Appendix A – Appin Longwalls 709 to 711 and 905 Groundwater Impact Assessment (SLR 2022)

APPIN MINE EXTRACTION PLAN

Groundwater Impact Assessment

Prepared for:

South 32 - Illawarra Metallurgical Coal

SLR Ref: 665.10015-R03
Version No: -v8.0
September 2022

SLR

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BASIS OF REPORT

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APPENDICES

1 Introduction

The Appin Mine is located approximately 25 km north-west of Wollongong. Appin Mine is owned and operated by Illawarra Metallurgical Coal (IMC), a subsidiary of South32 Limited (South32). The existing mining operations are undertaken in accordance with Project Approval 08_0150 for the Bulli Seam Operations (BSO), granted in December 2011 and modified in October 2016 to incorporate the Appin Ventilation Shaft No. 6 Approval.

IMC is currently extracting Longwall 709 in Appin Area 7 and is preparing to extract Longwall 905 in Area 9. In accordance with the Bulli Seam Operations Project Approval conditions, an Extraction Plan (EP) is required to be prepared prior to commencement of secondary extraction. The EP outlines the proposed management, mitigation, monitoring, and reporting of potential impacts from the secondary extraction of approved longwalls at Appin Mine. IMC was granted EP approval on 29 July 2022 for Longwalls 709, 710A, 710B, 711 and 905, henceforth referred to as the Project. Condition 4 of the EP approval requires IMC to submit an updated groundwater assessment report to the Department of Planning and Environment. This report has been developed to address condition 4.

Heritage Computing (2009) conducted the groundwater impact assessment for the approved operations relevant to the Project. SLR Consulting Australia Pty Ltd (SLR) was engaged by South32 to complete a technical review of the groundwater impacts for the Project (Longwalls 709, 710A, 710B, 711 and 905). SLR has prepared this revision report in response to a review from the Biodiversity and Conservation Division of the NSW Department of Planning and Environment, dated 6 August 2021. The initial report prepared by SLR was issued in December 2020 and was revised in April 2021. This report presents the latest groundwater modelling methodology and results, as well as discussion on the impact predictions for the Project compared to the remodelled approved operations and predictions by Heritage Computing (2009).

1.1 Project Description

The Project relates to Longwalls 709, 710A, 710B, 711 and 905, as presented in **Figure 1**. The proposed mining includes:

- Longwall 709 – Planned to be mined from January 2022 to July 2023, panel width of 319 m and average extraction height up to 3.02 m;
- Longwall 710A – Planned to be mined from July 2023 to April 2025, panel width of 319 m and average extraction height up to 3.10 m;
- Longwall 710B – Planned to be mined from January 2024 to April 2025, panel width of 319 m and average extraction height up to 3.00 m;
- Longwall 711 – Planned to be mined from April 2025 to October 2026, panel width of 319 m and average extraction height up to 3.15 m; and
- Longwall 905 – Planned to be mined from May 2022 to March 2023, panel width of 300 m and average extraction height up to 3.03 m.

The Project is within Areas 7 and 9 of the approved BSO, which has been previously assessed by Heritage Computing (2009). Appin Mine as shown in **Figure 1** is defined as the existing and proposed mining operations at Appin from January 2010 to December 2026 including Longwalls 709, 710A, 710B, 711 and 905 in this study.

Details on the approved operations at Appin Mine and the previously predicted groundwater impacts are included in **Section 2.4.1.1**.

APPIN MINE GROUNDWATER ASSESSMENT

PROJECT LAYOUT

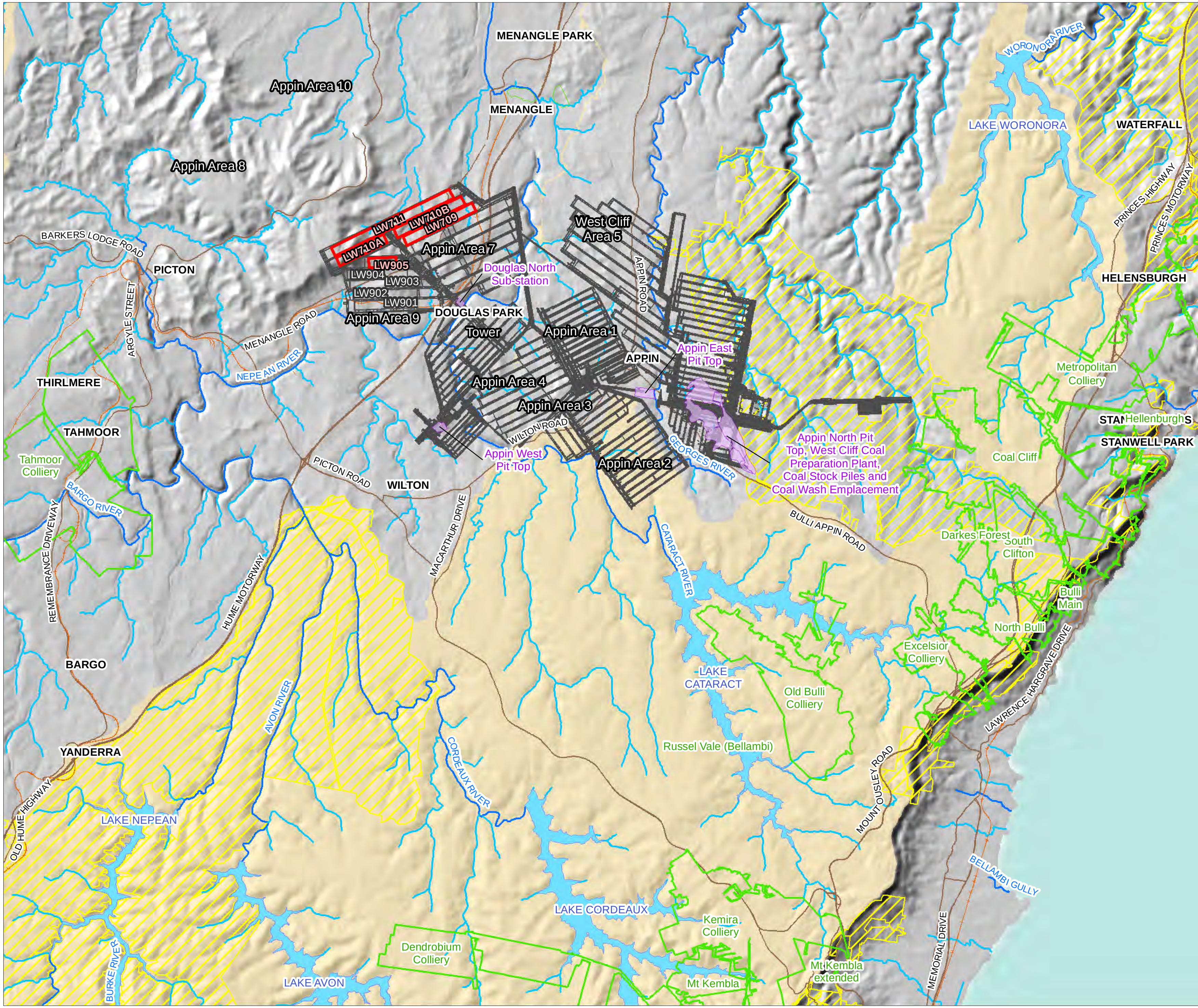

FIGURE 1

- Road
- Railway
- Major watercourses
- Minor watercourses
- Appin Mine
- Other mine workings
- Lake
- NPWS estate area
- Water NSW special area
- S32 Surface Site Location
- Project Area

0 2.5 5 km

Projection: GDA 1994 MGA Zone 56
Scale: 1:175,000 at A4

Project No.:	665.10015
Date:	07-Sep-2022
Drawn by:	JG

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1.2 Study Objectives and Scope of Work

The main objectives of the groundwater assessment was to develop:

(i) a description of the existing hydrogeological environment

(ii) an assessment of the potential impacts of mining on the groundwater related environment.

To this end, the stated scope of work was to:

- Provide a brief background on the site setting and conceptual groundwater model utilising work completed for the Appin Mine Groundwater Assessment – Mine Closure report completed in April 2020;
- Construct and calibrate a numerical groundwater flow model suitable for the assessment of potential impacts of the Project, in accordance with the Australian Groundwater Modelling Guidelines (Barnett et al., 2012) and Murray Darling Basin Commission guidelines (Middlemis et al., 2001);
- Provide a comparison of the estimate of height of fracture zone above the longwall panels between the Ditton and Tammetta methods;
- Calibrate the model to improve the area which addresses the mismatch between modelled and observed groundwater levels;
- Update the calibration statistics, check the mine inflows changes and depressurisations;
- Perform predictive modelling for the scale and extent of mining impacts upon groundwater levels, groundwater quality and groundwater users at various stages during mine operations;
- Calculate the river baseflow/leakage reduction for Navigation Creek, Navigation Creek Tributary 1 or Foot Onslow Creek;
- Predictive modelling of the cumulative impacts of the Project, surrounding mines and the other relevant developments (e.g. Camden Gas Project);
- Assess the extent of groundwater impacts due to the Project, including long-term impacts on regional groundwater interception, groundwater depressurisation and incidental water impact. Assessment of potential hydrogeological impacts and management measures relating to subsidence during extraction of the proposed longwalls;
- Assess the potential impact on key environmental receptor (e.g., private water supply bores) due the project;
- Provide recommendations for monitoring of impacts;
- Establish groundwater trigger levels for investigating any potentially adverse impacts on water resources or water quality, monitor and report on groundwater inflows, as well as predict, manage and monitor impacts on bores on privately-owned land;
- Address the Before-After-Reference-Impact (BACI) design requirement by updating the Hydrogeology (Section 3) and Appin Mine Monitoring Network (Section 5.1).

1.3 Water Regulation

The groundwater assessment provides information about potential groundwater behaviour in response to longwall mining. The following water regulations were considered when assessing the impacts of the longwall mining on groundwater and users:

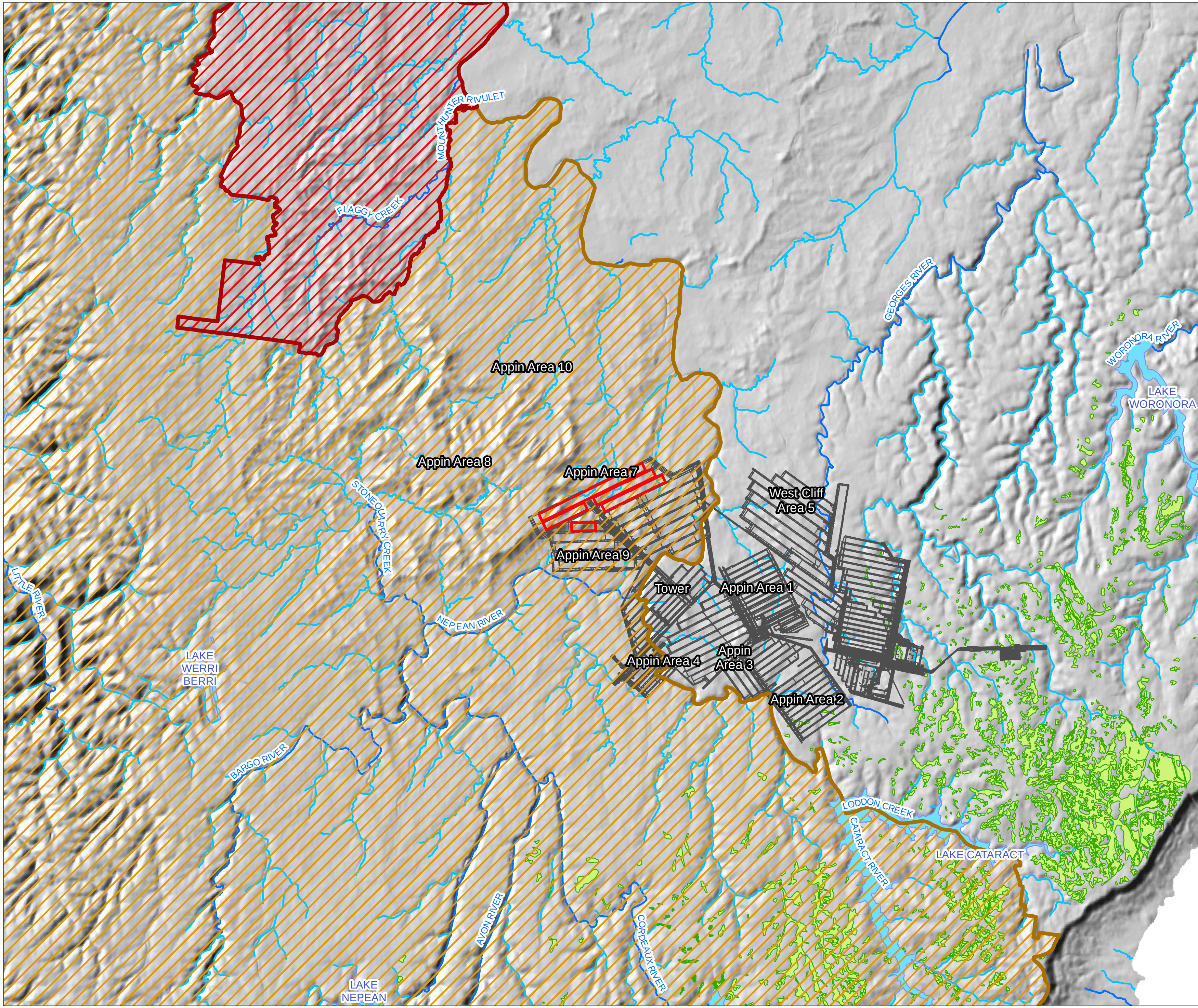
- Water sharing plans and groundwater management areas under the Water Management Act 2000;
- NSW Aquifer Interference Policy 2012.

1.3.1 Water Sharing Plans and Groundwater Management Zones

Water Sharing Plans (WSPs) have been declared across much of the state and these establish rules for sharing and trading of groundwater and surface water between needs and users. The WSP covering the Appin mine is the 'Greater Metropolitan Region Groundwater Sources' Plan. These Groundwater Sources are used to manage the average long-term annual volume of water extracted. The source directly relevant to the Project is the Sydney Basin Nepean Groundwater Source.

The project may result in an impact or 'take of groundwater'. Modelling and discussion of such impacts is presented in **Section 4.4**.

The Sydney Basin Nepean Groundwater Source is further subdivided into Management Zones (MGZ) as shown using the hatching in **Figure 2**. The project is located within the Nepean Management Zone 2.



APPIN MINE
GROUNDWATER ASSESSMENT

GROUNDWATER MANAGEMENT ZONE

FIGURE 2

- Major watercourses
- Minor watercourses
- Appin Mine
- Nepean Management Zone 1
- Nepean Management Zone 2
- Lake
- IC mapped swamp
- Project Area

0 2.5 5 km

Projection: GDA 1994 MGA Zone 56
Scale: 1:200,000 at A4

Project No.: 665.10015
Date: 07-Sep-2022
Drawn by: JG

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H:\Projects-SLR\620-BNE\665-WOL\665.10015 Illawarra Coal Closure - Water\CADGIS\ArcGIS\EP Report\665.10015 F02 Groundwater Management Zone.mxd

1.3.2 NSW Aquifer Interference Policy

The NSW Aquifer Interference (AI) Policy is designed to provide a framework for the assessment of impacts from the taking of water under a proposed development, such as the Appin Mine. The AI policy divides groundwater sources into "highly productive" and "less productive" categories based on salinity and aquifer yield.

The water sources that are directly relevant to the Project are the 'highly productive' porous rock aquifers of the Sydney Basin Nepean Groundwater Source (Nepean Management Zones 1 and 2).

The AI Policy also specifies 'minimal impact considerations' for both highly productive and less productive aquifers; these comprise thresholds for water table and groundwater pressure drawdown, and changes in groundwater and surface water quality. These thresholds and their applicability to the Project are summarised in **Table 1**.

Table 1 Summary of AI Policy Assessment for Porous Rock

Category	Threshold	Application for Project
Water Table	Less than or equal to a 10% cumulative variation in the water table, allowing for typical climatic "post-water sharing plan" variations, 40 m from any: High priority groundwater dependent ecosystem; or High priority culturally significant site; listed in the schedule of the relevant WSP. A maximum of a 2 m water table decline cumulatively at any water supply work.	The relevant Water Sharing Plan is the 'Greater Metropolitan Groundwater Sources' (dated 1 October 2011). There are no high priority Groundwater Dependent Ecosystems (GDEs) listed in this WSP within 5 km of Appin Mine, including Area 7 and Area 9. Hence there are no known groundwater related risks to such sites due to activity at Appin Mine. There are no culturally significant sites in the Study Area listed in the WSP. Hence there are no known risks of this development to such sites. There is negligible risk of drawdown in excess of the water supply work drawdown criterion at any 'water supply works' within the Permo-Triassic or shallow strata due to mining at Appin Mine. Level 1 minimal impact consideration classification
Water Pressure	A cumulative pressure head decline of not more than a 2 m decline, at any water supply work.	See landholder bores listed in **Section 3.4.3** and predicted impacts described in **Section 4.4.4**.
Water Quality	Any change in the groundwater quality should not lower the beneficial use category of the groundwater source beyond 40 m from the activity.	See discussion in **Section 4.4.6.**

2 Environmental Setting

2.1 Climate

Daily rainfall observations have been recorded by IMC since 2014 at Appin East, Appin North, Appin West (part) and at the Ventilation Shaft No.6. However, due to the short period of monitoring, long-term Bureau of Meteorology (BoM) site data associated with the Scientific Information for Landowners (SILO) point grid has been used for this Project. There are several BoM stations in the area with long-term data, including Darkes Forest (068024), Cataract Dam (068016), Wedderburn (068159), Douglas Park (068200). The BoM data was obtained from SILO point grid (Latitude -34.20 Longitude 150.75) located between Douglas Park and Appin and used to evaluate the climatic conditions at Appin Mine. The data was obtained through the SILO database, from January 1890 to January 2022. Based on the SILO data, the long-term (1890 to 2022) average yearly rainfall for the Project area is 986 mm/year.

Figure 3 shows the long-term rainfall trends based on the SILO data, as defined by the cumulative departure from mean or cumulative rainfall deficit curve. This shows the historical occurrence of dry periods (downward rainfall trend), wetter than average periods (upward rainfall trend). After the Millennium Drought, there was a period of average conditions, followed by another period of below average rainfall. Over the past two years (2020-2021), rainfall trends have reverted to average conditions.

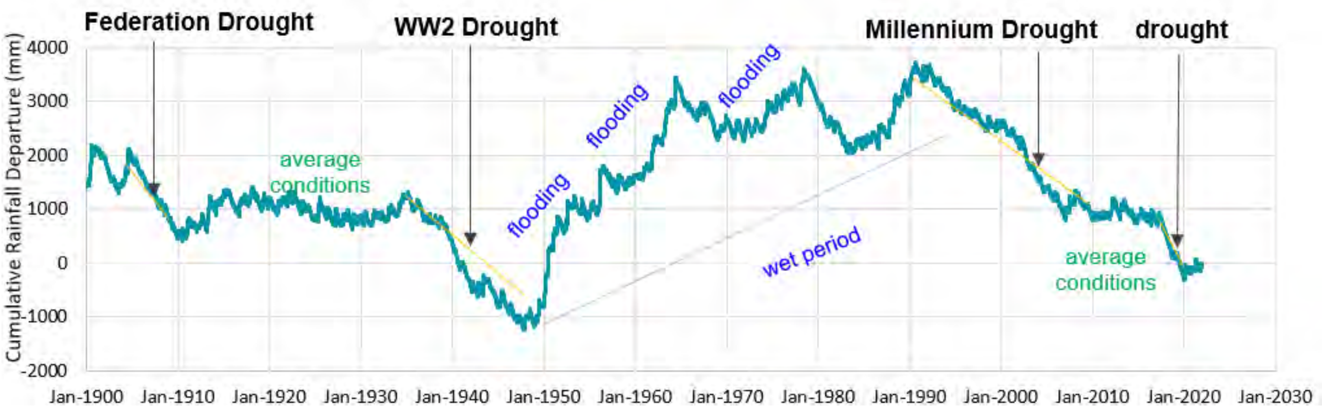


Figure 3 Cumulative Rainfall Departure

Potential evaporation (PE) data is also available from BoM. Long-term average PE is approximately 1576 mm/yr at Appin, and slightly lower at Wollongong on the coast (1520 mm/yr). Actual evapotranspiration (ET) at Appin is approximately 922 mm/yr. A comparison of average daily rainfall for each month and PE is presented in **Figure 4**. This shows that in June there is a rainfall excess, with a rainfall deficit in all other months.

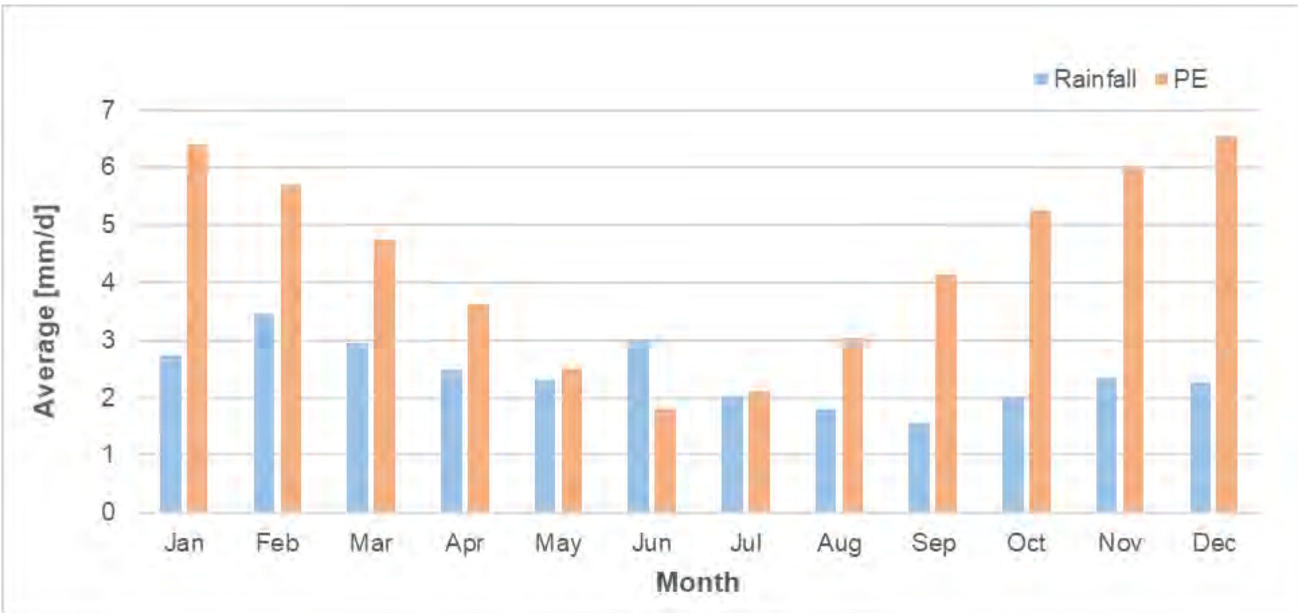


Figure 4 Average Monthly Rainfall and Potential Evaporation

2.2 Topography

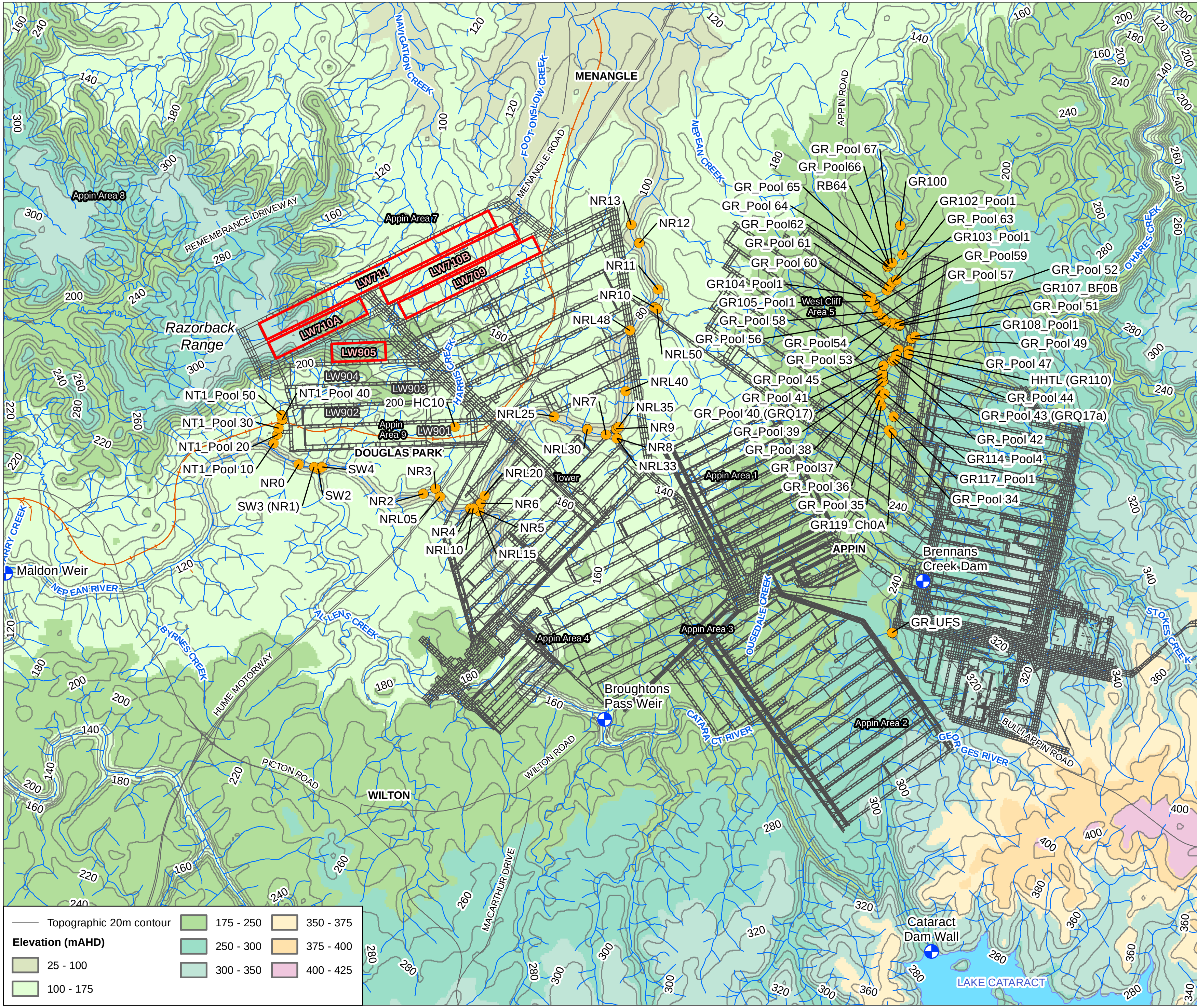
Appin Mine is located to the west of the Woronora Plateau and the Cumberland Plain inland of the Illawarra Escarpment approximately 25 km northwest of Wollongong, NSW. Topography within the Project area ranges from 100 mAHD to 320 mAHD, with the topographic high associated with Razorback Range on the western part of the Project area (**Figure 5**).

On the plateau to the north the topography generally slopes to the north or northwest, toward the centre of the Sydney Basin. The topography of the eastern part (West Cliff Area 5) falls from 250 mAHD to 130 mAHD while the western area slopes gently from approximately 250 mAHD (south along the Nepean Valley) to 60 mAHD near Menangle Park to the north.

APPIN MINE GROUNDWATER ASSESSMENT

TOPOGRAPHY AND DRAINAGE OF APPIN MINE

FIGURE 5



Projection: GDA 1994 MGA Zone 56
Scale: 1:90,000 at A4

Project No.: 665.10015
Date: 07-Sep-2022
Drawn by: JG

SLR

H:\Projects-SLR\620-BNE\665-WOL\665.10015 Illawarra Coal Closure - Water\CADGIS\ArcGIS\EP Report\665.10015 F05 Topography and Drainage of Appin Mine.mxd

2.3 Surface Water and Drainage

Appin Mine is located within the Georges River and the Hawkesbury-Nepean catchments. Major rivers in the area include the Nepean River, Cataract River, Stonequarry Creek and Georges River (**Figure 5**). The rivers within the Appin Mine area generally flow in a northerly direction and have perennial flows influenced by dam releases and baseflow contributions from the incised Hawkesbury Sandstone (HBSS).

The closest river is the Nepean River, which is 1.5 km south of the Project footprint. Minor creeks and tributaries of the Nepean River are present across the Appin Mine area. This includes Navigation Creek, Navigation Creek Tributary 1, Foot Onslow Creek and Harris Creek that are third order streams within the Project area. The creeks are largely ephemeral, but pools have naturally formed in some areas, and farm dams have also been established in some locations (MSEC, 2021).

Surface water monitoring is conducted at the main rivers at government stream gauges. IMC also conduct monitoring of surface water levels and quality at the major rivers as well as creeks and tributaries across the site and to the north. This includes monitoring of ponded water (pools) along Georges River and Nepean River.

Summary details for each of the main rivers near the Project are included in **Table 2**. River stage levels for Nepean River, Cataract River and Stonequarry Creek are shown in **Figure 6**, along with IMC observation data for one of the Georges River pools (GR_POOL63). The river levels generally correlate with rainfall trends (CRD), but also show influence from dam releases/regulation where water levels rise during periods of below average rainfall.

Table 2 Major River System at Appin Mine

River	Characteristics	Surface Water Flow
Nepean River	Regulated flows from upstream dams and baseflow contributions where incised into Hawkesbury Sandstone. Present across surface of Appin Mine area (Area 7).	Main government stream gauge 212216 (Nepean River at Camden Weir), as well as 212238 (Menangle Weir) and 212208 (Maldon Weir). Plus IMC Nepean River (NR) monitoring. Flows in a northerly direction, with flow of around 310 ML/day (Maldon Weir) since 2010.
Cataract River	Regulated flows from Lake Cataract. Present across surface of Appin Mine area (Area 4 and Tower).	Main government stream gauge 212230 (Cataract River at Broughtons Pass), as well as 212231 (Jordans Crossing) and 212232 (Cataract Dam). Flows in a northerly direction towards Nepean River, with flow of around 92 ML/day (Broughton Pass Weir) since 2010, with surface water elevations generally around 130 mAHD to 132 mAHD.
Stonequarry Creek	Stonequarry Creek Management Area at north-west side of Area 9.	Government stream gauge 212053 (Stonequarry Creek at Picton). Flows in a general southerly direction to the Nepean River near Maldon. Flow around 22 ML/day (Picton) since 2010, with surface water elevations generally around 148 mAHD.
Georges River	Regulated flows from upstream dam (Brennans Creek Dam). Present across surface of Appin Mine area (West Cliff area).	IMC monitoring of pool levels along Georges River (GR_POOL). River flows in a northerly direction, with flow of around 4.2 ML/day (Brennans Creek Dam) since 2010.

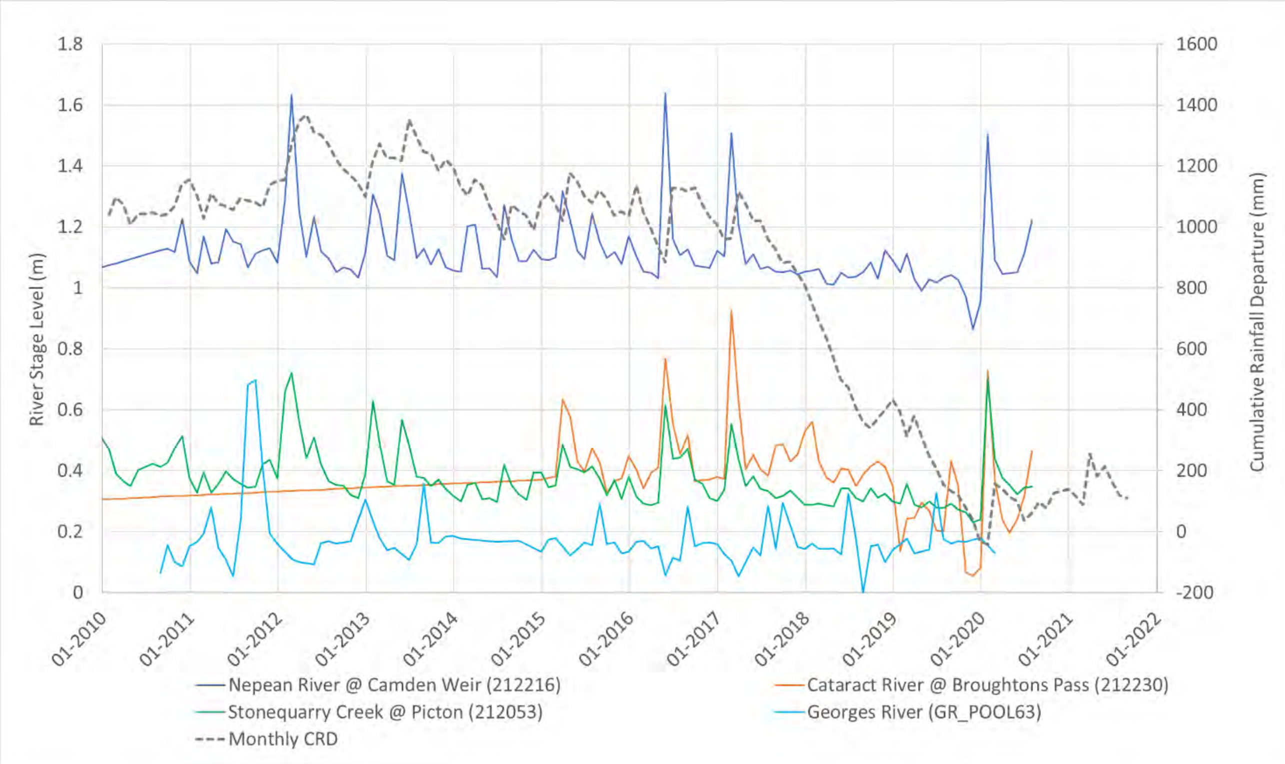


Figure 6 Surface Water Stages

A summary of average water quality results monitored at the site surface water monitoring points is included in **Table 3**. The summary data shows that the major rivers have contributions from dam releases, and are incised into the HBSS (i.e. Nepean River, Cataract River and Georges River) and generally contain fresh (low salinity/ electrical conductivity (EC)) water. In contrast the minor tributaries, particularly those that occur where the Wianamatta Group is present at surface (i.e. Navigation Creek), have more brackish water quality and higher total dissolved solids (TDS).

Table 3 Summary of Surface Water Quality Monitoring at Appin Mine

River	Average EC (µS/cm)	Average pH	Average TDS (mg/L)	Monitoring Period Reviewed
Nepean River	291	8	164	2002 - 2020
Cataract River	168	7	97	2002 - 2020
Georges River	929	7	538	2008 - 2020
Ousedale Creek	1478	8	801	2002 - 2020
Menangle Creek	1373	8	725	2003 - 2020
Elladale Creek	1632	8	904	2002 - 2020
Allens Creek	743	8	397	2003 - 2020
Navigation Creek	2793	8	1581	2006 - 2020
Harris Creek	1663	8	924	2002 – 2020 / 2010 - 2020
Foot Onslow Creek	1680	8	944	2008 - 2020

Comparison between rainfall trends and the Nepean River surface water quality over time is presented in **Figure 7**. The Nepean River at Appin Mine has a long-term EC average of 291 µS/cm and median of 244 µS/cm, with no significant change between its downstream (NR0) and upstream (NR50) segment. The decreases in EC correlate to above average rainfall conditions over time, which freshen water in the river system. The peak EC at downstream location (NR0) correlate to the first flush of the runoff.

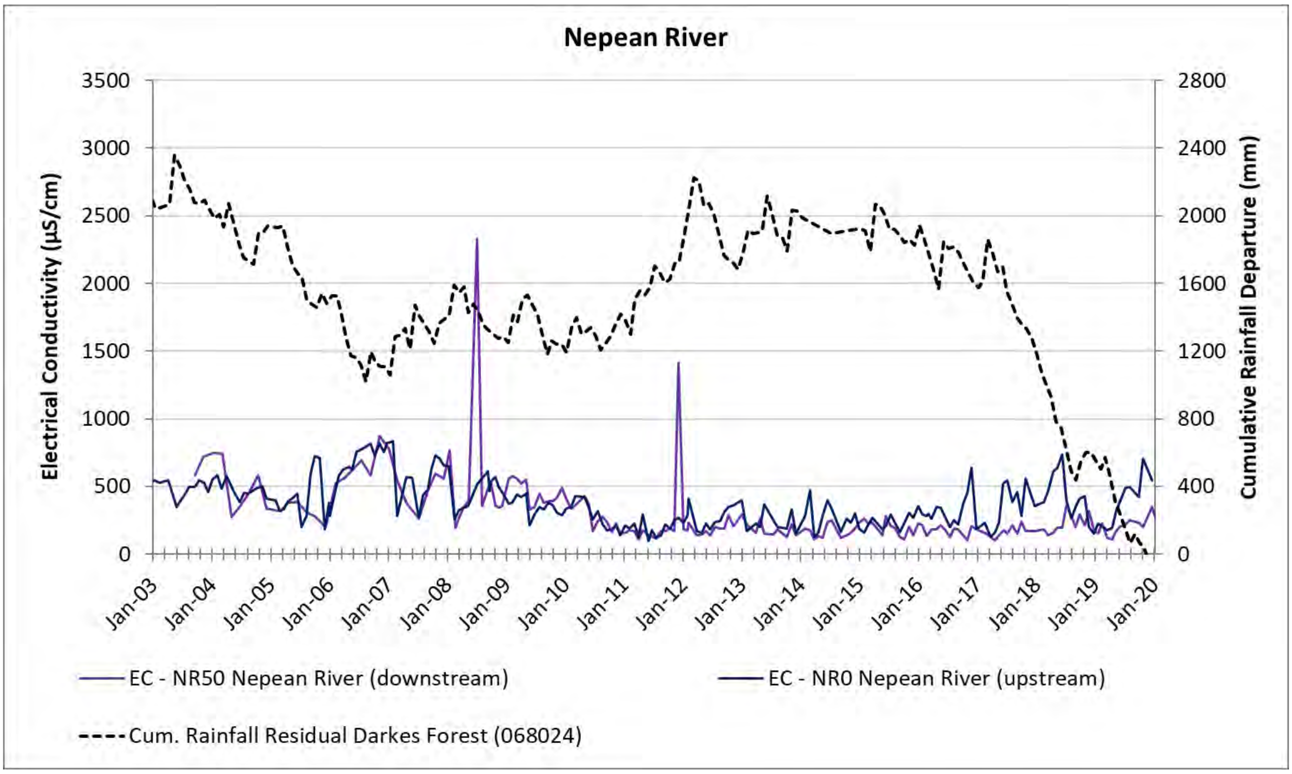


Figure 7 Water Quality along the Nepean River

2.4 Land Use

2.4.1 Mining

2.4.1.1 Approved Operations at Appin Mine

Appin Mine extracts coal from the Bulli Coal Seam within the Permian aged Illawarra Coal Measures via the longwall mining method. The Appin Mine refers to the current and previous mine areas, which comprises the former Tower Colliery and West Cliff Colliery.

The Appin Mine includes Area 1, Area 2, Area 3, Area 4, Area 5, Area 7, Area 9 and North Cliff (**Figure 1**). The current active mine areas are in Area 7 and Area 9. It should be noted that the approved Area 9 (BSO) is more extensive than the currently mined Area 9, as shown in **Figure 1**. A summary of the mine areas, years mined, and current status is shown in **Table 4.**

Table 4 Appin Mine Areas and Timing

Mine Area	Longwall Panels	Date From	Date To	Date Approved To	Status/ Comment
Tower	1 - 20	1978	2002	-	Historic mining
Appin Area 1	1 - 12	1969	1986	-	Currently used for underground mine water storage (White Panel), transferred from current mining areas.
Appin Area 2	12 - 29	1986	1997	-	Historic mining
Appin Area 3	301 - 302	1998	2007	-	Historic mining
Appin Area 4	401 - 408	1998	2007	-	Currently used for underground mine water storage, transferred from current mining areas.
West Cliff Area 5	1 - 32	1983	2016	2040 (BSO)	Historic mining
Appin Area 7	701 - 714	2007	Present	2040 (BSO)	Active Mining
Appin Area 9	901 - 910	2016	Present	2040 (BSO)	Active Mining

The groundwater impact assessment for the BSO conducted by Heritage Computing (2009) included development of a numerical groundwater model to predict impacts. The BSO groundwater assessment findings included:

- Negligible loss of groundwater to the Cataract Reservoir, Broughtons Pass Weir and Woronora Reservoir;
- Negligible reduction in groundwater contribution to total stream flows;
- Drawdown in Hawkesbury Sandstone (HBSS) with predicted 1 m drawdown contour extending up to 5 km from the mine footprint. The extent of drawdown was most significant north to north-east of Area 8 and Area 9;
- Extensive depressurisation predicted for aquifers beneath the Bald Hill Claystone (i.e. Bulgo Sandstone, Scarborough Sandstone and Bulli Seam), with the 10 m drawdown contour extending over 6 km north of the mine footprint;
- Reduction in water level of up to 23 m at some private production bores intersecting the HBSS and up to 85 m for bores within the Bulgo Sandstone, with main impacts around the Razorback Range at Area 9 (Appin West);

- Mine inflows of around 4 ML/day across the entire BSO operations at the end of mining, averaging 2 ML/day each year over 30 years.

2.4.1.2 Surrounding Mines

Several historic and active mines surround the Appin Mine, as summarised in **Table 5**, and mine locations are shown in **Figure 1**. The closest mine workings are associated with Russell Vale, which are within approximately 2 km of Appin Mine and extend towards the coast and mined the Bulli Seam, Balgownie Seam and Wongawilli Seam. The proximity of this mine may influence groundwater conditions post-closure.

Table 5 Neighbouring Mines within the Southern Coalfield

Mine	Current Operator	Seam	Status	Distance from Dendrobium
Russell Vale (Bellambi)	Wollongong Coal	Bulli Seam, Balgownie Seam and Wongawilli Seam	Active/ Proposed	Located 2 km south east of Appin Mine. Bulli Seam and Balgownie Seam mined from 1887 to 1950 as bord and pillar. Mining restarted in 1960's as continuous miners then from 1970 to 1982 as longwall. Gibson Colliery then in operation between 2001 to 2003 within Bulli and Balgownie seams, using continuous miner and longwall methods. From 2007 to present in Wongawilli Seam, with a current modification proposed. Historical inflows have been reported between 0.05 ML/day to 0.7 ML/day (SLR 2020) and around 1.1 ML/year for current (NRE 2019, Umwelt 2020).
Tahmoor Mine	SIMEC	Bulli Seam	Active	Located approximately 10 km west of Appin Mine and about 4 km west of the Approved Appin Mine plan. In operation since 1975 and approved until 2020. EIS submitted to extend life of mining to 2035 and was approved. Historical inflows to mine workings have been reported between 0.3 ML/day and 5 ML/day.
Coal Cliff (Darkes Forest)	-	Bulli Seam	Mine Closed	Located approximately 5 km east of Appin Mine. In operation from 1877 to 1992.
Metropolitan Mine	Peabody	Bulli Seam	Active	Located approximately 8 km east of Appin Mine. In operation from 1886 to present, approved until at least 2022. Measured mine inflows generally less than 1 ML/day (Peabody 2019).
Dendrobium	Illawarra Metallurgical Coal	Bulli Seam and Wongawilli Seam	Active	Located 14 km south of Appin Mine. In operation from 2001 and approved until 2043. EIS submitted to extend life of mining to 2048, but not yet approved. Historical inflows vary by region, but in recent years has been recorded between 4 ML/day and 12 ML/day (HydroSimulations 2019).

2.4.2 Camden Gas Project

The AGL Camden Gas Project is on Petroleum Production Lease (PPL) 1 to 6 and Petroleum Exploration Licence (PEL2), at the northern end of Appin Mine. The Camden Gas Project has been in operation since 2001. AGL hold two Water Access Licences (24856 and 24736) and Works and Use Approvals (10WA112288 and 10WA112294) with a current total allocation of 30 ML/year. The Camden Gas Project comprises 137 wells (86 currently active) shown in **Figure 8** targeting the Bulli and Balgownie seams north of the Project. Further discussion on the geology is provided in **Section 2.5**.

The Coal Seam Gas (CSG) activities involve abstraction of water to induce gas flow, resulting in a reduction in water pressure in the target seam. This depressurisation around the CSG wells is observed in the site monitoring data discussed in **Section 3.2**. Previous studies by AGL (2013) predicted limited potential for impact on the overlying stratigraphy, due to the presence of the low permeability claystones preventing any significant vertical flow. IMC groundwater monitoring indicates potential localised depressurisation within the Scarborough Sandstone of the Narrabeen Group (**Section 3**). However, there are no impacts predicted or observed within the HBSS due to CSG activities (AGL, 2013).

2.5 Geology

Appin Mine is located within the Southern Coalfield of the Sydney Basin. The stratigraphy of the Southern Sydney Basin is presented in **Table 6.**

Table 6 Southern Sydney Basin Stratigraphy

Period	Stratigraphic Unit		Description
Quaternary	Alluvium and colluvium and other sediments in floodplains, alluvial fans, and high terraces (Qal, Tal, Qs)		Alluvial and residual deposits comprising quartz and lithic fluvial sand, silt and clay.
Triassic	Wianamatta Group	Camden Sub-group	Shale with sporadic thin lithic sandstone.
		Liverpool Sub-group: Bringelly Shale (Rwb), Minchinbury Sandstone and Ashfield Shale (Rwa)	Dark green and black shales with thin graywacke-type sandstone lenses. Calcareous graywacke-type sandstone and black mudstones and silty shales with sideritic mudstone bands.
	Hawkesbury Sandstone (Rh)		Consists of thickly bedded or massive quartzose sandstone (with grey shale lenses up to several metres thick).
	Narrabeen Group	Newport Formation	Interbedded grey shales and sandstones
		Garie Formation	Cream to brown, massive, characteristically oolitic claystone.
		Bald Hill Claystone	Brownish-red coloured “chocolate shale”, a lithologically stable unit.
		Bulgo Sandstone	Strong, thickly bedded, medium to coarse-grained lithic sandstone with occasional beds of conglomerate or shale.
		Stanwell Park Claystone	Greenish-grey mudstones and sandstones.
		Scarborough Sandstone	Mainly of thickly bedded sandstone with shale and sandy shale lenses up to several metres thick.
		Wombarra Claystone	Similar properties to the Stanwell Park Claystone.
		Coal Cliff Sandstone	Basal shales and mudstones that are contiguous with the underlying Bulli Coal seam.

Period	Stratigraphic Unit	Description
Permian	Illawarra Coal Measures	Interbedded shales, mudstones, lithic sandstones and coals, including the Bulli Seam (2 – 3 m thick), Balgownie Seam (5 – 10 m below Bulli Seam), Loddon Sandstone, Wongawilli Seam (7 – 9 m thick) and Kembla Sandstone.

The surface geology is shown in **Figure 8**, based on the Southern Coalfield 1:100,000 geological map (Moffitt 1999). A cross section through Area 7, Area 8 and Area 9 has also been created based on the site geological model and presented in **Figure 9**. The location of the cross section is presented in **Figure 8**.

2.5.1 Quaternary and Triassic

The Triassic Wianamatta Group is present at surface across the site (**Figure 8**) and ranges in thickness from less than 10 m to 200 m at Razorback Range. Quaternary floodplain alluvium is also mapped as being present on the northern side of the Project area, localised along Nepean River and its tributaries (i.e. Navigation Creek). The Quaternary alluvium along the Nepean River is currently mined at Menangle Quarry, approximately 4.5 km north-east of the Project (**Figure 8**).

The HBSS is also present at surface and underlies the Wianamatta Group where it is present. The HBSS comprises bedded sandstone units and is around 170 m thick (MSEC, 2021). The HBSS is incised along the major rivers (i.e. Nepean River) and contributes baseflow. Around the Project there are also several registered bores accessing groundwater from the HBSS (Sydney Basin Nepean Groundwater Source) for stock, domestic, irrigation and industrial uses as discussed further in **Section 3.4.3**.

The HBSS is underlain by the Triassic sandstones, siltstones and claystones of the Narrabeen Group. This includes the Bulgo Sandstone, Scarborough Sandstone and Coal Cliff Sandstone, as well as the Bald Hill Claystone, Stanwell Park Claystone and Wombarra Claystone.

2.5.2 Permian

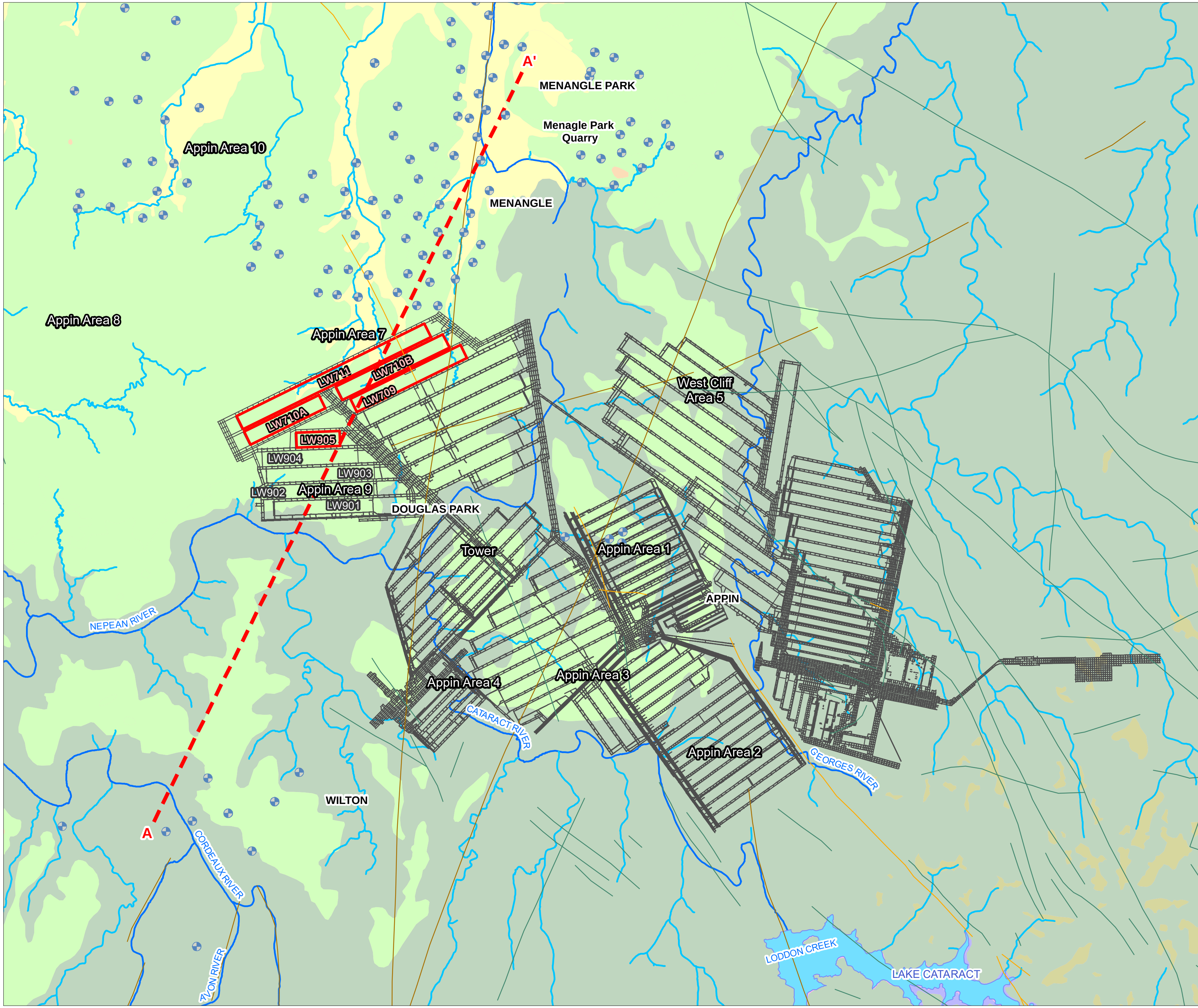
As illustrated in **Figure 9**, the Permian aged Illawarra Coal Measures underlie the Narrabeen Group. The Illawarra Coal Measures consist of interbedded sandstone, shale and coal seams, with a thickness of approximately 200 m to 300 m. The Bulli Seam is the primary economic sequence of interest at Appin Mine. Within the Project area the Bulli Seam is around 2.8 m to 3.3 m thick and around 530 m to 750 m below surface (MSEC, 2021). The strata around the Bulli Seam provides good conditions for longwall mining and in particular the floor is hard and competent (Moffitt, 1999). The immediate roof can range from mudstone, interbedded siltstone and, sandstone to sandstone.

The Permian coal measures dip approximately 2 % in a north-westerly direction, towards the Douglas Park syncline (MSEC, 2021). The major geological structures (faults) in the region include the Nepean Fault Zone, O'Hares Fault and J-Line Fault. Within the Project area (Area 7 and 9) there is a series of NNW-SSE orientated dykes and minor faults with displacement of less than 3 m (MSEC, 2021). However, previous mining through these structures at Longwall 703 to Longwall 706 and Longwall 901 to Longwall 903 did not cause any change in vertical subsidence (MSEC, 2021).

APPIN MINE
GROUNDWATER ASSESSMENT

GEOLOGY AROUND APPIN MINE

FIGURE 8



- CSG Well
- Appin Mine
- Cross Section
- Major watercourse
- Minor watercourse
- Fault
- Dyke
- Lineament
- Lake
- Qal/ Tal – Alluvium
- Wianamatta group
- Rh - HBSS
- Project Area

Projection: GDA 1994 MGA Zone 56
Scale: 1:110,000 at A4

Project No.: 665.10015
Date: 07-Sep-2022
Drawn by: JG

SLR

H:\Projects-SLR\620-BNE\665-WOL\665.10015 Illawarra Coal Closure - Water\CADGIS\ArcGIS\EP Report\665.10015 F08 Geology around Appin Mine.mxd

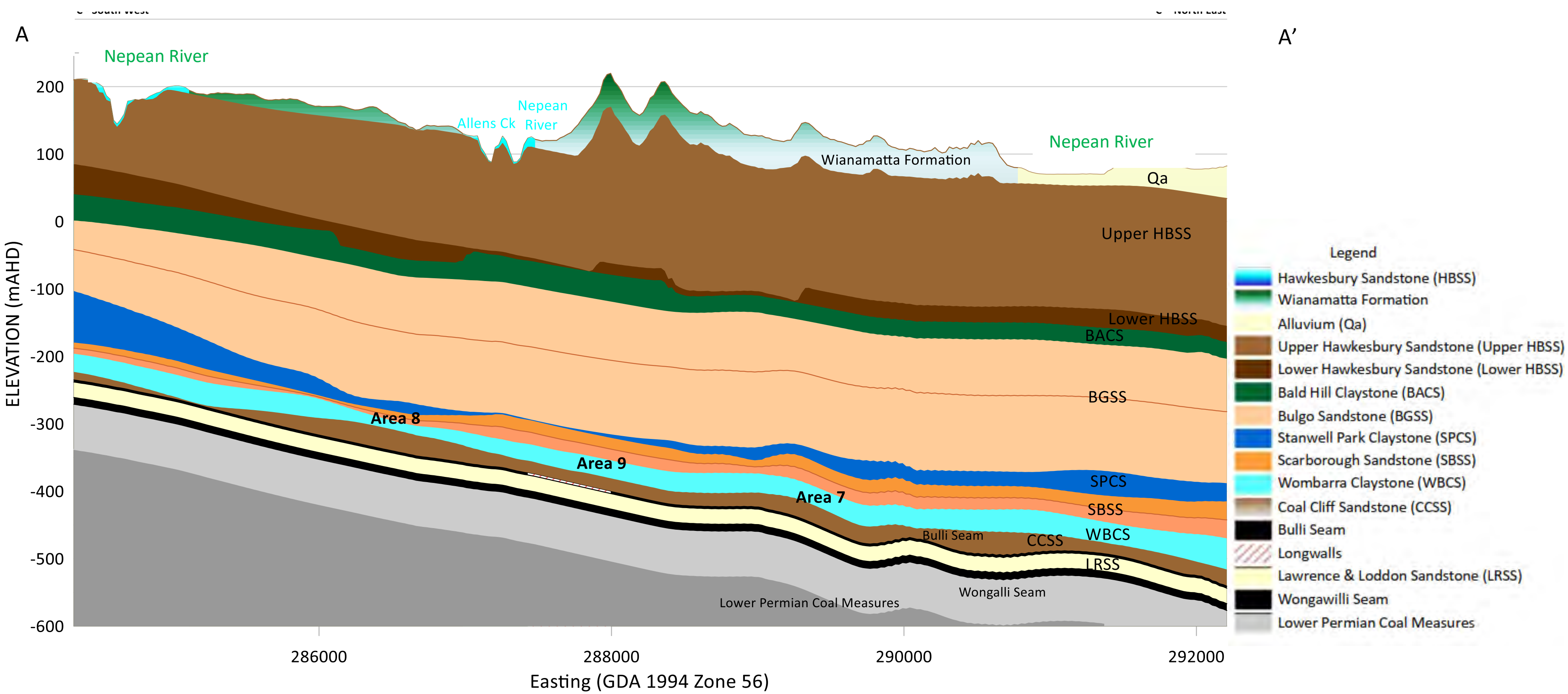


Figure 9 Geological Section A-A’ – Appin Area 7, 8 and 9

3 Hydrogeology

3.1 Groundwater Network

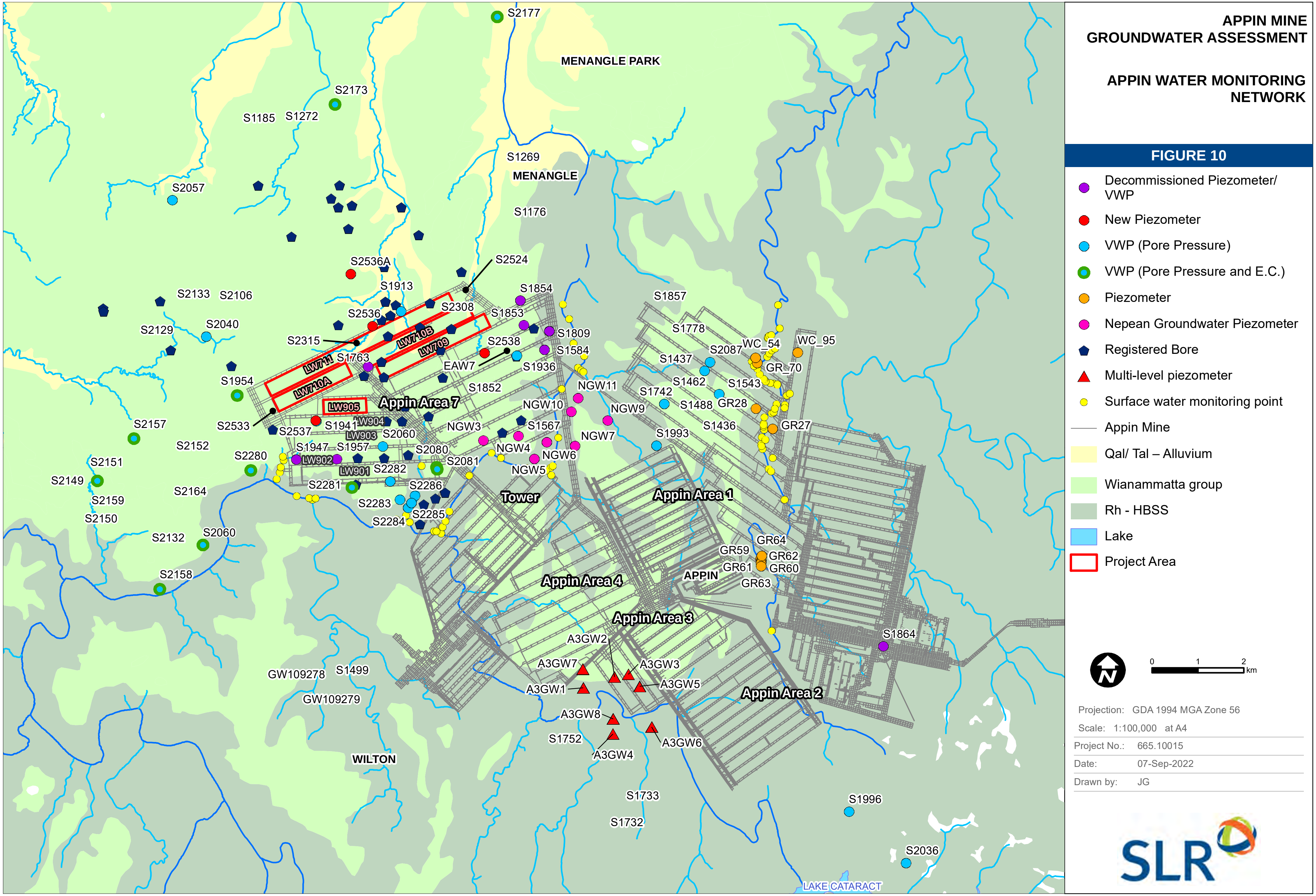
Appin Mine has an extensive network of groundwater monitoring infrastructure that provides the capability to monitor:

- Deep groundwater levels using vibrating wire piezometers (VWPs) in each mining area;
- Shallow groundwater levels using VWPs, shallow screened bores and open standpipes along Nepean River, Georges River and Cataract River; and
- Groundwater quality via in-built borehole pumps and within the mine workings (goaf seep).

Monitoring instruments are positioned throughout the mining lease with instruments installed:

- Above the longwall footprints in all areas;
- Adjacent to the key receptors (alluvium, high economic aquifers, and landholder bores); and
- Adjacent to key watercourses being monitored from mining related subsidence (Nepean River, Georges River, and Cataract River).

IMC has installed four new groundwater monitoring boreholes, one of them located close to Navigation Creek to monitor water levels, as recommended by SLR in a previous version of this groundwater impact assessment (SLR, 2021a). The VWPs and site and government monitoring bores for Appin, and Appin Area 7 and 9 are shown in **Figure 10** and **Figure 11** respectively**.** A full list of monitoring bores with their coordinates, sensor depths, screened geology and available data range is presented in **Appendix A**. The groundwater monitoring program includes daily readings of pressure head (pore pressure) at the VWPs, daily readings of electrical conductivity (E.C.) at some VWPs and manual measurement of water levels at the monitoring bores, as well as quality sampling and analysis for electrical conductivity (EC), pH, major ions, minor ions, metals, and a range of isotopes.



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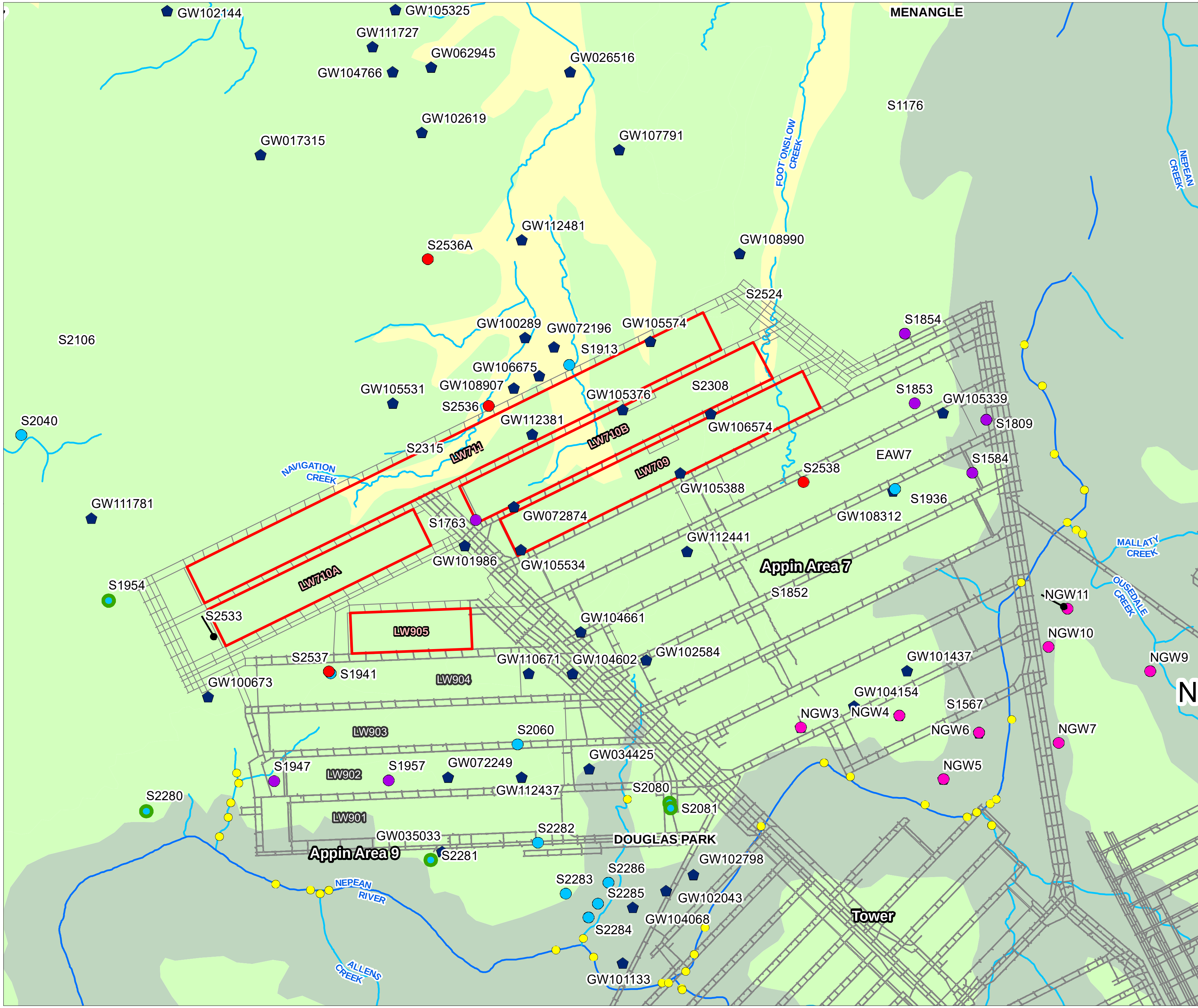


APPIN MINE GROUNDWATER ASSESSMENT

APPIN AREA 7 AND 9 WATER MONITORING NETWORK

FIGURE 11

- Decommissioned Piezometer/ VWP
- New Piezometer
- VWP (Pore Pressure)
- VWP (Pore Pressure and E.C.)
- Nepean Groundwater Piezometer
- Registered bore
- Surface water monitoring point
- Major watercourse
- Minor watercourse
- Appin Mine
- Qal/ Tal –
- Wianamatta group
- Rh - HBSS
- Project

0 0.5 1 km

Projection: GDA 1994 MGA Zone 56

Scale: 1:40,000 at A4

Project No.:	665.10015
Date:	07-Sep-2022
Drawn by:	JG

SLR

3.2 Groundwater Levels and Flow Direction

3.2.1 Alluvium

Based on 1:100,000 Southern Coalfield geology mapping (Moffitt, 1999), Quaternary alluvium has been mapped within the Project area along Navigation Creek and Foot Onslow Creek. Quaternary alluvium is also mapped along the Nepean River over 3 km north of the Project.

The alluvium generally comprises heterogenous distribution of clay, silt, sand and gravel. CSIRO (2015) regolith mapping indicates the alluvium within the Project area is likely less than 10 m thick, increasing in thickness to around 20 m, 3 km to the north. There are registered bores within alluvium along Navigation Creek and Nepean River (and its tributaries) to the north. The data from these registered bores indicates groundwater is present within the alluvium around 5 m to 8 m below surface. Alluvial groundwater flow likely follows topography and streamflow, flowing in a general northerly direction.

A review of the NSW groundwater registered bores database showed there are no alluvium bores near the Project listed in the database (most of the groundwater bores near the site monitor the HBSS).

To refine the conceptual model near the Project area, South32 have installed four monitoring bores during July and August 2021, the locations of these are shown in **Figure 11**. One of these bores, S2536, is located within the alluvium associated with Navigation Creek, approximately 600 m southwest of bore S1913. **Figure 12** shows the groundwater levels in S2536 since monitoring began in September 2021. Groundwater levels show a response to rainfall and have remained between 121 and 124 mAHD.

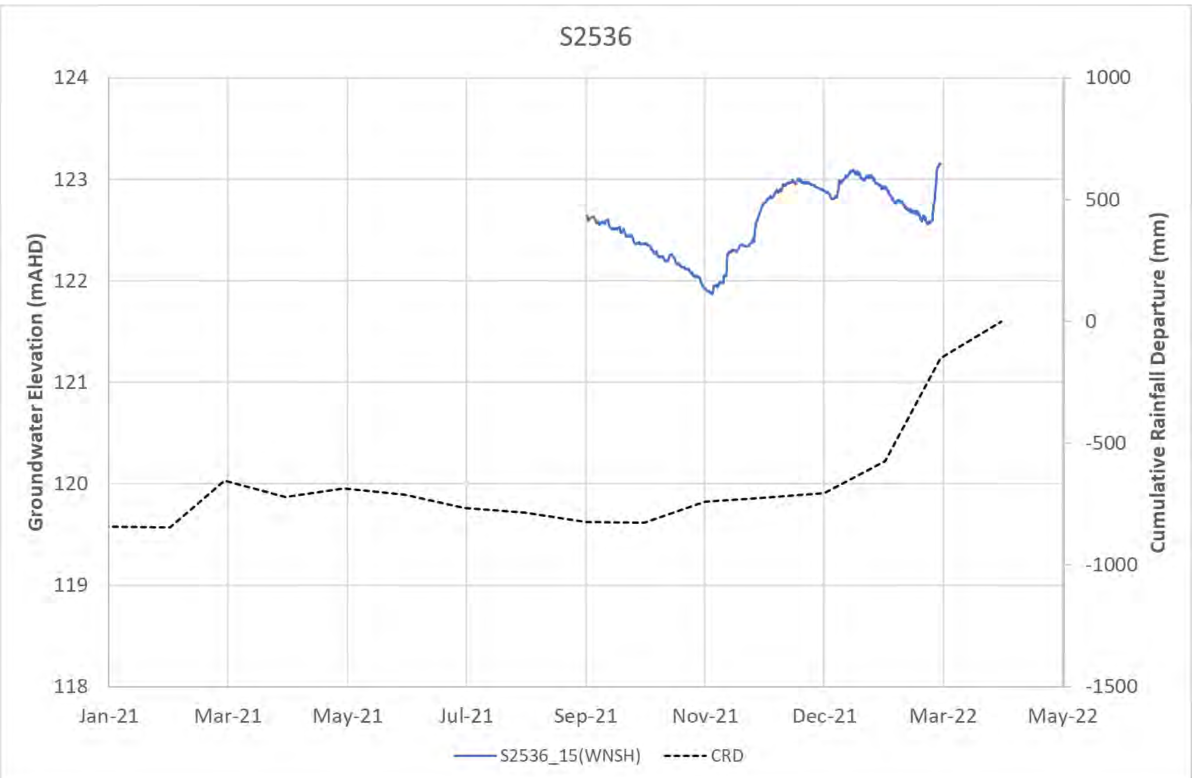


Figure 12 Hydrograph – S2536

3.2.2 Wianamatta Group

The Triassic Wianamatta Group is present at outcrops across the Project area. The Wianamatta Group thickens with distance to the north-west and can be up to 100 m thick. The Wianamatta Group is composed of the Bringelly Shale (BrSh), Minchinbury Sandstone and Ashfield Shale (AsSh).

Figure 13 shows groundwater levels at S1954 (Area 7). S1954 was installed in 2008 approximately 600m southwest of the end of Longwall 711. Between the period of 2014 to July 2017, all the loggers were not working and therefore, no data was recorded in that period. The groundwater flow at S1954 is controlled by a downward vertical head gradient in the Bringelly Shale from 280 mAHD to 220 mAHD. The water level observations at different depths show large pressure differences, which may indicate a limited vertical connectivity. The sensors below S1954_85 show a slight decline in groundwater levels that is likely due to a combination of mining in Area 9 (Longwall 902) and climate.

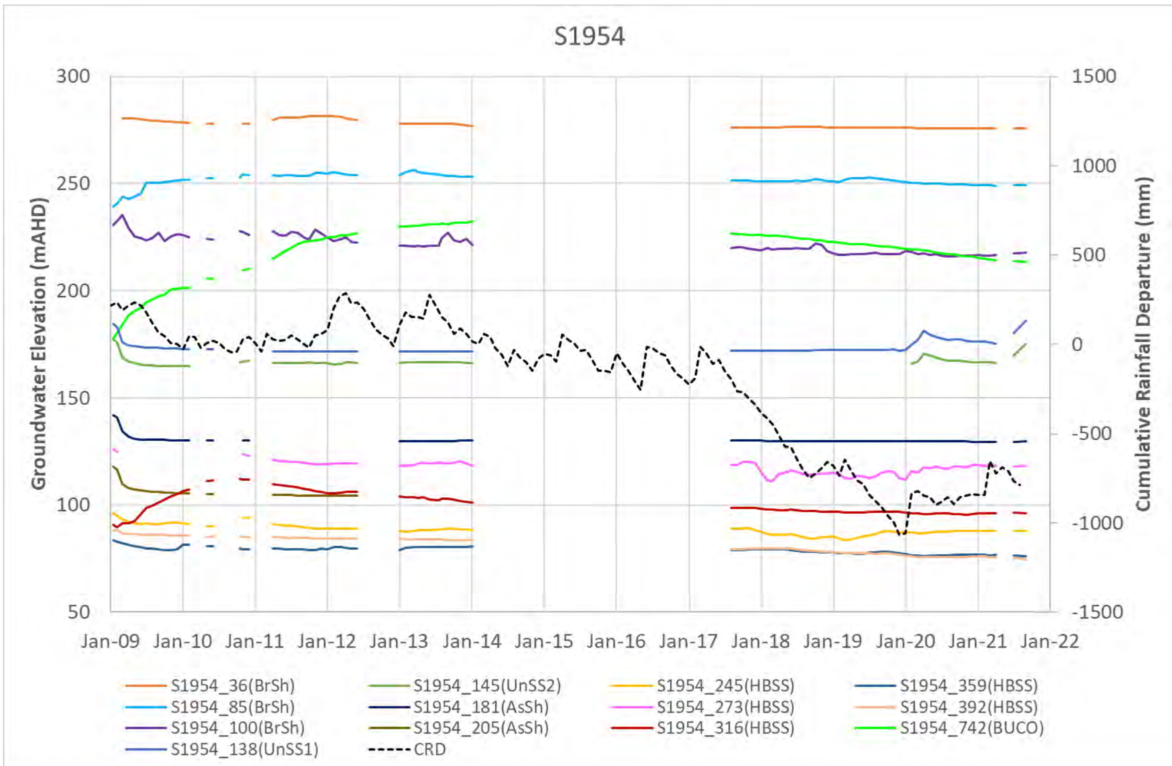


Figure 13 Hydrograph – S1954

3.2.3 Hawkesbury Sandstone (HBSS)

The Triassic HBSS outcrops in the region as the Woronora Plateau and is present across most of the historical mining at Appin (West Cliff, Tower, Area 1, 2, 3 and 4). The HBSS forms a major aquifer, due to its regional extent, coverage at surface that enables rainfall recharge and accessibility for landholder water usage (bores). It is a thick aquifer (>200 m) with numerous high and low permeability horizons or lenses. Within the Appin Mine area, it has been described as having low groundwater yields but good groundwater quality (Heritage Computing 2009).

Due to the stratification of the sandstone sequences, groundwater flow is primarily horizontal, with minor vertical leakage. Groundwater movement is controlled by the topography with flow towards major rivers that are deeply incised into the sandstone (i.e. Nepean River).

Surrounding the Project area monitoring within a range of vertical profiles is conducted at VWPs S1954 (**Figure 13**), S1913 (**Figure 14**), S1941 (**Figure 15**) and S2308 (**Figure 17**).

VWP S1913 is located approximately 100 m north of Longwall 711 and 3 km north of Longwall 902. As shown in **Figure 14**, the groundwater levels in all the three Hawkesbury Sandstone sensors showed a declining trend. S1913_194, recorded the largest decline of up to 15m from 2017 to 2018. The decline in the groundwater levels is likely a combination of response to the drought period and mining activities in Area 9 (i.e., Longwall 901 and 902).

The hydrograph for the VWP S1941 (**Figure 15**), located at Longwall 904, shows decline in groundwater levels in S1941_65, S1941_126 and S1941_201 within the HBSS. The decline in groundwater levels is likely due to mining in Area 9 (start of Longwall 901 and Longwall 902). The decline in groundwater levels is more significant (up to 15 m) in the deepest sensor in HBSS (S1941_201).

All sensors at VWP S1936 except the shallowest sensor (65 m) have stopped working since 2014 (**Figure 16**). This is likely due to the loggers being damaged or destroyed by mine induced subsidence in Area 7. The shallow sensor S1936_65 in HBSS shows up to 8 m of decline in groundwater level which is likely due to mining.

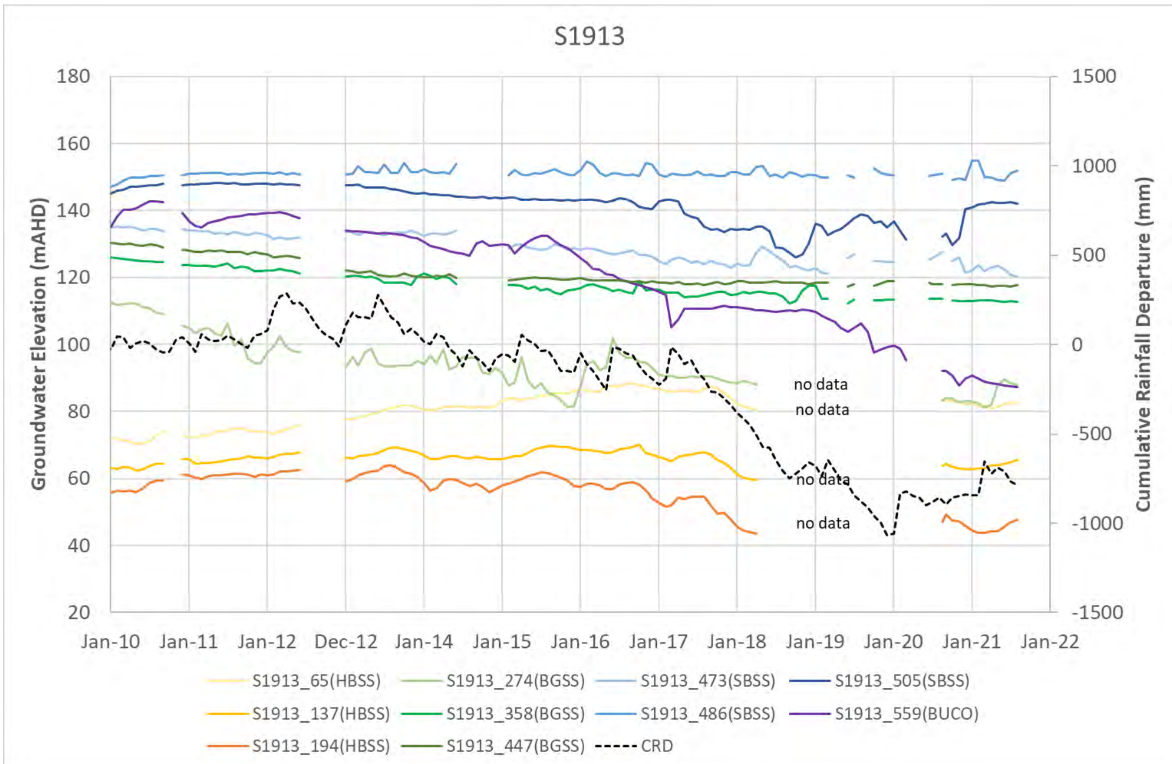


Figure 14 Hydrograph – S1913

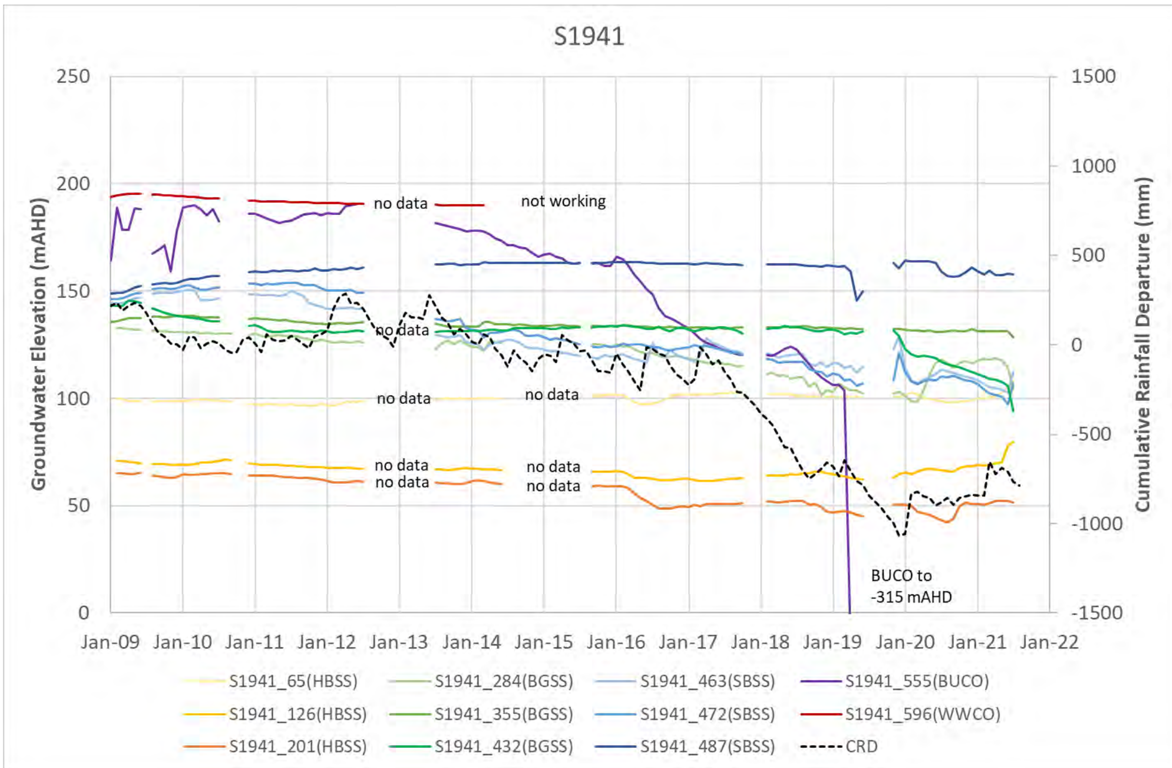


Figure 15 Hydrograph – S1941

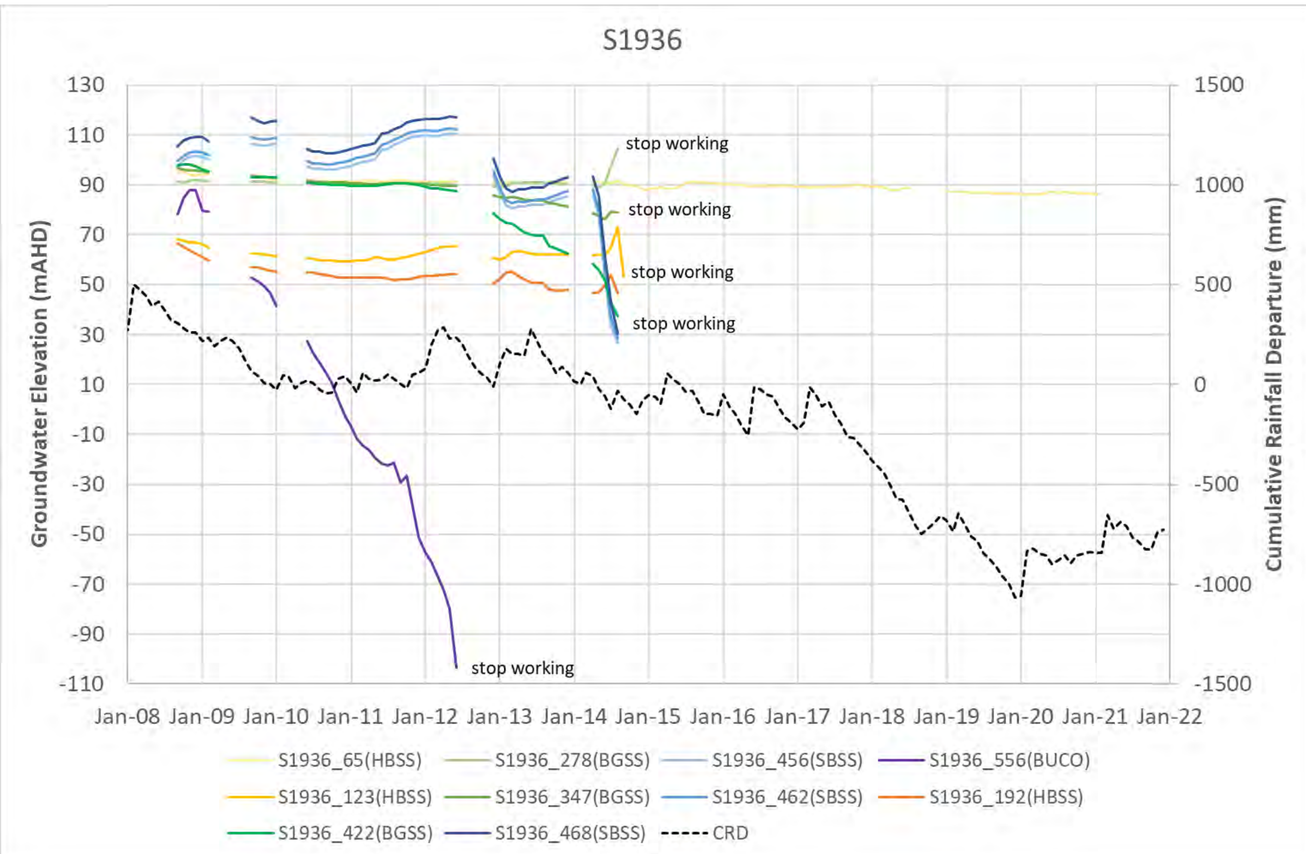


Figure 16 Hydrograph - S1936

In the VWP S2308, located within Longwall 710 footprint, most of the sensors except the first sensor depth at 70 mbgl in HBSS and, 503 and 514 mbgl in SBSS show a decline in groundwater levels (**Figure 17**). The measured data for the sensors at 70, 503 and 514 mbgl have recorded a significant increase in groundwater levels in recent years (approximately 50 m) and appear erroneous. Therefore, the data from these sensors are not considered in this groundwater assessment and model calibration. The remaining hydrographs for S2308 show a gradual decline in groundwater levels which is likely a result of mining at the nearby longwall panels.

The hydrograph for the VWP S2080 is shown in **Figure 18**. The hydrograph for S2080 shows decline in groundwater levels in HBSS consistent with the timing of the longwall mining but it also shows correlation with the CRD. Therefore, it is likely the groundwater levels in S2080 are impacted by both climate and mining.

VWPs S2281, S2282 and S2283 located close to Harris Creek and Longwall 901, monitor the HBSS. The hydrographs for these VWPs are shown in **Figure 19**, **Figure 20**, and **Figure 21**, respectively. There was a decline of between 5 to 7 m recorded in the lower sensor in HBSS in S2281, S2282 and S2283 between 2016 to 2017. These changes in groundwater levels correlate with the CRD but also the timing of the longwall mining. Therefore, it is likely the groundwater levels in HBSS were impacted by both mining and climate. The groundwater levels in HBSS in these VWPs show steady groundwater levels between 2017 to 2020 (during the drought period in NSW). However, since 2020 the bores are showing slight signs of recovery with gradual increase in groundwater levels.

Figure 22 shows the recently installed VWPs in the Hawkesbury Sandstone – S2536A, S2537, and S2538. To the east groundwater levels range from 380 mAHD across the Woronora Plateau, down to around 70 mAHD to 90 mAHD along the Nepean River (**Figure 24**).

Figure 23 shows the hydrographs for the sensors at S2524. S2524 is located approximately 100 north east of Longwall 711 and has groundwater level measurements since 2021. The hydrographs for sensors at different depths show steady groundwater levels. The hydrographs for S2524 show an upward vertical head gradient.

Interpreted groundwater level elevation contours for the lower HBSS are shown on **Figure 24** based on data collected in August 2021. Groundwater in HBSS at Appin in Area 7 and 9 generally flows towards the active mine dewatering area as well as towards areas to the north (S2165) and southwest (S2160), which are likely influenced by the CSG extraction activities in these areas.

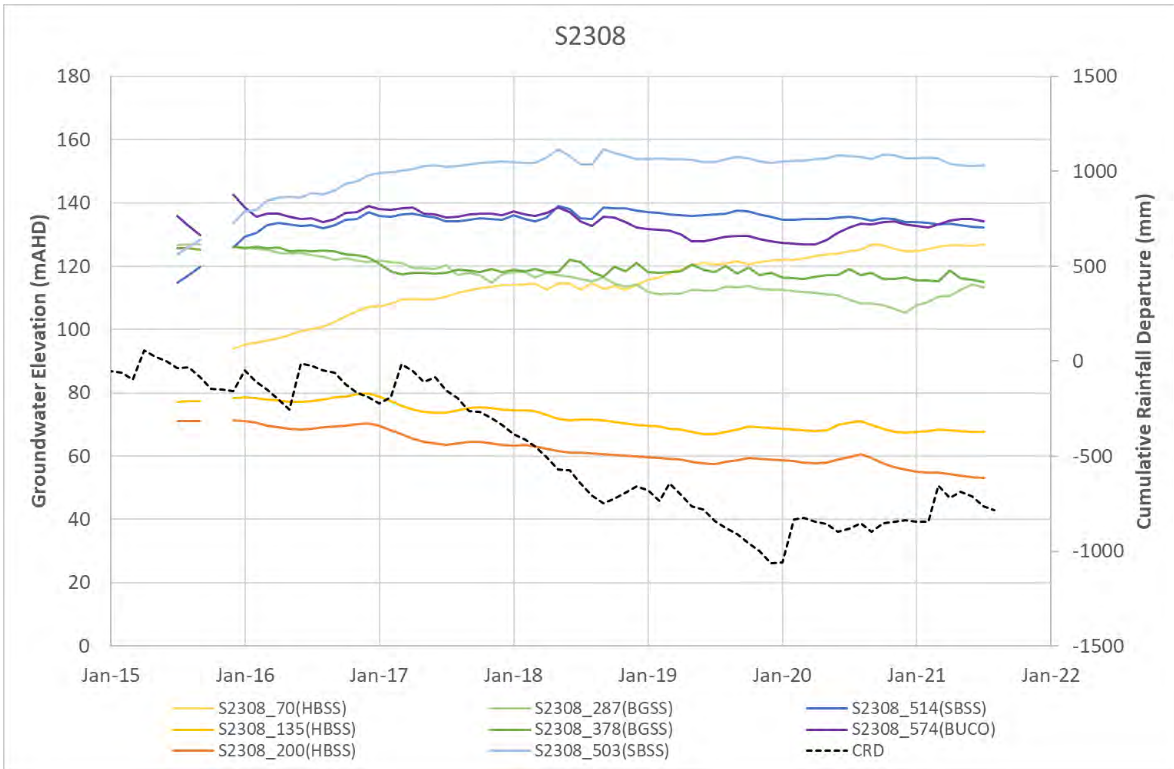


Figure 17 Hydrograph – S2308

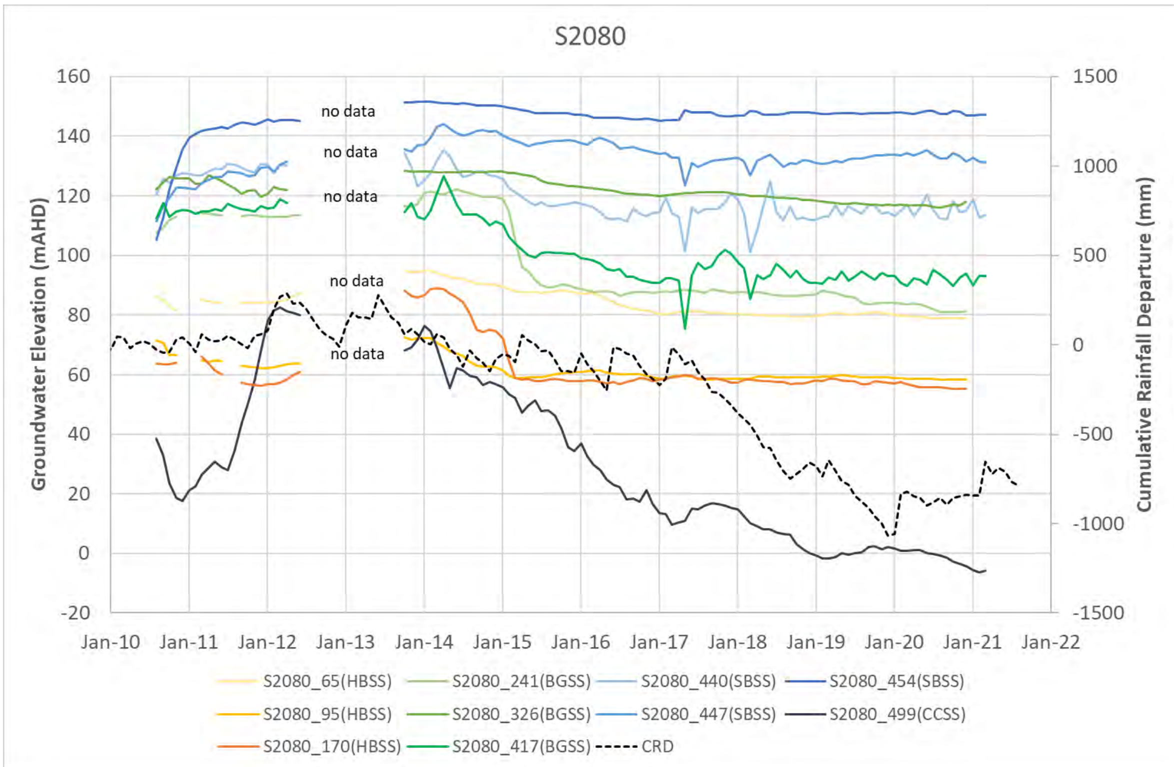


Figure 18 Hydrograph – S2080

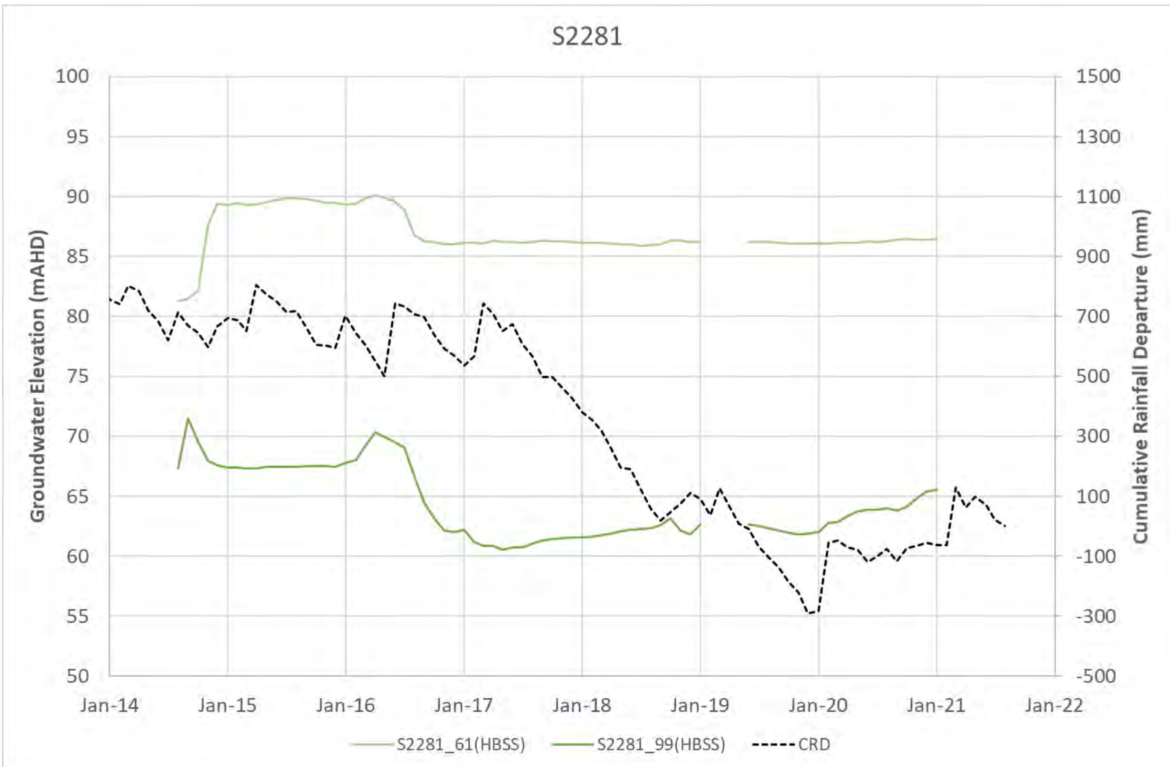


Figure 19 Hydrograph – S2281

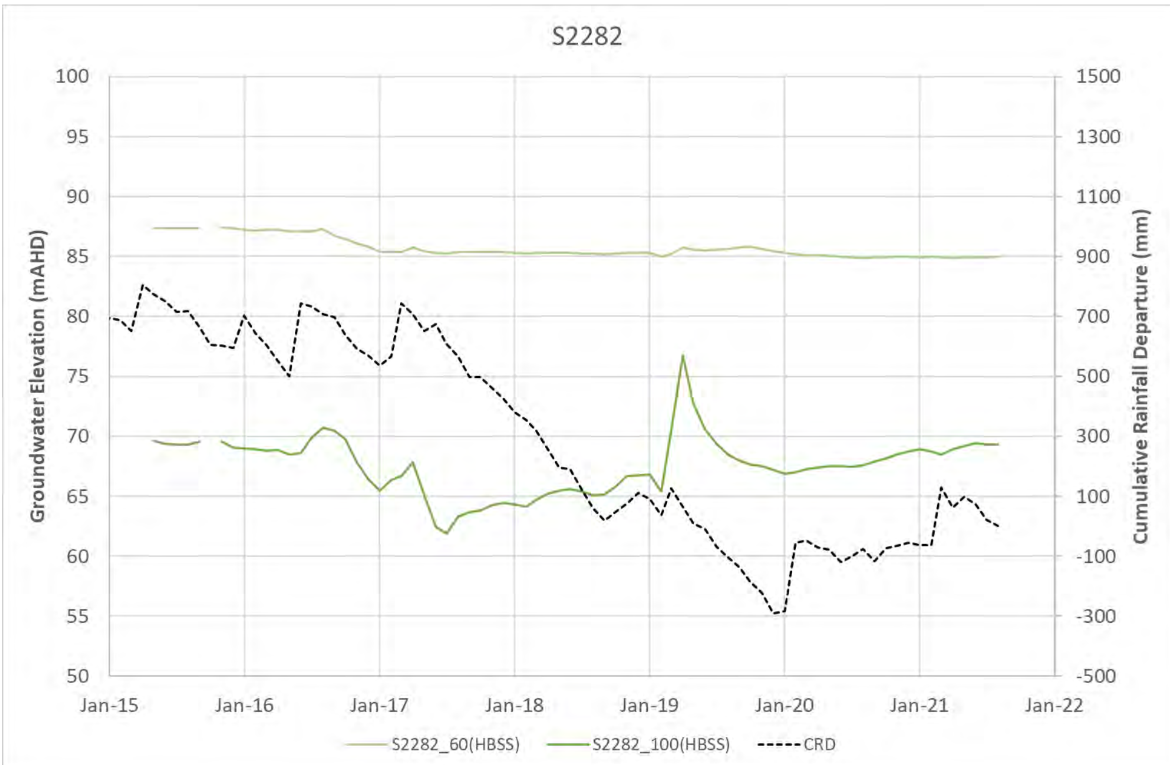


Figure 20 Hydrograph – S2282

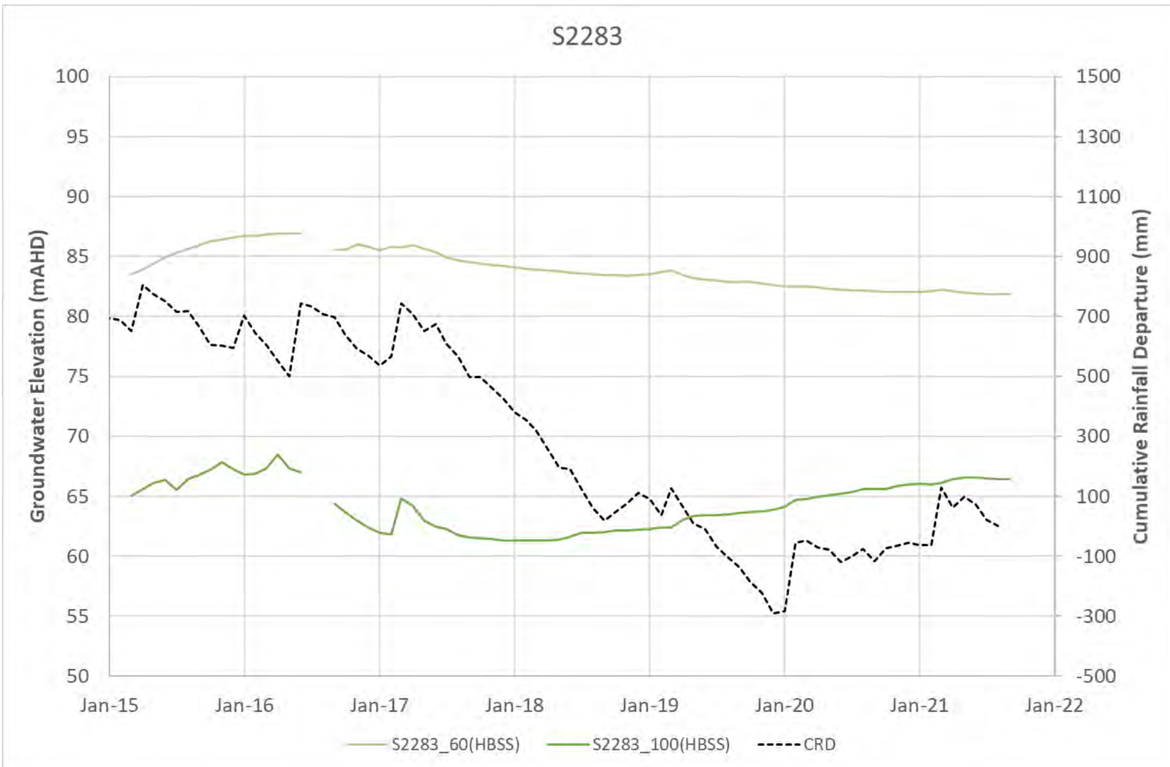


Figure 21 Hydrograph – S2283

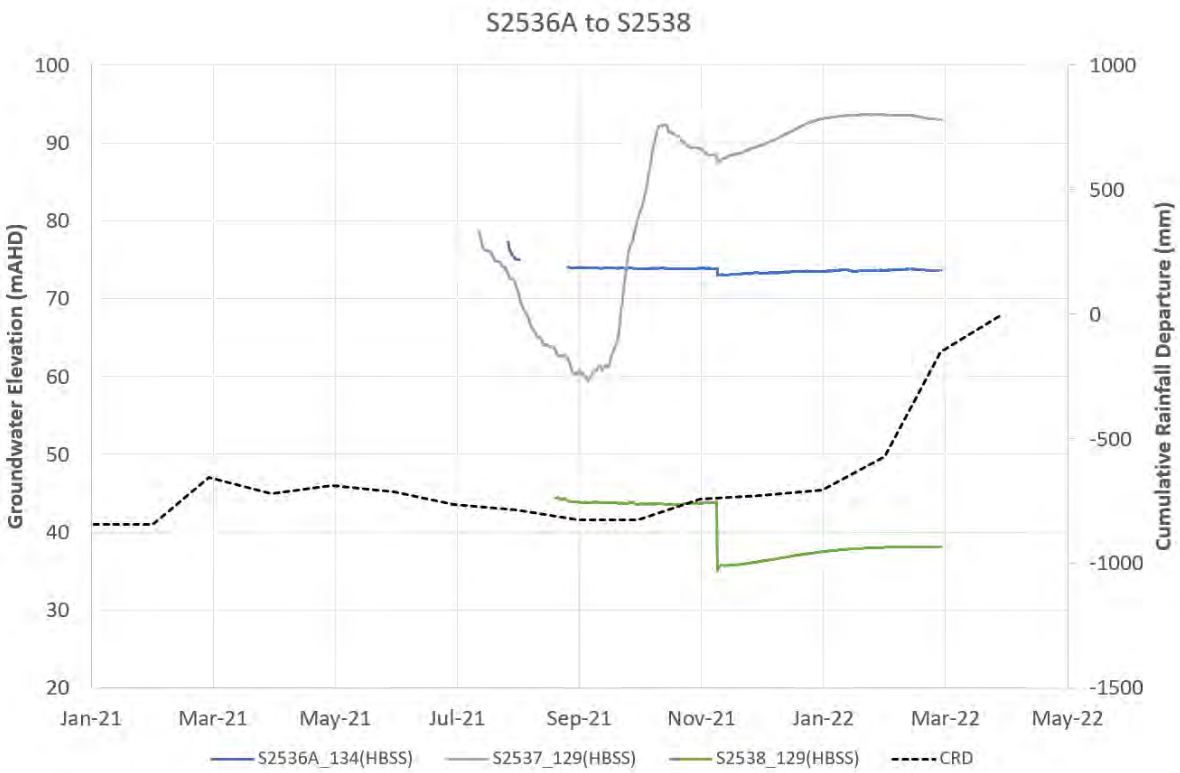


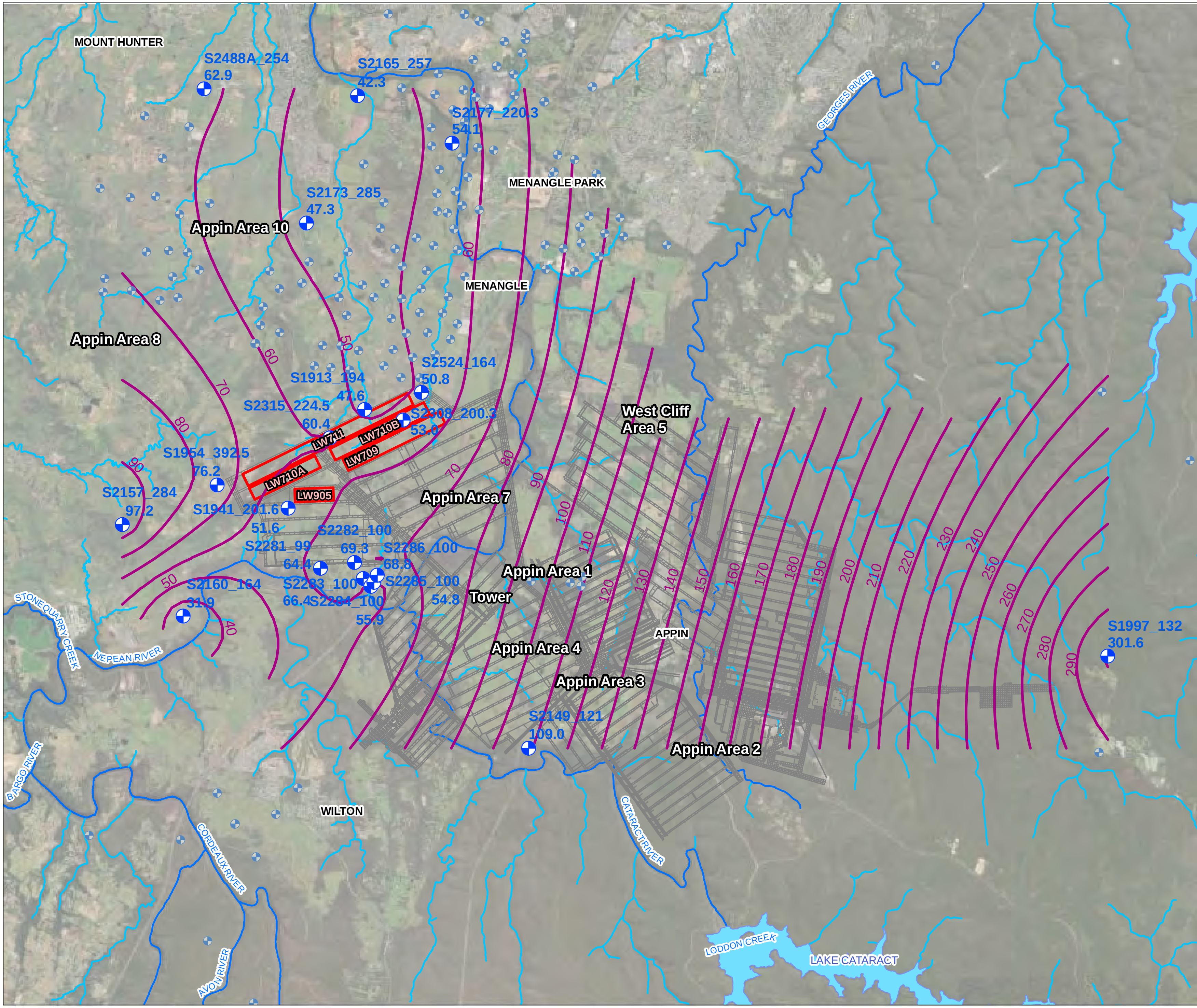
Figure 22 Hydrograph – S2536A, S2537 and S2538

Figure 23 Hydrograph – S2524

APPIN MINE
GROUNDWATER ASSESSMENT

INFERRED GROUNDWATER LEVEL IN THE LOWER HBSS

FIGURE 24



Vibrating Wire Piezometer Groundwater Level Elevation (mAHD)

Inferred Groundwater Level Elevation Contour in the lower HBSS (m AHD)

Major watercourse

Minor watercourse

Appin Mine

Lake

Project Area

Projection: GDA 1994 MGA Zone 56
Scale: 1:125,000 at A4

Project No.: 665.10015
Date: 21-Sep-2022
Drawn by: JG

SLR

H:\Projects-SLR\620-BNE\665-WOL\665.10015 Illawarra Coal Closure - Water\CADGIS\ArcGIS\EP Report\665.10015 F24 Inferred Groundwater Level in Hawkesbury Sandstone.mxd

3.2.4 Narrabeen Group

The Triassic Narrabeen Group is a sequence of interbedded sandstone, claystone, and siltstone present across the Appin Mine. It thickens in a north westerly direction from Appin Area 3 extended to Appin Area 7. The major unit is the Bulgo Sandstone which has poor groundwater quality. Groundwater flows north-westerly at the base of the unit through bedding planes, joints and fractures. The Narrabeen Group comprises three formations of very low permeability (i.e. aquitards). These aquitards impede vertical flow within the unit and are described below:

- The Bald Hill Claystone at the top of the Bulgo Sandstones limits vertical groundwater flow from the HBSS. The aquitard is present across the Appin Mine and has a thickness of approximately 25 m.
- The Stanwell Park Claystone limits the interaction of groundwater between the Bulgo Sandstone and the Scarborough Sandstone and is present across the Appin Mine with a higher thickness over Area 7 (20 m) than in Area 3 extended (6 m).
- The Wombarra Claystone forms the base of the Narrabeen Group and impedes vertical flow to the Illawarra Coal Measures. It is present across the Appin Mine and thickens south-easterly from 30 m at Appin Area 7 to 41 m in Area 3 extended.

The hydraulic gradient within the Narrabeen Formation varies spatially due to the differences in hydraulic properties over varying depths. In the Project area, groundwater levels at depth tend to be higher than those observed in the HBSS (see S1913_194, S1913_274 and S1913_473 in **Figure 14**) indicating an upward gradient.

As shown in **Figure 15,** the hydrograph for VWP S1941 indicates gradual depressurisation in the lower Bulgo Sandstone (S1941_432) and Scarborough Sandstone (S1941_472 and S1941_487) with progression of mining and depressurisation of the Bulli Seam.

As discussed in **Section 2.4.2**, impacts from the gas extraction activities at Camden Gas Project is expected in the Narrabeen Group within the Project area. This can be seen by the potentiometric level trends for VWP S2177_510 shown in **Figure 25**. VWP S2177 is located around 5.7 km north of the Project and 500 m to 1 km from five active CSG wells (EM05, EM07, EM09, MP15 and MP30). **Figure 25** shows a 40 m decline in potentiometric levels in the Scarborough Sandstone from commencement of monitoring, along with a decline in the Bulli Seam (S2177_621), likely impacted by the CSG extraction activities.

Interpreted groundwater level elevation contours for the upper Bulgo Sandstone are shown on **Figure 26** based on data collected in August 2021. On a regional scale, groundwater flows horizontally from elevated areas in the southeast and western side of Appin Mine towards the active mine dewatering area, with a hydraulic gradient towards the north which is likely influenced by the CSG extraction activities in this area. Potentiometric levels in the upper Bulgo Sandstone range from 285 mAHD in the south-east to 90 mAHD to 120 mAHD across Appin Mine (**Figure 26**).

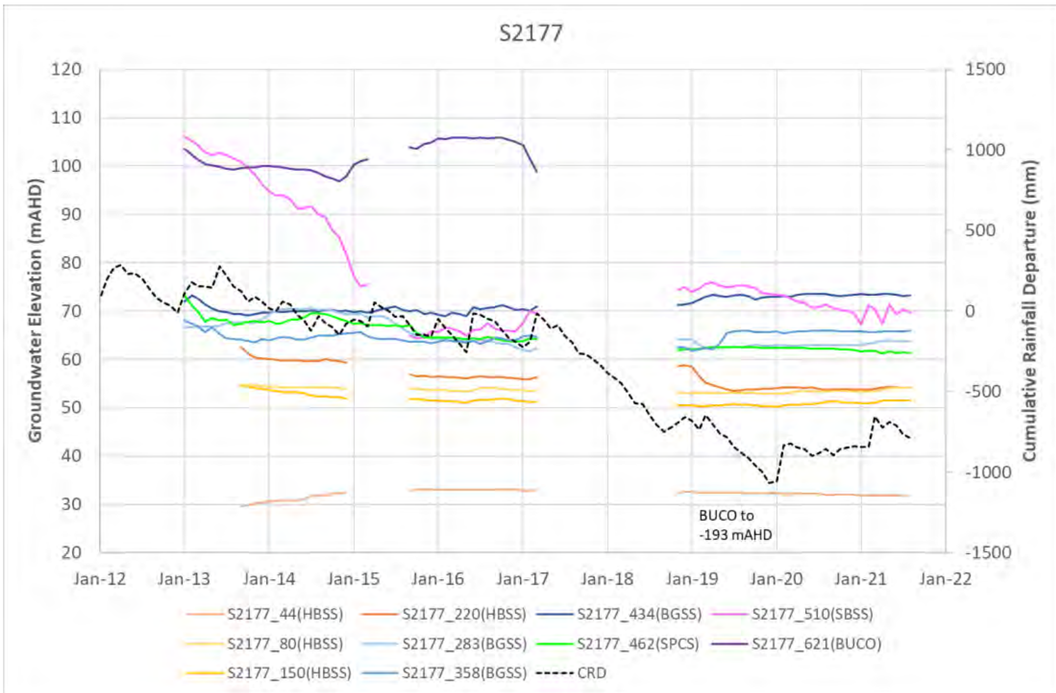
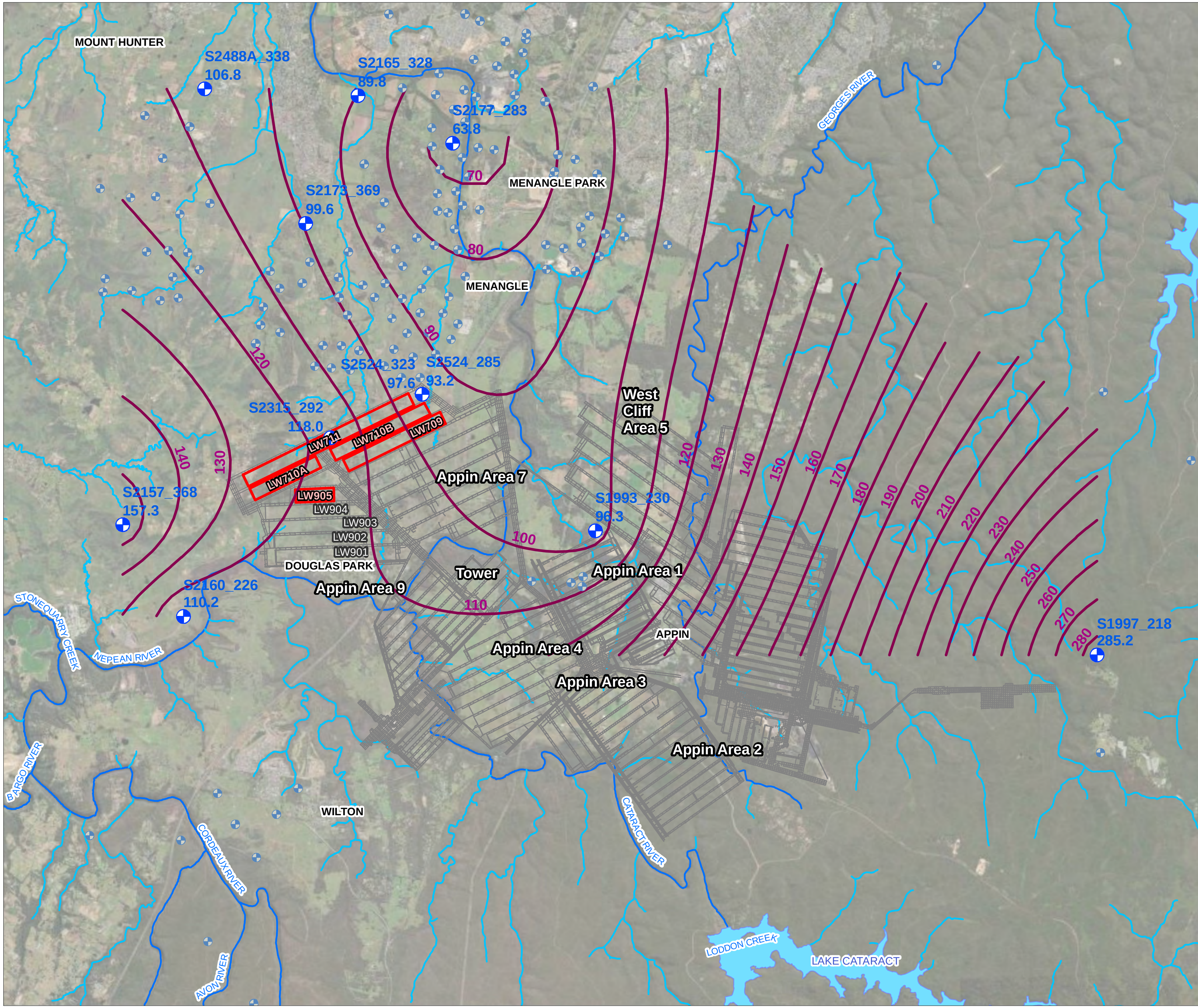


Figure 25 Hydrograph – S2177



APPIN MINE GROUNDWATER ASSESSMENT

INFERRED GROUNDWATER LEVEL IN THE UPPER BULGO SANDSTONE

FIGURE 26

- CSG Well
- Vibrating Wire Piezometer Groundwater Level Elevation (mAHD)
- Inferred Groundwater Level Elevation Contour in the upper Bulgo Sandstone (mAHD)
- Major watercourse
- Minor watercourse
- Appin Mine
- Lake
- Project

0 1 2 km

Projection: GDA 1994 MGA Zone 56
Scale: 1:125,000 at A4

Project No.:	665.10015
Date:	15-Sep-2022
Drawn by:	JG

SLR

H:\Projects-SLR\620-BNE\665-WOL\665.10015 Illawarra Coal Closure - Water\CADGIS\ArcGIS\EP Report\665.10015 F26 Inferred Groundwater Level in the Upper Bulgo Sandstone.mxd

3.2.5 Illawarra Coal Measures

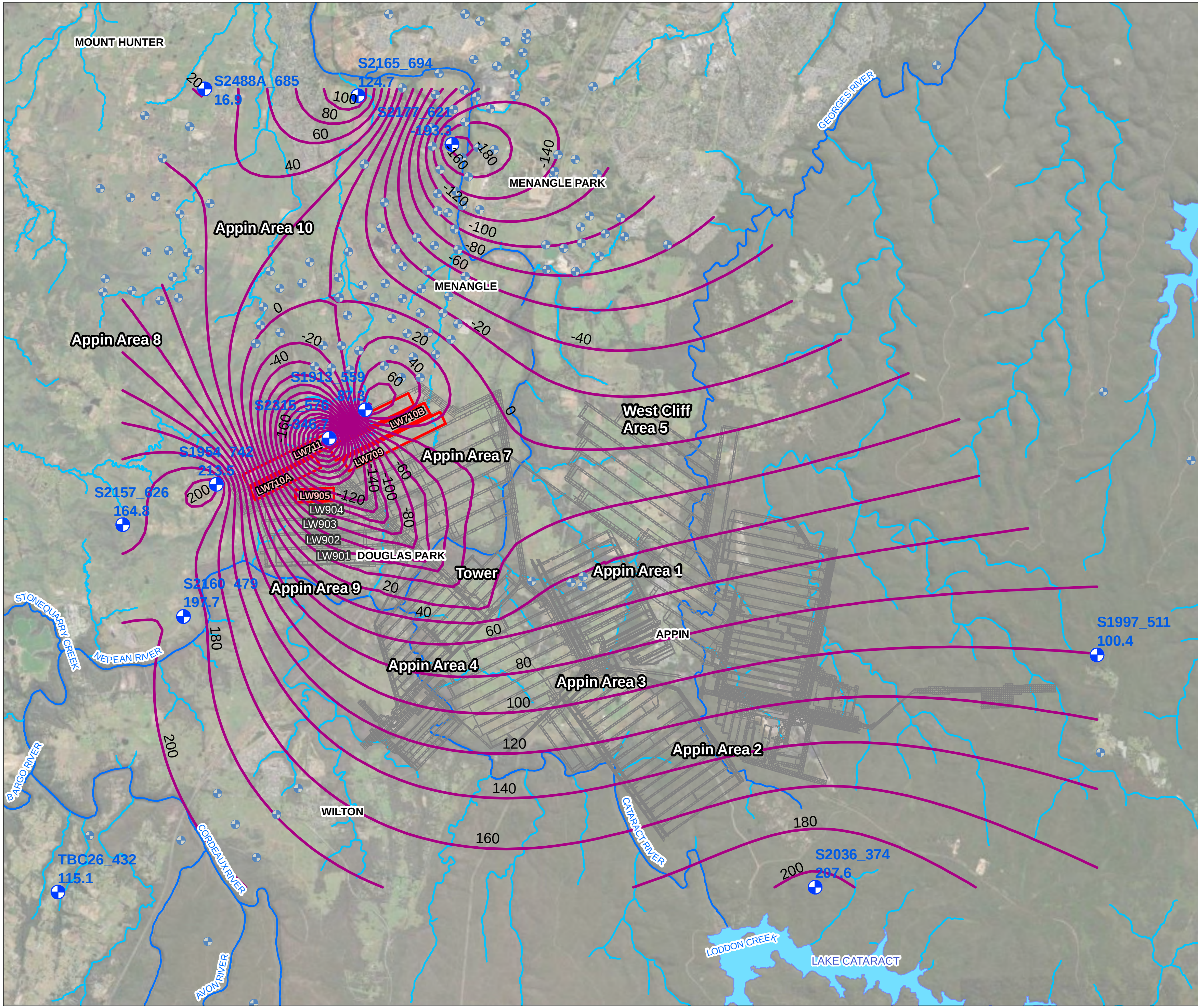
The Illawarra Coal Measures are the primary economic sequence of interest in the Sydney Basin, and consist of interbedded sandstones, shale and coal seams with a thickness of approximately 200 m to 300 m. The two main coal seams mined in the Southern Coalfield are the uppermost Bulli Seam and the Wongawilli Seam (Holla and Barclay, 2000). Within the Project extent of the longwall mining area, the Bulli Seam is around 530 m to 750 m below surface. The coal seams outcrop to the east of Appin Mine, where coal seams are truncated (eroded) along the Illawarra Escarpment.

Figure 27 shows the inferred potentiometric levels in the Bulli Seam in August 2021. As shown in **Figure 27**, historical mining activities at the Appin Mine have resulted in significant depressurisation of groundwater levels in the Bulli Seam. Therefore, on a site scale, the groundwater flow in the Bulli Seam and Wongawilli Seam is towards the mine workings. On a regional scale, the groundwater in both the Bulli Seam and Wongawilli Seam flows towards the north. Significant depressurisation is also observed north of the Appin Mine due to CSG extraction activities. Groundwater within the Permian coal measures are semi-confined where they occur at subcrop, becoming confined with depth towards the north-west. Groundwater levels range from 200 mAHD in the south-east to 120 mAHD north of Appin Mine away from the CSG extraction (**Figure 27**).

The hydrograph for S2315 (**Figure 28**) shows significant decline in groundwater levels in the Bulli Coal Seam in response to the longwall mining. However, S2308 located 1.8 km to the west of S2315 has recorded stable groundwater levels due to a greater distance from the current mining works (**Figure 17**).

As shown in **Figure 14**, the decline in groundwater levels in S1913_559 which is monitoring the Bulli Seam recorded drawdown before commencement of the longwall near this VWP and is likely a response to the active CSG wells less than 200 m away as well as subsequent longwall mining. The depressurisation of the strata is observed across the historical and active mining areas as seen in VWPs S1941_555 and S2060_603 in Area 9. The significant decline of approximately 450 m is observed in groundwater levels in VWP S1941_555 monitoring the Bulli Coal Seam (**Figure 15** and **Figure 29**). There is 500 m depressurisation observed at bore S2060 in the Bulli Coal Seam and Balgownie Seam which is a response to the longwall mining (**Figure 30**).

There are several VWPs that used to monitor the Bulli Coal Seam but have been deactivated in the vicinity of the Longwall 709 to Longwall 711 and Longwall 905 area. These include S1584, S1763, S1809, S1853, S1854, S1957, and S1947. **Figure 31** shows the hydrographs for these listed VWPs. The groundwater level measurements for S1584 were only recorded for a short period of time. The hydrographs for the other VWPs presented in **Figure 31** show groundwater levels are impacted by mining in the nearby longwall panels.



APPIN MINE
GROUNDWATER ASSESSMENT

INFERRED GROUNDWATER LEVEL IN THE BULLI SEAM

FIGURE 27

- CSG Well
- Vibrating Wire Piezometer Groundwater Elevation (mAHD)
- Inferred Groundwater Level Contour in the Bulli Seam (mAHD)
- Major watercourse
- Minor watercourse
- Appin Mine
- Lake
- Project Area

0 1 2 km

Projection: GDA 1994 MGA Zone 56
Scale: 1:125,000 at A4

Project No.: 665.10015
Date: 20-Sep-2022
Drawn by: JG

SLR

H:\Projects-SLR\620-BNE\665-WOL\665.10015 Illawarra Coal Closure - Water\CADGIS\ArcGIS\EP Report\665.10015 F27 Inferred Groundwater in the Bulli Seam.mxd

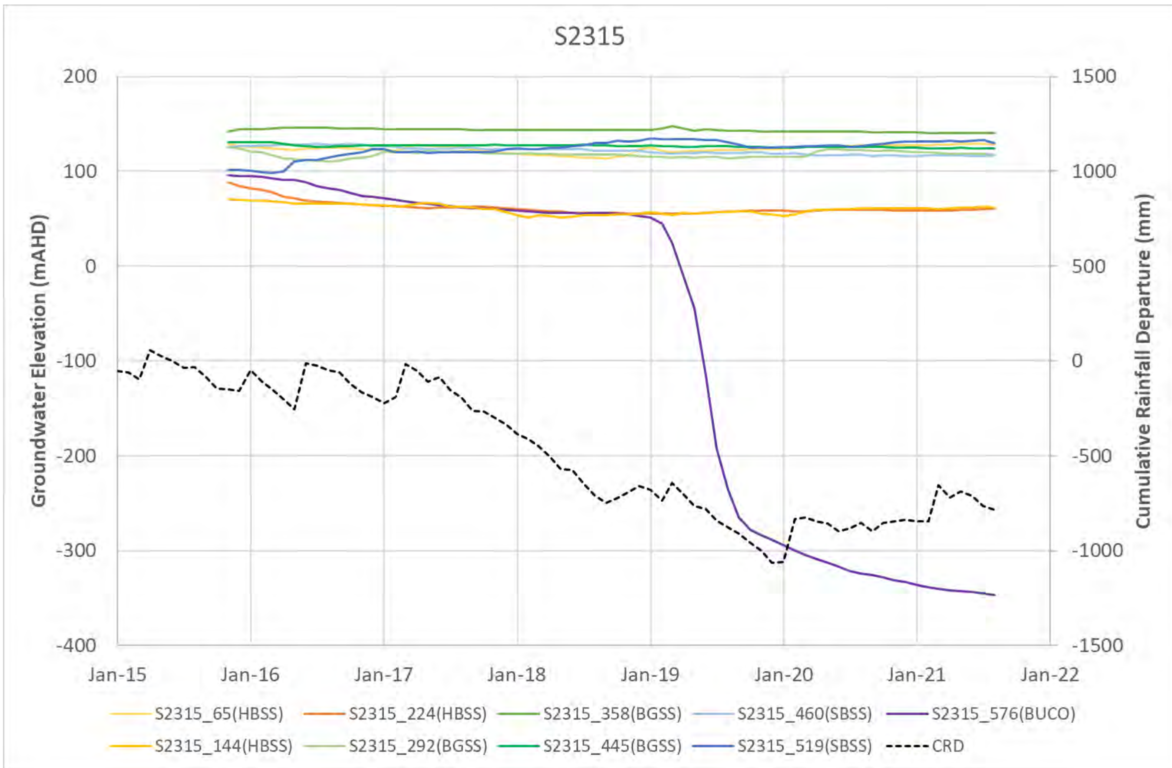


Figure 28 Hydrograph – S2315

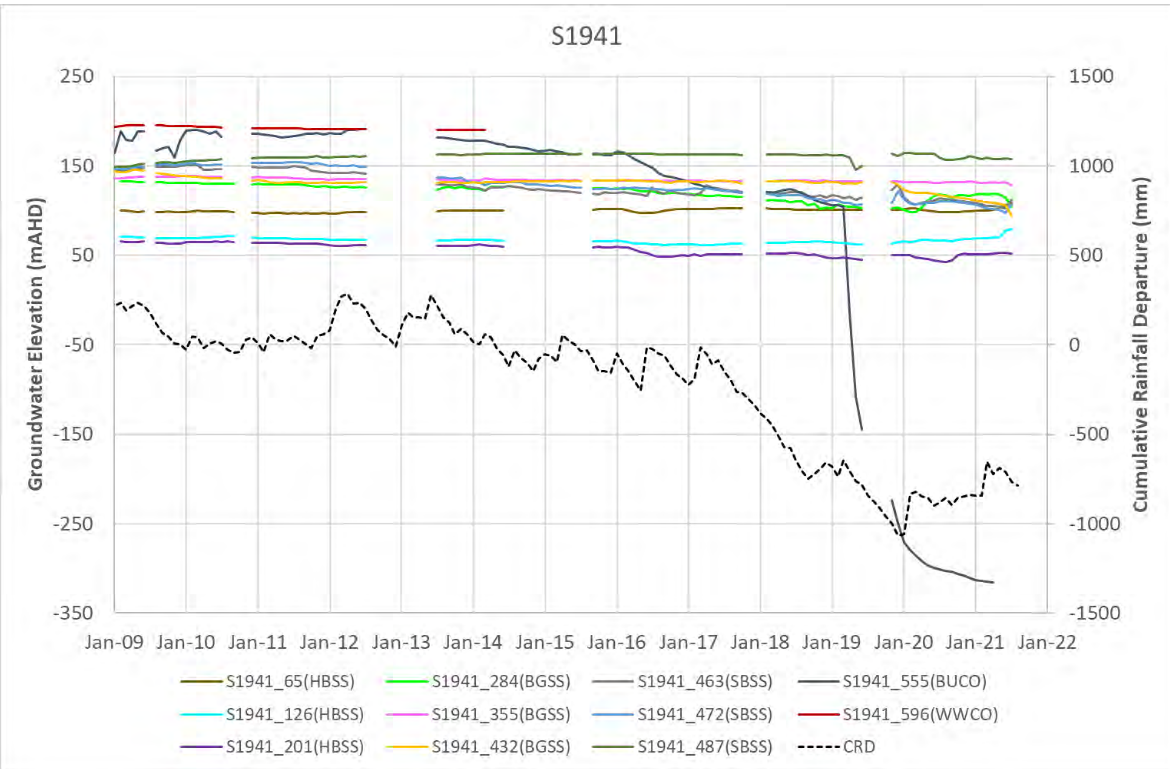


Figure 29 Hydrograph - S1941

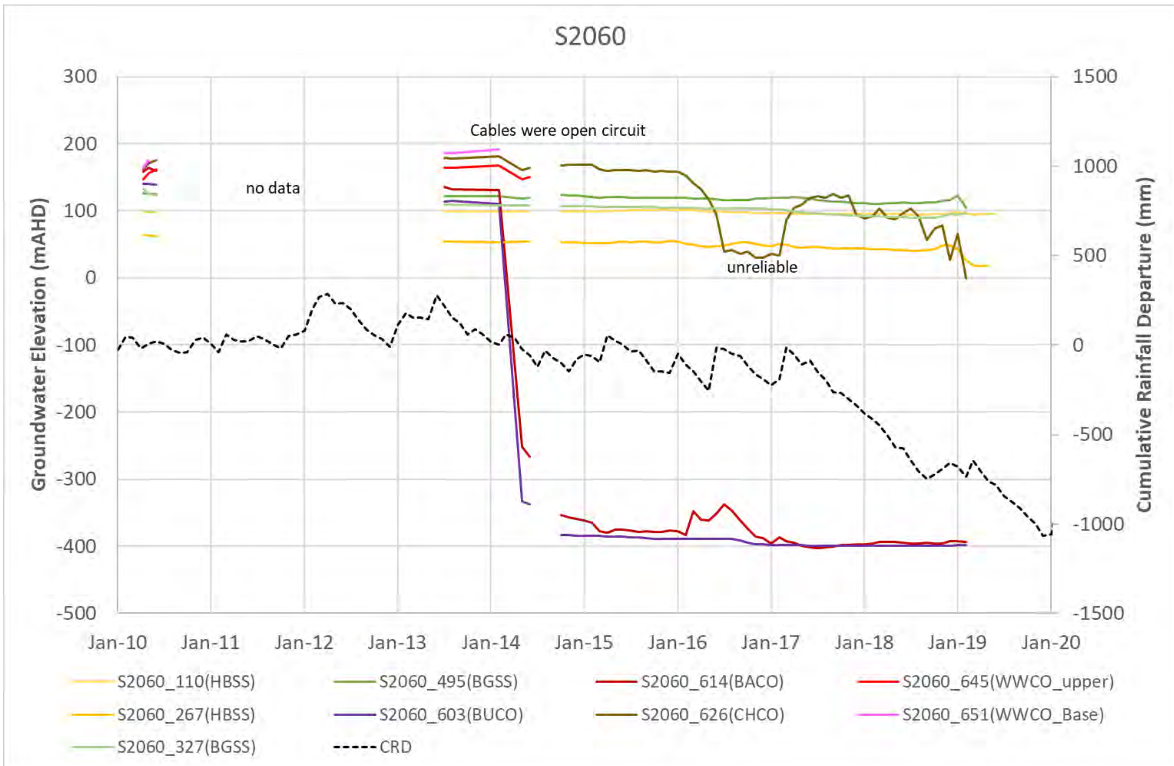


Figure 30 Hydrograph – S2060

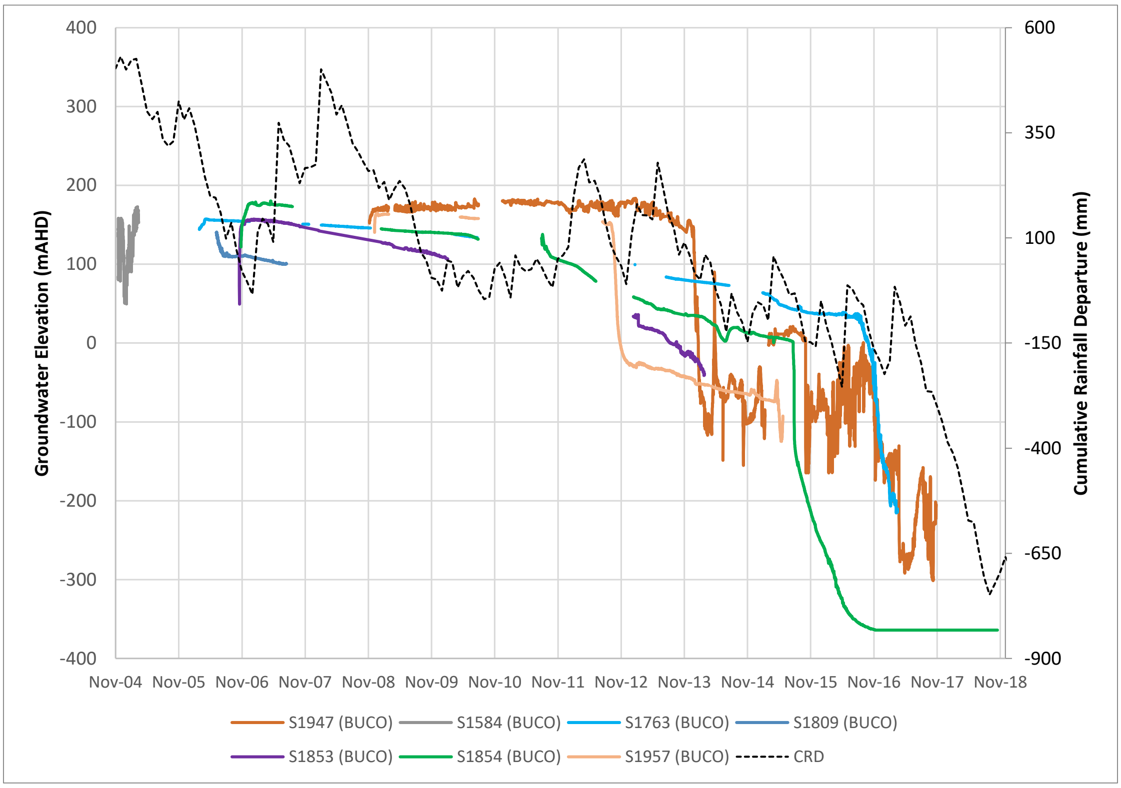


Figure 31 Hydrograph – S1947, S1584, S1763, S1809, S1853, S1854, S1957

3.3 Groundwater Quality

A summary table of groundwater quality data collected at site from bores screened within the Wianamatta Group, Hawkesbury Sandstone (HBSS) and Narrabeen Group (Bulgo Sandstone) is presented in **Appendix B**.

In summary, water within:

- Nepean River surface water is generally fresh (median EC 244 µS/cm) and generally has neutral to slightly alkaline pH (median pH 7.7).
- Wianamatta Group is generally moderately saline (median EC 4,750 µS/cm). The results show that water is not suitable for drinking water, generally suitable for short term irrigation and water for some stock (i.e. sheep and beef or dairy cattle). But generally, has iron concentration above the trigger for long term irrigation water use, and low yields so not considered a productive groundwater source (Heritage Computing, 2009).
- HBSS is brackish (median EC 2,063 µS/cm) but can have variable water quality with the 5th and 95th percentile of site data ranging between 460 µS/cm and 6,458 µS/cm. The groundwater generally has a neutral to slightly alkaline pH (median pH of 7.5), but is also highly variable with a 5th and 95th percentile of site data ranging between 6.4 and 11.9. The HBSS typically has a sodium-calcium type water and is generally suitable for short term irrigation and stock water. However, the iron concentrations are generally above the trigger for long term irrigation water use.
- Bulgo Sandstone within the Narrabeen Group is generally moderately saline (median EC ~4,950 µS/cm) and generally has neutral pH (median pH 7.2). The groundwater in the Bulgo Sandstone typically has a sodium-bicarbonate type water and is generally suitable for short term irrigation and water for some stock (i.e. sheep and beef or dairy cattle). However, the iron concentrations are generally above the trigger for long term irrigation water use.

The available data indicates there are no groundwater bores on site where water quality data is collected from the Permian coal measures. It is assumed water within the coal measures would generally be moderately saline to saline.

3.4 Groundwater Receptors

3.4.1 Groundwater Dependent Ecosystems

The NSW State Groundwater Dependent Ecosystems Policy (DLWC, 2002) describes the five broad types of groundwater systems in NSW, each with associated dependent ecosystems as follows:

- Deep Alluvial Groundwater Systems – occurring under floodplains of major rivers west of the Great Dividing Range (e.g. Namoi, Macquarie, Lachlan, Murrumbidgee and Murray alluvium).
- Shallow Alluvial Groundwater Systems – coastal rivers and higher reaches west of the Great Dividing Range (e.g. Hunter, Peel and Cudgegong alluvium, and beds and lateral bars of the lower Macleay, Bellinger and Nambucca Rivers).
- Fractured Rock Groundwater Systems – outcropping and sub-cropping rocks containing a mixture of fractures, joints, bedding planes and faults that contain and transmit small and occasionally large amounts of groundwater (e.g. Alstonville Basalt, Molong Limestone and the Young Granite).
- Coastal Sand Bed Groundwater Systems – significant sand beds along the coast of NSW (e.g. Botany and Tomago sand beds).
- Sedimentary Rock Groundwater Systems – sedimentary rock aquifers including sandstone, shale and coal (e.g. Great Artesian Basin, Sydney Basin and Clarence Moreton Basin).

Groundwater resources in the Appin Mine area are located within the Porous sedimentary rock groundwater system, as classified in the Sydney Basin Nepean Groundwater Source, refer to **Section 1.3.1**.

The NSW State Groundwater Dependent Ecosystems Policy (DLWC, 2002) also recognises the four Australian groundwater dependent ecosystem types (Hatton and Evans, 1998) in NSW, namely:

- Terrestrial vegetation;
- Base flows in streams;
- Aquifer and cave ecosystems; and
- Wetlands.

A review of the Bureau of Meterology (BoM) GDE Atlas (accessed on 4 September 2022) and the relevant WSP for the Project has been conducted and is presented in the following sections.

3.4.1.1 BoM GDE Atlas

The BoM GDE Atlas provides mapping of features that are potentially reliant on the surface expression of groundwater and other features that are potentially reliant on what the GDE Atlas refers to as 'subsurface groundwater', which is both the saturated zone and the vadose zone or capillary fringe. The BoM's mapping of these is presented on **Figure 32**, with the features classified to show their likely interaction with groundwater (low, moderate, high). BoM's mapping is based on remote sensing data (and often not verified in the field) that "indicates landscapes that are most likely to access additional water sources. The additional water source may be soil water, surface water, or groundwater." **Table 7** lists the GDEs present within 10 km of the Project and their potential for interaction with subsurface groundwater.

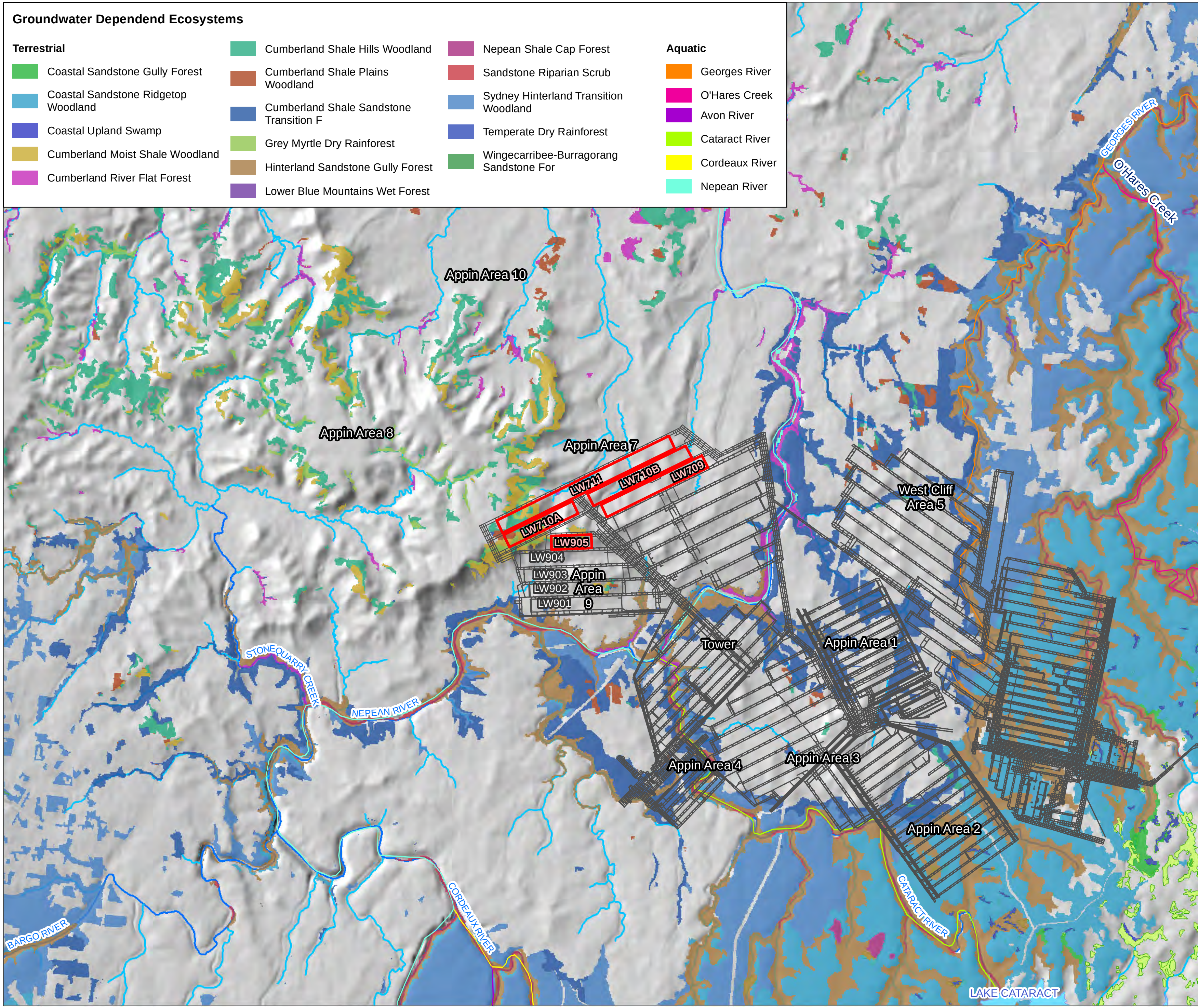
Table 7 Groundwater Dependent Ecosystems (GDE) located within 10 km of Project from Bureau of Meteorology GDE Atlas

GDE type	Name	Location	Potential for interaction with subsurface groundwater
Aquatic	Cataract River	3 km south of Area 7 and 9	Moderate
	Nepean River	1 to 3 km south and east of Area 7 and 9	Moderate to high
	Avon River	9 km south of Area 7 and 9	Moderate
	Cordeaux River	9 km south of Area 7 and 9	Moderate
Terrestrial	Coastal Sandstone Ridgetop Woodland	Located on the ridgelines and interfluves 1 km south and 5 km east of Area 7 and Area 9	Low to moderate
	Cumberland Moist Shale Woodland	Above Area 7 and Area 9 and along the Nepean River	Moderate to high
	Cumberland Shale Hills Woodland	Along the creek north northwest of Area 7 and Area 9	Low to high
	Hinterland Sandstone Gully Forest	In lower lying areas along the edges of gullies	Low to high
	Coastal Upland Swamp	8 km east of Area 7 and Area 9	Low to high
	Cumberland River flat Forest	Above Area 7 and Area 9 and along the Nepean River	Low to high
	Cumberland Shale Plains Woodland	Along the creek north and northwest of Area 7 and Area 9	Low to high
	Cumberland Shale Sandstone Transition F	Along the Nepean River and George River	Low to high
	Grey Myrtle Dry Rainforest	Above Area 7 and Area 9 and along the creeks northwest of Area 7 and Area 9	Low to high
	Lower Blue Mountains Wet Forest	Two areas 7 and 8 km north east of Area 9 along Georges River	High
	Sandstone Riparian Scrub	Along the Nepean and Georges River	Low to high
	Sydney Hinterland Transition Woodland	Along the Nepean and Georges River	Low to high

APPIN MINE
GROUNDWATER ASSESSMENT

GROUNDWATER DEPENDENT ECOSYSTEMS

FIGURE 32



Major watercourses
Minor watercourses
Appin Mine
Lake
IC mapped swamp
Project Area

0 1 2 km

Projection: GDA 1994 MGA Zone 56
Scale: 1:120,000 at A4

Project No.: 665.10015
Date: 21-Sep-2022
Drawn by: JG

SLR

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3.4.1.2 GDE Water Sharing Plan

A search of legislation (see WSP in **Section 1.3.1**) was carried out to identify any high priority GDEs in the region. The Greater Metropolitan Region Groundwater Sources WSP specifies a number of high priority GDEs. The nearest of these are:

- O'Hares Creek catchment: located 8 km east of Appin Area 7 and 9. This includes O'Hares, Stokes and Four Mile Creeks, downstream to the junction of O'Hares and Stokes Creeks.
- Thirlmere Lakes: located 16 km west of Appin Area 7 and 9 and just west of Tahmoor Mine.

These high priority GDEs are shown on **Figure 32.**

3.4.2 Swamps

Upland headwater swamps have been mapped in the region. However, the closest swamps are approximately 9 km from the Project area and are therefore not considered potential receptors for this Project.

3.4.3 Landholder Bores

A search of the BoM's National Groundwater Information System (NGIS) was carried out for registered bores within the model extent (refer to **Figure 44**). 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 8.** There are 49 registered bores within 5 km of Appin Mine/Project area. The location of these bores is shown in **Figure 33**.

Table 8 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	37.6
Other	9	0.9
Stock and Domestic	33	3.3
Unknown	34	3.4
Water Supply	377	37.5
Total	**1,006**	**100.0**

Most groundwater users are located to the north of the Project, within the Wianamatta Group outcrop area, and to the southwest, within the HBSS outcrop area. Most landholder bores are located within the HBSS (453 bores) and Bulgo Sandstone (322 bores). Of these, 207 bores could be extracting water from the HBSS for water supply, irrigation, household, stock, and domestic purposes.

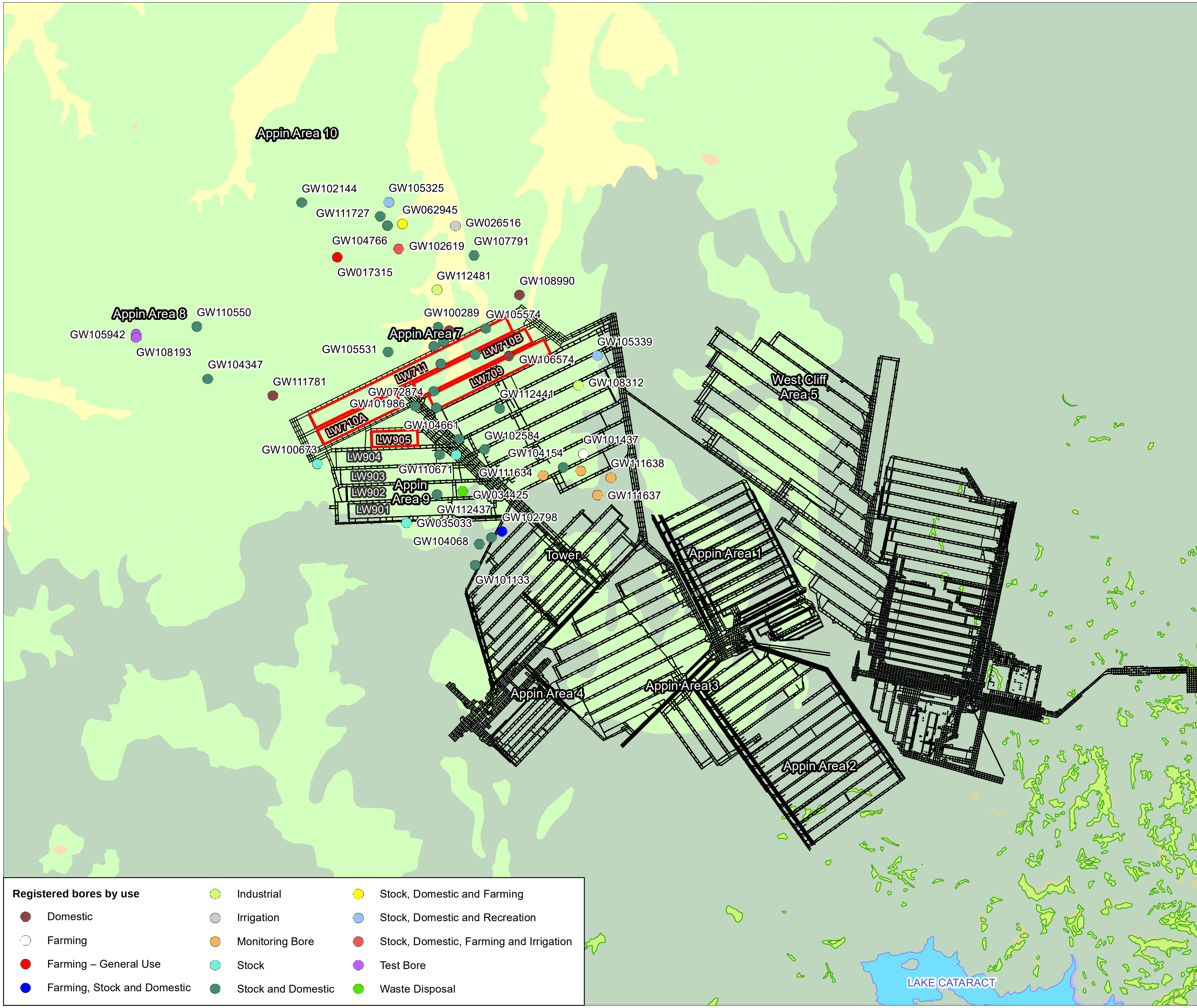
There are 237 bores extracting water from the Bulgo Sandstone. Detailed construction details for the bores are missing in most cases. Using the known bore depth and the surface geology map, there is potential for approximately 64 registered bores with depths of less than 30 m targeting alluvium along the Nepean River and the Mount Hunter Rivulet, 25 km north of Appin Mine. These bores are used for monitoring (39 bores), irrigation (15 bores), water supply (4 bores), stock (1 bore) and other uses (5 bores). Maximum yield of private bores surrounding Appin Mine does not exceed 1.5 L/s. Details of the registered bores in the Appin Mine Area are shown in **Appendix C**.

A desktop assessment of landholder bores within the Project area was carried out in 2020 (SLR, 2020). 37 bores were assessed, nine were classified as operational, six were decommissioned or non-operational and the remaining bores were unknown. IMC is required to make good for impacts to landholder bores in accordance with the Coal Mine Subsidence Compensation Act 2017.

APPIN MINE GROUNDWATER ASSESSMENT

GROUNDWATER USERS IN THE APPIN MINE AREA

FIGURE 33



Appin Mine
Lakes
IC mapped swamp
Qal/ Tal – Alluvium
Wianamatta group
Rh - HBSS
Project Area

0 1 2 km

Projection: GDA 1994 MGA Zone 56
Scale: 1:105,000 at A4

Project No.: 665.10015
Date: 07-Sep-2022
Drawn by: JG

SLR

H:\Projects-SLR\620-BNE\665-WOL\665.10015 Illawarra Coal Closure - Water\CADGIS\ArcGIS\EP Report\665.10015 F33 Groundwater Users in the Appin Mine area.mxd

3.5 Hydraulic Properties

This section outlines pre-mining or 'host' hydraulic properties most relevant to regional groundwater flow which includes hydraulic conductivity and aquifer storage (specific storage (Ss) and specific yield (Sy)). Longwall mining results in significant changes in hydraulic property of the strata. **Section 3.6** discusses these changes.

3.5.1 Hydraulic conductivity (K)

Geological formations are not homogenous in nature, and the sedimentary environment is generally made up of layers of alternating sediments. This means that analysis of available hydraulic conductivity testing must take account of the influence of the different units and lithologies on horizontal and vertical flow.

Hydraulic conductivity data assessed for the main lithological units relevant to Appin are presented in **Figure 34** and **Figure 35**, and summarised and tabulated in **Table 9**. Data has been sourced mainly from packer testing with some data available from core testing, conducted at Appin, Tahmoor and Dendrobium Mines. Packer testing primarily tests horizontal hydraulic conductivity (Kh), depending on the distribution of sub-horizontal and sub-vertical defects.

Data indicated that there is a large range of values among formations, however it should be noted that there is no pumping test data with multiple observation bore elevations to assess Kv and limited Kv core testing data, particularly for formations other than the Hawkesbury Sandstone (HBSS). **Table 9** shows that there is generally not a huge contrast between mean Kh for units termed as claystone (CS) and sandstone (SS). The large range of observed Kh values are likely due to testing of more clay or sand rich layers. **Figure 35** shows that units termed claystone generally have lower Kv, however these units are on average less than 10 m thick and more difficult to characterise.

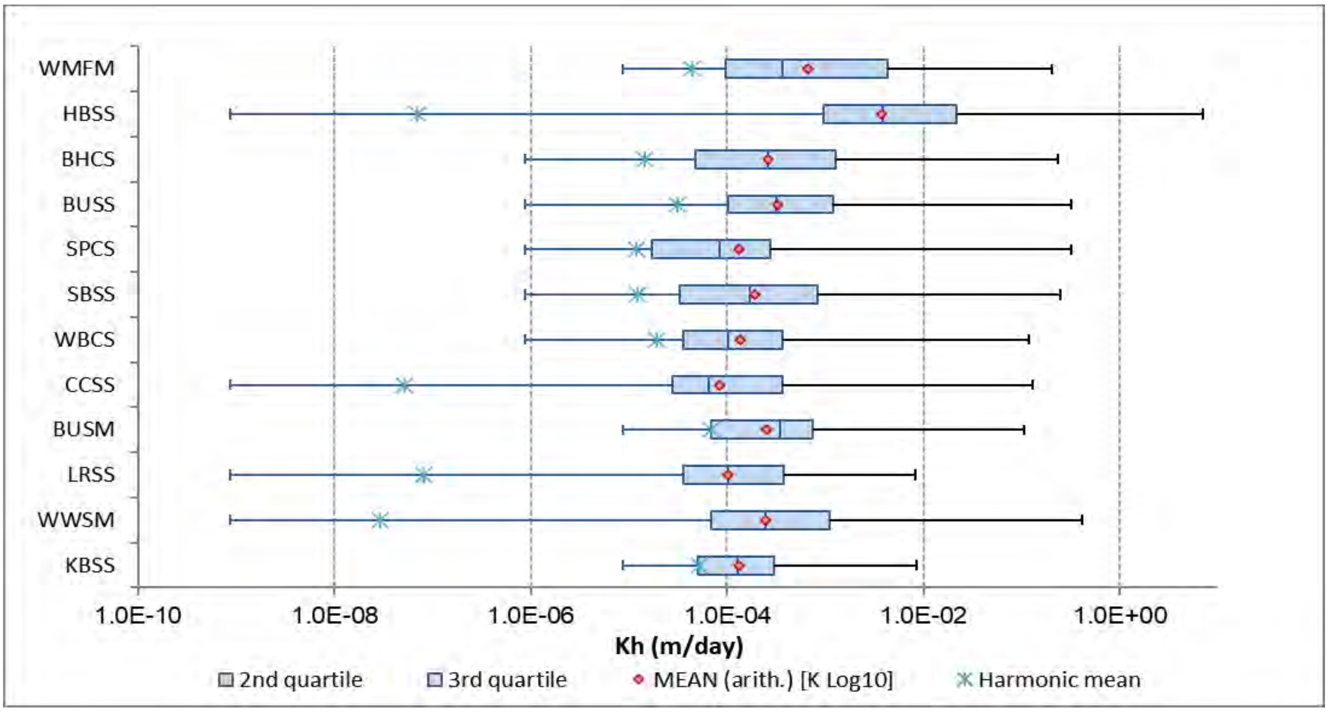


Figure 34 Box and whisker plot of horizontal hydraulic conductivity for each formation

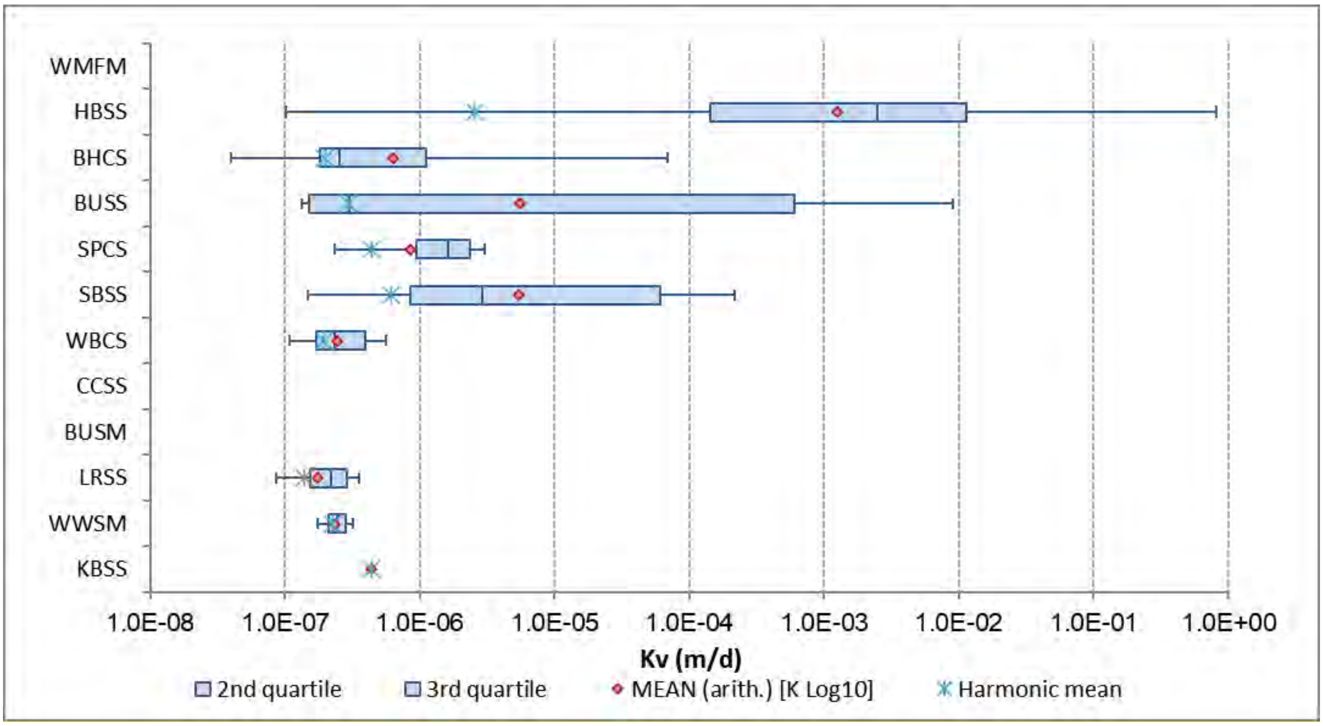


Figure 35 Box and whisker plot of vertical hydraulic conductivity for each formation

Table 9 Hydraulic conductivity data summary

Unit	Horizontal, Kh (m/d)				Vertical, Kv (m/d)			
	Packer, Arithmetic mean	Packer, 5th Perc.	Packer, Max	Packer, Population	Core testing, Arithmetic	Core, Min	Core, Max	Core, Population
WMFM	6.70×10^{-04}	8.64×10^{-06}	2.03×10^{-01}	18	na	na	na	0
HBSS	3.73×10^{-03}	7.99×10^{-05}	$7.07\times10^{+00}$	820	1.25×10^{-03}	1.01×10^{-07}	8.18×10^{-01}	40
BHCS	2.64×10^{-04}	5.12×10^{-06}	2.33×10^{-01}	164	6.34×10^{-07}	3.94×10^{-08}	6.85×10^{-05}	20
BUSS	3.30×10^{-04}	8.64×10^{-06}	3.20×10^{-01}	657	5.54×10^{-06}	1.34×10^{-07}	9.05×10^{-03}	13
SPCS	1.34×10^{-04}	8.64×10^{-06}	3.20×10^{-01}	44	8.42×10^{-07}	2.33×10^{-07}	3.04×10^{-06}	2
SBSS	1.90×10^{-04}	3.57×10^{-06}	2.51×10^{-01}	118	5.47×10^{-06}	1.48×10^{-07}	2.19×10^{-04}	5
WBCS	1.36×10^{-04}	6.45×10^{-06}	1.21×10^{-01}	93	2.41×10^{-07}	1.07×10^{-07}	5.57×10^{-07}	3
CCSS	8.40×10^{-05}	2.78×10^{-06}	1.30×10^{-01}	59	na	na	na	0
BUSM	2.57×10^{-04}	1.26×10^{-05}	1.06×10^{-01}	52	na	na	na	0
LRSS	1.02×10^{-04}	8.59×10^{-06}	8.29×10^{-03}	95	1.74×10^{-07}	8.64×10^{-08}	3.51×10^{-07}	2
WWSM	2.48×10^{-04}	8.93×10^{-06}	4.15×10^{-01}	68	2.34×10^{-07}	1.73×10^{-07}	3.17×10^{-07}	2
KBSS	1.33×10^{-04}	1.40×10^{-05}	8.55×10^{-03}	34	4.34×10^{-07}	4.34×10^{-07}	4.34×10^{-07}	1

Arithmetic mean is best for describing 'average' Kh, noting that given the range in K over several orders of magnitude, average Log10 K is reported.

Hydraulic conductivity versus depth is presented in **Figure 36** (horizontal) and **Figure 37** (vertical). Both figures demonstrate that there is an overall decreasing trend of hydraulic conductivity with depth. **Figure 36** shows that Kh decreases with depth both overall (pre- and post-mining) and for each formation. **Figure 37** shows that Kv decreases with depth overall, however there is insufficient data to assess this trend for formations other than the Hawkesbury Sandstone and Bald Hill Claystone. Decreasing hydraulic conductivity with depth is expected due to increasing overburden pressure reducing secondary porosity (essentially fracture or defect aperture) via compression.

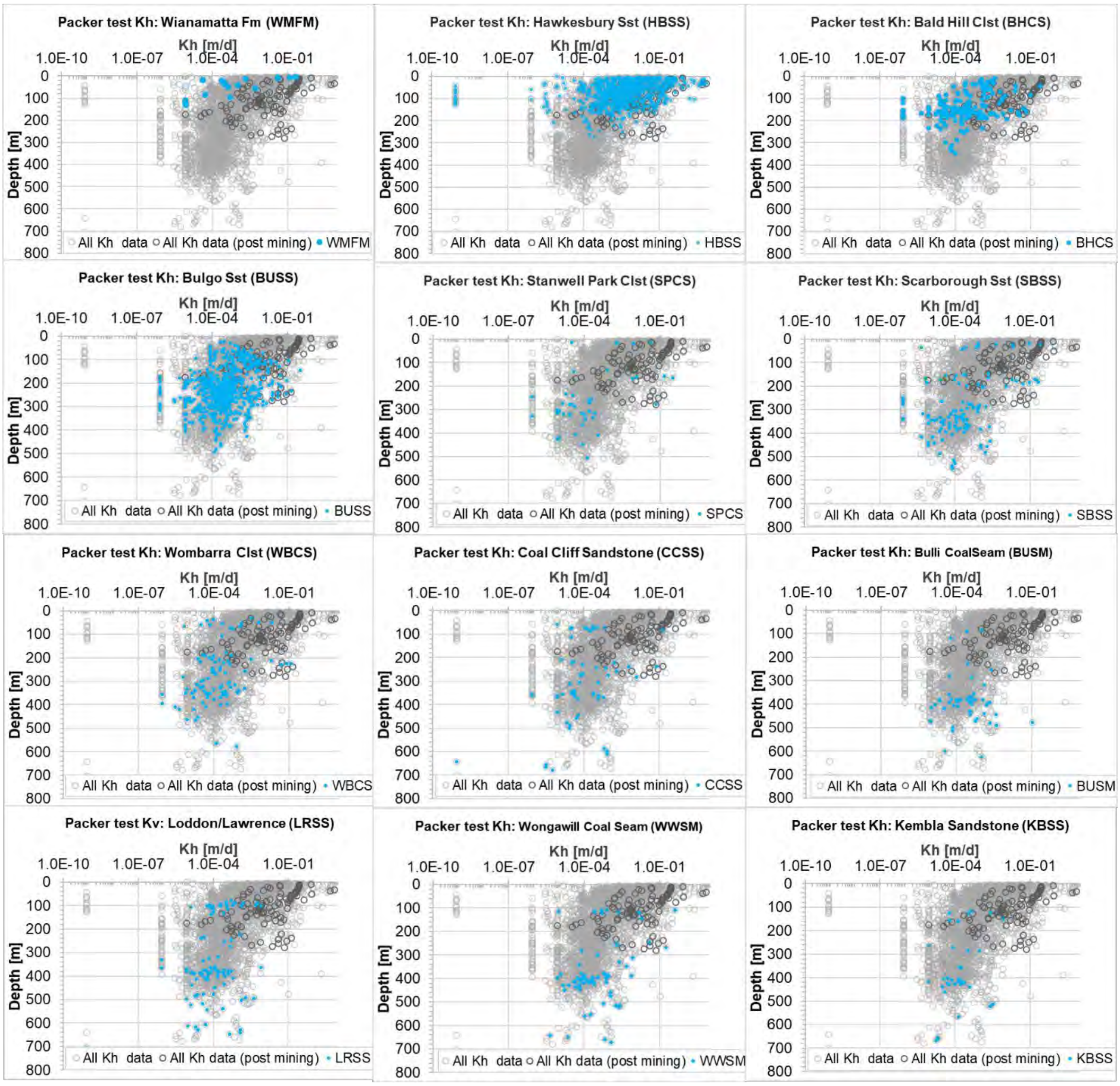


Figure 36 Horizontal hydraulic conductivity vs depth

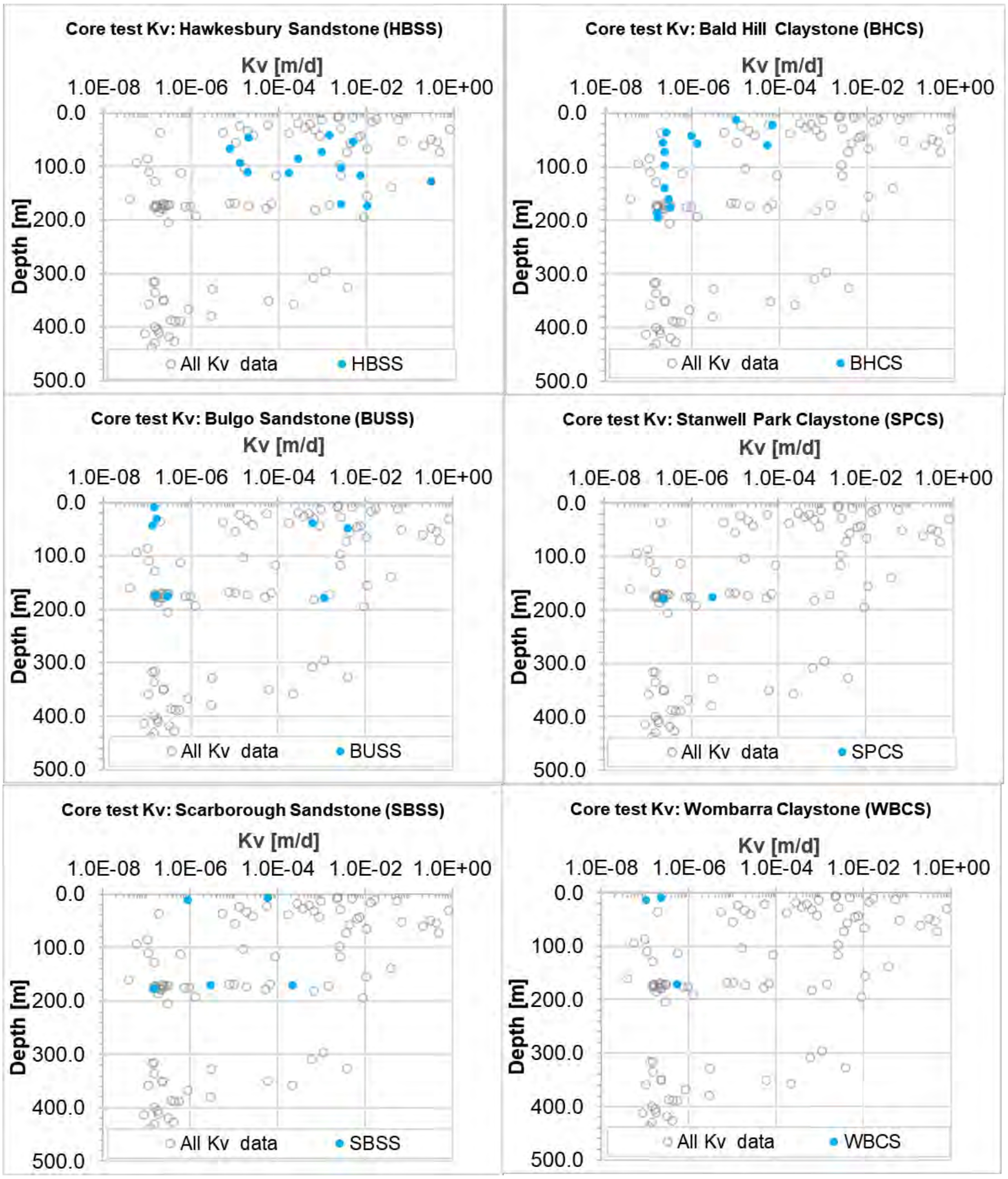


Figure 37 Vertical hydraulic conductivity vs depth

3.5.2 Aquifer Storage Properties (Sy and Ss)

There is currently no field data concerning aquifer storage properties at Appin Mine for specific yield (Sy) or specific storage (Ss), although there is some core testing of porosity at Tahmoor Mine. Groundwater specific storage varies by orders of magnitude, is difficult to quantify, and prone to significant uncertainty (Rau et al, 2018).

HydroSimulations (2020) reports that there are three measurements of total porosity (n) (which would be the highest possible specific yield) available from core tests at bore TBC037 including:

- Two measurements from the HBSS, where n = 5.3% and 11%.
- One measurement from the BHCS, where n = 4%.

Data collected elsewhere in the Sydney Basin provides a Sy estimate of between 1 and 2% for undeformed HBSS (Tammetta and Hewitt, 2004), confirming that Sy is lower than the total porosity stated above. Storage properties are expected to decrease with depth due to a reduction in porosity from overburden pressure.

Alluvium is expected to possess a specific yield in the range of 0.03 to 0.2, i.e. 3-20% (HydroSimulations, 2020).

There is no site-specific data available from Appin mine to estimate specific storage. Results of long duration pump testing in Hawkesbury Sandstone in western Sydney (Tammetta and Hawkes, 2009) indicated an average specific storage of 1.5×10^{-6} m^{-1} for depths between ground surface and 300 m.

Estimates of specific storage can also be made based on Young's Modulus and porosity, based on calculations in Mackie (2009). Calculations for this site suggest that for coal, Ss generally lies in the range 5×10^{-6} m^{-1} to 5×10^{-5} m^{-1}, and interburden from 1.7×10^{-6} (unfractured, fresh rock) to 8×10^{-6} (fractured rock). These values are consistent with the appropriate range of Ss stated by Rau et al (2018).

3.6 Fracturing and Deformation Associated with Longwall Mining

3.6.1 Conceptual Model of Strata Deformation

As longwall mining progresses through the coal seam, the removal of a panel of coal subsequently results in the overburden caving into the void, resulting in stresses propagating upward, and outward, through the overlying strata. Fracturing and deformation of these strata can perpetuate impacts, from very large to no change, in the hydraulic conductivity (permeability) and aquifer storage properties of this overburden. Fracturing of the overburden can cause significant changes in aquifer characteristics such as hydraulic conductivity and secondary porosity (storage), and potentially can provide pathways for vertical groundwater movement between shallow groundwater and surface water systems and underground mines.

Forster and Enever (1992) carried out studies at NSW mines that used both pillar and longwall extraction methods. They developed a conceptual model to describe a sequence of deformational zones that exists above the longwall extraction areas. The conceptual zones presented in **Figure 38** are:

- the caved zone: located immediately above the mining interval and is composed of loose blocks that have collapsed from the roof once the longwall has progressed. Upward migration is limited by bulking of the collapsed loose rocks occupying a greater volume than solid rock;

- the fractured zone: this zone contains disturbed units supported by the underlying caved zone. These units have sagged downwards, undergoing bending, fracturing, joint opening, and bed separation. The fractured zone is based on hydrogeologic response with increased permeability in both the vertical direction (e.g. connected vertical fracturing) and horizontal direction (e.g. bed separation) consisting of a lower zone of connective-cracking and an upper zone of disconnected-cracking.
- the constrained zone: the constrained zone is comprised of the units overlying the fractured zone that have sagged but have absorbed most of the strain energy without significant fracture or change to hydrogeologic properties. Some slippages disconnected vertical fracturing and bed separation can be present. This zone is seen to be the most important in the maintenance of hydraulic pressures in overlying units and can form an effective barrier to vertical drainage.
- the surface (cracking) zone: subsidence resulting from longwall extraction causes tensile and compressive strain in the unconfined units at the surface, which may result in surface cracking or ground heaving. Overburden soil and rock may absorb these strains without observable effect.

More recent work by Ditton (2013) divided the strata deformation profile above longwalls to five zones of strata deformation. These zones are shown as Zones A to D, in **Figure 39**. The definition of Zone A and D by Ditton (2014) are consistent with the fractured zone and the surface cracking zone in the Forster and Enever (1992) conceptualisation. Ditton (2013) split the constrained zone to two separate zones:

- Zone B: Discontinuous cracking (dilated bedding and constrained): Minor vertical cracking due to bending that do not extend through strata units. Increased bedding parting dilation and similar groundwater response to Zone C.
- Zone C: Elastic Deformation Zone (dilated bedding and constrained): Generally unaffected by strains with some bedding parting dilation. Horizontal strains constrained by overlying/underlying strata. Groundwater levels may be lowered temporarily due to new storage volume in voids between beds, but likely to recover at a rate dependent on climate.

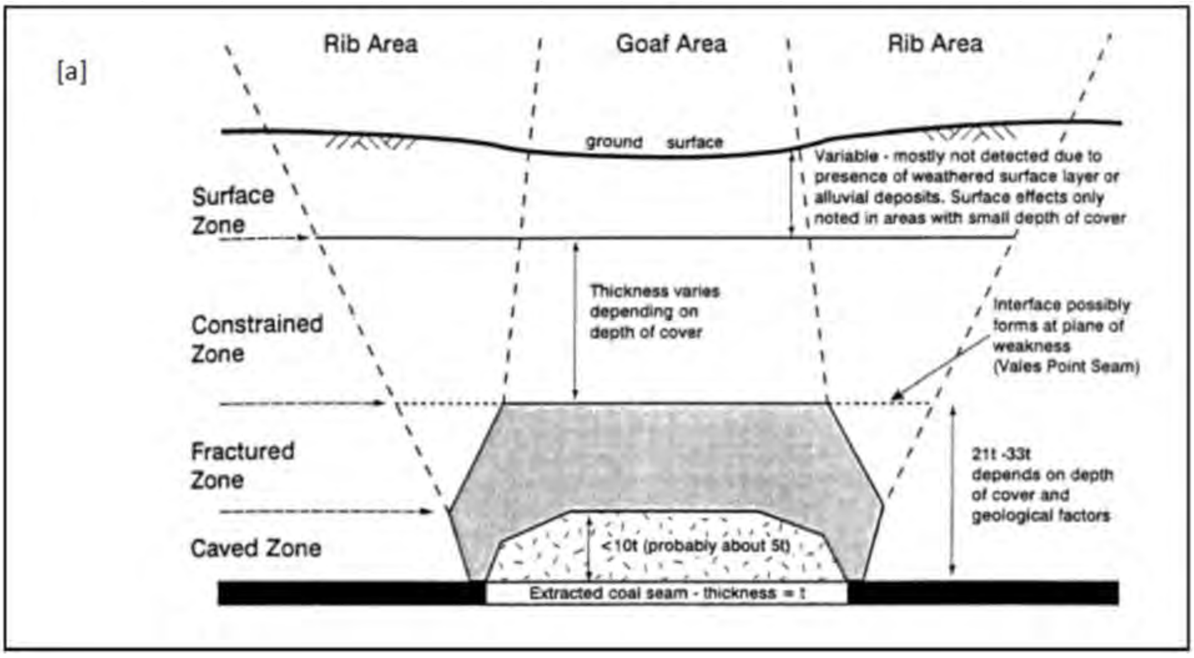


Figure 38 Conceptual Model Based on Forster and Enever (1992) of Longwall Mining-Induced Rock Deformation

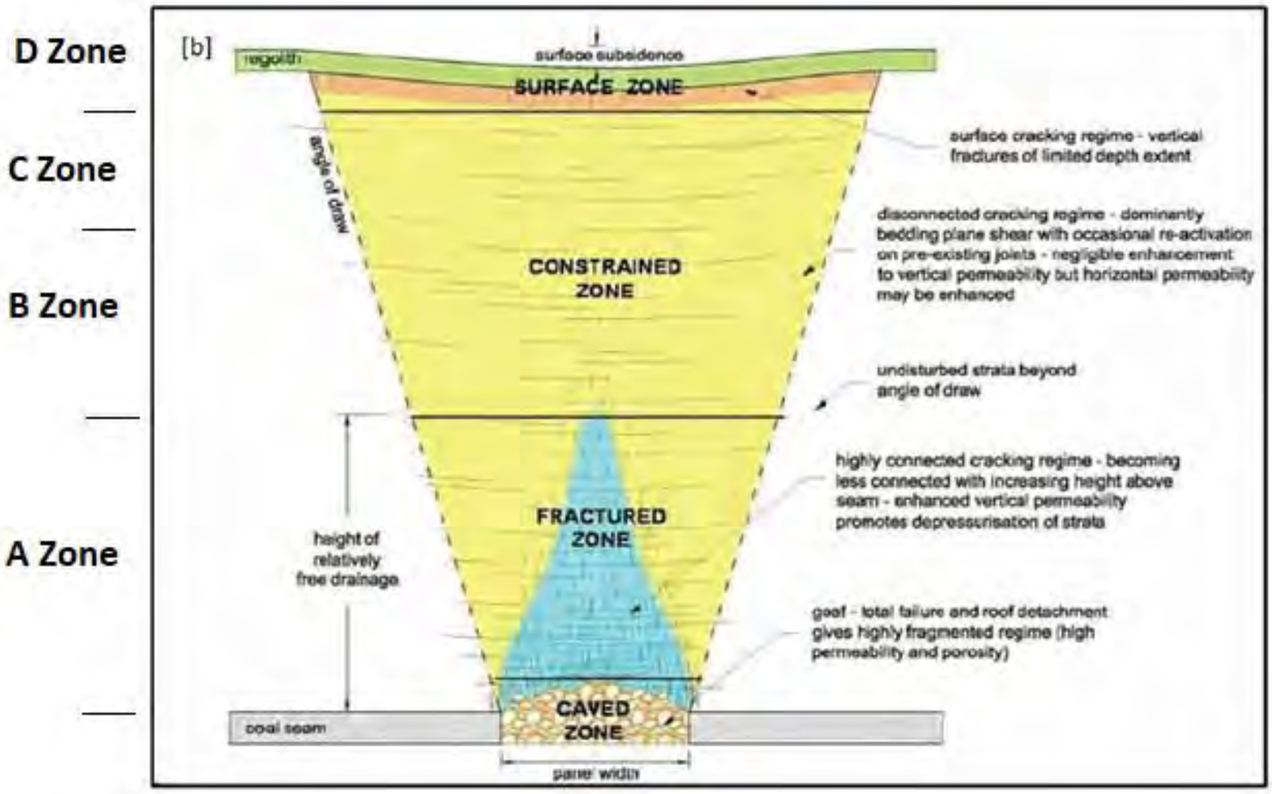


Figure 39 Conceptual Model by Ditton (2013) of Longwall Mining-Induced Rock Deformation (Department of Planning, 2008)

There are a number of empirically based equations developed for the purpose of calculating the height of fractured zone and/or the zone of complete groundwater depressurisation. In Australia, two of these equations or models are used most frequently:

- the Tammetta Equation (Tammetta, 2013) based on a groundwater depressurisation approach and,
- the Ditton Equation (Ditton and Merrick, 2014), based on a geotechnical approach.

The methods calculate the height of their conceptualised disturbance zones (Ditton) or height of depressurisation (Tammetta) based on panel width, thickness of overlaying overburden and the seam extraction height. Depending on the physical property and the location of the longwalls, the two methods can result in similar or very different estimation of fracture height.

The maximum height of the depressurised zone (i.e., the height of the collapsed strata) can be estimated from the Tammetta (2013) method:

$$A = 1438 \ln [(4.315 \times 10^{-5}) H^{0.2} T^{1.4} W + 0.9818] + 26) \quad (1)$$

where in Equation 1, *A* is the height of fracturing (m), *W* is width of the panel, *T* is the extraction height and *H* is the overburden thickness above the longwall panel. Due to the nature of the Tammetta algorithm which uses a power law (exponent of 1.4), the estimated fracture height using this method is highly sensitive to extraction height. A small increase in extraction height results in significant increase in estimated fracture zone height. Therefore, in general, the Tammetta equation tends to predict higher fractured height and is considered more conservative.

Unlike the Tammetta equation, the Ditton (2014) equation provides an estimate of the height of both the A-zone (connected cracking) and the B-zone (disconnected cracking). Ditton (2014) Formula offered for the model is referred to as the Geology Model, which depends on W, H, T and t' (where t' is the 'beam thickness' of the strata inferred to be located above where the A Zone height occurs). The Geology Model formula for fractured zone height (A) and disconnected cracking (B) is:

$$A = 1.52\, W'^{0.4}\, H^{0.535}\, T^{0.464}\, t'^{0.4} \;\; +/- \; aW' \quad (2)$$

$$B = 1.873\, W'^{0.205}\, H^{0.635}\, T^{0.257}\, t'^{-0.097} \; +/- \; bW' \quad (3)$$

Where *T* is the extraction height, *H* is the overburden thickness above the longwall panel, *W*' is the minimum of the panel width (*W*) and the critical panel width (1.4 H). *a* varies from 0.1 for supercritical panels to 0.15 to give 95th percentile (maximum) A-zone heights. *b* varies from 0.1 for supercritical panels to 0.15 to give 95th percentile (maximum) B-zone heights.

Ditton notes that 't' is the most difficult of the parameters to assess, as the strata units may 'break down' into thinner units during subsidence development. The assignment of the appropriate value therefore requires engineering judgement and analysis that includes a review of borehole logs and rock mass properties with extensometer and piezometer data (if available)". A study by Ditton and Merrick (2014) on longwall mines in the NSW coalfields indicated that t'=15 m to 20 m is considered appropriate for the Southern Coalfield (Ditton, 2014). A summary of the results from Ditton (2014) are shown in **Table 10**. The 2014 study considered t'=10 as an extreme value (i.e., worst case scenario). Given that the depth of cover above the Appin longwalls varies between 450 and 750 m, t'=20 (which is a mid-range estimate) is considered to be an appropriate value to be adopted for the Appin mine.

Ditton (2013) states the term 'Upper 95% Confidence Limit' (U95%CL) infer that the predicted maximum subsidence effect values may be exceeded by 50% and 5% of the observations above the mined panels respectively. Therefore, on a small number of occasions, the predicted values and impacts may be exceeded due to the presence of adverse or anomalous geological or topographical conditions.

Table 10 Recommended Values for Effective Thickness of the Strata (t') for Longwall Mines in the NSW Coalfields (Ditton and Merrick, 2014)

Coalfield (NSW)	Normal Condition t' (m)	Adverse Condition t'
Southern	40-20	15
Western	30-20	10
Newcastle	20-15	10
Hunter	20-15	10
Gunnedah	20-15	10

Figure 40 compares the estimated height of depressurisation using Tammetta (2013) against the height of connected fracture zone using Ditton and Merrick (2014) for Appin Mine. As shown in **Figure 40**, at the Appin Area 7 and Area 9 where the extraction height is between 2.9 to 3.2 m, the Tammetta equation estimates greater heights compared to the Ditton (A 95%) model but the difference in estimated fractured or depressurised height for the two models is less than 50 m. It should be noted t'=20 was adopted in the calculations of fractured height using the Ditton method. A shown in **Figure 40**, using the Ditton A95 model, the calculated height of the fractured zone above Appin Area 7 and Area 9 longwalls varies between 240 and 320 m.

As discussed in the IEPMC report (2019), there is no evidence which method is more suitable for predicting the height of the fractured zone. Where site measurements are available, they should be used to determine which formulation is more suitable to estimate the height of the fractured or depressurised zone. There are no site measurements of the fractured height at Appin. However, SCT carried out drilling above Longwall 10A (TBF040) at Tahmoor Mine in 2014. Post-mining borehole TBF040 drilled at Tahmoor mine had a total depth of almost 243.9 m, terminating almost 50 m into the upper Bulgo Sandstone. Core logging from TBF040 showed a general trend of increasing defect frequency with depth from about 70 m to the bottom of the hole, as well as occurrences of 'borehole breakout' from 75-80 m depth. Borehole breakout is a sign of stress and SCT interpreted this location as the height to which mining-induced fractures occur above the mined seam (SCT, 2014).

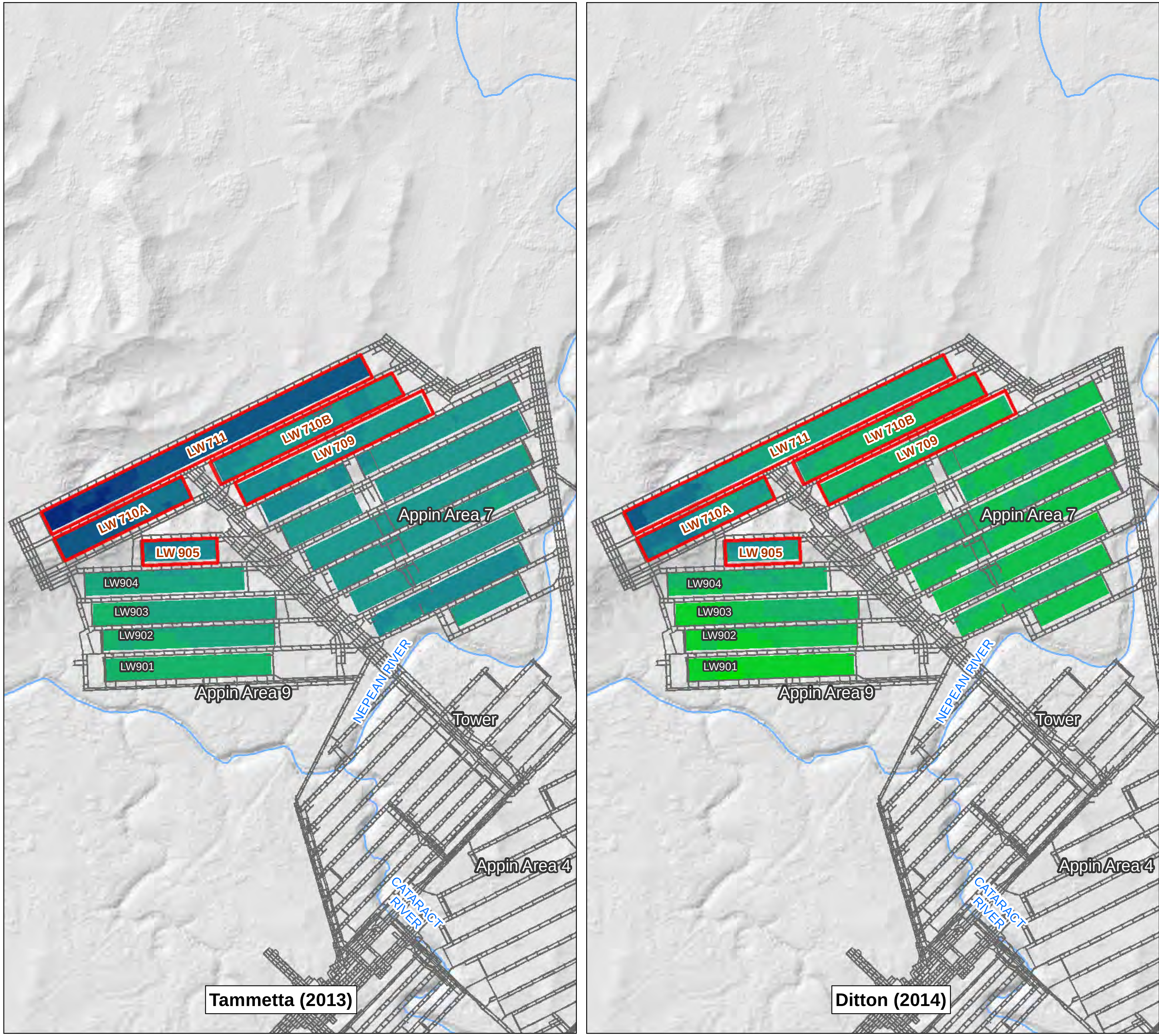
Figure 41 shows a summary of SCT (2014) work on the fractured zone in TBF040. SCT (2014) stated that the observed and inferred drawdown in TBF040 is consistent with the approach suggested by Tammetta (2013). **Figure 41** shows the observed fractured zone height is also consistent with the estimation from Ditton (2014) method.

The combined height of both connected and disconnected cracking from Ditton (2014) results in a greater height of facture zone compared to Tammetta's formulation (2013). To understand the sensitivity of the model predictions to the height of the fracture zone, a sensitivity analysis was carried out where the depressurisation was simulated using the Tammetta (2013) method. The results from this sensitivity analysis are presented in **Section 5** of this report.

APPIN MINE GROUNDWATER ASSESSMENT

ESTIMATED HEIGHT OF CONNECTED FRACTURE ZONE

FIGURE 40



Watercourse

Mine Plan

Project

Fracture Zone Height (m)

240 - 250
250 - 260
260 - 270
270 - 280
280 - 290
290 - 300
300 - 310
310 - 320
320 - 330
330 - 340
340 - 350

0 1 2 km

Coordinate System:	GDA 1994 MGA Zone 56
Scale:	1:65,000 at A4
Project Number:	665.10015
Date:	07-Sep-2022
Drawn by:	JG
Reviewed by:	DE/SH

SLR

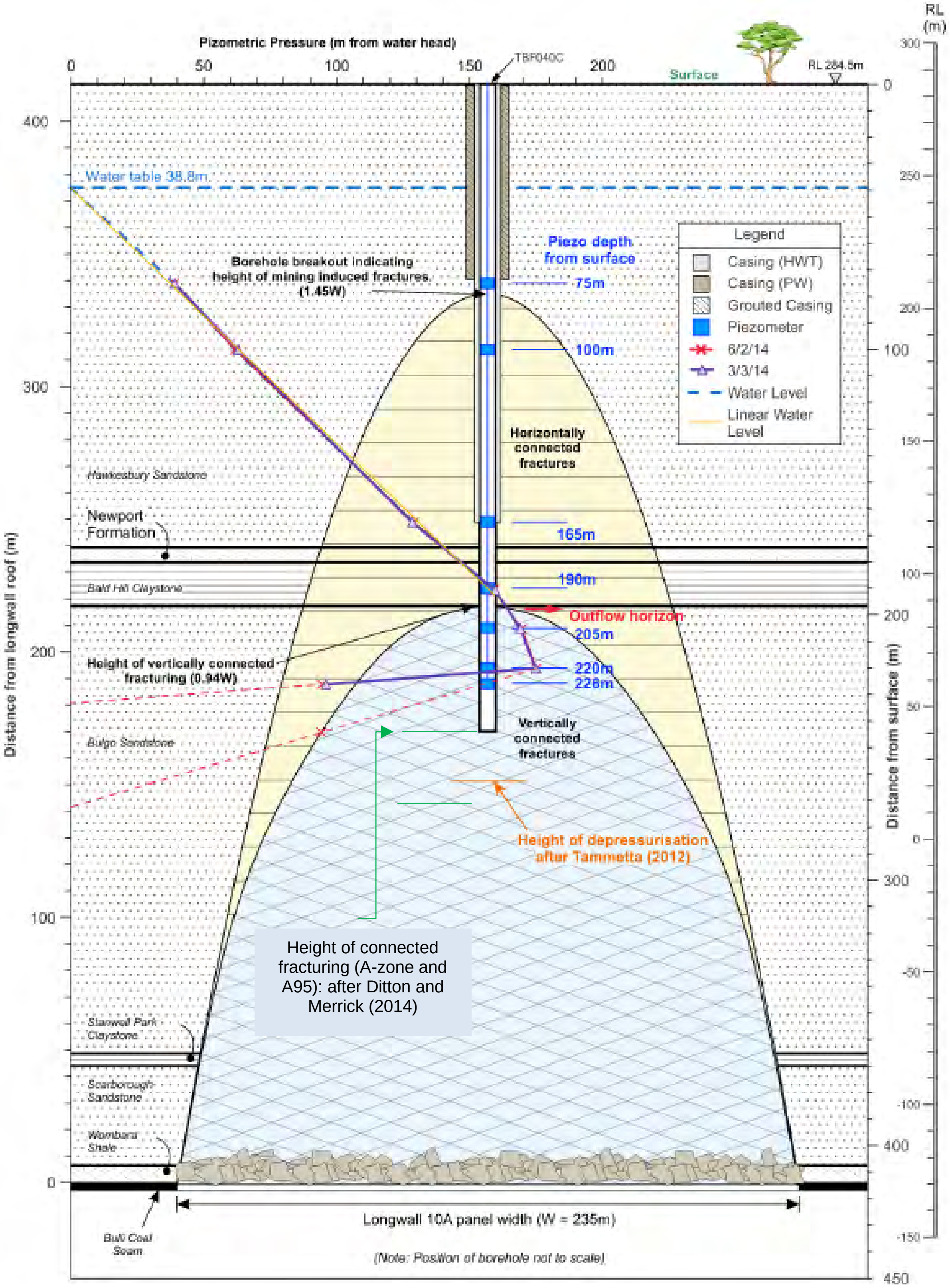


Figure 41 Profile with piezometric and geotechnical observations from TBF040 (SCT, 2014)

(Figure slightly modified original by SLR, re: Ditton and Merrick A-zone)

3.6.2 Mine Subsidence

Above Longwalls 709 to 711 and 905 in the Bulli Seam, the depth of cover is between 450 m to 750 m. Potential subsidence impacts to the creeks and watercourses directly above and adjacent to longwalls have been assessed by MSEC (2021). MSEC (2021) found localised ponding could develop in some isolated locations due to subsidence related tilt. However, there are no predicted reversals of stream grade due to the Project, and no large-scale adverse changes in levels of ponding or scouring of banks along creeks due to subsidence related tilt.

Based on the experience of mining beneath ephemeral creeks and tributaries in the Southern Coalfield, it is likely that some fracturing will occur along the streams within the Study Area, particularly those located directly above or adjacent to the mining area. Some standing pools could experience a reduction or loss of water holding capacity. Fracturing will predominately occur where the creeks and tributaries are located directly above the mining area. Impacts can also occur outside the mining area, with minor and isolated fracturing occurring at distances up to approximately 400 m outside the longwalls, as previously observed at Appin Mine and elsewhere in the Southern Coalfield. The mining-induced compression due to valley closure effects can also result in dilation and the development of bed separation in the topmost bedrock, as it is less confined. This additional dilation due to valley closure is expected to develop predominately within the top 10 m to 20 m of the bedrock. Compression can also result in buckling of the topmost bedrock resulting in heaving in the overlying surface soils.

The maximum predicted total vertical subsidence for the existing, approved, and proposed longwalls is 1,550 mm and maximum predicted total tilt is 8 mm (MSEC 2021). The maximum predicted subsidence effects on the Nepean River due to the Project is less than 20 mm vertical subsidence, upsidence and closure (MSEC, 2021). The maximum predicted subsidence effects on the third order creeks (i.e. Navigation, Foot Onslow and Harris) is 1,400 mm vertical subsidence, 525 mm upsidence and 800 mm total closure.

3.7 Rainfall recharge

Estimates of rainfall recharge have been made by others in the southern coalfields. These have been summarised in **Table 11**. These estimates are usually expressed in % of long-term annual rainfall. The method of analysis, when noted in the references, has been included in **Table 11**.

Table 11 Summary of Recharge Estimates

Reference	Analysis Method	Recharge
		% long-term annual rainfall
URS, 2007	Water table fluctuation	3 – 10%
DPI, 2011	unknown	6%
Coffey, 2012a, b	Baseflow separation, water table fluctuation	2.7 or 6%
Pells, 2013	unknown	5%
Crosbie, 2015	Chloride mass balance in shallow groundwater	3 – 8.5%
HS, 2016b	Chloride mass balance, baseflow separation, water table fluctuation	6.5 %
EMM, 2015	Sydney basin-wide estimate, based on review of Crosbie modelling assessments.	5% Triassic
		1% Permian

Reference	Analysis Method	Recharge
		% long-term annual rainfall
BoM, 2016	AWRA-L model results (2005-2018) for (5x5 km) model cell at Lat -24.19, Long 150.71	6.9%

Rainfall recharge estimates vary between 1% and 10 %. Recharge to swamps is expected to be higher. Swamps are composed of unconsolidated sands, silts, clays and organic matter. As such they behave as “sponges” during drier spells and accept more water during rainfall periods. It is estimated that swamps would accept more rainfall than the hard-rock outcrop areas.

3.8 Conceptual Groundwater Model

The primary hydrostratigraphic units within the Appin Mine area are:

- Quaternary alluvium – localised along rivers and creeks, likely unconfined and recharged from rainfall and surface water flow. Discharge to surface water (baseflow contributions) possible where gradients enable this, with potential for downward seepage where unconformably overlies HBSS. Groundwater flow likely follows topography and streamflow direction towards the north;
- HBSS – main groundwater source and widely accessed for groundwater supply and provides baseflow contributions where incised along major rivers (i.e. Cataract River, Nepean River and Georges River). Groundwater flow generally in a northerly direction, and locally influenced where intersected by rivers and private abstraction bores;
- Narrabeen Group – sandstones that can be used for groundwater supply, and low permeability claystones that generally act as aquitards; and
- Illawarra Coal Measures – groundwater occurrence largely associated with the more permeable coal seams, with semi-confined to confined groundwater conditions. Groundwater flow generally in a northerly direction, and locally depressurised due to current and historical mining and CSG.

Appin conceptual groundwater cross section is presented in **Figure 42**. As shown in the figure, recharge to the groundwater system is from rainfall and from lateral groundwater flow at the boundaries of the study area. Although groundwater levels are sustained by rainfall infiltration, they are controlled by topography, geology, and surface water levels. A local groundwater mound develops beneath hills with ultimate discharge to incised creeks and water bodies, and loss by evapotranspiration through vegetation where the water table is within a few metres of the ground surface within upland swamps and outcropping sandstone/shales.

Major rivers in the area include the Nepean River, Cataract River, Stonequarry Creek and Georges River. During short events of high surface flow, streams can lose water to the aquifers that host the streams, but during recession the aquifer will discharge water slowly back into the stream from bank storage. In gaining streams, baseflow is caused by slow drainage of groundwater from the surrounding rock strata or alluvium. Groundwater also discharges naturally to cliff faces and ultimately to the sea, east of the Project area. In places where historical mining has occurred, groundwater discharge is expected to occur to the mined seam from above and below in proportion to local permeabilities.

Stream beds can experience cracking in response to subsidence to a depth of 10-20 metres. There will be no loss of shallow water to a deep mine because there will be no continuity of fractures from the surface to the mine. There will be diversion of a portion of surface water flows through the rock fractures beneath the stream bed, which will move as underflow through the aquifer immediately beneath the stream, with emergence further downstream.

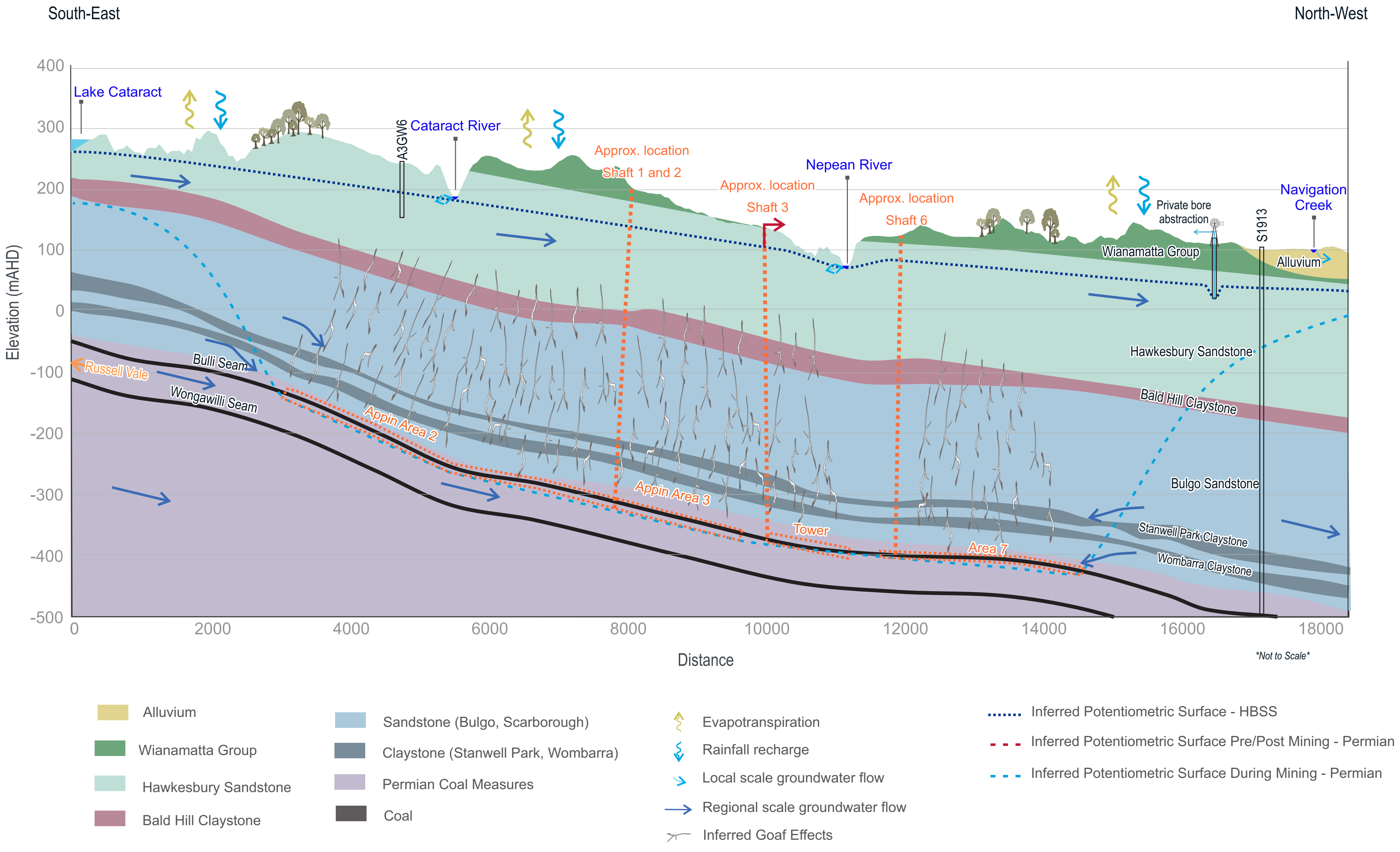
The Appin Mine intersects the Bulli Seam, which ranges from 450 m to 750 m below surface at the Project, and generally dips in a north-westerly direction. With mine progression at Appin, the hydraulic properties of the stratigraphy overlying the Bulli Seam is changed due to goaf effects from longwall mining. There is no site-specific data on the in-situ post-mining hydraulic properties for Appin, but extensive data for surrounding mines (Dendrobium and Tahmoor) indicates the goaf and fractured zone can result in an enhanced permeability of 2 to 3 orders of magnitude, depending on the strata (Watershed HydroGeo, 2020).

Within overlying stratigraphy, not impacted by goaf effects, the influence from depressurisation of the mined coal seam is limited by the low vertical conductivity and the presence of low permeability claystones that can act as aquitards (i.e. Bald Hill Claystone).

Current groundwater levels indicate depressurisation within the Bulli Seam extends approximately 1 km to 2 km from active mine areas, consistent with previously assessed impacts for the BSO (Heritage Computing 2009). Current monitoring data also shows depressurisation within the Scarborough Sandstone and Bulgo Sandstone due to mining and within the Scarborough Sandstone due to CSG activities (Camden Gas Project). Drawdown within the Scarborough Sandstone, Bulgo Sandstone and lower HBSS was previously predicted for BSO (Heritage Computing, 2009).

Regionally, there is depressurisation or drawdown observed within the HBSS in response to mining or landowner pumping as well as the response to climate. The groundwater levels in landholder bore GW106574, located above Appin Area 7 Longwall 709, shows decline since September 2020 with approximately 10 m depressurisation in HBSS. This decline is likely an impact from the longwall mining activities.

South32 Illawarra Coal post-mining inspection report (South32, 2019) indicates that longwall mining activities had a likely impact on the bore GW072249 yield.



South-East
North-West
Lake Cataract
Cataract River
A3GW6
Approx. location
Shaft 1 and 2
Nepean River
Approx. location
Shaft 3
Approx. location
Shaft 6
Private bore
abstraction
S1913
Navigation
Creek
Wianamatta Group
Alluvium
Hawkesbury Sandstone
Bald Hill Claystone
Bulgo Sandstone
Stanwell Park Claystone
Wombarra Claystone
Russell Vale
Bulli Seam
Wongawilli Seam
Appin Area 2
Appin Area 3
Tower
Area 7
Elevation (mAHD)
400
300
200
100
0
-100
-200
-300
-400
-500
0
2000
4000
6000
8000
10000
12000
14000
16000
18000
Distance
Not to Scale
Alluvium
Wianamatta Group
Hawkesbury Sandstone
Bald Hill Claystone
Sandstone (Bulgo, Scarborough)
Claystone (Stanwell Park, Wombarra)
Permian Coal Measures
Coal
Evapotranspiration
Rainfall recharge
Local scale groundwater flow
Regional scale groundwater flow
Inferred Goaf Effects
Inferred Potentiometric Surface - HBSS
Inferred Potentiometric Surface Pre/Post Mining - Permian
Inferred Potentiometric Surface During Mining - Permian

3.8.1 Fracture Profile Conceptual Model adopted for Appin Mine

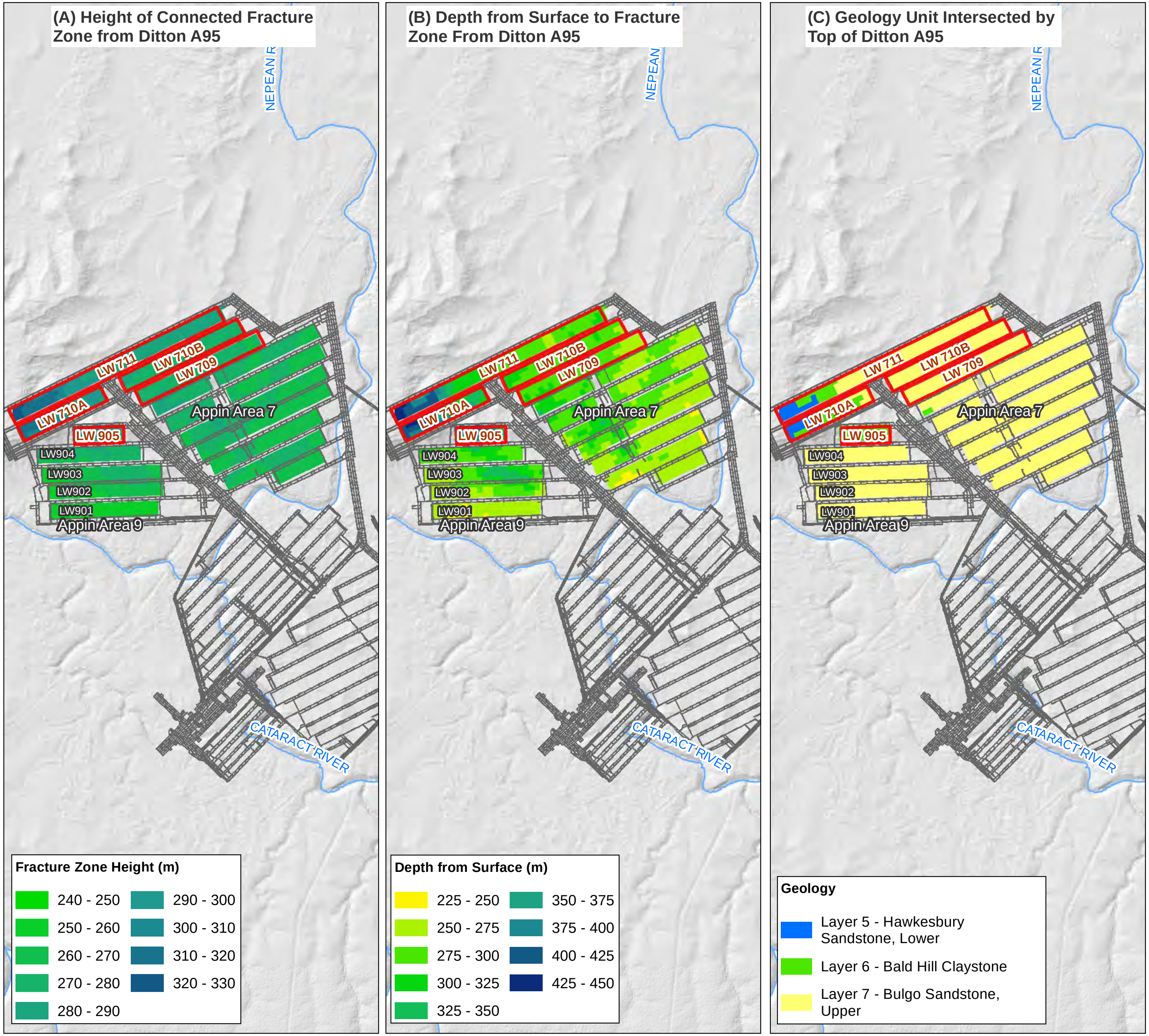
This study has adopted the Ditton geology model due to its inclusion of the height of both connected and disconnected cracking within the conceptual model and algorithm developed by Ditton (2014).

Table 12 lists different zones adopted in the Appin conceptual fracture profile and how the heights are calculated. **Table 12** also discusses how the conceptualisation of the fracture profile was implemented in the groundwater model.

Table 12 Conceptual Fracture Profile Adopted in Appin Model

<table>
<tr><th colspan="2">Conceptual Zone</th><th>Ditton (2014)</th><th>Geometry</th></tr>
<tr><td colspan="2">Surface Fracture Zone
(i.e. surface cracking)</td><td>D-zone</td><td>Depth of increased surface fracturing (due to lower depth of cover/confinement) <=20 m, with enhanced horizontal and vertical hydraulic conductivity.
• 8 x T (extraction height)</td></tr>
<tr><td colspan="2">Constrained Zone</td><td>C-zone</td><td></td></tr>
<tr><td rowspan="2">Fractured Zone</td><td>upper zone of Disconnected Fracturing</td><td>B-zone</td><td>• B95 – Ditton and Merrick (2014).</td></tr>
<tr><td>lower zone of Connected Fracturing</td><td>A-zone</td><td>• A95 – Ditton and Merrick (2014).</td></tr>
<tr><td colspan="2">Caved Zone</td><td rowspan="2"></td><td>• 5-10 x t (Forster & Enever, 1992; Guo et al., 2007).</td></tr>
<tr><td colspan="2">Mined Zone (extracted seam)</td><td>Mined seam thickness (t)</td></tr>
</table>

Figure 43 shows the calculated height of connected cracking zone using Ditton A95 model, the vertical distance between the top of the connected fracture zone and ground surface, and the strata unit that connected fracture zone is inferred to intersect. As shown in **Figure 43,** the connected fracturing above Appin Area 7 and Area 9 is estimated to occur mainly up to and within the Bulgo Sandstone. However, within the southwestern parts of Longwalls Longwall 711 and Longwall 710A, there is an increased likelihood of connected fracturing extending into the Bald Hill Claystone and HBSS. The vertical distance between the top of the connected fractured zone and the ground surface is over 240 m in Appin Area 7 and Area 9. Therefore, it is unlikely that connected fracturing above the seams extends to the surface.



APPIN MINE GROUNDWATER ASSESSMENT

CONNECTED FRACTURE ZONE

FIGURE 43

Watercourse

Mine Plan

Project Area

0 1 2 km

Coordinate System:	GDA 1994 MGA Zone 56
Scale:	1:100,000 at A4
Project Number:	665.10015
Date:	07-Sep-2022
Drawn by:	NT
Reviewed by:	AM

Data Source: Mining Lease NSW Mineview Coal Lease 2019

SLR

H:\Projects-SLR\620-BNE\665-WOL\665.10015 Illawarra Coal Closure - Water\CADGIS\ArcGIS\EP Report\665.10015 F42 Ditton A95 height above seam.mxd

4 Groundwater Modelling

4.1 Groundwater Model Setup

This study utilised the SLR (2021) numerical model, which was based on the groundwater model HydroSimulations (2018) and previously based on the Heritage Computing (2009) which was used for the Appin Mine groundwater assessment (Heritage Computing, 2009). The SLR (2020) groundwater model utilises MODFLOW-USG code and was developed in Groundwater Vistas Version 7 (GWVistas 7).

As part of the study, the following updates were undertaken on the SLR (2020) model:

- Extending the model and creating a 3D mesh of Voronoi cells.
- Update model layer elevation to reflect Lidar data (Layer 1).
- Differentiate alluvial materials (Layer 1) from the Wianamatta Group and the weathered HBSS (Layer 2), plus refine thickness of alluvial materials along rivers and across swamp areas.
- Divide the thick groundwater units such as the HBSSs and the Bulgo Sandstones into three separate layers to better accommodate groundwater model targets (i.e. VWP sensors) and to improve the alignment of the height of fracture within the numerical model layers.
- Use the pinch out function in MODFLOW-USG to remove the dummy layers based on geological layers. These features allow the total cell count to be reduced, and the conceptual correctness of the model to be improved.
- Update model timing to quarterly stress periods (SP) to account for seasonal changes and mining schedule.

4.1.1 Model Extent and Mesh Design

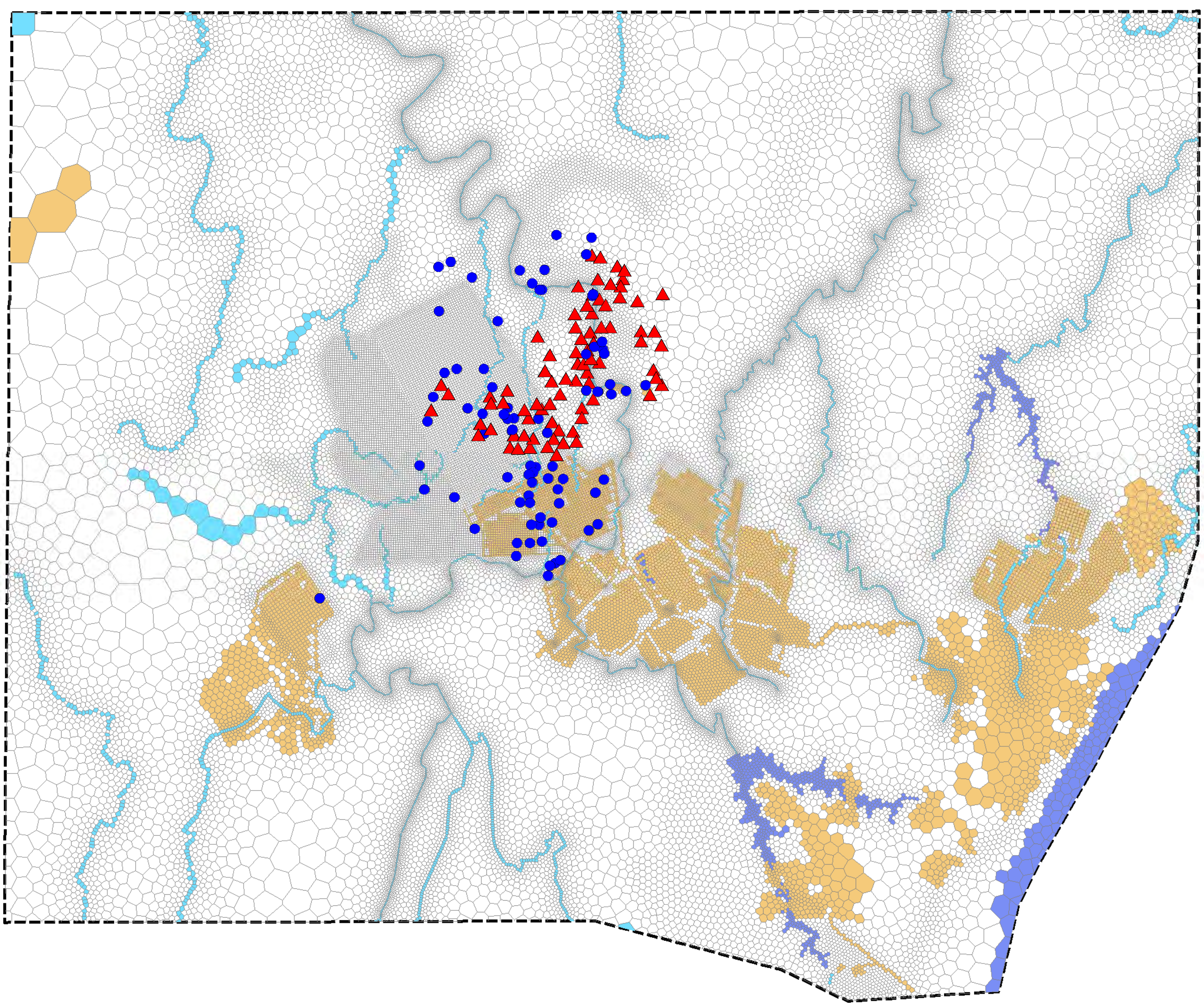
The groundwater model domain is shown in **Figure 44**. The model extends approximately 52 km from west to east and approximately 43 km from north to south, covering an area of approximately 2070 km^2. The groundwater model extent was designed to be large enough to accommodate future mining at Appin Mine and to cover any potential associated impacts.

The HydroAlgorithmics software “AlgoMesh” was used to generate the 3D Voronoi cells grid. The large spatial area of the model extent resulted in the need for an unstructured grid with varying cell sizes, and refinement in the areas of interest, in order to reduce the total cell count to a manageable size. The mesh over the whole model extent is shown in **Figure 44**. The following features have been included in the mesh design:

- A regular (aligned) square grid of cells was enforced in Appin Mine proposed and historical longwall mining after 2009, rotated in line with the longwalls (100 m), and in those of Tahmoor Mine (150 m) and Metropolitan Mine (150 m).
- A regular hexagonal grid of cells was used to refine all historical mining before 2009 with cell size of 200 m in Appin, Metropolitan and Russell Vale Mines and 300 m in Tahmoor.
- Polylines along mapped rivers and creeks were used to ensure the mesh conformed to mapped drainage network, and to enforce variable details along streams (e.g. greater detail along streams closest to Appin Mine). Voronoi cell sizes along rivers and creeks varies from 100 m to 300 m.
- A regular hexagonal grid of cells was used to refine the mesh across the different Appin Mine shafts, with maximum cell size of 50 m.

- The mapped alluvial boundaries present across the model extent were used to enforce finer cell resolution in a range of 200 m and 400 m cell size.
- Escarpment areas were refined by 300 m cell size.
- Regular hexagonal grid of cells was used to refine the mesh across the reservoirs (i.e. Cataract and Woronora) with maximum cell size of 200 m.

The cell count for layer one is 56,110. Over the 18 model layers, with pinch-out areas (where a layer is not present) in layers 2 to 17, the total cell count for the model is 1,009,980.



APPIN MINE
GROUNDWATER ASSESSMENT

MODEL GRID AND BOUNDARY CONDITIONS

FIGURE 44

Extraction Bore
CSG
RIV
DRN
CHD
GRID
Model Extent

Projection: GDA 1994 MGA Zone 56
Scale: 1:230,000 at A4

Project No.: 665.10015
Date: 07-Sep-2022
Drawn by: JG

SLR

H:\Projects-SLR\620-BNE\665-WOL\665.10015 Illawarra Coal Closure - Water\CADGIS\ArcGIS\EP Report\665.10015 F43 Model Grid and Boundary Conditions.mxd

4.1.2 Layers

The groundwater model consists of 18 layers as listed in **Table 13**. Model layer 1 is present across the whole model extent, and includes the Quaternary Alluvium, swamps, Wianamatta Group and HBSS. The Wianamatta Group has been divided across layers 1 and 2 where present. The HBSS has been divided into 5 layers, and the Bulgo Sandstone has been divided into 3 layers to allow vertical gradients through the stratigraphic column to be represented.

The Bulli Seam is represented in layer 15 for the purpose of modelling longwall mining at Appin, Metropolitan, Tahmoor and all other historical mines. The Wongawilli Seam is represented in layer 17 for the purpose of modelling longwall mining at Russell Vale East.

Model layers 2 to 17 are not present across the whole model domain, the layers have been pinched out where the geology has been eroded at outcrop.

Table 13 Groundwater Model Layers

Layer	Geology	Average Thickness (m)	Source
1	Alluvium/ Wianamatta Group / Weathered HBSS	7.4	CSIRO Depth of Regolith, Bore logs
2	Wianamatta Group / Weathered HBSS	34.7	Geo100k, Syd Basin Model, Bore Logs, Site Geo Models
3	Upper HBSS	57.6	Geo100k, Site Geo Models, Syd Basin Model
4	Middle HBSS	53.4	Site Geo Models, Syd Basin Model
5	Lower HBSS	59.2	Site Geo Models, Syd Basin Model
6	Bald Hill Claystone	30.7	Site Geo Models, Syd Basin Model
7	Bulgo Sandstone	62.8	Site Geo Models, Syd Basin Model
8	Bulgo Sandstone	62.2	Site Geo Models, Syd Basin Model
9	Bulgo Sandstone	66.2	Site Geo Models, Syd Basin Model
10	Stanwell Park Claystone	18.7	Site Geo Models, Syd Basin Model
11	Upper Scarborough	14.4	Site Geo Models, Syd Basin Model
12	Lower Scarborough	14.3	Site Geo Models, Syd Basin Model
13	Wombarra Claystone	24.8	Site Geo Models, Syd Basin Model
14	Coal Cliff Sandstone	23.7	Site Geo Models, Syd Basin Model
15	Bulli Coal Seam	2.7	Site Geo Models, Syd Basin Model
16	Loddon Sandstone	24.9	Site Geo Models, Syd Basin Model
17	Wongawilli Seam	2.3	Site Geo Models, Syd Basin Model
18	Lower Permian Coal Measures	200.0	Site Geo Models, Syd Basin Model

4.1.3 Model Timing

The stress period timing in the model was updated to include more temporal detail to better capture seasonal trends in recharge to alluvium and outcrop formations, as well as a better inclusion of the mine schedule into the model. To achieve this, the historical and predictive stages of the model were updated to:

- Steady-state to represent pre-mining conditions and initial heads;
- Transient warm up period from 1 January 1960 to 31 December 2009 with all historical mines within the model area;
- Transient historical period from 1 January 2010 to 30 June 2021 with quarterly stress periods; and
- Transient predictive period from 1 July 2021 to 31 December 2027 (one year after Longwall 711) with quarterly stress periods.

The transient warm-up model period was built to incorporate pre-2009 mining activities and their impacts on groundwater levels around the Project Area. The transient warm up model covered a time from 1960 to December 2009 and included 9 time slices (i.e. stress periods). The first stress period had a length of 10 years and the remaining 8 stress periods had lengths of 5 years. The warm-up model was used to change model cell properties due to the underground mining within the model extent before 2009.

To assist the model in overcoming the numerical difficulties, MODFLOW-USG Adaptive Time-Stepping (ATS) option was used. The ATS option of MODFLOW automatically decreases time-step size when the simulation becomes numerically difficult and increases it when the difficulty passes. The minimum time step size used in the simulations was one day.

MODFLOW-USG Sparse Matrix Solver (SMS) is used. Max head change between outer iterations (HCLOSE) and max head change between inner iterations (HICLOSE) are set to 0.005 m and 0.001 m respectively.

4.1.4 System Stresses

This section presents a summary of the main model inputs to replicate system stresses that were varied as part of this study, including wells, streamflow, recharge and mining.

4.1.4.1 Wells

AGL held 137 bore licences for the Camden Gas Project gas production wells from two Water Access Licences (24856 and 24736) which have a combined allocation of 30 ML per year, with 15 ML allocated to the Sydney Basin Central Groundwater Source and 15 ML allocated to the Sydney Basin Nepean Groundwater Source, and are licensed for industrial purposes (AGL, 2018).

The MODFLOW Well (WELL) package has been used to present these Camden Gas Project production wells to replicate depressurisation within the Bulli Seam (**Figure 44**). Within the model the Camden Gas Project wells commenced operation based on the date of installation and were turned off at 2023 (AGL, 2018).

The WELL package was also used to capture the water take from 83 licensed registered water supply bores within the model domain. Four wells are screened in the Wianamatta Group, one in the Bulgo Sandstone with the remainder screened in the HBSS. The extraction rate has been assumed as 5 ML/year or if unknown the shared component volume. Within the model the wells were started based on information on the drilled date and remain active until the end of model prediction period.

4.1.4.2 Water Storages

Old underground workings at Appin are used for water storage. The measured water levels at water storages were provided by South32. MODFLOW-USG Time variant constant head package (CHD) was used to represent these water levels. **Figure 45** shows the actual water levels measured for underground workings in Area 4 and White Panel compared to modelled levels.

No information was provided on water storage levels for Area 4 and White Panel prior to 2018. Therefore, a simplified approach was adopted where the water levels were set based on the short period of available data, and then extrapolated out for where no data was available as shown in **Figure 45**.

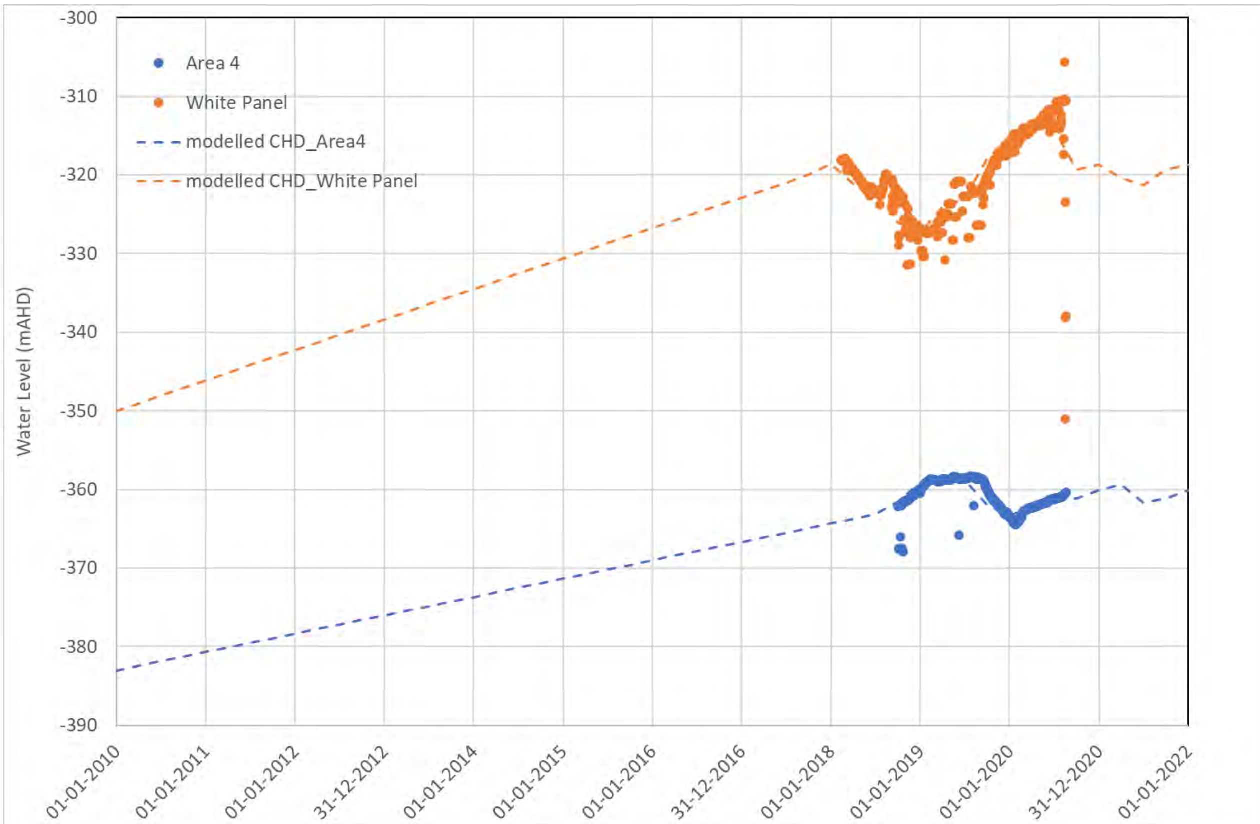


Figure 45 Underground Ponded Water Levels

4.1.4.3 Streamflow

All major watercourses are represented using the MODFLOW River (RIV) package. **Figure 46** shows the modelled versus observed water levels at the three locations. The main streams (Nepean River, Cataract River and Stonequarry Creek) were replicated with a time-variant stage based on the observed levels from the stream gauging stations (212216, 212230 and 212053). Remaining third order streams with no observation data available were modelled with a constant 1 m stage. Fourth order streams/ephemeral drainage lines were represented as 'river' boundary cells in the model, with the stage equal to the base of the riverbed to present the river only gaining water from the groundwater system.

River cells in the model are shown in **Figure 44**. As shown in the figure, major rivers and streams as well as minor creeks were built into the model. The major rivers within and around the Project area included in the RIV package are presented in **Table 14**. River and creek widths were adopted from the SLR (2020) model. The river conductance was calculated using river width, river length, riverbed thickness, and the vertical hydraulic conductivity of river bed material (Kz). Therefore, the river conductance is variable due to the non-constant spatial discretisation in each of the model river cells. The initial values of riverbed vertical hydraulic conductivity (Kz) were adopted from the 2020 model and were not adjusted during the calibration process.

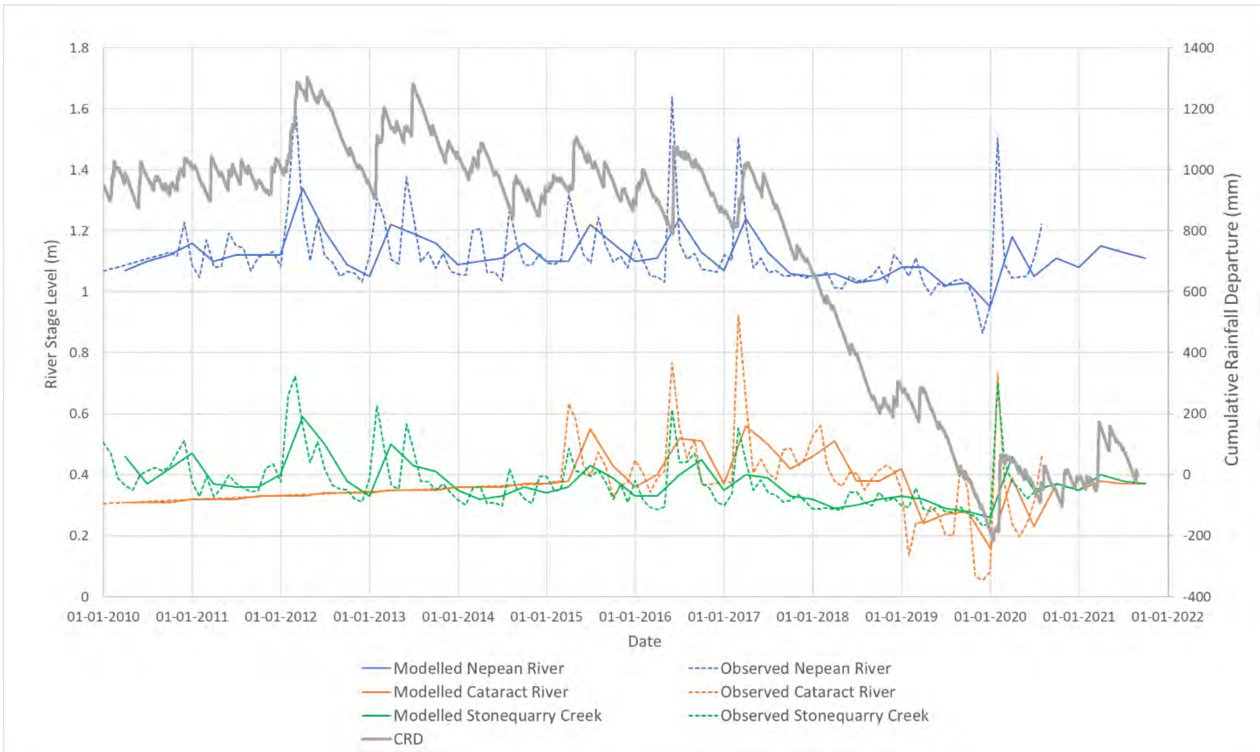


Figure 46 Modelled Stage Levels vs Cumulative Rainfall Departure (CRD)

Table 14 River and Surface Water Features in the Appin Model

Boundary	River Stage (m)	River Bed Kz
Nepean River	- SS simulation - Long-term Average - Calibration simulation - Historical Quarterly Average - Prediction simulation- Transient Stage Height- Long Term Quarterly Average	0.1
Cataract River	- SS simulation - Long-term Average - Calibration simulation - Historical Quarterly Average - Prediction simulation- Transient Stage Height - Long Term Quarterly Average	0.1
Stonequarry Creek	- SS simulation - Long-term Average - Calibration simulation - Historical Quarterly Average - Prediction simulation- Transient Stage Height- Long Term Quarterly Average	0.05
Georges River	- SS simulation - Long-term Average - Calibration simulation - Historical Quarterly Average - Prediction simulation- Transient Stage Height- Long Term Quarterly Average	0.1
Other minor creeks including Navigation Creek, Navigation Creek Tributary 1, Foot Onslow Creek and Harris	- SS simulation - Long-term Average - Calibration simulation - Fixed Stage - Prediction simulation - Fixed Stage	0.001-0.1

4.1.4.4 Recharge and Evapotranspiration

Diffuse rainfall recharge is simulated using the recharge package (RCH). Recharge was distributed in laterally distinct zones within the model domain. In this study, the zones are based on outcropping geology (**Figure 8**) and observed rainfall from multiple rainfall stations. A portion of annual rainfall was assigned to each zone and varied to match historical observed quarterly rainfall. The final calibrated values for the percentage of rainfall is presented in **Table 20**.

For the predictive model, average quarterly rainfall was applied from July 2021 to December 2027. The modelled recharge for alluvium is presented in **Figure 47**.

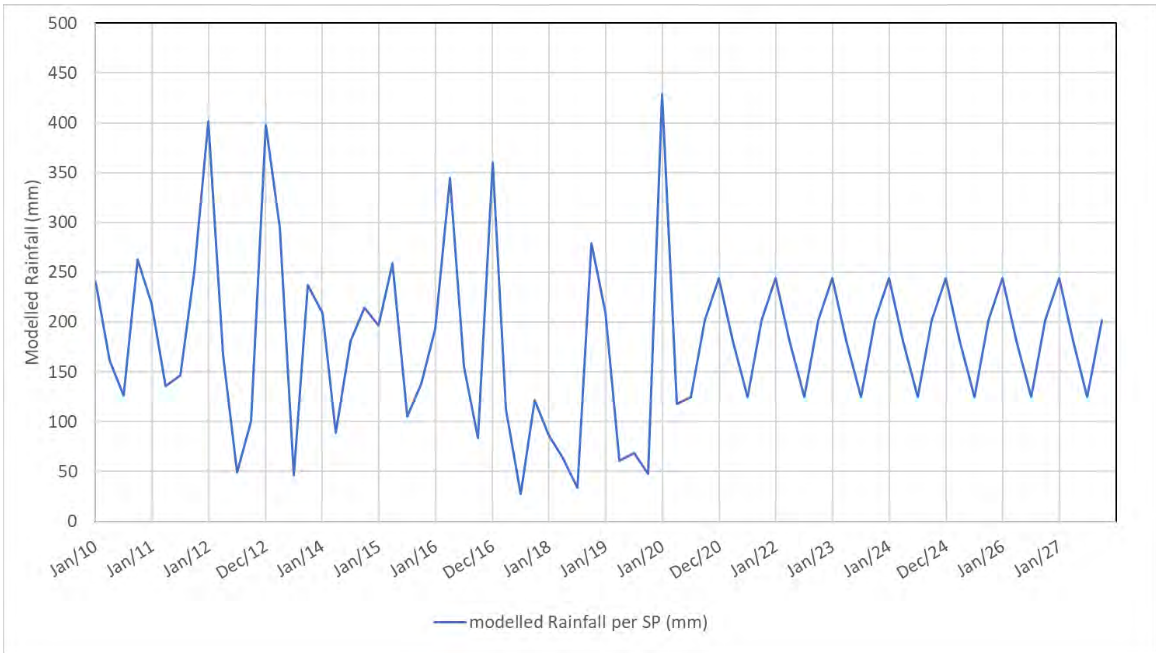


Figure 47 Modelled Rainfall Recharge to Alluvium and Outcrop Formations

Evapotranspiration (ET) from shallow water tables is simulated using the ET package and is represented in the upper most cells of the model domain down to an extinction depth of 3 m. A uniform ET rate of 1.4 mm/day was applied to the model.

4.1.4.5 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.

Longwall extraction drain cells are only applied to the layer representing the mined coal seam. A high drain conductance of 100 m^2/day was applied to the drain cells to simulate the effect of mining. The hydraulic properties were varied with time using the Time-Variant Materials (TVM) package of MODFLOW-USG. For the underground mines, the hydraulic properties were changed with time in the goaf and overlying fractured zone directly above each longwall panel. The DRN and TVM packages were updated for the study to align with the updated model timing.

4.1.5 Variation in Model Hydraulic Properties due to Longwall Mining

As discussed in **Section 3.8.1**, the Ditton method was adopted in this model to represent the fractured zone. Ditton (2014) estimates the height of disconnected fracturing (Zone B) as well as connected fracturing zone. Therefore, simulating Zone A and Zone B combined results in an overall higher fracture zone compared to Tammetta (2013).

The height of connected fracturing was estimated on a cell-by-cell basis using the method of Ditton A95 and the height of disconnected fracturing was estimated on a cell-by-cell basis using Ditton B95.

Figure 48 shows the highest layer in the model for the height of Zone A and Zone B fracturing across the mine area. As shown in **Figure 48**, the connected fracturing primarily reaches Layers 7 of the model (Bulgo Sandstone), except a small area within the south western parts of Longwall 711 and Longwall 710A where connected cracking is modelled to reach Layer 5 (HBSS) and Layer 6 (Bald Hill Claystone). **Figure 48** shows the simulated disconnected fracturing reached Layer 4 and Layer 5 of the model which represent the middle and lower HBSS, respectively.

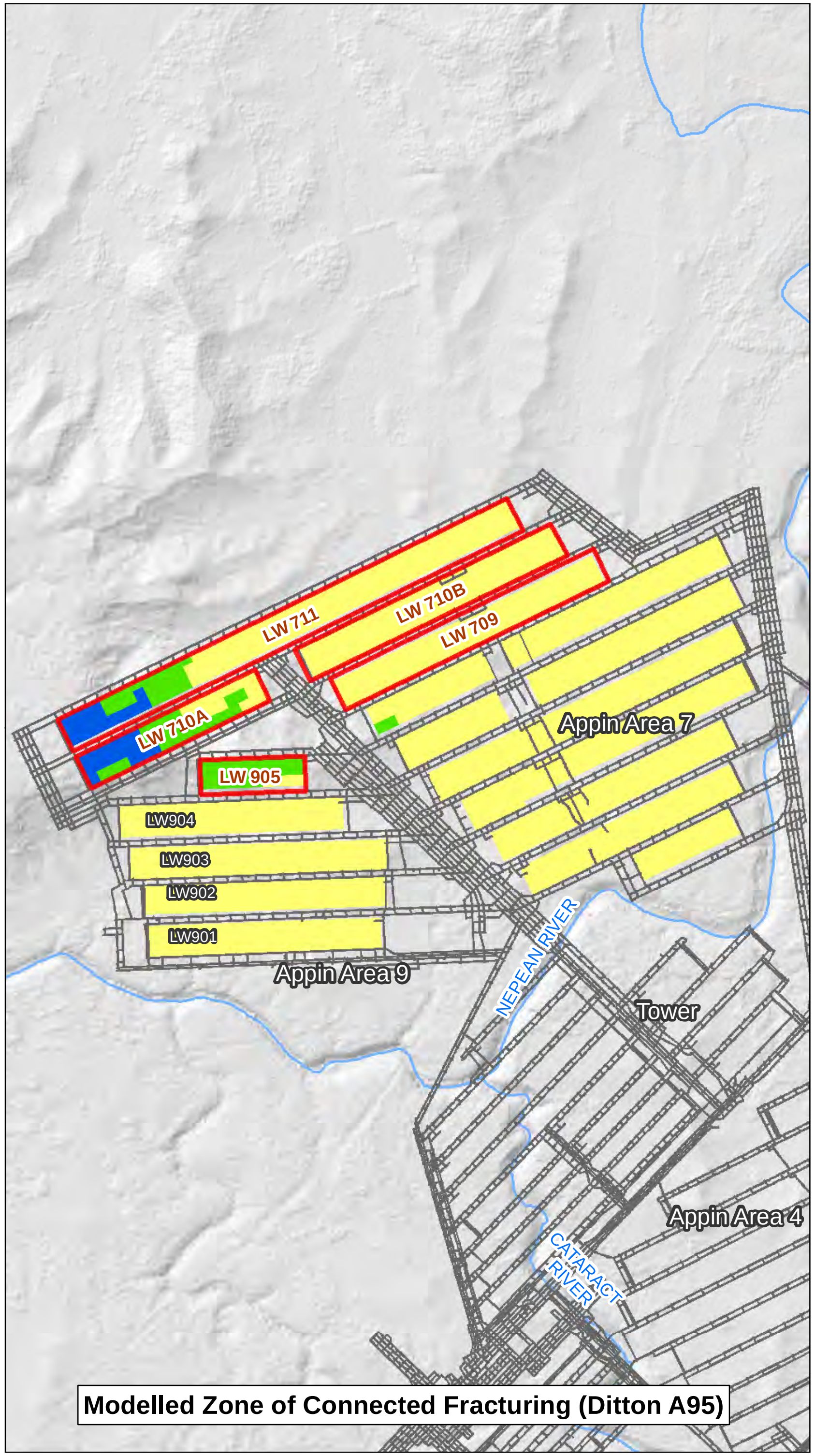
The fracture zones are represented in the groundwater model via an increase in the horizontal and vertical hydraulic conductivity of the model layers above the seam in each extracted longwall panel using the Time-Varying Material properties (TVM) package of MODFLOW-USG-Transport.

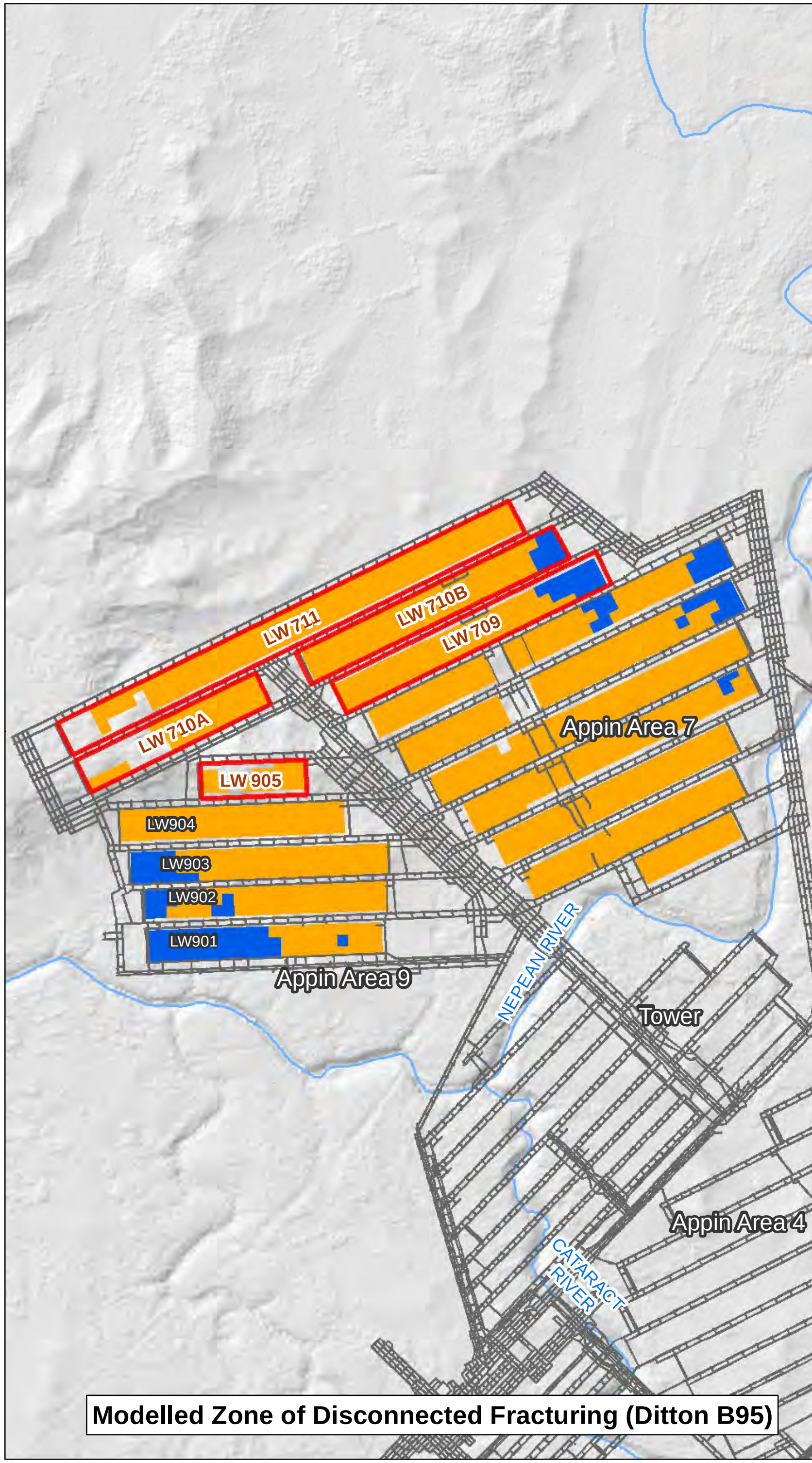
As discussed in **Section 3.8.1**, site-specific measurements of post-mining strata properties in the fracture profile are not available. However, data from boreholes S2398 and S2398A, which were used for pre- and post-mining investigations at Dendrobium Mine, is available (Watershed HydroGeo, 2020). The observed post-mining values at these bores and the Gua (2007) study were used to guide post-mining properties simulated in the groundwater model for Appin Mine.

APPIN MINE GROUNDWATER ASSESSMENT

MODELLED ZONE OF CONNECTED FRACTURING (DITTON A95) AND DISCONNECTED FRACTURING (DITTON B95)

FIGURE 48





Watercourse

Mine Plan

Project

Model Layer Intersected

Layer 4 - Hawkesbury Sandstone, Middle

Layer 5 - Hawkesbury Sandstone, Lower

Layer 6 - Bald Hill Claystone

Layer 7 - Bulgo Sandstone, Upper

0 1 2 km

Coordinate System:	GDA 1994 MGA Zone 56
Scale:	1:65,000 at A4
Project Number:	665.10015
Date:	07-Sep-2022
Drawn by:	NT
Reviewed by:	AM

Data Source: Mining Lease NSW Mineview Coal Lease 2019

H:\Projects-SLR\620-BNE\665-WOL\665.10015 Illawarra Coal Closure - Water\CADGIS\ArcGIS\EP Report\665.10015 F47 Modelled Zone of Connected Fracturing (Ditton A95) and Disconnected Fracturing (Ditton B95).mxd

Table 15 show the changes in model properties in different zones of the fracturing profile adopted in the TVM package. As shown in the table, within the mined coal seam (goaf), the specific yield was modified to a value of 0.1 or 10%. This value provides for an increased storage capacity by removal of coal, but also accounts for reduced volume in the workings from collapse of overlying strata into the void space left by the removal of coal. The Caved Zone located immediately above the mined seam was simulated by increasing the horizontal and vertical conductivity of the cells within the Caved Zone. The enhanced horizontal and vertical conductivity of the cells within the Caved Zone were manually adjusted. Higher fracture multipliers in the A and B zone were tested. Higher fracture properties in Zone A and B resulted in unrealistic historic depressurisation and inflows and an uncalibrated model.

As listed in **Table 15**, the hydraulic properties (horizonal and vertical conductivity) of the cells that fell within this connected fracturing zone were modified from the ‘host’ or natural values by increasing the horizonal and vertical conductivity by 5 times. For the disconnected fracturing zone, the horizontal conductivity in the model cells was increased up to 10 times the host values. The horizontal conductivity was capped at a maximum absolute value of 0.01 m/d. This value was suggested from Dendrobium data (Watershed HydroGeo, 2020). The enhanced horizontal and vertical conductivity in the disconnected fracturing zone were increased to 10 and 2.5 times the host properties respectively.

To provide a more accurate representation of subsidence-induced impacts to the groundwater and surface water systems, changes in hydraulic properties that occur in areas where surface cracking occurs or is likely to occur were simulated. The horizontal and vertical hydraulic conductivity were increased in the model cells within the surface fracture zone. Evidence from boreholes in the area suggests that surface cracking does not occur at distances outside the panel footprint (SCT, 2020). Therefore, in the numerical model, surface cracking parameters were only adopted in model cells overlying the longwall panel. As shown in **Table 15**, the depth below the surface to where surface cracking extends was calculated as eight times the extraction height of a given longwall. In areas estimated to be affected by surface cracking, the host horizontal and vertical hydraulic conductivity were both multiplied by 10 to represent the enhanced permeability of the fracture zone. The use of these multipliers is supported by a recent investigation into the changed hydraulic properties of sections of Redbank Creek that have experienced surface subsidence (SCT, 2018 and 2020).

Figure 49 presents a conceptual illustration of the deformation zones commonly observed above longwall panels, alongside a schematic of the numerical model representation of that conceptual model in **Figure 49 (B)**.

To illustrate the departure between the host Kx and Kz, and post-mining Kx and Kz, **Figure 50** compares the simulated Kx and Kz host and post mining values in a model cell located within Appin Area 7. As shown in **Figure 50**, the changes in Kx and Kz decreases with vertical distance (height) above the coal seam to the upper limit of the estimated height of fracturing and surface fracturing.

Table 15 Change in the Model Properties due to Longwall Mining

<table>
<tr><th colspan="2">Conceptual Zone</th><th>Zone</th><th>Geometry</th><th>Change in the Model Properties</th></tr>
<tr><td colspan="2">Surface Fracture Zone
(i.e. surface cracking)</td><td>D-zone</td><td>Depth of increased surface fracturing (due to lower depth of cover/confinement) <=20 m, with enhanced horizontal and vertical hydraulic conductivity.
• 8 x T (extraction height)</td><td>High Kx, Higher Kz
-Enhanced Kx was set to 10 times the host value.
-Enhanced Kz was set to 10 times the host value.</td></tr>
<tr><td colspan="2">Constrained Zone</td><td>C-zone</td><td></td><td>No change</td></tr>
<tr><td rowspan="2">Fractured Zone</td><td>upper zone of Disconnected Fracturing</td><td>B-zone</td><td>• B95 – Ditton and Merrick (2014).</td><td>High Kx, Higher Kz
Enhanced Kx was set to 10 times the host value.
Enhanced Kz was set to 2.5 times the host value</td></tr>
<tr><td>lower zone of Connected Fracturing</td><td>A-zone</td><td>• A95 – Ditton and Merrick (2014).</td><td>High Kx, Higher Kz.
Enhanced Kx was set to 5 times the host value.
Enhanced Kz was set to 5 times the host value</td></tr>
<tr><td colspan="2">Caved Zone</td><td rowspan="2"></td><td>5-10 x t (Forster & Enever, 1992; Guo et al., 2007).</td><td>High Kx, Higher Kz.
Kx and Kz set to 10 times the host values.</td></tr>
<tr><td colspan="2">Mined Zone (extracted seam)</td><td>Mined seam thickness (t)</td><td>Kx= 100 m/day, Kz=100m/day, Sy=0.1</td></tr>
</table>

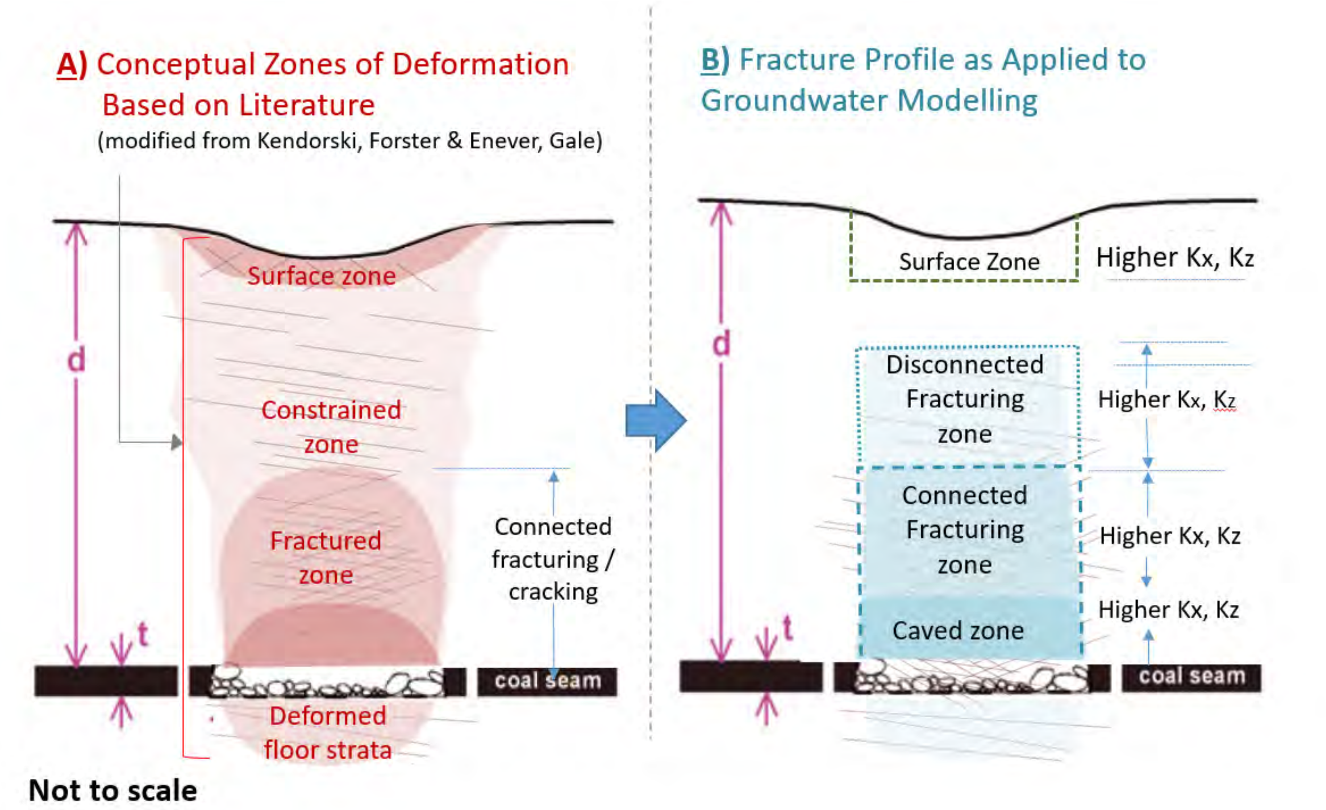


Figure 49 Application of Enhanced Permeability within the Groundwater Model

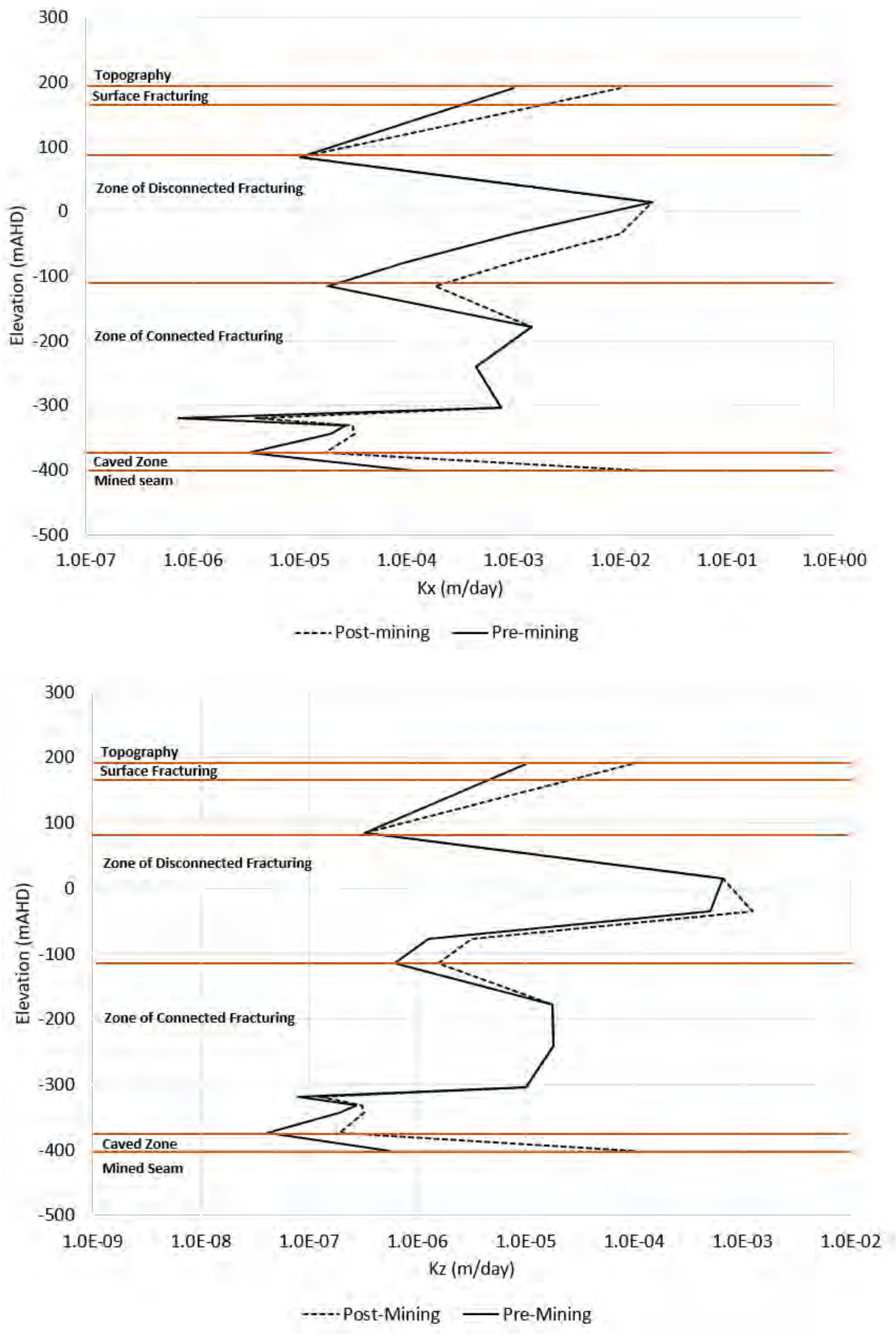


Figure 50 Enhanced Permeability in Cell 8363 within the Groundwater Model

4.2 Model Calibration

Automated calibration utility PEST ++ (Doherty 2019) and manual calibration were used to match the available transient water level data. The groundwater levels recorded between January 2010 to June 2021 were used for the model calibration. In all, 12,280 target water levels were established for 190 bores and VWPs from the following sites:

- Appin: included 151 groundwater level observations sites and VWPs; and
- Tahmoor and Metropolitan: included 39 groundwater level observations sites and VWPs.

To ensure the quality of the data used in the calibration, a filtering process is applied. The filtering was based on the available data on bore construction details, elevation source, coordinates source, lithology, and groundwater measurement. Where this information was available, bores were given a weight of 1 and where this information was partially available bores were given a weight of 0.1.

Piezometers with erroneous data were removed from the calibration data set. These include piezometers that indicted sensor error or recovery and stabilisation trends post-installation. These measurements considered are summarised in **Table 21** and were excluded from the calibration data set.

The final dataset has a good distribution between lithologies. Details on each of the observation points and their residuals (measured minus modelled) are presented in **Appendix D** of this report. The locations of these bores are shown in **Figure 53.**

The hydraulic properties (i.e., horizontal, vertical conductivity, specific yield and specific storage), recharge rates and pumping rates were adjusted during the calibration to provide best match between the measurements and model simulated water levels.

Table 16 Omitted VWP Observations

Bore/VWP	Removed	Reason for Removal
S1176	All measurements	Observed heads inconsistent with surrounding bore data and appear erroneous. Starting heads are -290 mAHD.
S1183, S1185	All measurements	Approximately 5.5 km to the north of the Project. Observed heads (~100m AHD) inconsistent with surrounding bore data and appear erroneous.
S1189_683	All measurements	Located 7 km to the north of the project. Observed trend shows 80m of recovery which indicates possible issue with the sensor or CSG related response.
S1269_549	All measurements except the first measurement	Located 2.5 km to the Northeast of Area 7. Observed starting heads consistent with the surrounding bores. However, observations show a decline of 400 m after 2006 which indicates possible issue with the sensor or CSG related response.
S2173_596	All measurements	Observed trend indicates the VWP still stabilising or malfunctioning.
S1272, S1274	All measurements	Located approximately 8 km to the north of the Project. Unknown depth. Measured levels significantly higher than the surrounding bore

Bore/VWP	Removed	Reason for Removal
S1272	All measurements	Erroneous data.
S1499_478	All measurements	Only recorded one measurement.
S1732_453	All measurements	Located 2 km to the south of Appin Area 2. Observed heads significantly higher than the surrounding bores data and appear erroneous.
S1752	All measurements	Located to the south of Appin Area 9. Observed heads show a continuous recovery trend since 2006 which is unlikely to be mining related. m the surrounding bores data and appear erroneous.
S1778	All measurements	Above the West Cliff Area 5 longwall. Sensor is likely to be damaged by mining. Measurements stopped in 2008.
S2308_70, S2308_503, S2308_514	All measurements after 2018	Located within Longwall 710 footprint, most of the sensors The measured data for the sensors at 70, 503 and 514 mbgl have recorded a significant increase in groundwater levels in recent years (approximately 50 m) and appear erroneous.
S1954_359	All measurements	1 km to the north of the Project area. Observed heads inconsistent with the other sensors in the same bore.
1993 (all sensors)	All measurements	Located above West Cliff Area 5. Measured levels inconsistent with the surrounding bores.
1997 (all sensors)	All measurements	Located close to the Metropolitan Mine. The measurements should recovery in groundwater levels which are unlikely due to mining and could not be due to sensors malfunctioning.
S2040	All measurements	Located to the south of the Project area. Measured levels significantly lower than the surrounding bores.
S2106	All measurements	Located to the south of the Project area. Measured levels showing continues declining trend since installation which is likely due to a malfunctioning sensor. Measurements stopped in 2017.
S2129_722	All measurements	Located 6 pm to the northwest of the Project area. The measurements appear erroneous.
S2157 (all sensors)	All measurements	Located to the west of the project area. Measurements show non mining or climate related trends. Possible CSG related response that could not be captured in the model.
S2160 (all sensors)	All measurements	Located to the northwest of the project area. Measurements show non mining or climate related trends. Possible CSG related response that could not be captured in the model.
S2165 (all sensors)	All measurements	Located 11 km to the north of the project area. Measurements show non mining or climate related trends. Possible CSG related response that could not be captured in the model.
S2173_596	All measurements	Located 9 km to the north of the project area. Measurements show significant recovery after 2014 (approximately 50 m) measurements appear erroneous.

Bore/VWP	Removed	Reason for Removal
S2488A (all sensors)	All measurements	Located 10 km to the north of the project area. Measurements show non mining or climate related trends. Possible CSG related response that could not be captured in the model.
S2524_399	All measurements	Located 500 m to the north of the project area. Measurements show very high groundwater levels (400 mAHD) which are inconsistent with the surrounding bores and are likely due to an issue with the sensor.
S2533 (all sensors)	All measurements	Located 2 km to the west of the project area. The measurements indicate stabilisation trends post-installation.

4.2.1 Calibration Performance

Figure 51 presents the observed and simulated groundwater levels graphically as a scattergram. The industry standard method to evaluate the performance of the model is to examine the error between the modelled and observed (measured) water levels in terms of the root mean square (RMS). A root mean square (RMS) expressed as:

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

where: n =number of measurements

ho =observed water level

hm =simulated water level

RMS is considered to be the most suitable measure of error, if errors are normally distributed. The RMS error calculated for the calibrated model is 44.1 m. 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. The mean absolute residual across the model domain is 10.3 m; therefore, the ratio of RMS to the total head loss (SRMS) is 4.7 % with weighting applied to the values and a mass balance error of less than 0.01%. The SRMS is a useful guide on the measure of fit between observed and modelled data (Barnett *et al.*, 2012). 61% of the observations (7,690 out of 12,280 calibration targets) are within ±20 m of the observed measurements. This provides an indication of reasonable fit for the large calibration dataset; however, further discussion on the fit between modelled and observed trends is included in **Section 4.2.2**.

Figure 52 shows the distribution of calibration residuals. As shown in the figure the calibration residuals for the majority of the calibration data points are within ± 20 m. The model results further indicate that in general the model tends to overpredict the groundwater levels as the number of observations with the negative residuals is larger than the number of observations with the positive residuals.

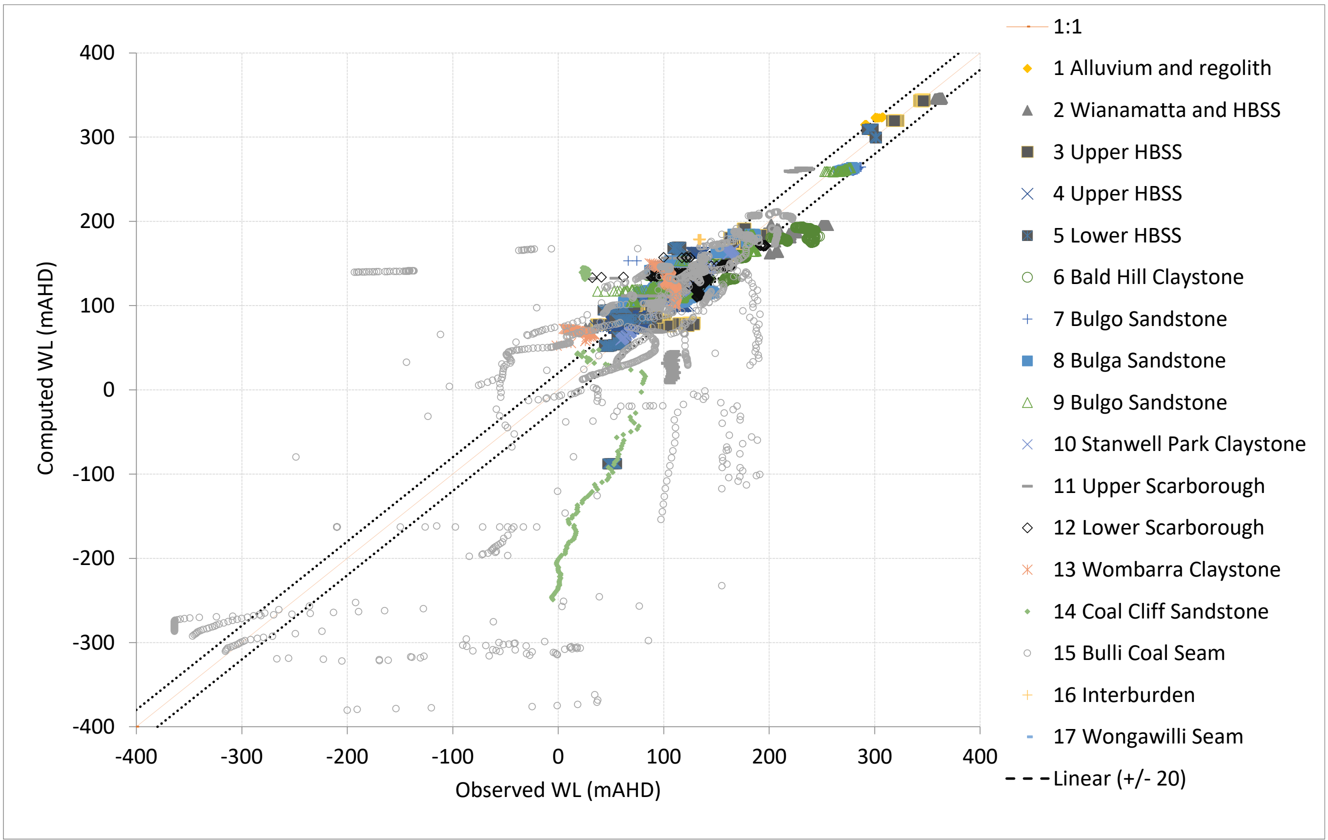


Figure 51 Modelled vs Observed Groundwater Levels

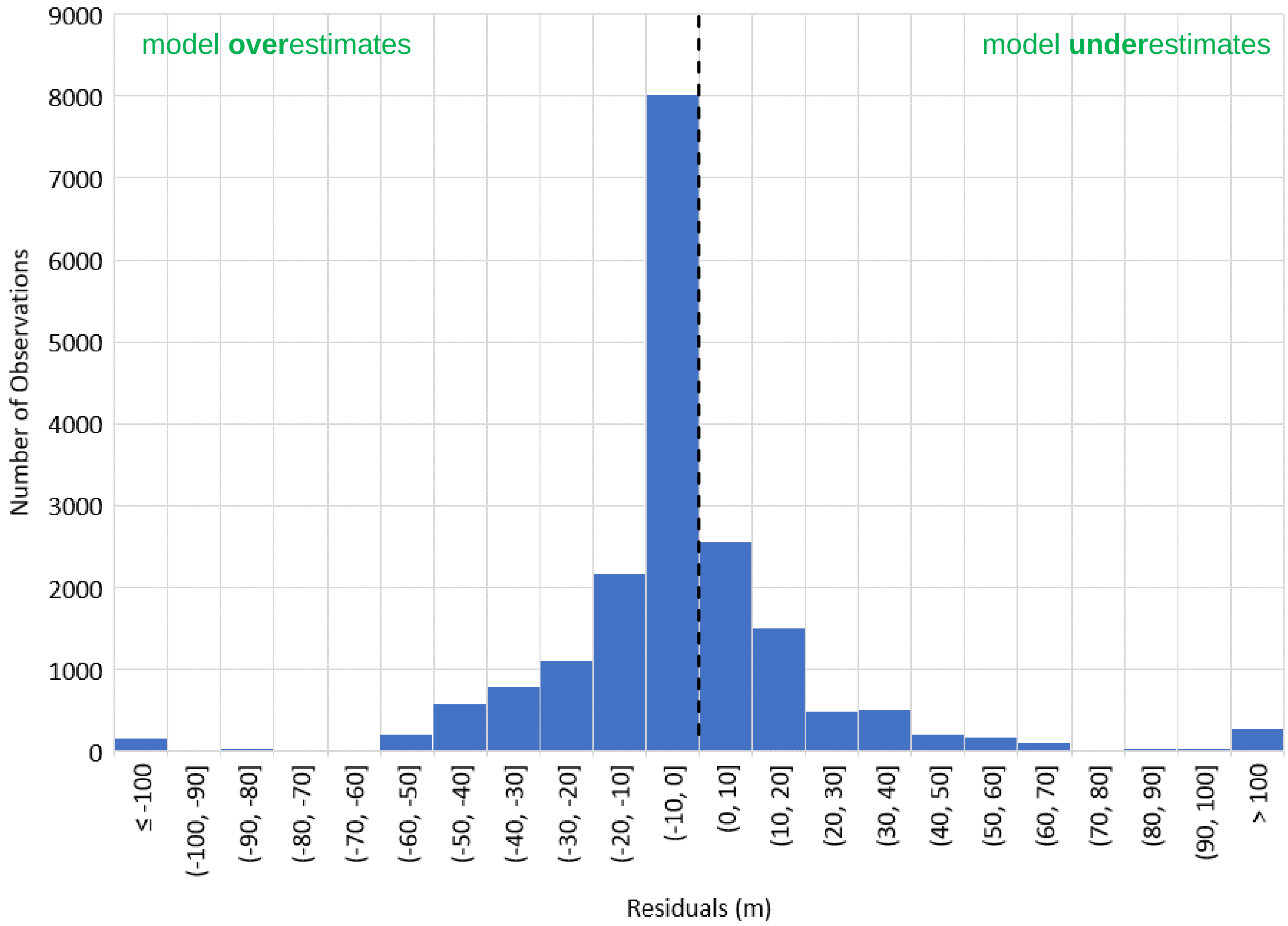


Figure 52 Calibration Residual Histogram Scattergram

Table 17 shows a mix of over and underestimation of groundwater levels in the model layers across the model domain. The table shows Layer 18 (Kembla Sandstone) has the highest absolute average residual. **Table 17** shows HBSS layers in the model have the highest number of observations while the average residuals in these layers are less than 25 m.

Table 17 Average Residual by Model Layer

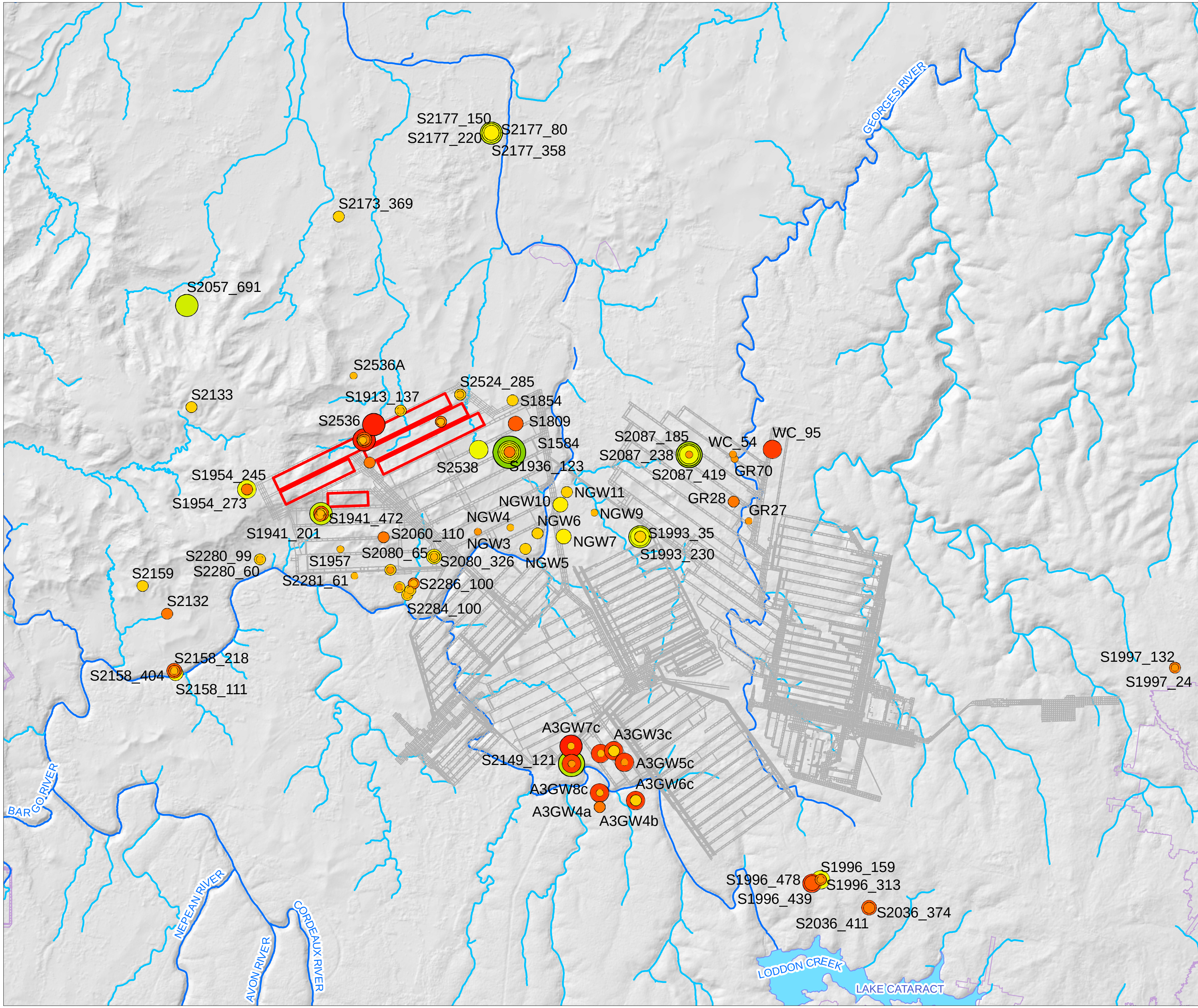
Model Layer	Formation	Average Residual (m)	Average Absolute Residual (m)	Number of Observation Targets	Number of bores / VWPs
1	Alluvium/ Wianamatta Group / Weathered HBSS	-18.2	6.2	45	3
2	Wianamatta Group / Weathered HBSS	11.2	10.4	947	18
3	Upper HBSS	-0.9	22.7	2097	40
4	Upper HBSS	-13.4	24.6	1536	19
5	Lower HBSS	-14.3	16.3	871	11
6	Bald Hill Claystone	28.2	28.0	677	7
7	Bulgo Sandstone	-13.3	32.5	874	14
8	Bulgo Sandstone	-5.9	27.2	821	12
9	Bulgo Sandstone	-4.6	37.5	760	10
10	Stanwell Park Claystone	0.4	32.3	774	9
11	Upper Scarborough	-5.4	33.5	607	8
12	Lower Scarborough	2.1	41.6	401	6
13	Wombarra Claystone	-27.2	33.5	133	2
14	Coal Cliff Sandstone	23.2	65.2	219	2
15	Bulli Coal Seam	7.3	49.5	1633	25
16	Loddon Sandstone	-44.7	35.9	50	1
17	Wongawilli Seam	29.4	45.9	135	3
18	Lower Permian Coal Measures	-18.2	92.7	45	3

Table 18 compares the calibration statistics to the previous versions of the model. The RMS error, SRMS, mean and absolute residual values for SLR model are all less than the results in the previous models (Heritage Computing, 2009 and HydroSimulations, 2018) indicating that the calibration model has been improved with the good fit between observed and modelled groundwater levels and is within the Australian guideline indicator of 10% scaled RMS (MDBC, 2001; Barnett *et al*., 2012).

Table 18 Transient Calibration Statistics

Calibration Statistics	Heritage Computing (2009)	HydroSimulations (2018)	SLR (2022)
Number of Data (n)	220	4275	12580
Root Mean Square (RMS) (m)	98.3	95	44.4
Scaled Root Mean Square (SRMS) (%)	9.6	33	4.7
Mean residual (m)	39.5	36.1	-1.0
Mean absolute residual (m)	117.9	56.1	25.5

The average residuals for points around the study area are also presented in **Figure 53**. The residuals were calculated as observed minus modelled, therefore a positive value indicates observed levels are higher than modelled and vice versa.



APPIN MINE GROUNDWATER ASSESSMENT

AVERAGE GROUNDWATER LEVEL RESIDUALS

FIGURE 53

- Appin Mine
- Major watercourses
- Minor watercourses
- Other Mine Workings
- Lakes
- Project Area

Calibration Residuals

- < -100
- -100 - -90
- -90 - -80
- -80 - -70
- -70 - -60
- -60 - -50
- -50- -40
- -40 - -30
- -30 - -20
- -20 - -10
- -10 - 0
- 0 - 10
- 10 - 20
- 20 - 30
- 30 - 40
- 40 - 50
- > 50

0 2 4 km

Coordinate System:	GDA 1994 MGA Zone 56
Scale:	1:120,000 at A4
Project Number:	665.10015
Date:	07-Sep-2022
Drawn by:	NT
Reviewed by:	AM

Data Source: Mining Lease NSW Mineview Coal Lease 2019

SLR

H:\Projects-SLR\620-BNE\665-WOL\665.10015 Illawarra Coal Closure - Water\CADGIS\ArcGIS\EP Report\665.10015 F52 Map of Average Groundwater Level Residuals.mxd

4.2.2 Calibration Fit

This section provides discussion on the modelled to observed groundwater level trends (calibration hydrographs) for bores around the Appin Longwalls 709, 710A, 710B, 711 and 905. Calibration hydrographs for the full calibration dataset are presented as **Appendix D**.

The hydrographs for most of the bores highlight the challenge in simulating groundwater levels in the complex groundwater system which has been subjected to significant historical stresses such as pumping from registered and unregistered bores, gas extraction and historical mining activities that could not be replicated in the model as there was no information available on the timing and magnitude of these stresses.

Across the entire model domain, the weighted average head difference between simulated and observed water levels are less than 10 m for in the Permian units and less than 15 in HBSS. This average difference is considered a small variance in head for a regional-scale model.

Overall, across the model domain, there is a better match between simulated groundwater levels and observed levels in the deeper units (including the bores in alluvium and HBSS) which are connected to the surface water features and which host almost all the private bores. This is also shown through calibration residuals presented in **Table 17**. The hydrographs show increasing error in the deeper layers where there is greater, more significant drawdown and higher gradients around the mine. Potential sources of error when comparing simulated and observed water levels are:

- Imperfect simulation of mining operations, roadway development, landowner pumping and CSG extraction (where present in the model). As an example, the discrepancy in observed and simulated groundwater levels in the bores in HBSS discussed in **Section 4.2.2.1**. While the bores are located close to each other, they recorded significantly different groundwater level likely due to the historical stress (e.g., landowner pumping and CSG extraction) to the groundwater system. The groundwater model was not able to replicate all the historical stresses in the area. The hydrograph for the bores such as S1763 and S1809 shown in Appendix D represent a timing influence, thought to be from the representation of the historical mine plan in this model compared to the actual progression of that mine;
- Longwall progression and commencement of significant impacts at a monitoring point occurs over small time increments compared to model stress periods;
- Structural simplifications in the model, including the vertical and horizontal discretization of the model and resulting ‘coarse’ representation of features and hydraulic gradients at scales of a model cell (or layer) or less. For example, strong vertical gradients may mean that a model, which predicts average water levels for a cell, will struggle to replicate an observed water level if that water level is from the upper or lower portion of that layer. For a layer that is 50 metres thick and where a gradient is 1 in 10, this leads to errors of ± 5m;
- Structural errors may also occur because of the discretisation of time in the model. In this case, stress period lengths are quarterly. Behaviour within this may significantly influence the observed water level, and the model may either not simulate the relevant stress or may smooth out the response to such a stress.
- High residuals but good match: examples are illustrated in the Bulli Coal seam piezometers in VWPs S1853 and S1936_556, which show large residuals but also suggests that the model does a reasonable job of simulating groundwater levels and their response to mining;

- Processing / installation record errors: The bores with erroneous data were removed from the calibration dataset. However, given the number of bores and measurements available for the calibration, further review of the calibration data may identify more bores with erroneous data that should be removed from the calibration. There were uncertainties about installation depth/formation (i.e. model layer) in some of the bores but the data from these bores were included in the calibration but were assigned lower weights; and
- Representation of fracture profile properties: It is evident that the bores screened within the fracture zone above the longwalls are impacted by post-mining properties of the fracture zone. The fracture zone properties are likely to be highly variable in different parts of the mine. However, the model uses one value across the site for the fracture zone which is a simplified representation of a highly complex stress system.

4.2.2.1 Hawkesbury Sandstone (HBSS)

Figure 54 to **Figure 66** present the fit between modelled and measured water levels for some of the VWPs located within or near Appin Mine (S1913_137, S1913_194, S2315_144, S2281_61, S2308_135, S1941_126, S2524_40, S1954_245, S2060_110, S2282_60, S1936_65 and S2538). All these sensors monitor the HBSS. The hydrographs for the other bores monitoring the HBSS are shown in **Appendix D**.

The hydrographs for VWP S1913 with sensor depths of 137 mbgl and 194 mbgl, located 100 m north of Longwall 711, show the model overpredicts groundwater levels at sensor depth 137 mbgl by approximately 15 m, and matches well with the observed level at sensor 194 mbgl. Although the model does not predict the variability in the observed water levels, it captured the long-term groundwater trends in the HBSS (**Figure 54** and **Figure 55**).

VWP S2315_144 is located within Longwall 711. The hydrograph for S2315_144 shows that the model overpredicts the observed water levels at this bore by 10 m to 25 m. The reason for this poor match is that groundwater levels at this bore are likely impacted by extraction bores screened in the HBSS. Due to the lack of information for these extraction bores, the model used an assumption of the pumping rates and timing, which likely differs from the actual extractions (**Figure 56**).

The hydrograph for VWP S2281 sensor depth 61 mbgl, located close to Harris Creek and Longwall 901, shows that the groundwater levels are underpredicted at sensor depth 61 mbgl by approximately 7 m (**Figure 57**). The model is predicting stable groundwater levels and does not respond to the impact from mining in the HBSS at this location.

Figure 58 shows the hydrograph for S2308_135 located above Longwall 710B shows the model can match the groundwater level closely but it is simulating less drawdown in the VWP compared to the observed data.

The hydrographs for S1941_126, S2060_110 and S2280_60 show the model was not able to match the groundwater levels and trends at these VWPs closely. S1941, S2280 and S2060 are located 1 km from each other above Appin Area 9. While the VWPs are located close to each other, the observed levels for these three locations are significantly different (shown in **Figure 62**, **Figure 63** and **Figure 64**). Therefore, the model calibration was not able to match the difference in groundwater levels and found the middle point and simulated the groundwater levels at 80 to 85 mAHD.

Figure 65 and **Figure 66** show the hydrograph for S1936_65 and S2538 located less than 1 km south of Longwall 709 and Longwall 710B. S1936_65 and S2538 recorded average groundwater levels of 90 mAHD and 45 mAHD. The calibration was not able to match the observations at these two VWPs and simulated groundwater levels were between 75 to 80 mAHD.

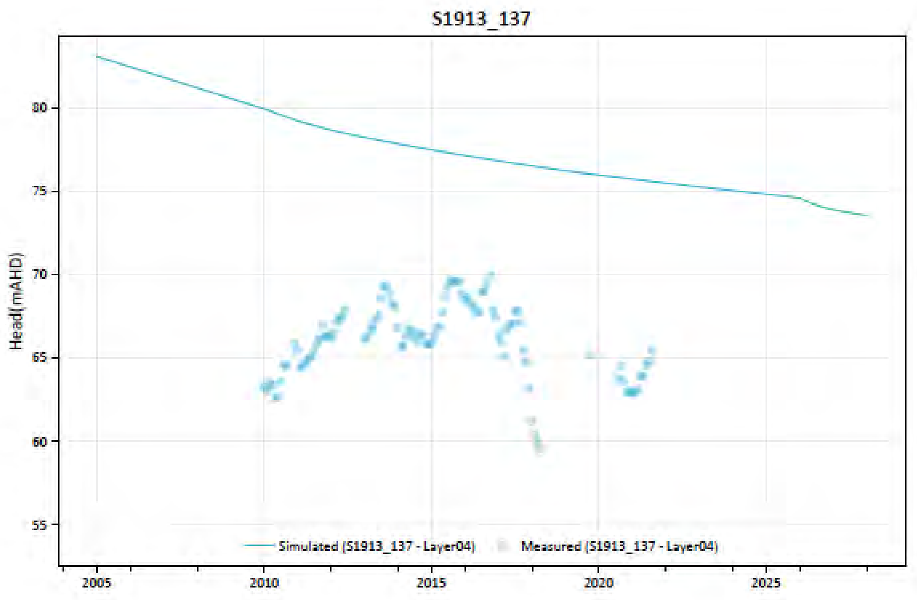


Figure 54 Modelled and Observed Hydrographs in S1913_137 in the HBSS

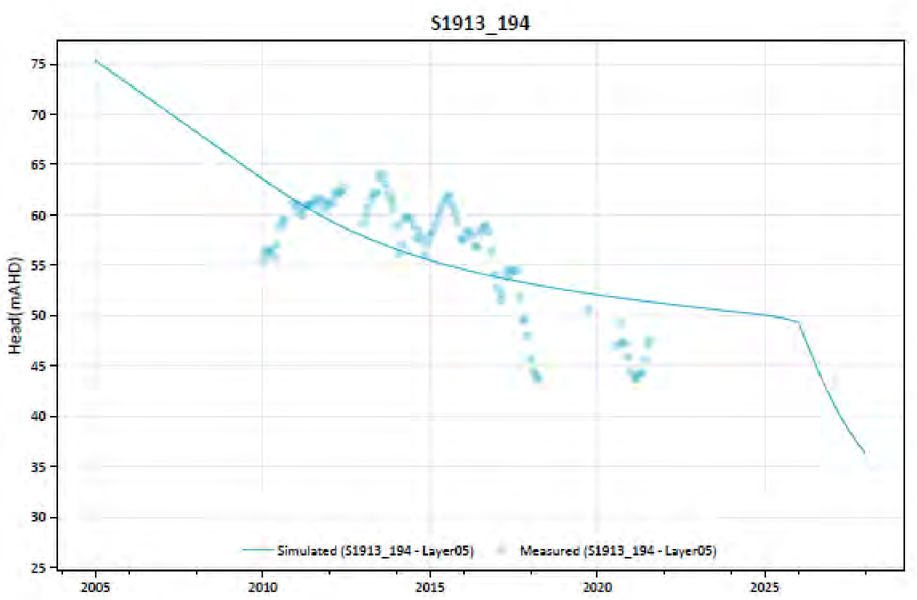


Figure 55 Modelled and Observed Hydrographs in S1913_194 in the HBSS

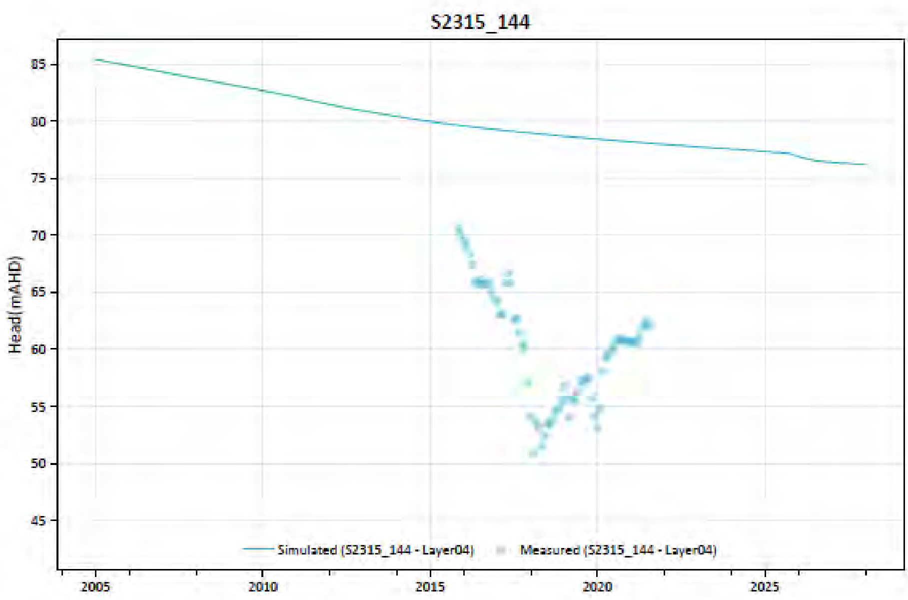


Figure 56 Modelled and Observed Hydrographs in S2315_144 in the HBSS

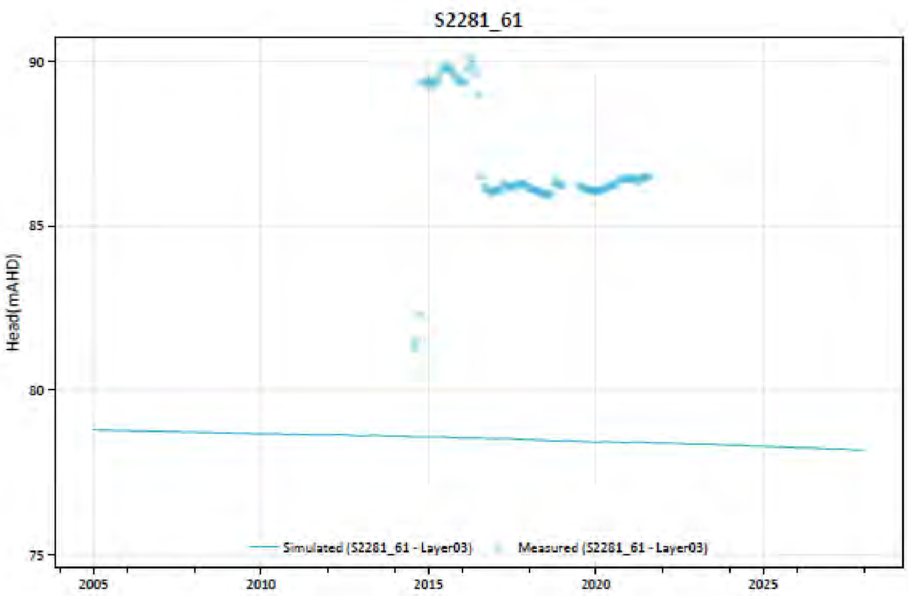


Figure 57 Modelled and Observed Hydrographs in S2281_61 in the HBSS

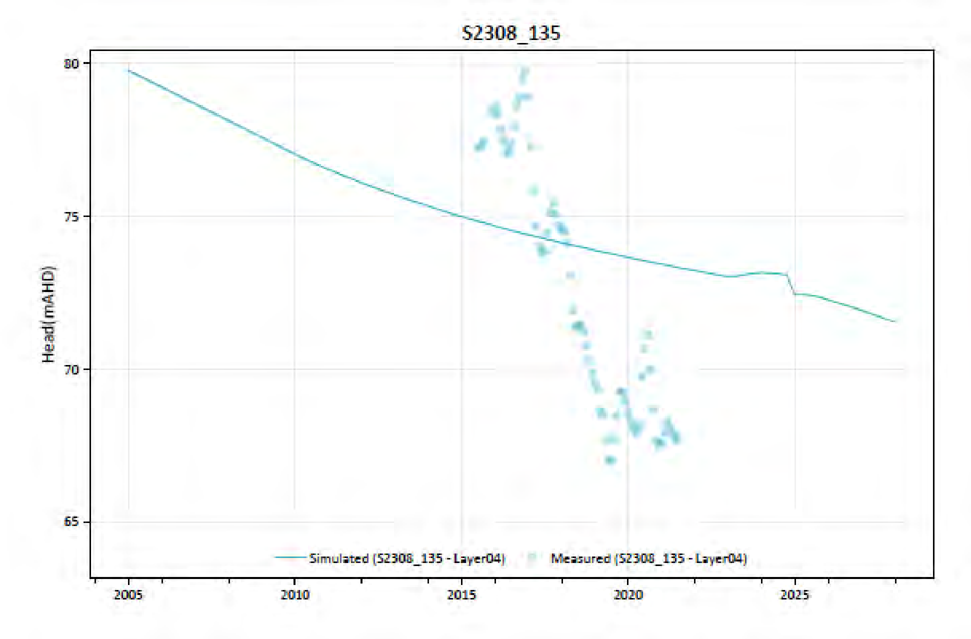


Figure 58 Modelled and Observed Hydrographs in S2308_135 in the HBSS

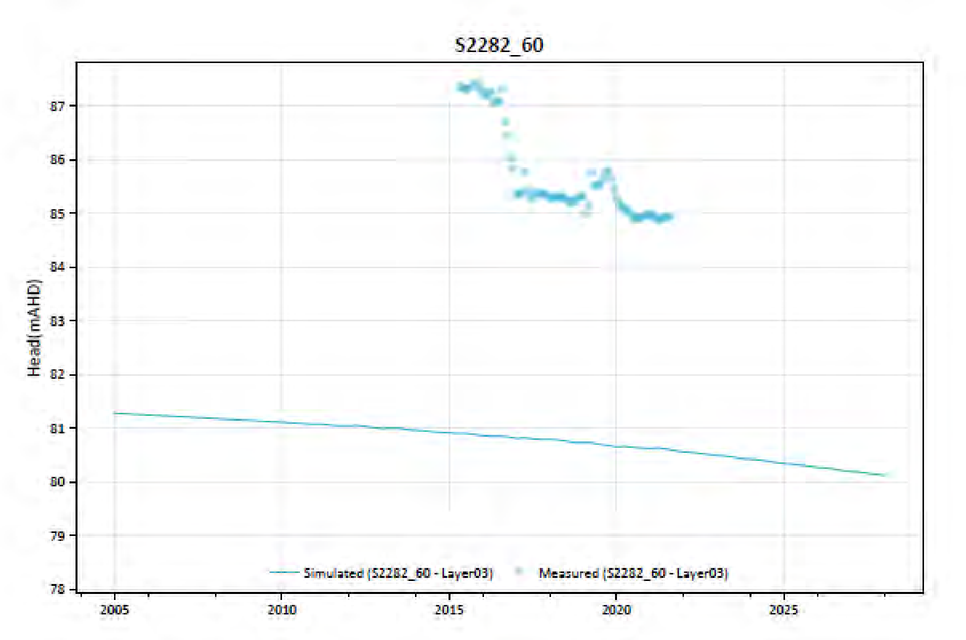


Figure 59 Modelled and Observed Hydrographs in S2282_60 in the HBSS

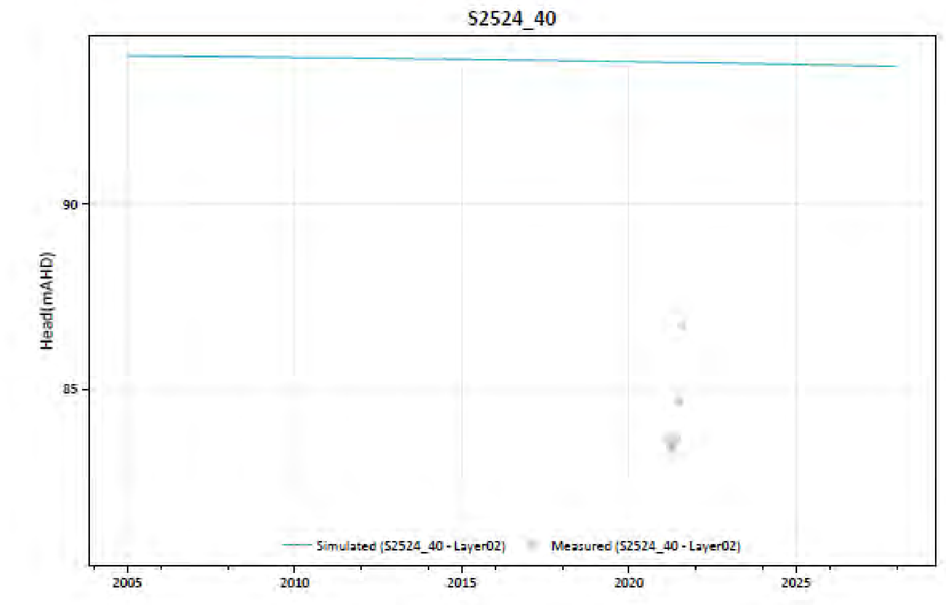


Figure 60 Modelled and Observed Hydrographs in S2524_40 in the HBSS

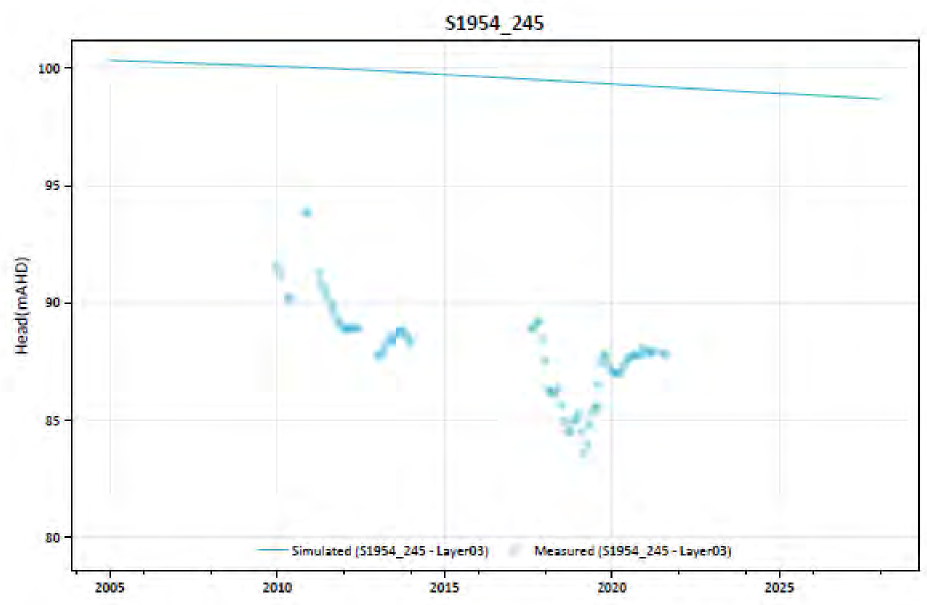


Figure 61 Modelled and Observed Hydrographs in S1954_245 in the HBSS

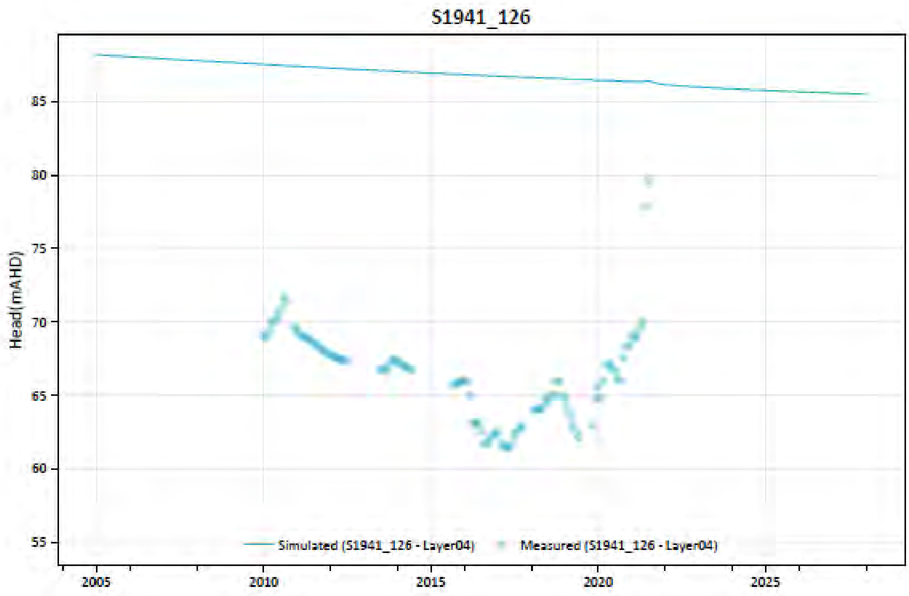


Figure 62 Modelled and Observed Hydrographs in S1941_126 in the HBSS

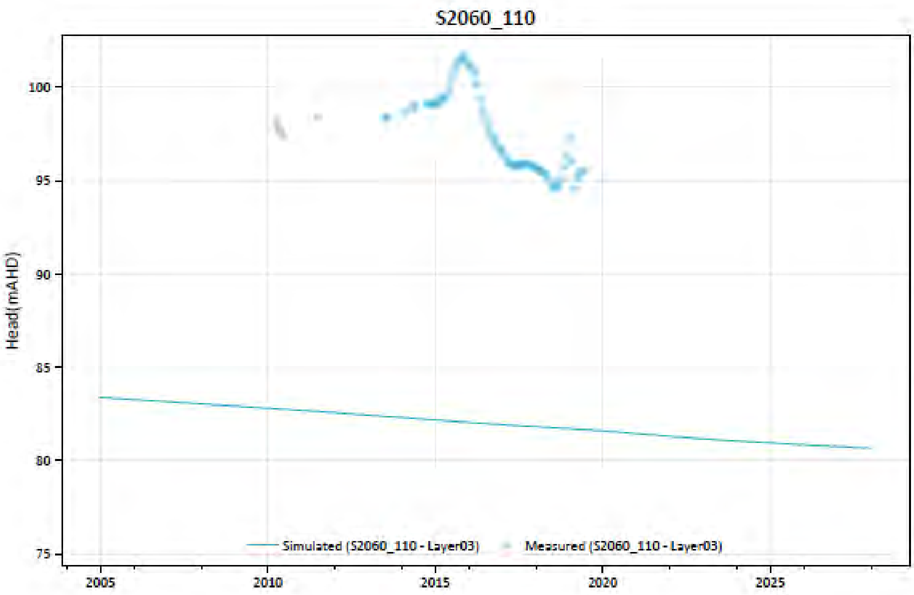


Figure 63 Modelled and Observed Hydrographs in S2060_110 in the HBSS

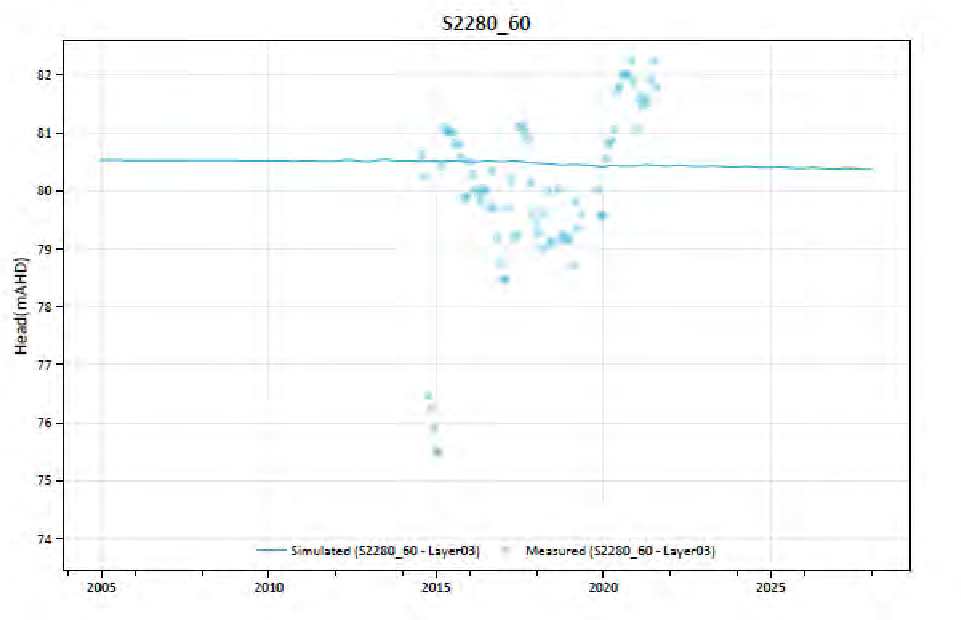


Figure 64 Modelled and Observed Hydrographs in S2280_60 in the HBSS

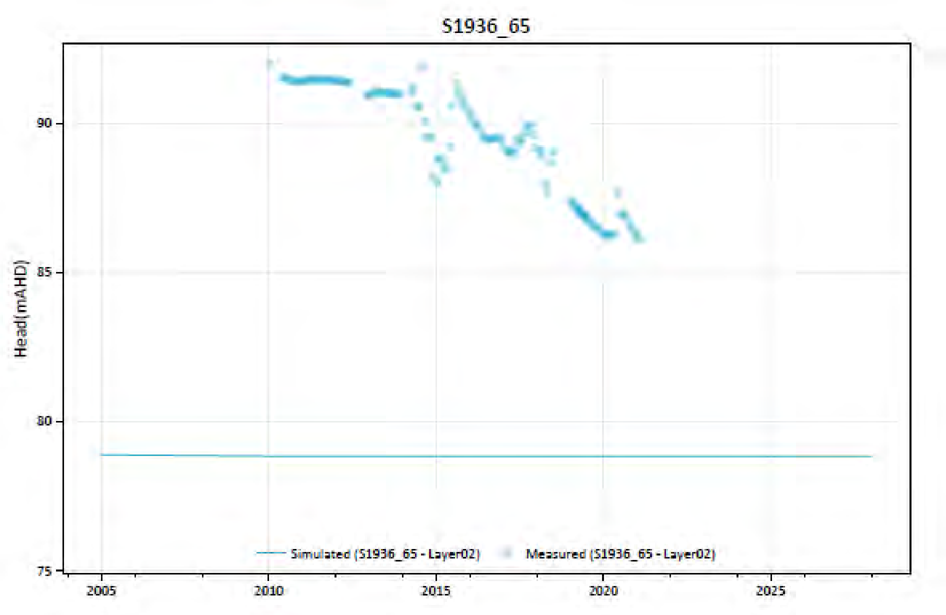


Figure 65 Modelled and Observed Hydrographs in S1936_65 in the HBSS

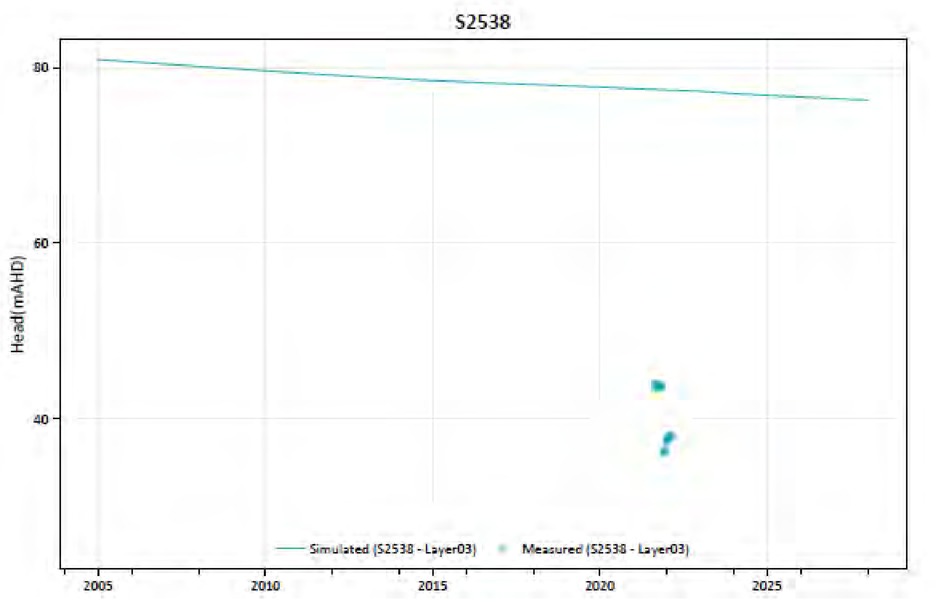


Figure 66 Modelled and Observed Hydrographs in S2538 in the HBSS

4.2.2.2 Wianamatta Group

VWP S1954 is located approximately 600 m west of Longwall 711 with seven sensor depths (36 mbgl, 85 mbgl, 100 mbgl, 138 mbgl, 145 mbgl, 181 mbgl and 205 mbgl) in the Wianamatta Group. Observed groundwater levels range from 130 mAHD to 230 mAHD (**Figure 13**). Of those seven sensors, all are within Layer 2 of the model, and the middle sensor S1954_85 has been selected to calibrate. As shown in the hydrograph for S1954_85 (**Figure 67**) the model underpredicts groundwater levels at sensor depth 85 mbgl but is in the range of the measured levels in the Wianamatta Group.

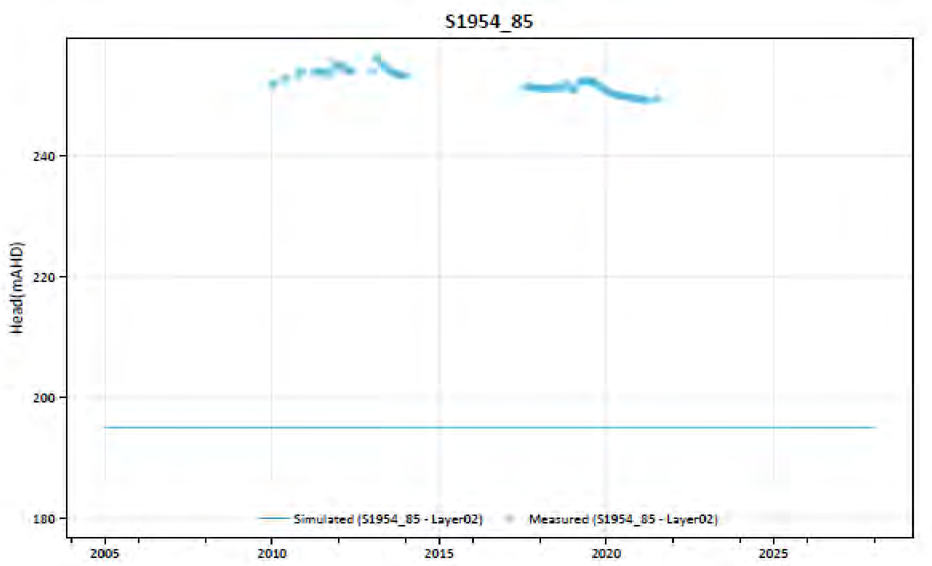


Figure 67 Modelled and Observed Hydrograph in S1954_85

4.2.2.3 Narrabeen Group

The hydrographs for VWPs S2308_378, S2060_327, S1941_355, S2524_285 and S2315_358, screened in the Bulgo Sandstone (BGSS), and S1913_473 and S1936_456 screened in the Scarborough Sandstone (SBSS) are shown in **Figure 68** to **Figure 74**.

While the general trends in the groundwater levels are matched in these bores, the simulated groundwater levels are over or underpredicted with a difference of +/-25 m. Although the model does not predict the variability in water levels over time due to using quarterly model stress periods to capture the mining progression, the predicted maximum depressurisations generally match the measured maximum depressurisations in most bore in BGSS and SBSS during the mining period.

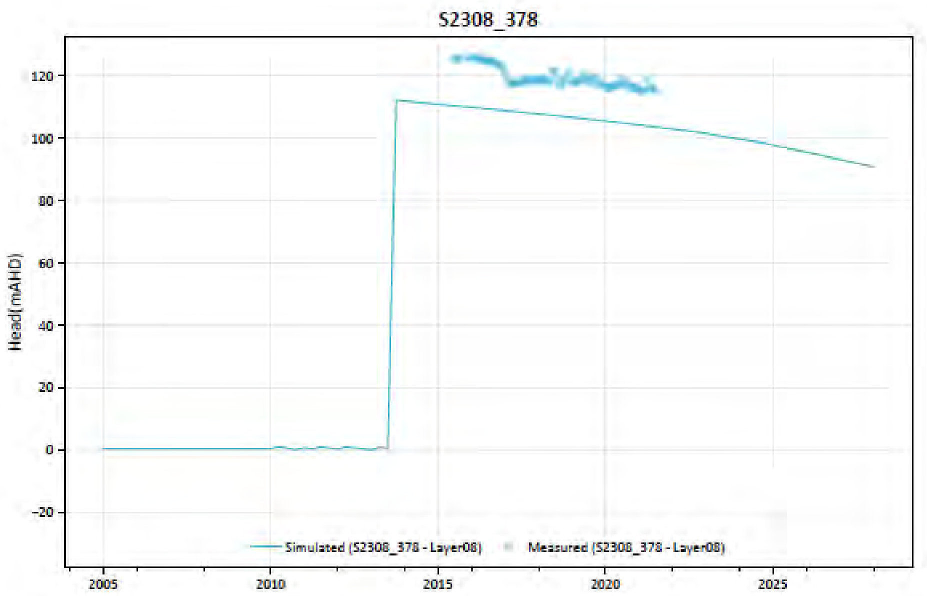


Figure 68 Modelled and Observed Hydrograph in S2308_378 in the BGSS

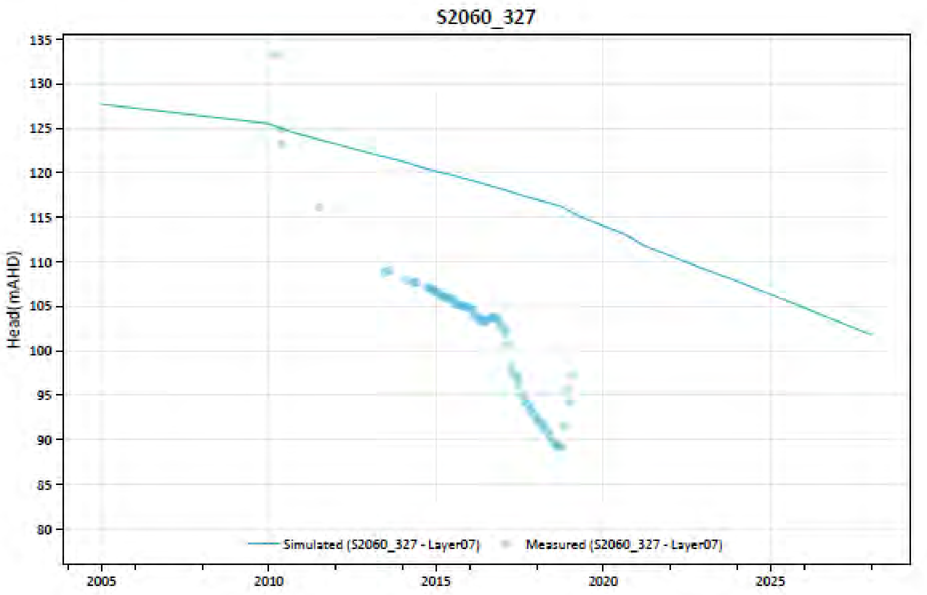


Figure 69 Modelled and Observed Hydrograph in S2060_327 in the BGSS

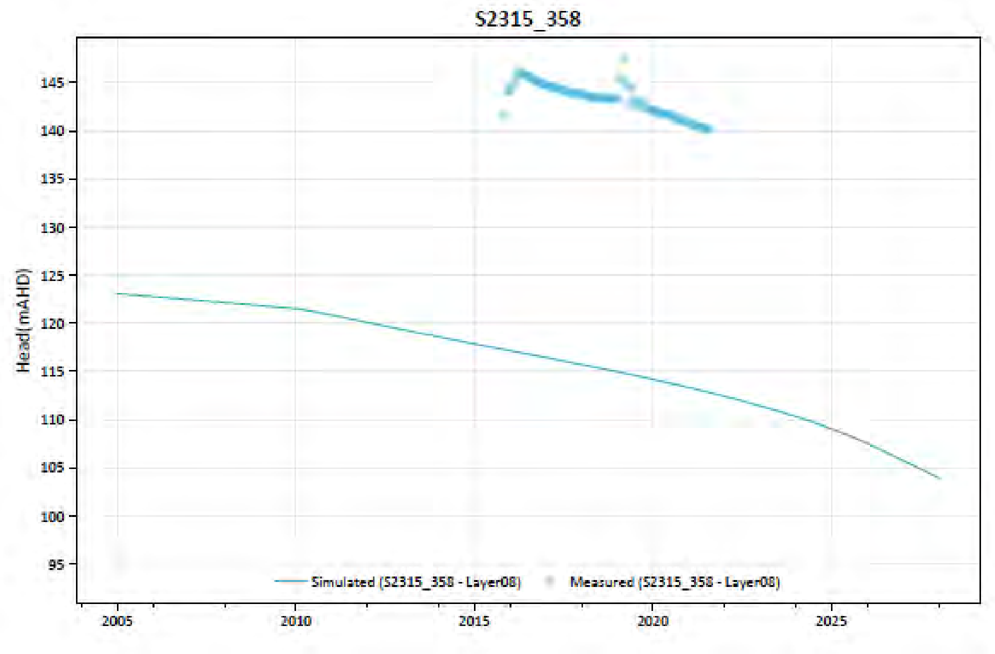


Figure 70 Modelled and Observed Hydrograph in S2315_358 in the BGSS

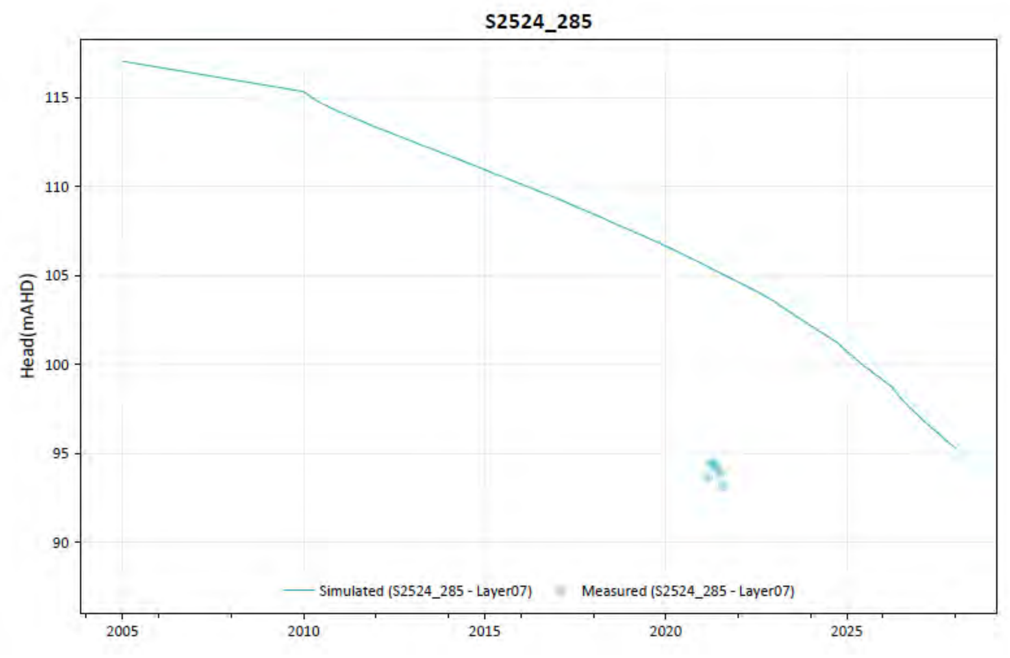


Figure 71 Modelled and Observed Hydrograph in S2524_285 in the BGSS

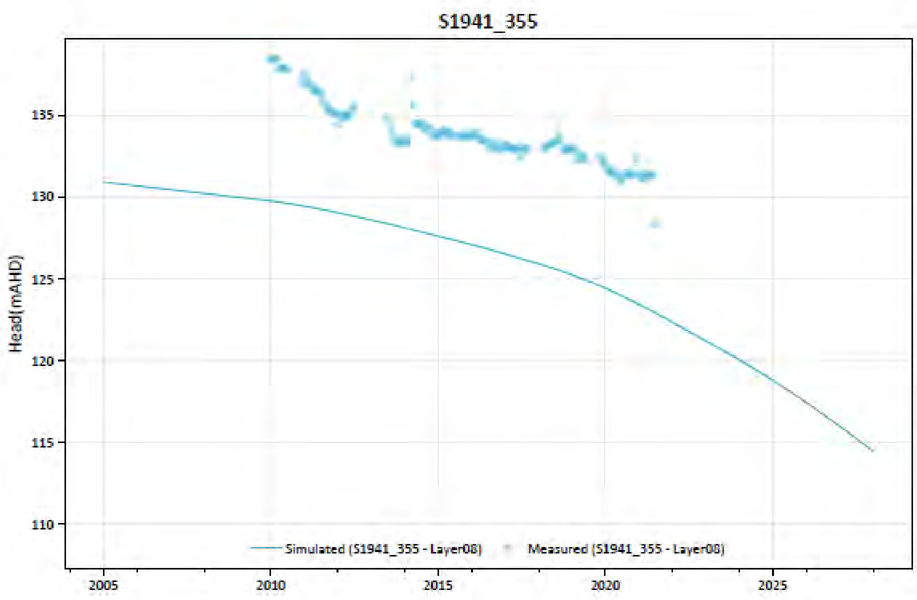


Figure 72 Modelled and Observed Hydrograph in S1941_355 in the BGSS

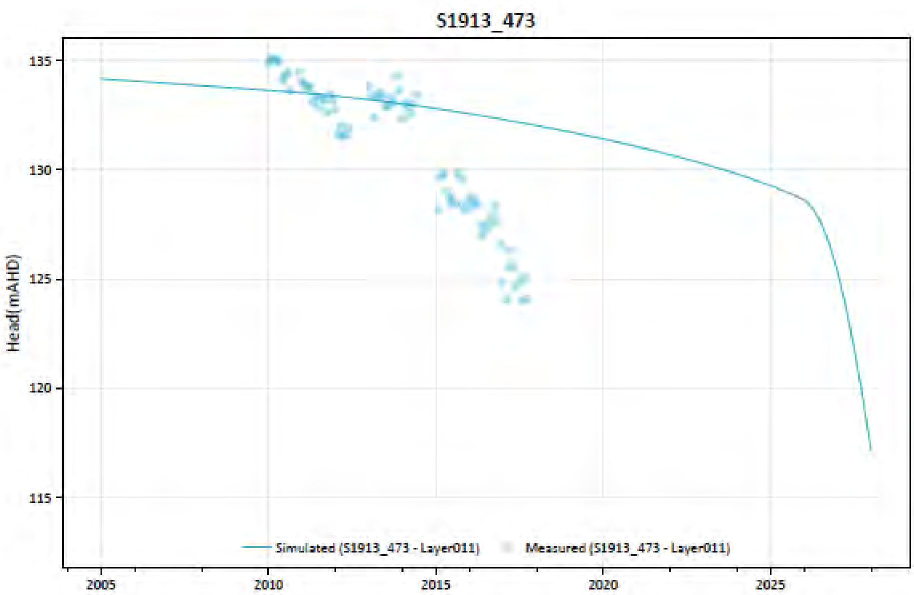


Figure 73 Modelled and Observed Hydrograph in S1913_473 in the SBSS

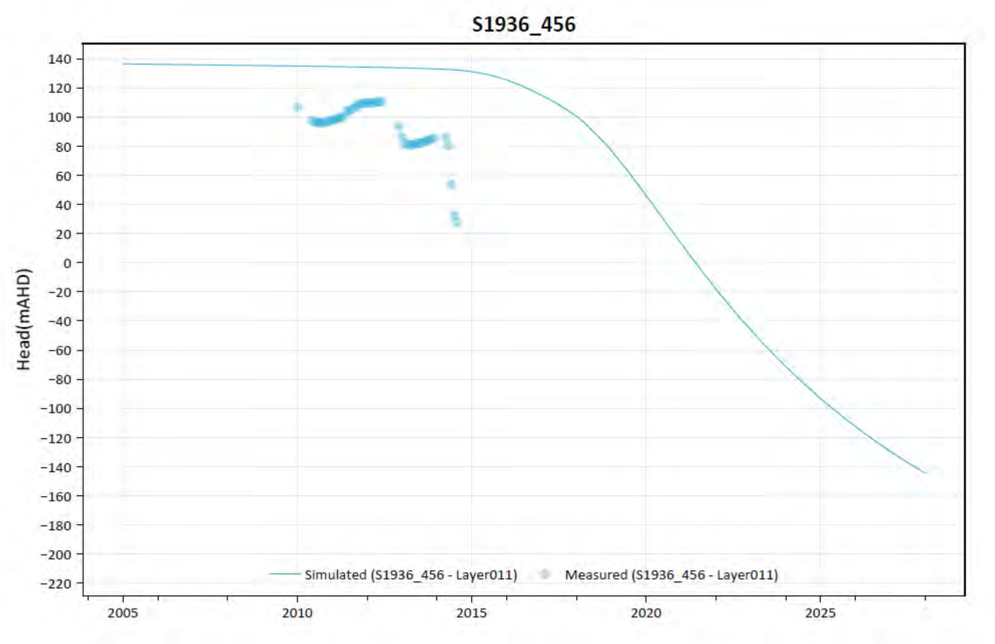


Figure 74 Modelled and Observed Hydrograph in S1936_347 in the SBSS

4.2.2.4 Illawarra Coal Measures

Figure 75 to **Figure 83** show the hydrographs for the VWPs S1913_559, S1941_555, S2315_576, S2308_574, S1763, S2133, S1936_556, S1854 and S2060_603 screened in the Bulli Coal Seam and located within or immediately around Longwalls 709, 710A, 710B, 711 and 905. The hydrographs show while there is generally a good match between observed and measured water levels with the depressurisation in the Bulli Coal Seam, in some locations the model was not able to match the initial heads and the trends close to the observed values.

The hydrograph for S1763 above Longwall 710B shows modelled mining time does not match the actual mining progression exactly and the initial heads at this bore are underpredicted by up to 20 m (**Figure 79**).

The hydrograph for S2133 located 2 km to the northwest of Longwall 711 shows the model overpredicts water levels at this bore by 20 m (**Figure 80**).

The hydrograph for S2315_576 shows that the model overpredicts the groundwater levels during 2020 by approximately 30 m (**Figure 77**). The reason for this is that the modelled mining time does not match the actual mining progression exactly. This same reason is likely the cause for the modelled higher groundwater levels compared to the measured levels at S2060_603 (**Figure 83**).

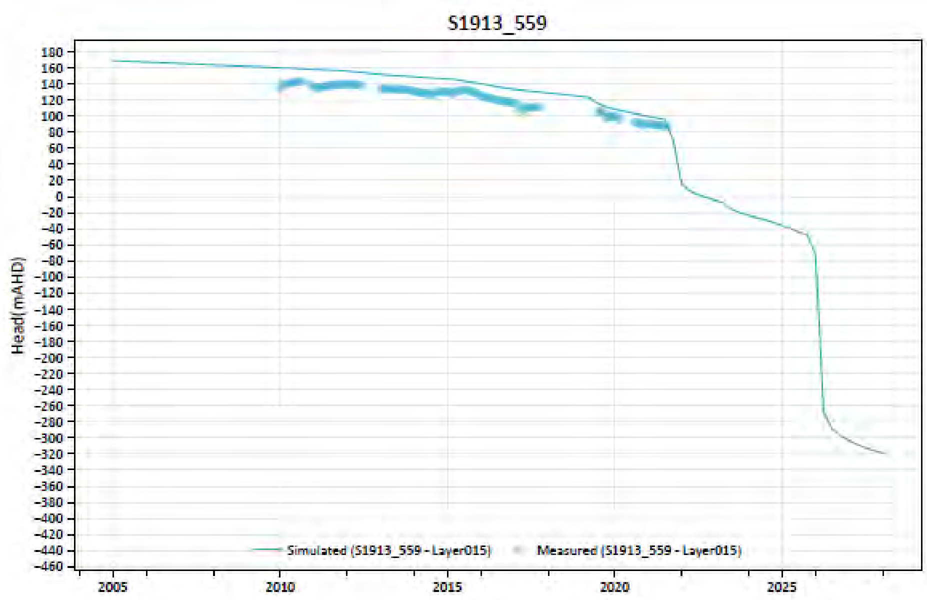


Figure 75 Modelled and Observed Hydrographs in S1913_559 in the Bulli Seam

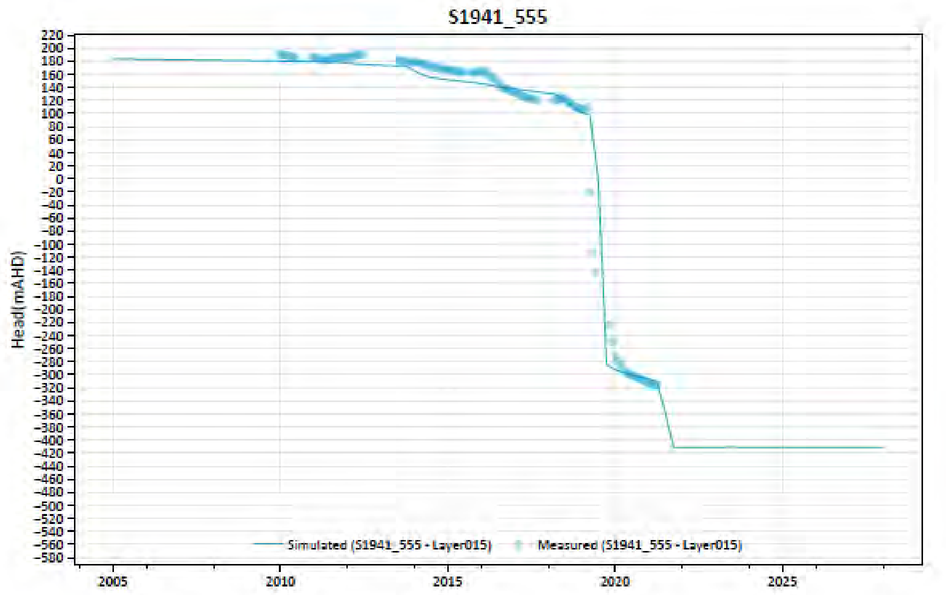


Figure 76 Modelled and Observed Hydrographs in S1941_555 in the Bulli Seam

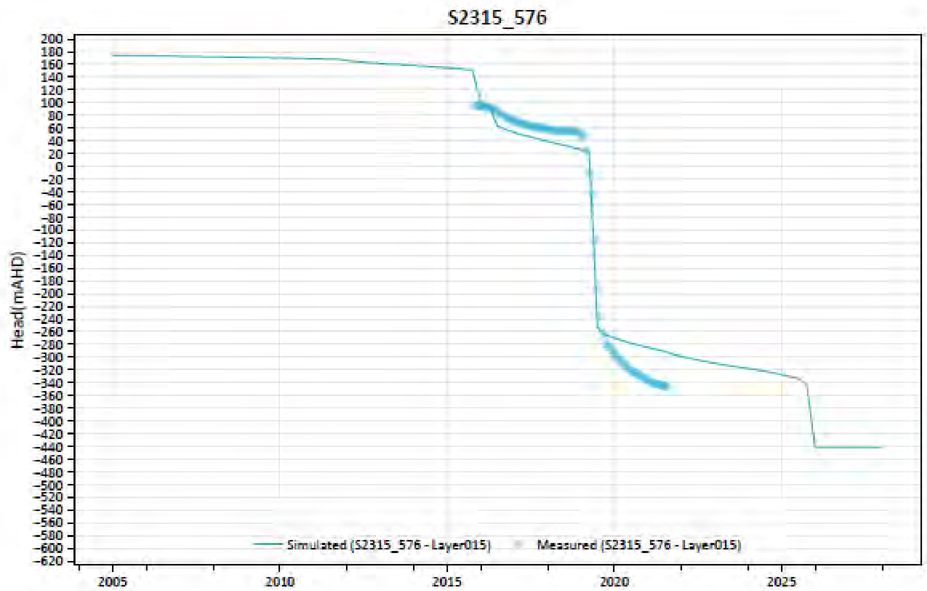


Figure 77 Modelled and Observed Hydrographs in S2315_576 in the Bulli Seam

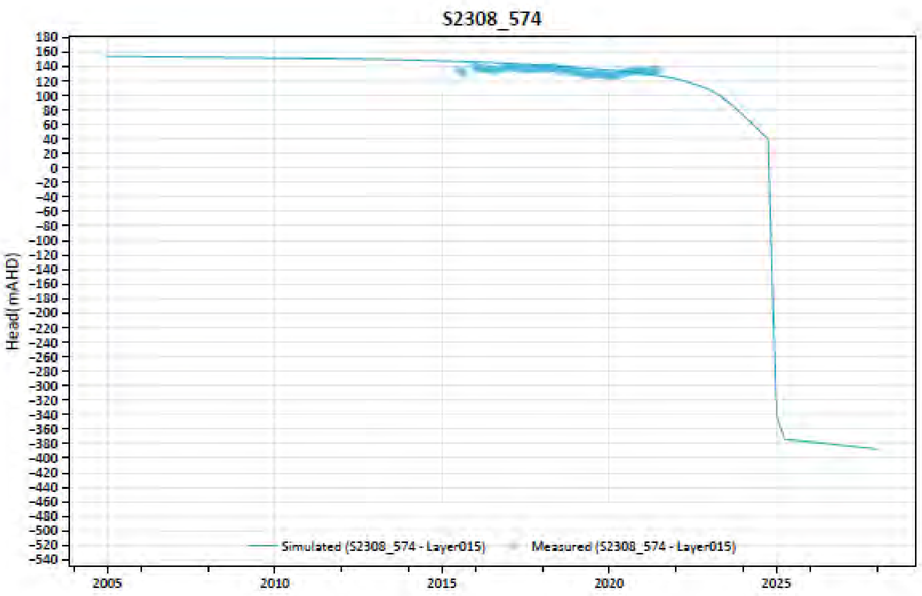


Figure 78 Modelled and Observed Hydrographs in S2308_574 in the Bulli Seam

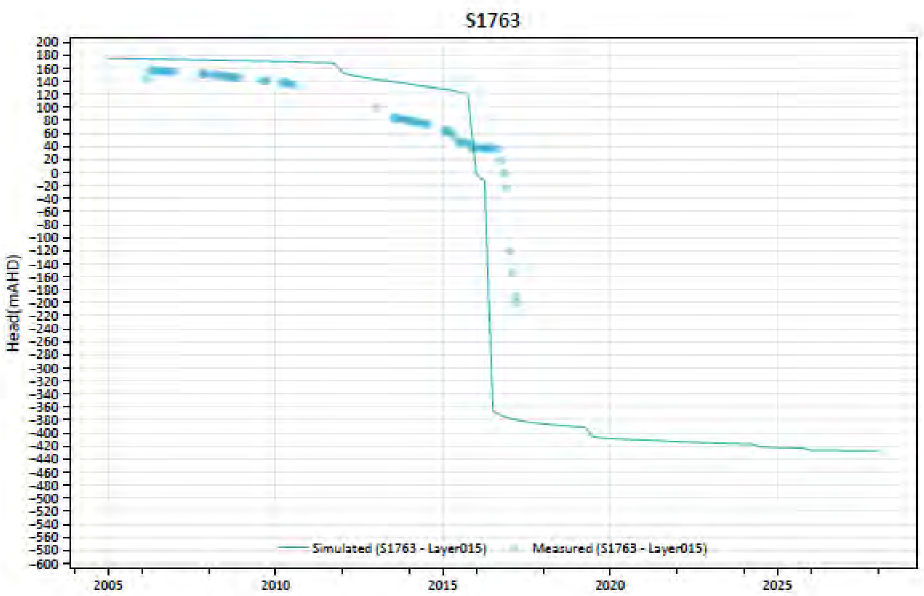


Figure 79 Modelled and Observed Hydrographs in S1763 in the Bulli Seam

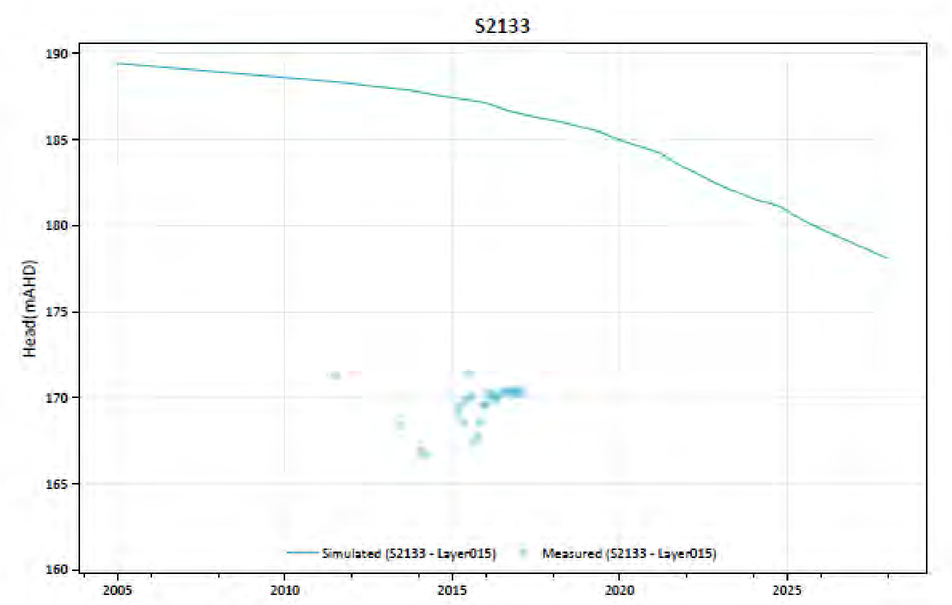


Figure 80 Modelled and Observed Hydrographs in S2133 in the Bulli Seam

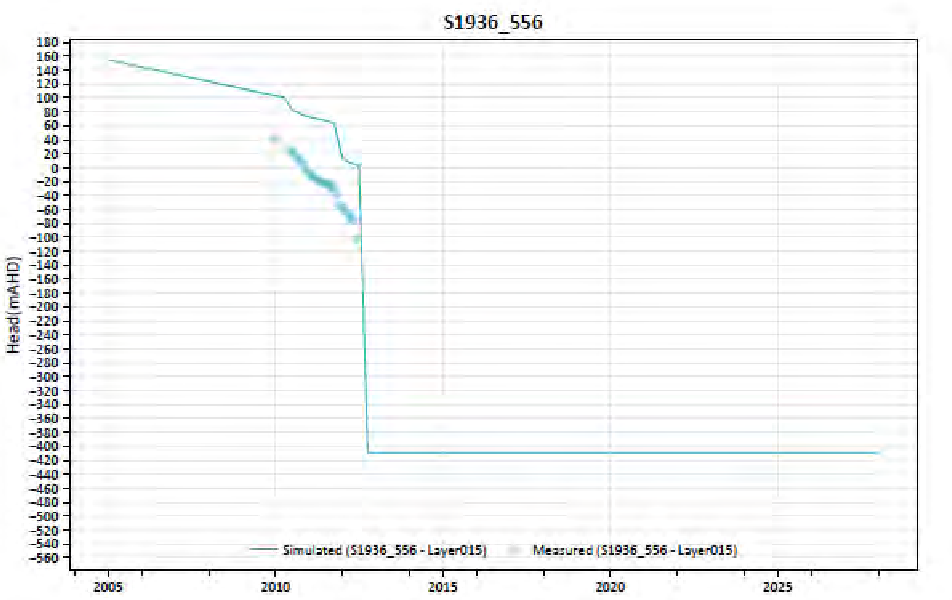


Figure 81 Modelled and Observed Hydrographs in S1936_556 in the Bulli Seam

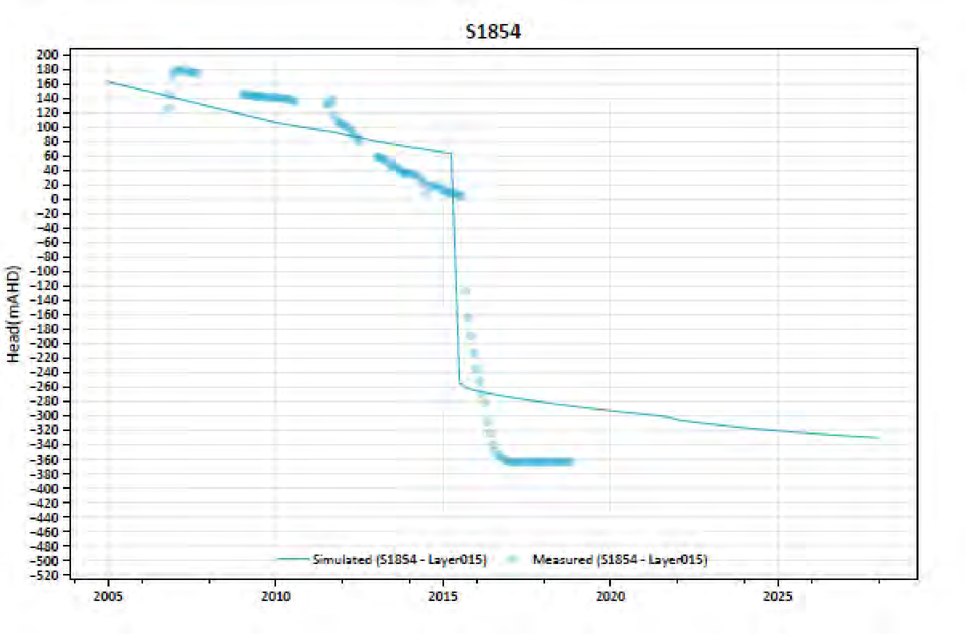


Figure 82 Modelled and Observed Hydrographs in S1854 in the Bulli Seam

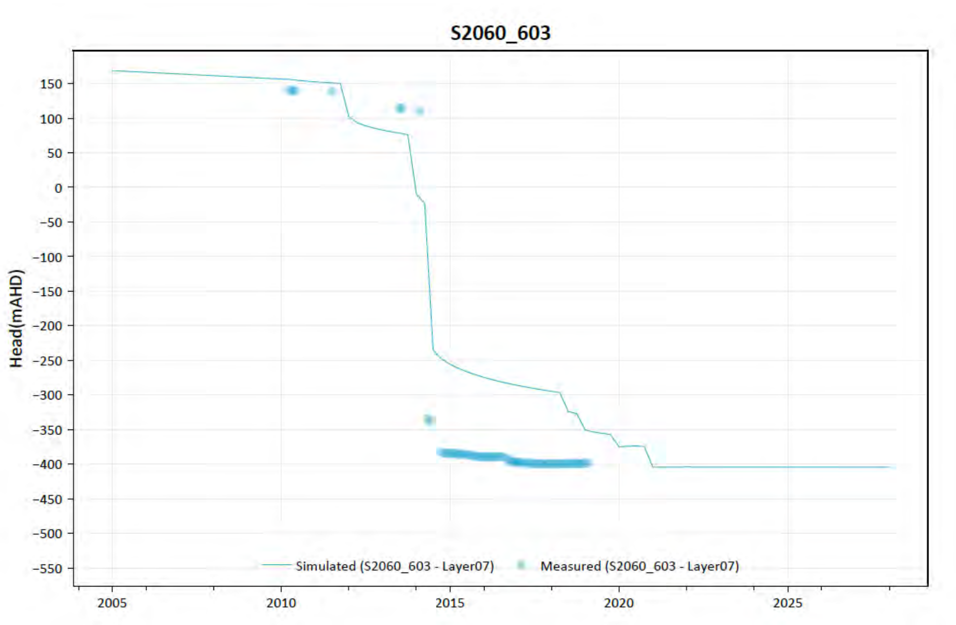


Figure 83 Modelled and Observed Hydrographs in S2060_603 in the Bulli Seam

4.2.2.5 Vertical Gradient

Groundwater flow systems are strongly influenced by heterogeneity and anisotropy of hydraulic conductivity (K). Particularly in stratified sedimentary aquifers, the vertical hydraulic gradient is often very high, due to the low vertical hydraulic conductivity or high anisotropy (Kx/Kz).

Structural simplifications are made in the model, including the vertical discretisation of the model and resulting 'coarse' representation of features and hydraulic gradients at scales of a model cell (or layer) or less. For example, strong vertical gradients may mean that a model, which predicts average water levels for a cell, will struggle to replicate an observed water level if that water level is from the upper or lower portion of that layer. For example, if a model layer that is 50 m thick and the vertical gradient is 1 in 10, this can lead to errors of +/- 5 m.

The vertical gradient at the project area is mainly the result of the aquifer system and properties and mining impacts rather than abstraction rate, which is too limited at depth to make an imprint.

Figure 84 to **Figure 92**show the observed against simulated water levels at selected VWPs within or close to the project area. From each plot, the difference in water level between two sensors divided by the vertical distance of the two sensors can be interpreted as the vertical gradient. The observed vertical gradients were discussed in **Section 3.2.4**. For simplicity, a downward hydraulic gradient is defined as the shallower sensor showing the higher water level, which means water is migrating toward the lower sensor. Conversely, an upward hydraulic gradient is defined as the deeper sensor showing the higher water level, which means water is migrating toward the shallower sensor. Even if the model cannot always capture absolute water levels correctly, it is a sign of a well calibrated model if the gradients are captured correctly (i.e. which way the water is travelling).

The model captures the observed upwards hydraulic gradients at S1913 (**Figure 84**) and S2315 (**Figure 85**) presenting higher water levels in Scarborough Sandstone than Bulgo Sandstone and HBSS.

The downwards hydraulic gradients from upper HBSS to lower HBSS at S2308 (**Figure 86**), S1941 (**Figure 87**) and S2080 (**Figure 89)**, are also captured by the model.

The model was not able to match the vertical gradient in some locations (e.g., S1954 shown in **Figure 91** or S1996 in **Figure 88).** The model inability to match the vertical gradient is due to structural simplifications in the model resulting in 'coarse' representation of features and hydraulic gradients at scales of a model cell (or layer) or less.

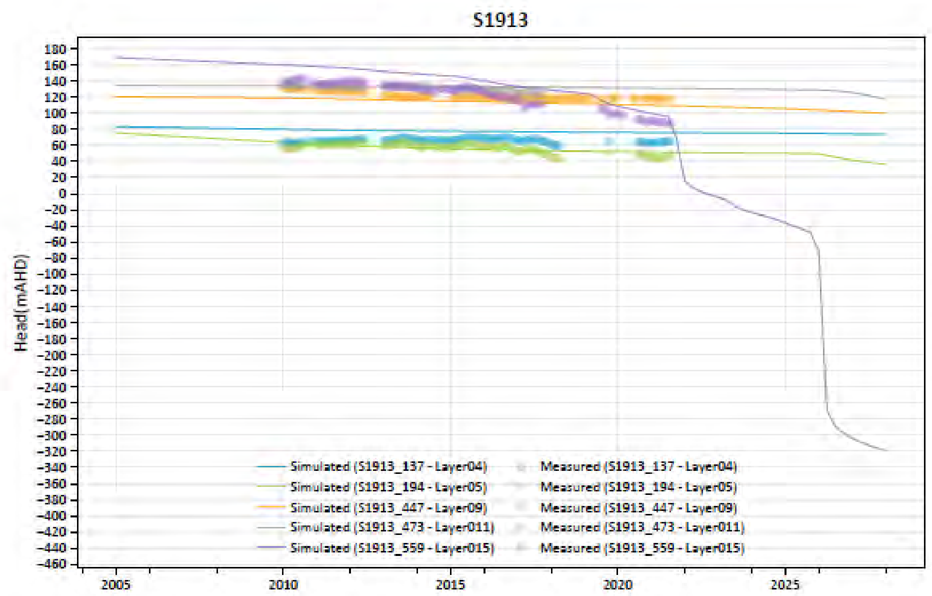


Figure 84 Modelled and Observed Hydrograph at S1913

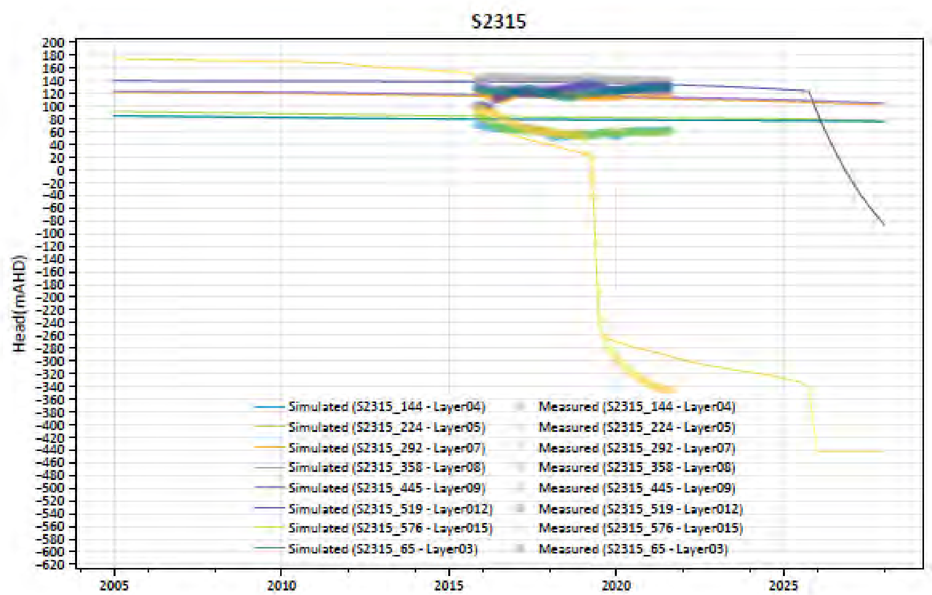


Figure 85 Modelled and Observed Hydrograph at S2315

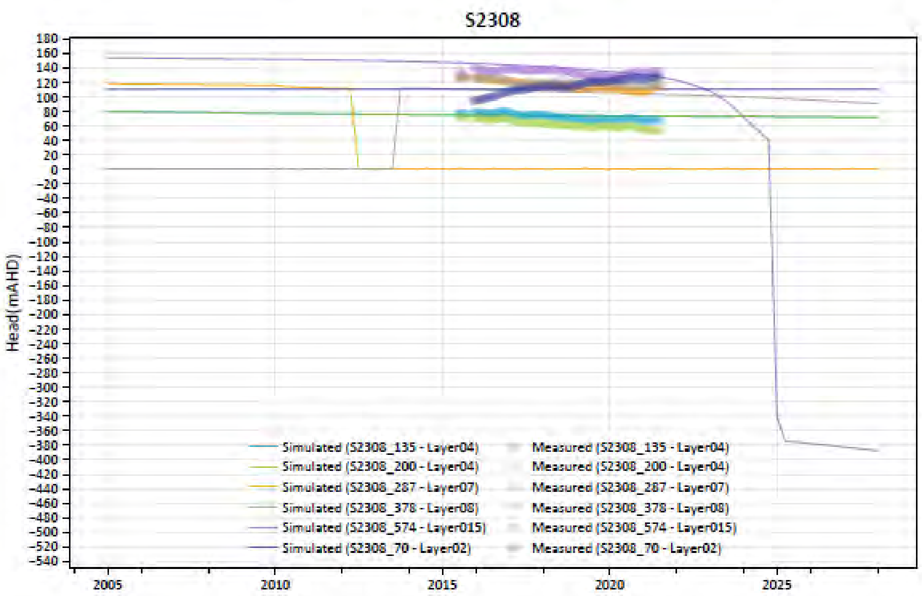


Figure 86 Modelled and Observed Hydrograph at S2308

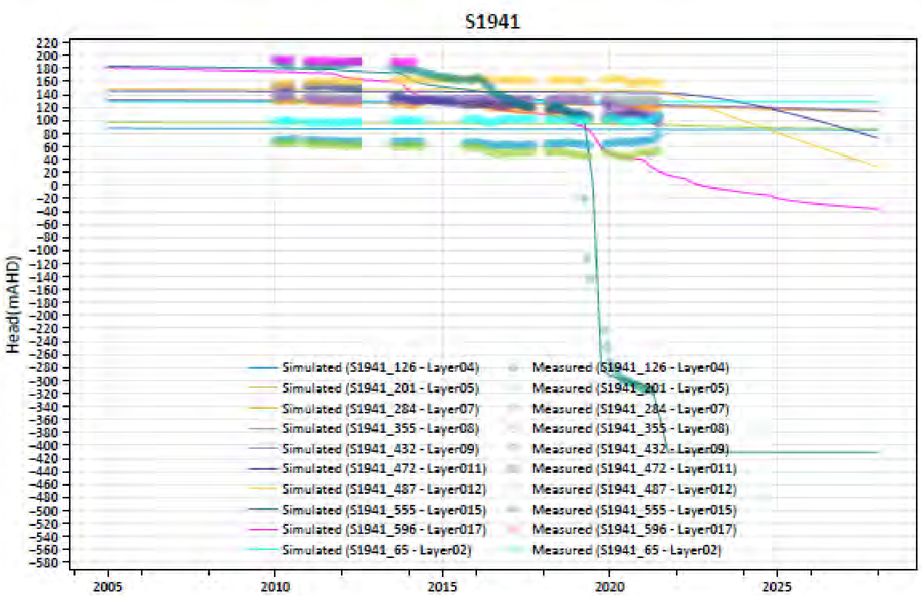


Figure 87 Modelled and Observed Hydrograph at S1941

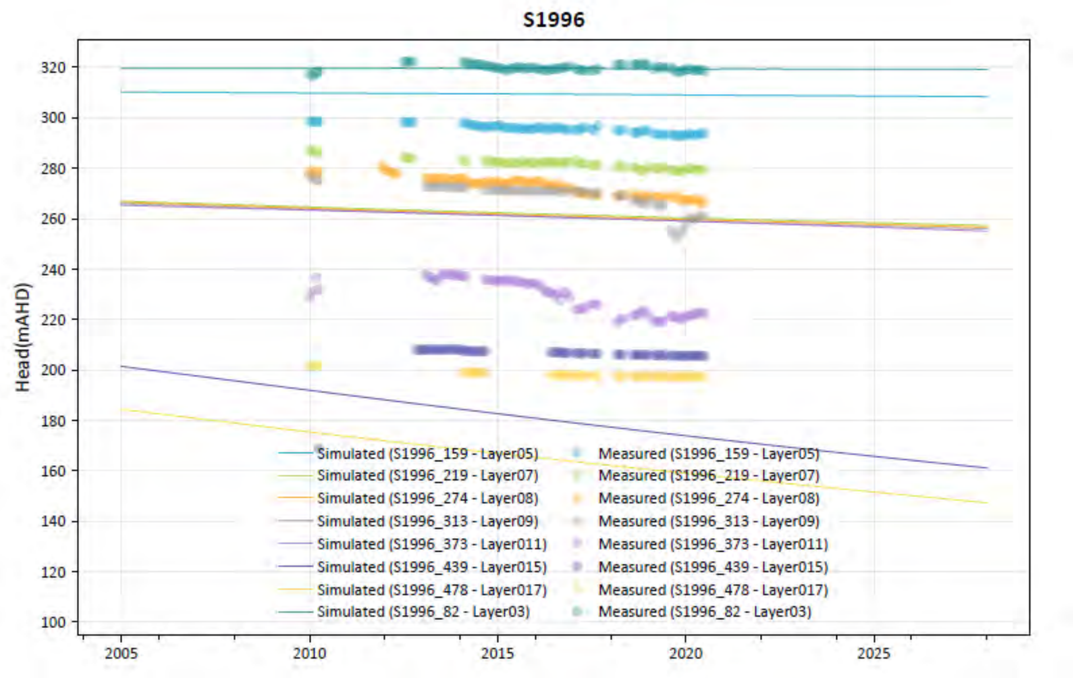


Figure 88 Modelled and Observed Hydrograph at S1996

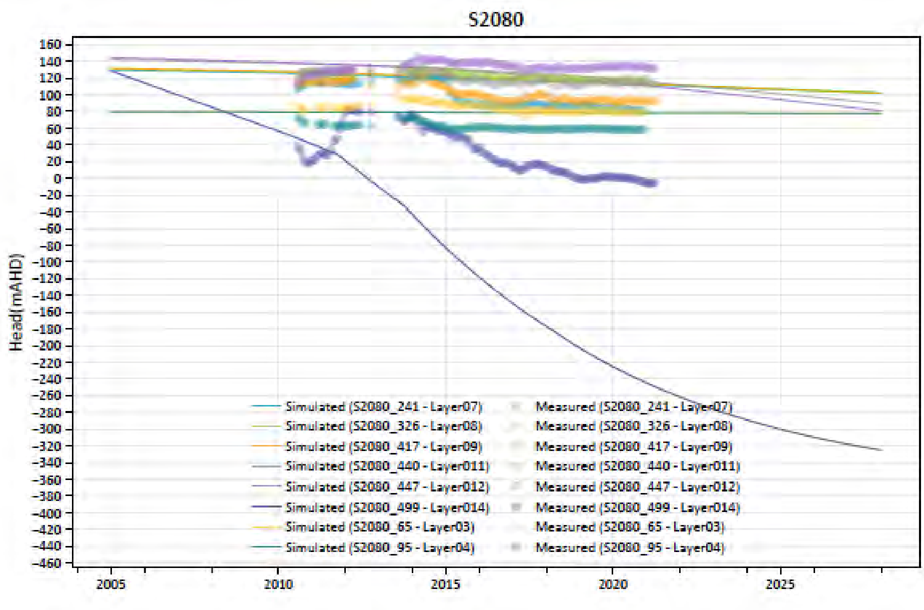


Figure 89 Modelled and Observed Hydrograph at S2080

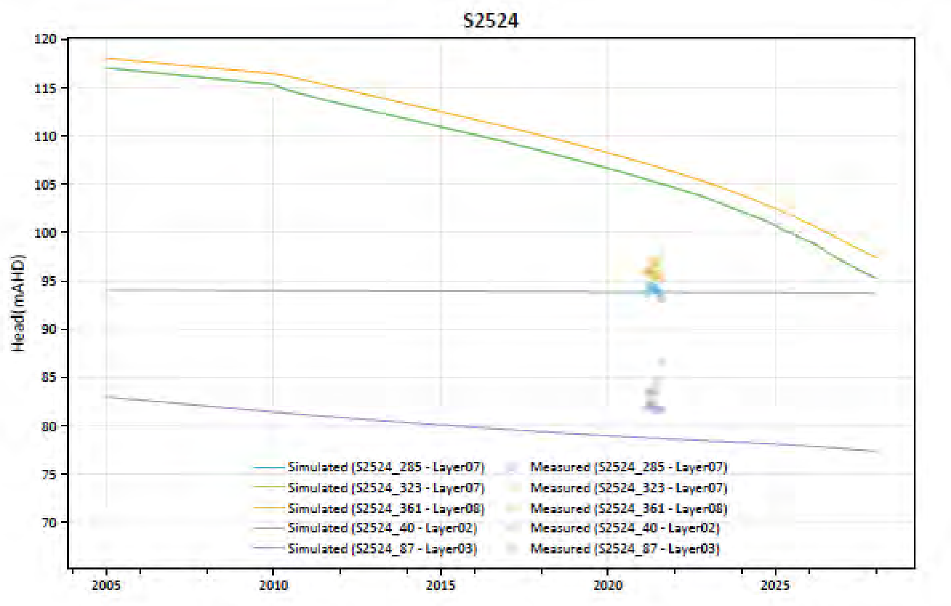


Figure 90 Modelled and Observed Hydrograph at S2524

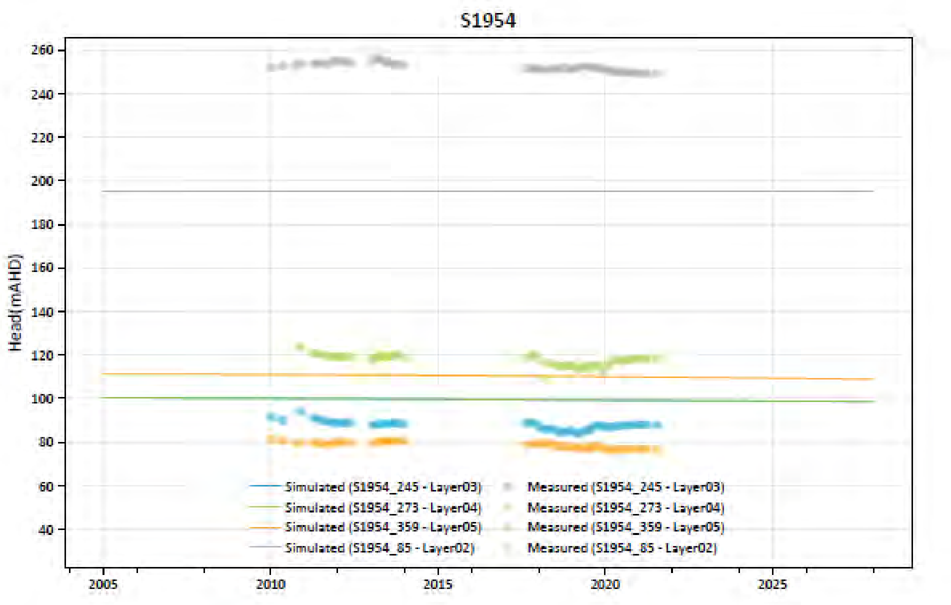


Figure 91 Modelled and Observed Hydrograph at S1954

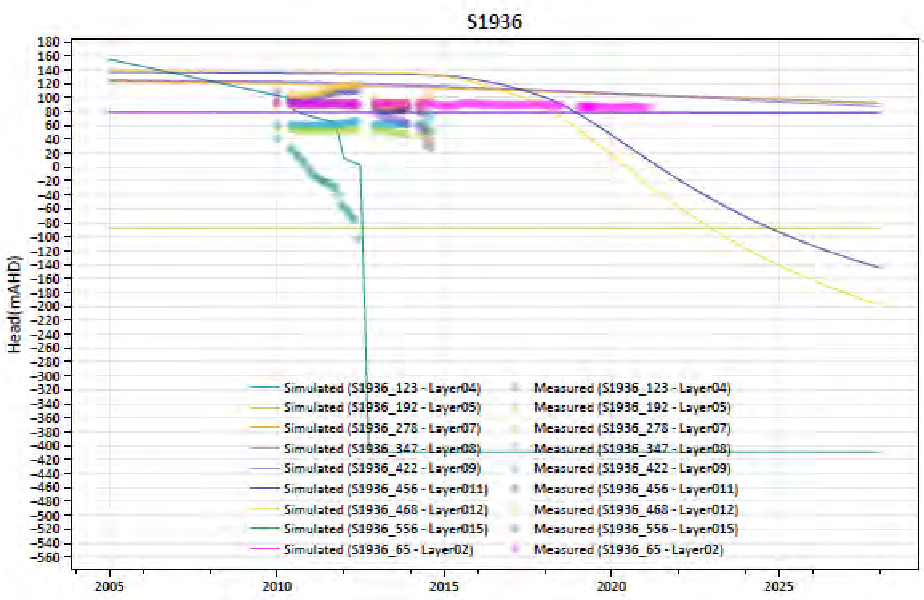


Figure 92 Modelled and Observed Hydrograph at S1936

4.2.2.6 Inflows to Underground Mine Workings

While the observed groundwater inflows were not included in the calibration data base the simulated calibrated inflows were compare against the observed inflows to verify the predicted inflow.

Mine inflows were extracted from the groundwater model files using the MODFLOW-USG 'Zone Budget' utility. This was done on a zone-by-zone basis for the various mine areas within the model domain. **Figure 93** compares the simulated mine inflows against the historical measurements at Appin Area 7 and 9. The figure shows that the model matches the magnitude of inflows and the general trend, with the exception of overestimation of inflows for Area 7 in 2019.

The site balance for Appin Area 9 (HGEO, 2019) reported average inflow of approximately 0.5 ML/day for 2017-2019 period which is slightly higher than predicted inflows for Area 9 for the same period.

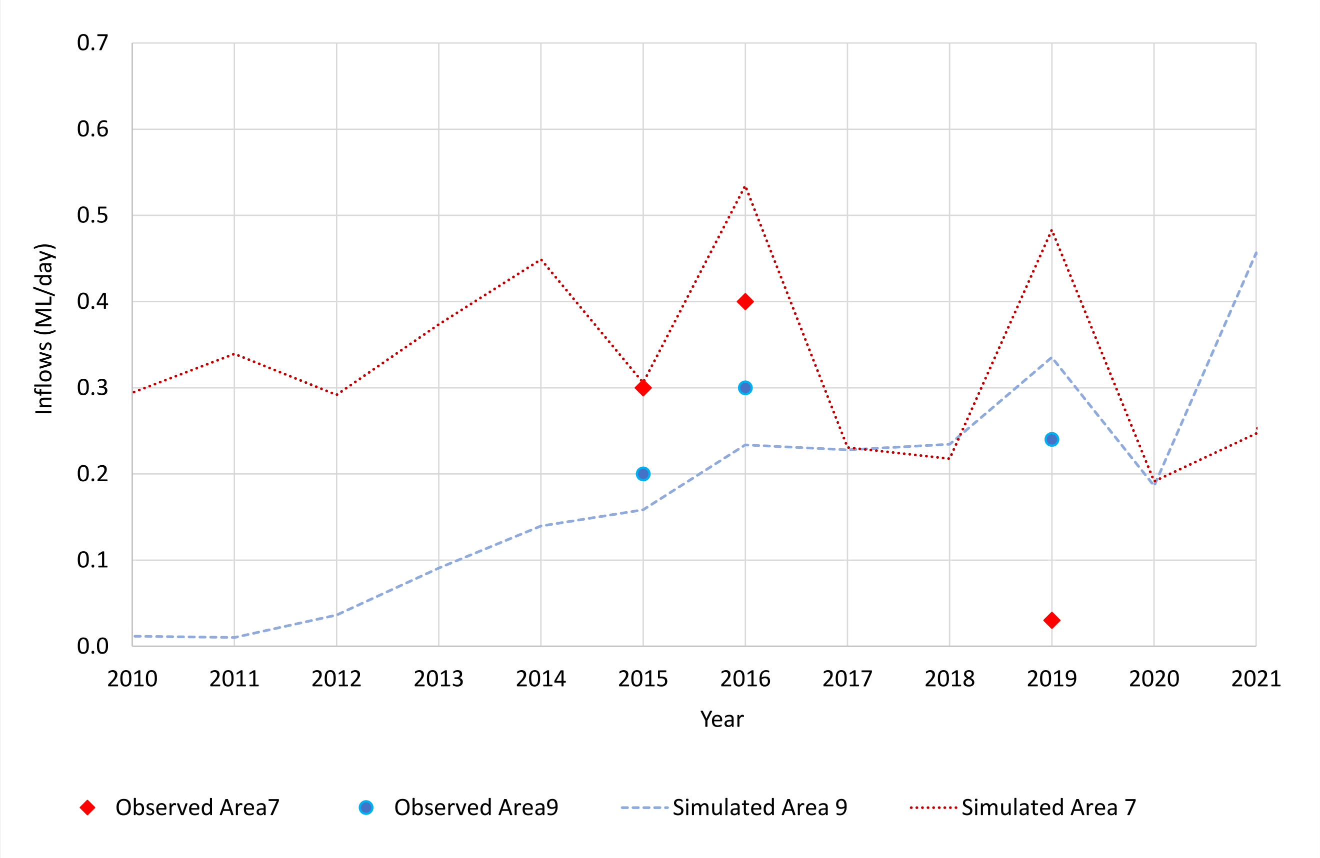


Figure 93 Comparison of Observed and Modelled Inflow at Appin

4.2.3 Calibrated Parameters

Table 19 summarises the calibrated values for horizontal and vertical hydraulic conductivity as well as specific yield and specific storage. Both manual and automatic (Parameter Estimation (PEST) calibration were carried out. PEST was used to identify the most suitable hydraulic conductivity, specific yield, specific storage and percentage rainfall recharge in zones within the Appin, Tahmoor and Metropolitan mining areas.

Parameter ranges used during calibration are shown in **Appendix E**.

Table 19 Calibrated Hydraulic Properties

Layer	Zone	Kx [m/d]	Kz [m/d]	Kz/Kx	Sy	Ss [m^{-1}]
1	Alluvium - 1	$4.2\times10^{+00}$	6.5×10^{-02}	1.5×10^{-02}	2.7×10^{-01}	3.0×10^{-05}
	Wianamatta Group - 19	1.0×10^{-03}	1.0×10^{-05}	1.0×10^{-02}	1.0×10^{-02}	1.0×10^{-07}
	HBSS - 20	1.0×10^{-02}	3.3×10^{-04}	3.0×10^{-02}	9.1×10^{-02}	1.0×10^{-07}
	Swamps - 21	$6.9\times10^{+00}$	5.9×10^{-01}	8.5×10^{-02}	1.0×10^{-01}	1.0×10^{-07}
	Lake and Bay - 22	$2.00\times10^{+02}$	$1.6\times10^{+02}$	8.0×10^{-01}	8.3×10^{-02}	1.0×10^{-07}
	Escarpment Zone -23	3.9×10^{-01}	3.9×10^{-01}	$1.0\times10^{+00}$	6.6×10^{-03}	1.0×10^{-07}
2	Wianamatta Group - 2	1.0×10^{-05}	3.2×10^{-07}	3.2×10^{-02}	2.5×10^{-03}	1.0×10^{-05}
	HBSS - 24	6.2×10^{-03}	6.2×10^{-03}	$1.0\times10^{+00}$	2.6×10^{-02}	1.5×10^{-05}
	HBSS under Wianamatta Group -25	3.3×10^{-03}	3.3×10^{-03}	$1.0\times10^{+00}$	1.4×10^{-02}	9.8×10^{-06}
3	Upper HBSS	1.9×10^{-02}	6.5×10^{-04}	3.3×10^{-02}	4.3×10^{-02}	1.0×10^{-05}
4	Upper HBSS	1.0×10^{-03}	5.0×10^{-04}	5.0×10^{-01}	1.0×10^{-02}	2.6×10^{-05}
5	Lower HBSS	1.0×10^{-04}	1.2×10^{-06}	1.2×10^{-02}	1.2×10^{-02}	3.0×10^{-06}
6	Bald Hill Claystone	1.8×10^{-05}	6.1×10^{-07}	3.3×10^{-02}	9.4×10^{-03}	1.0×10^{-07}
7	Bulgo Sandstone	1.4×10^{-03}	1.7×10^{-05}	1.2×10^{-02}	8.1×10^{-02}	1.0×10^{-07}
8	Bulgo Sandstone	4.4×10^{-04}	1.8×10^{-05}	4.0×10^{-02}	1.3×10^{-02}	1.0×10^{-06}
9	Bulgo Sandstone	7.5×10^{-04}	9.9×10^{-06}	1.3×10^{-02}	1.6×10^{-02}	1.0×10^{-06}
10	Stanwell Park Claystone	$7.3\times10\text{-}^{07}$	7.8×10^{-08}	1.0×10^{-01}	4.5×10^{-03}	1.0×10^{-07}
11	Upper Scarborough	2.7×10^{-05}	2.7×10^{-07}	1.0×10^{-02}	1.3×10^{-02}	1.7×10^{-06}
12	Lower Scarborough	1.9×10^{-05}	1.9×10^{-07}	1.0×10^{-02}	9.1×10^{-03}	3.4×10^{-06}
13	Wombarra Claystone	3.3×10^{-06}	4.1×10^{-08}	1.2×10^{-02}	7.6×10^{-03}	1.0×10^{-07}
14	Coal Cliff Sandstone	1.1×10^{-04}	5.5×10^{-07}	4.8×10^{-03}	4.5×10^{-03}	5.0×10^{-06}
15	Bulli Coal Seam	1.0×10^{-03}	5.6×10^{-05}	5.6×10^{-02}	9.0×10^{-03}	1.0×10^{-07}
16	Interburden	3.5×10^{-05}	3.5×10^{-07}	1.0×10^{-02}	7.3×10^{-03}	1.0×10^{-07}
17	Wongawilli Seam	1.8×10^{-02}	2.9×10^{-03}	1.6×10^{-01}	4.8×10^{-03}	1.0×10^{-07}
18	Lower Permian Coal Measures	7.2×10^{-05}	2.6×10^{-06}	3.6×10^{-02}	2.1×10^{-03}	1.0×10^{-06}
7 - 18	Faults	1.1×10^{-02}	1.7×10^{-03}	1.5×10^{-01}	4.5×10^{-02}	1.7×10^{-07}

Figure 94 shows that the calibrated horizontal and vertical conductivities are within the range of the observed dataset in the Bulgo Sandstone, Bald Hill Claystone and HBSS. The calibrated vertical conductivities for the Stanwell Park Claystone, Scarborough Sandstone and Wombarra Claystone are lower than the lower range of the core testing results.

The calibrated horizontal conductivity values for the HBSS are within the ranges of site measurements. For Wombarra Claystone, Stanwell Park Claystone and Wombarra Claystone, the calibrated horizontal conductivity values are lower than the lower range of the site measurements.

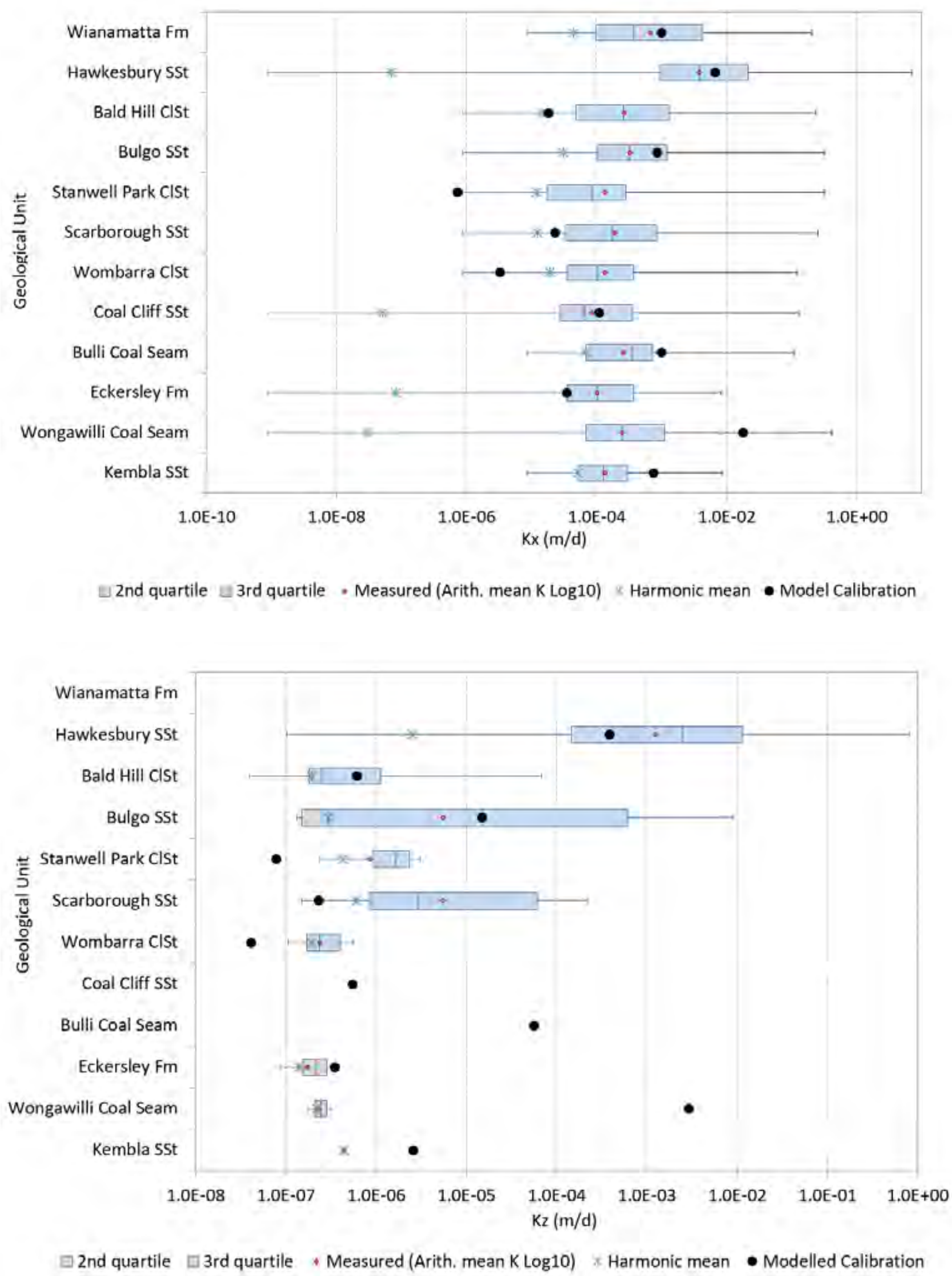


Figure 94 Modelled vs Measured Horizontal and Vertical Conductivity

Table 20 presents the range in recharge values for the model domain, as a percentage of quarterly rainfall. The PEST calibration simulates an optimised rainfall recharge. The calibrated recharge rates are lower than the Heritage Computing (2009) model, which may relate to a significantly greater calibration dataset and the increase in model time resolution to quarterly time steps and the use of observed streamflow data to better capture seasonality. The calibrated recharge rates shown in **Table 20** are at the lower range of the recharge rates presented in **Section 3.7**.

Table 20 Calibrated Rainfall Recharge

Zone	Calibrated Recharge (% Quarterly Rainfall)	Heritage Computing (2009) Recharge (% Annual Rainfall)
Alluvium/Swamps	5	20
Wianamatta Group	0.5	7.5
Western HBSSs	0.5	5
Eastern HBSSs	0.7	5
Central HBSSs	1.7	5

As discussed in **Section 4.2**, the bore pumping rates were included in the calibration. The calibrated pumping rates were in a range of 0.001 L/s and 2.4 L/s. The average calibrated pumping rate was 0.18 L/s.

4.2.4 Water Balance

4.2.4.1 Steady State Calibration

The water balance for the steady state model calibration is shown in **Table 21.** The water balance for the steady-state model indicates that recharge was the largest net inflow contributor to the model (55.2 ML/d). The process that contributes significantly to outflow from the groundwater system is evapotranspiration (47.8 ML/d outflow). A net outflow of 7.0 ML/d from the model occurs due to baseflow seepage. This is the second largest component of outflow from the model during steady state calibration.

The mass balance error for the steady state calibration is 0.00 %, within the error threshold recommended by the Australian Groundwater Modelling Guidelines (AGMG) (Barnett et al., 2012), and indicating the model is stable and achieves an accurate numerical solution.

Table 21 Groundwater Model - Water Budget/Balance (Steady state)

Component	Groundwater Inflow (Recharge) (ML/day)	Groundwater Outflow (Discharge) (ML/day)	Inflow – Outflow (ML/day)
Rainfall Recharge	55.2	-	55.2
Evapotranspiration	-	47.8	-47.8
Rivers/Creeks	4.1	11.1	-7.0
Constant Head (CHD)	1.4	1.8	-0.4
Mines	-	-	-
Wells	-	-	-
Storage	-	-	-

Component	Groundwater Inflow (Recharge) (ML/day)	Groundwater Outflow (Discharge) (ML/day)	Inflow – Outflow (ML/day)
Total	**60.7**	**60.7**	**0.0**

4.2.4.2 Transient Calibration

The water balance during the transient calibration period across the entire model area is summarised in **Table 22**. The average inflow (recharge) to the groundwater system is approximately 54.4 megalitres per day (ML/d), comprising rainfall recharge (80%), leakage from streams to the groundwater system (6%) and constant head boundary inflow from lakes and ocean (3%).

Consitent with the steady-state model, the largest proportion of model outflows is the evapotranspiration (69%), followed by baseflow to rivers and streams (16%), constant head boundary outflow (3.4%), mine inflows (4%) and wells (<1%). There was a net gain in storage of approximately 3.0 ML/d over the calibration period.

The mass balance error for the transition calibration is less than <0.001 % which is within the error threshold recommended by the AGMG (Barnett et al., 2012). The mass balance error in all the model timesteps was less than 0.01% indicating the model is stable and achieves an accurate numerical solution.

Table 22 Groundwater Model - Water Budget/Balance (January 2010 -June 2021)

Component	Groundwater Inflow (Recharge) (ML/day)	Groundwater Outflow (Discharge) (ML/day)	Inflow – Outflow (ML/day)
Rainfall Recharge	54.4	-	54.4
Evapotranspiration	-	47.2	-47.2
Rivers/Creeks	4.3	10.9	-6.6
Constant Head (CHD)	1.9	2.2	-0.3
Mines	-	2.5	-2.5
Wells	-	0.8	-0.8
Storage	7.6	4.6	3.0
Total	**68.2**	**68.2**	**0.0**

4.3 Summary of Model Performance

4.3.1.1 Model Confidence

The groundwater modelling was conducted in accordance with the AGMG (Barnett et al. 2012), the MDBC Groundwater Flow Modelling Guideline (MDBC, 2001) and the released IESC Explanatory Note for Uncertainty Analysis (IESC, 2018). These are mostly generic guides and do not include specific guidelines on special applications, such as underground coal mine modelling.

The AGMG has replaced the model complexity classification of the previous guideline by a "model confidence level" (Class 1, Class 2 or Class 3 in order of increasing confidence) typically depending on:

- Available data (and the accuracy of that data) for the conceptualisation, design and construction.
- Calibration procedures that are undertaken during model development.
- Consistency between the calibration and predictive analysis.
- Level of stresses applied in predictive models.

Table 23 (based on Table 2.1, Barnett et al. 2012) summarises the classification criteria and shows a scoring system allowing model classification. Based on **Table 23**, the Appin groundwater model developed for this Groundwater Assessment may be classified primarily as Class 2 (effectively "medium confidence") with some items meeting Class 3 criteria, which is considered an appropriate level.

Table 23 Groundwater Model Classification Table

Class	Data	Calibration	Prediction	Indicators	Total
1	Not much. Sparse No metered usage Low res. Top DEM Poor aquifer geometry Basic conceptualisation 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>10xcalibration. Stresses>5xcalibration Mass balance>1% (or single 5%). Properties<>Field. Bad discretisation. No review.	
Count	0	0	0	0	0
2	**Some, poor coverage**. **Some usage info.** Baseflow estimates. Some high res topo DEM and adequate aquifer geometry **Sound conceptualisation reviewed & stress-tested**	**Partial performance.** Some long-term trends wrong. Short time record. **Weak seasonal replication.** No use of targets compatible with model purpose. Non-unique sensitivity ad qualitative uncertainty addressed	**Timeframe>calibration.** **Long stress periods.** New stresses not in calibration. Poor verification. Calibration and prediction consistent (transient and SS)	Timeframe=3-10x. Stresses=2-5x. **Mass balance<1%.** **Properties<>Field measurements.** **Some key coarse discretisation.** **Reviewed by hydrogeologist.**	
Count	3	2	2	4	11
3	Plenty of data, good coverage Good aquifer geometry Good, metered usage **Local climate info.** **K measurements** **Hi –res DEM.** Mature conceptualisation	Good performance stats. Long-term trends replicated. Seasonal fluctuations OK. **Present day data targets.** **Head and flux targets.** Non-uniqueness minimised & or parameter identifiable/minimum error variance or RCS assessed Sensitivity &/or qualitative uncertainty	Timeframe~calibration. Similar stress periods. Similar stresses to those in calibration. Steady state prediction consistent with steady state calibration. Good verification. Quantitative uncertainty analysis Suitable computational methods applies & parameters are consistent with conceptualisation	**Timeframe<3x.** **Stresses<2x.** **Mass balance<0.5%** Properties~Field measurements. Some key coarse discretisation. **Reviewed by modeller.**	
Count	3	1	0	4	8

4.3.1.2 Model Limitations

Table 24 presents the limitations related to the groundwater model and data and provides a commentary on whether the model is considered 'Fit for purpose' for the intended modelling objective (i.e. assess the potential impacts of mining on the groundwater related environment).

Table 24 Groundwater Model and Data Limitations

Type	Part	Status	Comment
Structural/ Conceptual	Grid and Model Extent	Fit for purpose	The model used an unstructured Voronoi grid that includes detailed cell refinement around site and along drainage features. The model extent has been revised to include current and future mine expansion.
		Fit for purpose	The model layers are not fully extensive. Use of the MODFLOW-USG 'pinch-out' functionality was employed to reduce overall cell count. This process removed the need to have a minimum thickness and layer continuity where a stratigraphic unit is absent.
	Layers / geometry	Fit for purpose	Top of layer 1 incorporates site LiDAR data for Appin Mine.
		Fit for purpose	The structure of the geology is based on detailed data at site but regional model geometry (outside of site) interpolated based on the latest available Southern Coalfields Geological Model (July 2018) (herein referred to as the Sydney Basin Model).
	Conceptualisation – Geological Structure	Fit for purpose, with future improvements possible, with review of future geological investigations	On-going geological investigations conducted across Appin have been reviewed and findings incorporated in the model conceptualisation. No new potential causal pathways were identified with no significant changes implemented in the conceptual model. Future field studies can improve representation of all zones of fracturing (especially disconnected/dilated zone).

Type	Part	Status	Comment
	Conceptualisation – Surface Water Groundwater Interactions	Fit for purpose, future improvements possible where new data collected	The understanding of interaction between surface water and groundwater (i.e. Nepean River, Cataract River, Stonequarry Creek and Georges River) was discussed in the conceptual model using latest observations and findings across the Appin Mine. The new alluvium bore S2536 installed recently will improve the conceptualisation of surface water groundwater interactions.
	Conceptualisation – GDEs	Fit for purpose	A review of the Bureau of Meterology (BoM) GDE and the relevant WSP for the Project has been conducted and is presented in the conceptual section of the report.
	Conceptualisation – Saturated Extent of Alluvium and Regolith/Hawkesbury Sandstone	Fit for purpose, with improvements possible where new data collected.	The conceptual model has presented all the existing groundwater monitoring data and recent data collected. Future groundwater monitoring sites will be presented in future work.
Parameterisation	Hydraulic Conductivity	Fit for purpose, with improvements possible where additional site data become available	Existing hydraulic conductivity database has been updated with the latest field testing of hydraulic conductivity (horizontal and to a lesser extent vertical) at Appin Mine, Tahmoor Mine and Dendrobium Mine. The data shows a general decline in hydraulic conductivity with depth that is replicated in the model. The current model does not use depth dependence function for the coal seams, and this is considered a future improvement for the model.
	Hydraulic Conductivity - Heterogeneity	Fit for purpose with improvements possible	Zones and uniform parameter values have been used to delineate hydraulic properties (K and S). The model has adopted uniform properties in layers while the actual hydraulic properties is more heterogenous than represented in the model. As more data are gathered, the spatial distributions of aquifer properties can be refined. The use of pilot points for hydraulic properties to allow a better representation of the natural heterogeneity of aquifer properties can help with improvement in calibration.

Type	Part	Status	Comment
	Goaf Effects	Fit for purpose, with improvements possible where new data collected	A full fracture profile including Ditton Zone A, Ditton Zone B, Cave Zone, and surface fracturing was included in the model. The parameters for all these zones were manually adjusted. Calibrating fracture profile properties could be considered in the future updates of the model.
	Rivers	Fit for purpose, with improvements possible where new data collected	River stage heights are changed temporally in the historical calibration model based on observed levels from government stream gauges, and average quarterly levels assumed in the predictive model. No site-specific information on surface water discharge, flow monitoring has been included in the model but could be included in future. No measurement of bed-conductance and hydraulic properties was conducted but if available, they could be included in the future version of the model. The riverbed conductance can be added to the calibration parameters in the future versions of the model.
	Recharge	Fit for purpose, Future improvements possible	Recharge zonation is based on mapped surface geology and recharge rates calibrated. Future improvement using LUMPREM2 soil moisture model to calculate the recharge. LUMPREM2 is a soil moisture store model developed by Watermark Numerical Computing (2021). Recharge rates and LUMPREM2 parameters can be adjusted by the calibration process. Using pilot points for recharge could also provide better special variability for recharge entering the groundwater model.
	Evapotranspiration	Fit for purpose with future improvements possible	Simulated as a constant potential EVT rate from groundwater. Future improvement includes adding the EVT parameters to the calibration data set in the future version of the model.
	Drains (mine operations)	Fit for purpose	Historical and approved mine plan data has been sought by IMC and used to simulate up-to-date mine plans.

Type	Part	Status	Comment
	Groundwater pumping	Fit for purpose, with improvements possible where reliable data is available.	Groundwater pumping by third party bore users is highly uncertain (in terms of rates). Bore use across Appin Mine was included in the model. Groundwater pumping via MODFLOW Wells has been included in calibration and prediction. If more reliable data is available from WaterNSW/DPE-Water (although review of the Water Register suggests that it is not), this will be incorporated into future work.
Data Sources	Observation Data Quality	Fit for purpose, with improvements possible where new data is collected.	Recent groundwater observations ending in 2021 have been incorporated for the observation bore file prior to calibration. This includes observation data across the Appin Mine but could in the future also include new monitoring sites installed as part of the Groundwater Monitoring Plan.
	Landholder Bore Data Quality	Fit for purpose, but potentially review in future.	Impacts on registered landholder bores are influenced by the assumptions of the bore design, target geology and use. A landowner bore survey is recommended
	Temporal spread	Fit for purpose	Timeseries groundwater level data from the site as well as the neighbouring mines. SLR incorporated all data for Appin up to late 2021. Some additional data for Tahmoor and Dendrobium mine were also included in the calibration dataset.

Type	Part	Status	Comment
Measurement Error	Settings	Fit for purpose	The model has 'solver' settings where the head close (HCLOSE) criteria is currently set to 0.001 m.
Scenario Uncertainties Future stresses/ conditions	Calibration	Fit for purpose	A combined steady state and transient calibration was carried out with data available between 2009 to 2021. Automated (PEST++) was used to calibrate the model. The model was only calibrated to observed groundwater levels. The simulated inflows were verified by comparing to measured inflows for Appin Area 7 and 9. The calibration was carried out by changing hydraulic conductivities, storage parameters and recharge. Boundary conditions such as rivers and EVT were not calibrated. Limited verification against baseflow estimates along local watercourses, this needs to be improved if sufficient data is available.
	Predictive	Fit for purpose	Latest mine plan for Appin mine was incorporated in the model.
	Sensitivity and uncertainty	To be completed	Sensitivity analysis was carried out on hydraulic conductivity, storage parameters, recharge rates and fracture zone properties). The primary outcome of sensitivity was that many of the model parameters can be highly constrained by calibration. An uncertainty analysis could be carried out using the outcome of the sensitivity analysis.

4.4 Model Predictions

Transient predictive modelling was used to simulate the proposed mining at the Project as well as mining at other approved and foreseeable mines within the model domain. As discussed in **Section 4.1.3**, the predictive part of the model comprises quarterly stress periods starting from July 2021 until December 2027. Transient predictive models are developed for model scenarios:

- Null Run – No mining in region;
- Basecase Run - All approved Appin Mine and all foreseeable neighbour mines, AGL CSG and registered borefields excluding mining of Longwalls 709 to 711 and 905;
- Cumulative Run - All approved Appin Mine and all foreseeable neighbour mines, AGL CSG and registered borefields including mining of Longwalls 709 to 711 and 905; and
- Null Appin Mine Run – All foreseeable neighbours' mines, AGL CSG and registered borefields, excluding the Appin Mine.

Timings of active drain cells at the Project were based on mine progression stage plans. As discussed in **Section 4.1.4.5**, MODFLOW Time Varying Materials (TVM) package was used to assign fractured properties to the cells above the longwall panels.

The model predictions include mine inflows, change in river baseflow, groundwater depressurisation and depressurisation at landholder bores which are presented in the following sections.

4.4.1 Predicted Groundwater Interception

Mine inflow volumes have been calculated as time weighted averages of the outflow reported by Zone Budget software for the drain cells.

The predicted inflows due to the Project mining (i.e., Longwalls 709 to 711 and Longwall 905) and the total combined (Approved plus Project) for Appin are presented in **Figure 95**. The predicted average future total inflow rate over the duration of mining (Approved plus Project) is 165.3 ML/year (0.45 ML/day).

As shown in **Figure 95**, inflows due to the Project are predicted to reach a maximum peak in year 2024, with 47.5 ML inflow predicted for the year (0.13 ML/day). The average inflow rate due to the Project is 16.7 ML/year (0.05 ML/day).

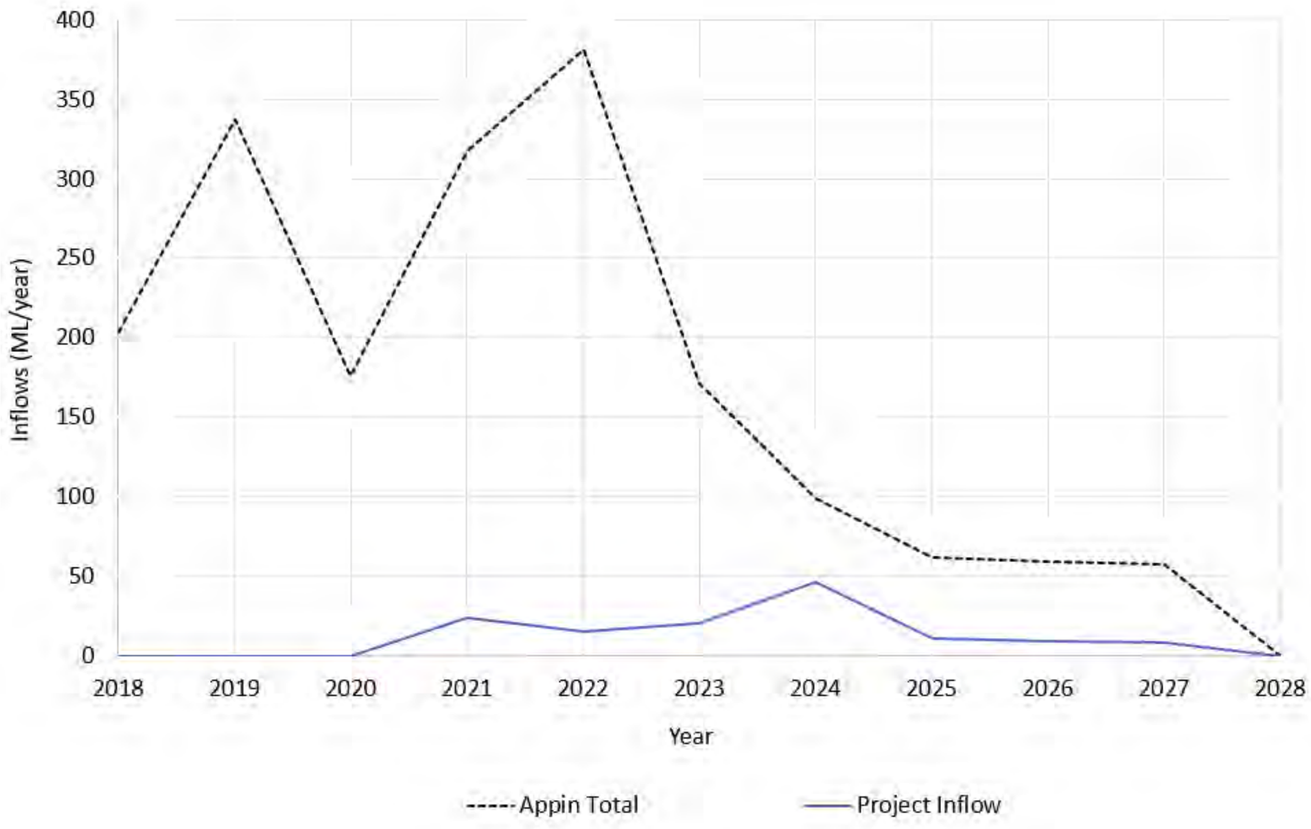


Figure 95 Predicted Mine Inflow for Appin Mine

4.4.2 Baseflow Change

The change in river leakage due to the Project was calculated by comparing the river flow budgets for Navigation Creek, Navigation Creek Tributary 1 and Foot Onslow Creek in the Approved plus Project Appin Mine scenario against the Null Extension scenario. This calculation showed that over the life of the Project, the change in the baseflow is insignificant. This prediction is consistent with the predicted depressurisations shown in **Section 4.4.3** where the model predicted no depressurisation along Nepean River, Cataract River and Stonequarry Creek.

4.4.3 Maximum Predicted Depressurisation During Operations

The process of mining directly removes water from the groundwater system and reduces groundwater levels in surrounding groundwater units. The extent of the zone affected is dependent on the properties of the aquifers/aquitards and is referred to as the zone of depressurisation. Aquifer depressurisation is greatest at the working coal-face and decreases with distance from the mine.

4.4.3.1 Maximum Incremental Depressurisations during Operations

Maximum incremental depressurisation refers to the depressurisation impact associated with mining of Longwalls 709 to 711 and 905 and is obtained by comparing the difference in predicted aquifer groundwater levels for the Approved plus Project Appin Mine scenario and NULL Extension scenario at matching times. The maximum depressurisation represents the maximum depressurisation values recorded at each model cell at any time over the model duration. **Figure 96** to **Figure 99** show where maximum depressurisation impacts due to mining at Longwalls 709 to 711 and 905 are predicted to exceed 2 m in Lower HBSS (Layer 5), Upper Bulgo Sandstone (Layer 7), Lower Scarborough Sandstone (Layer 12) and Bulli Seam (Layer 15).

Negligible depressurisation impact is predicted in the Alluvium (Layer 1), Wianamatta Group (Layer 2), upper HBSS (Layer 3) and Middle HBSS (Layer 4).

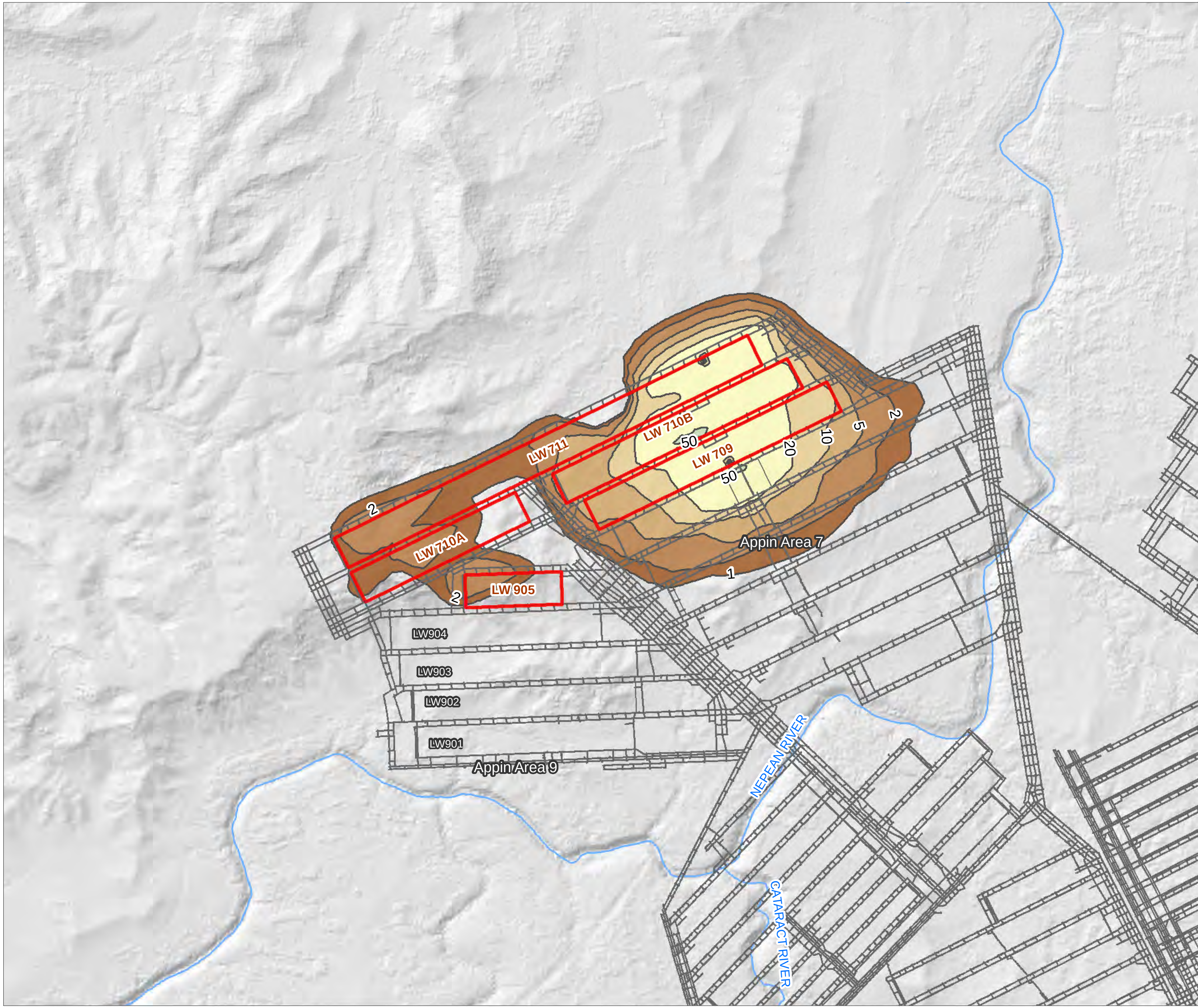
The figures show:

- The Lower HBSS Sandstone (Layer 5) is predicted to experience depressurisation up to 50 m within the footprint of Longwalls 709, 710, 711 and up to 4 m within the footprint of Longwall 905. The 1 m depressurisation contour is predicted to primarily remain within the footprint of the Project area and within 400 m (**Figure 96**).
- Upper Bulgo Sandstone (Layer 7) is predicted to experience depressurisation (up to 8 m) within the footprint of Longwalls 709, 710, 711 and 905 due to mining at these longwalls with the 2 m depressurisation predicted to extend to 600 m surrounding the Longwalls 710, 711 and 905 footprint.
- The Lower Scarborough Sandstone (Layer 12) is predicted to experience significant depressurisation (up to 200 m within the footprint of Longwalls 710, 711 and 905, 200 m on Longwall 709) due to mining at these longwalls and 2 m depressurisation contour extending approximately 300 m surrounding the Longwalls 710, 711 and 905 footprint (**Figure 98**).
- For the Bulli Coal Seam (Layer 15) there is significant depressurisation predicted due to mining at Longwalls 709 to 711 and 905 (**Figure 99**). As is to be expected, the area of greatest impact closely coincides with the mined area (about 500 m depressurisation at Longwall 711, 450 m on Longwall 710, 400 m on Longwall 709 and 150 m on Longwall 905 within the coal seam). The predicted 2 m depressurisation contour extending from Longwalls 710, 711 and 905 footprint extent up to approximately 2,200 – 2,700 m to the north and northeast, 1,400 m to the west and 150 m to the south.

APPIN MINE GROUNDWATER ASSESSMENT

INCREMENTAL MAXIMUM DEPRESSURISATION (M) IN LOWER HBSS DUE TO MINING AT LONGWALLS 709 TO 711 AND 905

FIGURE 96



Watercourse
Mine Plan
Project Area

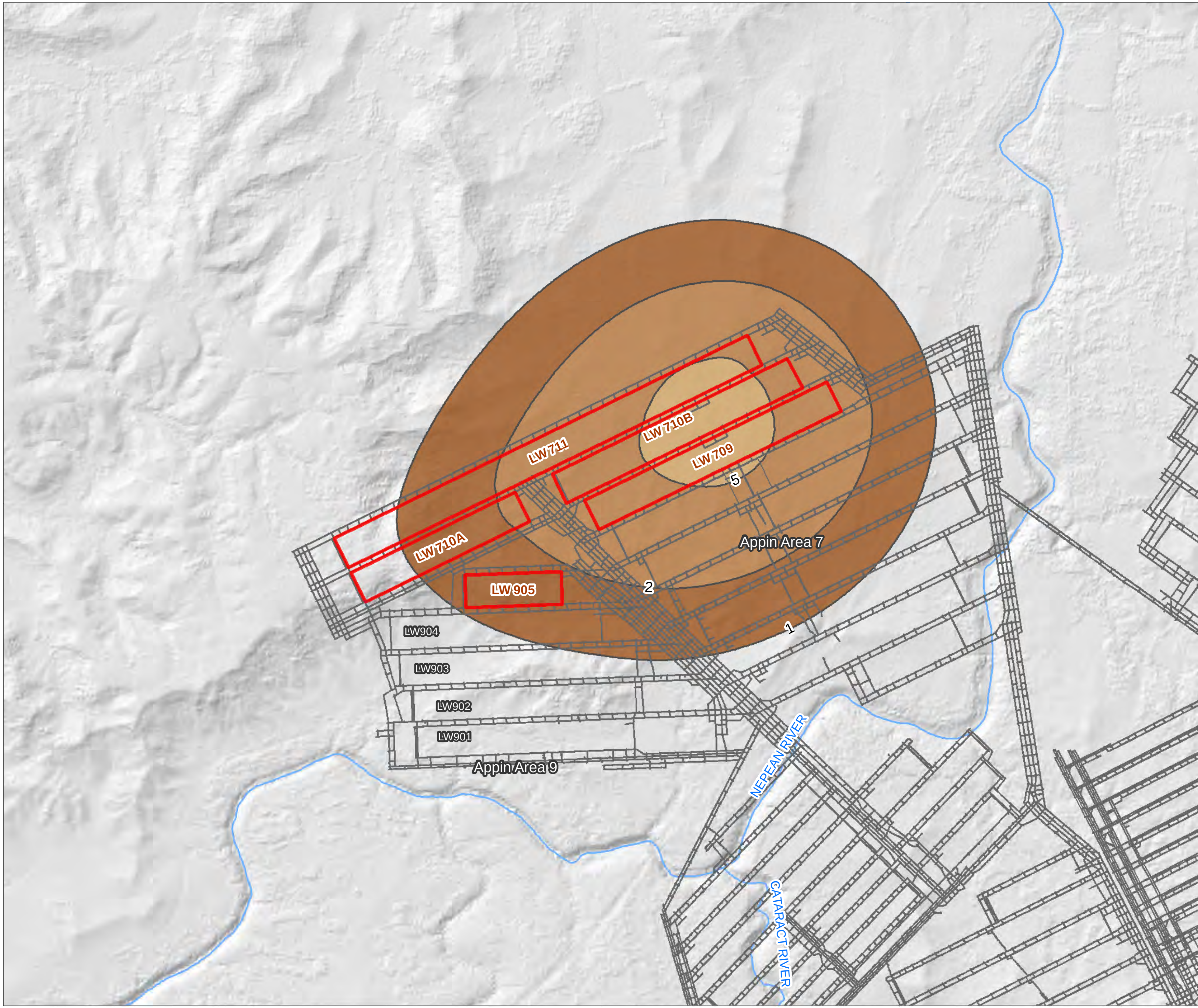
Groundwater Depressurisation (m)

1 - 2
2 - 5
5 - 10
10 - 20
20 - 50
50 - 100
100 - 200
200 - 500
> 500

0 1 2 km

Coordinate System:	GDA 1994 MGA Zone 56
Scale:	1:50,000 at A4
Project Number:	665.10015
Date:	07-Sep-2022
Drawn by:	NT
Reviewed by:	AM

Data Source: Mining Lease NSW Mineview Coal Lease 2019



APPIN MINE GROUNDWATER ASSESSMENT

INCREMENTAL MAXIMUM DEPRESSURISATION (M) IN UPPER BULGO SANDSTONE DUE TO MINING AT LONGWALLS 709 TO 711 AND 905

FIGURE 97

Watercourse
Mine Plan
Project Area

Groundwater Depressurisation (m)

1 - 2
2 - 5
5 - 10
10 - 20
20 - 50
50 - 100
100 - 200
200 - 500
> 500

0 1 2 km

Coordinate System:	GDA 1994 MGA Zone 56
Scale:	1:50,000 at A4
Project Number:	665.10015
Date:	07-Sep-2022
Drawn by:	NT
Reviewed by:	AM

Data Source: Mining Lease NSW Mineview Coal Lease 2019

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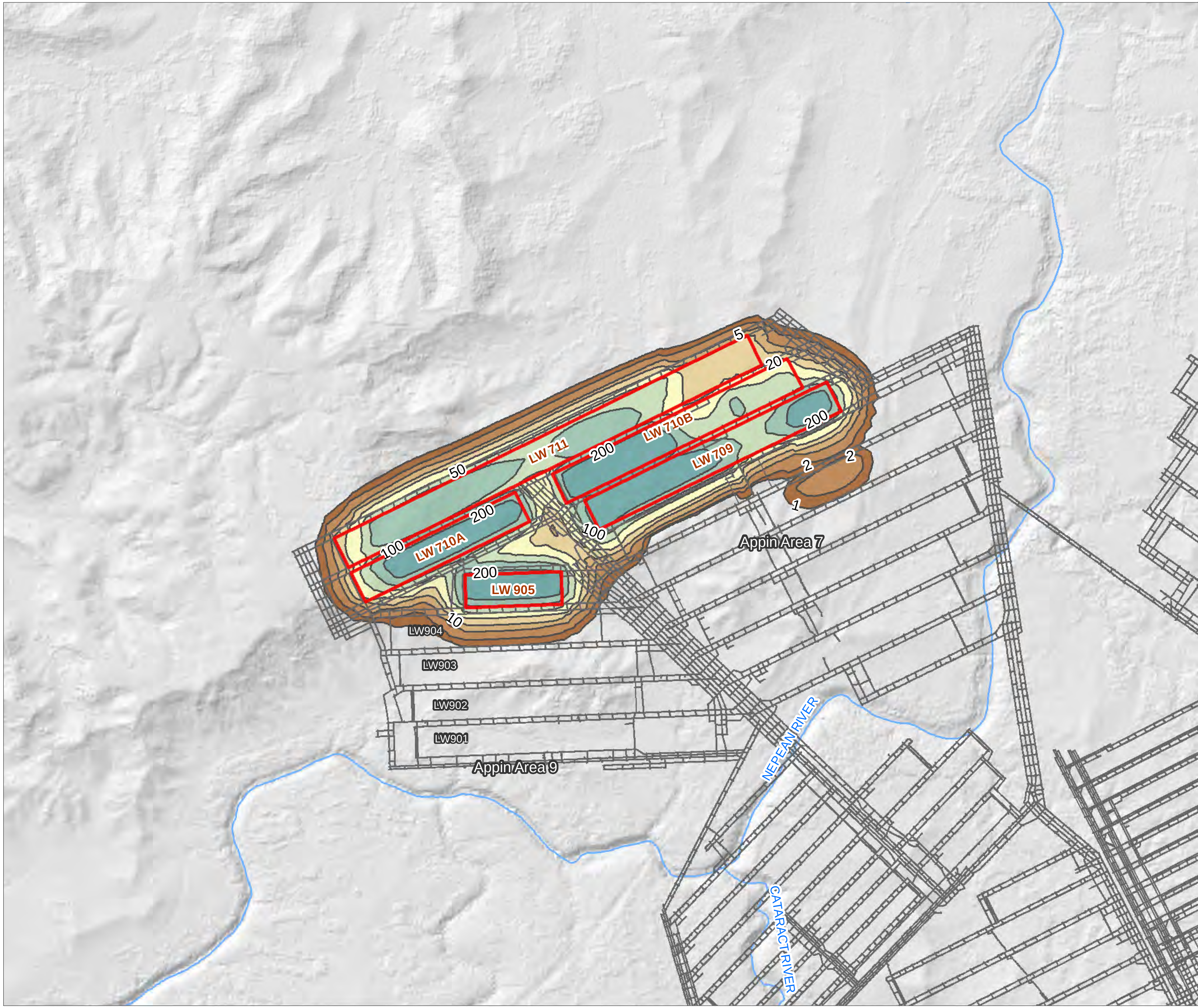


APPIN MINE GROUNDWATER ASSESSMENT

INCREMENTAL MAXIMUM DEPRESSURISATION (M) IN LOWER SCARBOROUGH SANDSTONE DUE TO MINING AT LONGWALLS 709 TO 711 AND 905

FIGURE 98

Watercourse

Mine Plan

Project Area

Groundwater Depressurisation (m)

1 - 2

2 - 5

5 - 10

10 - 20

20 - 50

50 - 100

100 - 200

200 - 500

> 500

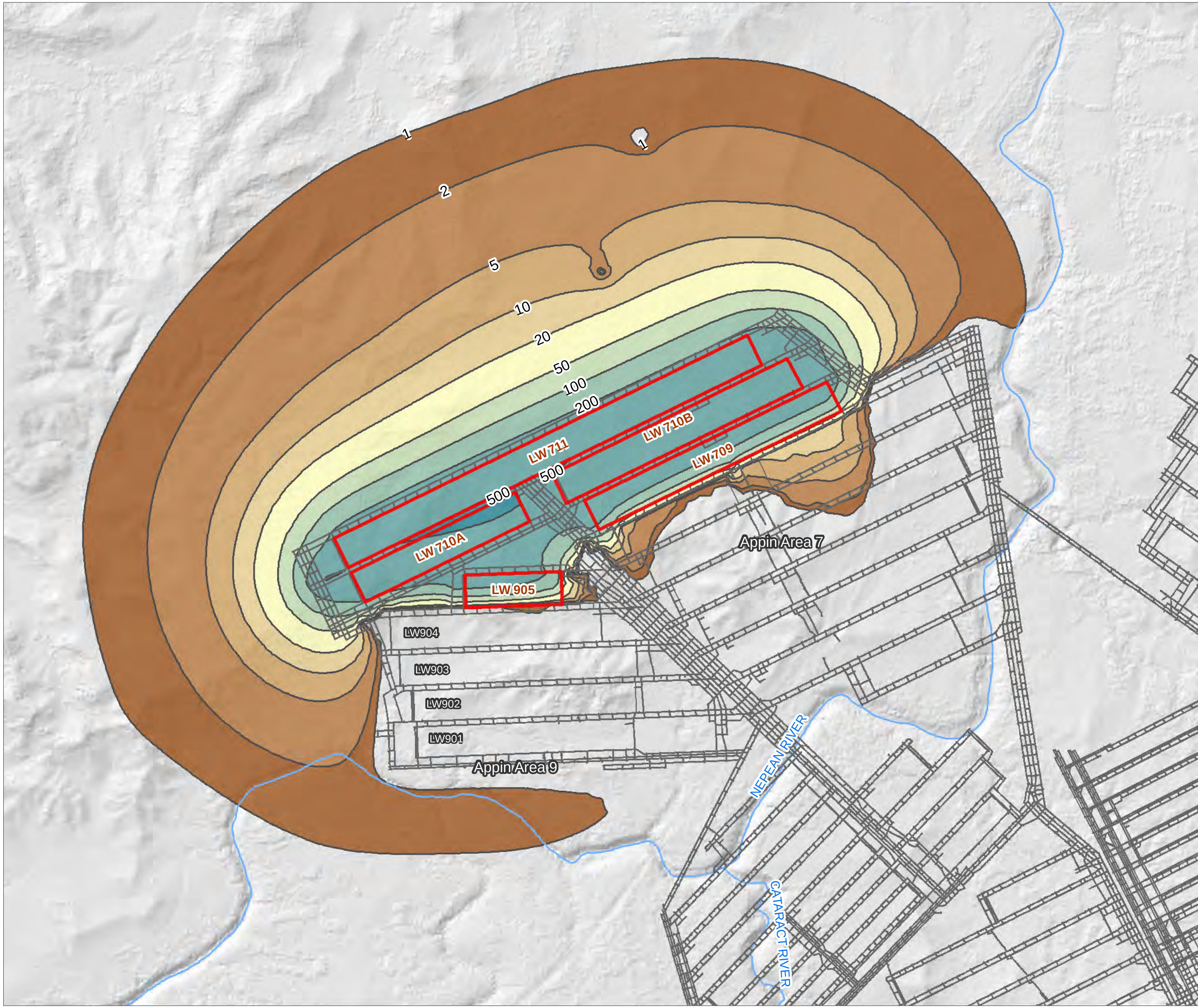
0 1 2 km

Coordinate System:	GDA 1994 MGA Zone 56
Scale:	1:50,000 at A4
Project Number:	665.10015
Date:	07-Sep-2022
Drawn by:	NT
Reviewed by:	AM

Data Source: Mining Lease NSW Mineview Coal Lease 2019

SLR

H:\Projects-SLR\620-BNE\665-WOL\665.10015 Illawarra Coal Closure - Water\CADGIS\ArcGIS\EP Report\665.10015 F96 Incremental Maximum Depressurisation (m) in Lower Scarborough due to Mining at Longwalls 709 to 711 and 905.mxd



APPIN MINE GROUNDWATER ASSESSMENT

INCREMENTAL MAXIMUM DEPRESSURISATION (M) IN BULLI SEAM DUE TO MINING AT LONGWALLS 709 TO 711 AND 905

FIGURE 99

Watercourse
Mine Plan
Project Area

Groundwater Depressurisation (m)

1 - 2
2 - 5
5 - 10
10 - 20
20 - 50
50 - 100
100 - 200
200 - 500
> 500

Coordinate System:	GDA 1994 MGA Zone 56
Scale:	1:50,000 at A4
Project Number:	665.10015
Date:	07-Sep-2022
Drawn by:	NT
Reviewed by:	AM

Data Source: Mining Lease NSW Mineview Coal Lease 2019

H:\Projects-SLR\620-BNE\665-WOL\665.10015 Illawarra Coal Closure - Water\CADGIS\ArcGIS\EP Report\665.10015 F97 Incremental Maximum Depressurisation (m) in Bulli Seam due to Mining at Longwalls 709 to 711 and 905.mxd

4.4.3.2 Maximum Cumulative Depressurisations during Operations

Maximum cumulative depressurisation impacts are shown in **Figure 100** to **Figure 106**. These depressurisations represent the total impact of mining to model groundwater levels by comparing the maximum difference in aquifer groundwater levels for the Approved plus Project Appin Mine scenario with those in a theoretical "No Mining" or Null Run scenario, for all times during the predictive model period.

Figure 100 to **Figure 106** present the predicted maximum cumulative depressurisation in the Alluvium (Layer 1), Wianamatta Group (Layer 2), Upper HBSS (Layer 3), Lower HBSS (Layer 5), Upper Bulgo Sandstone (Layer 7), Lower Scarborough Sandstone (Layer 12) and Bulli Seam (Layer 15), respectively.

The findings are:

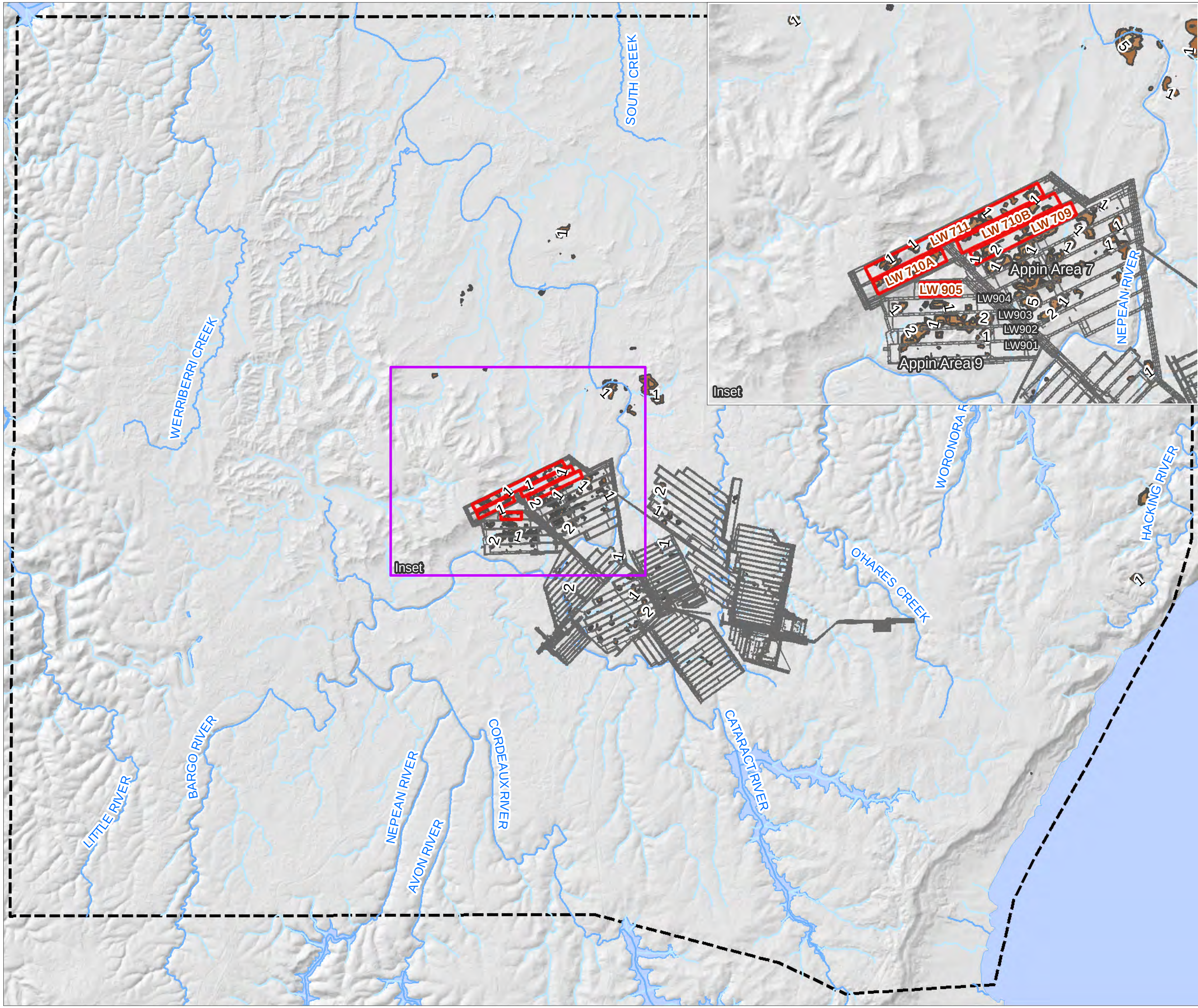
- There is a 5 m depressurisation contour surrounding Menangle Quarry in the Alluvium (Layer 1) and no additional depressurisation due to Appin Mine.
- Up to 10 m cumulative depressurisation is predicted to at least 2,000 m away from Appin Mine in the Wianamatta Group around the registered bores. This is due to both groundwater extraction and cumulative mining impacts.
- For the Upper HBSS there is 20 m predicted depressurisation around the central of Longwalls 710 and 711 surrounding the registered bores caused by the water supply extraction. The predicted 10 m depressurisation is extending from Longwalls 709 to 711 and 905 footprints 6,000 m to the north and 700 m to the south caused by the cumulative extraction from the registered bores.
- Similar to the predicted depressurisation in the Upper HBSS, the Lower HBSS (Layer 5) is predicted to experience significant depressurisation (up to 100 m), located around the registered bores caused by the water supply extraction. The predicted 2 m depressurisation contours from Appin Mine and Metropolitan Mine join, which means that there is cumulative impact in those areas.
- There is up to 40 m predicted depressurisation in the upper Bulgo Sandstone (Layer 7) at the Appin Mine, which consists of 30 m depressurisation surrounding two registered bores caused by the regional extraction and 10 m depressurisation caused by the historical mining at Appin. A maximum cumulative depressurisation of 50 m is predicted southeast of the Appin Mine. The predicted 10 m depressurisation contour from Appin Mine and Metropolitan Mine join, as do the 2 m depressurisation contours from Appin Mine and Tahmoor Mine, which means that there is cumulative impact in those areas.
- The Lower Scarborough Sandstone (Layer 12) is predicted to experience significant depressurisation up to 400 m within the approved Appin Mine footprint and 350 m within the project area. The predicted 10 m depressurisation contour from Appin Mine and Metropolitan Mine join, which means that there is cumulative impact in those areas.
- For the Bulli Coal Seam (Layer 15) there is significant depressurisation predicted up to approximately 600 m within the project area and 500 m within the approved mining area. The 200 m predicted depressurisation contour from Appin Mine and Metropolitan old mining area overlap, which means that there is cumulative impact in those areas. The predicted depressurisations outside the mine layout are all located around AGL CSG wells in response to CSG activities in the Bulli Coal Seam.

The shape and extent of the predicted maximum cumulative drawdown shown in **Figure 100** to **Figure 106** are consistent with the impact assessment conclusions for BSO by Heritage Computing (2009). However, the revised model includes additional layers which allows for greater granularity of impacts to individual strata units. This allows the revised model to predict maximum cumulative drawdowns which are larger than the previous model. The difference in drawdown magnitude is also likely due to refined fracture height profile in the model and updates in model calibration including the mine plans.

APPIN MINE GROUNDWATER ASSESSMENT

CUMULATIVE MAXIMUM DEPRESSURISATION (M) IN ALLUVIUM AND REGOLITH

FIGURE 100



- Major watercourse
- Minor watercourse
- Mine Plan
- Project Area
- Model Extent

Groundwater Depressurisation (m)

- 1 - 2
- 2 - 5
- 5 - 10
- 10 - 20
- 20 - 50
- 50 - 100
- 100 - 200
- 200 - 500
- > 500

0 2.5 5 km

Coordinate System:	GDA 1994 MGA Zone 56
Scale:	1:230,000 at A4
Project Number:	665.10015
Date:	07-Sep-2022
Drawn by:	NT
Reviewed by:	AM

Data Source: Mining Lease NSW Mineview Coal Lease 2019

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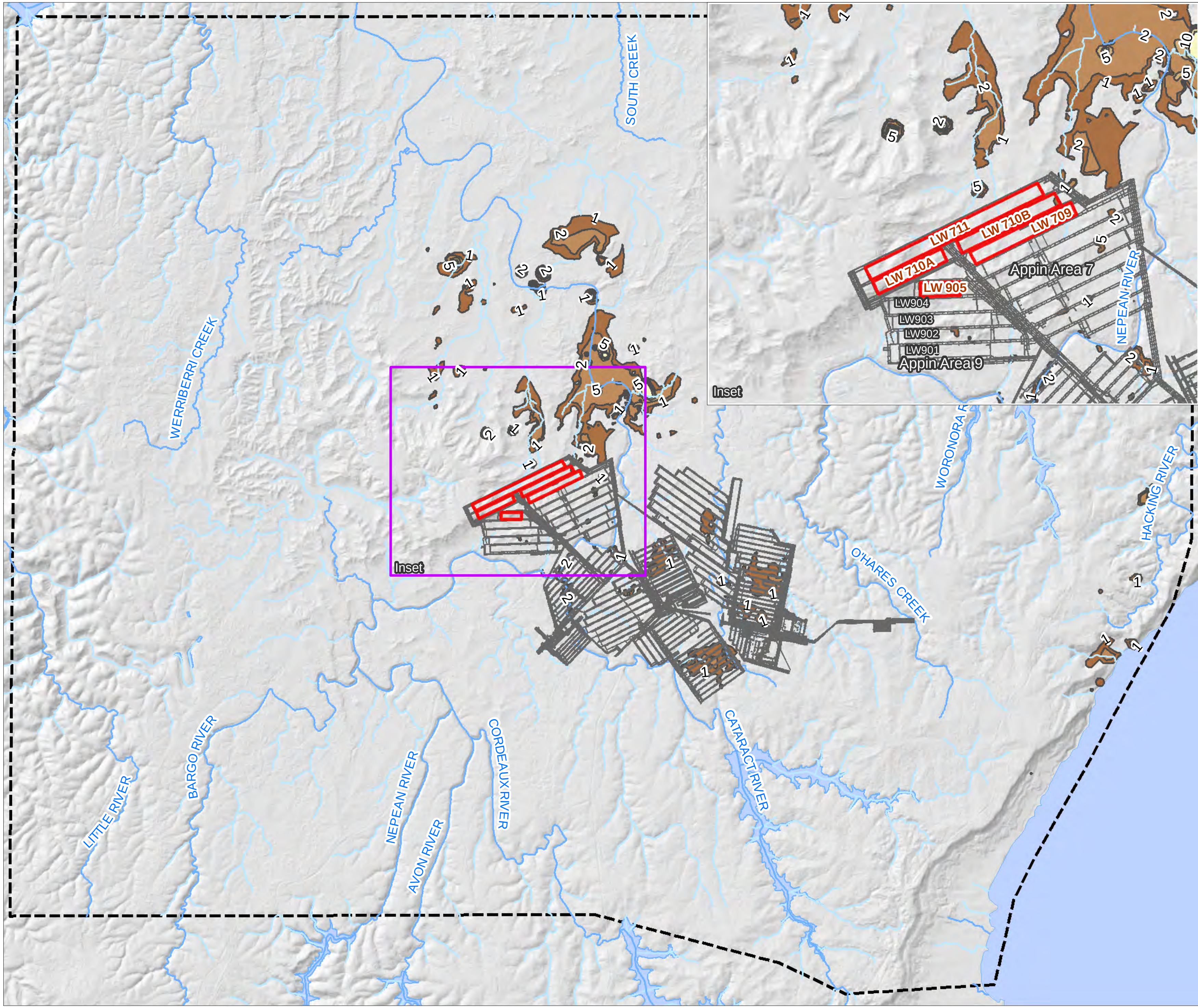


APPIN MINE GROUNDWATER ASSESSMENT

CUMULATIVE MAXIMUM DEPRESSURISATION (M) IN WIANAMATTA GROUP

FIGURE 101

Major watercourse
Minor watercourse
Mine Plan
Project Area
Model Extent

Groundwater Depressurisation (m)

1 - 2
2 - 5
5 - 10
10 - 20
20 - 50
50 - 100
100 - 200
200 - 500
> 500

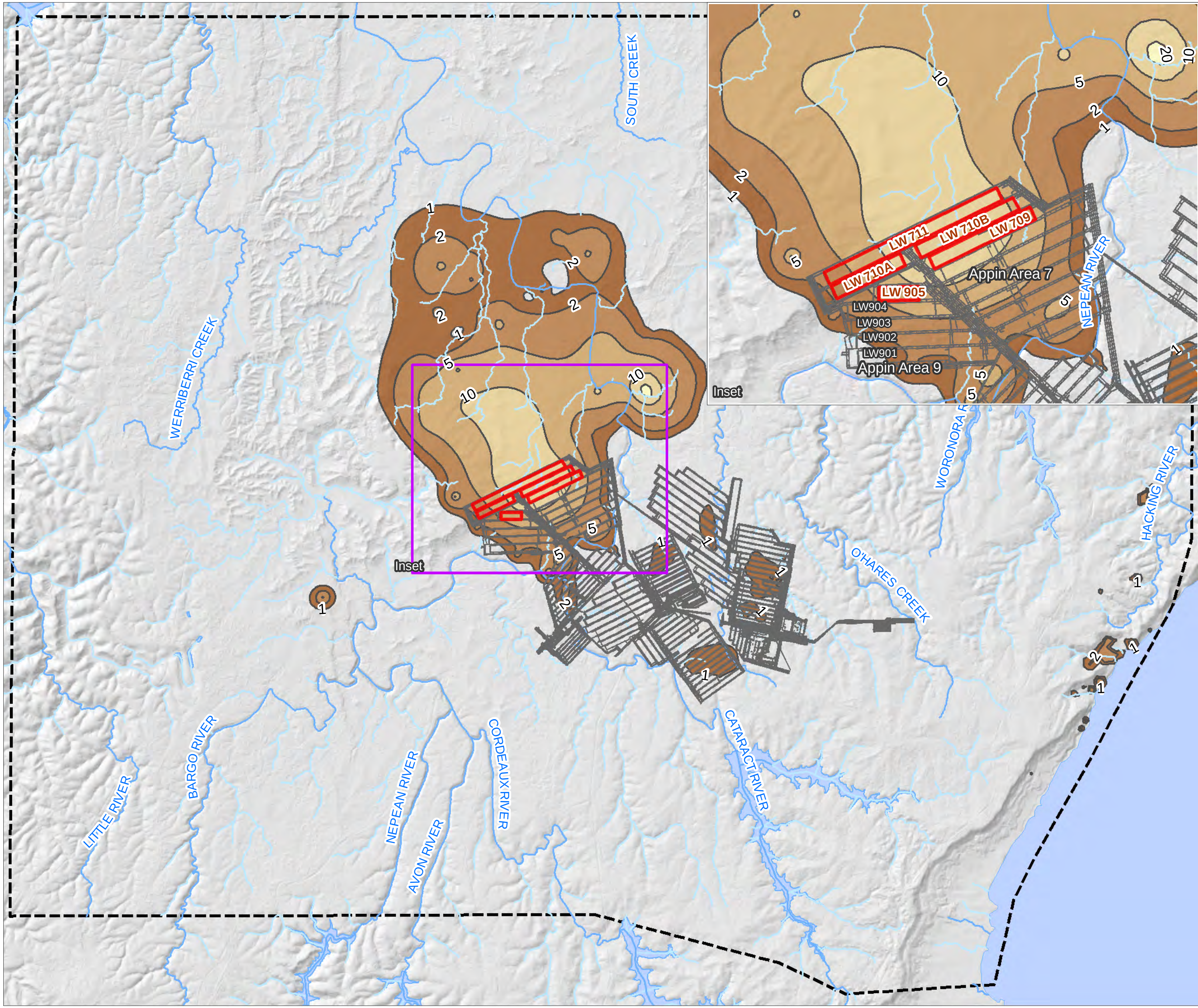
0 2.5 5 km

Coordinate System:	GDA 1994 MGA Zone 56
Scale:	1:230,000 at A4
Project Number:	665.10015
Date:	07-Sep-2022
Drawn by:	NT
Reviewed by:	AM

Data Source: Mining Lease NSW Mineview Coal Lease 2019

SLR

H:\Projects-SLR\620-BNE\665-WOL\665.10015 Illawarra Coal Closure - Water\CADGIS\ArcGIS\EP Report\665.10015 F99 Cumulative Maximum Depressurisation (m) in Wianamatta Group.mxd



APPIN MINE GROUNDWATER ASSESSMENT

CUMULATIVE MAXIMUM DEPRESSURISATION (M) IN UPPER HBSS

FIGURE 102

Major watercourse

Minor watercourse

Mine Plan

Project Area

Model Extent

Groundwater Depressurisation (m)

1 - 2

2 - 5

5 - 10

10 - 20

20 - 50

50 - 100

100 - 200

200 - 500

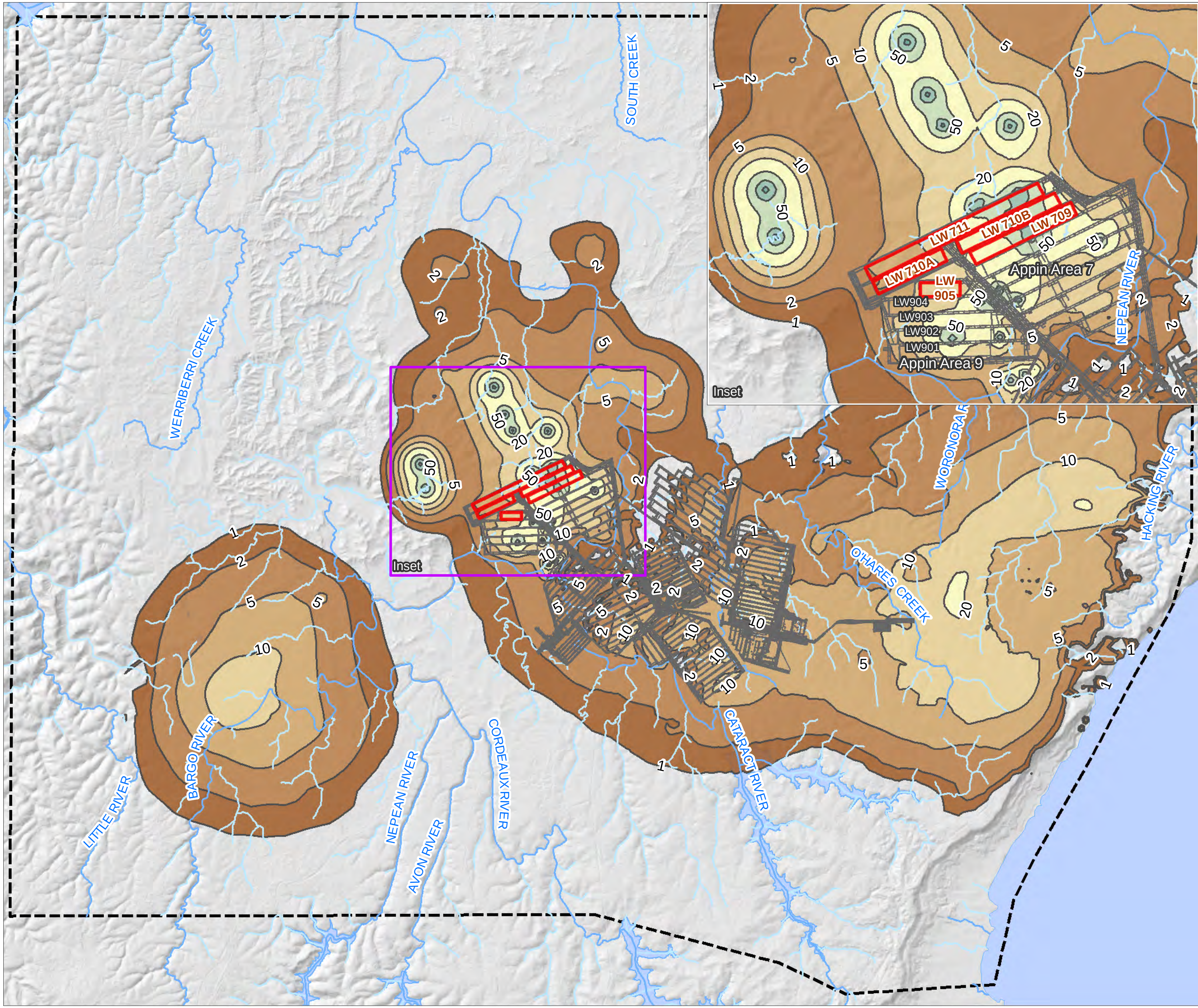
> 500

Coordinate System:	GDA 1994 MGA Zone 56
Scale:	1:230,000 at A4
Project Number:	665.10015
Date:	07-Sep-2022
Drawn by:	NT
Reviewed by:	AM

Data Source: Mining Lease NSW Mineview Coal Lease 2019

SLR

H:\Projects-SLR\620-BNE\665-WOL\665.10015 Illawarra Coal Closure - Water\CADGIS\ArcGIS\EP Report\665.10015 F100 Cumulative Maximum Depressurisation (m) in Upper HBSS.mxd



APPIN MINE GROUNDWATER ASSESSMENT

CUMULATIVE MAXIMUM DEPRESSURISATION (M) IN LOWER HBSS

FIGURE 103

- Major watercourse
- Minor watercourse
- Mine Plan
- Project Area
- Model Extent

Groundwater Depressurisation (m)

- 1 - 2
- 2 - 5
- 5 - 10
- 10 - 20
- 20 - 50
- 50 - 100
- 100 - 200
- 200 - 500
- > 500

0 2.5 5 km

Coordinate System:	GDA 1994 MGA Zone 56
Scale:	1:230,000 at A4
Project Number:	665.10015
Date:	07-Sep-2022
Drawn by:	NT
Reviewed by:	AM

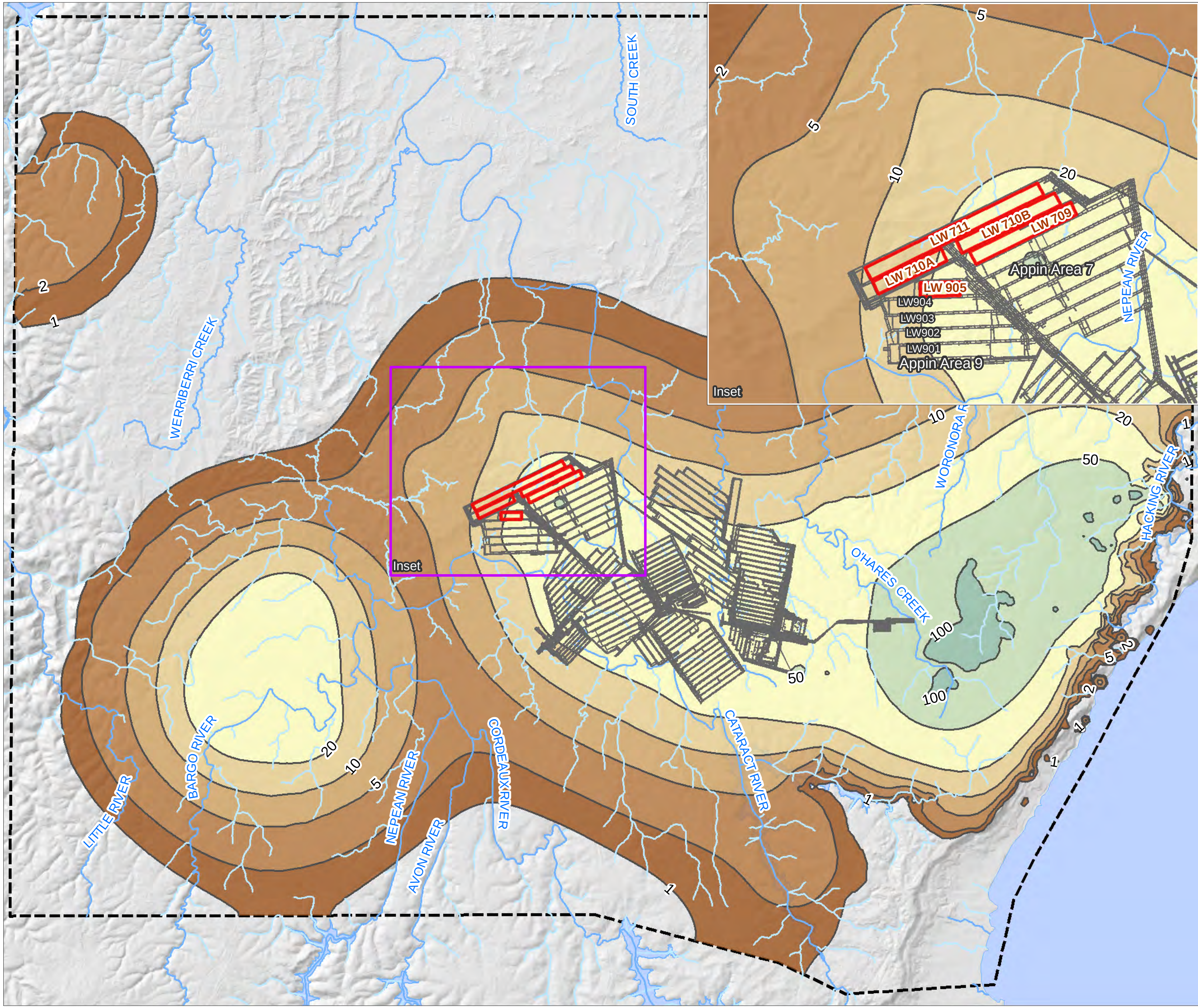
Data Source: Mining Lease NSW Mineview Coal Lease 2019

SLR

APPIN MINE GROUNDWATER ASSESSMENT

CUMULATIVE MAXIMUM DEPRESSURISATION (M) IN UPPER BULGO SANDSTONE

FIGURE 104



Major watercourse
Minor watercourse
Mine Plan
Project Area
Model Extent

Groundwater Depressurisation (m)

1 - 2
2 - 5
5 - 10
10 - 20
20 - 50
50 - 100
100 - 200
200 - 500
> 500

0 2.5 5 km

Coordinate System:	GDA 1994 MGA Zone 56
Scale:	1:230,000 at A4
Project Number:	665.10015
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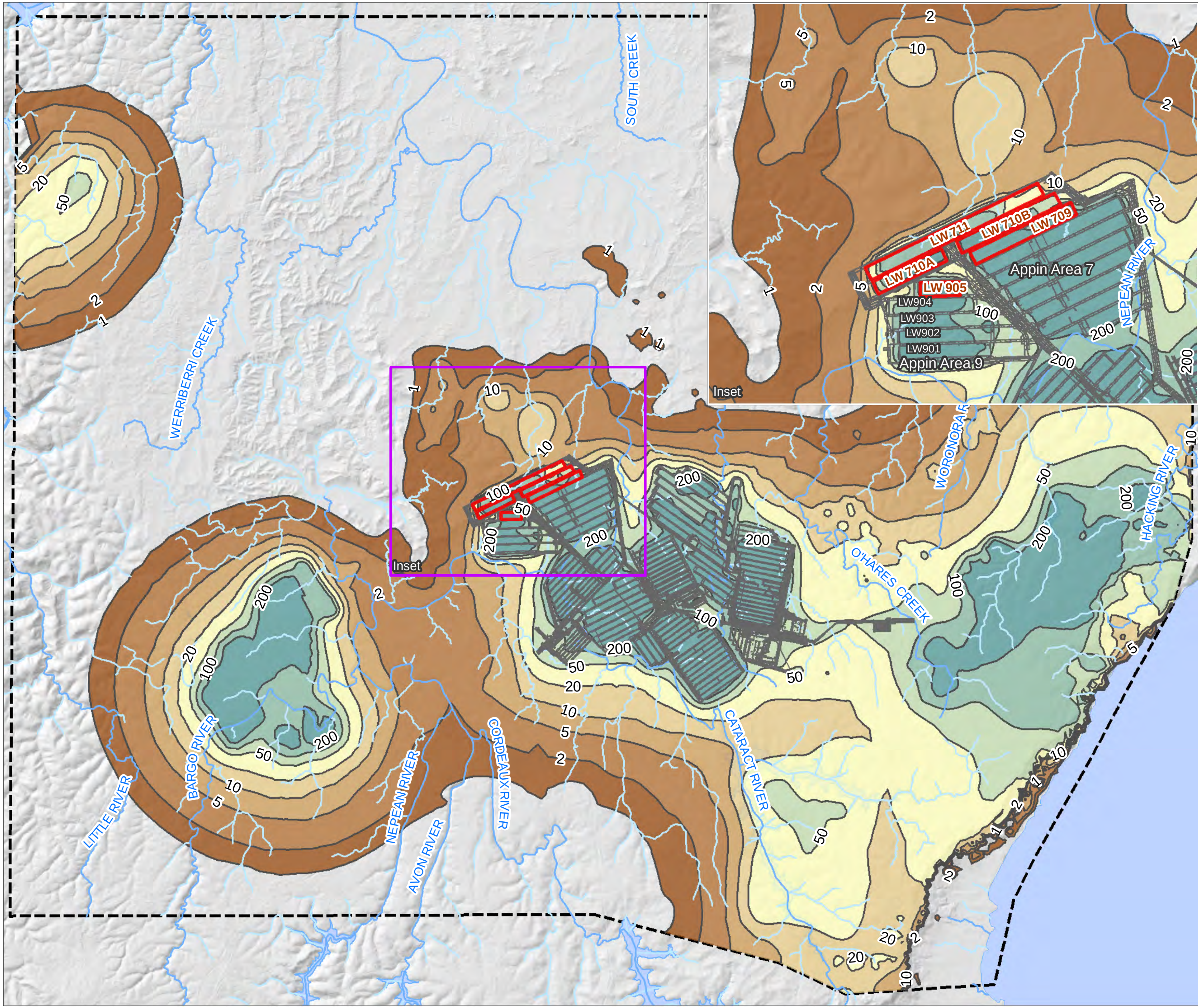
Reviewed by:	AM

Data Source: Mining Lease NSW Mineview Coal Lease 2019



APPIN MINE GROUNDWATER ASSESSMENT

CUMULATIVE MAXIMUM DEPRESSURISATION (M) IN LOWER SCARBOROUGH SANDSTONE

FIGURE 105

- Major watercourse
- Minor watercourse
- Mine Plan
- Project Area
- Model Extent

Groundwater Depressurisation (m)

- 1 - 2
- 2 - 5
- 5 - 10
- 10 - 20
- 20 - 50
- 50 - 100
- 100 - 200
- 200 - 500
- > 500

0 2.5 5 km

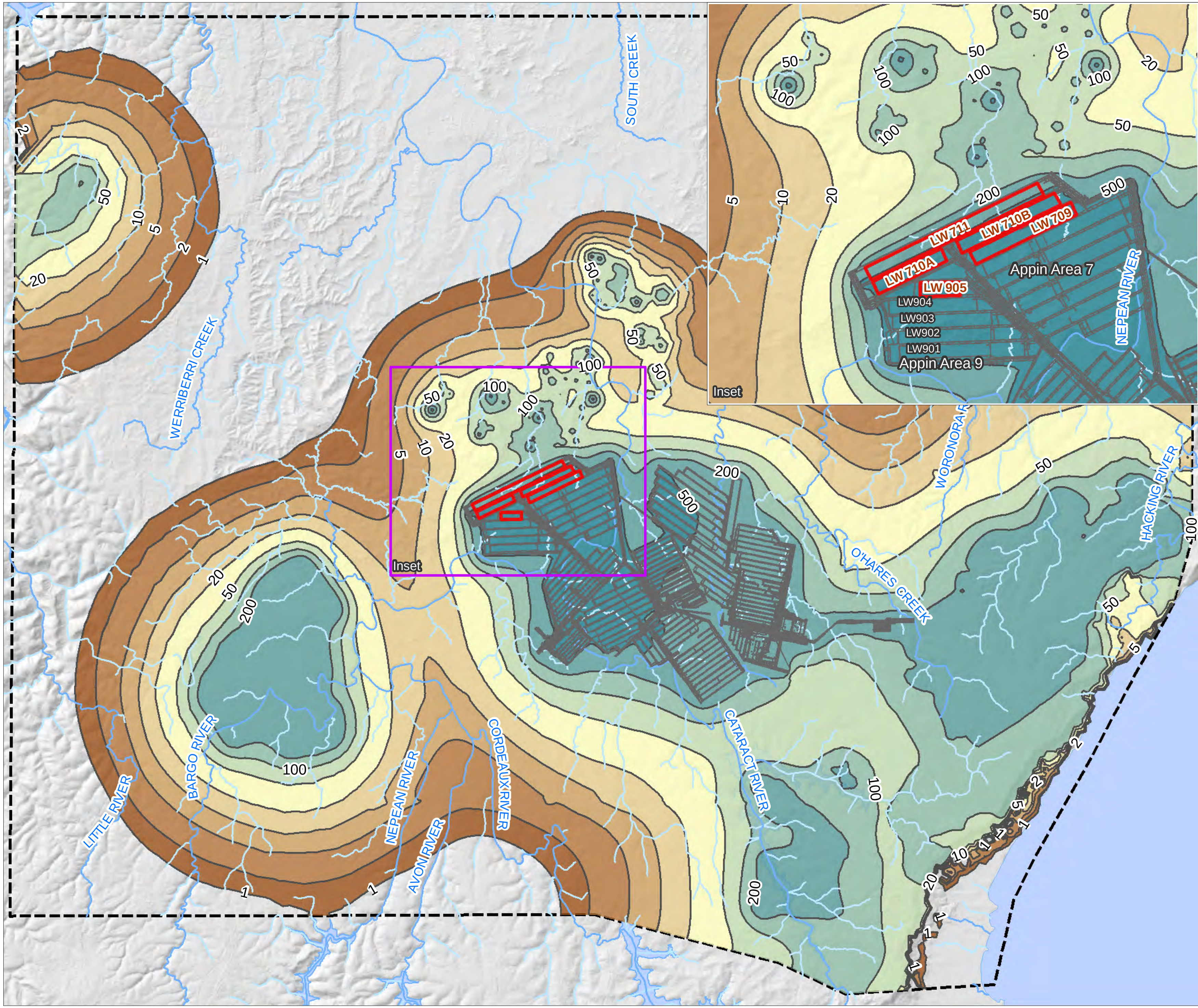
Coordinate System:	GDA 1994 MGA Zone 56
Scale:	1:230,000 at A4
Project Number:	665.10015
Date:	07-Sep-2022
Drawn by:	NT
Reviewed by:	AM

Data Source: Mining Lease NSW Mineview Coal Lease 2019

APPIN MINE GROUNDWATER ASSESSMENT

CUMULATIVE MAXIMUM DEPRESSURISATION (M) IN BULLI SEAM

FIGURE 106



Major watercourse
Minor watercourse
Mine Plan
Project Area
Model Extent

Groundwater Depressurisation (m)

- 1 - 2
- 2 - 5
- 5 - 10
- 10 - 20
- 20 - 50
- 50 - 100
- 100 - 200
- 200 - 500
- > 500

0 2.5 5 km

Coordinate System:	GDA 1994 MGA Zone 56
Scale:	1:230,000 at A4
Project Number:	665.10015
Date:	07-Sep-2022
Drawn by:	NT
Reviewed by:	AM

Data Source: Mining Lease NSW Mineview Coal Lease 2019

SLR

H:\Projects-SLR\620-BNE\665-WOL\665.10015 Illawarra Coal Closure - Water\CADGIS\ArcGIS\EP Report\665.10015 F104 Cumulative Maximum Depressurisation (m) in Bulli Seam.mxd

4.4.4 Depressurisation at Landholder Bores

As discussed in **Section 3.4.3**, there are 49 registered bores within 5 km of the Appin Mine/Project area. **Table 25** shows the maximum predicted depressurisation at privately owned bores. A conservative approach was taken where the predicted depressurisation at the bores was calculated based on maximum depressurisation across all layers representing the HBSS and Bulgo Sandstone.

As shown in **Table 25**, up to 11 m of depressurisation was predicted at landholder bores due to mining at Longwalls 709 to 711 and Longwall 905. Greater than 2 m of depressurisation (AIP threshold for highly productive aquifer) was predicted at five bores, as follows:

- 11 m at GW105376
- 9.6 m at GW105574
- 6.2 m at GW072874
- 4.9 m at GW105534
- 3.9 m at GW112481

The cumulative maximum predicted depressurisation at these bores ranges from 24.5 m to 485.4 m. Make good provisions apply for these bores shown to be impacted by the Project.

The prediction for incremental depressurisation for privately owned bores due to Appin Mine was determined by subtracting the Approved plus Project Appin Mine water levels from the Null Appin Mine Run water levels. The five bores listed above are predicted to have depressurisation greater than 2 m.

For bores located directly above mined longwalls, there is a risk of damage to bore casing from subsidence related movement, as previously discussed by Heritage Computing (2009).

While no depressurisation is predicted within the surficial strata (Alluvium/ Wianamatta Group / Weathered HBSS) as part of the groundwater assessment, the subsidence assessment (MSEC, 2021) identified potential for surface cracking including along Navigation Creek. This has the potential for localised impacts at the surface, including Navigation Creek surface water flow, which may influence recharge to the alluvium in proximity to the Project and potentially landholder bores accessing alluvial groundwater (i.e. GW100289). Local geological structures such as fracturing, and shearing could cause significantly greater depressurisation at individual bores. As discussed in **Section 3.6**, to capture the potential impacts of subsidence, the groundwater model simulated subsidence with increased hydraulic properties in the cells in Layer 1 of the model.

Table 25 Predicted Change in Maximum Predicted Depressurisation (m) at Landholder Bores

Work ID	Bore Type / Role	Geology	Cumulative Maximum Depressurisation (m)	Incremental Maximum Depressurisation (m) due to Appin Mine	Incremental Maximum Depressurisation (m) due to Project
GW026516	Water Supply, Stock, Irrigation (BH Reg); IRAG (NGIS)	Unconsolidated Clay/Silt	562.8	1.0	<1
GW112481*	Industrial (BH Reg); INDS (NGIS)	Bulli Coal Seam	485.4	5.7	3.9
GW072196	Domestic (BH Reg); HUSE (NGIS)	Unknown. Information on depth, likely HBSS	14.3	0.0	0.0
GW110550	Stock, Domestic (BH Reg); HUSE (NGIS)	Sandstone and Shale from Open Hole to TD	254.7	0.0	0.0
GW111727	Stock, Domestic (BH Reg); HUSE (NGIS)	-	267.7	0.0	0.0
GW104347	Stock, Domestic (BH Reg); HUSE (NGIS)	Sandstone from Open Hole to TD	270.7	0.0	0.0
GW107791	Stock, Domestic (BH Reg); HUSE (NGIS)	Sandstone from Open Hole to TD	186.3	<1	0.0
GW105376	Stock, Domestic (BH Reg); HUSE (NGIS)	Sandstone from Open Hole to TD	184.3	11.1	11.0
GW105325	Stock, Domestic, Recreation (BH Reg); RECN (NGIS)	Sandstone and Shale from Open Hole to TD	58.0	0.0	0.0
GW104661	Stock, Domestic (BH Reg); HUSE (NGIS)	Sandstone from Open Hole to TD	115.6	<1	0.5
GW104766	Stock, Domestic (BH Reg); HUSE (NGIS)	Sandstone and Shale from Open Hole to TD	45.7	0.0	0.0
GW062945	Stock, Domestic (BH Reg); HUSE (NGIS)	Sandstone from Open Hole to TD	41.5	0.0	0.0

Work ID	Bore Type / Role	Geology	Cumulative Maximum Depressurisation (m)	Incremental Maximum Depressurisation (m) due to Appin Mine	Incremental Maximum Depressurisation (m) due to Project
GW102584	Stock, Domestic (BH Reg); HUSE (NGIS)	Sandstone from Open Hole to TD	158.4	<1	<1
GW110671	Stock, Domestic (BH Reg); HUSE (NGIS)	Sandstone, Shale and Granite from Open hole to TD	106.3	<1	0.0
GW101986	Stock, Domestic (BH Reg); HUSE (NGIS)	Sandstone in open hole section	39.6	0.0	0.0
GW104602	Stock (BH Reg); STOK (NGIS)	Sandstone and Claystone from Open hole to TD	135.7	<1	0.0
GW105574	Stock, Domestic (BH Reg); HUSE (NGIS)	Sandstone, Clay and Shale from Surface	174.6	9.7	9.6
GW105534	Stock, Domestic (BH Reg); HUSE (NGIS)	Sandstone and Slate from open hole to TD	24.5	6.7	4.9
GW104154	Stock, Domestic (BH Reg); HUSE (NGIS)	Sandstone and Shale from Open Hole to TD	36.0	<1	0.0
GW072874	Stock, Domestic (BH Reg); HUSE (NGIS)	Sandstone, Siltstone and Shale from Open Hole to TD	26.8	7.8	6.2
GW101437	Farming (BH Reg); IRAG (NGIS)	Sandstone and Shale from Open Hole to TD	48.6	<1	0.0
GW108907	Stock, Domestic (BH Reg); HUSE (NGIS)	Sandstone and Shale from Open Hole to TD	139.2	<1	0.0
GW102144	Stock, Domestic (BH Reg); HUSE (NGIS)	Sandstone and Shale from Open Hole to TD	13.1	0.0	0.0
GW112437	Stock, Domestic (BH Reg); HUSE (NGIS)	Sandstone and Shale from Open Hole to TD	5.5	<1	0.0

Work ID	Bore Type / Role	Geology	Cumulative Maximum Depressurisation (m)	Incremental Maximum Depressurisation (m) due to Appin Mine	Incremental Maximum Depressurisation (m) due to Project
GW108312	Test Bore (BH Reg); INDS (NGIS)	Sandstone from Slots and Open Hole to TD	3.4	0.0	0.0
GW112381	Stock, Domestic (BH Reg); HUSE (NGIS)	Sandstone from Open Hole to TD	61.0	0.0	0.0
GW102043	Stock, Domestic (BH Reg); HUSE (NGIS)	Sandstone, Siltstone and Clay from Open Hole to TD.	119.6	<1	0.0
GW104068	Stock, Domestic (BH Reg); HUSE (NGIS)	Sandstone, Siltstone and Shale from Open Hole to TD	92.3	<1	0.0
GW105531	Stock, Domestic (BH Reg); HUSE (NGIS)	Sandstone and Shale from Open Hole to TD	40.8	0.0	0.0
GW111781	Domestic (BH Reg); HUSE (NGIS)	Sandstone from Open Hole to TD	6.1	0.0	0.0
GW106675	Stock, Domestic (BH Reg); HUSE (NGIS)	Sandstone and Shale from Open Hole to TD	39.6	0.0	0.0
GW034425	Waste Disposal (BH Reg); WSUP, INDS (NGIS)	Sandstone from Open Hole to TD	2.9	0.0	0.0
GW017315	Water Supply, Farming / General Purpose (BH Reg); WSUP (NGIS)	-	10.5	0.0	0.0
GW035033	Stock (BH Reg); STOK (NGIS)	Sandstone and Shale from Open Hole to TD	18.8	0.0	0.0
GW102619	Stock, Domestic, Irrigation (BH Reg); IRAG (NGIS)	Sandstone and Shale from Open Hole to TD	38.5	0.0	0.0

Work ID	Bore Type / Role	Geology	Cumulative Maximum Depressurisation (m)	Incremental Maximum Depressurisation (m) due to Appin Mine	Incremental Maximum Depressurisation (m) due to Project
GW101133	Stock, Domestic (BH Reg); HUSE (NGIS)	Sandstone, Siltstone and Ironstone from Open Hole to TD	80.6	0.0	0.0
GW102798	Stock, Domestic, Farming (BH Reg); IRAG (NGIS)	Sandstone from Open Hole to TD	69.8	<1	0.0
GW100673	Stock (BH Reg); STOK (NGIS)	-	2.6	0.0	0.0
GW105339	Stock, Domestic, Irrigation (BH Reg); HUSE (NGIS)	Sandstone and Shale from Open Hole to TD	1.6	0.0	0.0
GW100289	Stock, Domestic (BH Reg); HUSE (NGIS)	Bore is screened in Gravel	11.4	0.0	0.0
GW108990	Test Bore (BH Reg); HUSE (NGIS)	-	7.1	<1	0.2
GW111637	Monitoring Bore (BH Reg); MON (NGIS)	-	1.6	<1	0.0
GW111638	Monitoring Bore (BH Reg); MON (NGIS)	-	1.6	<1	0.0
GW111636	Monitoring Bore (BH Reg); MON (NGIS)	-	4.4	<1	0.0
GW111634	Monitoring Bore (BH Reg); MON (NGIS)	-	2.9	<1	0.0
GW105942	Test Bore (BH Reg); MON (NGIS)	Shale and Clay from Open Hole to TD	0.0	0.0	0.0
GW108193	Test Bore (BH Reg); MON (NGIS)	Clay and Shale from Open Hole to TD	0.0	0.0	0.0

Note: * Water supply bore, part of the AGL Camden CSG project

NGIS naming convention: HUSE: household, INDS: industry, IRAG: irrigated agriculture, MON Monitoring, STOK: Water supply for livestock, WSUP Water supply

TD – Total depth

The above predictions from the regional groundwater model relate to changes in groundwater levels and pressures due to regional depressurisation from the proposed mining. Local subsidence effects such as shear and localised fracturing of a bore can result in additional changes to groundwater level at that location.

4.4.5 Loss of Flow in Streams

Mining activities can result in changes in gradient from the aquifer into the watercourse thereby reducing the rate at which baseflow occurs. This effect can be amplified in areas above longwall panels, where surface cracking may increase the permeability of the stream bed and the near-surface strata, as is evident around Appin Area 7 and 9.

Estimates of predicted baseflow were calculated using the MODFLOW 'ZoneBudget' utility. The change in baseflow due to Longwalls 709 to 711 and Longwall 905 extraction was calculated by comparing the net river flow in the Base Case scenario and Cumulative scenario. The cumulative loss of baseflow was calculated by comparing the Cumulative scenario against the Null scenario (i.e. no mining scenario).

Table 26 presents a summary of the predicted maximum baseflow loss at several creeks directly related to the Longwalls 709 to 711 and Longwall 905 extraction. Overall, the model predicts negligible impacts on surface water bodies due to depressurisation of the coal measures as part of Longwalls 709 to 711 and Longwall 905 extraction. The impact in ML/day represents the maximum baseflow impact from any time in the predictive run.

Table 26 also shows cumulative baseflow losses due to mining are much greater with O'Hares Creek and Nepean River predicted to experience the largest loss in baseflow (between 0.010 to 0.039 ML/day). **Table 26** shows the predicted inflow loss from the groundwater model is less than the predicted inflows in the Impact Assessment for BSO (Heritage Computing, 2009). The Impact Assessment modelling results showed that the maximum predicted reduction in groundwater baseflow due to the mining operations was 0.21 ML/day in the Nepean River. As suggested in the BSO Impact Assessment when the size of the catchment is taken into consideration, the predicted impact on baseflow is considered negligible.

Table 26 Baseflow Impacts in Local Watercourses

Watercourse	Impact Assessment for BSO (Heritage Computing, 2009) (ML/day)	Longwall 709-711 and 905 Extraction Impact (ML/day)	Cumulative Impact (ML/day)
Cataract River	0.105	<0.001	0.030
Georges River	0.040	<0.001	0.001
Nepean River	0.213	<0.001	0.039
O'Hares Creek	0.056	<0.001	0.010
Woronora River	0.001	<0.001	<0.001
Navigation Creek	Not reported	<0.001	0.001
Navigation Creek Tributary 1	Not reported	<0.001	0.001
Foot Onslow Creek	Not reported	<0.001	0.001
Harris Creek	Not reported	<0.001	<0.001

4.4.6 Impacts on Water Quality

The height of fracture calculations indicate longwall mining as part of the Project could result in fracturing from the Bulli Seam to the Scarborough Sandstone and in some localised areas the Bulgo Sandstone (lower) and HBSS (lower). Increased iron staining has been observed and is attributed to groundwater becoming oxidised while in contact with fresh fractures or shears. Additional fracturing can also cause the liberation of formation gas particularly from deeper bores such as those intersecting the Bulgo Sandstone. Post closure, this could create hydraulic connection between the confined Permian coal measures and overlying Narrabeen Group. As discussed in **Section 3.3**, the Bulgo Sandstone is generally moderately saline with sodium-bicarbonate type water and can be suitable for some stock water supply and short-term irrigation. However, the Bulgo Sandstone has limited usage within the region, with preferential use of the shallower HBSS.

There is limited data on water quality within the coal measures at Appin, but regionally it is characterised as moderately saline to saline. The impact on groundwater salinity within the hydrostratigraphic units above the Bulli Seam due to cracking is unknown since there is little water quality information available in these units including the Coalcliff Sandstone, Wombarra Claystone, Scarborough Sandstone and Stanwell Park Claystone. Water leakage from the upper units to the lower units will be partially restricted as the Stanwell Park Claystone and Wombarra Claystone units will continue to act as aquitards, which may be impacted by some minor cracking. Ongoing monitoring of site mine water should be conducted and incorporated for ongoing mine closure planning and management.

5 Sensitivity Analysis

5.1 Identifiability

Calibration identifiability describes a parameters capability to be constrained by the model calibration. Identifiability values range from zero to one. As identifiability approaches one, the parameter is increasingly able to be constrained. Likewise, as values approach zero the parameter is increasingly unable to be constrained by the calibration and uncertainty of model results is not reduced through calibration.

The PEST utility GENLINPRED was used to provide an estimate of parameter identifiability for each of the model parameters. Estimated identifiability values for all parameters tested are summarised in **Figure 107** through **Figure 112** for both calibration and predictions.

Figure 107 indicates the calibration process was highly successful in constraining the horizonal conductivity as most of the units are well constrained by calibration (high identifiability values above 0.70). Identifiability of hydraulic conductivity anisotropy for model zones is presented in **Figure 108.** Anisotropy in some of the units simulated such as HBSS, Bulgo Sandstone, Scarborough Sandstone, and some of the faults have high identifiability values indicating these can be constrained and contribute to reducing model uncertainty. All other zones such as Alluvium, Wongawilli Seam, Bulli Seam feature low values (equal to and below 0.60) and are less constrained by calibration.

In general, specific yield of the zones in the model domain has low identifiability except for HBSS, Bulli Seam and faults (**Figure 109**). Specific storage of the units such as HBSS, Bulgo Sandstone, Scarborough Sandstone, and Coal Cliff Sandstone have high identifiability values (>0.8) indicating these can be constrained by calibration (**Figure 110**).

The identifiability of the recharge rates for all the zones are higher than 0.7 indicating that recharge rate can be well constrained by the calibration (**Figure 111**).

The identifiability of the fracture zone properties is shown in **Figure 112**. As shown in the figure, in general the vertical conductivity of the fracture zone can be constrained more through the model calibration comparing to the horizonal conductivity of the fracture zone. **Figure 112** shows the vertical conductivity of the disconnected fractured zone (Zone A) has a higher identifiability and can be constrained more in the calibration process comparing to the vertical conductivity of the connected fracture zone (Zone A).

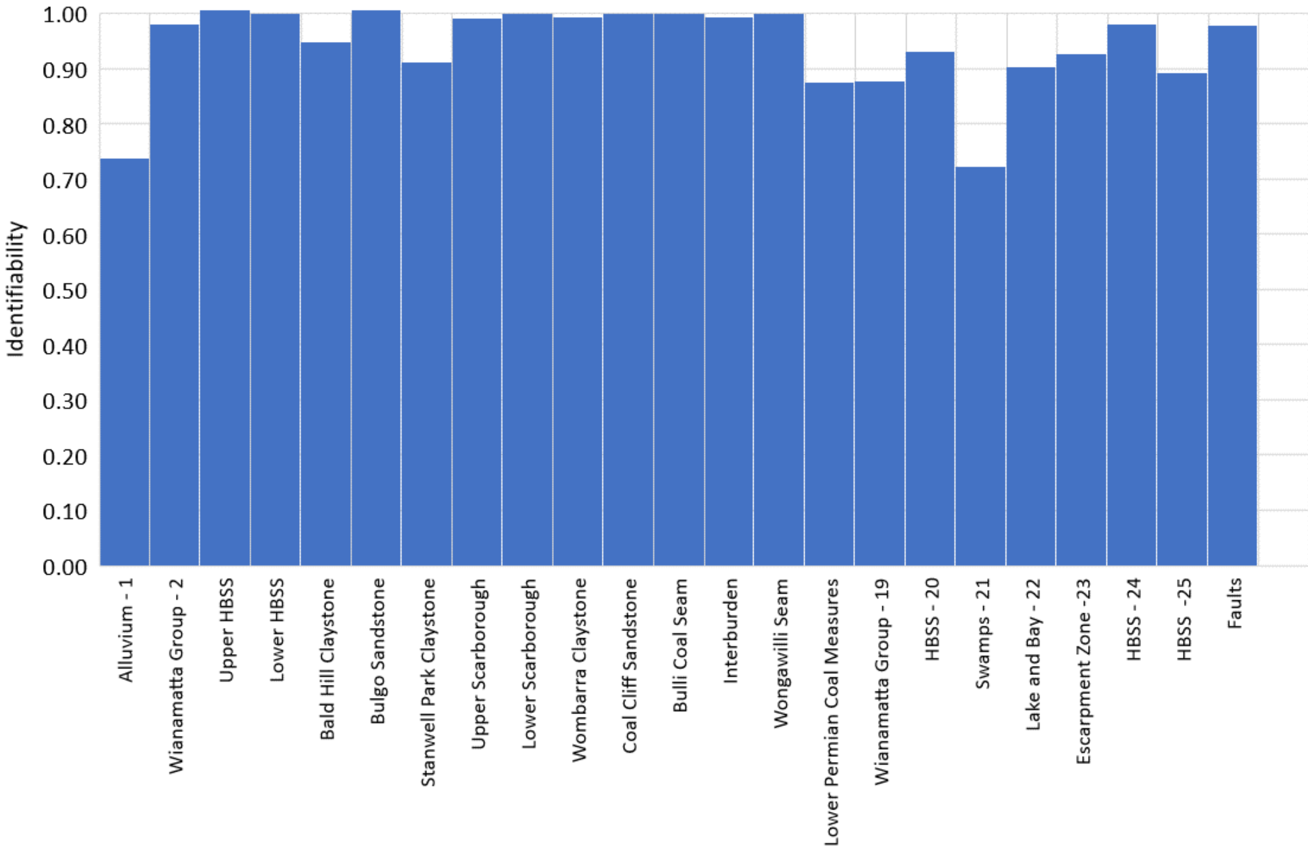


Figure 107 Identifiability – Horizontal Hydraulic Conductivity (Kx)

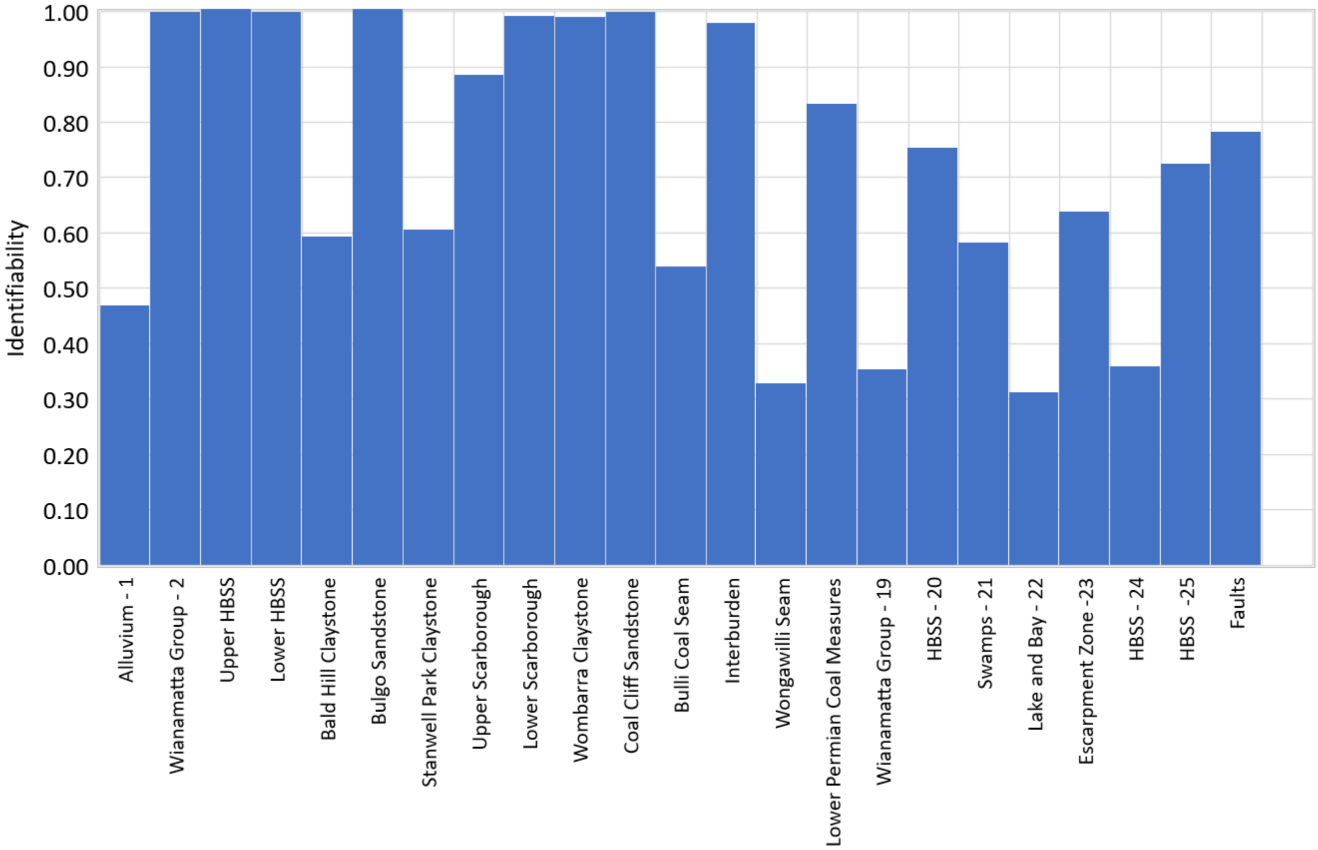


Figure 108 Identifiability – Anisotropy (Kz/Kx)

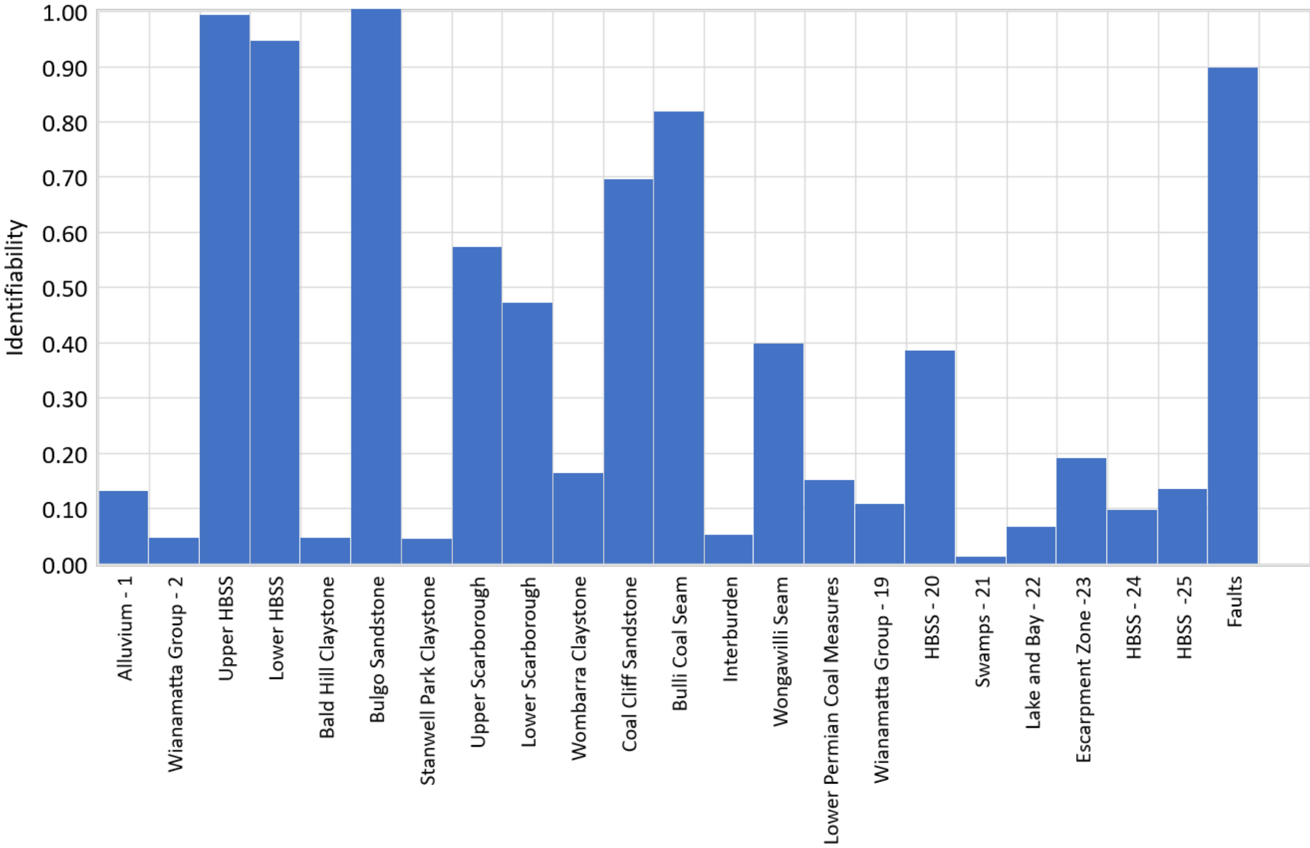


Figure 109 Identifiability – Specific Yield (Sy)

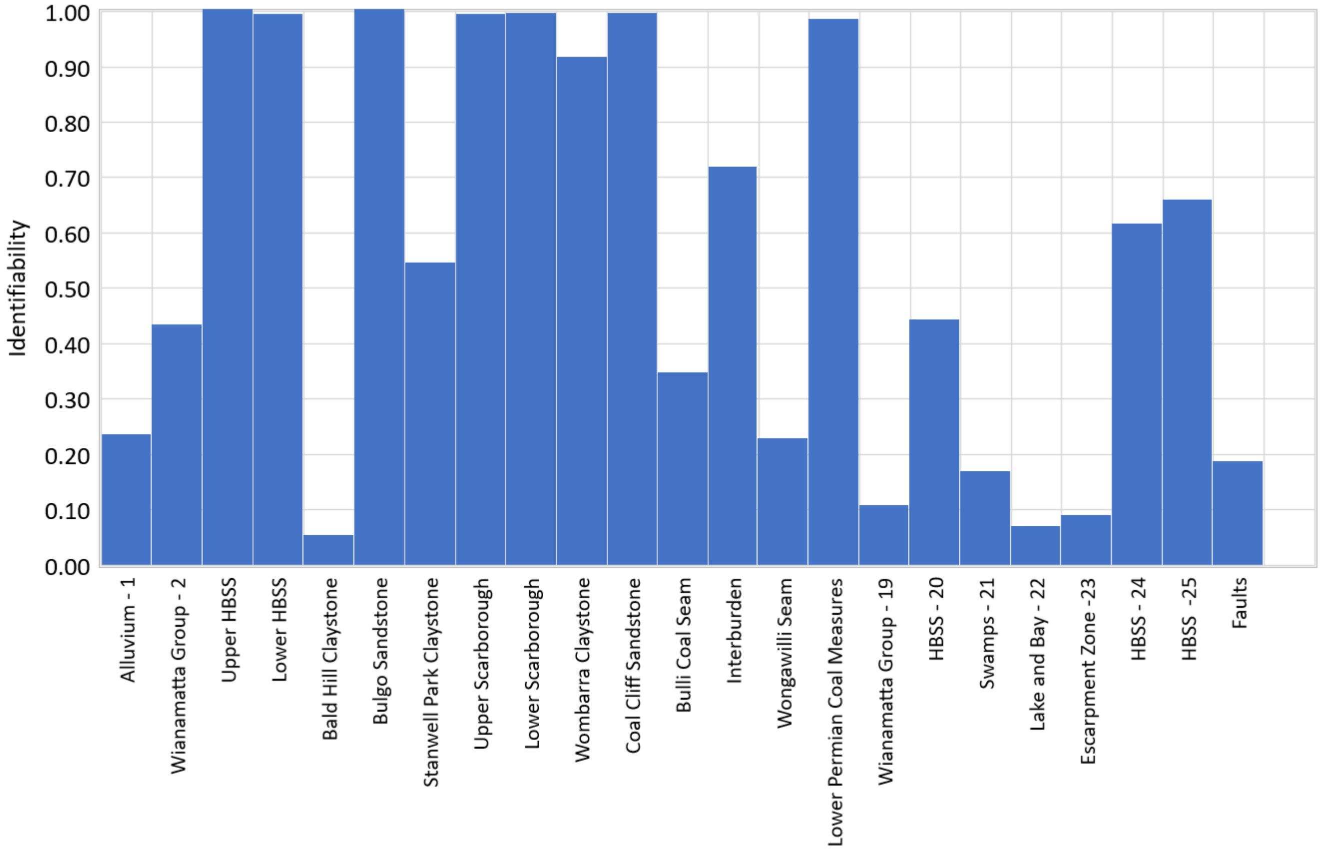


Figure 110 Identifiability – Specific Storage (Ss)

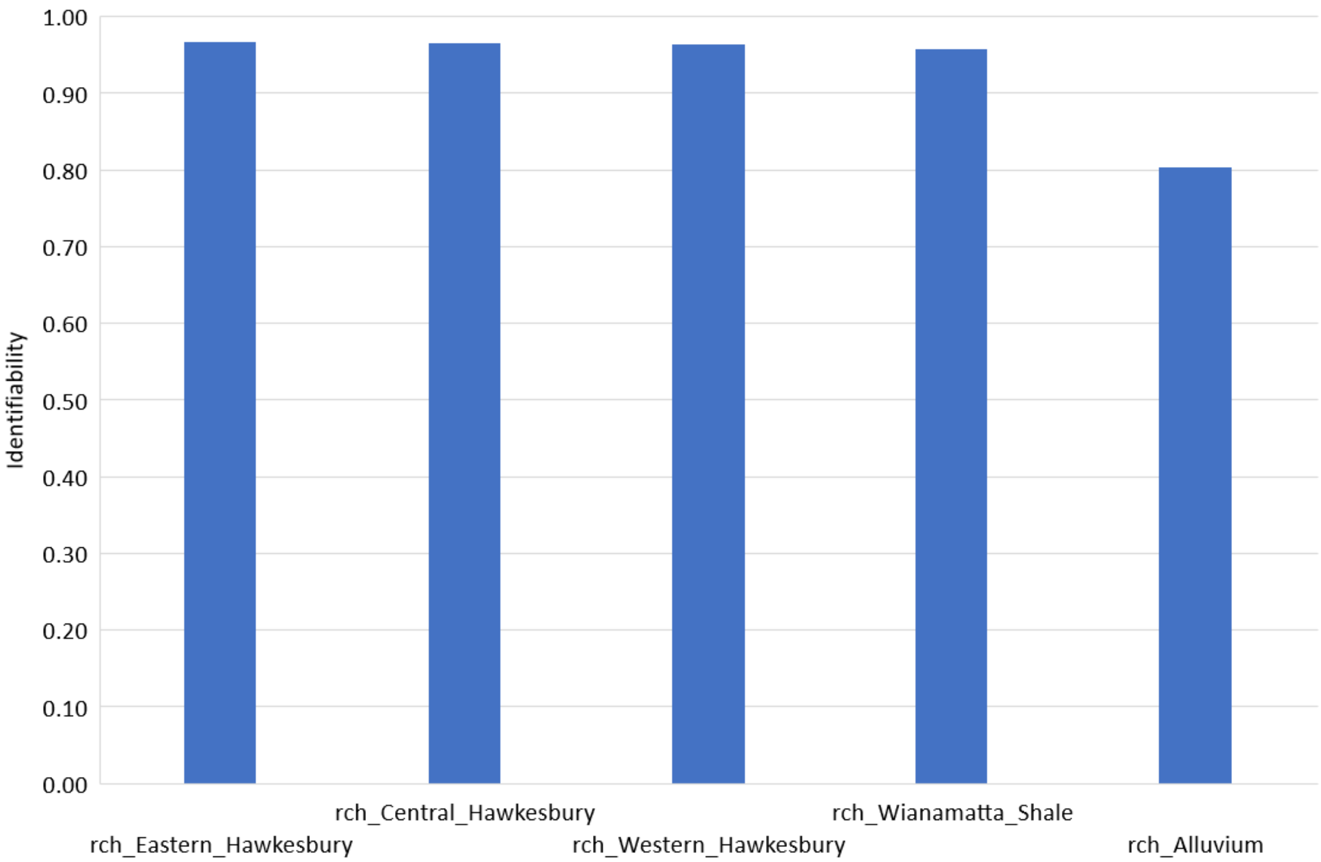


Figure 111 Identifiability – Recharge (RCH)

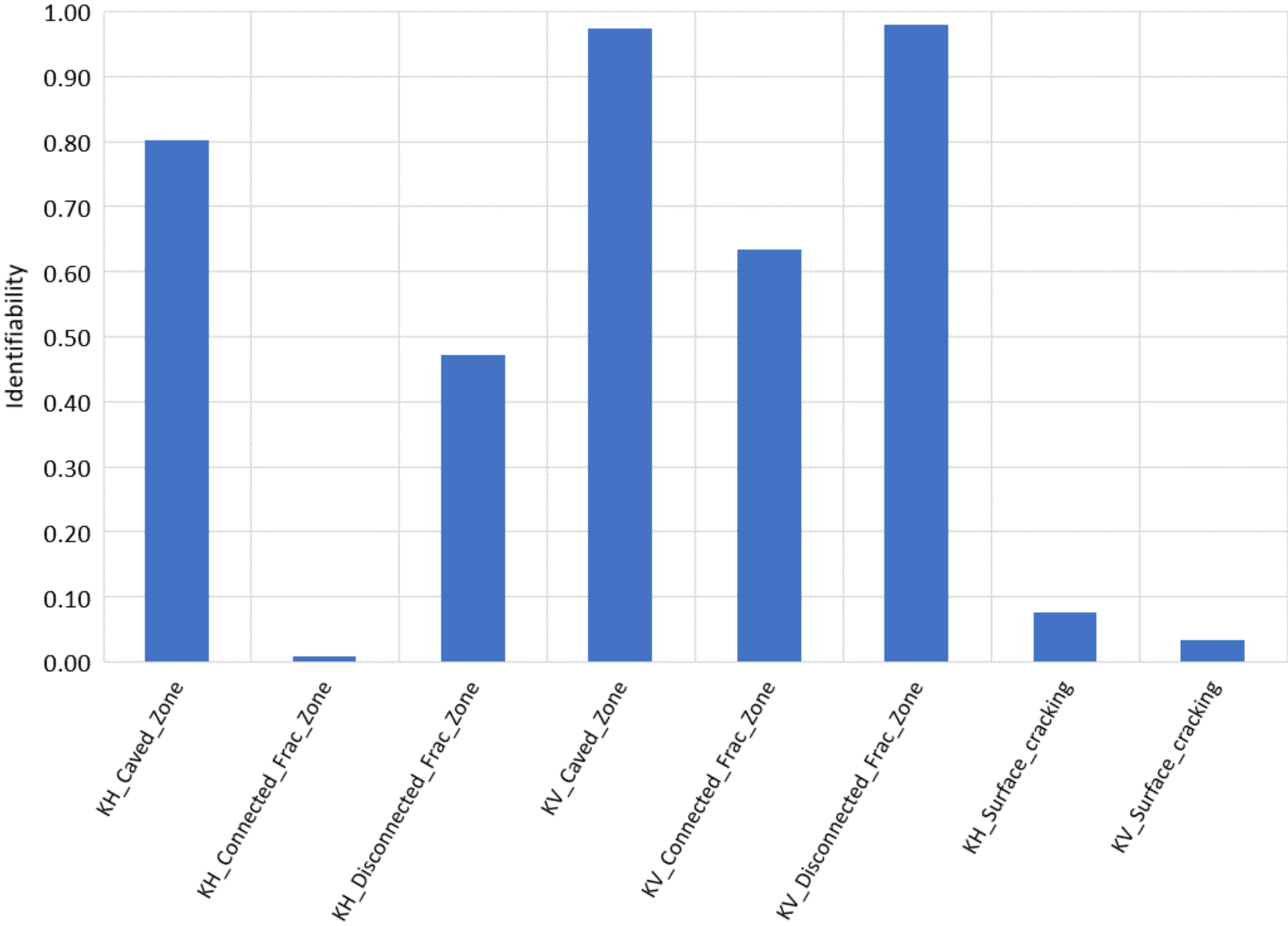


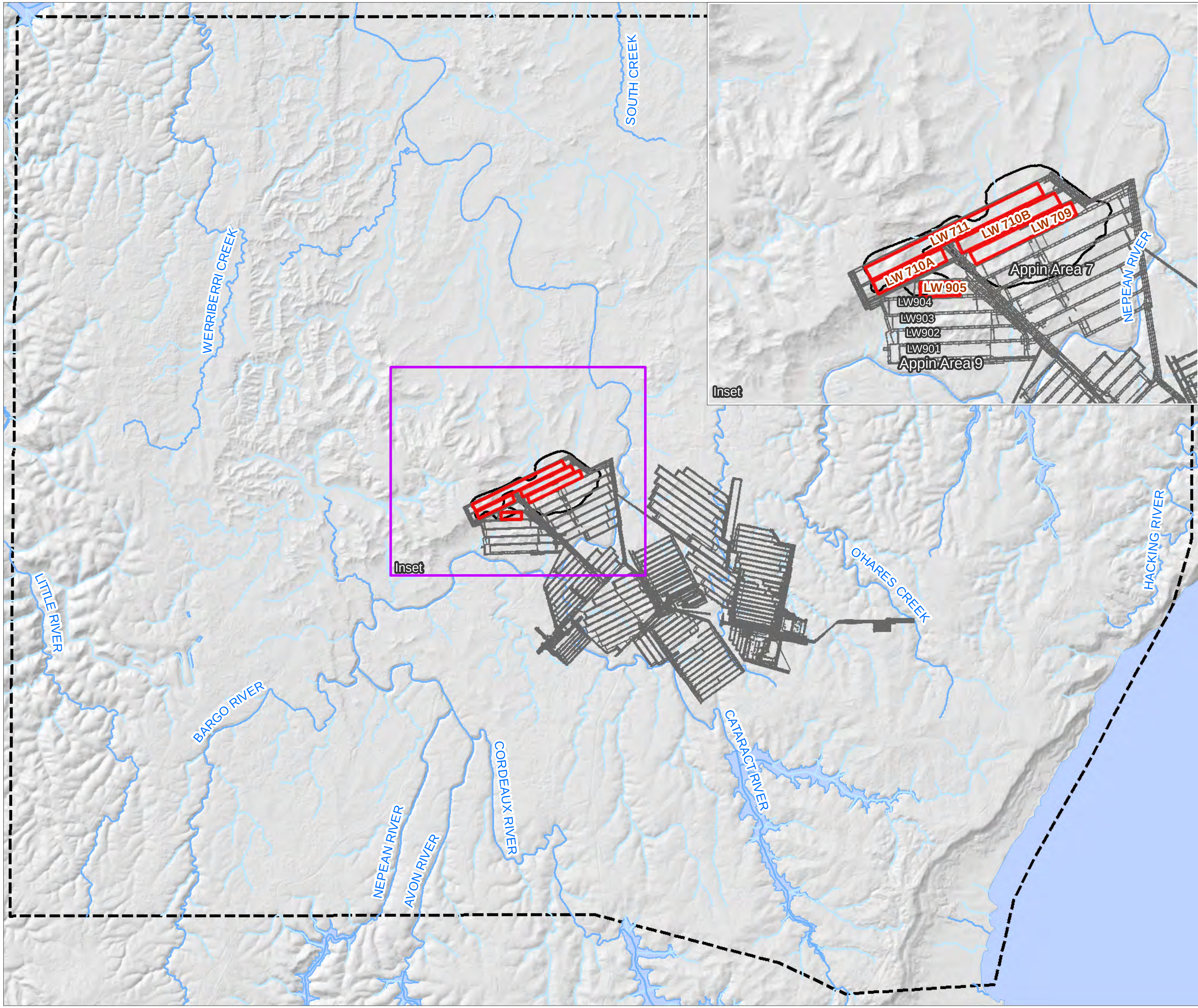
Figure 112 Identifiability – Fracture Zone Properties

5.2 Sensitivity Analysis on Fracture Height Formulation

Sensitivity analysis was conducted to understand how changes to the fracture height model assumptions influenced the model predictions. As discussed in **Section 3.6**, the Ditton A95 and B95 methods (2014) were adopted in the calibration and the prediction model.

A model run was set up with Ditton A95 and B95 (2014) in the model replaced with Tammetta (2013) to simulate the fractured height above the longwalls. The model was run from the start of calibration to the end of the prediction period.

Figure 113 compares the maximum incremental 1 m drawdown extent in the HBBS for the base model (i.e., with Ditton A95 and B95 method) and the sensitivity run with Tammetta (2013) method. **Figure 114** compares the maximum incremental 1 m drawdown extent in the Bulli Coal Seam for the base model and the sensitivity run with Tammetta (2013) method. The figure shows minimal change in the drawdown extents in the Bulli Seam when Tammetta (2013) was used. When Tammetta (2013) was used to simulate the fracture height, the model did not predict drawdowns in the Lower HBSS. Therefore, **Figure 113** does not show drawdown contours lines for Tammetta (2013). **Figure 113** shows when Ditton A95 and B95 combined does predict drawdown in lower HBSS.



APPIN MINE GROUNDWATER ASSESSMENT

SENSITIVITY OF 1m INCREMENTAL MAXIMUM DEPRESSURISATION (M) IN LOWER HBSS DUE TO MINING AT LONGWALLS 709 TO 711 AND 905

FIGURE 113

- 1m Drawdown Ditton A95 and B95 (2014)
- 1m Drawdown Tammetta (2013)
- Major watercourse
- Minor watercourse
- Mine Plan
- Project Area
- Model Extent

0 2.5 5 km

Coordinate System:	GDA 1994 MGA Zone 56
Scale:	1:230,000 at A4
Project Number:	665.10015
Date:	07-Sep-2022
Drawn by:	NT
Reviewed by:	AM

Data Source: Mining Lease NSW Mineview Coal Lease 2019

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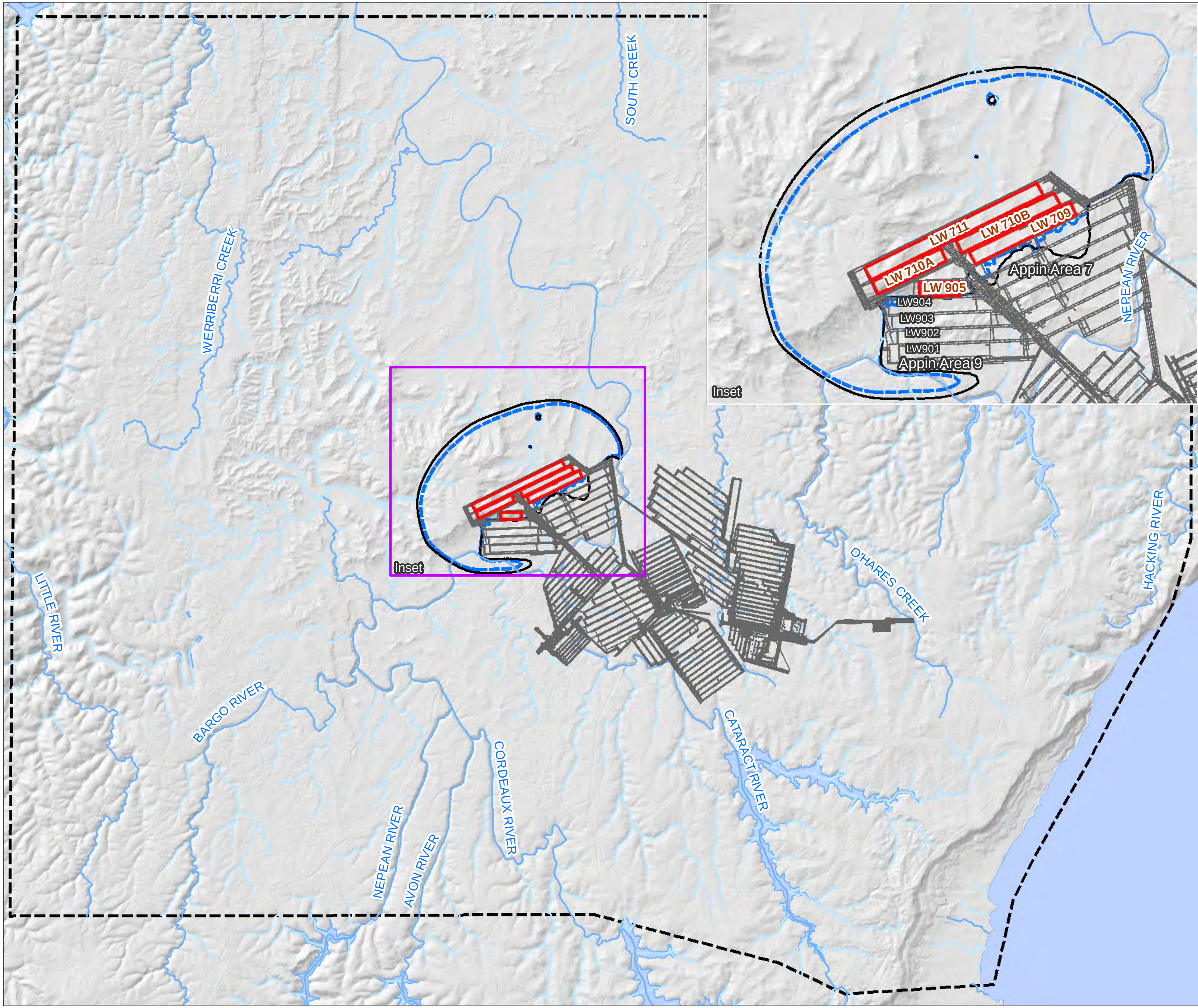
APPIN MINE GROUNDWATER ASSESSMENT

SENSITIVITY OF 1m INCREMENTAL MAXIMUM DEPRESSURISATION (M) IN BULLI SEAM DUE TO MINING AT LONGWALLS 709 TO 711 AND 905

FIGURE 114



1m Drawdown Ditton A95 and B95 (2014)
1m Drawdown Tammetta (2013)
Major watercourse
Minor watercourse
Mine Plan
Project Area
Model Extent

0 2.5 5 km

Coordinate System:	GDA 1994 MGA Zone 56
Scale:	1:230,000 at A4
Project Number:	665.10015
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Data Source: Mining Lease NSW Mineview Coal Lease 2019

SLR

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5.3 Sensitivity Analysis on Fracture Height Hydraulic Properties

As discussed in **Section 4.1.5**, different versions of the model with different fracture height properties were run and tested. Those model runs were rejected as they did not fit the historical measurements and therefore were not a valid prediction. **Table 27** compares the fracture zone properties in one of the rejected model runs to the calibrated model. As shown in the table, the adopted horizontal and vertical conductivity of Zone A and Zone B in this model run was between 5 to 10 times higher than the calibrated model. The RMS and SRMS for this model run were 85.1 m and 8.0% which are significantly higher than the values reported for the calibrated model in **Section 4.2.1**.

Figure 115 shows the sensitivity of the predicted inflows for Appin Area 9 to an increase in hydraulic properties of the fracture zone. The figure shows a significant increase in predicted inflows in response to an increase in the fracture zone horizontal and vertical hydraulic conductivity.

Figure 116 compares the 1 m maximum incremental drawdown in the lower HBSS from the model run with increased hydraulic properties in the fracture zone and the calibrated model. The figure shows an increase in the extent of predicted drawdown due to an increase in the hydraulic properties in the fracture zone.

Table 27 Sensitivity of the Fracture Height Hydraulic Properties

<table>
<tr><th colspan="2">Conceptual Zone</th><th>Zone</th><th>Calibrated Model</th><th>Sensitivity</th></tr>
<tr><td rowspan="2">Fractured Zone</td><td>Upper zone of Disconnected Fracturing</td><td>B-zone</td><td>High Kx, Higher Kz
Enhanced Kx was set to 10 times the host value.
Enhanced Kz was set to 2.5 times the host value</td><td>High Kx, Higher Kz
Enhanced Kx was set to 50 times the host value.
Enhanced Kz was set to 10 times the host value</td></tr>
<tr><td>Lower zone of Connected Fracturing</td><td>A-zone</td><td>High Kx, Higher Kz.
Enhanced Kx was set to 5 times the host value.
Enhanced Kz was set to 5 times the host value</td><td>High Kx, Higher Kz.
Enhanced Kx was set to 50 times the host value.
Enhanced Kz was set to 50 times the host value</td></tr>
</table>

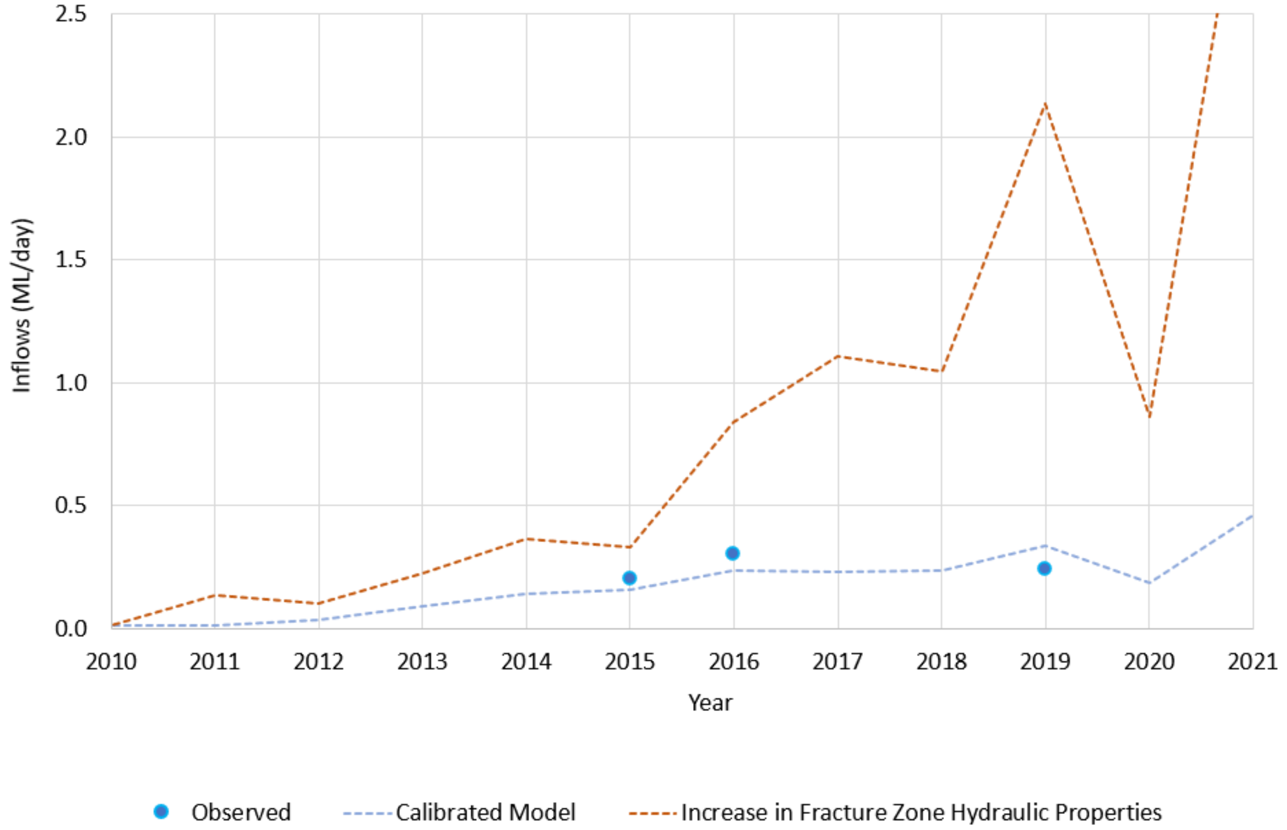
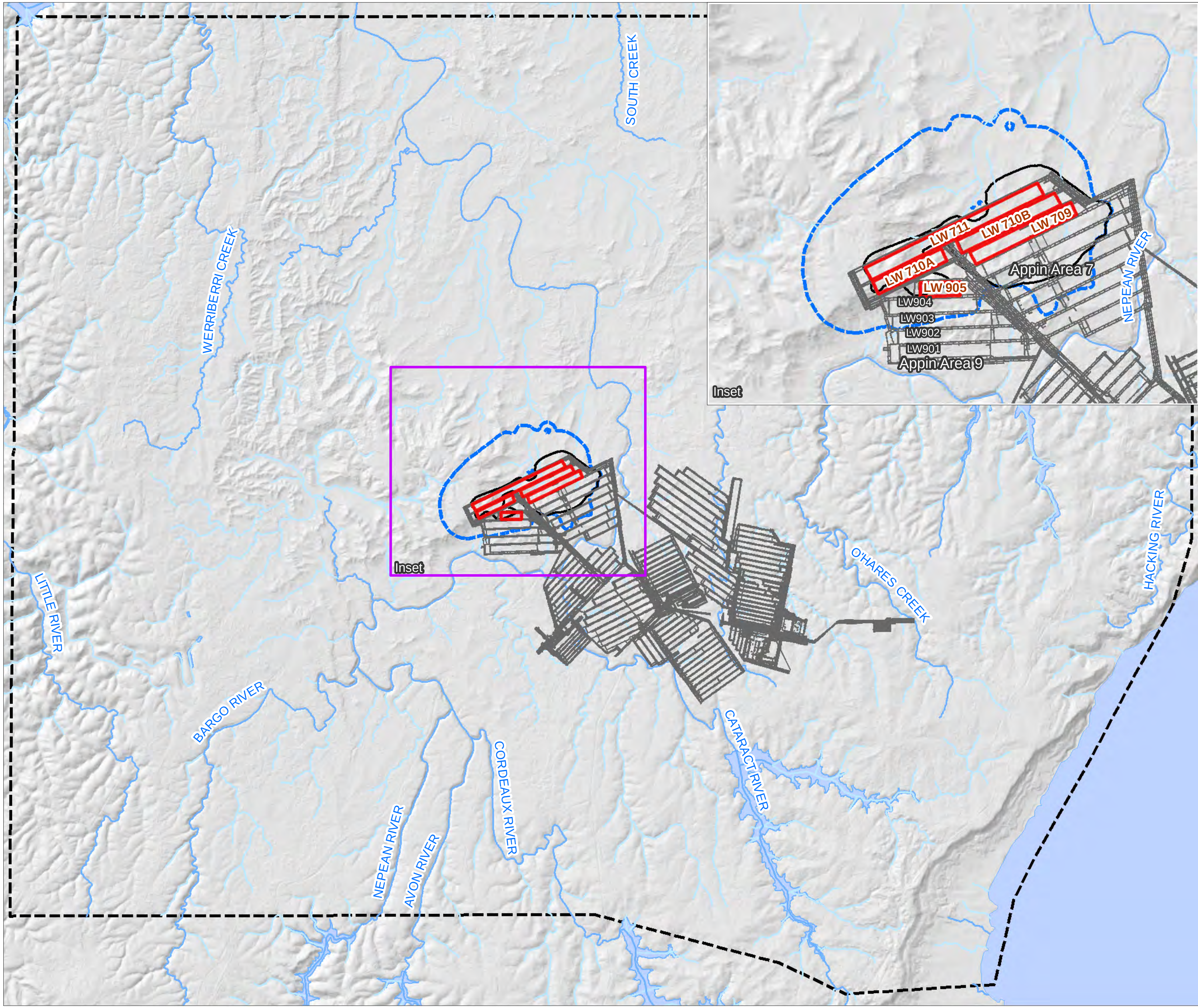


Figure 115 Sensitivity of Area 9 Mine Inflow to Fracture Height Properties



APPIN MINE GROUNDWATER ASSESSMENT

SENSITIVITY OF 1M INCREMENTAL MAXIMUM DEPRESSURISATION (M) IN LOWER HBSS TO FRACTURE HEIGHT PROPERTIES

FIGURE 116

- 1m Drawdown Ditton A95 and B95 (2014)
- 1m Drawdown Increase in Fractured Hydraulic Properties
- Major watercourse
- Minor watercourse
- Mine Plan
- Project
- Model Extent

0 2.5 5 km

Coordinate System:	GDA 1994 MGA Zone 56
Scale:	1:230,000 at A4
Project Number:	665.10015
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Reviewed by:	AM

Data Source: Mining Lease NSW Mineview Coal Lease 2019

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6 Recommendations - Monitoring

6.1 Appin Mine Monitoring Network

Groundwater monitoring will be conducted in accordance with a Groundwater Monitoring Plan (GWMP) that will be prepared in consultation with the regulator. The GWMP will include full details on how, when and what groundwater parameters will be monitored across Appin Mine and surrounds.

Table 28 presents the updated monitoring network and program for the Project, and **Figure 117** shows the new bore and existing VWP locations. In addition, it is recommended that monthly monitoring of mine water inflows (water quality) is conducted to monitor groundwater quality. Groundwater criteria have been developed and are discussed in **Section 5.3**.

Three exploration boreholes (S1913, S1941 and S1954) have been fitted with vibrating wire piezometers with 10 sensors in S1913 and S1941 and 13 sensors in S1954. Each piezometer monitors water pressure on an hourly interval and transmits data automatically via File Transfer Protocol (FTP). These VWPs are suitable for the early warning of the mining impact as part of the assessment criteria (**Section 6.3**).

VWP S1936 has only one remaining sensor operational (65 m) as all other sensors have sheared. This VWP is not suitable for the early warning of mining impacts. Data from the remaining piezometer is captured manually via irregular site visits. Exploration borehole S2157 has 10 sensors, however their condition is unknown as the VWP is not fitted with a FTP and property access has not been possible since 2015. Renewed access to this site is currently being negotiated. This VWP is not suitable for the early warning of mining impacts.

The existing VWPs each have multiple sensors monitoring water pressure at hourly intervals with data transmitted automatically to a FTP. Four new open standpipe monitoring bores have been installed to monitor groundwater levels and quality in the alluvium (S2536) and Hawkesbury Sandstone (S2536A, S2537 and S2538). These new bores are to have water level sensors installed to the depth and within the lithology as outlined in **Table 28**. S2537 is to be used to calibrate the nearby VWPs.

Table 28 Updated Project Monitoring Program

Bore / VWP ID	Type	Easting	Northing	Ground Level (mAHD)	Screen/ Sensor	Geology	Purpose	SWL (mAHD)		WQ	
								Frequency	Trigger	Frequency	Trigger
S1913	VWP (EX)	289028	6218729	117.04	65	HBSS	VWP immediately north of Project (Longwall 711). Verify predicted water level impacts and early identification of adverse impacts not previously predicted.	Hourly	-	N/A	-
					137	HBSS		Hourly	74	N/A	-
					194	HBSS		Hourly	47	N/A	-
					274	BGSS		Hourly	-	N/A	-
					358	BGSS		Hourly	-	N/A	-
					447	BGSS		Hourly	112	N/A	-
					473	SBSS		Hourly	119	N/A	-
					486	SBSS		Hourly	-	N/A	-
					505	SBSS		Hourly	127	N/A	-
					559.5	BUCO		Hourly	70	N/A	-
S1936	VWP (AD)	291547	6217768	148.14	65	HBSS	VWP within 1 km of Project (Longwall 709). Verify predicted water level impacts and early identification of adverse impacts not previously predicted	Irregular	85	N/A	-
					123.8	HBSS		Broken	-	N/A	-
					192	HBSS		Broken	36	N/A	-
					278	BGSS		Broken	-10	N/A	-
					347.8	BGSS		Broken	-10	N/A	-
					422.5	BGSS		Broken	-46	N/A	-
					456.2	SBSS		Broken	-50	N/A	-
					462.1	SBSS		Broken	-25	N/A	-
					468	SBSS		Broken	-	N/A	-
					556.1	BUCO		Broken	-400	N/A	-
S1941	VWP (EX)	287181	6216341	148.82	65	HBSS	VWP within 200 m of Project (Longwall 905). Verify predicted water level impacts and early identification of adverse impacts not previously predicted	Hourly	108	N/A	-
					126.5	HBSS		Hourly	75	N/A	-
					201.6	HBSS		Hourly	40	N/A	-
					284.3	BGSS		Hourly	65	N/A	-
					355.7	BGSS		Hourly	85	N/A	-
					432	BGSS		Hourly	80	N/A	-
					463	SBSS		Hourly	-	N/A	-
					472.8	SBSS		Hourly	8.5	N/A	-
					487.5	SBSS		Hourly	-5	N/A	-
					555.4	BUCO		Hourly	-400	N/A	-

Bore / VWP ID	Type	Easting	Northing	Ground Level	Screen/ Sensor	Geology	Purpose	SWL (mAHD)		WQ	
					596	WWCO		Hourly	-242	N/A	-
S1954	VWP (EX)	285466	6216904	310	36	BrSh	VWP within 1 km of Project (Longwall 711). Verify predicted water level impacts and early identification of adverse impacts not previously predicted	Hourly	-	N/A	-
					85	BrSh		Hourly	-	N/A	-
					100.5	BrSh		Hourly	-	N/A	-
					138.5	UnSS		Hourly	-	N/A	-
					145.3	UnSS		Hourly	-	N/A	-
					181	AsSh		Hourly	-	N/A	-
					205	AsSh		Hourly	-	N/A	-
					245	HBSS		Hourly	-	N/A	-
					273.1	HBSS		Hourly	-	N/A	-
					316.3	HBSS		Hourly	-	N/A	-
					359.4	HBSS		Hourly	67	N/A	-
					392.5	HBSS		Hourly	-	N/A	-
					742.9	BUCO		Hourly	-200	N/A	-
S2157	VWP (AD)	283212.0	6215968.0	224.45	82.5	WNSH	VWP approximately 3 km west of Project (Longwall 711). To verify predicted water level impacts and early identification of adverse impacts not previously predicted	Hourly	-	N/A	-
					135	HBSS		Hourly	105*	N/A	-
					207	HBSS		Hourly	-	N/A	-
					284	HBSS		Hourly	90*	N/A	-
					368	BGSS		Hourly	-	N/A	-
					418	BGSS		Hourly	165*	N/A	-
					468	BGSS		Hourly	160*	N/A	-
					518	SPCS		Hourly	-	N/A	-
					568	SBSS		Hourly	165*	N/A	-
					626.9	BUCO		Hourly	160*	N/A	-
S2536	MB NEW	288404.1	6218410.7	128	15.6	Qa	Near VWP S1913, to characterise alluvial groundwater conditions and monitor trends. Water level and water quality monitoring	Quarterly	122	Quarterly	EC, pH TBC
S2536A	MB NEW	287932.4	6219544.1	117	136.6	HBSS	1.2km north of the project, levels in HBSS and monitor groundwater quality.	Quarterly	134	Quarterly	EC, pH TBC
S2537	MB NEW	287168.9	6216357.0	148	129.5	HBSS	Near VWP S1941, to verify VWP levels in HBSS and monitor groundwater quality.	Quarterly	78	Quarterly	EC, pH TBC

Bore / VWP ID	Type	Easting	Northing	Ground Level	Screen/ Sensor	Geology	Purpose	SWL (mAHD)		WQ	
S2538	MB NEW	290840.83	6217822.03	148	129.5	HBSS	Within 400 m of Project (Longwall 707). Verify predicted water level impacts and monitor groundwater quality.	Quarterly	44	Quarterly	EC, pH TBC

Note: MB – Monitoring bore (open standpipe)   NEW – New bores (installed 05/Jul/21-27/Aug/21)

EX – Existing

AD – Abandoned and destroyed

TBC – to be confirmed once sufficient data has been collected following bore installation

Coordinates in metres (GDA94 - MGA zone 56)

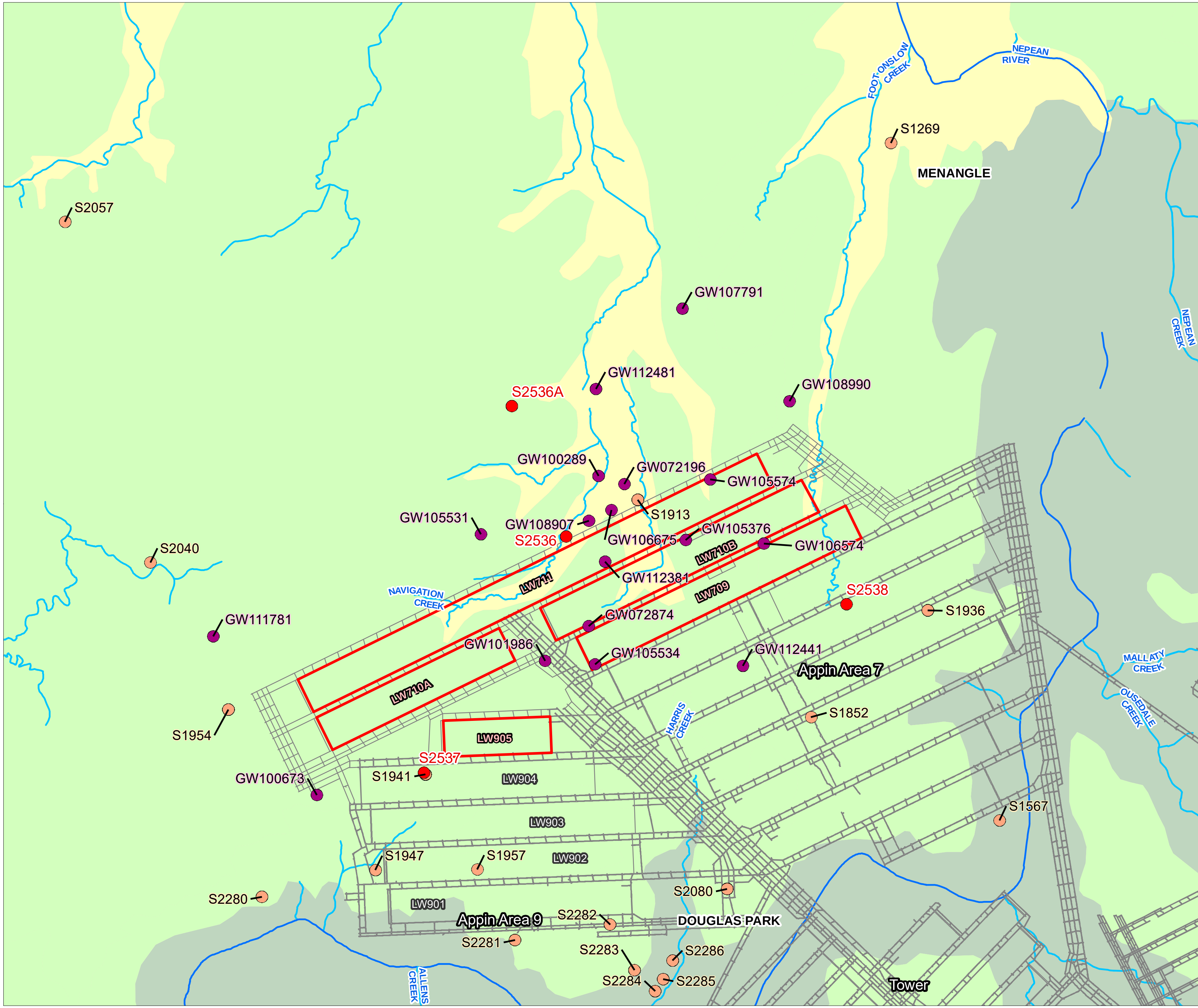
(*) Note: S2157 requires manual data pickup, but due to land access issues, data has not been picked up since 2015 and the status of the piezometers in this drill hole cannot be confirmed at this stage.

Qa – Quaternary alluvium   BrSh – Wianamatta Bringelly Shale   UnSS – Wianamatta - Minchinbury Sandstone   AsSh – Wianamatta – Ashfield Shale

HBSS – Hawkesbury Sandstone   BGSS – Bulgo Sandstone

CCSS – Coal Cliff Sandstone   SBSS – Scarborough Sandstone   BUCO – Bulli Coal Seam

WWCO - Wongawilli Coal Seam LDSS – Loddon Sandstone



APPIN MINE
GROUNDWATER ASSESSMENT

PROPOSED MONITORING PROGRAM

FIGURE 117

- New Piezometer
- Registered Bore
- Vibrating Wire Piezometer
- Major watercourse
- Minor watercourse
- Qal/ Tal – Alluvium
- Wianammatta group
- Rh - HBSS
- Project Area

0 0.5 1 km

Projection: GDA 1994 MGA Zone 56
Scale: 1:45,000 at A4

Project No.: 665.10015
Date: 21-Sep-2022
Drawn by: JG

SLR

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6.2 Appin Monitoring Program

Manual groundwater level monitoring should be conducted for the four new monitoring bores, with data loggers installed to gather temporal variations in groundwater levels. Data should also continue to be downloaded from the existing VWPs, pressure readings recorded and converted to groundwater elevations within a central database.

Ongoing monitoring will enable natural groundwater level fluctuations (such as responses to rainfall) to be distinguished from potential groundwater level impacts due to depressurisation resulting from the Project. Ongoing monitoring of groundwater levels can also be used to assess the extent and rate of depressurisation against model predictions.

It is recommended that a monitoring program is conducted in accordance with a Groundwater Monitoring Plan (GWMP). The following actions are recommended to support on-going groundwater monitoring:

- Continue to update and refine the central groundwater monitoring database;
- An assessment of water level and quality results from the monitoring network should be included in annual reviews;
- Monitoring data (groundwater levels, discharges and water quality) is reviewed and compared to targets (predicted) on a five yearly basis;
- Where access is available monitor landowner bores; and
- If a landowner bore is suitable, undertake the following:
  - Install a datalogger to automatically record groundwater levels;
  - Install a flow meter on landowner water extraction bores to monitor usage;
  - Conduct an annual water quality analysis including pH and electrical conductivity (EC) as well as laboratory analysis as outlined below; and
  - Annual or quarterly manual groundwater level monitoring with an electronic dip meter to calibrate the dataloggers where access is available.

Groundwater quality sampling should be conducted to detect any changes in groundwater quality during and post mining.

Water quality monitoring should include field analysis of pH and EC, as well as annual sampling for laboratory analysis of a full suite of analytes, including:

- physio-chemical indicators – pH, electrical conductivity, total dissolved solids;
- major ions – calcium, fluoride, magnesium, potassium, sodium, chloride, sulphate;
- total alkalinity as CaCO3, HCO3, CO3; and
- dissolved metals – aluminium, arsenic, barium, boron, beryllium, cadmium, chromium, cobalt, copper, iron, lead, manganese, mercury, molybdenum, nickel, selenium, strontium, silver, vanadium and zinc.

6.3 Criteria Assessment

Proposed groundwater trigger criteria for the Project are presented in **Table 29**. Groundwater assessment levels at monitoring bores and VWPs are based on the numerical model predicted change in groundwater levels, as outlined in **Table 28**. Investigation into groundwater level trends should be undertaken if there are three consecutive readings outside of the proposed trigger level. Investigation should include review of climate trends, the quality of the data/condition of the monitoring point, as well as water level and quality trends at other relevant bores and VWPs to identify the cause for the change in levels beyond those predicted.

Water quality assessments are proposed for the four new standpipe bores, three within the HBSS and one within the alluvium. It is proposed that assessments of field pH and electrical conductivity (are undertaken, with EC be used for early detection of potential adverse changes in water quality. Indicative assessment levels for the HBSS bores have been included based on the 5th and 95th percentile for pH and 95th percentile for EC from site baseline data (**Section 3.3**). These assessment levels are indicative only and should be reviewed following bore installation and collection of data to ensure they are applicable and capable of early detection of potential impacts. The triggers for the new bores will be established once two years of groundwater quality data is available.

Table 29 Proposed Appin Mine Assessment Criteria

Type	Proposed Assessment Criteria
Groundwater Levels	Three consecutive readings are outside of the proposed trigger levels for the individual bore/sensor as specified in **Table 28**.
Quaternary Alluvium Groundwater Quality	Three consecutive readings for pH outside of the 5th and 95th percentile and EC outside of the 95th percentile of baseline data for Quaternary alluvium at bore S2536, to be determined from baseline data (two years of data with a minimum of 18 samples).
Hawkesbury Sandstone Groundwater Quality	Three consecutive readings for pH outside of the 5th and 95th percentile of baseline site data of 6.4 and 11.9 for bores S2536A, S2537 and S2538. Three consecutive readings for EC outside the 95th percentile of baseline site data of 6,458 µS/cm for bores S2536A, S2537 and S2538.

There is available baseline data for alluvial water quality from the Navigation Creek site (NAV1) that would be used to establish surface water quality assessment levels. Water level and quality results from the monitoring network should be included in an annual review. An assessment of water level and quality is undertaken in the relevant End of Panel Report. This information is summarised in the Annual Review. The reporting should include a review comparing predicted and observed levels and vertical head profiles to identify any potential adverse changes beyond those predicted. The review should include a comparison to climate trends and surface water monitoring results to identify any changes in the surface water and groundwater interactions, where relevant. The annual review or End of Panel Review should also identify if any additional monitoring sites are required, or if optimisation of the existing monitoring sites should be undertaken.

6.4 Landholder Bore Monitoring

If accessible, and landholder access is granted, it is recommended that landholder bores within the immediate vicinity of the Appin Mine are monitored for groundwater levels, quality and details on bore usage. **Table 30** presents a summary of landholder bores above and in the vicinity of the Appin Mine, with available details on the bore construction, likely geology and recommended monitoring frequency. The location of the bores is shown in **Figure 117**. It should be noted that this is indicative only and would be dependent on landholder access.

It is recommended that the construction of bore GW100289 be verified to confirm if it is within alluvium or the Wianamatta Group. Currently, GW106574 has nested piezometers installed at depths of 65 m, 129 m and 190 m.

Table 30 Proposed Landholder Bore Monitoring

Bore ID	Easting (GDA94)	Northing (GDA94)	Ground Elevation (mAHD)	Total Depth (mbgl)	Screen (mbgl)	Use	Geology	SWL	WQ
GW108990	290347	6219588	108.75		-	Domestic	Unknown (likely HBSS)	A	A
GW100289	288686	6218937	124.22	30	Slots (12 – 18)	Stock and Domestic	Wianamatta? Or alluvium?	D/Q	Q
GW072874	288601	6217630	140.9	189	OH (45 – TD)	Stock and Domestic	Upper HBSS	D/Q	Q
GW100673	286235	6216160	154.16	104	-	Stock	Upper HBSS	GS	A
GW101986	288223	6217328	174.71	210	OH (103 – TD)	Stock and Domestic	Upper HBSS	Q	A
GW105531	287664	6218430	150.51	210	OH (33 – TD)	Stock and Domestic	Upper HBSS	A	A
GW105534	288655	6217297	167.82		OH (72 – TD)	Stock and Domestic	Upper HBSS	D/Q	Q
GW106675	288797	6218642	124.43	183	OH (43 – TD)	Stock and Domestic	Upper HBSS	Q	A
GW111781	285334	6217542	-	305	OH (120 – TD)	Domestic	Upper HBSS	A	A
GW112381	288743	6218191	-	152	OH (72 – TD)	Stock and Domestic	Upper HBSS	D/Q	Q
GW105376	289443	6218380	151.54	218.5	OH (102 – TD)	Stock and Domestic	Lower HBSS	D/Q	Q
GW105574	289656	6218908	125.42	210	OH (Surface – TD)	Stock and Domestic	Lower HBSS	D/Q	Q
GW106574	290123	6218350	140.52	238	OH (6 – TD)	Domestic	Lower HBSS	D/Q	Q
GW107791	289415	6220392	114.32	231	OH (81 – TD)	-	Lower HBSS	A	A
GW108907	288602	6218547	125.78	210	OH (72 – TD)	Stock and Domestic	Lower HBSS	Q	A
GW108990	290347	6219588	108.75	-	-	-	Unknown	A	A
GW072196	288911	6218867	118.01	-	-	Domestic	HBSS?	A	A
GW110671	288717	6216340	141.86	240	OH (28 – TD)	Stock and Domestic	Lower HBSS	GS	A

Note: A – Annual Q – Quarterly D – Daily water levels from datalogger if it can be installed within landholder bore
D/Q – Daily water levels and quarterly manual dipped water level readings to verify logger performance
GS – Bores are already monitored with piezometer data presented on the Geosensing website

Water levels at bores GW100673 and GW110671 are currently monitored with data loggers. Pending individual site evaluation and with the approval of the landholder, it is recommended that a datalogger be installed within the other 16 bores above the mine workings to monitor time series groundwater levels. In addition, quarterly manual groundwater level and quality monitoring should be conducted in these bores. As the registered bores are used for groundwater supply the water levels would be influenced by bore usage.

It is recommended that annual water quality analysis include field parameters of pH and EC as well as laboratory analysis as outlined in **Section 6.2**.

7 Conclusions

IMC are proposing to continue extracting coal from Longwalls 709, 710A, 710B, 711 in Appin Area 7 and Longwall 905 in Area 9. Groundwater modelling has been conducted to predict potential impacts to the local hydrogeological system to support the EP approval process.

The groundwater model was developed utilising existing numerical groundwater models developed by SLR (2021), HydroSimulations (2018) and Heritage Computing (2009). The model extends approximately 52 km from west to east and approximately 43 km from north to south, covering an area of approximately 2,070 km^2, centred on the Appin Mine. The model consists of 18 layers, simulating extraction from the Bulli Seam and potential impacts in the overlying hydrostratigraphy. Ditton A95 and B95 (2014) methods were used to simulate the fracturing above the longwalls. Surface fracturing was also simulated in the model by adopting enhanced horizontal and vertical conductivity in the model. As discussed in **Section 4.2**, transient model calibration was carried out via PEST++ to match observed groundwater levels at Appin Mine.

Transient prediction included four different model scenarios to simulate the impacts from workings within the Longwalls 709, 710A, 710B, 711 and 905 extraction, impacts due to the Appin Mine and the cumulative impacts from existing and approved parts of Tahmoor Mine and neighbouring mines. The model predictions were generally consistent with the predictions from the BSO EIS report (Heritage Computing, 2009). The differences in prediction results between the current model and the Heritage Computing (2009) model are likely due to an update in model structure, change in vertical resolution, updates to model calibration and updates to the fracture profile.

The key conclusions from the groundwater assessment are summarised as follows:

- The predicted total annual take of groundwater from the Permian-Triassic rock aquifer as mine inflows to Longwalls 709, 710A, 710B, 711 and 905 is approximately 0.05 ML/day on average, peaking at an annualised rate of 0.13 ML/day (or up to 46.5 ML for a 12-month period) in 2024.
- Negligible groundwater drawdown is predicted in the alluvium due to Longwalls 709, 710A, 710B, 711 and 905 extractions.
- Substantial decrease in potentiometric head in the fractured and porous rock groundwater sources compared to pre-mining conditions in the vicinity of Longwalls 709 to 711 and Longwall 905. Drawdown of up to 50 m is predicted in the lower HBSS for areas overlying the longwall footprint. The predicted 1 m and 2 m drawdown contours in the lower HBSS remain primarily within the mine footprint.
- Regional depressurisation of aquifers including the lower HBSS, Bulgo Sandstone and Scarborough Sandstone is likely to occur. Depressurisation is predicted to extend up to 1.7 km from the proposed longwall panels. The extent of depressurisation is consistent with previous predictions by Heritage Computing (2009) while the magnitudes of the predicted drawdowns are larger than the 2009 model due to the updates to model structure, model parameters, and the fracture zone above the longwalls.
- There are negligible predicted impacts on surface water bodies including stream baseflow due to depressurisation of the coal measures.
- Greater than 2 m of depressurisation (AIP threshold for highly productive aquifer) was predicted at five bores, with a maximum of 11 m of depressurisation due to mining at Longwalls 709 to 711 and Longwall 905. The predicted impacts on landholder bores due to the cumulative mining are consistent with previous predictions by Heritage Computing (2009) for BSO.

- The groundwater model predicted drawdowns in HBSS (lower) groundwater source. Therefore, impacts on the water quality within the HBSS are possible. Although there is limited data on water quality within the coal measures at Appin, ongoing monitoring of site mine water is recommended.
- The groundwater data analysis, based on currently available records, has shown that there are no observed material impacts from longwall mining beyond what was foreseen for the cumulative impacts described in the BSO study by Heritage Computing (2009).
- A groundwater monitoring program is recommended in accordance with a GWMP that will be prepared in consultation with the regulator. The GWMP will include details on how, when and what groundwater parameters will be monitored across the Project area and surrounds. Monitoring will include groundwater level monitoring of mine bores and landowner bores (subject to gaining access), groundwater and surface water quality monitoring, with results compared to trigger levels to assist in recommending any additional management or mitigation measures.
- A landholder bore survey is recommended in the Project area to assess current groundwater usage, bore construction, and pump infrastructure details including depth of installation.

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APPENDIX A

Groundwater Monitoring Network

Mine Bore ID	Site ID	Type (Status)	Easting (m)	Northing (m)	Ground Level (mAHD)	Sensor/ Screen Depth (mbgl)	Stratigraphy	Data Range
S1176	Appin West 07 (EAW7)	VWP (EX)	291506	6220611	102.30	542.00	BUCO	1992 - 2021
S1269	Appin West 07 (EAW7)	VWP (AD)	291339	6221781	72.4	549.55	BUCO	2005 - 2019
S1437	West Cliff	VWP (AD)	294802	6217460	169.9	507.1	BUCO	2002 - 2008
S1462	West Cliff	VWP (AD)	295590	6217460			BUCO	2002 - 2007
S1488	West Cliff	VWP (AD)	295996	6216958	213.25	521.9	BUCO	2003- 2009
S1584								
S1742	West Cliff	VWP (AD)	294754	6216695		249		2005 - 2006
						317.5		2005 - 2006
						390		2005 - 2006
S1763	Appin West 09 (EAW9)	VWP (AD)	288307	6217555	147.62	577	BUCO	2005 - 2017
S1778	West Cliff	VWP (AD)	294921	6218080	198.17			2006 - 2008
S1809	Appin West 07 (EAW7)	VWP (AD)	292294	6218319	120.3	511	BUCO	2006 - 2011
S1852	Appin West 07 (EAW7)	VWP (AD)	290623	6216815	171.24	574.5	BUCO	2006 - 2010
S1853	Appin West 07 (EAW7)	VWP (AD)	291697	6218462	128.12	639.34	BUCO	2006 - 2014
S1854	Appin West 07 (EAW7)	VWP (AD)	291650	6218916	142.19	556	BUCO	2006 - 2018
S1857	Appin West 09 (EAW9)	VWP (AD)	287662	6215525	164	475.75		2006 -2011
S1864		VWP (AD)	299530	6211418				
S1913	Appin West (EAW5)	VWP (EX)	289028	6218729	117.04	65	HBSS	2008 – 2021
						137	HBSS	2008 – 2021
						194	HBSS	2008 – 2021
						274	BGSS	2008 – 2021
						358	BGSS	2008 – 2021
						447	BGSS	2008 – 2021
						473	SBSS	2008 – 2021
						486	SBSS	2008 – 2021
						505	SBSS	2008 – 2021
						559.5	BUCO	2008 – 2021
S1936	Appin West 07 (EAW7)	VWP (AD)	291547	6217768	148.14	65	HBSS	2008 - 2021
						123.8	HBSS	2008 - 2014
						192	HBSS	2008 - 2014
						278	BGSS	2008 - 2014
						347.8	BGSS	2008 - 2014
						422.5	BGSS	2008 - 2014
						456.2	SBSS	2008 - 2014
						462.1	SBSS	2008 - 2014
						468	SBSS	2008 - 2014
						556.1	BUCO	2008 - 2012
S1941	Appin West 09 (EAW9)	VWP (EX)	287181	6216341	148.82	65	HBSS	2009 - 2021
						126.5	HBSS	2009 - 2021
						201.6	HBSS	2009 - 2021
						284.3	BGSS	2009 - 2021
						355.7	BGSS	2009 - 2021
						432	BGSS	2009 - 2021
						463	SBSS	2009 - 2021
						472.8	SBSS	2009 - 2021
						487.5	SBSS	2009 - 2021
						555.4	BUCO	2009 - 2021

Mine Bore ID	Site ID	Type (Status)	Easting (m)	Northing (m)	Ground Level (mAHD)	Sensor/ Screen Depth (mbgl)	Stratigraphy	Data Range
						596	WWCO	2009 - 2014
S1947	Appin West 09 (EAW9)	VWP (AD)	286755	6215478	116.92	502.45	BUCO	2008 -2017
S1954	Appin West 18 (EAW18)	VWP (EX)	285466	6216904	310	36	BrSh	2009 - 2021
						85	BrSh	2009 - 2021
						100.5	BrSh	2009 - 2021
						138.5	UnSS	2009 - 2021
						145.3	UnSS	2009 - 2021
						181	AsSh	2009 - 2021
						205	AsSh	2009 - 2012
						245	HBSS	2009 - 2021
						273.1	HBSS	2009 - 2021
						316.3	HBSS	2009 - 2021
						359.4	HBSS	2009 - 2021
						392.5	HBSS	2009 - 2021
						742.9	BUCO	2009 - 2021
S1957	Appin West 09 (EAW9)	VWP (AD)	287662	6215502	131.00	518.8	BUCO	2008 - 2016
S1993	West Cliff	VWP (EX)	296778	6217610	164.39	35	HBSS	2009 - 2021
						86.5	HBSS	2009 - 2021
						168	HBSS	2009 - 2021
						230.9	BGSS	2009 - 2021
						319	BGSS	2009 - 2021
						412	BGSS	2009 - 2021
						435	SBSS	2009 - 2021
						441.5	SBSS	2009 - 2021
						448	SBSS	2009 - 2021
						508.2	BUCO	AD
S1996	North to Cataract Lake	VWP (EX)	298772	6207843	381.65	82	HBSS	2010 - 2020
						159	HBSS	
						219	BGSS	
						274	BGSS	
						313	BGSS	
						355	SBSS	
						373	SBSS	
						380	SBSS	
						439	CCSS	
						478	BUCO	
S1997	West to Metropolitan Mine	VWP (EX)	306997	6212764	370.17	24	HBSS	2010 - 2021
						68.5	HBSS	
						132	HBSS	
						218	BGSS	
						292.5	BGSS	
						372	BGSS	
						429	SBSS	
						441.5	SBSS	
						454	SBSS	
						504.5	CCSS	
						511.63	BUCO	
S2036	North to Cataract Lake	VWP (EX)	300016	6206725.5	358.76	374.2	BUCO	2017 - 2021
						411.2	WWCO	
S2040	Appin Area 9	VWP (AD)	284789	6218183	251.45	773	BUCO	2009 - 2014
S2057	North to Appin Area 9	VWP (AD)	284047	6221149	137.4	691	LDSS	2010 - 2014
S2060		VWP (EX)	288629.07	6215791.6	202.46	110	HBSS	2010 - 2019

Mine Bore ID	Site ID	Type (Status)	Easting (m)	Northing (m)	Ground Level (mAHD)	Sensor/ Screen Depth (mbgl)	Stratigraphy	Data Range
	Appin West 51					267	HBSS	2010 - 2019
						327	BGSS	2010 - 2019
						495	BGSS	2010 - 2019
						603.9	BUCO	2010 - 2019
						614.6	BACO	2010 - 2019
						626.7	CHCO	2010 - 2019
						645.7	WWCO_upper	2010 - 2014
						651.1	WWCO_Base	2010 - 2014
						663.1	ACCO	2010 - 2016
						668.5	ACFM	2010 - 2014
						706.3	TGCO	2010 - 2015
S2080	Appin West 58 (EAW58)	VWP (EX)	297111	6216174	125.9	65	HBSS	2010 - 2021
						95	HBSS	
						170	HBSS	
						241	BGSS	
						326.5	BGSS	
						417	BGSS	
						440	SBSS	
						447	SBSS	
						454	SBSS	
						499	CCSS	
S2081	Appin West 58 (EAW58)	XX	289819	6215294				
S2087	West Cliff	VWP (AD)	295752	6217627.5	192.97	55	HBSS	2010 - 2021
						95	HBSS	2010 - 2021
						185	HBSS	2010
						238	BGSS	2010 - 2021
						313.5	BGSS	2010
						394	BGSS	2010
						419	SBSS	2010
						440	SBSS	2010
S2106	Appin West 07 (EAW7)	VWP (AD)	285098	6218772	306.77	793.00	CCSS	2010 -2017
S2129	Appin West 07 (EAW7)	VWP (AD)	283394	6217998	245.00	722.50	BUCO	2011 -2020
S2132	Appin Area 8	VWP (EX)	283616	6214090	145.90	491.00	BUCO	2011 - 2022
S2133	Appin Area 9	VWP (AD)	284194	6218851	295.22	799.00	BUCO	2011 - 2017
S2149	Appin Area 8	VWP (EX)	282415	6215044	153.5	65	HBSS	2011 - 2021
						121.5	HBSS	
						203	HBSS	
						262	BGSS	
						326	BGSS	
						395	BGSS	
						429.5	SBSS	
						515.7	BUCO	
						525.4	BACO	
						541.4	CHCO	
S2152	Appin Area 8	VWP (AD)	284141	6215533	299.5	692.00	BUCO	2011 - 2018
S2157	Appin Area 8	VWP (AD)	283212	6215968	224.5	82.5	WNSH	2013 - 2021
						135	HBSS	
						207	HBSS	
						284	HBSS	
						368	BGSS	
						418	BGSS	
						468	BGSS	

Mine Bore ID	Site ID	Type (Status)	Easting (m)	Northing (m)	Ground Level (mAHD)	Sensor/ Screen Depth (mbgl)	Stratigraphy	Data Range
						518	SPCS	
						568	SBSS	
						626.9	BUCO	
S2158	Appin Area 8	VWP (EX)	283778	6212690	138.9	44	HBSS	2012 - 2021
						65	HBSS	
						111.6	HBSS	
						158.2	HBSS	
						218.9	BGSS	
						295.4	BGSS	
						377	BGSS	
						404	SBSS	
						473	BUCO	
						511	UWWCO	
						516.5	LWWCO	
						528	ACCO	
S2160	Appin Area 8	VWP (AD)	284717	6213651	133.4	44	HBSS	2012 - 2021
						87	HBSS	
						164	HBSS	
						226	BGSS	
						273	BGSS	
						320.5	BGSS	
						367.8	SPCS	
						415	SBSS	
						479.6	BUCO	
						486	BACO	
S2164	Appin Area 8	VWP (AD)	283905	6214851	171.2	542.51	BUCO	2011 - 2015
S2165	North to Appin Area 7	VWP (EX)	288766	6226269	66.95	40	WNSH	2012 - 2021
						116	HBSS	
						112	HBSS	
						168.5	HBSS	
						257	HBSS	
						328	BGSS	
						414.2	BGSS	
						500.4	BGSS	
						586.5	SPCS	
						672.7	SBSS	
						694.7	BUCO	
						713.6	BACO	
						765	WWCO	
S2173	North to Appin Area 7	VWP (EX)	287589	6223237	110.22	76	WNSH	2012 - 2020
						91.5	WNSH	
						116	HBSS	
						198	HBSS	
						285	HBSS	
						369	BGSS	
						451	BGSS	
						533	BGSS	
						554	SPCS	
						596.8	SBSS	
S2177	Appin Area 10	VWP (EX)	291122	6225144	70	44	HBSS	2013 - 2021
						80	HBSS	
						150.2	HBSS	
						220.3	HBSS	
						283.6	BGSS	

Mine Bore ID	Site ID	Type (Status)	Easting (m)	Northing (m)	Ground Level (mAHD)	Sensor/ Screen Depth (mbgl)	Stratigraphy	Data Range
						358.9	BGSS	
						434.2	BGSS	
						462.1	SPCS	
						510	SBSS	
						621.1	BUCO	
S2280	Harris Creek 6	VWP (EX)	296752	6216617	129.86	60	HBSS	2014 - 2021
						99	HBSS	2014 - 2021
S2281	Harris Creek 7	VWP (EX)	289028	6218729	125.15	61	HBSS	2014 - 2021
						99	HBSS	2014 - 2021
S2282	Harris Creek	VWP (EX)	288787	6215032	133.01	60	HBSS	2014 - 2021
						100	HBSS	2014 - 2021
S2283	Harris Creek	VWP (EX)	288999	6214636	127.1	60	HBSS	2015 - 2021
						100	HBSS	2015 - 2021
S2284	Harris Creek	VWP (EX)	289176	6214454	110.45	60	HBSS	2015 - 2021
						100	HBSS	2015 - 2021
S2285	Harris Creek	VWP (EX)	289248	6214558	113.33	60	HBSS	2015 - 2021
						100	HBSS	2015 - 2021
S2286	Harris Creek	VWP (EX)	289329	6214721	114.55	60	HBSS	2015 - 2021
						100	HBSS	2015 - 2021
S2308		VWP (EX)	289885	6218497	144.70	70	HBSS	2015 - 2022
						135	HBSS	2015 - 2022
						200	HBSS	2015 - 2022
						287	BGSS	2015 - 2022
						378	BGSS	2015 - 2022
						503	SBSS	2015 - 2022
						514	SBSS	2015 - 2022
						574	BUCO	2015 - 2022
S2524	North to Appin Area 7	VWP (EX)	290397	6219126	105.69	40	HBSS	2021 - 2022
						87.4	HBSS	2021 - 2022
						134.8	HBSS	2021 - 2022
						164.2	HBSS	2021 - 2022
						219.4	BHCS	2021 - 2022
						247.1	BGSS	2021 - 2022
						285.1	BGSS	2021 - 2022
						323.1	BGSS	2021 - 2022
						361.2	BGSS	2021 - 2022
S2533	Appin Area 9	VWP (EX)	286266	6216595		11.5	WNSH	2021 - 2022
						29.5	WNSH	2021 - 2022
						65.0	WNSH	2021 - 2022
						102.0	WNSH	2021 - 2022
S2536	North to Appin Area 7	VWP (EX)	288416	6218405	128.25	15.5	WNSH	2021 - 2022
S2536A	North to Appin Area 7	VWP (EX)	287918	6219546	134.3	134.5	HBSS	2021 - 2022
					134.6	616.6	BUCO	2021 - 2022
S2537	Appin Area 9	VWP (EX)	287169	6216357	147.47	129	HBSS	2021 - 2022
S2538	Appin Area 7	VWP (EX)	290856	6217789	122.38	129.50	HBAA	2021 - 2022
WC_54	West Cliff Area 5	MB (EX)	291547	6217768	206.49	46.8	HBSS	2014 - 2020
WC_95	West Cliff Area 5	MB (EX)	287181	6216341	228.68	20.24	HBSS	2014 - 2020
A3GW1	A3GW1a	MB (AD)	292997	6210540	209.4	62	HBSS	2006 - 2011
	A3GW1b					38.5	HBSS	2005 - 2012
	A3GW1c					9.9	HBSS	2005 - 2012
A3GW2	A3GW2a	MB (AD)	293674	6210776	215	59.6	HBSS	2006 - 2012
	A3GW2b					28.3	HBSS	2006 - 2012

Mine Bore ID	Site ID	Type (Status)	Easting (m)	Northing (m)	Ground Level (mAHD)	Sensor/ Screen Depth (mbgl)	Stratigraphy	Data Range
	A3GW2c					9.9	HBSS	2006 - 2012
A3GW3	A3GW3a	MB (AD)	293974	6210832	219.7	70	HBSS	2006 - 2012
	A3GW3b					27	HBSS	2006 - 2010
	A3GW3c					9.9	HBSS	2006 - 2012
A3GW4	A3GW4a	MB (AD)	293640	6209537	236	84	HBSS	2005 - 2012
	A3GW4b					29.9	HBSS	2005 - 2012
A3GW5	A3GW5a	MB (AD)	294222	6210572	228.1	77	HBSS	2006 - 2010
	A3GW5b					50.75	HBSS	2006 - 2011
	A3GW5c					10	HBSS	2006 - 2011
A3GW6	A3GW6a	MB (AD)	294482	6209688	240.9	74.5	HBSS	2006 - 2012
	A3GW6b					47.5	HBSS	2006 - 2012
	A3GW6c					9.85	HBSS	2006 - 2012
A3GW7	A3GW7a	MB (AD)	292988	6210942	226.6	75	HBSS	2006 - 2011
	A3GW7b					56.5	HBSS	2006 - 2011
	A3GW7c					25	HBSS	2006 - 2012
A3GW8	A3GW8a	MB (AD)	293646	6209862	228.5	53	HBSS	2005 - 2012
	A3GW8b					22.8	HBSS	2005 - 2012
	A3GW8c					8.3	HBSS	2005 - 2012
EAW7								
GR27	S1428	MB (AD)	297111	6216174	217.57	30.1	HBSS	2001 - 2020
GR28	S1429	MB (AD)	296752	6216617	206.9	24.31	HBSS	2001 - 2020
GR59	S1481	MB (AD)	296850	6213349	227.95	-	-	2002 - 2011
GR60	S1482	MB (AD)	296865	6213317	227.97	-	-	2002 - 2011
GR61	S1483	MB (AD)	296863	6213272	227.3	-	-	2002 - 2011
GR62	S1484	MB (AD)	296854	6213250	224.11	-	-	2002 - 2011
GR63	S1485	MB (AD)	296860	6213185	225.75	-	-	2002 - 2011
GR64	S1486	MB (AD)	296873	6213409	234.12	-	-	2002 - 2011
GR70	-	MB	296778	6217610	186.54	28.88	HBSS	2014 - 2019
NGW3	-	MB (AD)	6216750	275027	123.087	72.1	Shale / sandstone	2004 - 2015
NGW4	-	MB (AD)	6216826	275790	125.244	78.75	Sandstone	2004 - 2015
NGW5	-	MB (AD)	6216327	276124	110.85	66.45	Sandstone	2004 - 2015
NGW6	-	MB (AD)	6216681	276403	116.45	66.75	Sandstone	2004 - 2015
NGW7	-	MB (AD)	6216591	277027	124.333	69.18	Sandstone	2004 - 2013
NGW9	-	MB (AD)	6217131	277737	124.333	69.19	Sandstone	2004 - 2012
NGW10	-	MB (AD)	6217333	276952	123.252	69.5	Sandstone	2004 - 2013
NGW11	-	MB (AD)	6217625	277105	127.336	72.15	Sandstone	2004 - 2013

Coordinates in metres (GDA94 - MGA zone 56)
VWP – Vibrating Wire Piezometer
MB – monitoring bore/open standpipe
EX – Existing
AD – abandoned and destroyed
GW – Georges River Bores AGW – Cataract River Bores NGW – Nepean River Bores
HBSS – Hawkesbury Sandstone BGSS – Bulgo Sandstone SBSS – Scarborough Sandstone
BUCO – Bulli Coal Seam WWCO - Wongawilli Coal Seam BrSh – Wianamatta (WnSh)– Bringelly Shale
UnSS – Wianamatta - Minchinbury Sandstone AsSh – Wianamatta – Ashfield Shale CCSS – Coal Cliff Sandstone

APPENDIX B

Water Quality Data

Analyte		NHMRC Drinking water	ANZG 2018 Fresh Water Aquatic (95% protection)	ANZG 2018 Short term irrigation	ANZG 2018 Long term irrigation	ANZG 2018 Stock Water	Nepean River (Surface water)	Wianamatta Group	Hawkesbury Sandstone	Bulgo Sandstone
pH (Field)	Av.						7.7	8.1	8.0	7.4
	Med.						7.7	7.9	7.5	7.2
	Min.	6.5 - 8.5b	6.5 – 8.5	6.0 - 8.5	6.0 - 8.5	-	5.6	7.1	4.8	4.2
	Max.						9.8	9.7	13.1	12.8
	Pop.						3561	19	205.0	48.0
EC (Field)	Av.						321	4354	2653	4379
	Med.						244	4750	2063	4950
	Min.	-	120 - 300	-	-	-	12	7	7	7
	Max.						5596	9310	15820	10070
	Pop.						3575	19	206	48
TDS	Av.						173	2917^	1778^	2934^
	Med.						135	**3183^**	1382^	**3317^**
	Min.	600b	-	-	-	2,000 - 13,000*	10	5^	5^	4^
	Max.						1460	6238^	10599^	6747^
	Pop.						1738	19	206	48
Chloride	Av.						41	979	548	114
	Med.						33	675	233	122
	Min.	250b	-	-	-	-	14	289	22	16
	Max.						724	2820	8530	332
	Pop.						1761	23	213	60
Calcium	Av.						5	42	76	60
	Med.						4	36	70	50
	Min.	-	-	-	-	1,000	1	7	1	1
	Max.						83	108	384	190
	Pop.						1763	23	212	60
Sodium	Av.						48	1018	336	1203
	Med.						34	**1050**	**261**	**1300**
	Min.	180b	-	-	-	-	11	162	20	63
	Max.						**362**	1930	1390	2230
	Pop.						1763	23	213	60
Magnesium	Av.						5	15	52	24
	Med.						4	14	30	22
	Min.	-	-	-	-	-	1	6	1	4
	Max.						112	34	332	48

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Analyte		NHMRC Drinking water	ANZG 2018 Fresh Water Aquatic (95% protection)	ANZG 2018 Short term irrigation	ANZG 2018 Long term irrigation	ANZG 2018 Stock Water	Nepean River (Surface water)	Wianamatta Group	Hawkesbury Sandstone	Bulgo Sandstone
	Pop.						1763	23	194	60
Sulphate	Av.	500a / 250b	-	-	-	1,000 – 2,000	5	2	11	5
	Med.						4	1	5	3
	Min.						1	1	2	2
	Max.						100	4	38	9
	Pop.						252	3	13	3
Potassium	Av.	-	-	-	-	-	4	36	151	33
	Med.						3	23	16	29
	Min.						1	11	3	3
	Max.						17	318	7190	106
	Pop.						1763	23	213	60
Fluoride	Av.	1.5a	-	2	1	2	0.2	0.5	0.2	0.2
	Med.						0.1	0.5	0.2	0.2
	Min.						0.1	0.2	0.1	0.1
	Max.						0.3	0.9	1.3	0.6
	Pop.						201	7	68.0	24.0
Bicarbonate	Av.	-	-	-	-	-	81	1140	540	2834
	Med.						55	789	374	2900
	Min.						1	252	29	1360
	Max.						399	2810	2570	4430
	Pop.						1754	1140	540	2834
Iron (t)	Av.	0.3b	-	10	0.2	-	0.3	1.5	2.0	3.8
	Med.						**0.3**	**1.4**	**1.1**	**1.9**
	Min.						0.01	0.01	0.03	0.03
	Max.						12.2	4	19	12
	Pop.						1766	20	186	55
Aluminium (d)	Av.	0.2b c	0.055	20	5	5	0.1	0.1	0.4	0.01
	Med.						0.1	0.03	0.02	0.01
	Min.						0.01	0.01	0.01	0.01
	Max.						5.2	0.5	7.6	0.2
	Pop.						1766	14	101	50
Arsenic (d)	Av.	0.01a	As (III) 0.024 As (V) 0.013	2	0.1	0.5	0.003	0.004	0.007	0.004
	Med.						0.001	0.002	0.003	0.003
	Min.						0.001	0.001	0.001	0.001
	Max.						0.2	0.010	0.061	0.013

Analyte		NHMRC Drinking water	ANZG 2018 Fresh Water Aquatic (95% protection)	ANZG 2018 Short term irrigation	ANZG 2018 Long term irrigation	ANZG 2018 Stock Water	Nepean River (Surface water)	Wianamatta Group	Hawkesbury Sandstone	Bulgo Sandstone
	Pop.						1764	18	173	60
Barium (d)	Av.	2a	-	-	-	-	0.2	7.2	2.3	16.8
	Med.						0.2	**6.0**	1.08	**15.50**
	Min.						0.1	3.1	0.03	0.4
	Max.						0.2	17.0	14.5	38.8
	Pop.						5.0	19	205	58
Boron (d)	Av.	4a	0.94	refer to guideline	0.5	5	0.2	-	-	-
	Med.						0.8	-	-	-
	Min.						0.0	-	-	-
	Max.						4.9	-	-	-
	Pop.						45.0	-	-	-
Cadmium (d)	Av.	0.002a	0.0002	0.05	0.01	0.01	0.0001	-	-	-
	Med.						0.0001	-	-	-
	Min.						0.0001	-	-	-
	Max.						0.0001	-	-	-
	Pop.						2.0	-	-	-
Chromium (d)	Av.	0.05a	CrIII – ID Cr(VI) 0.001	1	0.1	1	0.001	-	-	-
	Med.						0.001	-	-	-
	Min.						0.001	-	-	-
	Max.						0.001	-	-	-
	Pop.						2	-	-	-
Copper (d)	Av.	2a / 1b	0.0014	5	0.2	0.5	0.001	0.001	0.002	0.007
	Med.						0.001	0.001	0.002	0.001
	Min.						0.001	0.001	0.001	0.001
	Max.						0.03	0.005	0.006	0.17
	Pop.						1764	16	18	31
Iron (d)	Av.	-	-	10	0.2	-	0.3	-	-	-
	Med.						0.3	-	-	-
	Min.						0.0	-	-	-
	Max.						12.2	-	-	-
	Pop.						1766	-	-	-
Lead (d)	Av.	0.01a	0.0034	5	2	0.1	0.001	0.04	0.24	0.7
	Med.						0.001	0.001	0.04	0.7
	Min.						0.001	0.001	0.001	0

Analyte		NHMRC Drinking water	ANZG 2018 Fresh Water Aquatic (95% protection)	ANZG 2018 Short term irrigation	ANZG 2018 Long term irrigation	ANZG 2018 Stock Water	Nepean River (Surface water)	Wianamatta Group	Hawkesbury Sandstone	Bulgo Sandstone
	Max.						0.05	0.7	1.4	1.4
	Pop.						1764	16	7	2
Manganese (d)	Av.	0.5a / 0.1b	1.9	10	0.2	-	0.04	0.1	0.1	0.04
	Med.						0.03	0.03	0.1	0.02
	Min.						0.001	0.01	0.001	0.001
	Max.						1.6	0.3	0.7	0.5
	Pop.						1766	18	145	45
Mercury (d)	Av.	-	0.0006	0.002	0.002	0.002	0.0001	-	-	-
	Med.						0.0001	-	-	-
	Min.						0.0001	-	-	-
	Max.						0.0001	-	-	-
	Pop.						2	-	-	-
Nickel (d)	Av.	0.02a	0.011	2	0.2	1	0.006	0.001	0.005	0.003
	Med.						0.003	0.001	0.002	0.002
	Min.						0.001	0.001	0.001	0.001
	Max.						0.1	0.002	0.09	0.02
	Pop.						1764	20	136	47
Selenium (d)	Av.	0.01a	Total – 0.011 SeIIV - ID	0.05	0.02	0.02	0.01	0.01	0.009	0.007
	Med.						**0.01**	**0.01**	**0.01**	0.009
	Min.						0.02	0.005	0.006	0.001
	Max.						0.1	0.01	0.01	0.01
	Pop.						1764	16	3	3
Zinc (d)	Av.	3b	0.008	5	2	20	0.01	0.14	0.044	0.058
	Med.						0.01	0.006	0.003	0.010
	Min.						0.004	0.003	0.003	0.001
	Max.						0.24	2.5	1.4	2.4
	Pop.						1764	20	116	54

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 (2011, version 3.8 September 2022)

b NHMRC Aesthetic Guidelines for Drinking Water (2011, version 3.8 September 2022)

c NHMRC acid-soluble aluminium concentrations (2011, version 3.8 September 2022)

(d) dissolved metals

Av. Average; Med. Median

^ Calculated based on field EC

APPENDIX C

Registered Bores in the Appin Mine Area

Bore ID	Easting	Northing	Elevation (mAHD)	Year Drilled	Total Depth (mbgl)	Screen (mbgl)	SWL (mbgl)	EC/ Salinity	Status	Use	Geology	Comment
GW017315	286642	6220354	140.51	1938	36.5	OH (0.9 – TD)	-	3001-7000 ppm	Current	Farming – General Use	-	-
GW026516	289037	6220994	96.21	1965	10	-	-	-	Test Hole (Unknown)	Irrigation	Unconsolidated Clay, Silt and Shale	WBZ 4.5 m (Clay)
GW034425	289184	6215603	121	1972	70.1	OH (12 – TD)	-	Good	non-operational	Waste Disposal	Sandstone	WBZ (Sandstone) 9.1 - 10.6 m (SWL 4.7 m, Yield 0.03 L/s) WBZ (Sandstone) 21.3 - 24.3 m (SWL 14.6 m, Yield 0.04 L/s) WBZ (Sandstone) 64 - 69.4 m (SWL 14.6 m, Yield 0.63 L/s)
GW035033	288045	6214961	129.67	1973	131	OH (20.4 – TD)	-	-	Current	Stock	Sandstone and Shale	WBZ (Sandstone/Shale) 17.6 - 17.7 m (SWL 17.6 m, Yield 0.13 L/s) WBZ (Sandstone) 54.8 - 55.1 m (SWL 54.8 m, Yield 0.23 L/s)
GW062945	287960	6221031	115.28	1986	150	OH (86.9 – TD)	-	Fresh	Current	Stock, Domestic and Farming	Sandstone	WBZ (Fractured Shale) 29.6 - 30.8 m (SWL 15 m, Yield 1.2 L/s) WBZ (Sandstone) 101.3 - 101.7 m (SWL 85 m, Yield 0.2 L/s) WBZ (Sandstone) 144.8 - 145.9 m (SWL 40 m, Yield 0.7 L/s)
GW072196	288911	6218867	118.01	2006	-	-	-	-	Current	Domestic	-	Drilled in mapped alluvium (NGIS) potentially in HBSS
GW072874	288601	6217630	140.9	1992	189	OH (45 – TD)	-	Good	Current	Stock and Domestic	Sandstone, Shale and Siltstone	WBZ (Gravels) 6 - 7 m (Yield 0.2 L/s) WBZ (Shale) 30 - 36 m (Yield 0.1 L/s) WBZ (Sandstone) 80 - 85 m (Yield 0.3 L/s) WBZ (Siltstone) 98 - 104 m (Yield 0.1 L/s) WBZ (Sandstone) 164 - 170 m (Yield 0.2 L/s) WBZ (Sandstone) 176 - 189 m (Yield 1.4 L/s)

Bore ID	Easting	Northing	Elevation (mAHD)	Year Drilled	Total Depth (mbgl)	Screen (mbgl)	SWL (mbgl)	EC/ Salinity	Status	Use	Geology	Comment
GW100289	288686	6218937	124.22	1994	30	Slots (12 – 18) OH (18 - TD)	10	Good	Current	Stock and Domestic	Gravel (Slots) Shale (OH)	WBZ (Gravel) (Yield 0.3 L/s, SWL 10 m)
GW100673	286235	6216160	154.16	1995	104	-	49	Good	Current	Stock	-	Yield: 0.6 L/s (BH Reg), Work Summary (Unavailable)
GW101133	289443	6214100	117.02	1997	96	OH (5.5 – TD)	61	1100 mg/L	Current	Stock and Domestic	Sandstone, Ironstone and Siltstone	WBZ (Sandstone) 78.5 - 78.8 m (Yield 1.8 L/s, SWL 61 m)
GW101437	291642	6216361	135.89	1997	128	OH (6 – TD)	75	2500 mg/L	Current	Farming	Sandstone and Shale	WBZ (Sandstone and Shale) 119 – 121 m (Yield: 0.7 L/s, SWL 75 m, Salinity 2500 mg/L)
GW101986	288223	6217328	174.71	1998	210	OH (103 – TD)	82	-	Current	Stock and Domestic	Sandstone	WBZ (Sandstone) 119 - 120 m (SWL 82 m , Yield 0.25 L/s) WBZ (Sandstone) 132 - 133 m (SWL 82 m, Yield 0.31 L/s) WBZ (Sandstone) 146 - 148 m (SWL 82 m, Yield 0.05 L/s) WBZ (Sandstone) 173 - 179 m (SWL 82 m, Yield 0.05 L/s)
GW102043	289777	6214659	125.56	1999	192	OH (11.6 – TD)	104	260 mg/L	Current	Stock and Domestic	Sandstone, Siltstone and Clay	WBZ (Sandstone) 40 - 41 m (Yield 0.1 L/s, Salinity 291 mg/L) WBZ (Sandstone) 161.5 - 162 m (Yield 0.2 L/s, Salinity 260 mg/L)

Bore ID	Easting	Northing	Elevation (mAHD)	Year Drilled	Total Depth (mbgl)	Screen (mbgl)	SWL (mbgl)	EC/ Salinity	Status	Use	Geology	Comment
GW102144	285921	6221466	143.24	1992	182	OH (17 – TD)	6	-	Current	Stock and Domestic	Sandstone and Shale	NGIS reports northing as 6220466, BH Reg lists as 6221466 WBZ (Shale) 114 - 115 m (SWL 6 m, Yield 0.07 L/s) WBZ (Shale) 140 - 140.4 m (SWL 6 m, Yield 0.06 L/s) WBZ (Sandstone) 162 - 163 m (SWL 6 m, Yield 0.13 L/s) WBZ (Sandstone) 168 - 168.6 m (SWL 6 m, Yield 0.12 L/s)
GW102584	289626	6216445	136.76	1999	186	OH (29.5 – TD)	-	1300 mg/L	Grouted	Stock and Domestic	Sandstone	WBZ (Sandstone) 54 - 60 m (Yield 0.1 L/s, Salinity 1370 mg/L) WBZ (Sandstone) 64 - 70 m (Yield 0.1 L/s, Salinity 1190 mg/L) WBZ (Sandstone) 108 - 112 m (Yield 0.2 L/s, Salinity 1300 mg/L) WBZ (Sandstone) 144 - 150 m (Yield 0.2 L/s, Salinity 1300 mg/L, SWL 60 m) WBZ (Sandstone) 177 - 179 m (Yield 0.9 L/s, Salinity 1300 mg/L)
GW102619	287887	6220525	124.74	1999	224	OH (95 – TD)	95	-	Current	Stock, Domestic, Farming and Irrigation	Sandstone and Shale	WBZ (Sandstone) 38 - 39 m (Yield 0.13 L/s, SWL 24 m) WBZ (Sandstone) 81 - 83 m (Yield 0.75 L/s) WBZ (Shale) 145 - 150 m (Yield 0.25 L/s, SWL 95 m) WBZ (Sandstone) 165 - 200 m (Yield 0.75 L/s, SWL 95 m) WBZ (Sandstone) 200 - 225 m (Yield 0.75 L/s, SWL 95 m)
GW102798	289990	6214783	127.16	See comment	122	OH (3 – TD)	148	700 mg/L	Current	Farming, Stock and Domestic	Sandstone	WBZ (Sandstone) 95 - 96 m (Yield 0.25 L/s) WBZ (Sandstone) 103 - 104 m) (SWL 148 m, Yield 1 L/s, Salinity 700 mg/L)

Bore ID	Easting	Northing	Elevation (mAHD)	Year Drilled	Total Depth (mbgl)	Screen (mbgl)	SWL (mbgl)	EC/ Salinity	Status	Use	Geology	Comment
GW104068	289519	6214530	118.66	2001	180	OH (12 – TD)	62	1000 mg/L	Current	Stock and Domestic	Sandstone, Siltstone and Shale	WBZ (Sandstone) 95 - 118 m (Yield 0.52 L/s, Salinity 990 mg/L, SWL 62 m) WBZ (Sandstone) 152 - 153 m (Yield 0.26 L/s, Salinity 1000 mg/L, SWL 62 m) WBZ (Sandstone) 163 - 164 m (Yield 0.88 L/s, Salinity 1000 mg/L, SWL 62 m)
GW104154	291233	6216088	134.69	2000	165	OH (18 – TD)	74	-	Current	Stock and Domestic	Sandstone and Shale	WBZ (Sandstone) 116 - 117 m (Yield 0.7 L/s) WBZ (Sandstone) 134 - 135 m (Yield 0.9 L/s) WBZ (Sandstone) 160 - 161 m (Yield 1.3 L/s, SWL 74 m)
GW104347	284012	6217884	199.9	2002	298	OH (145 – TD)	110	Brackish	Current	Stock and Domestic	Sandstone	WBZ (Sandstone) 195 - 196 m (Yield 0.3 L/s, SWL 110 m) WBZ (Sandstone) 207 - 208 m (Yield 0.4 L/s, SWL 110 m) WBZ (Sandstone) 273 - 274 m (Yield 0.2 L/s, SWL 110 m)
GW104602	289054	6216338	133.52	Unknown	231	OH (101.5 – TD)	42	Fresh	Current	Stock	Sandstone and Clay	WBZ (Shale) 29.9 - 30 m (Yield 0.13 L/s, Salinity 2500 mg/L, SWL 27 m) WBZ (Sandstone) 161 - 161.5 m (Yield 0.75 L/s, SWL 42 m) WBZ (Sandstone) 213 - 213.15 m (Yield 0.75 L/s, SWL 42 m)
GW104661	289118	6216661	140.74	2003	219.3	OH (42 – TD)	68	Fresh	Grouted	Stock and Domestic	Sandstone	WBZ (Sandstone) 113 - 113.1 m (Yield 0.38 L/s, SWL 68 m) WBZ (Sandstone) 154 - 154.1 m (Yield 0.53 L/s, SWL 68 m) WBZ (Sandstone) 197 - 197.1 m (Yield 0.53 L/s, SWL 68 m) WBZ (Sandstone) 212 - 212.15 m (Yield 1.05 L/s, SWL 68 m)

Bore ID	Easting	Northing	Elevation (mAHD)	Year Drilled	Total Depth (mbgl)	Screen (mbgl)	SWL (mbgl)	EC/ Salinity	Status	Use	Geology	Comment
GW104766	287663	6220995	117.31	2002	192	OH (29.5 – TD)	82	662 mg/L	Current	Stock and Domestic	Sandstone and Shale	WBZ (Sandstone) 121.5 - 123 m (Yield 0.2 L/s, Salinity 860 mg/L) WBZ (Sandstone) 128.5 - 129 m (Yield 0.15 L/s, Salinity 850 mg/L) WBZ (Sandstone) 175 - 176 m (Yield 0.1 L/s, Salinity 740 mg/L) WBZ (Sandstone) 184 - 187 m (Yield 0.15 L/s, Salinity 662 mg/L, SWL 82 m)
GW105325	287685	6221474	111.02	2001	159	OH (122 - TD)	-	2000 mg/L	Current	Stock, Domestic and Recreation	Sandstone and Shale	WBZ (Shale) 72 - 73 m (Yield 0.3 L/s, Salinity 2000 mg/L) WBZ (Shale) 121 - 122 m (Yield 0.5 L/s, Salinity 1800 mg/L) WBZ (Sandstone) 130 - 137 m (Yield 1.2 L/s, Salinity 2000 mg/L)
GW105339	291919	6218356	129	2003	238	OH (30 – TD)	-	-	Grouted	Stock, Domestic and Recreation	Sandstone and Shale	WBZ (Sandstone) 139 - 140 m (Yield 0.25 L/s) WBZ (Sandstone) 183 - 184 m (Yield Unknown)
GW105376	289443	6218380	151.54	2002	218.5	OH (102 – TD)	76	Fresh	Current	Stock and Domestic	Sandstone	WBZ (Sandstone) 180 - 180.1 m (Yield 1.13 L/s, SWL 76 m) WBZ (Sandstone) 191 - 191.2 m (Yield 1.63 L/s, SWL 76 m) WBZ (Sandstone) 204 - 204.2 m (Yield 1.5 L/s, SWL 76 m)
GW105531	287664	6218430	150.51	2003	210	OH (33 – TD)	79	2070 mg/L	Current	Stock and Domestic	Sandstone and Shale	WBZ (Sandstone) 96.2 - 96.8 m (Yield 0.2 L/s, Salinity 2070 mg/L) WBZ (Sandstone) 110.5 - 113 m (Yield 0.20 L/s, Salinity 2450 mg/L) WBZ (Sandstone) 175.5 - 177 m (Yield 0.15 L/s, Salinity 2190 mg/L) WBZ (Sandstone) 188 - 188.2 m (Yield 0.15 L/s, Salinity 2070 mg/L)

Bore ID	Easting	Northing	Elevation (mAHD)	Year Drilled	Total Depth (mbgl)	Screen (mbgl)	SWL (mbgl)	EC/ Salinity	Status	Use	Geology	Comment
GW105534	288655	6217297	167.82	1905	See comment	OH (72 – TD)	92	Fresh	Current	Stock and Domestic	Sandstone and Slate	NGIS lists -total depth as 207, BH Reg lists as 201 WBZ (Sandstone) 113 - 113.1 m (Yield 0.1 L/s, SWL 92 m) WBZ (Sandstone) 161 - 161.1 m (Yield 0.5 L/s, SWL 92 m) WBZ (Sandstone) 188 - 188.1 m (Yield 0.68 L/s, SWL 92 m) WBZ (Sandstone) 197 - 197.1 m (Yield 0.42 L/s, SWL 92 m)
GW105574	289656	6218908	125.42	2003	210	OH (Surface – TD)	-	3630	Current	Stock and Domestic	Sandstone, Clay and Shale	WBZ (Shale) 27 - 28.5 m (Yield 0.5 L/s, Salinity 2960 mg/L) WBZ (Sandstone) 85 - 86 m (Yield 0.5 L/s, Salinity 2840 mg/L) WBZ (Shale) 145 - 147 m (Yield 0.45 L/s, Salinity 3630 mg/L)
GW105942	282545	6218791	307.01	2002	214	OH (Surface – TD)	11	Fresh	Unknown	Test Bore	Shale and Clay	WBZ (Shale) 18 - 18.1 m (Yield 0.03 L/s, SWL 11 m) WBZ (Shale) 64 - 64.1 m (Yield 0.13 L/s, SWL 11 m)
GW106574	290123	6218350	140.52	2002	238	OH (6 – TD)	-	3000 mg/L	Grouted	Domestic	Sandstone and Shale	WBZ (Sandstone) 115 - 116 m (Yield 0.2 L/s, Salinity 1400 mg/L) WBZ (Sandstone) 133 - 114 m (Yield 0.55 L/s, Salinity 3000 mg/L)
GW106675	288797	6218642	124.43	2003	183	OH (43 – TD)	20	Fresh	Current	Stock and Domestic	Sandstone and Shale	WBZ (Sandstone) 60 - 60.1 m (Yield 1 L/s, SWL 42 m) WBZ (Sandstone) 83 - 83.1 m (Yield 0.9 L/s, SWL 42 m) WBZ (Sandstone) 145 - 145.1 m (Yield 1.1 L/s, SWL 42 m) WBZ (Sandstone) 162 - 162.15 m (Yield 1.05 L/s, SWL 42 m)

Bore ID	Easting	Northing	Elevation (mAHD)	Year Drilled	Total Depth (mbgl)	Screen (mbgl)	SWL (mbgl)	EC/ Salinity	Status	Use	Geology	Comment
GW107791	289415	6220392	114.32	2003	231	OH (81 – TD)	37	Fresh	Current	Stock and Domestic	Sandstone	WBZ (Sandstone) 128 - 128.2 m (Yield 0.85 L/s, SWL 37 m) WBZ (Sandstone) 151 - 151.1 m (Yield 0.28 L/s, SWL 37 m) WBZ (Sandstone) 162 - 162.1 m (Yield 0.15 L/s, SWL 37 m) WBZ (Sandstone) 217 - 217.2 m (Yield 0.53 L/s, SWL 37 m) WBZ (Sandstone) 222 - 222.25 m (Yield 1.2 L/s, SWL 37 m)
GW108193	282555	6218724	308.35	2002	214	OH (Surface – TD)	16	2800 mg/L	Unknown	Test Bore	Clay and Shale	WBZ (Shale) 17.8 - 18 m (Yield 0.03 L/s, SWL 16 m) WBZ (Shale) 63.8 - 64 m (Yield 0.13 L/s, SWL 16 m, Salinity 2800 mg/L)
GW108312	291534	6217750	144.97	2004	175	Slots (78 – 84 - No WBZ listed at this depth) OH (85 – TD)	84	500 mg/L	Current	Industrial	Sandstone (Slots and OH to TD)	WBZ (Sandstone) 119 - 120 m (Yield 0.1 L/s, SWL 84 m, Salinity 1200 mg/L) WBZ (Sandstone) 156 - 157 m (Yield 0.16 L/s, Salinity 500 mg/L)
GW108907	288602	6218547	125.78	2007	210	OH (72 – TD)	40	1200 mg/L	Current	Stock and Domestic	Sandstone and Shale	WBZ (Sandstone/Shale) 62 - 64 (Yield 0.8 L/s, Salinity 3000 mg/L) WBZ (Sandstone) 126 - 130 m (Yield 1 L/s, SWL 40 , Salinity 1830 mg/L) WBZ (Sandstone) 186 - 188 m (Yield 1.4 L/s, SWL 40 m, Salinity 1300 mg/L) WBZ (Shale) 206 - 208 m (Yield 1.8 L/s, SWL 40 m, Salinity 1200 mg/L)
GW108990	290347	6219588	108.75	2008	See comment	-	-	-	Current	Domestic	-	NGIS lists total depth as 150 m, BH Reg lists as 0;

Bore ID	Easting	Northing	Elevation (mAHD)	Year Drilled	Total Depth (mbgl)	Screen (mbgl)	SWL (mbgl)	EC/ Salinity	Status	Use	Geology	Comment
GW110550	283788	6218949	249.41	2009	See comment	OH (2.5 – TD)	200	670 mg/L	Current	Stock and Domestic	Sandstone and Shale	NGIS lists total depth as 336 m; BH Reg lists as 339 m WBZ (Sandstone) 277 - 279 m (Yield 0.5 L/s, Salinity 800 mg/L) WBZ (Sandstone) 310 - 312 m (Yield 0.6 L/s, Salinity 616 mg/L) WBZ (Sandstone) 320 - 322 m (Yield 0.75 L/s, SWL 200 m, Salinity 670 mg/L)
GW110671	288717	6216340	141.86	2010	240	OH (28 – TD)	82	400 mg/L	Current	Stock and Domestic	Sandstone, Shale and Granite	WBZ (Sandstone) 72 - 72.2 m (Yield 0.05 L/s, SWL 82 m, Salinity 400 mg/L) WBZ (Sandstone) 150 - 150.3 m (Yield 0.1 L/s) WBZ (Sandstone) 166 - 166.2 m (Yield 0.9 L/s) WBZ (Sandstone) 211 - 211.1 m (Yield 0.15 L/s)
GW111634	290819	6215923	128.36	2004	72.14	-	-	-	Active	Monitoring Bore	-	No construction or geology information
GW111636	291580	6216015	125.72	2004	78.75	-	-	-	Active	Monitoring Bore	-	No construction or geology information
GW111637	291924	6215523	115.57	2004	78.75	-	-	-	-	Monitoring Bore	-	No construction or geology information
GW111638	292197	6215881	119.03	2004	78.75	-	-	-	-	Monitoring Bore	-	No construction or geology information
GW111727	287506	6221188	-	2004	261	OH (Surface – TD)	150	Salty	Current	Stock and Domestic	-	Yield: 1 L/s (BH Reg) No information on geology
GW111781	285334	6217542	-	2005	305	OH (120 – TD)	185	Fresh	Current	Domestic	Sandstone	Yield: 1 L/s (BH Reg) WBZ (Sandstone) 243 - 243.05 m (Yield 0.2 L/s, SWL 185 m) WBZ (Sandstone) 283 - 283.01 m (Yield 1 L/s, SWL 185 m)

Bore ID	Easting	Northing	Elevation (mAHD)	Year Drilled	Total Depth (mbgl)	Screen (mbgl)	SWL (mbgl)	EC/ Salinity	Status	Use	Geology	Comment
GW112381	288743	6218191	-	2010	152	OH (72 – TD)	70	Fresh	Current	Stock and Domestic	Sandstone	WBZ (Sandstone) 102 - 102.5 m (Yield 0.1 L/s, SWL 70 m) WBZ (Sandstone) 142 - 142.05 m (Yield 0.5 L/s)
GW112437	288659	6215538	-	2010	156	OH (72 – TD)	63	1500 mg/L	Current	Stock and Domestic	Sandstone and Shale	WBZ (Sandstone) 50 - 50.05 m (Yield 0.25 L/s, SWL 63 m, Salinity 3200 mg/L) WBZ (Sandstone) 62 - 62.05 m (Yield 0.19 L/s, SWL 63 m, Salinity 3200 mg/L) WBZ (Sandstone) 141 - 141.5 m (Yield 1.9 L/s, SWL 63 m, Salinity 1500 mg/L)
GW112441	289940	6217284	-	2010	294	OH (60 – TD)	70	400	Grouted	Stock and Domestic	Sandstone	WBZ (Sandstone) 113 - 113.05 m (Yield 0.1 L/s, SWL 70 m, Salinity 400 mg/L) WBZ (Sandstone) 136 - 136.05 m (Yield 0.2 L/s) WBZ (Sandstone) 140 - 140.05 m (Yield 0.2 L/s) WBZ (Sandstone) 225 - 225.01 m (Yield 0.1 L/s)
GW112481	288663	6219694	-	2007	633.2	-	-	-	-	Industrial	-	No construction or geology information

Datum: GDA94/MGA Zone 56

OH – Open Hole TD – Total Depth WBZ – Water Bearing Zone SWL – Static Water Level

APPENDIX D

Calibration Hydrographs

APPENDIX E

Calibration Parameter Ranges

Table E-1 Parameter Range for Horizontal Hydraulic Conductivity (m/d)

Layer	Zone	Calibrated Value	Lower Bound	Upper Bound
1	Alluvium - 1	$4.3X10^{+00}$	$1.0X10^{-01}$	$5.0X10^{+01}$
	Wianamatta Group - 19	$1.0X10^{-03}$	$1.0X10^{-03}$	$1.0X10^{+00}$
	HBSS - 20	$1.1X10^{-02}$	$1.0X10^{-03}$	$1.0X10^{+00}$
	Swamps - 21	$7.0X10^{+00}$	$1.0X10^{-02}$	$5.0X10^{+01}$
	Lake and Bay - 22	$2.0X10^{+02}$	$1.0X10^{-01}$	$2.0X10^{+02}$
	Escarpment Zone -23	$4.0X10^{-01}$	$1.0X10^{-04}$	$1.0X10^{+00}$
2	Wianamatta Group - 2	$1.0X10^{-05}$	$1.0X10^{-05}$	$1.0X10^{+00}$
	HBSS - 24	$6.3X10^{-03}$	$1.0X10^{-03}$	$1.0X10^{+00}$
	HBSS under Wianamatta Group -25	$3.3X10^{-03}$	$1.0X10^{-03}$	$1.0X10^{+00}$
3	Upper HBSS	$2.0X10^{-02}$	$1.0X10^{-03}$	$1.0X10^{+00}$
4	Middle HBSS	$1.0X10^{-03}$	$1.0X10^{-03}$	$1.0X10^{+00}$
5	Lower HBSS	$1.0X10^{-04}$	$1.0X10^{-04}$	$1.0X10^{+00}$
6	Bald Hill Claystone	$1.8X10^{-05}$	$1.0X10^{-05}$	$5.0X10^{-03}$
7	Bulgo Sandstone	$1.5X10^{-03}$	$1.0X10^{-04}$	$1.0X10^{-02}$
8	Bulgo Sandstone	$4.5X10^{-04}$	$1.0X10^{-05}$	$1.0X10^{-02}$
9	Bulgo Sandstone	$7.6X10^{-04}$	$1.0X10^{-05}$	$1.0X10^{-02}$
10	Stanwell Park Claystone	$7.4X10^{-07}$	$1.0X10^{-07}$	$1.0X10^{-03}$
11	Upper Scarborough	$2.7X10^{-05}$	$1.0X10^{-05}$	$1.0X10^{-02}$
12	Lower Scarborough	$1.9X10^{-05}$	$1.0X10^{-05}$	$1.0X10^{-02}$
13	Wombarra Claystone	$3.3X10^{-06}$	$1.0X10^{-07}$	$1.0X10^{-03}$
14	Coal Cliff Sandstone	$1.1X10^{-04}$	$1.0X10^{-05}$	$1.0X10^{-02}$
15	Bulli Coal Seam	$1.0X10^{-03}$	$1.0X10^{-03}$	$5.0X10^{+00}$
16	Interburden	$3.6X10^{-05}$	$1.0X10^{-05}$	$1.0X10^{-02}$
17	Wongawilli Seam	$1.8X10^{-02}$	$1.0X10^{-03}$	$5.0X10^{+00}$
18	Lower Permian Coal Measures	$7.3X10^{-05}$	$1.0X10^{-05}$	$1.0X10^{-03}$
7 - 18	Faults	$1.2X10^{-02}$	$1.0X10^{-03}$	$1.0X10^{+00}$

Table E-2 Parameter Range for Vertical to Horizontal Conductivity (Kz/Kx)

Layer	Zone	Calibrated Value	Lower Bound	Upper Bound
1	Alluvium - 1	$1.0X10^{-01}$	$1.0X10^{-02}$	$8.0X10^{-01}$
	Wianamatta Group - 19	$1.0X10^{-02}$	$1.0X10^{-03}$	$5.0X10^{-01}$
	HBSS - 20	$1.0X10^{-02}$	$1.0X10^{-03}$	$8.0X10^{-01}$
	Swamps - 21	$1.0X10^{-02}$	$1.0X10^{-03}$	$8.0X10^{-01}$
	Lake and Bay - 22	$1.0X10^{-01}$	$1.0X10^{-03}$	$8.0X10^{-01}$
	Escarpment Zone -23	$1.0X10^{-02}$	$1.0X10^{-03}$	$1.0X10^{+00}$
2	Wianamatta Group - 2	$1.0X10^{-02}$	$1.0X10^{-03}$	$5.0X10^{-01}$
	HBSS - 24	$1.0X10^{-01}$	$1.0X10^{-03}$	$1.0X10^{+00}$
	HBSS under Wianamatta Group -25	$1.0X10^{-01}$	$1.0X10^{-03}$	$1.0X10^{+00}$
3	Upper HBSS	$1.0X10^{-01}$	$1.0X10^{-03}$	$1.0X10^{-01}$
4	Middle HBSS	$1.0X10^{-01}$	$1.0X10^{-03}$	$5.0X10^{-01}$
5	Lower HBSS	$1.0X10^{-01}$	$1.0X10^{-03}$	$1.0X10^{-01}$
6	Bald Hill Claystone	$1.0X10^{-02}$	$1.0X10^{-03}$	$1.0X10^{-01}$
7	Bulgo Sandstone	$1.0X10^{-01}$	$1.0X10^{-03}$	$1.0X10^{-01}$
8	Bulgo Sandstone	$1.0X10^{-01}$	$1.0X10^{-03}$	$1.0X10^{-01}$
9	Bulgo Sandstone	$1.0X10^{-01}$	$1.0X10^{-03}$	$1.0X10^{-01}$
10	Stanwell Park Claystone	$1.0X10^{-01}$	$1.0X10^{-03}$	$8.0X10^{-01}$
11	Upper Scarborough	$1.0X10^{-01}$	$1.0X10^{-03}$	$8.0X10^{-01}$
12	Lower Scarborough	$1.0X10^{-01}$	$1.0X10^{-03}$	$8.0X10^{-01}$
13	Wombarra Claystone	$1.0X10^{-01}$	$1.0X10^{-03}$	$8.0X10^{-01}$
14	Coal Cliff Sandstone	$1.0X10^{-02}$	$1.0X10^{-03}$	$8.0X10^{-01}$
15	Bulli Coal Seam	$1.0X10^{-01}$	$1.0X10^{-03}$	$8.0X10^{-01}$
16	Interburden	$1.0X10^{-02}$	$1.0X10^{-03}$	$8.0X10^{-01}$
17	Wongawilli Seam	$1.0X10^{-01}$	$1.0X10^{-03}$	$8.0X10^{-01}$
18	Lower Permian Coal Measures	$1.0X10^{-02}$	$1.0X10^{-03}$	$8.0X10^{-01}$
7 - 18	Faults	$1.0X10^{+00}$	$1.0X10^{-02}$	$1.0X10^{+00}$

Table E-3 Parameter Range for Specific Storage (1/m)

Layer	Zone	Calibrated Value	Lower Bound	Upper Bound
1	Alluvium - 1	$2.2X10^{-05}$	$1.0X10^{-06}$	$5.0X10^{-05}$
	Wianamatta Group - 19	$5.0X10^{-07}$	$1.0X10^{-07}$	$1.0X10^{-06}$
	HBSS - 20	$5.0X10^{-07}$	$1.0X10^{-07}$	$5.0X10^{-06}$
	Swamps - 21	$5.0X10^{-07}$	$1.0X10^{-07}$	$1.0X10^{-06}$
	Lake and Bay - 22	$5.0X10^{-07}$	$1.0X10^{-07}$	$1.0X10^{-06}$
	Escarpment Zone -23	$5.0X10^{-07}$	$1.0X10^{-07}$	$1.0X10^{-06}$
2	Wianamatta Group - 2	$1.0X10^{-06}$	$1.0X10^{-07}$	$1.0X10^{-05}$
	HBSS - 24	$1.0X10^{-05}$	$1.0X10^{-07}$	$5.0X10^{-05}$
	HBSS under Wianamatta Group -25	$1.0X10^{-05}$	$1.0X10^{-07}$	$5.0X10^{-05}$
3	Upper HBSS	$7.2X10^{-06}$	$1.0X10^{-07}$	$1.0X10^{-05}$
4	Middle HBSS	$1.0X10^{-05}$	$1.0X10^{-07}$	$5.0X10^{-05}$
5	Lower HBSS	$1.0X10^{-05}$	$1.0X10^{-07}$	$5.0X10^{-05}$
6	Bald Hill Claystone	$5.0X10^{-07}$	$1.0X10^{-07}$	$1.0X10^{-06}$
7	Bulgo Sandstone	$5.0X10^{-07}$	$1.0X10^{-07}$	$1.0X10^{-06}$
8	Bulgo Sandstone	$5.0X10^{-06}$	$1.0X10^{-07}$	$1.0X10^{-05}$
9	Bulgo Sandstone	$5.0X10^{-06}$	$1.0X10^{-07}$	$1.0X10^{-05}$
10	Stanwell Park Claystone	$5.0X10^{-06}$	$1.0X10^{-07}$	$1.0X10^{-05}$
11	Upper Scarborough	$5.0X10^{-06}$	1.0X10-07	$1.0X10^{-05}$
12	Lower Scarborough	$5.0X10^{-06}$	$1.0X10^{-07}$	$1.0X10^{-05}$
13	Wombarra Claystone	$5.0X10^{-07}$	$1.0X10^{-07}$	$5.0X10^{-06}$
14	Coal Cliff Sandstone	$2.4X10^{-06}$	$1.0X10^{-07}$	$5.0X10^{-06}$
15	Bulli Coal Seam	$5.0X10^{-07}$	$1.0X10^{-07}$	$5.0X10^{-06}$
16	Interburden	$5.0X10^{-07}$	$1.0X10^{-07}$	$5.0X10^{-06}$
17	Wongawilli Seam	$5.0X10^{-07}$	$1.0X10^{-07}$	$5.0X10^{-06}$
18	Lower Permian Coal Measures	$5.0X10^{-07}$	$1.0X10^{-07}$	$5.0X10^{-06}$
7 - 18	Faults	$1.2X10^{-07}$	$1.0X10^{-07}$	$5.0X10^{-06}$

Table E-4 Parameter Range for Specific Yield

Layer	Zone	Calibrated Value	Lower Bound	Upper Bound
1	Alluvium - 1	$1.0X10^{-01}$	$5.0X10^{-02}$	$5.0X10^{-01}$
	Wianamatta Group - 19	$5.0X10^{-03}$	$1.0X10^{-03}$	$1.0X10^{-02}$
	HBSS - 20	$5.0X10^{-03}$	$1.0X10^{-03}$	$1.0X10^{-02}$
	Swamps - 21	$5.0X10^{-03}$	$1.0X10^{-03}$	$1.0X10^{-02}$
	Lake and Bay - 22	$1.0X10^{-02}$	$1.0X10^{-03}$	$5.0X10^{-02}$
	Escarpment Zone -23	$5.0X10^{-03}$	$1.0X10^{-03}$	$1.0X10^{-02}$
2	Wianamatta Group - 2	$5.0X10^{-03}$	$1.0X10^{-03}$	$1.0X10^{-02}$
	HBSS - 24	$1.0X10^{-02}$	$1.0X10^{-03}$	$5.0X10^{-02}$
	HBSS under Wianamatta Group -25	$1.0X10^{-02}$	$1.0X10^{-03}$	$5.0X10^{-02}$
3	Upper HBSS	$1.0X10^{-02}$	$1.0X10^{-03}$	$5.0X10^{-02}$
4	Middle HBSS	$1.0X10^{-02}$	$1.0X10^{-03}$	$5.0X10^{-02}$
5	Lower HBSS	$1.0X10^{-02}$	$1.0X10^{-03}$	$5.0X10^{-02}$
6	Bald Hill Claystone	$5.0X10^{-03}$	$1.0X10^{-03}$	$1.0X10^{-02}$
7	Bulgo Sandstone	$5.0X10^{-03}$	$1.0X10^{-03}$	$1.0X10^{-02}$
8	Bulgo Sandstone	$5.0X10^{-03}$	$1.0X10^{-03}$	$1.0X10^{-02}$
9	Bulgo Sandstone	$5.0X10^{-03}$	$1.0X10^{-03}$	$1.0X10^{-02}$
10	Stanwell Park Claystone	$5.0X10^{-03}$	$1.0X10^{-03}$	$1.0X10^{-02}$
11	Upper Scarborough	$5.0X10^{-03}$	$1.0X10^{-03}$	$1.0X10^{-02}$
12	Lower Scarborough	$5.0X10^{-03}$	$1.0X10^{-03}$	$1.0X10^{-02}$
13	Wombarra Claystone	$5.0X10^{-03}$	$1.0X10^{-03}$	$1.0X10^{-02}$
14	Coal Cliff Sandstone	$5.0X10^{-03}$	$1.0X10^{-0}3$	$1.0X10^{-02}$
15	Bulli Coal Seam	$5.0X10^{-03}$	$1.0X10^{-03}$	$1.0X10^{-02}$
16	Interburden	$5.0X10^{-03}$	$1.0X10^{-03}$	$1.0X10^{-02}$
17	Wongawilli Seam	$5.0X10^{-03}$	$1.0X10^{-03}$	$1.0X10^{-02}$
18	Lower Permian Coal Measures	$5.0X10^{-03}$	$1.0X10^{-03}$	$1.0X10^{-02}$
7 - 18	Faults	$1.0X10^{-02}$	$1.0X10^{-03}$	$5.0X10^{-02}$

Table E-5 Parameter Range for Recharge Rates

Zone	Calibrated Value	Lower Bound	Upper Bound
Alluvium/Swamps	1.7%	1.0%	10.0%
Wianamatta Group	0.7%	0.5%	10.0%
Western HBSSs	0.5%	0.5%	10.0%
Eastern HBSSs	0.5%	0.5%	10.0%
Central HBSSs	5.0%	0.5%	10.0%

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