APPENDIX E

Aquatic Ecology Assessment

Dendrobium Mine – Plan for the Future: Coal for Steelmaking

Aquatic Ecology Assessment

59917027

Prepared for
Illawarra Coal Holdings Pty Ltd

10 May 2019

Cardno
Shaping the Future

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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 Coal), 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.

Illawarra Coal is seeking a new Development Consent to gain access to Areas 5 and 6 within Consolidated Coal Lease (CCL) 768 and for the use of supporting infrastructure, referred to as the Dendrobium Mine – Plan for the Future: Coal for Steelmaking (hereafter referred to as the Project). Area 5 is located to the northwest of DA3B and east of Lake Avon and Area 6 is located to the north of DA3B, downstream of Lake Cordeaux (**Figure 1-1**).

South32 proposes to seek the necessary approvals to allow longwall mining in these areas and submit an Environmental Impact Statement (EIS) and associated documents to obtain a new development consent and secure approval under the *Environmental Planning and Assessment Act 1979* (the EP&A Act) and the *Environmental Protection and Biodiversity Conservation Act 1999* (the EPBC Act).

The primary potential impact to aquatic ecology associated with the Project is the potential for mining-related subsidence and fracturing of bedrock in overlying watercourses. This has potential to result in diversion of flows, reduction in pool water levels and impact aquatic habitat, flora and fauna in the various watercourses traversing these areas.

It is noted the Project falls within the definition of a “pending or interim planning application” under the *Biodiversity Conservation (Savings and Transitional) Regulation 2017*, which means that the *Biodiversity Conservation Act 2016* (BC Act) does not apply. Rather the *Threatened Species Conservation Act 1995* (TSC Act) (now repealed) applies when assessing impacts to threated species listed under this Act previously.

Cardno (NSW/ACT) Pty Ltd (Cardno) has been engaged by South32 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 Area 5 and Area 6 longwalls. The extraction of these proposed longwalls will 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 reduce 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 sections of the perennial Avon River and Cordeaux River, Donalds Castle Creek and several associated and largely

ephemeral drainage lines (draining upland swamps) traversing the Study Area. 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 (i.e. contain fewer taxa than expected based on the creek's physical and chemical characteristics) macroinvertebrate assemblages, 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 Cordeaux River and their associated upstream lakes. Several species of native fish have been identified in these waterbodies previously and they are mapped as Key Fish Habitat (KFH) (NSW DPI 2017a) and include Type 1 - Highly sensitive KFH (aquatic vegetation and larger rocks and wood debris). Type 1 – Highly Sensitive KFH also occurs in Donalds Castle Creek and Type 2 - Moderately sensitive KFH occurs in the lower, third order reaches of ephemeral drainage lines. The majority of ephemeral drainage lines are first and second order and 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, particularly Climbing Galaxias (*Galaxias brevipinnis*) and together provide a substantial proportion of habitat for fish, and other aquatic species, across the Study Area.

> Macquarie Perch (*Macquaria australasica*), 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 Cordeaux River. 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. Based on previous records and known distributions, Sydney Hawk Dragonfly (*Austrocordulia leonardi*) and Adams Emerald Dragonfly (*Archaeophya adamsi*), both listed as Endangered under the FM Act, are very unlikely to occur in the Study Area. Similarly, Australian Grayling (*Prototrocetes maraena*), listed as Vulnerable under the EPBC Act and protected under the FM Act, does not occur in the Study Area.

> Giant Dragonfly (*Petalura gigantea*), listed as Endangered under the BC Act, potential foraging and / or potential breeding habitat was identified in several swamps in the Study Area. The relatively large number (> 30) of dragonfly larvae burrows identified in Area 6 Swamp Den83 potentially indicates the swamp provides particularly important breeding habitat for this species.

> Previous stygofauna studies undertaken approximately 10 kilometres 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 and Area 6. 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

Predictions of ground movements following longwall extraction indicate there is a low (< 10 %) probability of significant fracturing resulting in flow diversions in sections of Avon River, Cordeaux River and Donalds Castle Creek within 400 m of the proposed longwalls. Minor fracturing may occur in these watercourses within 400 m of the proposed longwalls. Fracturing is also predicted to occur in drainage lines directly above and up to 400 m away from 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:

> Substantial impacts to aquatic habitat and biota due to fracturing in Avon River and Cordeaux River are unlikely given the low probability of significant fracturing and the size of these rivers (i.e. greater water flow and volume and somewhat flooded nature) that prevent habitat loss due to any flow diversion. Any impacts to aquatic habitat and biota in Donalds Castle Creek due to fracturing and flow diversions are expected to be larger to its relatively small size and presence of many flow controlling rockbars. Fracturing and flow diversions here and in drainage lines (i.e. first, second and third order tributaries that drain upland swamps) are expected to result in localised (i.e. within 600 m of Area 5 and Area 6 longwalls) reductions in aquatic habitat and loss of some biota. 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 Donalds Castle Creek and drainage lines that traverse the Study Area which would be expected to be most susceptible to potential mining related subsidence, compared with Avon and Cordeaux Rivers. The two dragonflies appear very unlikely to occur in 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, such as rockbar fractures resulting in water loss in a pool within Donalds Castle Creek or third order or higher drainage lines or significant changes in water chemistry 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 significant impacts to threatened aquatic ecology species, populations or communities listed under the FM Act or EPBC Act are predicted, no associated biodiversity offsets would be required. The requirement for and form of any offsets associated with significant impacts to Key Fish Habitat in third order and higher watercourses identified during monitoring, would be identified following the completion of any required stream remediation activities.

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1 Introduction

1.1 Background

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 Coal), 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.

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South32 proposes to seek the necessary approvals to allow longwall mining in these areas and submit an Environmental Impact Statement (EIS) and associated documents to obtain a new development consent and secure approval under the *Environmental Planning and Assessment Act 1979* (the EP&A Act) and the *Environmental Protection and Biodiversity Conservation Act 1999* (the EPBC Act).

The primary potential impact to aquatic ecology represented by the Project is the potential for subsidence and fracturing of the ground above the mine, including at the surface in overlying watercourses, resulting in reduced groundwater levels, diversion of flows, reduction in pool water levels and loss of aquatic habitat. It is noted the Project falls within the definition of a “pending or interim planning application” under the Biodiversity Conservation (Savings and Transitional) Regulation 2017, which means that the *Biodiversity Conservation Act 2016* (BC Act) does not apply.

1.2 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 support the extraction of approximately 78 million tonnes (Mt) of Run-of-Mine (ROM) coal. The life of the Project would be to 31 December 2048.

The Project would include the following activities:

- Longwall mining of the Bulli Seam in a new underground mining area (Area 5);
- Longwall mining of the Wongawilli Seam in a new underground mining area (Area 6);
- Development of underground roadways within the Bulli Seam, Wongawilli Seam and adjacent strata to access mining areas;
- Use of existing underground roadways and drifts for personnel and materials access, ventilation, dewatering and other ancillary activities related to Areas 5 and 6;
- Development of surface infrastructure associated with mine ventilation and gas management and abatement, and other ancillary infrastructure;
- Handling and processing of up to 5.2 million tonnes per annum (Mtpa) of ROM coal;
- 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;
- Use of the Cordeaux Pit Top for mining support activities;

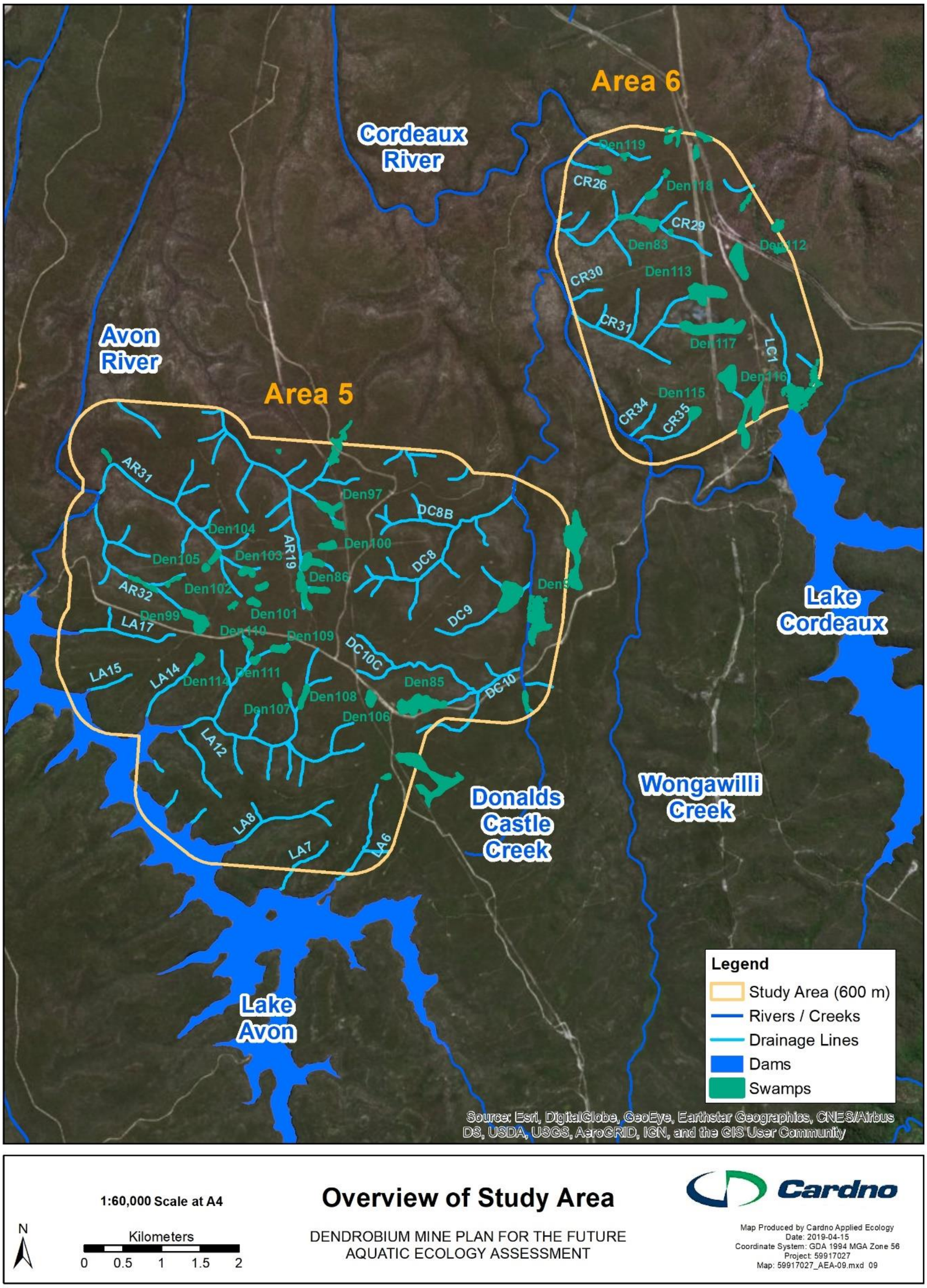

Figure 1-1 Overview of Study Area. For clarity, drainage lines identified within the Study Area only

> Augmentation of mine access arrangements, including upgrades to, and the use of, the Cordeaux Pit Top;

> Transport of sized ROM coal from the Kemira Valley Coal Loading Facility to the Dendrobium CPP via the Kemira Valley Rail Line;

> Delivery of product coal from the Dendrobium CPP to the Port Kembla Steelworks for domestic use or to the Port Kembla Coal Terminal for export;

> Transport of coal wash by road to customers for engineering purposes (e.g. civil construction fill), for other beneficial uses and/or for emplacement at the West Cliff Stage 3 and Stage 4 Coal Wash Emplacement;

> Development and rehabilitation of the West Cliff Stage 3 Coal Wash Emplacement;

> Progressive development of sumps, pumps, pipelines, water storages and other water management infrastructure;

> Controlled release of excess water in accordance with the conditions of Environmental Protection Licence 3241 and/or beneficial industrial re-use.

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

> Other associated minor infrastructure, plant, equipment and activities.

1.3 Scope of Works

Cardno (NSW/ACT) Pty Ltd (Cardno) was engaged by South32 to undertake baseline aquatic ecology survey for the Project and prepare an Aquatic Ecology Assessment (AEA) (this report). The AEA will form a key part of the EIS for this State Significant Development (SSD). The work undertaken by Cardno incorporates three components:

1. **Survey Plan and Methodology**

The Survey Plan and Methodology (Cardno 2016a) provided recommendations for the survey requirements and methodology for the baseline field studies. It includes the following:

> An outline of aquatic ecology issues, including listed threatened species with potential to occur in Area 5 and Area 6, for consideration in the Baseline Studies (Cardno 2017) and the AEA;

> Details of the timing and locations of Baseline Surveys to facilitate access requirements and field planning; and

> Description of the sampling methods and effort included in the Baseline Surveys, including specific sampling methodology for listed threatened species and details of how these comply with relevant government policies and guidelines, where applicable.

2. **Baseline Studies**

The Baseline Studies (Cardno 2017), included the following:

> Review and synthesis of existing information on aquatic habitat, flora and fauna, including stygofauna, within, and adjacent to, Area 5 and Area 6, and the broader Cordeaux River and Avon River catchments. Existing information includes previous investigations for DA1, DA2 and DA3, which began in 2001, online literature searches and other available records of aquatic flora and fauna;

> Baseline field surveys on aquatic habitat, flora and fauna, including macroinvertebrates, fish, plants and threatened species in, and adjacent to, Area 5 and Area 6;

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

> Specific advice on Secretary's Environmental Assessment Requirements (SEARs) relating to aquatic ecology (where applicable).

3. Aquatic Ecology Assessment

The AEA (this report) was prepared following completion of all field studies and the Baseline Studies (Cardno 2017) report and includes the following:

> Findings from the Baseline Studies (Cardno 2017);

> 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);

> A table clearly identifying where in the AEA each SEAR, relevant to aquatic ecology, has been addressed;

> 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 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.

2 Legislative Requirements, Guidelines and Policy

2.1 NSW Legislation

2.1.1 Environmental Planning and Assessment Act 1979

The *Environmental Planning and Assessment Act 1979* (EP&A Act) institutes a system of environmental planning and assessment in NSW and is administered by the NSW Department of Planning and Environment (DPE). Part 4 of the EP&A Act sets out the approvals process for SSD.

Part 4 of the EP&A Act indicates some of the authorisations required under other Acts are not required for SSDs (in accordance with Section 89J). 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 5(A) of the EP&A Act outlines the factors that must be taken into account when deciding whether a project would be likely to have a significant impact on threatened species, populations or communities or their habitats listed under the former *Threatened Species Conservation Act 1995* (TSC Act) (now the *Biodiversity Conservation Act, 2016* [BC Act]) under which the Project is being assessed (**Section 2.1.3**), known as the Assessment of Significance, and previously the seven-part test and the eight-part test. The factors relevant to consideration of effects on threatened species include:

> Whether the proposed action 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 extent to which the species habitat is likely to be removed or modified as a result of the action proposed, whether an area of habitat is likely to become fragmented or isolated from other areas of habitat as a result of the proposed action, and whether the habitat to be removed, modified, fragmented or isolated is important to the long-term survival of the species in the locality;

> Whether the proposed action is likely to have an adverse effect on critical habitat (either directly or indirectly;

> Whether the proposed action is consistent with the objectives or actions of a recovery plan or threat abatement plan; and

> Whether the action proposed constitutes or is part of a Key Threatening Process (KTP) or is likely to result in the operation of, or increase the impact of, a KTP.

2.1.2 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. The FM Act regulates the conservation of fish, marine vegetation and some aquatic macroinvertebrates and the development and sharing of the fishery resources of NSW for present and future generations. 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 habitat are listed in a register kept by the Minister of Primary Industries. Impacts to these species, population, communities, processes and habitats due to the Project need to be considered. Assessment guidelines to determine whether a significant impact is expected, are detailed in Section 220ZZ and 220ZZA of the FM Act.

Another objective of the FM Act is to conserve KFH. 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 Project 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 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 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, threatened populations or threatened communities listed under the provisions of FM Act.

2.1.3 Threatened Species Conservation Act 1995

The TSC Act provides for the conservation of species, populations and ecological communities of animals and plants in NSW that are threatened with extinction. The TSC Act contains provisions for the preparation of recovery plans for listed threatened species, populations and ecological communities, the declaration and mapping of habitats that are critical to their survival and threat abatement plans to manage KTPs. The TSC Act also provides for the facilitation of the appropriate assessment, management and regulation of actions that may damage critical or other habitat or significantly affect threatened species, populations and ecological communities. The provisions of the BC Act apply to algae, aquatic plants, invertebrates and all major vertebrate groups except fish.

In November 2016, the BC Act was passed and the State is currently developing supporting regulations and other subordinate instruments to support to BC Act. While the BC Act has replaced the TSC Act and sections of the *National Parks and Wildlife Act 1974* (NPW Act) as of the 25 August 2017, it does not apply to the Project due to transitional arrangements (**Section 1.1**).

Assessment in this report is undertaken in accordance with the FM Act. The assessment of other species not listed under the FM Act are undertaken in Appendix D of the Project EIS. Notwithstanding, references in this report to threatened species listings and status, as well as the KTP's etc., use the most recent BC Act listing.

2.2 Commonwealth Legislation

2.2.1 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 the Environment and Energy (DEE) 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 DEE should be submitted (Department of the Environment [DOE] 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.

2.3 Secretary's Environmental Assessment Requirements

2.3.1 Project SEARs

Following submission of the Preliminary Environmental Assessment for the Project (South32 2016a), SEARs for the Project were issued by the Department of Planning and Environment (DPE) on 6 February 2017 and re-issued on 18 September 2018. Those directly applicable to aquatic ecology are provided in **Table 2-1**. 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 the Illawarra Coal Environmental Field Team (ICEFT) as part of ongoing monitoring and assessment.

Table 2-1 Project Secretary's Environmental Assessment Requirements applicable to aquatic ecology

Source	SEARs / 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 5
	▪ An assessment of the likely biodiversity impacts of the development.	Section 5
NSW Department of Primary Industries (DPI)	The EIS should include the following:	
	▪ Identification of KFHs within the proposal area;	Section 4.3.1
	▪ 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 4.3
	▪ Assessment of impacts on watercourses, riparian land, wetlands, and Groundwater Dependent Ecosystems (GDEs)[1], and measures proposed to reduce and mitigate these impacts.	Section 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 5.1, 5.2.1, 6.4 and 6.5
	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].	Section 4.3*
	The EIS must assess the impact of the development on hydrology, including:	
	▪ Effects to downstream rivers, wetlands, estuaries, marine waters and floodplain areas;	Section 5
	▪ Effects to downstream water-dependent fauna and flora including GDEs[1]; and	Sections 5.2.2 and 5.2.3
	▪ 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 5.2.1.1
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*

*See also mapping by ICEFT

1 Note surface GDE's have been assessed within Appendix D of the Project EIS. This AEA includes assessment of stygofauna (a subterranean GDE).

2.4 Policies and Guidelines

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

The NSW DPI *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* (NSW DPI 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 taken into account 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 KFHs. Other freshwater habitats plus weir pools and dams across natural waterways are considered to be moderately sensitive KFHs. Ephemeral 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.

2.5 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: *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 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 coalfields 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 significantly 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 Department of Environment and Conservation (now OEH) 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 Extraction Plans.

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 (**Section 2.1.2**).

3 Existing Information

3.1 Physical Setting and Study Area

Area 5 and Area 6 are located within the Metropolitan Catchment Area, which is a special declared area controlled by Water NSW (previously the Sydney Catchment Authority (SCA)). The main watercourses within the vicinity of Area 5 and Area 6 are Donalds Castle Creek, Cordeaux River and Avon River, which flow alongside the boundaries of the proposed mining. There are also numerous drainage lines and upland swamps, feeding into these watercourses. The extent of Area 5 and Area 6 and identified watercourses and swamp habitat within, and adjacent to, these areas are identified in **Figure 3-1**.

The Study Area for the baseline surveys and AEA includes the aquatic ecology directly above and within 600 m of the proposed longwalls within Area 5 and Area 6. This includes the sections of Avon River and Donalds Castle Creek adjacent to Area 5 and the Cordeaux River adjacent to Area 6, as well as their associated drainage lines that traverse the Study Area. The locations and names of major watercourses (Donalds Castle Creek, Cordeaux River and Avon River), associated drainage lines and upland swamp habitat have been provided by the ICEFT and other specialists. Wongawilli Creek, which joins the Cordeaux River just upstream of Area 6, is further than 600 m from the proposed longwalls (i.e. outside the Study Area) and would not be affected by the Project. Swamps in the Study Area may provide habitat for Giant Dragonfly (*Petalura gigantea*), listed as Endangered under the BC Act. Baseline surveys of the Giant Dragonfly have been undertaken as a component of this AEA. However, potential impacts to the Giant Dragonfly and upland swamp habitat, have been assessed in Appendix D of the Project EIS.

3.2 Overview of Previous Studies

Numerous studies of aquatic habitat, flora and fauna in the Dendrobium Mine area have been undertaken by Cardno (formerly Cardno Ecology Lab and The Ecology Lab). These included studies in Dendrobium Area 1 (DA1) (The Ecology Lab 2001a, b; 2003 and 2005), Dendrobium Area 2 (DA2) (The Ecology Lab 2006; Cardno Ecology Lab 2009) and Dendrobium Area 3A and 3B (DA3A and DA3B) (The Ecology Lab 2007; Cardno Ecology Lab 2011, 2012a, b; 2013; 2014; 2015; and 2016b). In these studies, the primary watercourses considered were in the Wongawilli, Native Dog, Donalds Castle and Sandy Creek Catchments.

Detailed information on aquatic ecology in the Study Area and adjacent areas is provided in **Sections 3.3 to 3.9**. This includes the findings of surveys undertaken in Donalds Castle Creek, particularly information from DA3 monitoring Sites 14 and X1 on Donalds Castle Creek, just downstream of the Fire Road 6 crossing and just downstream of where it emerges from a headwater swamp (Den05), respectively. Where available, information from surveys undertaken in Avon River, Cordeaux River, Lake Avon and Cordeaux Dam, and adjacent areas, has also been included.

3.3 Aquatic Habitat and Vegetation

Aquatic ecology investigations undertaken for Donalds Castle Creek as part of the *Dendrobium Area 3B Subsidence Management Plan (SMP) - Aquatic Flora and Fauna Assessment* (Cardno Ecology Lab 2012a) indicated the following:

> 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 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;

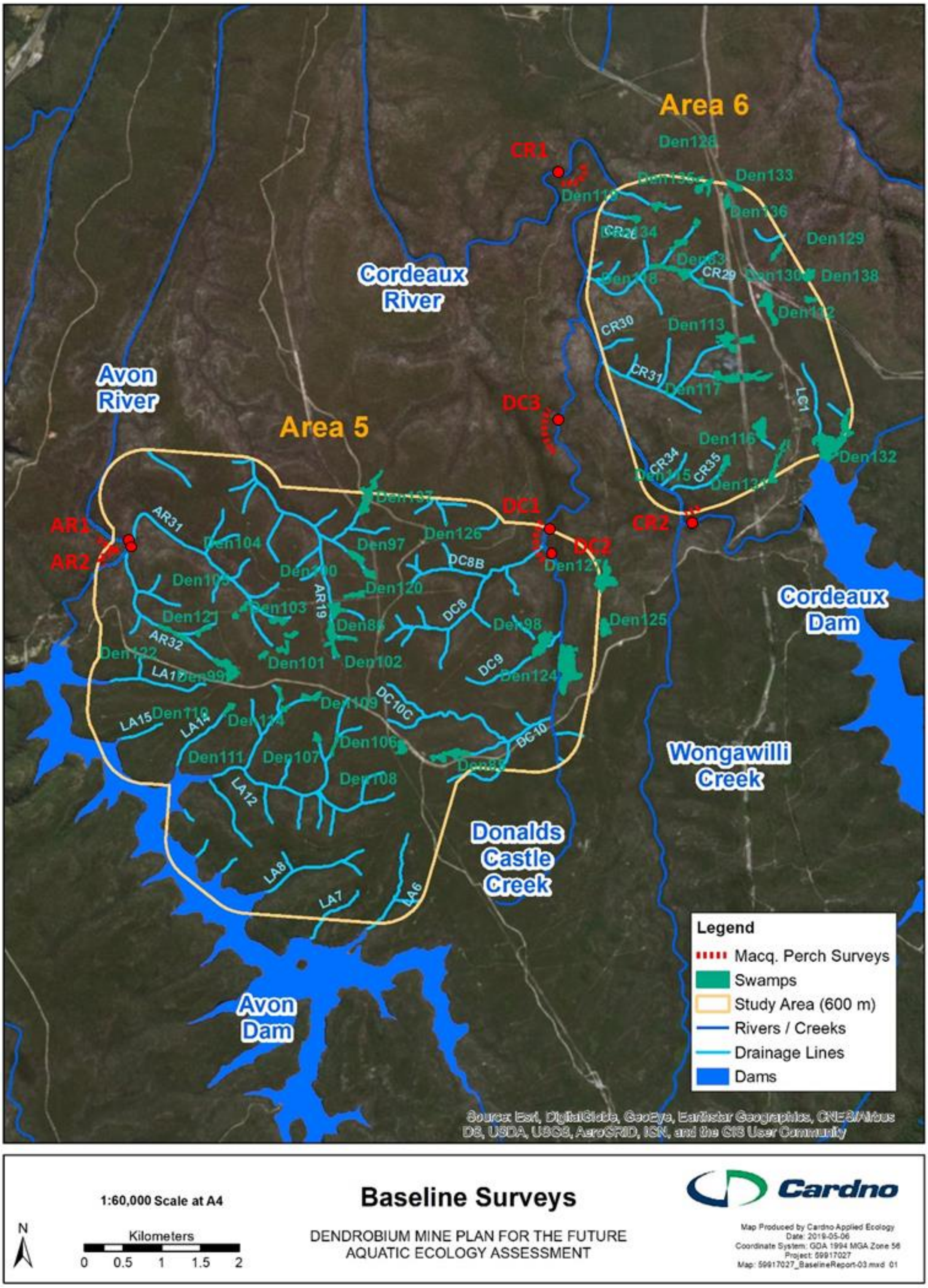

Figure 3-1 Baseline Surveys

> 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 creek which could pose a barrier to passage for some fish; and

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

While no literature could be located on the aquatic habitat and vegetation within the drainage lines that traverse Area 5 and Area 6, composition and condition of riparian vegetation here would very likely be similar to that found along Donalds Castle Creek. These drainage lines would also provide some habitat for aquatic fauna, but it is likely to be less substantial and less permanent, compared with that in Donalds Castle Creek, due to the smaller catchment areas and, therefore, flows present. As is the case within Donalds Castle Creek, several natural barriers to fish passage, such as waterfalls and cascades, are present.

Avon River and Cordeaux River are perennial, regulated rivers that flow from Avon Dam and Cordeaux Dam, respectively. The riparian vegetation in reaches of these rivers within the Study Area are likely to be largely undisturbed, and likely include the species identified along Donalds Castle Creek. These rivers would provide substantial habitat for native fish, including deep pools, aquatic vegetation, large wood debris and likely also gravel beds.

The KFH map for Wollongong available on the NSW DPI website indicates that Avon River, Cordeaux River, their upstream lakes and Wongawilli Creek (not in the Study Area) are KFH (NSW DPI 2017a). Donalds Castle Creek and the drainage lines that traverse the Study Area are not identified as KFH.

3.4 Water Quality

Previous surveys have indicated that some measures of water quality within Donalds Castle Creek have often been outside of 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) and during recent ongoing monitoring (Cardno Ecology Lab 2015) showed levels were generally within the ANZECC/ARMCANZ (2000) default trigger values (DTVs) (30 to 350 micro Siemen 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.

3.5 Macroinvertebrates

Several AUSRIVAS surveys have been undertaken in Donalds Castle Creek. These have indicated macroinvertebrate assemblages range from equivalent to AUSRIVAS reference condition (AUSRIVAS Band A) to significantly impaired (AUSRIVAS Band B) (Cardno Ecology Lab 2012b). AUSRIVAS Band scores are derived from the OE50 Taxa Scores, which is a biotic index of habitat and water quality. OE50 Taxa Scores and Bands from recent sampling undertaken as part of the ongoing DA3B investigations have also been within this range (**Table 3-1**). The SIGNAL2 indices, a biotic index of water pollution, suggested severe to moderate water pollution, and are comparable to those from the ongoing investigations.

However, while the results of AUSRIVAS sampling suggest potential anthropogenic disturbance to habitat and / or water quality, there is no other evidence to support this. It is possible that the relatively 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 2012b; Ecoengineers 2006).

Table 3-1 Results of AUSRIVAS sampling undertaken on DA3B monitoring Sites 14 and X1 on Donalds Castle Creek, just upstream of Area 5, as part of the ongoing monitoring associated with DA3B 2010 to 2015 (Cardno Ecology Lab 2016b)

Index:		No. of Taxa	OE50 Taxa Score	SIGNAL2 Index	No. of Taxa	OE50 Taxa Score	SIGNAL2 Index
		Site 14			Site X1		
2010	Mar	25	1.16	4.5	15	0.92	3.7
	May	29	1.11	4.8	21	0.82	4.7
	Sep	24	0.92	4.2	21	0.61	4.2
	Nov	19	0.64	4.5	20	0.88	4.3
2011	Apr	20	0.69	4.7	19	0.62	3.9
	Jun	15	0.54	4.7	18	0.62	4.6
	Sep	19	0.55	4.4	13	0.57	4.8
	Oct	19	0.73	4.4	22	0.97	3.8
2013	Apr	20	0.79	4.4	25	1.03	4.4
	Jun	20	0.89	4.8	20	0.82	4.5
	Sep	11	0.59	4.8	19	0.79	4.3
	Nov	20	0.91	4.7	19	1.05	4.3
2015	May	13	0.65	5.0	9	0.41	3.6
	Jun	19	0.65	5.0	15	0.82	3.8
	Sep	20	0.7	4.8	15	0.79	4.6
	Nov	18	0.73	4.5	16	0.79	4

3.6 Fish

Fish surveys have been undertaken in the Cordeaux Catchment previously. A survey of Lake Cordeaux, undertaken in 1994 using gill nets and electro-fishing, indicated that three native fish species, Long-finned Eel (*Anguilla reinhardtii*), Australian Smelt (*Retropinna semoni*) and the listed threatened Macquarie Perch (*Macquaria australasica*) (**Section 3.7.2**) as well as Goldfish (*Carassius auratus*), an invasive species, were present (Gehrke and Harris 1996). During subsequent surveys, numerous smelt, modest numbers of Goldfish, Long-finned Eels, Mountain Galaxids (*Galaxias olidus*), Short-finned Eels (*Anguilla australis*) and a single Macquarie Perch were caught (Growns and Gehrke 2001). Freshwater crayfish (*Euastacus* sp.) were also caught in Cordeaux Dam (Growns and Gehrke 2001). During the third survey, undertaken when Macquarie Perch are known to migrate from reservoirs to spawning habitats in creeks, four specimens were caught in Lake Cordeaux, but none were found in the creeks entering the lake. This was despite the presence of habitats suitable for spawning in Goondarrin and Kembla Creeks (Creese and Hartley 2003). It is possible that a low storage level in the dam at the time of sampling may have prevented Macquarie Perch from accessing these spawning areas. In Lake Avon, Macquarie Perch, Long-finned Eel, and Brown Trout (*Salmo trutta*) have been recorded (Cardno Ecology Lab 2012a).

Some of these species were also present in Donalds Castle Creek. The bi-annual surveys undertaken for Elouera Colliery Longwalls 7 to 10 between 2002 and 2006 indicated that Australian Smelt and Mountain Galaxias were present in Donalds Castle Creek (MPR 2002, 2003a and b, 2004a and b, 2005, 2006a, b and c). Climbing Galaxias (*Galaxias brevipinnis*) and Short-finned Eel were also caught during backpack electrofishing surveys upstream of Area 5 undertaken in November 2011 (Cardno Ecology Lab 2012b). Climbing Galaxias were caught at DA3 Site 14 (just downstream of the Fire Road 6 Crossing) and approximately 150 m further upstream. Short-finned Eels were caught downstream of Site X1. Freshwater crayfish were also caught in this reach. More recently, galaxids (*Galaxias* sp.) have also been caught in Donalds Castle Creek on several occasions during the ongoing DA3A (Cardno 2015) and DA3B (Cardno 2016b) aquatic ecology monitoring program. This species was 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. While not sampled during these surveys, it is possible that drainage lines within Area 5 and Area 6, 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.

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 Cordeaux (Goldfish) and Lake Avon (Brown Trout), no invasive species of fish have been identified in the Study Area.

3.7 Listed Threatened Aquatic Ecology

3.7.1 Desktop Searches

A search of studies undertaken by Cardno and any other consultants was undertaken to identify records of any listed-threatened aquatic ecology within the Study Area. A search for information on records and distributions of listed threatened aquatic ecology listed under the FM Act, EPBC Act and BC Act in Donalds Castle Creek and nearby reaches of Avon River and Cordeaux River was also undertaken using the following resources:

> The DEE Protected Matters Search Tool was used to determine whether any MNES listed under schedules of the EPBC Act occurred in a 10 km radius from the centre of the proposed longwalls within Area 5 and Area 6;

> The OEH Geographic Region Search was used to determine whether any threatened aquatic plant species or Threatened Ecological Communities listed under the BC Act were present in the Sydney Cataract sub-region of the Hawkesbury-Nepean Catchment Management Authority Region. The OEH managed BioNet was also searched for records of BC Act listed flora and fauna within the Dendrobium Mine area held in the Atlas of NSW Wildlife; 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 (**Sections 3.7.2** to **3.7.6**). Amphibians, aquatic mammals and reptiles are being considered by other specialists and were excluded from the search.

3.7.2 Macquarie Perch

Macquarie Perch (*Macquaria australasia*) 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 3.6**) 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 has recently been released (Commonwealth of Australia 2018). The Recovery Plan 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.

3.7.3 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.

3.7.4 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 2004). 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 Wilton. There are no records for this species within the Study Area or the Cordeaux and Lake Avon catchments. Extensive sampling has failed to discover further specimens in other areas suggesting that it has a highly restricted distribution within the catchment of the Nepean River (NSW DPI 2007).

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, 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.

No Recovery and Threat Abatement Plans are associated with this species. However, several conservation and recovery actions for Sydney Hawk Dragonfly are included in the Primefact for this species NSW DPI (2007):

> Allocate and manage environmental water through water sharing planning processes, to lessen the impacts of altered flows;

> Prevent sedimentation and poor water quality by using conservation farming and grazing practices, conserve and restore riparian (river bank) vegetation and use effective erosion and sediment control measures;

> Rehabilitate degraded habitats. Protect riparian vegetation and encourage the use of effective sediment control measures in catchments where the dragonfly may occur;

> 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; and

> Implement the Protected, Threatened and Pest Species Sighting Program and report any sightings to NSW DPI.

3.7.5 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 Lake 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 the baseline 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 within these watercourses (Cardno Ecology Lab 2011).

The larvae of Adam's Emerald Dragonfly inhabit small creeks with gravel or sandy bottoms in narrow, shaded riffle zones with moss and lush riparian vegetation (NSW DPI 2013b). The larvae live for approximately 7 years before metamorphosing into adults that probably live for only a few months. They return to water to breed, with males congregating at breeding sites and guarding a territory and females laying their eggs into the water. They are thought to have a low natural rate of recruitment and limited dispersal abilities.

There are no Recovery and Threat Abatement Plans associated with this species. However, conservation and recovery actions in the Primefact (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.

3.7.6 Giant Dragonfly

3.7.6.1 Background, Ecology and Threats

Giant Dragonfly *(Petalura gigantea)*, listed as Endangered under the BC Act, is known to occur in the Sydney Cataract sub-region of the Hawkesbury-Nepean System and was identified previously in swamps within DA3B a few kilometres from the Study Area in January 2016 (Biosis 2016). The results of the OEH BioNet search also reflect these records, with the nearest swamp where this species was recorded previously located just over 500 m southeast of swamp Den85 in Area 5. Many of the swamps in the Dendrobium Mine area, and the Study Area, consist of a shallow (1 m to 3 m deep) peat / sand substratum, situated in a perched water table (accumulation of groundwater in an unsaturated zone located above the water table) above a relatively impermeable layer of bedrock. Water levels and soil moisture would fluctuate with rainfall, which would likely provide the only recharge to the swamp. These swamps are also likely to form part of the *Coastal Upland Swamp in the Sydney Basin Bioregion Endangered Ecological Community* (EEC), listed under the BC Act and EPBC Act.

Giant Dragonfly is found typically in permanent swamps and bogs containing some free water and open vegetation. It is considered an obligate groundwater dependent mire (peat-forming wetland) dwelling species. Its breeding success is dependent on sites with a groundwater regime that provides enough surface moisture to minimise desiccation of eggs and early larval instars, peatland soils suitable for burrowing by larvae, and that have a water table height that allows larvae to access or extend their burrows (Baird 2012).

Females lay eggs into moss, under other soft ground layer vegetation, and into moist litter and humic soils, often associated with groundwater seepage areas within appropriate swamp and bog habitats (OEH 2016a). The species does not utilise areas of standing water wetland, although it may utilise suitable boggy areas adjacent to open water wetlands. Larvae dig long branching burrows 18 to 75 m deep under the swamp around 2 to 4 cm in diameter. Larvae are slow growing and the larval stage may last 10 years or more. It is thought that larvae leave their burrows at night and feed on insects and other invertebrates on the surface and also use underwater entrances to hunt for food in the aquatic vegetation.

Threats to this species identified in its species profile (OEH 2016a) directly relevant to the Project include:

> Loss of groundwater resources (including perched swamp aquifers) and reduced water quality from longwall mining; and

> Increased sedimentation caused by construction, maintenance, and lack of maintenance of unsealed roads and tracks.

Recovery strategies to assist this species (OEH 2016a) are:

> Retain or reintroduce natural water flows to swamp habitats;

> Protect swamps from pollution;

> Minimise the use of pesticides in and adjacent to swamps;

> Reduce urban runoff, sewerage overflows, illegal stormwater connections and groundwater extraction;

> Prevent access to swamp habitats by off-road vehicles, bushwalkers or other trampling agents through signage, fencing or re-routing of tracks;

> Undertake weed control as required using bush regeneration techniques that will not damage the sensitive swamp habitat;

> Exclude pigs and cattle from swamp habitat; and

> Manage fire trails and unsealed roads to reduce sedimentation impacts.

Further actions supplementary to NSW legislation, policy and programs that can be used by stakeholders to guide management at a site, regional or state scale include (OEH 2016b):

> Monitor impacts of longwall mining and other extractive industry (particularly on groundwater levels) using an appropriate scale and units that identify meaningful levels of change over appropriate time periods using a Before-After-Control-Impact design. Undertake a cumulative impact assessment using species habitat models to determine impacts on populations of this species;

> Refine understanding of species distribution and the distribution of additional potential habitat through targeted surveying of known or predicted suitable habitat across the species' range. Identify swamps likely to have the greatest resilience to climate change impacts in order to prioritise these for management; and

> Manage fire trails and unsealed roads adjacent to, and in the upstream catchments of, wetlands to reduce sedimentation impacts on this species' habitat. Avoid unnecessary disturbance of road surfaces and where feasible seal unsealed roads (or parts thereof where runoff will flow towards wetlands) where other options are unavailable to prevent further sedimentation of swamps. Implement appropriate sediment controls on water diversions to ensure flows are maintained but sediment loads are as low as possible.

Other actions include:

> Research into the impacts of fire, and the long-term effects of more frequent and/or more intense fires on peat soils in order to inform fire management. Following this, revise relevant fire management prescriptions in the Bushfire Environmental Assessment Code guidelines for ecological communities; and

> Consult with the Rural Fire Service and/or National Parks and Wildlife Service to ensure that any burning is conducted with minimal impact on swamp habitat, e.g. no vehicles in swamps, maintain buffers around swamps, hydrate peat soils (especially at margins) prior to burning, if needed.

3.7.6.2 Previous Studies

The nearest previous studies undertaken on Giant Dragonfly were surveys undertaken in swamps in DA3B just south of the Study Area in December 2016 (Biosis 2016). Three adults were observed in one and eight in another of the thirteen swamps surveyed. The two swamps where adults were observed provided breeding habitat and / or foraging habitat and the remaining swamps provided potential breeding, foraging and / or dispersal habitat. Given the distance between these swamps and those throughout the broader area, all swamps within DA3B and associated adjacent woodland are likely to provide foraging and dispersal habitat, though only a sub-set are utilised for reproduction (Biosis 2016).

Giant Dragonfly were also recorded within several swamps that may potentially be affected by longwall mining as part of the Springvale Mine Extension Project, near Lithgow, NSW (RPS 2014). The assessment of impacts to this species focussed on effects to its habitat due to predicted mining related subsidence and its effect on swamp water levels. This relied on comparison of predicted reductions in water levels in swamps where Giant Dragonfly were known to occur with the reported burrowing depth (18 cm to 75 cm) (Baird 2012) of their larvae.

3.8 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 NOW 2012). Groundwater systems may be associated with existing features of the land surface (e.g. permanent, seasonal 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 h (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 <u>Previous Studies</u>

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 a 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 < 1500 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, b). 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 & b).

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 2015) 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 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 and 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, b), 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; and

> 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 3-2**).

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 be restricted also.

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 and Area 6 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 (HydroSimulations 2017).

Table 3-2 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)*
Groundwater quality (EC µS/cm)	< 3,000[1] < 5,000[2]	60 to 130	614	581	1,891 to 2,169
Groundwater quality (pH)	Known range: 4.3 to 8.5 units[2]	4 to 6	6.8	8.4	7.7 to 9.1
Groundwater quality (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], HydroSimulations (2017)[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.

3.10 Previous Mining Impacts

3.10.1 Mine Areas

Several operations have undertaken mining previously in the Metropolitan Special Area, including:

> Longwall mines: Dendrobium Mine (DA1, DA2, DA3A, DA3B Longwalls 9 to 13), Elouera Mine, Cordeaux Mine, Kemira Mine; and

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

In addition to the Project, future mining is proposed in DA3B (Longwalls 14 to 18), DA3A (Longwall 19) and DA3C. This mining is located within the upper Avon River and Cordeaux River catchments (including catchments of Wongawilli Creek, Donalds Castle Creek and tributaries of Lake Avon and Lake Cordeaux) (**Figure 3-2**).

3.10.2 Impacts to Watercourses

Subsidence induced impacts (fracturing, reduced groundwater levels, flow diversions and/or reductions in pool water levels) have been observed in watercourses overlying each of the previous mine 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 ICEFT using the following categories:

> Category 1 - Not impacted by mining (no future mining proposed).

> Category 2A - Not impacted by mining but located above and expected to experience physical mining impacts due to the proposed longwalls for the Project (i.e. Area 5 and Area 6).

> Category 2B - Not impacted by mining but located above and expected to experience physical mining impacts due to future/proposed longwalls (DA3B Longwalls 14 to 18, DA3A Longwall 19 and DA3C).

> Category 3 - Possible indirect impacts downstream of longwall mining: Relatively high confidence (based on field observations) of iron staining, reductions of flow and/or changes in water quality due to upstream impacts associated with longwall mining (Category 4). Potential for indirect impacts downstream of historical bord and pillar mining not assessed due to absence of field data.

> Category 4 - Directly impacted by longwall mining: Known or high probability of subsidence induced impacts (fracturing, flow diversion, reductions of aquatic habitat) in watercourses directly mined under by longwalls.

> Category 5 - Possibly impacted by historical bord and pillar mining: Likely to have experienced direct impacts (fracturing, flow diversion, reductions aquatic habitat) inferred from observations of longwall mining impacts.

As of May 2018 direct longwall mining impacts (fracturing, flow diversions and/or pool water loss) had or were highly likely to have occurred in approximately 36 km of watercourses (**Table 3-3**; **Figure 3-2**). This included first, second and higher order streams within the Wongawilli, Sandy and Donalds Castle Creek Catchments. The most significant impacts observed include fracturing, flow diversions, reductions in pool water levels in SC10C (a tributary of Sandy Creek) and WC17 (a tributary of Wongawilli Creek) in DA3A and in WC21 (a second order tributary of Wongawilli Creek) and in the upper Donalds Castle Creek in DA3B. In each case there was an associated loss of aquatic habitat and likely also biota. By May 2018 the length of complete habitat loss in WC21 was 710 m and in Donalds Castle Creek it was 291 m. The impacts in WC21 represented a significant impact to aquatic ecology at the scale of the watercourse (Cardno 2018).

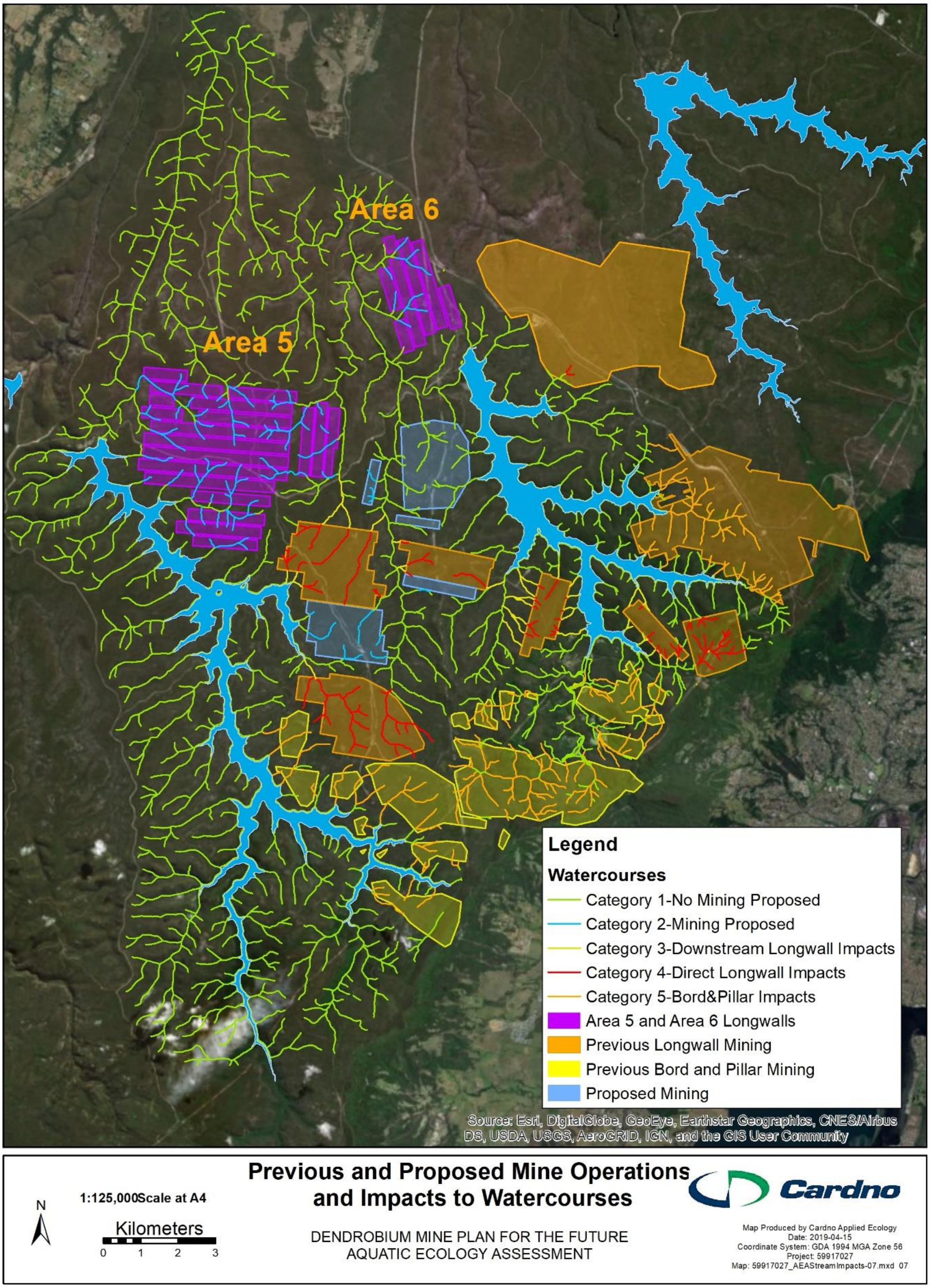

Figure 3-2 Previous and Proposed Mine Operations and Cordeaux River Catchments and Impacts to Watercourses

Table 3-3 Type and Extent of Mining Impacts in Watercourses in the upper Avon and Cordeaux River Catchments (Source: ICEFT)

Category	Length (km)	Percentage (%) of Total Length
Category 1 - Not impacted by mining (no future mining proposed)	550	76.9
Category 2A - Not impacted by mining (future mining proposed in Area 5 and Area 6)	37	5.2
Category 2B - Not impacted by mining (future mining proposed in DA3C and DA3B)	12	1.7
Category 3 - Possibly impacted by downstream effects from longwall mining	18	2.5
Category 4 - Impacted by longwall mining	36	5.0
Category 5 - Possibly impacted by bord and pillar mining	62	8.7
Total	715	100.0

Reductions in pool water levels have also recently been observed in Wongawilli Creek adjacent to Area 3 longwalls. These reductions were due to groundwater depressurisation resulting from the extraction of multiple longwalls in DA3 and extreme rainfall deficits at the time the pools were dry. Approximately 62km of watercourse is located above previous bord and pillar mines. 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.

Associated reductions in aquatic habitat will impact aquatic biota. Changes in the abundance of several macroinvertebrate taxa in SC10C, WC21 and Donalds Castle Creek were attributed to reductions in pool water levels observed at the site (Cardno 2018). These included reductions in the numbers of pollution sensitive (e.g. leptophlebiids (mayflies)) and pollution tolerant (e.g. chironomids (non-biting midges)) taxa. 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 and 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 surface water and flow reappears (Cardno 2018).

The most significant watercourse impacts described above (fracturing and flow diversions resulting in part or complete drainage of pools and loss of water) tend to occur when watercourses are directly undermined. However, such impacts may also occur in watercourses that are not directly undermined. This includes the recent reductions in pool water levels in LA4 and WC15 and elsewhere, up to approximately 300 m away from longwall extraction. Fracturing has been observed up to approximately 400 m outside of previously extracted longwalls in the Southern Coalfield (MSEC 2019).

Approximately 98 km of watercourse is likely to have experienced direct impacts due to longwall and bord and pillar mining. This represents around 14 % of the total length of watercourse within the upper Avon River and Cordeaux River catchments. Indirect impacts to watercourses (potential iron staining and/or reductions in flow) due to upstream direct impacts associated with longwall mining are likely to have occurred in approximately 18 km (2 %) of watercourses. Approximately 37 km (5 %) of watercourse is located above the proposed longwalls for the Project (i.e. Area 5 and Area 6) and would be expected to experience direct mining induced impacts comparable to that observed above previous mine areas. A further 12 km (1.7 %) of watercourse is located above longwalls planned to be extracted from DA3B and DA3C.

3.10.3 Impacts to Swamps

Previous mining in the upper Avon and Cordeaux catchments has affected swamps overlying these 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 ICEFT using the following categories (**Table 3-4**):

> Category 1 - Not impacted by mining (no future mining proposed).

> Category 2A - Not impacted by mining but located above and expected to experience physical mining impacts due to Area 5 and Area 6 longwalls.

> Category 2B - Not impacted by mining but located above and expected to experience physical mining impacts due to future/proposed longwalls (DA3B Longwalls 14 to 18, DA3A Longwall 19 and DA3C).

> Category 3 - Impacted previously by longwall mining: Any swamp within 400 m of a Dendrobium, Elouera, Cordeaux, Kemira longwall goaf.

> Category 4 - Possibly impacted by bord and pillar mining: Any swamp intersects a bord and pillar goaf.

Table 3-4 Type and Extent of Mining Impacts in Swamps in the upper Avon and Cordeaux River Catchments (Source: ICEFT)

Category	Area (km^2)	Percentage (%) of Total Area
Category 1 - Not impacted by mining (no future mining proposed)	8.04	57.5
Category 2A - Not impacted by mining (future mining proposed in Area 5 and Area 6)	0.35	2.5
Category 2B - Not impacted by mining (future mining proposed in DA3C and DA3B)	0.58	4.1
Category 3 - Impacted by longwall mining	2.03	14.5
Category 4 - Possibly impacted by bord and pillar mining	2.98	21.3
Total	13.98	100

Previous longwall and bord and pillar mines have impacted approximately 5 km^2 or 35 % of the total area of swamp habitat within the upper Avon and Cordeaux River catchments (**Table 3-4**; **Figure 3-3**). Mining of DA1, DA2, DA3A and DA3B longwalls 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 DA3B, 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 and 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).

Some surface evidence of subsidence (soil cracking and vegetation dieback) was observed in or near to Swamp 5 and fracturing was observed at the base of Swamp 4. There was also evidence of mining induced reduction in swamp sizes and also reductions in extent of groundwater dependant sub-communities relative to reference swamps in Swamps 1A, 1B 5 and 8 (South32 2016b). By May 2017 there had been three consecutive years of decline of the sub-community: Upland Swamps: Banksia Thicket (Swamp 5) and Upland Swamps: Tea-Tree Thicket (Swamp 1A and Swamp 5). These declines were greater than at the reference swamps (South32 2017). Further information along with respective TARP triggers is provided in (South32 2016b). It has been suggested that desiccation in swamps makes them more vulnerable to subsequent bushfire and erosion (Advisian 2016).

Following field surveys in January 2016 each of the swamps affected by mining in DA3B and several nearby swamps (Swamps 13, 14, 23, 35a and 35b) was identified as providing suitable breeding and/or foraging habitat for Giant Dragonfly (Biosis 2016). All these swamps also provided suitable dispersal habitat and adult Giant Dragonflies were observed in Swamps 1a, 11 and 14. They were also recorded previously in Swamp 1b and in nine swamps to the north of DA3B on the Woronora Plateau (Biosis 2016).

By May 2017 Swamp15b, previously impacted by mining in DA3A, had continued to experience a change in vegetation species composition 3 years following the completion of mining (South32 2017). A decline in total species richness was also evident in Swamp 15b at least 4 years after completion of mining (South32 2016b). Reductions in shallow groundwater levels and other associated impacts (drying and/or fracturing have also been observed in other swamps in DA3A (Swamps 1a, 5 and 12). Subsidence related fracturing has also been observed in Swamp 1 in DA2 and in Drillhole Swamp and Swamps 18 and 19 overlying the Elouera Colliery.

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).

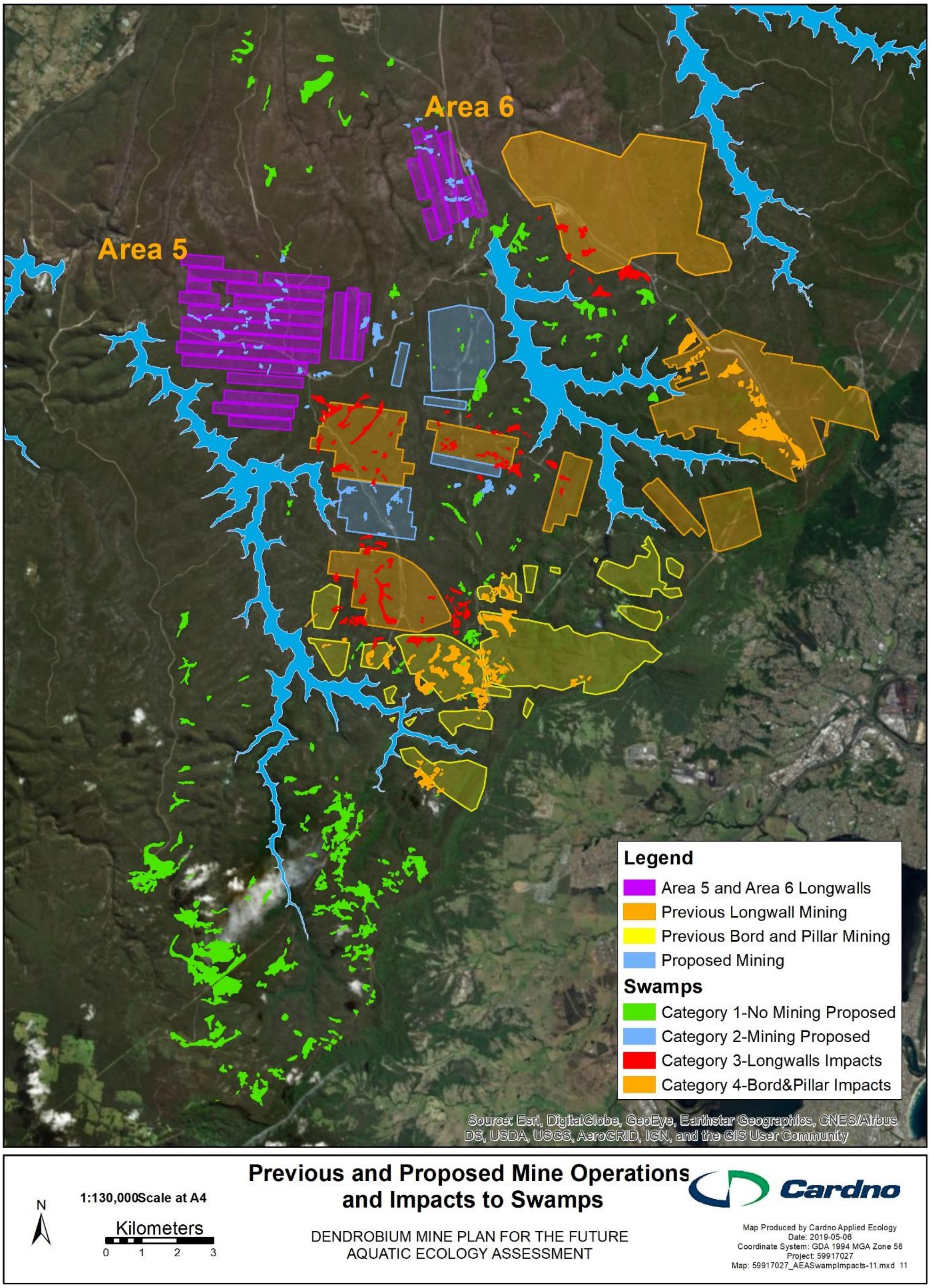

Figure 3-3 Previous and Proposed Mine Operations and Cordeaux River Catchments and Impacts to Swamps

4 Baseline Field Surveys

4.1 Rationale

The baseline surveys were undertaken in sections of Donalds Castle Creek, Cordeaux River and Avon River within and adjacent to the 600 m Study Area (**Figure 3-1**). Aquatic habitat was also assessed in several drainage lines of these watercourses that traverse the proposed longwalls. Surveys in Lake Avon and Lake Cordeaux were not considered necessary. These areas are known already to support aquatic ecology that would be considered in the AEA, with information on these lakes (for example in NSW DPI 2016a) derived from the desktop review of existing information considered sufficient. Also, with regard to the listed threatened Macquarie Perch, this species has been recorded previously in these lakes and the AEA would assume their presence, even if none were identified during any surveys.

The baseline surveys included the following components:

> Classification and mapping of aquatic habitat in rivers, creeks and drainage lines within, and adjacent to, the Study Area using classification criteria in NSW DPI (Fisheries) (2013a);

> General (i.e. non-listed threatened) aquatic ecology surveys undertaken in Cordeaux River, Donalds Castle Creek, and drainage lines of Avon River, that included assessment of aquatic habitat, vegetation, aquatic macroinvertebrates and fish. This included consideration of Sydney Hawk Dragonfly and Adam's Emerald Dragonfly;

> Targeted surveys for Macquarie Perch in sections of Avon River, Cordeaux River and Donalds Castle Creek; and

> Targeted surveys for Giant Dragonfly and identification of potential Giant Dragonfly foraging and / or breeding habitat in swamps in the Study Area.

The primary objective of the field studies was to characterise the aquatic ecology of the Study Area and place it in context of the wider Cordeaux and Avon catchment areas by comparison of the findings with those from nearby areas within the catchment visited as part of monitoring undertaken for previous and current mine areas. A summary of the location, timing and methods associated with each component of aquatic ecology included in the field surveys is provided in **Table 4-1** and described in detail in **Section 4.2**.

4.2 Methods

Field surveys of KFH and general aquatic ecology were undertaken 28 to 30 September 2016. In the preceding 7 days and during the survey 9.6 mm and 4 mm of rain, respectively, was recorded at the Berkeley (Northcliffe Drive) gauge. Surveys for Giant Dragonfly were undertaken 19 and 20 December 2016 (44.6 mm and 0.4 mm of rainfall recorded in the 7 days prior and during the survey, respectively), 30 January 2017 (5.6 mm and 0.0 mm of rainfall recorded in the 7 days prior and during the survey, respectively) and 23 to 26 July 2018 (no rainfall recorded 7 days prior and during the survey). See **Table 4-8** for information on the swamps visited during each survey. Each survey was undertaken by two ecologists.

4.2.1 <u>Mapping of Key Fish Habitat</u>

Avon River, Cordeaux River and their upstream lakes are KFH (**Section 3.3**). Donalds Castle Creek and the several drainage lines that traverse the Study Area are not mapped by NSW DPI as KFH, though they may still contain, or constitute, sensitive KFH as described in NSW DPI (2013a) (**Section 2.4.1**). The occurrence of sensitive fish habitat in the Study Area, and in particular, Donalds Castle Creek and drainage lines, was assessed using the criteria in NSW DPI (2013a) relevant to freshwater habitat (**Table 4-2**).

Mapping was done initially as a desktop exercise, with ground-truthing undertaken in the majority of waterways during September and December 2016 when the majority of swamps were visited for targeted searches for Giant Dragonfly (**Section 3.7.6**). Some drainage lines could not be accessed due to steep valley sides and waterfalls (mainly drainage line LA12 and further upstream in drainage line DC8B). 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 4-1 Summary of aquatic ecology and associated monitoring undertaken in the baseline surveys

Aquatic Ecology Component	Survey Extent	Brief Description of Methods	Timing	Relevant Methodological References
General Aquatic Ecology				
Key Fish Habitat Mapping	Major watercourses and drainage lines within the Study Area	Desktop classification and mapping Type 1 – highly sensitive KFH, Type 2 – Moderately sensitive KFH, Type 3 – Minimally sensitive KFH and field validation	28 to 30 September 2016	NSW DPI (2013a).
Aquatic Habitat	Seven sites across the Study Area (**Figure 3-1**)	Riparian, Channel and Environmental Inventory method (RCE), Occurrence of key aquatic habitat	28 to 30 September 2016	Chessman *et al.* (1997)
Aquatic Vegetation	Seven sites across the Study Area (**Figure 3-1**)	Identification of riparian and in-stream vegetation (including species composition and total area of coverage, where identified)	28 to 30 September 2016	
Aquatic Macroinvertebrates	Seven sites across the Study Area (**Figure 3-1**)	AUSRIVAS edge sampling	28 to 30 September 2016	Turak *et al.* (2004)
Fish	Seven sites across the Study Area (**Figure 3-1**)	Backpack electrofishing, bait traps	28 to 30 September 2016	NSW Fisheries (1997)
Water Quality	Seven sites across the Study Area (**Figure 3-1**)	Limited *in-situ* measurements of DO, EC, oxidation-reduction potential (ORP), pH, temperature and turbidity	28 to 30 September 2016	ANZECC (2000)
Listed Threatened Ecology				
Macquarie Perch	Sections of major watercourses within the Study Area (where habitat suitable for this species was most likely to occur) (**Figure 3-1**)	Backpack electrofishing, fyke netting, snorkelling	28 to 30 September 2016	Commonwealth of Australia (2011) NSW Fisheries (1997)
Giant Dragonfly	Swamp habitat within, and adjacent to Area 5 and Area 6	Assessment of potential breeding habitat and searches for adults, burrows and exuviae	7 to 9 December 2016; 30 January 2017 (Swamps 98 and 112)	Baird (2012) Biosis (2016)
Sydney Hawk Dragonfly	As for aquatic macroinvertebrates (**Figure 3-1**)	Searches for larvae in AUSRIVAS samples collected during macroinvertebrate sampling	28 to 30 September 2016	Turak *et al.* (2004)
Adam's Emerald Dragonfly	As for aquatic macroinvertebrates (**Figure 3-1**)	Searches for larvae in AUSRIVAS samples collected during macroinvertebrate sampling	28 to 30 September 2016	Turak *et al.* (2004)

Table 4-2 Classification of Key Fish Habitat according to sensitivity (NSW DPI 2013a)

Classification	Habitat Type
Type 1 – Highly sensitive Key Fish Habitat	Instream gravel beds, rocks greater than 500 mm in two dimensions, snags (wood debris) greater than 300 mm in diameter or 3 m in length, native aquatic plants, and areas known or expected to contain threatened and protected species
Type 2 – Moderately sensitive Key Fish Habitat	Freshwater habitats other than those defined in Type 1
Type 3 – Minimally sensitive Key Fish Habitat	Ephemeral aquatic habitat not supporting native aquatic or wetland vegetation
Not considered Key Fish Habitat	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)

This was undertaken initially as a desktop analysis using aerial imagery, topographic mapping and the results of watercourse mapping undertaken by ICEFT. Initial mapping was ground-truthed by inspecting major watercourses and a subset of larger (generally second order) drainage lines. Field access to many of the drainage lines was difficult, due to the incised channel form, steep cliffs and waterfalls. Where drainage lines could not be accessed, their classifications were inferred using the classifications from the surrounding area.

4.2.2 General Aquatic Ecology

4.2.2.1 Sites

Seven sites were visited and assessed for aquatic ecology aspects (**Table 4-3, Figure 3-1**). As was the case with drainage lines, access was difficult. In particular, sites on Cordeaux River could be located only at a fire road crossing and gauging station. Elsewhere, the river was deeply incised and the river could not be accessed safely.

Table 4-3 Sampling sites in the Study Area visited 28 to 30 September 2016

Site	Watercourse	Easting	Northing
CR1	Cordeaux River	289567	6202469
CR2	Cordeaux River	291277	6198013
DC1	Donalds Castle Creek	289327	6197932
DC2	Donalds Castle Creek	289397	6197545
DC3	Donalds Castle Creek	289463	6199293
AR1	Tributary of Avon River*	283931	6197696
AR2	Tributary of Avon River	283937	6197587

*Fish surveys at AR1 were undertaken partly at the confluence with the Avon River

4.2.2.2 Aquatic Habitat and Vegetation

The condition of the aquatic habitat at each site was assessed using a modified version of the RCE (Chessman *et al*. 1997) (**Appendix Ai**). 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.

Observations 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.

4.2.2.3 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.

4.2.2.4 AUSRIVAS Macroinvertebrates

4.2.2.4.1 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 X 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 were to be identified to species level. However, no specimens from these families were found (**Section 4.3.4**).

4.2.2.4.2 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 OE50 Taxa scores that indicate the level of impairment of the assemblage. These bands are graded as described in **Table 4-4**.

Table 4-4 AUSRIVAS Bands and corresponding OE50 Taxa Scores for AUSRIVAS edge habitat sampled in spring

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

4.2.2.5 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, including amongst aquatic plants and snags, in deep holes and over bare substratum. The backpack electrofisher was operated around the edge of pools and in riffles (if present), with ten 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 were handled with care to minimise stress, and released as soon as possible. Sampling was undertaken with consideration of the Australian Code of Electrofishing Practice (NSW DPI 1997), including the presence of an experienced electrofishing operator at all times.

Four bait traps and two fyke nets were also set for two to six hours during daytime at the sites on the Cordeaux River, on the Avon River adjacent to AR1 and AR2 and at Donalds Castle Creek at the Fire Road 6 crossing. 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. Fyke nets were constructed of 20 mm aperture mesh and had two 5 m long panels either side of the entrance (approximately 300 mm diameter) to direct fish into the net. Where possible, fyke nets were set across the entire creek to maximise the potential for capture, though this was not always possible in deeper sections. Care was taken to ensure an air space was available for any air breathing animals, such as platypus (*Ornithorhynchus anatinus*) that may be caught inadvertently, either by tying the end of the net to a bankside tree or placing floats inside the net. No platypus were caught in fyke nets or observed during the surveys. This species is considered by other specialists.

Visual searches for other aquatic fauna (platypus and turtles) were also undertaken.

4.2.3 Threatened Aquatic Ecology

4.2.3.1 Macquarie Perch

Targeted surveys for Macquarie Perch were undertaken in sections of major watercourses within the Study Area (where habitat suitable for this species is most likely to occur (**Section 3.7.2**). The red dashed lines in **Figure 3-1** indicate the areas where surveys were undertaken. Surveys were undertaken using a Smith-Root LR24 backpack electrofisher as described in **Section 4.2.2.5**, with electrofishing for Macquarie Perch undertaken around features known to provide suitable habitat for this species, particularly fallen trees around the edges of pools. The deployment of fyke nets also targeted this species. Visual searches using a dive mask were also undertaken from the edges of deeper pools in Donalds Castle Creek near DC1 and DC2.

All sampling was done in accordance with the Survey Guidelines for Australia's Threatened Fish (Commonwealth of Australia 2011), including:

> Surveys were undertaken during the recommended survey period for this species of March to September; and

> Appropriate sampling methods including backpack electrofishing and fyke netting were used.

4.2.3.2 Giant Dragonfly

Targeted surveys for Giant Dragonfly were undertaken in swamp habitat present within the Study Area (**Figure 3-1**). The survey methods were developed based on Baird (2012) and the findings of the Giant Dragonfly surveys undertaken in DA3B in January 2016 (Biosis 2016), as well as Cardno's experience with similar surveys.

To maximise the probability of observing adults, burrows and exuviae (shed larval skins) surveys were consistent with the following favourable weather conditions for flying adults (Baird 2012):

> Temperature above 20 degrees Celsius (ºC);

> Maximum gusting wind speed below 15 km/h;

> No precipitation;

> Surveys undertaken between 9:00 am and 3:00 pm; and

> Fine to moderately sunny days, or overcast days above 20 ºC.

Meandering walking searches were undertaken in each swamp, targeting areas providing potential breeding habitat, where present (see below), and included searches for burrows and exuviae in ground layer vegetation and shrubs and for flying and perched adults in sedgeland / shrubs within swamps and around swamp edges. It is noted that burrow openings of Giant Dragonfly may be confused with those of juvenile burrowing crayfish (Family: Parastacidae) or other invertebrates, and cannot be differentiated unless excavated (Baird 2012).

In addition to searches, swamp habitat was assessed for its potential to provide suitable breeding habitat using the following indicators:

> Presence of emergent groundwater seepage or obvious substrata surface moisture that indicates localised waterlogging or surface moistness due to capillary action;

> Relatively soft organic-rich or peaty substrata identified initially by some sponginess of the substrate when walking; and

> Presence of moist swamp vegetation sub-communities of cyperoid (Family: Cyperaceae) heath, Swamp Banksia (*Banksia robur*), Pouched Coral Fern (*Gleichenia dicarpa*) or tea-tree thicket.

Digital photographs were taken of swamps, burrows and adults, where possible. It is noted that surveys undertaken during July 2018 were done so when adult flying stages would not be present. Assessment of the suitability of swamps as breeding habitat was undertaken using the above criteria.

4.2.3.3 Adam's Emerald Dragonfly and Sydney Hawk Dragonfly

Surveys for Adam's Emerald Dragonfly and Sydney Hawk Dragonfly were included in the AUSRIVAS sampling (**Section 4.2.2.4**).

4.3 Results and Discussion

4.3.1 Key Fish Habitat Mapping

Figure 4-1 provides the results of the KFH mapping. Photographs are provided in **Appendix B**. Avon River (**Appendix B-i**) and Cordeaux River (**Appendix B-ii** to **iv**) provide Type 1 – Highly sensitive KFH, and contain extensive areas of aquatic plants, large rocks, large wood debris and are known to provide pool habitat for Macquarie Perch. Lake Avon and Lake Cordeaux also contain Type 1 - Highly sensitive KFH as they provide habitat for the threatened Macquarie Perch. Donalds Castle Creek also provided some Type 1 KFH (some small, discreet patches of aquatic vegetation and large rocks and wood debris) (**Appendix B-v** to **viii**). 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 Cordeaux River and Avon River. Also, not too far upstream of the Fire Road 6 crossing, Donalds Castle Creek transitions into upland swamp.

The lower, 3rd order reaches of some drainage lines provide Type 2 – Moderately sensitive KFH. This classification was based primarily on the absence of aquatic plants and larger rocks and wood debris. Drainage lines, such as AR1 and AR2 (**Appendix B-ix** to **x**), do not provide KFH. This assessment was based primarily on their stream order (i.e. first and second order). While they may contain some rocks and wood debris, they would have intermittent flow, with disconnected pools that would provide sporadic refuges for aquatic fauna such as fish and freshwater crayfish, if present.

Furthermore, several substantial natural barriers to fish passage (such as waterfalls, cascades, and low flow over rock bars) were present on these drainage lines, which would also limit the number and type of fish species present. For example, 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). Indeed, a galaxid, likely Climbing Galaxias, was found in AR1 upstream of several substantial natural barriers (**Section 4.3.4**).

4.3.2 Aquatic Habitat and Vegetation

Results of the RCE assessment are provided in **Appendix A-ii**. Total scores ranged from 46 to 48 (out of a total score of 52) and were relatively high, indicative of relatively undisturbed systems. All sites scored high (i.e. 4, no evidence of disturbance) in categories associated with the condition of riparian vegetation and channel morphology. While there was some evidence of sediment accumulation, this appears to be a natural occurrence given the general undisturbed nature of the surrounding environment.

The surrounding vegetation in this reach of Donalds Castle Creek is dominated by dry Eucalypt forest which extends to the banks of the creek. Along the banks there are numerous native grasses, shrubs and trees including saw grass, mat rush, wattles and tea-trees. Stream banks consisted mainly of well vegetated sandy soil with little erosion or undercutting evident and extensive overhanging vegetation along the stream margin. There were numerous in-stream habitat features, including snags and tree roots. The main channel of this reach of Donalds Castle Creek consists of a series of relatively small permanent pools with a maximum depth of 1.5 m, width of 6 m and length of 25 m (e.g. **Appendix B-v**). These pools have a mainly sand substratum with some areas of bedrock, boulder and gravel. These pools are connected by narrow channels with a mainly sand substratum with small sections of gravel riffles and some sandstone rockbars with small cascades up to 1 m in height. It is expected that this connectivity between pools would not persist through extended dry periods. The water within Donalds Castle Creek appeared very clear and there were no apparent signs of contamination such as odour, emulsion, or discolouration.

Riparian vegetation and bank structure along drainage lines were 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 of pools in drainage lines. This would limit the amount of aquatic habitat available for aquatic flora and fauna. Nevertheless, the abundance of this habitat means that, cumulatively, it provides a substantial contribution to overall aquatic habitat in the Study Area.

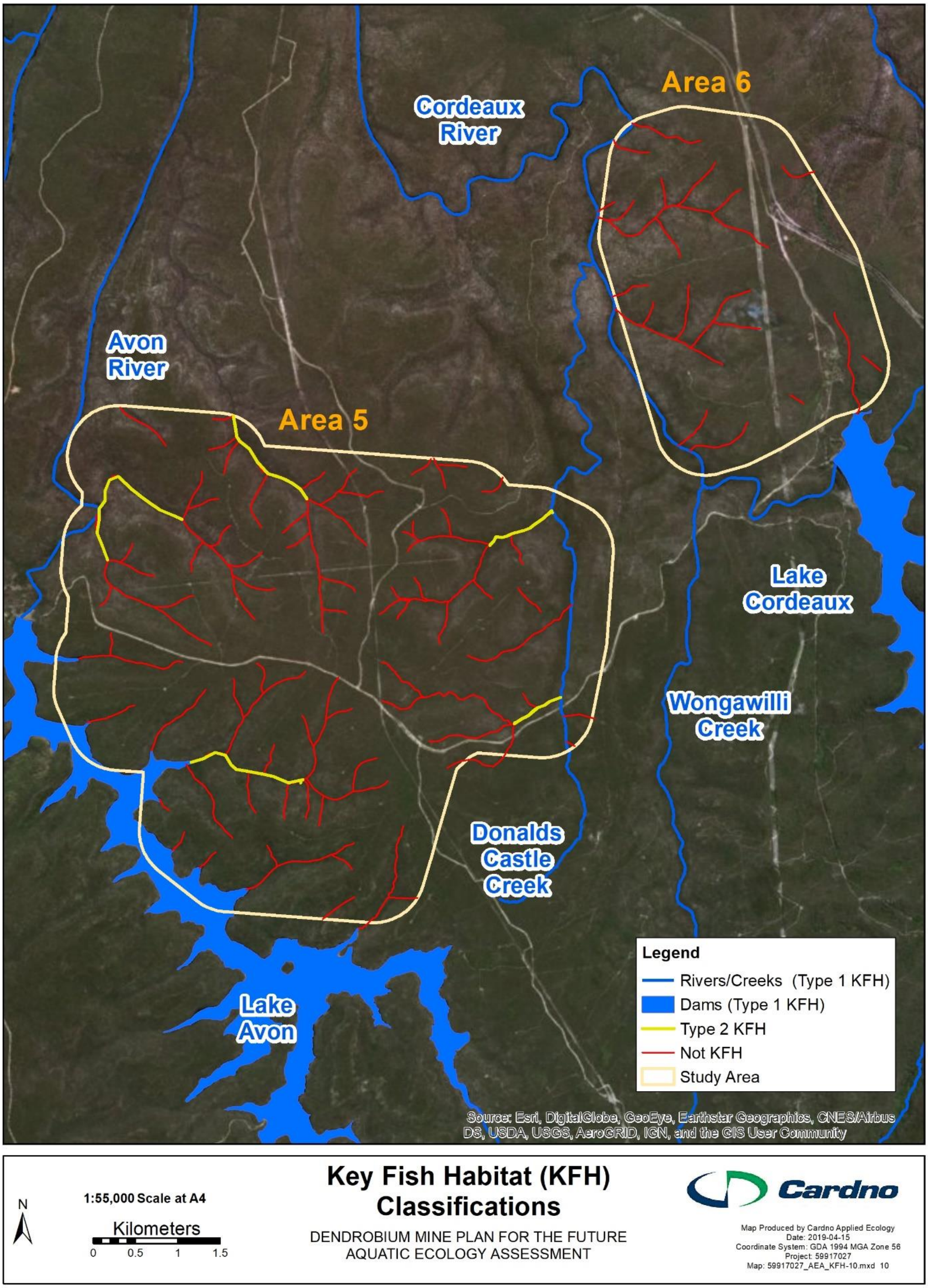

Figure 4-1 Key Fish Habitat (KFH) Classifications

There is some variability in the composition and extent of aquatic vegetation, which explains some of the small differences observed among sites from different watercourses. Vegetation is more abundant on the larger Avon River and Cordeaux River. In particular, CR1 which supports relatively extensive beds of *Triglochin* sp., *Myriophyllum* sp. (water milfoil) and some of what appeared to be *Ruppia* sp. (**Table 4-5**). Green filamentous algae were also abundant here, though not found at any other site. This vegetation can be indicative of nutrient enrichment. *Triglochin* sp. was also observed in pools within Donalds Castle Creek, possibly, where it was able to establish roots and persist through high flow events. Some species of *Myriophyllum* sp. are invasive to Australia, however, their potential occurrence in the Study Area is highly unlikely to be related to past or current mining practices. Rather, if present, they would most likely occur here due to introduction upstream in Lake Cordeaux.

Table 4-5 Species and Percent Cover of Aquatic Plants Identified at each Sampling Site

Taxon	CR1	CR2	DC1	DC2	DC3	AR1	AR2
Triglochin sp.	20 %	15 %	15 %	10 %		20 %	20 %
Ruppia sp.	15 %						
Myriophyllum sp.	15 %						
Green filamentous algae	30 %						

4.3.3 *In-situ* Water Quality

Mean water quality values are provided in **Appendix C**. The findings were:

> Temperature ranged from 14.1 to 15.6 ºC and was slightly higher in Cordeaux River than Avon River and Donalds Castle Creek;

> Conductivity was within DTVs and ranged from 82 to 145 µS/cm. It was greater in Cordeaux River than Avon River and Donalds Castle Creek;

> pH ranged from 5.4 to 7.2 and was more alkaline in the Cordeaux River, where it was within DTVs, than in Avon River and Donalds Castle Creek, where it was below the lower DTV;

> DO ranged from 90 % to 97 % saturation and was within DTVs at each site; and

> Turbidity ranged from 0 to 5 NTU and was below the lower DTV at each site except those on Cordeaux River.

Measures of water quality were generally within DTVs and did not indicate any disturbance to water quality. Measures of water quality on Donalds Castle Creek and Avon River were comparable with those measured previously on these and other drainage lines in the Dendrobium Mine area by Cardno. Naturally low pH and turbidity in Donalds Castle Creek and Avon River are not cause for concern (**Section 3.4**)

4.3.4 AUSRIVAS Macroinvertebrates

The macroinvertebrate taxa identified from each AUSRIVAS sample are provided in **Appendix D**. The number of taxa, OE50 Taxa Scores and SIGNAL2 Indices for each of the AUSRIVAS samples are provided in **Table 4-6**. The number of taxa found at each site ranged from 11 to 23 and was somewhat variable, with fewer taxa at AR1 and AR2 than at sites on Cordeaux River and Donalds Castle Creek. OE50 Taxa Scores ranged from 0.45 (Band C) to 0.89 (Band A) and were greater on Donalds Castle Creek than Cordeaux River and Avon River. SIGNAL2 Indices ranged from 4.2 (indicative of moderate water pollution) to 5.1 (indicative of mild water pollution). These scores may indicate some form of water pollution, as more pollution sensitive taxa were caught, including leptophlebiids (SIGNAL2 Score: 8), which were present at each site sampled. It is noted also that while several relatively pollution tolerant taxa were caught, these would also be expected to be present in un-polluted water. No. of Taxa and SIGNAL2 Indices on Donalds Castle Creek are within the range of values sampled previously in this creek as part of the DA3B aquatic ecology monitoring (**Section 3.5**). Those from the other sites sampled are also comparable to those from previous sampling in the Dendrobium Area 3A and 3B areas (Cardno Ecology Lab 2013; 2014; 2015; 2016a; 2016b). As appeared to be the case in these previous investigations, low SIGNAL2 Indices are more likely reflective of natural water quality, rather than any anthropogenic disturbance. No Adam's Emerald Dragonfly or Sydney Hawk Dragonfly were identified in the AUSRIVAS samples.

Table 4-6 Total number of taxa, OE50 Taxa Scores and SIGNAL2 Indices for each of the AUSRIVAS Samples

Index	CR1	CR2	DC1	DC2	DC3	AR1	AR2
Number of Taxa	13	17	16	16	23	11	12
OE50 Taxa Score	0.63	0.46	0.73	0.85	0.89	0.45	0.58
Band Score	B	C	B	A	A	C	B
SIGNAL2 Index	5.1	4.5	4.2	4.9	4.8	5.1	4.4

4.3.5 Fish

The total number of each species of fish and freshwater crayfish caught whilst backpack electrofishing at each site is presented in **Table 4-7**.

Table 4-7 Total Numbers of each Species of Fish Species and Freshwater Crayfish caught whilst Electrofishing at Sites within the Study Area

Species	CR1	CR2	DC1	DC2	DC3	AR1	AR2
Flathead Gudgeon (*Philypnodon grandiceps*)						2	
Galaxid (*Galaxias* sp.)				3			1
Australian Smelt (*Retropinna semoni*)	1						
Freshwater crayfish (*Euasticus* sp.)				>10			

No fish were caught in bait traps or fyke nets. Galaxids (**Appendix B-xi**) were caught at AR2 and DC2, Flathead Gudgeon at AR1, Australian Smelt at CR1 and several freshwater crayfish at DC2. These are all common and widespread species caught previously in the Dendrobium Mine area. While numbers of fish caught could be considered low, they are comparable with those caught in other watercourses that traverse DA3 (Cardno Ecology Lab 2013; 2014; 2015; 2016a, b). The galaxid caught at AR2 was likely to have been Climbing Galaxais, 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).

4.3.6 Listed Threatened Species

4.3.6.1 Macquarie Perch

No Macquarie Perch were caught using electrofishing or fyke nets in sections of Avon River, Cordeaux River and Donalds Castle Creek or observed in visual surveys in Donalds Castle Creek. Nevertheless, suitable habitat including deep pools is present in Avon River and Cordeaux River. The sections of Donalds Castle Creek visited consist of a series of disconnected pools or pools connected by low flow over rockbars and vegetation debris dams. It is considered that this would not provide suitable habitat for this species. Similarly, drainage lines do not provide suitable habitat for this species.

While Donalds Castle Creek may provide some marginal habitat for Macquarie Perch in its lower reaches near its confluence with Cordeaux River, the cascade / waterfall just downstream of DC3 (comparable to the natural barriers in **Appendix B-vii** and **viii**) would likely prevent upstream movement of this species, except possibly during high flow events. This barrier is comparable to that present on Wongawilli Creek just upstream of the Fire Road 6 Crossing.

No Macquarie Perch have been found in Wongawilli Creek upstream of the barrier despite extensive fish surveys by Cardno (**Section 3.7.2**). Even if Macquarie Perch could pass this barrier on Wongawilli Creek, the habitat upstream of here would not be suitable, consisting of small pools connected by low flow over rockbars and boulders, with substantial vegetation debris. Macquarie Perch prefer deeper and larger systems of pools.

4.3.6.2 Giant Dragonfly

One or two adult Giant Dragonflies were observed in each of three swamps (Den83, Den112 and Den116) in Area 6 (**Table 4-8**; **Figure 4-2**; **Plate 1a**). Burrows (**Plate 1b**) were also observed in Swamps Den02, Den98, Den121 and Den127 in Area 5 and Den83, Den113, Den116, Den128, Den129, Den131, Den132 and Den133 in Area 6. Swamp Den83 was observed to have over 30 burrows. These may have been burrows of Giant Dragonfly larvae or burrowing crayfish (**Section 3.7.6**).

Based on the presence of indicator vegetation species, including pouched coral fern (**Plate 1c**), sedges (**Plate 1d**), tea-tree and swamp banksia and / or suitable hydrological regime (damp soil conducive to burrowing (e.g. **Plate 1d**)), these swamps, and swamps Den01b and Den124 in Area 5 and Den112 in Area 6 are also considered to provide potential breeding habitat for this species. The remaining swamps provide unsuitable breeding habitat, based primarily on the presence of hard, dry and compact ground, which would likely have hindered or prevented the construction of burrows. Although intense searches were undertaken near all burrows, no exuviae were found. Notwithstanding, it is possible that several other swamps in Area 5 and Area 6 provide foraging habitat for this species (i.e. those within 500 m of potential breeding habitat (OEH 2017)) (**Table 4-8**).

It is possible that low rainfall in the preceding months may have contributed to the relatively dry conditions seen in many of these swamps, particularly those in Area 5, which generally appeared dryer than those in Area 6. Potential impacts to the Giant Dragonfly and upland swamp habitat have been assessed in Appendix D of the Project EIS.

Table 4-8 Giant Dragonfly Adults and Potential Burrows Observed and Presence of Potential Breeding Habitat in Swamps in Area 5 and Area 6

Swamp	Survey Date	Giant Dragonfly Observed	Burrows Present	Potential for Breeding Habitat (Based on Vegetation and Suitable Hydrological Regime)*	Provides Potential Foraging Habitat (500 m of breeding habitat (OEH 2017))
Dendrobium Area 5					
Den85	19 to 20 Dec 2016			Unsuitable	No
Den86	19 to 20 Dec 2016			Unsuitable	No
Den97	19 to 20 Dec 2016			Unsuitable	No
Den98	19 to 20 Dec 2016		Present	Potential	Yes
Den99	19 to 20 Dec 2016			Unsuitable	No
Den100	19 to 20 Dec 2016			Unsuitable	No
Den101	19 to 20 Dec 2016			Unsuitable	No
Den102	19 to 20 Dec 2016			Unsuitable	No
Den103	19 to 20 Dec 2016			Unsuitable	No
Den104	19 to 20 Dec 2016			Unsuitable	No
Den105	19 to 20 Dec 2016			Unsuitable	No
Den106	19 to 20 Dec 2016			Unsuitable	No
Den107	19 to 20 Dec 2016			Unsuitable	No
Den108	19 to 20 Dec 2016			Unsuitable	No
Den109	19 to 20 Dec 2016			Unsuitable	No
Den110	19 to 20 Dec 2016			Unsuitable	No
Den111	19 to 20 Dec 2016			Unsuitable	No
Den114	19 to 20 Dec 2016			Unsuitable	No
Den01b	23 to 26 July 2018			Potential*	Yes
Den02	23 to 26 July 2018		Present	Potential	Yes

Swamp	Survey Date	Giant Dragonfly Observed	Burrows Present	Potential for Breeding Habitat (Based on Vegetation and Suitable Hydrological Regime)*	Provides Potential Foraging Habitat (500 m of breeding habitat (OEH 2017))
Den120	23 to 26 July 2018			Unsuitable	No
Den121	23 to 26 July 2018		Present	Potential	Yes
Den122	23 to 26 July 2018			Unsuitable	Yes
Den123	23 to 26 July 2018			Unsuitable	No
Den124	23 to 26 July 2018			Potential**	Yes
Den125	23 to 26 July 2018			Unsuitable	Yes
Den126	23 to 26 July 2018			Unsuitable	No
Deb127	23 to 26 July 2018		Present	Potential	Yes
Den137	23 to 26 July 2018			Unsuitable	No
Den138	23 to 26 July 2018			Unsuitable	Yes
Dendrobium Area 6					
Den83	19 to 20 Dec 2016	Two adults perched / flying	Present	Potential	Yes
Den83 (east)	23 to 26 July 2018		Present	Potential	Yes
Den112	30 Jan 2017	One adult flying		Potential	Yes
Den113	30 Jan 2017		Present	Potential	Yes
Den115	30 Jan 2017			Unsuitable	Yes
Den116	30 Jan 2017	Two adults perched / flying	Present	Potential	Yes
Den117	30 Jan 2017			Unsuitable	Yes
Den118	30 Jan 2017			Unsuitable	Yes
Den119	30 Jan 2017			Unsuitable	No
Den128	23 to 26 July 2018		Present	Potential	Yes
Den129	23 to 26 July 2018		Present	Potential	Yes
Den130	23 to 26 July 2018			Unsuitable	Yes
Den131	23 to 26 July 2018		Present	Potential	Yes
Den132	23 to 26 July 2018		Present	Potential	Yes
Den133	23 to 26 July 2018		Present***	Potential	Yes
Den134	23 to 26 July 2018			Unsuitable	Yes
Den135	23 to 26 July 2018			Unsuitable	Yes
Den136	23 to 26 July 2018			Unsuitable	Yes
Den138	23 to 26 July 2018			Unsuitable	Yes

*Suitable breeding habitat identified by Biosis (2016).

**Small patch of potential breeding habitat in northeast corner.

***Possibly unlikely to be those of giant dragonfly due to dry, hard substratum.

Note: burrow openings of giant dragonfly may be confused with those of juvenile burrowing crayfish (Family: Parastacidae) or other invertebrates, and cannot be differentiated unless excavated (Baird 2012).

Plate 1 a) Adult Giant Dragonfly perched on a branch in Swamp Den83. b) burrows within potential breeding habitat in Swamp Den98, c) Pouched Coral Fern and d) sedges (Family: Cyperaceae) in relatively moist soil in Swamp Den83 where over 30 burrows were observed.

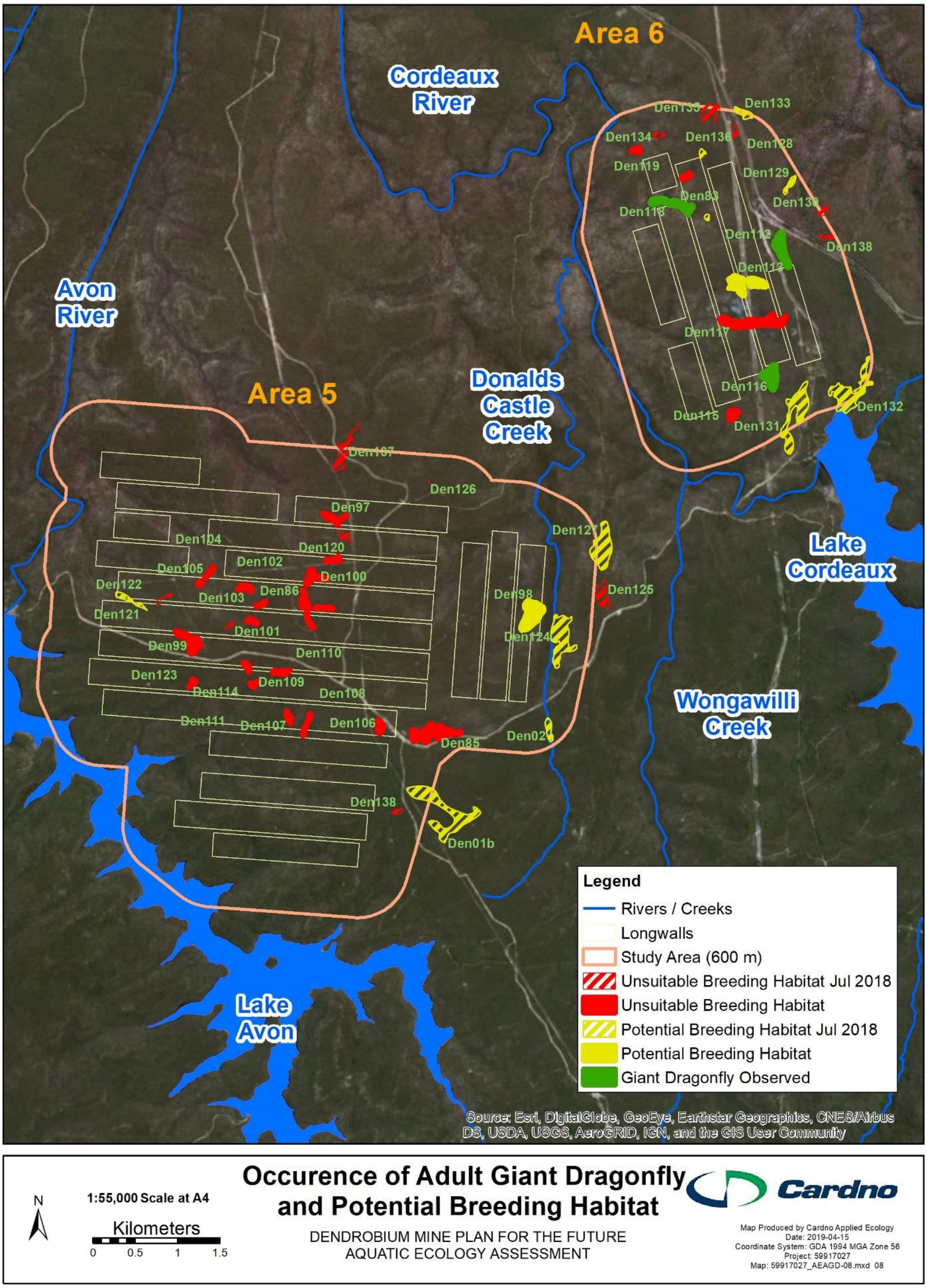

Figure 4-2 Occurrence of Adult Giant Dragonfly and Potential Breeding Habitat

4.4 Summary

The findings of the baseline surveys undertaken by Cardno are summarised as follows:

General Aquatic Ecology

> Aquatic habitat in the Study Area appears largely undisturbed. Some waterway fire road crossings and associated vegetation clearing is present; however, riparian vegetation is generally in very good condition with little or no introduced species. Some sediment input into the watercourses would be expected to occur during high rainfall when run-off from roads and other cleared areas may enter creeks, though these areas represent a very small proportion of the Study Area. Aquatic habitat within the Study Area is comparable to that within other areas of the Dendrobium Mine. The results of these and previous surveys in these areas indicate aquatic vegetation is relatively sparse across the Study Area, and is found primarily in the larger Avon River and Cordeaux River. Some aquatic vegetation was present in Donalds Castle Creek in some of the larger pools, but it was relatively more substantial in the larger Avon and Cordeaux Rivers. Water quality measures sampled in the current study are comparable with those measured in previous studies and there is no indication of any anthropogenic effect on water quality in the Study Area.

> While AUSRIVAS macroinvertebrate sampling undertaken in the current study and previously in Donalds Castle Creek and the wider Dendrobium Mine area suggests potentially impaired macroinvertebrate assemblages, there is no evidence that this is related to anthropogenic disturbance. Rather, low SIGNAL2 Indices may be reflective of naturally low values of pH. Additionally, metals may be mobile within the water which are associated with local geology. Overall, the AUSRIVAS macroinvertebrate assemblages sampled in the Study Area appear comparable with those sampled from across the Dendrobium Mine area during previous studies by Cardno.

> The most substantial fish habitat in the Study Area is provided by Avon River and Cordeaux River, which flow alongside, and in some areas within, the western boundaries of the Study Area, respectively, and their associated upstream lakes. These are mapped KFH and support Type 1 – Highly sensitive KFH. Several species of fish have been identified here previously. The reach of Donalds Castle Creek adjacent to Area 5, consists largely of relatively small pools connected by low flow over cascades, rock bars and through debris dams. It is not mapped KFH but contains Type 1 – Highly sensitive KFH. It provides more limited fish habitat compared with the larger rivers and lakes. Drainage lines which traverse the Study Area consist largely of disconnected pools, sometimes separated by waterfalls that represent substantial natural barriers to fish passage. They are not mapped KFH and include more limited Type 2 – Moderately sensitive KFH or no sensitive KFH. Nevertheless, these watercourses would provide habitat for some native species, particularly Climbing Galaxias, and together would provide a substantial proportion of habitat for fish, and other aquatic species, across the Study Area.

> While some invasive species of fish, including Goldfish and Brown Trout, may occur in Cordeaux River and Avon River, and their upstream reservoirs, it is very unlikely that these or any other invasive species of fish occur in the creeks and drainage lines within, and adjacent to, the Study Area. The potential presence of specimens of the invasive aquatic plant, water milfoil, which may occur in Cordeaux River is most likely related to its potential non-mining related introduction to Lake Cordeaux. This plant would be unlikely to be affected by the Project as there would not be any associated process, such as inadvertent translocation, that would result in the spread of this species. No invasive aquatic plants have been identified in the other watercourses within the Study Area during the current and previous studies undertaken by Cardno.

Listed Threatened Species

> Macquarie Perch have previously been recorded in Avon River and Cordeaux River, and these rivers provide substantial suitable habitat for this species. Donalds Castle Creek provides only limited fish habitat unsuitable for Macquarie Perch. The presence of several natural barriers to movement of this species on Donalds Castle Creek, particularly the cascade downstream of Area 5, would also prevent or severely hinder this species utilising the vast majority of this watercourse. This, and the presence of a similar natural barrier on Wongawilli Creek, upstream of which this species has not been identified despite its presence downstream, strongly suggest Macquarie Perch would not utilise the section of Donalds Castle Creek adjacent to Area 5 and the several drainage lines that traverse the Study Area.

> Giant Dragonfly and / or potential foraging and breeding habitat for this species was identified in several swamps in the Study Area. Many swamps do not appear to support potential breeding habitat and the dry conditions observed appeared unsuitable for burrowing larvae. However, they may provide foraging habitat for adults. The relatively large number (> 30) of potential burrows identified in swamp Den83 within Area 6 could indicate that this swamp provides important breeding habitat for this species. Previous surveys undertaken in the Dendrobium Mine area have identified Giant Dragonfly within swamps in DA3B approximately 500 m to several kilometres to the southeast of the Study Area.

> Sydney Hawk Dragonfly and Adam's Emerald Dragonfly were not found in the AUSRIVAS samples collected during the current study nor have any been found in the samples collected as part of several previous studies within, and adjacent to, the Study Area. While suitable microhabitat for these species occurs in the Study Area, their absence in the numerous collected samples, and known distributions outside of the Study Area, provides evidence that they do not currently occur here. Additionally, Australian Grayling was not recorded in the Study Area during surveys.

Stygofauna

> Previous stygofauna studies undertaken approximately 10 km south of the Study Area indicate that stygofauna may occur in perched swamps such as those within Area 5 and Area 6. These studies also suggest that these assemblages may be somewhat diverse (Hose 2009). Morphological analysis of specimens suggests some evidence of historic connectivity between swamps and the underlying sandstone aquifers in these studies, possibly via migration of stygofauna during wet weather in overland flow and saturated rock fractures. However, hydraulic testing and microbial and DNA analysis suggest some degree of isolation between different swamps and between swamps and the underlying sandstone aquifer. It is unclear exactly how well the swamps in Area 5 and Area 6 would compare, though they could be expected to have similar hydraulic characteristics to those south of the Study Area.

> The quality of groundwater (primarily measures of EC and pH) in the various aquifers in the Study Area does not preclude the presence of stygofauna, though the shallow perched (i.e. swamp) and Hawkesbury sandstone aquifers would appear to provide more suitable habitat than those associated with Bulgo sandstone and the coal measures. The abundance and diversity of any stygofauna present in these aquifers would likely also depend on depth and permeability of the aquifers, among other considerations. Stygofauna research is limited, which makes an assessment of the uniqueness of any stygofauna communities in the Study Area, particularly any associated with the swamps, problematic. It is possible, due to the somewhat restricted nature of these perched swamps, that any associated stygofauna communities could be also. It is possible also that swamps that do not retain groundwater during low rainfall periods may not provide suitable stygofauna habitat.

Table 4-9 summarises the likelihood of occurrence of components of aquatic ecology investigated in the Study Area.

Table 4-9 Likelihood of Occurrence of components of aquatic ecology in the Study Area, brief preliminary assessment and AEA assessment process

Component of Aquatic Ecology	Likelihood of Occurrence in Study Area
General Aquatic Ecology	
Non-threatened aquatic habitat, vegetation, macroinvertebrates and fish	Occurs throughout the Study Area.
Stygofauna	Considered present in perched swamp aquifers and shallow sandstone aquifers. Unlikely to occur in deeper fractured sandstone and coal measure associated aquifers.
Listed Threatened Aquatic Ecology	
Macquarie Perch (Endangered under FM Act and EPBC Act)	Occurs in Avon River and Cordeaux River. Very unlikely to occur in Donalds Castle Creek and other watercourses in the Study Area.
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.
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 here.
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 here.
Giant Dragonfly (Endangered under BC Act)	Occurs within the Study Area. Adults and potential breeding habitat confirmed in swamps in the Study Area.

5 Impact Assessment

5.1 Mine Layout Design

A number of longwall design constraints have been incorporated in the Project underground mining layout to reduce potential environmental impacts. These were included based on previous mining experience in DA3B and key stakeholder feedback. The layout of longwalls in Area 5 and Area 6 has been designed to avoid or minimise impacts on major watercourses, incorporating setback distances from major watercourses and key stream features (**Table 5-1**). Numerous unnamed first, second and third order drainage lines are located above the proposed longwalls in Area 5 and Area 6, however it is not possible to design an economic mine layout that will avoid all these watercourses (MSEC 2019).

Due to the implemented longwall design constraints, predicted subsidence attributed to Area 5 and Area 6 longwalls is less than that predicted for the existing and approved longwalls in DA3B and DA3C.

Table 5-1 Summary of Constraints Incorporated in the Project Longwall Mining Layout

Adopted Project Constraint	Context
≥ 1,000 m minimum setback from existing Avon/Cordeaux Dam walls for any secondary extraction.	The Dams Safety Committee (DSC) must endorse any mining within the DSC Notification Zones. The DSC has published Guidance notes, including: ▪ No uncontrolled extraction (e.g. full-sized longwalls) within 1.7x depth of cover of existing dam structures. ▪ No mining (any) within 1.2x depth of cover of existing dam structures.
No mining below existing Avon/Cordeaux Dams waterbodies, adopting a 300 m setback from existing dam Full Supply Level.	The DSC must endorse any extraction under stored water for existing storages, including first workings and secondary workings. The DSC has endorsed several instances of first workings under Lake Cordeaux at the Approved Dendrobium Mine. DSC endorsement for mining to date in the Approved Area 3B has included a minimum horizontal distance to the FSL equal to 300 m.
Setbacks from named watercourses (as defined by the NSW Department of Lands) to achieve 200 mm or less predicted Project closure.	Relevant to Cordeaux River, Avon River and Donald Castle Creek for the Project mining domains.
Setbacks from mapped "key stream features": ▪ Setback 50 m when mining will occur on one side of the "key stream feature". ▪ Setback of 100 m when mining will occur on more than one side of the "key stream feature".	Applies to South32 mapped features along streams within the Project Study Area as follows: ▪ Pools (>100 m^3 and permanent). ▪ Waterfalls/Steps (>5 m and with a permanent pool at base). Setback distances are based on observations from the Dendrobium Mine, and the setbacks are designed to maximise the likelihood that the stream feature will not be physically damaged by subsidence.

5.2 Impacts on Aquatic Ecology

This section incorporates relevant predictions from the Subsidence, Groundwater and Surface Water Assessments prepared for the Project EIS (Appendices A, B and C of the Project EIS, respectively).

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. Where information on the aquatic ecology present in the Study Area is limited and/or when the extent or magnitude of physical mining impacts and impacts on water availability is unclear, a 'worst-case scenario' has been assessed (**Section 2.3.1**). Cumulative impacts have also been addressed.

5.2.1 Watercourses

5.2.1.1 Aquatic Habitat

Avon River, Cordeaux River, Donalds Castle Creek and Wongawilli Creek are all located outside the extent of the proposed longwalls. MSEC (2019) did not predict any changes in grade in Avon River, Cordeaux River and Wongawilli Creek due to subsidence induced tilt. Thus, no increases in the levels of ponding, flooding or scouring of banks along these watercourses are expected as a result of subsidence induced tilt. Only minor (0.05 %) change in grade is predicted in Donalds Castle Creek which is considerably less than the average natural grade and is not expected to increase the potential for ponding, flooding or scouring of the banks along the creek as a result of mining induced tilt. However, where the maximum changes in grade coincide with existing pools, steps or cascades along the creek, there could be some localised changes in the levels of ponding or flooding, though adverse impacts as a result are not predicted. Associated impacts to aquatic ecology are thus expected to be very minor to negligible.

Wongawilli Creek is further than 600m from the proposed longwalls and is not expected to experience fracturing or flow diversions and therefore no impacts to aquatic habitat are expected. The potential for significant fracturing resulting in surface water flow diversions is approximately 7% for the Avon River, 5% for the Cordeaux River and 9% for Donalds Castle Creek sections within 400 m of the proposed longwalls. Due to the low likelihood of significant fracturing there is an associated low likelihood of impacts to aquatic ecology due to any reductions in the amount of aquatic habitat. While impacts at the scale of individual pools could be significant, at the scale of watercourses they would be relatively minor. Furthermore, aquatic habitat within Donalds Castle Creek, while more substantial than within drainage lines, is also relatively limited compared with larger watercourses (i.e. Wongawilli Creek, Avon River and Cordeaux River). Any impacts in Donalds Castle Creek would have limited associated impact on aquatic habitat in the wider Avon River and Cordeaux River catchments. A reduction in aquatic habitat in Avon River and Cordeaux River associated with any flow diversion here is not expected to occur. This is due to the flow in these watercourses (> 2 ML/day) being sufficient to fill any fracture network without affecting pool water levels, as was observed previously in the Cataract and Nepean Rivers, mined under by Tower Colliery.

Minor fracturing may occur in rivers and creeks up to approximately 400 m from the proposed longwalls. Whilst minor fracturing is not expected to cause any significant diversion of surface flows, 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. request

Sections of ephemeral drainage lines located directly above the proposed longwalls are expected to experience the full range of predicted subsidence movements, with the potential for localised tilt-induced ponding along drainage lines where the natural gradients are low (MSEC 2019). Predicted fracturing in drainage lines overlying the proposed longwalls is expected to 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 and likely also from sections downstream until surface water flows reappear. Associated changes in the availability of ephemeral aquatic habitat that would occur are not expected to result in any significant impact to overall aquatic ecology, due to the limited value of habitat within ephemeral drainage lines. Due to their ephemeral flow and naturally disconnected pool habitat, any reduction in connectivity of aquatic habitat in these watercourses are expected to result in negligible impacts to aquatic ecology.

The abundance of drainage line habitat in the wider catchment would also suggest such additional impacts would be very small to negligible in the context of the local and regional area. Approximately 37 km of first, second and third order watercourse is located directly above the proposed longwalls and immediate surrounds. This represents approximately 5 % of that present within the upper Avon River and Cordeaux River catchments. The majority of this is first and second order drainage line, with approximately 1 km only of third order drainage lines located directly above the longwalls. Longwall extraction is expected to result in a loss of this habitat. Aquatic habitat in these drainage lines is likely to be ephemeral, consisting of a series of small pools with shallow flow over connecting rockbars. Although of relatively limited value to aquatic ecology, compared with the aquatic habitat present in larger watercourses in the Study Area, these areas would still support fish, such as galaxiids, macroinvertebrates including freshwater crayfish and several species of frogs (Niche 2019). The loss of this habitat would impact these species via reductions in their population size and area of occupancy (**Section 5.2.1.2**). These drainage lines, however, are highly unlikely to provide habitat for the threatened Macquarie Perch, Sydney Hawk Dragonfly and Adam’s Emerald Dragonfly (**Section 5.2.3**). Together with the length of comparable drainage line habitat expected to have been impacted (i.e. experienced fracturing, flow diversions and reduction in the amount of aquatic habitat) due to previous longwall mining, this would represent a cumulative impact to approximately 73 km (10 %) of such habitat within the upper Avon River and Cordeaux River catchments. With the addition of the probable length of previous habitat possibly impacted due to bord and pillar mining (62 km) and the length of watercourse habitat that would potentially be impacted due to other planned longwalls in the Dendrobium Mine (12 km), the potential cumulative length of watercourse habitat impacted by previous and proposed mining in these catchments would be 147 km (20.6 %).

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.

For catchments (i.e. drainage lines and a portion of Donalds Castle Creek) overlying Area 5 there would be a 6 to 22 % reduction in streamflow due to the Project and for catchments (drainage lines) overlying Area 6 there would be a 1 to 5 % reduction in streamflow due to the Project (for a median climatic year). This culminates in an estimated average of 0.55 % reduction in yield to Lake Avon and 0.39 % reduction in yield to Pheasants Nest Weir. Extraction of the longwall panels has the potential to affect groundwater discharge to and recharge from streams, swamps and their drainages subsequently, affecting baseflow. However, only minor impacts to the baseflow of Avon River, Cordeaux River or Donalds Castle Creek are predicted. Reductions in flow in ephemeral drainage lines are expected to have negligible consequences to aquatic habitat due their ephemeral flow regime. The very small predicted reductions in flow in Avon River, Cordeaux River and Donalds Castle Creek are also expected to result in no more than negligible impacts to aquatic ecology.

5.2.1.2 Biota

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.

Overall, impacts to aquatic biota in Avon River, Cordeaux River and Donalds Castle Creek would be unlikely due to the low rate of fracturing predicted (<10 %) that could result in surface flow diversions in these watercourses (**Section 5.2.1.1**). If fracturing did occur in the larger watercourses (i.e. Avon River and Cordeaux River), significant impacts are not expected due to the greater volumes of water and flow present that would prevent loss of habitat and associated biota. In smaller watercourses such as Donalds Castle Creek and drainage lines with substantial bedrock substratum and where there are few natural refuges, except cracks and cavities, few organisms may survive complete pool drainage. It is expected that some individuals of macroinvertebrates and fish would be lost due to the fracturing and reductions in water levels in Donalds Castle Creek. Any biota associated with disconnected pools in ephemeral drainage lines directly above the proposed longwalls would also be impacted. While associated impacts to biota such as reduced populations size and area of occupancy are likely to persist for the duration of mining and for some time afterwards, relative to the population and extent of these biota in the wider catchment such impacts are likely to be minor to negligible at this scale. It is difficult to quantify the absolute impacts to biota associated with ephemeral drainage lines, though based on the length of watercourses habitat expected to be lost due to the proposed longwalls, a 5 % reduction in population size could be expected within the upper Avon River and Cordeaux River catchments. This would be in addition to the approximate 15 % population reduction associated with the potential impact to 105 km of first, second and third order watercourses with known/predicted impacts due to previous and planned mining activities in these catchments.

Potential water quality impacts as a result of mining-induced subsidence from the proposed longwalls would be localised (HEC 2019). Although mine subsidence effects can result in isolated, episodic pulses in iron, manganese, aluminium and electrical conductivity, there have been no reports of any measurable effect on water quality in downstream reservoirs in the Southern Coalfield. Potential localised changes in water quality as a result of the Project are expected to result in negligible or undetectable downstream impacts including at Lake Avon and Lake Cordeaux (HydroSimulations 2019).

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 ephemeral 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 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 anymore 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 watercourses are not expected to result in any more than negligible impacts to associated aquatic biota.

5.2.1.3 Key Fish Habitat

There are unlikely to be any substantial impacts to the Avon River and Cordeaux River Type 1 – Highly Sensitive KFH given the low likelihood (<10 %) of significant fracturing, the limited extent of predicted fracturing and only minor potential changes in water quality and flow expected. Significant fracturing is also predicted to occur only within a limited length (0.8 km in Avon River and 1.4 km in Cordeaux River) of each river within 400 m of the proposed longwalls. Minor fracturing is predicted to occur within a limited length (0.25 km to 0.4 km) of each river within 400 m of the proposed longwalls. Type 1 – Highly Sensitive KFH is also abundant throughout these rivers, and the potential loss of a small amount is not expected to have substantial impacts on natural aquatic processes in the rivers. Although not mapped as KFH, Donalds Castle Creek also contains some Type 1 – Highly Sensitive KFH that could be impacted following any reductions in pool water levels due to proposed mining. Approximately 1 km of Type 2 – Moderately sensitive KFH (present within third order drainage lines located directly above Area 5 longwalls) would be impacted due to predicted fracturing and flow diversions. At the scale of the upper Avon River and Cordeaux River catchment area, impacts to this KFH would be relatively minor. First and second order drainage lines are not KFH and there would be no impact to KFH due to fracturing and flow diversions within this habitat directly above the proposed longwalls.

5.2.2 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 (2019) 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. Also, some swamps within the Study Area recorded sustained saturated conditions at depth over the duration of the monitoring period (HEC 2019). 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, HEC (2019) 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 undermined and expected to experience direct impacts due to extraction of the proposed longwalls is 0.35 km^2 or 2.5 % of the total area of pre-mining swamp habitat within the upper Avon River and Cordeaux River catchments (**Section 3.10.3**). 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 future longwalls in DA3A, DA3B and DA3C (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 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.

5.2.3 Threatened Species

Habitat for the following threatened species listed under the FM Act and the EPBC Act has been identified as occurring or potentially occurring within the Study Area; Macquarie Perch, Sydney Hawk Dragonfly and Adam's Emerald Dragonfly.

Macquarie Perch is known to occur in Avon River and Cordeaux River. 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 E**). Although Macquarie Perch are expected to occur in Avon River and Cordeaux River, the probability of significant fracturing resulting in flow diversions in these streams is low (**Section 5.2.1**). Thus, there is very unlikely to be a significant impact on this species due to the Project.

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 (**Appendices F** [Sydney Hawk Dragonfly] and **G** [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.

6 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; and
> Contingency measures should impacts exceed predictions.

6.1 Minimisation

The design of the Project includes measures to minimise potential impacts on aquatic ecology. These include set back of longwalls from major watercourses and key stream features to reduce the probability of physical mining impacts occurring.

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.

6.2 Monitoring Plan

6.2.1 Outline and Aims

The strategic review of the impacts of underground mining in the Southern Coalfield 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 (NSW DoP 2008). 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.

A recommended comprehensive monitoring plan to assess the potential impacts of mine subsidence on aquatic habitat and biota within watercourses of the Study Area is outlined below. The plan was prepared in-line with that undertaken in DA3A and DA3B in accordance with the Dendrobium Mine Development Consent and the Director General’s Requirements (DoP) to modify the DA3 mine area and in support of the SMP application for DA3B.

The aims of the recommended monitoring plan are to:

> Determine the nature and extent of any subsidence-induced impacts on aquatic ecology; and
> Assess the response of aquatic ecosystems to any stream remediation and management works implemented.

6.2.2 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, Cordeaux River and Donalds Castle Creek) and in sections of the larger drainage lines in Area 5 and/or Area 6 predicted to experience 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 24 month baseline period is considered appropriate given the number of longwalls, their size and estimated time required to extract longwalls from Areas 5 and 6, is longer than that required for DA3B. This would provide a better 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 each of Area 5 and Area 6 be monitored prior to that area's development. Monitoring and surveys at individual sites would also be staged relative to the extraction timeline for each longwall.

6.2.3 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.

6.2.3.1 Aquatic Habitat

During the first baseline survey, condition of the aquatic habitat at each site was assessed using a modified version of the RCE (Chessman et al. 1997). This assessment involved 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 2m tall x 1m 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.

6.2.3.2 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 aquatic ecology specific water quality monitoring should be undertaken in addition to that outlined in Appendix C of the Project EIS.

6.2.3.3 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.

6.2.3.4 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 for freshwater environmental impact assessment.

6.2.3.4.1 AUSRIVAS

At each site, samples of aquatic macroinvertebrates associated with the pool edge habitat should be collected using dip nets (250 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 river, in accordance with the AUSRIVAS 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 forty minutes, after which they should be picked at ten 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 X 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 (April 15 to June 15) and/or Spring (Oct 15 to Dec 15).

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.

6.2.3.4.2 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.

6.2.3.5 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.

6.2.3.6 Fish

Fish should be sampled using a back-pack electrofisher (model LR-24 Smith-Root) and baited traps. 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. The back-pack electrofisher should be operated around the edge of pools and in riffles, with four two minute shots being performed at each site. Fish stunned by the current should be collected in a scoop net, identified and measured. Native species would be released unharmed. Exotics should not be returned to the water in accordance with Cardno Ecology Lab's Scientific Research Permit.

6.2.3.7 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 Generalised Linear Mixed Modelling (GLMM) with an appropriate distributional assumption. This technique is more appropriate than distance based methods (e.g. 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.

6.3 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 ICEFT. Current trigger values for aquatic ecology monitoring parameters are outlined in South32 (2018). These values may be revised in consultation with relevant stakeholders following analysis of natural variability within the pre-mining baseline data. Each trigger value corresponds to either a negligible or significant impact on the aquatic habitat and/or biota within the Extraction Plan area and management actions are presented if thresholds are exceeded.

6.4 Contingency Measures

In the event that impacts of extraction of the proposed longwalls on aquatic habitats and biota in Avon River, Cordeaux River and Donalds Castle Creek occur 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/or

> 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.

In the event that impacts of extraction of the proposed longwalls are greater than predicted, South32 should consider reviewing the mine layout and appropriate setback distances from major watercourses and/or consider further stream remediation and erosion and sediment control measures.

6.5 Offsetting

The Project would not require biodiversity offsets associated with threatened aquatic species, populations or communities listed under the FM Act or EPBC Act as significant impacts 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).

If impacts to KFH in third order and higher watercourses occur that are unable to be remediated, 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 improve 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 NSW DPI (Fisheries).

7 Conclusion

The design of the Project includes measures to minimise potential impacts on aquatic ecology. These include set back of longwalls from major watercourses and key stream features to reduce the probability of physical mining impacts occurring. Nevertheless, impacts to aquatic habitat, vegetation, macroinvertebrates or fish will occur following predicted mine subsidence and associated fracturing in streams and ephemeral 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 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 or Adam's Emerald Dragonfly are expected. These species are very unlikely to occur in Donalds Castle Creek and drainage lines that traverse the Study Area and that would be most susceptible to mining related subsidence impacts. Although Macquarie Perch is expected to occur in Avon River and Cordeaux River, the mine layout has been designed to ensure significant fracturing resulting in flow diversions have a low likelihood (<10 %). of occurrence within these rivers In any case, any flow diversions are not expected to result in reductions in aquatic habitat due to the large amount of flow in Avon River and Cordeaux River.

Although no bores suitable for sampling of stygofauna are present in the Study Area, 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 Study Area. 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. Water level data from shallow groundwater bores suggests the majority of swamps within the Study Area would lose standing water during prolonged dry periods. However, some swamps within the Study Area also recorded sustained saturated conditions at depth over the duration of the monitoring period (HEC 2019), providing limited habitat for stygofauna

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.

Implementation of the recommended aquatic ecology monitoring program outlined in **Section 6.2** will assist to determine the magnitude and extent of impacts to aquatic ecology associated with extraction of the proposed longwalls. The location of monitoring sites and staging of monitoring should be refined following further consultation with ICEFT 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.

8 References

Advisian (2016). Literature Review of Underground Mining Beneath Catchments and Water Bodies, prepared for WaterNSW by Advisian, Pells Sulllivan Meynink, MacTaggart & Associates, John Ross & Grant Sutton & Associates, December 2016.

ALS (2010). Grosvenor Stygofauna Survey. Prepared for Anglo Coal (Grosvenor) by ALS Water Sciences Group, Yeerongpilly, QLD. Document No. EE2010-79, 20 pages.

ANZECC/ARMCANZ (2000). *Australian guidelines for water quality monitoring and reporting.* National water quality management strategy, No. 7. Prepared for: Australian & New Zealand Governments. ANZECC//ARMCANZ, Australia.

Australian Coal Association Research Program (ACARP) (2015). Stygofauna in Australian Groundwater Systems: Extent of Knowledge. Grant C Hose, J Sreekanth, Olga Barron and Carmel Pollino

Baird, I. R. C. (2012). The wetland habitats, biogeography and population dynamics of *Petalura gigantean* (Odonta: Petaluridae) in the Blue Mountains of New South Wales. A thesis submitted in fulfilment of the requirements for the Degree of Doctor of Philosophy. The University of Western Sydney.

BHP Billiton Illawarra Coal (BHPBIC) (2015). Dendrobium Area 3B. Longwall 10. End of Panel Report.

Biosis (2016). Targeted surveys for Giant Dragonfly *Petalura gigantean* in Dendrobium Area 3B.

Boulton, A. J., Fenwick, G. D., Hancock, P. J. and Harvey, M. S. (2008). Biodiversity, functional roles and ecosystem services of groundwater invertebrates. *Invertebrate Systematics* 22, pp. 103-116.

Bureau of Meteorology (BOM). (2015). Atlas of Groundwater Dependent Ecosystems.

Cardno Ecology Lab (2009). Dendrobium Area 2. Aquatic Ecology Monitoring Program.

Cardno Ecology Lab (2011). Dendrobium Area 3 – Baseline Aquatic Ecology Monitoring Spring 2008 – Spring 2010. Report Prepared for BHP Billiton.

Cardno Ecology Lab (2012a). Dendrobium Area 3B SMP – Aquatic Flora and Fauna Assessment. Report Prepared for BHP Billiton. Report No. EL1112029A.

Cardno Ecology Lab (2012b). Dendrobium Area 3 – Aquatic Ecology Monitoring 2008 to 2011. Report Prepared for BHP Billiton. Report No. EL1112073A.

Cardno Ecology Lab (2013). Dendrobium Area 3 – Aquatic Ecology Monitoring 2008-2012. Prepared for BHP Billiton. February 2013.

Cardno Ecology Lab (2014). Dendrobium Areas 3A and B. Aquatic Ecology Monitoring 2008 to 2013.

Cardno Ecology Lab (2015). Dendrobium Area 3A. Aquatic Ecology Monitoring 2008 to 2014.

Cardno Ecology Lab (2016a). Dendrobium Area 3A. Aquatic Ecology Monitoring 2010 to 2015

Cardno Ecology Lab (2016b). Dendrobium Area 3B. Aquatic Ecology Monitoring 2010 to 2015.

Chessman, B.C Growns, J.E and Kotlash, A.R. (1997). Objective derivation of macroinvertebrate family sensitivity grade numbers for the SIGNAL biotic index: Application to the Hunter River system, New South Wales. Marine and Freshwater Research, 48, pp. 159-172.

Coffey 2006. Sydney Catchment Authority Upper Nepean Borefield Development Groundwater Modelling Study, Southern Highlands NSW. GW031-06-06V1. Coffey Pty Ltd.

Commonwealth of Australia (2011). Survey guidelines for Australia's threatened fish. Guidelines for detecting fish listed as threatened under the Environment Protection and Biodiversity Conservation Act (1999).

Commonwealth of Australia (2018). National Recovery Plan for the Macquarie Perch (*Macquaria australasica*).

Creese, B. and Hartley, S. (2003). Resurvey of the Cordeaux River System for Macquarie Perch. Report to The Ecology Lab Pty Ltd, February 2003.

Coysh, J., Nichols, S., Ransom, G., Simpson, J., Norris, R., Barmuta, L., Chessman, B. (2000). AUSRIVAS Macroinvertebrate Bioassessment. Predictive Modelling Manual.

Department of Sustainability, Environment, Water, Population and Communities (2012) Environment Protection and Biodiversity Conservation Act 1999 Environmental Offsets Policy, October 2012.

Eberhard, S. (2007). Classification of Subterranean Fauna. Subterranean Ecology. Prepared for the Department of Environment and Conservation, Western Australia, Greenwood, WA. Project 49, pp 2–7.

Eberhard, S. M., Halse, S. A. and Humphreys, W. F. (2005). Stygofauna in the Pilbara region of north-west Western Australia: a review. *Journal of the Royal Society of Western Australia* 88, pp 167–176.

Ebner, B.C., Lintermans, M.,Jekabsons and Dunford, M. (2010). Convoluted shorelines confound diel-range estimates of radio-tracked fish. *Marine and Freshwater Research* 61(12):1360-1365

Ecoengineers Pty Ltd (2006). Assessment of Surface Water Effects in Native Dog and Wongawilli Creek of Undermining by Elouera Colliery July 2004 – December 2004. Report prepared for BHP Billiton Illawarra Coal.

Ecological (2015a). Drayton South Coal Project Stygofauna Impact Assessment. Report prepared for Hansen Bailey Environmental Consultants. February 2015.

Ecological (2015b). Bylong Coal Project Environmental Impact Statement: Stygofauna Impact Assessment. Report prepared for Hansen Bailey Environmental Consultants. July 2015.

Fisheries Scientific Committee (2008). Final Determination. *Archaeophya adamsi* – Adam's emerald dragonfly. https://www.dpi.nsw.gov.au/__data/assets/pdf_file/0005/636494/FD33-Adams-emerald-dragon.pdf

Gehrke, P.C. and Harris, J.H. (1996). Fisheries and Fisheries of the Hawkesbury-Nepean River system. Final Report to the Sydney Water Corporation. NSW Fisheries Research Institute, Cronulla.

Growns, I. and Gehrke, P. C. (2001). Macquarie Perch and fish habitat survey of the Cordeaux River system. Report prepared by NSW Fisheries Office of Conservation, Nelson Bay, NSW for BHP Billiton.

Hancock, P. J. and Boulton, A. J. (2008). Stygofauna biodiversity and endemism in four alluvial aquifers in eastern Australia. *Invertebrate Systematics* 22, pp. 117-126.

Hancock, P. J. and Boulton, A. J. (2009). Sampling groundwater fauna: efficiency of rapid assessment methods tested in bores in eastern Australia. *Freshwater Biology* **54**, pp. 902-917.

Hancock, P. J., Boulton, A. J. and Humphreys, W. F. (2005). Aquifers and hyporheic zones: Towards an ecological understanding of groundwater. *Hydrogeology Journal* 13, pp. 98-111.

Herrmann, J. (2001). Aluminium is Harmful to Benthic Invertebrates in Acidified Waters, but at What Threshold(s)? Water Air and Soil Pollution. 130. pp 837-842.

Hose, G. (2008). Stygofauna Baseline Assessment for Kangaloon Borefield Investigations – Southern Highlands NSW. Access Macquarie Limited. Macquarie University. October 2008.

Hose, G. (2009). Stygofauna Baseline Assessment for Kangaloon Borefield Investigations – Southern Highlands NSW. Supplementary Report. Stygofauna Molecular Studies. Access Macquarie Limited. Macquarie University. May 2009.

Humphreys, W. F. (2006). Aquifers: the ultimate groundwater-dependent ecosystems. *Australian Journal of Botany 54*, pp. 115-132. HydroSimulations (2017). Dendrobium Mine: Plan for the Future. Groundwater Conceptual Model. February 2017.

HydroSimulations (2019). Dendrobium Mine: Plan for the Future: Coal for Steelmaking. Groundwater Assessment.Liu, K., Paterson, L. & Boult, Peter. (1996). Outcrop Analog for Sandy Braided Stream Reservoirs: Permeability Patterns in the Triassic Hawkesbury Sandstone, Sydney Basin, Australia.

Marine Pollution Research Pty Ltd (2002). Elouera Colliery Integrated Environmental Monitoring Program – First Aquatic Ecology Report: Initial Summer 01/02 Survey – Native Dog Creek and First Full Survey-Autumn 2002. Report prepared for BHP Billiton Illawarra Coal.

Marine Pollution Research Pty Ltd (2003a). Elouera Colliery Integrated Environmental Monitoring Program – Spring 2002 Aquatic Ecology Report to BHP Billiton Illawarra Coal.

Marine Pollution Research Pty Ltd (2003b). Elouera Colliery Integrated Environmental Monitoring Program – Autumn 2003 Aquatic Ecology Report to BHP Billiton Illawarra Coal.

Marine Pollution Research Pty Ltd (2004a). Elouera Colliery Integrated Environmental Monitoring Program – Spring 2003 Aquatic Ecology Report to BHP Billiton Illawarra Coal.

Marine Pollution Research Pty Ltd (2004b). Elouera Colliery Integrated Environmental Monitoring Program – Autumn 2004 Aquatic Ecology Report to BHP Billiton Illawarra Coal.

Marine Pollution Research Pty Ltd (2005). Elouera Colliery Integrated Environmental Monitoring Program – Spring 2004 Aquatic Ecology Report to BHP Billiton Illawarra Coal.

Marine Pollution Research Pty Ltd (2006a). Elouera Colliery Integrated Environmental Monitoring Program – Autumn 2005 Aquatic Ecology Report to BHP Billiton Illawarra Coal.

Marine Pollution Research Pty Ltd (2006b). Elouera Colliery Integrated Environmental Monitoring Program – Spring 2005 Aquatic Ecology Report to BHP Billiton Illawarra Coal.

Marine Pollution Research Pty Ltd (2006c). Elouera Colliery Integrated Environmental Monitoring Program – Autumn 2006 Aquatic Ecology Report to BHP Billiton Illawarra Coal.

McDowall, R. (1996). Freshwater Fishes of South-eastern Australia. Reed Books, Chatswood, NSW.

Mine Subsidence Engineering Consultants (2019). Dendrobium Mine – Plan for the Future: Coal for Steelmaking. Subsidence Assessment.

Morris, S. A., Pollard, D. A., Gehrke, P. and Pogonoski, J. J. (2001). Threatened and Potentially Threatened Freshwater Fishes of Coastal New South Wales and the Murray-Darling Basin. Prepared for: Commonwealth Government's Fisheries Action Program//World Wide Fund for Nature. NSW Fisheries Office of Conservation, NSW. New South Wales Department of Primary Industries (1999). Policy and Guidelines for Aquatic Habitat Management and Fish Conservation.

New South Wales Department of Primary Industries (2003). Fish Friendly Waterway Crossings.

New South Wales Department of Primary Industries (2006). Primefact 162. Threatened species in NSW Australian Grayling *Prototroctes maraena*.

New South Wales Department of Primary Industries (2007). Primefact 184. Threatened species in NSW Sydney Hawk Dragonfly Austrocordulia *leonardi*.

New South Wales Department of Primary Industries (2013a). Policy and guidelines for fish habitat conservation and management (Update 2013).

New South Wales Department of Primary Industries (2013b) Primefact. Adams emerald dragonfly, *Archaeophya adamsi.* December 2013, Primefact 187, Third edition. Fisheries Ecosystems Unit, Port Stephens Fisheries Institute.

New South Wales Department of Primary Industries (2016a). Fish communities and threatened species distributions of NSW.

New South Wales Department of Primary Industries (2016b). Primefact. Macquarie Perch - *Macquaria australasica*. April 2016, Primefact 9, Third Edition. Threatened Species Unit, Port Stephens Fisheries Institute. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0010/635257/primefact-9-macquarie-perch-macquaria-australasica-2.pdf

New South Wales Department of Primary Industries (2017a). Home. Fishing. Habitat management. Publications. Key Fish Habitat. Wollongong. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0004/634378/WollongongKFHMap.pdf

New South Wales Department of Primary Industries (2017b). Priorities Action Statement - Actions for Macquarie Perch.

http://www.dpi.nsw.gov.au/fishing/species-protection/conservation/what-current/endangered-species/macquarie-perch/priorities-action-statement-actions-for-macquarie-perch

New South Wales Fisheries Scientific Committee (2004) Recommendation *Austrocordulia leonardi* – Sydney Hawk Dragonfly.

New South Wales National Parks and Wildlife Service (NPWS) (2003). The Native Vegetation of the Woronora, O'Hares and Metropolitan Catchments. NSW National Parks and Wildlife Service, Sydney. https://www.environment.nsw.gov.au/resources/nature/surveys/030143VegWoronoraOHaresCatchmts.pdf

New South Wales Office of Water (2012). Risk Assessment Guidelines for Groundwater Dependent Ecosystems: Volume 1 – The Conceptual Framework. NSW Department of Primary Industries (NSW Office of Water). 140 pages. www.water.nsw.gov.au, May 2012.

Office of Environment and Heritage (2014). Framework for Biodiversity Assessment. NSW Biodiversity Offsets Policy for Major Projects. http://www.environment.nsw.gov.au/resources/biodiversity/140675fba.pdf

Office of Environment and Heritage (2016a). Giant Dragonfly – Profile. http://www.environment.nsw.gov.au/threatenedspeciesapp/profile.aspx?id=10600

Office of Environment and Heritage (2016b) Help save the Giant Dragonfly (*Petalura gigantea*). http://www.environment.nsw.gov.au/resources/threatenedspecies/PASconsultation/CP/CPPetaluragigantea.pdf

Office of Environment and Heritage (2017). Home, Topics, Animals and plants, threatened species, Search for threatened species, Find by region. Giant Dragonfly - Hawkesbury-Nepean: Distribution and vegetation associations. http://www.environment.nsw.gov.au/threatenedSpeciesApp/profileData.aspx?id=10600&cmaName=Hawkesbury-Nepean

RES 2006, Upper Nepean Groundwater Pilot Studies: Pumping Test Interpretation and Data Logger Installation, May 2006, Responsive Environmental Solutions, Sydney.

RPS (2014). Springvale Mine Extension Project. Flora and Fauna Assessment Report. Prepared for Springvale Coal PTY Limited.

SMEC (2006). Baseline Groundwater Depednent Ecosystem Evaluation Study – Upper Nepean Groundwater Pilot Studies. Final Report. Prepared for Sydney Catchment Authority. September 2006.

South32 (2016a). Dendrobium Mine – Plan for the Future: Coal for Steelmaking. Preliminary Environmental Assessment. December 2016.

South32 (2016b) Dendrobium Area 3B. Longwall 11 End of Panel Report.

South32 (2017) Dendrobium Area 3B. Longwall 12 End of Panel Report.

South32 (2018) Dendrobium Area 3B. Longwall 13 End of Panel Report.

Tessier, A. and Turner, D.R. (1995) Metal Speciation and Bioavailability in Aquatic Systems, IUPAC Series on Analytical Chemistry of Environmental Systems. John Wilend and Sons.

The Ecology Lab (2001a). Assessment of Aquatic Habitats for Dendrobium Coal Mine. Prepared for Olsen Environmental Consulting.

The Ecology Lab (2001b). Proposed Monitoring Program for Macquarie Perch and Aquatic Habitats in Cordeaux River System.

The Ecology Lab (2003). Dendrobium Coal Mine. Subsidence Management Plan for Aquatic Ecology in Area 1.

The Ecology Lab (2005). Dendrobium Coal Mine Area 1 Baseline Study. Aquatic Ecology. Baseline Report.

The Ecology Lab (2006). Dendrobium Area 2. Assessment of Mine Subsidence Impacts on Aquatic Habitat and Biota.

The Ecology Lab (2007). Dendrobium Area 3. Assessment of Mine Subsidence Impacts on Aquatic Habitats and Biota.Tomlinson, M. and Boulton, A. J. (2010). Ecology and management of subsurface groundwater dependent ecosystems in Australia - a review. *Marine & Freshwater Research* 61, pp. 936-949.

Turak, E., Waddell. N., Johnstone, G. (2004). New South Wales (NSW) Australian River Assessment System (AUSRIVAS) Sampling and Processing Manual.

URS 2007a. Kangaloon Borefield Trial – End of Trial Pumping Test – Water Level and Drawdown Assessment, August 2007. URS Australia Pty Ltd, Sydney.

URS 2007b. Upper Nepean (Kangaloon). Trial Borefield Segment. Drilling and Testing of Production and Monitoring Bores. Completion Report, May 2007. URS Australia Pty Ltd, Sydney.

APPENDIX

A

RIPARIAN CHANNEL AND ENVIRONMENTAL INVENTORY ASSESSMENT

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i) River, Channel and Environmental (RCE) Categories

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

ii) Results of the RCE assessment

RCE Category	CR1	CR2	DC1	DC2	DC3	AR1	AR2
Land use pattern beyond the immediate riparian zone	4	4	4	4	4	4	4
Width of riparian strip of woody vegetation	4	4	4	4	4	4	4
Completeness of riparian strip of woody vegetation	4	4	4	4	4	4	4
Vegetation of riparian zone within 10 m of channel	4	4	4	4	4	4	4
Stream bank structure	4	4	4	4	4	4	4
Bank undercutting	4	4	4	4	4	4	4
Channel form	4	4	3	3	3	4	4
Riffle/pool sequence	3	3	2	2	2	3	3
Retention devices in stream	3	3	4	4	4	3	3
Channel sediment accumulations	3	3	3	3	3	3	3
Stream bottom	4	4	4	4	4	4	4
Stream detritus	4	4	4	4	4	4	4
Aquatic vegetation	1	2	4	4	4	2	2
Total	46	47	48	48	48	47	47

APPENDIX

B

PHOTOGRAPHS

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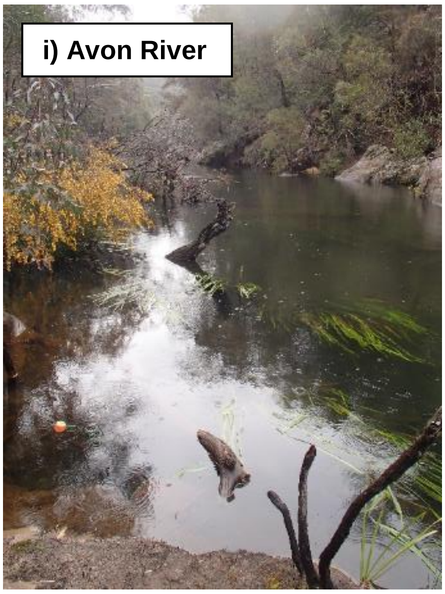

i) Avon River


ii) Cordeaux River


iii) CR1

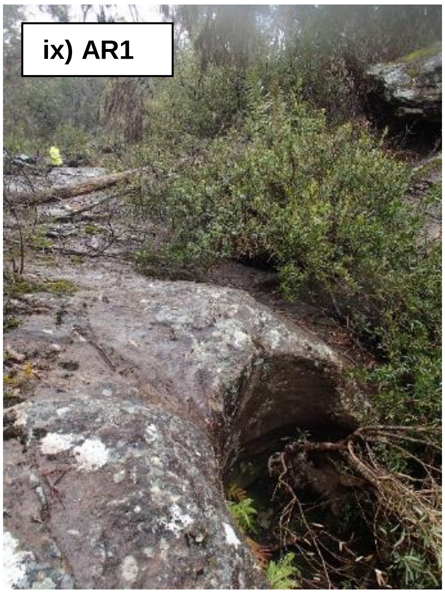

iv) CR2


v) DC1

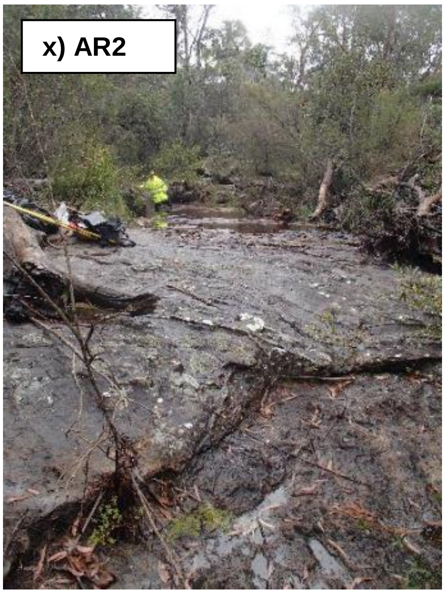

vi) DC2

vii) DC3

viii) DC3



ix) AR1



x) AR2

xi) *Galaxais* sp.

xi) DC2

APPENDIX

C

MEAN WATER QUALITY DATA

	DTV	CR1		CR2		DC1		DC2		DC3		AR1		AR1	
		M	SE	M	SE	M	SE	M	SE	M	SE	M	SE	M	SE
Temp (°C)		15.2	0	15.6	0	14.1	0	14.2	0	14.1	0	14.2	0	14.5	0
Cond	30-350	134	0	145	0	83	0	82	0	83	0	92	0	94	0
pH	6.5-8.0	7.2	0	7.2	0	5.4	0	5.4	0	5.4	0	6.2	0	6.2	0
DO (%Sat)	90-110	90	0	92	0	96	0	97	0	92	0	90	0	90	0
Turbidity	2-25	5	0	5	0	0.3	0	0.2	0	0.3	0	0.4	0	0.4	0

SE = Standard Error, n = 2. Default Trigger Values (DTV) taken from ANZECC/ARMCANZ (2000) guidelines for slightly disturbed upland rivers in southeast Australia. Grey shading indicates measure outside of DTVs.

APPENDIX

D

MACROINVERTEBRATE TAXA IDENTIFIED IN AUSRIVAS SAMPLES

Taxon	CR1	CR2	DC1	DC2	DC3	AR1	AR2	SIGNAL2 Score (where available)
Aeshnidae			1			1		4
Atyidae			2	3	1			3
Baetidae	10	1		4	10	10	8	5
Caenidae				3	10			4
Calamoceratidae				2				7
Ceinidae	13	5						2
Ceratopogonidae					1		1	4
Chironomidae: Chironominae	3		2	6	8	10	10	3
Chironomidae: Tanypodinae	2	1	1	8	2		5	4
Cirolanidae							1	2
Cladocera		10						
Coenagrionidae		2	2					2
Copepoda		1		1	1		5	
Dixidae		1		1	2			7
Dytiscidae	1	3	1	2	1	8	1	2
Ecnomidae				3				4
Elmidae							2	7
Gelastocoridae			1		1	1		5
Gerridae	1							4
Gomphidae	2	1	1	1	3			5
Gripopterygiidae				3	2			8
Gyrinidae		1	1					4
Haliplidae		3						2
Helicopsychidae	1					1		8
Hemicorduliidae			1		2			5
Hydracarina	10	1	10	18	10	4		6
Hydrobiosidae		1						8
Hydrophilidae				1	1	4	1	2
Leptoceridae	10	10	10	6	10	10	7	6
Leptophlebiidae	10	10	10	4	8	7	10	8
Lestidae		1						1
Megapodagrionidae		4	1		1		1	5
Notonectidae			1					1
Odontoceridae	1		1			1		7
Protoneuridae					1			4
Scirtidae	2							6
Simuliidae					1			5
Synlestidae					1			7
Synthemistidae					1			2
Tipulidae					1			5
Aeshnidae			1			1		4

Maximum number of 10 individuals counted

APPENDIX

E

ASSESSMENT OF SIGNIFICANCE: MACQUARIE PERCH

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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 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, 2001 and pers. obs. 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 has been recorded also in Lake Avon and Lake Cordeaux and previously recorded, or potentially present, in the upper reaches of Cordeaux and Avon Rivers (NSW DPI 2016a). The steep bedrock cascade features directly upstream of the crossing at Fire Road No. 6 would pose a significant barrier to the upstream passage of the Macquarie Perch populations within the lower to mid reaches of Wongawilli Creek. The presence of several natural barriers to movement of this species on Donalds Castle Creek, particularly the cascade downstream of Area 5, would also prevent or severely hinder this species utilising the vast majority of this watercourse.

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.

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 is likely to result in minor, localised changes in the availability, quality and connectivity of aquatic habitats within Avon River and Cordeaux River. Macquarie Perch habitat (woody debris, rocks and boulders) is likely to be abundant throughout these rivers within and adjacent to the areas potentially affected by mining. Given the extensive amount of potential habitat available for this species within these rivers and nature of the impacts, if any, it is highly unlikely that mining would have any adverse effects on the life cycle of Macquarie Perch in Avon River or Cordeaux River or place a viable local population at risk of extinction. Macquarie Perch are considered very unlikely to occur in Donalds Castle Creek and drainage lines, and, thus, would not be affected by any mining induced impacts here. The population in Wongawilli Creek is located downstream of the proposed mining where no fracturing would occur and is not expected to be affected by the project. Likewise, any impacts to water quality in these creeks and rivers due to the project are expected to be minor and localised not affect 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 a low probability of occurrence of significant fracturing resulting in flow diversions in Avon River and Cordeaux 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 Donalds Castle Creek and drainage lines, these are very unlikely to provide habitat for Macquarie Perch. 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 has recently been released (Commonwealth of Australia 2018). This 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.

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 unlikely. Macquarie Perch is very unlikely to be found in Donalds Castle Creek and drainage lines that have high probability of experiencing fracturing resulting in flow diversions and loss of aquatic habitat. Significant fracturing in Avon River and Cordeaux rive resulting in flow diversions is unlikely, and, if it did occur, the relatively greater volume of water in these watercourses would limit the amount of habitat loss due flow diversions.

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 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 has been recorded also in Lake Avon and Lake Cordeaux and previously recorded, or potentially present, in the upper reaches of Cordeaux and Avon Rivers (NSW DPI 2016a). The steep bedrock cascade features directly upstream of the crossing at Fire Road No. 6 would pose a significant barrier to the upstream passage of the Macquarie Perch populations within the lower to mid reaches of Wongawilli Creek. The presence of several natural barriers to movement of this species on Donalds Castle Creek, particularly the cascade downstream of Area 5, would also prevent or severely hinder this species utilising the vast majority of this watercourse.

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 Cordeaux River. The subsidence predictions indicate that extraction of the proposed longwalls is likely to result in minor, localised changes in the availability, quality and connectivity of aquatic habitats within Avon River and Cordeaux River. Given the extensive amount of potential habitat available for this species within these rivers and nature of the impacts, if any, it is highly unlikely that mining would have any adverse effects on the population size Macquarie Perch in Avon River or Cordeaux River or place a viable local population at risk of extinction. Macquarie Perch are considered very unlikely to occur in Donalds Castle Creek and drainage lines, and, thus, would not be affected by any mining induced impacts here. The population in Wongawilli Creek is located downstream of the proposed mining where no fracturing would occur and is not expected to be affected by the project. Likewise, any impacts to water quality in these creeks and rivers due to the project are expected to be minor and localised not affect Macquarie Perch.

b) Reduce the area of occupancy of the species

As described above, significant fracturing resulting in flow diversions are unlikely in Avon River and Cordeaux River. Thus, potential impacts to identified Macquarie Perch habitat due to the Project are unlikely. Any habitat loss due to any flow diversions due in these rivers may also to some extent be limited due to the large volumes of water present here, compare with flow diversions occurring in smaller watercourses. The Project would also not require any crossings over Avon River and Cordeaux River 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 die 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 and Cordeaux River, where they are known to occur, have a low probability of occurrence.

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 likely to result in minor, localised changes in the availability, quality and connectivity of aquatic habitats within Avon River and Cordeaux River. Macquarie Perch habitat (woody debris, rocks and boulders) is likely to be abundant throughout these rivers within and adjacent to the areas potentially affected by mining. Given the extensive amount of potential habitat available for this species within these rivers and nature of the impacts, if any, it is highly unlikely that mining would have any adverse effects on the life cycle of Macquarie Perch in Avon River or Cordeaux River or place a viable local population at risk of extinction. Macquarie Perch are considered very unlikely to occur in Donalds Castle Creek and drainage lines, and, thus, would not be affected by any mining induced impacts here. The population in Wongawilli Creek is located downstream of the proposed mining where no fracturing would occur and is not expected to be affected by the project. Likewise, any impacts to water quality in these creeks and rivers due to the project are expected to be minor and localised not affect Macquarie Perch.

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.

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 has recently been released (Commonwealth of Australia 2018). This 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 F

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. Although such habitat is present within Avon River and Cordeaux River, the sections of river within the Study Area, 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 life cycle of this 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 and Cordeaux River indicate a low probability of significant fracturing resulting in flow diversions. The changes in availability of aquatic habitat and water quality that may occur as a result of these physical impacts would be temporary, localised and minor in nature and would not be significant relative to the total amount of potential habitat within these rivers. 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 EEC 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 and Cordeaux River, the sections of river within the Study Area, there are no records for this species within the Study Area or the Cordeaux and Lake Avon catchments. Such habitat would also be present throughout these rivers.

Extraction of the longwalls could have an adverse effect on the habitat of this 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 and Cordeaux River indicate a low probability of significant fracturing resulting in flow diversions. The changes in availability of aquatic habitat and water quality that may occur as a result of these physical impacts would be temporary, localised and minor in nature and would not be significant relative to the total amount of potential habitat within these rivers. It is therefore highly unlikely that mining would have any adverse effects on the habitat Sydney Hawk 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 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. Sydney Hawk Dragonfly is very unlikely to be found in Donalds Castle Creek and drainage lines that have high probability of experiencing fracturing resulting in flow diversions and loss of aquatic habitat. Significant fracturing in Avon River and Cordeaux rive resulting in flow diversions is unlikely, and, if it did occur, the relatively greater volume of water in these watercourses would limit the amount of habitat loss due flow diversions. In any case, this species appears very unlikely to occur in the Study Area.

APPENDIX

G

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 the baseline 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 watercourses (Cardno Ecology Lab 2011). 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.

Extraction of the longwalls could have an adverse effect on the life cycle of this 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 and Cordeaux River indicate a low probability of significant fracturing resulting in flow diversions. The changes in availability of aquatic habitat and water quality that may occur as a result of these physical impacts would be temporary, localised and minor in nature and would not be significant relative to the total amount of potential habitat within these rivers. Although Donalds Castle Creek and drainage lines may provide more suitable habitat than the larger Avon and Cordeaux Rivers, they do not provide any substantial gravel or sand substratum. Together with the apparent absence of this species from the Study Area, 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 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 EEC 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), the sections of river within the Study Area, 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 Sydney Hawk 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 Donalds Castle Creek and drainage lines that have high probability of experiencing fracturing resulting in flow diversions and loss of aquatic habitat. Significant fracturing in Avon River and Cordeaux rive resulting in flow diversions is unlikely, and, if it did occur, the relatively greater volume of water in these watercourses would limit the amount of habitat loss due flow diversions. In any case, this species appears very unlikely to occur in the Study Area.