APPENDIX C

Surface Water Assessment

REPORT

Dendrobium Mine Extension Project Surface Water Assessment

Prepared for: Illawarra Coal Holdings Pty Ltd

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EXECUTIVE SUMMARY

Illawarra Metallurgical Coal is seeking Infrastructure Approval for the *Dendrobium Mine Extension Project* (the Project), which would support the extraction of approximately 31 million tonnes (Mt) of run-of-mine (ROM) coal from Area 5, within Consolidated Coal Lease 768. The life of the Project includes longwall mining in Area 5 up to approximately 31 December 2034, and ongoing use of existing surface facilities for handling of Area 3C ROM coal until 2041.

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 Bulli Seam, in the Illawarra Coal Measures, which are overlain by the Narrabeen Group and Hawkesbury Sandstone.

The Study Area (600 m buffer around proposed longwalls) 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. WaterNSW releases water from the Avon Dam and the adjacent Cordeaux Dam and Nepean Dam to enable withdrawal for water supply purposes from the Pheasants Nest Weir located further downstream on the Nepean River.

The water quality of the Study Area is characterised by acidic to slightly alkaline pH conditions and slightly elevated concentrations of some dissolved metals and nutrients. Elevated concentrations of total phosphorus, total nitrogen, aluminium, iron and zinc, in excess of default guideline values for aquatic ecosystems, have been reported at some sites located outside of influences of current mining activities.

Mining within the Study Area has the potential to affect the hydrology, water balance and stability of undermined upland swamps and the quantity and quality of surface waters within and adjacent to the Study Area. The results of seepage modelling, undertaken for three representative swamp types and three climate scenarios, indicates that seepage from the base of the swamps overlying longwall mining areas is predicted to increase from between 1.4 and 19.8 m^3/m width of swamp per annum without the Project to between 42.7 and 125.5 m^3/m width of swamp per annum as a result of the Project.

Baseflow reduction associated with Area 5 mining is likely to result in distinguishable effects on flows in the Avon River tributaries, Lake Avon tributaries and Donalds Castle Creek and its tributaries when flow rates are less than approximately 1 ML/d.

Fracturing of bedrock and reduction in baseflow may result in partial or complete loss of pool holding capacity in first and second order streams that are located directly above and adjacent to the proposed longwalls (note that no longwall mining would occur under third order streams). Approximately 15% of the stream controlling features in third order sections of streams located within 400 m of the proposed longwalls could experience fracturing and an associated reduction in pool holding capacity, water level and overland connective flow.

However, the estimated reduction in mean daily inflow rates to Lake Avon and Pheasants Nest Weir, based on both the Project and cumulative mining effects, is low and is likely to be indistinguishable from natural variability in catchment conditions.

It is unlikely that erosion and scouring of upland swamps in the Study Area would occur during frequent flow events (represented by the 50% Annual Exceedance Probability [AEP] peak flow). There is potential that erosion and scouring could occur in three of the 22 upland swamps located in the Study Area during a 1% AEP peak flow as a result of subsidence induced tilt.

Potential impacts on water quality as a result of the predicted Project subsidence impacts would be localised. Although mine subsidence effects may result in isolated, episodic pulses in elevated dissolved metals 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 to date.

The existing water management systems at the Dendrobium Mine facilities 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 Portal and mine water discharge pipeline to the existing Licenced Discharge Point (LDP) 5 at Allans Creek.

Surface water runoff at the proposed Area 5 ventilation shaft site would be directed to two sediment basins where the stored water would be automatically dosed with gypsum or other approved flocculant to aid in the sediment settling process. Water stored in the sediment basins would be periodically pumped to a discharge borehole and directed to the underground mine workings, thereby avoiding concentrated surface water discharges from the ventilation shaft site to the Metropolitan Special Area.

Increased groundwater inflows associated with mining in Area 5 would continue to be managed in accordance with the Environmental Protection Licence (EPL) 3241 conditions (i.e. discharge via LDP5). Additional infrastructure would be implemented to accommodate the expected increased controlled release volumes if required for the Project. The groundwater quality estimates for Area 5 are expected to remain within the range of existing concentrations measured at LDP5 and licensed under EPL 3241.

1.0 INTRODUCTION

1.1 BACKGROUND

The Dendrobium Mine is an underground coal mine situated in the Southern Coalfield of New South Wales (NSW) approximately 8 kilometres (km) west of Wollongong (Figure 1).

Dendrobium Coal Pty Ltd, a wholly owned subsidiary of Illawarra Coal Holdings Pty Ltd (Illawarra Metallurgical Coal [IMC]) which is in turn a wholly owned subsidiary of South32 Limited (South32), is the owner and operator of the Dendrobium Mine. The Dendrobium Mine, nearby Appin Mine and supporting operations are managed by IMC.

Development Consent DA 60-03-2001 for the Dendrobium Mine was granted by the NSW Minister for Urban Affairs and Planning under the NSW *Environmental Planning and Assessment Act 1979* (EP&A Act) in November 2001.

The Dendrobium Mine extracts coal from the Wongawilli Seam (also known as the No. 3 Seam) within Consolidated Coal Lease (CCL) 768 using underground longwall mining methods. The Dendrobium Mine includes five approved underground mining domains, named Areas 1, 2, 3A, 3B and 3C. Longwall mining is currently being undertaken in Area 3B, with extraction largely complete in Areas 1, 2 and 3A (Figure 1).

The Dendrobium Mine has an approved operational capacity of up to 5.2 million tonnes per annum (Mtpa) of run-of-mine (ROM) coal until 31 December 2030.

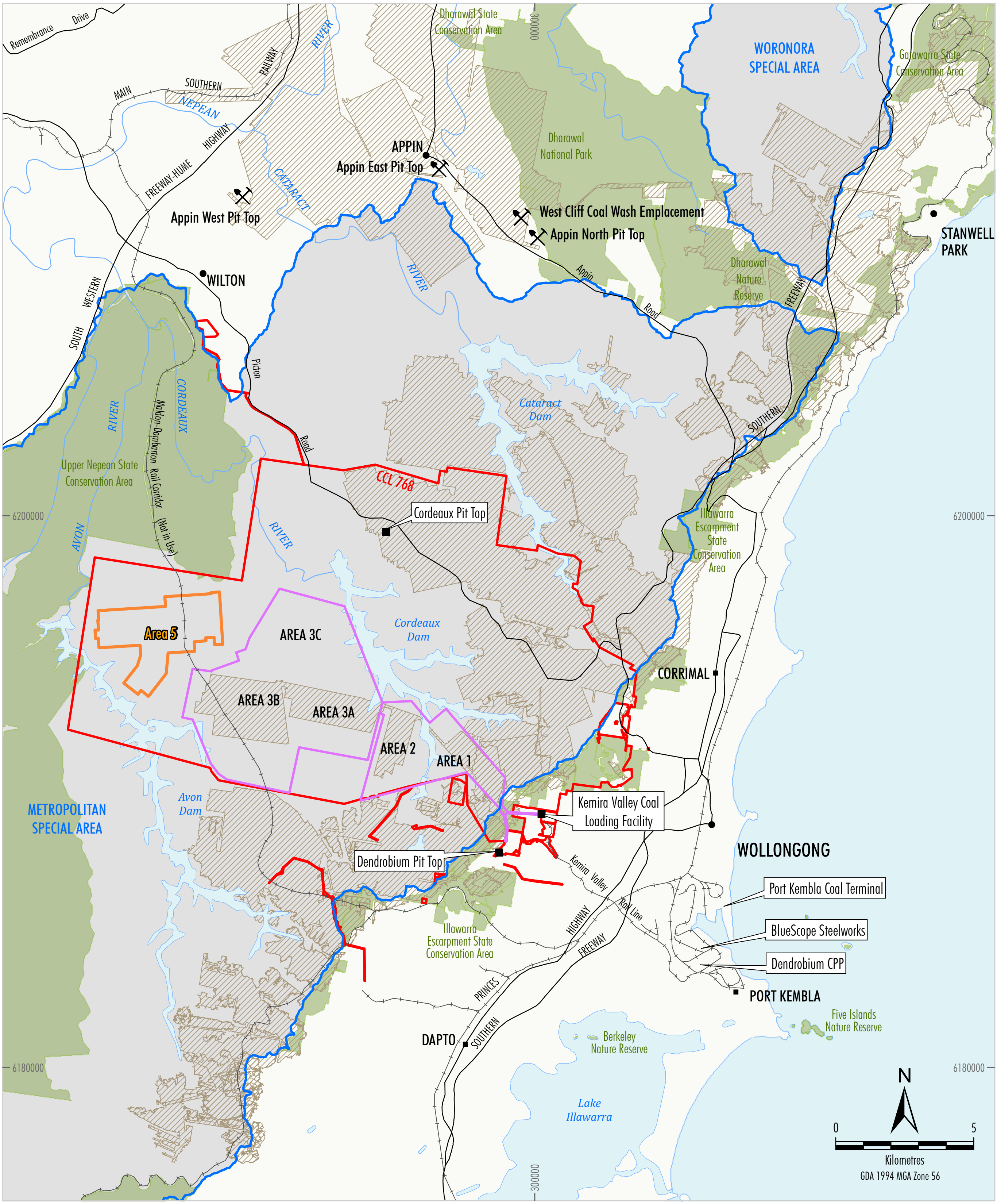
1.2 PROJECT OVERVIEW

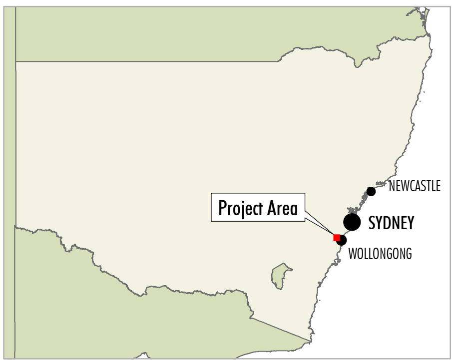
IMC is seeking Infrastructure Approval for the Dendrobium Mine Extension Project (the Project), which would support the extraction of approximately 31 million tonnes (Mt) of ROM coal from Area 5 (Figure 2), within CCL 768. The life of the Project includes longwall mining in Area 5 up to approximately 31 December 2034, and ongoing use of existing surface facilities for handling of Area 3C ROM coal until 2041[1].

The Project would include the following activities:

- longwall mining of the Bulli Seam in a new underground mining area (Area 5);
- development of underground roadways from existing Dendrobium Mine underground areas (namely Area 3) to Area 5;
- use of existing underground roadways and drifts for personnel and materials access, ventilation, dewatering and other ancillary activities related to Area 5;
- development of new surface infrastructure associated with mine ventilation and gas management and abatement, water management and other ancillary infrastructure;
- handling and processing of up to 5.2 Mtpa of ROM coal;
- extension of mining operations within Area 5 until approximately 2035;
- use of the existing Dendrobium Pit Top, Kemira Valley Coal Loading Facility, Dendrobium Coal Preparation Plant (CPP) and Dendrobium Shafts with minor upgrades and extensions until approximately 2041;
- transport of sized ROM coal from the Kemira Valley Coal Loading Facility to the Dendrobium CPP via the Kemira Valley Rail Line;

[1] The Project does not include approved underground mining operations in the Wongawilli Seam in Areas 1, 2, 3A, 3B and 3C at the Dendrobium Mine and associated surface activities (such as monitoring and remediation). These activities will continue to operate in accordance with Development Consent DA 60-03-2001 (as modified).





LEGEND
- Dendrobium Mining Lease
- Road
- Railway
- National Park, Nature Reserve and State Conservation Area
- Historic Mine Workings
- Declared Catchment Area
- Dendrobium Underground Mining Area - Existing Mine (DA 60-03-2001)
- Dendrobium Underground Mining Area Extension Project

Source: Geoscience Australia, (2006); Department of Industry (2018); Department Finance, Services & Innovation (2018);

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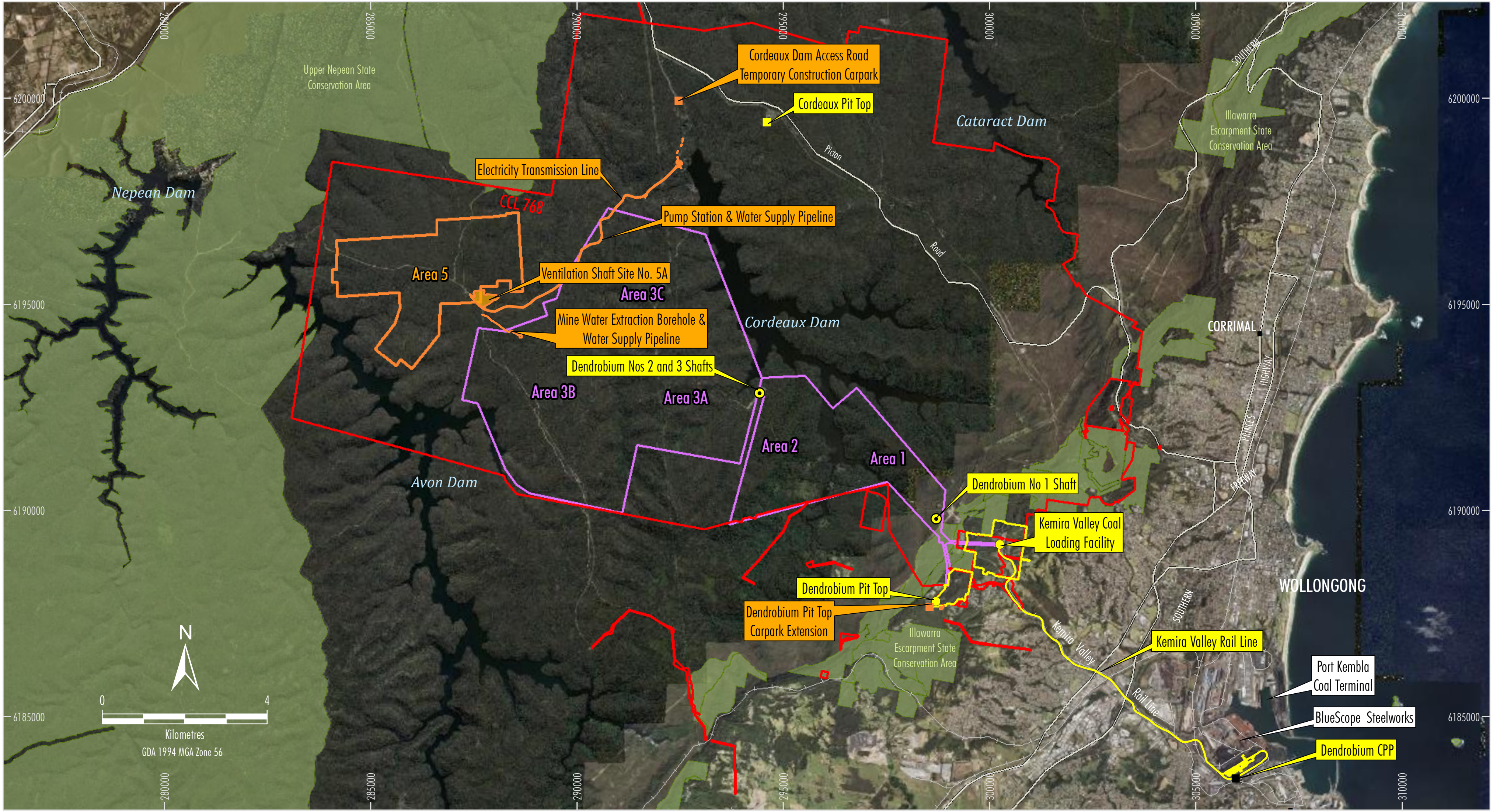
D E N D R O B I U M   M I N E
Regional Location

Figure 1



LEGEND

- Dendrobium Mining Lease
- Road
- Railway
- National Park, Nature Reserve and State Conservation Area

Dendrobium Mine

- Dendrobium Underground Mining Area - Existing Mine (DA 60-03-2001)

Dendrobium Mine Extension Project

- Underground Mining Area
- Surface Facilities (Existing Dendrobium Mine)
- Surface Facilities (Proposed Dendrobium Mine Extension Project)

Source: Geoscience Australia, (2006); Department of Industry (2018); Department Finance, Services & Innovation (2018);

SOUTH32 Illawarra Coal

DENDROBIUM MINE

General Arrangement
Dendrobium Mine Extension Project

Figure 2

- handling and processing of coal from the Dendrobium Mine (including the Project) and IMC's Appin Mine (if required) to the Dendrobium CPP to 2041;
- delivery of coal from the Dendrobium CPP to Port Kembla for domestic use at the Port Kembla Steelworks and Liberty Primary Steel Whyalla Steelworks or export through the Port Kembla Coal Terminal (PKCT);
- 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 Stage 3 and Stage 4 Coal Wash Emplacement;
- development and rehabilitation of the West Cliff Stage 3 Coal Wash Emplacement (noting that opportunities for beneficial use of coal wash would be maximised);
- continued use of the Cordeaux Pit Top for mining support activities such as exploration, environmental monitoring, survey, rehabilitation, administration and other ancillary activities;
- progressive development of sumps, pumps, pipelines, water storages and other water management infrastructure;
- controlled release of excess water (similar to the current regime in the Environmental Protection Licence [EPL] 3241) and/or beneficial use;
- monitoring, rehabilitation and remediation of subsidence and other mining effects; and
- other associated infrastructure, plant, equipment and activities.

1.3 SCOPE AND PREPARATION

Hydro Engineering & Consulting Pty Ltd (HEC), a division of ATC Williams Pty Ltd (ATCW), was commissioned by IMC to undertake a Surface Water Assessment as a component of the Environmental Impact Statement (EIS) prepared in support of the Infrastructure Approval application for the Project.

The Surface Water Assessment covers a Study Area comprising the 35 degree (°) angle of draw and a 600 metre (m) buffer area associated with the proposed Area 5 longwall (LW) 501 to LW510.

The Surface Water Assessment has been prepared by Dr Camilla West who has been endorsed by the Department of Planning and Environment (DPE) as a suitability qualified person for preparation of surface water management plans for mining operations in the Southern Coalfield.

1.4 STUDY REQUIREMENTS

This assessment has been prepared in accordance with the Secretary's Environmental Assessment Requirements (SEARs) for the Project dated 23 December 2021. Table 1 provides a summary of the SEARs relating to surface water, including those provided by WaterNSW, the NSW DPE, Natural Resources Access Regulator (NRAR) and the NSW Environment Protection Agency (EPA), and 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 – General	A description of the existing environment likely to be affected by the development, using sufficient baseline data.	Section 2.0
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 the NSW Aquifer Interference Policy and the advice of DPE Water, WaterNSW and the EPA.	Section 5.0 and Section 6.0 Groundwater resources are addressed in Watershed HydroGeo (2022).
	An assessment of the likely impacts of the development on aquifers, watercourses, swamps, riparian land, groundwater dependent ecosystems, water supply infrastructure and systems including Cordeaux Dam and Avon Dam, basic landholder rights and other water users.	
	An assessment of all water take for the life of the project and post-closure, including water taken directly and indirectly and itemised to quantify the contributions from each water source.	Section 5.3 and Section 5.6
	An assessment on 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 (Sydney Drinking Water Catchment) 2021*. Note: The *State Environmental Planning Policy (Sydney Drinking Water Catchment) 2011* has been transferred to Chapter 8 of the *State Environmental Planning Policy (Biodiversity and Conservation) 2021*.	Section 6.0
	A detailed site water balance, including a description of site water demands, water disposal methods (including the location, volume and frequency of any water discharges and management of discharge water quality), water supply and transfer infrastructure and water storage structures, including: • An assessment of the reliability of water supply, including consideration of climate change; and • Demonstration that water can be obtained from an appropriately authorised supply in accordance with the operating rules of any relevant Water Sharing Plans (WSP) or any alternative mechanisms agreed following consultation with the relevant NSW government agencies/state authorities.	Section 3.3
	Identification of an adequate and secure water supply for the life of the project and any licensing requirements or other approvals under the *Water Act 1912* and/or *Water Management Act 2000*, including a description of the measures proposed to ensure the development can operate in accordance with the requirements of any relevant water sharing plan or water source embargo, or any alternative mechanisms agreed following consultation with the relevant NSW government agencies/statutory authorities.	N/A
	A detailed description of the proposed water management system (including sewerage), beneficial water re-use program, water monitoring program and other measures to mitigate surface water and groundwater impacts.	Section 3.0
	An assessment of the potential flooding impacts of the development.	Section 5.5
	A description of proposed surface and groundwater monitoring activities and methodologies.	Section 8.0 Groundwater resources are addressed in Watershed HydroGeo (2022).

Table 1 (Cont.) Summary of SEARs and Relevant Sections

Document	Requirements	Report Section
SEARs – Specific Issues (Water)	An assessment of any potential cumulative impacts on water resources, and any proposed options to manage the cumulative impacts.	Section 5.3, Section 5.6 and Section 6.0
	A description of the reasonable and feasible mitigation and management measures proposed to prevent pollution of waters and to avoid or mitigate impacts to the quality or quantity of surface and groundwater resources, including assessment of the predicted effectiveness and cost of the mitigation measures.	Section 6.0
WaterNSW	The full description of the development and existing environment should also include those aspects which have the potential to impact on the quality and quantity of surface and groundwaters 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 • the location and description of all water monitoring locations/points (surface and groundwaters)	Section 2.0, Section 3.1, Section 3.2 and Section 8.0
	The detailed assessment of the mining proposal on water resources associated with subsidence should also consider the design, construction, operational, decommissioning phases, and cumulative impacts and include: • impacts on water quantity and quality of overlying and adjacent water resources including Avon and Cordeaux Reservoirs, Rivers and their tributaries and swamps; • 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 performances measures; and • 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.	Section 5.3, Section 5.6, Section 5.8 and Section 6.0 Section 6.0 Section 8.0
DPIE Water and NRAR	A detailed and consolidated site water balance.	Section 3.3
	Assessment of impacts on surface and ground water sources (both quality and quantity), related infrastructure, adjacent licensed water users, basic landholder rights, watercourses, riparian land, and groundwater dependent ecosystems, and measures proposed to reduce and mitigate these impacts.	Section 6.0
	Proposed surface and groundwater monitoring activities and methodologies including details and timing of specific studies which demonstrate accuracy and resolution of the above methods.	Section 8.0
	Assessment of any potential cumulative impacts on water resources, and any proposed options to manage the cumulative impacts.	Section 6.0
EPA	A description of site surface water infrastructure and water management systems. This includes infrastructure for the capture of stormwater and mine water, transport, treatment and release structures.	Section 3.0
	A description of the characteristics and quantities of water discharged through the licence discharge points.	
	An assessment of the impact of the licenced discharges.	

The objects of the NSW Water Management Act, 2000, which is the principal statute governing management of water resources in NSW, were considered in relation to 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.*

The Surface Water Assessment has also been prepared with consideration to the following key guidelines:

- 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).
- Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZG, 2018).
- Draft Upland Swamp Environmental Assessment Guidelines – Guidance for the Underground Mining Industry Operating in the Southern Coalfield (NSW Office of Environment and Heritage, 2012).
- Neutral or Beneficial Effect on Water Quality Assessment Guideline (WaterNSW, 2015).
- Impacts of Underground Coal Mining on Natural Features in the Southern Coalfield Strategic Review (Department of Planning, 2008).

2.0 BASELINE HYDROLOGY

The Project is located in the NSW Southern Coalfield within the southern portion of the Permo-Triassic Sydney Basin. Mining of Area 5 will target the Bulli Coal seam which forms a component of the Illawarra Coal Measures. Above the Illawarra Coal Measures, the stratigraphy of the area consists of a sequence of sandstone, shale and claystone units within the Narrabeen Group. The Narrabeen Group is overlain by the Hawkesbury Sandstone which outcrops at surface in the Area 5 region (Watershed HydroGeo, 2022). Small pockets of Quaternary-aged swamp deposits are also present in Area 5 (Watershed HydroGeo, 2022).

There is significant topographic relief and a relatively high drainage density in the catchments across Area 5. Surface elevations vary from approximately 445 metres Australian Height Datum (m AHD) in the south to approximately 284 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 area is situated in 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. Natural vegetation is present over the majority of Area 5 with the exception of fire roads, powerlines, the Maldon-Dombarton rail corridor and other minor disturbances (refer Figure 1).

2.1 CLIMATE

2.1.1 Temperature, Wind Speed and Humidity

Long term climate records for the Bureau of Meteorology (BoM) Bellambi AWS (068228) weather station are summarised in Table 2. Bellambi AWS (068228) is the nearest open weather station to Area 5, located approximately 23 km to the east (Figure 3). It should be noted that the weather station is located on the coast and therefore may not accurately reflect climatic conditions at Area 5.

Table 2 Summary of Regional Climatic Variables

Site Number		068228
Site Name		Bellambi AWS
Latitude (degrees)		-34.37
Longitude (degrees)		150.93
Mean Monthly Minimum Temperature (ºC)	Minimum	10.2 (Jul)
	Maximum	19.2 (Feb)
Mean Monthly Maximum Temperature (ºC)	Minimum	17.2 (Jul)
	Maximum	25.0 (Jan)
Mean 9 am Wind Speed (km/hr)	Minimum	15.0 (Mar)
	Maximum	18.7 (Nov)
Mean 9 am Relative Humidity (%)	Minimum	56 (Aug)
	Maximum	76 (Feb)

The data presented in Table 2 illustrates that the region experiences a temperate climate with mean monthly maximum temperatures ranging from 17.2 degrees Celsius (ºC) in July to 25 ºC in January. Mean monthly minimum temperatures range from 10.2 ºC in July to 19.2 ºC in February.

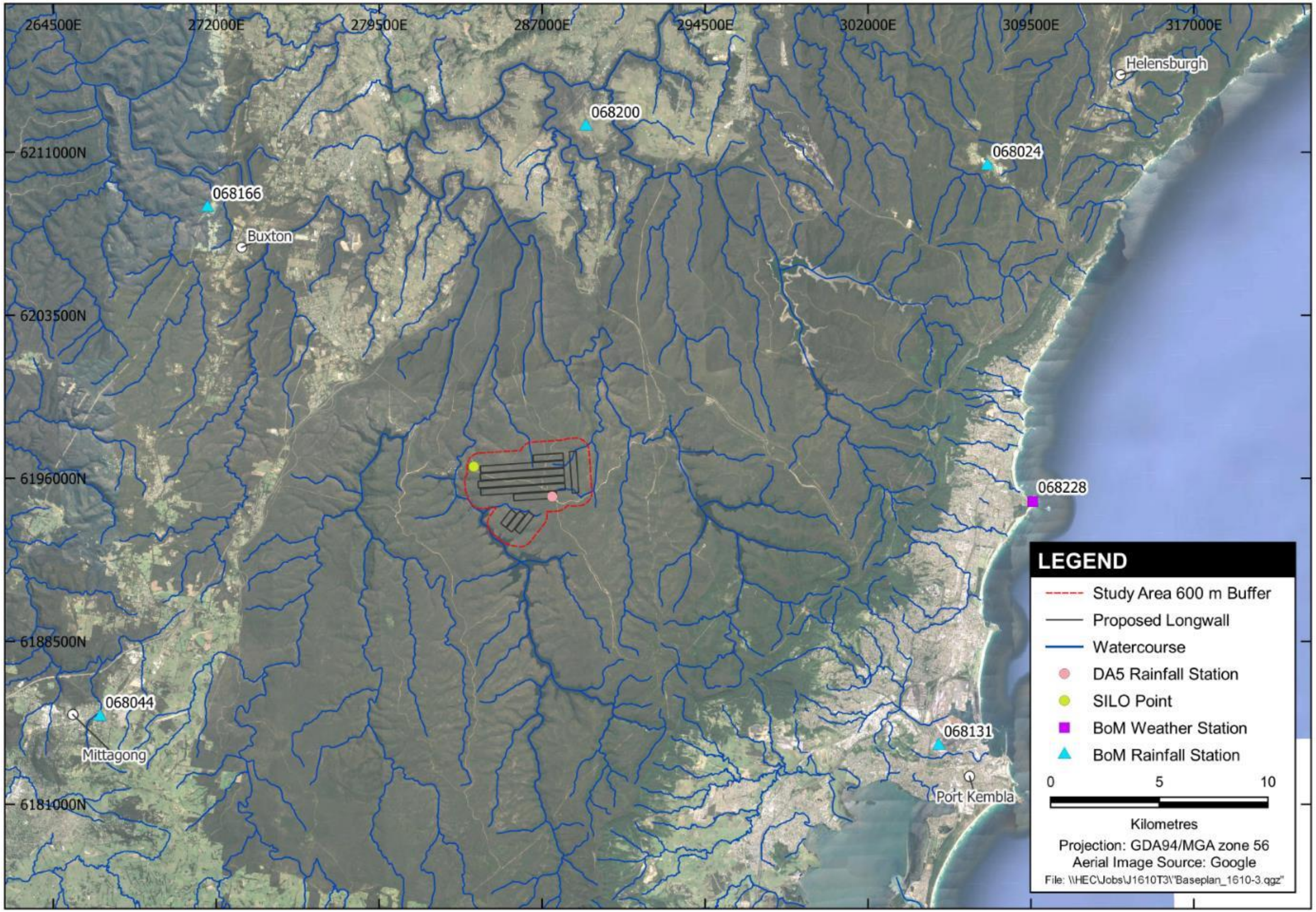


Figure 3 Regional Weather and Rainfall Stations

2.1.2 Rainfall and Evaporation

The long-term average monthly rainfall recorded at open regional BoM stations is summarised in Table 3 in comparison with Scientific Information for Land Owners (SILO) Point Data[2] monthly rainfall. The locations of the stations are shown in Figure 3.

Table 3 Summary of Average Regional Rainfall and Pan Evaporation

Site Number	**068166**	**068200**	**068024**	**068131**	**068044**	**SILO Point Data (point in Area 5)**	
Site Name	**Buxton (Amaroo)**	**Douglas Park (St. Marys Towers)**	**Darkes Forest (Kintyre)**	**Port Kembla (Bsl Central Lab)**	**Mittagong (Alfred Street)**		
Latitude	-34.24	-34.21	-34.23	-34.47	-34.45	-34.35	
Longitude	150.52	150.71	150.91	150.88	150.46	150.7	
Data Period	1967 - 2021	1974 - 2021	1894 - 2021	1963 - 2021	1886 - 2021	1889 - 2021	
Average Rainfall (mm)*							**Average Pan Evaporation (mm)**
January	92.2	68.1	131.1	96.3	86.6	118	174
February	122.0	89.2	158.4	129.7	93.2	134	139
March	87.8	89.5	156.3	143.9	96.5	124	122
April	69.5	60.1	125.3	106.0	73.3	97	90
May	50.6	55.9	128.4	79.5	73.5	93	63
June	65.0	68.5	145.1	116.2	88.7	111	49
July	34.8	39.6	95.4	52.5	65.9	78	56
August	50.7	43.8	88.6	71.6	57.5	69	82
September	44.0	40.3	76.5	56.5	51.7	61	110
October	63.2	55	92.0	85.3	64.3	77	139
November	88.4	72.5	104.6	85.2	70.2	84	154
December	75.6	56.6	103.0	72.7	76.4	89	181
Annual	844	739	1,405	1,095	898	1,136	1,358

* mm = millimetres

The data presented in Table 3 illustrates that rainfall is typically spread throughout the year although tends to be higher in the summer months. Average annual rainfall varies from 739 mm to 1,405 mm across the region. On average, rainfall is generally 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.

Based on the SILO Point Data, annual average pan evaporation is slightly higher than annual average rainfall, with average monthly pan evaporation exceeding rainfall from August to February and average rainfall exceeding average pan evaporation from April to July.

Daily rainfall has been recorded at the IMC DA5 rainfall station, located in Area 5, from July 2017. Table 4 presents the average monthly rainfall records for Area 5 in comparison with average monthly rainfall and evaporation data calculated from SILO Point Data for the corresponding period (refer Figure 3 for location).

[2] SILO Point Data 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 4 Study Area Average Monthly Rainfall and Evaporation

Month	Area 5	SILO Point Data (Point in Area 5)	
	Rainfall (mm)		Evaporation (mm)
Jan	90	84	194
Feb	180	146	147
Mar	181	151	128
Apr	20	22	94
May	35	43	69
Jun	47	50	45
Jul	72	60	60
Aug	63	48	84
Sep	38	29	119
Oct	70	75	140
Nov	74	67	176
Dec	50	59	194
Annual	920	835	1,450

The data in Table 4 illustrates that rainfall recorded at Area 5 from July 2017 to present is comparable to that obtained from SILO Point Data. As the SILO Point Data values generally compare well with rainfall records for Area 5, the long-term rainfall and evaporation datasets obtained from the SILO Point Data have been used in the water balance (Section 3.3).

2.2 CATCHMENTS AND SURFACE WATER RESOURCES

2.2.1 Catchments and Watercourses

The Study Area (proposed underground mining area plus 600 m boundary) covers a total area of 18.95 square kilometres (km^2) and is located within the Avon and Cordeaux River catchments, as shown in Figure 4. The catchment area of the Avon River is approximately 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 Study 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 Pheasants 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.

The Study 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 eucalypt woodland, heaths and mallee and upland swamp vegetation comprising banksia thickets, tea-tree thickets, sedgeland-heath complexes and eucalypt fringing woodland (Niche, 2022).

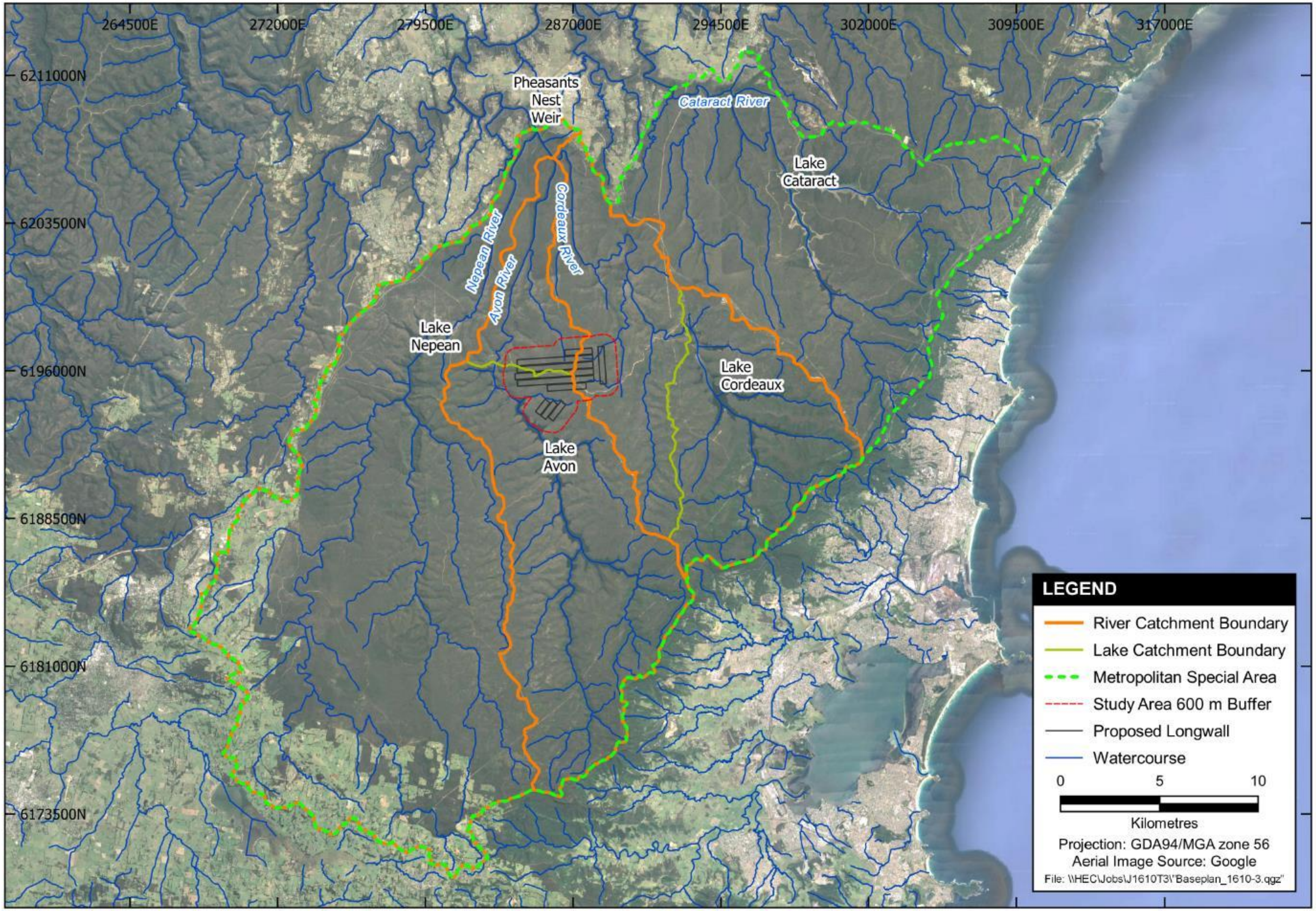


Figure 4 Regional Surface Water Catchments

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). Area 5 is located within the Upper Nepean River Tributaries Headwaters Management Zone of the Upper Nepean and Upstream Warragamba Water Source and is adjacent to the Avon River Management Zone.

The Avon River travels adjacent to the western and south-western boundary of the Study Area, with Lake Avon situated adjacent to the western boundary of the Study Area. The headwaters of Donalds Castle Creek are located within the eastern portion of the Study Area. The confluence of Donalds Castle Creek and the Cordeaux River is located approximately 3 km downstream of the north-eastern Study Area boundary.

Streams in plateau areas of outcropping Hawkesbury Sandstone are typically dish-shaped drainage lines with ill-defined bed and banks. Upland swamps are present 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 of deeper valleys. From the confined incised valley and gorges which make up the dissected plateau areas, the character of the streams changes 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 create 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 main tributaries of the Avon River, Lake Avon and Donalds Castle Creek overlying Area 5 are shown in Figure 5. A summary of the catchment area, stream order, average stream gradient and stream length for these streams is provided in Table 5.

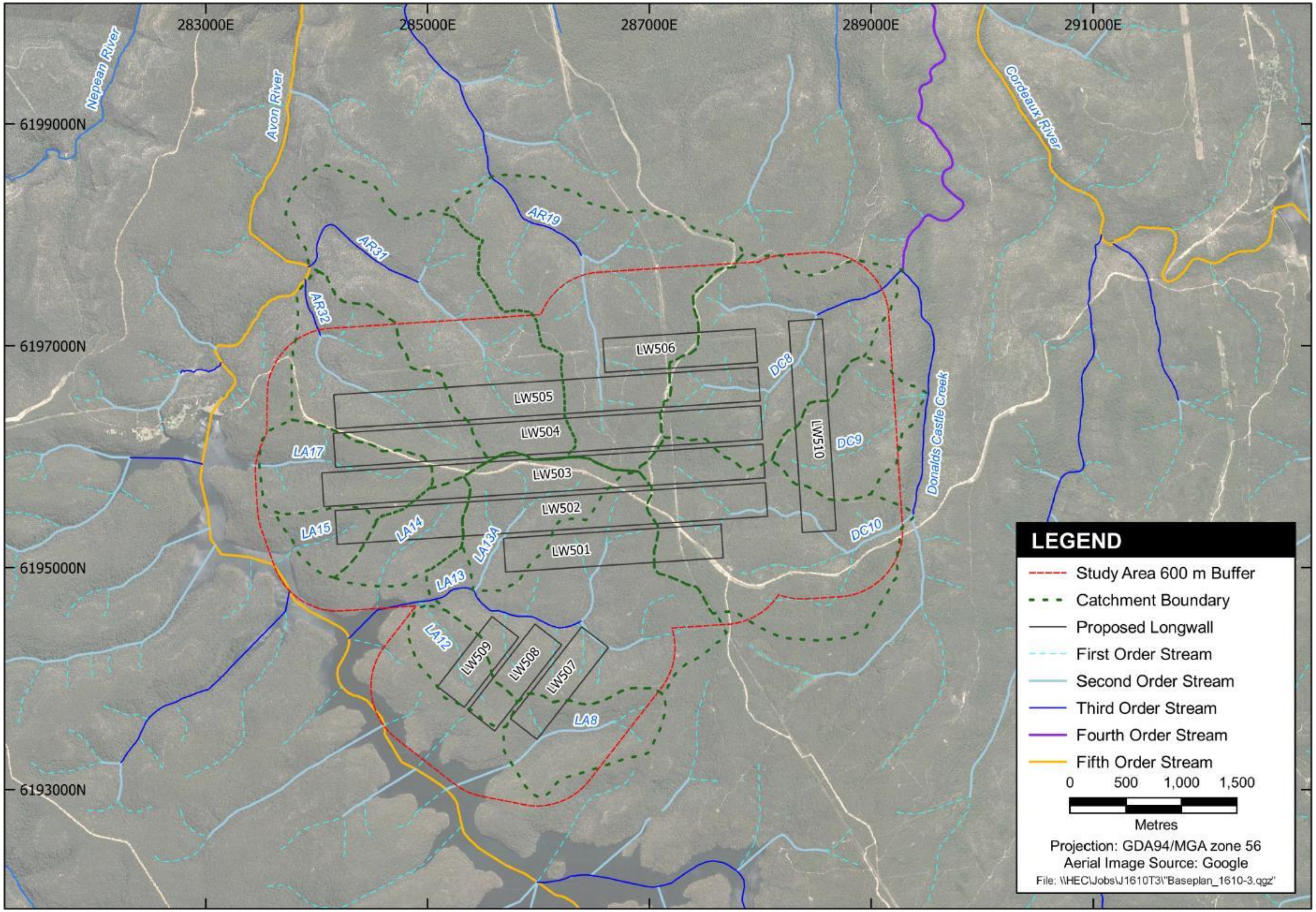


Figure 5 Study Area Watercourses and Stream Order

Table 5 Summary of Area 5 Stream Characteristics

Stream ID	Catchment Area (km^2)	Maximum Stream Order[3]	Average Stream Gradient[4] (m/km)[#]	Stream Length (km)[#]
Avon River Catchment				
AR19	3.6^	3	29	2.7
AR31	3.0	3	39	2.9
AR32	1.7	3	46	2.2
Avon River	150.4	5	7	38.4[##] (6.8[#])
Lake Avon Catchment				
LA8	0.9	2	45	1.3
LA12	0.6	1	72	1.1
LA13A	1.1	2	54	1.5
LA13	4.0	3	29	2.8
LA14	0.6	1	71	1.0
LA15	0.4	1	87	0.6
LA17	1.0	2	51	1.5
Donalds Castle Creek Catchment				
DC8	2.6	3	43	2.6
DC9	1.1	1	55	1.5
DC10	2.9	2	50	1.7
Donalds Castle Creek	11.4	4	14	8.8[##] (3.3[#])

[#] Within the Study Area (underground mining area plus 600 m buffer); m/km = metres per kilometre.
[##] Total length of river/creek
^ Partial catchment area to monitoring site AR19S1

2.2.2 Streamflow Characteristics

IMC has established streamflow monitoring locations at nine sites within and adjacent to Area 5 as shown in Figure 6. Streamflow monitoring has been conducted from 2007 at monitoring site DCU, from 2012 at monitoring site DC2, from 2017 at monitoring sites DC8S1, AR19S1, AR31S1, AR32S1, LA13AS1 and LA13S1 and from 2019 at monitoring sites LA8S1. Table 6 presents the mean annual flow statistics for the streamflow gauging sites with at least one complete year of streamflow data records (eight of nine sites[5]). The catchment yield/rainfall percentage based on the mean annual SILO Point Data rainfall for the period of the monitored flow is also presented for comparative purposes.

Streamflow monitoring sites on Donalds Castle Creek (DCU and DCS2) are subject to influences from Dendrobium Mine Area 3. As such, the flow statistics presented for these sites are not representative of baseline (pre-mining) conditions.

[3] 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'.

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

[5] LA8S1 monitoring data records are incomplete for 2019 – 2021 due to catchment closure prohibiting data download.

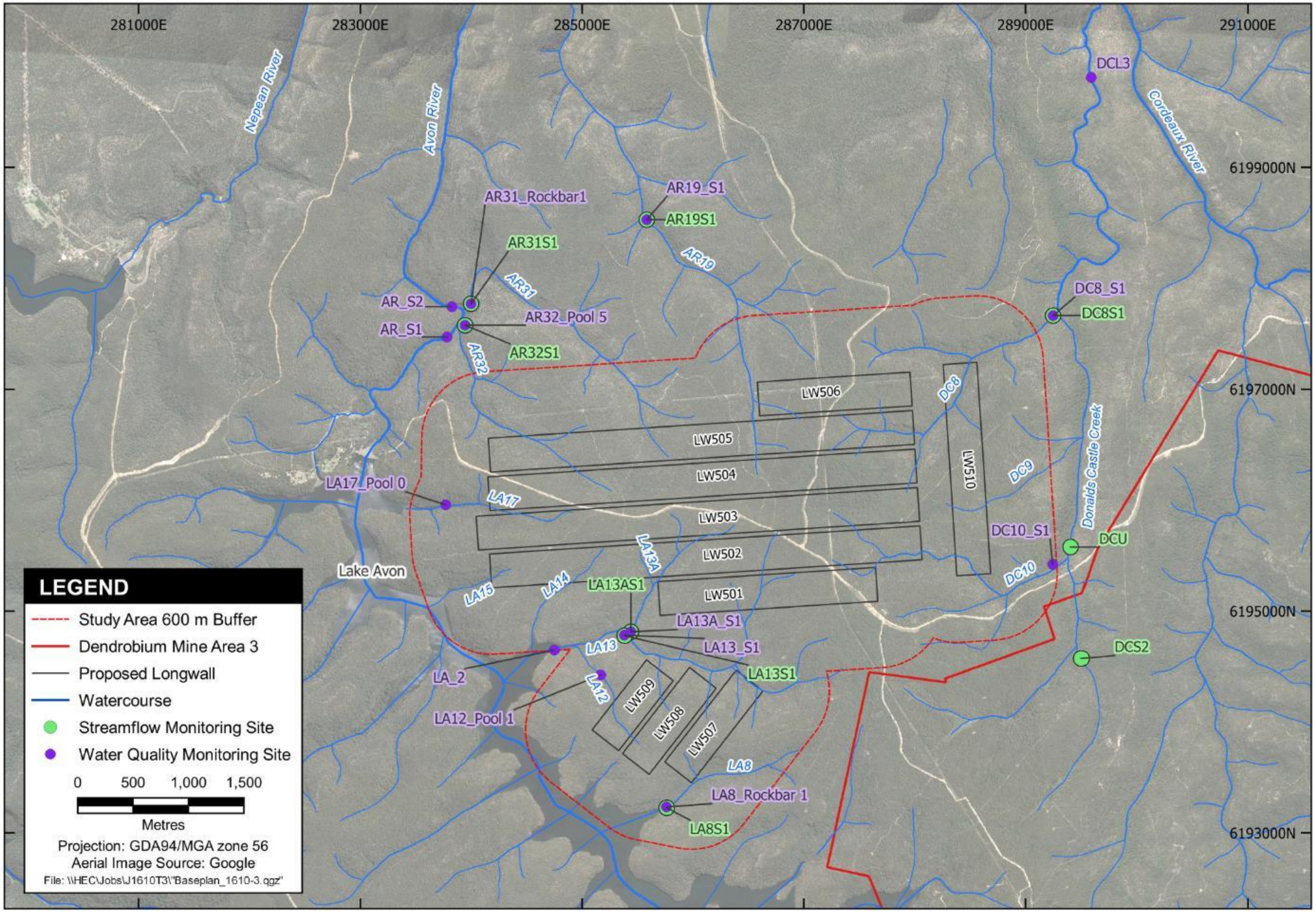


Figure 6 Study Area Surface Water Monitoring

Table 6 Area 5 Streamflow Statistics

Catchment	Site Name	Catchment Area (km^2)	Mean Flow (ML/year)**	Mean Flow Depth (mm/year)#	Yield/Rainfall Ratio
Donalds Castle Creek	DCU*	6.2	944	152	17%
	DC8S1	2.6	344	134	17%
	DCS2*	6.2	169	27	3%
Avon River	AR31S1	3.0	483	163	21%
	AR32S1	1.7	73	43	5%
	AR19S1	3.6	106	29	4%
Lake Avon	LA13AS1	1.1	47	43	5%
	LA13S1	2.8	47	17	2%
	LA8S1	0.9	220	249	31%

* Monitoring site located within or downstream of Dendrobium Mine Area 3.

** ML/year - megalitres per year

mm/year = millimetres per year

The results presented in Table 6 indicate that the yield percentage at site AR31S1 is considered high for a forested catchment, while those for the remainder are more typical for Australian streams.

Flow duration curves for the streamflow monitoring sites which are not influenced by existing mining activities are shown in Figure 7. The rate of streamflow is expressed in ML/d per km^2 of catchment (or mm/day) to enable direct comparison between streamflow sites.

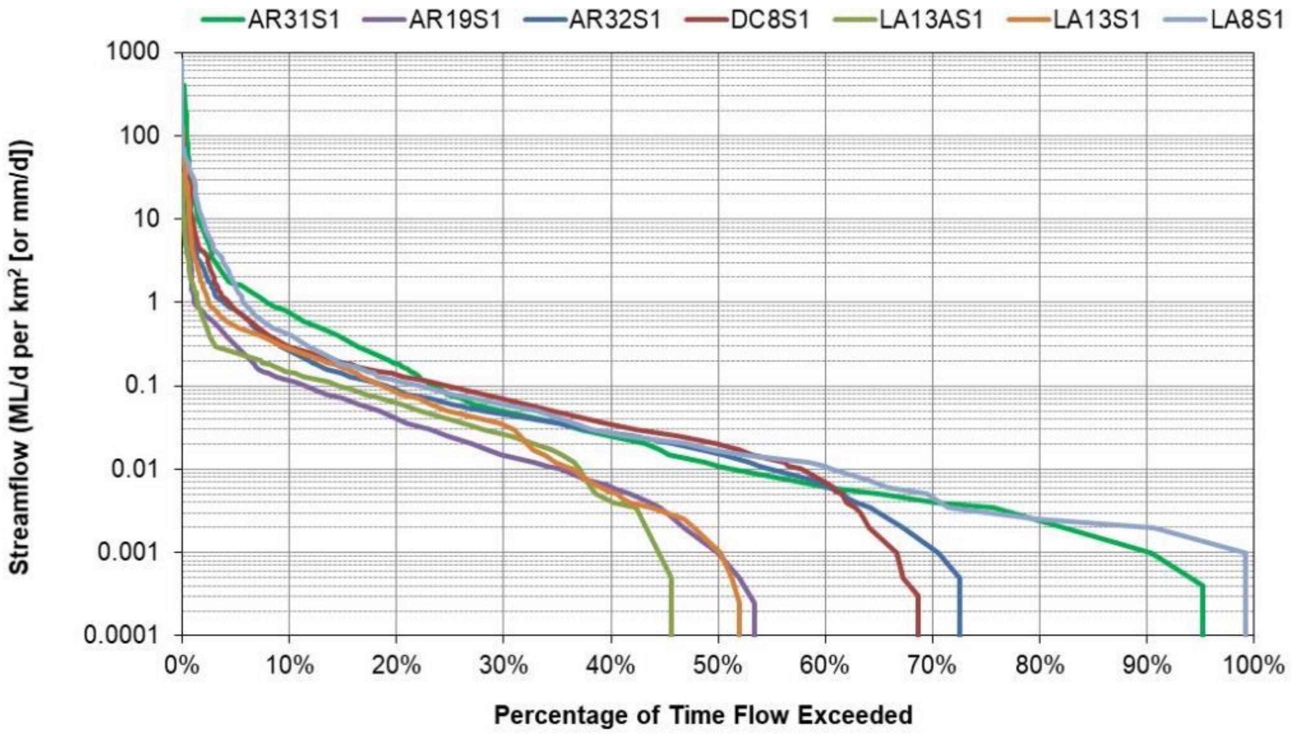


Figure 7 Flow Duration Curves for Donalds Castle Creek, Avon River and Lake Avon Tributaries

Figure 7 illustrates that monitoring site LA8S1, located on a tributary of Lake Avon, and monitoring site AR31S1, located on a tributary of the Avon River, recorded similar streamflow characteristics over the duration of monitoring with near perennial flow recorded. The streamflow monitoring data for DC8S1, located on a tributary of Donalds Castle Creek, and AR32S1, located on a tributary of the Avon River, indicate intermittent conditions with flow rates of 0.02 mm/d and 0.017 mm/d exceeded 50% of the time respectively. The streamflow monitoring data for LA13S1 and LA13AS1, located on tributaries of Lake Avon, and AR19S1, located on a tributary of the Avon River, indicate similar streamflow characteristics at these sites with intermittent flow recorded.

2.2.3 Water Quality Characteristics

2.2.3.1 Default Guideline Values

The revised Water Quality Management Framework detailed in the ANZG (2018) Guidelines states that where locally relevant water quality guideline values are not yet available, the default guideline values should be adopted. However, updated default guideline values are yet to be published under the ANZG (2018) Guidelines for physicochemical constituents and, as such, adoption of the ANZECC & ARMCANZ (2000) Guideline default values are recommended. Updated default guideline values for toxicants have been published by ANZG (2018) and are adopted in the assessment of water quality monitoring data presented in the following sections.

In NSW, the level of protection applied to most waterways is that for ‘slightly to moderately disturbed’ ecosystems, for which ANZG (2018) recommends adoption of the default guideline values for aquatic ecosystems at the 95% protection level. The water quality monitoring data for physicochemical constituents have been assessed against the ANZECC & ARMCANZ (2000) default guideline values for the protection of slightly disturbed aquatic ecosystems in south-east Australian Upland Rivers. Upland streams are defined as those above 150 m altitude.

Due to the proximity of the Study Area to Lake Avon, the water quality monitoring data have also been considered in relation to the Australian Drinking Water Guidelines (ADWG) (National Health and Medical Research Council [NHMRC], 2022) for health and aesthetic purposes. The ADWG pertain specifically to the microbial, chemical and physical characteristics of water. Table 7 summarises the water quality objectives for parameters monitored by IMC in the Study Area.

Table 7 Default Guideline Values for the Study Area

Parameter	ANZG (2018)	ANZECC Guidelines (2000)	Australian Drinking Water Guidelines (2022)	
	Aquatic Ecosystems (95th percentile protection level)	Upland Rivers (NSW)	Health	Aesthetic
pH (pH units)	-	6.5 - 8.5	-	6.5 - 8.5
EC* (µS/cm) and TDS† (mg/L)	-	350*	-	600†
Dissolved Oxygen (%)	-	90-110	-	> 85
Sodium (mg/L)	-	180	-	-
Chloride (mg/L)	-	250	-	-
Ammonia (mg/L)	-	0.5	-	-
Total Phosphorous (mg/L)	-	0.02	-	-
Total Nitrogen (mg/L)	-	0.25	-	-
Nitrate (mg/L)	-	-	50	-
Nitrite (mg/L)	-	-	3	-
Sulphate as SO_4 (mg/L)	400	-	-	-
Aluminium (pH > 6.5)	0.055	-	-	-
Barium (mg/L)	1	-	-	-
Iron (mg/L)	0.3	-	-	-
Manganese (mg/L)	1.9	-	-	-
Nickel (mg/L)	0.011	-	-	-
Zinc (mg/L)	0.008	-	-	-

* Electrical Conductivity – a measure of salinity; µS/cm = MicroSiemens per centimetre

† Total Dissolved Solids; mg/L = milligrams per litre

2.2.3.2 Water Quality Summary

IMC commenced water quality monitoring in October 2016 at sites within and adjacent to the Study Area, with monitoring at DCL3 in Donalds Castle Creek commencing in October 2001. 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.

Monitoring site DCL3 is located downstream of Dendrobium Mine Area 3 and therefore may potentially be impacted by changes in water quality associated with existing mine activities. The remainder of the monitoring sites are located outside of the potential zone of influence of Dendrobium Mine Area 3.

Water quality summary tables are presented in Appendix A for each monitoring site. The water quality default guidelines listed in Table 6 have been used as a basis for interpretation of the data. Where multiple default guideline values are specified for a parameter, the most conservative value has been adopted for comparison. Where laboratory results have been recorded at below the limit of detection the result has been analysed assuming the concentration was equal to the limit of detection.

Lake Avon Catchment

The water quality monitoring data indicates that surface water systems in the Lake Avon catchment vary from acidic to near neutral conditions, with field pH values ranging from 4.6 to 7.6. Lake Avon (LA_2) field pH values ranged from 5.3 to 7.6, with 36% of samples exceeding the lower default guideline value for pH. Electrical conductivity values recorded at all sites were low (less than 252 µS/cm) with no exceedances of the default guideline value for electrical conductivity.

Total alkalinity concentrations recorded at all sites were low (less than 15 mg/L) indicating a low capacity to buffer against changes in pH. An exceedance of the default guideline value for total nitrogen (0.25 mg/L) was recorded at LA13_S1 while exceedances of the default guideline value for total phosphorus were recorded at LA_2, LA13_S1, LA13A_S1, LA17_Pool 0 and LA8_Rockbar 1.

Dissolved aluminium concentrations ranged from <0.01 mg/L to 0.78 mg/L in the Lake Avon tributaries, with exceedances of the default guideline value for aluminium (0.055 mg/L) recorded at all sites. Lake Avon (LA_2) dissolved aluminium concentrations ranged from <0.01 mg/L to 0.09 mg/L, with 7% of samples exceeding the default guideline value for aluminium.

Dissolved iron concentrations ranged from <0.05 mg/L to 4.4 mg/L in the Lake Avon tributaries, with exceedances of the default guideline value for iron (0.3 mg/L) recorded at all sites except LA 12_Pool 1. Lake Avon (LA_2) dissolved iron concentrations ranged from <0.05 mg/L to 0.37 mg/L, with 2% of samples exceeding the default guideline value for iron.

Exceedances of the default guideline value for manganese (1.9 mg/L) were recorded for 4% of total manganese samples collected at monitoring site LA8_Rockbar 1. No exceedances of the default guideline value for manganese were recorded at other monitoring sites in the Lake Avon catchment.

Total zinc concentrations ranged from <0.005 mg/L to 0.14 mg/L in the Lake Avon tributaries, with exceedances of the default guideline value for total zinc (0.008 mg/L) recorded at all sites. Lake Avon (LA_2) total zinc concentrations ranged from <0.005 mg/L to 0.018 mg/L, with 4% of samples exceeding the default guideline value for zinc.

No exceedances of the default guideline values for sulfate, barium and nickel were recorded at any monitoring site in the Lake Avon catchment.

In summary, the water quality monitoring data indicates that total phosphorus, aluminium, iron and zinc are naturally elevated in the Lake Avon catchment surface water systems, with naturally elevated concentrations of total nitrogen and total manganese also recorded at some sites.

Avon River Catchment

The water quality monitoring data indicates that surface water systems in the Avon River catchment vary from acidic to near neutral conditions, with field pH values ranging from 4.8 to 7.2. Avon River (AR_S1 and AR_S2) field pH values ranged from 5.7 to 7.2, with 69% of samples collected at AR_S2 exceeding the lower default guideline value for pH. Electrical conductivity values recorded at all sites were low (less than 285 µS/cm) with no exceedances of the default guideline value for electrical conductivity.

Total alkalinity concentrations recorded at all sites were low (less than 19 mg/L) indicating a low capacity to buffer against changes in pH. Total nitrogen concentrations ranged from 0.1 to 0.6 mg/L at monitoring site AR_S1 in the Avon River and from 0.1 to 0.3 mg/L at AR31_Rockbar 1 and AR32_Pool 9. Total phosphorus concentrations ranged from 0.01 to 0.06 mg/L at monitoring site AR_S1 in the Avon River and from 0.01 to 0.18 mg/L at AR31_Rockbar 1 and AR32_Pool 9. Exceedances of the default guideline values for total nitrogen and total phosphorus were recorded at all monitored sites.

Dissolved aluminium concentrations ranged from <0.01 mg/L to 0.07 mg/L at the Avon River sites (AR_S1 and AR_S2), with 5% and 8% of samples respectively exceeding the default guideline value for aluminium (0.055 mg/L). The dissolved aluminium concentrations recorded at monitoring sites in the Avon River tributaries ranged from <0.01 mg/L to 0.2 mg/L, with exceedances of the default guideline value for aluminium recorded at AR19_S1 and AR31_Rockbar 1.

Dissolved iron concentrations ranged from <0.05 mg/L to 0.54 mg/L at the Avon River sites (AR_S1 and AR_S2) and from <0.05 mg/L to 3 mg/L at monitoring sites in the Avon River tributaries. Exceedances of the default guideline value for iron (0.3 mg/L) were recorded at all sites.

Total zinc concentrations ranged from <0.005 mg/L to 0.04 mg/L in the Avon River tributaries, with exceedances of the default guideline value for total zinc (0.008 mg/L) recorded at all sites. At the Avon River sites (AR_S1 and AR_S2), total zinc concentrations ranged from <0.005 mg/L to 0.02mg/L, with 10% and 13% of samples respectively exceeding the default guideline value for zinc.

No exceedances of the default guideline values for sulfate, barium, manganese and nickel were recorded at any monitoring site in the Avon River catchment.

In summary, the water quality monitoring data indicates that total phosphorus, total nitrogen, aluminium, iron and zinc are naturally elevated in the Avon River catchment surface water systems.

Donalds Castle Creek Catchment

The water quality monitoring data indicates that surface water systems in Donalds Castle Creek catchment vary from acidic to slightly alkaline conditions, with field pH values ranging from 4.9 to 7.8. Donalds Castle Creek (DCL3) field pH values ranged from 5 to 6.7, with 94% of samples collected at DCL3 exceeding the lower default guideline value for pH. Electrical conductivity values recorded at all sites were low (less than 349 µS/cm) with no exceedances of the default guideline value for electrical conductivity.

Total alkalinity concentrations recorded at site DC8_S1 were low (less than 8mg/L) indicating a low capacity to buffer against changes in pH. Total nitrogen concentrations ranged from 0.2 to 0.4 mg/L at monitoring site DC8_S1, with 50% of samples exceeding the default guideline value for total nitrogen (0.25 mg/L). Total phosphorus concentrations ranged from 0.01 to 0.06 mg/L at monitoring site DC8_S1, with 9% of samples exceeding the default guideline value for total phosphorus (0.02 mg/L).

Dissolved aluminium concentrations ranged from <0.01 mg/L to 0.2 mg/L at the Donalds Castle Creek catchment sites (DC8_S1 and DC10_S1), with 60% and 9% of samples respectively exceeding the default guideline value for aluminium (0.055 mg/L). The dissolved aluminium concentrations recorded at DCL3 tributaries ranged from <0.01 mg/L to 0.18 mg/L, with 30% of samples exceeding the default guideline value for aluminium.

Dissolved iron concentrations ranged from <0.05 mg/L to 8.65 mg/L at the Donalds Castle Creek catchment sites (DC8_S1 and DC10_S1) and from <0.05 mg/L to 3.3 mg/L at DCL3. Exceedances of the default guideline value for iron (0.3 mg/L) were recorded at all sites.

Total zinc concentrations ranged from <0.005 mg/L to 0.08 mg/L at the Donalds Castle Creek catchment sites (DC8_S1 and DC10_S1) and from <0.005 mg/L to 0.35 mg/L at DCL3. Exceedances of the default guideline value for zinc (0.008 mg/L) were recorded at all sites.

No exceedances of the default guideline values for sulfate, barium, manganese and nickel were recorded at any monitoring site in the Donalds Castle Creek catchment.

In summary, the water quality monitoring data indicates that total phosphorus, total nitrogen, aluminium, iron and zinc are naturally elevated in the Donalds Castle Creek catchment surface water systems.

Based on comparison of the water quality monitoring data for sites DC8_S1, DC10_S1 and DCL3 in Donalds Castle Creek catchment, there is little indication that mining activities in Dendrobium Mine Area 3 have influenced water quality downstream in Donalds Castle Creek at monitoring site DCL3.

2.2.3.3 Water Quality Influences

The pH of water within the Upper Nepean catchment has been found to be invariably below the lower default guideline value of pH 6.5 (WaterNSW, 2022). 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). Total aluminium in excess of the default guideline value has been recorded historically in the region (Ecoengineers, 2007; WaterNSW, 2018a).

2.3 COASTAL UPLAND SWAMPS

2.3.1 Description and Occurrence Within Study 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 (Niche, 2022). 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 Study 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 22 upland swamps located partially or entirely within the Study Area (based on the proposed underground mining area plus 600 m), as shown in Figure 8. Of the 22 upland swamps within the Study Area, 16 are within 60 m of the proposed longwalls and six upland swamps are located outside the immediate extents of the proposed longwalls (although within the 600 m buffer).

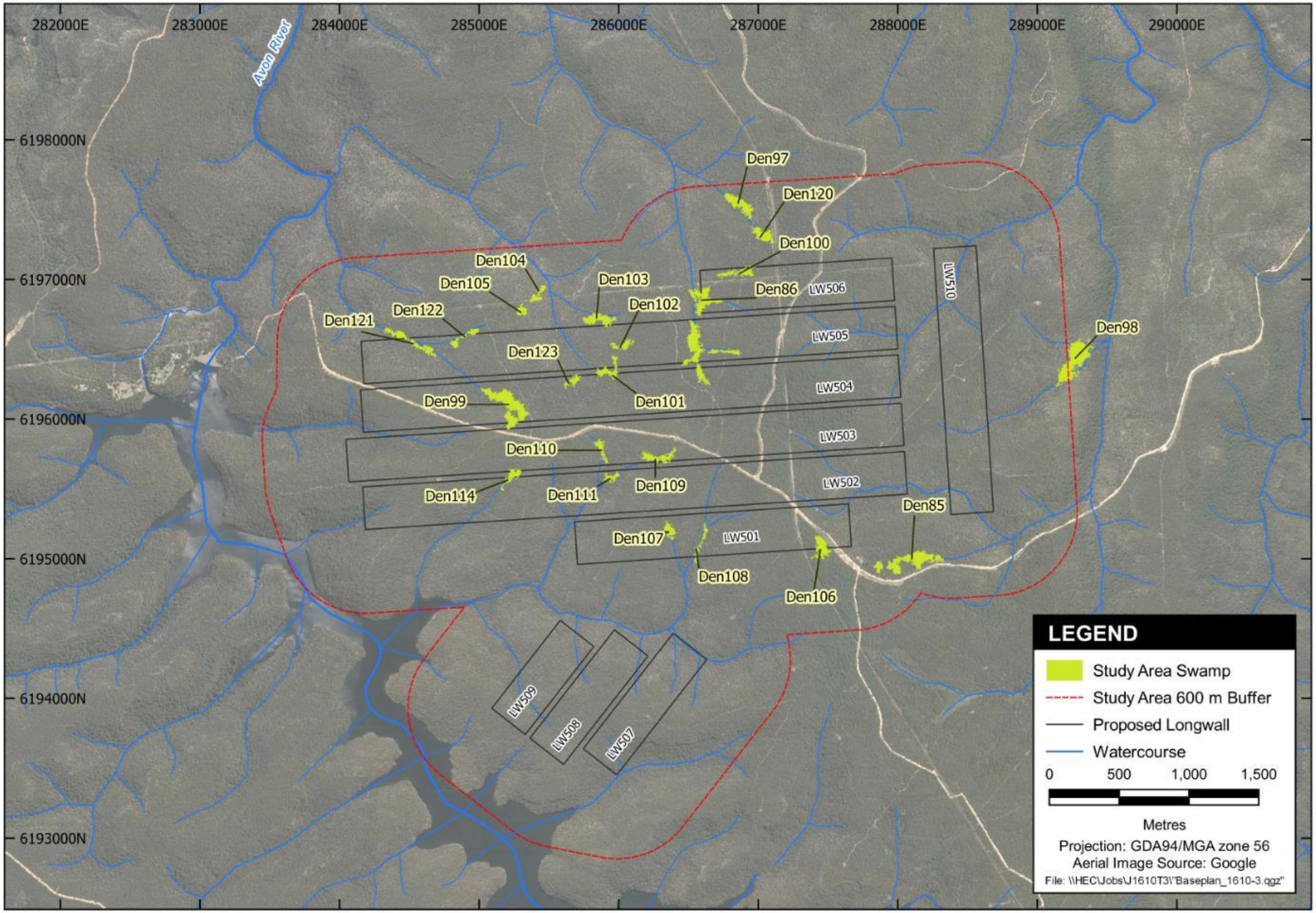


Figure 8 **Area 5 Swamp Locations**

A summary of the characteristics of the swamps located within the Study Area is provided in Table 8.

Table 8 Study Area Swamp Characteristics

Swamp Number	Swamp Type	Plan Area of Swamp (ha)	Total Swamp Catchment Area (ha)*	Longitudinal Length of Swamp (km)	Average Surface Longitudinal Slope (%)
Den 85†	Headwater	2.8	24.8	0.5	4.1
Den 86^	Headwater	4.8	85.0	0.9	3.9
Den 97†	Headwater	1.4	55.5	0.3	4.5
Den 98^	Valley In-fill	3.4	105.4	0.4	4.4
Den 99+	Headwater	3.2	23.9	0.4	4.2
Den 100†	Headwater	0.8	7.4	0.3	4.5
Den 101^	Headwater	0.8	23.8	0.2	5.2
Den 102+	Headwater	0.5	4.0	0.2	2.1
Den 103†	Headwater	1.2	19.9	0.3	6.3
Den 104	Valley In-fill	0.5	5.9	0.2	9.1
Den 105+	Headwater	0.4	3.6	0.1	16.3
Den 106^	Headwater	1.1	17.6	0.2	2.8
Den 107^	Headwater	0.5	11.0	0.2	9.6
Den 108^	Valley In-fill	0.4	45.9	0.3	3.4
Den 109†	Headwater	1.0	21.5	0.3	3.8
Den 110†	Headwater	0.5	12.5	0.2	6.4
Den 111^	Valley In-fill	0.4	49.5	0.2	10.7
Den 114^	Headwater	0.6	9.2	0.2	10.8
Den 120	Headwater	0.9	9.3	0.2	4.6
Den 121	Valley In-fill	1.2	78.9	0.4	5.9
Den 122	Headwater	0.6	10.2	0.2	9.1
Den 123	Headwater	0.4	9.1	0.1	5.8

+ 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.

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

2.3.2 Shallow Groundwater and Soil Moisture Monitoring

Groundwater monitoring bores were installed by IMC in 17 swamps in the Study 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. Soil moisture probes were also installed in 14 swamps in the Study Area.

Swamp groundwater level and soil moisture data was provided by IMC for the period June 2017 to July 2021 (approximately 4 years). The groundwater level and soil moisture monitoring data plots are presented in Appendix B.

3.0 SURFACE FACILITY WATER MANAGEMENT

3.1 EXISTING WATER MANAGEMENT AT PIT TOP FACILITIES

The Dendrobium Mine 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 IMC staff. The location of each area is shown in Figure 9.

3.1.1 Licensed Discharge Points

Water release from the Dendrobium Mine operations is undertaken in accordance with the conditions of EPL 3241. The EPL 3241 allows for release from three licensed discharge points (LDPs) and specifies monitoring of dewatering rates from the underground operations and Kemira Valley sediment ponds (Point 24 and 25). The locations of the LDPs and monitoring points are shown in Figure 9 and summarised in Table 9.

Table 9 EPL 3241 Release Limits and Monitoring Requirements

EPA Identification No.	Type of Monitoring Point	Type of Discharge Point	Location Description
LDP5	Quality monitoring	Stormwater and mine water discharge from Dendrobium Mine. Brine discharge from Appin West Mine.	Pipeline discharging to Allans Creek.
LDP22		Wet weather discharge*	Spillway overflow from Dendrobium Mine Pit Top sediment pond to American Creek.
LDP23		Wet weather discharge*	Spillway overflow from Kemira Valley Coal Loading Facility sediment pond to Brandy and Water Creek.
Point 24	Volume monitoring		Pipeline dewatering underground water storage area.
Point 25	Volume monitoring		Pipeline discharge for Kemira Valley sediment ponds.

* rainfall totalling greater than 60 mm in the preceding 5 days.

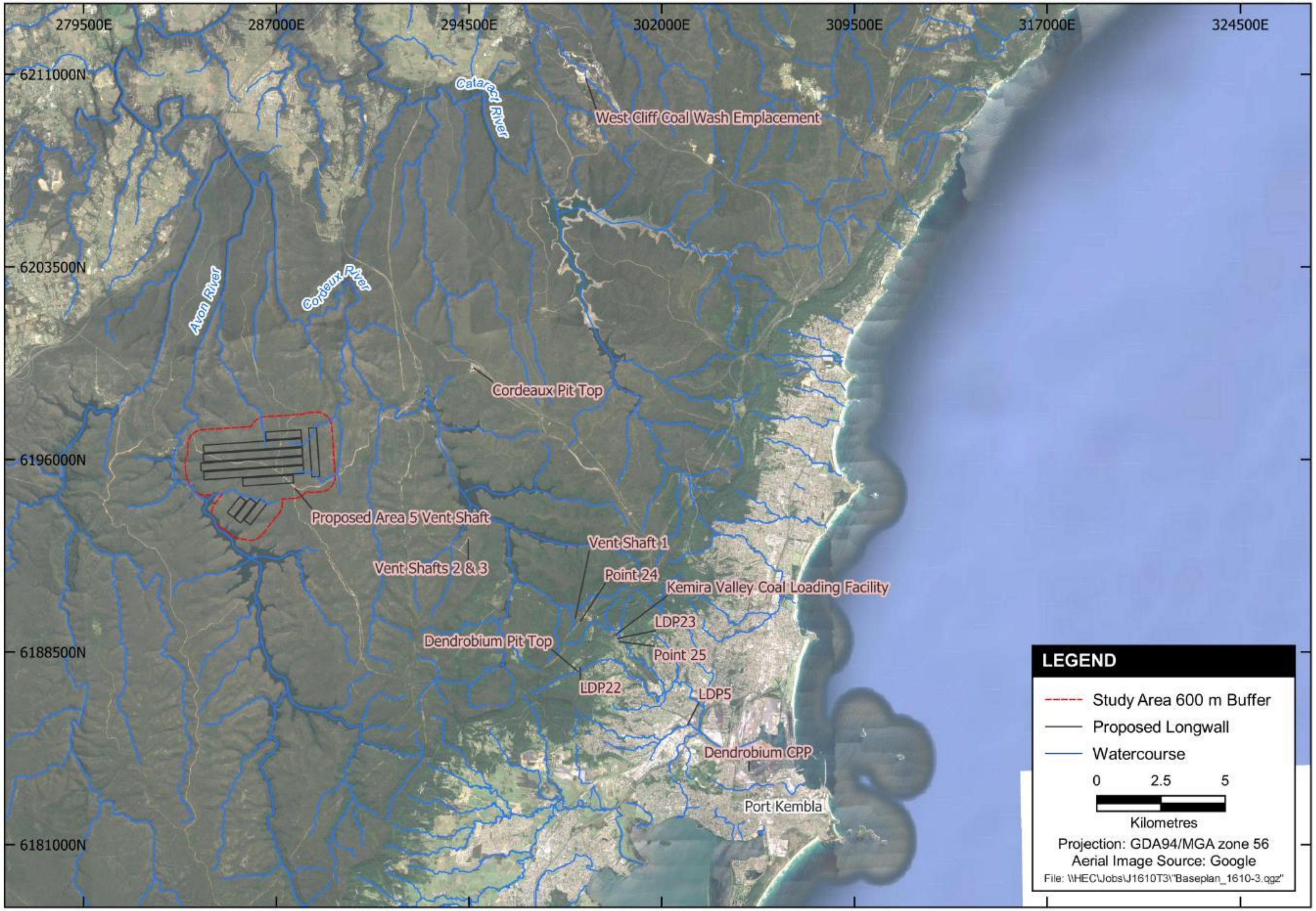


Figure 9 **Site Layout Plan**

Water quality discharge limits for LDP5, as specified in EPL 3241, are listed in Table 10.

Table 10 LDP5 Water Quality Discharge Limits

Constituent	Discharge Limit
Arsenic (mg/L)	1.3
Copper (mg/L)	0.08
Nickel (mg/L)	5
Oil and grease (mg/L)	10
pH	6.5 - 9
Total Suspended Solids (mg/L)	30*
Zinc (mg/L)	0.4

* discharge from LDP5 can exceed the limit for total suspended solids during release of stormwater from the Kemira Valley sediment ponds caused by rainfall totalling greater than 60 mm in the preceding 5 days.

3.1.2 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 Dendrobium 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.

3.1.3 Kemira Valley Coal Loading Facility

The Kemira Valley Coal Loading Facility 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.

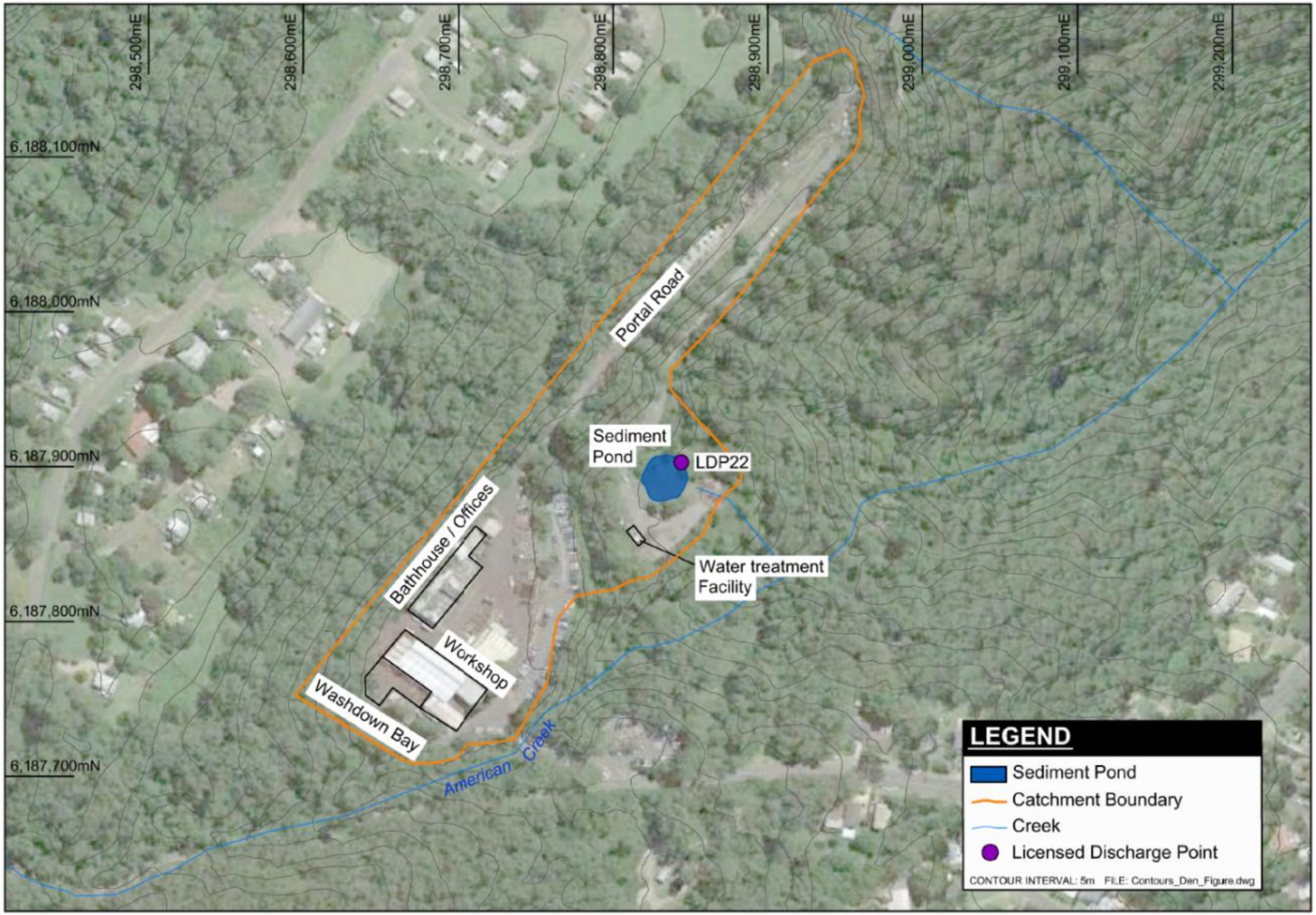


Figure 10 Dendrobium Pit Top Layout and Catchment Boundary

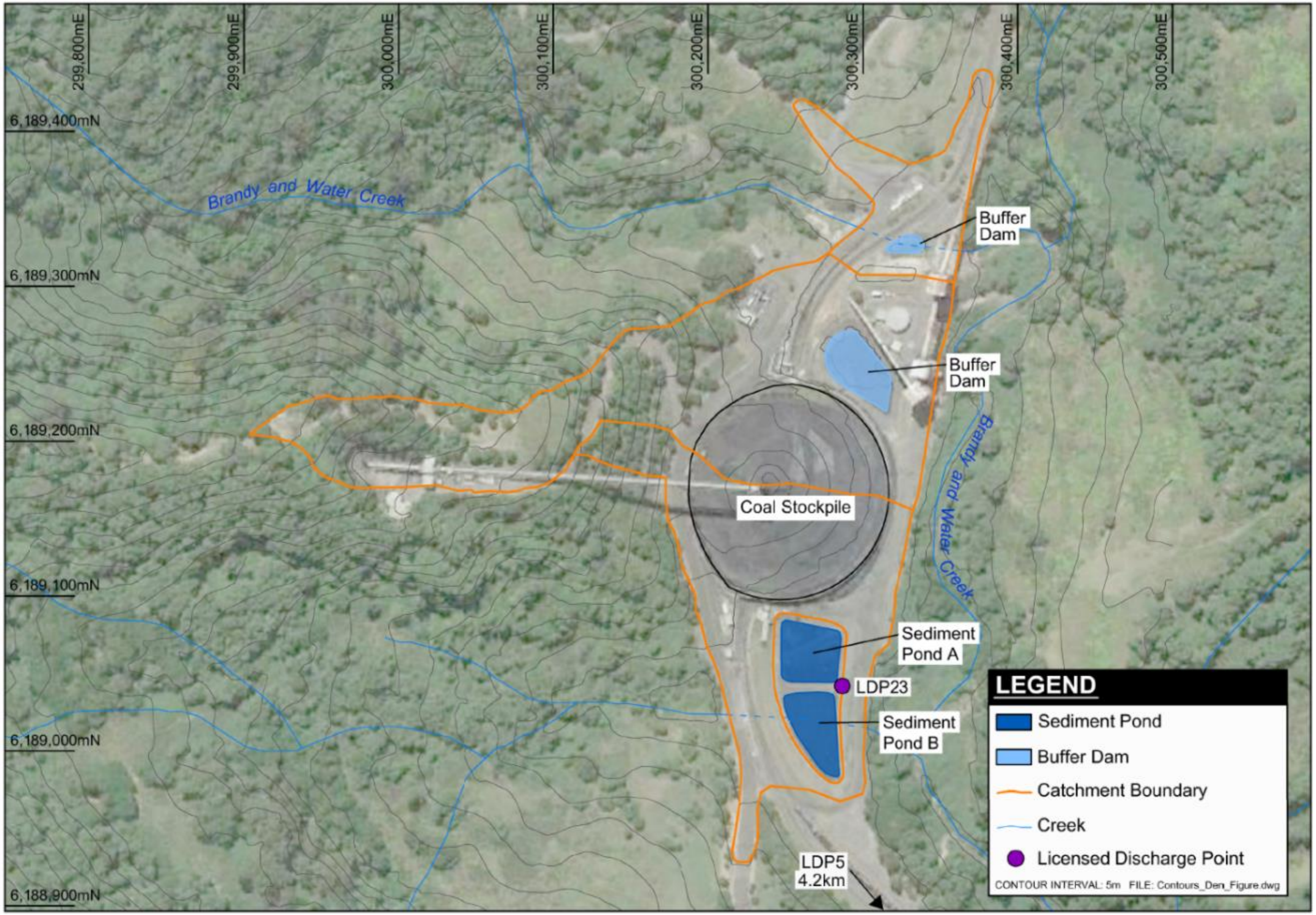


Figure 11 Kemira Valley Coal Loading Facility Layout and Catchment Boundary

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 Kemira Valley Coal Loading Facility 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.

3.1.4 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.

3.1.5 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 is 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.

3.1.6 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.

3.1.7 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.

3.1.8 Cordeaux Pit Top

The surface facilities at the Cordeaux Pit Top have been designed to prevent runoff from the site entering WaterNSW land. Runoff from hardstand areas is directed to a holding lagoon which is then 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 of the Cordeaux Pit Top (e.g. sealed employee car parking areas) reports to a sand filter lagoon and discharges from the site via a sand filter underflow discharge point. Potable water is brought to the Cordeaux Pit Top by road tanker as required.

3.2 PROPOSED CHANGES TO WATER MANAGEMENT

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

Accumulated water from the Project underground workings would continue to be directed into the Nebo workings and/or the Kemira workings for storage, with excess water discharged via the Kemira Valley Coal Loading Facility and existing LDP5 to Allans Creek. The water management system associated with the 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 the new ventilation shaft in Area 5; and
- increase in predicted groundwater inflows to underground workings, which are required to be managed as part of the Project water management system.

3.2.1 Area 5 Ventilation Shaft

The location of the proposed Area 5 ventilation shaft site is shown in Figure 9 and a detailed design plan is presented in Figure 12. The proposed ventilation shaft site is to comprise the following key components:

- upcast 5.5 m diameter finished (lined) and downcast 4.5 m diameter finished (lined) ventilation shafts;
- ventilation fans on upcast shaft;
- Gas Drainage Plant, flare stacks and vent stacks;
- transformer switchyard and tube bundle room;
- miscellaneous service boreholes;
- compressor plant; and
- demountable buildings for staff.

The surface water management system has been designed such that the site will operate as a zero surface water discharge site.

Up to approximately 44 ML of raw water is expected to be required for construction purposes. Water supply for construction purposes is proposed to be provided via one of the following options:

- pumping from the underground workings via a surface to seam borehole;
- pumped water from Cordeaux River (which would be purchased from WaterNSW); or
- delivery of water by truck.

During the operational phase, water would be pumped from the underground workings via a surface to seam borehole for supply to the Gas Drainage Plant. Following processing, return water would be piped to a surface to seam disposal borehole for disposal into the underground water management system.

Surface water runoff from the site would be directed to two sediment basins which will be designed in accordance with Landcom (2004) and Department of Environment and Climate Change (DECC) (2008) guidelines. Stored water in the sediment basins would be automatically dosed with gypsum or other approved flocculant to aid in the sediment settling process. Water stored in the sediment basins would be pumped to a discharge borehole and directed to the underground mine workings thereby avoiding concentrated surface water discharges from the ventilation shaft site to the Metropolitan Special Area.

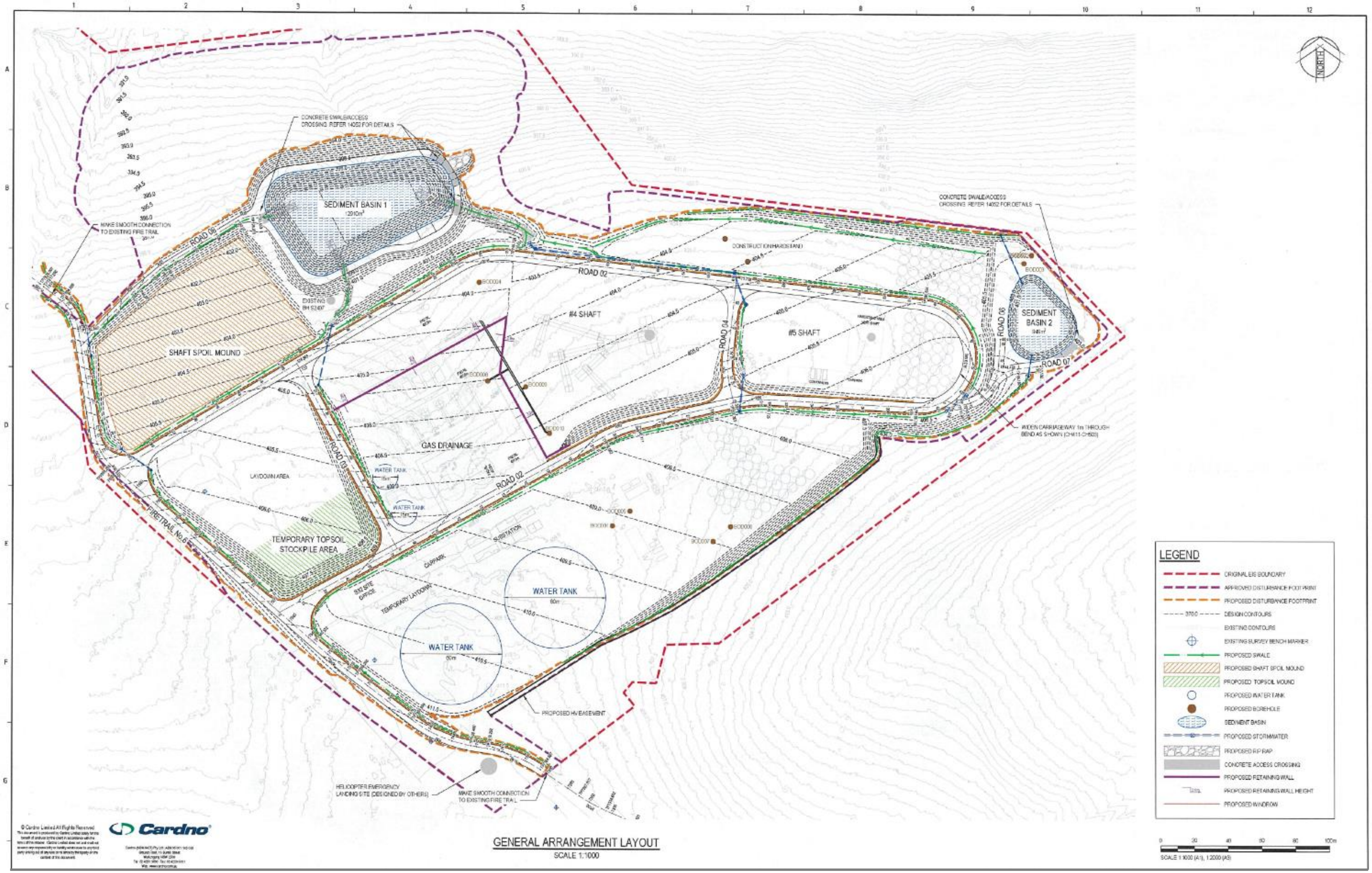


Figure 12 Area 5 Ventilation Shaft Site Concept Design

3.2.2 Predicted Groundwater Inflows

Predicted groundwater inflow rates, detailed in Watershed HydroGeo (2022), over the proposed Dendrobium Mine life are shown in Figure 13 for each mining area including Area 5.

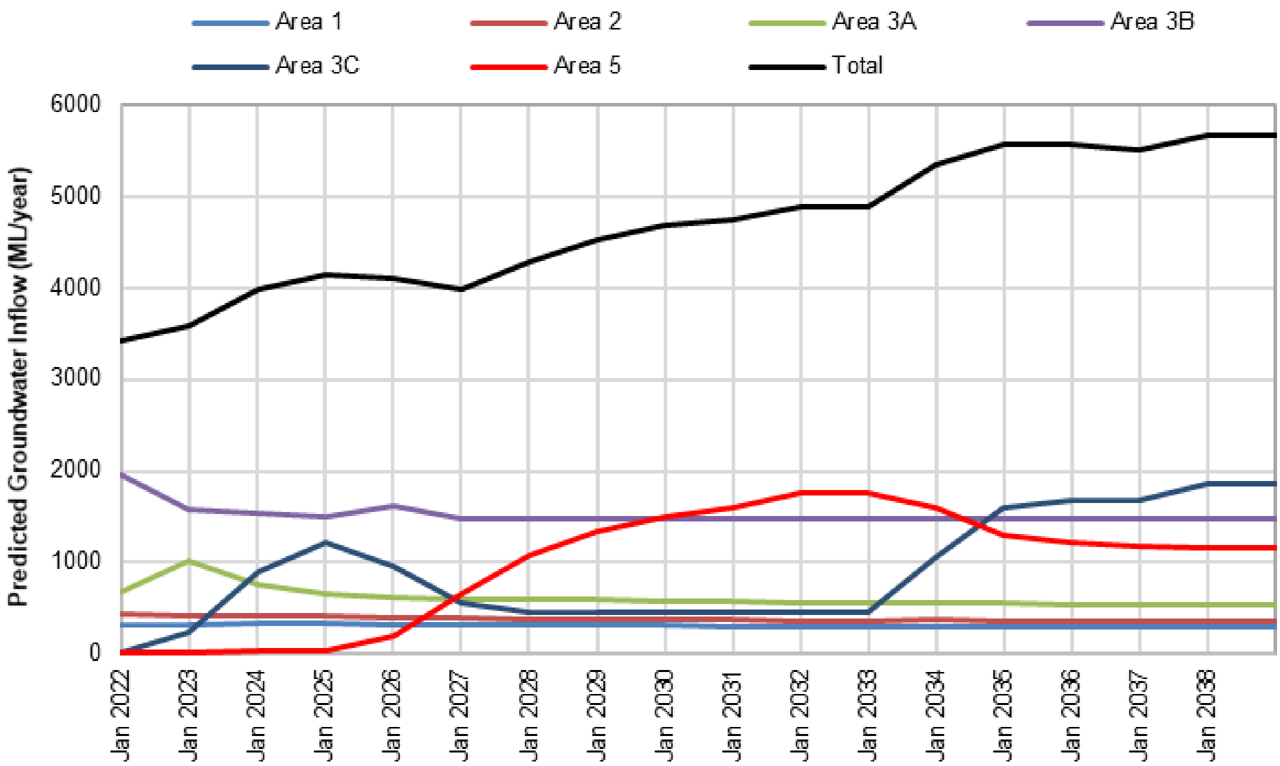


Figure 13 Predicted Groundwater Inflow to Underground Areas

Total annual groundwater inflow to the Dendrobium Mine (all areas including Area 5) is expected to peak in late 2038 at between 5,600 and 5,900 ML. The annual groundwater inflow rate to Area 5 is expected to peak at 1,760 ML in 2032. The groundwater modelling results indicate a peak daily groundwater inflow rate of 5.5 ML/d associated with the Project and a peak daily inflow rate of 16 ML/d associated with the Dendrobium Mine (Watershed HydroGeo, 2022). Ongoing inflows to existing and former underground mining areas will continue to be managed as part of the Dendrobium Mine 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 remaining approved mine life from July 2022 to June 2039 (17 years), which includes the proposed period of mining Area 5 from July 2023 to June 2034 (11 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.

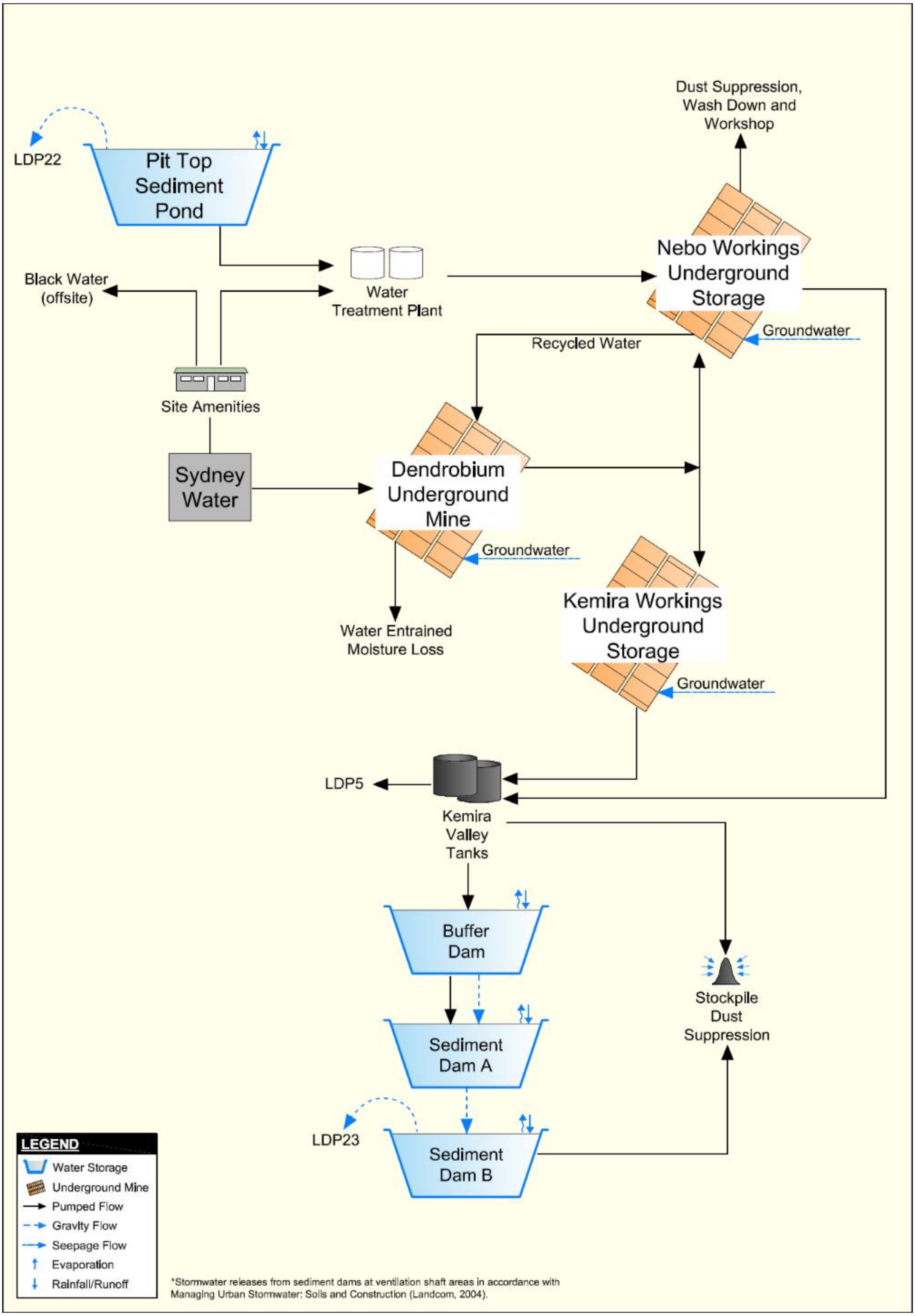


Figure 14 Water Management Schematic

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.

The model was developed using the GoldSim® simulation package. The model simulates 133, 17 year "realizations", derived using a climatic data set from 1889 to 2021. The first realization uses climatic data from 1889-1905, the second 1890-1906, the third 1891-1907, and so on[6]. 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 as presented in Section 3.3.3.

3.3.2 Model Input and Assumptions

3.3.2.1 Rainfall and Evaporation Data

A record of 133 years of rainfall data (1889 - 2021 inclusive) was obtained for the site location from SILO Data Drill (refer Section 2.1.2). A 133 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 Kemira Valley Coal Loading Facility water storages from 1 m interval topographic contour data supplied by IMC as well as information regarding upslope diversions. Figure 10 and Figure 11 show the contours and assumed catchment boundaries, while Table 11 lists the catchment areas adopted in the water balance model.

Table 11 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.

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[6] Additional climate data after 2021 was generated by "wrapping" data from the beginning of the climate data set to after 2021. 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.

Level-volume-area relationships for each modelled storage were estimated from contour plans and storage volume data stated in the 2017 Annual Review (IMC, 2017). The water surface area of each storage was multiplied by daily evaporation and by a pan factor[7] 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 12.

Table 12 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

3.3.2.4 Storage Capacities and Initial Stored Water Volumes

Storage capacities, specified in IMC (2017), and the assumed initial stored water volume as at the model start date (1/7/2022) for each modelled water storage are summarised in Table 13.

Table 13 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

3.3.2.5 Underground Workings Groundwater Inflow Rates

Groundwater inflow rates to the underground workings were provided by Watershed HydroGeo (2022) for the historic and approved mine areas (Areas 1, 2, 3A, 3B, 3C) and for the proposed Area 5 as shown in Figure 13.

Groundwater inflow estimates for the former Nebo and Kemira underground workings were also provided by Watershed HydroGeo (2022): constant average rates of 1 ML/d and 0.05 ML/d respectively.

3.3.2.6 Sydney Water Demand

A constant rate of 136 kilolitres per day (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 37 kL/d was assumed to be supplied from Sydney Water mains to the mine based on long-term average recorded data provided by IMC.

3.3.2.7 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.

3.3.2.8 Pit Top Water Treatment Plant

The supply to the Dendrobium 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

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

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 litres per second (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 IMC).

3.3.2.9 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 1,032 kL/d was adopted based on long-term average recorded data provided by IMC. The net moisture lost in air ventilation was averaged from long-term recorded data as 134.6 kL/d.

Net groundwater entrained in coal was calculated based on the total ROM coal tonnage multiplied by the average ROM moisture content (8.47% w/w based on averaged recorded data) minus the in-situ moisture content (1.9% based on estimates for Area 5 as advised by IMC). Figure 15 presents a comparison of the annual ROM coal tonnage (as provided by IMC) and the calculated net water entrained. Note that this includes both the approved Dendrobium Mine Area 3 and the proposed Area 5.

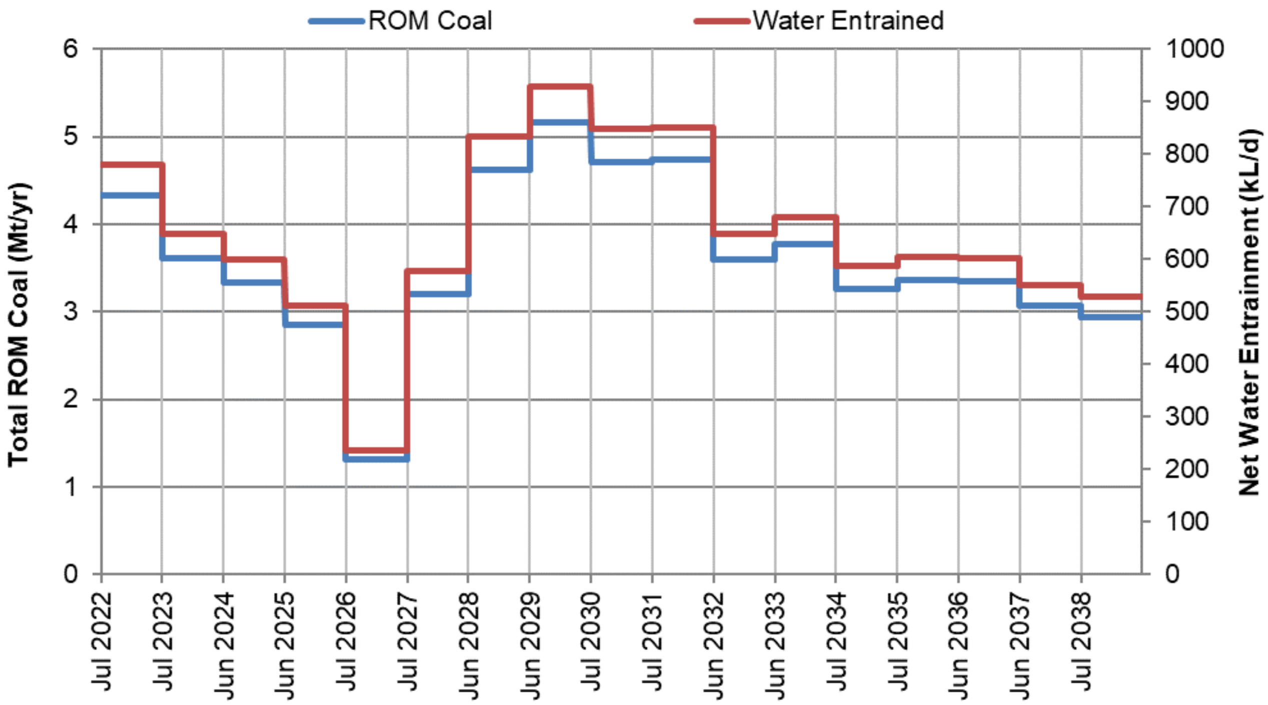

Figure 15 Total ROM Coal Tonnage and Water Entrained in Ore

3.3.2.10 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 IMC.

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 14 summarises the average water balance (averaged over all realizations and the 17 year simulation period).

Table 14 Average Water Balance

Inflows	Average (ML/year)
Rainfall runoff	54
Groundwater	5,160
Sydney Water supply	63
TOTAL	**5,278**
Outflows	**Average (ML/year)**
Evaporation	4
Blackwater to sewer	20
Water entrained in ore	237
Underground ventilation net loss	49
Portal Road dust suppression	6
Kemira Valley dust suppression	17
Pit Top Sediment Pond overflow to LDP22	1
Kemira Valley Sediment Pond overflow to LDP23	17
Kemira Valley Tank Discharge to LDP5	4,918
TOTAL	**5,269**

Table 14 illustrates that groundwater contributes the majority of system inflows while release via LDP5 dominates system outflows.

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 133 of the 17 year realizations simulated.

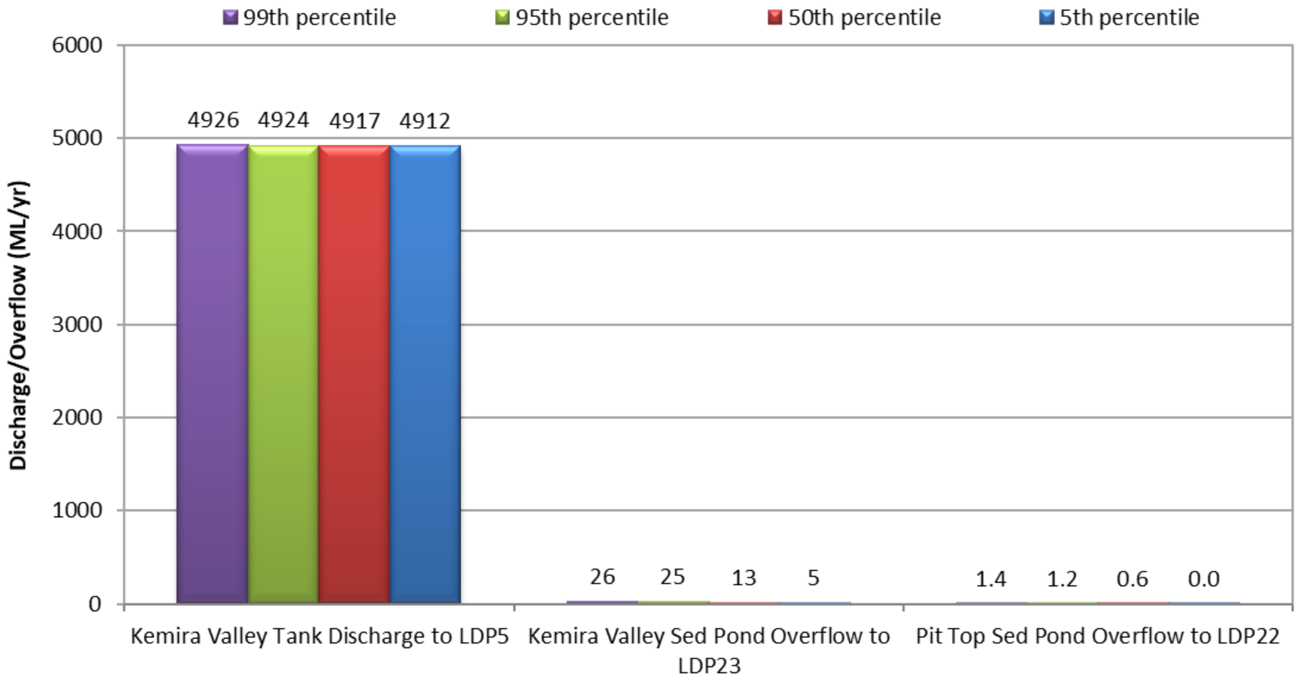

Figure 16 Simulated Licensed Discharge Volumes from Kemira Valley and Dendrobium Pit Top

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 5 ML/year (5th percentile) to 26 ML/year (99th percentile) while simulated overflow from the Pit Top sediment pond to LDP22 ranges between 0 ML/year (5th percentile) to 1.4 ML/year (99th percentile). As the Project involves little change to the site layout and water management strategy for the Kemira Valley Coal Loading Facility 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 rainfall sequence.

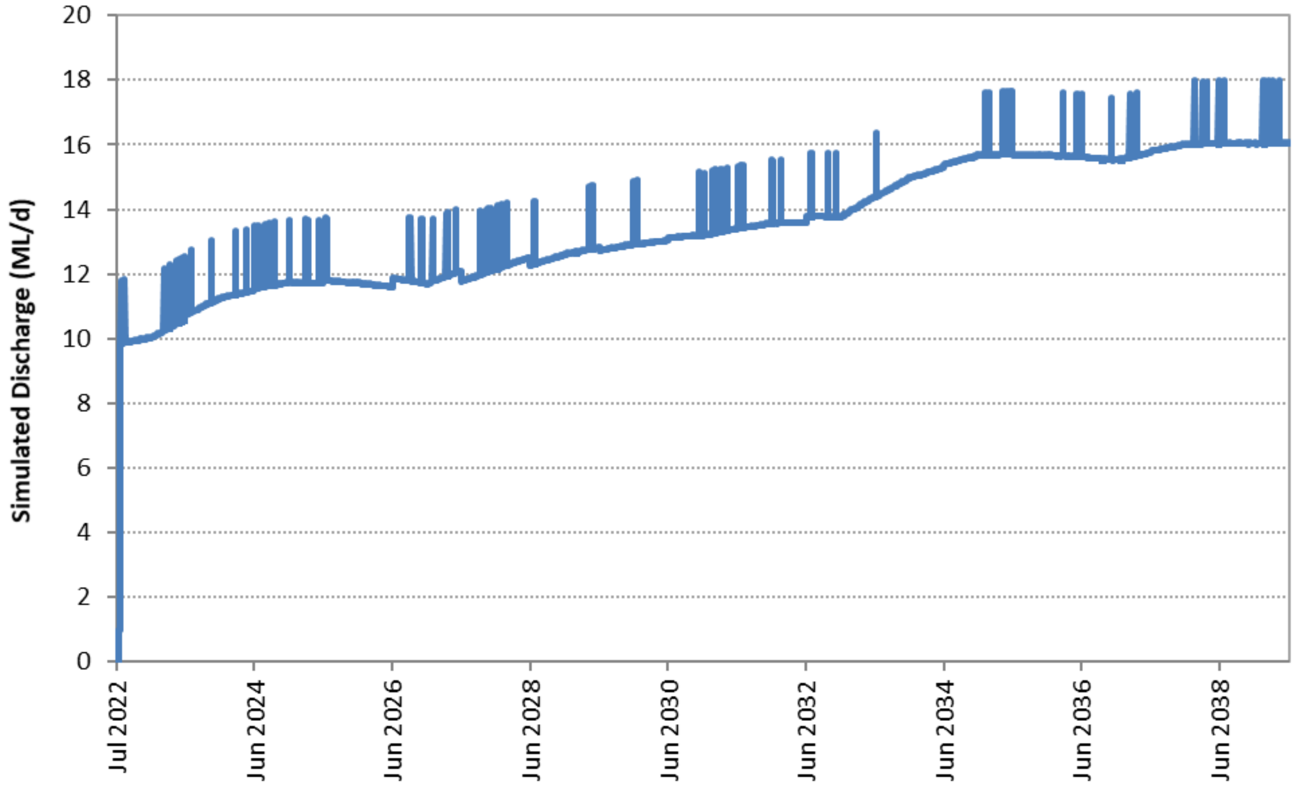

Figure 17 Predicted Daily Discharge to LDP5 for Median Rainfall Sequence

Figure 17 shows that the daily discharge rate to LDP5, based on the median rainfall sequence, is predicted to average 16 ML/d and peak at 18 ML/d from June 2037. The predicted discharge rate is largely reflective of the predicted groundwater inflow rate to the Dendrobium Mine and surface water runoff managed at the Dendrobium Mine surface facilities. This compares with a historical average rate of 6.4 ML/d and a historical peak rate of 9.8 ML/d discharged to LDP5 over the period of January 2014 to October 2021.

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 all 133 of the 17 year realizations simulated.

3.3.4 Implications for Water Management of Surface Facilities

For the existing operations, an average of 2,261 ML/year has been recorded as discharged to LDP5 based on flow meter records from August 2018 to July 2021. The model simulations indicate that an average of 4,918 ML/year is the estimated discharge to LDP5 for the Project from the Kemira Valley tank. This equates to an estimated additional 2,657 ML/year discharge to LDP5 from the Kemira Valley tank on average over the remaining Dendrobium Mine life.

The existing pipeline capacity for discharge to LDP5 is approximately 10 ML/d (as advised by IMC). Based on a maximum rate of 18 ML/d predicted to be discharged to LDP5 for all modelled realizations, supplementary discharge capability, such as an additional pipeline with a nominal conservative diameter of 300 mm would 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 Kemira Valley Coal Loading Facility. The water quality monitoring indicates that the water management system in operation at the Kemira Valley Coal Loading Facility is effective, with negligible influence on the surrounding Brandy and Water Creek (IMC, 2021a).

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 guideline default 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 Kemira Valley Coal Loading Facility 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 Kemira Valley Coal Loading Facility 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. Table 15 presents the licence limits for LDP5, a summary of the water quality monitoring results for LDP5 for 2021 (IMC, 2021a) and the estimated groundwater quality for Area 5. The estimated groundwater quality for Area 5 was calculated based on monitored water quality records for Area 3B mine goaf.

Table 15 LDP5 Water Quality and Estimated Area 5 Groundwater Quality

Parameter*	Licence Limit	Monitored Water Quality at LDP5			Estimated Groundwater Quality		
		Min	Average	Max	Min	Average	Max
Arsenic (mg/L)	1.3	0.008	0.011	0.02	<0.001	0.01	0.045
Copper (mg/L)	0.08	<0.001	0.001	0.002	<0.001	0.001	0.006
Nickel (mg/L)	5	0.01	0.019	0.075	<0.001	0.017	0.46
Oil and Grease (mg/L)	10	<5	5	9	-	-	-
Total Suspended Solids (mg/L)	30	<5	9	34	-	-	-
pH	6.5 – 9.0	8.0	8.3	8.5	6.99	7.86	8.83
Zinc (mg/L)	0.4	0.026	0.052	0.093	<0.005	0.05	0.4

* 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 15 illustrates that the monitored water quality at LDP5 during 2021 was within the licence limits for all parameters with the exception of total suspended solids, which was the result of a single recorded non-compliance. This non-compliance was reported in IMC (2021a) and noted to be an outlier when compared with long-term records.

The groundwater quality estimates for Area 5 are expected to remain 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 measurable 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, which experiences a tidal/estuarine environment downstream. Therefore, the impacts of the additional flow on the stability of Allans Creek are considered 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 system and infrastructure would continue to operate for the Project at the Dendrobium Pit Top, Kemira Valley Coal Loading Facility, 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 change to water management for the Dendrobium Mine is associated with additional water supply based on the predicted Area 5 groundwater inflows.
- Area 5 groundwater inflows would be managed in accordance with current EPL conditions (i.e. discharge via LDP5), however, additional infrastructure would be required to accommodate the expected increase in controlled release volumes. It is understood that IMC is also investigating options for the beneficial use of this excess water.
- The increase in discharge to LDP5 is considered 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 Mine Subsidence Engineering Consultants (MSEC) (2022). 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 HISTORICAL SUBSIDENCE EFFECTS ON SURFACE WATER RESOURCES IN DENDROBIUM MINING AREAS

4.1.1 Dendrobium Longwall Mining – Lake Avon, Donalds Castle Creek and Wongawilli Creek Catchments

Longwall mining in Dendrobium Area 3B has resulted in subsidence impacts to stream beds including rock fracturing, rock displacement/falls, uplift to the base of the stream bed, iron staining and erosion. Based on monitoring undertaken during the extraction of each longwall panel, the total number of new surface impacts identified, including those occurring in stream beds are summarised in Table 16.

The effects of subsidence on surface water hydrology are assessed using Trigger Action Response Plans (TARPs) (noting that an updated TARP assessment method and introduction of performance measures were introduced for assessment of Longwall 15 onwards). In general, mining-related effects on the flow regime are reported to have occurred in tributaries to Donalds Castle Creek (DCS2, DC13S1) and in the upper reaches of Wongawilli Creek (as well tributaries of Lake Avon).

Table 16 Surface and Flow Regime Impacts Summary

Longwall Panel	New Surface Impacts		Flow Regime Impacts
	Total	Stream Beds	
Longwall 11	11	2	Reported reductions in total discharge of 20% (DCS2) and 15% (DC13S1) in Donalds Castle Creek; and, 11% in a tributary of Wongawilli Creek (WC21S1) (HydroSimulations, 2016).
Longwall 12	24	4	Reported reductions in total discharge of 22% (DC13S1) and 28% (DCS2) in Donalds Castle Creek (HGEO, 2017).
Longwall 13	43	18	Reported reductions in total discharge of 7% (DC13S1) and 22% (DCS2) in Donalds Castle Creek (HGEO, 2018).
Longwall 14	28	8	Reported reductions in total discharge of 17% (DC13S1) and 20% (DCS2) in Donalds Castle Creek; 6% (LA4S1) in tributary LA4 of Lake Avon; and, 24% (WC21S1) and 10% (WC15S1) in tributaries of Wongawilli Creek (IMC, 2019).
Longwall 15	28	4	Similar to the above Longwall 14 impacts, assessments indicate DC13S1 and DCS2 in Donalds Castle Creek, LA4S1 in tributary LA4 of Lake Avon, WC21S1 and WC15S1 within the Wongawilli Creek catchment have been and continue to be affected by mining. It is probable that tributary LA3 of Lake Avon has also been affected by mining for the first time by Longwall 15. At downstream monitoring sites, analysis indicates that mining effects are probable at DCU in Donalds Castle Creek; however, effects are not evident at WWL in Wongawilli Creek. Water flow performance measures were met for Longwall 15 (IMC, 2020).
Longwall 16	52	3	Consistent with Longwall 15, assessments indicate similar mining effects at DC13S1 and DCS2 in Donalds Castle Creek, tributaries LA4 and LA3 of Lake Avon, and WC21S1 and WC15S1 within the Wongawilli Creek catchment. LA2 of Lake Avon has also been affected by mining for the first time by Longwall 16. It is noted that despite Longwall 16 terminating within 50 m of WC12 within a tributary of Wongawilli Creek, no mining effects are discernible. Findings relating to downstream monitoring sites are consistent with those for Longwall 15. Water flow performance measures were met for Longwall 16 (IMC, 2021b).
Longwall 17	40	13	Outcomes of assessments undertaken for Longwall 17 are consistent with those for Longwall 16 and indicate similar mining effects to the streams as described above. Water flow performance measures were met for Longwall 17 (HGEO, 2022).

The effects of subsidence on surface water quality are assessed using TARPs applied to monitoring locations in Wongawilli Creek, Donalds Castle Creek and tributary LA4 of Lake Avon for field parameters pH, electrical conductivity and dissolved oxygen. Quantitative assessment of water quality trends at two monitoring locations on Wongawilli Creek and Donalds Castle Creek is also undertaken for these parameters plus sulphate and dissolved metals.

In general terms, assessment indicates that anomalous water quality effects including increases in electrical conductivity, changes in pH and increases in dissolved metal concentrations (iron, manganese, aluminium and zinc) are noted in streams that have been directly mined beneath. Iron staining in creek beds is also commonly associated with streams that have been directly mined beneath or are within the mining area of influence.

4.1.2 Monitored and Observed Effects of Subsidence on Swamps

Watershed HydroGeo (2021) conducted a detailed review of monitoring data recorded at 73 shallow piezometers in upland swamps within Area 2, 3A and 3B. The assessment identified that the data from 37 of the upland swamp monitoring sites indicated impacts to the shallow groundwater level and/or the rate of shallow groundwater level decline (recession) post-mining in comparison with pre-mining conditions.

The assessment also identified that the majority of impacts occurred following the passing of a longwall, either directly beneath the site or within 60 m of the site (Watershed HydroGeo, 2021). Monitored data from 25 of 26 piezometers in upland swamps overlying longwall panels indicated an impact to water level and/or recession rate while monitored data from 11 of 12 piezometers in upland swamps located within 1 to 60 m from the longwall edge indicated an impact. Impacts to the water level of upland swamps were not recorded at distances greater than 60 m from a longwall panel (Watershed HydroGeo, 2021).

Niche (2022) identified that, while changes in shallow groundwater level and/or the rate of shallow groundwater level decline have been recorded at upland swamps within Area 2, 3A and 3B following mining, no strong link between subsidence effects and vegetation response have been identified (i.e. reduction in swamp size, extent and total species richness).

Niche (2022) note that, while no strong links between subsidence impacts and vegetation response have been identified to date, vegetation response may not be immediate and, as such, may not have been detected through biodiversity monitoring to date.

4.1.3 Monitored and Observed Effects of Subsidence on Lake Avon

Ground subsidence associated with historical longwall mining has resulted in the development of surface cracking of the stream bed of tributaries of Lake Avon (LA4, LA3, LA2). The surface cracking has subsequently resulted in the diversion of flows and a measurable reduction in flows recorded at streamflow gauging stations within these tributaries. The flow reductions have resulted in triggers based on the adopted TARPs; however, the overall performance measure relating to negligible reduction in the overall quantity of surface water inflows to Lake Avon was determined to have been met based on recent assessment of Longwall 17 effects (HGEO, 2022). Further information is summarised in Table 16.

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 to 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).

This conclusion is consistent with the IEPMC (2019) which states:

> 'Reservoir leakage rates – there is no measured evidence of significant long-term leakage from reservoirs due to mining in the Special Areas.'

> ‘Watercourse bed leakage (at catchment scale) – from material presented to the Panel, there remains no strong evidence that cracking of watercourse beds leads to significant losses of water at catchment scales relevant for water supplies.’

Despite localised, low spikes in water quality constituents recorded for some catchments reporting to Lake Avon, there have been no reports of water quality impacts to Lake Avon associated with mining activities in the region. As of 2021, water quality in the Upper Nepean lakes continued to remain at a high standard, with high compliance recorded in comparison to the majority of ANZECC default guideline values (WaterNSW, 2022).

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 MSEC (2022), the proposed longwalls in Area 5 have been designed to reduce the potential impacts on major streams and significant stream features. The Project mine design is as follows:

- no direct undermining of Lake Avon;
- longwall setback from the Avon Dam wall (minimum setback distance of 1,000 m);
- longwall setback from the Full Supply Level (FSL) of Lake Avon (minimum setback distance of 300 m from the FSL);
- longwall mining at least 400 m from named watercourses (i.e. Avon River and Donalds Castle Creek); and
- no longwall mining under third order sections of unnamed watercourses.

The following subsidence, upsidence and closure predictions are as per that detailed in MSEC (2022).

5.1.2 Subsidence, Upsidence and Closure Predictions for Area 5

The maximum predicted subsidence parameters for the proposed longwalls in Area 5 are: 2,000 mm vertical subsidence, 25 mm/m tilt (i.e. 2.5 % or 1 in 40), 0.50 km^{-1} hogging (i.e. 2.0 km minimum radius) and 0.60 km^{-1} sagging curvature (i.e. 1.70 km minimum radius). The maximum predicted total upsidence within Area 5 is 750 mm and the maximum predicted total valley related closure is 750 mm.

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

The Avon River and Donalds Castle Creek are located outside the extents of the proposed longwalls (at distances of at least 700 m) and are not predicted to experience measurable conventional subsidence effects due to the proposed mining in Area 5.

The sections of the Avon River and Donalds Castle Creek located closest to the proposed longwalls could experience very small valley closure effects, with maximum predicted closure for these sections of 30 mm. On this basis, fracturing in the beds of the named streams is not expected, and is supported by the observation that fracturing has not been observed in streams at distances greater than 400 m from previously extracted longwalls. Consequently, it is considered unlikely that the named streams would experience adverse physical impacts (i.e. fracturing or mining-induced surface water diversions) due to the mining of the proposed longwalls in Area 5.

5.1.2.2 Subsidence, Upsidence and Closure Predictions for Unnamed Watercourses

The predicted total subsidence, valley-related upsidence and valley-related closure for the unnamed streams within the Study Area are provided in Table 17. The predictions for the third order sections of the unnamed streams AR32, DC8 and LA13 are displayed separately to those for the first and second order streams.

Table 17 Maximum Predicted Total Vertical Subsidence, Upsidence and Closure for Unnamed Streams

Stream	Maximum Predicted Total Vertical Subsidence (mm)	Maximum Predicted Total Valley-Related Upsidence (mm)	Maximum Predicted Total Valley-Related Closure (mm)
Third order sections			
AR32	<20	30	30
DC8	<20	125	175
LA13	<20	250	325
First and second order streams			
AR19	1,850	225	170
AR31	1,850	160	130
AR32	1,850	200	225
DC8	1,650	600	550
DC9	225	70	140
DC10(C)	1,550	300	180
LCA12	1,250	375	375
LA13	1,650	475	375
LA13A	1,950	750	750

The third order sections of the streams are predicted to experience very low levels of vertical subsidence (<20 mm) and valley related effects up to 250 mm upsidence and 325 mm closure. The first and second order streams are located across the Study Area and are expected to experience the full range of predicted subsidence effects, with vertical subsidence between 225 and 1,950 mm and valley related effects up to 750 mm upsidence and 750 mm closure.

Based on MSEC (2022), it is expected that fracturing of bedrock would occur along the sections of the first and second order streams that are located directly above and adjacent to the proposed longwalls. Minor fracturing could also 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) is therefore recognised. Type 3 impacts are defined as *fracturing in a rockbar or upstream pool resulting in reduction in standing water level based on current rainfall and surface water flow* (MSEC, 2022). MSEC (2022) has predicted that approximately 15% of the stream controlling features (i.e. rockbars, steps and other controlling features) located within 400 m of the proposed longwalls could experience Type 3 impacts. This represents approximately five rockbars along the third order sections of the streams within 400 m of the proposed longwalls.

The maximum predicted tilt for the first and second order streams within the Study 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 (refer Section 5.5).

5.1.2.3 Subsidence, Upsidence and Closure Predictions for Upland Swamps

The maximum predicted total vertical subsidence for the swamps in Area 5 is 1,950 mm. The maximum predicted total upsidence for the swamps in Area 5 is 375 mm. Maximum predicted total valley related closure is 375 mm for swamps in Area 5.

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 Area 5 are expected to be less, on average, than those previously measured at Dendrobium Mine Area 2, Area 3A and Area 3B. The measured surface deformations were generally less than 50 mm in width (i.e. in 79% of cases) but had widths between 50 mm and 150 mm in 15% of cases, between 150 mm and 300 mm in 5% of cases and greater than 300 mm in 1% 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 predicted subsidence induced tilt. 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 predicted tilt or vertical subsidence. Notwithstanding, potential impacts to swamp hydrology are presented in Section 5.2 and potential impacts to swamp stability are presented in Section 5.7.

5.2 POTENTIAL IMPACTS TO SWAMP HYDROLOGY

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[8] 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 Area 5. The thicknesses of the rock layers were set based on Project exploration drilling (Mine Geology Database) interpretation by Watershed HydroGeo (2022). The model longitudinal sections represent a 1 m wide ‘slice’ through the swamp.

An analysis of the climatic sequence for the Study Area (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

[8] Parallel to the main direction of flow.

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 mm 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 18. The surface layer of sand illustrated in Figure 18 reflects the swamp extent.

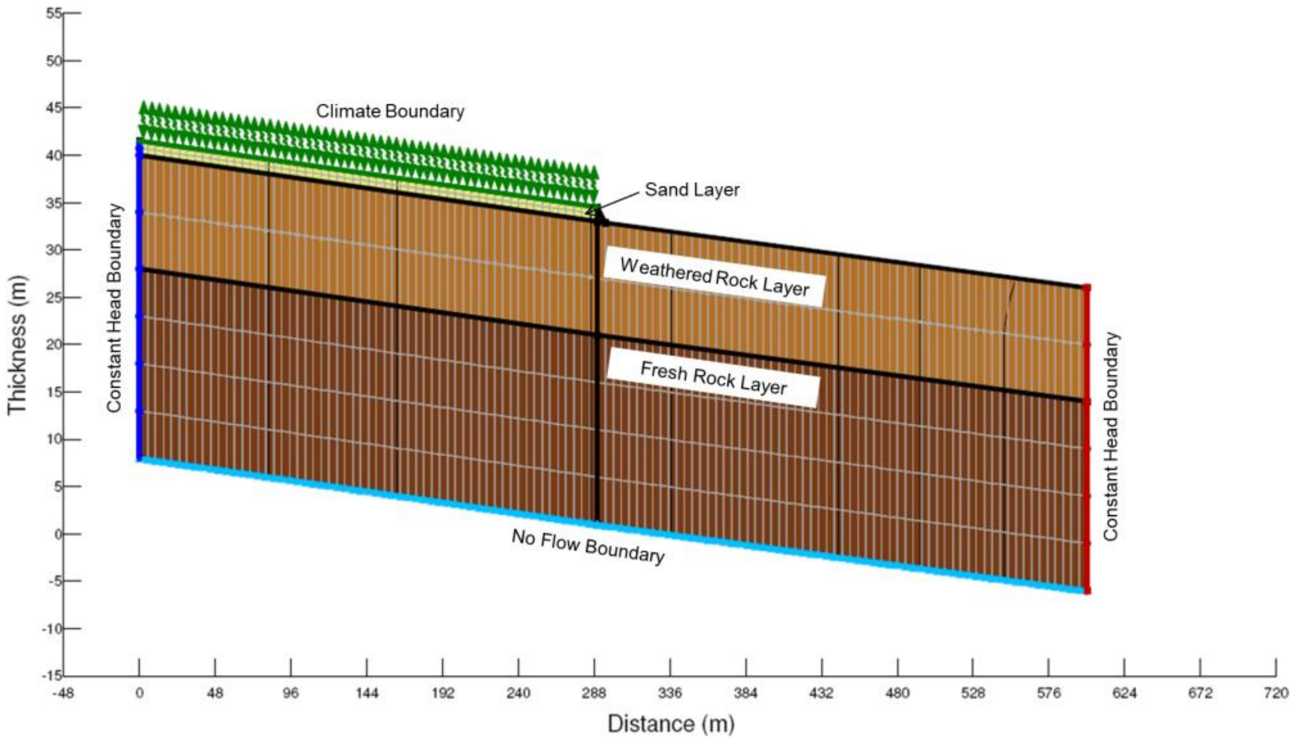

Figure 18 Swamp Seepage Model Schematic

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 18 below. The values were based on parameters in Watershed HydroGeo (2022) and modified during calibration of the local-scale swamp models presented below.

Table 18 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 three representative swamp types and a median swamp length (refer Table 19). The three swamp types represented minimum, median and maximum swamp gradients 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 MSEC (2022). These three modelled geometries therefore provide information on the likely range of impacts for all swamps.

Table 19 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	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 8 for swamp characteristics) were used for the model calibration. A representative recessionary period (June to November 2017) was selected for the calibration period. 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 19. 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).

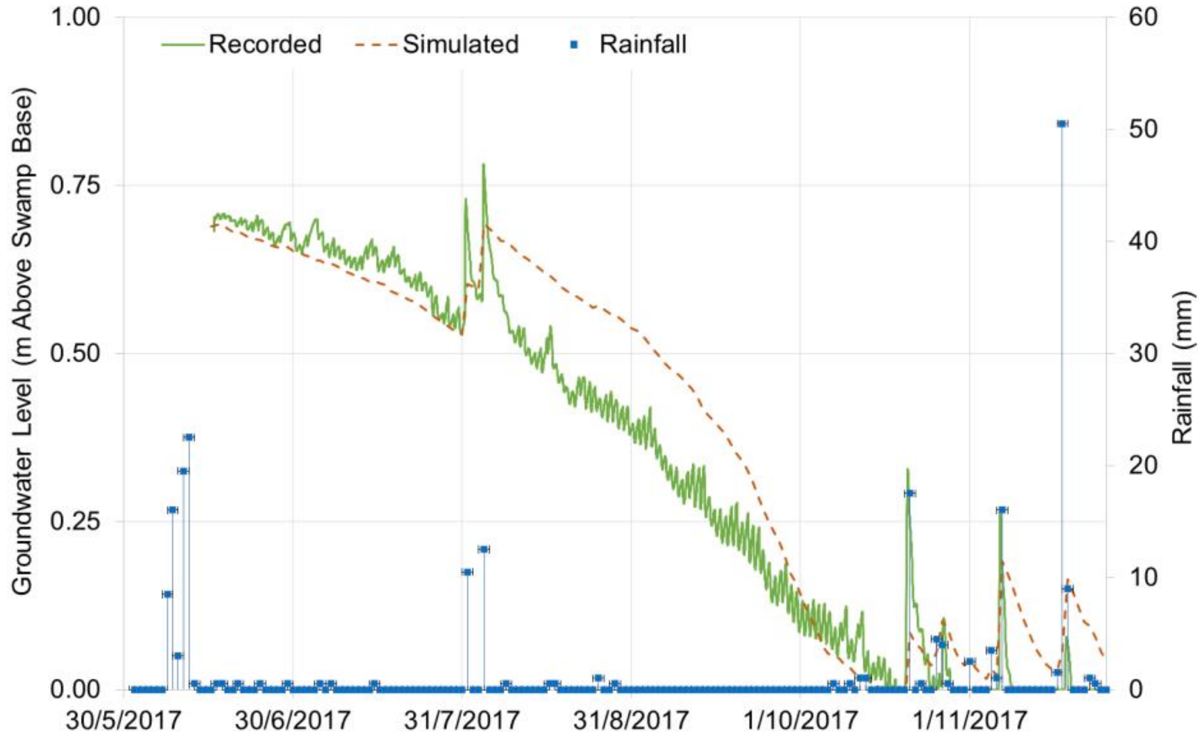

Figure 19 Recorded and Simulated Head – Swamp Den 98

Figure 19 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 4.2.2) which have been monitored by IMC during pre-mine and post-mine periods and the simulated recessions under 'With Project' and 'Without Project' cases. Figure 20 presents the recorded pre-mine and post-mine recession rate in comparison with the simulated pre-mine and post-mine recession rates, with the equal rate and triple rate line presented for comparative purposes.

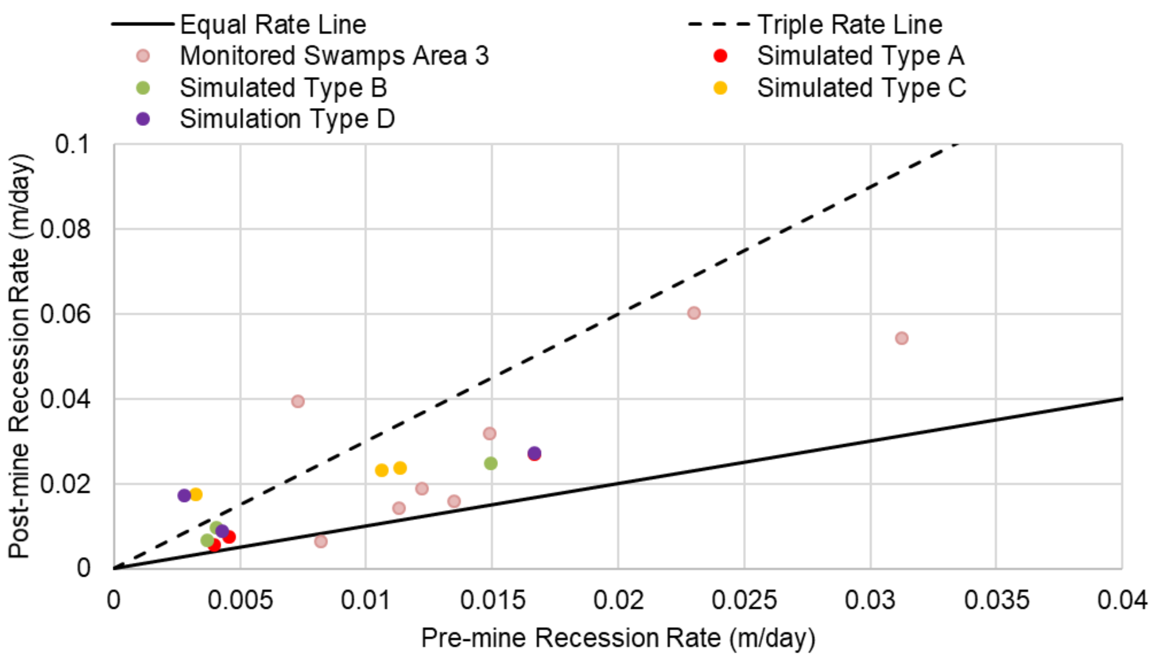

Figure 20 Monitored and Simulated Swamp Groundwater Recessions – With and Without Project

Figure 20 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 20. The total flux is indicative of drainage from the swamp to underlying strata.

Table 20 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	19.4	19.6	19.8
	With Project	105.0	125.5	112.6

The results presented in Table 20 above indicate that seepage from the base of the swamps is predicted to increase from very low values of between 0.1 and 19.8 cubic metres per meter (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 Type C, 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 fracturing 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 fracturing and may not represent long-term conditions.

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 24) while the 90th percentile rainfall sequence is dominated by less regular, though higher rainfall events (see Figure 27). 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 24 to Figure 32.

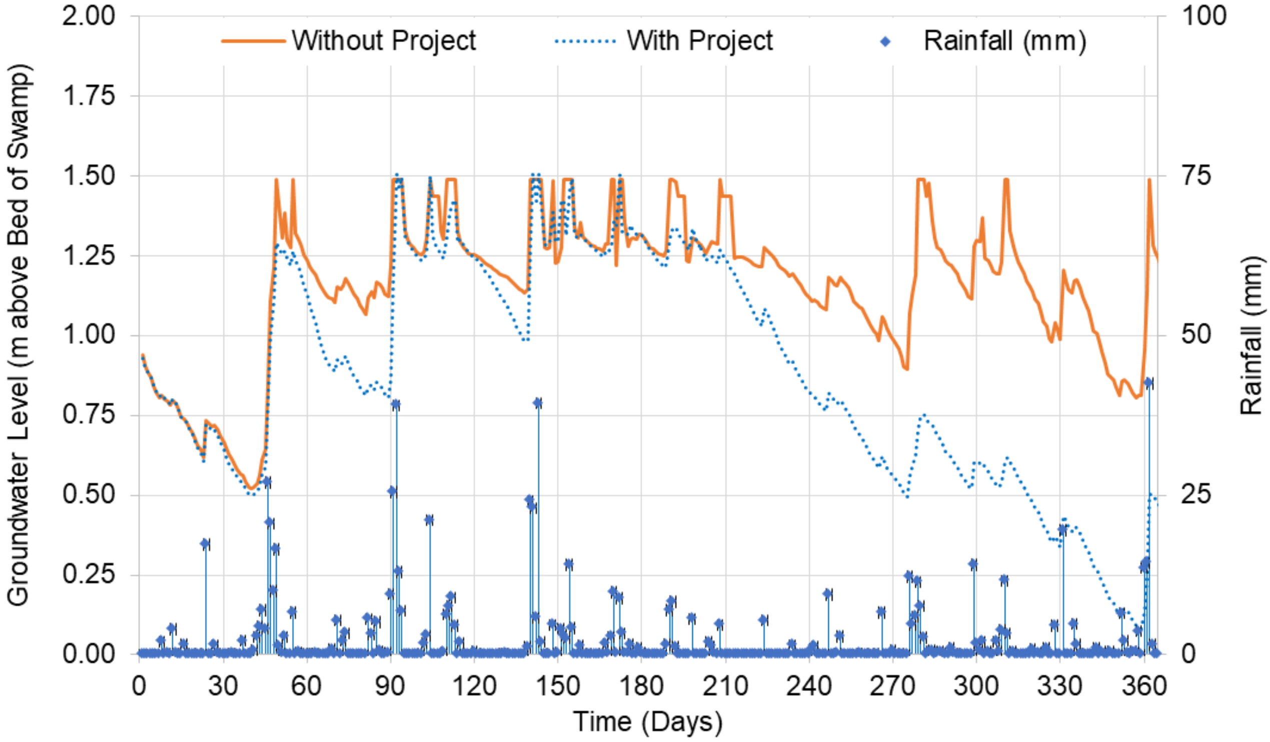

Figure 21 Simulated Groundwater Levels – Swamp Type A, 10th Percentile Climate Scenario

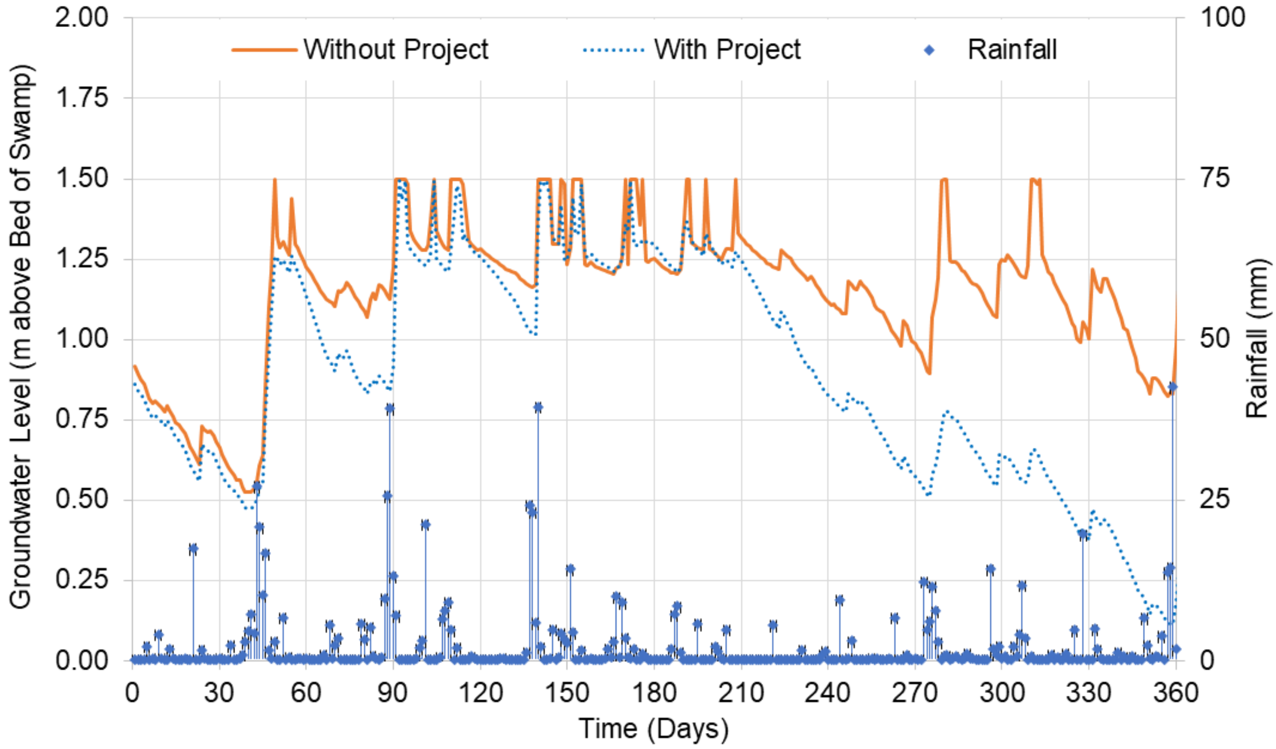

Figure 22 Simulated Groundwater Levels – Swamp Type B, 10th Percentile Climate Scenario

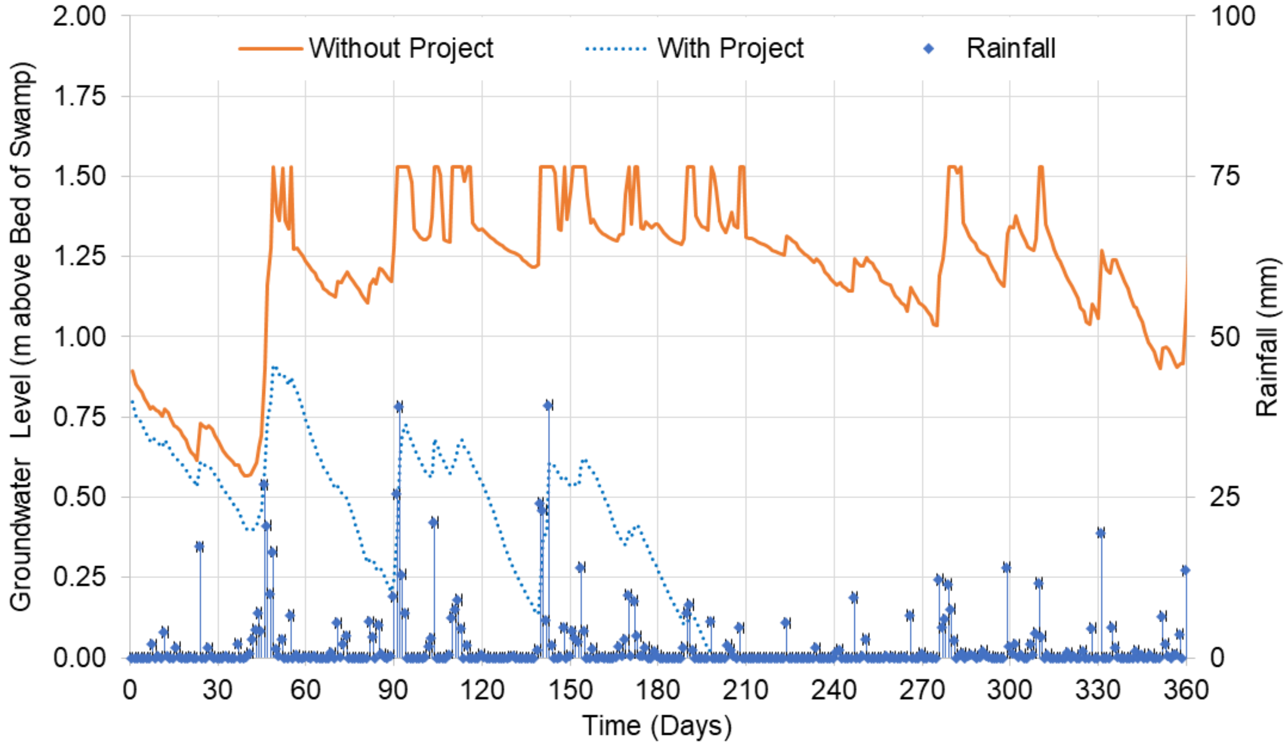

Figure 23 Simulated Groundwater Levels – Swamp Type C, 10th Percentile Climate Scenario

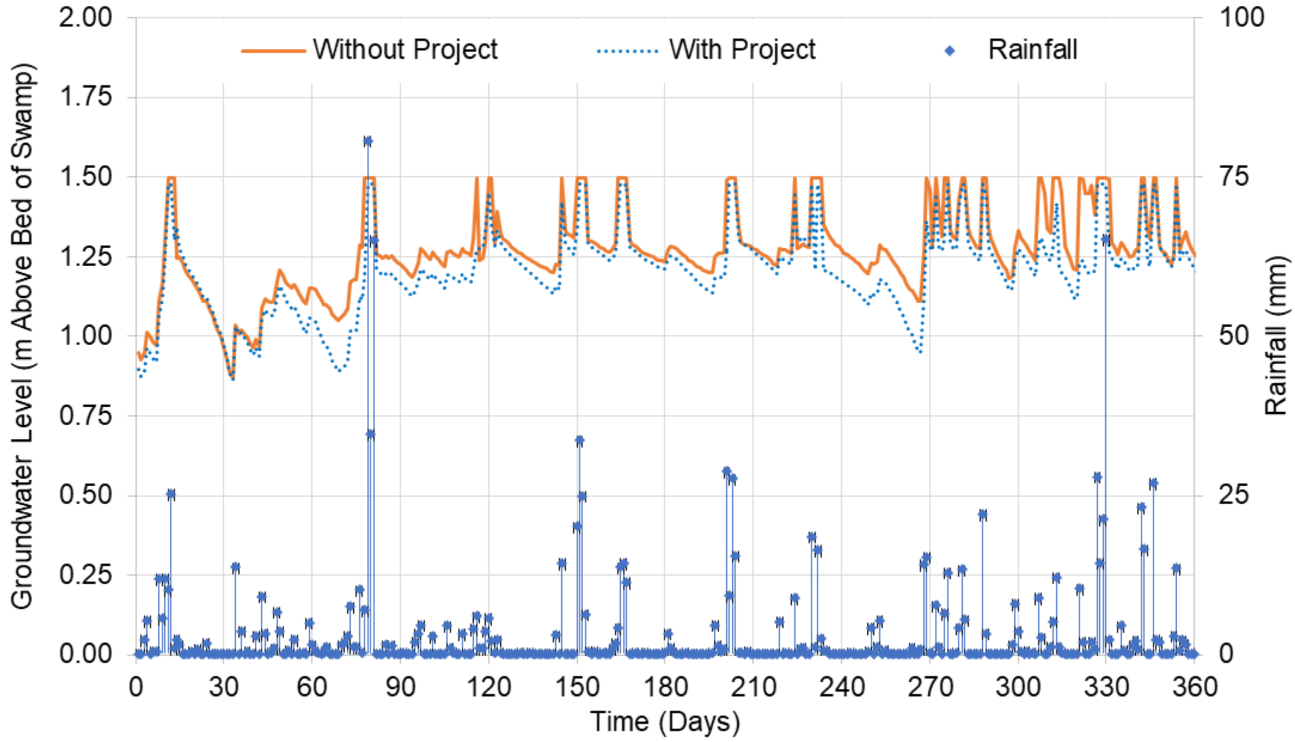

Figure 24 Simulated Groundwater Levels – Swamp Type A, Median Climate Scenario

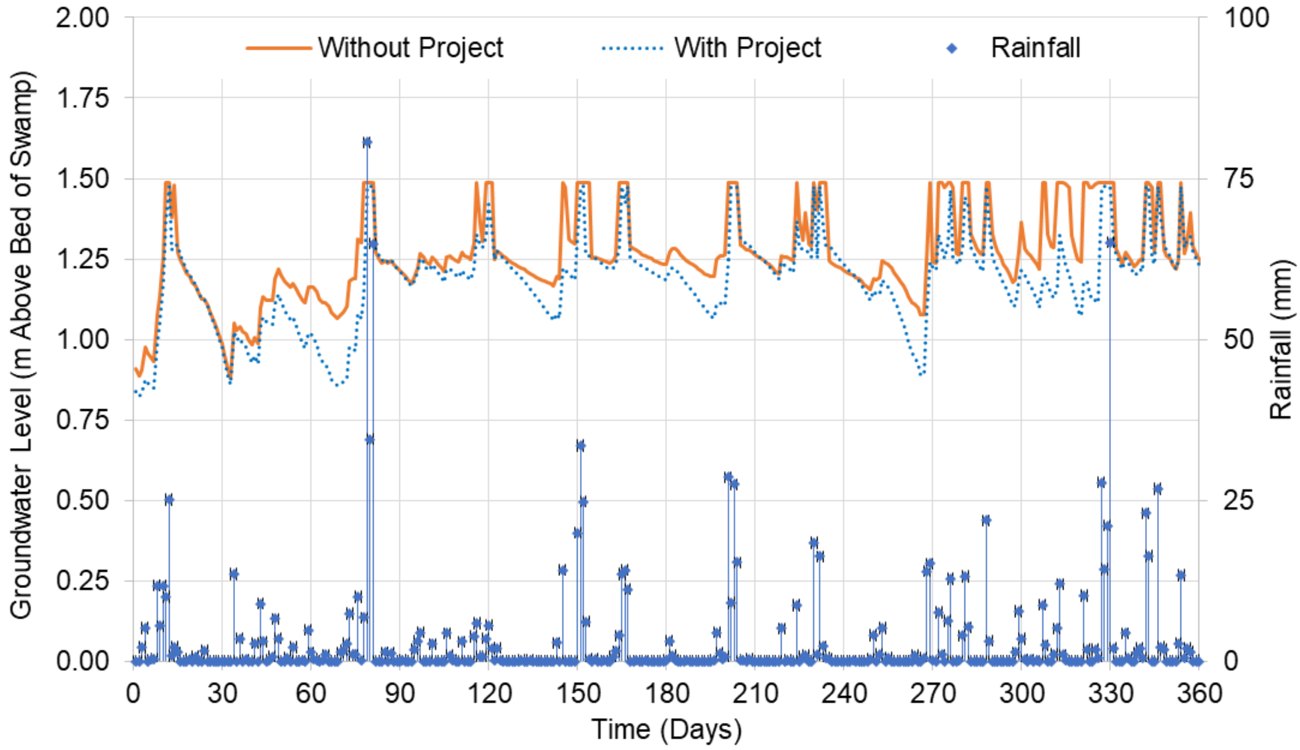

Figure 25 Simulated Groundwater Levels – Swamp Type B, Median Climate Scenario

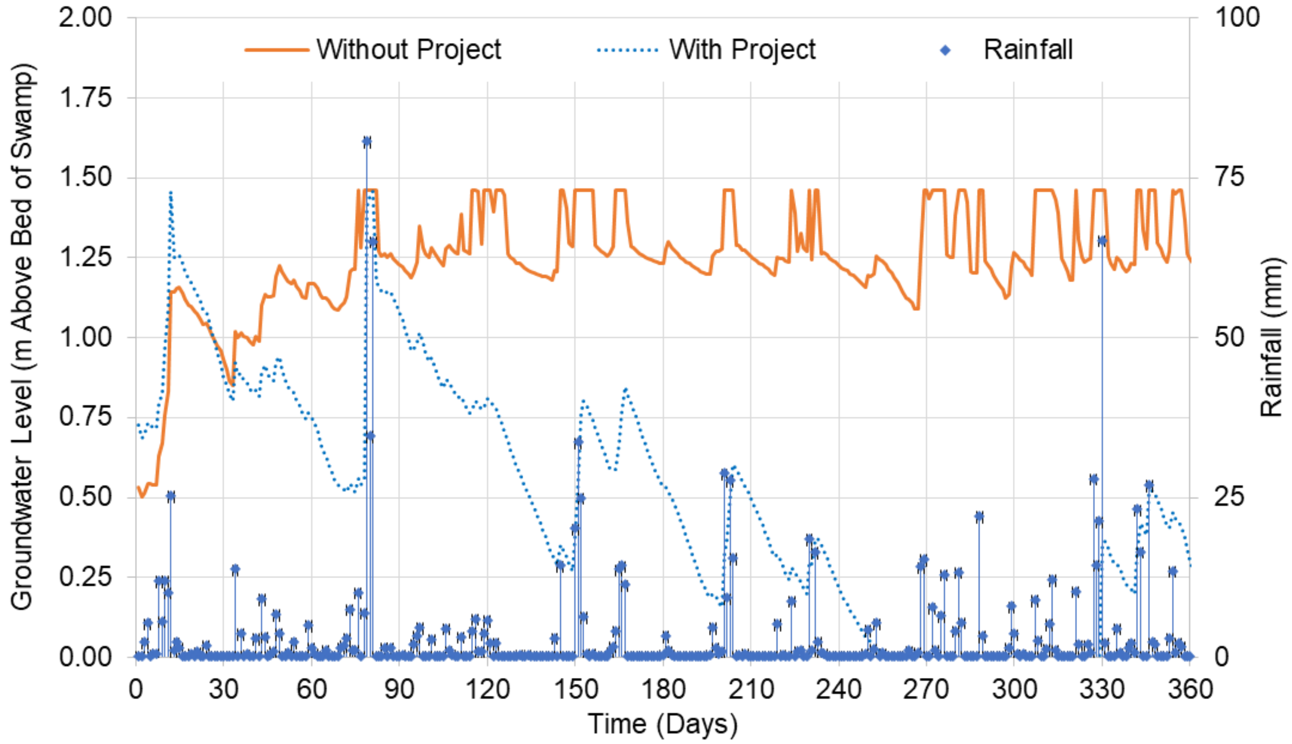

Figure 26 Simulated Groundwater Levels – Swamp Type C, Median Climate Scenario

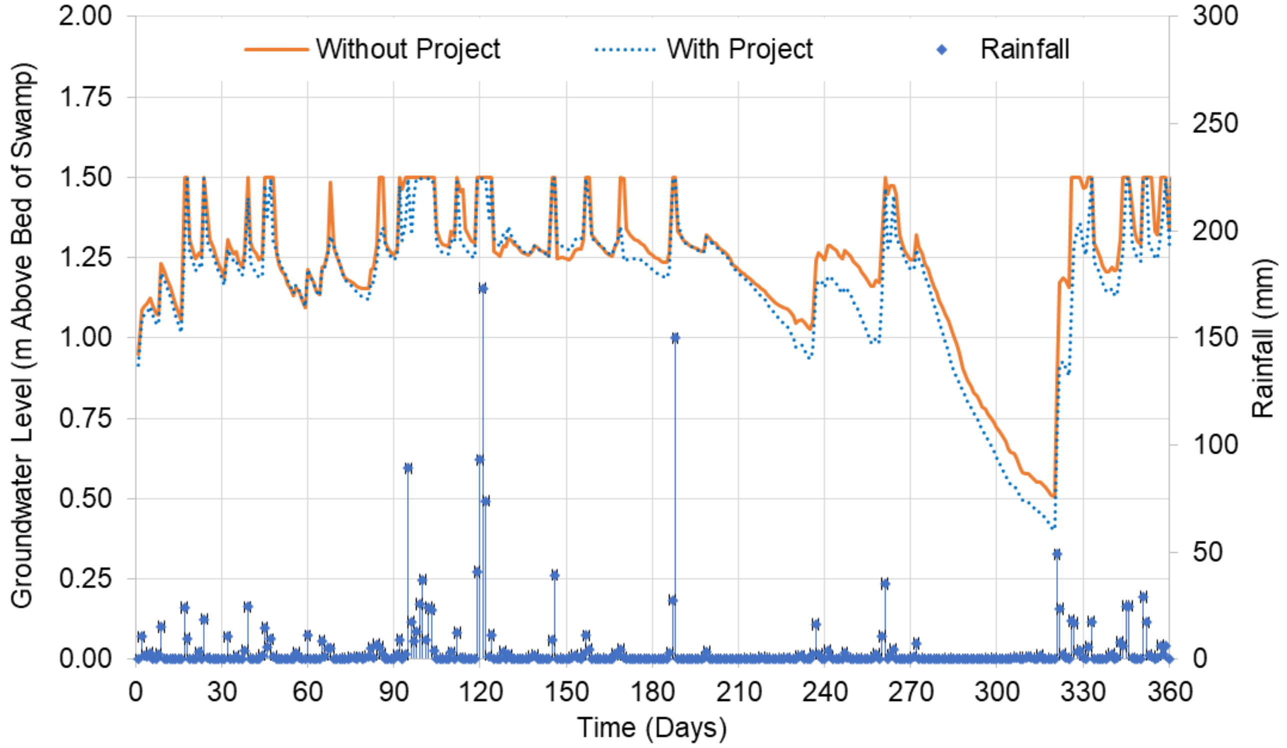

Figure 27 Simulated Groundwater Levels – Swamp Type A, 90th Percentile Climate Scenario

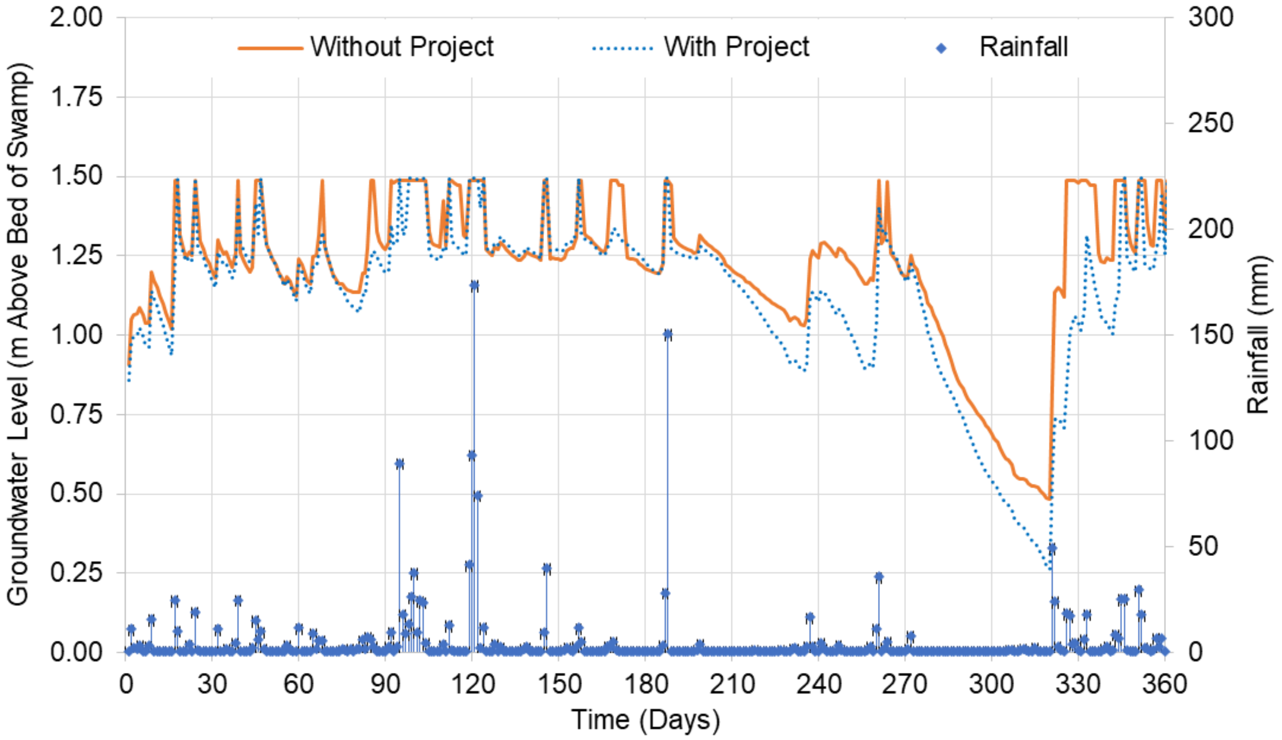

Figure 28 Simulated Groundwater Levels – Swamp Type B, 90th Percentile Climate Scenario

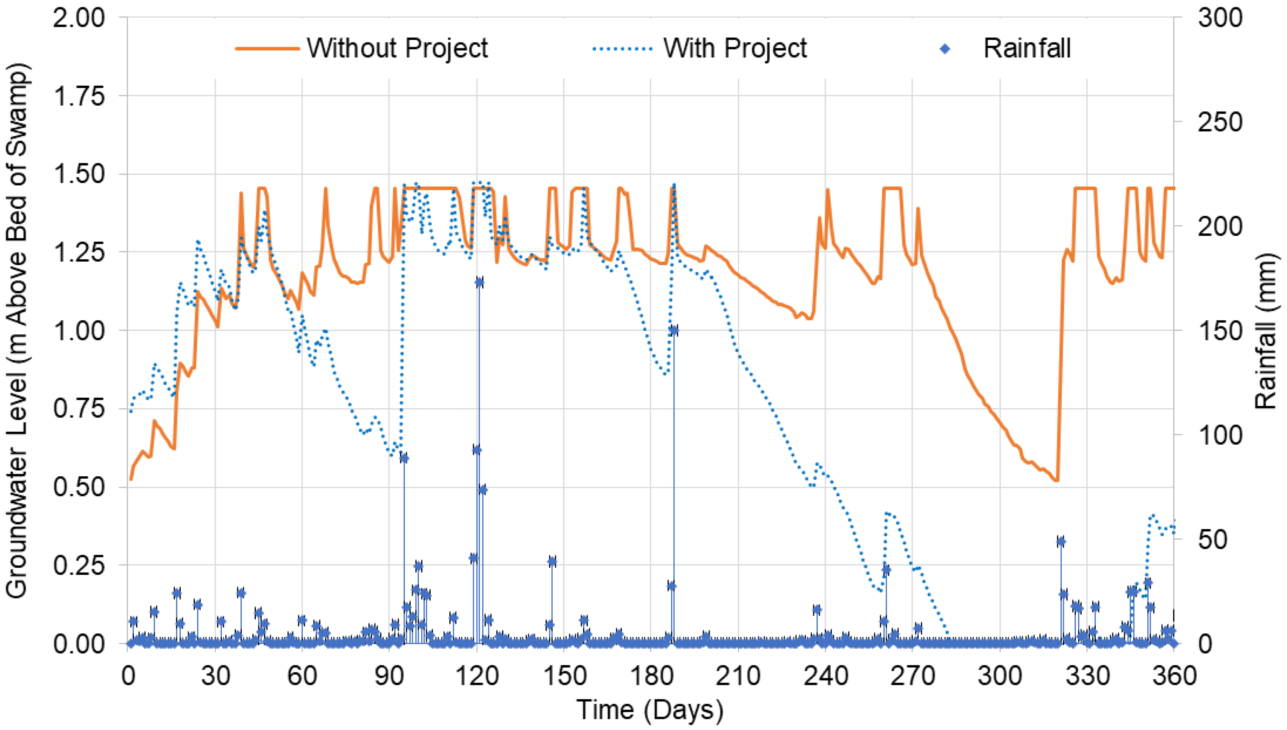

Figure 29 Simulated Groundwater Levels – Swamp Type C, 90th Percentile Climate Scenario

The existing swamps exhibit wetting and drying cycles in response to climate cycles (refer to graphs of monitoring data for swamps in Area 5 shown in Appendix B). These cycles result in groundwater levels which fluctuate from complete saturation of the swamp during prolonged wet periods to the groundwater level declining below 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.

5.3 POTENTIAL IMPACTS TO CATCHMENT STREAMFLOW

As stated in Section 5.1, surface water flow diversions are likely to occur along the sections of watercourses that are located directly above and adjacent to the proposed longwalls. Watercourses, where sufficient valley closure occurs, may experience dilation fracturing and shearing of rock strata and development of a fracture network beneath the watercourse bed. This would result in the diversion of a portion of streamflow via the fracture network. Where the watercourse 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.

Additionally, longwall mining in Area 5 is predicted to result in a reduction in baseflow contribution to the surface water systems within and adjacent to Area 5. Watershed HydroGeo (2022) describe baseflow reduction as '…the process of inducing leakage from a creek or river into the aquifer via a downward gradient or weakening an upward gradient from the aquifer into the watercourse and thereby reducing the rate at which baseflow occurs'.

Table 21 presents the short-term and longer-term reductions in baseflow associated with the Project as detailed in Watershed HydroGeo (2022). The short-term period comprises the nine year mining period plus three years immediately following while the longer-term period comprises a 20 year recovery period.

Table 21 Predicted Watercourse Baseflow Reduction – Project Effects

Catchment	Watercourse	Short-Term Baseflow Reduction (ML/day)		Longer-term Baseflow Reduction (ML/day)	
		Mean	Max	Mean	Max
Donalds Castle Creek	DC8	0.085	0.158	0.018	0.049
	DC9	0.014	0.022	0.000	0.002
	DC10	0.074	0.127	0.006	0.023
	DCU	0.074	0.129	0.009	0.026
Avon River	AR19	0.178	0.265	0.147	0.266
	AR31	0.019	0.030	0.003	0.006
	AR32	0.107	0.155	0.070	0.120
Lake Avon	LA8	0.018	0.037	0.003	0.012
	LA12	0.015	0.035	0.000	0.001
	LA13	0.169	0.295	0.062	0.141
	LA14	0.040	0.053	0.002	0.008
	LA15	0.018	0.024	0.004	0.007
	LA17	0.030	0.044	0.001	0.004

Table 22 presents the short-term and longer-term predicted watercourse baseflow reduction associated with cumulative regional mining as detailed in Watershed HydroGeo (2022).

Table 22 Predicted Watercourse Baseflow Reduction – Cumulative Mining Effects

Catchment	Watercourse	Short-Term Baseflow Reduction (ML/day)		Longer-term Baseflow Reduction (ML/day)	
		Mean	Max	Mean	Max
Donalds Castle Creek	DC8	0.086	0.160	0.018	0.051
	DC9	0.014	0.022	0.001	0.002
	DC10	0.075	0.129	0.006	0.024
	DCU	0.966	1.258	0.708	1.562
Avon River	AR19	0.178	0.265	0.147	0.268
	AR31	0.017	0.030	0.003	0.006
	AR32	0.107	0.155	0.070	0.120
Lake Avon	LA8	0.014	0.039	0.004	0.013
	LA12	0.015	0.035	0.001	0.001
	LA13	0.157	0.297	0.063	0.141
	LA14	0.040	0.053	0.002	0.009
	LA15	0.018	0.024	0.004	0.007
	LA17	0.030	0.044	0.001	0.004

Baseflow reduction is expected to be most noticeable during periods of low flow which would normally be dominated by baseflow. The effect on low flows can be seen by comparing the flow duration curves for the pre-mining, mining (short-term) and post-mining (longer-term) scenarios. Figure 30 to Figure 36 present the flow duration curves for streamflow monitoring sites in Donalds Castle Creek, Avon River and Lake Avon catchments (refer Figure 6 for site locations) accounting for the predicted Area 5 mining effects.

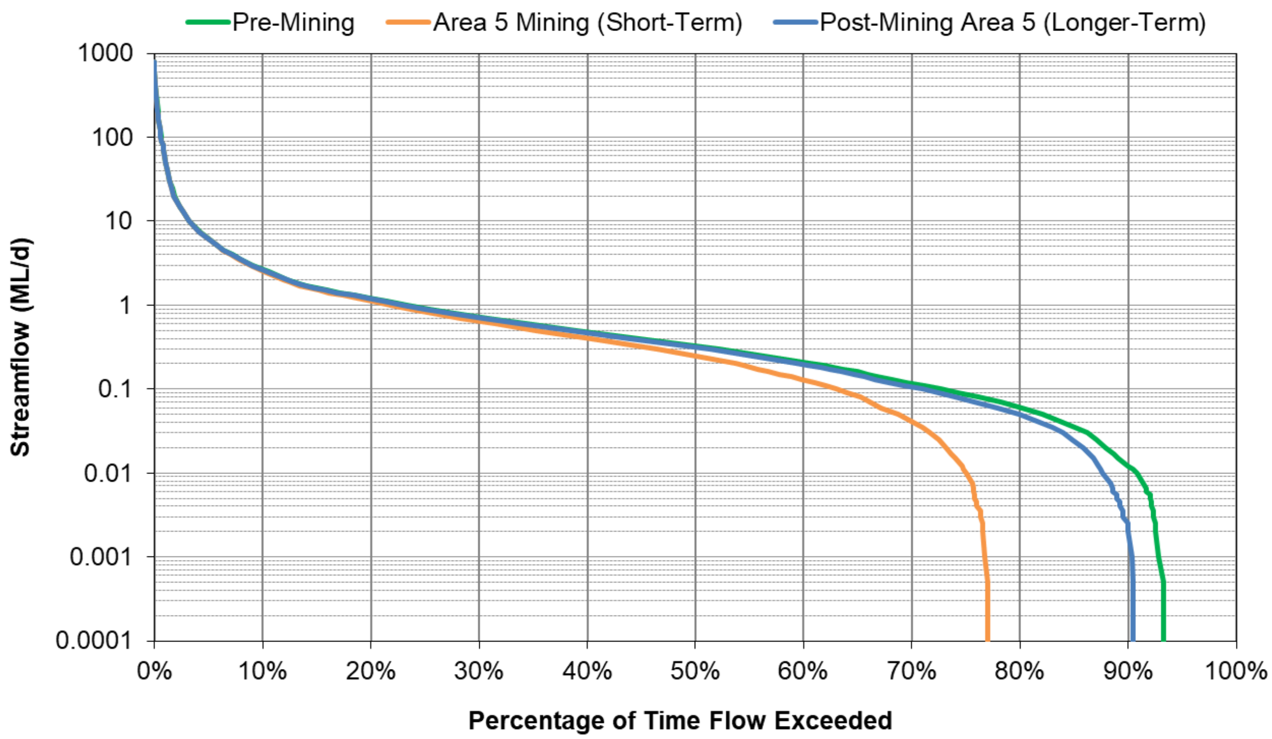

Figure 30 Flow Duration Curve – Donalds Castle Creek (Monitoring Site DCU)

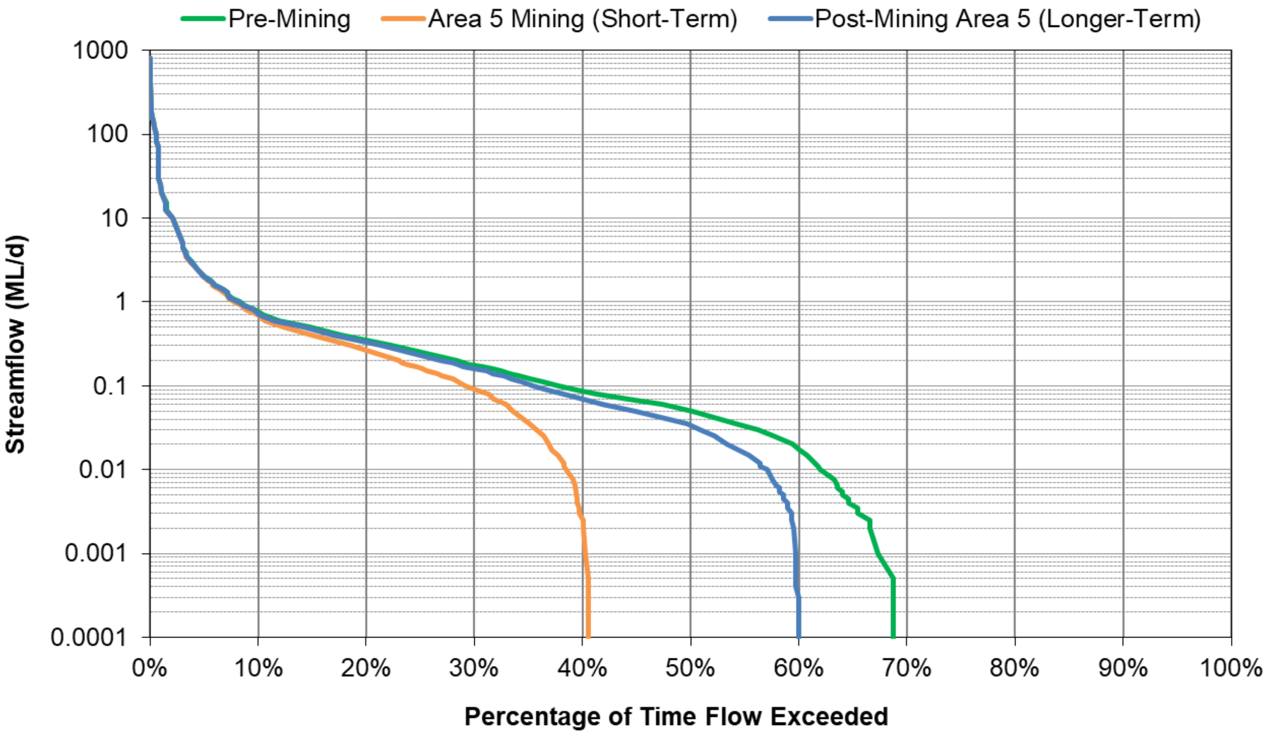

Figure 31 Flow Duration Curve – Donalds Castle Creek Tributary (Monitoring Site DC8S1)

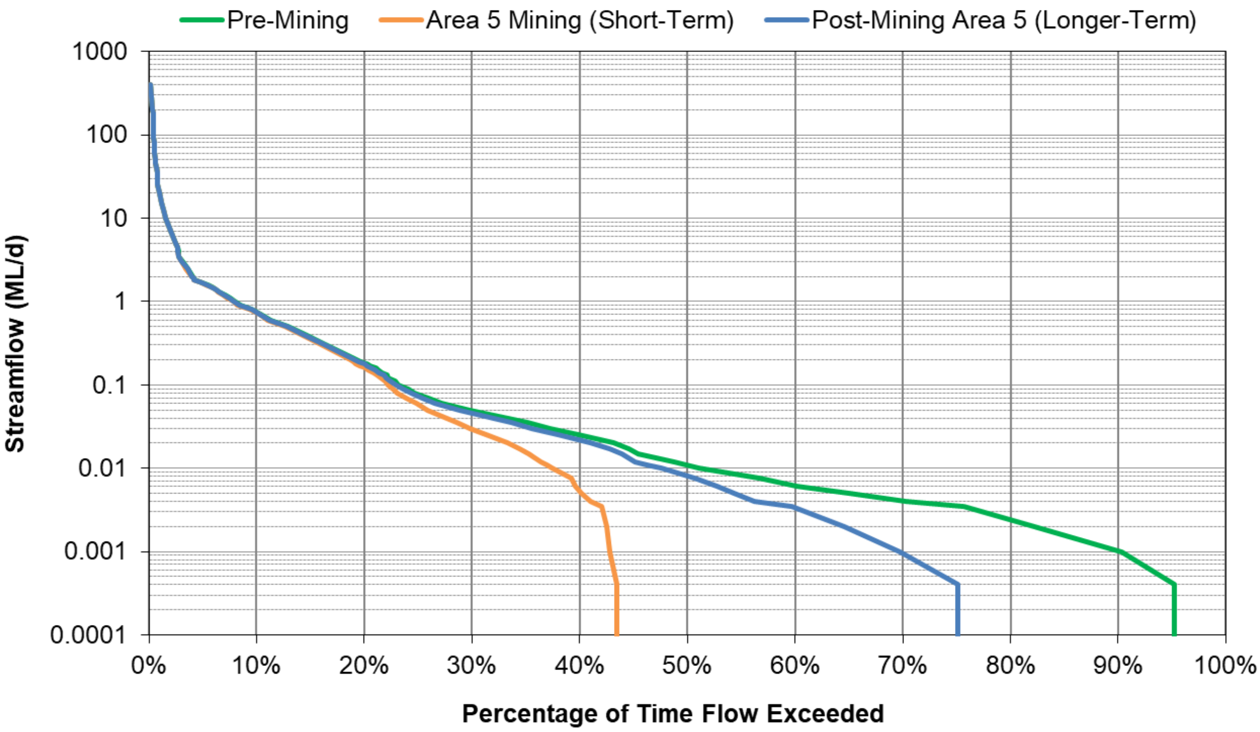

Figure 32 Flow Duration Curve – Avon River Tributary (Monitoring Site AR31S1)

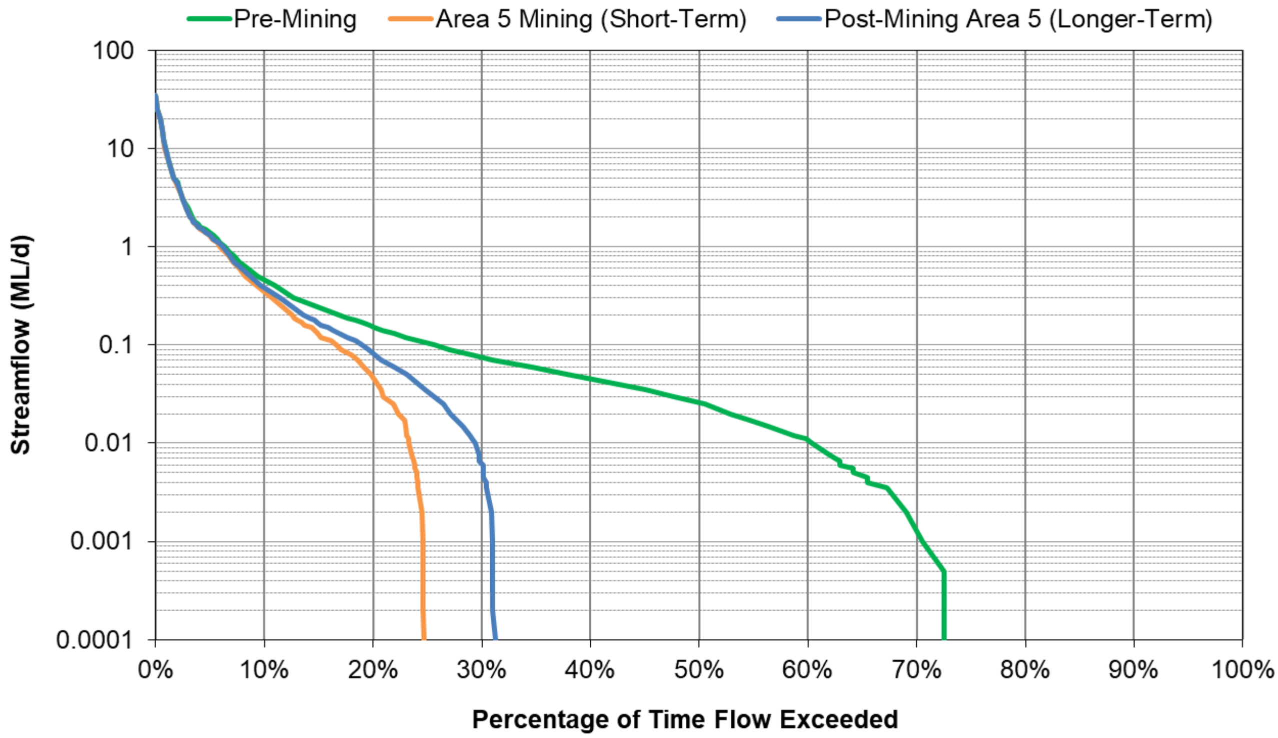

Figure 33 Flow Duration Curve – Avon River Tributary (Monitoring Site AR32S1)

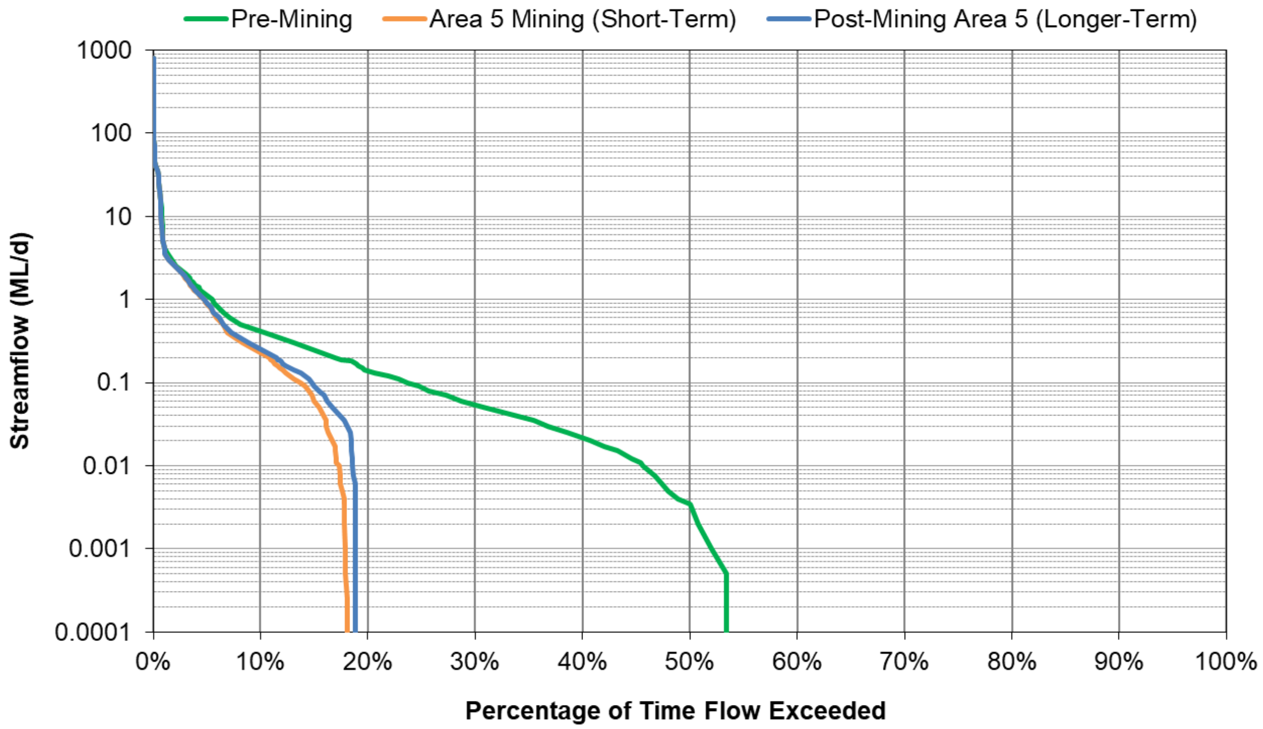

Figure 34 Flow Duration Curve – Avon River Tributary (Monitoring Site AR19S1)

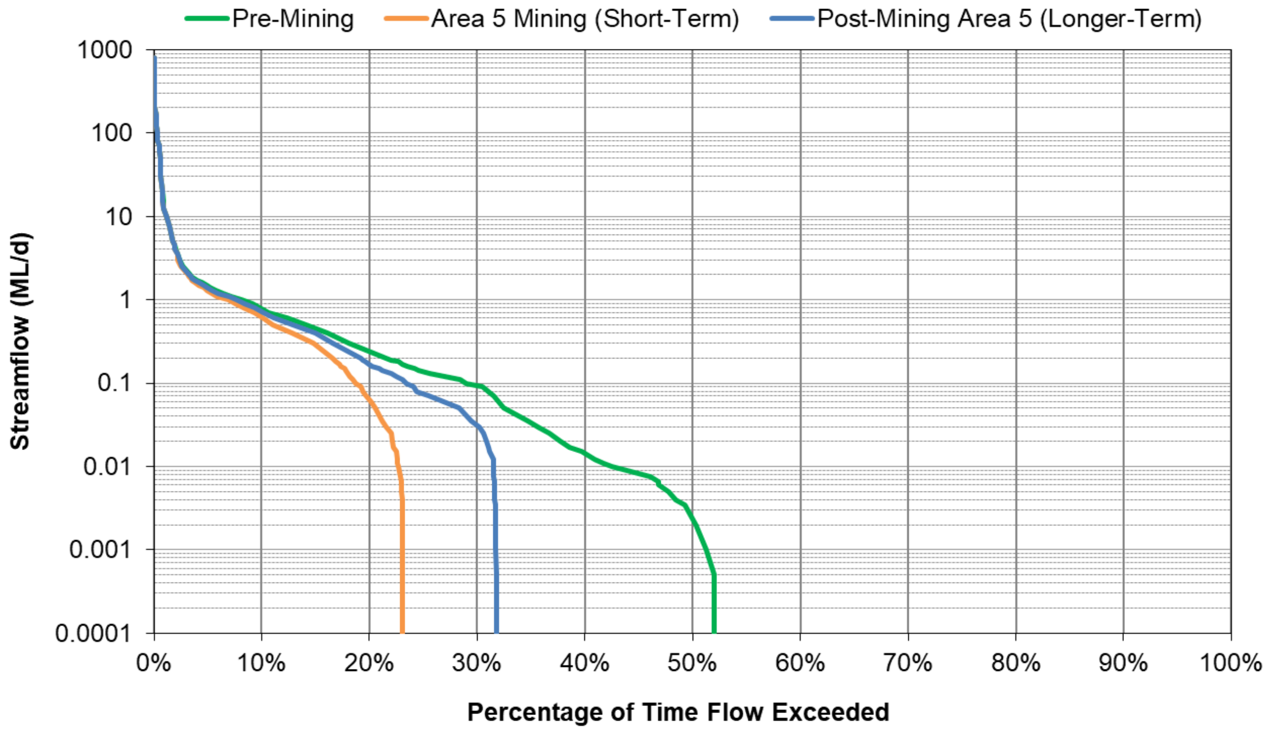

Figure 35 Flow Duration Curve – Lake Avon Tributary (Monitoring Site LA13S1)

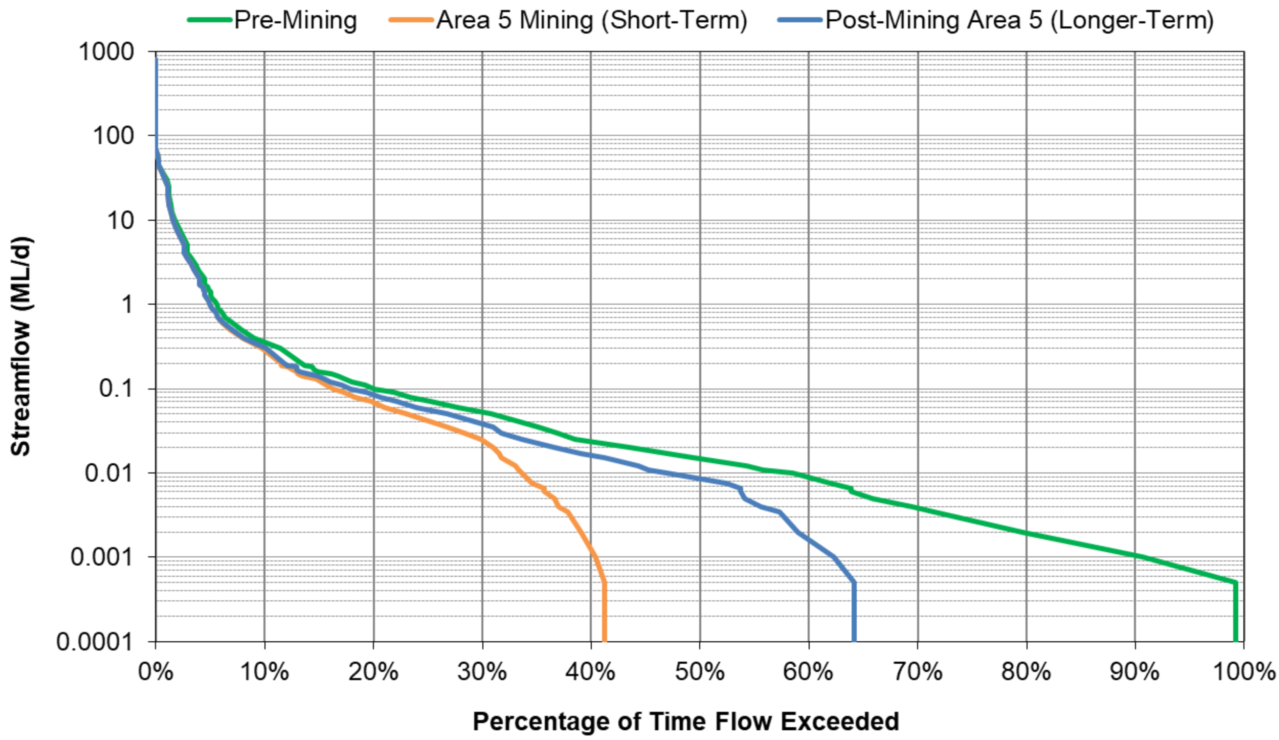

Figure 36 Flow Duration Curve – Lake Avon Tributary (Monitoring Site LA8S1)

The flow duration curves shown in Figure 30 to Figure 36 indicate the following:

- Baseflow reduction associated with Area 5 mining is likely to result in distinguishable effects on flows in Donalds Castle Creek (DCU) when flow rates are less than approximately 1 ML/d. The median flow rate is predicted to decrease from 0.33 ML/d pre-mining to 0.25 ML/d during and immediately following mining (short-term), with a predicted median post-mining (longer-term) flow rate of 0.32 ML/d. The probability that flow would be greater than 0.01 ML/d would reduce from 90.8% of days to between 75% of days during and immediately following mining and 88% of days post-mining (longer-term).

- Baseflow reduction associated with Area 5 mining is likely to result in distinguishable effects on flows in Donalds Castle Creek tributary (DC8) when flow rates are less than approximately 3 ML/d. The median flow rate is predicted to decrease from 0.05 ML/d pre-mining to 0 ML/d during and immediately following mining (short-term), with a predicted median post-mining (longer-term) flow rate of 0.03 ML/d. The probability that flow would be greater than 0.01 ML/d would reduce from 62% of days to between 38% of days during and immediately following mining and 57% of days post-mining (longer-term).
- Baseflow reduction associated with Area 5 mining is likely to result in distinguishable effects on flows in the Avon River tributaries (AR19, AR31 and AR32) when flow rates are less than approximately 1 ML/d, 0.1 ML/d and 1 ML/d respectively. For AR19, the probability that flow would be greater than 0.01 ML/d would reduce from 46% of days to between 17% of days during and immediately following mining and 19% of days post-mining (longer-term). For AR31, the probability that flow would be greater than 0.01 ML/d would reduce from 51% of days to between 37% of days during and immediately following mining and 48% of days post-mining (longer-term). For AR32, the probability that flow would be greater than 0.01 ML/d would reduce from 60% of days to between 23% of days during and immediately following mining and 29% of days post-mining (longer-term).
- Baseflow reduction associated with Area 5 mining is likely to result in distinguishable effects on flows in the Lake Avon tributary LA13 when flow rates are less than approximately 1 ML/d. The probability that flow would be greater than 0.01 ML/d would reduce from 43% of days to between 23% of days during and immediately following mining and 31% of days post-mining (longer-term).
- Baseflow reduction associated with Area 5 mining is likely to result in distinguishable effects on flows in the Lake Avon tributary LA8 when flow rates are less than approximately 1 ML/d. The median flow rate is predicted to decrease from 0.015 ML/d pre-mining to 0 ML/d during and immediately following mining (short-term), with a predicted median post-mining (longer-term) flow rate of 0.008 ML/d. The probability that flow would be greater than 0.01 ML/d would reduce from 58% of days to between 34% of days during and immediately following mining and 47% of days post-mining (longer-term).

5.4 POTENTIAL IMPACTS TO POOL WATER LEVEL AND IN-STREAM CONNECTIVITY

Pool water levels and in-stream connectivity are influenced by the storage characteristics of the pool, the volume of surface runoff and streamflow from the upstream catchment and the rate of rainfall, evaporation and seepage. The assessment of potential impacts to streamflow (Section 5.3) indicates that it is likely that there will be a reduction in surface runoff and streamflow rates as a result of the Project. As such, there is potential for pool water level and in-stream connectivity to be impacted as a result of reduced streamflow yield.

Based on MSEC (2022), it is expected that fracturing of bedrock would occur along the sections of the first and second order streams that are located directly above and adjacent to the proposed longwalls (note that no longwall mining will occur under third order streams). As such, there is potential for partial or complete loss of pool holding capacity to occur at these locations.

Minor fracturing could also occur along third order streams at distances up to approximately 400 m from the proposed longwalls. MSEC (2022) has predicted that approximately 15% of the stream controlling features (i.e. rockbars, steps and other controlling features) located within 400 m of the proposed longwalls could experience Type 3 impacts (fracturing in a rockbar or upstream pool resulting in reduction in standing water level). This represents approximately five rockbars along the third order sections of the streams which may also incur partial or complete loss of pool holding capacity. It is noted that no longwall mining under third order sections of watercourses is to occur.

5.5 POTENTIAL IMPACTS TO FLOODING AND OVERLAND FLOW

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

MSEC (2022) note that reductions in watercourse grades may occur due to the predicted mining induced tilts. A reduction in grade is expected to occur in watercourse DC8 and, to lesser extents, other first and second order watercourses within the Study Area. As such, there is potential for localised ponding to occur in sections of these watercourses (MSEC, 2022).

However, it is unlikely that large-scale adverse changes would occur in the levels of ponding or scouring of the banks along the first and second order streams as a result of the predicted mining-induced tilt. The potential impacts of increased ponding and scouring of the first and second order streams, therefore, are expected to be minor and localised (MSEC, 2022).

The tributaries of the first and second order streams have high natural gradients as they are located on the sides of the ridgelines. It is unlikely, therefore, that increased ponding or scouring would develop along these tributaries due to the predicted mining-induced tilt (MSEC, 2022).

5.6 POTENTIAL IMPACTS TO LAKE AVON, LAKE CORDEAUX AND PHEASANTS NEST WEIR

Watershed HydroGeo (2022) presents predictions of the estimated leakage from Lake Avon and Lake Cordeaux in addition to the predicted reduction in baseflow from the Lake Avon and Lake Cordeaux catchment associated with Area 5 mining and cumulative mining effects.

Lake Cordeaux is situated more than 4 km to the east of the eastern edge of the Area 5 longwalls (refer Figure 4). A maximum leakage rate from Lake Cordeaux of 0.02 ML/d associated with Area 5 mining has been predicted in addition to a maximum baseflow reduction to Lake Cordeaux catchment surface water systems of 0.01 ML/d (Watershed HydroGeo, 2022). Variable inflows of up to 4.5 ML/day are released from Cordeaux Dam for environmental flow purposes (WaterNSW, 2018b). A maximum reduction in Lake Cordeaux yield of 0.03 ML/d equates to 0.6% of the maximum environmental flow release. This represents a likely indiscernible impact to Lake Cordeaux inflow and environmental flow releases.

Table 23 presents the predicted reduction in yield to Lake Avon and Pheasants Nest Weir, as detailed in Watershed HydroGeo (2022), in comparison with the mean daily inflow rate for the Project and cumulative mining. The reduction in yield to Lake Avon comprises the predicted leakage rate and the predicted maximum baseflow reduction to Lake Avon catchment surface water systems. The reduction in yield to Pheasants Nest Weir comprises the sum of the predicted reduction in yield to Lake Avon, Lake Cordeaux, Lake Nepean and associated catchments.

Table 23 Comparison of Predicted Project and Cumulative Yield Reduction Rates on Mean Flow to Lake Avon and Pheasants Nest Weir

		Water Supply Source:	Lake Avon	Pheasants Nest Weir
Mean Daily Inflow Rate (ML/d)			186*	451**
Yield Reduction due to Project	Short-term Maximum	Predicted Reduction in Yield (ML/d)^	0.58	1.2
		% Mean Daily Inflow Rate	0.3%	0.3%
	Longer-term Maximum	Predicted Reduction in Yield (ML/d)^	0.36	0.9
		% Mean Daily Inflow Rate	0.2%	0.2%
Yield Reduction due to Cumulative Mining	Short-term Maximum	Predicted Reduction in Yield (ML/d)^	1.3	4.6
		% Mean Daily Inflow Rate	0.7%	1.0%
	Longer-term Maximum	Predicted Reduction in Yield (ML/d)^	0.7	3.9
		% Mean Daily Inflow Rate	0.4%	0.9%

* Source: WaterNSW – calculated from the average annual total inflow to Lake Avon for 1909 to 2020

** Source: https://realtimedata.waternsw.com.au/ - calculated from the average annual total inflow to Pheasants Nest Weir for 1984 to 2021

^ Source: Watershed HydroGeo (2022)

The data in Table 23 shows a predicted maximum reduction in mean daily inflow to Lake Avon and Pheasants Nest Weir of 0.3% due to short-term Project effects and 0.2% due to longer-term Project effects. Based on the cumulative mining predictions, a maximum reduction in mean daily inflow to Lake Avon of 0.7% is expected in the short-term and 0.4% in the longer-term. At Pheasants Nest Weir, a maximum reduction in mean daily inflow of 1% is expected in the short-term and 0.9% in the longer-term due to cumulative mining effects.

The estimated reduction in mean daily inflow rates to Lake Avon and Pheasants Nest Weir, based on both the Project and cumulative mining effects, is low and is likely to be indistinguishable from natural variability in catchment conditions.

5.6.1 Climate Change Effects

Climate change effects and the predicted changes to rainfall have been described in Watershed HydroGeo (2022) which suggests that, based on the NSW and ACT Regional Climate Modelling projections, 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 intermittent 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.

5.7 SWAMP STABILITY ASSESSMENT

5.7.1 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 (Niche, 2022). Vegetation increases the erosion resistance of a swamp and therefore reductions 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.

5.7.2 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 Newtons per metre squared (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 swamp TSR and extent may decline post-mining.

A simple hydraulic (surface flow) model was developed for each swamp overlying the proposed longwall panels in Area 5. The hydraulic model was developed in the Hydrologic Engineering Center River Analysis System (HEC-RAS). Using the RAS Mapper function within HEC-RAS, cross sections and slopes were derived for the swamps from the 'With Project' and 'Without Project' contours (supplied by MSEC). A one-dimensional steady, mixed (subcritical and supercritical) flow simulation was then performed. 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 24, were estimated using the Regional Flood Frequency Estimation Model[9].

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.

The predicted subsidence contours, obtained from MSEC (2022) 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.

[9] https://rffe.arr-software.org/

Table 24 summarises the existing gradient of each modelled swamp and the expected change in gradient due to potential subsidence impacts resulting from tilt.

Table 24 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 85	1.16	14.4	11.7	10.9	< 0.5
Den 86	2.81	34.5	6.7	6.3	20
Den 97	1.54	18.8	4.5	4.1	< 0.5
Den 98	3.17	39.2	2.9	3.0	< 0.5
Den 99	1.35	16.5	4.6	4.4	16
Den 100	0.37	4.48	9.3	8.3	15
Den 101	1.12	13.7	4.6	5.3	12
Den 102	0.21	2.58	6.1	5.5	16
Den 103	0.63	7.76	6.2	6.0	6
Den 104	0.08	1.08	3.8	4.4	< 0.5
Den 105	0.2	2.45	9.9	10.3	< 0.5
Den 106	0.8	9.9	6.7	6.7	15
Den 107	0.62	7.71	11.1	9.2	13
Den 108	1.7	20.9	5.4	4.7	18
Den 109	1.08	13.3	3.7	3.5	11
Den 110	0.56	6.93	7.8	6.2	12
Den 111	2.03	25	7.6	1.7	16
Den 114	0.47	5.72	5.2	5.3	14
Den 120	0.46	5.63	3.8	3.7	< 0.5
Den 121	0.98	12	21.1	19.4	20
Den 122	0.41	5.07	4.2	4.3	20
Den 123	0.37	4.56	6.9	7.9	17

* Source: MSEC (2022). Note: maximum predicted tilt may not occur in the same direction as the existing swamp gradient.

5.7.3 Assessment Results

Results of the hydraulic modelling assessment are summarised in Table 25. 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 25 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 85	45.53	26.87	119.81	119.81
Den 86	79.75	79.75	96.34	96.34
Den 97	40.1	**43.28**	105.63	**113.21**
Den 98	109.92	106.59	*303.31*	*294.91*
Den 99	63.56	29.83	81.52	**84.07**
Den 100	51.24	48.3	127.29	127.29
Den 101	34.44	31.68	108.37	99.46
Den 102	16.22	15.14	40.34	37.54
Den 103	47.26	**49.66**	111.98	111.98
Den 104	25.12	25.12	55.11	55.11
Den 105	62	**64.16**	193.88	***200.84***
Den 106	56.24	56.24	85.43	**85.5**
Den 107	69.74	69.74	207.95	*207.95*
Den 108	78.38	70.71	195.71	*191.58*
Den 110	60.15	50.64	134.06	134.06
Den 111	86.05	86.05	176.95	176.95
Den 114	54.29	54.29	146.57	146.57
Den 120	28.68	**29.33**	81.27	**82.84**
Den 121	78.26	78.26	152.93	152.93
Den 122	58.08	58.08	130.09	130.09
Den 123	43.17	43.17	73.35	73.35

The results in Table 25 indicate that an increase in shear stress is predicted to occur in 6 of the 21 swamps simulated in the Study Area. The increase in shear stress is estimated to result in an exceedance of erosion threshold in four 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 for Den 105 is predicted at approximately 200 N/m^2 for the 'With Project' case which exceeds the shear stress erosion threshold for disturbed tussocks and sedges, bunch grass 2 – 25 cm high (180 N/m^2) (Fishchenich, 2001 and DSE, 2007). The shear stress for Den 107 during a 1% AEP peak flow for the 'With Project' case is predicted at 208 N/m^2 which exceeds the shear stress erosion threshold for disturbed tussocks and sedges, bunch grass 2 – 25 cm high (180 N/m^2) (Fishchenich, 2001 and DSE, 2007). During a 1% AEP peak flow, the shear stress for Den 108 is predicted at 192 N/m^2 for the 'With Project' case which exceeds the shear stress erosion threshold for 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 at Den 105, Den 107 and Den 108 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.

5.8 WATER QUALITY ASSESSMENT

Potential impacts to water quality as a result of the predicted subsidence effects associated with the Project would be localised (e.g. localised changes in water quality in the Avon River and Donalds Castle Creek and 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 Lake Avon or Pheasants Nest Weir. Water quality monitoring downstream of mine areas is recommended (refer Section 8.0).

Where monitoring indicates that subsidence-related impacts have occurred to named watercourses or key stream features, IMC would implement remediation measures where it is practicable to do so (see Section 7.0).

5.9 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 26 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 26 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 Study Area, and potentially downstream of the Study Area. However, the impact on inflows to Lake Avon and Pheasants Nest Weir are likely to be indiscernible (refer Section 5.6).
Recharge rates	The Project is likely to result in localised changes to recharge rates from surface water systems within the Study Area (refer Watershed HydroGeo [2022]).
Aquifer pressure or pressure relationships between aquifers	Refer Watershed HydroGeo (2022).
Groundwater table levels	Refer Watershed HydroGeo (2022).
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 Section 5.2 and Section 5.3).
River/floodplain connectivity	The Project is unlikely to have an impact on river/floodplain connectivity.
Inter-aquifer connectivity	Refer Watershed HydroGeo (2022).
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 5.6). • 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 5.8). • A reduction in streamflow yield in the Study Area has the potential to reduce the extent and TSR of swamp vegetation (refer Niche, 2022).
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)	Mine subsidence effects may result in isolated, episodic pulses in iron, manganese, aluminium, zinc and electrical conductivity (refer Section 4.1.1).
High quality water is released into an ecosystem which is adapted to a lower quality of water	Not applicable.

5.10 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 Area 5 longwalls is predicted to increase from between 0.1 and 19.8 cubic metres per metre (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 decline 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 less steep swamps.
- Baseflow reduction associated with Area 5 mining is likely to result in distinguishable effects on flows in the Avon River tributaries, Lake Avon tributaries and Donalds Castle Creek and its tributaries when flow rates are less than approximately 1 ML/d.
- Fracturing of bedrock and reduction in baseflow may result in partial or complete loss of pool holding capacity in first and second order streams that are located directly above and adjacent to the proposed longwalls (note that no longwall mining will occur under third order streams).
- Approximately 15% of the stream controlling features (i.e. rockbars, steps and other controlling features) in third order sections of steams located within 400 m of the proposed longwalls could experience Type 3 impacts (fracturing in a rockbar or upstream pool resulting in reduction in standing water level).
- However, the estimated reduction in mean daily inflow rates to Lake Avon and Pheasants Nest Weir, based on both the Project and cumulative mining effects, is low and is likely to be indistinguishable from natural variability in catchment conditions.
- A reduction in grade is expected to occur in watercourse DC8 and, to lesser extents, other first and second order watercourses within the Study Area. As such, there is potential for localised ponding to occur in sections of these watercourses.
- It is unlikely that erosion and scouring will occur in any swamp in the Study 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 at Den 105, Den 107 and Den 108 during a rare flow event (represented by the 1% AEP peak flow) as a result of mining induced tilt.

6.0 NEUTRAL OR BENEFICIAL EFFECTS

Under the *State Environmental Planning Policy (Biodiversity and Conservation) 2021* 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.*

The *State Environmental Planning Policy (Biodiversity and Conservation) 2021* would apply to the Project if not for its State Significant Infrastructure (SSI) declaration.

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 recorded in surface water catchments within the region, located outside of the zone of influence of mining activities, due to naturally elevated concentrations of constituents (refer Section 2.2.3.2).

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, IMC 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 27.

Table 27 Water Quality Improvement Works

Water Quality Improvement Works	Estimated Financial Contribution
Fire management measures (e.g. slashing for fire breaks, hazard reduction burns)	$371,500
Maintenance of unsealed road network	$146,000
Installation and maintenance of barriers and fences	$100,000
Total	**$617,500**

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

6.2 WATER QUALITY IMPACTS FROM PROPOSED AREA 5 VENTILATION SHAFT

The proposed Area 5 ventilation shaft site would be located in the DC10 catchment which is a sub-catchment of Donalds Castle Creek (refer Figure 9). Donalds Castle Creek is a tributary of the Cordeaux River which discharges to the Nepean River approximately 1.6 km upstream of Pheasants Nest Weir.

Sediment and erosion control for the proposed Area 5 ventilation shaft site construction activities is to be undertaken in accordance with Landcom (2004) and DECC (2008) guidelines. During operations, surface water runoff at the proposed Area 5 ventilation shaft site would be directed to two sediment basins which would be designed in accordance with Landcom (2004) and DECC (2008) guidelines. Stored water in the sediment basins would be automatically dosed with gypsum or other approved flocculant to aid in the sediment settling process. Water stored in the sediment basins would be pumped to a discharge borehole and directed to the underground mine workings thereby avoiding concentrated surface water discharges from the ventilation shaft site to the Metropolitan Special Area.

As such, construction and operation of the proposed Area 5 ventilation shaft site is not expected to result in impacts to water quality in the downstream water supply catchment. Consequently, construction and operation of the proposed Area 5 ventilation shaft site is expected to have a neutral effect on water quality in the Sydney water supply catchment.

However, the surface water runoff would be captured and directed to the underground mine water management system resulting in a reduction in surface water yield to the water supply catchment. The potential impact on surface water yield would be mitigated by IMC conducting offset works, as agreed with WaterNSW, to compensate for potential impacts to the water supply yield of Pheasants Nest Weir.

7.0 STREAM REMEDIATION OPTIONS AND WORKS

Various techniques have previously been adopted to successfully reduce subsidence impacts to streams associated with longwall mining, including by IMC 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 28. The full range of available techniques would be considered by IMC in the design of any future stream restoration programs should these be required.

Table 28 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 Metropolitan 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.

8.0 MONITORING RECOMMENDATIONS

Climatological, surface water and upland swamp monitoring would continue to be undertaken within and adjacent to the Study Area as described in Section 2.0. Monitoring of the Dendrobium Mine water management system would continue to be undertaken in accordance with EPL 3241 and as described in the Dendrobium Mine Water Management Plan (IMC, 2021).

Recommendations for continued and additional monitoring associated with the Dendrobium Mine water management system and surface water resources within and adjacent to the Study Area are described in Table 29.

Table 29 Recommended Monitoring

Parameter	Monitoring Sites	Description
Water Level/Flow Rate		
Surface water flow rate	Existing streamflow monitoring sites (refer Figure 6). Proposed streamflow monitoring sites: • DCL3, DC9, DC10 • LA14, LA17 • AR19, AR31 - just downstream of the predicted 20 mm subsidence boundary associated with Area 5	• The mine area flow monitoring sites should be progressively developed over the Project life. • Monitoring at existing sites should continue and additional streamflow monitoring sites are recommended if site reconnaissance identifies suitable locations. • 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. • Periodic (monthly during flow) manual flow gauging should be undertaken to verify adopted streamflow ratings.
Swamp water level	Existing sites (refer Table 8) plus two 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 to assess changes during and following mining in comparison with baseline conditions and the need for and subsequent success of any remedial works.
Swamp flow rate	Suitable sites (to be identified 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, provision of leakage rate estimates to inform the groundwater modelling and to identify the need for and subsequent success of any remedial works.
Pool water level	Pools which may experience a Type 3 impact as predicted by MSEC (2022) – refer Section 5.1 Two additional reference site pools outside of mining influences	• Continuous data collected by water levels sensors/loggers with levels recorded to AHD. • Recommended minimum one pool per longwall in each watercourse. • 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.

Table 29 (Cont.) Recommended Monitoring

Parameter	Monitoring Sites	Description
Water Quality		
Surface water quality	Existing sites (refer Figure 6). Proposed water quality monitoring sites: AR19, AR31 - just downstream of the predicted 20 mm subsidence boundary associated with Area 5	• The mine area water quality monitoring sites should be further developed over the Project life. • Monitoring at existing sites should continue and additional surface water quality monitoring sites are recommended if site reconnaissance identifies suitable locations. • 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.
Appearance		
Observational and photographic monitoring	All flow and quality monitoring sites Swamps DEN105, DEN107 and DEN108	• Visual signs of impacts to creeks, drainage lines and swamps (i.e. cracking, vegetation changes, increased erosion and scouring, 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).

Table 29 (Cont.) Recommended Monitoring

Parameter	Monitoring Sites	Description
Water Balance		
Flow monitoring	All pumped flows	• The existing monitoring of the main water transfers within the underground workings, 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.

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APPENDIX A – WATER QUALITY MONITORING SUMMARY TABLES

Lake Avon Catchment Water Quality Summary – LA_2, LA12_Pool 1, LA13_S1

Parameter (mg/L unless otherwise stated)	Guideline Value	LA_2					LA12_Pool 1					LA13_S1				
		No. Samples	Min	Median	Max	% Exceedance	No. Samples	Min	Median	Max	% Exceedance	No. Samples	Min	Median	Max	% Exceedance
pH - Field (pH Units)	6.5-8‡	47	5.34	6.67	7.6	36%	13	5.33	5.7	7.6	92%	45	4.66	5.51	6.4	100%
pH (pH Units)	6.5-8‡	51	5.55	6.4	7.5	59%	14	4.69	5.7	6.3	100%	43	4.76	5.8	7.0	93%
Dissolved Oxygen - Field (%)	90-110‡	47	33	97	110	36%	13	85	91	102	31%	45	7	62	95	93%
Electrical Conductivity - Field (µS/cm)	350‡	47	45	63	86	0%	13	75	106	122	0%	45	57	110	170	0%
Electrical Conductivity @ 25°C (µS/cm)	350‡	51	51	64	165	0%	14	75	103.5	136	0%	43	62	108	191	0%
Total Alkalinity as $CaCO_3$ (mg/L)		51	<1	4	10		14	<1	1	4		43	<1	1	15	
Dissolved Organic Carbon (mg/L)		51	1	4	14		14	1	3	5		43	1	4	81	
Suspended Solids (mg/L)		34	5	5	35		14	5	5	204		30	5	5	72	
Sulfate as SO_4 (mg/L)	400†	2	2	-	3	0%	0	-	-	-		2	<1	-	1	0%
Nitrite + Nitrate (mg/L)		51	0.01	0.04	0.8		14	0.01	0.01	0.4		43	0.01	0.01	0.8	
Nitrate (mg/L)	50*	4	0.02	-	0.04	0%	2	0.01	-	0.01	0%	4	0.02	-	0.04	0%
Nitrite (mg/L)	3*	4	0.01	-	0.01	0%	2	0.01	-	0.01	0%	4	0.01	-	0.01	0%
Total Kjeldahl Nitrogen (mg/L)		51	0.1	0.1	1.4		14	0.1	0.1	0.2		43	0.1	0.1	3.1	
Total Nitrogen (mg/L)	0.25‡	4	0.1	-	0.2	0%	2	0.1	-	0.1	0%	4	0.1	-	0.3	25%
Total Phosphorus (mg/L)	0.02‡	51	0.01	0.01	0.11	4%	14	0.01	0.01	0.02	0%	43	0.01	0.01	0.58	5%
Reactive Phosphorus (mg/L)		17	0.01	0.01	0.01		0	-	-	-		15	0.01	0.01	0.01	

†ANZG (2018) default guideline value for aquatic ecosystems (95% level of species protection for slightly to moderately disturbed ecosystems) – the default guideline value relates to the total concentration of a constituent although should also be compared with the dissolved concentration which represents the bioavailable fraction; ‡ ANZECC (2000) default guideline value for Upland Rivers in NSW; * NHMRC (2022) water quality guideline value for health purposes.

Lake Avon Catchment Water Quality Summary – LA_2, LA12_Pool 1, LA13_S1

Parameter (mg/L unless otherwise stated)	Guideline Value	LA_2					LA12_Pool 1					LA13_S1				
		No. Samples	Min	Median	Max	% Exceedance	No. Samples	Min	Median	Max	% Exceedance	No. Samples	Min	Median	Max	% Exceedance
Calcium (mg/L)		51	<1	1	1		14	<1	1	2		43	<1	1	1	
Magnesium (mg/L)		51	<1	1	4		14	<1	2	3		43	<1	2	5	
Potassium (mg/L)		51	<1	1	4		14	<1	1	1		43	<1	1	2	
Sodium (mg/L)	180^	51	5	8	22	0%	14	10	15.5	19	0%	43	10	15	21	0%
Chloride (mg/L)	250^	51	10	14	46	0%	14	18	28.5	37	0%	43	14	28	46	0%
Ammonia (mg/L)	0.5^	51	0.01	0.01	0.05	0%	14	0.01	0.01	0.01	0%	43	0.01	0.01	0.12	0%
Dissolved Aluminium (mg/L)	0.055†	45	<0.01	0.01	0.09	7%	14	0.04	0.055	0.15	50%	37	0.03	0.05	0.78	46%
Total Aluminium (mg/L)	0.055†	51	<0.01	0.02	1.07	25%	14	0.05	0.07	0.31	93%	43	0.03	0.08	1.41	81%
Barium (mg/L)	1†	45	0.004	0.006	0.012	0%	14	0.002	0.003	0.007	0%	37	0.003	0.005	0.011	0%
Dissolved Iron (mg/L)	0.3^	45	<0.05	0.05	0.37	2%	14	<0.05	0.05	0.2	0%	37	<0.05	0.21	3.42	43%
Total Iron (mg/L)	0.3^	51	<0.05	0.08	3.54	16%	14	<0.05	0.05	0.3	0%	43	0.07	0.53	3.09	60%
Dissolved Manganese (mg/L)	1.9†	45	0.002	0.012	0.087	0%	14	0.003	0.007	0.027	0%	37	0.011	0.044	0.267	0%
Total Manganese (mg/L)	1.9†	51	0.00	0.02	0.51	0%	14	0.00	0.01	0.03	0%	43	0.01	0.05	0.29	0%
Nickel (mg/L)	0.011†	51	<0.001	0.001	0.002	0%	14	<0.001	0.001	0.001	0%	43	<0.001	0.001	0.003	0%
Silicon (mg/L)		51	0.3	0.6	2.6		14	1.6	1.9	2.4		43	0.8	2.2	3.0	
Strontium (mg/L)		45	0.004	0.01	0.013		14	<0.001	0.002	0.009		37	0.002	0.006	0.017	
Zinc (mg/L)	0.008†	51	<0.005	0.005	0.018	4%	14	<0.005	0.005	0.009	7%	43	<0.005	0.005	0.091	19%

†ANZG (2018) default guideline value for aquatic ecosystems (95% level of species protection for slightly to moderately disturbed ecosystems) – the default guideline value relates to the total concentration of a constituent although should also be compared with the dissolved concentration which represents the bioavailable fraction; ^ NHMRC (2022) water quality guideline value for aesthetic purposes.

Lake Avon Catchment Water Quality Summary – LA13A_S1, LA17_Pool 0 and LA8_Rockbar 1

Parameter (mg/L unless otherwise stated)	Guideline Value	LA13A_S1					LA17_Pool 0					LA8_Rockbar 1				
		No. Samples	Min	Median	Max	% Exceedance	No. Samples	Min	Median	Max	% Exceedance	No. Samples	Min	Median	Max	% Exceedance
pH - Field (pH Units)	6.5-8‡	35	5.07	5.62	6.5	100%	33	4.64	5.19	6.5	97%	26	4.78	5.17	7.1	96%
pH (pH Units)	6.5-8‡	34	4.87	5.9	7.7	97%	31	4.66	5.5	6.8	97%	26	4.93	5.7	6.5	96%
Dissolved Oxygen - Field (%)	90-110‡	35	15	61	93	97%	33	26	79	90	100%	26	16	82	105	81%
Electrical Conductivity - Field (µS/cm)	350‡	35	87	148	223	0%	33	86	158	252	0%	26	80	129	146	0%
Electrical Conductivity @ 25°C (µS/cm)	350‡	34	83	152	222	0%	31	82	153	225	0%	26	70	118	171	0%
Total Alkalinity as $CaCO_3$ (mg/L)		34	<1	2	15		31	<1	1	6		26	<1	2	5	
Dissolved Organic Carbon (mg/L)		34	1	3	50		31	1	5	190		26	2	4	85	
Suspended Solids (mg/L)		27	5	5	137		31	5	5	47		26	5	5	37	
Sulfate as SO_4 (mg/L)	400†	0	-	-	-		0	-	-	-		0	-	-	-	
Nitrite + Nitrate (mg/L)		34	0.01	0.01	0.3		31	0.01	0.01	0.2		26	0.01	0.01	0.6	
Nitrate (mg/L)	50*	2	0.01	-	0.02	0%	2	0.03	-	0.12	0%	1	0.03	-	0.03	0%
Nitrite (mg/L)	3*	2	0.01	-	0.01	0%	2	0.01	-	0.01	0%	1	0.01	-	0.01	0%
Total Kjeldahl Nitrogen (mg/L)		34	0.1	0.1	1.2		31	0.1	0.1	0.7		26	0.1	0.1	0.7	
Total Nitrogen (mg/L)	0.25‡	2	0.1	-	0.1	0%	2	0.1	-	0.2	0%	1	0.1	-	0.1	0%
Total Phosphorus (mg/L)	0.02‡	34	0.01	0.01	0.1	15%	31	0.01	0.01	0.05	13%	26	0.01	0.01	0.11	15%
Reactive Phosphorus (mg/L)		7	0.01	0.01	0.01		0	-	-	-		0	-	-	-	

†ANZG (2018) default guideline value for aquatic ecosystems (95% level of species protection for slightly to moderately disturbed ecosystems) – the default guideline value relates to the total concentration of a constituent although should also be compared with the dissolved concentration which represents the bioavailable fraction; ‡ ANZECC (2000) default guideline value for Upland Rivers in NSW; * NHMRC (2022) water quality guideline value for health purposes.

Lake Avon Catchment Water Quality Summary – LA13A_S1, LA17_Pool 0 and LA8_Rockbar 1

Parameter (mg/L unless otherwise stated)	Guideline Value	LA13A_S1					LA17_Pool 0					LA8_Rockbar 1				
		No. Samples	Min	Median	Max	% Exceedance	No. Samples	Min	Median	Max	% Exceedance	No. Samples	Min	Median	Max	% Exceedance
Calcium (mg/L)		34	<1	1	2		31	<1	1	1		26	<1	1	1	
Magnesium (mg/L)		34	2	3	5		31	<1	3	6		26	<1	3	4	
Potassium (mg/L)		34	<1	1	3		31	<1	1	2		26	<1	1	1	
Sodium (mg/L)	180^	34	12	21.5	28	0%	31	11	21	33	0%	26	11	16	20	0%
Chloride (mg/L)	250^	34	20	38.5	65	0%	31	20	40	64	0%	26	19	33.5	42	0%
Ammonia (mg/L)	0.5^	34	0.01	0.01	0.02	0%	31	0.01	0.01	0.02	0%	26	0.01	0.01	0.19	0%
Dissolved Aluminium (mg/L)	0.055†	30	<0.01	0.035	0.44	30%	31	0.08	0.12	0.34	100%	25	0.05	0.12	0.28	96%
Total Aluminium (mg/L)	0.055†	34	0.03	0.055	0.42	50%	31	0.1	0.16	0.73	100%	26	0.08	0.18	5.76	100%
Barium (mg/L)	1†	30	0.007	0.012	0.019	0%	31	0.002	0.007	0.015	0%	25	0.003	0.008	0.013	0%
Dissolved Iron (mg/L)	0.3^	30	0.1	0.28	4.38	47%	31	<0.05	0.12	1.61	26%	25	<0.05	0.1	1.13	20%
Total Iron (mg/L)	0.3^	34	0.12	0.555	4.06	71%	31	0.07	0.24	3.52	39%	26	<0.05	0.25	7.16	42%
Dissolved Manganese (mg/L)	1.9†	30	0.011	0.049	0.614	0%	31	0.008	0.044	0.185	0%	25	0.007	0.097	0.421	0%
Total Manganese (mg/L)	1.9†	34	0.01	0.05	0.59	0%	31	0.01	0.05	0.32	0%	26	0.01	0.10	2.25	4%
Nickel (mg/L)	0.011†	34	<0.001	0.001	0.004	0%	31	<0.001	0.001	0.002	0%	26	<0.001	0.0015	0.005	0%
Silicon (mg/L)		34	1.6	2.3	7.3		31	0.8	2.7	3.6		26	0.2	2.0	3.0	
Strontium (mg/L)		30	0.004	0.008	0.026		31	<0.001	0.006	0.018		25	0.003	0.007	0.012	
Zinc (mg/L)	0.008†	34	<0.005	0.008	0.09	44%	31	<0.005	0.008	0.143	35%	26	<0.005	0.016	0.035	58%

†ANZG (2018) default guideline value for aquatic ecosystems (95% level of species protection for slightly to moderately disturbed ecosystems) – the default guideline value relates to the total concentration of a constituent although should also be compared with the dissolved concentration which represents the bioavailable fraction; ^ NHMRC (2022) water quality guideline value for aesthetic purposes.

Avon River Catchment Water Quality Summary – AR_S1, AR_S2 and AR19_S1

Parameter (mg/L unless otherwise stated)	Guideline Value	AR_S1					AR_S2					AR19_S1				
		No. Samples	Min	Median	Max	% Exceedance	No. Samples	Min	Median	Max	% Exceedance	No. Samples	Min	Median	Max	% Exceedance
pH - Field (pH Units)	6.5-8‡	2	6.7	-	6.9	0%	49	5.7	6.4	7.2	69%	49	4.8	5.6	6.3	100%
pH (pH Units)	6.5-8‡	49	5.1	6.8	7.5	24%	47	5.2	6.6	7.1	43%	48	5.1	5.8	6.6	96%
Dissolved Oxygen - Field (%)	90-110‡	51	62	85	106	63%	49	30	82	106	78%	48	13	61	123	92%
Electrical Conductivity - Field (µS/cm)	350‡	51	54	72	109	0%	49	55	74	98	0%	49	112	203	285	0%
Electrical Conductivity @ 25°C (µS/cm)	350‡	49	56	74	96	0%	47	55	76	99	0%	48	122	202	267	0%
Total Alkalinity as $CaCO_3$ (mg/L)		49	3	8	19		47	3	7	13		48	<1	2	7	
Dissolved Organic Carbon (mg/L)		49	2	4	34		47	2	4	81		48	1	5	73	
Suspended Solids (mg/L)		33	5	5	13		31	5	5	12		31	5	5	126	
Sulfate as SO_4 (mg/L)	400†	2	2	-	6	0%	2	2	-	3	0%	2	<1	-	1	0%
Nitrite + Nitrate (mg/L)		49	0.01	0.04	1.5		47	0.01	0.04	0.3		48	0.01	0.01	0.5	
Nitrate (mg/L)	50*	4	0.03	-	0.09	0%	3	0.04	-	0.09	0%	3	0.02	-	0.09	0%
Nitrite (mg/L)	3*	4	0.01	-	0.01	0%	3	0.01	-	0.01	0%	3	0.01	-	0.01	0%
Total Kjeldahl Nitrogen (mg/L)		49	0.1	0.1	0.6		47	0.1	0.1	0.6		48	0.1	0.1	1.8	
Total Nitrogen (mg/L)	0.25‡	5	0.1	0.2	0.6	20%	0	-	-	-	-	0	-	-	-	-
Total Phosphorus (mg/L)	0.02‡	49	0.01	0.01	0.06	4%	0	-	-	-	-	0	-	-	-	-
Reactive Phosphorus (mg/L)		16	0.01	0.01	0.03		16	0.01	0.01	0.02		17	0.01	0.01	0.01	

†ANZG (2018) default guideline value for aquatic ecosystems (95% level of species protection for slightly to moderately disturbed ecosystems) – the default guideline value relates to the total concentration of a constituent although should also be compared with the dissolved concentration which represents the bioavailable fraction; ‡ ANZECC (2000) default guideline value for Upland Rivers in NSW; * NHMRC (2022) water quality guideline value for health purposes.

Avon River Catchment Water Quality Summary - AR_S1, AR_S2 and AR19_S1

Parameter (mg/L unless otherwise stated)	Guideline Value	AR_S1					AR_S2					AR19_S1				
		No. Samples	Min	Median	Max	% Exceedance	No. Samples	Min	Median	Max	% Exceedance	No. Samples	Min	Median	Max	% Exceedance
Calcium (mg/L)		49	<1	1	3		47	<1	2	3		48	<1	1	1	
Magnesium (mg/L)		49	<1	2	2		47	<1	2	2		48	2	4	7	
Potassium (mg/L)		49	<1	1	1		47	<1	1	1		48	<1	1	4	
Sodium (mg/L)	180^	49	7	9	13	0%	47	7	9	13	0%	48	14	27	41	0%
Chloride (mg/L)	250^	49	10	15	22	0%	47	9	16	23	0%	48	20	53	80	0%
Ammonia (mg/L)	0.5^	49	0.01	0.02	0.12	0%	47	0.01	0.01	0.14	0%	48	0.01	0.01	1.1	2%
Dissolved Aluminium (mg/L)	0.055†	42	<0.01	0.01	0.07	5%	40	<0.01	0.01	0.07	8%	41	0.02	0.04	0.17	22%
Total Aluminium (mg/L)	0.055†	49	<0.01	0.02	0.13	10%	47	<0.01	0.02	0.15	13%	48	0.02	0.06	0.32	56%
Barium (mg/L)	1†	42	0.006	0.008	0.014	0%	40	0.006	0.008	0.012	0%	41	0.01	0.016	0.03	0%
Dissolved Iron (mg/L)	0.3^	42	<0.05	0.18	0.54	17%	40	<0.05	0.18	0.48	15%	41	<0.05	0.3	3.0	51%
Total Iron (mg/L)	0.3^	49	0.11	0.38	1.13	67%	47	0.1	0.42	0.96	66%	48	<0.05	0.5	5.7	52%
Dissolved Manganese (mg/L)	1.9†	42	0.008	0.05	0.3	0%	40	0.007	0.04	0.18	0%	41	0.008	0.15	0.49	0%
Total Manganese (mg/L)	1.9†	49	0.01	0.06	0.48	0%	47	0.01	0.05	0.29	0%	48	0.01	0.12	0.5	0%
Nickel (mg/L)	0.011†	49	<0.001	0.001	0.001	0%	47	<0.001	0.001	0.005	0%	48	<0.001	0.002	0.004	0%
Silicon (mg/L)		49	0.5	0.9	1.6		47	0.5	0.9	1.6		48	0.3	2.3	3.1	
Strontium (mg/L)		42	0.007	0.012	0.02		40	0.009	0.012	0.019		41	0.006	0.011	0.022	
Zinc (mg/L)	0.008†	49	<0.005	0.005	0.02	10%	47	<0.005	0.005	0.019	13%	48	<0.005	0.014	0.04	79%

†ANZG (2018) default guideline value for aquatic ecosystems (95% level of species protection for slightly to moderately disturbed ecosystems) – the default guideline value relates to the total concentration of a constituent although should also be compared with the dissolved concentration which represents the bioavailable fraction; ^ NHMRC (2022) water quality guideline value for aesthetic purposes.

Avon River Catchment Water Quality Summary – AR31_Rockbar 1 and AR32_Pool 9

Parameter (mg/L unless otherwise stated)	Guideline Value	AR31_Rockbar 1					AR32_Pool 9				
		No. Samples	Min	Median	Max	% Exceedance	No. Samples	Min	Median	Max	% Exceedance
pH - Field (pH Units)	6.5-8‡	51	5.0	5.8	7.2	92%	14	5.2	5.7	6.0	100%
pH (pH Units)	6.5-8‡	50	4.9	5.8	6.6	94%	17	5.2	5.8	6.2	100%
Dissolved Oxygen - Field (%)	90-110‡	51	53	88	103	63%	14	47	77	94	86%
Electrical Conductivity - Field (µS/cm)	350‡	51	80	182	257	0%	14	98	177	222	0%
Electrical Conductivity @ 25°C (µS/cm)	350‡	50	74	191	253	0%	17	111	203	266	0%
Total Alkalinity as $CaCO_3$ (mg/L)		50	<1	1.5	11		17	<1	1	6	
Dissolved Organic Carbon (mg/L)		50	1	2.5	20		17	1	3	174	
Suspended Solids (mg/L)		34	5	5	64		5	5	5	12	
Sulfate as SO_4 (mg/L)	400†	2	2	-	2	0%	2	<1	-	1	0%
Nitrite + Nitrate (mg/L)		50	0.01	0.01	1		17	0.01	0.02	0.1	
Nitrate (mg/L)	50*	4	0.01	-	0.08	0%	2	0.06	-	0.07	0%
Nitrite (mg/L)	3*	4	0.01	-	0.01	0%	2	0.01	-	0.01	0%
Total Kjeldahl Nitrogen (mg/L)		50	0.1	0.1	0.2		17	0.1	0.1	1	
Total Nitrogen (mg/L)	0.25‡	5	0.1	0.1	0.3	20%	2	0.1	-	0.3	50%
Total Phosphorus (mg/L)	0.02‡	50	0.01	0.01	0.18	4%	17	0.01	0.01	0.03	6%
Reactive Phosphorus (mg/L)		16	0.01	0.01	0.01		13	0.01	0.01	0.03	

†ANZG (2018) default guideline value for aquatic ecosystems (95% level of species protection for slightly to moderately disturbed ecosystems) – the default guideline value relates to the total concentration of a constituent although should also be compared with the dissolved concentration which represents the bioavailable fraction; ‡ ANZECC (2000) default guideline value for Upland Rivers in NSW; * NHMRC (2022) water quality guideline value for health purposes.

Avon River Catchment Water Quality Summary – AR31_Rockbar 1 and AR32_Pool 9

Parameter (mg/L unless otherwise stated)	Guideline Value	AR31_Rockbar 1					AR32_Pool 9				
		No. Samples	Min	Median	Max	% Exceedance	No. Samples	Min	Median	Max	% Exceedance
Calcium (mg/L)		50	<1	1	5		17	<1	1	1	
Magnesium (mg/L)		50	<1	4	6		17	2	5	7	
Potassium (mg/L)		50	<1	1	1		17	<1	1	2	
Sodium (mg/L)	180^	50	12	25	35	0%	17	14	25	32	0%
Chloride (mg/L)	250^	50	20	46.5	69	0%	17	31	49	64	0%
Ammonia (mg/L)	0.5^	50	0.01	0.01	0.05	0%	17	0.01	0.01	0.99	6%
Dissolved Aluminium (mg/L)	0.055†	43	<0.01	0.04	0.2	42%	11	<0.01	0.03	0.05	0%
Total Aluminium (mg/L)	0.055†	50	0.03	0.075	0.9	78%	17	0.02	0.04	0.12	29%
Barium (mg/L)	1†	43	0.005	0.021	0.03	0%	11	0.013	0.016	0.02	0%
Dissolved Iron (mg/L)	0.3^	43	<0.05	0.3	2.47	47%	11	<0.05	0.14	0.48	18%
Total Iron (mg/L)	0.3^	50	0.08	1.275	5.91	72%	17	<0.05	0.24	1.14	35%
Dissolved Manganese (mg/L)	1.9†	43	0.011	0.25	0.66	0%	11	0.02	0.08	0.35	0%
Total Manganese (mg/L)	1.9†	50	0.01	0.24	0.78	0%	17	0.02	0.06	0.41	0%
Nickel (mg/L)	0.011†	50	<0.001	0.003	0.007	0%	17	<0.001	0.001	0.002	0%
Silicon (mg/L)		50	0.3	2.8	4.1		17	1.2	2.4	2.7	
Strontium (mg/L)		43	0.003	0.011	0.016		11	0.01	0.012	0.016	
Zinc (mg/L)	0.008†	50	<0.005	0.016	0.042	70%	17	<0.005	0.006	0.021	29%

†ANZG (2018) default guideline value for aquatic ecosystems (95% level of species protection for slightly to moderately disturbed ecosystems) – the default guideline value relates to the total concentration of a constituent although should also be compared with the dissolved concentration which represents the bioavailable fraction; ^ NHMRC (2022) water quality guideline value for aesthetic purposes.

Donalds Castle Creek Catchment Water Quality Summary – DC8_S1, DC10_S2 and DCL3

Parameter (mg/L unless otherwise stated)	Guideline Value	DC8_S1					DC10_S1					DCL3				
		No. Samples	Min	Median	Max	% Exceedance	No. Samples	Min	Median	Max	% Exceedance	No. Samples	Min	Median	Max	% Exceedance
pH - Field (pH Units)	6.5-8‡	56	4.9	5.52	7.8	96%	51	5.23	5.74	7.7	98%	71	5.03	5.86	6.7	94%
pH (pH Units)	6.5-8‡	54	4.8	5.6	7.4	89%	50	4.86	5.8	7.4	88%	219	4.46	6.0	7.9	94%
Dissolved Oxygen - Field (%)	90-110‡	55	40	89	106	55%	50	27	75	103	84%	71	17	79	108	75%
Electrical Conductivity - Field (µS/cm)	350‡	56	93	177.5	327	0%	51	77	149	230	0%	72	86	133.5	190	0%
Electrical Conductivity @ 25°C (µS/cm)	350‡	54	81	187	349	0%	50	74	153	221	0%	219	86	140	225	0%
Total Alkalinity as $CaCO_3$ (mg/L)		54	<1	<1	8		0	-	-	-		0	-	-	-	
Dissolved Organic Carbon (mg/L)		54	1	4	188		50	1	2	17		218	0.5	3	220	
Suspended Solids (mg/L)		36	5	5	25		34	5	5	24		52	5	5	47	
Sulfate as SO_4 (mg/L)	400†	2	3	-	4	0%	2	<1	-	3	0%	23	<1	2	4	0%
Nitrite + Nitrate (mg/L)		54	0.01	0.01	0.5		50	0.01	0.01	0.3		181	<0.005	0.01	0.4	
Nitrate (mg/L)	50*	4	0.01	-	0.06	0%	2	0.01	-	0.03	0%	26	0.01	0.015	0.37	0%
Nitrite (mg/L)	3*	4	0.01	-	0.01	0%	2	0.01	-	0.01	0%	26	0.01	0.01	0.01	0%
Total Kjeldahl Nitrogen (mg/L)		54	0.1	0.2	2.6		50	0.1	0.1	0.3		183	<0.005	0.1	2.8	
Total Nitrogen (mg/L)	0.25‡	4	0.2	-	0.4	50%	0	-	-	-		0	-	-	-	
Total Phosphorus (mg/L)	0.02‡	54	0.01	0.01	0.06	9%	0	-	-	-		0	-	-	-	
Reactive Phosphorus (mg/L)		17	0.01	0.01	0.01		16	0.01	0.01	0.01		120	<0.001	0.005	0.017	

†ANZG (2018) default guideline value for aquatic ecosystems (95% level of species protection for slightly to moderately disturbed ecosystems) – the default guideline value relates to the total concentration of a constituent although should also be compared with the dissolved concentration which represents the bioavailable fraction; ‡ ANZECC (2000) default guideline value for Upland Rivers in NSW; * NHMRC (2022) water quality guideline value for health purposes.

Donalds Castle Creek Catchment Water Quality Summary - DC8_S1, DC10_S2 and DCL3

Parameter (mg/L unless otherwise stated)	Guideline Value	DC8_S1					DC10_S1					DCL3				
		No. Samples	Min	Median	Max	% Exceedance	No. Samples	Min	Median	Max	% Exceedance	No. Samples	Min	Median	Max	% Exceedance
Calcium (mg/L)		54	<1	1	2		50	<1	1	2		182	<0.5	0.5	5	
Magnesium (mg/L)		54	2	4	8		50	<1	3	7		182	<0.5	3	6	
Potassium (mg/L)		54	<1	1	5		50	<1	1	2		182	<0.5	1	3	
Sodium (mg/L)	180^	54	14	24	43	0%	50	13	20.5	33	0%	182	12	18	27	0%
Chloride (mg/L)	250^	54	22	50	85	0%	50	13	39	63	0%	182	21	36	59	0%
Ammonia (mg/L)	0.5^	54	0.01	0.01	0.09	0%	50	0.01	0.01	0.04	0%	183	<0.005	0.01	0.28	0%
Dissolved Aluminium (mg/L)	0.055†	47	0.03	0.06	0.2	60%	43	<0.01	0.02	0.07	9%	203	<0.01	0.04	0.18	30%
Total Aluminium (mg/L)	0.055†	54	0.04	0.085	1.89	80%	50	<0.01	0.04	0.21	30%	218	<0.01	0.06	0.71	61%
Barium (mg/L)	1†	47	0.005	0.012	0.024	0%	43	0.003	0.011	0.018	0%	63	<0.001	0.008	0.014	0%
Dissolved Iron (mg/L)	0.3^	47	<0.05	0.08	1.02	6%	43	<0.05	0.26	3.22	40%	203	<0.02	0.24	3.29	40%
Total Iron (mg/L)	0.3^	54	<0.05	0.18	8.65	22%	50	<0.05	0.5	7.27	76%	218	0.07	0.46	4.7	70%
Dissolved Manganese (mg/L)	1.9†	47	0.015	0.056	1.11	0%	43	0.006	0.058	0.571	0%	203	0.01	0.036	0.601	0%
Total Manganese (mg/L)	1.9†	54	0.02	0.07	1.90	0%	50	0.01	0.06	0.62	0%	218	<0.001	0.04	0.95	0%
Nickel (mg/L)	0.011†	54	<0.001	0.002	0.008	0%	50	<0.001	0.001	0.003	0%	219	<0.001	0.001	0.008	0%
Silicon (mg/L)		54	1.3	2.6	3.6		50	1.6	2.8	3.4		149	0.1	2.2	4.9	
Strontium (mg/L)		47	0.004	0.01	0.026		43	0.002	0.007	0.025		63	0.002	0.008	0.013	
Zinc (mg/L)	0.008†	54	<0.005	0.012	0.081	83%	50	<0.005	0.007	0.016	22%	219	<0.005	0.005	0.345	10%

†ANZG (2018) default guideline value for aquatic ecosystems (95% level of species protection for slightly to moderately disturbed ecosystems) – the default guideline value relates to the total concentration of a constituent although should also be compared with the dissolved concentration which represents the bioavailable fraction; ^ NHMRC (2022) water quality guideline value for aesthetic purposes.

APPENDIX B – SWAMP MONITORING PLOTS

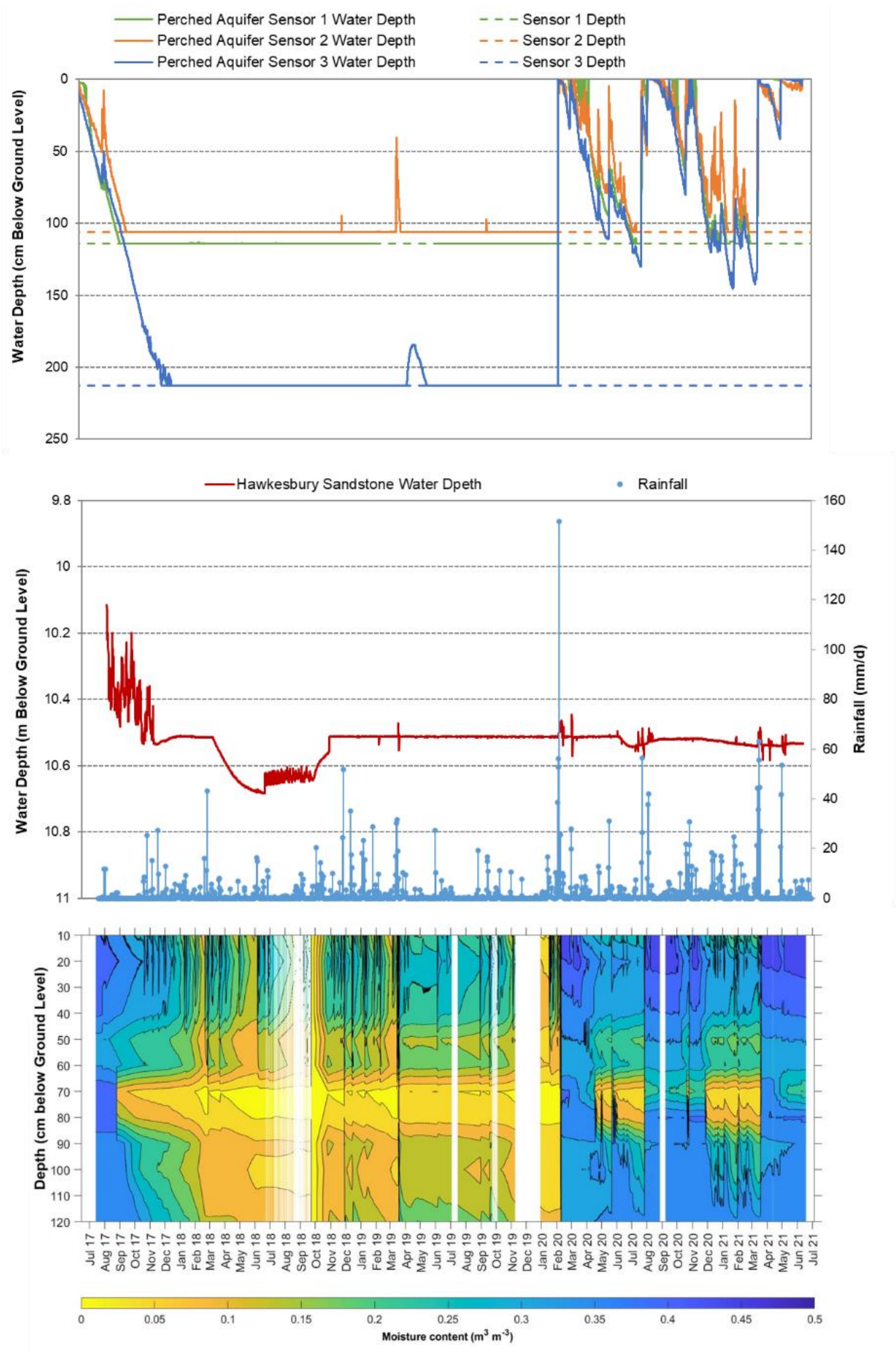

Chart A1 Den 85 - Shallow Groundwater Level and Moisture Content[10]

[10] Blank (white) patches in moisture content plots indicate periods of no data or data errors.

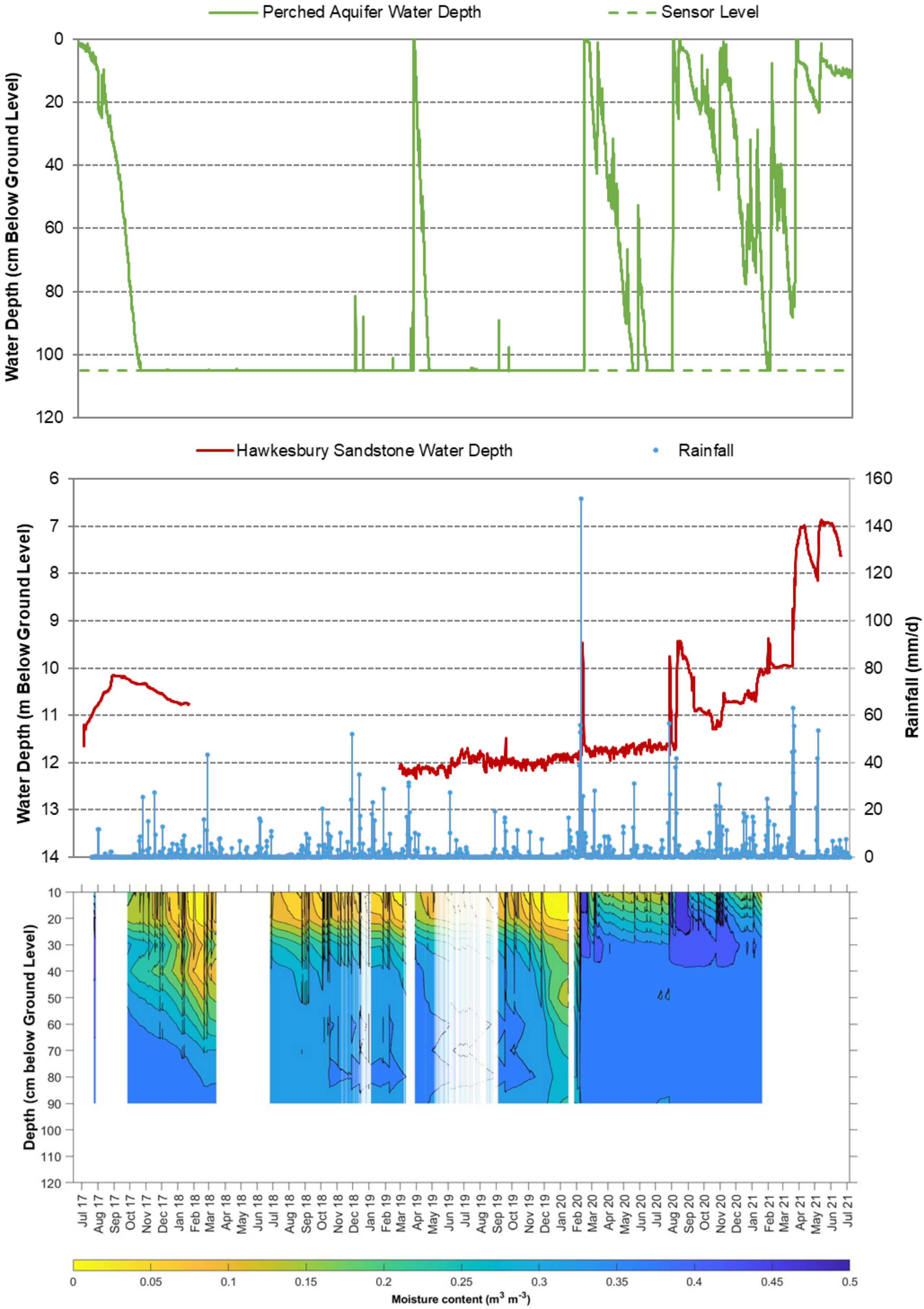

Chart A2 Den 97 - Shallow Groundwater Level and Moisture Content

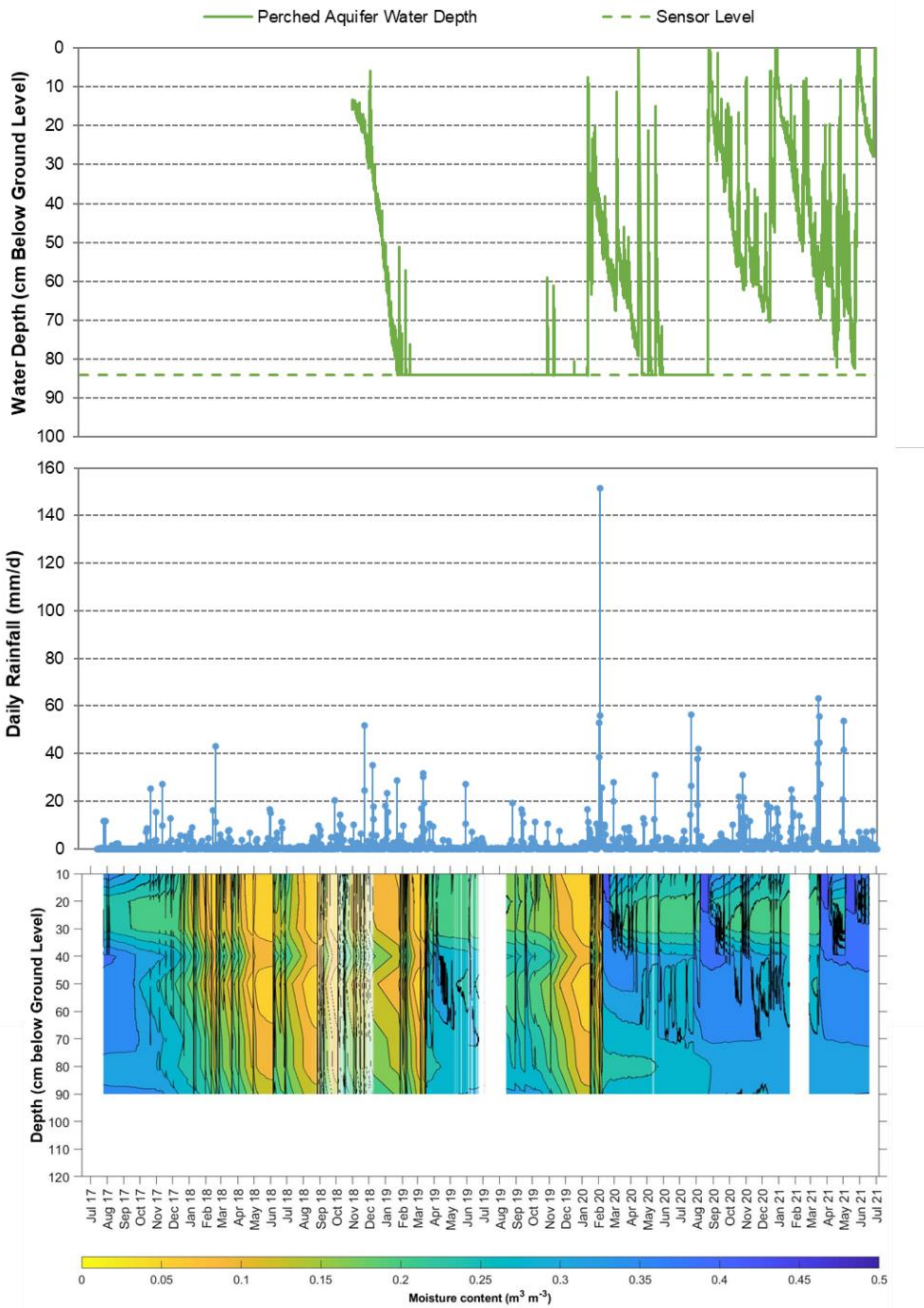

Chart A3 **Den 98 - Shallow Groundwater Level and Moisture Content**

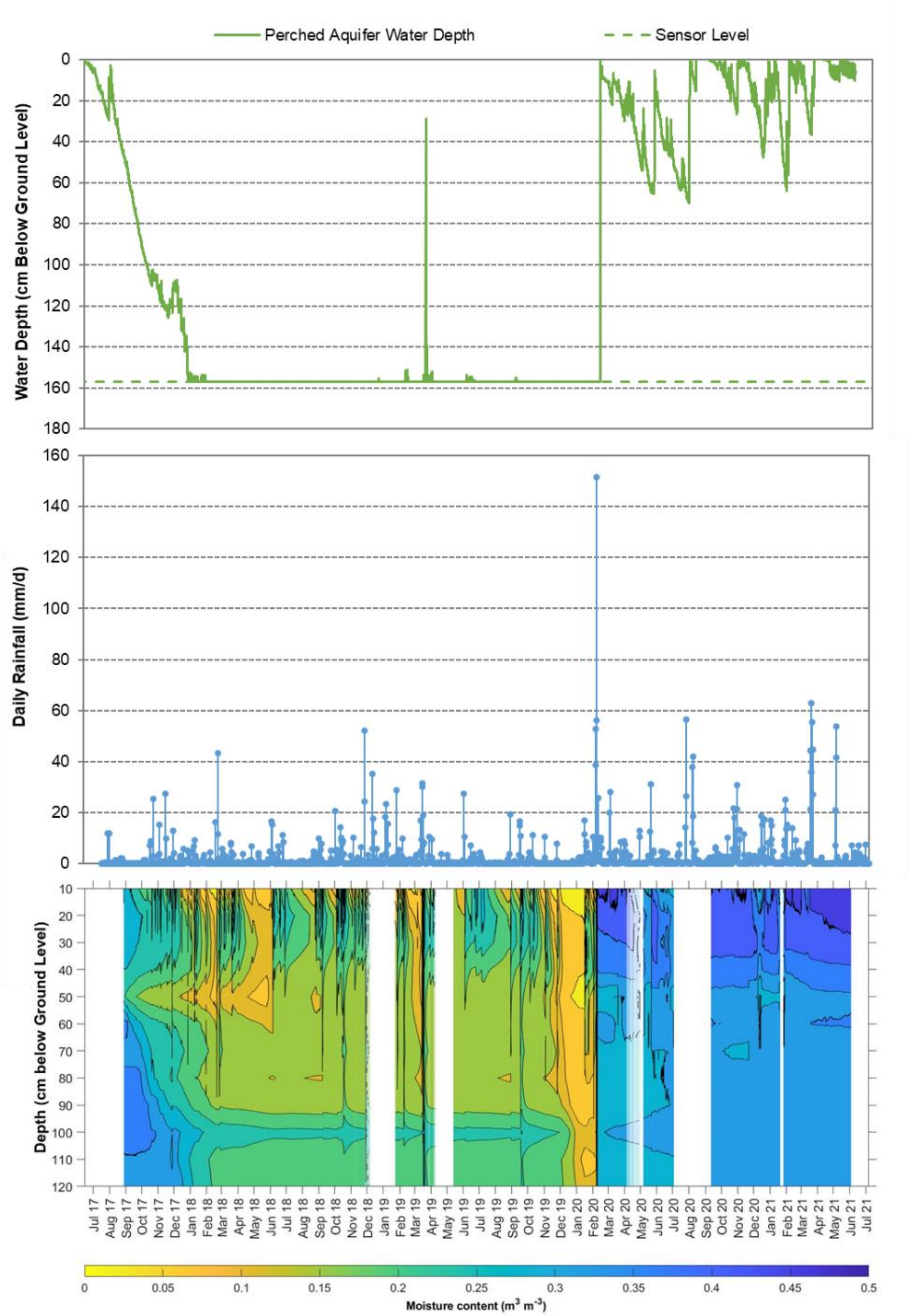

Chart A4 **Den 99 - Shallow Groundwater Level and Moisture Content**

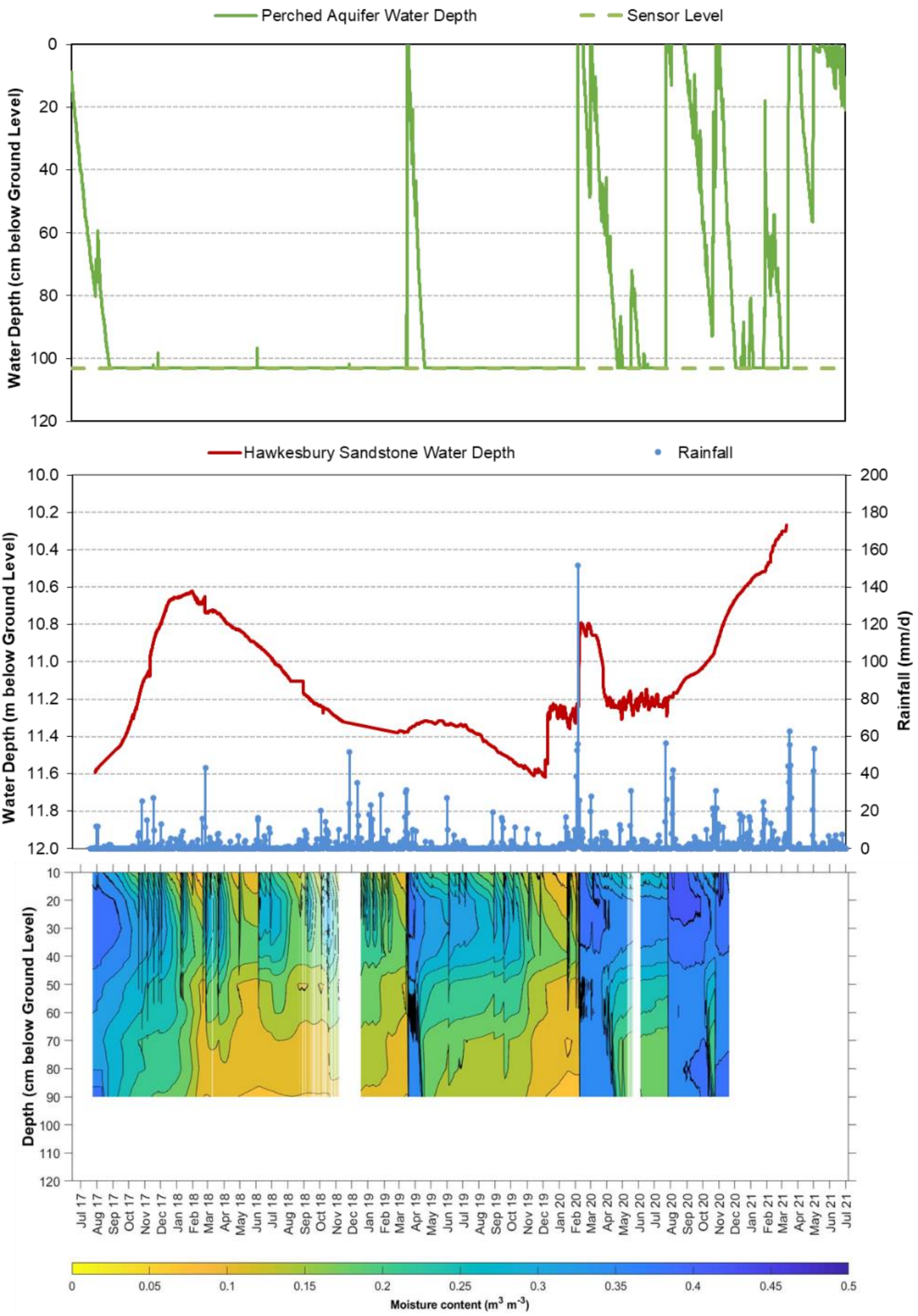

Chart A5 Den 100 - Shallow Groundwater Level and Moisture Content

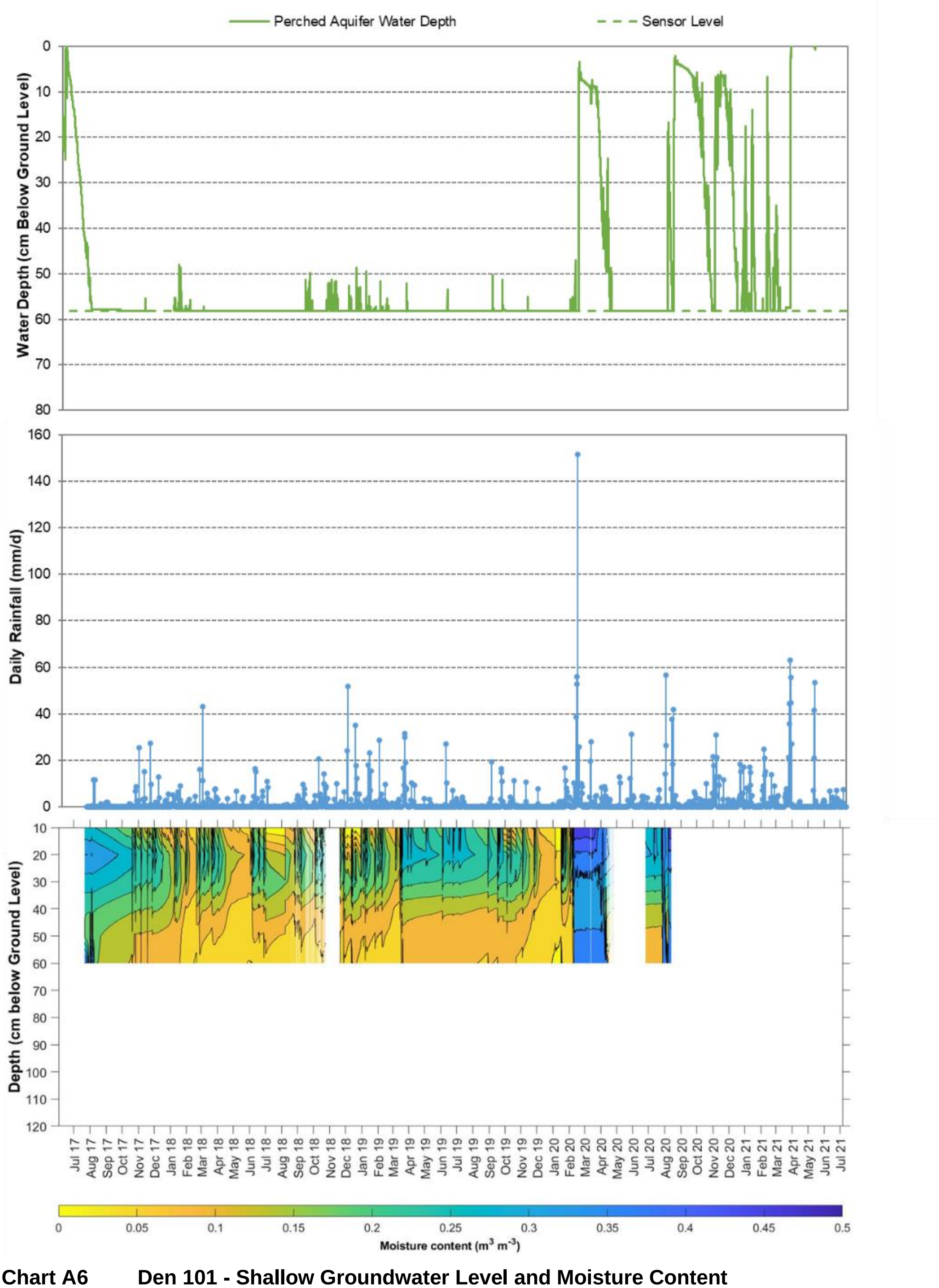

Chart A6 Den 101 - Shallow Groundwater Level and Moisture Content

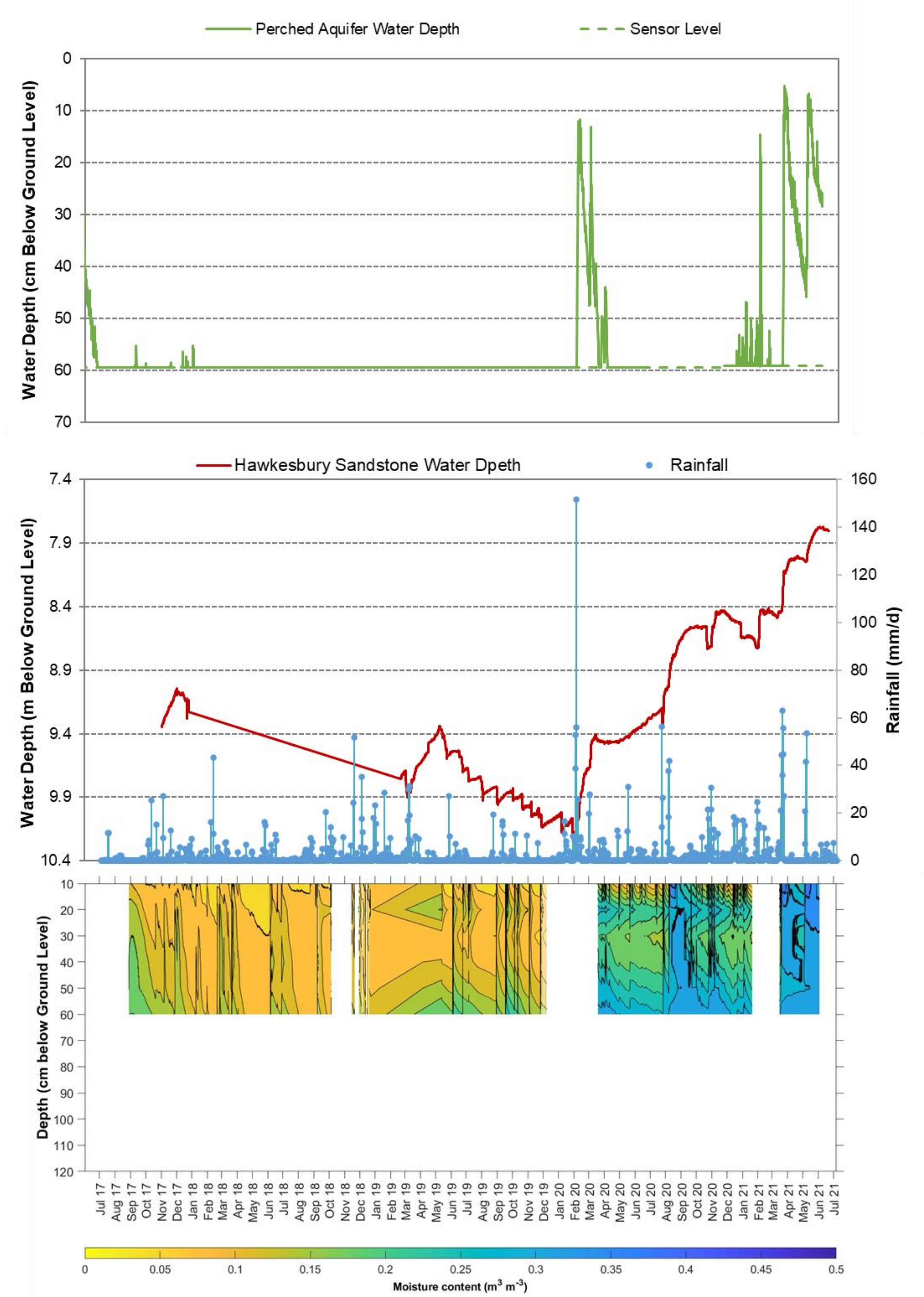

Chart A7 Den 103 - Shallow Groundwater Level and Moisture Content

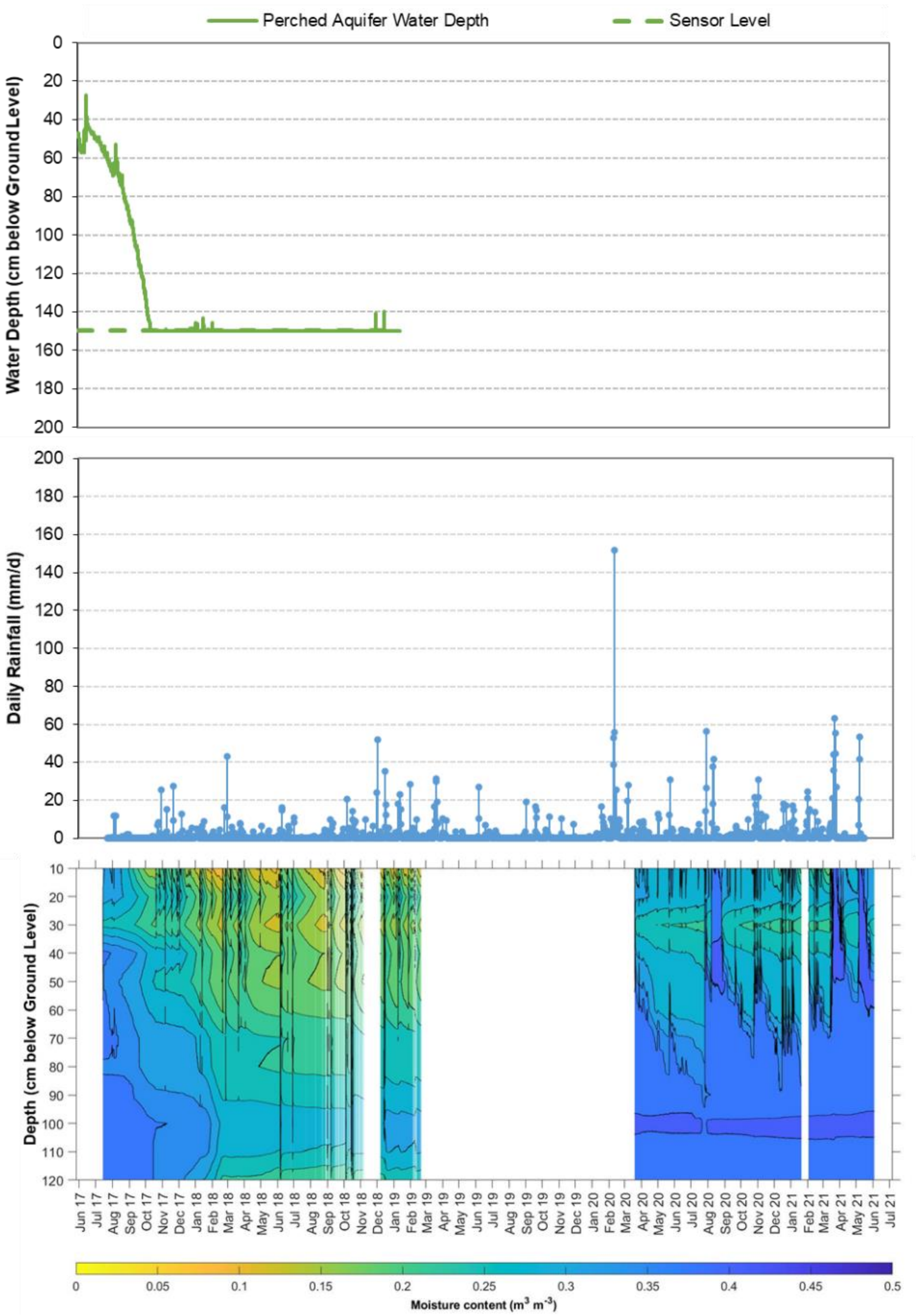

Chart A8 **Den 106 - Shallow Groundwater Level and Moisture Content**

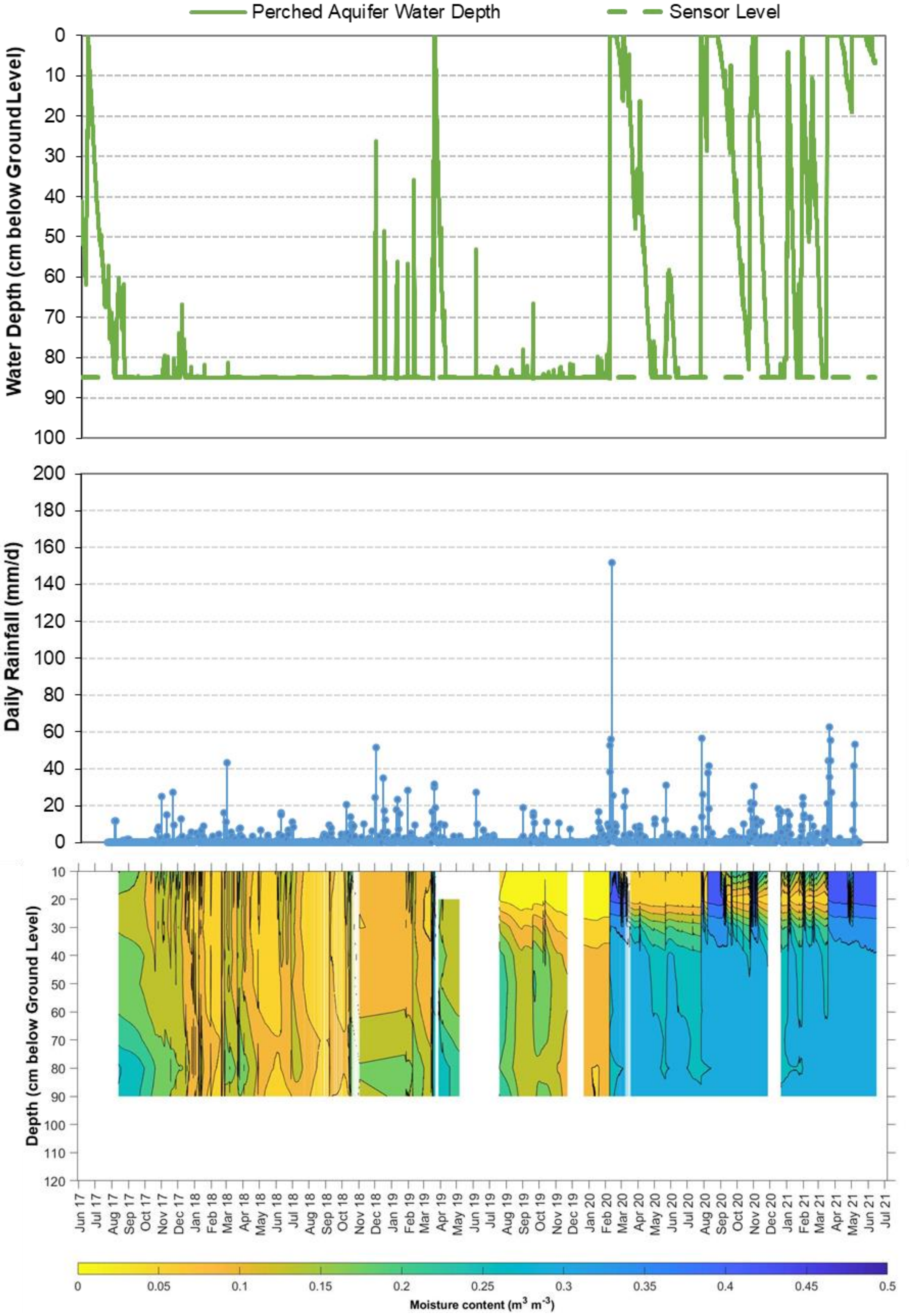

Chart A9 Den 107 - Shallow Groundwater Level and Moisture Content

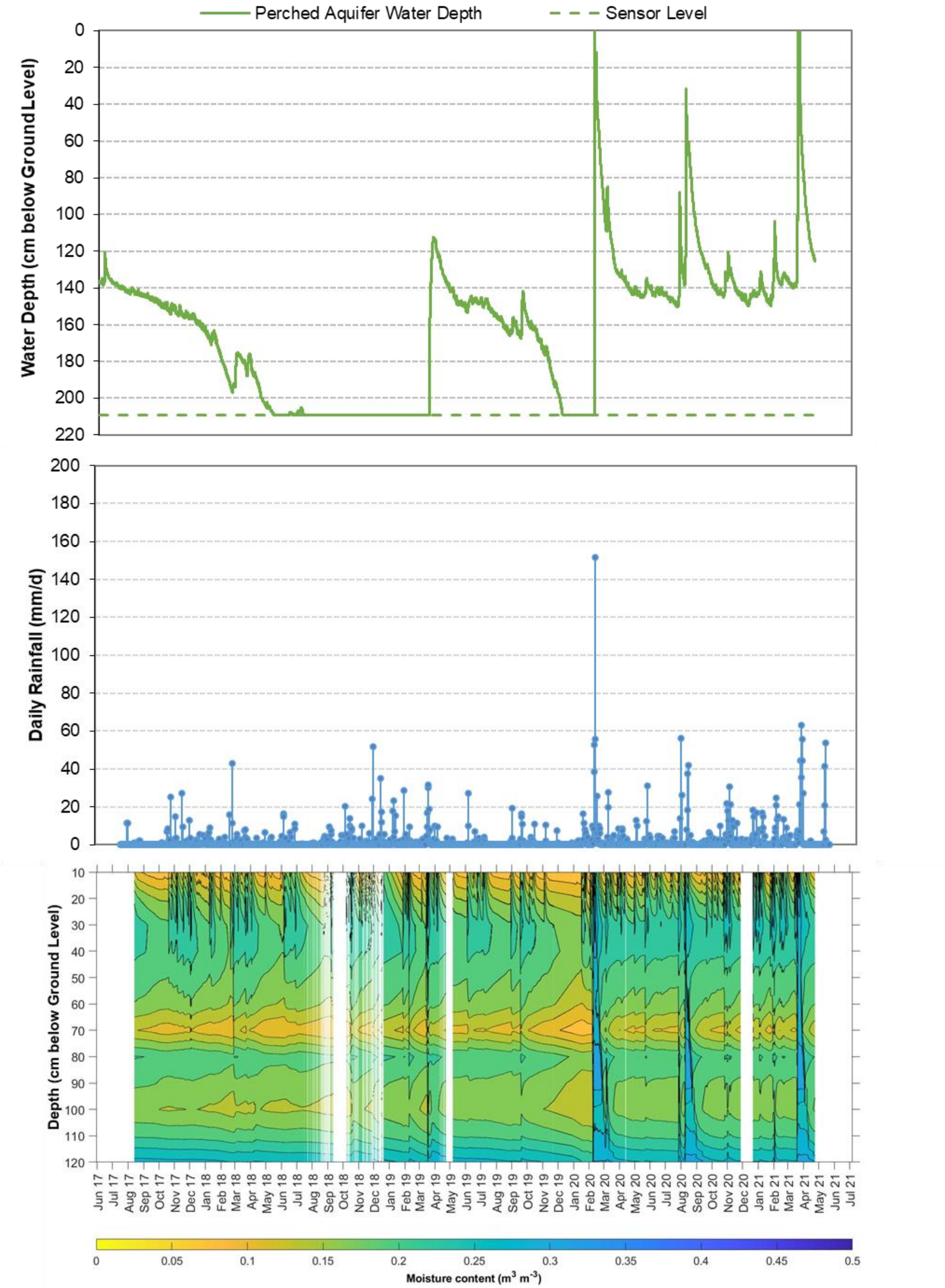

Chart A10 Den 108 - Shallow Groundwater Level and Moisture Content

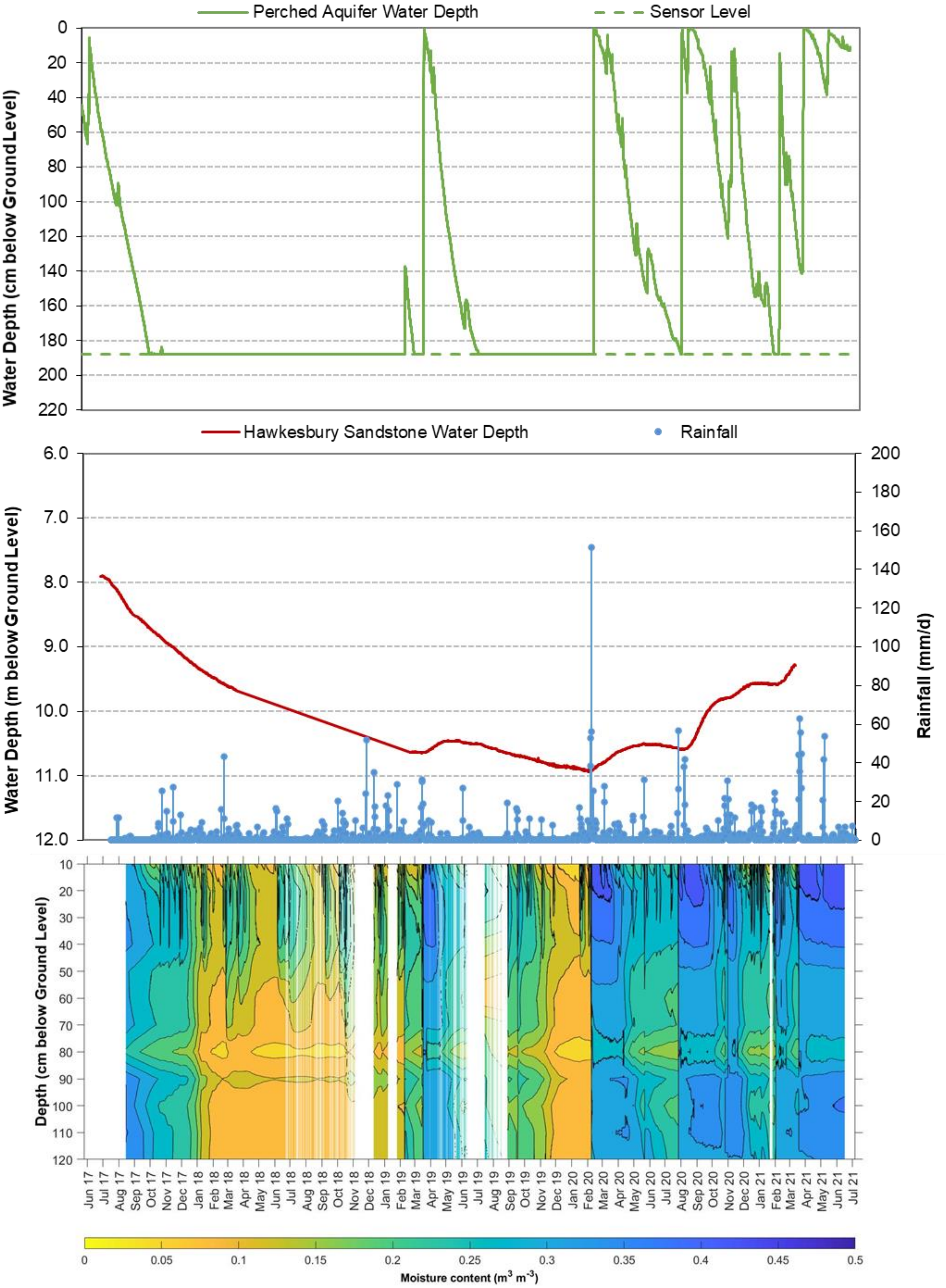

Chart A11 Den 109 - Shallow Groundwater Level and Moisture Content

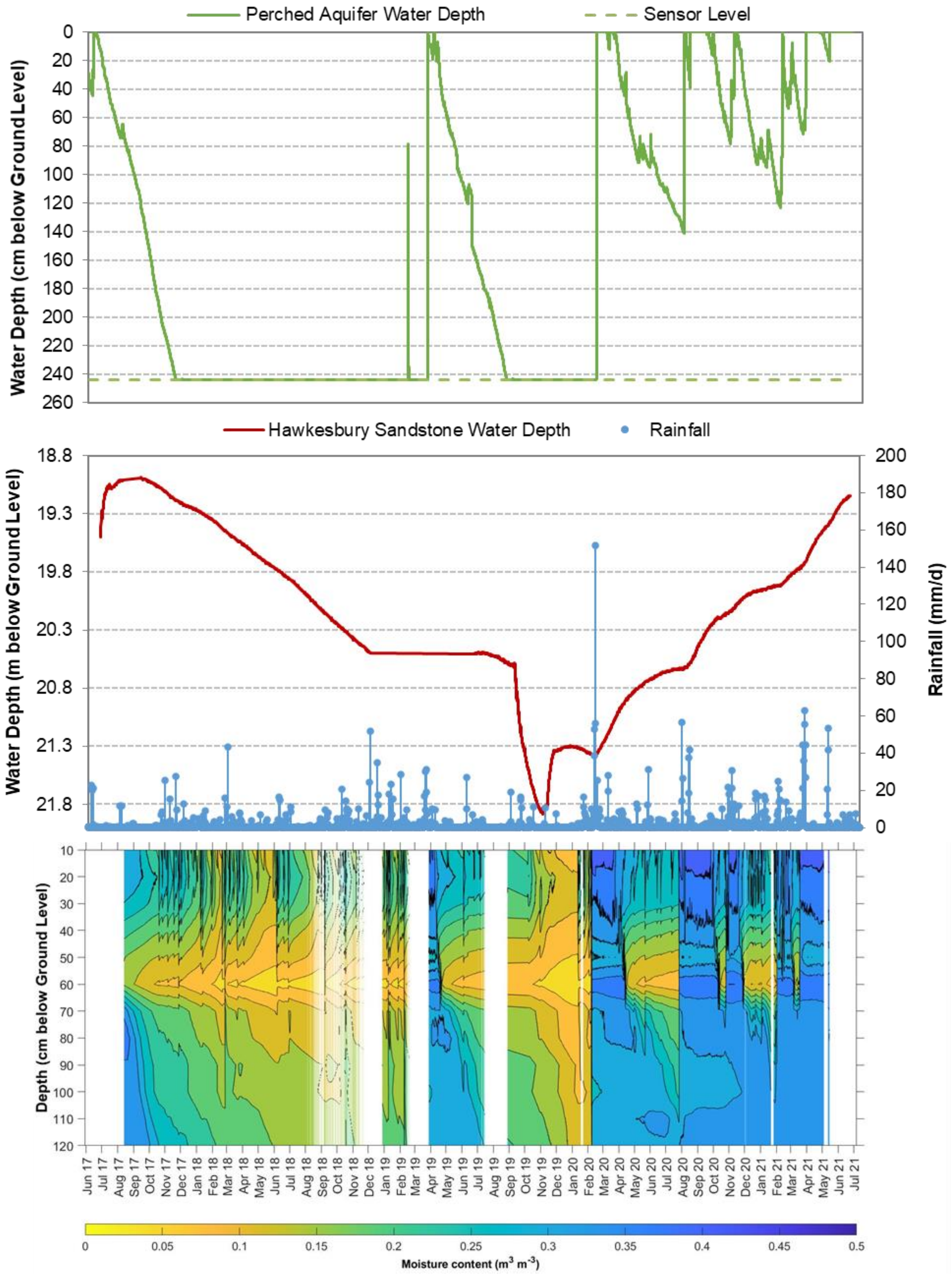

Chart A12 Den 110 - Shallow Groundwater Level and Moisture Content

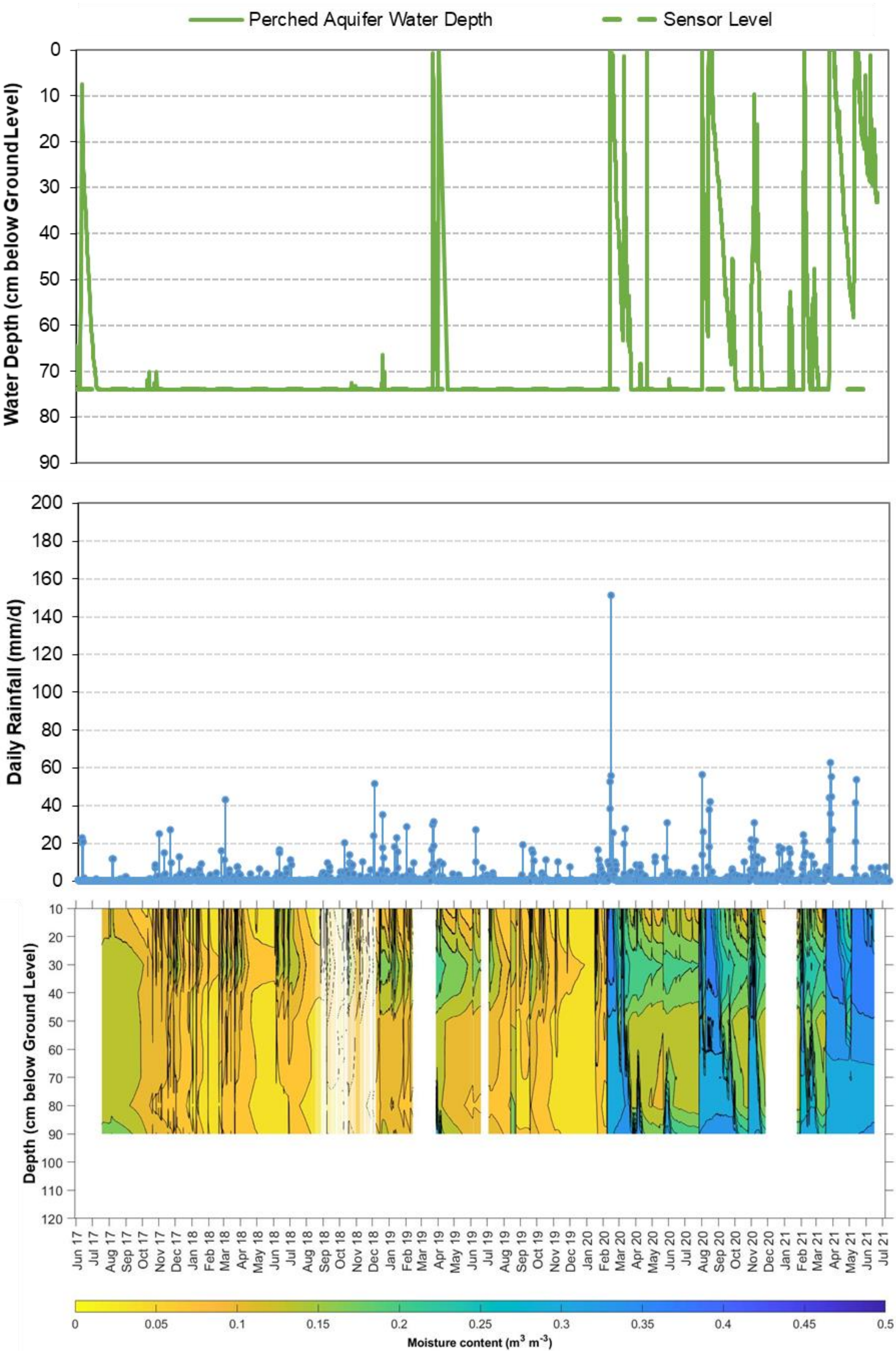

Chart A13 Den 114 - Shallow Groundwater Level and Moisture Content