APPENDIX E

Aquatic Ecology Assessment

Dendrobium Mine Extension Project - Aquatic Ecology Assessment

Dendrobium Mine Extension Project

NE30130 R002

Prepared for
Illawarra Metallurgical Coal

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Cardno®

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Executive Summary

INTRODUCTION AND SCOPE

The Dendrobium Mine is an existing underground coal mine situated in the Southern Coalfield of New South Wales (NSW), approximately 8 kilometres (km) west of Wollongong. Illawarra Coal Holdings Pty Ltd (Illawarra Metallurgical Coal [IMC]), a wholly owned subsidiary of South32 Limited (South32), is the owner and operator of the Dendrobium Mine. The Dendrobium Mine includes five approved underground mining areas, 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. IMC is seeking 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 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.

Cardno (NSW/ACT) Pty Ltd (Cardno) has been engaged by IMC to undertake the aquatic ecology studies for the Project. The work undertaken by Cardno includes baseline survey and preparation of an Aquatic Ecology Assessment (AEA), which will assess potential impacts on aquatic ecology due to potential mining-related subsidence. The AEA (this report) provides:

> Assessment of the potential impacts of the Project on aquatic ecology, threatened species and stygofauna, including consideration of advice from groundwater, surface water and other specialists and associated assessments;

> A review of previous monitoring data and description of the previous observed impacts on aquatic ecology from the existing operations (both surface operations, e.g. pit top facilities, and underground mining) to indicate the cumulative impact of the Project with other major projects; and

> Recommendations on measures to avoid, mitigate and/or minimise potential impacts on aquatic ecology.

The AEA was based on the predicted physical impacts of mining due to ground movements (including subsidence, upsidence and valley closure) associated with extraction of the proposed longwalls in Area 5. The extraction of these proposed longwalls may result in fracturing of overlying bedrock and diversion of surface water in watercourses and swamps into underlying strata. Fracturing of bedrock will also reduce groundwater levels within the mining area, resulting in a reduced groundwater contribution to baseflow. These impacts are likely to result in reduction/alterations of aquatic habitat, changed water quality and impacted aquatic biota.

EXISTING ENVIRONMENT

The findings of the desktop assessment and baseline field studies are summarised as follows:

> Aquatic habitat within 600 metres (m) of the proposed longwalls (the Study Area) includes a portion of Lake Avon and several ephemeral/intermittent drainage lines (draining upland swamps) traversing the Study Area, and hereafter referred to as drainage lines. These drainage lines are tributaries of Lake Avon, Avon River and Donalds Castle Creek, though these main watercourses are located outside the Study Area. Although flow may cease in drainage lines soon after rainfall, several contain semi-permanent pools that provide aquatic habitat during periods of low rainfall. No mining works have previously been undertaken in these areas and they are largely undisturbed. Riparian habitat is in good condition and no invasive species have been identified. Water quality measures sampled in the current study are comparable with those measured previously and there is no indication of any water pollution.

> Overall, the AUSRIVAS macroinvertebrate assemblages sampled in the current study are comparable with those sampled from across the Dendrobium Mine area during previous studies by Cardno. While AUSRIVAS results suggest somewhat impaired macroinvertebrate assemblages (i.e. contain fewer taxa than expected based on the physical and chemical characteristics of the watercourse), there is no evidence this is related to any anthropogenic disturbance. Rather, this appears a natural occurrence reflective of naturally low values of pH and possibly also dissolved metals associated with local geology.

> The most substantial fish habitat in the Study Area is provided by Avon River and Lake Avon. Several species of native fish have been identified in these waterbodies previously and they are mapped as Key Fish Habitat (KFH) and include Type 1 - Highly sensitive KFH (aquatic vegetation and larger rocks and wood debris). Type 2 - Moderately sensitive KFH occurs in third order reaches of drainage lines. The drainage lines directly above the proposed longwalls are all first and second order streams, do not contain KFH and consist largely of disconnected pools, sometimes separated by waterfalls that represent substantial natural barriers to fish passage. Nevertheless, these watercourses would provide habitat for some native species, including species of native (but not threatened) fish, and together provide a substantial proportion of habitat for fish, and other aquatic species, across the Study Area.

> Macquarie Perch, listed as an Endangered fish under the *Fisheries Management Act 1994* (the FM Act) and the *Environment Protection and Biodiversity Conservation Act 1999* (the EPBC Act), has been recorded previously in Avon River and has potential to occur in Lake Avon. Donalds Castle Creek does not provide suitable habitat for Macquarie Perch and based on its habitat requirements and the presence of natural barriers to passage, this species is considered very unlikely to occur here and in drainage lines directly above the proposed longwalls. Based on previous records and known distributions, Sydney Hawk Dragonfly and Adam’s Emerald Dragonfly, both listed as Endangered under the FM Act, are very unlikely to occur in the Study Area. Similarly, Australian Grayling, listed as Vulnerable under the EPBC Act and protected under the FM Act, does not occur in the Study Area.

> Previous stygofauna studies undertaken approximately 10 km south of the Study Area indicate that stygofauna may occur in perched swamp aquifers (i.e. reliant on recharge from rainfall and disconnected from underlying aquifers) such as those within Area 5. Groundwater quality (primarily electrical conductivity and pH) measured in aquifers in the Study Area does not preclude the presence of stygofauna, though the shallow perched swamp and Hawkesbury sandstone aquifers appear to provide more suitable habitat than those associated with Bulgo sandstone and coal measures.

SUBSIDENCE PREDICTIONS AND ASSESSMENT OF IMPACTS TO AQUATIC ECOLOGY

Subsidence predictions for Area 5 indicate that Lake Avon, Avon River, Cordeaux River and Donalds Castle Creek are not expected to experience measurable conventional subsidence effects and are unlikely to experience adverse physical impacts (i.e. fracturing or mining-induced surface water diversions). There would also be negligible changes to surface flow and water quality in these watercourses. Thus, impacts to aquatic ecology in Lake Avon, Avon River, Cordeaux River and Donalds Castle Creek are not expected to occur.

Subsidence induced fracturing and flow diversion is expected to occur in first and second order drainage lines directly above the proposed longwalls and in first, second and third order watercourses located up to 400 m from the longwalls. Fracturing would also occur in bedrock underlying swamps resulting in reductions in shallow groundwater levels, levels of soil moisture and changes in extent and composition of swamp vegetation communities. These are expected to impact aquatic ecology as follows:

> Fracturing and flow diversions in first, second and third order drainage lines are expected to result in localised (i.e. within 400 m of proposed longwalls in Area 5) reductions in aquatic habitat and loss of some biota. This could result in the loss of semi-permanent pool habitat and likely also associated biota (primarily aquatic macroinvertebrates and potentially some non-threatened native fish). However, based on experience of previous mining at Dendrobium Mine, such impacts would be localised and relatively minor compared to the extensive aquatic habitat in the broader region. The cumulative impact to the upper Avon River and Cordeaux River catchments due to loss of such habitat should, however, be considered. No significant reductions in catchment yield and no more than minor, localised and short-term impacts to water quality are predicted. Thus, impacts to downstream aquatic ecology due to reduced water availability are not expected nor are any more than localised and minor impacts to aquatic ecology due to the minor changes in water quality.

> Significant impacts to threatened Macquarie Perch, Sydney Hawk Dragonfly and Adam’s Emerald Dragonfly are not expected as they are very unlikely to occur in drainage lines that traverse the Study Area.

> The loss of perched swamp aquifers and disturbance to the shallow Hawkesbury sandstone aquifer due to mining induced subsidence is likely also to impact stygofauna expected to be present in the Study Area. The severity of impacts to stygofauna in perched swamp aquifers would depend on the severity and extent of impacts to groundwater levels and levels of moisture. Based on experience of previous mining at Dendrobium Mine, it could be expected that there would be a reduction in the extent and population size of stygofauna in the Study Area due to longwall extraction. It is, however, possible that at least some swamps impacted by mining may still retain some groundwater and moisture and support stygofauna (albeit potentially with reduced abundance/diversity).

CONCLUSION

Implementation of the aquatic ecology monitoring recommended in this AEA would assist in determining the magnitude and extent of impacts to aquatic ecology associated with extraction of the proposed longwalls. The detection of physical impacts in third order drainage lines or significant changes in water quality within such areas, should trigger further investigation into potential impacts on aquatic ecology. The implementation of such management measures would help reduce potential impacts on aquatic ecology.

As no impacts to threatened aquatic ecology listed under the FM Act and EPBC Act are predicted, no associated biodiversity offsets would be required. The requirement and form of any offsets associated with potential impacts to a relatively small proportion of KFH in third order watercourses would be identified following the completion of any stream remediation activities, if required.

Table of Contents

Appendices

Tables

Figures

1 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.

Illawarra Coal Holdings Pty Ltd (Illawarra Metallurgical Coal [IMC]), a wholly owned subsidiary of South32 Limited (South32), is the owner and operator of the Dendrobium Mine. The Dendrobium Mine, 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.

IMC is seeking 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 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 Dendrobium Mine has an approved operational capacity of up to 5.2 million tonnes per annum (Mtpa) of ROM coal until 31 December 2030.

IMC have engaged Cardno (NSW/ACT) Pty. Ltd. (Cardno) to undertake the Aquatic Ecology Assessment (AEA) for the Project. Over the last 15 years, Cardno has undertaken numerous studies, including impact assessments, baseline surveys, threatened species assessments and designed and implemented monitoring programs aimed at detecting potential impacts on aquatic ecology for the Dendrobium Mine. The primary potential impact to aquatic ecology represented by the Project is the potential for subsidence and fracturing of the ground above the underground mining area, including at the surface in overlying watercourses, resulting in reduced groundwater levels, diversion of flows, reduction in pool water levels and potential impacts to aquatic habitat and biota. The AEA ensures that potential impacts to aquatic ecology due to the Project are identified, considered and adequately assessed during the environmental impact assessment process.

1.2 Scope of Works

The AEA is based on findings of 2017 baseline field surveys of aquatic habitat, flora and fauna, including macroinvertebrates, fish, plants and threatened species in, and adjacent to, Area 5 and on substantial previous work undertaken by Cardno as part of the previous work at the Dendrobium Mine. The AEA includes:

> Review and synthesis of existing information on aquatic habitat, flora and fauna, including stygofauna, within, and adjacent to, Area 5, and the broader Dendrobium Mine Area and the Cordeaux River and Avon River catchments. Existing information includes previous investigations for Area 1, Area 2 and Area 3, which began in 2001, online literature searches and other available records of aquatic flora and fauna.

> Review of relevant legislation, policies and guidelines pertaining to aquatic ecology and the effects of longwall mining;

> Consideration of Secretary’s Environmental Assessment Requirements (SEARs) relating to aquatic ecology;

[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).

> A review of previous monitoring data and description of the previous observed impacts on aquatic ecology from the existing operations (both surface operations, e.g. pit top facilities, and underground mining);
> Assessment of the potential impacts of the Project on aquatic ecology and stygofauna, including consideration of advice from groundwater, surface water and other specialists and associated assessments;
> Assessment of the cumulative impacts of the Project with other major projects at a local and regional scale;
> Assessments of Significance for listed threatened aquatic species, populations and/or communities under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) and the *Fisheries Management Act 1994* (FM Act); and
> Recommendations for monitoring and management measures to avoid, mitigate and/or minimise potential impacts on aquatic ecology.

1.3 Project Overview

The Project proposes the extraction of additional coal within CCL 768. This would be supported by the development of supporting infrastructure and the use and augmentation of existing Dendrobium Mine surface facilities.

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 Dendrobium Mine 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 (no change from the approved Dendrobium Mine).
> Extension of underground mining operations within Area 5 until approximately 31 December 2034.
> Use of the existing Dendrobium Pit Top, Kemira Valley Coal Loading Facility, Dendrobium Coal Processing Plant (CPP) and Dendrobium Shafts with minor upgrades and extensions until approximately 2041.
> Transport of ROM coal from the Kemira Valley Coal Loading Facility to the Dendrobium CPP via the Kemira Valley Rail Line.
> Handling and processing of coal from the Dendrobium Mine (including the Project) and IMC’s Appin Mine (if required) at 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 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 Area.
> Development and rehabilitation of the West Cliff Stage 3 Coal Wash Emplacement Area (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 in accordance with the conditions of Environmental Protection Licence 3241 and/or beneficial use.

> Monitoring, rehabilitation and remediation of subsidence and other mining effects.

> Other associated infrastructure, plant, equipment and activities.

One of the ventilation shaft construction water supply options for the Project involves extraction from Cordeaux River, near Ryan's Crossing. If this option was implemented, a proposed temporary pumping station would extract up to 44 megalitres of raw water (in total) from the Cordeaux River for temporary water supply for Shaft Site 5A during September 2023 to August 2024. Two pumps would be mounted on floats in the Cordeaux River crossing which would be temporary and removed following the completion of construction of the ventilation shaft site.

1.4 Secretary's Environmental Assessment Requirements

Following submission of the Scoping Report for the Project (IMC 2021), SEARs were issued by the Department of Planning, Industry and Environment (DPIE) (now the Department of Planning and Environment [DPE]) on 17 December 2021. Those directly applicable to aquatic ecology are provided in **Table 1-1**.

Table 1-1 Project Secretary's Environmental Assessment Requirements Relevant to Aquatic Ecology

Source	Assessment Requirements	Section
Department of Planning and Environment	Assessment of environmental impacts to include:	
	▪ A description of the existing environment likely to be affected by the development, using sufficient baseline data;	**Section 3**
	▪ An assessment of the likely impacts of all stages of the development, including appropriate worst-case scenarios and consideration of any cumulative impacts, taking into consideration any relevant legislation, environmental planning instruments, guidelines, policies, plans and industry codes of practice; and	**Section 4**
	▪ An assessment of the likely biodiversity impacts of the development, including Key Fish Habitat.	**Section 4**
	▪ Impacts to natural processes and functions within rivers, wetlands, estuaries and floodplains that affect river system and landscape health such as nutrient flow, aquatic connectivity and access to habitat for spawning and refuge (e.g. river benches).	**Section 4**
NSW Department of Primary Industries (DPI)	The EIS should include the following:	
	▪ Identification of KFHs within the proposal area;	**Section 3.4**
	▪ Description of aquatic and riparian environments in the vicinity of the development, particularly extent and condition of riparian vegetation and instream aquatic vegetation, water depth, and permanence of water flow and snags (large woody debris) within the footprint of the proposal area; and	**Section 3.3**
	▪ Assessment of impacts on watercourses, riparian land, wetlands, aquatic habitat, threatened aquatic species and Groundwater Dependent Ecosystems (GDEs)[1], and measures proposed to reduce and mitigate these impacts.	**Sections 4** and **5**
NSW Office of Environment and Heritage (OEH)	Full justification for impacts upon 3rd order or above streams, including reasons for the damage, alternatives considered, suggested remediation and offsets for any such damage.	**Section 5**
	The EIS must map the following features relevant to water and soils including: ▪ Rivers, streams, wetlands, estuaries (as described in Appendix 2 of the Framework for Biodiversity Assessment (OEH 2014)); and ▪ GDEs[1].	**Sections 3**
	The EIS must assess the impact of the development on hydrology, including:	
	▪ Effects to downstream rivers, wetlands, estuaries, marine waters and floodplain areas;	**Section 4.2**
	▪ Effects to downstream water-dependent fauna and flora including GDEs[1]; and	**Section 4.2.4**
	▪ Impacts to natural processes and functions within rivers, wetlands, estuaries and floodplains that affect river system and landscape health such as nutrient flow, aquatic connectivity and access to habitat for spawning and refuge (e.g. river benches).	**Section 4.2**

Source	Assessment Requirements	Section
WaterNSW	The full description of the development and existing environment should include those aspects which have the potential to impact on the biodiversity at and adjacent to the site. This includes the location, mapping and geomorphology of Avon and Cordeaux Rivers and their tributaries, rockbars, water pools, waterfalls, cliffs, swamps overlying and adjacent to the proposed mining areas.	**Sections 3** and **4***

*Detailed mapping of Avon River and Cordeaux River and their tributaries / streams, rockbars, water pools, waterfalls, cliffs, swamps / wetlands overlying and adjacent to the proposed mining areas has been undertaken by IMC as part of ongoing monitoring and assessment.

1 Note surface GDE's have been assessed within the Biodiversity Development Assessment Report (Appendix D of the Project EIS) (Niche Environment and Heritage [Niche] 2022). This AEA includes assessment of stygofauna (a subterranean GDE).

2 Legislation, Guidelines and Policy

2.1 Commonwealth Environment Protection and Biodiversity Conservation Act 1999

The EPBC Act is the Australian Government's key instrument of environmental legislation, focusing on Matters of National Environmental Significance (MNES), with States and Territories having responsibility for matters of state and local significance. The EPBC Act provides a legal framework for the protection and management of nationally and internationally important flora, fauna, ecological communities and heritage places. It also includes provisions for nationally threatened species of plants, fish, birds, frogs, reptiles, mammals and other animals. These conservation assets are referred to collectively as MNES or "protected matters". The Department of Agriculture, Water and the Environment (DAWE) is also responsible for the development and implementation of recovery plans for threatened fauna, threatened flora (other than conservation dependent species) and threatened ecological communities listed under the EPBC Act.

Under the EPBC Act, an action will require approval from the Minister if the action has, will have, or is likely to have, a significant impact on MNES. Significant Impact Criteria have been developed to assist proponents in deciding if a referral to the DAWE should be submitted (Department of the Environment 2013). The referral process involves a decision on whether or not the action is a 'controlled action'. When an action is declared a controlled action, approval from the Minister for the Environment is required.

2.2 New South Wales

2.2.1 Environmental Planning and Assessment Act 1979

The EP&A Act institutes a system of environmental planning and assessment in NSW and is administered by the DPE. Part 5 of the EP&A Act sets out the approvals process for State Significant Infrastructure (SSI).

Part 5 of the EP&A Act indicates some of the authorisations required under other acts are not required for SSI. These include provisions under the FM Act with respect to permits for dredging and reclamation work, harm to aquatic vegetation and blockage of fish passage. Controlled activity approvals issued under section 91 of the *Water Management Act 2000* (that confers a right on its holder to carry out a specified controlled activity at a specified location in, on or under waterfront land), are also not required.

Section 1.7 of the EP&A Act outlines the provisions of Part 7 of the *Biodiversity Conservation Act, 2016* (BC Act) and Part 7A of the FM Act that relate to terrestrial and aquatic environment are subject to the EP&A Act.

2.2.2 Fisheries Management Act 1994

The FM Act contains provisions for the conservation of fish stocks, Key Fish Habitat (KFH), biodiversity, threatened species, populations and ecological communities. It regulates the conservation of fish, vegetation and some aquatic macroinvertebrates and the development and sharing of the fishery resources of NSW.

The FM Act lists threatened species, populations and ecological communities under Schedules 4, 4A and 5. Schedule 6 lists key threatening processes (KTPs) for species, populations and ecological communities in NSW waters and declared critical habitats are listed in a register kept by the Minister of Primary Industries. Impacts to these species, population, communities, processes and habitats due to the proposal need to be considered and assessed as part of the impact assessment. Section 220ZZ of FM Act outlines significant impact considerations for threatened species, populations and ecological communities listed under the FM Act. Guidelines for the 7-part test are outlined in the *Threatened Species Assessment Guidelines: The Assessment of Significance* (NSW DPI 2008). The Assessment of Significance guidelines specify the important factors that must be taken into considered when assessing potential impacts on threatened species, populations, or ecological communities. The factors requiring consideration are:

> How is the proposal likely to affect the lifecycle of a threatened species and/or population?

> How is the proposal likely to affect the extent and composition of a threatened ecological community?

> How is the proposal likely to affect the habitat of a threatened species, population or ecological community?

> Will the proposal affect any critical habitat?

> Is the proposal consistent with the objectives or actions of a recovery plan or threat abatement plan?

> Is the proposal part of a Key Threatening Process or is it likely to exacerbate a Key Threatening Process?

If the Assessment of Significance indicates a significant impact may occur, further assessment via a Species Impact Statement (SIS) may be recommended.

Another objective of the FM Act is to conserve KFH. KFH is defined in sections 3.2.1 and 3.2.2 of the *Policy and Guidelines for Fish Conservation and Management* (NSW DPI 2013a). These are defined as aquatic habitats that are important to the sustainability of recreational and commercial fishing industries, the maintenance of fish populations generally and the survival and recovery of threatened aquatic species. In freshwater systems, most permanent and semi-permanent rivers, creeks, lakes, lagoons, billabongs, weir impoundments and impoundments up to the top of the bank are considered KFH. Small headwater creeks and gullies that flow for a short period after rain and farm dams on such systems are excluded, as are artificial water bodies except for those that support populations of threatened fish or invertebrates. At a broad scale, KFH relevant to the proposal includes the following:

> Permanently flowing rivers and creeks including those where the flow is modified by upstream dam(s), up to the top of the natural bank regardless of whether or not the channel has been physically modified;

> Intermittently flowing rivers and creeks that retain water in a series of disconnected pools after flow ceases including those where the flow is modified by upstream dam(s), up to the top of the natural bank regardless of whether or not the channel has been physically modified; and

> Any waterbody if it is known to support or could be confidently expected (based on predictive modelling) to support threatened species, populations or communities listed under the FM Act.

2.2.3 Biodiversity Conservation Act 2016

The BC Act contains provisions for the conservation of some aquatic species and communities except for those listed under the FM Act (i.e. fish, crayfish and all other aquatic animals, but not freshwater vegetation). Impacts to species listed under the BC Act are assessed using the Test of Significance, also known as the 5-Part Test (DPIE 2018).

2.2.4 NSW DPI (Fisheries) Policy and Guidelines for Fish Habitat Conservation and Management

The *Policy and Guidelines for Fish Habitat Conservation and Management (Update 2013)* (NSW DPI 2013a) replaces the *Policy and Guidelines for Aquatic Habitat Management and Fish Conservation* (NSW DPI 1999) and the former *Fisheries NSW Policy and Guidelines for Fish Friendly Waterway Crossings* (Fairfull and Witheridge 2003). These updated policies and guidelines are applicable to all planning and development proposals and various activities that affect freshwater, estuarine and marine ecosystems. The aims of the updated policies and guidelines are to maintain and enhance fish habitat for the benefit of native fish species, including threatened species, in marine, estuarine and freshwater environments. The updated document assists developers, their consultants and government and non-government organisations to ensure their actions comply with legislation, policies and guidelines that relate to fish habitat conservation and management. It is also intended to inform land use and natural resource management planning, development planning and assessment processes, and to improve awareness and understanding of the importance of fish habitats and how impacts can be mitigated, managed or offset. The policies and guidelines outlined in this document are considered when NSW DPI assesses proposals for developments and other activities that affect fish habitats. The document contains:

> Background information on aquatic habitats and fisheries resources of NSW;

> An outline of the legislative requirements relevant to planning and development which may affect fisheries or aquatic habitats in NSW;

> General policies and classification schemes for the protection and management of fish habitats and an outline of the information that NSW DPI requires to be included in development proposals that affect fish habitat;

> Specific policies and guidelines aimed at maintaining and enhancing the free passage of fish through instream structures and barriers;

> Specific policies and guidelines for foreshore works and waterfront developments; and

> Specific policies and guidelines for the management of other activities that affect waterways.

NSW DPI considers the 'sensitivity' of any KFH that would be affected by the proposal (NSW DPI 2013a). The term 'sensitivity' refers to the importance of the habitat to the survival of fish and its ability to withstand disturbance. In freshwater ecosystems, instream gravel beds, rocks greater than 500 millimetres (mm) in two dimensions, snags greater than 300 mm in diameter or 3 metres (m) in length, native aquatic plants, and areas known or expected to contain threatened and protected species are considered highly sensitive KFH. Other freshwater habitats plus weir pools and dams across natural waterways are considered to be moderately sensitive KFH. Ephemeral and intermittent aquatic habitat that does not support native aquatic or wetland vegetation is considered to be of minimal sensitivity. It is important to note that aquatic habitats within first and second order gaining streams, sections of stream that have been concrete-lined or piped (excluding waterway crossings) and artificial ponds are not regarded as KFH unless they support a listed threatened species, population or ecological community or 'critical habitat'. NSW DPI may in addition assess development proposals in relation to waterway class (i.e. their ability to provide habitat that is suitable for fish), which in turn determines the appropriate type of any waterway crossings. KFH Type is used within the policy and guidelines to differentiate between permissible and prohibited activities or developments and for determining value in the event offsetting is required. KFH criteria are provided in **Appendix A**.

2.3 Key Threatening Processes

A KTP is a process that threatens, or may have the capability to threaten, the survival or evolutionary development of species, population or ecological community. KTPs are listed under the FM Act, BC Act and EPBC Act. There are eight listed KTPs under the FM Act, 38 listed under the BC Act and 21 listed under the EPBC Act. Broadly, the KTPs include threats to threatened species, population and ecological communities as well as cause species, population or ecological communities to become threatened.

One KTP listed under the BC Act is directly applicable to the Project, namely *Alteration of habitat following subsidence due to longwall mining.*

In the final determination for this KTP, the NSW Scientific Committee found that:

> Mining subsidence following longwall mining is frequently associated with cracking of valley floors and creek lines and with subsequent effects on surface and groundwater hydrology.

> Subsidence-induced cracks occurring beneath a stream or other surface water body may result in the loss of water to near-surface groundwater flows. If the water body is located in an area where the coal seam is less than approximately 100 to 120 m below the surface, longwall mining can cause the water body to lose flow permanently. If the coal seam is deeper than approximately 150 m, the water loss may be temporary unless the area is affected by severe geological disturbances such as strong faulting.

> In the majority of cases, surface waters lost to the sub-surface re-emerge downstream. The ability of the water body to recover is dependent on the width of the crack, the surface gradient, the substrate composition and the presence of organic matter. An already-reduced flow rate due to drought conditions or an upstream dam or weir will increase the impact of water loss through cracking.

> Subsidence can cause decreased stability of slopes and escarpments, contamination of groundwater by acid drainage, increased sedimentation, bank instability and loss, creation or alteration of riffle and pool sequences, changes to flood behaviour, increased rates of erosion with associated turbidity impacts, and deterioration of water quality due to a reduction in dissolved oxygen (DO) and to increased salinity, iron oxides, manganese, and electrical conductivity (EC).

> Loss of native plants and animals may occur directly via iron toxicity, or indirectly via smothering. Long-term studies in the United States indicate that reductions in diversity and abundance of aquatic invertebrates occur in streams in the vicinity of longwall mining and these effects may still be evident 12 years after mining.

> In the Southern Coalfield, substantial surface cracking has occurred in watercourses within the Upper Nepean, Avon, Cordeaux, Cataract, Bargo, Georges and Woronora catchments, including Flying Fox Creek, Wongawilli Creek, Native Dog Creek and Waratah Rivulet. The usual sequence of events has been subsidence-induced cracking within the streambed, followed by significant dewatering of permanent pools and in some cases complete absence of surface flow.

> Subsidence associated with longwall mining has contributed to adverse effects on upland swamps. The conversion of perched water table flows into subsurface flows through voids, as a result of mining-induced subsidence may affect the water balance of upland swamps. The timeframe of these changes is likely to be long-term. While subsidence may be detected and monitored within months of a mining operation, displacement of susceptible species by those suited to altered conditions is likely to extend over years to decades as the vegetation equilibrates to the new hydrological regime.

The former Department of Environment and Conservation (now the DPE) has identified several priority actions to promote the abatement of this KTP, including:

> Examine the effects of subsidence from longwall mining on priority ecosystems including streams, wetlands and threatened species, populations and ecological communities.

> Prepare guidelines outlining key factors that should be considered when assessing impacts of new longwall mines on biodiversity.

> Develop recommendations for monitoring impacts of new longwall mines on biodiversity and mitigation methods.

> Ensure rigorous assessment of new mines continues through existing approval processes including the preparation of Subsidence Management Plans (SMPs).

Consideration of the effect of exacerbation of any KTP on a listed threatened species, population or ecological community must be taken into consideration during any assessment.

2.4 Strategic Review of Coal Mining in the Southern Coalfield

Due to concerns on the potential impacts associated with past and future mining in the Southern Coalfield, an independent inquiry was established to review these impacts and identify appropriate management measures. This *Strategic Review of the Impacts of Underground Mining in the Southern Coalfield* (NSW Department of Planning [DoP] 2008) was completed in 2008 based on the following terms of reference:

1. Undertake a strategic review of the impacts of underground mining in the Southern Coalfield on significant natural features (i.e. rivers and significant streams, swamps and cliff lines), with particular emphasis on risks to water flows, water quality and aquatic ecosystems; and
2. Provide advice on best practice in regard to:
   a) assessment of subsidence impacts;
   b) avoiding and/or minimising adverse impacts on significant natural features; and
   c) management, monitoring and remediation of subsidence and subsidence-related impacts; and
3. Report on the social and economic significance to the region and the State of the coal resources in the Southern Coalfield.

With regard to monitoring of ecology, the review recommends that baseline data be collected at sufficient intensity over a minimum period of 18 to 24 months to gain a better understanding of the variability and seasonality in distribution of flora and fauna, prior to any mining activity The review also recommends that replicate surveys be undertaken at sites directly above the mine and at comparable control sites outside the direct impact zone, so that changes and fluctuations due to mining can be distinguished from those due to natural variability.

2.5 Independent Expert Panel for Mining in the Catchment and Independent Advisory Panel for Underground Mining

The Independent Expert Panel for Mining in the Catchment (IEPMC) was established in late February 2018 to provide informed expert advice to DPE on the impact of mining activities in the Greater Sydney Water Catchment Special Areas, with a focus on risks to the quantity of water and swamps. Part 1 (IEPMC 2019a) reviewed specific mining activities at the Dendrobium Mine and Metropolitan Mine and Part 2 (IEPMC 2019b) focused on the impacts of mining on water quantity and swamps, including cumulative impacts, and includes a review and update of relevant findings of the strategic review (NSW DoP 2008). Recommendations specific to monitoring of aquatic ecology were not included, though several recommendations relevant to monitoring of groundwater and surface water and the development of associated Trigger Action Response Plans (TARPs) will assist in the future assessment and identification of causes of any impacts to aquatic ecology. These suggestions have been adopted by IMC and are reported in End of Panel reports following extraction of each longwall.

The Independent Advisory Panel for Underground Mining (IAPUM) was established in August 2020 to provide expert advice to DPE regarding underground coal mining proposals and subsidence-related impacts and performance outcomes. The IAPUM provided advice to DPE on the previous application to extend the Dendrobium Mine (IAPUM 2020) and the outcomes have been considered as part of the development of the Project and as part of the assessments undertaken to support the EIS.

3 Existing Environment

3.1 Physical Setting and Study Area

Area 5 is located within the Metropolitan Special Area, which is a special declared area controlled by WaterNSW (previously the Sydney Catchment Authority). The main waterbodies within the vicinity of Area 5 are Donalds Castle Creek, Avon River and Lake Avon. These flow outside the boundaries of the proposed mining area, though several of their tributaries flow over the proposed Area 5 longwalls and within the Study Area (**Figure 3-1**). The Study Area for Area 5 includes the aquatic habitat and biota directly above and within 600 m of the proposed Longwalls 501 to 510 in Area 5. Although located outside the Study Area, the main channel of Donalds Castle Creek and Avon River have been included in this assessment for comparative purposes.

At its closest point the main channel of Wongawilli Creek is 2 km from the proposed longwalls (i.e. outside the Study Area) and would not be affected by the Project. Thus, it has not been considered here except for comparative purposes. The several swamps in the Study Area and their associated biota are considered in the Biodiversity Development Assessment Report (Niche Environment and Heritage 2022).

3.2 Overview of Previous Studies

Numerous studies of aquatic habitat, flora and fauna at the Dendrobium Mine have been undertaken by Cardno (formerly Cardno Ecology Lab and The Ecology Lab). These studies assessed impacts of predicted mine subsidence on aquatic ecology, including threatened species, and undertook monitoring before, during and after mining. These include:

> Dendrobium Area 1: AEA studies (The Ecology Lab 2001a, b and 2003) and monitoring study (The Ecology Lab 2005).

> Dendrobium Area 2: AEA studies (The Ecology Lab 2006) and monitoring studies (Cardno Ecology Lab 2009).

> Dendrobium Area 3: AEA studies (The Ecology Lab 2007), including the Area 3B AEA (Cardno Ecology Lab 2012a), baseline studies (Cardno Ecology Lab 2011) and ongoing monitoring studies (Cardno Ecology Lab 2012; 2013; 2014; 2015 and 2016 and Cardno 2018a) and most recently (in 2019) (Cardno 2020a). Recent assessments were also undertaken for Longwalls 20 and 21 in Area 3C (Cardno 2019a), Longwall 19 in Area 3A (Cardno 2020b) and Longwall 18 in Area 3B (Cardno 2020c).

> Dendrobium Area 5: Baseline studies in additional sections of Avon River and Donalds Castle Creek close to Area 5 visited in 2016 (Cardno 2017; Cardno 2019b).

Information on aquatic habitat, water quality, aquatic macroinvertebrates and fish in the Lake Avon, Avon River, and Donalds Castle Creek catchments (i.e. those catchments located within or directly adjacent to the Study Area for Area 5) from these previous studies is reviewed in **Sections 3.3** to **3.8**. This includes the following sites (**Figure 3-1**):

> Donalds Castle Creek: Sites 14 and X1 (part of the ongoing monitoring for Area 3A and 3B), 17 and 18 (visited June 2017 as part of the Longwall 20 and 21 assessment) and DC1, DC2 and DC3 (baseline studies for Area 5 in 2016).

> Avon River tributaries AR31 (Site AR1) and AR32 (Site AR2), with some fish survey undertaken in the nearby Avon River channel (baseline studies for Area 5).

Surveys of aquatic habitat, KFH, aquatic macroinvertebrates and fish have been undertaken at each of these sites. KFH was also assessed in first, second and third order watercourses in Area 5. Details of the methods used in these studies and the GPS coordinates of monitoring sites are provided in **Appendix A**.

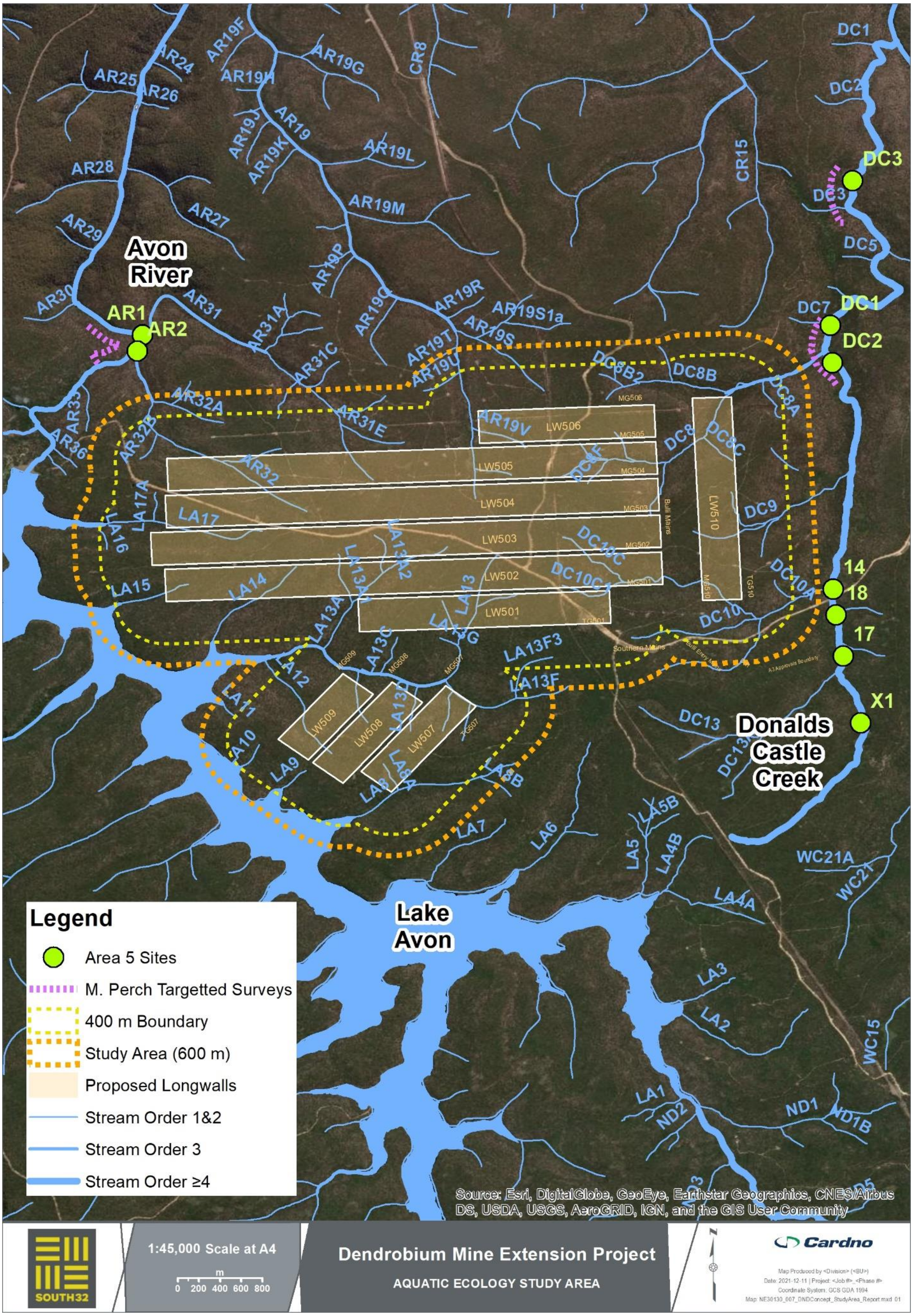

Figure 3-1 Study Area and Adjacent Aquatic Ecology Survey Sites.

3.3 Aquatic Habitat and Vegetation

3.3.1 Donalds Castle Creek

Aquatic ecology investigations undertaken at sites in Donalds Castle Creek (**Plates 1a** to **1f**) have identified the following in regard to aquatic habitat and vegetation:

> The vegetation surrounding Donalds Castle Creek to the east of Area 5 is dominated by dry Eucalypt forest which extends to the banks of the creek;

> The stream banks are composed mostly of well vegetated sandy soil with little erosion or undercutting evident and extensive overhanging vegetation along the stream margin;

> Riparian vegetation comprises numerous native plants, including saw grass (*Gahnia* sp.), mat rush (*Lomandra* sp.), wattles (*Acacia* sp.), and tea-tree (*Leptospermum* sp.) along the creek banks;

> The main channel of Donalds Castle Creek comprises a series of relatively small permanent pools with a maximum depth of 1.5 m, width of 6 m and length of 25 m. The pools are connected by narrow channels with a sandy substratum, small sections of gravel riffles and some sandstone rockbars with small cascades up to 1 m in height;

> The pools have a sandy substratum also, with some areas of bedrock, boulder and gravel. The connectivity between pools is not expected to persist through extended dry periods. There are numerous in-stream habitat features, including snags and tree roots;

> Aquatic vegetation is relatively sparse, and includes brown and green algae, twig-rush (*Baumea* sp.) and club-rush (*Schoenoplectus* sp.). No submerged aquatic macrophytes were observed in the areas inspected;

> Waterfalls are present on the Donalds Castle Creek which could pose a barrier to passage for some fish; and

> Riparian Channel and Environmental Inventory (RCE) undertaken during the Area 5 baseline surveys indicated the aquatic habitat in Donalds Castle Creek was in very good condition, with sites having an overall score of 49 out of a possible total of 52.

3.3.2 Avon River and Lake Avon

Avon River (**Plate 1f**) is a perennial, regulated river that flows from Lake Avon. The riparian vegetation in reaches of Avon River and Lake Avon near the Study Area is largely undisturbed, and consists of dry Eucalypt forest which extends to the banks of the creek and the lake. Avon River and Lake Avon would provide significant habitat for native fish, including deep pools, aquatic vegetation, large wood debris and likely also gravel beds. Avon River is classified as a moderate potential GDE on the GDE Atlas (Bureau of Meteorology [BOM] 2021).

3.3.3 Cordeaux River and Lake Cordeaux

Cordeaux River is a perennial, regulated river that flows from Lake Cordeaux located to the north-east of the Study Area. The riparian vegetation in reaches of the Cordeaux River are likely to be largely undisturbed, and likely include the species identified along Donalds Castle Creek. The Cordeaux River would provide substantial habitat for native fish, including deep pools, aquatic vegetation, large wood debris and likely also gravel beds. One of the Project Ventilation Shaft construction water supply options, proposed in the EIS, involves extraction from Cordeaux River, near Ryan’s Crossing.

3.3.4 Drainage Lines

The following main drainage lines are located within the Study Area:

> Drainage lines of Donalds Castle Creek: DC8, DC9, DC10.

> Drainage lines of Avon River: AR19, AR31 and AR32.

> Drainage lines of Lake Avon: LA8, LA9. LA10, LA11, LA12, LA13, LA14, LA15, LA16 and LA17.

Plates 1a to 1g Aquatic Habitat present in Donalds Castle Creek and Avon River

Several of these drainage lines also have tributaries that traverse the Study Area. Within the Study Area, all these are first or second order, except the lower sections DC8 and LA13, which are third order. These third order streams are located within the Study Area, but are not located above any proposed longwall mining areas for the Project. Riparian vegetation and bank structure along the drainage lines is very similar to that along Donalds Castle Creek. The primary difference in aquatic habitat between drainage lines and Donalds Castle Creek is the relatively smaller size and reduced connectivity pools. While these drainage lines would provide some habitat for aquatic fauna (primarily macroinvertebrates), this habitat would be less permanent, compared with that in Donalds Castle Creek, due to the smaller catchment areas and, therefore, flows present. Nevertheless, lower sections of larger drainage lines with greater catchment areas near the main channels of Donalds Castle Creek, Avon River and Lake Avon, particularly DC8 and LA13, would be expected to provide relatively more permanent aquatic habitat in the form of larger pools that would persist for some time and provide refuge habitat during drought. Mapping undertaken by IMC identified several relatively large (estimated ≥ 100 m^3) pools in some of these drainage lines within 400 m or 600 m of the proposed longwalls in Area 5:

- AR31: Pool 52 (**Plate 2a**) within 600 m and Pool 63 (**Plate 2b**) within 400 m;
- AR32: Pools 35 (**Plate 2c**), 31 and 22 within 400 m and Pool 17 (**Plate 2d**) within 600 m;
- LA13: Pools 17 (**Plate 2e**), 9, 4, 2 (**Pool 2f**) within 400 m
- DC8: Pool 9 (**Plate 3a**) partly within 400 m and Pool 16 (**Plate 3b**) within 400 m;
- DC10C: Pool 7 (**Plate 3c**) within 400 m.

These pools would be expected to provide relatively permanent pool habitat that would provide refuge for aquatic macroinvertebrates and fish (if present) except perhaps during severe drought. However, these pools may only be connected by shallow flow over rockbars and may become disconnected during periods of low rainfall. Further upstream in these drainage lines, aquatic habitat becomes increasingly limited as baseflow reduces due to the smaller sub-catchment areas. While these areas may contain some rocks and wood debris, they would have ephemeral/intermittent flow, with disconnected pools that would provide sporadic refuges for aquatic fauna. Aquatic fauna present would primarily consist of aquatic macroinvertebrates, including mobile freshwater crayfish. Some fish, potentially galaxiids, may occur in the lower reaches. However, the several substantial natural barriers to fish passage (such as small waterfalls, cascades, and shallow flow over rock bars) likely to be present in these drainage lines would limit the number and type of fish species present to those capable of passing such barriers, such as Climbing Galaxias (*Galaxias brevipinnis*). The waterfall at drainage line DC8 just upstream of its confluence with Donalds Castle Creek would almost certainly constitute a barrier to passage of fish except those adapted to climbing such barriers (e.g. Climbing Galaxias). A galaxiid, likely Climbing Galaxias, was found in AR1 upstream of several substantial natural barriers (**Section 3.7**).

3.4 Key Fish Habitat

The broad scale KFH map for Wollongong available on the NSW DPI website indicates that Avon River and Lake Avon are KFH (NSW DPI 2017a). Donalds Castle Creek and the drainage lines that traverse the Study Area are not identified as KFH on this map. Avon River provides Type 1 – Highly sensitive KFH and includes aquatic plants, large rocks, large wood debris (**Figure 3-2**). Macquarie Perch (*Macquaria australasica*) also has potential to occur here. Lake Avon is also considered to provide Type 1 - Highly sensitive KFH due to the predicted presence of Macquarie Perch. Donalds Castle Creek provides Type 1 KFH in the form of some small, discreet patches of aquatic vegetation and large rocks and wood debris. It is noted that Donalds Castle Creek is significantly smaller (in terms of channel width, water and pool depth) and provides far less abundant and diverse fish habitat than Avon River. Macquarie Perch is not expected to occur in Donalds Castle Creek in the Study Area due to the presence of significant barriers to passage downstream (**Section 3.3.1**).

The third order reaches of drainage lines LA13 and DC8 provide Type 2 – Moderately sensitive KFH. These drainage lines are not directly above the proposed longwalls for the Project. This classification was due to general the absence of aquatic plants and larger rocks and wood debris. Other first and second order drainage lines do not provide KFH. First and second order gaining streams (i.e. those moderately or highly groundwater dependant) do not provide KFH (NSW DPI 2013a).

Plates 2a to 2f Pools present in AR31, AR32 and LA13

Plates 3a to 3c Pools present in DC8 and DC10C

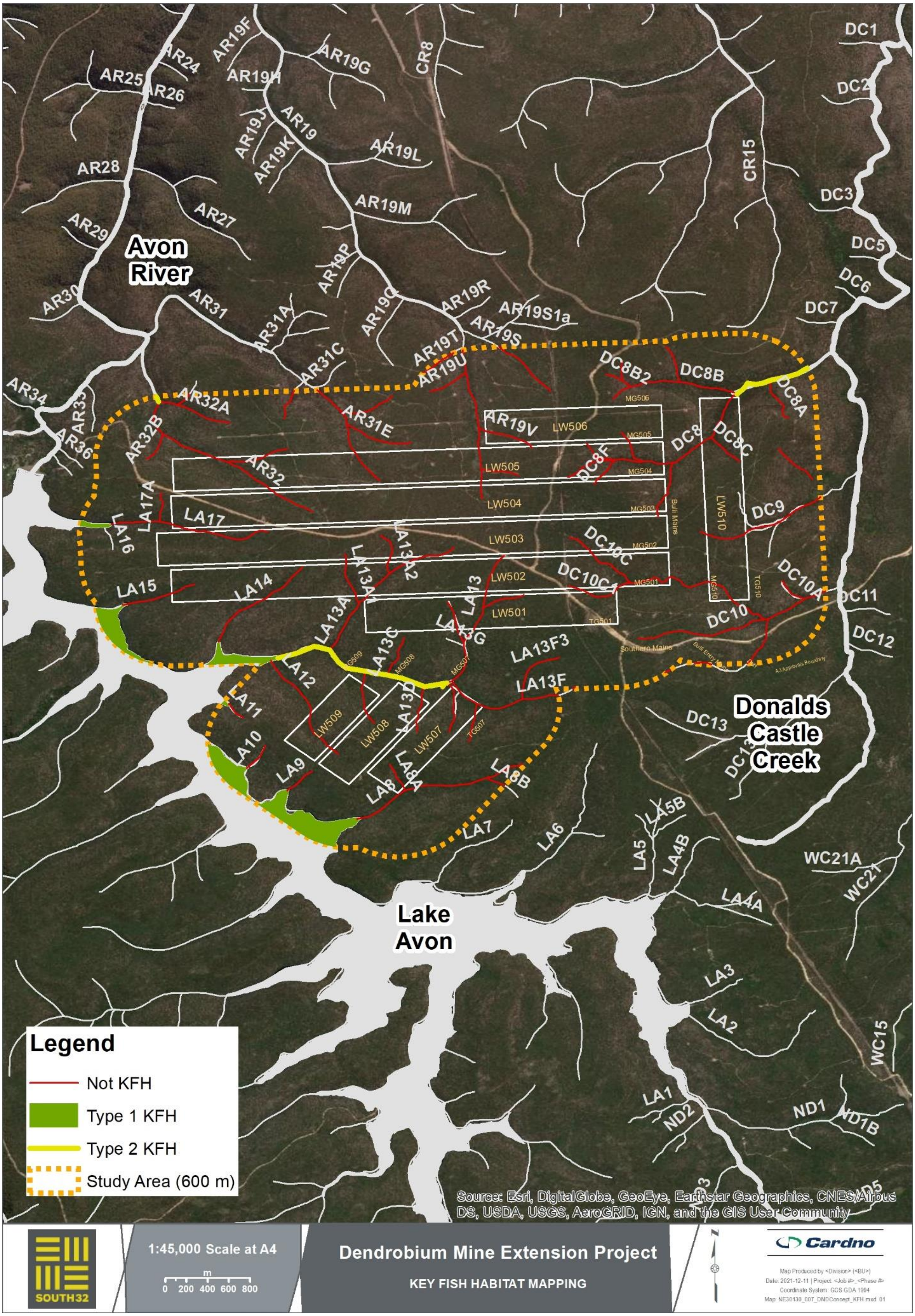

Figure 3-2 Key Fish Habitat present within the Study Area

3.5 Surface Water Quality

Previous studies have indicated that some measures of water quality within Donalds Castle Creek have often been outside of Australian and New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand (ANZECC/ARMCANZ) (2000) guidelines. However, the relatively remote and undisturbed catchment area does not suggest influence by any anthropogenic disturbance. EC measurements taken during the baseline aquatic ecology monitoring for DA3B (Cardno Ecology Lab 2012a), the Area 5 baseline surveys and during recent ongoing monitoring (Cardno 2020a) showed levels were generally within the ANZECC/ARMCANZ (2000) default trigger values (DTVs) (30 to 350 microSiemens per centimetre [µS/cm]) for upland rivers in south-east Australia. The exception was at one site (Site X1), where the level occasionally fell below the lower guideline value. The pH of the water at monitoring sites was always below the lower (pH 6.5) DTV. Low pH levels have been recorded generally across the Dendrobium Mine area, and appear to occur naturally, most likely associated with local geology and its influence on water chemistry. DO levels at one site (Site X1) were either within DTVs (90 to 110 % saturation) or sometimes below the lower DTV. DO measurements at another site (Site 14) were more variable, ranging above and below the DTVs. The turbidity measurements were within, or below, the guidelines (2 to 25 NTU [Turbidity]). NTU values below 2 are not cause for concern, and most likely reflect the relatively low organic content of the water.

In-situ water quality data from tributaries AR31 and AR32 in the Area 5 during the baseline surveys were comparable with those collected elsewhere at the Dendrobium Mine Area including in Donalds Castle Creek. EC ranged from 92 µS/cm to 95 µS/cm, DO was 90% saturation, turbidity 0.4 NTU and pH 6.2.

3.6 Macroinvertebrates

AUSRIVAS surveys have been undertaken in Sites 14 and X1 for several years during the ongoing Area 3A and Area 3B monitoring programs (Cardno 2020a) and Sites 17 and 18 as part of the Longwalls 20 and 21 Assessment (Cardno 2017) (**Figure 3-3**). Results of the AUSRIVAS surveys are also provided in **Table 3-1**.

Table 3-1 AUSRIVAS Data Collected from Donalds Castle Creek and Avon River Tributaries

Site	Survey	SIGNAL	OE50	Taxa	Site	Survey	SIGNAL	OE50	Taxa
Donalds Castle Creek									
14	Nov 2010	4.5	0.64	19	X1	Nov 2010	4.3	0.88	20
14	Sep 2010	4.2	0.92	24	X1	Sep 2010	4.2	0.61	21
14	May 2010	4.8	1.11	29	X1	May 2010	4.7	0.82	21
14	Mar 2010	4.5	1.16	25	X1	Mar 2010	3.7	0.92	15
14	Oct 2011	4.4	0.73	19	X1	Oct 2011	3.8	0.97	22
14	Sep 2011	4.4	0.55	19	X1	Sep 2011	4.8	0.57	13
14	Jun 2011	4.7	0.54	15	X1	Jun 2011	4.6	0.62	18
14	Apr 2011	4.7	0.69	20	X1	Apr 2011	3.9	0.62	19
14	Apr 2013	4.4	0.79	20	X1	Apr 2013	4.4	1.03	25
14	Jun 2013	4.8	0.89	20	X1	Jun 2013	4.5	0.82	20
14	Sep 2013	4.8	0.59	11	X1	Sep 2013	4.3	0.79	19
14	Nov 2013	4.7	0.91	20	X1	Nov 2013	4.3	1.05	19
14	May 2015	5.0	0.65	13	X1	May 2015	3.6	0.41	9
14	Jun 2015	5.0	0.65	19	X1	Jun 2015	3.8	0.82	15
14	Oct 2015	4.8	0.7	20	X1	Oct 2015	4.6	0.79	15
14	Nov 2015	4.5	0.73	18	X1	Nov 2015	4.0	0.79	16
14	Apr 2017	4.2	1.02	18	X1	Apr 2017	3.3	0.72	11
14	Jun 2017	4.1	1.02	15	X1	Jun 2017	3.6	0.72	11
14	Sep 2017	4.6	0.79	13	DC1	Sep 2016	4.2	0.73	16
14	Nov 2017	4.4	0.88	16	DC2	Sep 2016	4.9	0.85	16
14	May 2019	4.3	0.65	13	DC3	Sep 2016	4.8	0.89	23
14	Jun 2019	3.8	0.58	11	17	Jun 2017	4.1	0.72	10
14	Oct 2019	3.9	0.89	23	18	Jun 2017	5.3	0.37	8
14	Nov 2019	4.2	0.61	15	17	Jun 2017	4.1	0.72	10
Avon River Drainage Lines									
AR31	Sep 2016	5.1	0.45	11					
AR32	Sep 2016	4.4	0.58	12					

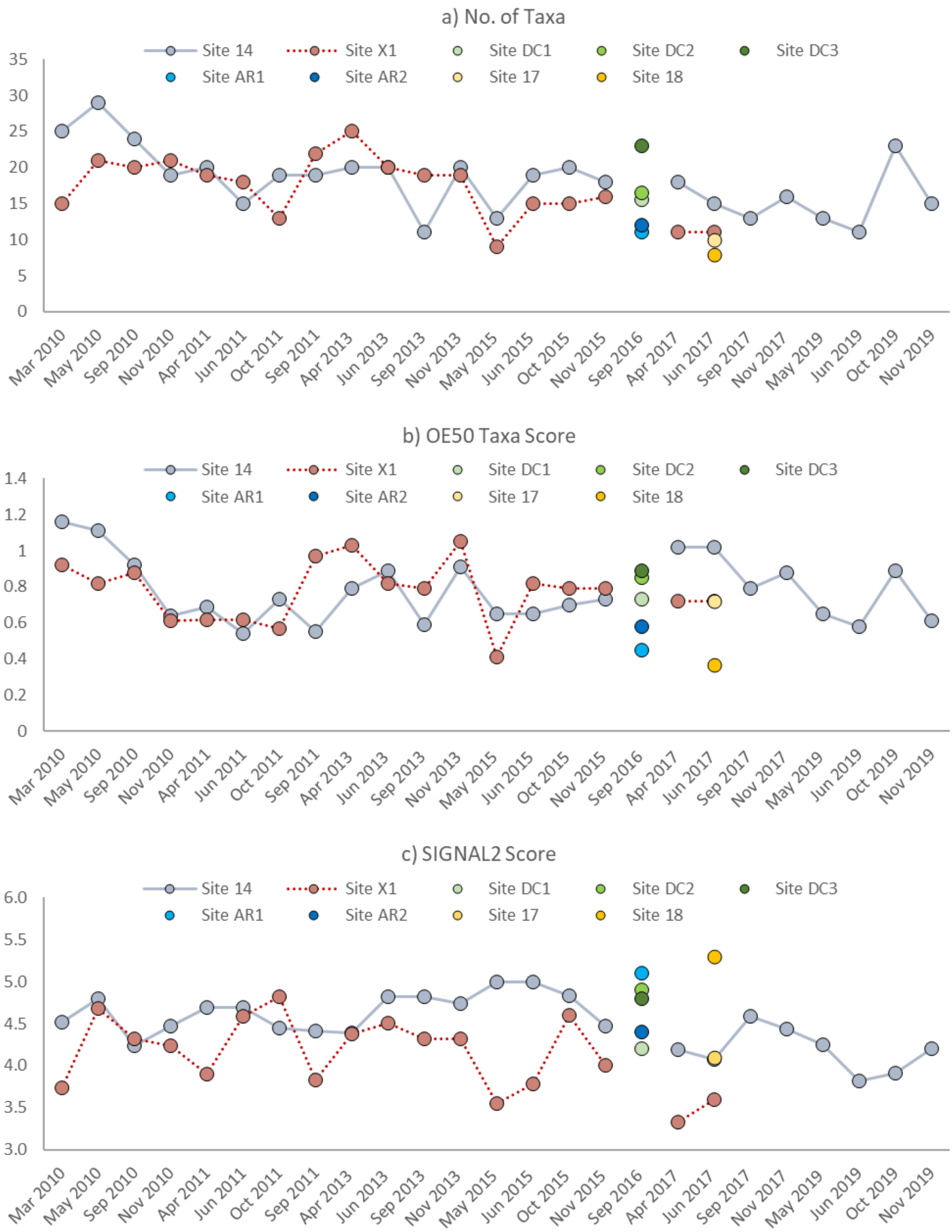

Figure 3-3 a) Total Number of Taxa, b) OE50 Taxa Scores and c) SIGNAL2 Scores from AUSRIVAS Samples Collected from Sites within the Study Area

Baseline surveys for Area 5 also included AUSRIVAS surveys in Donalds Castle Creek Sites DC1, DC2 and DC3 and Avon River drainage lines AR31 and AR32. Across all the AUSRIVAS sites, the number of taxa per sample ranged from 8 to 29, OE50 Taxa Scores ranged from 0.37 (Band D - severely impaired relative to reference condition) to 1.16 (Band A - richer assemblage than reference condition) and SIGNAL2 Scores ranged from 3.3 (indicative of severe water pollution) to 5.3 (indicative of moderate water pollution). AUSRIVAS Band Scores are derived from the OE50 Taxa Scores, which is a biotic index of habitat and water quality.

These data from Donalds Castle Creek, AR31 and AR32 are comparable to AUSRIVAS data collected from other watercourses (primarily Wongawilli Creek and Sand Creek) throughout the Dendrobium Mine area from 2010 to present. While these results suggest potential anthropogenic disturbance to habitat and/or water quality, there is no other evidence to support this. It is possible that the naturally low pH levels in this watercourse, and others that traverse the Dendrobium Mine area may be influencing the type of macroinvertebrates that are present. Other measures of water quality, such as naturally occurring levels of some heavy metals, may also influence the type of macroinvertebrates, and other organisms, present (Cardno Ecology Lab 2012a; b; Ecoengineers 2006).

3.7 Fish

Fish surveys undertaken as part of the ongoing monitoring in Dendrobium Area 3A and 3B has included backpack electrofishing and bait trapping in Donalds Castle Creek at Sites 14 since 2010 and X1 since 2012. Galaxiids, either Mountain Galaxias (*Galaxias olidus*) and/or Climbing Galaxias, have been caught and observed at Site 14 during each year of survey (Cardno 2020a). Galaxiids have been relatively scarce at Site X1, compared with Site 14 (Cardno 2016b), which likely reflects the disconnected nature (i.e. a series of isolated pools) of the aquatic habitat further upstream in Donalds Castle Creek. It is possible that drainage lines within Area 5 including those of Donalds Castle Creek, may also support some fish, most likely Climbing Galaxias. The presence and abundance of fish in drainage lines would depend on the size of drainage lines, flow, and the presence of natural barriers to fish passage. It is likely that due to their highly disconnected nature, pools in many drainage lines would provide no, or sub-optimal at best, habitat for these fish.

During the 2016 baseline surveys for Area 5, fish backpack electrofishing surveys were undertaken at Sites DC1, DC2 and DC3 on Donalds Castle Creek. Backpack electrofishing was undertaken in AR31 and AR32 and bait trapping, backpack electrofishing and fyke netting in Avon River at the confluences with AR31 and AR32. This included targeted surveys for Macquarie Perch. Galaxiids were caught at DC2 and AR32 (**Plates 4a** and **4b**) and Flathead Gudgeon (*Philypnodon grandiceps*) in AR31. All were caught whilst backpack electrofishing. The galaxiid caught in AR32 was likely Climbing Galaxias, as it was found upstream of several substantial natural barriers to fish passage. This species is adapted to traversing barriers such as these (McDowell 1996). These watercourses also provide habitat for freshwater crayfish (*Euastacus* sp.).

Freshwater eels (*Anguilla* spp.) have also been identified in Wongawilli Creek and have potential to be present in Avon River and the lower sections of Donalds Castle Creek. The bi-annual surveys undertaken for Elouera Colliery Longwalls 7 to 10 between 2002 and 2006 indicated that Australian Smelt (*Retropinna semoni*) and Mountain Galaxias were present in Donalds Castle Creek (MPR 2002, 2003a and b, 2004a and b, 2005, 2006a, b and c). Although only a small number of native fish species have been identified from these watercourses, except for Avon River and Lake Avon, the fish assemblage is undistributed and no non-native species have been observed here or in other watercourses in the Dendrobium Mine area. In Lake Avon, Long-finned Eel (*Anguilla reinhardtii*) and Brown Trout (*Salmo trutta*) have been recorded (Cardno Ecology Lab 2012a).

There is a 2005 record of Macquarie Perch from outside the Study Area in the Cordeaux River approximately 1 km downstream of the confluence with the Avon River (Atlas of Living Australia [ALA] 2021). The predicted distribution of Macquarie Perch also includes Avon River and Lake Avon (Lake Avon is partly within the Study Area), but not within the drainage lines associated with Donalds Castle Creek (NSW DPI 2016b). Aside from Macquarie Perch, all species of fish identified from the Study Area are widespread and abundant, and currently have no cause for conservation concern. Aside from some invasive species identified in Lake Avon (Brown Trout), no invasive species of fish have been identified in the Study Area.

Plates 4a and 4b Galaxiids caught in at Sites DC2 and AR2 in Donalds Castle Creek and Avon River drainage line AR32

3.8 Listed Threatened Aquatic Ecology

3.8.1 Desktop Searches

A search for information on records and distributions of threatened species, populations and ecological communities listed under the FM Act, EPBC Act and BC Act in the relevant catchments was undertaken to update searches completed for previous assessments (The Ecology Lab 2007; Cardno Ecology Lab 2011). The search used the following resources:

> The DAWE Protected Matters Search Tool (DAWE 2021) was used to determine whether any Matters of National Environmental Significance (MNES) listed under schedules of the EPBC Act occurred in a 10 km radius from the centre of the Study Area;

> The DPE managed BioNet searched for records of BC Act listed flora and fauna within the Sydney – Cataract sub-region held in the Atlas of NSW Wildlife. ALA (2021) was also searched for records of species of fish (including invertebrates and vertebrates) listed under the FM Act occurring in the catchments of Lake Avon, Avon River, Donalds Castle Creek, Lake Cordeaux and Wongawilli Creek; and

> Species distribution maps contained in the NSW DPI Fish Communities and Threatened Species Distributions of NSW (NSW DPI 2016a) were examined for the occurrence of threatened species listed under the FM Act in the upper catchments of Cordeaux River and Avon River.

The desktop search indicated several species that occur, or have potential to occur, in the Study Area. Amphibians, aquatic mammals, reptiles and Giant Dragonfly (*Petalura gigantea*) are being considered by other specialists and were excluded from the search.

3.8.2 Macquarie Perch

Macquarie Perch is listed as Endangered under the EPBC Act and the FM Act. It has been recorded in the Dendrobium Mine area in the mid to lower reaches of Wongawilli Creek, including pools just upstream and downstream of Fire trail 6A (NSW DPI [Fisheries], pers. com.; The Ecology Lab, 2001b and 2005; MPR 2006b; Matt Richardson, Niche, pers. obs. 2011). However, this species was not caught further upstream in Wongawilli Creek despite extensive sampling (Cardno 2012a, b and 2016a, b). It is possible that this species is unable to pass the natural barrier in the form of a cascade/waterfall present a few hundred metres upstream of the crossing, at least not in any appreciable numbers.

It has been recorded also in Lake Avon and Lake Cordeaux (**Section 3.7**) and previously recorded, or potentially present, in the upper reaches of Cordeaux River and Avon River (NSW DPI 2016a). Outside of these areas, Macquarie Perch are found in the Murray-Darling Basin, particularly the upstream reaches of the Lachlan, Murrumbidgee and Murray Rivers, and parts of south-eastern coastal NSW, including the Hawkesbury and Shoalhaven catchments (NSW Fisheries 2016b).

Macquarie Perch prefer clear water and deep, rocky holes with extensive cover in the form of aquatic vegetation, large boulders, debris and overhanging banks (NSW DPI 2016). They spawn in spring or summer and lay their adhesive eggs over stones and gravel in shallow, fast-flowing upland streams or flowing parts of rivers. Macquarie Perch is an active predator of macroinvertebrates. While other large-bodied percichthyids are generally higher-order ambush predators that may have limited range, the Macquarie Perch tends to have a relatively larger linear (along shore) diel range (Ebner *et al*. 2010). A study in a Canberra reservoir found that Macquarie Perch have a mean linear diel range of 516 m (± 89 S.E.) which suggests that discontinuous and small pools would not provide suitable habitat for this species (Ebner *et al*. 2010).

The National Recovery Plan for Macquarie Perch (Commonwealth of Australia 2018) contains background information on the biology, ecology, distribution and populations, decline and threats and recovery objectives and strategies and associated actions for this species. Identified threats include:

> Habitat degradation;
> Introduced fish species;
> Barriers to fish movement;
> Altered flow and thermal regimes;
> Disease and parasites;
> Illegal/incidental capture;
> Chemical water pollution; and
> Climate change.

Recovery Plan strategies include:

> Conserve existing Macquarie Perch populations;
> Protect and restore Macquarie Perch habitat;
> Understand and address threats to Macquarie Perch populations and habitats;
> Establish additional Macquarie Perch populations;
> Improve understanding of the biology and ecology of the Macquarie Perch and its distribution and abundance; and
> Increase participation by community groups in Macquarie Perch conservation.

The following Priority Action Statements for Macquarie Perch (NSW DPI 2017b) exist:

> Advice to consent and determining authorities;
> Collate and review existing information;
> Community and stakeholder liaison, awareness and education;
> Compliance/enforcement;
> Enhance, modify or implement natural resource management planning processes to minimize adverse impacts on threatened species;
> Habitat rehabilitation;
> Pest eradication and control;
> Research/monitoring;
> Stocking/translocation; and
> Survey/mapping.

Actions directly applicable to the Project include the provision of advice on the distribution of Macquarie Perch to determining authorities to ensure appropriate consideration during development assessment processes, and the undertaking of targeted surveys to determine the current distribution and abundance of Macquarie Perch.

No Threat Abatement Plans are associated with this species.

3.8.3 Australian Grayling

The Australian Grayling (*Prototroctes maraena*) is listed as a Vulnerable species under the EPBC Act and is listed as Endangered under the FM Act. It occurs in coastal streams and rivers on the eastern and southern flanks of the Great Dividing Range from Sydney southwards to the Otway Ranges in Victoria, and Tasmania (NSW DPI 2006). Australian Grayling have been recorded in the Grose River, but there are no records of this species from the upper Nepean Catchment. They have also been recorded in estuarine areas. The life cycle of the Australian Grayling is dependent upon migration to and from the sea (McDowall 1996). Spawning occurs in late summer or autumn and larvae are swept downstream to the sea (NSW DPI 2006). Juvenile fish return to freshwater when they are about six months old and remain in rivers and streams for the rest of their life. Australian Grayling has undergone a considerable decline in its distribution and abundance and, although it was historically present in the Hawkesbury-Nepean, it is now restricted to the coastal rivers of southern NSW (Morris *et al*. 2001; NSW DPI 2016a). The decline of this species has been attributed to dams, weirs and culverts preventing it from migrating to and from the sea and completing its life cycle. As Australian Grayling are highly unlikely to occur within the Study Area, further consideration of this species is not considered necessary.

3.8.4 Sydney Hawk Dragonfly

The Sydney Hawk Dragonfly (*Austrocordulia leonardi*) is listed as endangered under the FM Act. It is extremely rare, having been collected in small numbers at only a few locations in a small area to the south of Sydney, between Audley and Picton (NSW Fisheries Scientific Committee [FSC] 2004; NSW DPI 2016). The species is also known from the Hawkesbury-Nepean, Georges River and Port Hacking drainages. It was discovered in 1968 from Woronora River and Kangaroo Creek, south of Sydney, and has subsequently been found in the Nepean River at Maldon Bridge near Picton and further upstream at Nepean Dam (ALA 2021). There are no records for this species within the Study Area or the Cordeaux and Lake Avon catchments despite extensive sampling by Cardno in the Dendrobium Mine area. Recent surveys have also recorded Sydney Hawk Dragonfly north of Sydney and north of the Hunter Valley, however, its distribution is still considered highly restricted and fragmented (NSW DPI 2016).

Most of the lifecycle of this species is spent as an aquatic larva, with adults living for only a few weeks. The larvae appear to have specific habitat requirements, being found under rocks in deep, cool, shady pools (NSW DPI 2016). Relative environmental stability appears to be an important habitat feature, with rapid variation in water level and flow rate likely to have a negative effect on the suitability of habitat for larvae.

No Recovery and Threat Abatement Plans exist for this species. Several conservation and recovery actions for Sydney Hawk Dragonfly are provided in NSW DPI (2016), including:

> Undertake work to identify, restore and protect known and potential Sydney Hawk Dragonfly habitats and address key threats such as habitat degradation and water quality declines from expanding development;

> Undertake priority rehabilitation, restoration and enhancement work at key sites known to support Sydney Hawk Dragonfly;

> Protect the few remaining sites with the potential to support the species, and address key threats such as habitat degradation and water quality decline.

> Conduct further research into the species' biology, ecology and distribution.

3.8.5 Adam's Emerald Dragonfly

Adam's Emerald Dragonfly (*Archaeophya adamsi*) is listed as endangered under the FM Act. It is extremely rare, having been collected only in small numbers at a few locations in the greater Sydney region (NSW DPI 2013b). Specimens have been collected at five localities: Somersby Falls and Floods Creek in Brisbane Waters National Park near Gosford; Berowra Creek near Berowra and Hornsby; Bedford Creek in the Lower Blue Mountains; and Hungry Way Creek in Wollemi National Park. There are no records for this species within the Study Area or the Cordeaux and Lake Avon catchments (ALA 2021). There are no records of Adam's Emerald Dragonfly occurring south of Sydney, despite active collecting in the Hawkesbury-Nepean River catchment (NSW FSC 2008). This species was not collected by Cardno during surveys of aquatic macroinvertebrates in Wongawilli, Sandy, Donalds Castle or Native Dog Creeks as part of the Dendrobium Mine area studies, but aquatic habitat that appears suitable for this species within some sections of these watercourses (Cardno Ecology Lab 2011).Drainage lines are unlikely to provide optimal habitat for this species.

The larvae of Adam's Emerald Dragonfly inhabit small creeks with gravel or sandy bottoms in narrow, shaded riffle zones with moss and abundant riparian vegetation (NSW DPI 2013b). The larvae live for approximately seven years before metamorphosing into adults that probably live for only a few months. They are thought to have a low natural rate of recruitment and limited dispersal abilities.

No Recovery and Threat Abatement Plans exist for this species. Conservation and recovery actions (NSW DPI 2013b) for Adam's Emerald Dragonfly are:

> Rehabilitate degraded habitats. Protect riparian vegetation and encourage the use of effective erosion and sediment control measures in catchments where the dragonfly may occur;
> Protect the few remaining sites that still support the species, and address key threats such as habitat degradation and water quality decline from expanding development;
> Conduct further research into the biology and distribution of the species; and
> Report any sightings to NSW DPI.

3.8.6 Likelihood of Occurrence

Table 3-2 assesses the likelihood of occurrence of Listed Threatened Species in the Study Area.

Table 3-2 Likelihood of Occurrence of Listed Threatened Species in the Study Area

Species and Listing	Likelihood of Occurrence
Macquarie Perch (Endangered under FM Act and EPBC Act)	Likely to occur in Lake Avon within the Study Area. Very unlikely to occur in Donalds Castle Creek or in drainage lines in the Study Area.
Adam's Emerald Dragonfly (Endangered under FM Act)	Unlikely to occur within the Study Area. No records within, or adjacent to the Study Area despite extensive sampling, though suitable microhabitat appears to exist in creeks and drainage lines.
Sydney Hawk Dragonfly (Endangered under FM Act)	Unlikely to occur within the Study Area. No records within, or adjacent to the Study Area despite extensive sampling, though suitable microhabitat appears to exist in creeks and drainage lines.
Australian Grayling (Endangered under FM Act and Vulnerable under EPBC Act)	Does not occur in the Study Area. Present in coastal rivers of southern NSW outside of the Study Area.

3.8.7 Critical Habitat

The Study Area does not contain any critical habitats listed under the FM Act, BC Act or EPBC Act.

3.9 Stygofauna

3.9.1 Background, Ecology and Threats

Stygofauna comprise highly specialised aquatic macroinvertebrates and (rarely) some fish that are adapted to living in groundwater habitats, including groundwater systems (i.e. can provide productive volumes of groundwater, also known as aquifers), waters held within spaces surrounding fractured rock and water-filled subterranean cavities (Tomlinson and Boulton 2010, Eberhard 2007; see also review in NSW Office of Water [NOW] 2012). Groundwater systems may be associated with existing features of the land surface (e.g. permanent, intermittent or ephemeral watercourses typically referred to as alluvial groundwater systems) or deeper features which may or may not be partitioned from the existing land surface (e.g. deep coal seams). Stygofauna have been characterised into three broad groups:

> Stygoxenes, which occur in subterranean waters but must leave for some period(s) to complete their life cycles;

> Stygophiles, which are able to live out life cycles in subterranean or surface waters; and

> Stygobites, which are obligate dwellers in subterranean waters.

The latter group typically displays common morphological characteristics, such as loss of eyes, pale or no pigmentation and enhanced non-optic sensory structures (Eberhard 2007). Sampling of groundwater may yield all three types of stygofauna. It may also yield obligate surface dwellers, for example where samples are taken from hyporheic habitats (the mixing zone between surface and groundwater typically beneath or adjacent to streams). Terrestrial or flying organisms may be sampled in groundwater when they fall into boreholes from the air or land surface.

Stygofauna include crustaceans, worms, snails, insects and a few other invertebrate groups. Taxa are often closely related to those on other continents, a pattern of relationship indicating that they had common ancestry on the ancient supercontinents of Gondwana and Pangaea or in the Tethys Ocean (Humphreys 2006). Notwithstanding this broad origin, stygofauna may exhibit high levels of endemism (i.e. species that are restricted to particular localities) and, given the poor understanding of detailed taxonomy of the group, DNA analyses are being used to discriminate taxonomic groups where identification of species based on morphological features may not always be reliable.

Stygofauna contribute to the biodiversity of Australia (Tomlinson and Boulton 2010, Humphreys 2006). They may be functionally important, especially in hyporheic zones, and they may function in breakdown of organic material and grazing of biofilms and assist in the transfer of water by altering interstitial pore size as a result of burrowing/tunnelling within groundwater systems (Hancock *et al*. 2005). Boulton *et al*. (2008) identified ecosystem services that may be provided by groundwater and/or stygofauna, including: prevention of land subsidence; erosion and flood control via absorption of flood waters, reception and bioremediation of wastes and other by-products of human activities; and improvement in water quality through biogeochemical water purification.

Threats that have been identified in relation to stygofauna typically relate to disturbance of groundwater habitats, such as water abstraction, artificial filling and contamination (including introduction of toxic chemicals or clogging of pore spaces by fine sediments) (NOW 2012, Tomlinson and Boulton 2010, Humphreys 2006). Additionally, life-history adaptations to the groundwater environment may make stygofauna more susceptible to environmental disturbance, including production of fewer but larger eggs, prolonged egg development and greater longevity compared with surface-dwelling relatives (Tomlinson and Boulton 2010). Stygofauna are particularly sensitive to groundwater environmental disturbance because they are adapted to near steady-state environmental conditions and have very narrow spatial distributions (Australian Coal Association Research Program [ACARP] 2015). They also have limited capacity to recover from such disturbances because they have low mobility and low reproductive rates, meaning recolonisation will be slow. Changes to such conditions, particularly groundwater levels, groundwater quality and or changes in aquifer pore media, are a threat to stygofauna. Following groundwater drawdown, stygofauna can be stranded and have limited ability to survive in unsaturated conditions for more than 48 hours (ACARP 2015). Predictions of coal mining related effects should consider local changes in groundwater level and connectivity among aquifers above and below the target coal seams. For underground mines, this includes understanding how subsidence might interfere with the hydrology of overlying aquifers.

3.9.2 Previous Studies

3.9.2.1 Australia Wide

Research on stygofauna in Australia has been relatively intensive in northern Western Australia, particularly in relation to mining activities (e.g. Pilbara region – Eberhard *et al*. 2005). Several studies in eastern Australia have identified relatively diverse stygofauna present in alluvial groundwater systems, including sites in Queensland and the Hunter Region of NSW (Tomlinson and Boulton 2010, Hancock and Boulton 2008, 2009). In these latter studies, the greatest number of taxa came from boreholes with low EC (i.e. EC < 1,500 µS/cm) and the richest boreholes (in terms of stygofauna) occurred where the water table was less than 10 m deep, associated with the alluvium of larger river systems and near phraeophytic trees (i.e. with deep roots penetrating the saturated water of groundwater systems). There is some evidence that stygofauna occur in coal seams despite the depth and water quality conditions in coal seam aquifers being potentially sub-optimal for stygofauna (ACARP 2015). Previous studies have only reported a small number of individuals in coal seams, and generally only in those aquifers closely linked to alluvium.

Comparative studies in NSW and Queensland have indicated that stygofauna in alluvial groundwater systems tend to be present in greater diversity and abundance than in Permian coal seam groundwater systems (ALS 2010, Ecological 2015a, 2015b). The frequently high EC of waters, low oxygen concentrations and limited connectivity within coal seam aquifers and between coal seam aquifers and upper, alluvial aquifers has been suggested as a cause of these depauperate assemblages of stygofauna (ALS 2010, Ecological 2015a, 2015b).

3.9.2.2 Nepean Catchment

No known stygofauna studies have been undertaken in the Dendrobium Mine area and information on stygofauna in the coal fields in the Sydney Basin is scarce (ACARP 2015). The GDE Atlas (BOM 2021) does not contain any records of subterranean GDEs within the Study Area. The nearest known studies were those in the Kangaloon Borefield, approximately 10 km south of the Study Area, undertaken as part of initial investigations into the feasibility of this area providing potable water for Sydney Water from 2006 to 2008 (SMEC 2006; Hose 2008 and 2009).

SMEC (2006) sampled stygofauna in groundwater bores in February 2006 using water bailers and/or modified plankton nets. Stygofauna were found in two of the four bores. Two *Diacyclops* sp. (Class: Copepoda) specimens were found in a bore 24 m deep that accessed a shallow aquifer in fractured sandstone, and one *Psammaspides* .sp. (Super Order: Syncardia) was found in a bore 1.8 m deep that accessed the perched water table in Butlers Swamp. The presence of the Copepod within the uppermost portion of the sandstone indicated that there is a stygofauna community present within these fracture zones, however, their distribution may be patchy given none were found in the two remaining bores that accessed similar aquifers (SMEC 2006). Preliminary pumping tests suggest that the hydrology of Butlers Swamp was not connected with the underlying aquifer, however, the occurrence of stygofauna in this near surface water suggested that some connectivity could not be ruled out (SMEC 2006).

Hose (2008, 2009) undertook further stygofauna sampling in 21 bores, including several in the perched Butlers Swamp and nearby Stockyard Swamps, across the bore field in 2008 using net, bailor and/or pump sampling. Stygofauna were identified using morphological identification and DNA analysis. The productivity of microbial communities was also assessed using Fluorescein Diacetate (FDA) ß-glucosidase enzyme activity tests and assemblage diversity investigated using Biolog-Ecoplate (Carbon source) analysis.

Notable findings from the Stygofauna morphological and microbial analysis (Hose 2008) and Stygofauna DNA study (Hose 2009) included:

> Stygofauna were present in bores within both swamps, and in several of the other bores that accessed shallow and deep fractured sandstone aquifers. Diversity and abundance tended to be greatest in fractured sandstone, though the sample size within aquifers was sometimes small. Nevertheless, there was indication of a relatively diverse stygofauna assemblage within the perched Butlers and Stockyard swamps and the main fractured sandstone aquifer beneath.

> Morphologically similar species were present in many bores across the Study Area, and in both the perched water bearing zone and sandstone aquifers. These findings suggest two things (Hose 2008); first, that individual taxa are not limited to single areas, and second, that there is or has been some hydraulic linkage between the perched water bearing zone and the main aquifer in these areas. Linkage could occur from fracture zones becoming saturated during recharge events, enabling stygofauna to migrate from perched water tables to the uppermost portion of the regional sandstone aquifer. However, recent hydraulic testing indicated no hydraulic connectivity between Stockyard and Butlers Swamps and the underlying aquifer (Coffey 2006, RES 2006, URS 2007a, 2007b), suggesting that perched water is disconnected from the main sandstone aquifer, at least for some of the time. It is possible also that these taxa can exist in moist (non-saturated) strata and migrate many metres between the different water bearing zones.

> Based on the results of enzyme tests, microbial activity and productivity in samples from bores situated in fractured sandstone was greater than that in bores in Butlers Swamp. Microbial assemblage diversity in bores from Butlers Swamp appeared comparable with that in bores in fractured sandstone. However, interestingly, diversity in one bore in fractured sandstone, that with greatest species richness and abundance, was lower than that from bores in fractured sandstone and Butlers Swamp.

> While some taxa appeared to be relatively widespread based on morphological analysis, the relatively limited DNA analysis of copepods indicated genetically distinct populations in each different perched water-bearing zone sampled, and that these populations differ from those in the underlying sandstone aquifers. There was also some evidence of copepod genetic divergence over a range of less than 1 km within stockyard swamp. These results also suggested no hydraulic connectivity between the swamps and the underlying sandstone aquifer.

3.9.3 Environmental Tolerances of Stygofauna and Suitability of the Study Area

As a rough guide, deep groundwater systems and/or anoxic groundwater, groundwater EC exceeding 3000 µS/cm, or outside pH 4.3 to 8.5 are thought generally to be unsuitable for stygofauna (**Table 3-3**).

Comparison of these findings with measures of the groundwater quality in aquifers in the Study Area suggest that conditions for stygofauna would be suitable, particularly within perched swamp and Hawkesbury sandstone aquifers, where EC and pH were measured well within ranges considered suitable. It is possible that stygofauna occur in these aquifers, and are more likely to occur in those that retain groundwater during extended periods of low rainfall. It is possible that dryer swamp systems that retain groundwater for a relatively short period following rainfall may not provide suitable habitat for stygofauna, particularly as there is some indication that stygofauna are susceptible to lowering of the water table and desiccation and are dependent on a permanent source of high quality groundwater. Due to the somewhat restricted nature of these perched swamps any associated stygofauna communities could also be restricted.

Table 3-3 Summary of Chemical and Physical Conditions considered Suitable for Stygofauna

Characteristic	Reported Conditions Conducive to Stygofauna	Characteristics of Known Aquifers in the Study Area			
		Perched Swamp	Hawkesbury Sandstone (mean)	Bulgo Sandstone (mean)	Coal Measures (mean)*
Electrical Conductivity (EC)(µS/cm)	< 3,000[1] < 5,000[2]	60 to 130	614	581	1,891 to 2,169
pH	Known range: 4.3 to 8.5 units[2]	4 to 6	6.8	8.4	7.7 to 9.1
Dissolved Oxygen (DO)	> 0.3 mg/L[2] (approximately < 3 % saturation)	50 to 100 % saturation	n/a	n/a	n/a
Depth of groundwater body	< 10 m bgl, rarely found > 100 m bgl	< 10 m bgl	up to 120 m bgl	150 m to 250 m	200 m to 400 m bgl
Geology	Presence of 1 mm or greater size cavities and interstices. Occur occasionally in coal seam aquifers[2]	> 1 mm due to loose accumulations of unconsolidated sediments and biotic material	Likely > 1 mm due to relatively small degree of compression near the surface	Likely <1 mm, due to depth and thus degree of compression from overlaying units	Likely <1 mm, due to depth and thus degree of compression from overlaying units
Hydraulic Connectivity	More abundant in areas of surface water-groundwater exchange, compared with deeper areas or those further along the groundwater flow path remote from areas of exchange or recharge.	Relatively large amount of hydraulic exchange due to exposed location at the surface.	Relatively large degree of hydraulic exchange due to location at (i.e. outcrops) or near the surface, though this would be patchy depending on location and depth. Mean effective porosity 11.3 %[3]	Relatively small amount of exchange due to depth and presence of overlying units. Mean effective porosity 3.3 %, All other geological unites ≤ 1.5 %[3]	Relatively small amount of exchange due to depth and presence of overlying units

Hancock and Boulton (2008) in (ALS 2010)[1], ACARP (2015)[2], Watershed HydroGeo (2022)[3], below ground level = bgl. *values measured in goaf (mine void) water and mine seepage and may be influenced by water from any aquifer associated with Wongawilli sandstone formation, n/a data not available.

Though still within reported tolerances of stygofauna, the pH in Bulgo sandstone and coal measure groundwater, and EC in the coal measure were found more towards the extreme of the suitable range, and may be relatively less suitable for stygofauna. The relatively small size of cavities and low porosity of the Bulgo sandstone and coal measures further suggests they would be unsuitable for stygofauna. In particular, coal seams in Area 5 are 200 m to 400 m deep, with stygofauna rarely found more than 100 m below ground level (ACARP 2015). In addition, while current research suggests that shallow alluvium groundwater systems associated with moderate to large rivers tend to support a greater diversity and abundance of stygofauna, there is very little alluvial material in the Study Area (Watershed HydroGeo 2022).

A total of 22 swamps have been mapped within 600 m of the proposed longwalls in Area 5 (**Figure 3-4**). It is possible stygofauna may be present within the perched aquifers associated with these swamps. The suitability of this habitat would depend on the permanence of water within the aquifers, and the degree to which habitats dry during periods of drought. Aquifers that experience substantial and frequent reductions in water levels and volume would be less suitable as habitat for stygofauna. Water levels in groundwater bores in a selection of these swamps have all dropped below zero since they were constructed. However, this does not necessarily indicate that the associated aquifers dried completely as the bores may not access the deepest part of the aquifer available to stygofauna. Thus, although large fluctuations in water levels in these swamps may limit their value as stygofauna habitat, they may provide some habitat refuge during extended dry periods.

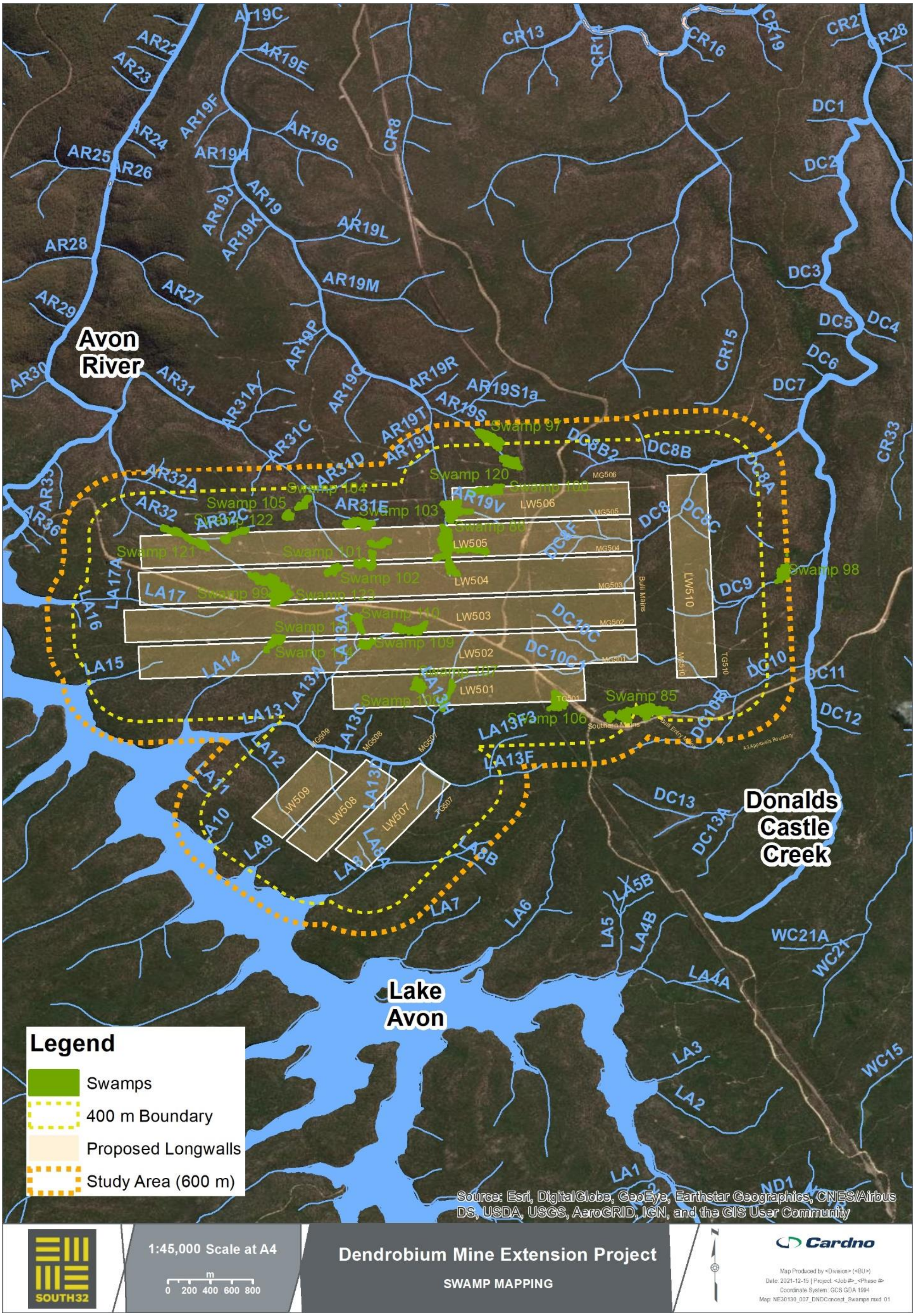

Figure 3-4 Swamps Mapped within the Study Area.

3.10 Existing Mining Impacts

3.10.1 Watercourses

Cardno (2018b) undertook a review of existing mining impacts that have occurred due to previous and existing mining in the upper Avon and Cordeaux River catchments. These include the following mining in the Metropolitan Special Area:

> Longwall mines: Dendrobium Areas 1, 2, 3A, 3B, Longwalls 9 to 13, Elouera Mine, Cordeaux Mine, Kemira Mine; and

> Bord and pillar mines: Nebo Mine and Wongawilli Mine.

Subsidence induced impacts (fracturing, flow diversions and/or reductions in pool water levels) have been observed in watercourses overlying each of the previous underground mining areas. To provide an indication of the cumulative impact of these mines on aquatic ecology in these and the upper Avon and Cordeaux River catchments, the length of watercourse known or expected to experience subsidence related impacts was calculated by IMC. As of January 2022, of the 716 km of watercourses (first order and above) mapped within the upper Avon and Cordeaux River catchments, direct mining impacts (fracturing, flow diversions and/or pool water loss) had or were highly likely to have occurred in approximately 38.6 km of watercourses located directly above longwall mining. This included first, second and higher order streams within the Wongawilli, Sandy and Donalds Castle Creek catchments.

Some of the most recent impacts observed (associated with mining in Area 3) include fracturing, flow diversions and reductions in pool water levels in SC10C (a tributary of Sandy Creek) and WC17 (a tributary of Wongawilli Creek) in Area 3A. Fracturing of bedrock and flow diversions have also been experienced in WC15, which is also within the current Study Area. In each case, there was an associated loss of aquatic habitat and likely also biota. Impacts occurring in SC10C were assessed in detail in Cardno Ecology Lab (2015). Fracturing of bedrock and reductions in pool water levels and flow occurred here in December 2011, and in early 2013 low pool water levels were evident throughout SC10C. These changes were attributed to the extraction of Longwalls 7 and 8 which took place below SC10C and the adjacent area between May 2011 and December 2012. During the 2013 and 2014 aquatic ecology surveys, the only water present in SC10C was a small, shallow pool at Site 13. The complete drainage of all but one pool in SC10C resulted in a direct loss of aquatic habitat and likely some biota. Other impacts to aquatic ecology associated with the physical impacts include the loss of longitudinal connectivity. The impact to aquatic ecology due to desiccation of aquatic macrophytes was considered minimal, as very little in-stream aquatic vegetation has been identified in SC10C. A reduction in abundance of Leptoplebiidae (a pollution sensitive Family of mayfly in the Order Odonata) and an increase in abundance of Chironomidae (consisting of three pollution tolerant Subfamilies: Chironominae, Orthocladiinae and Tanypodinae) was also detected, indicating associated impacts to aquatic biota. The impacts to aquatic ecology observed in SC10C were localised to the areas directly affected by physical mining impacts and were considered relatively minor in the context of the Cordeaux River catchment. More recently in November 2019 as part of investigations for the Longwall 19 impact assessment, observations of SC10C by Cardno suggested some recovery in flow and pool water levels.

Approximately 86 km of watercourse is located above previous bord and pillar mining. Based on observations of impacts due to longwall mining there is potential for these to have also experienced direct subsidence related impacts similar to that experienced above longwall mining. The most severe watercourse impacts described above (fracturing and flow diversions resulting in part or complete drainage of pools and loss of surface water) tend to occur when watercourses are directly mined under. However, such impacts may also occur in watercourses that are not directly mined under. A further 23 km of watercourse located directly downstream of longwall mining is expected to have experienced indirect impacts (including reductions in pool water levels and flow). Fracturing of rockbars was observed in Donalds Castle Creek, LA4 (tributary of Lake Avon) and WC15 100 m to 300 m from longwalls in Area 3B. Fracturing has been observed up to approximately 400 m outside of previously extracted longwalls in the Southern Coalfield (Mine Subsidence Engineering Consultant [MSEC] 2022).

Collectively, the length of watercourse that has experienced indirect and direct mining impacts (147.6 km) is estimated to be 21% of that present in the upper Avon and Cordeaux River catchments (717 km). The majority of this would be first and second order drainage lines. However, impacts of groundwater depressurisation have been observed in Wongawilli Creek. During inspections in May 2018, a reduction in flow and a series of disconnected pools were observed within an approximate 1,400 m section of Wongawilli Creek and representing about 10% of the total 12 km length of Wongawilli Creek. This section included Pool 44 to Pool 53. Surface flow was observed just downstream of the confluence with Wongawilli Creek tributary WC21. Although fracturing in one rockbar at Pool 43a in Wongawilli Creek was observed during extraction of Longwall 9 in December 2012, this is not considered to be the cause of the reduced flow and reduction in pool water levels here. Rather, assessment of flow and water level data with rainfall and rates of pool water recession from before and after commencement of mining and the timing of fracturing suggest mining induced groundwater depression coinciding with low rainfall explain the low flow and water levels observed in Wongawilli Creek (HGeo 2018). Low pool water levels were not restricted to Pool 43a but were also observed in Pool 49. Pool water levels also begun to decline 2 years before the fracture was observed. The pool recession rate, calculated as the decline in pool level between consecutive observations averaged over the number of days, was not greater after the observation of the fracture. Mining is considered to be the primary cause of reductions in groundwater levels in the lower Hawksbury Sandstone and upper Bulgo Sandstone. This has contributed to a reduction in baseflow in Wongawilli Creek, which was most noticeable during periods of low rainfall and greater evapotranspiration that occurred in 2018. Extraction of each individual longwall would be expected to contribute to reductions in groundwater levels. HGeo (2018) estimated baseflow capture of approximately 0.3 megalitres per day (ML/d) in Wongawilli Creek, this would be a significant fraction of flow under conditions of very low rainfall such as those that have occurred during 2018 with typical surface flow below 1 ML/day (HGeo 2018). It is noted that no significant mining effect on surface flow in Wongawilli Creek was apparent approximately 3 km downstream at the Wongawilli Creek gauge.

Pool water levels and flow are also restored following rainfall events, thus impacts to the availability and connectivity of aquatic habitat is temporary. During aquatic ecology surveys throughout 2019, water and flow was present in the sections of Wongawilli Creek previously affected by reductions in water levels and flow, albeit water levels appeared reduced slightly during the current survey in November 2019. Nevertheless, temporary reductions in flow and pool water levels would be expected to affect aquatic biota. Such as the changes observed in SC10C in the Sandy Creek catchment. Changes in the abundance of several macroinvertebrate taxa have also been observed in WC21 and Donalds Castle Creek and have been attributed to reductions in pool water levels observed here (Cardno 2018a). Temporary reductions in longitudinal connectivity would also be expected to affect fish and aquatic macroinvertebrates by limiting movement in search of food and refuge. It may also result in reduction in genetic transfer, particular if it coincides with migration as part of reproduction. Species of freshwater eel (*Anguilla* sp.), for example, undertake long distance reproductive migration that could be hindered during times of low flow and pool water level. As well as direct habitat loss, associated reductions in water quality could also affect the type and number of macroinvertebrates and other aquatic biota (fish, large mobile invertebrates and aquatic macrophytes) in watercourses. However, the changes in water quality observed that are associated with mining (reduced DO and elevated EC) have been relatively minor. Changes in macroinvertebrates appear to be localised to the areas of watercourse directly affected by physical mining impacts and habitat loss. They do not appear to persist downstream once water reappears (Cardno 2018a).

3.10.2 Swamps

Previous mining in the upper Avon and Cordeaux River catchments has affected swamps overlying these underground mining areas. To provide an indication of the cumulative impacts of these mines on swamps in the catchments, area of swamp known or expected to experience subsidence related impacts was calculated by IMC.

Previous longwall and bord and pillar mines have impacted approximately 5 square kilometres (km^2) or 35% of the total 14.3 km^2 of swamp habitat within the upper Avon and Cordeaux River catchments. Longwall mining in Areas 1, 2, 3A, 3B at the Dendrobium Mine resulted in increased rates of groundwater recession, reduced soil moisture, reductions in size and/or changes in the vegetation community in swamps. Following extraction of Longwalls 9 to 12 in Area 3B, each overlying swamp (at least those monitored: Swamps 1a, 1b, 3, 5, 8 and 10) experienced reductions in shallow groundwater. Reductions in soil moisture was observed in Swamps 5, 8 and 11 (BHP Billiton Illawarra Coal [BHPBIC] 2015, South32 2016b, 2017*)*. Examination of shallow groundwater levels in swamps suggests reductions of up to 1 to 2 m in groundwater levels following longwall extraction. Water levels generally return to baseline levels following large rainfall events, but only for short periods of time (several days following the rainfall event).

Monitoring results of shallow Hawkesbury sandstone aquifers adjacent to swamps or perched aquifers within swamps suggest that the Dendrobium Mine has impacted each swamp that has been mined under and each immediately adjacent swamp (Advisian 2016).

3.11 Summary

The findings of the current and previous investigations indicated that aquatic habitat in drainage lines within the Study Area is relatively limited. This habitat comprises relatively small (in terms of length, catchment size and area of aquatic habitat) first and second order drainage lines of Donalds Castle Creek, Avon River and Lake Avon. These drainage lines support semi-permanent pools that would retain water for some time after rainfall and provide habitat for aquatic biota and have been largely unaffected by mining. The current and previous investigations indicate that the aquatic ecology in sections of these watercourses in the Study Area are comparable with that present throughout the larger catchment area.

Though some of the biotic indices derived from AUSRIVAS aquatic macroinvertebrate sampling in watercourse adjacent to the Study Area indicative of degraded habitat or water quality, these more likely reflect natural conditions and the naturally low pH of stream water within the catchment, rather than any anthropogenic disturbance. DC8 and LA13 provide the most substantial habitat for native fish, aquatic plants and macroinvertebrates in the Study Area. Macquarie Perch (listed as Endangered under FM Act and EPBC Act) is likely to be present in Lake Avon. The presence of natural barriers and lack of suitable large pool habitat in drainage lines in the Study Area and in Donalds Castle Creek suggests it is very unlikely to occur in these watercourses. Other threatened species (Australian Grayling, Adam’s Emerald Dragonfly and Sydney Hawk Dragonfly) do not, or are highly unlikely to, occur in the Study Area. There is very little evidence of invasive plant species instream or within the riparian zone.

4 Impact Assessment

4.1 Mine Layout Design

A number of longwall design constraints have been incorporated in the underground mining layout for the Project to reduce potential environmental impacts. These were included based on previous mining experience at the Dendrobium Mine and key stakeholder feedback. The layout of longwalls in Area 5 has been designed to avoid or minimise impacts on a number of key features (including third order and above watercourses). For the Project the mine layout would include:

> No predicted connective fracturing from the seam-to-surface when using the Tammetta equation;

> No longwall mining beneath 3rd, 4th and 5th order (or above) streams;

> Avoidance of longwall mining beneath identified key stream features (setbacks of 50 m when longwall mining will occur on one side of the "key stream feature" or 100 m when longwall mining will occur on more than one side);[2]

> Distance of at least 400 m from named watercourses (i.e. the Avon River, Cordeaux River and Donalds Castle Creek);

> Minimum longwall mining setback distance of 300 m from the Full Supply Level of the Avon Dam;

> Minimum longwall mining setback distance of 1,000 m from dam walls;

The predicted subsidence impacts of the proposed longwalls in Area 5 is less than that predicted for the existing and approved longwalls in Area 3B and Area 3C, as well as predicted subsidence impacts of the previous application.

4.2 Impacts on Aquatic Ecology

Longwall mining-related ground movement can impact landscape features in a number of ways, including subsidence of uplands, plateaus and ridge tops, reductions in groundwater level, bulging of incised valleys and gorge walls and upward strain of creek and river beds. Valley closure and down slope movements associated with incised valley and gorge walls can in turn result in the erosion of slopes, mobilisation of sediment and its deposition in watercourses. The upsidence and closure caused by valley bulging can also lead to the fracturing of the substratum of creeks and rivers and result in changes to the stream morphology, such as the draining of pools, increased or decreased ponding, scouring and subsurface flow diversion. These changes in turn, can impact upon the aquatic ecology through loss of habitat, desiccation, sedimentation, stream discontinuity, and deterioration in water quality due to leaching of minerals through fractured bedrock or groundwater inflows. Fracturing can also result in changes in the habitat provided by perched and fractured rock aquifers with associated impacts to biota that depend on groundwater resources, including stygofauna. Cumulative impacts have also been addressed.

4.2.1 Aquatic Habitat

Avon River, Cordeaux River, Donalds Castle Creek and Wongawilli Creek are all located outside the extent of the proposed longwalls. MSEC (2022) indicated Avon River, Cordeaux River, Wongawilli Creek or Donalds Castle Creek are not expected to experience measurable conventional subsidence effects. The sections of Avon River and Donalds Castle Creek located closest to the proposed mining area could experience low-level valley-related effects, however, it was considered unlikely that these named watercourses would experience adverse physical 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) based on their distances from the proposed mining area. There would also be negligible changes to flow in these watercourses and water levels in Lake Avon due to any groundwater depressurisation associated with extraction of the proposed Area 5 Longwalls (Watershed HydroGeo 2022). Associated impacts to aquatic habitat in these watercourses is thus expected to be negligible.

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[2] (defined as pools with volumes greater than 100 m^3 and waterfalls with heights greater than 5 m and with a pool at the base) (MSEC 2022).

The third order sections of the streams are predicted to experience less than 20 mm vertical subsidence. While these sections of stream could experience very low levels of vertical subsidence, they are not expected to experience measurable conventional tilts, curvatures of strains. Fracturing could occur along the third order sections of drainage lines within 400 m of the proposed mining area (DC8 and LA13). 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 (significant fracturing associated with flow diversions). At total of 1.7 km of third order drainage line habitat is located within 400 m of the proposed longwalls in Area 5, however no third order steams would be beneath the proposed longwalls for the Project. First and second order drainage lines located directly above the proposed longwalls are expected to experience the full range of predicted subsidence effects. Although the maximum predicted changes in grade along first and second order drainage lines are similar to the natural gradients, it is expected that fracturing of bedrock may occur along the sections of the first and second order streams that are located directly above and adjacent to the proposed longwalls. The majority of the pools along the first and second order streams located directly above the proposed longwalls in Area 5 may experience fracturing and flow diversions. Fracturing also possible in these drainage lines up to 400 m away. Approximately 13 km and 19 km of first/second order drainage line, respectively, is located directly above and within 400 m, respectively, of the proposed longwalls.

Fracturing in third, second and first order drainage lines may result in diversion of flows into underlying strata. This would cause drainage of nearby pools and loss of surface water from the affected areas, with potential for complete loss of surface water from the drainage lines directly above the longwalls. If fracturing occurs, it could cause localised reductions in the availability of aquatic habitat The extent and severity of any associated reductions in aquatic habitat would depend on the size, extent and location of fractures, though minor changes in pool water levels and flow are not expected to have any more than minor or negligible associated impacts to aquatic habitat at the catchment scale. The loss of water from larger pools (such as those identified in third order drainage lines within 400 of the proposed longwalls) would impact the availability of aquatic habitat at the scale of individual pools and drainage lines. At the scale of the Avon River and Cordeaux River catchment, however, associated changes in the availability of aquatic habitat that would occur would be minor, due to the limited value of habitat within the drainage lines (compared to larger and more permanent watercourses such as Donalds Castle Creek and Wongawilli Creek). Due to largely ephemeral/intermittent flow and naturally disconnected pool habitat for the drainage lines, any further reduction in connectivity of aquatic habitat in these drainage lines is expected to result in minor impact to aquatic ecology.

The abundance of drainage line habitat in the wider catchment would also suggest such impacts would be very small to negligible in the context of the wider catchment area. Notwithstanding, the total length of first, second and third order drainage line habitat (approximately 33 km) directly above and within 400 m of the proposed longwalls represents approximately 4.6% of drainage line habitat present within the upper Avon River and Cordeaux River catchments. Together with the length of comparable drainage line habitat directly and indirectly impacted due to previous longwall mining, this would represent potential impacts to approximately 95.0 km (13.3%) of such habitat within the upper Avon River and Cordeaux River catchments due to longwall mining. It is noted that third order watercourses are not located directly above the proposed Area 5 longwalls, and that only 15 % of the stream controlling features (i.e. rockbars, steps and other controlling features) in third order watercourses located within 400 m of the proposed longwalls are predicted to experience Type 3 impacts (significant fracturing associated with flow diversions) (MSEC 2022). There is potential for cumulative impacts with previous bord and pillar mining in the vicinity of the Project (approximately 86 km of drainage line habitat previously mined beneath using bord and pillar mining).

Minor and localised impacts on riparian habitat are expected. There may be some die-back of fringing aquatic vegetation following flow diversions and drainage of pools and subsidence induced rockfalls could damage some vegetation. However, riparian vegetation is abundant throughout the Study Area and wider catchments and the loss of a small amount is expected to have negligible impacts on aquatic ecology. Some minor clearing will be undertaken to facilitate access road construction/upgrades, though again such areas would be a very small proportion of that present in the Study Area and wider catchments.

There would be negligible changes to water levels in Lake Avon due to any groundwater depressurisation associated with extraction of the proposed longwalls in Area 5 (Watershed HydroGeo 2022). 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 (HEC 2022).

Baseflow reduction associated with longwall mining in Area 5 is likely to result in 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/day (Hydro Engineering & Consulting Pty Ltd [HEC] 2022). Impacts to flow in drainage lines is expected to be indistinguishable from natural variability given their natural intermittent flow and that their flow is largely or wholly derived from rainfall and surface run-off. In any case, first and second order drainage lines located directly above, and potentially up to 400 m of the proposed longwalls are expected to experience the full range of subsidence effects (e.g. induced fracturing, flow diversions and reductions in availability of aquatic habitat) (MSEC, 2022). Impacts to aquatic habitat and ecology in these watercourses (first and second order drainage lines) due to groundwater depressurisation are expected to be minor in comparison to predicted impacts associated with subsidence induced fracturing. The Project would not directly mine beneath third order sections of drainage lines and a low rate of fracturing (15 % of flow controlling features) is expected in third order drainage lines within 400 m of the longwalls. At further distances (minimum distance of 550 m for AR32), it is considered unlikely that physical impacts would occur along the third order drainage lines (MSEC, 2022). Notwithstanding, there would be an increase in the proportion of zero-flow days in Donalds Castle Creek, which is located outside the 400 m boundary, with 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). This would likely result in a reduction in the connectivity of aquatic habitat and pool levels in Donalds Castle Creek during drought conditions. However, flow and pool water levels would return to normal soon after rainfall, and associated impacts to availability of aquatic habitat are expected to be localised to the area of creek adjacent to the proposed longwalls, short-term and minor. Flow in Avon River is maintained by discharge from Lake Avon, and it is very unlikely that groundwater depressurisation would result in noticeable changes in aquatic habitat in Avon River. Associated impacts to availability of aquatic habitat in Avon River are expected to be negligible.

Given the proposed Cordeaux River pumping station option would consist of temporary floating pumps, it is not expected there would be any significant impact on aquatic habitat, with any impacts being localised and temporary and overall of minor consequence. The Cordeaux River substratum and banks in this location is also predominantly bedrock and boulder, which would not be susceptible to any erosion and suspension of river sediment due to localised changes in hydrology during temporary pumping.

4.2.2 Biota

Overall, impacts to aquatic biota in Lake Avon, Avon River, and Donalds Castle Creek (as well as Cordeaux River, Wongawilli Creek and Lake Cordeaux) are not expected as these watercourses would not experience fracturing or flow diversions (**Section 4.2.1**). In drainage lines, the drainage of pools or rapid drop in stream flow due to fracturing induced flow diversions have potential to have localised, significant impact on aquatic biota, particularly on organisms that are left stranded in air or unable to move to areas that are damp or submerged. Aquatic plants and sessile animals are particularly vulnerable to desiccation, because of their inability to move elsewhere to other available habitat. The survival of mobile organisms is difficult to predict, because it depends on their tolerance and response to desiccation, and rapid changes in water level, ability to move, weather conditions, the underlying substratum and duration of exposure. Although of relatively limited value to aquatic ecology, compared with the aquatic habitat present in larger watercourses in the Dendrobium Mine area, drainage lines would still support fish, such as galaxiids, macroinvertebrates including freshwater crayfish and several species of frogs (Niche 2022). The loss of this habitat due to fracturing and flow diversions would impact these species via reductions in their population size and area of occupancy. These drainage lines, however, are highly unlikely to provide habitat for the threatened Macquarie Perch, Sydney Hawk Dragonfly and Adam’s Emerald Dragonfly (**Section 4.2.5**). It is difficult to quantify the absolute impacts to biota associated with drainage lines, though based on the length of watercourses habitat that would be lost due to the proposed longwalls, a 4% reduction in population size of drainage line associated aquatic biota could be expected within the upper Avon River and Cordeaux River catchments. This would be in addition to the loss of similar habitat expected to be lost due to previous and planned mining activities (**Section 3.10**).

Potential impacts to water quality as a result of the predicted subsidence effects associated with the Project would be localised and minor (HEC 2022). 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 dams in the Southern Coalfield.

Localised increases in sediment load in the water due to mine-induced erosion, reductions in DO levels and increases in acidity and metal concentrations, resulting from the diversion of sub-surface flows and weathering or leaching of minerals may impact on aquatic biota. As mining-induced erosion is predicted to be localised and short-term and limited to drainage lines overlying the proposed longwalls, impacts on biota are likely to also be minor, localised and short-term. Also, there are likely to be negligible impacts on primary productivity in drainage lines due to the general absence of aquatic plants in these watercourses. The weathering of freshly exposed fractures in the sandstone rocks could result in minor, localised, transient increases in salinity and concentrations of iron, manganese, aluminium, zinc and nickel, and decreases in DO levels. Increases in iron staining could result in smothering of the substratum and sessile biota, but this would only extend a short distance (< 1km) downstream from where surface water flow re-emerges. The diversion of surface water into sub-surface layers could affect the quality of the water in the drainage lines at and immediately downstream of the point where surface flows return. These effects are expected to be localised. Changes in oxygen level (e.g. DO) due to mining are predicted to be minor, localised and short-term and are therefore likely to have only a low impact on aquatic biota.

Acidic waters with high aluminium concentrations are known to be ecotoxic to a wide range of aquatic species, including benthic macroinvertebrates and fish (Tessier and Turner 1995; Herrmann 2001). Localised acidification from strata diversion would not be expected to cause any more than minor, localised and short-term impacts to aquatic ecology.

The negligible changes in aquatic habitat that would occur due to predicted changes in flow in Avon River, Cordeaux River, and Wongawilli Creek associated with the Project are not expected to result in any more than negligible impacts to associated aquatic biota in these watercourses. The increase in zero flow days in Donalds Castle Creek near the eastern end of Area 5 Longwalls could result in reductions in the availability and connectivity of aquatic habitat during drought conditions. However, aquatic refuge should remain for some time, and flow would return soon after rainfall. Such impacts would be localised and temporary and result in relatively minor impacts to aquatic habitat and biota in Donalds Castle Creek.

If the proposed pump and water extraction from Cordeaux River was the option selected for water supply for the construction of Shaft Site No. 5A, it is not expected to result in significant impacts to native fish in Cordeaux River. The water velocity at the pump intake would be approximately 0.3 m/s. The pump would also include a 5 mm aperture mesh screen approximately 2 m from the pump intake. At this distance, the water velocity at the screen would be approximately 0.1 m/s. In a laboratory study investigating entrainment and impingement of Australian native fish golden perch (*Macquaria ambigua*) and silver perch (*Bidyanus bidyanus*) (albeit these species are not present in Cordeaux River), Boys et al. (2012) found that water velocity (measured at 8 cm from a perforated 3 mm mesh size aluminium screen) of up to 0.4 m/s approaching the screen and of 1.5 m/s through the screen was effective in reducing entrainment of juveniles of these species. There was also very little injury or mortality resulting from incidental screen contacts or impingement. This study also indicated that velocities less than 0.5 m/s have great potential for reducing entrainment of a wide range of species and size ranges of fish in the Murray Darling Basin. However, field observations of an assemblage of fish at a screen in a river demonstrated that even modest increases in approach velocity (from 0.1 m/s to 0.5 m/s) produced a significant increase in the rate of screen contact for fish smaller than 150 mm, with the impact being more marked the smaller fish were. Boys et al. (2012) recommended that approach velocities for Murray-Darling Basin fish, at least, should not exceed 0.1 m/s. This was provided as a precautionary measure, as there was some uncertainty if the reported approach velocities are applicable to all fish species and life history stages. It was also recommended, that in the absence of screening criteria for Australian freshwater fish, designs should aim to minimise fish entrainment by optimising approach velocities. The results of this study suggested that approach velocity, rather than mesh size, appeared to be more important in minimising fish entrainment. Although these findings focussed on Murray-Darling Basin species, they do indicate that the proposed approach velocities in Cordeaux River would have minor potential impacts for native fish species here. Potential impacts to native species would also be limited due to the temporary nature of the pump and that there would be no direct impact to fish habitat due to its floating design.

4.2.3 Key Fish Habitat

Impacts to the Lake Avon Type 1 – Highly Sensitive KFH are not expected given there would be no subsidence-induced impacts to water levels or quality in Lake Avon. Approximately 2.2 km of Type 2 – Moderately Sensitive KFH in third order drainage lines is located within 400 m of, but not directly above, the proposed longwalls. This habitat could be lost due to subsidence-induced fracturing and diversion of flow . However, at the scale of the upper Avon River and Cordeaux River catchments, the loss of this KFH would be relatively minor. First and second order drainage lines are not classified as KFH and therefore, there would be no loss of KFH in these watercourses directly above the proposed longwalls. The proposed Cordeaux River pumping option would consist of temporary floating pumps, which would not be expected to impact KFH in the river.

4.2.4 Stygofauna

The findings of previous studies, particularly those undertaken in the nearby Kangaloon Borefield, suggest that stygofauna are likely also present within the perched water and fractured shallow Hawkesbury sandstone aquifer in the Study Area. As the information on likely occurrence of stygofauna in the Study Area is based on inference using data from Kangaloon Borefield, and information on the distribution of stygofauna within NSW aquifers generally is sparse, a conservative assessment approach has been adopted. Therefore, it is predicted that stygofauna are likely to occur in shallower fractured sandstone (i.e. Hawkesbury) and perched swamp aquifers within the Study Area. The conservative approach is justified as information on the hydrogeological regime of these aquifers in the Study Area does not preclude the presence of stygofauna (**Section 3.9.3**). Stygofauna are threatened by activities including: change in the quality or quantity of groundwater, disruption in the connectivity between different aquifers and between aquifers and surface systems, or removal of soil pores. Stygofauna appear unlikely to occur in aquifers associated with the deeper Bulgo Sandstone and the coal measures in the Study Area. Thus, impacts to stygofauna due to disturbance of deep aquifers associated with Bulgo Sandstone and the coal measures during mining are not expected. The Hawkesbury sandstone aquifer extends over an approximate area of more than 200 km by 100 km (Liu *et al*. 1996). Based on this comparison, any potential impacts to stygofauna in shallow Hawkesbury sandstone within the Study Area would be minor relative to the extent of possible stygofauna habitat in the aquifer as a whole.

Impacts to stygofauna associated with perched swamp aquifers will also depend on the permanence of water in swamps during extended dry periods. If a swamp were susceptible to complete drying during extended periods of low rainfall, then it may not support a permanent stygofauna assemblage. Examination of shallow groundwater levels in swamps in the Study Area by HEC (2022) indicate that water levels in the majority of swamps drop to the underlying bedrock during periods of low rainfall. While this indicates periodic complete drying of the majority of swamps making them unsuitable as stygofauna habitat, it is possible that some water may be retained for some time in areas not accessed by the existing bores. Even if the soil were to remain moist with no standing water detectable, this may be sufficient for at least some stygofauna to survive until water levels could be recharged during rainfall. Thus, periodic drying of some bores does not necessarily indicate that the swamp does not support a stygofauna assemblage, though such swamps may provide somewhat limited stygofauna habitat. As a result of proposed longwall mining and predicted subsidence induced fracturing of bedrock below swamps, HEC (2022) predicted swamp water levels are likely to fall more rapidly during prolonged dry periods and take longer to recover following rainfall events, however the swamps will still exhibit wetting and drying cycles in response to rainfall.

Such changes would be expected to make these areas less suitable for stygofauna. An indication of the impact to the stygofauna population in the upper Avon River and Cordeaux River catchments can be provided by examination of upland swamp habitat to be impacted by mining. The area of swamp habitat that would be mined beneath and expected to experience direct impacts due to extraction of the proposed longwalls is 0.27 km^2 or 1.9 % of the total area of pre-mining swamp habitat within the upper Avon River and Cordeaux River catchments (**Section 3.10.2**). While this is a small proportion of the total swamp habitat, it is estimated that 5 km^2 of swamp habitat (or 36 %) of the pre-mining swamp habitat has been mined under by previous longwall and bord and pillar mining. Together with the area expected to be impacted by approved longwalls in Area 3 (0.58 km^2), the cumulative impacts to swamp habitat within the upper Avon and Cordeaux River catchments due to previous and proposed mining would be 6 km^2 or 43% of the pre-mining area of swamp habitat. In a regional context, the cumulative area of potentially impacted swamp habitat in the upper Avon and Cordeaux River catchments represents a relatively small (approximately 9%) proportion of the approximate 6,445 km^2 swamp habitat mapped within the Woronora, O'Hares and Metropolitan Catchments (covering the catchments of Nepean, Avon, Cordeaux, Cataract and Woronora rivers and O'Hares Creek) (NSW NPWS 2003). This would suggest that at a regional scale, such impacts would be minor. It is unclear, however, if all these swamps and types of swamp (banksia thicket, tea-tree thicket, sedgeland-heath complex, fringing eucalypt woodland and mallee-heath upland swamps) included in the mapping would be associated with stygofauna and whether these areas were or have since been disturbed by non-project activities.

The assessment of impacts to stygofauna is limited due to an absence of information on their extent within the local and regional area and absence of detailed information on the ecology of these fauna. However, based on the availability of information, it could be expected that there would be a reduction in the extent and population size of stygofauna in the Study Area. Based on comparison with the amount of swamp habitat in the regional area (approximately 9 % of the swamp habitat within the Woronora, O'Hares and Metropolitan Catchments [NSW NPWS 2003]) and extent of the Hawkesbury sandstone aquifer (more than approximately 200 km by 100 km [Liu *et al*. 1996]), potential impacts would be expected to be relatively minor. However, such a comparison is made with caution given the uncertainty surrounding the suitability of the various swamp types as habitat for stygofauna.

4.2.5 Threatened Species

Macquarie Perch is known to occur in Avon River, Cordeaux River, and has potential to occur in Lake Avon and Lake Cordeaux. As such, impacts to this species were assessed via an Assessment of Significance under the FM Act and using Significant Impact Criteria under the EPBC Act (**Appendix B**). Although Macquarie Perch have potential to occur, significant fracturing resulting in flow diversions and impacts to water quality are not expected in the Avon River or Lake Avon (**Section 4.2**). If implemented, the proposed pump and water extraction in Cordeaux River would be floating and temporary, would be screened with mesh and would include relatively low approach water velocities. Thus, it is very unlikely there would be a significant impact on the Macquarie Perch due to the Project and a SIS is not recommended.

There are no records of Sydney Hawk Dragonfly and Adam's Emerald Dragonfly within, or adjacent to the Study Area despite extensive sampling, though suitable microhabitat may exist in creeks and drainage lines. As a conservative approach, impacts to these species were assessed via an Assessment of Significance under the FM Act (**Appendix C** [Sydney Hawk Dragonfly] and **Appendix D** [Adam's Emerald Dragonfly]). Sydney Hawk Dragonfly and Adam's Emerald Dragonfly are unlikely to occur in the Study Area. If a viable population of Sydney Hawk Dragonfly or Adam's Emerald Dragonfly exist, it is highly unlikely that the proposed mining operations would have any significant impact on these species.

Australian Grayling does not occur in the Study Area and therefore impacts to would not occur.

5 Recommendations

Four approaches are recommended to be used for aquatic ecology impact minimisation and management within the Study Area:

> Impact minimisation;

> Aquatic ecology monitoring;

> Additional aquatic ecology studies (including studies that would be triggered by specific impacts on physical and water quality characteristics of the watercourses); and

> Contingency measures should impacts exceed predictions.

5.1 Minimisation

The design of the Project includes measures to minimise potential impacts on aquatic ecology, including consideration of feedback from key stakeholders. These include:

> significantly reducing predicted peak annual surface water losses by approximately 78% (from the previous application);

> protecting the Avon Dam and dam wall through minimum longwall mining setback distances of 1,000 m from the dam wall and 300 m from the Full Supply Level;

> no longwall mining beneath 3rd, 4th and 5th order (or above) streams;

> longwall mining distance of at least 400 m from named watercourses(i.e. Avon River, Cordeaux River and Donalds Castle Creek);

> reducing the number of swamps (listed as threatened) longwall mined beneath by approximately 40%; and

> no longwall mining beneath identified key stream features.

Temporary erosion and sediment control measures such as sediment fences, sandbag weirs, temporary drains and temporary silt traps would be installed prior to any minor surface works (e.g. road construction and clearing of vegetation) in the vicinity of watercourses and swamps to prevent the input of sediment into watercourses and perched aquifer systems during rainfall events.

5.2 Monitoring Plan

5.2.1 Outline and Aims

An aquatic ecology monitoring program would be implemented to:

> Determine the nature and extent of any subsidence-induced impacts on aquatic ecology due to the extraction of longwalls in Area 5; and

> Assess the response of aquatic ecosystems to any stream remediation and management works implemented.

Previously, a comprehensive monitoring plan designed to assess the potential impacts of mine subsidence on aquatic habitat and biota within watercourses of Area 3 was outlined in The Ecology Lab (2007). The monitoring plan indicated that baseline sampling would be conducted in impact and control locations quarterly prior to the commencement of longwall mining and that during-extraction and post-extraction monitoring would be undertaken at the same seasonal periods to determine the extent and nature of any impacts and recovery. The plan also advocated a temporally staged monitoring approach be adopted and that impact and control locations relevant to each of Areas 3A, 3B and 3C be monitored over a 12-month period prior to that area's development. The strategic review of the impacts of underground mining in the Southern Coalfield, recommends that baseline studies be conducted at sufficient intensity over a minimum period of 18 to 24 months to gain a better understanding of the variability and seasonality in distribution of flora and fauna, prior to any mining activity (NSW DoP 2008). The review also recommended that replicate surveys be undertaken at sites directly above the mine and at comparable control sites outside the direct impact zone, so that changes and fluctuations due to mining can be distinguished from those due to natural variability. As such, a comparable monitoring program included is recommended for Area 5 and outlined in **Sections 5.2.2** and **5.2.3**

The IEPMC was established in late February 2018 to provide informed expert advice to DPE on the impact of mining activities in the Greater Sydney Water Catchment Special Areas, with a focus on risks to the quantity of water and swamps. Part 1 (IEPMC 2019a) reviewed specific mining activities at the Dendrobium Mine and Metropolitan Mine and Part 2 (IEPMC 2019b) focused on the impacts of mining on water quantity and swamps, including cumulative impacts, and includes a review and update of relevant findings of the strategic review (NSW DoP 2008). Recommendations specific to monitoring of aquatic ecology were not included, though several recommendations relevant to monitoring of groundwater and surface water and the development of associated TARPs will assist in the future assessment and identification of causes of any impacts to aquatic ecology. These suggestions have been adopted by IMC and are reported in End of Panel reports following extraction of each longwall.

5.2.2 Sites and Timing

Two types of monitoring sites should be incorporated into the monitoring plan: 'impact' sites that may be subject to mine subsidence impacts during and after longwall extraction and 'control' sites that would provide a measure of the background environmental variability within the catchments as distinct from any mine subsidence impacts.

Monitoring sites should be established in major watercourses (i.e. Avon River and Donalds Castle Creek) and in some sections of the larger third order drainage lines in Area 5 predicted to experience potential impacts due to the proposed longwall mining. Impact sites should be located within, or immediately downstream of the areas expected to be most at risk of mining-related impacts. Ideally, control sites would be located on the same watercourses upstream of where any impacts associated with extraction of proposed longwalls would occur. At least two control sites should be established on each monitored watercourse to provide a measure of natural variability. The location and number of sites should be confirmed during preparation of Extraction Plans and following consultation with key stakeholders regarding suitable watercourses, baseline flow, access and timing of longwall extraction.

Baseline surveys at impact and control sites should be undertaken over a 24-month period prior to the commencement of longwall mining, as well as during and post-extraction to determine the extent and nature of any impacts and recovery. A 12-month baseline period is considered appropriate given that impacts to significant aquatic ecology are not expected. This would provide a measure of background temporal variability and provide more confidence regarding potential changes occurring several years into the future. The plan includes a temporally staged monitoring approach that includes impact and control locations relevant to Area 5 be monitored prior to development. Monitoring and surveys at individual sites would also be staged relative to the extraction timeline for each longwall.

5.2.3 Indicators and Methods

The following indicators of aquatic ecology should be monitored at each site:

> Aquatic habitat;

> *In situ* water quality;

> Aquatic macrophytes;

> Aquatic macroinvertebrates; and

> Fish.

5.2.3.1 Aquatic Habitat

During the first baseline survey, condition of the aquatic habitat at each site should be assessed using a modified version of the RCE (Chessman et al. 1997). This assessment would involve evaluation and scoring of the characteristics of the adjacent land, the condition of riverbanks, channel and bed of the watercourse, and degree of disturbance evident at each site. Any changes in the condition of the aquatic habitat should be recorded during subsequent surveys.

During each survey, a comprehensive photo record of each site should be taken to gain an understanding of environmental variation within the watercourses. This would be done by taking standardised photos, using a 2 m tall x 1 m wide T-bar, from the top of the site looking downstream, the middle of the site looking upstream, the middle of the site looking downstream, and the bottom of the site looking upstream.

5.2.3.2 Water Quality

At each site, two replicate measurements of DO, EC, oxidation-reduction potential (ORP), pH, temperature and turbidity of the water should be taken from just below the surface of the water. The measurements taken would be used to assist in the interpretation of differences in biotic assemblages. The EC, DO, pH and turbidity measures should also be compared with the ANZECC (2000) DTVs for slightly disturbed upland rivers in south-east Australia. Specific guidelines are not available for temperature and ORP measures.

This specific aquatic ecology water quality monitoring should be undertaken in addition to the water quality monitoring recommended for the Project.

5.2.3.3 Aquatic Macrophytes

At each site where instream aquatic macrophytes are present, their species composition and total area of coverage should be recorded. Features such as the presence of algae or flocculant on the surface of macrophytes should also be noted.

5.2.3.4 Aquatic Macroinvertebrates

Two methods should be used to sample aquatic macroinvertebrates: the AUSRIVAS protocol for NSW streams (Turak *et al.* 2004) and artificial aquatic macroinvertebrate collectors; a quantitative method developed by Cardno for freshwater environmental impact assessment.

5.2.3.5 AUSRIVAS

At each site, samples of aquatic macroinvertebrates associated with the pool edge habitat should be collected using dip nets (250 micrometre [µm] mesh) to agitate and scoop up material from vegetated areas of the river bank. Samples should be collected over a period of 3-5 mins from a 10 m length of habitat along the relevant watercourses, in accordance with the AUSRIVAS Rapid Assessment Method (RAM) (Turak *et al.* 2004). If the required habitat was discontinuous, patches of habitats with a total length of 10 m should be sampled. Each RAM sample should be rinsed from the net onto a white sorting tray from which animals are picked using forceps and pipettes. Each tray should be picked for a minimum period of 40 minutes, after which they should be picked at 10 minute intervals for either a total of one hour or until no new specimens are found. These samples would be preserved in alcohol and transported to the laboratory for identification.

In accordance with the AUSRIVAS protocol, RAM samples should be sorted under a binocular microscope (at 40 times magnification), macroinvertebrates identified to family level and up to ten animals of any one taxon counted (Turak *et al.* 2004). A randomly chosen 10% of the RAM sample identifications should be checked by a second experienced scientist to validate macroinvertebrate identifications.

Data should be analysed using the spring AUSRIVAS predictive models for the edge habitat (Coysh *et al.* 2000). The AUSRIVAS methodology and predictive model requires that sampling be done in Autumn (15 April to 15 June) and/or Spring (15 October to 15 December).

AUSRIVAS models generate the following indices:

> OE50 Taxa Score - This is the ratio of the number of macroinvertebrate families with a greater than 50% predicted probability of occurrence that were observed (i.e. collected) at a site to the number of macroinvertebrate families expected with a greater than 50 % probability of occurrence. OE50 taxa values range from 0 to 1 and provide a measure of the impairment of macroinvertebrate assemblages at each site, with values close to 0 indicating an impoverished assemblage and values close to 1 indicating that the condition of the assemblage is similar to that of the reference streams.

> Overall Bands - These indicate the level of impairment of the assemblage and are derived from OE50 Taxa scores. These bands are graded as follows:

  - Band X = Richer invertebrate assemblage than reference condition.
  - Band A = Equivalent to reference condition.
  - Band B = Sites below reference condition (i.e. significantly impaired).
  - Band C = Sites well below reference condition (i.e. severely impaired).
  - Band D = Impoverished.

The revised SIGNAL2 biotic index (Stream Invertebrate Grade Number Average Level) developed by Chessman (2003) should also be used to determine the environmental quality of sites based on the presence or absence of families of macroinvertebrates. This method assigns grade numbers to each macroinvertebrate family or taxa found, based largely on their responses to chemical pollutants. The sum of all grade numbers for that habitat is then divided by the total number of families recorded in each habitat to calculate the SIGNAL2 index. The SIGNAL2 index therefore uses the average sensitivity of macroinvertebrate families to present a snapshot of biotic integrity at a site. SIGNAL2 values greater than 6, between 5 and 6, 4 and 5 and less than 4 indicate that the quality of the water is clean, doubtful, mildly, moderately or severely degraded, respectively.

5.2.3.6 Artificial Macroinvertebrate Collectors

Eight replicate artificial collector units, consisting of 24 cm long x 3 cm diameter bundles of 18 wooden chopsticks held together with plastic cable ties, should be deployed at each monitoring site. The collectors should be attached to vegetation with nylon twine and submerged at least 1 m apart at the edge of pools in 30 to 60 cm of water. The collectors should be retrieved six weeks after being deployed. During retrieval the collectors would be carefully cut away from their anchors, placed into plastic bags, labelled and preserved in 70% ethanol for subsequent laboratory identification and analysis.

The aquatic macroinvertebrates that colonise each bundle of chopsticks should be rinsed onto a 0.5 mm mesh sieve and examined in the laboratory using a binocular microscope. The samples should be sorted and macroinvertebrates identified to family (most invertebrate taxa), sub-family (chironomids) or class (flatworms and leeches) level and counted. Mayflies, damselflies and stoneflies should be identified to genus, where possible. Genus level taxonomic resolution may be more appropriate when attempting to detect an environmental impact on aquatic ecology, as some taxa within the same family may response differently to disturbance. SIGNAL2 scores should also be calculated for the macroinvertebrate assemblages that developed on the artificial collectors.

5.2.3.7 Threatened Species

As there is a possibility, albeit unlikely, that two threatened aquatic macroinvertebrate species (Adam’s Emerald Dragonfly and Sydney Hawk Dragonfly) occur in watercourses within the Study Area, all the dragonfly larvae collected should be identified to family level. Any individuals of the genera Austrocorduliidae and Gomphomacromiidae found should be identified to species level, if possible. If there is any uncertainty as to their identification, specimens will be referred to a specialist taxonomist. The presence of either one or both threatened species would trigger further investigations into the species and its habitats in relation to potential subsidence impacts.

5.2.3.8 Fish

Fish should be sampled using baited traps, dip nets, and visual observations. At each site, eight baited traps should be deployed for 30 to 45 minutes in a variety of habitats, such as amongst aquatic plants and snags, in deep holes and over bare substratum. Native species should be released unharmed. Exotics should not be returned to the water in accordance with Cardno Ecology Lab’s Scientific Research Permit.

5.2.3.9 Statistical Analysis

The aim of the statistical analyses should be to identify differences in the selected indicators of aquatic ecology at the impact sites that are in a different direction, or of a different magnitude, to those at the control. Statistically significant differences provide evidence that an impact may have occurred. Evidence is assessed by examining baseline data against those collected after longwall extraction. Spatial and temporal changes in macroinvertebrate abundance data from artificial collectors should be examined using techniques such as permutational analysis of variance (PERMANOVA) for analysis of univariate data. Spatial differences and temporal changes, and their interaction, in macroinvertebrate assemblages sampled using artificial collectors should be examined (PERMANOVA). Multivariate patterns in the data should also be examined using the unconstrained ordination technique Principal Coordinates Analysis (PCO). This provides a graphical representation of assemblages based on their similarity within and among places or times sampled. In these plots, samples which have similar sets of organisms are grouped closer together than ones containing different sets of organisms.

5.3 Additional Aquatic Ecology Studies

Additional aquatic ecology studies should be triggered by events such as significant changes in water quality and availability of aquatic habitats monitored by IMC. Trigger values would be developed for Area 5 and in consultation with relevant stakeholders following analysis of natural variability within the pre-mining baseline data. Each trigger value would correspond to either a negligible or significant impact on the aquatic habitat and/or biota within the Extraction Plan. Management actions would be implemented if thresholds are exceeded.

5.4 Contingency Measures

In the event that the potential impacts on aquatic habitats and biota exceed predictions, the following contingency measures should be considered:

> Implementing stream remediation measures, such as backfilling or grouting, in areas where fracturing of controlling rock bars and/or the stream bed leads to diversion of stream flow and drainage of pools; and

> Implementing appropriate control measures, such as installation of sediment fences down slope of areas where subsidence has led to erosion and stabilisation of areas prone to erosion and soil slumping using rock, brush matting or vegetation, to limit the potential for deposition of eroded sediment into the watercourses.

5.5 Offsetting

The Project would not require biodiversity offsets associated with threatened species, populations or communities listed under the FM Act or EPBC Act as significant impacts to these are not expected, in accordance with DPI Fisheries (2013) *Policy and Guidelines for Fish Habitat Conservation and Management (Update 2013)* and the *Environment Protection and Biodiversity Conservation Act 1999 Environmental Offsets Policy* (SEWPaC 2012).

No areas of KFH are located directly above the proposed longwalls for the Project. However, if there are any impacts to KFH in third order and higher watercourses occur that are unable to be remediated using contingency measures such as those described in **Section 5.4,** then environmental offsets should be considered. Appropriate offsets associated with impacts to KFH could include contribution to threatened aquatic species research and stocking programs and measures that improved water quality in nearby catchments. The requirement for, and form of any offsets relating to aquatic ecology would be identified during consultation with relevant stakeholders including DPI Fisheries.

6 Conclusion

The design of the Project includes measures to minimise potential impacts on aquatic ecology. These include set back of longwalls from 3rd order and above watercourses and key stream features to reduce the probability of potential impacts. Nevertheless, impacts to aquatic habitat, vegetation, macroinvertebrates or fish will occur following predicted mine subsidence and associated fracturing in streams and drainage lines adjacent to and overlaying the proposed longwalls. These predicted impacts, primarily subsidence induced fracturing, groundwater level reductions, flow diversions and loss of aquatic habitat in drainage lines could potentially be relatively significant at a local scale. Based on previous experience, and dependant on the extent and magnitude of any mining related impacts, the abundance of these components of aquatic ecology in the local and regional area would suggest that any impacts would be relatively minor in the context of the wider catchment area. However, the cumulative effect of such impacts should be considered, given the effects of previous mining that has occurred in the upper Avon River and Cordeaux River catchments.

No significant impacts to listed threatened Macquarie Perch, Sydney Hawk Dragonfly, Australian Grayling or Adam's Emerald Dragonfly are expected. These species are very unlikely to occur in drainage lines that within Area 5. Although Macquarie Perch is expected to occur in Avon River and Lake Avon, fracturing induced flow diversions and impacts to water quality are not expected and therefore would not be impacted by the Project.

Although no bores suitable for sampling of stygofauna are present in the Area 5, findings from previous studies in the local and regional area suggest it is likely that stygofauna occur in perched upland swamp and the shallow Hawkesbury sandstone aquifers. These aquifers are expected to be impacted by mine subsidence (i.e. fracturing) effects on groundwater availability and quality. The loss of perched swamp aquifers and disturbance to the shallow Hawkesbury sandstone aquifer due to mining induced subsidence is likely to impact stygofauna expected to be present in the Area 5. The severity of impacts to stygofauna in perched upland swamp aquifers would depend on the severity and extent of impacts to groundwater levels and levels of moisture in swamps. The proposed mining would be expected to result in some reduction in the habitat available to stygofauna, and, thus, population sizes. Based on comparison with the amount of swamp habitat in the regional area, potential impacts would be expected to be relatively minor.

Implementation of the recommended aquatic ecology monitoring program outlined in **Section 5.2** would assist to determine the magnitude and extent of impacts to aquatic ecology associated with the proposed longwalls. The location of monitoring sites and staging of monitoring should be refined following further consultation with IMC and confirmation of the timing of extraction of each longwall. The detection of physical impacts, such as fracturing of bedrock and streamflow losses, should trigger investigations into potential impacts on aquatic ecology. The level of impact found would determine the type of response. Significant changes in aquatic biota detected 'during mining' monitoring would also provide triggers for further investigation. The implementation of such management measures would aim to reduce impacts on aquatic ecology.

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APPENDIX

A

SURVEY METHODOLOGY

Site Coordinates

Table A-i. Site Coordinates

Watercourse	Site	Easting	Northing
Donalds Castle Creek	14	289400	6195445
Donalds Castle Creek	17	289493	6194818
Donalds Castle Creek	18	289429	6195203
Donalds Castle Creek	X1	289643	6194191
Donalds Castle Creek	DC1	289327	6197932
Donalds Castle Creek	DC2	289397	6197545
Donalds Castle Creek	DC3	289463	6199293
Tributary of Avon River	AR1	283931	6197696
Tributary of Avon River	AR2	283937	6197587

Datum: GDA 94 Zone 56H

Aquatic Habitat and Vegetation

Habitat Types

The July 2007 investigations (The Ecology Lab 2007) mapped four habitat types (adapted from Fairfull and Witheridge 2003) within Wongawilli Creek and drainage lines:

- Unlikely habitat: drainage lines that only contain flow during and immediately after significant rainfall. Permanent or semi-permanent pools that could provide refuge for aquatic biota during prolonged dry weather are absent.
- Minimal habitat: Watercourses that contain some small semi-permanent refuge pools which are unlikely to persist through prolonged drought. Flow connectivity would only occur during and following significant rainfall. These pools may provide habitat for some aquatic species including aquatic macroinvertebrates and freshwater crayfish.
- Moderate habitat: Watercourses that contain some larger permanent and semi-permanent refuge pools, which would persist through prolonged drought, although become greatly reduced in extent. These watercourses should support a relatively diverse array of aquatic biota including some fish, freshwater crayfish and aquatic macroinvertebrates. There may also be some aquatic plant species present.
- Significant habitat: Watercourses that contain numerous large, permanent pools and generally have flow connectivity except during prolonged drought. They provide extensive and diverse aquatic habitat for aquatic flora and fauna.

REC Inventory

The condition of the aquatic habitat at each site was assessed using a modified version of the Riparian, Channel and Environmental Inventory (RCE) method (Chessman *et al*. 1997) (**Table A-ii**). This assessment involves evaluation and scoring of the characteristics of the adjacent land, the condition of riverbanks, channel and bed of the watercourse, and degree of disturbance evident at each site. The occurrence of key aquatic habitat (e.g. gravel beds, pools, macrophytes, riffles, and woody debris) in these watercourses was also identified along with surrounding land uses.

Notes were also taken on the presence of the following features:

- Surrounding vegetation and riparian vegetation;
- Barriers to fish passage;
- The species and percent cover (in an approximate 100 m reach) of in-stream aquatic vegetation present at each site; and
- The presence of algae or flocculent on the surface of macrophytes was also be noted, if present.

Table A-ii. River, Channel and Environmental (RCE) Criteria

Descriptor and category	Score
1. Land use pattern beyond the immediate riparian zone	
Undisturbed native vegetation	4
Mixed native vegetation and pasture/exotics	3
Mainly pasture, crops or pine plantation	2
Urban	1
2. Width of riparian strip of woody vegetation	
More than 30 m	4
Between 5 and 30 m	3
Less than 5 m	2
No woody vegetation	1
3. Completeness of riparian strip of woody vegetation	
Riparian strip without breaks in vegetation	4
Breaks at intervals of more than 50 m	3
Breaks at intervals of 10 - 50 m	2
Breaks at intervals of less than 10 m	1
4. Vegetation of riparian zone within 10 m of channel	
Native tree and shrub species	4
Mixed native and exotic trees and shrubs	3
Exotic trees and shrubs	2
Exotic grasses / weeds only	1
5. Stream bank structure	
Banks fully stabilised by trees, shrubs etc.	4
Banks firm but held mainly by grass and herbs	3
Banks loose, partly held by sparse grass etc.	2
Banks unstable, mainly loose sand or soil	1
6. Bank undercutting	
None, or restricted by tree roots	4
Only on curves and at constrictions	3
Frequent along all parts of stream	2
Severe, bank collapses common	1
7. Channel form	
Deep: width / depth ratio < 7:1	4
Medium: width / depth ratio 8:1 to 15:1	3
Shallow: width / depth ratio > 15:1	2
Artificial: concrete or excavated channel	1

Descriptor and category	Score
8. Riffle / pool sequence	
Frequent alternation of riffles and pools	4
Long pools with infrequent short riffles	3
Natural channel without riffle / pool sequence	2
Artificial channel; no riffle / pool sequence	1
9. Retention devices in stream	
Many large boulders and/or debris dams	4
Rocks / logs present; limited damming effect	3
Rocks / logs present, but unstable, no damming	2
Stream with few or no rocks / logs	1
10. Channel sediment accumulations	
Little or no accumulation of loose sediments	4
Some gravel bars but little sand or silt	3
Bars of sand and silt common	2
Braiding by loose sediment	1
11. Stream bottom	
Mainly clean stones with obvious interstices	4
Mainly stones with some cover of algae / silt	3
Bottom heavily silted but stable	2
Bottom mainly loose and mobile sediment	1
12. Stream detritus	
Mainly un-silted wood, bark, leaves	4
Some wood, leaves etc. with much fine detritus	3
Mainly fine detritus mixed with sediment	2
Little or no organic detritus	1
13. Aquatic vegetation	
Little or no macrophyte or algal growth	4
Substantial algal growth; few macrophytes	3
Substantial macrophyte growth; little algae	2
Substantial macrophyte and algal growth	1

Key Fish Habitat

The occurrence of sensitive fish habitat in the Study Area was assessed using the criteria in NSW DPI (2013a) relevant to freshwater habitat (**Table A-iii**).

Mapping was done initially as a desktop exercise with the aid of existing information from previous surveys including information on habitat types (Fairfull and Witheridge 2003). Findings were used to inform the detailed KFH mapping using the updated classifications in NSW DPI (2013a). Where sections of drainage lines could not be accessed, KFH type was inferred based on the findings from other drainage lines in the Study Area.

Table A-iii. Classification of KFH according to sensitivity (NSW DPI 2013a)

Classification	Habitat Type
Type 1 – Highly sensitive KFH	Instream gravel beds, rocks greater than five hundred millimeters in two dimensions, snags (wood debris) greater than three hundred millimeters in diameter or three meters in length, native aquatic plants, and areas known or expected to contain threatened and protected species
Type 2 – Moderately sensitive KFH:	Freshwater habitats other than those defined in Type 1
Type 3 – Minimally sensitive KFH	Ephemeral aquatic habitat not supporting native aquatic or wetland vegetation
Not considered KFH	First and second order streams on gaining (those where streams are coming together and becoming progressively larger) streams (based on the Strahler method of stream ordering)

In-situ Water Quality

At each site, two replicate measurements of DO, EC, oxidation-reduction potential (ORP), pH, temperature and turbidity of the water were taken from just below the surface of the water using a YSI multiprobe. The measurements taken would be used to assist in interpretation of the results of biotic sampling. The EC, DO, pH and turbidity measures were also compared with the ANZECC (2000) DTVs for slightly disturbed upland rivers in south-east Australia. Specific guidelines are not available for temperature and ORP measures.

AUSRIVAS Macroinvertebrates

Field and Laboratory Methods

At each site, samples of aquatic macroinvertebrates associated with the pool edge habitat were collected by using dip nets (250 µm mesh) to agitate and scoop up material from vegetated areas of the river bank. Samples were collected over a period of 3 to 5 minutes from a 10 m length of habitat along the river, in accordance with the AUSRIVAS Rapid Assessment Method (RAM) (Turak *et al*. 2004). If the required habitat was discontinuous, patches of habitats with a total length of 10 m were sampled. Each RAM sample was rinsed from the net onto a white sorting tray from which animals were picked using forceps and pipettes. Each tray was picked for a minimum period of forty minutes, after which they were picked at ten-minute intervals for either a total of one hour or until no new specimens were found. Samples were preserved in alcohol and transported to the laboratory for identification and subsequent derivation of biotic indices and assessment of habitat and water quality using the AUSRIVAS modelling software.

AUSRIVAS samples were sorted under a binocular microscope (at 40 times magnification) and identified to family level with the exception of Oligochaeta and Polychaeta (to class), Ostracoda (to subclass), Nematoda and Nemertea (to phylum), Acarina (to order) and Chironomidae (to subfamily). Up to ten animals of each family were counted, in accordance with the latest AUSRIVAS protocol (Turak *et al*. 2004). There is a possibility, albeit unlikely, that two threatened aquatic macroinvertebrate species (Adam’s Emerald Dragonfly and Sydney Hawk Dragonfly) occur in the Study Area. Therefore, if any individuals of the family Austrocorduliidae and Gomphomacromiidae were found these would have been identified to species level. However, no specimens from these families were found.

AUSRIVAS Model

The AUSRIVAS protocol uses an internet-based software package to determine the environmental condition of a waterway based on predictive models of the distribution of aquatic macroinvertebrates at reference sites (Coysh *et al.* 2000). The ecological health of the creek is assessed by comparing the macroinvertebrate assemblages collected in the field (i.e. 'observed') with macroinvertebrate assemblages expected to occur in reference waterways with similar environmental characteristics. The data from this study were analysed using the NSW models for pool edge habitat sampled in spring. The AUSRIVAS predictive model generates the following indices:

> OE50Taxa Score – The ratio of the number of macroinvertebrate families with a greater than 50% predicted probability of occurrence that were actually observed (i.e. collected) at a site to the number of macroinvertebrate families expected with a greater than 50% probability of occurrence. OE50 taxa scores provide a measure of the impairment of macroinvertebrate assemblages at each site, with values close to 0 indicating an impoverished assemblage and values close to 1 indicating that the condition of the assemblage is similar to that of the reference streams.

> Overall Bands derived from OE50Taxa scores that indicate the level of impairment of the assemblage. These bands are graded as described in **Table A-iv**.

Table A-iv. AUSRIVAS Bands and corresponding OE50 Taxa Scores for AUSRIVAS edge habitat.

Band	Description	Autumn OE50 Score	Spring OE50 Score
X	Richer invertebrate assemblage than reference condition	> 1.17	>1.16
A	Equivalent to reference condition	0.82 to 1.17	0.84 to 1.16
B	Sites below reference condition (i.e. significantly impaired)	0.47 to 0.81	0.52 to 0.83
C	Sites well below reference condition (i.e. severely impaired)	0.12 to 0.46	0.20 to 0.51
D	Impoverished (i.e. extremely impaired)	≤0.11	≤0.19

The SIGNAL2 biotic index (Stream Invertebrate Grade Number Average Level) developed by Chessman (2003) was also used to determine the environmental quality of sites on the basis of the presence or absence of families of macroinvertebrates. This method assigns grade numbers between 1 and 10 to each macroinvertebrate family, based largely on their responses to chemical pollutants. The sum of all grade numbers for that site was then divided by the total number of families recorded in each site to obtain an average SIGNAL2 index. The SIGNAL2 index therefore uses the average sensitivity of macroinvertebrate families to present a snapshot of biotic integrity at a site. SIGNAL2 values are as follows:

> SIGNAL > 6 = Healthy habitat;

> SIGNAL 5 – 6 = Mild pollution;

> SIGNAL 4 – 5 = Moderate pollution; and

> SIGNAL < 4 = Severe pollution.

Fish

Fish were sampled using a backpack electrofisher (model LR-24 Smith-Root) and baited traps. At each site, four baited traps were set for approximately one hour in a variety of habitats, such as amongst aquatic plants and snags, in deep holes and over bare substratum. Bait traps were approximately 30 cm x 30 cm x 40 cm with 0.3 cm aperture mesh and a 3 cm opening and were unbaited. The backpack electrofisher was operated around the edge of pools and in riffles (if present), with four two-minute shots being performed at each site. Fish stunned by the current were collected in a scoop net, identified and measured. All captured fish would be handled with care to minimise stress and be released as soon as possible.

APPENDIX

B

AOS - MACQUARIE PERCH

1) Assessment of Significance (FM Act) – Macquarie Perch

a) In the case of a threatened species, whether the action proposed is likely to have an adverse effect on the life cycle of the species such that a viable local population of the species is likely to be placed at risk of extinction.

Macquarie Perch has been recorded at Lake Avon and Lake Cordeaux and previously recorded, or potentially present, in the upper reaches of Cordeaux and Avon Rivers (NSW DPI 2016a). Life history studies of Macquarie Perch have been largely carried out on western drainage populations. These populations are known to spawn just above riffles in shallow upland streams in October to January when water temperatures rise to around 16 Celsius (°C). Eastern populations, however, inhabit rivers with very different hydrological conditions to the inland populations and very little is known of their life cycle. The eggs are adhesive and stick to gravel. Hatching commences 13 days after fertilisation and is completed by 18 days after fertilisation at water temperatures of 11°C to 18°C. Newly-hatched larvae shelter amongst pebbles. In impounded waters, hatched fish move back downstream to the lake habitat from their upstream spawning sites.

The lifecycle of Macquarie Perch could be adversely affected if mining results in changes in levels of ponding, flooding or scouring of river banks, fracturing of rock bars and diversion of surface flows and these, in turn, lead to drainage of pools, loss of habitat, and reductions in habitat connectivity and/or water quality. The subsidence predictions indicate that extraction of the proposed longwalls would not result in changes to the availability, quality and connectivity of aquatic habitats within Avon River and Lake Avon. Given the extensive amount of potential habitat available for this species it is highly unlikely that mining would have any adverse effects on the life cycle of Macquarie Perch in Avon River or Lake Avon or place a viable local population at risk of extinction. Macquarie Perch are considered very unlikely to occur in drainage lines, and, thus, would not be affected by any mining induced impacts on drainage lines. Any impacts to water quality in these creeks and rivers due to the Project are expected to be minor and localised and would not affect Macquarie Perch.

Significant impacts to Macquarie Perch due to proposed water extraction in Cordeaux River are not expected. The water velocity at the pump intake would be approximately 0.3 m/s. The pump would also include a 5 mm aperture mesh screen approximately 2 m from the pump intake. At this distance, the water velocity would be approximately 0.1 m/s. In a laboratory study investigating entrainment and impingement of Australian native fish golden perch (*Macquaria ambigua*) and silver perch (*Bidyanus bidyanus*) (albeit these species are not present in Cordeaux River), Boys et al. (2012) found that water velocity (measured at 8 cm from a perforated 3 mm mesh size aluminium screen) of up to 0.4 m/s approaching the screen and of 1.5 m/s through the screen was effective in reducing entrainment of juveniles of these species. There was also very little injury or mortality resulting from incidental screen contacts or impingement. This study also indicated that velocities less than 0.5 m/s have great potential for reducing entrainment of a wide range of species and size ranges of fish in the Murray Darling Basin. However, field observations of an assemblage of fish at a screen in a river demonstrated that even modest increases in approach velocity (from 0.1 m/s to 0.5 m/s) produced a significant increase in the rate of screen contact for fish smaller than 150 mm, with the impact being more marked the smaller fish were. Boys et al. (2012) recommended that approach velocities for Murray-Darling Basin fish, at least, should not exceed 0.1 m/s. This was provided as a precautionary measure, as there was some uncertainty if the reported approach velocities are applicable to all fish species and life history stages. It was also recommended, that in the absence of screening criteria for Australian freshwater fish, designs should aim to minimise fish entrainment by optimising approach velocities. The results of this study suggested that approach velocity, rather than mesh size, appeared to be more important in minimising fish entrainment. Although these findings focussed on other species, they do indicate that the proposed approach velocities in Cordeaux River would have minor potential impacts for Macquarie Perch. Although the planned pumping would take place during the Macquarie Perch spawning period, potential impacts to this species would be further limited due to the temporary nature of the pump. There would also be no direct impact to fish habitat due to its floating design. The pumps would also not be situated over gravel beds where Macquarie Perch lay their eggs. In any case, Macquarie Perch eggs are demersal and adhesive, which would limit their susceptibility to entrainment. Thus, the proposed pump and water extraction does not represent a significant impact to the life cycle of Macquarie Perch.

b) In the case of an endangered population, whether the action proposed is likely to have an adverse effect on the life cycle of the species that constitutes the endangered population such that a viable local population of the species is likely to be placed at risk of extinction.

No endangered populations of Macquarie Perch have been listed on the Schedules of the FM Act.

c) In the case of an endangered ecological community or critically endangered ecological community, whether the proposed action is likely to:

i) Have an adverse effect on the extent of the ecological community such that its local occurrence is likely to be placed at risk of extinction, or

ii) Substantially and adversely modify the composition of the ecological community such that its local occurrence is likely to be placed at risk of extinction.

Macquarie Perch is not part of a listed endangered ecological community.

d) In relation to the habitat of a threatened species, population or ecological community:

i) The extent to which habitat is likely to be removed or modified as a result of the action proposed;

ii) Whether an area of habitat is likely to become fragmented or isolated from other areas of habitat as a result of the proposed action;

iii) the importance of the habitat to be removed, modified, fragmented or isolated to the long-term survival of the species, population or ecological community in the locality.

Subsidence predictions indicate fracturing would not occur in Lake Avon or Avon River. Thus, there are unlikely to be any reduction in Macquarie Perch habitat availability, quality or connectivity here. Although fracturing and flow diversions are likely to result in more severe impacts to habitat in drainage lines, these are very unlikely to provide habitat for Macquarie Perch. If implemented, the proposed pump in Cordeaux River would be small scale, floating and would not be installed above any gravel beds. Thus, it is highly unlikely that mining would lead to removal, fragmentation or isolation of a Macquarie Perch population.

e) Whether the action proposed is likely to have an adverse effect on critical habitat (either directly or indirectly).

There is no listed critical habitat for Macquarie Perch listed on the NSW Register of Critical Habitat.

f) Whether the action proposed is consistent with the objectives or actions of a recovery plan or threat abatement plan.

The draft National Recovery Plan for Macquarie Perch (Commonwealth of Australia 2018) contains background information on the biology, ecology, distribution and populations, decline and threats and recovery objectives and strategies and associated actions. The objectives are:

> Conserve existing Macquarie Perch populations;
> Protect and restore Macquarie Perch habitat;
> Investigate threats to Macquarie Perch populations and habitats;
> Establish additional Macquarie Perch populations;
> Improve understanding of the biology and ecology of the Macquarie Perch and its distribution and abundance; and
> Increase participation by community groups in Macquarie Perch conservation.

Identified threats include:

> Habitat degradation;
> Invasive fish;
> Barriers to fish movement;
> Altered flow and thermal regimes;
> Disease;
> Illegal and incidental capture;
> Chemical water pollution;
> Climate change.

The following Priority Action Statements for Macquarie Perch (NSW DPI 2017b) exist:

> Advise consent and determining authorities;
> Collate and review existing information;
> Community and stakeholder liaison, awareness and education;
> Compliance/enforcement;
> Enhance, modify or implement Natural Resource Management planning processes to minimize adverse impacts on threatened species;
> Habitat rehabilitation;
> Pest eradication and control;
> Research/monitoring;
> Stocking/translocation; and
> Survey/mapping.

Potential impacts to Macquarie Perch associated with the Project (primarily loss of habitat following significant fracturing leading to flow diversions and reductions in pool water levels) are unlikely. The Project is not expected to interfere with these objectives and the recovery of the species.

g) Whether the action proposed constitutes or is part of a key threatening process or is likely to result in the operation of, or increase the impact of, a key threatening process.

One KTP listed under the BC Act is directly applicable to the Project: *Alteration of habitat following subsidence due to longwall mining.*

While the Project is expected to exacerbate this KTP, associated impacts to Macquarie Perch due to subsidence are not expected. Macquarie Perch is very unlikely to be found in drainage lines that have high probability of experiencing fracturing resulting in flow diversions and loss of aquatic habitat.

2) Assessment of Significance Based on Significant Impact Criteria for Endangered Species (EPBC Act) – Macquarie Perch

An action is likely to have a significant impact on an endangered species if there is a real chance or possibility that it will:

a) Lead to a long-term decrease in the size of a population

Macquarie Perch has been recorded Lake Avon and Lake Cordeaux and previously recorded, or potentially present, in the upper reaches of Cordeaux and Avon Rivers (NSW DPI 2016a). Life history studies of Macquarie Perch have been largely carried out on western drainage populations. These populations are known to spawn just above riffles in shallow upland streams in October to January when water temperatures rise to around 16°C. Eastern populations, however, inhabit rivers with very different hydrological conditions to the inland populations and very little is known of their life cycle. The eggs are adhesive and stick to gravel. Hatching commences 13 days after fertilisation and is completed by 18 days after fertilisation at water temperatures of 11°C to 18°C. Newly-hatched larvae shelter amongst pebbles. In impounded waters, hatched fish move back downstream to the lake habitat from their upstream spawning sites.

Life history studies of Macquarie Perch have been largely carried out on western drainage populations. These populations are known to spawn just above riffles in shallow upland streams in October to January when water temperatures rise to around 16 C. Eastern populations, however, inhabit rivers with very different hydrological conditions to the inland populations and very little is known of their life cycle. The eggs are adhesive and stick to gravel. Hatching commences 13 days after fertilisation and is completed by 18 days after fertilisation at water temperatures of 11 to 18°C Newly-hatched larvae shelter amongst pebbles. In impounded waters, hatched fish move back downstream to the lake habitat from their upstream spawning sites.

A reduction the population size of Macquarie Perch could occur if mining results in changes in levels of ponding, flooding or scouring of river banks, fracturing of rock bars and diversion of surface flows and these, in turn, lead to drainage of pools, loss of habitat, and reductions in habitat connectivity and/or water quality. A loss of habitat may result in decrease in size of the local population present in Avon River and Lake Avon. The subsidence predictions indicate that extraction of the proposed longwalls would not result in adverse impacts here. Given the extensive amount of potential habitat available for this species within these areas, it is highly unlikely that mining would have any adverse effects on the population size Macquarie Perch or place a viable local population at risk of extinction. Macquarie Perch are considered very unlikely to occur in drainage lines, and, thus, would not be affected by any mining induced impacts on drainage lines. Any impacts to water quality in these creeks and rivers due to the project are expected to be minor and localised and not affect Macquarie Perch.

Significant impacts to Macquarie Perch due to proposed water extraction in Cordeaux River are not expected (if implemented). The water velocity at the pump intake would be approximately 0.3 m/s. The pump would also include a 5 mm aperture mesh screen approximately 2 m from the pump intake. At this distance, the water velocity would be approximately 0.1 m/s. In a laboratory study investigating entrainment and impingement of Australian native fish golden perch (*Macquaria ambigua*) and silver perch (*Bidyanus bidyanus*) (albeit these species are not present in Cordeaux River), Boys et al. (2012) found that water velocity (measured at 8 cm from a perforated 3 mm mesh size aluminium screen) of up to 0.4 m/s approaching the screen and of 1.5 m/s through the screen was effective in reducing entrainment of juveniles of these species. There was also very little injury or mortality resulting from incidental screen contacts or impingement. This study also indicated that velocities less than 0.5 m/s have great potential for reducing entrainment of a wide range of species and size ranges of fish in the Murray Darling Basin. However, field observations of an assemblage of fish at a screen in a river demonstrated that even modest increases in approach velocity (from 0.1 m/s to 0.5 m/s) produced a significant increase in the rate of screen contact for fish smaller than 150 mm, with the impact being more marked the smaller fish were. Boys et al. (2012) recommended that approach velocities for Murray-Darling Basin fish, at least, should not exceed 0.1 m/s. This was provided as a precautionary measure, as there was some uncertainty if the reported approach velocities are applicable to all fish species and life history stages. It was also recommended, that in the absence of screening criteria for Australian freshwater fish, designs should aim to minimise fish entrainment by optimising approach velocities. The results of this study suggested that approach velocity, rather than mesh size, appeared to be more important in minimising fish entrainment. Although these findings focussed on other species, they do indicate that the proposed approach velocities in Cordeaux River would have minor potential impacts for Macquarie Perch. Although the planned pumping would take place during the Macquarie Perch spawning period, potential impacts to this species would be further limited due to the temporary nature of the pump. There would also be no direct impact to fish habitat due to its floating design. The pumps would also not be situated over gravel beds where Macquarie Perch lay their eggs. In any case, Macquarie Perch eggs are demersal and adhesive, which would limit their susceptibility to entrainment. Thus, the proposed pump and water extraction (if implemented) does not represent a significant impact to the population size of Macquarie perch.

b) Reduce the area of occupancy of the species

As described above, significant fracturing resulting in flow diversions is not expected in Lake Avon or Avon River. Thus, potential impacts to identified Macquarie Perch habitat due to the Project are unlikely. The Project would also not require any crossings over Avon River and that could hinder fish passage and any impacts to water quality are expected to be localised and miner. Thus, reductions in the occupancy of this species due to the Project are unlikely.

c) Fragment an existing population into two or more populations

As described in a) and b), potential impacts to Macquarie Perch due to the Project are unlikely. No structures that may hinder fish passage would be installed and significant fracturing resulting in flow diversions in Avon River, where they are known to occur, are not expected.

d) Adversely affect habitat critical to the survival of a species

As described in a), potential impacts to Macquarie Perch habitat are unlikely. Critical breeding habitat (shallow flowing sections of rivers) is likely to be present throughout Avon River and Cordeaux River and there is unlikely to be any substantial alteration to this habitat due to the Project.

e) Disrupt the breeding cycle of a population

The subsidence predictions indicate that extraction of the proposed longwalls is not expected to result in changes in the availability, quality and connectivity of aquatic habitats within Avon River or Lake Avon. Given the extensive amount of potential habitat available for this species within these areas, it is highly unlikely that mining would have any adverse effects on the life cycle of Macquarie Perch or place a viable local population at risk of extinction. Macquarie Perch are considered very unlikely to occur in drainage lines, and, thus, would not be affected by any mining induced impacts here. Any impacts to water quality in these creeks and rivers due to the project are expected to be minor and localised and would not affect Macquarie Perch. If implemented, the proposed pump is not expected to result in significant entrainment of Macquarie perch eggs, larvae or adults.

f) Modify, destroy, remove or isolate or decrease the availability or quality of habitat to the extent that the species is likely to decline

As described in a) – d) potential impacts to Macquarie Perch and their habitat due to the Project are unlikely and not expect to affect its forage, resting or spawning habitat to the extent that the species is likely to decline. If implemented, the proposed pump in Cordeaux River would be small scale, floating and would not be installed above any gravel beds. Thus, it does not represent a significant impact to Macquarie perch habitat.

g) Result in invasive species that are harmful to an endangered species becoming established in the endangered species' habitat

Invasive species that may predate on Macquarie Perch eggs or young fish and/or potentially compete with Macquarie Perch for food and habitat include Redfin Perch (*Perca fluviatilis*), Rainbow Trout (*Oncorhynchus mykiss*), Brown Trout, Wild Goldfish, Eastern Gambusia (*Gambusia holbrooki*) and Carp (*Cyprinus carpio*). The Project does not include any vectors that may introduce/further introduce these species to Macquarie Perch habitat within the Study Area.

h) Introduce disease that may cause the species to decline

The invasive species listed in g) may carry disease or parasites that could infect Macquarie Perch. However, the Project would not result in the introduction or further introduction of these species to the Study Area.

i) Interfere substantially with the recovery of the species

The draft National Recovery Plan for Macquarie Perch (Commonwealth of Australia 2018) contains background information on the biology, ecology, distribution and populations, decline and threats and recovery objectives and strategies and associated actions for this species. The objectives are:

> Conserve existing Macquarie Perch populations;
> Protect and restore Macquarie Perch habitat;
> Investigate threats to Macquarie Perch populations and habitats;
> Establish additional Macquarie Perch populations;
> Improve understanding of the biology and ecology of the Macquarie Perch and its distribution and abundance; and
> Increase participation by community groups in Macquarie Perch conservation.

Identified threats include:

> Habitat degradation;
> Invasive fish;
> Barriers to fish movement;
> Altered flow and thermal regimes;
> Disease;
> Illegal and incidental capture;
> Chemical water pollution;
> Climate change.

The following Priority Action Statements for Macquarie Perch (NSW DPI 2017b) exist:

> Advise consent and determining authorities;
> Collate and review existing information;
> Community and stakeholder liaison, awareness and education;
> Compliance/enforcement;
> Enhance, modify or implement Natural Resource Management planning processes to minimize adverse impacts on threatened species;
> Habitat rehabilitation;
> Pest eradication and control;
> Research/monitoring;
> Stocking/translocation; and
> Survey/mapping.

Potential impacts to Macquarie Perch associated with the Project (primarily loss of habitat following significant fracturing leading to flow diversions and reductions in pool water levels) are unlikely. The Project is not expected to interfere with these objectives and the recovery of the species.

APPENDIX

C

ASSESSMENT OF SIGNIFICANCE
SYDNEY HAWK DRAGONFLY

1) Assessment of Significance (FM Act) – Sydney Hawk Dragonfly

a) In the case of a threatened species, whether the action proposed is likely to have an adverse effect on the life cycle of the species such that a viable local population of the species is likely to be placed at risk of extinction.

The larvae of Sydney Hawk Dragonfly appear to have specific habitat requirements, being found under rocks in deep, cool, shady pools (NSW DPI, 2007). Relative environmental stability appears to be an important habitat feature, with rapid variation in water level and flow rate likely to have a negative effect on the suitability of habitat for larvae. The largely ephemeral/intermittent aquatic habitat provided by drainage lines would therefore likely provide sub-optimal habitat for this species. Although more suitable habitat is present within Avon River, there are no records for this species within the Study Area or the wider Cordeaux and Lake Avon catchments, despite extensive sampling of macroinvertebrates by Cardno.

Extraction of the longwalls could have an adverse effect on the life cycle of the Sydney Hawk Dragonfly if subsidence results in significant changes in levels of ponding, flooding or scouring of banks, fracturing of bedrock and diversion of surface flows, which, in turn, result in significant loss of aquatic habitat and reductions in habitat connectivity or water quality. The mine subsidence predictions for Avon River indicate there would be no flow diversions due to fracturing. Aquatic habitat in drainage lines is relatively ephemeral/intermittent, and would be unlikely to provide optimal habitat for this species even if its range included the Dendrobium Mine area. In any case, impacts to drainage lines represent a small proportion of potential habitat for this species in the Cordeaux River and Avon River catchments. It is therefore highly unlikely that mining would have any adverse effects on the life cycle of Sydney Hawk Dragonfly, if a viable population exists within these watercourses.

b) In the case of an endangered population, whether the action proposed is likely to have an adverse effect on the life cycle of the species that constitutes the endangered population such that a viable local population of the species is likely to be placed at risk of extinction.

There are no threatened populations of Sydney Hawk Dragonfly listed on the Threatened Species Schedules of the FM Act.

c) In the case of an endangered ecological community or critically endangered ecological community, whether the proposed action is likely to:

i) Have an adverse effect on the extent of the ecological community such that its local occurrence is likely to be placed at risk of extinction, or

ii) Substantially and adversely modify the composition of the ecological community such that its local occurrence is likely placed at risk of extinction.

The Sydney Hawk Dragonfly is not part of an endangered ecological community listed on the Threatened Species Schedules of the FM Act.

d) In relation to the habitat of a threatened species, population or ecological community:

i) The extent to which habitat is likely to be removed or modified as a result of the action proposed;

ii) Whether an area of habitat is likely to become fragmented or isolated from other areas of habitat as a result of the proposed action;

iii) the importance of the habitat to be removed, modified, fragmented or isolated to the long-term survival of the species, population or ecological community in the locality.

The larvae of Sydney Hawk Dragonfly appear to have specific habitat requirements, being found under rocks in deep, cool, shady pools (NSW DPI, 2007). Relative environmental stability appears to be an important habitat feature, with rapid variation in water level and flow rate likely to have a negative effect on the suitability of habitat for larvae. Although such habitat is present within Avon River, there are no records for this species within the Study Area or the Cordeaux and Lake Avon catchments.

Extraction of the longwalls could have an adverse effect on the habitat of the Sydney Hawk Dragonfly if subsidence results in significant changes in levels of ponding, flooding or scouring of banks, fracturing of bedrock and diversion of surface flows, which, in turn, result in significant loss of aquatic habitat and reductions in habitat connectivity or water quality. The mine subsidence predictions for Avon River indicate there would be no flow diversions due to fracturing. Impacts to drainage lines represent a small proportion of potential habitat for this species, however, drainage lines would not provide optimal habitat for this species. It is therefore highly unlikely that mining would have any adverse effects on the habitat Sydney Hawk Dragonfly, if a viable population exists here.

e) Whether the action proposed is likely to have an adverse effect on critical habitat (either directly or indirectly).

There are no areas of critical habitat for Sydney Hawk Dragonfly listed on the NSW Register of Critical Habitat.

f) Whether the action proposed is consistent with the objectives or actions of a recovery plan or threat abatement plan.

At present there is no recovery or threat abatement plan for Sydney Hawk Dragonfly.

g) Whether the action proposed constitutes or is part of a key threatening process or is likely to result in the operation of, or increase the impact of, a key threatening process.

One KTP listed under the BC Act is directly applicable to the Project: *Alteration of habitat following subsidence due to longwall mining.*

While the Project is expected to exacerbate this KTP, associated impacts to Sydney Hawk Dragonfly due to subsidence are unlikely. Although Avon River appears to provide suitable habitat, the mine subsidence predictions for Avon River indicate there would be no flow diversions due to fracturing. In any case, this species appears very unlikely to occur in the Study Area.

APPENDIX

D

ASSESSMENT OF SIGNIFICANCE
ADAM'S EMERALD DRAGONFLY

1) Assessment of Significance (FM Act) – Adam's Emerald Dragonfly

a) In the case of a threatened species, whether the action proposed is likely to have an adverse effect on the life cycle of the species such that a viable local population of the species is likely to be placed at risk of extinction.

Adam's Emerald Dragonfly is extremely rare, having been collected only in small numbers at a few locations in the greater Sydney region (NSW DPI 2013b). Specimens have been collected at five localities: Somersby Falls and Floods Creek in Brisbane Waters National Park near Gosford; Berowra Creek near Berowra and Hornsby; Bedford Creek in the Lower Blue Mountains; and Hungry Way Creek in Wollemi National Park. There are no records for this species within the Study Area or the Cordeaux and Lake Avon catchments. There are no records of Adam's Emerald Dragonfly occurring south of Sydney, despite active collecting in the Hawkesbury-Nepean River catchment (Fisheries Scientific Committee 2008). This species was not collected by Cardno during surveys of aquatic macroinvertebrates in Wongawilli, Donalds Castle or Native Dog Creeks as part of the Dendrobium Mine area studies, but aquatic habitat appears suitable for this species does occur within these larger watercourses (Cardno Ecology Lab 2011). Elsewhere, larval Adam's Emerald Dragonfly have been found in small creeks with gravel or sandy bottoms and narrow shaded riffle zones with moss and extensive riparian vegetation. Ephemeral/intermittent drainage lines are unlikely to provide optimal habitat for this species.

Extraction of the longwalls could have an adverse effect on the life cycle of the Adam's Emerald Dragonfly if subsidence results in significant changes in levels of ponding, flooding or scouring of banks, fracturing of bedrock and diversion of surface flows, which, in turn, result in significant loss of aquatic habitat and reductions in habitat connectivity or water quality. The mine subsidence predictions for larger watercourses including Avon River, Donalds Castle Creek and Wongawilli Creek indicate there would not be any fracturing . Although larger drainage lines may provide more suitable habitat, they do not provide any substantial gravel or sand substratum. Together with the apparent absence of this species from the Study Area, it is highly unlikely that mining would have any adverse effects on the life cycle of Adam's Emerald Dragonfly, if a viable population exists within these watercourses.

b) In the case of an endangered population, whether the action proposed is likely to have an adverse effect on the life cycle of the species that constitutes the endangered population such that a viable local population of the species is likely to be placed at risk of extinction.

There are no threatened populations of Adam's Emerald Dragonfly listed on the Threatened Species Schedules of the FM Act.

c) In the case of an endangered ecological community or critically endangered ecological community, whether the proposed action is likely to:

i) Have an adverse effect on the extent of the ecological community such that its local occurrence is likely to be placed at risk of extinction, or

ii) Substantially and adversely modify the composition of the ecological community such that its local occurrence is likely placed at risk of extinction.

The Adam's Emerald Dragonfly is not part of an endangered ecological community listed on the Threatened Species Schedules of the FM Act.

d) In relation to the habitat of a threatened species, population or ecological community:

i) The extent to which habitat is likely to be removed or modified as a result of the action proposed;

ii) Whether an area of habitat is likely to become fragmented or isolated from other areas of habitat as a result of the proposed action;

iii) the importance of the habitat to be removed, modified, fragmented or isolated to the long-term survival of the species, population or ecological community in the locality.

Larval Adam's Emerald Dragonfly is aquatic and inhabit small creeks with gravel or sandy substratum and narrow shaded riffle zones with moss and extensive riparian vegetation. The adults are terrestrial, but return to water to breed. Such habitat is largely absent within the Study Area (watercourses here are larger or do not support substantial gravel or sand substratum), and there are no records for this species within the Study Area. It is therefore highly unlikely that mining would have any adverse effects on the habitat of Adam's Emerald Dragonfly, if a viable population exists within these watercourses.

e) Whether the action proposed is likely to have an adverse effect on critical habitat (either directly or indirectly).

There are no areas of critical habitat for Adam's Emerald Dragonfly listed on the NSW Register of Critical Habitat.

f) Whether the action proposed is consistent with the objectives or actions of a recovery plan or threat abatement plan.

At present there is no recovery or threat abatement plan for Adam's emerald dragonfly.

g) Whether the action proposed constitutes or is part of a key threatening process or is likely to result in the operation of, or increase the impact of, a key threatening process.

One KTP listed under the BC Act is directly applicable to the Project: *Alteration of habitat following subsidence due to longwall mining.*

While the Project is expected to exacerbate this KTP, associated impacts to Adam's Emerald Dragonfly due to subsidence are unlikely. Adam's Emerald Dragonfly is very unlikely to be found in drainage lines that have high probability of experiencing fracturing resulting in flow diversions and loss of aquatic habitat. The mine subsidence predictions for Avon River, Wongawilli Creek and Donalds Castle Creek indicate there would not be any fracturing, and therefore flow diversions are not expected. In any case, this species appears very unlikely to occur in the Study Area.