SECTION 6

Environmental Assessment

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6 ENVIRONMENTAL ASSESSMENT

6.1 ENVIRONMENTAL RISK ASSESSMENT

As a component of the environmental assessment of the Project, an Environmental Risk Assessment (ERA) was undertaken to identify key potential environmental issues and associated controls for further assessment in the EIS. An ERA scoping session was conducted and was facilitated by an independent risk assessment specialist (AXYS Consulting, 2019).

The risks associated with the potential environmental issues identified are ranked in accordance with the frameworks detailed in Australian/New Zealand Standard (AS/NZ) *International Standards Principles and Guidelines* (ISO) 31000:2009 *Risk Management – Guideline* and MDG1010 *Minerals Industry Safety and Health Risk Management Guideline* (Mine Safety Operations Branch, 2011).

The risk assessment team consisted of representatives from:

- South32;
- Niche;
- Hydro Engineering Consultants (HEC);
- HGEO;
- Mine Subsidence Engineering Consultants (MSEC);
- Watershed HydroGeo; and
- Resource Strategies.

The key potential environmental issues identified during the ERA scoping session were associated with (Appendix M):

- Land Resources and Land Uses (Section 6.4);
- Groundwater (Section 6.5);
- Surface Water (Section 6.6);
- Aquatic Ecology and Upland Swamps (Sections 6.7, 6.8 and 6.9);
- Aboriginal and non-Aboriginal Heritage (Sections 6.10 and 6.11);
- Road Transport (Section 6.12);
- Noise and Blasting (Sections 6.13, 6.14, 6.15 and 6.16);
- Air Quality and Greenhouse Gas Emissions (Section 6.17 and 6.21);
- Visual Character (Section 6.18); and
- Socio-Economic Effects (Sections 6.19 and 6.20).

For all risks, mitigation measures, comprising a combination of existing controls and additional treatments were identified to reduce levels to as low as reasonably tolerable. The ERA is provided in full as Appendix M.

The risk assessment was updated following additional review by all participants in April 2019, including consideration of recommendations identified in the Independent Expert Panel for Mining in the Catchment's (IEP) *Initial Report on Specific Mining Activities at the Metropolitan and Dendrobium Coal Mines* (IEP, 2018). A reconciliation of the Project's mitigation measures and monitoring against the IEP's recommendations is provided in Section 8.

6.2 CLIMATE AND TOPOGRAPHY

Long-term meteorological data is available from Bureau of Meteorology (BoM) weather stations.

The BoM weather stations proximal to the Project measure a number of meteorological parameters, including temperature, humidity and rainfall.

Evaporation data relevant to the Project has been decided based on the Scientific Information for Landowners (SILO) Data Drill System.

Details of the BoM stations in the vicinity of the Project are provided in Table 6-1. Meteorological data collected from these sources is summarised in Table 6-2 and discussed below.

6.2.1 Existing Environment

Climate

Rainfall Data and Statistics

Table 6-2 provides a summary of long-term rainfall data from regional BoM stations.

The long-term average annual rainfall at nearby stations varies from approximately 756 mm at Douglas Park to 1,118 mm at Port Kembla (BSL Central Lab).

Table 6-1
Bureau of Meteorology Monitoring Station Locations and Recording Periods

Station Name	Station Number	Location	Latitude (degrees S)	Longitude (degrees E)	Elevation (m AHD)	Period of Record
Cataract Dam	068016	Approximately 7 km north-east of Area 6	34.26	150.81	340 m	1904 to 2013
Douglas Park (St. Marys Towers)	068200	Approximately 9 km north of Area 6 and approximately 15 km north of Area 5	34.21	150.71	165 m	1974 to present
Port Kembla (BSL Central Lab)	068131	Approximately 0.5 km from the Dendrobium CPP and approximately 7 km from the Dendrobium Pit Top and Kemira Valley Coal Loading Facility	34.47	150.88	9 m	1963 to present
Port Kembla NTC AWS	068253	Approximately 2 km from the Dendrobium CPP	34.47	150.91	-	2012 to present
Picton Council Depot	068052	Approximately 15 km north-west of Area 6 and approximately 19 km north of Area 5	34.11	150.37	165 m	1880 to present
Bellambi AWS	068228	Approximately 11 km north-east of the Kemira Valley Coal Loading Facility	34.37	150.93	10 m	1997 to 2010

Source: Bureau of Meteorology (2018)
AHD = Australian Height Datum

Table 6-2
Relevant Meteorological Information

Month	Relative Humidity Monthly Average (%) Bellambi AWS (068228) 1997 - 2010		Average Daily Temperature (°C) Port Kembla NTC AWS (068253) 2012 - 2018		Picton Council Depot (068052) 1907 - 2018		Average Monthly Rainfall (mm) Cataract Dam (068016) 1904 - 2013	Douglas Park (St. Marys Towers) (068200) 1974 - 2018	Port Kembla (BSL Central Lab) (068131) 1963 - 2018	Average Monthly Evaporation (mm) SILO Drill Location in Area 5
	9 am	3 pm	Min.	Max.	Min.	Max.				
January	75	72	20.0	24.6	15.2	30.1	94	68	97	169
February	76	74	20.0	24.0	15.7	29.1	116	87	127	134
March	74	70	19.3	24.0	11.8	28.7	109	84	143	120
April	66	67	16.8	22.3	9.7	23.5	99	63	108	87
May	63	61	14.4	20.3	7.1	20.4	97	56	81	61
June	63	59	12.1	17.5	3.6	17.3	113	71	118	50
July	60	56	10.7	17.0	1.6	16.7	76	40	54	53
August	56	54	11.4	17.5	2.8	17.8	70	43	71	76
September	59	61	13.4	20.1	5.4	21.4	55	41	58	98
October	62	64	15.4	21.1	9.0	23.1	78	56	86	127
November	72	70	16.8	22.3	12.4	24.5	79	73	88	149
December	71	69	18.6	23.9	14.0	28.4	78	56	73	172
Annual Average Monthly	66	65	15.8	21.2	9.1	23.6	89	62	92	-
			Annual Average Total				1,065	756	1,118	1,294

Source: Bureau of Meteorology (2018)
°C = degrees Celsius

Generally, the rainfall records indicate moderate seasonality, with higher rainfall being recorded in late summer and autumn and lower rainfall in the winter and spring (Table 6-2).

Evaporation

Evaporation records indicate a distinct seasonality, with higher evaporation rates in November through February and lower evaporation in June and July (Table 6-2).

When compared to long-term average rainfall, the rate of evaporation exceeds rainfall on an average annual basis, as well as generally for all average monthly rainfalls.

Temperature

The data presented in Table 6-2 indicates that temperatures are warmest from November to March and coolest in the winter months of June, July and August. Average daily maximum temperatures are highest in January and lowest in July (1.6 ° C and 10.7°C for Port Picton Council Depot and Kembla NTC AWS, respectively) (Table 6-2).

Relative Humidity

Relative humidity records from the Bellambi AWS station exhibit a generally uniform seasonal pattern for the period 1997-2010 (Table 6-2). The lowest morning (9.00 am) monthly average relative humidity has been recorded in August (56%) and the highest recorded in February (76%) (Table 6-2). The lowest afternoon (3.00 pm) monthly average relative humidity has been recorded in August (54%) and the highest recorded in February (74%) (Table 6-2).

Wind Speed and Direction

As part of the Air Quality and Greenhouse Gas Assessment (Appendix I), wind roses were developed using wind direction and wind speed from several meteorological stations in the region.

On an annual basis, the most common winds are from the west and north-east (Appendix I). Seasonal and diurnal winds demonstrate relatively consistent wind speeds and directions across all seasons and day and night periods (Appendix I).

Temperature Inversions

Temperature inversions occur in the wider Project area, the frequency of inversions is described in Section 6.13 and the Noise and Blasting Assessment (Appendix J).

Topography, Landforms and Geology

The Project underground mining areas are located to the west of Wollongong on the southern Woronora Plateau, which is characterised by undulating topography and naturally vegetated landscapes, with elevations generally higher than the Project surface facilities located east of the Illawarra Escarpment and proximal to Wollongong.

The Project underground mining areas are located entirely within the Upper Nepean Catchment, and within a declared catchment area (i.e. the Metropolitan Special Area), and is characterised by various watercourses and their associated tributaries and natural features (e.g. the Avon and Cordeaux Rivers).

The area is generally undisturbed (apart from water supply infrastructure including the Avon and Cordeaux Dams) due to public access to the Metropolitan Special Area being restricted by WaterNSW.

The Upper Nepean Catchment is located at the southern end of the Woronora Plateau, which extends from Robertson, northwards to Liverpool and is bordered by the Illawarra Escarpment to the east, Campbelltown to the north-west and the towns of Bargo and Yerrinbool in the south-west.

The majority of the surface facilities that would be used by the Project are located to the east of the Illawarra Escarpment in the suburban and industrial areas of Mount Kembla, Figtree and Port Kembla.

The West Cliff Coal Wash Emplacement is located north of the Project underground mining areas proximal to the town of Appin, and is located between the Dharawal National Park and Metropolitan Special Area.

The geology of the area typically comprises sedimentary sandstones, shales and claystones of the Permian and Triassic Periods, composed largely of Hawkesbury Sandstone, the Narrabeen Group and Illawarra Coal Measures. The Wianamatta Group is also present only in localised areas.

The surface geology is characterised by features such as cliffs, rock outcrops and steep slopes that have been identified within the vicinity of the Project underground mining areas. These features primarily occur in alignment with streams and valleys (Appendix A).

Topography in the vicinity of the Project varies. Elevations in Area 5 vary from approximately 295 m AHD to 440 m AHD, while in Area 6, elevations vary from approximately 285 m AHD to 370 m AHD.

6.2.2 Assessment

Topography

Modifications to existing topography could occur as a result of the following Project activities:

- subsidence from underground longwall mining;
- surface disturbance work associated with the development of proposed Shaft Nos 5A, 5B, 6A and 6B and associated sediment dams; and
- development and rehabilitation of the West Cliff Stage 3 Coal Wash Emplacement.

Underground mining would result in subsidence effects on the natural topography as described in Section 6.3 and Appendix A.

The use and rehabilitation of the West Cliff Coal Wash Stage 3 Emplacement is approved as per Development Consent DA 60-03-2001 for the Dendrobium Mine. The currently approved rehabilitation concept (i.e. a vegetated final landform that is compatible with the surrounding natural vegetation and topography) would not change for the Project (Section 7).

Potential visual impacts associated with the development of the proposed ventilation shaft sites for the Project are described in Section 6.18.

6.3 SUBSIDENCE

Subsidence is the vertical and horizontal movement of the overburden and land surface that results from the extraction of underlying coal. These land surface movements are generically referred to as subsidence effects. The different types of subsidence effects, including conventional subsidence movements and non-conventional subsidence movements, are described in Section 6.3.1 and Appendix A (MSEC, 2019).

A detailed Subsidence Assessment, prepared by MSEC, is presented in Appendix A and includes predictions of the potential subsidence effects associated with the Project (including the application of specific longwall design constraints to reduce potential subsidence impacts on streams and major water supply infrastructure items as described in Section 3.5.3), paying particular attention to features that are considered to have significant ecological, economic, social, cultural and environmental value, and recorded regional and historic subsidence and sensitivity analysis of these predictions. The Subsidence Assessment describes assessment of the potential impacts on key natural and built features.

Section 6.3.1 provides a description of subsidence effects, and a summary of subsidence impacts observed at the Dendrobium Mine is provided in Section 6.3.2. Section 6.3.3 describes the subsidence prediction methodology and the main findings of the subsidence assessment for key natural and built features, and/or provides reference to where these findings are provided elsewhere in the EIS. Subsidence mitigation and adaptive management measures for the Project are described in Sections 6.3.4 and 6.3.5.

Assessment of the environmental consequences of subsidence impacts on groundwater, surface water, aquatic ecology, terrestrial flora and fauna, Aboriginal cultural heritage, non-Aboriginal heritage and visual character are provided in Sections 6.5 to 6.11 and 6.18 and Appendices B to G.

This section describes the potential subsidence impacts on the key natural and built features as a result of the Project on the surface only. Potential subsidence impacts on sub-surface features (e.g. groundwater) are described in Section 6.5 and Appendix B.

6.3.1 Description of Subsidence Effects, Impacts and Consequences

Subsidence effects, impacts and consequences are defined as follows (IEP, 2018):

- *Effect* – the nature of mining-induced deformation of the ground mass. This includes all mining-induced ground movements such as vertical and horizontal displacements and their expression as ground curvatures, strains and tilts.

- *Impact* – any physical change caused by subsidence effects to the fabric of the ground, the ground surface, or a structure. In the natural environment these impacts are principally tensile and shear cracking of the rock mass, localised buckling of the strata and changes in ground profile.
- *Consequence* – any change caused by a subsidence impact to the amenity, function or risk profile of a natural or constructed feature. Some consequences may give rise to secondary consequences. For example, the redirection of surface water to the subsurface through mining-induced fractures may be a primary consequence for water inflow to a reservoir and result in secondary consequences for ecology.

The different types of subsidence effects are described below in more detail.

Subsidence Effects

The normal ground movements from the extraction of longwalls can be categorised as conventional or non-conventional subsidence movements. Subsidence movements associated with the Project are presented below.

Conventional Subsidence Movements

- *Subsidence* – usually refers to vertical displacement of a point at the surface and is expressed in units of mm. In the Southern Coalfield it is generally accepted that the maximum achievable subsidence is up to approximately 65% of the extracted seam thickness (for single seam operations).
- *Tilt* – is the change in the slope of the ground as a result of differential subsidence and is expressed in units of millimetres per metre (mm/m) or a change in grade where 1 mm/m = 0.1%.
- *Curvature* – is approximately the rate of change of tilt over distance (or bending of the land surface) and is expressed in units of 1/km or is inverted to obtain the radius of curvature expressed in units of km. Locations that experience ‘hogging’ curvature are more likely to experience tensile strains and locations that experience ‘sagging’ curvature are more likely to experience compressive strains. In the Southern Coalfield, a multiplication factor of 15 to the curvature provides a reasonable estimate for the maximum predicted conventional tensile and compressive strains (Appendix A).
- *Tensile Strain* – is the change in horizontal distance between two points at the surface where the distance increases and is typically expressed in units of mm/m.
- *Compressive Strain* – is the change in horizontal distance between two points at the surface where the distance decreases and is typically expressed in units of mm/m.
- *Horizontal Shear Deformation* – occurs across monitoring lines and can be described by various parameters including horizontal tilt, horizontal curvature, mid-ordinate deviation, angular distortion and shear index.

The above conventional subsidence movement parameters vary during and following longwall extraction, and can be influenced by previously extracted longwalls, and are defined as follows:

- *Incremental* – additional subsidence, tilts, curvatures and strains that result from the extraction of each individual longwall.
- *Cumulative* – accumulated subsidence, tilts, curvatures and stains that result from the extraction of a series of longwalls (e.g. all of proposed Area 5 or Area 6).
- *Total* – accumulated subsidence, tilts, curvatures and strains as a result of the extraction of all Project longwalls.
- *Travelling* – transient tilts, curvatures and strains which occur as the longwall extraction face mines directly beneath a point on the surface.

Non-conventional Subsidence Movements

Far-Field Horizontal Movements

Far-field horizontal movements tend to be bodily movements towards the extracted longwall area, and are accompanied by low levels of strain (Appendix A). These movements generally do not result in impacts on natural or built features, except where the movements occur at large structures which are very sensitive to differential horizontal movements (Appendix A).

Irregular Subsidence Movements

The presence of geological features near the surface can lead to irregularities in the predicted subsidence profiles. Where faults, dykes, other geological structures, thin and brittle surface strata and cross-bedded strata exist close to the surface, irregular subsidence movements can occur (Appendix A).

Movements Due to Steep Topography

Non-conventional movements can result from the extraction of longwalls directly beneath steep slopes. These movements are typically increased horizontal movements in the downslope direction, described by elevated tensile strains near the tops and on the sides of steep slopes and elevated compressive strains near the bases of steep slopes (Appendix A).

Valley Related Movements

Valley related movements are commonly observed along stream alignments and are a natural phenomenon resulting from the formation and ongoing development of valleys. These movements can be accelerated by mining.

Valley related movements are described using the following parameters:

- *Upsidence* – is the reduced subsidence or relative uplift movement within a valley and is typically expressed in units of mm.
- *Closure* – is the reduction in the horizontal distance between the valley sides and is expressed in units of mm.
- *Compressive Strain* – occurs within the bases of valleys as a result of valley closure and upsidence movements and is calculated as the change in horizontal distance over a standard bay length, divided by the original bay length, and is typically expressed in units of mm/m.

6.3.2 Subsidence Impacts Observed at the Existing Dendrobium Mine

Secondary longwall extraction commenced at the Dendrobium Mine in Area 1 in 2005. Since mining operations began at the Dendrobium Mine, monitoring of the subsidence movements and impacts above the extracted panels at the Dendrobium Mine has been undertaken in accordance with approved SMPs.

The subsidence prediction model developed for the Dendrobium Mine has been continually reviewed and recalibrated using the available monitoring data from Areas 2, 3A and 3B (Section 6.3.3).

Monitoring data shows that observed subsidence movements are typically less than the subsidence predictions obtained from the Dendrobium Mine calibrated model. Although some observed subsidence movements exceeded the predictions, MSEC (2019) considers that the calibrated model provides adequate predictions of subsidence movements, and that while measured movements can be greater than predictions, exceedances are expected to be within the orders of accuracy of the predictive methods.

Monitoring data and observed subsidence impacts at the existing Dendrobium Mine have also been used by South32 to develop a number of longwall setbacks from both natural and built features in the longwall design developed for the Project.

6.3.3 Assessment

Modelling Methodology

Predictions of the conventional subsidence parameters for the Project longwalls were made using the Incremental Profile Method (IPM) (MSEC, 2019). This method is an empirical model based on a large database of observed monitoring data from collieries within the Southern, Newcastle, Hunter and Western Coalfields of NSW (including nearby collieries such as Dendrobium, Appin, Bulli, Metropolitan and Tahmoor) (Appendix A).

The IPM has been used throughout the life of the existing Dendrobium Mine, and has been continually reviewed and refined based on the latest available data (Appendix A), including:

- the initial IPM model developed for Areas 1, 2 and 3A for the Dendrobium Mine, based on ground monitoring data from collieries mining in the Bulli Seam in the Southern Coalfield;

- model calibration for Area 3B based on monitoring data from Longwalls 3 to 5 (Area 2) and Longwall 6 (Area 3A);
- review of the calibrated model based on additional monitoring data from Longwalls 7 and 8 (Area 3A) and Longwalls 9 and 10 (Area 3B); and
- review and calibration of the model for the Project to reflect latest monitoring data from Area 3B.

The IPM has a tendency to over-predict conventional subsidence parameters where the proposed mining geometry and geology are within the range of the empirical database (i.e. the method is generally conservative) (Appendix A).

Maximum Conventional Subsidence Effects

A summary of the maximum predicted total conventional subsidence, tilts and curvatures resulting from the extraction of the proposed longwalls in Areas 5 and 6 is provided in Table 6-3.

Conventional subsidence movement predictions for specific surface features, namely upland swamps, flora and fauna and Aboriginal heritage sites are tabulated in Appendices A and D to F.

It is noted that the maximum predicted subsidence parameters for the proposed longwalls in Areas 5 and 6 are less than the maximum predicted for the existing longwalls in Areas 3A and 3B at Dendrobium Mine. The predicted subsidence parameters for the proposed longwalls are less than the existing and approved longwalls due to the smaller seam thickness to be extracted. In addition, the width-to-depth ratios for the proposed longwalls in Areas 5 and 6 are, on average, less than the ratios for the existing and approved longwalls in Areas 3A and 3B (Appendix A).

Prediction of Non-conventional Subsidence Effects

Non-conventional subsidence movements have been included for the Project. Potential impacts and consequences of predicted non-conventional subsidence movements are discussed below and in Appendix A.

Predicted Consequences of Subsidence on Key Natural Features

Named Streams

The proposed longwalls in Areas 5 and 6 have been setback from the Avon River, Cordeaux River and Donalds Castle Creek so that the maximum predicted incremental closure is limited to 200 mm (Appendix A).

The longwall setbacks from the named watercourses have been determined using the rockbar impact model which relates the likelihood of impact on rockbars with predicted valley closure along the stream using data from longwall mining in the Southern Coalfield, including an extensive database from Dendrobium Mine. Using this historical data, the rockbar model predicts that the adoption of a target value of 200 mm predicted closure represents low-likelihood of 'Type 3' impacts (i.e. impact rate of approximately 10%) (MSEC, 2019). Type 3 impacts is defined as fracturing in a rockbar or upstream pool resulting in reduction in standing water level based on current rainfall and surface water flow.

The rockbar model has been used successfully at Dendrobium Mine, and other mines in the Southern Coalfield as an indication for low-likelihood (10%) of Type 3 impacts to stream features.

Table 6-3
Predicted Conventional Subsidence Effects for the Project Underground Mining Areas

Location	Maximum Predicted Total Subsidence (mm)	Maximum Predicted Total Tilt (mm/m)	Maximum Predicted Total Hogging Curvature (km^{-1})	Maximum Predicted Total Sagging Curvature (km^{-1})
Area 5	2,050	25	0.5	0.6
Area 6	2,450	20	0.3	0.5
Area 3A	3,600	50	1.4	1.4
Area 3B	3,600	50	1.4	1.4

Source: After Appendix A.

As a result of the Project setbacks from named watercourses, the maximum predicted vertical subsidence is less than 20 mm at the Avon River, Cordeaux River, Donalds Castle Creek and Wongawilli Creek.

Using the rockbar impact model and the specific closure predictions for the named watercourses closest to the Project longwalls, MSEC (2019) has predicted the average likelihood of potential impacts resulting in observable stream flow diversion for the short sections of named watercourses within 400 m of the proposed longwalls as follows:

- Avon River – approximately 7% of pools and channels along the 400 m section of the Avon River located within 400 m of proposed longwalls are predicted to be affected by Type 3 impacts.
- Cordeaux River – approximately 5% of pools and channels along the 250 m section of the Cordeaux River located within 400 m of proposed longwalls are predicted to be affected by Type 3 impacts.
- Donalds Castle Creek – approximately 9% of pools and channels along the 2.9 km section of Donalds Castle Creek located within 400 m of proposed longwalls are predicted to be affected by Type 3 impacts.

Impacts to stream features resulting in fracturing and diversion of flow have not been observed in the Southern Coalfield beyond 400 m from longwalls. Therefore, for the majority of the lengths of the named watercourses that are beyond 400 m from the longwalls, impacts resulting in fracturing and diversion of stream flow are not expected.

As Wongawilli Creek is located more than 600 m from the proposed longwalls, subsidence-related impacts from the Project are considered unlikely (Appendix A).

Drainage Lines

There are a number of unnamed drainage lines located directly above the proposed longwalls in Areas 5 and 6, which are typically first and second order streams (Appendix A).

The drainage lines in Area 5 are tributaries to Avon Dam and the Avon River in the western part of Area 5, and are tributaries to Donalds Castle Creek in the eastern part of Area 5. The drainage lines in Area 6 are tributaries to the Cordeaux River (Appendix A).

The drainage lines are located across the Project underground mining area and, therefore, are expected to experience the full range of predicted subsidence movements (Appendix A).

Potential subsidence impacts to the drainage lines include increased levels of ponding, flooding and scouring due to mining-induced tilt. There is also likely to be cracking, fracturing and dilation of bedrock in the creek beds (Appendix A), leading to surface water diversion and reduced pool water levels.

The potential impacts of increased ponding and scouring of the drainage lines due to mining-induced tilt are expected to be minor and localised. Fracturing of the bedrock is expected to occur along the sections of the drainage lines that are located directly above the proposed longwalls and may occur beyond the longwalls at distances of up to 400 m (Appendix A).

As the predicted subsidence parameters for the proposed longwalls are less than the maximum predicted for the existing and approved longwalls at the Dendrobium Mine due to their reduced extraction heights, the likelihood and extents of the assessed impacts on the drainage lines due to the extraction of the proposed longwalls in Areas 5 and 6 are expected to be similar or less than those observed above the previously extracted longwalls in Area 3B (Appendix A).

Stream Features

A number of stream features along the named streams and drainage lines have been identified and mapped by South32.

Of these mapped features, a number of “key stream features” (i.e. pools >100 m^3 and permanent, waterfalls >5 m and with a permanent pool at the base) were identified on stream reaches of second order or above.

Based on the relative significance of these stream features (Section 6.6.3), the longwall layout for the Project incorporates setbacks to avoid the direct undermining of these mapped key stream features (Section 3.5.3).

The setback distances incorporated into the Project longwall layout are based on observations from the Dendrobium Mine Area 3B, and have been developed to minimise the likelihood that the stream features will be physically damaged by subsidence impacts. A description of the setbacks incorporated is provided in Section 3.5.3 and Appendix A.

These setbacks may also result in the avoidance of additional stream features that do not meet the definition of a key stream feature. The likelihood of potential impacts to these additional stream features may also be reduced if they are not directly undermined.

Other stream features not identified as key stream features would be directly undermined and are predicted to experience the full range of subsidence impacts (Appendix A).

Potential environmental consequences as a result of subsidence for stream features are assessed in Section 6.6 and Appendix C.

Cliffs

A cliff is defined as a continuous rockface having a minimum height of 10 m, a minimum length of 20 m and minimum slope of 2 in 1 (i.e. 63°) (Appendix A).

The cliffs in the Project underground mining area have formed predominantly from Hawkesbury Sandstone, with the faces being at various stages of weathering and erosion. There are 40 cliffs that have been identified directly above the proposed longwalls in Area 5. There are no cliffs located directly above the proposed longwalls in Area 6 (Appendix A).

Potential subsidence impacts on cliffs located directly above the proposed longwalls (i.e. cliffs in Area 5) include fracturing, and where the exposed rock face is marginally stable, cliff instabilities (Appendix A).

Based on previous experience at the Dendrobium Mine, MSEC (2019) predicts that on average between 7 and 10% of the total length, or between 3 and 5% of the total face area of the cliffs located directly or partially above the proposed longwalls in Area 5 would be impacted by subsidence.

Isolated rock falls could potentially occur at some of the cliffs located outside the extents of the proposed longwalls in Area 5 and Area 6, however, it is predicted this would represent less than 1% of the affected cliffs (Appendix A).

Rock Outcrops and Steep Slopes

Steep slopes occur across the Project underground mining area and predominately occur along the alignments of streams. Rock outcrops are defined as exposed rockfaces and are found primarily within the valleys of streams and along steep slopes (Appendix A).

These features are predicted to experience the full range of subsidence movements, with potential subsidence impacts including tension cracks at the tops and the sides of rock outcrops and steep slopes, buckling of bedrock at the bottom of rock outcrops, and compression ridges at the bottoms of steep slopes (Appendix A). If tension cracks are left untreated, there is potential for soil erosion to occur.

State Conservation Areas

The Project underground mining areas are located proximal to the Upper Nepean State Conservation Area. The proposed longwalls do not directly undermine the Upper Nepean State Conservation Area. A small portion of the Upper Nepean State Conservation Area is located within the 600 m boundary from proposed Longwall 508B.

Although not directly undermined, potential subsidence impacts to the Upper Nepean State Conservation Area could include low-level vertical subsidence and surface cracking (Appendix A).

Predicted Consequences of Subsidence on Key Built Features

Water Supply Infrastructure

The proposed Project underground mining areas are located proximal to the Avon and Cordeaux Dams and their associated dam walls.

The longwall layout proposed for the Project has been designed by South32 to reflect the adoption of a number of longwall mine constraints to minimise potential impacts, including (Section 3.5.3):

- a minimum setback distance of 1 km from the existing Avon and Cordeaux Dam walls for any secondary extraction; and
- no direct undermining of the existing Avon and Cordeaux Dam waterbodies, with a minimum 300 m longwall setback adopted from the existing dam FSLs.

Appendix A presents the predicted potential maximum subsidence, tilt and curvature and far-field horizontal movements for the Avon and Cordeaux Dam walls. Based on the distances from the dam walls to longwall mining, adverse subsidence impacts due to the Project are not expected (Appendix A).

Other Surface Infrastructure

The potential impacts of subsidence on other surface infrastructure are assessed in Appendix A, including:

- railway infrastructure (e.g. the Maldon-Dombarton Railway Corridor [not currently operational]);
- public roads (e.g. Picton Road);
- gas infrastructure (e.g. EGP and a portion of the Sydney Region Trunk Distribution System gas distribution network);
- electrical infrastructure (e.g. TransGrid ETLs and towers, and Endeavour Energy powerlines);
- telecommunications infrastructure (e.g. Telstra telecommunications antennae);
- survey control marks;
- other structures and facilities (e.g. WaterNSW owned buildings and structures); and
- fire trails and other minor tracks and roads.

Potential impacts to these key built features include cracking of roads and building surfaces, rippling and stepping of unsealed road surfaces, bending and axial loads on gas pipelines, and increased loads on transmission line infrastructure.

The locations of the key built features in the vicinity of the Project underground mining areas are shown on Figure 6-1.

6.3.4 Mitigation Measures

Section 3.5.3 describes the specific setbacks that have been incorporated into the Project longwall layout design to reduce potential subsidence impacts on the key natural and built features in consideration of previous mining experience in Dendrobium Mine Area 3B and key stakeholder feedback.

Measures to manage the impacts of subsidence on key built features would be developed in consultation with the infrastructure owners as a component of future Extraction Plans.

Mitigation measures for subsidence impacts on groundwater, surface water, aquatic ecology, terrestrial flora and fauna, Aboriginal cultural heritage, non-Aboriginal heritage and visual character are provided in Sections 6.5 to 6.11, 6.18 and Appendices B to F.

Named Streams, Drainage Lines and Mapped Stream Features

Avoidance

While it is not considered economic for the Project to avoid undermining all ephemeral drainage lines (Section 9), the longwall layout proposed for the Project has been designed by South32 to avoid the direct undermining of mapped key stream features (Section 3.5.3), to minimise the likelihood that the stream feature will be physically damaged by subsidence impacts.

Mitigation and Remediation

Potential stream mitigation and remediation measures have been developed in consideration of previous mining experience in the Southern Coalfield and are discussed in Section 7.

If physical damage to named streams and key stream features occurs due to the Project as a result of subsidence impacts, remediation techniques would be implemented to repair the damage.

Current mitigation and remediation methods for subsidence impacts on streams at the Dendrobium Mine are described within the *Dendrobium Area 3B Watercourse Impact, Monitoring, Management and Contingency Plan* (South32, 2017a) (WIMMCP) (Section 7.3.6).

The WIMMCP would be reviewed and updated accordingly for the Project, and it is proposed that similar remediation methods would be implemented for the Project as required, incorporating any learnings and experience from existing operations using an adaptive management approach (Section 7.3.6).

Cliffs, Rock Outcrops and Steep Slopes

The mitigation, management and monitoring measures developed to manage potential subsidence impacts to cliffs, rock outcrops and steep slopes for the Project would be included as a component of future Extraction Plans for the Project.

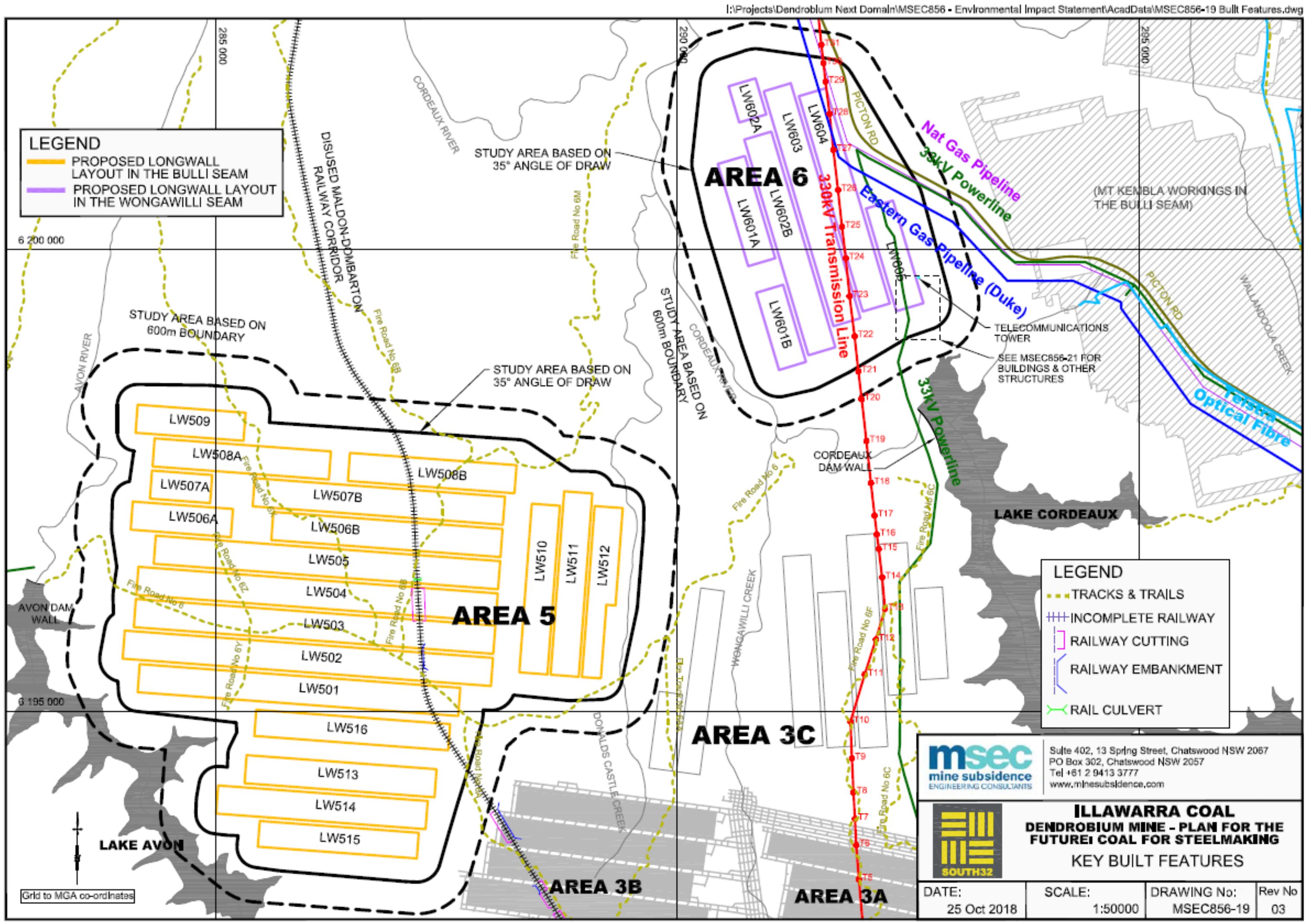


Figure 6-1 **Key Built Features Located in the Project Extent of Longwall Mining and Surrounds** (Drawing No MSEC856-19 from MSEC, 2019)

Remediation measures may be required for the Project to manage any potential subsidence impacts to rock outcrops and steep slopes. These remediation measures would include:

- infilling of surface cracks with soil or other suitable materials;
- regrading and recompacting of the surface; and
- implementation of erosion protection measures, such as planting of additional vegetation, where appropriate.

State Conservation Areas

While a small portion of CCL 768 underlies the Upper Nepean State Conservation Area, there would be no longwall mining beneath the Upper Nepean State Conservation Area for the Project.

Railway Infrastructure

Construction of the Maldon-Dombarton Rail Corridor was suspended in 1988, however there is potential for development of this corridor to recommence in the future (Section 5). At the time of abandoning the work, the major earthworks had been completed, but no tracks or associated equipment had been installed (Appendix A).

In its current state of completion, South32 would undertake periodic inspections of the disused railway corridor during active subsidence and remediate larger surface cracking in the embankment and cutting if this were to occur as a result of the Project (Appendix A).

If the railway were to be completed prior to active subsidence at the Project, a management plan for the Project would be developed to manage subsidence impacts on the Maldon-Dombarton Rail Corridor, in consultation with the ARTC.

The future track and associated infrastructure could be managed using strategies similar to those adopted for the Main Southern Railway at Appin and Tahmoor Collieries. The management strategies could include the installation of rail expansion switches and real-time rail stress monitoring during active subsidence (Appendix A).

Roads

South32 would develop a Picton Road Management Plan, in consultation with RMS for the Project for managing potential subsidence-related impacts on Picton Road during the extraction of Longwalls 604 and 605 in Area 6.

The development of management measures would involve input from RMS, and would include:

- ground monitoring; and
- periodic visual inspections of Picton Road.

The mitigation, management and monitoring measures developed to manage potential subsidence impacts to Picton Road for the Project would be included as a component of the relevant Extraction Plan for longwalls in Area 6.

Unsealed Roads and Tracks

Monitoring and maintenance of the unsealed roads and access tracks (e.g. firetrails) would be detailed in future Extraction Plans. It is anticipated that any subsidence-related impacts would be remediated in accordance with existing management strategies implemented at the Dendrobium Mine.

Water Supply Infrastructure

Mining has previously occurred proximal to a number of WaterNSW infrastructure items in the Southern Coalfield (Appendix A). At the Dendrobium Mine, longwalls in Area 1 and Area 2 have been extracted proximal to the Upper Cordeaux No. 2 reservoir and associated dam wall (Appendix A).

The longwall layout proposed for the Project has been designed by South32 to reflect the adoption of a number of longwall mine constraints to minimise potential impacts to WaterNSW infrastructure (Section 3.5.3).

South32 would develop mitigation, management and monitoring measures for potential subsidence impacts to the Cordeaux Dam, Avon Dam and associated dam walls, in consultation with WaterNSW and the DSC. Measures may include the development of a detailed monitoring program and Trigger Action Response Plan (TARP). South32's existing WaterNSW Asset Management Plan would, as relevant, be reviewed and revised for the Project.

South32 would comply with any DSC requirements or conditions relating to mining within the Cordeaux Dam and Avon Dam Notification Areas for the Project (Section 4.5.1).

Gas Supply Infrastructure

South32 would conduct a numerical analysis of the pipelines based on the predicted subsidence movements to assess whether the existing gas pipelines could accommodate the predicted subsidence movements. If it was found that the existing gas pipelines could not accommodate these movements, then potential impacts would be managed using similar strategies to those adopted at the Appin and West Cliff Collieries, including:

- uncovering and exposing the sections of the pipelines located within the larger stream valleys;
- temporarily supporting the pipelines on sandbags to isolate them from the mining-induced ground movements;
- monitoring the mine subsidence movements using ground monitoring lines;
- monitoring the pipe stresses using strain gauges; and
- the implementation of a TARP where preventive measures are undertaken when prescribed triggers have been reached, such as adjusting the profiles of the pipelines using sandbags or by reducing the operating pressures.

South32 would develop management strategies to address the potential subsidence impacts, in consultation with the gas pipeline owners (i.e. Jemena Gas Networks) as a component of future Extraction Plans.

Electricity Supply Infrastructure

South32 has developed a number of management measures for electricity supply infrastructure that have been directly undermined previously at the Dendrobium Mine (Appendix A).

South32 would review these existing measures, where appropriate, and develop management strategies to manage potential subsidence impacts on the electricity supply infrastructure for the Project, in consultation with the relevant infrastructure owners (i.e. TransGrid and Endeavour Energy) as a component of future Extraction Plans.

Predicted subsidence movements to the 330 kV transmission towers would be reviewed by TransGrid and a detailed structural analysis undertaken. If required, any necessary mitigation measures would be implemented so the towers could be maintained in a safe and serviceable condition throughout the life of the Project, including:

- the installation of cable rollers;
- the construction of cruciform bases;
- provision of monitoring points on the tower bases and tops; and
- development of a TARP.

Predicted subsidence movements to the 33 kV powerlines would be reviewed by Endeavour Energy and relevant preventative measures developed. These measures may include the installation of cable rollers, guy wires or additional poles, or the adjustment of cable catenaries. South32 would monitor the powerlines during active subsidence to maintain them in a safe and serviceable condition.

Telecommunications Infrastructure

Predicted subsidence movements to the telecommunications infrastructure (i.e. circular telecommunications antennae) would be reviewed by Telstra and relevant preventative measures developed. It is expected that potential subsidence impacts that affect the antennae line of sight can be managed by making relevant adjustments to the direction of the antennae during active subsidence (Appendix A).

South32 would develop management strategies to address the potential subsidence impacts to the telecommunications infrastructure, in consultation with the relevant infrastructure owner (i.e. Telstra) as a component of future Extraction Plans.

Other Structures and Facilities

Other structures and buildings potentially affected by subsidence impacts from the Project are those located proximal to proposed Area 6, including structures associated with Cordeaux Dam Picnic Area, owned by WaterNSW (Appendix A).

South32 would develop Property Subsidence Management Plans (PSMPs) in consultation with WaterNSW to manage any potential subsidence on these structures.

Survey Control Marks

Survey control marks that are required for future use would be re-established, as required following mining, in consultation with the Department of Lands (Appendix A).

6.3.5 Adaptive Management

Subsidence performance measures and mining constraints would be detailed in Extraction Plans for the Project, along with monitoring, mitigation, adaptive management and contingency measures.

Where relevant, performance measures, monitoring locations/methods, TARPs and contingency measures would be developed in consultation with relevant asset owners and government agencies.

6.4 LAND RESOURCES AND LAND USES

A description of land resources in the vicinity of the Project is provided in Section 6.4.1. Section 6.4.2 describes the potential impacts associated with the Project on land resources, while Section 6.4.3 outlines applicable mitigation measures.

6.4.1 Existing Environment

A description of land resources including land use, soils and agricultural suitability of the Project area and surrounds are presented below.

Land Use

The Project underground mining areas are located on land that was once the traditional country of the Tharawal people (Appendix F). European settlement of the area began in the early 1840s in the Cordeaux River Area (Appendix G).

Historical research conducted for the Project (Appendix G) indicates that the initial European land use in the area involved the planting of orchards, grazing and small-scale timber industries in the 1860s.

Coal mining also commenced in the 1800s and continues throughout the region.

The majority of the Project area and surrounds is located within reserves set aside for conservation (e.g. the Upper Nepean and Illawarra Escarpment State Conservation Areas) and/or water catchment areas (e.g. the Metropolitan Special Area) (Figure 3-3).

"Special Areas" are lands declared under the *WaterNSW Act, 2014* for their value in protecting the quality of the raw water, for provision of drinking water to regions including Sydney, the Illawarra and the Blue Mountains, as well as for their ecological integrity (WaterNSW and OEH, 2015). Public access to the Metropolitan Special Area is restricted by WaterNSW.

Major water storage facilities in the vicinity of the Project underground mining areas, including Cordeaux and Avon Dams are significant man-made features in the regional setting (Figure 3-3).

The majority of the Project area proximal to Wollongong (i.e. proximal to the existing Dendrobium Mine surface facilities such as the Kemira Valley Rail Line and Dendrobium CPP) has been cleared for residential and industrial uses (Figure 3-3). Key land zoning in the vicinity of the Project is described further in Attachment 6.

Project Underground Mining Areas

Land use in the Project underground mining areas and surrounds (including the areas proposed for the ventilation shaft sites) include:

- the Metropolitan Special Area;
- the Upper Nepean State Conservation Area, located north of Area 5 and to the west of Area 6;
- a public road corridor (Picton Road);
- the disused Maldon-Dombarton Rail Corridor;
- infrastructure (e.g. ETLs, gas pipelines, telecommunications lines and associated facilities); and
- mining-related land uses including surface infrastructure, environmental monitoring and restoration works associated with existing and historic underground mining operations.

The Project underground mining areas are entirely located within the Metropolitan Special Area, which makes up a portion of the Sydney Drinking Water Catchment.

Existing Surface Infrastructure Facilities

Local land uses proximal to the Project surface facilities (including the Dendrobium Pit Top, Cordeaux Pit Top, Kemira Valley Coal Loading Facility, Kemira Valley Rail Line and Dendrobium CPP), include:

- the Illawarra Escarpment State Conservation Area;
- the Metropolitan Special Area;
- a range of public roads;
- rural residential, suburban and recreational areas;
- infrastructure (e.g. ETLs, rail lines, telecommunications lines and associated facilities);
- mining-related land uses; and
- steel production, port facilities and major industrial complexes.

Land uses proximal to the West Cliff Coal Wash Emplacement include:

- Dharawal National Park;
- the Metropolitan Special Area (however the West Cliff Coal Wash Emplacement is not located within the Special Area);
- rural residential and suburban areas;
- Appin Township;
- a public road corridor (Appin Road); and
- other mining-related infrastructure and land uses.

Soils

Soil landscapes in the vicinity of the Project have been mapped by the Soil Conservation Service of NSW as described in the document Soil Landscapes of the Wollongong – Port Hacking 1:100,000 Sheet (Hazelton and Tille, 1990).

Two dominant soil landscapes (i.e. Hawkesbury and Lucas Heights) were identified in the vicinity of Project underground mining areas, including at the proposed ventilation shaft sites. Of these, the Hawkesbury colluvial soil landscape dominates the valleys of the Cordeaux and Avon Dams as well as the Cordeaux and Avon River systems, while the Lucas Heights residual soil landscape dominates the ridges and areas of higher elevation.

Small areas of Volcanic residual soil landscape were also identified in the mapping within Area 5 in areas of higher elevation. The Volcanic residual soil landscape is characterised by gently undulating valley floors surrounded by steep colluvial side slopes formed on volcanic intrusions.

In addition, the dominant soil types identified at surface infrastructure facilities related to the Project include:

- Lucas Heights residual soil landscape at the Cordeaux Pit Top;
- Illawarra Escarpment soil landscape at the Dendrobium Pit Top;
- Illawarra Escarpment and Gwynneville soil landscapes identified at the Kemira Valley Coal Loading Facility;
- Lucas Heights and Hawkesbury soil landscapes at the West Cliff Coal Wash Emplacement; and
- Fairy Meadow and Gwynneville soil landscape along the Kemira Valley Rail Line, as well as disturbed terrain where the rail line is located proximal to the Port Kembla industrial precinct.

The Dendrobium CPP is located on disturbed terrain within the Port Kembla industrial precinct.

Hazelton and Tille's (1990) analysis of the limitations of the soils indicated that the soils identified exhibited various limitations, including low fertility (e.g. Hawkesbury, Lucas Heights and Illawarra Escarpment soil landscapes) as well as high erosion potential (e.g. Hawkesbury, Gwynneville and Volcanic soil landscapes) (Hazelton and Tille, 1990).

Agricultural and Rural Suitability

None of the areas associated with the Project are currently used for agriculture.

The majority of land within the Project area is not available for agricultural use as it is located within the Metropolitan Special Area and is reserved land for the protection of the Sydney Drinking Water Catchment.

The existing West Cliff Coal Wash Emplacement is not located within the Metropolitan Special Area, however, it would be rehabilitated to be consistent with the surrounding vegetation and topography rather than rehabilitated for agricultural use (Section 7).

The remaining surface facilities for the Project (e.g. the Dendrobium Pit Top, Kemira Valley Coal Loading Facility, Dendrobium CPP and the Kemira Valley Rail Line) are existing Dendrobium Mine facilities located in rural, residential, suburban and industrial settings.

As the Project would not result in any impact to existing agriculture, an Agricultural Impact Statement was not required for the Project.

6.4.2 Assessment

Land Use

As described in Section 3, the Project would largely comprise underground mining activities. There would be limited upgrades to the existing Dendrobium Mine surface infrastructure and minor additional surface development for surface infrastructure ancillary to underground mining (e.g. proposed ventilation shaft sites).

The Project would involve the continued development and rehabilitation of the West Cliff Stage 3 Coal Wash Emplacement, which is currently approved in accordance with Development Consent DA 60-03-2001 and ongoing use of the West Cliff Stage 4 Coal Wash Emplacement, which is currently approved in accordance with Bulli Seam Operations Project Approval 08_0150.

Consideration of the potential impacts of the Project on the Metropolitan Special Areas' water supply catchments (e.g. yield and water quality) is provided in Section 6.6, and indicate that the Project would not have a significant adverse impact on the quality or yield of the water in the Metropolitan Special Area within the Sydney Drinking Water Catchment.

Potential subsidence impacts on surface features associated with other land uses that are above or in close proximity to the Project extent of longwall mining are considered in Section 6.3 and Appendix A, including streams, cliffs, steep slopes, roads, railway corridors (disused) and service supply infrastructure (e.g. ETLs and gas pipelines) and the Upper Nepean and Illawarra Escarpment State Conservation Areas.

The Subsidence Assessment (Appendix A) concludes that potential subsidence effects on these features can be managed to minimise impacts. Specific measures that would be implemented for the management of key surface features as the Project progresses would be prepared as a component of future Extraction Plans.

Consideration of potential impacts to biodiversity are considered in Section 6.7 to 6.9, along with mitigation, monitoring and offset measures.

Soil and Erosion Potential

A number of the soil landscapes within the Project area are highly susceptible to erosion (i.e. Hawkesbury, Gwynneville and Volcanic soil landscapes) (Section 6.4.1).

Potential impacts of the Project on soils would primarily be associated with the development of the proposed ventilation shaft sites and Dendrobium Pit Top Carpark Extension and supporting infrastructure, and other short-term surface activities. The potential impacts of these Project components would relate primarily to:

- disturbance of *in-situ* soil resources (e.g. during construction);
- alteration of soil structure beneath infrastructure items, hardstand areas and water management structures;
- possible soil contamination resulting from spillage of fuels, lubricants and other chemicals;
- increased erosion and sediment movement due to exposure of soils during construction, exploration or stream remediation activities; and
- alteration of physical and chemical soil properties (e.g. structure, fertility, permeability and microbial activity) during soil stripping and stockpiling operations (e.g. at the West Cliff Coal Wash Emplacement).

The potential impacts of Project-related subsidence on slope stability and surface cracking is assessed in Section 6.3 and Appendix A. The potential impact of the Project on streams and swamps (e.g. scour/erosion potential) is described in Sections 6.6 and 6.8.

Water management systems to control sediment runoff are described in Appendix C.

Land Contamination Potential

A Land Contamination Assessment was undertaken in accordance with *Managing Land Contamination – Planning Guidelines SEPP 55 – Remediation of Land* (Department of Urban Affairs and Planning and Environment Protection Agency, 1998) by JBS&G (2019) and is presented in Appendix O. The Land Contamination Assessment included a desktop review of the Project surface facilities and underground mining areas, and site inspection of the proposed ventilation shaft sites and proposed site of the Dendrobium Pit Top Carpark Extension.

Potential sources of land contamination in these areas and the existing surface facilities included spills from historical and/or existing activities, (e.g. from fuel and oil storages), disposal of historical waste and rainfall runoff. JBS&G (2019) concluded there is a low potential for the proposed Dendrobium Pit Top Carpark Extension site to have become contaminated as a result of historical and/or existing site uses, and no contamination has been identified that would preclude the development of the Project.

JBS&G (2019) concluded that for the existing surface facilities, any potential contamination (e.g. existing under pavements or on unsealed work or storage areas) is not significant and not likely to migrate off-site. Upgrades to the existing infrastructure for the Project occur within the existing disturbance footprint, and no requirement for remediation measures to make the existing surface facilities suitable for supporting the proposed extension of the underground mining operation for the Project was identified. JBS&G (2019) concluded that the only parts of the Project that would constitutes a 'change of use' is the development of the proposed Dendrobium Pit Top Carpark Extension as well as the proposed underground mining Areas 5 and 6.

In regard to the Cordeaux Pit Top, while the Project involves its used for men and materials access to the underground operations, the Cordeaux Pit Top is an existing facility (e.g. comprising paved carparks, office buildings, existing sediment controls) (Figures 2-11), which is currently used for office space by South32 employees. The Cordeaux Pit Top is located within existing ML 25.

No potential contamination was identified within the proposed Project underground mining areas due to their location within the Metropolitan Special Area (Appendix O).

6.4.3 Mitigation Measures

Land Use

Management measures to reduce the potential impacts of subsidence on built infrastructure are provided in Section 6.3.4.

Surface works in the Metropolitan Special Area would be undertaken in consultation with WaterNSW and in accordance with existing Dendrobium Mine procedures, to avoid significant adverse impacts on existing land use in the Metropolitan Special Area. Access to the Metropolitan Special Area would also continue to be undertaken in accordance with WaterNSW requirements.

Management and adaptive management measures with respect to potential impacts of the Project on surface water, aquatic ecology, upland swamps and terrestrial flora and terrestrial fauna within the Project area are provided in Sections 6.6 to 6.9, respectively and are summarised in Section 8.

Section 7 describes the rehabilitation principles for Project land disturbance areas, including those within the Metropolitan Special Area.

Soil and Erosion Potential

Erosion and sediment control strategies for the Project would be based on similar practices currently undertaken as part of the existing Erosion and Sediment Control Plan (part of the existing Water Management Plan) for the Dendrobium Mine, which would be reviewed and updated for the Project.

Mitigation measures to control erosion and sediment migration would include:

- minimising disturbance of land;
- use of sediment retention storages to contain and treat runoff from surface facilities, where appropriate (e.g. sediment dams, Dendrobium Pit Top treatment plant);
- rehabilitation and revegetation of surface disturbance areas after the completion of construction works;
- track rehabilitation works; and
- installation of sediment traps and pits.

Specific erosion and sediment control works and additional minor controls would be developed in consultation with WaterNSW as required over the Project life within the Metropolitan Special Area.

Land Contamination Potential

Measures to reduce the potential for the contamination of land for the Project would be based on accepted practices currently undertaken at the Dendrobium Mine and would be further documented in relevant environmental management plans for the Project.

General measures to reduce the potential for contamination of land include the following:

- Contractors that transport dangerous goods to and from the site would be appropriately licensed in accordance with the provisions of the *Australian Code for the Transport of Dangerous Goods by Road and Rail* (National Transport Commission, 2014) (or its latest version).
- Fuel and explosive storage areas would be regularly inspected and maintained.

Prior to commencing any potential works on the historical structures at the Dendrobium Pit Top, a hazardous material survey would be undertaken to assess the potential for lead paints and asbestos-containing material within building structures to allow management/removal actions to be appropriately implemented.

Additional mitigation and management measures would be implemented during activities such as surface development works to reduce the potential for land contamination in the Metropolitan Special Areas in consultation with WaterNSW, where appropriate.

6.5 GROUNDWATER

6.5.1 Methodology

A Groundwater Assessment for the Project was undertaken by HydroSimulations and is presented in Appendix B.

Peer review of the Groundwater Assessment has been undertaken by Dr Frans Kalf (Kalf & Associates) (Attachment 5).

A description of the existing groundwater environment is provided in Section 6.5.2. Section 6.5.3 describes the assessment of potential impacts for the Project, while Sections 6.5.4 and 6.5.5 outline mitigation measures and adaptive management, respectively.

6.5.2 Existing Environment

Stratigraphy

The Dendrobium Mine is located within the Southern Coalfield, which lies within the Sydney Basin.

The typical stratigraphy of the Southern Coalfield is presented in Table 6-4. Formations in the Southern Coalfield are primarily Permo-Triassic sedimentary rock sequences underlain by undifferentiated sediments of Carboniferous and Devonian age.

The coal seams within the Illawarra Coal Measures are those mined in this part of the Sydney Basin. The two main coal seams mined in the Southern Coalfield are the Bulli and Wongawilli Seams. These are the target coal seams for the Project in Areas 5 and 6, respectively (Section 3).

Within and around the Project underground mining areas, the Hawkesbury Sandstone is the dominant outcropping formation (Appendix B), along with small pockets of Quaternary-aged swamp deposits (Appendix B).

To the north of the Project underground mining areas are isolated shale cappings of the Wianamatta Group.

Plate 6-1 provides a geological cross-section through Areas 5 and 6.

Hydrostratigraphy

The main groundwater-bearing strata relevant to the Project underground mining areas is the Hawkesbury Sandstone. It primarily comprises sandstone, however, it also contains shales, mudstone and clay-rich lenses and horizons. The effect of these clay-rich lenses and horizons is that, while the Hawkesbury Sandstone is considered as a single stratigraphic entity, it essentially forms a series of layered aquifers (Appendix B).

Table 6-4
Summary of Typical Southern Coalfield Permo-Triassic Stratigraphic Sequence

Period	Group	Sub-Group	Formation		Typical Thickness
Triassic	Hawkesbury Sandstone (**HBSS**)				<120 m
	Narrabeen Group		Newport Formation		10 m
			Garie Formation		3 m
		Clifton Sub-group	Bald Hill Claystone (**BHCS**)		12 m
			Colo Vale Sandstone	Bulgo Sandstone (**BGSS**)	95 m
				Stanwell Park Claystone (**SPCS**)	20 m
				Scarborough Sandstone (**SBSS**)	30 m
			Wombarra Formation	Wombarra Claystone (**WBCS**)	25 m
				Coal Cliff Sandstone (**CCSS**)	15 m
Permian	Illawarra Coal Measures		Bulli Seam (**BUSM/BUCO**)[1]		200 to 300 m
			Eckersley Formation		
			Wongawilli Seam (**WWSM/WWCO**)[2]		
			Kembla Sandstone		

Source: After Appendix B

1 Target coal seam for Area 5, with seam thickness approximately 2.1 to 3.2 m and extraction height up to 3.2 m.

2 Target coal seam for Area 6, with seam thickness approximately 9 to 11 m and extraction height up to 3.9 m.

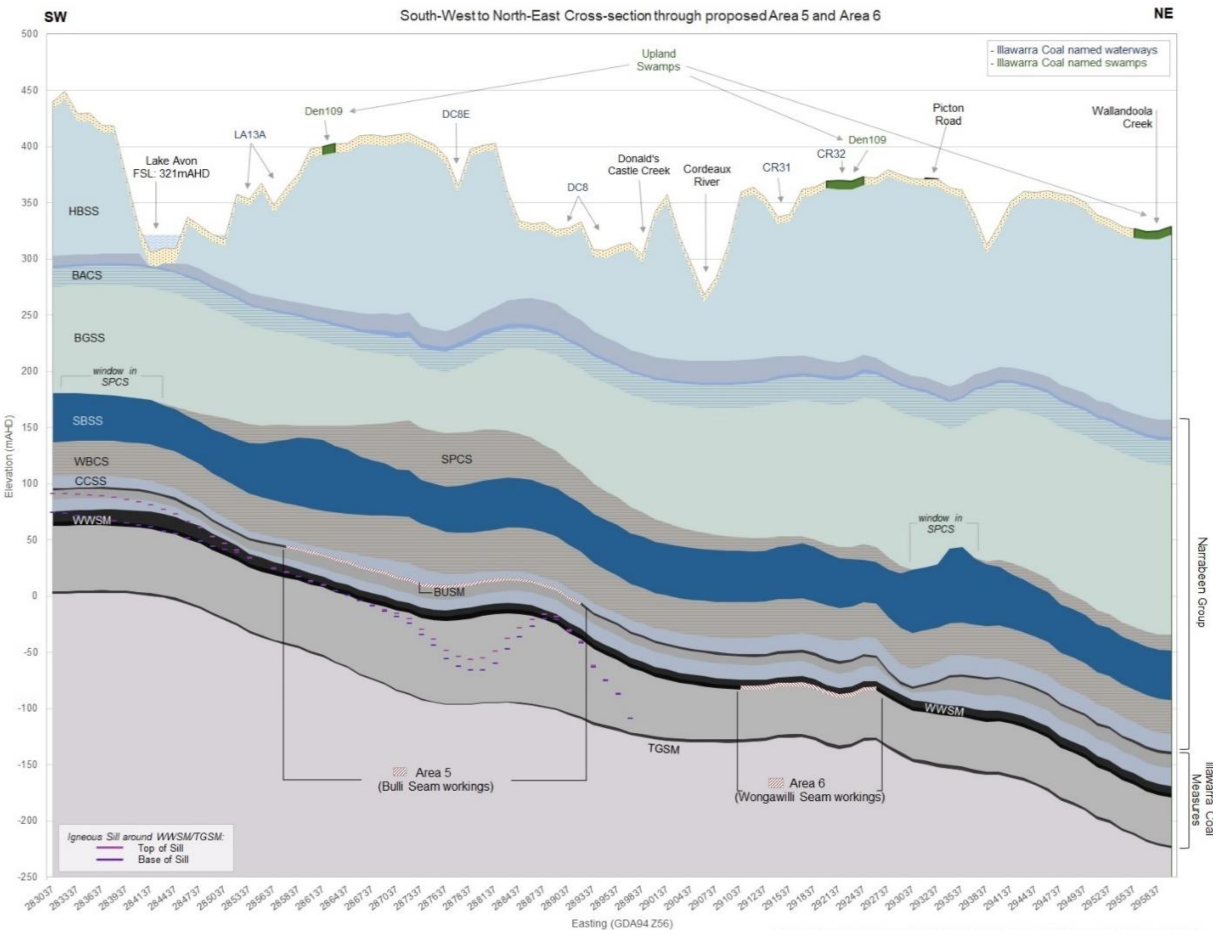


Plate 6-1 Geological Cross-section through Areas 5 and 6 [Figure 3-4 from HydroSimulations, 2019]

Bore yields within the Hawkesbury Sandstone are variable. Drilling and testing undertaken near the Avon Dam indicated yields of 2 to 26 litres per second (L/s) (Appendix B) at the following bores:

- GW040952 – screened at 80 to 145 m below ground level [mBGL]), with yield of 26 L/s.
- GW040946 – screened at 92 to 148 mBGL with yield of 2 L/s.

Smaller quantities of groundwater can be extracted from parts of the Narrabeen Group, such as the Bulgo Sandstone and Illawarra Coal Measures (Appendix B).

Small pockets of unconsolidated material, typically 1 to 3 m thick, found in the Project mining area and surrounds can be associated with upland swamps (Section 6.8).

Groundwater Levels

Figure 6-2 shows South32's groundwater level monitoring network in the vicinity of the Project underground mining areas and the Dendrobium Mine.

The network includes monitoring of groundwater levels in the Hawkesbury Sandstone, Bulgo Sandstone, Scarborough Sandstone, Coal Cliff Sandstone, Bulli Seam and Wongawilli Seam.

Regional groundwater level contours for the Hawkesbury Sandstone indicate the dominant regional groundwater flow direction is to the north, generally aligning with surface topography and drainage toward the centre of the Sydney Basin. For the Bulgo Sandstone, the regional pattern of groundwater flow is less influenced by surface drainage, however, groundwater flow is still generally towards the north (Appendix B).

Similarly, groundwater levels in the Bulli Seam are generally toward the north, with localised drawdown apparent around the Dendrobium Mine, Bulli Seam Operations and Tahmoor Mine (Appendix B). Due to limited availability of data beyond the Dendrobium Mine area, regional groundwater level contours were not prepared for the Wongawilli Seam (Appendix B).

Groundwater Quality

More than 3,280 groundwater samples have been collected and analysed at Dendrobium Mine since 2004, with groundwater quality found to be highly variable depending on the geological unit and sampling depth (Appendix B).

In general, the Hawkesbury Sandstone has relatively fresh groundwater, with salinity less than 1,000 microSiemens per centimetre (µS/cm). Salinity typically increases with depth, reflecting the longer groundwater residence times in the older stratigraphic units (Appendix B).

In the Project area, groundwater throughout the stratigraphic sequence is typically less than 2,500 µS/cm (one of the criteria for 'highly productive groundwater' in the NSW Aquifer Interference Policy [AIP]). This includes analysis of data from the Hawkesbury Sandstone, Bald Hill Claystone, Scarborough Sandstone and mine seeps (i.e. samples from development roadway roofs, mining faces and goaf, which are generally representative of the quality of the Wongawilli Seam) (Graph 6-1) (Appendix B).

Existing Water Use

There is limited groundwater use in the Metropolitan Special Area.

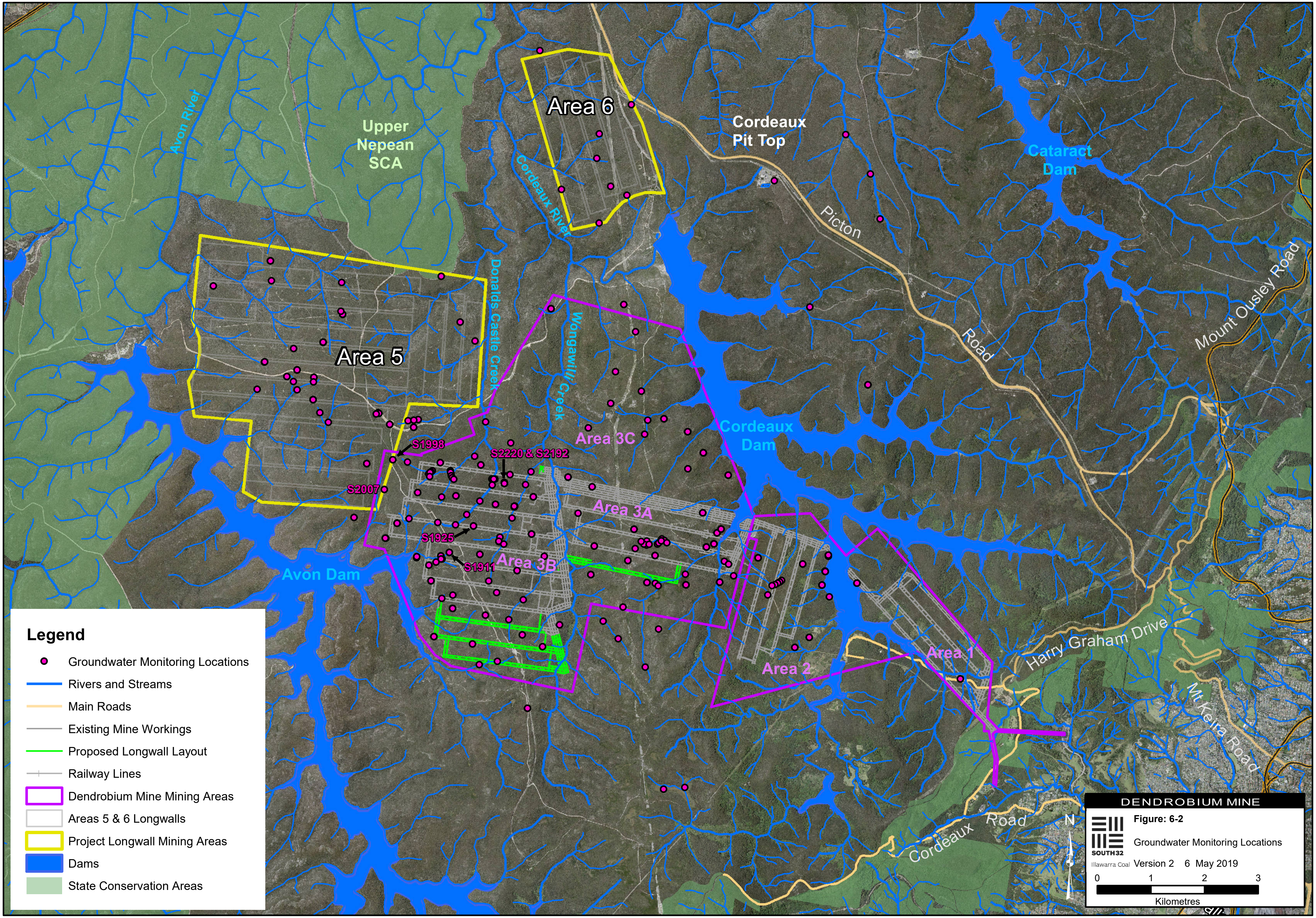
Groundwater bores in the Project region (i.e. a 40 by 40 km area centred on the Project underground mining areas) are predominantly located to the north-west of the Metropolitan Special Area around Tahmoor, Picton and Bargo, and to the east of the Metropolitan Special Area along the coastal plains.

Based on review of WAL information there are over 700 bores within the Project region. Of these 700 bores, 309 have been classified as water supply works as per the definition in the NSW AIP (Appendix B).

Licensed groundwater entitlements for these bores total approximately 3,272 megalitres per annum (ML/annum) for private or small-scale government use. It is noted there is an additional 981,000 ML/annum entitlement associated with unregulated river licences held by government agencies in the region (Appendix B).

To the west of the Illawarra Escarpment, approximately 90% of the licensed groundwater entitlement by bores in the Project region is from the Hawkesbury Sandstone, with the remaining 10% from the Bulgo Sandstone (Appendix B).

Along the coastal plain to the east of the Illawarra Escarpment the majority of licensed extraction is from the outcropping Permian strata (Appendix B).



Area 6
Upper Nepean SCA
Avon River
Cordeaux River
Cordeaux Pit Top
Picton Road
Cataract Dam
Mount Ousley Road
Area 5
Donalds Castle Creek
Wongawilli Creek
Area 3C
Cordeaux Dam
S1998
S2220 & S2192
S2007
Area 3A
S1925
S1911
Area 3B
Avon Dam
Area 2
Area 1
Harry Graham Drive
Mt Keira Road
Cordeaux Road
Legend
Groundwater Monitoring Locations
Rivers and Streams
Main Roads
Existing Mine Workings
Proposed Longwall Layout
Railway Lines
Dendrobium Mine Mining Areas
Areas 5 & 6 Longwalls
Project Longwall Mining Areas
Dams
State Conservation Areas
DENDROBIUM MINE
SOUTH32
Illawarra Coal
Figure: 6-2
Groundwater Monitoring Locations
Version 2 6 May 2019
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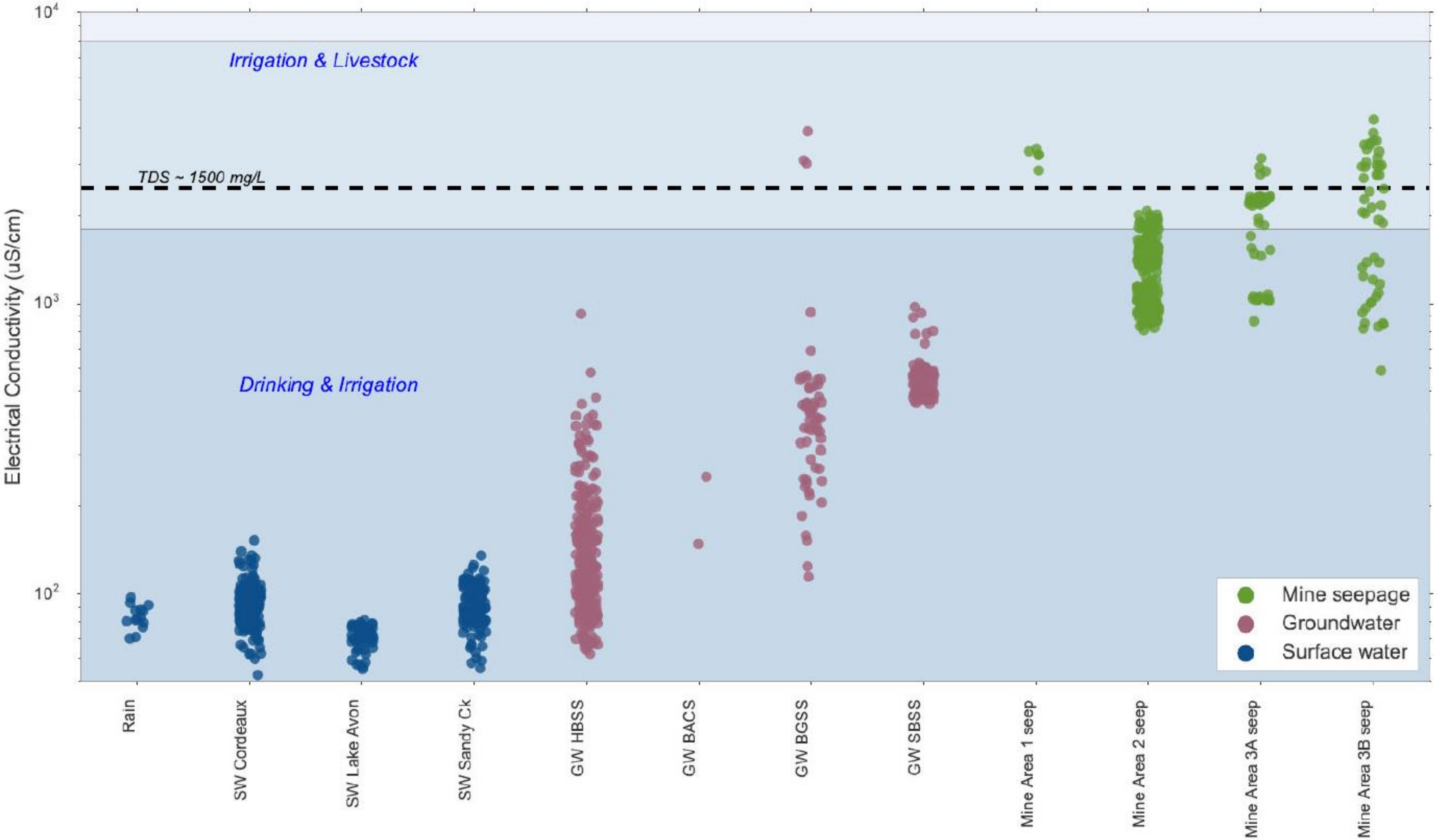


Graph 6-1 **Plot Showing the Ranges of Electrical Conductivity for Various Water Sources** [Figure 4-16 from HydroSimulations, 2019]

Groundwater Sensitive Features

Groundwater Dependent Features

The BoM Groundwater Dependent Ecosystems (GDE) Atlas indicates there is low potential for groundwater interaction across the majority of the Project underground mining areas due to the elevation of the topography in these areas. There is moderate potential for groundwater interaction in lower-lying areas within the Project underground mining areas and along the Avon and Cordeaux Rivers downstream of the Avon and Cordeaux Dams, respectively (Appendix B).

There are no high priority GDEs within the Project underground mining areas, with the nearest high-priority GDE being the O'Hares Creek catchment located 13 to 18 km to the north-east of Area 5 (Appendix B).

Upland Swamps

Upland swamps are not defined as high-priority GDEs (Appendix B). Groundwater levels proximal to swamps within the Project underground mining areas are typically more than 10 m below the swamp water level, indicating baseflow to the swamps from the surrounding groundwater does not typically occur (Appendix B).

Section 6.8 provides a description of the hydrogeology of upland swamps and potential impacts to upland swamps associated with the Project.

Streams

A number of ephemeral drainage lines overlie the Project underground mining areas. The Project longwalls would be set back from named watercourses (e.g. the Avon and Cordeaux Rivers and Donalds Castle Creek) to achieve 200 mm of additional predicted closure or less (Section 3.5.3).

Section 6.6 provides a description of streams in the Project area and surrounds. Potential subsidence-related impacts associated with the Project to streams are described in Section 6.3, while potential consequences to stream flow and biodiversity from Project subsidence impacts are provided in Sections 6.6 to 6.9.

Avon Dam and Cordeaux Dam

The Avon and Cordeaux Dams are water supply reservoirs formed by the damming of the Upper Avon and Cordeaux Rivers, respectively.

The groundwater table surrounding the Avon and Cordeaux Dams can be higher in elevation than the dam waterbody(s), and where this occurs, it can result in baseflow from groundwater to the dams (Appendix B).

Effects of Previous Mining

Groundwater Drawdown

Extensive underground mining has occurred within the Project region, and continues to occur (e.g. at the Dendrobium Mine, Bulli Seam Operations and Tahmoor Mine).

The historic and existing mines typically target the Bulli Seam and/or Wongawilli Seam, resulting in localised depressurisation in the Illawarra Coal Measures, particularly around the current mining operations (Appendix B).

Groundwater levels near to active mining show different extents of drawdown, depending on the proximity to mining, the type of mining employed and the vertical height above the mined seam (Appendix B).

For example, groundwater bores located between Area 5 and Area 3B (where mining at the Dendrobium Mine is currently occurring) show a response to Area 3B mining with drawdown in the coal seams of approximately 20 m (i.e. at S1998 and S2007). However, further west and north at monitoring bores in Area 5 there are limited discernible signs of historic mining (Appendix B).

In regard to groundwater levels above active mining, longwalls in Area 3B have undermined or passed a number of monitoring bores, including S1911, S1925, S2192 and S2220 (Figure 6-2).

In the deeper formations (such as the Illawarra Coal Measures and Bulgo Sandstone) significant drawdown was observed, as is typical given complete depressurisation can occur due to fracturing in the strata above mining (Appendix B).

However, in strata nearer the surface such as the shallowest horizons of the Hawkesbury Sandstone, little or no discernible drawdown was observed, with mining resulting in (Appendix B):

- No mining-related drawdown at a depth of 10 m (S1925).

- 0 to 3 m at a depth of 50 m (S2192 and S2220 combined record[1]).
- Approximately 6 m at a depth of 65 m (S1911).
- Approximately 10 to 20 m at a depth of 95 m (S2192 and S2220 combined record).

Mine Inflows

Groundwater inflows to mine workings cannot be directly measured, but are calculated by a detailed mine water balance that considers:

- continuous monitoring of water pumped underground; and
- measurements of water entering, circulating and leaving the mine, including via air moisture and coal moisture.

Estimates of groundwater inflow to each of the Dendrobium Mine areas (i.e. Areas 1, 2, 3A and 3B) for the period February 2018 to February 2019 are summarised in Table 6-5 (Appendix B).

Since the commencement of Longwall 9 in Area 3B total groundwater inflow to the Dendrobium Mine (combined total from Areas 1, 2, 3A and 3B) has varied between 4 and 12 megalitres per day (ML/day), with an average of 6.8 ML/day (Appendix B).

6.5.3 Assessment

Model Development

Software

The groundwater model for the Project has been developed using MODFLOW-USG software. This industry-standard software allows modelling to be conducted using unstructured grids, which provide the ability to refine grid geometry where required (e.g. around the longwall panels).

The model for the Project is an extension of the previous models developed for the Dendrobium Mine.

Table 6-5
Dendrobium Mine Groundwater Inflows

Area	Average Inflow (February 2018 to February 2019)	Comments
1	0.33 ML/day*	• Two significant inflow peaks occurred in 2007 to 2008, which correlated to rainfall events. • Since then, inflow has been relatively consistent, typically fluctuating between 0.2 and 0.8 ML/day. • Since the early peaks there has been a weak correlation with residual rainfall trends, with inflow peaks delayed by several months, with the exception of an unexplained peak (up to 1.9 ML/day) in September 2016.
2	0.33 ML/day	• Highly variable inflow that strongly correlated with large recharge events. • Baseline inflow is between 0.2 and 1 ML/day, and has declined since 2016. • Peak inflows were 6.4 ML/day in 2014, 4.6 ML/day in 2015 and 4.5 ML/day in 2017, with inflow delayed by 8 to 10 days after heavy rainfall events.
3A	0.95 ML/day	• Linear increase in inflow with area mined during active mining (2010 to 2012). • From mid-2012 inflows fluctuated between approximately 1 and 4 ML/day, with average inflows correlated with residual rainfall trends. • Since 2013 (when mining moved to Area 3B) baseline inflow has reduced from approximately 3 to 1.5 ML/day or lower, likely correlated with recent dry conditions.
3B	4.38 ML/day	• Groundwater ingress to Area 3B has increased steadily since the start of mining (2013), and correlates approximately with the total area mined, however, the overall rate of increase has slowed during the mining of Longwalls 12 and 13. • Inflows have a moderate correlation to rainfall, with peak inflows to Area 3B following high rainfall events with a lag time of between 2 to 3 months.

Source: After Appendix B.

* Area 1 flow meter failed in September 2016. Due to the low rate of inflow, the average (approximately 0.3 ML/day) is reported after that date.

[1] S2192 was located at the centre of Longwall 9 and was damaged as a result of undermining, and subsequently replaced with S2220.

In regard to the groundwater modelling conducted for the Dendrobium Mine to date, the IEP (2018) noted:

> *There has been a major effort over the last decade by Metropolitan Mine and Dendrobium Mine to employ up-to-date 3-dimensional groundwater models and best practice modelling methods undertaken by suitable experts, with expert peer review.*

The Project groundwater model builds on the previous groundwater modelling efforts acknowledged by the IEP (2018).

Model Domain

The groundwater model domain is shown on Figures 6-3 and 6-4, and extends 10 to 15 km from the edge of the Project underground mining areas.

To account for historic stresses to the groundwater system, the model domain incorporates historic, active, approved and proposed mining operations (Figures 6-3 and 6-4), including the (Appendix B):

- Dendrobium Mine (active/approved);
- Tahmoor Mine (active/approved);
- proposed Tahmoor South mining domain;
- Bulli Seam Operations;
- Russell Vale Colliery;
- Wongawilli (Elouera) Colliery;
- Cordeaux Colliery; and
- Kemira Colliery.

The model domain also incorporates sensitive receptors that may be potentially affected by the Project (Figures 6-3 and 6-4), including (Appendix B):

- surface water features, including water supply reservoirs, rivers, drainage lines and escarpment springs;
- relevant high priority GDEs;
- upland swamps; and
- registered groundwater bores, including water supply works.

Model Layers and Mesh Design

The model incorporates 17 layers, relating to each of the major stratigraphic units (i.e. formations) provided in Table 6-4 plus the lower Permian Measures and Shoalhaven Group (beneath the Kembla Sandstone), and regolith above the Hawksbury Sandstone (e.g. to represent isolated swamp deposits and alluvium). The Hawkesbury Sandstone is split into three layers (upper, middle and lower) and the Bulgo Sandstone into two layers (upper and lower) (Appendix B).

Stratigraphic depths and extents across the model domain are based on the South32 geological model and hundreds of exploration drill logs and data obtained from other mining operations and literature (Appendix B).

The model contains approximately 700,000 cells in an unstructured mesh (Figures 6-3 and 6-4) to simulate the 17 model layers (Appendix B).

Cell sizes are smallest where groundwater stresses occur (e.g. around longwall panels) and at sensitive receptors (e.g. Avon Dam shoreline and along watercourses) to allow for more refined model predictions at these locations (Figures 6-3 and 6-4).

Key Groundwater Inflows to the Model Domain

Rainfall recharge is the dominant inflow to the regional groundwater balance. This has been estimated for the model domain based on literature and calibrated model against BoM's AWRA-L Landscape Model.

The average recharge across the model domain is 7% of long-term average rainfall (or 84 mm per annum). Rainfall recharge within the model domain has been refined to account for (Appendix B):

- long-term average rainfall (which declines with distance from the coast);
- outcrop geology (i.e. relative reductions in recharge for hard rock and increases for swamp sediments); and
- the presence of a permanent waterbody, where no rainfall recharge is assumed (as the waterbody can provide infiltration to the underlying model layer).

Waterbodies also provide a source of recharge to the groundwater system.

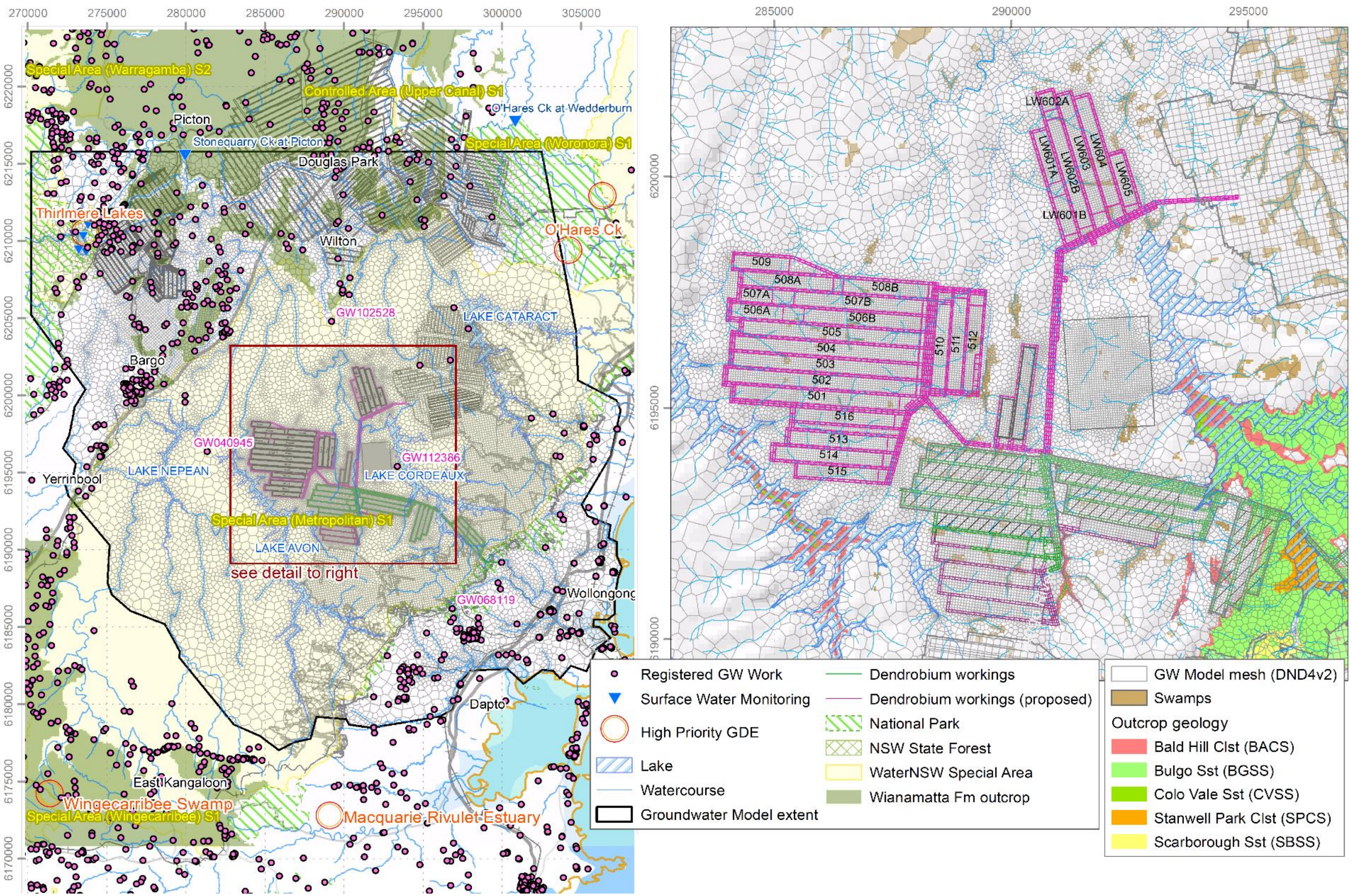


Figure 6-3 **Groundwater Model Extent and Mesh** [Figure 6-1 from HydroSimulations, 2019]

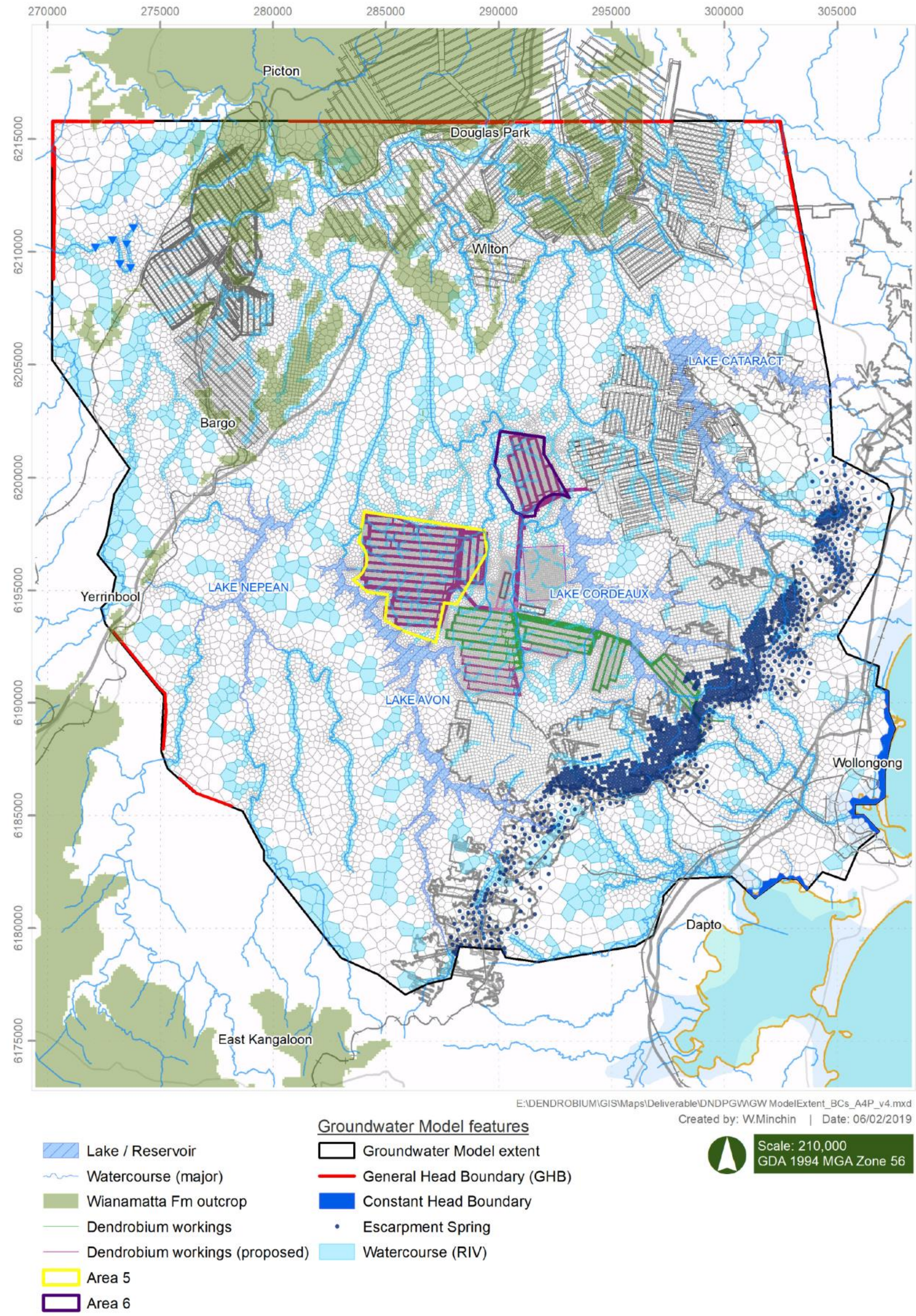


Figure 6-4 **Groundwater Model Boundary Conditions** [Figure 6-2 from HydroSimulations, 2019]

Reservoirs (e.g. the Avon and Cordeaux Dams) are represented in the groundwater model as permanent waterbodies, with the water level estimated in consideration of the relevant FSLs.

Similarly, watercourses are simulated as permanent waterbodies, with the water level and width of watercourse varied across the model domain to account for differences between rivers (such as the Nepean River) and ephemeral drainage lines (such as those that overlie the Project underground mining areas) (Appendix B).

Key Groundwater Outflows from the Model Domain

Evapotranspiration is the dominant groundwater outflow from the regional groundwater system.

Evapotranspiration has been estimated based on actual evapotranspiration in the soil, and whether there is excess potential evapotranspiration available to be removed from the groundwater table (e.g. in consideration of plant rooting depths and the depth of the groundwater table below the surface) (Appendix B).

The significant change in elevation associated with the Illawarra Escarpment also provides a source of groundwater discharge where the stratigraphic units, from the Hawkesbury Sandstone down to the coal measures, are truncated by erosion. Groundwater losses at the face of the escarpment have been simulated, with the magnitude of losses varying according to local topography (Appendix B).

While watercourses can be a source of groundwater recharge, groundwater is also lost to watercourses within the model domain. Whether groundwater is gained or lost depends on the stage of the watercourse and the relative elevation of the surrounding groundwater system. The rate of groundwater discharge to watercourses varies spatially and temporally (Appendix B).

Groundwater is also lost as inflow to mine workings (Appendix B).

Hydraulic Properties

Extensive datasets have been used by HydroSimulations (2019) to develop horizontal and vertical hydraulic conductivities and storage properties for each of the groundwater model layers. This includes analysis of the results of hundreds of packer tests, pumping tests and core sample measurements undertaken at the Dendrobium Mine, Bulli Seam Operations and Tahmoor Mine. The results of this analysis are plotted in Appendix B.

Horizontal hydraulic conductivities were found to be controlled by depth and lithology. Horizontal hydraulic conductivities were found to be typically greater at shallow depths due to the greater prevalence of open joints, bedding planes and weathering near the surface, whereas for the deeper lithologies joints and bedding planes are more likely to be closed due to the pressure from the overlying overburden resulting in lower horizontal hydraulic conductivities (Appendix B).

The adopted horizontal hydraulic conductivities for each groundwater model layer are within the range of data from the Dendrobium Mine, Bulli Seam Operations and the Tahmoor Mine (Appendix B).

Vertical hydraulic conductivities were found to be governed by the host lithology. The adopted vertical hydraulic conductivities for each groundwater model layer are consistent with the mean of the core sample measurements undertaken at the Dendrobium Mine, Bulli Seam Operations and Tahmoor Mine (Appendix B).

Storage characteristics have been established by analysis of core tests, Nuclear Magnetic Resonance imaging conducted by South32 and the outcomes of previous modelling studies. Adopted storage values for each groundwater model layer have been established based on trends indicating storage decreases with depth, noting higher storages in layers that are predominantly sandstone compared to layers that are predominantly claystone/mudstone have been adopted (Appendix B).

Geological Structures

Faults, lineaments, dykes, horizontal shears and other geological structures are mapped in the vicinity of the Project underground mining areas.

A study (Tonkin and Timms, 2015) of geological structures in the Southern Coalfield and their role in transmitting groundwater found that 95% (1,580 of 1,660) of structures near reservoirs and underground mines were not associated with any groundwater flow (Appendix B).

For all of the remaining 5%, groundwater flow was found to be less than 0.001 ML/day, with the exception of two structures where flows were 0.01 ML/day (Appendix B).

Based on analysis of dyke and fault systems at the Dendrobium Mine, horizontal stresses (i.e. due to mine subsidence) were found to typically close structures, reducing their effective hydraulic conductivity (Appendix B).

Larger structures, such as the Nepean Fault near Tahmoor, have been known to result in increased inflow to adjacent workings (Appendix B).

An investigation of geological structures (e.g. lineaments, faults, igneous intrusions and dykes) within Areas 5 and 6 was undertaken by Pells Sullivan Meynink (PSM) (2019) for the EIS (Appendix P). PSM (2019) reviewed the results of site-specific investigations undertaken by South32 as well as published data.

PSM (2019) concluded that, based on the information available, there is no strong evidence suggesting there are geological structures persistent from seam to surface that would be affected by Areas 5 or 6 mine subsidence.

Geological structures are common and are frequently intersected by mining operations. Modelled horizontal hydraulic conductivities have been derived based on extensive packer and pumping tests, which include measurements across discrete and connected fractures. The modelled horizontal hydraulic conductivities are considered by HydroSimulations (2019) to be representative of the relevant strata simulated by the model layers, inclusive of secondary porosity such as fractures.

Changes to Hydraulic Properties due to Mining

Sub-surface Fracturing

Sub-surface fracturing of overburden above the longwall panels can cause significant changes in hydraulic properties, and potentially provide pathways for vertical and horizontal groundwater movement (Appendix B).

Fracturing is most significant and vertically connected immediately above the goaf, with the degree of vertical connection decreasing with height (Appendix B). The height of fracturing above the goaf, and associated height of groundwater depressurisation, is a key factor in assessing the potential impacts of longwall mining to groundwater and surface water.

Various methodologies for estimating the height of sub-surface fracturing and groundwater depressurisation are described in Appendix B, including empirical methods such as the 'Tammetta Equation' and 'Ditton Equation', as well as geotechnical modelling using FLAC2D software.

In regard to the methodology for estimating heights of sub-surface fracturing and groundwater depressurisation, the IEP (2018) states (emphasis added):

> *Notwithstanding that uncertainty is associated with both the Tammetta and the Ditton height of complete drainage equations, it is recommended* ***to err on the side of caution and defer to the Tammetta equation*** *until:*
>
> - *field investigations quantify the height of complete drainage at the Dendrobium Mine and Metropolitan Mine, and/or*
> - *alternative geomechanical modelling of rock fracturing and fluid flow is utilised to inform the calibration of groundwater models*

For longwalls with void width of 305 m within the Project underground mining areas (i.e. all proposed longwalls with the exception of Longwalls 512, 515 and 516) the height of connective fracturing has been estimated using FLAC2D geomechanical modelling simulations (Appendix B).

In most cases the FLAC2D modelling results in connective fracturing that extends from the mined seam to the surface. HydroSimulations (2019) therefore conservatively adopted a seam-to-surface fracture network for all Project longwalls with void width of 305 m (Appendix B).

For comparison, HydroSimulations (2019) calculated the height of connected fracturing using the Tammetta Equation (Figure 6-5). This indicated that connected fracturing would remain some 60 m or more below the surface across the majority of Area 5 and Area 6 (Appendix B).

Simulation of changes in hydraulic properties as a result of sub-surface fracturing has been conducted for the Project groundwater modelling using the 'stacked drain' method.

Dr Frans Kalf in the peer review of the Groundwater Assessment (Attachment 5) supports the use of the stacked drain method, and states it likely results in conservative predictions of associated drawdown:

> *KA has no objection to the use of this 'Stacked Drain' method as it has been used by MER* [Mackie Environmental Research Pty Ltd] *for a number of years and has proved to be suitable. In addition it has been found on some projects by MER to overestimate the mining effects such as drawdown and overall inflow and therefore can be considered to be a conservative overall methodology for determining fracture propagation and associated draining in the geological profile.*

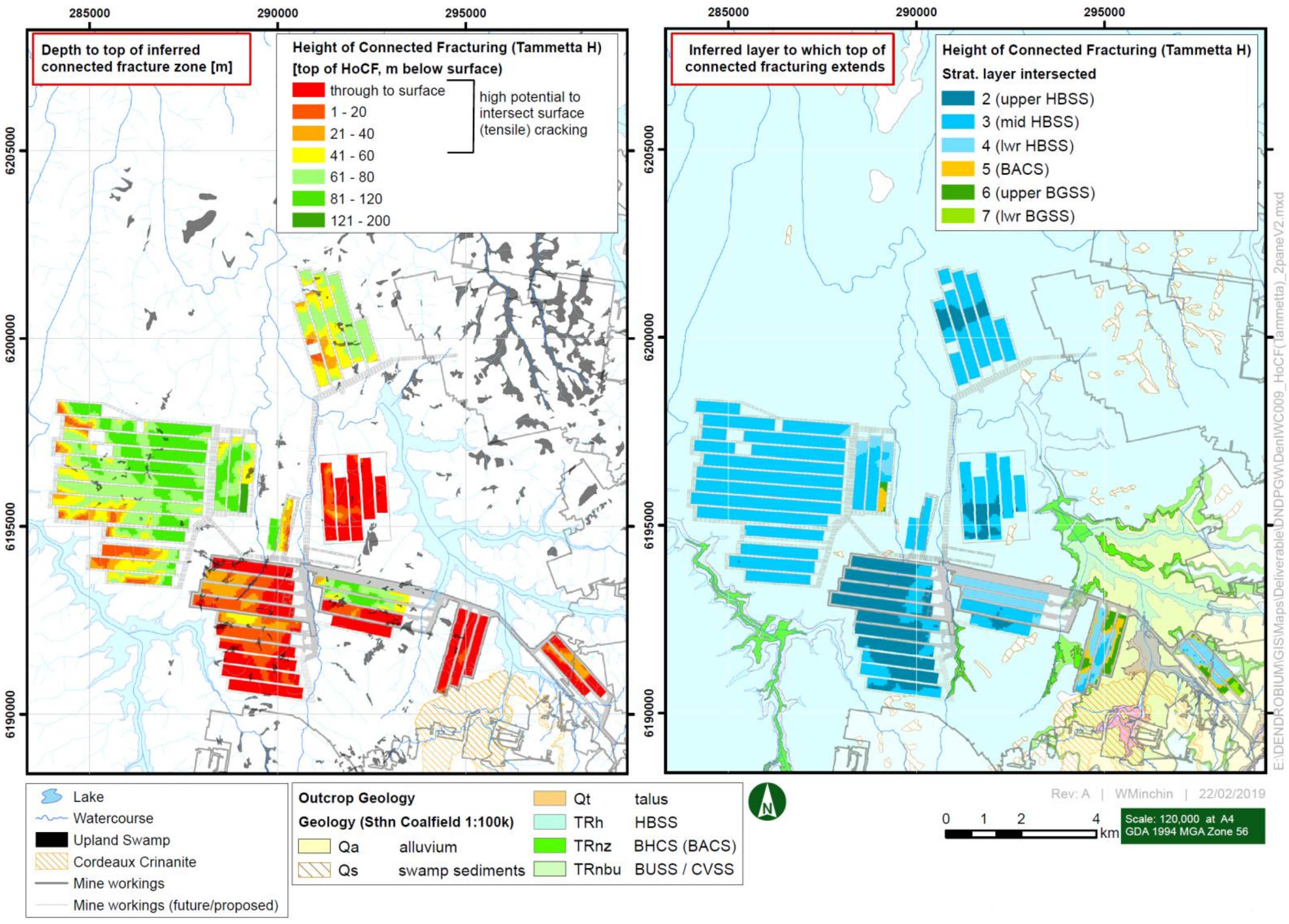


Figure 6-5 **Variation in Inferred Height of Fracturing Estimated using the Tammetta Equation** [Figure E4 from HydroSimulations, 2019]

Surface Cracking

Increased horizontal and vertical hydraulic conductivities associated with subsidence-related surface cracking have been simulated to a depth of 10 times the longwall cutting height, resulting in depths of 32 m for Area 5 and 39 m for Area 6 (Appendix B).

HydroSimulations (2019) considers this to be conservative based on comparison to depths of cracking simulated in other groundwater studies (Appendix B).

Lateral Effects

While the most significant effects of longwall mining to hydraulic properties occur in the strata overlying the longwalls, potential changes in hydraulic properties beyond the longwall footprint have also been investigated.

HydroSimulations (2019) has investigated the potential for increases to horizontal hydraulic conductivity beyond the longwall area due to shear plane development resulting from valley closure. Such effects were considered possible based on the results of site-specific investigations, but not definitive, and no simple relationship between horizontal hydraulic conductivity and lateral distance from the goaf was identified. Therefore, sensitivity of the groundwater model results to increases in horizontal hydraulic conductivity beyond the Project longwall areas has been considered as part of model sensitivity and uncertainty analysis (Appendix B).

Model Calibration

The groundwater model has been calibrated against groundwater levels and mine inflows, while constraining hydraulic conductivities to the range of values measured at the Dendrobium Mine, Bulli Seam Operations and Tahmoor Mine (Appendix B).

Groundwater levels were calibrated against 38,250 groundwater level targets from approximately 700 bores and piezometers. This includes bores and piezometers monitoring stresses to the groundwater system resulting from historic mining, which have been replicated by the model for the calibration period.

Simulated mine inflows were matched to each of the historic inflows to Areas 1, 2, 3A and 3B (Table 6-5). Simulated inflows were generally higher than historic inflow, indicating the model predictions are conservatively high (Appendix B).

At the end of the model calibration period the scaled root mean squared (SRMS) error was 8.7% (within the acceptable range of 5 to 10% suggested in the *Australian Groundwater Modelling Guidelines* [Barnett et al, 2012]), and the modelled mass balance error was less than 0.01% (better than the 1 to 2% error recommended by the *Australian Groundwater Modelling Guidelines*).

Modelling Predictions

Groundwater Inflows

Inflows to Area 5 are predicted to peak at approximately 18 ML/day in 2033 and 2037, averaging approximately 12 ML/day. Inflows to Area 6 are predicted to peak at approximately 4 ML/day in 2047, averaging approximately 3 ML/day (Appendix B).

As Area 5 and Area 6 are down-dip of Areas 1, 2 and 3, dewatering of the existing and approved mining areas for the Dendrobium Mine is required to continue to allow safe mining of Areas 5 and 6.

The total inflow for the Project and Dendrobium Mine is predicted to peak at approximately 26 ML/day in 2032 and 2036, averaging approximately 22 ML/day for the period 2023 to 2049 (of which approximately 10 ML/day is due to inflows from Areas 1 to 3) (Appendix B).

As the calibrated model overpredicts historic mine inflows (e.g. due to the conservative approach adopted with respect to the heights of sub-surface fracturing and the depths of surface cracking) the predicted inflows over the life of the Project are considered by HydroSimulations (2019) and Dr Frans Kalf (Attachment 5) to be conservative.

Predicted Drawdown

Predicted drawdown within Areas 5 and 6 is expected to be most significant in the coal seams (i.e. approximately 300 m due to extraction of the Bulli Seam in Area 5 and 320 to 350 m due to extraction of the Wongawilli Seam in Area 6).

Drawdown greater than 100 m is predicted to occur in layers up to the Bulgo Sandstone in Areas 5 and 6. In the overlying Hawkesbury Sandstone, drawdown of up to approximately 80 m is predicted in Area 5 and 10 to 40 m in Area 6.

Predicted drawdown reduces with distance from Areas 5 and 6, particularly in the Hawkesbury Sandstone and regolith.

At the location of the Avon Dam wall (approximately 900 m west of Area 5) predicted drawdown is approximately (Appendix B):

- 150 m in the coal seams;
- 2 to 3 m in the lower Hawkesbury Sandstone;
- 1 to 2 m in the middle and upper Hawkesbury Sandstone; and
- less than 1 m in the regolith.

At a location adjacent to the Cordeaux River (approximately 400 m north of Area 5) predicted drawdown is approximately (Appendix B):

- 120 m in the coal seams;
- 25 m in the lower Hawkesbury Sandstone;
- 4 m in the middle Hawkesbury Sandstone; and
- less than 1 m in the regolith.

High Priority GDEs

No drawdown effects are predicted at the nearest high-priority GDEs (Appendix B).

Swamps

Assessment of potential impacts to the hydrogeology of swamps due to the Project is provided in Section 6.8.

Stream Flow

Project longwall mining has the potential to reduce streamflow as a result of (Appendix B):

- groundwater depressurisation in the groundwater system that is connected to the stream (i.e. either reduced baseflow gained by the stream, or increased baseflow lost from the stream); and
- subsidence impacts such as cracking (Section 6.3) resulting in enhanced hydraulic conductivity in the stream bed.

HydroSimulations (2019) has predicted potential surface water losses from streams of up to approximately 4.4 ML/day (1,600 ML/annum) due to the Project. However, the groundwater modelling conservatively assumes water is available at all times to be lost from the drainage lines overlying Areas 5 and 6, whereas in reality, flow in these drainage lines is not persistent (Appendix C).

Potential surface water losses based on consideration of the groundwater model predictions and daily varying rainfall and evaporation are presented in HEC (2019) and summarised in Section 6.6.

Due to the conservative approach adopted with respect to the heights of sub-surface fracturing and the depths of surface cracking, the groundwater modelling assumes the predicted surface water losses report to the groundwater system.

However, a portion of the predicted surface water losses are likely to re-emerge downstream, rather than report to the groundwater system. As noted by Dr Frans Kalf in his peer review of the Groundwater Assessment (Attachment 5):

> *It should also be noted that there is no horizontal fracture zone observed in these figures* [showing FLAC2D modelling] *that are due to tensile forces that are typical 10 to 30 m below the ground surface.*
>
> *It is understood that the FLAC2D code does not simulate these horizontal fractures (Gale KA pers. comm.). It is quite possible that in reality that the presence of the horizontal shallow fracturing zone would still allow in part flow downstream and likely re-emergence outside of the mining zone with a proportion of inflow migrating down to the mining zone through vertical fracture zone as depicted in HS Figure 4.20.*
>
> *It suggests further that the 'stacked drains' approach by HS would very likely capture most flow and therefore would indeed be conservative with respect to mine inflow.*

The predicted surface water losses are expected to result in negligible (i.e. less than 1%) reductions in the yields of the Metropolitan Special Area catchment (Appendix C). This conclusion is consistent with the IEP's (2018) comment that there have been no observed material impacts to drinking water supplies due to mining in the Special Catchment Areas to date:

> *Reservoir leakage rates – there is no measured evidence of significant long-term leakage from reservoirs due to mining in the Special Areas.*
>
> …
>
> *Watercourse bed leakage (at catchment scale) – from material presented to the Panel, there remains no strong evidence that cracking of watercourse beds leads to significant losses of water at catchment scales relevant for water supplies.*

When compared to other losses from the drinking water network, the predicted upper maximum of surface water losses due to the Project (peaking at approximately 1,600 ML/annum) is equivalent to approximately 4% of estimated leaks from the Sydney Water pipe network (based on Sydney Water estimates for 2016 to 2017).

It is also equivalent to approximately 0.2% of the 981,000 ML/annum entitlement for unregulated river licences held by government organisations in the region.

Reservoirs

The Project does not undermine the Avon or Cordeaux Dams, with Project longwalls set back at least 300 m from the FSLs of the dams (Section 3).

PSM (2019) concludes that, based on the information available, there is no strong evidence suggesting there are geological structures persistent from seam to surface that would be affected by Areas 5 or 6 mine subsidence.

Indirect potential losses from reservoirs in the Metropolitan Special Area are predicted by HydroSimulations (2019) as a result of predicted groundwater depressurisation in the underlying strata due to the Project. The potential losses due to longwall mining in Area 5 and Area 6 are estimated to be (Appendix B):

- 0.1 ML/day at Cordeaux Dam;
- 0.36 ML/day at Avon Dam; and
- 0.01 ML/day at Nepean Dam.

The sensitivity of these results to increases in horizontal and vertical hydraulic conductivities between the Project longwalls and the reservoirs, as well as increases in the hydraulic conductivity of the base of the reservoirs, was tested by HydroSimulations (2019).

The sensitivity run resulting in the highest predicted reservoir losses had poor calibration to inflow, suggesting these results are unlikely to occur (Appendix B). Average results from all sensitivity runs are similar to those described above for the base case (i.e. best calibrated) model run (Appendix B).

Water Supply Works

No water supply works are predicted to experience greater than 2 m drawdown due to the Project (Appendix B).

Groundwater Quality

It is considered unlikely that the Project would result in changes to the existing beneficial use category of groundwater (Appendix B).

Assessment Against Aquifer Interference Policy Minimal Impact Considerations

The Project has been assessed against the AIP minimal impact considerations for highly productive aquifers (i.e. the Sydney Basin Porous Rock).

HydroSimulations (2019) concludes there would be ‘Level 1’ (i.e. minimal impact) on the basis that:

- there is no drawdown effect predicted at high priority GDEs;
- there are no culturally significant sites listed in relevant water sharing plans;
- there are no water supply works predicted to experience greater than 2 m drawdown from the Project; and
- no change to the beneficial use category of groundwater is predicted.

6.5.4 Licensing, Mitigation Measures and Monitoring

Licensing

Existing Licencing

Sufficient licences for groundwater inflows to the current underground mining operations are held for the groundwater sources in which the Project is physically located (i.e. Sydney Basin – Nepean [MZ2] for the underground mining areas, and Sydney Basin – South for the access drives).

Details of the current WALs held by Illawarra Coal for the Dendrobium Mine are summarised in Table 6-6.

Project Licencing Requirements

Project licensing requirements have been estimated using the groundwater model for the Project. The approach is consistent with that outlined in Section 2.1 of the AIP, which states “*the predictions should be based on complex groundwater modelling and conducted in accordance with the Australian Groundwater Modelling Guidelines*”.

Table 6-6
Existing Water Licensing Summary for the Dendrobium Mine

Water Sharing Plan	Water Source (Management Zone)	Licence Category	WAL Number	Allocation (Shares)
Water Sharing Plan for the Greater Metropolitan Region Groundwater Sources 2011	Sydney Basin – Nepean (MZ2)	Aquifer	37464	300
			37465	3,962
			42386	3,653
			42385	1,840
	Sydney Basin – South	Aquifer	36473	75

A range of conservative assumptions, consistent with recommendations by the IEP (2018), have been adopted in groundwater modelling (Appendix B and Attachment 5), including:

- The height of fracturing and groundwater depressurisation applied to the groundwater model has been estimated using geomechanical modelling for longwall panels with void width of 305 m, producing results greater than those estimated using the 'Tammetta Equation'. The Tammetta Equation has been used to estimate heights of fracturing and depressurisation for longwall panels with void width less than 305 m.
- For the calibration period (which includes mining in Areas 1, 2, 3A and 3B of the Dendrobium Mine), the model overpredicted historic groundwater inflows to the Dendrobium Mine by approximately 20%.
- The groundwater modelling assumes predicted surface water losses are lost to the groundwater system, whereas a portion of any surface water diverted from streams may re-emerge as surface water downstream.

The result of the application of these assumptions is the modelled licensing requirements are likely to be conservatively high.

Table 6-7 provides estimated peak water licencing requirements of the Dendrobium Mine and the incremental demands of the Project based on the conservative assumptions adopted in the groundwater assessment.

The peak predicted take includes the volume of water that may be lost from the surface to the groundwater system.

As shown, South32 holds total licences sufficient to account for the peak predicted groundwater inflow to the underground mine (i.e. for the Dendrobium Mine plus the Project increment).

These licenses are held for the groundwater sources in which the Project is physically located (i.e. Sydney Basin – Nepean [MZ2] and Sydney Basin – South for the access drives) (Table 6-6).

While South32 has sufficient volumetric entitlements to account for direct groundwater inflow, the WALs held by South32 are not currently distributed to all of the administrative water sources and management zones modelled to experience some impact from the Dendrobium Mine and the Project (Table 6-7).

Due to existing restrictions on the availability of licences in the water sources that the Project is not physically located within, South32 is reliant on the NSW Government creating additional licences or entitlements available to facilitate the development of the Project in the applicable adjoining Water Sharing Plan management areas and zones.

Any additional licences required under the *Water Management Act, 2000* would be sought and obtained in consultation with DI Water.

Mitigation

Predicted Surface Water Losses

Although surface water losses are predicted to result in negligible changes to catchment yields, South32 would pay WaterNSW for the volume of surface water diverted from the Drinking Water Catchment (i.e. as it would be no longer available for sale to other water users). Such payments would be in addition to holding appropriate licences under the *Water Management Act, 2000.*

Table 6-7
Estimated Water Licensing Requirements for the Project

<table>
<tr><th>Water Sharing Plan</th><th>Water Source (Management Zone)</th><th>Allocation (Shares) held by South32</th><th>Maximum Dendrobium (inclusive of Project) Licensing Requirement (ML/year)[1]</th><th>Maximum Project Increment</th></tr>
<tr><td rowspan="3">Water Sharing Plan for the Greater Metropolitan Region Groundwater Sources 2011</td><td>Sydney Basin – Nepean (MZ2)</td><td>9,455^</td><td>6,700</td><td>5,700</td></tr>
<tr><td>Sydney Basin – Nepean (MZ1)</td><td>-</td><td>32</td><td>7</td></tr>
<tr><td>Sydney Basin – South</td><td>75</td><td>4</td><td>3</td></tr>
<tr><td rowspan="2">Water Sharing Plan for the Greater Metropolitan Region Unregulated River Water Sources 2011</td><td>Upper Nepean and Upstream Warragamba Water Source</td><td>-</td><td>3,330</td><td>1,935</td></tr>
<tr><td>Illawarra Rivers Water Source</td><td>-</td><td>10</td><td>3</td></tr>
<tr><td colspan="2">Total – all water sources</td><td>9,530</td><td>9,490[2]</td><td>-</td></tr>
</table>

After: HydroSimulations (2019)
ML/year = Megalitres per year
^ *Refer Table 6-6 for a breakdown of this volume.*
[1] *Licensing requirement for groundwater includes direct pit inflows from the porous rock and induced leakage from surface water systems.*
[2] *Peak annual predicted licensing requirement from all water sources in any given Project year. This total does not equal the sum of peak licensing requirements in each individual source/zone, as these peaks do not occur in the same Project year.*

It is proposed that payment would be calculated based on the following:

- Price per megalitres (ML) ($53.85 per ML) consistent with the Independent Pricing and Regulatory Tribunal (IPART) determination for WaterNSW's prices for bulk water operations in the Greater Sydney area for Council use of bulk water (IPART, 2016).
- To account for climate variability and the progressive stage of longwall mining, actual losses would be quantified annually using a combination of streamflow, mine inflow and climate data, and predictive groundwater and catchment runoff modelling.

It is expected that this would result in payment of approximately $100,000 per annum during peak predicted surface water losses for the Project.

Further, South32 would seek to divert a proportion of Project excess mine water to beneficial re-use at the Port Kembla industrial precinct, with the intention that the re-use volume matches or exceeds predicted Project surface water take, achieving no net reduction in the total WaterNSW water budget.

Monitoring

The recommendations of the Groundwater Assessment (Appendix B), in regard to ongoing monitoring, would be adopted for the Project.

Groundwater Inflow

The continuous monitoring that supports the calculation of groundwater inflow to the Dendrobium Mine would continue for the Project.

Analysis of water reporting to mine workings (e.g. water quality 'finger-printing') in Area 5 and Area 6 would also be conducted to inform the source of this water (e.g. overburden, surface water or upward flow from the underlying strata).

Groundwater Levels

The extensive groundwater monitoring network currently in place at Area 5 and Area 6 would be continued for the Project. This includes monitoring of groundwater levels in the deep and shallow strata.

Should the Project be approved, further review of the monitoring network would be conducted, including consideration of the IEP (2018) recommendations regarding the period of baseline data (e.g. the installation of additional monitoring sites in Area 5 and Area 6 to facilitate the recording of sufficient baseline data).

Groundwater Quality

Water quality sampling would be conducted for the Project, targeting electrical conductivity and pH (to confirm beneficial use categories) and tritium (as an indicator of the presence of modern water).

Hydraulic Conductivity

Packer testing is currently undertaken at the Dendrobium Mine Area 3B, including pre-mining and post-mining testing. Should the Project be approved, similar packer and permeability monitoring techniques would be employed, focussing on the hydraulic conductivity of the Hawkesbury Sandstone, Bald Hill Claystone and upper Bulgo Sandstone.

Surface Water Monitoring

The existing surface water monitoring network for Area 5 and Area 6 would be continued and expanded for the Project (Section 6.6.4). The network would include the installation of a monitoring site on Donalds Castle Creek, downstream of Area 5.

Model Review

Hydraulic Property Testing

Hydraulic property testing would continue at the Dendrobium Mine and for the Project, including permeability testing above longwalls prior to and following the completion of mining.

Geological Feature Investigation

The identification of geological structures has been undertaken using published data and surface-based exploration including boreholes, 2D seismic surveys and aerial magnetic surveys. These techniques identify the locations of geological structures, but do not necessarily identify their hydraulic characteristics.

As per the recommendations of PSM (2019), in-seam drilling would be undertaken during development works (i.e. longwall roadways) to further define the extent and character of geological structures as they are intersected, and to identify the hydraulic characteristics of any intersected structures (particularly those between the longwall areas and the reservoirs).

As in-seam drilling would be conducted during roadway development, Project approval would be pre-requisite to conducting these additional investigations (Appendix P).

Further surface-based exploration would also be undertaken along the FSLs of the Avon and Cordeaux Dams and around the dam wall structures (Appendix P).

Geological structures would be included in the South32 geological model as they are identified.

Model Updates

The groundwater model would be progressively updated over the life of the Project to account for additional monitoring data, hydraulic property testing and geological structures.

Consistent with the recommendations of Dr Frans Kalf (Attachment 5) a full review of the groundwater model would be conducted every 3 to 5 years, including comparison (verification) of monitoring data against predictions and recalibration of the model if necessary.

6.5.5 Adaptive Management

Monitoring locations, methods, trigger levels and contingencies relating to groundwater would be detailed in Extraction Plans for the Project.

If monitoring data indicates that the Project longwalls are resulting in trigger exceedances then adaptive management measures would be implemented.

Potential contingency measures for greater than expected groundwater impacts could include:

- obtaining additional water licences;
- increased payments to WaterNSW for estimated surface water take;
- remediation of surface cracks (i.e. to minimise diversion of surface flows to the groundwater system) (Section 7);

- increased biodiversity offsets (e.g. for upland swamps); and
- mine plan review.

6.6 SURFACE WATER

6.6.1 Methodology

A Surface Water Assessment for the Project was undertaken by HEC (2019) and is presented in Appendix C.

The Surface Water Assessment includes a description of the surface water management system (and associated site water balance) and assessment of potential subsidence-related impacts to surface water features.

A description of sewage systems, beneficial re-use of water and the outcomes of the site water balance are provided in Section 3. Flooding has been considered in the Surface Water Assessment (Appendix C).

Peer review of the Surface Water Assessment has been undertaken by Emeritus Professor Thomas McMahon (University of Melbourne) (Attachment 5).

HEC (2019) also undertook a stream risk assessment in consideration of the methodologies recommended by the NSW Planning Assessment Commission (now the IPC) during their assessments of the Metropolitan Mine and Bulli Seam Operations. The stream risk assessment is included as an appendix to the Surface Water Assessment.

Existing surface infrastructure that would continue to be used for the Project, and are located outside the Metropolitan Special Area, includes the Dendrobium Pit Top, Kemira Valley Coal Loading Facility, Dendrobium CPP and West Cliff Coal Wash Emplacement.

The continuation of water management at this existing surface infrastructure is described in Appendix C. The remainder of this section provides an assessment of potential impacts associated with the proposed underground mining areas and surface infrastructure associated with the Project that are located within the Metropolitan Special Area.

A description of the existing surface water environment is provided in Section 6.6.2. Section 6.6.3 describes the assessment of potential impacts for the Project, while Sections 6.6.4 and 6.6.5 outline mitigation measures and adaptive management respectively.

6.6.2 Existing Environment

Major Surface Water Catchments

Area 5 is located within the catchments of the Avon Dam, the Avon River (downstream of the Avon Dam wall) and Donalds Castle Creek (Figure 6-6).

Area 6 is generally located within the catchment of the Cordeaux River (downstream of the Cordeaux Dam wall) (Figure 6-6).

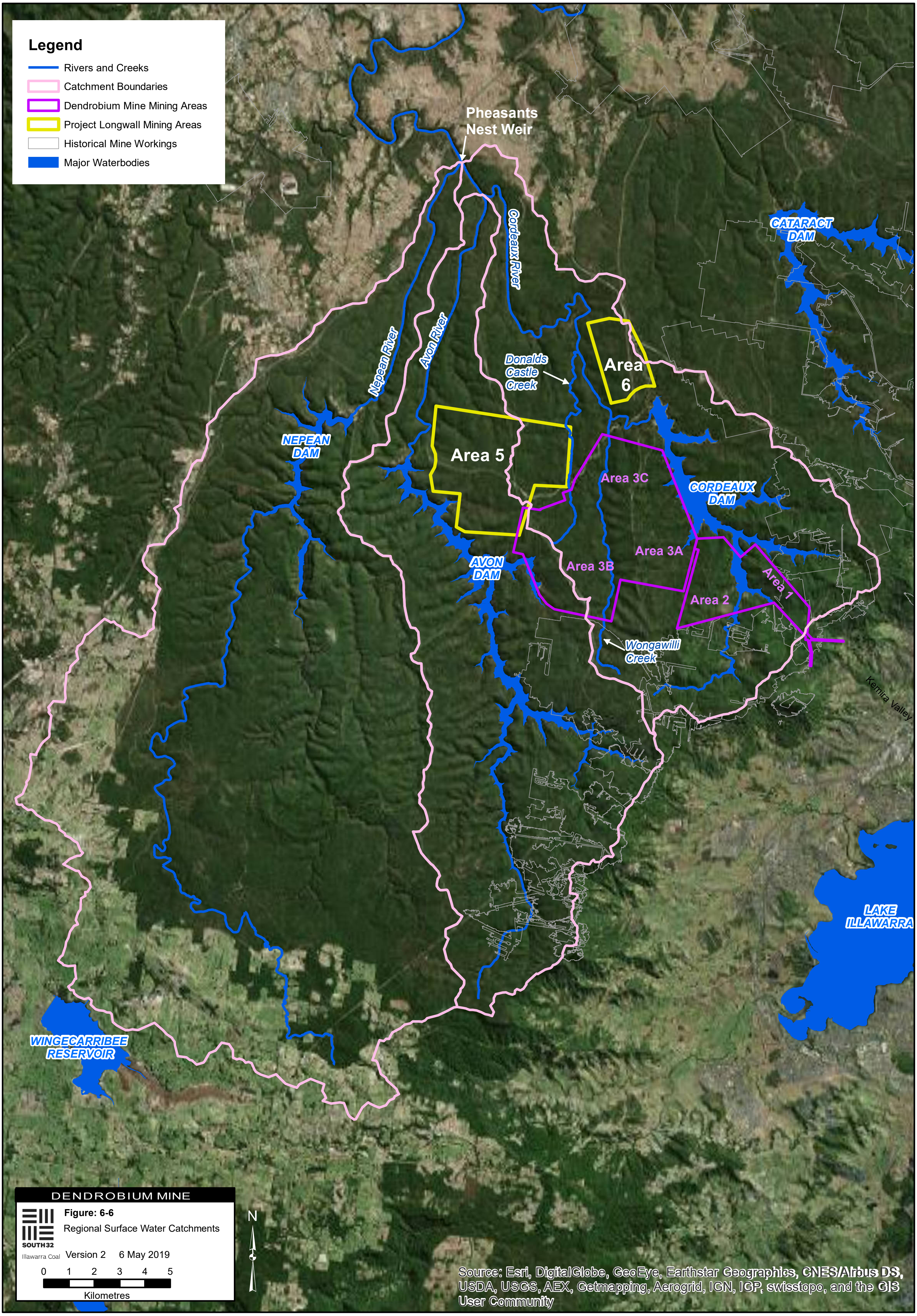
Donalds Castle Creek, which runs adjacent to Area 5, flows into the Cordeaux River and forms part of the overall Cordeaux River catchment (Figure 6-6).

The Avon River flows into the Cordeaux River downstream of the Project underground mining areas (Figure 6-6). At its confluence with the Cordeaux River, the catchment area of the Avon River is approximately 174 square kilometres (km^2) (including the catchment area of the Avon Dam).

Further downstream, the Cordeaux River flows into the Nepean River (Figure 6-6). At its confluence with the Nepean River, the Cordeaux River has a catchment area of approximately 339 km^2 (including the Avon River catchment and the catchment areas of the Cordeaux Dam and Donalds Castle Creek).

Immediately downstream of the Cordeaux River and Nepean River confluence is Pheasants Nest Weir (Figure 6-6), which is an off-take point for water to be transferred by WaterNSW to Broughtons Pass Weir via the Nepean Tunnel for raw drinking water supply.

The catchment area of the Nepean River at Pheasants Nest Weir is 681 km^2. This includes the catchment area of the Cordeaux River, Avon River and the Project underground mining areas (which have an area of approximately 35 km^2 based on the 35 degree angle of draw from the longwalls in Area 5 and Area 6). The Nepean River is a major river system, and has a total catchment area of approximately 21,400 km^2.


Legend
Rivers and Creeks
Catchment Boundaries
Dendrobium Mine Mining Areas
Project Longwall Mining Areas
Historical Mine Workings
Major Waterbodies
Pheasants Nest Weir
Cordeaux River
Nepean River
Avon River
Donalds Castle Creek
Area 6
Area 5
Area 3C
Area 3A
Area 3B
Area 2
Area 1
CATARACT DAM
NEPEAN DAM
CORDEAUX DAM
AVON DAM
Wongawilli Creek
Kemira Valley
LAKE ILLAWARRA
WINGECARRIBEE RESERVOIR
DENDROBIUM MINE
Figure: 6-6
Regional Surface Water Catchments
SOUTH32
Illawarra Coal
Version 2 6 May 2019
0 1 2 3 4 5
Kilometres
N
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Flows in the Avon and Cordeaux Rivers are regulated downstream of the Avon and Cordeaux Dam walls, respectively. That is, flows are controlled by releases from the dams.

Area 5 Catchment

Tributaries to the Avon River, Donalds Castle Creek and Avon Dam overlie Area 5 (Figure 6-7). Characteristics of these tributaries are provided in Table 6-8.

Table 6-8 indicates that the tributaries overlying Area 5 are ephemeral drainage lines, that have relatively small catchment areas and are of lower Strahler stream order.

It is noted that although several of the ephemeral drainage lines are of third order within 600 m of the proposed longwalls, the only third order section of stream crossing a longwall panel is located on AR31.

South32 has installed several stream gauges on the ephemeral drainage lines within Area 5 and Donalds Castle Creek (Figure 6-8). Due to low rainfall and inability to access sites during periods of high flow, limited stream flow data is available (Appendix C).

Accordingly, HEC (2019) has developed a catchment runoff model to estimate stream flows in the drainage lines for various scenarios reflecting historic rainfall data.

The modelling indicates pre-mine stream flow rates of between approximately 151 to 2,122 ML/annum (i.e. an average of 0.4 to 5.8 ML/day) at the catchment outlet of the various drainage lines based on the median climatic sequence (Appendix C).

Area 6 Catchment

Tributaries to the Cordeaux River overlie Area 6. Characteristics of these tributaries are provided in Table 6-8.

Table 6-8 indicates the tributaries overlying Area 6 are ephemeral drainage lines, that have relatively small catchment areas and are of lower Strahler stream order (maximum 2^{nd} order).

The catchment modelling indicates pre-mine stream flow rates of between approximately 1,206 to 1,342 ML/annum (i.e. an average of 3.3 to 3.7 ML/day) at the catchment outlet of the drainage lines based on the median climatic sequence.

Water Quality

Analysis of water quality data collected from sites within Area 5, Area 6 and at downstream locations (Figure 6-8) is presented in Appendix C. In summary (Appendix C):

- pH was found to be acidic to neutral, with no observable differences between monitoring sites on Donalds Castle Creek downstream of potential influences from Area 3B and monitoring sites in catchments with no potential for previous mining impacts.
- Salinity levels were consistently below the Australian and New Zealand Environmental and Conservation Council (ANZECC) water quality objective for upland rivers of 350 µS/cm.
- Elevated levels (when compared to water quality objectives) of metals, including iron, manganese and aluminium were recorded at sites within and outside the influence of historic mining, indicating spikes of these parameters occur naturally in the catchments overlying Areas 5 and 6.

Upland Swamps

Upland swamps are located within the surface water catchments that overlie Area 5 and Area 6.

Based on review of the area, all upland swamps identified within the Project underground mining areas comprise between 0 and 3% of the catchment areas of the individual drainage lines overlying Areas 5 and 6 (Appendix C).

Section 6.8 provides a description of the upland swamps and the potential impacts to upland swamps associated with the Project.

Effects of Previous Mining

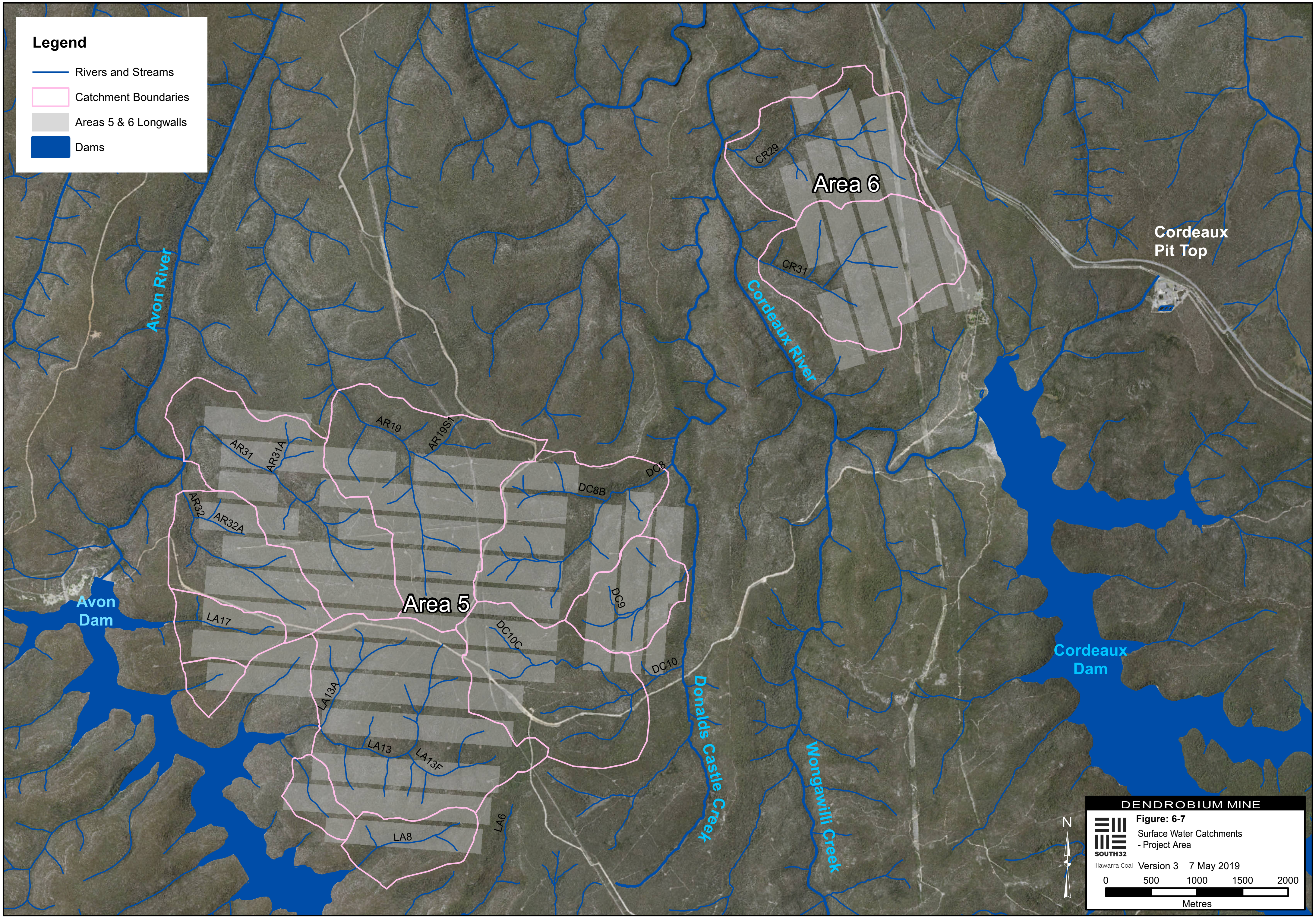
Surface Water Flow

Previous mining at the Dendrobium Mine has resulted in observed reduction in stream flow, primarily as a result of subsidence-related impacts to the stream beds (Appendix B).

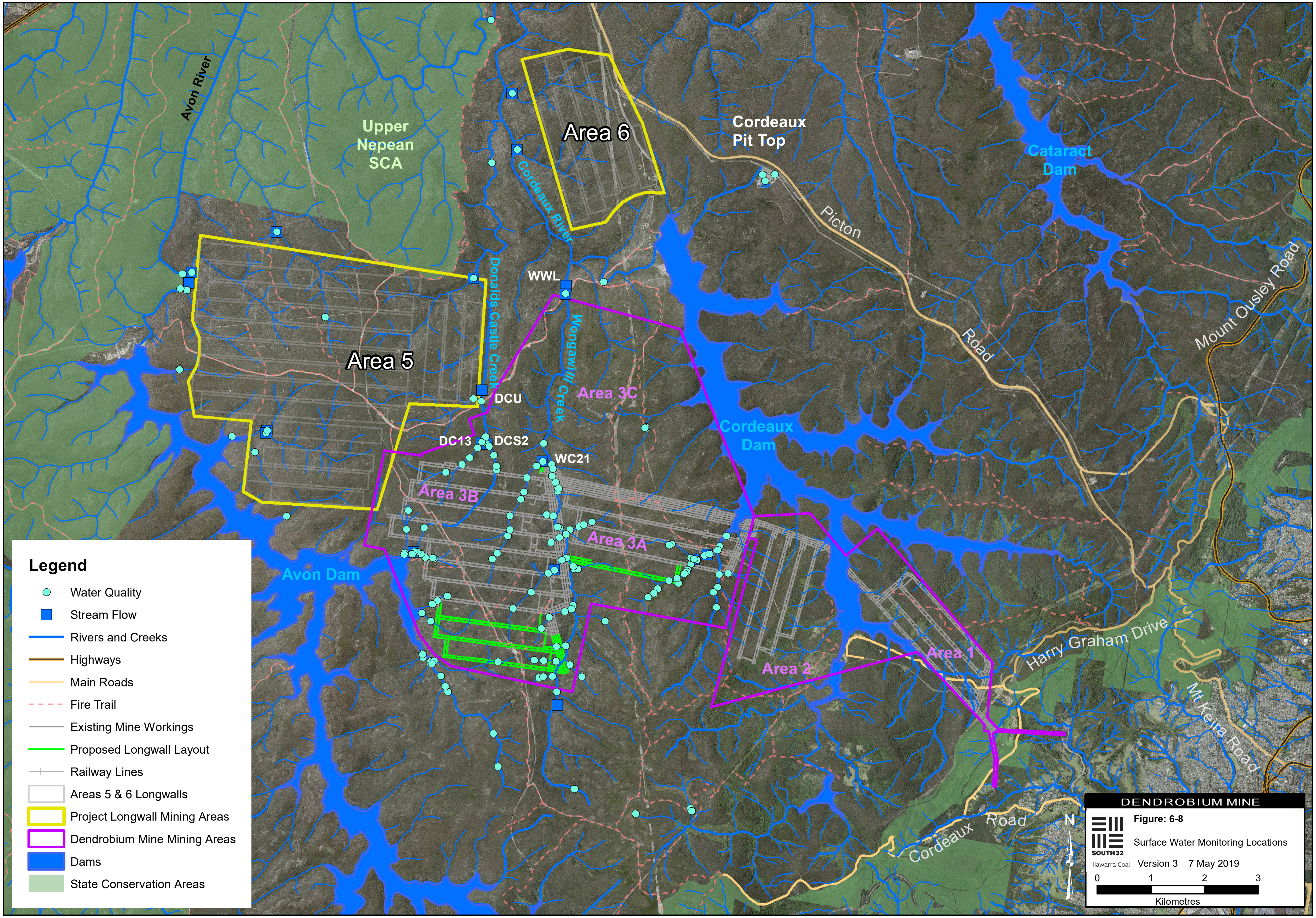
Table 6-8
Stream Characteristics – Areas 5 and 6

Project Underground Mining Area	Stream	Catchment Area (km²)	Maximum Strahler Stream Order	Stream Length within 600 m of Proposed Longwalls (km)	Permanence of Flow
Area 5	***Avon River Catchment***				
	AR19S1	0.4	2	0.6	Intermittent
	AR19S	1.1	2	0.8	Intermittent
	AR19	3.9	3	2.8	Intermittent
	AR31A	0.3	2	0.6	Intermittent
	AR31	3.0	3	2.8	Intermittent
	AR32A	0.3	2	0.7	Intermittent
	AR32	1.7	3	2.4	Intermittent
	Avon Dam Catchment				
	LA6	1.0	2	1.3	Intermittent
	LA8	1.3	2	2.1	Intermittent
	LA13A	1.1	2	1.4	Intermittent
	LA13F	1.0	2	1.2	Intermittent
	LA13	5.6	3	3.6	Intermittent
	LA17	1.0	2	1.5	Intermittent
	Donalds Castle Creek Catchment				
	DC8B	0.7	2	1.2	Intermittent
	DC8	2.6	3	2.7	Intermittent
	DC9	1.1	2	1.3	Intermittent
	DC10	2.9	2	1.3	Intermittent
	DC10C	1.6	2	2	Intermittent
Area 6	***Cordeaux River Catchment***				
	CR29	2.3	2	2.3	Intermittent
	CR31	2.6	2	1.4	Intermittent
	CR31C	1.1	2	1.2	Intermittent

Source: After Appendix C.



Legend
Rivers and Streams
Catchment Boundaries
Areas 5 & 6 Longwalls
Dams
Area 6
CR29
CR31
Cordeaux River
Cordeaux Pit Top
Avon River
Area 5
AR19
AR19S1
AR31
AR31A
AR32
AR32A
DC8
DC8B
DC9
DC10C
DC10
LA17
LA13A
LA13
LA13F
LA8
LA6
Avon Dam
Cordeaux Dam
Donalds Castle Creek
Wongawilli Creek
N
DENDROBIUM MINE
Figure: 6-7
Surface Water Catchments
- Project Area
SOUTH32
Illawarra Coal
Version 3 7 May 2019
0 500 1000 1500 2000
Metres



Avon River
Upper Nepean SCA
Area 6
Cordeaux Pit Top
Cataract Dam
Cordeaux River
Picton Road
Mount Ousley Road
Donalds Castle Creek
WWL
Area 5
Wongawilli Creek
Area 3C
DCU
DC13
DCS2
WC21
Cordeaux Dam
Area 3B
Area 3A
Avon Dam
Area 2
Area 1
Harry Graham Drive
Mt Keira Road
Cordeaux Road
Legend
Water Quality
Stream Flow
Rivers and Creeks
Highways
Main Roads
Fire Trail
Existing Mine Workings
Proposed Longwall Layout
Railway Lines
Areas 5 & 6 Longwalls
Project Longwall Mining Areas
Dendrobium Mine Mining Areas
Dams
State Conservation Areas
DENDROBIUM MINE
Figure: 6-8
Surface Water Monitoring Locations
SOUTH32
Illawarra Coal
Version 3 7 May 2019
N
0 1 2 3
Kilometres

Loss of surface flow has been discernible on hydrographs at stream flow gauges located immediately downstream of Area 3B, such as WC21, DC13S1 and DCS2 (Figure 6-8) (Appendix B).

However, corresponding changes in surface water flow at downstream gauges (DCU and WWL) (Figure 6-8) were not discernible, as the volume of water lost was insignificant compared to total flow at the downstream gauging stations and/or was within the accuracy of the flow gauges (Appendix B) (Advisian, 2016).

This is supported by the comments by the IEP (2018), who note that there has been no strong evidence that subsidence-related impacts to watercourse beds leads to significant losses of water at the scale of the drinking water supply catchments.

Water Quality

Watercourses that have been impacted by subsidence (e.g. WC21 during mining of Longwalls 10 and 11 in Area 3B) have shown temporary increases in dissolved iron and manganese, and an increase in pH to near neutral (pH 7) at sampling locations immediately downstream (Appendix B). Subsidence effects have also resulted in localised iron staining in creek beds.

Localised and short-term impacts to water quality in watercourses have not resulted in discernible changes in water quality at reservoirs in the Special Catchment Areas (HEC, 2019; Advisian, 2016). This is supported by analysis from Professor Chris Fell AM in the discussion paper for the Office of the NSW Chief Scientist and Engineer (Fell, 2014), which stated:

> *Although the impact of underground long-wall mining in the catchment could lead to small changes in the levels of impurities in water entering SCA's dams, these changes can be coped with by SW's treatment plants as evidence to date does not suggest a sufficiently large change in soluble organic concentrations to be of concern.*

6.6.3 Assessment

Site Water Balance

A water balance model was developed for the Dendrobium Mine water management system and has been used to simulate the Project. The water balance model simulates changes in stored volumes of water in all storages in response to inflows, outflows and internal pumped transfers.

While reuse of mine water to meet operational demands is maximised, the results of the site water balance show that groundwater contributes the majority of system inflows while release via LDP5 dominates system outflows for the Project, and would result in a required duplication of the existing excess water pipeline. The potential impacts of increased excess mine water release at LDP5 as a result of the Project is provided in the sections below.

The model results also demonstrate that there is sufficient water supply to meet the Project water demands.

Setbacks from Significant Streams and Stream Features

Assessment of 'Significance'

The stream risk assessment methodologies outlined in the NSW Planning Assessment Commission assessments of the Metropolitan Mine and Bulli Seam Operations were considered for the Project to identify the relative significance of streams and stream features in the Project underground mining areas and immediate surrounds.

When considering stream order, catchment area, importance to catchment yield, permanence of flow, mapped Key Fish Habitat (KFH) and function as a regulated watercourse for drinking water supply, the most significant streams were identified to be the Avon River and Cordeaux River (i.e. downstream of the Avon and Cordeaux Dams, respectively) (Appendix C).

The next most significant stream in terms of stream order, catchment area, KFH and importance to catchment yield is Donalds Castle Creek. However, when compared to the Avon and Cordeaux Rivers, this stream is not perennial and is not a regulated watercourse for water supply (Appendix C).

The remaining unnamed streams are lower order (maximum third order), ephemeral, have lower importance to catchment yield and are not regulated watercourses. While third order sections of these streams are considered to contain Type 2 ('Moderately sensitive') KFH, streams of this type are common throughout the catchment area (Appendix C).

Site inspection and mapping of the ephemeral drainage lines by South32 identified that particular stream features (i.e. pools and steps) were more ‘significant’ than other stream features. As such, stream features meeting the following definition have been classified by South32 as ‘key stream features’:

- Pools with volume greater than 100 m³ and holding water.
- Steps with greater than 5 m height with a permanent pool at the base.

The mapped key stream features are listed in Table 6-9.

Table 6-9
Key Stream Features

Stream	Features Identified as Key Stream Features
AR19	13 pools
AR31	4 pools, 1 step
AR32	3 pools, 3 steps
LA13	4 pools
DCC	12 pools
DC10C	1 pool
DC8	2 pools, 2 steps
CR29	4 pools
CR31	8 pools

Source: After Appendix C.

Setbacks from Significant Streams and Key Stream Features

The Project proposes longwall setbacks from the relatively significant named watercourses (i.e. Cordeaux River, Avon River and Donalds Castle Creek) such that 200 mm of additional predicted closure or less would be achieved (Section 3.5.3).

MSEC (2019) predicts this would result in a low likelihood (less than 10%) of subsidence-related fracturing resulting in the diversion of flow in the short sections of these named watercourses within 400 m of the Project longwalls. Fracturing and flow diversion impacts for the majority of the lengths of these watercourses which are beyond 400 m from the Project longwalls are not expected.

With the implementation of these mining setbacks there would be no undermining of perennial watercourses, or watercourses greater than 3rd order.

The Project would also setback longwalls from key stream features by 50 m (where longwall mining occurs on one side) and 100 m (where mining occurs on two or more sides) to reduce the likelihood of subsidence-related impacts to these key stream features.

South32 does not consider it to be economically feasible to avoid the direct undermining of all ephemeral drainage lines (Section 9), however, as direct undermining of key stream features would be avoided, this would reduce the likelihood of damage to these features (Appendix A).

Where physical damage is observed in sections of streams for which setbacks have been proposed, this damage would be remediated (Section 7).

The setbacks from significant streams and key stream features are additional to those proposed for the protection of water supply infrastructure (i.e. 1,000 m setbacks from the Avon and Cordeaux Dam walls and 300 m setbacks from the FSLs of these reservoirs).

Figure 6-9 illustrates the Project mining constraints relating to named watercourses, key stream features and water supply infrastructure. Maps A to D show the key stream features and associated setbacks in greater detail.

Residual impacts to stream attributes, in consideration of proposed mining setbacks, have been assessed by MSEC (2019), HydroSimulations (2019), HEC (2019), Niche (2019a) and Cardno (2019).

Stream Flow

Modelling Methodology

HEC (2019) has assessed potential changes to stream flow in consideration of potential subsidence-related impacts (Section 6.3 and Appendix A) and associated groundwater depressurisation (Section 6.5 and Appendix B).

In addition, the potential for increased streamflow loss from the swamps to the groundwater system, has been considered by HEC (2019) with modelling using VADOSE software.

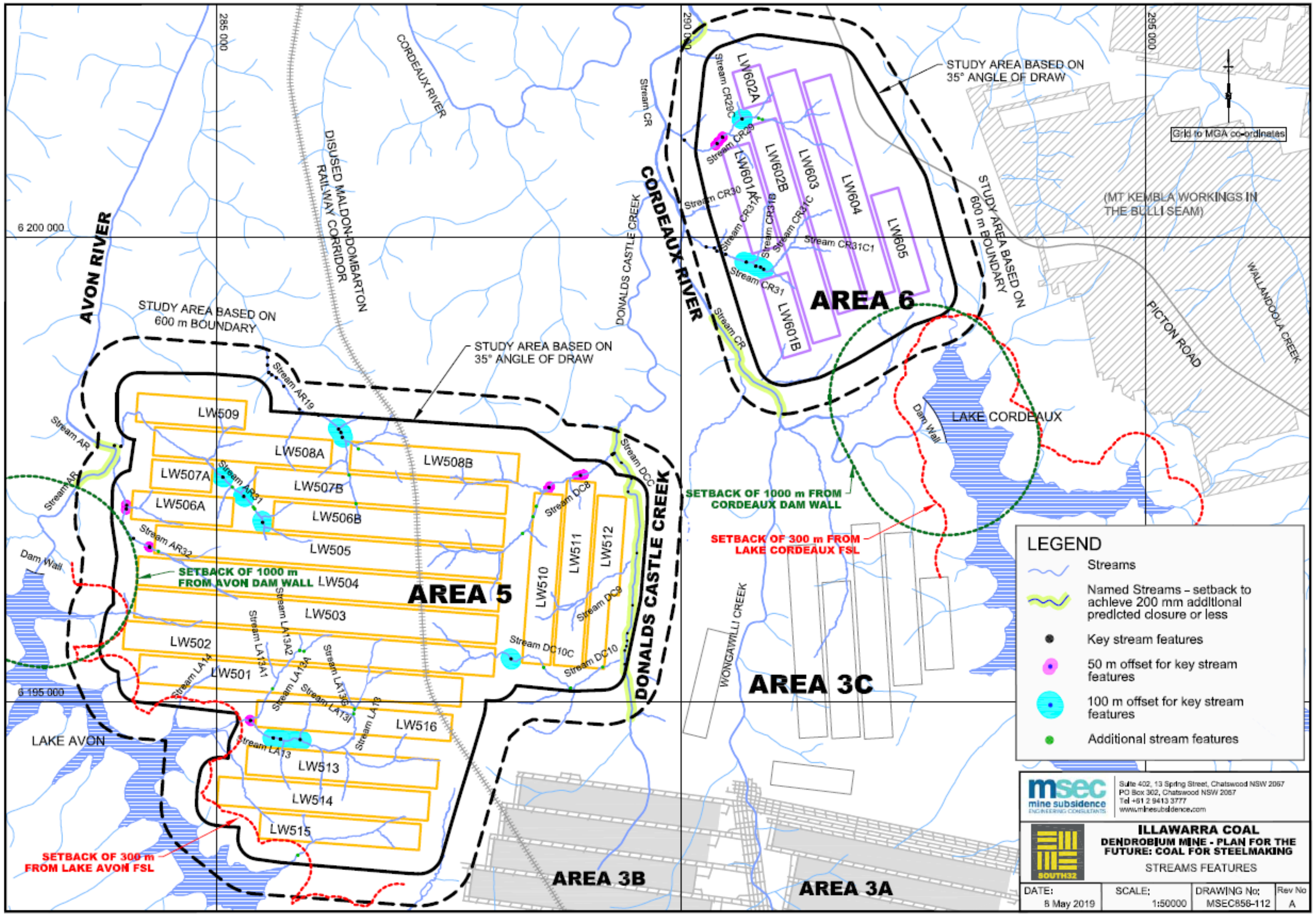
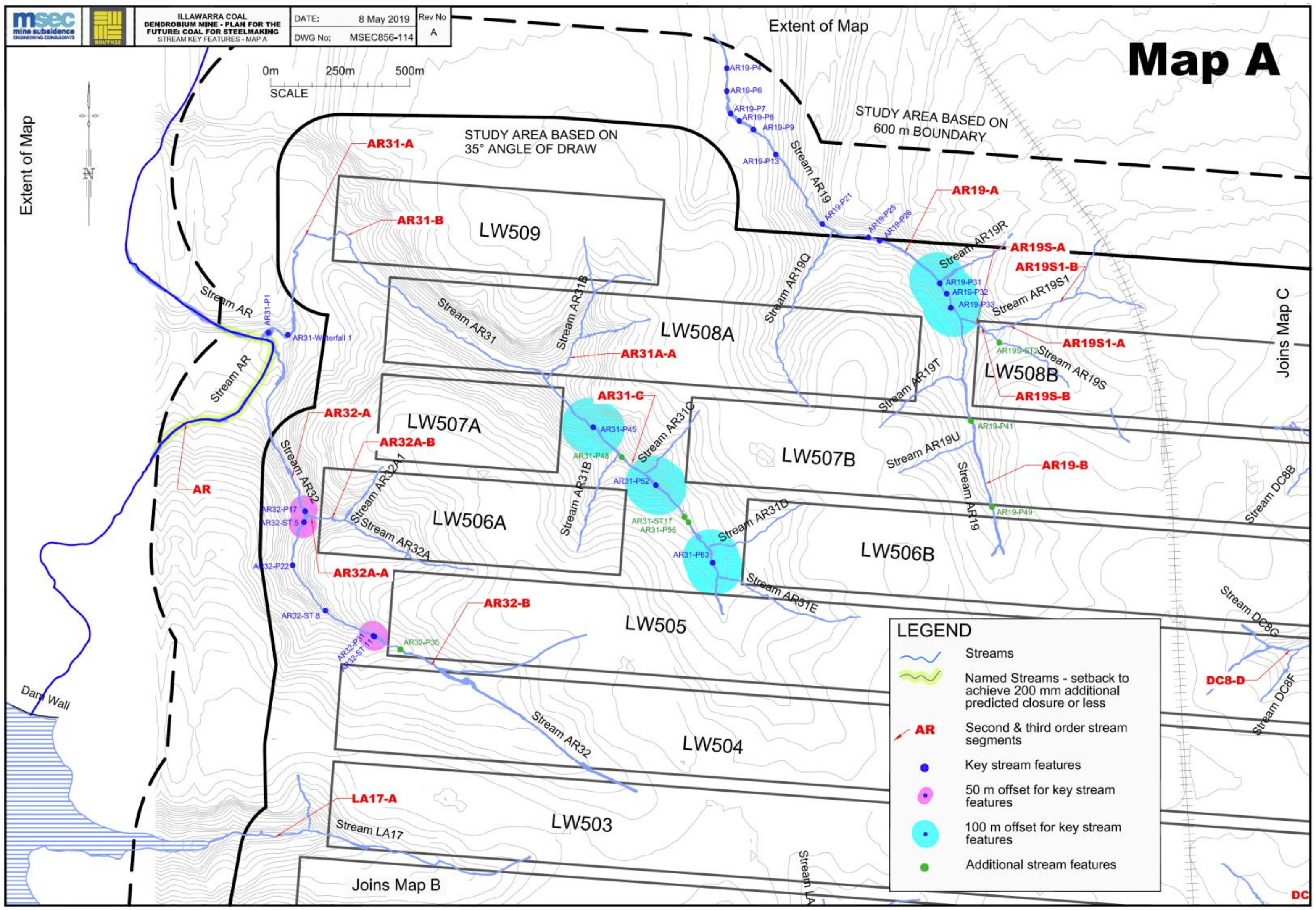
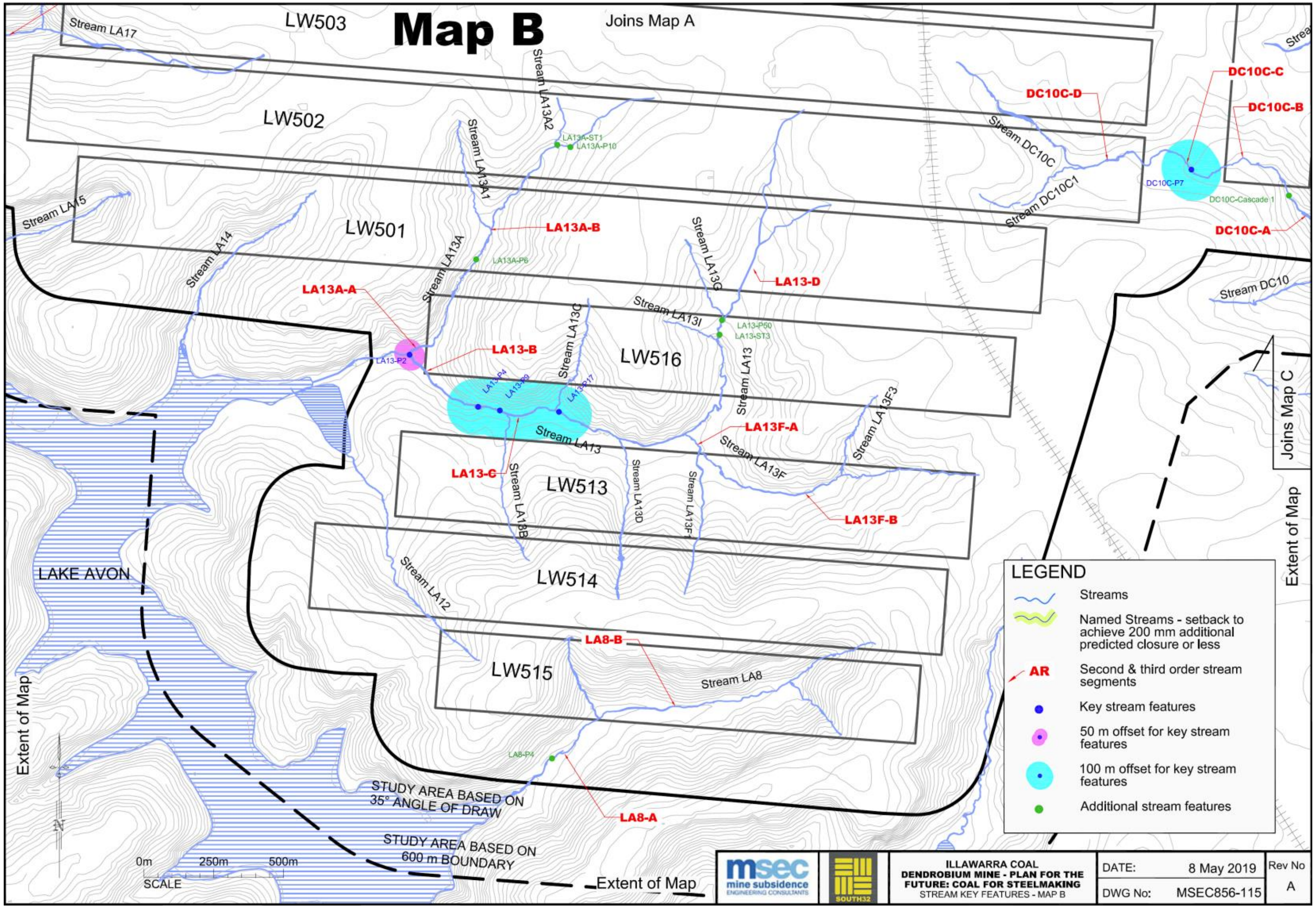


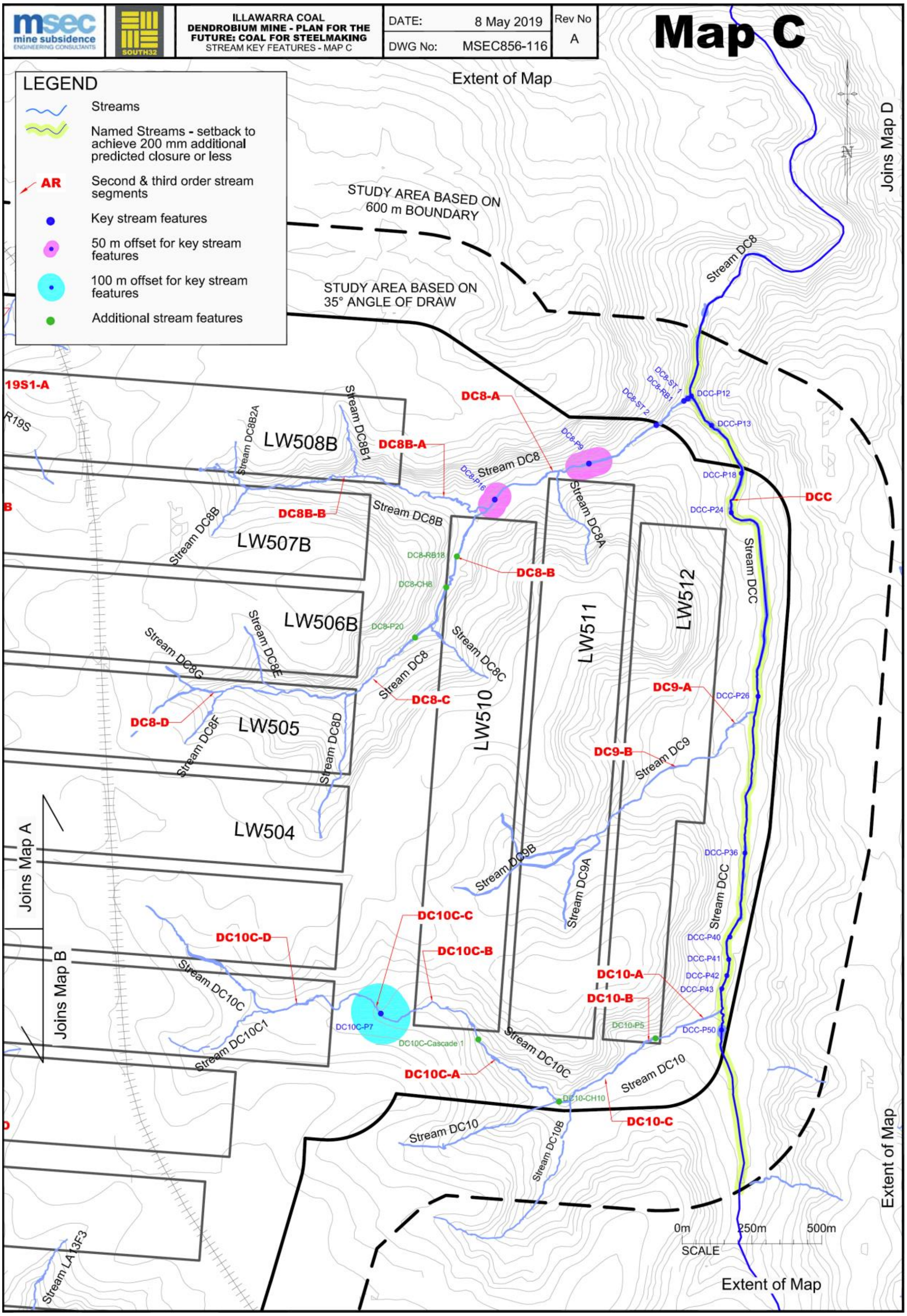
Figure 6-9 **Project Mining Constraints for Named Watercourses, Key Stream Features and Water Supply Infrastructure**



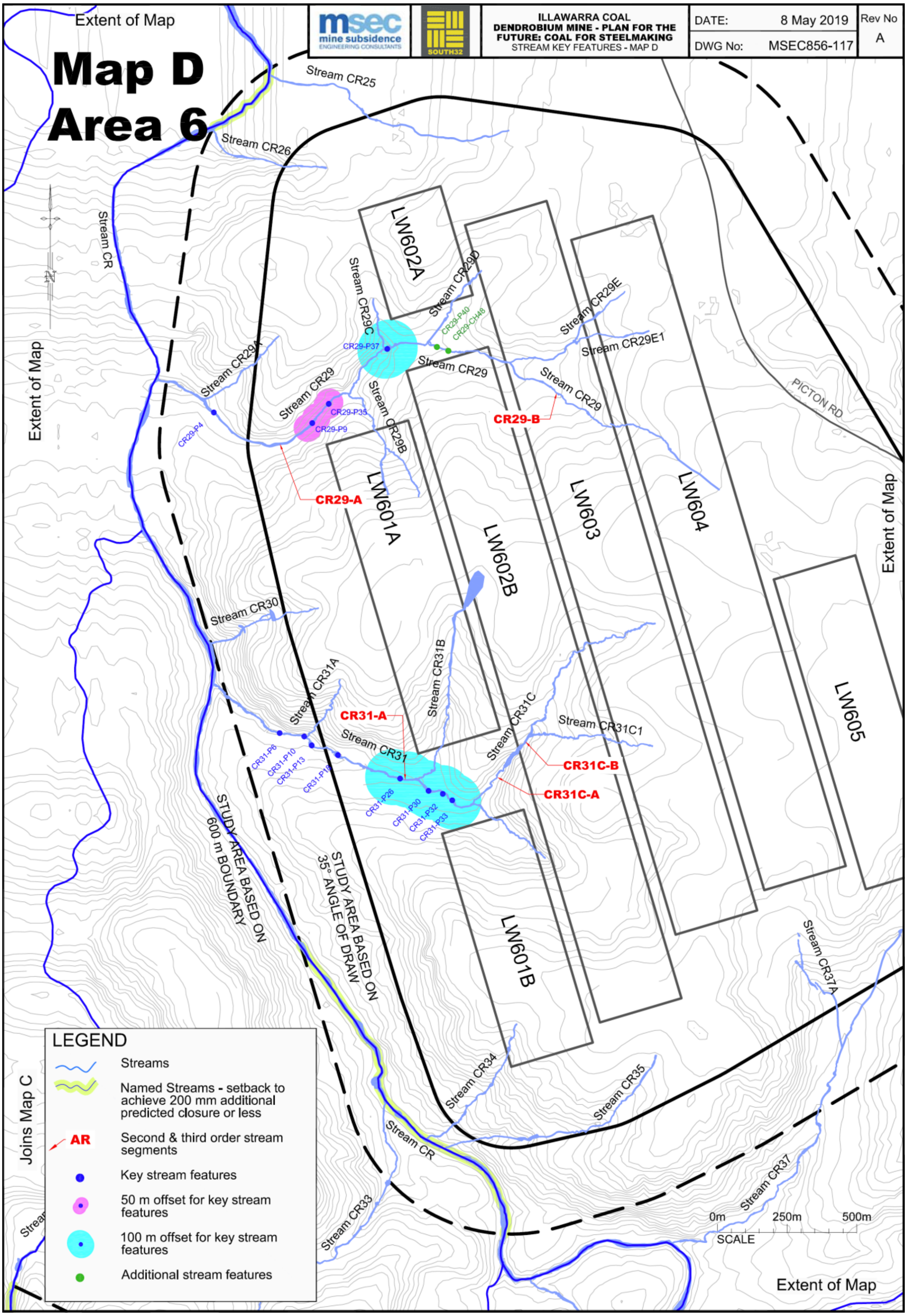
Map A Key Stream Features – Area 5 Tributaries to the Avon River



Map B Key Stream Features – Area 5 Tributaries to Avon Dam



Map C Key Stream Features – Area 5 Tributaries to Donalds Castle Creek



Map D Key Stream Features – Area 6 Tributaries to the Cordeaux River

The VADOSE modelling was undertaken to estimate seepage from the base of the swamp as a result of subsidence-related increases in hydraulic conductivity and swamp gradient. The modelling was undertaken at the scale of the swamps to refine the modelling of seepage from swamps undertaken at the regional scale for the Groundwater Assessment.

Calibration of the VADOSE model was undertaken using data from piezometers installed in swamps overlying Area 5. The modelled effects of longwall mining to swamp water levels were compared against measured swamp water levels from Area 3B to confirm the validity of the modelling results (Appendix C).

The assessment of potential stream flow reductions is, therefore, based on a combination of (Appendix C):

- the surface water losses predicted by the groundwater model (Section 6.5 and Appendix B), which are considered an upper maximum of potential losses to the groundwater system as the groundwater modelling assumes water is available in the ephemeral drainage lines to be lost, as it does not consider daily variations in rainfall and associated stream flow;
- potential losses from swamps predicted by the VADOSE modelling, which are considered in addition to the groundwater modelling predictions; and
- the catchment runoff model, which accounts for daily variations in rainfall (i.e. to determine whether water is available to be lost from the ephemeral drainage lines).

Drainage Lines

The modelling indicates that for the drainage lines overlying Areas 5 and 6 (Appendix C):

- **Dry (10th percentile) climate sequence**: the volumes of predicted stream flow losses are lowest, as less flow is available in the stream to be lost, however, the percentage reduction in stream flow (63 to 100% in Area 5 and 19 to 51% in Area 6) and the increase in the durations of no-flow conditions is predicted to be greatest.
- **Median climate sequence**: there is a predicted 6 to 22% reduction in stream flow in Area 5 under the median climate sequence and a 1 to 5% reduction in stream flow in Area 6, with increased durations of no-flow conditions predicted.
- **Wet (90th percentile) climate sequence**: the volume of predicted stream flow loss is greatest, with the percentage reduction in stream flow (3 to 11% for Area 5 and 1 to 2% for Area 6) and the increase in the durations of no-flow conditions is predicted to be lowest.

The contribution of yields from a swamp to stream flow in the downstream drainage line was estimated to be a maximum of 2% for the median climate sequence. Increased seepage from swamps due to longwall mining was estimated to represent approximately 1% or less of downstream flow in the drainage line.

Cordeaux River and Avon River

As the Cordeaux River and Avon River are regulated streams downstream of the respective dams, flows cannot be accurately estimated using the catchment runoff modelling.

Catchment Yields

Stream flow losses due to the Project are predicted to result in a negligible reduction in catchment yields (i.e. less than 1% reduction to Avon Dam and Pheasant's Nest Weir) for the median climate sequence (Appendix C).

This conclusion is consistent with previous findings regarding the lack of the observed evidence of longwall mining in the Special Catchments resulting in any significant reductions in catchment yields (IEP, 2018; Advisian, 2016).

Stream Features

Based on the potential for direct subsidence impacts and reductions in stream flow in drainage lines overlying Areas 5 and 6, there is associated potential for reductions in stream pool levels (Appendix C).

As access to the Metropolitan Special Area is restricted for the public, there is no recreational use of these drainage lines or their stream features.

Potential consequences of reductions in stream pool levels to aquatic and terrestrial ecology are provided in Sections 6.7 and 6.9.

Water Quality

Potential impacts on water quality as a result of the subsidence-related impacts from the Project are predicted to be localised and temporary (Appendix C).

The water management systems for the Project surface infrastructure in the Metropolitan Special Area have been designed to minimise the potential for downstream water quality impacts (Appendix C).

The potential for erosion as a result of subsidence-related tilt is considered to be low and localised (Appendix A), and as such, significant increases in erosion are considered to be unlikely (Appendix C).

HEC (2019) concludes that any localised changes in water quality due to the Project are likely to result in negligible impacts to water quality at reservoirs, consistent with the observations of Advisian (2016) and Fell (2014) in regard to the effects of historic mining.

Consideration of the Project against the 'Neutral or Beneficial Effects (NorBE) Test' is provided in Section 9, along with justification that the Project would result in a net beneficial effect to water quality with the implementation of proposed water quality improvement actions in the Special Catchment Areas.

EPL Controlled Releases

Groundwater inflows (Section 6.5) would continue to be managed in accordance with current EPL conditions (i.e. discharge via LDP5 to Port Kembla via Allans Creek).

South32 is investigating options for the beneficial reuse of excess mine water to reduce the quantity of water required to be released via LDP5 (Section 3). However, for excess mine water that is not diverted and reused for industrial purposes, the predicted increases in groundwater inflows for the Project (Section 6.5) may result in increases in controlled release volumes at LDP5 (Plate 6-2) through the existing excess water pipeline and proposed excess water pipeline upgrade, replacement or duplication.

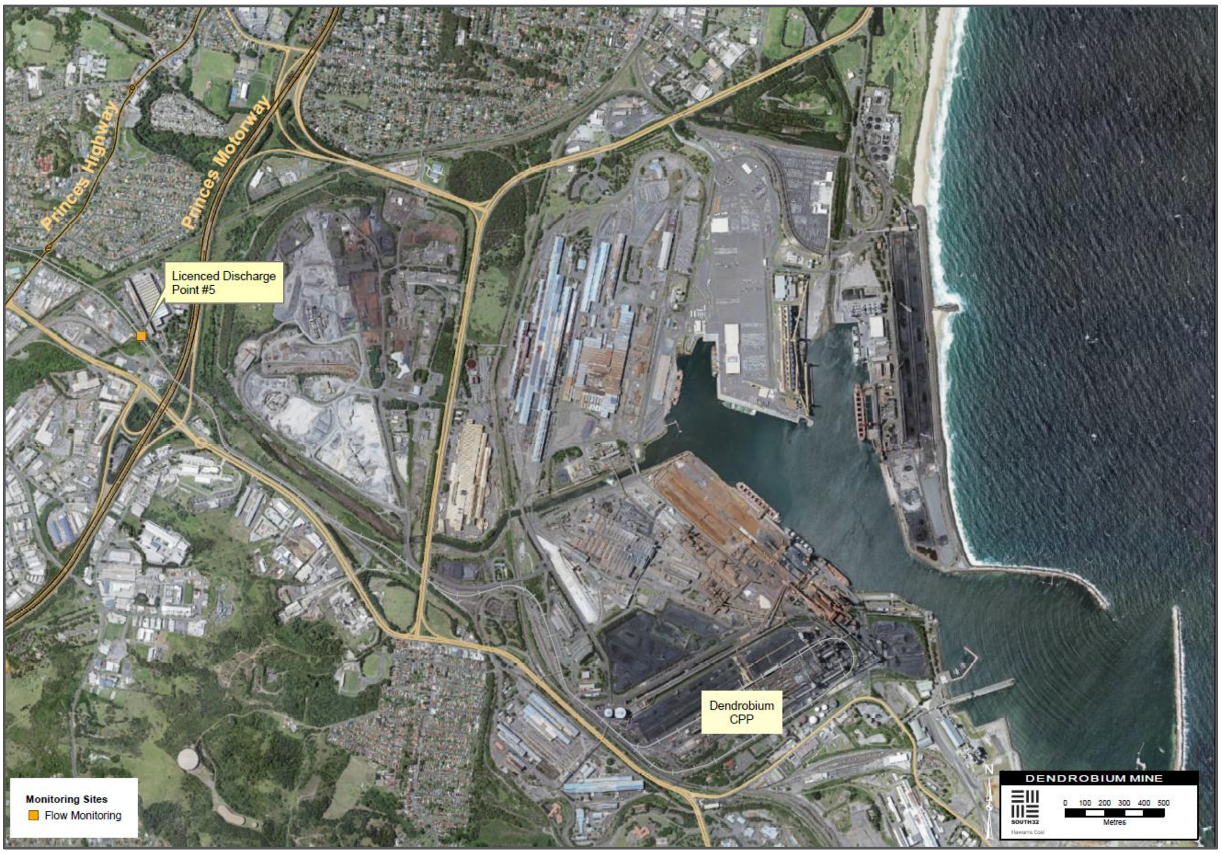


Plate 6-2 – Licensed Discharge Point 5

Based on review of the expected groundwater quality estimates by HEC (2019), controlled releases via LDP5 are expected to continue to comply with the existing EPL water quality limits, as the groundwater quality estimates for Area 5 and Area 6 are similar to those of the existing concentrations measures at LDP5 (Appendix C).

As the bed and banks of Allans Creek are concrete lined in the vicinity of LDP5, and a short distance downstream the creek joins the much larger American Creek which comprises a tidal/estuarine environment (Plate 6-2), the impacts of additional volumes of controlled releases on stream stability are likely to be negligible (Appendix C).

In summary, HEC (2019) concluded that the increase in discharge to LDP5 is unlikely to result in an exceedance of the EPL water quality limits or impacts on Allans Creek or any significant impacts to the stability of the channel. A short distance downstream, Allans Creek joins the tidal/estuarine environments of American Creek and the wider Port Kembla area, which is surrounded by various industrial complexes.

6.6.4 Mitigation Measures and Monitoring

Management Measures

The existing and approved water management systems at the Dendrobium Mine would continue to be used for the Project.

Additional surface water management requirements for the Project would include:

- management of surface runoff associated with Shaft Nos 5A, 5B, 6A and 6B through the implementation of sediment dams; and
- management of increased groundwater inflows to the underground mine workings, including the upgrade, replacement or duplication of the existing excess water pipeline following the Kemira Valley Rail Line to LDP5.

Mitigation Measures

Surface Water Flows

Section 6.5.4 describes proposed mitigation measures for the negligible predicted reductions in catchment yields due to the Project (i.e. paying WaterNSW for surface water that may no longer be available for sale to other water users).

This would be in addition to:

- appropriate licensing of predicted water take under the *Water Management Act, 2000*; and
- the objective of beneficial re-use of excess mine water at the Port Kembla industrial precinct, with the intention that the re-use volume matches or exceeds predicted Project surface water take, achieving no net reduction in the total WaterNSW water budget.

Water Quality

Although the potential impacts on water quality as a result of the subsidence-related impacts from the Project are predicted to be localised and temporary, the Project is required to demonstrate that the carrying out of the proposed development would have a neutral or beneficial effect on water quality (i.e. the NorBE Test) (Section 9.3.6).

Project sediment controls for surface disturbance activities would be designed consistent with *Managing Urban Stormwater Soils and Construction – Volume 2E – Mines and Quarries* (Commonwealth Department of Environment and Climate Change [DECC], 2008).

Controlled releases via LDP5 would be monitored to confirm EPL water quality objectives are being achieved. The volume of water to be released would be minimised as far as practicable through the proposed beneficial re-use of excess mine water.

Water quality improvement actions are proposed as part of the Project to offset potential localised effects associated with subsidence-related impacts (e.g. pulses of iron and manganese) and demonstrate the Project would have a net neutral or beneficial effect on water quality.

These actions for the Project would be additional to those already proposed and funded by WaterNSW and would target reduced sedimentation in the Special Catchment Areas, and would include:

1. Transfer of 28.5 ha of South32-owned land within the Metropolitan Special Area to WaterNSW.

   This would enable WaterNSW to manage and protect this land in accordance with the *Special Areas Strategic Plan of Management 2015*, which does not cover privately-owned land in the Special Catchment Areas.

For example, access restrictions could be imposed on land transferred from South32 to WaterNSW, as access restrictions do not apply to privately-owned land in the Special Catchment Areas (WaterNSW and OEH, 2015).

2. Direct implementation (by South32) or funding (to WaterNSW) of water quality improvement works within the Special Catchment Areas (Table 6-10).

   WaterNSW's *Catchment Protection Work Program 2018-19: Sydney Catchment Area* outlines planned activities for water quality management in the Sydney Catchment Area, as well as the planned benefits for these activities.

   The additional works proposed for the Project would complement those planned by WaterNSW.

Remediation

Where monitoring indicates that subsidence-related impacts have occurred to key stream features (i.e. named watercourses and key stream features), South32 would implement remediation measures to mitigate physical damage to the streams where it is practicable to do so.

An example of where it may not be practicable to implement remediation is where the works themselves may cause greater environmental impacts than the subsidence-related impact (e.g. if clearance is required to provide access for materials and equipment to the remediation site).

Section 7 provides details of techniques that have been successfully used to remediate subsidence-related impacts to streams.

Monitoring

Surface water monitoring of water management systems would be undertaken in accordance with EPL 3241 for the Dendrobium Mine (and any other EPL required for the Project) targeting discharge locations and key water storages.

HEC (2019) has provided recommendations for ongoing and additional surface water monitoring for the Project, which are summarised below.

Meteorological Monitoring

An automatic weather station would be installed in Area 5 or 6 and would include meteorological monitoring such as temperature, humidity, wind speed, wind direction and solar radiation.

Pluviometers would also be installed in locations representative of catchments of the drainage lines overlying Areas 5 and 6 to provide rainfall data.

Table 6-10
Proposed Water Quality Improvement Works

Water Quality Improvement Work	Estimated Financial Contribution (if works not conducted by South32)
Fire Management: • Slashing grass and vegetation for fire breaks (100 km and 200 ha). • Mulching trees and woodland along fire trails to maintain fire breaks (at least 22.5 km). • Conducting hazard reduction burns (at least 100 ha) in consultation with relevant authorities.	$371,500[1]
Inspect and Maintain Unsealed Road Network: • Inspect 150 km of unsealed roads. • Repair and upgrade 40 km of unsealed roads within the Special Catchment Areas.	$146,000[1]
Install and Maintain Appropriate Barriers and Fences: • Install barriers as required around any land transferred to WaterNSW. • Install barriers and fences to replace those that are damaged or vandalised.	$100,000[2]
Total	**$617,500**

1 Based on conducting an additional 50% of WaterNSW's Planned Activities for Fire Management and Unsealed Roads Program as per the *Catchment Protection Work Program 2018-19: Sydney Catchment Area*.

2 Estimation only.

Flow Rates

The existing Area 5 and Area 6 gauging station network would be expanded and augmented.

The gauging station would target low flow accuracy of ±0.0025 ML/day resolution and ±10% accuracy over the flow range 0.01 to 10 ML/day.

Manual flow gauging would also be conducted to verify flow rating curves.

Pool Water Levels

Continuous pool level data would be collected on a selection of key stream features, plus control pools.

Manual water level monitoring would also be conducted to verify the continuous monitoring.

Water Quality

The existing water quality monitoring network for Areas 5 and 6 would be continued and expanded for the Project.

Water quality monitoring would also continue in existing surface water storages and at LDP5 to confirm compliance with EPL water quality objectives. Water quality monitoring would also be conducted in new water management storages required for the Project (e.g. at the ventilation shaft sites).

Observational and Photographic Monitoring

Observations and photographs along streams (e.g. at key stream features) would be undertaken before, during and following mining to identify visual signs of impacts (e.g. cracking, erosion, iron floc).

Monitoring of Water Transfers

Monitoring of water transfers between the underground and surface water management systems would continue for the Project.

Model Review

Catchment Runoff Model

The catchment runoff model would be progressively updated over the life of the Project in consideration of the stage of longwall mining, data collected from the monitoring network (e.g. rainfall and flow rates) and updated predictions from the groundwater model.

Site Water Balance

The site water balance would be reviewed over the life of the Project in consideration of monitoring data (e.g. water transfers) and updated predictions from the groundwater model.

6.6.5 Adaptive Management

Monitoring locations, methods, trigger levels and contingencies relating to surface water would be detailed in Extraction Plans for the Project.

If monitoring data indicates that the Project longwalls are resulting in trigger exceedances then adaptive management measures would be implemented.

Potential contingency measures for greater than expected groundwater impacts could include:

- increased payments to WaterNSW for estimated surface water take;
- remediation of surface cracks or physical damage to key stream features (i.e. to minimise diversion of surface flows to the groundwater system) (Section 7);
- increased biodiversity offsets (e.g. for upland swamps); and
- mine plan review.

6.7 AQUATIC ECOLOGY

6.7.1 Methodology

The Aquatic Ecology Assessment for the Project was undertaken by Cardno and is presented in Appendix E.

The Aquatic Ecology Assessment was prepared in accordance with the SEARs for the Project as well as relevant State and Commonwealth requirements, including the FM Act, EPBC Act and the *Policy and Guidelines for Fish Habitat Conservation and Management* (DPI Fisheries, 2013).

Where relevant, the Aquatic Ecology Assessment incorporates outcomes of the Subsidence, Groundwater and Surface Water Assessments (Appendices A, B and C, respectively).

Due to the different assessment and offset consideration methodologies, potential impacts, mitigation and adaptive management measures for threatened aquatic ecology listed under the BC Act (i.e. the Giant Dragonfly) are described in Section 6.9.

A summary of the existing aquatic ecology and results of surveys within the Project area is provided in Section 6.7.2. Section 6.7.3 describes the potential impacts to aquatic ecology listed under the FM Act, while Sections 6.7.4 and 6.7.5 outline mitigation and adaptive management measures, respectively.

6.7.2 Existing Environment

The Project underground mining areas are located entirely within the Upper Nepean Catchment and Metropolitan Special Area. Surface water hydrology in the vicinity of the Project is detailed in Section 6.6.2.

Approved Mine Aquatic Ecology Monitoring

Monitoring of aquatic habitat, macroinvertebrates and fish in Dendrobium Mine Areas 1, 2, 3A and 3B has been undertaken by Cardno since 2000, including watercourses within the Wongawilli, Native Dog, Donalds Castle and Sandy Creek catchments (Appendix E).

The results of the monitoring indicate that aquatic habitat and fauna within the Dendrobium Mine area is largely undisturbed. Riparian vegetation is generally in very good condition with little or no introduced species. Aquatic vegetation is relatively sparse and found primarily in the Avon River and Cordeaux River.

Macroinvertebrate sampling results assessed against the Australian River Assessment System (AUSRIVAS) reflect the largely undisturbed catchment. Although the results suggest fewer taxa than may be expected based on the AUSRIVAS approach, this is considered to be the natural condition and possibly related to naturally low pH of the surface water. The fish assemblage in watercourses is in good condition and no invasive fish have been identified in the Wongawilli Creek and Donalds Castle Creek catchments (Appendix E).

Project Aquatic Ecology Surveys

Baseline Surveys

Baseline aquatic ecology surveys for the Project were undertaken by Cardno between 28 and 30 September 2016 at a total of seven sites within Avon River, Cordeaux River and Donalds Castle Creek (Figure 6-10). The surveys included (Appendix E):

- characterisation of aquatic habitat, aquatic flora, macroinvertebrates and fish; and
- targeted surveys of Macquarie Perch (*Macquaria australasica*).

Plates 6-3a to 6-3f show photographs of aquatic ecology sampling sites.

KFH, as described in DPI Fisheries (2013), within the Project area and surrounds was identified via desktop mapping and field validation during surveys (Figure 6-10).

Aquatic Habitat

The Avon and Cordeaux Rivers provide substantial aquatic habitat and Type 1 – Highly Sensitive KFH. Wongawilli Creek and Donalds Castle Creek also provide Type 1 – Highly Sensitive KFH. The first and second order ephemeral drainage lines overlying the Project underground mining areas consist generally of disconnected pools, some also separated by waterfalls, providing barriers to fish movement and limiting the value of this habitat for fish.

These drainage lines do not provide KFH. Type 2 – Moderately Sensitive KFH habitat is provided by the third order sections of drainage lines. Aquatic habitat within these sections is comparable to that in the lower order ephemeral drainage lines.

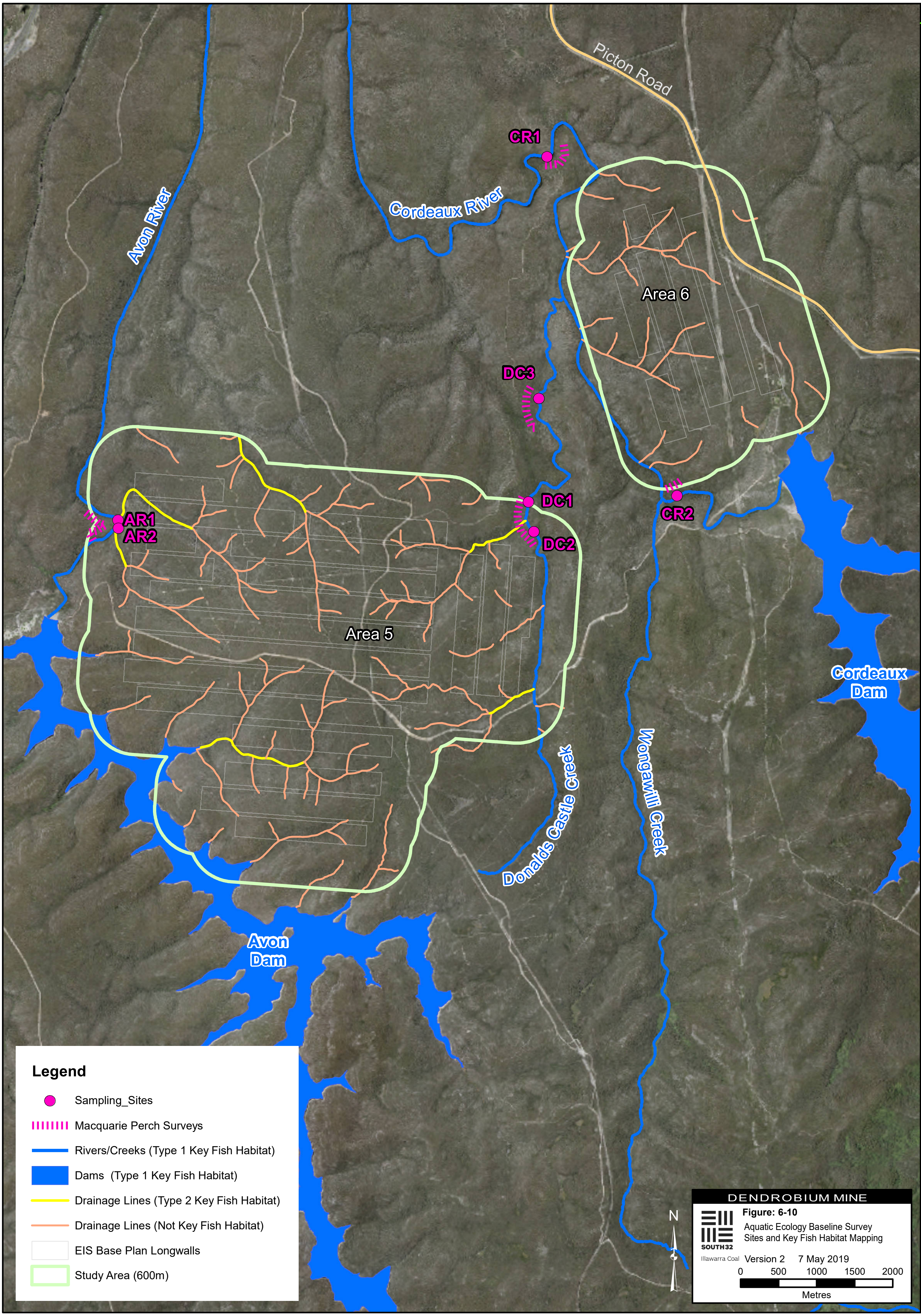

Picton Road
CR1
Cordeaux River
Avon River
Area 6
DC3
DC1
AR1
AR2
DC2
CR2
Area 5
Cordeaux Dam
Donalds Castle Creek
Wongawilli Creek
Avon Dam
Legend
Sampling_Sites
Macquarie Perch Surveys
Rivers/Creeks (Type 1 Key Fish Habitat)
Dams (Type 1 Key Fish Habitat)
Drainage Lines (Type 2 Key Fish Habitat)
Drainage Lines (Not Key Fish Habitat)
EIS Base Plan Longwalls
Study Area (600m)
N
DENDROBIUM MINE
SOUTH32
Illawarra Coal
Figure: 6-10
Aquatic Ecology Baseline Survey Sites and Key Fish Habitat Mapping
Version 2 7 May 2019
0 500 1000 1500 2000
Metres

Plate 6-3a – Sampling Site CR1
Source: Cardno (2019).

Plate 6-3b – Sampling Site CR2
Source: Cardno (2019).

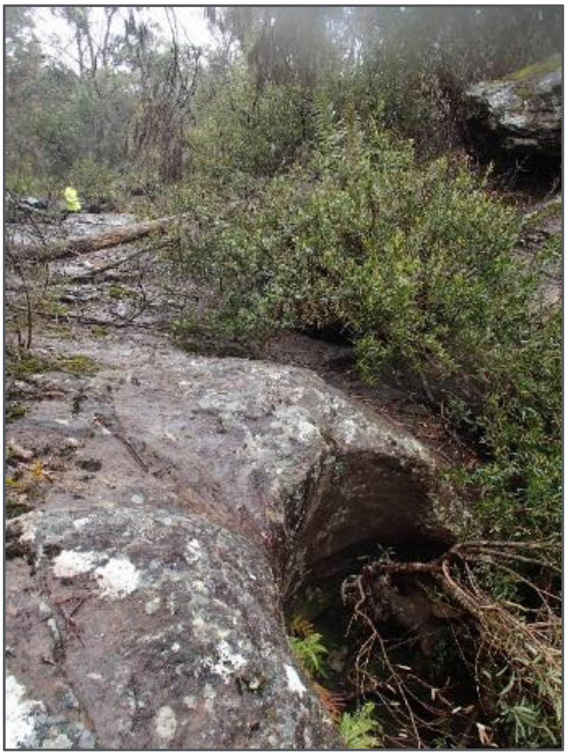


Plate 6-3c – Sampling Site AR1
Source: Cardno (2019).

Plate 6-3d – Sampling Site AR2
Source: Cardno (2019).

Plate 6-3e – Sampling Site DC1
Source: Cardno (2019).

Plate 6-3f – Sampling Site DC2
Source: Cardno (2019).

The Project area does not contain any critical aquatic habitat listed under the FM Act or EPBC Act.

Macroinvertebrates

Macroinvertebrate assemblages sampled for the Project area (i.e. Areas 5 and 6 and immediately downstream) were somewhat impaired according to the AUSRIVAS model, however, there is no evidence that this is mining-related (Appendix E). Rather, it likely reflects the natural water quality and naturally low pH within the watercourses. These assemblages were comparable to those sampled across the area during previous monitoring undertaken by Cardno (Appendix E).

Fish

Three native species of fish and a crayfish (considered to be common and widespread in the region) were caught during the surveys of Avon River, Cordeaux River and Donalds Castle Creek. These were the Flathead Gudgeon (*Philypnodon grandiceps*), Galaxid (*Galaxias sp.*), Australian Smelt (*Retropinna semoni*) and Freshwater Crayfish (*Euastacus sp.*).

Threatened Aquatic Species

No threatened aquatic ecology species listed under the FM Act and/or EPBC Act were recorded during baseline surveys.

A review of relevant studies and databases determined the following threatened aquatic species have been recorded or suitable habitat exists within 600 m of the proposed longwalls:

- Macquarie Perch (*Macquaria australasica*) – listed as Endangered under the FM Act and the EPBC Act.
- Adam's Emerald Dragonfly (*Archaeophya adamsi*) – listed as Endangered under the FM Act.
- Sydney Hawk Dragonfly (*Austrocordulia leonardi*) – listed as Endangered under the FM Act.

Macquarie Perch have been historically recorded within the Dendrobium Mine area within Wongawilli Creek. Although there are no known records of Adam's Emerald Dragonfly or Sydney Hawk Dragonfly within the Project area, potentially suitable micro-habitat for these species exists within the Project area.

6.7.3 Assessment

Potential Consequences of Aquatic Habitat Clearance

Direct disturbance of aquatic habitat would be avoided where possible, however minor works may be required (e.g. maintenance of stream crossings along access roads). Such works would have a negligible impact to aquatic ecology in the Project area (Appendix E).

Potential Consequences of Subsidence Impacts

Potential consequences of subsidence to streams are provided in Sections 6.3 and 6.6.

As a result of the adopted mining setbacks from named watercourses for the Project (Section 3.5.3), there would be a low likelihood (less than 10%) of subsidence-related fracturing resulting in diversion of flow in the short sections of the Avon River, Cordeaux River and Donalds Castle Creek within 400 m of the proposed longwalls. Fracturing and flow diversion impacts to the majority of these named watercourses located beyond 400 m from the proposed longwalls are not expected (Appendix A). Associated impacts to aquatic ecology are expected to be localised and relatively minor compared to the extensive aquatic habitat in the broader region (Appendix E).

Wongawilli Creek is further than 600 m from the proposed longwalls and therefore is not predicted to experience impacts to aquatic ecology as a result of the proposed underground mining (Appendix E).

Ephemeral drainage lines located directly above the proposed longwalls have been conservatively assessed on the basis that the full range of subsidence movements occurs (Appendix E), irrespective of the mining setbacks for key stream features (Section 3.5.3). Associated changes in the availability of ephemeral aquatic habitat that would occur are not expected to result in any significant impacts to overall aquatic ecology, due to the limited value of habitat within ephemeral drainage lines. The abundance of drainage line habitat in the wider catchment would also suggest such impacts would be very small to negligible in the context of the local and regional area (Appendix E).

The reductions in streamflow for the ephemeral drainage lines within the Project underground mining area are predicted to result in negligible changes in water yields in Avon Dam and downstream at Pheasants Nest Weir (Appendix C). Area 6 is located downstream of the Cordeaux Dam.

No significant impacts to aquatic ecology in watercourses downstream of the Project area or Avon Dam are predicted (Appendix E), noting that flows in the Avon River and Cordeaux River are controlled by releases from the Avon Dam and Cordeaux Dam, respectively (Appendix C).

Stygofauna are predicted to occur within the shallow fractured Hawkesbury sandstone aquifer as well as perched swamp aquifers. Potential impacts to stygofauna habitat within the Project underground mining area would be minor relative to the extent of possible stygofauna habitat in the entire Hawkesbury sandstone aquifer (which covers an approximate area of 200 km by 100 km) and mapped swamp habitat within the Woronora, O'Hares and Metropolitan Catchments (totalling approximately 6,445 km^2).

Potential impacts to aquatic ecology as a result of localised and temporary subsidence-related changes to water quality predicted to occur within the ephemeral drainage lines overlying the proposed longwalls would be minor and short-term (Appendix E).

Threatened Species – Assessment of Significance under Section 5A of the EP&A Act

Assessments of Significance for threatened aquatic species known or predicted to occur within the Project area have been undertaken in accordance with section 5A of the EP&A Act and the *Threatened Species Assessment Guidelines – the Assessment of Significance* (DECC, 2007) (Appendix E).

The Project is not likely to result in a significant impact to any threatened aquatic species listed under the FM Act, including aquatic species listed under both the FM Act and the EPBC Act (Appendix E).

The Project would not require biodiversity offsets for threatened species as it would not result in significant impact to any aquatic ecology listed under the FM Act and/or the EPBC Act (Appendix E).

6.7.4 Mitigation Measures

Avoidance and mitigation measures for streams, as described in Section 6.6.4, would also reduce potential impacts to aquatic ecology habitat. This includes:

- longwall setbacks from named watercourses and key stream features (e.g. certain pools and waterfalls/steps);
- erosion and sediment control strategies; and
- remediation of physical damage to stream features.

6.7.5 Adaptive Management

South32 would continue to conduct aquatic ecology monitoring within the Project underground mining area throughout the Project life, consistent with the methods outlined in the WIMMCP (South32, 2017a), as amended for the Project.

The Project-specific aquatic ecology monitoring plan would be detailed in Extraction Plans to be prepared for the Project, along with performance measures, triggers and contingency measures.

Consistent with the recommendations of the Aquatic Ecology Assessment (Appendix E), the Project-specific monitoring plan would include monitoring at sites both upstream and downstream of the proposed longwalls for the following indicators:

- changes in aquatic habitat, including photo recording;
- water quality;
- macrophyte composition and coverage area;
- AUSRIVAS macroinvertebrate sampling and artificial macroinvertebrate collection;
- threatened species identification; and
- electrofishing.

Monitoring specific to aquatic ecology would be undertaken in addition to the groundwater and surface water monitoring detailed in Sections 6.5 and 6.6.

In the event that monitoring identifies impacts to aquatic ecology greater than those predicted, South32 would consider implementing contingency measures such as further stream remediation, further erosion and sediment control measures and review of the mine layout with respect to watercourses. Stream remediation techniques are detailed in Section 7.3.6.

6.8 UPLAND SWAMPS

6.8.1 Methodology

Upland swamps were considered as part of the Subsidence Assessment (Appendix A), Groundwater Assessment (Appendix B), Surface Water Assessment (Appendix C) and Biodiversity Assessment Report and Biodiversity Offset Strategy (BARBOS) (Appendix D).

A description of upland swamps, observed impacts to upland swamps within the Dendrobium Mine areas and existing offset and remediation measures are provided in Section 6.8.2. Upland swamps within the Project underground mining area are described in Section 6.8.3. Section 6.8.4 describes the assessment of the Project with respect to potential impacts to upland swamps, while Sections 6.8.5 and 6.8.6 outline avoidance/mitigation and adaptive management measures, respectively.

6.8.2 Background

Upland Swamp Description

Upland swamps develop on relatively low permeability Hawkesbury Sandstone terrain, where sandy sediment has accumulated over time behind rockbars. The low permeability sandstone beds act to form a locally perched groundwater system (hydraulically separated from underlying Hawkesbury Sandstone aquifers). Flow from the outlet of upland swamps contributes to overall flow in the catchment (Appendices B and C).

The water level (i.e. groundwater table) within upland swamps naturally recedes during extended dry periods and recovers during prolonged rainfall events (Appendices B and C).

Upland swamps can be categorised into three broad types (Commonwealth Government, 2014):

1. Headwater swamps – occur in catchment divides at the headwaters of streams within relatively low-sloped areas of weathered Hawkesbury Sandstone where hillslope aquifers exist.
2. Valley in-fill swamps – occur in steeper terrain of incised valleys associated with second or third order streams.
3. Hanging swamps – occur on steep valley sides or cliffs.

There are more than 1,400 upland swamps in the Woronora and Metropolitan Special Areas (Advisian, 2016) (Figure 6-11).

Within the vicinity of the Project, upland swamps comprise four vegetation community types. These include (NPWS, 2013): ‘Coastal Upland Swamps: Banksia Thicket’ (MU42); ‘Coastal Upland Swamps: Tea-tree Thicket' (MU43); ‘Coastal Upland Swamps: Sedgeland-Heath Complex’ (MU44); and ‘Coastal Upland Swamps: Fringing Eucalypt Woodland’ (MU45).

Of these communities, three align with the Coastal Upland Swamp of the Sydney Basin Bioregion TEC, listed as ‘endangered’ under the BC Act and the EPBC Act (NSW Scientific Committee, 2012; DoE, 2014a).

‘Coastal Upland Swamps: Fringing Eucalypt Woodland’ (MU45) is not a component of the upland swamp TEC.

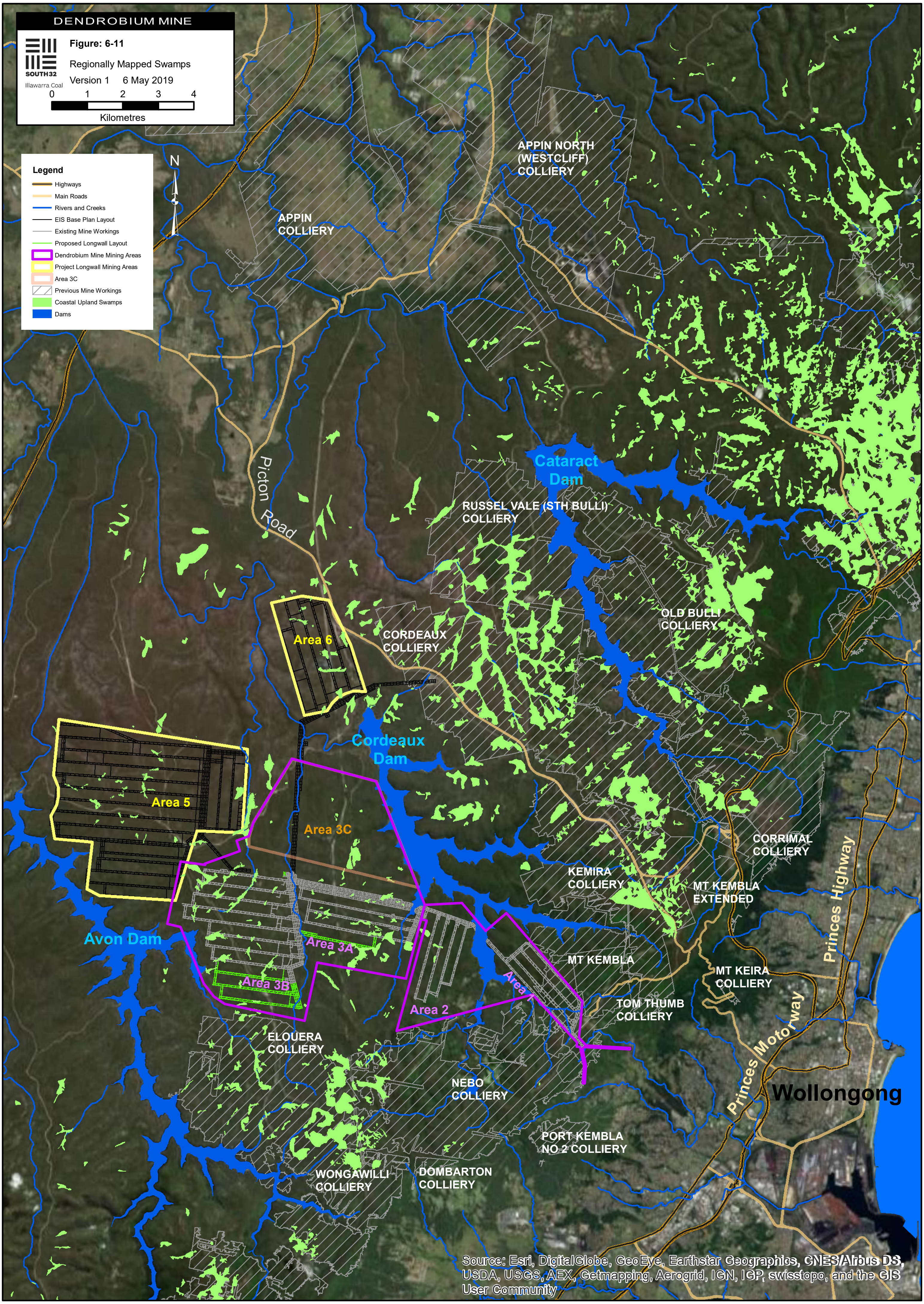
Previous Impacts to Upland Swamps from Mining

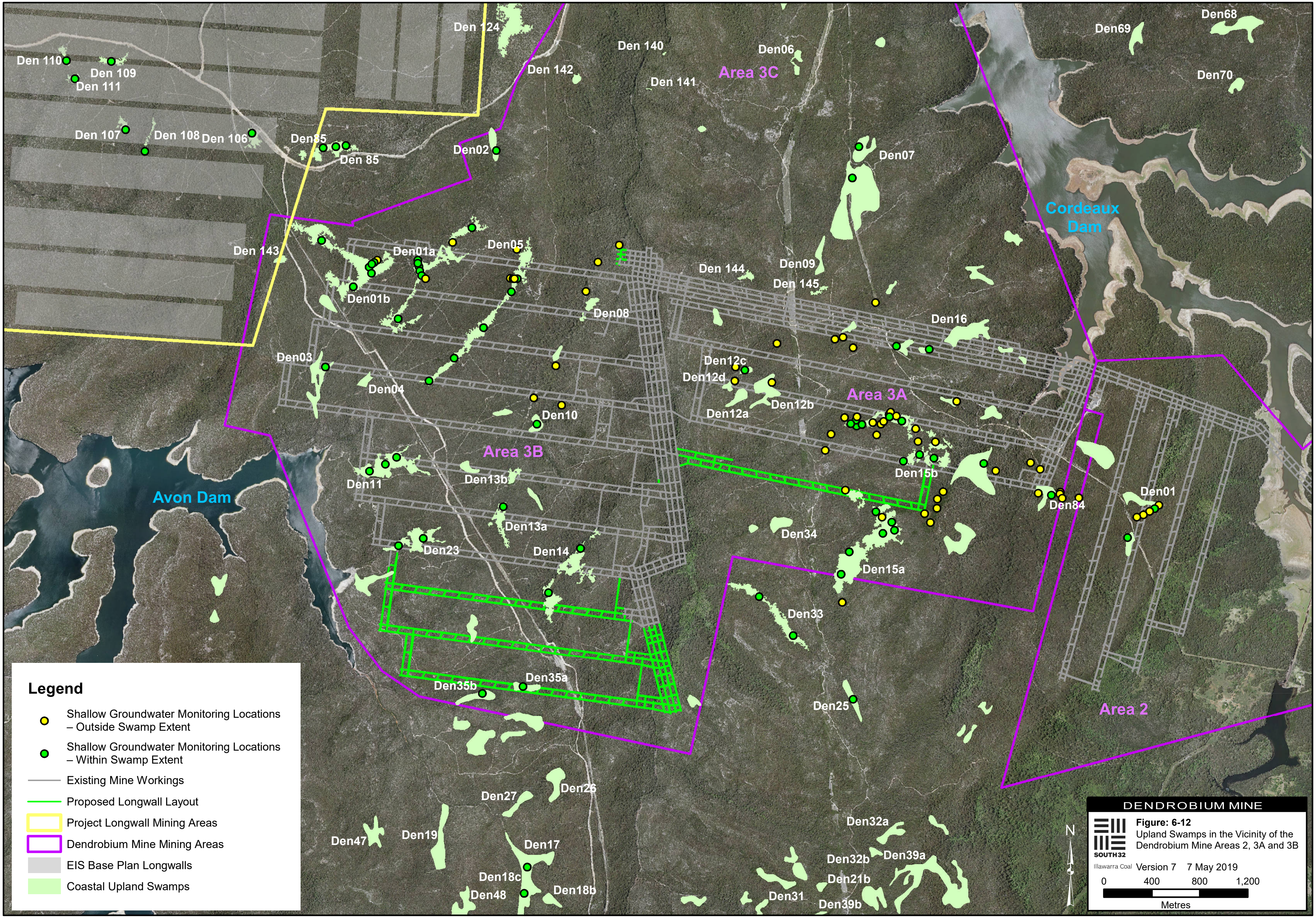
More than 500 upland swamps have been directly mined under in the region (Appendix D) with more swamps located within various offset distances from longwall extraction. Of these, only three (0.6%) have had reported significant visual changes from scour and/or erosion events (Appendix D).

Specific to the Dendrobium Mine, South32 has undertaken monitoring of upland swamps within 400 m of longwalls since 2003, as well as monitoring of relevant control swamps (Figure 6-12). This monitoring was initially focused on vegetation change (floristic plots and photo monitoring) however has been augmented to include piezometer water level data and Airborne Laser Survey. This monitoring program collects data for approximately 20 upland swamps at the Dendrobium Mine.

Review of water level data indicates that upland swamps overlying longwall mining at the Dendrobium Mine have experienced changes in hydrology, such as increased rates of water recession following rainfall events and increased duration of dry periods between rainfall events (Appendix D).

However, a review undertaken by Niche (2019a) of the monitoring data collected during the previous 11.5 years in Area 2, 7.5 years in Area 3A and 4.5 years in Area 3B did not conclude there is a strong link between subsidence effects and upland swamp vegetation response (Appendix D).


DENDROBIUM MINE
SOUTH32
Illawarra Coal
Figure: 6-11
Regionally Mapped Swamps
Version 1 6 May 2019
0 1 2 3 4
Kilometres
Legend
Highways
Main Roads
Rivers and Creeks
EIS Base Plan Layout
Existing Mine Workings
Proposed Longwall Layout
Dendrobium Mine Mining Areas
Project Longwall Mining Areas
Area 3C
Previous Mine Workings
Coastal Upland Swamps
Dams
N
APPIN NORTH (WESTCLIFF) COLLIERY
APPIN COLLIERY
Cataract Dam
Picton Road
RUSSEL VALE (STH BULLI) COLLIERY
OLD BULLI COLLIERY
Area 6
CORDEAUX COLLIERY
Cordeaux Dam
Area 5
Area 3C
CORRIMAL COLLIERY
KEMIRA COLLIERY
MT KEMBLA EXTENDED
Princes Highway
Avon Dam
Area 3A
MT KEMBLA
Area 1
Area 3B
MT KEIRA COLLIERY
TOM THUMB COLLIERY
Area 2
ELOUERA COLLIERY
Princes Motorway
NEBO COLLIERY
Wollongong
PORT KEMBLA NO 2 COLLIERY
WONGAWILLI COLLIERY
DOMBARTON COLLIERY
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community



Den 110
Den 109
Den 111
Den 107
Den 108
Den 106
Den 35
Den 85
Den 124
Den 142
Den 140
Den 141
Den06
Area 3C
Den69
Den68
Den70
Den02
Den07
Cordeaux Dam
Den 143
Den01a
Den05
Den01b
Den08
Den 144
Den09
Den 145
Den16
Den03
Den04
Den12c
Den12d
Den12b
Den12a
Area 3A
Den10
Area 3B
Den11
Den13b
Den15b
Avon Dam
Den01
Den84
Den13a
Den23
Den14
Den34
Den15a
Den33
Den35a
Den35b
Den25
Area 2
Den27
Den26
Den47
Den19
Den17
Den18c
Den48
Den18b
Den32a
Den32b
Den39a
Den21b
Den31
Den39b
Legend
Shallow Groundwater Monitoring Locations – Outside Swamp Extent
Shallow Groundwater Monitoring Locations – Within Swamp Extent
Existing Mine Workings
Proposed Longwall Layout
Project Longwall Mining Areas
Dendrobium Mine Mining Areas
EIS Base Plan Longwalls
Coastal Upland Swamps
DENDROBIUM MINE
SOUTH32
Illawarra Coal
Figure: 6-12
Upland Swamps in the Vicinity of the Dendrobium Mine Areas 2, 3A and 3B
Version 7 7 May 2019
0 400 800 1,200
Metres
N