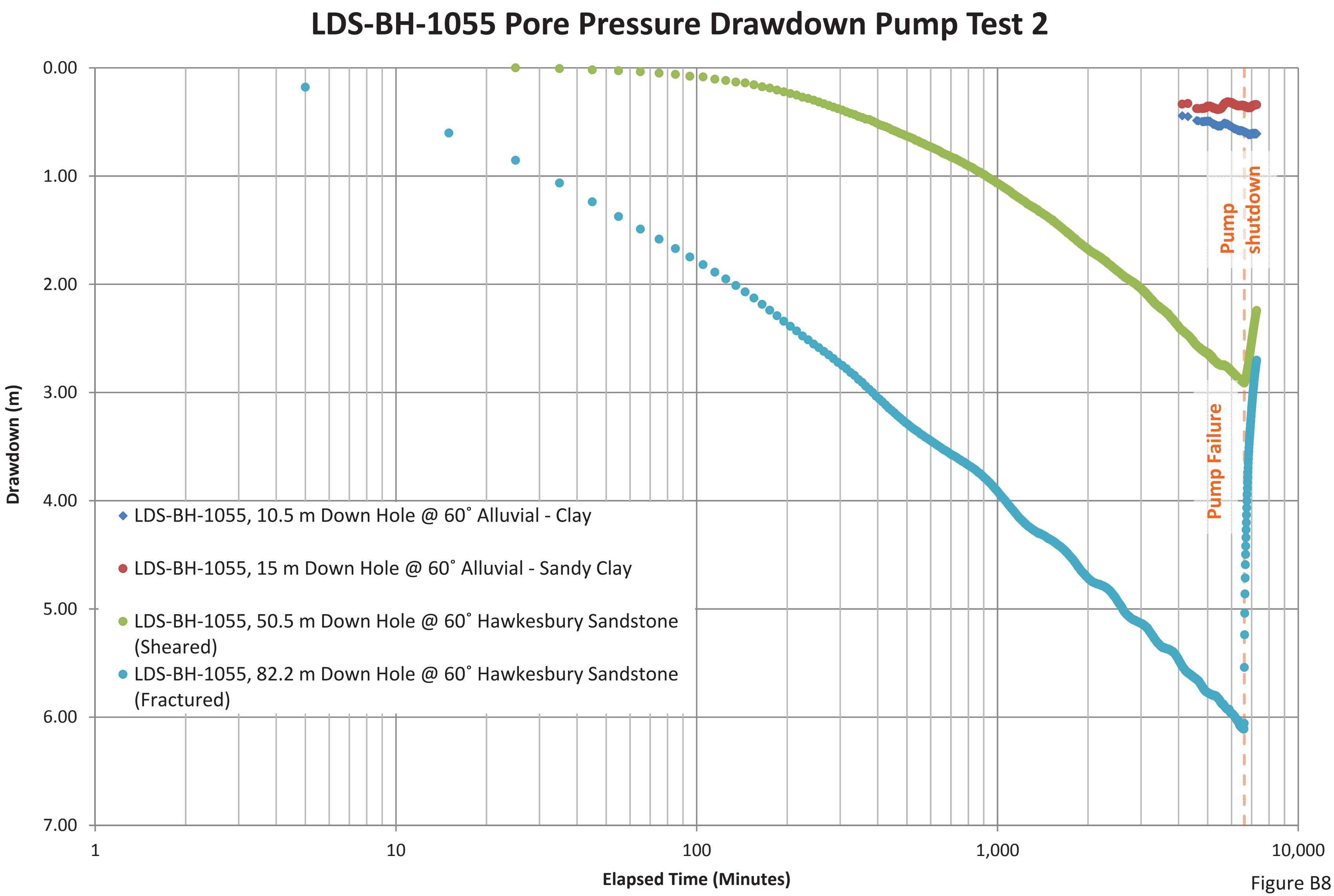
Figure B5


LDS-BH-1054 Pore Pressure Drawdown Pump Test 2
Drawdown (m)
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
1
10
100
1,000
10,000
Elapsed Time (Minutes)
Pump shutdown
LDS-BH-1054, 11 m Down Hole @ 60˚ Alluvial - Clay
LDS-BH-1054, 15 m Down Hole @ 60˚ Alluvial - Sandy Clay
LDS-BH-1054, 47.7 m Down Hole @ 60˚ Hawkesbury Sandstone (Fracture)
LDS-BH-1054, 87.1 m Down Hole @ 60˚ Hawkesbury Sandstone (Fracture)
Figure B6



LDS-BH-1054 Pore Pressure Drawdown In Alluvium
Drawdown (m)
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
1.60
100
1,000
10,000
Elapsed Time (Minutes)
LDS-BH-1054, 11 m Down Hole @ 60˚ Alluvial - Clay
LDS-BH-1054, 15 m Down Hole @ 60˚ Alluvial - Sandy Clay
Pump shutdown

Figure B7



LDS-BH-1055 Pore Pressure Drawdown Pump Test 2
Drawdown (m)
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
1
10
100
1,000
10,000
Elapsed Time (Minutes)
Pump shutdown
Pump Failure
LDS-BH-1055, 10.5 m Down Hole @ 60˚ Alluvial - Clay
LDS-BH-1055, 15 m Down Hole @ 60˚ Alluvial - Sandy Clay
LDS-BH-1055, 50.5 m Down Hole @ 60˚ Hawkesbury Sandstone (Sheared)
LDS-BH-1055, 82.2 m Down Hole @ 60˚ Hawkesbury Sandstone (Fractured)

Figure B8

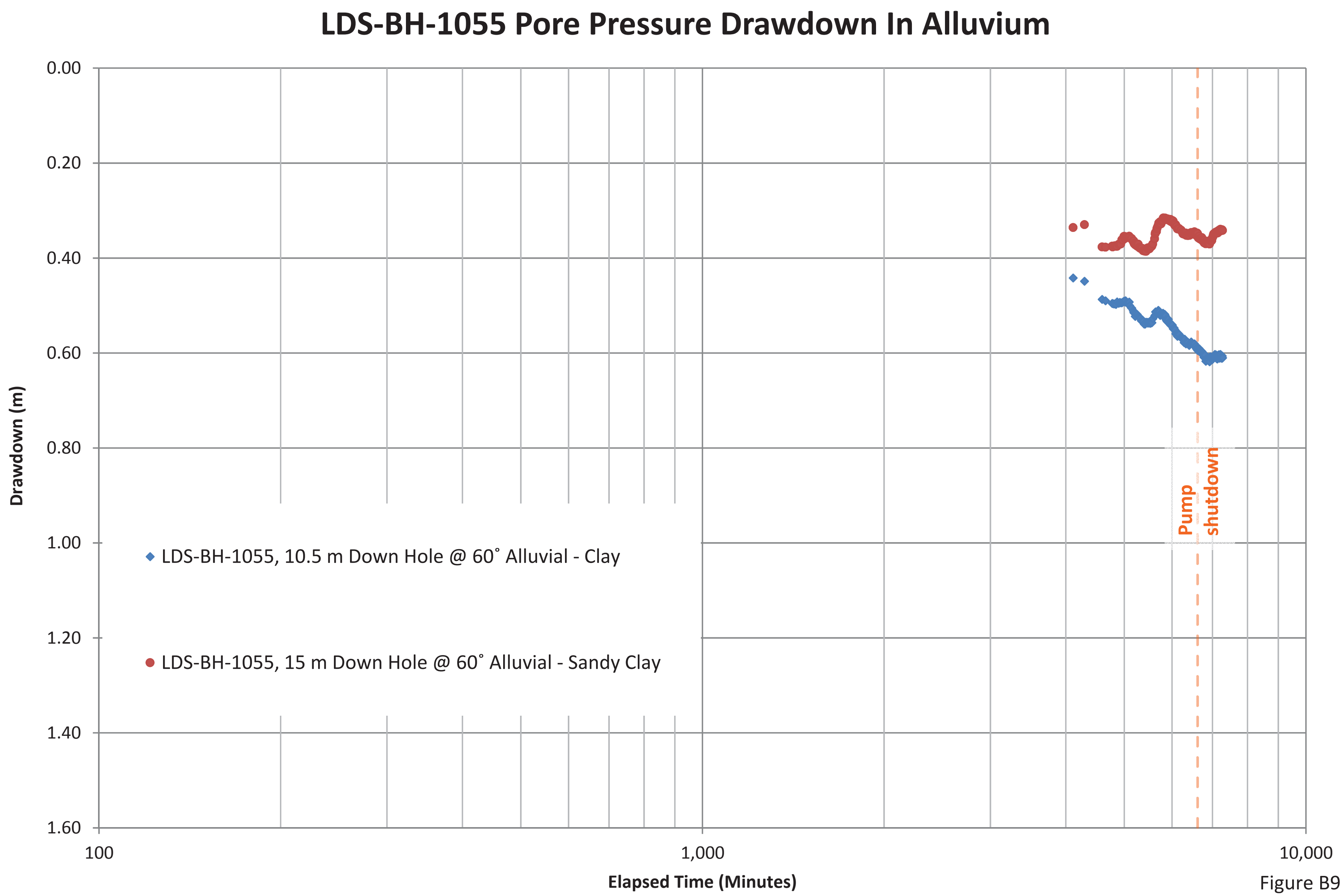
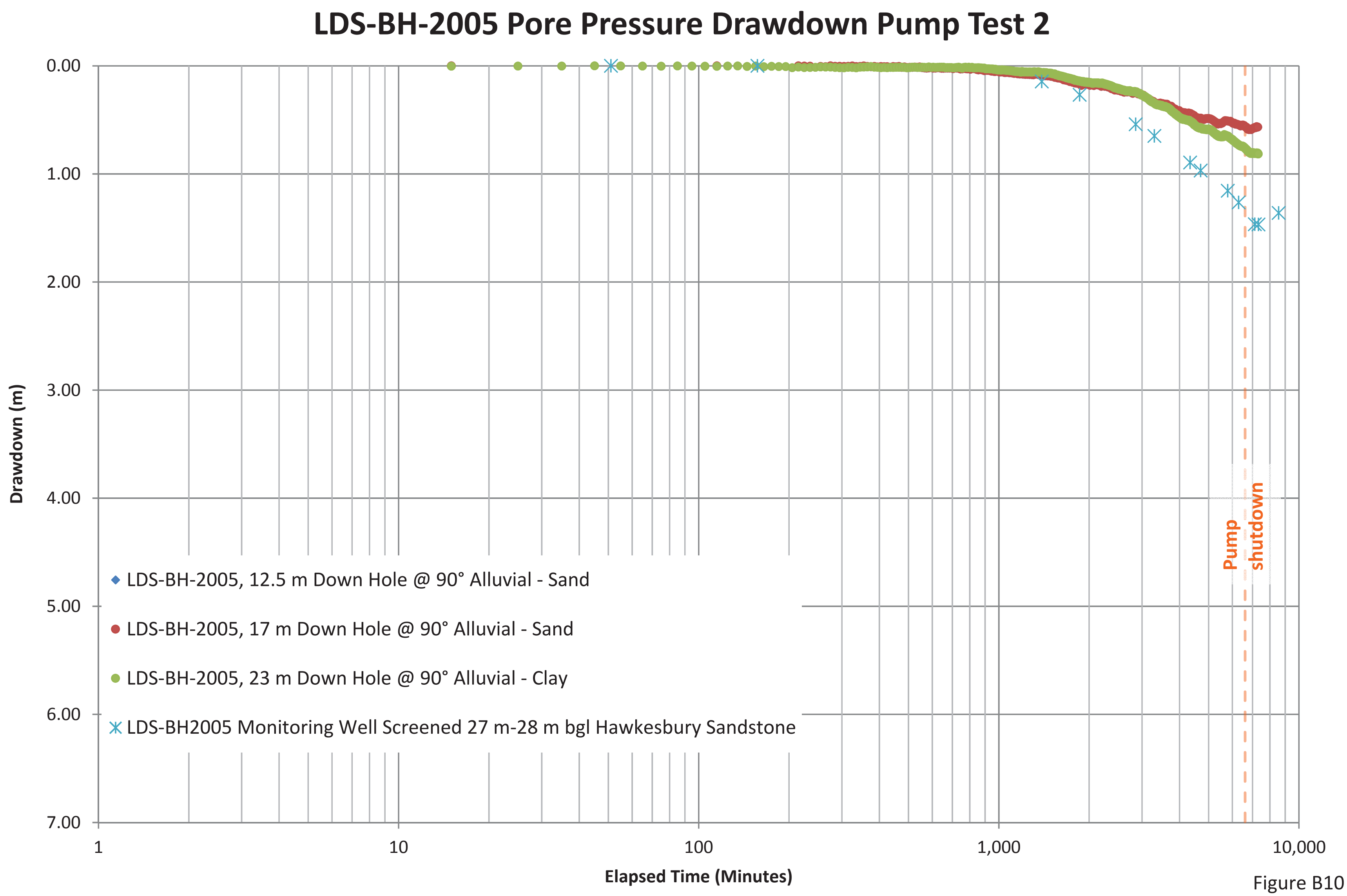
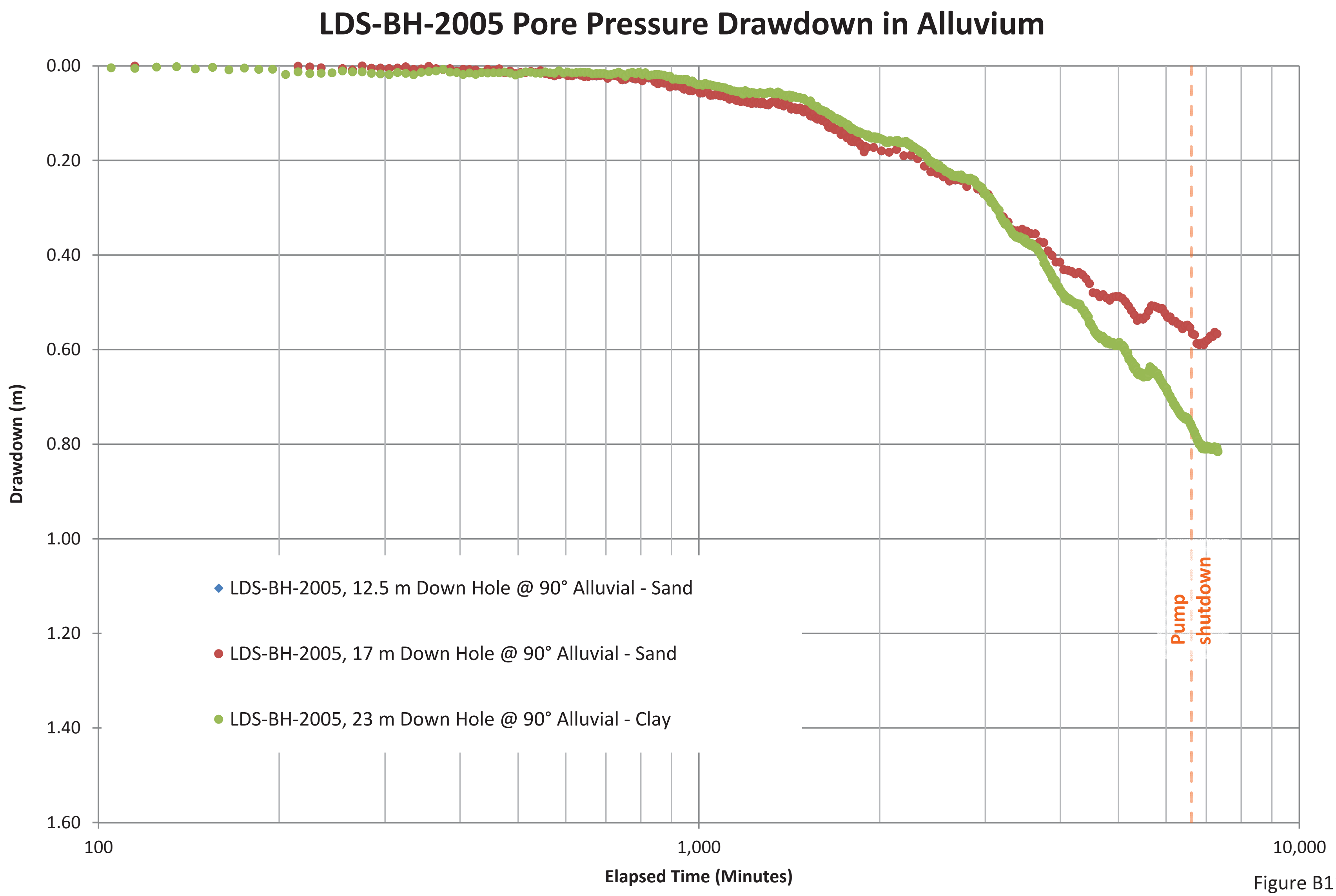

LDS-BH-1055 Pore Pressure Drawdown In Alluvium
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
1.60
Drawdown (m)
100
1,000
10,000
Elapsed Time (Minutes)
LDS-BH-1055, 10.5 m Down Hole @ 60˚ Alluvial - Clay
LDS-BH-1055, 15 m Down Hole @ 60˚ Alluvial - Sandy Clay
Pump shutdown

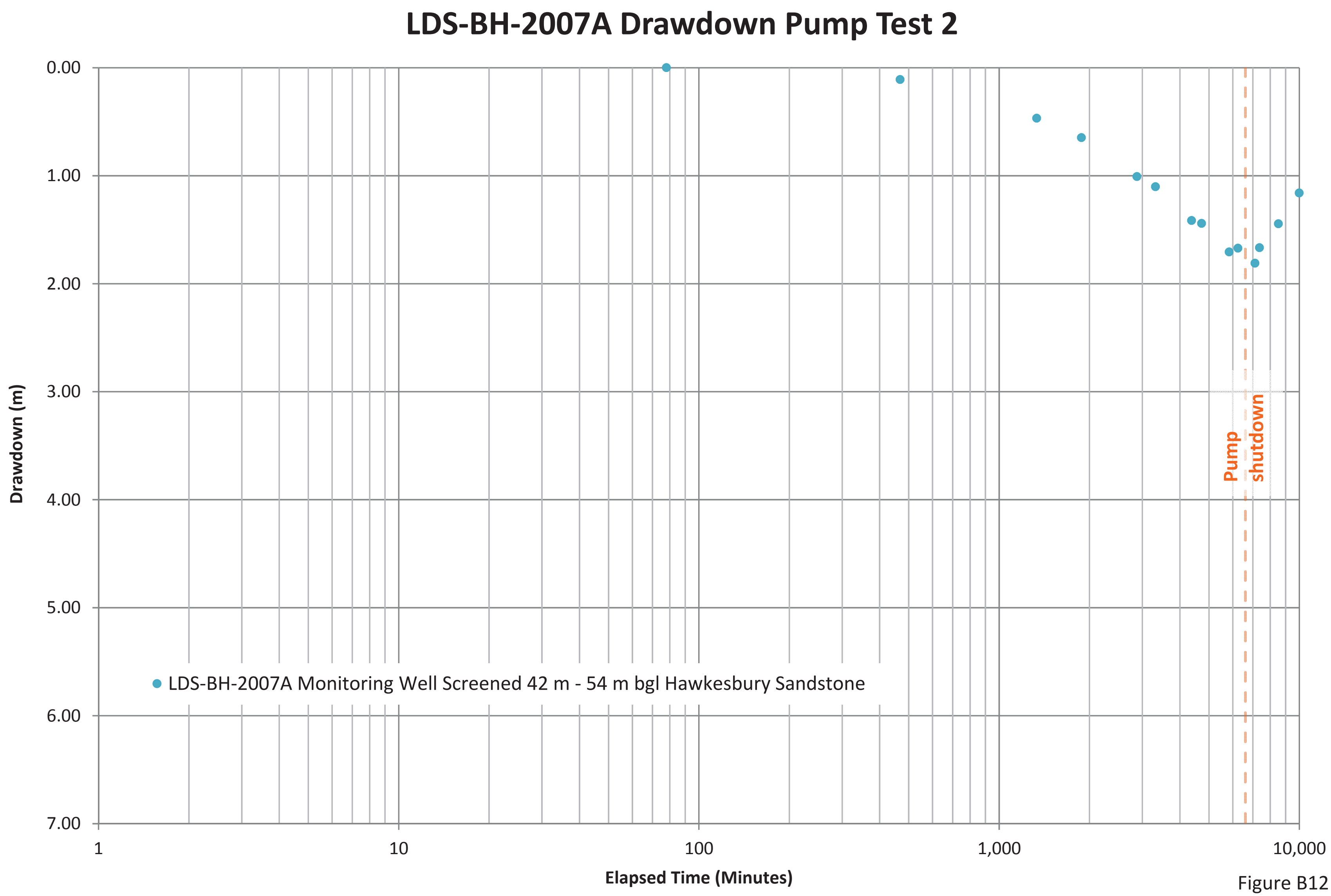
Figure B9


LDS-BH-2005 Pore Pressure Drawdown Pump Test 2
Drawdown (m)
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
1
10
100
1,000
10,000
Elapsed Time (Minutes)
LDS-BH-2005, 12.5 m Down Hole @ 90° Alluvial - Sand
LDS-BH-2005, 17 m Down Hole @ 90° Alluvial - Sand
LDS-BH-2005, 23 m Down Hole @ 90° Alluvial - Clay
LDS-BH2005 Monitoring Well Screened 27 m-28 m bgl Hawkesbury Sandstone
Pump shutdown
Figure B10



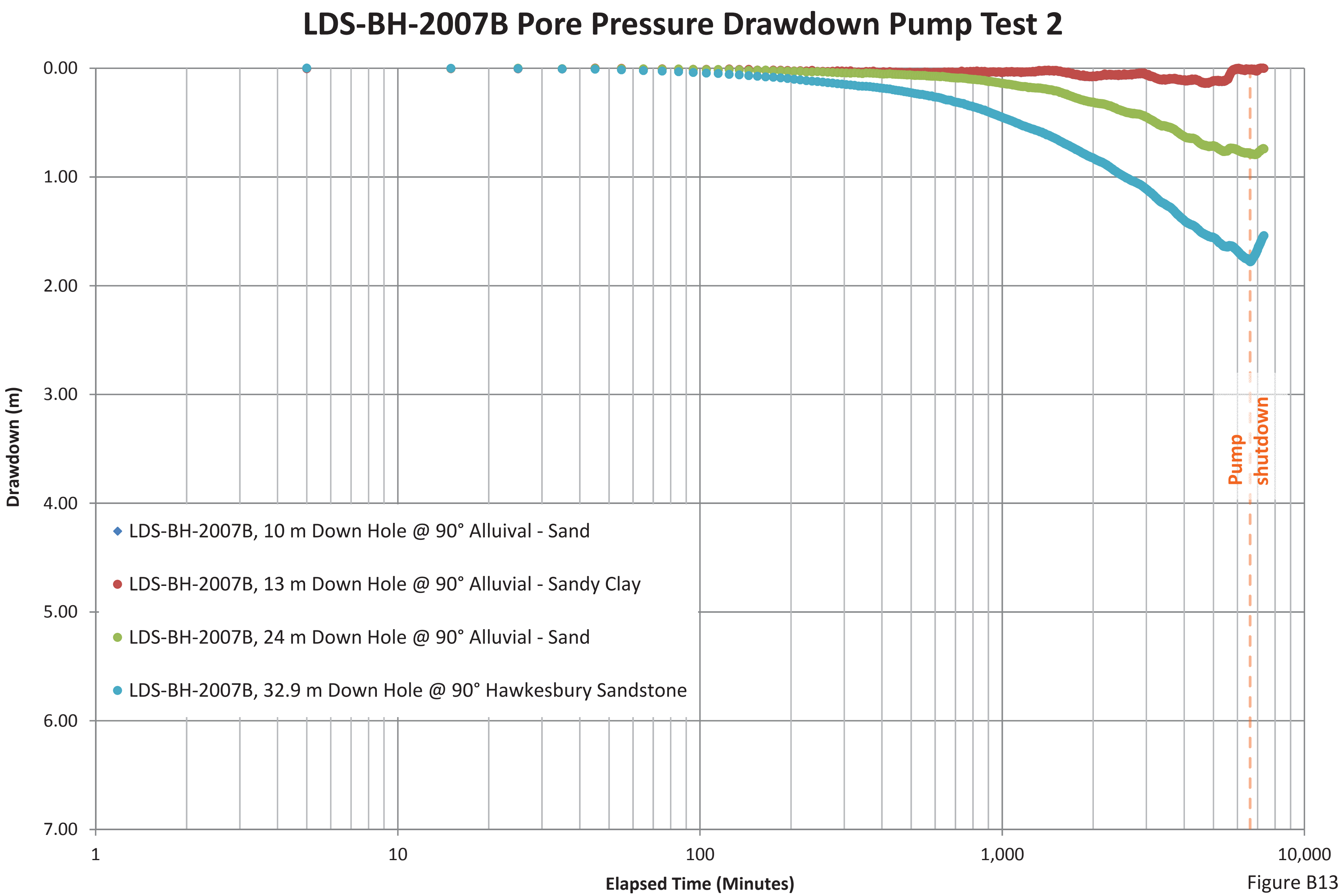
LDS-BH-2005 Pore Pressure Drawdown in Alluvium
Drawdown (m)
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
1.60
100
1,000
10,000
Elapsed Time (Minutes)
LDS-BH-2005, 12.5 m Down Hole @ 90° Alluvial - Sand
LDS-BH-2005, 17 m Down Hole @ 90° Alluvial - Sand
LDS-BH-2005, 23 m Down Hole @ 90° Alluvial - Clay
Pump shutdown

Figure B11



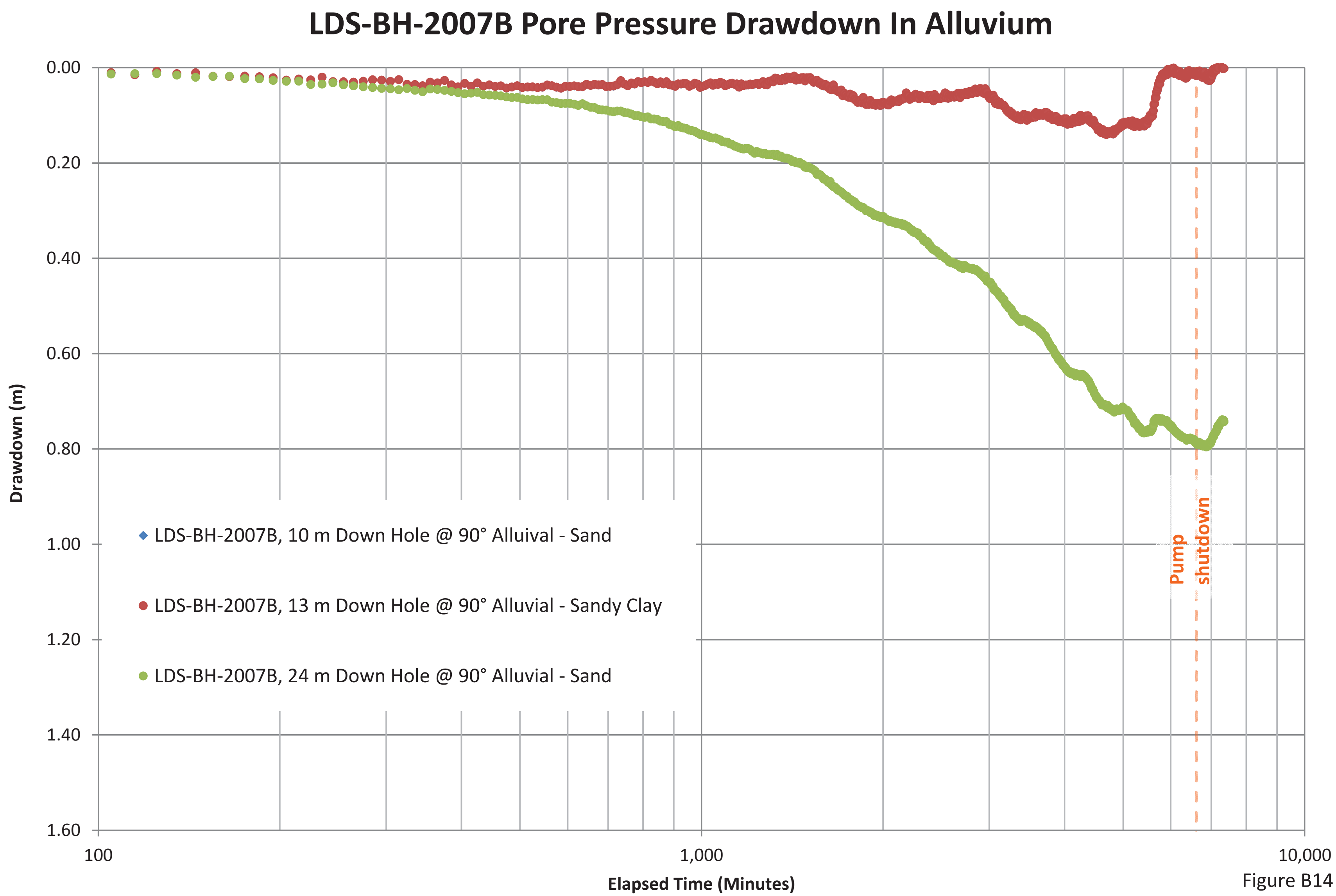
LDS-BH-2007A Drawdown Pump Test 2
Drawdown (m)
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
1
10
100
1,000
10,000
Elapsed Time (Minutes)
Pump shutdown
LDS-BH-2007A Monitoring Well Screened 42 m - 54 m bgl Hawkesbury Sandstone

Figure B12



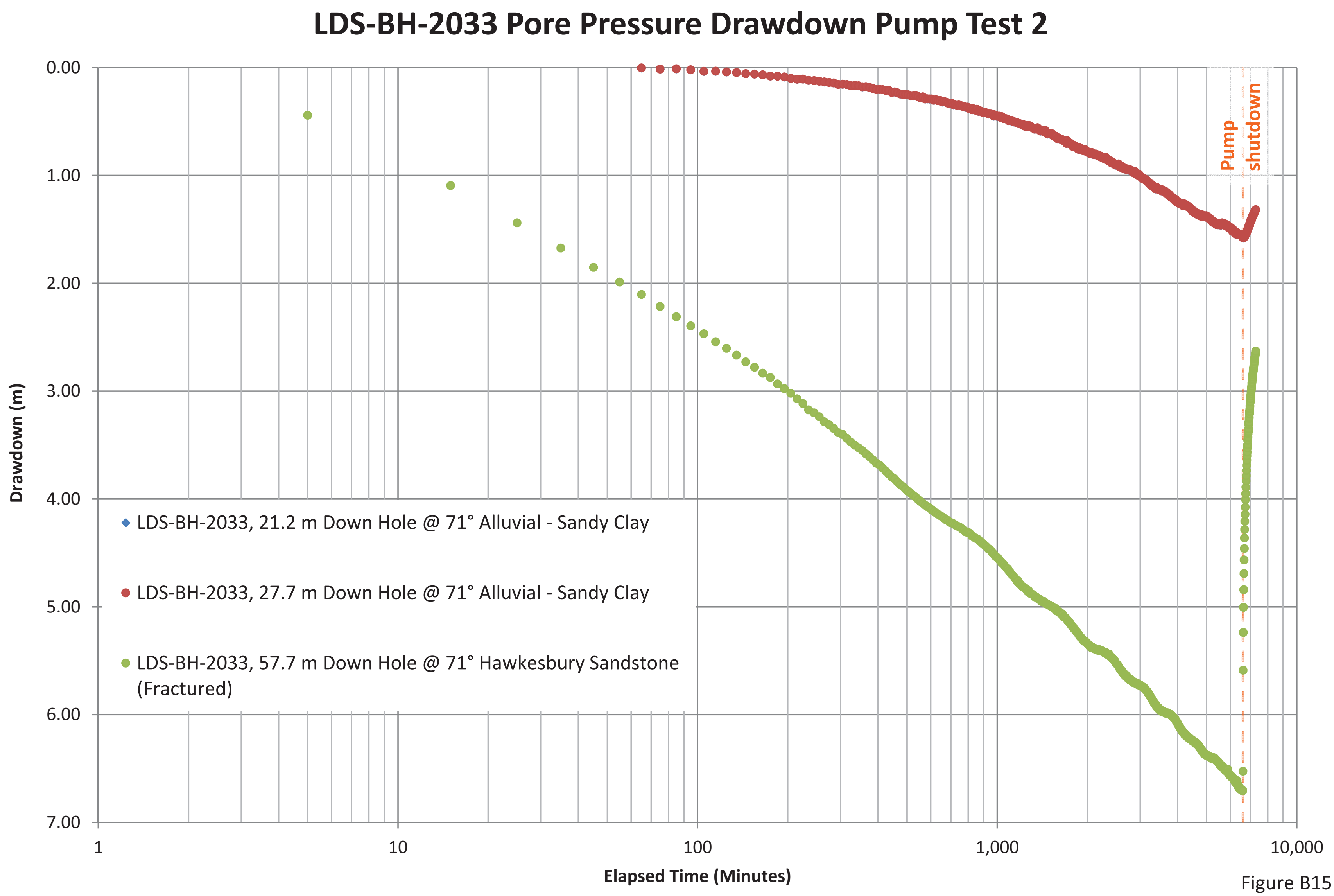
LDS-BH-2007B Pore Pressure Drawdown Pump Test 2
Drawdown (m)
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
1
10
100
1,000
10,000
Elapsed Time (Minutes)
Pump shutdown
LDS-BH-2007B, 10 m Down Hole @ 90° Alluvial - Sand
LDS-BH-2007B, 13 m Down Hole @ 90° Alluvial - Sandy Clay
LDS-BH-2007B, 24 m Down Hole @ 90° Alluvial - Sand
LDS-BH-2007B, 32.9 m Down Hole @ 90° Hawkesbury Sandstone

Figure B13



LDS-BH-2007B Pore Pressure Drawdown In Alluvium
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
1.60
Drawdown (m)
100
1,000
10,000
Elapsed Time (Minutes)
LDS-BH-2007B, 10 m Down Hole @ 90° Alluvival - Sand
LDS-BH-2007B, 13 m Down Hole @ 90° Alluvial - Sandy Clay
LDS-BH-2007B, 24 m Down Hole @ 90° Alluvial - Sand
Pump shutdown

Figure B14



LDS-BH-2033 Pore Pressure Drawdown Pump Test 2
Drawdown (m)
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
1
10
100
1,000
10,000
Elapsed Time (Minutes)
Pump shutdown
LDS-BH-2033, 21.2 m Down Hole @ 71° Alluvial - Sandy Clay
LDS-BH-2033, 27.7 m Down Hole @ 71° Alluvial - Sandy Clay
LDS-BH-2033, 57.7 m Down Hole @ 71° Hawkesbury Sandstone (Fractured)

Figure B15

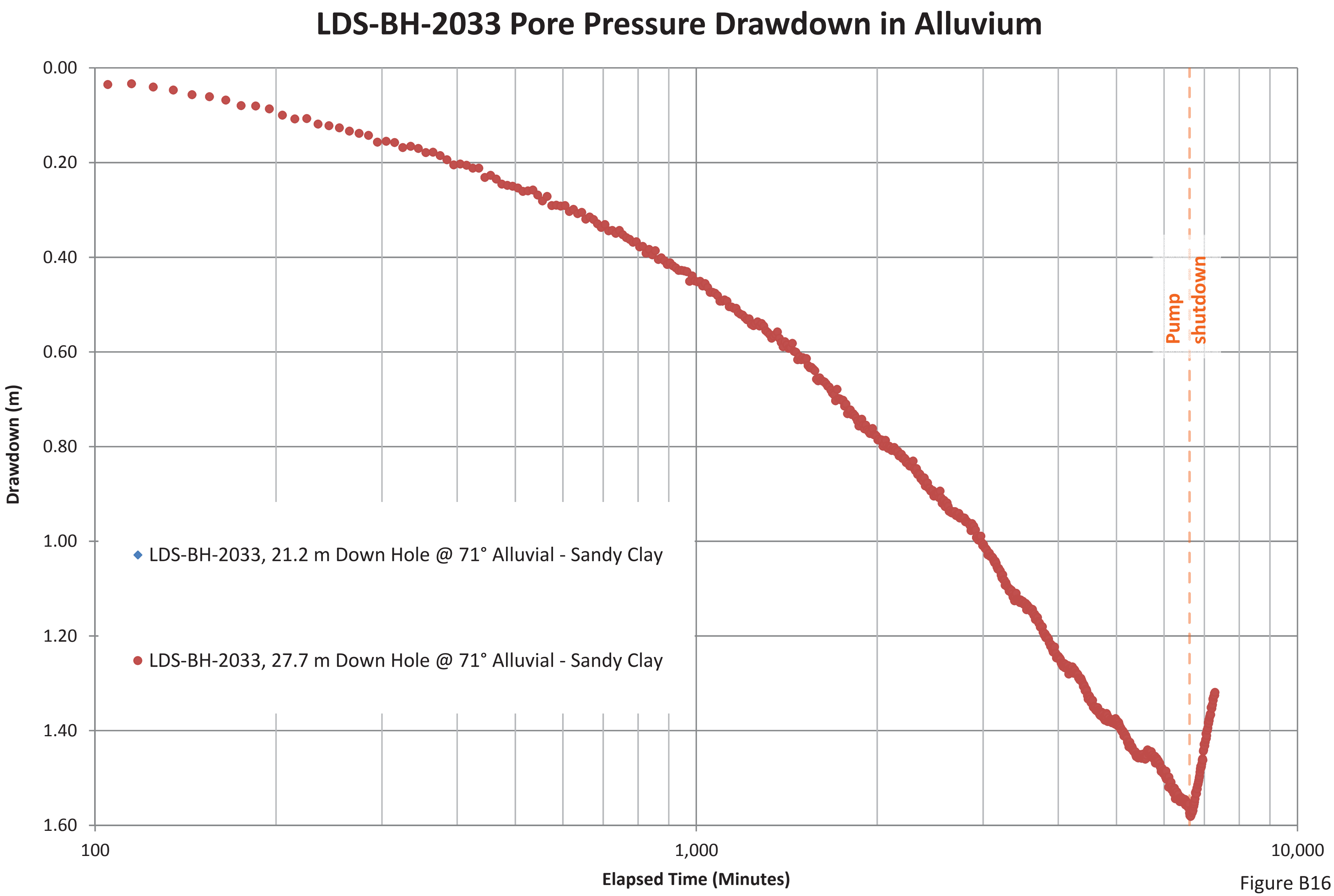

LDS-BH-2033 Pore Pressure Drawdown in Alluvium
Drawdown (m)
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
1.60
100
1,000
10,000
Elapsed Time (Minutes)
LDS-BH-2033, 21.2 m Down Hole @ 71° Alluvial - Sandy Clay
LDS-BH-2033, 27.7 m Down Hole @ 71° Alluvial - Sandy Clay
Pump shutdown

Figure B16

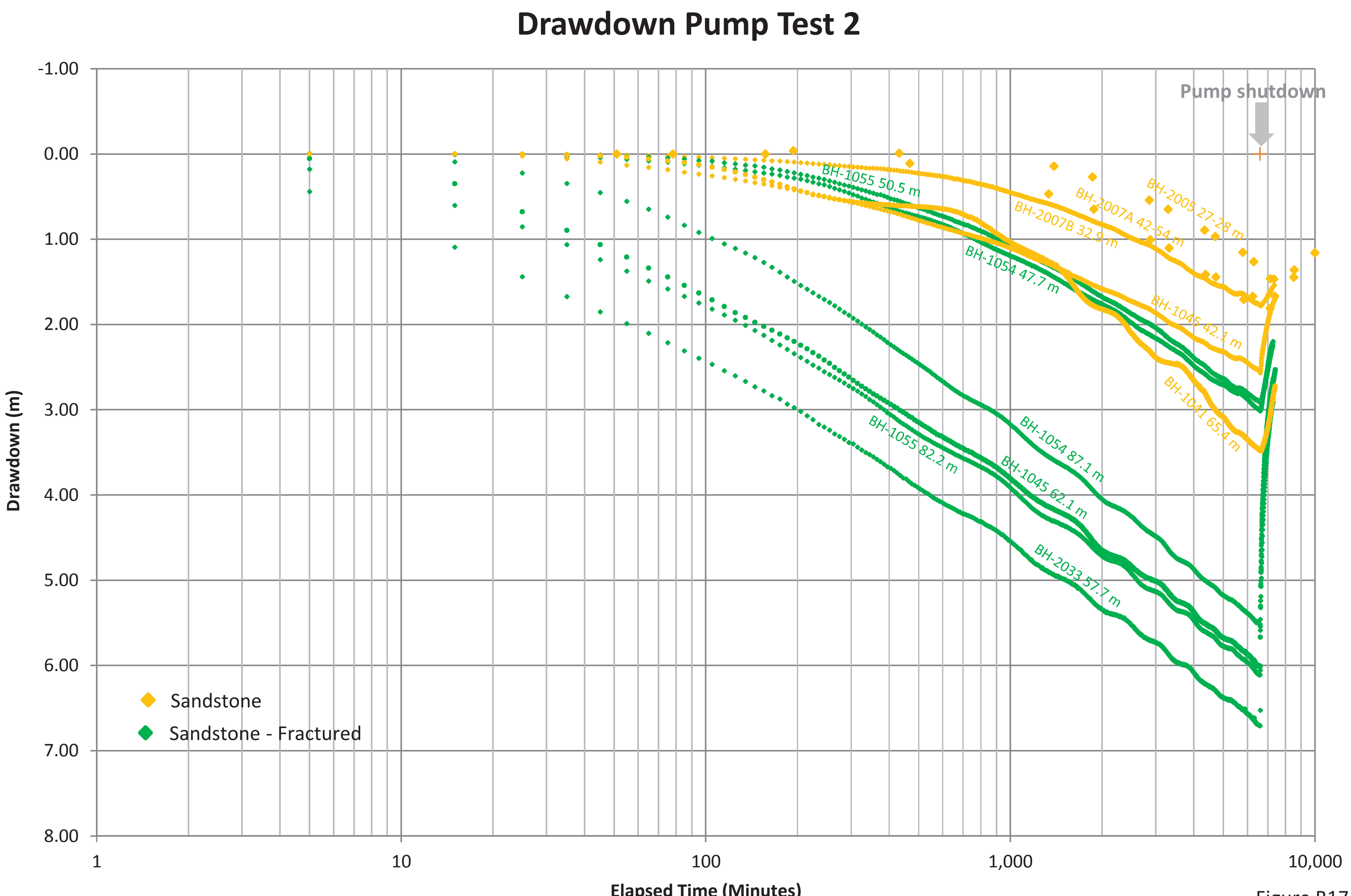
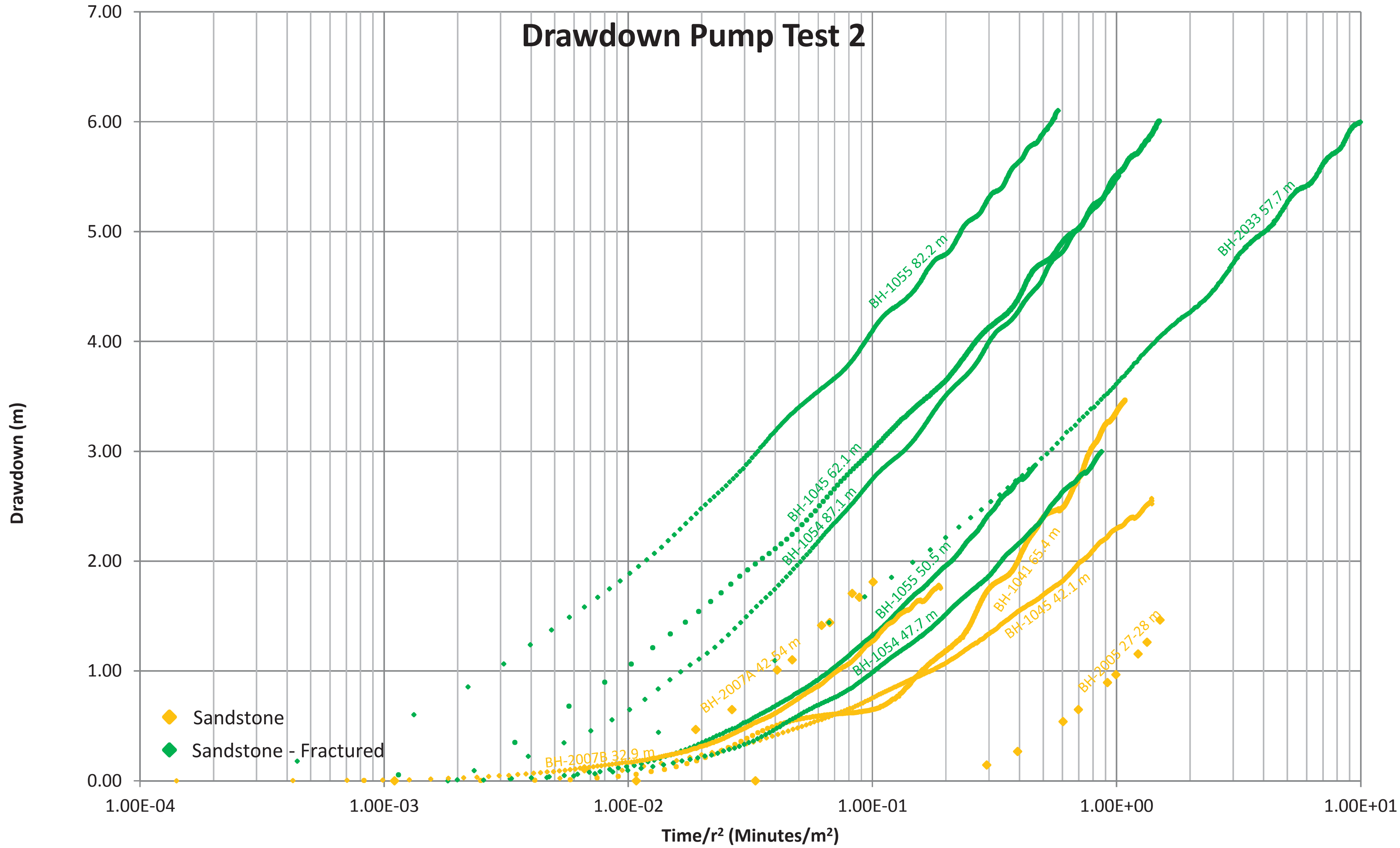

Drawdown Pump Test 2
Pump shutdown
BH-1055 50.5 m
BH-2007B 32.9 m
BH-2007A 42-54 m
BH-2005 27-28 m
BH-1054 47.7 m
BH-1045 42.1 m
BH-1041 65.4 m
BH-1054 87.1 m
BH-1055 82.2 m
BH-1045 62.1 m
BH-2033 57.7 m
Sandstone
Sandstone - Fractured
Drawdown (m)
Elapsed Time (Minutes)
-1.00
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
8.00
1
10
100
1,000
10,000

Figure B17



Drawdown Pump Test 2
Drawdown (m)
Time/r² (Minutes/m²)
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
1.00E-04
1.00E-03
1.00E-02
1.00E-01
1.00E+00
1.00E+01
Sandstone
Sandstone - Fractured
BH-1055 82.2 m
BH-2033 57.7 m
BH-1045 62.1 m
BH-1054 87.1 m
BH-1055 50.5 m
BH-1054 47.7 m
BH-1041 65.4 m
BH-1045 42.1 m
BH-2007A 42.54 m
BH-2007B 32.9 m
BH-2005 27-28 m

Figure B18

APPENDIX C

Groundwater Quality Test Results

Table D-1: LDS-PW-2901 Field Water Quality Parameters (Pre-treatment)

LDS-PW-2901 PRE pH TREATMENT FIELD WATER QUALITY									
Date and Time	pH	Redox	Electrical Conductivity	Temperature	Dissolved Oxygen				
		mV	µS/cm	°C	mg/L	Appearance	Turbidity (NTU)	Odour	Sample type
Airlift Testing									
23/02/2016 14:43	5.96	-37	26568	21.9	-	moderately turbid, grey-brown	-	N/A	Airlift Sample
SRT / Commissioning pH Dosing Unit									
3/03/2016 12:10	5.25	-24.9	35752	34.1	1.71	Clear	7.2	N/A	Return Grab Sample
3/03/2016 12:53	5.23	-50.4	37002	35.4	1.74	Clear	9.3	N/A	Return Grab Sample
3/03/2016 13:31	5.99	-120	29694	22.9	0.37	Clear	4.6	N/A	Return Grab Sample
3/03/2016 14:44	5.39	-29.5	29908	22.8	2.92	Clear	3.8	N/A	Return Grab Sample
3/03/2016 15:55	5.48	-3.2	31903	37.1	2.44	Clear	4.2	N/A	Return Grab Sample
CRT (26 hrs) Operational Test Results									
4/03/2016 10:55	6.48	18.7	29164	22	1.99	Clear	6.6	N/A	Return Grab Sample
4/03/2016 11:53	6.33	17.5	29610	21.5	3.26	Clear	6.1	N/A	Return Grab Sample
4/03/2016 12:55	6.35	5.2	30158	21.8	2.5	Clear	6.9	N/A	Return Grab Sample
4/03/2016 13:59	6.38	10.4	30355	21.6	3.07	Clear	8.4	N/A	Return Grab Sample
4/03/2016 14:46	6.34	5.7	30155	22.4	1.95	Clear	7.7	N/A	Return Grab Sample
4/03/2016 16:20	6.46	-0.8	29551	21.1	1.81	Clear	8	N/A	Return Grab Sample
4/03/2016 17:02	6.47	-9.5	29744	21.5	0.99	Clear	6.4	N/A	Return Grab Sample
5/03/2016 8:35	6.46	20.4	30748	19.9	2.99	Clear	4.6	N/A	Return Grab Sample
5/03/2016 10:52	7.09	23.5	34505	23.4	2.03	Clear	7.9	N/A	Return Grab Sample
CRT (4.5 days) Operational Test Results									
11/03/2016 10:22	6.03	-21	30297	20.8	4.46	Clear	26	N/A	Return Grab Sample
11/03/2016 11:32	6.96	-17.7	30062	22.6	4.22	Clear	13.1	N/A	Return Grab Sample
11/03/2016 12:26	6.55	13.2	31632	22.5	4.2	Clear	13	N/A	Return Grab Sample
11/03/2016 14:26	6.24	-16.6	35077	23.5	3.49	Clear	13.6	N/A	Return Grab Sample
11/03/2016 15:59	6.73	-11.8	32030	20.6	0.7	Clear	32.6	N/A	Return Grab Sample
12/03/2016 9:28	5.94	32.1	32379	21	0.73	Clear	32.7	N/A	Return Grab Sample
12/03/2016 16:13	5.82	-7.3	33121	21.3	0.5	Clear	12.8	N/A	Return Grab Sample
13/03/2016 8:43	6.2	-40.7	32600	20.2	0.53	Clear	34.1	N/A	Return Grab Sample
13/03/2016 15:54	5.75	-45.9	33192	20.5	1.01	Clear	24.1	N/A	Return Grab Sample
14/03/2016 8:37	6.37	-25.1	33335	20.5	2.89	Clear	22.6	N/A	Return Grab Sample
14/03/2016 15:33	5.88	-41.7	32135	20.7	0.8	Clear	24.2	N/A	Return Grab Sample
15/03/2016 9:47	6.33	-44.4	32636	22	3.72	Clear	25.3	N/A	Return Grab Sample
15/03/2016 16:55	5.75	307.9	32238	21.2	3.88	Clear	26.1	N/A	Return Grab Sample

Table D-2: LDS-PW-2901 Field Water Quality Parameters (Post-treatment)

LDS-PW-2901 POST pH TREATMENT FIELD WATER QUALITY									
	pH	Redox	Electrical Conductivity	Temperature	Dissolved Oxygen				
Date and Time		mV	µS/cm	°C	mg/L	Appearance	Turbidity (NTU)	Odour	Sample type
SRT / Commissioning pH Dosing Unit									
3/03/2016 12:05	5.28	-25.8	36836	35.3	1.15	Medium Turbidity	24.9	N/A	Return Grab Sample
3/03/2016 12:49	5.56	-118	36043	34.1	0.21	Blue	46	N/A	Return Grab Sample
3/03/2016 13:29	6.84	-358.7	31192	24.5	0.02	Blue	35.9	N/A	Return Grab Sample
3/03/2016 14:46	5.82	-91.9	29985	22.7	0.74	Clear	4.3	N/A	Return Grab Sample
3/03/2016 15:53	5.72	-84.1	29697	21.9	0.82	Clear	8.6	N/A	Return Grab Sample
CRT (26 hrs) Operational Test Results									
4/03/2016 10:47	6.73	-46.3	29206	23.4	1.00	Clear	9.9	N/A	Return Grab Sample
4/03/2016 11:55	6.70	-53.9	31077	24.4	0.73	Clear	6.5	N/A	Return Grab Sample
4/03/2016 12:57	6.70	-67.2	30120	22.7	0.81	Clear	4.2	N/A	Return Grab Sample
4/03/2016 14:01	6.75	-83.5	32953	26.4	0.53	Clear	5.1	N/A	Return Grab Sample
4/03/2016 14:48	6.65	-66.2	30260	22.2	0.73	Clear	10.1	N/A	Return Grab Sample
4/03/2016 16:18	6.65	-81	30452	21.9	1.06	Clear	9.1	N/A	Return Grab Sample
4/03/2016 17:00	6.73	-69.2	30007	21.4	0.89	Clear	8.9	N/A	Return Grab Sample
5/03/2016 8:37	7.72	-32.3	31325	20.1	1.12	Clear	8.9	N/A	Return Grab Sample
5/03/2016 10:55	7.41	-54.6	36103	26.4	1.28	Clear	7	N/A	Return Grab Sample
CRT (4.5 days) Operational Test Results									
11/03/2016 10:26	6.53	-81.3	30414	20.1	0.41	Clear	9.3	N/A	Return Grab Sample
11/03/2016 11:34	7.12	-28.9	30911	20.4	2.21	Clear	16.2	N/A	Return Grab Sample
11/03/2016 12:28	6.75	-39.8	31770	22.4	0.55	Clear	13.7	N/A	Return Grab Sample
11/03/2016 14:28	6.78	-77.1	32699	21.4	0.68	Clear	15.5	N/A	Return Grab Sample
11/03/2016 15:58	6.86	-78.9	32619	21	1.09	Clear	22	N/A	Return Grab Sample
12/03/2016 9:30	6.04	-48.1	34852	24.2	0.59	Clear	18.2	N/A	Return Grab Sample
12/03/2016 16:11	5.8	-61	33861	21.7	0.75	Clear	18.3	N/A	Return Grab Sample
13/03/2016 8:46	6.2	-89	32479	19.9	0.72	Clear	21	N/A	Return Grab Sample
13/03/2016 15:55	5.91	-79.7	33143	20.6	0.67	Clear	24.2	N/A	Return Grab Sample
13/03/2016 16:53	6.02	-67.7	34263	22.1	2.6	Clear	34.5	N/A	Discharge Point Sample
14/03/2016 8:30	6.66	102.1	33796	21	0.61	Clear	26.8	N/A	Return Grab Sample
14/03/2016 14:06	6.2	-17.4	27909	24.1	4.13	Clear		N/A	Discharge Point Sample
14/03/2016 15:31	6.03	-18.6	32365	21.1	0.66	Clear	20.4	N/A	Return Grab Sample
15/03/2016 9:45	6.78	-118.2	32968	22	0.84	Clear	70.6	N/A	Return Grab Sample
15/03/2016 17:00	6.61	-105.8	31906	20.3	1.67	Clear	27.4	N/A	Return Grab Sample

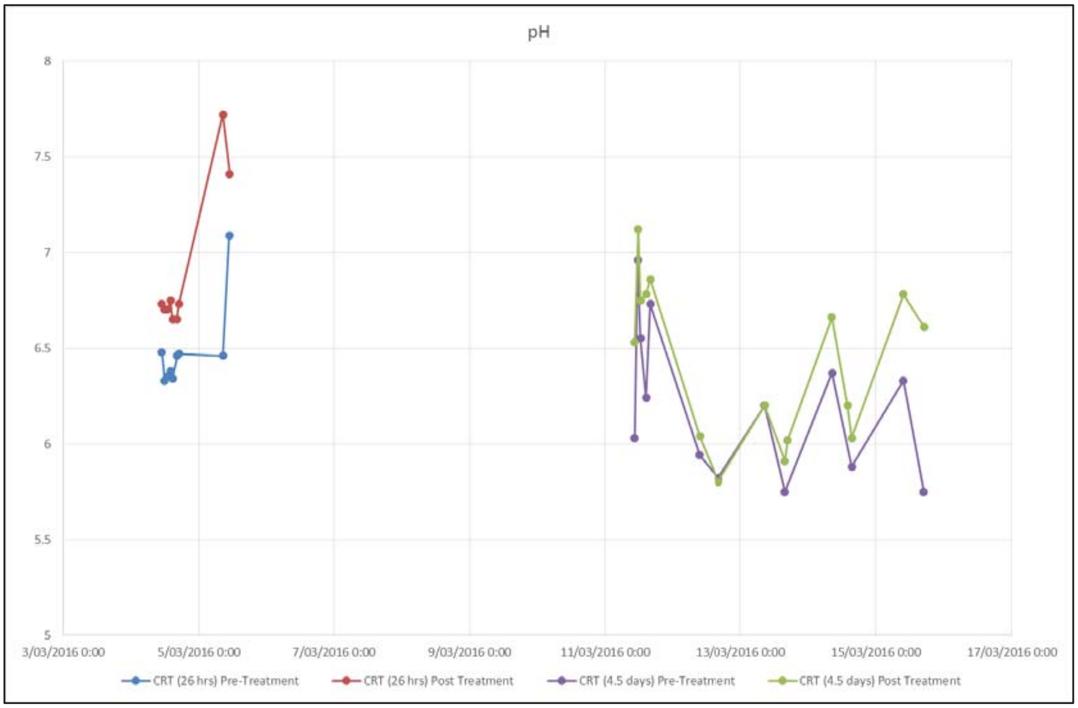


Figure D-1: LDS-PW-2901 pH

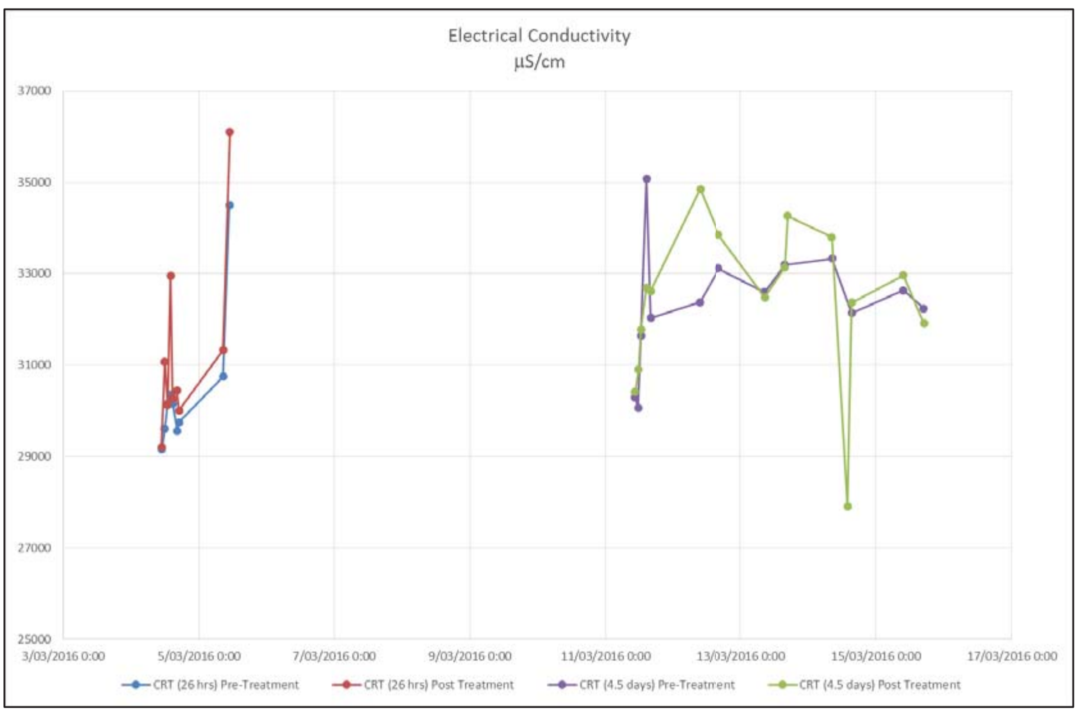


Figure D-2: LDS-PW-2901 Electrical Conductivity

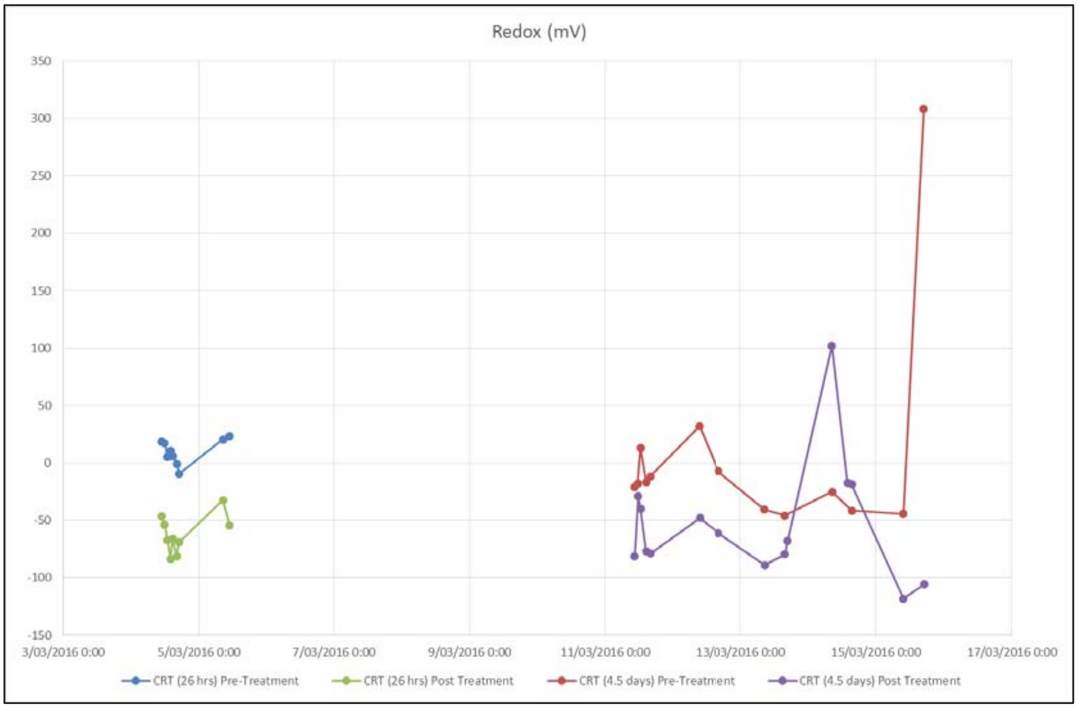


Figure D-3: LDS-PW-2901 Redox Potential

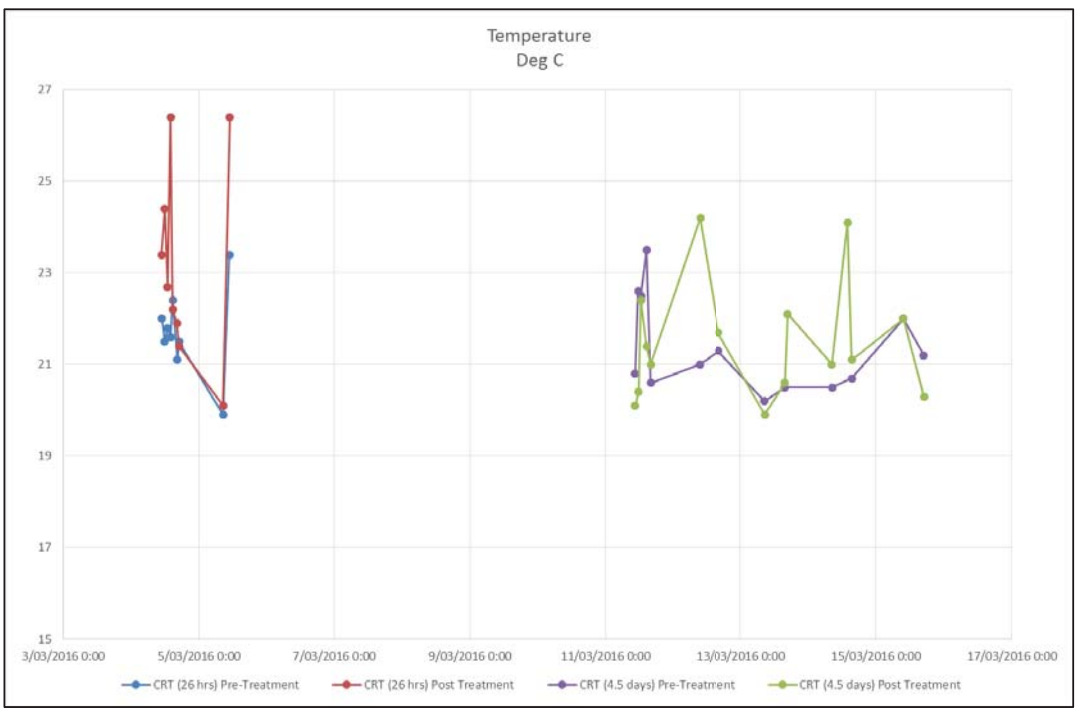


Figure D-4: LDS-PW-2901 Temperature

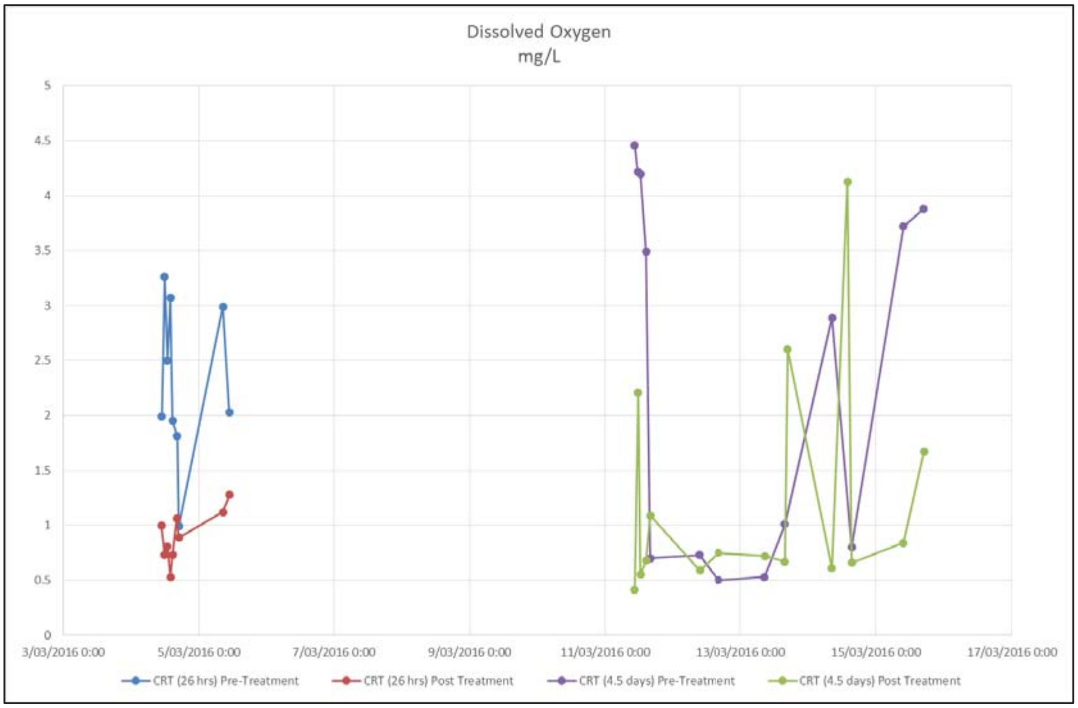


Figure D-5: LDS-PW-2901 Dissolved Oxygen

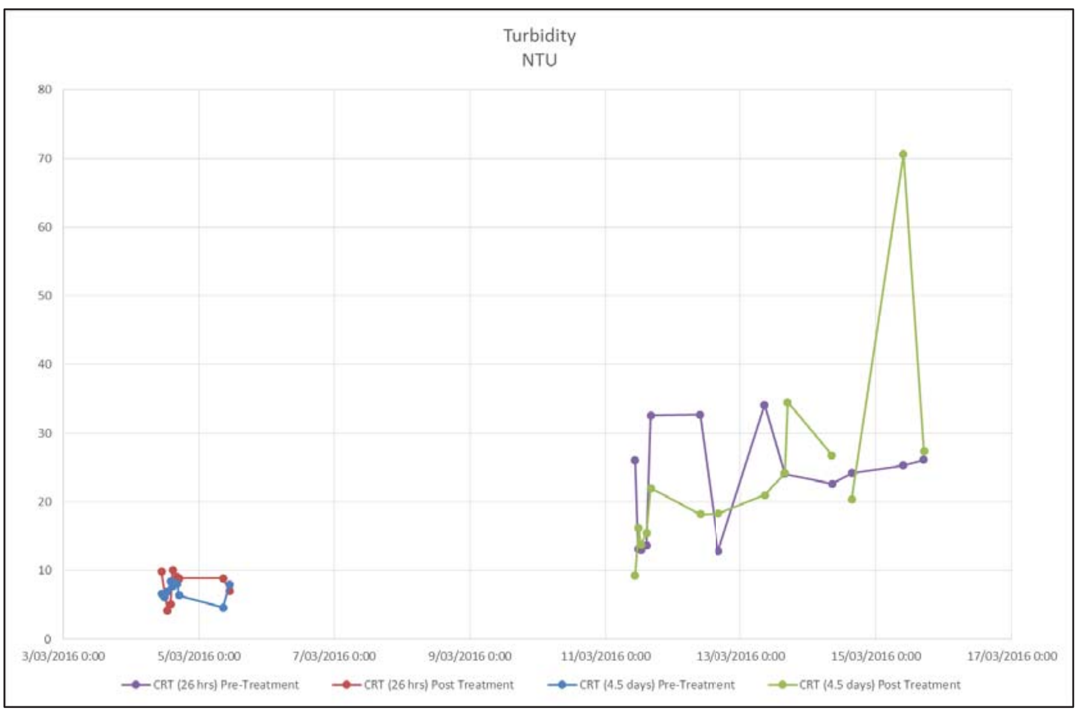


Figure D-6: LDS-PW-2901 Turbidity

Table D-3: Laboratory Analytical Results

	Sample ID	BH2029 _17/02/16	BH2029A _17/02/16	PW2901 _55.5	BH2005 _24/2/16	PW2901 _4/03/2016	PW2901 _11/03/2016	PW2901 _13/03/2016
	Sample Date	17/2/2016	17/2/2016	23/2/2016	24/2/2016	4/3/2016	11/3/2016	13/3/2016
Field Parameters								
Parameter	**Units**							
Temperature	°C	19.4	19.4	21.9	22.3	26.5	21.4	24.2
pH	pH units	6.33	5.41	5.96	5.23	6.75	6.78	-
ORP	mV	-83.8	-86.3	-37	-22.6	-83.5	-77.1	-79.7
Electrical Conductivity	µS/cm	28218	32818	26568	23091	32953	32699	33143
Dissolved Oxygen	mg/L	-	-	-	-	0.53	0.68	0.67
Turbidity	NTU	-	-	-	-	5.1	15.5	24.2

Sample ID			BH2029 _17/02/16	BH2029A _17/02/16	PW2901 _55.5	BH2005 _24/2/16	PW2901 _4/03/2016	PW2901 _11/03/2016	PW2901 _13/03/2016
Sample date			17/2/2016	17/2/2016	23/2/2016	24/2/2016	4/3/2016	11/3/2016	13/3/2016
Analyte	**Unit**	**Limit of Reporting**							
pH**	No unit	0	**5.9**	**5.3**	**5.8**	**5.9**	**5.7**	**5.7**	**6.0**
Conductivity @ 25 C	µS/cm	2	**36000**	**40000**	**30000**	**25000**	**42000**	**43000**	**43000**
Total Dissolved Solids Dried at 175-185°C	mg/L	10	**20000**	**25000**	**17000**	**18000**	**21000**	**23000**	**24000**
Total Suspended Solids Dried at 103-105°C	mg/L	5	**110**	**6**	**320**	**300**	**140**	**120**	**88**
Bicarbonate Alkalinity as HCO3	mg/L	5	**130**	**33**	**11**	**12**	**170**	**71**	**140**
Carbonate Alkalinity as CO3	mg/L	1	<1	<1	<1	<1	<1	<1	<1
Total Alkalinity as CaCO3	mg/L	5	**110**	**27**	**9**	**10**	**140**	**58**	**110**
Chloride	mg/L	1	**11000**	**12000**	**11000**	**9100**	**12000**	**12000**	**12000**
Nitrate Nitrogen, NO3-N	mg/L	0.005	<0.1	<0.1	<0.025	<0.1	<0.025	<0.25	<0.25
Sulphate, SO4	mg/L	1	**1300**	**1400**	**1300**	**170**	**1500**	**1500**	**1500**
Nitrite Nitrogen, NO2 as N	mg/L	0.005	<0.025	<0.025	<0.005	<0.005	<0.005	<0.005	<0.005
Total Kjeldahl Nitrogen	mg/L	0.05	**2.3**	**2.4**	**2.7**	**4.1**	**2.6**	**2.5**	**2.4**
Total Nitrogen (calc)	mg/L	0.05	**2.3**	**2.4**	**2.7**	**4.1**	**2.6**	**2.5**	**2.4**
Total Phosphorus (Kjeldahl Digestion)	mg/L	0.01	**0.07**	**0.10**	**0.11**	<0.01	**0.04**	**0.06**	**0.06**
Filterable Reactive Phosphorus	mg/L	0.005	<0.025	<0.025	**0.012**	**0.006**	**0.016**	**0.035**	**0.110**

Sample ID			BH2029 _17/02/16	BH2029A _17/02/16	PW2901 _55.5	BH2005 _24/2/16	PW2901 _4/03/2016	PW2901 _11/03/2016	PW2901 _13/03/2016
Ammonia Nitrogen, NH_3 as N	mg/L	0.005	**1.4**	**0.56**	**2.1**	**1.0**	**1.9**	**1.7**	**1.5**
Calcium, Ca	mg/L	0.2	**530**	**530**	**770**	**720**	**660**	**620**	**590**
Magnesium, Mg	mg/L	0.1	**750**	**820**	**840**	**810**	**910**	**900**	**930**
Sodium, Na	mg/L	0.5	**5300**	**6200**	**5100**	**3500**	**6100**	**6500**	**6500**
Potassium, K	mg/L	0.1	**210**	**260**	**130**	**130**	**150**	**130**	**140**
Total Hardness by Calculation	mg CaCO3/L	5	**4400**	**4700**	**5400**	**5100**	**5400**	**5200**	**5300**
Iron, Fe	µg/L	5	**150000**	**300000**	**100000**	**330000**	**150000**	**140000**	**200000**
Manganese, Mn	µg/L	1	**3400**	**2300**	**2900**	**3700**	**3600**	**3700**	**3800**
Aluminium, Al	µg/L	5	**12**	**82**	<5	**10**	**7**	**6**	**7**
Arsenic, As	µg/L	1	<1	<1	<1	<1	<1	<1	<1
Cadmium, Cd	µg/L	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Copper, Cu	µg/L	1	<1	<1	<1	<1	<1	<1	<1
Chromium, Cr	µg/L	1	**2**	**2**	<1	<1	<1	<1	<1
Nickel, Ni	µg/L	1	<1	<1	**4**	<1	<1	<1	<1
Lead, Pb	µg/L	1	<1	<1	<1	<1	<1	<1	<1
Zinc, Zn	µg/L	5	**7**	**17**	**80**	**7**	**73**	61	55
Mercury	mg/L	0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Total Iron	µg/L	5	**170000**	**310000**	**140000**	**340000**	**160000**	**170000**	**210000**
Total Manganese	µg/L	1	**3300**	**2400**	**3000**	**3800**	**3600**	**3700**	**3800**
Total Mercury	mg/L	0.0001	<0.0001	<0.0001	-	<0.0001	-	-	-
Hexavalent Chromium, Cr6+	mg/L	0.004	<0.004	<0.004	-	-	-	-	-
Trivalent Chromium, Cr3+	mg/L	0.05	<0.05	<0.05	-	-	-	-	-
Trivalent Chromium, Cr3+	mg/L	0.05	<0.05	<0.05	-	-	-	-	-
Chromium, Cr	mg/L	0.005	<0.005	<0.005	-	-	-	-	-
Benzene	µg/L	0.5	<0.5	<0.5	<0.5	-	<0.5	<0.5	<0.5
Toluene	µg/L	0.5	<0.5	<0.5	<0.5	-	<0.5	1.8	<0.5
Ethylbenzene	µg/L	0.5	<0.5	<0.5	<0.5	-	<0.5	<0.5	<0.5
m/p-xylene	µg/L	1	<1	<1	<1	-	<1	<1	<1
o-xylene	µg/L	0.5	<0.5	<0.5	<0.5	-	<0.5	<0.5	<0.5
Total Xylenes	µg/L	1.5	<1.5	<1.5	<1.5	-	<1.5	<1.5	<1.5
Total BTEX	µg/L	3	<3	<3	<3	-	<3	<3	<3
Naphthalene	µg/L	0.5	<0.5	<0.5	<0.5	-	<0.5	<0.5	<0.5
Dibromofluoromethane (Surrogate)	%	0	**112**	**116**	**115**	-	**108**	**116**	**125**

Sample ID			BH2029 _17/02/16	BH2029A _17/02/16	PW2901 _55.5	BH2005 _24/2/16	PW2901 _4/03/2016	PW2901 _11/03/2016	PW2901 _13/03/2016
d4-1,2-dichloroethane (Surrogate)	%	0	**113**	**114**	**115**	-	**119**	**122**	**125**
d8-toluene (Surrogate)	%	0	**100**	**103**	**97**	-	**88**	**109**	**112**
Bromofluorobenzene (Surrogate)	%	0	**81**	**80**	**80**	-	**90**	**87**	**85**
TRH C6-C9	µg/L	40	<40	<40	<40	-	<40	<40	<40
Benzene (F0)	µg/L	0.5	<0.5	<0.5	<0.5	-	<0.5	<0.5	<0.5
TRH C6-C10	µg/L	50	<50	<50	<50	-	<50	<50	<50
TRH C6-C10 minus BTEX (F1)	µg/L	50	<50	<50	<50	-	<50	<50	<50
Dibromofluoromethane (Surrogate)	%	0	**112**	**116**	**115**	-	**108**	**116**	**125**
d4-1,2-dichloroethane (Surrogate)	%	0	**113**	**114**	**115**	-	**119**	**122**	**125**
d8-toluene (Surrogate)	%	0	**100**	**103**	**97**	-	**88**	**109**	**112**
Bromofluorobenzene (Surrogate)	%	0	**81**	**80**	**80**	-	**90**	**87**	**85**
TRH C10-C14	µg/L	50	<50	<50	**79**	-	<50	<50	<50
TRH C15-C28	µg/L	200	<200	<200	<200	-	<200	<200	<200
TRH C29-C36	µg/L	200	<200	<200	<200	-	<200	<200	<200
TRH C37-C40	µg/L	200	<200	<200	<200	-	<200	<200	<200
TRH >C10-C16 (F2)	µg/L	60	<60	**61**	**120**	-	<60	<60	<60
TRH >C16-C34 (F3)	µg/L	500	<500	<500	<500	-	<500	<500	<500
TRH >C34-C40 (F4)	µg/L	500	<500	<500	<500	-	<500	<500	<500
TRH C10-C36	µg/L	450	<450	<450	<450	-	<450	<450	<450
TRH C10-C40	µg/L	650	<650	<650	<650	-	<650	<650	<650
Alpha BHC	µg/L	0.1	<0.1	<0.1	<0.1	-	N.A.	<0.1	<0.1
Hexachlorobenzene (HCB)	µg/L	0.1	<0.1	<0.1	<0.1	-	N.A.	<0.1	<0.1
Beta BHC	µg/L	0.1	<0.1	<0.1	<0.1	-	N.A.	<0.1	<0.1
Lindane (gamma BHC)	µg/L	0.1	<0.1	<0.1	<0.1	-	N.A.	<0.1	<0.1
Delta BHC	µg/L	0.1	<0.1	<0.1	<0.1	-	N.A.	<0.1	<0.1
Heptachlor	µg/L	0.1	<0.1	<0.1	<0.1	-	N.A.	<0.1	<0.1
Aldrin	µg/L	0.1	<0.1	<0.1	<0.1	-	N.A.	<0.1	<0.1
Heptachlor epoxide	µg/L	0.1	<0.1	<0.1	<0.1	-	N.A.	<0.1	<0.1
Gamma Chlordane	µg/L	0.1	<0.1	<0.1	<0.1	-	N.A.	<0.1	<0.1
Alpha Chlordane	µg/L	0.1	<0.1	<0.1	<0.1	-	N.A.	<0.1	<0.1
Alpha Endosulfan	µg/L	0.1	<0.1	<0.1	<0.1	-	N.A.	<0.1	<0.1
o,p'-DDE	µg/L	0.1	<0.1	<0.1	<0.1	-	N.A.	<0.1	<0.1
p,p'-DDE	µg/L	0.1	<0.1	<0.1	<0.1	-	N.A.	<0.1	<0.1

Sample ID			BH2029 _17/02/16	BH2029A _17/02/16	PW2901 _55.5	BH2005 _24/2/16	PW2901 _4/03/2016	PW2901 _11/03/2016	PW2901 _13/03/2016
Dieldrin	µg/L	0.1	<0.1	<0.1	<0.1	-	N.A.	<0.1	<0.1
Endrin	µg/L	0.1	<0.1	<0.1	<0.1	-	N.A.	<0.1	<0.1
Beta Endosulfan	µg/L	0.1	<0.1	<0.1	<0.1	-	N.A.	<0.1	<0.1
o,p'-DDD	µg/L	0.1	<0.1	<0.1	<0.1	-	N.A.	<0.1	<0.1
p,p'-DDD	µg/L	0.1	<0.1	<0.1	<0.1	-	N.A.	<0.1	<0.1
Endosulfan sulphate	µg/L	0.1	<0.1	<0.1	<0.1	-	N.A.	<0.1	<0.1
o,p'-DDT	µg/L	0.1	<0.1	<0.1	<0.1	-	N.A.	<0.1	<0.1
p,p'-DDT	µg/L	0.1	<0.1	<0.1	<0.1	-	N.A.	<0.1	<0.1
Endrin ketone	µg/L	0.1	<0.1	<0.1	<0.1	-	N.A.	<0.1	<0.1
Methoxychlor	µg/L	0.1	<0.1	<0.1	<0.1	-	N.A.	<0.1	<0.1
trans-Nonachlor	µg/L	0.1	<0.1	<0.1	<0.1	-	N.A.	<0.1	<0.1
Endrin aldehyde	µg/L	0.1	<0.1	<0.1	<0.1	-	N.A.	<0.1	<0.1
Isodrin	µg/L	0.1	<0.1	<0.1	<0.1	-	N.A.	<0.1	<0.1
Mirex	µg/L	0.1	<0.1	<0.1	<0.1	-	N.A.	<0.1	<0.1
Tetrachloro-m-xylene (TCMX) (Surrogate)	%	0	**81**	**79**	**91**	-	N.A.	**95**	**61**
Dichlorvos	µg/L	0.5	<0.5	<0.5	<0.5	-	<0.5	<0.5	<0.5
Dimethoate	µg/L	0.5	<0.5	<0.5	<0.5	-	<0.5	<0.5	<0.5
Diazinon (Dimpylate)	µg/L	0.5	<0.5	<0.5	<0.5	-	<0.5	<0.5	<0.5
Fenitrothion	µg/L	0.2	<0.2	<0.2	<0.2	-	<0.2	<0.2	<0.2
Malathion	µg/L	0.2	<0.2	<0.2	<0.2	-	<0.2	<0.2	<0.2
Chlorpyrifos (Chlorpyrifos Ethyl)	µg/L	0.2	<0.2	<0.2	<0.2	-	<0.2	<0.2	<0.2
Parathion-ethyl (Parathion)	µg/L	0.2	<0.2	<0.2	<0.2	-	<0.2	<0.2	<0.2
Bromophos Ethyl	µg/L	0.2	<0.2	<0.2	<0.2	-	<0.2	<0.2	<0.2
Methidathion	µg/L	0.5	<0.5	<0.5	<0.5	-	<0.5	<0.5	<0.5
Ethion	µg/L	0.2	<0.2	<0.2	<0.2	-	<0.2	<0.2	<0.2
Azinphos-methyl	µg/L	0.2	<0.2	<0.2	<0.2	-	<0.2	<0.2	<0.2
2-fluorobiphenyl (Surrogate)	%	0	**46**	**52**	**52**	-	**48**	**58**	**52**
d14-p-terphenyl (Surrogate)	%	0	**54**	**72**	**78**	-	**92**	**78**	**88**

Note: 'TBC' indicates results pending

'-' indicates the parameter was not analysed

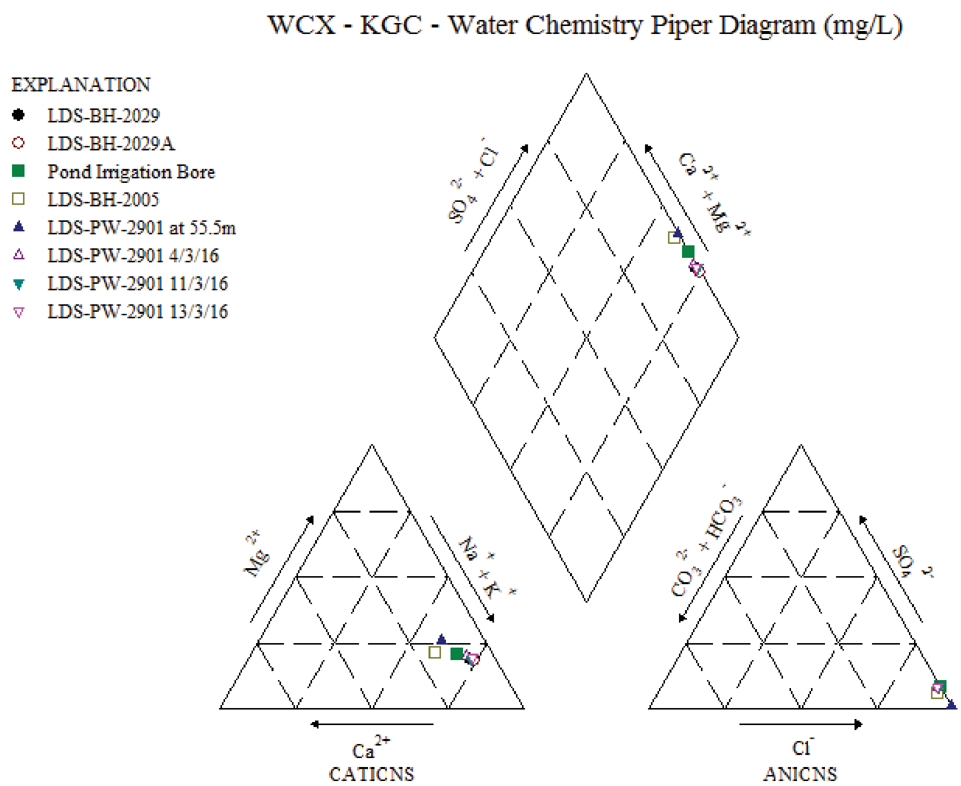


Figure D-7: KGC Water Chemistry Piper Diagram

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Annexure K –Pumping Test Summary

Pumping Wells LDS–PW-2902 and LDS-PW-2004

1.0 TEST PUMPING CONFIGURATION

Pumping wells and monitoring locations were installed for the test pumping on the Kogarah Golf Course (KGC) and in the adjacent area to assess possible impacts of dewatering during tunnel construction and operation. The locations of the pumping wells and associated monitoring network is presented in Appendix A and includes the following:

- 2 newly installed test pumping wells (referred to as LDS-PW-2902 and LDS-PW-2904)
- 4 monitoring wells installed previously by external consultants
- 4 monitoring wells previously installed by Golder
- 6 nested Vibrating Wire Piezometer (VWP) locations previously installed by Golder
- 5 nested VWP locations newly installed by Golder
- 1 barometric logger at the entrance to KGC
- 1 tidal monitoring point in the Cooks River

Additional information on the installations is provided in the following sections.

1.1 Pumping Well LDS-PW-2902

Drilling of pumping well LDS-PW-2902 commenced on the 4th of July 2016 and was completed on the 11th July 2016. The well was drilled and constructed by TerraTest using a sonic drilling rig. The pumping well was located within CDS's construction area (formerly part of the Kogarah Golf Course). PW-2902 was drilled approximately 70m east of LDS-PW-2901 which was drilled and test pumped in February and March 2016.

The well was completed as follows:

1) VW 8 $^{5}/_{8}$" (219 mm OD) flush joint temporary casing was progressed to 22.5 mbgs using sonic drilling methods to case off the alluvium. Competent rock (Hawkesbury Sandstone) was encountered at approximately 18.5mbgs.
2) A 152 mm borehole was drilled to 33 mbgs using down hole air hammer drilling techniques. PW 5 $^{2}/_{3}$" (143.8 mm OD) flush joint steel casing installed in the borehole and pressure grouted in place to isolate the overlying alluvials from the borehole.
3) The hole was drilled to a total depth of 80mbgs using 123 mm down hole air hammer bit. This section forms the production portion of the well and was left uncased and unscreened (i.e. it is an open hole in rock).

A fractured zone was intersected at approximately 43-44 mbgs and produced 2.5-3 litres per second (L/s) during airlifting. The airlift yield remained reasonably constant below this depth. No other significant water bearing intersections were encountered.

Once the well was completed an acoustic and an optical televiewer were run in the well to image the open hole section of the well.

1.2 Pumping Well LDS-PW-2904

Drilling of the pumping well LDS-PW-2904 commenced on the 8th of July 2016 and was completed on the 14th of July 2016. The well was drilled and constructed by Star Drilling using a sonic LS600 drilling rig. The pumping well was located in the grassed area at the corner of Rockwell and Levey Streets.

The well was completed as follows:

1) VW 7 $^{5}/_{8}$" (193.7 mm OD) flush joint temporary casing was progressed to 39mbgs using sonic drilling methods and to case off the alluvium. Competent rock (Hawkesbury Sandstone) was encountered at approximately 38 mbgs.
2) SW 6" (158.8 mm OD) flush joint casing was progressed to 52 mbgs using sonic drilling methods.

3) PVC casing (125 mm) was installed in the hole and pressure grouted to isolate the overlying alluvials from the borehole.

4) The hole was drilled to a total depth of 92mbgs using a 123 mm down hole air hammer. This section forms the production portion of the well and was left uncased and unscreened (i.e. it is an open hole in rock).

A significant fracture zone was intersected at approximately 83 mbgs and produced and estimated 13-14 L/s during airlifting. No significant water bearing intersections were encountered above this depth.

At the completion of the well, an acoustic and an optical televiewer were run in the well to image the open hole section of the well.

1.3 Groundwater level monitoring

The groundwater monitoring network consisted of nested VWP's equipped with data loggers and standpipe monitoring wells equipped with pressure transducers. Data was gathered prior to the commencement of pumping to collect baseline data for groundwater level behaviour. Data was downloaded periodically during pump testing to progressively monitor aquifer response to pumping.

Data recording frequency was set to 30 minutes on the hour for all monitoring locations except for the LDS-BH-1057. The frequency for this location was increased because it is immediately adjacent to LDS-PW-2902.

Hydrographs for each monitoring location are provided in Appendix B. The analysis of the test is principally on drawdown responses and not absolute water levels and as such the hydrographs have not been corrected for barometric effects or density.

1.4 Pump installation and flow control

Three phase Variable Speed Drive (VSD) pumps were used in both pumping wells for the testing, the pumps were capable of delivering up to 6 litres/second at the installed depth. Flow rates were adjusted via a control panel and monitored using a flow meter/totaliser installed in the discharge line. A 25mm HDPE (PN12) was installed in each well to a depth just above the pumping intake to allow a pressure transducer to be placed in the hole and to allow manual water level measurements. Pump installation details were as follows;

- **LDS-PW2902**
  - Power supply - 30kVA generator (AGMEK supplied)
  - Electro-submersible pump – Caprari E4XPD60
  - Pump intake set at 44.6mbgs
  - Test section 33-78mbgs
  - 75 mm flexible rising main
- **LDS-PW2904**
  - Power Supply - 30kVA generator (Coates hire)
  - Electro-submersible pump – Caprari E4XPD60
  - Pump intake set at 50mbgs
  - Test section 52-92mbgs
  - 75 mm flexible rising main

1.5 Groundwater discharge

A discharge permit from Rockdale Council was obtained to allow groundwater discharge during the testing. . Water was discharged to a gully in the easement adjacent to Marsh Street. The discharge line was equipped with a diffuser to dissipate the energy of the discharge water at the outflow point. A condition of the permit was for the pH of the discharge water to be greater than 6.5. CDS required the turbidity of the discharge water be less than 50 NTU.

1.5.1 pH treatment

Untreated groundwater abstracted during testing had a pH typically between pH 5 to pH 6. Prior to discharge the water was treated to raise the pH using an in line dosing station and injecting 30% Sodium Hydroxide (caustic soda). Dosing rates were typically 3-4 litres/hour for LDS-PW-2902 and 9-10 litres/hour for LDS-PW-2904.

1.5.2 Turbidity treatment

After pH dosing, water from the pumping wells was discharged into a series of three baffled sediment collection tanks. The combination of increasing pH and the residence time in the sediment tanks allowed iron to precipitate and settle. This process lowered the turbidity to acceptable levels prior to being pumped to the discharge point. The waste sludge was removed once testing was completed by vacuum truck for disposal.

1.5.3 Discharge Reticulation

A transfer pump was needed to pump the water from the sediment tanks at LDS-PW-2902 and LDS-PW-2904 to the discharge point. The reticulation for water discharge for the two wells were as follows:

- At LDS-PW-2902
  - Transfer pump - Grundfos 15-5 vertical multistage pump - equipped with float-type level switches.
  - Discharge line – 600 m of 63 mm PN12 (PE100) HDPE
  - Diffuser – 1.5 m length of perforated 125 mm PVC pipe
- At LDS-PW-2904
  - Transfer pump – Davey DT22S submersible pump - equipped with float-type level switches.
  - Discharge line – 75 m of 63 mm PN12 (PE100) HDPE
  - Diffuser – 1.5 m length of perforated 125 mm PVC pipe

2.0 HYDRAULIC TESTING

Hydraulic testing consisted of pumping from LDS-PW2902 only (initially) and then concurrently with LDS-PW-2904. The drawdown response in the Hawkesbury Sandstone Fractured rock aquifer and in the overlying alluvials was monitored throughout. Testing was carried out as follows;

2.1 LDS-PW2902

- A Step Rate Test (SRT) was carried out on the 14th of July 2016 commencing at 12:55pm. Results of the SRT were analysed to assess an appropriate pumping rate for the well. The SRT comprised 4 steps at flow rates of 0.75, 1, 2 and 3.5 litres/second. Each step was run for 60 minutes with the final step being extended to 90minutes.
- A Constant Rate Test (CRT) was initiated on the 15th of July 2016 at 12:45pm and was stopped on the 27th of July 2016 at 12:20pm (12 days of testing). The pumping rate for the CRT was set at 2 litres/second. The interference effects on drawdown once pumping from LDS-PW2904 commenced was considered in selecting the CRT flowrate.

2.2 LDS-PW2904

- A SRT was not carried out in PW2904 for two reasons: firstly to minimise the effect of variable pumping rates on the quality of the data being collected for pumping from LDS-PW-2902; and secondly, the maximum capacity of the pump available for the test was limited to 6 L/s.

Test pumping for LDS-PW-2904 was intermittent due to generator failure issues throughout testing. Test pumping commenced on the 21st of July 2016 at 3:10pm and was terminated on the 29th of July 2016 at 5:26pm (8 days of intermittent testing). A summary of generator stoppages follows:

- Failure on 23rd of July 2016 at 1:00pm due to Residual Current Device (RCD) fault in generator. Generator and restarted at 7pm on 23rd of July 2016.
- Failure on 24th of July 2016 at 5:00am due to RCD fault. Testing resumed Monday 25th of July 2016 at 2:00pm after supplier technician addressed RCD fault issue.
- Failure on 25th of July at 5:00pm due to earth leakage trip. Pumping resumed on 26th of July 2016 at 12:31pm.
- Failure on the 29th of July at 5:26pm due to earth leakage trip. Decision made to cease test pumping.

3.0 WATER CHEMISTRY

Field parameters were collected throughout the test pumping and water samples collected from the discharge stream for laboratory analysis as summarised below in Table 1. Field parameters and water chemistry results are provided in Appendix C.

Table 1: Groundwater analysis summary

Event	Field Parameters	Laboratory Sample
LDS-PW-2902 CRT	Collected twice daily (Temperature, pH, Electrical Conductivity, Redox Potential, Dissolved Oxygen, Turbidity)	a) 16th July 2016 (Characteristics, Total Metals, Dissolved Metals, Ferrous Iron, Volatile Organics, Semi Volatile Organics, Phenols) b) 17th July 2016 (Characteristics, Total Metals, Dissolved Metals, Ferrous Iron, Volatile Organics, Semi Volatile Organics, Phenols) c) 22nd July 2016 (Characteristics, Total Metals, Dissolved Metals, Nutrients, Petroleum Hydrocarbons) d) 26th July 2016 (Characteristics, Total Metals, Dissolved Metals, Nutrients, Petroleum Hydrocarbons) e) 27th July 2016 (Characteristics, Total Metals, Dissolved Metals, Nutrients, Petroleum Hydrocarbons)
LDS-PW-2904 CRT	Collected twice daily (Temperature, pH, Electrical Conductivity, Redox Potential, Dissolved Oxygen, Turbidity)	a) 22nd July 2016 (Characteristics, Total Metals, Dissolved Metals, Nutrients, Petroleum Hydrocarbons) b) 27th July 2016 (Characteristics, Total Metals, Dissolved Metals, Nutrients, Petroleum Hydrocarbons)

4.0 SETTLEMENT MONITORING

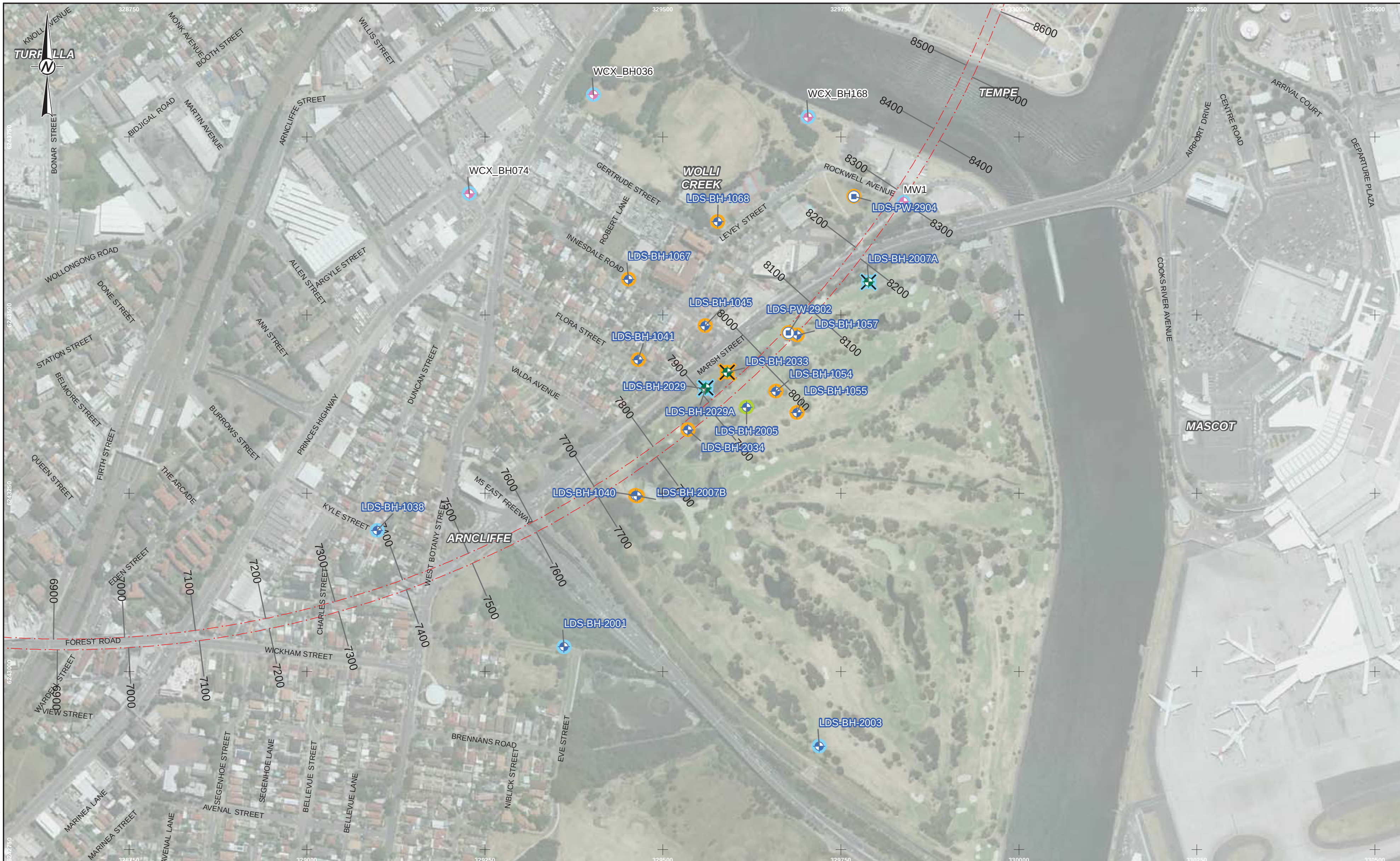
CDS collected level surveys throughout the test pumping program at 37 locations. Appendix D provides a plan showing the locations of the settlement point locations; raw settlement monitoring data provided by CDS; and graphs of the data.

5.0 OTHER OBSERVATIONS

A number of construction works were in progress and are known to have been actively dewatering while the testing documented here was in progress. These are summarised below. It is likely there will be some degree of interference between construction dewatering activities and this program of test pumping.

- Marsh Street road widening works - dewatering of alluvium material along an alignment of approximately 500m and close to LDS-PW2902.
- Basement construction dewatering on North side of Marsh Street within sheet piled excavation. Located close to LDS-BH1045
- Sheet-pile installation at the corner of Princes Highway and Gertrude Street - close to LDS-BH1068.

APPENDIX A
Monitoring Network Summary



LEGEND

Completed
- Borehole
- Pump Well

Installation
- MW
- VWP

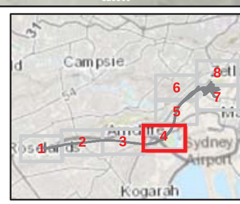
VWP+MW

Historical
- Borehole

Historical
- MW

Completed (Destroyed)
- Borehole

Installation (Destroyed)
- MW
- VWP



CLIENT
CPB DRAGADOS SAMSUNG JV

PROJECT
WESTCONNEX STAGE 2 NEW M5 MOTORWAY

0 50 100 150 200 250
METRES

Control Line: Control_Line_Option_H2
REFERENCE SCALE: 1:5,000 (at A3)
PROJECTION: GDA 1994 MGA Zone 56

TITLE
MONITORING LOCATION PLAN - ARNCLIFFE

YYYY-MM-DD	2016-08-18
PREPARED	ICD
DESIGN	-
REVIEW	DB
APPROVED	

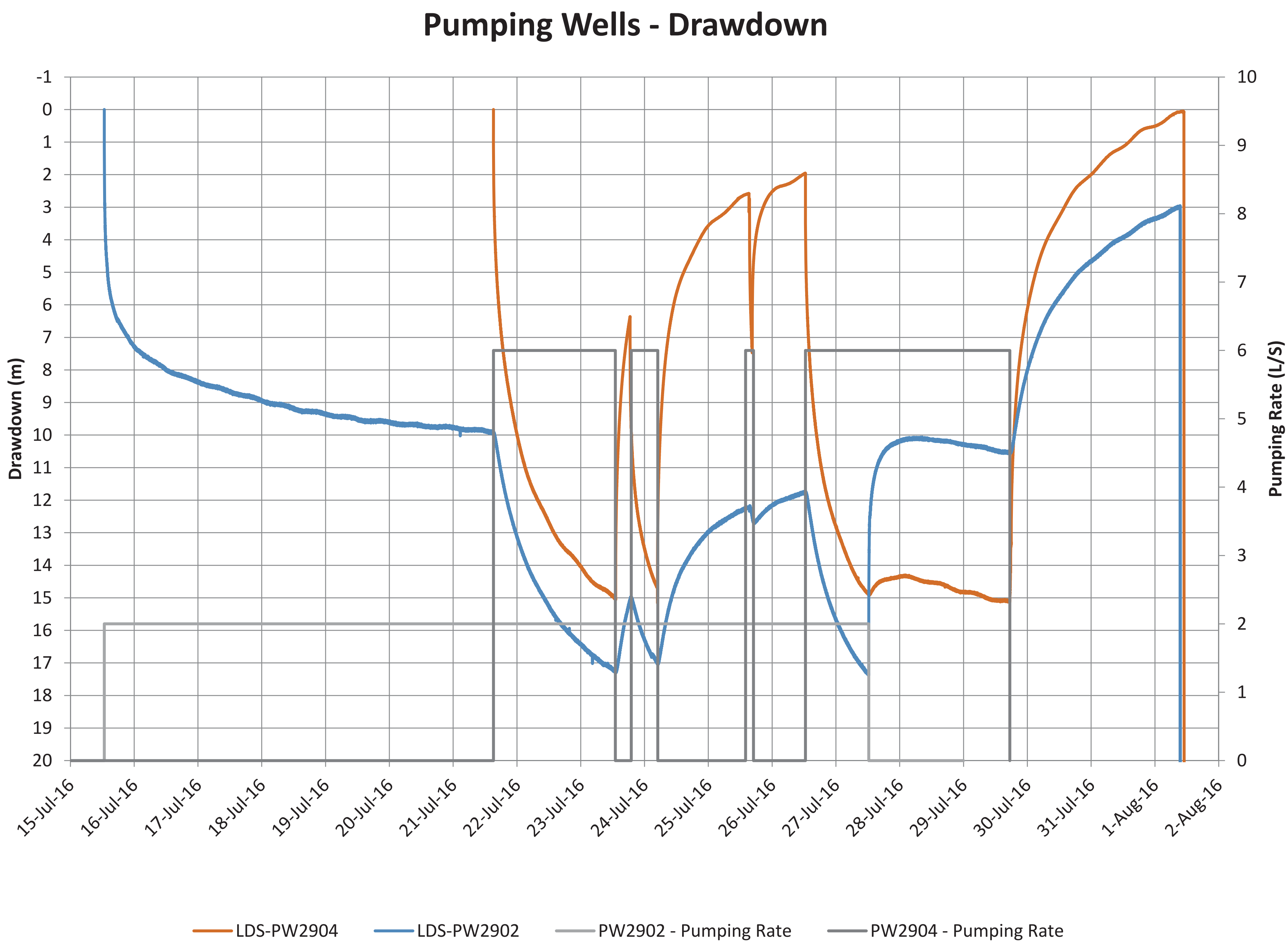
PROJECT No. 1524285 | Rev. A | FIGURE

Monitoring point ID	Installation Type	Monitored Interval (mRL)*	Formation
LDS-PW-2902	Test pumping well	-31.97 to -80.0	Hawkesbury Sandstone - Fractured
LDS-PW-2904	Test pumping well	-50.26 to -92.0	Hawkesbury Sandstone - Fractured
LDS-BH-2003	Standpipe Piezometer	-2.6 to -7.6	Alluvial - Sand
LDS-BH-2005	VWP - Grouted	-11.4	Alluvial - Sand
	VWP - Grouted	-15.9	Alluvial - Sand
	VWP - Grouted	-21.9	Alluvial - Clay
	Standpipe Piezometer	-24.9 to -26.9	Hawkesbury Sandstone - massive
LDS-BH-2007B	VWP - Grouted	-8.77	Alluvial - Sand
	VWP - Grouted	-11.77	Alluvial - sandy clay
	VWP - Grouted	-22.77	Alluvial - Sand
	VWP - Grouted	-31.67	Hawkesbury Sandstone
LDS-BH-1041 (inclined)	VWP - Grouted	-12.17	Alluvial - Sandy Clay
	VWP - Grouted	-20.72	Alluvial - Clay
	VWP - Grouted	-25.32	Alluvial - Sand
	VWP - Grouted	-59.53	Hawkesbury Sandstone
LDS-BH-1045 (inclined)	VWP - Grouted	-7.32	Alluvial - Sand
	VWP - Grouted	-27.99	Alluvial - Silty-sandy Clay
	VWP - Grouted	-37.48	Hawkesbury Sandstone - Core Loss zone, Fractured?
	VWP - Grouted	-56.27	Hawkesbury Sandstone - Joint
LDS-BH-1054 (inclined)	VWP - Grouted	-8.31	Alluvial - Clay
	VWP - Grouted	-11.77	Alluvial - Sandy Clay

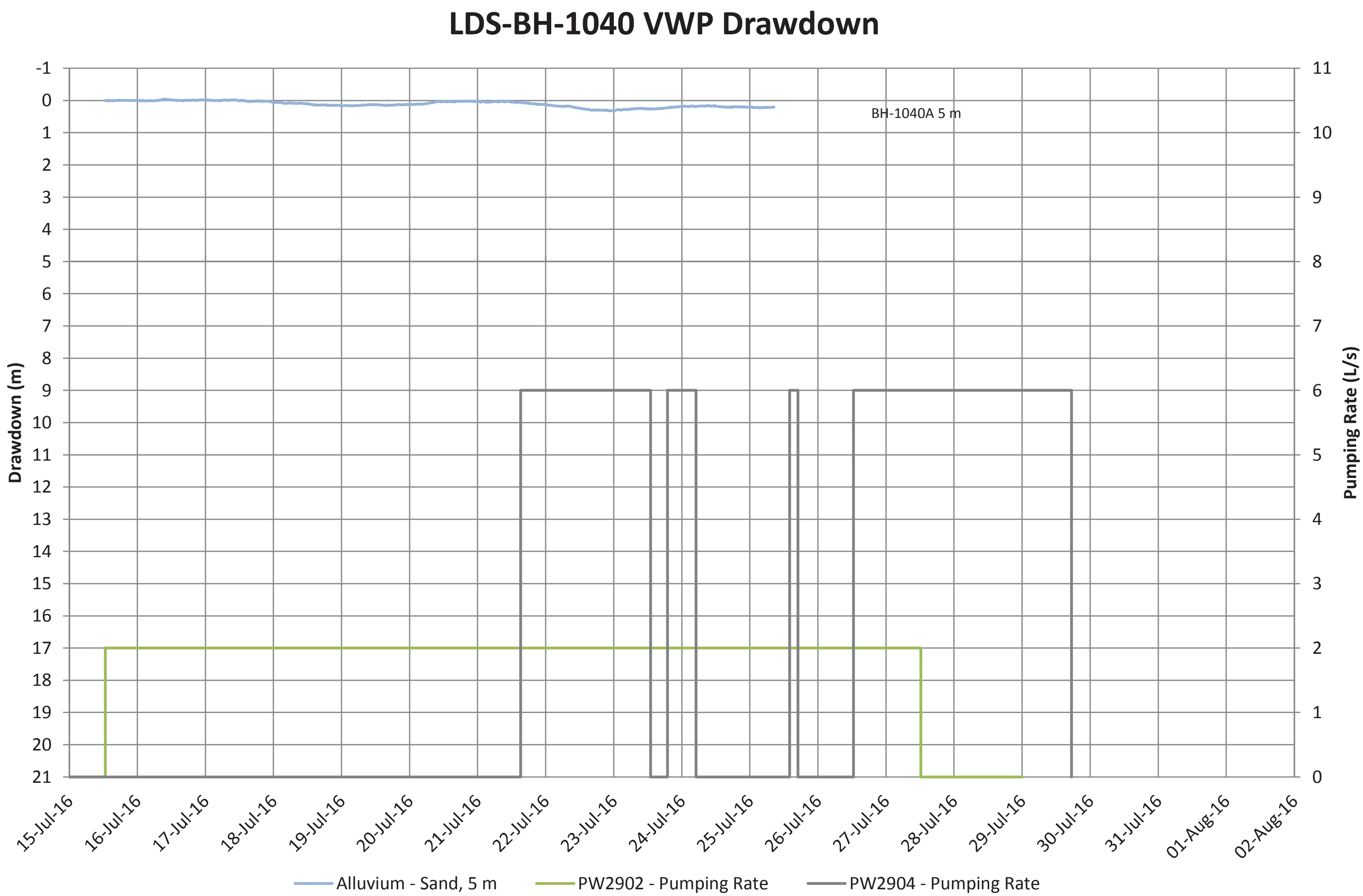
	VWP - Grouted	-40.09	Hawkesbury Sandstone - Fractured
	VWP - Grouted	-74.21	Hawkesbury Sandstone - Fractured
LDS-BH-1055 (inclined)	VWP - Grouted	-7.83	Alluvial - Clay
	VWP - Grouted	-11.73	Alluvial - Sandy Clay
	VWP - Grouted	-42.47	Hawkesbury Sandstone - sheared
	VWP - Grouted	-69.93	Hawkesbury Sandstone - Fractured
LDS-BH-1067 (inclined)	VWP - Grouted	-2.33	Alluvial – Silty Sand
	VWP - Grouted	-19.65	Alluvial – Silty Clay
	VWP - Grouted	-54.29	Hawkesbury Sandstone - Fractured
LDS-BH-1068	VWP - Grouted	-3.49	Alluvial – Silty Sand
	VWP - Grouted	-23.49	Alluvial – Sand
	VWP - Grouted	-43.49	Hawkesbury Sandstone
LDS-BH-2034 (Including 2034A)	VWP - Grouted	-3.98	Alluvial – Silty Sand
	VWP - Grouted	-26.48	Alluvial – Sand
	VWP - Grouted	-45.98	Hawkesbury Sandstone

	VWP - Grouted	-73.98	Hawkesbury Sandstone-Fractured
LDS-BH-1057 (Including 1057A)	VWP - Grouted	-3.98	Alluvial – Sand
	VWP - Grouted	-36.73	Hawkesbury Sandstone
	VWP - Grouted	-57.4	Hawkesbury Sandstone - Fractured
	VWP - Grouted	-75.38	Hawkesbury Sandstone - Fractured
LDS-BH-1038	Standpipe Piezometer	-49.85 to -58.85	Hawkesbury Sandstone
LDS-BH-2001	Standpipe Piezometer	-0.71 to -2.79	Alluvial - Sand
LDS-BH-1040A	VWP - Grouted	-3.92	Alluvial – Sand
WCX_BH036	Standpipe Piezometer	-58.42 to -61.42	Hawkesbury Sandstone
WCX_BH074	Standpipe Piezometer	-36.42 to -39.42	Hawkesbury Sandstone
WCX_BH168	Standpipe Piezometer	-46.64 to -49.64	Hawkesbury Sandstone
GEOTECHNIQUE MW1	Standpipe Piezometer	0.167 to 3.333	Alluvial – Silty Sand
Marsh Street Bridge	Conduit in Open Water	-	Cooks River – Tidal Monitoring
*			

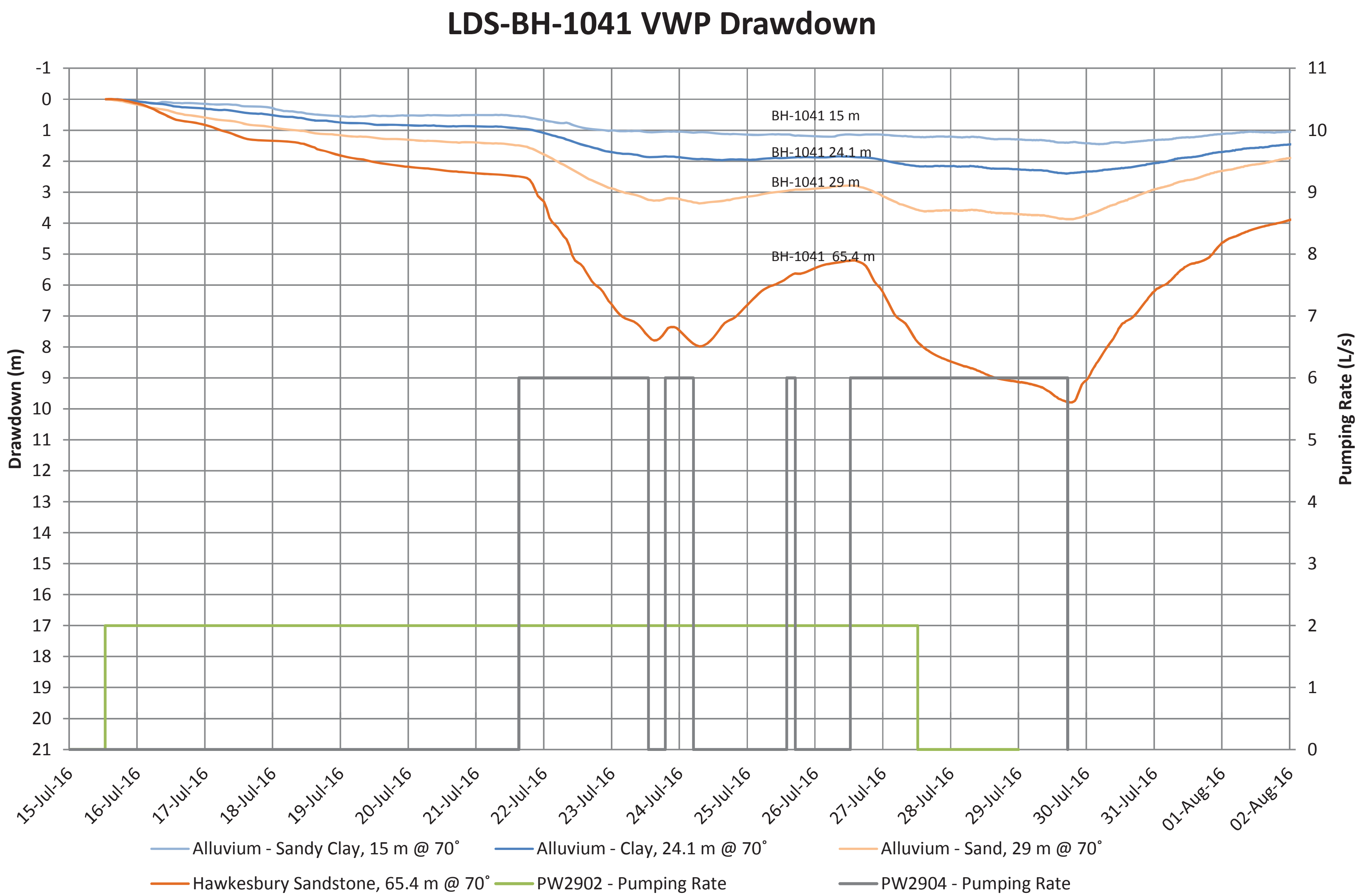
APPENDIX B
Hydrographs



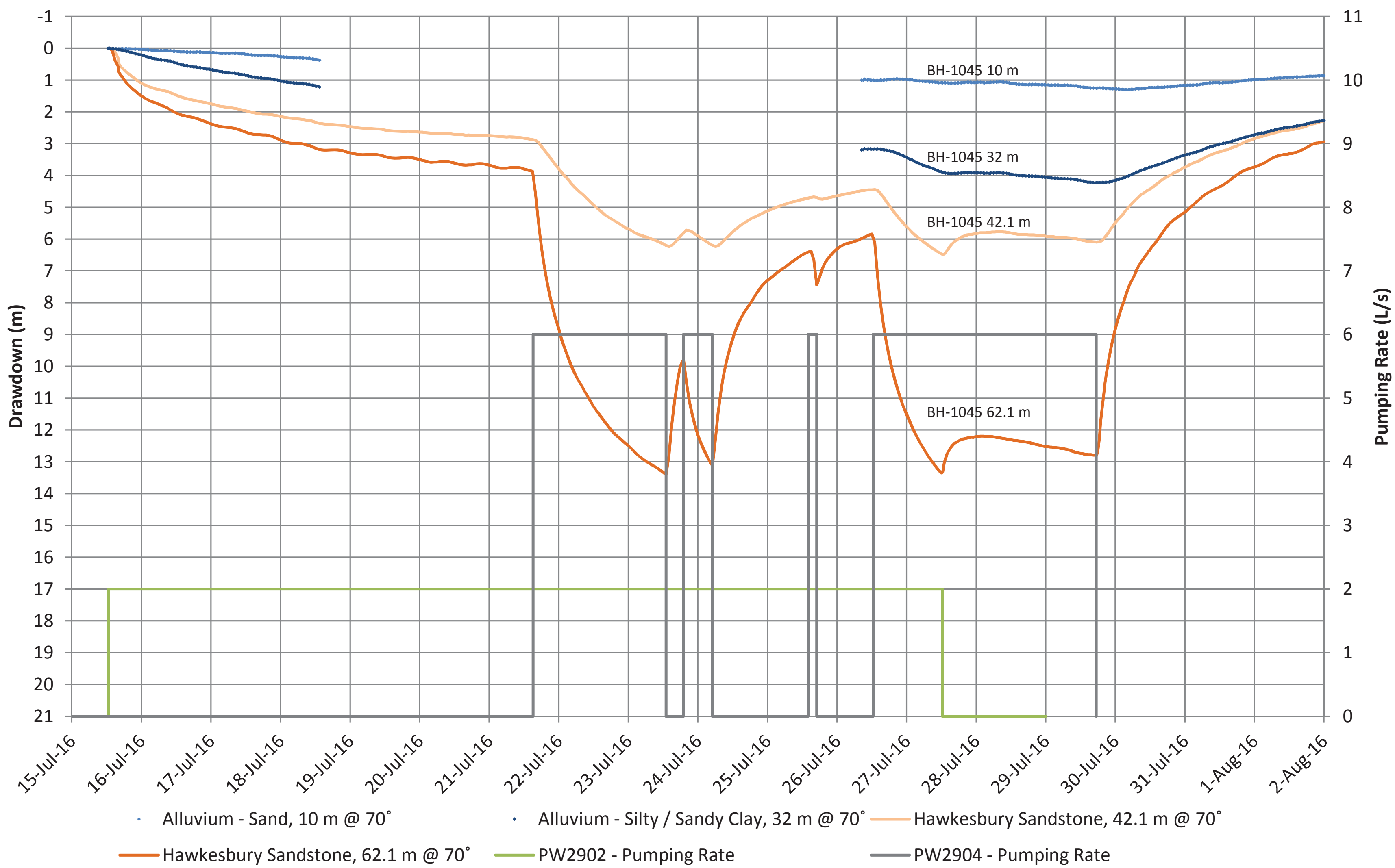
Pumping Wells - Drawdown
Drawdown (m)
Pumping Rate (L/S)
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
15-Jul-16
16-Jul-16
17-Jul-16
18-Jul-16
19-Jul-16
20-Jul-16
21-Jul-16
22-Jul-16
23-Jul-16
24-Jul-16
25-Jul-16
26-Jul-16
27-Jul-16
28-Jul-16
29-Jul-16
30-Jul-16
31-Jul-16
1-Aug-16
2-Aug-16
LDS-PW2904
LDS-PW2902
PW2902 - Pumping Rate
PW2904 - Pumping Rate



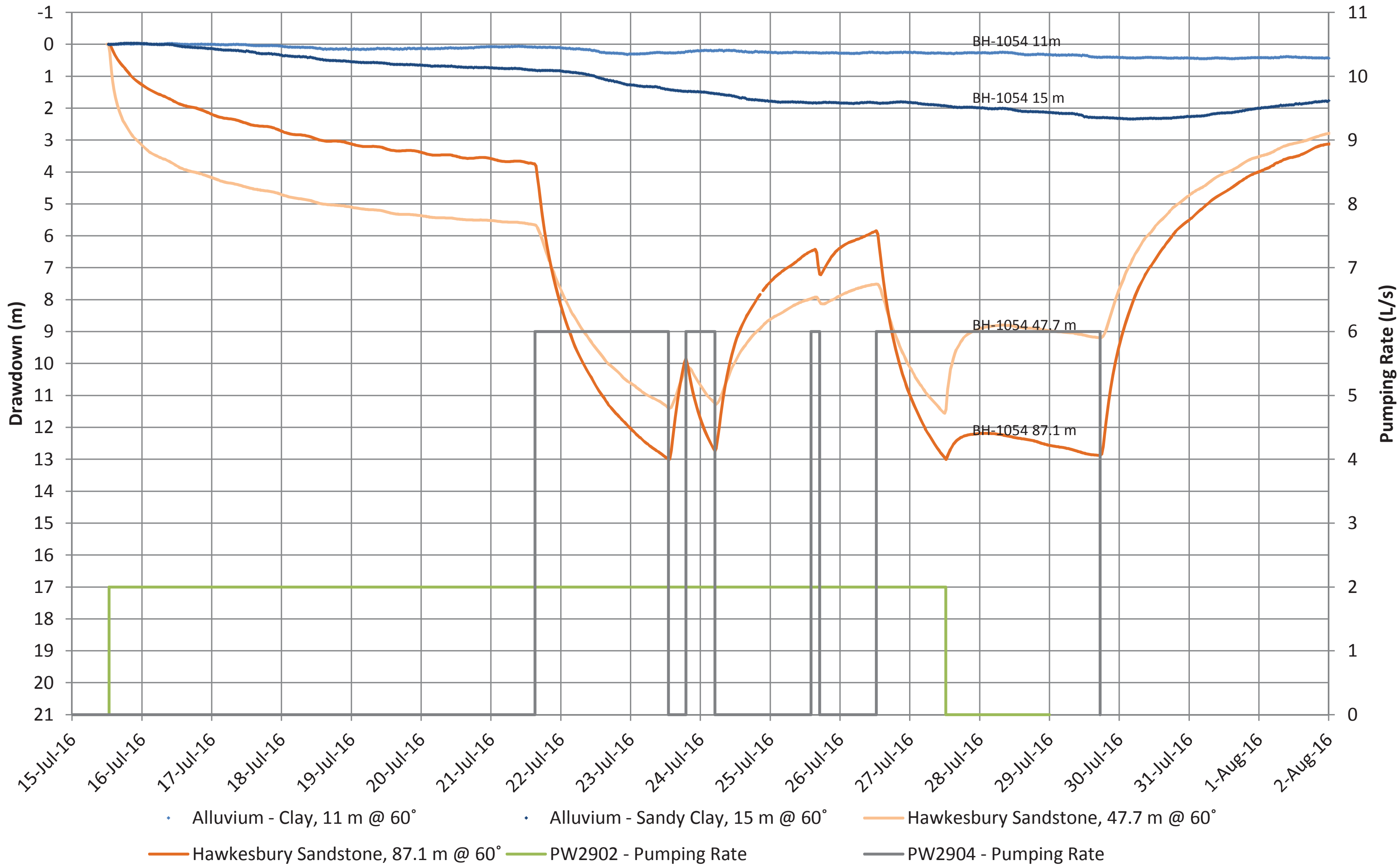
LDS-BH-1040 VWP Drawdown
Drawdown (m)
Pumping Rate (L/s)
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
11
10
9
8
7
6
5
4
3
2
1
0
BH-1040A 5 m
15-Jul-16
16-Jul-16
17-Jul-16
18-Jul-16
19-Jul-16
20-Jul-16
21-Jul-16
22-Jul-16
23-Jul-16
24-Jul-16
25-Jul-16
26-Jul-16
27-Jul-16
28-Jul-16
29-Jul-16
30-Jul-16
31-Jul-16
01-Aug-16
02-Aug-16
Alluvium - Sand, 5 m
PW2902 - Pumping Rate
PW2904 - Pumping Rate

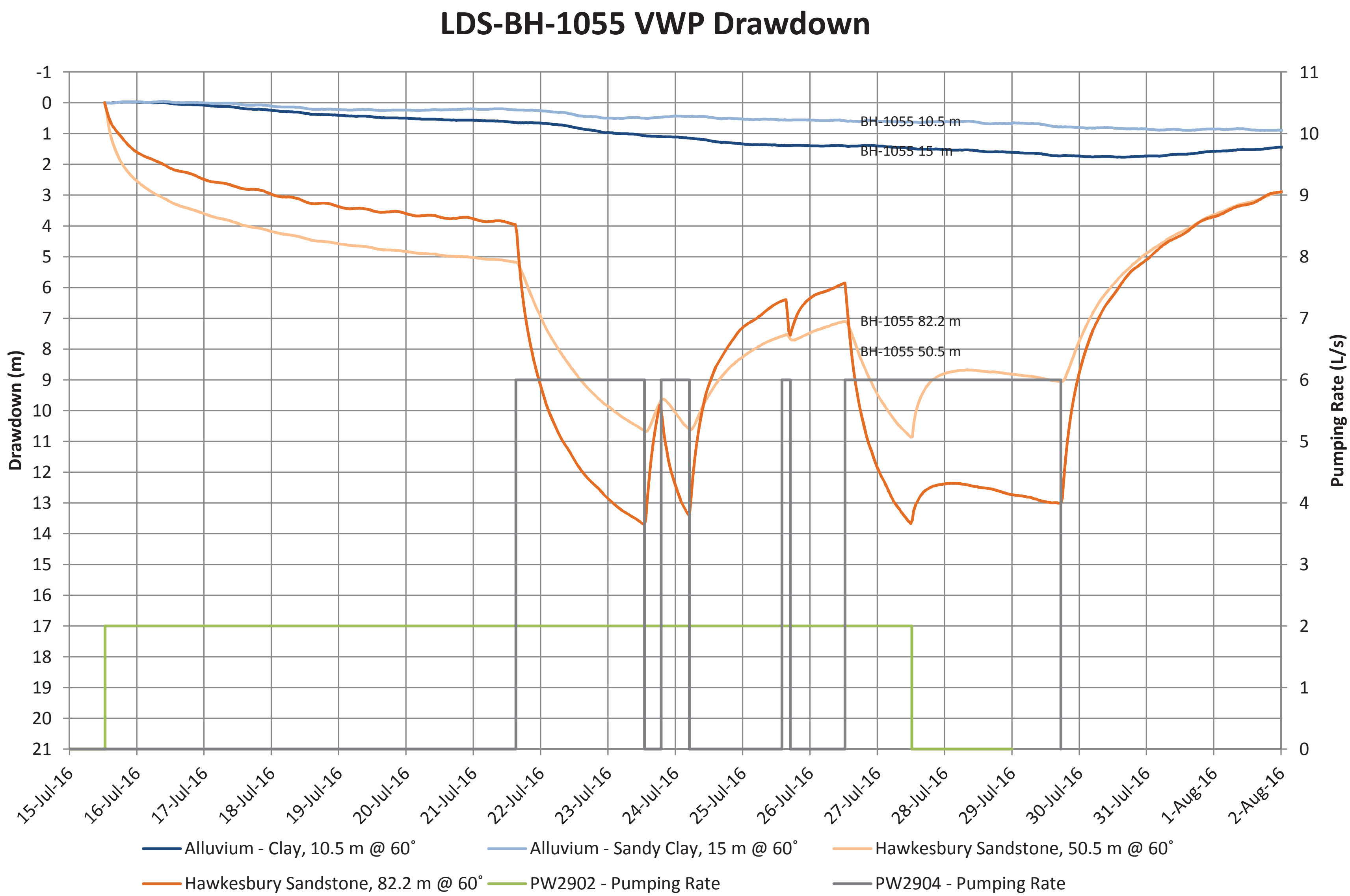

LDS-BH-1041 VWP Drawdown
Drawdown (m)
Pumping Rate (L/s)
BH-1041 15 m
BH-1041 24.1 m
BH-1041 29 m
BH-1041 65.4 m
15-Jul-16
16-Jul-16
17-Jul-16
18-Jul-16
19-Jul-16
20-Jul-16
21-Jul-16
22-Jul-16
23-Jul-16
24-Jul-16
25-Jul-16
26-Jul-16
27-Jul-16
28-Jul-16
29-Jul-16
30-Jul-16
31-Jul-16
01-Aug-16
02-Aug-16
Alluvium - Sandy Clay, 15 m @ 70˚
Alluvium - Clay, 24.1 m @ 70˚
Alluvium - Sand, 29 m @ 70˚
Hawkesbury Sandstone, 65.4 m @ 70˚
PW2902 - Pumping Rate
PW2904 - Pumping Rate

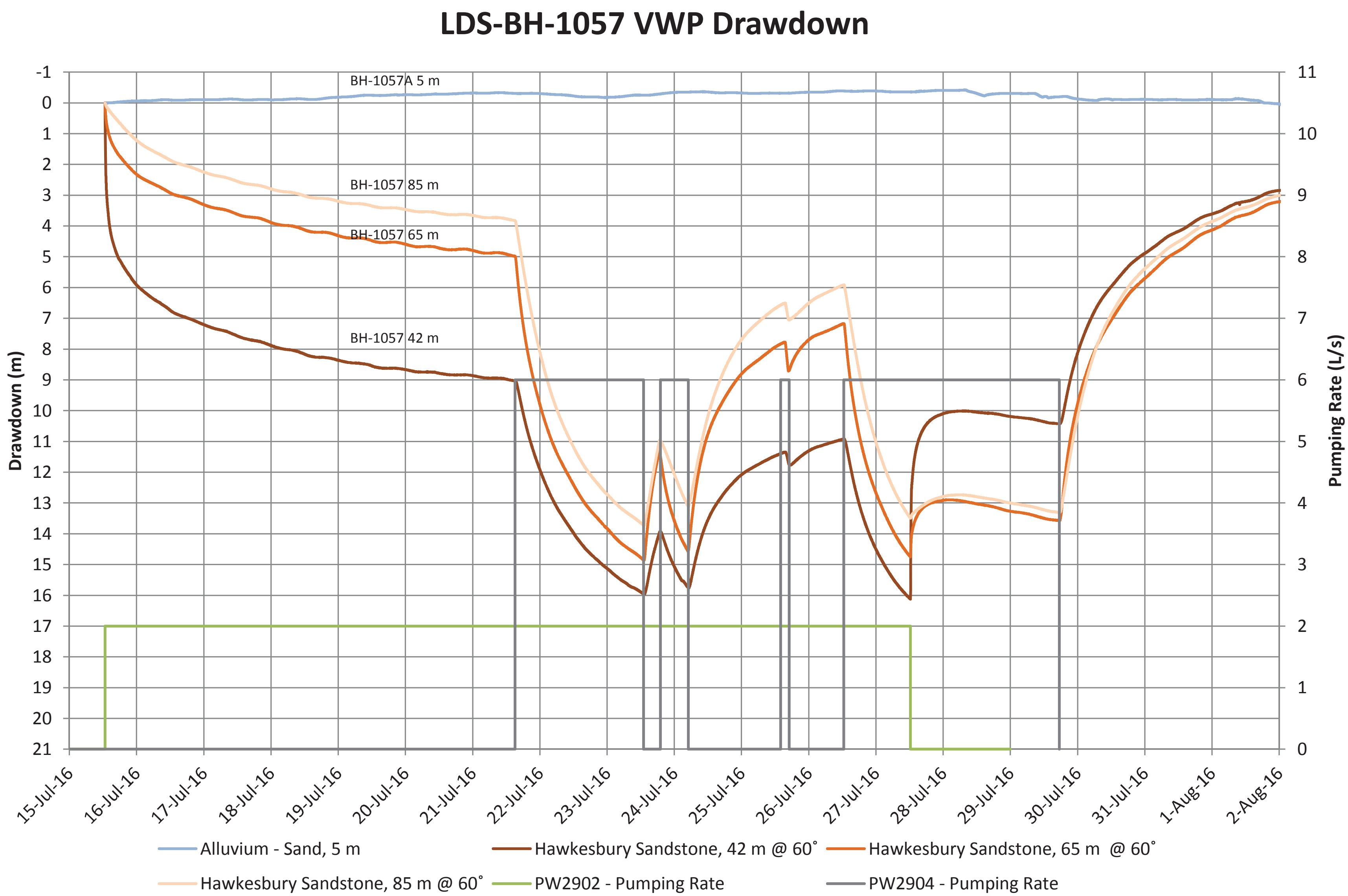
LDS-BH-1045 VWP Drawdown



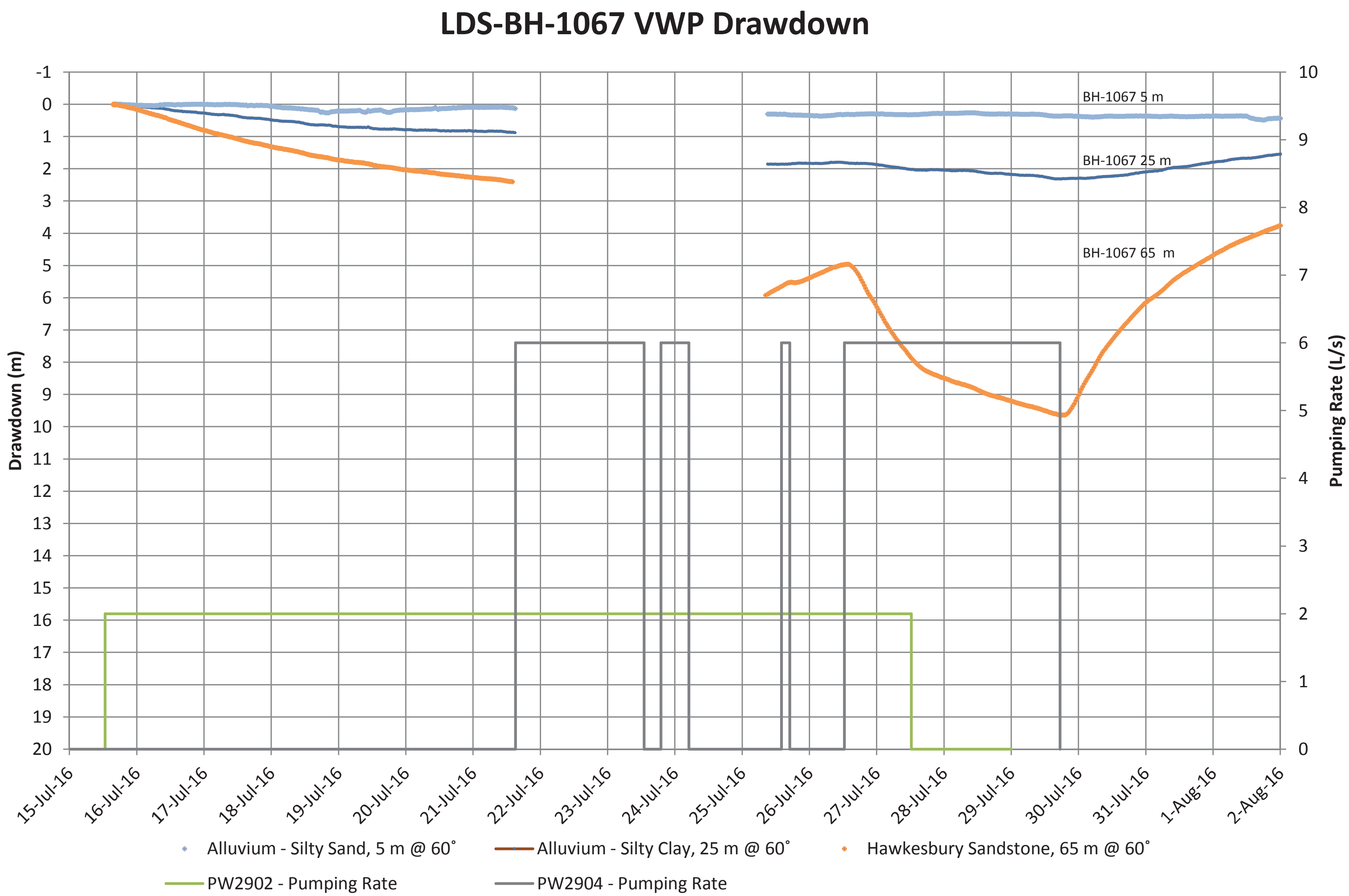
LDS-BH-1054 VWP Drawdown



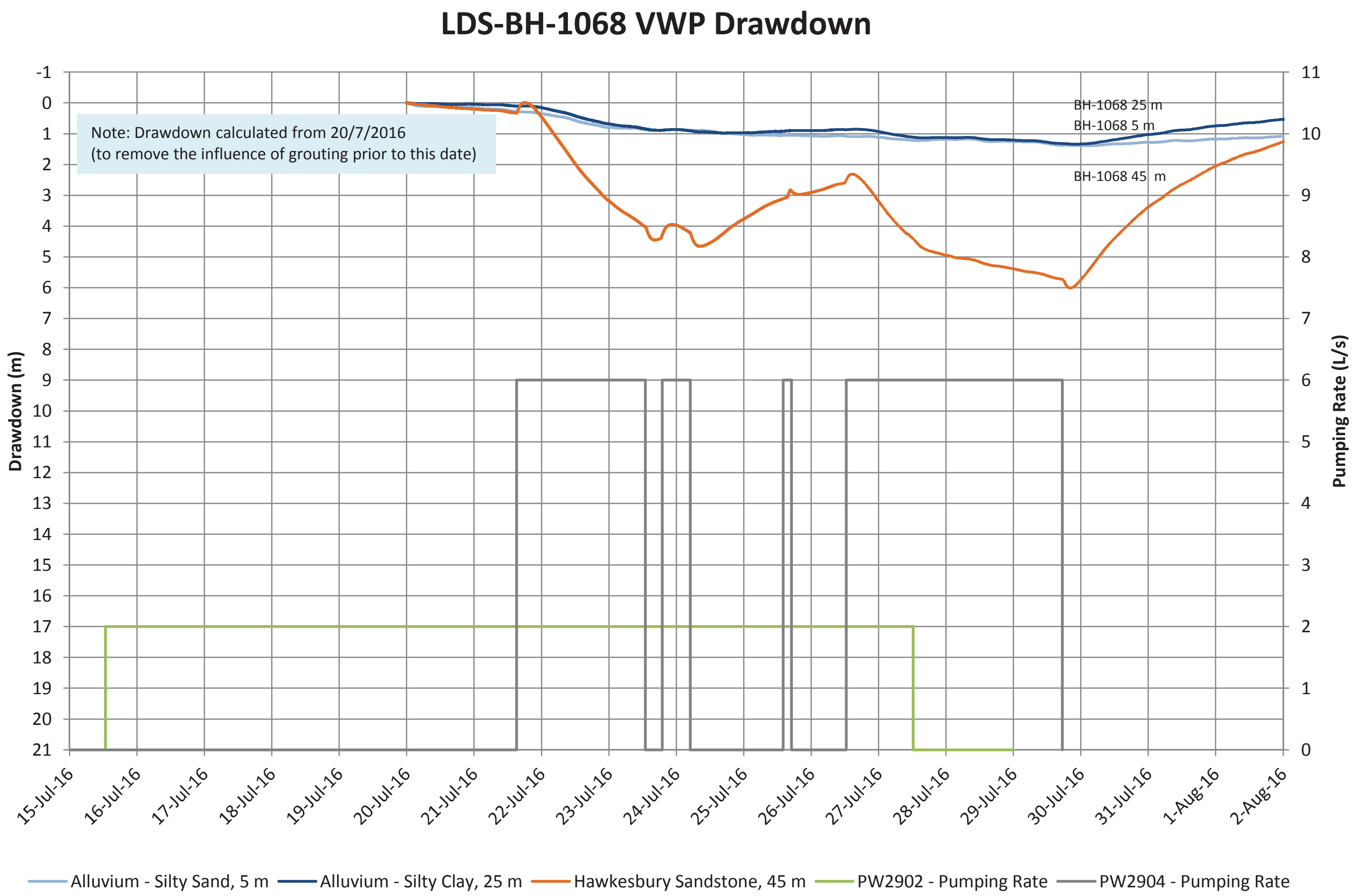

LDS-BH-1055 VWP Drawdown
Drawdown (m)
Pumping Rate (L/s)
BH-1055 10.5 m
BH-1055 15 m
BH-1055 82.2 m
BH-1055 50.5 m
15-Jul-16
16-Jul-16
17-Jul-16
18-Jul-16
19-Jul-16
20-Jul-16
21-Jul-16
22-Jul-16
23-Jul-16
24-Jul-16
25-Jul-16
26-Jul-16
27-Jul-16
28-Jul-16
29-Jul-16
30-Jul-16
31-Jul-16
1-Aug-16
2-Aug-16
Alluvium - Clay, 10.5 m @ 60˚
Alluvium - Sandy Clay, 15 m @ 60˚
Hawkesbury Sandstone, 50.5 m @ 60˚
Hawkesbury Sandstone, 82.2 m @ 60˚
PW2902 - Pumping Rate
PW2904 - Pumping Rate

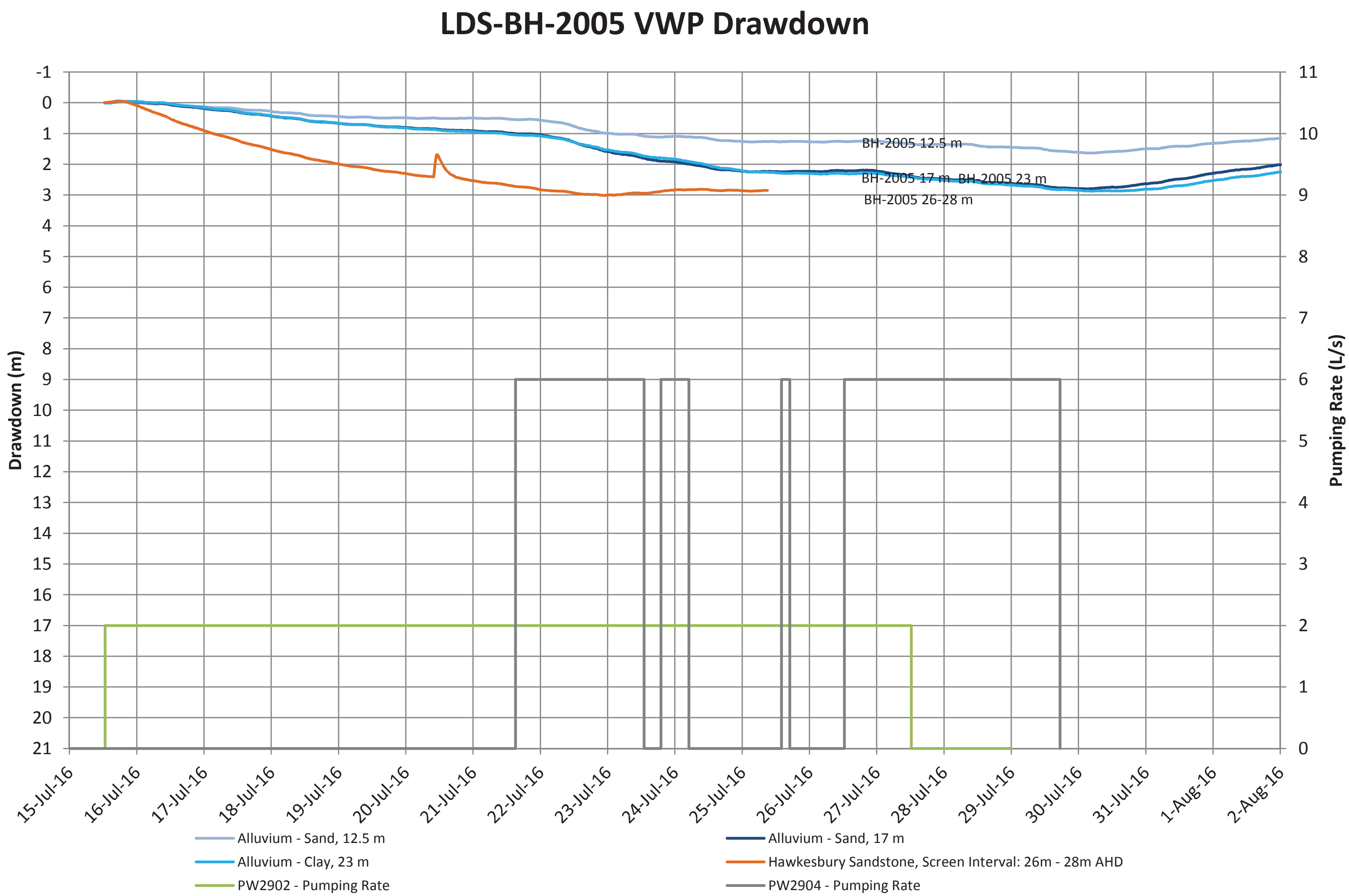


LDS-BH-1057 VWP Drawdown
BH-1057A 5 m
BH-1057 85 m
BH-1057 65 m
BH-1057 42 m
Drawdown (m)
Pumping Rate (L/s)
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
11
10
9
8
7
6
5
4
3
2
1
0
15-Jul-16
16-Jul-16
17-Jul-16
18-Jul-16
19-Jul-16
20-Jul-16
21-Jul-16
22-Jul-16
23-Jul-16
24-Jul-16
25-Jul-16
26-Jul-16
27-Jul-16
28-Jul-16
29-Jul-16
30-Jul-16
31-Jul-16
1-Aug-16
2-Aug-16
Alluvium - Sand, 5 m
Hawkesbury Sandstone, 42 m @ 60˚
Hawkesbury Sandstone, 65 m @ 60˚
Hawkesbury Sandstone, 85 m @ 60˚
PW2902 - Pumping Rate
PW2904 - Pumping Rate

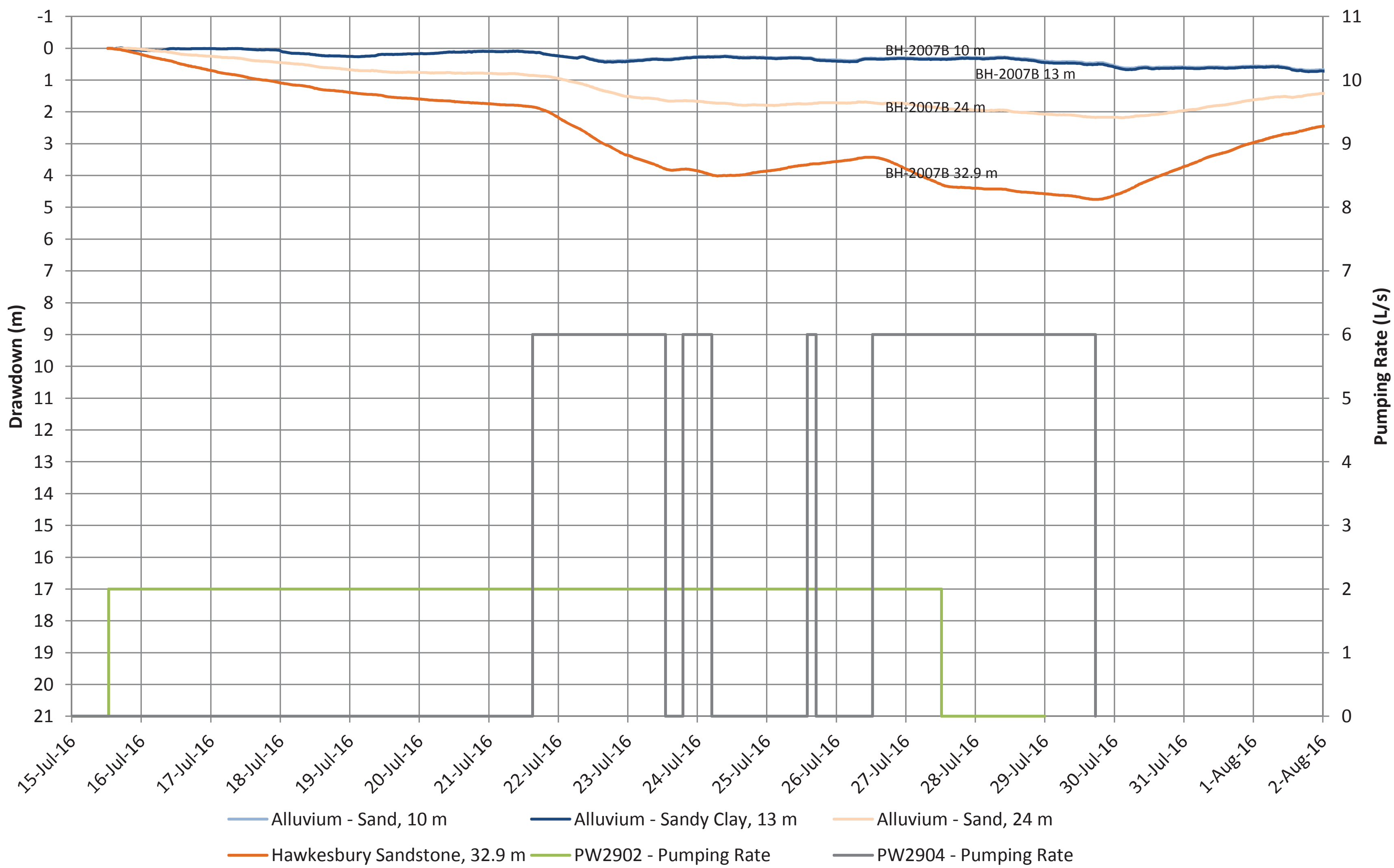


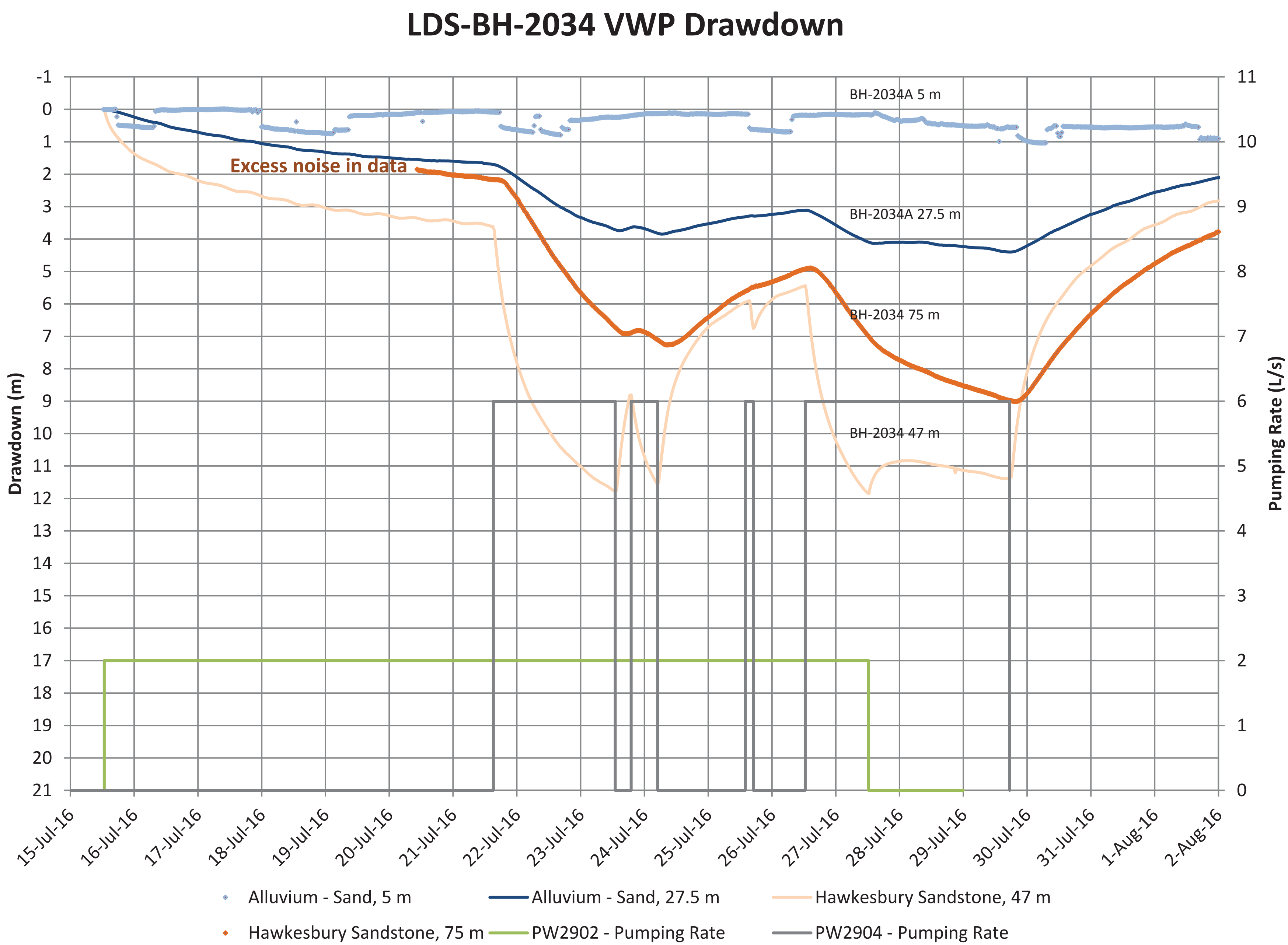
LDS-BH-1067 VWP Drawdown
Drawdown (m)
Pumping Rate (L/s)
BH-1067 5 m
BH-1067 25 m
BH-1067 65 m
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
10
9
8
7
6
5
4
3
2
1
0
15-Jul-16
16-Jul-16
17-Jul-16
18-Jul-16
19-Jul-16
20-Jul-16
21-Jul-16
22-Jul-16
23-Jul-16
24-Jul-16
25-Jul-16
26-Jul-16
27-Jul-16
28-Jul-16
29-Jul-16
30-Jul-16
31-Jul-16
1-Aug-16
2-Aug-16
Alluvium - Silty Sand, 5 m @ 60˚
Alluvium - Silty Clay, 25 m @ 60˚
Hawkesbury Sandstone, 65 m @ 60˚
PW2902 - Pumping Rate
PW2904 - Pumping Rate


LDS-BH-1068 VWP Drawdown
Note: Drawdown calculated from 20/7/2016
(to remove the influence of grouting prior to this date)
BH-1068 25 m
BH-1068 5 m
BH-1068 45 m
Drawdown (m)
Pumping Rate (L/s)
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
15-Jul-16
16-Jul-16
17-Jul-16
18-Jul-16
19-Jul-16
20-Jul-16
21-Jul-16
22-Jul-16
23-Jul-16
24-Jul-16
25-Jul-16
26-Jul-16
27-Jul-16
28-Jul-16
29-Jul-16
30-Jul-16
31-Jul-16
1-Aug-16
2-Aug-16
Alluvium - Silty Sand, 5 m
Alluvium - Silty Clay, 25 m
Hawkesbury Sandstone, 45 m
PW2902 - Pumping Rate
PW2904 - Pumping Rate

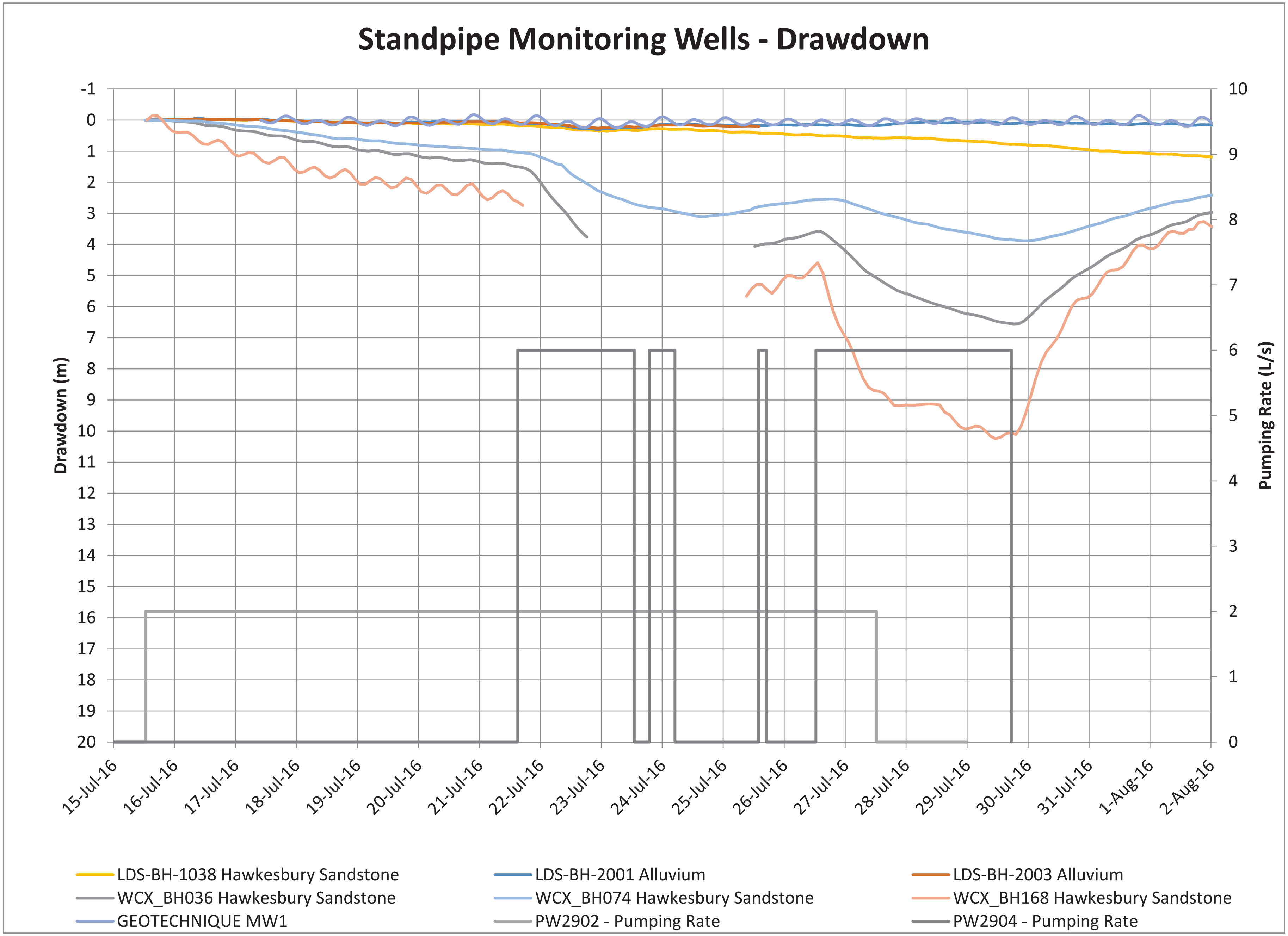

LDS-BH-2005 VWP Drawdown
Drawdown (m)
Pumping Rate (L/s)
BH-2005 12.5 m
BH-2005 17 m
BH-2005 23 m
BH-2005 26-28 m
15-Jul-16
16-Jul-16
17-Jul-16
18-Jul-16
19-Jul-16
20-Jul-16
21-Jul-16
22-Jul-16
23-Jul-16
24-Jul-16
25-Jul-16
26-Jul-16
27-Jul-16
28-Jul-16
29-Jul-16
30-Jul-16
31-Jul-16
1-Aug-16
2-Aug-16
Alluvium - Sand, 12.5 m
Alluvium - Sand, 17 m
Alluvium - Clay, 23 m
Hawkesbury Sandstone, Screen Interval: 26m - 28m AHD
PW2902 - Pumping Rate
PW2904 - Pumping Rate

LDS-BH-2007B VWP Drawdown





LDS-BH-2034 VWP Drawdown
Drawdown (m)
Pumping Rate (L/s)
Excess noise in data
BH-2034A 5 m
BH-2034A 27.5 m
BH-2034 75 m
BH-2034 47 m
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
11
10
9
8
7
6
5
4
3
2
1
0
15-Jul-16
16-Jul-16
17-Jul-16
18-Jul-16
19-Jul-16
20-Jul-16
21-Jul-16
22-Jul-16
23-Jul-16
24-Jul-16
25-Jul-16
26-Jul-16
27-Jul-16
28-Jul-16
29-Jul-16
30-Jul-16
31-Jul-16
1-Aug-16
2-Aug-16
Alluvium - Sand, 5 m
Alluvium - Sand, 27.5 m
Hawkesbury Sandstone, 47 m
Hawkesbury Sandstone, 75 m
PW2902 - Pumping Rate
PW2904 - Pumping Rate



Standpipe Monitoring Wells - Drawdown
Drawdown (m)
Pumping Rate (L/s)
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
15-Jul-16
16-Jul-16
17-Jul-16
18-Jul-16
19-Jul-16
20-Jul-16
21-Jul-16
22-Jul-16
23-Jul-16
24-Jul-16
25-Jul-16
26-Jul-16
27-Jul-16
28-Jul-16
29-Jul-16
30-Jul-16
31-Jul-16
1-Aug-16
2-Aug-16
LDS-BH-1038 Hawkesbury Sandstone
LDS-BH-2001 Alluvium
LDS-BH-2003 Alluvium
WCX_BH036 Hawkesbury Sandstone
WCX_BH074 Hawkesbury Sandstone
WCX_BH168 Hawkesbury Sandstone
GEOTECHNIQUE MW1
PW2902 - Pumping Rate
PW2904 - Pumping Rate

APPENDIX C

Groundwater Quality Test Results

Table C-1: LDS-PW-2902 Field Water Quality Parameters (Pre-treatment)

LDS-PW-2902 PRE pH TREATMENT FIELD WATER QUALITY							
Date and Time	pH	Redox	Electrical Conductivity	Temperature	Dissolved Oxygen	Turbidity (NTU)	Sample type
		mV	µS/cm	°C	mg/L		
7/16/16 08:29	6.26	-57.1	24512	18.6	0.39	3.2	Return Grab Sample
7/16/16 16:05	6.49	-38.2	25016	18.9	11.22	18	Return Grab Sample
7/17/16 07:59	6.58	-34.1	25079	18.7	18.00	23.9	Return Grab Sample
7/17/16 14:42	6.05	-24.8	25468	19.5	19.57	6.3	Return Grab Sample
7/18/16 08:45	6.7	-35.8	25058	18.1	6.48	13.2	Return Grab Sample
7/18/16 16:38	6.33	-7.8	25796	19.2	2.74	18.5	Return Grab Sample
7/19/16 08:11	6.02	-7.7	25060	18.5	6.61	12.7	Return Grab Sample
7/19/16 17:07	6.13	-16.6	26101	19.1	5.09	1.1	Return Grab Sample
7/20/16 09:35	6.09	-22.5	25669	18.5	7.26	7.6	Return Grab Sample
7/20/16 16:53	6.21	-20	25777	18.4	15.78	4.8	Return Grab Sample
7/21/16 08:02	5.96	-32.4	26052	18.7	6.65	13.4	Return Grab Sample
7/21/16 17:15	6.3	-54.9	26035	18.8	10.57	2.1	Return Grab Sample
7/22/16 10:01	5.78	-20.6	25742	19.2	9.78	0.3	Return Grab Sample
7/22/16 16:55	5.88	-17.4	25753	19.3	12.91	3.3	Return Grab Sample
7/23/16 10:06	5.95	-19.3	25569	18.9	10.57	9	Return Grab Sample
7/23/16 17:15	5.95	-40	25712	18.6	12.30	27	Return Grab Sample
7/24/16 11:45	5.86	-13	25820	18.5	6.83	2.8	Return Grab Sample
7/24/16 16:58	5.87	-14	29616	18.6	22.78	1.8	Return Grab Sample
7/25/16 09:40	5.8	-43.2	30473	19	0.00	2.5	Return Grab Sample
7/25/16 17:23	5.68	10.3	30665	18.6	10.91	5.3	Return Grab Sample
7/26/16 08:55	5.83	-18.9	30070	18.4	8.61	4	Return Grab Sample
7/26/16 15:57	6.32	-47.4	30539	19	13.78	2.8	Return Grab Sample
7/27/16 09:13	5.88	-7	27540	18.5	16.87	8.2	Return Grab Sample

Table C-2: LDS-PW-2902 Field Water Quality Parameters (Post-treatment)

LDS-PW-2902 POST pH TREATMENT FIELD WATER QUALITY							
Date and Time	pH	Redox	Electrical Conductivity	Temperature	Dissolved Oxygen	Turbidity (NTU)	Sample type
		mV	µS/cm	°C	mg/L		
7/15/16 13:28	7.31	-319.7	24947	19.1	0.01		Return Grab Sample
7/16/16 08:37	6.25	-91	24609	18.1	0.74	65.7	Return Grab Sample
7/16/16 16:07	6.03	-70.1	25235	19.1	6.57	80	Return Grab Sample
7/17/16 08:00	6.19	-67.1	24720	17.6	6.57	38.5	Return Grab Sample
7/17/16 14:45	6.32	-100.8	26485	20.8	1.87	45.3	Return Grab Sample
7/17/16 15:27	6.21	-73.5	25647	19.7	7.00	42	Return Grab Sample
7/18/16 08:24	6.79	-62.5	25322	18.6	6.48	70.5	Return Grab Sample
7/18/16 15:50	6.75	-92.5	26153	19.8	2.74	56.6	Return Grab Sample
7/19/16 08:53	7.45	-252.6	25766	19	0.00	48.3	Return Grab Sample
7/19/16 17:08	7.15	-145.6	26279	19.4	1.09	17.8	Return Grab Sample
7/20/16 09:30	6.87	-115.7	25755	18.6	1.83	30.8	Return Grab Sample
7/20/16 16:05	6.73	-113.5	25711	18.3	0.96	23.3	Return Grab Sample
7/21/16 07:43	6.75	-104.8	25616	18	2.30	39.1	Return Grab Sample
7/21/16 17:13	6.62	-77.6	26431	18.9	6.87	49	Return Grab Sample
7/22/16 09:58	6.5	-39.7	26129	19.5	4.43	36.3	Return Grab Sample
7/22/16 17:00	6.5	-69.9	26345	20	11.30	42.7	Return Grab Sample
7/23/16 10:12	6.52	-68.5	25030	18.2	1.91	45.9	Return Grab Sample
7/23/16 17:23	7.29	-200.3	25631	18.5	0.00	32	Return Grab Sample
7/24/16 09:55	6.88	-118	25020	17.7	0.26	36.3	Return Grab Sample
7/24/16 16:53	7	-195.7	30143	18.6	0.26	32.6	Return Grab Sample
7/25/16 09:34	6.95	-159.7	29906	18.1	0.00	47.2	Return Grab Sample
7/25/16 17:27	6.56	-113.3	30728	18.4	0.35	35.2	Return Grab Sample
7/26/16 09:02	7.12	-201.4	30351	18.3	0.00	31.2	Return Grab Sample
7/26/16 15:53	7.12	-194.9	31344	19.4	0.30	38.2	Return Grab Sample
7/27/16 09:13	7.13	-239	27320	18.4	0.00	37	Return Grab Sample

Table C-3: LDS-PW-2904 Field Water Quality Parameters (Pre-treatment)

LDS-PW-2904 PRE pH TREATMENT FIELD WATER QUALITY							
Date and Time	pH	Redox	Electrical Conductivity	Temperature	Dissolved Oxygen	Turbidity (NTU)	Sample type
		mV	µS/cm	°C	mg/L		
7/21/16 18:10	6	-17.3	34333	19.3	24.26	11	Return Grab Sample
7/22/16 02:59	5.87	-8.9	34037	19.1	16.09	6.1	Return Grab Sample
7/22/16 08:51	6	-30	33932	19.4	8.39	13.2	Return Grab Sample
7/22/16 17:41	5.83	-4	34181	19.7	6.87	3.1	Return Grab Sample
7/23/16 08:50	5.73	-30.3	33055	19.3	12.39	1.4	Return Grab Sample
7/24/16 03:29	5.88	-77.3	32697	18.5	8.39	10.3	Return Grab Sample
7/26/16 16:35	5.92	-8.4	39075	19.4	9.22	3.7	Return Grab Sample
7/27/16 08:30	5.82	-7.6	34666	18.7	14.00	3.6	Return Grab Sample
7/27/16 17:06	5.72	-17.2	35150	19.2	7.43	2.6	Return Grab Sample
7/28/16 08:30	5.99	-10	34850	18.9	7.74	2.9	Return Grab Sample

Table C-4: LDS-PW-2904 Field Water Quality Parameters (Post-treatment)

LDS-PW-2904 POST pH TREATMENT FIELD WATER QUALITY							
Date and Time	pH	Redox	Electrical Conductivity	Temperature	Dissolved Oxygen	Turbidity (NTU)	Sample type
		mV	µS/cm	°C	mg/L		
7/21/16 18:07	6.32	-94.4	33175	18.4	0.61	9.1	Return Grab Sample
7/22/16 02:53	6.36	-118.5	33877	18.6	0.17	38	Return Grab Sample
7/22/16 08:48	6.57	-103.8	33796	19.1	0.65	35	Return Grab Sample
7/22/16 17:51	5.62	5.4	34332	19.6	7.17	15.6	Return Grab Sample
7/23/16 08:58	6.74	100	34100	18.5	1.30	13.3	Return Grab Sample
7/24/16 03:39	6.5	-45.5	33490	19.3	0.57	9.2	Return Grab Sample
7/26/16 16:35	6.45	-85.5	39205	19.4	5.61	21.2	Return Grab Sample
7/27/16 08:35	6.5	-101.7	35217	19.3	0.65	10	Return Grab Sample
7/27/16 17:13	6.54	-77.4	35524	19.2	0.26	13.2	Return Grab Sample
7/28/16 08:30	7.05	-145.7	34200	18	0.09	25.1	Return Grab Sample

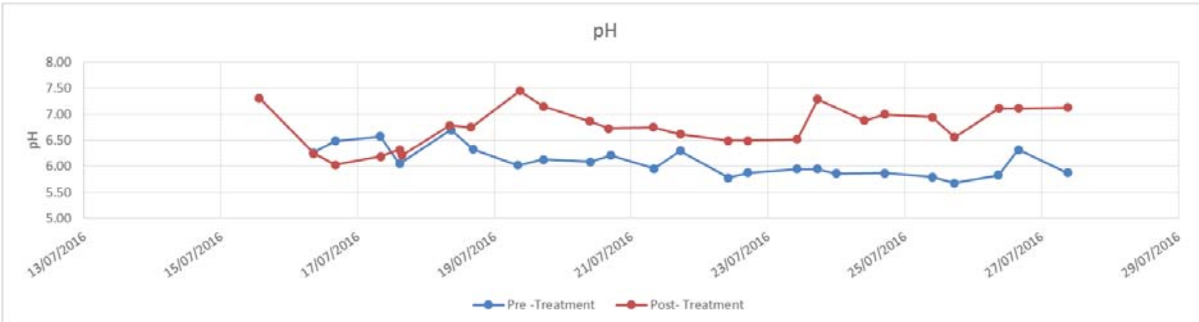


Figure C-1: Groundwater pH fluctuation at LDS-PW-2902

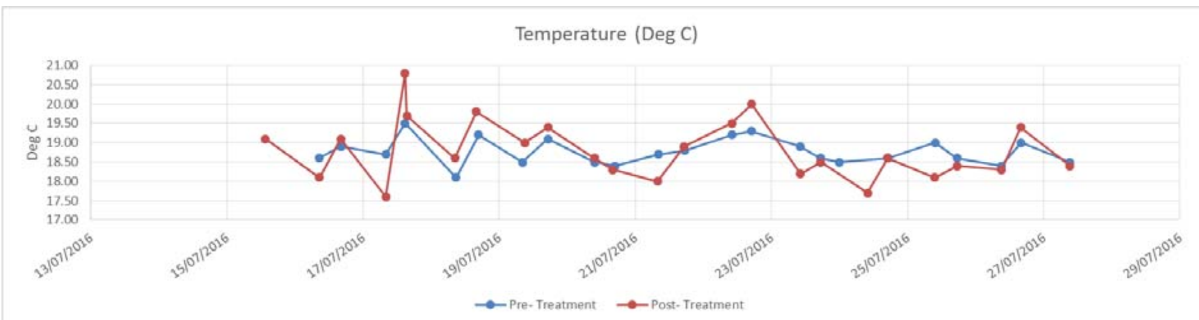


Figure C-2: Groundwater temperature fluctuation at LDS-PW-2902

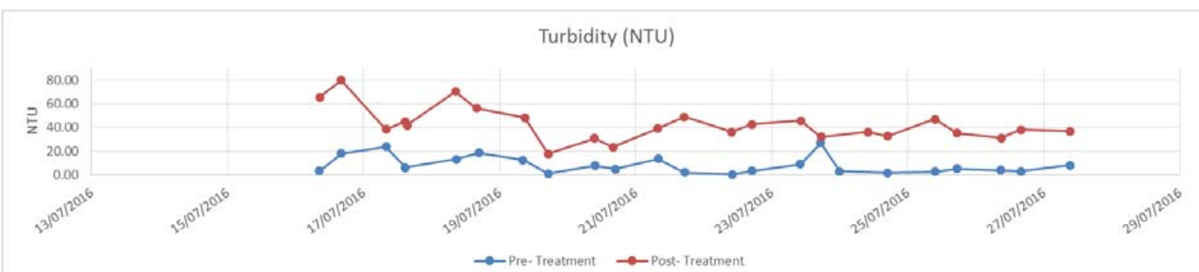


Figure C-3: Groundwater turbidity fluctuation at LDS-PW-2902

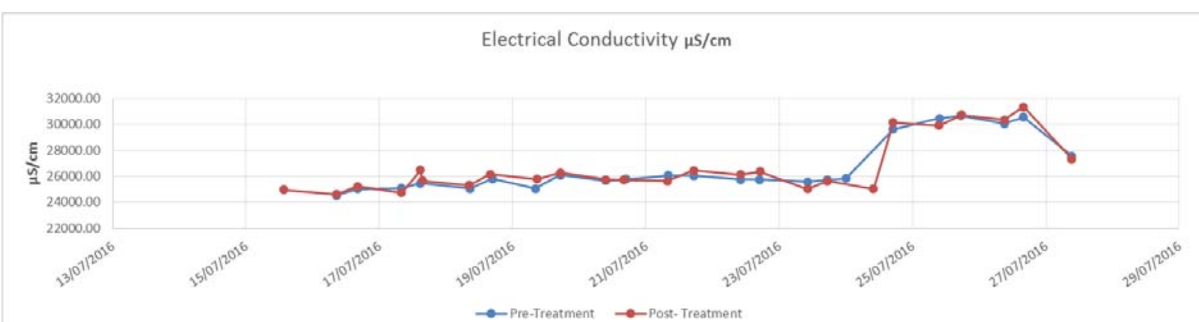


Figure C-4: Groundwater conductivity fluctuation at LDS-PW-2902

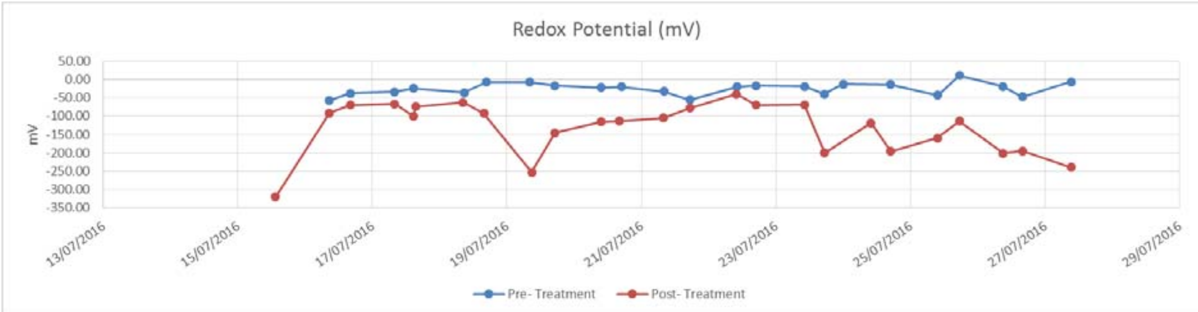


Figure C-5: Groundwater redox potential fluctuation at LDS-PW-2902

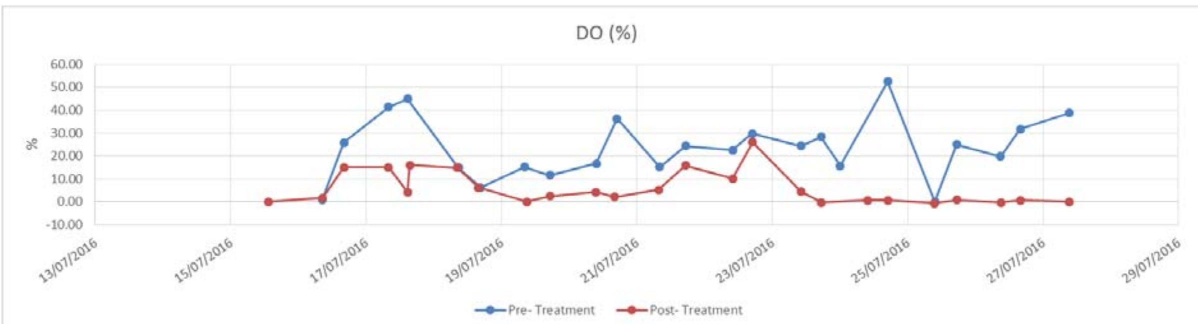


Figure C-6: Groundwater dissolved oxygen fluctuation at LDS-PW-2902

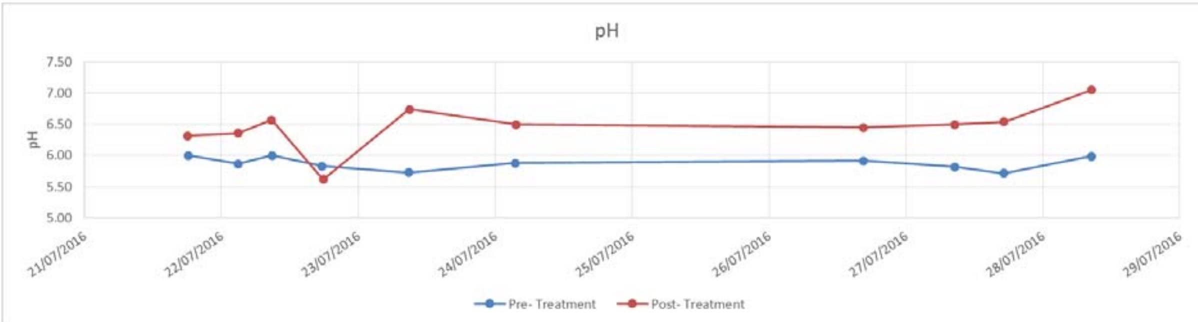


Figure C-7: Groundwater pH fluctuation at LDS-PW-2904

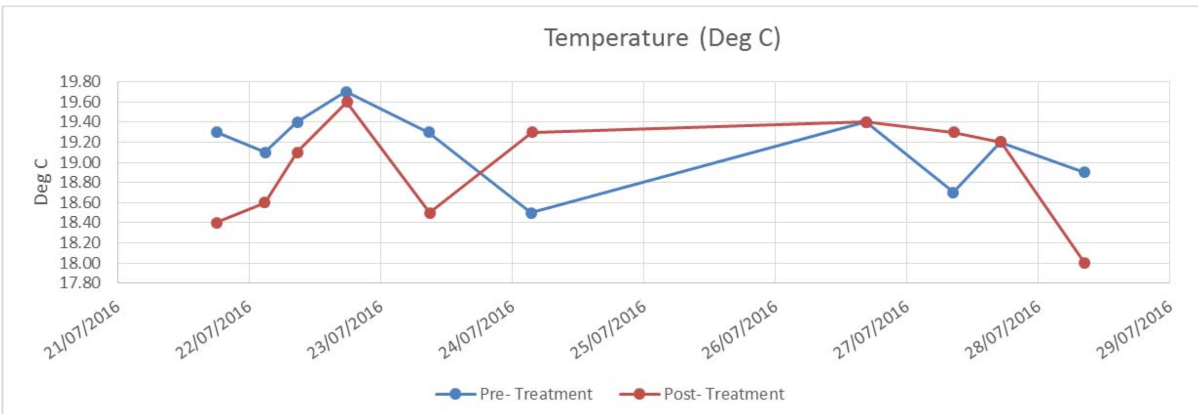


Figure C-8: Groundwater temperature fluctuation at LDS-PW-2904

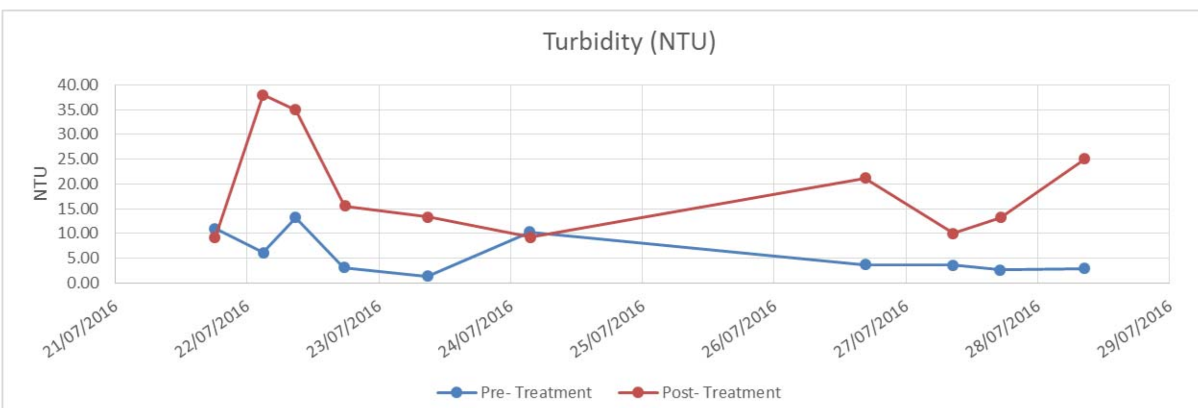


Figure C-9: Groundwater turbidity fluctuation at LDS-PW-2904

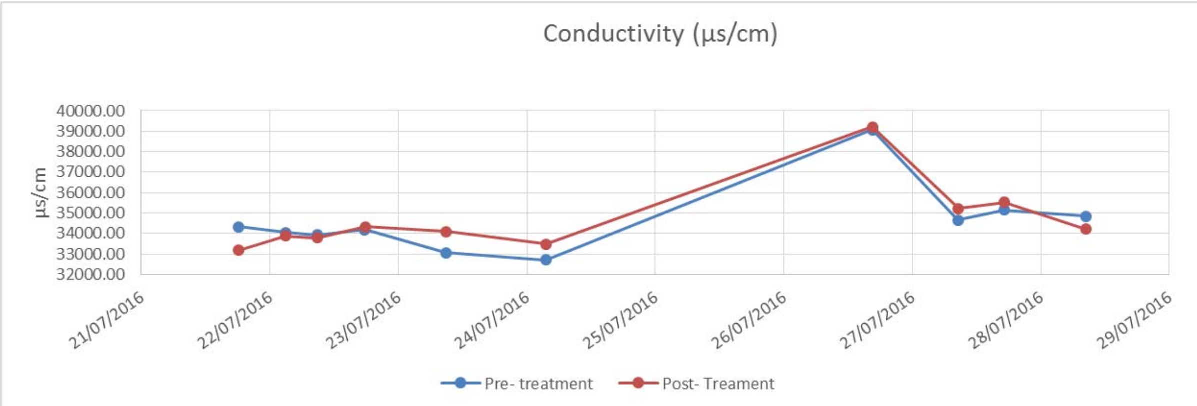


Figure C-10: Groundwater conductivity fluctuation at LDS-PW-2904

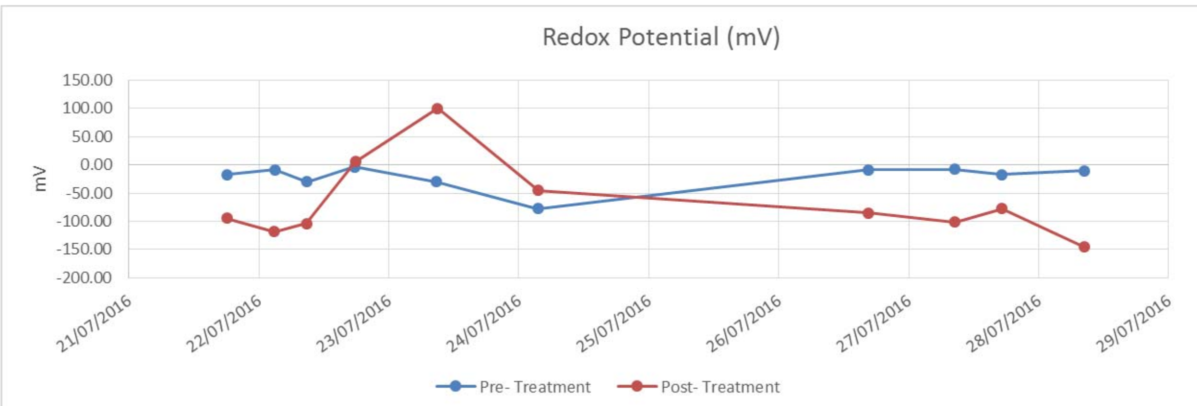


Figure C-11: Groundwater redox potential fluctuation at LDS-PW-2904

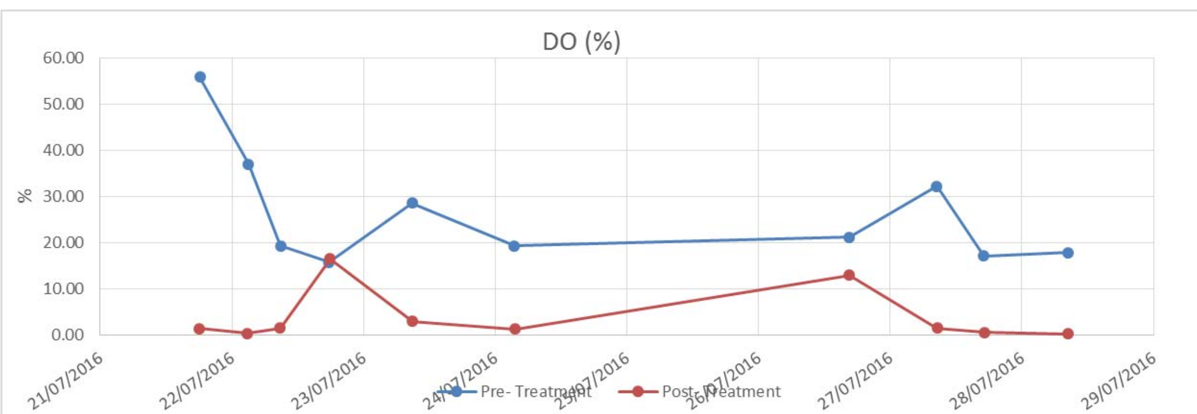


Figure C-12: Groundwater dissolved oxygen fluctuation at LDS-PW-2904

Table C-5: LDS-PW-2902 Lab Analyses Results (16/7/2016 & 17/7/2016)

		Description	**PW2902_POST**	**PW2902_DIS**
		Sample Date	16/7/2016	17/7/2016
		Matrix	Water	Water
Analyte Name	**Units**	**Reporting Limit**	**Result**	**Result**
Benzene	µg/L	0.5	<0.5	<0.5
Toluene	µg/L	0.5	<0.5	<0.5
Ethylbenzene	µg/L	0.5	<0.5	<0.5
m/p-xylene	µg/L	1	<1	<1
o-xylene	µg/L	0.5	<0.5	<0.5
Total Xylenes	µg/L	1.5	<1.5	<1.5
Total BTEX	µg/L	3	<3	<3
Naphthalene	µg/L	0.5	<0.5	<0.5
Dichlorodifluoromethane (CFC-12)	µg/L	5	<5	<5
Chloromethane	µg/L	5	<5	<5
Vinyl chloride (Chloroethene)	µg/L	0.3	<0.3	<0.3
Bromomethane	µg/L	10	<10	<10
Chloroethane	µg/L	5	<5	<5
Trichlorofluoromethane	µg/L	1	<1	<1
Acetone (2-propanone)	µg/L	10	<10	<10
Iodomethane	µg/L	5	<5	<5
1,1-dichloroethene	µg/L	0.5	<0.5	<0.5
Acrylonitrile	µg/L	0.5	<0.5	<0.5
Dichloromethane (Methylene chloride)	µg/L	5	<5	<5
Allyl chloride	µg/L	2	<2	<2
Carbon disulfide	µg/L	2	<2	<2
trans-1,2-dichloroethene	µg/L	0.5	<0.5	<0.5
MtBE (Methyl-tert-butyl ether)	µg/L	2	<2	<2
1,1-dichloroethane	µg/L	0.5	<0.5	<0.5
Vinyl acetate	µg/L	10	<10	<10
MEK (2-butanone)	µg/L	10	<10	<10
cis-1,2-dichloroethene	µg/L	0.5	<0.5	<0.5
Bromochloromethane	µg/L	0.5	<0.5	<0.5
Chloroform (THM)	µg/L	0.5	<0.5	<0.5
2,2-dichloropropane	µg/L	0.5	<0.5	<0.5
1,2-dichloroethane	µg/L	0.5	<0.5	<0.5
1,1,1-trichloroethane	µg/L	0.5	<0.5	<0.5

		Description	PW2902_POST	PW2902_DIS
		Sample Date	16/7/2016	17/7/2016
		Matrix	Water	Water
1,1-dichloropropene	µg/L	0.5	<0.5	<0.5
Carbon tetrachloride	µg/L	0.5	<0.5	<0.5
Dibromomethane	µg/L	0.5	<0.5	<0.5
1,2-dichloropropane	µg/L	0.5	<0.5	<0.5
Trichloroethene (Trichloroethylene,TCE)	µg/L	0.5	<0.5	<0.5
2-nitropropane	µg/L	100	<100	<100
Bromodichloromethane (THM)	µg/L	0.5	<0.5	<0.5
MIBK (4-methyl-2-pentanone)	µg/L	5	<5	<5
cis-1,3-dichloropropene	µg/L	0.5	<0.5	<0.5
trans-1,3-dichloropropene	µg/L	0.5	<0.5	<0.5
1,1,2-trichloroethane	µg/L	0.5	<0.5	<0.5
1,3-dichloropropane	µg/L	0.5	<0.5	<0.5
Dibromochloromethane (THM)	µg/L	0.5	<0.5	<0.5
2-hexanone (MBK)	µg/L	5	<5	<5
1,2-dibromoethane (EDB)	µg/L	0.5	<0.5	<0.5
Tetrachloroethene (Perchloroethylene,PCE)	µg/L	0.5	<0.5	<0.5
1,1,1,2-tetrachloroethane	µg/L	0.5	<0.5	<0.5
Chlorobenzene	µg/L	0.5	<0.5	<0.5
Bromoform (THM)	µg/L	0.5	<0.5	<0.5
cis-1,4-dichloro-2-butene	µg/L	1	<1	<1
Styrene (Vinyl benzene)	µg/L	0.5	<0.5	<0.5
1,1,2,2-tetrachloroethane	µg/L	0.5	<0.5	<0.5
1,2,3-trichloropropane	µg/L	0.5	<0.5	<0.5
trans-1,4-dichloro-2-butene	µg/L	1	<1	<1
Isopropylbenzene (Cumene)	µg/L	0.5	<0.5	<0.5
Bromobenzene	µg/L	0.5	<0.5	<0.5
n-propylbenzene	µg/L	0.5	<0.5	<0.5
2-chlorotoluene	µg/L	0.5	<0.5	<0.5
4-chlorotoluene	µg/L	0.5	<0.5	<0.5
1,3,5-trimethylbenzene	µg/L	0.5	<0.5	<0.5
tert-butylbenzene	µg/L	0.5	<0.5	<0.5
1,2,4-trimethylbenzene	µg/L	0.5	<0.5	<0.5
sec-butylbenzene	µg/L	0.5	<0.5	<0.5

		Description	PW2902_POST	PW2902_DIS
		Sample Date	16/7/2016	17/7/2016
		Matrix	Water	Water
1,3-dichlorobenzene	µg/L	0.5	<0.5	<0.5
1,4-dichlorobenzene	µg/L	0.3	<0.3	<0.3
p-isopropyltoluene	µg/L	0.5	<0.5	<0.5
1,2-dichlorobenzene	µg/L	0.5	<0.5	<0.5
n-butylbenzene	µg/L	0.5	<0.5	<0.5
1,2-dibromo-3-chloropropane	µg/L	0.5	<0.5	<0.5
1,2,4-trichlorobenzene	µg/L	0.5	<0.5	<0.5
Hexachlorobutadiene	µg/L	0.5	<0.5	<0.5
1,2,3-trichlorobenzene	µg/L	0.5	<0.5	<0.5
Total VOC	µg/L	10	N.A.	N.A.
TRH C6-C9	µg/L	40	<40	<40
Benzene (F0)	µg/L	0.5	<0.5	<0.5
TRH C6-C10	µg/L	50	<50	<50
TRH C6-C10 minus BTEX (F1)	µg/L	50	<50	<50
TRH C10-C14	µg/L	50	<50	<50
TRH C15-C28	µg/L	200	<200	<200
TRH C29-C36	µg/L	200	<200	<200
TRH C37-C40	µg/L	200	<200	<200
TRH >C10-C16 (F2)	µg/L	60	<60	<60
TRH >C16-C34 (F3)	µg/L	500	<500	<500
TRH >C34-C40 (F4)	µg/L	500	<500	<500
TRH C10-C36	µg/L	450	<450	<450
TRH C10-C40	µg/L	650	<650	<650
Acenaphthene	µg/L	0.1	<0.1	<0.1
Acenaphthylene	µg/L	0.1	<0.1	<0.1
Anthracene	µg/L	0.1	<0.1	<0.1
Benzo(a)anthracene	µg/L	0.1	<0.1	<0.1
Total Benzofluoranthenes (b&j&k)	µg/L	0.2	<0.2	<0.2
Benzo(b&j)fluoranthene	µg/L	0.1	<0.1	<0.1
Benzo(k)fluoranthene	µg/L	0.1	<0.1	<0.1
Benzo(ghi)perylene	µg/L	0.1	<0.1	<0.1
Benzo(a)pyrene	µg/L	0.1	<0.1	<0.1
Chrysene	µg/L	0.1	<0.1	<0.1
Dibenzo(ah)anthracene	µg/L	0.1	<0.1	<0.1

		Description	PW2902_POST	PW2902_DIS
		Sample Date	16/7/2016	17/7/2016
		Matrix	Water	Water
Fluoranthene	µg/L	0.1	<0.1	<0.1
Fluorene	µg/L	0.1	<0.1	<0.1
Indeno(1,2,3-cd)pyrene	µg/L	0.1	<0.1	<0.1
1-methylnaphthalene	µg/L	0.1	<0.1	<0.1
2-methylnaphthalene	µg/L	0.1	<0.1	<0.1
Naphthalene	µg/L	0.1	<0.1	<0.1
Phenanthrene	µg/L	0.1	<0.1	<0.1
Pyrene	µg/L	0.1	<0.1	<0.1
2-acetylaminofluorene	µg/L	0.5	<0.5	<0.5
7,12-dimethyl-benz(a)anthracene	µg/L	0.5	<0.5	<0.5
3-methylcholanthrene	µg/L	0.5	<0.5	<0.5
Aldrin	µg/L	0.1	<0.1	<0.1
Alpha-BHC	µg/L	0.1	<0.1	<0.1
Beta-BHC	µg/L	0.1	<0.1	<0.1
Delta-BHC	µg/L	0.1	<0.1	<0.1
Gamma-BHC (Lindane)	µg/L	0.1	<0.1	<0.1
p,p-DDD	µg/L	0.1	<0.1	<0.1
p,p-DDE	µg/L	0.1	<0.1	<0.1
p,p-DDT	µg/L	0.1	<0.1	<0.1
Dieldrin	µg/L	0.1	<0.1	<0.1
Alpha-endosulfan	µg/L	0.1	<0.1	<0.1
Beta-endosulfan	µg/L	0.1	<0.1	<0.1
Endosulfan sulphate	µg/L	0.1	<0.1	<0.1
Endrin	µg/L	0.1	<0.1	<0.1
Heptachlor	µg/L	0.1	<0.1	<0.1
Heptachlor epoxide	µg/L	0.1	<0.1	<0.1
Isodrin	µg/L	0.1	<0.1	<0.1
Methoxychlor	µg/L	0.1	<0.1	<0.1
Mirex	µg/L	0.1	<0.1	<0.1
Alpha-chlordane	µg/L	0.1	<0.1	<0.1
Gamma-chlordane	µg/L	0.1	<0.1	<0.1
Endrin ketone	µg/L	0.1	<0.1	<0.1
Azinphos-methyl (Guthion)	µg/L	0.2	<0.2	<0.2
Bromophos ethyl	µg/L	0.2	<0.2	<0.2

		Description	PW2902_POST	PW2902_DIS
		Sample Date	16/7/2016	17/7/2016
		Matrix	Water	Water
Carbophenothion	µg/L	0.5	<0.5	<0.5
Chlorfenvinphos-cis	µg/L	5	<5	<5
Chlorfenvinphos-trans	µg/L	0.5	<0.5	<0.5
Chlorpyrifos (Chlorpyrifos Ethyl)	µg/L	0.2	<0.2	<0.2
Chlorpyrifos-methyl	µg/L	0.5	<0.5	<0.5
Co-Ral (Coumaphos)	µg/L	0.5	<0.5	<0.5
Diazinon (Dimpylate)	µg/L	0.5	<0.5	<0.5
Dichlorvos	µg/L	0.5	<0.5	<0.5
1/2-Chloronaphthalene	µg/L	1	<1	<1
Demeton-S-methyl	µg/L	0.5	<0.5	<0.5
Dimethoate	µg/L	0.5	<0.5	<0.5
Disulfoton (Di-syston)	µg/L	0.5	<0.5	<0.5
EPN	µg/L	0.5	<0.5	<0.5
Ethion	µg/L	0.2	<0.2	<0.2
Ethoprophos (Ethoprop or Prophos)	µg/L	0.5	<0.5	<0.5
Famphur (Famophos)	µg/L	0.5	<0.5	<0.5
Fenamiphos (Phenamiphos)	µg/L	0.5	<0.5	<0.5
Fenchlorophos (Ronnel)	µg/L	0.5	<0.5	<0.5
Fenitrothion	µg/L	0.2	<0.2	<0.2
Fenthion	µg/L	0.5	<0.5	<0.5
Malathion (Maldison)	µg/L	0.2	<0.2	<0.2
Methidathion	µg/L	0.5	<0.5	<0.5
Mevinphos-cis/trans	µg/L	1	<1	<1
o,o,o-triethyl phosphorothioate	µg/L	0.5	<0.5	<0.5
Parathion ethyl (Parathion)	µg/L	0.2	<0.2	<0.2
Parathion methyl	µg/L	0.5	<0.5	<0.5
Phorate	µg/L	0.5	<0.5	<0.5
Pirimiphos-ethyl	µg/L	0.5	<0.5	<0.5
Pirimiphos-methyl	µg/L	0.5	<0.5	<0.5
Profenofos	µg/L	0.5	<0.5	<0.5
Prothiophos (Tokuthion)	µg/L	0.5	<0.5	<0.5
Sulfotepp	µg/L	0.5	<0.5	<0.5
Tetrachlorvinphos (Stirophos)	µg/L	0.5	<0.5	<0.5
PCB Congener C28	µg/L	0.1	<0.1	<0.1

		Description	PW2902_POST	PW2902_DIS
		Sample Date	16/7/2016	17/7/2016
		Matrix	Water	Water
PCB Congener C52	µg/L	0.1	<0.1	<0.1
PCB Congener C101	µg/L	0.1	<0.1	<0.1
PCB Congener C118	µg/L	0.1	<0.1	<0.1
PCB Congener C138	µg/L	0.1	<0.1	<0.1
PCB Congener C153	µg/L	0.1	<0.1	<0.1
PCB Congener C180	µg/L	0.1	<0.1	<0.1
Hexachlorobenzene (HCB)	µg/L	0.1	<0.1	<0.1
1,2-dichlorobenzene	µg/L	0.5	<0.5	<0.5
1,3-dichlorobenzene	µg/L	0.5	<0.5	<0.5
1,4-dichlorobenzene	µg/L	0.5	<0.5	<0.5
Hexachlorobutadiene	µg/L	0.5	<0.5	<0.5
Hexachlorocyclopentadiene	µg/L	2	<2	<2
Hexachloroethane	µg/L	0.5	<0.5	<0.5
Hexachloroproprene	µg/L	0.5	<0.5	<0.5
Pentachlorobenzene	µg/L	0.5	<0.5	<0.5
Pentachloroethane	µg/L	0.5	<0.5	<0.5
1,2,3,5 and 1,2,4,5-tetrachlorobenzene	µg/L	1	<1	<1
1,2,3,4-tetrachlorobenzene	µg/L	0.5	<0.5	<0.5
1,2,4-trichlorobenzene	µg/L	0.5	<0.5	<0.5
Bis(2-ethylhexyl)phthalate	µg/L	50	<50	<50
Bis(2-ethylhexyl)adipate	µg/L	1	<1	<1
Butyl benzyl phthalate	µg/L	1	<1	<1
Di-n-butyl phthalate	µg/L	10	<10	<10
Diethyl phthalate	µg/L	5	<5	<5
Dimethyl phthalate	µg/L	1	<1	<1
Dioctyl phthalate	µg/L	1	<1	<1
Carbofuran	µg/L	0.5	<0.5	<0.5
Carbaryl	µg/L	0.5	<0.5	<0.5
Trifluralin	µg/L	0.5	<0.5	<0.5
N-nitroso-di-n-butylamine (NDBA)	µg/L	1	<1	<1
N-nitroso-diethylamine (NDEA)	µg/L	1	<1	<1
N-nitroso-di-n-propylamine (NDPA)	µg/L	1	<1	<1
N-nitroso-morpholine (NMOR)	µg/L	1	<1	<1
N-nitroso-piperidine (NPIP)	µg/L	1	<1	<1

		Description	PW2902_POST	PW2902_DIS
		Sample Date	16/7/2016	17/7/2016
		Matrix	Water	Water
N-nitroso-pyrrolidine (NPYR)	µg/L	1	<1	<1
4-amino biphenyl	µg/L	1	<1	<1
Acetophenone	µg/L	1	<1	<1
1,3-dinitrobenzene	µg/L	1	<1	<1
2,4-dinitrotoluene	µg/L	1	<1	<1
2,6-dinitrotoluene	µg/L	1	<1	<1
Isophorone	µg/L	1	<1	<1
Nitrobenzene	µg/L	1	<1	<1
p-(dimethylamino) azobenzene	µg/L	1	<1	<1
Phenacetin	µg/L	1	<1	<1
Pentachloronitrobenzene (quintozene)	µg/L	1	<1	<1
Aniline	µg/L	5	<5	<5
4-chloroaniline	µg/L	1	<1	<1
2-nitroaniline	µg/L	1	<1	<1
3-nitroaniline	µg/L	1	<1	<1
4-nitroaniline	µg/L	1	<1	<1
Diphenylamine	µg/L	1	<1	<1
o-Toluidine	µg/L	1	<1	<1
5-nitro-o-toluidine	µg/L	1	<1	<1
1-naphthylamine	µg/L	2	<2	<2
2-naphthylamine	µg/L	2	<2	<2
Bis(2-chloroethoxy) methane	µg/L	1	<1	<1
Bis(2-chloroethyl) ether	µg/L	1	<1	<1
Bis(2-chloroisopropyl) ether	µg/L	1	<1	<1
4-chlorophenyl phenyl ether	µg/L	1	<1	<1
4-bromophenyl phenyl ether	µg/L	1	<1	<1
Methyl methanesulfonate	µg/L	1	<1	<1
Ethyl methanesulfonate	µg/L	1	<1	<1
Dibenzofuran	µg/L	1	<1	<1
Benzyl alcohol	µg/L	1	<1	<1
Safrole	µg/L	1	<1	<1
Isosafrole Isomer 1	µg/L	1	<1	<1
Isosafrole Isomer 2	µg/L	1	<1	<1
1,4-naphthoquinone	µg/L	1	<1	<1

		Description	PW2902_POST	PW2902_DIS
		Sample Date	16/7/2016	17/7/2016
		Matrix	Water	Water
Thionazin	µg/L	1	<1	<1
3/4-methyl phenol (m/p-cresol)	µg/L	1	<1	<1
2-methyl phenol (o-cresol)	µg/L	0.5	<0.5	<0.5
2,6-dichlorophenol	µg/L	0.5	<0.5	<0.5
2,3,4,6 and 2,3,5,6-tetrachlorophenol	µg/L	1	<1	<1
2,4,5-trichlorophenol	µg/L	0.5	<0.5	<0.5
4-chloro-3-methylphenol	µg/L	2	<2	<2
2-chlorophenol	µg/L	0.5	<0.5	<0.5
2,4-dichlorophenol	µg/L	0.5	<0.5	<0.5
2,4-dimethylphenol	µg/L	0.5	<0.5	<0.5
2-nitrophenol	µg/L	0.5	<0.5	<0.5
Phenol	µg/L	0.5	<0.5	<0.5
2,4,6-trichlorophenol	µg/L	0.5	<0.5	<0.5
Pentachlorophenol	µg/L	0.5	<0.5	<0.5
4-nitrophenol	µg/L	1	<1	<1
Total Phenols	mg/L	0.01	<0.01	<0.01
pH**	No unit	0	6.4	6.4
Ferrous Iron, Fe2+	mg/L	0.05	52	59
Chloride	mg/L	1	10000	11000
Sulphate, SO4	mg/L	1	950	990
Total Suspended Solids Dried at 103-105°C	mg/L	5	N.A.	N.A.
Conductivity @ 25 C	µS/cm	2	28000	28000
Total Alkalinity as CaCO3	mg/L	5	110	99
Biochemical Oxygen Demand (BOD5)	mg/L	5	<5	<5
Calcium, Ca	mg/L	0.1	870	890
Magnesium, Mg	mg/L	0.1	930	960
Sodium, Na	mg/L	0.1	4100	4200
Potassium, K	mg/L	0.2	160	160
Arsenic, As	µg/L	1	<1	<1
Cadmium, Cd	µg/L	0.1	<0.1	<0.1
Copper, Cu	µg/L	1	15	<1
Chromium, Cr	µg/L	1	<1	<1

		Description	PW2902_POST	PW2902_DIS
		Sample Date	16/7/2016	17/7/2016
		Matrix	Water	Water
Nickel, Ni	µg/L	1	16	<1
Lead, Pb	µg/L	1	<1	<1
Zinc, Zn	µg/L	5	20	8
Mercury	mg/L	0.0001	<0.0001	<0.0001
Total Arsenic	µg/L	1	<1	<1
Total Cadmium	µg/L	0.1	<0.1	<0.1
Total Chromium	µg/L	1	<1	<1
Total Copper	µg/L	1	31	1
Total Nickel	µg/L	1	22	<1
Total Lead	µg/L	1	2	<1
Total Zinc	µg/L	5	150	55
Total Mercury	mg/L	0.0001	<0.0001	<0.0001

Table C-6: LDS-PW-2902 Lab Analyses Results (22/7/2016 & 26/7/2016)

		Description	**PW2902_DIS_22072016**	**PW2902_DIS_26072016**
		Sample Date	22/7/2016	26/7/2016
		Matrix	Water	Water
Analyte Name	**Units**	**Reporting Limit**	**Result**	**Result**
Benzene (F0)	µg/L	0.5	<0.5	<0.5
TRH C6-C9	µg/L	40	<40	<40
TRH C6-C10	µg/L	50	<50	<50
TRH C6-C10 minus BTEX (F1)	µg/L	50	<50	<50
TRH C10-C14	µg/L	50	<50	<50
TRH C15-C28	µg/L	200	<200	<200
TRH C29-C36	µg/L	200	<200	<200
TRH C37-C40	µg/L	200	<200	<200
TRH >C10-C16 (F2)	µg/L	60	<60	<60
TRH >C16-C34 (F3)	µg/L	500	<500	<500
TRH >C34-C40 (F4)	µg/L	500	<500	<500
TRH C10-C36	µg/L	450	<450	<450
TRH C10-C40	µg/L	650	<650	<650
pH**	No unit	0	6.6	6.5
Conductivity @ 25 C	µS/cm	2	29000	31000
Total Dissolved Solids Dried at 175-185°C	mg/L	10	19000	20000
Total Suspended Solids Dried at 103-105°C	mg/L	5	160	250
Chloride	mg/L	1	9400	10000
Nitrate Nitrogen, NO3-N	mg/L	0.005	<0.25	<0.25
Sulphate, SO4	mg/L	1	910	1000
Total Alkalinity as CaCO3	mg/L	5	120	130
Nitrite Nitrogen, NO2 as N	mg/L	0.005	<0.005	<0.005
Total Oxidised Nitrogen, NOx-N	mg/L	0.005	N.A.	N.A.
Total Kjeldahl Nitrogen	mg/L	0.05	2.7	0.38
Total Nitrogen (calc)	mg/L	0.05	2.7	0.38
Total Phosphorus (Kjeldahl Digestion)	mg/L	0.01	0.02	<0.01
Arsenic, As	µg/L	1	<1	<1

Cadmium, Cd	µg/L	0.1	<1	<1
Copper, Cu	µg/L	1	<2	<2
Chromium, Cr	µg/L	1	<1	<1
Nickel, Ni	µg/L	1	4	<2
Lead, Pb	µg/L	1	<1	<1
Zinc, Zn	µg/L	5	<10	<10
Calcium, Ca	mg/L	0.2	810	800
Magnesium, Mg	mg/L	0.1	930	950
Sodium, Na	mg/L	0.5	4300	4600
Potassium, K	mg/L	0.1	170	180
Total Hardness by Calculation	mg CaCO3/L	5	5800	5900
Mercury	mg/L	0.0001	<0.0001	<0.0001
Total Arsenic	µg/L	1	<1	<1
Total Cadmium	µg/L	0.1	<1	<1
Total Chromium	µg/L	1	<1	<1
Total Copper	µg/L	1	5	<2
Total Nickel	µg/L	1	18	<2
Total Lead	µg/L	1	<1	<1
Total Zinc	µg/L	5	44	20
Total Mercury	mg/L	0.0001	<0.0001	<0.0001

Table C-7: LDS-PW-2902 Lab Analyses Results (27/7/2016)

		Description	**PW2902_DIS_27716**
		Sample Date	27/7/2016
		Matrix	Water
Analyte Name	**Units**	**Reporting Limit**	**Result**
Benzene	µg/L	0.5	<0.5
Toluene	µg/L	0.5	<0.5
Ethylbenzene	µg/L	0.5	<0.5
m/p-xylene	µg/L	1	<1
o-xylene	µg/L	0.5	<0.5
Total Xylenes	µg/L	1.5	<1.5
Total BTEX	µg/L	3	<3
Naphthalene	µg/L	0.5	1.0
TRH C6-C9	µg/L	40	<40
Benzene (F0)	µg/L	0.5	<0.5
TRH C6-C10	µg/L	50	<50
TRH C6-C10 minus BTEX (F1)	µg/L	50	<50
TRH C10-C14	µg/L	50	<50
TRH C15-C28	µg/L	200	<200
TRH C29-C36	µg/L	200	<200
TRH C37-C40	µg/L	200	<200
TRH >C10-C16 (F2)	µg/L	60	<60
TRH >C16-C34 (F3)	µg/L	500	<500
TRH >C34-C40 (F4)	µg/L	500	<500
TRH C10-C36	µg/L	450	<450
TRH C10-C40	µg/L	650	<650
Hexachlorobenzene (HCB)	µg/L	0.1	<0.1
Alpha BHC	µg/L	0.1	<0.1
Lindane (gamma BHC)	µg/L	0.1	<0.1
Heptachlor	µg/L	0.1	<0.1
Aldrin	µg/L	0.1	<0.1
Beta BHC	µg/L	0.1	<0.1
Delta BHC	µg/L	0.1	<0.1
Heptachlor epoxide	µg/L	0.1	<0.1
o,p'-DDE	µg/L	0.1	<0.1
Alpha Endosulfan	µg/L	0.1	<0.1
Gamma Chlordane	µg/L	0.1	<0.1
Alpha Chlordane	µg/L	0.1	<0.1
trans-Nonachlor	µg/L	0.1	<0.1
p,p'-DDE	µg/L	0.1	<0.1
Dieldrin	µg/L	0.1	<0.1

		Description	PW2902_DIS_27716
		Sample Date	27/7/2016
		Matrix	Water
Endrin	µg/L	0.1	<0.1
o,p'-DDD	µg/L	0.1	<0.1
o,p'-DDT	µg/L	0.1	<0.1
Beta Endosulfan	µg/L	0.1	<0.1
p,p'-DDD	µg/L	0.1	<0.1
p,p'-DDT	µg/L	0.1	<0.1
Endosulfan sulphate	µg/L	0.1	<0.1
Endrin aldehyde	µg/L	0.1	<0.1
Methoxychlor	µg/L	0.1	<0.1
Endrin ketone	µg/L	0.1	<0.1
Isodrin	µg/L	0.1	<0.1
Mirex	µg/L	0.1	<0.1
Dichlorvos	µg/L	0.5	<0.5
Dimethoate	µg/L	0.5	<0.5
Diazinon (Dimpylate)	µg/L	0.5	<0.5
Fenitrothion	µg/L	0.2	<0.2
Malathion	µg/L	0.2	<0.2
Chlorpyrifos (Chlorpyrifos Ethyl)	µg/L	0.2	<0.2
Parathion-ethyl (Parathion)	µg/L	0.2	<0.2
Bromophos Ethyl	µg/L	0.2	<0.2
Methidathion	µg/L	0.5	<0.5
Ethion	µg/L	0.2	<0.2
Azinphos-methyl	µg/L	0.2	<0.2
pH**	No unit	0	6.6
Conductivity @ 25 C	µS/cm	2	30000
Total Dissolved Solids Dried at 175-185°C	mg/L	10	19000
Total Suspended Solids Dried at 103-105°C	mg/L	5	100
Chloride	mg/L	1	10000
Nitrate Nitrogen, NO3-N	mg/L	0.005	<0.25
Sulphate, SO4	mg/L	1	1000
Total Alkalinity as CaCO3	mg/L	5	140
Nitrite Nitrogen, NO2 as N	mg/L	0.005	<0.005
Total Oxidised Nitrogen, NOx-N	mg/L	0.005	<0.005
Total Kjeldahl Nitrogen	mg/L	0.05	3.5

		Description	PW2902_DIS_27716
		Sample Date	27/7/2016
		Matrix	Water
Total Phosphorus (Kjeldahl Digestion)	mg/L	0.01	<0.01
Calcium, Ca	mg/L	0.2	770
Magnesium, Mg	mg/L	0.1	910
Sodium, Na	mg/L	0.5	4200
Potassium, K	mg/L	0.1	140
Total Hardness by Calculation	mg CaCO3/L	5	5700
Arsenic, As	µg/L	1	<1
Cadmium, Cd	µg/L	0.1	<1
Copper, Cu	µg/L	1	<2
Chromium, Cr	µg/L	1	<1
Nickel, Ni	µg/L	1	<2
Lead, Pb	µg/L	1	<1
Zinc, Zn	µg/L	5	<10
Mercury	mg/L	0.0001	<0.0001
Total Arsenic	µg/L	1	<1
Total Cadmium	µg/L	0.1	<1
Total Chromium	µg/L	1	<1
Total Copper	µg/L	1	<2
Total Nickel	µg/L	1	<2
Total Lead	µg/L	1	<1
Total Zinc	µg/L	5	<10
Total Mercury	mg/L	0.0001	<0.0001

Table C-8: LDS-PW-2904 Lab Analyses Results (22/7/2016)

		Description	**PW2904_DIS_22072016**
		Sample Date	22/7/2016
		Matrix	Water
Analyte Name	**Units**	**Reporting Limit**	**Result**
Benzene (F0)	µg/L	0.5	<0.5
TRH C6-C9	µg/L	40	<40
TRH C6-C10	µg/L	50	<50
TRH C6-C10 minus BTEX (F1)	µg/L	50	<50
TRH C10-C14	µg/L	50	<50
TRH C15-C28	µg/L	200	<200
TRH C29-C36	µg/L	200	<200
TRH C37-C40	µg/L	200	<200
TRH >C10-C16 (F2)	µg/L	60	<60
TRH >C16-C34 (F3)	µg/L	500	<500
TRH >C34-C40 (F4)	µg/L	500	<500
TRH C10-C36	µg/L	450	<450
TRH C10-C40	µg/L	650	<650
pH**	No unit	0	5.6
Conductivity @ 25 C	µS/cm	2	39000
Total Dissolved Solids Dried at 175-185°C	mg/L	10	24000
Total Suspended Solids Dried at 103-105°C	mg/L	5	320
Chloride	mg/L	1	13000
Nitrate Nitrogen, NO3-N	mg/L	0.005	<0.25
Sulphate, SO4	mg/L	1	1700
Total Alkalinity as CaCO3	mg/L	5	78
Nitrite Nitrogen, NO2 as N	mg/L	0.005	<0.005
Total Oxidised Nitrogen, NOx-N	mg/L	0.005	N.A.
Total Kjeldahl Nitrogen	mg/L	0.05	2.4
Total Nitrogen (calc)	mg/L	0.05	2.4
Total Phosphorus (Kjeldahl Digestion)	mg/L	0.01	0.01
Arsenic, As	µg/L	1	<1
Cadmium, Cd	µg/L	0.1	<1
Copper, Cu	µg/L	1	<2
Chromium, Cr	µg/L	1	<1
Nickel, Ni	µg/L	1	27

		Description	PW2904_DIS_22072016
		Sample Date	22/7/2016
		Matrix	Water
Lead, Pb	µg/L	1	<1
Zinc, Zn	µg/L	5	10
Calcium, Ca	mg/L	0.2	650
Magnesium, Mg	mg/L	0.1	1000
Sodium, Na	mg/L	0.5	6500
Potassium, K	mg/L	0.1	230
Total Hardness by Calculation	mg CaCO3/L	5	5800
Mercury	mg/L	0.0001	<0.0001
Total Arsenic	µg/L	1	<1
Total Cadmium	µg/L	0.1	<1
Total Chromium	µg/L	1	<1
Total Copper	µg/L	1	<2
Total Nickel	µg/L	1	<2
Total Lead	µg/L	1	<1
Total Zinc	µg/L	5	28
Total Mercury	mg/L	0.0001	<0.0001

Table C-9: LDS-PW-2904 Lab Analyses Results (27/7/2016)

		Description	PW2904_DIS_27716
		Sample Date	27/7/2016
		Matrix	Water
Analyte Name	**Units**	**Reporting Limit**	**Result**
Benzene	µg/L	0.5	<0.5
Toluene	µg/L	0.5	<0.5
Ethylbenzene	µg/L	0.5	<0.5
m/p-xylene	µg/L	1	<1
o-xylene	µg/L	0.5	<0.5
Total Xylenes	µg/L	1.5	<1.5
Total BTEX	µg/L	3	<3
Naphthalene	µg/L	0.5	<0.5
TRH C6-C9	µg/L	40	<40
Benzene (F0)	µg/L	0.5	<0.5
TRH C6-C10	µg/L	50	<50
TRH C6-C10 minus BTEX (F1)	µg/L	50	<50
TRH C10-C14	µg/L	50	<50
TRH C15-C28	µg/L	200	<200
TRH C29-C36	µg/L	200	<200
TRH C37-C40	µg/L	200	<200
TRH >C10-C16 (F2)	µg/L	60	<60
TRH >C16-C34 (F3)	µg/L	500	<500
TRH >C34-C40 (F4)	µg/L	500	<500
TRH C10-C36	µg/L	450	<450
TRH C10-C40	µg/L	650	<650
Hexachlorobenzene (HCB)	µg/L	0.1	<0.1
Alpha BHC	µg/L	0.1	<0.1
Lindane (gamma BHC)	µg/L	0.1	<0.1
Heptachlor	µg/L	0.1	<0.1
Aldrin	µg/L	0.1	<0.1
Beta BHC	µg/L	0.1	<0.1
Delta BHC	µg/L	0.1	<0.1
Heptachlor epoxide	µg/L	0.1	<0.1
o,p'-DDE	µg/L	0.1	<0.1
Alpha Endosulfan	µg/L	0.1	<0.1
Gamma Chlordane	µg/L	0.1	<0.1
Alpha Chlordane	µg/L	0.1	<0.1
trans-Nonachlor	µg/L	0.1	<0.1

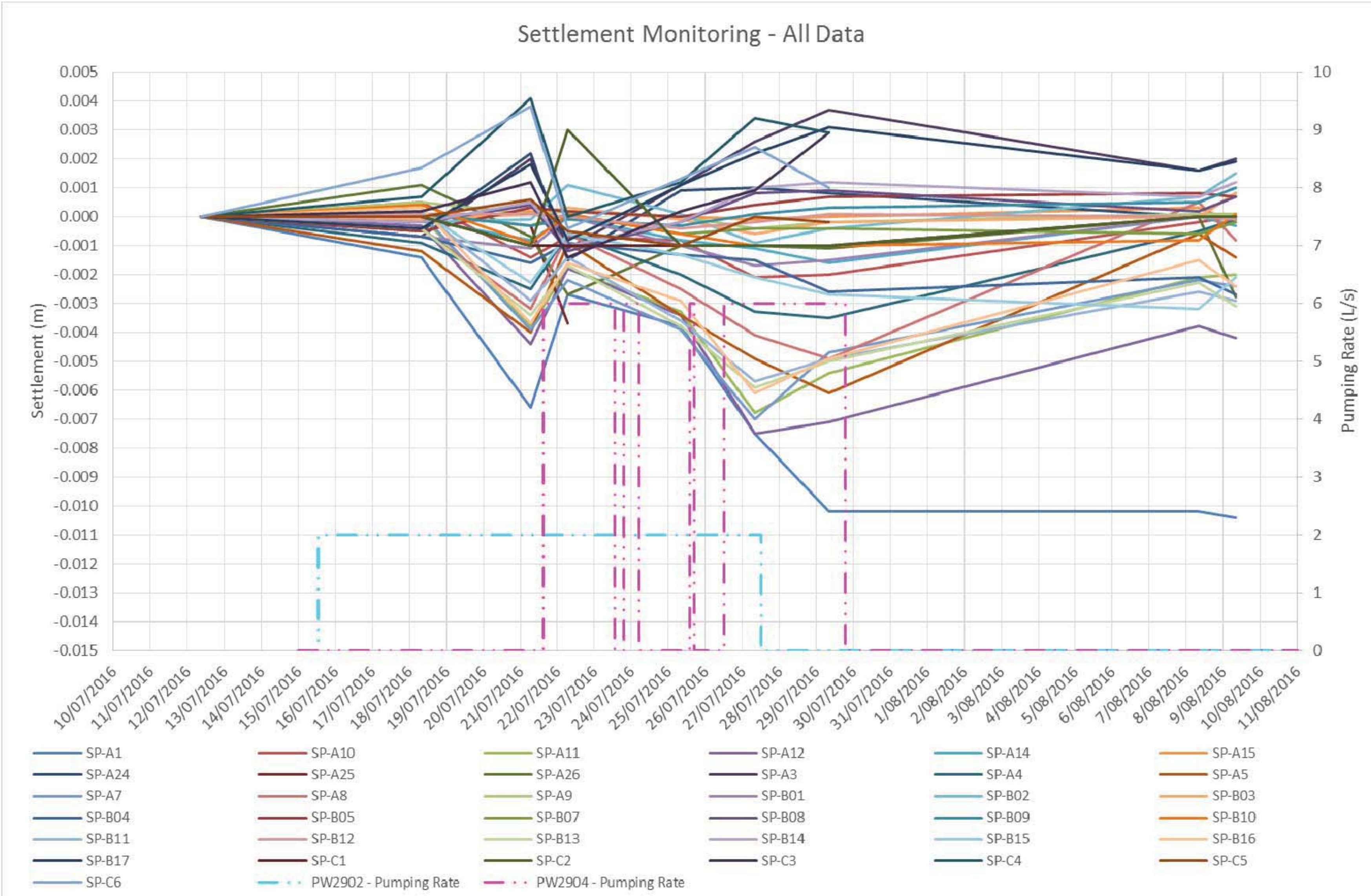
p,p'-DDE	µg/L	0.1	<0.1
Dieldrin	µg/L	0.1	<0.1
Endrin	µg/L	0.1	<0.1
o,p'-DDD	µg/L	0.1	<0.1
o,p'-DDT	µg/L	0.1	<0.1
Beta Endosulfan	µg/L	0.1	<0.1
p,p'-DDD	µg/L	0.1	<0.1
p,p'-DDT	µg/L	0.1	<0.1
Endosulfan sulphate	µg/L	0.1	<0.1
Endrin aldehyde	µg/L	0.1	<0.1
Methoxychlor	µg/L	0.1	<0.1
Endrin ketone	µg/L	0.1	<0.1
Isodrin	µg/L	0.1	<0.1
Mirex	µg/L	0.1	<0.1
Dichlorvos	µg/L	0.5	<0.5
Dimethoate	µg/L	0.5	<0.5
Diazinon (Dimpylate)	µg/L	0.5	<0.5
Fenitrothion	µg/L	0.2	<0.2
Malathion	µg/L	0.2	<0.2
Chlorpyrifos (Chlorpyrifos Ethyl)	µg/L	0.2	<0.2
Parathion-ethyl (Parathion)	µg/L	0.2	<0.2
Bromophos Ethyl	µg/L	0.2	<0.2
Methidathion	µg/L	0.5	<0.5
Ethion	µg/L	0.2	<0.2
Azinphos-methyl	µg/L	0.2	<0.2
pH**	No unit	0	6.0
Conductivity @ 25 C	µS/cm	2	38000
Total Dissolved Solids Dried at 175-185°C	mg/L	10	25000
Total Suspended Solids Dried at 103-105°C	mg/L	5	310
Chloride	mg/L	1	13000
Nitrate Nitrogen, NO3-N	mg/L	0.005	<0.25
Sulphate, SO4	mg/L	1	1700
Total Alkalinity as CaCO3	mg/L	5	100
Nitrite Nitrogen, NO2 as N	mg/L	0.005	<0.005
Total Oxidised Nitrogen, NOx-N	mg/L	0.005	<0.005
Total Kjeldahl Nitrogen	mg/L	0.05	2.8
Total Phosphorus (Kjeldahl Digestion)	mg/L	0.01	0.04
Calcium, Ca	mg/L	0.2	670
Magnesium, Mg	mg/L	0.1	1000

Sodium, Na	mg/L	0.5	6300
Potassium, K	mg/L	0.1	190
Total Hardness by Calculation	mg CaCO3/L	5	5800
Arsenic, As	µg/L	1	<1
Cadmium, Cd	µg/L	0.1	<1
Copper, Cu	µg/L	1	<2
Chromium, Cr	µg/L	1	<1
Nickel, Ni	µg/L	1	<2
Lead, Pb	µg/L	1	<1
Zinc, Zn	µg/L	5	<10
Mercury	mg/L	0.0001	<0.0001
Total Arsenic	µg/L	1	<1
Total Cadmium	µg/L	0.1	<1
Total Chromium	µg/L	1	<1
Total Copper	µg/L	1	<2
Total Nickel	µg/L	1	<2
Total Lead	µg/L	1	<1
Total Zinc	µg/L	5	29
Total Mercury	mg/L	0.0001	<0.0001

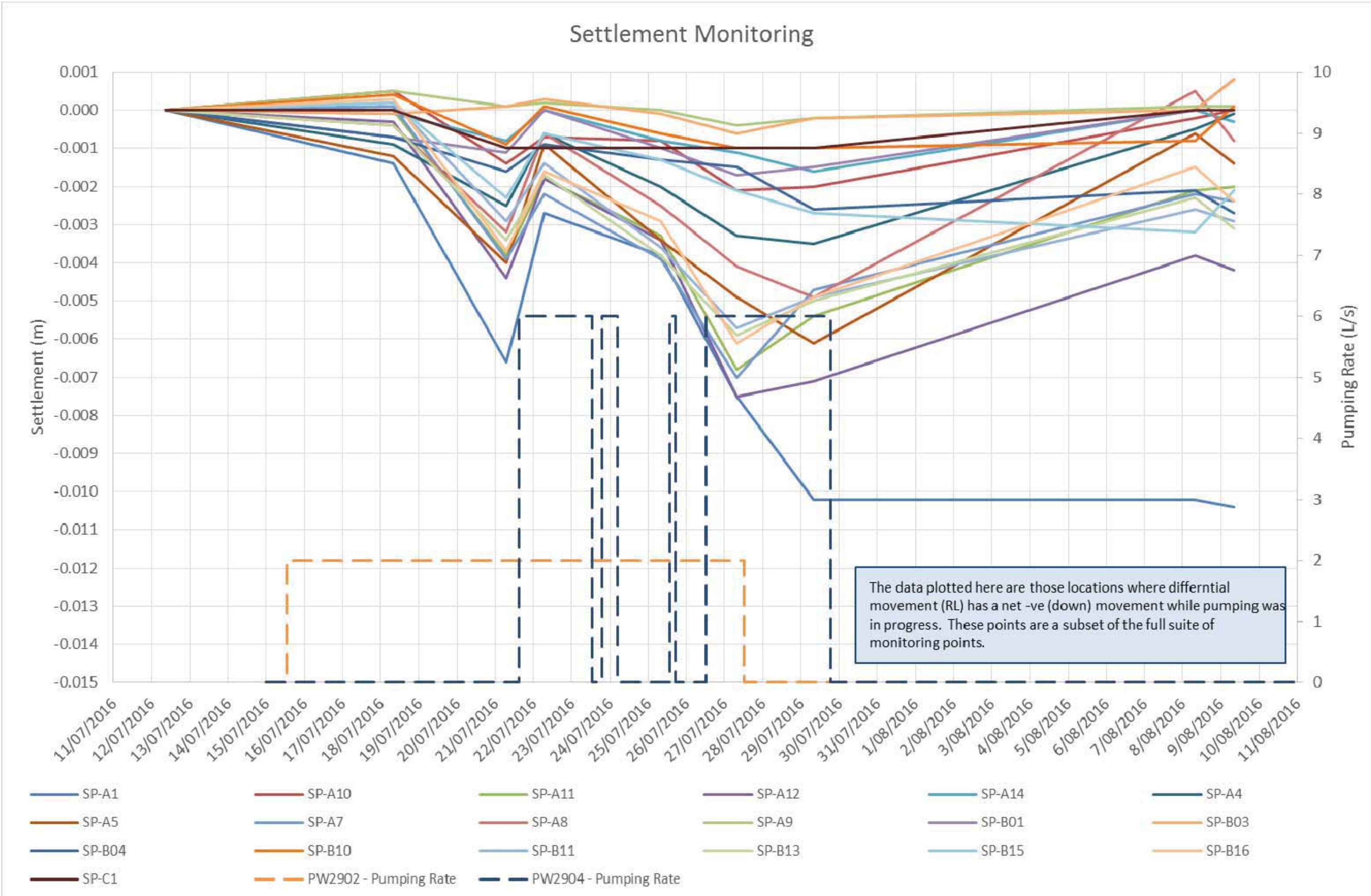
APPENDIX D
Settlement Measurements

Blue points are locations where survey data to date indicates a net settlement.

Golder Associates	CLIENT CPB DRAGADOS SAMSUNG JV		PROJECT West Connex Stage 2 New Motorway	
	DRAWN CMC	DATE 27/7/16	TITLE Settlement Monitoring Locations	
	CHECKED SF	DATE 28/07/16		
	SCALE N.T.S		PROJECT No 1524285-140	FIGURE No D1 · REV No 0 · A3



Golder Associates	CLIENT: CPB DRAGADOS SAMSUNG JV	PROJECT: West Connex Stage 2 New Motorway
	DRAWN: CMC / DATE: 27/7/16	TITLE: Settlement Monitoring – all monitoring locations
	CHECKED: SF / DATE: 28/07/16	
	SCALE: N.T.S	PROJECT No: 1524285-140 / FIGURE No: D2 / REV No: 0 / A3



Golder Associates

CLIENT CPB DRAGADOS SAMSUNG JV		PROJECT West Connex Stage 2 New Motorway	
DRAWN CMC	DATE 27/7/16	TITLE Settlement Monitoring – locations with net downward movement	
CHECKED SF	DATE 28/07/16		
SCALE N.T.S		PROJECT No 1524285-140	FIGURE No D3 REV No 0 A3

Annexure L – Summary of hydraulic parameter data from other sources

Hewitt (2005) outlines the regional sandstone permeability is typically an average mass permeability varying from 10^{-6} m/s [10 Lugeons (uL)] near the surface to about 2 x 10^{-8} m/s (0.2 uL) at 50 m depth. Higher permeability is likely near vertical dykes, sheared zones or open joints at relatively low cover below valleys and palaeochannels.

Based on observations in brick pits and from bores in the Sydney metropolitan area, McNally (2004) suggests that the Ashfield Shale is best thought of as leaky aquiclude that includes scattered zones of fracture permeability within the weathered shale profile, and also at depth in the fresh shale bedrock. He reported extremely variable bulk permeability values for the Ashfield Shale, typically between 10^{-7} and 10^{-9} m/s (1 uL to 0.01 uL) in fresh shale and 10^{-6} to 10^{-9} m/s in the weathered shale horizon.

A review of historical reports within the Project Corridor and the Sydney area was conducted to obtain aquifer parameters for the Hawkesbury Sandstone, Ashfield Shale, Quaternary sediments (including Botany Sands, marine and terrestrial sediments) and fill material. The values collected are based on hydraulic tests including pump tests, WPTs, laboratory tests and reported literature values or groundwater models parameters reported in Table 1. A summary of the statistical analysis of the WPTs in Golder's regional database and WPTs conducted as part of WCX2 site investigations are presented in Table 2. It should be noted that WPTs were not conducted in Quaternary sediments because the pressures required would be greater than the overburden confining pressure or the expected flow rates would be very high.

Hydraulic conductivities values are based on WPTs from the regional and project alignment data bases. Values obtained from the literature review have been compared to these values as a verification of the data. Specific yield, specific storage, storativity and porosity have been adopted based on regional literature and investigations for the Hawkesbury Sandstone, the Ashfield Shale and the Quaternary sediments reported Table 3, Table 4 and Table 5 respectively.

Table 1: Summary of hydraulic conductivity (K) from literature review

Statistic	Hawkesbury Sandstone (m/s)	Hawkesbury Sandstone (m/s)	Hawkesbury Sandstone (m/s)	Ashfield Shale (m/s)	Quaternary Sediments (m/s)	Quaternary Sediments (m/s)	Quaternary Sediments (m/s)	Fill (m/s)
Geometric mean	3.7×10^{-7}	-	-	4.4×10^{-8}	1.2×10^{-5}	-	-	5.8×10^{-6}
Arithmetic Mean	4.1×10^{-6}	-	-	6.5×10^{-7}	1.2×10^{-4}	-	-	2.0×10^{-5}
Minimum	1.0×10^{-11}	8.1×10^{-9}	1.3×10^{-10}	1.2×10^{-12}	3.8×10^{-10}	1.0×10^{-7}	1.0×10^{-9}	4.1×10^{-9}
Maximum	6.4×10^{-5}	1.5×10^{-5}	5.8×10^{-6}	2.3×10^{-5}	2.1	3.5×10^{-4}	1.2×10^{-4}	7.8×10^{-5}
Median	4.4×10^{-7}	2.1×10^{-7}	1.1×10^{-8}	1.2×10^{-8}	1.0×10^{-5}	5.8×10^{-6}	5.8×10^{-7}	9.5×10^{-6}
Standard Deviation	1.1×10^{-5}	-	-	2.4×10^{-6}	2.1×10^{-4}	-	-	2.3×10^{-6}
# data points	67	19	24	34	138	19	19	22

1 "Data source: Golder data base, Tammetta & Hewitt (2004), Hatley (2004), Golder (2015b), Golder (1999), CDM Smith (2015), AECOM (2015b), AECOM (2015c), AECOM (2015d)"

Table 2: Summary of statistical packer test results from the regional database and the Project Corridor

Statistic	Regional Ashfield Shale (m/s)	Regional Mittagong Formation (m/s)	Regional Hawkesbury Sandstone (m/s)	Ashfield Shale WCX2 Project Corridor (m/s)	Mittagong Formation WCX2 Project Corridor (m/s)	Hawkesbury Sandstone WCX2 Project Corridor (m/s)
Geometric mean	4.15×10^{-8}	8.74×10^{-8}	7.79×10^{-8}	4.15×10^{-8}	5.14×10^{-8}	4.18×10^{-8}
Arithmetic Mean	5.49×10^{-7}	6.87×10^{-7}	7.82×10^{-7}	1.40×10^{-7}	1.18×10^{-6}	5.40×10^{-7}
Standard Error	6.40×10^{-8}	1.67×10^{-7}	6.42×10^{-8}	1.13×10^{-7}	9.66×10^{-7}	9.69×10^{-7}
Median	6.50×10^{-8}	1.00×10^{-7}	8.00×10^{-8}	3.15×10^{-8}	9.30×10^{-8}	5.00×10^{-8}
Mode	5.00×10^{-9}	1.00×10^{-8}	1.00×10^{-9}	#N/A	#N/A	1.00×10^{-9}
Standard Deviation	1.26×10^{-6}	1.54×10^{-6}	2.12×10^{-6}	2.76×10^{-7}	3.05×10^{-6}	1.63×10^{-6}
Sample Variance	1.60×10^{-12}	2.38×10^{-12}	4.49×10^{-12}	7.60×10^{-14}	9.33×10^{-12}	2.66×10^{-12}
Kurtosis	23.11	1.63×10^{1}	12.04	5.95	9.67	20.94
Skewness	4.35	3.71	3.58	2.44	3.09	4.44
Range	1.00×10^{-5}	9.82×10^{-6}	1.00×10^{-5}	6.95×10^{-7}	9.82×10^{-6}	1.00×10^{-5}

Minimum	5.00×10^{-9}	2.00×10^{-10}	1.00×10^{-9}	7.60×10^{-9}	2.00×10^{-10}	1.00×10^{-9}
Maximum	1.00×10^{-5}	9.82×10^{-6}	1.00×10^{-5}	7.02×10^{-7}	9.82×10^{-6}	1.00×10^{-5}
Sum	2.14×10^{-4}	5.84×10^{-5}	8.53×10^{-4}	8.42×10^{-7}	1.18×10^{-5}	1.53×10^{-4}
Count	390	85	1091	6	10	283
Largest(1)	1.00×10^{-5}	9.82×10^{-6}	1.00×10^{-5}	7.02×10^{-7}	9.82×10^{-6}	1.00×10^{-5}
Smallest(1)	5.00×10^{-9}	2.00×10^{-10}	1.00×10^{-9}	7.60 X 10-9	2.00×10^{-10}	1.00×10^{-9}
Confidence Level (95.0%)	1.26×10^{-7}	3.33×10^{-7}	1.26×10^{-7}	2.89×10^{-7}	2.19×10^{-6}	1.91×10^{-7}

Note: Statistical data excludes boreholes where test data was determined to be inconclusive from CDS investigations (LDS-BH-2029 and LDSBH1030).

Table 3: Summary of aquifer storage parameters for the Hawkesbury Sandstone

Storativity (-)	Specific Storage (m^{-1})	Specific Yield (-)	Porosity (-)	Data Source	Source
			5% to 20%	Laboratory Tests[1]	Lieu et al., 1996
4.0×10^{-4} to 6.0×10^{3}	10^{-5}			Pump Test[2]	Golder, 1999
4×10^{-5} to 2.0×10^{-3}				Slug Tests[3]	Golder, 1999
10^{-5} to 10^{-4}				Pumping Test[4]	PB, 2001
2.3×10^{-6}		1.4×10^{-1}	15%	Pumping Test[5]	Pells, S., and Pells, P., 2013
1.5×10^{-6}		1.1×10^{-2}	12%	Pumping Test[5]	Pells, S., and Pells, P., 2013
2.1×10^{-6}		1.8×10^{-1}	20%	Pumping Test[5]	Pells, S., and Pells, P., 2013
	4.5×10^{-6}			Pumping Test[6]	Tammetta and Hawkes, 2009
	1.0×10^{-5} to 1.0×10^{-7}			Fracture specific storage model	Tammetta and Hawkes, 2009
	1.0×10^{-6}			Pumping Test[7] (single porosity)	Tammetta and Hawkes, 2009
	2.0×10^{-4}			Pumping Test[7] (double porosity – no fracture skin)	Tammetta and Hawkes, 2009
	4.0×10^{-5}			Pumping Test[7] (single porosity – fracture skin)	Tammetta and Hawkes, 2009
	3.0×10^{-6}	1.5×10^{-2} to 2.5×10^{-2}		Model	Coffey, 2006
			20%	Literature	McNally and Evans, 2007
4.0×10^{-4}		4.0×10^{-2}		Model	CSIRO, 2009
	1.0×10^{-5}	1.0×10^{-2}	5%	Model	IGGC, 2009
10^{-5}		5.0×10^{-3}		Model	Illawarra Coal, 2009
		1.5×10^{-2}	3%	Model	SCA, 2009
		5.0×10^{-2}		Case Study	Short et al., 2009
2.0×10^{-4} to 5.0×10^{-4}		2.0×10^{-2} to 5.0×10^{-2}		Calibrated hydraulic parameters in model	Hydro Tasmania Consulting, 2010
		4.5×10^{-4}	10%	Referenced conceptual model of the Maroota area	Hydro Tasmania Consulting, 2010
		2.0×10^{-2} to 5.0×10^{-2}		Model – fractured sandstone	Hydro Tasmania Consulting, 2010
10^{-6}		1.5×10^{-2}		Model	Coffey, 2012
10^{-6}		1.2×10^{-2}		Model	Coffey, 2012

		1.0×10^{-2}		Model	Golder, 2012
2.7×10^{-5} to 7.4×10^{-4}				Literature – massive sandstone	SKM, 2012
1.3×10^{-4} to 2.4×10^{-4}				Literature –fractured sandstone	SKM, 2012
1.0×10^{-5}	1.0×10^{-6}	1.2×10^{-2} to 1.0×10^{-1}		Model	Golder, 2013
1.0×10^{-5} to 3.0×10^{-2}	1.0×10^{-6}	1.2×10^{-2} to 1.0×10^{-1}		Regional scale model calibration multiple consultants	Golder, 2013

Full references to the cited data sources are included in Section 6 of the main text

1 – Statistical analysis on 1228 core plugs in the Hawkesbury Sandstone.

2 – Based on the analysis of a 14 day pumping test conducted at the Turrella exhaust ventilation tunnel for the M5 East Motorway in Sydney.

3 – Based on 3 slug tests and 1 pumping test near the Turrella ventilation shaft for the M5 Motorway.

4 – Based on 4 bores were pumped simultaneously for 57 days 60 km west of Sydney at Leonay, NSW.

5 – Based on analysis of 28 pumping tests conducted in the Southern Highlands, NSW.

6 – Based on 2 pumping tests conducted at the Leonay Oval, NSW.

7 – Based on 1 pumping test conducted at the Koloona Reserve, NSW and analysed using a single porosity model, two cases using a double porosity model.

Table 4: Summary of aquifer storage parameters for the Ashfield Shale

Specific Storage (m^{-1})	Specific Yield (-)	Porosity (-)	Data Source	Source
1×10^{-5}	5×10^{-2}	10%	Model parameter – residual clay	IGGC, 2009
1×10^{-5}	1×10^{-2}	5%	Model parameter – weathered shale	IGGC, 2009
1×10^{-5}	1×10^{-2}	5%	Model parameter – fresh shale	IGGC, 2009

Full references to the cited data sources are included in Section 6 of the main text.

Table 5: Summary of aquifer storage parameters for Quaternary sediments

Storativity (-)	Specific Yield (-)	Porosity (-)	Data Source	Source
4.0×10^{-5} to 6.0×10^{-3}	-	-	Slug tests and pumping tests[1]	Golder, 1999
1.0×10^{-3} to 2.4×10^{-1}	1.0×10^{-1} to 2.5×10^{-1}	-	Literature review of pump tests[2]	Hatley, 2004
4.0×10^{-4} to 4.0×10^{-1}	1.1×10^{-1} to 2.6×10^{-1}	33% to 40%	Literature review of reported and modelled parameters	Hatley, 2004
-	2.0×10^{-1}	-	Calibrated hydraulic parameters for referenced model	Hydro Tasmania Consulting, 2010
1.0×10^{-3} to 5.0×10^{-3}	2.0×10^{-1} to 2.8×10^{-1}	30% to 44%; average 36%	Field investigations	Confidential, 2010

1 – Pump and slug tests in alluvium near the Turrella ventilation shaft for the M5 East Motorway.

2 – Review of various technical papers.

A summary of the adopted parameters for the hydrogeological conceptualization are presented in Table 6.

Table 6: Summary of hydrogeological parameters

Hydrogeological Unit	Sub-unit or Vertical Zone	Hydraulic Conductivity (m/s)	Kh:Kv ratio	Storativity (-)	Specific Storage (m^{-1})	Specific Yield (-)	Porosity (-)
Anthropogenic Fill	Landfill	10^{-5}	1:1				
Anthropogenic Fill	Reclaimed land	Not yet defined	Not yet defined				
Anthropogenic Fill	Urban areas	Not yet defined	Not yet defined				
Quaternary Sediments	Unconsolidated Quaternary sediments	10^{-4} to 10^{-6}	1:10 to 100	5.0×10^{-2} to 5.0×10^{-3}		2.0×10^{-1}	35%
Quaternary Sediments	Botany Sand Beds	10^{-4} to 10^{-6}	1:10 to 100	5.0×10^{-2} to 5.0×10^{-3}		2.0×10^{-1}	35%
Ashfield Shale	Unweathered	10^{-7} to 10^{-9}	1:100 to 1000		1.0×10^{-5}	1.0×10^{-2}	5%
Ashfield Shale	Weathered	10^{-6} to 10^{-9}	1:100 to 1000		1.0×10^{-5}	1.0×10^{-2}	5%
Hawkesbury Sandstone		10^{-5} to 10^{-8}	1:10 to 100	5.0×10^{-5} to 5.0×10^{-4}	5×10^{-6} to 5.0×10^{-5}	2.5×10^{-2}	15%
Structures (fracture / fault)					1.0×10^{-5}		

Note: Values are subject to change with results from on-going CDS investigations. Hydraulic conductivity to Lugeon value conversion factor of 1×10^{-7} m

Annexure M – Groundwater Chemistry

Bore ID	Easting	Northing	Interpretive Formation	Screened Interval (m)	pH	EC (µS/cm)	TDS (mg/L)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	CO_3^{-2} (mg/L)	HCO_3 (mg/L)	Chloride (mg/L)	Sulfate (mg/L)
BH17	332459	6246324	Fill	ND	ND	ND	ND	120	47	640	93			1100	54
BH18	332376	6246422	Fill	ND	ND	ND	ND	200	73	190	69			360	<.4
BH19	332066	6246332	Fill	ND	ND	ND	ND	69	110	1500	570			2500	0.69
BH20	332281	6246182	Fill	ND	ND	ND	ND	100	50	790	300			870	<.4
BH21	332095	6246148	Fill	ND	ND	ND	ND	140	60	440	170			380	0.51
BH22	332022	6245954	Fill	ND	ND	ND	ND	40	35	690	400			690	0.77
BH23	331954	6245971	Fill	ND	6.88	3351	ND	150	71	400	94			470	0.62
211			Quaternary Sediments		5.4									64	24
215			Quaternary Sediments		4.9									24	54
220A			Quaternary Sediments	ND	4.8	ND	ND							29	20
BH11	332585	6246457	Quaternary Sediments	ND	ND	369	269	23	11	33	12			64	53
BH16	332089	6245874	Quaternary Sediments	ND	ND	2987	2147	25	190	520	30			390	54
BH25	331981	6245884	Quaternary Sediments	ND	ND	ND	ND	63	49	250	48			270	42
BH26	332086.4	6245786.03	Quaternary Sediments	ND	6.97	3655	ND	150	47	430	140	<5	1800	280	<1
BH3	332307	6246016	Quaternary Sediments	ND	7.14	1983	1496	67	43	340	67			420	39
BH4	332110	6245830	Quaternary Sediments	ND	7.03	2201	1625	120	32	200	84			160	19
BH5	332132	6245925	Quaternary Sediments	ND	ND	ND	ND							ND	n
BH7	332156	6245808	Quaternary Sediments	ND	ND	1207	886	60	46	210	26			300	49
BH8	332209	6245895	Quaternary Sediments	ND	7.17	1100	790	32	36	160	21			250	69
GA06	331994	6246649	Quaternary Sediments	2 - 20.7	7.15	2313	ND							ND	ND
GA08	332425	6246226	Quaternary Sediments	1 to 6	6.84	4179	ND	84	41	820	170	<5	1600	490	<1
GW023262			Quaternary Sediments	ND	ND	580	ND							ND	ND
GW023291			Quaternary Sediments	ND	ND	266	ND							ND	ND
GW025558			Quaternary Sediments	ND	ND	173	ND							ND	ND
GW027055			Quaternary Sediments	ND	ND	380	ND							ND	ND
GW104652			Quaternary Sediments	ND	ND	ND	300							ND	ND

Bore ID	Easting	Northing	Interpretive Formation	Screened Interval (m)	pH	EC (µS/cm)	TDS (mg/L)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	CO_3^{-2} (mg/L)	HCO_3 (mg/L)	Chloride (mg/L)	Sulfate (mg/L)
GW104653			Quaternary Sediments	ND	ND	ND	334							ND	ND
GW104654			Quaternary Sediments	ND	ND	ND	300							ND	ND
GW104655			Quaternary Sediments	ND	ND	ND	300							ND	ND
GW104656			Quaternary Sediments	ND	ND	ND	300							ND	ND
GW104657			Quaternary Sediments	ND	ND	ND	300							ND	ND
GW111296			Quaternary Sediments	ND	ND	ND	6000							ND	ND
LDS-BH-2005			Quaternary Sediments		5.9	25000	18000	720	810	3500	130	<1	12	9100	170
LDS-BH-2029A			Quaternary Sediments		5.3	40,000	25000	530	820	6200	260	<1	33	12000	1400
MW02S			Quaternary Sediments	ND	7.21-7.71	2184 to 2435	1410	185	15	219	55		157	476	239
WCX-BH-063a			Quaternary Sediments		6.79	1,800		240	32	56	33	<1	740	55	<10
WCX-BH-063a			Quaternary Sediments		6.34	866	563	66	18	52	19	<1	388	51	13
WCX-BH-152s			Quaternary Sediments		6.78	626		18	4	104	2	<1	68	132	8
Wet Well	332525	6246404	Quaternary Sediments	ND	6.85	3137	ND							ND	ND
BH10	332511	6246371	Quaternary Sediments & Ashfield Shale	ND	ND	846	608	48	32	93	21			83	100
WCX-BH-109			Ashfield Shale		8.43	1550		108	7	136	11	<1	227	315	38
WCX-BH-109			Ashfield Shale		11.4	10700	6960	321	<1	1880	73	55	<1	3010	40
WCX-BH-115			Ashfield Shale		12.2	5700	3700	258	<1	371	237	84	<1	255	63
WCX-BH-115			Ashfield Shale		11.3	540		47	<1	39	42	121	<1	19	38
WCX-BH-122			Ashfield Shale		6.75	3140		34	50	551	15	<1	233	760	93
WCX-BH-122			Ashfield Shale		6.21	3210	2090	31	53	534	13	<1	319	677	122
BH12	332371	6246542	Ashfield Shale	ND	ND	966	679	9.3	4	210	7.7			37	280
BH24	331878	6245919	Ashfield Shale	ND	5.9	6310	ND	13	90	1700	10	<5	140	2100	720
MW01			Ashfield Shale	ND	6.05-7.04	4270 to 11130	3880	117	120	1160	58		2060	1090	<1
MW02D			Ashfield Shale	ND	ND	ND	9400	352	548	2280	41		334	5690	268
MW04c			Ashfield Shale	ND	5.74-6.11	4513 to 5472	3000	29	62	985	11		152	1310	311
GW102673	295163	6255774	Ashfield Shale and	Multiple	ND	ND	4750							ND	ND

Bore ID	Easting	Northing	Interpretive Formation	Screened Interval (m)	pH	EC (µS/cm)	TDS (mg/L)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	CO^{-2}_3 (mg/L)	HCO_3 (mg/L)	Chloride (mg/L)	Sulfate (mg/L)
			Hawkesbury Sandstone												
GW102674	295369	6255779	Ashfield Shale and Hawkesbury Sandstone	Multiple	ND	ND	4400							ND	ND
MW03			Ashfield Shale and Hawkesbury Sandstone	ND	6.73	8154	5070	221	204	1410	30		45	2920	294
WCX-BH-018			Hawkesbury Sandstone		12.3	5110	3320	421	<1	112	36	31	<1	73	59
WCX-BH-018			Hawkesbury Sandstone			1750		177	<1	115	26	23	<1	171	85
WCX-BH-024			Hawkesbury Sandstone		6.38	839		23	10	119	12	<1	168	113	34
WCX-BH-024			Hawkesbury Sandstone		6.57	797	518	25	18	83	5	<1	131	146	21
WCX-BH-029			Hawkesbury Sandstone		12.27	7080		1060	<1	48	74	63	<1	59	881
WCX-BH-029			Hawkesbury Sandstone		7.37	21300	13800	951	129	3120	97	<1	215	7030	753
WCX-BH-036			Hawkesbury Sandstone		10.7	2020	1310	140	<1	241	21	44	<1	593	16
WCX-BH-036			Hawkesbury Sandstone		9.15	2440		118	24	342	21	16	32	712	22
WCX-BH-039			Hawkesbury Sandstone		10.1	1300	845	141	1	148	10	66	20	119	356
WCX-BH-039			Hawkesbury Sandstone		10.1	1000		80	10	121	8	<1	136	136	117
WCX-BH-042			Hawkesbury Sandstone		7.7	2060	1340	83	40	300	8	<1	307	480	19
WCX-BH-042			Hawkesbury Sandstone		7.82	2000	1340	75	36	277	8	<1	224	468	28
WCX-BH-063			Hawkesbury Sandstone		6.56	516	541	11	7	73	10	<1	77	81	8
WCX-BH-063			Hawkesbury Sandstone		7.26	833	541	14	11	114	5	<1	124	175	18
WCX-BH-072			Hawkesbury Sandstone		11.27	5500		336	<1	886	27	123	<1	1190	466
WCX-BH-072			Hawkesbury Sandstone		11.7	6410	4170	392	<1	834	33	146	<1	891	614
WCX-BH-084			Hawkesbury Sandstone		11.4	2250	1460	207	<1	190	21	43	<1	222	484
WCX-BH-084			Hawkesbury Sandstone		11.58	1970	1460	257	<1	175	14	25	<1	208	569

Bore ID	Easting	Northing	Interpretive Formation	Screened Interval (m)	pH	EC (µS/cm)	TDS (mg/L)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	CO^{-2}_3 (mg/L)	HCO_3 (mg/L)	Chloride (mg/L)	Sulfate (mg/L)
WCX-BH-143			Hawkesbury Sandstone		8.37	1170	760	61	16	153	40	6	168	185	124
WCX-BH-143			Hawkesbury Sandstone		11.71	1070	760	42	<1	143	54	43	<1	168	94
WCX-BH-152d			Hawkesbury Sandstone		8.97	1200		51	19	167	11	<1	73	304	28
WCX-BH-153			Hawkesbury Sandstone		12.5	8310	5400	681	<1	181	140	56	<1	49	<1
WCX-BH-153			Hawkesbury Sandstone		12	3620		281	<1	131	83	58	<1	53	162
WCX-BH-168			Hawkesbury Sandstone		7.38	3300	2140	146	116	361	27	<1	209	933	<1
WCX-BH-168			Hawkesbury Sandstone		7.53	2390	2140	93	68	256	55	<1	123	640	35
GW072161			Hawkesbury Sandstone	ND	ND	ND	1600							ND	ND
GW107993	328242	6243424	Hawkesbury Sandstone	ND	ND	ND	140							ND	ND
GW111316			Hawkesbury Sandstone	ND	ND	ND	1400							ND	ND
LDS-BH-2029			Hawkesbury Sandstone		5.9	36,000	20000	530	750	5300	210	<1	130	11000	1300
LDS-PW-2901-1			Hawkesbury Sandstone		5.8	30,000	17000	770	840	5100	130	<1	11	11000	1300
LDS-PW-2901-2			Hawkesbury Sandstone		5.7	42,000	21000	660	910	6100	150	<1	170	12000	1500
LDS-PW-2901-3			Hawkesbury Sandstone		5.7	43,000	23000	620	900	6500	130	<1	71	12000	1500
LDS-PW-2901-4			Hawkesbury Sandstone		6	43,000	24000	590	930	6500	140	<1	140	12000	1500
MW029	329350	6242709	Hawkesbury Sandstone		12.27	7,080		1060	<1	48	74	63	<1	59	881
212			Hawkesbury Sandstone		6.5									610	40
216			Hawkesbury Sandstone		6.7									41	5
220			Hawkesbury Sandstone	ND	6.9	ND	ND							61	55
WCX-BH-040			Basalt		8.1	7,490		294	170	990	22	<1	195	2350	92
B2	331856	6246276	Not known	ND	5.16	1025	ND							ND	ND
BS1	331829	6245592	Not known	ND	7.7	1690	1100							ND	ND
BS2	331987	6245456	Not known	ND	7.7	1400	910							ND	ND
DPB1	330716	6242165	Not known	ND	ND	ND	ND							7600	ND
DPB12	328425	6243471	Not known	ND	10	ND	ND							40	ND
DPB14	328243	6243482	Not known	ND	ND	ND	ND							34	18

Bore ID	Easting	Northing	Interpretive Formation	Screened Interval (m)	pH	EC (µS/cm)	TDS (mg/L)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	CO^{-2}_3 (mg/L)	HCO_3 (mg/L)	Chloride (mg/L)	Sulfate (mg/L)
DPB20	325976	6243298	Not known	ND	ND	ND	ND							2100	51
DPB22	325465	6243313	Not known	ND	7.3	ND	ND							94	63
DPB25			Not known											360	230
DPB27			Not known	ND	ND	ND	ND							4200	560
DPB3	330300	6242411	Not known	ND	ND	ND	ND							1600	ND
DPB31			Not known	ND	ND	ND	ND							7100	660
DPB34			Not known	ND	ND	ND	ND							2300	800
DPB35			Not known	ND	ND	ND	ND							2100	220
DPB6			Not known	ND	ND	ND	ND							9200	1600
DPB7	329386	6243200	Not known	ND	ND	ND	ND							35	17
DPB8			Not known	ND	7.4	ND	ND							38	8
DPB9	328843	6243448	Not known	ND	ND	ND	ND							41	ND
GABH25			Not known	ND	ND	ND	ND							24	26
GABH28			Not known	ND	ND	ND	ND							7536	1190
GABH31			Not known	ND	ND	ND	ND							18200	48
GABH35			Not known	ND	ND	ND	ND							24	137
GW016836			Not known	ND	ND	480	ND							ND	ND
GW023288			Not known	ND	ND	267	ND							ND	ND
GW025546			Not known	ND	ND	142	ND							ND	ND
GW100209			Not known	ND	ND	ND	8000							ND	ND
GW101	331868	6246522	Not known	ND	5.37	475	ND	3	7	110	1	<5	8	31	170
GW102580	328186	6244163	Not known	ND	ND	ND	420							ND	ND
GW103951			Not known	ND	ND	ND	560							ND	ND
GW104062	302387	6255420	Not known	5.4 to 23.4	ND	ND	2800							ND	ND
GW105603			Not known	ND	ND	ND	4							ND	ND
GW106811			Not known	ND	ND	ND	200							ND	ND
GW109152			Not known	ND	ND	ND	7							ND	ND
GW109256			Not known	ND	ND	ND	970							ND	ND
GW114A*	331961	6245900	Not known	ND	7.3	9219	ND	63	48	1000	450	<5	4300	890	<1
MW04b			Not known		5.7									425	115
MW202			Not known		12.4	10400	6760	606	<1	562	250	124	<1	445	3
MW021A			Not known		11.5	3840	2500	142	<1	492	198	125	<1	516	450
SKM03B			Not known	ND	6.08	968	ND	30	19	190	6	<5	270	81	110
TurrellaPump Test (241)			Not known			627-1010	401-643	15.3-35.4	13.9-26.3	70-65.2	1.9-2.6			134-236	3
Unknown			Not known	ND	6.89	1720	ND	160	29	100	37	<5	880	57	<1
WCX-BH-204			Not known		12.1	3650	2370	239	<1	164	66	100	<1	194	9

Note: Refer to the Groundwater Baseline report M5N-GOL-TER-100-200-GT-1510-J for the most current water chemistry data

			ANZECC (2000)	BH2029	BH2029A	PW2901	BH2005	PW2901_4/03/2016	PW2901_11/03/2016	PW2901_13/03/2016
Field Parameters										
Parameter	**Units**									
Temperature	°C			19.4	19.4	21.9	22.3	26.5	21.4	24.2
pH	pH units			6.33	5.41	5.96	5.23	6.75	6.78	-
ORP	mV			-83.8	-86.3	-37	-22.6	-83.5	-77.1	-79.7
Electrical Conductivity	µS/cm		350-2200[3]	**28218**	**32818**	**26568**	**23091**	**32953**	**32699**	**33143**
Dissolved Oxygen	mg/L			-	-	-	-	0.53	0.68	0.67
Turbidity	NTU			-	-	-	-	5.1	15.5	24.2
Laboratory Analysis										
Analyte Name	**Units**	**Lab reporting Limit**								
pH**	No unit	0	6.5-8	**5.9**	**5.3**	**5.8**	**5.9**	**5.7**	**5.7**	**6.0**
Conductivity @ 25 C	µS/cm	2		**36000**	**40000**	**30000**	**25000**	**42000**	**43000**	**43000**
Total Dissolved Solids Dried at 175-185°C	mg/L	10		20000	25000	17000	18000	21000	23000	24000
Total Suspended Solids Dried at 103-105°C	mg/L	5		110	6	320	300	140	120	88
Bicarbonate Alkalinity as HCO3	mg/L	5		130	33	11	12	170	71	140
Carbonate Alkalinity as CO3	mg/L	1		<1	<1	<1	<1	<1	<1	<1
Total Alkalinity as CaCO3	mg/L	5		110	27	9	10	140	58	110
Chloride	mg/L	1		11000	12000	11000	9100	12000	12000	12000
Nitrate Nitrogen, NO3-N	mg/L	0.005	0.7	<0.1	<0.1	<0.025	<0.1	<0.025	<0.25	<0.25
Sulphate, SO4	mg/L	1		1300	1400	1300	170	1500	1500	1500
Nitrite Nitrogen, NO2 as N	mg/L	0.005		<0.025	<0.025	<0.005	<0.005	<0.005	<0.005	<0.005
Total Kjeldahl Nitrogen	mg/L	0.05		2.3	2.4	2.7	4.1	2.6	2.5	2.4
Total Nitrogen (calc)	mg/L	0.05	0.5	**2.3**	**2.4**	**2.7**	**4.1**	**2.6**	**2.5**	**2.4**
Total Phosphorus (Kjeldahl Digestion)	mg/L	0.01	0.05	**0.07**	**0.10**	**0.11**	<0.01	0.04	**0.06**	**0.06**
Filterable Reactive Phosphorus	mg/L	0.005	0.020	<0.025	<0.025	**0.012**	**0.006**	**0.016**	**0.035**	**0.110**
Ammonia Nitrogen, NH_3 as N	mg/L	0.005	0.9[1] (0.91[2])	**1.4**	**0.56**	**2.1**	**1.0**	**1.9**	**1.7**	**1.5**
Calcium, Ca	mg/L	0.2		530	530	770	720	660	620	590
Magnesium, Mg	mg/L	0.1		750	820	840	810	910	900	930
Sodium, Na	mg/L	0.5		5300	6200	5100	3500	6100	6500	6500
Potassium, K	mg/L	0.1		210	260	130	130	150	130	140
Total Hardness by Calculation	mg CaCO3	5		4400	4700	5400	5100	5400	5200	5300
Iron, Fe	µg/L	5		150000	300000	100000	330000	150000	140000	200000
Manganese, Mn	µg/L	1	900	**3400**	**2300**	**2900**	**3700**	**3600**	**3700**	**3800**
Aluminium, Al	µg/L	5		12	82	<5	10	7	6	7
Arsenic, As	µg/L	1	37	<1	<1	<1	<1	<1	<1	<1
Cadmium, Cd	µg/L	0.1	0.2[1] (5.5[2])	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Copper, Cu	µg/L	1	1.4[1] (1.3[2])	<1	<1	<1	<1	<1	<1	<1
Chromium, Cr	µg/L	1	1[1] (31.8[2])	**2**	**2**	<1	<1	<1	<1	<1
Nickel, Ni	µg/L	1	1[1] (4.4[2])	<1	<1	**4**	<1	<1	<1	<1
Lead, Pb	µg/L	1	3.4[1] (4.4[2])	<1	<1	<1	<1	<1	<1	<1
Zinc, Zn	µg/L	5	8[1] (15[2])	7	**17**	**80**	7	**73**	**61**	**55**
Mercury	mg/L	0.0001	0.6[1] (0.4[2])	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Total Iron	µg/L	5		170000	310000	140000	340000	160000	170000	210000
Total Manganese	µg/L	1		3300	2400	3000	3800	3600	3700	3800
Total Mercury	mg/L	0.0001		<0.0001	<0.0001	-	<0.0001	-	-	-
Hexavalent Chromium, Cr6+	mg/L	0.004	1[1] (4.4[2])	<0.004	<0.004	-	-	-	-	-
Trivalent Chromium, Cr3+	mg/L	0.05	27.4	<0.05	<0.05	-	-	-	-	-
Chromium, Cr	mg/L	0.005		<0.005	<0.005	-	-	-	-	-
2-fluorobiphenyl (Surrogate)	%	0		46	52	52	-	48	58	52
Aldrin	µg/L	0.1		<0.1	<0.1	<0.1	-	N.A.	<0.1	<0.1
Alpha BHC	µg/L	0.1		<0.1	<0.1	<0.1	-	N.A.	<0.1	<0.1
Alpha Chlordane	µg/L	0.1		<0.1	<0.1	<0.1	-	N.A.	<0.1	<0.1
Alpha Endosulfan	µg/L	0.1		<0.1	<0.1	<0.1	-	N.A.	<0.1	<0.1
Azinphos-methyl	µg/L	0.2	0.02	<0.2	<0.2	<0.2	-	<0.2	<0.2	<0.2
Benzene	µg/L	0.5	950[1] (700[2])	<0.5	<0.5	<0.5	-	<0.5	<0.5	<0.5
Benzene (F0)	µg/L	0.5		<0.5	<0.5	<0.5	-	<0.5	<0.5	<0.5
Beta BHC	µg/L	0.1		<0.1	<0.1	<0.1	-	N.A.	<0.1	<0.1
Beta Endosulfan	µg/L	0.1		<0.1	<0.1	<0.1	-	N.A.	<0.1	<0.1
Bromofluorobenzene (Surrogate)	%	0		81	80	80	-	90	87	85
Bromofluorobenzene (Surrogate)	%	0		81	80	80	-	90	87	85
Bromophos Ethyl	µg/L	0.2		<0.2	<0.2	<0.2	-	<0.2	<0.2	<0.2
Chlorpyrifos (Chlorpyrifos Ethyl)	µg/L	0.2	0.01	<0.2	<0.2	<0.2	-	<0.2	<0.2	<0.2
d14-p-terphenyl (Surrogate)	%	0		54	72	78	-	92	78	88
d4-1,2-dichloroethane (Surrogate)	%	0		113	114	115	-	119	122	125
d4-1,2-dichloroethane (Surrogate)	%	0		113	114	115	-	119	122	125
d8-toluene (Surrogate)	%	0		100	103	97	-	88	109	112
d8-toluene (Surrogate)	%	0		100	103	97	-	88	109	112
Delta BHC	µg/L	0.1		<0.1	<0.1	<0.1	-	N.A.	<0.1	<0.1
Diazinon (Dimpylate)	µg/L	0.5	0.01	<0.5	<0.5	<0.5	-	<0.5	<0.5	<0.5
Dibromofluoromethane (Surrogate)	%	0		112	116	115	-	108	116	125
Dibromofluoromethane (Surrogate)	%	0		112	116	115	-	108	116	125
Dichlorvos	µg/L	0.5		<0.5	<0.5	<0.5	-	<0.5	<0.5	<0.5
Dieldrin	µg/L	0.1		<0.1	<0.1	<0.1	-	N.A.	<0.1	<0.1
Dimethoate	µg/L	0.5	0.15	<0.5	<0.5	<0.5	-	<0.5	<0.5	<0.5
Endosulfan sulphate	µg/L	0.1		<0.1	<0.1	<0.1	-	N.A.	<0.1	<0.1
Endrin	µg/L	0.1		<0.1	<0.1	<0.1	-	N.A.	<0.1	<0.1
Endrin aldehyde	µg/L	0.1		<0.1	<0.1	<0.1	-	N.A.	<0.1	<0.1
Endrin ketone	µg/L	0.1		<0.1	<0.1	<0.1	-	N.A.	<0.1	<0.1
Ethion	µg/L	0.2		<0.2	<0.2	<0.2	-	<0.2	<0.2	<0.2
Ethylbenzene	µg/L	0.5		<0.5	<0.5	<0.5	-	<0.5	<0.5	<0.5
Fenitrothion	µg/L	0.2		<0.2	<0.2	<0.2	-	<0.2	<0.2	<0.2
Gamma Chlordane	µg/L	0.1		<0.1	<0.1	<0.1	-	N.A.	<0.1	<0.1
Heptachlor	µg/L	0.1		<0.1	<0.1	<0.1	-	N.A.	<0.1	<0.1
Heptachlor epoxide	µg/L	0.1		<0.1	<0.1	<0.1	-	N.A.	<0.1	<0.1
Hexachlorobenzene (HCB)	µg/L	0.1		<0.1	<0.1	<0.1	-	N.A.	<0.1	<0.1
Isodrin	µg/L	0.1		<0.1	<0.1	<0.1	-	N.A.	<0.1	<0.1
Lindane (gamma BHC)	µg/L	0.1		<0.1	<0.1	<0.1	-	N.A.	<0.1	<0.1
m/p-xylene	µg/L	1		<1	<1	<1	-	<1	<1	<1
Malathion	µg/L	0.2	0.05	<0.2	<0.2	<0.2	-	<0.2	<0.2	<0.2
Methidathion	µg/L	0.5		<0.5	<0.5	<0.5	-	<0.5	<0.5	<0.5
Methoxychlor	µg/L	0.1		<0.1	<0.1	<0.1	-	N.A.	<0.1	<0.1
Mirex	µg/L	0.1		<0.1	<0.1	<0.1	-	N.A.	<0.1	<0.1
Naphthalene	µg/L	0.5	16[1] (70[2])	<0.5	<0.5	<0.5	-	<0.5	<0.5	<0.5
o,p'-DDD	µg/L	0.1		<0.1	<0.1	<0.1	-	N.A.	<0.1	<0.1
o,p'-DDE	µg/L	0.1		<0.1	<0.1	<0.1	-	N.A.	<0.1	<0.1
o,p'-DDT	µg/L	0.1		<0.1	<0.1	<0.1	-	N.A.	<0.1	<0.1
o-xylene	µg/L	0.5		<0.5	<0.5	<0.5	-	<0.5	<0.5	<0.5
p,p'-DDD	µg/L	0.1		<0.1	<0.1	<0.1	-	N.A.	<0.1	<0.1
p,p'-DDE	µg/L	0.1		<0.1	<0.1	<0.1	-	N.A.	<0.1	<0.1
p,p'-DDT	µg/L	0.1		<0.1	<0.1	<0.1	-	N.A.	<0.1	<0.1
Parathion-ethyl (Parathion)	µg/L	0.2	0.004	<0.2	<0.2	<0.2	-	<0.2	<0.2	<0.2
Tetrachloro-m-xylene (TCMX) (Surrogate)	%	0		**81**	**79**	**91**	-	N.A.	**95**	**61**
Toluene	µg/L	0.5		<0.5	<0.5	<0.5	-	<0.5	1.8	<0.5
Total BTEX	µg/L	3		<3	<3	<3	-	<3	<3	<3
Total Xylenes	µg/L	1.5		<1.5	<1.5	<1.5	-	<1.5	<1.5	<1.5
trans-Nonachlor	µg/L	0.1		<0.1	<0.1	<0.1	-	N.A.	<0.1	<0.1
TRH >C10-C16 (F2)	µg/L	60		<60	**61**	**120**	-	<60	<60	<60
TRH >C16-C34 (F3)	µg/L	500		<500	<500	<500	-	<500	<500	<500
TRH >C34-C40 (F4)	µg/L	500		<500	<500	<500	-	<500	<500	<500
TRH C10-C14	µg/L	50		<50	<50	**79**	-	<50	<50	<50
TRH C10-C36	µg/L	450		<450	<450	<450	-	<450	<450	<450
TRH C10-C40	µg/L	650		<650	<650	<650	-	<650	<650	<650
TRH C15-C28	µg/L	200		<200	<200	<200	-	<200	<200	<200
TRH C29-C36	µg/L	200		<200	<200	<200	-	<200	<200	<200
TRH C37-C40	µg/L	200		<200	<200	<200	-	<200	<200	<200
TRH C6-C10	µg/L	50		<50	<50	<50	-	<50	<50	<50
TRH C6-C10 minus BTEX (F1)	µg/L	50		<50	<50	<50	-	<50	<50	<50
TRH C6-C9	µg/L	40		<40	<40	<40	-	<40	<40	<40

1 ANZECC(2000) 95% protection of freshwater species
2 ANZECC(2000) 95% protection of marine species
3 ANZECC(2000) SE Australia lowland river

	Lab detection limit	ANZECC (2000) 1	ANZECC (2000) 2	MW018	MW036	MW039	MW042	MW084	MW143	MW153	MW168	MW204
EC (uS/cm)	1	2200		5110	2020	1300	2060	2250	1170	8310	3300	3650
pH Value	0.01	6.5-8		12.3	10.7	10.1	7.7	11.4	8.37	12.5	7.38	12.1
Cd (mg/L)	0.0001	0.0002	0.0055	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Cu (mg/L)	0.0001	0.0014	0.0013	0.001	0.001	0.001	0.001	0.005	0.001	0.006	0.001	0.001
Pb (mg/L)	0.001	0.0034	0.0044	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Zn (mg/L)	0.005	0.008	0.015	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.006	0.005
Ni (mg/L)	0.001	0.011	0.07	0.001	0.005	0.002	0.001	0.007	0.001	0.001	0.001	0.021
As (mg/L)	0.001	0.047		0.001	0.001	0.009	0.001	0.001	0.001	0.001	0.001	0.001
Nitrate (mg/L)	0.01	0.7		0.34	0.01	0.01	0.01	0.01	0.01	0.13	0.01	0.01
Mn (mg/L)	0.001	0.9		0.001	0.001	0.003	0.079	0.001	0.133	0.001	0.993	0.001
Naphthalene (μg/L)	5	16		5	5	5	5	5	5	5	6	5
1.4-Dichlorobenzene (μg/L)	2	60		2	2	2	2	2	2	2	2	2
2.4-Dinitrotoluene (μg/L)	4	65		4	4	4	4	4	4	4	4	4
1.2-Dichlorobenzene (μg/L)	2	160		2	2	2	2	2	2	2	2	2
2.4-Dichlorophenol (μg/L)	2	160		2	2	2	2	2	2	2	2	2
Aniline (μg/L)	2	250		2	2	2	2	2	2	2	2	2
1.3-Dichlorobenzene (μg/L)	2	260		2	2	2	2	2	2	2	2	2
ortho-Xylene (μg/L)	2	350		2	2	2	2	2	2	2	2	2
Hexachloroethane (μg/L)	2	360		2	2	2	2	2	2	2	2	2
Nitrobenzene (μg/L)	2	550		2	2	2	2	2	2	2	2	2
Benzene(μg/L)	1	700	950	1	1	1	1	1	1	1	1	1
Ammonia as N (mg/L)	0.01	0.9	0.91	0.3	1.74	1.31	0.25	1.24	0.18	0.75	0.67	1.96
Diethyl phthalate(μg/L)	2	1000		2	2	2	2	2	2	2	2	2
1.1.2-Trichloroethane(μg/L)	5	1900		5	5	5	5	5	5	5	5	5
Dimethyl phthalate(μg/L)	2	3700		2	2	2	2	2	2	2	2	2

1 ANZECC(2000) 95% protection of freshwater species

2 ANZECC(2000) 95% protection of marine species

Units (mg/L)	Lab detection limits	ANZECC (2000)	MW018	MW024	MW029	MW036	MW039	MW040	MW042	MW063	MW063A	MW072	MW084	MW109	MW115	MW122	MW143	MW152S	MW152D	MW153	MW168
Electrical Conductivity @ 25°C (µS/cm)	1	350-2200	1750	839	7080	2440	1000	7490	2000	516	1800	5500	1970	1550	540	3140	1070	626	1200	3620	2390
Resistivity at 25°C(ohm cm)	1		571	1190	141	410	1000	134	500	1940	556	182	508	645	1850	318	934	1600	833	276	418
Hydroxide Alkalinity as CaCO3	1		200	<1	1140	<1	<1	<1	<1	<1	<1	44	40	<1	23	<1	23	<1	<1	605	<1
Carbonate Alkalinity as CaCO3	1		23	<1	63	16	<1	<1	<1	<1	<1	123	25	<1	121	<1	43	<1	<1	58	<1
Bicarbonate Alkalinity as CaCO3	1		<1	168	<1	32	136	195	224	77	740	<1	<1	227	<1	233	<1	68	73	<1	123
Total Alkalinity as CaCO3	1		223	168	1200	48	137	195	224	77	740	167	66	227	144	233	66	68	73	664	123
Sulfate as SO4 - Turbidimetric	1		85	34	881	22	117	92	28	8	<10	465	569	38	38	93	94	8	28	162	35
Chloride	1		171	113	59	712	136	2350	468	81	55	1190	208	315	19	760	168	132	304	53	640
Calcium	1		177	23	1060	118	80	294	75	11	240	336	257	108	47	34	42	18	51	281	93
Magnesium	1		<1	10	<1	24	10	170	36	7	32	<1	<1	7	<1	50	<1	4	19	<1	68
Sodium	1		115	119	48	342	121	990	277	73	56	886	175	136	39	551	143	104	167	131	256
Potassium	1		26	12	74	21	8	22	8	10	33	27	14	11	42	15	54	2	11	83	55
Arsenic	0.001	0.037	----	<0.001	----	0.001	0.006	<0.001	----	<0.001	<0.001	<0.001	----	<0.001	0.001	<0.001	----	<0.001	----	<0.001	----
Cadmium	0.0001	0.0002[1] (0.0055[2])	----	<0.0001	----	<0.0001	<0.0001	<0.0001	----	<0.0001	<0.0001	<0.0001	----	<0.0001	<0.0001	<0.0001	----	<0.0001	----	<0.0001	----
Chromium	0.001	0.0001[1] (0.0318[2])	----	0.001	----	<0.001	0.001	<0.001	----	<0.001	0.002	<0.001	----	<0.001	0.023	<0.001	----	<0.001	----	0.167	----
Copper	0.001	0.00014[1] (0.0013[2])	----	<0.001	----	<0.001	0.001	0.001	----	<0.001	<0.001	0.002	----	0.004	0.011	<0.001	----	<0.001	----	0.006	----
Lead	0.001	0.00034[1] (0.0044[2])	----	<0.001	----	0.001	<0.001	<0.001	----	<0.001	<0.001	<0.001	----	<0.001	<0.001	<0.001	----	<0.001	----	<0.001	----
Nickel	0.001	0.011[1] (0.07[2])	----	0.001	----	0.002	<0.001	<0.001	----	<0.001	<0.001	0.004	----	0.001	0.002	0.003	----	0.005	----	<0.001	----
Zinc	0.005	0.008[1] (0.015[2])	----	0.038	----	<0.005	0.009	0.025	----	0.022	0.008	0.012	----	0.042	0.020	<0.005	----	<0.005	----	<0.005	----
Manganese	0.001	0.91	0.008	0.504	0.008	0.340	0.028	0.468	0.058	0.184	0.680	0.016	0.038	0.150	0.175	1.36	0.034	1.90	0.211	0.007	0.252
Iron	0.05		0.13	21.1	0.38	16.7	0.84	0.97	0.11	7.75	41.6	0.63	1.38	1.74	2.05	51.1	0.74	261	12.6	0.19	9.68
Mercury	0.0001	0.0006[1] (0.0004[2])	----	<0.0001	----	<0.0001	<0.0001	<0.0001	----	<0.0001	<0.0001	<0.0001	----	<0.0001	<0.0001	<0.0001	----	<0.0001	----	<0.0001	----
Ammonia as N	0.01	0.9[1] (0.91[2])	0.16	5.02	4.69	1.30	0.29	0.08	0.07	0.11	36.7	1.31	0.57	0.18	1.21	8.88	0.39	0.17	0.20	0.42	0.80
Nitrite as N	0.01		0.01	0.18	0.02	<0.01	<0.01	0.76	<0.01	<0.01	<0.05	<0.01	<0.01	0.01	0.46	<0.01	<0.01	<0.01	<0.01	0.30	<0.01
Nitrate as N	0.01	0.71	0.12	<0.01	0.02	0.02	0.05	0.09	0.04	0.25	0.12	0.03	0.14	0.42	0.49	0.21	0.02	0.21	0.09	0.09	0.03
Nitrite + Nitrate as N	0.01		0.13	0.16	0.04	0.02	0.05	0.85	0.04	0.25	0.12	0.03	0.14	0.43	0.95	0.21	0.02	0.21	0.09	0.39	0.03
Total Kjeldahl Nitrogen as N	0.1		0.4	6.8	7.7	3.1	1.2	0.2	0.2	0.5	47.0	1.8	1.0	2.1	4.2	9.1	0.6	1.9	0.4	1.4	1.5
Total Nitrogen as N	0.1	0.5	0.5	7.0	7.7	3.1	1.2	1.0	0.2	0.8	47.1	1.8	1.1	2.5	5.2	9.3	0.6	2.1	0.5	1.8	1.5
Total Phosphorus as P	0.01	0.05	<0.01	0.62	0.02	0.29	0.04	0.02	0.02	0.07	1.11	0.04	0.05	0.22	0.72	1.13	<0.01	2.20	0.20	<0.01	0.09
Reactive Phosphorus as P	0.01		<0.01	<0.01	<0.01	0.02	<0.01	<0.01	<0.01	<0.01	<0.05	<0.01	<0.01	0.10	0.08	<0.01	<0.01	<0.01	0.02	<0.01	0.02
Sulphate Reducing Bacteria Population Es	20		----	----	----	<20	320	----	----	----	----	----	1400	----	----	6000	1400	----	20	----	----
Aggressivity	1		----	----	----	Not Aggressive	Moderate	----	----	----	----	----	Moderate	----	----	Aggressive	Moderate	----	Not Aggressive	----	----

1 ANZECC(2000) 95% protection of freshwater species

2 ANZECC(2000) 95% protection of marine species

Annexure N – Sensitivity Analysis and Drain Conductance Assessment

Analyses were carried out with the regional groundwater model to assess the conductance value to be assigned for drains representing tunnels in the Hawkesbury Sandstone, using the observed inflow rates and drawdown associated with the M5 East tunnel as the basis for assessing the drainage impacts of tunnels.

In these analyses, the impact on inflow rates and drawdown was assessed for conductance values between 0.004 m^2/day and 400 m^2/day for the drain boundary condition assigned along the M5 East tunnel.

The variation in calculated tunnel inflow rate (for 2 tunnels), and the RMSE error between measured heads with conductance value are illustrated in Figure 1 and summarised in Table 2. Correlations between measured water levels and calculated water levels are illustrated for all monitoring bores and for monitoring bores in sandstone in Figures 2 and 3 respectively.

The results indicate that a conductance value of 0.4 m^2/day yield both an inflow rate that is close to the observed inflow rate, and a high degree of correlation between measured levels in the sandstone and the calculated levels.

It is noted that this value is specific to the size of model cells used to represent the tunnels in the regional model, and the hydraulic conductivity of the rock surrounding the tunnels. For the predictive modelling to assess inflows and drawdowns associated with the WestConnex tunnels in both the regional and local scale models, adjustments to the conductance value has been made where different model grid size is used, and where the tunnel is located is zones with different hydraulic conductivity.

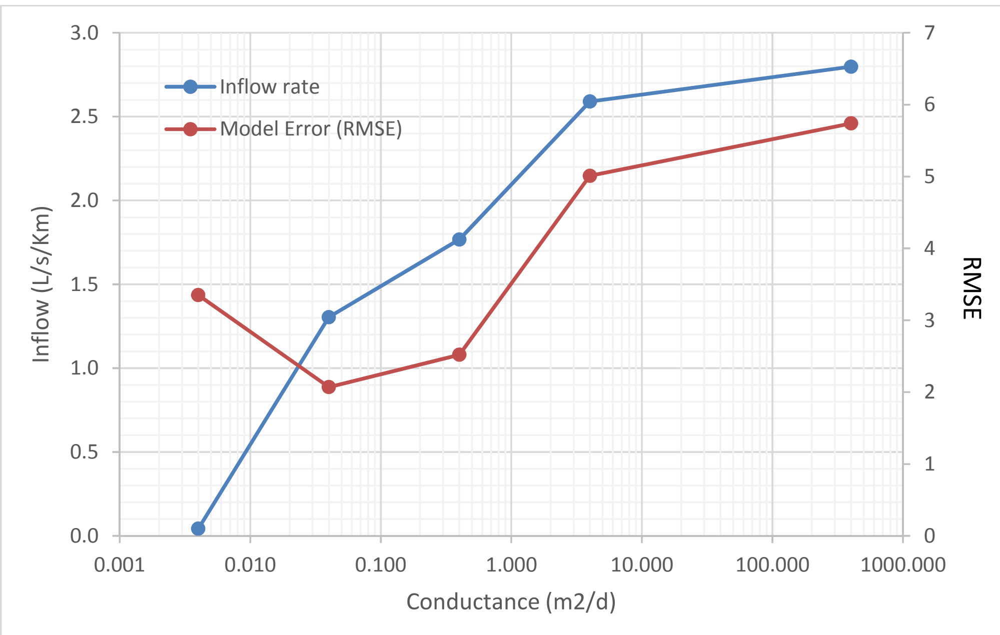
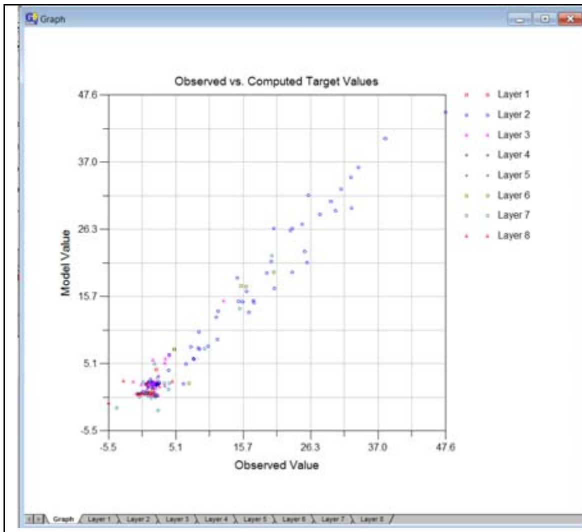


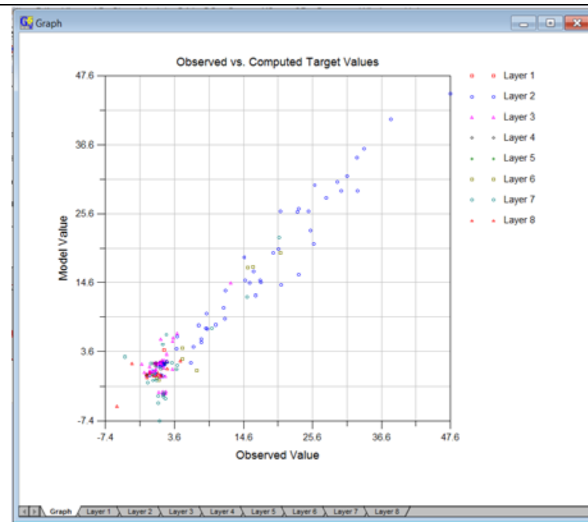
Figure 1: Impact of conductance of drains on tunnel inflow rates and model errors.

Model	*WCX8450*	*WCX2922*	*WCX8451*	*WCX8452*	*WCX8453*
Conductance (m2/d)	0.004	0.04	0.40	4	400
Inflow (L/s/Km)	0.04	1.30	1.77	2.59	2.80
RMSE	3.35	2.07	2.52	5.01	5.74
Correlation (all monitoring data)	0.89	0.98	0.95	0.85	0.73
Correlation (monitoring data in sandstone)	0.62	0.95	0.72	0.56	0.48

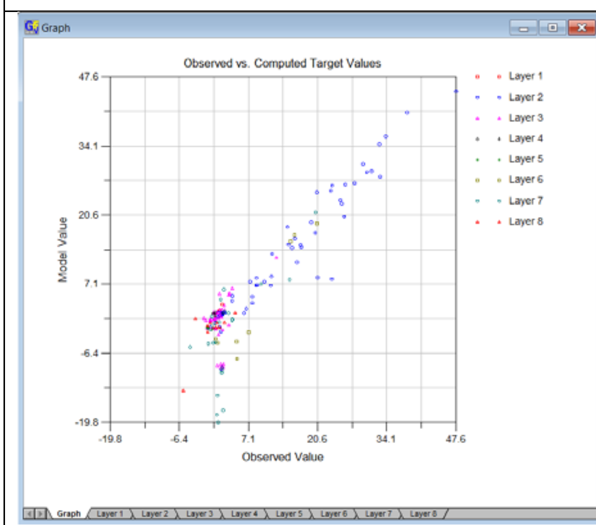
Table 1: Comparison of impact of conductance of drains on tunnel inflow rates and modelling results.



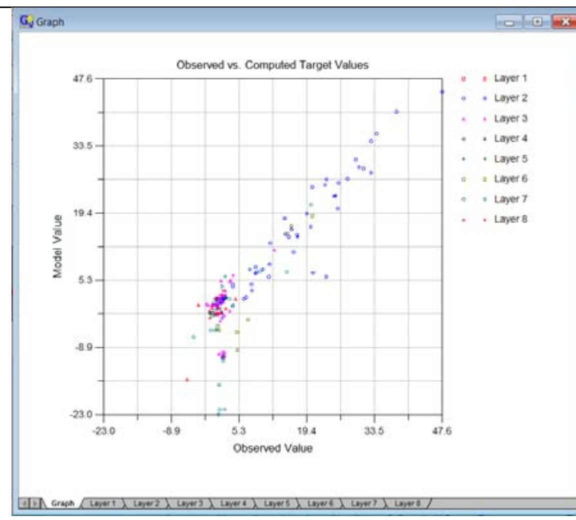
Calibrated Conductance (C=0.04 m2/d)



Conductance (C=0.4 m2/d)

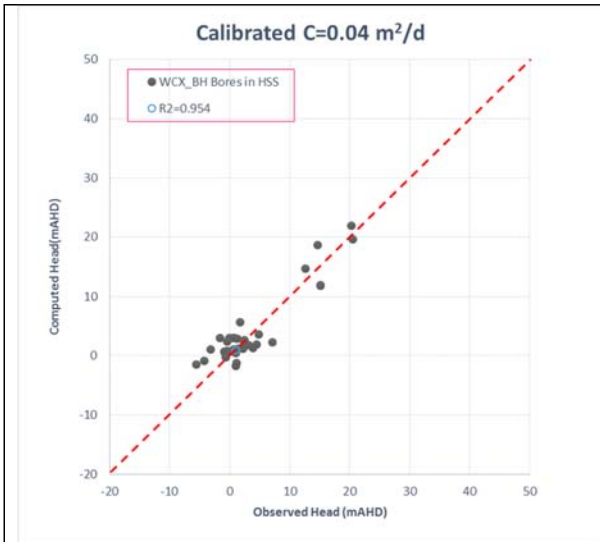


Conductance (C=4 m2/d)

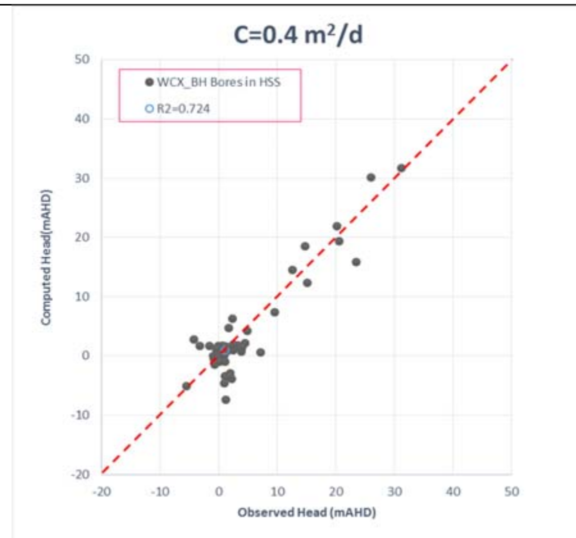


Conductance (C=400 m2/d)

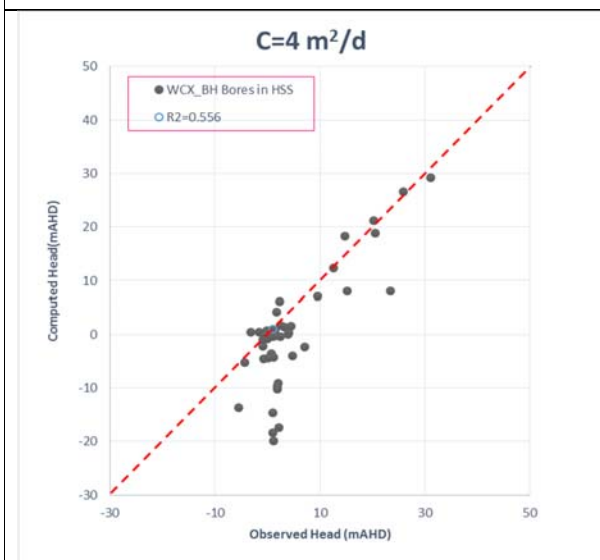
Figure 2: Q-Q plots showing modelled VS observed groundwater levels in all monitored bores



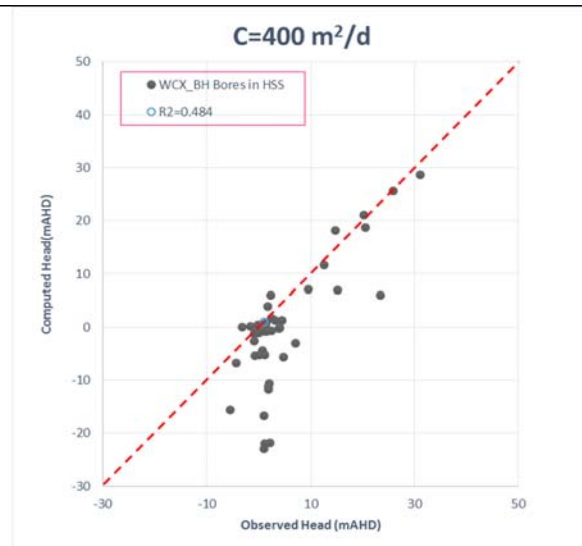
Calibrated Conductance (C=0.04 m2/d)



Conductance (C=0.4 m2/d)



Conductance (C=4 m2/d)



Conductance (C=400 m2/d)

Figure 3: Q-Q plots showing modelled VS observed groundwater levels in Hawkesbury Sandstone

Annexure O – Local Scale Groundwater Model Details and Calibration to Pumping Test Results

Local Scale Model Set-Up

Based on the calibrated regional groundwater model a telescoped model of the Arncliffe area was developed to allow for finer grid resolution around the proposed tunnels and caverns at Arncliffe. The extent of the local scale model and model grid refinement is illustrated in Figure O1. Horizontal grid size ranges between 5 m and 40 m, with 21 layers to allow detailed modelling of vertical layering of palaeochannel sediments and more accurate modelling of screen interval depth of pumping test observation bores. MODFLOW General Head boundary conditions were applied to the local scale model boundary. Groundwater heads at the boundary were adopted from the regional groundwater model and the conductance parameter of the General Head boundary was altered until groundwater gradients at the boundary of the local scale model matched gradients of the regional model.

The model structure has been adapted to allow explicit representation of sub-horizontal shear zones and sub-vertical faulting that has been identified in the area, as illustrated in Figure O2. A higher permeability zone in the Hawkesbury Sandstone immediately below the base of the paleochannels in this area has also been included in the model. The structure of the model and the distribution of hydrogeologic units in the model are outlined in the following.

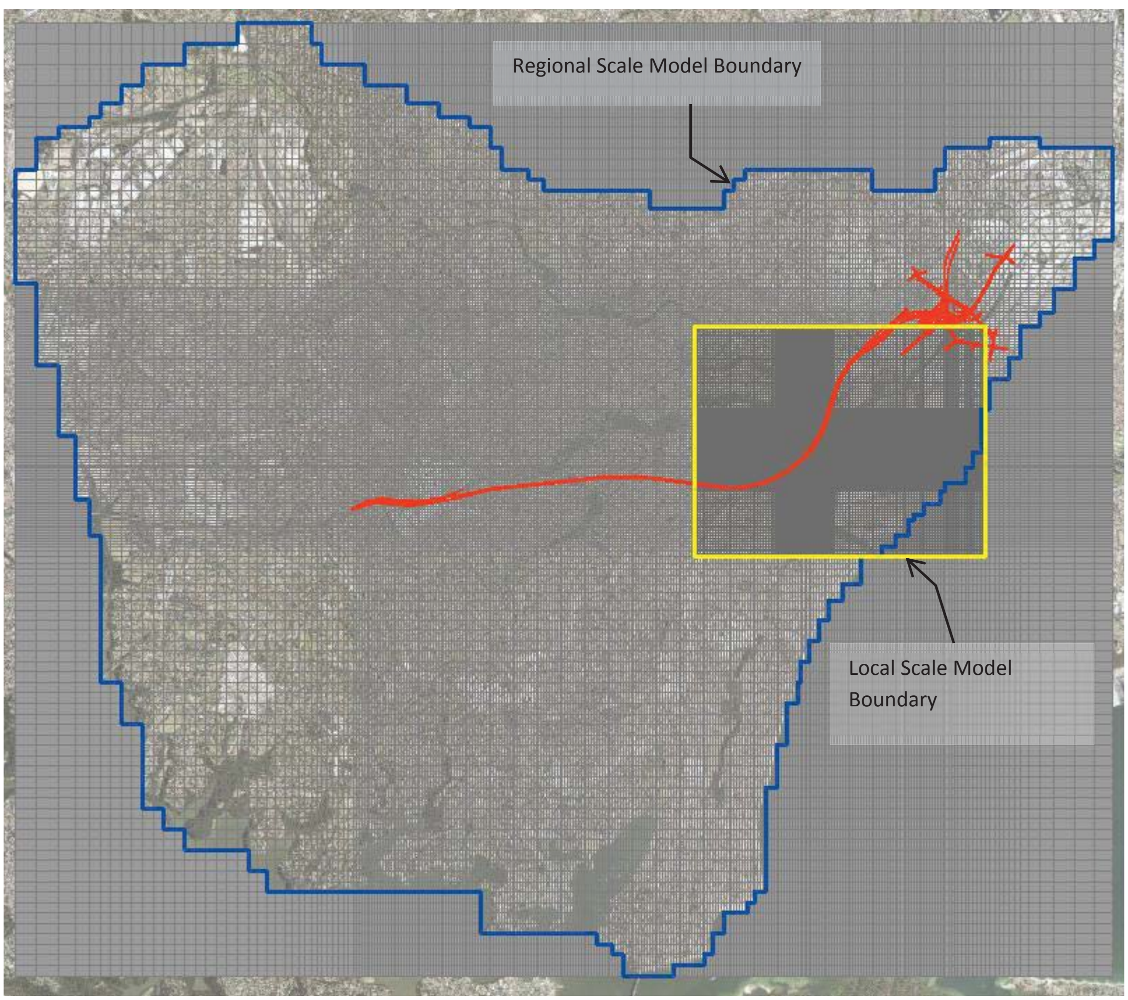
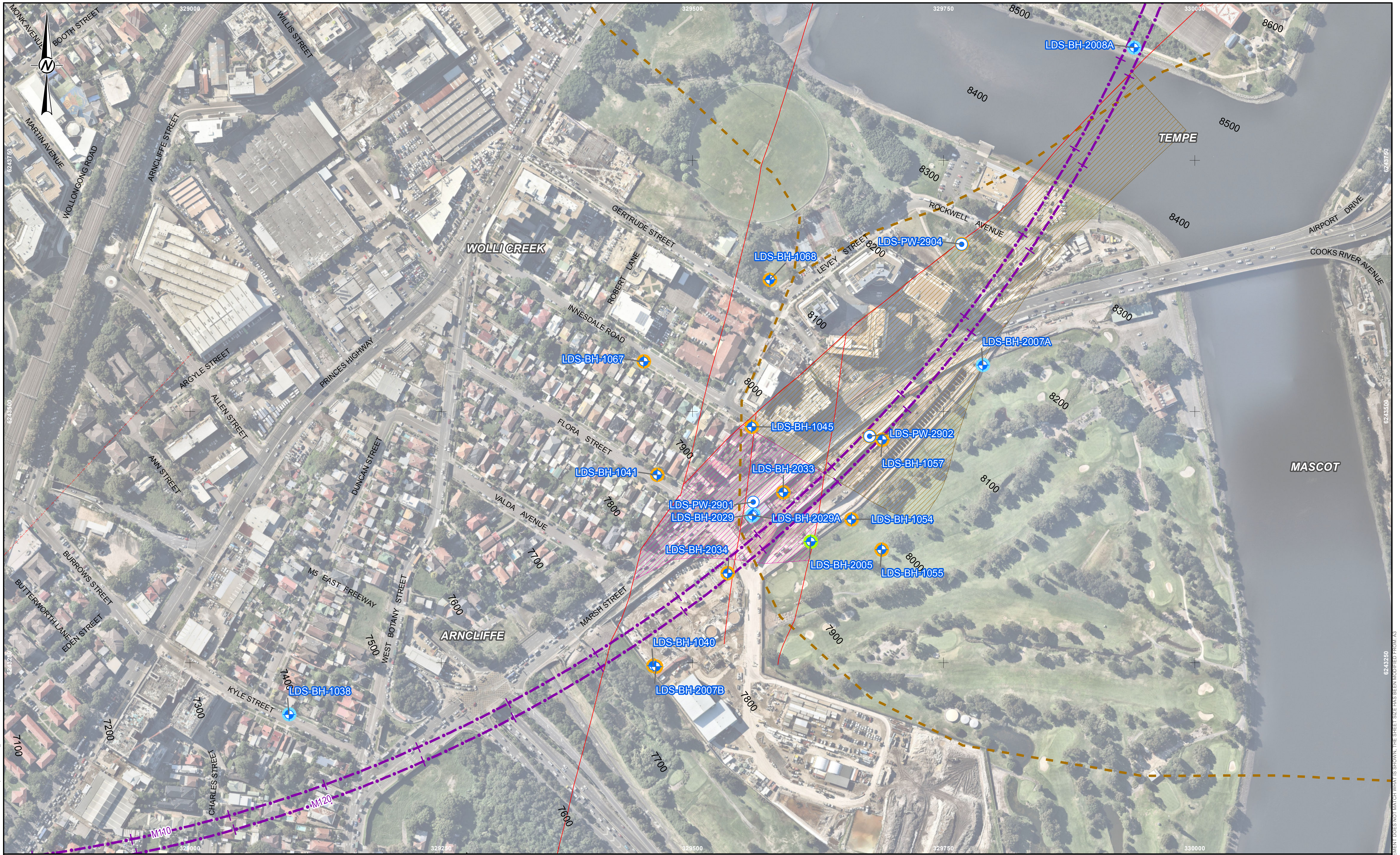


Figure O1: Extent and grid resolution of local scale model



LEGEND

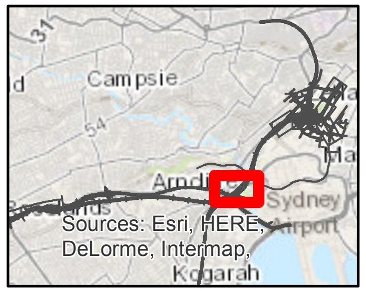
Installation

- MW
- VWP
- VWP+MW

Complete

- Borehole
- Pump Well
- Fault
- Fault (Inferred)

- Palaeochannel Axis
- Sub-horizontal shear zone RL -54 m to RL-59 m AHD
- Sub-horizontal shear zone RL -70 m AHD



Sources: Esri, HERE, DeLorme, Intermap.

CLIENT
CPB DRAGADOS SAMSUNG JV

PROJECT
WESTCONNEX STAGE 2 NEW M5 MOTORWAY

0 40 80 120 160 200
METRES

REFERENCE SCALE: 1:3,500 (at A3)
PROJECTION: GDA 1994 MGA Zone 56

TITLE
ARNCLIFFE SHAFT ZONES OF HIGHER PERMEABILITY
M5N-GOL-DRT-100-200-GT-1525

CPB CONTRACTORS | DRAGADOS | SAMSUNG C&T | WestConnex Stage 2 M5 | Golder Associates

YYYY-MM-DD	2017-05-01
PREPARED	JEC
DESIGN	LBM
REVIEW	-
APPROVED	

PROJECT No.	Rev.	FIGURE
1524285	A	O2

IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: A3

25mm

Table O1: Model layer assignment

Layer #	Thickness (m)	Hydrostratigraphic Units
1	3 – 31.2	Landfills, Holocene, Botany, Alluvium and Residual
2	3 – 15.8	Landfills, Holocene, Alluvium and Residual
3-4	3 – 30.4	Landfills, Pleistocene Alluvium and Residual
5-6	3 – 17.6	Pleistocene Alluvium and Marine and Residual
7	3 – 12.9	Pleistocene Alluvium and Marine, Residual and Ashfield Shale
8-10	5-15	Hawkesbury Sandstone, faults, dyke
11	5 – 7	Hawkesbury Sandstone, Upper Shear Zone, faults, dyke
12-13	7 – 10	Hawkesbury Sandstone, faults, dyke
14	5 – 7	Hawkesbury Sandstone, Arncliffe Fault Zone, faults, dyke
15	5 – 10	Hawkesbury Sandstone, faults, dyke
16	5 – 7	Hawkesbury Sandstone, Lower Shear Zone, faults, dyke
17-21	7 - 30	Hawkesbury Sandstone, faults, dyke

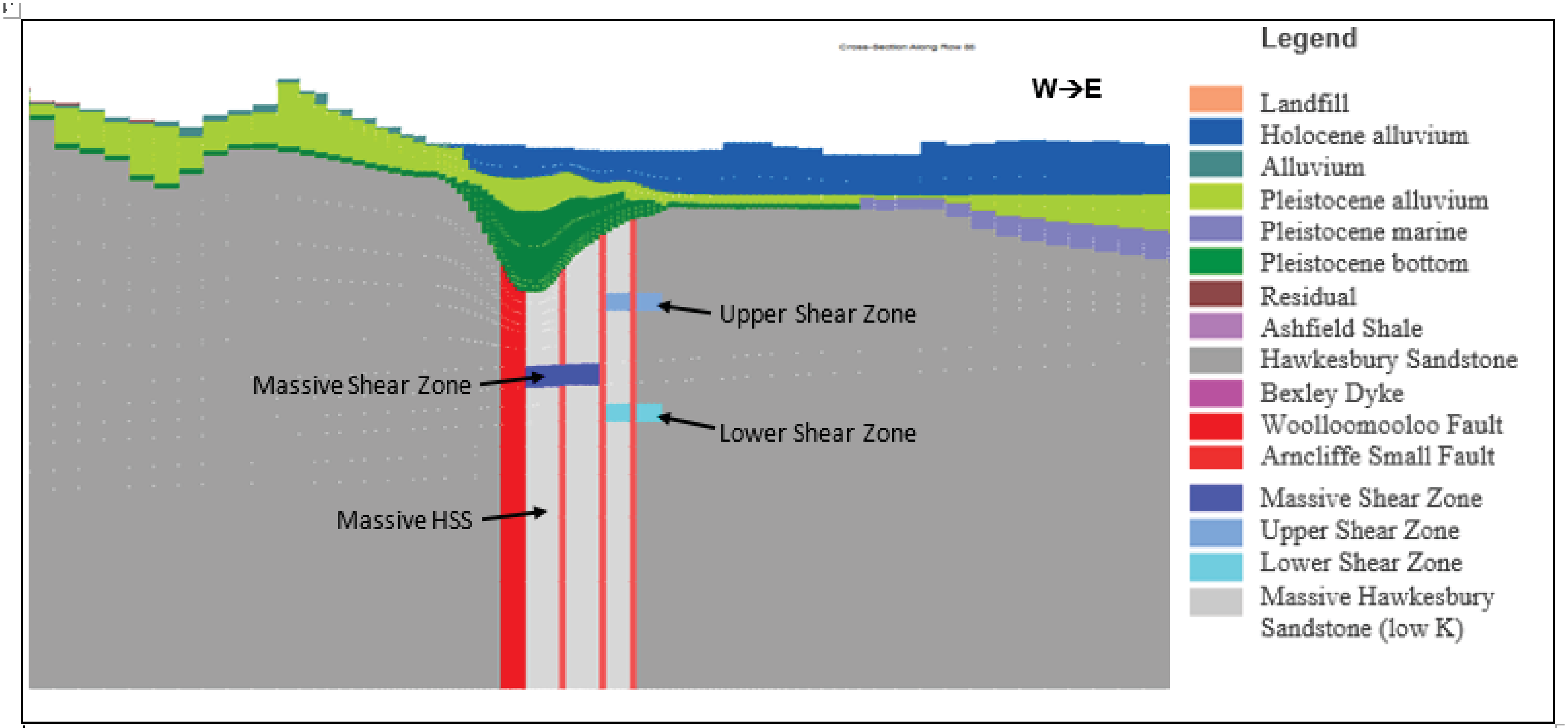


Figure O3: Vertical West – East section through the local scale model at the test well location

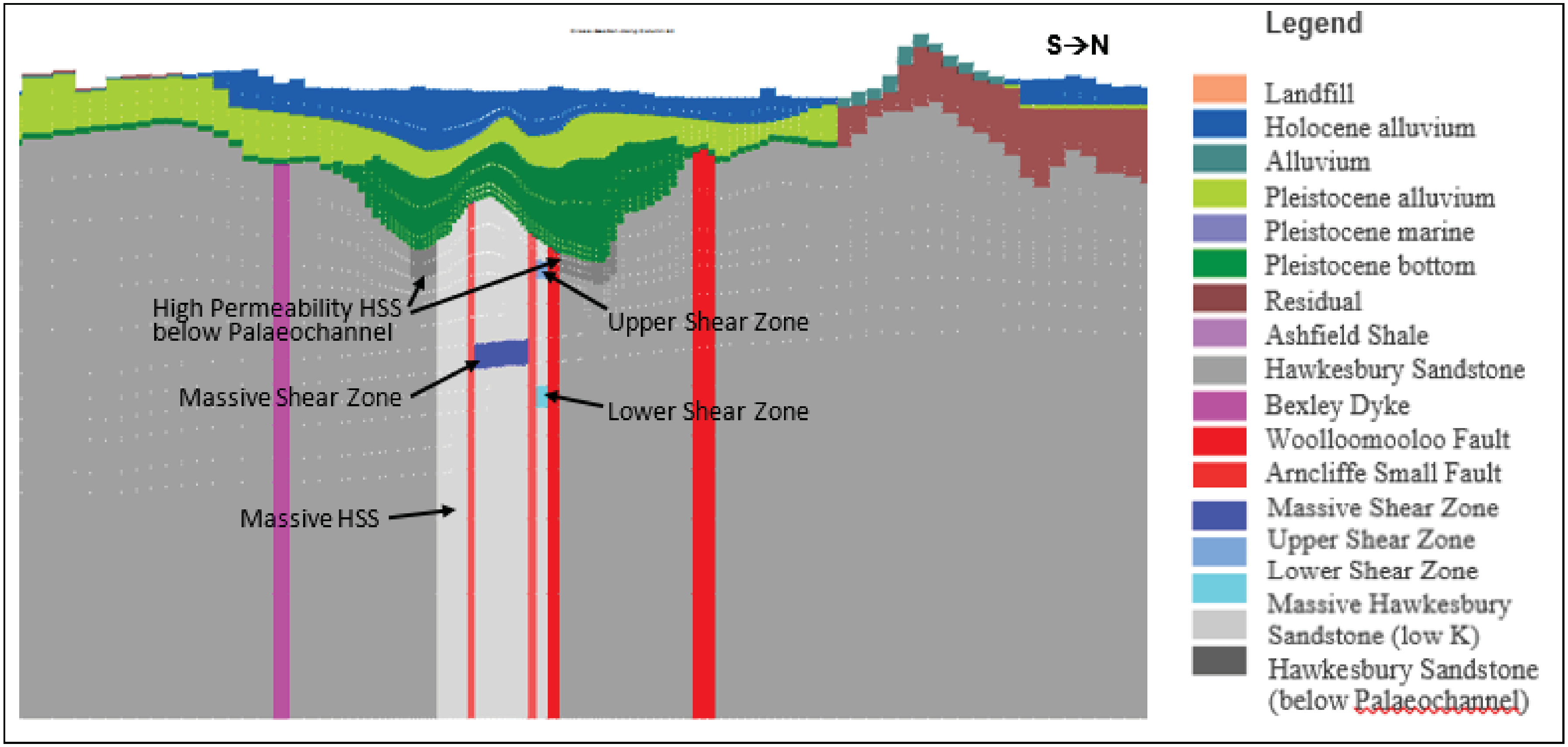


Figure O4: Vertical North – South section through the local scale model at the test well location

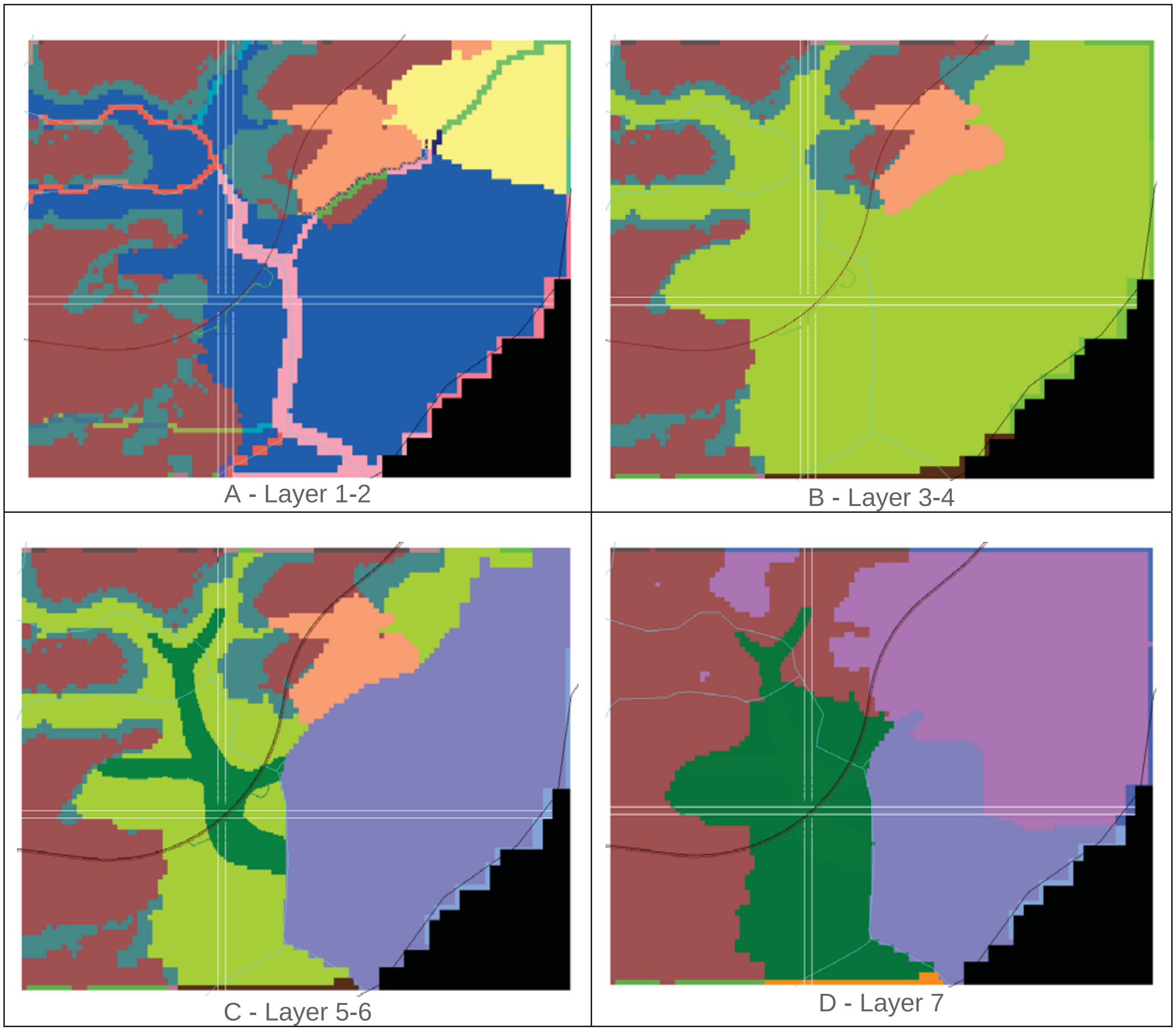


Figure O5: Spatial extent of Hydrogeological units in layers 1 to 7 of the local scale model. See Figure 3 for colour legend.

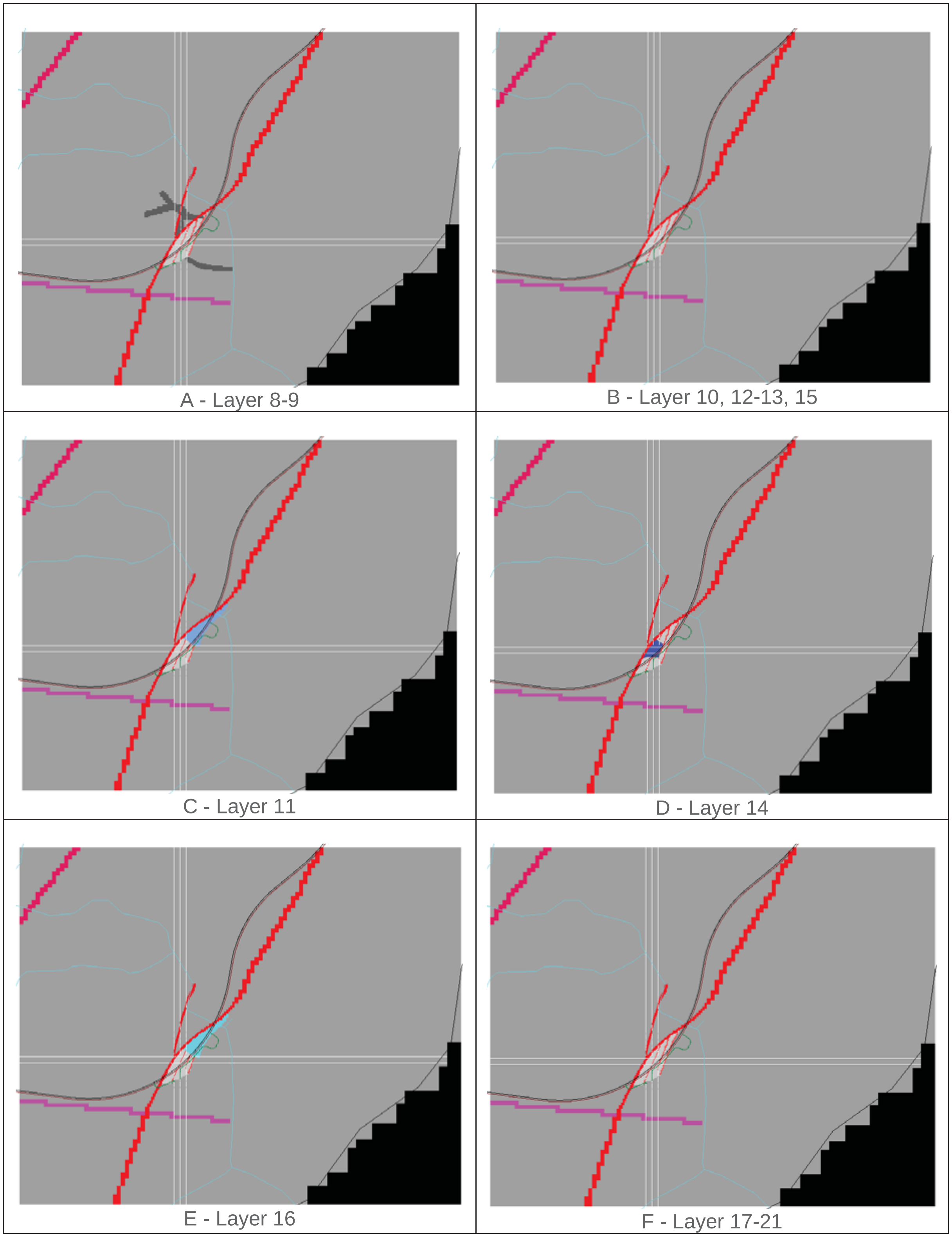


Figure O6: Spatial extent of Hydrogeological units in layers 8 to 21 of the local scale model. See Figure 3 for colour legend

Local Scale Model Calibration

The local scale model has been calibrated to the results of the pumping test carried out at Arncliffe in July 2016. Pumping was carried out from pumping wells LSD-PW-2902 and LDS-PW-2904 over the period from 15 July 2016 to 29 July 2016. The locations of the pumping wells, and monitoring wells are illustrated in Figure O7. Pumping rates from the two wells during this period are illustrated in Figure O8. A comparison between model predicted drawdowns and measured response in monitoring wells is illustrated in Figures O9 to O19. The model predictions demonstrate a good match to observed drawdowns in both the alluvium and the Hawkesbury Sandstone in most cases.

Statistical calibration parameters for the late stages of the multiple well pumping test were derived and are summarised in Table O2. Plots of the observed versus predicted heads for the single and two-well tests are shown in Figure O20 and Figure O21, respectively. After 6.5 days of pumping well LSD-PW-2902 groundwater levels at the test well and observations bores only changed slightly with time and groundwater conditions at the test site were assumed close to equilibrium. At this stage, pumping of well LDS-PW-2904 commenced for additional 7.5 days and calibration parameters were derived for the late stage (14 days after pumping commenced at bore LSD-PW-2902) of pumping both wells.

Table O2: Statistics of local scale transient model calibration to drawdown records for discharge tests at wells LSD-PW-2902 and LSD-PW-2904

Statistics	Units	LSD-PW-2902		LSD-PW-2902 & LSD-PW-2902	
		All bores	Hawkesbury Sandstone	All bores	Hawkesbury Sandstone
Number of calibration targets	-	40	22	38	18
RMS	m	7.64	7.60	5.53	6.17
SRMS	%	81.7	81.3	40.8	45.5
Minimum Residuals	m	-1.42	-1.42	-2.89	-1.52
Maximum Residuals	m	4.43	4.43	2.54	3.60
Coefficient of determination R^2 for linear regression between computed and observed heads	-	0.91	0.91	0.98	0.95

Hydraulic parameters determined through calibration to the pumping test are summarised in Table O3.

Table O3: Local scale model parameter adapted after completion of transient model calibration

GWV Zone	Unit	Layer	Ratio(Kx/Kz)	Kx(m/s)	Ky(m/s)	Kz(m/s)	Ss	Sy
1	Landfill	1-5	12	6.43E-05	6.44E-05	5.34E-06	2.00E-05	0.2
2	Holocene Sediment	1-2	8	7.55E-06	7.55E-06	1.00E-06	2.00E-04	0.2
3	Botany sands	4-5	50	1.00E-05	1.00E-05	2.00E-07	1.00E-04	0.2
4	Alluvium	1-6	50	8.33E-06	8.33E-06	1.67E-07	2.00E-04	0.2
13	Pleistocene Sediment	3-6	50	8.33E-06	8.33E-06	1.67E-07	3.00E-04	0.2
15	Pleistocene Sediment (bottom)	4-7	20	1.67E-06	1.67E-06	8.33E-08	2.00E-04	0.2
14	Pleistocene Marine (east side)	7	10	2.91E-08	2.91E-08	2.91E-09	1.00E-04	0.15
5	Residual (weathered shale)	1-7	40	6.48E-06	6.48E-06	1.62E-07	1.00E-05	0.2
6	Ashfield Shale	8	10	8.91E-09	8.91E-09	8.91E-10	1.00E-05	0.01
7	Hawkesbury Sandstone	8-21	10	1.00E-07	1.00E-07	1.00E-08	2.00E-06	0.01
18	Hawkebury Sandstine at Palaeochannel	8-9	5	3.33E-06	3.33E-06	6.67E-07	2.00E-06	0.05
19	Massive Hawkesbury Sandstone	8-21	4	4.00E-08	4.00E-08	1.00E-08	3.00E-06	0.01
8	Bexley Dyke	8-21	50	6.53E-06	1.19E-08	1.30E-07	1.00E-05	0.05
9	Woolloomooloo Fault zones	8-21	2	7.06E-06	7.06E-06	3.13E-06	1.00E-05	0.05
10	Luna Park Fault	8-21	1	3.33E-06	3.33E-06	3.33E-06	1.00E-05	0.05
12	Arncliffe Shear Zone (Red -54mRL)	14	2	6.94E-06	6.94E-06	3.33E-06	2.00E-06	0.02
11	Arncliffe Small Fault	8-21	1	1.00E-05	1.00E-05	1.00E-05	5.00E-06	0.05
16	Arncliffe Shear Zone (blue -38mRL)	11	5	3.33E-06	3.33E-06	6.67E-07	2.00E-06	0.02
17	Arncliffe Shear Zone (blue -70mRL)	16	5	5.01E-06	5.01E-06	1.00E-06	2.00E-06	0.02

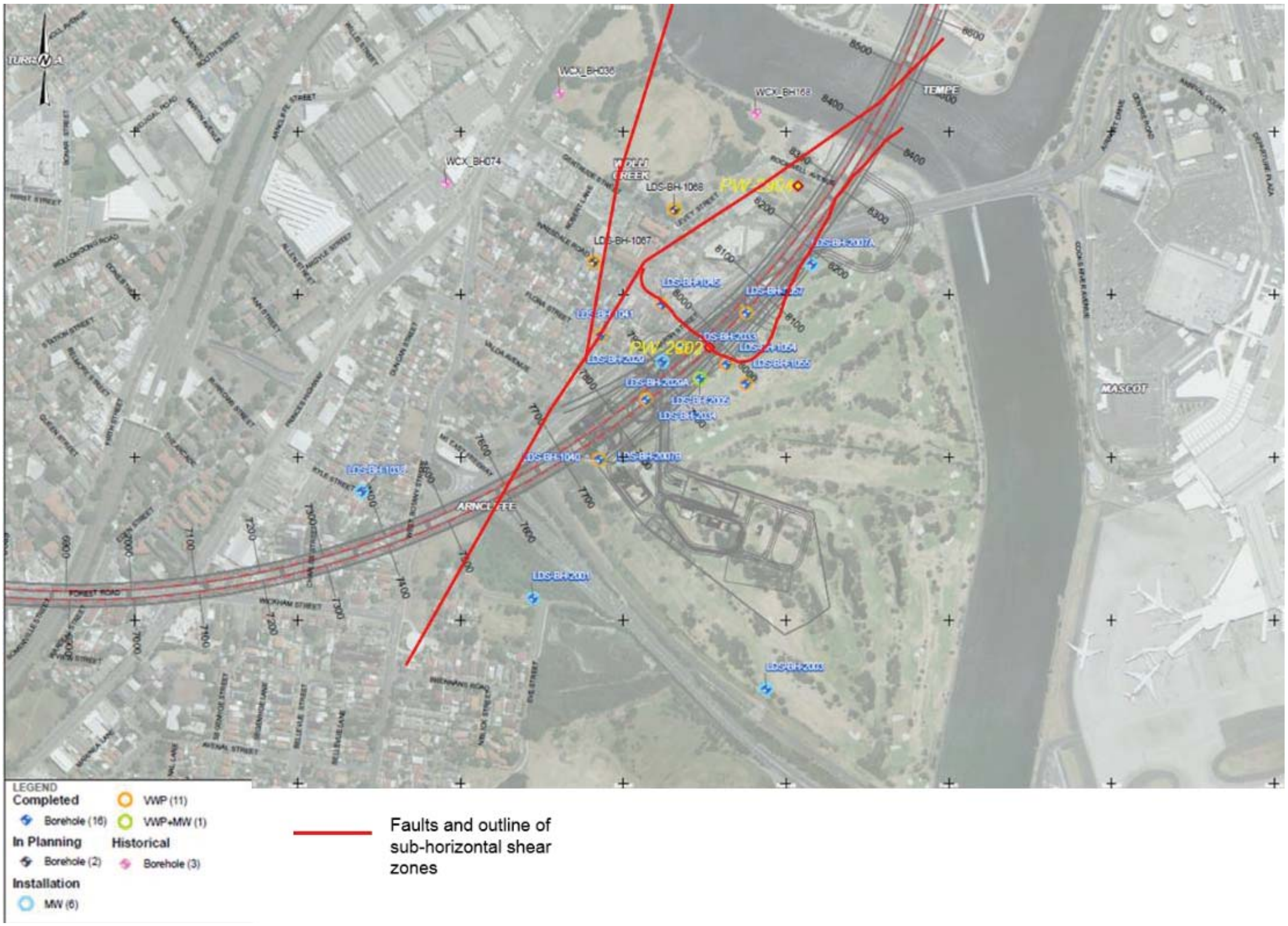


Figure O7: Kogarah golf course pumping test layout

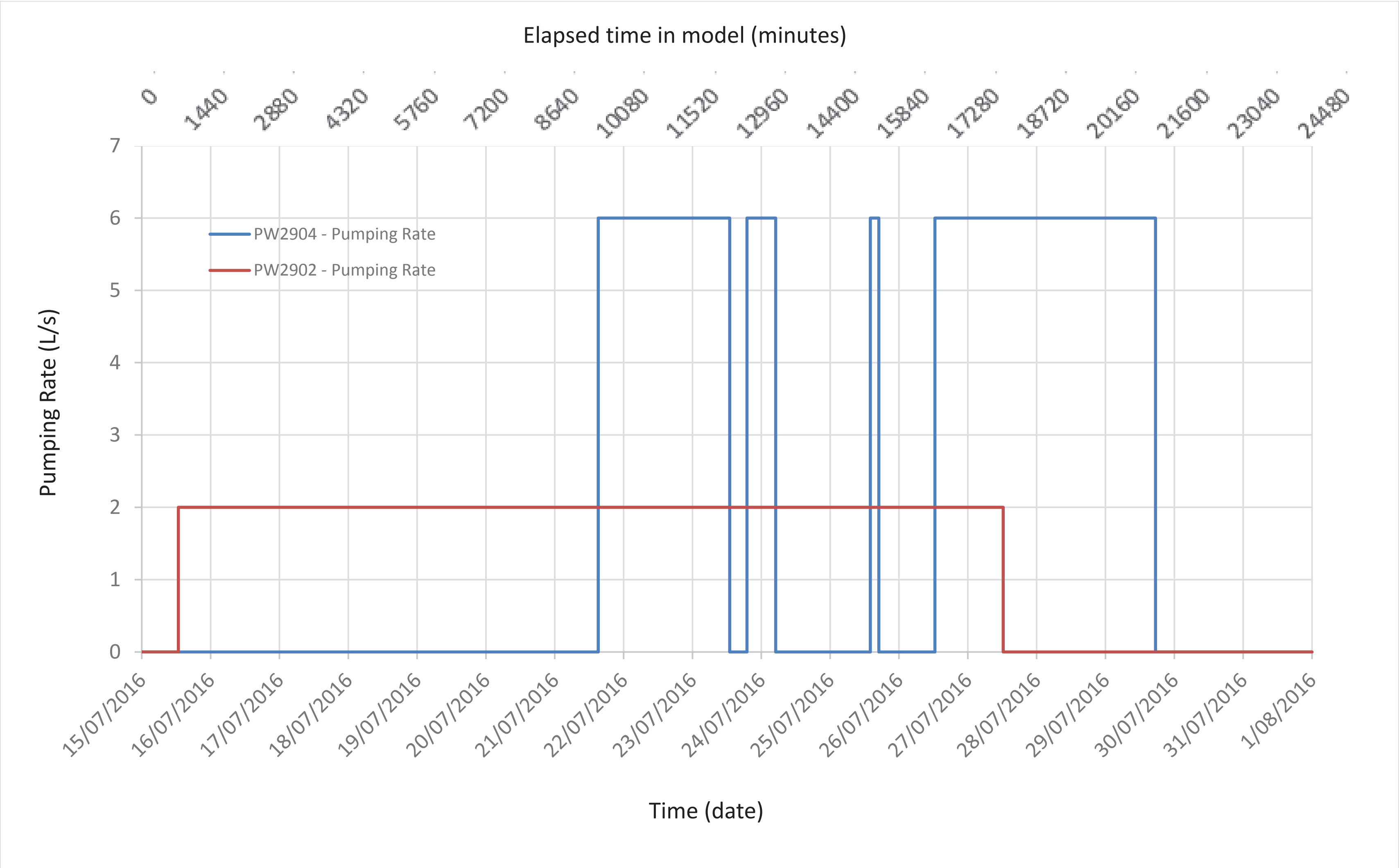


Figure O8: Pumping rates from PW2902 and PW2904 applied in model (note- t=0 for transient modelling of pumping test corresponds to 12:00 am on 15 July 2016).

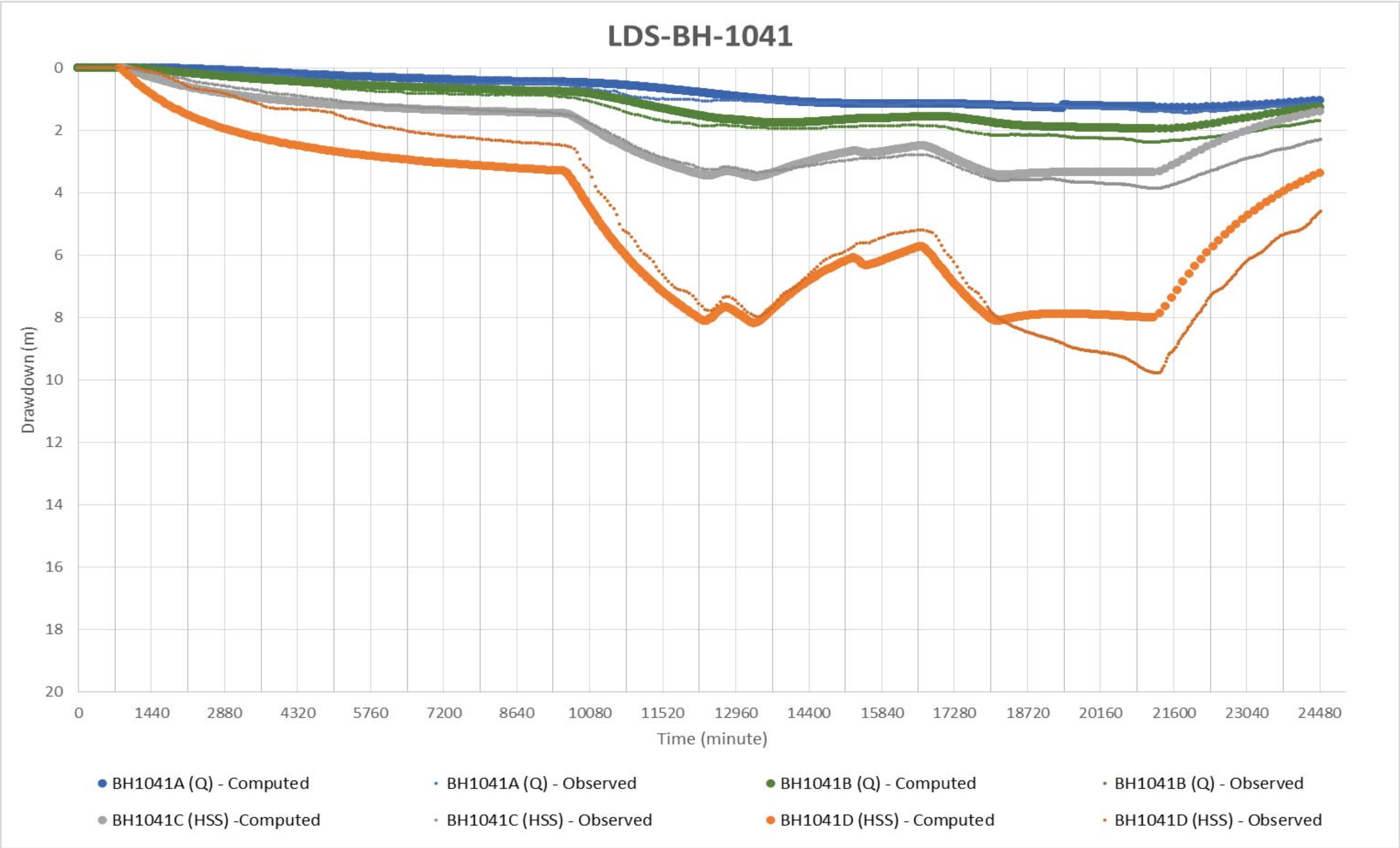


Figure O9: Comparison of observed and computed groundwater drawdown at LDS –BH-1041 for the duration of the two-well discharge test and recovery stage.

(Q – VWPs in alluvium, HSS – VWPs in Hawkesbury Sandstone)

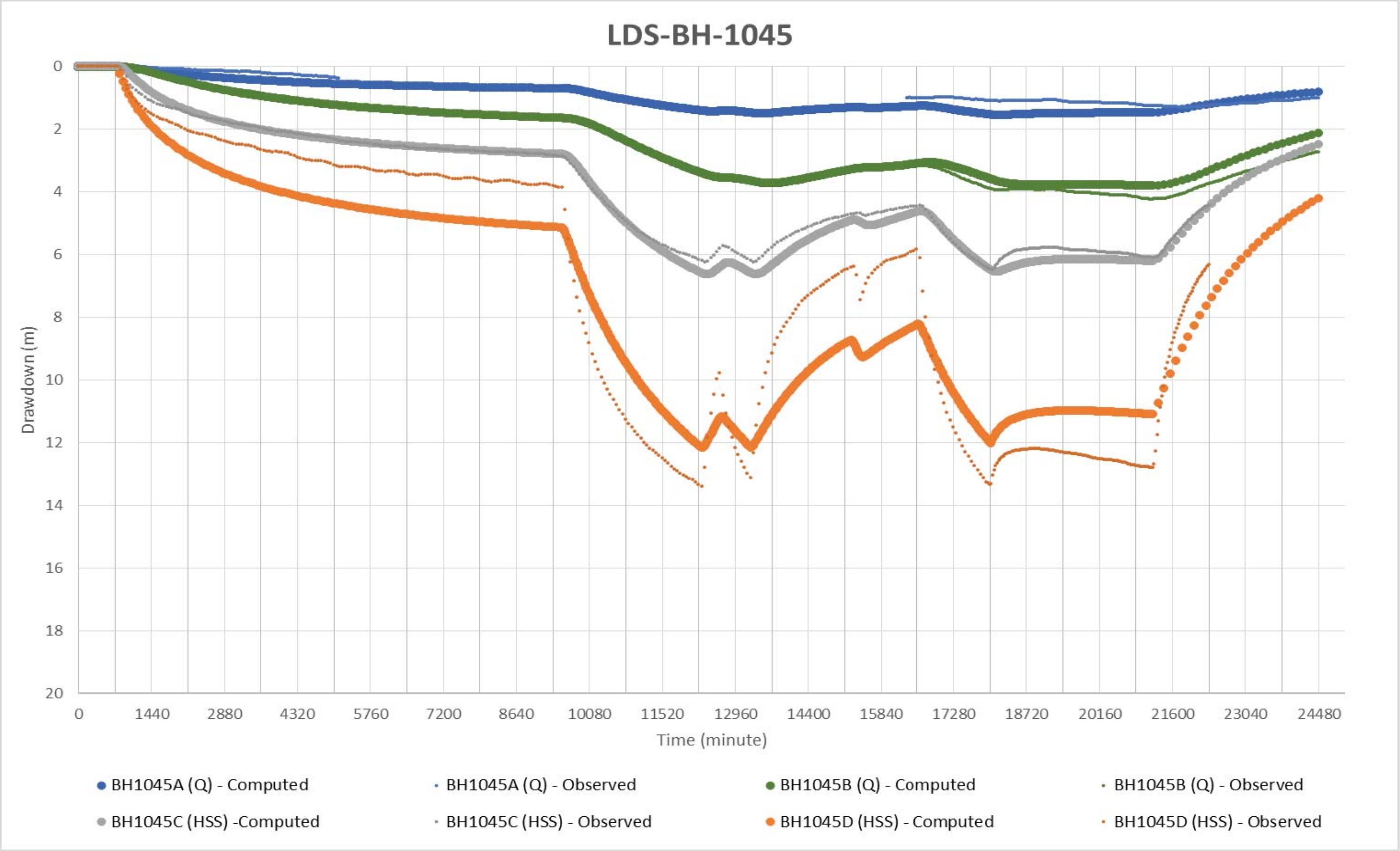


Figure O10: Comparison of observed and computed groundwater drawdown LDS – BH1045 for the duration of the two-well discharge test and recovery stage.

(Q – VWPs in alluvium, HSS – VWPs in Hawkesbury Sandstone)

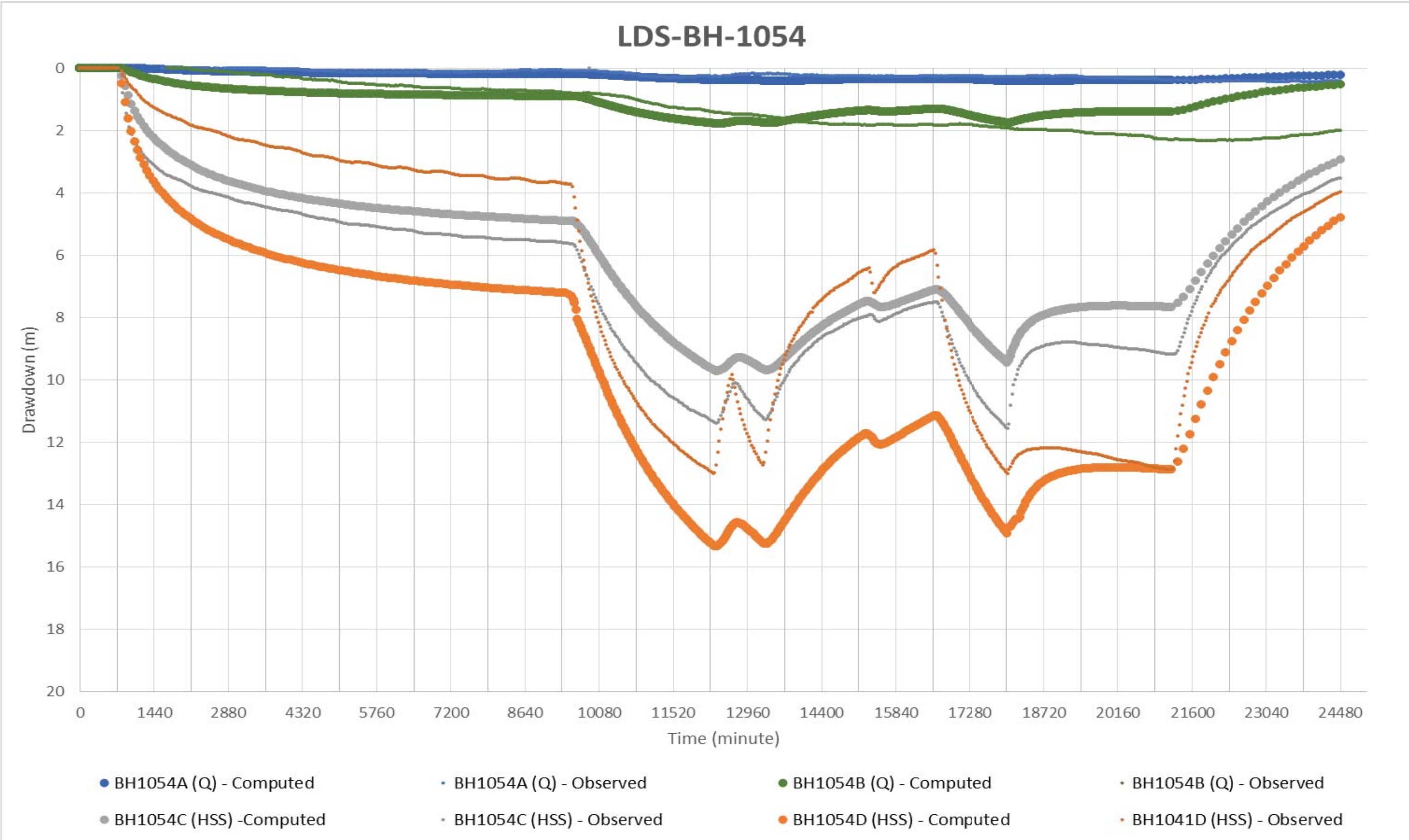


Figure O11: Comparison of observed and computed groundwater drawdown at LDS -BH1054 for the duration of the two-well discharge test and recovery stage. (Q – VWPs in alluvium, HSS – VWPs in Hawkesbury Sandstone)

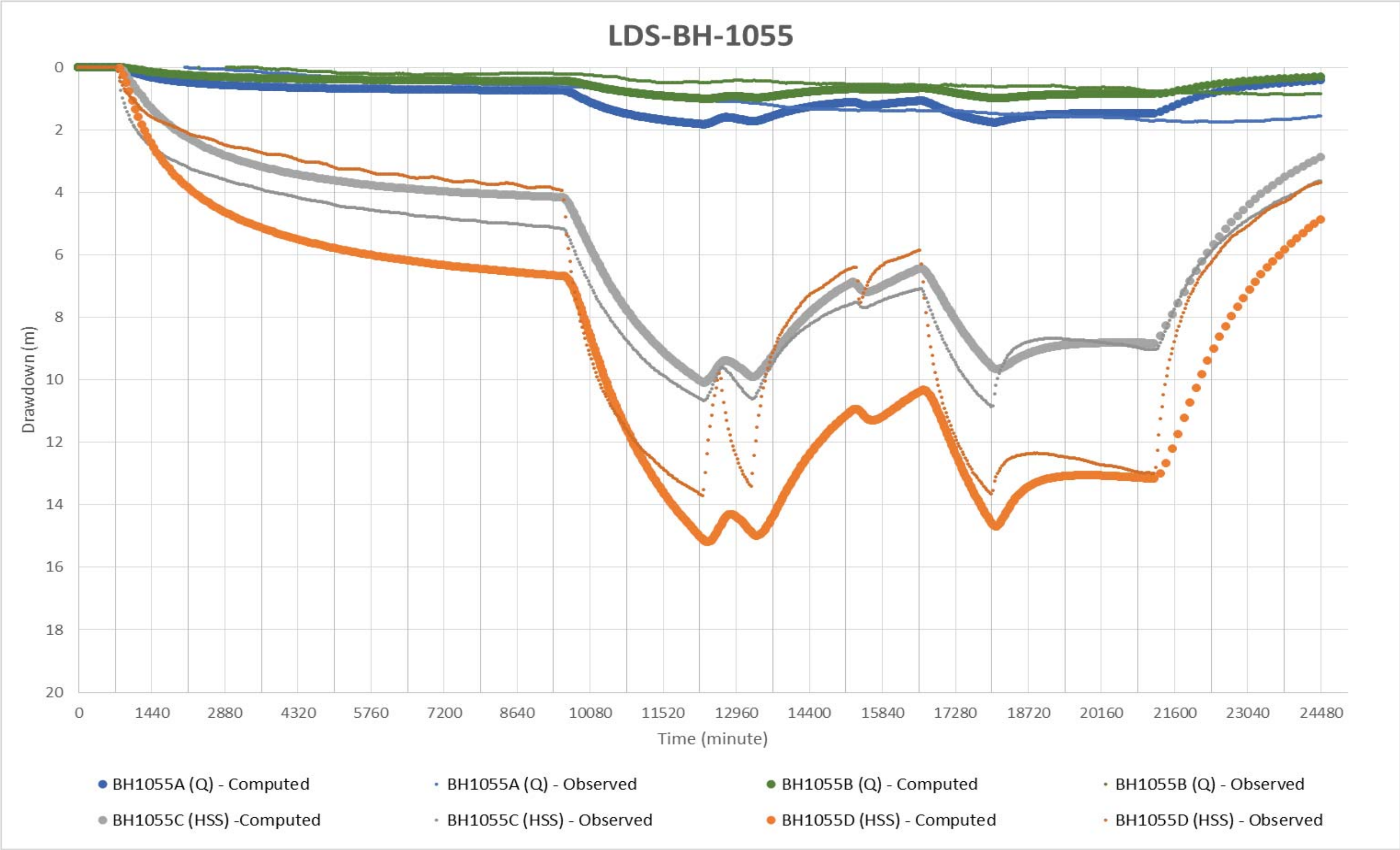


Figure O12: Comparison of observed and computed groundwater drawdown at LDS -BH1055 for the duration of the two-well discharge test and recovery stage. (Q – VWPs in alluvium, HSS – VWPs in Hawkesbury Sandstone)

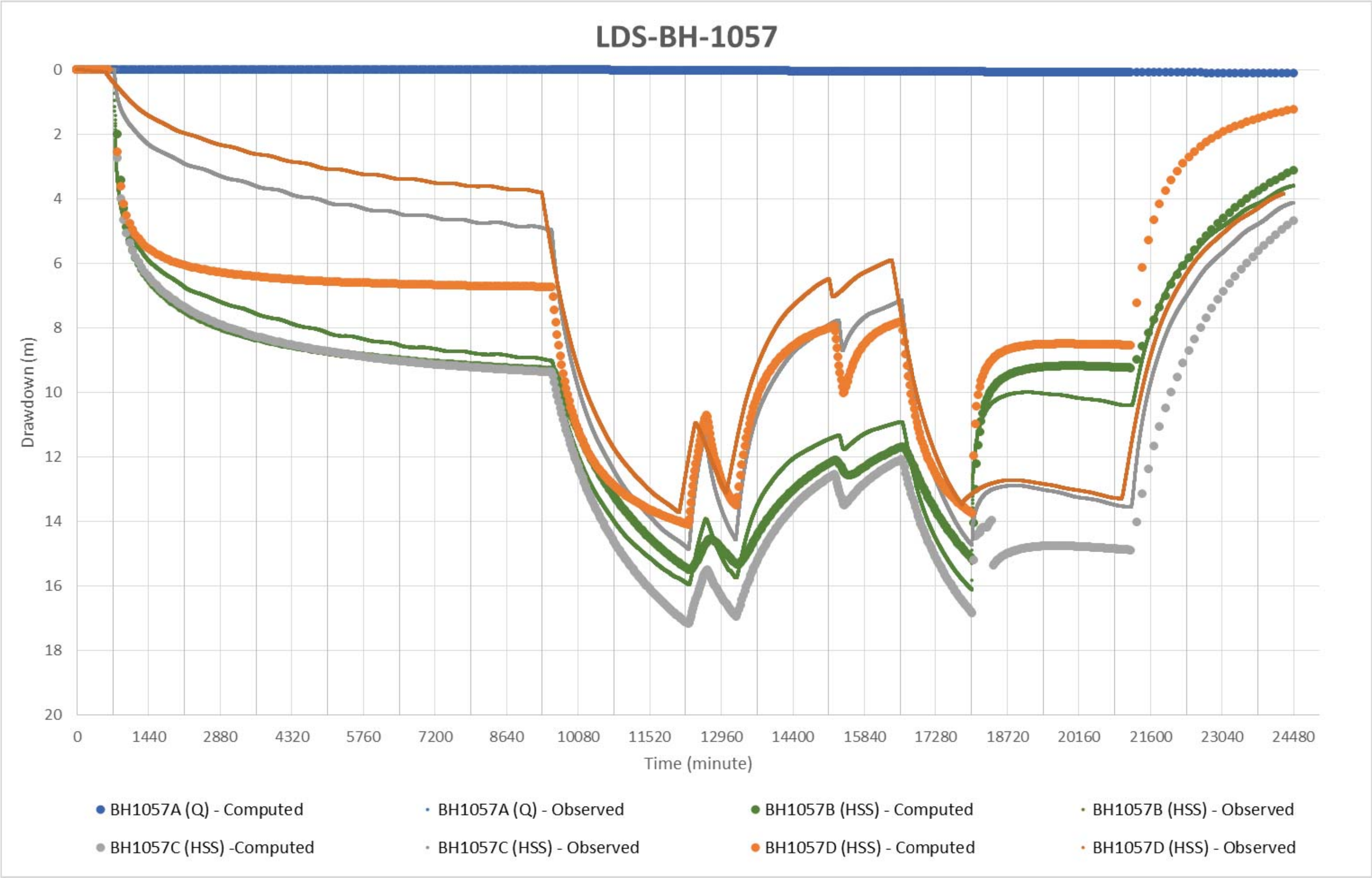


Figure O13: Comparison of observed and computed groundwater drawdown at LDS -BH1057 for the duration of the two-well discharge test and recovery stage. (Q – VWPs in alluvium, HSS – VWPs in Hawkesbury Sandstone)

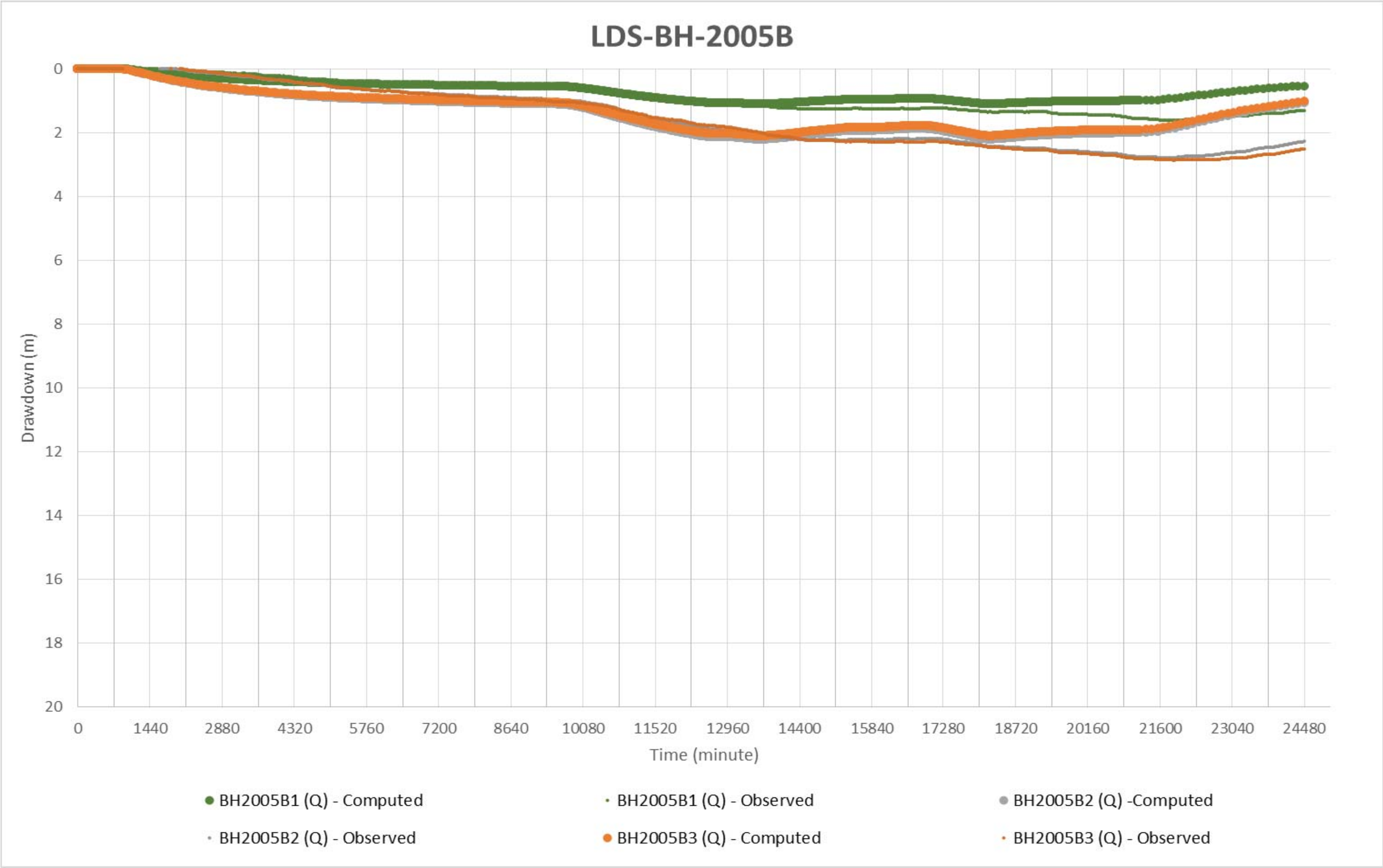


Figure O14: Comparison of observed and computed groundwater drawdown at LDS-BH2005B for the duration of the two-well discharge test and recovery stage. (Q – VWPs in alluvium, HSS – VWPs in Hawkesbury Sandstone)

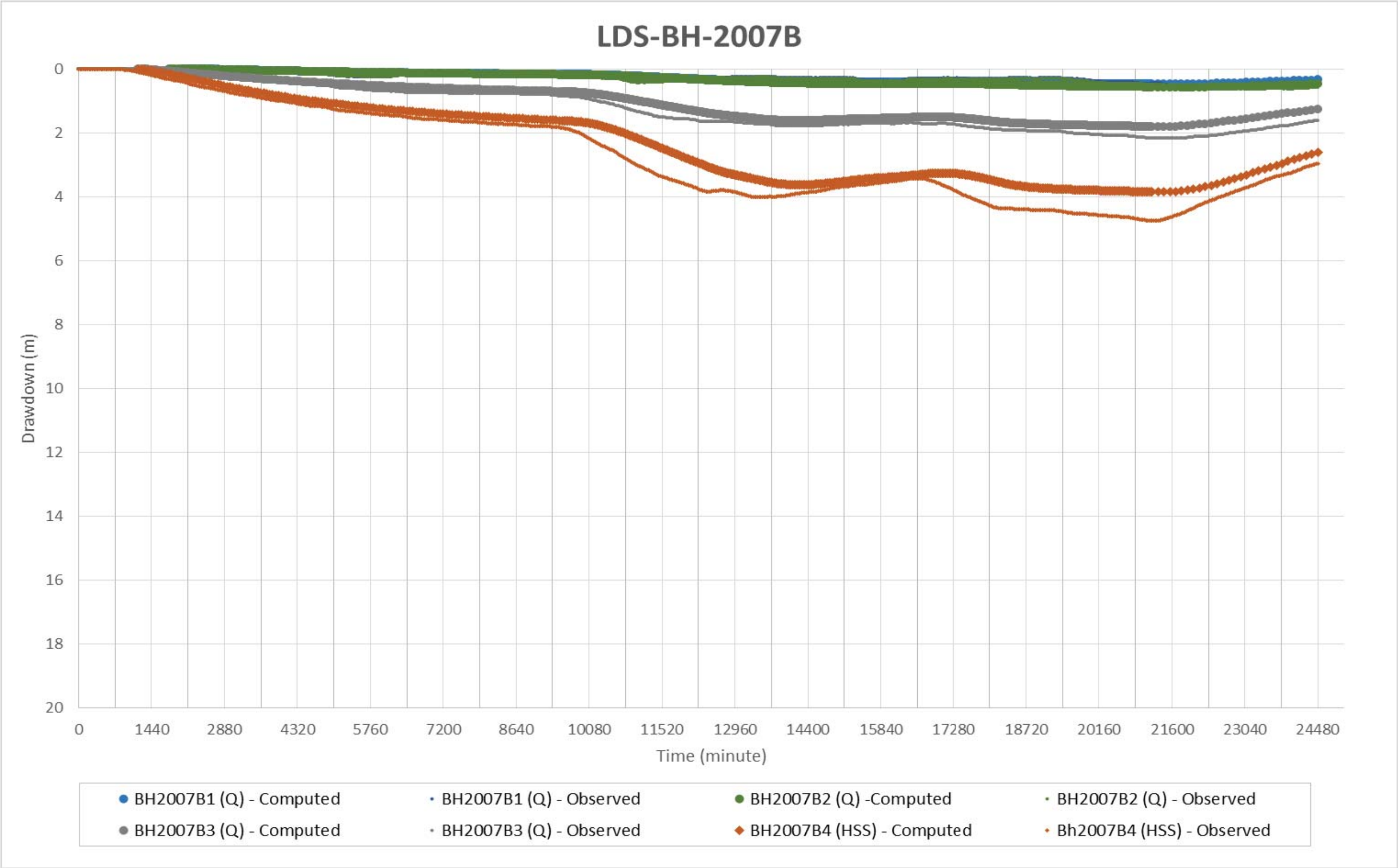


Figure O15: Comparison of observed and computed groundwater drawdown at LDS –BH2007B for the duration of the two-well discharge test and recovery stage. (Q – VWPs in alluvium, HSS – VWPs in Hawkesbury Sandstone)

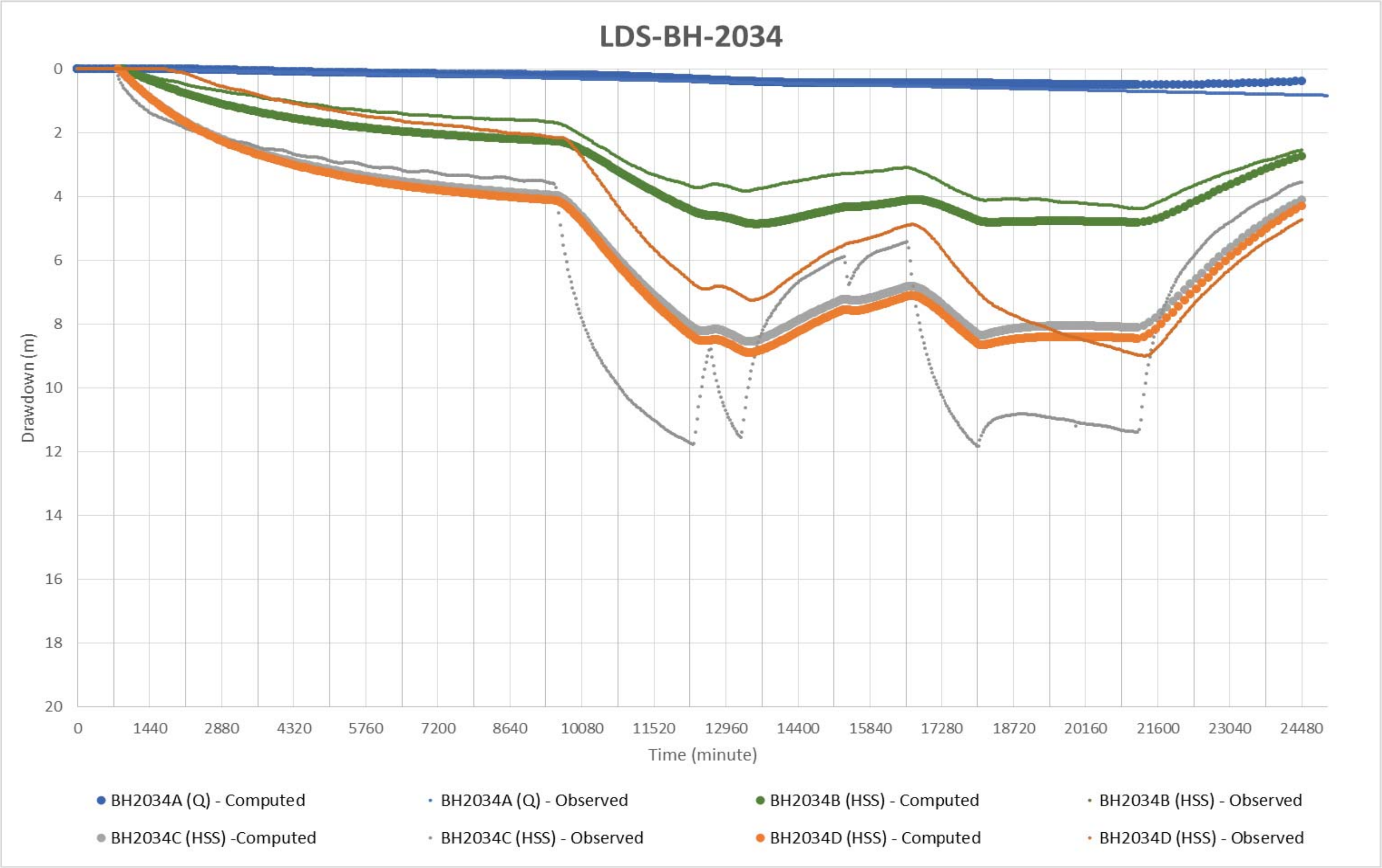


Figure O16: Comparison of observed and computed groundwater drawdown at LDS –BH2034 for the duration of the two-well discharge test and recovery stage. (Q – VWPs in alluvium, HSS – VWPs in Hawkesbury Sandstone)

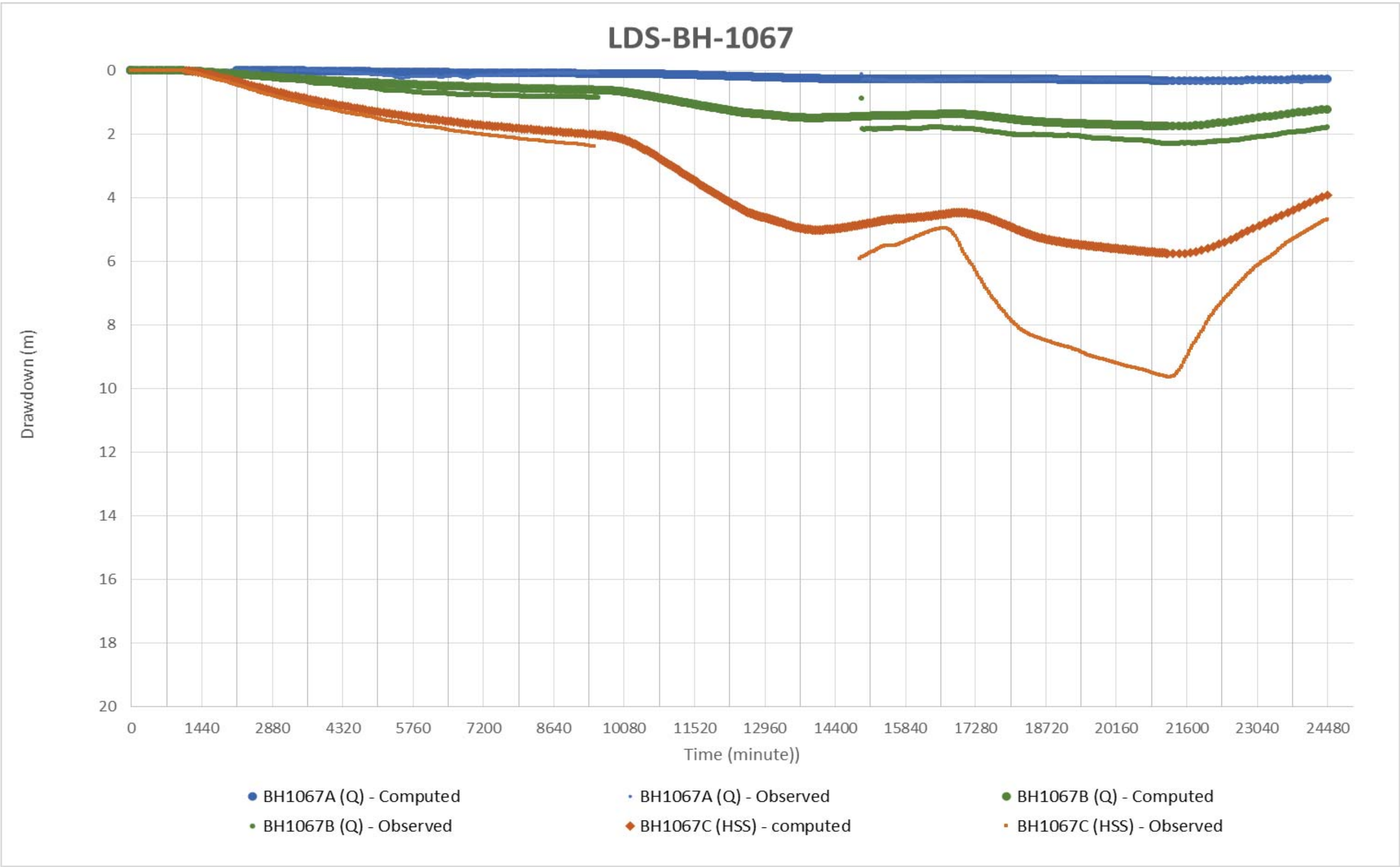


Figure O17: Comparison of observed and computed groundwater drawdown at LDS –BH1067 for the duration of the two-well discharge test and recovery stage. (Q – VWPs in alluvium, HSS – VWPs in Hawkesbury Sandstone)

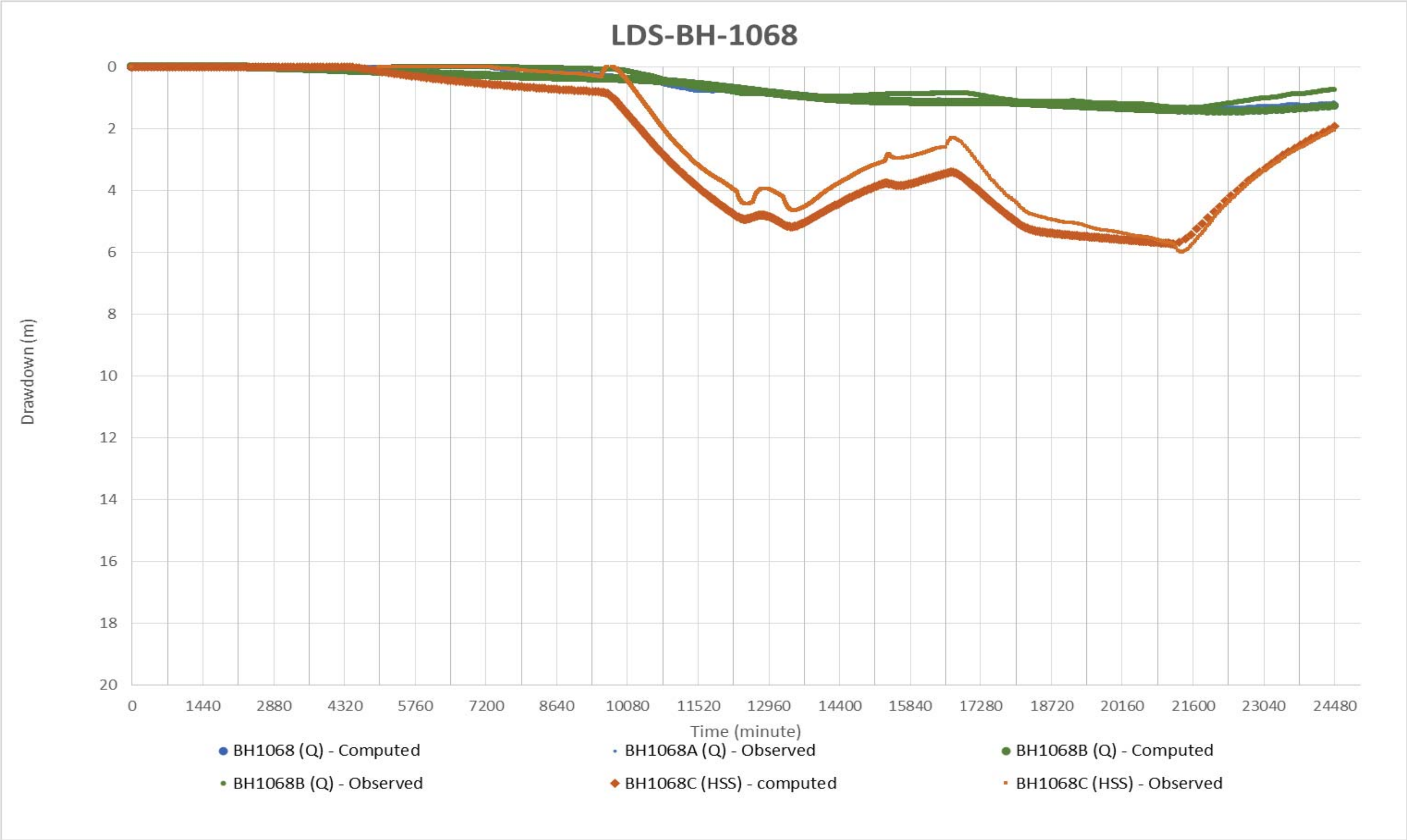


Figure O18: Comparison of observed and computed groundwater drawdown at LDS –BH1068 for the duration of the two-well discharge test and recovery stage. (Q – VWPs in alluvium, HSS – VWPs in Hawkesbury Sandstone)

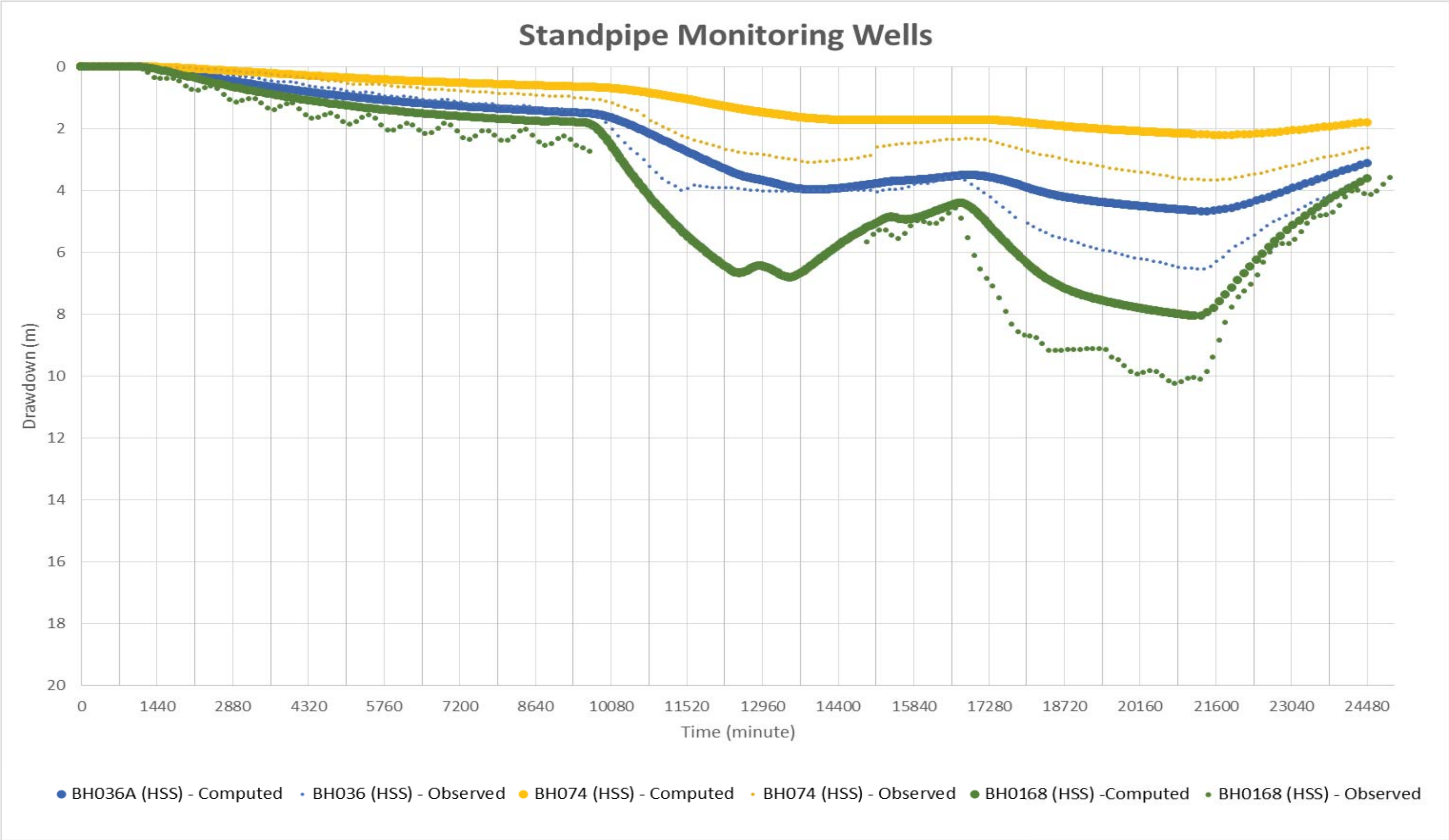
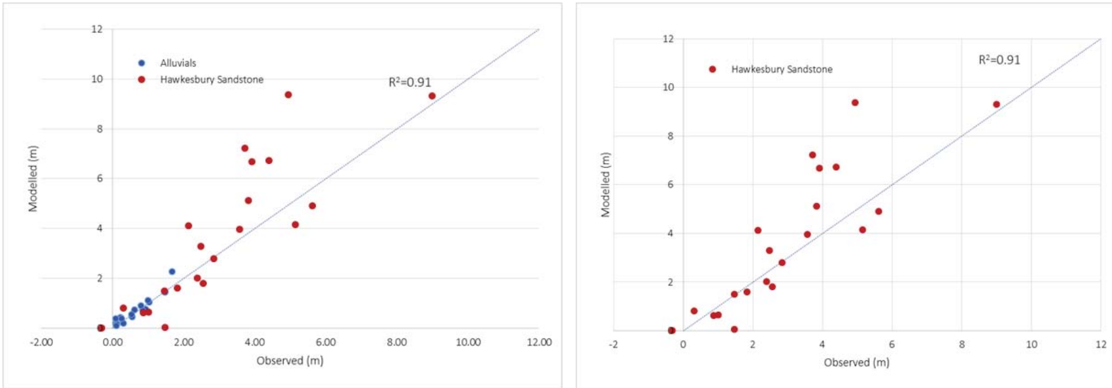
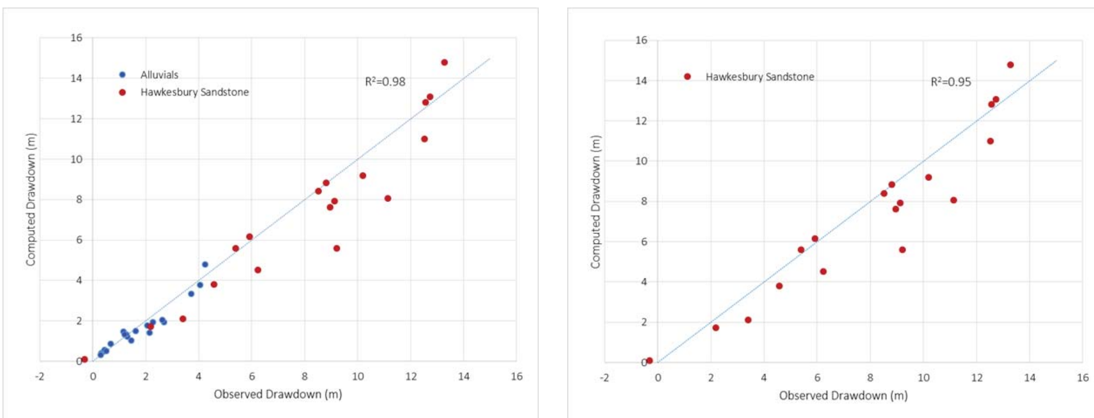


Figure O19: Comparison of observed and computed groundwater drawdown at WCX–BH036, WCX–BH074 and WCX–BH168 for the duration of the two-well discharge test and recovery stage. Wells all screened in Hawkesbury Sandstone.



(A) (B)

Figure O20: Comparison of observed and computed groundwater drawdown at observation bores for the late stage (6.5 days) of pumping from well LSD-PW-2902. A) Scatter plot and linear regression line for all observation bores, B) Scatter plot and linear regression line for observation bores screened in Hawkesbury Sandstone.



(A) (B)

Figure O21: Comparison of observed and computed groundwater drawdown at observation bores for the late stage (14 days) of pumping from wells LSD-PW-2902 and LSD-PW-2904. A) Scatter plot and linear regression line for all observation bores, B) Scatter plot and linear regression line for observation bores screened in Hawkesbury Sandstone.

Annexure P – Water Quality Parameters for Assessment of Tunnel Inflow Water Quality

Parameter	Det Limit	unit	Cooks River	Landfills #	2000 - 2500	2500 - 3000	3000 - 3500	3500 - 4000	4000 - 4500	4500 - 5000
Tunnel Chainage [m] / Inflow [L/s]			4.08[1]	0.23[2]/0.16[3]/0.04[4]	0.44	0.41	0.67	0.48	0.44	0.99
COD	10	mg/L	NA / NA	202.00 / 202.00	13 / 13	**53 / 56.5**	**53 / 56.5**	**53 / 56.5**	**53 / 56.5**	**53 / 83**
Total Nitrogen ^	0.05	mg/L	1.20 / 0.45	8.13 / 9.10	1.8 / 1.8	1.12 / 2.2	3.85 / 3.9	1.335 / 1.8	0.595 / 0.65	0.615 / 0.73
Ammonia Nitrogen, NH_3 as N	0.005	mg/L	0.0 / 0.0	3.55 / 190	1.7 / 1.7	1.12 / 2.2	3.85 / 3.9	0.94 / 1.5	0.595 / 0.65	0.16 / 0.16
Total Suspended Solids Dried at 103-105°C	5	mg/L	NA / NA	430 / 16000	96 / 96	**1248 / 1748**	**1248 / 1748**	**1248 / 1748**	**1248 / 1748**	**1248 / 1748**
Total Dissolved Solids Dried at 175-185°C	10	mg/L	23840 / 18952	1400 / 21000	8750 / 9100	**6869.9 / 7197.5**	**4989.8 / 5294.9**	*3109.7 / 3392.4*	**2261.47 / 2458.3**	**1413.23 / 1524.1**
Conductivity @ 25 C	2	µS/cm	47680 / 37904	2261 / 6402	*15476 / 16095*	**12150.8 / 12730**	**3292.5 / 3550**	5500 / 6000	**4028.33 / 4366.7**	**2556.67 / 2733.3**
Total Iron	0.005	mg/L	1.03 / 0.68	6.95 / 6.95	NA / NA	NA / NA	NA / NA	NA / NA	NA / NA	NA / NA
TPH (mg/L)										
C6 - C9 Fraction	0.02	mg/L	<0.02 / NA	0.00 / 0.00	0.01 / 0.02	0.01 / 0.02	0.01 / 0.02	0.01 / 0.02	**0.01 / 0.02**	**0.01 / 0.02**
C10 - C14 Fraction	0.05	mg/L	<0.1 / NA	0.00 / 0.00	**0.025 / 0.05**	**0.025 / 0.05**	**0.025 / 0.05**	**0.025 / 0.05**	**0.025 / 0.05**	0.025 / 0.05
C15 - C28 Fraction	0.1	mg/L	<0.1 / NA	0.00 / 0.00	**0.05 / 0.1**	**0.05 / 0.1**	**0.05 / 0.1**	**0.05 / 0.1**	**0.05 / 0.1**	0.05 / 0.1
C29 - C36 Fraction	0.05	mg/L	<0.1 / NA	0.00 / 0.00	0.025 / 0.05	0.025 / 0.05	0.025 / 0.05	0.025 / 0.05	**0.025 / 0.05**	0.025 / 0.05
C10 - C36 Fraction (sum)	0.05	mg/L	<0.1 / <0.1	0.00 / 0.00	**0.025 / 0.05**	**0.025 / 0.05**	**0.025 / 0.05**	**0.025 / 0.05**	**0.025 / 0.05**	0.025 / 0.05
TRH C10-C14	0.05	mg/L	NA / NA	0.19 / 0.57	0.025 / 0.05	0.025 / 0.05	0.025 / 0.05	0.33 / 0.35	0.1185 / 0.16	**0.12425 / 0.145**
TRH C15-C28	0.2	mg/L	NA / NA	0.39 / 0.89	0.1 / 0.2	0.1 / 0.2	0.1 / 0.2	0.49 / 0.49	0.1 / 0.2	**0.1 / 0.2**
TRH C29-C36	0.2	mg/L	NA / NA	0.28 / 0.53	0.1 / 0.2	0.1 / 0.2	0.1 / 0.2	0.1 / 0.2	0.1 / 0.2	**0.1 / 0.2**
TRH C37-C40	0.2	mg/L	NA / NA	0.00 / 0.00	0.1 / 0.2	0.1 / 0.2	0.1 / 0.2	0.1 / 0.2	0.1 / 0.2	**0.1 / 0.2**
Cyanide	0.004	mg/L	NA / NA	0.00 / 0.00	0.002 / 0.004	**0.002 / 0.004**	**0.002 / 0.004**	**0.002 / 0.004**	**0.002 / 0.004**	**0.002 / 0.004**
Phenol	0.0005	mg/L	NA / NA	0.00055 / 0.00	0.00025 / 0.005	0.00025 / 0.0005	0.0008 / 0.0008	0.0025 / 0.0025	0.0041 / 0.0041	0.00025 / 0.0005
Faecal and total coliform	0	cfu/100mL	NA / NA	NA / NA	NA / NA	NA / NA	NA / NA	NA / NA	NA / NA	NA / NA
Dissolved heavy metals (mg/L)										
Aluminium, Al	0.005	mg/L	0 / 0	0.02 / 0.05	**0.011 / 0.082**	**0.011 / 0.082**	**0.011 / 0.082**	**0.011 / 0.082**	**0.011 / 0.082**	**0.011 / 0.082**
Arsenic, As	0.001	mg/L	0.028 / 0.02	0.004 / 0.320	0.001 / 0.001	0.0005 / 0.001	0.0005 / 0.001	0.0005 / 0.001	0.0005 / 0.001	0.0005 / 0.001
Cadmium, Cd	0.0001	mg/L	0.0055 / 0.01	0.0003 / 0.024	0.00005 / 0.0001	0.00035 / 0.0004	0.00005 / 0.0001	0.00005 / 0.0001	0.00005 / 0.0001	0.00005 / 0.0001
Chromium, Cr	0.001	mg/L	0.022 / 0.01	0.002 / 0.018	0.0005 / 0.001	0.0005 / 0.001	0.0005 / 0.001	0.0005 / 0.001	0.0005 / 0.001	0.07 / 0.07
Copper, Cu	0.001	mg/L	0.107 / 0.05	0.003 / 0.030	0.0005 / 0.001	0.003 / 0.003	0.0005 / 0.001	0.005 / 0.005	0.0005 / 0.001	0.001 / 0.001
Lead, Pb	0.001	mg/L	0.036 / 0.02	0.002 / 0.046	0.0005 / 0.001	0.003 / 0.003	0.0005 / 0.001	0.0005 / 0.001	0.0005 / 0.001	0.0005 / 0.001
Nickel, Ni	0.001	mg/L	0.016 / 0.02	0.01 / 0.04	0.004 / 0.006	0.008 / 0.013	0.0035 / 0.004	0.005 / 0.007	0.0005 / 0.001	0.0005 / 0.001
Zinc, Zn	0.005	mg/L	0.12 / 0.08	0.01 / 1.30	0.0025 / 0.005	0.015 / 0.073	0.0025 / 0.005	0.012 / 0.012	0.0025 /	0.0025 / 0.005
Mercury	0.0001	mg/L	<0.0001 / 0.0001	0.0005 / 0.001	0.0005 / 0.001	0.00005 / 0.0001	0.00005 / 0.0001	0.00005 / 0.0001	0.00005 / 0.0001	0.00005 / 0.0001
Iron, Fe	0.005	mg/L	NA / NA	25.57 / 51.10	3 / 3	**1.90 / 2.19**	**1.90 / 2.19**	0.795 / 1.38	**0.46 / 0.76**	0.13 / 0.13
Manganese, Mn	0.001	mg/L	0.05 / 0.03	0.66 / 2.60	**0.027 / 0.038**	**0.027 / 0.038**	**0.027 / 0.038**	0.027 / 0.038	**0.02 / 0.02**	0.008 / 0.008

Parameter	5000 - 5500	5500 - 6000	6000 - 6500	6500 - 7000	7000 - 7500	7500 - 7800	7800 - 8100
Inflow [L/s]	0.44	0.35	0.38	0.56	0.59	3.05	3.26
COD	93.0 / 100.0	**73.0 / 73.0**	**250.9 / 250.9**	**428.8 / 428.8**	535.0 / 710.0	**322.5 / 410.0**	110.0 / 110.0
Total Nitrogen ^	5.9 / 49	0.01 / 0.01	**0.99 / 0.99**	1.97 / 1.97	4.345 / 47.1	**3.41 / 25.6**	2.48 / 4.1
Ammonia Nitrogen, NH_3 as N	5.5 / 41	0.01 / 0.01	**0.985 / 0.985**	1.96 / 1.96	2.685 / 36.7	2.4 / 10	1.3 / 2.7
Total Suspended Solids Dried at 103-105°C	2400 / 3400	**2795 / 4700**	**2795 / 4700**	**2795 / 4700**	3190 / 6000	**1655 / 3160**	120 / 320
Total Dissolved Solids Dried at 175-185°C	565 / 590	**422.5 / 505**	280 / 420	**890 / 1810**	1500 / 3200	25000 / 25000	21000 / 25000
Conductivity @ 25 C	1085 / 1100	**790.118 / 505**	*495.24 / 742.85*	**826.618 / 1271.4**	1158 / 1800	240 / 240	38000 / 43000
Total Iron	NA / NA	NA / NA	NA / NA	NA / NA	NA / NA	NA / NA	240 / 340
TPH (mg/L)							
C6 - C9 Fraction	0.01 / 0.02	**0.01 / 0.02**	**0.01 / 0.02**	0.01 / 0.02	**0.01 / 0.02**	**0.01 / 0.02**	0.01 / 0.02
C10 - C14 Fraction	0.025 / 0.05	**0.025 / 0.05**	**0.025 / 0.05**	0.025 / 0.05	**0.025 / 0.05**	**0.025 / 0.05**	0.025 / 0.05
C15 - C28 Fraction	0.05 / 0.1	**0.05 / 0.1**	**0.05 / 0.1**	0.05 / 0.1	**0.05 / 0.1**	**0.05 / 0.1**	0.05 / 0.1
C29 - C36 Fraction	0.025 / 0.05	**0.025 / 0.05**	**0.025 / 0.05**	0.025 / 0.05	**0.025 / 0.05**	**0.025 / 0.05**	0.025 / 0.05
C10 - C36 Fraction (sum)	0.025 / 0.05	**0.025 / 0.05**	**0.025 / 0.05**	0.025 / 0.05	**0.025 / 0.05**	**0.025 / 0.05**	0.025 / 0.05
TRH C10-C14	0.13 / 0.13	0.025 / 0.05	**0.0775 / 0.09**	**0.05925 / 0.085**	0.0935 / 0.12	0.025 / 0.05	0.079 / 0.079
TRH C15-C28	0.1 / 0.2	0.1 / 0.2	**0.1 / 0.2**	**0.15 / 0.2**	0.2 / 0.2	0.1 / 0.2	**0.22 / 0.27**
TRH C29-C36	0.1 / 0.2	0.1 / 0.2	**0.1 / 0.2**	**0.17 / 0.22**	0.1 / 0.2	0.24 / 0.24	0.245 / 0.27
TRH C37-C40	0.1 / 0.2	0.1 / 0.2	**0.1 / 0.2**	**0.1 / 0.2**	0.1 / 0.2	0.1 / 0.2	**0.1 / 0.2**
Cyanide	0.002 / 0.004	**0.002 / 0.004**	**0.002 / 0.004**	**0.002 / 0.004**	**0.002 / 0.004**	**0.002 / 0.004**	0.002 / 0.004
Phenol	0.00025 / 0.0005	0.00025 / 0.0005	**0.00025 / 0.0005**	**0.00418 / 0.0043**	0.0081 / 0.0081	0.00025 / 0.0005	0.00025 / 0.0005
Faecal and total coliform	NA / NA	NA / NA	NA / NA	NA / NA	NA / NA	NA / NA	NA / NA
Dissolved heavy metals (mg/L)							
Aluminium, Al	**0.011 / 0.082**	**0.011 / 0.082**	**0.011 / 0.082**	**0.011 / 0.082**	**0.011 / 0.082**	**0.011 / 0.082**	0.011 / 0.082
Arsenic, As	0.0005 / 0.001	0.0005 / 0.001	**0.0005 / 0.001**	0.0005 / 0.001	0.0005 / 0.001	0.006 / 0.12	0.005 / 0.015
Cadmium, Cd	0.00005 / 0.0001	0.00005 / 0.0001	**0.00005 / 0.0001**	0.00005 / 0.0001	0.00005 / 0.0001	0.0002 / 0.0002	0.00005 / 0.0001
Chromium, Cr	0.001 / 0.001	0.0005 / 0.001	**0.0005 / 0.001**	0.0005 / 0.001	0.0705 / 0.074	0.0015 / 0.002	0.002 / 0.004
Copper, Cu	**0.00075 / 0.001**	0.0005 / 0.001	**0.0005 / 0.001**	0.0005 / 0.001	0.0225 / 0.024	0.001 / 0.001	0.0045 / 0.006
Lead, Pb	**0.0005 / 0.001**	0.0005 / 0.001	**0.0005 / 0.001**	0.0005 / 0.001	0.0005 / 0.001	0.002 / 0.002	0.0005 / 0.001
Nickel, Ni	0.00375 / 0.006	0.0005 / 0.001	**0.01075 / 0.011**	0.021 / 0.021	0.001 / 0.001	0.00225 / 0.003	0.004 / 0.005
Zinc, Zn	0.027 / 0.038	0.011 / 0.011	**0.00675 / 0.008**	0.0025 / 0.005	0.015 / 0.022	0.011 / 0.029	0.01375 / 0.08
Mercury	0.00005 / 0.0001	0.00005 / 0.0001	**0.00005 / 0.0001**	0.00005 / 0.0001	0.00005 / 0.0001	0.00005 / 0.0001	0.00005 / 0.00
Iron, Fe	3.795 / 21.1	**1.96 / 10.615**	**2.4175 / 21.185**	0.77 / 0.77	4.065 / 41.6	**77.03 / 185.8**	150 / 330
Manganese, Mn	0.269 / 0.504	**0.14 / 0.256**	**0.09225 / 0.3405**	0.0005 / 0.001	0.184 / 0.68	**1.792 / 2.24**	3.4 / 3.8

Parameter	8100 - 8300	8300 - 8500	8500 - 9000	9000 - 9500	9500 - 10000	10000 - 10500	10500 - 11000
Inflow [L/s]	1.06	1.53	3.31	0.6	0.62	2.22	1.45
COD	68.0 / 110.0	**82.0 / 110.0**	**102.9 / 131.3**	**102.9 / 131.3**	**111.5 / 135.0**	150.0 / 170.0	34.5 / 65.0
Total Nitrogen ^	1.8 / 2	**1.4 / 1.66**	1 / 1.31	**1.175 / 1.555**	1.35 / 1.8	1.57 / 2.2	5.15 / 5.8
Ammonia Nitrogen, NH_3 as N	0.775 / 1.3	**0.425 / 0.69**	0.075 / 0.08	0.185 / 0.2	0.42 / 0.42	0.575 / 0.67	1.25 / 1.3
Total Suspended Solids Dried at 103-105°C	56 / 71	**88 / 195.5**	**88 / 195.5**	**1667.5 / 3050**	**1667.5 / 3050**	2370 / 4000	965 / 2100
Total Dissolved Solids Dried at 175-185°C	1950 / 2400	**2316 / 3317**	*2682.8 / 4234.8*	*516.21 / 678.48*	*2046.7 / 2046.7*	6150 / 6400	4600 / 8000
Conductivity @ 25 C	2390 / 2390	**3568 / 4940**	4745 / 7490	913 / 1200	3620 / 3620	10000 / 10000	1550 / 1550
Total Iron	NA / NA	NA / NA	NA / NA	NA / NA	NA / NA	NA / NA	NA / NA
TPH (mg/L)							
C6 - C9 Fraction	0.03 / 0.03	**0.02 / 0.025**	0.01 / 0.02	**0.01 / 0.02**	**0.01 / 0.02**	**0.01 / 0.02**	**0.01 / 0.02**
C10 - C14 Fraction	0.09 / 0.09	**0.66 / 0.66**	1.23 / 1.23	**0.6275 / 0.64**	0.025 / 0.05	**0.025 / 0.05**	**0.025 / 0.05**
C15 - C28 Fraction	0.14 / 0.14	**0.21 / 0.21**	0.28 / 0.28	**0.165 / 0.19**	0.05 / 0.1	**0.05 / 0.1**	**0.05 / 0.1**
C29 - C36 Fraction	0.025 / 0.05	**0.025 / 0.05**	0.025 / 0.05	**0.025 / 0.05**	0.025 / 0.05	**0.025 / 0.05**	**0.025 / 0.05**
C10 - C36 Fraction (sum)	0.23 / 0.23	**0.1275 / 0.14**	**0.1275 / 0.14**	**0.1275 / 0.095**	0.025 / 0.05	**0.025 / 0.05**	**0.025 / 0.05**
TRH C10-C14	0.025 / 0.05	**0.052 / 0.0645**	**0.0385 / 0.0573**	**0.025 / 0.05**	**0.025 / 0.05**	0.025 / 0.05	0.025 / 0.05
TRH C15-C28	0.34 / 0.34	**0.22 / 0.27**	**0.22 / 0.27**	**0.22 / 0.27**	**0.22 / 0.27**	0.1 / 0.2	0.1 / 0.2
TRH C29-C36	0.74 / 0.74	**0.4925 / 0.505**	**0.4925 / 0.505**	**0.1 / 0.2**	**0.1 / 0.2**	0.1 / 0.2	0.1 / 0.2
TRH C37-C40	0.1 / 0.2	**0.1 / 0.2**	**0.1 / 0.2**	**0.1 / 0.2**	**0.1 / 0.2**	0.1 / 0.2	0.1 / 0.2
Cyanide	0.002 / 0.004	**0.002 / 0.004**	**0.002 / 0.004**	**0.002 / 0.004**	**0.002 / 0.004**	0.002 / 0.004	0.002 / 0.004
Phenol	0.00025 / 0.005	**0.00025 / 0.0005**	**0.00025 / 0.0005**	**0.00025 / 0.0005**	**0.00025 / 0.0005**	0.00025 / 0.0005	0.00025 / 0.0005
Faecal and total coliform	NA / NA	NA / NA	NA / NA	NA / NA	NA / NA	NA / NA	NA / NA
Dissolved heavy metals (mg/L)							
Aluminium, Al	**0.0215 / 0.057**	**0.0215 / 0.057**	**0.0215 / 0.057**	**0.0215 / 0.057**	**0.0215 / 0.057**	**0.0215 / 0.057**	0.032 / 0.032
Arsenic, As	0.0005 / 0.001	**0.00475 / 0.005**	0.009 / 0.009	0.0005 / 0.001	0.0005 / 0.001	0.0005 / 0.001	0.001 / 0.001
Cadmium, Cd	0.00005 / 0.0001	**0.00005 / 0.0001**	0.00005 / 0.001	0.00005 / 0.0001	0.00005 / 0.0001	0.00015 / 0.0002	0.00005 / 0.0001
Chromium, Cr	0.001 / 0.001	**0.00075 / 0.001**	0.0005 / 0.001	0.0005 / 0.001	0.1435 / 0.167	0.0005 / 0.001	0.0005 / 0.001
Copper, Cu	0.0005 / 0.001	**0.00075 / 0.001**	0.001 / 0.001	0.0005 / 0.001	0.006 / 0.006	0.0005 / 0.001	0.004 / 0.004
Lead, Pb	0.0005 / 0.001	**0.0005 / 0.001**	0.0005 / 0.001	0.0005 / 0.001	0.0005 / 0.001	0.0005 / 0.001	0.0005 / 0.001
Nickel, Ni	0.0005 / 0.001	**0.00125 / 0.0015**	0.002 / 0.002	0.005 / 0.005	0.0005 / 0.001	0.0125 / 0.013	0.001 / 0.002
Zinc, Zn	0.006 / 0.006	**0.0155 / 0.0155**	0.025 / 0.025	0.0025 / 0.005	0.0025 / 0.005	0.0335 / 0.038	0.0265 / 0.04
Mercury	0.00005 / 0.0001	**0.00005 / 0.00010**	0.00005 / 0.0001	0.00005 / 0.0001	0.00005 / 0.0001	0.00005 / 0.0001	0.00005 / 0.0001
Iron, Fe	5.64 / 12.8	**3.305 / 8.055**	0.97 / 3.31	136.8 / 261	0.145 / 0.19	155 / 160	0.019 / 1.74
Manganese, Mn	0.1265 / 0.252	**0.19474825 / 0.36**	0.263 / 0.468	1.0555 / 1.9	0.007 / 0.007	**0.0475 / 0.0785**	0.088 / 0.15

Data format: 50% Percentile / Maximum Value

NA - no analysis is available

- values derived from groundwater samples taken at Sydney Park, Camdenville Park and Alexandria historical lanfills

* - analyte concentration of samples were below detection limit, Maximum Value set to detection limit, 50% Percentile set to 50% of the detection limit

^ - values derived from Total Kejdal Nitrogen or Total Nitrogen calculated

bold - no analysis or insufficient data, value derived by linear interpolation using the values of the two neares tunnel sections

italic - value calculated based on linear regression equation: EC = 1.7687*TDS

[1] Inflow from Cooks River to WCX2 twin-tunnel

[2] Inflow from Bexley Valley Landfill to WCX2 twin-tunnel

[3] Inflow from Tempe Landfill to WCX2 twin-tunnel

[4] Inflow from Sydney Park and Alexandria Landfill to WCX2 twin-tunnel

	Western Portal to Tunnel Sump (Cooks River)		Tunnel Sump (Cooks River) to St Peters Interchange	
Parameter	Expected #	Upper Range#	Expected#	Upper Range#
COD	168	195	90	112
Total nitrogen (mg/L)	2.37	9.97	1.91	2.33
Ammonia (mg/L)	1.53	8.52	0.48	5.11
Suspended solids mg/L*	1000	1998	812	1849
TDS (mg/L)	11333	12724	3476	5249
EC (uS/cm)	10314	11629	4757	5967
Total Iron (mg/L)	NA	NA	NA	NA
TPH (mg/L)				
C6 - C9 Fraction(mg/L)	0.01171	0.01903	0.00832	0.01663
C10 - C14 Fraction(mg/L)	0.09607	0.11436	0.50720	0.51790
C15 - C28 Fraction(mg/L)	0.06964	0.10623	0.13443	0.15583
C29 - C36 Fraction(mg/L)	0.02285	0.04114	0.02079	0.04159
C10 - C36 Fraction (sum)(mg/L)	0.04918	0.06747	0.06217	0.07791
TRH C10-C14	0.06158	0.08008	0.03092	0.05855
TRH C15-C28	0.17542	0.23578	0.14122	0.21652
TRH C29-C36	0.25205	0.28866	0.24850	0.30251
TRH C37-C40	0.09140	0.16457	0.08317	0.16634
Cyanide (mg/L)	0.00186	0.00336	0.00171	0.00343
Phenol (mg/L)	0.00094	0.00108	0.00022	0.00043
Faecal and total coliform (cfu/100mL)	NA	NA	NA	NA
Disolved heavy metals (mg/L)				
Aluminium	0.01225	0.06472	0.02016	0.04419
Arsenic	0.00319	0.03526	0.00403	0.01194
Cadmium	0.00009	0.00050	0.00007	0.00106
Chromium	0.00403	0.00511	0.00047	0.00128
Copper	0.00270	0.00363	0.00131	0.00210
Lead	0.00088	0.00185	0.00047	0.00196
Nickel	0.00346	0.00464	0.00425	0.00529
Zinc	0.01045	0.05282	0.02351	0.05874
Mercury	0.00005	0.00010	0.00005	0.00011
Iron	53	120	40	43
Manganese	1.23	1.48	0.15	0.30

NA - no analysis is available

- Values derived from Table O1, contribution of landfill leakage to water quality of tunnel inflow not accounted for compounds without any analysis results (NA)

* - Suspended solid concentrations may vary depending on drainage design and flow velocity in the drainage

Annexure Q – New M5 East Groundwater Model Peer Review Report

DATE: 26 July 2016

TO:

Design and Engineering Director
WestConnex
197-201 Coward Street
Mascot, NSW 2020

FROM:

RE: **New M5 East Groundwater Model Peer Review**

OUR REF: HS2016/34

---

1. Introduction

This report provides a peer review of the groundwater modelling undertaken for the Design and Construction of WestConnex New M5 Main Works (the Project). The modelling has been done by Golder Associates Pty Ltd (Golder) for the CPB Dragados Samsung Joint Venture. The peer review has been undertaken by NPM Technical Pty Ltd, trading as HydroSimulations, under Contract .

The Project is located to the south of Sydney from the existing M5 motorway at its western extent near King Georges Road, through tunnels beneath Earlwood, Bardwell Park, Bardwell Valley and Arncliffe, emerging at its eastern extent at St Peters.

In particular, the Project is required to comply with Baseline Conditions of Approval (BCoA) B26 and B27 pertaining to groundwater:

> **B26**: *The Proponent must take all feasible and reasonable measures to limit operational groundwater inflows into each tunnel to no greater than one litre per second across any given kilometre.*
>
> **B27:** *The Proponent must undertake further modelling of groundwater drawdown, tunnel inflows and saline water migration prior to finalising the design of the tunnel and undertaking any works that would impact on groundwater flows or levels.*
>
> *The modelling must be undertaken in consultation with DPI (Water) and include the results of at least 12 months of current baseline groundwater monitoring data.*
>
> *The results of the modelling must be documented in a Groundwater Modelling Report.*
>
> *The Groundwater Modelling Report must be finalised in accordance with the Australian Groundwater Modelling Guidelines (National Water Commission, 2012) and prepared in consultation with DPI (Water).*
>
> *The Groundwater Modelling Report must include, but not be limited to:*
> *(a) justification for layer choice;*

(b) specification of matrix hydraulic and storage parameters for each layer;
(c) statistical evaluation of the model's calibration;
(d) details of the groundwater monitoring data inputs (levels and quality);
(e) details of the proposed groundwater model update and validation as additional data is collected;
(Ð assessment of impacts of groundwater drawdown, taking into consideration the NSW Aquifer Interference Policy (DPI, 2012), including potential impacts on licensed bores and groundwater dependent ecosystems;
(g) a comparison of the results with the modelling results detailed in the document referred to in condition A2(b); and
(h) documentation of any additional measures that would be implemented to manage and/or mitigate groundwater impacts not previously identified or identified but at a smaller scale.

A copy of the Groundwater Modelling Report must be submitted to the Secretary prior to finalising the tunnel design.

The Groundwater Modelling Report must include details of consultation with DPI (Water).

The groundwater model must be updated once 24 months of groundwater monitoring data are available and the results of the modelling provided to the Secretary and DPI (Water) in an updated Groundwater Modelling Report.

2. Terms of Reference

The Terms of Reference for this peer review are as follows:

Review the modelling and design advice set out in design package M5N-GOL-DRT-100-200-GT-1525 Hydrogeological Design Report (*The Report*) and associated Design Advice Notifications (DANs) with regard to:

1. Overall appropriateness of design inputs and seepage modelling methodology, making reference to pump test results, calibration and steady state predictions.

2. Compliance with the requirements of the BCoA Sections B26 and B27.

3. Opinion on whether *The Repor*t has been undertaken in accordance with the Australian Groundwater Modelling Guidelines (National Water Commission, 2012).

4. Provide a view on the need for any supplementary investigations and requirements for any additional pump testing and recommendations for groundwater modelling and monitoring.

3. Documentation

The following report comprises the primary documentation for the groundwater assessment:

1. Golder Associates, 2016, Hydrogeological Design Report. Document M5N-GOL-DRT-100-200-GT-1525-G, Version G, 19 July 2016. 107p + 15 Annexures.

Two DANs were provided also for review:

2. Golder Associates, 2016, Estimates of groundwater inflow to shafts to Kingsgrove, Bexley, Arncliffe and St Peters. Document M5N-GOL-DAN-100-114-GT-0042-A, Version A, 14 March 2016. 10p.

3. Golder Associates, 2016, Arncliffe Trough Dewatering. Document M5N-GOL-DAN-400-200-GT-0127-A, Version A, 6 July 2016. 5p.

Other Project documents taken into consideration for this peer review are:

4. Golder Associates, 2016, Geotechnical Interpretive Report. Document M5N-GOL-TER-100-200-

GT-1505-F, Version F, 20 June2016. 139p + 9 Appendices.

5. Golder Associates, 2016, Groundwater Baseline Report (Project-wide). Document M5N-GOL-TER-100-200-GT-1510-C, Version C, 24 June2016. 25p + 5 Annexures. Annexure C is:

6. AECOM Australia, 2016, WestConnex New M5 Groundwater Monitoring Report. Doc No. WCX2-REP-2101-RD-010A, Revision 03,Progress Report, 1 February 2016. 24p + 7 Appendices.

Document #1 has the following major sections:

1. Introduction
    - 1.1 Description of Design Package
    - 1.2 Scope of report
    - 1.3 Design submission stage
    - 1.4 Definitions and abbreviations
2. Design Development
    - 2.1 Description of Design Package
    - 2.2 Design inputs
    - 2.3 Method of analysis
        - 2.3.1 Conceptual Model used for Groundwater Model Development
        - 2.3.2 Numerical Groundwater Model - Regional Scale Model
        - 2.3.3 Numerical Groundwater Model - Local Scale Model
        - 2.3.4 Construction Sequence Considered for Predictive Modelling
    - 2.4 Interface requirements
    - 2.5 Design software
3. Design Outcomes
    - 3.1 Design details
        - 3.1.1 Predictive Simulations
        - 3.1.2 Groundwater Inflow Summary
        - 3.1.3 Groundwater Drawdown
        - 3.1.4 Inflow Groundwater Quality
        - 3.1.5 Sensitivity Analysis
    - 3.2 Review and verification
    - 3.3 Proposed additional non-conformances
4. Design Considerations
    - 4.1 Safety-in-Design
    - 4.2 Durability
    - 4.3 Compliance
        - 4.3.1 Tunnel Inflows
    - 4.4 Environment
    - 4.5 Sustainability
    - 4.6 Predicted effects and monitoring
5. Items for Resolution
6. References

The Annexures are:

A. Design Drawings
B. Project Verifier Comments and Responses
C. SMC/RMS Comments and Responses
D. Safety-in-Design Register
E. Registered Groundwater Bores
F. Summary of Groundwater Levels
G. Hydrographs WestConnex Wells
H. Arncliffe VWPs Feb March 2016
I. Assessment of Recharge from Rainfall Response
J. Kogarah Golf Course Pumping Test Summary
K. Summary of Hydraulic Parameter Data from Other Sources
L. Groundwater Chemistry
M. Tunnel Drain Conductance Assessment
N. Local Scale Groundwater Model Details and Calibration to Pumping Test Results
O. Water Quality Parameters for Assessment of Tunnel Inflow Water Quality.

4. Review Methodology

There are two accepted guides to the review of groundwater models: (A) the Murray-Darling Basin Commission (MDBC) Groundwater Flow Modelling Guideline[1], issued in 2001, and (B) newer guidelines issued by the National Water Commission in June 2012 (Barnett *et al*., 2012[2]). Both guides also offer techniques for reviewing the non-modelling components of a groundwater impact assessment. The 2012 national guidelines build on the 2001 MDBC guide, with substantial consistency in the model conceptualisation, design, construction and calibration principles, and the performance and review criteria, although there are differences in details. The new guide carries an expectation of more effort in uncertainty analysis, although the guide is not prescriptive as to which methodology should be adopted.

The NWC 2012 guide has the concept of "model confidence level", which is defined using a number of criteria that relate to data availability, calibration, prediction scenarios and key indicators. Golder has assessed the Project model as having a confidence level of Class 2, which is appropriate, but no justification has been made for this opinion. The decision table in Table 2-1 of the guidelines, or the simplified list in **Table 1** (supplied here), should be completed with ticks or highlights to indicate elements of the model that are Class 1, 2 or 3. In practice, a model is likely to straddle all classes to some degree.

Table 1. Model Confidence Class Characteristics

CLASS	DATA	CALIBRATION	PREDICTION	INDICATORS
1	Not much. Sparse. No metered usage. Remote climate data.	Not possible. Large error statistic. Inadequate data spread. Targets incompatible with model purpose.	Timeframe >> calibration Long stress periods. Transient prediction but steady-state calibration. Bad verification.	Timeframe > 10x Stresses > 5x Mass balance > 1% (or single 5%) Properties <> field. Bad discretisation. No review.
2	Some. Poor coverage. Some usage info. Baseflow estimates.	Partial performance. Long-term trends wrong. Short time record. Weak seasonal replication. No use of targets compatible with model purpose.	Timeframe > calibration. Long stress periods. New stresses not in calibration. Poor verification.	Timeframe = 3-10x Stresses = 2-5x Mass balance < 1% Some properties <> field measurements. Some key coarse discretisation. Review by hydrogeo.
3	Lots. Good aquifer geometry. Good usage info. Local climate info. K measurements. Hi-res DEM.	Good performance stats. Long-term trends replicated. Seasonal fluctuations OK. Present day data targets. Head and flux targets.	Timeframe ~ calibration. Similar stress periods. Similar stresses to those in calibration. Steady-state prediction consistent with steady-state calibration. Good verification.	Timeframe < 3x Stresses < 2x Mass balance < 0.5% Properties ~ field measurements. Some key coarse discretisation. Review by modeller.

The groundwater guides include useful checklists for peer review. For example, the MDBC (2001) has a Model Appraisal checklist[3] that has questions on: (1) The Report; (2) Data Analysis; (3) Conceptualisation; (4) Model Design; (5) Calibration; (6) Verification; (7) Prediction; (8) Sensitivity Analysis; and (9) Uncertainty Analysis. This checklist provides useful guidance on what is required in a fully documented groundwater modelling report.

No electronic model files were examined for this review, and no reliance has been placed on

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[1] MDBC (2001). Groundwater flow modelling guideline. Murray-Darling Basin Commission. URL: www.mdbc.gov.au/nrm/water_management/groundwater/groundwater_guides

[2] Barnett, B, Townley, L.R., Post, V., Evans, R.E., Hunt, R.J., Peeters, L., Richardson, S., Werner, A.D., Knapton, A. and Boronkay, A. (2012). *Australian Groundwater Modelling Guidelines*. Waterlines report 82, National Water Commission, Canberra.

[3] The new guidelines include a more detailed checklist but they do not offer the graded assessments of the 2001 checklist, which this reviewer regards as more informative for readers.

documents other than Documents #1 to #6 apart from earlier work in the Botany Basin by the author and a journal paper referenced in Document #2.

The detailed review of the groundwater assessment is recorded in the peer review checklist in **Table 2**. Supplementary comment is offered in the following sections of this review.

5. Commentary

5.1 Report Matters

Document #1 is well structured and follows a strict format adopted for other reports in the Design Package. Some elements of a construction nature are not directly pertinent. Although links to companion studies and their reports are recognised and documented, Document #1 still serves well as a standalone report. It consists of 107 pages of text in the body of the report, including figures, as well as 15 Annexures. There is no List of Figures or List of Tables in the report.

The objectives of the study are specified by the design criteria in Section 2.1 and by the statement in Section 1.1 "*to demonstrate that the WCX2 twin tunnel and associated underground structures are designed and can be constructed to comply with project and approval requirements relating to groundwater capture, drawdown and quality*".

The appropriate Water Sharing Plans (WSP) cover the *Groundwater Metropolitan Region Groundwater Sources* and the *Greater Metropolitan Region Unregulated River Water*. The first of these is acknowledged in Section 2.2.7 where it is noted that "*two groundwater sources are encountered which include the Botany Sands Groundwater Source (BSGS) and the Sydney Central Basin Groundwater Source (SCBGS)*", as illustrated in Figure 2.12. There is no specific reference to the minimal harm considerations of the Aquifer Interference Policy, other than the wording in BCoA conditions. The key drawdown constraint is implied in one comment: "*Groundwater drawdown in the unconsolidated Quaternary sediments underlying the Tempe Wetlands located close to Alexandra Canal are estimated to be less than 2 m*"; and in a commitment to "make good" for permanent declines in water levels "*in excess of two metres*". However, there is ample discussion and illustration of the expected drawdowns due to the Project, and to their mitigation by grouting of permeable structures.

There is no section on licensing requirements for each water source, but it could be that the Project is exempt. Normally, a prolonged aquifer interference activity would require quantification of the reduction in baseflow to gaining streams, or increased leakage from losing streams, due to the activity. This would necessitate a calculation of the differential impacts between a null scenario (without the activity) and a production scenario (with the activity).

There is a deficiency in reporting of total water balances derived from the groundwater model. This has been done only for steady state calibration, in absolute terms, whereas relativities (as percentages) of each element would be instructive. The same should be done for the predictive simulation by averaging over the duration of the Project, comparing the results of the null and production scenarios to show the differential effects of the Project on each water balance element. Only tunnel inflows are reported at present. The effects on stream/baseflow and evapotranspiration (ET) would be of interest. The steady state result for "drains" (Table 20) would benefit from a statement in the text giving the splits between the various features represented by drains.

While there is adequate reference to past work on the whole, there is only incidental mention of a previous modelling study (by CDM Smith). The report on that model has not been examined by the reviewer.

In "Drawdown reductions for various grouting designs" (Section 3.1.3), there is no discussion on the results of mitigation. This is the most important finding by the study and should be featured here and in the Conclusions.

Editorial matters are addressed in **Appendix A** to this review.

5.2 Data Matters

While relevant data for the Project are covered in a number of reports, for example Documents #4, #5 and #6, there is sufficient presentation in Document #1 for standalone coverage. There is a very detailed discussion on regional geology and geological structures. Extensive packer testing has added to the broad database for hydraulic conductivity along and adjacent to the Project corridor. One 7-day pumping test was run in sandstone beneath alluvium at Kogarah Golf Course.

There is very substantial monitoring of groundwater levels and groundwater chemistry. The earliest date for presented groundwater levels is November 2014, while the vibrating wire piezometer (VWP) records date from February 2016. A full cause-and-effect assessment is offered at 30 monitoring sites in Annexure I.

The Project is fortunate to have access to historical data on actual inflows to the existing M5 tunnels. This dataset provides important control for model calibration.

Document #1 would have benefited from inclusion of a contour map of observed groundwater levels to indicate groundwater flow directions and serve as a yardstick for the spatial patterns derived by the steady state groundwater model. Unfortunately, no regional groundwater level contours are presented to show hydraulic gradients and flow directions along the Project corridor. There are whole-of-basin flow directions shown, but no local patterns based on measurements. It should have been possible to do this.

Separate conceptual models are presented for four segments along the Project corridor. The diagrams for these are excellent, taking into account the expected effects of geological structures. The conceptualisations are quite complex but not unnecessarily so, as the details are critical for reliable tunnel inflow estimation.

The summary of groundwater quality from 125 monitoring bores is adequate, supported by a Piper diagram which would have benefited from more explanation.

5.3 Model Matters

5.3.1 Document #1

The modelling approach followed for the Project is steady state calibration supplemented by transient calibration to a 7-day pumping test. Following this, transient prediction was undertaken. No recovery is simulated, as the effects on the groundwater system are expected to be permanent.

This approach is regarded as adequate and appropriate for the purpose of the project, primarily to assess the amount and timing of tunnel inflows and the drawdown impacts occasioned by the Project. Effort could have been put into transient calibration of regional and corridor hydrographs but this would have been a major undertaking, given the very many disparate stresses that are influencing the measured hydrographs. It is doubtful that more extensive transient calibration would have added much value to satisfying the purpose of the Project.

The steady state calibration is very good, as indicated by performance statistics of about 4 %RMS and 2 mRMS, well within the expectations of national modelling guidelines. Although not supported by statistics, the short-term transient calibration of hydrographs is excellent.

The calibrated hydraulic and storage properties are generally consistent with reported field-estimated values. The hydraulic conductivities and recharge rates for exposed lithologies are not separably defined by model calibration, as a matter of principle, but the ratio of the two should be well resolved. Such values (presented in Table 17 and Table 18) are possibly on the "low" side, as

Merrick (1998)[4] found 2 m/day for residual soil (on Ashfield Shale) and 36 m/day for the Botany Sands, as well as rain recharge varying from 6% to 37% of rainfall.

It is not clear what is meant by "quasi-steady state"? Is this not the state of the groundwater system at the end of a transient stress period? If so, it will be far from steady state.

In Section 3.1.4, there is no quantitative estimate of enhanced leakage from the streams. Instead, there is a qualitative statement that "*tunnel inflow is interpreted to be derived from outflow from the Cooks River and Alexandra Canal in the Arncliffe area*". This could be alarming to readers. The likelihood is that most of the tunnel inflow would come from groundwater storage in the rocks, rather than being drawn from the streams.

In Section 3.1.5, Hawkesbury Sandstone hydraulic conductivity (K) is said to be subjected to sensitivity analysis but no results are presented for this property. For the other parameters investigated, there should be discussion of the results shown in Table 27. The text should clarify that "Palaeochannel sediment" and Pleistocene Sediment" in Table 27 is the same material.

The adopted boundary of the model is somewhat close to the tunnelling stresses in the north-eastern corner of the model (near St Peters). The northern no-flow boundary (near the north-eastern corner) is likely to result in an overestimation of drawdowns there, while the eastern general head boundary should compensate for drawdown effects reaching the boundary.

The use of the quad-tree refinement facility in MODFLOW-USG has allowed the inclusion of fine scale along the tunnel alignment for the local scale pumping test model and the regional predictive model.

As the predictive modelling found several tunnel segment inflows in excess of 1 L/s/km, several mitigation options were trialled by conceptual grouting of permeable geological structures. These runs show that it would be possible to meet the inflow criterion through a grouting program.

The uncertainty in predicted impacts is assessed sufficiently through sensitivity analysis.

Overall, the modelling has been performed in a logical and competent manner.

5.3.2 Document #2

Document #2 provides a separate estimation of the groundwater inflows to four shafts (Kingsgrove, Bexley, Arncliffe and St Peters). The purpose of the adopted model is to estimate probable maximum inflow rates for the capacity design of water treatment plants.

The approach is to use an analytical model published by Marechal *et al.* (2014)[5]. Although Document #2 does not provide the analytical formulas, or much of the conceptual model that underpins the method, the reviewer has read the journal paper and finds that it has reasonably good (though not perfect) applicability to the Project. The method is designed for progressive tunnelling through a highly diffusive (high K and/or low S) heterogeneous unconfined aquifer. The sandstone along the tunnel alignment is "leaky confined" rather than "unconfined". Nevertheless, this method probably comes closest of available analytical models to meeting the site characteristics. In the journal paper, a case study is presented for a very deep tunnel (1,000 m deep) with excellent replication of measured inflows.

The authors of Document #2 have applied some (unstated) correction for the presence of saturated alluvium and Cooks River, overlying the tunnels.

Results are presented at the start time and end time of 100 m excavated segments. As initial inflows would be overestimates, given inflow spikes due to instantaneous excavation, it would be more

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[4] Merrick, N.P., 1998, Prior modelling of groundwater impacts of the New Southern Railway. *In* McNally, G., and Jankowski, J. (eds.) : *Collected Case Studies in Engineering Geology, Hydrogeology and Environmental Geology* (Fourth Series): *Environmental Geology of the Botany Basin.* Conference Publications, Springwood, 24-36.
[5] Marechal, J-C., Lanini, S., Aunay, B. and Perrochet, P., 2014, Analytical Solution for Modeling Discharge into a Tunnel Drilled in a Heterogeneous Unconfined Aquifer. Groundwater, Vol.52, no.4, 597-605.

practical to present time-weighted inflow estimates as a better indication of likely inflows than presenting two extremes. This is a common procedure in mining groundwater models.

There is an error in either Figure 7 or Figure 8, as the two figures are incorrectly identical.

The reviewer considers that the modelling approach is sound.

5.3.3 Document #3

Document #3 provides a separate estimation of the dewatering requirements at Arncliffe for a temporary decline and adit. Eight dewatering wells are envisaged, each about 20 m deep, inside a sheet pile wall. The purpose of the adopted model is to estimate probable bore yields and time for significant dewatering.

The approach is to use a fine-scale (1 m x 1 m grid) numerical model based on MODFLOW software. It is not clear whether the Horizontal Flow Boundary (HFB), or Wall, package is used to represent the sheet piles, or whether an hydraulic conductivity zone is employed. The former would be simpler, but the results would be equivalent.

The sheet pile hydraulic conductivity (equivalent to about 10^{-4} m/day) is considered very "lossy", and could easily be 1-2 orders of magnitude lower. The results, consequently, are expected to be conservative in terms of final pumping rates and dewatering times. As the model has assumed homogeneous sandy conditions (about 1 m/day), the dewatering could create perched conditions above clay/silt bands. Document #3 recognises this as a possibility and recommends supplemental shallow pumping in that event.

The reviewer considers that the modelling approach is sound.

6. Conclusion

The primary predictive numerical groundwater model for the Project is judged to be *fit for purpose*, where the purpose is for estimation of likely tunnel inflows, mitigation by grouting of permeable geological structures, and evaluation of drawdown impacts. The model could be used, but has not been used so far, to quantify the impact on Cooks River in particular (and other streams) for the amount of enhanced leakage due to tunnelling, or the amount of reduced baseflow where streams are naturally gaining.

The supplementary modelling of shaft inflows, using an analytical model, and dewatering requirements, using a simple numerical model, is also considered sound.

More specific reference could have been made to the minimal harm considerations of the Aquifer Interference Policy. However, the 2 m drawdown criterion is addressed implicitly and there is a stated commitment to "make good" arrangements. Mitigation scenarios have been trialled to demonstrate a grouting mechanism for meeting the criterion for tunnel inflows per kilometre.

The conceptual model has taken into account at least 12 months of current baseline groundwater monitoring data, as required. The numerical model has focused on steady state calibration and short-term transient calibration, both of which have good performance.

In terms of the Terms of Reference:

1. The design inputs and seepage modelling methodology are considered appropriate.

2. Compliance with the requirements of the BCoA Sections B26 and B27 has been achieved.

3. The groundwater modelling report has been undertaken in accordance with the Australian Groundwater Modelling Guidelines (National Water Commission, 2012).

4. Given the substantial monitoring record already available, the reviewer is of the opinion that there is no need for any supplementary investigations. The packer testing is more than sufficient to characterise the Hawkesbury Sandstone, and the 7-day pumping test at Kogarah Golf Club is sufficient to characterise the alluvium and the interactions between the alluvium and sandstone. There is no need for additional groundwater modelling, as adequate sensitivity analysis has been done to indicate the uncertainty in tunnel inflows, and sufficient exploration of mitigation options has demonstrated the practicality of a grouting solution to the higher inflows expected when a tunnel intersects a geological structure.

Table 2. MODEL APPRAISAL: NEW M5 PROJECT

Q.	QUESTION	Not Applicable or Unknown	Score 0	Score 1	Score 3	Score 5	Score	Max. Score (0, 3, 5)	COMMENT
1.0	THE REPORT								
1.1	Is there a clear statement of project objectives in the modelling report?		Missing	Deficient	Adequate	Very Good			S1.1. Criteria S2.1.
1.2	Is the level of model complexity clear or acknowledged?		Missing	No	Yes				Class 2 confidence = Impact Assessment Model, medium complexity. Add attributes table.
1.3	Is a water or mass balance reported?		Missing	Deficient	Adequate	Very Good			Table 20: Steady-state calibration – add percentage splits. Not provided for local transient calibration. Prediction: tunnel inflow; other components not contrasted with null scenario values.
1.4	Has the modelling study satisfied project objectives?		Missing	Deficient	Adequate	Very Good			Tunnel inflows with mitigation options.
1.5	Are the model results of any practical use?			No	Maybe	Yes			Informs water management and likely impacts. No licensing requirements (exempt?).
2.0	DATA ANALYSIS								
2.1	Has hydrogeology data been collected and analysed?		Missing	Deficient	Adequate	Very Good			Detailed knowledge of regional geology and structures. Extensive packer testing; one pumping test. Substantial monitoring (water levels and chemistry). Incorporation of results from previous studies, especially M5 actual inflows.
2.2	Are groundwater contours or flow directions presented?		Missing	Deficient	Adequate	Very Good			Figure 2.11 shows regional pattern. No local patterns are offered graphically, despite plenty of data. No contour maps of water levels.
2.3	Have all potential recharge data been collected and analysed? (rainfall, streamflow, irrigation, floods, etc.)		Missing	Deficient	Adequate	Very Good			Rainfall – 6 stations. Blocky rain contours. Residual mass curve useful. Six waterways with stated lining. Discussion on potential urban sources of water (leaks).

2.4	Have all potential discharge data been collected and analysed? (abstraction, evapotranspiration, drainage, springflow, etc.)		Missing	Deficient	Adequate	Very Good			Confusion between evaporation (EV) and evapotranspiration (ET). Actual ET (AET) from BoM not stated – more relevant to groundwater modelling. Actual M5 inflows. Registered bores.
2.5	Have the recharge and discharge datasets been analysed for their groundwater response?		Missing	Deficient	Adequate	Very Good			Rainfall residual mass not compared with hydrographs to facilitate cause-and-effect analysis. Annexure I and S2.2.10: discussion on causes – rain, streams, air pressure, tides, cutoff walls, pumping, tunnels, perching.
2.6	Are groundwater hydrographs used for calibration?			No	Maybe	Yes			Local model only. 31 hydrographs.
2.7	Have consistent data units and standard geometrical datums been used?			No	Yes				K: m/s, m/day, lugeon. Flow: m^3/day, L/s. Provide approximate conversions in glossary. Add lugeon to glossary. Appendix N has "m" not "min" for minutes.
3.0	CONCEPTUALISATION								
3.1	Is the conceptual model consistent with project objectives and the required model complexity?		Unknown	No	Maybe	Yes			S2.3.1.
3.2	Is there a clear description of the conceptual model?		Missing	Deficient	Adequate	Very Good			Especially geological structures.
3.3	Is there a graphical representation of the modeller's conceptualisation?		Missing	Deficient	Adequate	Very Good			Excellent cross-sections (4) along tunnel intersections with structures: Figures 2.26 – 2.29. Better if diagram and text are on the same page.
3.4	Is the conceptual model unnecessarily simple or unnecessarily complex?			Yes	No				Quite complex but essential for purpose of tunnel inflow estimation.
4.0	MODEL DESIGN								Class 2.

4.1	Is the spatial extent of the model appropriate?			No	Maybe	Yes			N.E. boundary is close to St Peters end of tunnel (Figure 2.7). Figure 3.2 shows drawdown at boundary here – likely to be overestimate on northern edge due to no-flow assumption; mitigated on eastern side by GHB. Steady-state regional: 12 layers, 40-320m cells. Local: 19 layers, 5-40m cells. Regional transient: 10-320m (quad tree).
4.2	Are the applied boundary conditions plausible and unrestrictive?		Missing	Deficient	Adequate	Very Good			Either no flow or general heads along boundaries. RIV and DRN boundaries are appropriate. Other than N.E. corner, BCs are sensible. Alexandra Canal zero mAHD for full length: c.f. Merrick (1994) has 0.1 m gradient – only a minor issue.
4.3	Is the software appropriate for the objectives of the study?			No	Maybe	Yes			GUI: Groundwater Vistas. Steady-state: MODFLOW-NWT or MODFLOW-2000 (both are mentioned). Local and regional prediction: MODFLOW-USG – no information on selected options for pseudo-soil/Richards; vertical conductance options; solver; closure accuracy.

5.0	CALIBRATION								Steady-state & 7-day pumping tests
5.1	Is there sufficient evidence provided for model calibration?		Missing	Deficient	Adequate	Very Good			Scattergram and performance statistics for steady-state. Local model: comparative hydrographs.
5.2	Is the model sufficiently calibrated against spatial observations?		Missing	Deficient	Adequate	Very Good			Good: 3.8%RMS & 2.1mRMS steady state (Table 19). No WL map of simulated versus observed. Similar mine inflows to M5 observed.
5.3	Is the model sufficiently calibrated against temporal observations?	N/A	Missing	Deficient	Adequate	Very Good			Local model only: very good hydrograph matches at 31 sites (Appendix N, 7 figures).

5.4	Are calibrated parameter distributions and ranges plausible?		Missing	No	Maybe	Yes			Table 18: calibrated K; Appendix N Table N2 K and S. Homogeneous properties per lithology (OK). Botany Sands K is low but exposure is small. %Rain recharge is possibly low overall – but affected by urban catchment characteristics.
5.5	Does the calibration statistic satisfy agreed performance criteria?		Missing	Deficient	Adequate	Very Good			<<10 %RMS.
5.6	Are there good reasons for not meeting agreed performance criteria?	N/A	Missing	Deficient	Adequate	Very Good			
6.0	VERIFICATION								This is not a compulsory step (Barnett et al., 2012).
6.1	Is there sufficient evidence provided for model verification?	N/A	Missing	Deficient	Adequate	Very Good			
6.2	Does the reserved dataset include stresses consistent with the prediction scenarios?	N/A	Unknown	No	Maybe	Yes			
6.3	Are there good reasons for an unsatisfactory verification?	N/A	Missing	Deficient	Adequate	Very Good			
7.0	PREDICTION								17 years production plus 10 years recovery
7.1	Have multiple scenarios been run for climate variability?		Missing	Deficient	Adequate	Very Good			Assumed average weather conditions – not stated.
7.2	Have multiple scenarios been run for operational /management alternatives?	N/A	Missing	Deficient	Adequate	Very Good			One tunnel plan [H2 Option]. Mitigation options [grouting of permeable structures].
7.3	Is the time horizon for prediction comparable with the length of the calibration / verification period?		Missing	No	Maybe	Yes			Transient calibration 7 days. Prediction 25 years.
7.4	Are the model predictions plausible?			No	Maybe	Yes			Well justified.
8.0	SENSITIVITY ANALYSIS								
8.1	Is the sensitivity analysis sufficiently intensive for key parameters?		Missing	Deficient	Adequate	Very Good			Done for alluvium K, Arncliffe fault zone K – up/down 1 order of magnitude. Text lists Hawkesbury Sandstone K – but no results. Also rain recharge +- 50% and tunnel drain conductance across 5 orders of magnitude.

8.2	Are sensitivity results used to qualify the reliability of model calibration?		Missing	Deficient	Adequate	Very Good			Each perturbed model is said to be recalibrated, but how, and how substantial are the effects on other properties? Effect on calibration performance is reported only for drain conductance. (Missing unit for RMSE.)
8.3	Are sensitivity results used to qualify the accuracy of model prediction?		Missing	Deficient	Adequate	Very Good			Percentage shift in tunnel inflow – maximum 6%.
9.0	UNCERTAINTY ANALYSIS								
9.1	If required by the project brief, is uncertainty quantified in any way?		Missing	No	Maybe	Yes			Through sensitivity analysis for tunnel inflow.

APPENDIX A

Editorial Matters

- Add to Abbreviations: Lugeon; NGIS
- Section 2.2.1: The model extent is shown for the first time in Figure 2.3, without comment. Note its presence on the figure and refer to later discussion.
- Capitalise Quaternary.
- Section 2.2.6: influence by --> influenced by
- Section 2.2.10: impact by --> impacted by
- Table 12: Could add reference to New Southern Railway reported tunnel inflow of 1.7 L/s/lm at July 1997 (Merrick, 1998)[6]
- Section 2.2.14: Give an explanation for the Piper Diagram
- phosphorous --> phosphorus
- Align conceptual model diagram and text on the one page
- Figure 2.26: verticle --> vertical
- Figure 2.29: Alexandra Canal
- Section 2.3.2: sufficiently distance --> sufficiently distant
- Table 16: Alexandria Fill; Cooks River
- Table 18: Not referenced until 4 pages later; reduce K values to 2 significant figures; add shear K value(s)
- Section 2.3.2 - Model Calibration and Sensitivity Analysis: Explain what is meant by "time averaged groundwater level observations" - is this a simple average across a range of years? Comment on typical natural fluctuations in groundwater levels.
- Section 2.3.2 - Model Calibration and Sensitivity Analysis: paragraph 2 - evaporation --> evapotranspiration
- Table 19: reduce values to 2 significant figures; is SRMS 3.8%? (not 0.038%)
- After Table 19: match that --> matched that; intersecting the tunnel --> intersected the tunnel; material parameter --> material properties
- Fourth paragraph after Table 19: "are with" --> "is"; clarify whether the range of K for Quaternary is measured or calibrated; the cited calibrated K values (in parentheses) do not match those in Table 18.
- Middlemis (2000) is not in the References. This is probably the MDBC guide by Middlemis, Merrick and Ross - reference to MDBC (2001) is preferred.
- Table 20: Add a column for OUT (%)
- Table 24: uncomplete --> incomplete
- Section 3.1.1: Clarify start and end dates for the predictive simulation
- Section 3.1.1: Cases 1 to 4 state "reduced" K values by grouting, but the first two cases have higher K than the base case Hawkesbury Sandstone value. In the definition of the Base Case, state the K value(s) for Hawkesbury Sandstone. Table 18 has 1.2E-7 m/s.
- Section 3.1.2: L/s/k/tunnel --> L/s/km/tunnel
- Table 27: twine --> twin
- Table 27, row 14: Eastbound --> Westbound; the totals should be 6.94, 4.87, 4.44, 2.65, 1.51 L/s.
- Section 3.1.4 - paragraph 1: impacted --> influenced
- Table 27: Add results for Hawkesbury Sandstone (if analysed).

[6] Merrick, N.P., 1998, Prior modelling of groundwater impacts of the New Southern Railway. *In* McNally, G., and Jankowski, J. (eds.) : *Collected Case Studies in Engineering Geology, Hydrogeology and Environmental Geology* (Fourth Series): *Environmental Geology of the Botany Basin.* Conference Publications, Springwood, 24-36.

Annexure R – Not used

Annexure S – Not used