APPENDIX J REVISED AQUATIC ECOLOGY IMPACT ASSESSMENT

Angus Place Amended Project

Aquatic Ecology and Stygofauna Assessment

59919118

Prepared for

Angus Centennial

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Cardno®

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Executive Summary

Introduction

Centennial Angus Place Pty Limited (Centennial Angus Place), the operator of the Angus Place Colliery is seeking approval for a new State Significant Development (SSD) for the Angus Place Mine Extension Project (APMEP or the Project). The current Angus Place Mine consent MP06_0021 will expire in August 2024. The Project will allow mining to continue until 2053.

Cardno (NSW/ACT) Pty Ltd (Cardno) was engaged by Centennial Angus Place to undertake the Aquatic Ecology and Stygofauna Assessment (AESA) for the APMEP. Previously, Cardno prepared the APMEP in 2014 and the current study updates the findings of the previous APMEP with updated subsidence predictions following a change to the longwall layout and further aquatic ecology studies that have been undertaken since 2014.

The primary potential impact pathway 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. Longwall mining may also result in disturbance of overlying aquifers, resulting in drepessuisation of groundwater and associated reduction in surface flow and water levels in watercourses. Both fractuing of bedrock and flow diversions, and reductions in groundwater levels due to groundwater depressurisation, can also result in reductions in the availibility of stygofauna in perched swamp and undelying aquifers, potentially resulting in impacts to associated stygofauna assemblages (impacts to swamps and other associated biota are considered in the terrestrial ecology assessment). There would be no discharge of any mine water to watercourses.

Existing Environment

The Study Area for the AESA is the area within 600 m of the proposed longwalls extents and including the longwalls. The primary watercourses within and adjacent to this area are the perennial Wolgan River and its tributary, Carne Creek. These watercourses do not flow directly over the proposed longwalls but flow in a northerly direction to the west and east of the longwalls, respectively. A number of first, second and higher tributaries are located directly over the longwalls. These include third order and higher sections of watercourses associated with Twin Gully, Tri-Star and Bird Rock swamps. Field investigations undertaken by Cardno and other specialist consultants indicated that the perennial sections of Wolgan River, Carne Creek and those that flow through the swamps are undisturbed and support a relatively diverse aquatic macroinvertebrate assemblage and also freshwater crayfish (Family: Parastacidae). The fish assemblage supported by these watercourses appears relatively limited, with sparse records of freshwater eels (*Anguilla* sp.) in Wolgan River and potentially mountain galaxias in Carne Creek. No threatened aquatic species are considered likely to occur within the Study Area.

The majority of Wolgan River and Carne Creek provide Type 1 – Highly Sensitive Key Fish Habitat (KFH) due to the presence of large rocks and wood debris. No instream aquatic plants have been identified at the sites visited on these watercourses. The section so these watercourses within the Study Area are general narrow (generally no more than 2 m wide, and often narrower) and shallow, with a silt, sand, gravel and pebble substratum with some bedrock in places. The inferred presence of natural barriers to movement of fish, and the presence of a weir structure on Wolgan River downstream of the Study Area and the confluence with Caren Creek, may limit the number of fish species and their abundance in sections in the Study Area. The third order and higher sections of tributaries, including those sections flowing through swamps, provide Type 2 – Moderately sensitive KFH. First and second order drainage lines are not KFH.

Sampling of stygofauna in groundwater bores within the Study Area and from other nearby mine areas indicate that stygofauna are present within shallow perched aquifers associated with swamps and in the underlying shallow regional groundwater aquifer both located above the proposed longwalls. They appear less likely to occur in deeper aquifers associated with the coal measures. Only one taxon was sampled from the shallow regional aquifer, though the assemblage present in the perched swamp aquifer appears more diverse and abundant.

Impact Assessment

Subsidence induced fracturing and flow diversions are unlikely to occur in the majority of the Wolgan River due to the set-back of the longwalls from this watercourse. It is possible that fracturing may occur in the section closest to the longwalls, however, if it did occur, fracturing would be minor and would not result in adverse impacts to surface flow. This second order section of the river in its headwaters consists of disconnected pool habitat and provides relatively limited aquatic habitat. No fracturing is expected to occur in Carne Creek due to its greater distance from the proposed longwalls. Mining induced groundwater depressurisation is predicted to result in between 2 % and 9 % reductions in surface flow in these watercourses, though the greatest magnitude reduction would be restricted to within the Study Area. Based on these predictions, reductions in the availability of aquatic habitat and associated impacts to aquatic biota (such as reduced population sizes) would be relatively minor and likely negligible outside of the Study Area.

Reductions in availability of aquatic habitat would be far more noticeable in the first, second, third and fourth order drainage lines located directly above the longwalls where fracturing and flow diversions are expected to occur. The aquatic habitat provided by first and second order drainage lines is limited, consisting largely of ephemeral habitat that would flow for short periods after rainfall and provide habitat for a limited number of aquatic biota. Aquatic habitat provided by the third and fourth order drainage lines that flow through the swamps directly above and adjacent to the longwalls is apparently perennial and more substantial (through still relatively limited, with general shallow and narrow channels). These watercourses are predicted also to experience fracturing and flow diversions, with associated loss of aquatic habitat and associated biota (aquatic macroinvertebrates, including freshwater crayfish). Based on the small size and ephemeral flow of these watercourse they are not expected to support significant population of fish, if any. An increased frequency of drying of largely ephemeral habitat in these watercourses is likely and this would result in relatively severe local impacts at the scale of individual watercourses. Some biota may be able to utilise unaffected habitat further downstream, though it is likely some would be lost. The length of watercourses that would experience such impacts is, however, a small proportion (no more than 5 %) of that present in the wider 600 km^2 catchment. In this context impacts to aquatic habitat and biota would be relatively minor.

Mining induced groundwater depressurisation would result in the reduction of groundwater levels of up to approximately 10 m in perched aquifers associated with swamps overlying the longwalls. This would reduce the availability of habitat for stygofauna here. Depending on the magnitude and extent of drawdown, and the ability of stygofauna to migrate with the receding water level and or to other aquifers, this could result in the loss of stygofauna assemblages from these perched swamp aquifers, representing relatively severe local impacts at the scale of individual swamps. The associated impact to more regional stygofauna biodiversity would depend on the degree of isolation of these affected swamps, and whether any unique taxa or stygofauna genetic diversity were associated with these swamps. The apparent connection of these swamp aquifers with underlying aquifers suggests that they would not necessarily be isolated from each other, and that they may not support stygofauna of particular conservation value. The relatively limited taxonomic knowledge of stygofauna hinders such assessment. Examination of the abundance of swamp habitat in the surrounding catchment does, however, suggest that at a regional scale impacts to stygofauna would be relatively minor. With the area of swamp habitat that would be affected by groundwater drawdown (56 ha) representing approximately 5 % of that mapped within the surrounding (1,000 km^2). The area of swamp habitat affected previously affected by longwall mining at Angus Place (0.9 ha) and Springvale (9.5 ha) should be noted. It is also unclear whether all swamps in these areas would support stygofauna or not.

Overall, impacts to watercourses and stygofauna associated with the Project, while relatively severe at the scale of individual watercourses and swamps, are relatively minor in the context of the wider catchment. None of the watercourses that would be affected directly appear to support threatened species or habitat of specific conservation value.

Recommendations

A recommended comprehensive monitoring plan to assess the potential impacts of mine subsidence on aquatic habitat and biota within watercourses of the Study Area should be implemented. 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.

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1 Introduction

1.1 Background

Angus Place Colliery is an existing underground coal mine producing high quality thermal coal for domestic markets, predominantly to the Mount Piper Power Station. It is located 15 kilometres to the northwest of the regional city of Lithgow and 120 kilometres west northwest of Sydney in New South Wales.

The mine's current State significant development consent (MP 06_0021) will expire in August 2024 and a new State Significant Development (SSD) consent is required to ensure Angus Place Colliery is operational beyond this date.

Centennial Angus Place Pty Limited (Centennial Angus Place), the operator of the Angus Place Colliery, previously prepared an Environmental Impact Statement (EIS) for the Angus Place Mine Extension Project (APMEP or the Project) in 2014 for proposed longwall mining on the eastern side of the Wolgan River and to the north of Springvale Colliery. Centennial Angus Place is now seeking approval to extract the proposed Longwalls 1001 to 1015 (LW1001 to LW1015) in the Lithgow Seam in an Amended Project Report for the APMEP.

Since the time of the original EIS submission, there have also been a number of changes made to the Extension Project and additional information has become available that require the EIS to be updated. Key changes to the Project design that will require incorporation into the amended report are:

> An updated mine plan with changes to the number of longwalls and their dimensions, increased production rate and an extension of the mine life to 2053;

> Revised subsidence predictions, mine inflows and groundwater impact assessments; and,

> Removal of the proposed discharges to watercourses. Rather, mine inflows would be transferred to the Springvale Water Treatment Project (SSD 7592) for treatment and use as cooling water at Mount Piper Power Station.

The proposed workings have been defined as the surface area that is likely to be affected by the extraction of the proposed LW1001 to LW1015 in the Lithgow Seam (MSEC 2019). The area includes the 26.5 degree angle of draw line from the extents of Longwalls 1001 to 1015 and the predicted 20 mm subsidence contour resulting from the extraction of the proposed longwalls.

Cardno (NSW/ACT) Pty Ltd (Cardno) was engaged by Centennial Angus Place to undertake the Aquatic Ecology and Stygofauna Assessment (AESA) for the APMEP. The previous AESA (Cardno 2014) was based on information compiled from biannual baseline aquatic ecology surveys of these watercourses undertaken by Marine Pollution Research Pty Ltd (MPR) from 2010 to 2012 (**Section 3.2.2**). The findings were reviewed and synthesised by Cardno (2014) to inform the assessment of impacts to aquatic ecology at that time. Findings from these and later studies undertaken by MPR and GHD have also been reviewed and incorporated into the current AESA.

1.2 Overview of Project and Aquatic Ecological Issues

The amended Project, in general, include all currently approved operations, facilities and infrastructure of the Angus Place Colliery. The amended Project would include the following additional components:

> Extend the life of the mine to 31 December 2053;

> Increase in Project Application Area from 10,460ha to 10,551ha;

> Increase in full time equivalent (FTE) personnel from 300 to 450;

> Increase the extraction up to 4.5 million tonnes per annum of run of mine (ROM) coal from the Lithgow Seam underlying the Project Application Area;

> Continued development of new roadways to enable access to the proposed 1000 panel longwall mining area;

> Extraction of existing approved longwall 910;

> Development and extraction of 15 longwalls (LW1001-1015) with void widths of 360m;

> Development of underground roadway connections between the Angus Place Colliery underground mine workings and the Springvale Mine underground mine workings;
> Transfer up to 4 Mtpa of run-of-mine (ROM) coal to the Angus Place pit top for processing and handling before being transported off site in accordance with the Western Coal Services Project development consent (SSD 5579)
> Transfer up to 4.5 Mtpa of ROM coal by underground conveyor to the Springvale Mine pit top via proposed new underground connection roadways for handling and processing in accordance with the Springvale Mine Extension Project development consent (SSD 5594);
> Enlargement of the ROM coal stockpile at the Angus Place Colliery pit top from 90,000 t to 110,000 t capacity
> Construction of the approved but not yet constructed 4.5 m shaft at the Angus Place Ventilation Facility (APC-VS2) on the Newnes Plateau.
> Installation and operation of the ventilation fan at the Angus Place Ventilation Facility (APC-VS2) on the Newnes Plateau.
> Construction and operation of one additional downcast shaft and mine services boreholes within the proposed Angus Place Ventilation Facility (APC-VS3) on the Newnes Plateau to support mining in the 1000 panel area;
> Construction and operation of additional dewatering facilities and associated infrastructure on the Newnes Plateau to support mining in the 1000 panel area to facilitate the transfer of mine water into the Springvale Delta Water Transfer Scheme (SDWTS);
> Transfer of mine inflows from the existing and proposed workings at Angus Place Colliery to the Springvale Water Treatment Project (SSD 7592) for treatment and beneficial reuse at the Mount Piper Power Station
> Operation of the Angus Place Colliery 930 Bore and 940 Bore and associated infrastructure for raw mine water transfer from the SDWTS to the underground mining area; and
> Connection to the Lithgow City Council main sewer line prior to the commencement of longwall extraction (subject to a separate development application through Lithgow City Council).

The Project Application Area (Project Area) (**Figure 1-1**) is traversed by the Wolgan River and Carne Creek, which form part of the Colo Rover Catchment within Hawkesbury-Nepean Catchment. The Study Area for the AESA is located within the Project Area (**Section 3.1**) The Angus Place Colliery (Angus Place) is located within the Lithgow Local Government Area (LGA) and is situated five kilometres north of the village of Lidsdale, eight kilometres northeast of the township of Wallerawang and 15 kilometres northwest of the City of Lithgow. The underground longwall mine is situated below a sandstone plateau of undulating bushland within the Newnes State Forest. The pit top, administration and surface water management infrastructure are located on the foot slopes of the Newnes Plateau. The Project Area is bordered by Gardens of Stone National Park to the north and north-east, Newnes State Forest and Birds Rock Flora Reserve to the east, the existing Angus Place Colliery longwalls (Longwalls 19 to 26), which were extracted to the west. Wolgan River is located west of the proposed longwalls, 180 m from LW1002, at its closest point. Carne Creek, a tributary of Wolgan River, is located 900 m southeast of LW1001, at its closest point to the proposed mining area. A number of unnamed watercourses are also located above the proposed longwalls.

The aquatic habitats and biota, including stygofauna, associated with these watercourses and swamps (swamps and associated biota are considered in the Terrestrial Ecology Assessment ERM 2019) could potentially be impacted by some of the following activities associated with the Project:

> Clearing of soils and vegetation and construction of dewatering boreholes, ventilation facility, site services and supporting surface infrastructure such as power lines, pipelines and sub-stations;
> Subsidence induced impacts to watercourses above and near to longwall extraction;
> Loss of groundwater and depressurisation of groundwater aquifers;
> Changes in the quality and quantity of surface water and ground water; and
> Rehabilitation works.

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

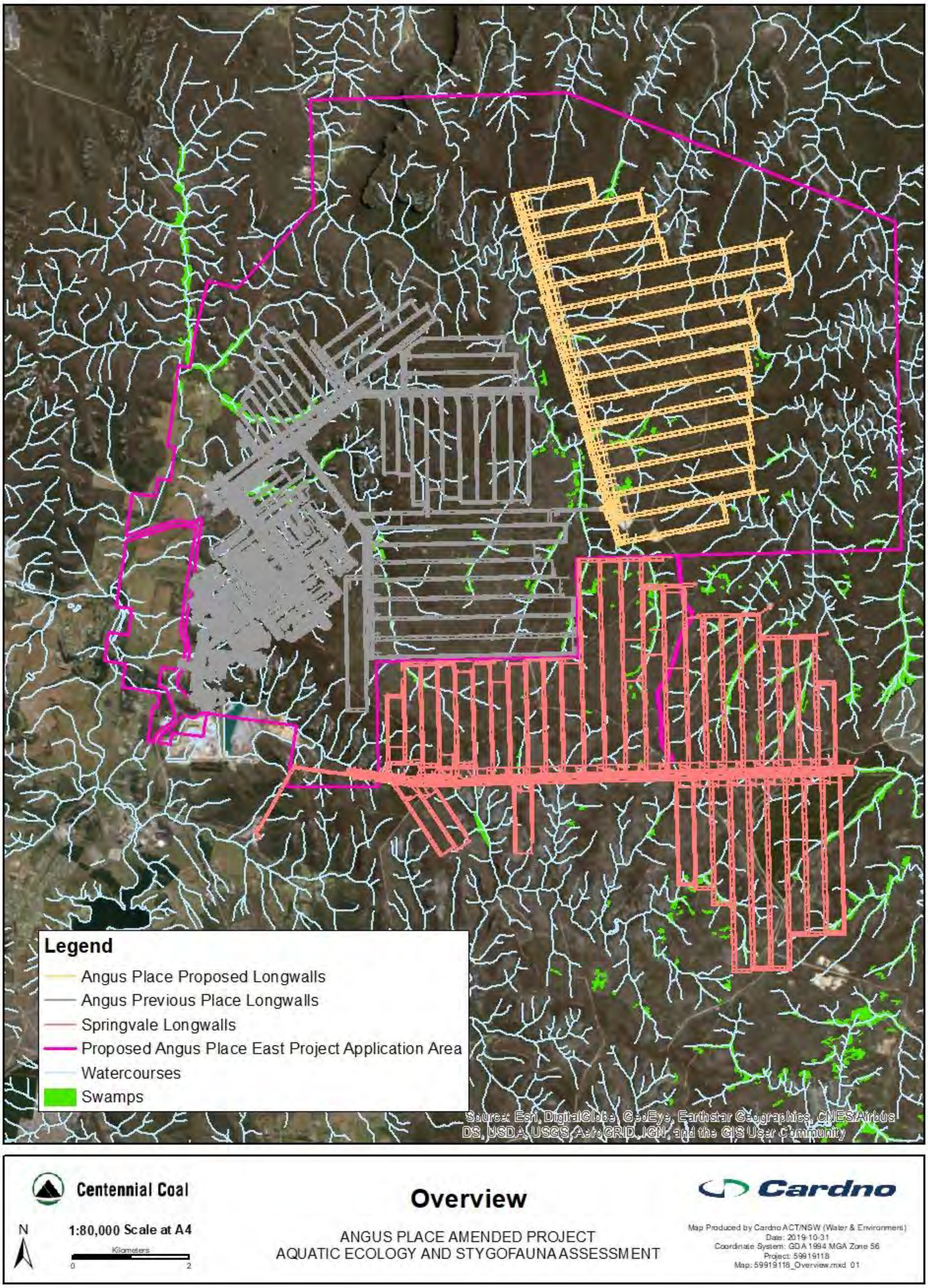


Figure 1-1 EIS Project Application Area and Amended Project Application Area

reduced groundwater levels, diversion of flows, reduction in pool water levels and loss of aquatic habitat. The extraction of coal from the longwalls is likely to result in vertical and horizontal movements of the rock and soil mass above the extracted coal seam, which in turn, may affect natural and man-made features on and below the land surface. In the case of surface watercourses, subsidence may result in fracturing of the stream bed and banks, movements of joint and bedding plates in the stream bed, uplift and buckling of strata in the stream bed. These physical impacts can cause diversions of surface and sub-surface flows, drainage of pools and increases in groundwater inflows. These changes, in turn, may result in loss of aquatic habitat, desiccation of fringing vegetation, reductions in longitudinal connectivity and deterioration of water quality. Ground movements can also lead to tilting of stream beds which can, in turn, lead to erosion of the stream bed and banks and increased instream sediment load, changes in flow rates and migration of stream channels. Subsidence may also allow the release of gas from sub-surface strata which could reduce water quality and in some cases lead to dieback of riparian vegetation. Longwall mining can also potentially result in increased levels of ponding in the locations where the mining-induced tilts considerably decrease the natural stream gradients. Longwall mining can potentially result in changes in stream alignment due to the mining-induced cross-bed tilts. Changes in stream alignment can potentially impact upon riparian vegetation, or result in increased scouring of the stream banks.

There is a potential for cumulative impacts to arise not only as a result of multiple types of disturbances associated with the Project and expansion of existing longwall blocks but also due to other activities (including mining) in the catchment. Angus Place is bordered by Baal Bone Colliery (Xstrata Coal Pty Ltd) to the north and Invincible Colliery (CET Resources Pty Ltd) (currently both under care and maintenance) to the northwest, Springvale Coal Pty Ltd to the south and Wolgan Valley and Newnes State Forest to the north and east, respectively. A number of measures could be used to avoid, manage or mitigate the impacts of mining and these other activities on aquatic ecosystems and stygofauna. If this cannot be done offsets will need to be considered. The subsidence impact assessment for watercourses undertaken by MSEC (2019) included the cumulative effects from the existing longwalls at Angus Place and Springvale Collieries (MSEC 2019).

1.3 Scope of Works

The work undertaken by Cardno includes the following:

- Review of Commonwealth and State legislative requirements, policies and guidelines, including those relevant to the effects of longwall mining on aquatic ecology and stygofauna;
- Review and synthesis of existing information on aquatic habitat, flora and fauna, including stygofauna, within, and adjacent to, the Project Area and broader catchments including existing information from previous surveys and surveys of stygofauna undertaken up to and including autumn 2019. Existing information includes previous investigations for Angus Place Colliery, online literature searches and other available records of aquatic flora and fauna;
- Autumn 2019 field surveys on aquatic habitat, flora and fauna in watercourses that may be affected by the Project to update existing information. This was undertaken at existing and new monitoring sites in and around the Study Area (**Section 3.1**);
- A table clearly identifying where in the AESA each DGR and other agency requirements, 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.

The scope of works for the AESA was determined by the requirements of NSW Department of Planning, Industry and Environment (DPIE), NSW Office of Water (NOW) and NSW Office of Environment and Heritage (now NSW Environment, Energy and Science) provided for the EIS in 2012. The specific issues identified by the government agencies and the sections in the report where these are addressed are summarised in **Table 1-1** to **Table 1-3.**

Table 1-1 2012 Director General's Requirements pertinent to the Aquatic Ecology and Stygofauna Assessment

Assessment Requirements	Relevant Section of the Report
Description of the existing environment, using sufficient baseline data.	3
Assessment of the potential impacts of all stages of the development, including any cumulative impacts.	4
Assessment of impacts on riparian, ecological, geo-morphological and hydrological values of watercourses, including GDEs and environmental flows.	3*
Detailed assessment of potential impacts of the development on aquatic threatened species or populations and their habitats, endangered ecological communities and GDEs	3
Description of measures that would be implemented to avoid, minimise and, if necessary, offset the potential impacts of the development.	5
Measures that would be taken to avoid, reduce or mitigate impacts on biodiversity, particularly that associated with Temperate Highland Peat Swamps;	5*
Offset strategy to ensure that the development maintains or improves aquatic biodiversity values of the region in the medium to long term.	5.4*

Table 1-2 NSW Office of Environment and Heritage's (OEH)[1] requirements pertinent to the Aquatic Ecology and Stygofauna Assessment

Assessment Requirements	Relevant Sections of the Report
Identification and assessment of Matters of National Environmental Significance	2.4
Identification of national and state-listed threatened species that could potentially occur on the site and their conservation status	3.8
Description of survey methodology	3.2.2
Likely impacts on biodiversity, native vegetation and habitat	4
Impact of changes to groundwater levels	4.2*
Likely impacts on threatened biodiversity	4.2.1.2
Measures to avoid, mitigate and manage impacts	5

Table 1-3 NSW Office of Water's (NOW) requirements pertinent to the Aquatic Ecology and Stygofauna Assessment

Assessment Requirements	Relevant Section of the Report
Identification of potential groundwater-dependent ecosystems (GDEs)	3.7*
Baseline monitoring of all groundwater and surface water dependent ecosystems within and adjacent to mining operation	3.7*
Assessment of GDEs for condition and water quality and quantity requirements for aquatic ecosystems (macroinvertebrate, macrophytes, stygofauna)	4
Assessments of impacts on groundwater and surface water dependent ecosystems within and adjacent to mining operation	4.2.2
Mitigation measures to address impacts on groundwater and surface water dependent ecosystems during and after mining operations	5
Monitoring to enable comparison with ongoing monitoring	5.2

[1] OEH is now NSW Biodiversity Conservation Division (BCD)

*Aquatic ecology and stygofauna only assessed in the AESA

2 Legislative Context

2.1 NSW 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, Industry and Environment (DPIE). Development that is SSD (this Project) is identified in the State and Regional Development SEPP; this includes coal mining (**Section 2.5.1**). Part 4 of the EP&A Act sets out the approvals process for SSD projects are assessed under Part 4, Division 4.7 of the EP&A Act, and require development consent from the Independent Planning Commission or the Minister for Planning (or delegate) before they may proceed.

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 4.41 (previous 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 *Biodiversity Conservation Act, 2016* [BC Act]) or the *Fisheries Management Act 1994* (FM Act), known as the Assessment of Significance, and previously the seven-part test (under the former *Threatened Species Conservation Act 1995*) and the eight-part test.

2.2 Fisheries Management Act 1994

The *Fisheries Management Act 1994* (FM Act) contains provisions for the conservation of fish stocks, key fish habitat (KFH), biodiversity, threatened species, populations and ecological communities. It regulates the conservation of fish, vegetation and some aquatic macroinvertebrates and the development and sharing of the fishery resources of NSW 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 for Agriculture and Western New South Wales. 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. KFH is defined in sections 3.2.1 and 3.2.2 of the *Policy and Guidelines for Fish Conservation and Management* (DPI (Fisheries), 2013) (**Section 2.5.2**). 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 or not the channel has been physically modified;
- Intermittently flowing rivers and creeks that retain water in a series of disconnected pools after flow ceases including those where the flow is modified by upstream dam(s), up to the top of the natural bank regardless of whether or not the channel has been physically modified; and
- Any waterbody if it is known to support or could be confidently expected (based on predictive modelling) to support threatened species, populations or communities listed under the FM Act.

2.3 Biodiversity Conservation Act 2016

The *Biodiversity Conservation Act 2016* (BC Act) contains provisions for the conservation of some aquatic species and communities except for those listed under the FM Act (i.e. fish, crayfish and all other aquatic animals, but not freshwater vegetation).

2.4 Commonwealth Legislation

The *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) protects nationally and internationally important flora, fauna, ecological communities and heritage places, which are defined in the EPBC Act as Matters of National Environmental Significance (MNES). Under the EPBC Act, an action will require approval from the Minister for the Environment and Energy if the action has, will have, or is likely to have, a significant impact on MNES. *Significant Impact Guidelines 1.1 – Matters of National Environmental Significance* (DoE, 2013) have been developed to assist proponents in deciding if a Referral to the Australian Department of Environment and Energy (DEE) would be required. 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.

A search of the Commonwealth's protected matters search tool (PMST) was used to generate a list of MNES or other matters protected by the EPBC Act. A search of the PMST was used to generate a list of MNES or other matters protected by the EPBC Act likely to occur within the Project Area (**Appendix A**). The search area was conservatively set as a rectangle encompassing Project Area. The results of the search as they relate to aquatic ecology are summarised in **Table 2-1**.

Table 2-1 MNES under the EPBC Act

MNES	Matter Relevant to Aquatic Ecology in the Study Area
Commonwealth listed threatened species	One threatened fish species or species habitat are known to occur within the Study Area: ▪ Macquarie perch (*Macquaria australasica*) listed as endangered; and One threatened fish species or species habitat likely to occur within the Study Area: ▪ Australian grayling (*Prototroctes maraena*) listed as vulnerable.

2.5 Policies and Guidelines

2.5.1 State Environmental Planning Policy (State and Regional Development SEPP) 2011

Under the EP&A Act, projects can be classified as SSD if they are important to the State for economic, environmental or social reasons. The Government has identified certain types of development that are SSD, for example, mining and extraction operations. Schedule 1 (5)1(a) of the State and Regional Development SEPP lists coal mining as SSD. In the event of an inconsistency between this SEPP and another environmental planning instrument, whether made before or after the commencement of this Policy, this Policy prevails to the extent of the inconsistency.

2.5.2 Policy and Guidelines for Fish Habitat Conservation and Management

The NSW DPI Policy and Guidelines for Fish Habitat Conservation and Management (Update 2013) (DPI (Fisheries), 2013a) are applicable to all planning and development proposals and various activities that affect freshwater ecosystems. The aims of the updated policy and guidelines are to maintain and enhance fish habitat for the benefit of native fish species, including threatened species in 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, and for determining their value in the event offsetting is required;

> An outline of the legislative requirements relevant to planning and development which may affect fisheries or aquatic habitats in NSW (SSD policy over-rides many of these, see **Sections 2.1** and **2.5.1**);

> 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.

One of the objectives of the FM Act is to conserve KFH.

NSW DPI focuses the application of the FM Act and FM Regulations and the policies and guidelines on KFH. 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. Categorisation and classification of KFH is achieved by determining fish habitat sensitivity (Type) and functionality (Class). The term 'sensitivity' refers to the importance of the habitat to the survival of fish and its ability to withstand disturbance while 'functionality' refers to the ability to provide habitat that is suitable for fish.

Fish habitat 'Type' is used within the policy and guideline to differentiate between permissible and prohibited activities or developments and for determining value in the event offsetting is required. Waterway 'Class' is used to assess the impacts of certain activities on fish habitats in conjunction with 'Type'. The waterway 'Class' can also be used to make management recommendations to minimise impacts on different fish habitats (e.g. waterway crossings). Sensitivity 'Types' and waterway 'Class' classifications are provided in **Section 2.5.4** and have been used to classify waterways in the Study Area.

2.5.3 Why Do Fish Need to Cross the Road? Fish Passage Requirements for Waterway Crossings

NSW DPI (Fisheries) *Why do Fish Need to Cross the Road? Fish Passage Requirements for Waterway Crossings* (Fairfull and Witheridge, 2003) provides practical guidelines for the planning, design, construction and maintenance of waterway crossings aimed at minimising impacts on fish passage and aquatic ecology in general. It should be used in conjunction with the *Policy and Guidelines for Fish Conservation and Management* (DPI (Fisheries), 2013a) by outlining potential impacts of instream structures and design specifications/recommendations for crossings to avoid erecting barriers to fish passage.

2.5.4 Key Fish Habitat

The classification of key fish habitat (KFH) type in the Study Area was determined using the criteria in NSW DPI (2013) for freshwater habitat (refer **Table 2-2**). The waterway Class was determined using the criteria in **0**.

Table 2-2 Classification of KFH according to sensitivity (NSW DPI (Fisheries) 2013a)

Classification	Habitat Type
Type 1 – highly sensitive KFH	▪ Freshwater habitats that contain in-stream gravel beds, rocks greater than 500 millimetres in two dimensions, snags greater than 300 millimetres in diameter or three metres in length, or native aquatic plants; ▪ Any known or expected protected or threatened species habitat or area of declared 'critical habitat' under the FM Act; and ▪ Mound springs.
Type 2 – Moderately sensitive KFH	▪ Freshwater habitats and brackish wetlands, lakes and lagoons other than those defined in Type 1; and ▪ Weir pools and dams up to full supply level where the weir or dam is across a natural waterway.
Type 3 – Minimally sensitive KFH	▪ Freshwater habitats not included in Types 1 or 2; and ▪ Ephemeral aquatic habitat not supporting native aquatic or wetland vegetation.
Not considered KFH	▪ First and second order gaining streams (based on the Strahler method of stream ordering); ▪ Farm dams on first and second order streams or unmapped gullies; ▪ Agricultural and urban drain; ▪ Urban or other artificial ponds (e.g. evaporation basins, aquaculture ponds; and ▪ Sections of stream that have been concrete-lined or piped (not including a waterway crossing)

Table 2-3 Classification of waterways for fish passage criteria. Adapted from Tables 2 and 3 NSW DPI (Fisheries) (2013a)

Classification	Characteristics of waterway type	Minimum recommended crossing type	Additional design information
Class 1 – Major fish habitat	Marine or estuarine waterway or permanently flowing or flooded freshwater waterway (e.g. river or major creek), habitat of a threatened or protected fish species or 'critical habitat'.	Bridge, arch structure or tunnel.	Bridges are preferred to arch structures.
Class 2 – Moderate fish habitat	Non-permanently flowing (intermittent) stream, creek or waterway (generally named) with clearly defined bed and banks with semi-permanent to permanent waters in pools or in connected wetland areas. Freshwater aquatic vegetation is present. Type 1 and 2 habitats present.	Bridge, arch structure, culvert(1) or ford.	Bridges are preferred to arch structures, box culverts and fords (in that order).
Class 3 – Minimal fish habitat	Named or unnamed waterway with intermittent flow and sporadic refuge, breeding or feeding areas for aquatic fauna (e.g. fish, yabbies). Semi-permanent pools form within the waterway or adjacent wetlands after a rain event. Otherwise, any minor waterway that interconnects with wetlands or other Class 1 - three fish habitats.	Culvert(2) or ford.	Box culverts are preferred to fords and pipe culverts (in that order).
Class 4 – Unlikely fish habitat	Waterway (generally unnamed) with intermittent flow following rain events only, little or no defined channel, little or no flow or free standing water or pools post rain events (e.g. dry gullies or shallow floodplain depressions with no aquatic flora present).	Culvert(3), causeway or ford.	Culverts and fords are preferred to causeways (in that order).

(1) High priority given to the 'High Flow Design' procedures presented for the design of these culverts—refer to the "Design Considerations" section of NSW DPI (2003). (2) Minimum culvert design using the 'Low Flow Design' procedures; however, 'High Flow Design' and 'Medium Flow Design' should be given priority where affordable — refer to the "Design Considerations" section of NSW DPI (2003). (3) Fish friendly waterway crossing designs possibly unwarranted. Fish passage requirements should be confirmed with NSW DPI.

2.6 Key Threatening Processes

A key threatening process (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 former Department of Environment and Conservation (now BCD) 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.

The KTPs: *Installation and operation of instream structures and other mechanisms that alter natural flow regimes of rivers and streams* (FM Act) and *alteration to the natural flow regimes of rivers and streams and their floodplains and wetlands* (BC Act) are also applicable to the project. Although the installation of instream structures is not proposed, subsidence induced fracturing resulting in flow diversions in watercourses has potential to alter the flow regime in the watercourses affected directly and downstream.

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

2.7 Wild Rivers

Wild Rivers are rivers that are in near-pristine condition in terms of animal and plant life and water flow, and are free of the unnatural rates of siltation or bank erosion that affect many of Australia's waterways. In NSW, Wild Rivers may be declared within national parks and other reserves that are protected under the NSW *National Parks and Wildlife Act* (*NP&W) 1974*. The declaration of 'wild rivers' ensures that their high conservation values are maintained and that Aboriginal objects and places associated with them are identified, conserved and protected. The Colo River and its four sub-catchments (Wolgan, Capertee, Colo, Wolgan and Wollemi) is one of the river systems declared a Wild River in 2008 (DECCW 2008). The Colo Wild River Assessment, however, recommended that only the section of the Wolgan River to its intersection with (and including) Rocky Creek and their tributaries be declared a Wild River. This section of the river is downstream of the Project Area.

2.8 Critical Habitat

The Study Area does not contain any critical habitats listed under the FM Act or EPBC Act, or similar Areas of Outstanding Biodiversity Value listed under the BC Act.

3 Existing Environment

3.1 Study Area

The Study Area for the AESA is the area within 600 m of the proposed longwalls (**Figure 3-1**). This distance is based on the recommendations from the Southern Coalfield Inquiry (DPIE 2008) for the risk management zones. The 600 m boundary provides a conservative measure of the extent of these potential mining impacts. The furthest observed fracture outside of longwall mining in the NSW coalfields is 415 m (MSEC 2019). Comparative information was also obtained from the wider area, when relevant (e.g. stygofauna data from within this area and from other nearby mines has been reviewed).

In this section, information is presented on the physical setting and aquatic ecology of the two primary watercourses, Wolgan River, Carne Creek that could potentially be impacted by the APMEP. The upper reaches of the Wolgan River and the headwaters of Carne Creek, situated to the west and east of the proposed workings respectively, have been included in the Study Area. Wolgan River and Carne Creek have previously experienced subsidence related impacts due to previously extracted longwalls at Angus Place and Springvale mines (MSEC 2019).

The sections of Kangaroo Creek and Coxs River situated in the western part of the Project Application Area have been excluded in the assessment because there would be no impacts due to mine subsidence in these watercourses. There would also be no discharges of water to these watercourses.

3.2 Information Sources

3.2.1 Publically Available Databases

The following key sources of information and publically available databases were searched for records of listed threatened aquatic species, populations and communities within the Study Area:

> Department of the Environment and Energy (DoEE) (formerly DoE) Protected Matters Search Tool (PMST): http://www.environment.gov.au/epbc/protected-matters-search-tool;

> NSW DPI Listed threatened species, populations and ecological communities website: https://www.dpi.nsw.gov.au/fishing/threatened-species/what-current;

> NSW DPI Fish communities and threatened species distribution of NSW (DPI 2016). It is noted that the presence of suitable habitat in DPI (2016) is based on landscape and flow parameters and does not consider impacts such as but not limited to fish passage, thermal pollution and the presence of pest fish species etc.;

> Atlas of Living Australia (ALA): http://www.ala.org.au/;

A search of the Bureau of Meteorology Groundwater Dependent Ecosystems Atlas (http://www.bom.gov.au/water/groundwater/gde/map.shtml) was undertaken by Jacobs (2019a). The Wolgan River (Western Branch) is identified as a potential aquatic GDE. The river is mapped as low to moderate potential as a GDE on the Newnes Plateau, and moderate to high potential in the Wolgan Valley.

Sensitive ecological sites (e.g. conservation areas, wetlands and other reserves) and areas protected by State and local environmental planning instruments (EPIs) due to their ecological significance were also identified using:

> NSW DPI Critical habitat register: http://www.dpi.nsw.gov.au/fisheries/species-protection/conservation/what/register;

> NSW DPI KFH maps: http://www.dpi.nsw.gov.au/fishing/habitat/publications/pubs/key-fish-habitat-maps; and

> NSW National Parks and Wildlife Service: http://www.nationalparks.nsw.gov.au/visit-a-park.

3.2.2 Project Studies

3.2.2.1 Watercourses

The review of information on the aquatic ecology of the watercourses within and adjacent to the Study Area was based primarily on a compilation of findings from a series of reports on the outcomes of the aquatic ecology monitoring program undertaken by MPR in autumn and spring of 2010 (MPR 2010 and 2011a),

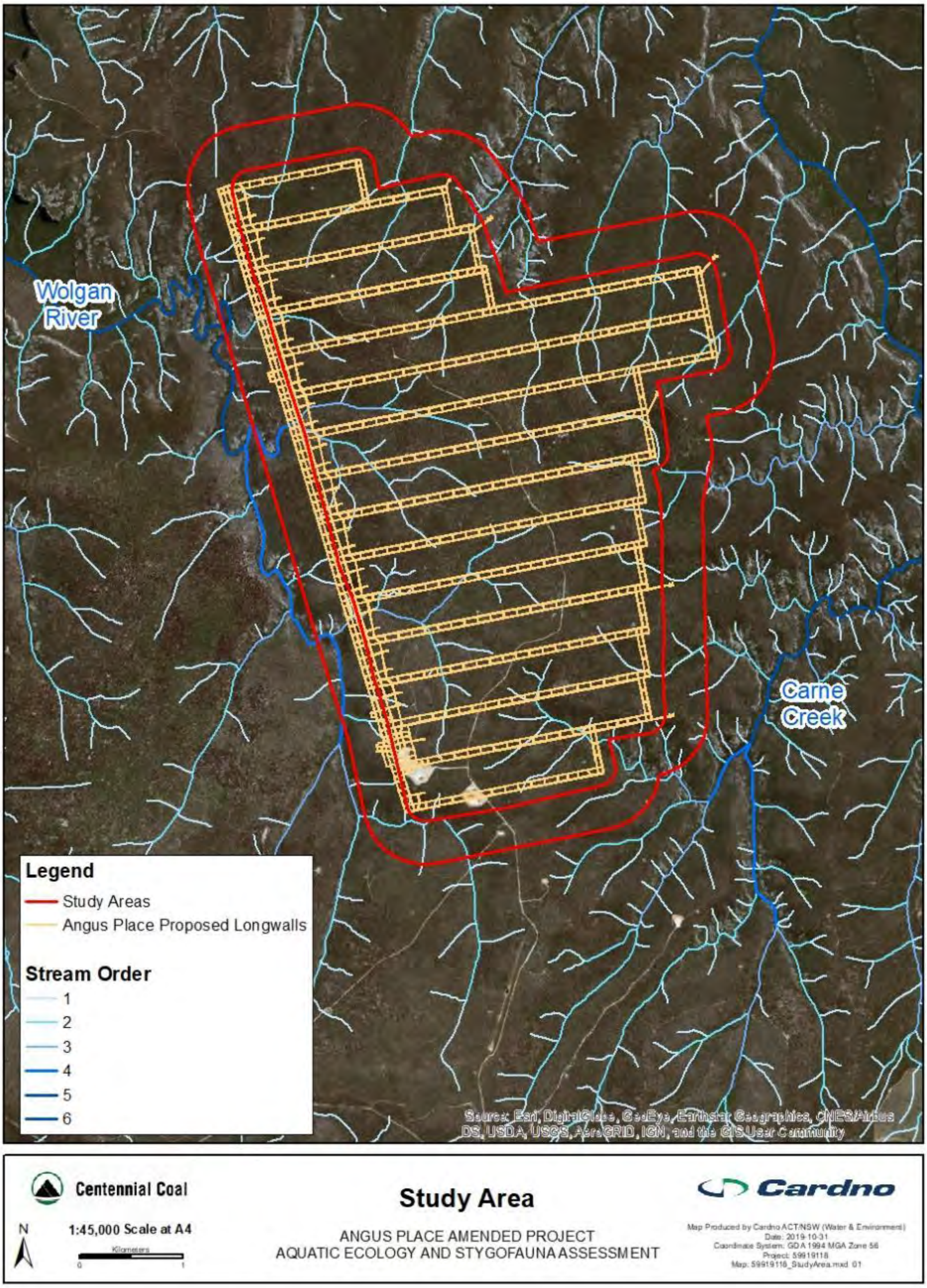


Figure 3-1 Aquatic Ecology Study Area (the outer 600 m Buffer from the Proposed Longwalls) overlaid with Watercourses and their Stream Order. The inner buffer is the MSEC 2019 Study Area based on the 26.5° angle of draw.

2011 (MPR 2011b, 2012a) 2012 (MPR 2012b, 2013a), 2013 (MPR 2013b, 2014a), 2014 (MPR 2014b, 2015a), spring of 2015 (MPR 2016a) and autumn and spring of 2016 (MPR 2016b, c). Centennial Angus Place currently undertake aquatic ecology monitoring for Centennial Coal's western operations.

The sites visited for the Angus Place amended project report were the existing WRup, WRmd and WRdn on the Wolgan River, CCXdn on Carne Creek, TGS in Twin Gully Swamp (a shrub swamp), TRIS in Tri-Star Swamp (a shrub swamp) and BRS in Bird Rock Swamp (a hanging swamp), though every site was not surveyed on each occasion (**Table 3-1**). These sites and an additional new site (TGSup) further upstream in Twin Gull Swamp and (TRISup) in Tri-Star Swamp were visited by Cardno in autumn 2019 as part of the current study. The location of these sites is shown in **Table 3-1** and **Figure 3-2** and their coordinates provided in **Appendix B**. The new sites TGSup and TRISup are located above the proposed longwalls and will experience subsidence impacts. It is noted that while sites TGS, TGSup, TRIS, TRISup and BRS are located in swamps, aquatic ecology surveys were undertaken within flowing water in channels within each.

The monitoring methodology used was:

> Assessment of the condition of the aquatic habitat using a version of the Riparian, Channel and Environmental Inventory (RCE) modified for Australian conditions by Chessman et al. (1997).

> Measurement of temperature, electrical conductivity (EC), salinity, pH, dissolved oxygen (DO) and turbidity just below the surface of the water column and at depth where sufficient water was available;

> Identification of aquatic macrophytes;

> Sampling, sorting and identification of aquatic macroinvertebrates associated with pool edge habitat in accordance with the Australian Rivers Assessment System (AUSRIVAS) protocols (Turak *et al*. 2004);

> Derivation of biotic indices (number of taxa, SIGNAL2 Score and OE50 Taxa Scores and AUSRIVAS Band Scores (some surveys only)) from AUSRIVAS macroinvertebrate data. Principal Coordinates Analysis (PCO) was undertaken for assemblage data collected using AUSRIVAS and artificial macroinvertebrate collectors (see below);

> Sampling of fish using a combination of bait trapping, dip netting and visual observation. Backpack electrofishing was also undertaken by Cardno at WRup and WRdn in autumn 2019.

In addition, in autumn 2019 aquatic macroinvertebrates were sampled at a selection of these sites (WRmd, WRup CCXdn) and at a further site on the Wolgan River downstream of the Study Area and just upstream of the Old Coach Road Crossing (WRocr) using quantitative macroinvertebrate collectors. This was undertaken to provide further data on the macroinvertebrates present in these watercourses, differences between the sites sampled and to trial this method as a tool for ongoing monitoring prior to, during and following mining.

Further detail of the field, laboratory and statistical methods is provided in **Appendix C**.

Table 3-1 Aquatic ecology surveys at each site for the Angus Place Extension Project sampled by MPR (2010 to 2016) and Cardno (2019).

Site	Location	Aut 2010	Spr 2010	Aut 2011	Spr 2011	Aut 2012	Spr 2012	Aut 2013	Spr 2013	Aut 2014	Spr 2014	Spr 2015	Aut 2016	Spr 2016	Aut 2019
WRup	Wolgan River	X	X	X	X	X	X	X	X						X
WRmd	Wolgan River		X	X	X	X	X	X	X	X	X	X	X	X	X
WRdn	Wolgan River	X	X	X	X	X	X	X	X						X
TRIS	Twin Gully		X	X	X	X	X	X	X	X	X	X	X	X	X
TRISup	Twin Gully														X
TGS	Tri-Star Swamp		X	X	X	X	X	X	X	X	X	X	X	X	X
TGSup	Tri-Star Swamp														X
CCXdn	Carne Creek					X	X								X
BRS	Bird Rock Swamp		X	X	X	X	X	X	X	X	X	X	X	X	X

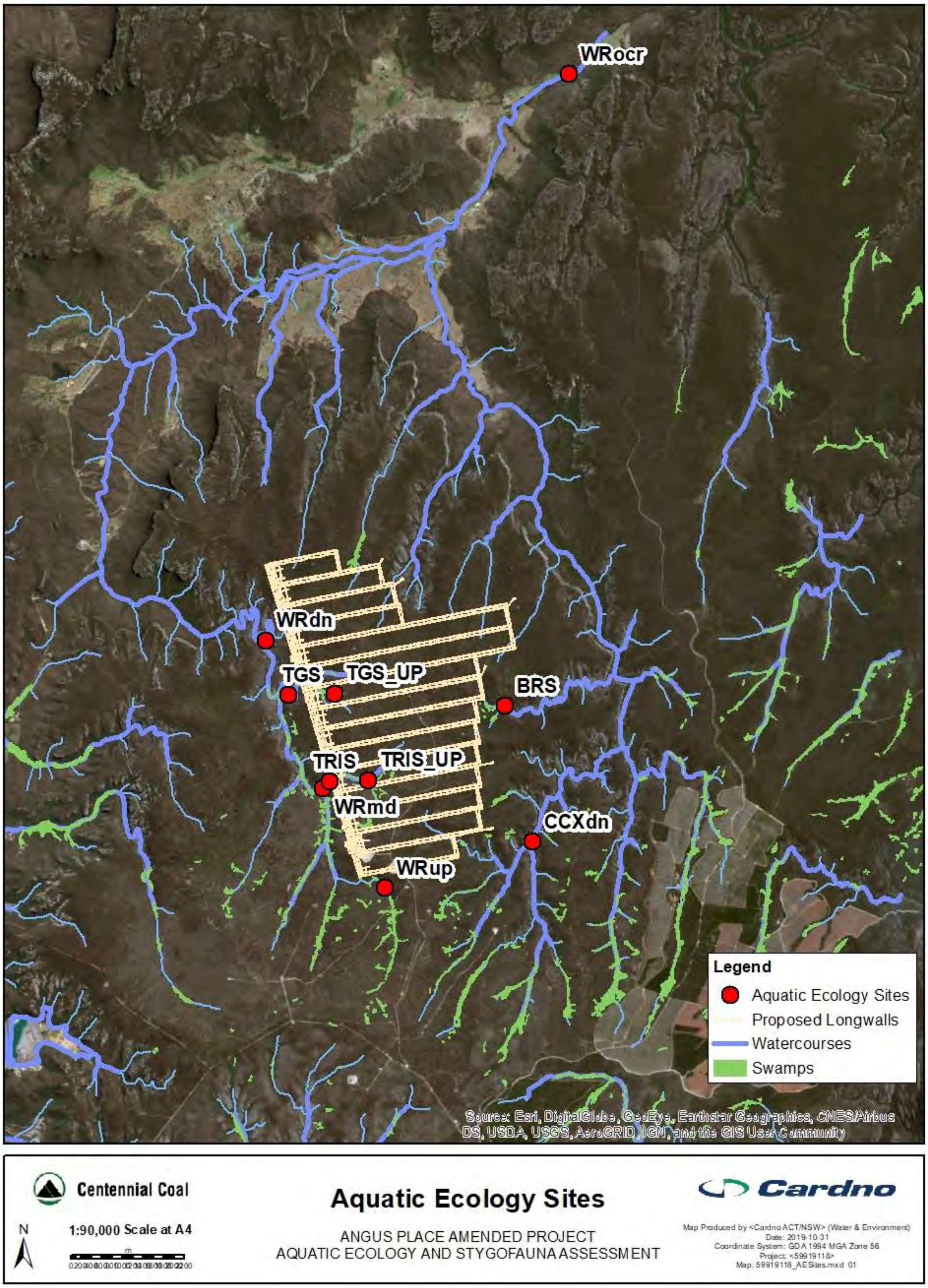


Figure 3-2 Location of the aquatic ecology survey sites in relation to the proposed Angus Place Extension Longwalls

3.2.2.2 Stygofauna

Table 3-2 identifies the groundwater bores that have been sampled for stygofauna within the Angus Place Application Area (**Figure 3-3**) and at other nearby mines operated by Centennial (**Figure 3-4**). A total of eight survey events have been undertaken across the five mine areas, with five surveys undertaken at Angus Place.

Table 3-2 Groundwater bores sampled for stygofauna in vicinity of Angus Place (Angus) and other nearby mines operated by Centennial. Datum: GDA 94 Zone 56.

Mine	Borehole	Easting	Northing	Month and Year of Survey Event. May 2012 surveyed by MPR, all other times GHD							
				May2012	Mar16	Dec2016	Feb2017	Aug2018	Nov2018	Mar2019	Jul2019
Angus	AP10PR	237247	6306777	X							
Angus	AP10PRB	237247	6306777				X	X		X	X
Angus	AP1105SP	238870	6305665				X	X		X	X
Angus	AP4PR	238870	6305665	X							
Angus	AP4PRB	237159	6308661								X
Angus	AP5PR	236526	6308525	X			X	X		X	X
Angus	AP9PR	237731	6306580	X							X
Angus	KV_MB2D	229718	6301382				X	X		X	X
Angus	TG1	236438	6308766	X							X
Angus	TS01	237552	6307291	X							
Angus	TS02	237440	6306776	X							
Angus	TS03	236897	6307159	X			X	X		X	X
Angus	XS01	237106	6311453								X
Airly	AM2B-1	220476	6332884		X	X	X	X			
Airly	ARP05	224069	6333272					X			
Airly	ARP09	225330	6332729			X					
Airly	ARP11	224173	6333525					X	X	X	
Airly	ARP13SP	225745	6333322						X	X	
Airly	ARP14	229222	6335367					X	X	X	
Airly	ARP15SP	225737	6333316					X	X	X	
Clarence	CLRP04	243213	6293120					X		X	X
Neubeck	NB4R	225985	6305826				X	X		X	X
Neubeck	NEU01	225398	6305912				X	X			
Neubeck	NEU03	225374	6305785							X	X
Springvale	CC1	241180	6302692				X	X			
Springvale	MS1	238865	6299166				X	X		X	X
Springvale	RSS	238074	6303497				X	X			
Springvale	SPR1104SP	239747	6303192				X				
Springvale	SPR1106SP	239978	6304222							X	X
Springvale	SPR1107SP	239750	6302337					X			
Springvale	SPR1211SP	240239	6298918				X	X		X	X
Springvale	SPR1401SP	238463	6303551							X	X
Springvale	SPR1601	239809	6303780							X	X
Springvale	SPR1605	241968	6301249								X
Springvale	SPR1801	240255	6298106							X	X
Springvale	SPR1802	240948	6300600							X	X
Springvale	SPR1803	240556	6302606							X	X

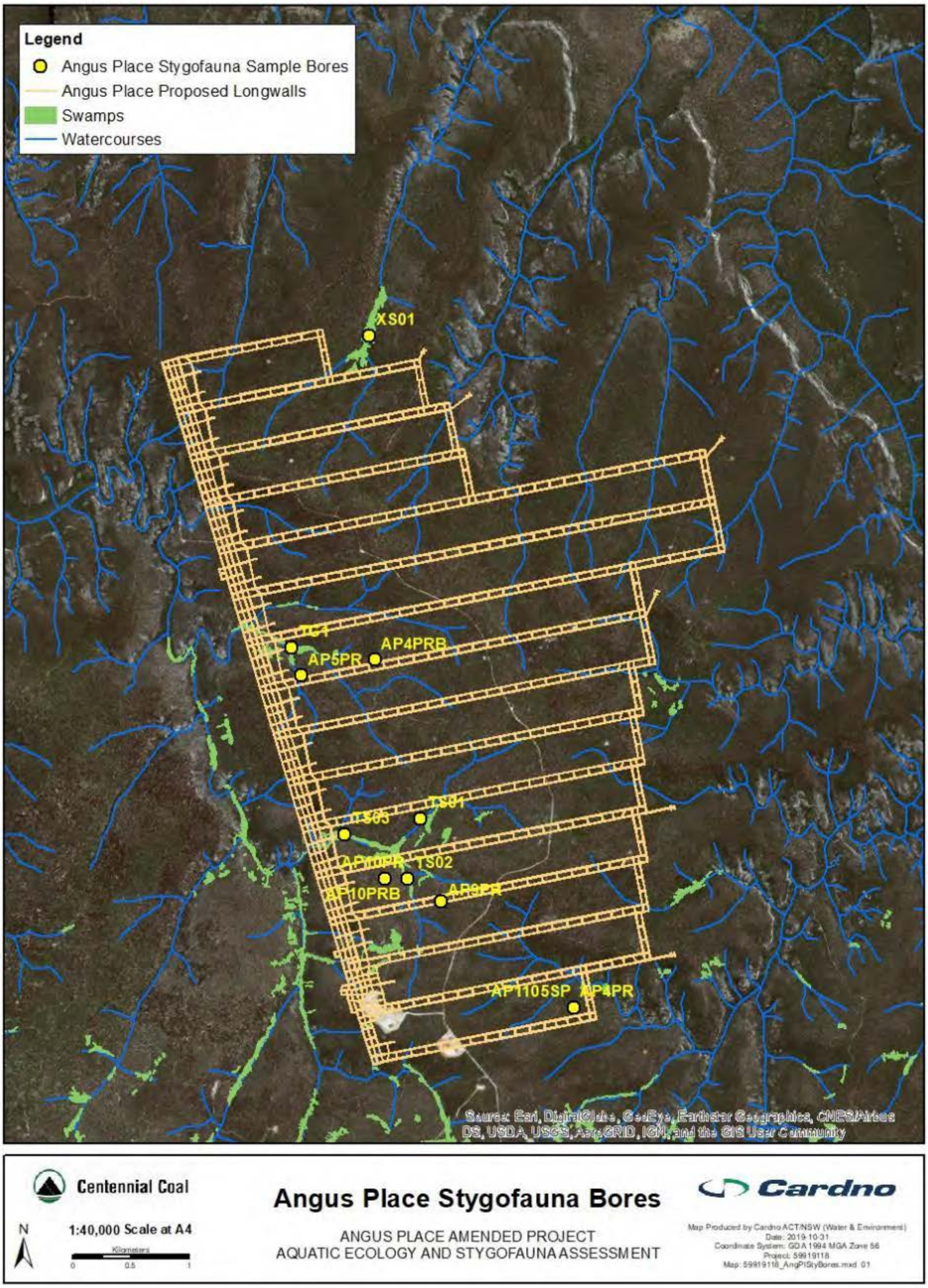


Figure 3-3 Groundwater bores sampled for stygofauna within the Angus Place Application Area

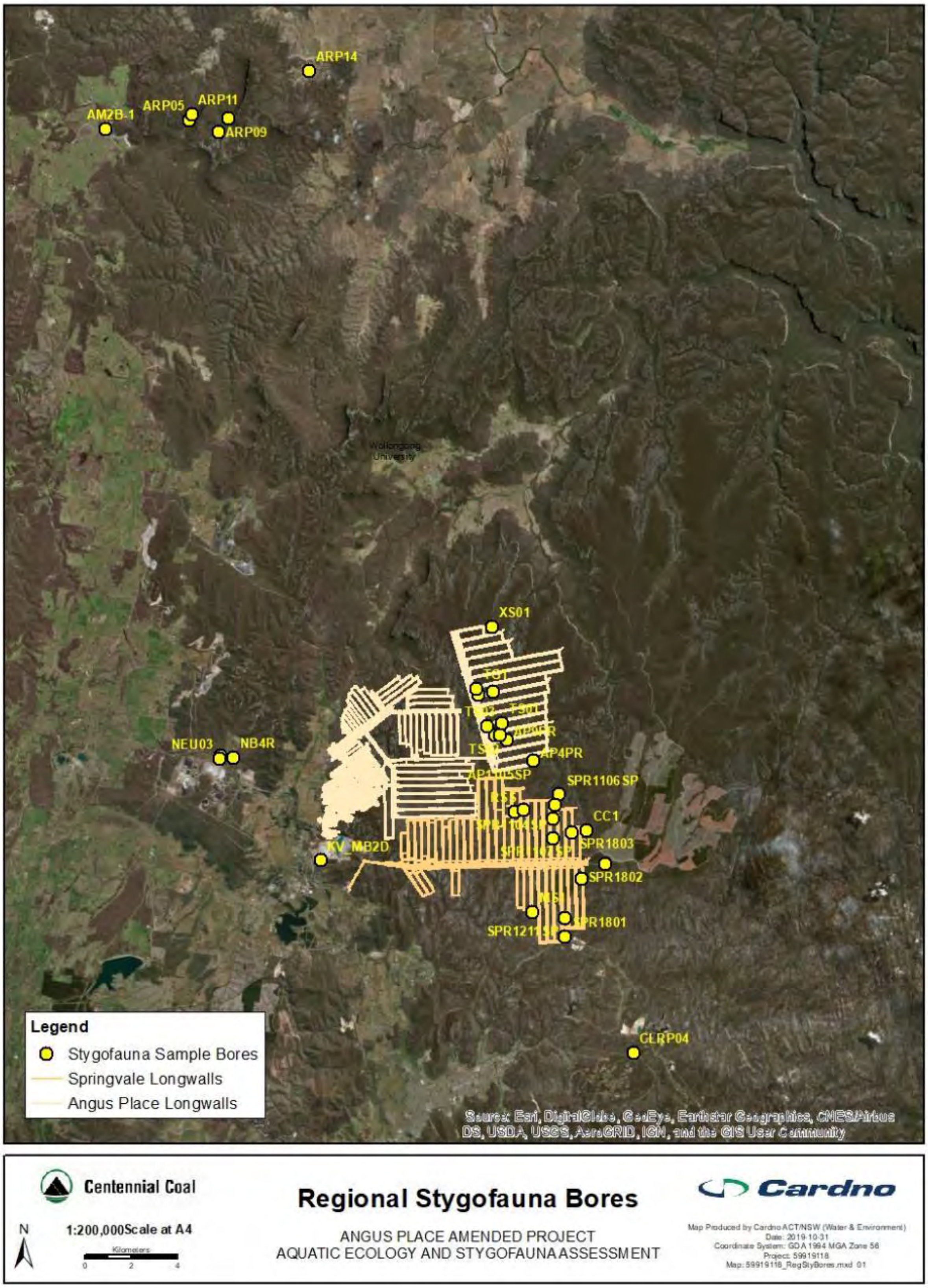


Figure 3-4 Groundwater bores sampled for stygofauna at Angus Place and at other mines (Airly, Clarence, Neubeck and Springvale mines) operated by Centennial.

The initial pilot survey undertaken by MPR in May 2012 sampled eight boreholes targeting the shallow groundwater below individual swamps and a near-surface unconfined aquifer in the Banks Wall Sandstone below the Project Application Area. A selection of these and other groundwater bores at Angus Place and at other mines owned by Centennial in the regional area from 2016 to 2019 were sampled by GHD as part of the regional Stygofauna Monitoring and Assessment Plan (SMAP) (Centennial Coal 2018). The SMAP was developed in order to monitor and assess existing communities of stygofauna across a number of Centennial sites located within the Western Coalfield, to meet Condition 17 under Schedule 3 of Springvale Mine's consent SSD 5594.

MPR (2012c) collected between 7 and 16 bailers from the bores, resulting in between 2 and 15.5 litres of water). During 2016 to 2019 generally 6, though on occasion 4 to 5 bailer samples were sampled from each bore. It is important to note that the invertebrates were identified to coarse taxonomic levels varying from family (e.g. Melitidae) to class (e.g. Ostracoda) and that some may have been borehole-colonisers rather than groundwater inhabitants (likely stygofauna) while others may have been terrestrial, surface water or surface saturated soil fauna. Only taxa known or likely to be an inhabitant of groundwater (phreatobites) have been reported here. For brevity, taxa identified as soil dwelling (edaphobites) by GHD have not been reported here.

Groundwater quality was measured before samples of stygofauna were collected from the swamp boreholes. The measurements were made on samples collected from just below the water surface. The underlying assumption underpinning such studies is that the taxa found in bore sampling were representative of those in the surrounding aquifer.

Three of the swamp boreholes (TG1 on Twin Gully Swamp, TS02 and TS03 on Tristar Swamp) are located in permanently waterlogged sections of the swamps, with the standpipes at Sites TG1 and TS02 being upstream relative to the main swamp inflows and that at TS03 being downstream (RPS 2013). TS01 is located upstream of the main inflows in a section of the Tri Star Swamp which is periodically waterlogged.

The pilot survey suffered from some methodological limitations. MPR (2012c) indicated the results may have been compromised by the monthly purging of the boreholes that occurred prior to the monitoring of groundwater quality. Stygofauna samples should be collected from boreholes prior to any purging (i.e. removal of all the standing water), because purging removes animals and it may take weeks or months for them to re-establish, in some cases this may be longer than the frequency of water quality sampling (Hose and Lategan 2012).

3.3 Aquatic Habitat and Plants

3.3.1 Overview

3.3.1.1 Wolgan River Catchment

The Wolgan River is an approximately 64 km long perennial watercourse that originates above Springvale Colliery on the Newnes Plateau about 9 km east by north of Wallerawang. The river then flows in a north to easterly direction before joining with the Capertee River, below Mount Morgan, east of Glen Davis to form the Colo River, which drains into the Hawkesbury-Nepean River system (**Figure 3-1**). The watershed on the Newnes Plateau consists of sandstone catchments within Newnes State Forest. The elevation of the river declines from 1070 m at its source to 550 m at its confluence with Carne Creek in the Wolgan Valley approximately 12 km from its headwaters and then to 178 m at its confluence with the Capertee River. Carne Creek is the largest tributary of Wolgan River to the east of the Study Area. It is approximately 20 km long and rises 2.5 km northwest Bungleboori on the Newnes Plateau and flows in a generally NNW direction before flowing down the plateau and draining into the Wolgan River in the lower part of the Wolgan Valley.

The Wolgan River is a perennial stream with small base surface water flows derived from the shrub swamps and perched aquifers. The bed of the river comprises surface soils derived from the Burralow Formation of the Triassic Narrabeen Group, with sandstone bedrock outcropping in some locations. (MSEC 2016). The vegetation within the catchments is relatively undisturbed, except where it has been cleared for fire and access roads and for Angus Place and Springvale mine surface infrastructure. The Wolgan River valley to the west of the proposed longwalls is steep (approximately 80 metres high) and composed of cliffs, pagodas and talus slopes. Base flows are small and derived from shrub swamps and perched aquifers. The river used to receive periodic inflows of mine water from borehole 940 of Angus Mine via emergency discharge point LDP006 and Narrow Swamp North, however, use of this LDP has now ceased. It also received periodic discharges from two emergency discharge points (LDP004 and LDP005) associated with Springvale Mine situated on an unnamed creek that drained into the river.

Twin Gully Swamp and Tri Star Swamp are located on unnamed tributaries of the Wolgan River and drain to the west from Sunnyside Ridge and discharge to the middle and downstream ends respectively of the Wolgan River within the Study Area. The water level monitoring that has been undertaken at Angus Place indicates Twin Gully Swamp and the southeastern section of Tri Star Swamp are permanently waterlogged systems, but the northeastern section of Tri-Star Swamp is only waterlogged periodically. The water level in permanently waterlogged swamps is relatively stable and is relatively unaffected by changes in climatic conditions (RPS 2013). The water level in these swamps depends mainly on aquifer recharge, with rainfall inflows being minor contributors. The water level in periodically waterlogged swamps, however, changes considerably and fairly rapidly in response to significant rainfall events and emergency discharge events. Groundwater monitoring indicates the water level in these swamps usually fluctuates by about 1 m but increases of up to 2 m can occur after significant rainfall events (RPS 2013). Aquifer recharge does not contribute significantly to baseflow in periodically waterlogged swamps. Aquatic ecology monitoring undertaken by MPR (2010, 2011a and b; 2012a and b; 2013) included monitoring of water quality. Neither Twin Gully nor Tri Star Swamp has been disturbed previously by mine water discharge or longwall mining.

The upper reaches of the Wolgan River have been undermined by longwalls extracted at Springvale Colliery and the previous longwalls at Angus Place Colliery were extracted up to 150 metres west from the centreline of the river (MSEC 2013). Approximately 2.8 km of the Wolgan River is located within 600 m of the proposed Angus Place longwalls.

3.3.1.2 Carne Creek Catchment

The headwaters of Carne Creek consist of at least six separate sub-catchments, five of which are located within sections of Newnes State Forest (**Figure 3-1**). The drainage lines in the western part of the Project Application Area flow into the Wolgan River. Bird Rock Swamp is situated on an unnamed tributary on the western side of Carne Creek. The unnamed tributary flows to the east from Sunnyside Ridge through Bird Rock Flora Reserve and joins Carne Creek midway along the study area. The lower part of the tributary flows through narrow steep sided escarpment, which falls over 80m in altitude over the last 700m before joining Carne Creek (MPR 2012c). Site BRS is situated at the headwaters of a tributary to Carne Creek within the Bird Rock Flora Reserve.

The eastern most sub-catchment of Carne Creek has been cleared for pine plantation and this extends down towards the upper limits of Barrier Swamp. The channel valleys downstream of the swamps are more incised and are bordered by steep sandstone escarpments, which increase in depth and frequency with increasing distance downstream (MPR 2010).

Carne Creek is not located within 600 m of the proposed Angus Place longwalls.

3.3.2 Wolgan River

3.3.2.1 General Observations

The monitoring sites on Wolgan River were surrounded by dense, overhanging riparian vegetation. The river channel was fairly narrow, varying in width from 1 m to 5 m, and water levels were shallow to moderate, with maximum depths varying from 0.2 m to 1.5 m. The substratum consisted mostly of sand but with areas of finer sediments, bedrock, boulders and cobbles. The aquatic habitats in the river had been exposed to small to moderate amounts of disturbance (mainly ford crossings), with the midstream site being in a slightly better condition than the other two sites. Orange precipitates (iron floc) were present at the upstream site only.

Previously, the Public Environment Report submitted to the then Department of Environment and Heritage (DEH) in relation to potential impacts from the proposed Emirates Wolgan Valley Resort included a general description of aquatic flora and fauna within the sections of the Wolgan River and Carne Creek that traverse that site (located downstream of the Study Area) (Cumberland Ecology 2006). Both streams were identified as highly modified due to vegetation clearing, erosion and grazing. The creek and river were heavily eroded and the channel beds had a heavy sediment deposition in many areas. Aquatic vegetation was sparse, though woody debris and submerged timber provided aquatic habitat for aquatic biota in the upper reaches of Carne Creek and lower sections of the Wolgan River.

3.3.2.2 WRup

WRup (**Plate 1a** and **b**) is located upstream of the Angus Place LDP006 and Springvale LDP004-5 emergency release sub-catchment confluences within Wolgan River and close to the downstream limits of Sunnyside Swamp and upstream of a fire trail crossing. The river channel at the upstream end of the site was narrow (average width of 1.0 m), shallow (mostly less than 10 cm depth) and surrounded by dense riparian vegetation. Below this there was a broad (up to 5 m), deep (1.2 - 1.5 m) pool caused by the damming effect of the crossing. The channel downstream of the road crossing was similar to upstream. The flow at the upstream and downstream ends of the site was more natural than that within the pool, where flow was piped under the road via a culvert. In autumn 2012, it was noted that a high flow event resulting in a 0.8 to 1 m increase in water level had occurred. The riparian habitat was dense and overhung the river throughout the site. It consisted of sedges, sword grass, coral ferns, heath shrubs and trees. Despite the dense riparian vegetation, undercutting of the banks and some erosion of bends and exposed banks were evident. The pool edge habitats included edge rushes, sedges, trailing bank vegetation, eucalypt detritus, undercut banks and logs. The pool substratum consisted mostly of sand, but with some isolated areas of clay-like sediments. Orange precipitates (iron flocs) were observed along some areas of the riverbanks in autumn 2010, covering submerged surfaces in isolated areas of the pool in autumn 2012, but smothered most of the submerged surfaces at the site in spring 2012.

Three different aquatic macrophytes have been reported to occur at WRup. The first plant observed in autumn 2010 was tentatively identified as a member of the family Cyperaceae (sedge). In autumn 2011, the Royal Botanical Gardens Sydney (RBGS) indicated this was in fact Bulbous Rush (*Juncus bulbosus*). This species was recorded in all the subsequent surveys. In spring 2012, an unidentified Baumea-like rush was found, but this has yet to be positively identified. Filamentous green algae were recorded during each survey, with amounts varying from small to moderate. In spring 2011 and 2012, it was reported that most of the substratum and submerged surfaces were smothered by algal mats. Charophyte algae were recorded for the first time in spring 2012.

The total Riparian, Channel and Environmental Inventory (RCE) score ranged from 38.5 to 39 and indicated the stream channel and adjacent features were subject to moderate disturbance.

3.3.2.3 WRmd

WRmd (**Plate 1c** and **d**) is located approximately 1 km downstream from the junction of Narrow Swamp tributary and Wolgan River. The river channel at this site was narrow (average width less than 1.0 m) and meandering, with bedrock races intersecting short sandy pools. The maximum depth varied from 0.2 m to 0.8 m across surveys. The site was surrounded by dense native heath and eucalypt woodlands. Instream bank vegetation was prominent throughout the site with a high degree of cover over the waterbody and consisted mostly of sword grass (*Gahnia* sp.), and coral ferns (*Gleichenia* sp.). The aquatic habitats along the pool edge included trailing bank vegetation, eucalypt detritus, undercut banks and logs. The substratum consisted mostly of bedrock, but with boulder/cobble sized sandstone fragments and some sand accumulations at the downstream end. In spring 2010 and autumn 2011, burrows (presumed to be made by crayfish) were observed along the river banks. In spring 2012, moderate amounts of silt were observed on the substratum.

Four different aquatic macrophytes have been identified. The first plant observed in spring 2010 was tentatively identified as a member of the family Cyperaceae (sedge). This was subsequently identified as Bulbous Rush (*Juncus bulbosus*) and was recorded in all the other surveys, except that in spring 2012. An introduced species, the Jointed Rush (*Juncus articulatus*), was found in autumn 2012, but not during the subsequent survey. In spring 2012, another macrophyte was found and subsequently identified as Swamp Clubrush (*Isolepis inundatus*). MPR (2013) indicates this species may previously have been recorded as Bulbous Rush. Filamentous green algae were absent in spring 2010, but present in small to moderate amounts in subsequent surveys. Charophytes were present during all surveys.

The total RCE score (44) was consistent across surveys and indicated the stream channel and adjacent features were subject to small-scale disturbance.

3.3.2.4 WRdn

WRdn (**Plate 1e** and **f**) is situated in a narrow steep sided valley bordered by vertical cliffs upstream of Fire Trail No. 5. The flow was piped under the road at the lower crossing. The channel meandered and an irregular sequence of shallow sandy constricted higher-flow zones alternated with deeper backwater pools. The maximum in-stream channel width was 3 m and maximum depth varied from 1.0 to 1.5 m. There was evidence that flow events had increased water levels by 1.0 m to 1.5 m and 1.5 m to 2 m between the first, second, third, and fourth surveys, respectively. The riparian vegetation was dense and overhung the stream banks throughout the site. The aquatic habitats along the pool edge included trailing bank vegetation, eucalypt detritus, charophytes, undercut banks and logs. The substratum throughout the site was sandy, with gravel and boulder fragments also present at the road crossings. Deepening of channel beds and erosion at the lower trail crossing was noted between the first and second surveys, while deepening and infilling of pools areas were noted between the third and fourth surveys In Spring 2012, detritus was abundant throughout the site.

Three different aquatic macrophytes have been recorded. The first plant observed in spring 2010 was tentatively identified as a member of the family Cyperaceae (sedge). This was subsequently identified as

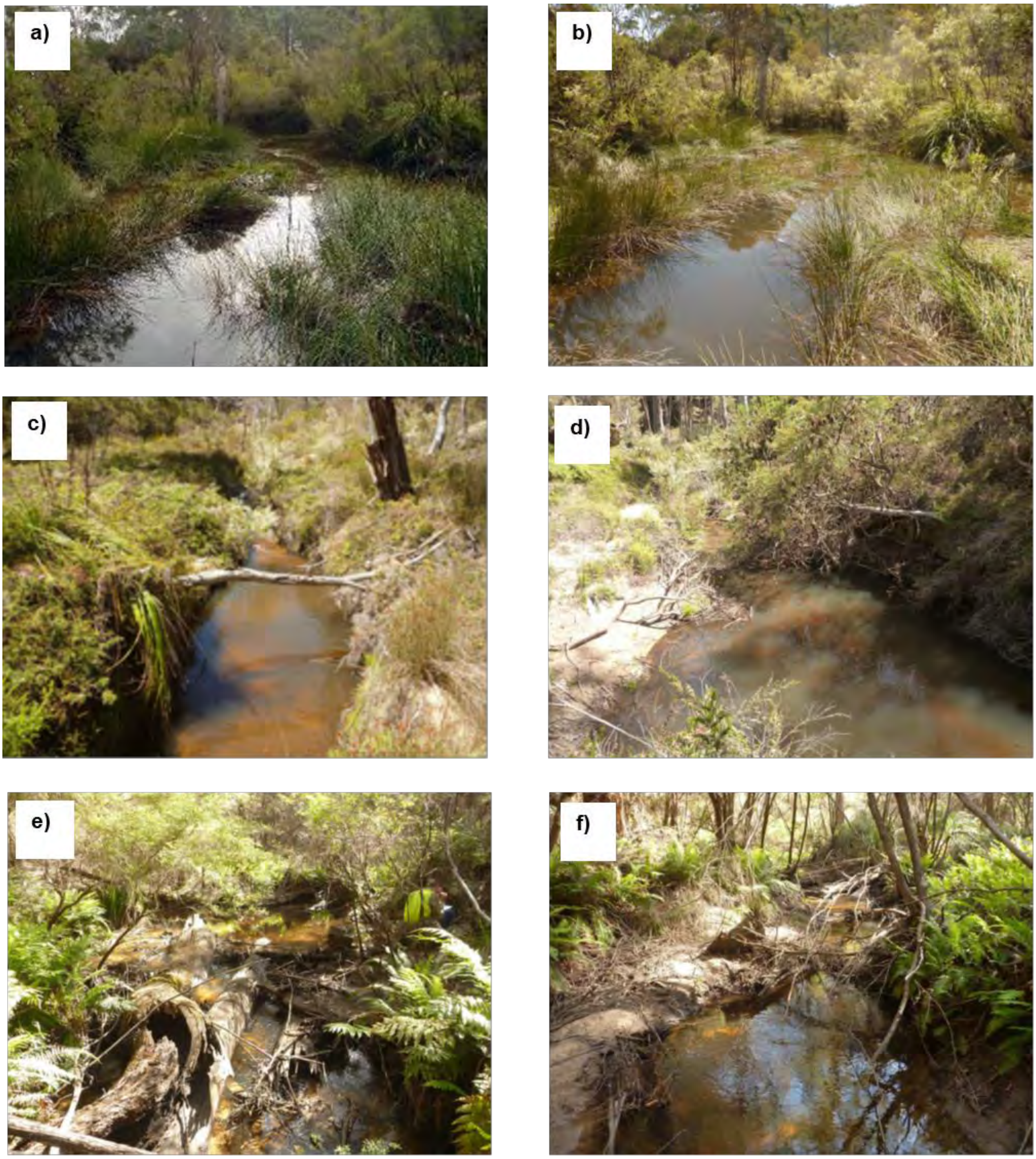


Plate 1 – a) and b) WRup, c) and d) WRmd and e) and f) WRdn in Wolgan River.

Bulbous Rush (*Juncus bulbosus*) and was recorded in spring 2011, but not subsequently. The third macrophyte was found in spring 2012 and identified as Swamp Clubrush (*Isolepis inundatus*) by RBGS. MPR (2013) indicates this species may previously have been recorded as Bulbous Rush. Small amounts of filamentous green algae were observed during all the surveys, except that in autumn 2012. Charophytes were recorded all the surveys except those undertaken in autumn 2010 and 2011.

The total RCE score (42) was consistent across surveys and indicated the stream channel and adjacent features were subject to small-scale disturbance.

3.3.3 Twin Gully Swamp

3.3.3.1 TGS

Twin Gully Swamp is dominated by *Baeckea linifolia*, *Grevillea acanthifolia*, *Gleichenia dicarpa* and *Sphagnum cristatum* (Centennial 2012b). Site TGS (**Plate 2a** and **b**) is situated adjacent to a rock pagoda approximately 500 m upstream of the Twin Gully Swamp tributary's confluence with the Wolgan River. It is located in a narrow gorge with cliff faces abutting the narrow valley floor and receives water from the southern cliff wall. The valley floor at the upper end of the site was covered with dense heath vegetation, primarily coral ferns and sword grass and these have overgrown the channel. In some areas there was no observable channel or surface water, suggesting that the flow had either gone underground or broadened to a wide shallow seepage flow in the swamp bed. The channel was narrow and shallow and formed a series of bedrock cascades. The pool had maximum and average widths of 2 m and 1 m, respectively and a maximum depth that varied from 0.3 m to 1.0 m.

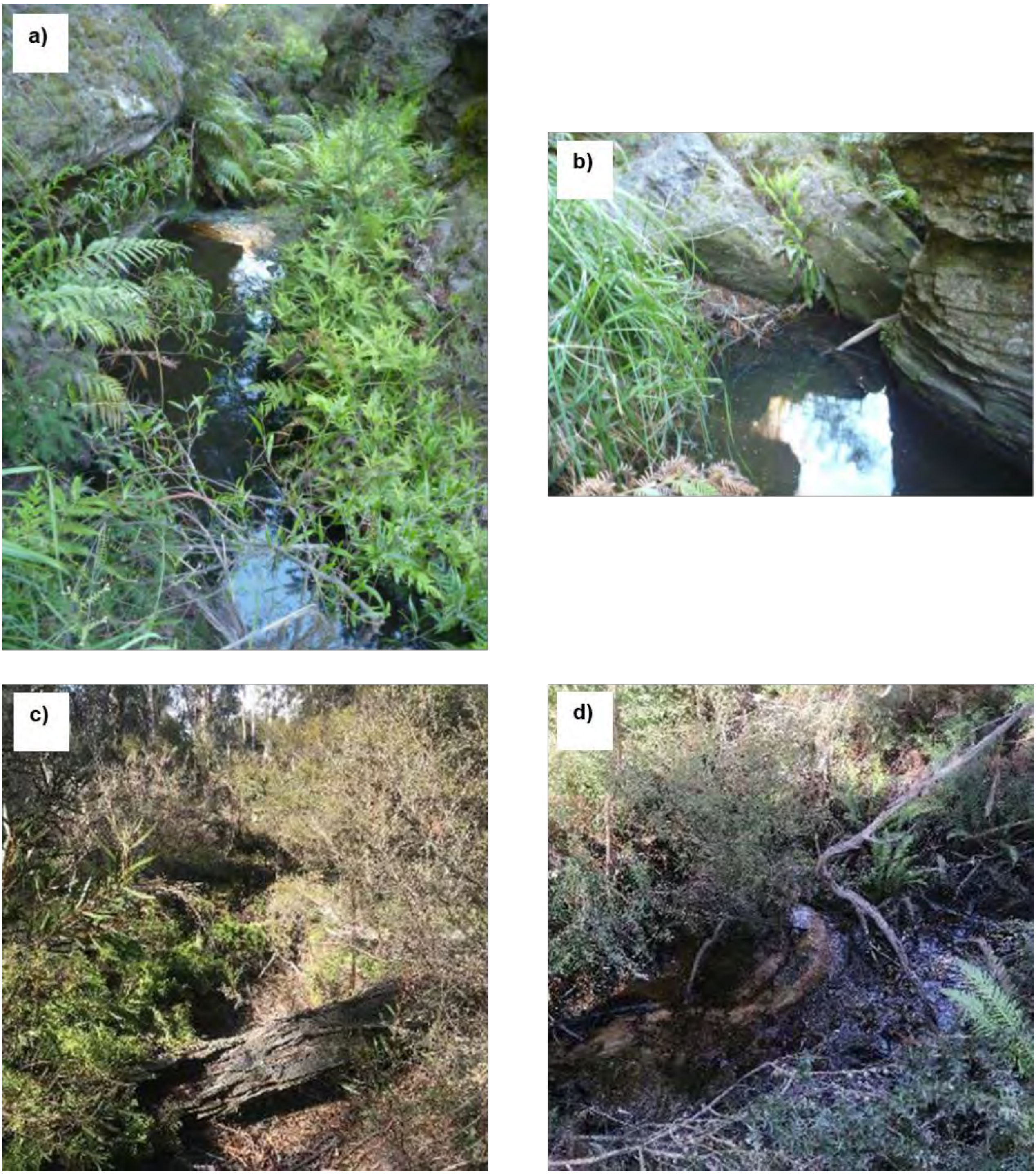


Plate 2 – a) and b) TGS and c) and d) TGSup in Twin Gully Swamp

Moss was prevalent on channel edges and cliff faces. Some of the pools in the channel were covered by a dense canopy of ferns. The aquatic habitats represented along the pool edge included trailing bank vegetation, detritus, undercut banks and logs. The channel substratum was initially sandy with particulate material and fine detritus overlying a bedrock base, but in subsequent surveys was found to be mostly bedrock with some sand and silt accumulations. Large boulders occurred throughout the site. In autumn 2012, it was noted that the pools had been scoured out since the previous survey. During three surveys, it was noted that the substratum and/or trailing bank vegetation were covered in silt. No macrophytes have been observed at TGS. Filamentous green algae has been observed, with amounts varying from very small to moderate.

The total RCE score varied from 48 to 49 across surveys, indicating the stream channel and adjacent features were subject to minimal disturbance.

3.3.3.2 TGSup

TGSup (**Plate 2c** and **d**) is located in a short and narrow section of flowing channel (approximately 0.5 m wide) further upstream from TGS. At this point the valley is broader (unlike TGS, which is located in a gorge). Flowing water could be heard beneath the swamp vegetation, though could only be accessed in short sections where it was not overgrown with vegetation. Watercourse substratum was a mixture of bedrock with gravel and sand in places. No macrophytes were observed at TGSup by Cardno.

3.3.4 Tri-Star Swamp

3.3.4.1 TRS

Tri Star Swamp is a permanently wet, groundwater fed system dominated by *Baeckea linifolia*, *Gleichenia dicarpa, Grevillea acanthifolia, Lepidosperma limicola* and *Leptospermum grandifolium* (Centennial Angus Place 2012b). Site TRIS (**Plate 3a** and **b**) is situated approximately 250 m upstream of the confluence with Wolgan River. Surveys by MPR indicated water seeping from the cliff face on both sides of the site. The valley floor adjoining the lower end of the site was covered with dense swamp and heath vegetation, including coral ferns and sword grass, which had overgrown the channel. In some areas there was no observable channel or surface water. During the first three surveys, the channel was narrow, with maximum and average widths of 1.5 m and 0.8 m, respectively and generally shallow (less than 15 cm deep). The maximum depth varied from 0.3 to 0.8 m. During the autumn 2012 survey, it was noted that flows up to 1 m above previous levels had occurred and that these had resulted in overland flow in new areas and that maximum and average depths had increased to 1.0 m and 0.4 m, respectively. The aquatic habitats at the pool edge included trailing bank vegetation, rushes, detritus, undercut banks and logs. The channel substratum consisted mainly of bedrock, but with accumulations of sand and fine silty matter in areas isolated from flow and deeper pools. Moss was present on the banks of channel throughout the site. Emergent bankside plants include Cyperaceae (sedge) and swamp clubrush (*Isolepis inundatus*). Charophytes (multicellular algae). These were recorded in spring 2010 and autumn 2011, but not in subsequent surveys. Filamentous green algae were present, with amounts varying from very small to moderate.

The total RCE score assessed by MPT was high (48) and consistent across surveys, indicating the stream channel and adjacent features were subject to minimal disturbance.

3.3.4.2 TRISup

TRISup (**Plate 3c** and **d**) is located further upstream in Tri-Star swamp. Similar to TGSup, it was located in an accessible flowing section of watercourse (approximately 0.5. m wide) within the swamp vegetation. Watercourse substratum was a mixture of bedrock with gravel and sand in places.

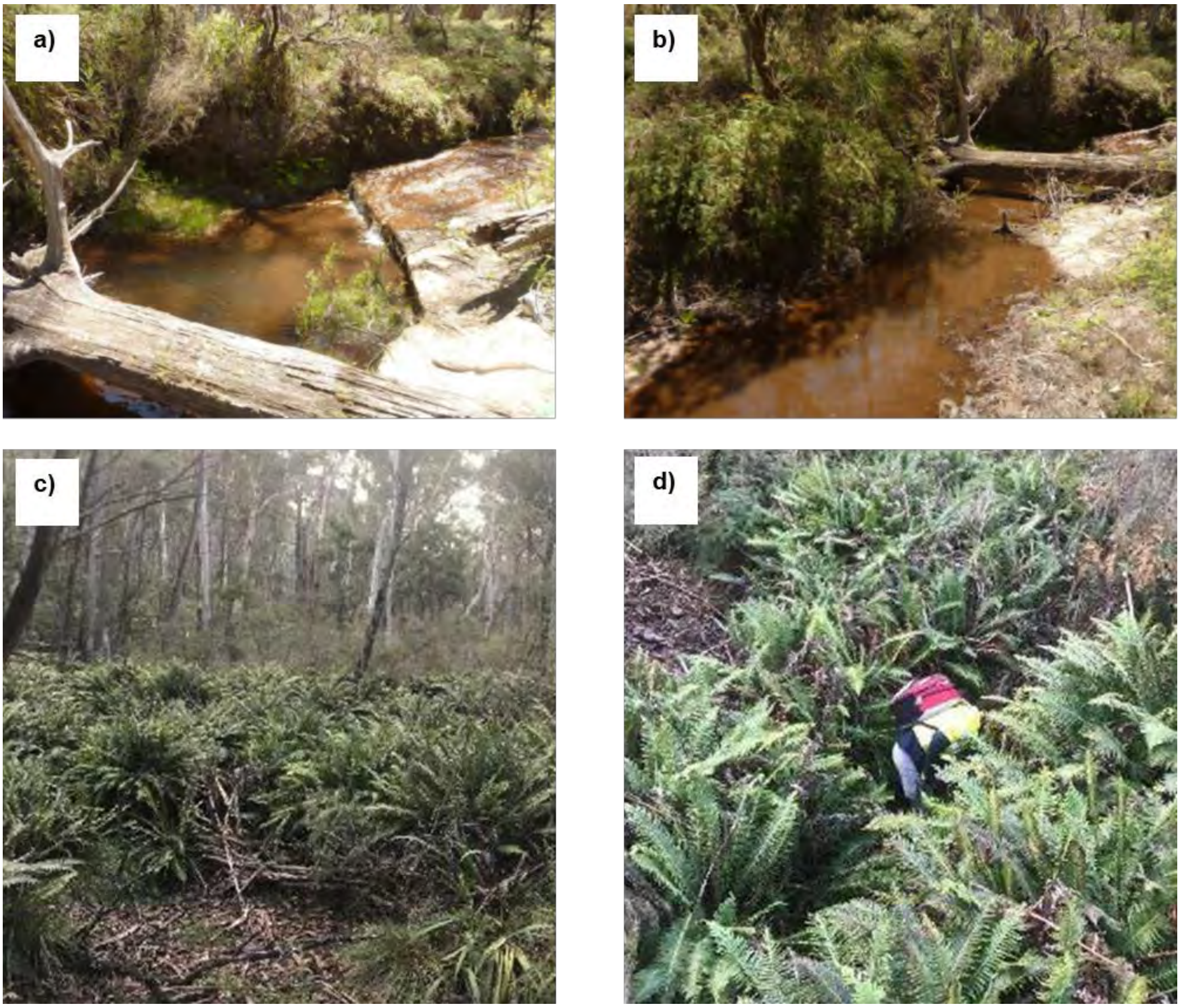


Plate 3 – a) and b) TRS and c) and d) TRSup in Tri-Star Swamp

3.3.1 Carne Creek

Site CCXdn (**Plate 4a** and **b**) on Carne Creek is situated below the confluence of the two upper catchment tributaries that drain sites CC1 and CC2/ CC3, midway along the Newnes Plateau section of Carne Creek around 5.5km from the headwaters of the catchment. The site situated in a greatly incised valley bordered by steep sandstone escarpment supporting native vegetation. The creek channel was incised below the surrounding valley floor by 3 m and was steep and undercut in parts, and generally straight, but with some slight bends and constrictions. The channel had a maximum width of 5 m, an average width of 3.5m, a maximum depth of 0.9 m and average depth of 0.4m. There was evidence that the water level was at least 2 m higher during high flow events. Boulder outcrops, numerous fallen logs and dense vegetation, consisting mostly of ferns, were present along the banks of the channel. The rocks and logs were covered with mosses. The channel substratum consisted of sandstone fragments, ranging in size from gravel to cobble, long sand drifts and boulder outcrops. No macrophytes or charophytes have been observed in Carne Creek.

A total RCE score of 49 was recorded, indicating the stream channel and adjacent features were subject to minimal disturbance.

Plate 4 – CCXdn in Carne Creek

3.3.2 Bird Rock Swamp

Bird Rock Swamp is situated on an unnamed tributary on the western side of Carne Creek. The unnamed tributary flows to the east from Sunnyside Ridge through Bird Rock Flora Reserve and joins Carne Creek midway along the study area. The lower part of the tributary flows through narrow steep sided escarpment, which falls over 80m in altitude over the last 700m before joining Carne Creek (MPR 2012c). Site BRS (**Plate 5a** and **b**) is situated at the headwaters of a tributary to Carne Creek within the Bird Rock Flora Reserve.

The riparian vegetation at site BRS was unbroken and forest eucalypts extended down to the middle of the drainage line. During the first three surveys by MPR, the swamp channel was narrow, with maximum and average widths of 1.0 m and 0.4 m respectively, had a maximum depth that varied from 0.2 m to 0.6 m but was mostly shallow (depth less than 0.1 m). In autumn 2012, it was noted that flows up to 1 m above previous water levels had occurred and that these had carved new flow paths in some parts of the site, increased the maximum depth of pools to 1.2 m and maximum and average width of the channel to 2.0 m and 0.5 m, respectively. The substratum consisted mainly of bedrock with accumulations of sand and pebbles, and fine silty matter in areas isolated from flow evident until autumn 2012 when they had been scoured away. Boulders were present throughout the site were noted by MPR. In spring 2012, fine silty matter was observed in areas of low flow.

No aquatic macrophytes have been observed. Very small amounts of filamentous green algae were observed in spring 2010, but none was found subsequently.

The total RCE score was high (48) and consistent across all surveys, indicating the stream channel and adjacent features were subject to minimal disturbance.

Plate 5 – BRS in Bird Rock Swamp

3.3.3 Key Fish Habitat

At a broad scale, all third order and greater sections of Wolgan River and Carne Creek are designated KFH by NSW DPI (Fisheries) (NSW DPI 2019).

The main channels of Wolgan River and Carne Creek were identified as providing Type 1 – Highly Sensitive KFH (**Figure 3-5**). This is based on the presence of large woody debris and rocks in some sections of watercourse at WRmd and WRdn. It is noted that this designation of Type 1 KFH is conservative, and the abundance of such habitats in the sections of these watercourses visited was relatively low. No instream native aquatic plants have been identified from these watercourses.

Third order sections of tributaries of Wolgan River (including the lower watercourses within Twin Gully Swamp, at TGS, and Tri-Star Swamps, at TRIS and TRISup) and the watercourse within Bird Rock Swamp at BRS, provide Type 2 – Moderately Sensitive KFH. The identification of Type 2 KFH in these third order sections of watercourses was based on their potentially for perennial flow, though apparent absence (at least at the sites visited) of large rocks or wood debris within the channel and of instream aquatic plants. Short sections of third order watercourses present in the north and southeast of the Study Area also provide Type 2 KFH (inferred).

All first and second order watercourses upstream of these areas and elsewhere within the Study Area are Type 3 - Minimally Sensitive KFH.

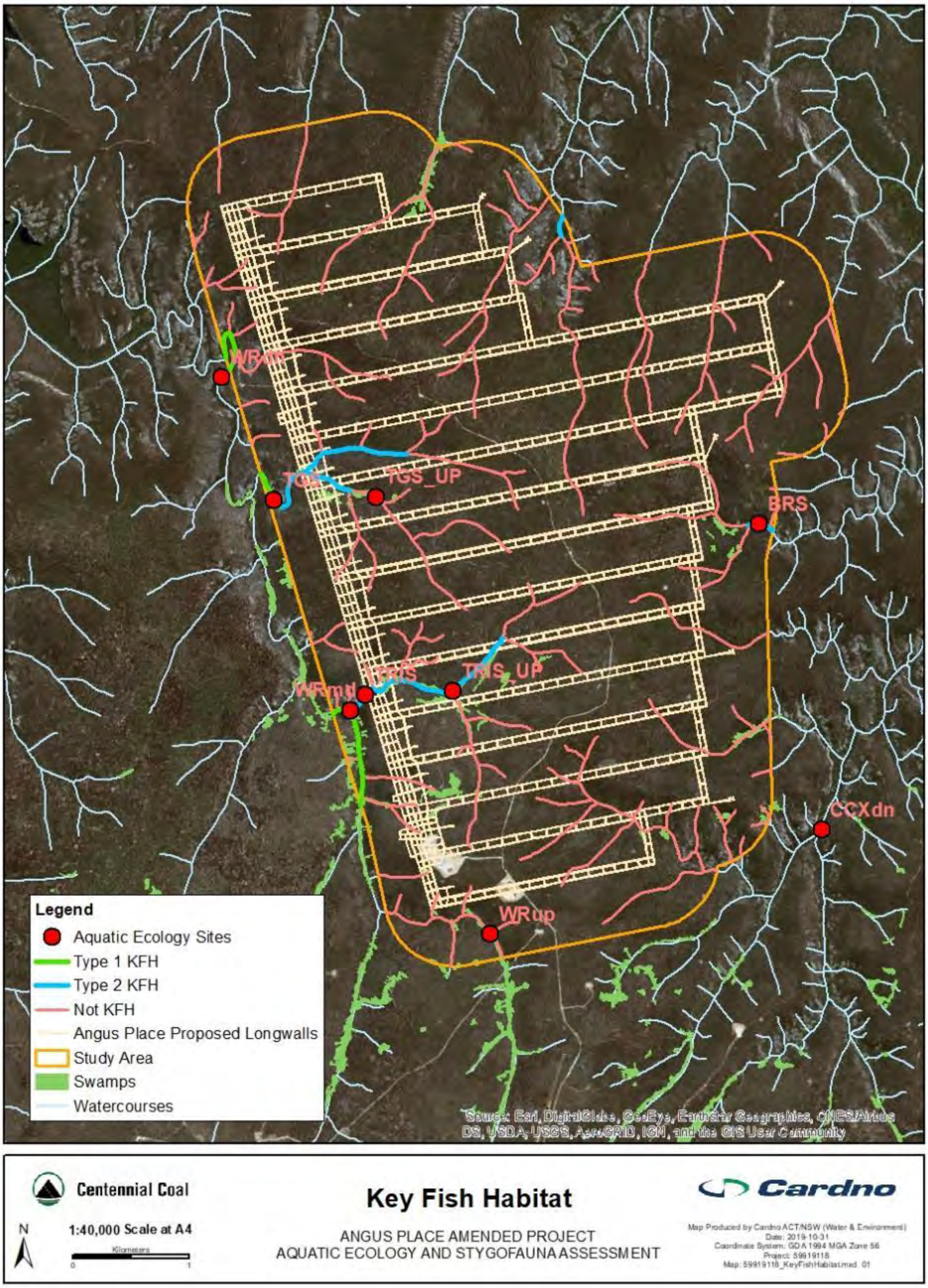


Figure 3-5 Key Fish Habitat Present in the Study Area

3.3.4 Aquifers

The aquifers and aquitards that occur in the Project Application Area form three basic groundwater systems. A perched surficial hydrogeological system, a shallow regional groundwater system, ranging from non-confined to semi-confined, and a deep confined groundwater system.

The perched groundwater system (AQ5 and AQ6) is discontinuous and generally situated close (within metres) to the ground surface. It is derived from excess rainfall that is unable to infiltrate into the deeper groundwater systems due to the presence of less permeable underlying rock layers. This system includes perched swamps and underlying rock groundwater systems recharged by direct rainfall infiltration and by interflows through surficial, weathered geological deposits. It is hydraulically independent of the underlying shallow regional groundwater system and deep confined groundwater system.

The shallow regional groundwater system (AQ4) extends from approximately 100 m below ground to 286 m above the Lithgow Seam. It is located primarily in the Banks Wall sandstone layer of the Narrabeen Group. The flow of groundwater within this system is generally horizontal and occurs along bedding planes and in a north-eastern direction. The infiltration of rainfall into this zone may also result in some vertical flow.

The deep groundwater system is separated from the shallow regional groundwater system by a sequence of interbedded claystone and sandstones of low permeability that comprise the Mount York Claystone. The deep groundwater system includes the Illawarra coal measures, which generally have low permeability, and three deep fractured rock aquifer units (AQ1, AQ2 and AQ3). In these aquifers, groundwater flows sub horizontally towards the northeast along fracture-plain conduits. Groundwater from this system drains into the goaf formed by longwall mining and results in most of the mine water inflows.

Recharge to swamps occurs as incident rainfall and runoff. Recharge to the deeper aquifers will occur primarily through infiltration of rainfall and runoff along the ridgelines and areas of exposed or shallow sub-cropping bedrock in the upper catchment areas (Jacobs 2019).

3.4 Water Quality

Key indicators of surface water quality (EC, pH, dissolved iron, and concentrations of iron and manganese) are monitoring at two sites in each of Wolgan River, Twin Gully Swamp and Tri-Star Swamp. Results of monitoring from 2008 to present indicate the following (Jacobs 2019b):

> Water quality at Wolgan River is characterised by slightly acidic to neutral conditions (10^{th} percentile pH 6.1 and 90^{th} percentile pH 7.9), and very fresh water with EC generally below 60 µS/cm (10^{th} percentile 31 µS/cm and 90^{th} percentile 444 µS/cm). The levels of Iron (10^{th} percentile 0.24 mg/L and 90^{th} percentile 1.21 mg/L) and Manganese (10^{th} percentile 0.004 mg/L and 90^{th} percentile 0.012 mg/L) at both sites were low.

> Surface water quality in the swamps are generally characterised by very low EC (10^{th} percentile 18 µS/cm and 90^{th} percentile 45 µS/cm)., and low concentrations of Iron (10^{th} percentile 0.13 mg/L and 90^{th} percentile 0.41 mg/L) and Manganese (10^{th} percentile 0.003 mg/L and 90^{th} percentile 0.015 mg/L). The pH is generally slightly acidic (10^{th} percentile pH 4.7 and 90^{th} percentile pH 7.8), from the release of humic acid from organic matter in the swamp. The primary source of water for the swamps comes from a combination of rainwater runoff from the local catchment and from shallow perched aquifer systems.

3.5 Aquatic Macroinvertebrates

3.5.1 AUSRIVAS

Raw AUSRIVAS data from 2010 to 2016 and 2019 (except spring 2016 where raw assemblage data is not available) is provided in **Appendix D** and biotic indices for each site sampled during 2010 to 2019 in Table 3-3 and in **Figure 3-6** and **Figure 3-7**.

The Wolgan River sites supported a relatively diverse range of aquatic macroinvertebrate fauna, with a total of 65 taxa being recorded across the surveys and total numbers per site ranging from 33 to 43. The range and mean number of taxa sample at each if WRup, WRmd and WRdn was largely comparable, ranging from 6 to 25, 11 to 31 and 13 to 25 and with a mean of 19.1, 22.1 and 20.4, respectively. Slightly fewer taxa were sampled at TRIS and TGS, ranging from 14 to 19 and 14 to 22, with a mean of 17.6 and 16.9, respectively. Fewer still were sampled further upstream from these sites TRISup and TGSup; 11 and 14 taxa, respectively (albeit there has been only survey event at these sites, in autumn 2019). At CCXdn and BRS, the number of taxa sampled ranged from 11 to 19 and 10 to 19, with a meant of 17.3 and 15.1, respectively. There was little evidence of any trends through time at any of the sites. However, it is noted that the fewest taxa at each

Table 3-3 Number of macroinvertebrate taxa, average SIGNAL2 score, OE50 taxa score and AUSRIVAS band for each site during each survey by MPR and Cardno.

Site	Source	Date	Month	Number of Taxa	SIGNAL2 Score	OE50 Taxa Score	AUSRIVAS Bands
WRup	Cardno	12/06/2019	Aut 2019	6	2.25	0.08	D
WRup	MPR	27/11/2013	Spr 2013	20	3.89		
WRup	MPR	16/05/2013	Aut 2013	21	4.00		
WRup	MPR	27/11/2012	Spr 2012	25	4.42	0.72	B
WRup	MPR	23/05/2012	Aut 2012	21	4.70	0.78	B
WRup	MPR	15/11/2011	Spr 2011	22	4.05	0.72	B
WRup	MPR	25/05/2011	Aut 2011	20	3.63	0.55	B
WRup	MPR	8/11/2010	Spr 2010	18	3.50		
WRup	MPR	9/06/2010	Aut 2010	19	3.78		
WRmd	Cardno	12/06/2019	Aut 2019	11	3.75	0.25	C
WRmd	MPR	14/12/2016	Spr 2016	21	4.95		
WRmd	MPR	10/05/2016	Aut 2016	22	4.80		
WRmd	MPR	16/11/2015	Spr 2015	24	5.39		
WRmd	MPR	25/11/2014	Spr 2014	31	5.41		
WRmd	MPR	6/05/2014	Aut 2014	25	5.38		
WRmd	MPR	26/11/2013	Spr 2013	26	5.52		
WRmd	MPR	16/05/2013	Aut 2013	21	5.48		
WRmd	MPR	26/11/2012	Spr 2012	20	5.26	0.9	A
WRmd	MPR	21/05/2012	Aut 2012	25	5.29	0.86	A
WRmd	MPR	16/11/2011	Spr 2011	20	5.35	0.82	B
WRmd	MPR	23/05/2011	Aut 2011	21	5.05	0.78	B
WRmd	MPR	9/11/2010	Spr 2010	20	5.53		
WRdn	Cardno	12/06/2019	Aut 2019	13	4.33	0.49	B
WRdn	MPR	26/11/2013	Spr 2013	25	5.56		
WRdn	MPR	17/05/2013	Aut 2013	19	4.68		
WRdn	MPR	27/11/2012	Spr 2012	21	5.81	0.94	A
WRdn	MPR	24/05/2012	Aut 2012	19	5.11	0.73	B
WRdn	MPR	17/11/2011	Spr 2011	20	4.74	0.86	A
WRdn	MPR	26/05/2011	Aut 2011	23	5.55	0.81	B
WRdn	MPR	9/11/2010	Spr 2010	24	5.00		
WRdn	MPR	9/06/2010	Aut 2010	20	4.56		
TGS	Cardno	12/06/2019	Aut 2019	14	5.23	0.57	B
TGS	MPR	14/12/2016	Spr 2016	16	4.53		
TGS	MPR	11/05/2016	Aut 2016	17	5.38		
TGS	MPR	17/11/2015	Spr 2015	16	5.71		
TGS	MPR	26/11/2014	Spr 2014	19	5.65		
TGS	MPR	7/05/2014	Aut 2014	19	5.59		
TGS	MPR	27/11/2013	Spr 2013	16	6.00		
TGS	MPR	5/06/2013	Aut 2013	19	6.00		
TGS	MPR	27/11/2012	Spr 2012	18	5.47		
TGS	MPR	23/05/2012	Aut 2012	19	5.35		
TGS	MPR	17/11/2011	Spr 2011	15	5.20		
TGS	MPR	24/05/2011	Aut 2011	17	5.44		
TGS	MPR	10/11/2010	Spr 2010	14	5.69		
TGSup	Cardno	12/06/2019	Aut 2019	14	4.80	0.41	C
TRIS	Cardno	12/06/2019	Aut 2019	14	5.54	0.41	C
TRIS	MPR	14/12/2016	Spr 2016	15	5.13		
TRIS	MPR	10/05/2016	Aut 2016	19	5.39		
TRIS	MPR	16/11/2015	Spr 2015	18	5.38		
TRIS	MPR	25/11/2014	Spr 2014	22	5.60		
TRIS	MPR	6/05/2014	Aut 2014	21	6.00		
TRIS	MPR	26/11/2013	Spr 2013	19	5.78		
TRIS	MPR	16/05/2013	Aut 2013	20	5.89		

Site	Source	Date	Month	Number of Taxa	SIGNAL2 Score	OE50 Taxa Score	AUSRIVAS Bands
TRIS	MPR	26/11/2012	Spr 2012	21	5.25		
TRIS	MPR	21/05/2012	Aut 2012	14	5.50		
TRIS	MPR	16/11/2011	Spr 2011	15	5.77		
TRIS	MPR	23/05/2011	Aut 2011	16	5.88		
TRIS	MPR	9/11/2010	Spr 2010	15	5.46		
TRISup	Cardno	12/06/2019	Aut 2019	11	3.90	0.41	C
CCXdn	Cardno	12/06/2019	Aut 2019	11	6.00	0.33	C
CCXdn	MPR	28/11/2012	Spr 2012	22	5.90		
CCXdn	MPR	6/06/2012	Aut 2012	19	6.47		
BRS	Cardno	12/06/2019	Aut 2019	13	5.09	0.49	B
BRS	MPR	15/12/2016	Spr 2016	13	5.50		
BRS	MPR	11/05/2016	Aut 2016	16	6.07		
BRS	MPR	18/11/2015	Spr 2015	17	5.25		
BRS	MPR	26/11/2014	Spr 2014	16	5.63		
BRS	MPR	7/05/2014	Aut 2014	17	6.06		
BRS	MPR	27/11/2013	Spr 2013	14	6.71		
BRS	MPR	5/06/2013	Aut 2013	15	6.13		
BRS	MPR	27/11/2012	Spr 2012	19	5.58		
BRS	MPR	23/05/2012	Aut 2012	16	5.67		
BRS	MPR	17/11/2011	Spr 2011	17	6.56		
BRS	MPR	24/05/2011	Aut 2011	13	6.08		
BRS	MPR	10/11/2010	Spr 2010	10	5.67		

site on Wolgan River was sampled in autumn 2019. It is unclear why this was the case, though it could be associated with inter-annual patterns and climate and its potential influence on water flow in the river.

The SIGNAL2 score at each of WRup, WRmd and WRdn ranged from 2.3 to 4.7, 3.8 to 5.5 and 4.3 to 5.8 and with a mean of 3.8, 5.2 and 5.0, respectively. SIGNAL2 scores were slightly greater at TRIS and TGS, ranging from 4.5 to 6.0 and 5.1 to 6.0, with a mean of 5.6 and 5.5, respectively. SIGNAL2 scores were slightly greater again at CCXdn and BRs, ranging from 5.9 to 6.5 and 5.1 to 6.7, with a mean of 6.1 and 5.9, respectively. SIGNAL2 scores at TRISup and TGSup were 3.9 and 4.8, respectively. These scores are suggestive of healthy habitat in Carne Creek and Bird Rock Swamp, and possibly some disturbance at in Wolgan River and its tributaries. It is possible also that scores indicative of environmental disturbance may be a natural occurrence, particularly in sections of watercourses with limited flow. For example, the pool habitat with no observable flow provided by WRup may favour some macroinvertebrate tolerant of potentially naturally poor water quality in these areas. For example, dissolved oxygen was often below the lower DTV at WRup, as it was at other sites also (**Section 3.4**). There were no obvious trends in SIGNAL2 score through time at any site.

The OE50 Taxa Score at each of WRup, WRmd and WRdn ranged from 0.08 to 0.78, 0.25 to 0.9 and 0.49 to 0.94 and with a mean of 0.57, 0.72 and 0.77, respectively. OE50 Taxa Scores at the other sites sampled in autumn 2019 were generally below those on Wolgan River, and largely comparable among each other, ranging from 0.33 to 0.57. These scores were generally indicative of impoverished habitat to habitat slightly below the condition that would be expected of streams with similar physical characteristics and water chemistry. On occasion, scores at WRmd and WRdn were equivalent to reference condition (i.e. supported a macroinvertebrate assemblage typical of that expected. Of note, were the relatively low scores at each site on the Wolgan River in autumn 2019, which were the lowest recorded from any sampling event. As was the case for number of taxa and SIGNAL2 Score data, such observations may be at least partly naturally occurring, and related to low flow and somewhat naturally impaired water quality.

The PCOs indicated that macroinvertebrate assemblages at Sites CCXdn and WRup were somewhat distinct from each other and from those at WRmd and WRdn (**Figure 3-8a**). This was evident in points from WRup tending to group towards the top right, those from CCXdn to the bottom, and those from WRmd and WRdn to the right of the PCO, respectively. Sites on Wolgan River and on watercourses associated with each of the swamps (BRS, TGS, TGSup, TRIS and TRISup) The assemblages sampled in autumn 2019 also differed those sampled during each other survey, with symbols tending to group to the left and right of the PCO, respectively (**Figure 3-8b**). The dispersion of the symbols in the ordination indicates the fauna at WRup was more variable over time than that at the other sites.

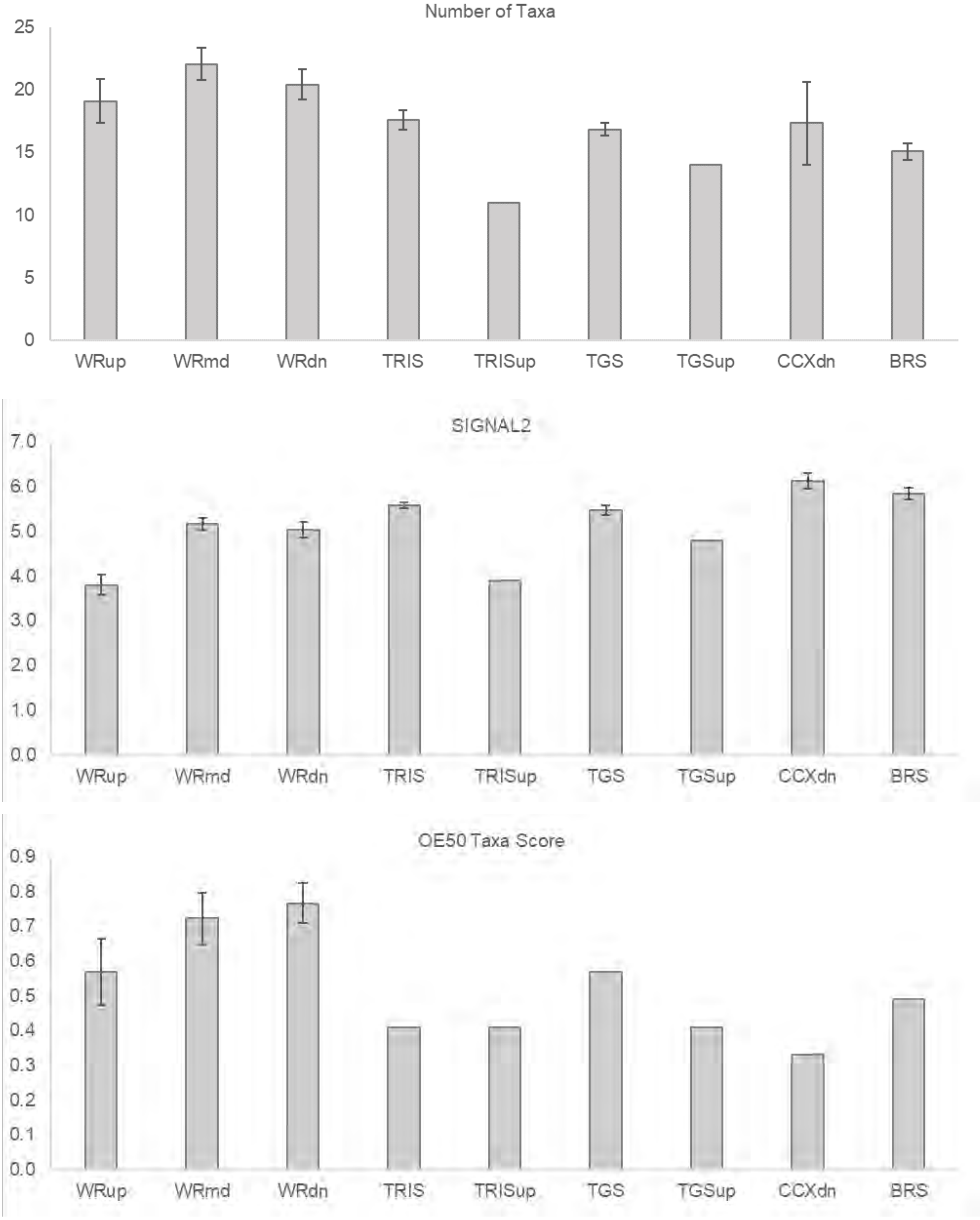


Figure 3-6 Mean number of macroinvertebrate taxa, SIGNAL2 score and OE50 taxa score at site averaged across all surveys.

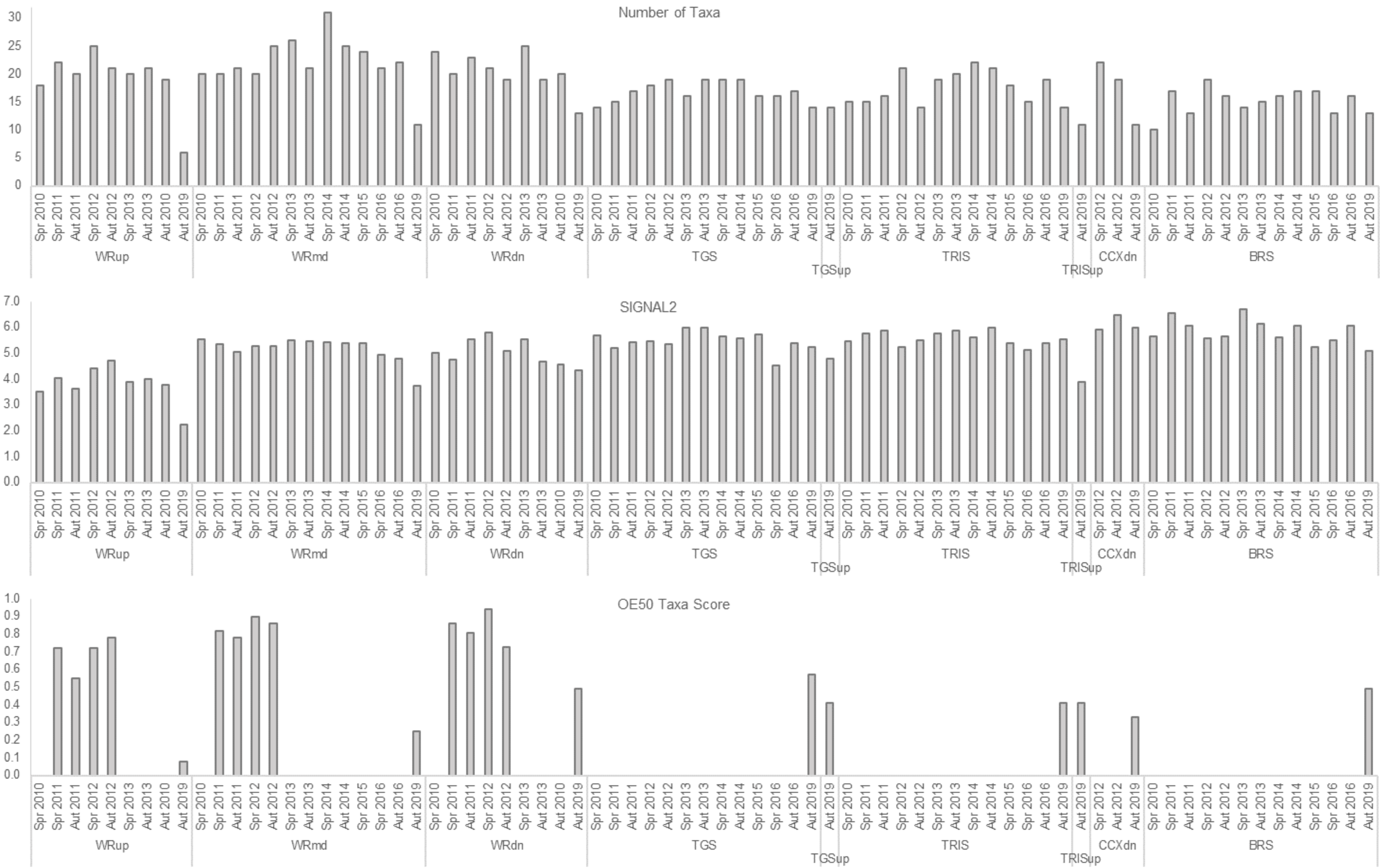
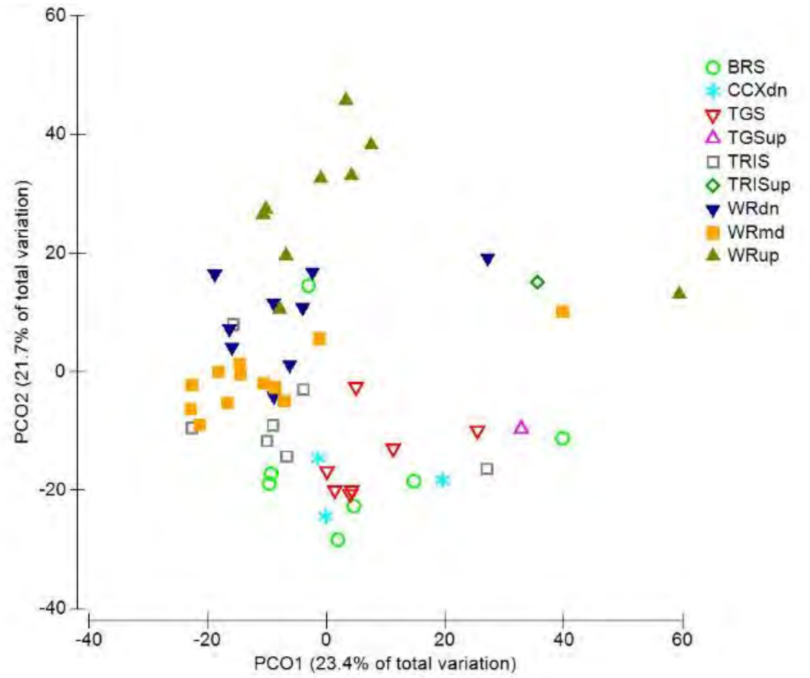


Figure 3-7 Number of macroinvertebrate taxa, SIGNAL2 score, OE50 taxa score and AUSRIVAS band for each site during each survey by MPR and Cardno.

a)



b)

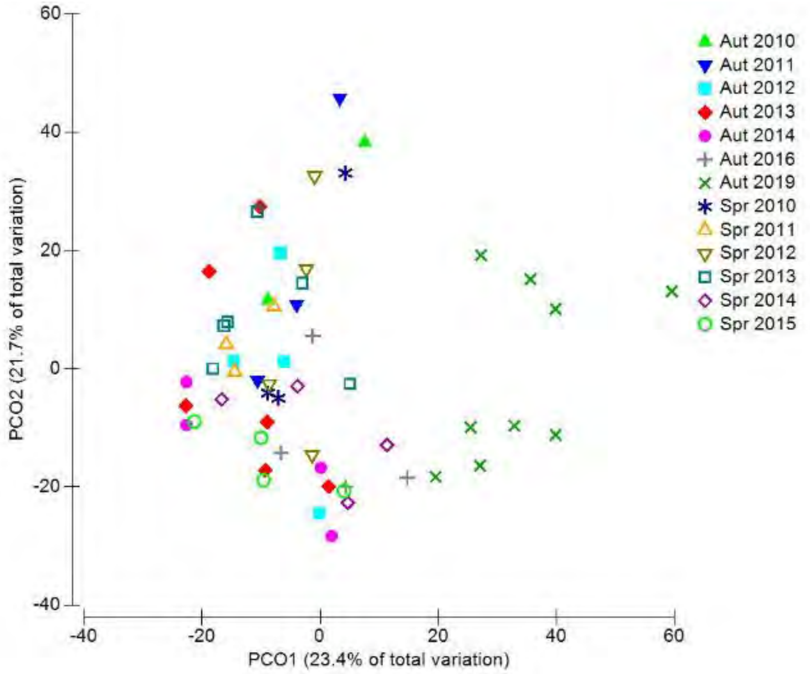


Figure 3-8 PCO plots comparing the multivariate structure of the aquatic macroinvertebrate fauna at a) each site and b) each survey between 2010 and 2016 and in 2019. Samples that have similar assemblages are grouped together on the graph, while those with dissimilar assemblages are relatively distant from each other.

Previously in May 2005, AUSRIVAS macroinvertebrate samples were collected from edge habitats in the upper reaches of Wolgan River as part of a study to determine whether the Colo River and its sub-catchments met the wild river criteria (DECCW 2008). Samples collected from sites within Wollemi National Park were similar to the AUSRIVAS reference condition, however, those from Newnes, just outside the national park, and Wolgan Gap gave mixed results, with some indicating slight impairment relative to the reference condition and others a slightly more diverse fauna. The overall results indicated that this section of river was in good condition with high aquatic biodiversity and that the condition of the river improved as it entered the national park.

3.5.2 Quantitative Collectors

The mean (± standard error (SE)) number of macroinvertebrates sampled at each of the sites is provided in **Appendix E**. A total of 36 taxa (including four sub-families of chironomid or non-biting midges) were identified from the samples, with the mean number of taxa identified at each site ranging from 4.9 to 9.7 (**Figure 3-9a**). Aside from any sub-families of chironomid (chironomids were not identified to sub-family in the AUSRIVAS samples), four taxa identified from the collectors were not found in the AUSRIVAS samples. These were Hirudinea (leaches), Macromiidae (a family of dragonfly), Nematoda (unsegmented worms) and Odontoceridae (a family of caddis fly) at WRocr. WRocr was not sampled using AUSRIVAS. The fourth taxon was Philopotamidae (a family of caddis fly) at CCXdn. The most abundant taxa were chironomids (**Figure 3-9b**), oligochaetes (segmented worms) (**Figure 3-9c**) and leptophlebiids (a family of mayfly) (**Figure 3-9d**), representing 90 % of total macroinvertebrate abundance across all samples. Each of these taxa are known to respond to changes in water quality and/or habitat condition and their abundances can provide indicators of stream health as part of ongoing monitoring programs.

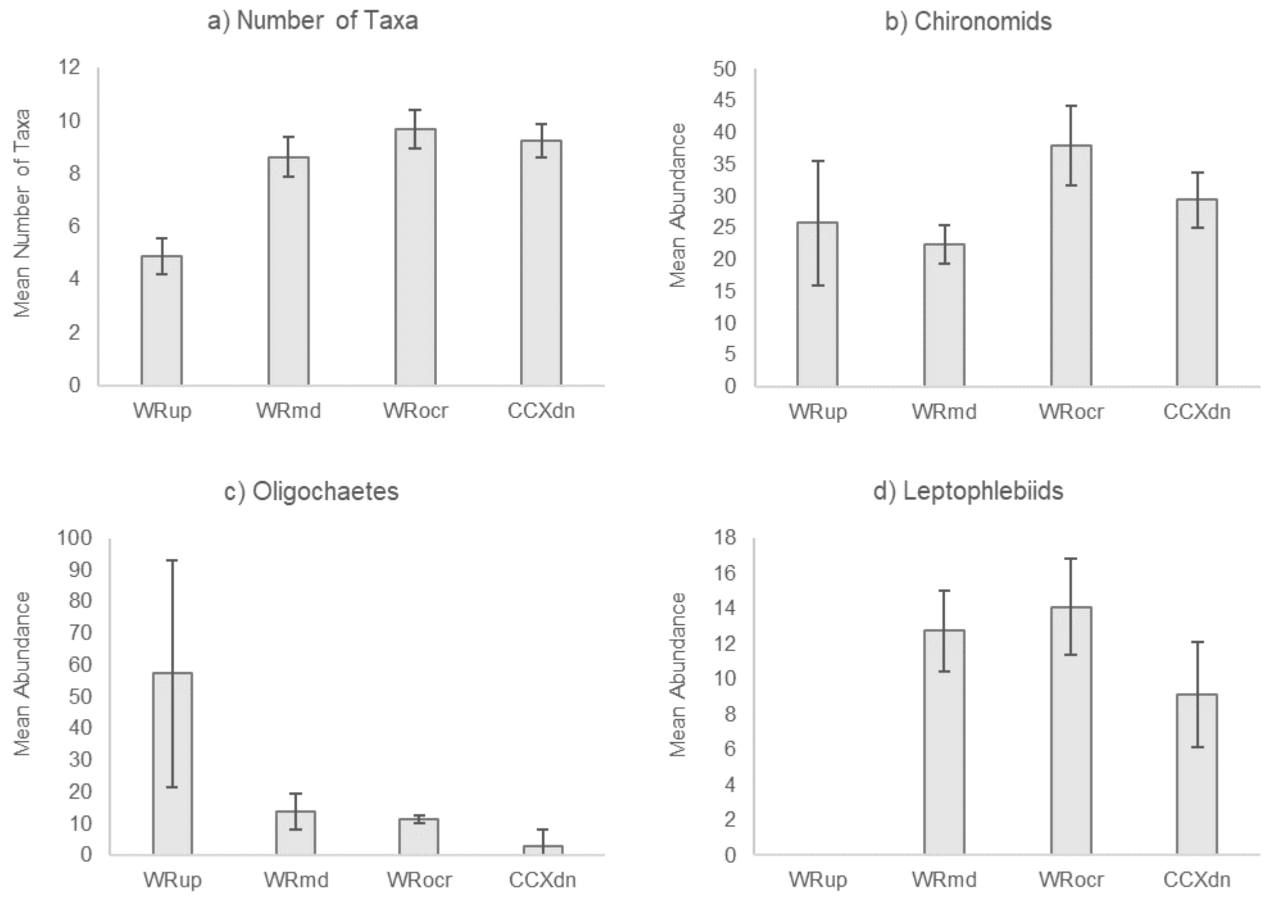


Figure 3-9 a) mean number of taxa and mean number of b) chironomids, c) oligochaetes and d) leptophlebiids identified on the artificial macroinvertebrate collectors deployed at WRup, WRmd, WRocr and CCXdn. Number of samples (n) is 8 except for WRocr where n = 12. Bars indicate standard error.

The PCO (**Figure 3-10**) indicated that macroinvertebrate assemblages at WRup differed from those at the other sites, with points from WRup tending to group towards the top right, and those from the other sites to the bottom left, of the PCO. Assemblages also appeared more variable at WRup compared to the other sites. This pattern was similar to that observed in the AUSRIVAS assemblage data (**Section 3.5.1**), with WRup tending to differ from all other sites sampled. It is probable that this is at least partly due to differences in habitat between these sites, particularly the presence of still pool habitat at WRup compared with flowing water at each of the other sites sampled.

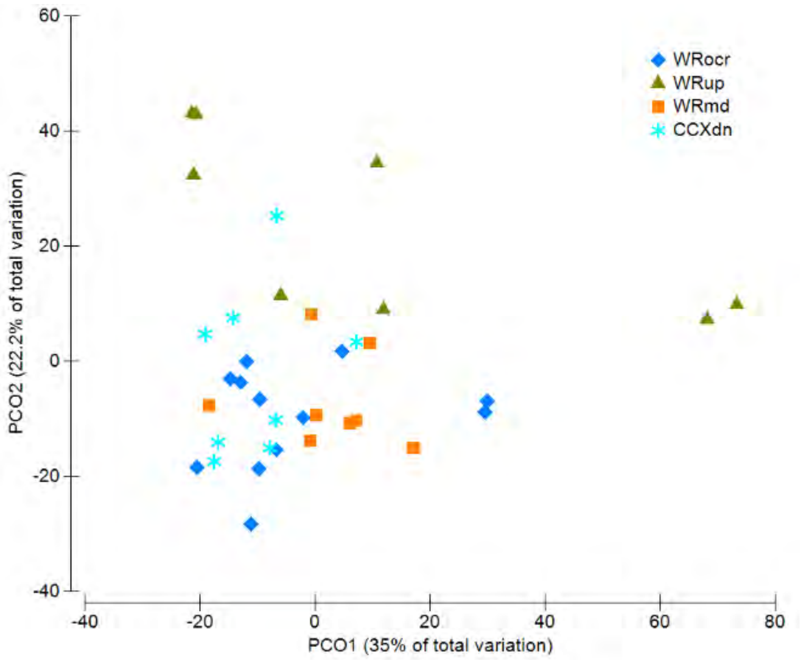


Figure 3-10 PCO plot comparing the multivariate structure of the aquatic macroinvertebrate fauna sampled using artificial macroinvertebrate collectors in autumn 2019. Samples that have similar assemblages are grouped together on the graph, while those with dissimilar assemblages are relatively distant from each other.

3.6 Fish

Cumberland Ecology (2006) includes report from NSW DPI (Fisheries) of several fish species that occur or occurred historically, in the Wolgan River (**Table 3-4**). There are no records of Macquarie perch and Australian grayling from within the Study Area and it is highly unlikely that they occur here (**Sections 3.8.1** and **3.8.2**). The watercourses in the Study Area do not provide suitable habitat for these species

Table 3-4 Species of fish reported to occur currently and or historically in the Wolgan River. From Cumberland Ecology (2006)

Common Name	Scientific Name	FM Act Listing	EPBC Act Listing
Macquarie perch	*Macquaria australasica*	Endangered	Endangered
Australian grayling	*Prototroctes maraena*	Endangered	Vulnerable
Short-finned eel	*Anguilla australis*		
Long-finned eel	*Anguilla reinhardtii*		
Climbing galaxias	*Galaxias brevipinnis*		
Mountain galaxias	*Galaxias olidus*		
Common Carp	*Cyprinus carpio*		
Eastern gambusia	*Gambusia holbrooki*		

A freshwater eel (*Anguilla* sp.) was caught at WRmd in spring 2010 and there is a 2018 record of shortfinned eel (Anguilla australis) in Wolgan River at WRup (ALA 2019). Fish and larvae, most likely mountain galaxias (*Galaxias olidus*), were sighted in Carne Creek in spring 2012.

The diversity and abundance of fish is also likely to have been impacted by weirs and other constructed damming structures on the Wolgan River towards Newnes hindering or preventing upstream migration from the Colo River.

There is also a 1978 Australian museum record of Sydney crayfish (*Euastacus australasiensis*) approximately 100 m west of the southern tributary of Twin Gully Swamp (ALA 2019). This crayfish is also found in the Blue Mountains where it can be a bright red colour. It is found in freshwater creeks and also in upland swamps where it may form burrows. Here they would be groundwater dependant. Freshwater crayfish (Family Parastacidae) were identified from TGS in autumn 2013 (MPR 2013b), TRIS in spring 2013 (MPR 2014a), BRS in autumn (May) 2014 (MPR 2016b), at TGS in autumn 2016 (MPR 2016b) and at each of these sites in spring 2016 (MPR 2016c).

3.7 Stygofauna

3.7.1 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 may 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.

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).

3.7.1 Environmental Tolerances of Stygofauna and Suitability of the Study Area

Deep groundwater systems, anoxic groundwater, groundwater EC exceeding 3,000 µS/cm, or outside pH 4.3 to 8.5 are thought to be generally unsuitable for stygofauna (**Table 3-5**).

Table 3-5 Summary of chemical and physical conditions considered suitable for stygofauna. Below ground level = bgl.

Characteristic	Reported Conditions Conducive to Stygofauna	Characteristics of Known Aquifers in the Study Area		
		Perched Swamp	Shallow Regional Groundwater System (Primarily Banks Wall Sandstone)	Deep Groundwater System (Inc. Coal Measures)
Groundwater quality (EC µS/cm)	< 3,000[1] < 5,000[2]	22 to 105[3] 34[4]	20 to 71[3] 23 to 45[4]	856 to 1,289[3] 1,045 to 3,584[4]
Groundwater quality (pH)	Known range: 4.3 to 8.5 units[2]	4.7 to 6.6[3] 4.6[4]	4.6 to 6.5[3] 4.6 to 8.1[4]	7.2 to 7.8[3] 8.5 to 12.4[4]
Groundwater quality (DO)	> 0.3 mg/L[2] (approximately < 3 % saturation)	37.4[4]	38 to 80[4]	7.4 to 80[4]
Depth of groundwater body	< 10 m bgl, rarely found > 100 m bgl	< 5 m	100 m to 300 m	230 m to 324 m
Geology	Presence of 1 mm or greater size cavities and interstices. Occur occasionally in coal seam aquifers[2]	Presence of medium to coarse grained sandstone[5] suggests presence of suitable cavities / interstices		Presence of suitable cavities / interstices less likely than for sandstone
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.	Well connected with surface water	Some limited connection of the upper layer with surface water, deeper sections are increasingly less well connected due to presence of claystone / siltstone aquitards	Minimal connection to overlying aquifers and surface water due to claystone aquitards

Hancock and Boulton (2008) in (ALS 2010)[1], ACARP (2015)[2], Palaris (2013)[5]

[3]Range of 10th and 90th percentile values (Jacobs 2019a) sampled bores TG01, TG02, TS01 to TS03 and XS1 in perched swamps, bores AP1204, AP4PR, AP5PR, AP8PR and AP9PR in the shallow regional groundwater system and bore 940 in the deep groundwater system.

[4]Range of groundwater water quality data collected by GHD during stygofauna sampling 2016 to 2019 (**Section 3.2.2.2**) from bores TG01, TS03 and XS1 in perched swamps, bores AP10PRB, AP1105SP, AP4PRB, AP5PR, AP9PR and KV_MB2D in the shallow regional groundwater system and SPR1801, SPR1802 and SPR1803 in the deep groundwater system.

The tendency for stygofauna to be more abundant and common in shallower aquifers is generally due to oxygen and nutrient concentrations being greatest in shallow aquifers compared with deeper aquifers (Humphreys 2006). Comparison of these tolerances with measures of the groundwater quality in aquifers in the Study Area suggest that conditions for stygofauna would be suitable within the perched swamp aquifers and within the shallow regional groundwater system, where EC, pH and DO were measured within ranges considered suitable. The greater depth of the shallow regional groundwater system, however, make this aquifer less suitable than the shallower perched aquifers. EC and pH measured from bores that access the deeper groundwater system are general greater than that measured in the shallower aquifers. There was also an indication DO may be lower, at least on occasion, in the deeper aquifers, though not outside the range thought to be suitable for stygofauna. The upper range of EC measured in the deep groundwater system appeared to be at the upper end of what would be considered suitable for stygofauna, and the pH measured here was outside what would be considered suitable. These findings suggest that the deep groundwater system may be sub-optimal, at best, for stygofauna. In particular, the pH measured here (albeit in limited locations, i.e. bores, and sampling events) suggest the aquifers here would be unsuitable habitat for stygofauna. In general, the geological characteristics (size of cavities / interstices and hydraulic connectivity) of the aquifers do not preclude the presence of stygofauna. The apparent larger cavity / interstices size and greater hydraulic connectivity associated with the perched swamp and shallow regional groundwater system suggests these aquifers are more suitable for stygofauna compared with the deep groundwater system.

3.7.2 Field Survey Results

Up to seven stygofauna taxa were identified from groundwater bores at Angus Place **Table 3-6**. Four of these and a further three taxa were sampled at bores from Airly, Neubeck and Springvale mines. Nematodes (worms), Cyclopoida (an order of planktonic copepod crustaceans) and Haplotaxidae (a family of aquatic oligochaetes) were the most widespread, and occurred in at least two bores from Angus Place and in bores from at least one other mine area. Bathynellidae (an order of groundwater dwelling syncarid crustaceans) were also found at Angus Place and Neubeck mines. Two taxa were found at Angus Place only, these were ostracoda (a class of planktonic crustaceans) and Naididae (a family of clitellate oligochaete worms). Two taxa were also found at Neubeck mine only, these were Turbellaria (a class of flatworms – phylum: Platyhelminthes) and Cyclopidae (a family of planktonic copepod crustaceans), and once taxa was found at Airly Mine only, this was Meilitidae (a family of amphipods). Oligocheates were also found in one bore at Angus Place, and it is possible these may have ben Haplotaxidae or Naididae. It is also possible that the cyclopoida identified from Angus Place, Airly and Springvale mines were cyclopids (i.e. the same as those identified from Neubeck Mine).

These findings suggest that the stygofauna assemblage present in aquifers in the Application Area are largely comparable to that present at the other mine areas. The one taxon, copepod, found at Angus Place only are common stygofauna taxa found throughout Australia (Hose *et al*. 2015). It is noted, however, that differences in the numbers of bores sampled and the number of sampling events in each mine area (**Table 3-2**) and difference in aquifer type, bore characteristics and survey methodology and the coarse taxonomic resolution hinders examination of the presence / absence of different taxa among these different mine areas.

Table 3-6 Total numbers of each taxa considered to be or likely to be stygofauna caught in groundwater bores in the Angus Place Project Application Area in at other mines operated by centennial in the regional area. Only bores where stygofauna were caught are included. See **Table 3-2** for a list of all bores that have been sampled for stygofauna.

Mine	Bore ID	Date	Oligochaetes			Platyhelminthes	Nematoda	Ostracoda	Copepods		Syncarida	Amphipoda
			Oligochaeta	Naididae	Haplotaxidae	Turbellaria	Nematoda	Ostracoda	Cyclopoida	Cyclopidae	Bathynellidae	Melitidae
Full Counts												
Angus Place	XS01	Jul2019							3			
Angus Place	AP9PR	Jul2019							2			
Angus Place	TS03	Jul2019		2								
Angus Place	TS03	Aug2018			1							
Angus Place	TS03	Mar2019		3								
Angus Place	AP10PRB	May2012									1	
Angus Place	AP5PR	May2012					1					
Angus Place	TS01	May2012	2				298		1			
Angus Place	TS02	May2012					1					
Angus Place	TS03	May2012						1				
Airly	ARP15SP	Mar2019										3
Airly	ARP11	Nov2018							2			
Neubeck	NEU01	Aug2018			2	15				10	8	
Neubeck	NEU01	Feb2017								4		
Springvale	SPR1601	Mar2019							5			
Springvale	SPR1601	Jul2019							4			
Springvale	RSS	Aug2018					40					
Springvale	CC1	Aug2018					20					
Springvale	CC1	Feb2017			5							
Springvale	SPR1211SP	Feb2017			5							
Presence (X) / Absence in Each Mine Area												
Angus Place			X	X	X		X	X	X		X	
Airly									X			X
Neubeck					X	X				X	X	
Springvale					X		X		X			

Table 3-7 Compares stygofauna data from groundwater bores sampled in shallow regional groundwater and perched swamp aquifers Angus Place, for comparative purposes in bores in the deep groundwater system in the Springvale Mine area (for bores where stygofauna were caught, and where they were not) with information on bore characteristics (e.g. screened interval, mesh of screen, if any) and groundwater quality sampled from each bore. It is apparent that the greatest number of taxa were sampled from bores in perched aquifers in swamps (total of 9 sampling events across the 5 bores), with six of the seven taxa identified from Angus Place. The one taxa not sampled from the perched swamps was Bathynellidae, sampled from bore AP10PRB within fractured rock in the shallow regional groundwater system (40 m deep). Overall, three taxa were sampled from the shallow regional groundwater system (22 sampling events across 7 bores), and none were sampled from the deep groundwater system (6 sampling events from 3 bores).

Table 3-7 Comparison of the groundwater bore and aquifer characteristics where stygofauna have and have not been found in shallow regional groundwater and perched swamp aquifers in the Angus Place Application Area and for comparative purposes in the deep groundwater system in the Springvale Mine area. Per. = perched swamp, FR = sandstone rock and DSR = deep sandstone rock.

Bore ID	Aquifer Type	Depth / Screened Interval (mbg)	EC (Jacobs 2019a)	pH (Jacobs 2019a)	EC (GHD)	pH (GHD)	DO (% Sat.) (GHD)	No. Sampling Events	Ostracoda	Oligochaeta	Turbellaria	Nematoda	Naididae	Melitidae	Haplotaxidae	Cyclopoida	Cyclopidae	Bathynellidae
Perched Swamp Aquifers (Angus Place Mine)																		
TG1	Per.	1	45	5.6	33	4.6	37.4	1										
TS01	Per.	4	27	5.2				1		2		298				1		
TS02	Per.	2	57	6.0				1				1						
TS03	Per.	2	46	5.0	41	6.6	33.6	5	1				5		1			
XS01	Per.	2	54	5.5	43	4.7	37.3	1								3		
Shallow Regional Groundwater Aquifer (Angus Place Mine)																		
AP10PRB	SR	40 m			30	5.2	55.3	5										1
AP1105SP	SR	60-75			35	5.8	64.7	4										
AP4PR	SR	36-51	31	5.4				1										
AP4PRB	SR	51			46	5.1	65.5	1										
AP5PR	SR	79-94	26	5.0	30	5.8	59.9	5				1						
AP9PR	SR	67-82	46	4.8	34	5.3	49.9	2								2		
KV_MB2D	SR	16-19			256	6.2	9.2	4										
Deep Aquifer System (Springvale Mine – for Comparative Purposes)																		
SPR1801	DSR	306-324			1,231	8.8	7.9	2										
SPR1801	DSR	309-318	1,116*	7.5*	3,537	12.1	23.7	2										
SPR1803	DSR	230-242			1,072	9.7	9.9	2										

*From Bore 940, which was not sampled for stygofauna.

Abundances were comparable across taxa and bores / aquifers, with the one exception of nematoda, which were far more abundant in TS01 than in AP5PR. Nematodes are also common stygofauna taxa found throughout Australia (Hose *et al*. 2015). These findings are supportive of the assessment of the suitability of aquifers in the Study Area as habitat for stygofauna (**Section 3.7.1**); with the perched aquifer system providing the most suitable habitat, followed by the shallow regional groundwater system and the deep aquifer system (where none were found, albeit associated with slightly less sampling effort compared with that for the other aquifers).

3.8 Threatened Species

3.8.1 Macquarie Perch

Macquarie perch (*Macquaria australasica*) is listed as Endangered under the FM Act and EPBC Act. Macquarie perch is an elongated, oval shaped fish with a rounded tail and large eyes and mouth. It can grow to 55 cm and 3.5 kg in weight but it generally occurs at less than 40 cm and 1 kg (NSW DPI 2016). It prefers clear water and deep, rocky holes with extensive cover in the form of aquatic vegetation, large boulders, debris and overhanging banks and it is found in both river and lake habitats, especially in the upper reaches of rivers and their tributaries (DPI 2016). It spawns in spring or summer and lays eggs over stones and gravel in shallow, fast-flowing upland streams or flowing parts of rivers. Macquarie perch inhabiting impoundments would likely undertake upstream spawning migration in October to mid-January after which adults usually return to the impoundments. Migration may not be necessary in stream-dwelling fish. Macquarie perch is an active predator of macroinvertebrates. While other large-bodied perch-like fish 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 has a mean linear diel range of 516 m (± 89 S.E.) which suggests that small and discontinuous pools would not provide preferred habitat for this species (Ebner *et al*. 2010).

The predicted habitat distribution of Macquarie perch includes the section of Wolgan River approximately 10 km upstream of its confluence with Colo River (NSW DPI 2016). This is over 25 km downstream of the Study Area. The weir present on the Wolgan River at Old Coach Trail road would also likely prevent upstream movement of Macquarie Perch into the Study Area. No known records were found from the Wolgan River, and the nearest recent record in the ALA database (ALA 2019) is from Bowens Creek near Bilpin approximately 50 km to the southeast.

3.8.2 Australian Grayling

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). 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.

In NSW the predicted habitat distribution of Australian grayling is restricted to coastal streams south of approximately Wollongong (NSW DPI 2016). Recent records existing only from coastal streams (ALA 2019). As Australian Grayling are highly unlikely to occur within the Study Area, further consideration of this species is not considered necessary.

3.8.3 Sydney Hawk Dragonfly

The Sydney hawk dragonfly (*Austrocordulia leonardi*) is listed as Endangered under the FM Act. 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. 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. 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). There are no records for this species within the Study Area or Wolgan River Catchment (ALA 2019).

Sydney hawk dragonfly is threatened by habitat loss and degradation resulting from the removal of riparian vegetation, drainage works, sedimentation, and river regulation and alteration of flows that cause the disappearance of natural deep pools.

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.

3.8.4 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 2013). 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 (ALA 2019), though its potential distribution includes the majority of the Hawkesbury-Nepean Catchment, including that within the Study Area (NSW DPI 2013).

Larvae have been found in narrow, shaded riffle zones with moss and abundant riparian vegetation (often closed canopy) in small to moderate sized creeks with gravel or sandy bottoms (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.

Adam's emerald dragonfly are threatened from habitat degradation resulting from removal of riparian (river bank) vegetation, drainage works, water pollution and sedimentation due to land clearing, waste disposal and stormwater runoff from urban, industrial and agricultural development in the catchment.

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.

4 Impact Assessment

4.1 Predictions

4.1.1 Physical Characteristics

The longwall layout has been designed to avoid or minimise impacts on major watercourses and the Garden of Stones National Park, incorporating setback from these areas. The longwalls are not located directly beneath Wolgan River or Carne Creek. At its closest point, the Wolgan River it is located 180 m from the longwalls (from Longwall 1002). The main channel of Carne Creek is situated to the southeast of the proposed longwalls at a minimum distance of 900 m from Longwall 1001. A number of unnamed first, second and third order drainage lines are, however, located above the proposed longwalls and it is not possible to design a feasible mine layout that will avoid all these watercourses.

The total length of watercourses of each stream order directly above the proposed longwalls, within the Study Area (i.e. within 600 m of the proposed longwalls), between the Study Area boundary and the 26.5° Angle of Draw, within the 26.5° Angle of Draw and within the wider catchment is provided in (**Table 4-1**). This includes the second, third and fourth order sections of Wolgan River that are located within the Study Area (approximately 2.8 km total watercourse length) and the first, second, third and fourth order sections of drainage lines assessed individually by MSEC (2019):

> Drainage lines 4 and 5, tributaries of Carne Creek with confluences north of the Study Area;

> Drainage lines 3a and 3b that flow through Twin Gully Swamp;

> Drainage lines 2a and 2b that flow through Tri-Star Swamp;

> Drainage line 6 that flows through Bird Rock Swamp; and

> Drainage line 1, a tributary of Carne Creek with a confluence to the southeast of the Study Area.

Table 4-1 Lengths of watercourse of each stream order in the wider catchment (surrounding 600 km^2 area), within the 26.5° Angle of Draw, between the 26.5 Angle of Draw and Study Area, and within the entire Study Area. The relative affected length is the percentage (%) of the length within the Study Area compared with that in the wider catchment.

Stream Order	Total in Wider Catchment (km)	Within 26.5 Angle of Draw (km)	Between the 26.5 Angle of Draw and Study Area (km)	Total in Study Area (km)	Relative Affected Length (%)
1	1,146	32.6	16.4	49.0	4.3
2	421	13.9	6.8	20.8	4.9
3	200	2.8	0.9	3.7	1.9
4	103	0.0	2.7	2.7	2.6
5	63	0.0	1.5	1.5	2.3
6	68	0.0	0.0	0.0	0.0

The first and second order drainage lines, including those located upstream of the swamps, are ephemeral and surface water generally flows during and for short periods after rain events (MSEC 2019). The third and fourth order sections are located within and downstream of the swamps.

The predictions of physical mining impacts expected to occur in Wolgan River and in drainage lines of Wolgan Rover and Carne Creek are provided in **Table 4-2**. It is possible that minor fracturing may occur in Wolgan River where it is closest to the proposed longwalls (i.e. next to the southwest west corner of Longwall 1002). The section of Wolgan River at this point is second order. Any fracturing is, however, expected to be minor and not result in adverse impacts on surface flow (MSEC 2019). It is unlikely that fracturing would occur elsewhere in Wolgan River.

It is likely that fracturing would occur along the drainage lines within the Study Area. This would predominantly occur directly above the longwalls. It could also occur up to 600 m away, though based on previous monitoring at other longwall mines fracturing greater than 400 m away is unlikely. Surface water flow diversions could occur along the sections of drainage lines where fracturing occurs. This would be most noticeable during periods of low flow. In times of heavy rainfall, the majority of flow would not be diverted into the dilated strata below. Due to its distance from the longwalls, Carne Creek is predicted to experience negligible conventional and valley related effects. It is unlikely, therefore, that Carne Creek would experience adverse physical impacts due to the extraction of the proposed LW1001 to LW1015 (MSEC 2019). Indirect impacts to flow could occur (**Table 4-2**).

Table 4-2 Physical mining impacts predicted to occur in watercourses within the Study Area (MSEC 2019)

Watercourse(s)	Changes in Grade and Alignment	Potential for Fracturing and Flow Diversion
Wolgan River	The predicted mining-induced changes in grade are very small when compared with the natural gradient of the Wolgan River. It is unlikely, therefore, that there would be adverse changes in the levels of ponding, flooding or scouring of the riverbanks due to the extraction of the proposed longwalls. The potential changes in stream alignment are expected to be very minor when compared with the changes in the surface water flow depths and widths that occur during natural flooding events. The increased flow velocities in such events are likely to be an order of magnitude greater than those resulting from mining induced changes to bed gradients.	It is possible that fracturing could occur along the section of the Wolgan River to the south of Longwall 1002, where it is located closest to the proposed mining area. However, the fracturing is expected to be minor and not result in adverse impacts on the surface water flows. Elsewhere, it is considered unlikely that fracturing would occur along the river due to its distance from the proposed mining area.
Drainage Lines (i.e. all watercourses not including the main channels of Wolgan River and Carne Creek)	The predicted post-mining grades are similar to their natural grades. There are no predicted significant reductions or reversals of stream grade. It is not expected, that there would be adverse changes in ponding or scouring along the drainage lines resulting from the mining-induced tilt. It is possible that there could be localised areas along the drainage lines that could experience small increases in the levels of ponding, but any localised changes in ponding are expected to be minor and not result in adverse impacts on the drainage lines.	It is likely that fracturing would occur along the drainage lines above the proposed longwalls. Minor and isolated fracturing could also occur at distances up to approximately 400 m from the longwalls. Fracturing could result in flow diversions in these sections of drainage lines

4.1.2 Water Flow, Availability and Quality

Interactions between surface and groundwater on the Newnes Plateau involve recharge to shallow groundwater aquifers and groundwater discharge to surface water (Jacobs 2019b). Groundwater discharge to surface water can occur as seepages from exposed cliff faces and bedrock in drainage lines. These discharges contribute to the establishment of hanging swamps and shrub swamps and to surface flow in drainage lines. Extraction of the proposed longwalls is expected to result in disturbance to aquifers resulting in groundwater depressurisation and associated reductions in surface flow in watercourses.

Stochastic modelling of surface flows undertaken by Jacobs (2019b) indicated the following potential for decreases in surface flows due to groundwater depressurisation:

> Wolgan River Catchment: Up to approximately 9 % reduction in surface flow Wolgan River just downstream of Twin Gully Swamp, reducing to an approximate 2 % reduction downstream of the Study Area. A minor 8 % reduction in surface flow upstream of Twin Gully Swamp and up to a 28 % reduction upstream of Tri-Star Swamp. There could also be a reduction in surface flows of up to 15 % in Japan Swamp (also known as Trail Six Swamp) located within the Study Area just north of the proposed longwalls.

> Carne Creek Catchment: Up to approximately 4 % reduction in surface flow in Carne Creek adjacent to and downstream of the Study Area, 19 % reduction in associated drainage line to the east of the longwalls and a 15 % reduction in associated drainage line to the north of the longwalls.

Jacobs (2019b) undertook assessment of impacts to stream geomorphology and flow due to predicted subsidence. No more than minor changes to the volume and timing of run-off did were predicted. Predicted changes in peak flow were typically less than 4 % and although localised increases and decreases in stream power could occur, this was not considered to represent a significant additional erosion risk, particularly given the dense riparian vegetation and undisturbed channels. Areas with larger predicted change in stream power would be monitored during mining to assess whether significant scouring or sedimentation is occurring.

Groundwater depressurisation would also result in a reduction in the water table and a reduction in groundwater levels in swamps. The maximum predicted water table decline beneath Tri Star Swamp is 10 m for the 10th percentile drawdown, with up to 5 m drawdown predicted at Twin Gully and Trail Six Swamps

(Jacobs 2019a). For the 90th percentile decline, the maximum predicted drawdown is 5 m at Tri Star Swamp and Twin Gully, and 0.5m at Japan Swamp. It is noted that the greater magnitude drawdowns are associated with greater areas of effect. Water level declines of this magnitude are likely to result in a corresponding decline of swamps water levels leading to the drying or partial drying of the swamps. No significant water table decline is predicted beneath the Wolgan River.

It is noted that all proposed surface infrastructure, including access corridors, will be located on elevated ridges and plateaus and that there will be no disturbance within or in close proximity to waterways (Jacobs 2019b). Therefore, there is low potential for input of sediments to waterways to occur due to the establishment and operation of surface infrastructure. Although mine subsidence effects can result in isolated, episodic pulses in iron, manganese, aluminium and electrical conductivity, there have been no reports such local surface water quality impacts due to sedimentation and subsidence following previous mining at Springvale or Angus Place and such changes in water quality are not expected (Jacobs 2019b). There is potential for acid generation within the mine voids and contributing overlying unsaturated formations. The potential for this will be assessed and managed at the mine closure planning stage. (Jacobs 2019a). Nevertheless, groundwater monitoring at Angus Place and Springvale Mine has not identified any water quality impacts to groundwater as a result of mining and accordingly, no future impacts to groundwater are anticipated during operation.

4.2 Impacts on Aquatic Ecology

4.2.1 Watercourses

4.2.1.1 Habitat and Biota

The greatest potential for fracturing in Wolgan River would be in the section located closest to Longwall 1002. If it occurred, fracturing would be minor and not expected to result in adverse impacts to surface water flow (**Section 4.1.1** and MSEC 2019). Given there would be no adverse impacts to flow, fracturing, if it occurred, would not be expected to result in associated reductions in the availability of aquatic habitat and associated impacts (such as reduced population sizes) of biota in the river. Furthermore, the aquatic habitat provided by this second order section of the Wolgan River within its headwaters is relatively limited, and consists of disconnected pool habitat with minimal observable flow. Any impacts would therefore have relatively minor consequences for the aquatic ecology of the river as a whole. It is considered unlikely that fracturing and flow diversions would occur elsewhere in the river and associated impacts to aquatic habitat and biota are not expected. Likewise, impacts to aquatic habitat and biota in Carne Creek are unlikely to occur, as fracturing and flow diversions are not expected in the creek due to its distance from the proposed longwalls.

Reductions in surface flow in Wolgan River and Carne Creek associated with groundwater depressurisation are expected, but these reductions are relatively minor. Reductions in Wolgan River also appear largely localised to the section just downstream of Twin Gully Swamp, and are far less noticeable downstream of the Study Area. The 9 % reduction predicted for the Wolgan River just downstream of Twin Gully Swamp may result in some reduction in the availability of aquatic habitat, most likely during drier months, and may result in the reduction in population size of aquatic biota such as crayfish and other aquatic macroinvertebrates. Such impacts would likely have minor consequences for the wider populations of aquatic biota in the river and would largely be restricted to the section just downstream of Twin Gully Swamp. In Wolgan River downstream of the Study Area, reductions in baseflow are predicted to be 2 %, which would be expected to result in negligible reductions in the availability of aquatic habitat and associated impacts to aquatic biota. Similarly, the 4 % reduction in surface flow predicted for Carne Creek would be unlikely to result in more than minor reductions in the availability of aquatic habitat and or more than minor associated impacts to aquatic biota.

More substantial reductions in the availability of aquatic habitat is expected to occur in first, second, third and fourth order drainage lines directly above and within 600 m of the proposed longwalls. This would be most noticeable in those sections direct above the longwalls that are expected to experience fracturing and flow diversions (**Section 4.1.1** and MSEC 2019). Reductions in habitat availability due to fracturing and flow diversions may also occur in these drainage lines up to 600 m from the longwalls. Reductions in surface flow in these watercourses would also occur do to groundwater depressurisation, with a reduction in surface flow in swamp associated drainage lines of up to 28 % (**Section 4.1.1** and MSEC 2019) (these predictions do not include any loss of flow that could occur due to fracturing and flow diversions). The aquatic habitat provided by first and second order drainage lines in the Study Area would be relatively limited, and likely mostly ephemeral and flow only for short periods following rainfall. They would provide temporary aquatic habitat but likely only for a relatively limited number of species able to utilise ephemeral habitat, such as flying insects with short aquatic larval stages. These watercourses would provide sub-optimal, at best, habitat for fish and crayfish. Given this habitat follows a natural wetting and drying cycle, and that aquatic biota present here would be adapted to such conditions, an increase in the number and during of dry periods brought about by fracturing and flow diversions would likely have limited consequences for such biota, compared with those present in and adapted to more permanent aquatic habitat in perennial watercourses.

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. The survival times of mobile animals are likely to be longer on cool and rainy days than on hot days. More hardy species, such as freshwater crayfish, may be able to relocate to other areas of aquatic habitat. These species can also withstand periods of drought by retreating into their burrows. If present, species of fish, such as freshwater eels, may also be able to relocate provided sufficient damp surfaces are available (McDowall 1996). It is possible that mobile species may be able to move to nearby areas unaffected by habitat loss due to flow diversions. In 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 would be lost due to the fracturing and reductions in water levels. Any biota associated with disconnected pools in ephemeral drainage lines directly above the proposed longwalls would also be impacted.

Third order and higher sections of drainage lines direct above the longwalls provide more substantial, though still relatively limited aquatic habitat, compared to that provided by the main channels of Wolgan River and Carne Creek. For example, the sections of watercourses that flow through Twin Gully Swamp and Tri-Star Swamp provide more permanent habitat, and appear perennial, although they are generally shallow (generally less than 10 cm deep, and in places only a few centimetres) and narrow, with silt, sand and gravel substratum. These watercourses provide habitat for a relatively diverse aquatic macroinvertebrate assemblage and likely also freshwater crayfish (*Euastacus* sp.), which would also be found in nearby saturated swamp habitats. Fracturing, flow diversions, and reductions in baseflow associated with groundwater depressurisation are likely to result in reductions in surface flow to the extent that these habitats would be lost, with associated reductions in the population sizes of these aquatic biota. Some fish, such as mountain galaxias, gudgeons or eels may use some deeper sections closer to the main channels of Wolgan River and Carne Creek. However, these areas are unlikely to support substantial fish populations and associated impacts to fish due to loss of this habitat would be minor.

While the loss of the aquatic habitat provided by the drainage lines would be relatively severe at the scale of individual drainage line, such impacts would be largely restricted to the sections affected directly by fracturing and flow diversions and are not expected, or would be far less severe, in the main channels of Wolgan River and Carne Creek. Further, the abundance of similar drainage line habitat in the wider catchment would suggest such impacts would be very small in the context of the local and regional area. Approximately 38 km of watercourse is located directly above the proposed longwalls, with a total of 81 km within the Study Area (**Table 4-1**). This represents less than 5 % of that present within the surrounding 600 km^2 wider catchment area. Together with the length of comparable drainage line habitat affected due to previous and planned mining at Springvale Mine (approximately 52 km, 21 km and 4 km of first, second and third order watercourse, respectively, is located directly above the Springvale longwalls), this would represent a cumulative loss of approximately 10 % of such habitat within the wider catchment area.

No more than 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. No impacts to water quality associated with potential sedimentation to subsidence are expected, therefor there would no associated impacts to aquatic habitat and biota in watercourses.

4.2.1.2 Key Fish Habitat and Threatened Species

There are unlikely to be any substantial impacts to the Wolgan River and Carne Creek KFH and Type 1 – Highly Sensitive KFH given the low likelihood and limited extent of predicted fracturing and only minor potential changes in flow expected. Approximately 3 km of Type 2 – Moderately Sensitive KFH located directly above the longwalls is likely to be impacted by fracturing and flow diversions. Type 2 – Moderately

Sensitive KFH is abundant throughout the Wolgan River catchment, and the potential loss of a small amount is not expected to have substantial impacts on aquatic habitat and biota.

Watercourses within the Study Area are highly unlikely to provide habitat for the threatened Macquarie perch. Given the habitat requirements of larvae of Sydney hawk dragonfly (deep pools) and Adam's emerald dragonfly (riffle sections), they are also highly unlikely to occur in drainage lines within the Study Area. Such habitats occur in Wolgan River and Carne Creek within the Study Area, though the main channels of these creeks would only experience relatively minor potential changes in surface flow. In any case, both these species of dragonfly appear to have restricted distributions that do not include the Study Area and there are no known records of them occurring here. As such, impacts to these threatened species are not expected and further consideration via Assessments of Significance are unnecessary.

4.2.2 Stygofauna

The findings of the literature review and field surveys indicate stygofauna are present within the perched swamp and shallow regional groundwater aquifers in the Study Area. Stygofauna appear unlikely to occur in the deeper aquifers associated with the coal measures in the Study Area. Although reductions in groundwater availability would likely be more extensive in the deeper aquifers and coal measures compared to the overlying aquifers, impacts to stygofauna due to disturbance of deep aquifers associated with mining are not expected to be significant as these do not provide preferred stygofauna habitat nor were any stygofauna found in deep aquifers during surveys at the nearby Springvale Mine. The shallow regional sandstone aquifer extends for several hundred square kilometres outside of the Study Area and disturbance to this aquifer (primarily due to reductions in groundwater levels) would be relatively minor in this context. It is possible also that stygofauna present in this aquifer would be able to migrate with changes in the water table, assuming hydrogeological conditions were suitable (e.g. cracks / fractures were available for migration to occur). This could limit impacts to stygofauna present in these aquifers, which, in any case, appear to support relatively few taxa and individuals compared with perched swamp aquifers closer to the surface.

At a local scale, impacts to stygofauna present in perched swamp aquifers could be relatively severe. Groundwater depressurisation could result in reductions in the water table of up to 10 m, resulting in the drying of swamps. It is unclear if stygofauna would be able to migrate along with the receding water level and use saturated deep parts of these aquifers. This would also depend on the presence of suitable hydrogeology at these depths. It is possible that the predicted drawdown and drying of swamp habitat would make these areas unsuitable for stygofauna. Smaller reductions in swamp water levels of a few metres may result in less severe impacts to stygofauna, resulting in a reduction in available habitat and associated population sizes, rather than loss of the entire assemblage.

Impacts to stygofauna at the scale of the wider catchment area would depend on the degree of isolation of the swamps that would be impacted to other swamps in the area. Compared with other, more hydrological connected aquifers, the nature of perched swamp aquifers would suggest some degree of hydrological isolation, which could encourage the divergence of unique taxa and a relatively high conservation value at the level of individual swamp aquifers. However, it appears that the perched aquifers present in the Study Area are somewhat connected to the deeper aquifer systems, as depressurisation in deeper aquifers would result in reductions in groundwater levels in swamps. If there was no or limited connection, then depressurisation of deeper aquifers may not be expected to affect water levels in swamps. If hydrological connections exist between swamps via deeper aquifers, then there may not be an opportunity for particularly divergent stygofauna assemblages to develop. The absence of unique taxa and assemblages in individual swamps would limit overall potential impacts to stygofauna biodiversity that could otherwise occur due to loss of habitat in individual swamps.

However, the relatively limited knowledge of stygofauna taxonomy hinders detailed assessment. Based on a relatively coarse assessment of the area of swamp habitat, and thus stygofauna, that would be affected by the Project compared with the area of swamp habitat in the wider catchment, the Project would represent a relatively small impact. The project would affect approximately 5 % of the swamp habitat present in the surrounding 100, 000 ha area (**Table 4-3**). Together with the area of swamp habitat impacted by previous Angus Place and Springvale longwalls, cumulatively, this would represent a total of approximately 170 ha of swamp habitat, or 15.5 % of that present in the surrounding 100,000 ha area. It is unclear, however, whether all the swamp habitat present in this area provides suitable stygofauna habitat, and, if it does, how comparable stygofauna assemblages are across different swamps. Based on this comparison, any potential impacts to stygofauna in these aquifers would be relatively minor relative to the extent of possible stygofauna habitat in the aquifer as a whole.

Table 4-3 Area of swamp (shrub and hanging) in the wider catchment (100,000 ha), the area that would be impacted by Angus Place Extension Project and that previously impacted by mining at Angus Place and Springvale mines

Area	Area of Swamp Within Area (ha)	% of Wider Catchment
Angus Place Extension Project	55.5	5.1
Previously Impacted - Angus Place	10.4	0.9
Previously Impacted - Springvale	103.6	9.5
Wider Catchment	1,094.6	

5 Recommendations

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

- Impact minimisation;
- Aquatic ecology monitoring;
- Additional aquatic ecology studies; and
- Contingency measures should impacts exceed predictions.

5.1 Minimisation

The design of the Project includes measures to avoid or minimise potential impacts on aquatic ecology. These include set back of longwalls from major watercourses 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 minimise the input of sediment into watercourses and perched aquifer systems during rainfall events.

5.2 Monitoring

5.2.1 Outline and Aims

Albeit the Study Area is located in the Western Coalfield, 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 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.

5.2.2 Sites and Timing

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

Monitoring sites should be established in major watercourses (i.e. Wolgan River and Carne Creek) and in sections of the larger drainage lines predicted to experience impacts due to the proposed longwall mining. Although no more than minor reductions in surface flow are predicted for Carne Creek, it is recommended that this creek is monitored for potential impacts to aquatic habitat and biota as a precautionary approach. 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 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. 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 should include a temporally staged monitoring approach that includes impact and control locations relevant to each of the longwalls. Monitoring and surveys at individual sites would be staged relative to the extraction timeline for each longwall.

5.2.3 Indicators and Methods

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

> Aquatic habitat;
> *In situ* water quality;
> Aquatic macrophytes;
> Aquatic macroinvertebrates;
> Fish; and,
> Stygofauna.

5.2.3.1 Aquatic Habitat and Plants

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.

Although no instream aquatic macrophytes have been identified, if any are observed in future surveys their species composition and total area of coverage should be recorded. Features such as the presence of algae or flocculent on the surface of macrophytes should also be noted.

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.

5.2.3.2 Water Quality

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

This aquatic ecology specific water quality monitoring should be undertaken in addition to that outlined in the Project EIS.

5.2.3.3 Aquatic Macroinvertebrates

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

5.2.3.3.1 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 minutes 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.

5.2.3.3.2 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.

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

5.2.3.4 Fish

Fish and large mobile macroinvertebrates (i.e. crayfish and yabbies) should be sampled using a backpack 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 (if present) and wood debris, in deep holes and over bare substratum. The backpack electrofisher should be operated around the edge of pools and in riffles, where present, with eight 150 s 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. Only select sites within Wolgan River are likely to provide suitable habitat for sampling of fish.

5.2.3.5 Stygofauna

5.2.4 Sampling of stygofauna should continue in line with the SMAP to provide at least two years of baseline data and data from during and after extraction of the proposed longwalls. 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. Appropriate aquatic ecology trigger values should be developed following collection of two-years of baseline data. These values may be revised in consultation with relevant stakeholders following analysis of natural variability within the pre-mining baseline data. Each trigger value would correspond to either a negligible or significant impact on the aquatic habitat and/or biota within the Study Area and management actions identified for consideration if thresholds are exceeded.

5.3 Contingency Measures

In the event that impacts of extraction of the proposed longwalls on aquatic habitats and biota in Wolgan River, Carne Creek and their major tributaries (third order and higher tributaries associated with Twin Gully, Tri-Star and Bird Rock swamps) 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
- Implementing appropriate control measures, such as installation of sediment fences down slope of areas where subsidence has led to erosion and stabilisation of areas prone to erosion and soil slumping using rock, brush matting or vegetation, to limit the potential for deposition of eroded sediment into the watercourses.

5.4 Offsetting

The Project would not require biodiversity offsets associated with threatened species, populations or communities listed under the FM Act or EPBC Act as significant impacts to these are not expected. If impacts to KFH in third order and higher watercourses occur that are unable to be remediated using contingency measures such as those described in **Section 5.3** then environmental offsets should be considered. Appropriate offsets associated with impacts to KFH could include contribution to threatened aquatic species research and stocking programs and measures that improved water quality in nearby catchments. The requirement for and form of any offsets relating to aquatic ecology would be identified during consultation with relevant stakeholders including NSW DPI (Fisheries).

6 Conclusion

The design of the Project includes measures to avoid or minimise potential impacts on aquatic ecology. These include set back of longwalls from major watercourses to reduce the probability of physical mining impacts occurring. Nevertheless, impacts to aquatic habitat, macroinvertebrates 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 Wolgan River and surrounding 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 drainage lines that traverse the Study Area and that would be most susceptible to mining related subsidence impacts. Based on habitat requirements, and the absence of previous records, and the findings of the current study, these species are also unlikely to occur in Wolgan River and Carne Creek within the Study Area. Impacts to KFH would be largely restricted to Type 2 – Moderately Sensitive KFH present in watercourses that flow through Twin Gully Swamp and Tri-Star Swamp. These watercourses are expected to experience subsidence induced fracturing and flow diversions that would affect aquatic habitat and associated aquatic biota.

Aquifers that provide habitat for stygofauna are expected to be impacted by reductions in groundwater levels following mining induced groundwater depressurisation. The loss of perched swamp aquifers represent the greatest potential impact to stygofauna than any that would occur in the deeper aquifers. The severity of impacts to stygofauna in perched upland swamp aquifers would depend on the severity and extent of impacts to groundwater levels in swamps. At the scale of individual swamps impacts to stygofauna could be relatively severe, and there is potential for the predicted reductions in groundwater levels in these swamps to result in the loss of assemblages associated with Twin Gully and Tri-Star swamps. However, in the wider context, abundance of swamp habitat suggests that impacts at the catchment scale would be relatively minor, assuming these swamps provide habitat for similar stygofauna assemblages.

Implementation of the recommended aquatic ecology-monitoring program outlined in **Section 5** would 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 would be confirmed following further consultation with Centennial and confirmation of the timing of extraction of each longwall.

The detection of physical impacts, such as fracturing of bedrock and streamflow losses, should trigger investigations into potential impacts on aquatic ecology. The level of impact found would determine the type of response. Significant changes in aquatic biota detected ‘during mining’ monitoring would also provide triggers for further investigation. The implementation of such management measures would aim to reduce impacts on aquatic ecology.

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APPENDIX

A

PMST RESULTS

Cardno

Australian Government
Department of the Environment and Energy

EPBC Act Protected Matters Report

This report provides general guidance on matters of national environmental significance and other matters protected by the EPBC Act in the area you have selected.

Information on the coverage of this report and qualifications on data supporting this report are contained in the caveat at the end of the report.

Information is available about Environment Assessments and the EPBC Act including significance guidelines, forms and application process details.

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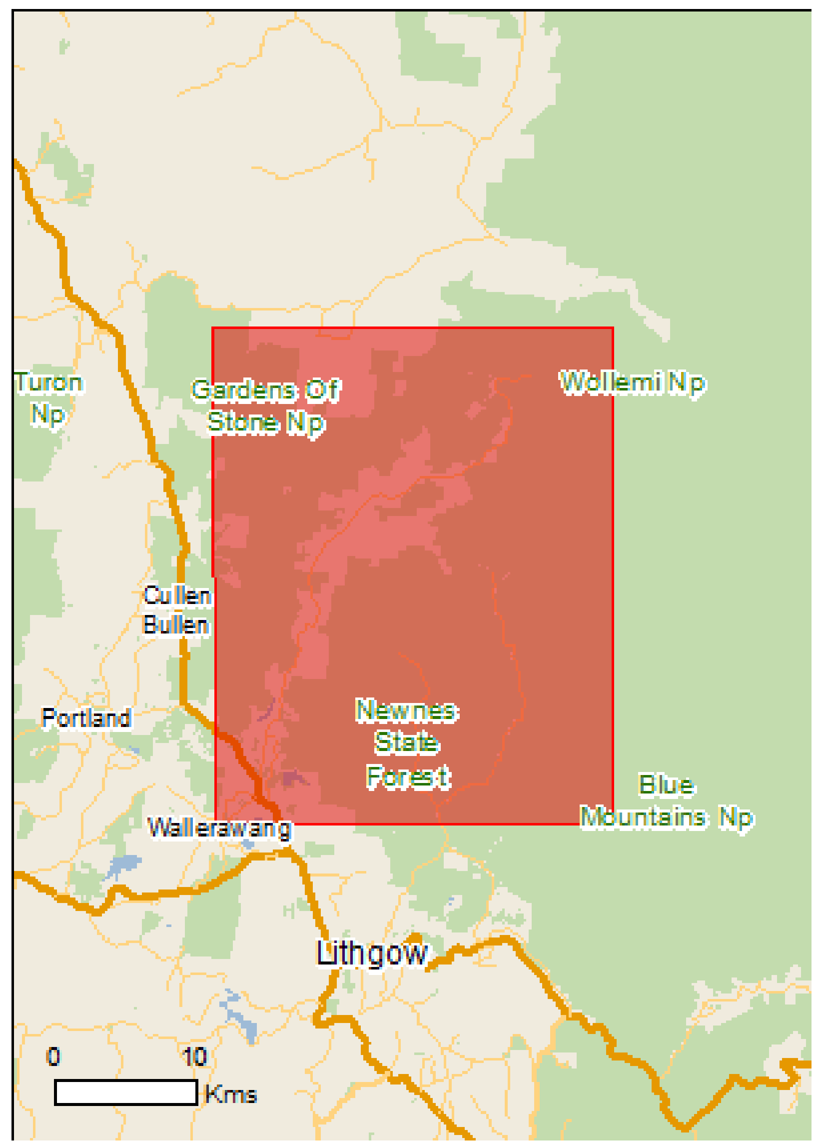

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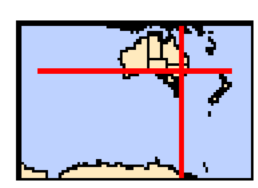

Summary

Matters of National Environmental Significance

This part of the report summarises the matters of national environmental significance that may occur in, or may relate to, the area you nominated. Further information is available in the detail part of the report, which can be accessed by scrolling or following the links below. If you are proposing to undertake an activity that may have a significant impact on one or more matters of national environmental significance then you should consider the Administrative Guidelines on Significance.

World Heritage Properties:	1
National Heritage Places:	1
Wetlands of International Importance:	4
Great Barrier Reef Marine Park:	None
Commonwealth Marine Area:	None
Listed Threatened Ecological Communities:	4
Listed Threatened Species:	51
Listed Migratory Species:	13

Other Matters Protected by the EPBC Act

This part of the report summarises other matters protected under the Act that may relate to the area you nominated. Approval may be required for a proposed activity that significantly affects the environment on Commonwealth land, when the action is outside the Commonwealth land, or the environment anywhere when the action is taken on Commonwealth land. Approval may also be required for the Commonwealth or Commonwealth agencies proposing to take an action that is likely to have a significant impact on the environment anywhere.

The EPBC Act protects the environment on Commonwealth land, the environment from the actions taken on Commonwealth land, and the environment from actions taken by Commonwealth agencies. As heritage values of a place are part of the 'environment', these aspects of the EPBC Act protect the Commonwealth Heritage values of a Commonwealth Heritage place. Information on the new heritage laws can be found at http://www.environment.gov.au/heritage

A permit may be required for activities in or on a Commonwealth area that may affect a member of a listed threatened species or ecological community, a member of a listed migratory species, whales and other cetaceans, or a member of a listed marine species.

Commonwealth Land:	2
Commonwealth Heritage Places:	None
Listed Marine Species:	20
Whales and Other Cetaceans:	None
Critical Habitats:	None
Commonwealth Reserves Terrestrial:	None
Australian Marine Parks:	None

Extra Information

This part of the report provides information that may also be relevant to the area you have nominated.

State and Territory Reserves:	6
Regional Forest Agreements:	None
Invasive Species:	35
Nationally Important Wetlands:	None
Key Ecological Features (Marine)	None

Details

Matters of National Environmental Significance

World Heritage Properties		[Resource Information]
Name	State	Status
The Greater Blue Mountains Area	NSW	Declared property

National Heritage Properties		[Resource Information]
Name	State	Status
Natural		
The Greater Blue Mountains Area	NSW	Listed place

Wetlands of International Importance (Ramsar)	[Resource Information]
Name	Proximity
Banrock station wetland complex	900 - 1000km upstream
Riverland	800 - 900km upstream
The coorong, and lakes alexandrina and albert wetland	900 - 1000km upstream
The macquarie marshes	300 - 400km upstream

Listed Threatened Ecological Communities [Resource Information]

For threatened ecological communities where the distribution is well known, maps are derived from recovery plans, State vegetation maps, remote sensing imagery and other sources. Where threatened ecological community distributions are less well known, existing vegetation maps and point location data are used to produce indicative distribution maps.

Name	Status	Type of Presence
Natural Temperate Grassland of the South Eastern Highlands	Critically Endangered	Community may occur within area
Temperate Highland Peat Swamps on Sandstone	Endangered	Community may occur within area
Upland Basalt Eucalypt Forests of the Sydney Basin Bioregion	Endangered	Community likely to occur within area
White Box-Yellow Box-Blakely's Red Gum Grassy Woodland and Derived Native Grassland	Critically Endangered	Community likely to occur within area

Listed Threatened Species		[Resource Information]
Name	Status	Type of Presence
Birds		
Anthochaera phrygia		
Regent Honeyeater [82338]	Critically Endangered	Species or species habitat known to occur within area
Botaurus poiciloptilus		
Australasian Bittern [1001]	Endangered	Species or species habitat likely to occur within area
Calidris ferruginea		
Curlew Sandpiper [856]	Critically Endangered	Species or species habitat may occur within area
Grantiella picta		
Painted Honeyeater [470]	Vulnerable	Species or species habitat known to occur within area
Hirundapus caudacutus		
White-throated Needletail [682]	Vulnerable	Species or species habitat known to occur within area
Lathamus discolor		
Swift Parrot [744]	Critically Endangered	Species or species habitat known to occur within area
Numenius madagascariensis		
Eastern Curlew, Far Eastern Curlew [847]	Critically Endangered	Species or species

Name	Status	Type of Presence
		habitat may occur within area
Rostratula australis Australian Painted-snipe, Australian Painted Snipe [77037]	Endangered	Species or species habitat known to occur within area
Fish		
Macquaria australasica Macquarie Perch [66632]	Endangered	Species or species habitat known to occur within area
Prototroctes maraena Australian Grayling [26179]	Vulnerable	Species or species habitat likely to occur within area
Frogs		
Heleioporus australiacus Giant Burrowing Frog [1973]	Vulnerable	Species or species habitat may occur within area
Litoria booroolongensis Booroolong Frog [1844]	Endangered	Species or species habitat likely to occur within area
Litoria littlejohni Littlejohn's Tree Frog, Heath Frog [64733]	Vulnerable	Species or species habitat known to occur within area
Mixophyes balbus Stuttering Frog, Southern Barred Frog (in Victoria) [1942]	Vulnerable	Species or species habitat may occur within area
Insects		
Paralucia spinifera Bathurst Copper Butterfly, Purple Copper Butterfly, Bathurst Copper, Bathurst Copper Wing, Bathurst-Lithgow Copper, Purple Copper [26335]	Vulnerable	Species or species habitat likely to occur within area
Mammals		
Chalinolobus dwyeri Large-eared Pied Bat, Large Pied Bat [183]	Vulnerable	Species or species habitat known to occur within area
Dasyurus maculatus maculatus (SE mainland population) Spot-tailed Quoll, Spotted-tail Quoll, Tiger Quoll (southeastern mainland population) [75184]	Endangered	Species or species habitat known to occur within area
Isoodon obesulus obesulus Southern Brown Bandicoot (eastern), Southern Brown Bandicoot (south-eastern) [68050]	Endangered	Species or species habitat may occur within area
Nyctophilus corbeni Corben's Long-eared Bat, South-eastern Long-eared Bat [83395]	Vulnerable	Species or species habitat may occur within area
Petauroides volans Greater Glider [254]	Vulnerable	Species or species habitat known to occur within area
Petrogale penicillata Brush-tailed Rock-wallaby [225]	Vulnerable	Species or species habitat known to occur within area
Phascolarctos cinereus (combined populations of Qld, NSW and the ACT) Koala (combined populations of Queensland, New South Wales and the Australian Capital Territory) [85104]	Vulnerable	Species or species habitat known to occur within area
Pseudomys novaehollandiae New Holland Mouse, Pookila [96]	Vulnerable	Species or species habitat known to occur within area
Pteropus poliocephalus Grey-headed Flying-fox [186]	Vulnerable	Foraging, feeding or related behaviour likely

Name	Status	Type of Presence
		to occur within area
Plants		
Acacia bynoeana Bynoe's Wattle, Tiny Wattle [8575]	Vulnerable	Species or species habitat may occur within area
Boronia deanei Deane's Boronia [8397]	Vulnerable	Species or species habitat known to occur within area
Cryptostylis hunteriana Leafless Tongue-orchid [19533]	Vulnerable	Species or species habitat may occur within area
Cynanchum elegans White-flowered Wax Plant [12533]	Endangered	Species or species habitat may occur within area
Eucalyptus aggregata Black Gum [20890]	Vulnerable	Species or species habitat known to occur within area
Eucalyptus pulverulenta Silver-leaved Mountain Gum, Silver-leaved Gum [21537]	Vulnerable	Species or species habitat known to occur within area
Euphrasia arguta [4325]	Critically Endangered	Species or species habitat may occur within area
Grevillea evansiana [22248]	Vulnerable	Species or species habitat likely to occur within area
Grevillea obtusiflora Grey Grevillea [23811]	Endangered	Species or species habitat known to occur within area
Haloragis exalata subsp. exalata Wingless Raspwort, Square Raspwort [24636]	Vulnerable	Species or species habitat may occur within area
Haloragodendron lucasii Hal [6480]	Endangered	Species or species habitat likely to occur within area
Homoranthus darwinioides [12974]	Vulnerable	Species or species habitat likely to occur within area
Leucochrysum albicans var. tricolor Hoary Sunray, Grassland Paper-daisy [56204]	Endangered	Species or species habitat likely to occur within area
Persoonia marginata Clandulla Geebung [10852]	Vulnerable	Species or species habitat known to occur within area
Pomaderris brunnea Rufous Pomaderris [16845]	Vulnerable	Species or species habitat likely to occur within area
Pomaderris cotoneaster Cotoneaster Pomaderris [2043]	Endangered	Species or species habitat may occur within area
Prasophyllum petilum Tarengo Leek Orchid [55144]	Endangered	Species or species habitat may occur within area
Prasophyllum sp. Wybong (C.Phelps ORG 5269) a leek-orchid [81964]	Critically Endangered	Species or species habitat may occur within

Name	Status	Type of Presence
		area
Prostanthera cryptandroides subsp. cryptandroides Wollemi Mint-bush [68496]	Vulnerable	Species or species habitat known to occur within area
Prostanthera stricta Mount Vincent Mintbush [17616]	Vulnerable	Species or species habitat likely to occur within area
Pultenaea glabra Smooth Bush-pea, Swamp Bush-pea [11887]	Vulnerable	Species or species habitat likely to occur within area
Thesium australe Austral Toadflax, Toadflax [15202]	Vulnerable	Species or species habitat known to occur within area
Wollemia nobilis Wollemi Pine [64545]	Critically Endangered	Species or species habitat likely to occur within area
Xerochrysum palustre Swamp Everlasting, Swamp Paper Daisy [76215]	Vulnerable	Species or species habitat likely to occur within area
Reptiles		
Aprasia parapulchella Pink-tailed Worm-lizard, Pink-tailed Legless Lizard [1665]	Vulnerable	Species or species habitat may occur within area
Eulamprus leuraensis Blue Mountains Water Skink [59199]	Endangered	Species or species habitat known to occur within area
Hoplocephalus bungaroides Broad-headed Snake [1182]	Vulnerable	Species or species habitat known to occur within area

Listed Migratory Species

[Resource Information]

* Species is listed under a different scientific name on the EPBC Act - Threatened Species list.

Name	Threatened	Type of Presence
Migratory Marine Birds		
Apus pacificus Fork-tailed Swift [678]		Species or species habitat likely to occur within area
Migratory Terrestrial Species		
Hirundapus caudacutus White-throated Needletail [682]	Vulnerable	Species or species habitat known to occur within area
Monarcha melanopsis Black-faced Monarch [609]		Species or species habitat known to occur within area
Motacilla flava Yellow Wagtail [644]		Species or species habitat may occur within area
Myiagra cyanoleuca Satin Flycatcher [612]		Breeding known to occur within area
Rhipidura rufifrons Rufous Fantail [592]		Species or species habitat known to occur within area
Migratory Wetlands Species		
Actitis hypoleucos Common Sandpiper [59309]		Species or species habitat may occur within area

Name	Threatened	Type of Presence
Calidris acuminata Sharp-tailed Sandpiper [874]		Species or species habitat may occur within area
Calidris ferruginea Curlew Sandpiper [856]	Critically Endangered	Species or species habitat may occur within area
Calidris melanotos Pectoral Sandpiper [858]		Species or species habitat may occur within area
Gallinago hardwickii Latham's Snipe, Japanese Snipe [863]		Species or species habitat may occur within area
Numenius madagascariensis Eastern Curlew, Far Eastern Curlew [847]	Critically Endangered	Species or species habitat may occur within area
Pandion haliaetus Osprey [952]		Species or species habitat may occur within area

Other Matters Protected by the EPBC Act

Commonwealth Land [Resource Information]

The Commonwealth area listed below may indicate the presence of Commonwealth land in this vicinity. Due to the unreliability of the data source, all proposals should be checked as to whether it impacts on a Commonwealth area, before making a definitive decision. Contact the State or Territory government land department for further information.

Name
Commonwealth Land - Australian Telecommunications Commission
Defence - MARRANGAROO

Listed Marine Species [Resource Information]

* Species is listed under a different scientific name on the EPBC Act - Threatened Species list.

Name	Threatened	Type of Presence
Birds		
Actitis hypoleucos Common Sandpiper [59309]		Species or species habitat may occur within area
Apus pacificus Fork-tailed Swift [678]		Species or species habitat likely to occur within area
Ardea alba Great Egret, White Egret [59541]		Species or species habitat likely to occur within area
Ardea ibis Cattle Egret [59542]		Species or species habitat may occur within area
Calidris acuminata Sharp-tailed Sandpiper [874]		Species or species habitat may occur within area
Calidris ferruginea Curlew Sandpiper [856]	Critically Endangered	Species or species habitat may occur within area
Calidris melanotos Pectoral Sandpiper [858]		Species or species habitat may occur within area

Name	Threatened	Type of Presence
Chrysococcyx osculans Black-eared Cuckoo [705]		Species or species habitat known to occur within area
Gallinago hardwickii Latham's Snipe, Japanese Snipe [863]		Species or species habitat may occur within area
Haliaeetus leucogaster White-bellied Sea-Eagle [943]		Species or species habitat likely to occur within area
Hirundapus caudacutus White-throated Needletail [682]	Vulnerable	Species or species habitat known to occur within area
Lathamus discolor Swift Parrot [744]	Critically Endangered	Species or species habitat known to occur within area
Merops ornatus Rainbow Bee-eater [670]		Species or species habitat may occur within area
Monarcha melanopsis Black-faced Monarch [609]		Species or species habitat known to occur within area
Motacilla flava Yellow Wagtail [644]		Species or species habitat may occur within area
Myiagra cyanoleuca Satin Flycatcher [612]		Breeding known to occur within area
Numenius madagascariensis Eastern Curlew, Far Eastern Curlew [847]	Critically Endangered	Species or species habitat may occur within area
Pandion haliaetus Osprey [952]		Species or species habitat may occur within area
Rhipidura rufifrons Rufous Fantail [592]		Species or species habitat known to occur within area
Rostratula benghalensis (sensu lato) Painted Snipe [889]	Endangered*	Species or species habitat known to occur within area

Extra Information

State and Territory Reserves [Resource Information]

Name	State
Birds Rock	NSW
Blue Mountains	NSW
Forestry Management Areas in Bathurst	NSW
Gardens of Stone	NSW
Snow Gum	NSW
Wollemi	NSW

Invasive Species [Resource Information]

Weeds reported here are the 20 species of national significance (WoNS), along with other introduced plants that are considered by the States and Territories to pose a particularly significant threat to biodiversity. The following feral animals are reported: Goat, Red Fox, Cat, Rabbit, Pig, Water Buffalo and Cane Toad. Maps from Landscape Health Project, National Land and Water Resouces Audit, 2001.

Name	Status	Type of Presence
Birds		
Acridotheres tristis Common Myna, Indian Myna [387]		Species or species habitat likely to occur within area
Alauda arvensis Skylark [656]		Species or species habitat likely to occur within area
Anas platyrhynchos Mallard [974]		Species or species habitat likely to occur within area
Carduelis carduelis European Goldfinch [403]		Species or species habitat likely to occur within area
Columba livia Rock Pigeon, Rock Dove, Domestic Pigeon [803]		Species or species habitat likely to occur within area
Passer domesticus House Sparrow [405]		Species or species habitat likely to occur within area
Pycnonotus jocosus Red-whiskered Bulbul [631]		Species or species habitat likely to occur within area
Streptopelia chinensis Spotted Turtle-Dove [780]		Species or species habitat likely to occur within area
Sturnus vulgaris Common Starling [389]		Species or species habitat likely to occur within area
Turdus merula Common Blackbird, Eurasian Blackbird [596]		Species or species habitat likely to occur within area
Frogs		
Rhinella marina Cane Toad [83218]		Species or species habitat may occur within area
Mammals		
Bos taurus Domestic Cattle [16]		Species or species habitat likely to occur within area
Canis lupus familiaris Domestic Dog [82654]		Species or species habitat likely to occur within area
Capra hircus Goat [2]		Species or species habitat likely to occur within area
Felis catus Cat, House Cat, Domestic Cat [19]		Species or species habitat likely to occur within area
Feral deer Feral deer species in Australia [85733]		Species or species habitat likely to occur within area
Lepus capensis Brown Hare [127]		Species or species habitat likely to occur within area
Mus musculus House Mouse [120]		Species or species

Name	Status	Type of Presence
		habitat likely to occur within area
Oryctolagus cuniculus		
Rabbit, European Rabbit [128]		Species or species habitat likely to occur within area
Rattus rattus		
Black Rat, Ship Rat [84]		Species or species habitat likely to occur within area
Sus scrofa		
Pig [6]		Species or species habitat likely to occur within area
Vulpes vulpes		
Red Fox, Fox [18]		Species or species habitat likely to occur within area
Plants		
Chrysanthemoides monilifera		
Bitou Bush, Boneseed [18983]		Species or species habitat may occur within area
Cytisus scoparius		
Broom, English Broom, Scotch Broom, Common Broom, Scottish Broom, Spanish Broom [5934]		Species or species habitat likely to occur within area
Genista linifolia		
Flax-leaved Broom, Mediterranean Broom, Flax Broom [2800]		Species or species habitat likely to occur within area
Genista monspessulana		
Montpellier Broom, Cape Broom, Canary Broom, Common Broom, French Broom, Soft Broom [20126]		Species or species habitat likely to occur within area
Genista sp. X Genista monspessulana		
Broom [67538]		Species or species habitat may occur within area
Lycium ferocissimum		
African Boxthorn, Boxthorn [19235]		Species or species habitat likely to occur within area
Nassella neesiana		
Chilean Needle grass [67699]		Species or species habitat likely to occur within area
Nassella trichotoma		
Serrated Tussock, Yass River Tussock, Yass Tussock, Nassella Tussock (NZ) [18884]		Species or species habitat likely to occur within area
Opuntia spp.		
Prickly Pears [82753]		Species or species habitat likely to occur within area
Pinus radiata		
Radiata Pine Monterey Pine, Insignis Pine, Wilding Pine [20780]		Species or species habitat may occur within area
Rubus fruticosus aggregate		
Blackberry, European Blackberry [68406]		Species or species habitat likely to occur within area
Salix spp. except S.babylonica, S.x calodendron & S.x reichardtii		
Willows except Weeping Willow, Pussy Willow and Sterile Pussy Willow [68497]		Species or species habitat likely to occur within area
Senecio madagascariensis		
Fireweed, Madagascar Ragwort, Madagascar Groundsel [2624]		Species or species habitat likely to occur within area

Caveat

The information presented in this report has been provided by a range of data sources as acknowledged at the end of the report.

This report is designed to assist in identifying the locations of places which may be relevant in determining obligations under the Environment Protection and Biodiversity Conservation Act 1999. It holds mapped locations of World and National Heritage properties, Wetlands of International and National Importance, Commonwealth and State/Territory reserves, listed threatened, migratory and marine species and listed threatened ecological communities. Mapping of Commonwealth land is not complete at this stage. Maps have been collated from a range of sources at various resolutions.

Not all species listed under the EPBC Act have been mapped (see below) and therefore a report is a general guide only. Where available data supports mapping, the type of presence that can be determined from the data is indicated in general terms. People using this information in making a referral may need to consider the qualifications below and may need to seek and consider other information sources.

For threatened ecological communities where the distribution is well known, maps are derived from recovery plans, State vegetation maps, remote sensing imagery and other sources. Where threatened ecological community distributions are less well known, existing vegetation maps and point location data are used to produce indicative distribution maps.

Threatened, migratory and marine species distributions have been derived through a variety of methods. Where distributions are well known and if time permits, maps are derived using either thematic spatial data (i.e. vegetation, soils, geology, elevation, aspect, terrain, etc) together with point locations and described habitat; or environmental modelling (MAXENT or BIOCLIM habitat modelling) using point locations and environmental data layers.

Where very little information is available for species or large number of maps are required in a short time-frame, maps are derived either from 0.04 or 0.02 decimal degree cells; by an automated process using polygon capture techniques (static two kilometre grid cells, alpha-hull and convex hull); or captured manually or by using topographic features (national park boundaries, islands, etc). In the early stages of the distribution mapping process (1999-early 2000s) distributions were defined by degree blocks, 100K or 250K map sheets to rapidly create distribution maps. More reliable distribution mapping methods are used to update these distributions as time permits.

Only selected species covered by the following provisions of the EPBC Act have been mapped:

- migratory and
- marine

The following species and ecological communities have not been mapped and do not appear in reports produced from this database:

- threatened species listed as extinct or considered as vagrants
- some species and ecological communities that have only recently been listed
- some terrestrial species that overfly the Commonwealth marine area
- migratory species that are very widespread, vagrant, or only occur in small numbers

The following groups have been mapped, but may not cover the complete distribution of the species:

- non-threatened seabirds which have only been mapped for recorded breeding sites
- seals which have only been mapped for breeding sites near the Australian continent

Such breeding sites may be important for the protection of the Commonwealth Marine environment.

Coordinates

-33.411289 150.309581,-33.411289 150.056896,-33.147231 150.055522,-33.147806 150.309581,-33.410716 150.308895,-33.411289 150.309581

Acknowledgements

This database has been compiled from a range of data sources. The department acknowledges the following custodians who have contributed valuable data and advice:

-Office of Environment and Heritage, New South Wales
-Department of Environment and Primary Industries, Victoria
-Department of Primary Industries, Parks, Water and Environment, Tasmania
-Department of Environment, Water and Natural Resources, South Australia
-Department of Land and Resource Management, Northern Territory
-Department of Environmental and Heritage Protection, Queensland
-Department of Parks and Wildlife, Western Australia
-Environment and Planning Directorate, ACT
-Birdlife Australia
-Australian Bird and Bat Banding Scheme
-Australian National Wildlife Collection
-Natural history museums of Australia
-Museum Victoria
-Australian Museum
-South Australian Museum
-Queensland Museum
-Online Zoological Collections of Australian Museums
-Queensland Herbarium
-National Herbarium of NSW
-Royal Botanic Gardens and National Herbarium of Victoria
-Tasmanian Herbarium
-State Herbarium of South Australia
-Northern Territory Herbarium
-Western Australian Herbarium
-Australian National Herbarium, Canberra
-University of New England
-Ocean Biogeographic Information System
-Australian Government, Department of Defence
Forestry Corporation, NSW
-Geoscience Australia
-CSIRO
-Australian Tropical Herbarium, Cairns
-eBird Australia
-Australian Government – Australian Antarctic Data Centre
-Museum and Art Gallery of the Northern Territory
-Australian Government National Environmental Science Program
-Australian Institute of Marine Science
-Reef Life Survey Australia
-American Museum of Natural History
-Queen Victoria Museum and Art Gallery, Inveresk, Tasmania
-Tasmanian Museum and Art Gallery, Hobart, Tasmania
-Other groups and individuals

The Department is extremely grateful to the many organisations and individuals who provided expert advice and information on numerous draft distributions.

Please feel free to provide feedback via the Contact Us page.

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APPENDIX

B

SITE COORDINATES

Site	Watercourse / Swamp	Lat	Long
WRdn	Wolgan River	-33.318873	150.156978
WRmd	Wolgan River	-33.344978	150.168056
WRup	Wolgan River	-33.362617	150.180431
TGS	Twin Gully Swamp	-33.328534	150.161467
TGS_UP	Twin Gully	-33.328479	150.170930
TRIS	Tri-Star Swamp	-33.343844	150.169466
TRIS_UP	Tri-Star Swamp	-33.343735	150.177529
BRS	Bird Rock Swamp	-33.331389	150.206278
CCXdn	Carne Creek	-33.355220	150.211267
WRocr*	Wolgan River	-33.221492	150.223167

*Artificial macroinvertebrate collectors only

APPENDIX

C

DETAILED METHODS

i) Aquatic Habitat

River, Channel and Environmental (RCE) Categories

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

> The species and percent cover (in an approximate 100 m reach) of in-stream aquatic vegetation present at each site; and

> The presence of algae or flocculent on the surface of macrophytes was also be noted, if present.

Table Ai – RCE Categories and Scores

Descriptor and category	Score	Descriptor and category	Score
1. Land use pattern beyond the immediate riparian zone		8. Riffle / pool sequence	
Undisturbed native vegetation	4	Frequent alternation of riffles and pools	4
Mixed native vegetation and pasture/exotics	3	Long pools with infrequent short riffles	3
Mainly pasture, crops or pine plantation	2	Natural channel without riffle / pool sequence	2
Urban	1	Artificial channel; no riffle / pool sequence	1
2. Width of riparian strip of woody vegetation		9. Retention devices in stream	
More than 30 m	4	Many large boulders and/or debris dams	4
Between 5 and 30 m	3	Rocks / logs present; limited damming effect	3
Less than 5 m	2	Rocks / logs present, but unstable, no damming	2
No woody vegetation	1	Stream with few or no rocks / logs	1
3. Completeness of riparian strip of woody vegetation		10. Channel sediment accumulations	
Riparian strip without breaks in vegetation	4	Little or no accumulation of loose sediments	4
Breaks at intervals of more than 50 m	3	Some gravel bars but little sand or silt	3
Breaks at intervals of 10 - 50 m	2	Bars of sand and silt common	2
Breaks at intervals of less than 10 m	1	Braiding by loose sediment	1
4. Vegetation of riparian zone within 10 m of channel		11. Stream bottom	
Native tree and shrub species	4	Mainly clean stones with obvious interstices	4
Mixed native and exotic trees and shrubs	3	Mainly stones with some cover of algae / silt	3
Exotic trees and shrubs	2	Bottom heavily silted but stable	2
Exotic grasses / weeds only	1	Bottom mainly loose and mobile sediment	1
5. Stream bank structure		12. Stream detritus	
Banks fully stabilised by trees, shrubs etc.	4	Mainly un-silted wood, bark, leaves	4
Banks firm but held mainly by grass and herbs	3	Some wood, leaves etc. with much fine detritus	3
Banks loose, partly held by sparse grass etc.	2	Mainly fine detritus mixed with sediment	2
Banks unstable, mainly loose sand or soil	1	Little or no organic detritus	1
6. Bank undercutting		13. Aquatic vegetation	

Descriptor and category	Score
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
Little or no macrophyte or algal growth	4
Substantial algal growth; few macrophytes	3
Substantial macrophyte growth; little algae	2
Substantial macrophyte and algal growth	1

Key Fish Habitat

The occurrence of sensitive KFH habitat in the Study Area was assessed using the criteria in NSW DPI (2013a) relevant to freshwater habitat (**Section 2.5.4**).

Mapping was done initially as a desktop exercise with the aid of existing information from previous mapping (**Section** Error! Reference source not found.), with ground-truthing undertaken in during autumn 2019. The identification of KFH was undertaken visually at each watercourse sampling location (**Section 3.2.2.1**) and was inferred (based primarily on stream order) for all other watercourses within the Study Area.

ii) Aquatic Macroinvertebrates - AUSRIVAS

Field

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.

Laboratory

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.

Modelling

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 **0**.

Table Aii – AUSRIVAS Bands and corresponding OE50 Taxa Scores for AUSRIVAS edge habitat sampled in spring

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

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

> SIGNAL > 6 = Healthy habitat;

> SIGNAL 5 – 6 = Mild pollution;

> SIGNAL 4 – 5 = Moderate pollution; and,

> SIGNAL < 4 = Severe pollution.

Multivariate patterns in AUSRIVAS macroinvertebrate data were also examined using the unconstrained ordination technique Principal Coordinates Analysis (PCO). This is a generalised form of Principal Components Analysis (PCA) in which samples are projected onto linear axes based on their dissimilarities in a way that best describes the patterns among them using as few dimensions as possible (Clarke and Gorley 2006). The amount of variation "explained" by each principal axis is indicated and the dissimilarity between data points can be determined from their distances apart on the axes (Anderson et al. 2008). The length and direction of the vectors indicate the strength and direction, respectively, of the taxa that contribute to the dissimilarity among replicates. A matrix of differences in the types and relative abundance of the taxa between all possible pairs of macroinvertebrate collector samples was compiled by calculating their respective Bray-Curtis dissimilarity coefficients, after transforming data, where appropriate, using Permutational analysis of variance (PERMANOVA+ in Primer v6).

iii) Aquatic Macroinvertebrates – Artificial Collectors

Replicate artificial collector units were deployed at WRmd, WRup and WRocr on the Wolgan River and at CCXdn on Carne Creek (upstream of the confluence with the nearby tributary). Eight replicates were deployed at each site, except at WRocr where 12 replicates were deployed. Each replicate consisted of 18 wooden chopsticks (24 cm long) held together with two small plastic cable ties one fixed at each end. To facilitate collection and deployment, the collectors were deployed in two sets of four replicates. Each set was tied together with nylon twine, attached to bankside vegetation and submerged at least 1 metre apart at the edge of pools in water depths of 30 cm to 60 cm. The collectors were retrieved approximately eight weeks following deployment.

Each replicate was put into a separate, labelled, plastic bag and preserved in 70% ethanol for subsequent macroinvertebrate identification and enumeration in the laboratory. The collectors provide a standardised habitat for colonisation by macroinvertebrates and enable the collection of quantitative data

iv) Fish

Fish and mobile invertebrates were sampled by Cardno (at WRup and WRdn) using a back-pack electrofisher (Model Smith-Root LR24). At each site, the back-pack electrofisher was operated around the edge of pools, around snags and aquatic vegetation, overhanging banks and rocky crevices. Electrofishing was conducted in sets of eight, 150 second shots. Fish were collected in a small scoop net and identified. Following identification, all native species were released unharmed.

APPENDIX

D

RAW AUSRIVAS DATA

Table Di - Raw AUSRIVAS data for 2010 to 2016 (MPR) and 2019 (Cardno), 1 indicates presence and 0 absence in the sample.

Site:	WRdn	WRup	WRdn	WRmd	WRup	CCXdn	WRdn	WRmd	WRup	BRS	TGS	TRIS	WRdn	WRmd	WRup	BRS	TGS	TRIS	WRmd	BRS	TGS	TRIS	WRmd	BRS	CCXdn	TGS	TGSup	TRIS	TRISup
Survey:	Aut 2010	Aut 2010	Aut 2011	Aut 2011	Aut 2011	Aut 2012	Aut 2012	Aut 2012	Aut 2012	Aut 2013	Aut 2013	Aut 2013	Aut 2013	Aut 2013	Aut 2013	Aut 2014	Aut 2014	Aut 2014	Aut 2014	Aut 2016	Aut 2016	Aut 2016	Aut 2016	Aut 2019	Aut 2019	Aut 2019	Aut 2019	Aut 2019	Aut 2019
Aeshnidae	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	1	0	1	0	0
Athericidae	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Atriplectididae	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Austroperlidae	0	0	0	0	0	1	0	0	0	1	1	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0
Baetidae	1	1	1	1	1	0	1	1	1	0	0	1	1	1	1	0	0	1	1	0	0	0	0	0	0	0	0	0	0
Calamoceratidae	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0
Calocidae/Helicophidae	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ceratopogonidae	1	1	1	1	1	0	1	1	1	1	0	1	1	1	1	0	0	1	1	1	0	1	1	0	0	0	1	1	0
Chironomidae	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	1	1	0	1	1	0	1	1	1	1
Cladocera	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coenagrionidae	0	1	0	0	1	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Conoesucidae	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Copepoda	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	1	1
Corbiculidae/Sphaeriidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Corduliidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0
Corixidae	0	1	0	0	1	0	0	0	1	0	0	0	1	0	1	0	0	0	1	0	0	0	1	0	0	0	0	0	0
Cordyalidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	1	0	0
Culicidae	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1
Cyclopidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0
Dytiscidae	1	1	1	1	1	0	1	1	1	1	0	1	1	0	1	0	0	1	1	0	1	1	1	0	0	0	0	0	1
Dixidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0
Dugesiidae	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0
Ecnomidae	0	1	0	0	0	1	0	0	1	0	1	1	0	0	1	1	1	0	0	1	1	1	1	1	1	1	1	1	1
Elmidae	1	0	1	0	0	1	1	1	1	1	0	0	1	0	0	0	1	0	1	0	0	0	0	0	0	0	1	1	1

Site:	WRdn	WRup	WRdn	WRmd	WRup	CCXdn	WRdn	WRmd	WRup	BRS	TGS	TRIS	WRdn	WRmd	WRup	BRS	TGS	TRIS	WRmd	BRS	TGS	TRIS	WRmd	BRS	CCXdn	TGS	TGSup	TRIS	TRISup
Survey:	Aut 2010	Aut 2010	Aut 2011	Aut 2011	Aut 2011	Aut 2012	Aut 2012	Aut 2012	Aut 2012	Aut 2013	Aut 2013	Aut 2013	Aut 2013	Aut 2013	Aut 2013	Aut 2014	Aut 2014	Aut 2014	Aut 2014	Aut 2016	Aut 2016	Aut 2016	Aut 2016	Aut 2019	Aut 2019	Aut 2019	Aut 2019	Aut 2019	Aut 2019
Empididae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gomphidae	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gripopterygidae	1	0	1	1	0	1	1	1	0	1	1	1	0	1	0	1	1	1	1	1	1	1	0	1	1	0	1	1	0
Gyrinidae	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	0	0	0
Helicopsychidae	1	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hemicorduliidae	1	1	0	0	1	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydracarina	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
Hydraenidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydrobiosidae	1	0	0	0	0	1	1	1	0	0	1	0	0	1	0	0	1	1	1	1	0	1	1	0	0	0	0	0	0
Hydrophilidae	1	0	1	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Hydropsychidae	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0
Hydroptilidae	0	0	0	1	0	0	0	1	0	0	1	0	0	1	1	1	1	0	1	0	0	0	1	0	0	0	0	0	0
Leptoceridae	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1
Leptophlebiidae	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0
Lestidae	0	1	0	0	1	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Libellulidae	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Megapodagrionidae	1	0	0	0	1	0	0	0	1	0	1	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Nannochoristidae	0	0	0	0	0	0	1	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Noteridae	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Notonectidae	1	1	1	0	1	0	0	1	1	0	0	0	1	1	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Notonemouridae	0	0	0	0	1	0	0	0	1	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oeconesidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Oligochaeta	1	0	1	1	1	0	0	1	1	0	1	1	0	0	0	1	1	0	0	1	0	0	1	1	0	0	1	1	0
Oniscigastridae	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Orthocladiinae	0	0	1	1	0	0	0	1	1	1	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0

Site:	WRdn	WRup	WRdn	WRmd	WRup	CCXdn	WRdn	WRmd	WRup	BRS	TGS	TRIS	WRdn	WRmd	WRup	BRS	TGS	TRIS	WRmd	BRS	TGS	TRIS	WRmd	BRS	CCXdn	TGS	TGSup	TRIS	TRISup
Survey:	Aut 2010	Aut 2010	Aut 2011	Aut 2011	Aut 2011	Aut 2012	Aut 2012	Aut 2012	Aut 2012	Aut 2013	Aut 2013	Aut 2013	Aut 2013	Aut 2013	Aut 2013	Aut 2014	Aut 2014	Aut 2014	Aut 2014	Aut 2016	Aut 2016	Aut 2016	Aut 2016	Aut 2019	Aut 2019	Aut 2019	Aut 2019	Aut 2019	Aut 2019
Ostracoda	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Osmylidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Philorheithridae	0	0	0	1	0	1	1	1	0	0	1	1	1	1	0	0	1	1	1	0	1	0	1	0	1	1	1	1	0
Phreatoicidae	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Polycentropodidae	0	0	1	0	1	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Psephenidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Protoneuridae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
Scirtidae	0	0	0	1	0	1	0	1	0	1	1	1	1	1	1	1	0	1	1	0	0	0	1	1	0	0	0	0	0
Simuliidae	1	0	0	0	0	1	0	1	1	0	0	1	0	1	0	1	1	1	1	0	1	1	0	0	0	0	0	0	0
Sphaeriidae	1	0	0	1	0	0	0	1	0	0	0	0	1	1	0	0	0	0	1	0	0	1	1	0	0	0	0	0	0
Synlestidae	1	0	1	1	1	0	1	1	1	0	0	1	1	1	1	0	1	1	1	0	0	0	1	0	0	1	0	0	1
Synthemistidae	1	0	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1
Tanypodinae	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	0	1	1	1	0	0	0	0	0	0	0	0	0	0
Telephlebiidae	0	0	0	1	0	1	0	1	1	1	1	1	0	1	0	1	0	1	1	1	1	1	1	0	0	0	0	0	0
Tipulidae	1	0	1	1	0	1	1	0	0	1	0	1	1	1	0	1	1	1	0	1	1	1	0	0	0	1	1	1	0
Veliidae	1	1	0	0	1	0	1	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1

Table Di - Continued

Site:	TRIS	TRISup	WRdn	WRmd	WRup	WRdn	WRmd	WRup	WRdn	WRmd	WRup	CCXdn	WRdn	WRmd	WRup	BRS	TGS	TRIS	WRdn	WRmd	WRup	BRS	TGS	TRIS	WRmd	BRS	TGS	TRIS	WRmd
Survey:	Aut 2019	Aut 2019	Aut 2019	Aut 2019	Aut 2019	Spr 2010	Spr 2010	Spr 2010	Spr 2011	Spr 2011	Spr 2011	Spr 2012	Spr 2012	Spr 2012	Spr 2012	Spr 2013	Spr 2013	Spr 2013	Spr 2013	Spr 2013	Spr 2013	Spr 2014	Spr 2014	Spr 2014	Spr 2014	Spr 2015	Spr 2015	Spr 2015	Spr 2015
Aeshnidae	0	0	0	1	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Athericidae	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0
Atriplectididae	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Austroperlidae	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0
Baetidae	0	0	0	0	0	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	0	0	1	1	0	0	1	1
Calamoceratidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Calocidae/Helicophidae	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ceratopogonidae	1	0	1	0	0	1	1	1	0	1	1	0	1	1	1	0	1	1	1	1	1	1	0	1	1	1	0	1	1
Chironomidae	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	1	1	1	0	0	0	0	0
Cladocera	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coenagrionidae	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Conoesucidae	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1
Copepoda	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Corbiculidae/Sphaeriidae	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Corduliidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Corixidae	0	0	1	0	0	0	0	1	0	0	1	0	0	0	1	0	0	0	1	1	1	0	0	1	1	0	0	0	0
Cordyalidae	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Culicidae	0	1	1	1	1	0	0	1	0	0	0	0	1	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0
Cyclopidae	0	0	0	0	0	0	0	1	0	0	1	0	1	0	0	1	0	1	0	0	0	0	1	0	1	0	0	0	0
Dytiscidae	0	1	0	0	0	1	1	1	1	1	1	1	1	1	1	0	0	1	1	1	1	0	0	1	1	0	0	0	1
Dixidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	1	0	0	0	0
Dugesiidae	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Ecnomidae	1	1	0	1	0	0	0	1	0	0	1	1	0	0	0	0	1	0	0	0	1	1	1	0	1	1	1	1	1
Elmidae	1	1	0	0	0	1	0	0	0	0	0	1	0	1	0	0	0	0	1	1	0	0	1	1	1	0	0	0	0

Site:	TRIS	TRISup	WRdn	WRmd	WRup	WRdn	WRmd	WRup	WRdn	WRmd	WRup	CCXdn	WRdn	WRmd	WRup	BRS	TGS	TRIS	WRdn	WRmd	WRup	BRS	TGS	TRIS	WRmd	BRS	TGS	TRIS	WRmd
Survey:	Aut 2019	Aut 2019	Aut 2019	Aut 2019	Aut 2019	Spr 2010	Spr 2010	Spr 2010	Spr 2011	Spr 2011	Spr 2011	Spr 2012	Spr 2012	Spr 2012	Spr 2012	Spr 2013	Spr 2013	Spr 2013	Spr 2013	Spr 2013	Spr 2013	Spr 2014	Spr 2014	Spr 2014	Spr 2014	Spr 2015	Spr 2015	Spr 2015	Spr 2015
Empididae	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gomphidae	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gripopterygidae	1	0	1	0	0	1	1	0	1	1	1	1	1	1	0	1	1	0	1	1	0	1	1	1	1	1	1	1	1
Gyrinidae	0	0	0	1	0	1	1	1	1	1	1	1	1	1	1	0	0	1	1	1	1	1	1	1	1	1	0	1	1
Helicopsychidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Hemicorduliidae	0	0	0	0	0	0	0	1	0	0	1	0	0	0	1	1	1	1	0	0	1	0	0	0	0	0	0	0	0
Hydracarina	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydraenidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydrobiosidae	0	0	0	0	0	1	0	0	1	0	0	1	0	1	0	0	0	0	1	1	0	0	0	0	1	0	0	0	1
Hydrophilidae	0	0	0	0	0	0	0	0	0	1	0	0	0	1	1	0	0	0	0	0	0	0	0	0	1	0	0	0	1
Hydropsychidae	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	1	1	0	1	0	0	1	0	1	0	0	1	0
Hydroptilidae	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	1	0	0
Leptoceridae	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1	1	1	1	1	1	1	1	1	1
Leptophlebiidae	1	0	1	1	0	1	1	1	1	1	1	1	1	1	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1
Lestidae	0	0	0	0	0	0	0	1	0	0	1	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Libellulidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Megapodagrionidae	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	1	1	1	1
Nannochoristidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0
Noteridae	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Notonectidae	0	0	1	1	0	0	0	1	1	0	1	0	1	0	1	1	0	1	0	1	1	0	0	0	0	0	0	0	0
Notonemouridae	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oeconesidae	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oligochaeta	1	0	1	1	1	1	1	0	0	0	0	1	0	1	1	0	0	0	0	1	0	0	1	1	1	0	1	0	0
Oniscigastridae	0	0	0	0	0	1	1	0	0	1	0	1	1	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0
Orthocladiinae	0	0	0	0	0	1	0	0	1	1	0	1	1	0	0	1	1	1	0	0	1	0	0	0	1	1	1	1	1

Site:	TRIS	TRISup	WRdn	WRmd	WRup	WRdn	WRmd	WRup	WRdn	WRmd	WRup	CCXdn	WRdn	WRmd	WRup	BRS	TGS	TRIS	WRdn	WRmd	WRup	BRS	TGS	TRIS	WRmd	BRS	TGS	TRIS	WRmd
Survey:	Aut 2019	Aut 2019	Aut 2019	Aut 2019	Aut 2019	Spr 2010	Spr 2010	Spr 2010	Spr 2011	Spr 2011	Spr 2011	Spr 2012	Spr 2012	Spr 2012	Spr 2012	Spr 2013	Spr 2013	Spr 2013	Spr 2013	Spr 2013	Spr 2013	Spr 2014	Spr 2014	Spr 2014	Spr 2014	Spr 2015	Spr 2015	Spr 2015	Spr 2015
Ostracoda	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0
Osmylidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Philorheithridae	1	0	0	0	0	1	1	0	0	1	1	1	0	1	0	0	1	0	0	1	0	1	0	1	1	0	0	0	1
Phreatoicidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Polycentropodidae	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	0	0	0	0	0	0
Psephenidae	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Protoneuridae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Scirtidae	0	0	0	0	0	1	0	0	1	0	1	1	0	1	0	0	1	1	1	1	1	1	0	1	1	1	1	1	1
Simuliidae	0	0	0	0	0	1	1	0	1	0	0	1	0	1	0	0	0	0	1	1	0	1	0	1	1	1	0	0	1
Sphaeriidae	0	0	0	0	0	0	1	0	1	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	1
Synlestidae	0	1	0	0	0	1	0	1	1	1	1	0	1	1	0	1	0	0	1	1	1	0	1	1	1	0	0	0	1
Synthemistidae	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1
Tanypodinae	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	0	0	0	1	1	1	0	0	0	1	1	1	1	1
Telephlebiidae	0	0	0	0	0	0	1	0	0	1	1	1	0	1	1	0	0	1	1	1	0	1	1	1	1	1	1	1	1
Tipulidae	1	0	0	0	0	1	1	0	1	1	1	0	1	0	0	0	0	1	0	1	0	1	1	1	1	1	1	1	1
Veliidae	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0

APPENDIX

E

MACROINVERT. COLLECTOR DATA

Taxon	WRup		WRmd		WRocr		CCXdn	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Austroperlidae	0.00	0.00	0.00	0.00	0.00	0.00	0.75	0.62
Calamoceratidae	0.00	0.00	0.00	0.00	1.83	0.72	0.00	0.00
Ceratopogonidae	5.63	3.68	0.50	0.38	0.00	0.00	0.25	0.16
Chironomidae-Aphroteniinae	0.00	0.00	0.13	0.13	0.00	0.00	0.25	0.16
Chironomidae-Chironominae	2.88	1.84	5.00	1.64	4.42	1.45	3.25	0.70
Chironomidae-Orthocladiinae	0.00	0.00	0.00	0.00	0.08	0.08	0.00	0.00
Chironomidae-Tanypodinae	22.88	8.77	17.25	2.48	33.42	5.02	25.88	3.83
Cladocera	0.25	0.25	0.00	0.00	0.00	0.00	0.00	0.00
Copepoda	0.00	0.00	0.13	0.13	0.00	0.00	0.00	0.00
Corbiculidae/Sphaeriidae	0.00	0.00	0.50	0.38	0.50	0.23	0.13	0.13
Culicidae	0.00	0.00	0.00	0.00	0.08	0.08	0.00	0.00
Dugesiidae	0.00	0.00	0.50	0.27	0.00	0.00	0.00	0.00
Dytiscidae	0.00	0.00	0.25	0.16	0.00	0.00	0.13	0.13
Ecnomidae	0.38	0.38	0.13	0.13	0.33	0.19	0.50	0.27
Elmidae	0.00	0.00	0.00	0.00	0.25	0.13	0.13	0.13
Empididae	0.00	0.00	0.00	0.00	0.00	0.00	0.13	0.13
Gripopterygidae	0.00	0.00	0.25	0.16	0.25	0.25	0.88	0.52
Gyrinidae	0.00	0.00	0.00	0.00	0.00	0.00	0.13	0.13
Hemicorduliidae	0.00	0.00	0.38	0.26	0.17	0.11	0.00	0.00
Hirudinea	0.00	0.00	0.00	0.00	0.08	0.08	0.00	0.00
Hydracarina	0.00	0.00	0.00	0.00	0.00	0.00	0.13	0.13
Hydrophilidae	0.00	0.00	0.00	0.00	0.17	0.11	0.00	0.00
Hydropsychidae	0.00	0.00	0.00	0.00	0.08	0.08	0.00	0.00
Hydroptilidae	0.00	0.00	0.00	0.00	0.17	0.11	0.00	0.00
Leptoceridae	0.00	0.00	4.50	1.50	0.75	0.28	1.00	0.46
Leptophlebiidae	0.00	0.00	12.75	2.29	14.08	3.00	9.13	2.73
Macromiidae	0.00	0.00	0.00	0.00	0.08	0.08	0.00	0.00
Nematoda	0.00	0.00	0.00	0.00	0.17	0.17	0.00	0.00
Odontoceridae	0.00	0.00	0.00	0.00	0.08	0.08	0.00	0.00
Oligochaeta	57.25	35.76	13.88	5.69	11.33	5.48	2.75	1.32
Ostracoda	0.63	0.42	0.00	0.00	0.00	0.00	0.00	0.00
Philopotamidae	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.25
Scirtidae	0.00	0.00	0.00	0.00	0.33	0.19	2.88	1.71
Simuliidae	0.00	0.00	0.00	0.00	0.17	0.11	0.13	0.13
Telephlebiidae	0.00	0.00	0.00	0.00	0.08	0.08	0.13	0.13
Tipulidae	0.00	0.00	0.00	0.00	0.25	0.13	0.13	0.13

SE = Standard error, n = 8 except WRocr n = 12.