APPENDIX C

Surface Water Assessment

Dendrobium Mine

Plan for the Future

Surface Water Assessment

Prepared for: South32

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Revision	Description	Author	Reviewer	Approved	Date
b	First Draft	CAW	DNB / TSM	TSM	7/12/2018
c	Second Draft following Resource Strategies review	CAW	DNB / TSM / RS	TSM	31/01/2019
d	Third Draft following TA McMahon review	CAW	TSM / RS	TSM	26/03/2019
e	Fourth Draft following TA McMahon review	CAW	TSM / RS	TSM	29/03/2019
f	Fifth Draft following TA McMahon review	CAW	TSM / RS	TSM	01/04/2019
g	Final	CAW	TSM / RS	TSM	06/05/2019

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EXECUTIVE SUMMARY

Illawarra Coal Holdings Pty Ltd (Illawarra Coal) is seeking a new Development Consent to gain access to Area 5 and Area 6 within Consolidated Coal Lease (CCL) 768, referred to as *Dendrobium Mine – Plan for the Future: Coal for Steelmaking* (hereafter referred to as the Project). This extension includes the development of supporting infrastructure and an extension to the life of approved surface operations to the year 2048.

The Project is located in the NSW Southern Coalfield within the southern portion of the Permo-Triassic Sydney Basin. The Project proposes longwall mining of the Illawarra Coal Measures, which are overlain by the Narrabeen Group and Hawkesbury Sandstone.

The Project Area lies within the WaterNSW Metropolitan Special Area and comprises land reserved for Sydney's drinking water catchments. Area 5 is located within the catchments of the Avon River, Lake Avon (also referred to as Avon Dam) and Donalds Castle Creek, while Area 6 is located within the Cordeaux River catchment and is adjacent to, though downstream of, Lake Cordeaux (also referred to as Cordeaux Dam). WaterNSW releases water from Cordeaux Dam, Avon Dam and the adjacent Nepean Dam to enable withdrawal for water supply purposes from the Pheasants Nest Weir located further downstream on the Nepean River.

The catchments within the Project Area are characterised by incised watercourses that have formed steep blocky valleys and cliff lines that contain sandstone overhangs. Upland swamps occur within these areas often culminating at a low rockbar, step or shelf. Further downstream, the streams typically plunge via a series of drops and waterfalls into the incised sections in the deeper valleys.

The water quality in Area 5 is characterised by acidic to near neutral conditions and slightly elevated concentrations of dissolved copper and dissolved zinc. 'Spikes' in total aluminium, total nitrogen and total phosphorus, in excess of guideline default trigger values for aquatic ecosystems, have been reported at some sites, though concentrations are generally below guideline default trigger values. The water quality in Area 6 is characterised by slightly acidic conditions with 'spikes' in dissolved zinc, total aluminium, total nitrogen and total phosphorus recorded in the Cordeaux River and its tributaries.

Mining within the Project Area has the potential to affect the hydrology, water balance and stability of undermined upland swamps and the quantity and quality of surface waters downstream of the swamps. Seepage from the base of the swamps overlying longwall mining areas is predicted by modelling to increase from between 1.4 and 19.8 m^3/m width of swamp per annum, to between 42.7 and 125.5 m^3/m width per annum as a result of the Project. For catchments overlying Area 5, model results suggest that there would be a 6% to 22% reduction in streamflow due to the Project for a median climatic year (63% to 100% for 10^{th} percentile [low rainfall] climate and 3% to 11% for 90^{th} percentile [high rainfall] climate). For Area 6, the results suggest there would be a 1% to 5% reduction in streamflow due to the Project for a median climatic year (19% to 51% for the 10^{th} percentile climate and 1% to 2% for the 90^{th} percentile climate). The estimated streamflow reduction in the median climatic year is within the range of observed reductions in total yield following longwall mining in Dendrobium Area 3B. Based on the streamflow yield assessment results, there is potential for a reduction in stream pool water levels to be observed in Area 5 and Area 6 as a result of the Project.

Under median climatic conditions, there is potential for an estimated 0.55% reduction in yield reporting to Lake Avon and an estimated 0.39% reduction in yield reporting to Pheasants Nest Weir (includes reduction in yield to Lake Avon) as a result of longwall mining in Area 5 and Area 6. This represents a likely indiscernible impact to inflows to Lake Avon and Pheasants Nest Weir. No reduction in yield reporting to Lake Cordeaux is predicted, as Area 6 is located downstream of Lake Cordeaux.

It is unlikely that erosion and scouring will occur in any swamps in the Project Area during frequent flow events (represented by the 50% Annual Exceedance Probability [AEP] peak flow) and in most swamps during rare (high) flow events (represented by the 1% AEP peak flow). There is potential that erosion and scouring could occur in two of 24 swamps during a 1% AEP peak flow as a result of mining induced tilt from subsidence.

Potential impacts on water quality as a result of the Project subsidence impacts would be localised (e.g. localised changes in water quality in the Avon and Cordeaux Rivers and their tributaries). Although mine subsidence effects can result in isolated, episodic pulses in iron, manganese, aluminium and electrical conductivity, these pulses have not had a measurable effect on water quality in reservoirs downstream of mine induced subsidence areas within the Southern Coalfield. These pulses have also been observed in surface water catchments within the region which are located outside of the zone of influence of mining activities.

The water quality parameters which may be potentially impacted by Project induced subsidence are not parameters of importance with respect to drinking water supply. WaterNSW is able to control the level of sediments, soluble iron and manganese in raw water flowing to the water treatment plants and the water treatment plants have been designed to allow for small changes in influent water quality. Although unlikely, should the isolated, episodic pulses in iron, manganese, aluminium and electrical conductivity be measurable at Lake Avon, Lake Cordeaux or Pheasants Nest Weir, it is unlikely that the performance of the dams or associated water supply system will be impacted. As such, the Project is likely to have a neutral or beneficial effect on water quality in Sydney's water supply catchments.

The existing water management systems at the Dendrobium Pit Top, Dendrobium Coal Preparation Plant, Cordeaux Pit Top, West Cliff Stage 3 Coal Wash Emplacement and Kemira Valley Coal Loading Facility would continue to be used for the Project. Accumulated water from the Project underground workings would continue to be directed into the former Nebo workings and/or the former Kemira workings (underground storages) for storage, with excess water discharged via the Kemira Valley Coal Loading Facility and existing Licensed Discharge Point (LDP) 5 to Allans Creek. The water management systems associated with existing approved ventilation shafts would also continue to be used.

The key changes to water management for the Project are associated with management of surface runoff from the new ventilation shafts in Areas 5 and 6 and an increase in predicted groundwater inflows to underground workings, which are required to be managed as part of the Project water management system. Sediment dams will be constructed to capture runoff from each of the four proposed ventilation shaft areas. While the predicted mean constituent concentration at the outlet of each ventilation shaft area catchment will increase as a result of the Project, the mean constituent concentrations are not expected to exceed the relevant Water Quality Objectives or to have a measurable impact on water quality at Pheasants Nest Weir.

Increased groundwater inflows would continue to be managed in accordance with current Environment Protection Licence (EPL) conditions (i.e. discharge via LDP5), however, additional infrastructure would be required to accommodate the expected increased controlled release volumes. It is understood that Illawarra Coal is also investigating options for the beneficial reuse of this excess water.

The daily discharge rate to LDP5, based on median climatic conditions, is predicted to peak at 27.6 ML/d in December 2035. This compares with an average recorded 6.5 ML/d (with a peak of 9.2 ML/d) discharge rate for the period from May 2014 to September 2018. The increase in discharge to LDP5 is unlikely to result in an exceedance of the EPL water quality limits or impacts on Allans Creek. Illawarra Coal has established streamflow monitoring, stream and pool water level monitoring, surface water quality monitoring and the monitoring of shallow groundwater and soil moisture levels adjacent to upland swamps within Area 5 and Area 6. This monitoring should be continued and expanded prior to longwall mining and throughout the Project duration. Observational and photographic monitoring should be undertaken to record visual signs of impacts on creeks and drainage lines during mining and subsidence.

Illawarra Coal's commitments regarding remediation of streams assessed in this report are given in the Environmental Impact Statement Main Report and the Stream Risk Assessment (Appendix B). Various techniques have been previously adopted to successfully reduce subsidence impacts to streams associated with longwall mining. Stream remediation measures should be implemented on named rivers and creeks (Avon and Cordeaux Rivers and Donalds Castle Creek) and on the key features of stream reaches of second order and above where subsidence results in impacts to pools in stream sections between controlling rockbars and where the remediation measures are considered technically feasible. The performance of the remediation works should be monitored and assessed against specific success criteria.

The existing monitoring of the main water transfers between the underground workings, Dendrobium Pit Top and Kemira Valley Coal Loading Facility should continue. The performance of the water management system should be reviewed at least annually using the monitored data in combination with the site water balance model to identify changes in the system and compare against predictions, particularly in regard to groundwater inflows.

1.0 INTRODUCTION

The Dendrobium Mine (the Mine) is an existing underground coal mine situated in the Southern Coalfield of New South Wales (NSW), with the Pit Top located approximately 8 kilometres (km) west of Wollongong (Figure 1). Illawarra Coal Holdings Pty Ltd (Illawarra Coal), a wholly owned subsidiary of South32 Limited (South32), is the owner and operator of the Mine.

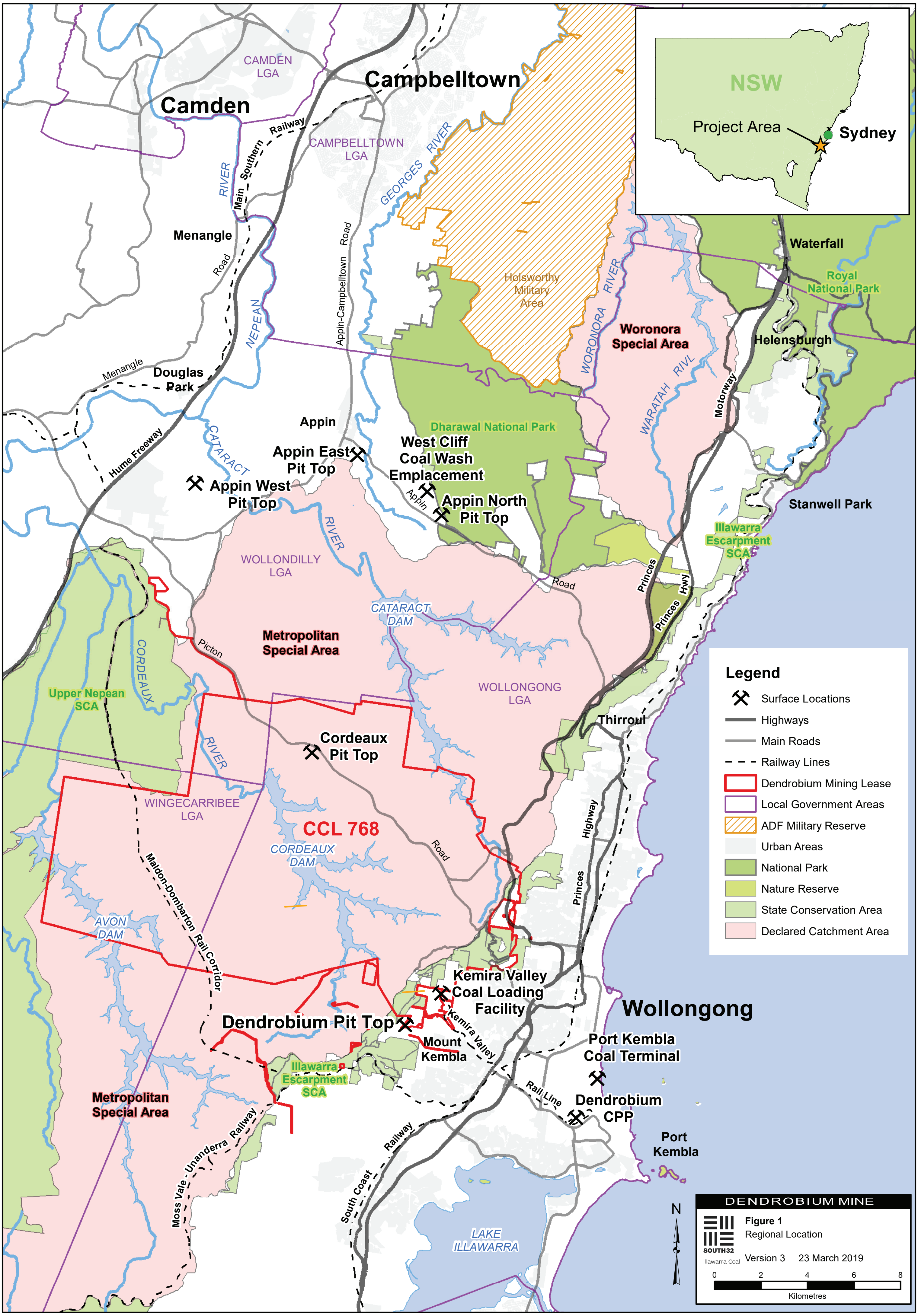
Illawarra Coal is seeking a new Development Consent to gain access to Area 5 and Area 6 within Consolidated Coal Lease (CCL) 768 and for the use of supporting infrastructure, and is referred to as *Dendrobium Mine – Plan for the Future: Coal for Steelmaking* (hereafter referred to as the Project).

1.1 PROJECT OVERVIEW

The Project seeks to gain access to additional coal within CCL 768 in two proposed future underground mining areas, Area 5 and Area 6 (Figure 2). This extension would be supported by the development of supporting infrastructure and an extension to the life of approved surface operations to 2048.

The Project would include the following activities:

- longwall mining of the Bulli Seam in a new underground mining area (Area 5);
- longwall mining of the Wongawilli Seam in a new underground mining area (Area 6);
- development of underground roadways within the Bulli Seam, Wongawilli Seam and adjacent strata to access mining areas;
- use of existing roadways and drifts for personnel and materials access, ventilation, dewatering and other ancillary activities related to Areas 5 and 6;
- development of surface infrastructure associated with mine ventilation, gas management and abatement, and other ancillary infrastructure;
- handling and processing of up to 5.2 million tonnes per annum (Mtpa) of run-of-mine (ROM) coal;
- use of the existing Dendrobium Pit Top, Kemira Valley Coal Loading Facility (KVCLF), Dendrobium Coal Preparation Plant (CPP) and Dendrobium Shafts with minor upgrades and extensions;
- use of the Cordeaux Pit Top for mining support activities;
- augmentation of mine access arrangements, including upgrades to, and the use of, the Cordeaux Pit Top;
- transport of sized ROM coal from the KVCLF to the Dendrobium CPP via the Kemira Valley Rail Line;
- delivery of product coal from the Dendrobium CPP to the Port Kembla Steelworks for domestic use or to the Port Kembla Coal Terminal for export;
- transport of coal wash by road to customers for engineering purposes (e.g. civil construction fill), for other beneficial uses and/or for emplacement at the West Cliff Colliery Stage 3 and Stage 4 Coal Wash Emplacement;
- development and rehabilitation of the West Cliff Stage 3 Coal Wash Emplacement;
- progressive development of sumps, pumps, pipelines, water storages and other water management infrastructure;
- monitoring, rehabilitation and remediation of subsidence and other mining effects; and
- other associated minor infrastructure, plant, equipment and activities.



Campbelltown
Camden
CAMDEN LGA
CAMPBELLTOWN LGA
Main Southern Railway
GEORGES RIVER
NEPEAN RIVER
Menangle
Menangle Road
Douglas Park
Appin-Campbelltown Road
Holsworthy Military Area
WORONORA RIVER
Woronora Special Area
WARATAH RIVL
Waterfall
Royal National Park
Helensburgh
Motorway
Hume Freeway
Appin
Dharawal National Park
Appin East Pit Top
West Cliff Coal Wash Emplacement
Appin West Pit Top
CATARACT RIVER
Appin North Pit Top
Appin Road
Stanwell Park
Illawarra Escarpment SCA
WOLLONDILLY LGA
Princes Hwy
CATARACT DAM
Metropolitan Special Area
Picton Road
CORDEAUX RIVER
Upper Nepean SCA
WOLLONGONG LGA
Thirroul
Cordeaux Pit Top
WINGECARRIBEE LGA
CCL 768
CORDEAUX DAM
Princes Highway
Maldon-Dombarton Rail Corridor
AVON DAM
Kemira Valley Coal Loading Facility
Wollongong
Dendrobium Pit Top
Mount Kembla
Kemira Valley
Port Kembla Coal Terminal
Illawarra Escarpment SCA
Rail Line
Dendrobium CPP
Metropolitan Special Area
Moss Vale - Unanderra Railway
South Coast Railway
Port Kembla
LAKE ILLAWARRA
NSW
Project Area
Sydney
Legend
Surface Locations
Highways
Main Roads
Railway Lines
Dendrobium Mining Lease
Local Government Areas
ADF Military Reserve
Urban Areas
National Park
Nature Reserve
State Conservation Area
Declared Catchment Area
N
DENDROBIUM MINE
SOUTH32 Illawarra Coal
Figure 1
Regional Location
Version 3 23 March 2019
0 2 4 6 8
Kilometres

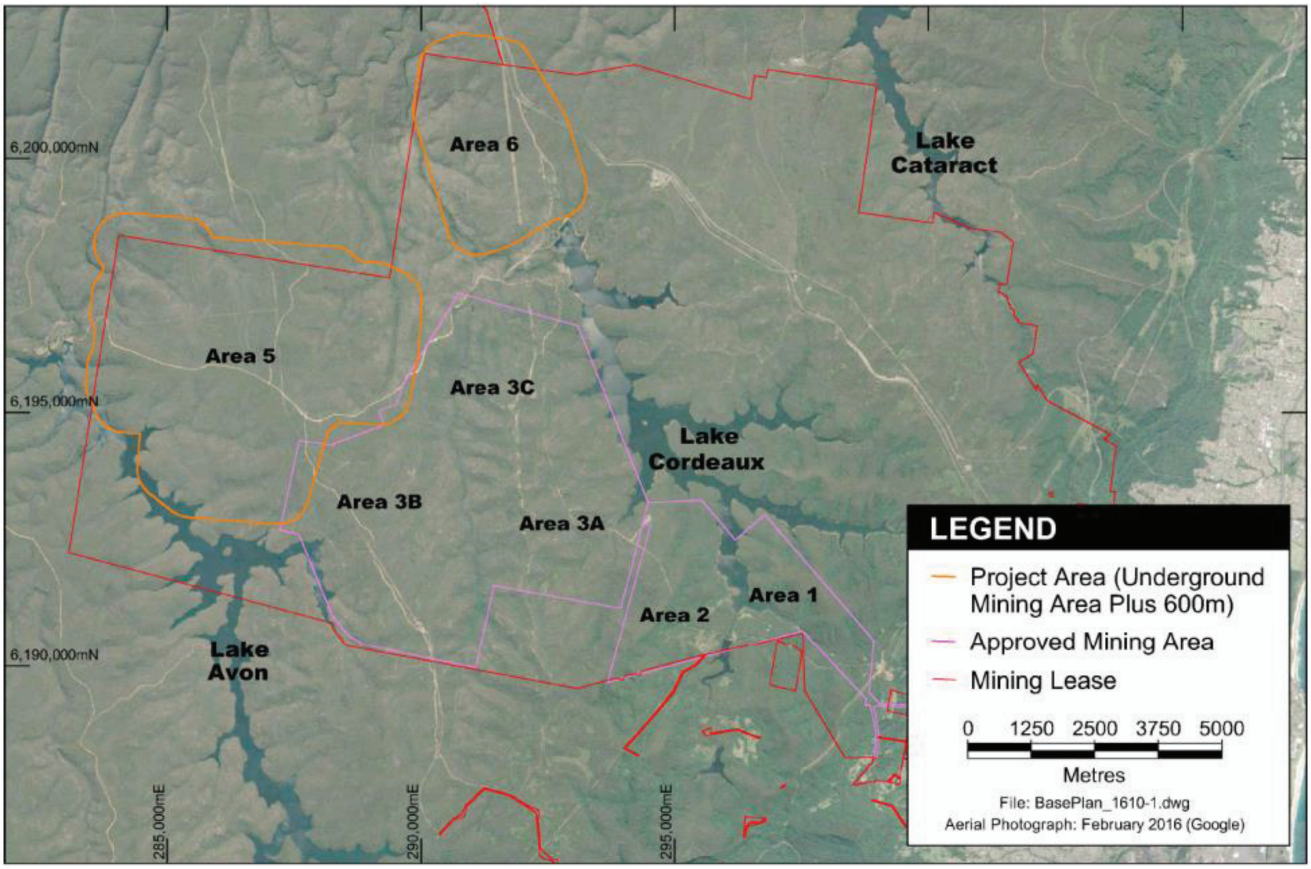


Figure 2 Project Area Overview

1.2 STUDY REQUIREMENTS AND SCOPE

This assessment has been prepared in accordance with the Secretary's Environmental Assessment Requirements (SEARs) for the Project dated 9 September 2018. Table 1 provides a summary of the SEARs (including those provided by relevant agencies) related to surface water along with a reference to the relevant section of the report which addresses the requirement.

Table 1 Summary of SEARs and Relevant Sections

Document	Requirements	Report Section
SEARs – Specific Issues (Water)	An assessment of the likely impacts of the development on the quantity and quality of surface and groundwater resources, having regard to EPA's, DPI Water's and WaterNSW's requirements and recommendations.	Section 5.0
	An assessment of the likely impacts of the development on aquifers, watercourses, swamps, riparian land, water supply infrastructure and systems including Cordeaux Dam and Avon Dam, and other water users.	Section 3.0, Section 5.0 and Section 6.0
	An assessment of any drinking water catchment losses from mining, and whether the development can be operated to achieve a neutral or beneficial effect on water quality in the Sydney Drinking Water Catchment, consistent with the provisions of *State Environmental Planning Policy (Sydney Drinking Water Catchment) 2011*.	Section 5.2.5 and Section 6.0
	A detailed site water balance, including a description of site water demands, water disposal methods (inclusive of volume and frequency of any water discharges), water supply and transfer infrastructure and water storage structures.	Section 3.0
	A detailed description of the proposed water management system (including sewerage), water monitoring regimes, beneficial water re-use program and all other proposed measures to mitigate surface water and groundwater impacts.	Section 3.0, Section 7.0 and Section 8.0
	An assessment of the potential flood impacts of the development.	Section 2.2.1
EPA (Attachment A)	If the Cordeaux Colliery Pit Top is to be used as part of the Project: • Review the adequacy of existing stormwater controls. • Review the separation and disposal of workshop cleaning and washdown waters. • Review the capacity and operability of sewage treatment and disposal in light of possible increased personnel numbers and site usage patterns.	Section 3.0
	A water balance for the mine should be prepared to determine any change in the quantity and character of groundwater discharged through Licensed Discharge Point (LDP) 5 to Allan's Creek, Port Kembla. Any significant deterioration as a consequence of changes in the discharge should be modelled (dilution and mixing zone model) and would require an ambient monitoring program to confirm that concentrations remain below appropriate ANZECC 2000 trigger values in Allan's Creek.	Section 3.0

Table 1 (Continued) Summary of SEARs and Relevant Sections

Document	Requirements	Report Section
DPI Water (Letter)	Assessment of impacts on surface and groundwater sources (both quality and quantity), related infrastructure, adjacent licensed water users, basic landholder rights, watercourses, riparian land, wetlands, and groundwater dependent ecosystems, and measures proposed to reduce and mitigate these impacts.	Section 3.0, Section 5.0, Section 6.0, Section 7.0 and Section 8.0
	Annual volumes of surface water and groundwater proposed to be taken by the activity (include through inflow and seepage) from each surface and groundwater source as defined by the relevant water sharing plan.	Appendix B of the Environmental Impact Statement (EIS)
	Assessment of any volumetric licensing requirements (including those for ongoing water take following completion of the project).	Appendix B of the EIS
	The identification of an adequate and secure water supply for the life of the project. Confirmation that water can be sourced from an appropriately authorised and reliable supply. This is to include an assessment of the current market depth where water entitlement is required to be purchased.	Section 3.0 and Appendix B of the EIS
	A detailed and consolidated site water balance.	Section 3.0
	Full technical details and data of all surface and groundwater modelling, and an independent peer review of the groundwater model.	Section 3.0, Section 5.0 and Appendix B of the EIS
	Proposed surface and groundwater monitoring activities and methodologies to assess impacts on surface and groundwater quantity and quality.	Section 8.0 and Appendix B of the EIS
	Proposed management and disposal of produced or incidental water.	Section 3.0
	Assessment of whether the activity may have a significant impact on water resources, with reference to the Commonwealth Department of Environment Significant Impact Guidelines.	Section 5.5
WaterNSW (Letter)	Demonstrate how the carrying out of the project would have a neutral or beneficial effect on receiving water quality pursuant to clause 10 of *State Environmental Planning Policy (Sydney Drinking Water Catchment) 2011*.	Section 6.0
	Detail the potential impact and proposed mitigation measures of the project on existing and options for future water supply infrastructure at and in the vicinity of the proposed mining areas.	Section 5.5, Section 7.0 and Section 8.0

Table 1 (Continued) Summary of SEARs and Relevant Sections

Document	Requirements	Report Section
WaterNSW (Attachment 1)	The full description of the development and existing environment should include those aspects which have the potential to impact on the quantity and quality of surface and ground waters, biodiversity and water supply infrastructure at and adjacent to the site. This includes: • the location of Avon and Cordeaux Dams and associated infrastructure in relation to the proposed longwalls in Areas 5 and 6. • the location, mapping and geomorphology of Avon and Cordeaux Rivers and their tributaries, rockbars, water pools, waterfalls, cliffs, swamps overlying and adjacent to the proposed mining areas. • the location, mapping and nature of any geological structures including faults, dykes, silts, and other intrusions. • the hydrogeological fluxes between surface and ground waters. • the location and description of all water and biodiversity monitoring locations/points (including surface and ground waters). • the location and features of all proposed surface infrastructure including ventilation facilities and access tracks.	Section 2.0, Section 3.0 and Appendix B of the EIS
	The detailed assessment of the mining proposal on water resources associated with subsidence should consider the design, construction, operational, decommissioning phases and cumulative impacts and include: • impacts on Avon and Cordeaux Dams and associated infrastructure including dam wall. • impacts on future water supply infrastructure options in the vicinity of the proposed mining areas. • impacts on water quantity and quality of overlying and adjacent water resources including Avon and Cordeaux reservoirs and rivers and their tributaries, rockbars, water pools, waterfalls, cliffs, swamps, and groundwater systems using scientifically sound and rigorous numerical modelling and sufficient, appropriate and representative baseline data. • impacts of the proposed mining on receiving water quantity and quality, both surface and groundwater systems and associated impacts on interaction and baseflows of surface waters. • details of proposed measures to be adopted to offset impacts and effectiveness of the measures including environmental performance measures. • details of proposed monitoring of groundwater levels, surface water flows, groundwater and surface water quality, along with information as to how the proposed monitoring will be used to monitor and, if necessary, mitigate impacts on surface water and groundwater resources. Monitoring programs shall be designed in consultation with WaterNSW. • details of the contingency plans to manage risks. • details of the structural stability, integrity, ongoing maintenance and monitoring of all site water management measures including water management ponds over the life of the project.	Section 2.0, Section 3.0, Section 5.0, Section 6.0, Section 7.0, Section 8.0 and Appendix B of the EIS
OEH (Letter)	A full justification for impacts upon upland swamps and 3rd order or above streams, including reasons for the damage, alternatives considered, suggested remediation and offsets for any such damage, be presented.	Section 4.0, Section 5.0 and Section 7.0

As part of the assessment process and as required by the SEARs, an Environmental Risk Assessment (refer Appendix M of the EIS) was undertaken. This included a facilitated, risk-based workshop involving experts across a range of disciplines and experienced South32 personnel. The objective of the assessment was to identify key potential environmental issues for inclusion in the EIS. The following key potential surface water related issues were identified:

- Reduction in water yield;
- Effects to water quality;
- Changes to erosion potential;
- Changes to swamp size and swamp vegetation;
- Impacts to railway associated infrastructure culverts;
- Impacts to water storage in Avon and Cordeaux Dams; and
- Extension of the use and volume of water discharge due to continued surface facilities use.

This Surface Water Assessment (SWA) has been prepared by Hydro Engineering & Consulting Pty Ltd (HEC). A number of key guidelines have also been used as a basis for assessing impacts in this report including:

- National Water Quality Management Strategy: Australian Guidelines for Fresh and Marine Water Quality (ANZECC/ARMCANZ, 2000a).
- National Water Quality Management Strategy: Australian Guidelines for Water Quality Monitoring and Reporting (ANZECC/ARMCANZ, 2000b).
- Using the ANZECC Guideline and Water Quality Objectives in NSW (Department of Environment and Climate Change [DECC], 2006).
- NSW Office of Environment and Heritage (2012) Draft Upland Swamp Environmental Assessment Guidelines – Guidance for the Underground Mining Industry Operating in the Southern Coalfield.
- WaterNSW (2015) Neutral or Beneficial Effect on Water Quality Assessment Guideline.

Where relevant, recommendations made in relation to surface water issues in the Southern Coalfield Strategic Review (Department of Planning [DoP], 2008) have also been incorporated in this assessment.

The objects of the NSW Water Management Act, 2000, which is the principal statute governing management of water resources in NSW, were also considered during the assessment. The objects of the Water Management Act, 2000 include:

> *to provide for the sustainable and integrated management of the water sources of the State for the benefit of both present and future generations and, in particular:*
>
> *a) to apply the principles of ecologically sustainable development, and*
>
> *b) to protect, enhance and restore water sources, their associated ecosystems, ecological processes and biological diversity and their water quality, and*
>
> *c) to recognise and foster the significant social and economic benefits to the State that result from the sustainable and efficient use of water, including:*
>
> *i. benefits to the environment, and*
>
> *ii. benefits to urban communities, agriculture, fisheries, industry and recreation, and*
>
> *iii. benefits to culture and heritage, and*
>
> *iv. benefits to the Aboriginal people in relation to their spiritual, social, customary and economic use of land and water,*

d) *to recognise the role of the community, as a partner with government, in resolving issues relating to the management of water sources,*
e) *to provide for the orderly, efficient and equitable sharing of water from water sources,*
f) *to integrate the management of water sources with the management of other aspects of the environment, including the land, its soil, its native vegetation and its native fauna,*
g) *to encourage the sharing of responsibility for the sustainable and efficient use of water between the Government and water users,*
h) *to encourage best practice in the management and use of water.*

2.0 BASELINE HYDROLOGY

The Project is located in the NSW Southern Coalfield within the southern portion of the Permo-Triassic Sydney Basin. Above the Illawarra Coal Measures, the stratigraphy of the area consists of a sequence of sandstone, shale and claystone units within the Narrabeen Group, which are in turn, overlain by the Hawkesbury Sandstone.

There is significant topographic relief and a relatively high drainage density in the catchments across the Project Area. Surface elevations in Area 5 vary from approximately 444 metres (m) Australian Height Datum (m AHD) at the southern boundary to approximately 284 m AHD near the western boundary. Surface elevations in Area 6 vary from approximately 374 m AHD near the south-east boundary to approximately 272 m AHD near the north-western boundary. Ridgelines vary in height from 10 m to 25 m above the valley floor in the incised predominantly Hawkesbury Sandstone terrain.

The underground mining areas are situated under the catchments of the Cordeaux River and Avon River. The catchments are characterised by incised watercourses that have formed steep, blocky valleys and cliff lines that contain sandstone overhangs.

Original vegetation remains over most of the underground mining areas, except for fire roads, Picton Road, powerlines, the Maldon-Dombarton rail corridor and other minor disturbances. The location of Picton Road and Maldon-Dombarton rail corridor with respect to the Project Area are shown in Figure 1.

2.1 CLIMATE

The region experiences a wet temperate climate with key climate variables summarised in the following sections.

2.1.1 Temperature, Wind Speed and Humidity

Long term climate records from four Bureau of Meteorology (BoM) weather stations have been identified for the area near the Project and are shown in Figure 3. The nearest station with long term records is Picton Council Depot (068052) which is approximately 18 km northeast of Area 6.

Table 2 provides average monthly statistics for key climatic variables including maximum temperature, minimum temperature, wind speed at 9 am and relative humidity at 9 am for the BoM weather stations.

Table 2 Summary of Regional Climatic Variables

Site Number		**068052**	**068102**	**068053**	**068228**
Site Name		Picton Council Depot	Bowral (Parry Drive)	Port Kembla Signal Station	Bellambi AWS
Latitude (degrees)		-34.17	-34.49	-34.48	-34.37
Longitude (degrees)		150.61	150.40	150.91	150.93
Mean Monthly Minimum Temperature (°C)	**Minimum**	1.7 (Jul)	2.1 (Jul)	9.8 (Jul)	10.1 (Jul)
	Maximum	15.4 (Feb)	13.5 (Feb)	18.7 (Feb)	19.2 (Feb)
Mean Monthly Maximum Temperature (°C)	**Minimum**	16.8 (Jul)	11.6 (Jul)	16.7 (Jul)	17.1 (Jul)
	Maximum	29.3 (Jan)	25.5 (Jan)	24.4 (Feb)	24.9 (Jan)
Mean 9 am Wind Speed (km/hr)	**Minimum**	4.5 (Feb)	7.6 (Mar)	12.4 (Jul)	15.0 (Mar)
	Maximum	9.0 (Nov)	13.1 (Sep)	21.6 (Feb)	18.7 (Nov)
Mean 9 am Relative Humidity (%)	**Minimum**	-	68 (Oct)	61 (Aug)	56 (Aug)
	Maximum	-	84 (Jun)	78 (Feb)	76 (Feb)

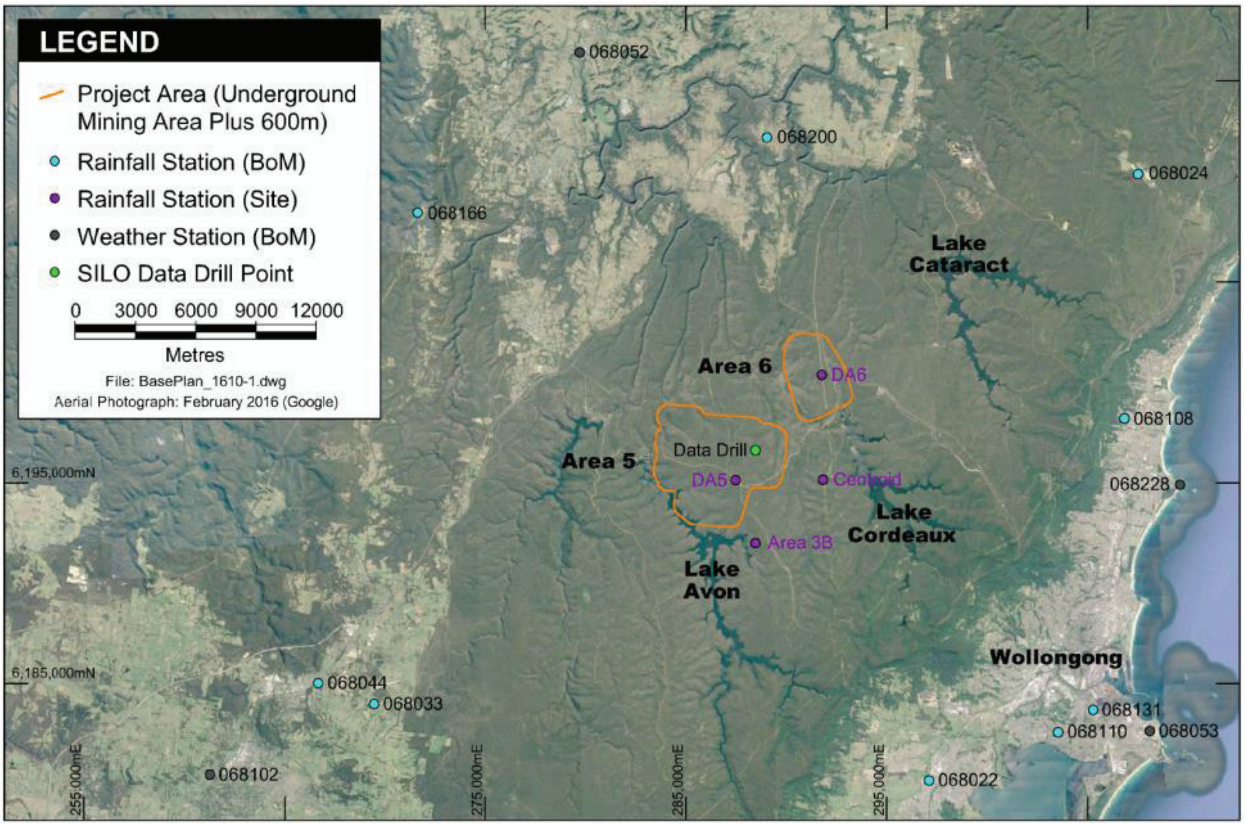


Figure 3 Regional Weather and Rainfall Stations

Table 2 illustrates that the region experiences a temperate climate with mean monthly maximum temperatures ranging from 16.8 degrees Celsius (ºC) in July to 29.3ºC in January (068052). Mean monthly minimum temperatures range from 1.7ºC in July to 15.4ºC in February (068052).

2.1.2 Rainfall and Evaporation

The long-term average monthly rainfall recorded at regional BoM stations is summarised in Table 3 in comparison with Scientific Information for Land Owners (SILO) Data Drill[1] monthly rainfall. The locations of the stations are shown in Figure 3.

Table 3 illustrates that rainfall is typically spread throughout the year but tends to be higher in the summer months. Average annual rainfall varies from 756mm to 1,423mm across the region. On average, rainfall is higher in the more elevated areas associated with the coastal ranges to the east and lower in the less elevated, more inland areas to the west.

[1] The SILO Data Drill is a system which provides synthetic data sets for a specified point by interpolation between surrounding point records held by the Bureau of Meteorology – refer https://legacy.longpaddock.qld.gov.au/silo/datadrill/

Table 3 Summary of Average Regional Rainfall (mm)

Site Number	068166	068200	068024	068108	068131	068022	068033	068044	SILO Data Drill (location in Area 5)
Site Name	**Buxton (Amaroo)**	**Douglas Park (St. Marys Towers)**	**Darkes Forest (Kintyre)**	**Woonona (Popes Rd)**	**Port Kembla (Bsl Central Lab)**	**Dapto Bowling Club**	**Mittagong (Marist Rileys Farm)**	**Mittagong (Alfred Street)**	
Latitude	-34.24	-34.21	-34.23	-34.34	-34.47	-34.5	-34.46	-34.45	-34.35
Longitude	150.52	150.71	150.91	150.9	150.88	150.79	150.49	150.46	150.7
Data Period	1966 - 2018	1974 - 2018	1984 - 2018	1929 - 2018	1963 - 2018	1906 - 2017	1902 - 2017	1886 - 2018	1889 - 2018
January	91	68.4	132.4	125.5	97.1	106.2	87.9	86.1	121.5
February	124.3	87	159.6	139	127.1	123	89.9	91.5	145.2
March	81.1	84	153.9	144.6	143.2	129.3	87.3	94.3	137.5
April	72.7	62.9	126.8	115.4	108.1	106.1	76.9	74.7	105.7
May	50.7	56.1	129.1	98.6	81.3	93.7	70.3	73.2	98.7
June	67	70.5	146.6	122.4	117.9	110.5	82.7	89.8	122.1
July	35.2	40.1	96.4	60.1	53.3	55.1	63.2	66.1	81.8
August	50.5	42.9	89.1	77.4	70.5	68.4	59	56.8	74.0
September	44.4	41.2	76.6	63.8	57.2	57.3	53	52.2	65.2
October	62	54.9	91	87.6	85.9	79.4	69.3	64.1	80.9
November	90.2	72.3	105.3	105.1	87.5	88.1	72.1	70.4	90.3
December	77.2	56.4	103.9	94.1	73.1	87.8	78.5	75.7	96.4
Annual	**853.4**	**755.5**	**1,423.3**	**1,266.1**	**1,117.8**	**1,107.1**	**898.9**	**910.9**	**1,219.6**

Rainfall records are available for four locations within or near the Project Area, illustrated on Figure 3. Centroid rainfall has been recorded since October 2007, Area 3B since May 2012, Area 5 since July 2017 and Area 6 since June 2017. Table 4 presents the total annual rainfall recorded at Centroid and Area 3B in comparison with the SILO Data Drill annual rainfall.

Table 4 Project Area Annual Rainfall (mm)

Year	Centroid	Area 3B	SILO Data Drill (location in Area 5)
2008	1,103		1,110
2009	891		822
2010	1,284		1,296
2011	1,207		1,206
2012	957		1,110
2013	1,391	1,487	1,320
2014	1,223	1,199	1,099
2015	1,186	1,187	1,181
2016	973	1,009	1,141
2017	956	1,020	1,038
Average	1,117	1,180	1,132

Table 4 illustrates comparative annual rainfall records for Centroid and Area 3B, with average annual rainfall of 1,146 mm recorded at Centroid since 2013 and 1,180 mm on average recorded at Area 3B for the same period. The SILO Data Drill average annual rainfall compares well with rainfall records for Centroid and Area 3B with an average of 1,156 mm reported between 2013 and 2017 inclusive. As the SILO Data Drill values compare well with rainfall records for Centroid and Area 3B, the long-term rainfall and evaporation datasets obtained from the SILO Data Drill have been used in the water balance (Section 3.3) and streamflow loss assessment (Section 5.2).

An analysis of the frequency of historical rain periods has been undertaken for the Project Area using rainfall records obtained from the SILO Data Drill, as illustrated in Figure 4.

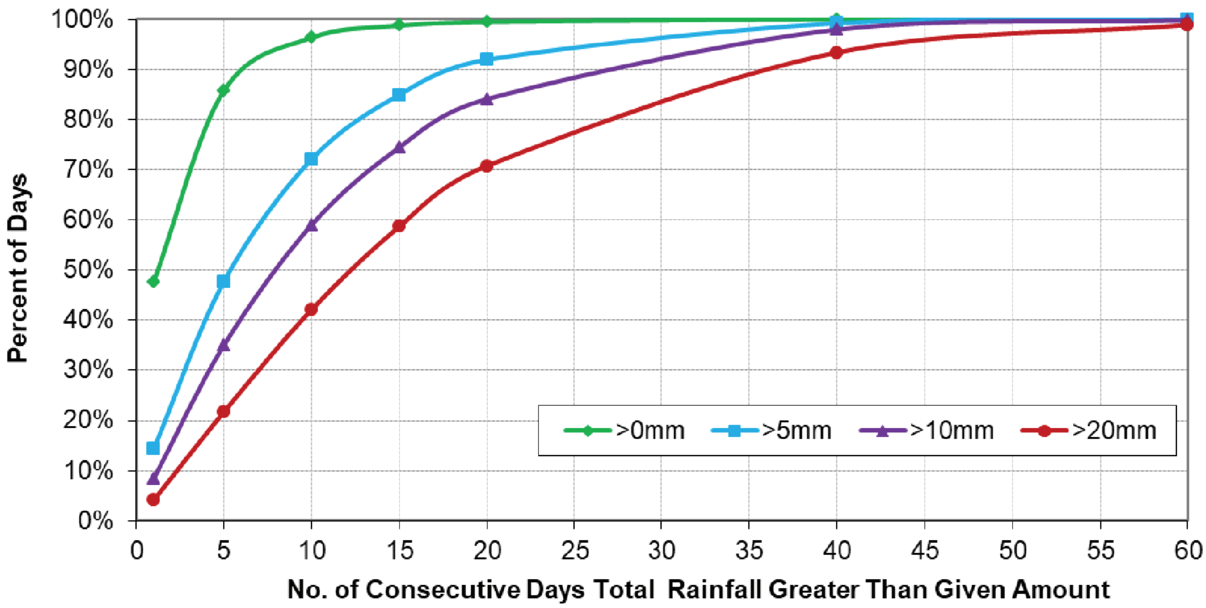


Figure 4 Frequency of Historical Rain Periods

The rain period analysis shows that 48% of days have some rain (i.e. greater than 0 mm of rain), 14% of days have 5 mm or more and 4% of days have 20 mm or more rainfall. The analysis also shows that the probability of experiencing 10 mm or more rainfall in any consecutive 5 day period is approximately 35%. The probability of experiencing 10 mm or more rainfall in any consecutive 20 day period is approximately 84% and of experiencing 20 mm or more rainfall in any 20 day period is approximately 71%.

Table 5 presents a comparison of monthly rainfall and pan evaporation from the SILO Data Drill for a location in Area 5.

Table 5 Summary of SILO Data Drill Rainfall and Evaporation Data (mm)

Month	Average Rainfall	Average Pan Evaporation
January	121.5	168.5
February	145.2	133.9
March	137.5	120.3
April	105.7	86.6
May	98.7	61.3
June	122.1	50.2
July	81.8	52.9
August	74.0	75.2
September	65.2	98.2
October	80.9	126.7
November	90.3	149.3
December	96.4	171.6
Annual	**1,219.1**	**1,294.6**

Table 5 illustrates that annual average pan evaporation is comparable to total annual average rainfall, with average monthly evaporation exceeding rainfall from August to January and average rainfall exceeding evaporation for the remaining months.

2.2 CATCHMENTS AND SURFACE WATER RESOURCES

2.2.1 Catchment Overview and Geology

The Project Area (proposed underground mining area plus 600 m) covers a total area of 40.3 km^2 and is located within the Avon and Cordeaux River catchments, as shown on Figure 5. The Avon River catchment covers an area of 173.9 km^2 extending from the Illawarra Range in the south to the confluence with the Cordeaux River in the north. Lying directly to the east of the Avon River catchment, the Cordeaux River catchment covers an area of 163.1 km^2 to the confluence with the Avon River and 339.3 km^2 to the confluence with the Nepean River. The Nepean River rises in the Great Dividing Range to the west of the Project Area. Flows in the upper reaches of the Nepean River are regulated by the Upper Nepean Water Supply Scheme, operated by WaterNSW, which incorporates four major water supply dams on the Cataract, Cordeaux, Avon and Nepean Rivers. Releases from the Cordeaux, Avon and Nepean Dams are made to enable withdrawal for water supply purposes from the Pheasant's Nest Weir located further downstream on the Nepean River. The Hawkesbury-Nepean catchment covers an area of 21,400 km^2 and is one of the major coastal river systems of NSW, providing the bulk of Sydney's water supply and supporting a large and diverse range of agricultural, industrial, power generation and mining activities.

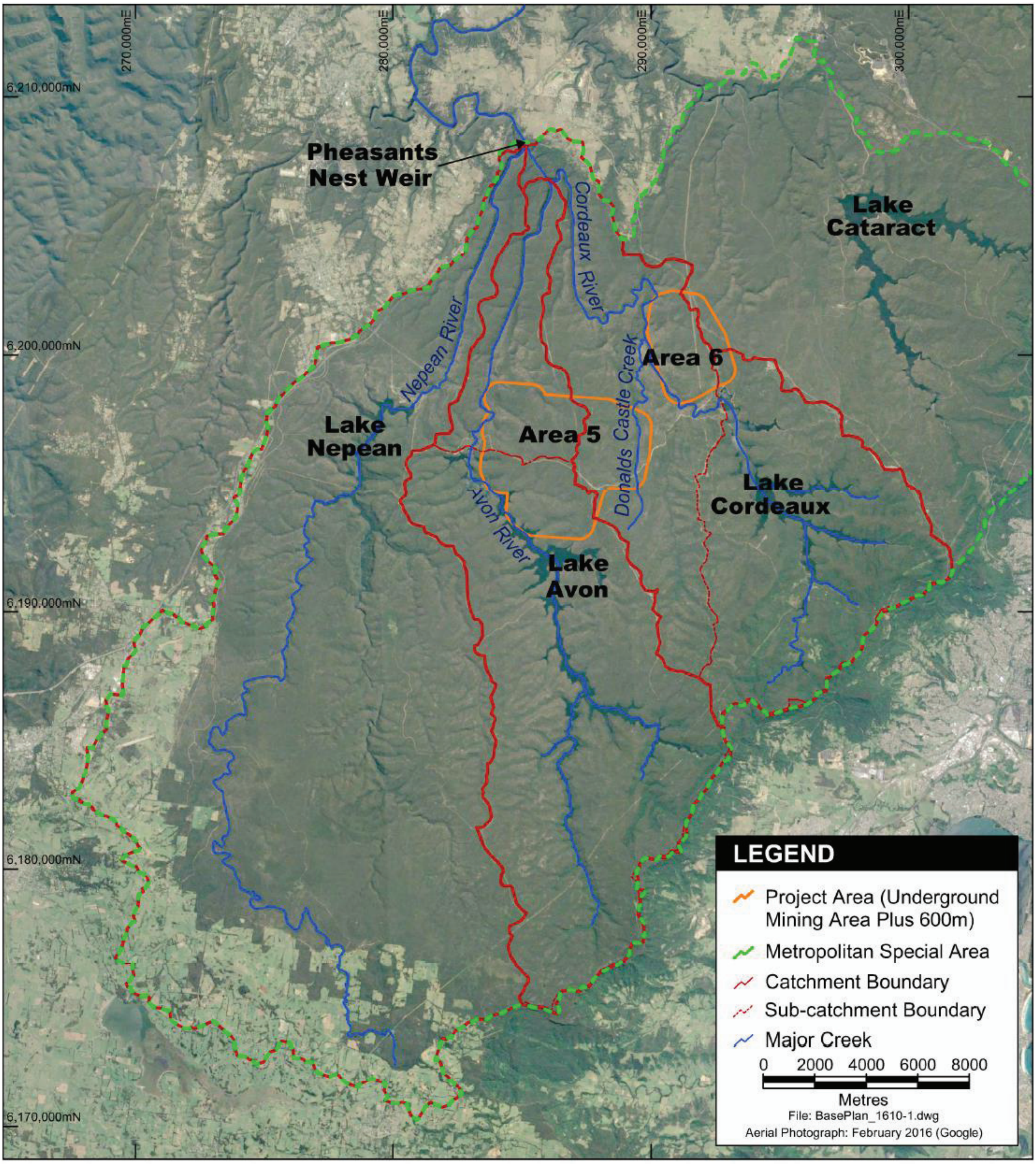


Figure 5 Regional Surface Water Catchments

The surface geology in the Project Area is dominated by the Hawkesbury Sandstone. Small pockets of Quaternary-aged swamp deposits are also present within Areas 5 and 6 (Appendix B of the EIS). The Hawkesbury Sandstone is underlain by Triassic sandstones, siltstones and claystones of the Narrabeen Group which overlie the Illawarra Coal Measures.

In the Hawkesbury Sandstone areas, streams in plateau areas are typically open, dish-shaped drainage lines with ill-defined bed and banks. Upland swamps frequently occur within these areas often culminating at a low rockbar, step or shelf. Further downstream, the streams typically plunge via a series of drops and waterfalls into the incised sections in the deeper valleys. The character of the streams changes with the confined incised valley and gorges which make up the dissected plateau areas into a series of rockbars, pools and boulder strewn reaches. The beds of the streams in these reaches are dominated by hard exposed rock with loose alluvium limited to the longer and deeper pools where flow energy is lower. Significant rainfall events result in rapid, 'flashy' runoff which results in highly turbulent, shallow flows with high velocity particularly over and downstream of rockbars. Velocities would reduce in the deeper longer pools which would act as sediment traps.

The Project Area lies within the WaterNSW Metropolitan Special Area and comprises land reserved for Sydney's drinking water catchments. The area is primarily native forest, comprising of eucalypt woodland, heaths and mallee and upland swamp vegetation comprising of banksia thickets, tea-tree thickets, sedgeland-heath complexes and eucalypt fringing woodland (Appendix D of the EIS). Area 5 is located adjacent to Lake Avon and Area 6 is located adjacent to, though downstream of, Cordeaux Dam.

Allocation of surface water resources in the Dendrobium Mine area comes under the *Water Sharing Plan for the Greater Metropolitan Region Unregulated River Water Sources 2011* (NSW Office of Water, 2011). The Project Area is located in the Upper Nepean and Upstream Warragamba Water Source. Area 5 is located within the Upper Nepean River Tributaries Headwaters Management Zone and adjacent to the Avon River Management Zone. Area 6 is located within the Upper Nepean River Tributaries Headwaters Management Zone and adjacent to the Cordeaux River Management Zone.

The Upper Nepean Rivers Tributaries Headwaters Management Zone includes the storages of Avon Dam, Cordeaux Dam and Cataract Dam. The Avon River Management Zone does not include the Avon Dam and the Cordeaux River Management Zone does not include the Cordeaux Dam.

The potential for flooding in the Project Area is limited due to the topographical nature of the area and the relatively small catchment areas of the streams within the Project Area which drain to Lake Avon, the Avon River, Donalds Castle Creek and the Cordeaux River.

2.2.2 Water Quality Objectives

The strategic framework for water quality improvement in the Hawkesbury-Nepean is provided by the water quality objectives (WQOs) determined by the NSW Healthy Rivers Commission (HRC) inquiry into the Hawkesbury-Nepean system (HRC, 1998) and the Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC Guidelines) (ANZECC, 2000 and ANZECC, 2018). The ANZECC Guidelines apply for all parameters excepting nutrients and chlorophyll-a. For nutrients and chlorophyll-a, the Healthy Rivers Commission (HRC, 1998) WQOs apply, as specified by the NSW Government in a Statement of Joint Intent (2001).

In NSW, the level of protection applied to most waterways is that for 'slightly to moderately disturbed' ecosystems, for which the ANZECC Guidelines recommend adoption of the 95% protection level trigger values for aquatic ecosystems. For water intended for drinking, the Australian Drinking Water Guidelines (ADWG) (National Health and Medical Research Council [NHMRC], 2011) apply. The ADWG pertain specifically to 'health related' water quality parameters including metals, pesticides and synthetic organic compounds. Table 6 summarises the water quality objectives for parameters monitored by South32 in the Project Area.

Table 6 Water Quality Objectives for Project Area

Parameter	ANZECC Guidelines (2000)		Australian Drinking Water Guidelines (2011)		HRC Guidelines (1998)
	Aquatic Ecosystems (95th percentile protection level)	Upland Rivers (NSW)	Health	Aesthetic	Forested areas and drinking water catchment
Aluminium (pH > 6.5)	0.055	-	-	0.2	-
Barium (mg/L)	-	-	2.0		-
Chloride (mg/L)	-	-	-	250	-
Copper (mg/L)	0.0014	-	2.0	1.0	-
Iron (mg/L)	-	-	-	0.3	-
Manganese (mg/L)	1.9	-	0.5	0.1	-
Nickel (mg/L)	0.011	-	0.02	-	-
Sodium (mg/L)	-	-	-	180	-
Sulphate (mg/L)	-	-	-	250	-
Zinc (mg/L)	0.008	-	-	3.0	-
EC* (µS/cm) and TDS† (mg/L)	-	EC* 350	-	TDS† 600	-
pH (pH units)	6.5 - 8	6.5 - 8	-	-	-
Dissolved Oxygen (%)	90 - 110	90 - 110	-	>85%	-
Total Phosphorous (mg/L)	-	-	-	-	0.05
Total Nitrogen (mg/L)	-	-	-	-	0.7

* Electrical Conductivity – a measure of salinity

† Total Dissolved Solids

2.2.3 Area 5 Catchment

2.2.3.1 General Description

Area 5 is situated within the catchments of the Avon River, Lake Avon and Donalds Castle Creek, as illustrated in Figure 6. The Avon River traverses the western boundary of Area 5, with Lake Avon situated adjacent to the south-west boundary of Area 5. The headwaters of Donalds Castle Creek are located within the north-eastern portion of Area 5. The main channel of Donalds Castle Creek commences at the downstream boundary of Area 5 and the creek discharges to the Cordeaux River approximately 3 km downstream of Area 5.

The main tributaries of the Avon River, Lake Avon and Donalds Castle Creek overlying Area 5 are shown on Figure 6. A summary of the catchment area, stream order, average stream gradient and stream length for these streams is provided in Table 7.

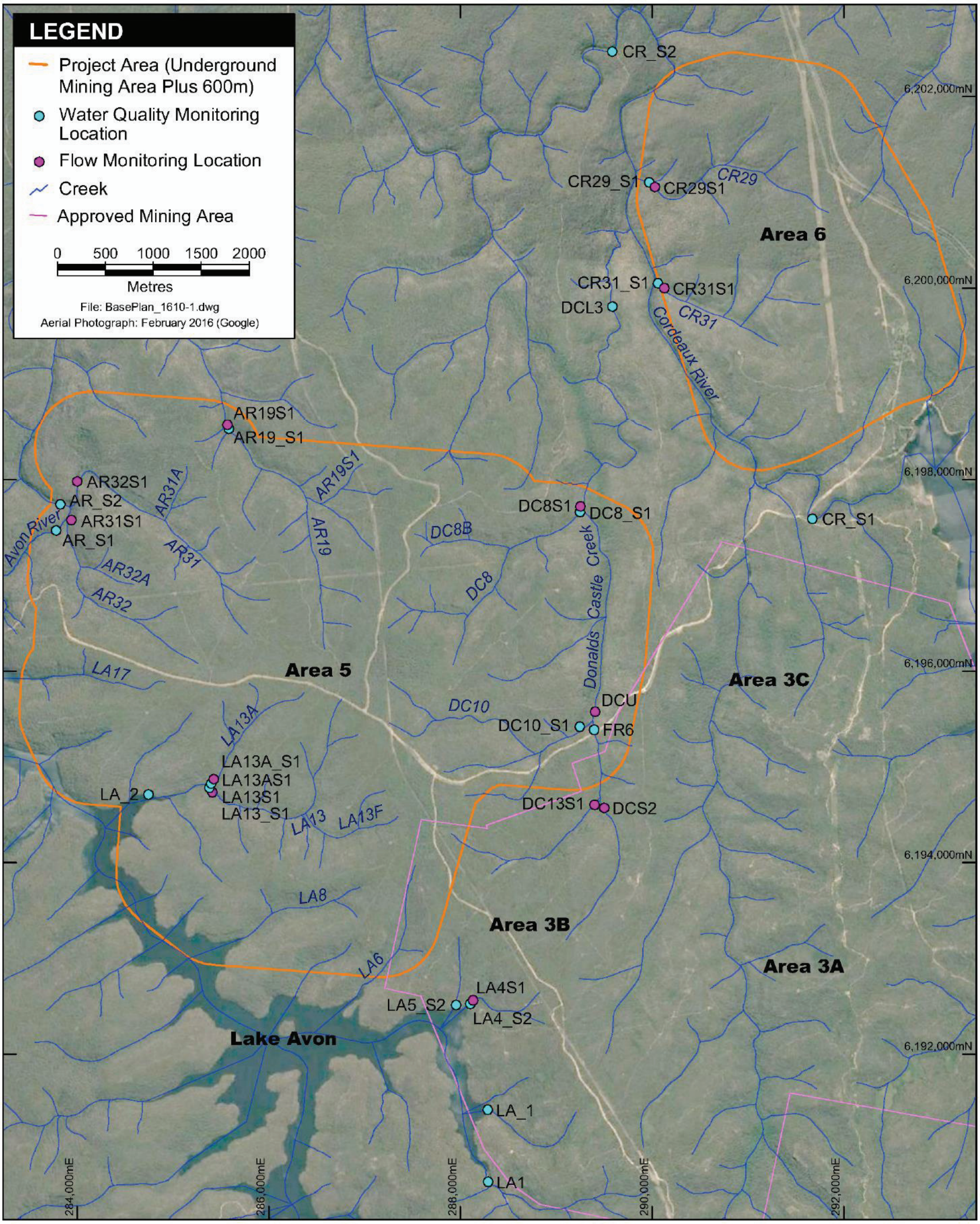


Figure 6 Area 5 and Area 6 Stream and Surface Water Monitoring

Table 7 Summary of Area 5 Stream Characteristics

Stream ID	Catchment Area (km^2)	Maximum Stream Order[2]	Average Stream Gradient[3] (m/km)#	Stream Length (km)#*
Avon River Catchment				
AR19S1	0.4	2	70	0.6
AR19S	1.1	2	62	0.8
AR19	3.9	3	29	2.8
AR31A	0.3	2	143	0.6
AR31	3.0	3	32	2.8
AR32A	0.3	2	146	0.7
AR32	1.7	3	48	2.4
Avon River	150.4	5	7	38.4## (6.8#)
Lake Avon Catchment				
LA6	1.0	2	43	1.3
LA8	1.3	2	40	2.1
LA13A	1.1	2	52	1.4
LA13F	1.0	2	51	1.2
LA13	5.6	3	22	3.6
LA17	1.0	2	42	1.5
Donalds Castle Creek Catchment				
DC8B	0.7	2	56	1.2
DC8	2.6	3	35	2.7
DC9	1.1	2	63	1.3
DC10C	1.6	2	28	2.0
DC10	2.9	2	79	1.3
Donalds Castle Creek	11.4	4	14	8.8## (3.3#)

Within the Project Area (underground mining area plus 600 m buffer)
Total length of river/creek
* Length of second-order or higher streams

2.2.3.2 Flow Characteristics

South32 has established streamflow monitoring locations at four sites in the catchments of the Avon River, Lake Avon and Donalds Castle Creek as shown in Figure 6. Figure 6 illustrates that the streamflow monitoring sites on Lake Avon (LA4S1) and Donalds Castle Creek tributaries (DC13S1 and DCS2) are located within Dendrobium Mine Area 3. Mining-related effects on the flow regime at these sites have been reported, as detailed in Section 4.2.4. As such, the flow statistics presented for these sites are not representative of baseline (pre-mining) conditions.

Table 8 presents the mean annual flow statistics for the rated[4] streamflow gauging sites and the catchment yield/rainfall percentage based on the mean annual rainfall for the Project Area Centroid for

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2 Stream order is a method for classifying a drainage network (Strahler, 1952). Headwater tributaries, at the very tops of catchments above any drainage network junction are classified as first order streams. Streams below the junction of two first order streams are defined as second order streams. Higher order streams occur according to the general rule that a stream of order ‘n+1’ is created below the junction of two streams of order ‘n’.

3 Stream gradient was calculated by dividing the creek bed elevation difference at the upstream and downstream ends of the creek by the stream length.

4 A ‘rating’ is an established relationship between stream depth (which can be continuously recorded) and streamflow.

the period of the monitored flow. The yield percentage at site LA4S1 is considered particularly high for a forested catchment, while those for the remainder are more typical for Australian streams.

Table 8 Area 5 Streamflow Statistics – Rated Gauging Stations

Catchment	Lake Avon	Donalds Castle Creek		
Site Name	**LA4S1***	**DCU****	**DC13S1***	**DCS2***
Catchment Area (ha)	82	622	164	108
Data Period	9/2012 – 5/2018	10/2007 – 5/2018	6/2012 – 5/2018	6/2012 – 5/2018
Mean Annual Flow (ML/year)	247	869	137	146
Average Yield (mm/year)	303	140	84	135
Yield/Rainfall Percentage	27%	13%	8%	12%

* Monitoring site located within Dendrobium Mine Area 3 where mining-related effects on the flow regime have been reported.
** Monitoring site located downstream of Dendrobium Mine Area 3.

Flow duration curves for the streamflow monitoring locations are shown in Figure 7. The rate of streamflow is expressed in ML/d per square kilometre (km^2) of catchment (or mm/day) to enable direct comparison between streamflow sites.

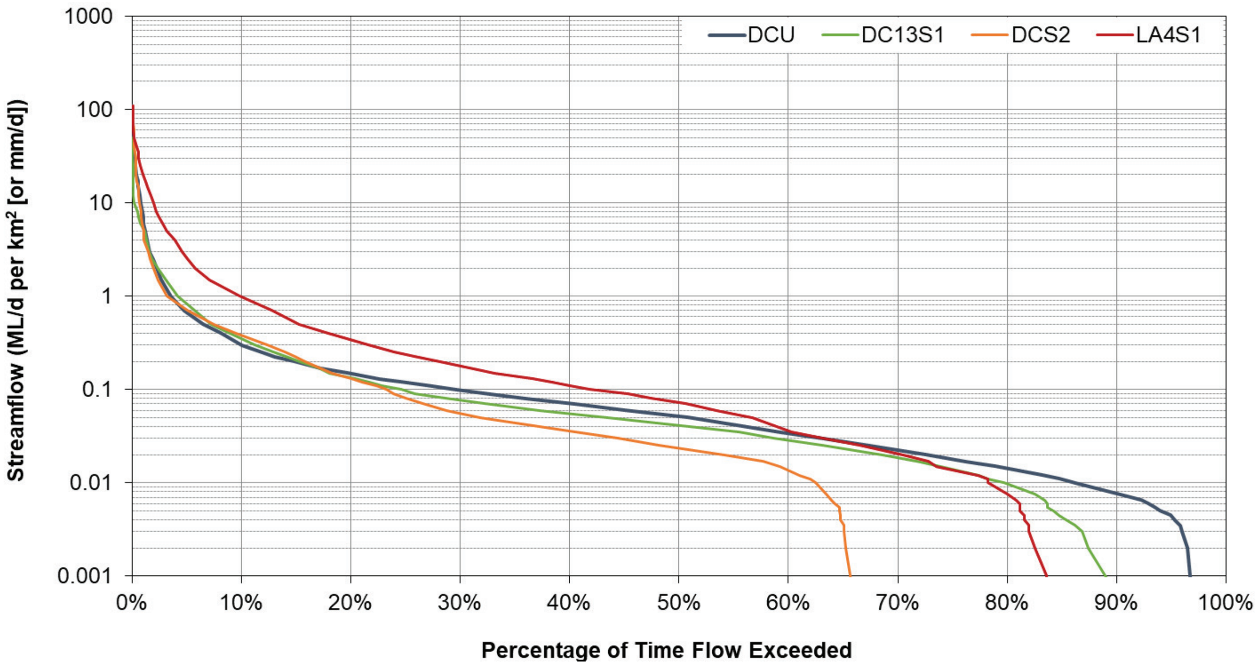

Figure 7 Flow Duration Curves for Donalds Castle Creek and Lake Avon Catchments

Figure 7 illustrates that the flow rate in Donalds Castle Creek (at DCU) exceeds 0.05 mm/d 50% of the time. The flow rate also exceeds 0.15 mm/d approximately 20% of the time and 10 mm/d approximately 2% of the time. The flow rate in the tributaries of Donalds Castle Creek exceeds 0.04 mm/d at DC13S1 and 0.02 mm/d at DCS2 50% of the time, while the flow rate in the Lake Avon tributary (at LA4S1) exceeds 0.07 mm/d 50% of the time. Figure 7 also illustrates that at the monitoring locations the streams are ephemeral, although non-negligible flow in Donalds Castle Creek at DCU was recorded approximately 98% of the time.

It should be noted that the streamflow data presented in Figure 7 is unreliable at the tail end of each flow duration curve. The rated streamflow ranges from 0.0002 to 74 mm/d for DCU, 0.003 to 35 mm/d for DC13S1, 0.036 to 82 mm/d for DCS2 and 0.002 to 62 mm/d for LA4S1.

Water level loggers have been installed in six additional surface water systems in Area 5 with near monthly spot flow measurements collected from May 2017. The spot flow measurements were recorded through volumetric gauging or using an Acoustic Doppler Velocimeter. Monitoring site DCU is located just downstream of Dendrobium Mine Area 3 and therefore may potentially be impacted by changes in flow regime associated with mine activities. The remainder of the monitoring sites are located outside of the potential zone of influence of Dendrobium Mine Area 3. A summary of the measured flows in megalitres per day (ML/d) is presented in Table 9.

Table 9 Area 5 Streamflow Statistics – Manual Gauged Flows

Catchment	Site Name	Number of Flow Measurements	Streamflow (ML/d)		
			Min	Median	Max
Avon River	AR31S1**	11	0.0	0.005	0.19
	AR32S1**	12	0.0	0.006	0.10
	AR19S1**	11	0.0	0.0	0.02
Lake Avon	LA13AS1**	9	0.0	0.0	0.003
	LA13S1**	8	0.0	0.0	0.01
Donalds Castle Creek	DC8S1*	10	0.0	0.0	1.36

* Located downstream of Dendrobium Mine Area 3 and may potentially be impacted by changes in flow regime associated with mine activities.

** Located outside of the potential zone of influence of Dendrobium Mine Area 3.

Table 9 illustrates that the streamflow measurements were collected during periods of low to no flow. A maximum flow rate of 1.36 ML/d was recorded at DC8S1 in April 2017. The low flows recorded were due to the low rainfall conditions experienced in the region in the 2018 winter and the inability to access the sites during periods of high flow. The limited available streamflow data suggests that the monitored streams within Area 5 are ephemeral.

2.2.3.3 Water Quality

South32 has undertaken multiple water quality monitoring campaigns within Area 5. The resulting surface water quality monitoring database includes both field parameters and chemical laboratory analyses. Locations of surface water quality monitoring sites are shown in Figure 6. The water quality guidelines and WQOs listed in Table 6 have been used as a basis for interpretation of the data.

Field Water Quality

Field data comprising Dissolved Oxygen (DO), pH and EC was recorded intermittently from October 2016 to May 2018 at 14 surface water monitoring sites in Area 5. Monitoring sites LA1, LA_1, LA4_S2 and LA5_S2 are located within Dendrobium Mine Area 3 and therefore may potentially be impacted by changes in water quality associated with mine activities. Monitoring sites LA_2, AR_S1, AR_S2, DC10_S1, FR6, DC8_S1 and DCL3 are located downstream of Dendrobium Mine Area 3 and therefore may potentially be impacted by changes in water quality associated with mine activities. The remainder of the monitoring sites are located outside of the potential zone of influence of Dendrobium Mine Area 3. Table 10 presents a summary of the field water quality monitoring data.

Table 10 Area 5 Surface Water Quality Summary – Field Records

Stream ID	Count	EC (µS/cm)			pH			DO (%)		
		Min	Median	Max	Min	Median	Max	Min	Median	Max
Avon River Catchment										
AR_S1*	17	54	69	76	5.8	6.5	6.9	65	90	98
AR_S2*	17	55	70	78	5.7	6.4	6.8	67	87	98
AR19_S1**	17	139	210	272	5.3	5.7	6.3	14	55	123
Lake Avon Catchment										
LA_1*	24	51	63	74	5.7	6.4	7.1	74	92	110
LA_2*	16	47	63	69	5.7	6.7	7.6	73	98	110
LA1*	5	62	67	143	6.1	6.3	7.5	87	92	99
LA13_S1**	16	57	108	123	5.2	5.8	6.4	23	65	88
LA13A_S1**	8	104	142	158	5.1	5.4	5.7	40	63	71
LA4_S2*	88	50	68	81	5.7	6.6	7.2	48	89	100
LA5_S2*	88	51	68	81	5.1	6.6	7.1	56	91	100
Donalds Castle Creek Catchment										
DC10_S1*	17	77	144	225	5.4	5.8	6.2	27	73	103
DC8_S1*	18	106	167	200	5.4	5.4	6.2	62	87	106
DCL3*	41	86	129	140	5.3	5.3	6.6	17	79	93
FR6*	+	11	108	145	3.7	5.5	5.8	14	89	105

+ 734 EC readings, 692 pH readings, 661 DO readings

* Located within or downstream of Dendrobium Mine Area 3 and may potentially be impacted by changes in water quality associated with mine activities.

** Located outside of the potential zone of influence of Dendrobium Mine Area 3.

Table 10 illustrates that the water quality of the surface water systems within Area 5 is acidic to near neutral, with pH values ranging from 3.7 to 7.6. No observable differences were noted in pH values reported in surface water systems located within or downstream of Dendrobium Mine Area 3 as opposed to surface water systems located outside of the potential zone of influence of Dendrobium Mine Area 3. EC records were consistently lower than the ANZECC WQO for upland rivers in NSW of 350 µS/cm, the highest recorded value being 272 µS/cm at AR19_S1 which is located outside of the potential zone of influence of Dendrobium Mine Area 3. Dissolved oxygen (DO) levels ranged from unsaturated (less than 90%) to supersaturated (greater than 110%), with only five of fourteen sites reporting median DO levels within the ANZECC WQO for NSW upland rivers (between 90 to 100%). No observable differences were noted in DO levels reported in surface water systems located within or downstream of Dendrobium Mine Area 3 as opposed to surface water systems located outside of the potential zone of influence of Dendrobium Mine Area 3.

Laboratory Analysis of Water Quality

Water quality data from laboratory analyses were obtained for a range of parameters at three sites within the Avon River catchment, two sites within the Lake Avon catchment and four sites within the Donalds Castle Creek catchments. The monitoring locations are shown in Figure 6, while Table 11, Table 12, Table 13 and Table 14 present a summary of the water quality data for the Avon River, Lake Avon, Donalds Castle Creek tributaries and Donalds Castle Creek monitoring sites respectively. Monitoring sites AR_S1, AR_S2, DC10_S1, FR6, DC8_S1 and DCL3 are located downstream of Dendrobium Mine Area 3 and therefore may potentially be impacted by changes in water quality associated with mine activities. The remainder of the monitoring sites are located outside of the potential zone of influence of Dendrobium Mine Area 3.

Table 11 Avon River Catchment Water Quality Summary

Parameter	WQO	AR_S1*				AR_S2*				AR19_S1**			
		Count	Min	Median	Max	Count	Min	Median	Max	Count	Min	Median	Max
Chloride (mg/L)	250[6]	15	12	14	16	15	12	15	16	16	43	51	61
Dissolved Aluminium (mg/L)		9	0.01	0.01	0.01	9	0.01	0.01	0.01	9	0.03	0.05	0.14
Dissolved Barium (mg/L)	2[5]	9	0.007	0.008	0.010	9	0.007	0.008	0.012	9	0.011	0.017	0.018
Dissolved Calcium (mg/L)		15	1	1	2	15	1	1	2	16	1	1	1
Dissolved Copper (mg/L)	0.0014[1]	13	0.001	0.001	**0.043**	13	0.001	0.001	**0.027**	14	0.001	0.001	**0.003**
Dissolved Iron (mg/L)		9	0.09	0.10	0.24	9	0.09	0.15	0.21	9	0.31	1.3	3.04
Dissolved Lithium (mg/L)		7	0.001	0.001	0.003	7	0.001	0.001	0.001	7	0.001	0.001	0.001
Dissolved Magnesium (mg/L)		15	1	2	2	15	1	2	2	16	3	4	6
Dissolved Manganese (mg/L)		9	0.03	0.04	0.11	9	0.02	0.04	0.08	9	0.18	0.29	0.49
Dissolved Nickel (mg/L)	0.011[1]	15	0.001	0.001	0.001	15	0.001	0.001	0.005	16	0.001	0.002	0.003
Dissolved Organic Carbon (mg/L)		15	3	4	34	15	3	4	7	16	1	6	73
Dissolved Potassium (mg/L)		15	1	1	1	15	1	1	1	16	1	1.5	4
Dissolved Silicon (mg/L)		15	0.54	0.72	1.09	15	0.53	0.73	1.02	16	0.30	1.78	2.59
Dissolved Sodium (mg/L)	180[6]	15	7	9	10	15	7	8	11	16	24	28	33
Dissolved Strontium (mg/L)		9	0.010	0.012	0.017	9	0.011	0.012	0.014	9	0.010	0.014	0.015
Dissolved Sulphate (mg/L)		13	1	2	3	13	1	2	3	14	1	1.5	5
Dissolved Zinc (mg/L)	0.008[1]	15	0.005	0.005	**0.010**	15	0.005	0.005	**0.012**	16	0.005	**0.012**	**0.040**
Electrical Conductivity (µS/cm)	350[3]	15	62	70	80	15	64	71	87	16	162	209	231
pH Value	6.5 – 8[2]	15	**6.2**	6.7	7.2	15	**6.2**	6.6	6.9	16	**5.5**	**6.0**	6.5
Sulphate (mg/L)	250[6]	2	2	4	6	2	2	3	3	2	1	1	1
Suspended Solids (mg/L)		2	5	6	6	2	5	9	12	2	5	66	126
Total Aluminium (mg/L)	0.055[2]	15	0.01	0.01	0.04	15	0.01	0.01	**0.06**	16	0.02	**0.07**	**0.32**
Total Dissolved Solids (mg/L)		2	51	52	52	2	50	61	71	2	148	171	194
Total Iron (mg/L)	0.3[6]	15	0.22	**0.32**	**0.72**	15	0.20	**0.30**	**0.70**	16	0.05	**1.12**	**5.73**
Total Manganese (mg/L)	0.1[6]	15	0.04	0.06	**0.19**	15	0.03	0.05	**0.29**	16	0.01	0.24	**0.50**
Total Nitrogen as N (mg/L)	0.7[4]	2	0.1	0.2	0.2	2	0.1	0.2	0.2	2	0.3	**1.0**	**1.7**
Total Phosphorus as P (mg/L)	0.05[4]	15	0.01	0.01	0.01	15	0.01	0.01	0.01	16	0.01	0.01	0.03

[1] ANZECC (2000) guideline trigger value for aquatic ecosystems (95th percentile level of species protection for slightly to moderately disturbed ecosystems) – guideline value relates to total concentration though can be compared to dissolved concentrations where total concentration is not available;

[2] ANZECC (2000) guideline trigger value for aquatic ecosystems (95th percentile level of species protection for slightly to moderately disturbed ecosystems);

[3] ANZECC (2000) guideline trigger value for Upland Rivers in NSW;

[4] HRC (1998) water quality objective;

[5] ADWG (NHMRC, 2011) 'health' water quality guideline;

[6] ADWG (NHMRC, 2011) 'aesthetic' water quality guideline.

* Located downstream of Dendrobium Mine Area 3 and may potentially be impacted by changes in water quality associated with mine activities.

**Located outside of the potential zone of influence of Dendrobium Mine Area 3.

Table 12 Lake Avon Catchment Water Quality Summary

Parameter	WQO	LA13_2**				LA13_S1**			
		Count	Min	Median	Max	Count	Min	Median	Max
Chloride (mg/L)	250[6]	16	10	13	15	15	14	26	30
Dissolved Aluminium (mg/L)		10	0.01	0.01	0.02	9	0.03	0.05	0.21
Dissolved Barium (mg/L)	2[5]	10	0.006	0.006	0.007	9	0.004	0.004	0.007
Dissolved Calcium (mg/L)		16	1	1	1	15	1	1	1
Dissolved Copper (mg/L)	0.0014[1]	14	0.001	0.001	**0.002**	13	0.001	0.001	0.001
Dissolved Iron (mg/L)		10	0.05	0.05	0.09	9	0.25	0.48	1.30
Dissolved Lithium (mg/L)		8	0.001	0.001	0.001	7	0.001	0.001	0.001
Dissolved Magnesium (mg/L)		16	1	1	2	15	1	2	2
Dissolved Manganese (mg/L)		10	0.004	0.011	0.039	9	0.036	0.077	0.094
Dissolved Nickel (mg/L)	0.011[1]	16	0.001	0.001	0.001	15	0.001	0.001	0.002
Dissolved Organic Carbon (mg/L)		16	3	4	14	15	2	6	52
Dissolved Potassium (mg/L)		16	1	1	4	15	1	1	1
Dissolved Silicon (mg/L)		16	0.28	0.55	0.85	15	0.77	2.21	2.66
Dissolved Sodium (mg/L)	180[6]	16	6	8	9	15	10	14	18
Dissolved Strontium (mg/L)		10	0.009	0.011	0.012	9	0.004	0.005	0.007
Dissolved Sulphate (mg/L)		14	1	2	11	13	1	1	2
Dissolved Zinc (mg/L)	0.008[1]	16	0.005	0.005	**0.014**	15	0.005	0.005	**0.012**
Electrical Conductivity (µS/cm)	350[3]	16	56	63	68	15	62	106	117
pH Value	6.5 – 8[2]	16	**6.1**	6.5	6.8	16.0	**5.1**	**5.7**	6.7
Sulphate (mg/L)	250[6]	2	2	3	3	2	1	1	1
Suspended Solids (mg/L)		2	5	5	5	2	5	9.5	14
Total Aluminium (mg/L)	0.055[2]	16	0.01	0.02	**1.07**	15	0.03	**0.12**	**0.42**
Total Dissolved Solids (mg/L)		2	38	50	61	2	64	77	90
Total Iron (mg/L)	0.3[6]	16	0.05	0.07	**1.21**	15	0.13	**1.08**	**2.18**
Total Manganese (mg/L)	0.1[6]	16	0.004	0.021	0.093	15	0.018	0.053	**0.108**
Total Nitrogen as N (mg/L)	0.7[4]	2	0.1	0.1	0.1	2	0.1	0.2	0.3
Total Phosphorus as P (mg/L)	0.05[4]	16	0.01	0.01	**0.06**	15	0.01	0.01	0.02

[1] ANZECC (2000) guideline trigger value for aquatic ecosystems (95th percentile level of species protection for slightly to moderately disturbed ecosystems) – guideline value relates to total concentration though can be compared to dissolved concentrations where total concentration is not available;

[2] ANZECC (2000) guideline trigger value for aquatic ecosystems (95th percentile level of species protection for slightly to moderately disturbed ecosystems);

[3] ANZECC (2000) guideline trigger value for Upland Rivers in NSW;

[4] HRC (1998) water quality objective;

[5] ADWG (NHMRC, 2011) 'health' water quality guideline;

[6] ADWG (NHMRC, 2011) 'aesthetic' water quality guideline.

* Located downstream of Dendrobium Mine Area 3 and may potentially be impacted by changes in water quality associated with mine activities.

**Located outside of the potential zone of influence of Dendrobium Mine Area 3.

Table 13 Donalds Castle Creek Tributaries Water Quality Summary

Parameter	WQO	DC10_S1*				DC8_S1*			
		Count	Min	Median	Max	Count	Min	Median	Max
Chloride (mg/L)	250[6]	4	13	37	42	15	26	45	57
Dissolved Aluminium (mg/L)		1	-	0.05	-	8	0.03	0.06	0.20
Dissolved Barium (mg/L)	2[5]	1	-	0.010	-	8	0.007	0.008	0.011
Dissolved Calcium (mg/L)		4	1.0	1.0	1.0	15	1.0	1.0	1.0
Dissolved Copper (mg/L)	0.0014[1]	4	0.001	0.001	0.001	13	0.001	0.001	**0.003**
Dissolved Iron (mg/L)		1	-	3.22	-	8	0.07	0.185	0.44
Dissolved Lithium (mg/L)		1	-	0.001	-	6	0.001	0.001	0.001
Dissolved Magnesium (mg/L)		4	2	3	3	15	3	3	4
Dissolved Manganese (mg/L)	0.1[6]	1	-	0.57	-	8	0.06	0.15	0.27
Dissolved Nickel (mg/L)	0.011[1]	4	0.001	0.001	0.002	15	0.001	0.001	0.002
Dissolved Organic Carbon (mg/L)		4	1	3	4	15	1	5	188
Dissolved Potassium (mg/L)		4	1	1	1	15	1	1	2
Dissolved Silicon (mg/L)		4	2.5	2.6	2.8	15	1.3	2.3	3.0
Dissolved Sodium (mg/L)	180[6]	4	15	18	24	15	18	22	27
Dissolved Strontium (mg/L)		1	-	0.009	-	8	0.007	0.009	0.01
Dissolved Sulphate (mg/L)		4	1	1	2	13	1	2	5
Dissolved Zinc (mg/L)	0.008[1]	4	0.005	0.005	0.006	15	0.005	**0.010**	**0.054**
Electrical Conductivity (µS/cm)	350[3]	4	116	148	176	15	140	176	201
pH Value	6.5 – 8[2]	4	**5.9**	**6.0**	**6.0**	15	**5.2**	**5.6**	**6.2**
Sulphate (mg/L)	250[6]	-	-	-	-	2	3	4	4
Suspended Solids (mg/L)		-	-	-	-	2	5	11	16
Total Aluminium (mg/L)	0.055[2]	4	0.01	0.04	**0.21**	15	0.04	**0.13**	**1.89**
Total Dissolved Solids (mg/L)		-	-	-	-	2	117	126	134
Total Iron (mg/L)	0.3[6]	4	0.16	**0.36**	**7.27**	15	0.06	**0.33**	**8.65**
Total Manganese (mg/L)	0.1[6]	4	0.05	0.05	**0.62**	15	0.03	**0.14**	**1.11**
Total Nitrogen as N (mg/L)	0.7[4]	-	-	-	-	2	0.2	0.25	0.3
Total Phosphorus as P (mg/L)	0.05[4]	4	0.01	0.01	0.01	15	0.01	0.01	**0.06**

[1] ANZECC (2000) guideline trigger value for aquatic ecosystems (95th percentile level of species protection for slightly to moderately disturbed ecosystems) – guideline value relates to total concentration though can be compared to dissolved concentrations where total concentration is not available;
[2] ANZECC (2000) guideline trigger value for aquatic ecosystems (95th percentile level of species protection for slightly to moderately disturbed ecosystems);
[3] ANZECC (2000) guideline trigger value for Upland Rivers in NSW;
[4] HRC (1998) water quality objective;
[5] ADWG (NHMRC, 2011) 'health' water quality guideline;
[6] ADWG (NHMRC, 2011) 'aesthetic' water quality guideline.
* Located downstream of Dendrobium Mine Area 3 and may potentially be impacted by changes in water quality associated with mine activities.
**Located outside of the potential zone of influence of Dendrobium Mine Area 3.

Table 14 Donalds Castle Creek Water Quality Summary

Parameter	WQO	DCL3*						FR6*					
		Count	Min	20%tile	Median	80%tile	Max	Count	Min	20%tile	Median	80%tile	Max
Chloride (mg/L)	250[6]	36	21	29	35	39	53	38	6	17	22	28	35
Dissolved Aluminium (mg/L)		170	0.01	0.03	0.04	0.06	0.18	165	0.03	0.07	0.10	0.15	0.44
Dissolved Barium (mg/L)	2[5]	30	0.001	0.006	0.007	0.009	0.013	32	0.001	0.003	0.004	0.005	0.008
Dissolved Calcium (mg/L)		148	0.5	0.5	0.5	1.0	5.0	142	0.5	0.5	0.5	1.0	9.0
Dissolved Copper (mg/L)	0.0014[1]	13	0.001	0.001	0.001	0.001	**0.009**	12	0.001	0.001	0.001	0.001	**0.002**
Dissolved Iron (mg/L)		170	0.02	0.11	0.24	0.62	3.29	165	0.01	0.06	0.12	0.31	1.56
Dissolved Lithium (mg/L)		7	0.001	0.001	0.001	0.001	0.001	5	0.001	0.001	0.001	0.001	0.001
Dissolved Magnesium (mg/L)		148	0.5	2.0	3.0	3.0	6.0	142	0.5	2.0	2.0	3.0	6.0
Dissolved Manganese (mg/L)		170	0.01	0.02	0.04	0.07	0.60	165	0.01	0.03	0.03	0.05	0.16
Dissolved Nickel (mg/L)	0.011[1]	185	0.0005	0.0005	0.0005	0.0010	0.0080	174	0.0005	0.0005	0.0005	0.0010	0.0050
Dissolved Organic Carbon (mg/L)		184	1	2	3	6	205	172	1	1	3	5	56
Dissolved Potassium (mg/L)		148	0.5	0.5	0.5	1.0	3.0	142	0.5	0.5	0.5	1.0	2.0
Dissolved Silicon (mg/L)		115	0.05	1.76	2.17	2.40	4.90	116	0.56	2.13	2.44	2.70	5.20
Dissolved Sodium (mg/L)	180[6]	148	13	16	18	20	27	142	4	13	16	18	24
Dissolved Strontium (mg/L)		30	0.003	0.005	0.008	0.009	0.011	32	0.002	0.003	0.004	0.013	0.036
Dissolved Sulphate (mg/L)		13	1	1	1	3	4	13	2	2	3	4	6
Dissolved Zinc (mg/L)	0.008[1]	185	0.003	0.003	0.005	0.006	**0.345**	174	0.003	0.003	0.005	0.007	**0.020**
Electrical Conductivity (µS/cm)	350[3]	36	97	116	136	154	193	38	58	84	100	111	173
pH Value	6.5 – 8[2]	185	**4.5**	**5.6**	**5.9**	**6.2**	7.9	174	**4.6**	**5.2**	**5.6**	**5.9**	7.6
Sulphate (mg/L)	250[6]	23	1.0	1.4	2.0	3.0	4.0	26	1.0	1.0	3.0	5.0	8.0
Suspended Solids (mg/L)		23	5	5	5	5	47	27	5	5	5	5	53
Total Aluminium (mg/L)	0.055[2]	184	0.01	0.04	**0.06**	**0.10**	**0.71**	172	0.04	**0.10**	**0.14**	**0.18**	**2.75**
Total Dissolved Solids (mg/L)		23	46	63	80	105	468	27	38	54	69	84	149
Total Iron (mg/L)	0.3[6]	184	0.07	0.21	**0.46**	**1.16**	**4.70**	173	0.03	0.07	0.20	**0.60**	**4.25**
Total Manganese (mg/L)	0.1[6]	184	0.00	0.02	0.04	0.07	**0.95**	173	0.01	0.03	0.03	0.05	**0.18**
Total Nitrogen as N (mg/L)	0.7[4]	23	0.1	0.1	0.1	0.2	0.4	26	0.1	0.1	0.1	0.2	2.3
Total Phosphorus as P (mg/L)	0.05[4]	149	0.01	0.01	0.01	0.03	**4.67**	142	0.01	0.01	0.01	0.04	**2.98**

[1] ANZECC (2000) guideline trigger value for aquatic ecosystems (95th percentile level of species protection for slightly to moderately disturbed ecosystems) – guideline value relates to total concentration though can be compared to dissolved concentrations where total concentration is not available;

[2] ANZECC (2000) guideline trigger value for aquatic ecosystems (95th percentile level of species protection for slightly to moderately disturbed ecosystems);

[3] ANZECC (2000) guideline trigger value for Upland Rivers in NSW;

[4] HRC (1998) water quality objective;

[5] ADWG (NHMRC, 2011) 'health' water quality guideline;

[6] ADWG (NHMRC, 2011) 'aesthetic' water quality guideline.

* Located downstream of Dendrobium Mine Area 3 and may potentially be impacted by changes in water quality associated with mine activities.

**Located outside of the potential zone of influence of Dendrobium Mine Area 3.

The water quality data has been compared with the WQOs listed in Table 6. Where both ANZECC and ADWG specify a WQO for a given parameter, the most conservative WQO has been adopted for benchmarking water quality. Reported values shown in bold outline exceedances of the WQO.

Table 11, Table 12, Table 13 and Table 14 show slightly elevated concentrations of dissolved copper and dissolved zinc at all sites monitored in Area 5. The laboratory pH data are generally consistent with field measurements, showing a range of acidic to near neutral conditions at all monitored sites. Elevated total aluminium concentrations were recorded at all sites excepting AR_S1, with a maximum recording of 2.75 mg/L at FR6 on Donalds Castle Creek. However, the total aluminium concentrations recorded at FR6 were less than 0.18 mg/L for 80% of the samples, with only three records greater than 1 mg/L.

Maximum recorded manganese concentrations exceeded the ADWG aesthetic WQO at all sites except LA13_2 and the ADWG health WQO at DC20_DS1, DC8_S1 and DCL3. Median and maximum recorded total iron concentrations exceeded the ADWG aesthetic WQO at all Avon River sites, LA13_S1 and DC20_DS1, DC8_S1 and DCL3. Maximum recorded iron concentrations also exceeded the ADWG aesthetic WQO at LA13_2 and FR6.

Total nitrogen concentrations were below the HRC (1998) WQO of 0.7 mg/L at all sites monitored in Area 5, excepting AR19_S1 which exceeded the WQO for both the median and maximum values. Total phosphorus concentrations were generally below the HRC (1998) WQO of 0.05 mg/L, excepting maximum concentrations of 0.06 mg/L recorded at LA13_2 and DC8_S1, 4.67 mg/L recorded at DCL3 and 2.98 mg/L recorded at FR6. However, the maximum phosphorus concentrations recorded at DCL3 and FR6 appear to be outliers, with the WQO of 0.05 mg/L exceeded for only one sample at each site.

Water Quality Influences

The pH of water within the Upper Nepean catchment has been found to be invariably below the ANZECC trigger value of 6.5 (WaterNSW, 2018a). The low pH arises naturally due to the equilibration of waters with silicic acid derived from dissolution of silica and the leaching of small concentrations of low molecular weight organic acids from peats and other organic matter (Ecoengineers, 2007). Levels of total aluminium are generally historically in excess of the ANZECC trigger value in the Dendrobium region (Ecoengineers, 2007; WaterNSW, 2018a).

Monitoring sites AR_S1, AR_S2, DC10_S1, FR6, DC8_S1 and DCL3 are located downstream of Dendrobium Mine Area 3 and therefore localised changes in water quality may be observed at these sites. As detailed in Section 4.2, mine subsidence effects have resulted in isolated, episodic pulses in iron, manganese, aluminium and electrical conductivity. However, it should be noted that AR19_S1, LA13_S1 and LA13_2 are located outside of the potential zone of influence of Dendrobium Mine Area 3 although spikes in manganese, iron and/or aluminium were recorded at these sites.

2.2.4 Area 6 Catchment

2.2.4.1 General Description

Area 6 is situated within the Cordeaux River catchment downstream of Cordeaux Dam, as illustrated in Figure 6. The Cordeaux River traverses the western boundary of Area 6, with Cordeaux Dam situated upstream of the southern boundary of Area 6. The main tributaries of the Cordeaux River which are located within the Project Area are shown on Figure 6. A summary of the catchment area, stream order, average stream gradient and stream length for these streams is provided in Table 15.

Table 15 Summary of Area 6 Stream Characteristics

Stream ID	Catchment Area (km^2)	Stream Order	Average Stream Gradient (m/km)#	Stream Length (km)#*
CR29	2.3	2	38	2.3
CR31C	1.2	2	54	1.1
CR31	2.6	2	26	1.4
Cordeaux River	135.5	5	2	37.7## (5.1#)

Within the Project Area (proposed underground mining area plus 600 m buffer)
Total length of river/creek
* Length of second-order or higher streams

2.2.4.2 Flow Characteristics

The Cordeaux Dam is situated directly upstream of Area 6. Variable inflows of up to 4.5 ML/day are released from Cordeaux Dam for environmental flow purposes (WaterNSW, 2018b). No flow monitoring stations are located on the Cordeaux River.

Water level loggers have been installed in two tributaries of Cordeaux River in Area 6 with monthly spot flow measurements collected from May 2017 summarised in Table 16. The spot flow measurements were recorded through volumetric gauging or using an Acoustic Doppler Velocimeter. The two monitoring sites are located outside of the potential zone of impact of the Dendrobium Mine Area 3.

Table 16 Area 6 Streamflow Statistics – Manual Gauging

Site Name	Streamflow (ML/d)		
	Min	Median	Max
CR29S1*	0.0	0.0	0.09
CR31S1*	0.0	0.0	1.28

* Located outside of the potential zone of influence of Dendrobium Mine Area 3.

Table 16 illustrates that the streamflow measurements were collected during periods of low to no flow. A maximum flow rate of 1.28 ML/d was recorded at CR31S1 in April 2017. The low flows recorded were due to the low rainfall conditions experienced in the region in the 2018 winter and the inability to access the sites during periods of high flow. The limited available streamflow data suggests that the monitored streams within Area 6 are ephemeral.

2.2.4.3 Water Quality

South32 has undertaken multiple water quality monitoring campaigns within Area 6. The resulting surface water quality monitoring database includes both field parameters and laboratory chemical analyses. Locations of surface water quality monitoring sites are shown in Figure 6. WQOs listed in Table 6 have been used as a basis for interpretation of the data.

Field Water Quality

Field data comprising DO, pH and EC was recorded intermittently from October 2016 to May 2018 at two monitoring sites on the Cordeaux River and two tributaries of the Cordeaux River. The two monitoring sites on the Cordeaux River are located downstream of Dendrobium Mine Area 3 and therefore the water quality may potentially be influenced by water quality impacts occurring upstream as a result of mining activities. However, no observable impacts on water quality in the Cordeaux River have been reported to date (refer Section 4.2). The two monitoring sites on tributaries of the Cordeaux

River are located outside the potential zone of impact of Dendrobium Mine Area 3. Table 17 presents a summary of the field water quality monitoring data.

Table 17 Area 6 Surface Water Quality Summary – Field Records

Stream ID	Count	EC (µS/cm)			pH			DO (%)		
		Min	Median	Max	Min	Median	Max	Min	Median	Max
Cordeaux River										
CR_S1*	17	70	83	93	6.3	7.0	7.4	78	99	113
CR_S2*	17	76	84	96	5.7	6.8	7.3	79	95	102
CR29_S1**	16	140	197	249	5.7	6.3	6.8	67	84	107
CR31_S1**	16	307	162	307	5.1	5.8	6.8	31	72	109

* Located downstream of Dendrobium Mine Area 3 and may potentially be impacted by changes in water quality associated with mine activities.

** Located outside of the potential zone of influence of Dendrobium Mine Area 3.

Table 17 illustrates that the Cordeaux River tributaries recorded slightly acidic conditions, with pH values ranging from 5.1 to 7.4. The pH values reported for the Cordeaux River sites were slightly higher and generally within the range of the ANZECC WQO (6.5 – 8). EC values were higher for the tributaries of the Cordeaux River (CR29_S1 and CR31_S1), though consistently less than the ANZECC WQO for upland rivers in NSW (350 µS/cm). DO levels ranged from 31% (unsaturated) to 113% (supersaturated), with the Cordeaux River sites reporting median DO levels within the ANZECC WQO for NSW upland rivers (between 90 to 100%).

Laboratory Analysis of Water Quality

Water quality data from laboratory analysis was obtained for a range of parameters at two sites on the Cordeaux River and two sites on its tributaries. As shown in Figure 6, the two monitoring sites on the Cordeaux River are located downstream of Dendrobium Mine Area 3 and therefore the water quality may potentially be influenced by water quality impacts occurring upstream as a result of mining activities. The two monitoring sites on tributaries of the Cordeaux River are located outside the potential zone of impact of Dendrobium Mine Area 3. Table 18 presents a summary of the water quality data for sites on the Cordeaux River and Table 19 presents a summary of the water quality data for sites on its tributaries. The water quality data has been compared with the WQOs listed in Table 6. Where both ANZECC and ADWG specify a WQO for a given parameter, the most conservative WQO has been adopted for benchmarking water quality. Reported values shown in bold outline exceedances of the WQO.

Table 18 Cordeaux River Water Quality Summary

Parameter	WQO	CR_S1*				CR_S2*			
		Count	Min	Median	Max	Count	Min	Median	Max
Chloride (mg/L)	250[6]	16	14	16	20	15	14	16	20
Dissolved Aluminium (mg/L)		9	0.01	0.01	0.03	9	0.01	0.01	0.03
Dissolved Barium (mg/L)	2[5]	9	0.02	0.02	0.03	9	0.02	0.02	0.02
Dissolved Calcium (mg/L)		16	2	2	2	15	1	2	2
Dissolved Copper (mg/L)	0.0014[1]	14	0.001	0.001	0.001	13	0.001	0.001	0.001
Dissolved Iron (mg/L)		9	0.05	0.07	0.18	9	0.05	0.07	0.21
Dissolved Lithium (mg/L)		7	0.001	0.001	0.001	7	0.001	0.001	0.001
Dissolved Magnesium (mg/L)		16	2	2	2	15	2	2	2
Dissolved Manganese (mg/L)		9	0.01	0.07	0.19	9	0.02	0.02	0.16
Dissolved Nickel (mg/L)	0.011[1]	16	0.001	0.001	0.001	15	0.001	0.001	0.001
Dissolved Organic Carbon (mg/L)		16	4	4	55	15	4	5	18
Dissolved Potassium (mg/L)		16	1	1	1	15	1	1	1
Dissolved Silicon (mg/L)		16	0.05	0.41	1.01	15	0.05	0.43	1.40
Dissolved Sodium (mg/L)	180[6]	16	8	9	12	15	8	10	12
Dissolved Strontium (mg/L)		9	0.019	0.023	0.026	9	0.02	0.022	0.026
Dissolved Sulphate (mg/L)		14	1	2	4	13	1	2	4
Dissolved Zinc (mg/L)	0.008[1]	16	0.005	0.005	**0.023**	15	0.005	0.005	0.005
Electrical Conductivity (μS/cm)	350[3]	16	79	85	91	15	81	86	100
pH Value	6.5 – 8[2]	16	6.5	6.8	7.3	15	**6.4**	6.9	7.3
Sulphate (mg/L)	250[6]	2	3	3	3	2	3	-	3
Suspended Solids (mg/L)		2	5	8	11	2	5	-	7
Total Aluminium (mg/L)	0.055[2]	16	0.01	0.03	**0.13**	15	0.01	0.03	**0.06**
Total Dissolved Solids (mg/L)		2	40	50	60	2	62	-	70
Total Iron (mg/L)	0.3[6]	16	0.09	0.17	**0.69**	15	0.1	0.18	**0.39**
Total Manganese (mg/L)	0.1[6]	16	0.007	**0.105**	**0.322**	15	0.013	0.039	**0.199**
Total Nitrogen as N (mg/L)	0.7[4]	2	0.3	0.3	0.3	2	0.3	-	**1.6**
Total Phosphorus as P (mg/L)	0.05[4]	16	0.01	0.01	0.03	15	0.01	0.01	**0.60**

[1] ANZECC (2000) guideline trigger value for aquatic ecosystems (95th percentile level of species protection for slightly to moderately disturbed ecosystems) – guideline value relates to total concentration though can be compared to dissolved concentrations where total concentration is not available; [2] ANZECC (2000) guideline trigger value for aquatic ecosystems (95th percentile level of species protection for slightly to moderately disturbed ecosystems); [3] ANZECC (2000) guideline trigger value for Upland Rivers in NSW; [4] HRC (1998) water quality objective;
[5] ADWG (NHMRC, 2011) 'health' water quality guideline; [6] ADWG (NHMRC, 2011) 'aesthetic' water quality guideline. * Located downstream of Dendrobium Mine Area 3 and may potentially be impacted by changes in water quality associated with mine activities.

Table 19 Cordeaux River Tributaries Water Quality Summary

Parameter	WQO	CR29_S1**				CR31_S1**			
		Count	Min	Median	Max	Count	Min	Median	Max
Chloride (mg/L)	250[6]	14	34	51	96	14	25	41	96
Dissolved Aluminium (mg/L)		9	0.01	0.04	0.1	9	0.11	0.33	1.08
Dissolved Barium (mg/L)	2[5]	9	0.008	0.012	0.021	9	0.004	0.007	0.009
Dissolved Calcium (mg/L)		14	1	1	1	14	1	1	2
Dissolved Copper (mg/L)	0.0014[1]	12	0.001	0.001	0.001	12	0.001	0.001	0.001
Dissolved Iron (mg/L)		9	0.05	0.16	0.52	9	0.22	0.62	5.42
Dissolved Lithium (mg/L)		7	0.001	0.001	0.001	7	0.001	0.001	0.001
Dissolved Magnesium (mg/L)		14	3	4	6	14	2	4	5
Dissolved Manganese (mg/L)		9	0.06	0.07	0.16	9	0.09	0.27	0.78
Dissolved Nickel (mg/L)	0.011[1]	14	0.001	0.001	0.002	14	0.001	0.001	0.003
Dissolved Organic Carbon (mg/L)		14	2	5	10	14	2	17	74
Dissolved Potassium (mg/L)		14	1	1	2	14	1	3	6
Dissolved Silicon (mg/L)		14	0.69	2.15	3.01	14	0.21	1.24	2.4
Dissolved Sodium (mg/L)	180[6]	14	20	27	34	14	15	21	34
Dissolved Strontium (mg/L)		9	0.009	0.013	0.018	9	0.007	0.014	0.020
Dissolved Sulphate (mg/L)		12	1	2.5	4	12	1	2	4
Dissolved Zinc (mg/L)	0.008[1]	14	0.005	0.005	**0.434**	14	0.005	0.006	**0.064**
Electrical Conductivity (µS/cm)	350[3]	14	133	203	234	14	111	167	284
pH Value	6.5 – 8[2]	14	**5.3**	**6.2**	6.7	14	**5.3**	**5.8**	**6.0**
Sulphate (mg/L)	250[6]	2	2	3	4	2	3	-	10
Suspended Solids (mg/L)		2	5	10	14	2	10	-	22
Total Aluminium (mg/L)	0.055[2]	14	0.02	0.07	0.14	14	0.04	**0.365**	**1.85**
Total Dissolved Solids (mg/L)		2	112	126	139	2	122	-	242
Total Iron (mg/L)	0.3[6]	14	0.06	0.27	**0.68**	14	0.05	**0.80**	**9.17**
Total Manganese (mg/L)	0.1[6]	14	0.007	0.073	**0.184**	14	0.007	**0.238**	**0.886**
Total Nitrogen as N (mg/L)	0.7[4]	2	0.2	0.3	0.3	2	**2.2**	-	**2.4**
Total Phosphorus as P (mg/L)	0.05[4]	14	0.01	0.01	0.04	14	0.01	0.03	**0.14**

[1] ANZECC (2000) guideline trigger value for aquatic ecosystems (95^{th} percentile level of species protection for slightly to moderately disturbed ecosystems) – guideline value relates to total concentration though can be compared to dissolved concentrations where total concentration is not available; [2] ANZECC (2000) guideline trigger value for aquatic ecosystems (95^{th} percentile level of species protection for slightly to moderately disturbed ecosystems); [3] ANZECC (2000) guideline trigger value for Upland Rivers in NSW; [4] HRC (1998) water quality objective;

[5] ADWG (NHMRC, 2011) 'health' water quality guideline; [6] ADWG (NHMRC, 2011) 'aesthetic' water quality guideline. ** Located outside of the potential zone of influence of Dendrobium Mine Area 3.

Table 18 and Table 19 show maximum concentrations of dissolved zinc at one site on the Cordeaux River (CR_S1) and maximum concentrations of total aluminium at two sites on the Cordeaux River in excess of the ANZECC WQO. However, the median concentrations for dissolved zinc and total aluminium fell below the ANZECC WQO at both sites. Similar observations are evident in the data for the Cordeaux River tributaries, although the median total aluminium concentrations recorded at CR31_S1 also exceeded the ANZECC WQO.

Maximum recorded total manganese concentrations exceeded the ADWG aesthetic WQO at all sites and the ADWG health WQO at CR31_S1. Median total manganese concentrations also exceeded the ADWG aesthetic WQO at CR_S1 and CR31_S1. Maximum recorded total iron concentrations exceeded the ADWG aesthetic WQO at all sites, with the median recorded total iron concentration exceeding the guidelines at CR31_S1.

The laboratory water quality records for pH are generally consistent with the field measurements, indicating slightly acidic conditions on the monitored Cordeaux River tributaries. Total nitrogen concentrations exceeded the HRC (1998) WQO of 0.7 mg/L at CR_S2 and CR31_S1, however, only two samples from each site have been analysed for total nitrogen to date. Maximum recordings of total phosphorus at CR_S2 and CR31_S1 exceeded the HRC (1998) WQO of 0.05 mg/L, although only one exceedance was recorded at CR_S2.

Water Quality Influences

Influences on water quality in Area 6 would be as per those described for Area 5 in Section 2.2.3.3. No major observable differences were noted in water quality concentrations reported in surface water systems located within or downstream of Dendrobium Mine Area 3 as opposed to surface water systems located outside of the potential zone of influence of Dendrobium Mine Area 3. For the majority of constituents, higher concentrations were reported in tributaries of Cordeaux River located outside of the potential zone of influence of Dendrobium Mine Area 3.

2.3 COASTAL UPLAND SWAMPS

2.3.1 Description and Occurrence Within Project Area

Coastal upland swamps are relatively common features of the Hawkesbury Sandstone terrain and tend to occur in the higher elevations and plateau areas of the catchment. These swamp types are endemic to the eastern part of the Sydney Basin of NSW and are listed as an endangered ecological community under the Commonwealth *Environment Protection and Biodiversity Conservation Act, 1999* (EPBC Act), and the NSW *Biodiversity Conservation Act, 2016*.

The upland swamps can be categorised into three geomorphological types: headwater swamps, valley infill swamps and hanging swamps (Appendix D of the EIS). Headwater swamps form near catchment divides within relatively low sloped areas of weathered sandstone. Valley infill swamps are located along the alignment of streams in areas of steeper topography while hanging swamps are found on steep valley sides. The predominant swamp types within the Project Area comprise headwater swamps and valley infill swamps.

The swamps typically form as perched sand deposits which are underlain by relatively low permeability Hawkesbury Sandstone beds. These beds act as an aquitard under the sand deposit forming a locally perched groundwater system (Heritage Computing, 2009 and NSW Planning Assessment Commission, 2009). Subsurface and surface flow from the outlet of the swamp contributes to the overall flow in the catchment.

There are 36 upland swamps located partially or entirely within the 35º angle of draw from the proposed longwalls panels and an additional 10 swamps that are located partially or entirely within the Project Area (based on the proposed underground mining area plus 600 m), as shown in Figure 8. Of the 46 swamps within the Project Area, 26 are partially or entirely located above the proposed longwalls and 20 swamps are located outside the immediate extents of the proposed longwalls (but are within the 600 m).

A summary of the characteristics of the swamps located within the 35º angle of draw, is provided in Table 20.

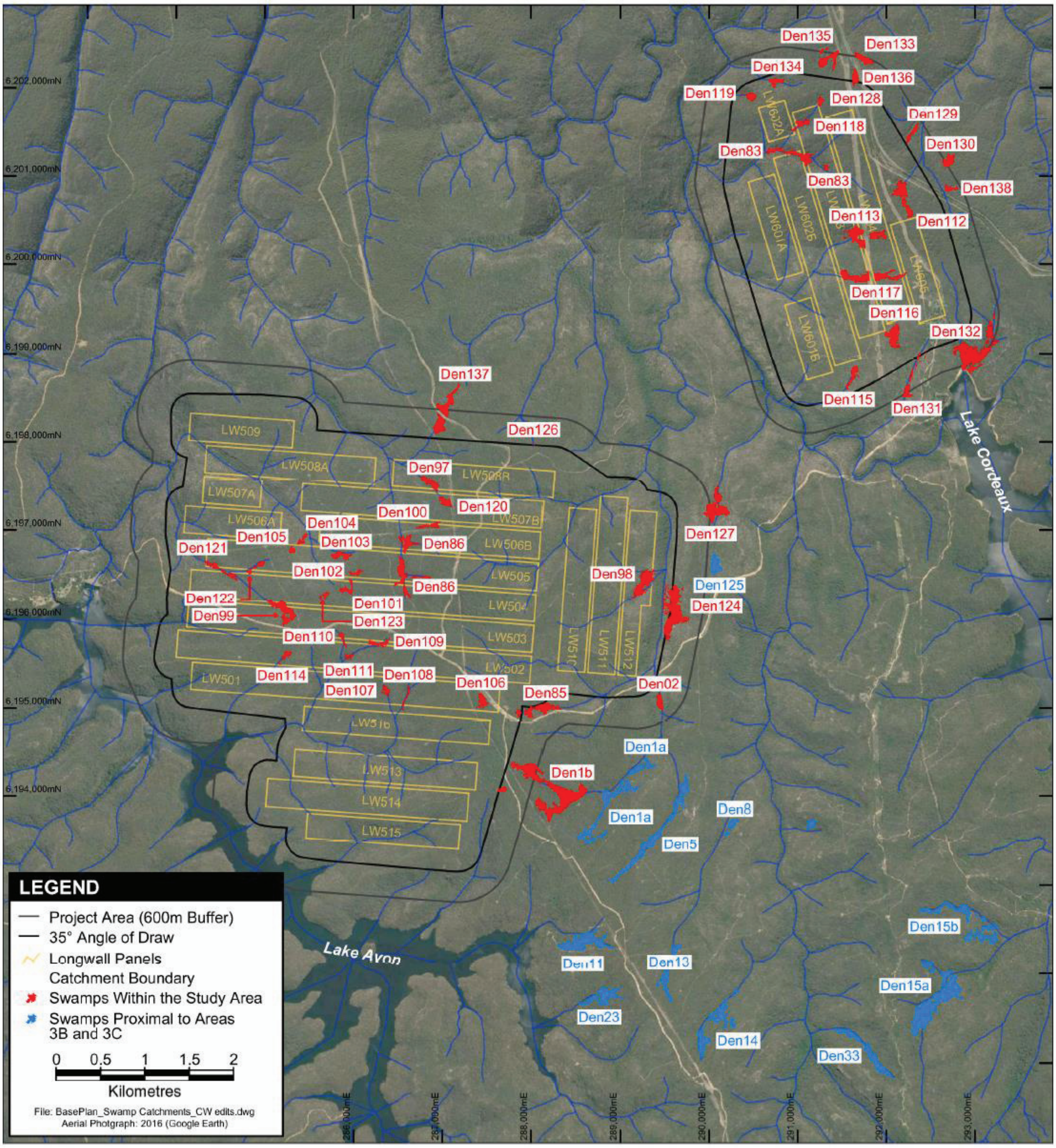

Figure 8 Swamp Locations and Catchment Boundaries

Table 20 Project Area Swamp Characteristics

Swamp Number	Swamp Type	Plan Area of Swamp (ha)	Area of Upslope Catchment (ha)*	Total Swamp Catchment Area (ha)**	Longitudinal Length of Swamp (km)	Average Surface Longitudinal Slope (%)
Den 83†	Headwater / Valley In-fill	2.8	25.3	149.7	0.8	5.4
Den 85†	Headwater	2.8	2.4	24.8	0.5	4.1
Den 86^	Headwater	4.8	19.9	85.0	0.9	3.9
Den 97†	Headwater	1.4	9.8	55.5	0.3	4.5
Den 98^	Valley In-fill	3.4	64.5	105.4	0.4	4.4
Den 99*	Headwater	3.2	5.3	23.9	0.4	4.2
Den 100†	Headwater	0.8	2.1	7.4	0.3	4.5
Den 101^	Headwater	0.8	12.3	23.8	0.2	5.2
Den 102+	Headwater	0.5	1.6	4.0	0.2	2.1
Den 103†	Headwater	1.2	6.1	19.9	0.3	6.3
Den 104	Valley In-fill	0.5	4.5	5.9	0.2	9.1
Den 105+	Headwater	0.4	2.1	3.6	0.1	16.3
Den 106^	Headwater	1.1	12.2	17.6	0.2	2.8
Den 107^	Headwater	0.5	6.9	11.0	0.2	9.6
Den 108^	Valley In-fill	0.4	28.1	45.9	0.3	3.4
Den 109†	Headwater	1.0	9.1	21.5	0.3	3.8
Den 110†	Headwater	0.5	6.2	12.5	0.2	6.4
Den 111^	Valley In-fill	0.4	44.0	49.5	0.2	10.7
Den 112†	Headwater	3.0	8.4	25.2	0.5	3.2
Den 113†	Headwater	3.6	11.0	37.9	0.5	3.9
Den 114^	Headwater	0.6	2.0	9.2	0.2	10.8
Den 115†	Headwater	1.2	1.6	11.7	0.3	5.1
Den 116†	Headwater	2.6	9.0	24.2	0.3	6.5
Den 117†	Headwater	4.3	8.9	40.4	0.7	3.9
Den 118^	Valley In-fill	1.0	17.8	28.1	0.3	3.9
Den 119^	Headwater	0.7	8.1	17.2	0.2	4.3
Den 120	Headwater	0.9	3.4	9.3	0.2	4.6
Den 121	Valley In-fill	1.2	55.5	78.9	0.4	5.9
Den 122	Headwater	0.6	3.3	10.2	0.2	9.1
Den 123	Headwater	0.4	5.3	9.1	0.1	5.8
Den 124	Valley In-fill	9.4	637.2	686.0	0.7	0.2
Den 128	Headwater	0.5	4.3	7.4	0.1	4.4
Den 131	Headwater	1.5	6.3	73.2	0.6	3.4
Den 134	Valley In-fill	0.9	13.4	15.2	0.2	9.2
Den 136	Headwater	1.0	13.5	18.0	0.2	2.3
Den 137	Headwater	1.8	0	1.8	0.2	1.0

+ Swamps monitored with piezometers in shallow groundwater bores.

^ Swamps monitored with piezometers in shallow groundwater bores and soil moisture probes.

† Swamps monitored with piezometers in shallow groundwater bores, soil moisture probes and adjacent Hawkesbury Sandstone groundwater level monitoring.

* External catchment area at the upstream boundary of the swamp.

** Total catchment area to the downstream boundary of the swamp.

2.3.2 Shallow Groundwater and Soil Moisture Monitoring

Groundwater monitoring bores and soil moisture probes were installed by South32 in 24 swamps in the Project Area, where sufficient depth of sediments allowed for the piezometer standpipe to be installed. The monitoring bores were typically constructed through the swamp sands to intersect the underlying Hawkesbury Sandstone bedrock.

Swamp groundwater level and soil moisture data was provided by South32 for the period June 2017 to February 2019 (approximately 20 months). The groundwater level and soil moisture data have been interpreted for a selection of swamps with plots provided in Appendix A.

Nested and clustered groundwater monitoring bores were also installed in the Hawkesbury Sandstone adjacent to 12 swamps in Area 5 and Area 6. The nested bores were equipped with sensors at four different depths, with the total depth of each bore between 70 and 75 m. The Hawkesbury Sandstone groundwater monitoring data was assessed in conjunction with the swamp shallow groundwater level data and the soil moisture data to ascertain connection between the swamp and the groundwater table.

Analysis of the soil moisture data enables an understanding of the dynamics of rainfall infiltration through the swamp profile. The wetting sequence of the soil moisture probes allows direct calculation of the wetting-front propagation velocity v (Dahan et al. 2008):

$$v = \Delta z / \Delta t \quad \text{Eq. 1}$$

Where Δz is the vertical distance between two adjacent probes and Δt is the time gap between the response to a change in water content.

Combining the calculated wetting-front propagation velocity (v) with the measured change in water content $\Delta\theta$ allows calculation of the downward flux q as follows:

$$q = v \times \Delta\theta \quad \text{Eq. 2}$$

Where $\Delta\theta$ is defined as the difference between the initial water content (θ_i) and final water content (θ_f) over the same time-step that v is estimated.

The soil moisture data has been analysed in conjunction with the shallow groundwater level data to gain an understanding of the infiltration dynamics of each swamp. Calculation of the vertical flux rate in six swamps during distinct rainfall events (following periods of little to no rainfall) was undertaken. Table 21 presents a summary of the findings.

Table 21 Swamp Infiltration Dynamics

Swamp	Type	Lithology	Description
Den 83	Headwater / Valley In-fill	86 – 144 cm saturated black peaty loam 144 – 172 cm black peaty sandy loam overlying pale unconsolidated sandy clay 172 – 202 cm pale course sand containing clay	Perched aquifer present at the beginning of the monitoring period with water level decline of 180 cm to the sensor level occurring over 6 months. The wetting front propagation occurs in a predominately sequential manner excepting at 60 cm depth where a layer of low water retention capacity is present resulting in rapid drainage. An average vertical flux rate of 0.3 cm/hr over the 120 cm profile was estimated based on assessment of three rainfall events (Chart A1 in Appendix A). Groundwater levels monitored in the Hawkesbury Sandstone varied between 21.9 and 22.2 m below ground level between May and August 2018, indicating that the swamp perched aquifer was not sustained by groundwater from the Hawkesbury Sandstone aquifer.
Den 85	Headwater	7 – 32 cm sandy clay, brown 32 – 93 cm sandy clay, light brown 93 – 233 cm mid-grained sand, clayey, light brown with orange mottles progressing to light grey at 170 cm	Perched aquifer present for 3.5 months at the beginning of the monitoring period before declining to the level of sensor (210 cm below ground level) over 6 months. Layer of low water retention capacity present at 70 – 80 cm. An average vertical flux rate of 0.1 – 0.2 cm/hr over the 120 cm profile was estimated based on assessment of two rainfall events (Chart A2 in Appendix A). Groundwater levels monitored in the Hawkesbury Sandstone were around 10.5 m below ground level between September 2017 and October 2018, indicating that the swamp perched aquifer was not sustained by groundwater from the Hawkesbury Sandstone aquifer.
Den 97	Headwater	54 – 117 cm dark brown clay with mottling progressing to light brown clay with orange mottling; 5 cm of basal sand at base	Perched aquifer present at the beginning of the monitoring period with water level decline of 100 cm over 4 months. Sustained saturated conditions at 90 cm depth for duration of monitoring period as evidenced by shallow groundwater level response to rainfall events in November and December 2018. An average vertical flux rate of 0.6 – 1.4 cm/hr over the 90 cm profile was estimated based on assessment of three rainfall events (Chart A3 in Appendix A). Groundwater levels monitored in the Hawkesbury Sandstone were around 10 m below ground level between July and September 2017, indicating that the swamp perched aquifer was not sustained by groundwater from the Hawkesbury Sandstone aquifer.
Den 98	Valley In-fill	53 – 72 cm dark brown soil transitioning to higher sand content at depth 72 – 103 cm coarse sand grains, sand content increasing with depth	Perched aquifer present at commencement of monitoring period, declining over 5 months to the level of the sensor (90 cm below ground level). Consistent drainage patterns observed throughout the swamp profile, with rapid wetting and drying cycles (Chart A4 in Appendix A).

Table 21 (Continued) Swamp Infiltration Dynamics

Swamp	Type	Lithology	Description
Den 100	Headwater	38 – 58 cm surface organic fines underlying clay loam and dense clay 58 – 116 cm dry clayey sand to fine grained sand at 116 cm	Perched aquifer present at commencement of monitoring period, declining over 3 months to the level of the sensor (103 cm below ground level). An average vertical flux rate of 0.1 cm/hr over the 90 cm profile was estimated based on assessment of one rainfall event (Chart A5 in Appendix A). Groundwater levels monitored in the Hawkesbury Sandstone varied between 10.6 m and 11.6 m below ground level between September 2017 and October 2018, indicating that the swamp perched aquifer was not sustained by groundwater from the Hawkesbury Sandstone aquifer.
Den 103	Headwater	27 – 50 cm sandy loam 50 – 75 cm light yellow uncohesive fine-grained sand with orange mottling	Low water retention capacity in upper profile, increasing with depth. Likely to drain predominately laterally with minimal deep drainage potential (Chart A6 in Appendix A). Groundwater levels monitored in the Hawkesbury Sandstone were around 9.2 m below ground level between November 2017 and January 2018, indicating that the swamp perched aquifer was not sustained by groundwater from the Hawkesbury Sandstone aquifer.
Den 106	Headwater	10 – 48 cm clay, dark brown progressing to light brown with depth 48 – 153 cm clay, light grey with orange mottles 153 – 163 cm sand, white, medium to large grain, clayey	Perched aquifer present at 60 cm depth for 2 months from commencement of monitoring period followed by water level decline to the sensor level (150 cm depth) occurring over 2 months. High water retention capacity throughout profile. Sustained saturated conditions at 150 cm as evidenced by water level rise following rainfall events (Chart A7 in Appendix A).
Den 107	Headwater	20 – 78 cm dark brown sandy clay transitioning to yellowish, clayey sand, uncohesive 78 – 99 cm clayey sand above white sand with diminishing clay content 99 – 111 cm white sand, orange mottling, non-cohesive	Low water retention capacity in upper profile, increasing with depth. Consistent drainage patterns observed throughout the swamp profile. Likely to drain predominately laterally with minimal deep drainage potential (Chart A8 in Appendix A).
Den 108	Valley In-fill	26 – 133 cm grey sandy clay, yellow mottling progressing to lighter grey sandy clay with and more cohesion with depth 133 – 153 cm lighter, sandy clay with increased sand content, less cohesive 153 – 225 cm saturated light grey clayey sand	Perched aquifer present at 140 cm depth at commencement of the monitoring period. Slow decline in water level to 210 cm depth over 11 months. Evidence of continued vertical drainage to 210 cm and sustained swamp moisture levels. An average vertical flux rate of 0.1 – 0.3 cm/hr in the top 120 cm profile was estimated based on assessment of three rainfall events (Chart A9 in Appendix A).

Table 21 (Continued) Swamp Infiltration Dynamics

Swamp	Type	Lithology	Description
Den 109	Headwater	15 – 40 cm brown clay, sandy 40 – 176 cm sand find grained, light brown progressing to light grey, clayey with depth 176 – 204 cm sand medium grained, orange mottled with sandstone pebbles	Perched aquifer present at commencement of monitoring period, declining by 185 cm over 4 months. Similar drainage patterns observed between 40 and 120 cm depth, consistent with lithology (Chart A10 in Appendix A). Groundwater levels monitored in the Hawkesbury Sandstone were around 8 m below ground level between June and August 2017, indicating that the swamp perched aquifer was not sustained by groundwater from the Hawkesbury Sandstone aquifer.
Den 110	Headwater	42 – 118 cm clay, light brown with fine sand (5%) progressing to sandy (50%) with depth 118 – 254 cm sand, fine to medium grained, clayey, yellow brown progressing to light grey with depth, orange mottles	Perched aquifer present at commencement of monitoring period, declining by 244 cm over 5 months. Four distinct drainage patterns observed over swamp profile with increased water retention capacity from 60 to 120 cm depth. An average vertical flux rate of 0.1 cm/hr in the top 120 cm profile was estimated based on assessment of one rainfall event (Chart A11 in Appendix A). Groundwater levels monitored in the Hawkesbury Sandstone varied between 19 and 19.5 m below ground level between July and November 2017, indicating that the swamp perched aquifer was not sustained by groundwater from the Hawkesbury Sandstone aquifer.
Den 111	Headwater	57 – 211 cm sand, mid grained with black carbonaceous material, clayey; progressing to medium to fine grained sand with depth 211 – 245 cm sandy clay, grey 245 – 254 cm clayey sand, grey, mid grained	Perched aquifer present at commencement of monitoring period, declining slowly by 200 cm over 11 months. Wetting front propagation occurs sequentially, with consistent drainage patterns throughout swamp profile. High water retention capacity throughout swamp profile (Chart A12 in Appendix A).
Den 112	Headwater	44 – 90 cm dark brown sandy soil grading to orange sandy clay 90 – 131.2 cm orange clayey sand 131.2 – 168.5 cm white sandy clay	Perched aquifer present at commencement of monitoring period, declining by 112 cm over 3.5 months. Wetting front propagation occurs sequentially with layer of lower water retention capacity present at 80 cm depth (Chart A13 in Appendix A). Groundwater levels monitored in the Hawkesbury Sandstone were around 10.5 m below ground level between October 2017 and November 2018, indicating that the swamp perched aquifer was not sustained by groundwater from the Hawkesbury Sandstone aquifer.
Den 113	Valley In-fill	52 – 84.5 cm soil becoming sandy and light in colour at depth 84.5 – 102.5 cm sandy grains becoming finer, greater clay matrix, orange mottles	Perched aquifer present for 2 months at commencement of monitoring period, declining by 89 cm over 2 months. Wetting front propagation occurs sequentially with consistent drainage patterns throughout swamp profile (Chart A14 in Appendix A). Groundwater levels monitored in the Hawkesbury Sandstone were around 7.7 m below ground level between May and July 2017, indicating that the swamp perched aquifer was not sustained by groundwater from the Hawkesbury Sandstone aquifer.

Table 21 (Continued) Swamp Infiltration Dynamics

Swamp	Type	Lithology	Description
Den 114	Headwater	29 – 50.5 cm dark brown sandy loam 50.5 – 105 cm cohesive fine yellow sand	Low water retention capacity throughout swamp profile. Likely drains predominately laterally at base (Chart A15 in Appendix A).
Den 115	Headwater	50.5 – 74 cm coarse sandy clay 74 – 142 cm coarse clayey sand	Perched aquifer present at commencement of monitoring period, declining by 70 cm over 1.5 months. Rapid wetting and drying patterns throughout swamp profile; low water retention capacity at 100 cm depth (Chart A16 in Appendix A). Groundwater levels monitored in the Hawkesbury Sandstone were around 37.1 m below ground level between October and December 2017, indicating that the swamp perched aquifer was not sustained by groundwater from the Hawkesbury Sandstone aquifer.
Den 116	Headwater	42 – 64.5 cm dark brown clay loam 64.5 – 165.5 cm light brown clayey coarse sand 165.5 – 178.5 cm white sandy clay to yellow coarse sand at depth	Perched aquifer present at commencement of monitoring period, declining by 140 cm over 5 months. Low water retention capacity at 80 cm depth, with consistent drainage patterns throughout the remainder of the swamp profile. An average vertical flux rate of 0.1 – 0.4 cm/hr in the top 120 cm profile was estimated based on assessment of three rainfall events (Chart A17 in Appendix A). Groundwater levels monitored in the Hawkesbury Sandstone were around 8.3 m below ground level between May and August 2018, indicating that the swamp perched aquifer was not sustained by groundwater from the Hawkesbury Sandstone aquifer.
Den 117	Headwater	30 – 88.8 cm organic fines overlying yellow/orange clayey sand 88.8 cm – 112 cm pale white sandy clay	Low water retention capacity throughout swamp profile. Likely drains predominately laterally at base (Chart A18 in Appendix A). Groundwater levels monitored in the Hawkesbury Sandstone were around 19 m below ground level between May and August 2018, indicating that the swamp perched aquifer was not sustained by groundwater from the Hawkesbury Sandstone aquifer.
Den 118	Valley In-fill	24.3 – 42.8 cm organic fines overlying orange clayey sand 42.8 – 99 cm orange clayey sand	Consistent drainage patterns observed throughout the swamp profile, with rapid wetting and drying cycles. An average vertical flux rate of 0.3 cm/hr in the top 90 cm profile was estimated based on assessment of two rainfall events (Chart A19 in Appendix A).
Den 119	Headwater	26 – 57 cm organic fines silty clay loam 57 – 78 cm coarse grained clayey sand	Low water retention capacity throughout swamp profile (Chart A20 in Appendix A).

Table 21 illustrates that a sustained perched aquifer was present within 14 swamps at the commencement of the monitoring period. Water levels then fell consistently in all swamps over a period of months to the base of each swamp as a result of low rainfall conditions. While some swamps recorded rapid wetting and drying sequences following rainfall events, only three headwater swamps recorded sustained saturated conditions at depth over the duration of the monitoring period. Five headwater swamps recorded low water retention capacity throughout the swamp profile for the duration of the monitoring period, with no sustained perched aquifer recorded.

Calculation of the vertical flux rate in seven swamps during distinct rainfall events (following periods of little to no rainfall) indicated similar flux rates in all swamps, varying between 0.1 – 0.4 cm/hr on average through the swamp profile. Vertical flux throughout the entire depth of the swamp profile was only recorded following rainfall events exceeding approximately 40 mm over one to two sequential days. Of note are the consistent flux rates reported for both headwater and valley in-fill swamps. An average vertical flux rate of 0.6 – 1.4 cm/hr over the 90 cm profile of Den 97 was estimated based on assessment of three rainfall events. The higher average vertical flux rate estimated for Den 97 is due to the higher water retention capacity of the clay swamp profile.

It is noteworthy that the recorded rainfall at the Project Area (SILO Data Drill for Area 5) from October 2017 to October 2018 was 576 mm compared with the long term annual average of approximately 1,220 mm (refer Section 2.1). It is likely that the swamps experience wetting and drying cycles with swamp water levels declining to low levels during prolonged low rainfall periods.

3.0 SURFACE FACILITY WATER MANAGEMENT

3.1 EXISTING WATER MANAGEMENT AT PIT TOP FACILITIES

The Dendrobium operation is comprised of the following key components:

- Surface Operations
  - Dendrobium Pit Top;
  - Kemira Valley Coal Loading Facility;
  - Dendrobium Coal Preparation Plant;
  - Ventilation Shafts;
- West Cliff Stage 3 Coal Wash Emplacement; and
- Underground Operations.

In addition, the Cordeaux Pit Top, which was used for personnel and material access, and coal clearance while the former Cordeaux Colliery was operating, currently functions as a storage facility and office space for South32 staff. The location of each area is shown in Figure 9.

3.1.1 Dendrobium Pit Top

The Dendrobium Pit Top water management infrastructure comprises a Pit Top sediment pond and water treatment facility, as illustrated in Figure 10. Potable water is supplied from the Sydney Water supply for use in the bathhouse and associated facilities, and for use in underground longwall mining equipment (it also forms a backup supply for other underground requirements). Effluent from the bathhouse and office facilities is separated into a greywater stream and a black water stream, with the greywater stream sent to the water treatment plant and the black water stream discharged to the Sydney Water sewer system. The water treatment plant enables greywater to be treated and recycled to the underground operations and surface facilities, thereby reducing the volume of potable water sourced from Sydney Water.

Runoff from upslope of the Dendrobium Pit Top area is diverted around the site. Runoff from the general Dendrobium Pit Top surface area and Portal Road, shown in Figure 10, is collected in the Pit Top sediment pond, where it is then pumped to the water treatment plant. During heavy rainfall, overflow from the sediment pond is discharged to the adjacent American Creek (LDP22). Recycled water from the water treatment plant is pumped into former underground workings, referred to as the Nebo workings, for storage. Water from the Nebo workings is recycled following dosing with sodium hypochlorite (for disinfection). A portion of this recycled water is pumped to the surface and a portion is sent to the Dendrobium Mine for underground operations use. Recycled water which is pumped to the surface at the Dendrobium Pit Top is used for Portal Road dust suppression, in a vehicle wash down bay and for general hose down and workshop purposes.

3.1.2 Kemira Valley Coal Loading Facility

The KVCLF site water management system includes two buffer dams and two sediment ponds, as shown in Figure 11. Upslope runoff and flow in two small creeks is diverted around and under the site via a system of upslope diversions and culverts. Stormwater runoff from the site is captured in the storages and used as the primary supply for the dust suppression system and for firefighting.

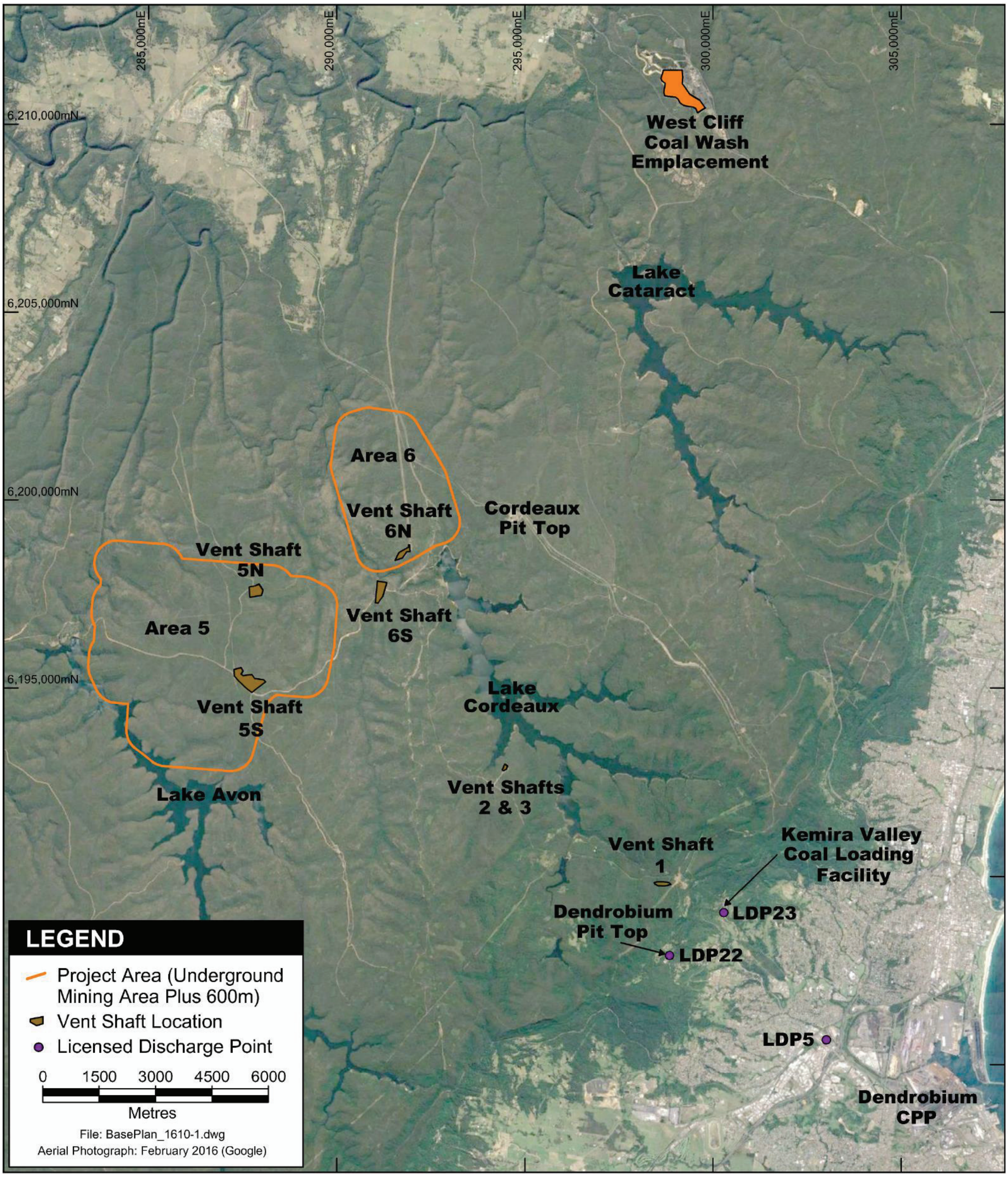

Figure 9 Site Layout Plan

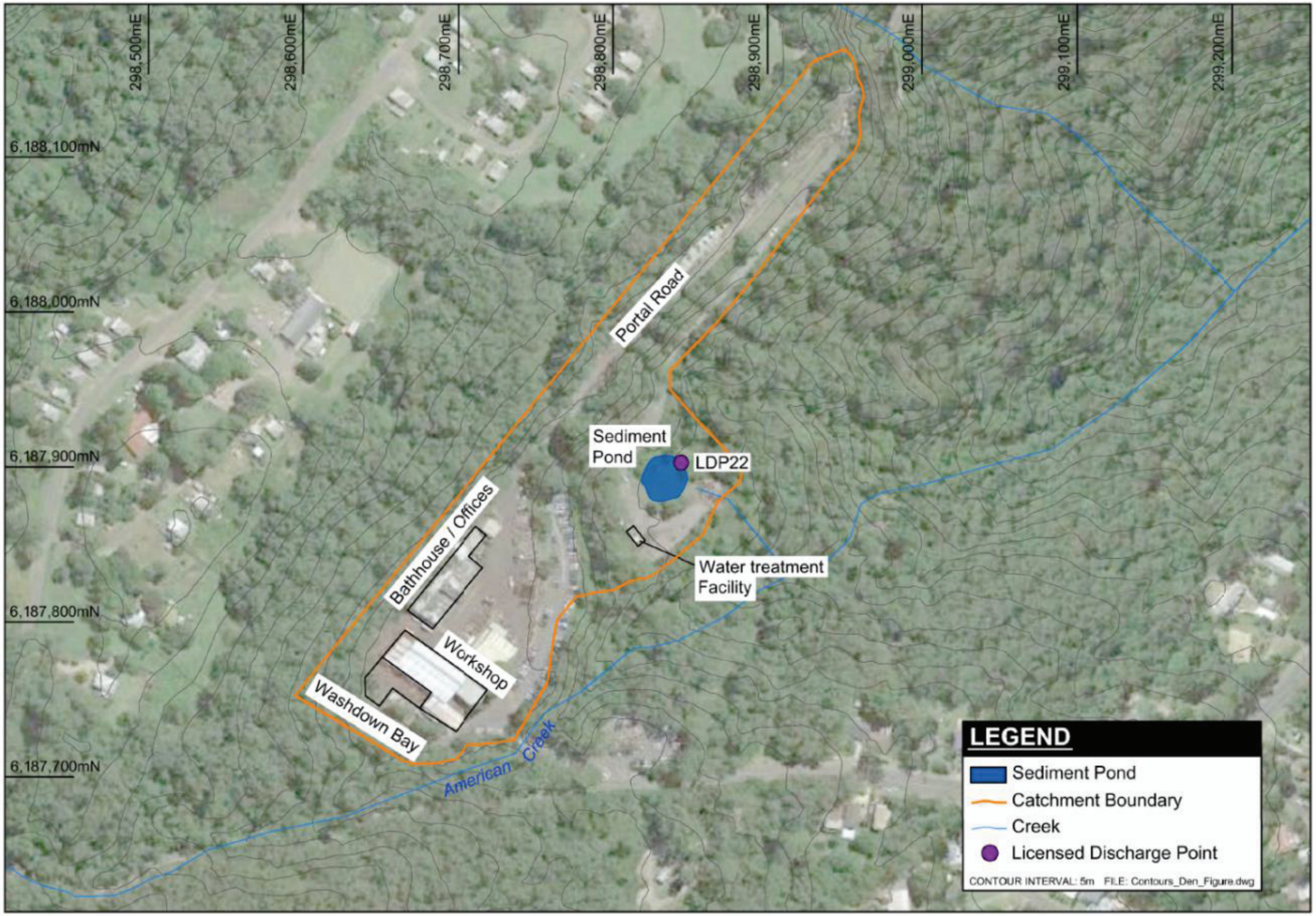

Figure 10 Dendrobium Pit Top Layout and Catchment Boundary

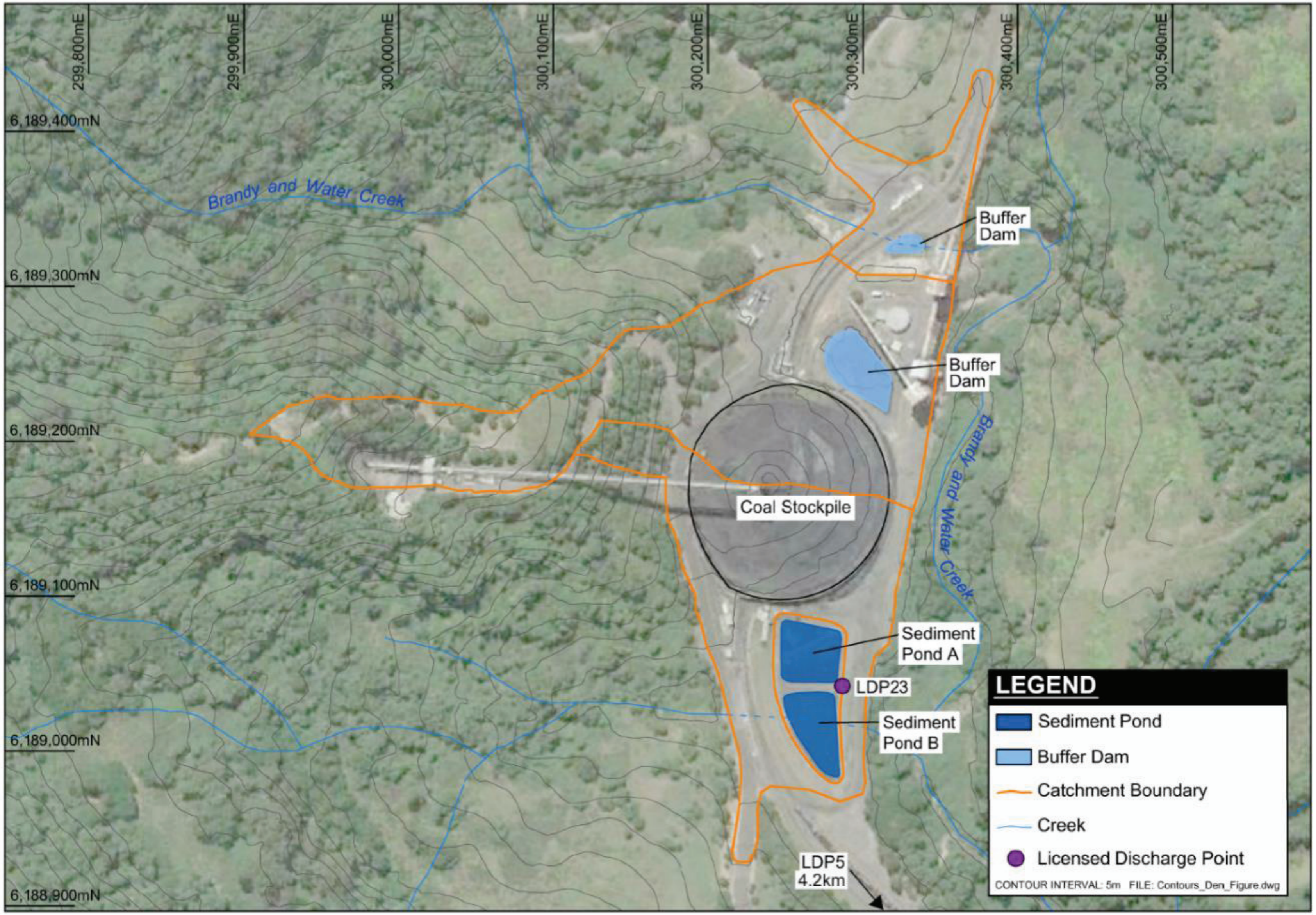

Figure 11 Kemira Valley Coal Loading Facility Layout and Catchment Boundary

The sediment ponds are periodically dosed with flocculant and discharged via a pipeline to LDP5 on Allans Creek located at Marley Place Unanderra, approximately 4.3 km to the south-east (refer Figure 9). During high rainfall events, the sediment ponds spill into nearby Brandy and Water Creek through LDP23 (Wet Weather Discharge). Brandy and Water Creek joins with American Creek which in turn flows into Allans Creek before discharging to Port Kembla Harbour.

The KVCLF does not use potable water sourced from Sydney Water as part of the operations. Recycled water pumped from the Nebo workings and Kemira workings underground storage is used for amenities, hose down purposes and as backup supply for the dust suppression system.

3.1.3 Dendrobium Coal Preparation Plant

The Dendrobium CPP uses recycled water from the nearby BlueScope Steel operation for use in the CPP and potable water sourced from Sydney Water for the administration building and associated amenities. Water used in the process is directed to collection pits and delivered back to the CPP.

3.1.4 West Cliff Stage 3 Coal Wash Emplacement

The water management infrastructure at the West Cliff Stage 3 Coal Wash Emplacement comprises clean water diversion drains and channels, site runoff collection drains and emplacement sediment ponds. Flows in upstream Brennans Creek are diverted around the emplacement area via a diversion channel. Upslope runoff from valley sides are captured in diversion drains and diverted to the Brennans Creek diversion channel. Sediment ponds are utilised to capture and treat runoff from the active emplacement areas.

3.1.5 Ventilation Shafts

The No. 1 Ventilation Shaft has been removed and the site has been revegetated, with runoff flowing freely to the surrounding landscape. The No. 2 and No. 3 Ventilation Shaft sites have a number of sediment ponds which are utilised to capture site runoff. The sediment ponds are designed to enable collection of sediment from site runoff prior to discharge via underflow drainage or overflow spillways.

3.1.6 Dendrobium Mine Underground Operations

The Dendrobium Mine underground operations use a combination of potable water from Sydney Water and recycled water from the Nebo workings. Excess water that accumulates in the underground operations, including groundwater inflow, is directed to the Nebo workings and/or an additional area of former underground workings, known as the Kemira workings, for storage and recycling as described above, or on-pumping to the Kemira Valley storage tank. Water is discharged from the storage tank to LDP5 via a 7 km pipeline. The Dendrobium underground operations have historically operated with a net water excess and therefore significant discharge occurs to the Kemira Valley storage tank and LDP5 (refer also Section 3.3).

3.1.7 Cordeaux Pit Top

The surface facilities at the Cordeaux Pit Top have been designed to prevent site runoff from the site entering WaterNSW land, as illustrated in Figure 12. Runoff from hardstand areas is directed to a holding lagoon. Water from the holding lagoon is transferred by pump to the upper level mine water holding lagoons for settlement. The water is then transferred to former underground mine workings via a gravity feed pipeline. This arrangement negates the need for surface discharge.

Catchment runoff from other areas at the Cordeaux Pit Top (e.g. sealed employee car parking areas) reports to a sand filter lagoon and leaves site via a sand filter underflow discharge point. Potable water is brought to the Cordeaux Pit Top by road tanker as required.

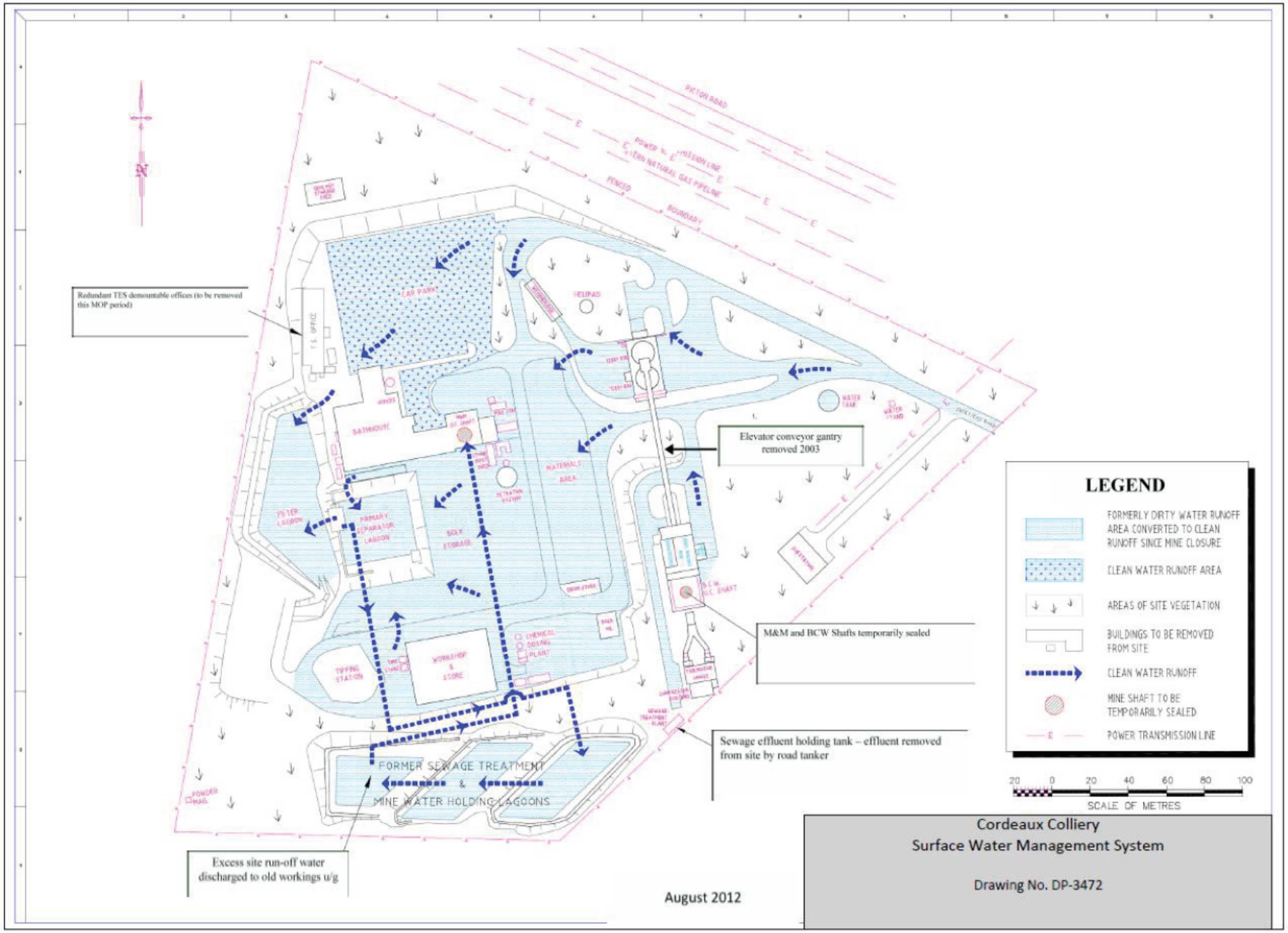

Figure 12 Cordeaux Pit Top Surface Water Management System (Source: South32, 2017)

3.2 PROPOSED CHANGES TO WATER MANAGEMENT

The existing and approved water management systems at the Dendrobium Pit Top, Dendrobium CPP, Cordeaux Pit Top, West Cliff Stage 3 Coal Wash Emplacement, KVCLF and ventilation shafts 1, 2 and 3 would continue to be used for the Project.

Accumulated water from the Project's underground workings would continue to be directed into the Nebo workings and/or the Kemira workings for storage, with excess water discharged via the KVCLF and existing LDP5 to Allans Creek. The water management systems associated with existing approved ventilation shafts 1, 2 and 3 would also continue to be used.

The key changes to water management for the Project are associated with:

- management of surface runoff associated with new ventilation shafts in Areas 5 and 6;
- increase in predicted groundwater inflows to underground workings, which are required to be managed as part of the Project water management system; and
- duplication of the existing LDP5 pipeline to accommodate the predicted increase in discharge rate.

3.2.1 Area 5 and 6 Ventilation Shafts

The capacities of sediment dams required to capture runoff from each of the four proposed ventilation shaft areas, shown in Figure 9, were calculated using Landcom (2004) and DECC (2008) guidelines, assuming:

- Type F (fine) sediment retention basin;
- sediment dams to be in place for more than three years;
- a sensitive receiving environment and therefore settling zone capacity should be adequate to capture a 95^{th} percentile 5 day duration rainfall event, which was calculated as 85.4 mm (average of values for Wollongong and Mittagong in Table 6.3a of Landcom [2004]);
- a volumetric runoff coefficient of 0.79 assuming soil hydrologic group D – Table F2 of Landcom (2004); and
- allowance for sediment storage zone capacity equal to 50% of the above calculated settling zone capacity.

The catchment areas of the proposed sediment dams were assumed to be the maximum cleared area of the vent shaft areas provided by South32. A summary of these catchment areas and resulting total required capacity of each sediment dam is provided in Table 22.

Table 22 Summary of Proposed Vent Shaft Area Sediment Dams

Description	Area 5 North	Area 5 South	Area 6 North	Area 6 South
Estimated Cleared Catchment Area (ha)	3.0	7.5	4.0	4.0
Settling Zone Capacity (m^3)	2,024	5,060	2,699	2,699
Sediment Zone Capacity (m^3)	1,012	2,530	1,349	1,349
Total Capacity (ML)	3.0	7.6	4.0	4.0

Water quality modelling has been undertaken to assess the treatment capacity of the ventilation shaft sediment dams, as described in Section 6.0.

3.2.2 Predicted Groundwater Inflows

Predicted groundwater inflow over the life of the Project is shown in Figure 13 for each Dendrobium mine area, including Project Areas 5 and 6 (Appendix B of the EIS).

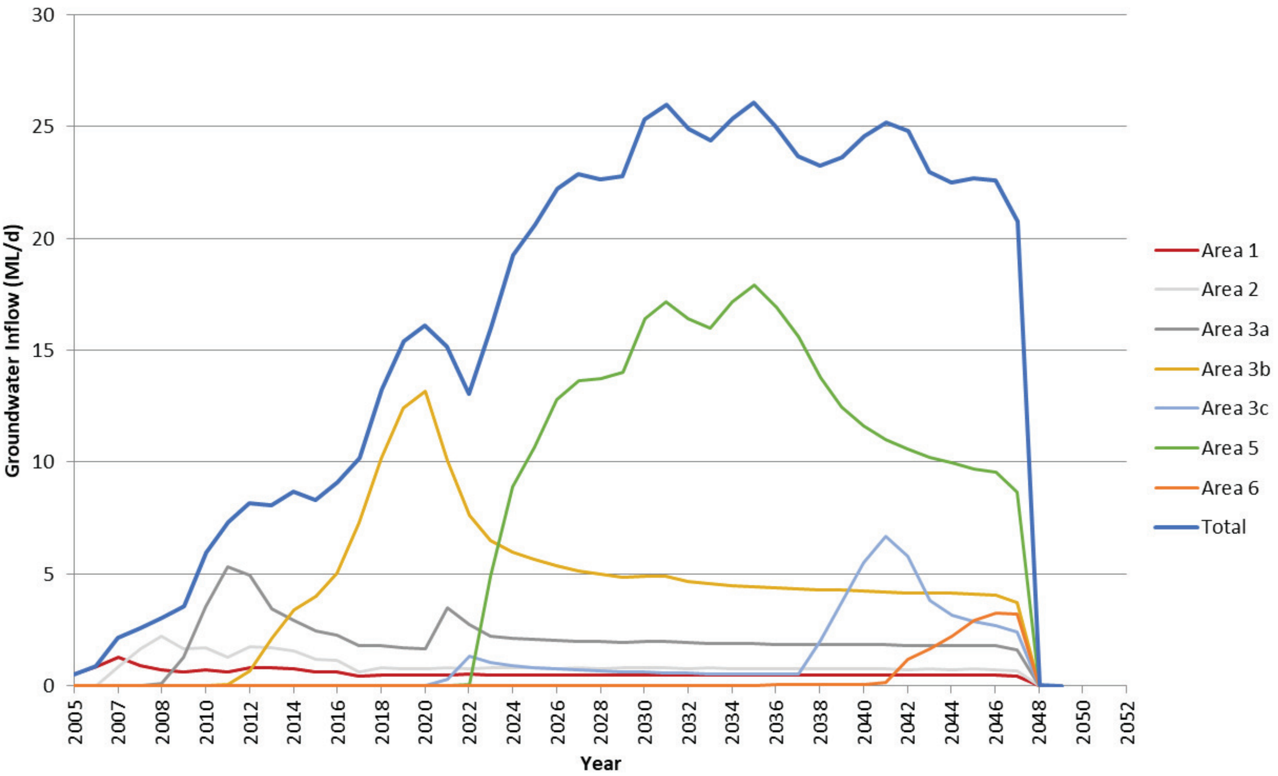

Figure 13 Predicted Underground Groundwater Inflow

Groundwater inflow rates for the Dendrobium Mine (all areas, including Project Area 5 and 6) are expected to peak in 2036 at a rate of 26.1 ML/d. The groundwater inflow rate from Areas 5 and 6 is expected to peak at 17.9 ML/d in 2036 for Area 5 and 3.3 ML/d in 2047 for Area 6. Ongoing inflows to existing and former underground mining areas will also need to continue to be managed as part of the Project water management system.

3.3 SIMULATED PERFORMANCE OF PROPOSED WATER MANAGEMENT SYSTEM

3.3.1 Water Balance Model Approach

A water balance model was developed for the Dendrobium Mine water management system and has been used to simulate the Project life: January 2020 to December 2048 (i.e. 29 years). The water balance model simulates changes in stored volumes of water in all storages in response to inflows, outflows and internal pumped transfers. The water management system simulated in the water balance model is illustrated in schematic form in Figure 14. For each storage, the model simulates:

Change in Storage = Inflow – Outflow

Where:

Inflow includes rainfall runoff (for surface storages), groundwater inflow to the former and proposed underground workings (including the Nebo and Kemira underground water storages), pumped inflow from other storages and supply from Sydney Water; and

Outflow includes evaporation, demand losses, licensed discharge and licensed overflows.

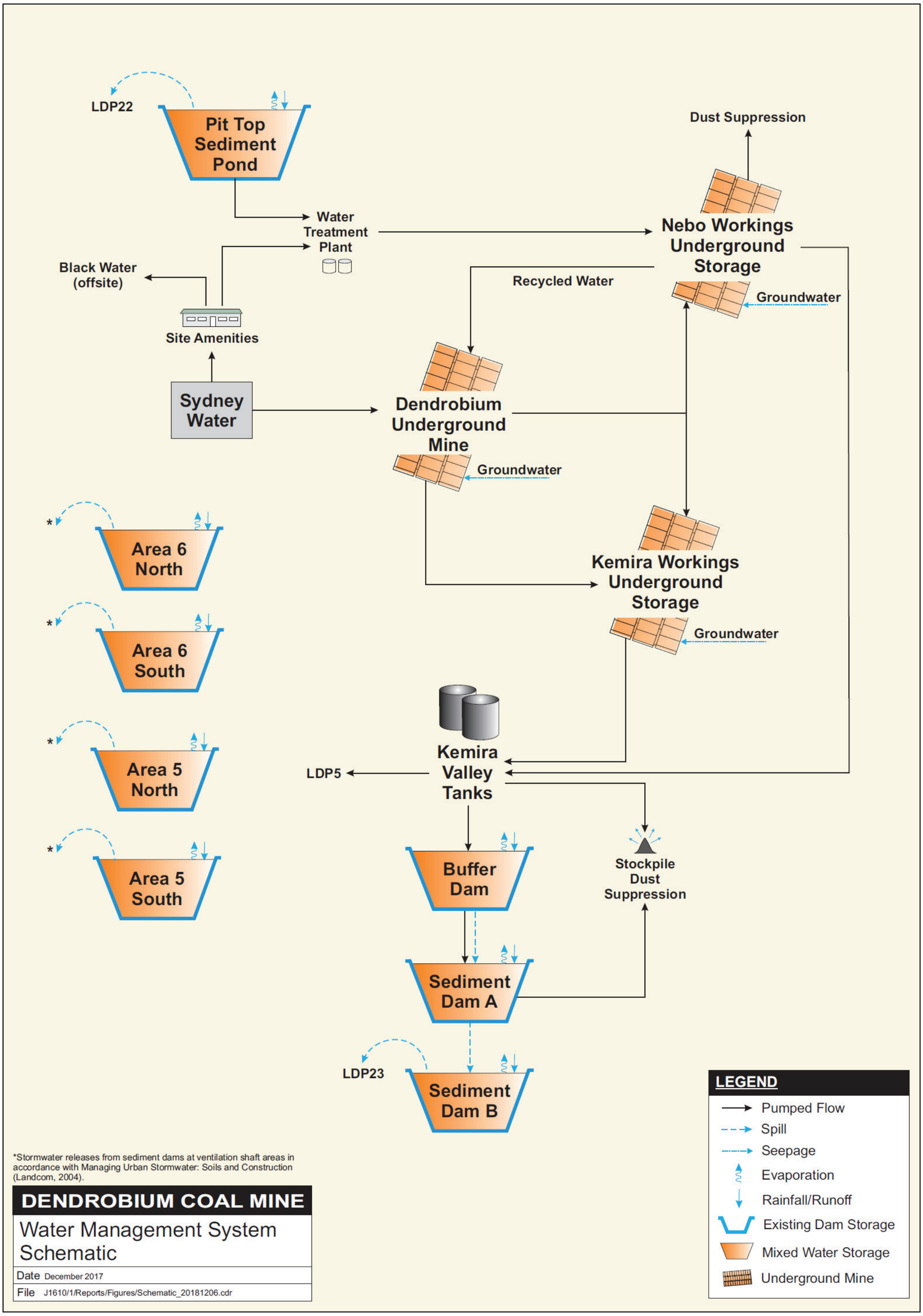

Figure 14 Water Management Schematic

The model was developed using the GoldSim® simulation package. The model simulates 129, 29 year "realizations", derived using a climatic data set from 1889 to 2017. The first realization uses climatic data from 1889-1917, the second 1890-1918, the third 1891-1919, and so on[5]. This method effectively includes all historical climatic events in the water balance model, including high, low and median rainfall periods. The results from all realizations were used to generate water storage volume estimates and other relevant water balance statistics. Results can be extracted for any water balance component for any time period in the simulation and statistical analyses undertaken.

3.3.2 Model Input and Assumptions

The key model input and assumptions are documented in the following sections.

3.3.2.1 Rainfall and Evaporation Data

A record of 129 years of rainfall data (1889 - 2017 inclusive) was obtained for the site location from SILO Data Drill (refer Section 2.1.2). A 129 year pan evaporation data set for the site was also obtained from this source.

3.3.2.2 Catchment Areas

Catchment areas were derived for the Dendrobium Pit Top and KVCLF water storages from 1 m interval topographic contour data supplied by South32 as well as information regarding upslope diversions. Figure 10 and Figure 11 show the contours and assumed catchment boundaries, while Table 23 lists the catchment areas adopted in the water balance model.

Table 23 Modelled Catchment Areas

Storage	Total Catchment Area (ha)
Dendrobium Pit Top sediment pond	48.4
Kemira Valley sediment ponds	25.5
Kemira Valley buffer dams	43.4

The catchment areas were split into different sub-catchment types, as defined for rainfall-runoff modelling. Sub-catchments were defined on the basis of vegetation coverage and surface type and derived from Google Earth aerial imagery. Sub-catchment types included in the model were: hardstand (i.e. roofs, paved areas, etc.), natural surface and stockpile areas.

3.3.2.3 Rainfall Runoff Modelling

The water balance model simulates rainfall-runoff from the different sub-catchment types. For water storages, direct rainfall on the water surface was simulated. For other sub-catchments, rainfall runoff was simulated using the Australian Water Balance Model (AWBM) – Boughton (2004). The AWBM is a catchment-scale water balance model that estimates runoff from rainfall and evaporation. AWBM parameters for each sub-catchment were adopted based on experience with similar projects.

5 Additional climate data after 2017 was generated by "wrapping" data from the beginning of the climate data set to after 2017. In this way, data from the beginning and end of the data set was used in the same number of realizations as all other data.

3.3.2.4 Evaporation from Water Storages

Level-volume-area relationships for each modelled storage were estimated from contour plans and storage volume data stated in the 2017 Annual Review (South32, 2017). The water surface area of each storage was multiplied by daily evaporation and by a pan factor[6] to calculate an evaporation volume. Monthly pan factors for Nowra (approximately 60 km south-west of the site) and Sydney Airport (approximately 60 km north-east of the site), obtained from McMahon et al. (2013), were used to estimate pan factors for the site - these are listed in Table 24.

Table 24 Adopted Monthly Pan Evaporation Factors

Month:	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Pan Factor:	0.842	0.856	0.827	0.812	0.766	0.709	0.734	0.74	0.732	0.773	0.788	0.848

3.3.2.5 Storage Capacities and Initial Stored Water Volumes

Storage capacities, specified in South32 (2017), and the assumed initial stored water volume as at the model start date (1/1/2020) for each modelled water storage are summarised in Table 25.

Table 25 Storage Capacity and Initial Stored Water Volumes

Storage Name	Capacity (ML)	Initial Stored Volume (ML)
Dendrobium Pit Top sediment pond	1.1	0.5
Kemira Valley sediment ponds	15	7.5
Kemira Valley buffer dams	4.9	2.5
Nebo underground workings	167	125
Kemira underground workings	200	150

3.3.2.6 Underground Workings Groundwater Inflow Rates

Groundwater inflow rates to the underground workings were provided by HydroSimulations (Appendix B of the EIS) for the historic and approved mine areas (Areas 1, 2, 3A, 3B, 3C) and the Project mine areas (Areas 5 and 6) as shown in Figure 13.

Groundwater inflow estimates for the former Nebo and Kemira underground workings were also provided by HydroSimulations (Appendix B of the EIS): constant rates of 0.2 ML/d and 0.02 ML/d respectively.

3.3.2.7 Sydney Water Demand

A constant rate of 89 kL/d was assumed to be supplied from Sydney Water mains to the bathhouse at Dendrobium Pit Top. This rate was calculated based on historical records of total Sydney Water supply and supply to the mine. A constant rate of 24 kL/d was assumed to be supplied from Sydney Water mains to the mine based on long-term average recorded data provided by South32.

3.3.2.8 Dust Suppression Demand

Dust suppression demands for the Portal Road at Dendrobium and the stockpile area at Kemira Valley were calculated in the model as the difference between daily evaporation and rainfall multiplied by the respective areas.

6 A pan factor is a multiplier (usually less than one) used to convert monitored pan evaporation data to estimates of open water evaporation.

3.3.2.9 Pit Top Water Treatment Plant

The supply to the Pit Top water treatment plant was simulated as the sum of the greywater from the bathhouse and the pumped rate from the Pit Top sediment pond. The rate of greywater from the bathhouse was assumed to be 60% of the total bathhouse supply rate (NSW Department of Water & Energy, 2008). The remaining 40% was assumed discharged to sewerage. A pump rate of 22.5 L/s from the sediment pond to the water treatment plant was adopted based on the existing pump and delivery pipeline specifications (as advised by South32).

3.3.2.10 Underground Demand

The inflow to the underground mine was simulated within the water balance model as comprising the recycled water demand, Sydney Water supply and groundwater inflow. Water consumed in the underground operations was simulated as the net groundwater entrained in the ROM coal and the net moisture lost in air ventilation. An underground recycled water demand rate of 971 kL/d was assumed based on long-term average recorded data provided by South32. A constant rate of 24 kL/d was assumed to be supplied from Sydney Water mains to the mine based on long-term average recorded data provided by South32. The net moisture lost in air ventilation was averaged from long-term recorded data as 131.8 kL/d.

Net groundwater entrained in coal was calculated based on the total ROM coal tonnage multiplied by the average ROM moisture content (9.16% w/w based on averaged recorded data) minus the in-situ moisture content (2.2% based on estimates for Area 5 and 6 as advised by South32). Figure 15 presents a comparison of the annual ROM coal tonnage (as provided by South32) and the calculated net water entrainment.

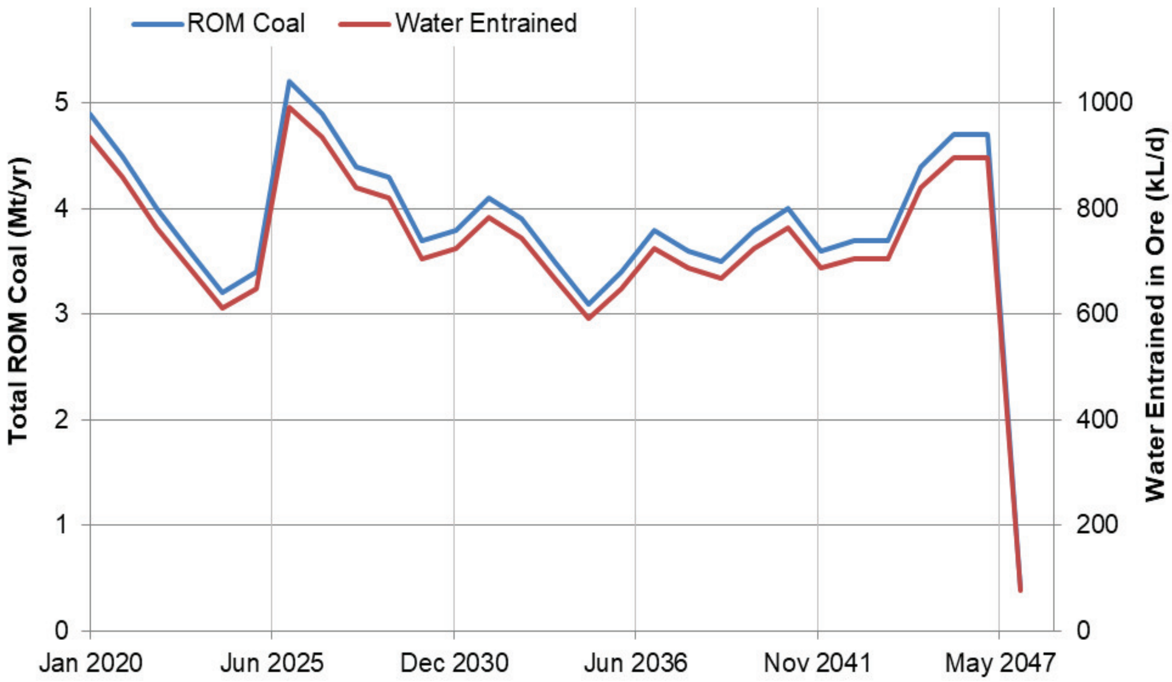

Figure 15 Total ROM Coal Tonnage and Water Entrained in Ore

3.3.2.11 Kemira Valley Pump Rates

A pump rate of 12 L/s from the Kemira Valley buffer dams to the sediment ponds was adopted based on the pump and delivery pipeline specifications provided by South32.

3.3.3 Results of Model Simulations

The following sections present key results of the Dendrobium Mine water balance model.

3.3.3.1 Overall Site Water Balance

Table 26 summarises the average water balance (averaged over all realizations and the 29 year simulation period).

Table 26 Average Water Balance

Inflows	Average (ML/year)
Rainfall runoff	95
Groundwater	8,038
Sydney Water supply	41
TOTAL	**8,174**
Outflows	**Average (ML/year)**
Evaporation	5
Blackwater to sewer	13
Water entrained in ore	268
Underground ventilation net loss	48
Portal Road dust suppression	5
Kemira Valley dust suppression	16
Pit Top Sediment Pond overflow to LDP22	1
Kemira Valley Sediment Pond overflow to LDP23	42
Kemira Valley Tank Discharge to LDP5	7,772
TOTAL	**8,170**

Table 26 illustrates that groundwater contributes the majority of system inflows while release via LDP5 dominates system outflows. It is understood that South32 is in the process of investigating beneficial reuse options for excess water.

3.3.3.2 Licensed Overflow/Discharge

Predicted annual average licensed discharge and overflow volumes, for the 99th percentile, 95th percentile, 50th percentile and 5th percentile, are presented in Figure 16 for Kemira Valley Coal Loading Facility and Dendrobium Pit Top. The annual average volumes have been calculated from the predicted discharge and overflow volumes for all 129 of the 29 year "realizations" simulated.

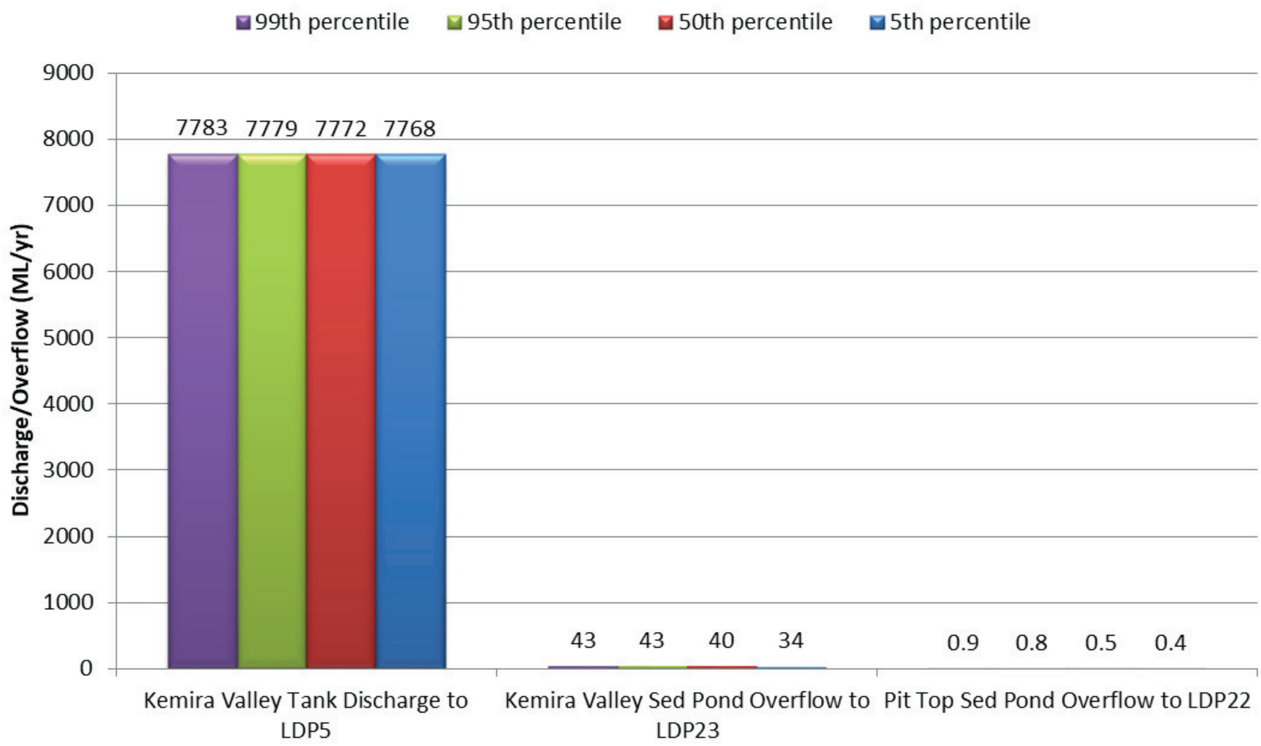

Figure 16 Simulated Licensed Discharge Volumes from Kemira Valley and Dendrobium Pit Top

Figure 16 shows that the simulated annual volume of discharge from the Kemira Valley tank to LDP5 varies over a very small range because it is dominated by predicted groundwater inflow to the underground, with little change as a result of catchment runoff.

Simulated overflow from the Kemira Valley sediment pond to LDP23 ranges between 34 ML/year (5th percentile) to 43 ML/year (99th percentile) while simulated overflow from the Pit Top sediment pond to LDP22 ranges between 0.4 ML/year (5th percentile) to 0.9 ML/year (99th percentile). As the Project involves small changes to the site layout and water management strategy for the KVCLF and Dendrobium Pit Top, overflow volumes to LDP22 and LDP23 are not expected to increase as a result of the Project.

Figure 17 presents the predicted daily discharge rates to LDP5 based on the median climatic sequence.

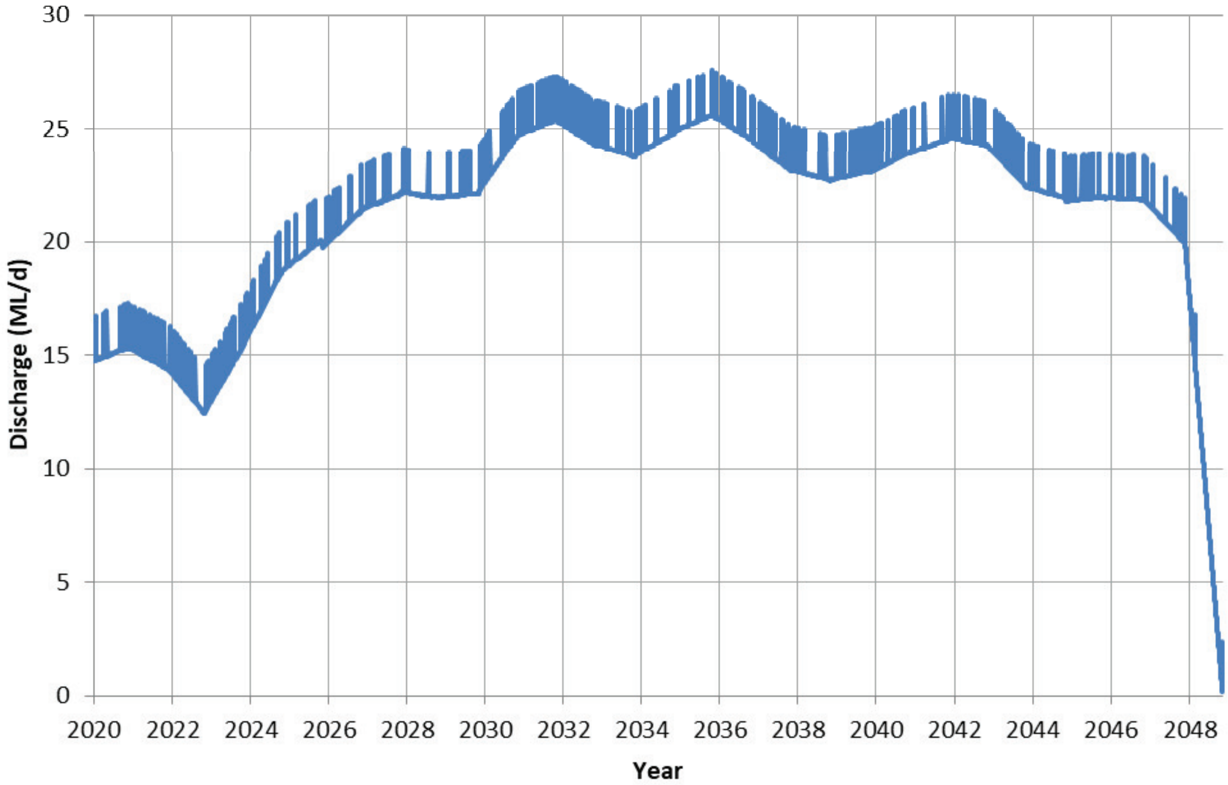

Figure 17 Predicted Daily Discharge to LDP5 for Median Climatic Sequence

Figure 17 shows that the daily discharge rate to LDP5, based on median climatic conditions, is predicted to peak at 27.6 ML/d in December 2035. This compares with an average 6.5 ML/d with a peak of 9.2 ML/d discharge rate obtained from South32 records for the period from May 2014 to September 2018.

Predicted annual average overflow volumes, for the 99th percentile, 95th percentile, 50th percentile and 5th percentile, are presented in Figure 18 for the ventilation shaft sediment ponds.

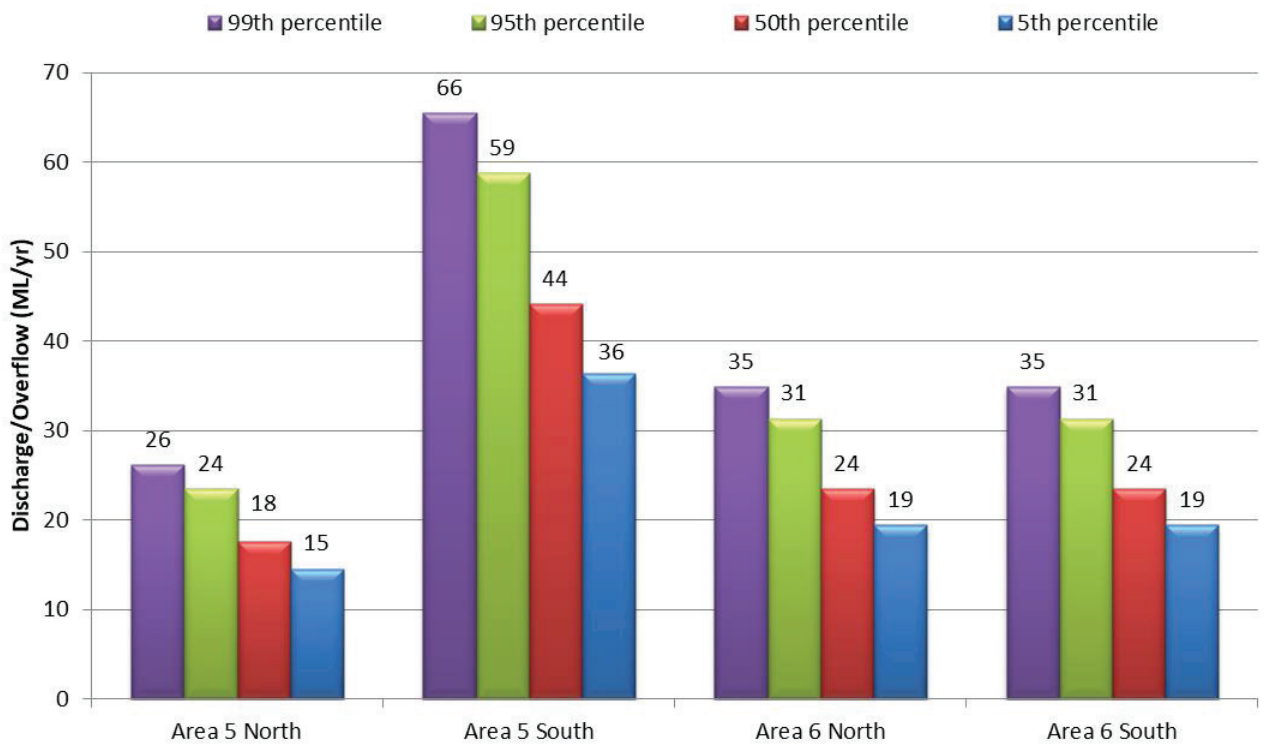

Figure 18 Simulated Overflow Volumes from Ventilation Shaft Sediment Ponds

Figure 18 shows that Area 5 North ventilation shaft sediment pond has a predicted median overflow rate of 18 ML/year while the Area 5 South ventilation shaft sediment pond has a predicted median overflow at rate of 44 ML/year. Both of the ventilation shaft sediment ponds in Area 6 have a predicted median overflow rate of 24 ML/year.

3.3.3.3 Water Supply Reliability

The model results indicate that there is sufficient water supply to meet the Project water demands based on the results of the simulated 129 climatic sequences.

3.3.4 Implications for Water Management of Surface Facilities

For the existing operations, an average of 2,378 ML/year has been recorded as discharged to LDP5 based on flow meter records from May 2014 to September 2018. The model simulations indicate that an average of 7,772 ML/year is the estimated discharge to LDP5 for the Project from the Kemira Valley tank. This equates to an estimated additional 5,330 ML/year discharge to LDP5 from the Kemira Valley tank on average over the Project life.

The existing pipeline capacity for discharge to LDP5 is approximately 10 ML/d (as advised by South32). Based on a maximum rate of 27.6 ML/d predicted to be discharged to LDP5 under median climatic conditions, an additional pipeline with a nominal diameter of 400 mm will be required to be installed for the Project (assuming a polyethylene pipeline at 1% average slope, following the route of the existing pipeline).

3.3.5 Implications for Water Quality at Licenced Discharge Points

Water quality monitoring is undertaken on natural watercourses upstream and downstream of the Dendrobium Pit Top and KVCLF. The water quality monitoring indicates that the water management system in operation at the Kemira Valley Coal Loading Facility is effective, with minimal influence on the surrounding Brandy and Water Creek (South32, 2017).

Monitoring undertaken upstream and downstream of the Dendrobium Pit Top indicates that there is no significant variation in total suspended solids, oil and grease levels or pH. Average water quality remains below the ANZECC guideline trigger values for slightly to moderately disturbed ecosystems in South-East Australia.

As the Project involves negligible changes to the site layout and water management strategy for the KVCLF and Dendrobium Pit Top, and overflow volumes to LDP22 and LDP23 are not expected to increase as a result of the Project, it is envisaged that changes in water quality downstream of the Dendrobium Pit Top and KVCLF will be negligible.

The outcomes of the water balance assessment detailed above, indicates that the discharge to LDP5 will be dominated by groundwater inflow to Area 5 and Area 6. Table 27 presents the licence limits for LDP5 (Environment Protection Licence [EPL] 3241), a summary of the water quality monitoring results for LDP5 for 2017 (South32, 2017) and the predicted groundwater quality for Area 5 and Area 6.

Table 27 LDP5 Water Quality and Predicted Area 5 and Area 6 Groundwater Quality

Parameter**	Licence Limit	Monitored Water Quality at LDP5			Predicted Groundwater quality*		
		Min	Average	Max	Min	Average	Max
Arsenic (mg/L)	1.3	0.013	0.015	0.018	0.007	0.008	0.018
Copper (mg/L)	0.08	<0.001	0.001	0.003	<0.001	0.002	0.007
Nickel (mg/L)	5	0.007	0.009	0.015	<0.001	0.016	0.235
Oil and Grease (mg/L)	10	<5	5	7	-	-	-
Total Suspended Solids (mg/L)	30	<5	6	10	-	-	-
pH	6.5 – 9.0	7.7	8.0	8.5	6.8	7.4	8.6
Zinc (mg/L)	0.4	0.017	0.025	0.042	0.004	0.02	0.103

* Source: HydroSimulations (Appendix B of the EIS)

** Licence limits and concentrations of metals are assumed to represent total, as opposed to dissolved, concentrations, however, EPL 3241 does not explicitly state total metals.

Table 27 illustrates that the monitored water quality at LDP5 has been within the licence limits for all parameters. The groundwater quality estimates for Area 5 and Area 6 are within the range of existing concentrations measured at LDP5 for arsenic, copper, nickel, zinc and pH. Therefore, it is unlikely that the proposed increase in discharge to LDP5 will result in a noticeable difference in water quality.

The increase in flow rate discharged to LDP5 has the potential to cause instability in the bed and banks of Allans Creek. However, 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 and downstream experiences a tidal/estuarine environment. Therefore, the impacts of the additional flow on the stability of Allans Creek are likely to be negligible.

3.4 SUMMARY

The following provides a summary of the existing and proposed surface facility water management for the Dendrobium Mine:

- Existing water management infrastructure at the Dendrobium Mine operates satisfactorily and in accordance with EPL conditions.
- The existing water management systems and infrastructure would continue to operate for the Project at the Dendrobium Pit Top, KVCLF, Dendrobium CPP, Cordeaux Pit Top and West Cliff Stage 3 Coal Wash Emplacement for the Project. In addition, no material change in existing water demand or supply reliability is expected to be required for the Project, when compared to the current operations.
- The key changes to water management for the Project are associated with the new Area 5 and 6 ventilation shafts and increased groundwater inflow predictions.
- Water management infrastructure (i.e. sediment dams) for the disturbance areas associated with the Area 5 and 6 ventilation shafts would be designed and operated in accordance with Landcom (2004) and DECC (2008) to manage pollution to the receiving environment.
- Increased groundwater inflows would continue to be managed in accordance with current EPL conditions (i.e. discharge via LDP5), however, additional infrastructure would be required to accommodate the expected increased controlled release volumes. It is understood that South32 is also investigating options for the beneficial reuse of this excess water.
- The increase in discharge to LDP5 is unlikely to result in an exceedance of the EPL water quality limits or impacts on Allans Creek.
- Sufficient water supply is predicted in all Project years.

4.0 EFFECTS OF LONGWALL MINING ON SURFACE WATER RESOURCES

Longwall mining results in subsidence movements at the surface above and adjacent to longwall mining activities. These movements and the resulting effects (e.g. fractures) at the surface have been described in the Subsidence Assessment (Appendix A of the EIS). The types of subsidence effects that can cause impacts and environmental consequences to surface water resources have been identified as follows:

- Vertical (downward) and horizontal displacements of the surface which are referred to as **vertical subsidence** and **horizontal subsidence**.
- Changes in surface slope, which is referred to as **tilt**.
- The rate of change of tilt, which is referred to as **curvature**.
- Changes in the horizontal distance between two points on the surface which is referred to as **tensile strain** if the distance between the two points increases and **compressive strain** if the distance between the two points decreases.
- **Horizontal shear deformation** across monitoring lines can be described by various parameters including horizontal tilt, horizontal curvature, mid-ordinate deviation, angular distortion and shear index.

Far-field movements are horizontal movements located beyond the longwall goaf edges and over solid unmined coal areas. These movements generally do not result in impacts on natural features or built environments, except where they are experienced by large structures which are very sensitive to differential horizontal movements.

In addition to the above systematic (or conventional) effects, there are also particular effects which occur when subsidence occurs in incised valleys and gorges typical of the Southern Coalfield which are referred to as non-systematic (or unconventional) effects. These include the following:

- **Upsidence** is the reduced downward subsidence, or the relative uplift within a valley which results from the dilation or buckling of near surface strata at or near the base of the valley.
- **Valley closure** is the reduction in the horizontal distance between the valley sides.
- **Compressive valley strains** occur within the bases of valleys as the result of valley closure and upsidence movements. **Tensile valley strains** also occur at the tops of the valleys as the result of valley closure movements.

4.1 MONITORED AND OBSERVED EFFECTS OF SUBSIDENCE ON SURFACE WATER RESOURCES IN THE SOUTHERN COALFIELD

Mine Subsidence Engineering Consultants (MSEC) (2009) developed a database of pool and rockbar sites that have experienced mining induced upsidence and valley closure movements in the Southern Coalfield. The 200 mm closure value has been adopted as a reference value below which it is expected that flow diversion and pool water level impacts are unlikely to occur (i.e. the adoption of a 200 mm valley closure criteria is viewed as an indicator of low probability of flow diversion and pool level impacts).

The impacts of subsidence on flow and water quality in streams would depend on the geomorphic nature and hydrological characteristics of the stream. The character of streams in the Project Area varies significantly in terms of:

- Scale – for example, the reach of the Cordeaux River within the Project Area has a catchment area of approximately 135 km^2 (at the downstream extent of the Project Area) compared to one of the tributaries flowing to the Avon River which has a catchment area of approximately 0.3 km^2.
- Geology and geomorphic character – ranging from headwater streams with no defined channel to smaller tributary streams further downstream characterised by a narrow channel generally dominated by Hawkesbury Sandstone to deeply incised gullies that follow a strata-controlled alignment dominated by rockbars, pools and boulders with sparse fine sediment deposits.
- Level of development – ranging from the two highly regulated reaches (Avon River and Cordeaux River) to the remaining smaller headwater streams in largely undisturbed catchments in the Metropolitan Special Area.

The Project longwall layout has been designed to achieve no more than 200 mm of additional predicted closure at the closest named watercourses (Avon River, Cordeaux River and Donalds Castle Creek) (Appendix A of the EIS). Achievement of the 200 mm criterion on these streams is likely to result in a reduction of subsidence effects on sections of stream between each rockbar feature.

For the ephemeral headwater streams overlying the Project longwall area, South32 has conducted field investigations and mapped 'key' stream features (defined as pools which hold water with an estimated volume greater than 100 m^3 and waterfalls/steps greater than 5m high with pools at the base which hold water). For these key stream features, setbacks from the Project longwalls of 50 m (where mining occurs on one side only) and 100 m (where mining occurs on two or more sides) would be implemented to reduce the likelihood of subsidence effects (Appendix A of the EIS).

Watercourses where sufficient valley closure occurs may experience dilation fracturing, shearing of rock strata and development of a fracture network beneath the stream bed. This would result in the diversion of a portion of streamflow via the fracture network and a reduction in water level in pools as they drain via hydraulic connections with the fracture network. There is the potential for reduced continuity of flow between affected pools during dry weather. The capacity of the fracture networks to convey flows via the subsurface network is unknown and may result in decreased flows in streams. Where the stream experiences low flow conditions, there is the potential that a higher proportion or all of the surface flow would be re-directed into the fractured strata.

Although mine subsidence effects can result in isolated, episodic pulses in iron, manganese, aluminium, other metals and electrical conductivity, there have been no reports of any measurable effect on water quality in downstream reservoirs in the Southern Coalfield.

Mining has the potential to affect the hydrology and water balance of undermined upland swamps and the quantity and quality of surface waters downstream of the swamps via the following mechanisms:

- formation of cracks in the swamp sediment resulting in increased leakage and a reduction in groundwater levels in the swamp;
- fracturing of the underlying bedrock which could lead to increased vertical drainage and accelerated drying of the swamp; and/or
- tilting and surface gradient changes in the vicinity of a swamp which may affect the rate of subsurface and surface flow in the swamp.

4.2 MONITORED AND OBSERVED EFFECTS OF SUBSIDENCE ON SURFACE WATER RESOURCES AT DENDROBIUM

Monitored and observed effects of subsidence on surface water resources have been observed at varying locations within and adjacent to the Dendrobium Mine. Figure 19 provides a locality map of mining areas and surface water resources at Dendrobium which are referenced in the following sections.

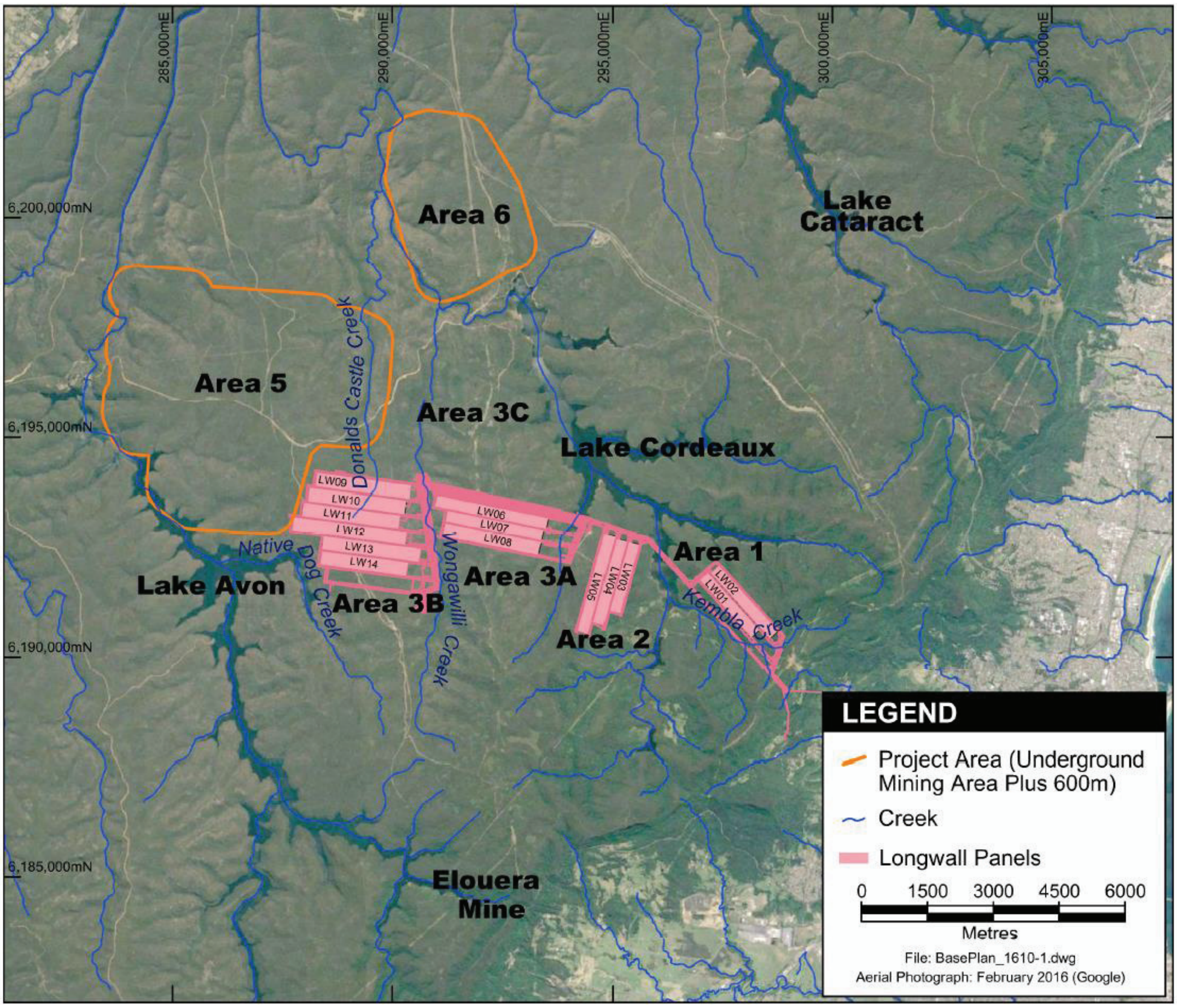

Figure 19 Referenced Mining Areas and Surface Water Resources

4.2.1 Past Longwall Mining Under or Near Lake Cordeaux

Mining of Longwalls 3 and 4 at Dendrobium Area 2 occurred between March 2007 and October 2008. Minor cracking of alluvium in the bed of two headwater creeks was observed following mining of Longwall 3, while mining of Longwall 4 resulted in three small fractures forming in a sandstone creek bed (Comur Consulting Pty Ltd, 2008 in Gilbert & Associates, 2009).

The analysis of water quality data collected from creeks draining and associated with Dendrobium Area 2 concluded that there were localised low spikes in aluminium and iron recorded in one creek which could be attributable to the effects of subsidence induced cracking. However, the peak concentrations measured were low compared with ANZECC Guidelines trigger values for aquatic ecosystems and were not in excess of other creeks monitored in the area (Comur Consulting Pty Ltd, 2009 in Gilbert & Associates, 2009).

Cracking was also observed in the bed of an upland swamp, with groundwater changes reported for Swamp 1 in Area 2 (Appendix D of the EIS). These changes included increased rates of groundwater level recession following recharge events, increased duration of low groundwater levels during and following mining and changes to soil moisture levels.

4.2.2 Past Longwall Mining Under or Near Kembla Creek

Longwall mining in Dendrobium Area 2 undermined several of the tributaries of Kembla Creek in 2007 (Dendrobium Coal Pty Ltd, 2008). It was concluded from visual observations supported by water quality monitoring and monitoring of water levels in the creek and in pools that observed periods of no flow and low pool levels in Kembla Creek were related to drought rather than any subsidence effects (Dendrobium Coal Pty Ltd, 2008). There were no observed releases of strata gas or of iron staining. Likewise there were no reported changes in water quality that could be related to mining effects. Minor fracturing and pool water level impacts were however reported in tributary streams that were directly undermined by the longwalls (Dendrobium Coal Pty Ltd, 2008).

4.2.3 Past Longwall Mining Under or Near Wongawilli and Native Dog Creeks

Elouera Mine Longwalls 9 and 10 were mined beneath Wongawilli Creek, Native Dog Creek and a number of upland swamps between October 2003 and May 2005. The headwaters of Wongawilli Creek and Native Dog Creek were undermined by Longwalls 1 to 6 between 1993 and 2001 (Comur Consulting Pty Ltd, 2007 in Gilbert & Associates, 2009). An intense and widespread fire in December 2001 had a major impact on vegetation in the area and resulted in erosion and redistribution of sediment in local drainages following subsequent intense rainfall events (Comur Consulting Pty Ltd, 2007 in Gilbert & Associates, 2009). Water quality monitoring revealed relatively low pH and DO and elevated metals concentrations (aluminium and zinc) in Native Dog Creek and Wongawilli Creek. These effects were attributed to longwall mining beneath these creeks and to the effects of drought. It was inferred from the data that these effects were ameliorating with time – having peaked in March/April 2003 (Comur Consulting Pty Ltd, 2007 in Gilbert & Associates, 2009). Monitoring and inspection undertaken for the Elouera Mine indicated that there was no evidence of sustained subsidence-induced erosion of the valley slopes of Wongawilli Creek and its tributaries (Ecoengineers, 2007).

4.2.4 Past Longwall Mining Under or Near Donalds Castle Creek and Wongawilli Creek

Mining of Longwall 11 in Dendrobium Area 3B resulted in 11 observed surface impacts, with two observed within a watercourse (WC21). Following mining of Longwall 12, a total of 24 new surface fractures were identified within the zone of influence, of which 4 were in stream beds (HGEO, 2017). Following mining of Longwall 13, a total of 43 new surface impacts were identified within the zone of influence, of which 18 were in stream beds (HGEO, 2018). The reported subsidence impacts to stream beds comprised rock fracturing, uplift to the base of the stream bed, iron staining and rock fall.

Mining-related effects on the flow regime were reported to have occurred in tributaries to Donalds Castle Creek (DCS2, DC13S1), Lake Avon (LA4), and in the upper reaches of Wongawilli Creek. Following mining of Longwall 11, a reduction in total discharge of 20% (DCS2) and 15% (DC13S1) was reported for Donalds Castle Creek (HydroSimulations, 2016). An 11% reduction in total discharge to a tributary of Wongawilli Creek (WC21S1) was also reported. In Donalds Castle Creek, a reduction in total discharge of 22% (DC13S1) and 28% (DCS2) was observed following mining of Longwall 12 (HGEO, 2017). Following mining of Longwall 13, a reduction in total discharge of 7% (DC13S1) and 22% (DCS2) was observed in Donalds Castle Creek (HGEO, 2018).

Subsidence impacts and associated redirection of flow through fractures were proposed to contribute to elevated electrical conductivity and DO readings in sites on Wongawilli Creek and to elevated EC readings in sites on Donalds Castle Creek (HGEO, 2018). An increase in pH, iron and manganese was noted in WC21_Pool 5 during mining of Longwall 10 and 11 (HydroSimulations, 2016).

4.3 MONITORED AND OBSERVED EFFECTS OF SUBSIDENCE ON SWAMPS AT DENDROBIUM

A change in shallow groundwater levels, and subsequent potential impact to surface water levels, has been observed in upland swamps monitored in Dendrobium Area 3B. The impacted swamps include Den 1A, Den 1B, Den 3, Den 5, Den 8, Den 10, Den 11, Den 12 and Den 15B (Appendix B of the EIS). The results of shallow groundwater monitoring within Dendrobium Areas 3A and 3B show a decrease in the duration of saturation of the swamp sediments following a significant rainfall event and/or a change in the shape of saturation peak and recession curves in response to significant rainfall events (Appendix B of the EIS).

Figure 20 to Figure 22 present shallow groundwater level records for Den 1A, Den 1B and Den 15B before and after longwall mining. Dry periods were selected from the full period of record in order to enable comparison of the water level recession at different points in time before and after longwall mining.

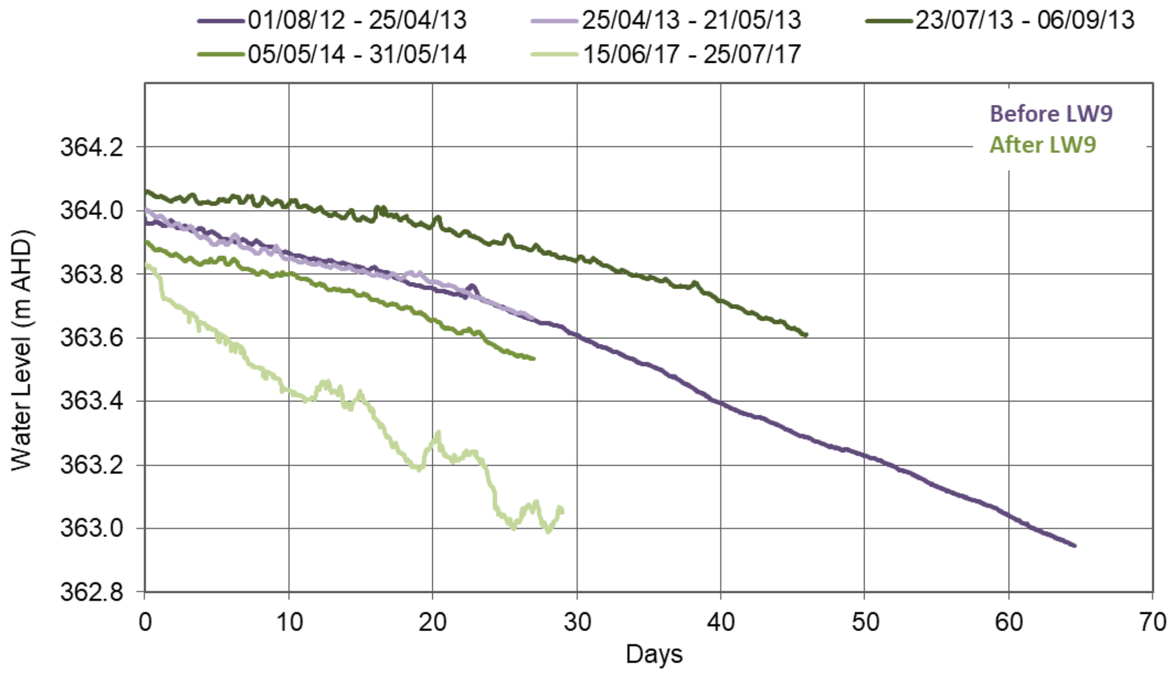

Figure 20 Swamp Den 1A Groundwater Recession Before and After Mining LW9

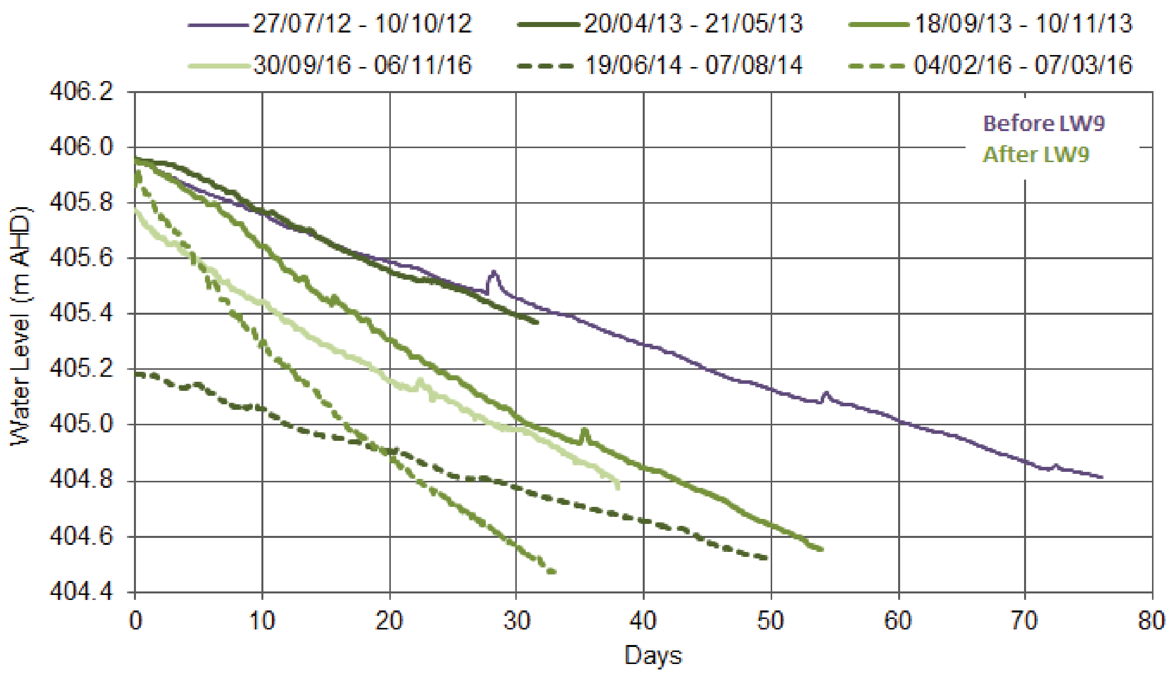

Figure 21 Swamp Den 1B Groundwater Recession Before and After Mining LW9

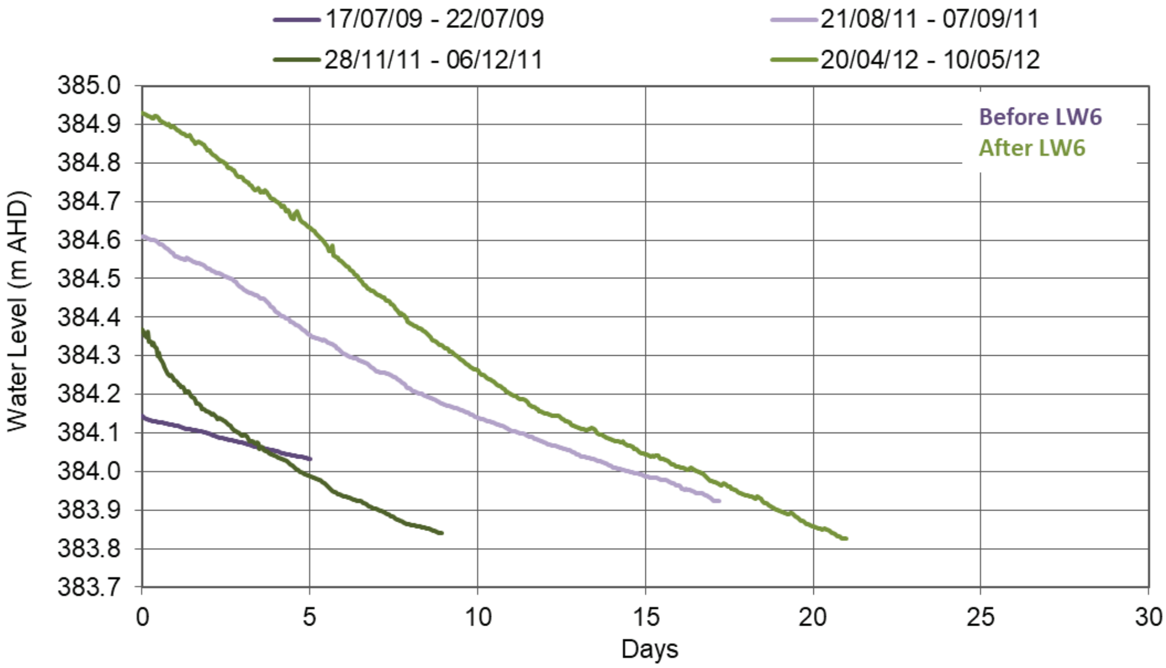

Figure 22 Swamp Den 15B Groundwater Recession Before and After Mining LW6

Figure 20 to Figure 22 clearly illustrate an increase in water level recession recorded at Den 1A, Den 1B and Den 15B following longwall mining. For Den 1A, a 16% increase in groundwater recession rate, on average, was observed following mining, while for Den 1B a 53% average increase was observed and for Den 15B the average increase post-mine was 43%.

As a result of changes to the groundwater and surface water flow regime, changes in the extent and Total Species Richness (TSR) have been reported for swamps overlying the Area 3 longwalls (Appendix D of the EIS). However, a universal trending decline in TSR across all Coast Upland Swamps monitored by South32 for Areas 3A and 3B (including 'control' sites that had not been undermined) was reported, indicative of natural turnover of species within Coastal Upland Swamps in response to seasonal and annual variability in climate, competition, disturbance and edaphic factors, including nutrient availability (Appendix D of the EIS).

4.4 MONITORED AND OBSERVED EFFECTS OF SUBSIDENCE ON LAKE AVON AND LAKE CORDEAUX

Ground subsidence associated with Longwalls 12 and 13 has resulted in the development of surface cracking of the stream bed of a tributary of Lake Avon (LA4). The surface cracking has subsequently resulted in the diversion of flows and a measurable reduction in flow recorded at the streamflow gauging station LA4S1. HGEO (2018) estimated a 6% reduction in total discharge at LA4S1, resulting in a Level 1 trigger according to the adopted Trigger Action Response Plan (TARP).

In assessing the Subsidence Management Plan for mining of Longwalls 14 and 15 in Area 3B, the NSW Department of Planning and Environment (DPE) found that there has been some loss of water (approximately 830 ML per year) into the Dendrobium Mine workings, which may have otherwise reported into catchment dams (DPE, 2016). However, at the time of the assessment, Sydney's catchment dams held over 2.3 million ML, with up to 420,000 ML lost per year through evaporation and environmental flows. DPE considered that a loss of up to 830 ML per year into the Dendrobium Mine was negligible in comparison to the total capacity of the catchment dams (0.03%) and annual losses from evaporation and environmental flows (0.19%) (DPE, 2016).

Despite localised, low spikes in water quality constituents recorded for some catchments reporting to Lake Avon and Lake Cordeaux, there have been no reports of water quality impacts to Lake Avon or Lake Cordeaux associated with mining activities in the region. As of 2018, water quality in the Upper Nepean lakes continued to record a high compliance against ANZECC Guideline benchmarks (WaterNSW, 2018a).

5.0 SUBSIDENCE PREDICTIONS AND ASSESSMENT OF POTENTIAL IMPACTS TO SURFACE WATER RESOURCES

5.1 SUMMARY OF SUBSIDENCE, UPSIDENCE AND CLOSURE PREDICTIONS

5.1.1 Mine Layout Optimisation

As detailed in the Subsidence Assessment (Appendix A of the EIS), the proposed longwalls in Area 5 and Area 6 have been designed to reduce the potential impacts on major streams and the significant stream features. The mine optimisation has been based on the potential for Type 3 impacts which 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* (Appendix A of the EIS). The following mine design features have been adopted in order to reduce potential impacts:

- no direct undermining of the existing Lake Avon and Lake Cordeaux waterbodies;
- longwall setbacks from both the Avon and Cordeaux Dam embankments (minimum setback distance of 1,000 m);
- longwall setback from the Full Supply Levels (FSLs) of both Lake Avon and Lake Cordeaux (minimum setback distance of 300 m from the FSLs);
- longwall setback from named watercourses (i.e. Cordeaux River, Avon River and Donalds Castle Creek) to achieve 200 mm or less predicted additional valley closure; and
- setback of longwall mining from key stream features along the unnamed streams overlying the Project longwalls by distances of 100 m (where longwall mining occurs on more than one side) and 50 m (where longwall mining occurs on one side only).

Significant stream features have been defined as:

- Pools with an estimated volume greater than or equal to 100 m^3 (and holding water).
- Waterfalls with a height greater than or equal to 5 m (where there is a pool at the base holding water).

The Stream Risk Assessment (Appendix B) lists the stream features mapped by South32 in Area 5 and Area 6.

5.1.2 Subsidence, Upsidence and Closure Predictions for Areas 5 and 6

The maximum predicted subsidence parameters as noted in Appendix A of the EIS for the proposed longwalls in Area 5 are: 2,050 mm vertical subsidence, 25 mm/m tilt (i.e. 2.5 % or 1 in 40) and 0.5 km^{-1} hogging (i.e. 2 km minimum radius) and 0.6 km^{-1} sagging curvature (i.e. 1.7 km minimum radius). The maximum predicted subsidence parameters for the proposed longwalls in Area 6 are: 2,450 mm vertical subsidence, 20 mm/m tilt (i.e. 2% or 1 in 50), 0.30 km^{-1} hogging curvature (i.e. 3.3 km minimum radius) and 0.5 km^{-1} sagging curvature (i.e. 2 km minimum radius).

The maximum predicted total upsidence within Area 5 is 525 mm and the maximum predicted total valley related closure is 575 mm. The maximum predicted total upsidence within Area 6 is 350 mm and the maximum predicted total valley related closure is 350 mm.

5.1.2.1 Subsidence, Upsidence and Closure Predictions for Rivers and Named Creeks

The Avon River, Cordeaux River and Donalds Castle Creek are located outside the extents of the proposed longwalls and Appendix A of the EIS predicts these will experience less than 20 mm vertical subsidence due to the proposed mining in Areas 5 and 6. The maximum upsidence predictions are 90 mm for the Avon River, 50 mm for the Cordeaux River and 100 mm for Donalds Castle Creek. The maximum total closure predictions are 200 mm for the Avon River, 80 mm for the Cordeaux River, 210 mm for Donalds Castle Creek (noting that additional closure is 200 mm) and less than 20 mm for Wongawilli Creek.

Minor fracturing could occur along these streams at distances up to approximately 400 m from the proposed longwalls. The potential for Type 3 impacts (i.e. fracturing in a rockbar or upstream pool resulting in reduction in standing water level based on current rainfall and surface water flow) has been noted by the Subsidence Assessment as low (Appendix A of the EIS), with the percentage of affected pools and channels within 400 m of the proposed longwalls predicted to be approximately 7% for the Avon River, 5% for the Cordeaux River and 9% for Donalds Castle Creek. Minor fracturing may also occur elsewhere along the rivers for distances up to approximately 400 m from the proposed longwalls (Appendix A of the EIS).

5.1.2.2 Subsidence, Upsidence and Closure Predictions for Unnamed Streams

The maximum predicted total vertical subsidence (Appendix A of the EIS) for unnamed streams in Area 5 ranges from 1,400 mm (DC8) to 1,950 mm (AR31) while for Area 6 unnamed streams a maximum of 2,300 mm is predicted. Maximum predicted total valley related upsidence ranges from 400 mm (AR32) to 875 mm (LA13A) in Area 5 and from 425 mm (CR29) to 675 mm (CR31) in Area 6. Maximum predicted total valley related closure ranges from 275 mm (DC10) to 1,150 mm (AR31) in Area 5 and from 350 mm (CR29) to 800 mm (CR31) in Area 6.

The maximum predicted tilt for the drainage lines within the Project Area is 25 mm/m, representing a change in grade of 1 in 40. The average natural gradients of the drainage lines are generally greater than the maximum predicted tilt, varying between 20 mm/m and 150 mm/m directly above the proposed longwalls. For some of the drainage lines, a reduction in grade is predicted. Where this occurs, there may be potential for localised ponding upstream due to the subsidence induced tilt.

5.1.2.3 Subsidence, Upsidence and Closure Predictions for Upland Swamps

The maximum predicted total vertical subsidence (Appendix A of the EIS) for the swamps in Area 5 is 1,800 mm and 2,300 mm for swamps in Area 6. The maximum predicted total upsidence for the swamps in Area 5 is 525 mm and 350 mm for swamps in Area 6. Maximum predicted total valley related closure is 575 mm for swamps in Area 5 and 350 mm for swamps in Area 6. Fracturing of the bedrock is expected to occur beneath the swamps that are located directly above the proposed longwalls. The soil crack and rock fracture widths due to the extraction of the proposed longwalls in Areas 5 and 6 are expected to be less, on average, than those previously measured at the Mine. The measured surface deformations were generally less than 50 mm in width (i.e. in 86% of cases) but had widths between 50 mm and 150 mm in 8% of cases, between 150 mm and 300 mm in 4% of cases and greater than 300 mm in 2% of cases.

The predicted post-mining gradients within the swamps are similar to the natural gradients and, therefore, it is not expected that there would be adverse changes in ponding or scouring within the swamps due to the subsidence induced tilt (refer also Section 5.3). It is also not anticipated that there would be significant changes in the distribution of the stored surface waters within the swamps due to the mining-induced tilt or vertical subsidence.

5.2 STREAMFLOW LOSS ASSESSMENT

Mining within the Project Area has the potential to affect the hydrology and water balance of undermined upland swamps and the quantity and quality of surface waters downstream of the swamps (refer Section 4.1). To assess the potential impact of the predicted subsidence on the yield of each swamp and the overall catchment yield, swamp seepage modelling and hydrological modelling have been undertaken as described below.

5.2.1 Swamp Seepage Modelling

Seepage models were developed for swamps using the VADOSE/W (GEO-SLOPE, 2004) software - a finite element, two-dimensional unsaturated/saturated groundwater seepage model. The model was used to assess the potential impact of the proposed Project (subsidence and associated fracturing) on enhanced horizontal and vertical drainage beneath the potentially affected swamps.

5.2.1.1 Model Design

VADOSE/W models were set up to represent a longitudinal[7] section through a given swamp deposit and a section of the underlying bedrock. The model comprised a surface layer of sand and two sub-surface layers representing weathered rock and fresh rock. The thicknesses of the layers were set at 1.5 m, 12 m and 20 m respectively. The layer thickness for the swamp deposit was set to the average of reported swamp sediment thickness obtained during piezometer installation in Areas 5 and 6. The thicknesses of the rock layers were set based on Project exploration drilling (Mine Geology Database) interpretation by HydroSimulations (Appendix B of the EIS). The model longitudinal sections represent a 1 m wide 'slice' through the swamp.

A statistical analysis of the 129 year climatic sequence for the Project location (obtained from the SILO Data Drill) was undertaken to derive climatic sequences for three representative years corresponding to median, 10th percentile (dry) and 90th percentile (wet) annual rainfall. The relevant years were selected from the SILO Data Drill data by totalling annual rainfalls, ranking these and then choosing the actual years with total rainfalls nearest to the three statistics.

The climatic data (rainfall, pan evaporation, temperature and relative humidity) were applied to the surface layer of the model, creating a surface boundary condition. Evapotranspiration was calculated in the model using pan evaporation as an input and variance in moisture levels over time. Surface vegetation conditions, namely leaf area index, root depth and moisture limiting function (indicates unsaturated conditions), were specified to enable calculation of evapotranspiration in the model. The model was calibrated by modifying the leaf area index and plant root depth parameters (refer Section 5.2.1.2). Swamps within the Dendrobium Mine area primarily comprise a dense cover of tall tussocks, rushes and sedges (Earth Tech, 2005), with root depths observed between 400 and 750 mm depth (Sustainable Minerals Institute [SMI], 2019).

A constant head boundary condition was applied to the upslope vertical boundary of the model. The adopted layer and boundary conditions are illustrated in Figure 23.

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7 Parallel to the main direction of flow.

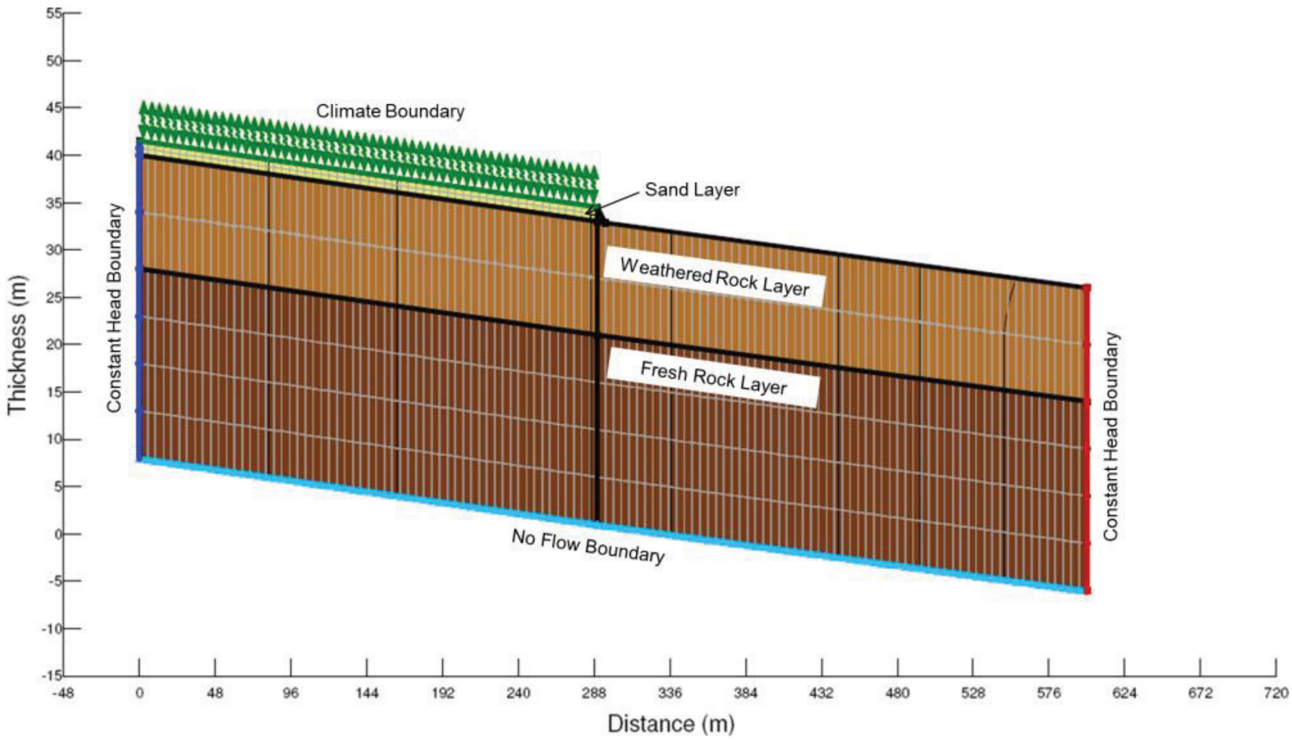

Figure 23 Swamp Seepage Model Schematic

The model was simulated for a 'Without Project' (i.e. existing) and 'With Project' case (i.e. with predicted subsidence). The vertical and horizontal hydraulic conductivity values adopted for the 'Without Project' and 'With Project' cases are summarised in Table 28 below. The values were based on parameters in the Project Groundwater Assessment (HydroSimulations, 2019) and discussions with the hydrogeologists (HydroSimulations pers. comm., 10 July 2018), and modified during calibration of the local-scale swamp models presented below.

Table 28 Horizontal and Vertical Hydraulic Conductivity

Layer Material Type	Without Project		With Project	
	Horizontal Saturated Hydraulic Conductivity (m/day)	Vertical Saturated Hydraulic Conductivity (m/day)	Horizontal Saturated Hydraulic Conductivity (m/day)	Vertical Saturated Hydraulic Conductivity (m/day)
Swamp Sand Sediment	1	1	1	1
Weathered Bed-rock	0.03	0.003	0.15	0.15
Fresh Bed-rock	0.01	0.0001	0.1	0.1

Transient model simulations were undertaken for three separate, one year periods with different total rainfall: median, 10th percentile (dry) and 90th percentile (wet). Model simulations were undertaken for four representative swamp types and the median swamp length (refer Table 29). The four swamp types represented minimum, median, 90th percentile and maximum swamp gradient without the Project. For the 'With Project' simulation, the swamps were tilted to represent the potential change in gradient as a result of the Project. The change in gradient was based on the maximum tilt predicted in Appendix A of the EIS. Note that for Swamp Type C, the 'With Project' gradient was not increased because the tilt is predicted to occur in the opposite direction to the existing slope of the swamp. These four modelled geometries therefore provide information on the likely range of impacts for all swamps. Model results were subsequently applied to each swamp in hydrological modelling (refer Section 5.2.1.3) by choosing a swamp type (based on the slope) and scaling the model results based on the actual swamp length.

Table 29 Modelled Swamp Types

Swamp Type	Length (m)	Without Project Slope (%)	With Project Slope (%)
Type A	290	2.1	4.4
Type B	290	4.3	5.9
Type C	290	9.0	9.0
Type D	290	16.3	17.5

5.2.1.2 Model Calibration and Verification

The water level records for a swamp with median gradient (Den 98 – refer Figure 8 for location and Table 20 for swamp characteristics) were used for the model calibration. The model was calibrated by modifying the leaf area index and plant root depth parameters. Recorded water levels were compared with simulated water levels until a reasonable fit was achieved, as illustrated in Figure 24. A leaf area index of 1.7 was selected guided by global field measurement data specified in Scurlock et al. (2001) and a root depth of 400 mm was selected based on the predominant vegetation species found in swamps within the Project Area (refer Section 5.2.1.1).

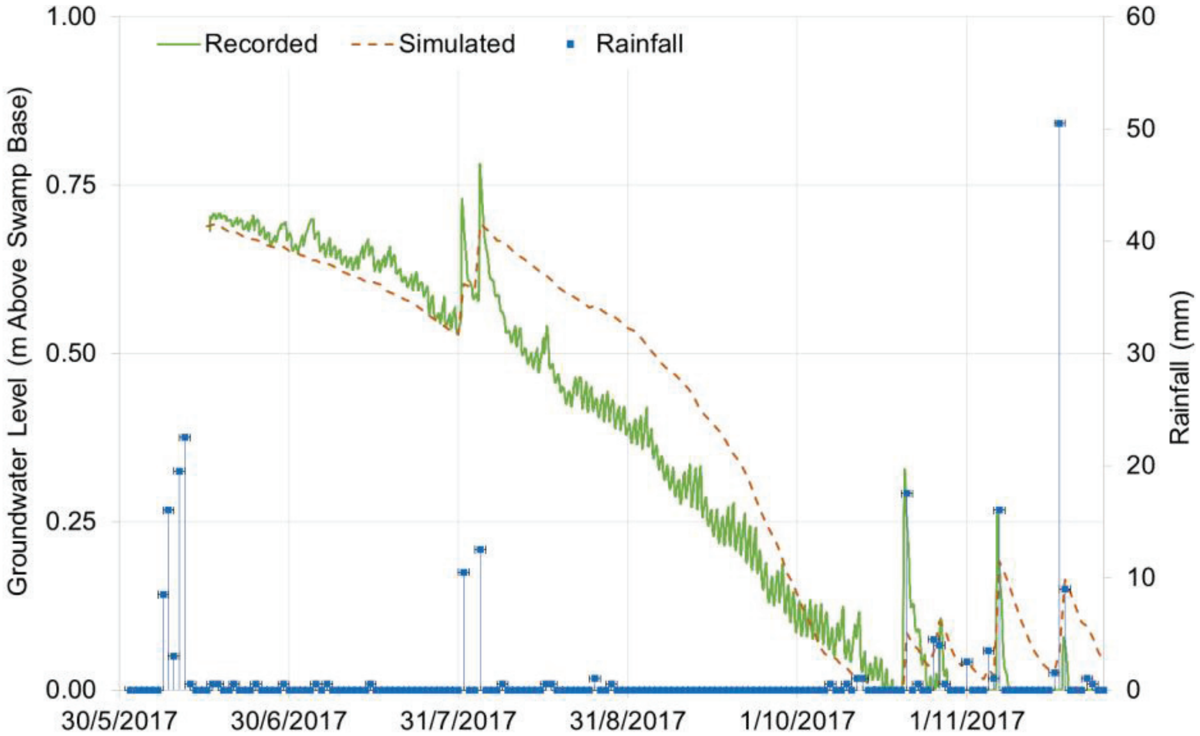

Figure 24 Recorded and Simulated Head – Swamp Den 98

Figure 24 illustrates a good comparison between the recorded water levels for Den 98 and the model simulated water levels for the corresponding swamp type.

A comparison was also made between the reported recession rates in Area 3 swamps (see Section 4.2.4) which have been monitored by South32 during pre-mine and post-mine periods and the simulated recessions under 'With Project' and 'Without Project' cases. Figure 25 presents the recorded pre-mine and post-mine recession rate in comparison with the simulated pre-mine and post-mine recession rates, with the equate rate and triple rate line presented for comparative purposes.

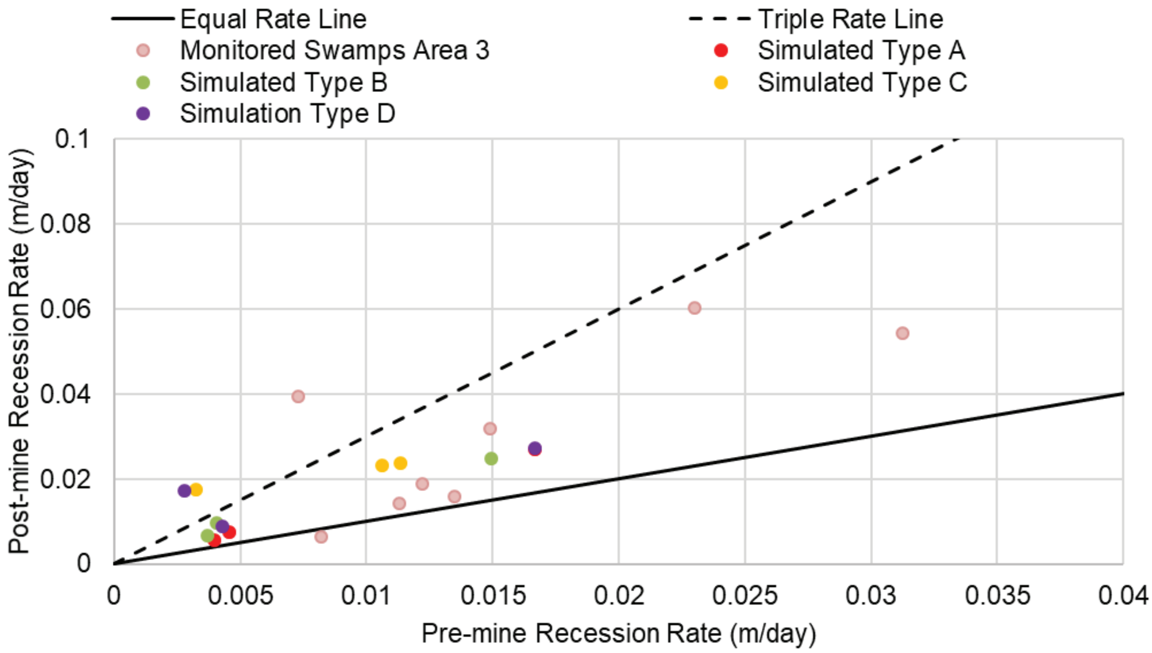

Figure 25 Monitored and Simulated Swamp Groundwater Recessions – With and Without Project

Figure 25 illustrates that the simulated with and without Project recession rates are within the range of that observed in monitored swamps in Area 3, pre and post-mining. This indicates that the model simulations are representative of observed conditions.

5.2.1.3 Model Forecast Results

The predicted total flux along the base of each modelled swamp section is presented in Table 30. The total flux is indicative of drainage from the swamp to underlying strata.

Table 30 Total Flux at Base of Swamp

Swamp Type	Condition	Total Annual Flux (m^3 per m width per year)		
		10th percentile (dry)	Median	90th percentile (wet)
Type A	Without Project	0.1	1.4	1.2
	With Project	67.2	42.8	42.7
Type B	Without Project	0.9	0.4	0.7
	With Project	57.4	59.5	59.5
Type C	Without Project	6.0	5.6	5.7
	With Project	91.5	99.4	98.4
Type D	Without Project	19.4	19.6	19.8
	With Project	105.0	125.5	112.6

Results presented in Table 30 above indicate that seepage from the base of the swamps is predicted to increase from very low values (i.e. between 0.1 and 19.8 m^3/m width of swamp per annum over a 290 m long swamp) to between 42.7 and 125.5 m^3/m width per annum. For Swamp Type A, with an average swamp width of 71 m, this equates to an increase in seepage from 0.07 to 2.1 mm/year under median climate conditions. For Swamp Type B, with an average width of 64 m, this equates to an increase in seepage from 0.02 to 3.2 mm/year under median climate conditions. For Swamp Type C, with an average width of 22 m, this equates to an increase in seepage from 0.9 to 16 mm/year under median climate conditions. For Type D, with an average width of 13 m, this equates to an increase in seepage from 5 to 33 mm/year under median climate conditions. This reflects the effect of cracking and the associated reduced capacity of the underlying bedrock to act as a perching layer. It should be noted that these flux rates represent the initial response of the swamp base to cracking and may not represent long-term conditions. The influence of the increased seepage from the base of the swamp on catchment yield is discussed in Section 5.2.2 below.

The seepage rate is dominated by the pattern of rainfall and its effect on water levels in the swamp and recharge to the surrounding groundwater table. The rainfall sequence corresponding to the median annual rainfall has more regular, smaller rainfall events (see Figure 30) while the 90th percentile rainfall sequence is dominated by less regular, though higher rainfall events (see Figure 34). Consequently, in some cases the total annual flux rate is higher for the median annual rainfall sequence, despite the 90th percentile annual rainfall sequence having a greater total annual rainfall volume.

The increased seepage rates from the base of the swamps would result in increased water level recession and reduced moisture levels in the swamp particularly during dry conditions. Simulated swamp groundwater level hydrographs for the 'With Project' and 'Without Project' cases, which illustrate this, are shown in Figure 26 to Figure 37.

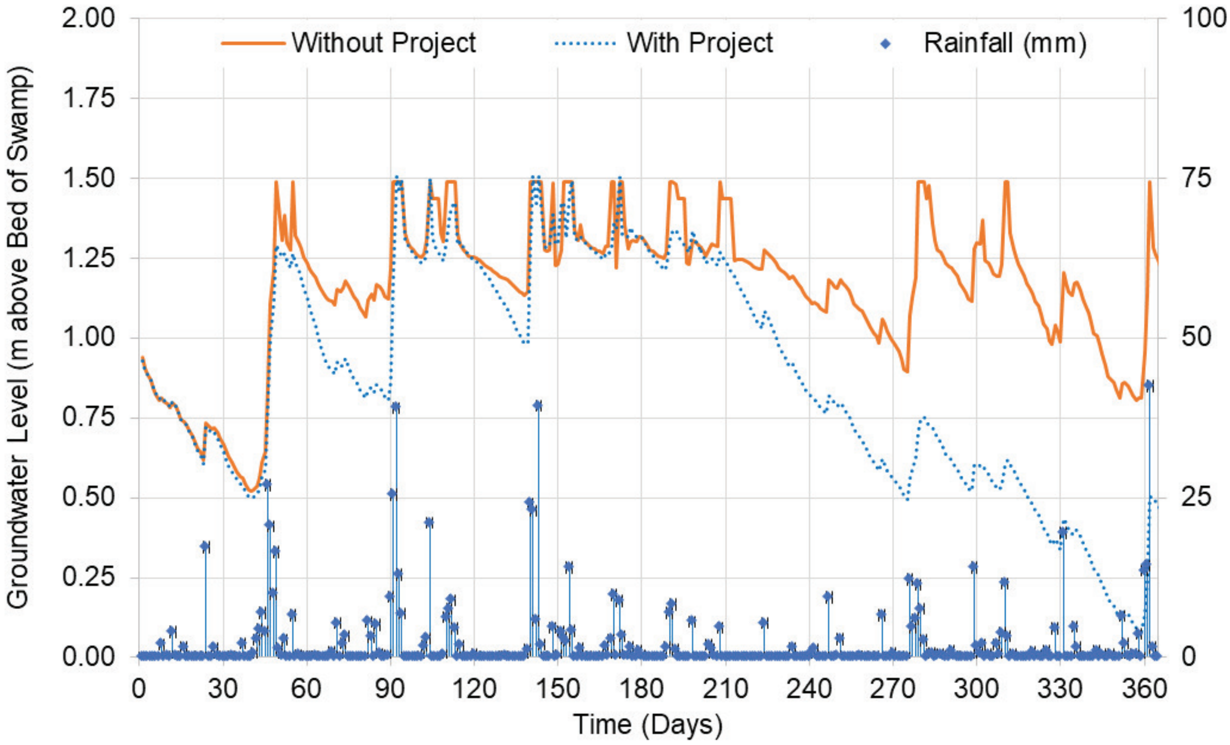

Figure 26 Simulated Groundwater Levels – Swamp Type A, 10th Percentile Climate Scenario

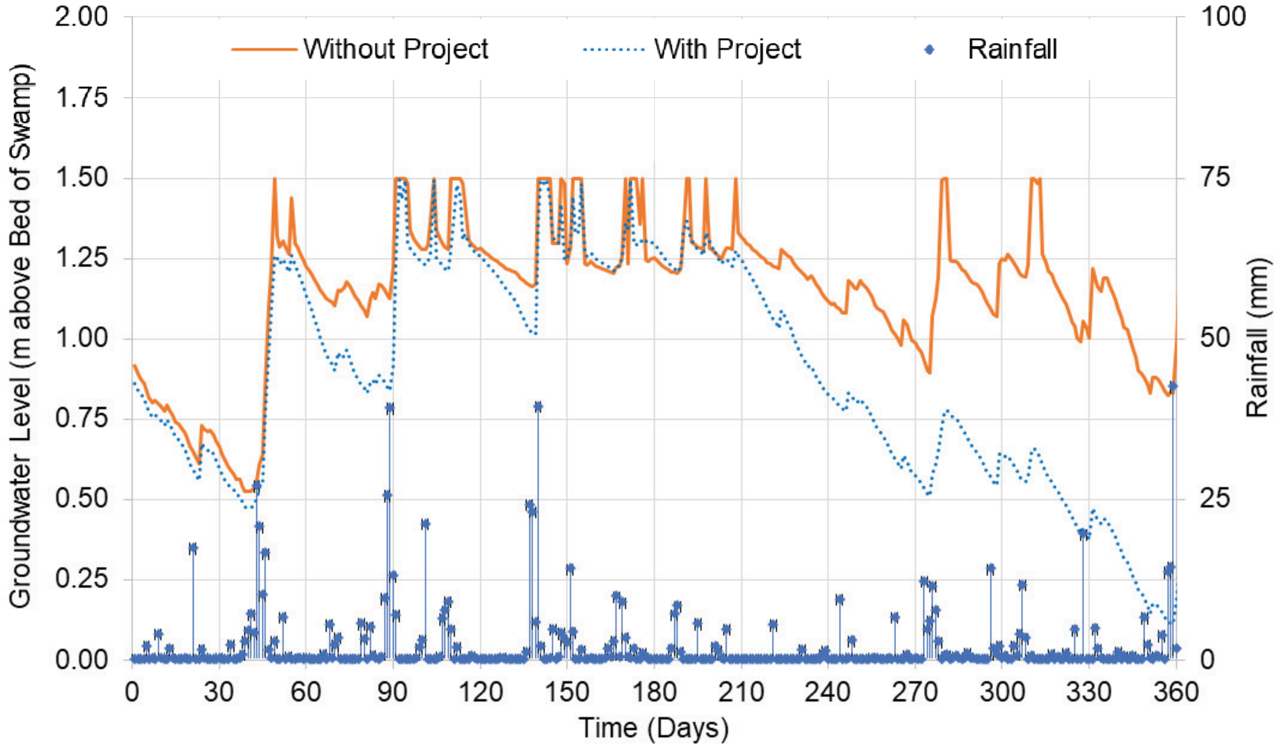

Figure 27 Simulated Groundwater Levels – Swamp Type B, 10th Percentile Climate Scenario

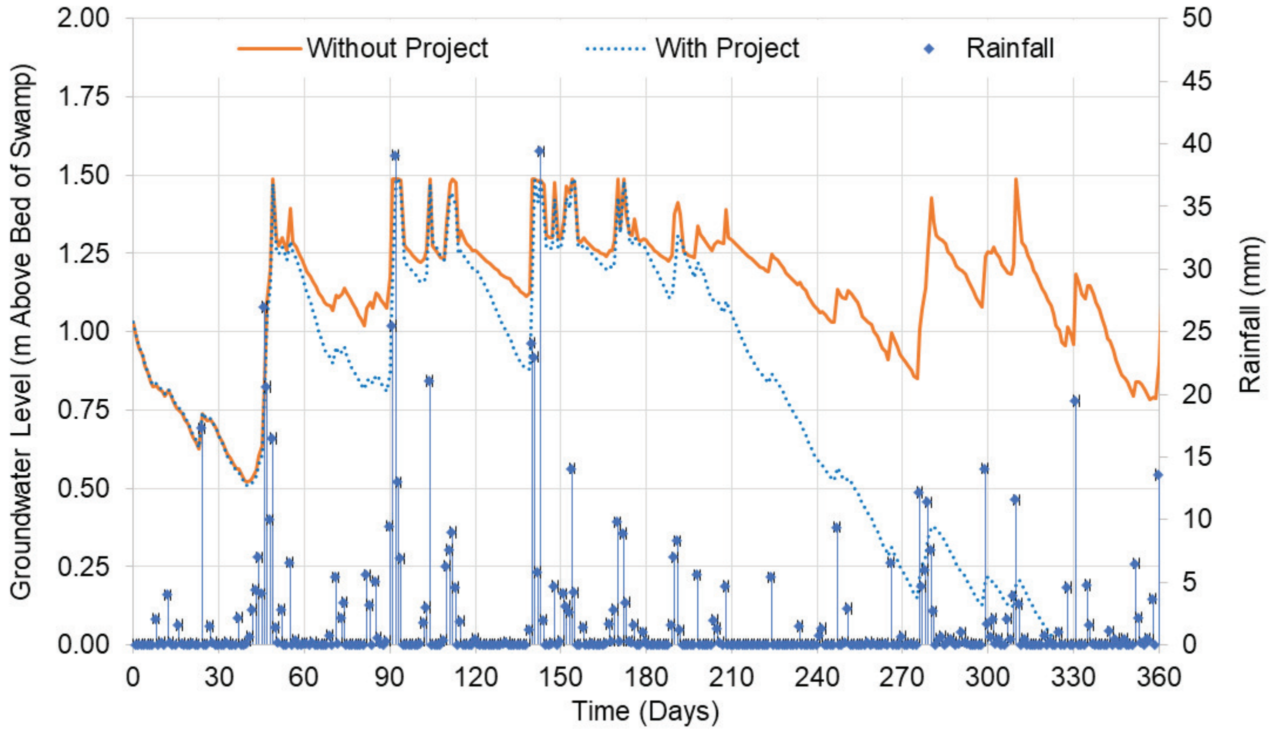

Figure 28 Simulated Groundwater Levels – Swamp Type C, 10th Percentile Climate Scenario

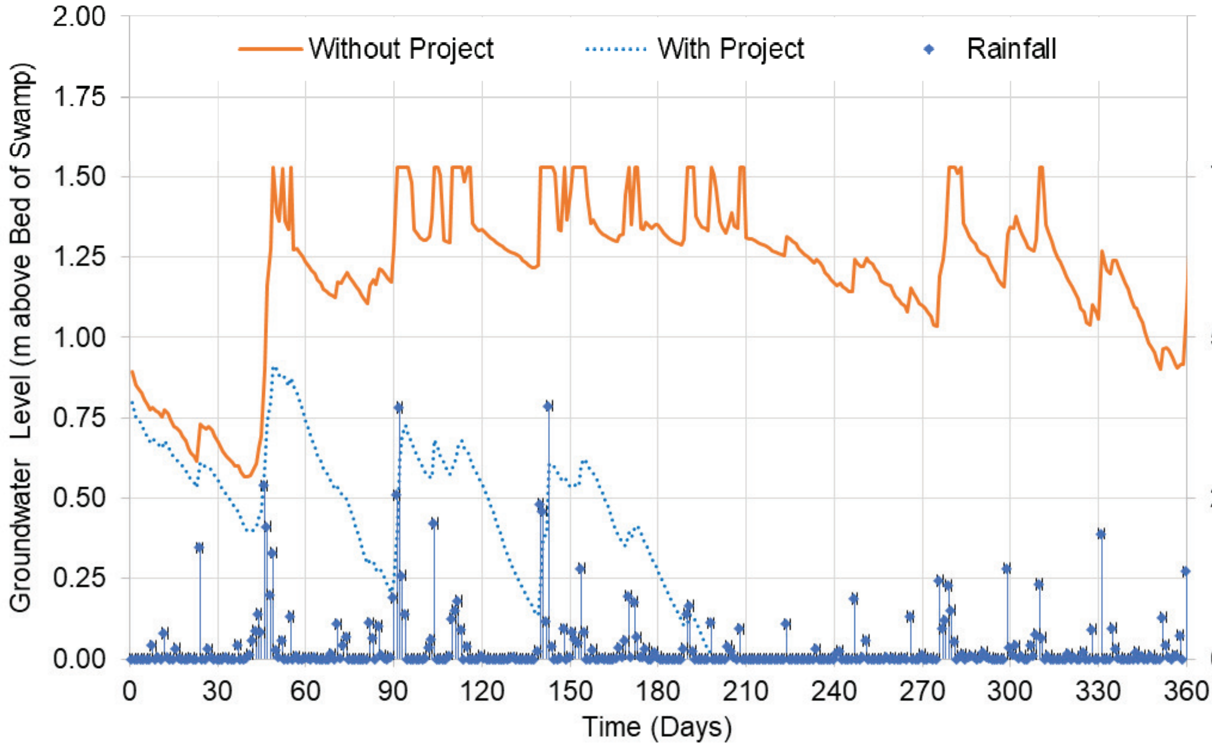

Figure 29 Simulated Groundwater Levels – Swamp Type D, 10th Percentile Climate Scenario

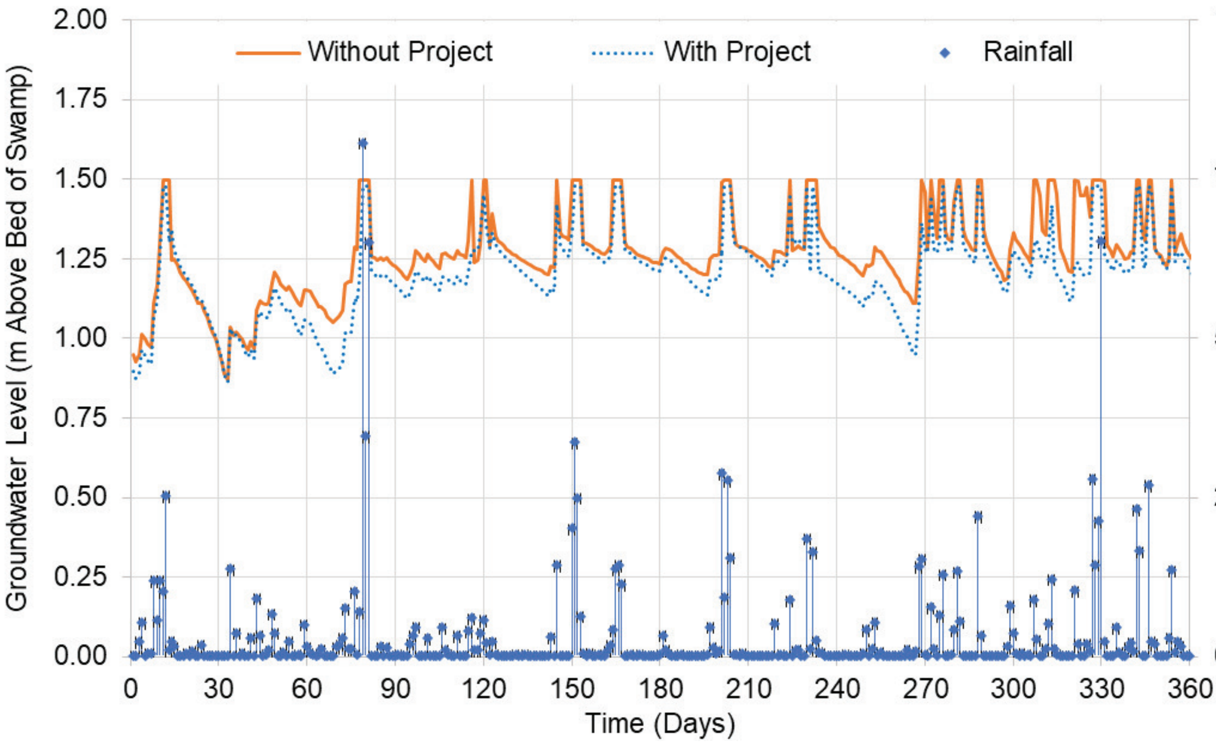

Figure 30 Simulated Groundwater Levels – Swamp Type A, Median Climate Scenario

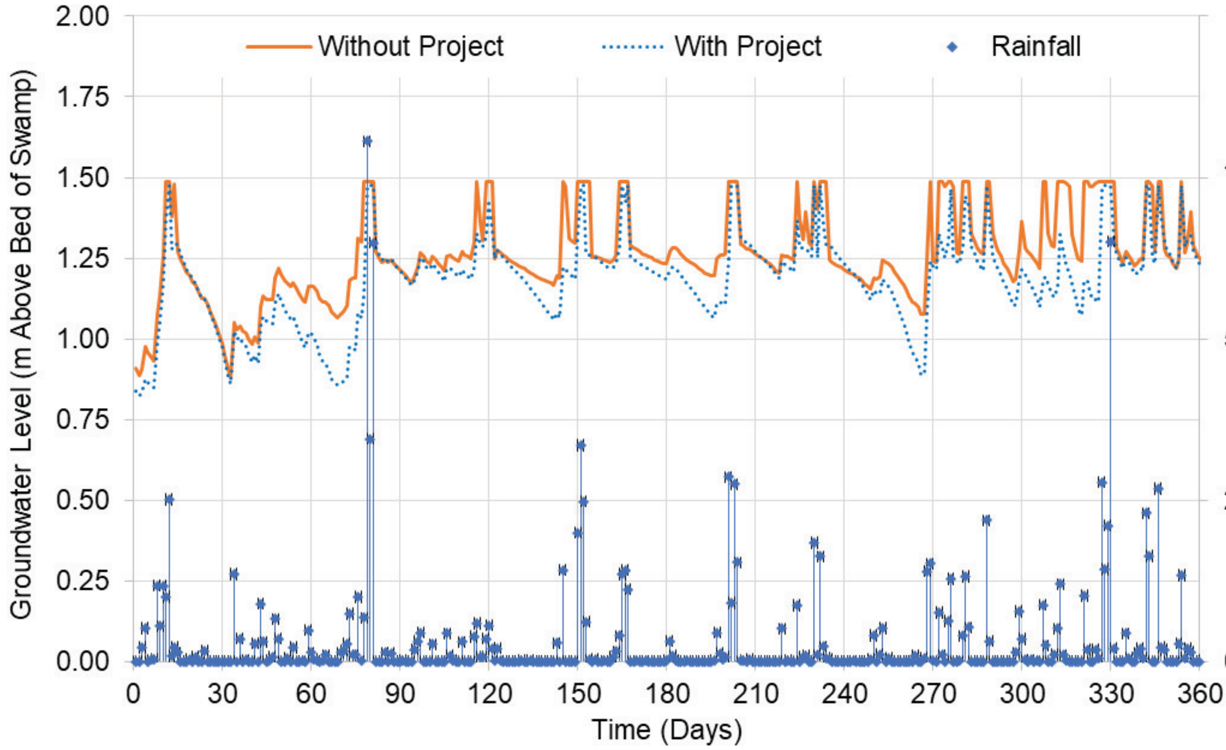

Figure 31 Simulated Groundwater Levels – Swamp Type B, Median Climate Scenario

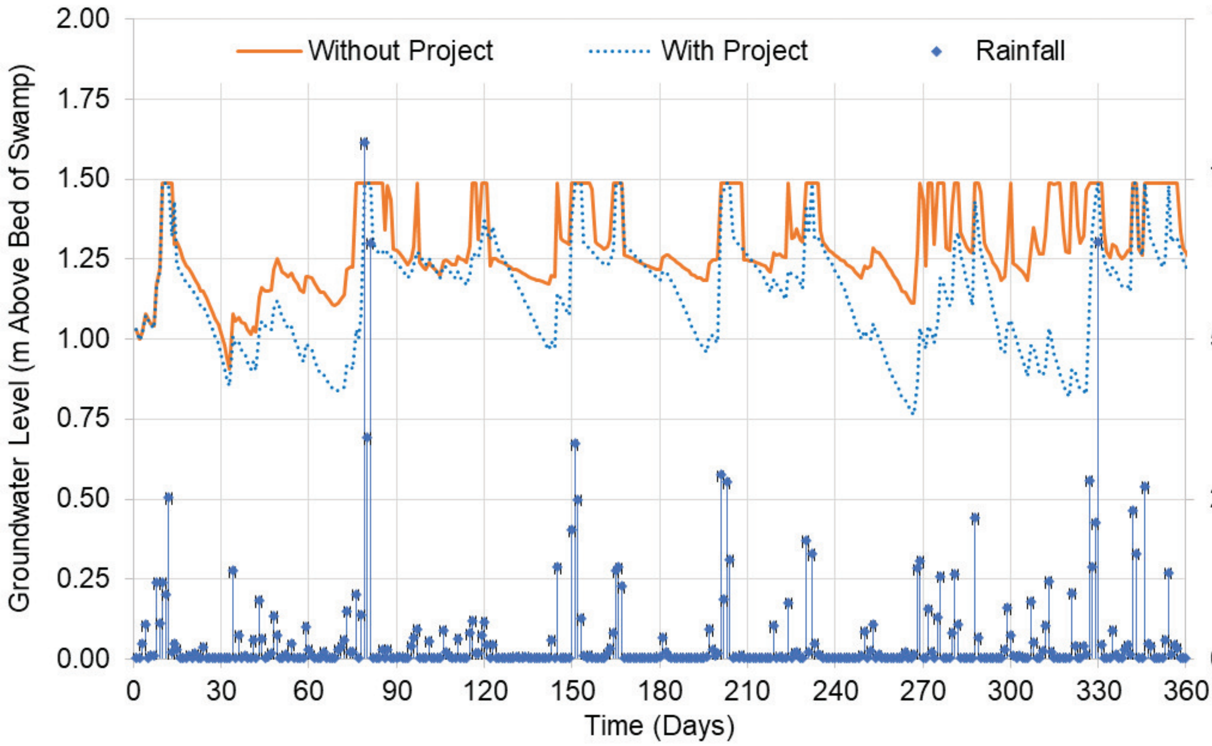

Figure 32 Simulated Groundwater Levels – Swamp Type C, Median Climate Scenario

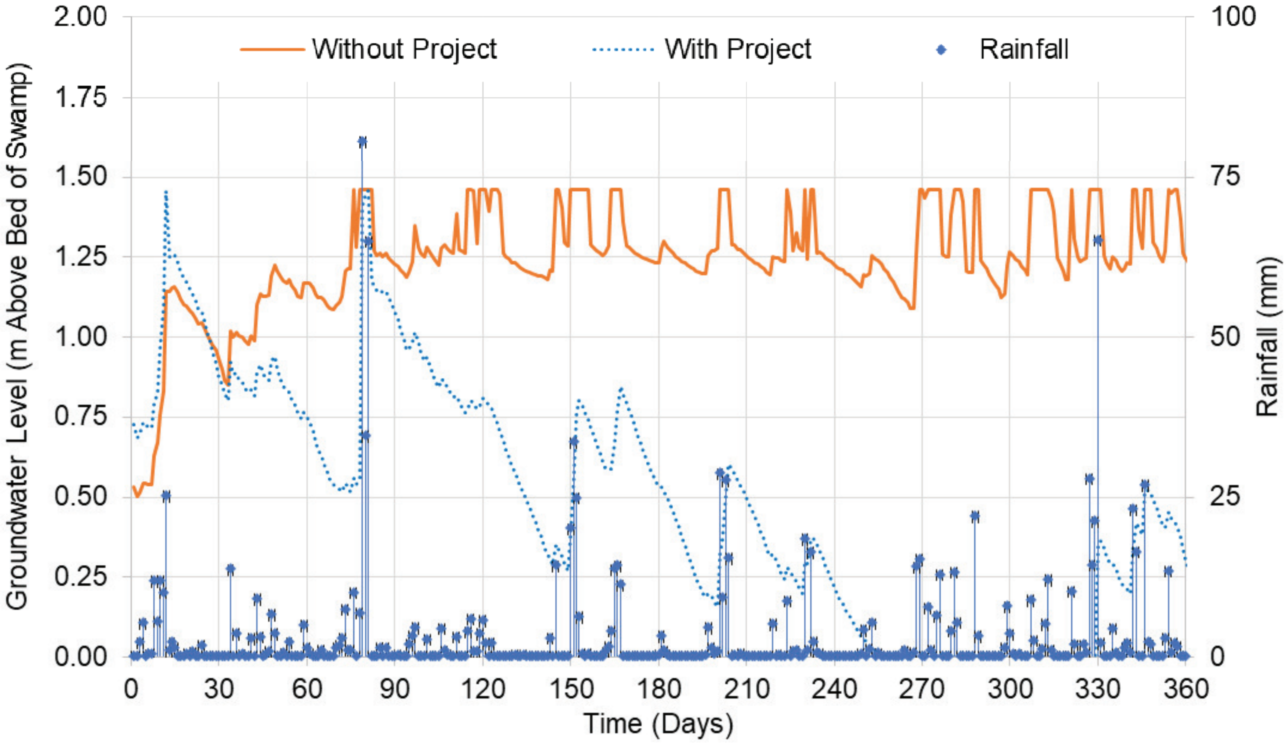

Figure 33 Simulated Groundwater Levels – Swamp Type D, Median Climate Scenario

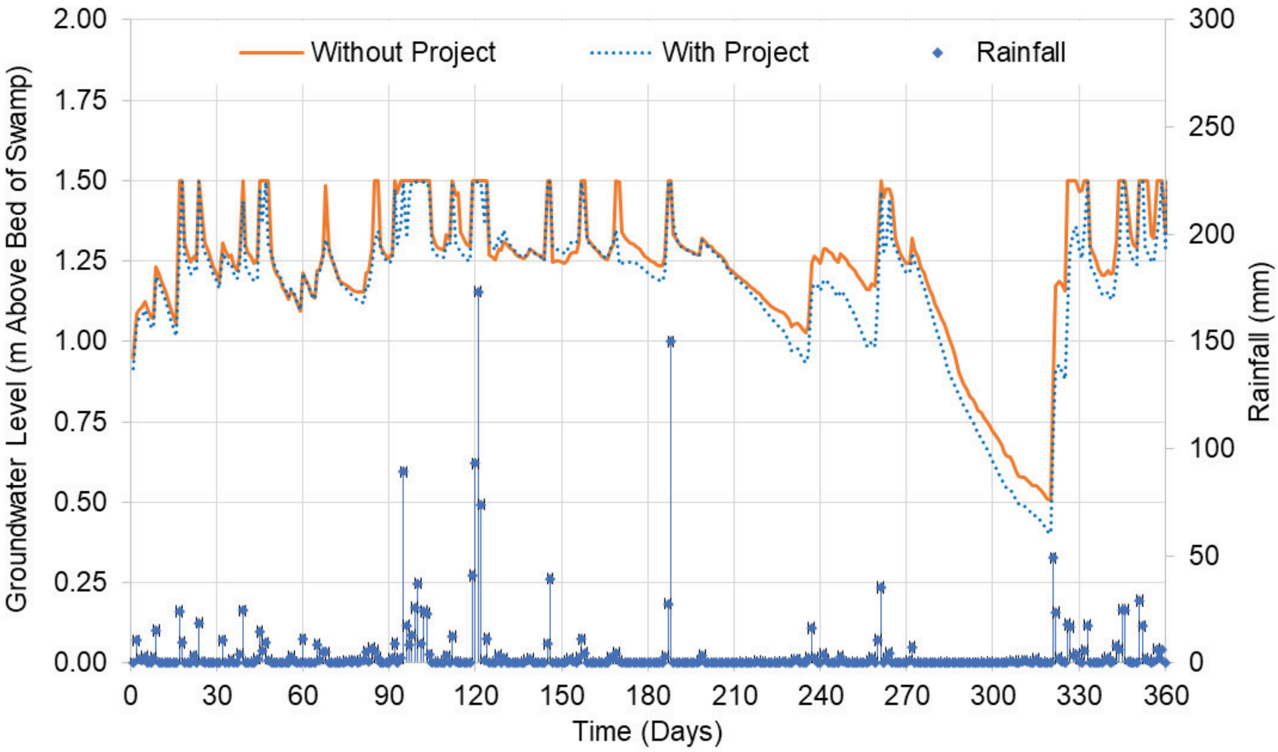

Figure 34 Simulated Groundwater Levels – Swamp Type A, 90th Percentile Climate Scenario

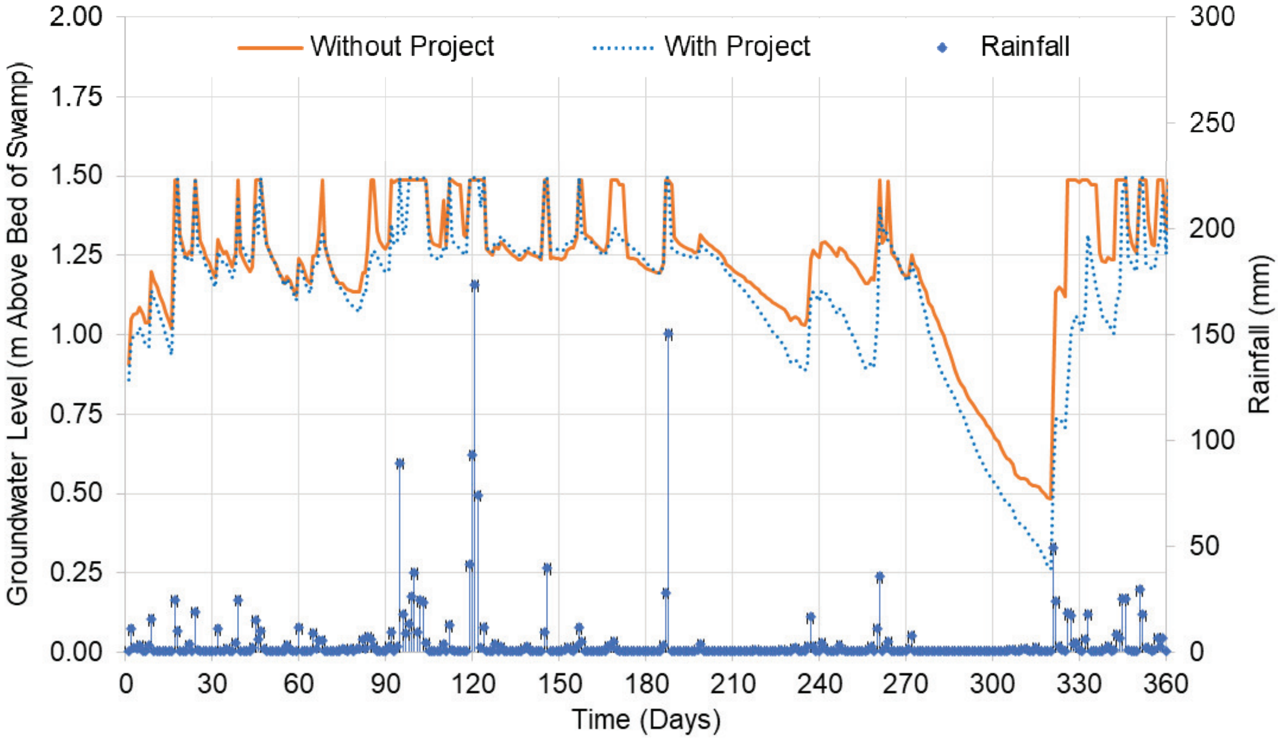

Figure 35 Simulated Groundwater Levels – Swamp Type B, 90th Percentile Climate Scenario

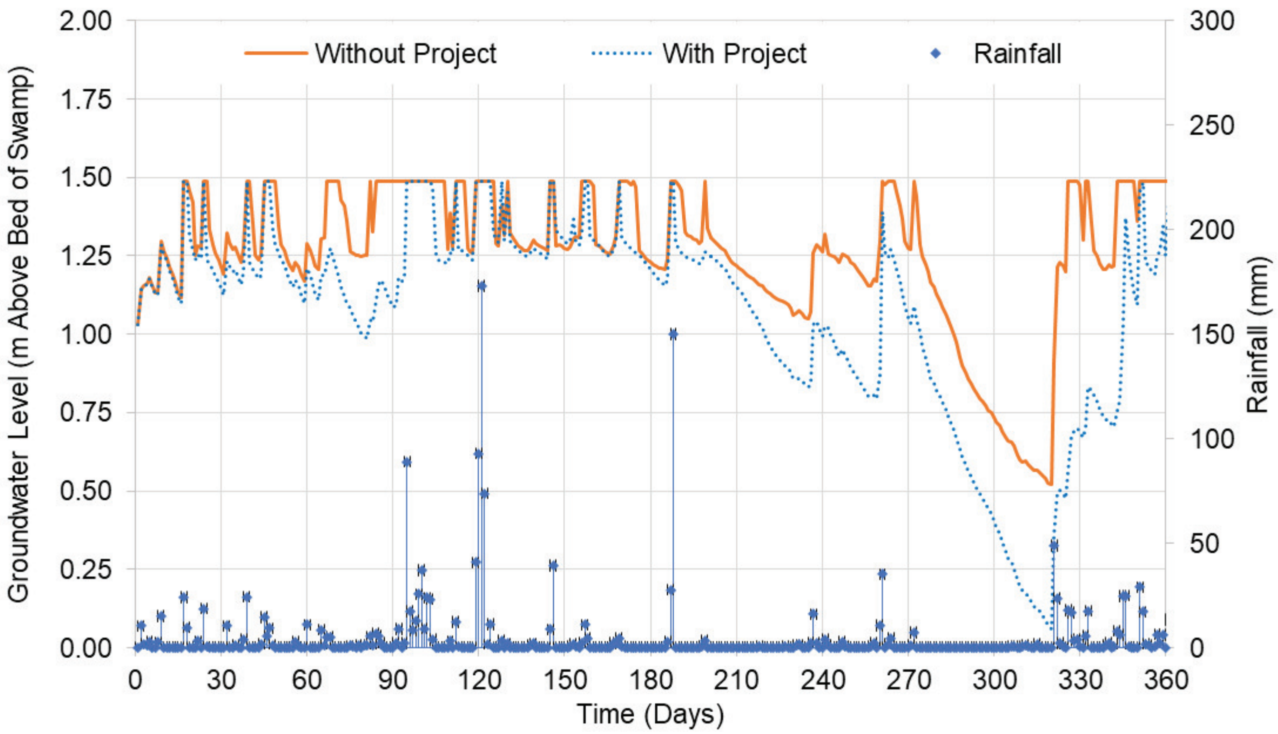

Figure 36 Simulated Groundwater Levels – Swamp Type C, 90th Percentile Climate Scenario

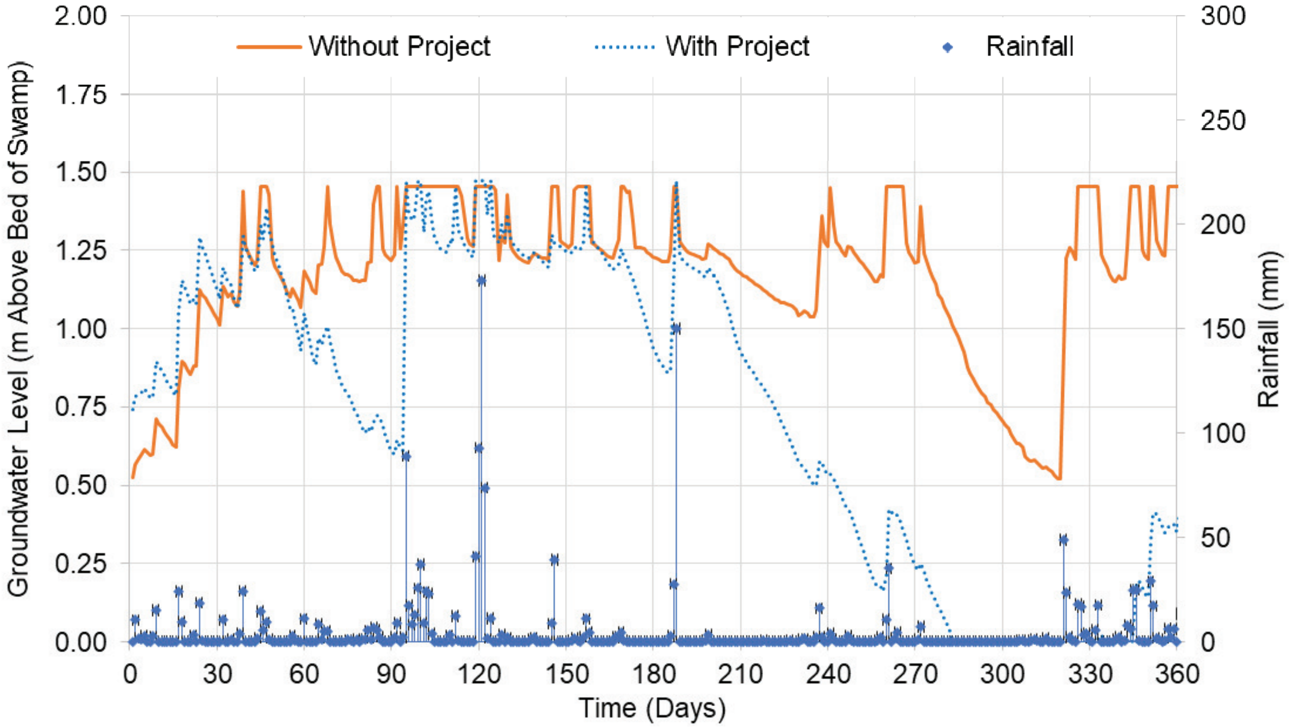

Figure 37 Simulated Groundwater Levels – Swamp Type D, 90th Percentile Climate Scenario

The existing swamps exhibit wetting and drying cycles in response to climate cycles (refer to graphs of monitoring data from swamps in Areas 5 and 6 shown in Appendix A). These cycles result in groundwater levels which fluctuate from complete saturation of the swamp during prolonged wet periods to the water table falling to near the bed of the swamp during prolonged low rainfall periods. The swamp model simulations indicate that mining-induced fracturing of the basement rocks below the swamps and consequential significant increased downward seepage has the potential to lead to the following.

- Swamp water levels that are likely to fall more rapidly during prolonged dry periods and take longer to recover during wetting periods. This is consistent with observed impacts from Area 3 swamps (Watershed, 2019).
- Impacts that are predicted to be greater in steeper swamps than in flatter swamps.

5.2.2 Catchment Hydrological Modelling

In addition to impacts to swamp hydrology, there are also potential subsidence impacts to streamflow in the Project Area catchments. To assess the implications of these impacts on the surface water catchments in the Project Area, catchment models have been developed for each catchment area as shown in Figure 38. These models were then used to simulate pre- and post-subsidence flow characteristics.

The AWBM was used to simulate the hydrological characteristics of catchments within the Project Area (refer Section 3.3.2.3). Model simulations were undertaken on a daily time-step for a one year period and for three rainfall sequences: median, 10th percentile (dry) and 90th percentile (wet) – as for the swamp seepage modelling (Section 5.2.1). The model input assumptions and results are detailed in the following sub-sections.

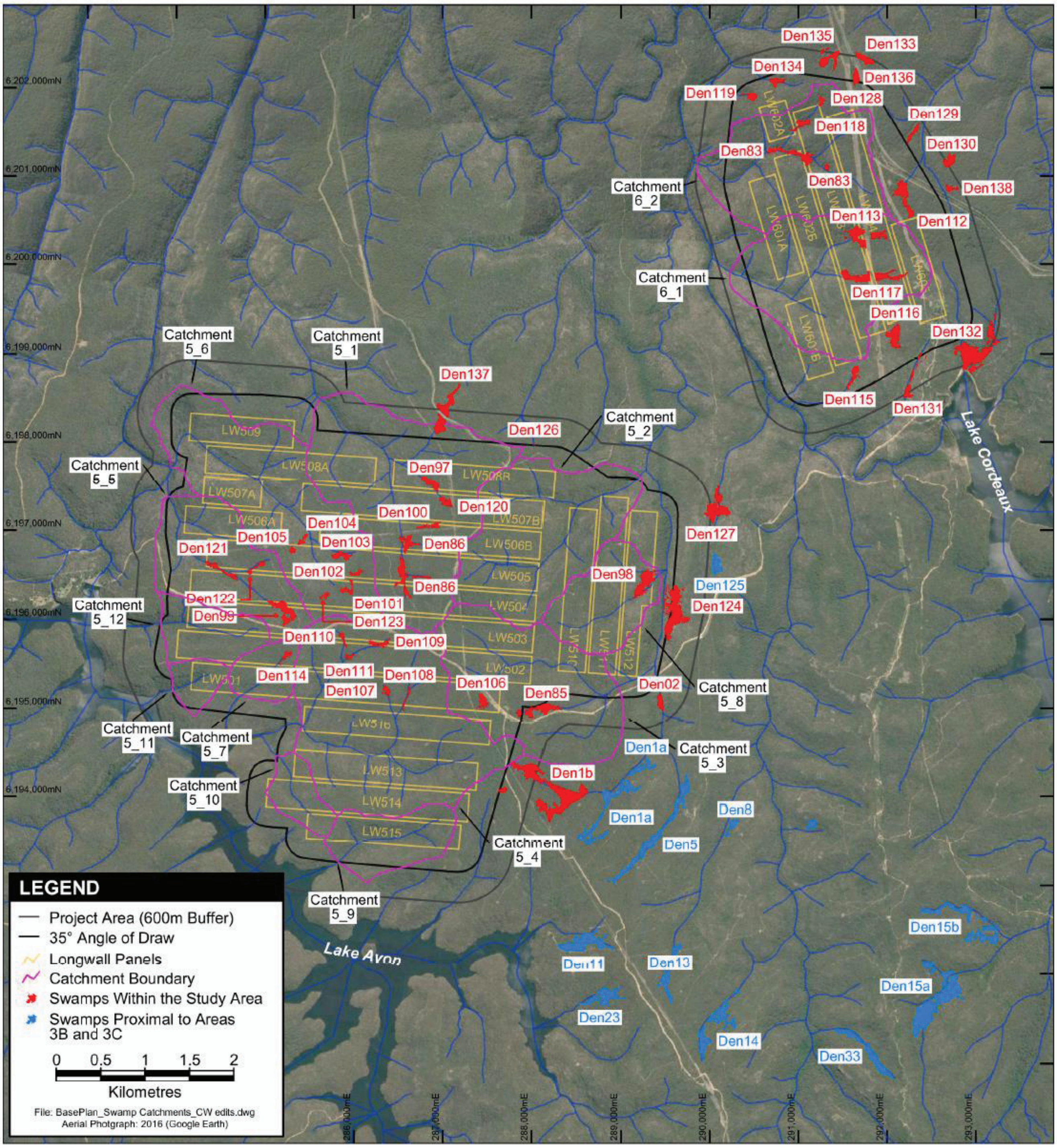

Figure 38 Modelled Swamps and Surface Water Catchments

5.2.2.1 Catchment Areas

The hydrological modelling was undertaken for 14 surface water catchments comprising the majority of the Project Area (based on the 35º degree angle of draw) and incorporating a total of 28 swamps. The swamps included in the assessment comprise the 26 swamps partially or entirely located above the proposed longwalls (refer Section 2.3.1) and two additional swamps which are located within associated catchments. Figure 38 shows the catchment boundaries and the swamps located within each catchment. The catchment boundary was assessed using 1 m interval topographic contour data for the Project Area produced from an Airborne Laser Scan (provided by South32) and 10 m contour data external to the Project Area, obtained from NASA SRTM[8]. The plan area of each swamp was obtained from Project baseline studies (Appendix D of the EIS) and used to calculate the total modelled swamp sub-catchment area. Table 31 lists the total area and swamp area within each catchment.

Table 31 Total Catchment and Swamp Area

Catchment Reference	Swamp Name or Location	Total Catchment Area (ha)	Total Swamp Area within Catchment (ha)	Proportion of Swamp in Catchment Area
5-1	Den 86	85.0	4.8	6%
	Den 100	7.4	0.8	11%
	Den 120	9.3	0.9	10%
	Den 97	55.5	1.4	3%
	Den 137	1.8	1.8	100%
	Catchment Outlet	350.0	9.8	3%
5-2	Catchment Outlet	253.4	0.0	0%
5-3	Den 85	24.8	2.8	11%
	Den 106	17.6	1.1	6%
	Catchment Outlet	258.0	3.8	1.5%
5-4	Den 107	11.0	0.5	5%
	Den 108	45.9	0.4	1%
	Den 109	21.5	1.0	4%
	Den 110	12.5	0.5	4%
	Den 111	49.5	0.4	1%
	Catchment Outlet	392.0	2.8	0.7%
5-5	Den 99	23.9	3.2	13%
	Den 122	10.2	0.6	6%
	Den 121	78.9	1.2	2%
	Catchment Outlet	166.0	5.0	3%
5-6	Den 101	23.8	0.8	3%
	Den 102	4.0	0.5	13%
	Den 103	19.9	1.2	6%
	Den 123	9.1	0.4	4%
	Den 105	3.6	0.4	11%
	Den 104	5.9	0.5	8%
	Catchment Outlet	302.0	3.8	1%
5-7	Den 114	9.2	0.6	7%
	Catchment Outlet	41.6	0.6	2%

8 NASA Shuttle Radar Topography Mission (SRTM) digital elevation model https://earthdata.nasa.gov/nasa-shuttle-radar-topography-mission-srtm-version-3-0-global-1-arc-second-data-released-over-asia-and-australia

Table 31 (Continued) Total Catchment and Swamp Area

Catchment Reference	Swamp Name or Location	Total Catchment Area (ha)	Total Swamp Area within Catchment (ha)	Proportion of Swamp in Catchment Area
5-8	Den 98	105.4	3.4	3%
	Catchment Outlet	105.4	3.4	3%
5-9	Catchment Outlet	85	0.0	0%
5-10	Catchment Outlet	40	0.0	0%
5-11	Catchment Outlet	28	0.0	0%
5-12	Catchment Outlet	69	0.0	0%
6-1	Den 113	37.9	3.6	10%
	Den 117	40.4	4.3	11%
	Catchment Outlet	253.0	8.0	3%
6-2	Den 128	7.4	0.5	6%
	Den 118	28.1	1.0	4%
	Den 83	149.7	2.8	2%
	Catchment Outlet	225.0	4.3	2%

5.2.2.2 Rainfall, Evaporation and Runoff Parameters

The same rainfall and evaporation data used in the swamp seepage modelling (refer Section 5.2.1) was used in the hydrological modelling.

The AWBM parameters for each catchment were adopted from previously undertaken modelling of catchments containing swamps within Hawkesbury Sandstone catchments (Gilbert & Associates, 2009). The adopted model parameters are listed in Table 32.

Table 32 AWBM Parameters

Model Parameter	Value
C1 (mm)	4
C2 (mm)	90
C3 (mm)	450
A1	0.151
A2	1 – A1 – A3
A3	Calculated for each catchment based on swamp area proportion of sub-catchment area (refer Table 31)
BFI	0.18
K_b	0.973
K_s	0.19
Evaporation factor	0.85

The C3 store in the AWBM simulates the swamp component of the catchment. The proportion of the catchment occupied by swamps is representative of the proportion of the catchment simulated by the C3 store (i.e. A3), therefore, the A2 and A3 parameters were changed for each catchment. Representative of swamps, the C3 store only contributes significantly to direct runoff during and following large rainfall events. Flow contributions at other times correspond to baseflow in the model, thereby reflecting the slow drainage/baseflow contributions from the swamps.

5.2.2.3 Catchment Deep Drainage

The impact of the Project on surface water loss to the groundwater system (deep drainage) was modelled by HydroSimulations (Appendix B of the EIS), with total annual rates provided for each catchment. The total deep drainage rates were scaled[9] and applied to the external (non-swamp) sub-catchment areas only, with the swamp deep drainage rates modelled separately (as described in Section 5.2.2.4). Table 33 presents the adopted total annual (scaled) deep drainage rates for each catchment.

Table 33 External (Non-Swamp) Sub-Catchment Total Annual Deep Drainage with Project

Catchment Reference	Deep Drainage With Project (ML/year)
5-1	188
5-2	213
5-3	71
5-4	327
5-5	114
5-6	272
5-7	47
5-8	64
5-9	68
5-10	29
5-11	20
5-12	45
6-1	5
6-2	46

Within the hydrological model, the maximum deep drainage rate for each catchment was set to the values in Table 33. The deep drainage rate was subtracted from the modelled total streamflow rate to simulate the surface water loss to the groundwater system due to the Project.

5.2.2.4 Swamp Deep Drainage

As described in Section 5.2.1, deep drainage rates for four different swamp types and three climatic sequences were derived for the 'Without Project' and 'With Project' cases using seepage modelling. The deep drainage rates (calculated per metre width) were multiplied by the total width of the swamps within each catchment, estimated from the 1 m interval topographic contour data for the Project Area (provided by South32) and swamp mapping (Appendix D of the EIS). The daily deep drainage rate for the swamps in each catchment was subtracted from the modelled total streamflow rate to simulate the surface water loss to the groundwater system for 'Without Project' and 'With Project' cases. This was in addition to the deep drainage losses described in Section 5.2.2.3.

9 On the basis of non-swamp to total catchment area

5.2.3 Simulated Effects on Streamflow

Table 34 presents the results of the streamflow assessment for the 'Without Project' and 'With Project' cases and for three representative rainfall years: median, 10^{th} percentile (dry) and 90^{th} percentile (wet). The contribution of each individual swamp yield to the total catchment yield is presented as a percentage for the median climatic conditions for the 'Without Project' and 'With Project' cases. The potential streamflow yield reduction for the 'With Project' case is presented for the median climatic condition and for the swamp external catchment and swamp itself.

Table 34 Estimated Effects on Streamflow at Swamp and Catchment Outlet

Catchment	Sub-Catchment		Contribution of Swamp Yield to Total Catchment Yield (Median Climatic Conditions)		Estimated Streamflow Yield (Median Climatic Conditions)			Estimated Streamflow Yield (10th Percentile Climatic Conditions)			Estimated Streamflow Yield (90th Percentile Climatic Conditions)			Potential Streamflow Yield Reduction with Project (Median Climatic Conditions)	
			Without Project	With Project	Without Project (ML/year)	With Project (ML/year)	% Reduction	Without Project (ML/year)	With Project (ML/year)	% Reduction	Without Project (ML/year)	With Project (ML/year)	% Reduction	External Catchment (ML/year)	Swamp (ML/year)
5-1	Den 86	External Catchment			427	383	10%	39	0	100%	836	792	5%	44.0	
		Swamp Outlet	1.4%	1.1%	453	402	11%	41	0	100%	887	835	6%		7.3
	Den 100	External Catchment			35	31	11%	3.2	0	100%	69	65	6%	4.0	
		Swamp Outlet	0.2%	0.2%	40	34	14%	3.6	0	100%	78	72	7%		1.6
	Den 120	External Catchment			45	40	11%	4.0	0	100%	87	83	5%	5.0	
		Swamp Outlet	0.2%	0.2%	50	43	13%	4.5	0	100%	97	91	7%		1.6
	Den 97	External Catchment			239	214	10%	22	0	100%	468	443	5%	25.0	
		Swamp Outlet	0.4%	0.3%	246	219	11%	22	0	100%	482	454	6%		2.3
	Den 137	External Catchment			0	0	-	0	0	-	0	0	-	0.0	
		Swamp Outlet	0.5%	0.4%	9	7	28%	0.9	0	100%	19	16	16%		2.6
	Downstream Catchment				1,066	956	10%	97.0	0	100%	2,087	1,977	5%	110.0	
	Total Catchment				**1,864**	**1,660**	**11%**	**169**	**0**	**100%**	**3,650**	**3,446**	**6%**	**189.0**	**15.4**

Note: Totals may not exactly match due to rounding error.

Table 34 (Continued) Estimated Effects on Streamflow at Swamp and Catchment Outlet

Catchment	Sub-Catchment		Contribution of Swamp Yield to Total Catchment Yield (Median Climatic Conditions)		Estimated Streamflow Yield (Median Climatic Conditions)			Estimated Streamflow Yield (10th Percentile Climatic Conditions)			Estimated Streamflow Yield (90th Percentile Climatic Conditions)			Potential Streamflow Yield Reduction with Project (Median Climatic Conditions)	
			Without Project	With Project	Without Project (ML/year)	With Project (ML/year)	% Reduction	Without Project (ML/year)	With Project (ML/year)	% Reduction	Without Project (ML/year)	With Project (ML/year)	% Reduction	External Catchment (ML/year)	Swamp (ML/year)
5-2					**1378**	**1165**	**15%**	**123**	**0**	**100%**	**2,654**	**2,440**	**8%**	**212.9**	
5-3	Den 106	External Catchment			89	84	6%	8.0	3.4	58%	172	168	2%	5.0	
		Swamp Outlet	0.4%	0.3%	94	88	7%	8.5	1.4	83%	184	177	3%		1.4
	Den 85	External Catchment			119	113	5%	10.7	4.5	58%	230	224	3%	6.0	
		Swamp Outlet	1.0%	0.7%	133	122	9%	11.9	0.4	96%	259	248	5%		5.7
	Downstream Catchment				1,160	1,101	5%	104	45	57%	2,255	2,195	3%	59.0	
	Total Catchment				**1,388**	**1,311**	**6%**	**125**	**46**	**63%**	**2,698**	**2,620**	**3%**	**70.0**	**7.1**
5-4	Den 107	External Catchment			57	48	16%	5.1	0	100%	110	101	8%	9.0	
		Swamp Outlet	0.1%	0.1%	60	49	17%	5.2	0	100%	115	105	9%		1.4
	Den 108	External Catchment			246	208	15%	22	0	100%	476	438	8%	38.0	
		Swamp Outlet	0.1%	0.1%	249	210	16%	22	0	100%	481	442	8%		0.8
	Den 109	External Catchment			111	94	15%	10	0	100%	215	198	8%	17.0	
		Swamp Outlet	0.2%	0.2%	116	98	16%	10	0	100%	225	206	8%		1.6

Table 34 (Continued) Estimated Effects on Streamflow at Swamp and Catchment Outlet

Catchment	Sub-Catchment		Contribution of Swamp Yield to Total Catchment Yield (Median Climatic Conditions)		Estimated Streamflow Yield (Median Climatic Conditions)			Estimated Streamflow Yield (10^{th} Percentile Climatic Conditions)			Estimated Streamflow Yield (90^{th} Percentile Climatic Conditions)			Potential Streamflow Yield Reduction with Project (Median Climatic Conditions)	
			Without Project	With Project	Without Project (ML/year)	With Project (ML/year)	% Reduction	Without Project (ML/year)	With Project (ML/year)	% Reduction	Without Project (ML/year)	With Project (ML/year)	% Reduction	External Catchment (ML/year)	Swamp (ML/year)
5-4	Den 110	External Catchment			65	55	15%	6	0	100%	125	115	8%	10.0	
		Swamp Outlet	0.1%	0.04%	67	56	17%	6	0	100%	225	206	8%		1.6
	Den 111	External Catchment			82	69	16%	7	0	100%	159	146	8%	13.0	
		Swamp Outlet	0.1%	0.1%	84	70	17%	8	0	100%	68	61	10%		1.0
	Downstream Catchment				1,546	1,306	16%	138	0	100%	2,990	2,751	8%	240.0	
	Total Catchment				**2,122**	**1,789**	**16%**	**190**	**0**	**100%**	**4,104**	**3,771**	**8%**	**327.0**	**6.4**
5-5	Den 99	External Catchment			110	95	14%	10	0	100%	216	210	3%	15.0	
		Swamp Outlet	2.0%	1.5%	127	106	17%	11	0	100%	250	228	9%		6.3
	Den 122	External Catchment			51	44	14%	5	0	100%	100	93	7%	7.0	
		Swamp Outlet	0.4%	0.1%	54	45	17%	5	0	100%	106	97	8%		2.1
	Den 121	External Catchment			232	201	13%	21	0	100%	456	424	7%	31.0	
		Swamp Outlet	0.7%	0.4%	238	204	14%	21	0	100%	467	433	7%		3.5
	Downstream Catchment				462	400	13%	42	0	100%	906	844	7%	62.0	
	Total Catchment				**882**	**755**	**14%**	**80**	**0**	**100%**	**1,729**	**1,602**	**7%**	**115.0**	**11.9**

Table 34 (Continued) Estimated Effects on Streamflow at Swamp and Catchment Outlet

Catchment	Sub-Catchment		Contribution of Swamp Yield to Total Catchment Yield (Median Climatic Conditions)		Estimated Streamflow Yield (Median Climatic Conditions)			Estimated Streamflow Yield (10th Percentile Climatic Conditions)			Estimated Streamflow Yield (90th Percentile Climatic Conditions)			Potential Streamflow Yield Reduction with Project (Median Climatic Conditions)	
			Without Project	With Project	Without Project (ML/year)	With Project (ML/year)	% Reduction	Without Project (ML/year)	With Project (ML/year)	% Reduction	Without Project (ML/year)	With Project (ML/year)	% Reduction	External Catchment (ML/year)	Swamp (ML/year)
5-6	Den 101	External Catchment			124	103	17%	11	0	100%	240	219	9%	21.0	
		Swamp Outlet	0.3%	0.2%	128	106	17%	11	0	100%	249	226	9%		1.1
	Den 102	External Catchment			19	15	21%	2	0	100%	36	33	8%	4.0	
		Swamp Outlet	0.1%	0.1%	21	17	19%	2	0	100%	41	37	10%		0.1
	Den 103	External Catchment			80	66	18%	7	0	100%	155	141	9%	14.0	
		Swamp Outlet	0.4%	0.2%	86	69	20%	8	0	100%	167	150	10%		2.9
	Den 123	External Catchment			47	39	17%	4	0	100%	91	83	9%	8.0	
		Swamp Outlet	0.1%	0.1%	49	40	18%	4.3	0	100%	95	86	9%		0.9
	Den 105	External Catchment			17	14	18%	1.6	0	100%	34	31	9%	3.0	
		Swamp Outlet	0.1%	0.1%	19	15	22%	1.5	0	100%	37	33	12%		1.3
	Den 104	External Catchment			10	8	20%	0.9	0	100%	19	17	11%	2.0	
		Swamp Outlet	0.1%	0.1%	12	9	25%	1	0	100%	24	21	11%		1.0
	Downstream Catchment				1,546	1,306	16%	138	0	100%	2,990	2,751	8%	240.0	

Table 34 (Continued) Estimated Effects on Streamflow at Swamp and Catchment Outlet

Catchment	Sub-Catchment		Contribution of Swamp Yield to Total Catchment Yield (Median Climatic Conditions)		Estimated Streamflow Yield (Median Climatic Conditions)			Estimated Streamflow Yield (10^{th} Percentile Climatic Conditions)			Estimated Streamflow Yield (90^{th} Percentile Climatic Conditions)			Potential Streamflow Yield Reduction with Project (Median Climatic Conditions)	
			Without Project	With Project	Without Project (ML/year)	With Project (ML/year)	% Reduction	Without Project (ML/year)	With Project (ML/year)	% Reduction	Without Project (ML/year)	With Project (ML/year)	% Reduction	External Catchment (ML/year)	Swamp (ML/year)
5-6	**Total Catchment**				**1,626**	**1,344**	**17%**	**145**	**0**	**100%**	**3,154**	**2,873**	**9%**	**273.0**	**7.4**
5-7	Den 114	External Catchment			46	36	22%	4	0	100%	90	80	11%	10.0	
		Swamp Outlet	1.8%	1.1%	50	38	24%	4	0	100%	96	85	12%		2.0
	Downstream Catchment				174	137	21%	16	0	100%	338	301	11%	37.0	
	Total Catchment				**224**	**174**	**22%**	**20**	**0**	**100%**	**434**	**385**	**11%**	**47.2**	**2.0**
5-8	Den 98	External Catchment			543	480	12%	49	0	100%	1065	1001	6%	63.0	
		Swamp Outlet	3.1%	2.2%	561	491	12%	51	0	100%	1,100	1,030	6%		6.6
	Total Catchment				**561**	**491**	**12%**	**51**	**0**	**100%**	**1,100**	**1,030**	**6%**	**63.0**	**6.6**
5-9					**464**	**396**	**15%**	**41**	**0**	**100%**	**893**	**825**	**8%**	**68.1**	
5-10					**217**	**188**	**14%**	**19**	**0**	**100%**	**419**	**390**	**7%**	**29.4**	
5-11					**151**	**131**	**13%**	**13**	**0**	**100%**	**291**	**271**	**7%**	**20.1**	
5-12					**373**	**329**	**12%**	**33**	**0**	**100%**	**719**	**674**	**6%**	**44.6**	
6-1	Den 113	External Catchment			182	181	1%	17	16	6%	357	356	0%	1.0	
		Swamp Outlet	1.4%	1.1%	201	195	3%	18	9	49%	395	389	1%		5.2

Table 34 (Continued) Estimated Effects on Streamflow at Swamp and Catchment Outlet

Catchment	Sub-Catchment		Contribution of Swamp Yield to Total Catchment Yield (Median Climatic Conditions)		Estimated Streamflow Yield (Median Climatic Conditions)			Estimated Streamflow Yield (10th Percentile Climatic Conditions)			Estimated Streamflow Yield (90th Percentile Climatic Conditions)			Potential Streamflow Yield Reduction with Project (Median Climatic Conditions)	
			Without Project	With Project	Without Project (ML/year)	With Project (ML/year)	% Reduction	Without Project (ML/year)	With Project (ML/year)	% Reduction	Without Project (ML/year)	With Project (ML/year)	% Reduction	External Catchment (ML/year)	Swamp (ML/year)
6-1	Den 117	External Catchment			192	191	1%	17	17	2%	376	375	0%	1.0	
		Swamp Outlet	1.7%	1.3%	214	208	3%	20	9	55%	421	414	2%		5.4
	Downstream Catchment				927	923	0.4%	84	81	4%	1,818	1,815	0%	4.0	
	Total Catchment				**1,342**	**1,326**	**1%**	**122**	**99**	**19%**	**2,634**	**2,618**	**1%**	**6.0**	**10.6**
6-2	Den 128	External Catchment			37	36	4%	3	2	42%	72	71	1%	1.4	
		Swamp Outlet	0.2%	0.1%	39	36	8%	3.5	0.5	86%	77	74	4%		1.7
	Den 118	External Catchment			145	139	4%	13.1	7.4	44%	283	277	2%	6.0	
		Swamp Outlet	0.5%	0.4%	151	143	5%	14	6	59%	293	286	2%		1.2
	Den 83	External Catchment			598	574	4%	54	30	44%	1,164	1,140	2%	24.0	
		Swamp Outlet	1.2%	0.8%	613	584	5%	55	27	52%	1,194	1,164	3%		5.4
	Downstream Catchment				403	387	4%	36	21	44%	786	770	2%	16.0	
	Total Catchment				**1,206**	**1,151**	**5%**	**109**	**53**	**51%**	**2,349**	**2,293**	**2%**	**47.4**	**8.2**

In summary, the model results presented in Table 34 indicate that for catchments overlying Area 5, there would be a 6% to 22% reduction in streamflow due to the Project for a median climatic year (63% to 100% for 10th percentile climate and 3% to 11% for 90th percentile climate). For Area 6, the results indicate there would be a 1% to 5% reduction in streamflow due to the Project for a median climatic year (19% to 51% for the 10th percentile climate and 1% to 2% for the 90th percentile climate). It should be noted that the streamflow reduction estimation for the 10th percentile climatic condition is a conservative estimate based on constant total annual estimates of deep drainage to the external (non-swamp) catchment provided by HydroSimulations (Appendix B of the EIS).

Table 34 illustrates that the potential streamflow loss due to increased deep drainage from the base of the swamps as a result of the Project ranges from 0.3% to 0.9% of the estimated current total catchment yield (without the Project). The majority of streamflow loss arises from increased deep drainage from the external catchment area, as opposed to the swamps.

The simulated streamflow reductions are within the range of impacts observed in Dendrobium Area 3B following longwall mining. A reduction in total discharge between 7% and 28% has been reported at monitoring sites on the upper section of Donalds Castle Creek as detailed in Section 4.2.4 while a reduction in total discharge of 6% has been reported for a Lake Avon tributary (LA4S1), as detailed in Section 4.4.

Figure 39 to Figure 52 show simulated flow duration curves at the outlet of each catchment for 'Without Project' and 'With Project' cases.

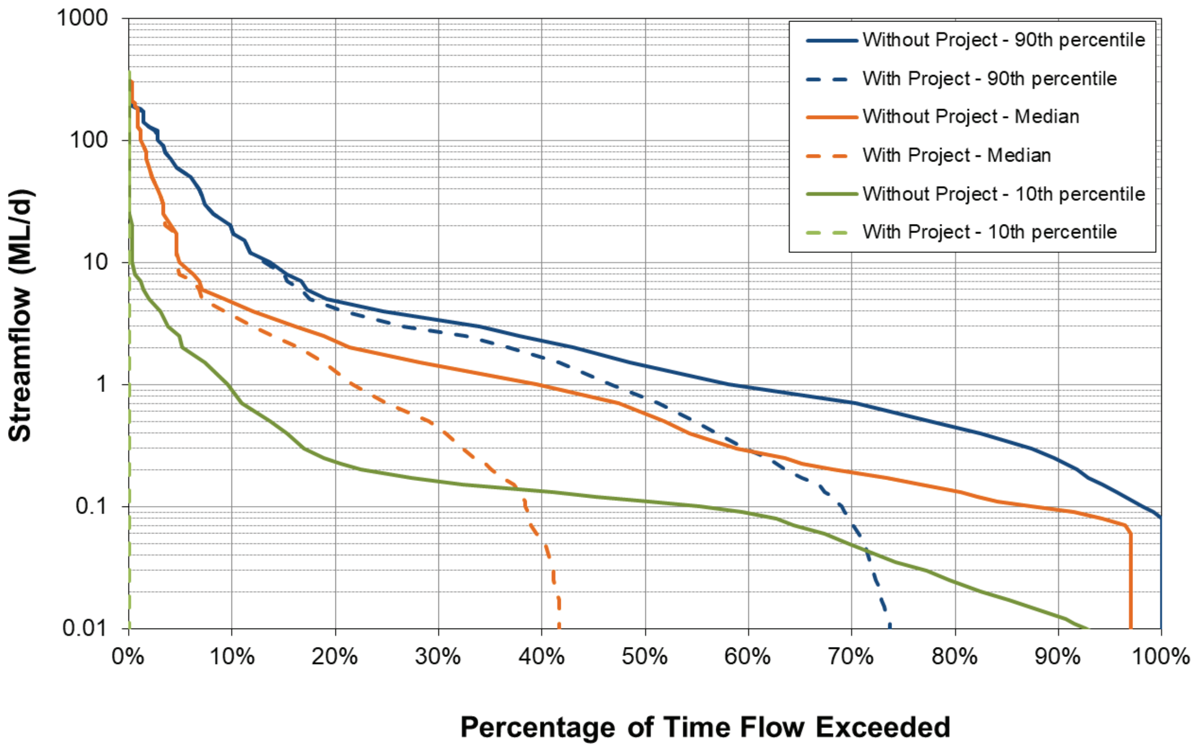

Figure 39 Catchment 5-1 Simulated Flow Duration Curve

Figure 39 shows that for the 'Without Project' case and median rainfall year, the median streamflow rate at the outlet of Catchment 5-1, exceeded approximately 50% of the time, is predicted as 0.6 ML/d. For the 'With Project' case and median rainfall year, an exceedance of 0.6 ML/d is predicted to occur approximately 28% of the time (as opposed to 50% of the time for the 'Without Project' case).

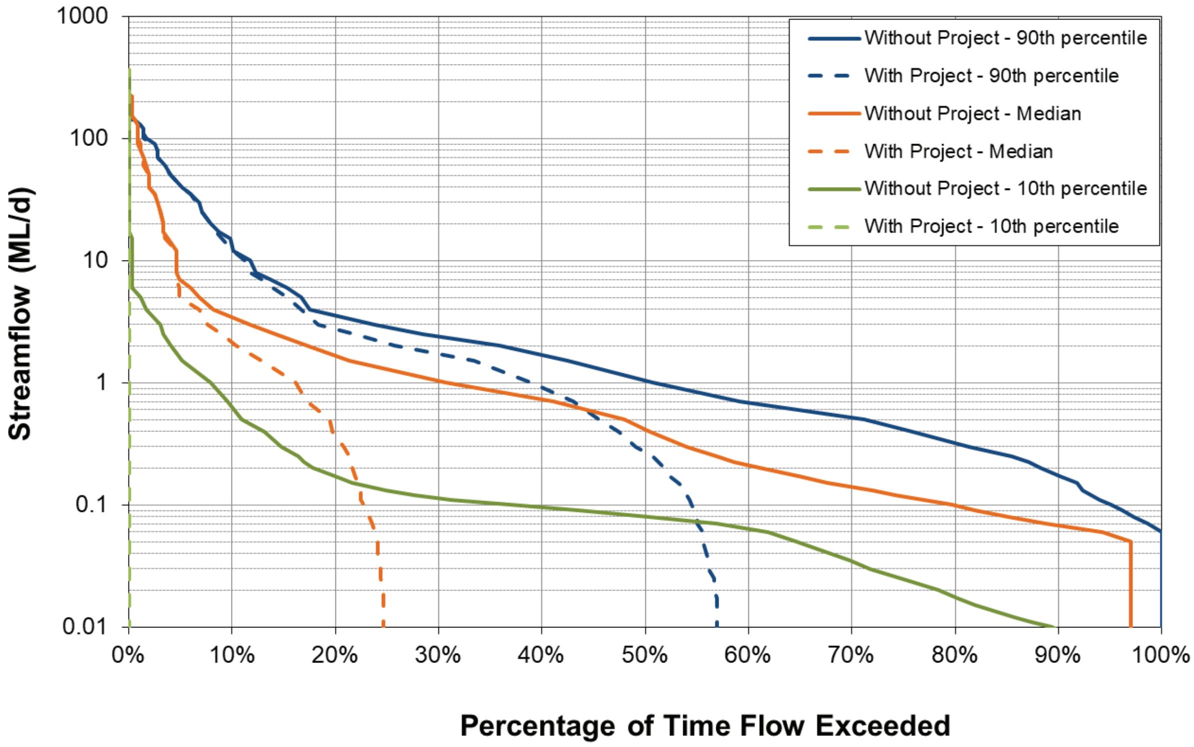

Figure 40 Catchment 5-2 Simulated Flow Duration Curve

Figure 40 shows that for the 'Without Project' case and median rainfall year, the streamflow rate at the outlet of Catchment 5-2, exceeded approximately 50% of the time, is predicted as 0.4 ML/d. For the 'With Project' case and median rainfall year, an exceedance of 0.4 ML/d is predicted to occur approximately 20% of the time (as opposed to 50% of the time for the 'Without Project' case).

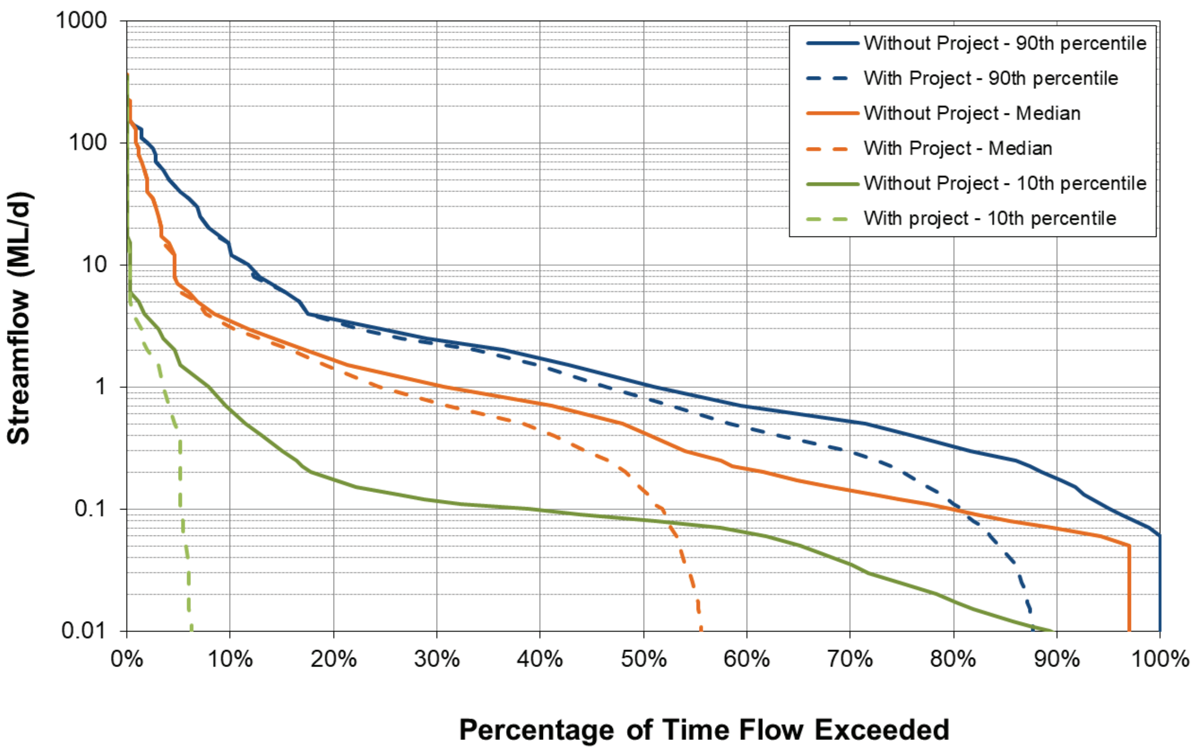

Figure 41 Catchment 5-3 Simulated Flow Duration Curve

Figure 41 shows that for the ‘Without Project’ case and median rainfall year, the streamflow rate at the outlet of Catchment 5-3, exceeded approximately 50% of the time, is predicted as 0.4 ML/d. For the ‘With Project’ case and median rainfall year, exceedance of 0.4 ML/d is predicted to occur approximately 41% of the time (as opposed to 50% of the time for the ‘Without Project’ case).

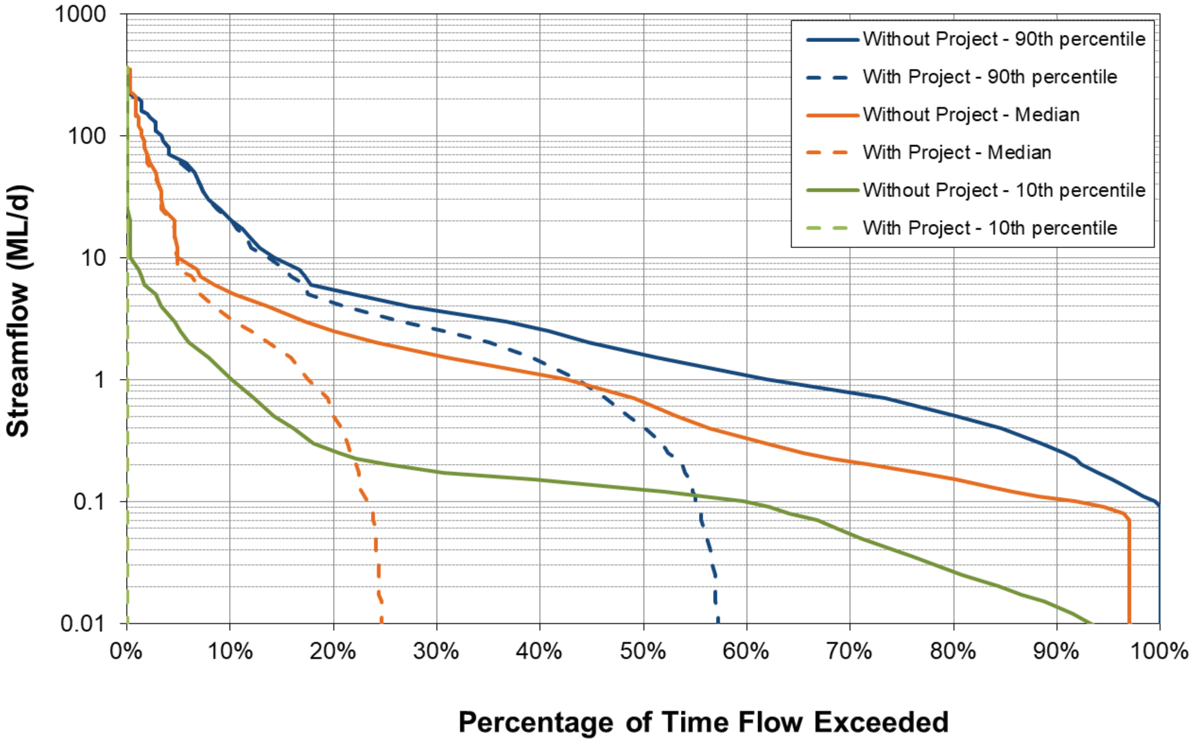

Figure 42 Catchment 5-4 Simulated Flow Duration Curve

Figure 42 shows that for the ‘Without Project’ case and median rainfall year, the streamflow rate at the outlet of Catchment 5-4, exceeded approximately 50% of the time, is predicted as 0.64 ML/d. For the ‘With Project’ case and median rainfall year, exceedance of 0.64 ML/d is predicted to occur approximately 19% of the time (as opposed to 50% of the time for the ‘Without Project’ case).

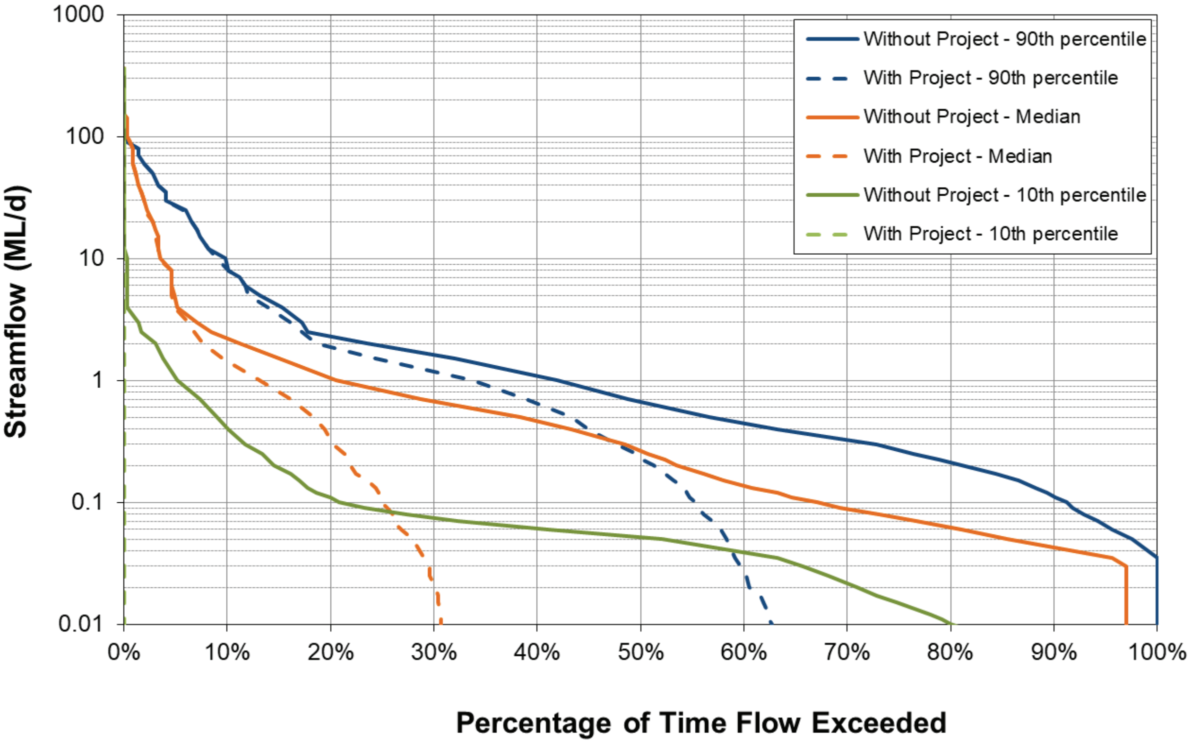

Figure 43 Catchment 5-5 Simulated Flow Duration Curve

Figure 43 shows that for the 'Without Project' case and median rainfall year, the streamflow rate at the outlet of Catchment 5-5, exceeded approximately 50% of the time, is predicted as 0.26 ML/d. For the 'With Project' case and median rainfall year, exceedance of 0.26 ML/d is predicted to occur approximately 21% of the time (as opposed to 50% of the time for the 'Without Project' case).

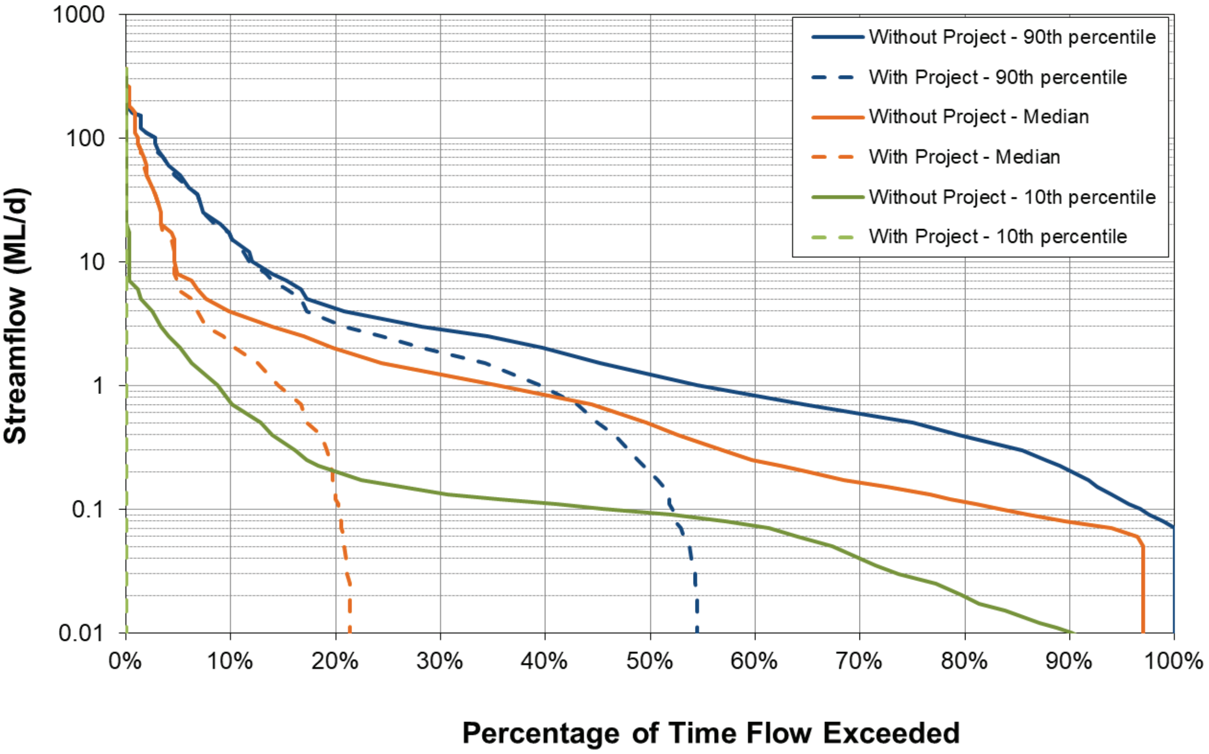

Figure 44 Catchment 5-6 Simulated Flow Duration Curve

Figure 44 shows that for the 'Without Project' case and median rainfall year, the streamflow rate at the outlet of Catchment 5-6, exceeded approximately 50% of the time, is predicted as 0.5 ML/d. For the 'With Project' case and median rainfall year, exceedance of 0.5 ML/d is predicted to occur approximately 18% of the time (as opposed to 50% of the time for the 'Without Project' case).

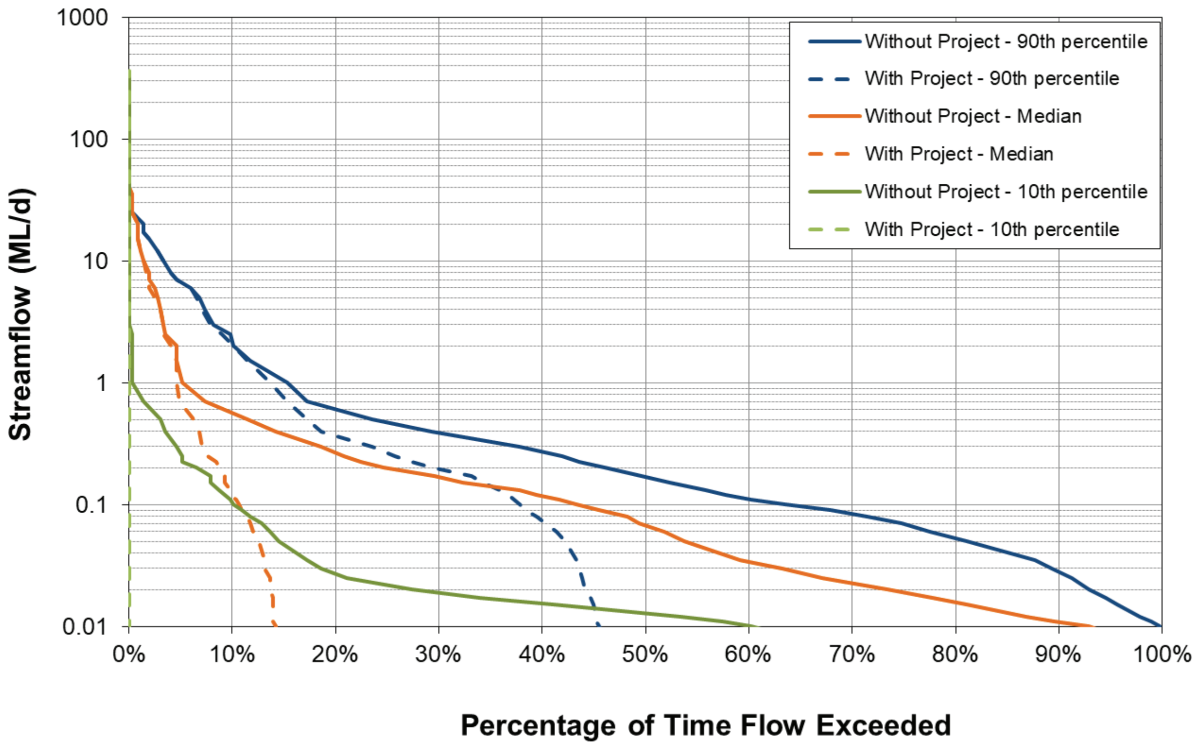

Figure 45 Catchment 5-7 Simulated Flow Duration Curve

Figure 45 shows that for the 'Without Project' case and median rainfall year, the streamflow rate at the outlet of Catchment 5-7, exceeded approximately 50% of the time, is predicted as 0.07 ML/d. For the 'With Project' case and median rainfall year, exceedance of 0.07 ML/d is predicted to occur approximately 13% of the time (as opposed to 50% of the time for the 'Without Project' case).

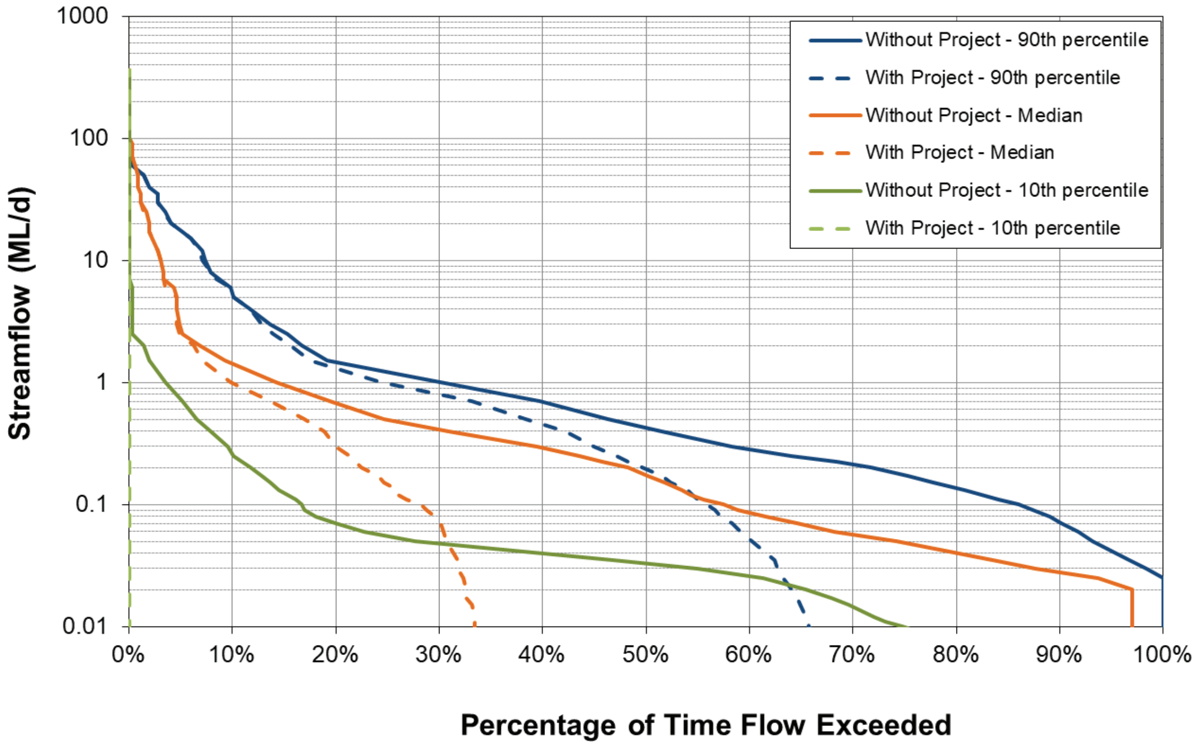

Figure 46 Catchment 5-8 Simulated Flow Duration Curve

Figure 46 shows that for the 'Without Project' case and median rainfall year, the streamflow rate at the outlet of Catchment 5-8, exceeded approximately 50% of the time, is predicted as 0.17 ML/d. For the 'With Project' case and median rainfall year, exceedance of 0.17 ML/d is predicted to occur approximately 24% of the time (as opposed to 50% of the time for the 'Without Project' case).

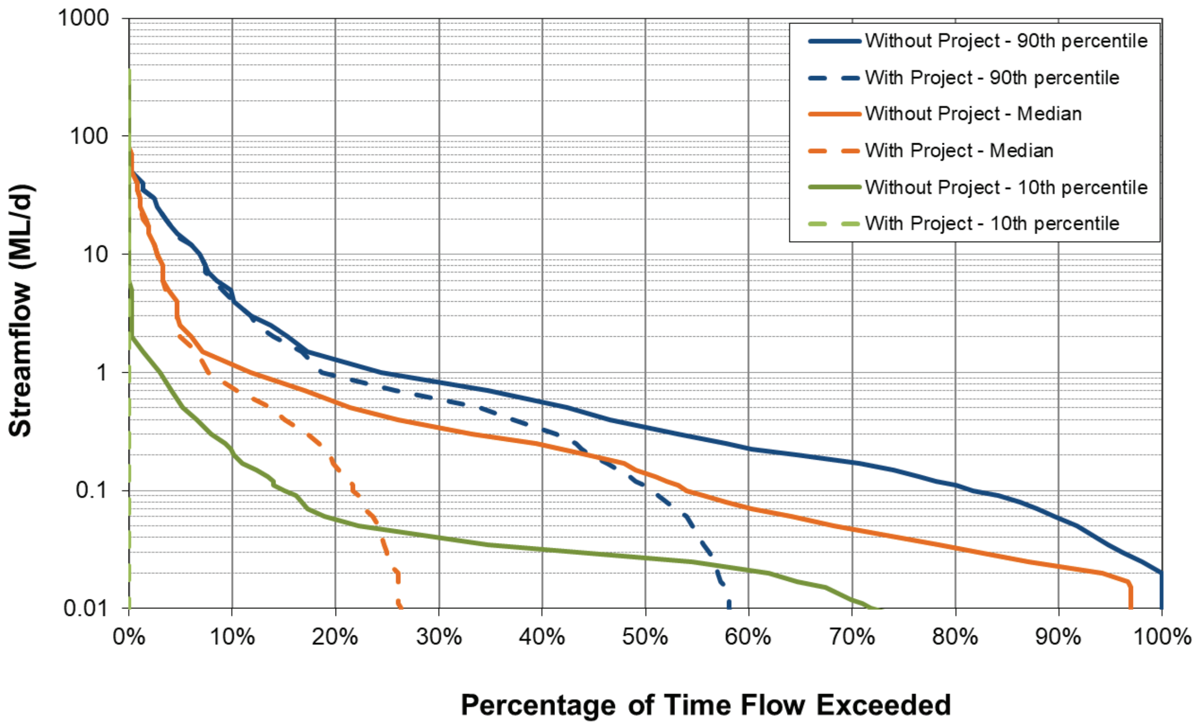

Figure 47 Catchment 5-9 Simulated Flow Duration Curve

Figure 47 shows that for the ‘Without Project’ case and median rainfall year, the streamflow rate at the outlet of Catchment 5-9, exceeded approximately 50% of the time, is predicted as 0.15 ML/d. For the ‘With Project’ case and median rainfall year, exceedance of 0.15 ML/d is predicted to occur approximately 22% of the time (as opposed to 50% of the time for the ‘Without Project’ case).

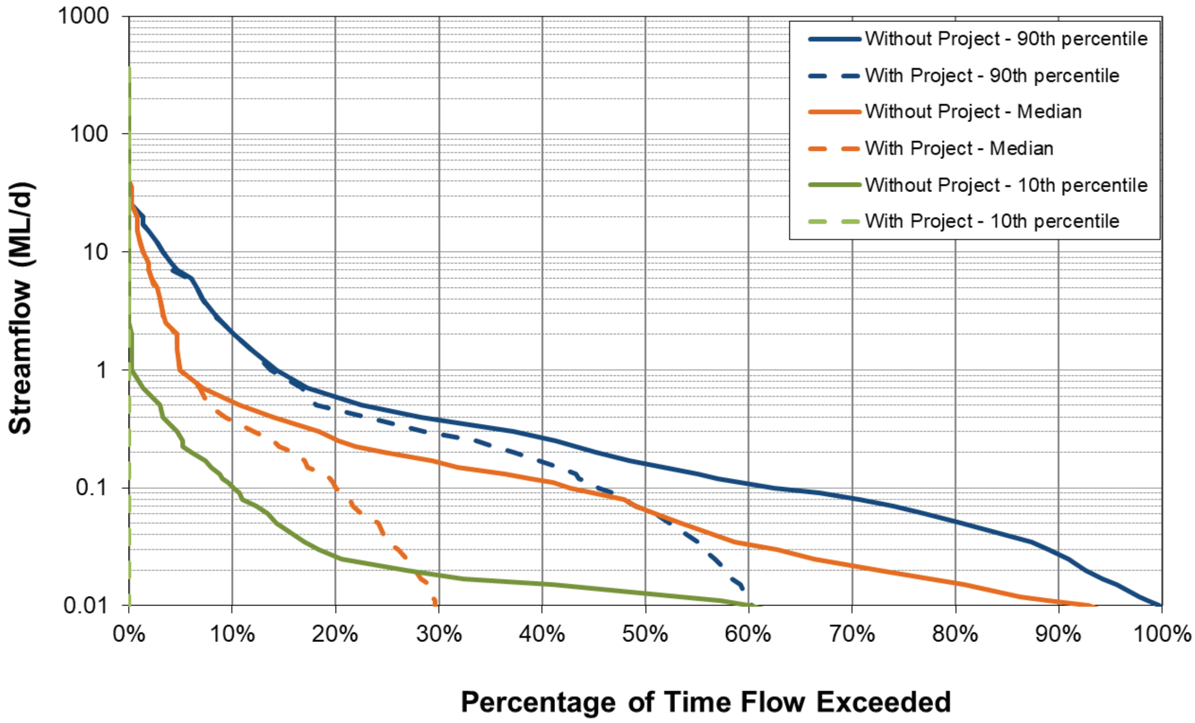

Figure 48 Catchment 5-10 Simulated Flow Duration Curve

Figure 48 shows that for the ‘Without Project’ case and median rainfall year, the streamflow rate at the outlet of Catchment 5-10, exceeded approximately 50% of the time, is predicted as 0.06 ML/d. For the ‘With Project’ case and median rainfall year, exceedance of 0.06 ML/d is predicted to occur approximately 24% of the time (as opposed to 50% of the time for the ‘Without Project’ case).

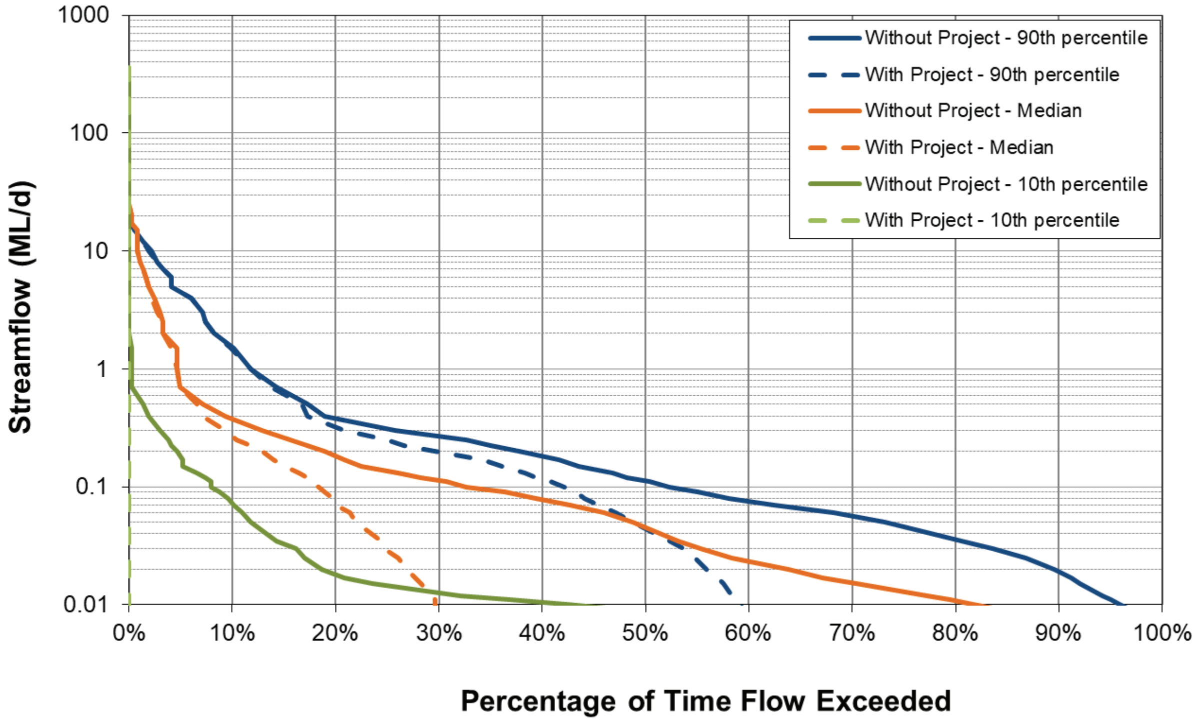

Figure 49 Catchment 5-11 Simulated Flow Duration Curve

Figure 49 shows that for the 'Without Project' case and median rainfall year, the streamflow rate at the outlet of Catchment 5-11, exceeded approximately 50% of the time, is predicted as 0.045 ML/d. For the 'With Project' case and median rainfall year, exceedance of 0.045 ML/d is predicted to occur approximately 23% of the time (as opposed to 50% of the time for the 'Without Project' case).

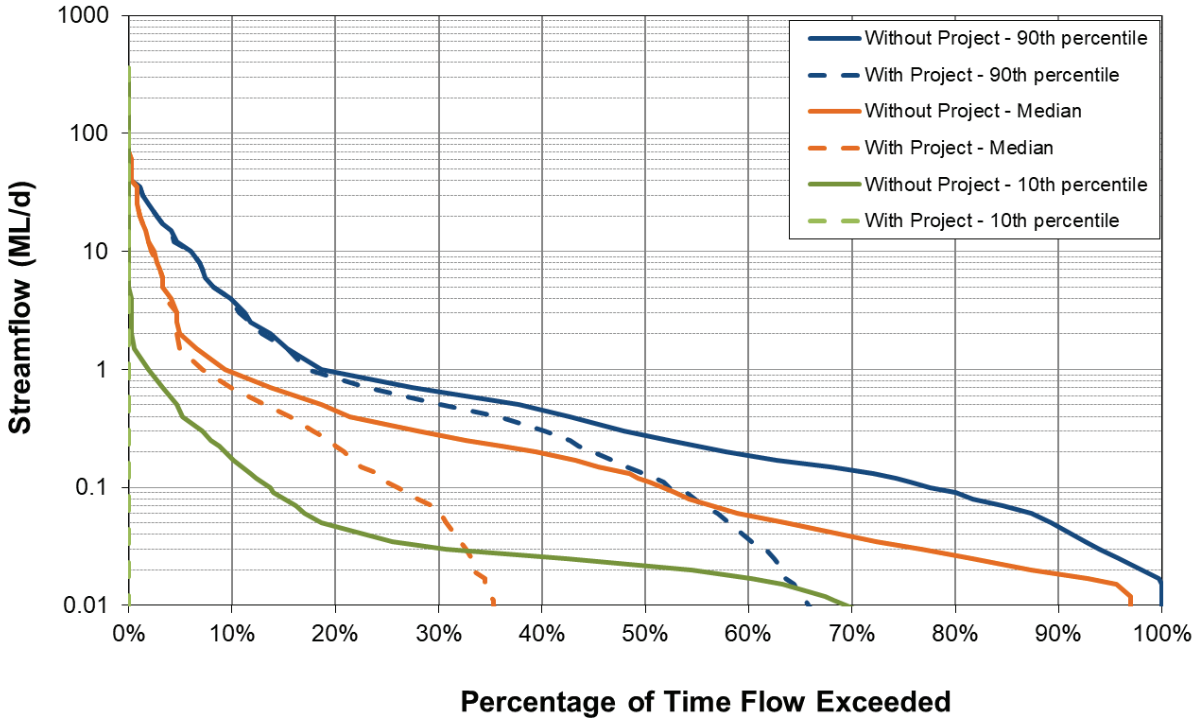

Figure 50 Catchment 5-12 Simulated Flow Duration Curve

Figure 50 shows that for the 'Without Project' case and median rainfall year, the streamflow rate at the outlet of Catchment 5-12, exceeded approximately 50% of the time, is predicted as 0.12 ML/d. For the 'With Project' case and median rainfall year, exceedance of 0.12 ML/d is predicted to occur approximately 25% of the time (as opposed to 50% of the time for the 'Without Project' case).

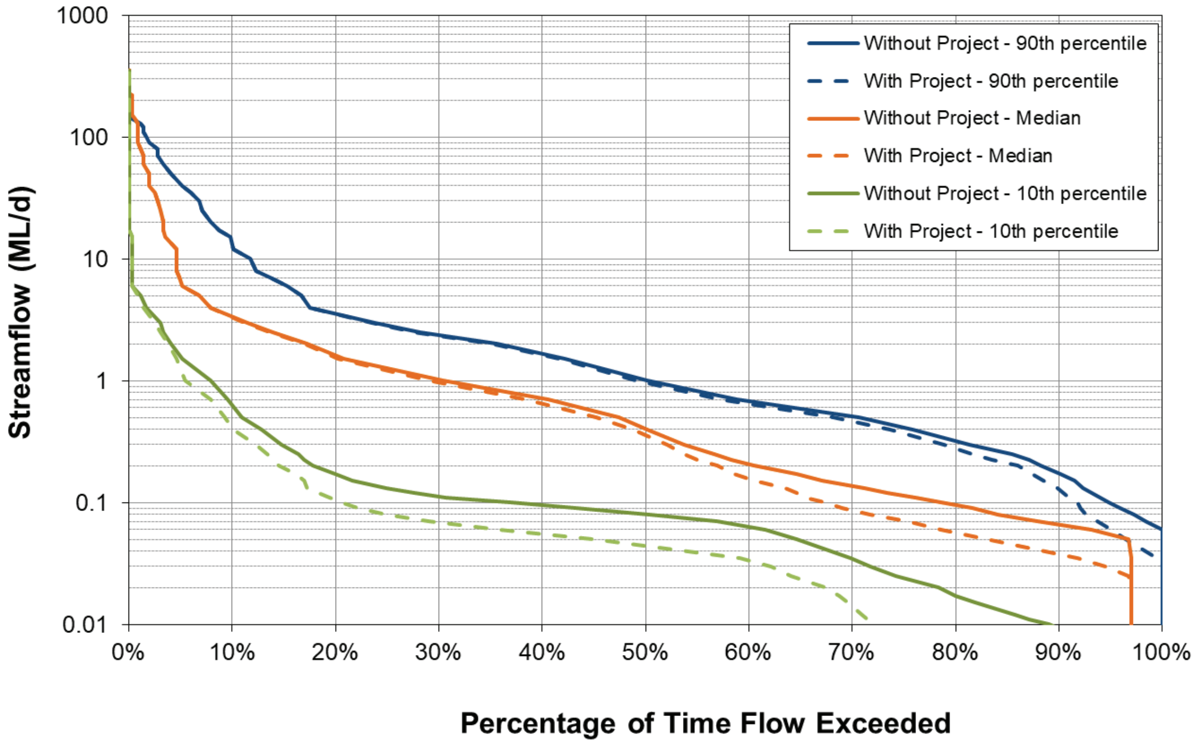

Figure 51 Catchment 6-1 Simulated Flow Duration Curve

Figure 51 shows that for the 'Without Project' case and median rainfall year, the streamflow rate at the outlet of Catchment 6-1, exceeded approximately 50% of the time, is predicted as 0.4 ML/d. For the 'With Project' case and median rainfall year, exceedance of 0.4 ML/d is predicted to occur approximately 49% of the time (as opposed to 50% of the time for the 'Without Project' case).

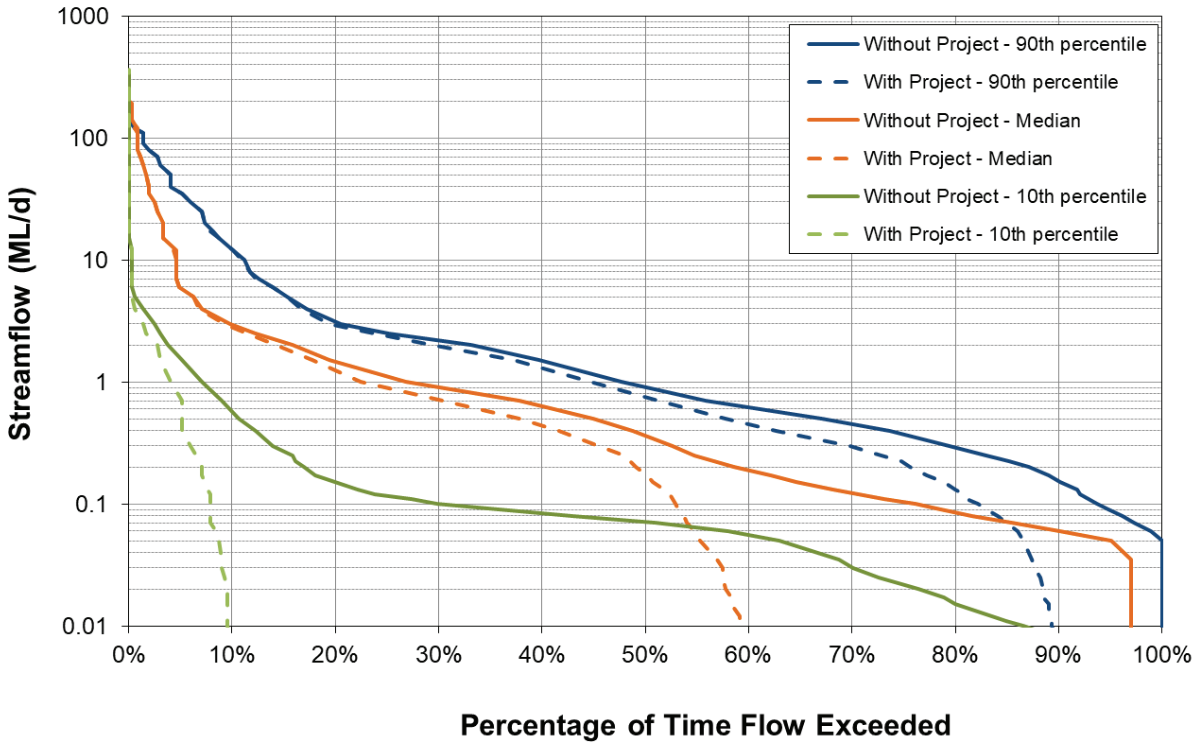

Figure 52 Catchment 6-2 Simulated Flow Duration Curve

Figure 52 shows that for the 'Without Project' case and median rainfall year, the streamflow rate at the outlet of Catchment 6-2, exceeded approximately 50% of the time, is predicted as 0.36 ML/d. For the 'With Project' case and median rainfall year, exceedance of 0.36 ML/d is predicted to occur approximately 43% of the time (as opposed to 50% of the time for the 'Without Project' case).

5.2.4 Implications for Pool Water Level and In-Stream Connectivity

Pool water levels and in-stream connectivity are influenced by the storage characteristics of the pool, surface runoff and streamflow from the upstream catchment and rate of rainfall, evaporation and seepage. The streamflow yield assessment indicates that there is potential for a reduction in surface runoff and streamflow rates as a result of the Project; with Area 5 streamflow yield potentially impacted to a greater extent than Area 6. As such, there is potential for pool water level and in-stream connectivity to be impacted as a result of reduced streamflow yield. Additionally, changes in pool water level will be dependent on the nature of subsidence impacts to the pools and associated stream beds. Watercourses, where sufficient valley closure occurs, may experience dilation fracturing and shearing of rock strata and development of a fracture network beneath the stream bed. This would result in the diversion of a portion of streamflow via the fracture network and a further reduction in water level in pools as they drain via hydraulic connections with the fracture network. Where the stream is experiencing low flow conditions, it is likely that a higher proportion or all of the surface flow would be re-directed into the fractured strata.

5.2.5 Implications for Lake Avon, Lake Cordeaux and Pheasants Nest Weir

Table 35 presents a summary of the catchment estimated effects on streamflow at Lake Avon and Pheasants Nest Weir as a result of mining in Area 5 and Area 6, using the results of modelling presented in Section 5.2.3. The Cordeaux Dam is situated upstream of the Project Area. As such, it is predicted that the impact of the Project on the streamflow yield to Lake Cordeaux would be negligible. The Lake Avon and Pheasants Nest Weir catchment boundary is shown in Figure 5.

Table 35 Estimated Reduction in Streamflow to Lake Avon and Pheasants Nest Weir

Catchment Currently Reports to		Lake Avon	Pheasants Nest Weir
Total Water Supply Catchment Area (km^2)		143	681
Catchment Area with Predicted Reduction (km^2)		5.6*	29.3*
Percentage of Total Water Supply Catchment with Predicted Reduction		3.9%	4.3%
Average Predicted Reduction in Streamflow (%) for Climatic Condition**	Median	14%	9%
	10^{th} Percentile	99%	67%
	90^{th} Percentile	7%	4%
Estimated Percent Reduction in Yield (Median)		0.55%	0.39%

* Total area overlying the Project Area based on the 35º angle of draw contributing to Lake Avon and Pheasants Nest Weir

** This reduction has been modelled in Section 5.2.3 for specific catchments and has been assumed to apply to the total area overlying the Project Area based on the 35º angle of draw

Table 34 illustrates that the proportion of the Project Area reporting to Lake Avon is 3.9% of the total water supply catchment. With a 14% average reduction in streamflow under median climatic conditions, this equates to an estimated average of 0.55% reduction in yield to Lake Avon. Assuming that the streamflow contribution to Lake Avon is consistent for all sub-catchments, this represents a reduction in yield of approximately 384 ML/year in comparison to an estimated total yield of 70,111 ML/year to Lake Avon. This represents a likely indiscernible impact to Lake Avon inflow.

The proportion of the Project Area reporting to Pheasants Nest Weir is 4.3% of the total water supply catchment. With a 9% average reduction in streamflow under median climatic conditions, this equates to an estimated average of 0.39% reduction in yield to Pheasants Nest Weir. Assuming that the streamflow contribution to Pheasants Nest Weir is consistent for all sub-catchments (i.e. no allowance has been made for water storage or environmental flow release), this represents a reduction in yield of approximately 1,036 ML/year in comparison to an estimated total yield of 267,400 ML/year to Pheasants Nest Weir. This again represents a likely indiscernible impact to Pheasants Nest Weir inflow.

5.2.6 Climate Change Effects

Climate change effects and the predicted changes to rainfall have been described in the Groundwater Assessment (HydroSimulations, 2019), and suggest based on the NSW and ACT Regional Climate Modelling projections that climate change may result in a wetter climate, while Climate Change in Australia projections favour a drier climate. If wetter climates were to occur during the Project life, there would likely be greater surface water losses from the catchment (as there would be more surface water available in the ephemeral drainage lines overlying the Project longwall area to be lost to groundwater). If the climate were to become drier and annual rainfall reduced, there would likely be reduced surface water losses from the catchment.

Over the life of the Project, climate variability has been considered through assessment of the 10^{th} percentile, median and 90^{th} percentile rainfall years.

The Groundwater Assessment (HydroSimulations, 2019) has considered the implications of climate change on the potential groundwater losses from the Project. The potential groundwater losses for each catchment have been incorporated in the streamflow loss assessment (Section 5.2) in addition to predictions of seepage from each swamp for the 10^{th} percentile, median and 90^{th} percentile rainfall years.

5.3 SWAMP STABILITY ASSESSMENT

5.3.1 Potential Subsidence Impacts on Swamp Stability

Subsidence induced by longwall mining has the potential to change the longitudinal gradient and cross-sectional characteristics of overlying swamps. Where the hydraulic gradient of flowing water is increased, there is potential for increased erosion and channelization of the swamp.

Longwall mining also has the potential to result in changes to the hydrological regime of a swamp and subsequently to the composition and extent of swamp vegetation (Appendix D of the EIS). Vegetation increases the erosion resistance of a swamp and therefore changes in vegetation may result in the potential for increased scour and erosion.

The onset of erosion and channel degradation can be directly related to bed shear stress. Shear stress is a function of the depth of flow and water surface slope of a swamp, both of which have the potential to be influenced by longwall mining. Where shear stress thresholds are exceeded, there is increased potential for erosion and scouring of swamps to occur.

The potential for increased erosion and scouring will be dependent on the nature of subsidence with respect to the swamp location and characteristics. If a swamp lies wholly within a longwall subsidence trough, the grade and cross-sectional characteristics of the swamp will not change and the likelihood of increased erosion is limited. Where the subsidence tilt is expected to occur in the opposite direction to that of the swamp gradient, the swamp gradient will be reduced and an increase in erosion will be unlikely. Where the expected direction of tilt is equivalent to that of the swamp slope, the hydraulic gradient will be increased and therefore the potential for erosion and scouring will increase.

5.3.2 Assessment Methodology

The risk of swamp erosion has been assessed by comparing the bed shear stress likely to be experienced in a swamp during a flood event with the threshold conditions of stability. The vulnerability of the swamps to erosion has been assessed for both pre and post-mining conditions, with the post-mining assessment considering potential changes to swamp vegetation, swamp cross-sectional characteristics and swamp gradient.

Swamps within the Dendrobium Mine area primarily comprise a dense cover of tall tussocks, rushes and sedges (Earth Tech, 2005). A shear stress erosion threshold of 240 N/m^2 for tussocks and sedges has been adopted from Fishchenich (2001) and Department of Sustainability and Environment (DSE) (2007) to assess pre-mining conditions. A shear stress threshold of 180 N/m^2 for disturbed tussocks and sedges (Fishchenich, 2001 and DSE, 2007) has been adopted to assess post-mining conditions on the basis that total species richness and extent has been observed to decline in some swamps post-mining.

A simple hydraulic (surface flow) model was developed for each swamp overlying the proposed longwall panels in Area 5 and Area 6. The hydraulic model was used to assess shear stress during the 50% Annual Exceedance Probability (AEP) and 1% AEP peak flow rates. The 50% AEP and 1% AEP peak flow rates for each swamp, listed in Table 36, were estimated using the Regional Flood Frequency Estimation Model[10].

A Manning's roughness coefficient (n) of 0.06, reflective of light brush and trees (Chow, 1973), was adopted for the channel of each swamp to simulate 'Without Project' conditions. The Manning's n was reduced to 0.04 for each swamp to reflect a potential decline in the TSR following mining.

10 https://rffe.arr-software.org/

The predicted subsidence contours, obtained from MSEC (Appendix A of the EIS), were used to identify the location in each swamp at which maximum impact was expected to occur (i.e. maximum tilt). The cross-sectional characteristics and gradient of each swamp were then modified to reflect changes following predicted subsidence. Den 102 was unable to be modelled as the swamp does not appear to have a clearly defined and confined channel (based on available contour data). Den 128 was also excluded from the assessment as only a small portion of the downstream boundary of the swamp overlies the proposed longwall panel and the predicted subsidence induced tilt is negligible (<0.5 mm/m).

Table 36 summarises the existing gradient of each modelled swamp and the expected change in gradient due to potential subsidence impacts resulting from tilt.

Table 36 Swamp Flow Rate and Gradient

Swamp	Peak flow rate (m^3/s)		Swamp Gradient at Location of Maximum Impact (mm/m)		Maximum Predicted Tilt (mm/m)*
	50% AEP	1% AEP	Without Project	With Project	
Den 83	0.5	6.2	73	78	17
Den 86	2.8	34.5	26	29	14
Den 97	1.9	23.2	49	52	9
Den 98	3.2	39.0	42	45	19
Den 99	1.1	13.2	39	38	14
Den 100	0.4	4.3	73	75	12
Den 101	1.1	13.7	37	36	15
Den 103	0.8	9.9	53	53	17
Den 104	0.2	2.9	88	87	4
Den 105	0.2	2.8	162	156	19
Den 106	0.8	10.2	28	36	13
Den 107	0.6	7.8	54	47	15
Den 108	1.7	20.8	41	53	15
Den 109	1.1	13.6	40	42	7
Den 110	0.5	33.7	55	58	11
Den 111	2.1	25.2	41	44	9
Den 113	0.4	4.7	44	53	18
Den 114	0.5	5.7	88	88	10
Den 117	1.2	14.2	39	36	15
Den 118	1.0	12.6	62	61	13
Den 120	0.5	5.5	41	37	12
Den 121	2.1	25.5	90	87	15
Den 122	0.4	5.0	69	68	10
Den 123	0.4	4.4	33	38	11

* Maximum predicted tilt may not occur in the same direction as the existing swamp gradient

5.3.3 Assessment Results

Results of the hydraulic modelling assessment are summarised in Table 37. Results shown in bold indicate an increase for the 'With Project' case and results shown in italics represent an exceedance of the shear stress threshold.

Table 37 Swamp Shear Stress Predictions

Swamp	50% AEP Flood Event		1% AEP Flood Event	
	Without Project (N/m^2)	With Project (N/m^2)	Without Project (N/m^2)	With Project (N/m^2)
Den 83	**42**	**59**	156	156
Den 86	**38**	**45**	**96**	**110**
Den 97	62	45	155	123
Den 98	**48**	**110**	*307*	*281*
Den 99	22	22	56	43
Den 100	79	47	157	117
Den 101	39	38	139	120
Den 103	43	30	126	98
Den 104	33	31	94	81
Den 105	68	48	156	126
Den 106	**25**	**34**	**63**	**82**
Den 107	51	28	125	68
Den 108	**65**	**65**	**166**	**167**
Den 109	53	42	135	107
Den 110	**48**	**52**	**208**	***257***
Den 111	68	63	174	163
Den 113	**18**	**26**	**46**	**67**
Den 114	53	38	110	94
Den 117	**47**	**60**	**119**	**154**
Den 118	**34**	**70**	**88**	***180***
Den 120	30	20	76	48
Den 121	106	73	208	178
Den 122	55	47	140	123
Den 123	24	22	62	57

The results in Table 37 indicate that an increase in shear stress is predicted to occur in 9 of the 24 swamps simulated in Area 5 and Area 6. The increase in shear stress is estimated to result in an exceedance of the erosion threshold in two of the swamps, and then only as a result of a 1% AEP (i.e. rare) peak flow event. No exceedance of the erosion threshold is predicted for the 50% AEP (i.e. frequent) peak flow event. During a 1% AEP peak flow, the shear stress in Den 118 is predicted to reach 180 N/m^2 for the 'With Project' case which is equal to the shear stress erosion threshold for disturbed tussocks and sedges, bunch grass 2 – 25 cm high (Fishchenich, 2001 and DSE, 2007). The shear stress in Den 110 during a 1% AEP peak flow for the 'With Project' case is predicted to be 257 N/m^2 which exceeds the shear stress erosion threshold for tussocks and sedges (240 N/m^2) and disturbed tussocks and sedges, bunch grass 2 – 25 cm high (180 N/m^2) (Fishchenich, 2001 and DSE, 2007). Therefore, there is potential that erosion and scouring could occur in Den 110 and Den 118 during a rare flow event as a result of mining induced tilt.

The shear stress erosion thresholds are predicted to be exceeded during a 1% AEP peak flow at Den 98, for both 'Without Project' and 'With Project' cases. However, the shear stress is predicted to decrease for the 1% AEP peak flow following mining beneath Den 98 due to changes in the cross-sectional characteristics of Den 98.

5.4 WATER QUALITY ASSESSMENT

Potential impacts on water quality as a result of the potential subsidence impacts associated with the Project would be localised (e.g. localised changes in water quality in the Avon and Cordeaux Rivers and their tributaries). Although mine subsidence effects can result in isolated, episodic pulses in iron, manganese, aluminium and electrical conductivity, there have been no reports of any measurable effect on water quality in downstream reservoirs in the Southern Coalfield. Water quality as a result of the Project is therefore not expected to impact on the performance of Avon Dam, Cordeaux Dam or Pheasants Nest Weir. Water quality monitoring downstream of mine areas is recommended (refer Section 8.0).

Stream remediation measures (see Section 7.0) would be conducted on rivers and named streams (Avon and Cordeaux Rivers and Donalds Castle Creek) and at key stream features in reaches of second order and above where subsidence results in the draining of pools in stream sections between controlling rockbars and where the remediation measures are considered technically feasible.

5.5 SIGNIFICANT IMPACT ASSESSMENT

Water resources are a matter of national environmental significance in relation to large coal mining development as stipulated by the *2013 EPBC Act Amendment*. A 'significant impact' is defined as an impact which is 'important, notable, or of consequence, having regard to its context or intensity' (Department of the Environment [DoE], 2013).

When assessing the significance of impacts to the hydrology or the water quality of a water resource, the value of a water resource, timing of potential impacts (short and long-term) and scale of potential impacts are required to be assessed. In addition, the cumulative impacts 'when considered with other developments, whether past, present or reasonably foreseeable developments' are to be assessed (DoE, 2013).

Table 38 presents a summary of the potential project impact relating to the hydrological and water quality assessment criteria specified in the DoE (2013) *Significant Impact Guidelines 1.3: Coal seam gas and large coal mining developments – impacts on water resources.* The potential project impact has been assessed with consideration to the value of each water resource, timing of potential impacts, scale of potential impacts and cumulative impacts.

Table 38 Summary of Water Resource Potential Project Impact

Assessment Criteria	Potential Project Impact
Changes to Hydrological Characteristics	
Flow regimes (volume, timing, duration and frequency of water flows)	The Project may result in localised changes to the flow regime of surface water systems within the Project Area, and potentially downstream of the Project Area. However, the impact on inflows to Lake Avon and Pheasants Nest Weir are likely to be indiscernible (refer Section 5.2.5).
Recharge rates	The Project may result in localised changes to recharge rates from surface water systems within the Project Area (refer Appendix B of the EIS).
Aquifer pressure or pressure relationships between aquifers	Refer Appendix B of the EIS.
Groundwater table levels	Refer Appendix B of the EIS.
Groundwater/surface interactions	The Project is likely to result in an increase in seepage rates from swamps and surface water systems to underlying strata (refer Sections 5.2.1 and 5.2.2).
River/floodplain connectivity	The Project is unlikely to have an impact on river/floodplain connectivity.
Inter-aquifer connectivity	Refer Appendix B of the EIS.
Coastal processes	Not applicable.
Changes to Water Quality	
Create risks to human or animal health or the condition of the natural environment • Substantially reduce the amount of water available for human consumptive uses or for other uses dependent on water quality • Cause persistent organic chemicals, heavy metals, salt or other potentially harmful substances to accumulate in the environment • Seriously affects the habitat or lifecycle of a native species dependent on a water resource	• The impact on inflows to Lake Avon and Pheasants Nest Weir are likely to be indiscernible (refer Section 5.2.5). • Based on monitoring undertaken in previously mined areas within the region, the Project is unlikely to have a persistent impact on the water quality of the region (refer Section 5.4). • The reduction in streamflow yield in the Project Area has the potential to reduce the extent and total species richness of swamp vegetation (refer Section 4.3).
Causes the establishment of an invasive species (or the spread of an existing invasive species) that is harmful to the ecosystem function of the water resources	Not applicable.
Results in worsening of local water quality where local water quality is superior to local or regional water quality objectives (i.e. ANZECC guidelines for Fresh and Marine Water Quality)	Although mine subsidence effects may result in isolated, episodic pulses in iron, manganese, aluminium and electrical conductivity, these occurrences are not expected to exceed pulses observed in background concentrations (refer Sections 2.2.3.3 and 2.2.4.3).
High quality water is released into an ecosystem which is adapted to a lower quality of water	Not applicable.

5.6 SUMMARY

The following provides a summary of the potential impacts to surface water resources as a result of the Project:

- Seepage from the base of the swamps overlying longwall mining areas is predicted to increase from between 0.1 and 19.8 m^3/m width of swamp per annum over a 290 m long swamp to between 42.7 and 125.5 m^3/m width per annum as a result of the Project.
- Swamp water levels (i.e. the groundwater table) are likely to fall more rapidly during prolonged dry periods and take longer to recover during wetting periods in swamps overlying longwall mining areas.
- The impacts are predicted to be greater in steeper swamps than in flatter swamps.
- For catchments overlying Area 5, model results suggest that there would be a 6% to 22% reduction in streamflow due to the Project for a median climatic year (63% to 100% for a 10th percentile climatic year and 3% to 11% for a 90th percentile climatic year).
- For Area 6, the results suggest there would be a 1% to 5% reduction in streamflow due to the Project for a median climatic year (19% to 51% for a 10th percentile climatic year and 1% to 2% for the 90th percentile climatic year).
- The estimated streamflow reduction in a median climatic year is within the range of observed reductions in total yield following longwall mining in Dendrobium Area 3B.
- Under median climatic conditions, there is potential for an estimated average of 0.55% reduction in yield to Lake Avon and an estimated average of 0.39% reduction in yield to Pheasants Nest Weir as a result of longwall mining in Area 5 and Area 6. This represents a likely indiscernible impact to inflows to Lake Avon and Pheasants Nest Weir.
- It is unlikely that erosion and scouring will occur in any swamps in the Project Area during frequent flow events (represented by the 50% AEP peak flow) and in most swamps during rare (high) flow events (represented by the 1% AEP peak flow). There is potential that erosion and scouring could occur in two swamps during a 1% AEP peak flow as a result of mining induced tilt.

6.0 NEUTRAL OR BENEFICIAL EFFECTS

Under the State Environmental Planning Policy (Sydney Drinking Water Catchment) 2011 all development in the Sydney drinking water catchment is required to demonstrate a neutral or beneficial effect on water quality. The following definition and criteria for satisfying the neutral or beneficial 'test' are contained in WaterNSW (2015).

> *A neutral or beneficial effect on water quality is satisfied if the development:*
>
> *(a) has no identifiable potential impact on water quality, or*
>
> *(b) will contain any water quality impact on the development site and prevent it from reaching any watercourse, water-body or drainage depression on the site, or*
>
> *(c) will transfer any water quality impact outside the site where it is treated and disposed of to standards approved by the consent authority.*

6.1 WATER QUALITY IMPACTS FROM SUBSIDENCE

Potential impacts on water quality as a result of the potential subsidence impacts associated with the Project would be localised (e.g. localised changes in water quality in the Avon and Cordeaux Rivers and their tributaries). Although mine subsidence effects can result in isolated, episodic pulses in iron, manganese, aluminium and electrical conductivity, these pulses have not had a measurable effect on water quality in reservoirs downstream of mine induced subsidence in the Southern Coalfield. Smaller examples of these pulses have also been observed in surface water catchments within the region which are located outside of the zone of influence of mining activities.

The water quality parameters which may be potentially impacted by Project induced subsidence are not parameters of importance with respect to drinking water supply (refer Table 3 of Fell, 2014). WaterNSW is able to control the level of sediments, soluble iron and manganese in raw water flowing to the water treatment plants and the water treatment plants have been designed to allow for small changes in influent water quality (Fell, 2014).

Although unlikely, should the isolated, episodic pulses in iron, manganese, aluminium and electrical conductivity be measurable at Lake Avon, Lake Cordeaux or Pheasants Nest Weir, it is unlikely that the performance of the dams or associated water supply system will be impacted.

In addition, as part of the Project, South32 would improve water quality within the catchment area through the transfer of land within the catchment area of the Dendrobium Mine to WaterNSW and fund water quality improvement works on this land (and other land in the catchment) to offset any potential impact the Project activities may have on water quality in the region. The additional works proposed for the Project would complement those planned by WaterNSW as outlined in Table 39.

As such, the Project is likely to have a neutral or beneficial effect on water quality in Sydney's water supply catchments.

Table 39 Water Quality Improvement Works

Water Quality Improvement Works	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 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 Work Program 2018-19: Sydney Catchment Area.*

[2] Estimation only.

6.2 PROJECT ACTIVITIES OUTSIDE THE MINE WATER MANAGEMENT SYSTEM

The current water management system in place at the Dendrobium Mine will be upgraded and augmented to manage the increase in predicted groundwater inflows to underground workings with no identifiable potential impact on water quality, as discussed in Section 3.3.5.

Management of surface runoff associated with new ventilation shafts in Areas 5 and 6 is required to be assessed in accordance with the Neutral or Beneficial Effects (NorBE) criteria. Construction of the Area 5 and Area 6 ventilation shafts will comprise clearing of land and construction of ventilation shafts within the cleared area. The sediment basins will drain relatively 'clean' catchments, i.e. no proposed coal stockpiling areas or direct contact between runoff and coal will occur within the catchment.

As detailed in Section 3.2, sediment dams will be constructed to capture runoff from each of the four proposed ventilation shaft areas, shown in Figure 9. The sediment dams have been conceptually designed in accordance with Landcom (2004) and DECC (2008) guidelines. The sediment basins will capture and detain stormwater runoff, with overflow discharged to the adjacent surface water system.

6.3 IMPACT ASSESSMENT

6.3.1 Assessment Criteria

WaterNSW (2015) has published guidelines for assessing compliance with the neutral or beneficial effect of development on water quality. The guidelines recommend the use of the Model for Urban Stormwater Improvement Conceptualisation (MUSIC) for all developments with an impervious area greater than or equal to 2,500 square metres. MUSIC enables the estimation of stormwater pollutant generation from development areas and simulates the performance of proposed stormwater treatment measures (eWater, 2012). Guidance on the use of MUSIC in Sydney's Drinking Water Catchment is provided in WaterNSW (2012), as detailed in Section 6.3.2.

A development and its associated treatment measures must be assessed against the following NorBE criteria (WaterNSW, 2015):

- The mean annual constituent loads for the post-development case (including mitigation measures) must be 10% less than the pre-development case for total suspended solids (TSS), total phosphorus (TP) and total nitrogen (TN). For gross constituents, the post-development load only needs to be equal to or less than pre-development load.
- Constituent concentrations for TP and TN for the post-development case (including mitigation measures) must be equal to or better compared to the pre-development case for between the 50^{th} and 98^{th} percentiles over the five year modelling period when runoff occurs.

6.3.2 Model Inputs

MUSIC was designed as a tool for simulating urban stormwater hydrology and for conceptually designing appropriate urban stormwater management systems (eWater, 2012). The model was not designed to simulate a range of land use types that are not representative of urban environments (such as mine ventilation shaft infrastructure). Regardless, MUSIC is required by WaterNSW (2015) to be used to simulate development in Sydney's drinking water catchments and therefore has been used to simulate the proposed ventilation shaft areas in Area 5 and Area 6.

MUSIC modelled nodes were used to represent the four ventilation shaft areas: Area 5 North which discharges to DC8, Area 5 South which discharges to DC10, Area 6 North which discharges to an un-named tributary of the Cordeaux River and Area 6 South which discharges to the Cordeaux River. Each model node was set up to represent the 'Without Project' (i.e. existing) and 'With Project' conditions of the ventilation shaft areas and associated catchment. The 'Without Project' and 'With Project' constituent concentrations were assessed at the catchment outlet for each ventilation shaft area as well as at the downstream Pheasants Nest Weir (Sydney water supply take-off point).

The 'Without Project' area was modelled as 'forest' catchment, utilising the model parameters specified in WaterNSW (2012) for that catchment type. The 'With Project' area was modelled partially as 'unsealed road' and partially as 'roof area', in lieu of more representative land use types for the ventilation shaft areas. It is a limitation of the MUSIC model that there are no catchment types that adequately represent the ventilation shaft areas. The areas of each land use type simulated in MUSIC are presented in Table 40.

Table 40 MUSIC Source Nodes

Land Use	MUSIC Source Node	Area 5 North Ventilation Shaft	Area 5 South Ventilation Shaft	Area 6 North Ventilation Shaft	Area 6 South Ventilation Shaft
Without the Project (ha)					
Forest	Forest	3.0	7.5	4.0	4.0
With the Project (ha)					
Cleared area	Unsealed roads	2.0	4.5	3.0	3.0
Ventilation shaft	Roof area	1.0	3.0	1.0	1.0

The Project Area modelled climate zone was identified as Zone 8 from WaterNSW (2018c). The 6-minute time step rainfall file for Zone 8 was obtained from WaterNSW (2018c) and imported to the MUSIC model.

The stormwater constituent parameters for the 'Without Project' and 'With Project' areas were adopted from WaterNSW (2012) as listed in Table 41.

Table 41 Source Node Mean Constituent Inputs for Storm Flow

Land Use	TSS		TP		TN	
	Mean (mg/L in log units)	SD (mg/L in log units)	Mean (mg/L in log units)	SD (mg/L in log units)	Mean (mg/L in log units)	SD (mg/L in log units)
Storm Flow						
Existing						
Forest	1.6	0.6	-1.1	0.22	-0.05	0.24
Proposed						
Unsealed roads	3.0	0.32	-0.3	0.25	0.34	0.19
Roof area	1.3	0.32	-0.89	0.25	0.30	0.19
Base Flow						
Existing						
Forest	0.78	0.13	-1.52	0.13	-0.52	0.13
Proposed						
Unsealed roads	1.2	0.17	-0.85	0.19	0.11	0.12
Roof area	-	-	-	-	-	-

It should be noted that the parameters for ‘roof area’ are based on roofs in urban areas and the parameters for ‘unsealed roads’ are arbitrarily defined on the basis of parameters for ‘sealed roads’. The parameters for ‘sealed roads’ are representative of moderate to highly trafficked roads in urban areas, which is not representative of the Area 5 and Area 6 ventilation shaft areas. However, these parameters have been adopted in the absence of more representative parameters.

6.3.3 Proposed Treatment Train

The proposed treatment train for the ventilation shaft areas comprises a sediment pond in each area with the design parameters specified in Table 22.

6.3.4 Model Outputs

Table 42 provides a summary of the ‘Without Project’ and ‘With Project’ scenario mean constituent concentrations assessed at the catchment outlet for each ventilation shaft area. The mean constituent concentrations have been assessed against the HRC (1998) WQOs for TP and TN.

Table 42 Ventilation Shaft Runoff Predicted Constituent Concentration

Parameter	HRC (1998) WQO	Area 5 North Ventilation Shaft Mean Constituent Concentration		Area 5 South Ventilation Shaft Mean Constituent Concentration		Area 6 South Ventilation Shaft Mean Constituent Concentration	
		Without Project	With Project	Without Project	With Project	Without Project	With Project
TSS (mg/L)	-	2.27	3.73	2.26	4.48	1.89	4.58
TP (mg/L)	0.05	0.01	0.02	0.01	0.03	0.01	0.03
TN (mg/L)	0.7	0.11	0.20	0.11	0.24	0.09	0.25

Although Table 42 indicates that the predicted mean constituent concentration at the outlet of each ventilation shaft area catchment will increase as a result of the Project thereby exceeding the NorBE criteria specified in Section 6.3.1, this is a result of the use of stormwater constituent parameters which do not accurately represent the post-mining land use, though are required to be adopted for the assessment (refer Section 6.3.2). As this result is not considered to reflect the effect to the receiving environment, the mean constituent concentrations have been assessed against the HRC (1998) WQOs for TP and TN and indicate a non-exceedance against the WQOs, based on the water quality simulations.

An assessment of the constituent concentrations at Pheasants Nest Weir (Sydney water supply take-off point) has been undertaken for the 'Without Project' and 'With Project' case. Due to limitations of MUSIC, the constituent concentration at Pheasants Nest Weir was estimated based on the MUSIC model output mean annual load at the catchment outlet scaled to the total catchment area of Pheasants Nest Weir.

Table 43 indicates that the mean constituent concentration at Pheasants Nest Weir will not exceed the HRC (1998) WQOs for TP and TN, based on the model results which show that there is no discernible change to the modelled constituent concentrations. The mean concentration predicted for TSS is likely to be less than the laboratory limit of detection of 5 mg/L for TSS. Therefore, it is estimated that the Project will have a neutral impact on water quality at Pheasants Nest Weir.

Table 43 Pheasants Nest Weir Constituent Concentration

Parameter	HRC (1998) WQO	Without Project	With Project
TSS (mg/L)	-	1.8	1.8
TP (mg/L)	0.05	0.05	0.05
TN (mg/L)	0.7	0.53	0.53

7.0 STREAM REMEDIATION OPTIONS AND WORKS

Illawarra Coal's commitments regarding remediation of streams assessed in this report are given in Section 7 of the EIS Main Report.

Various techniques have been previously adopted to successfully reduce subsidence impacts to streams associated with longwall mining, including by Illawarra Coal and at other operations in the Southern Coalfield. A summary of these methods, their possible application to different situations and their limitations is provided in Table 44.

Table 44 Proposed Stream Remediation Techniques

Restoration Technique	Description	Applications and Limitations
Hand grouting	Sealing of cracks exposed on the surface using hand applicators. A variety of sealants can be used including sealants that can be applied under water.	Limited to surface cracks which can be accessed using hand held application equipment.
Shallow pattern grouting	Drilling shallow holes using small hand held drilling equipment and low-pressure injection of a grout using a portable pump. Grouts used successfully on the Georges River (by Illawarra Coal) incorporated a cement mix that can be used with or without additives (e.g. bentonite).	Used to seal shallow fractures in rockbars and pools. Applicable to sensitive areas where access for larger equipment is problematic. Better results can be obtained if the target fractures are dewatered.
Deep pattern or curtain grouting	Drilling deeper holes using traditional air and/or reverse circulation drilling rigs. Higher pressure grouting techniques can also be used. Grouts used successfully on the Georges River incorporated a cement-bentonite mix.	Used to seal fracture networks at greater depths. Can seal larger and deeper fractures. Larger equipment may necessitate constructing access tracks. Less suitable for remote or difficult access sites.
Deep angle hole cement grouting	Remote directional drilling techniques can be used to access otherwise inaccessible sites. The same grouting methods as deep pattern/curtain grouting outlined above can be used.	Specialised technique which can be used in situations where drill access is available close to target site.
Polyurethane (PUR) grouting	Use of expanding PUR grouts to seal fracture networks. PUR, which is a rapid setting grout that sets under water, is pumped into closely spaced drill holes (pattern drilling) and fractures filled systematically from "bottom up".	Technique used successfully on Waratah Rivulet by Helensburgh Coal Pty Ltd. Can be used under water and under low flow conditions. Can be used to fill large aperture fractures in stages.
Knick point control	Use of 'coir log dams' at erosion knick points to remediate erosion channels and redirect flow to swamps.	Successfully used for swamp rehabilitation in the Blue Mountains and Snowy Mountains. Material eventually biodegrades to become integrated into the peat/organic matter complex of the swamps.
Water spreading techniques	Long lengths of coir logs and hessian 'sausages' linked together across the contour to enable build-up of water and facilitate seepage to swamps through water spreaders.	Used to maintain swamp moisture regime. Material eventually biodegrades to become integrated into the peat/organic matter complex of the swamps.

The full range of available techniques would be considered by South32 in the design of any future stream restoration programs should these be required.

8.0 MONITORING RECOMMENDATIONS

South32 has been undertaking baseline surface water monitoring within and adjacent to Area 5 and Area 6, as summarised in Section 2.2. It is recommended that this monitoring be continued and expanded upon as detailed in Table 45. Monitoring should continue for at least two years following mining in each Area or until the completion of successful remediation/restoration activities.

Table 45 Recommended Monitoring

Parameter	Monitoring Sites	Description
Water Level/Flow Rate		
Surface water flow rate	Existing rated gauging stations (refer Figure 6): • LA4S1 • DCU • DC13S1 • DCS2 Existing water level monitoring stations (refer Figure 6): • AR31S1 • AR32S1 • LA13AS1 • LA13S1 • AR19S1 • DC8S1 • CR29S1 • CR31S1 Plus rated gauging stations at three control catchment sites (catchments located outside mine-affected areas)	• The mine area flow monitoring sites should be progressively developed over the Project life. • Water level monitoring stations should be converted to rated gauging stations at least two years prior to the commencement of longwall mining within each catchment. • Gauging stations should provide suitable minimum low flow resolution and accuracy. Interim targets of ± 0.0025 ML/d resolution and ± 10% accuracy in flow rate over the flow range 0.01 to 10 ML/d are recommended. • Flow monitoring would contribute to the quantitative understanding of the pre-mine catchment via the use of baseline streamflow models, identify the need for remediation and inform the success criteria for remediation works. The data should be used for ongoing calibration of stream catchment/flow models and the assessment of impacts by comparison to the pre-mine models. • Additional pluviometers should be established within the catchment of either creek AR31 or AR19 (refer Figure 6) and within the control catchments to provide reliable rainfall information required to interpret and model the dynamics of catchments. • An automatic weather station monitoring temperature, humidity, wind speed, wind direction and solar radiation on at least an hourly basis should be established between Areas 5 and 6 in order to allow calculation of evaporation rates. • Periodic (monthly during flow) manual flow gauging should be undertaken to verify adopted rating curves.
Swamp water level	Existing sites (refer Table 20) plus three control sites to be located outside the area of mining	• Continuous data collected by sensors/loggers in shallow bores and soil moisture monitoring. • Data should be reviewed every 3 months to ensure consistency/accuracy. • The data should be used for ongoing calibration of swamp catchment/flow models, the assessment of impacts by comparison to the pre-mine models, and the need for and subsequent success of any remedial works.

Table 45 (Continued) Recommended Monitoring

Parameter	Monitoring Sites	Description
Water Level/Flow Rate (Continued)		
Swamp flow rate	Suitable sites (to be selected by field reconnaissance)	• Where surface outflows at the downstream end of the swamp are sufficiently concentrated to enable flow to be reliability measured, a low flow monitoring station (such as an instrumented V notch weir or flume) should be established. • The data should be used for calibration of swamp catchment/flow models, the assessment of impacts by comparison to the pre-mine models, and the need for and subsequent success of any remedial works.
Pool water level	Pools associated with key stream features identified by South 32 (as listed in the Stream Risk Assessment - Appendix B) plus four additional pools as 'controls' in areas outside the effects of mining and with similar morphology	• Continuous data collected by water levels sensors/loggers in at least half of the significant pools plus the four control pools, with levels recorded to AHD. • Manual water level measurements to confirm sensor data. • Manual monitoring of the remaining pools' water levels with levels recorded to AHD. • Data to be reviewed every 3 months to ensure consistency/accuracy. • Data to be used (during mining) to identify the need for and subsequent success of any remedial works.
Water Quality		
Surface water quality	Existing sites (refer Figure 6)	• The mine area water quality monitoring sites should be further developed over the Project life. • Water quality monitoring should provide at least two years of data prior to the commencement of extraction within each catchment. • Sampling should be undertaken on at least a monthly sampling frequency, flow permitting (intensity may be increased during periods of subsidence or changes in monitored water quality). • Water samples should be analysed by an appropriately accredited laboratory for the standard suite of parameters used by Illawarra Coal in their existing monitoring program. • Data collected during mining should be compared to baseline data to identify changes to water quality which indicate potential water quality impacts due to mining.

Table 45 (Continued) Recommended Monitoring

Parameter	Monitoring Sites	Description
Appearance		
Observational and photographic monitoring	All flow and quality monitoring sites	• Visual signs of impacts on creeks and drainage lines (i.e. cracking, vegetation changes, increased erosion, changes in water colour, development of iron floc, etc.): ○ Monthly monitoring during mining and subsidence. ○ Weekly when longwall mining is within 400 m of a site.
Remediation		
Stream (Pool) remediation	At sites on rivers and stream reaches where remediation works have been implemented.	• A programme should be developed to monitor the performance of any remediation works implemented for the Project. The plan would include specific success criteria to be informed by monitoring Examples of the type of monitoring parameters relevant to this programme include: ○ Monitoring of remediation methods (e.g. quantity of grout injection); ○ Hydraulic conductivity testing; ○ Water quality monitoring (refer above); ○ Pool water level monitoring (refer above); and ○ Other environmental monitoring (e.g. aquatic ecosystem monitoring).
Water Balance		
Flow monitoring	All pumped flows	• The existing monitoring of the main water transfers within the underground workings, Pit Top and KVCLF should continue. • The performance of the water management system should be reviewed at least annually using the monitored data in combination with the site water balance model to identify changes in the system and compare against predictions, particularly in regard to groundwater inflows.

9.0 REFERENCES

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