SOUTH32 Illawarra Metallurgical Coal

LONGWALLS 709 TO 711 AND 905 WATER MANAGEMENT PLAN

This document UNCONTROLLED once printed				Page 1 of 48
Document ID		**Version**	2.0	
Last Date Updated	October 2022	**Next Review Date**	October 2025	

Table of Contents

FIGURES

TABLES

APPENDICES

DOCUMENT REVISION LOG

Persons authorising this Plan

Name	Title	Date
Gary Brassington	Manager Approvals	October 2022

Document Revisions

Revision	Description of Changes	Date
ICH Document		
1.0	Original Document	July 2021
2.0	Updated to address EP Approval Conditions	October 2022

Persons involved in the review of this Plan

Name	Title	Company	Exp (yrs)	Date
Cody Brady	Principal Approvals	South32	7	October 2022
Gary Brassington	Manager Approvals	South32	26	October 2022
Josh Carlon	Coordinator Environment	South32	13	October 2022
Amy Bradbury	Specialist Environment	South32	4	October 2022

1. INTRODUCTION

1.1 Project Background

South32 Illawarra Metallurgical Coal (IMC) operates the Bulli Seam Operations (BSO) Appin Mine, extracting hard coking coal used for steel production.

On 22 December 2011 the Planning and Assessment Commission (PAC), under delegation of the Minister for Planning, approved BSO (MP 08_0150) under Part 3A of the *Environmental Planning and Assessment Act 1979* (EP&A Act) to continue mining operations until 2041.

This Water Management Plan (WMP) supports the Longwalls 709 to 711 and 905 Extraction Plan for mining of coal in Appin Areas (AA) 7 and 9 mining domains. The relationship between this WMP and the other components of the Extraction Plan is shown in Figure 1 of the Extraction Plan Main Document.

1.2 Scope

This WMP has been prepared in accordance with the BSO Approval (MP 08_0150) Condition 5 (h), Schedule 3 as follows:

> 5. The Proponent shall prepare and implement an Extraction Plan for first and second workings within each longwall mining domain to the satisfaction of the Planning Secretary. Each extraction plan must:
>
>   h) include a Water Management Plan, which has been prepared in consultation with BCS , WaterNSW and DPE Water which provides for the management of the potential impacts and/or environmental consequences of the proposed second workings on watercourses and aquifers, including:
>
>   - surface and groundwater impact assessment criteria, including trigger levels for investigating any potentially adverse impacts on water resources or water quality;
>   - a program to monitor and report stream flows and assess any changes resulting from subsidence impacts;
>   - a program to monitor and report ground water inflows to underground workings; and
>   - a program to predict, manage and monitor impacts on groundwater bores on privately owned land.

The Department of Planning and Environment (DPE) Secretary provided conditional approval of the Longwalls 709 to 711 and 905 Extraction Plan on 29 July 2022. Conditions of this approval are addressed in Section 2.2.

The Study Area for the Extraction Plan is defined in accordance with MSEC (2021) as the surface area predicted to be affected by the proposed mining of Longwalls 709 to 711 and 905 and encompasses the areas bounded by the following limits:

- A 35° angle of draw line from the maximum depth of cover, which equates to a horizontal distance varying between 530 m and 750 m around the limits of the proposed extraction areas for Longwalls 709 to 711 and 905;

- The predicted limit of vertical subsidence, taken as the 20 mm subsidence contour, resulting from the extraction of the proposed Longwalls 709 to 711 and 905; and

Additionally, features potentially sensitive to far field movements, which includes horizontal, valley closure and upsidence movements that may be outside the 20 mm subsidence zone or 35° angle of draw line have been assessed (600 m boundary around Longwalls 709 to 711 and 905).

1.3 Objectives

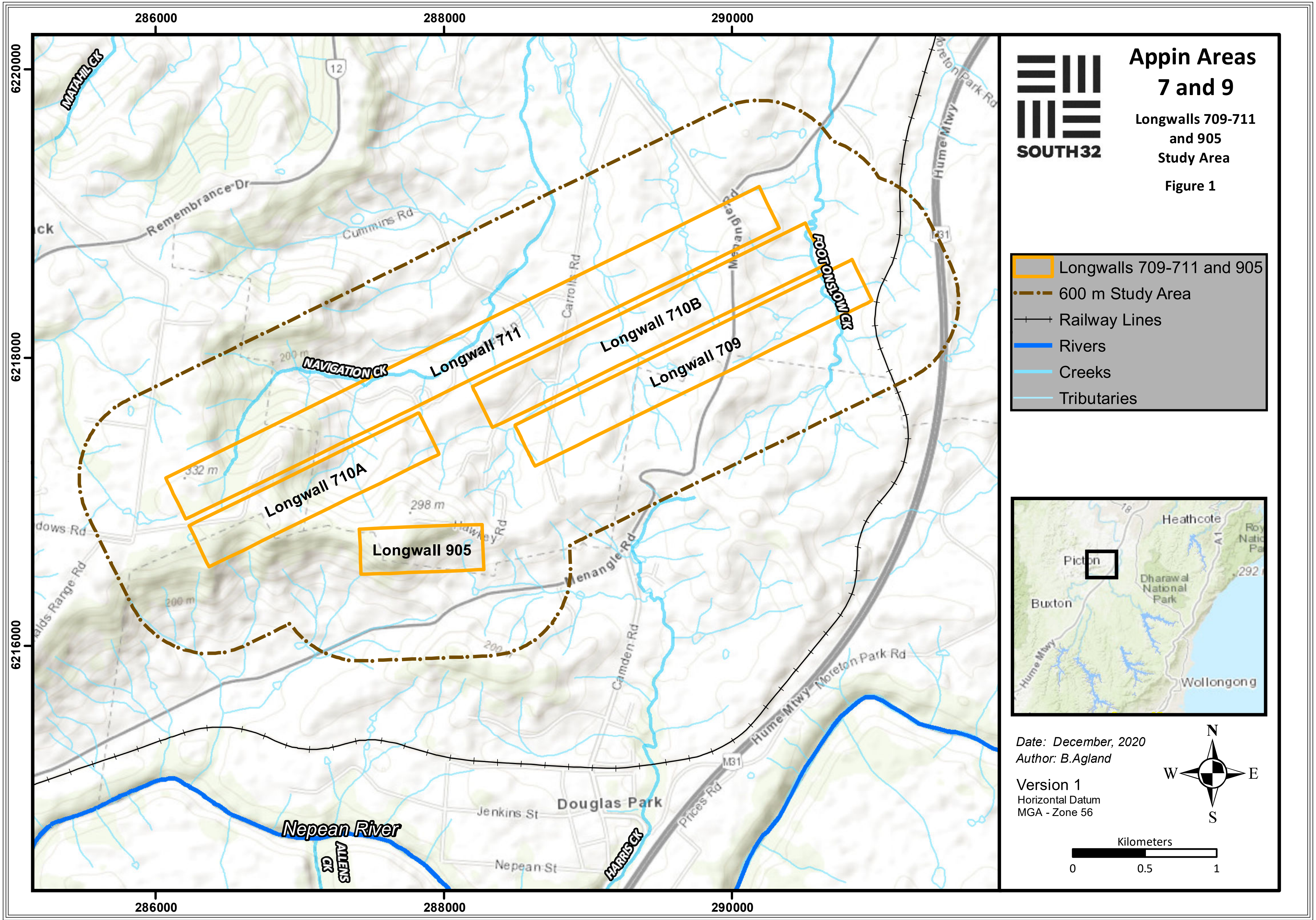
The objectives of this WMP are to identify at risk surface water and groundwater features and characteristics within the Longwalls 709 to 711 and 905 Study Area and to manage the potential impacts and/or environmental consequences of the proposed workings on watercourses and aquifers.

1.4 Consultation

This WMP will be developed in consultation with:

- Biodiversity Conservation and Science Directorate (BCS);
- DPE - Water; and
- WaterNSW.

South32 will make the WMP and associated documentation publicly available on the South32 website in accordance with Condition 11, Schedule 6 of the BSO Approval.


Appin Areas 7 and 9
Longwalls 709-711 and 905 Study Area
Figure 1
SOUTH32
Longwalls 709-711 and 905
600 m Study Area
Railway Lines
Rivers
Creeks
Tributaries
Longwall 711
Longwall 710B
Longwall 709
Longwall 710A
Longwall 905
NAVIGATION CK
FOOT ONSLOW CK
MATAHIL CK
HARRIS CK
ALLENS CK
Nepean River
Douglas Park
Remembrance Dr
Cummins Rd
Carrolls Rd
Menangle Rd
Camden Rd
Moreton Park Rd
Hume Mtwy
Prices Rd
Jenkins St
Nepean St
Hawkey Rd
M31
332 m
298 m
200 m
286000
288000
290000
6220000
6218000
6216000
Heathcote
Picton
Buxton
Dharawal National Park
Wollongong
Date: December, 2020
Author: B.Agland
Version 1
Horizontal Datum
MGA - Zone 56
Kilometers
0
0.5
1
N
S
E
W

2. STATUTORY REQUIREMENTS

Extraction of coal from Longwalls 709 to 711 and 905 will be in accordance with the conditions set out in the BSO Approval, Extraction Plan Approval and applicable legislation as detailed in Sections 2.1 and 2.2 and the requirements of relevant licences and permits, including conditions attached to mining leases.

2.1 BSO Approval

Condition 5 (h), Schedule 3 of the BSO Approval requires the preparation of a WMP to manage the potential impacts and/or environmental consequences of the proposed second workings on groundwater and surface water features in the Study Area, including the Nepean River.

This WMP also addresses the requirements detailed in Condition 6 Schedule 3 and Condition 2, Schedule 6 of the BSO Approval as shown in Table 1.

Due consideration has been given to all the BSO Approval Conditions in the preparation of this WMP, including those relating to auditing, rehabilitation and environmental management.

Table 1 Management Plan Requirements

Project Approval Conditions	Relevant WMP Section
Condition 6, Schedule 3 The Proponent shall ensure that the management plans required under Condition 5 (g)-(l) above include:	
a) an assessment of the potential environmental consequences of the Extraction Plan, incorporating any relevant information that has been obtained since this approval;	Section 3
b) a detailed description of the measures that would be implemented to remediate predicted impacts.	Section 8
Condition 2, Schedule 6 The Proponent shall ensure that the management plans required under this approval are prepared in accordance with any relevant guidelines, and include:	
(a) detailed baseline data;	Section 3
(b) a description of:	
- the relevant statutory requirements (including any relevant approval, licence or lease conditions);	Section 2
- any relevant limits or performance measures/criteria;	Section 5

- the specific performance indicators that are proposed to be used to judge the performance of, or guide the implementation of, the project or any management measures;	Section 5 to 8
(c) a description of the measures that would be implemented to comply with the relevant statutory, limits, requirements or performance measures/criteria;	Section 5 to 8
(d) a program to monitor and report on the: - impacts and environmental performance of the project; - effectiveness of any management measures (see c above);	Section 6
(e) a contingency plan to manage any predicted impacts and their consequences and to ensure that ongoing impacts reduce to levels below relevant impact assessment criteria as quickly as possible;	Section 8
(f) a program to investigate and implement ways to improve the environmental performance of the project over time;	Section 6
(g) a protocol for managing and reporting any: - incidents; - complaints; - non-compliances with statutory requirements; and - exceedances of the impact assessment criteria and/or performance criteria; and	Section 9
(h) a protocol for periodic review of the plan.	Section 10

2.2 Extraction Plan Approval

The Planning Secretary provided conditional approval of the Longwalls 709 to 711 and 905 Extraction Plan on 29 July 2022. Conditions 4, 5 and 6 of this approval are shown in Table 2.

Table 2 Extraction Plan Approval Conditions

Extraction Plan Approval Conditions	Relevant WMP Section
Condition 4 IMC must submit to the Department an updated groundwater assessment report within three months of this approval. This report must be supported by an updated groundwater model which has been peer-reviewed by an independent expert.	Section 2.2.1
Condition 5 Prior to extraction of LW710A, IMC must install a deep multi-level piezometer directly above LW711 for monitoring direct impacts of mining.	Section 2.2.2

Condition 6 IMC must within three months of this approval update the Water Management Plan to the satisfaction of the Planning Secretary. The management plan must include: a. a program to validate the groundwater model every three years with additional monitoring data and a comparison of monitoring results and modelled predictions; and b. a program for monitoring surface flows and water quality impacts on third order watercourses overlying the longwalls.	Section 2.2.3 and 2.2.4

2.2.1 Extraction Plan Condition 4

Condition 4 of the Longwalls 709 to 711 and 905 Extraction Plan Approval requires IMC to submit to the Department an updated groundwater assessment report within three months of the approval. The report must be supported by an updated groundwater model which has been peer-reviewed by an independent expert.

In addition, during consultation with agencies regarding the extraction plan application, BCS requested a number of improvements to the groundwater model. The Department subsequently requested IMC provide:

- an independent review of the updated groundwater model;
- a justification for the selection and exclusion of monitoring bores used in the model;
- a justification for the use of the Ditton-Merrick height of connected fracturing model instead of the more conservative Tammetta height of connective fracturing model by providing a comparison of the two models and a discussion of the potential surface impacts.

Peer Review

IMC engaged SLR to update the groundwater model and address the above requirements. The full document is attached to the WMP as Appendix A. IMC engaged Neil Manewell (Technical Modelling Lead / Principal – Groundwater Modeller) from Australasian Groundwater and Environmental Consultants Pty Ltd (AGE) to undertake an independent peer review of the Appin groundwater model. The peer review document (AGE 2022) is attached as Appendix C of the WMP. SLR (2022) adopted a number of recommendations and improvements from AGE (2022).

During this process the peer reviewer had active input in developing the updated SLR (2022) Appin groundwater model. AGE (2022) concluded "*The modelling described by SLR has been conducted with a methodology and care consistent with industry standard practice. The 2022 study has improved upon the 2020 study by: including: more deep groundwater level measurements in the history matching process, representing the enhanced permeability above the longwall more appropriately, and exploring an alternate fracture height configuration. The calibrated version is fit for purpose of predicting drawdown due to the proposed mining in the Appin Areas 7 and 9 series panels.*"

Monitoring bores used in the groundwater model

Piezometers with erroneous data were removed from the calibration data set in SLR (2022). These include piezometers that indicted sensor error or recovery and stabilisation trends post-installation. Table 16 of SLR (2022) provides monitoring bore data which was omitted from the calibration data set.

Height of connective fracturing comparison

Sections 3.6 and 3.8.1 of SLR (2022) discuss at length the comparison of the estimate of height of fracture zone above the longwall panels between the Ditton and Tammetta methods. The Ditton method was adopted in the SLR (2022) 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). A sensitivity analysis is provided in Section 5.2 of SLR (2022) which was conducted to understand how changes to the fracture height model assumptions influenced the model predictions. When Tammetta (2013) was used to simulate the fracture height, the model did not predict drawdowns in the Lower Hawkesbury Sandstone.

2.2.2 Extraction Plan Condition 5

Condition 5 of the Longwalls 709 to 711 and 905 Extraction Plan Approval requires IMC to install a deep multi-level piezometer directly above Longwall 711 for monitoring direct impacts of mining. The monitoring borehole must be established prior to extraction of Longwall 710A.

Borehole S2315 was drilled to a depth of 630.65 m and intersected the Bulli, Balgownie and Wongawilli seams. The borehole was installed with 9 piezometers (Table 3) and has been continuously monitoring since establishment. The borehole is located within the centre of Longwall 711, approximately 2 km between the start and finishing ends of the longwall (Figure 3).

Table 3 Monitoring Borehole S2315

Geological UNIT	Piezometer Depth (m)
Hawkesbury Sandstone	65
Hawkesbury Sandstone	160
Hawkesbury Sandstone	240
Bulgo Sandstone	292.1
Bulgo Sandstone	368.6
Bulgo Sandstone	445
Scarborough Sandstone	460
Scarborough Sandstone	519.5
Bulli Coal	576.4

For mine safety the borehole monitoring will be terminated just prior to the longwall mining under the hole and shearing the piezometer cabling. IMC intends to drill a post mining borehole for S2315 to a depth of 460 m (to the base of the Bulgo Sandstone) and install a new multi-level piezometer string. The pre and post mining monitoring of S2315 will allow for direct monitoring of mining related impacts and will be incorporated into future groundwater model updates.

The establishment of the post mining borehole is subject to the outcomes of a comprehensive risk assessment to determine the viability of deep drilling into strata containing fracture networks. Unlike Dendrobium where post mining boreholes are comparatively straightforward, Appin Mine operates in a highly gaseous environment (methane and carbon dioxide). Drilling into a fractured rock mass without fluid return limits the ability to control gas emission at the surface, in addition there is a risk that drilling into the fracture network could create a potential conduit between the goaf and the surface. This poses extreme risk to both surface exploration operations and underground operations. A risk assessment to fully understand these risks will be undertaken by IMC and the outcomes will determine the viability of the S2315 post mining borehole.

2.2.3 *Extraction Plan Condition 6a*

Condition 6a of the Longwalls 709 to 711 and 905 Extraction Plan Approval requires IMC to update this Water Management Plan to the satisfaction of the Planning Secretary, within three months of this Approval. The management plan must include:

a) a program to validate the groundwater model every three years with additional monitoring data and a comparison of monitoring results and modelled predictions; and

The proposed program includes:

- a comparison of modelled results (SLR 2022) to observed data from sites adjacent to the longwall(s) that are the subject of Annual Reviews. The results of this comparison will be presented in the Annual Review.
- IMC will conduct a wider validation of the groundwater model every three years with additional monitoring data and a comparison of monitoring results and modelled predictions;
- facility to engage a suitability qualified groundwater modelling expert to review and update the Appin groundwater model on a three yearly basis until the completion of Longwall 711. The groundwater model will be updated with the latest climatic and groundwater monitoring data and longwall progression, and be re-calibrated as necessary. Should significant deviation from observed data be found at the Annual Review stage (i.e. within the 3-year period), then this review and update could be brought forward pending further investigation.

2.2.4 *Extraction Plan Condition 6b*

Condition 6b of the Longwalls 709 to 711 and 905 Extraction Plan Approval requires IMC to update this Water Management Plan to the satisfaction of the Planning Secretary, within three months of this Approval. The management plan must include:

b) a program for monitoring surface flows and water quality impacts on third order watercourses overlying the longwalls.

Navigation Creek and Foot Onslow Creek overlay the longwall mining area. IMC has long term surface water quality and flow monitoring sites on both watercourses, sites NAV1 and FO1. IMC has installed two new surface water quality sites on Navigation Creek and Foot Onslow Creek (NAV2 and FO2). Further details on surface water quality sites is provided in Section 6.1.

IMC will install a single flow monitoring site on Navigation Creek and Foot Onslow Creek (NAVS1 and FOS1). These sites have been paired with the locations of the surface water monitoring sites above. Further details are provided in Section 6.2.2.

2.3 Legislation and Guidelines

Legislation applicable to water, erosion and sediment control management may include but is not limited to:

- *Protection of the Environment Operations Act 1997* (POEO Act);
- Protection and the Environment Operations (Underground Petroleum Storage Systems) Regulation 2014;
- *Environmental Planning and Assessment Act 1979 (EP&A Act)*;
- *Water Act 1912*;
- *Water Management Act 2000*;
- Water Management (General) Regulation 2018;
- *Mining Act 1992*;
- *Water NSW Act 2014*;
- Sydney Water Regulation 2017;
- *Soil Conservation Act 1938*; and
- National Environment Protection (National Pollutant Inventory) Measure 1998.

2.4 Relevant Leases and Licences

The following licences or permits may be applicable to South32's operations in AA7 and 9:

- Mining Leases as per Table 4.
- Environment Protection Licence (EPL) 2504 which applies to BSO, including Appin and West Cliff Mines. A copy of the licence can be accessed at the EPA website via the following link http://www.epa.nsw.gov.au/prpoeo/index.htm
- BSO Mining Operation Plan (MOP) 1/10/2020 to 30/09/2024 (V1.3).
- Water Access Licences (WALs) issued by the NSW DPE - Water (formerly the Department of Industry - Water) under the *NSW Water Management Act, 2000*, including WAL 36481, 36477 and 37464 under the *Water Sharing Plan for the Greater Metropolitan Region Groundwater Sources 2011* and WAL 30145 and 35519 under the *Water Sharing Plan for the Greater Metropolitan Region Unregulated River Water Sources 2011*.

- All relevant Occupational Health, Safety, Environment and Community approvals.
- Any additional leases, licences and approvals resulting from the BSO Approval.

Table 4 Mining Leases and Licences associated with Appin Mine

Mining Lease - Document Number	Start	Finish
CCL 767	29 Oct 1991	08 Jul 2029
CL 388	22 Jan 1992	22 Jan 2034
ML 1382	20 Dec 1995	20 Dec 2037
ML 1433	24 Jul 1998	23 Jul 2019[1]
ML 1678	27 Sep 2012	26 Sep 2033

[1] Application for the renewal of Mining Lease 1433 which was lodged with the NSW Department of Planning and Environment – Division of Resources and Geoscience (Division) on 18 July 2018.

3. BASELINE ASSESSMENT

Baseline groundwater (Heritage Computing, 2009) and surface water assessments (Gilbert and Associates, 2009) were undertaken in support of the BSO Environmental Assessment (EA). The Study Area for these assessments included the Longwalls 709 to 711 and 905 Study Area.

Supplementary Assessments for groundwater (SLR 2022) (refer Appendix A) and surface water (SLR 2021) (refer Appendix B) were undertaken for the purposes of this Extraction Plan.

The rivers within the Appin Mine area generally flow in a northerly direction and have perennial flows influenced by dam releases, catchment runoff and baseflow contributions from the incised Hawkesbury Sandstone. There are no drinking water catchment areas, or declared special areas within the Study Area. The Hawksbury-Nepean Catchment covers approximately 21,400 km^2.

3.1 Nepean River

The closest river is the Nepean River, which is 1.5 km south of the Longwalls 709 to 711 and 905 (MSEC, 2021). The Longwalls 709 to 711 and 905 Study Area includes drainage lines which predominately flow into the Nepean River.

Water flows from the Nepean River are derived from a number of sources and include flows from catchment areas, licensed discharges, including Appin and Tahmoor Mines, and runoff from agricultural and urban areas.

Water flows in the Nepean River:

- Vary greatly and are highly responsive to rain events due to the significant areas of catchment.
- Regulated flows from upstream dams and baseflow contributions where incised into Hawkesbury Sandstone.
- Natural flow within the Nepean River and its associated watercourses have been significantly altered by water storages such as dams and weirs. Some natural catchment flows are retained by large storage dams upstream of Appin Mine for the purpose of the Sydney water supply system. Water is also retained by numerous farm dams within the local part of the Nepean River catchment.
- Flows in a northerly direction, with flow of around 310 ML/day (Maldon Weir) since 2010.

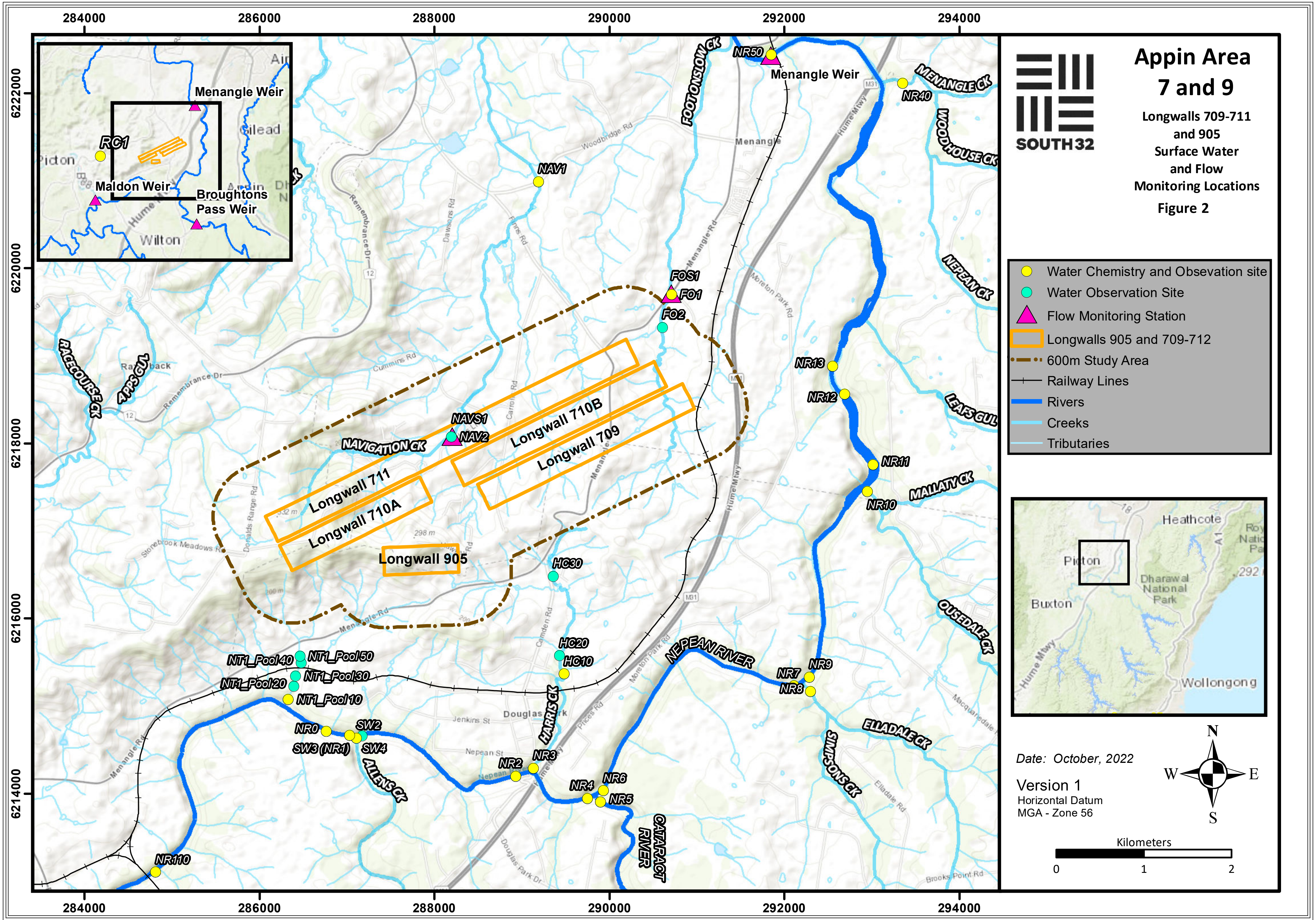
Surface water monitoring is conducted at the main rivers at government stream gauges (Maldon, Menangle and Broughtons Weirs). The locations of the Maldon, Menangle and Broughtons Pass gauging sites are included in Figure 2. These flow monitoring stations are located on the Cataract or Nepean River, being directly upstream and downstream of the approved BSO footprint. Flow monitoring on the Cataract River at Broughtons Pass Weir measures the flow of the major tributary input to Nepean River between the two Nepean River flow stations. The approach to monitoring of flow for the longwalls is proposed to be the same as for mining of the previous AA7 and 9 longwalls. Figure 2 shows the location of the existing water quality monitoring sites.

Daily flow records for Maldon, Menangle and Broughtons Pass weirs from 1990 have been assessed in order to study the dry weather recessions in the Nepean River adjacent to the proposed mining areas. The difference in flows should be equivalent to runoff from all catchments between these two weirs responding to local rainfall minus any abstractions by licensed pumps in the River.

The Nepean River is a 'gaining river' in terms of surface water - groundwater interaction. The potential for infiltration of water into the groundwater system is very low as the Nepean River lies in a well incised gorge which represents the regional low point in the piezometric surface (SLR 2021). The potential for sub-bed diversion of surface water is very low as the Nepean River is flooded and the gradient is very flat, significantly removing the effects of gravity to force surface flow through any fracture network that develops. Water levels in the Nepean River and its tributaries are monitored using observations and measured benchmarks. The water level is recorded before, during and after mining and is assessed against catchment rainfall and discharges from the WaterNSW controlled weirs. This method of monitoring has been used for the previous AA7 and 9 and will be implemented for the proposed longwalls.

IMC also conducts 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 the Georges River and Nepean River. Surface water monitoring has been undertaken at the site for a baseline period between 2002 – 2020.

Water quality monitoring of the Nepean River and tributaries within the Study Area are shown in Table 5.



Appin Area 7 and 9

Longwalls 709-711 and 905 Surface Water and Flow Monitoring Locations

Figure 2

Table 5 Baseline Water Quality Data (SLR 2021)

River	EC (uS/cm)		pH		DO (%)		TDS (mg/l)		Fe (mg/L)		Mn (mg/L)	
	Average	St.Dev.	Average	St.Dev.	Average	St.Dev.	Average	St.Dev.	Average	St.Dev.	Average	St.Dev.
Nepean River												
NR110	319	147	7.9	0.3	90.5	14.8	171	76	0.3	0.2	0.03	0.02
NR0	378	173	7.9	0.5	89.5	13.2	208	89	0.3	0.2	0.3	0.02
NR4	223	104	7.6	0.4	85.7	18.4	128	57.8	0.4	0.2	0.3	0.01
NR12	186	67	7.4	0.3	87.2	10.1	107	39	0.4	0.1	0.3	0.01
NR13	182	55	7.4	0.3	85.7	12.6	105	31	0.4	0.1	0.3	0.01
NR50	296	240	7.6	0.4	84.1	19.7	167	135	0.4	0.4	0.5	0.09
Allens Creek - Perturbation												
SW2	704	229	8.1	0.4	95.7	18.4	394	151	0.5	0.4	0.02	0.02
Cataract River - 169Perturbation												
NR5	169	118	7.2	0.5	73.1	29.6	97	61	0.7	0.8	0.08	0.12
Elladale Creek - Perturbation												
NR8	1640	1229	7.6	0.3	72.4	20.5	909	696	0.8	0.5	0.32	0.82

Ousedale Creek - Perturbation												
NR10	1486	1007	7.8	0.5	91.4	13.9	805	548	0.6	1.4	0.05	0.32
Menangle Creek - Perturbation												
NR40	1376	772	7.7	0.4	54.1	31.7	727	411	2.1	2.0	1.1	1.6
Foot Onslow Creek												
F01	1616	901	8.0	0.4	73.5	22.3	909	525	1.5	2.0	0.3	0.4
Navigation Creek												
NAV1	2565	1943	7.6	0.4	27.8	21.4	1470	1124	5.1	6.0	1.8	1.0
Harris Creek												
HC10	1561	688	7.9	0.3	81.5	25.0	935	425	0.7	2.3	0.2	0.4
NR3	1550	956	7.9	0.3	53.1	26.9	864	531	0.7	1.1	0.5	0.9

Note: Note that new established water quality and flow sites monitoring on Navigation Creek and Foot Onslow Creek sites FO2, FOS1, NAV2 and NAVS1 do not have baseline data at this time.

3.2 Watercourses within the Study Area

Minor creeks and tributaries of the Nepean River are present across the Appin Mine area. This includes the headwaters of Navigation Creek, Navigation Creek Tributary 1, Foot Onslow Creek and Harris Creek that are third order streams within the Study Area.

Watercourses within the Study Area have upper reaches with shallow incisions into the surface soils, which have been derived from the Wianamatta Group, and steep natural gradients ranging from 2-40%. The lower reaches of these creeks have substantial incisions into the surface soils, with exposed sandstone platforms in the bases and rock outcropping in the valley sides. Natural gradients of third order streams range from 0.5-4%.

Watercourses within the Study Area contribute to a small portion of the total Hawkesbury-Nepean Catchment (<0.2%) with runoff from predominately cleared, agricultural land with small pockets of remnant vegetation. The creeks are largely ephemeral, but pools have naturally formed in some areas. Like the receiving Nepean River, flows within ephemeral creeks have been altered by farm dams which intersect the drainage lines at a number of locations. Runoff from within the catchments is influenced by input of nutrients from adjacent farmland and salinity from the marine sediments of the Wianamatta Shale (SLR 2021).

The creeks that have third order sections located within the Study Area or within 600 m of the proposed longwalls are Foot Onslow Creek, Harris Creek, Navigation Creek and Navigation Creek Tributary 1. There are no creeks with sections greater than third order located within the Study Area or within 600 m of the proposed longwalls.

A summary of the third order creeks that are located within the Study Area are provided in Table 6.

Table 6 Third order creeks located within the Study Area

Name	Location	Total length of third order section above the mining area (km)	Total length of third order section within the Study Area (km)
Foot Onslow Creek	Directly above Longwalls 709 and 710B	1.3	2.1
Harris Creek	Outside mining area, adjacent to Longwall 706	0.04	0.4
Navigation Creek	Directly above Longwall 709, 710B and 711	1.2	2.1

3.3 Groundwater

The primary hydro stratigraphic 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 unconformity overlies HBSS. Groundwater flow likely follows topography and streamflow direction towards the north;

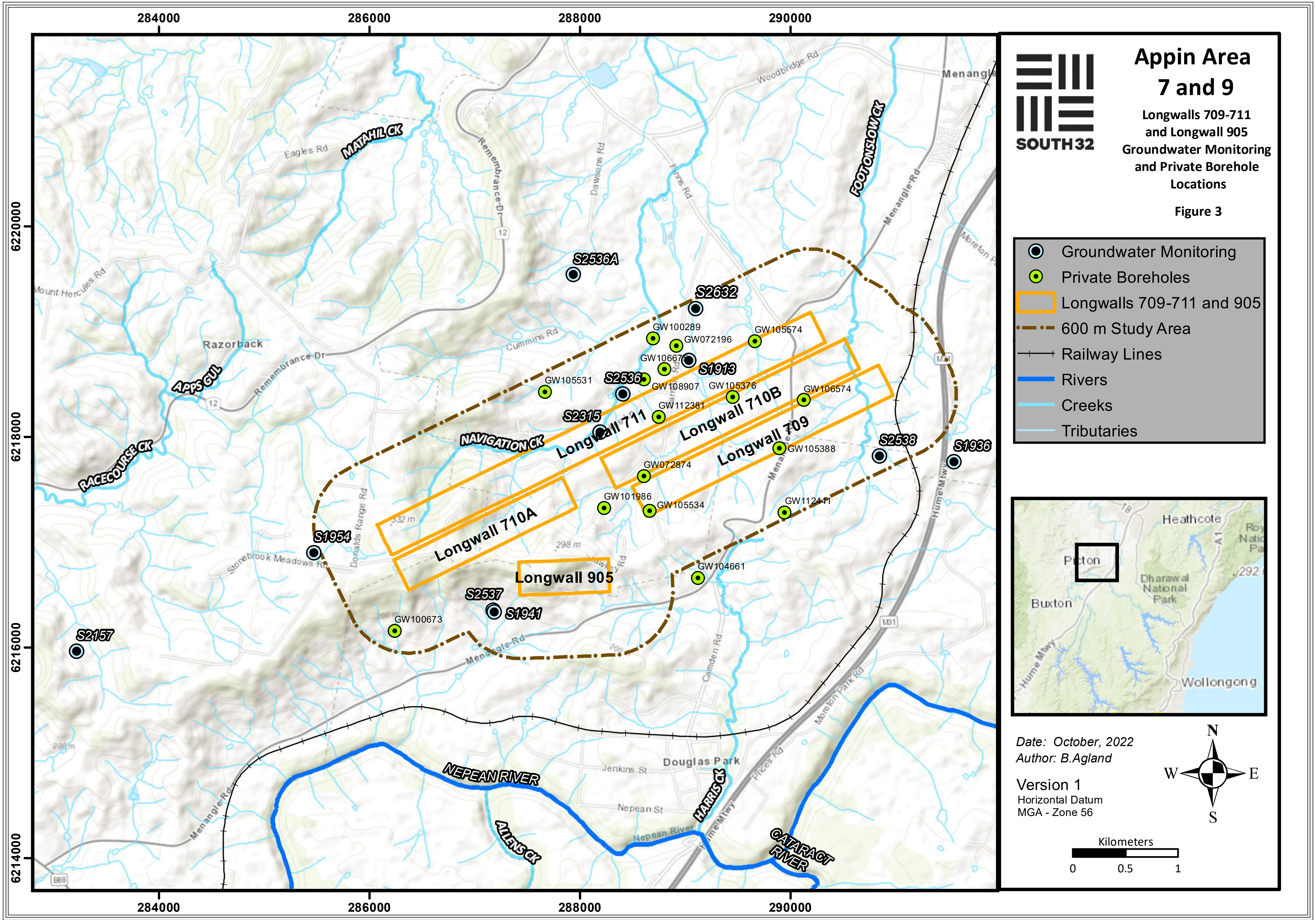
- Hawkesbury Sandstone – main groundwater source and widely accessed for groundwater supply and provides baseflow contributions where incised along major rivers (i.e. Cataract River, Nepean River and Georges River). Groundwater flow generally in a northerly direction, and locally influenced where intersected 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 – with groundwater occurrence largely associated with the more permeable coal seams, with confined groundwater conditions. Groundwater flow generally in a northerly direction, and locally depressurised due to current and historical mining and coal seam gas.

3.3.1 Landholder Bores

A search of the BoM's National Groundwater Information System (NGIS) was carried out for registered bores within the Appin groundwater model extent SLR (2022). There are 49 registered bores within 5 km of the Project area.

Most groundwater users are located to the north of Appin Mine, within the Wianamatta Group outcrop area, and to the southwest, within the Hawkesbury Sandstone outcrop area. Most landholder bores are located within the Hawkesbury Sandstone and Bulgo Sandstone

The details of the registered bores in the Appin Mine area are shown in Appendix C of SLR (2022).



Appin Area 7 and 9
Longwalls 709-711 and Longwall 905 Groundwater Monitoring and Private Borehole Locations
Figure 3
SOUTH32
Groundwater Monitoring
Private Boreholes
Longwalls 709-711 and 905
600 m Study Area
Railway Lines
Rivers
Creeks
Tributaries
Date: October, 2022
Author: B.Agland
Version 1
Horizontal Datum
MGA - Zone 56
Kilometers
0
0.5
1
N
S
E
W
284000
286000
288000
290000
6222000
6218000
6216000
6214000
Longwall 711
Longwall 710B
Longwall 709
Longwall 710A
Longwall 905
S2536A
S2632
S1913
S2536
S2315
S2538
S1936
S1954
S2537
S1941
S2157
GW100289
GW072196
GW105574
GW106674
GW105531
GW108907
GW105376
GW112381
GW106574
GW105388
GW072874
GW101986
GW105534
GW112441
GW104661
GW100673
MATAHIL CK
NAVIGATION CK
RACECOURSE CK
APPS GUL
FOOTONSLOW CK
NEPEAN RIVER
HARRIS CK
ALLENS CK
CATARACT RIVER
Razorback
Douglas Park
Menangle
Heathcote
Picton
Buxton
Dharawal National Park
Wollongong

4. PREDICTED IMPACTS

In accordance with the findings of the Southern Coalfield Inquiry (2008) and Independent Expert Panel for Mining in the Catchment (2019a), subsidence impacts are defined as:

- **Subsidence effects** are defined as the deformation of ground mass such as horizontal and vertical movement, curvature and strains.
- **Subsidence impacts** are the physical changes to the ground that are caused by subsidence effects, such as tensile and sheer cracking and buckling of strata.
- **Environmental consequences** are then identified, for example, as a loss of surface water flows and standing pools.

4.1 Subsidence Effects

There are no rivers within the 600 m Study Area. The closest river is the Nepean River which is located to the south and to the east of the proposed longwalls. The centreline of the Nepean River is located 1.5 km south of the commencing (i.e. western) end of Longwall 710A and 1.6 km east of the finishing (i.e. eastern) end of Longwall 709, at its closest points to the proposed longwalls.

The predicted impacts on the third order creeks that are located within the Study Area is provided in Table 7.

Table 7 Maximum Predicted Subsidence Effects for Rivers Creeks and Tributaries located within the Study Area (MSEC 2021)

Name	Maximum predicted total subsidence (mm)	Maximum predicted total upsidence (mm)	Maximum predicted total closure (mm)
Nepean River (not within Study Area)	<20	<20	<20
Foot Onslow Creek	1400	300	250
Harris Creek	500	350	300
Navigation Creek	950	350	475

The groundwater bores could experience adverse impacts due to the extraction of the proposed Longwalls 709 to 711 and 905, particularly the bores located directly above the proposed mining area. Impacts could include lowering of the piezometric surface, blockage of the bores due to differential horizontal displacements at different horizons within the strata and changes to groundwater quality.

Section 4.4.4 of SLR (2022) provides predicted depressurisation impacts for landholder bores due to mining of Longwalls 709 to 711 and 905. A conservative approach was taken where the predicted depressurisation at the bores was calculated based on maximum depressurisation across all layers representing the Hawkesbury Sandstone and Bulgo Sandstone.

Up to 11 m of depressurisation was predicted at landholder bores due to mining of 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; and
- 3.9 m at GW112481.

While no depressurisation is predicted within the surficial strata (Alluvium/ Wianamatta Group / Weathered Hawkesbury Sandstone) 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).

This is consistent with Heritage Computing (2009) findings 'for bores located directly above mined longwalls, there is a risk of damage to bore casing from subsidence related movement'.

4.2 Subsidence Impacts

The predicted subsidence effects for the Nepean River, due to the mining of Longwalls 709 to 711 and 905, are less than 20 mm vertical subsidence, less than 20 mm upsidence and less than 20 mm closure. While the Nepean River could experience very low levels of vertical subsidence or valley-related effects, it is not predicted to experience measurable tilts, curvatures or strains. It is unlikely, therefore, that the Nepean River would experience adverse physical impacts due to the mining-induced movements from Longwalls 709 to 711 and 905. Gas release zones have been observed along the river during the mining of longwalls in Areas 7 and 9. Further gas release zones could develop due to the mining of the proposed longwalls.

MSEC (2021) predict that fracturing of shallow (10 m to 20 m depth) bedrock for the creeks could develop due to the Project, particularly in areas immediately above the longwall panels. Surface tension cracks are also likely to occur, typically with widths in the order of 25 mm to 50 mm.

5. PERFORMANCE MEASURES AND INDICATORS

The BSO Approval provides subsidence impact performance measures (Condition 1, Schedule 3). Table 8 details the conditions relevant to watercourses within the Study Area.

The term 'negligible' is defined within the Project Approval as "s*mall and unimportant, such as not to be worth considering*" or as otherwise defined in Table 8 for the Nepean River and other watercourses.

Table 8 Subsidence Impact Performance Measures (BSO Approval)

Watercourses (Condition 1 Schedule 3)	
Nepean River	Negligible environmental consequences including: • negligible diversion of flows or changes in the natural drainage behaviour of pools; • negligible gas releases and iron staining; and • negligible increase in water cloudiness.
Other Watercourses	No greater subsidence impact or environmental consequences than predicted in the EA and PPR.

In order to mitigate the potential subsidence impacts and environmental consequences from the mining of Longwalls 709 to 711 and 905, monitoring and recording will be undertaken prior to mining, throughout the extraction and at the completion of subsidence (refer Section 6).

In the event that any subsidence impact is recorded, consideration would be given to implementing appropriate management, remediation and/or mitigation measures in consultation with the relevant stakeholders and with the approval of the landholder (refer Section 7).

If the subsidence impact performance measures are exceeded, IMC will notify DPE, BCS, Resources Regulator and other stakeholders and implement the Contingency Plan (Section 8).

6. MONITORING AND REPORTING

6.1 Surface Water Quality Monitoring

There is adequate baseline data to fully characterise water quality conditions prior to the commencement of mining in the Study Area[2]. This includes monitoring locations within the Study Area, as well as monitoring locations in downstream waterways (SLR 2021). There are no watercourses which flow into the Study Area, with the headwaters of Harris, Navigation and Foot Onslow Creeks being within the Study Area.

Locations of water quality monitoring sites are included in Table 10.

Riverine water quality TARPs will be implemented for the adjacent AA7 and 9 Nepean River monitoring sites (see section 7.1).

6.2 Water Flow Monitoring

6.2.1 Nepean River

Flow monitoring in the Nepean River is undertaken upstream and downstream of the mining area. Water levels in the Nepean River adjacent to the mining area are also monitored. Observational monitoring of streams will also take place within the mining area.

Nepean River flow monitoring and analysis for AA7 and 9 will be undertaken similar to the current monitoring program. The Longwall 701 to 708 and Longwalls 901 to 903 End of Panel Reports provide details of the proposed data analysis and approach. Daily flow records for Maldon, Menangle and Broughtons Pass weirs from 1990 have been assessed in order to study the dry weather recessions in the Nepean River adjacent to the proposed mining areas. The difference in flows should be equivalent to runoff from all catchments between these two weirs responding to local rainfall minus any abstractions by licensed pumps in the river.

Dry weather recessional phases in the Menangle minus Maldon and Broughtons Pass flow datasets significantly removes the influence of catchment inflows and allows analysis of those recessions for normal behaviour, i.e. relative to the record of baseline recessions prior to the commencement of mining. The recession flow period is more sensitive to any diversions of flow as the diversion would be a higher percentage of the total flow during that period and therefore this is the most appropriate period for detailed analysis. These tests have been conducted for the AA7 and 9 End of Panel Reports and proven to be an acceptable measure for identifying any diversions of flow.

The location of the Maldon, Menangle and Broughtons Pass gauging sites is included in Figure 2. These flow monitoring stations are ideally located on the Nepean River, being directly upstream and downstream of the approved Bulli Seam Operations footprint. Flow monitoring on the Cataract River at Broughtons Pass Weir measures the flow of the major tributary input to Nepean River between the two Nepean River flow stations.

The Nepean River low flow water surface is 61.10 mAHD at Douglas Park weir and 60.84 mAHD at Menangle. Groundwater monitoring bores between AA7 mining and the

[2] Excluding FO2 and NAV2 as they were established in 2022.

Nepean River show that the groundwater levels remain higher than the River, ensuring the hydraulic gradient toward the river is maintained. This approach to monitoring water levels in the river and the nearby piezometric gradient is a very useful approach to detect any redirection of surface water flow into nearby strata, which could represent a reduction in surface water flow in the river. Groundwater monitoring has been installed between AA9 mining and the Nepean River which will be able to identify any reversal of groundwater gradient away from the river.

The approach to monitoring the Nepean River flow during Longwalls 709 to 711 and 905 mining is proposed to be the same as for future mining in AA7 and 9. There are currently no plans to implement additional flow monitoring (e.g. Douglas Park Weir) on the following basis:

- The proposed photographic, groundwater level, pool water level, flow and cease to flow monitoring are adequate to compare pre, during and post mining recessional behaviour in the river.
- The Douglas Park Weir has a complex construction (e.g. multiple flow paths and a by-pass flow fish ladder) which does not lend itself to developing good gauging e.g. the relationship between water level and flow.

6.2.2 Navigation Creek and Foot Onslow Creek Flow Sites

Condition 6b of the Longwalls 709 to 711 and 905 Extraction Plan Approval requires IMC to implement a program for monitoring surface flows on third order watercourses overlying the longwalls.

Navigation Creek is ephemeral and only flows during periods of extended, moderate to high rainfall. The headwaters of Navigation Creek are located within the Longwalls 709 to 711 and 905 Study Area with first and second order streams within the steep ridgeline of remnant bushland to the northwest of Appin Mine. The majority of the remaining catchment, including that of the third order stream, is comprised of agricultural land. Navigation Creek is predominantly highly disturbed and in poor condition.

Stream banks are often steep with vegetation often consisting of weeds, and areas of minimal vegetation with evidence of erosion and scouring. Some pools have naturally established along the reaches; however the majority of the upper reaches consist of depressions and minor drainage lines intersected by a number of farm dams with little to no signs of flow. Any surface water flows from the upper reaches are predominantly captured within these established farm dams with runoff likely to only contribute to the downstream Nepean River during periods of extended or significant flow. The predicted influence of this watercourse on flow and water quality within the Nepean River is minimal (SLR 2021).

Foot Onslow Creek is ephemeral and likely only flows during periods of extended, moderate to high rainfall. Foot Onslow Creek is a third order creek within the Study Area, with some minor first and second order streams. Within the Study Area the watercourse resides chiefly within agricultural land. Foot Onslow Creek is predominantly highly disturbed and in poor condition.

Stream banks show areas of significant scouring and erosion with steep to near vertical walls. On shallower banks vegetation consist primarily of grassland and weeds. Stream bed material consists of loose sediment with grass and reed growth in some locations. Surface water flows from the upper reaches are predominantly captured within a number of established farm dams with runoff likely to contribute to the Nepean River during periods of extended or significant flow only. The predicted influence of this watercourse on flow and water quality within the Nepean River is minimal (SLR 2021).

Monitoring for surface cracking:

IMC will monitor and report observable fracturing resulting in loss of surface water flow.

Assessment of cease-to-flow frequency from qualitative observations:

Estimation of cease-to-flow frequency (% of days) at the sites NAV1 and FO1 for the pre- and the post-mining periods will be assessed via comparison of the long record of qualitative flow observations (Surface Flow/No Observable Flow) and pool water observations (Water in Pool/Pool Dry) at these sites with quantitative flow records at suitable Reference sites (e.g. O'Hares at Wedderburn, possibly Stonequarry Creek at Picton).

Installation of flow gauging:

IMC inspected several locations on both Navigation Creek and Foot Onslow Creeks to establish additional (quantitative) flow monitoring sites over the longwall footprint where access was granted by landholders. The majority of these watercourses were determined to be unsuitable by ALS.

Sites NAVS1 and FOS1 (Figure 2) were selected based on their existing solid rockbar or engineered control. Other potential locations inspected were of poor quality due to wide downstream controls and sediments banks which already displayed signs of erosion which would likely be exacerbated by the installation of flow monitoring equipment. The proposed sites will contain pool water level loggers and the modification of downstream controls, by means of a low-profile plate/weir from which to gauge flow. These gauging stations provide estimates of stream flow via:

- A structure behind which water pools and flows over.
- A sensor and logger that measure and record water level ("stage") in the pool at 15-minute intervals.
- A "rating curve" which is a chart or graph of discharge (flow) versus stage for each gauging station. A theoretical rating curve is developed initially following a site survey. This rating is improved using subsequent infield measurements of flow in the channel at a known water level.
- Estimates of mean daily flow are then provided.

IMC is in the process of gaining approval to install the Navigation Creek flow site NAVS1 and Foot Onslow Creek flow site FOS1 as they are located on public land and subject to Council/other approval. IMC will investigate an alternate site if approval cannot be secured.

Assessment of cease-to-flow frequency from flow gauging:

Once sites NAVS1 and FOS1 have been establish and baseline data collected, calculation of cease-to-flow frequency (% of days) at the sites for the pre- and post-mining periods will be assessed from this to augment the comparison of qualitative observations and the Reference Sites (above). This is reliant on approval/installation and assessment of the data gathered at these sites.

6.3 Pool Water Level Monitoring

The Nepean River is a ‘gaining river’ in terms of surface water - groundwater interaction. The potential for infiltration of water into the groundwater system is very low as the Nepean River lies in a well incised gorge which represents the regional low point in the piezometric surface. The potential for sub-bed diversion of surface water is very low as the Nepean River is flooded and the gradient is very flat, significantly removing the effects of gravity to force surface flow through any fracture network that develops.

Water levels in the Nepean River and its tributaries are monitored using observations and measured benchmarks. The water level is recorded before, during and after mining and is assessed against catchment rainfall and discharges from the WaterNSW controlled weirs. This method of monitoring has been used for AA7 and 9 with no impacts to the water levels of the Nepean River observed during the period of extraction. Pool water level monitoring sites are listed in Table 10.

Given the ephemeral natural of the other third order creeks within the Study Area, there is a lack of suitable pool water monitoring sites. No monitoring of pool water levels is proposed on these creeks.

6.4 Groundwater Monitoring

An extension of the current groundwater monitoring program will be used to monitor the subsidence effects from the extraction of Longwalls 709 to 711 and 905 on groundwater within the Study Area (refer Table 9).

If significant excursions from the predicted model outcomes occur, this will trigger the need for model re-calibration and/or further investigation.

Consultation with bore owners and the monitoring of bores will be incorporated into the PSMPs for relevant properties and, with the agreement of the landowner would include:

- Interview with landowner before a bore is mined beneath to determine the normal rate and duration of pumping.
- Details obtained on the type and set up of the pump in each bore, if installed.
- Post mining interview to compare rate and duration of pumping.
- Measurement of the bore yield if used and access is available.
- Observations on the presence and quantum of iron hydroxide precipitating from the pumped water before and after mining.
- Observations of any gas in the bores.

Table 9 Monitoring in IMC Piezometers

Reference	Standing water levels	Vertical profiles of potentiometric head	Groundwater Quality
S1913	-	Y	
S1936		Y	

S1941		Y	
S1954		Y	
S2157		Y	
S2315		Y	
S2536			Y
S2536A	Y		Y
S2537		Y	Y
S2538		Y	Y
S2632		Y	Y
Private Bores	Y	Y	Y

Notes: Where a private bore is used and access is granted, monitoring before and after the site is mined beneath. Monitoring sites which have piezometers and dataloggers installed will be measured and data logged at least twice daily in the pre-mining baseline, impact and post-mining period. Monitoring equipment in private bores also varies between sites i.e. water quality data is collected in some but not all boreholes.

6.5 Mine Water Inflows

Statutory inspections of the mine workings will be undertaken by IMC to ensure mine safety. The statutory inspections will identify the first indication of a water inflow to the mine.

The statutory inspections are well suited to this monitoring due to the frequency of inspections and familiarity with normal conditions. Any unusual inflows detected during inspections will be sampled and tested as part of the Appin water balance monitoring.

A Mine Water Balance will be used to quantify water inflows by calculating the difference between total mine inflows and mine outflows.

Monitoring of the mine water balance will comprise:

- Metered water reticulated into the mine.
- Metered water reticulated out of the mine.
- Measurement of the in-situ moisture content of the coal during routine channel sampling for coal quality.

Given the large fluctuations in daily water usage and the cycle period for water entering the mine, being used by machinery and draining to sumps for return pumping to the surface, an average (e.g. 20 day) will be used to provide a more realistic estimate of water make.

6.6 Reporting

Results from the monitoring program will be reported annually in the Annual Review. The Annual Review will detail the outcomes of monitoring undertaken; provide results of visual inspections; and determine whether performance indicators have been exceeded and whether CMAs are required.

Monitoring results will be reviewed monthly in the IMC Subsidence Review Meeting. However, if the findings of monitoring are deemed to warrant an immediate response the Principal Approvals will initiate the requirements of the TARP (refer Table 11).

Monitoring results will be made publicly available in accordance with BSO Approval Conditions 8 and 11, Schedule 6 and will also be included in the Annual Review in accordance with Condition 4, Schedule 6.

7. MANAGEMENT AND MITIGATION STRATEGIES

The predicted impacts for the watercourses and drainage lines within the Study Area are nil to negligible and no mitigation measures are currently proposed for any of these predicted impacts. Where there are impacts to farm dams these would be repaired utilising standard dam building techniques and/or an alternate water supply would be provided in consultation with and agreement of the landowner.

The main impacts predicted for groundwater are lowering of some groundwater levels due to dilation of the strata above the longwalls. Where this lowering impacts groundwater sources to landholders the following mitigation measures may be proposed:

- Automated and optimised pump system.
- Lowering of the pump intake.
- Establishment of a new bore.

With these mitigation measures in place the impact of lower groundwater levels are predicted to be negligible.

IMC will review the need to implement additional management and mitigation measures during routine monitoring (refer Section 6) and during the finalisation of PSMPs with affected landholders.

7.1 WMP Monitoring Plan and Trigger Action Response Plan

Water monitoring sites across the Longwalls 709 to 711 and 905 Study Area are provided in Table 10. The Trigger Action Response Plan (TARP) for these sites is provided in Table 11.

Table 10 Monitoring Plan

<table>
<tr><th colspan="2">MONITORING SITE</th><th>MONITORING TYPE</th><th>MONITORING FREQUENCY</th><th>PARAMETERS</th></tr>
<tr><td colspan="5">SURFACE WATER</td></tr>
<tr><td>Area 7 and 9</td><td>Foot Onslow Creek
FO1 (Lab, Field, Level, Obs)
FO2 (Obs)
Harris Creek
HC10 (Lab, Field, Obs)
HC20 (Level, Obs)
HC30 (Obs)
Navigation Creek
NAV1 (Lab, Field, Level, Obs)
NAV2 (Obs)
Nepean River
NR110 (Lab, Field, Level, Obs)
NR0 (Lab, Field, Level, Obs)
SW2 (Lab, Field, Obs)
SW3 (Lab, Field, Obs)
SW4 (Field, Obs)
NR2 (Lab, Field, Level, Obs)
NR3 (Lab, Field, Obs)
NR4 (Lab, Field, Level, Obs)
NR5 (Lab, Field, Obs)
NR6 (Lab, Field, Obs)
NR7 (Lab, Field, Obs)
NR8 (Lab, Field, Level, Obs)
NR9 (Lab, Field, Level, Obs)
NR10 (Lab, Field, Obs)
NR11 (Lab, Field, Obs)
NR12 (Lab, Field, Level, Obs)
NR13 (Lab, Field, Level, Obs)
NR40 (Lab, Field, Obs)
NR50 (Lab, Field, Obs)
NT1_POOL10 (Lab, Field, Level, Obs)
NT1_POOL20 (Field, Level, Obs)</td><td>• Laboratory analysis (Lab)
• Field parameters (Field)
• Observations (Obs)
• Water level (Level) (where a suitable structure exists)</td><td>• Monthly baseline monitoring prior to mining
• Weekly observations and field analysis during active subsidence
• Monthly laboratory analysis during active subsidence
• Monthly monitoring for two years post mining
• If required as a result of assessment of mining impacts</td><td>Field Parameters:
• Temperature
• Dissolved Oxygen (DO)
• Specific Conductivity
• pH
• ORP
Laboratory analysis:
• pH and EC
• Filtered, Na, K, Ca, Mg, Cl, Ni, Zn, Fe, Mn, Al, SO4
• Total Fe, Mn, Al
• Total Alkalinity
• TKN, TP, NH3-N, NOx-N (TON), FRP, TSS, DOC
Lab Sample for Gas Releases:
• CH4
• C2H6
• Trace Phenols
• Sulphide
Observations:
• Iron or salinity staining (e.g. orange or white staining in water or on banks/seeps)
• Evidence of springs in the Nepean River
• Visual signs of impacts (i.e. cracking, fracturing, vegetation changes, increased erosion, changes in water colour etc)
• Stream flow and pool water level
• Impacts determined from comparing photo points taken prior to, during and post mining</td></tr>
</table>

	NT1_POOL30 (Field, Level, Obs) NT1_POOL40 (Field, Level, Obs) NT1_POOL50 (Field, Level, Obs) **Remembrance Drive** RC1 (Lab, Field, Level, Obs) – Reference Site			
	Flow Monitoring Maldon Weir Broughtons Pass Weir Menangle Weir	• Gauged flow station	• Daily flow	• Monitoring undertaken by WaterNSW. Observational data to be compared with flow records at weir sites.
	Foot Onslow Creek FO1 (qualitative obs) FOS1 (gauge with logger) **Navigation Creek** NAV1 (qualitative obs) NAVS1 (gauge with logger)	• Visual observation of inflow and outflow • Gauged flow site	• Monthly/weekly inspection (obs sites) • Daily flow (logger sites)	• Inspection for potential fracturing for observable loss of surface water flow
Groundwater				
Area 7 and 9	**Private Bores** GW108990 GW100289 GW072874 GW100673 GW101986 GW105531 GW105534 GW106675 GW111781 GW112381 GW105376 GW105574 GW106574 GW107791 GW108907 GW108990 GW072196 GW110671	• Lab sample • Field parameters • Water levels • Observations	• Where access is available and granted, water level and water quality monitoring at least once before and once after the bore is mined under	**Field Parameters:** • Electrical conductivity • pH **Laboratory analysis:** • pH and EC • Filtered, Na, K, Ca, Mg, Cl, Ni, Zn, Fe, Mn, Al, SO4 • Total Fe, Mn, Al • Total Alkalinity • TKN, TP, NH3-N, NOx-N (TON), FRP, TSS, DOC Lab Sample for Gas Releases: • CH4 • C2H6 • Trace Phenols • Sulphide **Observations:** • Iron or salinity staining (e.g. orange or white staining in water or around borehole)

	(*in consultation with bore owner and if accessible and access is granted*)			• Visual signs of impacts (i.e. movement around borehole)
	IMC Boreholes S1913 S1936 S1941 S1954 S2157 S2315 S2536 S2536A S2537 S2538 S2632		• Water levels to be logged at least twice daily in the pre-mining baseline, impact and post-mining period • At least one appropriately purged sample pre-mining and post mining, where access permits, tested for the analytes in the previous column	
	Groundwater inflows to the mine	• Mine water balance • Observations	• Flow meters	Water flow from the goaf to the mine (analysed as a moving average i.e. 20 day average)

Note: Monitoring of sites which are located on private property is undertaken with the landowner's permission. Where access cannot be secured or safety is of concern, these sites will not be monitored.

Table 11 Trigger Action Response Plan

Monitoring	Trigger	Action
Surface Water Quality#		
Nepean River Control Sites: NR110 (Upstream perturbations) SW2 (Upstream perturbations from Allens Creek) NR5 (Upstream perturbations from Cataract River) NR8 (Upstream perturbations from Elladale Creek) NR10 (Upstream perturbations from Ouesdale Creek) NR40 (Upstream perturbation from Menangle Creek) Impact Sites: NR0 NR4 (assess influence from Harris Creek) NR12 NR13 NR50 **Creeks and Tributaries** Control Site: RC1 Impact Sites: NAV1 FO1 HC10 NR3	***Level 1**** Impact monitoring sites when comparing the baseline period to the mining period for that site: • Mining results in pH reduction greater than 1 standard deviation but less than 2 standard deviations from pre-mining mean resulting from the mining for two consecutive months • Mining results in DO reduction greater than 1 standard deviation but less than 2 standard deviations from pre-mining mean resulting from the mining for two consecutive months • Identification of strata gas plume of flow rate <3000 L/min • Trend analysis shows deviation from baseline post mining.	• Continue monitoring program • Submit an Impact Report to BCS, DPE – Water, WaterNSW and other relevant stakeholders • Report in the End of Panel Report • Summarise actions and monitoring in Annual Review
	Level 2* Impact monitoring sites when comparing the baseline period to the mining period for that site: • Mining results in pH reduction greater than 2 standard deviations from pre-mining mean resulting from the mining for two consecutive months • Mining results in DO reduction greater than 2 standard deviations from pre-mining mean resulting from the mining for two consecutive months • Mining results in EC increases greater than 2 standard deviations from pre-mining mean resulting from the mining for two consecutive months • Identification of strata gas plume of flow rate >3000 L/min • Trend analysis shows significant deviation from baseline post-mining.	• *Actions as stated for Level 1* • Review monitoring program • Notify relevant technical specialists and seek advice on any CMA required • Implement agreed CMAs as approved *Note: CMAs are to be proposed based on appropriate management of environmental and other consequences of mining impacts i.e. water quality changes with insignificant consequences may not require specific CMAs other than ongoing monitoring to confirm there are no ongoing impacts* Strata Gas Emission Plume: • Estimate gas emission flow rates. Re-estimate should significant change be observed • Take sample of plume (if possible) for: - chemical composition - dissolved methane from exactly above gas plume and at established downriver monitoring site - dissolved sulfide and total phenols from exactly above gas plume and at nearest downriver monitoring site
	Level 3* Impact monitoring sites when comparing the baseline period to the mining period for that site:	• *Actions stated for Level 2* • Notify BCS, DPE - Water, WaterNSW and relevant resource managers and technical specialists and seek advice on any CMA required • Invite stakeholders for site visit

	• Level 2-type reduction in water quality resulting from the mining observed for six consecutive months	• Develop site CMA (subject to stakeholder feedback) • Completion of works following approvals, including monitoring and reporting on success • Review the TARP and Management Plan in consultation with key stakeholders *Note: CMAs are to be proposed based on appropriate management of environmental and other consequences of mining impacts i.e. water quality changes with insignificant consequences may not require specific CMAs other than ongoing monitoring to confirm there are no ongoing impacts*
	Exceeding Performance Measures Mining results in more than negligible gas releases, iron staining or water cloudiness on Nepean River. Mining results in greater subsidence impact or environmental consequences than predicted in the EA and PPR	• *Actions stated for Level 3* • Investigate reasons for the exceedance • Update future predictions based on the outcomes of the investigation • Provide environmental offset if CMAs are unsuccessful
Surface Water Flow and Level		
Nepean River Maldon Weir Broughtons Pass Weir Menangle Weir **Creeks and Tributaries** NAV1 FO1 HC10 NR3	***Level 1**** • Mining results in observational changes to pool level (dry and/or flooded) in comparison to baseline observations and flows, for less than two consecutive months.	• Continue monitoring program • Submit an Impact Report to BCS, DPE – Water, WaterNSW and other relevant stakeholders • Report in the End of Panel Report • Summarise actions and monitoring in Annual Review
	Level 2* • Mining results in observational changes to pool level (dry and/or flooded) in comparison to baseline observations and flows, for more than two consecutive months.	*Actions as stated for Level 1* • Review monitoring program • Notify relevant technical specialists and seek advice on any CMA required • Implement agreed CMAs as approved
	Level 3* • Mining results in observational changes to pool level (dry and/or flooded) in comparison to baseline observations and flows, for six consecutive months.	*Actions stated for Level 2* • Notify BCS, DPE - Water, WaterNSW and relevant resource managers and technical specialists and seek advice on any CMA required • Invite stakeholders for site visit • Develop site CMA (subject to stakeholder feedback) • Completion of works following approvals, including monitoring and reporting on success • Review the TARP and Management Plan in consultation with key stakeholders
	Exceeding Performance Measures Mining results in more than negligible diversion of flows or changes in the natural drainage behaviour of pools in the Nepean River	*Actions stated for Level 3* • Investigate reasons for the exceedance • Update future predictions based on the outcomes of the investigation

		• Provide environmental offset if CMAs are unsuccessful
Creeks and Tributaries **Foot Onslow Creek** FO1 FOS1 **Navigation Creek** NAV1 NAVS1	***Level 1**** • Fracturing with no observable loss of surface water flow	• Continue monitoring program • Submit an Impact Report to BCS, DPE – Water, WaterNSW and other relevant stakeholders • Report in the End of Panel Report • Summarise actions and monitoring in Annual Review
	Level 2* • Fracturing resulting in loss of surface flow in some creeks or tributary	*Actions as stated for Level 1* • Review monitoring program • Notify relevant technical specialists and seek advice on any CMA required Implement agreed CMAs as approved
	Level 3* • Fracturing resulting in total loss of surface flow in all sections of a creek or tributary	*Actions stated for Level 2* • Notify BCS, DPE - Water, WaterNSW and relevant resource managers and technical specialists and seek advice on any CMA required • Invite stakeholders for site visit • Develop site CMA (subject to stakeholder feedback) • Completion of works following approvals, including monitoring and reporting on success • Review the TARP and Management Plan in consultation with key stakeholders
	Exceeding Performance Measures • Mining results in greater subsidence impact or environmental consequences than predicted in the EA and PPR	*Actions stated for Level 3* • Investigate reasons for the exceedance • Update future predictions based on the outcomes of the investigation • Provide environmental offset if CMAs are unsuccessful
Groundwater		
Groundwater inflows to the mine **Private Bores** GW072196 GW072874 GW100289 GW100673 GW101986 GW104661 GW105376 GW105388	***Level 1**** • Increase in water flow from the goaf between 2.7 to 3 ML/day (over 20-day average) • >10 m reduction in water level/pressure in the HBSS from the average level in the period of 12 months prior to the start of a longwall, over a minimum of two months	• Continue monitoring program • Submit an Impact Report to BCS, DPE - Water, WaterNSW and other relevant stakeholders • Report in the End of Panel Report • Summarise actions and monitoring in Annual Review
	Level 2* • Increase in water flow from the goaf between 3 to 3.4ML (over 20-day average) • >15 m reduction in water level/pressure in the HBSS from the average level in the period of 12 months prior to the start of a longwall, over a minimum of two months	• *Actions as stated for Level 1* • Review monitoring frequency • Notify relevant technical specialists and seek advice on any CMA required • Implement agreed CMAs as approved

GW105531 GW105534 GW105574 GW106574 (grouted) GW106675 GW108907 GW112381 GW112441 (grouted) **IMC Boreholes** S1913 S1941 S1954 S2157 S2315 S2536 S2536A S2537 S2538 S2632		*Note: CMAs are to be proposed based on appropriate management of environmental and other consequences of mining impacts i.e. cracking at the surface with insignificant consequences may not require specific CMAs other than ongoing monitoring to confirm there are no ongoing impacts*
	Level 3* • Abnormal increase in water flow from the goaf >3.4ML (20-day average) • >20 m reduction in water level/pressure in the HBSS from the average level in the period of 12 months prior to the start of a longwall, over a minimum of two months • Mining results in groundwater bores unsafe, unserviceable or damaged	• Actions as stated for Level 2 • Notify BCS, DPE - Water, WaterNSW and relevant resource managers and technical specialists and seek advice on any CMA required • Invite stakeholders for site visit • Develop site CMA (subject to stakeholder feedback). This may include: - Make area safe - Any actions agreed to in the Property Subsidence Management Plan - Provisions of alternate water supply where this has been impacted by mining • Completion of works following approvals, including monitoring and reporting on success • Review the Groundwater Model, TARP and Management Plan in consultation with key stakeholders *Note: CMAs are to be proposed based on appropriate management of environmental and other consequences of mining impacts i.e. cracking at the surface with insignificant consequences may not require specific CMAs other than ongoing monitoring to confirm there are no ongoing impacts*

* These may be revised in consultation with DPE and other key stakeholders following analysis of natural variability within the pre-mining baseline data.

The upstream monitoring site NR110 and a series of sites within tributaries of the Nepean River are utilised to indicate non-mining-related perturbations at the proposed Longwalls 709 to 711 and 905 impact monitoring sites within the Nepean River. This provides a means of distinguishing upstream or mid-river effects unrelated to the mining of the proposed longwalls. The following premise applies:

- A TARP at River site NR0 should only be considered to have been triggered whenever an equivalent change (from the long term mean) is not exhibited for the same parameter at the upstream site NR110.
- A TARP at River site NR4 should only be considered to have been triggered whenever an equivalent change (from the long term mean) is not exhibited for the same parameter at the upstream sites NR110 or SW2 (monitors for upstream perturbation from Allens Creek).
- A TARP at River site NR12 and NR13 should only be considered to have been triggered when an equivalent change (from the long term mean) is not exhibited for the same water quality analyte at the upriver sites; NR110, SW2, NR5, NR8 or NR10 (monitors upstream perturbation from Allens Creek, Cataract River, Elladale Creek and Ousedale Creek).
- A TARP at River site NR50 should only be considered to have been triggered when an equivalent change (from the long term mean) is not exhibited for the same water quality analyte at the upriver sites; NR110, SW2, NR5, NR8, NR10 or NR40 (monitors upstream perturbation from Allens Creek, Cataract River, Elladale Creek, Ousedale Creek and Menangle Creek).

8. CONTINGENCY RESPONSE PLAN

Contingency and emergency response options are available and will be implemented if it is demonstrated that environmental consequences are greater than those predicted or authorised by the BSO Consent. This would involve:

- Capture photographic record.
- Notify relevant stakeholders soon as practicable.
- Notify relevant agencies and specialists soon as practicable.
- Offer site visits with stakeholders.
- Contract specialists to investigate and report on changes identified.
- Provide incident report to relevant agencies.
- Establish weekly monitoring frequency until stabilised.
- Updates from specialists on investigation process.
- Inform relevant agencies and stakeholders of results of investigation.
- Develop site CMA in consultation with key stakeholders if required, (pending stakeholder availability) and seek approvals.
- Implement CMA as agreed with stakeholders following approvals.
- Conduct initial follow up monitoring and reporting of CMA completion.
- Review Management Plan.
- Report in regular reporting and Annual Review.

IMC will consult with appropriate specialists and relevant agencies in order to devise an appropriate response in respect to any identified exceedance.

The development and implementation of contingency measures will be specifically designed to address the circumstances of the exceedance and assessment of environmental consequences.

The following measures will be considered:

- Where low DO concentration in the Nepean River can be attributable to mining induced gas emissions (i.e. falling below the level of Level 1 TARPs), it is proposed that this would trigger a higher degree and frequency of monitoring as well as consultation with stakeholders.
- Where low DO concentration exceeds Level 2 TARPs - undertake further consultation for development and implementation of remedial action.
- Redrilling or cleaning and lowering of pumps for damaged bores.
- In the event that water flow diversion is identified within the Nepean River, grouting will be undertaken to restore surface flow. Either hand grouting, pattern or curtain grouting or deep angle hole cement grouting can be used with appropriate approvals.

If the contingency measures implemented by IMC fail to remediate the impact or the Secretary determines that it is not reasonable or feasible to remediate the impact, IMC will provide a suitable offset to compensate for the impact to the satisfaction of the Secretary in accordance with the BSO Approval Condition 2, Schedule 3 or Condition 14, Schedule 4.

9. COMPLAINTS AND COMPLIANCE MANAGEMENT

9.1 Incidents

IMC will notify DPE and any other relevant agencies of any incident associated with the BSO as soon as practicable after IMC becomes aware of the incident. IMC will provide DPE and any relevant agencies with a detailed report on the incident within seven days of confirmation of any event.

9.2 Complaints and Dispute Resolution

IMC has a 24 hour, free call community number (1800 102 210) and email address (illawarracommunity@south32.net) through which all complaints and general enquiries regarding environmental or community issues associated with IMC's operations can be reported.

All complaints received in relation to Appin Mine are managed in accordance with the Handling Community Complaints, Enquiries and Disputes Procedure.

Upon receipt of a community complaint, preliminary investigations will commence as soon as practicable to determine the likely cause of the complaint using information such as activities being undertaken on site at the time or area of the complaint.

An initial response will be provided to the complainant within 24 hours of the complaint being made, with a follow up response being provided as soon as practicable once a more detailed investigation is complete.

A summary of all complaints received during the reporting year will be provided as part of the Annual Review. A log of complaints is also maintained on the South32 website at:

https://www.south32.net/our-business/australia/illawarra-metallurgical-coal/documents.

9.3 Non-Compliance, Corrective Action and Preventative Action

Events, non-compliances, corrective actions and preventative actions are managed in accordance with the Reporting and Investigation Standard and Environmental Compliance/Conformance Assessment and Reporting Procedure. These procedures, which relate to all IMC operations, detail the processes to be utilised with respect to event and hazard reporting, investigation and corrective action identification. The key elements of the process include:

- identification of events, non-conformances and/or non-compliances:
- recording of the event, non-conformance and/or non-compliance in the event management system G360;
- investigation/evaluation of the event, non-conformance and/or non-compliance to determine specific corrective and preventative actions;
- assigning corrective and preventative actions to responsible persons in G360; and

- review of corrective actions to ensure the status and effectiveness of the actions.

Exceedances or non-compliances will be reported to all relevant agencies via the Annual Review or notified in accordance with Section 8.

For any incident, as defined by the BSO Approval, IMC will notify the Secretary and any other relevant agencies as soon as practicable after IMC identifies or is made aware of the incident.

10. PLAN ADMINISTRATION

This WMP will be administered in accordance with the requirements of the Appin Mine Environmental Management Strategy (EMS) and the BSO Approval Conditions. A summary of the administrative requirements is provided below.

10.1 Roles and Responsibilities

Statutory obligations applicable to this Plan are identified and managed via an online compliance management system (TICKIT). The online system can be accessed from the link below:

https://illawarracoal.tod.net.au/login.

The overall responsibility for the implementation of this Plan resides with the Manager Approvals who shall be the Plan's authorising officer.

Parties responsible for environmental management in AA7 and 9 and the implementation of the Plan include:

Manager Approvals

- Ensure that the requisite personnel and equipment are provided to enable this Plan to be implemented effectively.
- Authorise the Plan and any amendments thereto.

Principal Approvals

- Document any changes to the Plan, recognising the potential for those changes to affect other aspects of the Plan.
- Provide regular updates to IMC on the results of the Plan.
- Arrange information forums for key stakeholders as required.
- Prepare any report in accordance with the Plan.
- Maintain records required by the Plan.
- Organise and participate in assessment meetings called to review mining impacts.
- Within 24 hours, respond to any queries or complaints made by members of the public in relation to aspects of this Plan.
- Organise audits and reviews of the Plan.
- Address any identified non-conformances, assess improvement ideas submitted and implement if considered appropriate.

- Arrange for the implementation of any agreed actions, responses or remedial measures.
- Check surveys required by this Plan are conducted and record details of instances where circumstances prevent these from taking place.

Environmental Field Team Coordinator

- Instruct suitable person(s) in the required standards for inspections, recording and reporting and be satisfied that these standards are maintained.
- Investigate significant subsidence impacts.
- Identify and report any non-conformances with the Plan.
- Participate in any other assessment meetings called to review subsidence impacts in the area affected by mining.

Survey Coordinator

- Collate survey data and present in an acceptable form for review at assessment meetings.
- Bring to the attention of the Principal Approvals any findings indicating an immediate response may be warranted.
- Bring to the attention of the Principal Approvals any non-conformances identified with the Plan provisions or ideas aimed at improving the Plan.

Technical Experts

- Conduct the roles assigned to them in a competent and timely manner to the satisfaction of the Principal Approvals and formally provide expert opinion as requested.

Person(s) Performing Inspections

- Formally bring to the attention of the Environment Field Team Coordinator any nonconformances identified with the Plan, or ideas aimed at improving the Plan.
- Conduct inspections in a safe manner.

10.2 Resources Required

The Manager Approvals provides resources sufficient to support this Plan.

Equipment may be needed for this Plan. Where this equipment is of a specialised nature, it will be provided by the supplier of the relevant service. All equipment is to be appropriately maintained, calibrated and serviced as required in operation manuals.

It shall be the responsibility of the Manager Approvals to ensure that personnel and equipment are provided as required to allow the provisions of this Plan to be implemented.

10.3 Training

All staff and contractors working on IMC sites are required to complete the IMC training program which includes:

- An initial site induction (including all relevant aspects of heritage, environment, safety and community).
- Safe Work Methods Statements and Job Safety Analyses, Toolbox Talks and Preshift communications.
- On-going job specific training and re-training (where required).

All training records are maintained by the IMC Training Department.

It shall be the responsibility of the Manager Approvals to ensure that all persons and organisations having responsibilities under this Plan are trained and understand their responsibilities.

The person(s) performing regular inspections shall be under the supervision of the Environment Field Team Coordinator and be trained in observation and reporting. The Environment Field Team Coordinator shall be satisfied that the person(s) performing the inspections are capable of meeting and maintaining this standard.

10.4 Review and Update

In accordance with Condition 5 of Schedule 6 of the BSO Approval, the WMP will be reviewed, and if necessary revised, within three months, of:

- the submission of an Annual Review;
- the submission of an incident report;
- the submission of an Independent Environmental Audit (IEA) report; or
- any modification to the conditions of the BSO Approval (unless the conditions require otherwise).

If significant deficiencies in this WMP are identified in the interim period, the Plan will be modified as required. This process has been designed to ensure that documentation continues to meet current requirements, including changes in technology and operational practice, and expectations of stakeholders.

11. REFERENCES

Australasian Groundwater and Environmental Consultants, 2022. *Appin Mine Groundwater Model Technical Peer Review*, v01.01. September 2022.

Heritage Computing, 2009. *Bulli Seam Operations Groundwater Assessment, A Hydrogeological Assessment in support of the Bulli Seam Operations* Environmental Assessment for Illawarra Coal Holdings Pty Ltd, HC2009/5, July 2009.

Mine Subsidence Engineering Consultants, 2009, *Bulli Seam Operations Subsidence Assessment*. Report for BHP Billiton Illawarra Coal.

MSEC 2021, *Appin Longwalls 709 to 711 and 905: Subsidence Predictions and Impact Assessments for the Natural and Built Features due to the Extraction of the Proposed Longwalls 709 to 711 and 905 at Appin Colliery*. Report for South32 IMC.

NSW Department of Planning (2008). *Impacts of Underground Coal Mining on Natural Features in the Southern Coalfield. Strategic Review.*

SLR, 2022. *Appin Mine Extraction Plan Groundwater Impact Assessment*. Prepared for: South 32 - Illawarra Metallurgical Coal. SLR Ref No: 665.10015-R03-v8.0-20220928.docx, September 2022.

SLR, 2021. *Appin Mine Extraction Plan Surface Water Assessment Longwalls 709 to 711 And 905*. Prepared For: South 32 - Illawarra Metallurgical Coal. Water Assessment- Final-v2.0.docx, April 2021.

Appendix B – Appin Longwalls 709 to 711 and 905 Surface Water Impact Assessment (SLR 2021)

APPIN MINE EXTRACTION PLAN

Surface Water Assessment
Longwalls 709 to 711 and 905

Prepared for:

South 32 - Illawarra Metallurgical Coal

SLR Ref: 630.30102-R01
Version No: -v2.0
April 2021

PREPARED BY

SLR Consulting Australia Pty Ltd
ABN 29 001 584 612
Level 1, The Central Building, UoW Innovation Campus
North Wollongong NSW 2500 Australia

T: +61 2 4249 1000
E: wollongong@slrconsulting.com   www.slrconsulting.com

BASIS OF REPORT

This report has been prepared by SLR Consulting Australia Pty Ltd (SLR) with all reasonable skill, care and diligence, and taking account of the timescale and resources allocated to it by agreement with South 32 - Illawarra Metallurgical Coal (the Client). Information reported herein is based on the interpretation of data collected, which has been accepted in good faith as being accurate and valid.

This report is for the exclusive use of the Client. No warranties or guarantees are expressed or should be inferred by any third parties. This report may not be relied upon by other parties without written consent from SLR.

SLR disclaims any responsibility to the Client and others in respect of any matters outside the agreed scope of the work.

DOCUMENT CONTROL

Reference	Date	Prepared	Checked	Authorised
630.30102-R01-v.2.0	21 April 2021	Duncan Barnes / Emily Curtis	Paul Delaney	Paul Delaney
630.30102-R01-v.1.1	16 April 2021	Duncan Barnes / Emily Curtis	Paul Delaney	Paul Delaney
630.30102-R01-v.1.0	10 February 2021	Duncan Barnes / Emily Curtis	Paul Delaney	Paul Delaney
630.30102-R01-v.5	5 February 2021	Duncan Barnes / Emily Curtis	Paul Delaney	Paul Delaney

CONTENTS

CONTENTS

DOCUMENT REFERENCES

TABLES

FIGURES

PHOTOS

1 Introduction

The Appin Mine is located approximately 25 kilometres (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 708B in Appin Area 7 and Longwall 903 in Area 9. In accordance with the BSO Approval Condition 5, 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 will seek EP approval for Longwalls 709, 710A, 710B, 711 and 905 (the Project).

SLR Consulting Australia Pty Ltd (SLR) was engaged by South32 to complete a technical review of the surface water impacts for the Project (Longwalls 709, 710A, 710B, 711 and 905) and recommend management and mitigation strategies. This report presents the methodology and results of this work.

1.1 Project Description

The Project relates to Longwalls 709, 710A, 710B, 711 and 905 within Areas 7 and 9 of the approved BSO. The location of these longwalls are presented in **Figure 1**. The proposed mining includes:

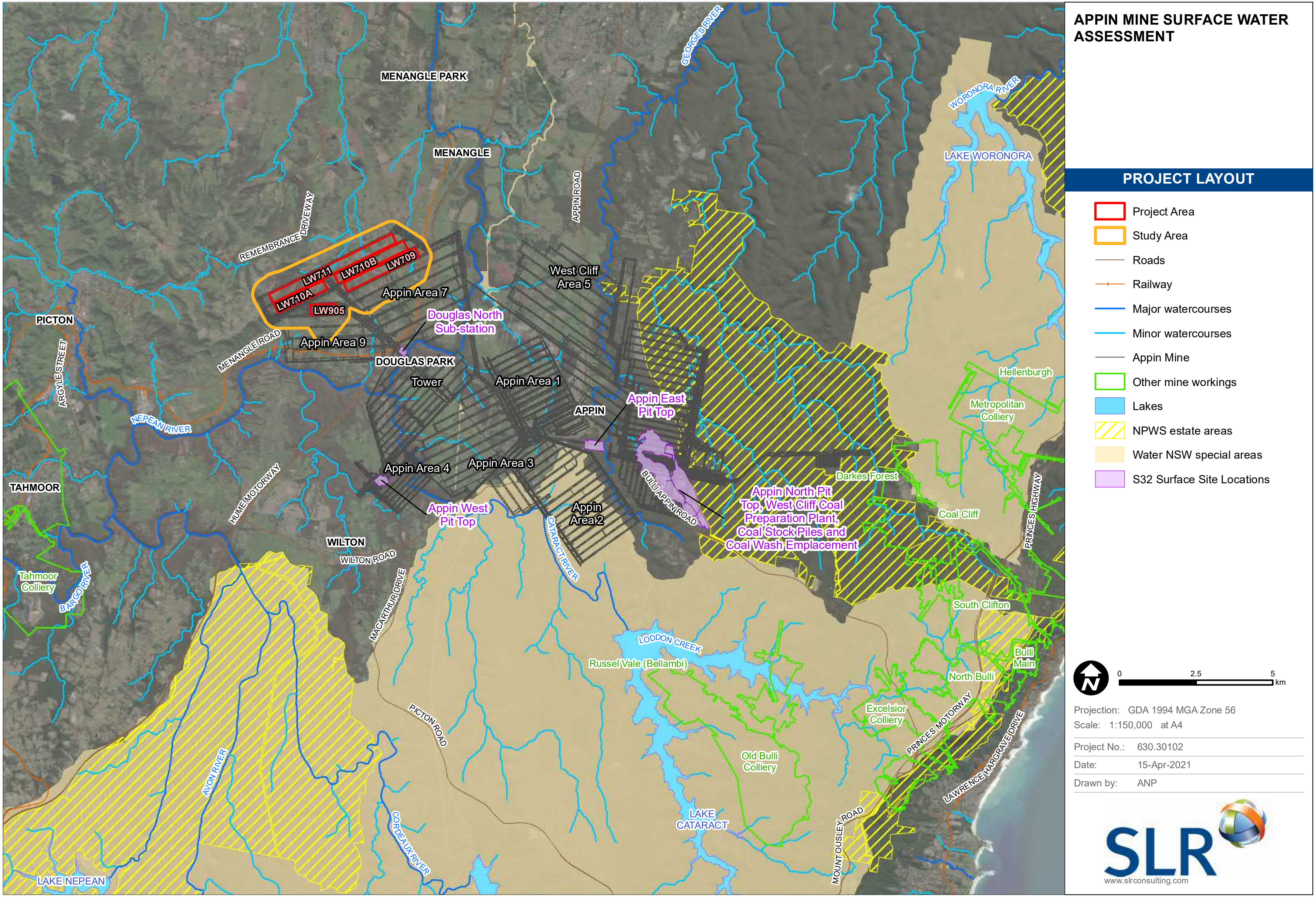
- Longwall 709 – Planned to be mined from December 2021 to June 2023, panel width of 319 metres (m) and average extraction height of 3.02 m;
- Longwall 710A – Planned to be mined from June 2023 to February 2024, panel width of 319 m and average extraction height of 3.10 m;
- Longwall 710B – Planned to be mined from March 2024 to December 2024, panel width of 319 m and average extraction height of 3.00 m;
- Longwall 711 – Planned to be mined from December 2024 to May 2026, panel width of 319 m and average extraction height of 3.15 m; and
- Longwall 905 – Planned to be mined from July 2022 to December 2022, panel width of 319 m and average extraction height of 3.03 m.

1.2 Study Area

The general Study Area consist of the 600 m boundary based on the likely extent of predicted subsidence due to mining of the proposed longwalls defined within the Subsidence Assessment (MSEC, 2021). The extent of the Study Area has been calculated by combining the areas bound by the following limits:

- A 35° angle of draw line; and
- Predicted 20mm subsidence contour.

The investigation also considers effects caused within the general Study Area to major downstream waterways i.e. The Nepean River and downstream effects of tributaries within the Study Area i.e. Foot Onslow Creek, Navigation Creek and Harris Creek.



H:\WOL\Projects-SLR-WOL\630-NTL\630.30102.00000 Appin SW Man Plan LW709 905\06 SLR Data\01 CADGIS\GIS\SLR63030102_G1_Site layout_002.mxd

1.3 Approved Operations

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 formerly Tower Colliery and West Cliff Mine.

The Appin Mine includes Area 1, Area 2, Area 3, Area 4, Area 5, Area 7 and Area 9 (**Figure 1**). The current active mining is in Area 7 and Area 9. It should be noted that the approved Area 9 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 1**.

Table 1 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 - 38	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

1.4 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, with production to cease by 2023. AGL hold two Water Access Licenses (24856 and 24736) and Works and Use Approvals (10WA112288 and 10WA112294) with a current total allocation of 30 ML/year (15ML allocated from the Sydney Basin Central Groundwater Source and 15 ML allocated from the Sydney Basin Nepean Groundwater Source) (AGL, 2018). The Camden Gas Project comprises 144 wells (92 currently active, 41 have been rehabilitated) targeting the Bulli and Balgownie seams north of the Project.

2 Environmental Setting

2.1 Climate and Topography

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 BoM site data associated to the SILO point grid has been used for this assessment of the Project. There are several Bureau of Meteorology (BoM) stations in the area with long-term data, including Darkes Forest (068024), Cataract Dam (068016), Wedderburn (068159) and 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 Scientific Information for Landowners (SILO) database, from January 1890 to September 2020. Based on the SILO data, the long-term (1890 to 2020) average yearly rainfall for the Project Area is 986 mm/yr.

Figure 2 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). The recent April 2017 to December 2019 rainfall deficit is assessed by BoM as the 'lowest on record'.

Potential evaporation (PE) 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 the average daily rainfall and PE for each month is presented in **Figure 3**. This shows that in July there is a slight rainfall excess, with a rainfall deficit in all other months.

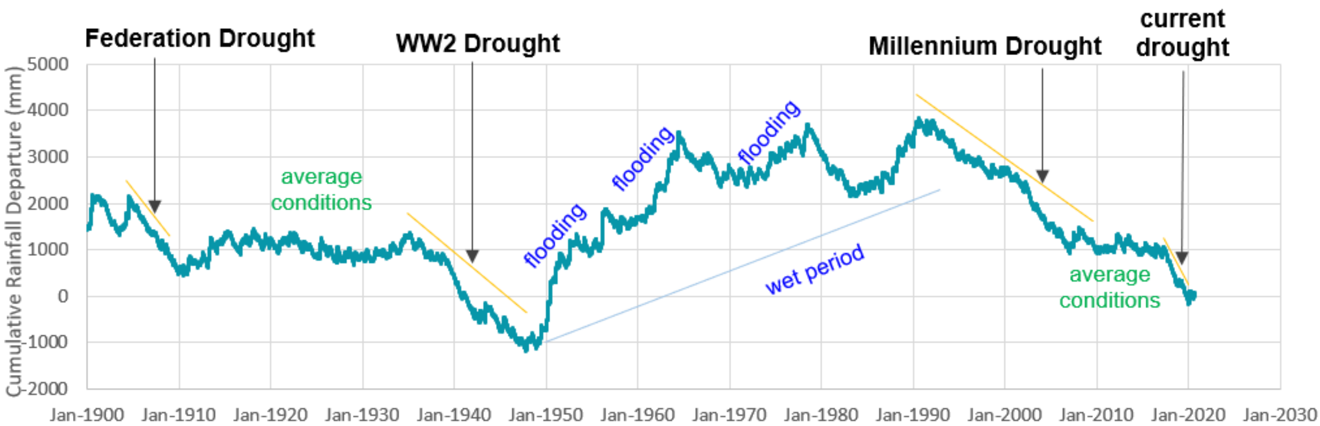


Figure 2 Cumulative Rainfall Departure

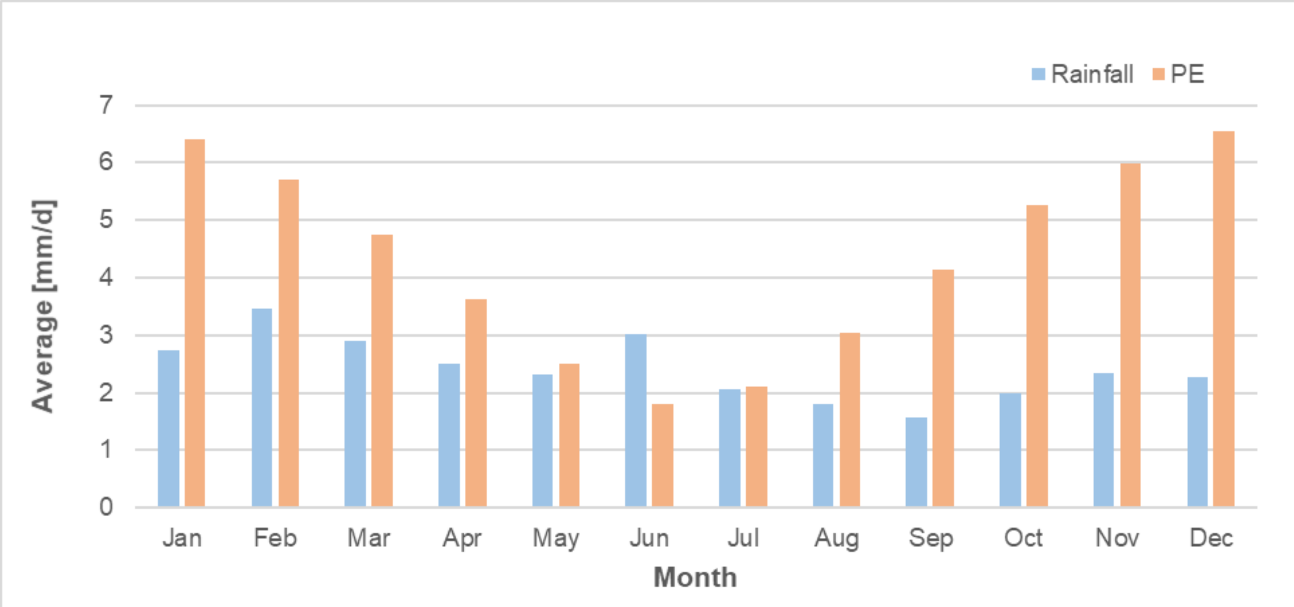
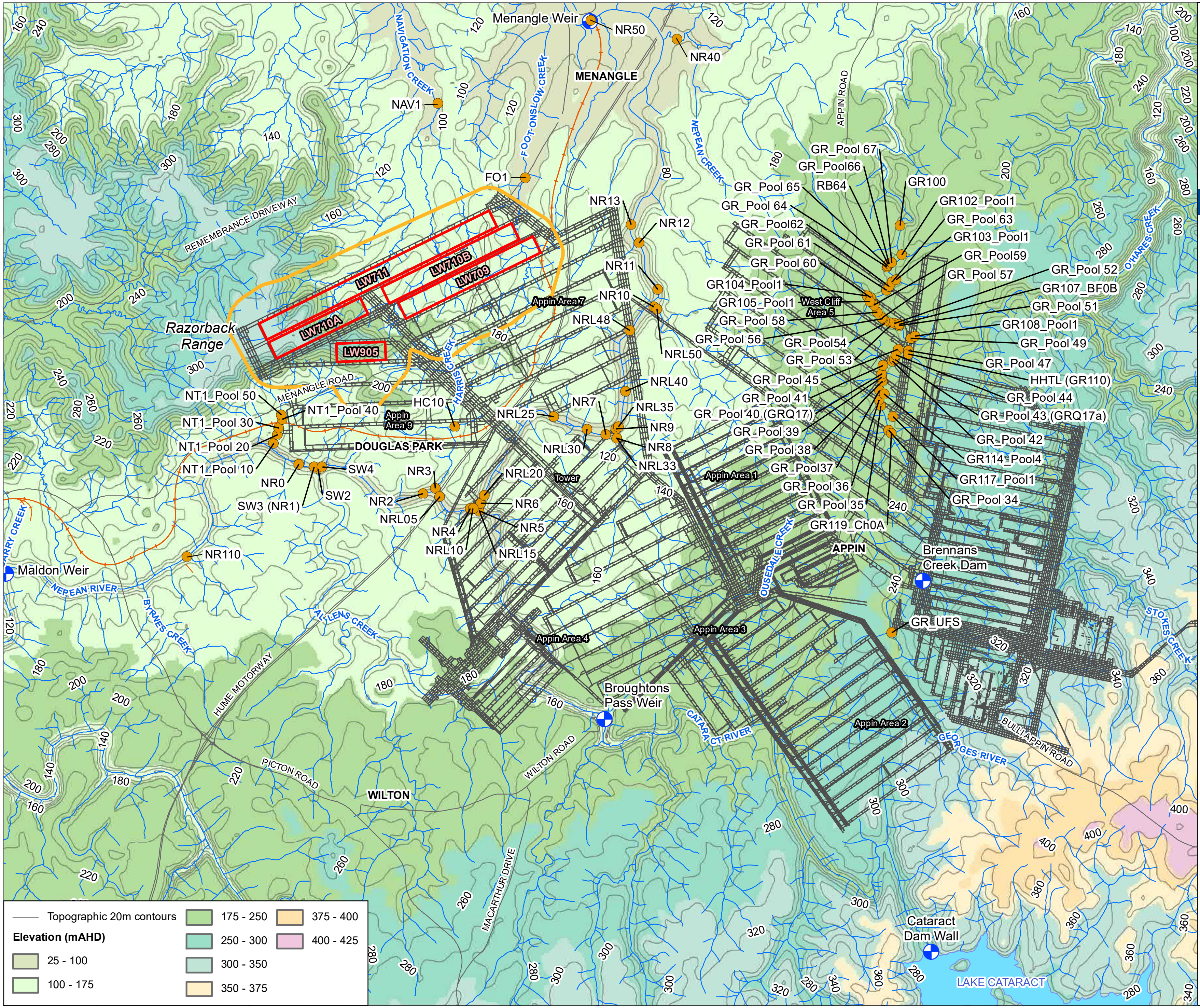


Figure 3 Average Daily Rainfall and Potential Evaporation

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 m AHD to 320 m AHD, with the topographic high associated with Razorback Range on the western part of the Project Area (**Figure 4**).

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



APPIN MINE SURFACE WATER ASSESSMENT

TOPOGRAPHY AND DRAINAGE

- Project Area
- Study Area
- Dams
- Surface water monitoring
- Roads
- Railway
- Appin Mine
- Watercourses
- Lakes

0 0.5 1 km

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

Project No.:	630.30102
Date:	15-Apr-2021
Drawn by:	ANP

SLR
www.slrconsulting.com

H:\WOL\Projects-SLR-WOL\630-NTL\630.30102.00000 Appin SW Man Plan LW709 905\06 SLR Data\01 CADGIS\GIS\SLR63030102_G2_Drainage_002.mxd

2.3 Geology

Appin Mine is located within the Southern Coalfield of the Sydney Basin. The stratigraphy of the Southern Sydney Basin is shown in **Figure 5**, based on the Southern Coalfield 1:100,000 geological map (Moffitt 1999).

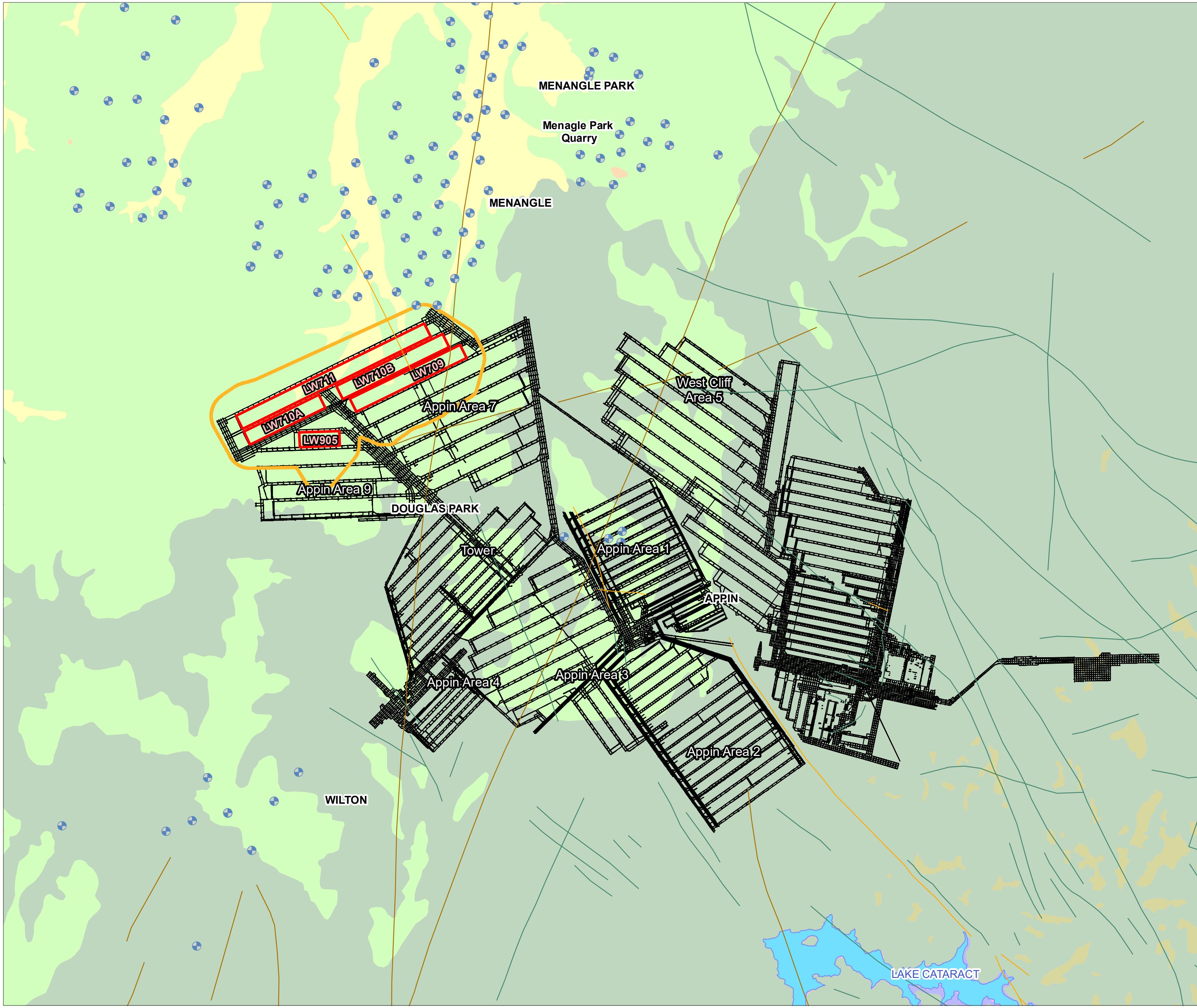
The Triassic Wianamatta Group is present at surface across the site (**Figure 5**) and ranges in thickness from less than 10 m to 200 m at Razorback Range. Quaternary floodplain alluvium is also mapped as being present on the northern side of the Project Area, localised along Nepean River and its tributaries (i.e. Navigation Creek).

The Hawkesbury Sandstone (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. 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.

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 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 are a series of NNW-SSE orientated dykes and minor faults (MSEC, 2021). However, previous mining through these structures at LW703 to LW706 and LW901 to LW903 did not cause any change in vertical subsidence (MSEC, 2021). In addition, since the 1970s in-seam drilling has been undertaken in advance of all development underground. No hydraulically charged structures were intersected at Appin Mine during the in-seam drilling process or progression of mining.

APPIN MINE SURFACE WATER ASSESSMENT



GEOLOGY

- Project Area
- Study Area
- CSG Wells
- Appin Mine
- Fault
- Dyke
- Lineament
- Lakes
- Qal/ Tal – Alluvium
- Wianamatta group
- Rh - HBSS

0 0.5 1 km

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

Project No.: 665.10015
Date: 15-Apr-2021
Drawn by: JG

SLR
www.slrconsulting.com

H:\WOL\Projects-SLR-WOL\630-NTL\630.30102.00000 Appin SW Man Plan LW709 905\06 SLR Data\01 CADGIS\GIS\SLR63030102_G3_Geology_002.mxd

2.4 Hydrogeology

Existing hydrogeology information is provided in the Groundwater Impact Assessment that was prepared for the Project by SLR in 2021. This Groundwater Impact Assessment included groundwater modelling to predict potential impacts to the local hydrogeological system to support the EP approval process. The assessment found that depressurisation of aquifers beneath the Bald Hill Claystone, including the Lower HBSS, Bulgo Sandstone and Scarborough Sandstone is likely to occur. Predicted peak mine inflows are not expected to change compared to the approved mining plan with up to 0.65 ML/day predicted groundwater inflows from the proposed longwalls.

Although some impacts to groundwater are predicted, the assessment concluded that there are negligible predicted impacts on surface water bodies including stream inflows due to depressurisation of the coal measures. This is because there is negligible predicted depressurisation within the upper layers, above the Bald Hill Claystone to induce downward seepage or reduce baseflow contributions. While negligible depressurisation is predicted within the surficial strata as part of the groundwater assessment, the subsidence assessment identified the potential for fracturing to develop along the creeks and tributaries due to the mining of the proposed Longwalls 709 to 711 and 905. 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 Colliery and elsewhere in the Southern Coalfield. Changes in shallow groundwater as a result of fracturing, dilatation and shear of shallow strata can result in changes to surface water bodies and shallow groundwater, where they are connected. This has the potential for localised impacts on surface water flow in creeks and tributaries, which may influence recharge to the alluvium within proximity to the Project.

While the assessment predicts no substantial depressurisation within the upper layers, during mining of recent adjacent longwalls some minor reduction in standing water levels in the stratigraphy above the Bulgo Sandstone was observed in groundwater monitoring. However, groundwater gradient towards the Nepean River is maintained. Additionally, IMC have observed declines in standing water levels in the upper and lower HBSS in landowner boreholes that have been mined under. It is suspected that changes in shallow groundwater are a result of fracturing, dilatation and shear of shallow strata. The data is observational only at this time as the baseline monitoring time period is short; therefore the pre-mining data is not able to be compared with the post mining data at this time.

The groundwater data analysis also concluded 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).

2.5 Surface Water and Drainage

2.5.1 Major Rivers

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 4**). 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 HBSS.

Summary details for each of the main rivers near the Project are included in **Table 2**.

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 m AHD to 132 m AHD.
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 m AHD.
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.

There are no drinking water catchment areas, or declared special areas within the Study Area. The closest river is the Nepean River, which is 1.5 km south of the Project footprint (MSEC, 2021). The Hawksbury-Nepean Catchment covers approximately 21,400 km^2 (DPIE, 2020). Water flows from the Nepean River are derived from a number of sources and include flows from catchment areas, licensed discharges, including Appin and Tahmoor Collieries, and runoff from agricultural and urban areas. Flows from catchment areas contribute the majority of base water flow into the river (Ecoengineers, 2012).

Natural flow within the Nepean River and its associated watercourses have been significantly altered by water storages such as dams and weirs. Some natural catchment flows are retained by large storage dams upstream of Appin Mine for the purpose of the Sydney water supply system. Water is also retained by numerous farm dams within the local part of the Nepean River catchment, particularly around the Project Area.

The Hawksbury-Nepean basin is considered an unregulated system as the water storages do not regulate flows downstream. They do not capture then release water into the river downstream for extraction by users (DPIE, 2020). Based on available information, two licensed extraction pumps are known to draw water from the Nepean River upstream of the Douglas Park Causeway, only one of which is located within the general Project Area (Ecoengineers, 2012). The majority of unregulated river access licences within the Hawksbury-Nepean catchment are for irrigation purposes, extraction also takes place largely through basic landholder rights, which do not require a licence (DPIE, 2016).

A significant portion of the Nepean River catchment has been cleared for housing, agriculture and industry. Chemical nutrient runoff from residences, farms and industries and treated waste from several sewage treatment plants have contributed to degraded water quality within the Nepean River, including excess nutrients and algae growth (WSU, 2017).

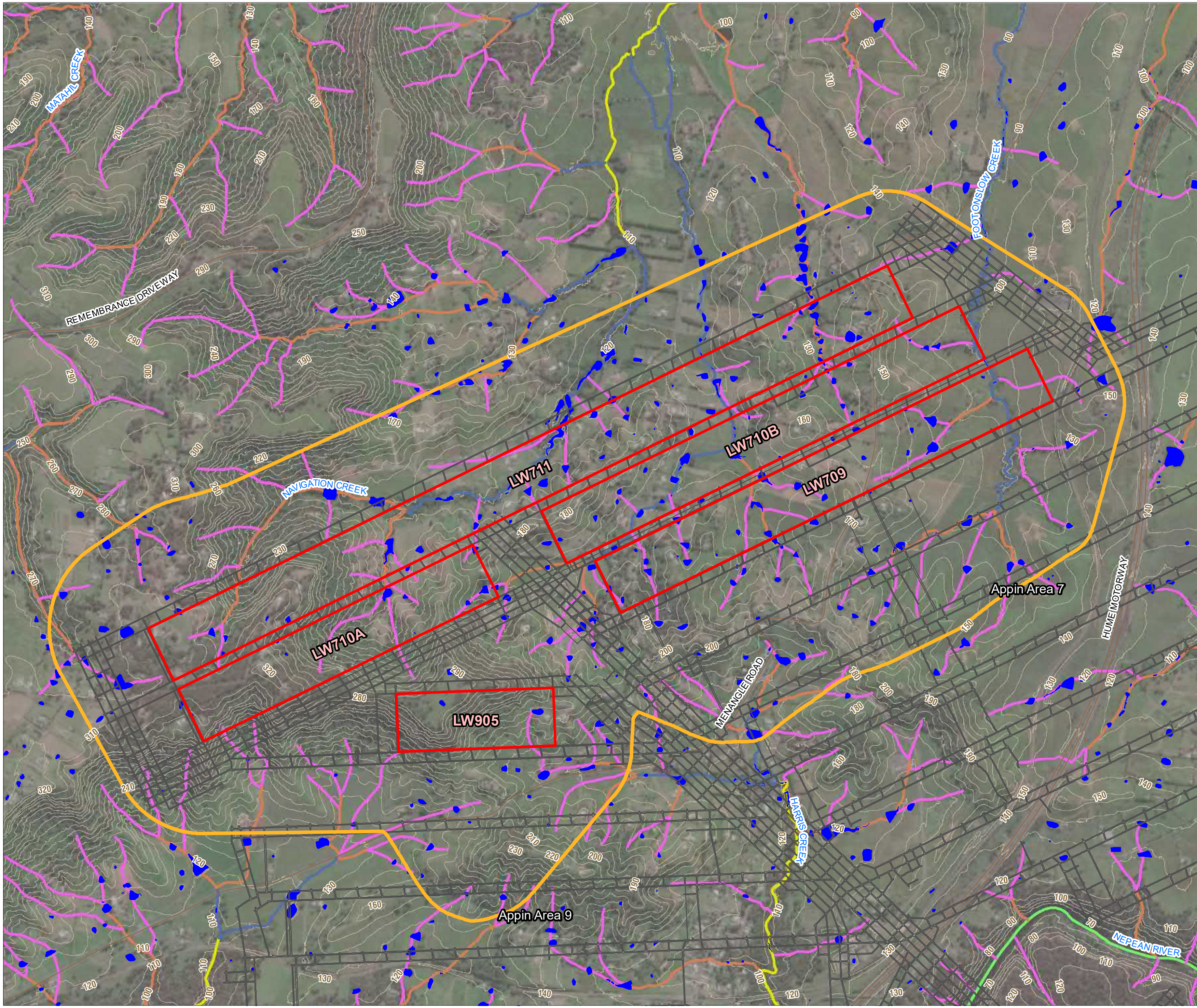
2.5.2 Watercourses within the Project Area

Minor creeks and tributaries of the Nepean River are present across the Appin Mine area. This includes the headwaters of Navigation Creek, Navigation Creek Tributary 1, Foot Onslow Creek and Harris Creek that are third order streams within the Study Area, see **Figure 6** .

Watercourses within the Study Area have upper reaches with shallow incisions into the surface soils, which have been derived from the Wianamatta Group, and steep natural gradients ranging from 2-40%. The lower reaches of these creeks have substantial incisions into the surface soils, with exposed sandstone platforms in the bases and rock outcropping in the valley sides. Natural gradients of third order streams range from 0.5-4%.

Watercourses within the Study Area contribute to a small portion of the total Hawkesbury-Nepean Catchment (<0.2%) with runoff from predominately cleared, agricultural land with small pockets of remnant vegetation. The creeks are largely ephemeral, but pools have naturally formed in some areas. Like the receiving Nepean River, flows within ephemeral creeks have been altered by farm dams which intersect the drainage lines at a number of locations. Runoff from within the catchments is influenced by input of nutrients from adjacent farmland and salinity from the marine sediments of the Wianamatta Shale.

Impacts to water related ecosystems with these watercourses are discussed as part of the Terrestrial Ecology Impact Assessment (Niche, 2021) and Aquatic Ecology Impact Assessment (Cardno, 2021).



APPIN MINE SURFACE WATER ASSESSMENT

WATERCOURSES WITHIN THE PROJECT AREA

- Project Area
- Study Area
- Roads
- Appin Mine
- 10m Contour (NSW SS, 2019)
- Farm Dam

Strahler Stream Order (WaterNSW)

- 1
- 2
- 3
- 4
- 7

0 0.5 1 km

Projection: GDA 1994 MGA Zone 56
Scale: 1:28,000 at A4

Project No.: 630.30102
Date: 15-Apr-2021
Drawn by: ANP

SLR
www.slrconsulting.com

H:\WOL\Projects-SLR-WOL\630-NTL\630.30102.00000 Appin SW Man Plan LW709 905\06 SLR Data\01 CADGIS\GIS\SLR63030102_G4_WatercoursesProjectArea_002.mxd

2.5.2.1 Navigation Creek

Navigation Creek (**Photo 1**) is a third order stream that is situated directly above Longwall 711, with a third order tributary (Navigation Creek Tributary 1) also directly above Longwalls 709, 710A and 711. A total length of Navigation Creek (including Navigation Creek Tributary 1) of 2.9 km is located within the Project Area with an additional 1.4 km within the Study Area. The upper reaches of Navigation Creek are located within the Study Area and flow north to its confluence with the Nepean River approximately 9.8 km downstream of the Project. The catchment area of Navigation Creek to its confluence with the Nepean River is approximately 24.9 km^2.

Navigation Creek is ephemeral and likely only flows during periods of extended, moderate or high rainfall. The headwaters of Navigation Creek are located within the Project Area with first and second order streams within the steep ridgeline of remnant bushland to the northwest of Appin Mine. The majority of the remaining catchment, including that of the third order stream, is comprised of agricultural land. Navigation Creek is predominantly highly disturbed and in poor condition. Stream banks are often steep with vegetation often consisting of weeds, and areas of minimal vegetation with evidence of erosion and scouring. Some pools have naturally established along the reaches, however the majority of the upper reaches consist of depressions and minor drainage lines intersected by a number of farm dams with little to no signs of flow. Any surface water flows from the upper reaches are predominantly captured within these established farm dams with runoff likely to only contribute to the downstream Nepean River during periods of extended or significant flow. Hence, the influence of this watercourse on flow and water quality within the Nepean River is minimal.

Photo 1 Navigation Creek (Source: IMC)

2.5.2.2 Foot Onslow Creek

Foot Onslow Creek (**Photo 2**) is a third order stream that is situated directly above Longwalls 708B, 709 and 710A. A total length of 1.5 km is located within the Project Area with an additional 2.2 km within the Study Area. The upper reaches of Foot Onslow Creek are located within the Study Area and flow north to its confluence with the Nepean River approximately 3.8 km downstream of the Project. The catchment area of Foot Onslow Creek to its confluence with the Nepean River is approximately 8.5 km^2.

Foot Onslow Creek is ephemeral and likely only flows during periods of extended, moderate or high rainfall. Foot Onslow Creek exists as a third order creek within the Project Area, with some minor first and second order streams. Within the Study Area the watercourse resides chiefly within agricultural land. Foot Onslow Creek is predominantly highly disturbed and in poor condition. Stream banks show areas of significant scouring and erosion with steep to near vertical walls. On shallower banks vegetation consist primarily of grassland and weeds. Stream bed material consists of loose sediment with grass and reed growth in some locations. Surface water flows from the upper reaches are predominantly captured within a number of established farm dams with runoff likely to contribute to the Nepean River during periods of extended or significant flow only. Hence, the influence of this watercourse on flow and water quality within the Nepean River is minimal.

Photo 2 Foot Onslow Creek (Source: IMC)

2.5.2.3 Harris Creek

Harris Creek (**Photo 3**) is a third order stream within 600 m of Longwall 905 and adjacent to the previously mined Longwall 706. A total length of 0.4 km is located within the Study Area. The upper reaches of Harris Creek are located within the Study Area and flow south to its confluence with the Nepean River approximately 3.6 km downstream of the Project. The catchment area of Navigation Creek to its confluence with the Nepean River is approximately 5.2 km^2.

Harris Creek is ephemeral and likely only flows during periods of extended, moderate or high rainfall. Only first order parts of Harris Creek exists within the Project Area within a steep ridgeline of agricultural land and remnant vegetation. The upper reaches of Harris Creek are predominantly disturbed with depressions and minor drainage lines which are intersected by a number of farm dams. Harris Creek becomes a third order stream adjacent to the Project Area and passes under a culvert at Menangle Road. Downstream of the Project, Harris Creek flows through a rural residential area before discharging to the Nepean River. Where Harris Creek is a third order stream the drainage line is shallow with well-vegetated banks. Natural pools have established in some areas. Surface water flows are limited due to catchment size in addition to flows from upper reaches predominantly captured within established farm dams. Runoff is likely to contribute to the Nepean River during period of extended or significant flow only and is expected to be minimal. Hence, the influence of this watercourse on flow and water quality within the Nepean River is minimal.

Photo 3 Harris Creek (Source: IMC)

3 Baseline Surface Water Monitoring

Surface water monitoring is conducted at the main rivers at government stream gauges (Meldon, Menangle and Broughtons Weirs). 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.

River stage levels for Nepean River, Cataract River and Stonequarry Creek are shown in **Figure 7**, 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.

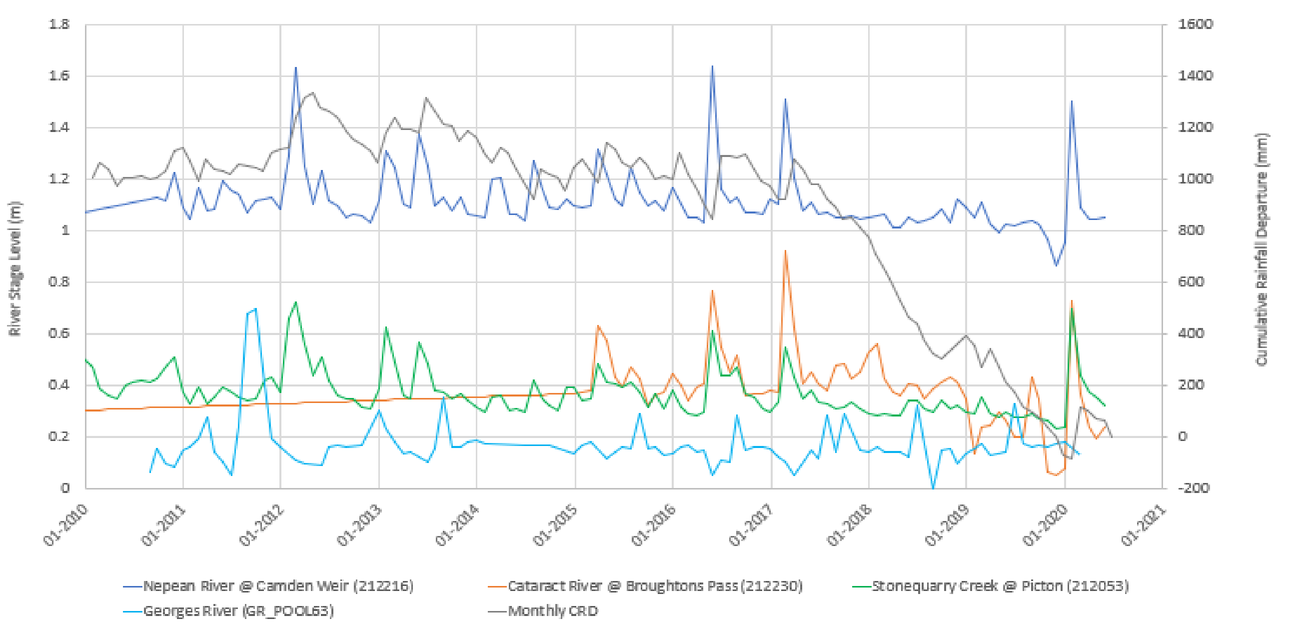


Figure 7 Surface Water Stages

Surface water monitoring has been undertaken at the site for a baseline period between 2002 – 2020. A summary of average water quality monitored at the site surface water monitoring points is included in **Table 3.** The results show 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) 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 Monitoring at Appin Mine

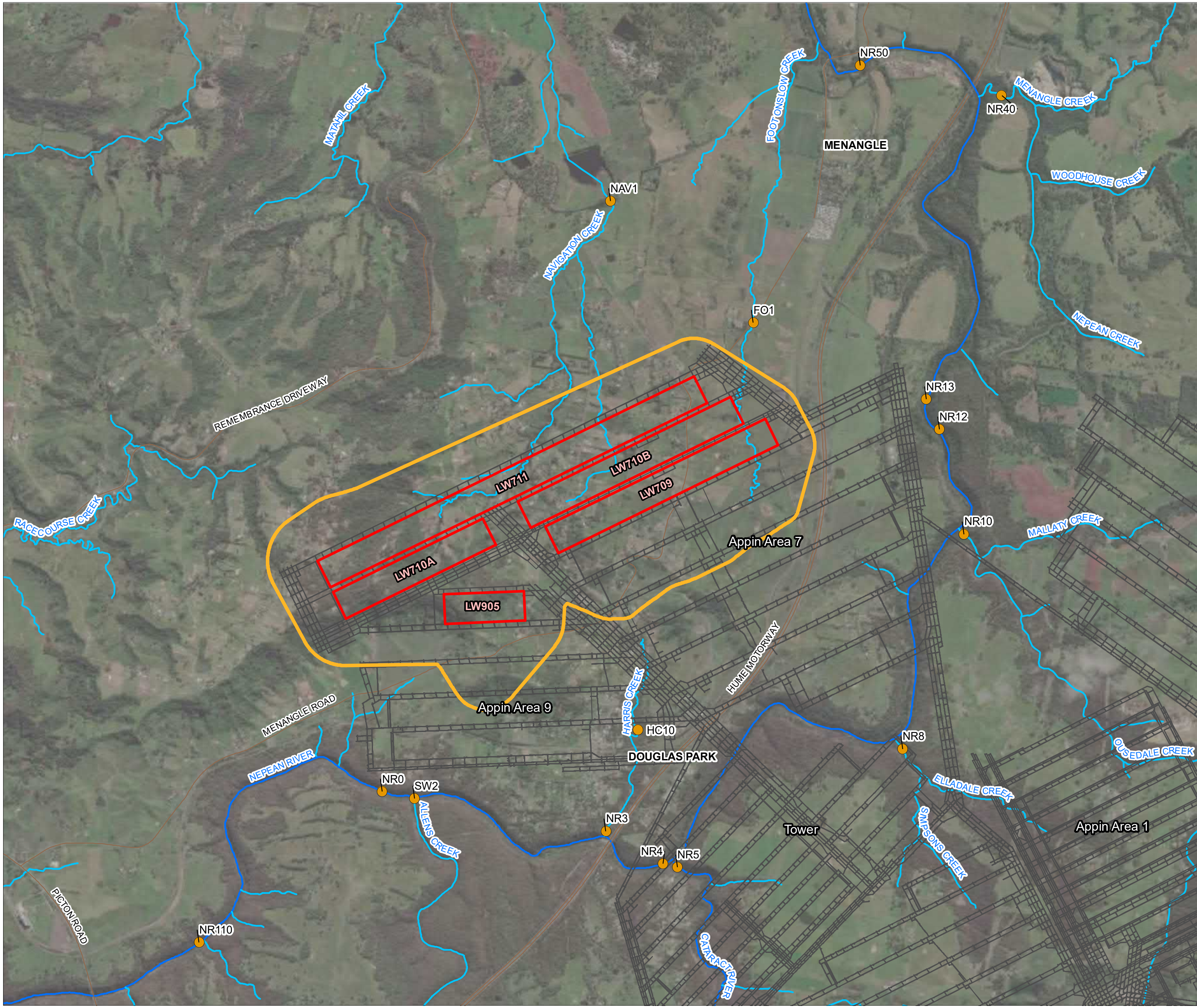
River	Average EC (µS/cm)	pH	TDS (mg/L)	Monitoring Period
Nepean River	309	8	172	2002 - Present
Cataract River	168	7	97	2002 - Present
Georges River	929	7	538	2008 - Present
Ousedale Creek	1478	8	801	2002 - Present
Menangle Creek	1373	8	725	2003 - Present
Elladale Creek	1632	8	904	2002 - Present
Allens Creek	743	8	397	2003 - Present
Navigation Creek	2565	8	1470	2006 - Present
Harris Creek	1490	8	872	2002 - Present / 2010 - Present
Foot Onslow Creek	1616	8	909	2008 - Present

There is an adequate baseline of water quality data to fully characterise water quality conditions prior to the commencement of mining in the Project Area. This includes monitoring locations within the Study Area, as well as monitoring locations in downstream waterways. There are no watercourses which flow into the Project Area, with the headwaters of Harris, Navigation and Foot Onslow Creeks being within the Project Area.

Locations of water quality monitoring sites relevant to this report are considered as shown in **Figure 8** and include:

- **Nepean River** – NR110, NR0, SW2, NR4, NR5, NR8, NR10, NR12, NR13, NR40, NR50;
- **Navigation Creek** – NAV1;
- **Foot Onslow Creek** – FO1; and
- **Harris Creek** – HC10, NR3.

Average water quality for salinity (EC), pH, Dissolved Oxygen (DO), TDS, Total Iron (Fe) and Total Manganese (Mn) over the baseline period for each watercourse at the existing water quality monitoring sites are shown in **Table 4** along with the standard deviation.



APPIN MINE SURFACE WATER ASSESSMENT

LONGWALLS 709 – 711 AND 905 SURFACE WATER MONITORING

- Project Area
- Study Area
- Surface water monitoring
- Roads
- Major watercourses
- Minor watercourses
- Appin Mine

0 0.5 1 km

Projection: GDA 1994 MGA Zone 56
Scale: 1:55,000 at A4

Project No.:	630.30102
Date:	15-Apr-2021
Drawn by:	ANP

SLR
www.slrconsulting.com

H:\WOL\Projects-SLR-WOL\630-NTL\630.30102.00000 Appin SW Man Plan LW709 905\06 SLR Data\01 CADGIS\GIS\SLR63030102_G5_SurfaceWaterMonitoring_003.mxd

Table 4 Baseline Water Quality Data

River	EC (µS/cm)		pH		DO (%)		TDS (mg/L)		Fe (mg/L)		Mn (mg/L)	
	Average	St.Dev.	Average	St.Dev.	Average	St.Dev.	Average	St.Dev.	Average	St.Dev.	Average	St.Dev.
Nepean River												
NR110	319	147	7.9	0.3	90.5	14.8	171	76	0.3	0.2	0.03	0.02
NR0	378	173	7.9	0.5	89.5	13.2	208	89	0.3	0.2	0.03	0.02
NR4	223	104	7.6	0.4	85.7	18.4	128	57.8	0.4	0.2	0.03	0.01
NR12	186	67	7.4	0.3	87.2	10.1	107	39	0.4	0.1	0.03	0.01
NR13	182	55	7.4	0.3	85.7	12.6	105	31	0.4	0.1	0.03	0.01
NR50	296	240	7.6	0.4	84.1	19.7	167	135	0.4	0.4	0.05	0.09
Allens Creek - Perturbation												
SW2	704	299	8.1	0.4	95.7	18.4	394	151	0.5	0.4	0.02	0.02
Cataract River - Perturbation												
NR5	169	118	7.2	0.5	73.1	29.6	97	61	0.7	0.8	0.08	0.12
Elladale Creek - Perturbation												
NR8	1640	1229	7.6	0.3	72.4	20.5	909	696	0.8	0.5	0.32	0.82
Ousedale Creek - Perturbation												
NR10	1486	1007	7.8	0.5	91.4	13.9	805	548	0.6	1.4	0.05	0.32
Menangle Creek - Perturbation												
NR40	1376	772	7.7	0.4	54.1	31.7	727	411	2.1	2.0	1.1	1.6
Foot Onslow Creek												
FO1	1616	901	8.0	0.4	73.5	22.3	909	525	1.5	2.0	0.3	0.4
Navigation Creek												

River	EC (µS/cm)		pH		DO (%)		TDS (mg/L)		Fe (mg/L)		Mn (mg/L)	
	Average	St.Dev.	Average	St.Dev.	Average	St.Dev.	Average	St.Dev.	Average	St.Dev.	Average	St.Dev.
NAV1	2565	1943	7.6	0.4	27.8	21.4	1470	1124	5.1	6.0	1.8	1.0
Harris Creek												
HC10	1561	688	7.9	0.3	81.5	25.0	935	425	0.7	2.3	0.2	0.4
NR3	1550	956	7.9	0.3	53.1	26.9	864	531	0.7	1.1	0.5	0.9

Comparison between rainfall trends and the Nepean River surface water quality over time is presented in **Figure** 9. 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 upstream (NR0 and NR110) and downstream (NR50) segment. The peaks in volume discharge correlate to above average rainfall conditions over time, which freshen water in the river system.

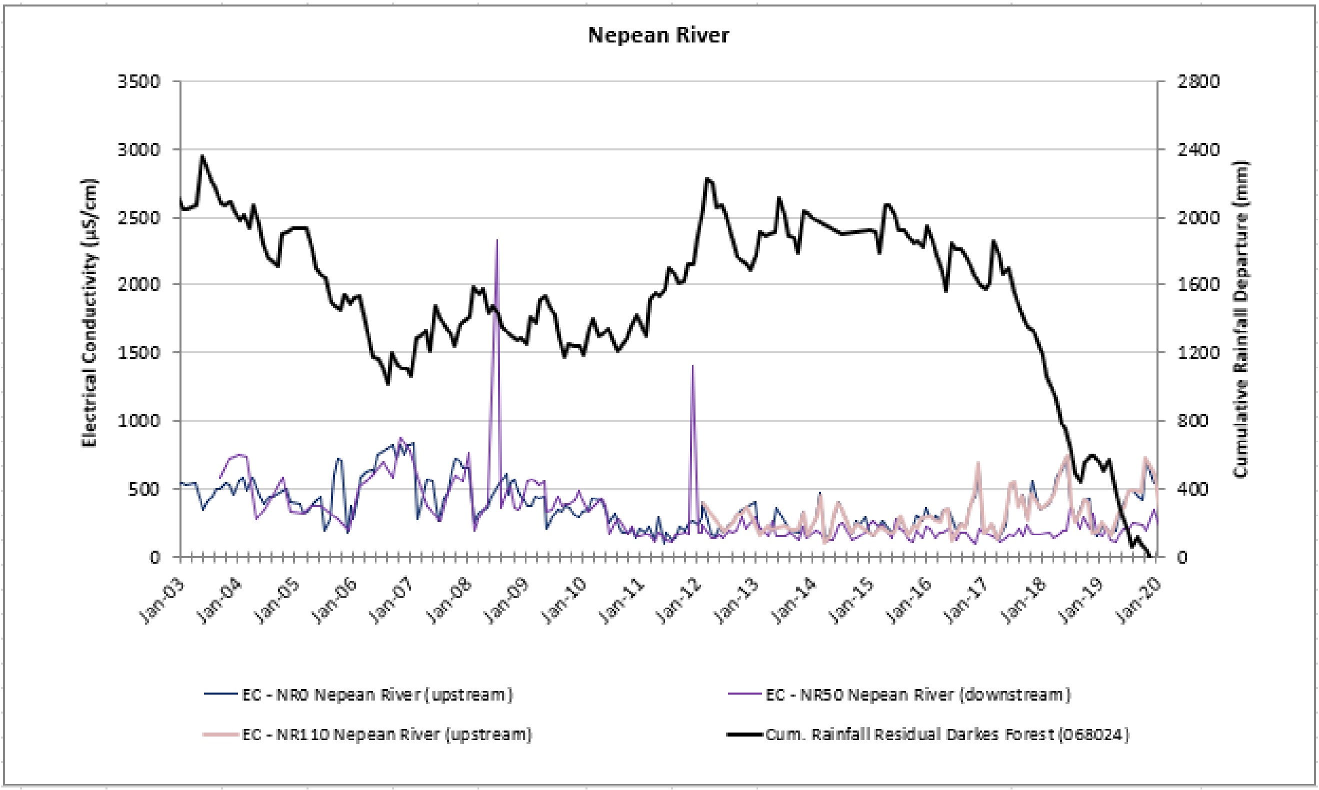


Figure 9 Water Quality along the Nepean River

In comparison **Figure 10** shows the surface water quality of creeks and tributaries within the Study Area over time. The long-term average EC of these watercourses is significantly higher than that of the Nepean River due to the occurrence of the Wianamatta Group at the surface. The salinity of waters within these shale catchment creeks is principally driven by the presence of the anion sodium (Na^+) and cation bicarbonate (HCO_3^-). Bicarbonate is well known to be the principle and most variable driver of salinity based ecotoxicity in such waters. These watercourses have also been observed to provide a consistent input of Fe and Mn to the Nepean River. The oxidation and precipitation of input Fe and Mn, which is enhanced by high pH levels of these streams, increases the ratio of bicarbonate to carbonate ions, ultimately, increasing the ecotoxicity due to salinity (Ecoengineers, 2012). The high variability of salinity over time is typical of ephemeral creeks, with higher salinity typically associated with low flows.

High pH values in the 8.2 – 9.4 pH range can be found within the Nepean River and ephemeral creeks surrounding the Project Area which is not unexpected due to land use dominated to farmland with pre-existing Total Phosphorus (TP) and Total Nitrogen (TN) inputs from fertilisation and livestock waste pollution in catchments draining into the watercourses predominantly during large rainfall events (Ecoengineers, 2012).

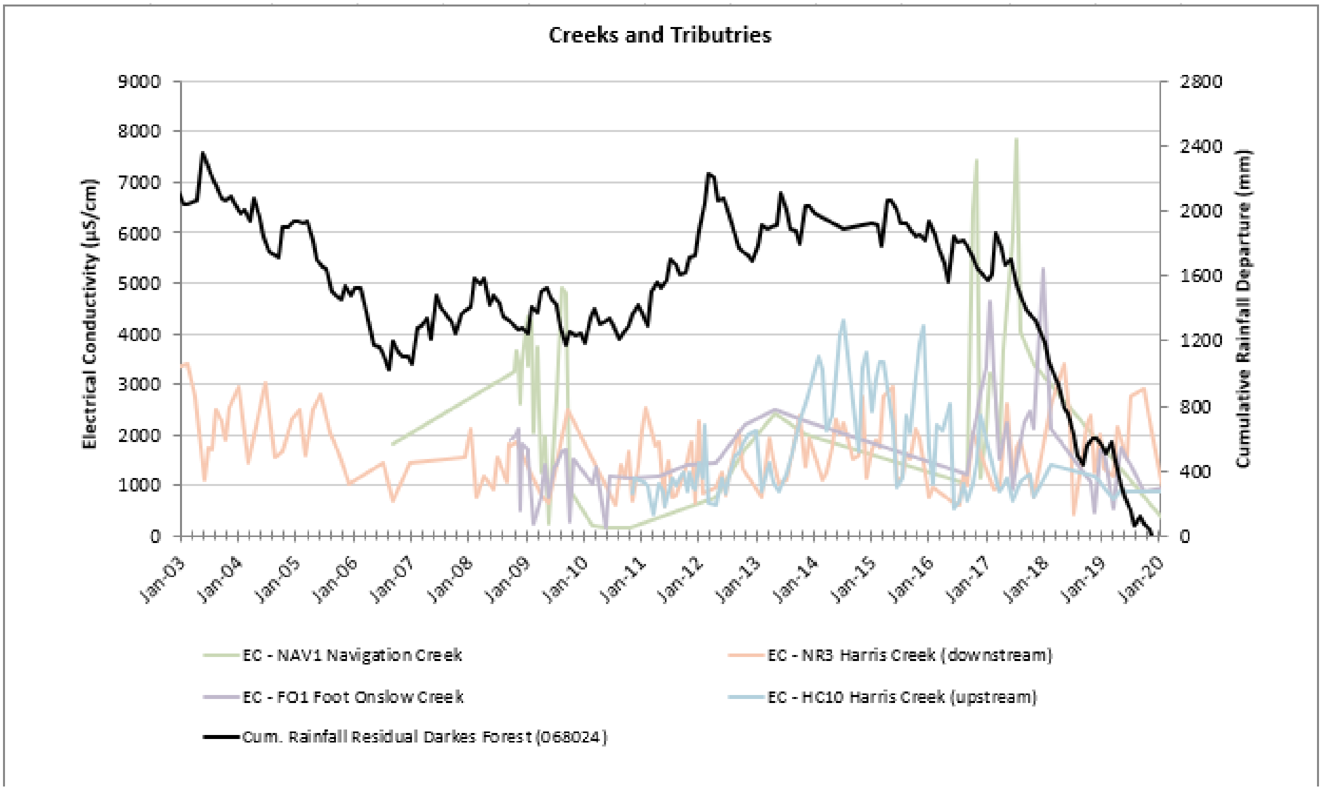


Figure 10 Water Quality in Creeks and Tributaries

4 Predicted Mine Subsidence

Above Longwalls 709 to 711 and 905 in the Bulli Seam, the depth of cover is between 530 m to 750 m. Watercourses located directly above and within 600 m of the proposed longwall panels, which represents the minimum extent for assessment of valley-related effects, are Navigation Creek, Navigation Creek Tributary 1, Foot Onslow Creek and Harris Creek. The closest river is the Nepean River which is located 1.5 km from the Project. Potential subsidence impacts to the creeks and watercourses directly above and adjacent (within 600 m) to longwalls have been assessed by MSEC (2021).

The maximum predicted total vertical subsidence for the existing, approved and proposed longwalls is 1,550 mm and maximum predicted total tilt is 7 mm/m (MSEC, 2021). Maximum predicted subsidence effects for rivers and third order creeks above or adjacent to the Project are listed in **Table 5**. The maximum predicted subsidence effects on the third order creeks (i.e. Navigation, Foot Onslow and Harris) is 1,400 mm vertical subsidence, comprising a predicted 550 mm upsidence and 800 mm total closure. 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).

Table 5 Maximum predicted subsidence in Rivers, Creeks and Tributaries

Name	Maximum predicted vertical subsidence (mm)	Maximum predicted upsidence (mm)	Maximum predicted total closure (mm)
Rivers			
Nepean River	<20	<20	<20
Creeks and Tributaries			
Foot Onslow Creek	1400	300	250
Harris Creek	500	350	300
Navigation Creek	950	350	475
Navigation Creek Tributary 1	1350	550	800

The assessment by MSEC (2021) found cracking in the creek bed and fracturing of shallow (10 m to 20 m depth) bedrock for the creeks could develop due to the Project, particularly in areas immediately above the longwall panels. Surface tension cracks are also likely to occur, typically with widths in the order of 25 mm to 50 mm.

MSEC (2021) found localised ponding could develop in some isolated locations. 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.

5 Surface Water Impact Assessment

5.1 Stream Flow Impact Assessment

Watercourses may experience dilation fracturing as a result of longwall mining. This is most likely to occur in streams located directly above the mining area. However, impacts can occur outside the mining area at distances up to 400 m outside the longwall, typically this is minor and isolated fracturing (MSEC, 2021). Where fracturing occurs, a portion of stream flow may be diverted via the fracture to the dilated strata below the stream bed resulting in a reduction in water flow. Diversion of surface water flow is more likely to occur during times of low flow as during heavy rainfall the majority of runoff is likely to flow over the fractured bed rather than diverting to the dilated strata below (MSEC, 2021). Therefore, there is the potential to reduce continuity of flow between pools during dry weather.

A total length of 4.2 km of the upper reaches of third order streams, discussed in Section 4, lie above the proposed longwall area with an additional 2.6 km within the Study Area. The Project will not extract from directly beneath or within 600 m of the Nepean River and thus the Nepean River is not expected to experience any fracturing as a result of the Project. Similarly, flows contributed to the Nepean River from the ephemeral watercourses within the Study Area are minimal and thus changes to flow within these streams is expected to have negligible impact on flows within the Nepean River.

Based on previous experience of mining beneath creeks and tributaries within the Southern Coalfield, it is likely that some fracturing will occur along watercourses, particularly those located above or adjacent to the proposed longwalls (MSEC, 2021). However, such watercourses are ephemeral and surface water flows only occur for short periods during and after rainfall events. During the mining of previous longwalls within Appin Area 7 and 9 ephemeral creeks with comparable predicted subsidence movements to those of third order creeks within the Study Area showed no reported observed fracturing that has resulted in surface water flow diversion. The assessment by MSEC (2021) found that although fracturing along streams may occur it is unlikely that there would be a significant loss of surface water yield from the catchment.

Nevertheless, monitoring of these creeks and the Nepean River to assess impacts is proposed (refer to Section 6) and trigger action response plans (TARPs) have been developed to manage impacts should they occur (refer to Section 7).

5.2 Stream Pools Impact Assessment

Longwall mining can result in increased levels of ponding in locations where the mining-induced tilts oppose and are greater than the natural drainage line gradients that exist before mining.

No adverse effect on stream pools is anticipated as a result of subsidence induced tilt due to the low predicted subsidence and the minimal predicted change in stream tilt (7mm/m). The predicted mining-induced tilt for creeks above and adjacent to the proposed longwalls is less than the average gradients with no predicted reversal of stream grade. Therefore, it is unlikely that any large-scale changes to ponding levels will occur, however, it is possible that minor localised increases in ponding could develop (MSEC, 2021). Any impacts resulting from changes in surface water flows due to tilt are expected to be small in comparison to those which occur during natural flooding conditions (MSEC, 2021).

Where dilation fracturing, discussed in Section 5.1, occurs within the pools of ephemeral watercourses a portion of streamflow may be diverted via the fracturing resulting in reduction in water level in the surface water system as they drain via the bed fractures. Small pools have formed naturally along the reaches of ephemeral streams within the Study Area, however, as discussed in Section 5.1, no significant loss of catchment yield is expected as a result of the proposed longwalls.

Furthermore, the Groundwater Impact Assessment (SLR, 2021) found that the Project is not predicted to induce downward seepage or reduced baseflow contributions in surface water bodies, including stream pools, as there is no predicted depressurisation within the upper layers. It is predicted that although the lower seams will be depressurised the depressurisation will not extend upwards and therefore not affect groundwater levels in the upper layers. The subsidence assessment identified the potential for fracturing to develop along the creeks and tributaries due to the mining of the proposed Longwalls 709 to 711 and 905, as discussed in Section 5.1. 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 Colliery and elsewhere in the Southern Coalfield. Changes in shallow groundwater as a result of fracturing, dilatation and shear of shallow strata can result in changes to surface water bodies and shallow groundwater, where they are connected.

MSEC (2021) determined that the risk of significant loss of stream flow and water levels within pools due to creek bed fracturing is low. Nevertheless, there is potential for fracturing of creek beds to reduce flows along ephemeral creeks during dry periods or periods of light rainfall. This potential impact will be monitored by:

- Routine inspection of creek lines for signs of fracturing; and
- Monitoring water levels in pools.

Water level monitoring of pools is planned (refer to Section 6.2) and TARPs have been developed to assess the need for management and remediation (refer to Section 7). In the unlikely event of significant impact to stream pools within ephemeral watercourses, remediation would be conducted where remediation is technically feasible and necessary.

5.3 Channel Stability Impact Assessment

Where subsidence induced fracturing or mining induced tilts are significant it is possible that bed and bank stability could be adversely affected with an associated loss of riparian vegetation. However, within the Study Area the predicted subsidence is unlikely to result in widespread impacts on stream stability.

Predicted subsidence impacts are expected to result in only small changes to the stream bed profile. As a result, changes in bed gradients are not likely to cause significant ponding or scouring of the banks. Any potential impacts on streams above and adjacent to the proposed longwalls are therefore expected to be minor and localised. Potential changes in surface water flows due to the Project are expected to be very small in comparison to flows which occur during heavy rainfall.

It is also noted that the streams in the Project Area are not intended to be relocated or reinstated, and that no instream structures are proposed.

Monitoring of creeks for potential instability as a result of mining is proposed (refer to Section 6) and TARPs will be in place to manage impacts should they occur and assess the need for remediation (refer to section 7).

5.4 Water Quality Impact Assessment

The Project is not anticipated to have any significant impacts on surface water quality as a result of mining the proposed longwalls. The Project does not include any direct abstraction of surface water nor is it expected to cause significant changes to flow regime and bank scouring, as outlined above. However, the occurrence of ferruginous springs has been observed occasionally when mining areas of the Bulli Seam, therefore is considered in the following section.

The Project includes associated minor activities on the land surface consisting of monitoring activities, rehabilitation and associated access tracks within the Study Area. Although These access tracks and rehabilitation areas will be managed with best practice runoff controls which comply with the 'Blue Book' (Managing Urban Stormwater: Soils and Construction Vol.1, 4th edition and Vol.2E Mines and Quarries (Landcom, 2004 and DECC, 2008)) to minimise the risk of adverse impacts to water quality of downstream areas. Water quality monitoring in downstream waterways will also be undertaken. With appropriate controls in place, it is considered that these surface activities will have minimal impacts to surface water quality. Ventilation shafts associated with the Project are included under this EP, however, is an activity that will require controls to prevent water quality impacts in the respective areas.

Water quality monitoring is planned on watercourses downstream of the Project Area; and continued monitoring of the Nepean River upstream of the confluences of those watercourses (refer to Section 6.1). TARPs have been developed to assess the need for management and remediation (refer to Section 7).

5.4.1 Ferruginous Springs

Induction or exacerbation of ferruginous/saline springs is believed to result from strata dilation and bed separation leading to increased storage of perched groundwater, especially at and near to the interface between Wianamatta Shale and underlying HBSS. The experience in the Southern Coalfield is that such springs do not occur in terrain where Wianamatta Shale and shale-derived soils do not outcrop (Ecoengineers, 2012).

The interface between the Hawkesbury Sandstone and the Wianamatta Shale sequences appears likely to undergo a mine subsidence-induced permeability enhancement along the sub-horizontal interface between these units due to dilation and bed separation induced by subsidence (Ecoengineers, 2012).

The shale, being marine sediment, continues to contain traces of connate water with an elevated (seawater composition) salt load and a significant load of major cations on cation exchange sites in ratios that are still relatively similar to that of seawater. These are displaced by protons in weakly acidic infiltrating meteoric water, so increases in salinity are predicted to occur from the subcrop of the basal interface between the shale and the underlying Hawkesbury Sandstone. The shale also contains a high concentration of finely disseminated crystalline iron (Fe) and manganese (Mn) oxides (after siderite and rhodocrosite). An elevated dissolved Fe and Mn load, largely due to microbiologically-mediated reductive dissolution of Fe and Mn oxides and oxyhydroxides within the base of the weathered shale during saturation (Lovley and Phillips, 1986), is expected from waters that become stored in the catchment of any spring.

The liberation of contaminants from subsidence induced fracturing in watercourses, with resulting localised and transient water quality impacts, has the potential to impact aquatic biota. This is particularly the case where increased iron precipitation occurs. Streams that are acidic and have low alkalinity are more likely to be impacted as these surface water systems have less buffering capacity against changes to pH (Niche, 2014).

The inducement of ferruginous springs due to mining has been occasionally observed in Bulli Seam mining areas especially along margins of outcropping Wianamatta Shale. As described in the previous Assessment of Water Quality for longwalls 705-710 (Ecoengineers, 2008) ephemeral creeks that overly the Project are more prone to arise or be enhanced due to their position within the Wianamatta Shale formation in the upper reaches. However, mining of previous longwalls within Appin Area 7 and 9 has not led to induction of any detectable ferruginous springs in the walls of the Nepean River or adjacent tributaries. It is therefore considered that there is a low likelihood of ferruginous springs induced by the mining of the proposed Longwalls 709 to 711 and 905.

Although it is possible that ferruginous saline springs may be induced or enhanced in the catchment directly overlying the longwalls, impacts are expected to be minor based on the findings of this assessment and the of the previous assessment of Longwalls 705-710 (Ecoengineers, 2008) and the Assessment of Area 9 Longwalls 901-904 (Ecoengineers, 2012), including the following principles:

- Streams above or adjacent to longwalls are slightly alkaline, as described in **Table 4**, and therefore have a greater buffer capacity against changes to pH;
- The consequence of springs within the ephemeral creeks would be insignificant to ecological health of downstream pools due to the reduced habitat that has resulted from existing effects of local agricultural land uses on stream water quality;
- Ephemeral flows in Harris Creek do not constitute a significant input to downstream rivers; and
- Ephemeral flows in Navigation and Foot Onslow Creeks would have negligible influence on the downstream Nepean River due to the significant distance waters from any springs would need to flow to reach the river.

Furthermore, the arise or enhancement of ferruginous springs are not predicted within the Subsidence Impact Assessment (MSEC, 2021) and Groundwater Impact Assessment (SLR, 2021).

Nevertheless, monitoring of these creeks to assess impacts is proposed (refer to Section 6) and trigger action response plans (TARPs) have been developed to manage impacts should they occur (refer to Section 7).

5.5 Surface Water Related Infrastructure Impact Assessment

5.5.1 Farm Dams

There are 241 farm dams located within and adjacent to the Project Area, 106 of which are located directly above the proposed longwalls. The locations of these farm dams are shown on **Figure 6**.

Farm dams located directly above the proposed mining area could experience cracking in their bases or walls due to mining-induced curvatures and strains. The predicted changes in freeboard for farm dams are small, varying from less than 50 mm to 200 mm. It is unlikely that the dams would experience adverse impacts on the storage capacities due to these small changes in freeboard (MSEC, 2021).

There is extensive experience of mining directly beneath farm dams in the Southern Coalfield, which indicates that the incidence of impacts on these features is low. Farm dams are commonly constructed with cohesive materials in the bases and walls which can absorb the conventional subsidence movements typically experienced in the Southern Coalfield without the development of substantial cracking. Non-conventional movements can result in localised cracking and deformations at the surface and, where coincident with farm dams, could result in adverse impacts (MSEC, 2021).

There are no predicted impacts on surface water bodies due to depressurisation of the coal measures as part of the Project. This is because there is no predicted drawdown from the lower stratigraphic units to the surface due to the Project to induce downward seepage or reduce baseflow contributions, as discussed further in the Groundwater Assessment undertaken by SLR in 2021. These findings are consistent with the impact assessment conclusions for BSO by Heritage Computing (2009).

It is predicted that impact to farm dams from mining Longwalls 709 to 711 and 905 will be unlikely. However, where subsidence results in loss of water from dams due to cracking and/or tilt, these impacts will be managed and compensated in accordance with the *Coal Mine Subsidence Compensation Act 2017* and/or an alternate water supply would be provided as required by Condition 14 of the BSO Project Approval (Compensatory Water Supply) in consultation with the landowner.

5.5.2 Culverts

Three culverts exist in the vicinity of the Project that convey flows under the Main Southern Railway embankment located to the east of the proposed longwalls. No culverts are located within the extents of the proposed longwalls. The railway culverts consist of a brick arch culvert and two concrete culverts. The culverts are expected to have already experienced vertical subsidence up to 1350 mm due to previous mining, and only low level additional movements are predicted as a result of the Project with a maximum predicted additional vertical subsidence of 150 mm. These small additional vertical movements are not considered likely to result in significant impacts to the culverts. Subsidence related management strategies are captured within the subsidence assessment by MSEC (2021).

5.6 Surface Gas Emissions Impact Assessment

Longwall mining can result in fracturing of the strata above the extracted area and/or relative movement of strata along pre-existing joint planes. This may result in the liberation of methane and other gases from the strata to the surface. The emission of such gases typically occurs within deep river valleys, although some gas emissions have also been observed in creeks and water bores. If substantial gas emissions occur at the surface, there is potential for aquatic and terrestrial dieback. Such dieback is rare and has only occurred in one location in the Southern Coalfield.

Gas emissions typically occur in isolated locations and are most vigorous when an area is directly mined beneath. However, gas emissions do occur in areas that have not been directly mined beneath. Gas emissions have previously been observed during the mining of Tower Longwalls 17 and 20 and Appin Longwalls 701-703 within the Nepean River indicated by both visual observation of gas release and dissolved oxygen (DO) sag (Ecoengineers, 2012). However, those dissolved oxygen sags could be principally attributed to inputs of dissolved iron from Cataract River in Nepean River and/or pulses of available nutrients in stormwater runoff from agricultural land on both sides of Nepean River (Ecoengineers, 2012). Nevertheless, some minor sagging attributable to reduction in dissolved oxygen in the river due to microbiological consumption of dissolved methane around gas releases by natural aerobic methanotrophic could not be ruled out. End of Panel reports of the most recent extraction area, Appin Area 9 longwalls 901-902, found that minor gas emissions were identified at a number of gas release zones in the Nepean River as a consequence of longwall mining, although the impacts are considered to be minor (HGEO, 2019).

Considering the previous observations regarding the potential for surface gas emissions and the nature of streams within the Study Area, it is considered unlikely that the Project will result in significant impacts to watercourses due to the release of surface gas emissions. The Project is located 1.5 km from the Nepean River where observed gas release zones are located. Previous DO sagging due to mining of longwalls has been a result of mining within close proximity to the river valley with no substantial impacts noted within ephemeral waterways. Creeks within the Study Area are ephemeral and predominantly within the upper reaches of the catchment. Hence, if gas releases were to occur into the water column there is insufficient time for any substantial amount of gas to dissolve into the water (HECONS, 2019). Thus, due to the nature of flows within these areas it is expected that if gas emissions occur the impacts would be negligible. Similarly, no potential surface gas emissions are predicted within the subsidence report.

6 Surface Water Monitoring

Appin Mine operates under the approved Water Management Plan (2020) which has been prepared to detail the control measures, compliance procedures, monitoring programs, evaluation protocols, notification and communication processes for water management for Appin Mine.

A Subsidence Management Plan (SMP) or EP are then developed to describe the measures and procedures which are site specific for the active mining area (currently Appin Area 9 Longwalls 901-904 EP (2014)).

6.1 Surface Water Quality Monitoring

Baseline water quality monitoring is occurring in the Nepean River upstream and adjacent to the proposed Longwalls 709 to 711 and 905. Monitoring also occurs in creeks within the Study Area in Harris Creek, Navigation Creek and Foot Onslow Creek.

Existing baseline water quality monitoring is discussed in Section 3.

A series of control sites at tributaries of the Nepean River are utilised to allow for a more quantitative understanding of any effects in the Nepean River which may be related to creeks outside the Longwalls 709 to 711 and 905 mining area, and provide a means of ensuring that the TARPs for the established impact sites are reasonable and not triggered by upstream effects unrelated to the mining of the proposed longwalls. A monitoring point (NR4) is included to assess the influence of any potential impacts within Harris Creek on the Nepean River.

The location, parameters and frequency of monitoring points considered relevant to this Project are described in **Table 6**. However, current monitoring within the Nepean River undertaken as part of the existing WMP should continue as required.

Table 6 Longwall 709 to 711 and 905 Surface Water Quality Monitoring

Location	ID	Frequency	Parameters
Nepean River	Upstream and at Junctions: NR110 SW2 NR4 NR5 NR8 NR10 NR40 Adjacent: NR12 NR13 Downstream: NR50	• Monthly baseline prior to mining • Monthly observations and field analysis during mining • Monthly detailed laboratory analysis during mining • Monthly monitoring for 2 years post mining (or as otherwise required/approved) • If required as a result of assessment of mining impacts	Field Measurements of: - Temperature - pH - ORP - DO - EC - Time - General Comments - Photo records Laboratory analysis of: - pH - EC - SO_4 filtered - Fe total - Na filtered - K filtered - Ca filtered - Cl filtered - DOC - Pb filtered - Ni filtered - Zn filtered - Fe filtered - Mn filtered - As filtered - Br filtered - Cu filtered - I filtered - Se filtered - NO_x-N - NH_3-N - TKN - TP - TRP - TDS - CH_4* - Trace Phenols* - Sulfide*
Navigation Creek	NAV1	• Monthly monitoring prior to mining of longwall underlying watercourses or mining of any immediately adjacent longwall • Monthly monitoring following the development of incremental subsidence for each longwall that will impact on the feature	
Foot Onslow Creek	FO1		
Harris Creek	HC10 NR3		

** Analytes tested at closest downstream sample site following Level 2 and above trigger for gas release*

6.2 Surface Water Flow and Level Monitoring

Flow monitoring within the Nepean River is currently undertaken upstream and downstream of the proposed longwalls via Maldon, Menangle and Broughtons Pass Weirs. Water levels and observational impacts in the Nepean River are also monitored. Observational monitoring of creeks within the Study Area should also be undertaken.

The location of the Maldon, Menangle and Broughtons Pass gauging sites is included in **Figure 4**. These flow monitoring stations are ideally located on the Nepean River, being directly upstream and downstream of the approved BSO footprint. Flow monitoring on the Cataract River at Broughtons Pass Weir measures the flow of the major tributary input to Nepean River between the two Nepean River flow stations.

The Longwall 707-710 Environmental Management Plan (IMC, 2015) and Area 9 Longwalls 901-904 WMP (2014) provides details of the proposed data analysis and approach associated with Areas 7 and 9 flow and water level monitoring. Daily flow records for Maldon, Menangle and Broughtons Pass weirs from 1990 have been assessed in order to study the dry weather recessions in the Nepean River adjacent to the proposed mining areas. The difference in flows should be equivalent to runoff from all catchments between these two weirs responding to local rainfall minus any abstractions by licensed pumps in the River.

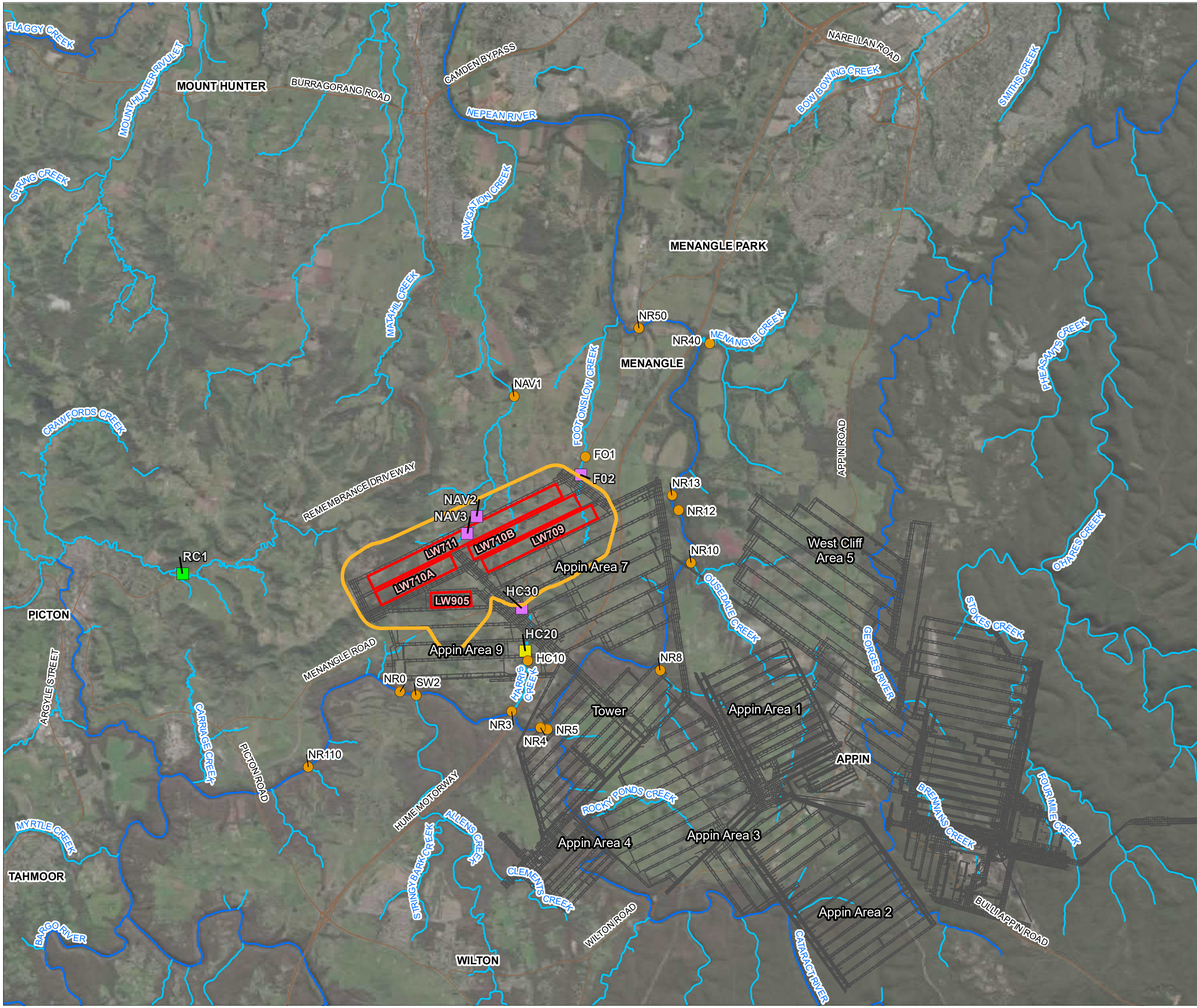
The approach to monitoring of flow for the longwalls is proposed to be the same as for mining of the previous Appin Area 7 and 9 longwalls.

The Nepean River is a ‘gaining river’ in terms of surface water - groundwater interaction. The potential for infiltration of water into the groundwater system is very low as the Nepean River lies in a well incised gorge which represents the regional low point in the piezometric surface. The potential for sub-bed diversion of surface water is very low as the Nepean River is flooded and the gradient is very flat, significantly removing the effects of gravity to force surface flow through any fracture network that develops. Water levels in the Nepean River and its tributaries are monitored using observations and measured benchmarks. The water level is recorded before, during and after mining and is assessed against catchment rainfall and discharges from the WaterNSW controlled weirs. This method of monitoring has been used for the previous Appin Areas 7 and 9 longwalls with no impacts to the water levels of the Nepean River observed during the period of extraction. Monitoring of water levels currently undertaken within the Nepean River should continue throughout the Project.

No water level monitoring is currently undertaken within the creeks and tributaries, specifically Navigation Creek, Foot Onslow Creek and Harris Creek. It is recommended that water level monitoring be established at sites shown in **Figure 11** and described in **Table 7**, and be undertaken prior to mining and following the development of incremental subsidence. Due to the ephemeral nature of creeks within the Study Area, continuous water flow monitoring is problematic. The potential impact of creek bed fracturing on environmental flows will be monitored via regular inspection for the presence of fracturing in the stream bed and observation of water levels within pools. No suitable pools for automated monitoring were identified on Navigation and Foot Onslow Creeks.

APPIN MINE SURFACE WATER ASSESSMENT

PROPOSED SURFACE WATER MONITORING SITES



- Project Area
- Study Area
- Proposed reference site & water level monitoring
- Proposed visual
- Proposed water level monitoring & visual monitoring
- Current surface water
- Roads
- Major watercourses
- Minor watercourses
- Appin Mine

0 0.5 1 km

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

Project No.: 630.30102
Date: 15-Apr-2021
Drawn by: ANP

www.slrconsulting.com

H:\WOL\Projects-SLR-WOL\630-NTL\630.30102.00000 Appin SW Man Plan LW709 905\06 SLR Data\01 CADGIS\GIS\SLR63030102_G6_ProposedSurfaceWaterMonitoring_004.mxd

Table 7 Longwall 709 to 711 and 905 Surface Water Flow and Level Monitoring

Location	ID	Frequency	Parameters
Nepean River	Water Level Monitoring: continue current monitoring. Water Flow Monitoring: • Maldon Weir • Broughtons Pass Weir • Menangle Weir	• Data sourced from Water NSW	• River flows at weirs
Navigation Creek	NAV1, NAV2, NAV3	• Prior to mining of longwall underlying watercourses or mining of any immediately adjacent longwall, and following the development of incremental subsidence for each longwall that will impact on the feature; • Monthly measurement of pool levels; and • Annual inspection (visual assessment) of creek line condition.	• Measurement of pool water levels # compared with baseline (Harris Creek only); • Inspection for potential fracturing for observable loss of surface water flow (Navigation, foot Onslow and Harris Creeks); and • Visual assessment as described in Section 6.3 below.
Foot Onslow Creek	FO1, FO2		
Harris Creek	HC20, HC30		
Racecourse Creek (Reference Site)	RC1		

#Where a suitable benchmark exists

6.3 Observational Monitoring of Watercourse Condition

Implementation of observational monitoring of watercourse condition is recommended prior, during and following mining of the proposed longwalls. Assessment should include:

- Erosion/sedimentation compared with baseline;
- Signs of impacts (e.g. cracking, vegetation changes, increased erosion, changes in water colour etc);
- Impacts determined from comparing photo points taken prior to, during and post mining;
- Iron or salinity staining (e.g. orange or white staining in water or on banks/seeps);
- Water cloudiness; and
- Evidence of springs.

Monitoring should be undertaken along Navigation Creek, Foot Onslow Creek and Harris Creek within the mining area (including a 600m buffer) annually (where access permits), with photo points at locations such as: NAV1, NAV2, NAV3, FO1, FO2, HC10, HC20, HC30, NR3 (**Figure 11**).

A reference site should be established in a similar ephemeral creek in order to assist in distinguishing natural and mining induced changes. Monitoring may be undertaken at a historical monitoring site within Racecourse Creek (RC1), see **Figure 11**.

7 Management and Mitigation Strategies

The predicted impacts for the Nepean River, Navigation Creek, Foot Onslow Creek and Harris Creek and other watercourses and drainage lines within the area are nil to negligible and mitigation measures are unlikely to be required for any of these predicted impacts.

Where there are impacts to farm dams these would be managed and compensated in accordance with the C*oal Mine Subsidence Compensation Act 2017* and/or an alternate water supply would be provided in consultation with the landowner as required by Condition 14 of the BSO Project Approval (Compensatory Water Supply).

TARPs have been developed to manage potential impacts to surface water in the Project Area. IMC will review the need to implement additional management and mitigation measures during routine monitoring and during the finalisation of BFMP's with affected landholders.

7.1 Trigger Action Response Plan (TARP)

A TARP has been developed for the management of surface water within the Project. The primary goal of this TARP is to monitor risks and then mitigate, control or eliminate the risk using the appropriate management action. The TARP is provided in **Table 8**.

It is recommended that, following commencement of the Project, water quality TARPs for pH, EC, DO, Total Fe and Total Mn be implemented for the proposed monitoring sites based on the principles described in **Table 8**. However, both the upstream (NR110) monitoring site and a series of sites within tributaries of the Nepean River are utilised to indicate perturbation at the proposed Longwall 709 to 711 and 905 impact monitoring sites within the Nepean River. This provides a means of distinguishing upstream effects unrelated to the mining of the proposed longwalls. Hence, the following premise should apply:

- A TARP at River site NR0 should only be considered to have been triggered whenever a two standard deviation change (from the long term mean) is not exhibited for the same parameter at the upstream site NR110.
- A TARP at River site NR4 should only be considered to have been triggered whenever a two standard deviation change (from the long term mean) is not exhibited for the same parameter at the upstream sites NR110 or SW2 (monitors for upstream perturbation from Allens Creek).
- A TARP at River site NR12 and NR13 should only be considered to have been triggered when an equivalent change (from the long term mean) in excess of two standard deviations is not exhibited for the same water quality analyte at the upriver sites; NR110, SW2, NR5, NR8 or NR10 (monitors upstream perturbation from Allens Creek, Cataract River, Elladale Creek and Ousedale Creek).
- A TARP at River site NR50 should only be considered to have been triggered when an equivalent change (from the long term mean) in excess of two standard deviations is not exhibited for the same water quality analyte at the upriver sites; NR110, SW2, NR5, NR8, NR10 or NR40 (monitors upstream perturbation from Allens Creek, Cataract River, Elladale Creek, Ousedale Creek and Menangle Creek).

Table 8 Appin Proposed Longwalls 709 to 711 and 905 Trigger Action Response Plan (TARP)

Monitoring	Trigger	Action
Surface Water Quality		
Nepean River Upriver Site N110 will be used for cross-checking upriver perturbation impacting the proposed longwall monitoring sites. Control Site: N110 (Upstream perturbations) SW2 (Upstream perturbations from Allens Creek) NR5 (Upstream perturbations from Cataract River)	**Level 1**[1] Impact monitoring sites: • pH reduction greater than 1 standard deviation but less than 2 standard deviation from pre-mining mean resulting from the mining for two consecutive months • DO reduction greater than 1 standard deviation but less than 2 standard deviation from pre-mining mean resulting from the mining for two consecutive months • Identification of strata gas plume of flow rate <3000 L/min [2] • Trend analysis (completed in End of Panel Report) shows deviation from baseline post mining.	• Continue monitoring program; • Investigate if impact is caused by or associated with mining; • Report impacts to key stakeholders; and • Summarise impacts and record.

Monitoring	Trigger	Action
NR8 (Upstream perturbations from Elladale Creek) NR10 (Upstream perturbations from Ouesdale Creek) NR40 (Upstream perturbation from Menangle Creek) Impact Sites: NR0 NR4 (assess influence from Harris Creek) NR12 NR13 NR50 **Creeks and Tributaries** Impact Sites: NAV1 FO1 HC10	**Level 2**[1] Impact monitoring sites: • pH reduction greater than 2 standard deviation from pre-mining mean resulting from the mining for two consecutive months • DO reduction greater than 2 standard deviation from pre-mining mean resulting from the mining for two consecutive months • EC increases greater than 2 standard deviation from pre-mining mean resulting from the mining for two consecutive months • Identification of strata gas plume of flow rate >3000 L/min[2] • Trend analysis (completed in End of Panel Report) shows significant deviation from baseline post mining.	Actions as stated for Level 1 plus: • Review monitoring program • Notify relevant specialists (South32 IMC) and seek advice on Corrective Management Actions (CMAs) • Develop and implement CMAs if necessary and approved Gas Emission Plume: • Estimate gas emission flow rates. Re-estimate should significant change be observed • Take sample of plume (if possible) for: - chemical composition - dissolved methane from exactly above gas plume and at established downriver monitoring sites - dissolved sulphide and total phenols from exactly above gas plume and at nearest downriver monitoring site(s)

Monitoring	Trigger	Action
NR3	**Level 3**[1] Impact monitoring sites: Level 2-type reduction in water quality resulting from the mining observed for six consecutive months	Actions as stated for Level 2 plus: • Notify DPIE, DPIE Water & Resource Regulator and any other relevant specialist • Consultation with key stakeholders • Collect laboratory samples and analyse for: – pH, EC, Total Fe and Mn – Suite of Filterable metals – Dissolved methane, sulphide and total phenols (if relevant) • Develop any CMAs as soon as practically possible (pending stakeholder availability) and seek any approvals required to implement • Review the relevant TARP and Management Plan in consultation with key stakeholders
Surface Water Level and Flow		
Nepean River Visual observations along the Nepean River adjacent to the active mining area	**Level 1**[1] Observation of areas of dry and/or flooded riverbed in comparison to baseline observations and flows, for less than two consecutive months.	• Continue monitoring program • Investigate if impact is caused by or associated with mining • Report impacts to key stakeholders • Summarise impacts and record

Monitoring	Trigger	Action
	Level 2[(1)] Observation of areas of dry and/or flooded riverbed in comparison to baseline observations and flows, for more than two consecutive months.	Actions as stated for Level 1 plus: • Review monitoring program • Notify relevant specialists (South32 IMC) and seek advice on CMAs • Develop and implement CMAs if necessary and approved
	Level 3[(1)] Observation of areas of dry and/or flooded riverbed in comparison to baseline observations and flows, for six consecutive months.	Actions as stated for Level 2 plus: • Notify relevant government agencies, other resource managers and relevant technical specialists and seek advice on any CMA required • Site visit with key stakeholders if required • Develop any CMAs as soon as practically possible (pending stakeholder availability) and seek any approvals required to implement • Review the relevant TARP and Management Plan in consultation with key stakeholders
Creeks and Tributaries Visual observations along: Navigation Creek Foot Onslow Creek Harris Creek	**Level 1**[(1)] • Fracturing with no observable loss of surface water flow • Fracturing with no reduction in pool water level when compared to baseline period	• Continue monitoring program • Investigate if impact is caused by or associated with mining • Report impacts to key stakeholders • Summarise impacts and record

Monitoring	Trigger	Action
	Level 2(1) • Fracturing resulting in loss of surface flow in some creeks or tributary • Fracturing resulting in water loss from some permanent pools • Reduced water retention time in pools	Actions as stated for Level 1 plus: • Review monitoring program • Notify relevant specialists (South32 IMC) and seek advice on Corrective Management Actions • Develop and implement Corrective Management Actions if necessary and approved
	Level 3(1) • Fracturing resulting in total loss of surface flow in all sections of a creek or tributary • Fracturing resulting in total water loss from all permanent pools in the mining area • Reduced water retention time in all pools in the mining area	Actions as stated for Level 2 plus: • Notify relevant government agencies, other resource managers and relevant technical specialists and seek advice on any CMA required • Site visit with key stakeholders if required • Develop any CMAs as soon as practically possible (pending stakeholder availability) and seek any approvals required to implement • Review the relevant TARP and Management Plan in consultation with key stakeholders
Surface Water Creek Stability		
Creeks and Tributaries Observations made in: Navigation Creek Foot Onslow Creek Harris Creek	**Level 1**(1) • Fracturing resulting in minimal change in stream bed or bank stability compared to baseline. • No impact on turbidity	• Continue monitoring program • Investigate if impact is caused by or associated with mining • Report impacts to key stakeholders • Summarise impacts and record

Monitoring	Trigger	Action
	Level 2(1) • Fracturing resulting in minor decrease in stream stability compared to baseline period. • Minor increase in turbidity	Actions as stated for Level 1 plus: • Review monitoring program • Notify relevant specialists (South32 IMC) and seek advice on CMAs • Develop and implement Corrective Management Actions if necessary and approved
	Level 3(1) • Fracturing resulting in major decrease in stream bed or bank stability compared to baseline. • Significant increase in turbidity	Actions as stated for Level 2 plus: • Notify relevant government agencies, other resource managers and relevant technical specialists and seek advice on any CMA required • Site visit with key stakeholders if required • Develop any CMAs as soon as practically possible (pending stakeholder availability) and seek any approvals required to implement • Review the relevant TARP and Management Plan in consultation with key stakeholders
Surface Water Other Observations		
Creeks and Tributaries Observations made in: Navigation Creek Foot Onslow Creek Harris Creek	**Level 1**(1) Minor increase iron staining, algal growth, or other visible water related parameters resulting from the mining for consecutive months determined by comparing baseline photos with photos during the mining period.	• Continue monitoring program • Investigate if impact is caused by or associated with mining • Report impacts to key stakeholders • Summarise impacts and record

Monitoring	Trigger	Action
	Level 2[1] Notable increase iron staining, algal growth, or other visible water related parameters resulting from the mining for consecutive months determined by comparing baseline photos within photos during the mining period.	Actions as stated for Level 1 plus: • Review monitoring program • Notify relevant specialists (South32 IMC) and seek advice on Corrective Management Actions • Develop and implement Corrective Management Actions if necessary and approved
	Level 3[1] Significant increase iron staining, algal growth, or other visible water related parameters resulting from the mining for consecutive months determined by comparing baseline photos within photos during the mining period.	Actions as stated for Level 2 plus: • Notify relevant government agencies, other resource managers and relevant technical specialists and seek advice on any CMA required • Site visit with key stakeholders if required • Develop any CMSa as soon as practically possible (pending stakeholder availability) and seek any approvals required to implement • Review the relevant TARP and Management Plan in consultation with key stakeholders

(1) These may be revised in consultation with DPIE and Other key stakeholders.
(2) If strata gas emission plumes are detected – particularly coinciding with low river flow and significant gas evolution.

8 Conclusions

IMC are proposing to continue extracting coal from Longwalls 709, 710A, 710B, 711 in Appin Area 7 and Longwall 905 in Area 9 and require EP approval prior to the commencement of secondary extraction. A Surface Water Assessment has been undertaken to predict potential impacts to the local surface water system to support the EP approval process.

Based on the assessment, there is expected to be:

- A low risk of broadscale fracturing of local creek beds within the Study Area. Some localised fracturing is probable, however no significant loss of catchment yield is anticipated. It is possible that environmental flows during periods of low rainfall could be impacted, and this potential impact will be monitored by pool level monitoring. No fracturing is anticipated within the Nepean River;
- No adverse effect on stream pools as a result of subsidence induced tilt are anticipated as a result of the Project with no reversal of stream grades; some localised ponding may occur however effects are expected to be negligible;
- Although impacts to groundwater are expected, the Project is not predicted to induce downward seepage or reduced baseflow contributions in surface water bodies, including stream pools, as there is no predicted depressurisation from the upper layers to deep strata. It is predicted that although the lower seams will be depressurised the depressurisation will not extend upwards and therefore not affect groundwater levels in the upper layers (SLR, 2021);
- Changes in shallow groundwater as a result of fracturing, dilatation and shear of shallow strata can result in changes to surface water bodies and shallow groundwater, where they are connected.
- No significant adverse impacts to channel stability are anticipated as subsidence is predicted to have minor impacts on stream bed profile;
- No significant impacts on surface water quality are predicted to occur as the Project includes only minor surface activities comprising vent shafts and associated access tracks, the Project does not include direct abstraction of surface water, and subsidence is not expected to cause significant changes to flow regime and bank scouring;
- The likelihood of the occurrence or enhancement of ferruginous springs in considered to be low due to previous mining experience within the area, however, if this were to occur the effects are anticipated to be minor; and
- Any impacts due to gas release as a result of mining the proposed longwalls are likely to be minor due to previous observations regarding potential surface gas emissions and the nature of creeks above and adjacent to the proposed longwalls.

A Water Management Plan (WMP) will be prepared in consultation with Biodiversity Conservation and Science Directorate, WaterNSW and DPIE Water in accordance with Condition 5(h) of the BSO Approval. It is recommended that the WMP include the recommendations in this assessment.

9 References

AGL, 2013. *Hydrogeological Summary of the Camden Gas Project area*, January 2013.

AGL, 2018. Groundwater Management Plan, July 2018.

Bureau of Meteorology (BoM), 2013. Weather and Climate data, http://www.bom.gov.au/climate/data, Accessed March 2020.

DPIE, 2016. *Water Sharing Plan Greater Metropolitan Region Unregulated River Water Sources: Background document for amended plan 2016 incorporating Kangaroo River Management Zone.* Department of Industries – Water Report June 2016.

DPIE, 2020. *Water in NSW: Hawksbury Nepean, https://www.industry.nsw.gov.au/water/basins-catchments/snapshots/hawksbury-nepean, Accessed December 2020.*

Ecoengineers, 2008. *Assessment of Surface Water Flow and Quality Effects: Appin Colliery Longwalls 705 to 710*. Report May 2008

Ecoengineers, 2012. *Assessment of Surface Water Flow and Quality Effects: Appin Colliery Longwalls 901 to 904*. Report June 2012

Heritage Computing 2009, *Bulli Seam Operations Groundwater Assessment*, A Hydrogeological Assessment in support of the Bulli Seam Operations Environmental Assessment for Illawarra Coal Holdings Pty Ltd, HC2009/5, July 2009

HGEO, 2019. *Appin Mine: Area 9 Longwall 902 End of Panel Surface Water and groundwater monitoring review.* Report August 2019.

Lovely D. R., and Phillips E. J. P., 1986. *Organic matter materialization with the reduction of ferric iron in anaerobic sediments*. Appl. Environ. Microbiol. 51:683-689

HECONS, 2019. *Tahmoor Mine Extraction Plan LW W1 – W2 Surface Water Technical Report (DRAFT).* TCCO Report, dated May 2019.

IMC, 2014. *Appin Area 9 Longwalls 901 to 904 Extraction Plan: Annex C Water Management Plan.* Report, dated September 2014.

IMC, 2015. *Longwall 707 to 710 Environmental Management Plan*. Report, dated August 2015.

IMC, 2020. *Appin Mine Water Management Plan.* Report number IMCMP0235, dated July 2020.

MSEC 2021; Subsidence Predictions and Impact Assessments, Subsidence Predictions and Impact Assessments for the Natural and Built Features due to the Extraction of the Proposed Longwalls 709, 710A, 710B, 711 and 905 at Appin Colliery, prepared for Illawarra Metallurgical Coal, dated February.

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

Niche, 2014. *Tahmoor North Longwalls 21 to 37 Aquatic Ecology Assessment*. Report December 2014.

SILO-Australian climate data from 1889 to yesterday, rainfall and Potential Evaporation, https://www.longpaddock.qld.gov.au/silo/point-data, Accessed November 2020.

SLR Consulting, 2021. *Appin Mine Extraction Plan: Groundwater Impact Assessment.* Report April 2021.

State of Queensland, 2020. SILO (Scientific Information for Land Owners) database of Australian climate data. © The State of Queensland 1995 - 2020, https://silo.longpaddock.qld.gov.au, Accessed March 2020.

Western Sydney University (WSU), 2017. *The Health of River Systems: Hawkesbury-Nepean River Watch Education and Sustainability Tools,* https://www.westernsydney.edu.au/harwest/harwest, Accessed December 2020.

ASIA PACIFIC OFFICES

BRISBANE
Level 2, 15 Astor Terrace
Spring Hill QLD 4000
Australia
T: +61 7 3858 4800
F: +61 7 3858 4801

CANBERRA
GPO 410
Canberra ACT 2600
Australia
T: +61 2 6287 0800
F: +61 2 9427 8200

DARWIN
Unit 5, 21 Parap Road
Parap NT 0820
Australia
T: +61 8 8998 0100
F: +61 8 9370 0101

GOLD COAST
Level 2, 194 Varsity Parade
Varsity Lakes QLD 4227
Australia
M: +61 438 763 516

MACKAY
21 River Street
Mackay QLD 4740
Australia
T: +61 7 3181 3300

MELBOURNE
Level 11, 176 Wellington Parade
East Melbourne VIC 3002
Australia
T: +61 3 9249 9400
F: +61 3 9249 9499

NEWCASTLE
10 Kings Road
New Lambton NSW 2305
Australia
T: +61 2 4037 3200
F: +61 2 4037 3201

PERTH
Ground Floor, 503 Murray Street
Perth WA 6000
Australia
T: +61 8 9422 5900
F: +61 8 9422 5901

SYDNEY
Tenancy 202 Submarine School
Sub Base Platypus
120 High Street
North Sydney NSW 2060
Australia
T: +61 2 9427 8100
F: +61 2 9427 8200

TOWNSVILLE
12 Cannan Street
South Townsville QLD 4810
Australia
T: +61 7 4722 8000
F: +61 7 4722 8001

WOLLONGONG
Level 1, The Central Building
UoW Innovation Campus
North Wollongong NSW 2500
Australia
T: +61 2 4249 1000

AUCKLAND
68 Beach Road
Auckland 1010
New Zealand
T: 0800 757 695

NELSON
6/A Cambridge Street
Richmond, Nelson 7020
New Zealand
T: +64 274 898 628

Appendix C – Appin Mine Groundwater Model Peer Review (AGE 2022)

Australasian Groundwater & Environmental Consultants

1 September 2022

South32 Ltd
Illawarra Metallurgical Coal
Port Kembla Road
Port Kembla 2505
New South Wales Australia

Attention: Cody Brady
via email: Cody.Brady@south32.net

Dear Cody,

Appin Mine Groundwater Model Peer Review

1 Introduction

The Appin Mine is an existing underground coal mine located approximately 25 kilometres north-west of Wollongong. Appin Mine is owned and operated by Illawarra Metallurgical Coal (IMC), a subsidiary of South32. The Appin mining operations in the Bulli Seam are known as the Bulli Seam Operations (BSO) and undertaken in accordance with Project Approval 08_0150. IMC is currently extracting Longwall 709 in Area 7 and Longwall 905 in Area 9 and has received Extraction Plan (EP) approval for Longwalls 709, 710A, 710B, 711 and 905, which are referred to as 'the Project' in reporting.

Heritage Computing (2009) developed the first groundwater model for Appin Mine. The model was updated in 2020 by SLR Consulting Australia Pty Ltd (SLR) to simulate groundwater impacts for the Project. SLR have recently revised the 2020 numerical model following a review from the then NSW Department of Planning, Industry and Environment (DPIE) (2021) Biodiversity and Conservation Division (now NSW Department of Planning and Environment).

This letter report provides a peer review of the updated 2022 groundwater modelling undertaken by SLR for the EP. Australasian Groundwater and Environmental Consultants Pty Ltd. (AGE) undertook this review at the request of South32 Limited (South32).

2 Methodology

The objective of the peer review was to assess the conceptual and numerical models described in the groundwater assessment report against available guidelines for groundwater modelling.

The following report was supplied for the review:

- Appin Mine Extraction Plan. Groundwater Impact Assessment. SLR. V8.0. August 2022.

The reviewer also attended three videoconference meetings with representatives of SLR and South32 to discuss the model calibration (14/06/2022), and model predictions (7/06/2022, 27/05/2022).

The other documents used during this peer review were:

- Barnett, B, Townley, LR, Post, V, Evans, RE, Hunt, RJ, Peeters, L Richardson, S, Werner, AD, Knapton, A, & Boronkay, A (2012), *Australian groundwater modelling guidelines*. Waterlines report, National Water Commission, Canberra (herein referred to as the AGMG).
- Commonwealth of Australia (CoA), (2018), Information guidelines for proponents preparing coal seam gas and large coal mining development proposals, Commonwealth of Australia, May 2018.
- Middlemis H and Peeters LJM (2018), Uncertainty Analysis – Guidance for groundwater modelling within a risk management framework. A report prepared for the Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development through the Department of the Environment and Energy, Commonwealth of Australia 2018.
- Murray–Darling Basin Commission (MDBC) 2001, Groundwater flow modelling guideline, report prepared by Aquaterra, January 2001.
- Doherty, J. and Moore C., (2021). Decision Support Modelling Viewed through the Lens of Model Complexity. A GMDSI Monograph. National Centre for Groundwater Research and Training, Flinders University, South Australia.

3 Review and discussion

The following sections review the SLR report against the Australian groundwater modelling guidelines (AGMG) as well as the other documents noted above.

3.1 Objectives

The objectives of the groundwater assessment were to describe the existing hydrogeological environment, and assess the potential impacts of mining on the groundwater regime. The scope of works developed by SLR was designed to meet this objective and respond to comments from DPIE including:

- providing background information on the site setting and conceptual groundwater model;
- calibrating the numerical flow model suitable to predict Project impacts in accordance AGMG and MDBC (2001), including improving previous mismatches between modelled and observed groundwater levels;
- predicting cumulative impacts on the groundwater regime from the Project and surrounding activities;
- calculating baseflow/leakage impacts, drawdown, groundwater interception and incidental water impact; and
- providing recommendations for ongoing monitoring and establishing groundwater triggers.

The numerical model has been employed for a wide range of purposes, which is typical for most models utilised to assess the impact of mining in NSW. This is driven by the requirements of the NSW Aquifer Interference Policy (AIP) that requires a wide range of potential impacts to be estimated. The key impacts to be predicted are mostly differences between two models rather than absolute values. This is preferable as predictive differences may be less uncertain than absolute values (Doherty and Moore 2021). One of the main purposes of the model is to estimate the potential impact on private water supply bores. This objective is not directly stated within introductory sections of the report, but relevant information is provided in latter sections that outline modelling predictions on this key receptor.

3.2 Conceptual model

The groundwater assessment report contains some 30 pages of text and graphics describing the available hydrogeological datasets, and four pages summarising the conceptual model of the groundwater regime. The Hawkesbury Sandstone is identified as the main aquifer with modest yields and relatively good water quality. Quaternary alluvium also forms a thin and sporadic aquifer where this occurs along some creek lines.

Upon review of the report the Project area and surrounds appears to be a challenging area to gather hydrogeological data. This is likely due to a range of factors including the significant depth of the Project, and restrictions to land access due to government and private land ownership. Despite these challenges a good monitoring network appears to have been built up over time. The groundwater monitoring network primarily utilises vibrating wire pressure sensors (VWPs) that are sealed within boreholes at different depths to measure pore pressure over time within the key hydrostratigraphic units.

This is considered a logical and appropriate monitoring methodology to measure changes within the groundwater regime over time given the relatively deep geological setting. The monitoring points are located across areas of historical mining, as well as within or adjacent to the Project area.

The length of the groundwater monitoring record varies depending on location, with some sites having a data record of more than 10 years. This length of the baseline monitoring is good, as it exceeds the eight-year Project life in some areas allowing the model calibration period to exceed the length of the future prediction period.

The climate during the monitoring period has included years of typically average rainfall, and a short but intense drought period between 2016 and 2020. This climate variability is reflected in measured groundwater levels at many monitoring sites. Declining groundwater levels attributed to mining induced depressurisation have also been recorded at some monitoring sites within the monitoring network, with the impact of mining reducing vertically above the longwall panels. The varying climate conditions and the recorded mining impacts vertically through the strata over the monitoring period provides an information-rich dataset for history matching as part of the numerical modelling.

Observed groundwater inflows to the active mining areas at Appin are not provided within the SLR report. It is acknowledged groundwater inflows occurring in underground mines can be challenging to estimate as water is pumped into the operations from the surface for dust suppression and machinery use. However, a simple water balance can often identify likely ranges of groundwater inflows that can be used to inform numerical modelling history matching.

The geology and associated hydrostratigraphic units occurring within the Quaternary, Triassic and Permian formations are described within the report, supported by a geological map and a vertical geological section. The groundwater assessment report does not contain any information on the measured hydraulic properties of the key hydrostratigraphic units. Whilst it is acknowledged the site setting would make in-situ measurement of hydraulic properties challenging, and properties can be inferred based on experience, the report would be improved by including a summary of any available hydraulic test results.

There is also no site-specific data available on the influence of longwall mining on the hydraulic properties of strata overlying Appin Mine. SLR note hydraulic conductivity is increased by 2 to 3 orders of magnitude within the goaf and fractured zone based on data from surrounding mines. In the absence of any measurements at Appin, SLR utilise common empirical methods to estimate the height of the fractured strata above the longwall mining areas.

Potentially sensitive receptors reliant on the groundwater regime within the Project area are groundwater fed creeks and rivers, and private water supply bores. A good summary of the location and details of registered water supply bores is provided within the SLR report, based on information within the NSW government groundwater database. Where the information in the government database is lacking, SLR identify the formation the bores are drawing water from based on the recorded bore depth. It is not stated within the groundwater assessment report if a survey of private properties within the Project area has ever been conducted to confirm the location and details of water supply bores. This would be an appropriate future step within the likely impact zone to identify the exact location of registered and any unregistered bore in use.

The report provides information on the main creek and rivers including flow gauging plots and a summary of water quality. There is no discussion on the nature of any groundwater-surface water interactions provided within the report. Whilst there is no discussion on this topic, the water level contour map included for the Hawkesbury sandstone does provide an indication of creek and river reaches that could be either losing, and/or gaining groundwater. It is not clear how this map was generated, but if numerical modelling was utilised this should be acknowledged. Simple comparisons between measured groundwater levels and gauged river levels would also assist with this interpretation.

There is also no comment on the potential for groundwater dependent ecosystems such as riparian vegetation to occur in the Project area. This is a common component of groundwater assessment reports so it is unclear why this information is omitted.

The report notes that after closure of the mine groundwater levels will recover, and that the pH could reduce over time, resulting in increases in the concentrations of metals such as zinc, iron and nickel. This statement in the report is not supported by site specific data, and the scope of work did not include an assessment of post mining impacts, so it's unclear why this speculation was included in the document.

Cumulative impacts on the groundwater regime in the region are significant, with the presence of other aquifer interference activities (operating or closed underground coal mines and coal seam gas extraction) as well as a network of private water supply bores that are constructed within strata that overlie and surround the Project. These are all described as much as possible within the groundwater assessment report utilising public domain information.

3.3 Numerical model setup

SLR constructed a large regional numerical model to represent the conceptual model of the area. The model was constructed using the MODFLOW-USG software, an industry standard package for this application. The model utilises a Voronoi shaped cells, which are refined to 100 m in areas of interest such as creek and longwall panels, with 50 m cells used to represent shafts. The model has 18 separate layers representing the main hydrostratigraphic units occurring in the region. Key aspects of the conceptual model are represented in the numerical model including rainfall recharge, evapotranspiration, stream stage height, private water bore pumping and coal seam gas pumping with standard MODFLOW packages and approaches.

Rainfall recharge is represented with the RCH package that applies a fixed percentage of the total annual rainfall as recharge to the water table. This is a commonly adopted approach in regional models, but one which introduces an averaging effect which means the model cannot closely replicate water level variability due to shorter duration rainfall events. Pumping from water bores and coal seam gas bores is represented using the WEL package with assumptions on pumping rate based on information in the public domain or plausible assumptions.

Longwall mining is represented with advancing DRN cells, with a drain conductance of $100m^2$/day. The TVM is used to represent fracturing above the longwall panels with vertical and horizontal hydraulic conductivity increases. The specific yield within the mined coal seam was changed to 10% to represent formation of the goaf, which is a plausible assumption of the residual air volume within the seam post mining.

Aspects of underground mining are also represented including longwall mining, strata fracturing and underground water storage. The total cell count is about individual 890,000 cells, and quarterly stress periods resulting in a model run time understood to be about one hour. The model is therefore a relatively large and complex model, but with a modest simulation time that allows history matching and uncertainty analysis.

Changes were also made to the model to address comments from DPE regarding the height of fracturing and the calibration to head measurements. To address these comments the height of fracturing was updated and a surface fracturing zone represented in the model (this is discussed further in Section 3.4). The period of groundwater levels utilised in the model was also extended to include data from 2010 to 2021.

3.4 Calibration

The 2022 model was calibrated using industry standard optimisation software (PEST++) through adjustable parameter zones. Regularisation was not used.

The model was setup with uniform hydraulic property values applied in zones where each hydrostratigraphic unit occurs. Model layers 1 and 2 contained zones representing the outcropping formations, with layers 3 to 18 representing single hydrostratigraphic units with uniform hydraulic properties. The actual hydraulic properties will be more heterogenous than represented in the model layers. The uniform parameter values in the model imposes a lack of flexibility during calibration that means the model cannot replicate every nuance in heads and drawdown measurements that are driven by localised hydraulic properties. The model is however able to replicate an averaged fit to the measurement data, meaning the average head trends can be replicated. Good replication of water level trends on a bore-by-bore level is not possible with the model setup which means a larger misfit must be accepted. This is not a deficiency of the model per se; it is simply something that needs to be considered upon review.

However, if the model was used as a predictive tool using linear analysis using this parameter scheme, the posterior uncertainty predicted would be overly constrained and under-representative of potential impacts. The future use of many pilot point multipliers to allow model parameters to vary more spatially during the history matching process would remedy this.

Whilst there are no measurements of hydraulic properties provided in the report, the calibrated parameter ranges appear plausible based on experience in similar geological settings.

The range of parameters used during calibration, and the sensitivity of those parameters are not presented by SLR. It is unknown if any of these parameters have hit their bounds or not, the latter implying some structural defect is not represented in the model, or an inappropriate range constrained by PEST. It is noted that the hydraulic conductivity of the layers above the Bulli Seam are at the low end of the range of anticipated values; in particular the Stanwell Park Claystone which is very low and almost one order of magnitude lower than any other layer at $7.3E^{-7}$m/day.

The report states Kh and Kv above the longwall were adjusted during the calibration process. However, it is understood they were adjusted using a fixed factor which was not specifically explored using PEST++. As a result, there is no information available on the sensitivity of the calibration/predictions to these important parameters. The report states Kh and Kv in lower zone of connected fracturing was increased according to the methodology to determine permeability in the fracture zone provided by Guo (2007). The Guo (2007) equation suggests Kh increases of 15-1000x the host value in the first 100m above the longwall, and Kv increases 2-40x. Increases to Kh and Kv from the zone 100-200m caused the models to decalibrate (failure to match head and inflows) meaning the magnitude of permeability changes recommended by Guo were not represented in the SLR model. The observation data supports the lack of vertical connectivity through the fracture zone as groundwater levels become less obviously impacted by mining as height above the longwall mining increases. There are two possibilities to explain this outcome, firstly, the model is correct and fracturing is very limited within the zone from 100-300m above the longwall, or secondly fracturing is more extensive, but the interconnection of fracture networks is poor, and regional throughflow buffers drawdown.

Calibrated specific storage (Ss) values appear reasonable; the geometric mean is approximately 1E-06 m^{-1}. Ss is generally constrained to theoretical bounds presented in Rau (2018), while some values in the model extend to the lower bound of about 1E-07 m^{-1}. It is not stated if Ss moved far from the initial values during history matching. This information would help identify whether hydraulic conductivity is more estimable than Ss with the given measurement dataset. It should be noted that according to poroelastic theory Ss is a function of bulk modulus, porosity, and Poissons ratio (Pells, 2017). Considering the properties of sandstone, interburden and coal measures in the region, an Ss value of around 2 E-06 m^{-1} is more likely. This could be validated with triaxial testing data. A higher value of Ss should be considered for sensitivity and uncertainty exercises.

Calibrated recharge appear plausible. Adopted recharge rates are significantly lower than the 2009 study, yet closer to estimates of recharge at surrounding projects. As highlighted, because recharge is applied as a percentage of rainfall it is difficult for the model to reproduce groundwater level highs (prolonged rainfall events that exceed soil storage) and the lows (prolonged rainfall events that are less than soil storage). This means stress periods with zero recharge where accumulating rainfall is consistently less than the soil store and evaporation are not represented in the model. Applying a zero recharge rate during dry periods in the model could temporarily increase impacts. This could be considered in sensitivity scenarios at least. Regardless, most of the measurement data used during the calibration process indicates deep groundwater levels around the Project area, suggesting a slow response to surface water stresses.

The scatterplots, RMS and SRMS statistics appear reasonable. The RMS and SRMS have reduced by approximately half compared to the 2009 modelling which represents an improvement. This is partly due to the extended range in the measurement set in the Bulli seam. There is no discussion on any observations that were removed from the measurement set during history matching. Some discussion on the rejection process would improve the understanding of the history matching process.

As discussed above, the setup of the model layers and uniform zones of hydraulic properties mean the model is unlikely to be able to reach a better statistical fit than was achieved. It is also likely that one of the most significant influences on groundwater levels and drawdown in the model is the hydraulic conductivity of the fracture zone above the historical longwall mining.

Although the hydraulic properties of the fractured zone were not adjusted during the calibration process, it is likely they are highly estimable (they lie squarely in the solution space) due to the available groundwater monitoring data influenced by mining. A better fit to available data might have been achieved if hydraulic properties of the fracture zone were adjustable in each layer and cell during the history matching process. The modelled groundwater levels generally replicate the vertical downward hydraulic gradient observed in the multilevel VWP sensors. Reallocating bores with uncertain screen intervals has also improved the fit with the observation data.

Spatial residuals in the pertinent aquifers/aquitards appear to be between about 10 m to 40 m around the Project area (it is difficult to interpret as the scale on the map is different to the legend). These residuals are primarily due to the models inability to simulate complicated dewatering mine processes and the lack of heterogeneity represented in the hydraulic properties. Vertical gradients are presented and discussed. These are generally well replicated by the model. Further calibration efforts could history match to these differences separately as well as absolute values of heads. This makes vertical hydraulic conductivity more estimable.

Groundwater inflows to the mine workings were not used for calibration, but to verify the predicted inflow. Whilst these values were not included in the report, it is understood the modelled values are close to measured data, which suggests the relatively low increases to hydraulic conductivity above the longwall panels in the model is justified.

Overall mass balance appears reasonable. It is not stated in the report if there is consistency between the steady state and transient model, and if there are any timesteps where percent error is greater than 2%.

3.5 Predictions

Longwall mining is represented using a permeability enhancing multiplier based on surrounding projects and verified using depressurisation signatures from site vibrating wire piezometers and inflow estimates (not presented). Drain cells with a nominally high conductance are used in the Bulli Seam and the TVM package is changed to the estimated height of fracturing above the panels. Representing enhanced fracturing using this approach can be problematic. If there are aquitards with very low vertical hydraulic conductivity close to the longwall, then the resultant enhanced permeability due to the applied factor remains low. These layers then act as a buffer to groundwater depressurisation propagating through the strata vertically. For this reason the use of 'stacked drains' has sometimes been adopted as an alternative approach. Notionally, the calibrated version of the Appin groundwater model can replicate some water level trends that suggest the fracture zone is not well interconnected hydraulically. It should be noted that enhancement of hydraulic conductivity in the fracture zone is much more significant than that represented by the 2009 groundwater model (Heritage Computing, 2009).

Groundwater drawdown at neighbouring landholder bores is presented and discussed. The predictions indicate that water levels at five private water supply bores will be impacted and will require make good agreements.

Forecasts of changes to baseflow is briefly discussed and reported to be "negligible". As discussed, it is unknown if this result is caused by the model under-representing measured baseflow due to low groundwater levels or low river conductance (calibrated values of river conductance are not presented). Fortuitously the model predicts minimal impact at the surface, meaning it is likely the negligible forecasts on baseflow impacts are justifiable.

The predictions are not compared to the Minimal Impact Considerations outlined in the NSW AIP. It is unclear why the predictions are not compared to the AIP thresholds, as this is standard practice for groundwater assessments conducted for mining projects in NSW.

3.6 Sensitivity/Uncertainty analysis

The report presents the results from a model that uses the Tammetta method to calculate the height of the A zone. Because of the configuration and depth of the seven and nine series longwall panels, the resultant height of fracturing is lower than the Ditton a95 surface, meaning the predicted impacts are less.

There is no further discussion of the sensitivity of hydraulic parameters to groundwater impacts. It is important to understand that this model represents one realisation in an infinite number of realisations that can calibrate the model. Different combinations of parameters can produce the same level of fit, but with different predicted impacts. It is best practice to explore sensitivity scenarios that consider the structural defects in the model and try to overcome them to quantify the likelihood of worse case impacts. In particular the sensitivity of the predicted groundwater impacts to the adopted fracturing multipliers should be quantified. Although not published, SLR developed a version of the model with much higher fracture multipliers in the A and B zone. This version of the model produced unrealistic historic depressurisation and inflows. On this basis, assuming recharge and storage is ‘correct’, the modeller could reject this as a worst case outcome.

On top of this, combinations of parameters should be considered (i.e., high fracturing, lower storage, and low recharge) to reject or prove the likelihood that the AIP thresholds will be exceeded (e.g., landholder drawdown, or significant baseflow reduction). When conducting this sort of sensitivity analysis, it is important that the realisations can fit historic water level and inflow measurements. It is possible that realisations can both fit historic measurements, but not predict significant future impacts that exceed AIP thresholds.

4 Australian modelling guidelines

The AGMG outlines a process for evaluating numerical models to determine if they are ‘fit for purpose’. The aim of the guidelines is to provide a more appropriate and consistent approach to model development across the industry. The guidelines include a series of checklists that are used to evaluate and classify models according to their complexity. Attached are a series of four tables that address the check lists within the AGMG, as well as a check list included in the predecessor to the AGMG (MDBC 2001).

Table 1 summaries how well the groundwater assessment complies with recommendations of the AGMG. It is concluded that the model and accompanying report were produced to a high standard, and the outcomes are fit for the intended purpose.

Table 2 summarises the three classes of numerical models outlined within the AGMG. The table shows that the model has elements of a class 2 (impact assessment) and class 3 model (complex simulator). This is a typical outcome for most models used for this type of application.

Table 3 is an additional check list that assesses the model against each of the eight stages recommended by the AGMG. The table shows that the numerical model meets many of the requirements of the AGMG, with the exception of uncertainty analysis which is limited.

Table 4 is a checklist from the predecessor to the AGMG (MDBC 2001) which is used to provide a rating for a model based on how well it implements the recommendations of the guideline. The numerical model commonly achieves an ‘adequate’ or ‘very good’ score against this guidance.

5 Conclusions

The modelling described by SLR has been conducted with a methodology and care consistent with industry standard practice. The 2022 study has improved upon the 2020 study by: including: more deep groundwater level measurements in the history matching process, representing the enhanced permeability above the longwall more appropriately, and exploring an alternate fracture height configuration. The calibrated version is fit for purpose of predicting drawdown due to the proposed mining in the Appin Areas 7 and 9 series panels. The ability of the numerical model to predict impacts on surface water and shallow systems is lower due to underprediction of shallow groundwater levels. Due to absence of parameter sensitivity or predictive uncertainty analysis it is unknown if there are other permutations of the model that replicate measurement data but cause more substantial impacts to the aquifers above the Appin Mine.

Yours faithfully,

Neil Manewell
Technical Modelling Lead / Principal - Groundwater Modeller
Australasian Groundwater and Environmental Consultants Pty Ltd

6 References

Barnett, B, Townley, LR, Post, V, Evans, RE, Hunt, RJ, Peeters, L Richardson, S, Werner, AD, Knapton, A, & Boronkay, A (2012), *Australian groundwater modelling guidelines*. Waterlines report, National Water Commission, Canberra (herein referred to as the AGMG).

Commonwealth of Australia (CoA), (2018), *Information guidelines for proponents preparing coal seam gas and large coal mining development proposals*, Commonwealth of Australia, May 2018.

Doherty, J. and Moore C., (2021). *Decision Support Modelling Viewed through the Lens of Model Complexity. A GMDSI Monograph*. National Centre for Groundwater Research and Training, Flinders University, South Australia

Guo, H., Adhikary, D., and Gaveva, D. (2007). *Hydrogeological response to longwall mining,* ACARP Report C14033, CSIRO Exploration and Mining: Australian Coal Industry's Research Program (ACARP)

Middlemis H and Peeters LJM (2018), *Uncertainty Analysis – Guidance for groundwater modelling within a risk management framework.* A report prepared for the Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development through the Department of the Environment and Energy, Commonwealth of Australia 2018.

Murray-Darling Basin Commission (2000) *Groundwater Flow Modelling Guideline*, November 2000, Aquaterra Consulting Pty Ltd, Project No. 125, Final Guideline – Issue I, 16 January 2001

Pells, S. (2017), *Groundwater Modelling of the Hume Coal Project,* https://majorprojects.planningportal.nsw.gov.au/prweb/PRRestService/mp/01/getContent?AttachRef=SSD-7172%2120190319T233221.791%20GMT

Rau,R. Acworth I, Halloran L, Timms W , Cuthbert M (2018). *Quantifying Compressible Groundwater Storage by Combining Cross-Hole Seismic Surveys and Head Response to Atmospheric Tides*

SLR (2022). *Appin Mine Extraction Plan. Groundwater Impact Assessment.* SLR. V8.0. August 2022

Murray–Darling Basin Commission (2001), *Groundwater flow modelling guideline*, report prepared by Aquaterra, January 2001

Table 1 Numerical model compliance checklist (AGMG, 2012)

Question	Comment	Yes/No
1a. Are the model objectives clearly stated?	Modelling objectives are clearly stated in Section 1.2 of the report. Model confidence level not stated. This review assessed Class 2/3 achieved (see Appendix A), which is fit for purpose.	Yes
1b. Model confidence level stated?	Missing. Based on the model report the Model confidence level is assessed as Class 2 (with some attributes of Class 3). This is not a material omission.	No
2. Are the objectives satisfied?	Model and reporting objectives are outlined in Section 1.2 are satisfied by the reported. Numerical groundwater modelling satisfies the project objectives.	Yes
3. Is the conceptual model consistent with objectives and confidence level?	An adequately detailed conceptual model is presented in the report. It reviews hydrogeology, groundwater levels, flows, surface water, hydraulic parameters. There is a detailed review and analysis of the height of fracturing and potential increases to hydraulic conductivity in the area above the longwalls.	Yes
4. Is the conceptual model based on all available data, presented clearly and reviewed by an appropriate reviewer?	Yes, the conceptual model is presented clearly and illustrated across numerous figures in Section 2 and 3.	Yes
5. Does the model design conform to best practice?	Model design detailed in Section 4. The modelling design and approach are consistent with modelling best practice. In recent times regulatory bodies have promoted the use of "stacked drains" to overcome potential disconnection through the fracture profile. The model however reproduces depressurisation signatures above the longwalls, suggested the approach is appropriate.	Yes
6. Is the model calibration satisfactory?	Section 4.2. Model calibration was carried out using PEST++. Calibration statistics are satisfactory. The model achieved good matching to groundwater level lowering in response to longwall mining. Although not presented, the model replicates longwall mining inflow adequately.	Yes
7. Are the calibrated parameter values and estimated fluxes plausible?	The history matched parameter values shown in Table 13 and 14 are plausible based on the site data and based on this reviewers experience in the region. It is unknown if the model replicates baseflow adequately.	Yes
8. Do the model predictions conform to best practice?	The calibrated model predicts groundwater drawdown, baseflow change, and estimates of inflow to the end of mine life. It is unknown how the groundwater system behaves during the recovery phase. Predictions are calculated and presented according to best practice.	Yes
9. Is the uncertainty associated with the simulations/predictions reported?	Conceptual, parametric, scenario uncertainty are not undertaken presented.	No
10. Is the model fit for purpose?	Yes, in this reviewers opinion, the model is fit for purpose for simulating and predicting groundwater inflow and potential drawdown associated with the Appin Mine Longwalls.	Yes

Table 2 Numerical model classification checklist (AGMG, 2012)

CLASS	DATA		CALIBRATION		PREDICTION		INDICATORS	
1 (Simple)	Not much/Sparse coverage		Not possible		Timeframe >> calibration		Timeframe > 10x calibration	
	No metered usage		Large error statistic		Long stress periods		Stresses > 5x calibration	
	Low resolution topo DEM		Inadequate data spread		Transient prediction but steady-state calibration		Mass balance > 1% (or one-off <5%)	
	Poor aquifer geometry		Targets incompatible with model purpose		Bad verification		Properties <> field	
	Basic/Initial conceptualisation		-		-		Poor performance stats/no review	
2 (Impact assessment)	Some data / OK coverage	✓	Weak seasonal match	✓	Predictive timeframe > calibration		Predictive timeframe = 3-10x calib.	
	Some usage info	✓	Some long-term trends wrong	~	Different stresses &/or periods		Predictive stresses = 2-5x calib.	
	Some baseflow estimates and some K/S measurements	~	Partial performance (e.g. some stats/part record/ model-measure offsets)		No verification but key simulations constrained by data	~	Mass balance < 1% (all stress periods)	
	Some high res. Topo DEM and adequate aquifer geometry	✓	Head and flux targets constrain calibration	~	Calib. & prediction consistent (transient of steady-state)	✓	Some properties <> field measurements	✓
	Sound conceptualisation, reviewed & stress-tested	✓	Non-uniqueness, sensitivity and qualitative uncertainty addressed	×	Magnitude & type of stresses outside range of cal. Stresses	✓	Some poor performance (but no coarse discretisation in key areas/times)	~
3 (Complex simulator)	Plenty of data, good coverage	~	Good performance stats	~	Timeframe ~ calibration	✓	Predictive timeframe < 3x calib.	✓
	Good metered volumes (all users)	~	Long-term trends replicated	✓	Similar stress periods	✓	Predictive stresses < 2x	✓
	Local climate data and baseflow	~	Seasonal fluctuations OK	×	Good verification or all simulations constrained by data	~	Mass balance <0.5% (all periods)	✓
	K measurements from range of tests	~	Calibration to present day data targets	~	Steady-state prediction only when calibration in steady state	NA	Properties ~ field measurements	~

CLASS	DATA		CALIBRATION		PREDICTION		INDICATORS	
	High res topo DEM in all areas & good aquifer geometry	~	Non-uniqueness minimised & or parameter identifiability/minimum error variance or RCS assessed	×	Suitable computational methods applied & parameters are consistent with conceptualisation	✓	No poor performance of coarse discretisation in key areas (grid/time)	~
	Mature conceptualisation	~	Sensitivity &/or Qualitative Uncertainty	×	Quantitative uncertainty analysis	×	Reviewed by experienced Hydro/Modeller	✓
							Criterion met at higher class	
							Criterion partially met at relevant class	~
							Criterion met at the relevant class	✓
							Criterion not met by current model study	×

Table 3 AGMG guideline model checklist

Review questions		Yes/No	Comment
1.	**Planning**		
1.1	Are the project objectives stated?	Yes	See section 1.2 of the model report
1.2	Are the model objectives stated?	Yes	Also in Section 1.2, but not segregated from the overall groundwater assessment
1.3	Is it clear how the model will contribute to meeting the project objectives?	Yes	See section 1.2
1.4	Is a groundwater model the best option to address the project and model objectives?	Yes	Assessment calls for calculating drawdown, baseflow change, inflow in a cumulative environment
1.5	Is the target model confidence-level classification stated and justified?	No	Not included
1.6	Are the planned limitations and exclusions of the model stated?	No	There is some discussion on the models inability to fit measurement data in section 4.2.2. However, there is no "Model limitations" section, or a discussion on the implied error in the model predictions.
2.	**Conceptualisation**		
2.1	Has a literature review been completed, including examination of prior investigations?	Yes	Literature review of previous reports and work at the site.
2.2	Is the aquifer system adequately described?	Yes	All aquifers are identified and justified
2.2.1	Hydrostratigraphy including aquifer type (porous, fractured rock ...)	Yes	Described in section 3
2.2.2	Lateral extent, boundaries and significant internal features such as faults and regional folds	Yes	Described in section 2
2.2.3	Aquifer geometry including layer elevations and thicknesses	Yes	Presented in Section 2.5 and Figure 7-8
2.2.4	Confined or unconfined flow and the variation of these conditions in space and time?	Yes	Described in section 3.2 and 3.6
2.3	Have data on groundwater stresses been collected and analysed?	Yes	Measured groundwater inflows discussed in Section 2. Abstraction rates from landholder wells, csg pumping are presented.

Review questions	Yes/No	Comment
2.3.1 Recharge from rainfall, irrigation, floods, lakes	No	Rainfall has been discussed in Section 2.1. There is no discussion on the range of recharge to the hydrostratigraphic units in the conceptual model section.
2.3.2 River or lake stage heights	Yes	Section 2.3 provides the flow rates and flow duration curves
2.3.3 Groundwater usage (pumping, returns etc)	Yes	local groundwater usage is described in Section 3.6 and 4.2
2.3.4 Evapotranspiration	Yes	Section 2.1 describes the evapotranspiration and potential/actual evapotranspiration estimates from BoM. However, the model uses 511 mm/year (~55% of actual).
2.3.5 Other?	NA	
2.4 Have groundwater level observations been collected and analysed?	Yes	Used as the measurement dataset for the calibration exercise.
2.4.1 Selection of representative bore hydrographs	Yes	Hydrographs are presented in Figures 11 to 30 and descriptions of groundwater behaviour in Sections 3.3
2.4.2 Comparison of hydrographs	Yes	Section 3.3 describes water levels and hydrographs are shown in Figures 11 to 30
2.4.3 Effect of stresses on hydrographs	Yes	Previous mining identified in bores screening deeper units. Climate and pumping responses discussed.
2.4.4 Watertable maps/piezometric surfaces?	Yes	Presented in Figure 23, 25, 26. Source of the data is unknown; the contour appear to have been derived from a groundwater model as opposed to an interpolated surface based on measurements.
2.4.5 If relevant, are density and barometric effects taken into account in the interpretation of groundwater head and flow data?	NA	
2.5 Have flow observations been collected and analysed?	No	No discussion on measured flow in streams/creeks or mine ingress.
2.5.1 Baseflow in rivers	No	No baseflow analysed. Main water course is gauged and stage results from this are presented.
2.5.2 Discharge in springs	NA	No springs identified in model area.

Review questions	Yes/No	Comment
2.5.3 Location of diffuse discharge areas?	Yes	Swamps identified have discussed, although they are far from the predictive impact area of the Project.
2.6 Is the measurement error or data uncertainty reported?	No	
2.6.1 Measurement error for directly measured quantities (e.g. piezometric level, concentration, flows)	No	Sources of measurement error not discussed.
2.6.2 spatial variability/heterogeneity of parameters	Yes	Variability in field measurements is discussed, the aquifer parameters are defined as uniform within geology types, however the values for same geological types varies in different model layers.
2.6.3 Interpolation algorithm(s) and uncertainty of gridded data?	No	Unknown
2.7 Have consistent data units and geometric datum been used?	Yes	It appears so, or at least the required conversions have been made as MODFLOW USG requires consistent units
2.8 Is there a clear description of the conceptual model?	Yes	See section 3.5, 3.6
2.8.1 Is there a graphical representation of the conceptual model?	Yes	See Figure 8 and Figure 33
2.8.2 Is the conceptual model based on all available, relevant data?	Yes	Conceptual model could include groundwater levels, stresses and flow directions to improve readability
2.9 Is the conceptual model consistent with the model objectives and target model confidence level classification?	Yes	
2.9.1 Are the relevant processes identified?	Yes	The key components of the bulk groundwater movement at the Appin Mine is captured in the conceptual model
2.9.2 Is justification provided for omission or simplification of processes?	Yes	Appropriate simplification to key components has taken place with evidence supporting the simplifications and omissions
2.10 Have alternative conceptual models been investigated?	No	Not initially - alternate fracturing height investigated as an alternate scenario.
3. Design and construction		
3.1 Is the design consistent with the conceptual model?	Yes	

Review questions		Yes/No	Comment
3.2	Is the choice of numerical method and software appropriate (Table 4-2)?	Yes	Modflow-USG provides a more stable numerical scheme with the control volume finite difference method over the cell centred finite difference method. Grid had been optimised to reduce cell count.
3.2.1	Are the numerical and discretisation methods appropriate?	Yes	Cell size in the mining areas ranges from 100-200m, down to 50m to represent the ventilation shafts. Pertinent creek cells have 100m resolution. This resolution is more than adequate to represent dewatering and changes to flow.
3.2.2	Is the software reputable?	Yes	MODFLOW USG is distributed by the USGS and is now the industry standard software for modelling groundwater.
3.2.3	Is the software included in the archive or are references to the software provided?	Yes	Reference provided
3.3	Are the spatial domain and discretisation appropriate?	Yes	The extent of the model is large enough to represent cumulative depressurisation. The proposed project drawdowns do not encroach on the model boundaries.
3.3.1	1D/2D/3D	Yes	3D - MODFLOW USG
3.3.2	Lateral extent	Yes	The model is bounded by no flow cells, with some CHD cells representing water storage bodies. The boundary conditions are far enough away not to influence the key predictions of the model.
3.3.3	Layer geometry?	Yes	The chosen vertical discretisation provides sufficient detail without being too simplified. The key coal seams are simulated discretely in separate model layers. The key Sandstone units are segregated according to measurement data.
3.3.4	Is the horizontal discretisation appropriate for the objectives, problem setting, conceptual model and target confidence level classification?	Yes	100m cell sizes are appropriate to meet the relevant criteria. Coarser cells may have been more appropriate to allow for faster run times, and a more robust calibration/uncertainty analysis
3.3.5	Is the vertical discretisation appropriate? Are aquitards divided in multiple layers to model time lags of propagation of responses in the vertical direction?	Yes	Model layering is sufficient to provide vertical disconnection, but still simple enough to provide a conservative response.
3.4	Are the temporal domain and discretisation appropriate?	Yes	Quarterly stress periods adequate to simulate the progression of mining and seasonality

Review questions		Yes/No	Comment
3.4.1	Steady state or transient	Yes	Both - steady state to provide initial conditions, and transient simulation that represents historical and future mining
3.4.2	Stress periods	Yes	Stress period duration is unknown between 1960 and 2009. Quarterly stress periods thereafter more than adequate to meet objectives.
3.4.3	Time steps?	No	Unknown
3.5	Are the boundary conditions plausible and sufficiently unrestrictive?	Yes	Rivers have appropriate stage heights to replicate the measured/average presence of water. Minor creeks have zero stage height. CHDs are sufficiently far from the project to not incur predictive contamination
3.5.1	Is the implementation of boundary conditions consistent with the conceptual model?	Yes	No flow boundaries are assigned where appropriate, river stage height appropriate, Water storage non-restrictive. Recharge and EVT as conceptualised.
3.5.2	Are the boundary conditions chosen to have a minimal impact on key model outcomes? How is this ascertained?	Yes	The predicted impact at steams is minimal due to the impedance of the hydrostratigraphic units. Therefore, different representations of streams would yield similar results. CHDs and No flow cells far from drawdown cone.
3.5.3	Is the calculation of diffuse recharge consistent with model objectives and confidence level?	Yes	No discussion on anticipated range of recharge. Zoned up based on outcrop geology.
3.5.4	Are lateral boundaries time-invariant?	Yes/No	CHD cells at boundary vary depending on measured water stages. No flow at boundaries elsewhere.
3.6	Are the initial conditions appropriate?	Yes	Derived from a calibrated steady state model.
3.6.1	Are the initial heads based on interpolation or on groundwater modelling?	Yes	Groundwater modelling - first stress period simulates steady state conditions, providing reliable initial conditions
3.6.2	Is the effect of initial conditions on key model outcomes assessed?	Yes	Steady state results would be affected by the changes to hydraulic conductivity and recharge explored through sensitivity/uncertainty analysis
3.6.3	How is the initial concentration of solutes obtained (when relevant)?	NA	

Review questions		Yes/No	Comment
3.7	Is the numerical solution of the model adequate?	Yes	The Overall water budget is 0.0 ML/day. It is unknown what the percent discrepancy is, or the maximum discrepancy measured at any timestep.
3.7.1	Solution method/solver	No	Not stated, although assumed that the SMS solver is used for control volume finite difference solution scheme of MODFLOW USG
3.7.2	Convergence criteria	No	Not stated
3.7.3	Numerical precision	No	Not stated
4.	**Calibration and sensitivity**		
4.1	Are all available types of observations used for calibration?	No	Calibrated to heads only. Inflows are available but only used as validation measure. No attempts at baseflow calibration in spite of numerous surface water monitoring locations near the project area.
4.1.1	Groundwater head data	Yes	Model is calibrated to water level data (up to 2021)
4.1.2	Flux observations	No	Inflow measurements used as validation only.
4.1.3	Other: environmental tracers, gradients, age, temperature, concentrations etc.	NA	
4.2	Does the calibration methodology conform to best practice?	Yes/No	Current best practice suggests all available measurements are used to form a well-posed problem for PEST to solve. Best practise also calls for a model to be endowed with many parameters to accommodate nuances in the groundwater system. Parameters that are likely to lie squarely in the solution space, namely the fracturing rate above the longwalls was not adjusted.
4.2.1	Parameterisation	Yes	Geological extents are used to define parameter zones
4.2.2	Objective function	Yes	Yes - below the suggested 10% at 4.7%
4.2.3	Identifiability of parameters	No	Composite sensitivity or identifiability of adjustable parameters not presented

Review questions	Yes/No	Comment
4.2.4 Which methodology is used for model calibration?		Calibration used PEST to perform gradient based automated optimisation.
4.3 Is a sensitivity of key model outcomes assessed against?	No	Sensitivity of the parameters to measurement data is not presented.
4.3.1 Parameters	No	Sensitivity of connective cracking multiplier was undertaken but not presented (because it failed to match historic measurements).
4.3.2 Boundary conditions	No	-
4.3.3 Initial conditions	No	-
4.3.4 Stresses	Yes/No	Tammetta fracture height explored through sensitivity. The height is lower than the Ditton approach.
4.4 Have the calibration results been adequately reported?	No	The sensitivity and range of parameters assessed during the calibration process is not reported.
4.4.1 Are there graphs showing modelled and observed hydrographs at an appropriate scale?	Yes	Some are provided in the original report - An appendix with all hydrographs used in the calibration should be presented as an appendix.
4.4.2 Is it clear whether observed or assumed vertical head gradients have been replicated by the model?	Yes	Hydrographs with measured and simulated heads are presented at several VWP locations. A chart showing pressure vs height would make the fit clearer.
4.4.3 Are calibration statistics reported and illustrated in a reasonable manner?	Yes	Scatterplot, histogram, table of residuals, SRMS/RMS presented
4.5 Are multiple methods of plotting calibration results used to highlight goodness of fit robustly? Is the model sufficiently calibrated?	Yes	Scatter diagram and hydrographs are used in conjunction with statistical measures of the error. The original 2009 calibration achieved a SRMS of 9%. Updating the model, adding more measurements, and recalibrating has reduced SRMS by approximately half.
4.5.1 Spatially	Yes	Map of average residuals presented (Figure 46)
4.5.2 Temporally	Yes	Hydrographs are shown comparing observed and simulated water levels

Review questions		Yes/No	Comment
4.6	Are the calibrated parameters plausible?	Yes	Hydraulic conductivities are typical of other assessments in the regional area. It should be noted that the Stanwell park claystone (Layer 10) is at the lower bound of conceptualised K that unit. Vertical conductivities have max kh/kv ratio of 200.
4.7	Are the water volumes and fluxes in the water balance realistic?	Yes	Volumes entering and leaving the model domain appear plausible for what they represent. Aerial recharge is generally lower than the river leakage conforming to the conceptual model where aquifers are recharged through the river. Baseflow is a large component of the budget (16%) due to the assumed incision into the aquifer.
4.8	Has the model been verified?	Yes	Model verified to mine inflow rates
5.	**Prediction**		
5.1	Are the model predictions designed in a manner that meets the model objectives?	Yes	Boundary conditions representing the dewatering from the mines are applied and impacts are defined by comparison to a null model
5.2	Is predictive uncertainty acknowledged and addressed?	No	Predictive uncertainty not undertaken
5.3	Are the assumed climatic stresses appropriate?	Yes	Quarterly averages used
5.4	Is a null scenario defined?	Yes	Null scenario includes the other mines in the model domain, but removes Appin and associated changes. A second null scenario simulates all mining with the exception of Longwalls 709-711, and 905. A third Null scenario simulates no mining in the region.
5.5	Are the scenarios defined in accordance with the model objectives and confidence level classification?	No	Model classification not discussed.
5.5.1	Are the pumping stresses similar in magnitude to those of the calibrated model? If not, is there reference to the associated reduction in model confidence?	Yes	Extraction due to mine dewatering is included in the historic period. Landholder pumping stresses continue through the predictive period.
5.5.2	Are well losses accounted for when estimating maximum pumping rates per well?	NA	

Review questions		Yes/No	Comment
5.5.3	Is the temporal scale of the predictions commensurate with the calibrated model? If not, is there reference to the associated reduction in model confidence?	Yes	Calibration period is longer than the prediction period
5.5.4	Are the assumed stresses and timescale appropriate for the stated objectives?	Yes	Quarterly stress periods adequate to simulate the progression of mining and seasonality
5.6	Do the prediction results meet the stated objectives?	Yes	Predictions show impact extent, water take from mine, and impact and landholders. "Insignificant" impact to baseflow to Creeks.
5.7	Are the components of the predicted mass balance realistic?	Yes	
5.7.1	Are the pumping rates assigned in the input files equal to the modelled pumping rates?	NA	-
5.7.2	Does predicted seepage to or from a river exceed measured or expected river flow?	No	Predicted leakage is less than baseflow. There is no discussion on measured baseflow in the creeks.
5.7.3	Are there any anomalous boundary fluxes due to superposition of head dependent sinks (e.g. evapotranspiration) on head-dependent boundary cells (Type 1 or 3 boundary conditions)?	No	No evidence of 'short circuiting' of flows between boundary conditions
5.7.4	Is diffuse recharge from rainfall smaller than rainfall?	Yes	recharge generally 0.5 to 5% of rainfall
5.7.5	Are model storage changes dominated by anomalous head increases in isolated cells that receive recharge?	No	-
5.8	Has particle tracking been considered as an alternative to solute transport modelling?	NA	-
6.	**Uncertainty**		
6.1	Is some qualitative or quantitative measure of uncertainty associated with the prediction reported together with the prediction?	No	No discussion or simulation of parametric, structural, or conceptual uncertainty. One scenario exploring a shallower height of fracturing.
6.2	Is the model with minimum prediction-error variance chosen for each prediction?	No	Uncertainty analysis not undertaken
6.3	Are the sources of uncertainty discussed?	No	
6.3.1	Measurement of uncertainty of observations and parameters	Yes	There is some discussion on the potential for error due to structural simplification of layers; strong vertical gradients in thick layers can lead to errors of +/- 5m.

Review questions		Yes/No	Comment
6.3.2	Structural or model uncertainty	No	-
6.4	Is the approach to estimation of uncertainty described and appropriate?	No	-
6.5	Are there useful depictions of uncertainty?	No	
7.	**Solute transport**		
7.1	Has all available data on the solute distributions, sources and transport processes been collected and analysed?	NA	
7.2	Has the appropriate extent of the model domain been delineated and are the adopted solute concentration boundaries defensible?	NA	
7.3	Is the choice of numerical method and software appropriate?	NA	
7.4	Is the grid design and resolution adequate, and has the effect of the discretisation on the model outcomes been systematically evaluated?	NA	
7.5	Is there sufficient basis for the description and parameterisation of the solute transport processes?	NA	
7.6	Are the solver and its parameters appropriate for the problem under consideration?	NA	
7.7	Has the relative importance of advection, dispersion and diffusion been assessed?	NA	
7.8	Has an assessment been made of the need to consider variable density conditions?	NA	
7.9	Is the initial solute concentration distribution sufficiently well-known for transient problems and consistent with the initial conditions for head/pressure?	NA	
7.10	Is the initial solute concentration distribution stable and in equilibrium with the solute boundary conditions and stresses?	NA	
7.11	Is the calibration based on meaningful metrics?	NA	
7.12	Has the effect of spatial and temporal discretisation and solution method taken into account in the sensitivity analysis?	NA	

Review questions		Yes/No	Comment
7.13	Has the effect of flow parameters on solute concentration predictions been evaluated, or have solute concentrations been used to constrain flow parameters?	NA	
7.14	Does the uncertainty analysis consider the effect of solute transport parameter uncertainty, grid design and solver selection/settings?	NA	
7.15	Does the report address the role of geologic heterogeneity on solute concentration distributions?	NA	-
8.	**Surface water–groundwater interaction**		
8.1	Is the conceptualisation of surface water–groundwater interaction in accordance with the model objectives?	Yes	Appropriately represented such that impacts on surface water bodies can be predicted.
8.2	Is the implementation of surface water–groundwater interaction appropriate?	Yes	Impacted creeks are represented in a way that the reduction of baseflow is adequately simulated.
8.3	Is the groundwater model coupled with a surface water model?	No	Not a separate model, but the influence of the surface water system is adequately simulated by the RIV package within MODFLOW
8.3.1	Is the adopted approach appropriate?	Yes	See above
8.3.2	Have appropriate time steps and stress periods been adopted?	Yes	Stage in the higher orders show variability that is appropriately represented with quarterly stress periods.
8.3.3	Are the interface fluxes consistent between the groundwater and surface water models?	Yes	Budgets are appropriate and plausible given the incision of the creeks into the surficial aquifers.

Table 4 MDBD guideline checklist

Q	Question	Not Applicable or Unknown	Score 0	Score 1	Score 3	Score 5	Score	Max Score (0, 3, 5)
1	**THE REPORT**							
1.1	Is there a clear statement of project objectives in the modelling report?	-	Missing	Deficient	Adequate	Very Good	3	5
1.2	Is the level of model complexity clear or acknowledged?	-	Missing	No	Yes	Very Good	1	5
1.3	Is a water or mass balance reported?	-	Missing	Deficient	Adequate	Very Good	3	5
1.4	Has the modelling study satisfied project objectives?	-	Missing	Deficient	Adequate	Very Good	3	5
1.5	Are the model results of any practical use?	-	-	No	Maybe	Yes	5	5
2	**DATA ANALYSIS**							
2.1	Has hydrogeology data been collected and analysed?	-	Missing	Deficient	Adequate	Very Good	5	5
2.2	Are groundwater contours or flow directions presented?	-	Missing	Deficient	Adequate	Very Good	3	5
2.3	Have all potential recharge data been collected and analysed? (rainfall, streamflow, irrigation, floods, etc.)	-	Missing	Deficient	Adequate	Very Good	3	5
2.4	Have all potential discharge data been collected and analysed? (abstraction, evapotranspiration, drainage, spring flow, etc.)	-	Missing	Deficient	Adequate	Very Good	3	5
2.5	Have the recharge and discharge datasets been analysed for their groundwater response?	-	Missing	Deficient	Adequate	Very Good	3	5
2.6	Are groundwater hydrographs used for calibration?	-	-	No	Maybe	Yes	5	5
2.7	Have consistent data units and standard geometrical datums been used?	-	-	No	Yes	-	3	3
3	**CONCEPTUALISATION**							
3.1	Is the conceptual model consistent with project objectives and the required model complexity?	-	Unknown	No	Maybe	Yes	5	5
3.2	Is there a clear description of the conceptual model?	-	Missing	Deficient	Adequate	Very Good	3	5
3.3	Is there a graphical representation of the modeller's conceptualisation?	-	Missing	Deficient	Adequate	Very Good	3	5
3.4	Is the conceptual model unnecessarily simple or unnecessarily complex?	-	-	Yes	No		3	3

Q	Question	Not Applicable or Unknown	Score 0	Score 1	Score 3	Score 5	Score	Max Score (0, 3, 5)
4	**MODEL DESIGN**							
4.1	Is the spatial extent of the model appropriate?	-	-	No	Maybe	Yes	5	5
4.2	Are the applied boundary conditions plausible and unrestrictive?	-	Missing	Deficient	Adequate	Very Good	3	5
4.3	Is the software appropriate for the objectives of the study?	-	-	No	Maybe	Yes	5	5
5	**CALIBRATION**							
5.1	Is there sufficient evidence provided for model calibration?	-	Missing	Deficient	Adequate	Very Good	3	5
5.2	Is the model sufficiently calibrated against spatial observations?	-	Missing	Deficient	Adequate	Very Good	3	5
5.3	Is the model sufficiently calibrated against temporal observations?	-	Missing	Deficient	Adequate	Very Good	3	5
5.4	Are calibrated parameter distributions and ranges plausible?	-	Missing	No	Maybe	Yes	3	5
5.5	Does the calibration statistic satisfy agreed performance criteria?	-	Missing	Deficient	Adequate	Very Good	3	5
5.6	Are there good reasons for not meeting agreed performance criteria?	-	Missing	Deficient	Adequate	Very Good	5	5
6	**VERIFICATION**							
6.1	Is there sufficient evidence provided for model verification?	-	Missing	Deficient	Adequate	Very Good	0	5
6.2	Does the reserved dataset include stresses consistent with the prediction scenarios?	-	Unknown	No	Maybe	Yes	5	5
6.3	Are there good reasons for an unsatisfactory verification?	-	Missing	Deficient	Adequate	Very Good	0	5
7	**PREDICTION**							
7.1	Have multiple scenarios been run for climate variability?	-	Missing	Deficient	Adequate	Very Good	0	5
7.2	Have multiple scenarios been run for operational /management alternatives?	-	Missing	Deficient	Adequate	Very Good	3	5
7.3	Is the time horizon for prediction comparable with the length of the calibration / verification period?	-	Missing	No	Maybe	Yes	5	5
7.4	Are the model predictions plausible?	-		No	Maybe	Yes	5	5

Q	Question	Not Applicable or Unknown	Score 0	Score 1	Score 3	Score 5	Score	Max Score (0, 3, 5)
8	**SENSITIVITY ANALYSIS**							
8.1	Is the sensitivity analysis sufficiently intensive for key parameters?	-	Missing	Deficient	Adequate	Very Good	1	5
8.2	Are sensitivity results used to qualify the reliability of model calibration?	-	Missing	Deficient	Adequate	Very Good	0	5
8.3	Are sensitivity results used to qualify the accuracy of model prediction?	-	Missing	Deficient	Adequate	Very Good	1	5
9	**UNCERTAINTY ANALYSIS**							
9.1	If required by the project brief, is uncertainty quantified in any way?	-	Missing	No	Maybe	Yes	1	5
						TOTAL SCORE	**108 (61%)**	**181**