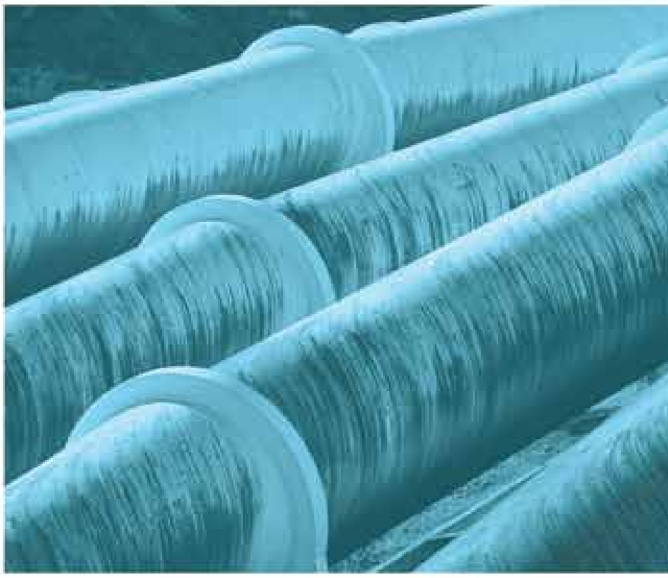
Wongawilli Colliery Modification Report

PA 09_0161 MOD 2 - North West Mains Development
Volume 6 - Appendix I (Part 1)

Prepared for Wollongong Coal Limited
December 2020



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Appendix I - Part 1

Groundwater impact assessment




WONGAWILLI COLLIERY - MODIFICATION

North West Mains Development
Groundwater Impact Assessment

Prepared for:

Wollongong Coal Limited

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November 2020

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CONTENTS

CONTENTS

CONTENTS

CONTENTS

DOCUMENT REFERENCES

TABLES

FIGURES

CONTENTS

CONTENTS

APPENDICES

1 Introduction

Wollongong Coal Limited (WCL) owns Wongawilli Colliery (WWC) an underground coal mine located approximately 14 km south-west of Wollongong. WWC is currently in care and maintenance but approved to operate until December 2020 under Project Approval 09-016. WCL is applying to extend operations to December 2025, referred to as the North West Mains Development (NW Mains) Modification.

1.1 Project Description

WWC is comprised of all or part of the historic Nebo, Wongawilli, Avon, Avondale and Huntley Collieries. The Nebo area of the WWC currently operates under Project Approval (PA) 09_0161, granted on the 2nd of November 2011 and authorises the following activities at WWC:

- Mining of six long wall panels in the Nebo Area (Nebo Longwalls 1 to 6);
- Continued development and construction of the NW Mains (referred to as the Western Driveage in the approvals) as initial first workings access to the proposed Wongawilli Seam South Western mining area within the WWC. The NW Mains are positioned under the Gallahers Creek arm of Lake Avon, within the Avon Dam Notification Area of the Dams Safety Committee of NSW;
- Coal processing and transport of coal at a maximum rate of 2 million tonnes per annum of Run of Mine (ROM) coal per calendar year;
- Continued use of the surface infrastructure at the WWC pit top;
- Continued transportation of ROM coal to Port Kembla Coal Terminal by rail; and
- Rehabilitation of the Project area.

Modification 1 of Project Approval 09-016 included extension of the mine life to 31 December 2020, which was granted on 27 November 2015.

WCL plan to extend approved mining activities for another five years, until the 31st of December 2025. As part of the Project WCL also proposed to extend the roadways in the Bulli Seam to intersect the existing Wonga Shaft. The planned mining activities are the NW Mains Modification and referred to in this report as the Project. The proposed, approved and existing layouts are shown in Figure 1-1. Operations would utilise the existing site infrastructure and the mining method will consist of first workings only.

1.2 Scope of Work

The key tasks for this groundwater modelling assessment are:

1. Review of mining literature and data as well as mining extensions;
2. Analysis of data including geology, groundwater levels, groundwater recharge, permeability, porosity parameters and existing mine workings;
3. Construction of a groundwater model for the Wongawilli mine area and surrounds that includes geology/layers, topography, rivers, recharge, discharge, hydraulic conductivity, storativity, mining voids (existing and proposed) and boundary conditions. The groundwater model is to be developed in a manner that enables use for potential future mine modifications and groundwater impact assessments;

4. Calibration of the model under steady state and transient conditions to historical groundwater levels;
5. Run a 'null' run to simulate baseline conditions (as per Barnett et al., 2012) and predictive mining scenarios to quantify the groundwater impact during mining and recovery;
6. Predict the groundwater drawdown around the mine workings due to groundwater inflow to the mine workings for approved operations;
7. Predict the groundwater drawdown impacts to nearby registered groundwater users and groundwater dependent ecosystems in accordance with the Aquifer Interference Policy (AIP) and any other requirements;
8. Calculate the height of complete groundwater drainage and the height of fracturing above the workings using the Tammetta (2012) and Ditton and Merrick (2014) methods respectively.
9. Preparation of a groundwater modelling report outlining the model development, assumptions, calibration and predictions in accordance with the Australian Groundwater Modelling Guidelines (Barnett et al., 2012).

Groundwater modelling has been conducted in accordance with the Australian Modelling Guidelines (Barnett et al., 2012) as well as the MDBC Groundwater Flow Modelling Guideline (MDBC, 2001). Analysis and assessment has been carried out with consideration of the following groundwater related technical and policy documents:

- NSW Aquifer Interference Policy (Department of Primary Industries Office of Water), September 2012;
- National Water Quality Management Strategy Guidelines for Groundwater Protection in Australia (Agriculture and Resource Management Council of Australia and Australian and New Zealand Environment and Conservation Council [ARMCANZ & ANZECC, 2000]);
- NSW State Groundwater Policy Framework Document (NSW Department of Land and Water Conservation [DLWC, 1998a]);
- NSW Wetlands Policy (DECCW, 2010);
- NSW State Groundwater Quality Protection Policy (DLWC, 1998b);
- NSW State Groundwater Quantity Management Policy (DLWC, undated) Draft;
- NSW Groundwater Dependent Ecosystem Policy (DLWC, 2002);
- Groundwater Modelling Guidelines:
    - Murray-Darling Basin Commission – Groundwater Flow Modelling Guideline. Report for MDBC. January 2001 (MDBC, 2001)); and
    - Australian Groundwater Modelling Guidelines, published by the National Water Commission (Barnett et al, 2012).

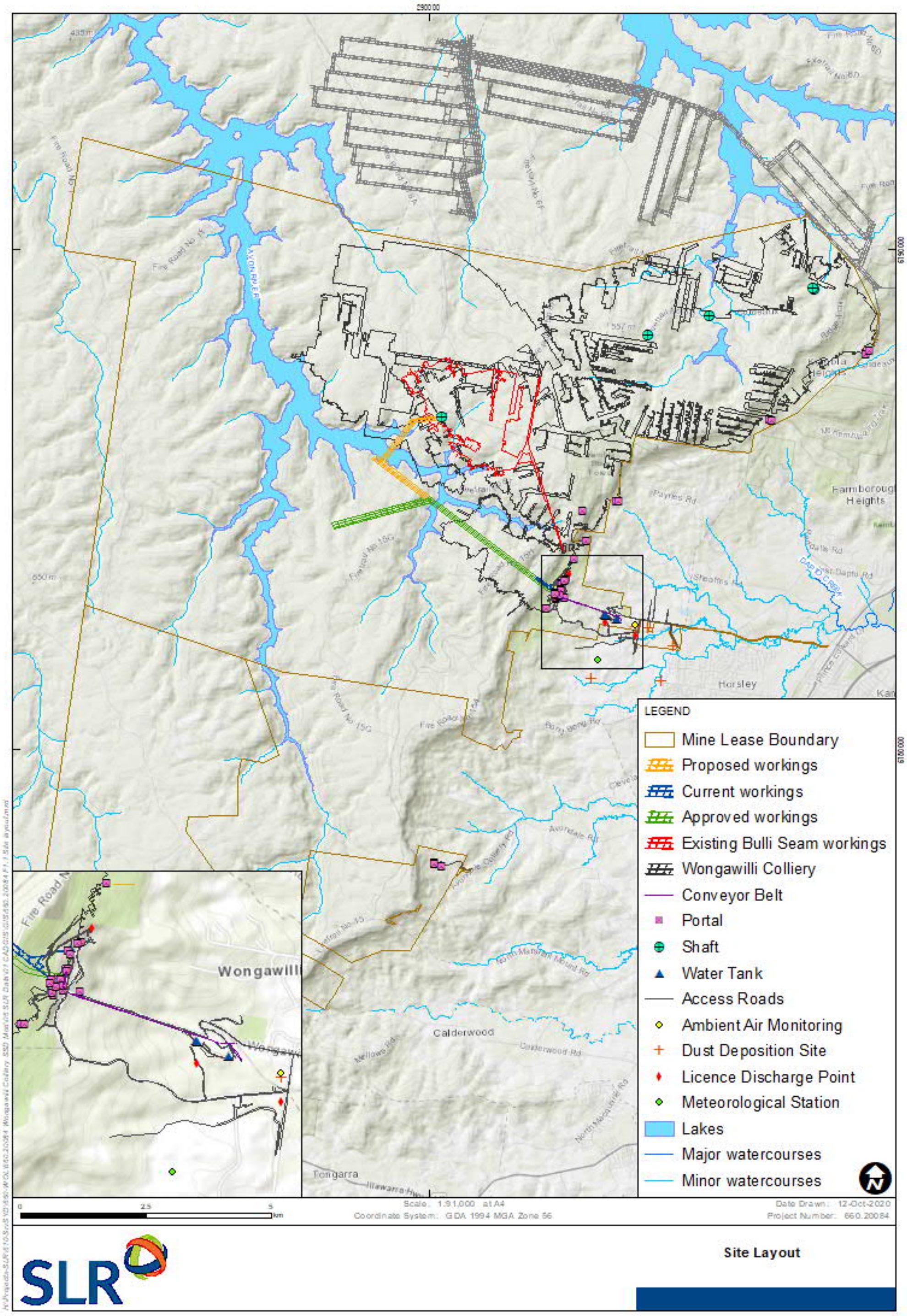


Figure 1-1 Project area Layout

1.3 Project area and Surrounding Mines

The Project is part of Wongawilli Colliery, which has been in operation intermittently since 1916 and includes bord and pillar and some longwall mining (i.e. Elouera). Further details on the history of mining at within the Project area is included in Section 1.3.1.

There is a long history of mining in the area, with several historical and active mines surrounding the Project area, as summarised in Table 1-1 and shown in Figure 1-2.

Table 1-1 Project area and Surrounding Mines

Mine	Operator	Seam	Timing	Distance from WWC
Wongawilli Colliery	Wollongong Coal	Wollongong Seam, Bulli Seam	1916 - present	Project area
Avon Colliery	Austen & Butta (1971-1987), Avon Colliery Pty. Ltd. (1987-2000)	Wongawilli and Bulli Seam	1971 - 2000	3.5 km south
Huntley Colliery	Waugh Bros. (1946-1951), Joint Coal Board (1951-1955), Electricity Commission of NSW (1955-1989)	Tongarra, Wongawilli and Bulli Seams	1946 - 1989	5.5 km south
Port Kembla No. 2 Colliery	Kembla Coal and Coke Co. Pty Ltd	Wongawilli Seam and Bulli Seam	1941 - 1964	6 km north-east
Nebo Colliery	AIS/BHP	Wongawilli Seam	1946 - 1993	6 km north
Avondale Colliery	Unknown	Bulli and Tongarra Seam	1908 - 1983	7 km south
Mt Kembla Colliery	Mount Kembla Collieries (1883-1946), AIS/BHP (1946-1970)	Bulli Seam	1882 - 1970	9.5 km north
Dendrobium (Area 1, 2, 3A, 3B, 3C, 5 and 6)	South32	Wongawilli Seam	2001 -2043	10 km north
Tom Thumb Colliery	Unknown	Bulli Seam	1967 - 1971	12 km north-east
Kemira Colliery	Mt Kembla	Bulli, Balgownie and Wongawilli Seam	1848 - 1991	14 km north-east
Cordeaux Colliery (merged with Corrimal Colliery 1986)	BHP	Bulli Seam	1976 - 2001	15 km east
Corrimal Colliery	Southern Coal Company (1912-1964), BHP/AIS (1964-1985)	Bulli Seam	1912 - 1985	17 km north-east
Russell Vale (Bellambi)	Wollongong Coal	Bulli Seam, Balgownie Seam and Wongawilli Seam	1887 – present	18 km north-east
Appin Colliery	South32/BHP	Bulli Seam	1961 - present	30 km north

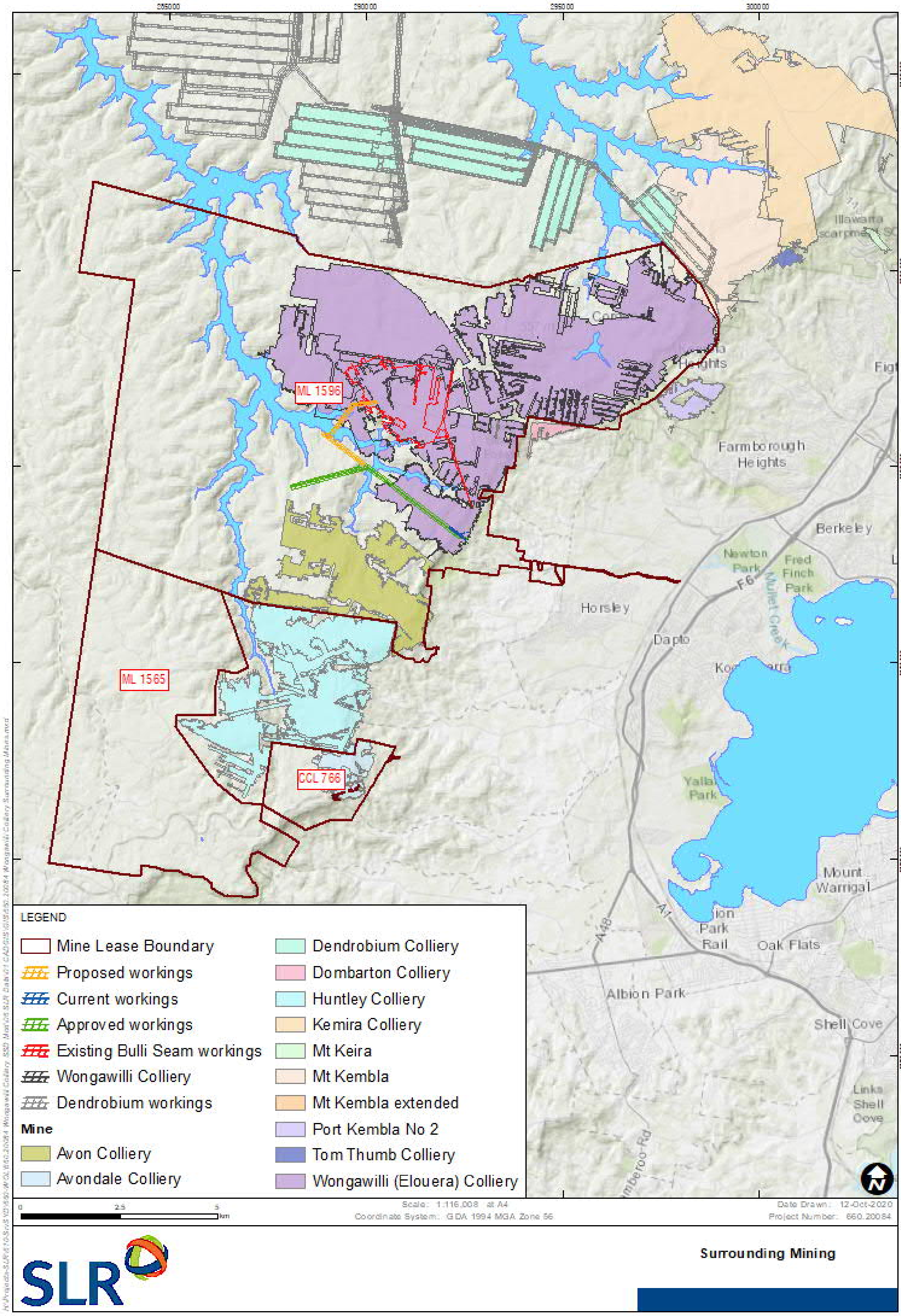


Figure 1-2 Surrounding Mining

1.3.1 Wongawilli Lease – ML 1596

Wongawilli Lease ML 1596 includes the NW Mains, Nebo longwalls, Wongawilli 1, Nebo 3 bord and pillar workings and Elouera workings, are shown on Figure 1-3 as discussed below.

1.3.1.1 Nebo Longwalls 1-6

The Nebo longwall area is located about 5.5 km north-east of the Project and about 1.4 km south-west of Upper Cordeaux Dam No.2. The longwall panels targeted the Wongawilli Seam and were designed to avoid subsiding and cracking the Wattle Creek bed based on the presence of crinanite. A 16 month development and 28 month extraction period was proposed.

Operations were approved as Project Approval (PA) 09_0161 and commenced but were shortly halted due to mine machinery becoming trapped underground in 2014. No future mining of the approved longwalls is planned.

1.3.1.2 NW Mains (Western Driveage)

Part of the Project Approval (PA) 09_0161, granted on the 2nd of November 2011, with Modification 1 to extend the life of operations to 31 December 2020. NW Mains was approved as four 5.5 m wide (approx.) and 3.2 m high headings (first workings) within the Bulli Seam, and extending down into the Wongawilli Seam at the western extent for future workings. Negligible (<20 mm) subsidence was predicted, and SEEP/W modelling conducted by Golder Associates (2010) predicted groundwater inflows of around 9.1 ML/year (when Wongawilli Seam workings depressurised).

To date, approximately 500 m of the NW Mains has been developed prior to the mine going into care and maintenance in 2019. Therefore the approved NW Mains were not fully mined.

1.3.1.3 Wongawilli 1

Bulli Seam was mined by the bord and pillar extraction method in the Wongawilli 1 workings to the north-east of the Project between 1961 and 1977, with further workings for access conducted between 1991 and 1997. The Bulli Seam has depth cover between 265 metres below ground level (mbgl) to 290 mbgl with a thickness of 1.7 m to 3 m in this area. A vent shaft is located at Wongawilli 1, which will be utilised as part of the Project.

1.3.1.4 Wongawilli (Gujarat) Longwalls 11, 12, 15, 16 and 19

Wongawilli longwall workings are located approximately 3.5 km at the north-east of Project. The Wongawilli Seam has depth of cover between 300 mbgl to 360 mbgl.

1.3.1.5 Nebo 3 Bord and Pillar Workings

Nebo Colliery is located about 4.5 km to the north-east of the Project. Extensive bord and pillar mining was opened at the Nebo Colliery in 1945. Some pillar extraction was conducted in the Wongawilli workings to the south- west and within the Nebo area surrounds to the east, west and south of the Upper Cordeaux No. 2 Dam reservoir, with a seam extraction thickness of approximately 2.8 m and depth of cover between 110 mbgl to 350 mbgl.

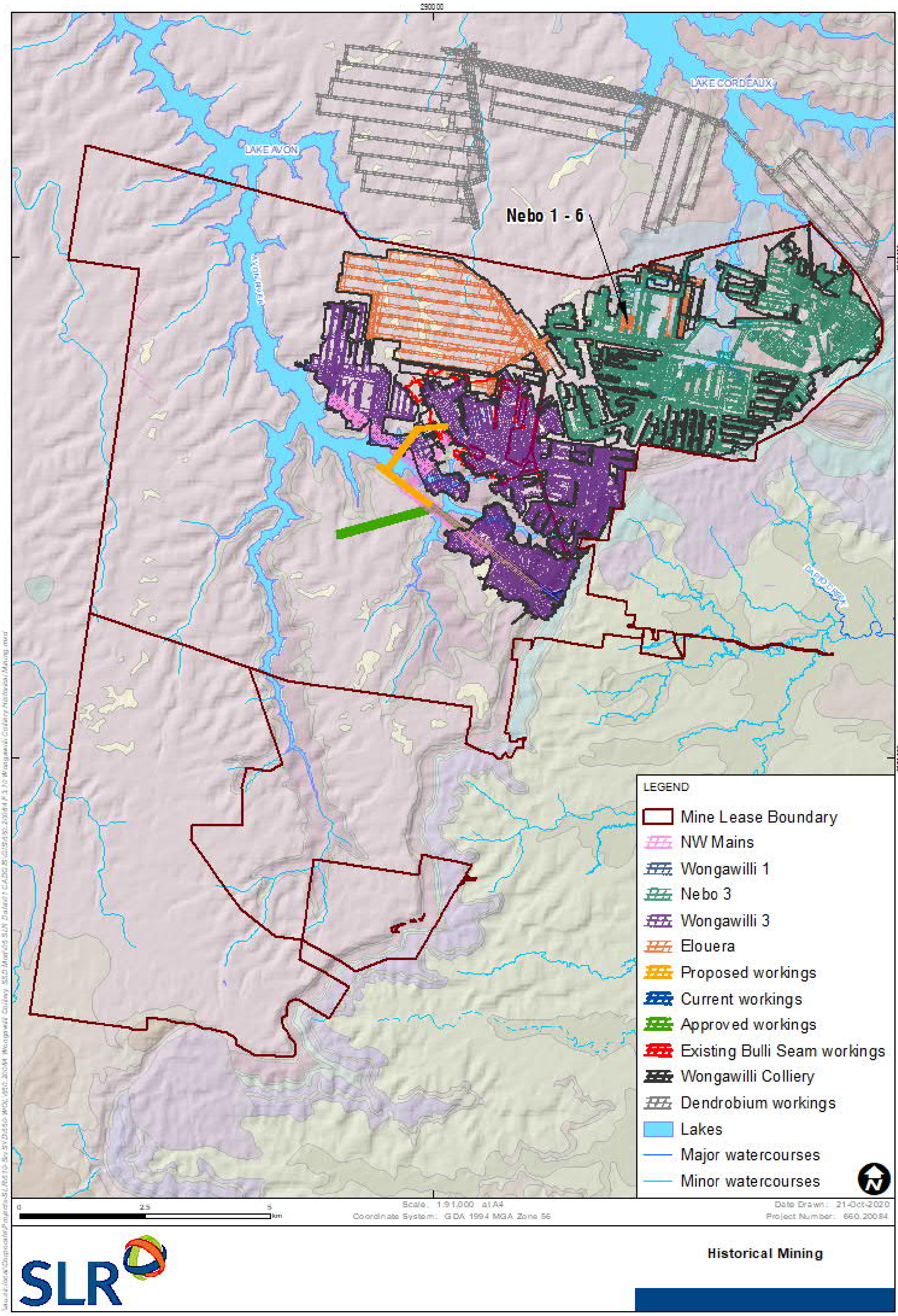


Figure 1-3 Historic mining

1.3.1.6 Elouera Longwalls

The historical BHP/Delta Mining Elouera mine workings are located about 3 km north-east of the Project alignment. The Wongawilli Seam was mined using the longwall extraction method from 1994 to 2007. The longwalls occur where the seam thickness is approximately 3 m to 4 m and depth of cover 290 mbgl to 390 mbgl.

1.3.2 Surface Facilities

The Wongawilli pit top facilities are located on the lower slopes of the Illawarra Escarpment. The land slopes from the mine entry point located at approximately 260 metres above height datum (mAHD), down to the coal handling facilities, at the base of the escarpment, located at approximately 40 mAHD. The Upper Wongawilli pit top facilities include:

- Two portal entries for workers and materials;
- Shaft;
- One portal for coal extraction;
- Two portals into the Project, one for workers and materials and one for coal clearance;
- Coal conveyor;
- Conveyor drive head buildings;
- Water tank;
- Water collection and treatment pond;
- Licence discharge point;
- Meteorological station;
- Administration office and amenities;
- Bath houses;
- Sewage treatment plant and septic system;
- Maintenance workshop and mining equipment storage;
- Fire station and water tank;
- Electrical substations and switching rooms; and
- Car parking space and inter roads.

The Lower Wongawilli pit top facilities include:

- Railway line;
- Coal storage bins and coal stockpile area and load out facilities;
- A decommissioned bath house;
- Storm water settling basin;
- Mine water holding dam; and
- Electrical transformer compound.

1.3.3 Ventilation Shafts Sites

Based on findings by ERM (2010) a summary of the ventilation shafts within the Project area are shown in Table 1-2 and the locations are shown in Figure 1-1.

Table 1-2 Mine Shaft Summary Details

Ventilation Shaft	Distance from Wongawilli Pit Top	Design	Status
Nebo No.1	6.5 km north-east	-	Rehabilitated
Nebo No.2	6.5 km north-east	-	Rehabilitated
Nebo No.3	5 km north-east	Down-cast, 3.6 m diameter	Rehabilitated
Nebo No.4	4.5 km north	Up-cast, 5 m diameter	In use
Wongawilli No.1	4 km north	-	Decommissioned

1.3.4 Site Water Features

The existing site water management system includes:

- Surface stormwater;
- Mine water from the underground workings;
- Raw water from Upper Cordeaux Reservoir No. 1;
- Potable water from the Wollongong reticulated supply systems; and
- Wastewater (sewage and greywater).

2 Regulatory Framework

2.1 Water Management Act (NSW) 2000

Avon, Cordeaux and Nepean Reservoirs are water supply reservoirs formed by the damming of the upper Avon, Cordeaux and Nepean Rivers, and form part of the Upper Nepean Scheme (along with Cataract Reservoir). This forms part of the water supply for Sydney and the Illawarra. WaterNSW manages the water supply areas and infrastructure, with additional oversight by the Dams Safety NSW.

2.2 Aquifer Interference Policy (NSW) 2012

The Water Group within the NSW Department of Planning, Industry and Environment (DPIE Water) manages water resources, including groundwater, through the use of Water Sharing Plans (WSPs). Groundwater at WWC is regulated by the Greater Metropolitan Region Groundwater Sources WSP. This WSP further divides the region into separate Groundwater Sources.

The WWC area is within Management Zone 1 (MZ1) of the Sydney Basin Nepean Sandstone Groundwater Source. This Groundwater Source is classified by DPIE as 'Highly Productive' under the Aquifer Interference Policy (AIP). The total assigned entitlement[1] for all users within this Groundwater Source (for both Management Zone 1 and 2) is 24,576 megalitres per year (ML/yr), equivalent to 67 megalitres per day [ML/d].

WCL has secured 1,500 units of shares from the Sydney Basin Nepean Groundwater Source under "Greater Metropolitan Region Groundwater Sources 2011" water sharing plan with water access license (WAL) 36487. WWC is within the Nepean Sandstone MZ1 and mining in these areas is considered unlikely to increase the incidental take from other Groundwater Sources.

2.3 Mining Act 1992

Mining leases in NSW are granted under the provisions of the Mining Act 1992. The Mining Act 1992 also refers to mining activities generally, places controls on methods of exploration and mining, the disposal of mining waste and rehabilitation and environmental management activities. Part 11 of this Act regulates the environmental protection and rehabilitation of lands disturbed by mining. The Mining Act 1992 is administered by the Department of Planning, Industry and Environment (DPIE).

Under the Mining Act 1992, environmental protection and rehabilitation are regulated by conditions in all Mining leases including the Project. Mining leases also include requirements for the submission and approval from the DPIE of a Mine Operation Plan (MOP) prior to the commencement of operations.

2.4 Protection of the Environment Operations Act (NSW) 1997

The Protection of the Environment Operations Act 1997 (POEO) is state based legislation administered by the NSW Environment Protection Agency (EPA). The object of the Act is to achieve the protection, restoration and enhancement of the quality of the NSW environment through the granting of Licenses that place conditions of scheduled developments such as mines like WWC. WCL holds an Environmental Protection Licence (EPL) no. 1087) which regulates the contribution of water (volume and quality) from the mine's discharge points.

[1] https://waterregister.waternsw.com.au/water-register-frame (accessed 03/02/2020)

2.5 Commonwealth Legislation

It is understood that the Project is not likely to have significant impacts requiring referral to the Commonwealth under the Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act). The EPBC Act is administered by the Department of Agriculture, Water and the Environment (DAWE, 1999), with advice from the Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development (IESC). The IESC is a statutory body established under the EPBC Act that provides scientific advice to the Commonwealth Environment Minister.

3 Environmental Setting

3.1 Climate

Climate data was obtained for the Project area from the Scientific Information for Land Owners (SILO) database of historical climate records for Australia (DSITI, 2015). It provides daily meteorological datasets for a range of climate variables in ready-to-use formats suitable for biophysical modelling, research and climate applications from 1889 to the present. SILO is hosted by the Queensland Department of Environment and Science.

To describe the long-term local climate, data from the gridded SILO database was downloaded for the closest available location to the Project area (-34.45 degrees latitude and 150.75 degrees longitude) and for the time period between 1900 and 2020. The location of the SILO data point is displayed in Figure 3-3.

A summary of rainfall, evapotranspiration and evaporation data for SILO is presented in Table 3-1 and displayed Figure 3-2.

Table 3-1 Climate Summary

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Historical Average Rainfall (mm)	143	172	160	132	120	138	96	85	74	101	113	121	1455
Evapotranspiration (mm)	134	110	93	55	28	19	22	38	66	96	117	135	915
Pan Evaporation (mm)	176	140	124	90	64	49	57	82	110	140	155	185	1374

SILO data is based on observational records provided by the Bureau of Meteorology (BoM), with data gaps addressed through data processing in order to provide a spatially and temporally complete climate dataset. Based on the SILO dataset, the region experiences 1455 millimetres (mm) rainfall per year on average. Historical rainfall averages indicate the majority of rainfall occurs in the first half of the year (summer and autumn). Figure 3-2 shows that average monthly rainfall exceeds the average monthly evapotranspiration during autumn, winter and the majority of the summer months, and exceeds the average monthly evaporation during autumn, winter and at the end of summer. This is the time when most steady recharge into groundwater would be expected to occur. However, the average conditions mask the fact that during the summer months recharge would also occur during large rain events.

Monthly records from the SILO dataset were used to calculate the Cumulative Rainfall Departure (CRD). The CRD shows trends in recorded rainfall compared to long-term averages and provides a historical record of relatively wet and dry periods. A rising trend in slope in the CRD graph indicates periods of above average rainfall, whilst a declining slope indicates periods when rainfall is below average. A level slope indicates average rainfall conditions.

Figure 3-1 shows the CRD and total monthly rainfall for the SILO data node from January 1940 to June 2020. The CRD shows:

- Periods of above average rainfall in 1949-1953, 1965-1969, 1975-1979, and 1988-1992;
- Periods of average rainfall in 1954-1956, 1958-1960, 1969-1974, 1984-1987 and 2011-2016; and

- Periods of below average rainfall in 1940-1948, 1956-1957, 1961-1964, 1980-1983, 1993-2010 and 2017-2020.

Figure 3-1 Rainfall and Cumulative Rainfall Departure

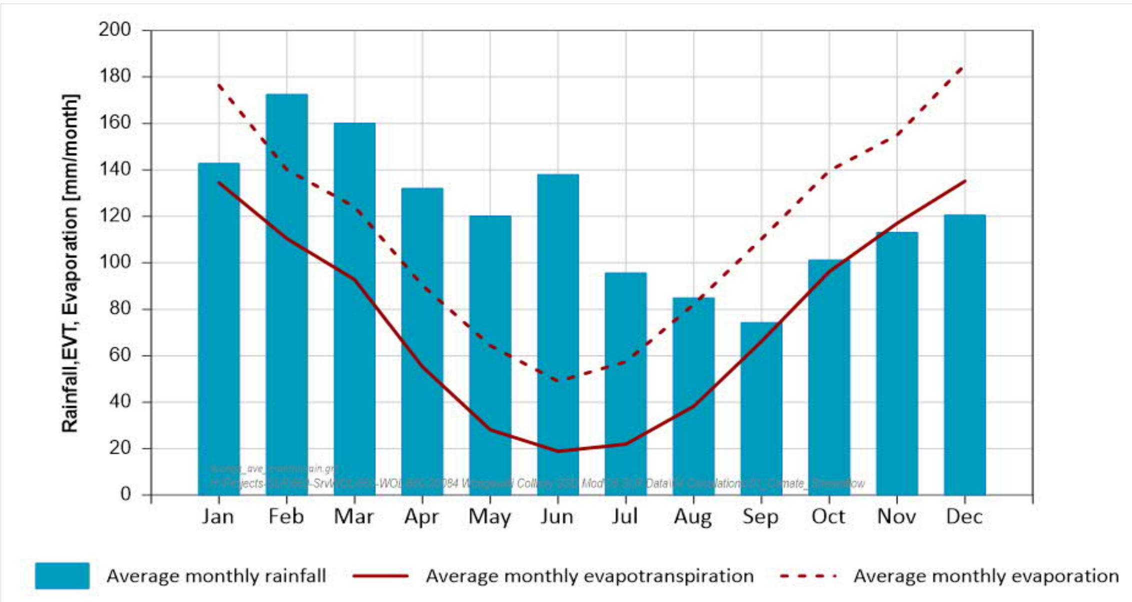


Figure 3-2 SILO Average Monthly Rainfall, Evapotranspiration and Pan Evaporation

3.2 Topography and Drainage

3.2.1 Topography

The Project is located on the Woronora Plateau, inland of the Illawarra Escarpment, approximately 14 km west of Wollongong, NSW. Locally the Project is west of Lake Illawarra and includes Lake Avon (Figure 3-3). The rise of the escarpment from the coastal plain to Wongawilli is approximately 400 mAHD.

On the plateau, topography generally slopes to the north or north-west, toward the center of the Sydney Basin. However, the plateau is incised with the larger river valleys such as those associated with Wongawilli Creek and Cordeaux Reservoir between 50 m and 100 m deep.

Primarily, topography of the Wongawilli area consists of gentle undulating terrain with increasing prevalence of steep gorges and ridges north across the WWC area. These valleys form part of the southern water catchment area for Sydney and Illawarra. A major reservoir, Avon, traverses the central / western area while the upper reaches of the Cordeaux Reservoir are in the north-eastern portion of the ML. Topographically, the WWC area has a minimal amount of surface infrastructure. DPIE-Water holds large tracts of land covered by native vegetation with high a biodiversity value. Access is mainly restricted to existing fire roads, except for dams and associated Water NSW infrastructure, the Moss Vale – Port Kembla railway line and power transmission lines. Minimal development has occurred in the area of Wongawilli, Huntley and Avondale (WCL, 2017).

3.2.2 Surface Water

The Wongawilli mining area is located within the Hawkesbury-Nepean catchment. Natural drainage is to the north-northwest, towards the Nepean River. Local surface runoff is captured by the headwater reservoirs (Nepean, Cordeaux, Avon, and Cataract Reservoirs) or rivers (Cordeaux, Avon) before eventually flowing into the Nepean River (Coffey, 2012). Additional information on these reservoirs is presented in Table 3-2.

There are a number of smaller lower-order streams that run within the Project area. The catchments of some of these lower-order streams (Wongawilli Creek and Donalds Castle Creek) have been undermined and the hydrographs exhibit some signs that they have been affected by mining (HydroSimulations, 2019).

Table 3-2 Summary of Surface Water Features (HEC, 2019)

Surface Water Feature	Flow Response	Mean Annual Flow (ML/year)	Lake Floor (mAHD)	Lake Full Storage Level (FSL)	EC (µS/cm)	pH
Nepean River	Major Perennial	-	N/A	N/A	52 - 338	7.23 (mean)[1]
Donalds Castle Creek	Perennial	137 - 869	N/A	N/A	11 - 225	3.7 - 6.6
Avon River	Perennial	-	-	-	61 - 128	7.01 (mean)[2]
Wongawilli Creek	Perennial	-	N/A	N/A	115	6.22
Cordeaux River	Perennial	33 - 468	N/A	N/A	70 - 307	5.1 - 7.4
Avon	Reservoir	247 (LA4S1)	253	320	47 - 158	5.1 - 7.6

1. BoM – Napean River at Napean Dam (accessed 29/07/20)
2. BoM – Avon River at Summit Tank (accessed 22/07/20)

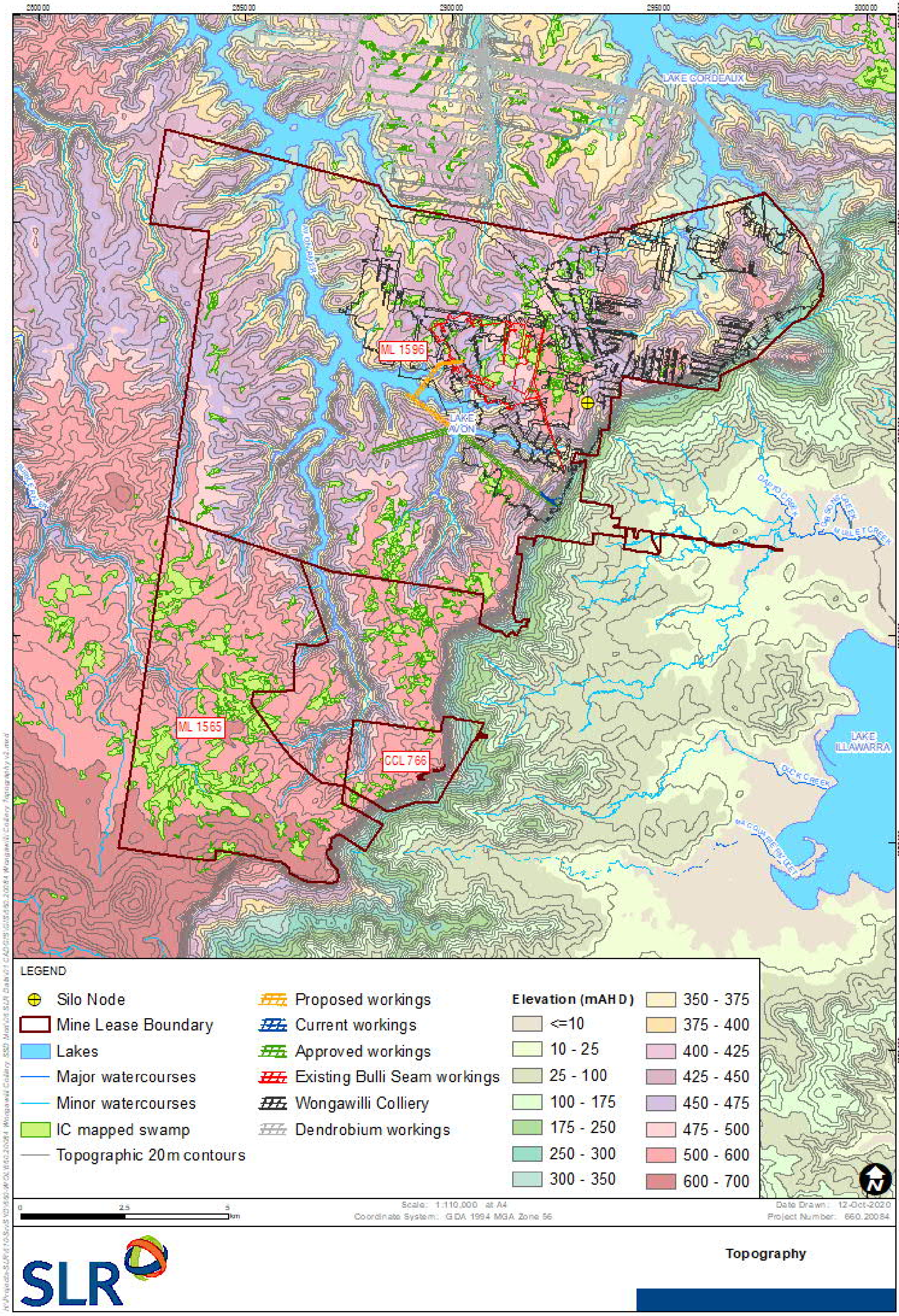


Figure 3-3 Topography

Surface water monitoring is conducted within four major waterways that have attributes as follows:

- Nepean River
  - Major perennial river of the Hawkesbury-Nepean catchment;
  - Prominent groundwater discharge system;
  - Flows north;
  - Receives runoff locally from the catchment;
  - Discharge to the river is licensed;
- Avon River
  - Perennial river of the Hawkesbury-Nepean catchment;
  - Flows north;
  - Water impounded by Lake Avon;
  - Flow diverted due to the Avon Dam;
- Cordeaux River
  - Perennial river of the Hawkesbury-Nepean catchment;
  - Flows north and north-west;
  - Joined by the Avon River;
  - Discharges into the Nepean River;
- Wongawilli Creek
  - Joins Cordeaux River about 1.7 km west of Cordeaux Dam;
  - Predominately flows north ;
  - Flows east following the confluence with the Cordeaux River;

Figure 3-4 shows the watercourses around WWC, as well as the upstream catchment area and other selected sub-catchments. This allows identification of those sub-catchments potentially affected by mining.

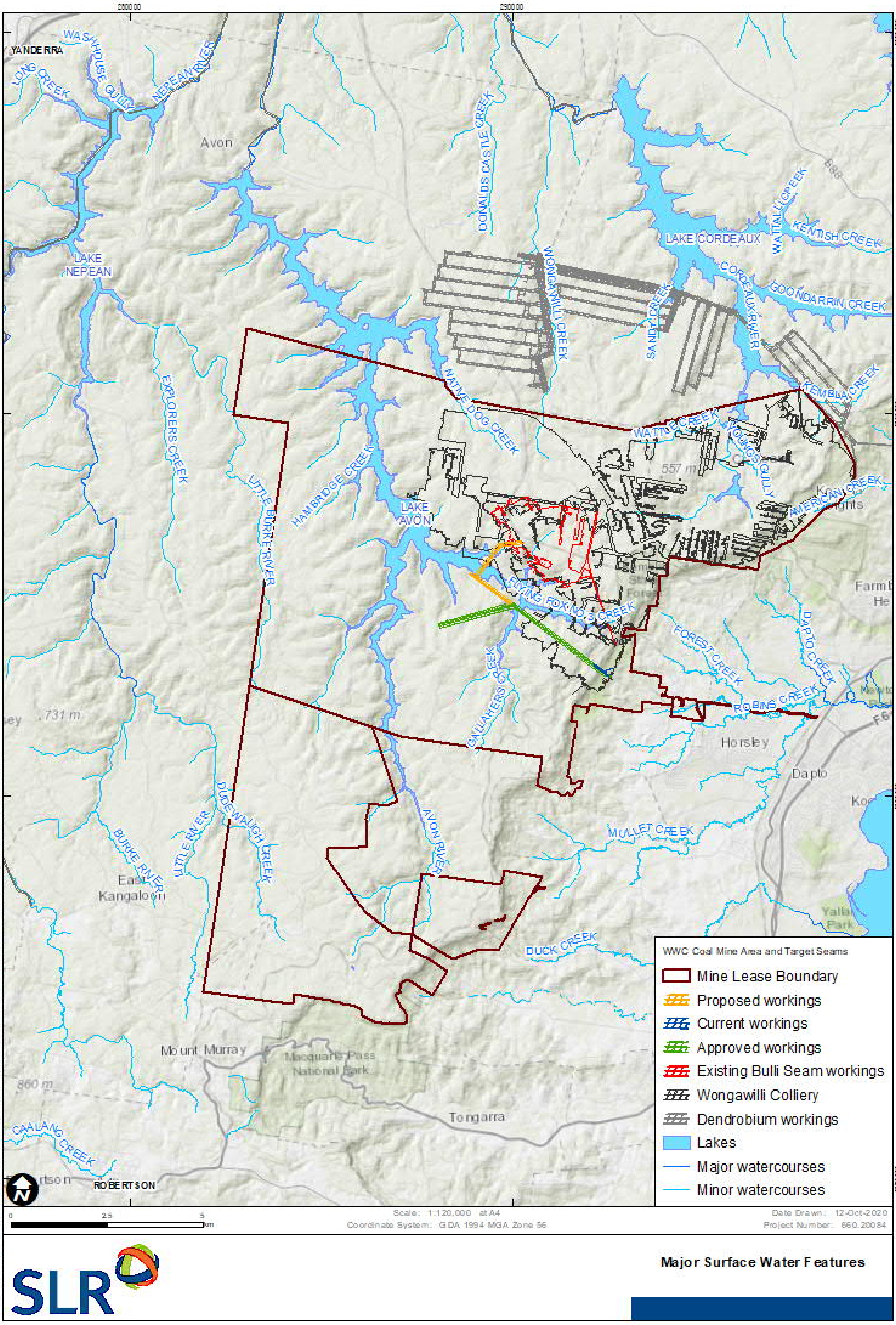


Figure 3-4 Surface Water Features

3.3 Geology

3.3.1 Regional Setting

The Project is located within the (southern) Sydney Basin, part of the Southern Coalfield. The stratigraphy of the Project area and surrounds is presented in Table 3-3 and shown in Figure 3-5. The area is primarily a Permo-Triassic sedimentary rock sequence and is underlain by undifferentiated consolidated sediments of Carboniferous and Devonian age.

Table 3-3 Stratigraphy

Age	Group	Unit		Description	WWC Average Thickness (m)
Quaternary	Upland swamp (Qs)			Headwater-drainage deposits and valley infill deposits	-
	Alluvium (Valley Floor)			Alluvial and residual deposits comprising quartz and lithic fluvial sand, silt and clay.	<2
	Colluvium (Hillslopes)			Colluvial soil comprising ferruginous clays or sandy soils.	<6.5
Tertiary to Jurassic	Volcanic intrusions – sills and dykes			Cordeaux Crinanite (Hawkesbury Sandstone and Narrabeen Group).	<68 (sills)
				Dendrobium Nephaline Syenite (Illawarra Coal Measures – WW).	3 (dykes)
Triassic	Hawkesbury Sandstone (HBSS)			Consists of thickly bedded or massive quartzose sandstone with grey shale lenses up to several metres thick.	87.4
	Narrabeen Group	BACS	Bald Hill Claystone	Newport Formation – Interbedded grey shales and sandstones.	5.9
				Garie Claystone – grey brown, massive, characteristically oolitic claystone.	3.8
				Bald Hill CS – Brownish-red coloured "chocolate shale", a lithological stable unit.	12.6
		BGSS	Bulgo Sandstone	Strong, thickly bedded, medium to coarse-grained lithic sandstone with occasional beds of conglomerate or shale.	65
		SPCS	Stanwell Park Claystone	Greenish-grey mudstones and sandstones.	6.6
		SBSS	Scarborough Sandstone	Thickly bedded sandstone with shale and sandy shale lenses up to several metres thick.	39.7
		WBCS	Wombarra Claystone	Greenish-grey mudstones and sandstones.	9.5
		CCSS	Coalcliff Sandstone	Basal shales and mudstones that are contiguous with the underlying Bulli Coal Seam.	8.3
Permian	Illawarra Coal Measures	BUSM	Bulli Coal Seam	Interbedded shales, mudstones, lithic sandstone and coals including the Bulli Seam, Wongawilli Seam, Tongarra Seam, plus Loddon & Lawrence Sandstone and Kembla Sandstone.	200-300
		LDSS	Lawrence & Loddon Sandstones		
		WWSM	Wongawilli Coal Seam		
		KBSS	Kembla Sandstone		
		TGSM	Tongarra Coal Seam		

3.3.2 Local Geology

Within the Project area the geology includes upland swamps, Triassic Narrabeen Group and the Permian Illawarra Coal Measures, as well as volcanic intrusions. Discussion on each of the sequences is included in Section 3.3.2.1 to Section 3.3.2.5 below. Discussion on the structural geology at the Project area is included in Section 3.3.2.6.

Figure 3-6 and Figure 3-8 present a series of geological cross-sections through historic, current and proposed mining areas, the position of each cross section is shown on Figure 3-5. These figures illustrate the relative thickness of the Hawkesbury Sandstone and Bulgo Sandstone in relation to the other units, as well as the layered nature of the geological sequence with alternating sandstones and claystones. These figures also show that the Stanwell Park Claystone is extensive and sufficiently distinguishable from the underlying Scarborough Sandstone or overlying Bulgo Sandstone across the Project area.

3.3.2.1 Upland Swamps

Small pockets of Quaternary-aged swamp deposits have been mapped across the Southern Coalfield, as shown on the Southern Coalfield Geology map (Qs) (Moffitt, 1999). Further local mapping as presented by HydroSimulations (2019) identifies additional coastal upland swamps in the area, including one swamp area above the proposed alignment of the Project and one above the approved NW Mains.

The upland swamps can occur as 'headwater-drainage divide' swamp deposits along the riparian zone of major creeks within the headwater valleys. Valley infill swamps also occur in the area, which are deposited within the steeply incised valleys of second or third order streams (Tomkins and Humphreys, 2006). The swamps generally comprise acidic soils and can vary from sandy loams likely derived from weathered sandstone (i.e. Hawkesbury Sandstone), with a shallow organic horizon to highly organic peats.

3.3.2.2 Triassic Hawkesbury Sandstone

The Triassic Hawkesbury Sandstone predominantly occurs at outcrop and comprises medium to coarse-grained quartz sandstone with minor shale and laminite lenses. The sandstone was deposited in a fluvial environment and consists of three main depositional environments, namely massive sandstone facies, cross-bedded or sheet facies and shale/siltstone interbedded facies. Interbedded shale lenses can provide local or extensive confining layers creating separate aquifers with different hydraulic properties and sometimes hydraulic heads. This lithological variation and the thickness of the unit mean that although this unit is considered a single stratigraphic entity, it essentially forms a vertical series of layered aquifers. Within the Project area the average and maximum thicknesses of the Hawkesbury Sandstone are 87.4 m and 154.7 m respectively (WCL, 2017).

The Hawkesbury Sandstone displays bedding but also contains secondary structural features such as joints, fractures and faults. The sandstone weathers to a clayey sand residual skeletal soil profile typically one to two metres deep.

3.3.2.3 Triassic Narrabeen Group

Narrabeen Group underlies the Hawkesbury Sandstone and comprises interbedded quartz-lithic to quartzose sandstone, conglomerate, mudstone, siltstone and rare coal. Within the Project area the Clifton Subgroup is present, which includes the Bald Hill Claystone, Bulgo Sandstone, Stanwell Park Claystone, Scarborough Sandstone, Wombarra Claystone and Boal Cliff Sandstone. The Bald Hill Claystone and Bulgo Sandstone occur at outcrop where the topography is deeply incised by rivers and lakes (Figure 3-5).

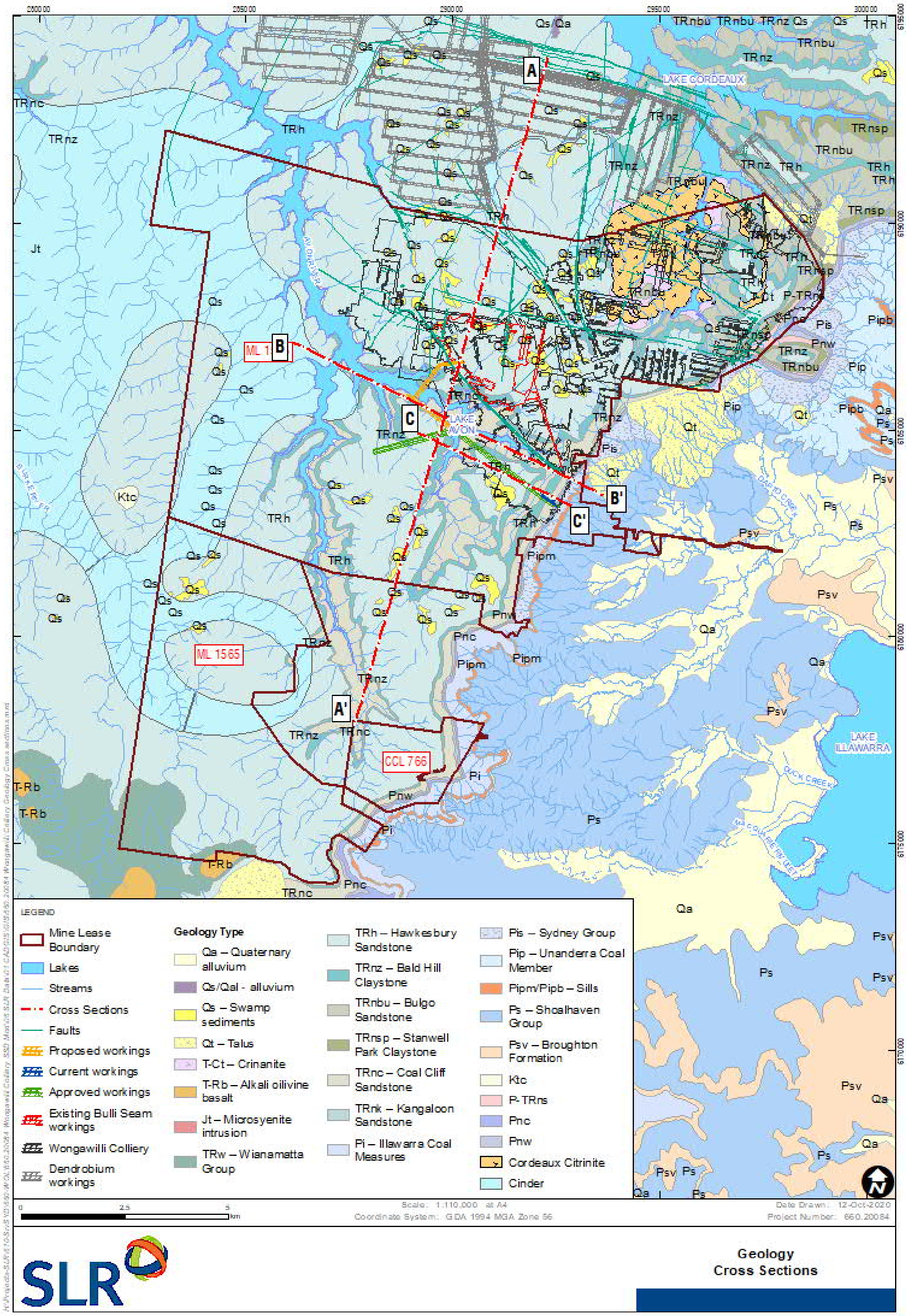


Figure 3-5 Geological Setting

3.3.2.4 Illawarra Coal Measures

The Illawarra Coal Measures are the primary economic sequence of interest in the Sydney Basin, and consist of interbedded sandstone, shale and coal seams, with a thickness of approximately 200 m to 300 m. The two main coal seams mined in the Southern Coalfield are the uppermost Bulli Seam and the Wongawilli Seam (Holla and Barclay, 2000).

Within the Illawarra Coal Measures the Bulli Seam is the uppermost coal member. Within the Project area the Bulli Seam occurs at elevations of around 300 mAHD in the south-east, down to around 165 mAHD to the north. Due to the steeply incised nature of the topography, the depth to Bulli Seam is variable, as shown in Figure 3-9. The shallowest depth to Bulli Seam of around 85 m is associated with the approved NW Mains beneath Gallahers Creek arm of Lake Avon. The shallowest depth to Bulli Seam for the proposed alignment is at around 140 m below the surface of Lake Avon.

The Bulli Seam in the Project area is situated primarily in the western part of Wongawilli Holding. Due to the Wongawilli fault zone and the intrusion of crininite replacing the Bulli Seam, the Bulli Seam workings were limited at the west. To the east the workings were limited by decreasing Bulli Seam thickness. In the southern portion of the WWC, the Bulli Seam consists primarily of thin coal bands and significant carbonaceous mudstone and claystone bands and is not considered economic. To the southwest the Bulli Seam is not recognisable in bore core. To the east within the Wongawilli Holding, over much of the mined Wongawilli Seam, the Bulli Seam has a deteriorated coal section due to high inherent ash or its thickness is less than 1.5 m (WCL, 2017).

There are large areas of the Bulli Seam that have been intruded. Along the west to north-western margins of WWC the Bulli Seam is extensively intruded by the Avon sill complex. In the Avondale area silling (Avondale sill complex) has also destroyed large areas of Bulli Seam.

The Bulli Seam is underlain by the Wongawilli Seam. The vertical separation between the Bulli and Wongawilli seams is approximately 22 m, on average in the Project area. Even though consistent in thickness across the southern part of the Coalfield from 9 m to 11 m, the Wongawilli Seam has significant deterioration in quality to the north when compared to the southern part of the Coalfield where a basal section has been extensively mined in the past (WCL, 2017).

3.3.2.5 Volcanics

There are several mapped intrusions within the Project area and surrounds, referred to as the Nebo Dome. Between Wongawilli (Nebo Colliery and Elouera) and Dendrobium is the Dendrobium Nephaline Syenite igneous intrusion that is up to 41 m in thickness within the Illawarra Coal Measures (BHP, 2005).

The intrusion includes a series of dykes and sills in the Tongarra, Wongawilli, Balgownie and Bulli coal seams. There are several northwest trending convergent dykes in the Nebo Colliery area. Dykes are generally doleritic, around 2 m thick and usually altered to white clay (BHP, 2005). Within the coal seam the coal is cindered (heat affected) around the dyke, generally to a thickness equal to the dyke (BHP, 2005).

The Cordeaux Crinanite is also mapped between Nebo and Dendrobium and described by Edwards (1953) as being comprised of thick (12 m to 50 m) olivine dolerite (crinanite) sills and thinner (2 m to 4 m) picrite sills at the base (SCT, 2010). The crinanite is intruded into the Narrabeen Group and Hawkesbury Sandstone. The Cordeaux Crinanite is exposed at surface in the Nebo area and was undermined in the Wongawilli Seam at Nebo Colliery (BHP, 2005).

Syenitic and doleritic sill intrusions vary in thickness up to 68 m. The doleritic Avondale sill complex is present within the Wongawilli Coal section and was intersected to the west and south of the Project area during exploration drilling (WCL, 2017).

The Project does not contain any crinanite found elsewhere in the Southern Coalfield stratigraphic sequence. The Bulli Seam thickness varies from 0.9 m to 1.93 m at the portal area at the first 3.3 km of the initial NW Main then thins to 1.7 m with the workings driveage turning to a WSW direction (Burea Veritas, 2010). The Project area is adjacent to the Blue Panel of the Project area where a combination of geological structures, shallow depth, underground ponded water storages and pillar extraction, together with the proximity of the Avon reservoir, may have previously contributed to an inflow of water into the workings (GeoTerra, 2010).

3.3.2.6 Structural Geology

There are regional geological structures, as mapped by Moffitt (1999) that run across the mining areas. A large syncline fold is present within the Project area, plunging to the north towards Dendrobium mine, with a dip of 1 in 25 towards the north. Another significant fold runs to the south within 3.5 m from the Bulli Seam Driveage.

There are several domed structures in the Wongawilli area which are believed to be due to volcanic intrusions. Nebo Colliery mined around the southern flanks of the Nebo Dome, which is also associated with a large intrusion above the Wongawilli Seam, exposed to the surface, and known as the Cordeaux Crinanite. A steep dip of about 1 in 12 to 1 in 16 of the Wongawilli Seam is associated with varying flanks of the domes (WCL, 2017).

Most of the faults in the vicinity of the Project area are of short length (less than one kilometre), apart from two faults close to the Nebo Dome that are at least three km long and a set of offset faults, named Avon Fault, along the Gallahers Creek, which are approximately 5.5 km long (Figure 3-5). South of the Avon Fault into the previous Avon, Huntley and Avondale Collieries, faulting is not a frequent geological feature.

Small scale faulting has been encountered in the workings of the Avondale and Huntley Collieries but not of a severity to impact significantly on mining. A prominent arcuate fault situated across the southern most part of the Project area is of low confidence and is estimated to have a throw of ten metres (WCL, 2017). As reported in Tonkin and Timms (2015), there has been no recorded “high level” mine inflows across the Southern Coalfield in the past 25 years. This suggests that faults are typically more barriers than conduits to groundwater flow.

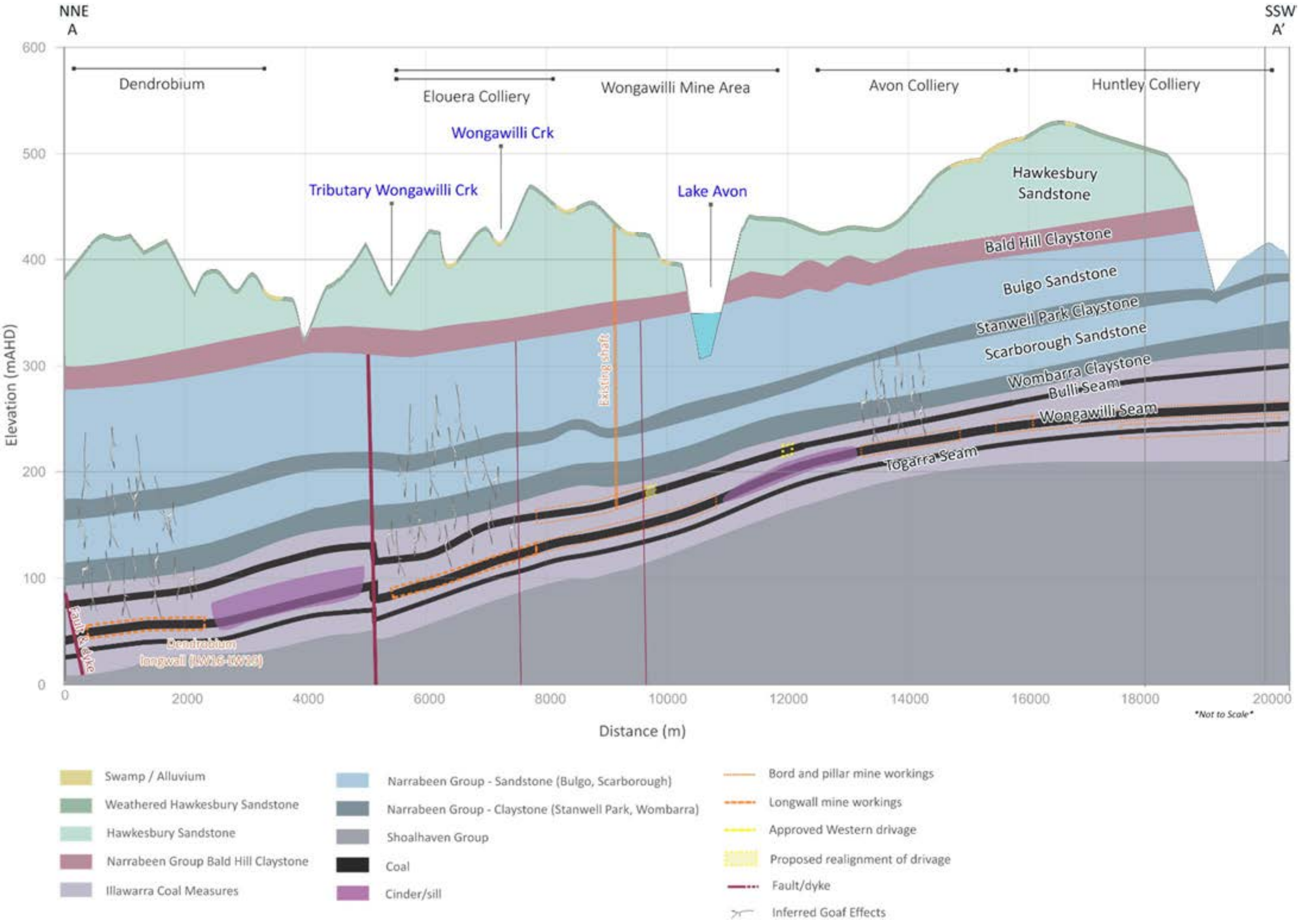


Figure 3-6 Geological Section – North to South (A-A')

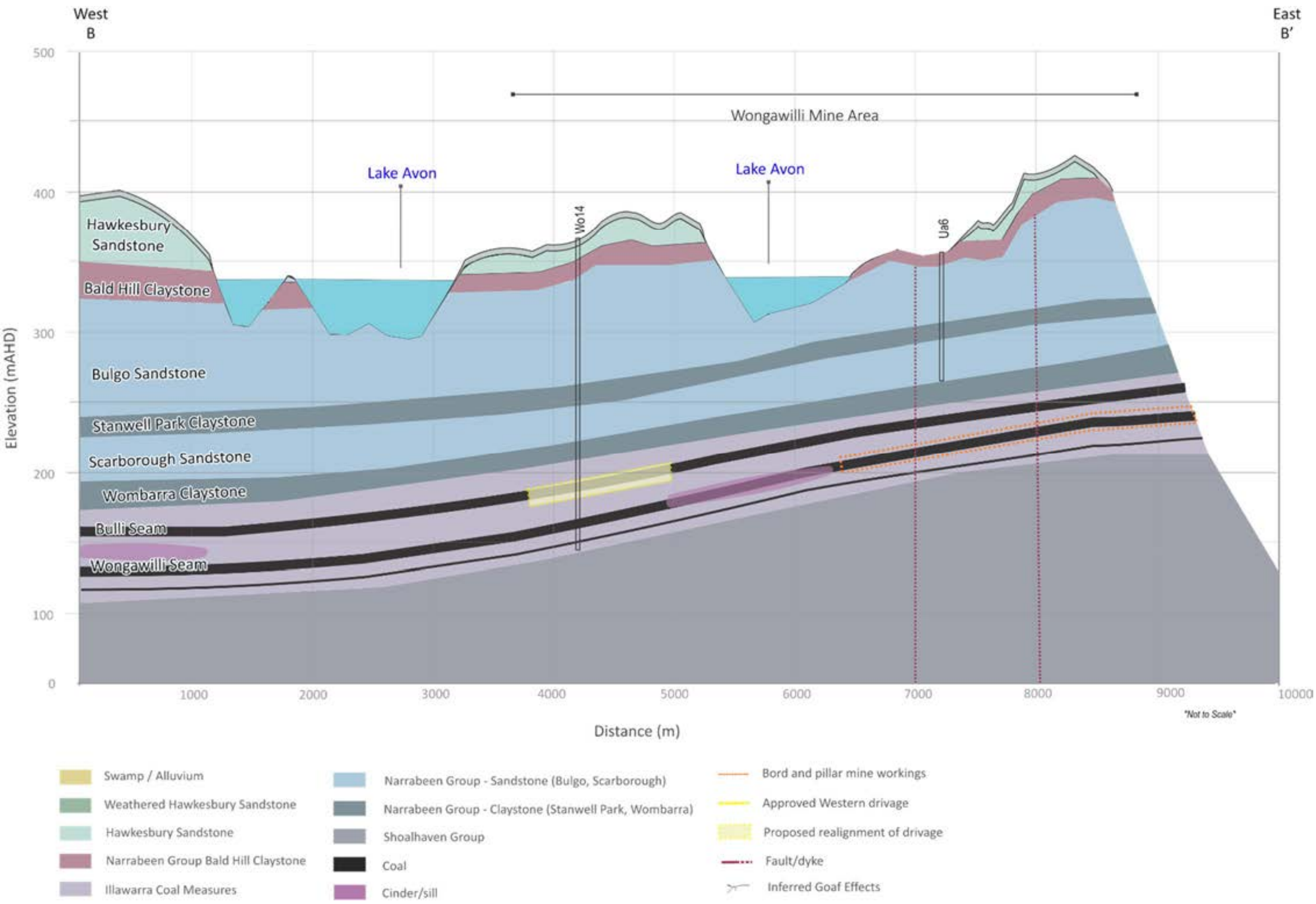


Figure 3-7 Geological Section – West to East (B-B')

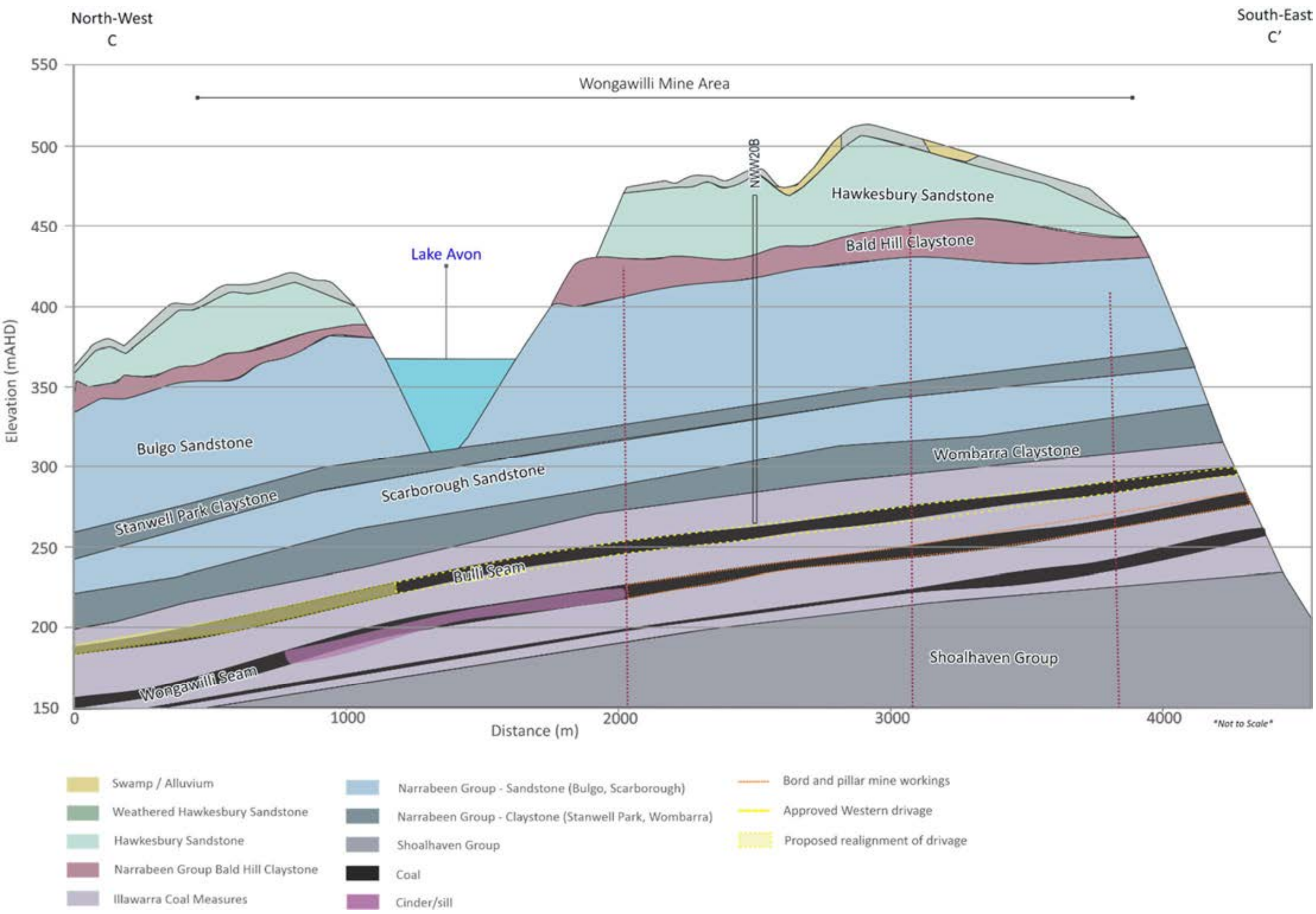


Figure 3-8 Geological Section – Project Alignment West to East (C-C')

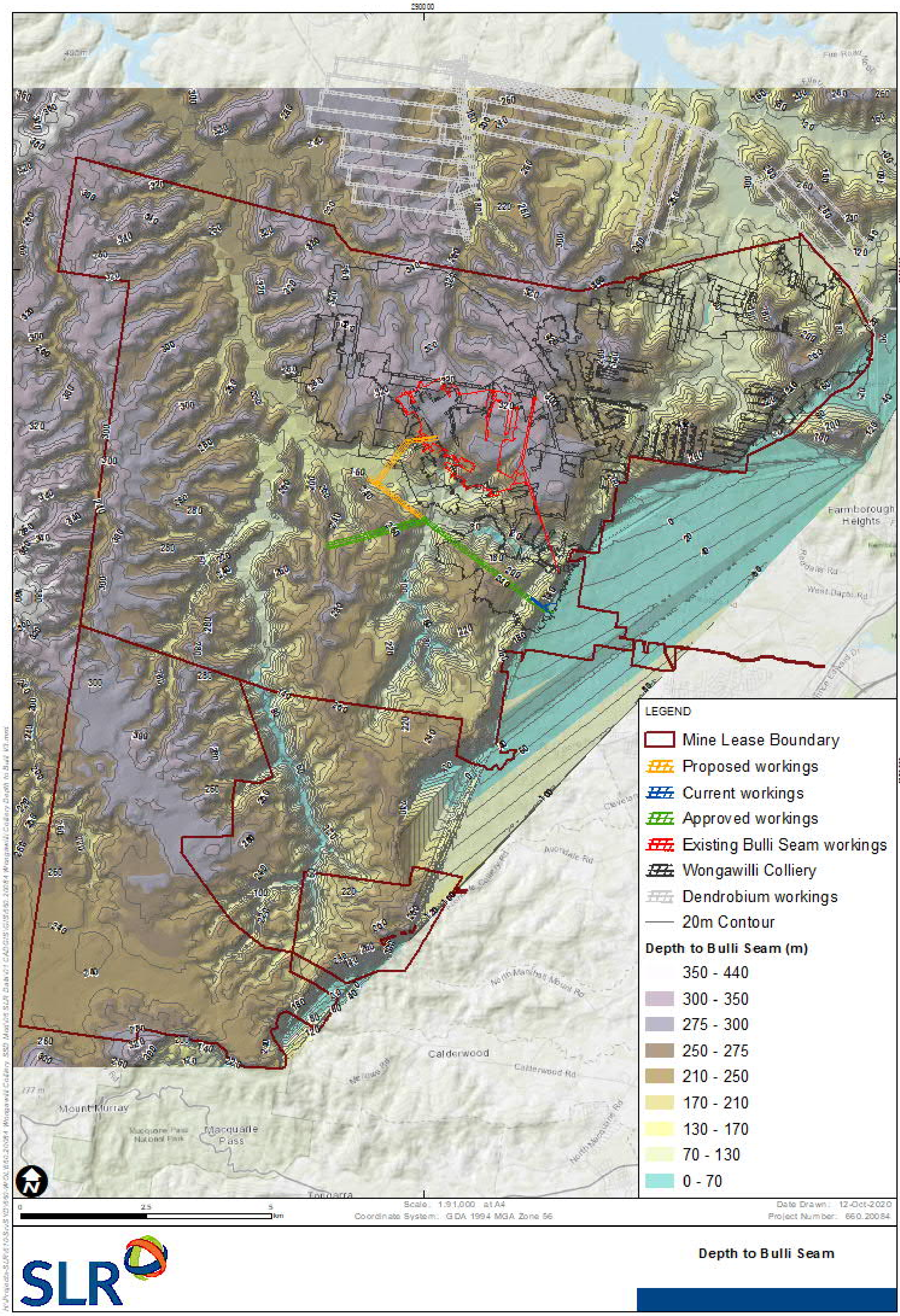


Figure 3-9 Depth to Bulli Seam

3.4 Hydraulic Properties

3.4.1 In situ Properties

3.4.1.1 Hydraulic Conductivity (K)

Testing of hydraulic properties of the various key geological units has been conducted within the Project area. This includes packer testing at the NW Mains within the Hawkesbury Sandstone (Piezometer WW11) and Bulgo Sandstone (piezometer WW20B) (GeoTerra, 2010) as well as packer testing in the Nebo area for various sequences. The hydraulic conductivity values derived from this packer testing is presented in Table 3-4 (from GeoTerra, 2010) from multiple boreholes in the NW Mains and Nebo areas. Hydraulic conductivity has been further defined as horizontal hydraulic conductivity (K_h) and vertical hydraulic conductivity (K_V). K_h is typically measured from packer testing whereas values for K_v (where tested) are measured in the laboratory analysis of drill core (Hawkes, 2017). In contrast hydraulic conductivity measured from test pumping is a combination of Kv and Kh and is referred to as the bulk hydraulic conductivity (K).

Typically the hydraulic conductivity within the Hawkesbury Sandstone is more variable and higher than the Bulgo Sandstone. Hydraulic conductivity also tends to reduce with depth, influenced by overburden pressures with fracture apertures decreasing with depth.

Table 3-4 Project Area Hydraulic Conductivity Summary (from GeoTerra, 2010)

Formation	Area	Interval tested (mbgl)	Median K (m/day)
Hawkesbury Sandstone	NW Mains	25.15 – 31.35	6.7×10^{-3}
Hawkesbury Sandstone	NW Mains	31.15 – 37.35	1.5×10^{-1}
Hawkesbury Sandstone	NW Mains	37.15 – 43.35	1.3×10^{-2}
Hawkesbury Sandstone	NW Mains	43.15 – 49.35	3.9×10^{-3}
Hawkesbury Sandstone	NW Mains	49.15 – 55.35	1.0×10^{-3}
Hawkesbury Sandstone	NW Mains	55.15 – 61.35	7.3×10^{-4}
Hawkesbury Sandstone	NW Mains	61.15 – 67.35	0
Hawkesbury Sandstone	NW Mains	67.15 – 73.35	1.0×10^{-1}
Hawkesbury Sandstone	NW Mains	73.15 – 79.35	7.3×10^{-2}
Bald Hill Claystone – Bulgo Sandstone	NW Mains	58.5 – 64.7	9.5×10^{-4}
Bulgo Sandstone	NW Mains	76.5 – 82.7	5.4×10^{-4}
Bulgo Sandstone	NW Mains	82.5 – 88.7	2.9×10^{-4}
Bulgo Sandstone	NW Mains	88.5 – 94.7	1.5×10^{-4}
Bulgo Sandstone	NW Mains	94.5 – 100.7	1.4×10^{-4}
Bulgo Sandstone	NW Mains	100.5 – 106.7	1.2×10^{-4}
Bulgo Sandstone	NW Mains	112.5 – 118.7	2.3×10^{-4}
Bulgo Sandstone	NW Mains	118.5 – 124.7	3.0×10^{-4}
Bulgo Sandstone	NW Mains	124.5 – 130.7	3.3×10^{-4}
Crinanite (fine to medium grained)	Nebo	0.0 – 72.1	2.12×10^{-5}

Formation	Area	Interval tested (mbgl)	Median K (m/day)
Crinanite (medium to coarse grained)	Nebo	45.1 – 78.1	3.95×10^{-4}
Stanwell Park Claystone	Nebo	51.4 – 63.3	7.43×10^{-5}
Scarborough Sandstone	Nebo	63.3 – 75.3	1.81×10^{-5}
Loddon Sandstone	Nebo	63.1 – 90.1	8.55×10^{-3}
Balgownie Seam	Nebo	90.1 – 96.1	3.02×10^{-3}
Lawrence Sandstone	Nebo	75.1 – 102.1	5.18×10^{-5}
Un-named Member 3	Nebo	87.1 – 108.1	1.66×10^{-2}
Wongawilli Seam / Kembla Sandstone	Nebo	108.1 – 117.1	1.21×10^{-3}

Notes: mbgl - metres below ground level

Extensive packer testing has also been conducted at surrounding mines, as presented in Table 3-5 from various sources.

Table 3-5 Hydraulic Conductivity Field Data Summary

Lithology	Location	Hydraulic Conductivity (m/day)			Count	Source
		Average	Min	Max		
Wianamatta Formation	Dendrobium	1.2×10^{-4}	8.6×10^{-6}	5.0×10^{-4}	5	HydroSimulations 2019
	Tahmoor	1.2×10^{-1}	1.2×10^{-1}	1.2×10^{-1}	1	SLR 2020
Hawkesbury Sandstone	Appin	-	1.0×10^{-4}	$1.0 \times 10^{+2}$	4+	Heritage Computing 2009
	Dendrobium	2.1×10^{-2}	8.6×10^{-10}	2.4	471	HydroSimulations 2019
	Tahmoor	4.2×10^{-2}	7.6×10^{-5}	4.5×10^{-1}	174	SLR 2020
Narrabeen Group	Appin	-	1.0×10^{-4}	1.0×10^{-2}	4+	Heritage Computing 2009
Bald Hill Claystone	Dendrobium	3.0×10^{-3}	8.6×10^{-7}	2.3×10^{-1}	131	HydroSimulations 2019
Bulgo Sandstone	Dendrobium	2.5×10^{-3}	8.6×10^{-7}	3.2×10^{-1}	424	HydroSimulations 2019
Stanwell Park Claystone	Dendrobium	1.5×10^{-2}	8.6×10^{-7}	3.2×10^{-1}	37	HydroSimulations 2019
	Tahmoor	1.1×10^{-4}	8.6×10^{-7}	3.5×10^{-4}	8	SLR 2020
Scarborough Sandstone	Dendrobium	1.4×10^{-2}	8.6×10^{-7}	2.5×10^{-1}	84	HydroSimulations 2019
	Tahmoor	3.4×10^{-4}	4.7×10^{-6}	2.5×10^{-3}	34	SLR 2020
Wombarra Claystone	Dendrobium	4.0×10^{-3}	6.0×10^{-6}	1.2×10^{-1}	80	HydroSimulations 2019
	Tahmoor	1.3×10^{-4}	8.6×10^{-7}	3.5×10^{-4}	9	SLR 2020
Coal Cliff Sandstone	Dendrobium	4.0×10^{-3}	8.6×10^{-10}	1.3×10^{-1}	59	HydroSimulations 2019
Bulli Coal	Dendrobium	6.0×10^{-3}	8.6×10^{-6}	1.1×10^{-1}	19	HydroSimulations 2019
	Tahmoor	7.3×10^{-4}	1.0×10^{-5}	3.9×10^{-3}	30	SLR 2020

Figure 3-10 illustrates the Kh range collected from samples at Dendrobium and Tahmoor. This figure shows that Kh is typically greater at shallower depths, which is expected due to the greater prevalence of open joints, bedding planes and degree of weathering in the near surface. In the deeper subsurface joints and bedding planes are more likely closed due to the overburden pressure, as noted in AGC (1984) and subsequently outlined by various authors. This figure also classifies each packer test interval by stratigraphy (see Table 3-3 for abbreviations). Comparison of Kh within stratigraphy units compared to Kh with depth suggests that depth is the primary modifying factor or control on the magnitude of Kh, while lithology is a secondary modifying factor. This is because each stratigraphic unit is comprised of facies of differing coarse- versus fine-grained sediment composition.

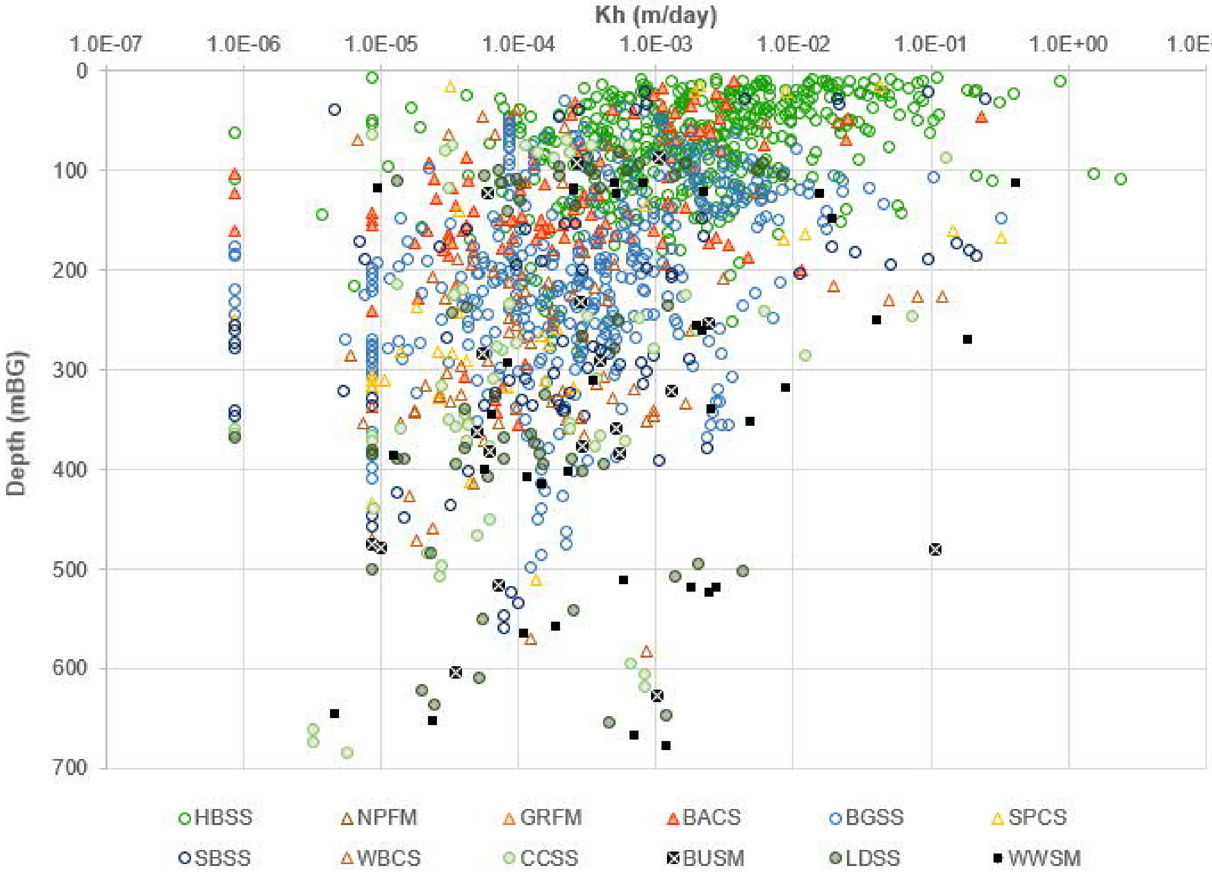


Figure 3-10 Hydraulic Conductivity (Kh) versus depth (field data)

3.4.1.2 Storage Properties (Sy and Ss)

There is no site specific data on storage properties. However, as reported in HydroSimulations (2019), testing of porosity (total) percentage has been completed at the neighbouring Dendrobium Mine. This included analysis of core from the upper stratigraphic units, such as the Hawkesbury Sandstone, Newport Formation, Bald Hill Claystone and Colo Vale Sandstone (essentially the equivalent of the Bulgo Sandstone). Estimates of total porosity have also been derived from data around Appin Mine as reported by Heritage Computing (2010). This includes average porosity and effective porosity for some geological units, where effective porosity is a reasonable approximation for specific yield. Table 3-6 provides total and effective porosity results from laboratory testing of core samples.

A review of the porosity data shows that this hydraulic parameter varies, and as for hydraulic conductivity, decreases approximately with depth. The values of total porosity range between 0.02% and 0.15%.

Direct test data is not generally available for confined storage, namely the specific storage (Ss). The specific storage of Hawkesbury Sandstone has been estimated to be approximately:

- $1x10^{-6}$ m^{-1} in the shallower zones where fracture flow is the dominant flow process (Kelly et al., 2005); and
- 1.5x 10^{-6} m^{-1}, for intervals between ground surface and 300 m depth based on pumping tests in Hawkesbury Sandstone from Tammetta and Hawkes (2009).

Table 3-6 Summary of Porosity from Dendrobium and BSO core samples

Geological Unit	Total Porosity (%)				Effective Porosity (%)	
	Min	Mean	Max	Count	Mean	Count
Hawkesbury Sandstone	3.8	15.4 (14.9)	23.6	68 (4)	11.2	2
Newport Formation	2	2.4	2.6	3		
Bald Hill Claystone	4.1	6.1	9.9	6		
Colo Vale Sandstone	3.7	9.4	18.1	10		
upper Bulgo Sandstone		(8.2)		(5)	3.3	5
lower Bulgo Sandstone		(5.6)		(4)	0.7	4
Stanwell Park Sandstone		(8.2)		(3)	0.2	2
Scarborough Sandstone		(8.5)		(4)	1.5	2
Wombara Sandstone		(3.7)		(1)	0.2	1
Coal Cliff Sandstone		(7)		(2)		

Notes Total porosity data from HydroSimulations, 2019
Total porosity data in parentheses is from BSO. All Effective Porosity measurements are from BSO

Model calibration at other mines in the Southern Coalfield suggest that Ss is in the order of 1E-7 to 3E-5 m^{-1} for the coal seams, and about 1E-6 m^{-1} for overburden or interburden. For the groundwater model developed for the Project, a range of generally decreasing Ss with depth is to be used, representing the concept that overburden pressure at depth steadily decreases the 'elastic storage' of the rock formation.

3.4.2 Mine Effects

Historical mining has occurred in the vicinity of the Project area. Blue Panels 2 and 4 were mined from 125 m to the north of the Project area. Coal was extracted via the bord and pillar method and partial pillar extraction secondary workings has since occurred which typically results in the partial collapse of the immediate roof structure strata over the mined void (IESC, 2014). Thus the void space within the mined area increases as does the hydraulic conductivity above the goaf due to induced or increased cracking.

To simulate the increased hydraulic conductivity above mine workings due to goaf effects previous modelling (Golder, 2010) has increased the hydraulic conductivity in the overlying hydrostratigraphic units as follows:

- Eckersley Formation – increase K by one order of magnitude
- Wombarra Formation - increase K by one order of magnitude
- Scarborough Formation - increase K by two orders of magnitude

A number of major dykes have been mapped in the within the Project area which may provide conduits for groundwater to enter the former workings (GeoTerra, 2010). During initial mining inflows to Panels 2 and 4 were reported to Recharge to the Panel 4 workings was observed to be of low significance, however inflows substantially increased after secondary extraction was completed. Inflows to Blue 2 Panel were interpreted as being sourced from storage within the confined aquifer system, that was not sustained from rainfall recharge whereas inflows to Blue 4 Panel were interpreted as being derived from a groundwater system sustained by rainfall recharge. It is also possible that inflows can increase where dykes provide a conduit between the workings and aquifer storage.

A subsidence assessment was conducted for the approved operations and it was predicted that there would be no observable subsidence, strain or tilt, stream bed uplift or bed cracking in Gallahers Creek due to the approved Project workings (MSEC,2010). A subsidence and geotechnical conducted for this Project (SCT, 2020) concluded there is no potential for the main heading development roadway (Additional Driveage) to cause surface ground movement of any consequence.

Longwall mining occurs in the region, which can change the hydraulic properties of the insitu strata. After the panels of coal are extracted using longwall methods the overlying strata immediately above the extracted seam collapses into the void (forming the goaf). The strata above the goaf deform and fracture in response, and some level of subsidence and fracturing of overlying and adjacent strata occurs (Peng and Chiang, 1984; Whittaker and Reddish, 1989). Subsidence and goaf effects can cause surface cracking, resulting in enhanced vertical conductivity at surface, which varies through natural deposition and infilling, as well as engineered remediation (i.e. surface grouting).

Fracturing is most intense and vertically connected immediately above the collapsed longwall (goaf), and grades upwards through zones of less fractured strata (Booth, 2002). Fracturing of the overburden can cause significant changes in aquifer characteristics such as hydraulic conductivity and storage, and potentially can provide pathways for vertical groundwater movement between shallow groundwater and surface water systems and underground mines (Advisian, 2016; McNally and Evans, 2007). Extensive data for surrounding mines (i.e. Dendrobium) indicates the goaf and fractured zone could result in an enhanced permeability of two to three orders of magnitude (HGEO, 2019).

The ratio of panel width (W) and depth of cover (D) is often used as a preliminary guide to the risk of connected fracturing extending from the goaf to the surface. The height of complete groundwater drainage and the height of fracturing above the workings can be calculated using the Tammetta (2012) and Ditton and Merrick (2014) methods respectively.

The impacts of subsidence and induced fracturing can be represented in groundwater models by increasing the hydraulic conductivity. Values for hydraulic conductivity applied in the previous (Golder) groundwater model for Nebo Panels 1 to 6 to represent the impacts of subsidence are presented in Table 3-7 (GeoTerra, 2010). The ratio of vertical hydraulic conductivity (K_v) to horizontal hydraulic conductivity (K_h) is given by the anisotropy factor provided.

Table 3-7 Hydraulic conductivity of mining impacted stratigraphy

Geological Unit	Hydraulic Conductivity (K_v)		Anisotropy Factor^
	m/s	m/day	Max
Hawkesbury Sandstone	$3x10^{-8}$	$3x10^{-3}$	0.1
Bald Hill Claystone	$5x10^{-9}$	$4x10^{-4}$	0.1
Upper Cordeaux Crinanite	$3x10^{-8}$	$3x10^{-3}$	1
Lower Cordeaux Crinanite	$3x10^{-10}$	$3x10^{-5}$	0.1
Bulgo Sandstone	$6x10^{-8}$	$5x10^{-3}$	0.05
Bulgo Sandstone - delaminated	$3x10^{-7}$	$3x10^{-2}$	0.05
Stanwell Park Claystone	$3x10^{-10}$	$3x10^{-5}$	0.05
fractured longwall	$3x10^{-9}$	$3x10^{-4}$	0.1

Geological Unit	Hydraulic Conductivity (K_v)		Anisotropy Factor^
	m/s	m/day	Max
fractured pillar extraction (bord & pillar)	$3x10^{-9}$	$3x10^{-4}$	0.05
Scarborough Sandstone	$2x10^{-8}$	$2x10^{-3}$	0.05
fractured longwall	$2x10^{-6}$	$2x10^{-1}$	0.05
fractured pillar extraction (bord & pillar)	$8x10^{-7}$	$7x10^{-2}$	0.1
Wombarra Shale	$1x10^{-9}$	$9x10^{-5}$	0.01
fractured longwall	$1x10^{-7}$	$9x10^{-3}$	0.1
fractured pillar extraction (bord & pillar)	$1x10^{-8}$	$9x10^{-4}$	0.1
Bulli Coal/Coalcliff Sandstone	$1x10^{-6}$	$9x10^{-2}$	0.5
fractured longwall	$1x10^{-3}$	$9x10^{-1}$	0.5
fractured pillar extraction (bord & pillar)	$1x10^{-4}$	9	0.5
Eckersley Formation	$1x10^{-9}$	$9x10^{-5}$	0.05
Fractured	$1x10^{-7}$	$9x10^{-3}$	0.1
Wongawilli Seam	$5x10^{-7}$	$4x10^{-2}$	0.1
Mine workings / roadways	n/a (Void)	n/a (Void)	n/a (Void)
Kembla Sandstone	$1x10^{-9}$	$9x10^{-5}$	0.1

Notes: ^ ratio of vertical hydraulic conductivity (K_v)to horizontal hydraulic conductivity (K_h)

3.5 Groundwater Monitoring Network

The groundwater monitoring network at WWC has been in place since 2009 and includes:

- 6 Nebo open standpipes (Nebo1 to Nebo 4) within the Hawkesbury Sandstone, Crinanite, Bulli Seam and Wongawilli Seam, with nested bores at Nebo 1 and Nebo2.
- 7 Swamp deposit bores.
- 11 vibrating wire piezometers (VWP) (Nebo/NWW/NRE) with multiple sensors across various units.

The construction details of the VWPs, monitoring bores at Wongawilli, and the monitored geology are shown in Table 3-8 and locations shown in Figure 3-11. The location of two proposed monitoring bore nests are also shown on Figure 3-11. The groundwater monitoring program includes daily readings of pressure head at the VWP's, and manual measurement of water levels at the monitoring bores, as well as water quality sampling and analysis for electrical conductivity (EC), pH, major ions, minor ions and metals.

In addition, a data sharing agreement is in place with South 32, which enabled use of extensive site groundwater monitoring data from their network of 149 VWPs with 615 sensors in Areas 3A, 3B and 3C. This network includes 241 sensors positioned within the Hawkesbury Sandstone. Details on the Dendrobium monitoring network are included within HydroSimulations (2019).

Table 3-8 Groundwater Monitoring Network

Bore	Easting (m)	Northing (m)	Ground Level (mAHD)	Total Depth (mbgl)	Screen/ Sensor Depth (mbgl)	Sensor Level (mAHD)	Unit intersected	Date From	Date To
Nebo 1s	295153	6188762	366.4	6.9	5.0 - 6.0	366.4	Soil	30-01-2010	12-05-2020
Nebo 1d	295152	6188761	366.5	98.6	85.6 - 97.6	366.5	Siltstone	30-01-2010	12-05-2020
Nebo 2s	294662	6189246	347.7	9.9	5.5 - 6.5	347.7	Crinanite	30-01-2010	12-05-2020
Nebo 2d	294662	6189237	348.5	32.2	19.0 - 31.0	348.5	HBSS	30-01-2010	12-05-2020
Nebo 3	295033	6189838	356.7	34.4	21.6 - 33.6	356.7	HBSS	28-01-2010	11-05-2020
Nebo 4	294661	6189893	374.1	110	107.5 - 109.5	374.1	WWCO		
Nebo 6	295237	6189510	354.2	115	60	294.2	Crinanite	14-12-2009	07-01-2019
					80	274.2	Crinanite	14-12-2009	07-01-2019
					100	254.2	EKFM	14-12-2009	07-01-2019
					115	239.2	WWCO	14-12-2009	07-01-2019
Nebo 7	295477	6189585	336.4	90	30	306.4	Crinanite	19-12-2009	02-09-2019
					45	291.4	Crinanite	19-12-2009	02-09-2019
					63	273.4	LDSS	19-12-2009	02-09-2019
					90	246.4	WWCO	19-12-2009	02-09-2019
Nebo 8	294679	6189485	343.4	72	15	328.4	Crinanite	15-12-2009	20-07-2019
					35	308.4	Crinanite	15-12-2009	20-07-2019
					52	291.4	SPCS	15-12-2009	20-07-2019
					72	271.4	CCSS	15-12-2009	20-07-2019
Nebo 8A	294549	6189499	359.6	45	25	334.6	Crinanite	01-02-2010	02-09-2019
					45	314.6	Crinanite	01-02-2010	02-09-2019
NWW PE1	291676	6187507	515.7	165	90	425.7	HBSS	19-11-2009	23-01-2019
					135	380.7	HBSS	19-11-2009	23-01-2019
					150	365.7	BHCS	19-11-2009	23-01-2019
					165	350.7	BGSS	19-11-2009	23-01-2019
NWW 11	288343	6184339	467.1	125	60	407.1	HBSS	30-03-2009	19-01-2018
					90	377.1	HBSS	30-03-2009	19-01-2018
					104	363.1	BHCS	30-03-2009	19-01-2018
					125	342.1	BGSS	30-03-2009	19-01-2018
NWW 16	283657	6183801	513.4	166	71	442.36	HBSS	11-05-2009	05-06-2015
					126	387.36	HBSS	11-05-2009	05-06-2015
					146	367.36	HBSS/NPFM	11-05-2009	05-06-2015
					166	347.36	BHCS/BGSS	11-05-2009	05-06-2015

Bore	Easting (m)	Northing (m)	Ground Level (mAHD)	Total Depth (mbgl)	Screen/ Sensor Depth (mbgl)	Sensor Level (mAHD)	Unit intersected	Date From	Date To
NWW20B	291099	6184158	488.3	135	33	455.3	HBSS	02-03-2009	25-01-2019
					60	428.3	BHCS	02-03-2009	25-01-2019
					75	413.3	BGSS	02-03-2009	25-01-2019
					135	353.3	BGSS	02-03-2009	25-01-2019
NWW SH1	288448	6184273	475.6	297	65	410.6	HBSS	19-09-2011	23-01-2019
					90	385.6	HBSS	19-09-2011	23-01-2019
					110	365.6	BHCS	19-09-2011	23-01-2019
					130	345.6	BGSS	19-09-2011	23-01-2019
					215	260.6	SBSS	19-09-2011	23-01-2019
					255	220.6	CCSS	19-09-2011	23-01-2019
					267	208.6	BUCO	19-09-2011	23-01-2019
					297	178.6	WWCO	19-09-2011	23-01-2019
NWW GW01	289391	6184417	460.5	227	30	430.5	HBSS	08-02-2012	14-04-2016
					50	410.5	HBSS	08-02-2012	14-04-2016
					70	390.5	BHCS	08-02-2012	14-04-2016
					90	370.5	BGSS	08-02-2012	14-04-2016
					150	310.5	BGSS	08-02-2012	14-04-2016
					195	265.5	SBSS	08-02-2012	14-04-2016
					227	233	BUCO	08-02-2012	14-04-2016
					259	201.5	WWCO	08-02-2012	14-04-2016
NWW GW02	285253	6184479	480	334	60	420	HBSS	15-04-2013	25-01-2019
					130	350	HBSS	15-04-2013	25-01-2019
					160	320	BHCS	15-04-2013	25-01-2019
					175	305	BGSS	15-04-2013	25-01-2019
					250	230	BGSS	15-04-2013	25-01-2019
					275	205	SBSS	15-04-2013	25-01-2019
					301	178.8	BUCO	15-04-2013	25-01-2019
					334	146	WWCO	15-04-2013	25-01-2019
P20	291144	6187583	486.2	-	2.93	483.3	Swamp	16-04-10	2018*
P21a	291860	6188293	462.1	-	3.37	458.7	Swamp	16-04-10	2018*
P24	292076	6187585	501.9	-	2.86	499.0	Swamp	16-04-10	2018*
P30	291867	6188897	479.6	-	3.07	476.5	Swamp	16-04-10	2018*
P46	291875	6187988	489.3	-	3.40	485.9	Swamp	16-04-10	2018*
PA	287655	6183160	483.6	-	-	-	Swamp	-	-

Bore	Easting (m)	Northing (m)	Ground Level (mAHD)	Total Depth (mbgl)	Screen/ Sensor Depth (mbgl)	Sensor Level (mAHD)	Unit intersected	Date From	Date To
PB	284921	6184365	483.6	-	-	-	Swamp	-	-

Notes: Coordinates in MGA94 Z56

LRSS – Lawrence Sandstone, LDSS – Loddon Sandstone, KBSS - Kembla Sandstone, the Project areaO – Wongawillie Coal, BACO Balgownie Coal, BGSS – Bulgo Sandstone, BHCS – Bald Hill Claystone, BUCO – Bulli Coal, CCSS, Coalcliff Sandstone, EKFM, Eckersley Formation, HBSS Hawkesbury Sandstone

* Data potentially erroneous, interpolated groundwater elevations from client data

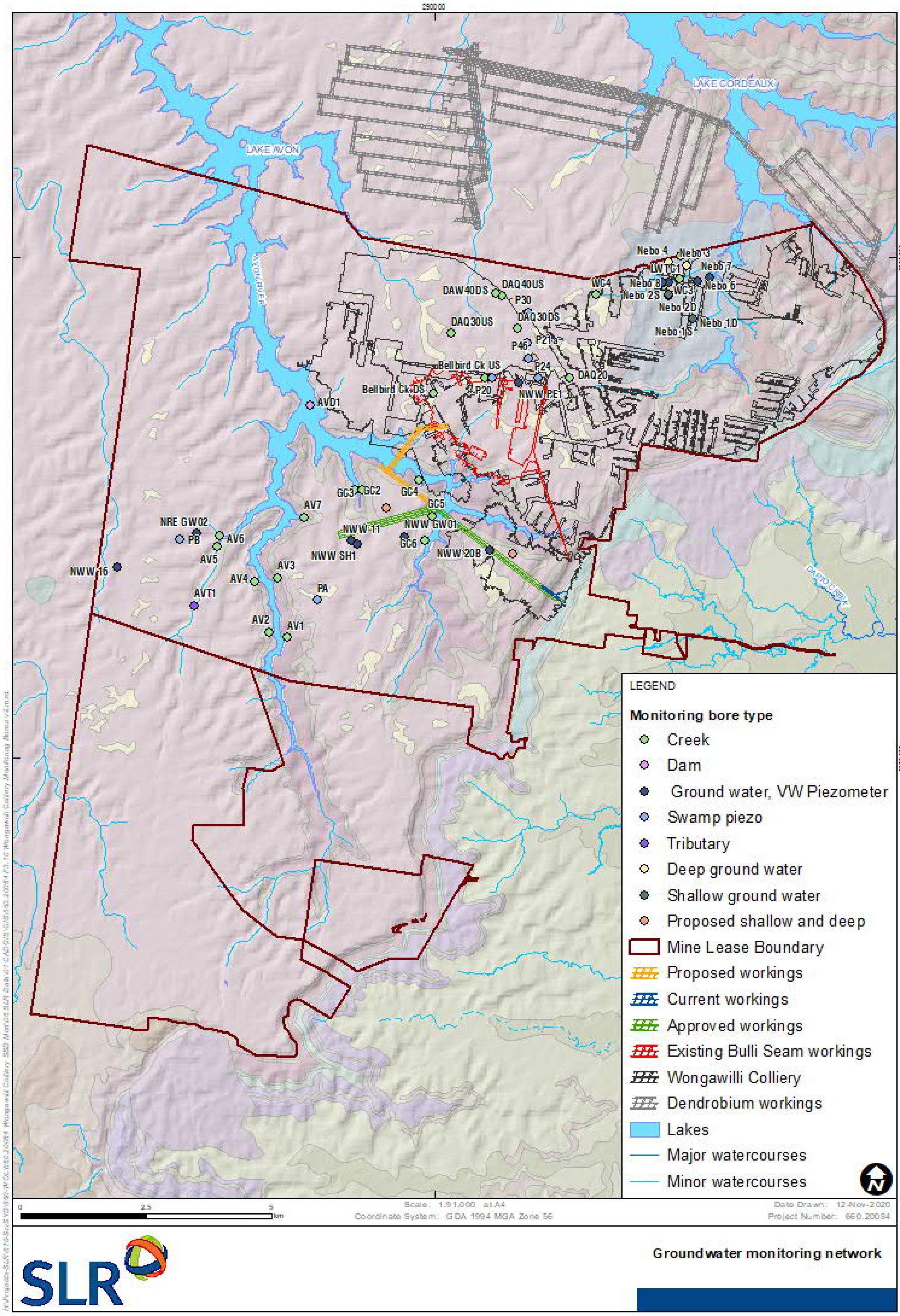


Figure 3-11 Groundwater Monitoring Network

3.6 Key Hydrostratigraphic Units

The major hydrostratigraphic units within the Project area include the surficial alluvium (upland swamps), Triassic aged Hawkesbury Sandstone and Narrabeen Group, and the Permian aged Illawarra Coal Measures. Hydrogeological characteristics of each key unit are described below.

3.6.1 Upland Swamps

3.6.1.1 Distribution and Flow

There is very little mapped alluvium within the Project area flanking rivers and creeks although small pockets of unconsolidated material (upland swamps) are mapped throughout the Project area. These features are generally oriented parallel to the direction of surface flow. Where present, geological mapping indicates minor outcrops of alluvium on valley floors and colluvium on hill slopes overlying the weathered Hawkesbury Sandstone.

There are no swamp monitoring bores in the Project area alignment, but there are five swamp monitoring points (P20, P21a, P24, P30 and P46) above the Wongawilli 1 workings around 1.2 km north-east. Water levels within the swamps have been monitored between 2009 and 2018, estimated groundwater elevations from the available data is presented in Figure 3-12. Monitoring was also conducted in 2019 but at the time of reporting no information was available to convert the pressure head data. The CRD data presented post 2017 indicates the continued influence of sustained low rainfall conditions.

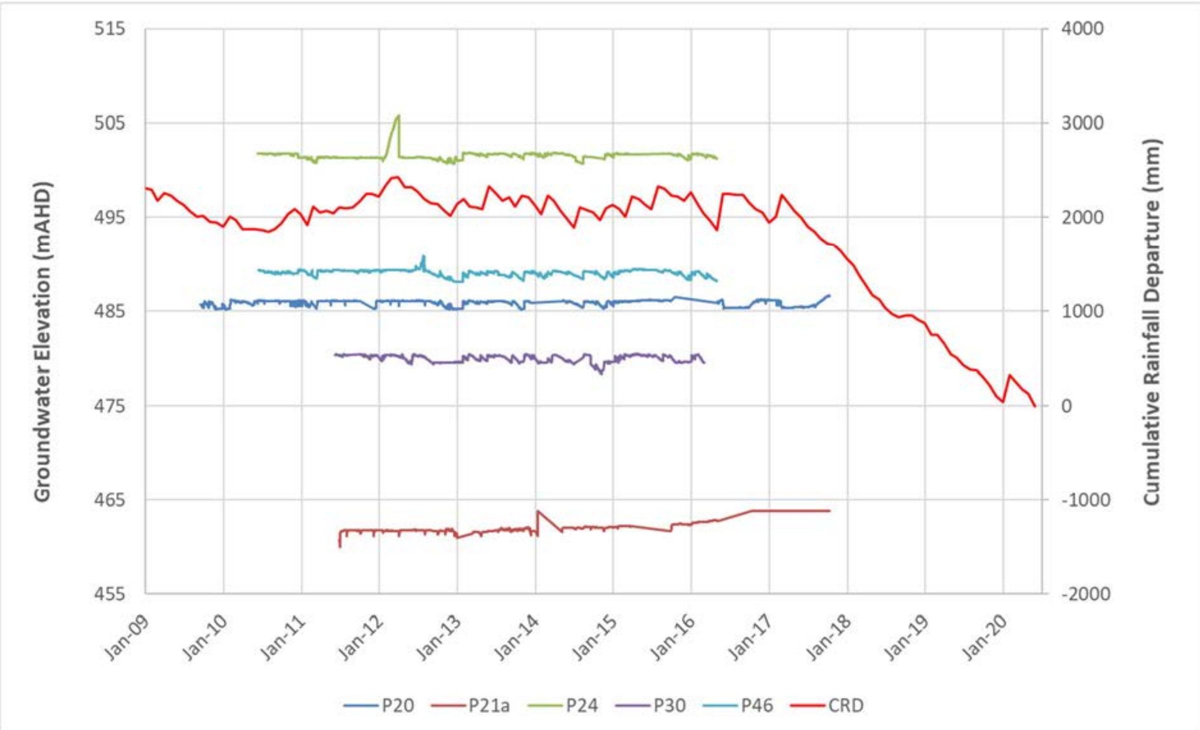


Figure 3-12 Hydrographs - Upland Swamps

Groundwater levels are generally within 1 m below surface, an exception to this was P30 that recorded levels around 2 m below surface in November 2014. P20 and P46 also recorded a decline in levels at this time, which corresponds with below average rainfall. This shows the influence of climate trends on groundwater occurrence and levels within the upland swamps. Impacts have also been predicted in the region related to surface cracking and subsidence due to longwall mining. No longwall mining is proposed as part of the Project.

3.6.1.2 Recharge and Discharge

Recharge to the upland swamps is dominated by direct rainfall and indirectly from runoff, with discharge to the underlying geological units and as river baseflow where there are positive hydraulic gradients towards the creeks or rivers.

3.6.2 Cordeaux Crinanite

3.6.2.1 Distribution and Flow

The Cordeaux Crinanite is not present within the Project area but is present to the north-east. The crinanite is considered a very low permeability aquitard up to 97.5 m thick (GeoTerra, 2010) that has intruded into and removed sections of the Bulli and Balgownie Seams. Feeder dykes from the main intrusion are also present in the Wongawilli Seam. The dykes are primarily dry and are not considered to provide permeability pathways in the mining area (GeoTerra, 2010).

Groundwater monitoring of the crinanite and underlying strata is conducted in the area, at monitoring points Nebo 1S and Nebo 2S, which are paired bores with well screens in the Bulli Seam and Hawkesbury Sandstone respectively. As shown in Figure 3-13, groundwater levels within the shallow crinanite show minimal change in response to below average rainfall experienced since 2017. Groundwater levels also remained stable despite depressurisation of the Bulli Seam at Nebo 1.

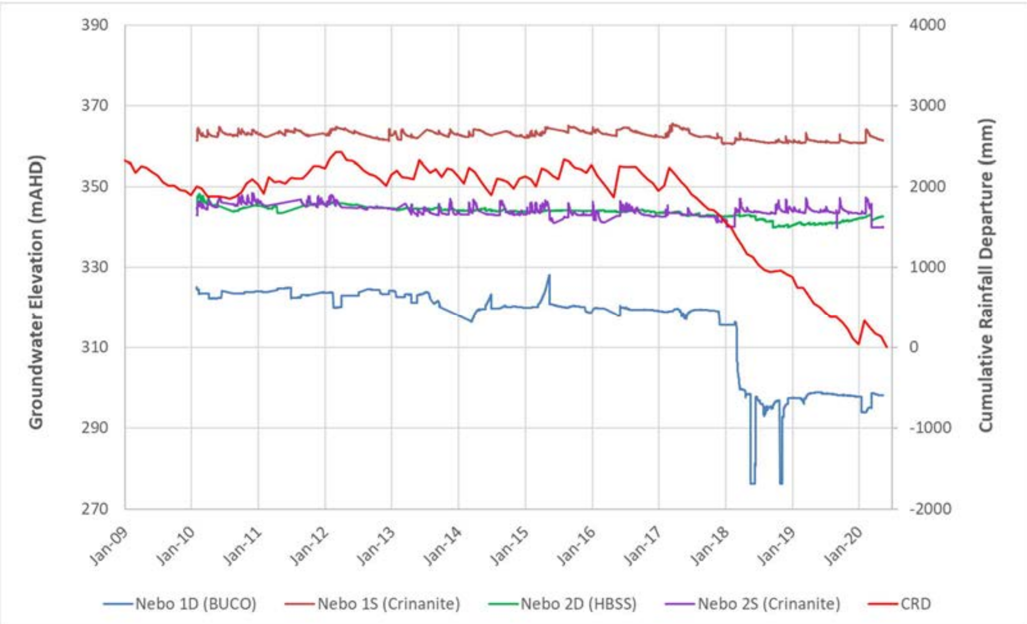


Figure 3-13 Hydrographs – Crinanite

3.6.2.2 Recharge and Discharge

Since the crinanite has a very low hydraulic conductivity and is considered an aquitard recharge and discharge are low. Limited recharge to the crinanite is via rainfall recharge and run-off where it outcrops and via leakage from overlying stratigraphic units. There is some minor leakage from the crinanite that discharges into the underlying hydrostratigraphic units.

3.6.3 Hawkesbury Sandstone

3.6.3.1 Distribution and Flow

The Hawkesbury Sandstone occurs at surface at the Project area and is a productive aquifer. It consists of thickly bedded massive quartz sandstone with siltstone, claystone and grey shale lenses up to several metres thick (Bowman, 1974; Moffitt, 1999).

Hawkesbury Sandstone is generally higher yielding than the underlying Narrabeen Group aquifers, including the Bulgo Sandstone, Scarborough Sandstone and the Coalcliff Sandstone. It is characterised as a dual porosity aquifer whereby groundwater is transmitted by both the primary and secondary porosity. Groundwater flows through the interconnected void space between grains of the rock matrix and the secondary porosity features consisting of structural features such as joints, fractures, faults, shear zones and bedding planes. The Project area lies within the Hawkesbury Sandstone groundwater flow system that supports the 'Metropolitan and Woronora Special Areas' of Water NSW, including the Nepean, Avon, Cordeaux, Cataract and Woronora Dams (the Avon and Cordeaux Dams shown on Figure 3-3.

Locally, the Hawkesbury Sandstone is present over the Project area except where it has been eroded away exposing the underlying Bald Hill Claystone and upper Bulgo Sandstone within the Gallahers Creek valley (GeoTerra, 2010). Groundwater flow is primarily horizontal along bedding planes, with minor vertical leakage along secondary structural features. Groundwater is controlled by the topography with flows towards major rivers that are deeply incised into the sandstone such as the Nepean River.

Within and surrounding the Project area groundwater levels within the Hawkesbury Sandstone are monitored at five VWPs (NWW11, NWWSH1, NWW GW01, NWW20B and NWWPE1). Groundwater trends for the monitoring points are presented in Figure 3-14 to Figure 3-19. Groundwater elevations in the Hawkesbury Sandstone range between 398 mAHD at NWW11 near Lake Avon, up to 470 mAHD at NWWPE1 to the north. The hydrographs also show a downward vertical gradient within the Hawkesbury Sandstone, and the underlying Narrabeen Group. In Figure 3-16 at NWW-GW01 the two deepest monitoring points at 310 m and 334 m appear to rise by 50 metres at the beginning of the monitoring however this is attributed to the pressure sensors equibrilating.

Figure 3-14 Hydrograph – NWW11

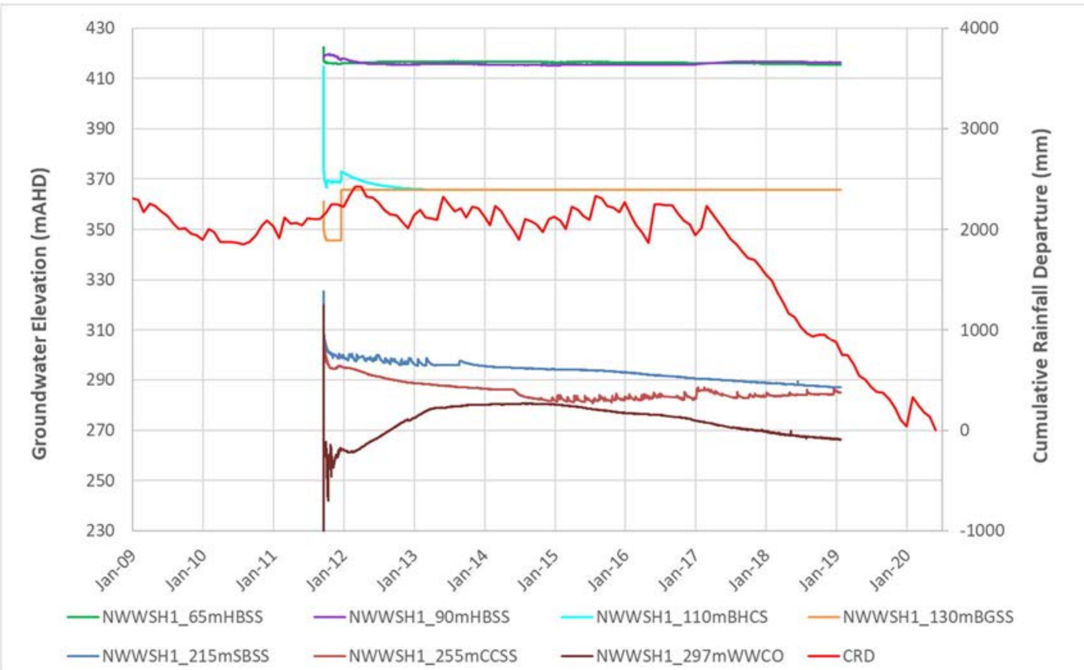


Figure 3-15 Hydrograph – NWWSH1

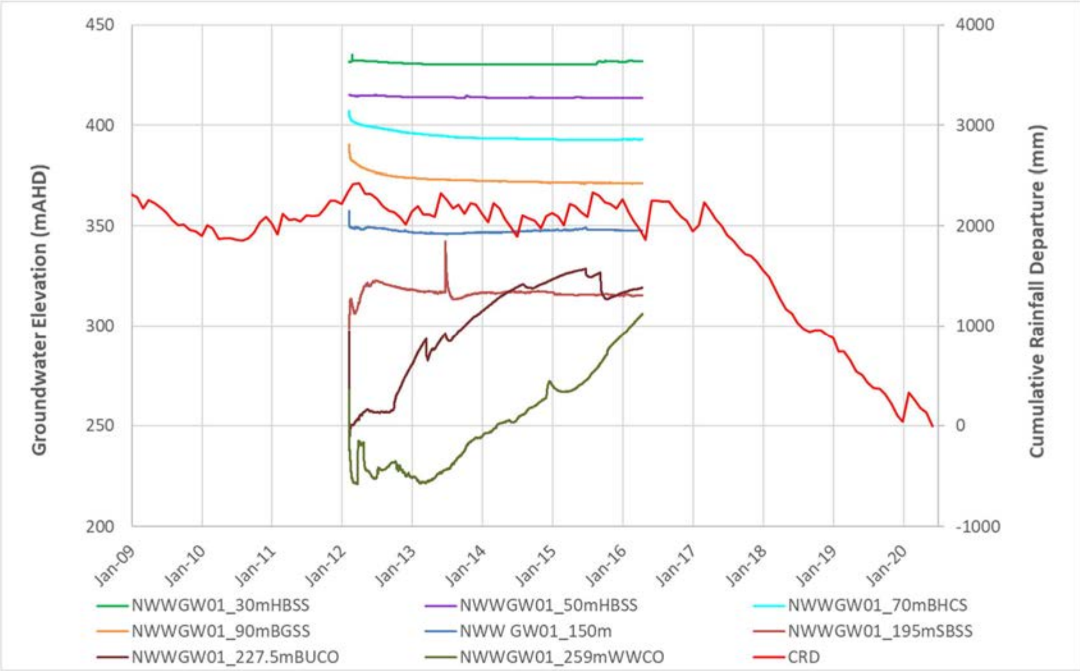


Figure 3-16 Hydrograph – NWW GW01

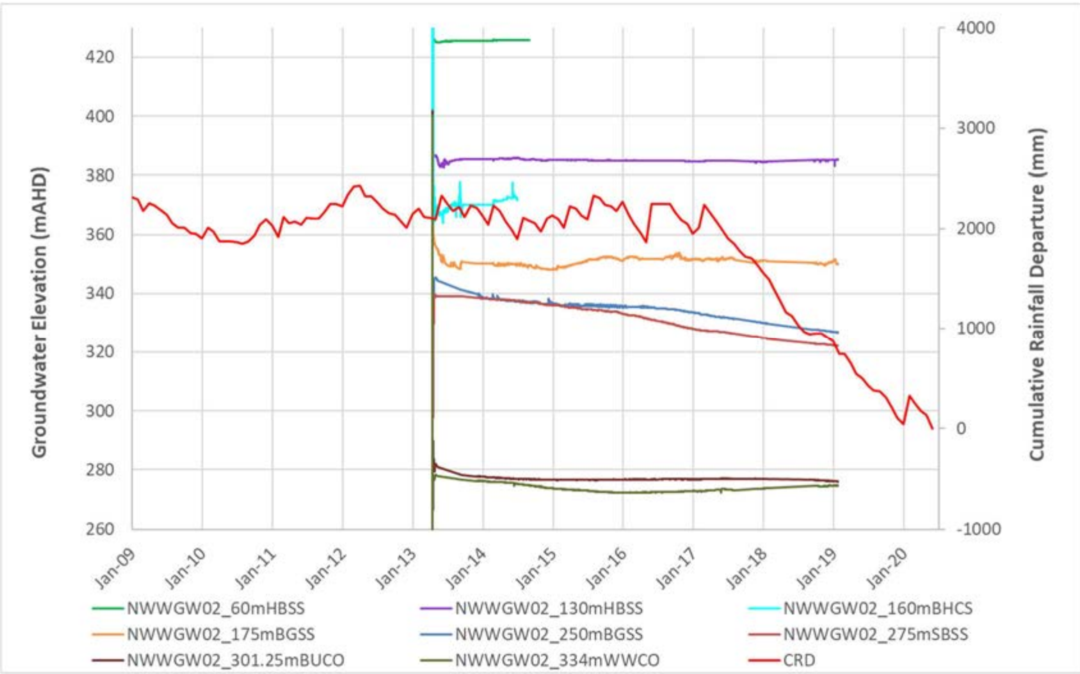


Figure 3-17 Hydrograph – NWW GW02

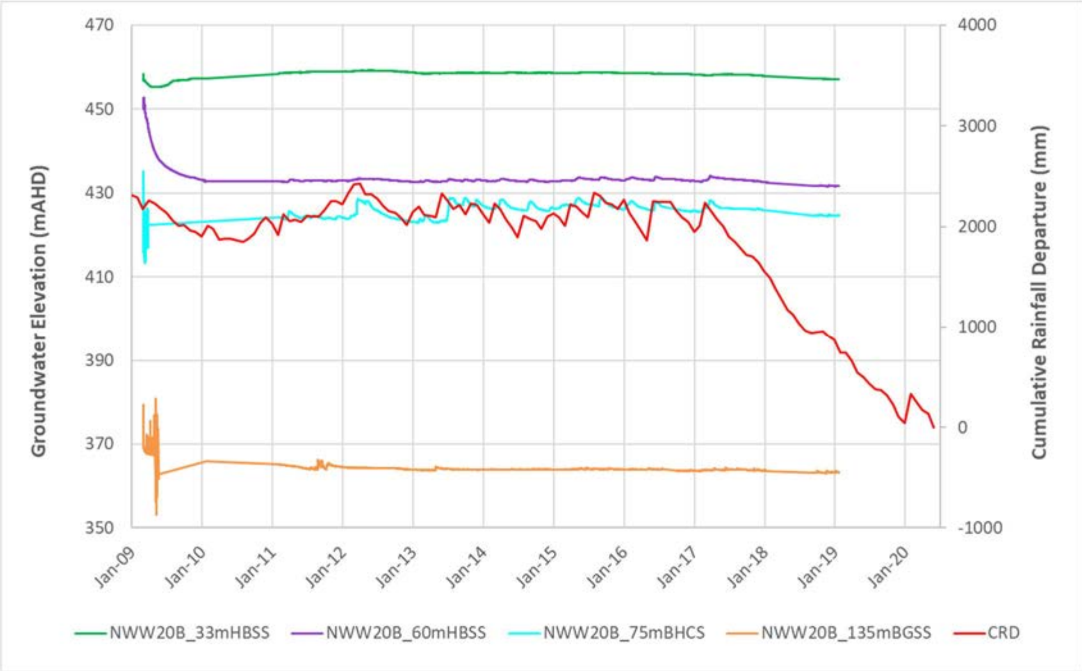


Figure 3-18 Hydrograph – NWW20B

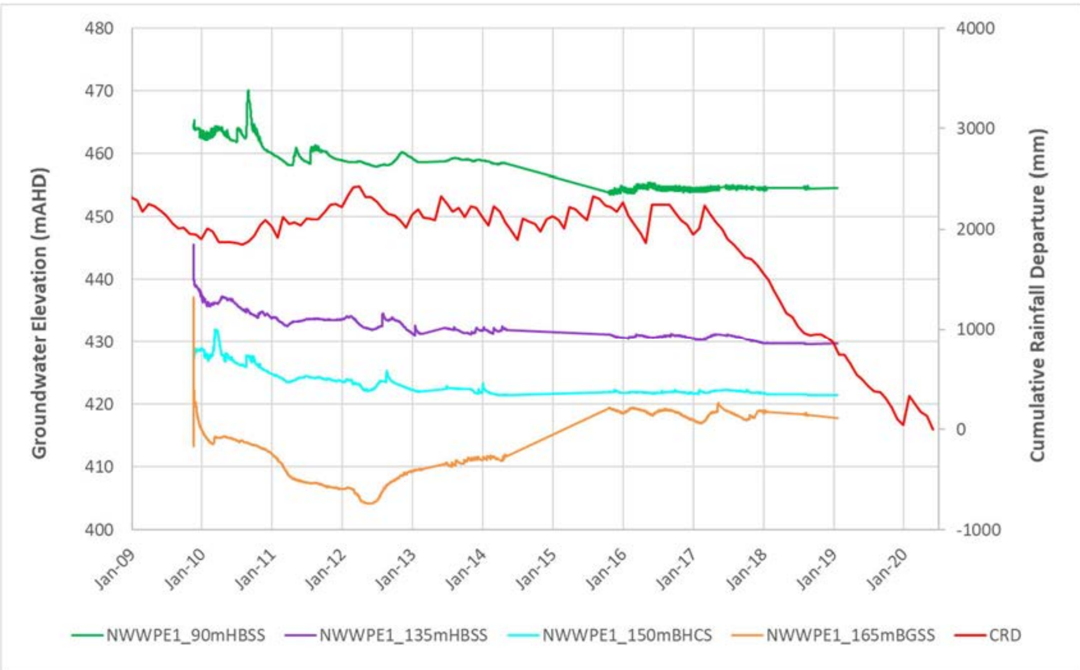


Figure 3-19 Hydrograph – NWWPE1

3.6.3.2 Recharge and Discharge

The Hawkesbury Sandstone is regionally extensive across the Sydney Basin and is recharged by rainfall through the sandstone outcrop, as well as from water storage dams (i.e. Lake Avon).

Groundwater from the Hawkesbury Sandstone also discharges into incised rivers intersecting the Hawkesbury Sandstones such as the Cataract and Nepean Rivers. Regionally the Hawkesbury Sandstone is used for groundwater supply (Section 3.8.1). However, within the Project area there are no registered landholder bores, due to land use restrictions within the Metropolitan and Woronora Special Areas.

3.6.4 Narrabeen Group

3.6.4.1 Distribution and Flow

The Narrabeen Group is a sequence of interbedded sandstone, claystone, and siltstone of late Permian and early Triassic age that underlies the Hawkesbury Sandstone. The sequence is present across the Project area that thickens to the north west.

The Narrabeen Group comprises three formations of low permeability aquitards. These aquitards impede vertical flow within the unit and are described as:

- The Bald Hill Claystone at the top of the Bulgo Sandstones interrupts the vertical groundwater flow from the Hawkesbury Sandstone. The aquitard is present across the Project area and is around 25 m thick.
- The Stanwell Park Claystone limits the interaction of groundwater between the Bulgo Sandstone and the Scarborough Sandstone and is present across the Project area, ranging in thickness from 6 m to 20 m.
- The Wombarra Claystone forms the base of the Narrabeen Group and also impedes vertical flow to the Illawarra Coal Measures. It is present across the Project area and thickens south-easterly ranging from around 30 m to 40 m.

Sandstone can provide porous storage with limited fracture flow and have a low water transmission capacity whilst mudstone, siltstone and shale effectively impede vertical flow. The Narrabeen Group is typically low yielding with its highest yields obtained from coal seams with lower yields obtained from the other lithologies. Few groundwater supplies are extracted from the Southern Coalfields due to the generally low hydraulic conductivity of the units and poor groundwater quality.

The hydraulic gradient within the Narrabeen Formation varies spatially due to the differences in hydraulic properties over varying depths. On a regional scale, groundwater flows horizontally from elevated areas in the southeast and western side of the Project area, with a hydraulic gradient towards the north.

The five VWPs (NWW11, NWWSH1, NWW GW01, NWW20B and NWWPE1) around the Project area also have sensors within the Bald Hill Claystone, Bulgo Sandstone, Scarborough Sandstone and Coal Cliff Sandstone. The hydrographs presented in Figure 3-14 to Figure 3-19 show groundwater levels within the Bald Hill Claystone range between around 395 mAHD at NWW11 near Lake Avon, up to 430 mAHD at NWWPE1 to the north. As discussed earlier, a downward vertical gradient is evident.

Groundwater levels within the Bulgo Sandstone at bores NWW11, NWWPE1 and NWW GW02 show a rise in groundwater levels from 2015. This is unique compared to groundwater levels within the overlying Bald Hill Claystone and Hawkesbury Sandstone and likely relates to recharge from water storage within Lake Avon. This apparent discrepancy is due to the Bulgo Sandstone not intersecting Lake Avon and hence not being recharged (refer to Section C-C' (Figure 3-8). This trend also contrasts with a general decline in groundwater levels within the underlying Scarborough Sandstone at NWW GW02.

The general decline in groundwater levels within the Scarborough Sandstone and Coal Cliff Claystone likely relates to depressurisation within the underlying mined coal seams, as observed in NWW SH1 (Figure 3-15) and NWW GW02 (Figure 3-17).

3.6.4.2 Recharge and Discharge

The Narrabeen Group occurs at surface in localised areas within the Project area, enabling recharge from Lake Avon and discharge to creeks where gradients enable this. Groundwater from the Narrabeen Group can also discharge naturally along the escarpment as springs, where it occurs at outcrops along the coast to the east. There are no registered bores within the Project area, but there are bores regionally that use groundwater from the Bulgo Sandstone for irrigation and water supply purposes.

3.6.5 Illawarra Coal Measures

3.6.5.1 Distribution and Flow

The Illawarra Coal Measures are the primary economic sequence of interest in the Sydney Basin, and consist of interbedded sandstones, shale and coal seams with a thickness of approximately 200 m to 300 m. The two main coal seams mined in the Project area are the uppermost Bulli Seam and the Wongawilli Seam.

On a regional scale, the groundwater in the Bulli Seam flows towards the north. Groundwater within the Permian coal measures is semi-confined where they occur at sub-crop, becoming confined with depth towards the north-west. Water quality within the Illawarra Coal measures is variable between coal measures and interburden typically ranging from brackish to saline.

Groundwater levels within the coal measures are monitored within the Project area at NWW SH1, NWW GW01 and NWW GW02 (Figure 3-15 to Figure 3-17). Groundwater levels were lowest at NWW GW01 at around 248 mAHD in the Bulli Seam and 220 mAHD in the underlying Wongawilli Seam in 2012. Since 2012, the Bulli Seam and Wongawilli Seam have recorded a gradual rise in water levels to a peak of 328 mAHD and 305 mAHD in 2016, respectively. These rises are attributed to an increase in storage due to recharge of the historical workings. Recovery of water levels, since the completion of mining reduces with increasing distance to the west. Water levels in the Wongawilli Seam at NWW SH1 have risen from around 250 mAHD in 2012 up to 280 mAHD in 2015. From 2015 groundwater levels show a slight decline over time, to 266 mAHD in 2019.

3.6.5.2 Recharge and Discharge

Groundwater recharge is from downward seepage from the overlying Narrabeen Group, as well as from recharge where the coal measures occur at outcrop along the escarpment. Recharge and groundwater trends are also influenced by water storage and movement associated with mine activities. Groundwater discharge occurs naturally as springs along the escarpment or where the coal measures are intersected by creeks. Discharge also occurs via seepage in the mine workings. Regionally there is discharge from the Illawarra Coal Measures where it discharges at the foot of the escarpment.

3.7 Water Quality

3.7.1 Surface Water

A summary of average water quality monitored within the Project area's 28 surface water monitoring points is included in Appendix A. Water quality is described in the Lake Avon and Gallahars Creek (Nebo) catchments.

Figure 3-20 shows the temporal distribution pattern of electrical conductivity (EC) and total dissolved solids (TDS) at two monitoring points (Creek bore AV1 and GC5) at Avon area with rainfall trends over the period 2011-2016. An assessment of EC and TDS in the Figure 3-20 indicates that the Gallahars Creek has high EC value due to higher TDS than the Avon River. The Avon River has a long-term EC average less than 100 µS/cm and the Gallahars Creek EC average exceeds 100 µS/cm. This surface water quality difference is attributed to the Lake Avon catchment having a high percentage of Hawkesbury Sandstone, which has a high quartz content and low salt content which in contrast to the dominant Bald Hill Claystone lithology of the Gallahars Creek catchment has a higher salt content.

Figure 3-21 and Figure 3-22 presents the spatial distribution of average pH and EC near Avon and Nebo (Gallahars Creek) area in the Project area. Mean values were estimated using available data over the period 2011 to 2016. Spatial distribution and variation of pH indicates water within the Avon area (average 5.5) is of lower pH than that of the Nebo area (average 6.5) (Figure 3-21). The resultant pH variation may be due to the influence of acid mine drainage, although HECON attribute low pH conditions in the Upper Nepean Catchment as natural due to the dissolution of silica and leaching of organic acids from peat and other organic matter. Under this scenario there may be more silica dissolution occurring and organic matter present in the Avon area than the Nebo area.

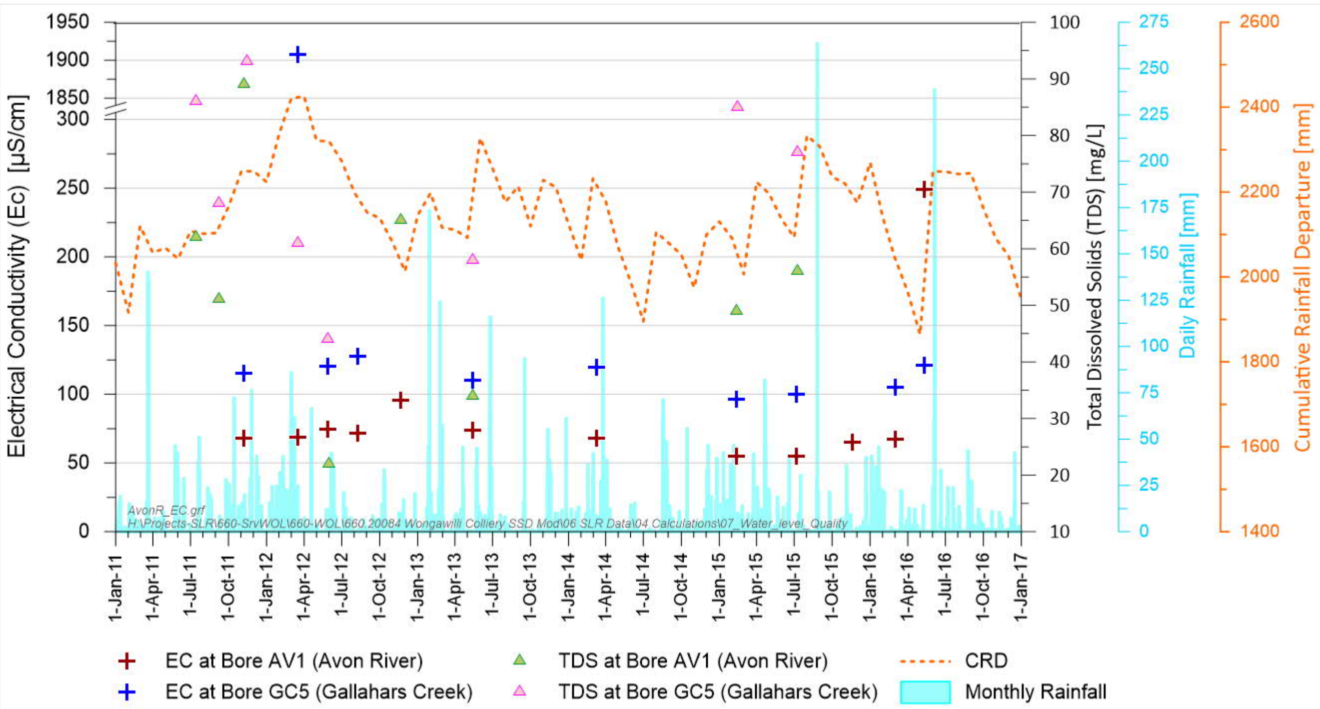


Figure 3-20 Temporal Electrical Conductivity and Total Dissolved Solids at Avon River and Gallahars Creek

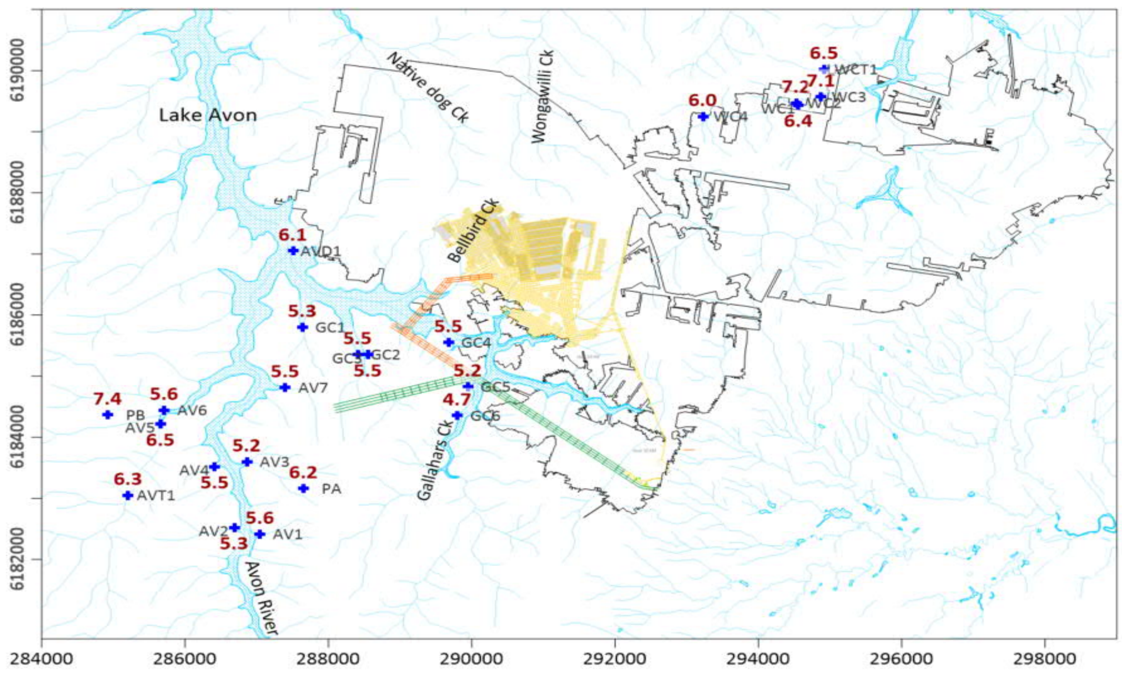


Figure 3-21 Spatial distribution of average pH at WWC

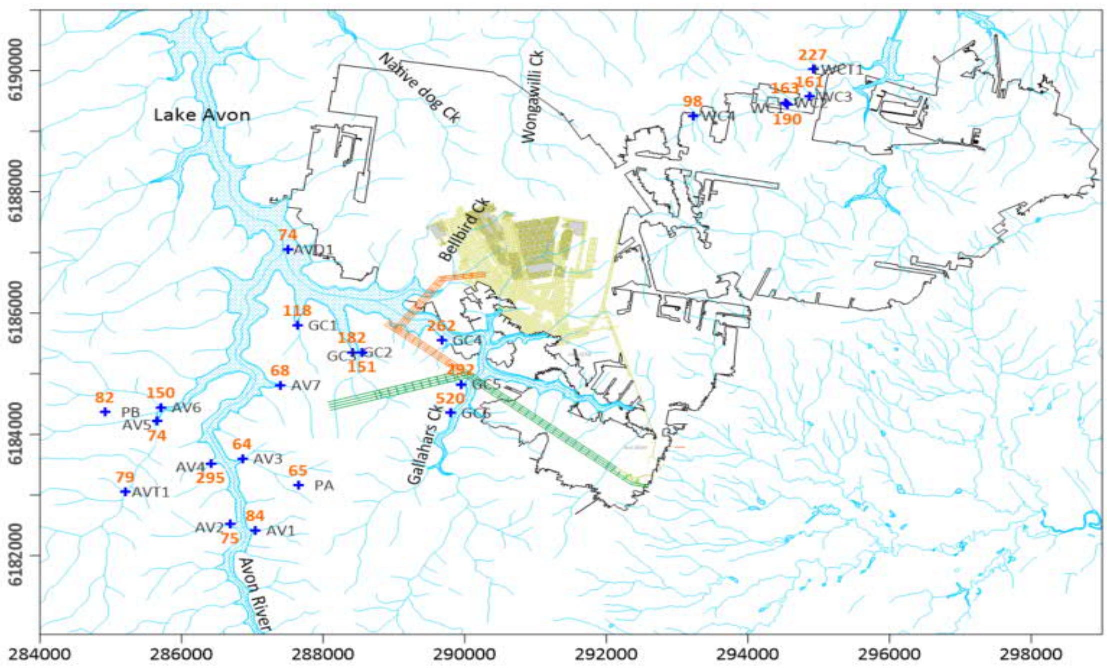


Figure 3-22 Spatial distribution of average EC (µS/cm) at WWC

3.7.2 Groundwater

A summary of groundwater quality data collected within the Project area from bores screened within the soil (Nebo 1s and 2s), crinanite (Nebo 2d and 3), Narrabeen Formation (Nebo 1d) and Bulli coal seam (Nebo 4) is presented in Appendix A. The groundwater quality data has been collected between 2010 and 2019. In summary, water within:

- Nepean River surface water is generally fresh (median EC 244 µS/cm) and generally has neutral pH (median pH 7.7).
- Groundwater within the soil is fresh (median EC 273 µS/cm) indicating the water is suitable for drinking water, irrigation and stock. pH conditions are relatively neutral (medium pH 6.5). The water is classified as sodium bi-carbonate type water.
- Groundwater within the crinanite is fresh to brackish (median EC 946 µS/cm, maximum EC 2,983 µS/cm) and generally has an alkaline pH (median pH of 9.7). The elevated pH is typical of these alkaline intrusive volcanics. Based on salinity the water is generally suitable for short term irrigation and stock water. The water is classified as calcium/sodium bi-carbonate type water.
- Groundwater within the Narrabeen Formation is generally fresh (median EC 724 µS/cm, maximum EC 1,404 µS/cm) indicating, based on salinity, the water is suitable for drinking water, irrigation and stock. pH conditions are generally alkaline (median pH 8.4). The water is classified as sodium bi-carbonate type water.
- Groundwater within the Bulli Seam is brackish (median TDS 2,375 mg/L) and, based on salinity, is suitable for irrigation and some stock (i.e. sheep and dairy cattle). The water is classified as sodium bi-carbonate type water.

Groundwater quality within the Permian coal measures is typically moderately saline to saline. With consideration of mine closure, as groundwater recovers, minerals that were oxidised under the drained conditions (i.e. sulphur) can undergo dissolution, in turn lowering the pH of the infilling waters (Wright et al., 2018). More acidic waters can lead to increased dissolution of precipitated metals such as zinc, iron and nickel (Wright et al., 2018; Price and Wright, 2016). The degree of acidity encountered during the saturation of the mine workings is dependent upon the acid forming potential of the mined material (Harries, 1997).

3.8 Groundwater Users

There are more than 1000 registered groundwater user bores within 5 km area at the south and south-east from the approved Project area. There are no registered groundwater bores near the Project to the west, south-west and north-west due to lack of population and the areas being reserved as drinking water catchment.

Almost 90% of the groundwater usage in the area to the west, north and south of the Project area is from the Hawkesbury Sandstone or from surficial alluvium and basalt aquifers far to the west and south of WWC. About 10% of the total entitlement is from the Bulgo Sandstone. This is probably due to generally lower bore yields, poorer water quality, and increased drilling costs for accessing deeper units (HydroSimulations, 2019).

Along the coastal plain to the east of WWC, most of the bores extract from the outcropping early Permian strata, i.e. the Cumberland Subgroup (i.e. the 'lower' Coal Measures) and the older Shoalhaven Group.

3.8.1 Groundwater Users – Anthropogenic

A search of the BoM's National Groundwater Information System (NGIS) was carried out for registered bores within 5 km of the approved Project area. The search indicated that there are 1,006 registered bores, of which 512 are functional, 454 are unknown, 26 are proposed, and 14 are abandoned, non-functional, or removed. The function of all bores identified in the database is presented below in Table 3-9 and the locations of bores shown in Figure 3-23.

Table 3-9 Registered Use of Groundwater Bores Within the Model Extent

Use	Count	Percent of Total
Commercial and Industrial	16	1.6
Dewatering	10	1.0
Exploration	9	0.9
Irrigation	139	13.8
Monitoring	379	37.7
Other	9	0.9
Stock and Domestic	33	3.3
Unknown	34	3.4
Water Supply	377	37.5
Total	1,006	100.0

A majority of groundwater users are located south of the Project area, within the Wianamatta Group outcrop area, and to the southwest, within the Hawkesbury Sandstone outcrop area. Most bores are located within the Hawkesbury Sandstone (453) and Bulgo Sandstone (322). Of these, 207 bores could be extracting water from the Hawkesbury Sandstone for water supply, irrigation, household, stock, and domestic purposes. Based on bore depth and the surface geology map, there is potential for approximately 64 registered bores (depth < 30m) targeting alluvium along the Nepean River and the Mount Hunter Rivulet, north to Appin Mine. These bores are used for monitoring (39), irrigation (15), water supply (4), stock (1) and other uses (5). Maximum yield of private bores surrounding Appin Mine do not exceed 1.5 litres per second (L/s).

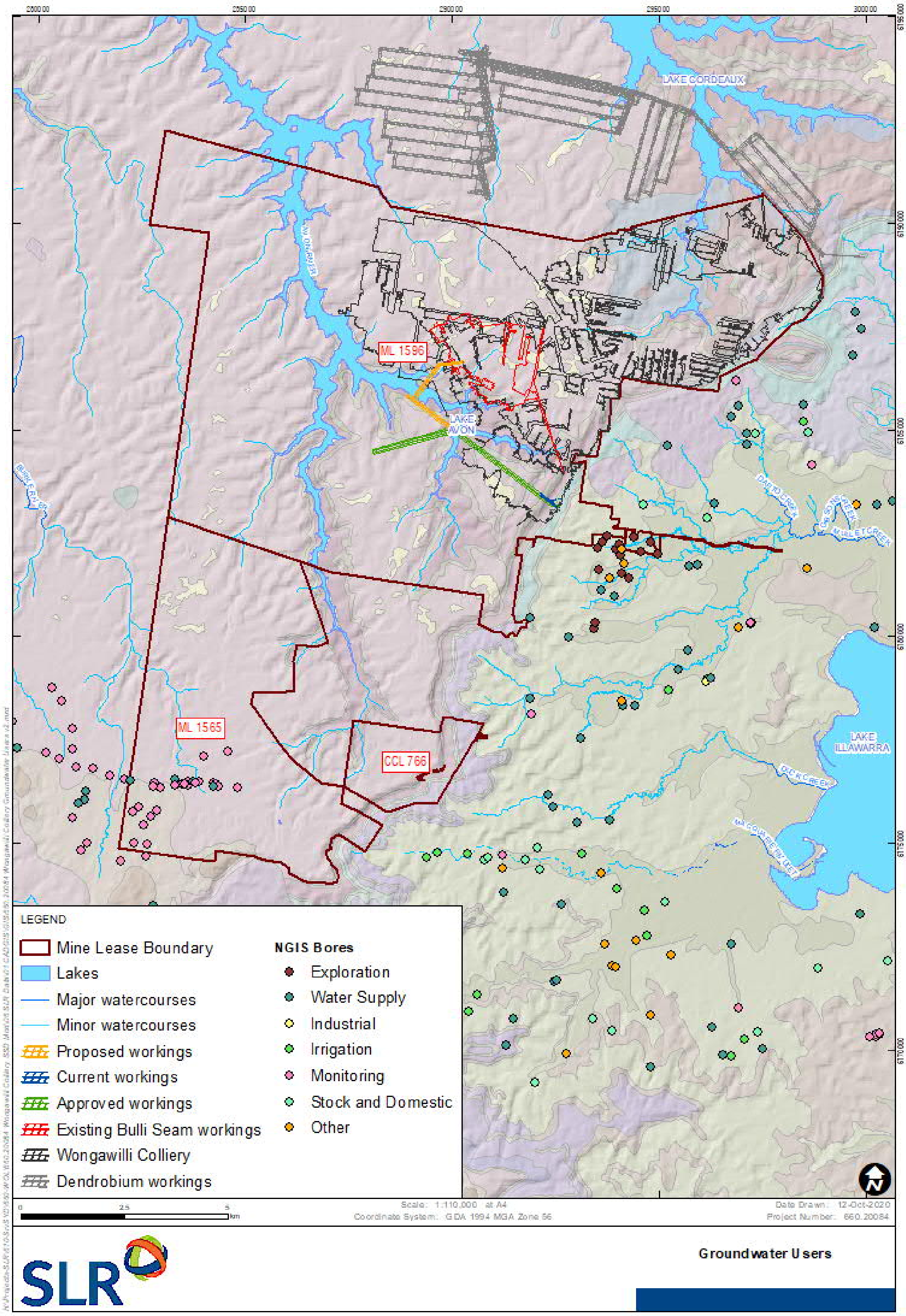


Figure 3-23 Groundwater Users

3.8.2 Groundwater Dependent Ecosystems

Groundwater dependent ecosystems (GDEs) are communities of plants, animals and other organisms whose extent and life processes are dependent on groundwater. There are several ecosystems that are dependent on groundwater such as terrestrial vegetation, aquifer and cave ecosystems, and wetlands. Groundwater discharge to streams is also an important discharge mechanism. Shallow groundwater can support terrestrial vegetation, such as forests and woodlands, either permanently or seasonally. Fauna depend on this vegetation and therefore indirectly depend on groundwater. River flow is often maintained largely by groundwater, which provides baseflow long after rainfall runoff ceases. Groundwater below the riverbed is partially recharged by surface water and is an important habitat for invertebrates.

Review of the Water Sharing Plan for the Greater Metropolitan Regional Groundwater Resources (NoW, 2013) indicated there are no high priority groundwater dependent ecosystems within the Project area. WWC undertook an assessment of creeks within the approved mining area and developed an aquatic ecology monitoring program for the collection of baseline data (Biosis, 2014a/b). A review of the National Atlas of Groundwater Dependent Ecosystems (Australian Bureau of Meteorology) accessed on 29 August 2020 identified the following GDEs as shown on Figure 3-24.

- Moderate potential groundwater interaction – localised areas immediately north of the proposed workings and south of the Avon River. Coastal sandstone gully forest, coastal warm temperate rainforest, escarpment foothills wet forest. (Moderate potential); and
- Low potential groundwater interaction – areas north of the southern extent of the proposed workings including escarpment foothills wet forest, coastal warm temperate rain forest, coastal sandstone gully forest.

As discussed in Section 3.3.2.1, upland swamps have also been mapped within the area, including one swamp area above the proposed Project alignment and one above the alignment of the approved NW Mains (Figure 3-24). Coastal upland swamps are listed as an endangered ecological community under the EPBC Act, and the NSW Threatened Species Conservation Act, 1995. Swamp vegetation is highly variable, ranging from open graminoid (grassy) heaths and sedgelands to fernlands and scrub (TSSC, 2014). Springs also occur along the escarpment.

3.8.3 Wetlands

The key receptors within the Project area consist of headwater swamps and valley infill swamps, as well as creeks in the vicinity of mining. These swamps are connected to groundwater within valley infill swamps and the sandstone aquifer. No upland swamps overly the proposed workings (GeoTerra, 2010).

The swamps nearest to the Nebo Area are Swamp 22 and Swamp 39 (Hansen Bailey, 2015), located approximately 288 m south-west and 280 m west of longwall N1. These are located beyond the predicted subsidence footprint of 20 mm. Groundwater modelling has been used to assess impacts to wetlands.

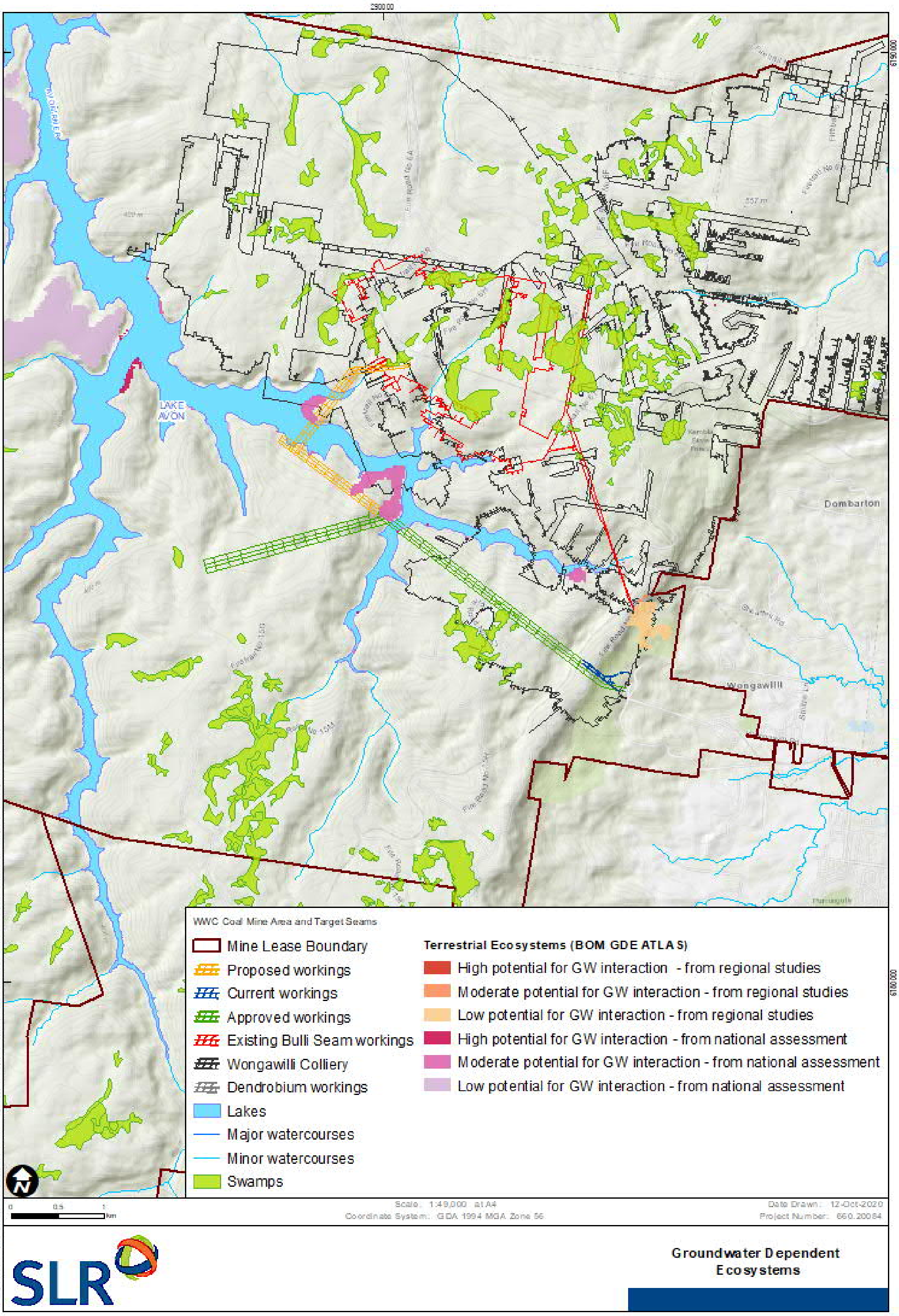


Figure 3-24 Groundwater Dependent Ecosystems

4 Conceptual Groundwater Model

The conceptual groundwater model for the Project area is depicted schematically in Figure 4-1. The figure shows the main stratigraphic sequences, recharge and discharge processes and inferred groundwater conditions during and after mining.

The main groundwater units within the Project area are:

- Upland swamps –saturated alluvial/colluvial sediments and organic matter. Recharged from rainfall as well as surface/subsurface water flow;
- The Cordeaux Crinanite is present in the Nebo area of the Project area and has similar characteristics to dolerite intrusions. The crinanite has intruded into and removed sections of the Bulli and Balgownie Seams. Feeder dykes from the main intrusion are also present in the Wongawilli Seam. The dykes are primarily dry and are not considered to provide permeability pathways in the mining area The crinanite is considered a very low permeability aquitard up to 97.5 m thick. The crinanite above the current and proposed workings is of low permeability, reducing leakage from overlying units into the workings where the crinanite is present;
- Hawkesbury Sandstone – main groundwater source and widely accessed for groundwater supply regionally and provides baseflow contributions where incised along major rivers (i.e. Cataract and Nepean Rivers). Groundwater flow is northward, and locally influenced where intersected by rivers and private abstraction bores. Current monitoring data indicates no depressurisation or drawdown within the Hawkesbury Sandstone in response to mining;
- Narrabeen Group – Sandstone interbedded with low permeability claystones that generally act as aquitards. Occur at outcrop in localised areas along Lake Avon. Recharge to the Narrabeen Group is from water storage areas where intersected, rainfall recharge along the escarpment and downward seepage from overlying Hawkesbury Sandstone; and
- Illawarra Coal Measures – with groundwater occurrence largely associated with the more permeable coal seams, with confined groundwater conditions. Groundwater flow generally northward, and locally depressurised due to current and historical mining. Current monitoring shows depressurisation from historical operations, with recovery in levels in localised areas, potentially influenced by underground water storage.

The Project area intersects the Bulli Seam that dips north-westward. The shallowest depth to Bulli Seam of around 85 m is associated with the approved alignment beneath Gallahers Creek arm of Lake Avon. The shallowest depth to Bulli Seam for the proposed new alignment is at around 140 m below the surface of Lake Avon.

The Project is likely to result in localised depressurisation within the Bulli Seam and Wongawilli Seam (where it declines) associated with direct interception with mine progression. Previous studies by Golder Associated predicted up to 9.1 ML/year of groundwater inflows associated with the approved alignment of the NW Mains.

The Project involves first workings along the approved NW Mains alignment and the proposed extension to connect to the existing vent shaft at Wongawilli 1. There is negligible subsidence predicted due to extraction associated with the Project, due to the design of the additional driveage. With no subsidence impacts predicted changes in hydraulic properties of the strata overlying the Bulli Seam is unlikely.

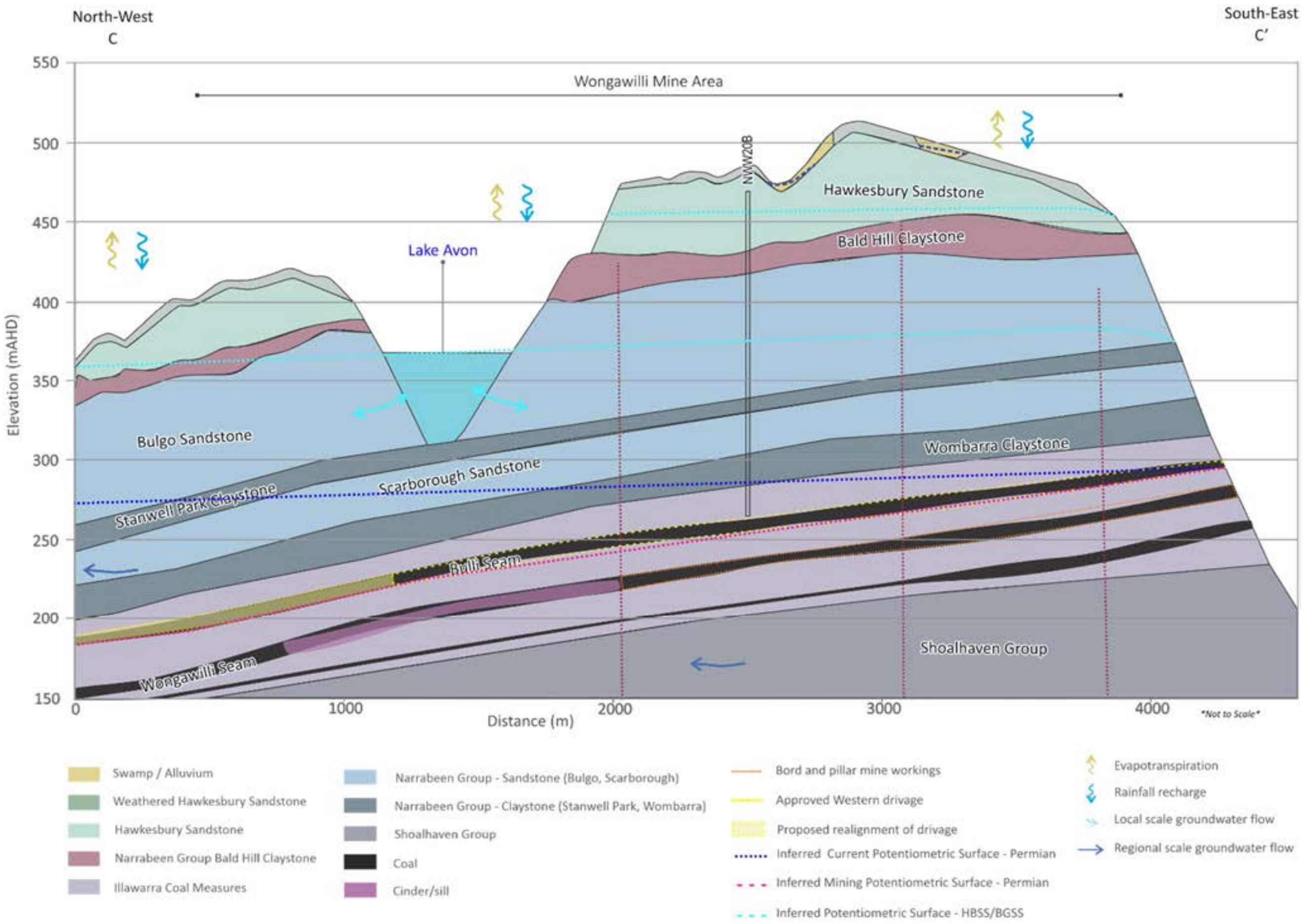


Figure 4-1 Groundwater Conceptual Model

Impacts to the groundwater system are shown conceptually on Figure 4-2 to Figure 4-4 and show the hydrogeological regime before, during and after mining.

Pre-mining groundwater flows (Figure 4-2) are north-westward down dip along the sandstone and coal beds. There is minimal vertical leakage between the hydrostratigraphic units with the Stanwell Park Claystone and Wombarra claystone that act as aquitards further restricting vertical groundwater movement. The inferred potentiometric surface for the Hawkesbury and Bulgo Sandstone is shown within the high in the stratigraphic sequence above the Stanwell park Claystone. In contrast the inferred potentiometric surface within the Permian sediments is lower in the sequence above the Bulli Seam within the Bulgo Sandstone Scarborough Sandstone and Eckersley Formation.

During mining (Figure 4-3) groundwater is pumped from the Bulli Seam to maintain dry working conditions. Consequently, the aquifers within the overlying hydrostratigraphic units of the Eckersley Formation, Wombarra Claystone and Scarborough Sandstone are depressurised lowering the potentiometric head within the Permian sequence to below the Bulli Seam. Above the workings where coal is extracted cracking is induced due to subsidence effects caused by the mining void. Similarly, cracking is induced in strata above historic bord and pillar mining where secondary extraction has occurred. The cracking is expected to extend into the Scarborough Sandstone enhancing vertical leakage into the workings. Locally groundwater flow directions are altered where there is greater vertical flow towards the Bulli Seam or towards cracked strata that provides a conduit into the mine void. Since cracking is not expected to extend into the Bulgo Sandstone there will be no leakage from surface water features including the Avon Dam. Higher in the stratigraphic sequence there will be no impacts to the potentiometric surface of the Hawkesbury and Bulgo Sandstone. Regional groundwater flow will continue to the north-west.

Post mining (Figure 4-4) groundwater will no longer be pumped from the mine workings, allowing the mine voids to become inundated and the recovery of potentiometric heads to pre-mining conditions, although this recovery may take many years. Induced cracking will remain in the strata overlying the flooded voids and there may be some minor mixing of groundwater between the hydrostratigraphic units via these cracks. However, as the strata becomes inundated following the cessation of pumping local groundwater flow will return to pre-mining conditions. Regional groundwater flow will continue to the north-west. Potentiometric heads within the Hawkesbury and Bulgo Sandstone will remain unchanged.

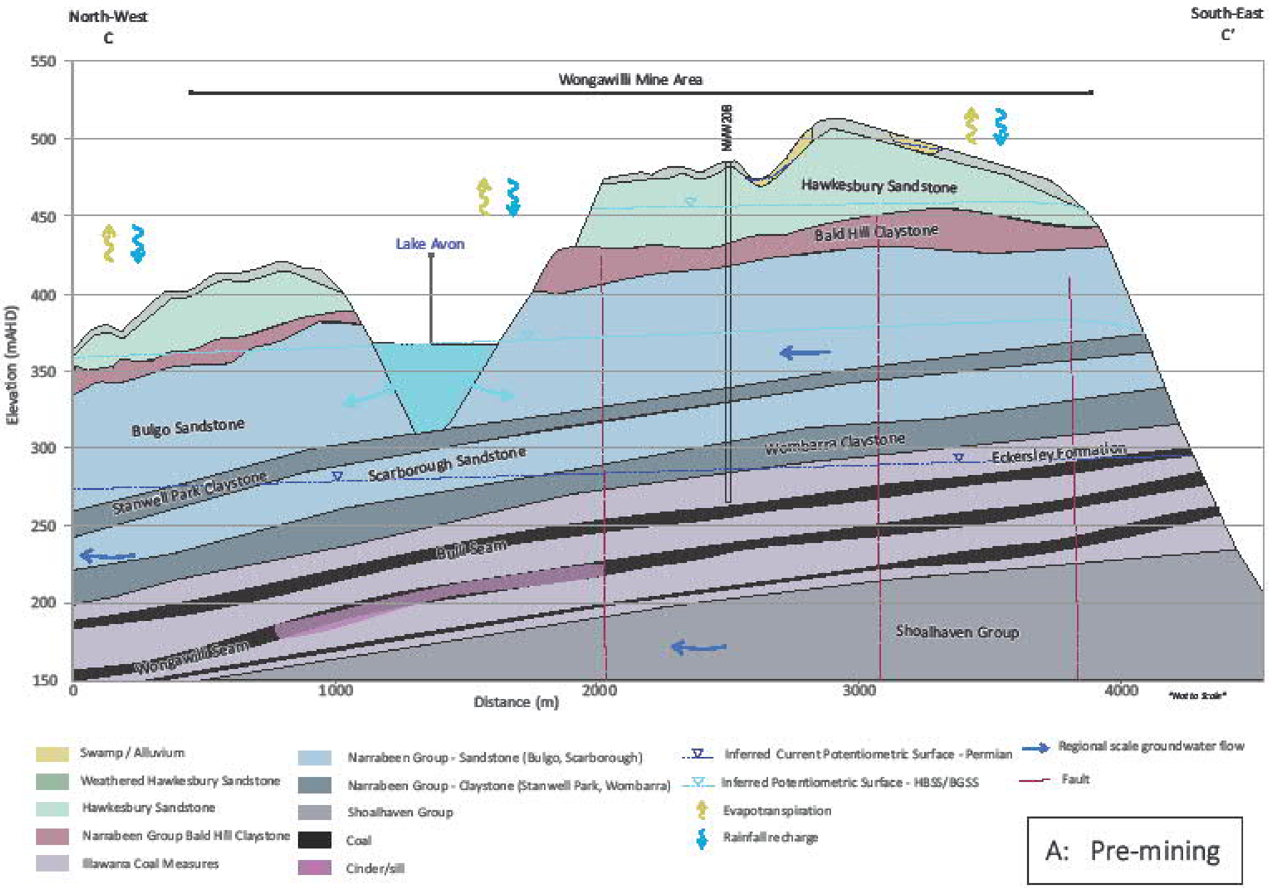


Figure 4-2 Groundwater Conceptual Model – Pre-mining

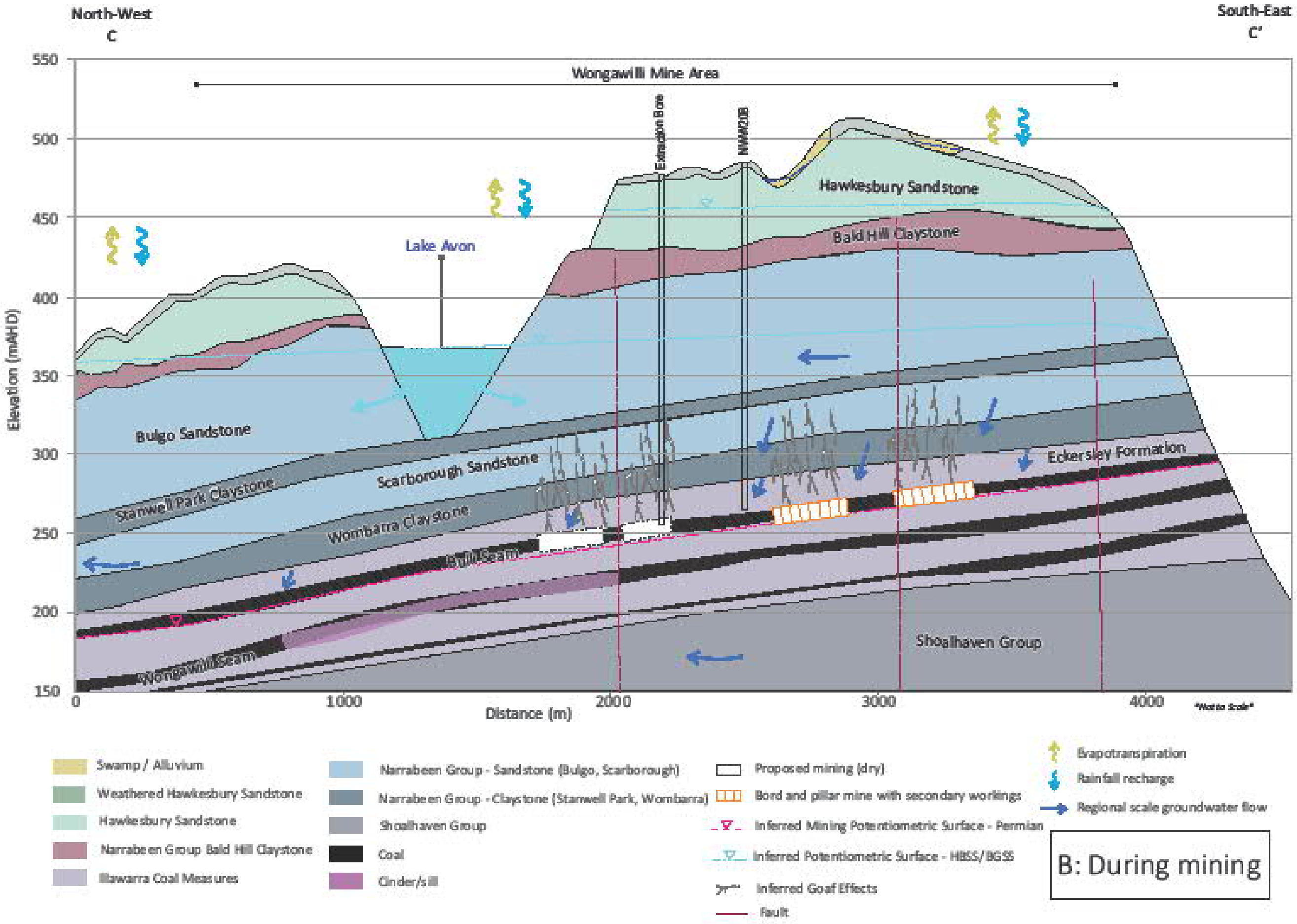


Figure 4-3 Groundwater Conceptual Model – Mining

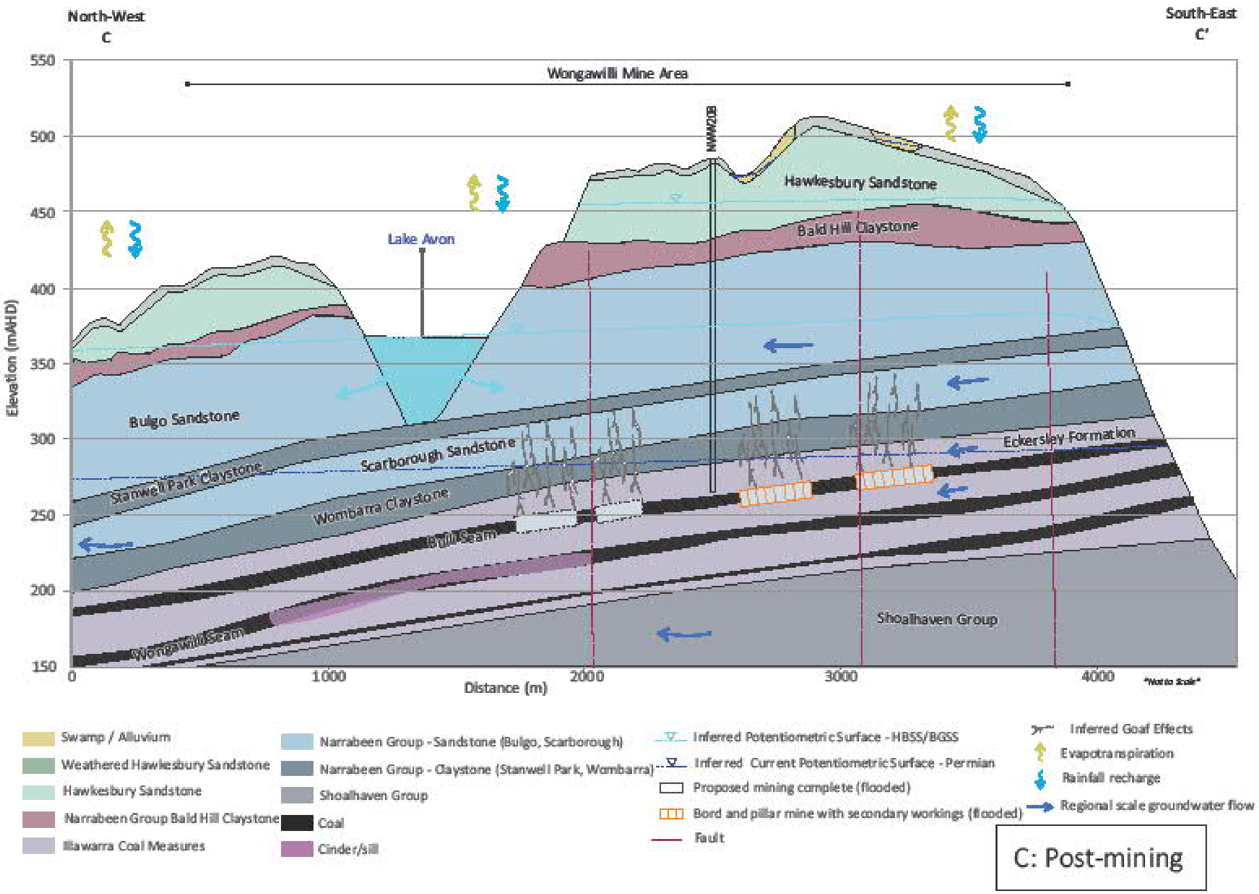


Figure 4-4 Groundwater Conceptual Model – Post-mining

5 Model Construction and Development

5.1 Initial Groundwater Modelling

Groundwater modelling of the Nebo Longwalls 1 to 6 was previously undertaken in 2011 to support the initial groundwater impact assessment (GeoTerra, 2010) to assess potential underground mining impacts on the local and regional groundwater systems. The numerical groundwater model was developed in SEEPW by Golder 2010. The model area is centred on the Wongawilli Colliery and includes the proposed Nebo workings, Elouera workings, Wongawilli workings and the Dendrobium workings. The hydrogeological conceptual model, aquifer parameters, geology and boundary conditions have been used as a basis for the MODFLOW model developed in this investigation and refined based on additional information. The SEEPW model consists of 11 layers ranging from the Hawkesbury Sandstone, the underlying Narrabeen Group Formations including the Cordeaux Crinanite, the Bulli and Balgownie coal seams as part of the Coalcliff Sandstone and the Wongawilli Seam.

This model has been developed by modifying a numerical model constructed to assess the impacts of coal mining at nearby Dendrobium (HydroSimulations 2019). The model was modified by increasing the cell size at the Dendrobium workings and refining the cell size at the Wongawilli workings.

5.2 Model Code

MODFLOW-USG Beta (Panday et al. 2015) was used to develop the model. MODFLOW-USG is a current version of MODFLOW code and was determined to be the most suitable modelling code for fulfilling the specified modelling objectives. MODFLOW-USG optimises the model grid and increases numerical stability by using unstructured, variably sized cells. These cells take any polygonal shape, and with variable size allowing for refinement in areas of interest, i.e. geological or mining features.

Where previous MODFLOW versions restricted flow to vertical connectivity between layers, MODFLOW-USG offers lateral connectivity between model layers. Lateral connectivity between layers enables more accurate representation of hydrostratigraphic units and faults, particularly those that pinch out or outcrop.

Unsaturated conditions are also able to be simulated using MODFLOW-USG. This allows the progressive mine dewatering and post closure rewetting to be represented by the model. For the model, vadose zone properties have been excluded, and the unsaturated zone was simulated using the upstream-weighting method, as is standard practice.

Python Code, Microsoft Excel and a MODFLOW-USG edition of the Groundwater Data Utilities (Watermark Numerical Computing) were used to create the MODFLOW-USG input files.

5.3 Model Extent and Mesh Design

The model domain is centred over the Project, and rectangular in shape, with the model boundaries extending 26.4 km from north to south and 35.4 km from east to west (Figure 5-1). The model domain was selected based on the following considerations;

- North: the northern boundary of the model was set 13 km from the proposed mining area and truncates the Dendrobium Mine from the model domain;

- South: the southern boundary of the model was set 12 km from the proposed mining area and follows a catchment boundary;
- West: the western boundary of the model was set 14 km from the proposed mining area. The eastern boundary for most part follows a north-south catchment boundary; and
- East: the eastern boundary of the model was set 8 km from the proposed mining area and follows the coastline.

To allow stable numerical modelling of the large spatial area of the model domain, an unstructured grid with varying Voronoi cell sizes was designed using Algomesh (HydroAlgorithmics, 2014). Refinement in areas of interest reduced the total cell count to a manageable size. The model domain was vertically discretised into 18 layers, each layer comprising a cell count up to 38,692. The total number of cells within the model is 555,074 and includes pinch-out areas in layers 2 to 18, where a layer is not present based on the structural geology.

Grid refinement was used to represent the following features:

- Main rivers and creeks, represented by cell size constraints of less than 100 m throughout the model domain;
- The escarpment refinement is represented by a cell size of less than 100 m throughout the model domain;
- Historical Mines are represented using square cells 100 m by 100 m; and
- The Proposed mining operations are represented using square cells, 25 m by 25 m.

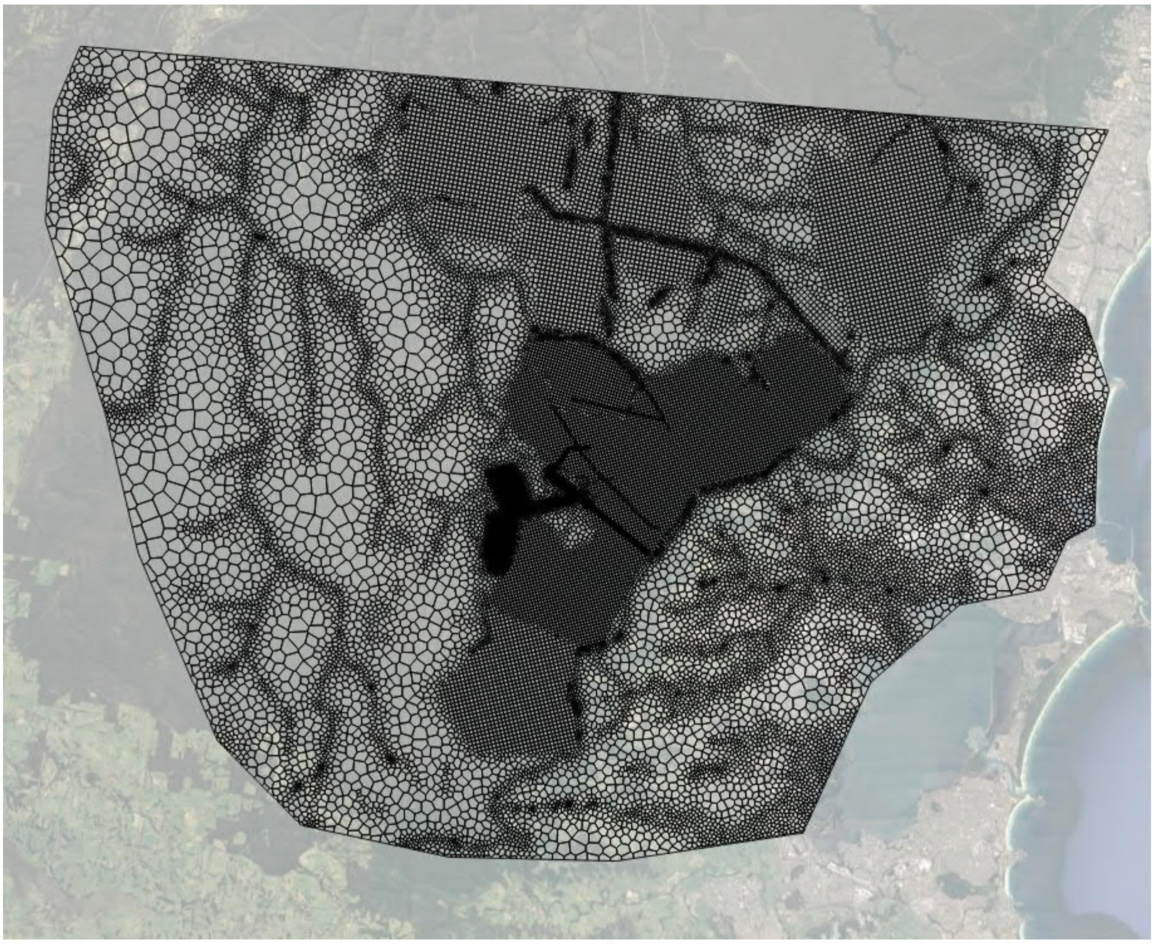


Figure 5-1 Model Domain and Model Grid

5.3.1 Model Layers

The model is discretised into 18 layers, as summarised in Table 5-1 showing the respective layer thicknesses. Model layers vary in thickness from 100 m to a minimum nominal thickness of 0.1 m. Layers pinch out where their thicknesses fall below this nominal value.

Table 5-1 Model Layers and Thicknesses

Model Layer	Stratigraphy		Secondary Strat / Lithology (Zonation)	Typical Thickness
1	Quaternary/ Tertiary	Alluvium/regolith	Swamp deposits Alluvium Weathered Hawkesbury Wianamatta Formation (shales)	Regolith 5 m, swamps 2 m, WMFM 10-30 m
2	HBSS	Hawkesbury Sandstone (upper)		25-40 m

Model Layer	Stratigraphy		Secondary Strat / Lithology (Zonation)	Typical Thickness
3		Hawkesbury Sandstone (middle)		40-50 m
4		Hawkesbury Sandstone (lower)	Crinanite	30-40 m
5	BACS	Bald Hill Claystone, (includes Garie [GRFM] and Newport Formations [NPFM])	Crinanite	20-30 m
6	BGSS	Bulgo Sandstone (upper)	Crinanite	40-60 m
7		Bulgo Sandstone (lower)	Crinanite	40-60 m
8	SPCS	Stanwell Park Claystone	Crinanite	10-20 m
9	SBSS	Scarborough Sandstone	Crinanite	30-40 m
10	WBCS	Wombarra Claystone	Crinanite	20-30 m
11	CCSS	Coalcliff Sandstone		15 m
12	BUSM	Bulli Coal seam	Fault zones, cindered coal, intrusions	2-4 m
13	LDSS	Lawrence & Loddon Sandstones	Fault zones, cindered coal, intrusions	20-30 m
14	WWSM	Wongawilli Coal seam	Fault zones, cindered coal, intrusions	4-10 m (~4 m working section)
15	KBSS	Interburden		15-25 m
16	-	Tongarra Seam		2 – 4 m
17	-	lower Permian Coal Measures		20-30 m
18	-	Shoalhaven Group and older		100 m

Model layer 1, is comprised of alluvium, regolith, weathered zones and swamp deposits, and extends across the whole model domain. Other layers are present to the limit of their subcrop extent with the exception of Layer 18 (Shoalhaven group) which does not subcrop within the model domain. For the model, the Shoalhaven Group and the older underlying stratigraphy is considered as the regional low-permeability basement.

The extent of the surficial stratigraphy in layer 1 was defined based on local site geological data (i.e. bore and drill hole data), State detailed surficial geological mapping and other public domain data (i.e. registered bores). The top of layer 1 was developed based on LiDAR data for the mine areas and along Gallahers Creek and Avon River. Outside of these areas Digital Elevation Model (DEM) from National Government data was used to define the top of layer 1. The thickness of alluvium and regolith was derived from site specific data (i.e. bore and drill logs) as well as the CSIRO (2015) regolith depth mapping.

The structure of the coal measures was based on the site geological models for the Project area. Outside of the Wongawilli mine areas, the groundwater model built for Dendrobium (HydroSimulations 2019) and public domain data were also used to define the model layers. The basal elevation of the target coal seam from the geological models was used, which captured displacement associated with localised minor faulting and folding. Coal seams have been simulated by combining the thicknesses of each constituent seam ply into a single coal seam layer.

5.3.2 Model Boundary Conditions

Where regional groundwater flow is likely to enter or leave the active model area a general head boundary (GHB) or constant head boundary (CHD) is specified. The GHB boundary condition was applied to the north and west boundaries of the model to represent the regional flow into and out of the model area and has been assigned in Layers 1 to 18 using pre-mining head elevation. Groundwater will enter the model where the head set in the GHB is higher than the modelled head in the adjacent cell, and exit the model when the water level is lower in the GHB. GHB conductance is calculated for each cell by multiplying the modelled hydraulic conductivity of the layer by the cross section of the cell and divided by the cell length. Boundary conditions showing cells assigned to GHB and CHB are presented in Figure 5-5-2.

The ocean and Lake Illawarra to the east and south east of the model has been specified as constant head boundaries set at 0 mAHD.

The southern extent of the model domain follows a catchment divide and has been represented as a no flow boundary condition.

Further flows into the model domain were in the form of recharge from rainfall. Flows into and out of the model domain also occur through baseflow in creeks and exit via evapotranspiration across the ground surface. Groundwater is also removed from the system using the drain package to represent mine dewatering. Recharge and evapotranspiration are discussed in more details in Section 5.4.1.

5.3.3 Model Timing

Both steady-state and transient calibration models have been developed as follows:

- Steady-state model of average pre-2005 conditions.
- Transient model calibration based on temporal pre-modification data at quarterly time intervals from December 2004 to June 2020.
- summarises the calibration model simulation periods and mining. Table 5-3 presents the timing intervals including when adjacent coal mines relevant to the Project are operational. While the Project is completed over a five year time span the predictive model extends to 2050 to simulate the available surrounding proposed mine plans.

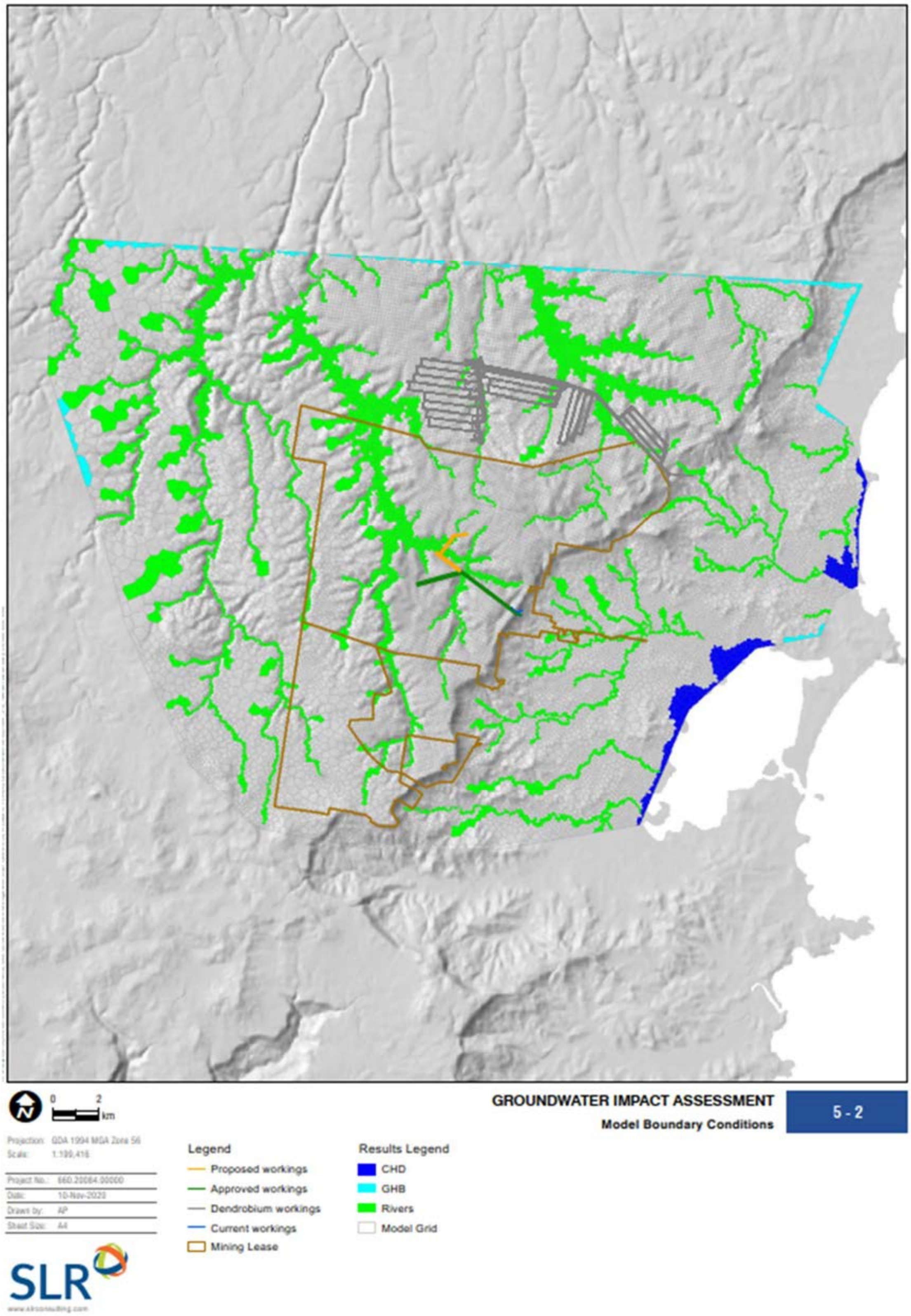


Figure 5-5-2 Model Boundary Conditions

Table 5-2 Model Plan timing

Model Purpose	Date from	Date to	Notes
Pre-mining Steady State			Natural conditions
Mining 'Warm up'	1 Jan 1940	31 Dec 2004	Variable stress periods to replicate historical mining and recovery in old mine workings over time
Transient Calibration	1 Jan 2005	30 Jun 2020	Quarterly stress periods, utilising observed temporal data (averaged per quarter) for rainfall, streamflow etc
Predictive Model	1 Jul 2020	31 Dec 2049	Quarterly stress periods, utilising long term historical average per quarter for rainfall, streamflow etc
Recovery Model	1 Jan 2050	31 Dec 2550	Variable stress periods, utilising long term historical average annual data

Table 5-3 Calibration model stress-period setup

Model Period	Interval	SP	Date from	Date to	Wongawilli Colliery	Dendrobium	Other Mines
Initial	-	1	Steady-state		x	x	x
Warmup	64 years	2	01-01-1940	01-01-2004	x	x	x
Transient Calibration	Quarterly	3	01-01-2004	02-04-2004	x	x	
Transient Calibration	Quarterly	4	02-04-2004	02-07-2004	x	x	
Transient Calibration	Quarterly	5	02-07-2004	01-10-2004	x	x	
Transient Calibration	Quarterly	6	01-10-2004	01-01-2005	x	x	
Transient Calibration	Quarterly	7	01-01-2005	02-04-2005	x	x	
Transient Calibration	Quarterly	8	02-04-2005	02-07-2005	x	x	
Transient Calibration	Quarterly	9	02-07-2005	01-10-2005	x	x	
Transient Calibration	Quarterly	10	01-10-2005	01-01-2006	x	x	
Transient Calibration	Quarterly	11	01-01-2006	02-04-2006	x	x	
Transient Calibration	Quarterly	12	02-04-2006	02-07-2006	x	x	
Transient Calibration	Quarterly	13	02-07-2006	02-10-2006	x	x	
Transient Calibration	Quarterly	14	02-10-2006	01-01-2007	x	x	
Transient Calibration	Quarterly	15	01-01-2007	02-04-2007	x	x	
Transient Calibration	Quarterly	16	02-04-2007	03-07-2007	x	x	
Transient Calibration	Quarterly	17	03-07-2007	02-10-2007	x	x	
Transient Calibration	Quarterly	18	02-10-2007	01-01-2008	x	x	
Transient Calibration	Quarterly	19	01-01-2008	02-04-2008	x	x	

Model Period	Interval	SP	Date from	Date to	Wongawilli Colliery	Dendrobium	Other Mines
Transient Calibration	Quarterly	20	02-04-2008	02-07-2008	x	x	
Transient Calibration	Quarterly	21	02-07-2008	01-10-2008	x	x	
Transient Calibration	Quarterly	22	01-10-2008	01-01-2009	x	x	
Transient Calibration	Quarterly	23	01-01-2009	02-04-2009	x	x	
Transient Calibration	Quarterly	24	02-04-2009	02-07-2009	x	x	
Transient Calibration	Quarterly	25	02-07-2009	01-10-2009	x	x	
Transient Calibration	Quarterly	26	01-10-2009	01-01-2010	x	x	
Transient Calibration	Quarterly	27	01-01-2010	02-04-2010	x	x	
Transient Calibration	Quarterly	28	02-04-2010	02-07-2010	x	x	
Transient Calibration	Quarterly	29	02-07-2010	02-10-2010	x	x	
Transient Calibration	Quarterly	30	02-10-2010	01-01-2011	x	x	
Transient Calibration	Quarterly	31	01-01-2011	02-04-2011	x	x	
Transient Calibration	Quarterly	32	02-04-2011	03-07-2011	x	x	
Transient Calibration	Quarterly	33	03-07-2011	02-10-2011	x	x	
Transient Calibration	Quarterly	34	02-10-2011	01-01-2012	x	x	
Transient Calibration	Quarterly	35	01-01-2012	02-04-2012	x	x	
Transient Calibration	Quarterly	36	02-04-2012	02-07-2012	x	x	
Transient Calibration	Quarterly	37	02-07-2012	01-10-2012	x	x	
Transient Calibration	Quarterly	38	01-10-2012	01-01-2013	x	x	
Transient Calibration	Quarterly	39	01-01-2013	02-04-2013	x	x	
Transient Calibration	Quarterly	40	02-04-2013	02-07-2013	x	x	
Transient Calibration	Quarterly	41	02-07-2013	01-10-2013	x	x	
Transient Calibration	Quarterly	42	01-10-2013	01-01-2014	x	x	
Transient Calibration	Quarterly	43	01-01-2014	02-04-2014	x	x	
Transient Calibration	Quarterly	44	02-04-2014	02-07-2014	x	x	
Transient Calibration	Quarterly	45	02-07-2014	02-10-2014	x	x	
Transient Calibration	Quarterly	46	02-10-2014	01-01-2015	x	x	
Transient Calibration	Quarterly	47	01-01-2015	02-04-2015	x	x	
Transient Calibration	Quarterly	48	02-04-2015	03-07-2015	x	x	
Transient Calibration	Quarterly	49	03-07-2015	02-10-2015	x	x	
Transient Calibration	Quarterly	50	02-10-2015	01-01-2016	x	x	
Transient Calibration	Quarterly	51	01-01-2016	02-04-2016	x	x	
Transient Calibration	Quarterly	52	02-04-2016	02-07-2016	x	x	

Model Period	Interval	SP	Date from	Date to	Wongawilli Colliery	Dendrobium	Other Mines
Transient Calibration	Quarterly	53	02-07-2016	01-10-2016	x	x	
Transient Calibration	Quarterly	54	01-10-2016	01-01-2017	x	x	
Transient Calibration	Quarterly	55	01-01-2017	02-04-2017	x	x	
Transient Calibration	Quarterly	56	02-04-2017	02-07-2017	x	x	
Transient Calibration	Quarterly	57	02-07-2017	01-10-2017	x	x	
Transient Calibration	Quarterly	58	01-10-2017	01-01-2018	x	x	
Transient Calibration	Quarterly	59	01-01-2018	02-04-2018	x	x	
Transient Calibration	Quarterly	60	02-04-2018	02-07-2018	x	x	
Transient Calibration	Quarterly	61	02-07-2018	02-10-2018	x	x	
Transient Calibration	Quarterly	62	02-10-2018	01-01-2019	x	x	
Transient Calibration	Quarterly	63	01-01-2019	02-04-2019	x	x	
Transient Calibration	Quarterly	64	02-04-2019	03-07-2019	x	x	
Transient Calibration	Quarterly	65	03-07-2019	02-10-2019	x	x	
Transient Calibration	Quarterly	66	02-10-2019	01-01-2020	x	x	
Transient Calibration	Quarterly	67	01-01-2020	02-04-2020	x	x	
Transient Calibration	Quarterly	68	02-04-2020	02-07-2020	x	x	

5.4 System Stresses

5.4.1 Recharge and Evaporation

Diffuse rainfall recharge is simulated in MODFLOW USG using the recharge package (RCH). Recharge is distributed in laterally distinct zones within the model domain. Zones are based on outcropping geology and a portion of annual rainfall was assigned to each zone. The proportion of rainfall entering the model as recharge varied through the calibration process. The calibrated recharge rates are discussed in Section 6.5.1.

Evapotranspiration from shallow water tables is simulated in MODFLOW USG using the evapotranspiration package (EVT). Evapotranspiration is represented in the upper most cells of the model domain down to an extinction depth of three metres. A maximum rate of evapotranspiration was set at 600 mm/year.

5.4.2 Surface Drainage

Groundwater interaction with surface drainage was simulated in MODFLOW-USG using the river package (RIV). Required RIV inputs are the elevation of the river bed and water depth. The modelled river stage heights were approximated from river gauges installed at various locations across the model domain. This included ten local river gauges along Gallahers Creek, Bellbird Creek and upper reaches of Avon River, and 16 public domain gauges for rivers including the : Nepean, Burke, Avon, Cordeaux and Cataract Rivers as well as dam level gauges for the Nepean, Avon, Cordeaux and Cataract Dams. Historical data averages were utilised to fill in data gaps where gauge information was not available. Seasonal averages were calculated from 1990 to present (July 2020). Stage heights were set at 0 m for all minor ephemeral streams and creeks. Modelled river zones are presented in Figure 5-3.

River bed conductance was calculated as a function of the vertical hydraulic conductivity and lateral and vertical dimensions of the river bed material. Drainage systems within the model domain have been categorised into 18 zones. Table 5-4 provides a summary of these zones with their modelled river bed parameters. The length component for the conductance varied on a cell by cell basis, calculated from the length of the of the river/drainage line that falls within the cell area.

Within the transient model the stage heights for the main creeks were varied on an average of the quarterly measured readings at the various gauges. The steady state stage was based upon the average of the gauge monitoring data. Where data was available, the water levels at gauge locations were averaged over that time period. If data was missing for a particular stress period, the long-term average for the months (eg. averaged across all January, February and March dates) was calculated. The predictive stress periods use the same method of averaging for long-term average as for the stress period months.

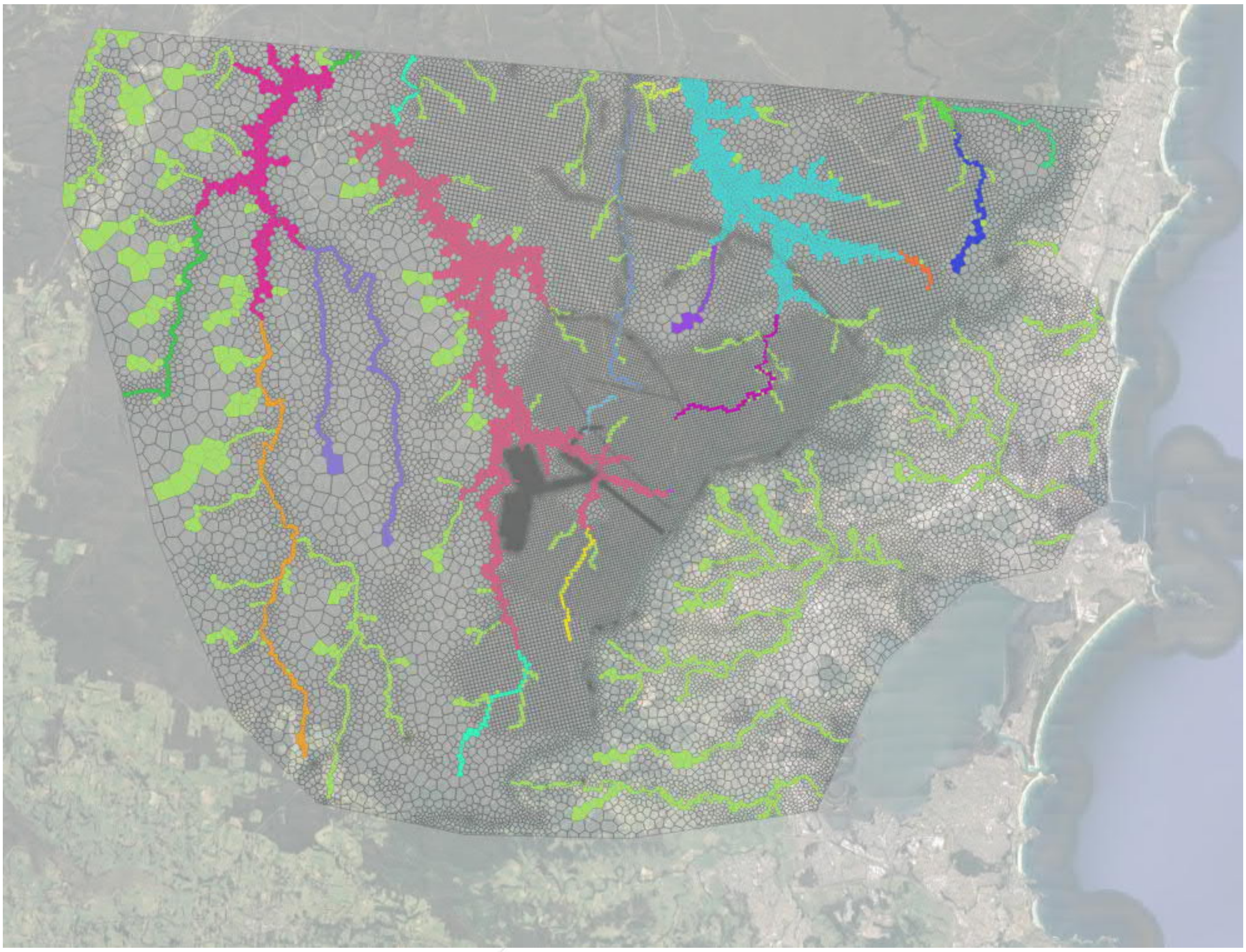


Figure 5-3 Modelled River Zones

Table 5-4 Modelled River Bed Parameters

Zone	River ID	Vertical hydraulic conductivity Kz (m/day)	Width (m)	Stage height (m)	Bed thickness (m)
1	AVON Lake	0.001	25	1 - 11.8	1
2	CATARACT Lake	0.001	25	1 - 12.61	1
3	CORDEAUX Lake	0.001	25	1 - 11.59	1
4	NEPEAN Lake	0.001	25	1 - 16.62	1
5	Nepean River	0.01	10	0 - 4.13	1
6	Burke River	0.01	10	0 - 2.24	1
7	Avon River	0.01	10	0.23 - 1.28	1
8	Wongawilli Creek	0.01	10	0 - 0.45	1
9	Sandy Creek	0.01	10	0.07 - 0.54	1
10	Goondarrin Creek	0.01	10	0 - 0.45	1
11	Cordeaux River	0.01	10	0 - 1.08	1
12	Cataract Creek	0.01	10	0 - 0.5	1
13	Cataract Creek (East)	0.01	10	0 - 0.49	1
14	Gallahers Creek	0.01	10	0 - 0.87	1
15	Bellbird Creek	0.01	10	0 - 0.19	1
16	Flying Fox Creek	0.01	10	0 - 0.24	1
17	Cordeaux Continued	0.01	10	1.01 - 1.48	1
18	Other Tributaries	0.01	10	0	1
19	Little Burke - Explorer	0.01	10	0.52 - 2.24	1

5.4.3 Mining

The MODFLOW Drain (DRN) package is used to simulate mine dewatering in the model for the Project and the surrounding mines. Drain boundary conditions allow a one-way flow of water out of the model. When the computed head drops below the stage of the drain, the drain cells become inactive (Rumbaugh and Rumbaugh, 2011). This is an effective way of theoretically representing removal of water seeping into a mine over time, with the actual removal of water being via pumping and evaporation. 'Stacked drains' are used to simulate the connected fracture zone.

Drain cells are applied to the layers containing target coal seams for each of the respective mines. The head elevation was set to drain to the base of the target layers. Drain cells have a nominal conductance of 100 m^2/day to ensure dewatering of the target layers is achieved. The majority of the underground mines simulated use the bord and pillar method but there is also some long wall mining occurring. The longwall extraction in the Dendrobium Mine to the north of the Project area, is represented as drain cells in model layer 14 only (Wongawilli Seam). The drain cells applied for the surrounding mines were interpolated from mine schedule information available from EIS documentation.

The hydraulic properties were varied with time using the Time-Variant Materials (TVM) package of MODFLOW-USG. For the underground mines, the hydraulic properties where changed with time in the goaf and overlying fractured zone directly above each longwall panel. In doing so, a series of multipliers were applied to enhance the hydraulic conductivity within the deformation zone overlying coal extraction areas. The multipliers follow the ramp function, so the multipliers with highest values are applied to the units closest to the mined seam and then gradually decay as the units become close to the maximum height of connective cracking. The maximum height of connective cracking was derived using the Tammetta equation (Tammetta 2014). A logarithmic stepping function was used to change the hydraulic properties across stress periods.

6 Model Calibration

6.1 Calibration Strategy

The numerical model was calibrated with a pre-mining steady state run, followed by a transient run (2005 to present). The transient run included available groundwater elevation data and documented pit inflows for the various stress periods. Aquifer parameters, system stresses and boundary conditions were adjusted to produce the closest possible match between observed and simulated water levels. Parameter ESTimation (PEST) software (Doherty 2010) was used to optimise hydraulic parameters and recharge rates to provide the most appropriate statistical calibration of the groundwater model.

The hydraulic heads, strata hydraulic properties and recharge from the steady state calibration provided the starting values for the transient calibration of the model. The hydraulic properties and recharge rates were estimated through the transient calibration. To begin each transient model calibration run, a steady state simulation was undertaken. The steady state heads for each calibration scenario were transferred into the transient calibration model as initial groundwater levels. This approach ensured that initial conditions (steady state groundwater levels) for the transient run were derived from the corresponding parameter set being applied in the transient simulation. Discrepancies between these two parameter sets would disrupt groundwater flow budgets as the transient version of the model settles to pseudo steady state conditions outside the mining areas throughout the simulation.

6.2 Calibration Targets

The earliest water level measurement for each bore was assigned to the initial steady state stress period. The observations used for calibration ranged from 2009 to 2013 depending on location. Observations used in the transient calibration period were averaged per month to reduce the frequency and thus the temporal weight to the calibration statistics. The source for these observations were site monitoring bores. A review of public records revealed no usable data.

The type of monitoring locations was made up of open standpipes (OSP) and VWPs. The monitoring network consisted of 5 OSP and 54 VWP. The water levels monitored for the different stratigraphy is summarised in Table 6-1 A total of 59 observation targets were used in the steady-state calibration. The transient model was calibrated against monthly average measurements at each site. A total of 4655 measurements across 59 monitoring points were used in the calibration. The groundwater levels have been recorded between March 2009 and May 2020. The locations of monitoring points used in the steady-state and transient calibration are presented in Figure 6-1.

Table 6-1 Monitoring Point Lithology

Stratigraphy	Count
Crinanite	10
Hawkesbury Sandstone	15
BaldHill Claystone	6
Newport Formation	1
Bulgo Sandstone	9

Stratigraphy	Count
Stanwell Park Claystone	1
Scarborough Sandstone	3
Coalcliff Sandstone	2
Bulli Coal	4
Loddon Sandstone	1
Eckersley Formation	1
Wongawilli Coal	6
Total	59

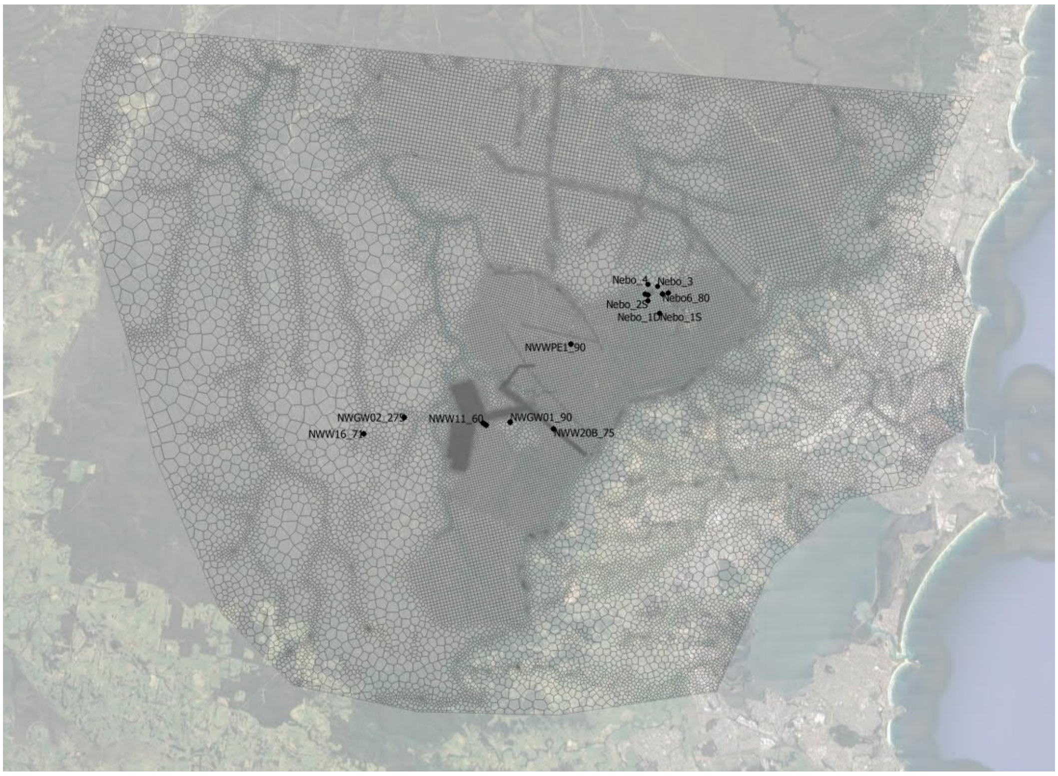


Figure 6-1 Calibration Points

6.3 Calibration Statistics

Calibration is achieved by matching trends over time, developing an equalised water balance and preparing statistical parameters to fit the historical observations. Statistically the industry standard method to evaluate the calibration of the model is to examine the statistical parameters associated with the calibration. Evaluation is conducted by assessing the error between the modelled and observed (measured) water levels in terms of the root mean square (RMS). RMS is expressed as:

$$RMS = \left[1/n \sum (h_o - h_m)_i^2\right]^{0.5}$$

where: n = number of measurements

ho = observed water level

hm = simulated water level

RMS is considered to be the optimal measure of error, if errors are normally distributed. The acceptable value for the calibration criterion depends on the magnitude of the change in heads over the model domain. If the ratio of the RMS error to the total head change in the system is small, the errors are only a small part of the overall model response. Table 6-2 provides the summary of calibration statistics. The RMS calculated for the calibrated model is 21.2 m. The total measured head change across the model domain is 250.8 m; therefore, the ratio of RMS to the total head loss (SMRS) is 8.44% (i.e. Scale Root Mean Square). This indicates an acceptable calibration and meets guidance provided in the Australian groundwater modelling guidelines of 10% Scaled RMS (Barnett et al, 2012).

Table 6-2 Transient Calibration Statistics

Statistic	Value
Mean Residual (m)	0.6
Abs. Residual Mean (m)	17.1
Standard Deviation (m)	21.2
Sum of squares (m^2)	2087853.5
RMS Error (m)	21.2
Min Residual (m)	-70.8
Max Residual (m)	45.5
Number of obs.	4655
Range in obs. (m)	250.8
Scaled Std	8.44%
Scaled Abs. Mean	6.80%
Scaled RMS	8.44%
Targets within ±2m	498
Targets within ±5m (excl. within ±2m)	453
Targets within ±10m (excl. within ±5m)	697
Targets within ±20m (excl. within ±10m)	1457
Targets residual over 20m	1550

6.4 Transient Calibration Results

6.4.1 Statistics

Figure 6-2 presents the observed and simulated groundwater levels graphically as a scattergram for the initial and historic transient calibration (2005 to 2018). Resulting calibration statistics for the transient simulation are shown in Table 6- 6-3. The model scaled RMS is 8.44 %, indicating a good fit using statistical targets and is fit for purpose for predictions as suggested by the MDBC (2001) and Barnett et al. (2012). Error! Reference source not found. shows the average calibration residual and absolute average residual per each model layer. The residual value is the difference between the measured and the modelled water level at each bore. A negative residual represents an over estimation of water levels, while a positive residual represents an underestimate. Error! Reference source not found. shows an overestimation of water levels in the model layers across the upper 6 layers whilst there is an overall underestimation of water levels for deeper layers (i.e. layers 7-14). The underestimation in deeper layers may be due to underground water storage and the lack of boundary conditions in the model to replicate this impact.

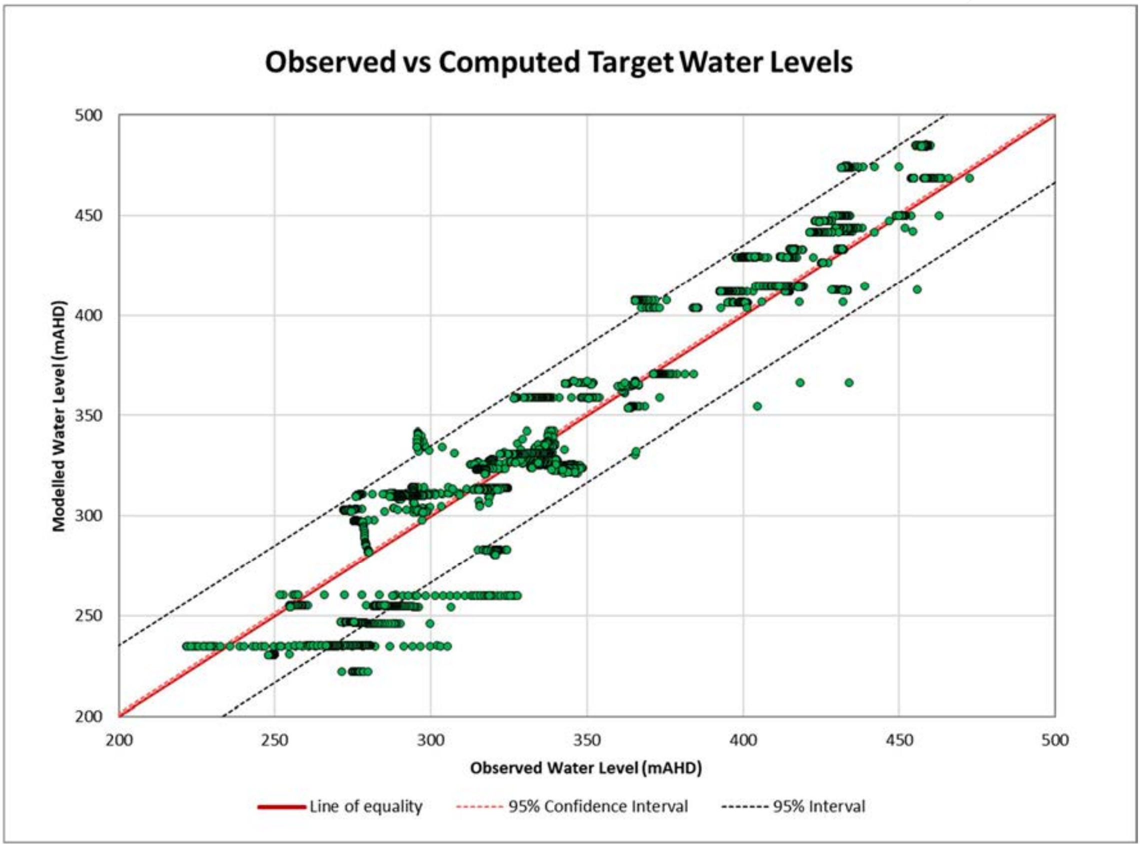


Figure 6-2 Transient Calibration – Modelled vs Observed Groundwater Levels

Table 6- 6-3 Average Residual by Model Layer

Model Layer	Formation	Mean Residual (m)	Mean Absolute Residual (m)	Number of Observation Targets	Number of bores
1	Weathered/Alluvium	2.0	2.0	192	1
3	Hawkesbury Sst (lower)	26.4	26.4	99.0	1
4	Hawkesbury Sst (lower)	19.0	19.1	573	9
5	Bald Hill Claystone and Crinanite	21.1	21.4	357.0	6
6	Bulgo Sst (upper) and Crinanite	5.2	7.9	201	3
7	Bulgo Sst (lower) and Crinanite	-1.3	15.0	259.0	4
8	Stanwell Park Claystone and Crinanite	6.0	9.6	194.0	3
9	Scarborough Sst and Crinanite	-16.8	18.3	444	3
10	Wombarra Claystone and Crinanite	-5.6	6.5	188.0	1
11	Coalcliff Sandstone and Crinanite	-7.3	24.6	171.0	2
12	Bulli Coal Seam and Crinanite	-15.3	34.7	194.0	3
13	Lawrence and Loddon Sandstones	-1.7	1.7	90	1
14	Wongawilli Coal Seam	-20.2	30.9	329	5

Calibration hydrographs, showing the fit between modelled and observed groundwater levels are presented in Appendix B. As shown by the hydrographs in general, the model has replicated the groundwater transient trends well in the bores.

6.4.2 Calibrated Heads and Water Table

Hydraulic heads at the end of the steady state calibration are presented in Figure 6-3 to Figure 6-6 for the alluvium/weathered zone, Bulgo Sandstone and Bulli and Wongawilli coal seams, respectively. Mining in Dendrobium underground and Elouera have caused depressurized zones within the centre of the model in the Bulli and Wongawilli coal seams. In addition, the depressurization has extended to the shallower layers (e.g. Bulga Sandstone) above the longwall panels indicating that the changes in hydraulic properties within the fracture zone have increased the vertical connection between the layers. Bord and pillar mining in Avon, Wongawilli, Kamira and Cordeaux Bord has also caused depressurisation in Wongawilli coal seam along the escarpment and north of model boundary.

Figure 6-7 shows the simulated water table at the end of the transient calibration. The simulated water table shows the level at which the ground is saturated with water.

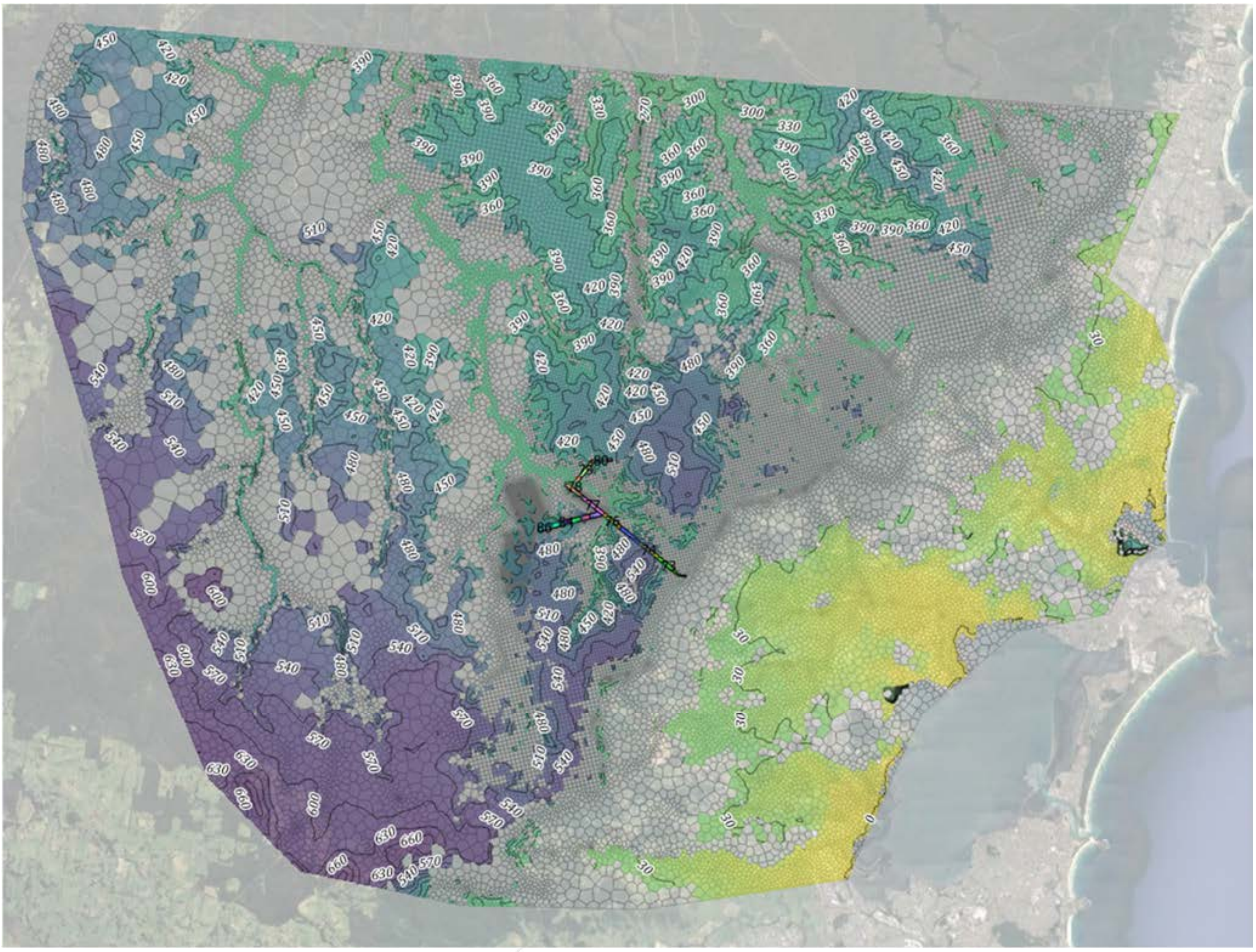


Figure 6-3 Steady State Calibration (pre-mining) Layers 1 (alluvium and weathered)

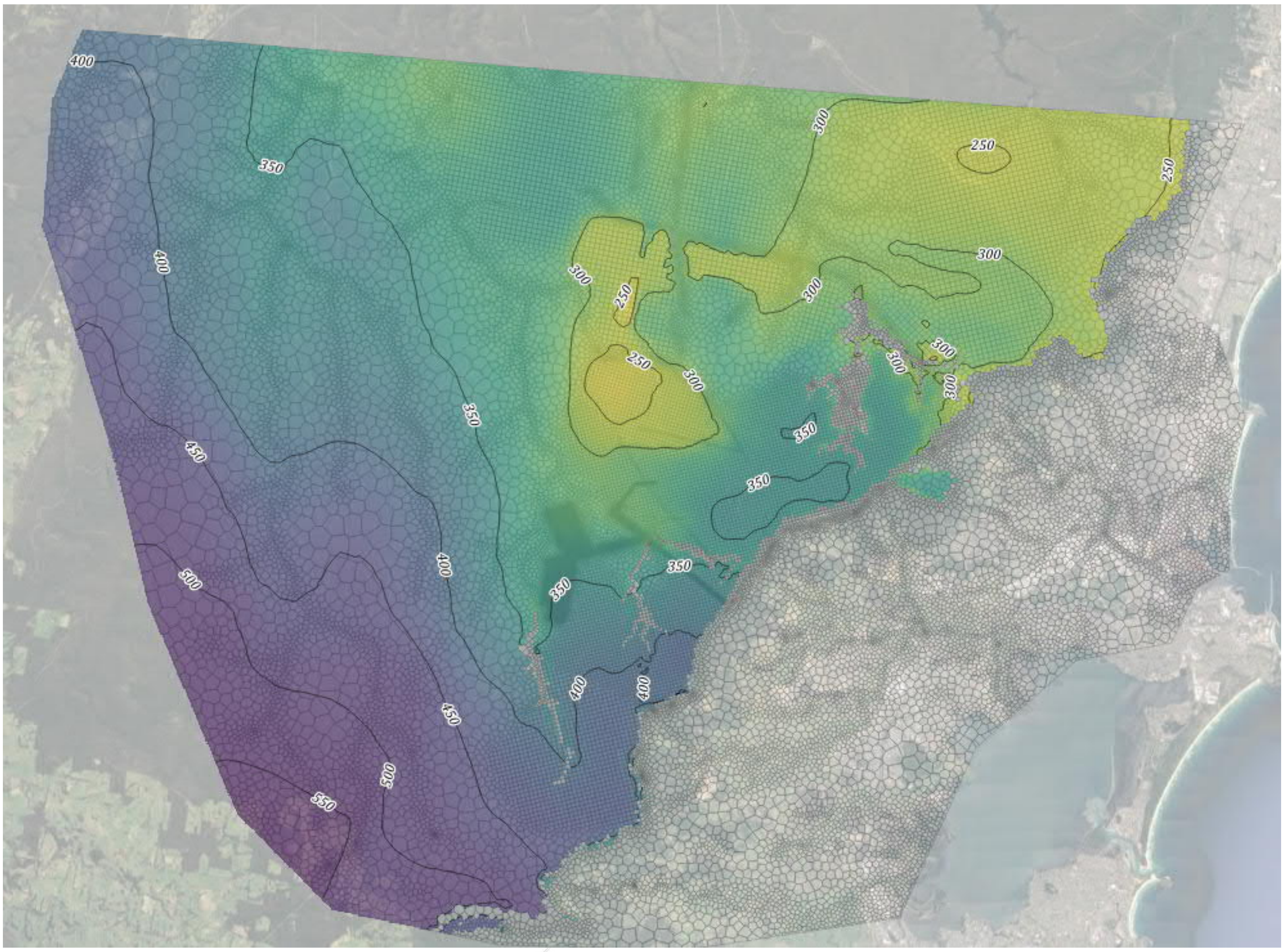


Figure 6-4 Steady State Calibration (pre-mining) Layer 7 – Bulgo Sandstone

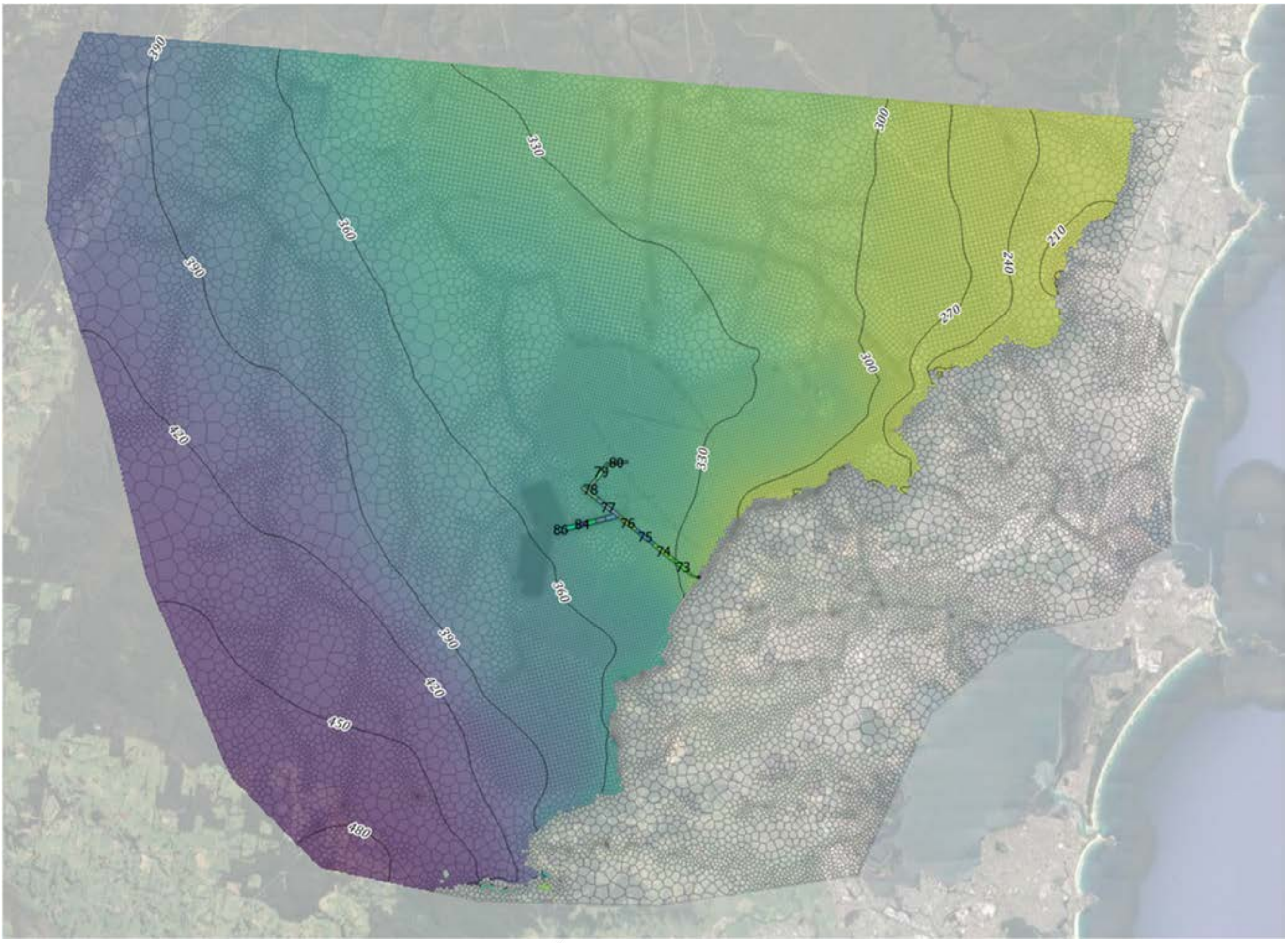


Figure 6-5 Steady State Calibration (pre-mining) Layer 12 – Bulli Coal Seam

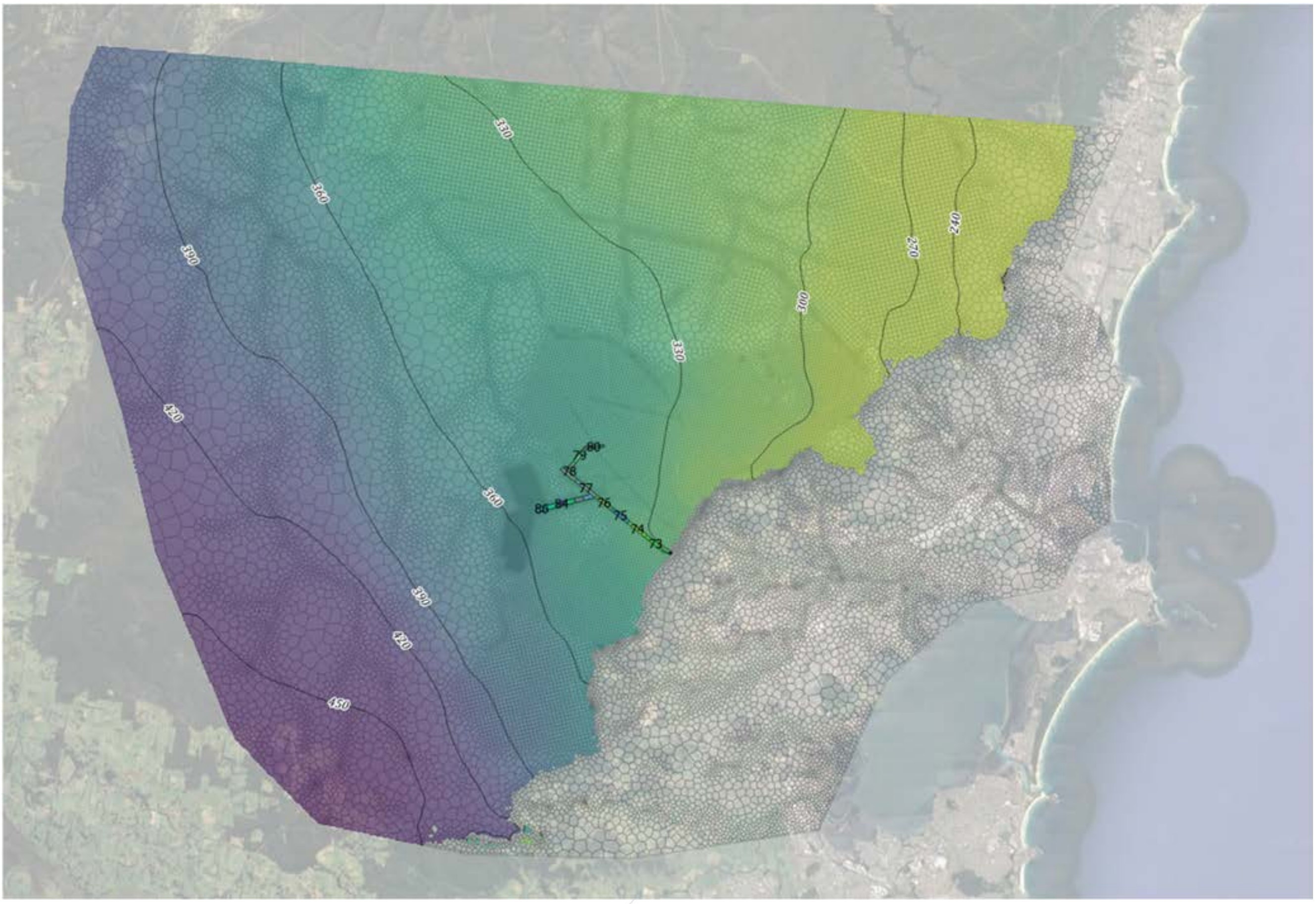


Figure 6-6 Steady State Calibration (pre-mining) Layer 14 – Wongawilli Coal Seam

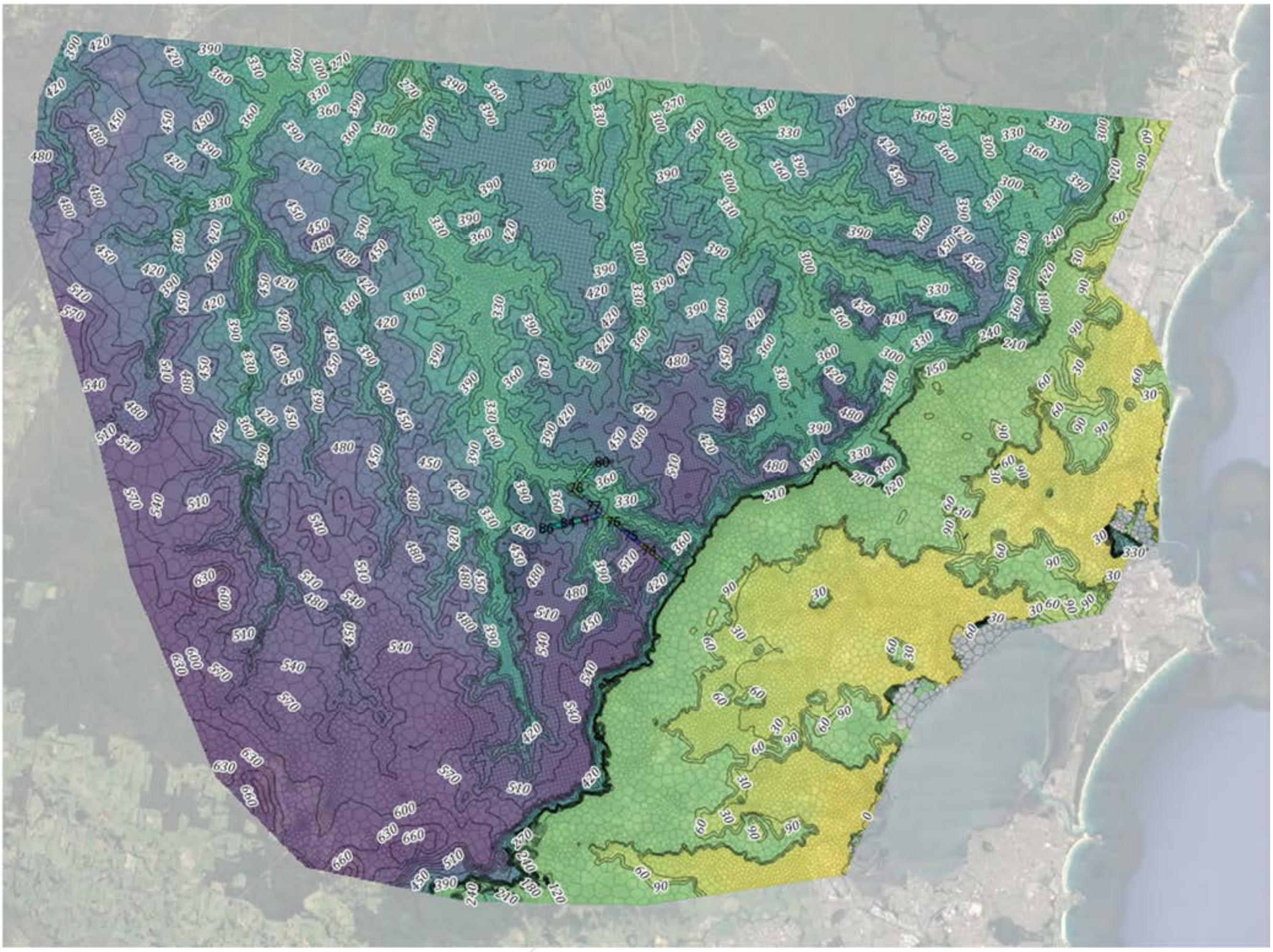


Figure 6-7 Steady State Calibration (Pre-mining) – Water Table Head

6.4.3 Water Budget

6.4.3.1 Steady state water budget

The water balance for the steady-state simulation is presented in Table 6-4. The mass balance error (the difference between calculated model inflows and outflows) at the completion of the steady state calibration was 0.0%. This value indicates that the model is stable and achieved an accurate numerical solution.

The water budget indicates a total of 185.11 ML/day in and out. The major recharge to the groundwater system within the model in steady state simulation is 173.76 ML/day, with other components made up of river inflows and regional groundwater inflow. The major loss to the system is 16.97 ML/day via evapotranspiration in areas where the water table is within 3 m of the ground surface with approximately 18.21 ML/day being discharged via surface drainage, and minor losses by regional groundwater outflow.

Table 6-4 Steady-State Mass Balance

Component	Inflow (ML/d)	Outflow (ML/d)
Recharge (RCH)	173.76	0.00
ET (from GW) (EVT)	0.00	163.97
Rivers (RIV)	11.12	18.21
Regional GW Flow (GHB)	0.24	0.43
Constant Head (CHD)	0.00	2.50
Mines (DRN)	0.00	0.00
Total	185.12	185.11
Mass Balance Error (%)	0.00	

The model calculates the volume of water removed by mining based on hydraulic properties and gradients, not by direct user input. It was important to ensure the magnitude of water being removed is comparable to actual extraction volumes. Table 6-5 shows the inflows against the observed inflows at Wongawilli historical bord and pillar and Elouera longwalls. As shown in the table, the predicted average groundwater mine inflows generally align with mining inflow measurements.

Table 6-5 Modelled Mine inflow

Mine	Type	Previous Modelled Inflow (ML/day)	Modelled inflow (ML/day)
Elouera	Longwall	Max 10 ML/day (GeoTerra 2010)	Max 3.4 - average 1.3 ML/day
Wongawilli	Bord and pillar	Max 3.4 ML/day – background 1.7 ML/day (GeoTerra 2010)	Max 14.5 – average 2.65 ML/day
Cordeaux	Bord and pillar	Average 1.2 ML/day (HydroSimulations, 2019)	Average 2.7 ML/day
Dendrobium	Longwall	Average 4.7 ML/day (HydroSimulations, 2019)	Average 2.5 ML/day

6.4.3.2 Transient water budget

The water balance for the transient simulation (from year 2004 to 2020) is presented in Table 6-6. The mass balance error (the difference between calculated model inflows and outflows) at the completion of the transient calibration was 0.0%. This value indicates that the model is stable and achieves an accurate numerical solution. The percentage of the water balance components for the transient calibration are similar to the steady state components with recharge being the largest inflow and evapotranspiration being the largest outflow.

Table 6-6 Transient Calibration Mass Balance

Component	Inflow (ML/day)	Outflow (ML/day)
Recharge (RCH)	160.60	0.00
ET (from GW) (EVT)	0.00	153.67

Component	Inflow (ML/day)	Outflow (ML/day)
Rivers (RIV)	13.78	19.65
Regional GW Flow (GHB)	0.93	0.40
Constant Head (CHD)	0.00	2.33
Mines (DRN)	0.00	1.80
Storage	31.69	29.17
Total	207.01	207.01
Mass Balance Error (%)	0.00	

6.5 Calibrated Hydraulic Parameters

The hydraulic conductivity of the coal and interburden material generally reduces with depth. Therefore, all units within Layers 2-18 have been modelled using the Kh-depth relationship estimated from analysis of packer tests of all stratigraphic units. The hydraulic conductivity of the interburden/overburden and coal seam layers decreases with depth according to the equation shown below:

$Kh = K_0 * exp(-cz)$ (Eq. 1)

- Where

Kh=horizontal hydraulic conductivity, K_0=multiplier, C=gradient and z=depth [m].

The gradient and depth were assigned as below:

$K = K_0 * exp(-1.7-0.022*z)$ (Eq. 2)

An additional part of the parameterisation of K_0 was the use of a lithological factor. These incorporate some additional variation in Kh based on the hydrogeological conceptual model. For example, the coal seams are more permeable than the surrounding siltstones and sandstones even though they occur at similar depths, so the calculated Kh for these have been multiplied by 10-40 times. Another example is that intrusions and cindered coal are considered less permeable than surrounding coal.

With regards to vertical hydraulic conductivity, the vertical hydraulic conductivity (Kv) was not varied with depth. To start the calibration, the initial values for K_0 and Kv were derived from the Dendrobium EIS model (HydroSimulations, 2019). These initial values are then allowed to change during calibration by half an order of magnitude. Table 6-7 summarises the minimum, maximum and average horizontal (Kh) and vertical (Kv) hydraulic conductivity values for each unit within the model domain derived from the final calibrated model. Table 6-8 shows the specific storage (Ss) and specific yield (Sy) for each hydrostratigraphic unit within the model domain. Maximum specific storage limits have been set at 1.3×10^{-5} which is in accordance with the maximum theoretical limit of specific storage as stated by Rau et al., 2018. It should be noted that no depth relationship was applied to any of the units in Layer 1.

Table 6-7 Hydraulic conductivity parameters

Layer- Geology Unit	Kh (m/day)			Kv (m/day)		
	Min	Mean	Max	Min	Mean	Max
L01 - alluvium	5.80E+00	5.80E+00	5.80E+00	5.90E-02	5.90E-02	5.90E-02
L01 – Escarpment	4.20E-01	4.20E-01	4.20E-01	7.50E-06	7.50E-06	7.50E-06
L01 – Lake and Ocean and Swamps	2.20E-01	5.84E+00	1.50E+01	7.40E-04	3.38E-03	5.00E-03
L01 – Regolith	1.50E-01	1.50E-01	1.50E-01	3.20E-02	3.20E-02	3.20E-02
L02 - Hawkesbury Sst (upper)	1.70E-02	4.25E-02	5.00E-02	1.90E-05	1.90E-05	1.90E-05
L03 - Hawkesbury Sst (mid)	2.40E-02	4.99E-02	5.00E-02	2.20E-04	2.20E-04	2.20E-04
L04 - Hawkesbury Sst (lower)	1.30E-03	2.23E-02	5.00E-02	1.50E-04	1.50E-04	1.50E-04
L05- Bald Hill Claystone	8.60E-06	3.12E-04	9.70E-04	3.10E-06	3.10E-06	3.10E-06
L05- Crinanite (weathered)	8.10E-03	3.63E-02	5.00E-02	3.20E-04	3.20E-04	3.20E-04
L06 - Bulgo Sst (upper)	4.10E-05	1.11E-02	5.00E-02	1.00E-05	1.03E-05	3.10E-05
L06 – Crinanite	2.00E-05	2.00E-05	2.00E-05	1.00E-05	1.00E-05	1.00E-05
L07 - Bulgo Sst (lower)	9.50E-06	1.41E-03	2.90E-02	1.20E-06	6.46E-06	1.50E-05
L07 – Crinanite	3.10E-05	3.78E-03	2.80E-02	7.90E-06	5.47E-05	1.00E-04
L08 – Stanwell Park Claystone	1.00E-05	1.02E-02	5.00E-02	1.00E-07	7.33E-06	1.60E-04
L08 – Crinanite	1.00E-04	7.66E-03	1.70E-02	5.20E-05	2.43E-04	2.50E-04
L09 – Scarborough Sst	8.10E-05	2.61E-02	5.00E-02	4.00E-06	9.01E-06	1.00E-05
L09 – Crinanite	2.80E-04	2.35E-02	5.00E-02	1.40E-04	2.50E-04	2.50E-04
L10 – Wombarra Claystone	1.00E-05	3.47E-04	8.10E-03	5.00E-06	1.68E-05	2.00E-05
L10 – Crinanite	8.60E-06	6.18E-04	3.40E-03	4.30E-06	2.00E-05	2.10E-05
L11 – Coalcliff Sandstone	2.00E-05	9.84E-04	3.20E-02	1.00E-05	1.44E-05	1.70E-05
L11 – Crinanite	1.00E-05	1.04E-03	8.00E-03	5.00E-06	1.38E-05	1.40E-05
L12- Bulli Coal Seam	2.00E-04	2.95E-02	5.00E-02	8.60E-06	8.36E-05	2.50E-04
L12- Crinanite	3.00E-05	2.70E-03	1.90E-02	6.80E-06	6.80E-06	6.80E-06
L13- Lawrence and Loddon Sandstones	4.00E-05	7.84E-04	2.80E-02	3.20E-06	3.20E-06	3.20E-06
L13- Nepheline syenite	1.60E-05	3.72E-04	3.30E-03	2.20E-06	2.57E-06	4.10E-06
L14- Wongawilli Coal Seam	1.00E-04	2.52E-02	1.00E-01	1.00E-07	8.79E-06	1.20E-05
L14- Nepheline syenite	2.00E-04	3.27E-04	1.00E-03	1.00E-05	9.41E-06	1.00E-05
L15- Kembla Sandstone	4.00E-05	1.73E-03	5.00E-02	1.30E-06	3.27E-06	1.70E-04
L16- Tongarra Coal Seam	2.90E-03	1.52E-02	1.00E-01	4.10E-05	4.10E-05	4.10E-05
L17- Lower Permian Coal	2.00E-04	3.64E-04	1.20E-02	8.60E-06	1.10E-05	1.00E-04
L18- Shaolhaven Group	1.00E-03	1.12E-02	5.00E-02	1.80E-07	1.80E-07	1.80E-07

Table 6-8 Storage parameters

Layer- Geology Unit	Ss (1/m)	Sy
L01 - alluvium	1.00E-05	1.00E-01
L01 - Escarpment	1.00E-05	1.00E-01
L01 - Regolith	1.00E-05	2.24E-01
L01 - Swamps	1.00E-05	1.00E-01
L02 - Hawkesbury Sst (upper)	1.30E-05	5.00E-02
L03 - Hawkesbury Sst (mid)	1.00E-06	2.50E-02
L04 - Hawkesbury Sst (lower)	1.00E-06	1.20E-02
L05- Bald Hill Claystone	1.00E-06	6.00E-03
L05- Crinanite (weathered)	1.00E-05	1.00E-02
L06 - Bulgo Sst (upper)	1.00E-05	8.75E-03
L06 - Crinanite	9.00E-07	8.00E-03
L07 - Bulgo Sst (lower)	1.00E-05	8.09E-03
L07 - Crinanite	9.00E-07	8.47E-03
L08 – Stanwell Park Claystone	1.00E-05	6.39E-03
L08 - Crinanite	7.00E-07	5.00E-03
L09 – Scarborough Sst	6.00E-06	1.00E-02
L09 - Crinanite	9.00E-07	1.00E-02
L10 – Wombarra Claystone	5.00E-07	3.50E-03
L10 - Crinanite	9.00E-07	1.00E-02
L11 – Coalcliff Sandstone	1.00E-05	6.52E-03
L11 - Crinanite	5.00E-07	4.00E-03
L12- Bulli Coal Seam	5.00E-07	1.04E-02
L12- Crinanite	9.00E-07	1.00E-02
L13- Lawrence and Loddon Sandstones	5.00E-07	1.00E-02
L13- Nepheline syenite	5.00E-07	1.00E-02
L14- Wongawilli Coal Seam	5.00E-07	1.02E-02
L14- Nepheline syenite	4.00E-06	2.00E-02
L15- Kembla Sandstone	5.00E-07	2.00E-02
L16- Tongarra Coal Seam	5.00E-07	4.00E-03
L17- Lower Permian Coal	5.00E-07	2.92E-02
L18- Shaolhaven Group	5.00E-07	5.00E-03

Figure 6-8 illustrates the range horizontal hydraulic conductivity values obtained from publicly available data. The data is focused on the key units, being the Bulga Sandstone (BGSS), Hawkesbury Sandstone (HBSS), Scarborough Sandstone (SBSS) and Wongawilli coal seam (WWSM). The data is compared to the horizontal hydraulic conductivity values derived from Equation 2 (assuming K_0 is 1). As shown in Figure 6-8, the derived Kh-depth relationship for the model is generally consistent with that data. It should be noted that the horizontal hydraulic conductivity K calculated by this relationship is limited to the range 8.0E-06 to 5E-01 m/d.

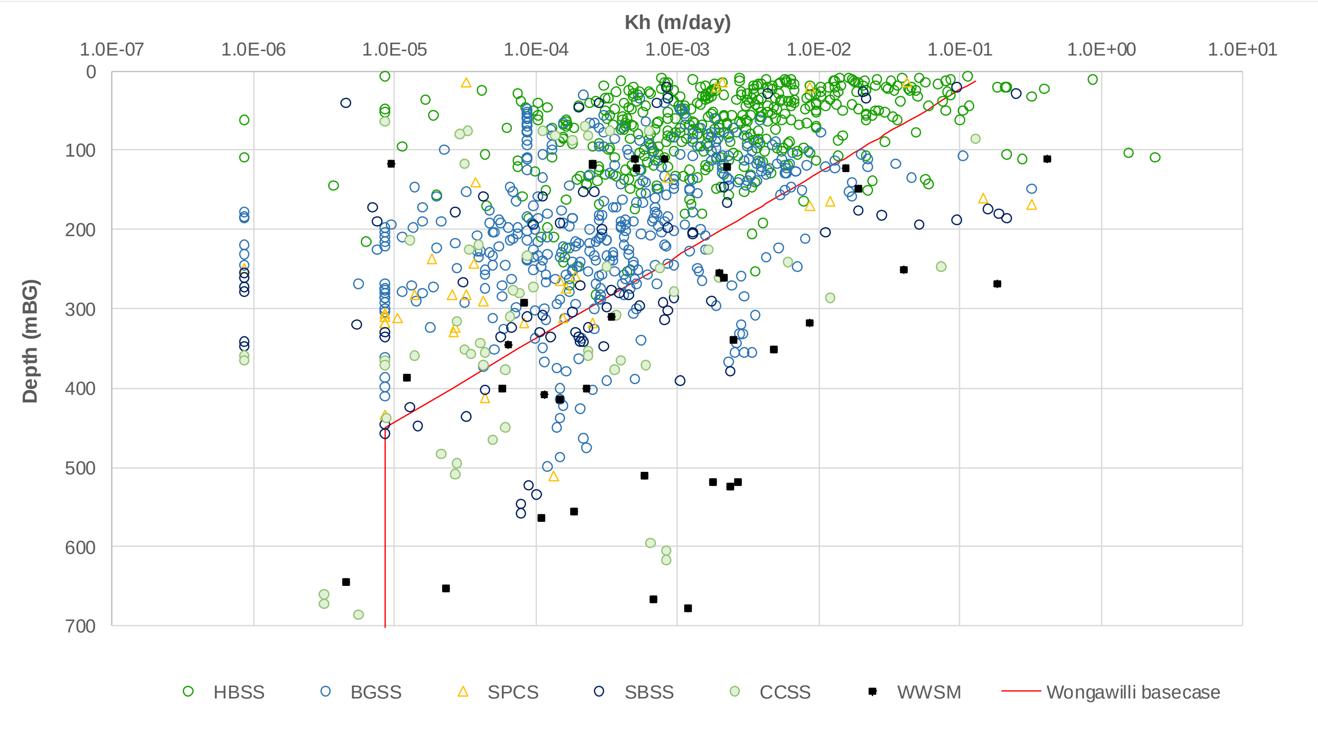


Figure 6-8 Comparison of Modelled K-with-Depth and packer test field data

6.5.1 Calibrated Recharge

Diffuse infiltration of rainfall through the soil profile and subsequent drainage to underlying hydrostratigraphic units is the primary method of groundwater recharge. In alluvial zones, river leakage can also provide recharge to groundwater systems. Model recharge zones and their corresponding annual recharge rates are summarised in Table 6-9. The calibrated recharge rates also vary quarterly to match with observed rainfall. For the predictive model the average quarterly rainfall (mm) was used.

Table 6-9 Rainfall Recharge Rates

	Wongawilli Model	
Unit	% of rainfall	Average recharge (mm/year)
Alluvium	12.00	166.8
Regolith and Escarpment	3.00	41.7
Swamp	45.00*	625.5

Note: *Recharge is attributed to seepage from perched surface water

6.5.2 Model Confidence Level Classification

Under the earlier MDBC, 2001 modelling guideline, the model is best categorised as an Impact Assessment Model of medium complexity. That guideline describes this model type as follows:

"Impact Assessment model - a moderate complexity model, requiring more data and a better understanding of the groundwater system dynamics, and suitable for predicting the impacts of proposed developments or management policies."

Barnett et al., 2012, developed a system within the modelling guidelines to classify the confidence level for groundwater models. Models are classified as Class 1, Class 2 or Class 3 in order of increasing confidence based on key indicators such as available data, calibration procedures, consistency between calibration and predictive analysis and level of stresses.

Table 6-10 summarises the classification criteria and shows a scoring system allowing model classification. In Table 6-10 , those criteria which are satisfied for this model have been bolded and in the total column, the total number of criteria which met for each classification is shown. Based on the data presented in Table 6-10, the groundwater model developed for this Groundwater Assessment has satisfied 12 criteria for Class two and hence can be classified as primarily Class 2 (effectively "medium confidence") with some items meeting the Class 3 criteria, which is considered an appropriate level for this Project context.

Table 6-10 Groundwater Models Classification Table for Wongawilli Model

Class	Data	Calibration	Prediction	Indicators	Total
1	Not much. Spares. Not metered usage. Remote climate data.	Not Possible. Large error statistics. 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.	
Count	1	0	0	0	1
2	Some data. 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%. Properties<>Field measurements. Some key coarse discretisation. Reviewed by hydrogeologist	.
Count	2	2	2	6	12
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. Reviewed by modeller.	
Count	3	1	0	2	6

Note: Bold indicates when a condition has been met

7 Predictive Simulations

Transient predictive modelling simulating both the mining at the Project and surrounding mines has been undertaken. The predictive transient model ran from 01/Jul/2021 to 31/Dec/2049. The model simulates mining with drain cells, which progress quarterly (see Table 7-1).

The model represented mining using the drain (DRN) package. During the predictive run, drain cells were used to simulate the effect of the proposed mine and other mines in the area. A nominally high drain conductance of 100 m^2/day was applied to the drain cells and the elevation of the base of the modelled layer was used as the drain level.

For the Project, during the predicted mine year, the drain cells were set to the base of the target coal seam, either layer 12 (Bulli Seam) or layer 14 (Wongawilli Seam). It was assumed that the drivages would remain dewatered for the duration of the underground mining, and therefore drains once activated, were active until the final year of mining. Once drains are deactivated, the drains undertaking the dewatering are removed and void parameters are assigned to these model cells.

The hydraulic properties were varied with time using the TVM package of MODFLOW-USG. Details on the timing of mining in the predictive model are presented in Table 7-1. The approved mine included in the predictive model the existing NW driveage and the western driveage while the Project included the additional extension into the Wongawilli workings.

Three numerical model scenarios were run:

- Null Run – No mining within the model domain.
- Approved – Approved and foreseeable mining within the model domain.
- Cumulative – Approved and foreseeable mining plus the Project.

The modelled mining schedule for the North West Mains Project is presented in Table 7-1 and Figure 7-1.

Table 7-1 Prediction model stress-period setup

Model Period	Interval	Stress Period	Date from	Date to	Proposed*	Dendrobium
Predictive	Quarterly	69	02-07-2020	01-10-2020		×
	Quarterly	70	01-10-2020	01-01-2021		×
	Quarterly	71	01-01-2021	02-04-2021		×
	Quarterly	72	02-04-2021	02-07-2021		×
	Quarterly	73	02-07-2021	01-10-2021	A-H	×
	Quarterly	74	01-10-2021	01-01-2022	A-H	×
	Quarterly	75	01-01-2022	02-04-2022	A-H	×
	Quarterly	76	02-04-2022	02-07-2022	A-H	×

	Quarterly	77	02-07-2022	02-10-2022	H-K	×
	Quarterly	78	02-10-2022	01-01-2023	H-K	×
	Quarterly	79	01-01-2023	02-04-2023	H-K	×
	Quarterly	80	02-04-2023	03-07-2023	H-K	×
	Quarterly	81	03-07-2023	02-10-2023	H-L	×
	Quarterly	82	02-10-2023	01-01-2024	H-L	×
	Quarterly	83	01-01-2024	02-04-2024	H-L	×
	Quarterly	84	02-04-2024	02-07-2024	H-L	×
	Quarterly	85	02-07-2024	01-10-2024	H-L	×
	Quarterly	86	01-10-2024	01-01-2025	H-L	×
	Quarterly	87	01-01-2025	02-04-2025	x	×
	Quarterly	88	02-04-2025	02-07-2025	x	×
	Quarterly	89	02-07-2025	01-10-2025	x	×
	Quarterly	90	01-10-2025	01-01-2026	x	×
	Quarterly	91 – 186	01-01-2026	31-12-2049		×

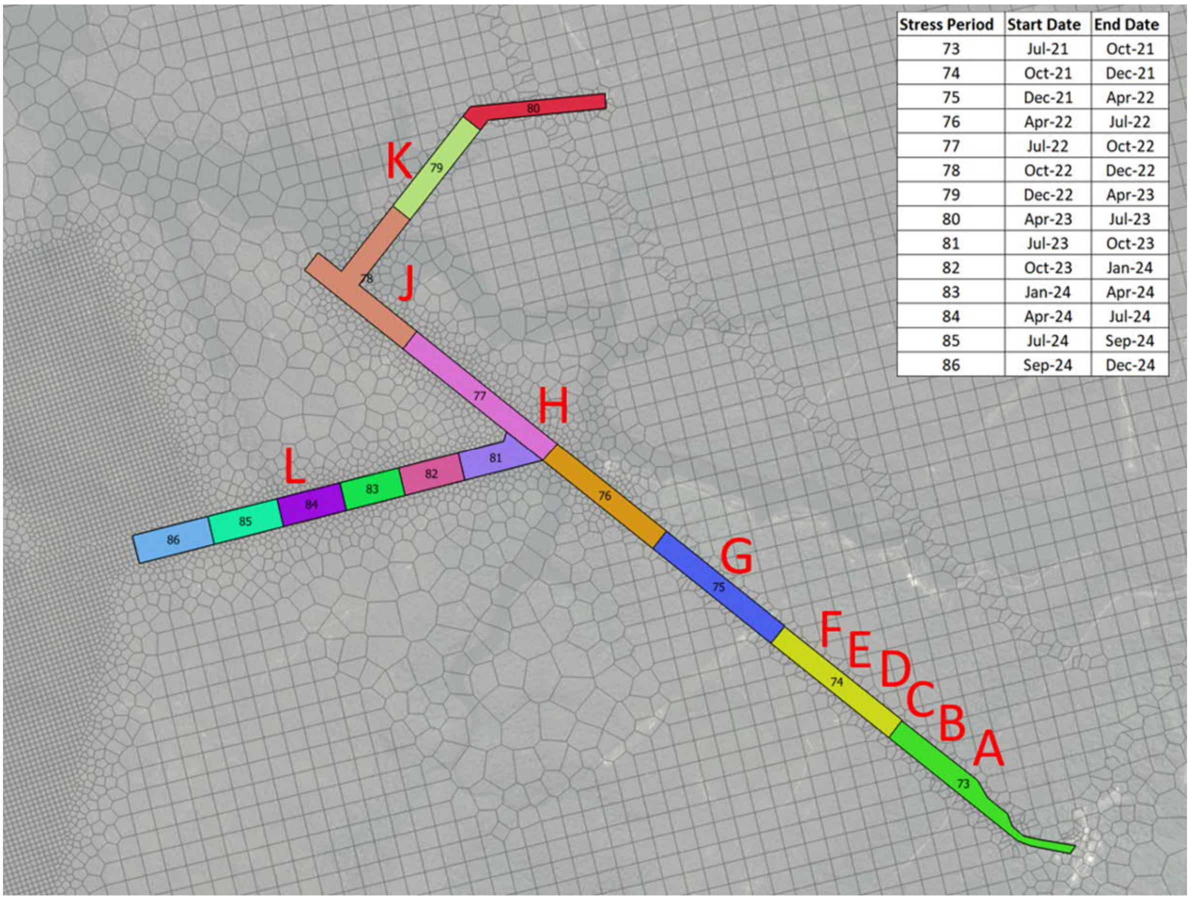


Figure 7-1 WWC Mine Progression

7.1 Water Balance

Table 7-2 shows the average rates of water transfer into and out of the model over the period of the predictive model (July 2020 to December 2049) for two scenarios:

- Approved scenario: which includes the approved surrounding mines; and
- Cumulative scenario: which includes the approved surrounding mine plans plus the Project.

Table 7-2 shows the Approved and Cumulative scenarios, with rainfall recharge to the groundwater system being 59.76 ML/day, with 0.96 ML/day entering the model through the regional groundwater flow (GHB). Evapotranspiration for the predictive model is at 58.25 ML/day where the groundwater is within 3 m of the ground surface across the model domain. 7.74 ML/day of water exits the model through baseflow and through the minor drainages.

The mass balance discrepancy for both predictive models was less than 0.01% indicating that the model achieved an accurate numerical solution.

Table 7-2 Average Simulated Water Balance During the Prediction Period

Component	Approved		Cumulative	
	Inflow (ML/d)	Outflow (ML/d)	Inflow (ML/d)	Outflow (ML/d)
Recharge (RCH)	179.29	0.00	179.29	0.00
ET (from GW) (EVT)	0.00	160.85	0.00	160.85
Rivers (RIV)	11.94	18.38	11.94	18.38
Regional GW Flow (GHB)	0.91	0.41	0.91	0.41
Constant Head (CHD)	0.00	2.54	0.00	2.54
Mines (DRN)	0.00	3.28	0.00	3.36
Storage	14.01	20.70	14.08	20.70
Total	206.16	206.16	206.23	206.23
Mass Balance	0.00		0.00	

7.2 Mine Inflows

The mine inflows are divided up into the previous approved driveages (A - H and H - L) and the proposed driveage (H – K) for the inflows. The results are presented in Table 7-3, Figure 7-2 and Figure 7-3 as Approved, Proposed and total (Approved + Proposed) inflows. Inflows for the Approved Project commence in January 2022 ranging from 0 to 0.14 ML/day. The notable spike during the mining of the 'L panel' (peaking at 0.16 ML/day) is due to the mine plan progressing into the lower Wongawilli Seam.

Table 7-3 Cumulative Annual Inflows for The Project

Calendar Year	Approved (ML)	Proposed (ML)	Total (ML)
2021	0	0	0
2022	9.61	4.50	14.11
2023	16.30	7.14	23.44
2024	13.95	22.80	36.75
2025	13.52	19.57	33.09

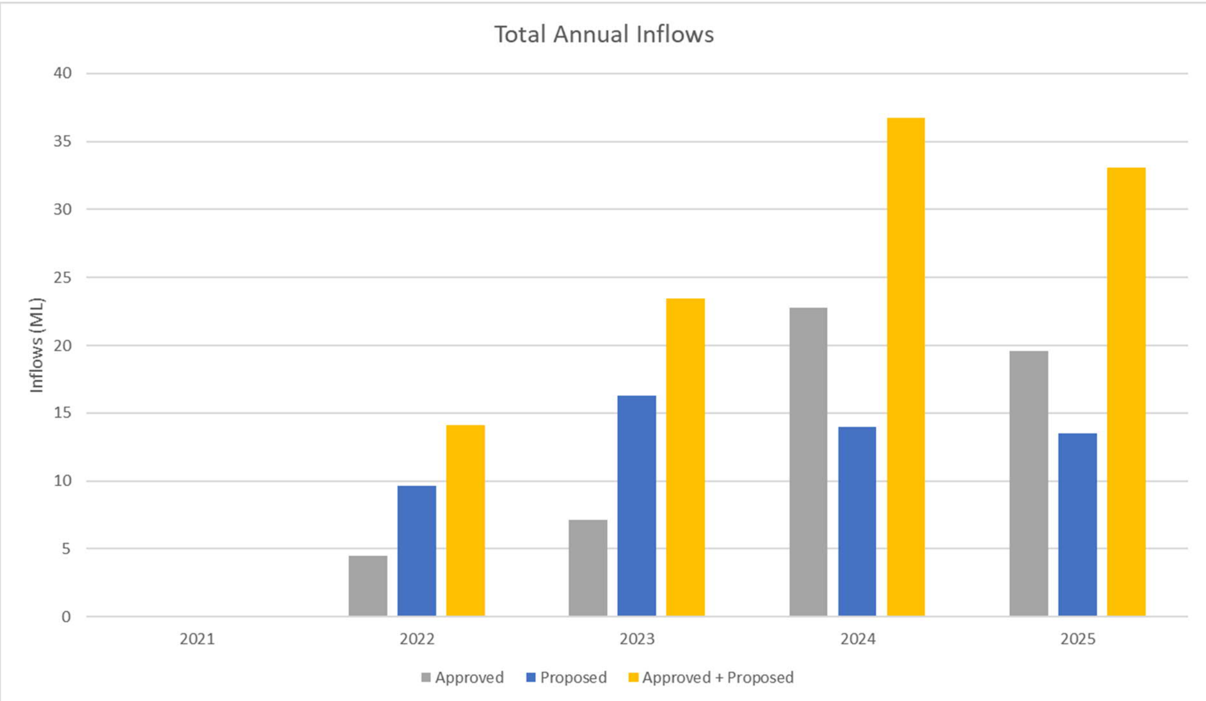


Figure 7-2 Total Annual inflows during mining

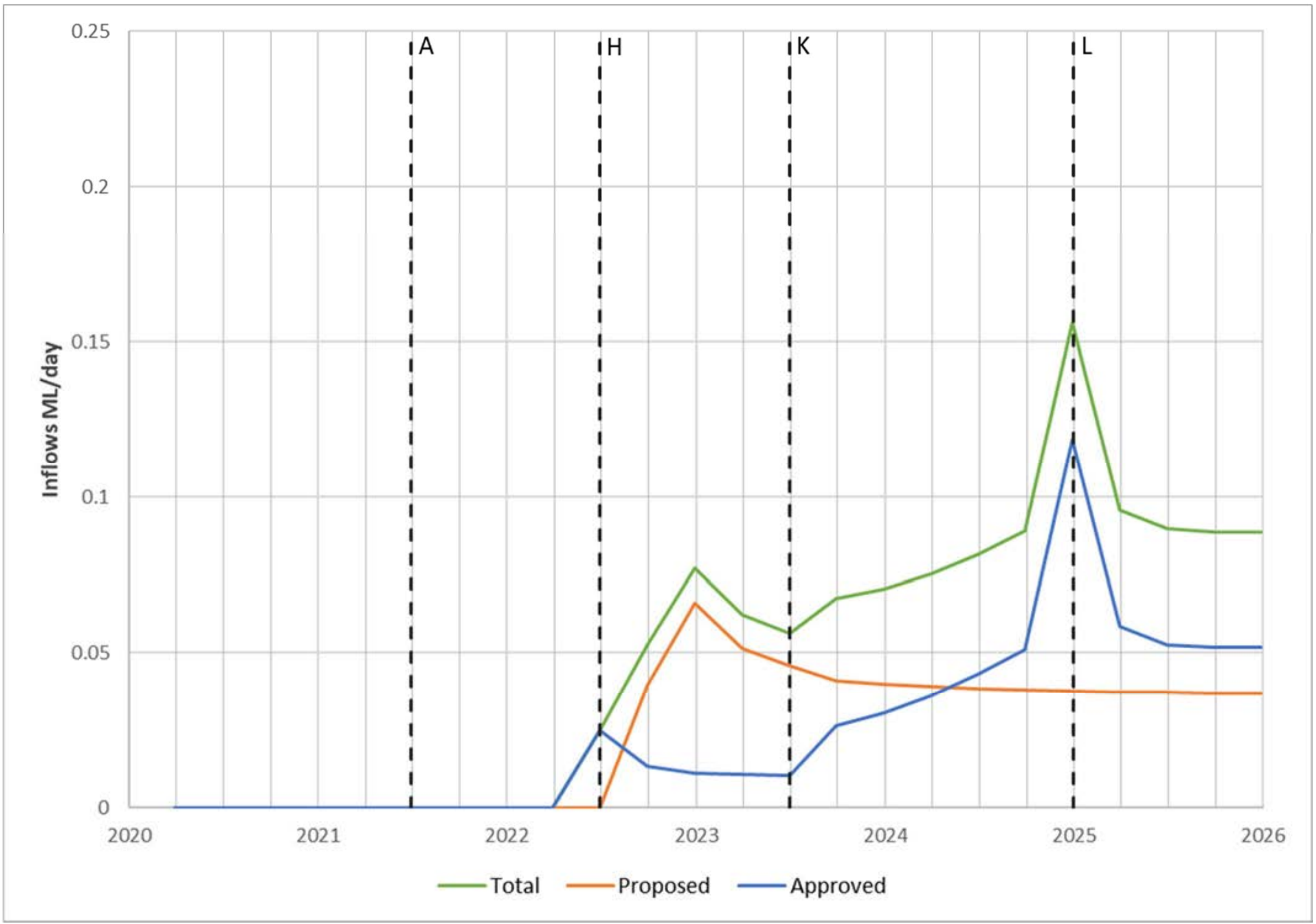


Figure 7-3 Mine Inflows for the Project

7.3 Predicted Groundwater Levels

Predicted groundwater levels at the end of mining operations for the cumulative scenario are shown in Figure 7-4 to Figure 7-7 Model output for predicted potentiometric heads for the alluvium/weathered layer, Bulgo Sandstone, Bulli Seam and the Wongawilli Seam for the calibration period, End of mining for years 2022, 2023, 2024 and 2025, surrounding mining (2050) and end of recovery period (2550) is presented in Appendix C.

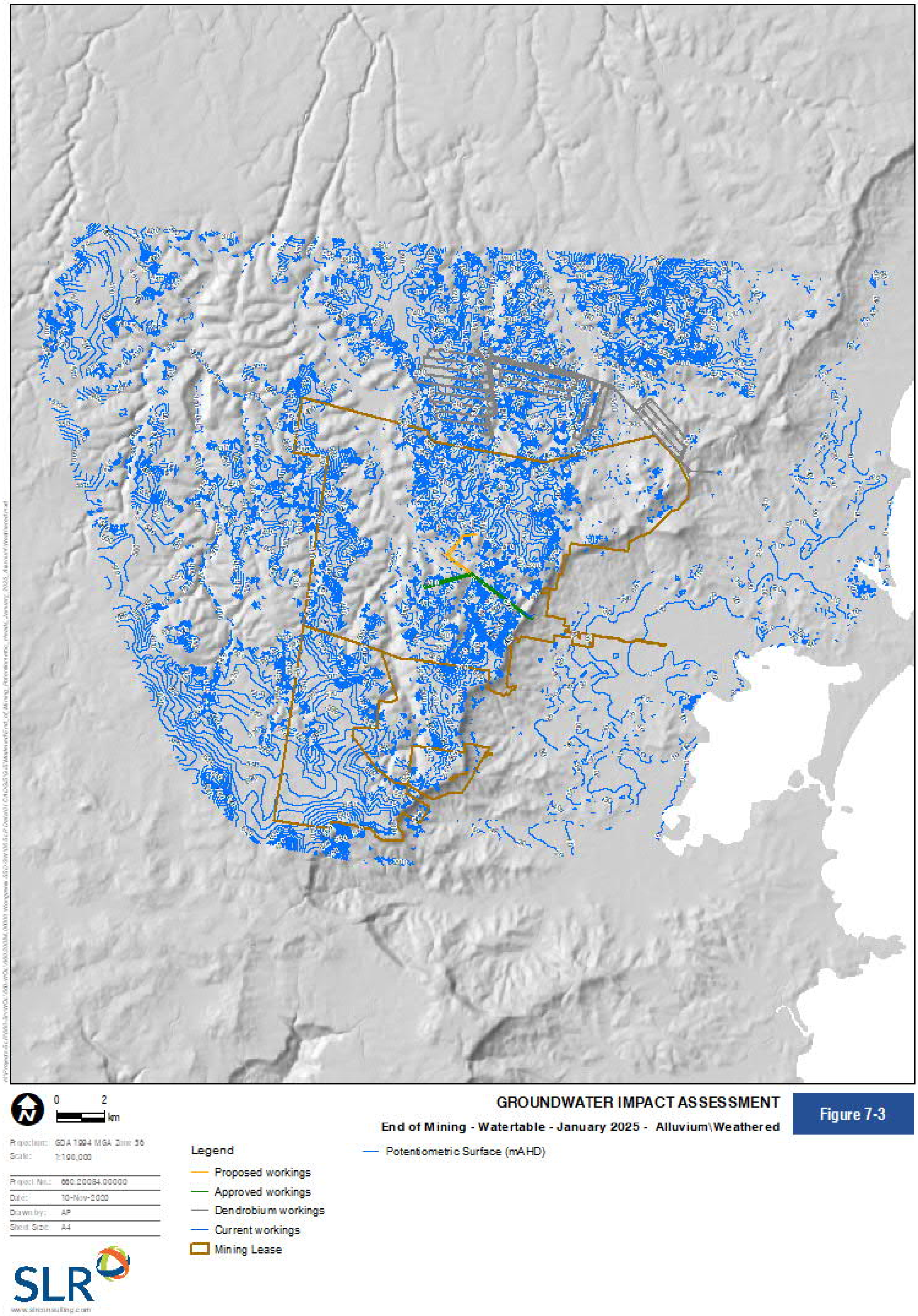


Figure 7-4 Predicted Watertable elevation within Alluvium/weathered - end of Mining (2026) (Layer 1)

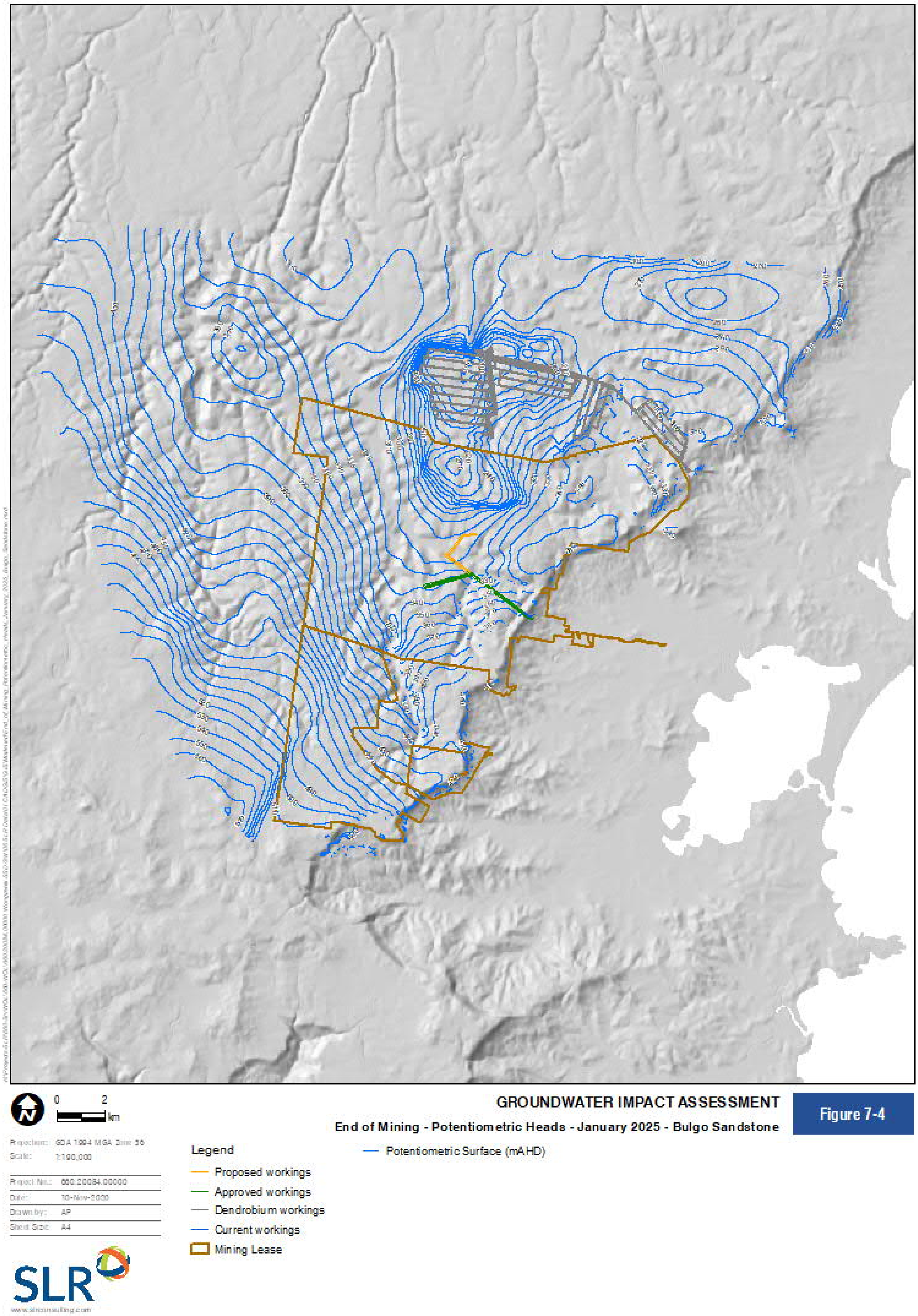


Figure 7-5 Predicted Potentiometric Heads within Bulgo Sandstone at the end of Mining (2026) (Layer 7)

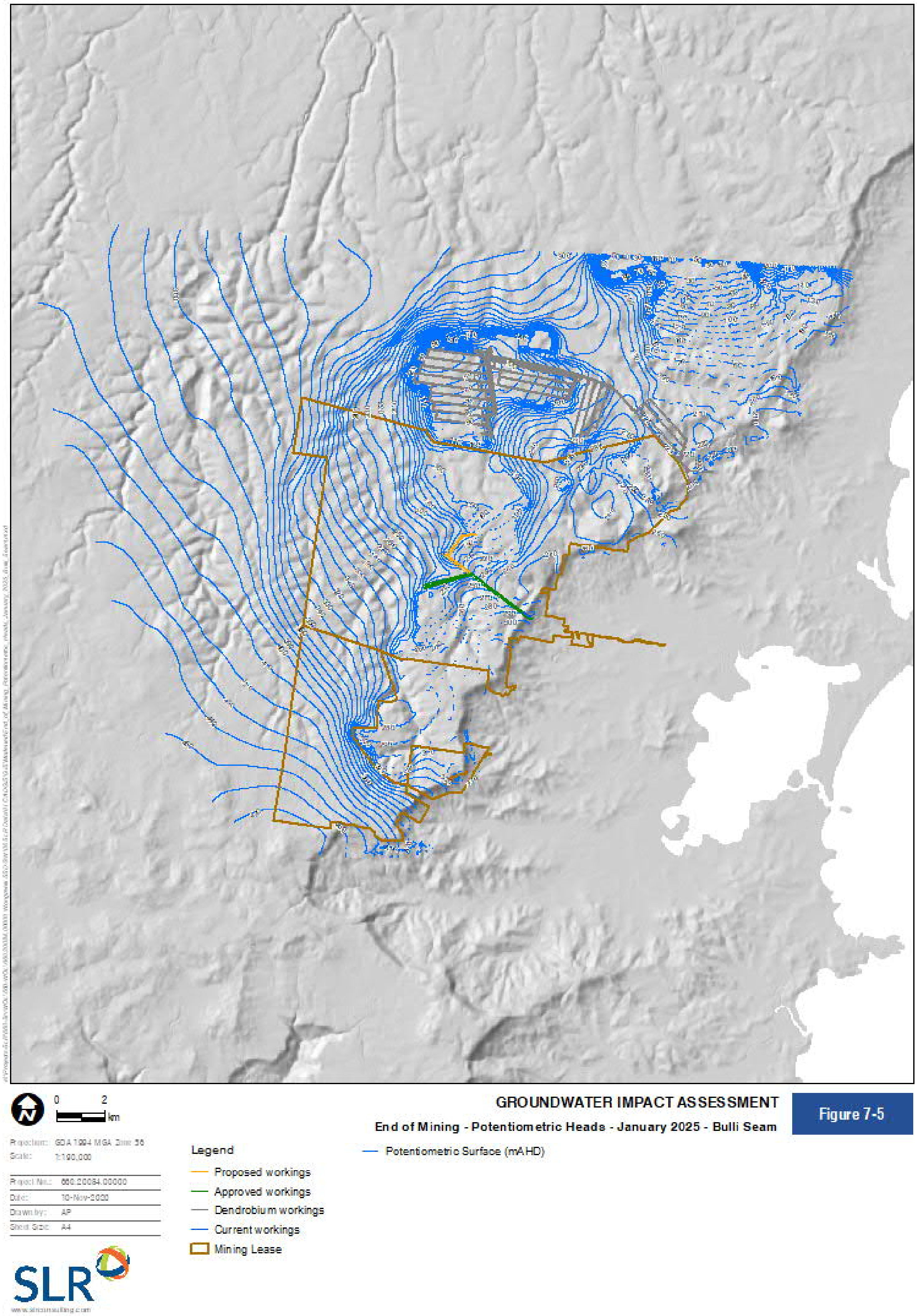


Figure 7-6 Predicted Potentiometric Heads within Bulli seam at the end of Mining (2026) (Layer 12)

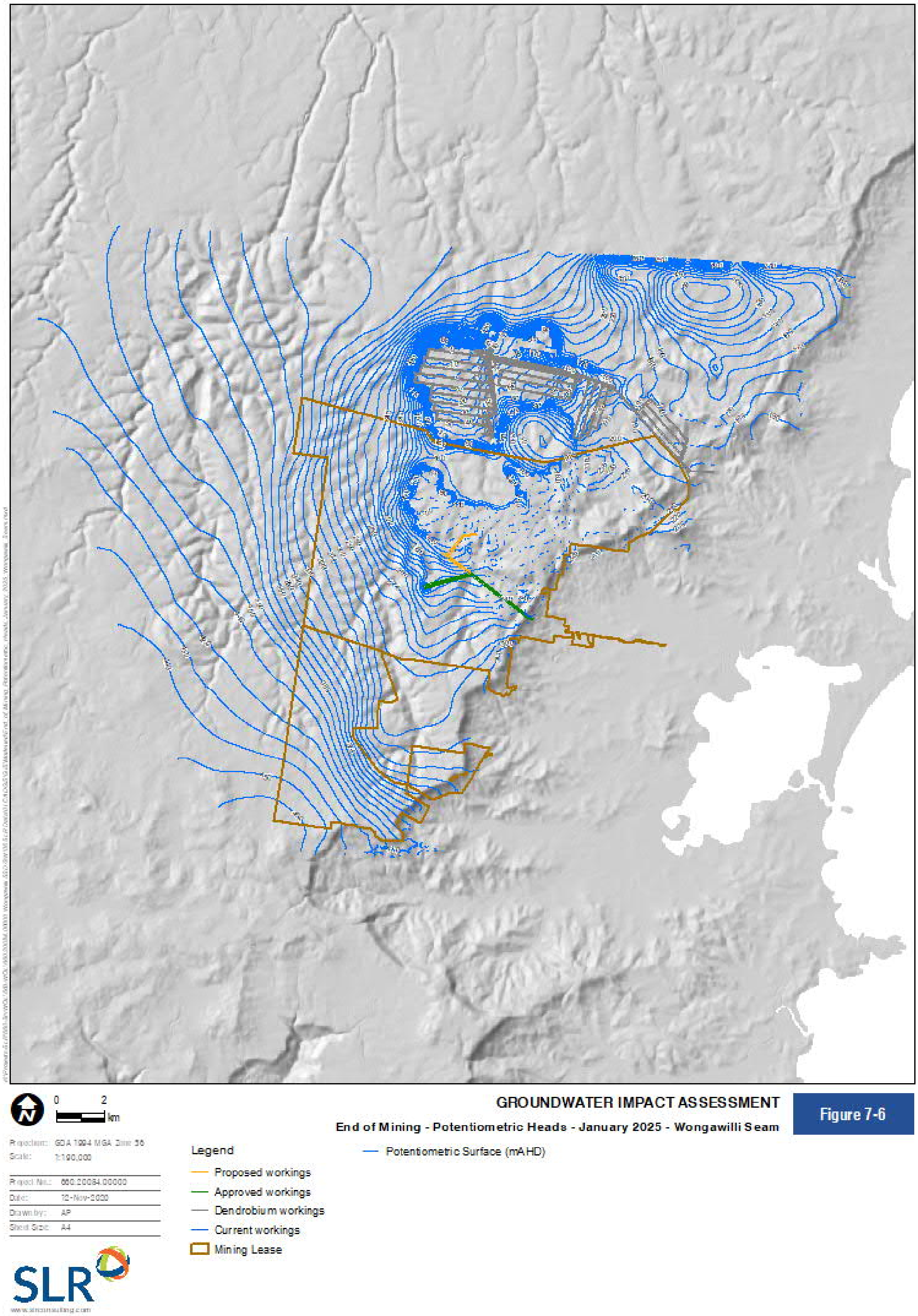


Figure 7-7 Predicted Potentiometric Heads within Wongawilli seam at the end of Mining (2026) (Layers 14)

7.4 Groundwater Drawdown

Groundwater drawdown is calculated against two measures: Cumulative Drawdown and Incremental Drawdown, based on the three modelled scenarios i.e. No Mining (Null), Approved and Cumulative. The cumulative drawdowns are calculated based on the cumulative scenario saturated heads minus the no mining scenario saturated heads, to give an overall impacted water levels across all mining (including The Project). The incremental drawdowns are calculated on the cumulative scenario saturated heads minus the approved scenario saturated heads to give an incremental impact to water levels specific only to the Project. A summary of the incremental drawdown is presented in Figure 7-8 and Figure 7-9 for the end of the Project mining in the Bulli Seam and Wongawilli Seam respectively. A collection of drawdowns for all mine years and recovery is presented in Appendix D and Appendix E for incremental drawdown and cumulative drawdown respectively for Alluvium/Weathered (Layer1) Bulgo Sandstone (Layer 7), Bulli Coal (Layer 12) and Wongawilli Coal (Layer 14). It should be noted that where the drawdown figure is omitted it was due to the no saturated drawdown values greater than 0.5 m. In this case for incremental drawdown in Alluvium and the Bulgo Sandstone.

Groundwater modelling suggests that groundwater drawdown is unlikely to exceed the AIP minimal impact criterion at any water supply works. That is no bores were predicted to be drawn down by the Project by more than 2 m due to mining. Similarly the watertable is not predicted to be drawn down by more than 2 m due to mining. In addition groundwater level variation in groundwater associated with GDEs will not vary by more than 10% which satisfies the requirements of the AIP.

The Independent Expert Panel for Mining in the Catchment Report (IEMPC, 2019) recommends that all future mine approvals in the Special Areas (as outlined in Section 3.6.3.1) should “include performance measures related to measured changes in groundwater pressure and/or pressure gradients where these have the potential to impact on surface water diversions or losses.” Groundwater modelling has predicted there will be negligible groundwater drawdown in the upper units of the alluvium/weathered zone or Hawkesbury Sandstone and consequently there are unlikely to be any losses or diversions of surface water. Consequently, the before mentioned performance measures will not be required.

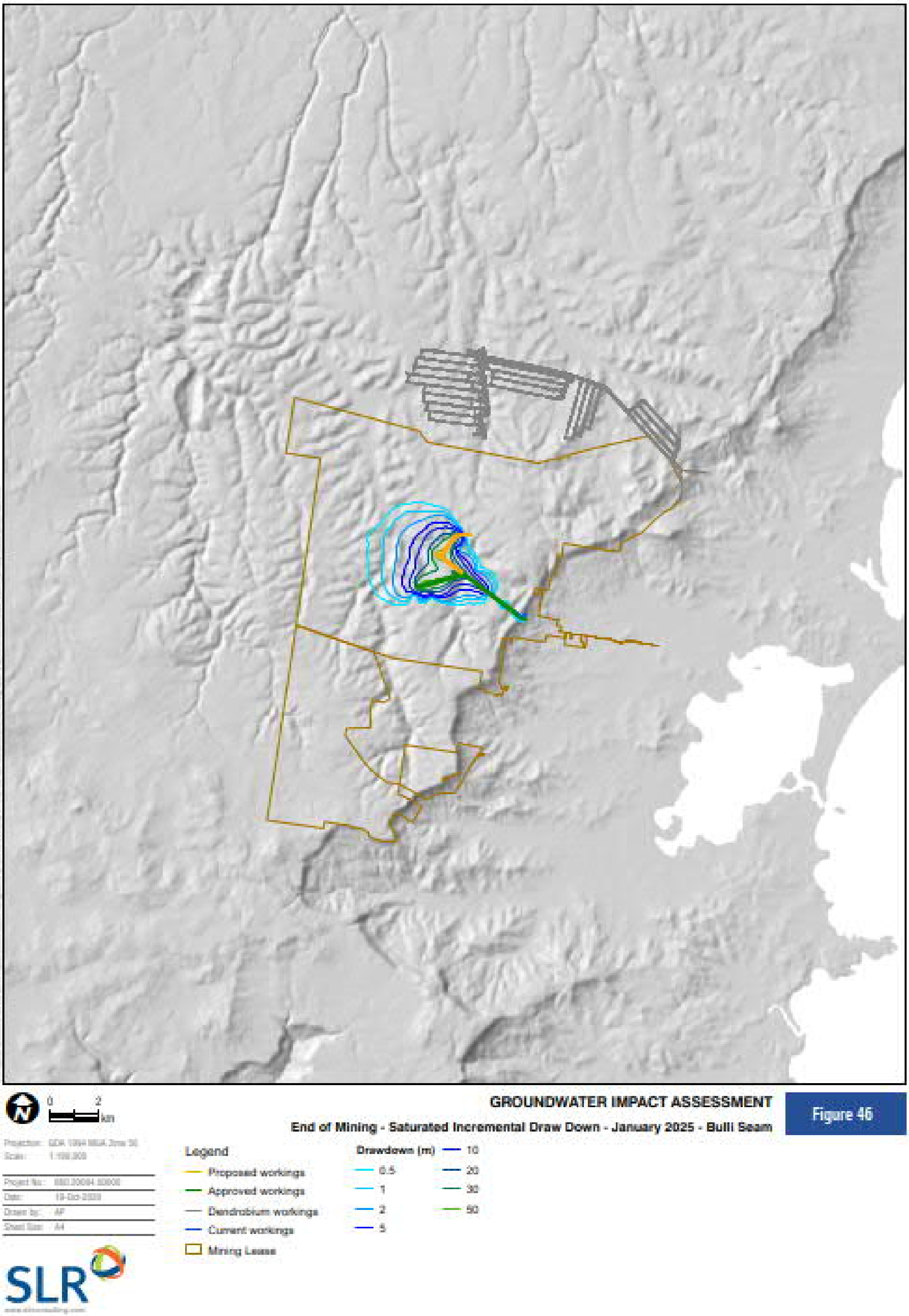


Figure 7-8 End of Mining – Saturated Incremental Drawdown – January 2025 – Bulli Seam

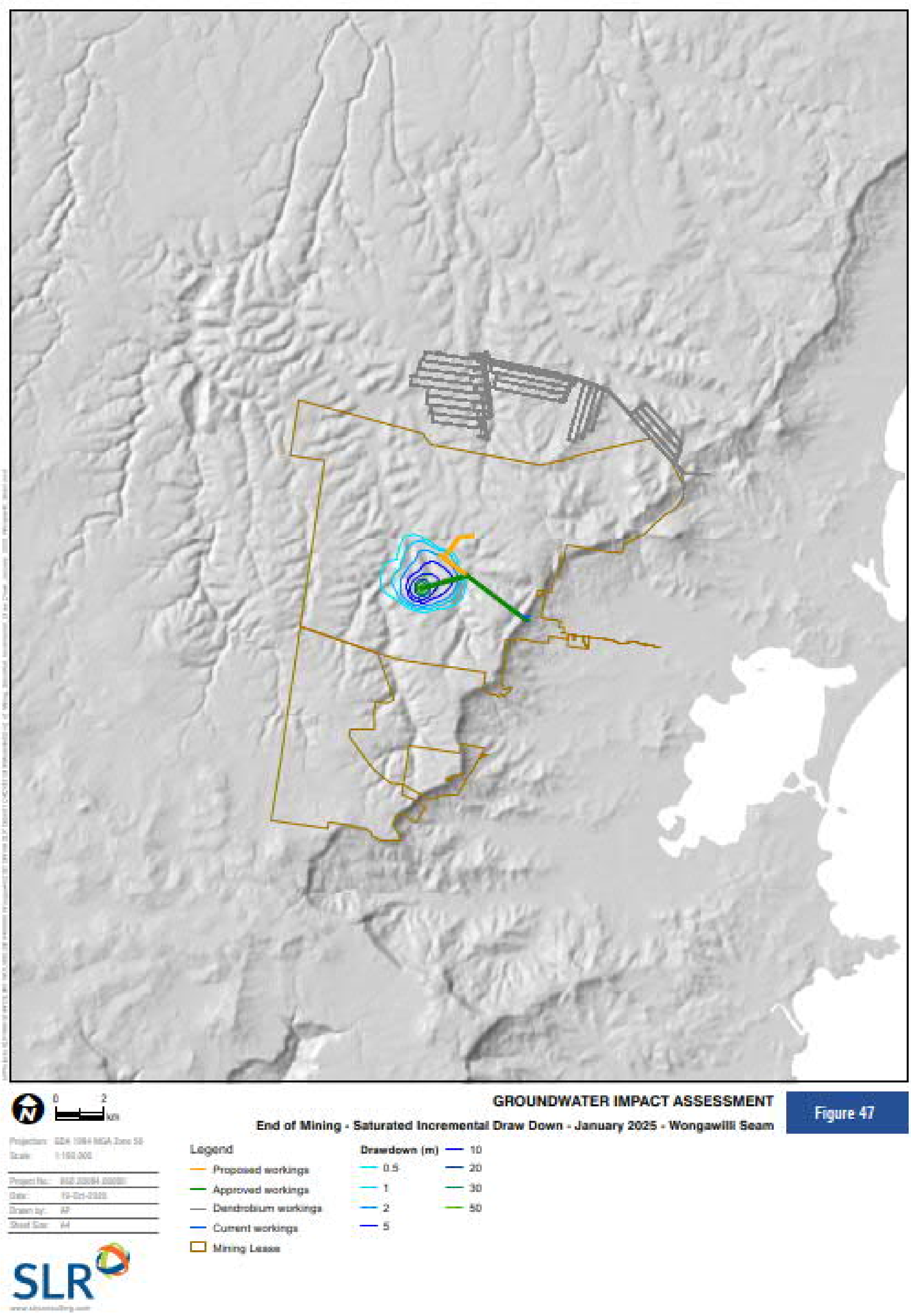


Figure 7-9 End of Mining – Saturated Incremental Drawdown – January 2025 – Wongawilli Seam

7.5 Groundwater Dependant Ecosystems

Groundwater dependant ecosystems situated within the shallow groundwater systems were identified as potentially being at risk due to the Project. To assess any incremental impacts to these the incremental drawdown for Layer 1 (Alluvial/Weathered/Swamps) was investigated for each year through active mining and recovery.

No incremental impacts of drawdown greater 0.01 m to Layer 1 were identified during the mining and only a maximum of 0.07 m drawdown was identified at the end of recovery. Consequently, since there is negligible drawdown in the Layer 1 and cracking is unlikely to extend into the Bulgo Sandstone and overlying hydrostratigraphic units, it is assessed to be unlikely that additional surface water will be lost to groundwater due to the Project. It is therefore very unlikely that any impacts to groundwater dependant ecosystems to occur due to The Project. Consequently the Project does not trigger any of the significant impact criteria under the Commonwealth Environment Protection and Biodiversity Conservation Act, 1999 (DAWE, 1999).

7.6 Recovery Modelling

Post mining impacts were investigated with a recovery model time period, commencing from the end of the predictive model and run for 500 years. The transient simulation was created for the purpose of predicting post-mining inflows, with all predictive model drain cells removed. The recovery model was a continuation of the predictive mining periods, where groundwater levels recover and eventually equilibrate. At the end of mining, the properties of the mined cells are maintained from the TVM package to simulate representative goaf properties. These properties, specifically high storage parameters (specific yield of 0.1, storage coefficient of 5.0×10^{-5} m^{-1} based on the compressibility of water), are applied to simulate increased water storage within the mined cells. Similarly, in surrounding mines where longwall mining was simulated, the cracking parameters were maintained.

The fluxes to the worked zones were calculated for the duration of the predictive model through to the end of the recovery model to assess the long-term fluxes after mining had ceased. The results are summarised in Table 7-4 and are presented in detail Figure 7-10. The system appears to be dynamic in recovery does not reach a stable zero net flux. This is likely due to the various other workings in the area recovering, contributing to a complex recovery system.

Table 7-4 Summary of long-term fluxes to and from the Project worked zone during recovery

Year	Inflow (ML/year)	Outflow (ML/year)	Net flux (ML/year)
2050	40.10	-29.07	11.03
2100	34.37	-21.00	13.37
2150	34.48	-25.06	9.42
2200	33.31	-18.41	14.90
2250	35.98	-20.97	15.01
2300	38.68	-23.52	15.16
2350	30.35	-13.22	17.13
2400	26.22	-8.15	18.08
2450	24.65	-9.68	14.98

Year	Inflow (ML/year)	Outflow (ML/year)	Net flux (ML/year)
2500	25.09	-13.30	11.80
2550	29.22	-19.07	10.15

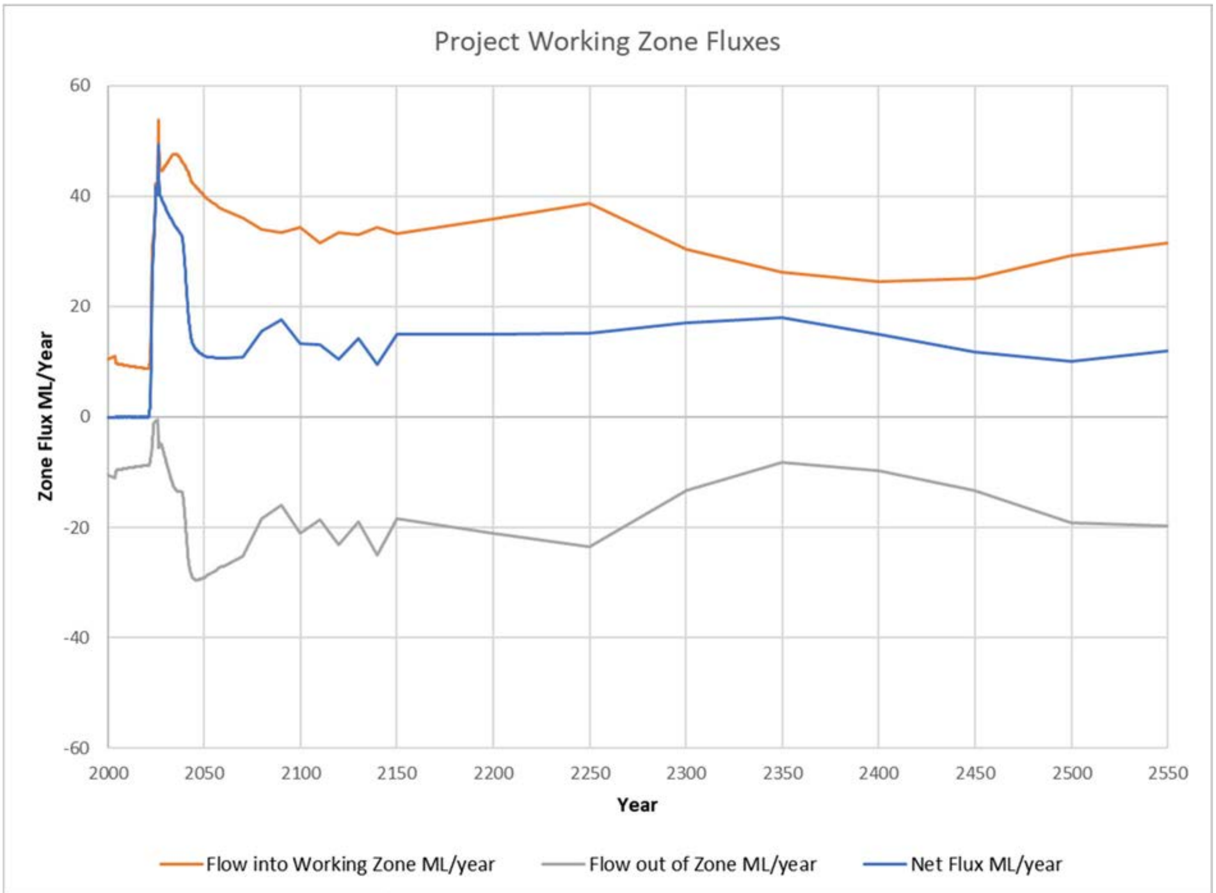


Figure 7-10 Long term fluxes to and from the Project worked zone during recovery

In accordance with the AIP a groundwater extraction license (WAL) will be required to account for intercepted groundwater until the aquifers have equilibrated. Post mining inflows (500 years) are predicted to be between 9.5 and 18.1 ML/year, although the recovery is not linear.

7.7 Water Extraction Licensing

An aquifer interference approval under the Water Management Act (WM Act) is required as the project intersects a groundwater source. The AIP explains the requirements of the WM Act. It clarifies the requirements for licences for aquifer interference activities and establishes the considerations required for assessing potential impacts on key water dependent assets. Any potential impact on local aquifers would be assessed under this policy. Under the AIP a water extraction licence is required for the water take and incidental take over the life of the mine and recovery period.

WCL has secured 1,500 units of shares from the Sydney Basin Nepean Groundwater Source under “Greater Metropolitan Region Groundwater Sources 2011” water sharing plan with water access license (WAL) 36487. The maximum volume of water per unit share is 1 ML/unit share (NoW, 2011), but can be reduced if growth in water usage is deemed to have occurred. Thus WCL hold a maximum entitlement of 1,500 ML/year.

Mine inflow modelling (Table 7-3) indicates the maximum total predicted inflows are 36.8 ML/year indicating the WCL WAL is sufficient to account for the water take, in accordance with the AIP.

8 Sensitivity and Uncertainty Analysis

Sensitivity is defined as the change in an output quantity as a result of the change in an input quantity. The sensitivity analysis evaluates the effects of model parameters on model results, and provides information on the degree to which the adopted values for the various parameters in the model influence the calibration and predictions. In groundwater modelling sensitivity analysis is undertaken intrinsically during the calibration process by varying one model parameter to establish a closeness of fit to the calibration dataset. The sensitivity analysis can provide an indication of the uncertainty in the results and guide future data collection to reduce this uncertainty.

Due to model non-uniqueness, whereby multiple combinations of parameters may be equally good at fitting historical measurements, there is inherent uncertainty in the parameterisation of the groundwater model. This parameter uncertainty leads to an uncertainty in model predictions.

Parameter sensitivity on the calibration period was explored through additional model simulations where model parameters were varied. These parameters and model inputs were considered potentially sensitive to the model with impacts on predictions. Changes in parameters are considered in terms of an Order of Magnitude (±OM). The following sensitivity analyses were assessed:

- ± 1 OM change in hydraulic conductivity in alluvium;
- ± 1 OM change in hydraulic conductivity in coal seams (Bulli, Wongawilli and Tongarra);
- ± 1 OM change in hydraulic conductivity in Bulgo Sandstone;
- RCH ± 300 % change in recharge;
- ± 500 % change in specific yield in coal seams (Bulli, Wongawilli and Tongarra);
- Global RIV conductance up 1 OM.

8.1 Calibration Statistics

Table 8-1 summarises the sensitivity of the calibration statistics to changes in the model parameters. Table 8-1 demonstrates that varying the parameters had little influence on the RMS and SRMS, with only less than 10% change indicating that the calibration performance is relatively insensitive to the input parameters. Thus the calibration may not be able to constrain the parameter values well.

Decreasing the Bulgo Sandstone hydraulic conductivity had the largest impacts on the calibration statistics while decreasing coal hydraulic conductivity resulted in an improved calibration result. These changes were not explicitly tested against the conceptual model understanding and results should be viewed as model sensitivity rather than results uncertainty. This indicates the model parameter sensitivity to calibration and thus how field measurements are valuable to constrain the parameter within a realistic range in the model.

The parameters that had the highest relative change in %SRMS were the recharge, hydraulic conductivity in the Bulgo Sandstone and coal layers even though the magnitude of change was considered low. As a result, the specific yield of the coal, alluvium horizontal hydraulic conductivity and river conductance are considered to have low calibration sensitivity.

Table 8-1 Calibration Sensitivity Statistics

Sensitivity Scenario	SRMS (%)	SRMS change
Base case	8.44%	
+ 1 OM change in hydraulic conductivity in alluvium	8.44%	0.00%
- 1 OM change in hydraulic conductivity in alluvium	8.44%	0.00%
+ 1 OM change in hydraulic conductivity in coal	8.68%	2.83%
- 1 OM change in hydraulic conductivity in coal	7.95%	-5.81%
+ 1 OM change in hydraulic/vertical conductivity in Bulgo Sandstone	8.42%	-0.33%
- 1 OM change in hydraulic/vertical conductivity in Bulgo Sandstone	9.14%	8.27%
+300 % change in recharge	8.50%	0.63%
-300 % change in recharge	8.63%	2.25%
+ 500 % change in specific yield in coal	8.44%	-0.11%
- 500 % change in specific yield in coal	8.45%	0.01%
+ 1oM Global RIV conductance	8.42%	-0.27%

Note: Percent changes are relative to the Base case SRMS and performed on unrounded values

8.2 Mine Inflows Sensitivity

Table 8-2 shows the sensitivity of the variation in predicted average annual mine inflow to the Project. As it can be seen in the table, changing the specific yield/hydraulic conductivity in the coal and the horizontal/vertical hydraulic conductivity of Bulgo Sandstone in the model provides the most significant changes to predicted mine inflows. A change in the hydraulic conductivity of the alluvium, recharge or river conductance only provides an insignificant change to mine inflow predictions. This is due to the depth of the underground mining and the changes do not transmit down with these parameters closer to the ground surface.

Table 8-2 Average Annual Mine Inflow- Sensitivity

Sensitivity Scenario	Inflow (ML/Year)	Inflow Change
Base case	28.6	
+ 1 OM change in hydraulic conductivity in alluvium	28.6	0.01%
- 1 OM change in hydraulic conductivity in alluvium	28.6	0.01%
+ 1 OM change in hydraulic conductivity in coal	31.2	8.86%
- 1 OM change in hydraulic conductivity in coal	21.1	-26.18%
+ 1 OM change in horizontal/vertical conductivity in Bulgo Sandstone	30.7	7.20%
- 1 OM change in horizontal/vertical conductivity in Bulgo Sandstone	25.7	-10.10%
+300 % change in recharge	28.7	0.21%
-300 % change in recharge	28.5	-0.38%
+ 500 % change in specific yield in coal	39.6	38.39%
- 500 % change in specific yield in coal	26.4	-7.83%
+ 1OM Global RIV conductance	31.5	9.86%

8.3 Zone of Depressurisation

The variation in model parameters also results in variation in the predicted extent of impacts.

Figure 8-1 is an example of a parameter that was sensitive to the maximum predicted groundwater drawdown due to the Project. Other sensitivity drawdown plots can be found in Appendix F.

The figures displayed for the drawdown sensitivity are for the incremental drawdown within the Bulli seam during the final year of mining to capture the most impacted time and aquifer. Overall the figures show that the drawdown is close to the base case for most of the scenarios, with only notable changes observed with changes to horizontal hydraulic conductivity of the coal seams scenarios. This indicates the model parameter sensitivity to zone of depressurisation and thus how field measurements are valuable to constrain the parameter within a realistic range in the model.

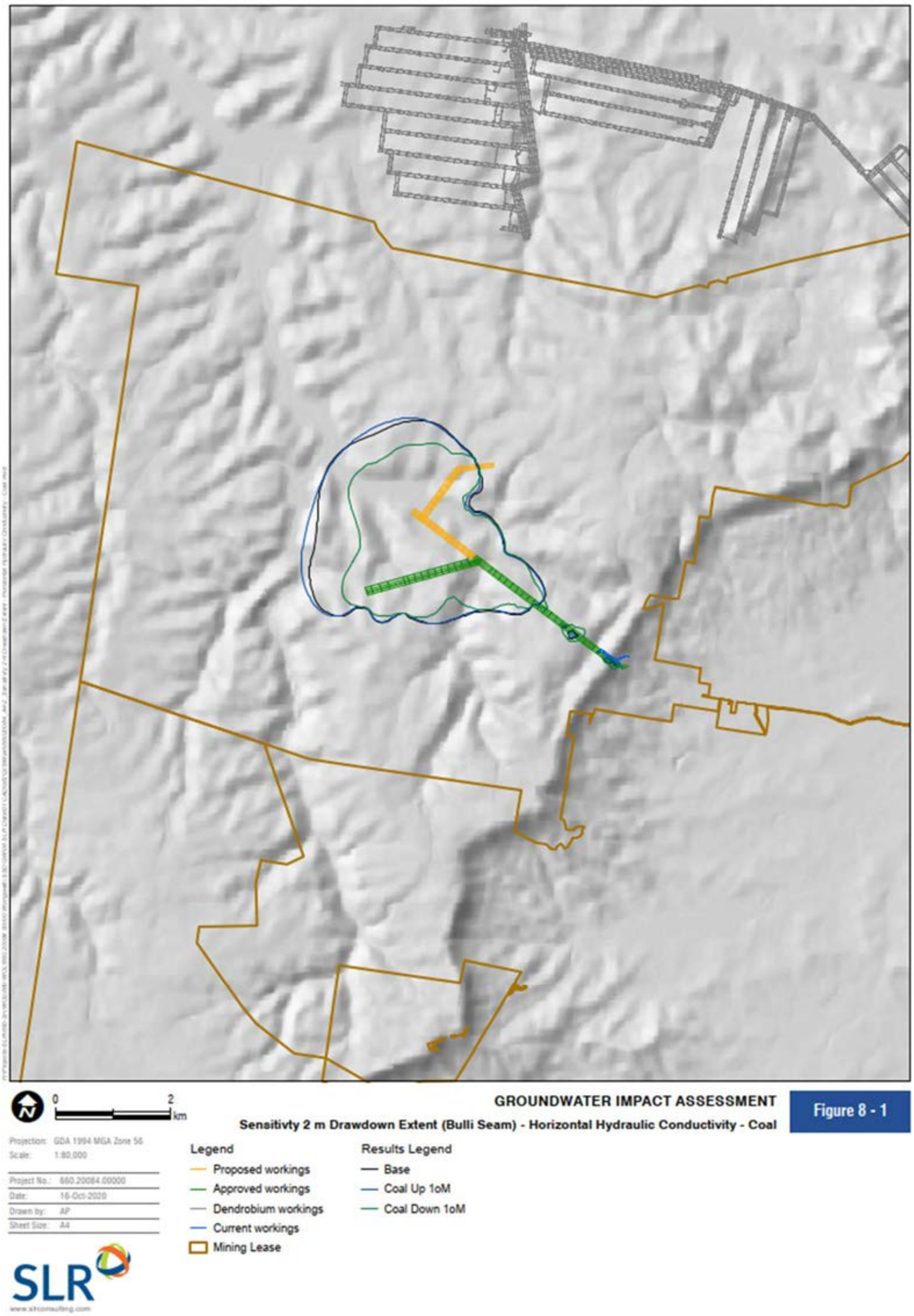


Figure 8-1 Hydraulic Conductivity of Coal Sensitivity to Incremental Drawdown in Bulli Seam (Layer 12) at end of mining (December 2024)

9 Model Limitations

The Groundwater Modelling Guidelines (Barnett et al, 2012) recommends the Model Limitations Section “states the limitations of data and code, the reliability of different outcomes of the model and how further data collection or research may improve reliability.”

9.1 Data Limitations

The process taken for the selection of water level calibration targets needs further refinement. Although a review and filtering of the database has been undertaken, the results of the modelling calibration have highlighted some areas for further review and potential refinements of the water level target datasets to be used as part of further calibration to be undertaken. Areas to be further reviewed within the calibration dataset for improvement include:

- Where VWP’s have been used, an assessment of sensor equilibration is needed to potential removal non-representative groundwater pressures;
- Bore/VWP construction details to identify correct aquifer designation;
- Further understanding of historical mine progression in the project area and details surrounding the water storages process causing the rapid head increases in the lower NWGW01 VWP sensors;
- Mine impacted water levels are sparse for the project and limited to Nebo 1D and Nebo 1S nested bore. To further verify the drawdown/mining relationship it is suggested that when a reasonable database of impacted water levels from the approved operations are visible (most likely NWW20B, NWWGW01, NWWSH1 and/or NWW11 VWP’s) that a recalibration be undertaken to verify these drawdowns;
- Limited spatial target data was available to constrain regional flow gradients.

9.2 Model Confidence

Model confidence has been assessed in terms of the attributes of Class1, 2 and 3 modelling the model classification system of Barnett et al. (2012). A self-assessment is offered at Table 6-10.

As all models would have elements of Class 1, Class 2 and/or Class 3 attributes, it is not possible to assign a model uniquely to a particular class. For the Wongawilli model, the occurrences of performance indicators are quantified here:

- Class 1 : 1 item [5%]
- Class 2 : 12 items [63%]
- Class 3 : 6 items [32%]

Although the classification system points to Class 3, subjective assessment would rate the model more as Class 1-2 for the following reasons:

- Mine inflow rates are not readily available for calibration purposes;
- Baseflow estimates are not ground-truthed;

- There is uncertainty as to the details for historical mining; and
- The groundwater system is complex as the result of a large number of previous and current simultaneous mining operations.

The model is not designed fate and transport modelling. The model would benefit by two additional monitoring bores nests (shallow and deep) being constructed, and time series groundwater level data being collected adjacent to the workings as shown in Figure 3-11.

10 Conclusions

A new, upgraded numerical groundwater model has been developed and calibrated for the Project. Groundwater modelling of the Nebo Longwalls 1 to 6 was previously undertaken in 2011 to support the initial groundwater impact assessment (GeoTerra, 2010) to assess potential underground mining impacts on the local and regional groundwater systems. This model has been developed by modifying a numerical model constructed to assess the impacts of coal mining at nearby Dendrobium (Hydrosimulation 2019).

The model has been calibrated in steady state and transient conditions in accordance with the Australian groundwater modelling guidelines (Barnett et al, 2012). Model parameters are based on the Dendrobium model but have been refined in the Wongawilli mining area based on site specific data, a literature review and through the calibration process. The proposed mining activities (NW Mains Modification) are to extend approved mining of six long wall panels in the Nebo Area (Nebo Longwalls 1 to 6) for another five years, until the 31st of December 2025 and to extend the roadways in the Bulli Seam to intersect the existing Wonga Shaft.

The key conclusions from this groundwater impact assessment are summarised as follows:

- The model predictions generally match the time series observations at the Wongawilli project area and nearby Dendrobium;
- The model scaled RMS is 8.44 %, indicating a good fit using statistical targets and is fit for purpose for predictions as suggested by the MDBC (2001) and Barnett et al. (2012);
- Mine inflows for the Project commence in January 2022 ranging from 0 to 0.14 ML/day. The inflows spike during the mining of the ‘L panel’ (peaking at 0.2 ML/day) is due to the mine plan progressing into the lower Wongawilli Seam;
- During mining groundwater will be drawn down to the base of the Bulli and Wongawilli Seams. Groundwater modelling has predicted there will be negligible groundwater drawdown in the upper units of the alluvium/weathered zone or Hawkesbury Sandstone and consequently there are unlikely to be any losses or diversions of surface water;
- Groundwater dependant ecosystems situated within the shallow groundwater systems were identified as potentially being at risk due to the Project. Since there is negligible drawdown in the Layer 1 and cracking is unlikely to extend into the Bulgo Sandstone and overlying hydrostratigtraphic units, it is assessed to be unlikely that additional surface water will be lost to groundwater due to the Project.
- A review of the registered bores near the Project area indicated that the water supply bores were located within the Hawkesbury Sandstone, Bulgo Sandstone or alluvium flanking the Nepean River or Mount Hunter Rivulet. Since it is predicted that there will be negligible groundwater drawdown within the Hawkesbury Sandstone, Bulgo Sandstone or alluvium it is considered there will be negligible impact on water supply bores due to the Project;
- Similarly since it is predicted that there will be negligible groundwater drawdown within the Hawkesbury Sandstone, Bulgo Sandstone or alluvium it is considered there will be negligible impact on baseflow to rivers and creeks due to the Project.
- Post mining inflows are predicted to be between 9.5 and 18.1 ML/year, although the recovery is not linear.
- Groundwater impacts due to the Project are assessed to satisfy to requirements of the AIP as:
    - modelling suggests that groundwater drawdown is unlikely to exceed the AIP minimal impact criterion at any water supply works. That is no bores were predicted to be drawn down by the Project by more than 2 m due to mining.

- The watertable is not predicted to be drawn down by more than 2 m due to mining.
- Groundwater level variation in groundwater associated with GDEs will not vary by more than 10%.
- Mine inflow modelling indicates the maximum total predicted inflows are 36.8 ML/year indicating the WCL WAL is sufficient to account for the water take, in accordance with the AIP.

The conclusions of this groundwater impact assessment are in general accordance with the previous groundwater impact assessment for the Project (GeoTerra, 2010).

11 References

Advisian, 2016, 2016. Literature Review of Underground Mining Beneath Catchments and Water Bodies. Report for Water NSW by Advisian, John Ross, PSM, Mactaggart and Grant Sutton & Assoc., dated December.

Australian Groundwater Consultants [AGC] 1984. Effects of Mining on Groundwater Resources in the Hunter Valley. Report for the NSW Combined Colliery Proprietor's Association.

Australian and New Zealand Environment Conservation Council and Agricultural Resource Management Council of Australia and New Zealand (ANZECC/ARMCANZ), (2000), Australian and New Zealand Guidelines for Fresh and Marine Water Quality, 2000.

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 Series No. 82, June 2012.

BHP 2005. Report on the Geology, Quality and Mineral Resources of Dendrobium Area 2, dated September

Biosis, 2014a; Wongawilli Colliery Aquatic Ecology Monitoring Program. Spring 2013. Report prepared for Wongawilli Coal Ltd, dated 1 August.

Biosis, 2014b; Wongawilli and Nebo Areas. Ecological monitoring Program Annual Report for the 2013 Calendar Year. Report prepared for Wongawilli Coal Ltd, dated 15 October.

Booth C.J., 2002; The Effects of Longwall Coal Mining on Overlying Aquifers. In P. Younger & N. Robins (Eds), Mine Water Hydrogeology and Geochemistry (Vol. 198, pp. 17-45).

Bowman H.N., 1974. Wollongong 1:50,000 Geological Map, 9029-II, Geological Survey of New South Wales, Sydney. Explanatory Notes

Burea Veritas, 2010. NRE Wongawilli Colliery Assessment of Planned Bulli Seam Driveage. Prepared by Barry Clark, dated March 2010.

Coffey, 2012; Groundwater Study – Area 3B Dendrobium Coal Mine: Data Analysis. Report GEOTLCOV24507AB-AB1 to BHP Billiton, dated November.

CSIRO, 2015; Soil and Landscape Grid National Soil Attribute Maps – Depth of Regolith. https://data.csiro.au/collections/collection/CIcsiro:11393v1#collection/CIcsiro:11393v006.

DAWE, 1999; Commonwealth Environment Protection and Biodiversity Conservation Act (EPBC Act). Department of Agriculture Water and the Environment. https://www.environment.gov.au/epbc

Ditton, S. and Merrick, N, 2014, A New Subsurface Fracture Height Prediction Model for Longwall Mines in the NSW Coalfields. Geological Society of Australia, 2014 Australian Earth Sciences Convention (AESC), Sustainable Australia. Abstract No 03EGE-03 of the 22nd Australian Geological Convention, Newcastle City Hall and Civic Theatre, Newcastle, New South Wales. July 7 - 10. Page 136.

Doherty, J., 2010. PEST - Model Independent Parameter Estimation. User Manual 5th Edition. Watermark Numerical Computing.

Doherty, J., 2015. Calibration and Uncertainty Analysis for Complex Environmental Models. Watermark Numerical Computing, Brisbane, Australia. ISBN: 978-0-9943786-0-6.

Domenico and Schwartz; 1998: Physical and Chemical Hydrogeology. John Wiley & Sons. 824p.

Edwards, A.B., 1953. Crinanite-picrite intrusions in the Nebo district of New South Wale: Proc. R. Soc. Vic., v. 65, p 9-29.

ERM, 2010; NRE Wongawilli Colliery. Nebo Area. Prepared for Gujarat NRE FCGL Pty Ltd. Report No 0097271RP01 Final, dated October.

Geoscience Australia, 2011. Digital Elevation Model (DEM) of Australia, National Location Information Online Database. Available at: http://www.ga.gov.au/scientific-topics/national-location-information/digital-elevation-data

GeoTerra, 2010; NRE Wongawilli Colliery Nebo Panels 1 to 6. Groundwater Assessment, Cordeaux, NSW. Prepared for Gujarat NRE FCGL Pty Ltd. Report No GUJ4-GWR1B, dated 25 June.

Gilbert and Associates, 2009. Bulli Seam Operations Environmental Assessment Surface Water Assessment. Report prepared for Illawarra Coal Holdings Pty Ltd.

Golder, 2010; Wongawilli Colliery: Nebo Panels 1 to 6 and Western Driveage Groundwater Modelling. Prepared for Gujarat NRE Minerals Ltd, dated 18 June. In GeoTerra, 2010.

Hansen Bailey, 2015; Nebo Area Modification 1 Response to Submissions. Prepared for Wollongong Coal Limited, dated August.

Harries, 1997. Acid mine drainage in Australia: Its extent and potential future liability. Department of the Environment. 1997

Hawkes G, 2017; Analysis of aquifer parameters in the Triassic Sydney Basin during the WestConnex hydrogeological investigations. Australasian Conference, University of NSW, Kensington, Sydney, 11 – 13 July 2017.

Hawkins, J.W., 1998. Hydrogeologic characteristics of surface-mine spoil. In Coal Mine Drainage Prediction and Pollution Prevention in Pennsylvania, ed. Brady, Smithy and Schueck. Harrisburg, Pennsylvania. Available at: http://www.techtransfer.osmre.gov/nttmainsite/Library/pub/cmdpppp/chapter3.pdf

HEC, 2019; Dendrobium Mine Plans for the future surface water assessment. Hydro Engineering and Consulting. Pty Ltd, prepared for South32, dated May.

HEC, 2020; Wongawilli Colliery - Surface Water Technical Report. Interim Draft Report Hydro Engineering and Consulting. Pty Ltd, prepared for Wongawilli Coal Pty Ltd, dated 16 October.

Heritage Computing, 2009. Bulli Seam Operations (BSO) – Groundwater Assessment. Report prepared for Illawarra Coal. HC2010/7, dated October.

HGEO, 2018. Assessment of water level, stream flow and water chemistry trends at Wongawilli Creek. Report J21450-D18295, dated February.

Holla and Barclay, 2000. Subsidence in the Southern Coalfield, NSW, Australia. NSW Department of Mineral Resources.

HydroAlgorithmics, 2018. AlgoCompute web site, https://www.algocompute.com/.

HydroSimulations, 2019. *Dendrobium Mine – Plan for the Future: Coal for Steelmaking Groundwater Assessment,* prepared for Illawarra Coal South32, Report HS2018/67, May 2019.

IESC, 2014; Subsidence from coal mining activities. Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development. Australian Government Department of the Environment, dated June.

IEMPC, 2019; Independent Expert Panel for Mining in the Catchment Report (IEMPC): Part 2. Coal Mining Impacts in the Special Areas of the Greater Sydney Water Catchment, prepared for the NSW Department of Planning, Industry and Environment.

Jewell, C and Associates, 2001. Assessment of groundwater impacts of coal-bed methane development, Cawdor, NSW

Kelly, B., Brown, S., and Merrick, N. 2005. Hydrogeology of the Blue Mountains, NSW: Simulating impacts of bore abstraction and sewer tunnel inflows on stream base-flow. New Zealand Hydrological Society, IAH Australian Chapter, New Zealand Society of Soil Science.

McDonald, M.G., and Harbaugh, A.W., 1988. A modular three-dimensional finite-difference ground-water flow model: Techniques of Water-Resources Investigations of the United States Geological Survey. Book 6. USGS.

McNally G. and Evans R., 2007. Impacts of longwall mining on surface water and groundwater, Southern Coalfield NSW. Report prepared for NSW Department of Environment and Climate Change. eWater Cooperative Research Centre, Canberra. Viewed 18 August 2014, http://www.ewater.com.au/uploads/files/McNally_Evans-2007-Longwall_mining.pdf.

MDBC (Middlemis, H., Merrick, N., and Ross, J.), 2001. Murray-Darling Basin Commission – Groundwater Flow Modelling Guideline. Report for MDBC. January 2001.

Merrick, D. and Merrick, N., 2015. AlgoMesh: A new software tool for building unstructured grid models. In Proc. MODFLOW and More, Golden, Colorado.

Merrick, D., 2017. AlgoCompute: Large-scale calibration and uncertainty analysis made easy in the cloud. In Proc. MODFLOW and More, Golden, Colorado.

Moffitt, R.S., 1999. Southern Coalfield Regional Geology Map, 1:100,000, First Edition. Geological Survey of NSW, Sydney

MSEC 2010. Prediction of subsidence parameters and the assessment of mine impacts on natural features and surface infrastructure resulting from the proposed extraction of Longwalls N1 to N6 in the Nebo area in support of Part 3A Application. Prepared for Gujarat NREFCGL Pty Ltd.

Natural Resources Environment 2019, *Underground Expansion Report Preferred Project Report*, Gujarat NRE Coking Coal Ltd,

NoW 2011; Water Sharing Plan, Greater Metropolitan Regional Groundwater Sources Background Document, Sydney: NSW Office of Water.

Panday, S., Langevin, C.D., Niswonger, R.G., Ibaraki, M., and Hughes, J.D., 2013., MODFLOW–USG version 1: An unstructured grid version of MODFLOW for simulating groundwater flow and tightly coupled processes using a control volume finite-difference formulation: USGS Techniques and Methods 6-A45.

Peng, S. S., and Chiang, H. S., 1984. Longwall mining. New York: Wiley.

Price and Wright, 2016. Water Quality Impact from the Discharge of Coal Mine Wastes to Receiving Streams: Comparison of Impacts from an Active Mine with a Closed Mine. Water, Air and Soil Pollution 2016.

Rau, G.C., Acworth R.I., Halloran, L.J.S., Timms W.A., and Cuthbert M.O., 2018; Quantifying compressible groundwater storage by combining cross-hole seismic surveys and head response to atmospheric tides. Journal of Geophysical Research: Earth Science, 123, 1910-1930. https://doi.org/10.1029/2018JF004660.

Rumbaugh J.O and Rumbaugh D.B., 2011; Tutorial Manual for Groundwater Vistas, Version 6. Environmental Simulations.

SCT., 2010. Implications of Nebo 8/8A Results for Subsidence and Groundwater Modelling. Prepared for Gujarat NRE FCGL Pty Ltd. Report No GUJ4-GWR1B, dated 8 April.

SCT., 2020. Wongawilli Colliery: Subsidence and Geotechnical Assessment for Application to Modify Project Approval 09_0161. Prepared for Wollongong Coal Limited. Report No WCW05136, dated 11 September.

SLR 2020, Tahmoor South Amended Project Report Groundwater Assessment, prepared for Tahmoor Coal Pty Ltd, NRE Wongawilli Coal. Report GUJWO3548A, February 2020.

South32 2019, *Appin Water Management Strategy 5 Year Plan FY21 to FY26*, October 2019.

Tammetta P. and Hewitt P., 2004; Hydrogeological properties of the Hawkesbury Sandstone in the Sydney Region. Australian Geomechanics, Volume 39, No. 3, pp. 91-107.

Tammetta, P. and Hawkes, G. 2009. Pump testing of Mesozoic Sandstones. IAH Sydney Basin Symposium, Sydney.

Tammetta P., 2012; Estimation of height of complete groundwater drainage above mined longwall panel. Ground Water. National Groundwater Association.

Tammetta P., 2014; Estimation of the change in hydraulic conductivity above mined longwall panels. Ground Water. National Groundwater Association

Tomkins, K.M. and Humphreys, G.S., (2006). Upland swamp development and erosion on the Woronora Plateau during the Holocene. North Ryde, NSW: Macquarie University.

Tonkin, C Timms W., 2015. Geological structures and fault-infill in the Southern Coalfields and implications for groundwater flow. Journal of Research Projects Review, 2015, 49-58, Mining Education Australia.

Watershed HydroGeo, 2018. Dendrobium Area 3B – Analysis of low flow and pool levels on Wongawilli Creek, Report IWC101\R003i2, dated October

Watershed HydroGeo, 2019. Geographical Review of mining effects on Upland Swamps at Dendrobium Mine. Doc R008i5.

WCL, 2017. Competent Person Report on the Resource Estimation of Wollongong Coal. Wongawilli Colliery as at 31st August 2017, prepared by Barry Clark.

Whittaker, B., and Reddish, D. 1989. Subsidence: occurrence, prediction and control. Amsterdam: Elsevier.

Wright I.A., Paciuszkiewicz K. and Belmer N.,., 2018. Increased Water Pollution after Closure of Australia's Longest Operating Underground Coal Mine: a 13-Month Study of Mine Drainage, Water Chemistry and River Ecology. Water, Air Soil Pollutant 229, 55.

Umwelt 2020, Russell Vale Colliery Revised Underground Expansion Project, Submissions Report Part B Final, February 2020.

APPENDIX A

Groundwater Quality Data Summary

Analyte		Wongawi lli River	Avon River	Nebo River	Crinanite	Narrabeen Group	Bulli Seam
pH (field)	Max	-	13.2	7.36	12.1	10.2	
	Mean	-	5.7	6.65	8.2	8.3	
	Median	-	5.5	6.55	8.2	8.4	
	Min	-	3.9	6.04	4.4	7.1	
	Count	-	177	14	207	51	
EC (field) µS/cm	Max	-	2224.0	227	2983	1404	
	Mean	-	154.9	167.8	632	736	
	Median	-	73.7	163	618	724	
	Min	-	41.0	98	-	-	
	Count	-	177	5	207	51	
Resistivity (Ω/cm)	Max	24.0	16.0	-	250000	1976	
	Mean	10.7	11.3	-	4692	1594	
	Median	9.5	11.0	-	3362	1617	
	Min	6.0	7.0	-	379	827	
	Count	225	127	-	205	50	
TDS (mg/L)	Max	13.0	4.0	-	1938	912	6560
	Mean	1.3	1.1	-	408	478	2526
	Median	1.0	1.0	-	398	470	2375
	Min	0.8	1.0	-	137	0	460
	Count	224	127	-	206	51	24
Sodium (Total) mg/L	Max	22.0	3.0	-	148	150	282
	Mean	1.5	1.0	-	51	126	231
	Median	1.0	1.0	-	38	130	236
	Min	0.1	1.0	-	6	29	130
	Count	224	126	-	185	46	24
Calcium (Total) mg/L	Max	4.0	3.0	-	770	15	780
	Mean	1.3	1.4	-	52	10	623
	Median	1.0	1.0	-	11	10	682
	Min	1.0	0.0	-	<1	2	30
	Count	225	127	-	185	46	24
Potassium (Total) mg/L	Max	-	-	23.0	105	33	300
	Mean	-	-	13.7	9	14	167
	Median	-	-	13.7	3	14	155
	Min	-	-	10.9	<1	1	7
	Count	-	-	101	185	46	24

Analyte		Wongawi Ili River	Avon River	Nebo River	Crinanite	Narrabeen Group	Bulli Seam
Magnesium (Total) mg/L	Max	-	-	6.0	50	9	15
	Mean	-	-	3.4	8	7	2
	Median	-	-	3.7	4	7	1
	Min	-	-	1.0	<1	4	<1
	Count	-	-	101	184	46	24
Chloride (Total) mg/L	Max	-	-	1.0	89	82	110
	Mean	-	-	1.0	24	45	46
	Median	-	-	1.0	21	44	46
	Min	-	-	1.0	4	32	24
	Count	-	-	101	185	46	24
Fluoride (Total) mg/L	Max	-	-	8.0	1.3	2	0.2
	Mean	-	-	4.4	0.4	0.4	0.1
	Median	-	-	4.8	0.3	0.4	0.1
	Min	-	-	2.0	<0.1	<0.1	0.1
	Count	-	-	101	185	46	24
Manganese (Total) mg/L	Max	50.0	34.0	45.0	2.240	0.24	0.51
	Mean	21.0	20.8	25.4	0.307	0.05	0.069
	Median	18.5	20.0	24.7	0.082	0.04	0.011
	Min	9.0	9.0	21.0	<0.001	0.01	0.003
	Count	225	126	101	185	46	24
Iron (Total) mg/L	Max	1.0	0.3	0.2	177	17.9	22
	Mean	0.1	0.1	0.1	8.57	2.42	3.1
	Median	0.1	0.1	0.1	1.54	0.81	0.84
	Min	0.010	0.100	0.1	<0.05	0.20	0.13
	Count	224	126	137	185	46	24
Copper (Filtered) mg/L	Max	0.2	0.2	-	0.048	0.015	0.103
	Mean	0.025	0.029	-	0.009	0.003	0.057
	Median	0.017	0.020	-	0.004	0.002	0.058
	Min	0.001	0.001	-	<0.001	<0.001	0.008
	Count	224	127	-	185	46	24
Lead (Filtered mg/L	Max	0.2	0.2	1.1	0.050	0.084	0.16
	Mean	0.030	0.036	0.034	0.003	0.006	0.02
	Median	0.018	0.023	0.023	0.001	0.001	0.012
	Min	0.001	0.007	0.006	<0.001	<0.001	0.006
	Count	225	115	202	185	46	24

Analyte		Wongawi Ili River	Avon River	Nebo River	Crinanite	Narrabeen Group	Bulli Seam
Zinc (Filtered mg/L	Max	115.0	1.8	2.8	0.250	0.47	1.2
	Mean	3.8	0.1	0.2	0.029	0.039	0.115
	Median	0.5	0.1	0.2	0.015	0.011	0.066
	Min	0.010	0.050	0.1	<0.001	<0.005	0.042
	Count	225	127	202	185	46	24
Nickel (Filtered mg/L	Max	4.6	5.3	-	0.190	0.011	0.17
	Mean	0.4	0.4	-	0.008	0.005	0.01
	Median	0.1	0.1	-	0.006	0.004	0.002
	Min	0.010	0.050	-	<0.001	0.001	0.002
	Count	224	115	-	185	46	24
Aluminium (Filtered mg/L)	Max	1.3	0.2	0.1	1.610	0.31	0.55
	Mean	0.1	0.0	0.0	0.20	0.06	0.40
	Median	0.001	0.001	0.001	0.07	0.04	0.42
	Min	0.001	0.001	0.001	0.01	0.01	0.04
	Count	220	113	106	161	40	24
Arsenic (Filtered mg/L	Max	0.3	0.0	0.0	0.096	0.01	0.01
	Mean	0.010	0.002	0.001	0.003	0.002	0.002
	Median	0.001	0.001	0.001	0.001	0.002	0.001
	Min	0.001	0.001	0.001	<0.001	<0.001	<0.001
	Count	222	113	106	185	46	24
Lithium (Total)	Max	2.5	2.2	0.1	0.120	0.096	0.902
	Mean	0.2	0.1	0.0	0.006	0.045	0.466
	Median	0.010	0.007	0.006	0.003	0.036	0.451
	Min	0.001	0.005	0.005	<0.001	0.002	0.007
	Count	223	113	106	185	46	24
Barium (Total)	Max	0.7	0.7	0.0	0.266	0.264	2.12
	Mean	0.018	0.021	0.001	0.043	0.203	1.30
	Median	0.001	0.001	0.001	0.021	0.213	1.31
	Min	0.001	0.001	0.001	0.003	0.05	0.02
	Count	222	113	106	185	46	24
Strontium (Total)	Max	4.7	0.7	0.2	10.000	0.501	8.00
	Mean	0.3	0.1	0.0	0.898	0.373	4.67
	Median	0.2	0.1	0.0	0.056	0.390	4.72
	Min	0.010	0.010	0.024	0.001	0.034	0.07
	Count	201	100	101	184	46	24

Analyte		Wongawilli River	Avon River	Nebo River	Crinanite	Narrabeen Group	Bulli Seam
Total Nitrogen as N	Max	0.030	0.001	0.001	79.7	47	17.0
	Mean	0.002	0.001	0.001	2.6	2.74	11.8
	Median	0.001	0.001	0.001	1.3	1.50	12.1
	Min	0.001	0.001	0.001	0.1	0.40	4.1
	Count	223	113	185	182	46	24
Total Phosphorus as P	Max	0.048	0.006	0.004	13.7	1.86	0.41
	Mean	0.002	0.001	0.001	0.60	0.12	0.11
	Median	0.001	0.001	0.001	0.13	0.07	0.07
	Min	0.001	0.001	0.001	<0.01	0.01	<0.01
	Count	223	113	185	170	46	24
Sulfate as SO4 Turbidimetric	Max	0.3	0.026	0.041	860	430	14
	Mean	0.005	0.008	0.017	69	66	4
	Median	0.002	0.007	0.018	11	68	3
	Min	0.001	0.001	0.008	<1	4	<1
	Count	223	113	185	163	46	24
Dissolved Organic Carbon	Max	0.039	0.018	0.071	210	155	18
	Mean	0.004	0.006	0.036	18	5	12
	Median	0.003	0.005	0.033	4	1	13
	Min	0.001	0.001	0.010	1	1	3
	Count	223	110	106	181	44	23

Note Values below the limit of reporting were set at the limit for the calculations

* Maximum concentration at which good condition might be expected, with 13,000 mg/L for sheep, 5,000 mg/L for beef cattle, 4,000 mg/L for dairy cattle, 6,000 mg/L for horses and 3,000 mg/L for pigs and poultry.

a NHMRC Health Guidelines for Drinking Water (2015)

b NHMRC Aesthetic Guidelines for Drinking Water (2015)

c NHMRC acid-soluble aluminium concentrations (2015)

(d) dissolved metals

Av. Average

Med. Median

^ Calculated based on field EC

APPENDIX B

Calibration Hydrographs

Calibration hydrographs

NWGW01_1 (195 m, 227 m, 259 m)

NWGW01_2 (30 m, 50 m, 700 m)

NWGW02_1 (60 m, 130m, 160 m, 175 m)

NWGW02_2 (250 m, 275 m, 301 m, 334 m)

NWW11 (60 m, 90 m, 104 m, 125 m)

NWW16 (71 m, 126 m, 146 m, 166 m)

NWW20B (33m, 60 m, 75 m, 135 m)

NWWPE1 (90 m, 135 m, 150 m, 165 m)

NWWSH1_1 (65 m, 90 m, 110 m, 130 m)

NWWSH1_2 (215 m, 255 m, 267 m, 297 m)

NEB06 (60 m, 80 m, 100 m, 115 m)

NEB07 (30 m, 45 m, 63 m, 90 m)

NEB08 (15 m, 35 m, 52 m, 72 m)

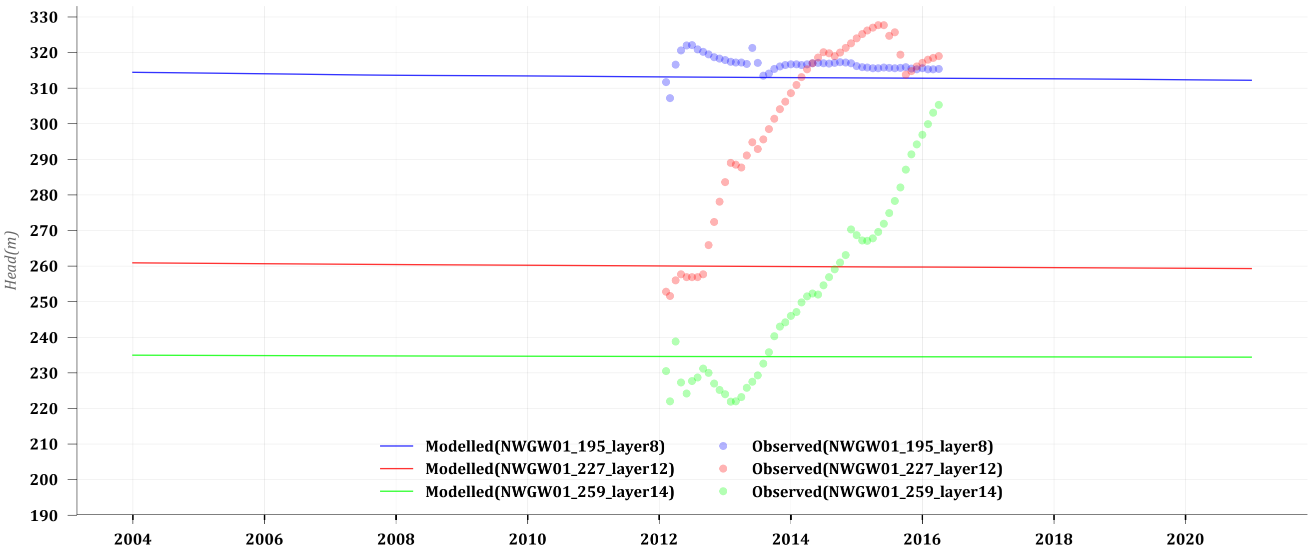
NEB08A (25 m, 45 m)

NEBO_1 (Layer 7, :Layer 12)

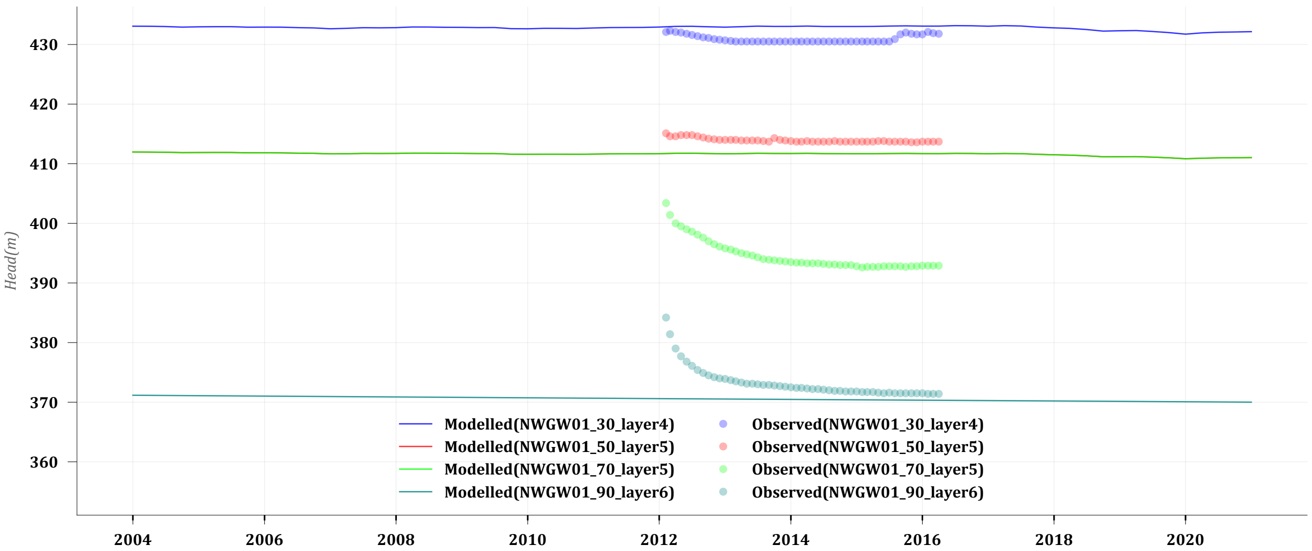
NEBO_3 (Layer 9)

NEBO_4 (Layer 14)

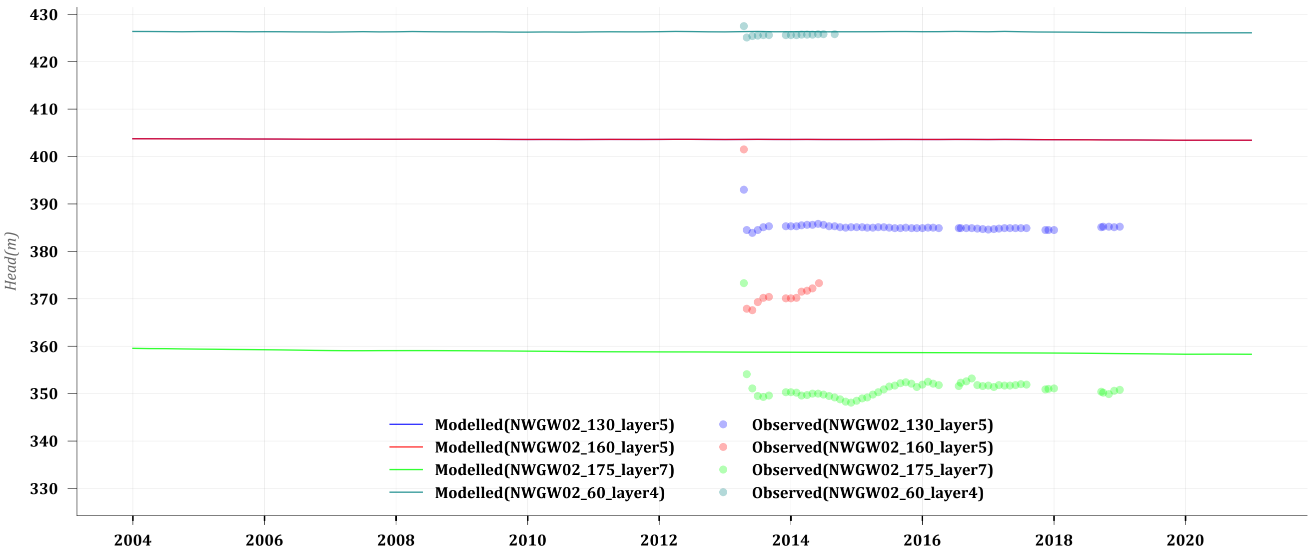
NWGW01_1

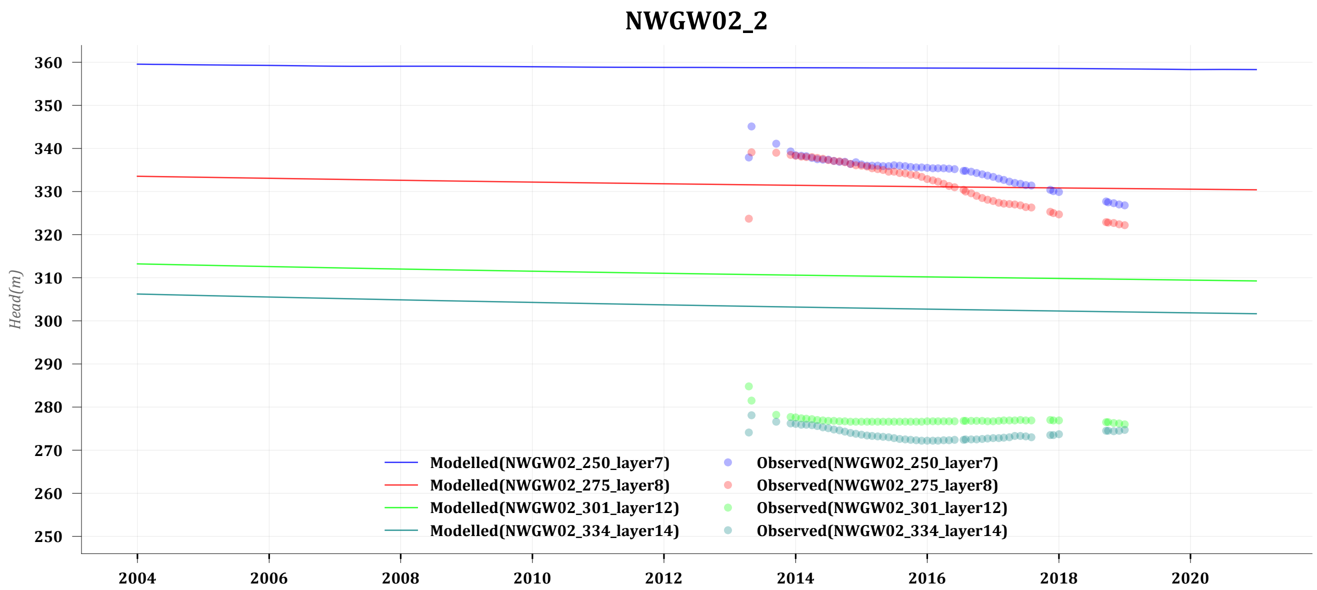


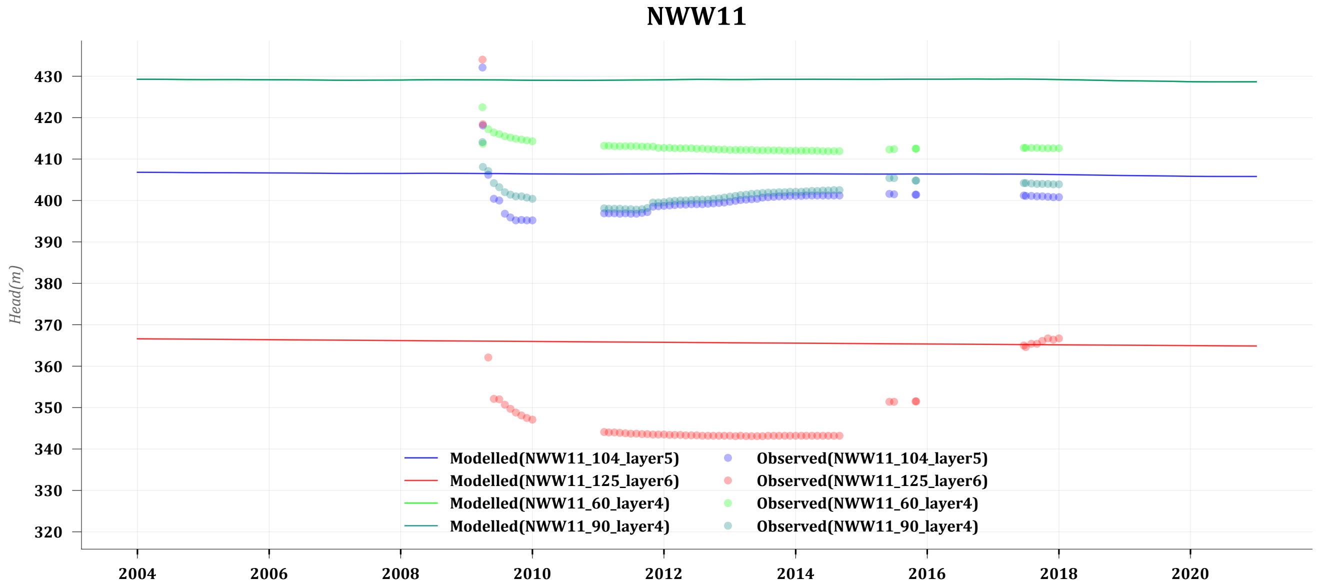
NWGW01_2

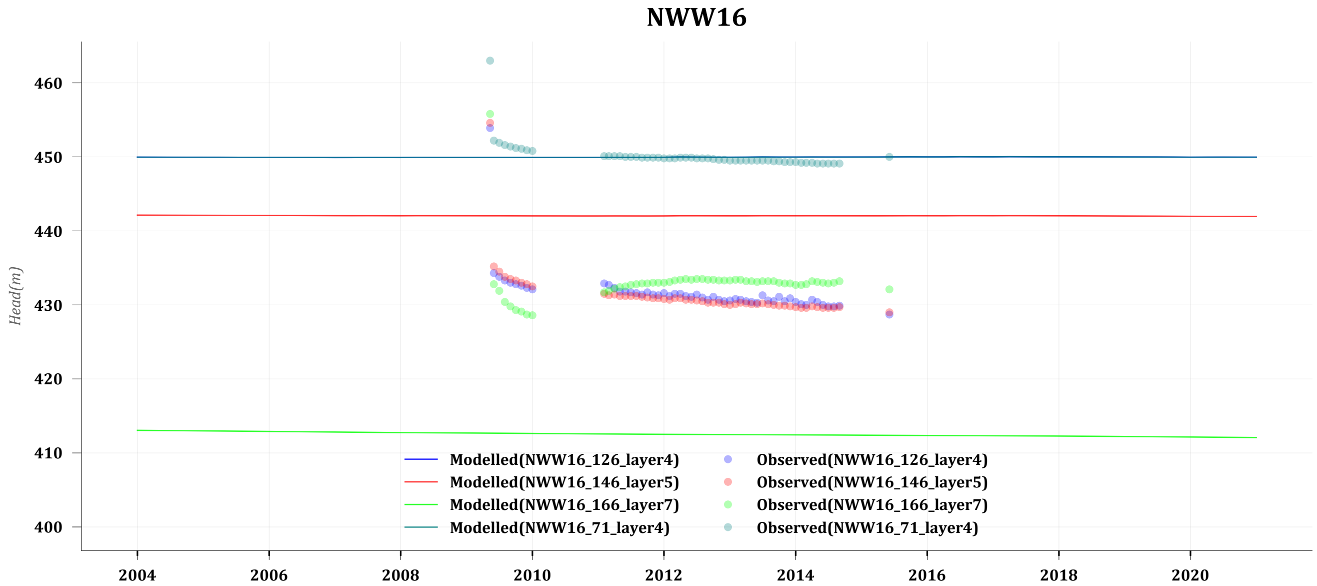


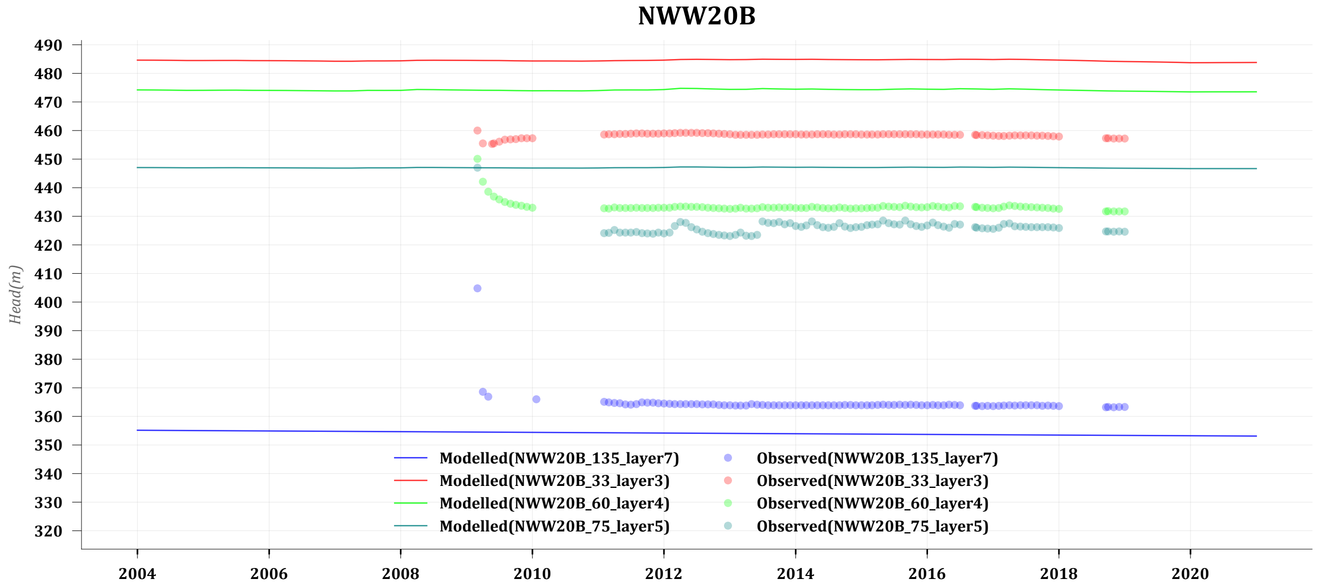
NWGW02_1

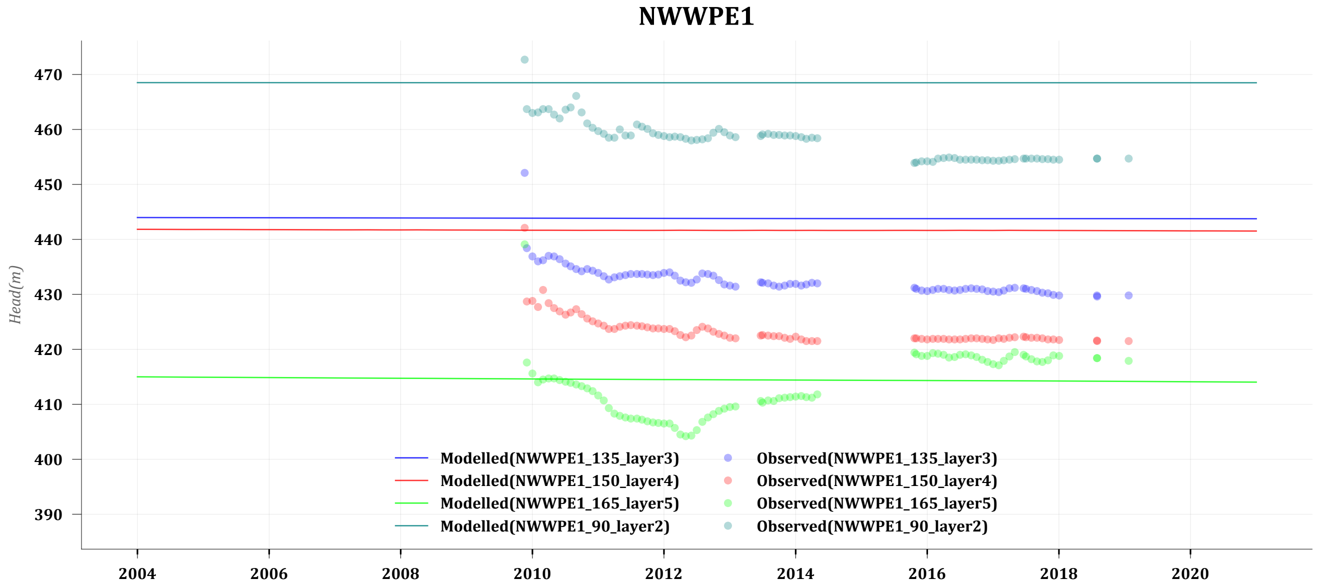


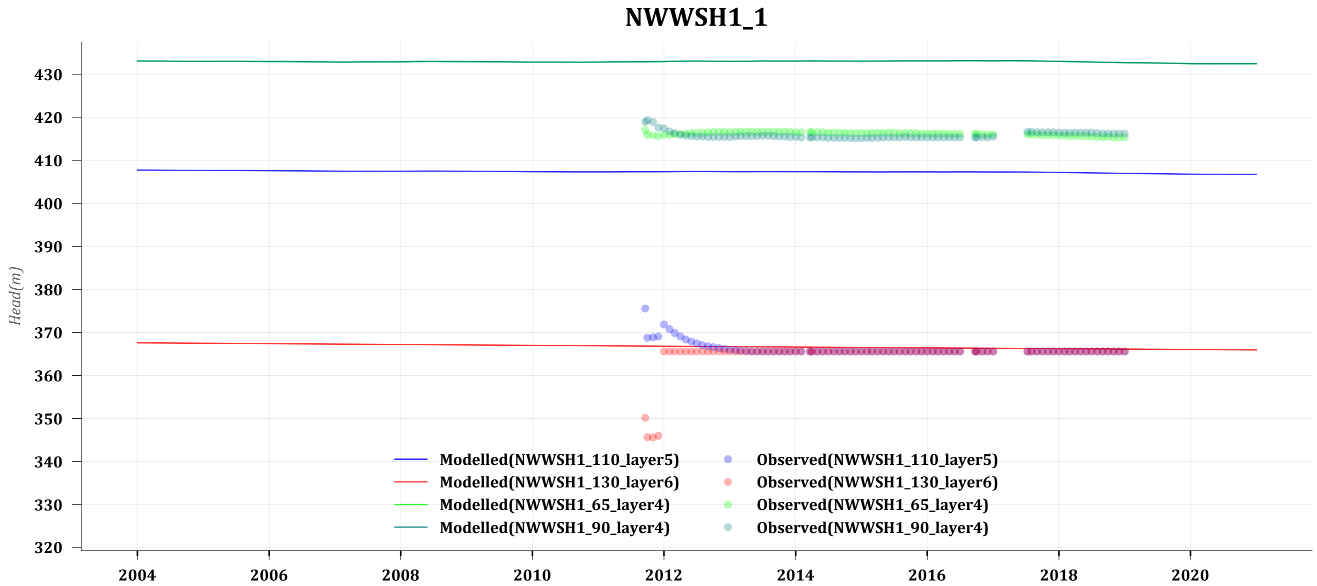

NWGW02_2
Head(m)
360
350
340
330
320
310
300
290
280
270
260
250
2004
2006
2008
2010
2012
2014
2016
2018
2020
Modelled(NWGW02_250_layer7)
Modelled(NWGW02_275_layer8)
Modelled(NWGW02_301_layer12)
Modelled(NWGW02_334_layer14)
Observed(NWGW02_250_layer7)
Observed(NWGW02_275_layer8)
Observed(NWGW02_301_layer12)
Observed(NWGW02_334_layer14)

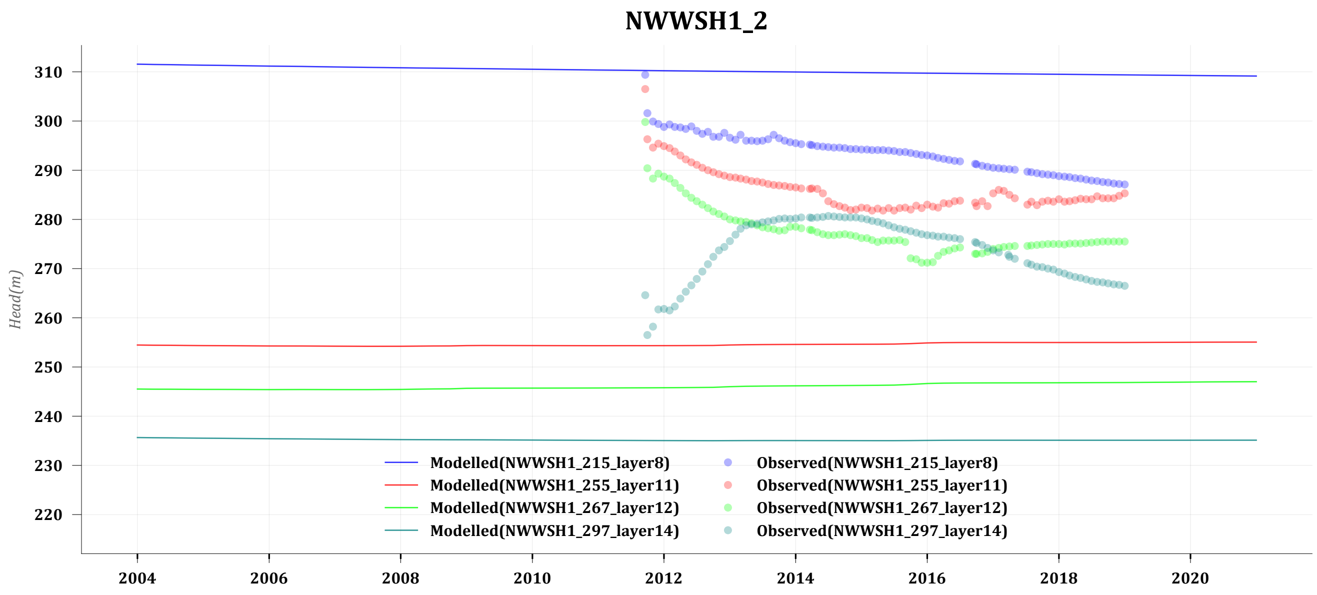

NWW11
Head(m)
430
420
410
400
390
380
370
360
350
340
330
320
2004
2006
2008
2010
2012
2014
2016
2018
2020
Modelled(NWW11_104_layer5)
Modelled(NWW11_125_layer6)
Modelled(NWW11_60_layer4)
Modelled(NWW11_90_layer4)
Observed(NWW11_104_layer5)
Observed(NWW11_125_layer6)
Observed(NWW11_60_layer4)
Observed(NWW11_90_layer4)

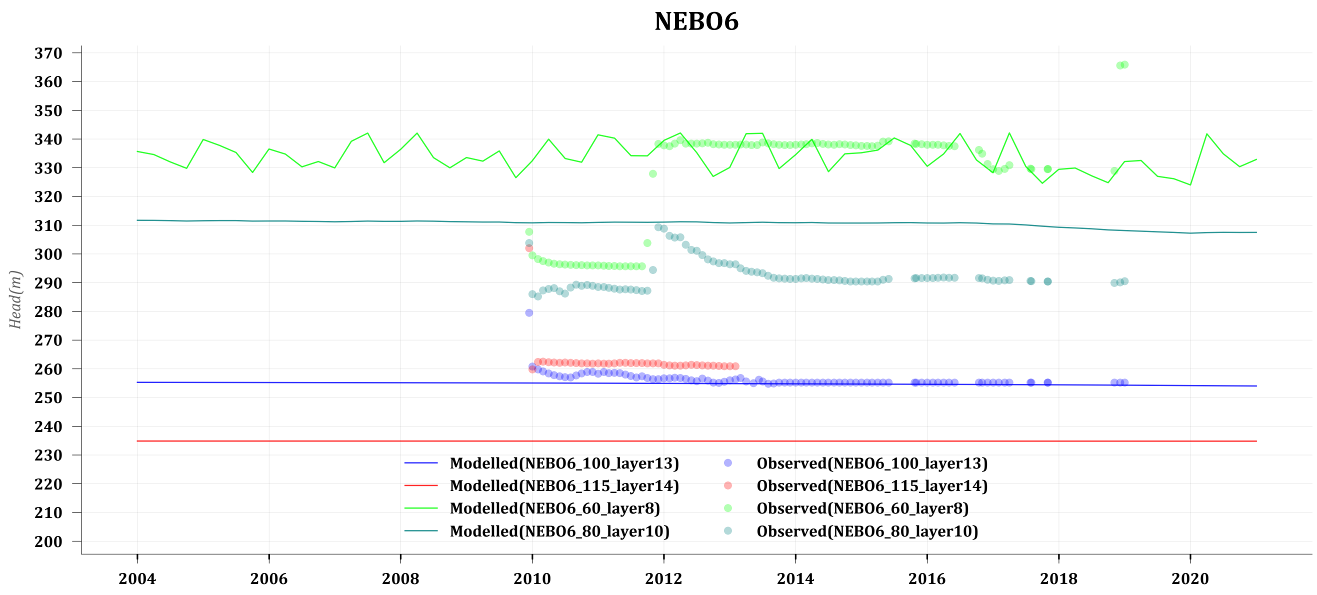

NWW16
Head(m)
460
450
440
430
420
410
400
2004
2006
2008
2010
2012
2014
2016
2018
2020
Modelled(NWW16_126_layer4)
Modelled(NWW16_146_layer5)
Modelled(NWW16_166_layer7)
Modelled(NWW16_71_layer4)
Observed(NWW16_126_layer4)
Observed(NWW16_146_layer5)
Observed(NWW16_166_layer7)
Observed(NWW16_71_layer4)

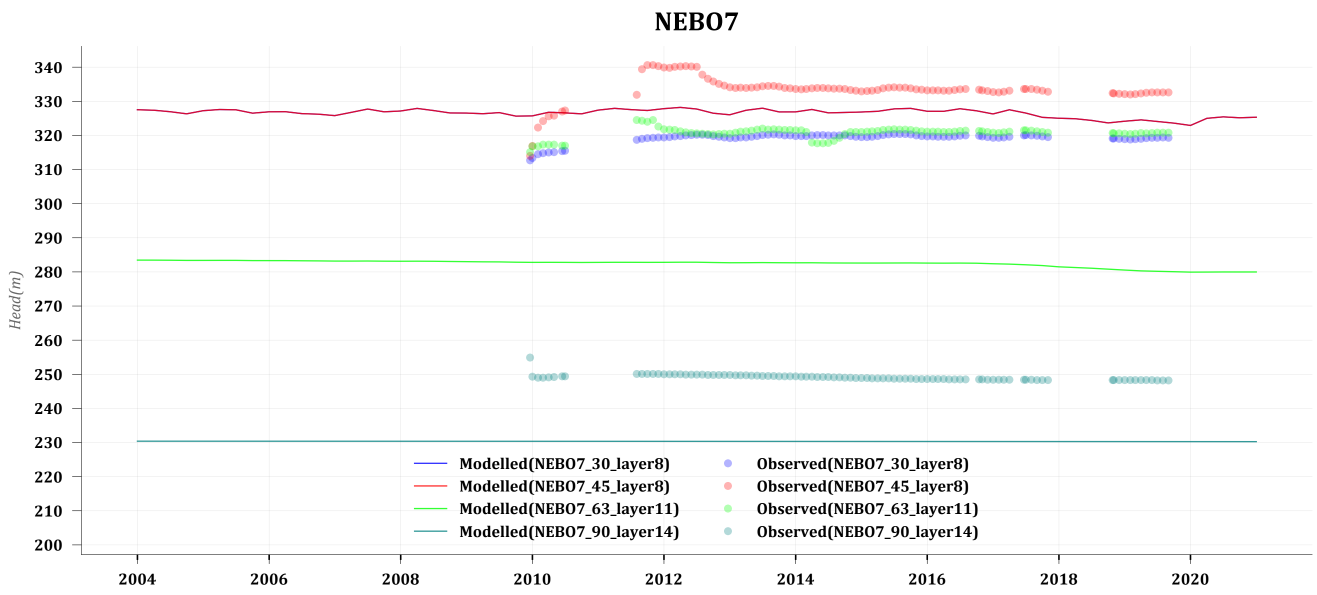

NWW20B
Head(m)
490
480
470
460
450
440
430
420
410
400
390
380
370
360
350
340
330
320
2004
2006
2008
2010
2012
2014
2016
2018
2020
Modelled(NWW20B_135_layer7)
Modelled(NWW20B_33_layer3)
Modelled(NWW20B_60_layer4)
Modelled(NWW20B_75_layer5)
Observed(NWW20B_135_layer7)
Observed(NWW20B_33_layer3)
Observed(NWW20B_60_layer4)
Observed(NWW20B_75_layer5)

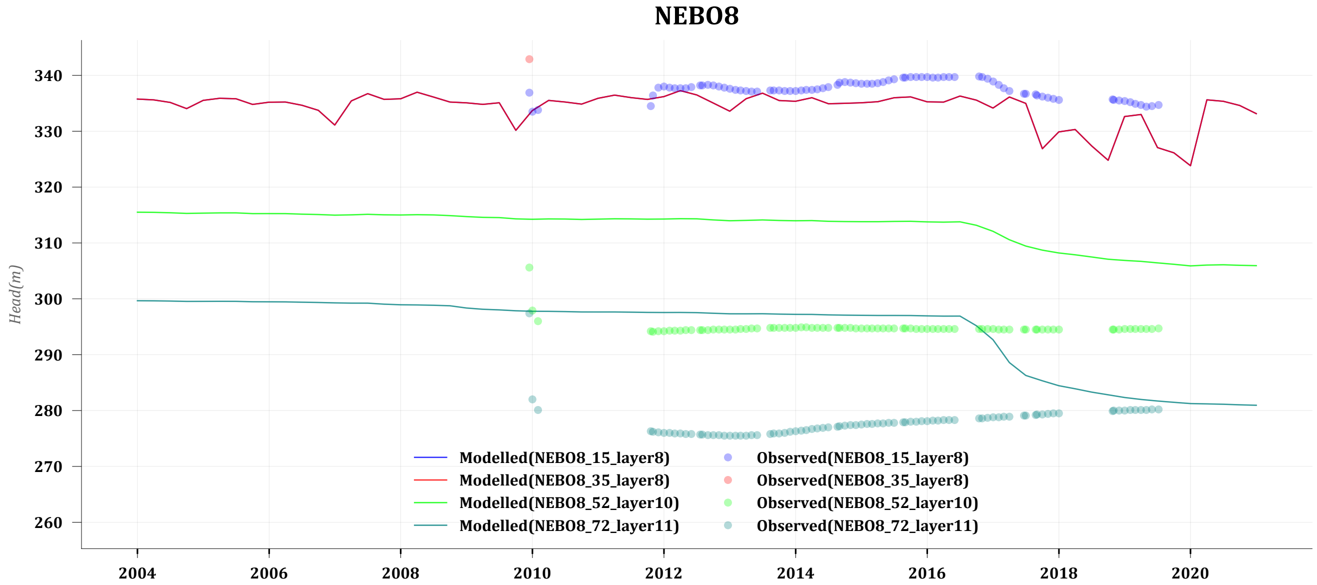

NWWPE1
Head(m)
470
460
450
440
430
420
410
400
390
2004
2006
2008
2010
2012
2014
2016
2018
2020
Modelled(NWWPE1_135_layer3)
Modelled(NWWPE1_150_layer4)
Modelled(NWWPE1_165_layer5)
Modelled(NWWPE1_90_layer2)
Observed(NWWPE1_135_layer3)
Observed(NWWPE1_150_layer4)
Observed(NWWPE1_165_layer5)
Observed(NWWPE1_90_layer2)

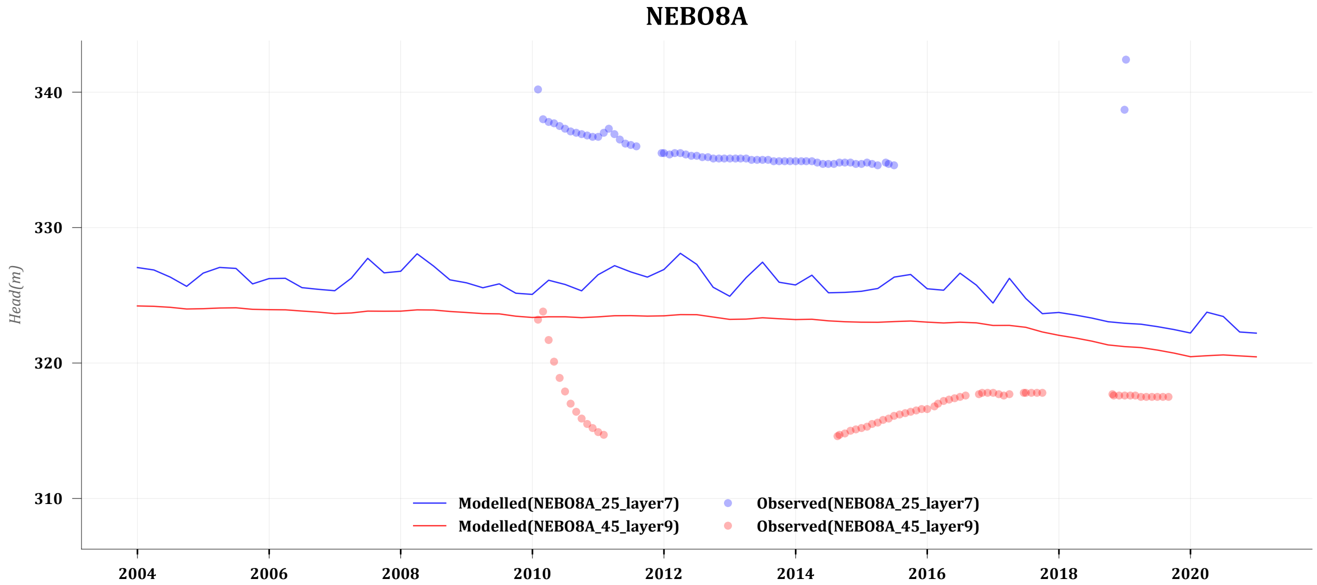

NWWSH1_1
Head(m)
430
420
410
400
390
380
370
360
350
340
330
320
2004
2006
2008
2010
2012
2014
2016
2018
2020
Modelled(NWWSH1_110_layer5)
Modelled(NWWSH1_130_layer6)
Modelled(NWWSH1_65_layer4)
Modelled(NWWSH1_90_layer4)
Observed(NWWSH1_110_layer5)
Observed(NWWSH1_130_layer6)
Observed(NWWSH1_65_layer4)
Observed(NWWSH1_90_layer4)

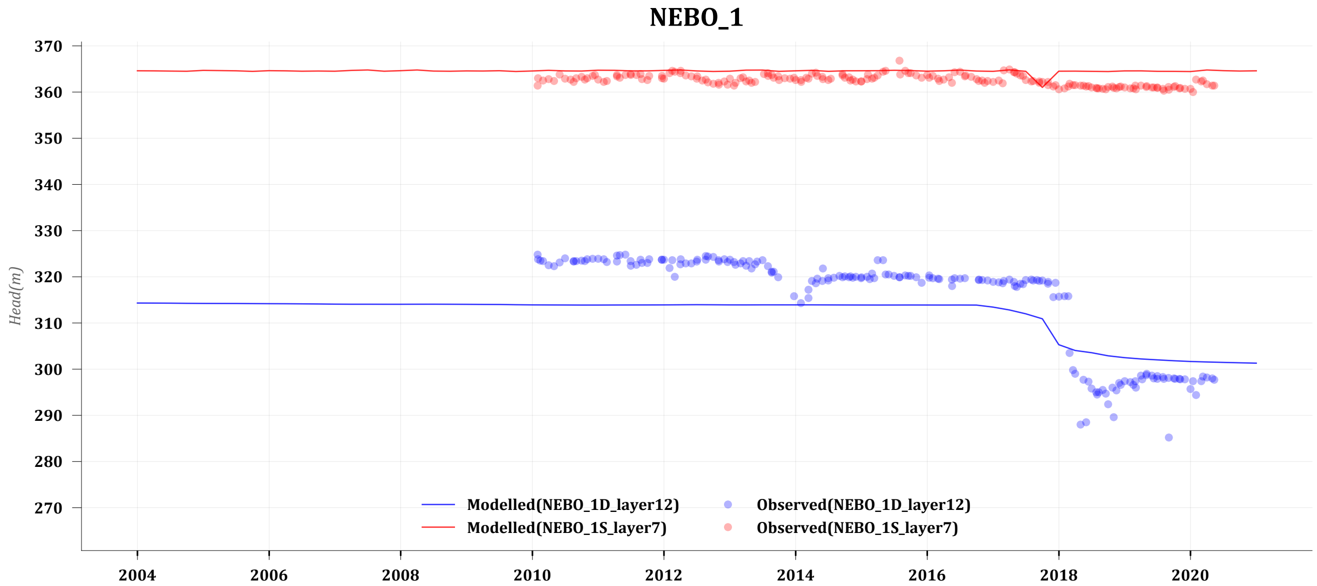

NWWSH1_2
Head(m)
310
300
290
280
270
260
250
240
230
220
2004
2006
2008
2010
2012
2014
2016
2018
2020
Modelled(NWWSH1_215_layer8)
Modelled(NWWSH1_255_layer11)
Modelled(NWWSH1_267_layer12)
Modelled(NWWSH1_297_layer14)
Observed(NWWSH1_215_layer8)
Observed(NWWSH1_255_layer11)
Observed(NWWSH1_267_layer12)
Observed(NWWSH1_297_layer14)

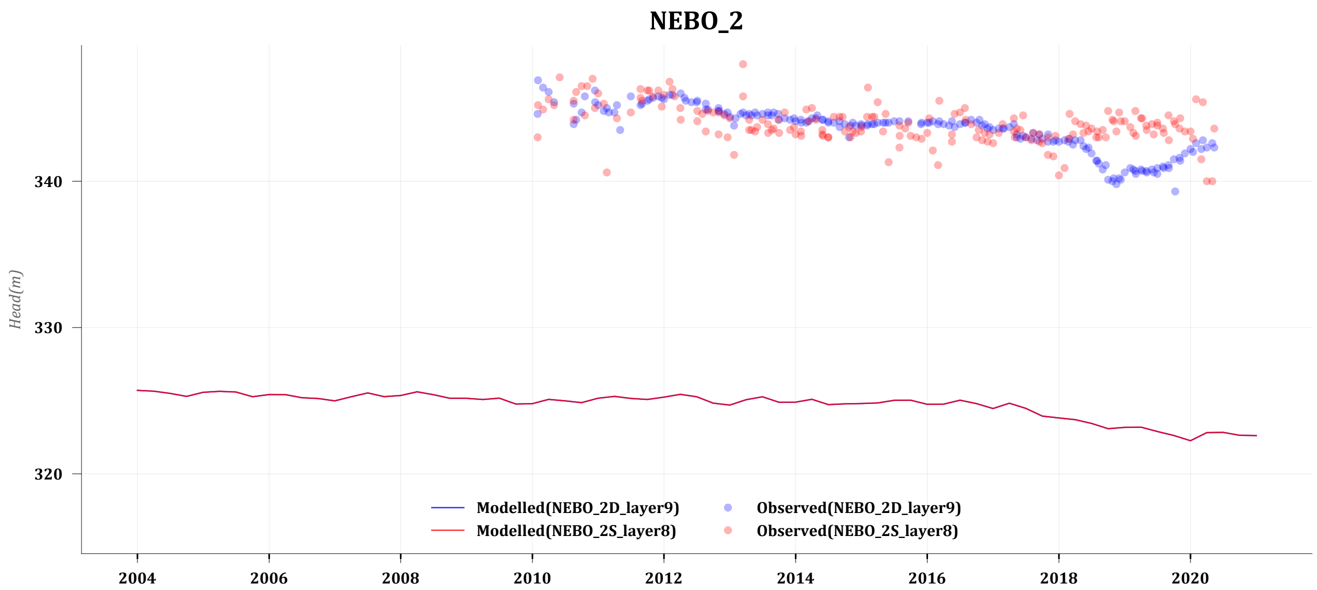

NEBO6
Head(m)
370
360
350
340
330
320
310
300
290
280
270
260
250
240
230
220
210
200
2004
2006
2008
2010
2012
2014
2016
2018
2020
Modelled(NEBO6_100_layer13)
Modelled(NEBO6_115_layer14)
Modelled(NEBO6_60_layer8)
Modelled(NEBO6_80_layer10)
Observed(NEBO6_100_layer13)
Observed(NEBO6_115_layer14)
Observed(NEBO6_60_layer8)
Observed(NEBO6_80_layer10)

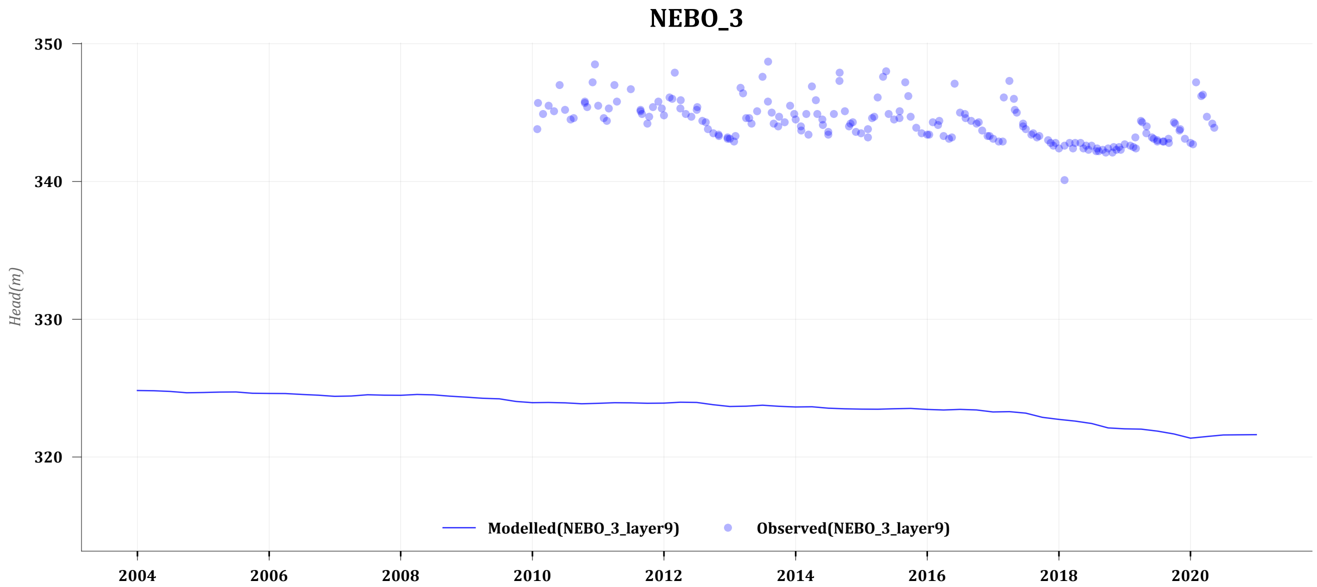

NEBO7
Head(m)
340
330
320
310
300
290
280
270
260
250
240
230
220
210
200
2004
2006
2008
2010
2012
2014
2016
2018
2020
Modelled(NEBO7_30_layer8)
Modelled(NEBO7_45_layer8)
Modelled(NEBO7_63_layer11)
Modelled(NEBO7_90_layer14)
Observed(NEBO7_30_layer8)
Observed(NEBO7_45_layer8)
Observed(NEBO7_63_layer11)
Observed(NEBO7_90_layer14)

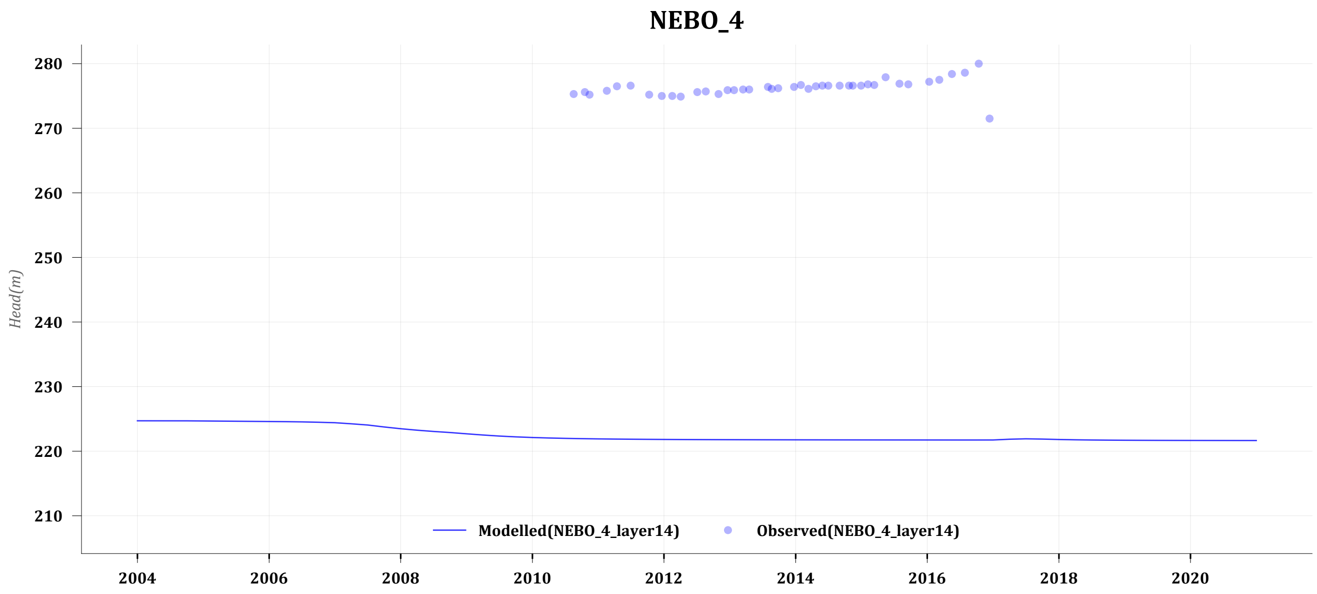

NEBO8
340
330
320
310
300
290
280
270
260
Head(m)
2004
2006
2008
2010
2012
2014
2016
2018
2020
Modelled(NEBO8_15_layer8)
Modelled(NEBO8_35_layer8)
Modelled(NEBO8_52_layer10)
Modelled(NEBO8_72_layer11)
Observed(NEBO8_15_layer8)
Observed(NEBO8_35_layer8)
Observed(NEBO8_52_layer10)
Observed(NEBO8_72_layer11)


NEBO8A
340
330
320
310
Head(m)
2004
2006
2008
2010
2012
2014
2016
2018
2020
Modelled(NEBO8A_25_layer7)
Modelled(NEBO8A_45_layer9)
Observed(NEBO8A_25_layer7)
Observed(NEBO8A_45_layer9)


NEBO_1
370
360
350
340
330
320
310
300
290
280
270
Head(m)
2004
2006
2008
2010
2012
2014
2016
2018
2020
Modelled(NEBO_1D_layer12)
Modelled(NEBO_1S_layer7)
Observed(NEBO_1D_layer12)
Observed(NEBO_1S_layer7)


NEBO_2
Head(m)
340
330
320
Modelled(NEBO_2D_layer9)
Modelled(NEBO_2S_layer8)
Observed(NEBO_2D_layer9)
Observed(NEBO_2S_layer8)
2004
2006
2008
2010
2012
2014
2016
2018
2020


NEBO_3
Head(m)
350
340
330
320
Modelled(NEBO_3_layer9)
Observed(NEBO_3_layer9)
2004
2006
2008
2010
2012
2014
2016
2018
2020

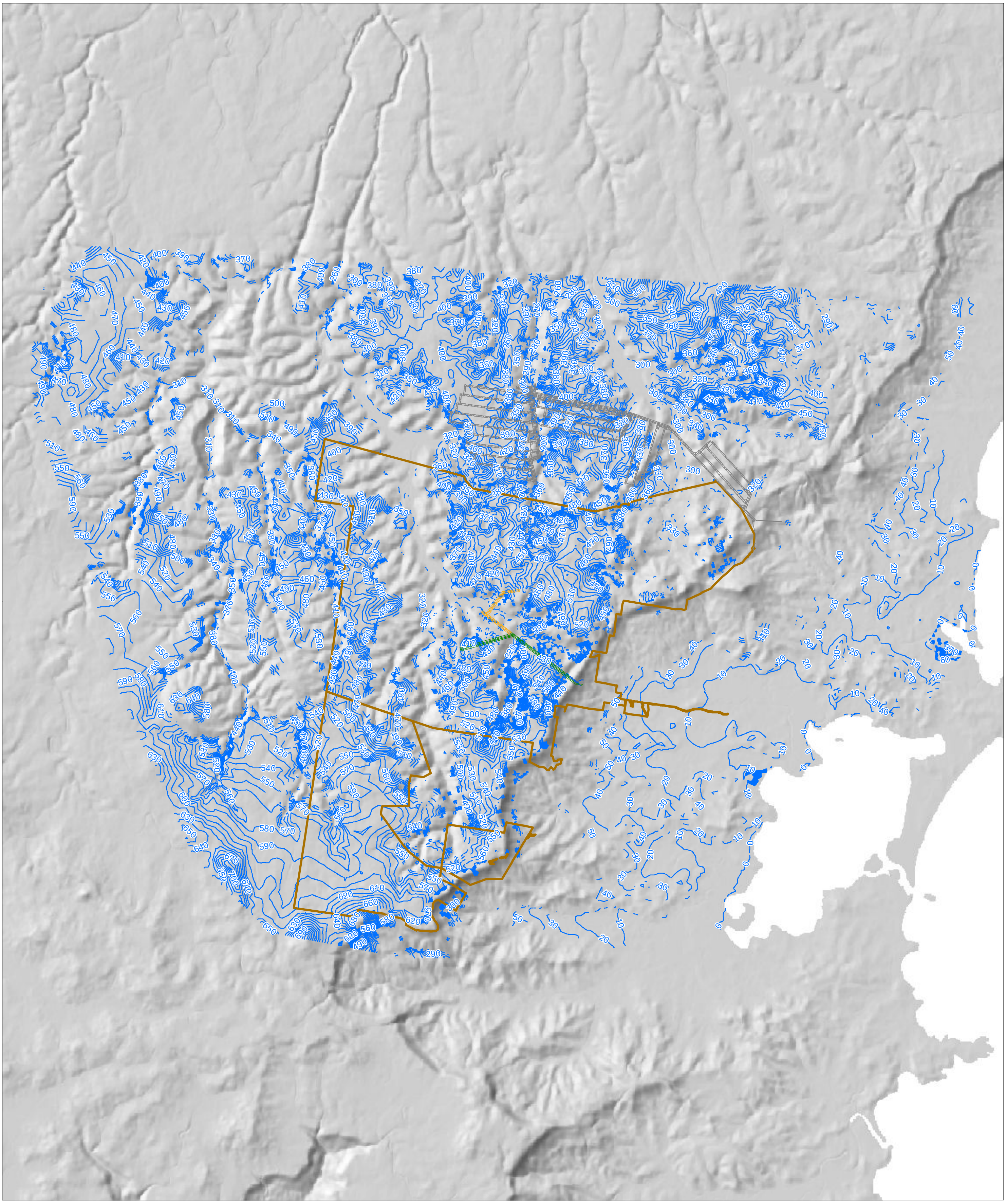

NEBO_4
Head(m)
280
270
260
250
240
230
220
210
Modelled(NEBO_4_layer14)
Observed(NEBO_4_layer14)
2004
2006
2008
2010
2012
2014
2016
2018
2020

APPENDIX C

Predicted Potentiometric Heads

Predicted Potentiometric Heads

C-1 Steady State Potentiometric Heads - Alluvium/weathered
C-2 End of Calibration Potentiometric Heads (July 2020) Alluvium/weathered
C-3 Potentiometric Heads - end Year 1 Mining (July 2022) Alluvium/weathered
C-4 Potentiometric Heads - end Year 2 Mining (July 2023) Alluvium/weathered
C-5 Potentiometric Heads - end Year 3 Mining (July 2024) Alluvium/weathered
C-6 Potentiometric Heads - end of Mining (Jan 2025) Alluvium/weathered
C-7 Potentiometric Heads - end of Surrounding Mining (Jan 2050) Alluvium/weathered
C-8 Potentiometric Heads - end of Recovery (Jan 2550) Alluvium/weathered
C-9 Steady State Potentiometric Heads - Bulgo Sandstone
C-10 End of Calibration Potentiometric Heads (July 2020) Bulgo Sandstone
C-11 Potentiometric Heads - end Year 1 Mining (July 2022) Bulgo Sandstone
C-12 Potentiometric Heads - end Year 2 Mining (July 2023) Bulgo Sandstone
C-13 Potentiometric Heads - end Year 3 Mining (July 2024) Bulgo Sandstone
C-14 Potentiometric Heads - end of Mining (Jan 2025) Bulgo Sandstone
C-15 Potentiometric Heads - end of Surrounding Mining (Jan 2050) Bulgo Sandstone
C-16 Potentiometric Heads - end of Recovery (Jan 2550) Bulgo Sandstone
C-17 Steady State Potentiometric Heads - Bulli Seam
C-18 End of Calibration Potentiometric Heads (July 2020) Bulli Seam
C-19 Potentiometric Heads - end Year 1 Mining (July 2022) Bulli Seam
C-20 Potentiometric Heads - end Year 2 Mining (July 2023) Bulli Seam
C-21 Potentiometric Heads - end Year 3 Mining (July 2024) Bulli Seam
C-22 Potentiometric Heads - end of Mining (Jan 2025) Bulli Seam
C-23 Potentiometric Heads - end of Surrounding Mining (Jan 2050) Bulli Seam
C-24 Potentiometric Heads - end of Recovery (Jan 2550) Bulli Seam
C-25 Steady State Potentiometric Heads - Wongawilli Seam
C-26 End of Calibration Potentiometric Heads (July 2020) Wongawilli Seam
C-27 Potentiometric Heads - end Year 1 Mining (July 2022) Wongawilli Seam
C-28 Potentiometric Heads - end Year 2 Mining (July 2023) Wongawilli Seam
C-29 Potentiometric Heads - end Year 3 Mining (July 2024) Wongawilli Seam
C-30 Potentiometric Heads - end of Mining (Jan 2025) Wongawilli Seam
C-31 Potentiometric Heads - end of Surrounding Mining (Jan 2050) Wongawilli Seam
C-32 Potentiometric Heads - end of Recovery (Jan 2550) Wongawilli Seam



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0 2 km

Projection: GDA 1994 MGA Zone 56
Scale: 1:190,000

Project No.: 660.20084.00000
Date: 10-Nov-2020
Drawn by: AP
Sheet Size: A4

GROUNDWATER IMPACT ASSESSMENT

Steady State - Potentiometric Heads - Alluvium\Weathered

C - 1

Legend

- Proposed workings
- Approved workings
- Dendrobium workings
- Current workings
- Mining Lease
- Potentiometric Surface (mAHD)

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