Member of the Surbana Jurong Group

local people
global experience

Environmental Impact Statement – Appendix F4: Aquatic Ecology

Warragamba Dam Raising

Reference No. 30012078
Prepared for WaterNSW
10 September 2021

SMEC INTERNAL REF. 30012078

Warragamba Dam Raising

Reference: WDR-EIS Appendix F4-Aquatic Ecology-Tracked-2020-10-28.docx
Date: July 2021

Contents

List of Figures

List of Tables

Glossary

Term/Acronym	Definition
BC Act	*Biodiversity Conservation Act 2016* (NSW)
DAWE	Australian Government Department of Agriculture, Water and the Environment
DoEE	Former Australian Government Department of the Environment and Energy
DPIE	NSW Department of Planning, Industry and Environment (previously Department of Planning and Environment)
EIA	Environmental impact assessment
EIS	Environmental Impact Statement
EP&A Act	*Environmental Planning and Assessment Act 1979* (NSW)
EPBC Act	*Environment Protection and Biodiversity Act 1999* (Commonwealth)
FBA	Framework for Biodiversity Assessment
FM Act	*Fisheries Management Act 1994* (NSW)
Infrastructure SEPP	State Environmental Planning Policy (Infrastructure) 2007
KTP	Key threatening process
LGA	Local government area
MNES	Matter(s) of national environmental significance (under the EPBC Act)
NPW Act	*National Parks and Wildlife Act 1974* (NSW)
NSW	New South Wales
PEA	Preliminary Environmental Assessment
PMF	Probable maximum flood
SEARs	Secretary's Environmental Assessment Requirements
SEPP	State Environmental Planning Policy
SRD SEPP	State Environmental Planning Policy (State and Regional Development) 2011
SSI	State significant infrastructure

1 Introduction

1.1 Background

The Hawkesbury-Nepean Valley (the valley) in western Sydney has the highest flood risk in New South Wales, if not Australia. The potential for significant flooding of the Hawkesbury-Nepean Valley was known by the local Aboriginal community before the first European settlement of the area in the 1790s. In the early years of European settlement, the risk of flooding was recognised and a series of proclamations were issued that warned of the risk of flooding. This high flood risk arises from the river being confined by narrow sandstone gorges, creating rapid deep backwater flooding over extensive floodplains. The floodplains are home to a large existing population who would be impacted in a major flood.

During the 1980s and 1990s updated flood investigation techniques and new geological evidence predicted that floods significantly larger than any historically recorded could occur in the Hawkesbury-Nepean Valley. The dam was raised by five metres in the late 1980s to meet modern dam safety requirements. Further investigations into flooding and flood mitigation were undertaken and culminated in 1995 in a proposal to raise Warragamba Dam by 23 metres primarily for dam safety but also to provide for flood mitigation. The 1995 proposal did not proceed. In the late 1990s, major upgrades of Warragamba Dam were undertaken to prevent dam failure during extreme flooding events, to protect Sydney's water supply, and to prevent catastrophic downstream floods from dam failure. This resulted in the construction of the auxiliary spillway. However, these works only dealt with dam safety issues and did not address the major flood risks to the people and businesses in the Hawkesbury-Nepean Valley and the NSW economy.

In 2011, an approximately 1 in 100 chance in a year flood impacted Brisbane, resulting in significant damage, economic costs, and social disruption. The substantial impacts of the 2011 Brisbane flood led the NSW Government to recommence investigations into flood mitigation options for the Hawkesbury-Nepean Valley.

In 2013, the NSW Government in response to the State Infrastructure Strategy and community concerns, initiated the Hawkesbury-Nepean Valley Flood Management Review to consider flood planning, flood mitigation and flood response in the Hawkesbury-Nepean Valley. The review found that current flood management and planning arrangements could be improved, and no single mitigation option could address all the flood risks present in the Hawkesbury-Nepean Valley (Department of Primary Industries (DPI) 2014a). The review concluded that raising Warragamba Dam to capture inflows is the most effective infrastructure measure that could have a major influence on flood levels during those events, when most of the damages occur. Other complementary and non-infrastructure options were also identified to mitigate flood risks (DPI 2014a).

Under the direction of Infrastructure NSW (INSW), the Hawkesbury-Nepean Valley Flood Management Taskforce was established to investigate feasible flood options to reduce overall risk to the Hawkesbury-Nepean Valley. In June 2016, the former Premier and Minister for Western Sydney, Mike Baird MP, announced the NSW Government plan to raise Warragamba Dam to significantly reduce the risk of flooding in the Hawkesbury-Nepean Valley. The cost-benefit analysis demonstrated that the Warragamba Dam Raising would provide a 75 percent reduction in flood damages on average, and reduce current levels of flood damages from $5 billion to $2 billion (2016 dollars).

Raising Warragamba Dam would significantly reduce flood risk; however, it would not eliminate the risk completely. Regardless of the increase in the dam's height, flooding can be generated from catchments other than Warragamba Dam. The raising of Warragamba Dam would therefore be complemented with other non-infrastructure and policy actions. In May 2017, INSW released Resilient Valley, Resilient Communities, which outlines the Hawkesbury-Nepean Valley Flood Risk Management Strategy (the Flood Strategy) (INSW 2017). The Flood Strategy covers the geographic region between Bents Bridge and the Brooklyn Bridge, encompassing areas within the Local Government Areas (LGAs) of Liverpool City, Penrith City, Hawkesbury City, The Hills Shire Blacktown City, Central Coast and Hornsby Shire.

The Flood Strategy's objective is to reduce flood risk to life, property and social amenity from floods in the Hawkesbury-Nepean Valley. The strategy includes nine key outcomes; a combination of infrastructure and non-infrastructure initiatives to mitigate the flood risk to the Hawkesbury-Nepean Valley floodplain downstream of Warragamba Dam. Actions include:

- coordinated flood risk management across the Hawkesbury-Nepean Valley now and in the future
- strategic and integrated consideration of flood risk in land use and emergency planning
- engaging and providing flood risk information for an aware, prepared and responsive community.

The Flood Strategy provides the context and policy impetus to mitigate flood risk in the Hawkesbury-Nepean Valley.

A description of alternatives considered as feasible flood options to reduce risk to the Hawkesbury-Nepean Valley, as well as alternatives considered for the Warragamba Dam Raising Project, are provided in Chapter 4.

After the submission of a Preliminary Environmental Assessment (PEA) for the proposed dam raising works, the NSW Department of Planning and Environment (DPE, now Department of Planning, Industry and Environment) issued the Secretary's Environmental Assessment Requirements (SEARs) to be addressed by the Warragamba Dam Raising Environmental Impact Statement (EIS). The EIS is required to inform planning assessments under the *Environmental Planning and Assessment Act 1979* (EP&A Act) and inform a final business case for Government consideration of whether to progress to Phase 2 (implementing the raising of Warragamba Dam wall), subject to environmental planning and approvals.

Additionally, an impact assessment is required to inform a determination by the Australian Government Department of Agriculture, Water and the Environment (DAWE)[1] under the *Environment Protection and Biodiversity Conservation Act 1999* (Cwlth.) (EPBC Act). As there is an Assessment Bilateral Agreement in place between the Commonwealth and NSW Government, the SEARs for the EIS also cover EPBC Act matters.

This Aquatic Ecology Assessment has been prepared to provide technical guidance and inform the broader EIS that is being prepared for the proposed dam raising project.

[1] The Environment portfolio within the former Department of the Environment and Energy (DoEE) was transferred to the new Department of Agriculture, Water and the Environment (DAWE) which commenced operation on 1 February 2020.

1.2 Project description

Warragamba Dam Raising is a project to provide flood mitigation to reduce the significant existing risk to life and property in the Hawkesbury-Nepean Valley downstream of the dam. This would be achieved through raising the level of the central spillway crest by around 12 metres and the auxiliary spillway crest by around 14 metres above the existing full supply level for temporary storage of inflows. The spillway crest levels and outlets control the extent and duration of the temporary upstream inundation. There would be no change to the existing maximum volume of water stored for water supply.

The NSW Government announcement in 2016 proposed that the dam wall be raised by 14 metres. Subsequently, the SEARs required the project to be designed, constructed and operated to be resilient to the future impacts of climate change and incorporate specific adaptation actions in the design.

Peer reviewed climate change research found that by 2090 it is likely an additional three metres of spillway height would be required to provide similar flood mitigation outcomes as the current flood mitigation proposal. Raising the dam side walls and roadway by an additional three metres may not be feasible in the future, both in terms of engineering constraints and cost. The current design includes raising the dam side walls and roadway by 17 metres now to enable adaptation to projected climate change. Any consideration of raising spillway heights is unlikely before the mid to late 21st century and would be subject to a separate planning approval process.

The 17-metre raising height of the dam abutments (side walls) and roadway have been considered and accounted for in the EIS and design. The potential maximum height and duration of upstream inundation remains consistent with what was originally proposed in 2016.

The Project also includes providing infrastructure to facilitate variable environmental flows to be released from Warragamba Dam.

The Project would include the following main activities and elements:

- demolition or removal of parts of the existing Warragamba Dam, including the existing drum and radial gates,
- thickening and raising of the dam abutments
- thickening and raising of the central spillway
- new gates or slots to control discharge of water from the flood mitigation zone (FMZ)
- modifications to the auxiliary spillway
- operation of the dam for flood mitigation
- environmental flow infrastructure.

The Project would take the opportunity, during the construction period for the dam raising, to install the physical infrastructure to allow for management of environmental flows as outlined in the NSW Government, 2017 Metropolitan Water Plan. However, the actual environmental flow releases themselves do not form part of the Project and are subject to administration under the *Water Management Act 2000.*

A detailed description of the Project including key elements of construction and operation for flood mitigation is provided in Chapter 5 of the EIS.

1.2.1 Location

The Project site is located approximately 65 km west of the Sydney Central Business District in the Wollondilly Local Government Area (LGA). The area upstream of the Project construction site (i.e., upstream study area) is dominated by conservation areas including national parks and state conservation areas and the Greater Blue Mountains World Heritage Area (GBMWHA). The area downstream of the Project construction site (i.e., the downstream study area) includes the townships of Warragamba and Silverdale townships, the floodplains of Penrith, Richmond and Windsor, and the Hawkesbury River gorge.

1.2.2 Existing operation

Water from the dam flows by gravity through two pipelines (27 km in length) to the Prospect Water Filtration Plant located 15 km west of Sydney's CBD. Water treated at this plant supplies water for around 80 percent of Sydney's population. Water from the dam is also supplied to the townships of Warragamba, Penrith, and the Lower Blue Mountains through filtration plants at both Warragamba and Orchard Hills. A deep-water pumping station is located at Warragamba Dam to enable continued supply if the water level falls below the outlets during extended dry periods. Water is also released into the Warragamba River to provide a secure water supply to the population of North Richmond and as e-flows (albeit limited at this stage) to maintain downstream river health and provide community benefits (WaterNSW, 2016a).

Since the completion of construction of the original dam in 1960, the flow contribution from Warragamba Dam to the Warragamba River and subsequently the Hawkesbury-Nepean River has been limited to the following releases:

- Fixed low flow releases (22 ML/day in winter and 30 ML/day in summer)
- Operational releases
- Flows during heavy rainfall when the dam has filled and water flows over the spillway.

1.2.3 Operation of the dam for flood mitigation

Operational objectives in order of priority are to:

- maintain the structural integrity of the dam
- minimise risk to life
- maintain Sydney's water supply
- minimise downstream impact of flooding to properties
- minimise environmental impact
- minimise social impact.

There would be two different modes of operation for the Project: normal and flood operations. In both modes Warragamba Dam would continue to store and supply up to 80 percent of Sydney's drinking water. The water supply storage capacity, which is the dam's Full Supply Level, would not change.

1.2.3.1 Normal operations

Normal operations would occur when the dam storage level is at or lower than Full Supply Level. Normal operations mode for the modified dam would be essentially the same as current operations. Inflows would be captured up until the Full Supply Level after which flood operation procedures would be implemented.

1.2.3.2 Flood operations

During large rainfall events when the storage level rises above Full Supply Level, flood operations mode would commence. In this mode, flood inflows to Lake Burragorang would be captured and temporarily stored (increasing water levels in Lake Burragorang and upstream tributaries). The raised dam would provide a flood mitigation zone to capture up to about 1000 GL of water during a flood event.

Water would be discharged in a controlled manner until the dam level returns to Full Supply Level. Flood mitigation zone operating protocols would guide this process and be developed for approval by the relevant regulatory authorities.

The raised dam would not be able to fully capture inflows from all floods. For floods that exceed the capacity of the flood mitigation zone, water would spill firstly over the central spillway and then, depending on the size of the flood, the auxiliary spillway.

1.2.4 Study area

The areas considered for this assessment have been described in the context of both the phase of the works (construction versus operation) and geographic extent of possible impacts. The entire Project study area is shown in Figure 1-1.

The study area encompasses the following areas:

- The **construction area** includes the area on and around the existing dam, including the dam wall itself, central spillway, auxiliary spillway as well as access roads and dam site buildings (refer Figure 1-2)
- The **operational area** includes the areas upstream and downstream of the dam that could be affected by the future operation of the Dam with a raised dam wall. This extent is defined as the probable maximum flood (PMF) with the existing PMF as the extent downstream and the Project PMF as the extent upstream.

1.2.5 Downstream study boundary

As the Hawkesbury River widens as it approaches the lower estuarine areas and tidal influences begin to dominate water levels closer to the ocean, potential downstream impacts decrease with distance downstream until they become negligible. Other influences on hydrology and water quality in the downstream catchment may also be significant, such as inflows from downstream catchments (for example the Nepean River, Grose River, Macdonald River and Colo River), runoff from rural and urban land uses, and the discharge of sewage treatment plants.

Identification of a practicable downstream boundary for the aquatic ecology impact assessment considered both changes to downstream hydrology and to water quality as follows.

1.2.5.1 Hydrology

An analysis of changes in water levels was carried out to identify where water levels were generally similar to pre and post-Project conditions. This was based on an assessment of the hydrographs at various downstream cross-sections. This identified that the change in water levels downstream would range from about 200 mm to 400 mm at Wisemans Ferry and decrease to less than 100 mm immediately downstream of Wisemans Ferry.

1.2.5.2 Water quality

A second consideration in establishing the downstream boundary was potential changes in water quality associated with operation of the flood mitigation zone (the Project would not result in any changes in water quality in the dam during normal operations as there would be no change in the full supply level or how the dam is operated currently).

When the flood mitigation zone is capturing inflows from the Lake Burragorang catchment, there would be no change in downstream water quality. However, when captured water is being released from the flood mitigation zone after a flood event there is potential for impacts if the water quality of the captured water is worse than downstream water quality.

A detailed discussion around the downstream water quality impacts of the Project is provided in Section 27.7.4 of the EIS. The assessment examined changes in the following water quality parameters:

- Total Nitrogen
- Total Phosphorus
- Chlorophyll-a
- Total Suspended Solids.

The assessment identified that water quality in the flood mitigation zone was generally better than the downstream receiving environment, and would not have any material impact on downstream quality.

1.2.5.3 Adopted downstream study boundary

On the basis of consideration of likely downstream hydrological and water quality changes, the downstream boundary for the aquatic ecology assessment has been set at Wisemans Ferry.

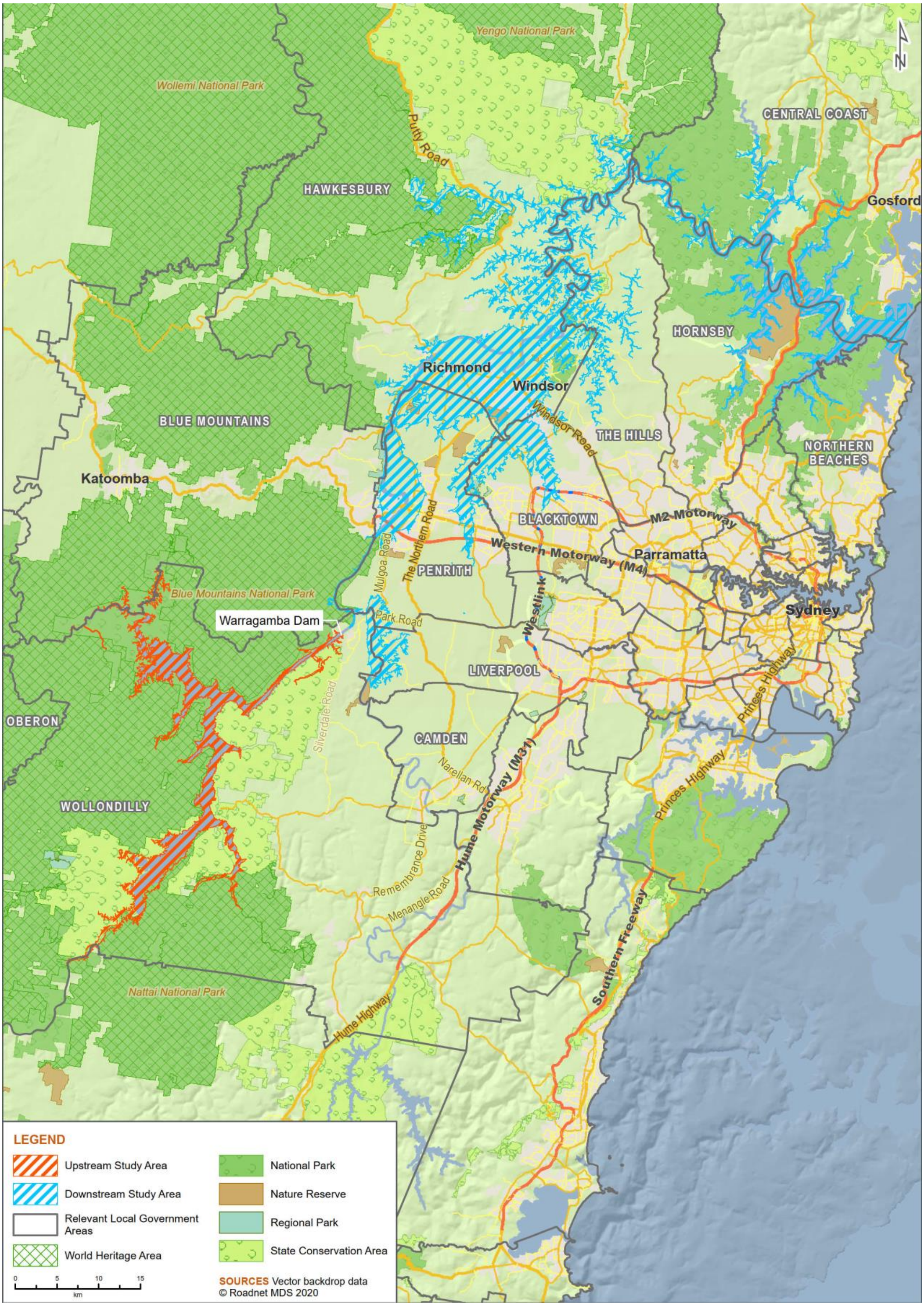


Figure 1-1 Project location and study areas

Figure 1-2 Project construction area

1.3 Secretary's Environmental Assessment Requirements

The Project requires approval from the NSW Minister for Planning under Division 5.2 of the EP&A Act for the reasons set out below.

Clause 125(2b) of State Environmental Planning Policy (Infrastructure) 2007 (Infrastructure SEPP) provides that works for the purpose of water storage facilities in the Sydney catchment areas, such as the Project, could be undertaken by WaterNSW without obtaining development consent under Part 4 of the EP&A Act. Clause 50 of the Infrastructure SEPP also allows the development by a public authority for the purposes of flood mitigation to be undertaken without consent. Section 5.12(2) of the EP&A Act provides that a State Environmental Planning Policy (SEPP) may declare any development or class of development to be State significant infrastructure (SSI), which requires approval from the NSW Minister for Planning under section 5.14 of the EP&A Act.

Clause 14(1) of State Environmental Planning Policy (State and Regional Development) 2011 (SRD SEPP) declares development to be SSI if the development is permissible without consent under Part 4 of the EP&A Act and is a type of development specified in Schedule 3 to the SRD SEPP. The Project meets the first of these requirements through the effect of the Infrastructure SEPP.

The Project is considered to meet the second requirement with regard to clause 1 (General public authority activities) and clause 4 (Water storage or water treatment facilities), specifically:

- Clause 1: WaterNSW is both the proponent and determining authority for the Project, and determined that preparation of an EIS would be required under Part 5 of the EP&A Act
- Clause 4: the Project comprises a water storage facility carried out by or on behalf of a public authority that has a capital investment value of more than $30 million.

On this basis, the Project is declared to be SSI under section 5.12(2) of the EP&A Act, and is subject to assessment under Division 5.2 of the EP&A Act. The Project will require the approval of the NSW Minister for Planning and Public Spaces under section 5.14 of Division 5.2.

In December 2016, WaterNSW prepared a Preliminary Environmental Assessment (PEA) report for the Project under section 5.15 of the EP&A Act. The PEA described the Project and identified and considered the potential environmental issues arising from the Project. The purpose of the PEA was to assist the formulation of the Secretary's Environmental Assessment Requirements (SEARs) by DPIE under section 5.16 of the EP&A Act and inform the preparation of an EIS for the Project. On 30 June 2017, SEARs for the Project were issued by DPIE. On 13 March 2018 revised SEARs were issued by DPIE.

Any SSI project may also be declared to be Critical State Significant Infrastructure (CSSI) under section 5.13 of the EP&A Act if it is of a category that, in the opinion of the Minister for Planning, is essential for the State for economic, environmental or social reasons.

Table 1-1 SEARs – Aquatic ecology

SECRETARY'S ENVIRONMENTAL ASSESSMENT REQUIREMENTS
SEAR 6 Biodiversity – Key Issue and Desired Performance Outcome The Project design considers all feasible measures to avoid and minimise impacts on terrestrial and ***aquatic biodiversity***. Offsets and/or supplementary measures are assured which are equivalent to any remaining impacts of Project construction and operation.
Requirement 1. The Proponent must assess biodiversity impacts in accordance with the current guidelines including the Framework for Biodiversity Assessment (FBA), unless otherwise agreed by OEH, by a person accredited in accordance with s142B(1)(c) of the *Threatened Species Conservation Act 1995*.
2. The proponent must assess the downstream impacts on threatened biodiversity, native vegetation and habitats resulting from any changes to hydrology and environmental flows. This assessment should address the matters in Attachment B.
3. The Proponent must assess impacts on the following: endangered ecological communities (EECs), threatened species and/or populations, and provide the information specified in s9.2 of the FBA. Specific environmental requirements are provided in Attachment C.
4. The Proponent must identify whether the Project as a whole, or any component of the Project, would be classified as a Key Threatening Process in accordance with the listings in the *Threatened Species Conservation Act 1997* (TSC Act), *Fisheries Management Act 1994* (FM Act) and *Environment Protection and Biodiversity Conservation Act 2000* (EPBC Act).
SEAR 13 Protected and Sensitive Lands – Key Issue and Desired Performance Outcome The project is designed, constructed and operated to avoid or minimise impacts on protected and sensitive lands.
1. The Proponent must assess the impacts of the project on the water catchment and processes (and the impact of processes on the project) including, but not limited to: (b) Key Fish Habitat as mapped and defined in accordance with the *Fisheries Management Act 1994* (FM Act) (d) land or waters identified as Critical Habitat under the TSC Act, FM Act or EPBC Act;

Attachment A to the SEARs identifies certain Protected Matters under the EPBC Act to be addressed in the assessment for the Project, with the following relevant to the aquatic ecology assessment:

- Macquarie perch (*Macquaria australasica*) - Endangered
- Australian grayling (*Prototroctes maraena*) – Vulnerable.

1.4 Scope of assessment

The scope of this assessment addresses the following matters:

- Surface water quality characteristics
- Aquatic macrophytes
- Aquatic macroinvertebrates
- Aquatic vertebrates, including threatened species

- Key fish habitat.

The scope of this assessment does not include semi-aquatic habitats and species groups, such as riparian vegetation, floodplain wetlands (except where relevant to the groups listed above), groundwater dependent ecosystems, or semi-aquatic mammals (platypus, water rats), reptiles (turtles) or amphibians. These matters are addressed in the separate terrestrial biodiversity assessments.

1.5 Impact assessment approach

The key objective of this technical assessment is to identify and assess aquatic ecological impacts related to the Project. The outcomes of the assessment are to inform the Warragamba Dam Raising EIS.

This assessment includes the following to inform the Warragamba Dam Raising EIS:

- Description of the environmental values of the area specifically related to hydrology and flooding that may be affected by the Project (i.e. baseline). The values are described by reference to background information, collected data and recent studies.
- Description of the potential adverse and beneficial impacts of the Project on the identified environmental values for both construction and operation phases.
- Discussion of viable strategies for managing or mitigating identified potential impacts and prospective residual impacts following application of these mitigation measures.

2 Statutory framework

2.1 Legislative context

2.1.1 Fisheries Management Act 1994

The *Fisheries Management Act 1994* (FM Act) provides for the management of fisheries and aquatic vegetation. As part of this framework, the Act requires the following:

- For any project with potential impacts on endangered aquatic species, populations and ecological communities, works must be assessed and approved under the Act
- For any project involving alteration of a dam or blockage to fish passage, works must be assessed in the context of fish passage and, if requested by the Minister, designed to include a suitable fishway or bypass to address identified passage impacts.

Both triggers for assessment apply to the Project due to potential impacts on the EPBC Act listed Macquarie perch (*Macquaria australasica*) and the potential alteration of fish passage associated with changes in the spillway and dam operations. Therefore, the EIS requires consideration of these specific impacts to inform determination of the Project. Note that the assessment of Macquarie perch, assessment of potential impacts to the Blue Mountains or Hawkesbury perch (*Macquaria sp. nov. 'hawkesbury taxon'*) which was identified as a separate species after *Macquaria australasica* was listed. *Macquaria sp. nov. 'hawkesbury taxon'* has been included on the provisional list of animals requiring urgent management attention, in the Australian Governments bushfire recovery package for wildlife and their habitat.

The Department of Primary Industries (DPI) was consulted with regard to matters falling under section 218 of the FM Act. It advised[2] the following:

- Fish passage is not required at Warragamba Dam for freshwater fish other than Anguilla eel passage
- Mitigation measures are included within the designs for the dam raising proposal to ensure juvenile eel passage is maintained or enhanced into Lake Burragorang to achieve a 'no net loss' outcome, with appropriate monitoring occurring to demonstrate the effectiveness of mitigation measures
- Spillway design ensures safe downstream passage of adult eels over the heightened dam wall during spill events.

With regard to the second bullet point above, it is not anticipated that the Project would affect existing movement of juvenile eels and as such WaterNSW does not propose to incorporate any compensatory measures into the design of the Project. A monitoring program would be prepared in consultation with DPI and would be submitted to DPI for approval (refer Section 4.4).

The DPI also advised that as an alternative to the outcomes listed above, WaterNSW may choose to consider the option of improving fishway attraction flows at existing vertical slot fishways on the

[2] Written correspondence (undated) responding to WaterNSW, letter dated 22 May 2018.

Nepean River as a potential offset agreement. These actions would be in lieu of the section 218 eel fish passage requirements for the Warragamba Dam Raising Project.

2.1.2 National Parks and Wildlife Act 1974 and Wilderness Act 1987

The Lake Burragorang catchment includes various conservation areas including National Parks, Wilderness Areas and Wild Rivers. No approval is required under the *National Parks and Wildlife Act 1974* (NPW Act) or *Wilderness Act 1987* for the Project where works do not occur within the limits of listed conservation areas. However, impacts to these areas need to be assessed as part of the EP&A Act EIS process, including changes to habitat values and water resources that are significant aspects of these areas. In particular, changes to the natural state of wild rivers and wilderness areas will be of significance in the assessment of approval for the Project under the EP&A Act.

2.1.3 Environment Protection and Biodiversity Conservation Act 1999

The *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) provides a legislative framework for the protection and management of matters of national environmental significance (MNES) including flora, fauna, ecological communities, and heritage places of national and international importance.

Under Part 9 of the EPBC Act, approval is required for any action occurring within, or outside, a heritage place that has, will have, or is likely to have a ‘significant impact’ on the heritage values of a world, national or Commonwealth heritage listed property (referred to as a ‘controlled action’ under the Act). A ‘significant impact’ is defined as:

2.2 Applicable guidelines

The SEARs identify guidelines to be considered as part of the environmental assessment. These are discussed below in the context of aquatic ecology. This report has been prepared to address the relevant requirements of these policies where applicable.

Guidelines applicable to aquatic ecology, their objectives, justification for use and how they have been applied are outlined in Table 2-1.

Table 2-1 Current guidelines applicable to aquatic ecology

Guideline	Justification for Use and Application
NSW Biodiversity Offsets Policy for Major Projects (OEH, 2014)	This Policy clarifies and standardises biodiversity impact assessment and offsetting for major project approvals in NSW. This Policy applies to state significant infrastructure projects and as such is relevant to the Project. This assessment will utilise and apply the Policy as needed during the impact assessment. The Policy is discussed further in Section 2.2.1
Framework for Biodiversity Assessment (OEH, 2014)	The then OEH produced the Framework for Biodiversity Assessments (FBA) in 2014 to underpin the NSW Biodiversity Offsets Policy for Major Projects. It contains the assessment methodology that is adopted by the Policy. The FBA must be used to assess all biodiversity values on site for a Major Project, thus, this assessment will apply the FBA during the assessment of aquatic ecology for the Project. The FBA is discussed further in Section 2.2.2.
Policy and Guidelines for Fish Habitat Conservation	This Policy promotes and provides guidance on compliance with legislation relating to fish habitat conservation and management. The Policy and Guidelines are used to assist Department of Primary Industries (DPI) with

Guideline	Justification for Use and Application
and Management – Update 2013 (DPI, 2013)	assessing development proposals and as such this assessment will address and apply them in relation to the Project. The Policy and Guidelines for Fish Habitat Conservation and Management is discussed further in Section 2.2.3.
Threatened Species Survey and Assessment Guidelines (Working Draft) (DEC, 2004) Threatened Species Assessment Guidelines (DECC, 2007)	The Threatened Species Survey and Assessment Guidelines (also known as the Threatened Biodiversity Survey and Assessment: Guidelines for Development Activities) are a draft set of guidelines for conducting ecological assessments of threatened species. However, these guidelines have mostly been replaced by the FBA. The Threatened Species Assessment Guidelines supplement the assessment of impacts to threatened species under the Threatened Species Survey and Assessment Guidelines. While also mostly replaced by the FBA process, these guidelines provide detail on the assessment of threatened species protected under biodiversity and fisheries legislation that is additional to the FBA.
Survey Guidelines for Australia's Threatened fish (DSEWPaC, 2011)	These guidelines were published to provide proponents and assessors with a guide to survey Australia's threatened fish listed under the EPBC Act. The guidelines outlined the preferred approach to determine the likelihood of the presence of a species, including survey methodology and timing.
Aquatic ecology in Environmental Impact Assessments – EIA Guideline (Lincoln Smith, 2003)	These guidelines were published to provide guidance in the identification, prediction and assessment of impacts of proposed projects on aquatic ecosystems. The guideline sets out a comprehensive approach and methodology to be used during the assessment to ensure consistency and an approach level of detail. This guideline applies directly to this assessment and was applied during this assessment. This EIA guideline is discussed further in Section 2.2.4.
Why Do Fish Need to Cross the Road? Fish Passage Requirements for Waterway Crossings (NSW Fisheries, 2003)	This document provides guidelines for those involved in planning, design, construction and maintenance of waterway crossings with the aim of minimising impacts on fish passage and general aquatic wildlife. The Project involves raising the existing Warragamba Dam wall and not creating a new waterway barrier or crossing and as such is less applicable. However, it provides valuable information on fish passage and will be referred to as needed during the impact assessment. This document is discussed further in Section 2.2.5.
NSW Sustainable Design Guidelines Version 3.0 (Transport for NSW 2013)	***Not applicable***: These guidelines aim to assist in delivering sustainable development practices by embedding sustainability initiatives into the design and construction of transport infrastructure projects. These guidelines cover train stations, transport interchanges, commuter car parks, maintenance facilities and depots, tunnels, light rail systems and associated civil infrastructure. The Project does not fall under these asset types and is not a transport infrastructure project and as such these guidelines have not been used.
Significant Impact Guidelines 1.1 – Matters of National Environmental Significance (DoE, 2013) Draft referral guidelines for the endangered Macquarie perch, *Macquaria australasica* (DSEWPaC, 2011)	These guidelines provide criteria for assessing the whether an activity is likely to have a significant impact to MNES. As Macquarie perch is listed as endangered under the EPBC Act, the 'Significant impact criteria' for critically endangered and endangered species were referenced in this assessment. The Macquarie perch referral guidelines relate primarily to preparation of a referral for activities with potential impacts on this species. However, the guidelines include advice on appropriate methods and techniques for assessing the presence of and impacts to the Macquarie perch.

2.2.1 NSW Biodiversity Offsets Policy for Major Projects

This policy was introduced to standardise biodiversity assessment and offsetting for major project approvals in NSW. The policy applies to 'major projects', identified as State Significant Development and SSI under the EP&A Act, and works in conjunction with the *Biodiversity Conservation Act 2016* (BC Act) and FM Act. The BC Act relates to protection and management of all threatened species, populations and ecological communities in NSW while the FM Act relates more specifically to the protection, conservation and recovery of fish stocks, key fish habitats, threatened species, populations and ecological communities of fish and marine vegetation.

The scope of the policy is generally limited to projects with impacts to vegetation (e.g. clearing) and is therefore mainly directed towards terrestrial biodiversity. However, aspects of the policy that are relevant to this assessment included potential impacts relating to non-saline wetlands that may otherwise support aquatic biodiversity values.

The two most important elements of the policy are the use of a hierarchy of 'avoid, minimise, offset' when considering environmental impacts, and establishing a system for biodiversity offsets.

2.2.2 Framework for Biodiversity Assessment

The objectives of the Biodiversity Offsets Policy are primarily achieved by ensuring the biodiversity values of a project area are assessed in accordance with the Framework for Biodiversity Assessment 2014 (FBA). Undertaking a biodiversity assessment consistent with the FBA involves development of a Biodiversity Assessment Report based on three stages:

(1) Assessment of existing landscape, native vegetation and threatened species values. This includes identifying the likely occurrence of a threatened species based on habitat surrogates (ecosystem credit species) or actual presence (species credit system), which can be done either through surveys or reliance on expert reports.

(2) Impact assessment, including identification of residual impacts for offsetting after application of the avoid, minimise, offset hierarchy. For certain impacts, further detail is required on the underlying values to inform decision-making.

(3) Development of a biodiversity offset strategy.

Each assessment is required to be undertaken by an accredited assessor. This report has been prepared by an accredited assessor and contributes to the first two of these stages as they relate to aquatic ecology associated with the Project. A separate biodiversity offset strategy would be prepared for the entire Project.

2.2.3 Policy and Guidelines for Fish Habitat Conservation and Management

The DPI *Policy and Guidelines for Fish Habitat Conservation and Management* supplements the assessment and management processes of the Offset Policy and FBA as they relate directly to fisheries values. It sets out DPI's policies related to fish habitat management for particular kinds of works, and guidelines for aligning project management with these policies.

The most relevant aspects of the policy and guidelines for this assessment are provisions for management of riparian habitat, in-stream structures and fish passage barriers, and temperature.

Additionally, the guidelines set requirements for aquatic habitat assessments and aquatic fauna surveys, which can integrate into the FBA process under the Offset Policy.

Section 3 of the policy and guidelines sets out requirements associated with general fish habitat conservation and management, while Section 4 relates to barriers to fish passage. Both sections also provide the requirements for development applications for these types of works as triggered under the Fisheries Management Act. Importantly, the sections require an assessment of waterways and aquatic habitat values to support an application, including categorisation based on waterway class and habitat type. This is based primarily upon desktop data, supplemented where necessary by a site assessment(s).

This assessment has been undertaken in accordance with the policy and guidelines requirements and includes classifications of aquatic habitat type and waterway class.

2.2.4 Aquatic Ecology in Environmental Impact Assessments – EIA Guidelines

The *Aquatic Ecology in Environmental Impact Assessments – EIA Guidelines* (Lincoln Smith, 2003) aid in undertaking assessment of impacts to aquatic ecology as part of environmental impact assessments (EIAs). Specifically, it sets out the process for aquatic ecology studies. While not mandatory, these guidelines are considered good practice in conduct of aquatic ecology EIA under the NSW EP&A Act. These guidelines have been generally adopted in the development of this EIS.

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

A key potential risk required for consideration and management for this project is the maintenances of upstream and downstream passage of fish species. Fish passage is critical to the survival of Australian native fish, as approximately 70 percent of coastal species in south-eastern Australia migrate to complete their lifecycle.

This document aims to minimise impacts of fish passage by providing best practice guidelines to those in the planning, design and construction and maintenance of waterway crossings. Effective fish passage designs need to be appropriately investigated, planned and designed for the local site conditions. Generic guideline designs are provided to suite a range of fish barriers and have been matched to the waterway types.

2.2.6 Significant Impact Guidelines and Macquarie Perch Referral Guideline

A key assessment priority for the Project under the EPBC Act is whether there will be significant impacts to MNES, including the Macquarie perch which is a listed threatened species (Endangered). The Significant Impact Guidelines 1.1 provide criteria for determining if an activity will have a significant impact while the draft referral guidelines provide additional information on impacting processes and mitigation specific to the Macquarie perch. Both need to be considered together, therefore, when evaluating impacts specific to this species.

3 Existing environment

The Hawkesbury-Nepean catchment is one of the largest coastal basins in NSW covering an area of some 21,400 km^2 from Lithgow to Goulburn and the Illawarra escarpment up to Gosford (Figure 3-1). The operational area or areas where impacts may occur is located wholly within the Hawkesbury-Nepean catchment.

A summary of aquatic ecology relevant to the existing study environments (upstream and receiving) is provided below. The aquatic ecology baseline characterisation provided in this section should be read in conjunction with the results of field surveys, including an aquatic habitat assessment (Appendix A) and environmental DNA (eDNA) results to identify the presence of threatened species (Appendix B).

3.1 Assessment approach

Aquatic habitats within the study area were characterised as follows:

- Historical conditions assessed through review of 2013 River Styles® mapping (GHD 2013). This assessment provides a geomorphological classification and assessment of physical habitat condition of streams within the Hawkesbury-Nepean catchment
- The boundaries of visible meso-habitat features (i.e. sand/gravel shoals, shallow rocky areas, macrophytes) were digitised using geo-rectified aerial photography (Nearmap – 2019)
- Bank profiles were interpreted using a digital elevation model (DEM) produced by Shuttle Radar Topography Mission (SRTM - supplied by WaterNSW with 30 m accuracy)
- Strahler stream order was characterised using data obtained through the Australian Government (www.data.gov.au)
- Habitat conditions of portions of the Nattai River, Little River, Wollondilly River, Kedumba River and Coxs River were characterised during site surveys undertaken in December 2017.

It is important to note the following mapping limitations: (i) many of the smaller tributary streams in confined (gorge) environments are narrow with a dense riparian canopy, and are therefore difficult to map from remote imagery; (ii) access to Lake Burragorang and its tributary streams is severely constrained (limited tracks, steep/rugged topography), and site inspections were limited to areas accessible by tracks. A mapping confidence level was provided to reflect these limitations.

The Project does not introduce any new obstructions to fish passage upstream or downstream. As such, this issue has not been considered as the Project does not introduce any material changes with regard to existing obstructions and was not identified by DPI as being of specific concern.

An aquatic habitat assessment was conducted to characterise the general habitat condition within the upstream reaches of Warragamba Dam (Appendix A). It also served to determine the appropriateness for threatened species habitat at each location. Note, that a dedicated aquatic habitat assessment was not conducted downstream. Potential impacts downstream relate mostly to flood flow, for which the main impacts would be within the floodplains of Penrith, Richmond and Windsor. Material impacts to downstream habitat preferred by the Macquarie perch (clear, cool, rocky fast-flowing streams with deep holes and riffles) resulting from the project are considered unlikely.

However, due to the inundation of the flood mitigation zone, material impacts to upstream habitats preferred by Macquarie perch may occur.

Nine sites were assessed – two on the Nattai River, one on Little River, three on the Wollondilly River, two on the Kedumba River, and one on the Upper Coxs River (see Figure 2-1 of Appendix A). The aquatic habitat assessment included:

- Records of approximate water depth
- Stream flow
- Wetted stream width and length
- Water clarity
- Sediment and water odour
- Mesohabitat structures (e.g., pool, riffle, run)
- Bank conditions (e.g. undercutting, slope, erosion, overhanging roots)
- Substrate composition (e.g. mud, sand, fine gravel, coarse gravel, cobble, rock, bedrock)
- Composition and abundance of macrophyte species (e.g. floating, emergent, submerged)
- Riparian and in-stream vegetation
- Filamentous algae
- Leaf litter
- Presence of small (less than 15 cm diameter) and large woody debris (more than 15 cm diameter)
- Animal activity (e.g. footprints, droppings) and
- Human activity (e.g. bridges, farms, weirs).

3.2 Aquatic habitats

3.2.1 Upstream environments

The major sub-catchments that drain into Lake Burragorang are the Wollondilly River and Coxs River systems, which collectively cover an area of 9,050 km^2. The other sub-catchments draining into Lake Burragorang are the Nattai River, Kowmung River, Wingecarribee River and Mulwaree River (Figure 3-2).

3.2.1.1 Lotic habitats

Lotic habitats are represented by rivers and streams, are characterised by water with a unidirectional water flow, and are classified based on ‘size’ as represented by stream order. For the purpose of this assessment the Strahler stream classification system was used to classify stream order. Figure 3-3 presents stream order mapping for the upstream study area.

Rivers within the upstream study area include the Wollondilly River, Coxs River, Nattai River, Kedumba River, Kowmung River, Jooriland River, Wingecarribee River, Mulwaree River, and Little

River (refer Figure 3-2). Creeks within the upstream study area include Kanangra Creek, Butchers Creek, Green Wattle Creek, Lacys Creek, Tonalli Creek, Brimstone Creek, Werriberri Creek, and Ripple Creek (refer Figure 3-9).

The River Styles® Framework has been used to characterise geomorphic river types, their behaviour, condition and recovery potential. The River Styles® geomorphic river type mapping is presented in Figure 3-4 and Appendix A. The predominant geomorphic river type (according to River Styles®) within the upstream study area is 'Confined Valley Setting' (CVS). Within this 'style', streams generally occur in steep, deeply dissected valleys, and floodplains are absent or poorly developed. The remainder of the upstream study area includes streams located in partly confined valleys (PVCS: partly confined valley setting) and alluvial valley settings (LUV CC: laterally unconfined valley setting – continuous channel; SMG: swampy meadow group)), which have a lower gradient and contain sediment deposits. All geomorphic river types in the River Styles® classification that are represented in the study area contain pool, rifle/run sequences. The geomorphic river types under the River Styles® classification that are represented in the upstream study area are shown in Table 3-1.

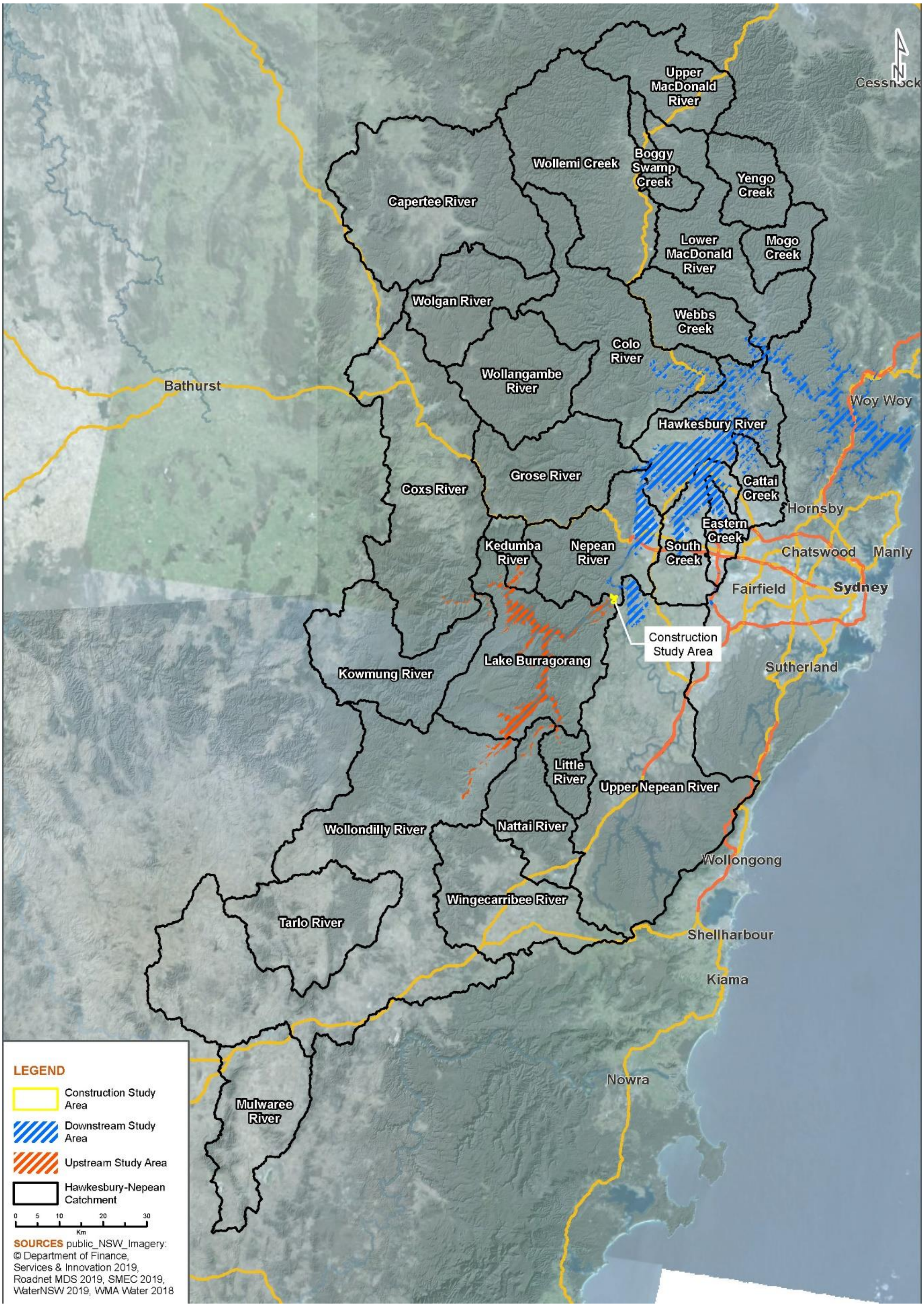


Figure 3-1 Hawkesbury–Nepean catchment

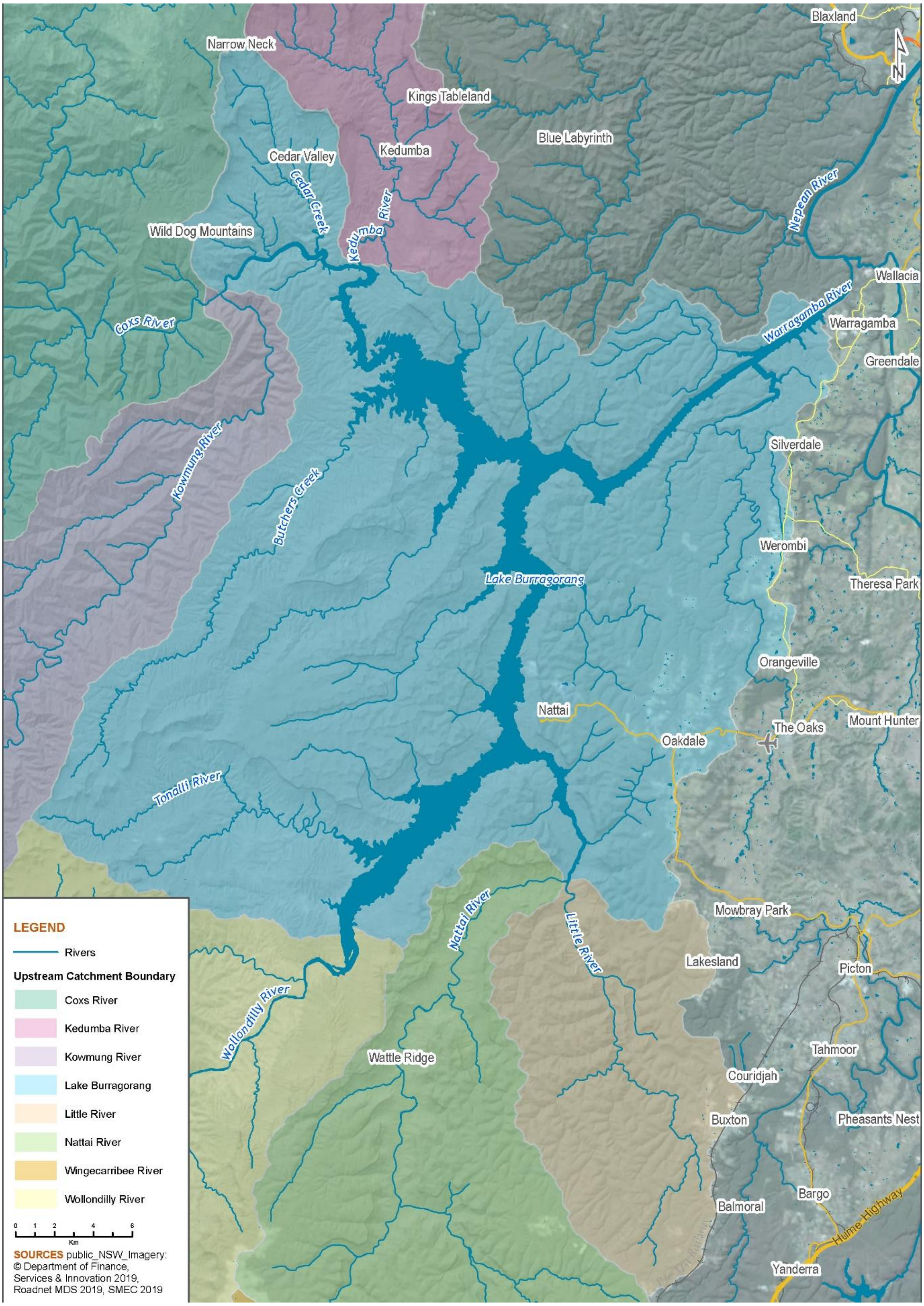


Figure 3-2 Upstream sub-catchments and major rivers

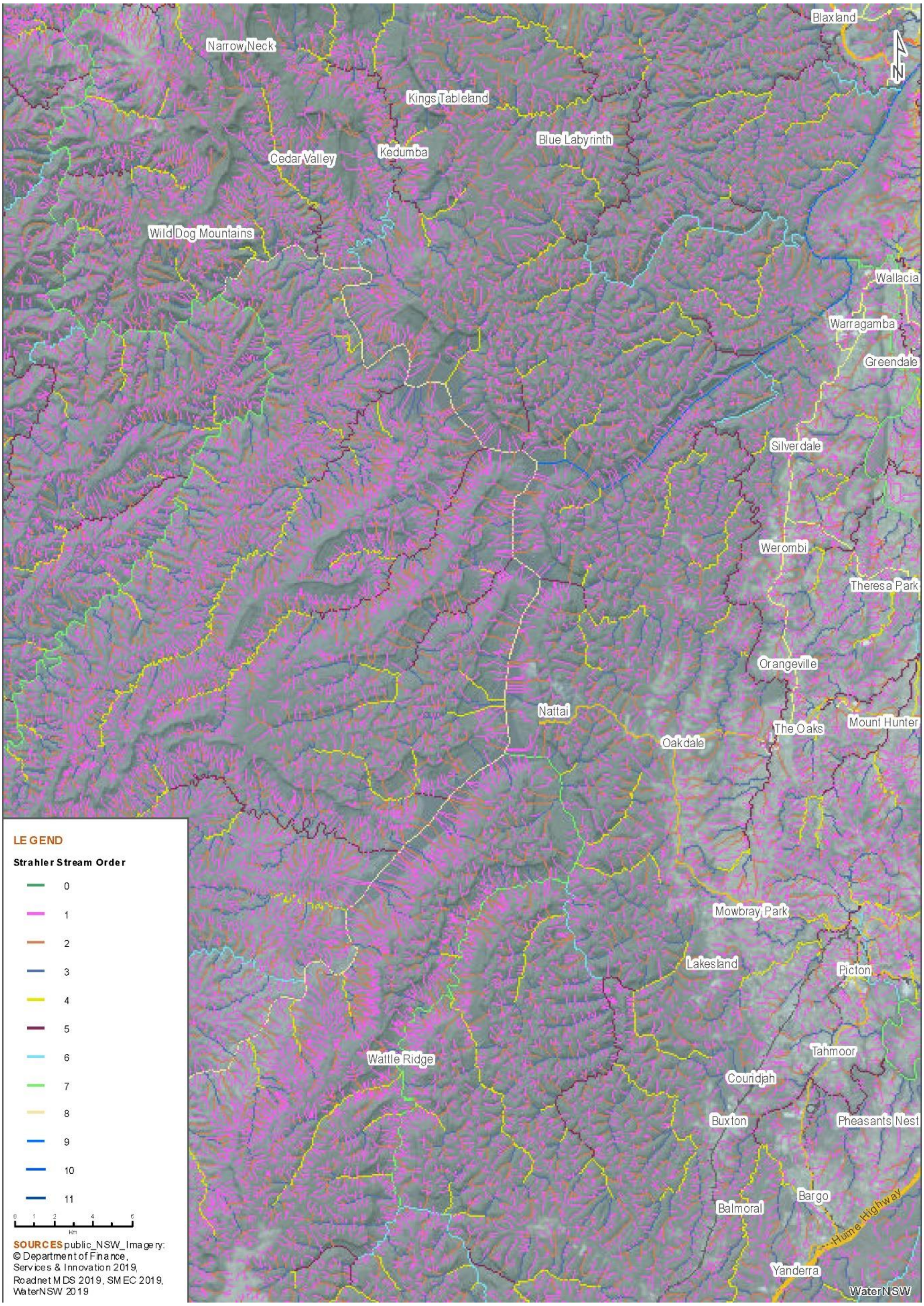


Figure 3-3 Strahler stream order – upstream

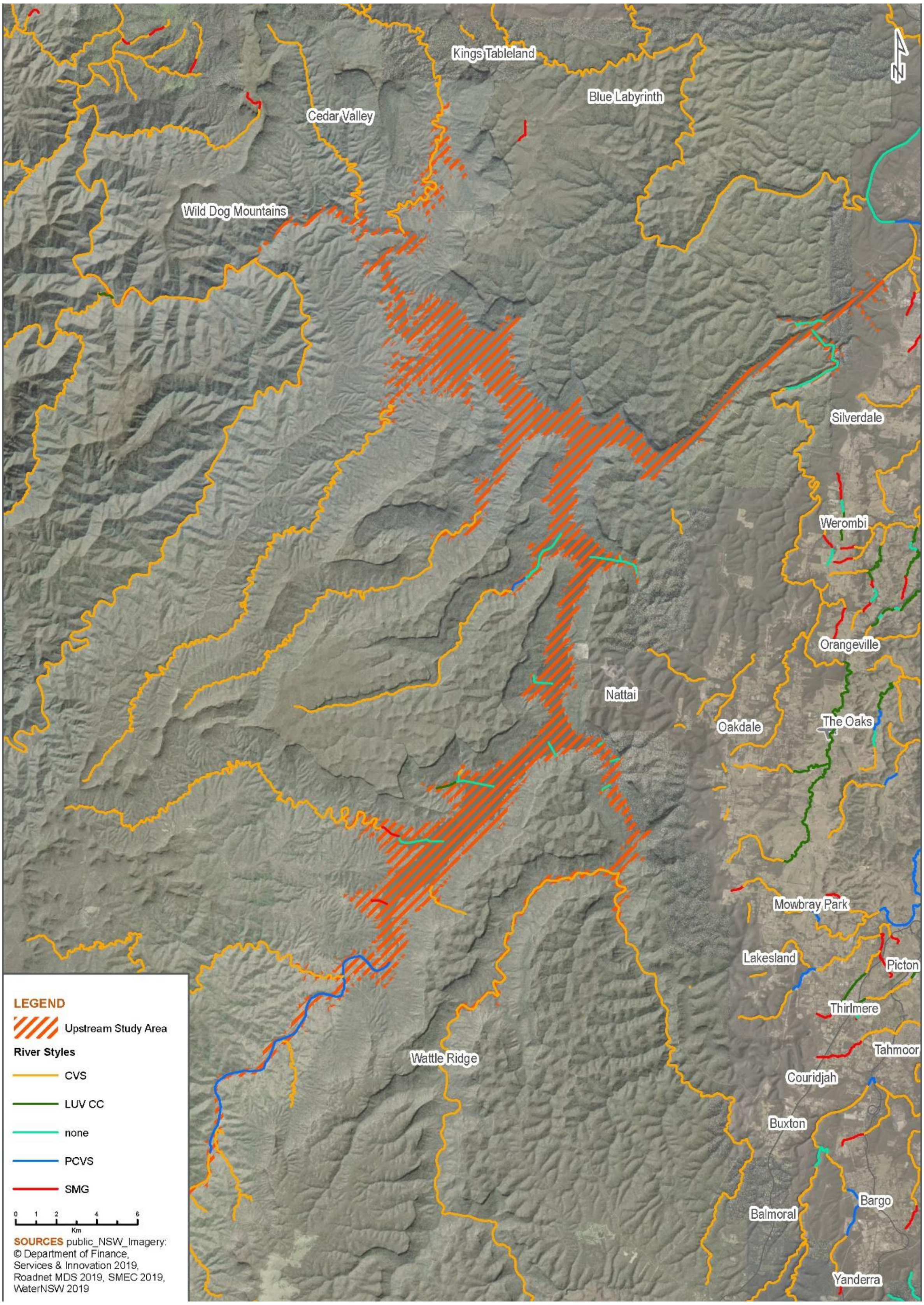


Figure 3-4 River Styles® geomorphic river type – upstream

Table 3-1 Length of River Styles within the study area and mapping area (GHD 2013)

River Styles® Setting	River Style	Total length (km):	
		Upstream study area	Sub-catchments within mapping area
Confined Valley Setting	Unclassified (low order streams)	77.5	N/A
	Floodplain pockets, gravel	61.8	Wollondilly River = 11.1 Kowmung River= 16.3 Coxs River= 0.4 Nattai River= 12.3
	Floodplain pockets, sand	22.3	Wollondilly River= 0.5 Kowmung River= 1.1 Coxs River= 11.9 Lake Burragorang = 9.2 Kedumba River = 4.1
	Gorge	14.8	Wollondilly River= 5.5 Kowmung River= 1.3 Nattai River= 4.5 Lake Burragorang = 3.2
Partly confined valley setting	Bedrock controlled, gravel	14.5	Wollondilly River= 14.5
	Planform controlled, low sinuosity, gravel	1.0	Lake Burragorang = 1.0
Alluvial valley setting	Low sinuosity, gravel	0.7	Coxs River= 0.7
Anthropogenic Systems	Water storage - dam or weir pool	2.3	Lake Burragorang = 2.3

Table 3-2 River Styles® descriptions

River Style®	Description relative to study area
Floodplain pockets (gravel, sand) – Confined valley setting.	This River Style® was represented in the mapping area at the Wollondilly River, Kowmung River, Coxs River, and Nattai River sub-catchments. The Floodplain pockets River Styles® is characterised by a bedrock or boulder dominated channel, leading to the formation of riffle and pool sequences. Gravel and/or sand is delivered to the channel during high flow events, leading to the formation of gravel and sand bars and floodplain pockets on inside bends. Depending on water levels, shallow areas can form dry bars (low flow), shoals or glides (high flow). Notable examples of gravel and sand shoals in the mapping area were: (i) depositional environments at the confluence of Wollondilly River and Lake Burragorang, (ii) the main channel of Nattai River; (iii) the main channel of Little River, and; (iv) Coxs River. Aquatic macrophyte beds occur in places, the largest occurring at the mouth of Wollondilly River, and smaller beds at Green Wattle Creek and Nattai River.
Gorge – Confined valley setting.	Within the mapping area this River Style® is represented in Wollondilly River, Coxs River (mid-section), Kangaroo River and Bungonia Creek sub-catchments. The Gorge River Style® is characterised by a confined channel with no floodplain, steep rocky banks, and bed comprised of bedrock, boulders, cobble and gravel. Streams in this River Styles® support riffle, run and pool sequences, which represent important value habitat for threatened aquatic fauna and many other aquatic species.

River Style®	Description relative to study area
Bedrock controlled (gravel) – Partly confined valley setting.	This River Style® was represented in the mapped area at the Wollondilly River sub-catchments. The Bedrock controlled (gravel) River Styles® occur in "V"-shaped valleys at the base of escarpments. The channel has a bedrock floor and contains discontinuous floodplain pockets in sheltered areas. Gravel point bars and benches are present. This River Styles® contains pools, riffles and glides/run. This River Styles® is subject to high flow velocities which prevents the establishment of large macrophyte beds.
Planform controlled, low sinuosity, gravel – Partly confined valley setting.	This River Style® was represented in the mapped area at the Lacys Creek River sub-catchments. The Planform controlled, low sinuosity, gravel River Styles® also occurs in a partly confined valley setting the valley is broader and the channel is less constrained than the Bedrock controlled River Styles®. Discontinuous floodplains are present. The bed is dominated by gravels, but sands and silts also occur. Pool and riffle sequences re the main instream habitat types. Extensive macrophyte beds are not present in this River Styles® within the study area.
Low sinuosity, gravel – Alluvial valley setting.	This River Style® was represented in Wollondilly River sub-catchment. Streams in this River Styles® occur in alluvial valley settings and have a gravel dominated bed. Habitat diversity is high, with pool-riffle sequences, runs, mid channel gravel bars and levees.

3.2.1.2 *Lacustrine habitats*

Lacustrine habitats are defined as inland depressions or dammed riverine channels containing standing water (Cowardin *et al.*, 1979). Within the upstream study area Lacustrine habitats are represented by Lake Burragorang.

Within Lake Burragorang there are two lacustrine meso-habitat types:

- Limnetic zone (deep waters) – which represents most of the area of Lake Burragorang. The lake has a maximum depth of about 105 m
- Littoral zone (shallow waters) – water levels in Lake Burragorang vary over time by up to approximately 25 m (Figure 3-5). The position and extent of the littoral zone therefore varies greatly over time, so it is not meaningful to map littoral zone boundaries. Most of Lake Burragorang has steep banks (Figure 3-6[3]), therefore the littoral zone extent is limited. An inspection of aerial photography indicates that the banks are comprised of bedrock, bounders and sand patches in places. Aquatic macrophyte beds occasionally occur on the sandy bench located near the dam wall.

[3] The profiles in Figure 3-6 do not extend below the water line. The heights of cross sections are in m AHD.

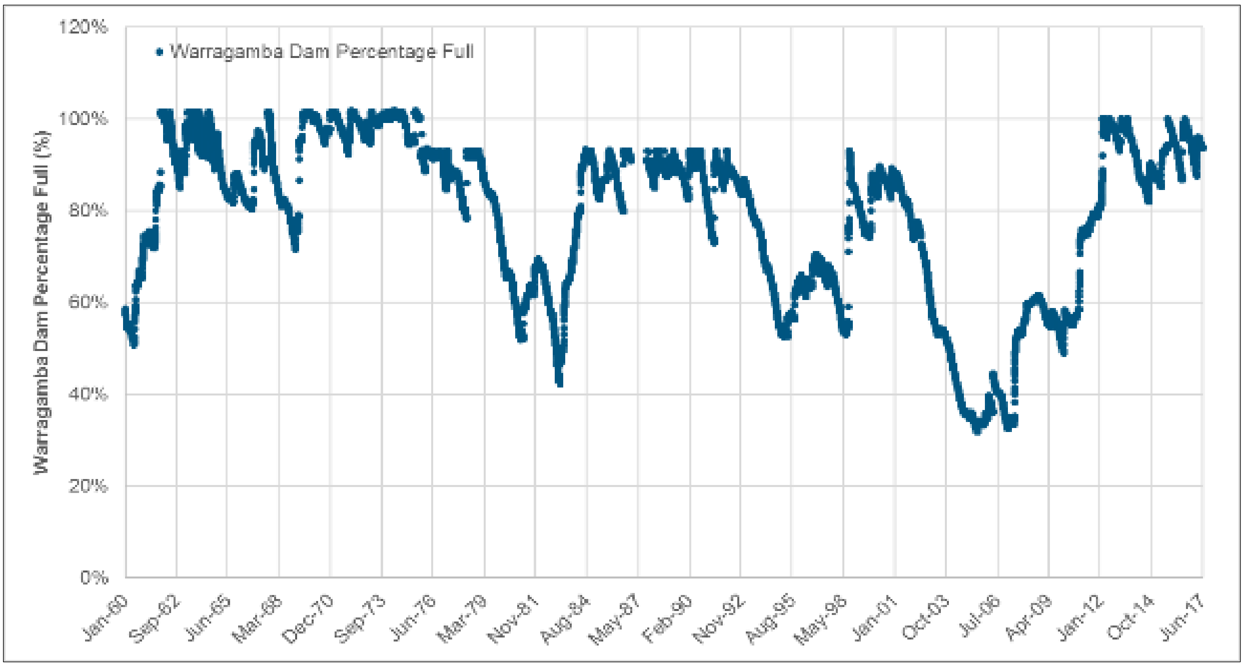


Figure 3-5 Warragamba Dam historic water levels (Source: WaterNSW unpublished)

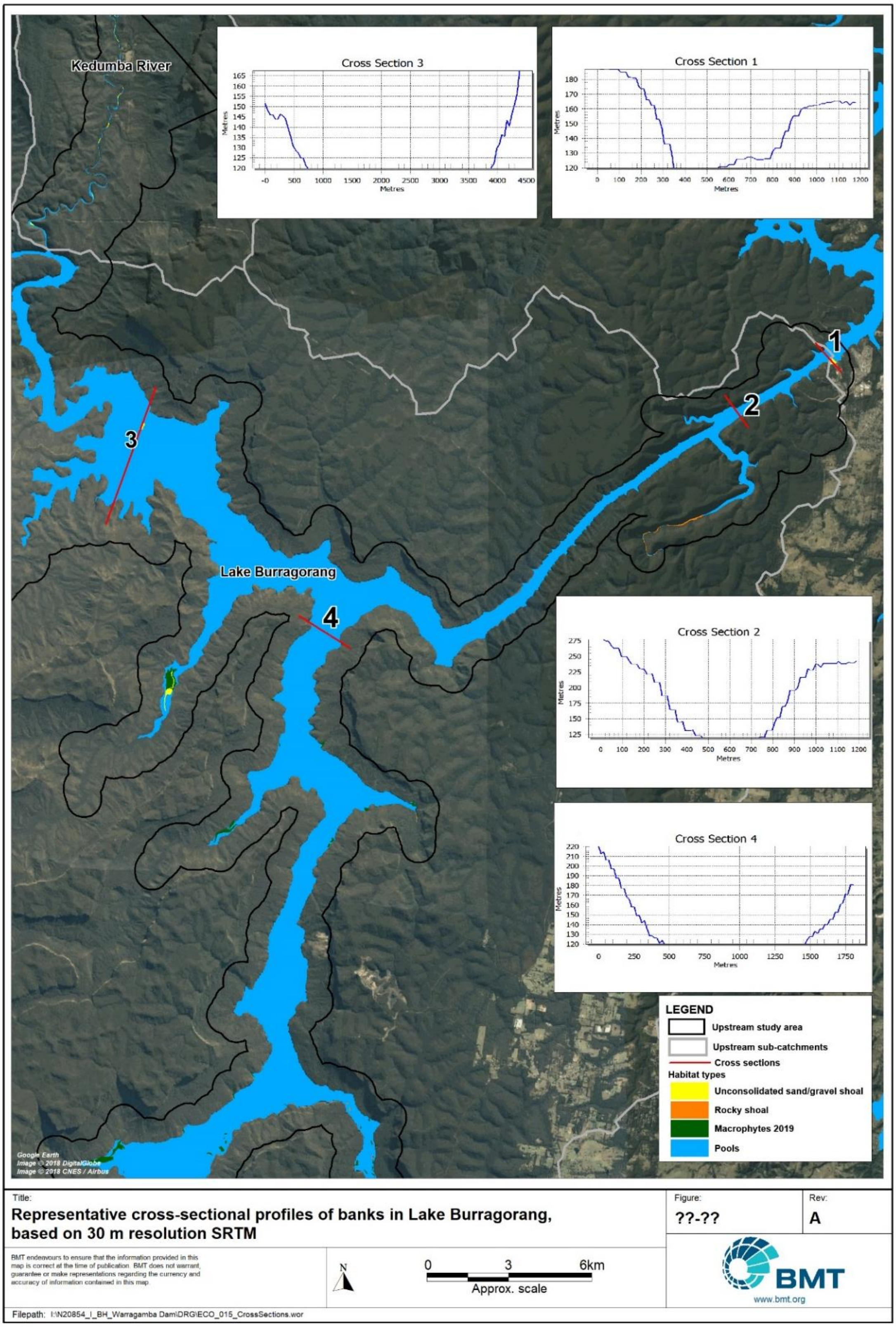


Figure 3-6 Representative cross-sectional profiles of banks in Lake Burragorang, based on 30 m resolution LiDAR

3.2.1.3 Wetlands

Wetland is a broad term used to describe bodies of water such as swamps, marshes, billabongs, and lakes. They provide valuable ecosystem services including reducing the impacts of floods, absorbing pollutants and improving water quality, and provide habitat for myriad flora and fauna species.

The Convention on Wetlands of International Importance (Ramsar Convention) commits contracting parties, such as Australia, to designate wetlands that meet the Ramsar criteria, and include the conservation and wise use of wetlands in relevant national policy. Australia has 66 Ramsar designated wetlands; however, none occur within the upstream and downstream study areas.

In Australia, the Directory of Nationally Important Wetlands (DIWA) identifies wetlands that are:

- A good example of a wetland type occurring within a biogeographic region in Australia
- Play an important ecological or hydrological role in natural functioning of a major wetland system/complex
- Important as the habitat for animal taxa at a vulnerable stage in their life cycles, or provides a refuge when adverse conditions such as drought prevail
- Supports one percent or more of the national populations of any native plant or animal taxa
- Supports native plant or animal taxa or communities which are considered endangered or vulnerable at the national level
- Of outstanding historical or cultural significance.

Four wetland areas listed under the DIWA occur in the sub-catchments of Lake Burragorang (Figure 3-7) including:

- Blue Mountains Swamps (NSW072)
- Boyd Plateau Bogs (NSW074)
- Wingecarribee Swamp (NSW093)
- Long, Hanging Rock, Mundego and Stingray Swamps (Paddys River Swamps) (NSW082)
- Lake Bathurst (NSW066).

The Blue Mountains sedge swamps are the closest DIWA wetland to the upstream study area. These wetlands are also known as hanging swamps because they frequently occur on steep slopes. The closest swamp/wetland within this complex is about seven kilometres north of Lake Burragorang; however, the swamps do not occur within the PMF or flood mitigation zone.

The Boyd Plateau Bogs area about 38 km west of the upstream study area. The wetland encompasses several palustrine wetlands that support flora and fauna of conservation significance.

The remaining DIWA wetlands are located in the Wollondilly-Mulwaree-Wingecarribee river sub-catchment, well outside the potential area of influence of the Project.

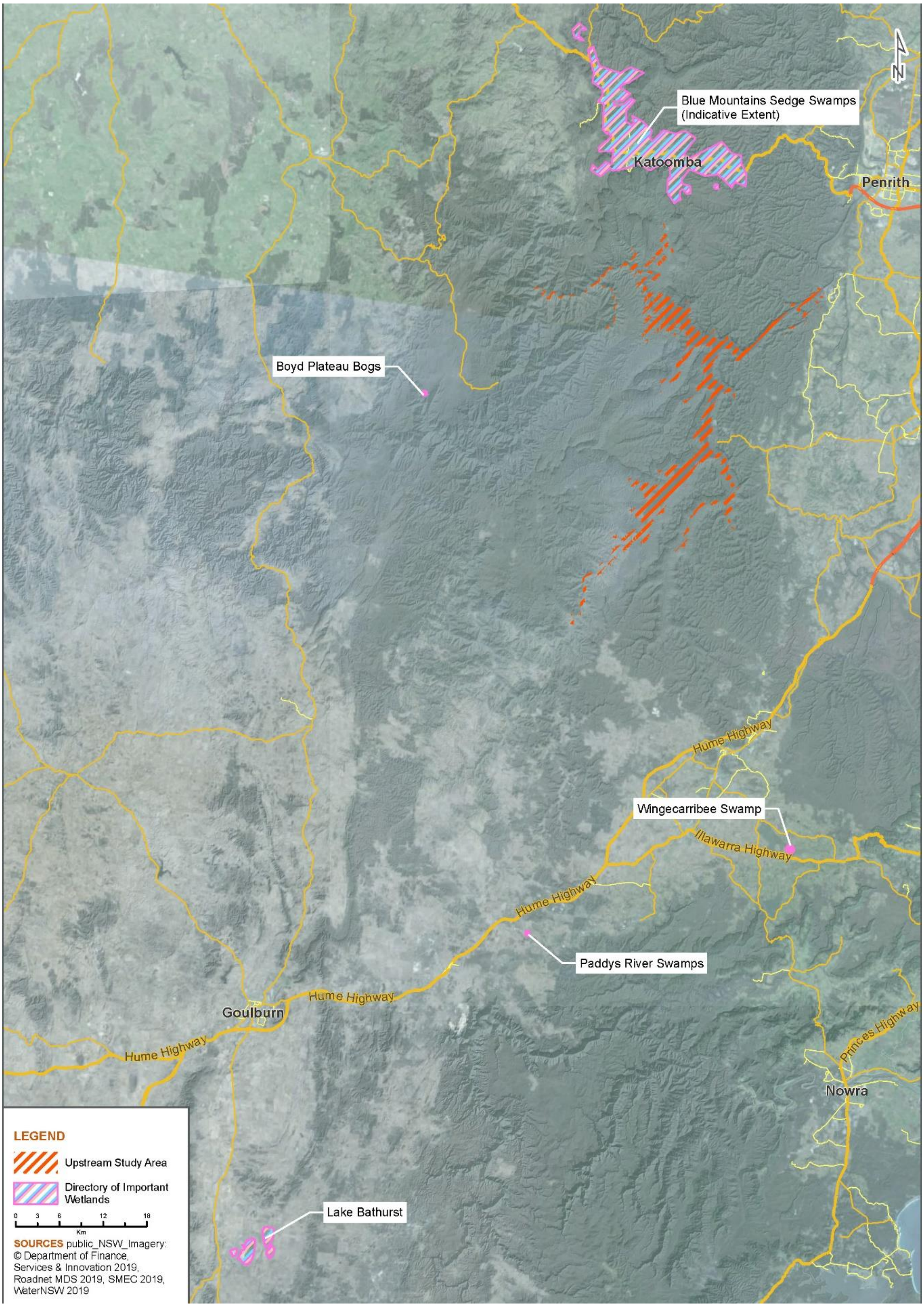


Figure 3-7 Directory of important wetlands of Australia – upstream

3.2.1.4 Key fish habitat

The NSW Department of Primary Industries (DPI) has carried out mapping of key fish habitat for NSW catchments, generally by local government area (LGA), including Wollondilly[4]. The map identifies all of Lake Burragorang and its tributaries as key fish habitat.

3.2.1.5 Habitat condition

A recent audit of the Sydney drinking water catchment undertaken by Alluvium (2017) provided an assessments of the state and trend of habitats. Habitat state was assessed as ‘good’, ‘moderate’ or ‘poor’, and the trend in condition assessed as ‘improving’, ‘stable’ or ‘worsening’. A ‘good’ state indicated no change or an improvement since the previous audit; ‘moderate’ state indicated mixed condition assessment outcomes across the catchment, and; ‘poor’ state indicated a significant decline. As an example, using water quality, monitoring data was assessed for compliance against water quality guidelines for ecosystem health.

The 2017 audit of the Sydney drinking water catchment determined that about 57 percent of the upstream catchment was in ‘good’ condition or within a protected area. The remaining 43 percent was characterised in ‘moderate’ to ‘poor’ condition (Alluvium, 2017). Most of the catchments classified as ‘poor’ condition were in the far-southern portion of the catchment. Storages and catchments that were found to have the poorest water quality during the audit period included the lower Coxs River and Lake Burragorang, and Wingecarribee River.

Previous habitat condition assessments concluded that the greatest risk of sediment and nutrient generation through fluvial geomorphic process is expected to arise from the Wollondilly sub-catchment and its two major sub-catchments, those of the Mulwaree River and upper Wollondilly River. Sediment and nutrient generation in this region could have a direct impact on areas downstream. The upper Coxs River and Wingecarribee River sub-catchments were also predicted to have a high proportion of streams with a high risk of sediment and nutrient loads; however, due to their small extent, they were not expected to exert the same degree of pressure as the Mulwaree River and upper Wollondilly River.

Previous habitat condition assessment results (Alluvium, 2017) are presented in Figure 3-8.

[4] https://www.dpi.nsw.gov.au/__data/assets/pdf_file/0003/634377/Wollondilly.pdf

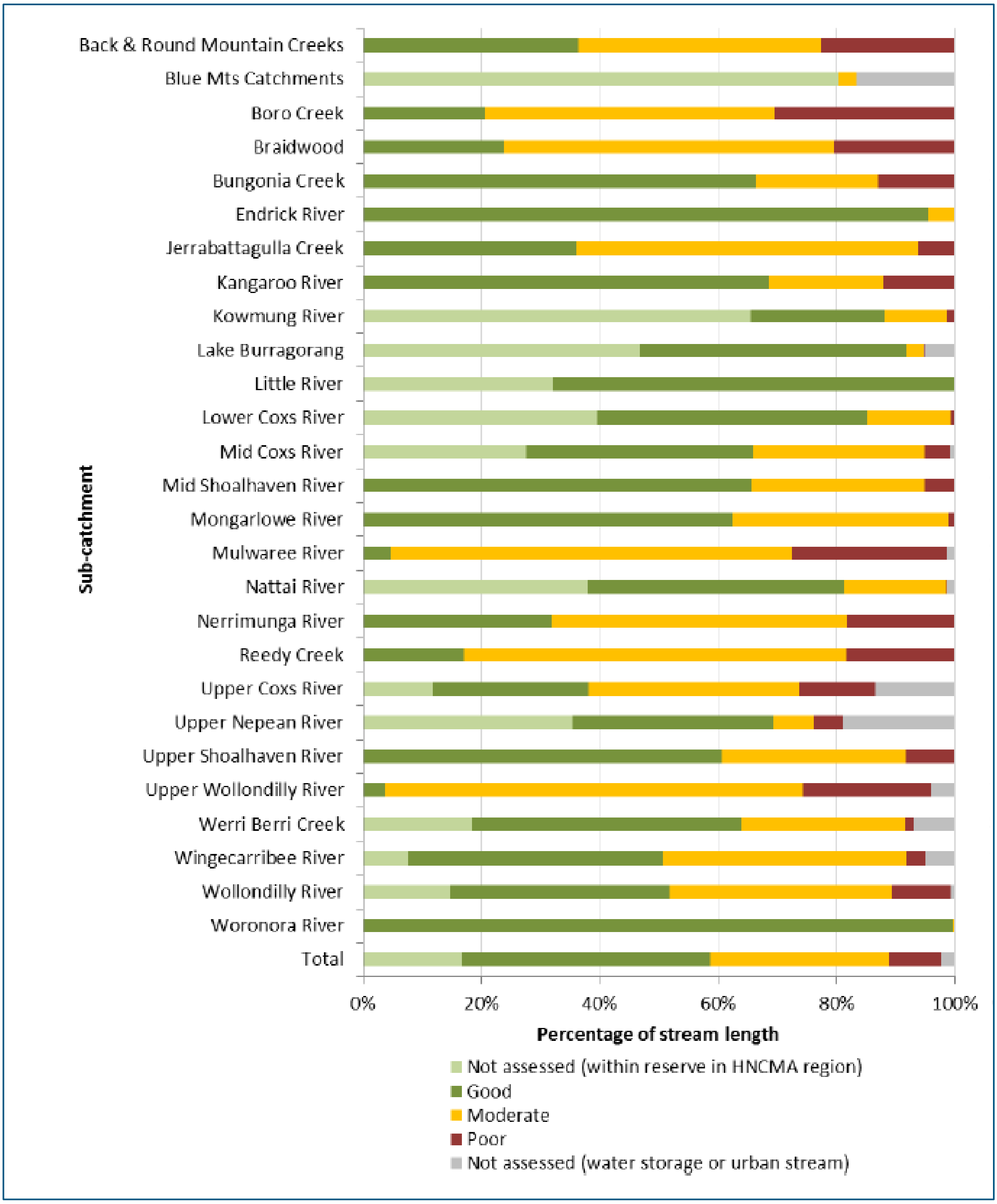


Figure 3-8 Stream length condition for each sub-catchment. (Alluvium 2017)

3.2.2 Downstream environments

The downstream catchment encompasses seven rivers and four major creeks, comprising an area of about 12,350 km^2 (Figure 3-9).

3.2.2.1 Lotic habitats

The seven rivers within the downstream study area include the Hawkesbury River, Hawkesbury River, Nepean River, Grose River, Colo River, and Macdonald River. The four major creeks within the downstream study area include Erskine Creek, Webbs Creek, South Creek, and Cattai Creek. Figure 3-10 presents stream order mapping for the upstream study area.

Most geomorphic river types (according to River Styles®) occur in the downstream study area including:

- *Water storage – dam or weir pool* geomorphic river type which includes the Nepean River from about the confluence of the Warragamba River to where Boundary Creek enters
- Low sinuosity, gravel geomorphic river type, which includes the Nepean River downstream of where Boundary Creek enters to the confluence with the Hawkesbury River
- Low sinuosity, fine grained geomorphic river type, which includes the Hawkesbury River from the confluence with the Nepean River downstream to about Ebenezer
- Planform controlled, low sinuosity, fine grained geomorphic river type, which includes the Hawkesbury River from about Ebenezer downstream to about Lower Portland
- Bedrock controlled, gravel geomorphic river type, which includes the Hawkesbury River from about Lower Portland downstream to Spencer
- Tidal geomorphic river type, which includes the Hawkesbury River from Spencer to the Pacific Ocean.

A map of geomorphic river types according to River Styles® for the downstream study area is shown in Figure 3-11.

Directly below Warragamba Dam, the dam pool is located in an incised, steep side channel with a largely intact riparian zone. The reach of Warragamba River immediately downstream of the dam is classified Gorge geomorphic river type under River Styles®. Flow regimes in this stretch of the Warragamba River are highly modified.

The Nepean River floodplain broadens with increasing distance downstream and is dominated by riverine pools habitat type, with extensive macrophyte beds are present in places.

The tidal limit of the Hawkesbury River occurs near Yarramundi, approximately 140 km upstream of the river mouth (Department of Natural Resources, 2006; Krogh *et al*., 2009). Near the tidal limit, the Hawkesbury River receives tributary inflows from the Grose River (at Yarramundi) and the Nepean River (further upstream of Yarramundi), and experiences moderate freshwater tidal influence (Gruber *et al.,* 2010). Major contributions of urban runoff are also received near Windsor from the highly modified urban creeks, namely South Creek and Eastern Creek which drain significant portions of Greater Western Sydney suburbs including Blacktown, Rooty Hill, St Mary's and Quakers Hill.

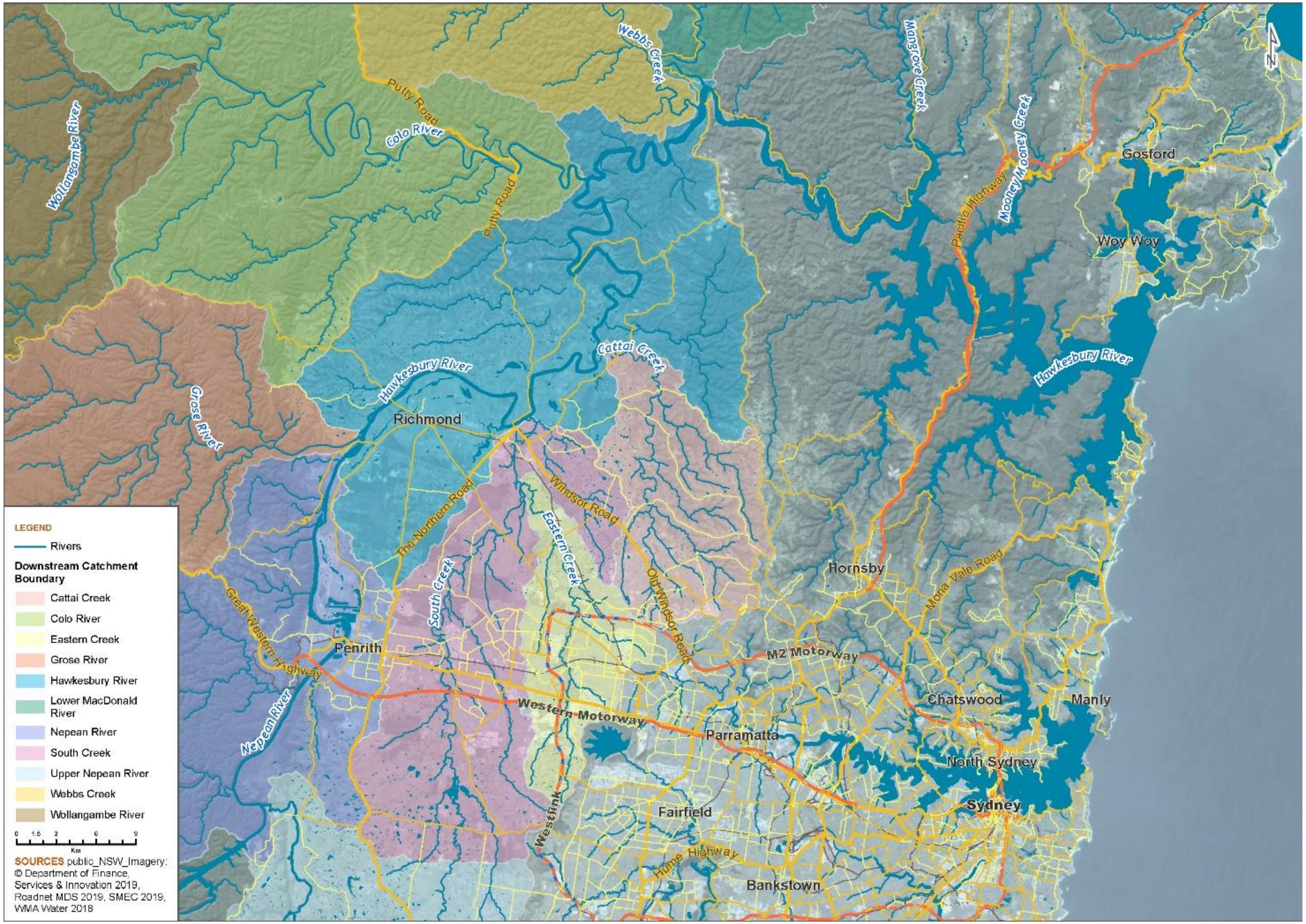
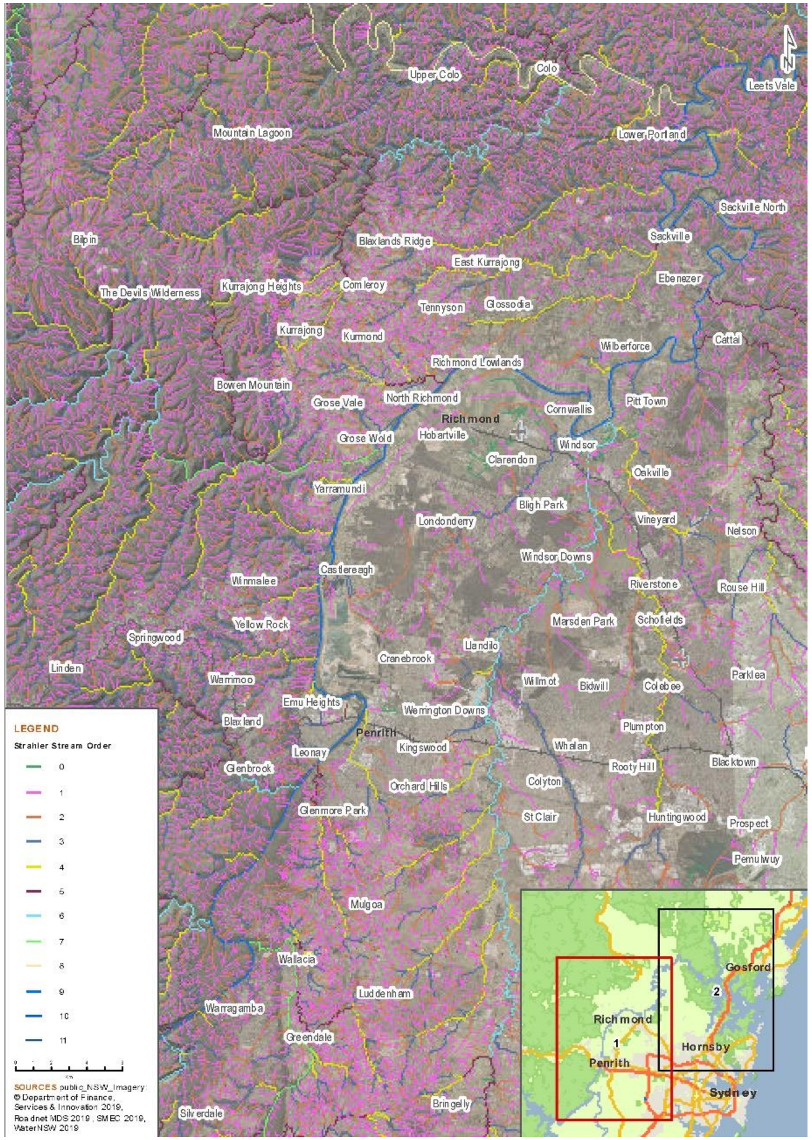


Figure 3-9 Downstream sub-catchments and major rivers



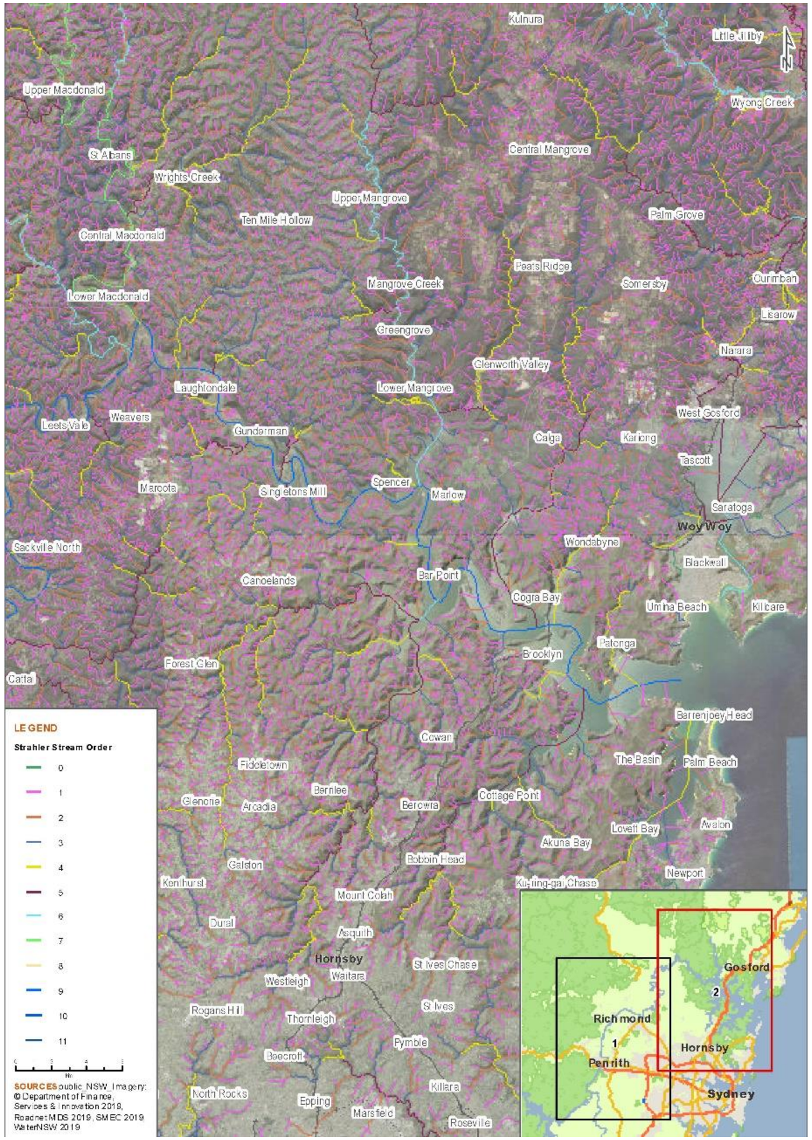


Figure 3-10 Strahler stream order – downstream

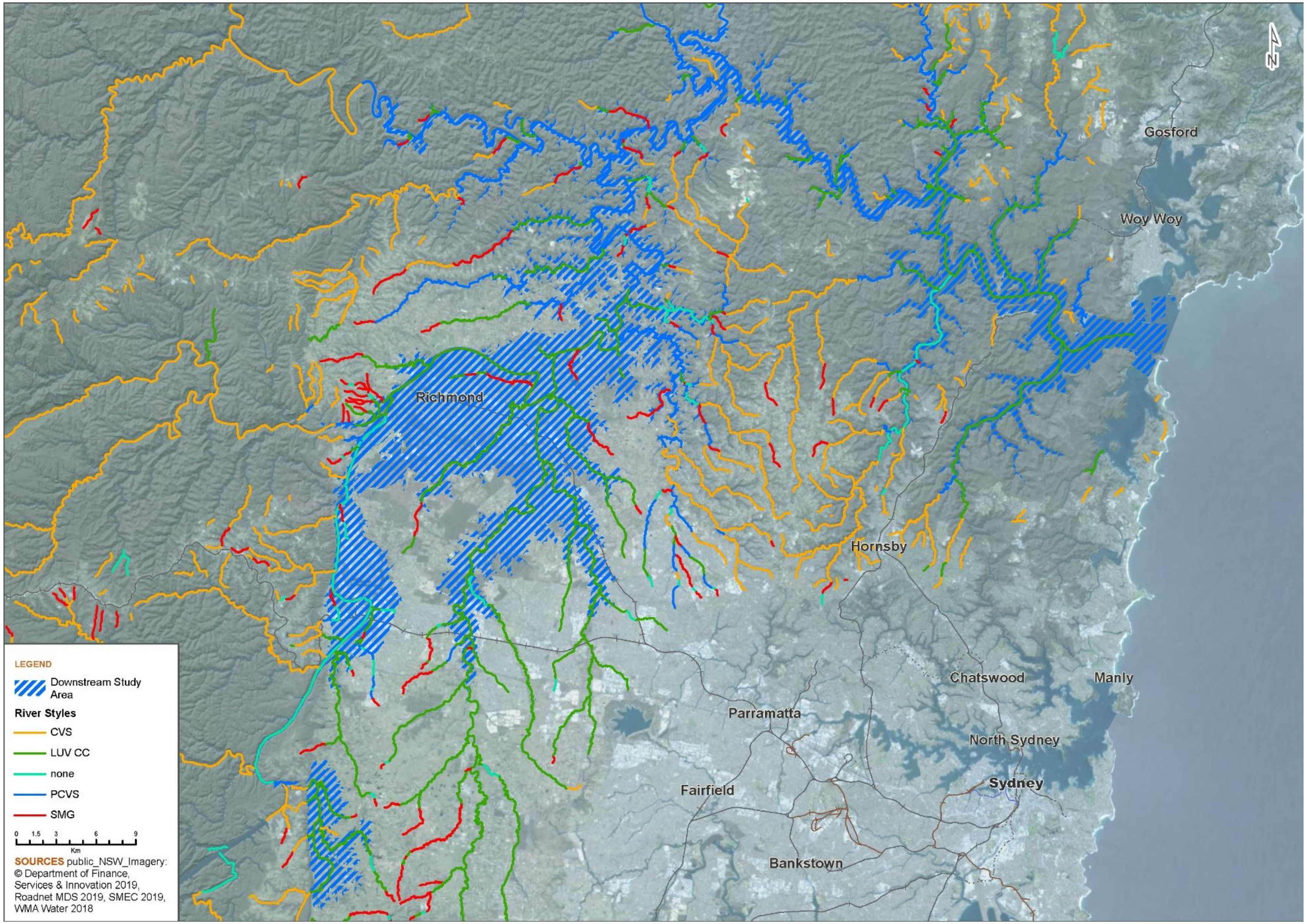


Figure 3-11 River Styles® geomorphic river type – downstream

3.2.2.2 Wetlands

The dominant wetlands in the downstream study area are floodplain wetlands, which include flood lakes, backwater swamps, ponded tributaries and creek swamps. Previous studies have identified up to 495 wetlands or wetland clusters of regional conservation significance that varied in size from 0.3-208 ha in the downstream reaches of the Hawkesbury-Nepean catchment (Smith and Smith, 1996). Only about 50 of these wetlands are associated with the Hawkesbury-Nepean River downstream of Pheasants Nest Weir and Broughtons Pass Weir to the confluence of the Colo River. The majority of the others are found on the floodplains from Richmond to Wisemans Ferry. Several other floodplain wetlands exist on the Richmond Lowlands in various tenure, including Irwins Swamp, Yarramundi Lagoon, Bakers and Triangle Lane Lagoons (both in private ownership), and Pughs and Bushells Lagoons spanning both public and private property (Hawkesbury-Nepean River Management Forum, 2004).

Wetlands in the downstream study area include:

- Ramsar wetlands – Nil located in the downstream study area or its sub-catchments
- DIWA listed wetlands (refer Figure 3-12)
  - Pitt Town Lagoon (NSW087)
  - Longneck Lagoon (NSW083)
- Coastal wetlands are located within the downstream study area or its sub-catchments.

Pitt Town Lagoon and Longneck Lagoon are examples of the endangered ecological community *Freshwater Wetlands on Coastal Floodplains of the New South Wales North Coast, Sydney Basin and South East Corner Bioregions*. These are discussed in the downstream biodiversity assessment.

The number and size of wetlands in the downstream study area has decreased since European settlement due to impacts associated with sedimentation, eutrophication, grazing, surrounding land use and introduced weed species. Many wetlands now rely only on their own catchments for water input as the construction of levy banks and flood mitigation devices has reduced or removed their connectivity to the Hawkesbury-Nepean River, with only overbank flows reaching many. This has reduced the ability of many downstream wetlands to be flushed by flows, either from their own catchments or from the river. This has resulted in nutrient and sediment build up, reducing the size and depth of the wetlands and increasing the likelihood of weed invasion (Independent Expert Panel for the Hawkesbury-Nepean, Shoalhaven and Woronora Catchments, 2002).

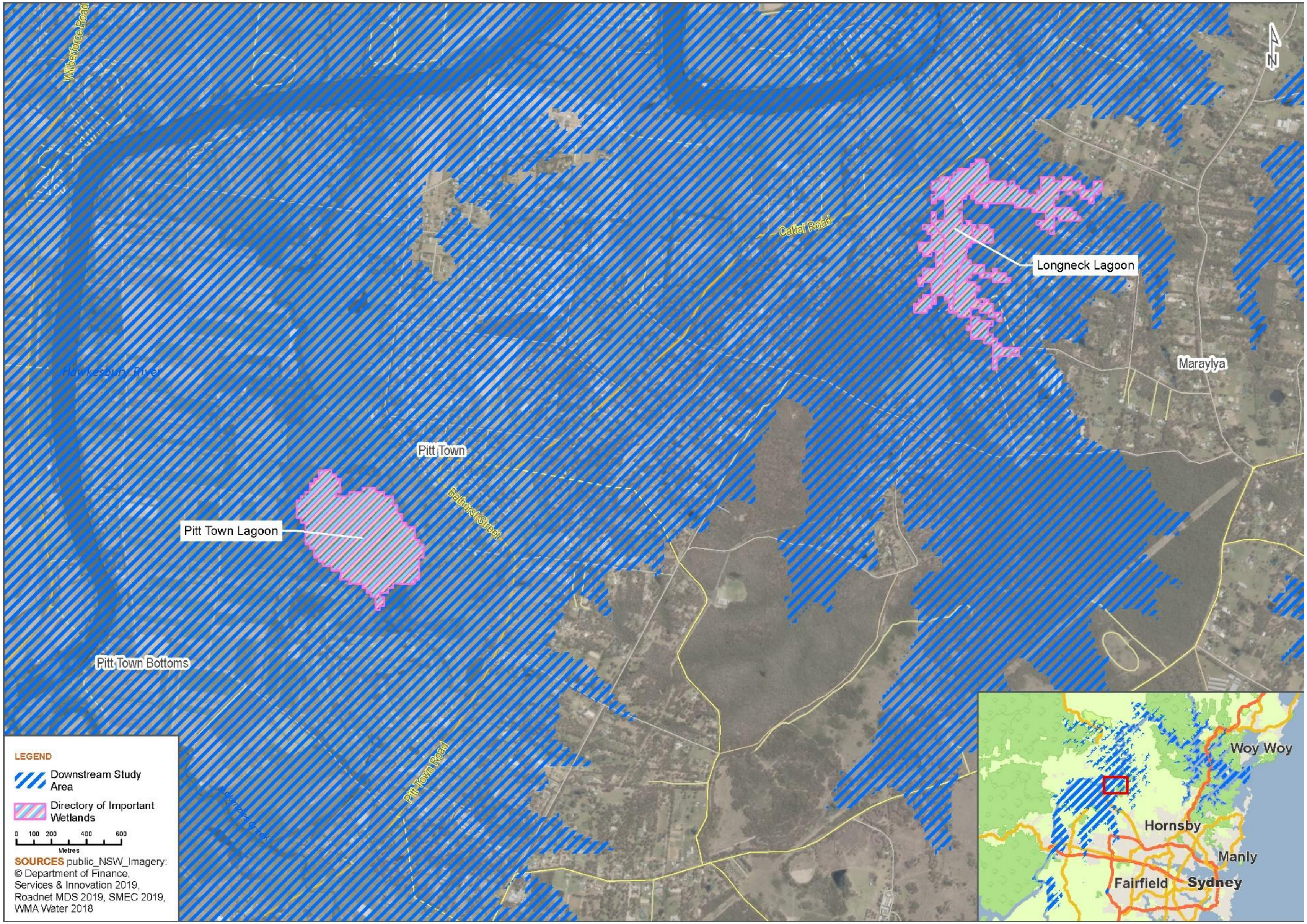


Figure 3-12 Directory of important wetlands of Australia – downstream

3.2.2.3 Key fish habitat

Mapping of key fish habitat carried out by NSW DPI includes the downstream study area[5]. The mapping identifies the Hawkesbury and major tributaries as key fish habitat.

3.2.2.4 Habitat condition

The condition of river reaches downstream of Warragamba Dam has been significantly modified since European settlement. Human impacts from changes in the catchment and in the channel have modify pre-existing processes and, in some cases, dominate them.

Recent River Styles® assessment concluded that the Hawkesbury-Nepean River was primarily in 'moderate' geomorphic condition with the river reaches closest to Warragamba Dam in 'good' geomorphic condition (GHD, 2013). Several waterways were identified as 'poor' geomorphic condition, particularly parts of the Grose River, Cooley Creek, Claremount Creek, McKenzies Creek, Greens Creek, and Webbs Creek.

River flow conditions and geomorphic features in the downstream study area has been altered by historical land use, particularly along the floodplain areas around Penrith, Richmond and Windsor. Weirs constructed on the Nepean River significantly regulate river flow and create a series of segmented weir ponds rather than a free-flowing river. One such example of this is Penrith Weir which creates a significant weir pool upstream of Penrith and Emu Plains. Artificial lakes (e.g., Shaws Lakes and Penrith Lakes) downstream from Penrith also influence local river flow conditions with various floodplain connections established between shallow offline lake storages during floods.

3.3 Aquatic flora

3.3.1 Assemblages in upstream environments

No comprehensive aquatic flora studies have previously been undertaken in the reaches upstream of Warragamba River confluence with the Nepean River, including the upstream study area.

Qualitative aquatic macrophyte surveys were undertaken to inform this assessment (Appendix A), through interrogation of aerial photograph and site inspections at Coxs River, Kedumba River, Wollondilly River, Nattai River and Little River.

Results from these surveys indicated that:

- The Wollondilly River had the most well developed aquatic macrophyte beds of the river reaches inspected; however, the macrophyte assemblage at this location was dominated by the aquatic weeds water primrose (*Ludwigia* sp.) and smart weed (*Persicaria* sp.) (Figure 3-13). The reach of the Wollondilly River that was inspected had low gradient and low riparian cover compared to other sites inspected. These attributes are known to promote growth of these (and other) weed species
- Aquatic macrophyte cover at the other sites inspected was sparse to moderate (<10%)
- Green filamentous algae were abundant at sites with low riparian cover

[5] https://www.dpi.nsw.gov.au/__data/assets/pdf_file/0007/634354/Sydney_updated.pdf

- Habitat conditions within the lower reaches of creeks and rivers that flow into Lake Burragorang were not conducive to the development of aquatic macrophyte assemblages, including:
  - Shading of streams - the dense canopy cover of riparian vegetation and narrow width of many streams results in a high degree of shading. The low light provides sub-optimal habitat conditions for aquatic macrophyte species
  - Substrate stability and flows - most of the upstream study area streams are ‘flashy’, and experience pulsed flows in response to rainfall events. High flow velocities limit the development of many aquatic macrophyte communities through substrate scour and direct physiological damage to plants.

These findings were consistent with those of historical studies which suggested that physical stressors and habitat characteristics of tributary streams (e.g., comparatively steep and fast flowing, highly mobile streambeds, containing sand, gravel, shingle and boulders) limited the development of aquatic macrophytes (ERM Mitchell McCotter, 1995).

Within Lake Burragorang, the highly variable water levels and steep littoral bed profiles create sub-optimal habitat conditions for submerged and emergent macrophytes. However, an inspection of aerial photographs indicated that macrophyte beds do periodically occur in shallow areas immediately upstream of the auxiliary spillway.

Figure 3-13 Water Primrose (*Ludwigia* sp.) growing on rocky banks – Wollondilly River

3.3.2 Assemblages in the downstream environment

Downstream aquatic environments support many native and introduced (exotic) macrophyte species (Table 3-3). Historical changes to flow, geomorphological and water quality processes have resulted in habitat conditions which favour the proliferation of several aquatic macrophyte species, including problematic species introduced and native species (DPI, 2014).

3.3.2.1 *Attached macrophytes*

Sixteen species of attached macrophyte have previously been recorded in downstream aquatic habitats. Historical records indicate that there have been marked changes in downstream aquatic macrophyte assemblages since the 1990s. For example, between 1994 and 1996, mixed beds of native *Potamogeton, Vallisneria*, *Hydrilla* and *Najas*, were recorded between Warragamba Dam and Penrith Weir (Roberts *et al.* 1999). The distribution of *Egeria* sp., a prolific aquatic weed, has increased substantially since 1996 (Section 3.3.3). Native macrophyte beds persist in the downstream environments despite the prevalence of *Egeria* sp., but in lower abundance than recorded in the 1990s.

Table 3-3 Characteristics of significant aquatic macrophyte species in the Hawkesbury-Nepean (DPI, 2014c; Roberts *et al.*, 1999)

Common name	Scientific name	Status*	Occurrence
Azolla	*Azolla filiculoides* *Azolla pinnata*	Native	Present
Alligator weed	*Alternanthera philoxeroides*	Exotic, Class 2, WoNS	Alligator weed is so persistent and wide-ranging in its spread through the Hawkesbury-Nepean River that it is now considered a core infestation area
Cabomba	*Cabomba* spp.	Exotic, Class 5, WoNS	Present
Hornwort	*Ceratophyllum demersum*	Native	Present
Egeria	*Egeria densa*	Exotic, Class 4	Egeria has been recorded in all reaches from Warragamba Dam to Wisemans Ferry
Water hyacinth	*Eichhornia crassipes*	Exotic, Class 4, WoNS	Occasional population explosions both in the river and on major tributaries (South Creek, Eastern Creek, Yarramundi Lagoon) require management.
Elodea, Canadian pondweed	*Elodea canadensis*	Exotic	Present from Menangle to Sackville, with excessive growth occurring between Warragamba River confluence and Sackville (Eleni Taylor-Wood, 2003b).
Senegal tea	*Gymnocoronis spilanthoides*	Exotic, Class 1, NEAL	Senegal tea has been present in Cattai Creek and Redbank Creek catchments for several years, with subsequent downstream spread into the river between North Richmond and Windsor.
Hydrilla	*Hydrilla verticillata*	Native	Present upstream of Penrith Weir
Lagarosiphon	*Lagarosiphon major*	Exotic, Class 1, NEAL	Present
Willow leaf ludwigia	*Ludwigia longifolia*	Exotic, Class 3	Present

Common name	Scientific name	Status*	Occurrence
Ludwigia	*Ludwigia peruviana*	Exotic Class 3	*L. peruviana* has been in the catchment for many years and is now well established along the river, appearing in large numbers from the Penrith Weir to the Grose River downstream.
Najas	*Najas browniana*	Native	Present upstream of Penrith Weir
Potamogeton	*Potamogeton tricarinatus*	Native	Present upstream of Penrith Weir
Sagittaria	*Sagittaria platyphylla*	Exotic, Class 4, WoNS	Sagittaria is now well established at certain sites from the Penrith Weir to South Creek.
Salvinia	*Salvinia molesta*	Exotic, Class 2/3, WoNS	Salvinia had been present in the Hawkesbury-Nepean system for some time and has been significance reduced by the salvinia weevil.
Vallisneria, ribbonweed	*Vallisneria gigantean*	Native	Present but the reaches are now dominated by egeria.

*Noxious status is based on the classes under NSW *Noxious Weeds Act 1993* and the Commonwealth register of Weeds of National Significance (WoNS).

3.3.2.2 Floating macrophytes

Floating macrophytes occur throughout the freshwater reaches of the Hawkesbury-Nepean River (anecdotal records upstream of Penrith Weir and results of studies undertaken between Penrith Weir and Windsor); however, their abundance is often low. Dense floating macrophyte beds typically occur in areas of low flow, high nutrients and where submerged macrophytes are present (Independent Expert Panel for the Hawkesbury-Nepean, Shoalhaven and Woronora Catchments, 2002).

Floating macrophyte weed species are discussed in Section 3.3.3.

3.3.3 Aquatic weeds

Invasive aquatic weeds known to occur in the Hawkesbury-Nepean catchment include:

- Salvinia (*Salvinia molesta*)
- Dense waterweed (*Egeria densa*)
- Alligator weed (*Alternanthera philoxeroides*
- Water hyacinth (*Eichhornia crassipes*)
- Lagarosiphon (*Lagarosiphon major*)
- Cabomba (*Cabomba* spp.)
- Willow leaf ludwigia (*Ludwigia longifolia*)
- Ludwigia (*Ludwigia peruviana*)
- Sagittaria (*Sagittaria platyphylla*).

The distribution of *Egeria densa*, a prolific aquatic weed, has increased substantially since 1996 and has represented the numerically dominant aquatic macrophyte species in many downstream areas (Roberts *et al*., 1999; Australian Museum Business Services, 2000; Taylor-Wood, 2002, Independent Expert Panel for the Hawkesbury-Nepean, Shoalhaven and Woronora Catchments, 2002; Thiebaud and Williams, 2007). *Egeria densa* has been recorded from Warragamba Dam to Wisemans Ferry (Roberts *et al*., 1999; Thiebaud and Williams 2007).

Floating macrophyte weed species that occur in the Hawkesbury-Nepean downstream from the dam include Alligator weed and water hyacinth (HRC, 1998; Hunt and Higgins, 1996). Both species are noxious weeds and are highly invasive. Alligator weed has been observed in outbreaks in the Nepean River at Menangle, Camden and Bents Basin downstream to Wallacia (Hunt and Higgins, 1996). Infestations have also been recorded between Penrith Weir and Yarramundi.

Alligator weed infestations occur throughout both the upstream and downstream study areas (Ecowise Environmental, 2008). The highest priority sites for treatment of Alligator weed include the upstream catchments of the Nepean River, Warragamba River and Hawkesbury River (Ecowise Environmental, 2008), up to the Warragamba Dam wall. Alligator weed has also been recorded within Lake Burragorang at abundances that impact the effectiveness of water infrastructure (DPI, 2018).

Downstream of the dam, prolific growth of water hyacinth, salvinia, alligator weed, and dense waterweed have led to a shift from native species dominated beds to exotic species dominated beds (particularly between Penrith Weir and Richmond Bridge). This has been attributed to flow modifications and surrounding land use and management. Exotic species have also been recorded in areas where they have previously not been. For example, dense waterweed was found growing in Penrith Weir (Australian Museum Business Service, 2000). Prior to this survey, it was thought to be restricted to areas downstream of Penrith weir. This discovery has raised concerns about this weeds potential to spread up the river and invade macrophyte beds that are relatively free of exotic species.

3.4 Aquatic macroinvertebrates

Macroinvertebrates play a vital role in stream ecosystems. Aquatic insects, including caddisflies, dragonflies and mayflies, have multi-stage life cycles – adult flies lay eggs in the water that develop into nymphs or aquatic larvae, which eventually emerge from the water as adult flies. Insects in all life cycle stages are one of the main sources of food for many fish, amphibians, and birds. As well as serving as prey, macroinvertebrates feed on plant matter, algae, or smaller invertebrates, and play an important role in the cycling of nutrients through aquatic systems.

3.4.1 Assemblages in upstream environments

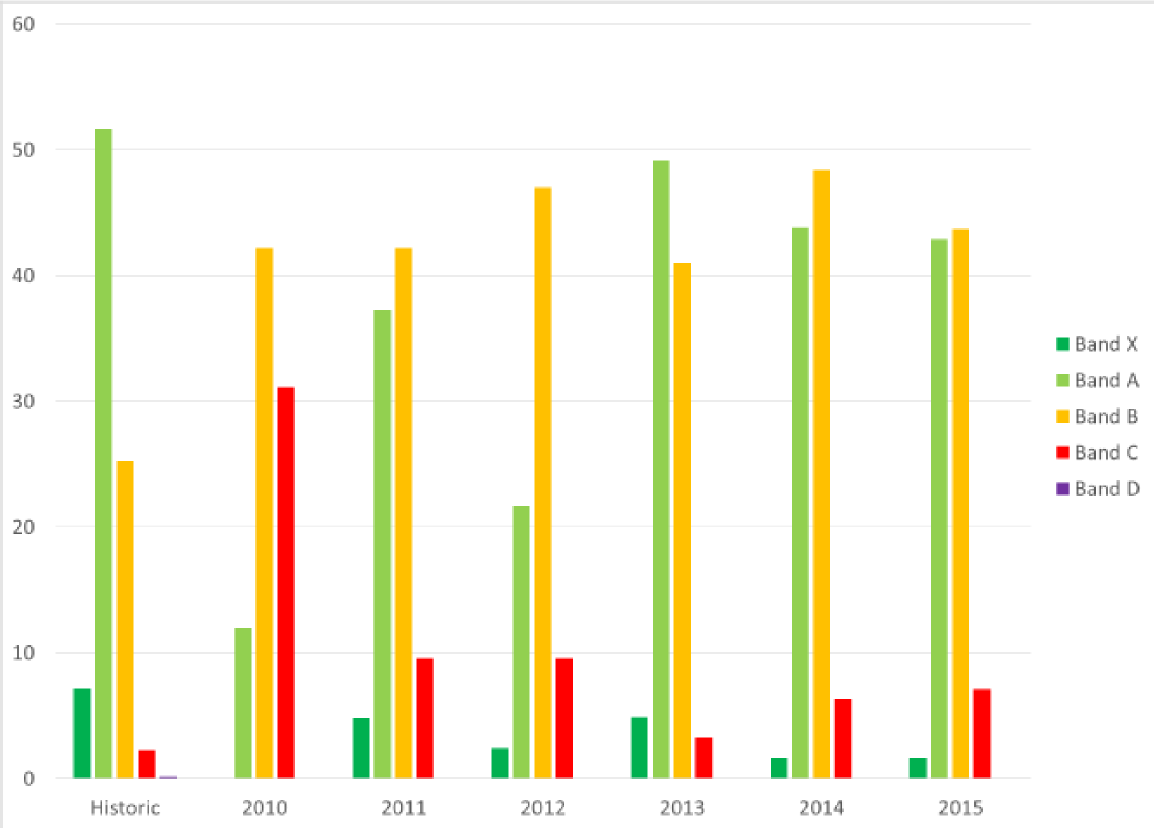
Regular macroinvertebrate monitoring in upstream environments was undertaken by Sydney Catchment Authority (SCA) since about 2001 (Note that in 2015, SCA merged with State Water to form Water NSW, a single organisation responsible for managing bulk water supply across the state).

Sampling was based on standard AusRivAS methods. Key findings of this monitoring, as identified in the *Audit of the Sydney Drinking Water Catchment* (Alluvium, 2017) included:

- Macroinvertebrate health showed a general trend of decline at many sites in the Hawkesbury-Nepean catchment, as demonstrated by:

    - Results of monitoring undertaken between 2001 and 2009 which suggest that about 28 percent of monitoring sites were in significant to severe ecological impairment
    - Results of monitoring undertaken between 2001 and 2013 which suggest about 50 percent of monitoring sites were in significant to severe ecological impairment
    - Results of monitoring undertaken between 2013 and 2016 which suggest that the declining trend had stabilised, with some monitoring sites showing slight improvement in ecological impairment, specifically those in the Lower Coxs River and Wollondilly River sub-catchments
- The number of monitoring sites within the AusRivAS ‘referenced condition’ category (the condition that is representative of a group of minimally disturbed sites organised by selected physical, chemical and biological characteristics' (Reynoldson *et al*., 1997)) showed significant variation over the monitoring period, as evidenced by:
    - 13 percent of monitoring sites within the ‘reference condition’ category in 2010
    - 40 percent of monitoring sites within the ‘reference condition’ category in 2011
    - 28 percent of monitoring sites within the ‘reference condition’ category in 2013
    - 45 percent of monitoring sites within the ‘reference condition’ category between 2013 and 2016
    - The long-term average of monitoring sites within the ‘reference condition’ category is 52 percent.
- Improvement in some of the sub-catchment macroinvertebrate condition assessments between 2013-2016 compared to previous years monitoring
- The Lower Coxs River sub-catchment had the largest proportional of sites in ‘reference condition’ compared to other sub-catchments monitored
- Many sub-catchments adjacent to the upstream study area demonstrated consistent macroinvertebrate assemblage condition ranging between ‘similar to’ and ‘better than’ ‘reference condition’, except for monitoring sites in the Nattai River, Little River, lower Wollondilly River and Kedumba Rivers, which showed higher levels of stress. Of these, the Kedumba River sub-catchment was subject to the highest stress - urban runoff and sewage discharges – demonstrated by high pathogen and nutrient loads
- During the 2010 to 2013 monitoring period, the Kowmung River (71.4 percent) and Lake Burragorang (62.5 percent) sub-catchments had the highest percentage of samples in the ‘similar to’ or ‘better than’ ‘reference condition’. During the 2013 to 2016 monitoring period, this number improved for the Kowmung sub-catchment, but declined for Lake Burragorang, which had a large proportion of sites within the ‘significantly impacted’ category
- During the monitoring period 2001 to 2009, the Upper Coxs River sub-catchment had the highest percentage of sites in the ‘severely impaired’ or ‘extremely impaired’ condition categories. Macroinvertebrate condition improved in the 2013 to 2016 monitoring period with about 58 percent sites categorised ‘similar to’ or ‘better than’ ‘reference condition’.

Figure 3-14 provides a summary of the total number of monitoring sites within each of the AusRivAS condition categories for 2010 through to 2015 monitoring, as well as historical conditions.



Key:

Band X	More diverse than reference sites	More taxa found than expected. Potential biodiversity hotspot. Possible mild organic enrichment.
Band A	Reference condition	Most/all expected families found. Water quality and/or habitat condition roughly equivalent to reference sites. impact on water quality and habitat condition does not result in a loss of macroinvertebrate diversity.
Band B	Significantly impaired	Fewer families than expected. Potential impact either on water quality or habitat quality or both, resulting in loss of taxa.
Band C	Severely impaired	Many fewer families than expected. Loss of macroinvertebrate biodiversity due to substantia impacts on water and/or habitat quality.
Band D	Extremely impaired	Few of the expected families remain. Extremely poor water and/or habitat quality. highly degraded.

Figure 3-14 Average annual AUSRIVAS categories for macroinvertebrates across all catchment sites (Alluvium, 2017)

3.4.2 Assemblages in the downstream environment

Macroinvertebrate monitoring in the downstream study area has been more infrequent that undertaken in the upstream environments. Recent monitoring of macroinvertebrates in the downstream study area (DECC, 2009; DPI, 2012), indicated that:

- Macroinvertebrate assemblages vary along a longitudinal gradient between Warragamba Dam to estuarine reaches of the Hawkesbury River at Brooklyn
- Spatial variability in macroinvertebrate assemblages was greater than temporal variability

- SIGNAL-SG scores (a stream health metric based on pollution sensitivity of different taxa) in edge habitats at sites upstream of Yarramundi were consistent over time
- Sites downstream of Yarramundi had lower taxonomic richness and SIGNAL-SG, and greater temporal variability than monitoring sites upstream from Yarramundi
- Macroinvertebrates assemblages in the upper Nepean River were determined to be impaired by river regulation.

Previous, historical macroinvertebrate assessments in the downstream study area found the Hawkesbury-Nepean River system to support a diverse range of macroinvertebrate fauna, with 443 recorded species and morpho-species (Chessman and Williams, 1999). Results of this assessment found that:

- The macroinvertebrate community was dominated by members of the phylum Arthropoda, for which the orders Diptera (flies/midges), Coleoptera (beetles), Acarina (mites), Odonata (dragon/damsel flies), Trichoptera (caddisflies) were the most abundant.
- 69 species of the order Coleoptera were recorded and of these the most speciose families were *Dytiscidae* sp. (20 species) and *Elmidae* sp. (18 species).
- Members of the order Diptera included 69 species of non-biting midge family *Chironomidae* sp. and unknown species from Tipulidae (craneflies) which was recorded only from O'Haras Creek. Several species were restricted in distribution, including the genus *Forcipomyia* sp. which has only been recorded in the Nepean River above Penrith.
- Members of the order Ephemeroptera (mayflies) were not well represented in the catchment with only 24 morpho-species recorded from four families. Members of the family Leptophlebiidae were the best represented of the Ephemeroptera with 14 species. Members of the family Baetidae, including *Centropltilum* sp. and *Cloeon* sp., which favour warm and still flowing waters and are tolerant of reduced water quality, were widespread and common throughout he downstream study area. Most mayfly species which were recorded in the downstream catchment appear to be confined to the larger rivers; however, a few were recorded in the less polluted smaller tributaries.
- Recorded members of the order Hemiptera comprised 23 species from 12 families. Note this does not account for families present in lentic environments which would have added substantially to the number recorded. Of the Hemiptera, the Water Boatman, *Micronecta batilla* from the family Corixidae, was the most abundant. This species is common throughout lowland rivers in south-eastern Australia.
- The region has a rich fauna of members of the order Odonata, which favour wetlands and slow-flowing rivers and creek habitats. Thirty-five species from 11 families were recorded by Chessman and Williams (1999) within the downstream study.
- Members of the order Plecoptera were not well represented in the downstream study area with only three species recorded, all from little Cattai Creek
- Members of the orders Diptera and Trichoptera (caddisflies) were the most diverse aquatic macroinvertebrates recorded by Chessman and Williams (1999) comprising 50 species or morpho-species across 13 families. Trichoptera were numerically dominated by families that

generally favoured warmer and slow-flowing or still waters such as *Hydroptilidae* sp. and *Leptoceridae* sp.

- Four species of freshwater mussel were recorded in the downstream catchment, *Hyridella australis, Hyridella depressa, Hyridella drapeta* and *Velesunio ambiguous*. Distribution of these species was not universal across the downstream catchment with lower abundance in some tributaries, suggesting their distribution may be limited by environmental factors
- 16 species of freshwater gastropod including the native species *Ferrissia petterdi* and *Ferrissia tasmanica,* and introduced species including *Physa acuta* (potentially associated with *Egeria densa*)*, Pseudosuccinea columella*, *Lymnaea viridus* and *Potamopyrhus antipdarum* were recorded in the downstream catchment. The latter, *Potamopyrhus antipdarum* was widespread in the downstream catchment and may have displaced native species, such as *Posticobia brazier* and *Posticobia antipodarum* through competition
- Crustaceans recorded included the crayfish *Euastacus spinifer*, and four species of prawns including *Paratya australiensis*, *Australatya striolata* and *Macrobrachium tolmerum* which are common throughout the Hawkesbury-Nepean River and tributaries.

The assessment by Chessman and Williams (1999) concluded that macroinvertebrate community composition was relative to waterway size, geology (e.g., tributaries of shale or sandstone), tidal intrusion, and urbanisation. Sites assessed from the Hawkesbury River and its tributaries had different macroinvertebrate assemblages to sites further upstream (e.g., the Nepean River), which was likely associated with different substratum in these habitats – e.g., rocky fluvial geology with riffle pool sequences in the Nepean River, compared to wide, deep, sandy, bi-directional tidal flow sections in the Hawkesbury River.

Macroinvertebrate assemblages were also different in the main channel reach above and below the Penrith weir, potentially related to natural physical changes in the catchment and increased anthropogenic influences downstream of the weir. Tributaries of the larger rivers tended to differ in macroinvertebrate assemblages to their associated main channel reaches. Tributaries with increased exposure to urban runoff and sewage effluent had, not surprisingly, very low diversity of macroinvertebrates compared to least impacted sites.

3.5 Fish

3.5.1 General context

At least 41 species of freshwater fish have been recorded in the Hawkesbury-Nepean River catchment. Many of these are migratory and therefore sensitive to instream barriers (Gehrke, 1996). A complete list of fish species identified in the catchment is provided in Table 3-4.

There is an extensive amount of literature describing the impacts of instream barriers on the distribution of fish species in the Hawkesbury-Nepean River catchment (as reviewed by Duncan *et al.*, 2016). Weirs and dams have a major effect on the distribution and abundance of freshwater fish and aquatic macroinvertebrates, especially migratory species such as common jollytail (*Galaxias maculatus*), sea mullet (*Mugil cephalus*), freshwater mullet (*Trachystoma petardi*), freshwater herring (*Potamalosa richmondia*), Australian bass (*Macquaria novemaculeata)* and the endangered

Australian grayling (*Prototroctes maraena*). Duncan *et al.* (2016) also suggest that dams and weirs may also be affecting the genetic diversity and population structure of fish species in the Hawkesbury-Nepean system. Consequently, some fish species have become locally extinct from some sections of the Hawkesbury-Nepean catchment.

Fish sampling undertaken by Duncan *et al.* (2016) at a site on the Warragamba River recorded 20 fish species, including several obligate migratory species (e.g. Anguilla eels, *Mugil cephalus*, *Trachystoma petard*, *Potamalosa richmondia*, *Gobiomorphus coxii*, *Macquaria novemaculeata*). This indicates that some migratory species are still able to make their way to the Warragamba Dam, despite the presence of numerous instream barriers downstream.

Warragamba Dam forms a barrier to dozens of fish species in the Hawkesbury-Nepean system that may otherwise migrate upstream. However, two species of Anguilla elvers (juvenile eels – short-finned and long-finned) are known to climb up the spillway, past the dam wall and into Lake Burragorang. Adult eels subsequently return to downstream aquatic environments and out to sea. In order for these eels to complete their obligatory migration life-cycle, they must continue to be able to descend over Warragamba Dam and the spillway (WaterNSW, 2018).

3.5.2 Assemblages in upstream environments

At least 27 species of freshwater fish are known to occur within the upstream study area (i.e., Warragamba River and associated tributaries) (Knight, 2010; GHD, 2013; Alluvium, 2017). Of these, 20 species are native to Australia and the remainder are introduced species.

No targeted extractive surveys of fish communities within the study area were undertaken as part of this assessment. However, data was obtained from existing sources supplemented by a rapid field assessment and targeted eDNA sampling at five sites. This site assessment was undertaken between September and December 2017, which coincided with the spawning period for Macquarie Perch and other threatened species, and as such extractive sampling (e.g., e-fishing, netting, trapping) were not feasible to undertake. Hence, non-destructive sampling methods were used. This rapid assessment agreed with previous studies. Table 3-4 summarises the freshwater fish species recorded in the catchment, including those within the upstream study area.

A long-term assessment of freshwater fishes undertaken for the Sydney Drinking Water Catchment Audit (GHD, 2013) found that the upstream sub-catchments with the greatest diversity of fish species were the Lower Coxs River (8), Upper Coxs River (7) and Wollondilly River (6). Low species diversity (<5 species) was found at all other sub-catchments. Species diversity was generally consistent between monitoring events at all monitoring locations; although the Wollondilly River sub-catchment experienced a reduction in species diversity (10 to six species) between the 2007 to 2010 and 2010 to 2013 monitoring periods. Species richness decreased between the 2007 to 2010 monitoring and the 2010 to 2013 monitoring periods. The reduction in richness was only observed in native fish species.

Other historical studies observed that the Freshwater Catfish (*Tandanus tandanus*) and Mountain Galaxias (*Galaxias olidus*) were sedentary, typically observed only in one locality (Knight, 2010). The *Hypseleotris* sp. gudgeons and dwarf flathead gudgeon (*Philypnodon macrostomus*) were only recorded from a small number of widely dispersed sites, suggesting a patchy distribution within upstream catchment (Knight, 2010). In contrast, the Australian smelt (*Retropinna semoni*) and flathead gudgeon (*Philypnodon grandiceps*) were the most widely distributed species recorded in the study area.

The aquatic habitat assessment (refer Appendix A) noted that Macquarie perch were not present at several investigation sites, noting that a possible reason may be due to disturbance of breeding sites by the introduced carp. However, it is noted that the two species co-exist in parts of the Murray-Darling Basin (DoEE 2018.) and accordingly other factors may be responsible for the absence of Macquarie perch at these locations.

Table 3-4 Freshwater fish species recorded in the Hawkesbury-Nepean River catchment, movement behaviours and habitat preferences

Scientific name	Common name	Origin	Migration pattern	Habitat requirements	Known / likely occurrence in study area[1]
Ambassidae (glassfishes)					
Ambassis jacksoniensis	Port Jackson glassfish	Native	Unknown	Schooling species found in estuarine and coastal marine waters and lower river habitats	DE
Anguillidae (freshwater eels)					
Anguilla australis	Short-finned eel	Native	Catadromous	Generalist, prefer still-flowing waterways, including lowland rivers, lakes, swamps and wetlands.	UE, DE
Anguilla reinhardtii	Long-finned eel	Native	Catadromous	Generalist, coastal rivers, lakes and wetlands.	UE, DE
Atherinidae (Old World silversides)					
Atherinosoma microstoma	Smallmouthed hardyhead	Native	Anadromous	Endemic to temperate waterways of south-eastern Australian and inhabits lower reaches of coastal drainages including estuarine and freshwater.	DE
Clupeidae (herrings and shads)					
Herklotsichthys castelnaui	Southern herring	Native	Unknown	Schooling species found in estuarine and coastal marine waters	DE
Potamalosa richmondia	Freshwater herring	Native	Catadromous	Inhabits clear, moderately-flowing waterways but also found in lowland rivers and estuaries.	DE
Cobitidae (true loaches)					
Misgurnus anguillicaudatus	Oriental weatherloach	Exotic	Unknown	Still and slow-flowing freshwaters rivers and lakes with sandy or muddy substrates	UE, DE
Cyprinidae (carps and minnows)					
Carassius auratus	Goldfish	Exotic	Potamodromous	Widespread inhabiting still or slow-flowing waterways. Species potential able to tolerance a range of salinities allowing them access estuaries and access other tributaries (Tweedley *et al*. 2017)	UE, DE
Cyprinus carpio	Common carp	Exotic, noxious listing	Potamodromous	Still and slow-flowing waterways with abundant aquatic vegetation.	UE, DE
Tanichthys albonubes	White cloud; Mountain minnow	Exotic	Unknown	Temperate freshwaters, prefer small streams with slow-flowing weedy areas.	DE
Eleotridae (sleeper gobies)					
Gobiomorphus australis	Striped gudgeon	Native	Amphidromous	Small coastal streams and rivers, floodplains wetlands and estuaries.	DE
Gobiomorphus coxii	Cox's gudgeon	Native	Potamodromous	Endemic to eastern Australia, inhabits inland and coastal rivers to an altitude of ~700m including rapids.	UE, DE
Hypseleotris compressa	Empire gudgeon	Native	Potamodromous	Lower reaches of coastal streams and rivers, juveniles commonly found in estuaries.	UE, DE
Hypseleotris galii	Firetailed gudgeon	Native	Potamodromous	Freshwater reaches of coastal streams, lakes and dams around aquatic vegetation.	UE, DE
Hypseleotris sp	Carp gudgeon	Native	Potamodromous	Lower reaches of coastal rivers, typically occurs around aquatic vegetation.	DE
Philypnodon grandiceps	Flathead gudgeon	Native	Amphidromous	Aquatic vegetation and muddy substrate in slow-flowing inland and coastal waterways, especially lakes and dams.	UE, DE
Philypnodon macrostomus	Dwarf flathead gudgeon	Native	Unknown	Slow-flowing inland and coastal waterways often over mud and rock substrates.	UE, DE
Galaxiidae (galaxias)					
Galaxias olidus	Mountain galaxias	Native	Potamodromous	Endemic to alpine and subalpine areas of south-eastern Australia. Inhabits clear small flowing ponds and streams preferring areas with sand, gravel/rock substrate.	UE, DE
Galaxias brevipinnis	Climbing galaxias	Native	Amphidromous	Clear flowing headwaters and forested streams, over gravel/rock substrate.	DE
Galaxias maculatus	Common jollytail	Native	Catadromous	Coastal streams, lakes and lagoons including saline and freshwater environments.	DE
Gerreidae (mojarras)					
Gerres subfasciatus	Common silver belly	Native	Unknown	Seagrass beds and sandy substrate in estuaries and coastal waters	DE

Scientific name	Common name	Origin	Migration pattern	Habitat requirements	Known / likely occurrence in study area[1]
Gobiidae (true gobies)					
Redigobius macrostoma	Largemouth goby	Native	Amphidromous	Estuaries and lower reaches of freshwater streams	DE
Megalopidae (tarpons)					
Megalops cyprinoides	Oxeye herring	Native	Amphidromous	Tropical waters, estuaries and northern coastal freshwater.	DE
Melanotaeniidae (rainbowfish)					
Melanotaenia duboulayi	Duboulay's rainbowfish	Native	Potamodromous	Endemic to eastern Australia, inhabits coastal waters from Macleay River north into Queensland	DE
Rhadinocentrus ornatus	Ornate rainbowfish	Native	Potamodromous	Known from subtropical waterways from Rockhampton to Coffs Harbour, inhabiting sandy country in slow-flowing tannin stained waters.	DE
Mordaciidae (southern topeyed lampreys)					
Mordacia praecox	Non-parasitic lamprey	Native	Anadromous	Endemic to temperate rives, has been found in Moruya and Tuross Rivers in NSW.	DE
Mugilidae (mullets)					
Aldrichetta forsteri	Yellow-eye mullet	Native	Catadromous	Schooling species utilising bays, estuaries and rivers	DE
Mugil cephalus	Striped mullet, Sea mullet	Common	Amphidromous	Widespread in tropical and subtropical waters, found in lower reaches and estuaries of coastal catchments.	DE
Trachystoma petardi	Freshwater mullet	Native	Catadromous	Deep, slow-flowing, freshwater reaches of coastal rivers north of Georges River into Queensland.	DE
Oxudercidae (eel gobies and mudskippers)					
Acanthogobius flavimanus	Yellowfin goby	Native	Amphidromous	Estuarine mud basins and flats.	DE
Percichthyidae (temperate perches)					
Acanthopagrus australis	Yellowfin Bream	Native	Amphidromous	Endemic to Australia and occur from Townsville in Queensland to Gippsland Lakes in Victoria. In NSW waters, yellowfin bream are found primarily within estuaries and along nearshore beaches and rocky reefs, although they also occur in the lower freshwater reaches of coastal rivers. In estuaries they are associated with all types of habitat – seagrass, mangrove, bare substrates, rock reefs.	DE
Maccullochella macquariensis	Trout cod	Native – translocated	Non-migratory	Endemic to Murray-Darling Basin, prefer deep flowing freshwater with woody debris, present because of stocking.	DE
Maccullochella peelii peelii	Murray cod	Native – translocated	Potamodromous	Endemic to Murray-Darling Basin, predominantly found in lowland rivers and floodplain wetlands, present because of stocking	DE
Macquaria australasica	Macquarie perch	Native	Potamodromous	Hawkesbury River, Shoalhaven River and inland NSW. Preferring clear, cool, rocky fast-flowing streams with deep holes and riffles.	UE, DE
Macquaria colonorum	Estuary perch	Native	Potamodromous	Estuaries and lower tidal reaches of rivers.	DE
Macquaria novemaculeata	Australian bass	Native	Catadromous	Endemic to coastal rivers and estuaries in south-eastern Australian. Inhabits lakes, rivers and small stream up to ~600 m in altitude.	DE
Percidae (Percid fishes)					
Perca fluviatilis	Redfin perch	Exotic, listed pest	Anadromous	Slow-flowing rivers, deep lakes and ponds.	UE
Platycephalidae (flatheads)					
Platycephalus fuscus	Dusky flathead	Native	Non-migratory	Sheltered rocky reefs to sandy or muddy areas	DE
Plotosidae (eeltail catfishes)					
Tandanus tandanus	Freshwater catfish	Native	Potamodromous	Still and slow-flowing freshwater waterways in mid to lowland slopes. Common in coastal catchments but considered endangered to the Murray-Darling Basin.	DE

Scientific name	Common name	Origin	Migration pattern	Habitat requirements	Known / likely occurrence in study area[1]
Poeciliidae (mosquitofishes, guppies, mollies, swordtails and platys)					
Gambusia holbrooki	Gambusia, Mosquitofish	Exotic, listed pest	Non-migratory	Widespread in coastal and inland NSW.	UE, DE
Pseudomugilidae (blue-eyes)					
Pseudomugil signifer	Pacific blue-eye	Native	Amphidromous	Widely distributed in eastern draining catchments of Qld and NSW.	DE
Retropinnidae (southern smelts)					
Prototroctes maraena	Australian grayling	Native	Catadromous	Endemic to coastal waterways of south-eastern Australia. Prefer moderate to fast-flowing rivers and streams usually in cool clear waters below ~200 m in altitude and over gravelly substrate.	DE
Retropinna semoni	Australian smelt	Native	Potamodromous	Slow-flowing streams and still waters, shoaling near surface or around cover of aquatic plants and woody debris.	DE
Scorpaenidae (scorpionfish)					
Notesthes robusta	Bullrout	Native	Catadromous	Endemic to eastern Australia, occurring low freshwater reaches of rives and estuaries around aquatic vegetation with rock/mud substrate.	DE
Salmonidae (salmonids)					
Oncorhynchus mykiss	Rainbow trout	Exotic	Anadromous	Montane regions along the Great Dividing Range	UE, DE
Salmo trutta	Brown trout	Exotic	Anadromous	Restricted to cooler waters; montane waterways above ~600m elevation.	UE, DE
Terapontidae (grunters)					
Bidyanus bidyanus	Silver perch	Native – translocated	Potamodromous	Rivers, lakes and reservoirs, preferring areas of rapid flow. Present because of stocking	DE
Amniataba percoides	Banded grunter	Native – translocated, pest listing NSW[3]	Potamodromous	Freshwater habitats – in Clarence River and has the potential to spread to the Hawkesbury-Nepean region	DE

[1] DE refers to downstream environment, UE refers to upstream environment
Sources: DPI, 2006; Knight, 2010; BMT WBM, 2014

Knight (2010) postulated that the diversity of fish assemblages in the upstream catchment was likely influenced by lifecycle stages of the species and the dam. Barriers to movement were likely to inhibit the distribution of catadromous (i.e., migrates from freshwater to estuarine habitats for breeding) and amphidromous (i.e., migrates between freshwater and marine environments at defined periods of their lifecycle) species.

Obstructions to fish passage in the Hawkesbury-Nepean River catchment have been implicated in a reduction of the number of catadromous (fish or eel species that migrate from freshwater to saltwater to spawn) and amphidromous (fish or eel species that migrate from freshwater to saltwater or vice versa to spawn) species, such as Australian bass, Firetail gudgeon and sea mullet in waterways upstream from major barriers (Knight, 2010; Baumgartner and Reynoldson, 2007). Consequently, the majority of fish species observed upstream of the dam do not have an obligatory marine life-stage. This includes the threatened Macquarie perch (*Macquaria australasica*), and the Blue Mountain perch (*Macquaria sp. nov. 'hawkesbury taxon'*) which migrate exclusively in freshwaters. Well-documented exceptions to this are *Anguilla* eels and Cox's gudgeon (*Gobiomorphus coxii*), which move into Lake Burragorang via a steep side stream that bypasses the dam wall. These species possess 'climbing' behaviour which allows them to negotiate such barriers.

3.5.3 Assemblages in the downstream environment

Fish survey data from the downstream study area was recently reviewed (DPI, 2016) with the following key findings:

- For reaches of the Warragamba River from the dam to the confluence with Nepean River, 18 fish species have been recorded since 1994, comprising 13 native and five exotic species. The most abundant species were Australian bass (*Macquaria novemaculeata*), Australian smelt (*Retropinna semoni*), sea mullet (*Mugil cephalus*), Eastern gambusia (*Gambusia holbrooki*), empire gudgeon (*Hypseleotris compressa*) and freshwater mullet (*Trachystoma petardi*). Following the spilling of Warragamba Dam for the first time in 14 years, Rainbow trout (*Oncorhynchus mykiss*) and Brown trout (*Salmo trutta*) were detected in this reach in 2012.
- For reaches of the Nepean River from the confluence with Warragamba River to Penrith Weir, 17 fish species have been recorded since 1994, comprising 14 native species and three exotic species. Assemblages were numerically dominated by Australian bass, Australian smelt, sea mullet and freshwater mullet, and the flathead gudgeon (*Philypnodon grandiceps*)
- For reaches of the Nepean River from Penrith Weir to the Grose River junction, 20 fish species have been recorded since 1994, comprising 17 native species and three exotic species. The most abundant species were Australian bass, sea mullet, freshwater mullet and freshwater herring (*Potamalosa richmondia*)
- For reaches of the Hawkesbury River from Grose River to Wilberforce (which includes the freshwater/estuarine interface), 24 fish species have been recorded since 1994, comprising 21 native species and three exotic species. The fish assemblage included freshwater and estuarine species, and was numerically dominated by the same set of species recorded in the reaches described above.

- For reaches of the Hawkesbury River from Wilberforce to Wisemans Ferry, 26 fish species have been recorded since 1993, comprising 24 native species and two exotic species. Southern herring (*Herklotsichthys castelnaui*), sea mullet and freshwater mullet were the numerically dominant species.

Fish species known to occur in the catchment downstream study area are summarised in Table 3-4; this includes species recorded within the downstream study area. These are discussed further in Section 3.5.5. As noted in Section 1.2.5, the downstream study area boundary has been set at Wisemans Ferry.

3.5.4 Fish habitat classification

Fish habitat sensitivity and classes were defined based on the Policy and Guideline for Fish Habitat Conservation and Management (DPI, 2013). In terms of sensitive habitats, the study area contains:

- Type 1 *High Sensitivity Fish Habitat*, which includes:
  - All streams within the upstream study area (except stream order 1 and 2 waterways). These streams contain in-stream gravel beds, rocks greater than 500 mm in two dimensions, snags greater than 300 mm in diameter or 3 metres in length, and/or native aquatic plants. These streams also provide suitable habitat for the threatened Macquarie perch (*Macquaria australasica*), and Blue Mountains perch (*Macquaria sp. nov. 'hawkesbury taxon'*) and two threatened semi-aquatic dragonfly species (see Section 3.7.1)
  - Sections of Lake Burragorang, which are known to support the threatened Macquarie perch (*Macquaria australasica)* and may potentially support the Blue Mountains perch (*Macquaria sp. nov. 'hawkesbury taxon'*). This excludes deeper deoxygenated areas of the lake that are unlikely to support fish (and are classified Type 2/3 Moderate/Minimally Sensitive Fish Habitat).
  - Riverine environments in the downstream study area which support native aquatic plants.
- *Type 2/3 Moderately/Minimally Sensitivity Fish Habitat*, which include:
  - Deep deoxygenated waters in Lake Burragorang
  - Riverine environments in the weir pool immediately downstream of Warragamba Dam, which are highly modified and do not support extensive native aquatic macrophyte beds or habitat for threatened aquatic species.

In terms of Waterway Classes:

- Class 1 Major, which includes Lake Burragorang and the streams and rivers flowing into Lake Burragorang other than those Class 3 waterways
- Class 3 Minimal, which includes all stream order 1 and 2 waterways, which are ephemeral streams that do not support aquatic vegetation.

Indicative fish habitat sensitivity and class maps are provided in Appendix C.

3.5.5 Recreational or commercial fisheries species

This section describes species of direct recreational and/or commercial fisheries importance; however, this section does not assess social (i.e., fishing locations, closures) or economic fisheries aspects. Several species of fish that are known to occur in the Hawkesbury-Nepean catchment are recreationally and/or commercially important, including:

- Anguilla eels: the Hawkesbury-Nepean River system supports a commercial eel fishery, based on the freshwater eels of the genus *Anguilla*. These species occur in a range of aquatic habitats throughout the catchment
- Native Percichthyidae (perch) species: the main Percichthyidae species of fisheries significance is Australian bass (*Macquaria novemaculeata*). This species is targeted by recreational anglers and occurs throughout the downstream study area. This species has been historically stocked in the Nepean River at Penrith and the Penrith Lakes system (NSW DPI 2018)
- Estuarine fish species: several estuarine/marine species of fisheries significance including bream and flathead (*Platycephalus fuscus)* have been recorded in the catchment. These species occur in the downstream study area and are more abundant in tidal waters
- Stocked native fish species: several native species have been stocked in the Hawkesbury River catchment for recreational fishing purposes including Silver perch (*Bidyanus bidyanus)* and Maccullochella cod species
- Stocked introduced fish species: brown trout (*Salmo trutta*) and rainbow trout (*Oncorhynchus mykiss)* have been stocked in the Hawkesbury River catchment for recreational fishing purposes. Much of the stocking has occurred in the Upper Cox's River catchment at Lake Lyell.

3.5.6 Exotic fish species

Seven exotic fish species are known to occur in the Warragamba catchment, four of which are classified as noxious species under the *Fisheries Management Act 1994* (refer Table 3-5). One Australian species that is not endemic to the area, *Amniataba percoides,* but has been translocated to NSW waters and is listed as a noxious species under the FM Act, has also been recorded in the catchment.

Exotic fish species can affect native fauna populations through competition for food and habitat resources, predation and direct habitat modifications. Exotic species can also act as disease vectors. Redfin perch (*Perca fluviatilis*) for example has been implicated in the decline of Australian freshwater fish through predation on young fish, competition for space and food, and the transfer of epizootic haematopoietic necrosis virus (EHNV) to native fish species. Redfin perch was first detected in the Wollondilly River in 2006, and has now been recorded in the Mulwaree River, Paddys River and Wingecarribee River.

Table 3-5 Exotic fish species recorded in study area and pest status under the FM Act

Scientific name	Common name	Pest status	Reason for introduction	Habitat
Misgurnus anguillicaudatus	Oriental weatherloach	Class 1 Noxious Pest	Aquarium fish	Prefers lakes and quiescent sections of streams and backwaters Suitable habitat at Lake Burragorang and most streams in the upstream and downstream study areas
Carassius auratus	Goldfish	Not listed	Aquarium fish	Prefers lakes and quiescent sections of streams and backwaters Suitable habitat at Lake Burragorang and most streams in the upstream and downstream study areas
Cyprinus carpio	Carp	Class 3 Noxious Pest	Aquarium fish	Prefers lakes and quiescent sections of streams and backwaters Suitable habitat at Lake Burragorang and most streams in the upstream and downstream study areas
Perca fluviatilis	Redfin perch	Class 1 Noxious Pest	Angling	Prefers lakes and quiescent sections of streams and backwaters Suitable habitat at Lake Burragorang and most streams in the upstream and downstream study areas
Gambusia holbrooki	Eastern gambusia	Class 1/3 Noxious Pest	Mosquito control	Prefers lakes and quiescent sections of streams and backwaters Suitable habitat at Lake Burragorang and most streams in the upstream and downstream study areas
Oncorhynchus mykiss	Rainbow trout	Not listed	Angling	Lakes, swift flowing and quiescent streams, preference for cooler waters (9-21°C) Suitable habitat at Lake Burragorang and most streams in the upstream and downstream study areas
Salmo trutta	Brown trout	Not listed	Angling	Prefers deep creeks but also found in lakes. Suitable habitat at Lake Burragorang and most streams in the upstream and downstream study areas
Amniataba percoides	Banded grunter	Class 2 Noxious Pest	Angling	Prefers lakes and quiescent sections of streams and backwaters Suitable habitat at Lake Burragorang and most streams in the upstream and downstream study areas

Scientific name	Common name	Pest status	Reason for introduction	Habitat
Tanichthys albonubes	White Cloud Mountain minnow	Not listed	Aquarium fish	Tolerate a wide range of temperatures and variations in water quality. Suitable habitat at Lake Burragorang and most streams in the upstream and downstream study areas

Source: Knight, 2010; DECCW, 2010

3.5.7 Aquatic finfish disease

Several of the native and exotic species recorded within the Hawkesbury-Nepean catchment may harbour aquatic diseases. These include the native Australian Bass (*Macquaria novemaculeata*), which is susceptible to viral encephalopathy and retinopathy (VER), and the exotic Redfin Perch (*Perca fluviatilis*), which may carry epizootic haematopoietic necrosis virus (EHNV). The Australian Bass (*Macquaria novemaculeata*) has only been recorded in downstream environments, while the Redfin Perch (*Perca fluviatilis*) has only been recorded in upstream environments.

VER is a disease of finfish caused by infection with nervous necrosis virus (NNV), also referred to as Betanodavirus. The virus is distributed globally and is endemic to Australia, where it has been the cause of mass mortality of larval and juvenile fish in aquaculture facilities since the 1980s (DAWR, 2017). NNV has a low host specificity and as such has been reported in over 50 species of fish, from 36 families across 10 orders (OIE, 2016). Overseas, VER has been recognised in marine, diadromous and freshwater species (OIE, 2016). Whereas in Australia, VER has only been observed in hatchery produced barramundi (*Lates calcarifer)*), Australia Bass (*Macquaria novemaculeata*), Yellow Tail Kingfish (*Seriola lalandi*), Sleepy Cod (*Oxyeleotris lineolatus*), Gold-spotted Rockcod (*Epinephelus coioides*), Giant Grouper (*Epinephelus lanceolatus*) and Striped Trumpeter (*Latris lineata*) (DAWR, 2017).

EHNV is an Australian iridovirus, known to affect introduced wild populations of Redfin Perch (*Perca fluviatilis*) and farmed Rainbow trout (*Oncorhynchus mykiss*). EHNV has the potential to negatively impact several native fish species. Most infected fish are believed to quickly succumb and die. EHNV poses no known threat to humans. EHNV has been documented in portions of the upper Murrumbidgee catchment in NSW, the Broken River catchment in Victoria and the lower Murray-Darling catchment in South Australia. Interestingly, after extensive testing and research, EHNV appears to be absent from the middle, western, and northern portions of the Murray Darling Basin (DPI, 2020a).

Native Silver Perch (*Bidyanus bidyanus*), Macquarie Perch (*Macquaria australasica*), Murray-Darling Rainbowfish (*Melanotaenia fluviatilis*), Freshwater Catfish (*Tandanus tandanus*), Mountain Galaxias (*Galaxias olidus)*, Murray Cod (*Maccullochella peelii peelii*), Golden Perch (*Macquaria ambigua*) and introduced Eastern Gambusia (*Gambusia holbrooki*) have shown susceptibility to EHNV infection in laboratory trials involving water borne exposure (DPI, 2020a).

These diseases are currently not known within the Hawkesbury-Nepean catchment (DPI, 2020b).

3.6 Threatened species and communities

An EPBC Act Protected Matters search (September 2019) and NSW BioNet Species search (October 2018) were conducted to cover both the upstream and downstream study areas. The search area was defined as the Project PMF plus a 10 km buffer. The NSW DPI publication, Fish Communities and threatened species distribution of NSW was also consulted. Threatened aquatic species identified through database and literature searches are summarised in Table 3-6. As noted in Section 1.2.5, the downstream limit of the material influence of the Project is at Wisemans Ferry, and as such the assessment does not considers areas downstream of this location.

Table 3-6 Protected Matters Search Tool results

Scientific name	Common name	Status	Likely occurrence
Archaeophya adamsi	Adam's emerald dragonfly	FM Act – Endangered	**Likely**. Potential habitat - cool clear streams with gravely riffles and extensive riparian vegetation – occurs throughout study area.
Austrocordulia leonardi	Sydney hawk dragonfly	FM Act – Endangered	**Likely**. Potential habitat - deep cool pools on slow flowing rivers with steep sides – occurs throughout study area.
Epinephelus daemelii	Black Rockcod	EPBC Act - Vulnerable	**Likely.** Known to occur in estuarine habitats in the downstream study area
Macquaria australasica	Macquarie perch	EPBC Act – Endangered FM Act - Endangered	**Likely.** Known records from upstream and downstream study area
Macquaria sp. nov. 'hawkesbury taxon'	Blue Mountains perch	*	**Likely** Known records from upstream
Mogurnda adspersa	Purple-spotted Gudgeon	FM Act - Endangered	**Unlikely**. Known distribution does not overlap the study area. Not recorded Hawkesbury-Nepean catchment.
Nannoperca australis	Southern Pygmy Perch	EPBC Act – nominated FM Act - Endangered	**Highly unlikely**. Known distribution not in the vicinity of study area.
Posidonia Australia	Fireball weed	EPBC Act - Endangered	**Likely.** Known distribution in estuarine habitats in the downstream study area
Prototroctes maraena	Australian Grayling	EPBC Act – Vulnerable FM Act - Endangered	**Unlikely**. Known distribution begins to the south of the study area. Not recorded in study area or Hawkesbury-Nepean catchment.

**Macquaria sp. nov. 'hawkesbury taxon'* was identified following the initial listing of *Macquaria australasica*. It is thought to be restricted to catchments within the Blue Mountains, and potentially others streams within the Hawkesbury catchment.

3.6.1 Threatened invertebrate species and communities

Two semi-aquatic invertebrate species listed as endangered under the FM Act occur within the Hawkesbury-Nepean catchment (DPI, 2007), the Adam's emerald dragonfly (*Archaeophya adamsi*) and Sydney hawk dragonfly (*Austrocordulia leonardi*). These two species have an aquatic larval stage that rely on a specific set of habitat requirements. They are therefore sensitive to habitat disturbance and water quality degradation (DPI, 2007; 2013). Table 3-6 summarises the habitat preferences for both of these species.

Larvae of the Adams emerald dragonfly (*Archaeophya adamsi*) generally occur in small to moderate sized creeks with gravel or sandy beds, with narrow, shaded riffle zones containing moss and abundant riparian vegetation (DPI, 2013). Such habitat conditions are present in tributary streams feeding into Lake Burragorang and within some parts of the downstream study area. Adams emerald dragonfly (*Archaeophya adamsi*) has been recorded around streams feeding into Ku-ring-gai Chase National Park, which is in the lower reaches of the downstream study area (Figure 3-15).

Sydney hawk dragonfly (*Austrocordulia leonardi*) larvae have only ever been collected from under rocks in deep and shady river pools with cooler water (DPI 2007). Such habitat conditions occur in tributary streams feeding into Lake Burragorang and within some parts of the downstream study area. Sydney hawk dragonfly (*Austrocordulia leonardi*) has been recorded in the Nepean River near Wilton, which is upstream from the confluence of the Warragamba River and Nepean River, and not within the area of the existing or Project PMFs (Figure 3-16).

Note the endangered Giant dragonfly *Petalura gigantea* is known to occur in the bioregion that includes the study area; however, larvae and adults of this species do not have a true aquatic stage and therefore they have not been considered in this assessment.

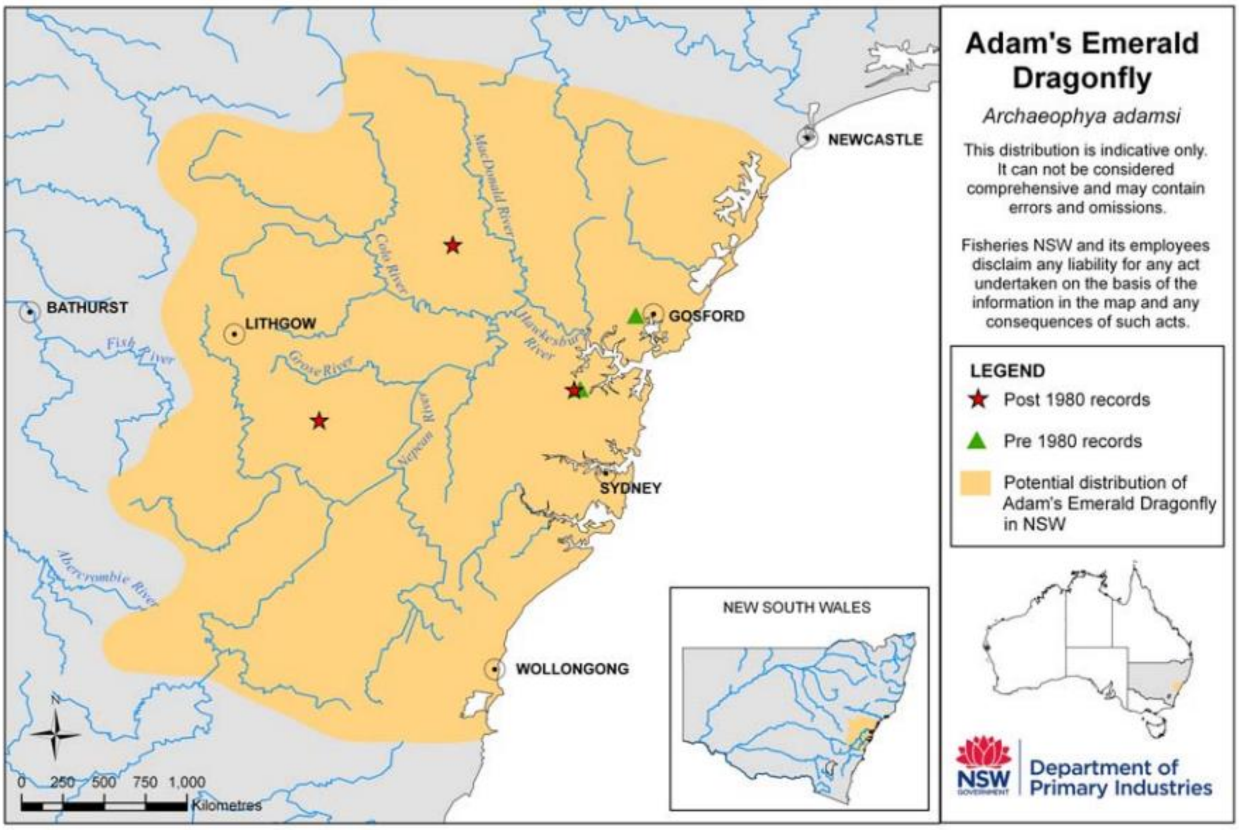


Figure 3-15 Potential distribution and recorded sightings - Adam's Emerald Dragonfly (DPI, 2013)

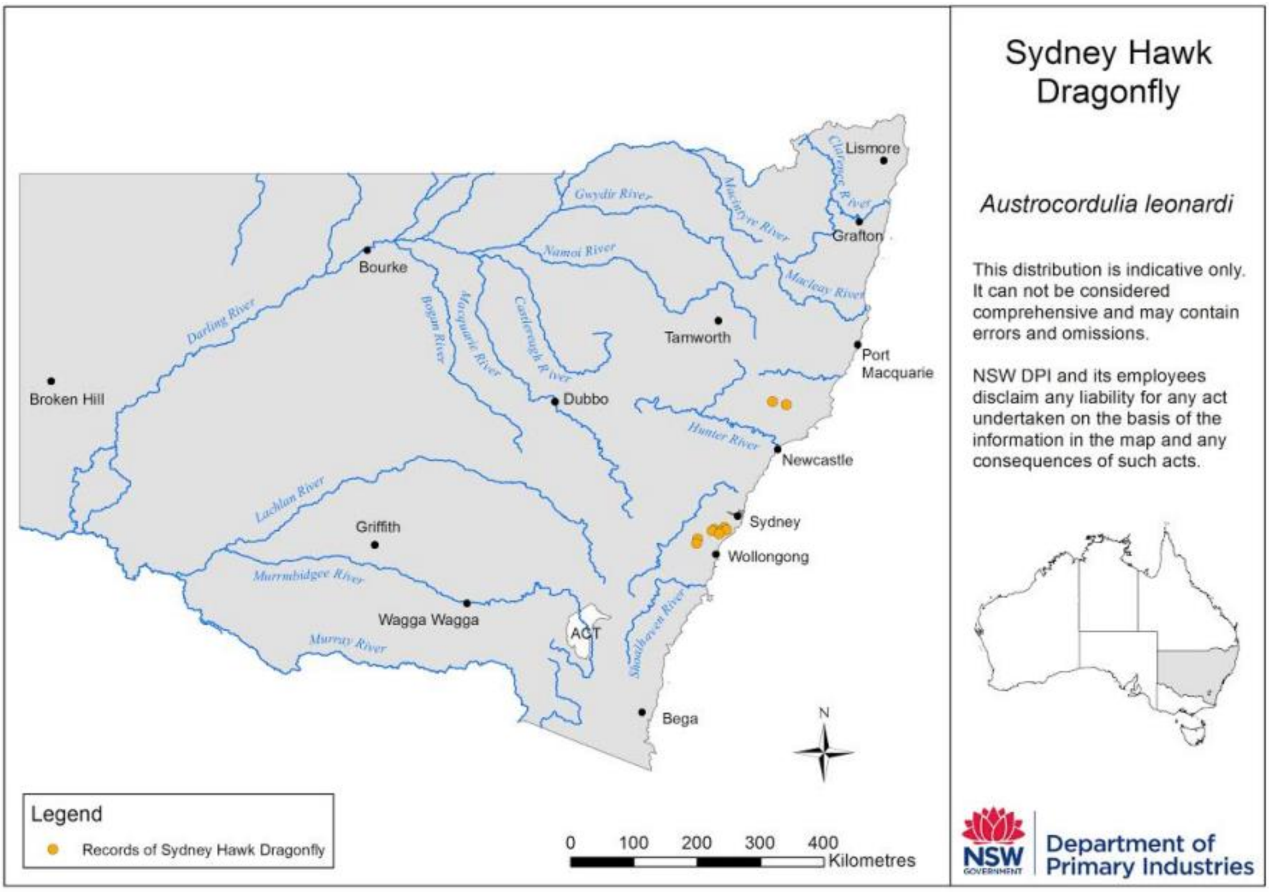


Figure 3-16 Recorded Sightings - Sydney Hawk Dragonfly (DPI, 2007)

3.6.2 Threatened vertebrate species and communities

Two threatened fish species that are indigenous to the Hawkesbury-Nepean catchment and occur in the study area were identified through a search of the EPBC Act protected matters search and BioNet search. These include the Macquarie perch (*Macquaria australasica*), which is listed as endangered under both the EPBC Act and FM Act, and the Australian grayling (*Prototroctes maraena*), which is listed as vulnerable under the EPBC Act and endangered under the FM Act.

At least three other threatened species may occur in the catchment, including trout cod (*Maccullochella macquariensis*), the Murray River cod (*Maccullochella peelii peelii*) and silver perch (*Bidyanus bidyanus*). These species are not indigenous to the catchment, but rather have historically been translocated to the catchment from elsewhere. There are no recent records of these species from the catchment, therefore it has been suggested that their introductions to the catchment have failed (DPI, 2006).

Distribution modelling provided by the EPBC Act protected matters search tool indicates the Black rockcod (*Epinephelus daemelii*) may occur in the lower reaches of the downstream study area; however, there have been no confirmed sightings of this species. This species is listed as Vulnerable under both the EPBC Act and FM Act.

Another fish species, that is likely related to the Macquarie perch, the Blue Mountains perch (*Macquaria sp. nov. 'Hawkesbury'*), is likely present within the study area. While not officially listed as threatened under the EPBC Act (or FM Act), the Blue Mountains perch has been included on the provisional list of animals requiring urgent management attention in the Australian Government's bushfire recovery package for wildlife and their habitats.

Table 3-7 provides a summary of potential threatened fish species occurring in the study area, with detailed descriptions provided for the species that are known or likely to occur: Macquarie perch (*Macquaria australasica*), Australia grayling (*Prototroctes maraena*) and black rockcod (*Epinephelus daemelii*).

Table 3-7 Threatened fish species known or possibly occurring within the study area

Species name	Common name	FM Act*	EPBC Act*	Habitat requirements	Potential habitat within the study area
Macquaria australasica	Macquarie perch	EN	EN	Cool clean water preferring deep slow flowing pools and lakes.	Yes – confirmed to occur in upstream study area
Macquaria sp. *nov. 'hawkesbury taxon'*	Blue Mountains perch	NL	Priority listed	Restricted to the mid-reaches of small near pristine streams, at elevations of 35-420 m above sea level, mostly commonly at 100-175 m above sea level.	Yes – likely to occur in the study area
Prototroctes maraena	Australian grayling	EN	VU	Clear gravely coastal streams and rivers from the sea to the first barrier, up to 1,000 m	No - numerous barriers in downstream environments. Not known to occur in study area
Maccullochella macquariensis	Trout cod	EN	EN	Inhabits large rivers and streams in the upper Murray-Darling Basin often associated with cover such as large woody debris rock outcrops, boulders and deep holes	No - known from translocated stocks within Cordeaux Dam
Maccullochella peelii peelii	Murray cod	NL	VU	Turbid, slow-flowing rivers and streams of the Murray-Darling Basin, often near deep holes with large woody debris. rocks and overhanging vegetation	No - stocked in the 19th century in the Coxs Nepean and Wollondilly rivers. Stock in Cataract Dam and several water storages (Rowland 1989)
Bidyanus bidyanus	Silver perch	VU	NL	Turbid, slow-flowing rivers and streams of the Murray-Darling Basin, often near deep holes with large woody debris. rocks and overhanging vegetation. Species is not found in cool, fast-flowing upland rivers of Murray-Darling Basin	No

Species name	Common name	FM Act*	EPBC Act*	Habitat requirements	Potential habitat within the study area
Epinephelus daemelii	Black rockcod	VU	VU	Occurs in caves, gutters and rocky reefs in near shore environments, with juveniles potentially also occurring in estuaries.	Possible but no confirmed sightings

* EN: Endangered, VU: Vulnerable, NL: Not Listed

3.6.2.1 Macquarie perch and Blue Mountains perch

The Macquarie perch (*Macquaria australasica*) is known to prefer waterways with rocky substrate (Bruce *et al*., 2007). It has been recorded at several locations in the Hawkesbury-Nepean catchment, as shown in Figure 3-17. Macquarie perch (*Macquaria australasica*) distribution within the study area is fragmented and they often occur in low numbers (Bruce *et al*., 2007; Knight, 2010). Bruce *et al*. (2007) and Knight (2010) recorded this species in 20 of 48 water bodies sampled, including the Colo River, lower Coxs River, Lake Burragorang and the Nepean River. This species was typically one of the most abundant species in locations where it was recorded (Bruce *et al.* 2007, Knight 2010).

eDNA analysis undertaken to inform this assessment suggest this species also occurs in the Kedumba River within the upstream study area.

Knight (2010) observed that all sites where Macquarie perch (*Macquaria australasica*) occurred were in an undisturbed condition, suggesting that their distribution is limited by their sensitivity to in-stream habitat conditions.

A recovery plan for the Macquarie perch has been prepared under the EPBC Act (DoEE, 2019), and came into effect in February 2019. The objective of the plan is to ensure the recovery and ongoing viability of Macquarie perch populations throughout the species' range (including historically translocated populations in Cataract Reservoir and the Mongarlowe and Yarra rivers). The plan defines the following six strategies to achieve this objective:

- Conserve existing Macquarie perch (including historically translocated populations in Cataract Reservoir and the Mongarlowe and Yarra rivers)
- Protect and restore Macquarie perch habitat
- Understand and address threats to Macquarie perch populations and habitats
- Establish additional Macquarie perch populations within the species' natural range
- Improve understanding of the biology and ecology of the Macquarie perch and its distribution and abundance
- Increase participation by community groups in Macquarie perch conservation.

Each strategy comprises a range of actions with associated performance criteria.

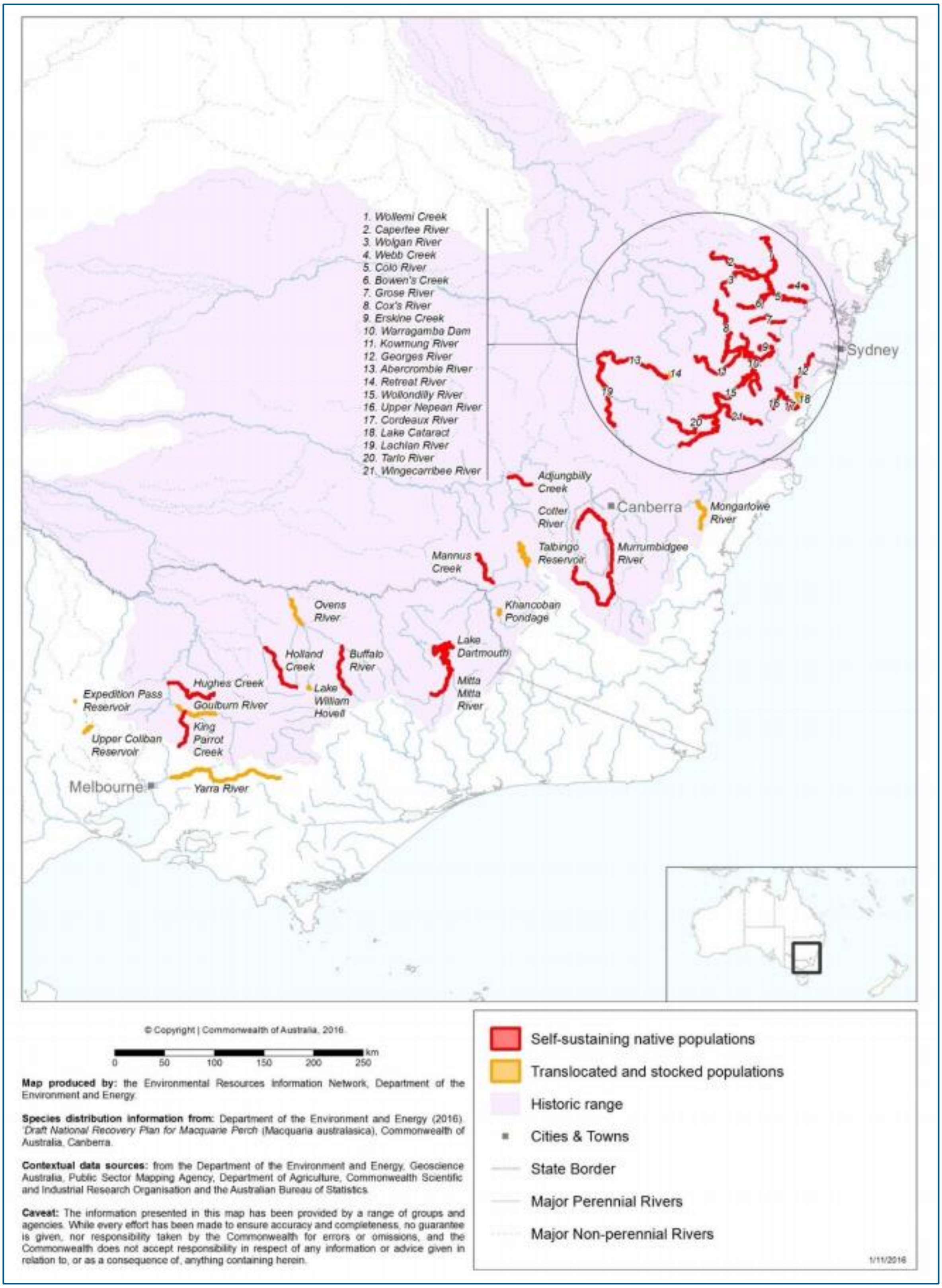


Figure 3-17 Potential distribution of Macquarie Perch (*Macquaria australasica*) (Commonwealth of Australia, 2017)

The Blue Mountains perch (*Macquaria sp. nov. 'hawkesbury taxon'*) is thought to be restricted to the mid-reaches of small near pristine streams, at elevations of 35-420 m above sea level, mostly commonly at 100-175 m above sea level. It occurs in complex boulder habitats near pristine, clear streams in rugged gorges, with minimal sediment and nutrient loads, and little or no instream vegetation.

Historically the species was more widespread and has disappeared from areas such as the upper Kowmung River, Wollondilly River, and approximately 80 kilometres of the Nepean River between the Bargo River junction and Penrith weir (Bray, 2020).

3.6.2.2 Australian grayling

Australian grayling (*Prototroctes maraena*) historically occurs in coastal streams of south-eastern Australia, ranging from the Grose River in the north of the Hawkesbury-Nepean River catchment to the Hopkins River near Warrnambool, Victoria.

NSW DPI (2006) indicates that the Australian grayling occurs in the Hawkesbury-Nepean River catchment; however, this is contradicted by the Australian Grayling Recovery Plan which indicates that this species has only ever been recorded south of Shoalwater River (Backhouse *et al*., 2008). No records of this species were identified through relevant database searches (NSW Online Threatened and Protected Species Records Viewer; NSW Rivers Survey data; DPI, 2014a).

This species prefers waterways with low turbidity and gravel substrate and can occur in lowland reaches through to the upper reaches to an altitude to 1,000 m AHD (Allen *et al*., 2002; McDowell, 1996). The species is catadromous with juveniles occurring in coastal reaches and adults in the upper reaches of catchments. The distribution of this species is therefore highly influenced by instream barriers, and as such is unlikely to occur upstream of Warragamba Dam.

3.6.2.3 Black rockcod

Black rockcod (*Epinephelus daemelii*) inhabit nearshore environments up to depths of 50 m, and seek refuge in caves, gutters and rocky reefs. The Black Rockcod Recovery Plan identifies estuaries as potentially important juvenile development grounds, based on the lifecycle of other serranids (e.g., *E. coioides* and *E. malabaricus*) (DPI, 2012). The species is known to occur from southern Queensland through to Kangaroo Island, with NSW at the centre of the species' distribution. Based on this distribution and habitat preferences, it is possible that juvenile rockcods occur within the lower reaches of the downstream study area.

3.7 Key threatening processes

Key threatening processes are activities or actions that, in the opinion of the Fisheries Scientific Committee, adversely affect threatened species populations or ecological communities, or could cause species, populations or ecological communities that are not threatened to become threatened. Schedule 6 to the FM Act currently identifies the following key threatening processes:

- Degradation of native riparian vegetation along New South Wales water courses
- Hook and line fishing in areas important for the survival of threatened fish species
- Human-caused climate change

- Installation and operation of instream structures and other mechanisms that alter natural flow regimes of rivers and streams
- Introduction of fish to waters within a river catchment outside their natural range
- Introduction of non-indigenous fish and marine vegetation to the coastal waters of New South Wales
- Removal of large woody debris from New South Wales rivers and streams
- The current shark meshing program in New South Wales waters.

Of these, the fourth and seventh key threatening process are considered to be of potential relevance to the Project. The fourth is related principally to the changed extents of inundation associated with operation of the flood mitigation zone. Removal of large woody debris may be relevant for works in the construction area but given the nature of the immediate downstream area of the dam, the potential for this is considered to be low.

4 Potential impacts of the Project

Impacts to aquatic ecology can occur through pollution, changes to landscape or hydrological conditions, land use practices, and broader environmental changes such as those associated with climate change.

Potential impacts to aquatic environments and ecology that may result from the Project have been assessed relative to the construction and operation of the Project, covering the upstream, construction, and downstream study areas.

4.1 Potential construction related impacts

Activities undertaken during construction of the Project that may result in impacts to aquatic environments and ecology include:

- Earthworks and other construction activities
- Construction of temporary in-stream structures and diversions
- Storage of construction plant, equipment and materials, particularly hazardous materials.

4.1.1 Potential construction related impacts to upstream aquatic environments

Impacts to the upstream aquatic environments are not anticipated to occur during construction. The full supply level will not be changed during construction. Construction of the dam may require temporary lowering of the lake/reservoir water level to 5 m below full supply; however, this will depend on the water level in the reservoir at the time of construction. This is not anticipated to lead to any additional impacts (to those already encountered).

The Adam's emerald dragonfly (*Archaeophya adamsi*) is listed as endangered under the FM Act. Larvae of the Adam's emerald dragonfly generally occur in small to moderate sized creeks with gravel or sandy beds, with narrow, shaded riffle zones containing moss and abundant riparian vegetation (DPI 2013). Such habitat conditions are present in tributary streams feeding into Lake Burragorang. Construction activities for the Project would be confined to a relatively small area and would not be expected to impact on habitat utilised by this species.

4.1.2 Potential construction related impacts to downstream aquatic environments

4.1.2.1 Earthworks and other construction activities

Earthworks would be required during construction of the Project. This would largely be undertaken in proximity to the existing dam, the existing spillway, the existing weir pool, and areas required for construction site compound and concrete batching plants (refer Figure 1-2). Works with the potential to expose soils and sediments, which can lead to increased sedimentation of waterways include:

- Early works
- Raising of the dam abutments
- Raising of the central spillway

- Modifications to the auxiliary spillway
- Installation of e-flows infrastructure
- Other infrastructure elements.

These activities would involve excavation and stockpiling, clearing of vegetation, construction of temporary and permanent infrastructure. Earthwork and clearing of vegetation expose soils and can lead to increased erosion (wind and/or rain driven) of sediments, which may enter aquatic environments leading to increased sedimentation. Sediments can carry nutrients and pollutants that can affect water quality, and ultimately aquatic ecology. Potential impacts associated with this include:

- Increased turbidity and nutrient concentrations, leading to deteriorated water quality
- Reduced light penetration due to increase turbidity, which hinders photosynthesis, which may lead to a reduction in aquatic macrophytes
- Proliferation of exotic or nuisance aquatic macrophyte and algae species due to increased nutrient concentration (liberated from saturated sediments). Exotic or nuisance aquatic macrophytes or algae species compete for space and resources with native macrophyte species, and their excessive growth (e.g. of blue green algae) can lead to decrease dissolved oxygen concentrations, which would have broad impacts to aquatic ecology
- Sedimentation of aquatic habitats, including filling of rocky areas, riffles and smothering of benthic habitats.

These impacts have the potential to affect downstream aquatic environments, as well as those in proximity to the construction zone. If suitable management measures are implemented, impacts associated with erosion and sedimentation in aquatic environments should be negligible or would only occur within a short distance from the construction study area.

In areas where macrophytes have been lost from aquatic systems, competition for nutrients and light, together with the loss of habitat for zooplankton and fish, has resulted in these systems becoming dominated by exotic or nuisance algae. In the worst-case scenario, macrophyte dominated systems can become dominated by blue-green algae (Independent Expert Panel for the Hawkesbury-Nepean, Shoalhaven and Woronora Catchments, 2002b).

Impacts to water quality have been assessed separately (refer Appendix Q, Chapter 27 of the EIS); however, the water quality assessment concluded that potential construction impacts would relate to erosion and sedimentation, wastewater runoff and potential spills of hazardous materials. The water quality assessment also considered changes to water quality following a major flood event (using events from 1998 and 2007) which is also a possibility during construction. This identified that turbidity was significantly lower in the 1998 event compared to the 2007 event; however, the mean turbidity of the 2007 event, while higher than the 1998 event, was substantially lower than turbidity measured at downstream sites.

Any impacts to water quality that occur during construction of the Project are anticipated to be temporary and limited in geographic extent to within the construction footprint. Temporary, short-term increases in turbidity associated with increased sediment loads may also be experienced downstream of the construction study area; however, under normal construction condition, these are expected to return to baseline concentrations rapidly and within a short distance of the construction study area. It is important to note that during the construction of the Project, flood levels of behaviour would not be significantly impacted. Therefore impacts associated with these events that are outside of the control of the Project, and not expected to change during construction of the Project.

Areas potentially affected by construction activities, particularly through vegetation clearing, do not support high quality habitat for native aquatic macrophytes. The weir pool at the base of the existing spillway has a bed rock and cobble bank and is subject to scour from periodic releases of water from the dam. The invasive weed species *Egeria densa* has been recorded up to the dam wall (see Section 3.3.3). Cleared areas would need to be managed in accordance with a Soil and Water Management Plan.

There is a link between adverse water quality and aquatic macroinvertebrates populations, and in fact aquatic macroinvertebrate assemblages are used as indicators of water quality. Adverse water quality influences aquatic macroinvertebrate abundance and diversity, which could in turn impact on species that rely on aquatic macroinvertebrates as a food source. The spatial extent of any impacts to water quality during construction is likely to be limited, particularly with the implementation of standard safeguards and management measures. Any impacts related directly to construction activities would likely be restricted to within the Warragamba River, and are unlikely to extend into the Nepean River. This extent of the Warragamba River has been modified by the construction and operation of the existing dam and is subject to land-based impacts which have reduced the quality of aquatic habitat. Although limited data is available on macroinvertebrate assemblages in downstream section of the Warragamba River, they are likely to have been influenced by historical activities such as the construction of the dam, and adjacent land uses. Construction activities are unlikely to lead to significant alteration of this habitat and are therefore unlikely to significantly impact aquatic macroinvertebrate assemblages, or any species that rely on these.

While the link between adverse water quality and increased incidence of finfish diseases remains unclear, adverse water quality can lead to stress in finfish species that may harbour viruses. Under typical environmental conditions, susceptible finfish may not exhibit clinical signs of a virus; however, adverse environmental conditions or stress may precipitate a disease response/exhibition in these species (Crane and Hyatt, 2011). As stated, impacts to water quality during construction of the Project are anticipated to be temporary and limited in geographic extent to within the construction footprint. Of the species recorded in the downstream study area, the Australian Bass (*Macquaria novemaculeata*) is known to be susceptible to VER; however, VER has only been observed in this species in hatchery environments. There are no known Australian Bass (*Macquaria novemaculeata*) hatcheries within the downstream study area, and owing to the habitat requirements of the species, its extent would likely be limited to the Hawkesbury River estuary, and potentially areas immediately upstream. However, as the species is susceptible to barriers to fish passage, such as weirs, it is unlikely to be found upstream of Penrith Weir, which is significantly downstream from any areas of potential construction impact. Furthermore, VER is not currently known to exist in any species in the Hawkesbury-Nepean catchment (DPI, 2020b).

4.1.2.2 *Construction of temporary in-stream structures*

Temporary in-stream structures would be installed during construction of the Project. These include:

- Coffer dams would need to be installed at multiple locations around the dam to manage the impact of construction works on the Warragamba River and protect the construction site from backflows. Indicative locations for coffer dams include at the end of the existing central spillway dissipator, immediately upstream of the auxiliary spillway and downstream of the auxiliary spillway. The number and size of the coffer dams would be informed by the detailed design
- Emptying/dewatering of the dissipator pool at the base of the dam to enable the undertaking of works
- Construction works to raise the dam
- Upgrading the existing boat ramp, pontoon and access road upstream of the dam (but still in the construction study area) to allow for water access to the dam wall.

Installation of these structures has the potential to impact aquatic environments through obstruction to fish passage, indirect effects from and impacts to water quality. Impacts to water quality have been assessed separately within the EIS and impacts that changed water quality might have on aquatic ecology are discussed in Section 4.1.1.

The temporary installation of coffer dams and dewatering of the dissipator pool would create obstruction to fish passage; however, this would not significantly alter the existing level of obstruction created by the dam, spillway, and weirs further downstream.

The eel passageway on the left bank would be maintained to continue to allow the migration of eels from Warragamba River downstream, to Lake Burragorang. Should construction activities require this passageway to be modified, it would be reinstated as required. The passageway would continue to operate for the majority of the construction period.

4.1.2.3 *Storage and use of construction plant, equipment, and materials*

Construction equipment, plant and materials, in particular the use and storage of petroleum hydrocarbons and other chemicals, have the potential to impact water quality through spills. These have been addressed in Chapter 27 of the EIS.

4.2 Potential operation-related impacts

Operation of the flood mitigation zone may result in impacts to aquatic environments and ecology related to:

- Use of the flood mitigation zone (temporary retention of flood inflows) in the upstream area
- Releases of water from the flood mitigation zone resulting in a temporary increase in flows in the downstream study area.

4.2.1 Potential operation related impacts to upstream aquatic environments

For the purpose of offsetting potential impacts related to terrestrial biodiversity in the upstream study area in accordance with the NSW Framework for Biodiversity Assessment, an area has been identified based on predicted flood levels within a notional 20-year timeframe. The area is defined by two contours: 119.5 mAHD (2.78 metres above Full Supply Level) and 126.97 mAHD (10.25 metres above Full Supply Level) which establish the lower and upper extents of this area respectively, referred to hereafter as the 'upstream impact area'. Further details on the derivation of this area are provided in Section 1.5.4 of the upstream biodiversity assessment (Appendix F1).

During flood events, areas of vegetation would be temporarily submerged with the depth and duration of inundation varying depending on where, in terms of elevation, the vegetation is located in the flood mitigation zone. For the upstream impact area, the existing duration of temporary inundation is about six to seven days and the Project would increase this by about three to eight days depending on the location upstream, with the largest increase in temporary inundation being associated with those parts of the upstream impact area in immediate proximity to Lake Burragorang.

The additional period of temporary inundation drops off markedly moving up the tributaries out of Lake Burragorang generally being in the order of less than half a day for most tributaries.

Inundation within the flood mitigation zone may result in impacts to aquatic ecology associated with:

- Decay of vegetation, which has the potential to have short-to-medium term impacts on water quality through the decomposition of organic matter. This could increase nutrient loads and organic matter concentrations, which in turn may contribute to the potential for algal blooms
- Geomorphic changes, including an increase in the risk of bank and in-stream erosion (relatively higher for tributaries to the west of Lake Burragorang), causing an increase in sedimentation and turbidity
- Creating additional temporary aquatic habitat which may become fragmented and isolated during operation of the flood mitigation zone, creating the potential for stranding of aquatic fauna; the likelihood of this is considered low, however, as the flood mitigation zone would be drawn down at a relatively constant rate allowing fauna to move back down tributaries and out of inundated floodplain areas
- Promotion of weed and exotic vegetation species growth in the flood mitigation zone.

Potential impacts on water quality associated with inundation from the flood mitigation zone are addressed in in detail in Appendix Q (Water Quality) of the EIS.

Water would be discharged from the flood mitigation zone in a controlled manner. Flood mitigation zone operating protocols would be developed for approval by the relevant regulatory authorities and would guide this process.

Regardless, operation of the Project may lead to impacts on the aquatic ecology of upstream environments relating to:

- Obstruction of fish passage
- General ecosystem health, including impacts to aquatic ecology associated with changes in water quality
- Potential spread of pest species and aquatic diseases
- Geomorphic impacts.

These are discussed further as follows.

4.2.1.1 *Obstruction of fish passage*

Lake Burragorang supports a range of native and introduced fish species, almost all of which do not have an obligatory marine phase. These include the threatened Macquarie perch (*Macquaria australasica*), which migrates exclusively in freshwaters. It also includes the priority listed Blue Mountains perch (*Macquaria sp. nov. 'hawkesbury taxon'*).

The Macquarie perch prefers waterways with rocky substrate, and many of the streams within the upstream catchment support such habitat. Potential impacts to such habitat could occur if there was an increase in the deposition of fine materials, which may subsequently alter bed structure by infilling the rocky substrate. Findings of the geomorphology assessment, as discussed below, indicate that these impacts are unlikely to occur. Under existing conditions, the majority of sediment loads entering Lake Burragorang originate from the Wollondilly and Coxs Rivers, which have large areas of cleared and developed catchment outside the Warragamba Special Area. This would not change with the Project.

The Blue Mountains perch (*Macquaria sp. nov. 'hawkesbury taxon'*) is thought to be restricted to the mid-reaches of small near pristine streams, at elevations of 35-420 m above sea level, mostly commonly at 100-175 m above sea level. It occurs in complex boulder habitats near pristine, clear streams in rugged gorges, with minimal sediment and nutrient loads, and little or no instream vegetation. Such habitat does not occur in the area that will be inundated should the flood mitigation zone be filled.

Loss or change in vegetation due to operation of the flood mitigation zone may potentially increase erosion potential; however, erosion hot-spot modelling suggests that only about 150 ha within the flood mitigation zone would experience an increase in erosion potential of two or more categories. This is largely in the rivers with existing cleared catchments rather than those that are surrounded by protected areas (Beca, 2019). The geomorphology assessment undertaken for the Project (Appendix N2) indicates that the majority of land in the flood mitigation zone would stay within the same erosion class for the 1 in 20 and 1 in 100 chance in a year events and the PMF. With the Project, for the 1 in 10 and 1 in 5 chance in a year events, erosion class increases on average by five percent and one percent respectively (Beca, 2019).

Similarly, existing conditions of deposition of debris under low flow conditions in streams that drain into Lake Burragorang would remain, and low density sediment deposits are expected to continue to be flushed out during high flow events under future conditions. Areas in rivers upstream from Lake Burragorang where sediments currently deposit are expected to show little change (BECA, 2019).

The geomorphology assessment also concluded that the proposal is unlikely to increase velocities in the upstream zone rivers. Conversely, velocities are predicted to decrease, and the depositional regime in the dry season for the rivers would not change from the existing case. However, the assessment could not establish quantitively whether the sediment transport regime for high flow events would change and if the magnitude of change would be great enough to alter the regime from one of erosion and suspended transport/bedload transport to one of deposition. However, it is likely that the depositional zone would extend further upstream when lake levels are higher for temporary storage of flood inflows, then the finer fractions of that deposited sediment would progressively move downstream in subsequent smaller runoff events. Overall, the effects would be a limited increase in the extent and lateral width of deposition in the upstream rivers and this is not expected to lead to obstruction of fish passage.

4.2.1.2 General ecosystem health

As discussed, and based on historical flood and water supply data, it is anticipated that the flood mitigation zone would be operational very infrequently. While flood levels for various flood events have been presented, these are considered worst case scenarios and assume that the dam would be at full supply level when a significant rainfall event occurs. In reality, the dam is rarely at full supply level and consequently the frequency and extent of temporary inundation of the flood mitigation zone would be substantially less than that suggested by the frequency of different flood events. For example, if a 1 in 20 chance in a year event was to occur at the time of writing this report (September 2020 storage at 96.5% capacity), the existing dam would spill, or if a flood mitigation on were in operation it *would* be inundated. However, if a 1 in 20 chance in a year event were to occur at the same time in 2019 (September 2019 storage at 50% capacity), the existing dam would have been able to capture the whole flood event, or if a flood mitigation zone was in operation it *would not* be inundated.

Regardless, when it occurs, inundation of the flood mitigation zone may impact aquatic ecology of upstream environments. It is unlikely that the inundation of the flood mitigation zone would lead to an increase in industrial or agricultural pollutants and contaminants as the area to be inundated is entirely within the Warragamba Special Area, and therefore land use and public access is heavily regulated. However, impacts to general aquatic ecosystem health may occur due to changes in natural processes, such as erosion and decay of organic matter (which is also an existing risk). Changes in flood inundation extents has the potential to alter the proportions of sand, silt and rock within the littoral zone of Lake Burragorang tributaries that flow into it, which may in turn influence the nature and availability of habitat by inundating:

- New substrate that may be substantially different to the substrate currently within the littoral zone
- Vegetation, the decay of which may increase the organic content of the sediments
- New substrate, which may introduce nutrients and metals into the upstream flood zone.

These impacts to water quality may in turn impact aquatic ecosystem health. For example, adverse changes in water quality can have a detrimental effect on macroinvertebrate assemblages, and they can also promote the onset of aquatic diseases (see Section 4.2.2.3 below). Changes to macroinvertebrate assemblages associated with impacts to water quality due to the operation of the Project could impact on species that rely on aquatic macroinvertebrates, such as fish.

While the flood mitigation zone is in operation, there would be a temporary increase in the depth and duration of upstream inundation, this being about less than half a day and half a metre for all events up to the PMF event. No material impacts on macrophytes is anticipated.

It is also important to note that there is potential to further improve aquatic habitat by allowing some or all of the woody terrestrial vegetation within the flood mitigation zone to remain standing.

The Adam's emerald dragonfly (*Archaeophya adamsi*) is listed as endangered under the FM Act. The species has been collected from only four localities in NSW, one being Bedford Creek in the Lower Blue Mountains (outside of the downstream study area). Larvae of the Adam's emerald dragonfly generally occur in small to moderate sized creeks with gravel or sandy beds, with narrow, shaded riffle zones containing moss and abundant riparian vegetation (DPI 2013). Such habitat conditions are present in tributary streams feeding into Lake Burragorang. Operation of the Project (intermittent inundation from operation of the flood mitigation zone) is considered unlikely to have a material impact on habitat in the upstream study area.

Threats to both species (DPI 2007, 2013) include:

- habitat degradation resulting from removal of riparian vegetation, drainage works, sedimentation from road crossings, and similar activities
- water pollution and sedimentation from land clearing, waste disposal and stormwater runoff from urban, industrial and agricultural development in catchments
- chance events such as natural disasters including bushfire and drought.

River regulation and alteration of flows resulting in the disappearance of natural deep pools has been identified as threat to the Sydney Hawk dragonfly (DPI 2007) while low population sizes and a long larval period (indicating an extremely low rate of natural recruitment and therefore slow recovery from any population decline) has been identified as threat to the Adam's Emerald dragonfly (DPI 2013).

The likelihood of habitat degradation is considered low; while habitat utilised by these species may be subject to temporary inundation (and which is also an existing risk), the limited duration (a maximum of about two weeks) would be unlikely to have a material affect on riparian habitat utilised by these species. There would be no change to the operation of the Special Areas therefore there would be no change to the risk of water pollution and sedimentation. The Project would not have any effect on chance events that may affect these species. The Project would not result in the loss of natural deep pools. Accordingly, it is unlikely that the Project would have a material impact on either of these two species.

4.2.1.3 Potential spread of pest species and aquatic diseases

Pest or exotic species of aquatic flora have been recorded in the upstream catchment. Links between adverse water quality and the proliferation of pest or exotic aquatic flora species are known. Therefore, adverse impacts to water quality that may occur through inundation of the flood mitigation zone, may lead to an increase in pest or exotic aquatic flora in the upstream catchment. The assessment of water quality impacts in the EIS (Chapter 27; Appendix Q) identified the potential for increased turbidity in the upstream study area, particularly Lake Burragorang, but noted that impacts would likely not be significant with regard to water quality. These changes to water quality would be associated with flooding events and would generally be temporary in nature. Periods of increased turbidity associated with flood events would also be influenced by the magnitude and frequency of the flood event, and which in turn would also influence the spatial extent of many such temporary changes in turbidity. Such changes in water quality have occurred following past floods.

Alligator weed (*Alternanthera philoxeroides*) occurs in Lake Burragorang and has in the past proliferated to an abundance that has necessitated management, such as physical removal. Existing impacts to water quality in the upstream catchment, such as land-based influences, erosion and sedimentation will remain post-construction of the Project.

Pest or exotic species of aquatic fauna are also known within the upstream catchment. Of these, the Redfin Perch (*Perca fluviatilis*) poses the biggest threat to native species, including the threatened Macquarie Perch (*Macquaria australasica*). The Redfin Perch has been previously recorded in the upper reaches of the Wollondilly River sub-catchment (DPI, 2020c).

Changes in the extent of temporary inundation in the flood mitigation zone may result in a change in the distribution of pest or nuisance aquatic species. Pest or nuisance aquatic flora have been recorded in Lake Burragorang, and these could be distributed further upstream during flood events. Redfin Perch is known in Wollondilly River and Potentially occurs in Lake Burragorang. No evidence was found during this assessment to suggest that the distribution of Redfin Perch in the upstream study area has been augmented by historical floods.

While the link between adverse water quality and increased incidence of finfish diseases remains unclear, adverse water quality can lead to stress in finfish species that may harbour viruses. Under usual environmental conditions, susceptible finfish may not exhibit clinical signs of a virus; however, adverse environmental conditions or stress may precipitate a disease in these species (Crane and Hyatt, 2011).

4.2.1.4 Geomorphic impacts

As noted previously, impacts to geomorphic processes may have direct impacts to water quality, which in turn could impact on aquatic ecology, such as increased turbidity. The assessment of water quality impacts in the EIS identified the potential for increased turbidity in the upstream study area, particularly Lake Burragorang, but noted that impacts would likely not be significant with regard to water quality. These changes to water quality would be associated with flooding events and would generally be temporary in nature. Periods of increased turbidity associated with flood events would also be influenced by the magnitude and frequency of the flood event, and which in turn would also influence the spatial extent of many such temporary changes in turbidity.

4.2.2 Potential operation-related impacts to downstream aquatic environments

Operation of the Project with a flood mitigation zone would still flood downstream environments; however, the extent of flooding relative to existing conditions would change. The operation of the Project (i.e., during a flood event) would impact water levels, lead to ecological impacts and benefits, and geomorphic impacts in downstream environments. However, these need to be viewed in the context that floods have and would continue to occur in the catchment. The operation of the project may alter some geomorphic processes, change flood inundation extents (largely reducing these), and alter flood inundation timeframes.

Based on historical flood and water supply data, it is anticipated that the flood mitigation zone would be operational very infrequently. While flood levels for various flood events have been presented, these are considered worst case scenarios and assume that the dam would be at Full Supply Level when a significant rainfall event occurs. In reality, the dam is rarely at Full Supply Level and consequently the frequency and extent of temporary inundation of the flood mitigation zone would be substantially less than that suggested by the frequency of different flood events. For example, if a 1 in 20 chance in a year event was to occur at the time of writing this report (September 2020 storage at 96.5% capacity), the existing dam would spill, or if a flood mitigation on were in operation it *would* be inundated. However, if a 1 in 20 chance in a year event were to occur at the same time in 2019 (September 2019 storage at 50% capacity), the existing dam would have been able to capture the whole flood event, or if a flood mitigation zone was in operation it *would not* be inundated.

4.2.2.1 Obstruction of fish passage

In terms of obstruction of fish passage, operation of the flood mitigation zone would not comprise or contribute to the key threatening process *Installation and operation of instream structures and other mechanisms that alter natural flow regimes of rivers and streams*. Warragamba Dam does not have a fishway and therefore, along with several weirs downstream from the dam, represents an impassable barrier to many fish species. A notable exception to this is Anguilla eels, which move into Lake Burragorang via a steep side stream that by-passes the dam wall. The existing eel passageway on the left bank would be maintained to continue to allow the migration of eels from the Warragamba River below the dam into Lake Burragorang.

Noting that the existing weirs and dams downstream of Warragamba Dam have a major effect on the distribution and abundance of fish and aquatic macroinvertebrates, and that the existing eel passageway would be maintained, the proposed upgrade is not anticipated to adversely impact obstruction to fish passage.

4.2.2.2 General ecosystem health

The Project includes the provision of infrastructure for environmental flows, or e-flows, however operation of this infrastructure does not form part of the Project, nor the assessment for this EIS. However, it is important to note that in terms of potential impacts to general ecosystem health, the e-flows regime would be designed and operated to positively support the aquatic ecosystems downstream of the dam. Procedures for e-flow releases would be developed as part of the implementation of the Metropolitan Water Plan. These would generally be designed to mimic the natural flow of the river as if the dam did not exist.

During operation of the flood mitigation zone, release of water stored in the flood mitigation zone would be controlled relative to existing flood releases to reduce the impact to downstream aquatic environments. This controlled release may not, however, be able to minimise all impacts.

The water quality assessment undertaken to inform the EIS concluded that, when required, the management of flows from the flood mitigation zone should not impact the flow and water quality benefits of the e-flow releases to be implemented for Warragamba Dam. The proposed e-flows and their impacts have been modelled in the Hawkesbury-Nepean Hydrodynamic Water Quality model, owned by the NSW Government and operated by Sydney Water. The model is endorsed by the EPA for scenario and comparison modelling. The scenario model uses a period from 1984 to 1994 as it provides a good spread of very low to flood flows across the Hawkesbury-Nepean Catchment.

All floods have the potential to affect water quality. Potential impacts that of the operation of the Project on water quality in downstream environments relate to liberation of sediments, pollutants and contaminants. How the Project will change this relative to impacts to water quality that may currently occur during flood events is difficult to quantify.

Impacts to downstream water quality from operation of the Project relate largely to the quality of the water released from the flood mitigation zone. These therefore need to be considered in the context of how inflows may change the quality of water temporarily stored within the flood mitigation zone and within Lake Burragorang prior to its release. These potential changes in water quality within the flood mitigation zone are discussed in detail in Appendix Q (Water Quality) of the EIS and discussed briefly in Section 4.2.2. In short, the operation of the flood mitigation zone may lead to temporary increases in turbidity and sedimentation, nutrients (e.g., through decay of inundated vegetation) and heavy metals (e.g., liberated from eroded sediments).

Downstream of the dam, the operational release of floodwaters stored in the flood mitigation zone may contribute to an increased risk of bank erosion in the Penrith and Windsor areas of the Nepean and Hawkesbury Rivers (see Section 4.2.1.4). This would increase turbidity and sedimentation of flood waters. Although, flood extents would be reduced, flood flows from areas not within the Lake Burragorang/Warragamba Dam catchment would remain unchanged due to the Project. Similarly, backwater flooding would continue in some of the highly modified urban creek sub-catchments, such as South Creek and Eastern Creek. These waterways drain significant portions of Greater Western Sydney suburbs including Blacktown, Rooty Hill, St Mary's and Quakers Hill and join with the Hawkesbury River near Windsor.

It is difficult to quantify the cumulative impacts that floodwater from the flood mitigation zone would have on downstream water quality. However, water quality would be impacted during a flood event which may in turn impact aquatic ecosystem health. For example, adverse changes in water quality can have a detrimental effect on macroinvertebrate assemblages, and they can also promote the onset of aquatic diseases (see Section 4.2.2.3). Changes to macroinvertebrate assemblages associated with impacts to water quality due to the operation of the Project could impact on species that rely on aquatic macroinvertebrates, such as fish. The healthiest (richness and abundance) macroinvertebrate assemblages in the downstream environment occur below Yarramundi. Flood impacts in this reach of the Hawkesbury would be considerably less than reaches upstream of Yarramundi.

4.2.2.3 Cold water stress

Cold water stress is not anticipated to be an impact from operation of the flood mitigation zone. Water stored in large dams can thermally stratify at certain times of the year, creating a warmer surface layer and colder bottom layer. For dams that operate through bottom release, this can create cold water pollution of downstream environments. Neither the current configuration of Warragamba Dam, nor the proposed upgrade allow for bottom water release under normal operations. During operation of the flood mitigation zone, water would be discharged in a controlled manner until the dam level returns to full supply level, and there would not be any reasonable or feasible measures to practically manage possible temperature differences between releases and the downstream environment.

4.2.2.4 Geomorphic impacts

Geomorphic impacts relate to flood flows that may exacerbate streambank erosion and slumping. Through operation of the flood mitigation zone, flood flows downstream would be able to be better controlled relative to the existing situation. Modelling of flood velocities indicates that Project flood waters at a given location and flow rate would comprise similar velocity distributions to existing conditions. However, due to the increased attenuation and management of flood waters associated with the Project, the exposure to peak flood velocities would be reduced, which would result in an associated reduction in flood hazard. When the flood mitigation zone is being emptied, the Project would result in an increase in the duration of sustained bank-full velocities associated with the steady release rate of 100 GL/day (see EIS Chapter 11 Flooding and Hydrology). This would not lead to any increase in impact to aquatic fauna breeding migration relative to existing conditions. Operation of the flood mitigation zone would result in a decrease in the extent of flooding downstream, including some ephemeral wetland areas. The extents of these areas are minor, and the wetlands could be supplied through natural groundwater recharge.

The geomorphology assessment (Appendix N2) concluded that during operation of the flood mitigation zone, the largest / least frequent flood events are less likely (relative to existing scenarios) to cause bank erosion. However, the intermediate / more frequent (e.g., 1 in 20 chance in a year) discharges from the flood mitigation zone may increase erosion risks. The rate of bank erosion in the Penrith and Windsor area of the Nepean and Hawkesbury Rivers may increase with the Project, and to a lesser extent on the Warragamba River. At Penrith and Warragamba, this is probably by virtue of a much more sustained period of flow associated with the flood mitigation zone release, exerting a greater degree of force on the banks. At Windsor however, the 1 in 20 chance in a year flood flows have a combination of high stream power and intermediate duration, resulting in a greater risk of bank erosion.

4.3 Summary of potential impacts on threatened species

Table 4-1 summarises the potential impact to threatened species known to occur within the study area. Assessments of significance with regard to potential impacts to Macquarie perch (and Blue Mountains perch) and Black rockcod are provided in Appendix D.

Table 4-1 Summary of potential impacts to threatened aquatic fauna

Species	Potential construction impacts	Potential operational impacts
Macquarie perch *(Macquaria australasica)*	While this species is known to occur throughout the Hawkesbury-Nepean catchment, it prefers waterways with rocky substrate and good water quality. Aquatic habitats that may potentially be impacted by construction activities do not meet these preferred habitat conditions.	There is potential for temporary indirect impacts to Macquarie Perch during operation of the flood mitigation zone. These indirect impacts relate to changes in water quality and degradation of habitat. There are likely to be areas within the flood mitigation zone that potentially support preferred habitat of the Macquarie Perch. Spawning of Macquarie Perch occurs above riffles (shallow running water), where adhesive eggs are deposited among small boulders, pebbles and gravel. It cannot be discounted that some of this type of habitat exists in the flood mitigation zone. The geomorphology assessment determined that changes in erosion and deposition in the upstream study area are unlikely to be significant, and therefore the risk of the preferred

Species	Potential construction impacts	Potential operational impacts
		habitat of the Macquarie perch (i.e., rocky substrates) being altered through sediment deposition is low. Increases in turbidity would generally be temporary in nature and associated with flood events, and therefore unlikely to contribute to a permanent reduction in quality of habitat.
Blue Mountains perch (*Macquaria sp. nov. 'Hawkesbury'*)	This species is thought be present within the study area. It is thought to be restricted to the mid-reaches of small near pristine streams, mostly commonly at elevations of 100-175 m above sea level. It occurs in complex boulder habitats, near pristine, clear streams in rugged gorges, with minimal sediment and nutrient loads, and little or no instream vegetation. Such habitat does not occur within the potential impact footprint.	It is considered unlikely that areas within the flood mitigation zone support preferred habitat of this species. The rugged gorges that this species prefers, occur in the upper reaches of streams in the upstream catchment, and below Yarramundi in the downstream catchment. As the species is thought to prefer streams with minimal sediment and nutrient loads, changes in sedimentation and turbidity would impact this species. However, such changes are not anticipated in areas where this species is likely to inhabit.
Australia grayling (*Prototroctes maraena)*	No known distribution within the study area. Construction impacts not anticipated to change existing threats.	No known distribution within the study area. Operational impacts not anticipated to change existing threats.
Black rockcod (*Epinephelus daemelii*)	None anticipated – species occurs in caves, gutters and rocky reefs in near shore environments, with juveniles potentially also occurring in estuaries. Construction study area is upstream of known habitat.	None anticipated – species occurs in caves, gutters and rocky reefs in near shore environments, with juveniles potentially also occurring in estuaries. These areas do not exist in the area of potential operational impact.
Adam's emerald dragonfly *(Archaeophya adamsi)*	Impacts to aquatic habitat that this species relies on during certain lifecycles stages not anticipated to be impacted during construction of the Project.	Impacts to aquatic habitat that this species relies on during certain lifecycles stages not anticipated to be impacted during operation of the Project. Increases in turbidity would generally be temporary in nature and associated with flood events, and therefore unlikely to contribute to a permanent reduction in quality of habitat.
Sydney hawk dragonfly *(Austrocordulia leonardi)*	Impacts to aquatic habitat that this species relies on during certain lifecycles stages not anticipated to be impacted during construction of the Project.	Impacts to aquatic habitat that this species relies on during certain lifecycles stages not anticipated to be impacted during operation of the Project. Increases in turbidity would generally be temporary in nature and associated with flood events, and

5 Conclusions

The Hawkesbury-Nepean Catchment covers an area of about 21,400 km^2 and comprises the Hawkesbury River, Nepean River, Kowmung River, Wollondilly River, Coxs River, Nattai River, Grose River, Colo River, Wingecarribee River, Kedumba River, Mulwaree River, Jooriland River, Little River and Macdonald River. These rivers are fed by numerous smaller tributaries including Kanangra Creek, Butchers Creek, Green Wattle Creek, Lacys Creek, Tonalli Creek, Brimstone Creek, Werriberri Creek, Ripple Creek, Erskine Creek, Webbs Creek, South Creek, and Cattai Creek.

The catchment upstream of Warragamba Dam is predominantly surrounded by protected areas. It is therefore not subject to the level of anthropogenic influence as the catchment downstream of Warragamba Dam, which is occupied by a variety of land uses including urban and heavy industrial. This land use influence in the downstream catchment has led to significant alterations to aquatic habitats, largely driven by habitat modification, and changes to water quality.

This difference in anthropogenic influence is somewhat reflected in the respective habitat conditions; however, because of the sheer scale of the downstream catchment, and the myriad surrounding land uses, there are many streams within the downstream catchment that display excellent habitat condition.

The potential impacts posed to aquatic habitats by the Project relate principally to changes in water quality, either directly through construction or operational activities, or indirectly through temporary inundation of vegetated areas within the flood mitigation zone, which may lead to an increase in organic and nutrient concentrations in Lake Burragorang. Potential impacts to water quality are addressed in Chapter 27 of the EIS. Some construction activities could lead to impacts to water quality which could subsequently impact aquatic ecology. The implementation of appropriate management measures as identified in Chapter 22 (Soils) and Chapter 27 (Water Quality) of the EIS would eliminate or reduce these risks.

Direct impacts to aquatic ecosystems or threatened species are not anticipated. While some construction activities would occur within aquatic habitats, the habitats in which these activities would occur are already heavily modified (due largely to the presence of the dam) and as stated above, these activities would be managed to minimise impacts to aquatic environments.

During operation of, and release of stored flood waters from the flood mitigation zone, the largest / least frequent flood events are less likely (relative to existing scenarios) to cause bank erosion. However, the intermediate / more frequent (e.g., 1 in 20 chance in a year) releases from the flood mitigation zone may cause increased erosion risks. The potential impact this may have on aquatic ecology is difficult to quantify, as the frequency of these events cannot be discerned. However, much of the material that would potentially be eroded during release of flood waters from the flood mitigation zone during the more frequent flood events, would be deposited at areas that are heavily modified such as Penrith Weir.

Threatened aquatic species present in the study area include the Macquarie perch, Adam's emerald dragonfly, and Sydney hawk dragonfly. Impacts to the Macquarie perch from construction or operation of the Project are not anticipated largely because this species likes secluded streams, with complex in-stream habitats, which are not generally present in the new PMF zone. There is potential for impacts to the two dragonfly species associated with temporary inundation when the species are in their larval stages.

6 References

Allen, GR, Midgely, SH and Allen, M (2002), *Field Guide to Freshwater Fishes of Australia*. Perth, Western Australia Museum.

Alluvium Consulting Australia (2017) 2016 Audit of the Sydney Drinking Water Catchment. Volume 2 – the indicators. Report prepared for Sydney Catchment Authority.

ANZECC (2000). Core Environmental Indicators for Reporting on the State of the Environment, Australian and New Zealand Environment and Conservation Council.

ANZECC & ARMCANZ (1994), *National Water Quality Management Strategy*. Canberra, Australian and New Zealand Environment and Conservation Council, and Agriculture and Resource Management Council of Australia and New Zealand.

ANZECC & ARMCANZ (2000). *Australian and New Zealand Guidelines for Fresh and Marine Water Quality*. Canberra, Australian and New Zealand Environment and Conservation Council, and Agriculture and Resource Management Council of Australia and New Zealand.

Bishop, K, Growns, I, Church, T, Warner, R and Taylor, E (2002), *Status of the Health of the Hawkesbury-Nepean River*. Independent Expert Panel on Environmental Flows. Prepared for Hawkesbury-Nepean, Shoalhaven and Woronora Catchments.

BMT WBM (2014), *Upper Hawkesbury River Bank Erosion, Foreshore Structure and Weed Mapping*. Prepared for Hawkesbury City Council.

BoM (2017), *Sydney: Geographic information*. Bureau of Meteorology: http://www.bom.gov.au/water/nwa/ 2016/sydney/regiondescription/geographicinformation.shtml.

Bray, D.J. (2020) *Macquaria sp. nov. 'Hawkesbury'* in Fishes of Australia, accessed 15 Oct 2020 https://fishesofaustralia.net.au/Home/species/5544#summary

Brizga, S and Finlayson, B (eds.) (2000), *River Management: The Australasian Experience*. Chichester, United Kingdom: John Wiley Ltd.

Bruce, A, Knight, J and Creese, B, (2007), *Survey of aquatic threatened species Macquarie perch (Macquaria australasica) and Adam's emerald dragonfly (Archaeophya adamsi) within the Hawkesbury-Nepean catchment*. Interim report to the Hawkesbury-Nepean Catchment Management Authority by the Department of Industry and Investment, Port Stephens Fisheries Centre.

Carpenter, S. and Lodge, D (1986), Effects of submersed macrophytes on ecosystem processes. *Aquatic Botany* 26: 341-370.

Chessman, B.B and Williams, S.A. (1999), *Biodiversity and conservation of river macroinvertebrates on an expanding urban fringe: western Sydney, New South Wales, Australia.* Pacific Conservation Biology, 1999, 5(1) pg36

Church, T. (2002), *Temperature Suppression in the Lower Hawkesbury River*, prepared for the Hawkesbury-Nepean River Management Forum.

Crane, M. and Hyatt A. (2011) Viruses of fish: An overview of significant pathogens. Viruses, 3(11): 2025 – 2046.

Creese, RG, Glasby, TM, West, G and Gallen, C (2009), *Mapping the habitats of NSW estuaries*. Report to Hunter Central Rivers Catchment Management Authority.

Department of the Environment and Energy (2018) *National Recovery Plan for Macquarie Perch (Macquaria australasica)*, DoEE, Canberra.

Cowardin LM, Carter V, Golet FC, LaRoe ET (1979) Classification of Wetlands and Deepwater habitats of the United States. US Department of the Interior, Fish and Wildlife Service.

DAWR (2017) Australian aquatic veterinary emergency plan (AQUAVETPLAN): Viral encephalopathy and retinopathy. Australian Government, Department of Agriculture and Water Resources.

DECCW (2010), *State of the Catchments 2010: Hawkesbury-Nepean Region – Overview*. Sydney, Department of Environment, Climate Change and Water.

DPI (2006), *Reducing the impact of road crossing on aquatic habitat in coastal waterways – Hawkesbury-Nepean*. Report to NSW Environmental Trust, Department of Primary Industries.

DPI (2007), *Sydney Hawk Dragonfly: Austrocordulia leonardi*. Port Stephens, Department of Primary Industries, Threatened Species Unit.

DPI (2013), *Adam's Emerald Dragonfly – Archaeophya adamsi*. Port Stephens, Department of Primary Industries, Fisheries Ecosystems Unit.

DPI (2014), *Warragamba Environmental Flows Baseline Reports: Geomorphology Report*. Sydney, Department of Primary Industries, Office of Water.

DPI (2016) Fish communities and threatened species distributions of NSW. NSW Department of Primary Industries.

DPI (2020a) Epizootic Haematopoietic Necrosis Virus (EHNV). NSW Department of Primary Industries. https://www.dpi.nsw.gov.au/fishing/aquatic/aquatic-biosecurity/recreational-waterway-users/wildfish-shellfish/ehnv

DPI (2020b) NSW Aquatic Pest and Disease Distribution. NSW Department of Primary Industries. https://www.dpi.nsw.gov.au/biosecurity/aquatic/pest-disease-distribution

DPI (2020c) Redfin perch. NSW Department of Primary Industries. https://www.dpi.nsw.gov.au/fishing/aquatic/freshwater-pests/finfish-species/redfin-perch

DoEE (2018), *Directory of Important Wetlands in Australia – Information sheet: Boyd Plateau Bogs – NSW074*. Canberra, Department of the Environment and Energy.

DoEE (2019), *National Recovery Plan for Macquarie Perch (Macquaria australasica)*. Canberra, Department of the Environment and Energy.

DECC (2009a), *NSW Diffuse Source Water Pollution Strategy*. Sydney, Department of Environment and Climate Change.

DECC (2009b), *Hawkesbury-Nepean River Environmental Monitoring Program: Final Technical Report*. Sydney, Department of Environment and Climate Change.

DECCW (2010a), *Lower Hawkesbury-Nepean River Nutrient Management Strategy*. Sydney, Department of Environment, Climate Change and Water.

DECCW (2010b), *NSW Diffuse Source Water Pollution Strategy: 2010 Annual Report*. Sydney, Department of Environment, Climate Change and Water.

DECCW (2010c), *State of the catchments 2010: Wetlands Hawkesbury-Nepean Region*. Sydney, Department of Environment, Climate Change and Water.

DPI (2017), *Hawkesbury-Nepean catchment*. Department of Primary Industry

DPI (2006), *Reducing the Impact of Weirs on Aquatic Habitat – New South Wales Detailed Weir Review Sydney Metropolitan CMA Region*. Report to the NSW Environmental Trust, Department of Primary Industries.

DPI (2014), *Warragamba Environmental Flows* | *Baseline Reports:*

Report 2: *Hydrology*

Report 4: *Water Quality*

Report 5: *Algae*

Report 6: *Zooplankton*

Report 7: *Aquatic Macrophytes*

Report 8: *Macroinvertebrates*

Report 9: *Freshwater Fish*

Report 10: *Other River Dependent Fauna*

Report 11: *Hawkesbury Estuary*

DSEWPaC (2011). *Draft referral guidelines for the endangered Macquarie perch, Macquaria australasica*. Canberra, Department of Sustainability, Environment, Water, Population and Communities.

Duncan, M, Robinson, W and Doyle, J (2016), *Improved fish passage along the Nepean River as a result of retrofitting weirs with vertical-slot fishways*. Fisheries Final Report Series No. 152, prepared for Department of Primary Industries.

Ecowise Environmental (2008), *Assessment of Risk of Spread for Strategic Management of the Core Alligator Weed Infestations in Australia – Taking Stock*. Prepared for Department of Agriculture, Fisheries and Forestry.

ERM Mitchell McCotter (1995), *Proposed Warragamba Flood Mitigation Dam Environmental Impact Statement*. Prepared for Sydney Water Ltd.

Erskine, WD and Green, D (2000), Geomorphic effects of extractive industries and their implications for river management - the case of the Hawkesbury–Nepean River, New South Wales. In SO Brizga & BL Finlayson (eds)*, River management - the Australasian experience*, Chichester, John Wiley Ltd.

GHD (2013), *Hawkesbury-Nepean CMA Report for River Styles Assessment.*

Gruber, R, Ferguson, A and Haine, B (2010), *Final Report. Nutrient Transformation and Attenuation within Tidal Rivers*. Research Project 2007/RD/0018 (July 2008 – July 2010), prepared for Department of Environment Climate Change and Water.

HNCMA (2008), *Hawkesbury-Nepean Catchment Action Plan 2007-2016*. Goulbourn, Hawkesbury-Nepean Catchment Management Authority.

INSW (2016), *Hawkesbury-Nepean Flood Risk Management Strategy*. Sydney, Infrastructure New South Wales.

James, L, Watson, D and Hansen W (2006*), Using LiDAR data to map gullies and headwater streams under forest canopy: South Carolina, USA*.

Kimmerikong (2005), *Scoping Study Hawkesbury-Nepean River Estuary Management Final Report*.

Knight JT (2010) The feasibility of excluding alien redfin perch from Macquarie perch habitat in the Hawkesbury-Nepean catchment. Report prepared for the Hawkesbury-Nepean Catchment Authority.

Krogh. M, Wright, A and Miller J (2009), *Hawkesbury-Nepean River Environmental Monitoring Program*. Prepared for NSW Department of Environment and Climate Change.

Kuruppu, U. (2016), *Water quality assessment in the Hawkesbury-Nepean River System, New South Wales*. Sydney.

Lincoln Smith, M 2003, *Aquatic Ecology in Environmental Impact Assessment*, EIA Guideline Series, Department of Planning, Sydney.

Manly Hydraulics Laboratory (2006), *Survey of Tidal Limits and Mangrove Limits in NSW Estuaries 1996 to 2005*. Report No. MHL 1286/Commerce Report No. 03081, prepared for Department of Natural Resources.

Mawhinney WA (2003), Restoring biodiversity in the Gwydir Wetlands through environmental flows. *Water Science & Technology* 48, 73-81.

McDowell, R (ed) (1996). *Freshwater Fishes of South-Eastern Australia*. Chatswood, Reed Books.

Muzirwa, R, Haque, MM, Rahman, A and Tomlinson, D (2015), *An exploratory water quality analysis of the Hawkesbury-Nepean River catchment*. 21st International Congress on Modelling and Simulation, Gold Coast.

NPWS (2015), *Burragorang State Conservation Area*. National Parks and Wildlife Service, available: http://www.environment.nsw.gov.au/nationalparks/parkHome.aspx?id=N0624.

NSW Public Works (2014), *Hawkesbury-Nepean Valley Flood Management Taskforce Project 1.1: Preliminary Identification of Natural and Heritage Impacts of Operating Warragamba Dam for Flood Mitigation*. Sydney, NSW Public Works.

OEH (2015), *Wild Rivers*. Office of Environment and Heritage

OEH (2013), *National Water Quality Management Strategy*. Sydney, Office of Environment and Heritage.

OIE (2016) 2016b, Chapter 2.3.12. Viral encephalopathy and retinopathy, in OIE Manual of Diagnostic Tests for Aquatic Animals, World Organisation for Animal Health (OIE), France.

Rae DJ (2007), *Water Management in South Creek Catchment: Current state, issues and challenges*. Available: https://www.irrigationaustralia.com.au/documents/item/234.

Reynoldson TB, Norris RH, Resh VH, Day KE, Rosenberg DM (1997) The reference condition: a comparison of multimetric and multivariate approaches to assess water-quality impairment using benthic macroinvertebrates. Journal of the North American Benthological Society, 16: 833-852.

Roberts D, Church AG and Cummins, SP (1999), Invasion of Egeria into the Hawkesbury-Nepean River, Australia, *Journal of Aquatic Plant Management* 37(1).

Room, P. and Gill, J (1985). The chemical environment of Salvinia molesta Mitchell: Ionic concentrations of infested waters. *Aquatic Botany* 23(2): 127-135.

Sammut, J and Erskine, WD (1995), Hydrological impacts of flow regulation associated with the Upper Nepean Water Supply Scheme, NSW. *The Australian Geographer 26.1*: 71-86.

Smith, P and J Smith 1996, *Hawkesbury-Nepean : significant wetlands of the Hawkesbury-Nepean River Valley*, prepared by P & J Smith Ecological Consultants for the NSW Department of Urban Affairs and Planning, Sydney.

Sydney Water (2015), *2014 Sewage Treatment System Impact Monitoring Program Interpretive Report*. Available: https://www.sydneywater.com.au/web/groups/publicwebcontent/documents/document/zgrf/mdc4/~edisp/dd_078228.pdf.

Taylor-Wood, E and Warner, R (2003), *Regionally significant wetlands and environmental flows*. Report to the Hawkesbury-Nepean River Management Forum.

Tonkins, Z, Kearns, J, O'Mahony, J and Mahoney, J (2016), Spatio-temporal spawning patterns of two riverine populations of the threatened Macquarie perch (*Macquaria australasica*). *Marine and Freshwater Research* 67(11):1762-1770.

Warner, RF (1995), Predicting and managing channel change in southeast Australia. *Catena 25.1*: 403-418.

Warner, R (2002a), *Fluvial Geomorphology Background Information*. Independent Expert Panel On Environmental Flows For The Hawkesbury-Nepean, Shoalhaven And Woronora Catchments, March 2002.

Warner, R (2002b), *Hawkesbury-Nepean River Reaches Geomorphology and Human Impacts*. Hawkesbury-Nepean River Management Forum, June 2002.

Warner, R (2002c), *A Preliminary Analysis of Reports and other Literature concerned with the Compensation Weirs, Nepean River NSW.* Hawkesbury-Nepean River Management Forum, November 2002.

Warner, RF (2014), Environmental flows in two highly regulated rivers: the Hawkesbury-Nepean in Australia and the Durance in France. *Water and Environment Journal* 28: 365-381.

Watene EM, Boubee JAT (2005), Selective opening of hydroelectric dam spillway gates for downstream migrant eels in New Zealand. *Fisheries Management and Ecology* 12, 69-75.

WaterNSW, 2015. *Hawkesbury-Nepean Valley Flood Management Taskforce Managing a Flood Mitigation Zone at Warragamba Dam Project 6.2 (2) Flood Mitigation Dam Operations*. Sydney, WaterNSW.

WaterNSW (2017a), *Warragamba Catchment*. WaterNSW, available: http://www.waternsw.com.au/water-quality/catchment/sub-catchment/warragamba.

WaterNSW (2016a), *Water Supply System Schematic*. WaterNSW

WaterNSW (2016b), *Annual Water Quality Monitoring Report Sydney Catchment Area 2015-16*. WaterNSW, available: http://www.waternsw.com.au/__data/assets/pdf_file/0009/123948/Annual-Water-Quality-Monitoring-Report-15-16.pdf.

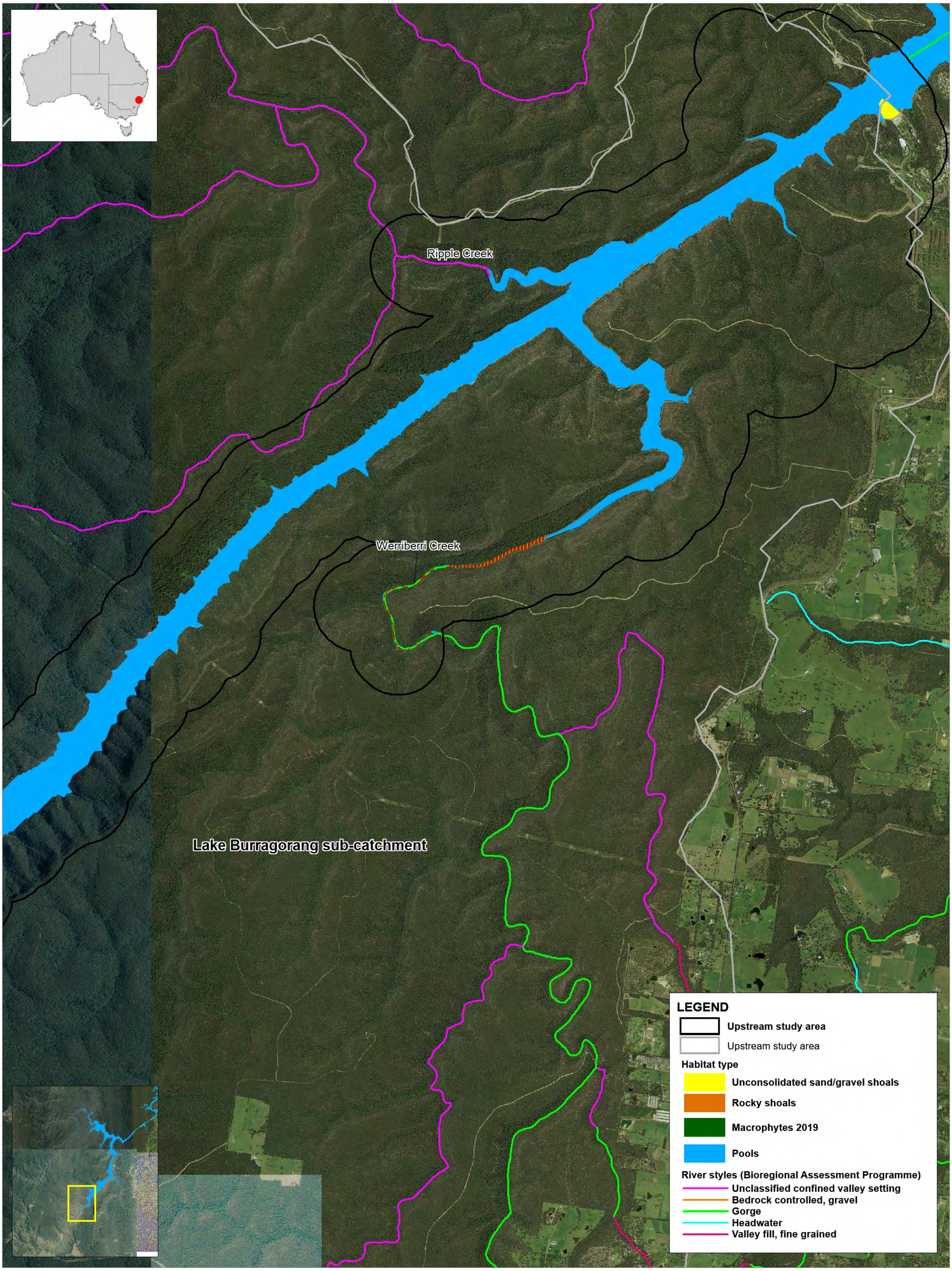
WaterNSW (2018) Eel Monitoring Program, Warragamba Dam Raising Project.

Wilkinson, S, Wallbrink, P, Shakesby, R, Blake, W and Doerr, S (2014), *Impacts on water quality by sediments and nutrients released during extreme bushfires: Summary of findings*. Prepared for Sydney Catchment Authority.

WMA Water (2013), *Hawkesbury-Nepean Flood Study Report.*

Young, WJ, Brock, MA, Chessman, BC, Gehrke, PC, Maher, WA, Marr, A, Olley, JM and Warner, RF (2000), *Assessment of river condition under the current flow regime and proposed flow regimes in the lower Coxs River, New South Wales*. Prepared for Department of Land and Water Conservation, CSIRO Land and Water.

Appendix A Aquatic habitat assessment



Title:

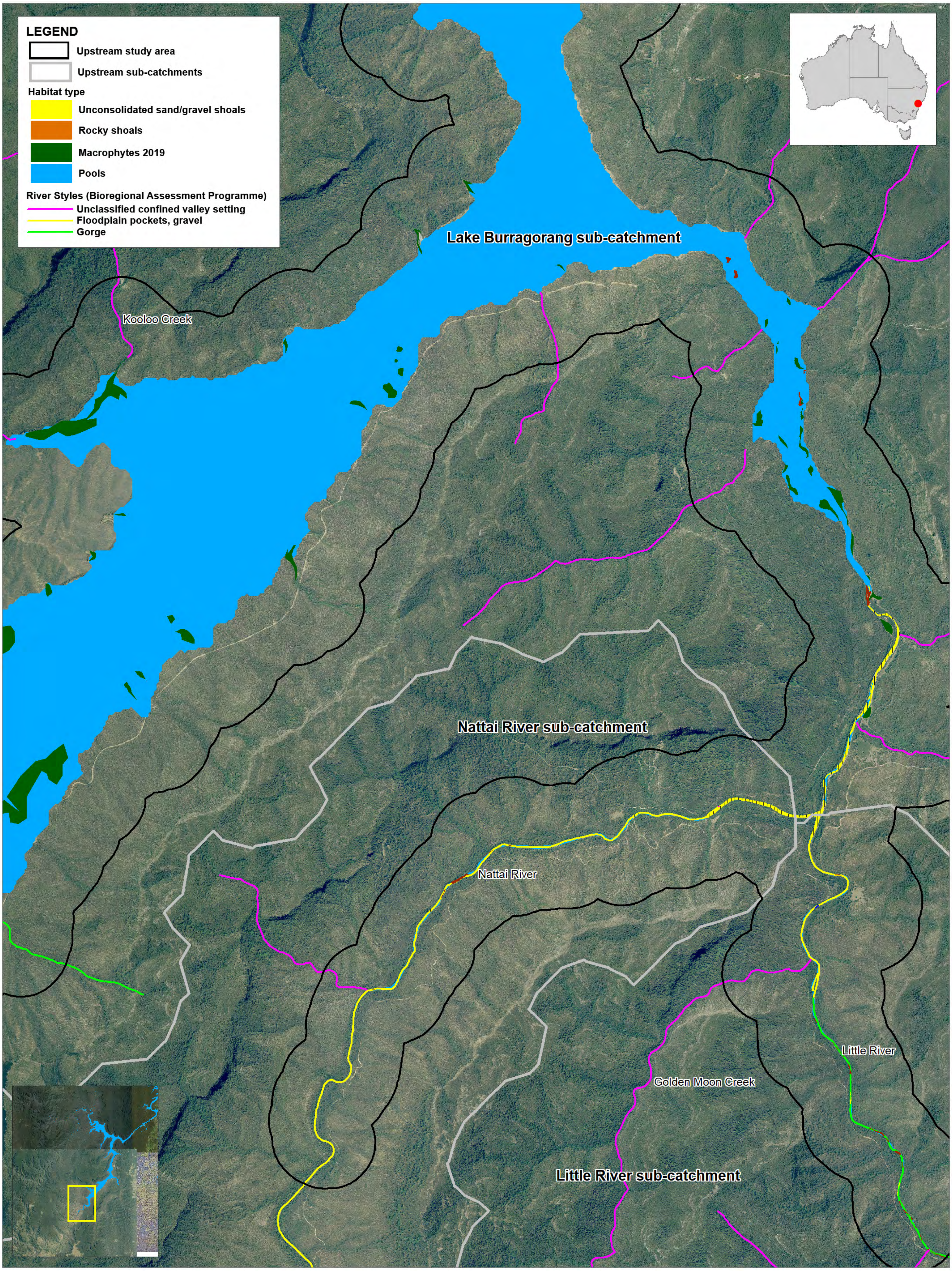
Aquatic habitat map for the study area, including River Styles mapping from GHD (2013)

Figure: A-1

Rev: A

BMT
www.bmt.org

Filepath: I:\N20854_I_BH_Warragamba Dam\DRG\ECO_005_DamWall.wor



Title:

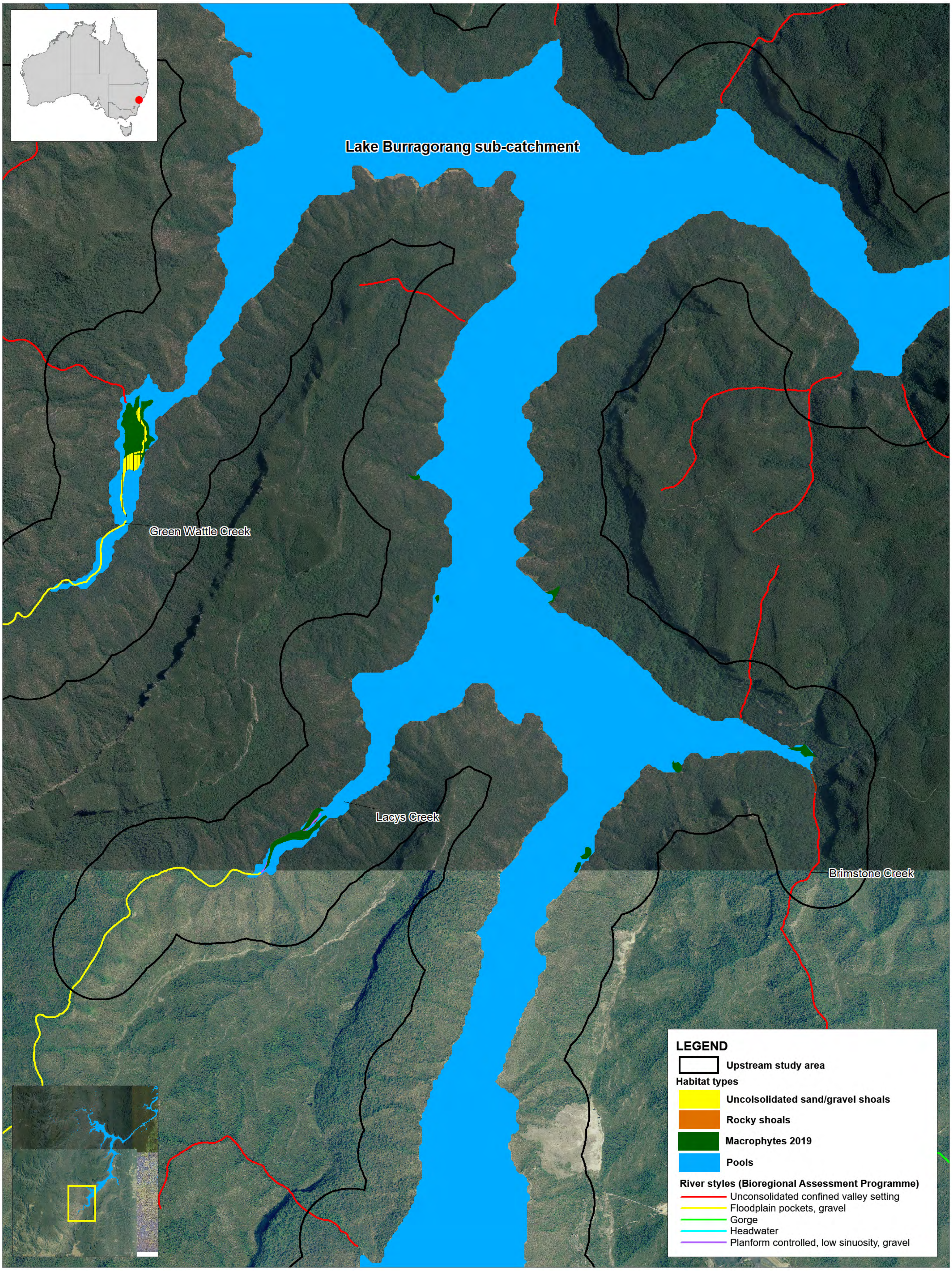
Aquatic habitat map for the study area, including River Styles mapping from GHD (2013)

Figure: A-2

Rev: A

BMT
www.bmt.org

Filepath: I:\N20854_I_BH_Warragamba Dam\DRG\ECO_005_DamUpper.wor



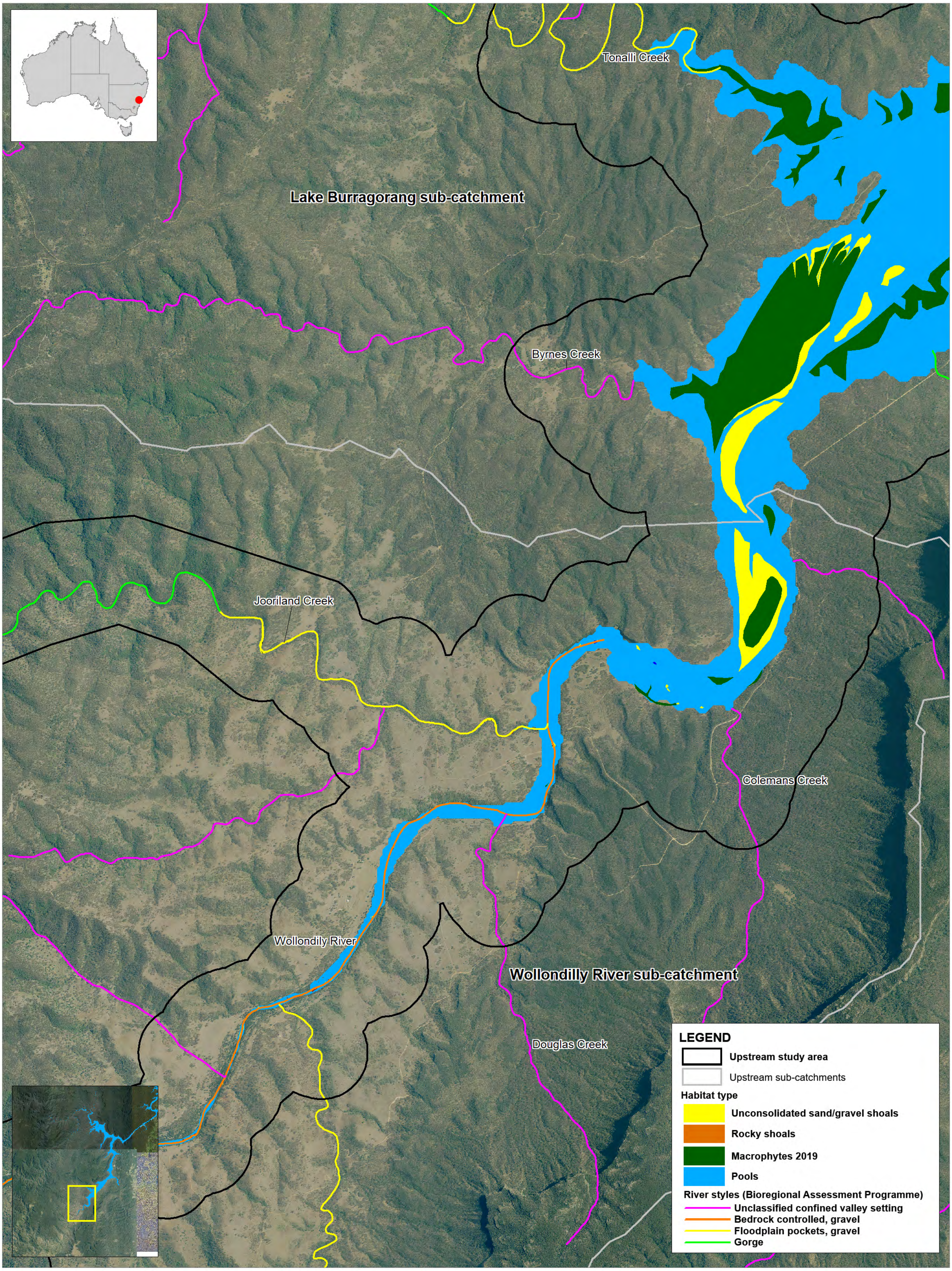
Title:
Aquatic habitat map for the study area, including River Styles mapping from GHD (2013)

Figure: **A-3**

Rev: **A**

BMT
www.bmt.org

Filepath: I:\N20854_I_BH_Warragamba Dam\DRG\ECO_005_DamWall.wor



Title:

Aquatic habitat map for the study area, including River Styles mapping from GHD (2013)

Figure: A-4

Rev: A

N

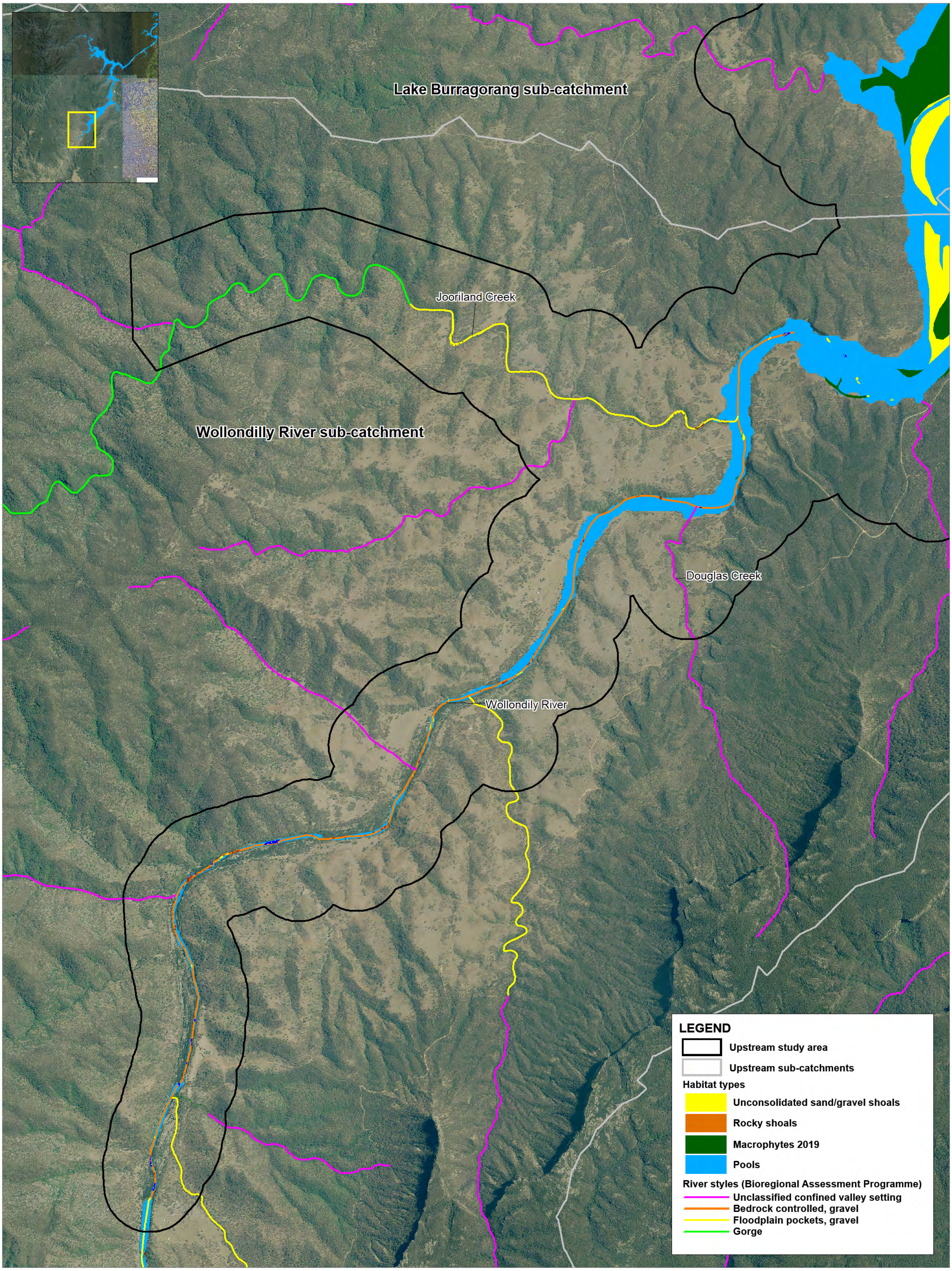
0 0.75 1.5

kilometres

BMT

www.bmt.org

Filepath: I:\N20854_I_BH_Warragamba Dam\DRG\ECO_005_DamSouthWest.wor



Title:

Aquatic habitat map for the study area, including River Styles mapping from GHD (2013)

Figure: A-5

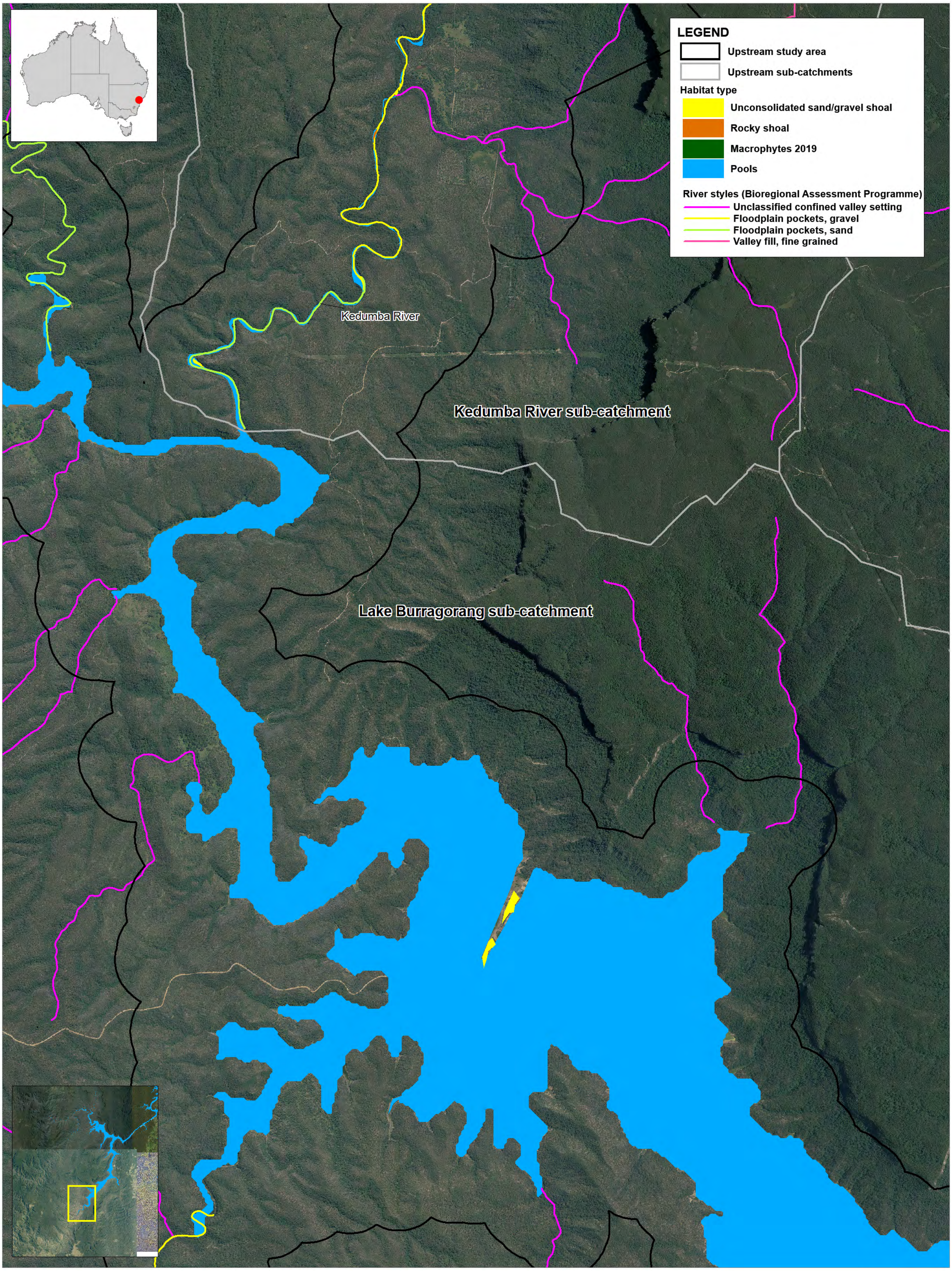
Rev: A

N

0 0.75 1.5
kilometres

BMT
www.bmt.org

Filepath: I:\N20854_I_BH_Warragamba Dam\DRG\ECO_009_DamSouthWestUpper.wor



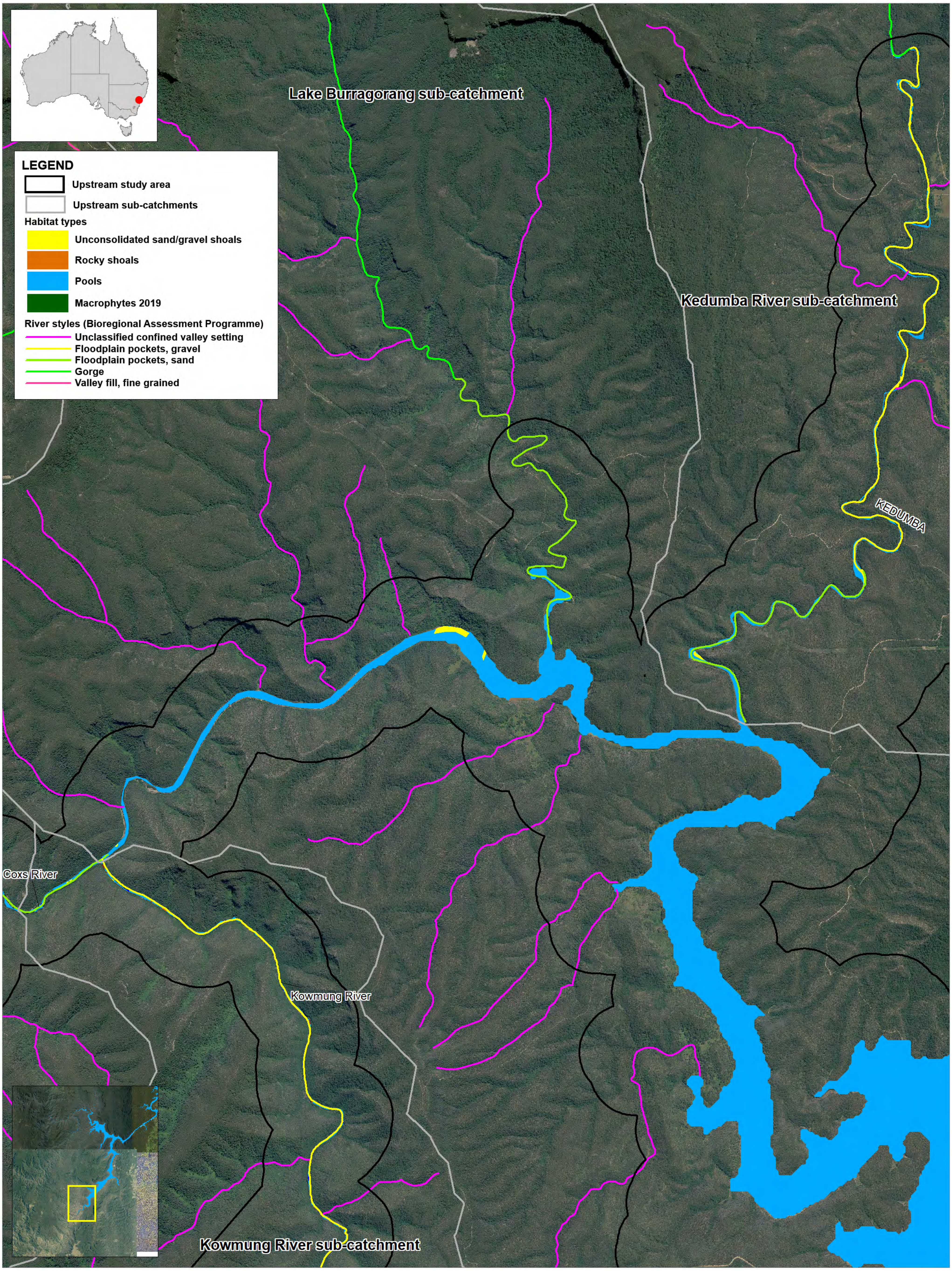
Title:

Aquatic habitat map for the study area, including River Styles mapping from GHD (2013)

Figure: **A-6**

Rev: **A**

Filepath: I:\N20854_I_BH_Warragamba Dam\DRG\ECO_0010_NorthWest.wor



Title:

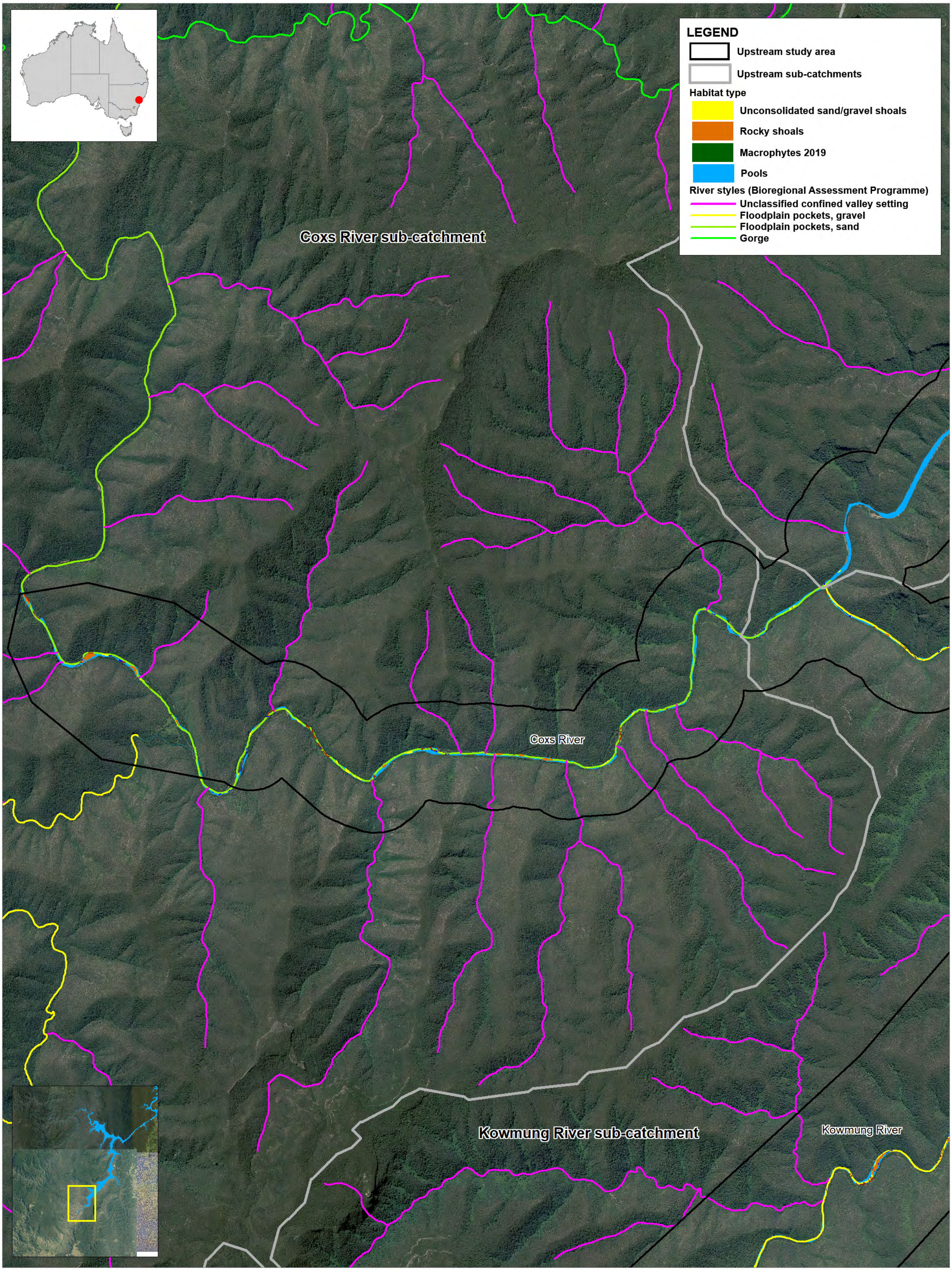
Aquatic habitat map for the study area, including River Styles mapping from GHD (2013)

Figure: A-7

Rev: A

BMT
www.bmt.org

Filepath: I:\N20854_I_BH_Warragamba Dam\DRG\ECO_0011_NorthWestUpper.wor



Title:

Aquatic habitat map for the study area, including River Styles mapping from GHD (2013)

Figure: A-8

Rev: A

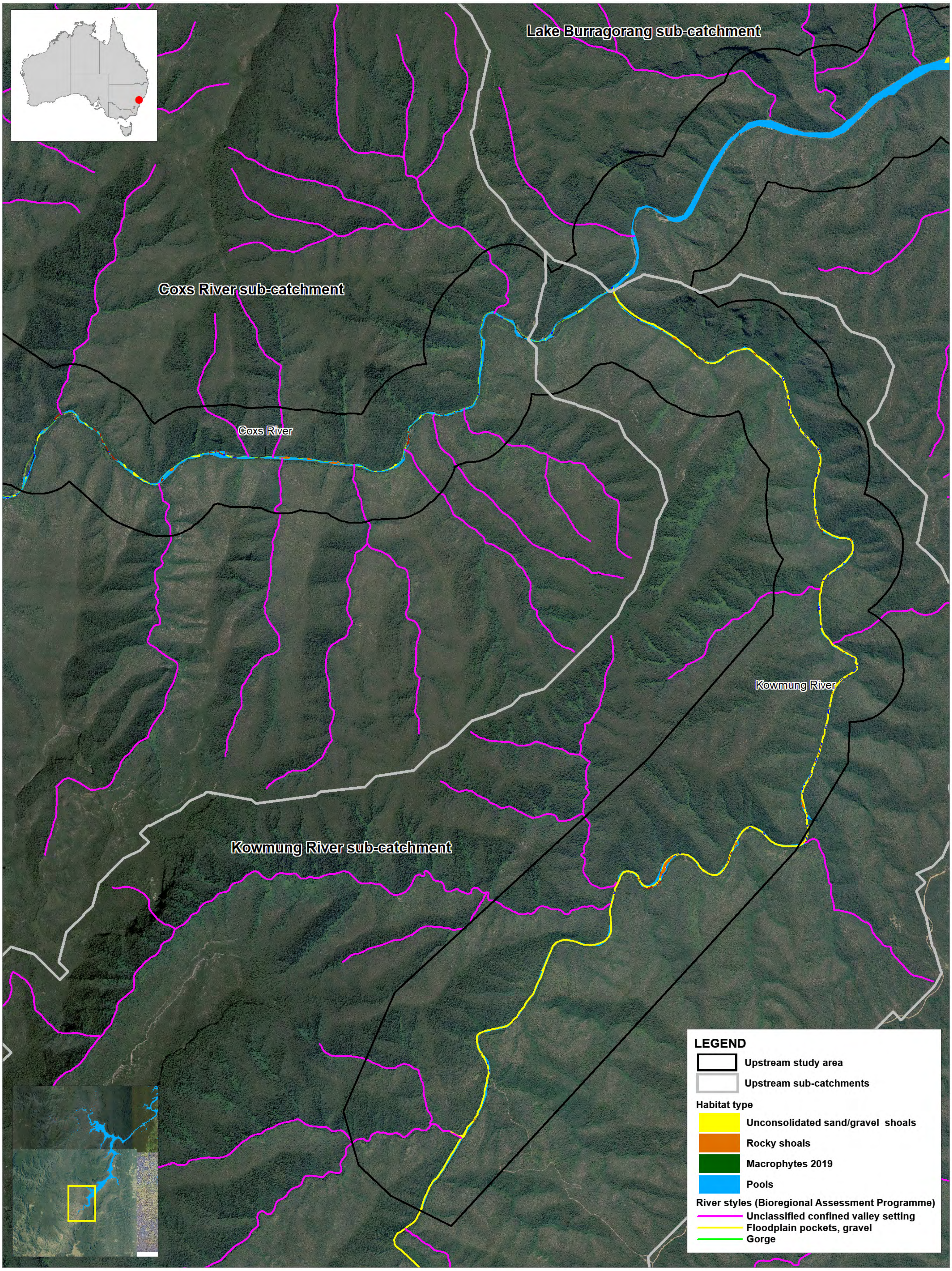
BMT endeavours to ensure that the information provided in this map is correct at the time of publication. BMT does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.

N

0 0.75 1.5 kilometres

BMT
www.bmt.org

Filepath: I:\N20854_I_BH_Warragamba Dam\DRG\ECO_0012_DamWest.wor



Title:

Aquatic habitat map for the study area, including River Styles mapping from GHD (2013)

Figure: A-9

Rev: A

BMT
www.bmt.org

Filepath: I:\N20854_I_BH_Warragamba Dam\DRG\ECO_0013_DamWest2.wor

Warragamba Dam Habitat Assessment

1 Introduction

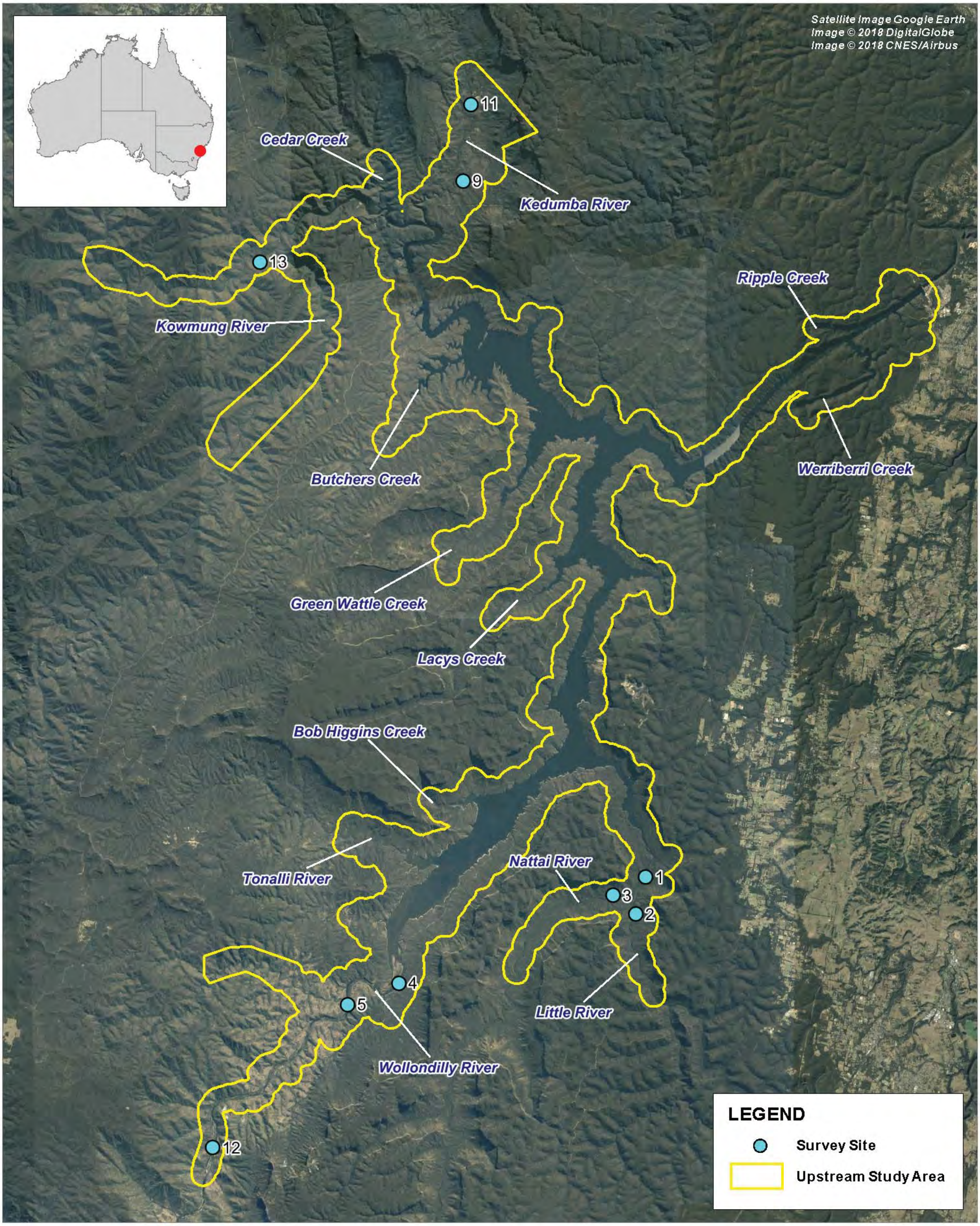
An aquatic habitat assessment was conducted to characterise the general habitat condition within the upstream reaches of Warragamba Dam. It also served to determine the appropriateness for Macquarie perch habitat at each location. The preferred habitat for Macquarie perch includes clear, cool, rocky fast-flowing streams with deep holes and riffles.

2 Methodology

An aquatic habitat assessment was conducted at nine sites between 5 and 8 December 2017 (inclusive). Survey sites are shown in Figure 2-1. Two sites were surveyed on the Nattai River, one on the Little River, three on the Wollondilly River, two on the Kedumba River and one on the Coxs River. The following parameters were assessed at each location:

- Approximate water depth
- Stream flow
- Wetted stream width and length
- Water clarity
- Sediment and water odour
- Mesohabitat structures (e.g. pool, riffle, run)
- Bank conditions (e.g. undercutting, slope, erosion, overhanging roots)
- Substrate composition (e.g. mud, sand, fine gravel, coarse gravel, cobble, rock, bedrock)
- Composition and abundance of macrophyte species (e.g. floating, emergent, submerged)
- Riparian and in-stream vegetation
- Filamentous algae
- Leaf litter
- Presence of small (less than 15 cm diameter) and large woody debris (more than 15 cm diameter)
- Animal activity (e.g. footprints, droppings) and
- Human activity (e.g. bridges, farms, weirs).

Photographs were also taken at each site.



Title:

Habitat assessment – survey sites

Figure: 2-1

Rev: A

BMT endeavours to ensure that the information provided in this map is correct at the time of publication. BMT does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.

N

0 4 8km

Approx. Scale

BMT

www.bmt.org

Filepath: \\BMT-BNE-FS01\drafting\N20854_I_BH_Warragamba Dam\DRG\ECO_002_sampling_sites.wor

3 Results

3.1 Site 1 – Nattai River (downstream)

Site 1 was located on the Nattai River (Figure 3-1). It covered a stream length of approximately 200 m, 100 m upstream and 100 m of the bridge on Sheehys Creek Road. Site 1 was characterised by an open, slow moving pool habitat, with no riffle habitat and a high amount of woody debris. There was minimal flow present during the survey, which had an average wetted stream width of approximately 50 m.

The channel was dominated by sandy substrates with some large cobbles on the edge of the river. The water had moderate clarity, which, when disturbed resulted in a sediment plume forming. There was no odour from the water or sediment. While the upper banks of the site had edges fringed with large trees, there was no in-stream canopy cover. There were some sparse submerged macrophytes and one isolated area of floating pond weed. There were no algae recorded within the site.

Animal activity was observed at the site. Some fish activity was observed from the banks, including two 30 cm fish, identified as likely to be carp. Bird footprints were also recorded on the banks.

The section downstream of the bridge had a high amount of woody debris, with dead trees in stream and on the bank. The downstream left bank had a steep bank, while the downstream right bank was less steep with some erosion and undercutting within the upper bank.

The section upstream of the bridge was notably shallower than the downstream section. The downstream had gentle banks, with less erosion, than the banks downstream of the bridge. These banks had trees that has been cut down.

It is unlikely that the Macquarie perch would occur at this site due to unsuitable habitat.

Figure 3-1 Site 1 – Nattai River photographs. Looking downstream (A); bioturbation holes on bank, with some emergent macrophytes (B); looking upstream at the bridge (C); floating pondweed (D); dead trees downstream (E); accumulated woody debris under the bridge (F); cut trees looking downstream, upstream of the bridge (G); woody debris on banks (H).

3.2 Site 3 – Nattai River (upstream)

Site 1 was the furthest upstream site on the Nattai River (Figure 3-2). The site was characterised by variable pool and riffle habitat, with a variable wetted stream width between 3 to 20 m. The upstream section of the site was mostly shallow pool habitats with estimated maximum depths of 1 m. The riffle habitat covered the downstream section, which saw the channel become shallow, rocky, narrowed to 3 m and fringed with terrestrial vegetation.

In the pool habitat, the sediment was dominated by coarse sand with scattered large boulders, while gravel and cobble sized rocks was the main substrate type within the riffle zone. There was low flow in the pool habitat and moderate flow in the riffle habitat. The water was very clear within the riffle habitat, while the deeper pools were slightly stagnant and had poorer water clarity. However, there was no sediment or water odours at the site.

Erosion of the banks was evident from the pushed over trees and woody debris mixed with trees on the edges. There was minimal woody debris within the channel. There was moderate leaf litter on bank edges. Riparian vegetation tree canopy shade was restricted to bank edges in the pool sections, while in the downstream riffle area, the narrow channel had almost entire canopy shade coverage. The banks had moderate coverage of Lomandra and other grass species. Within the riffle zone, green filamentous algae were attached to rocks. There was some animal activity, including birds and some terrestrial animal footprints.

It is possible that the Macquarie perch would occur at this site due to some suitable habitat.

Figure 3-2 Site 3 – Nattai River photographs. Looking upstream (A); pool habitat with sandy substrate (B); riffle habitat with rocky substrate (C); riffle habitat (D); green filamentous algae and aquatic macrophytes growing on rocky and sandy substrate within riffle zone (E); fallen trees and woody debris on downstream right bank (F); woody debris on bank (G); upstream pool habitat (H).

3.3 Site 2 – Little River

Site 2 was located on Little River (Figure 3-3). The average wetted stream width varied between 10 to 15 m. Site 2 was characterised by a shallow stretch of river with minimal to no flow. There was no riffle habitat but would likely be present during periods of higher flow. The dominant instream habitat was pool habitat, with estimated depths of up to 1.5 to 2 m within the deepest holes.

The channel was composed of a sandy substrate, with a high coverage of leaf litter. There was also a high amount of submerged and exposed gravel, cobbles and boulders. Both banks, as well as in-stream, had a high amount of woody debris composed of dead trees and branches, which provided reasonably good habitat for fish.

The banks were moderately steep. The downstream right bank was eroded, with undercut banks with *Casuarina sp.* root mat. The downstream left mat also had some erosion. The site had minimal emergent macrophytes and no algae was present. There were no sediment or water odours. Low canopy coverage, with greater tree cover on the downstream left bank.

It is unlikely that the Macquarie perch would occur at this site due to unsuitable habitat.

Figure 3-3 Site 2 – Little River photographs. Upstream pool habitat (A); fallen trees on right bank (B); downstream pool habitat (C); fallen trees on right bank (D); woody debris on bank (E); rocky substrate with woody debris (F); woody debris on bank (G); in-stream woody debris (H).

3.4 Site 12 – Wollondilly River (upstream)

Site 12 was the furthest upstream site on the Wollondilly River (Figure 3-4). There was an organic farm adjacent to the site. This site was characterised by riffle and pool habitat with low to moderate flow. The river had an average width of 30 m, with an average depth of approximately 40 cm, with depths in pools up to approximately 1 m.

The substrate in channel was composed entirely of a rocky bottom, with no sands or silts. The channel was fringed with *Casuarina sp.* trees, with some small in-stream trees growing on rocks instream, providing some in-stream shading. The in-stream habitat consisted of the rocky substrates and trees. On the banks, there was some silty sediments and a low amount of organic matter, including leaf litter. The water clarity was very clear, with no sediment or water odours recorded. There was a low amount of filamentous green algae attached on the rocks within the channel. There was some fish activity present and high bird activity.

Within the channel and lower banks there was limited debris, however there were large dead trees and debris on the floodplain beyond banks. There was a small amount of bank erosion, mostly on the downstream left bank which had some undercut banks and root mats.

It is possible that the Macquarie perch would occur at this site due to some suitable habitat.

Figure 3-4 Site 12 – Wollondilly River photographs. Run habitat upstream (A); *Casuarina sp*. lined left bank (B); *Casuarina sp.* growing on rocks in-stream (C); root mat, rocks and trees on bank (D); slight riffle area downstream (E); close up of green filamentous algae and aquatic macrophytes growing on rocky substrate within riffle zone (F); woody debris on bank (G); trees and grass on upper bank (H).

3.5 Site 5 – Wollondilly River (mid-stream)

Site 5 was the mid-stream site along the Wollondilly River (Figure 3-5). A river crossing at W4g Trail was at the upstream section of this site. Upstream of the river crossing, there was a slow- moving channel, approximately 100 m wide. Downstream of the crossing, the site was dominated by exposed small to medium rock cobbles creating riffle habitat. The riffle section had a stream width of approximately 50 m and was approximately 100 m in length. The banks of both sides were relatively flat and gentle.

The banks were lined with large trees on banks but limited shade over water. The in-stream habitat was dominated by rocky substrate, *Casuarina sp.* trees growing on rocks and a low to moderate amount of small to large woody debris.

There was a medium to high amount of submerged green filamentous algae, and a moderate amount of emergent macrophytes including water primrose (*Ludwigia sp.*), smart weed (*Persicaria sp.*) sedges and other plants on banks.

It is possible that the Macquarie perch would occur at this site due to some suitable habitat.

Figure 3-5 Site 5 – Wollondilly River photographs. Run habitat facing upstream (A); woody debris on bank (B); riffle area downstream of river crossing (C); riffle area downstream (D); macrophytes growing on rocky banks (E); *Casuarina sp.* growing between rocks in-stream (F); water primrose (*Ludwigia sp.*) growing between rocks (G); green filamentous algae growing on rocks within riffle habitat (H).

3.6 Site 4 – Wollondilly River (downstream)

Site 4 was the most downstream survey site along the Wollondilly River (Figure 3-6). This site was characterised by a slow flowing river, with no riffle habitat. There were dead trees throughout the channel.

The substrate was dominated by medium grained sand with some small gravel rocks. There was a high amount of dead trees and woody debris within the channel and on the banks. The water had moderate clarity, with a green- brown tinge, however there were no water or sediment odours. There was minimal erosion on the banks.

The dead trees provided a limited amount of in-stream shade, while the alive riparian vegetation, including *Casuarina sp*., provided very low shade within the channel. There were no algae or macrophytes within the channel, but some grass and other plants on the upper banks. There was some animal activity, including a freshwater turtle, water dragon and fish observed at the site.

It is very unlikely that the Macquarie perch would be found at this site, due to the lack of suitable habitat.

Figure 3-6 Site 4 – Wollondilly River photographs. Dead trees in water facing downstream (A); thick scrubby vegetation on right bank (B); close-up of sandy bank with small woody debris (C); dead trees in water facing across to left bank (D); dead trees in water facing upstream (E); sandy bank with vegetation (F); vegetation in foreground looking across to right bank (G); living and dead trees (H).

3.7 Site 11 – Kedumba River (upstream)

Site 11 was the furthest upstream site along the Kedumba River (Figure 3-7). This site was characterised by a well-shaded shallow, riffle-run-pool habitat. The riffle habitat was provided mostly by cobble rocks, with tree roots providing riffle habitat in some areas. Within the pools the flow was slow, while there was moderate flow in the riffle areas. The wetted width of the channel varied between approximately 6 to 12 m, while the riffle areas was generally around 30 cm and the pools were estimated at depths of up to 2 m.

The dominant substrate was small to large rocks, with some fine to coarse grained sediment. There was also a low to moderate amount of *Casuarina sp.* leaf litter in amongst rocks. There was low to moderate small woody debris mostly caught in rocks, and some large trunks on the edge of the banks. Water was very clear, with only slight plume when disturbed which settled out quickly.

On both banks of the channel, there was some undercut banks with some eroded areas. The site was very well shaded due to the narrow channel and *Casuarina sp.* lined riparian zone. The banks were dominated by cobbles and grass and ferns covered sediments. There was also a moderate amount of emergent macrophytes, dominated by *Lomandra sp.* A moderate amount of submerged macrophytes was recorded in riffle areas.

Open grounds were adjacent to the site, that had been cleared for camping. Upstream of the site there was also a small dam wall which was flowing. Despite the good condition of the river, the only animals (excluding birds and insects) that were observed were introduced species, which included brumbies and carp.

It is possible that Macquarie perch would be found at this site, due to suitable habitat. However, the presence of the introduced carp may suggest that the potential Macquarie perch breeding sites may be disturbed.

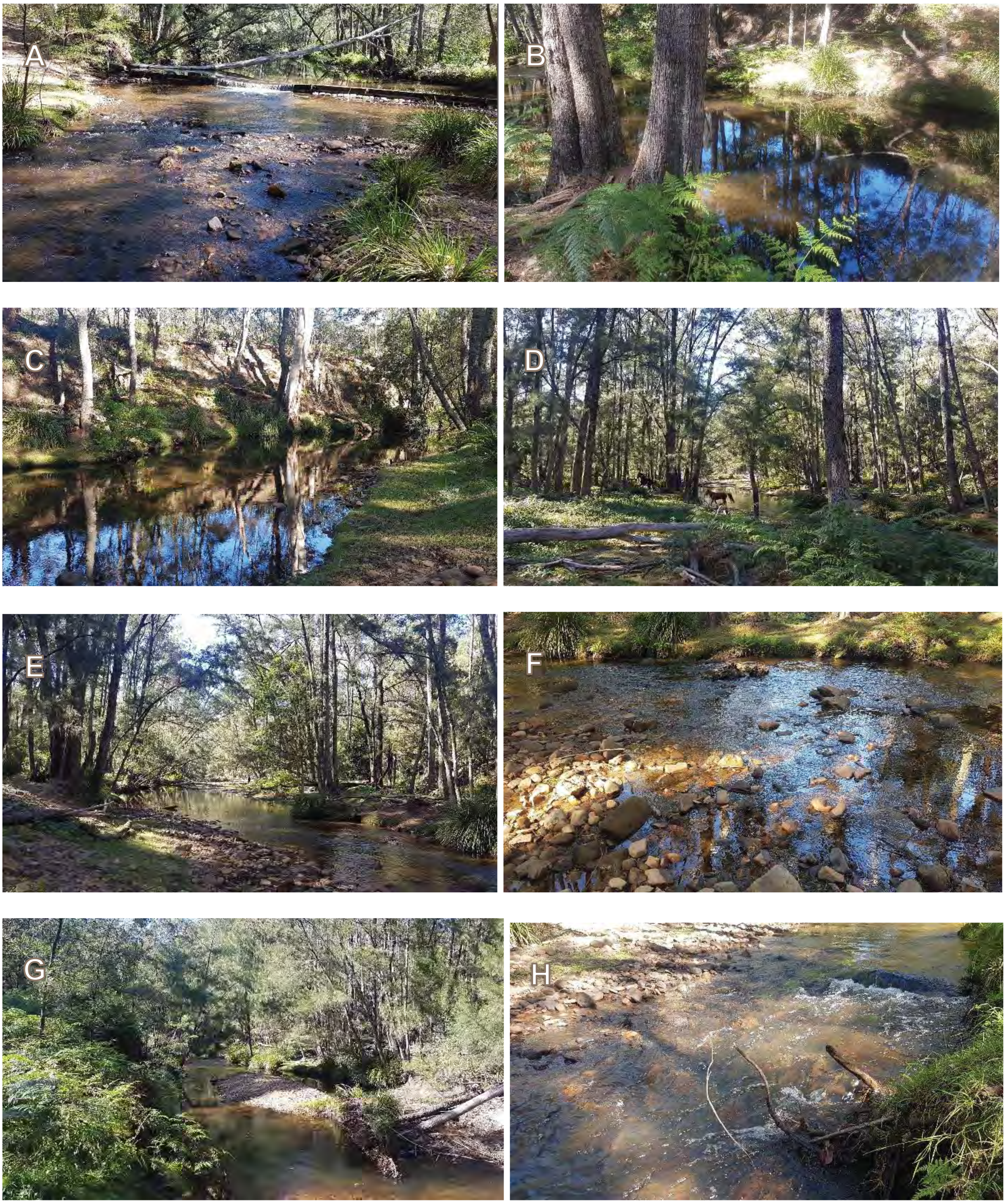


Figure 3-7 Site 11 – Kedumba River photographs. Small dam wall with pool habitat upstream and shallow rock area forming riffle habitat downstream (A); deeper well-shaded pool habitat (B); pool habitat (C); brumbies crossing the river (D); riffle habitat in foreground, forming in to slower moving pool habitat (E); riffle habitat on shallow rock substrate (F); deeper pool habitat with fallen trees on banks (G); fast flowing riffle area with rocks covered in submerged macrophytes (H).

3.8 Site 9 – Kedumba River (downstream)

Site 9 was the furthest downstream site on Kedumba River (Figure 3-8). The site was characterised by a well-shaded riffle-pool-run habitat that was divided by a river crossing on W7h Rucksack Ridge Trail. The dominant riffle habitat was approximately 100 m upstream of the river crossing, and was mostly provided by rock cobbles and some large woody debris. The site was relatively shallow, varying between less than 20 cm in riffle areas and at the river crossing to up to an estimated 1 m within pool areas. The reach of the river was narrow, with its width varying between 10 to 15 m.

The riffle section had medium flow, while the pools had low flows. There was a moderate flow over the river crossing. The dominant substrate was large gravel and cobble rocks, interspersed with medium grained sand that was more dominant within deeper pool habitats. There was a low to moderate amount of small to large woody debris. There was a moderate amount of leaf litter that was mostly restricted to the edges of banks. The water was clear with a slight brown stain, while there was no sediment or water odours. The water plumed slightly when disturbed, but settled quickly.

The banks of the site were covered with a moderate amount of emergent macrophytes, dominated by *Lomandra sp.*, ferns and grasses. The downstream right bank was characterised by a gentle sloped bank with some sections of erosion and bank undercutting and roots mat, while the downstream left bank was a large rock wall, with vegetation growing from it. The riffle section also had a moderate amount of submerged macrophytes. There was a moderate amount of in-stream shade due to the riparian vegetation on both banks, that was dominated by *Casuarina sp.* and tea trees. Animal activity included abundant bird calls and insect sounds. A moderate sized carp was also observed.

It is possible that Macquarie perch would be found at this site, due to suitable habitat. However, the presence of the introduced carp may suggest that the potential Macquarie perch breeding sites may be disturbed.

Figure 3-8 Site 9 – Kedumba River photographs. Slow moving run at upstream section of site (A); shallow riffle habitat over rocks (B); riffle habitat with shallow rocks and fallen trunks (C); large woody debris on banks (D); upstream of river crossing (E); close up of submerged macrophytes near river crossing (F); deeper pool habitat downstream of river crossing (G); slow moving pool habitat downstream of river crossing (H).

3.9 Site 13 – Coxs River

Site 13 was located on the Coxs River (Figure 3-9). At the upstream section of this site there was a concrete dam wall approximately 30 cm high. Upstream of the dam wall there was a large pool habitat approximately 40 m wide, while downstream the site was characterised by a riffle-pool-run habitat, which narrowed to around 20 m. The riffle areas were shallow, while pool habitats were estimated at approximately 1 m. The water flow was medium to high in riffle areas, while the pool section had a slow flow.

The main forms of in-stream habitat were mostly in-stream rocks in the form of cobbles and boulders. There was minimal woody debris in the river. There was some leaf little and decaying organic matter that was mostly at edges. The dominant substrate type was rocks in riffle habitat, while in pool habitat is was mainly medium coursed grained sand with some rocks. The water had high clarity, with no water or sediment odours. When the sandy bottom was disturbed, it resulted in a sediment plume, that settled quickly.

Banks were mostly lined with rocks with minimal undercutting and erosion. The downstream right bank mostly consisted of a large rock wall with vegetation growing from it, with a smaller section of a gentle sloped bank with small to medium cobbles. The moderate to dense *Casuarina sp.* lined riparian zone provided high shading on bank edges with minimal in-stream cover. There was some *Casuarina sp.*, *Lomandra sp.* and sedges growing within the stream amongst rocks, in addition to on banks. There was no algae was observed within the stream. Animal activity included snakes with some large fish that were likely carp upstream of dam.

It is possible that Macquarie perch would be found at this site, due to suitable habitat. However, the presence of the introduced carp may suggest that the potential Macquarie perch breeding sites may be disturbed.

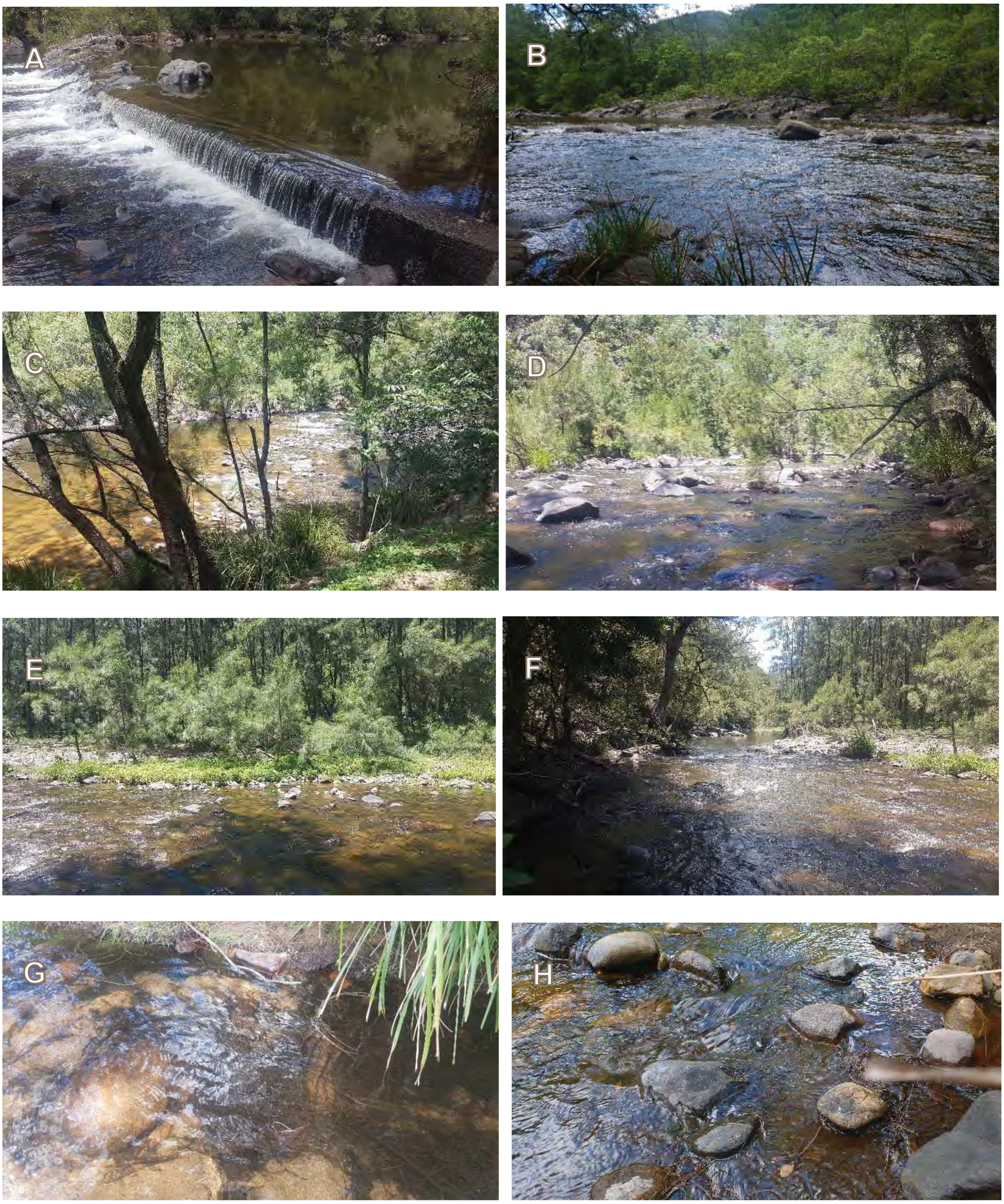


Figure 3-9 Site 13 – Coxs River photographs. Dam wall at the slow-moving pool habitat upstream section of site (A); riffle habitat downstream of dam wall (B); riffle habitat viewed from upper bank (C); riffle habitat with *Casuarina sp.* trees growing on rocks in-stream (D); rocky substrate with *Casuarina sp.* (E); riffle section looking downstream (F); close up of leaf litter and rocks on edge of banks, with *Lomandra sp.* in the top right (G); close up of riffle habitat with cobble sized rocks (H).

Appendix B eDNA report

eDNA Metabarcoding Report: Fish survey in NSW (December 2017)

BMT WBM Project number: N20854

Prepared for

BMT WBM

Prepared by

Trace and Environmental DNA (TrEnD) Laboratory

Curtin University

16th March 2018

Report Authors: Prof Michael Bunce, Katrina West and Dr Megan Coghlan (TrEnD laboratory)

Signature:

(Prof M.Bunce) **Date:** **16th March 2018**

Disclaimer:

The Trace and Environmental DNA (TrEnD) laboratory offers DNA services across a number of biological applications. While TrEnD stands by the validity of its work and the science that underpins it, stakeholders should use the information contained within the report at their own risk. We suggest using DNA results we report as a line of evidence in decision making processes and it may be appropriate to repeat results, re-sample at sites, corroborate data using other DNA markers or use other non-molecular methods. TrEnD accepts no liability or responsibility for it in respect of any use of or reliance upon this report by any third party.

Executive Summary:

Overall Project objective:

The aim of this pilot project was to use an environmental DNA (eDNA) metabarcoding approach to determine overall fish diversity and the presence of the threatened species Macquarie perch (*Macquaria australasica*) and Australian Greying (*Prototroctes maraena*) within a reservoir and surrounding tributaries in NSW. The data was to be incorporated into an environmental impact statement (EIS) by BMT WBM.

Outputs:

- 15 water samples were collected and filtered by BMT WBM and eDNA was successfully isolated by the TrEnD laboratory at Curtin University.

- The Fish 16S assays were performed using a 'holistic' metabarcoding approach to profile the fish DNA present in the water sample.

- A wide diversity of fish were detected in all of the samples. At least 15 different fish taxa were identified across all of the study sites. Three of the 15 samples tested were positive for Macquarie Perch. Australian Greyling was not detected from any of the water samples provided by BMT WBM.

Recommendations:

- This is the first time eDNA metabarcoding methods have been implemented in the NSW water systems. The fish 16S data indicate that eDNA is able to profile fish biodiversity in the area as a non-invasive method. At this time, the efficacy of eDNA metabarcoding cannot be compared with more traditional fish sampling methods, as it was not implemented as part of this survey. The presence of Macquarie perch (*Macquaria australasica*) DNA from 3 of the 15 samples indicates eDNA metabarcoding is capable of detecting threatened species. However, outstanding questions remain regarding the number of water sample replicates that are deemed sufficient in the study area of this report, including what role, if any, eDNA could play in the ongoing monitoring of this aquatic system.

1. Introduction

eDNA refers to all genetic material that is recovered from environmental substrates (such as water or sediment). DNA directly from an organism (e.g. microorganisms) as well as trace amounts of DNA that are shed by all organisms is collectively termed eDNA. This preserved, but often degraded, genetic material provides a means to audit species composition and communities at a given location. When combined with recently developed DNA sequencing technologies (termed 'next generation' or 'high-throughput' sequencing), eDNA can provide a wealth of information for studies of introduced marine pests (IMP), biodiversity, food web dynamics, community assemblages and diet analysis.

Potential applications for monitoring using eDNA include:

- Biosecurity: to detect the presence/absence of introduced species
- Environmental Impact Assessment: baseline/ongoing monitoring and assessment; audit
- Conservation: to detect the presence/absence of threatened species

BMT has partnered with the Trace and Environmental DNA (TrEnD) Laboratory at Curtin University, in an Australian Research Council -Linkage Project (2016-2019), to develop eDNA tools for stakeholders seeking to use DNA-based bio surveys in marine/aquatic monitoring and management.

eDNA sampling has benefits over other traditional survey methods including:

- highly cost-effective monitoring compared to traditional survey methods
- rapid sample collection that is non destructive to habitats, flora and fauna
- Collection using diver-less monitoring techniques that reduce occupational safety risks
- non-reliance on individuals with taxonomic expertise, provision of consistent results between monitoring programs, independent of surveyors

The objectives of this project were to use an environmental DNA (eDNA) metabarcoding approach to determine overall fish diversity and the presence of the threatened species Macquarie perch (*Macquaria australasica*) and Australian Greying (*Prototroctes maraena*) within a reservoir and surrounding tributaries in NSW. The data was to be incorporated into an environmental impact statement.

2. Methods and Samples

Water samples were collected by BMT on 6th, 7th and 8th of December 2017 and filtered using a Sentino pump over 0.2 micron membranes (Pall corporation) as outlined in TrEnD standard operating procedures (available upon request). Turbidity in the water resulted in varying volumes of water that could be filtered between the sites and number of replicates obtained (see table below and attached electronic data file).

Client:		BMT WBM				Project no:		N20854			
Field dates:		6-8/12/17				Sample type:		Water			
Location:		Warragamba Dam tributaries, NSW				Field personnel:		Grace Bourke, Ainslie Downes			
Contact:		grace.bourke@bmtglobal.com						brad.grant@bmtglobal.com			
Site	**Replicates**	**Sampling date**	**Sampling time**	**Latitude**	**Longitude**	**Location**	**Sampling collection depth (m)**	**Water depth (m)**	**Wind speed and direction (kt)**	**Air temp (degC)**	**Filtered amount (mL)**	**TrEnD AWFS #**
12	12A	6/12/17	10:30	-34.249024	150.230609	Wollondilly River, NSW	0.2	0.3	4 kts, W	20	700	AWFS-F18-041
12	12B	6/12/17	10:30	-34.249024	150.230609	Wollondilly River, NSW	0.2	0.3	4 kts, W	20	600	AWFS-F18-042
12	12C	6/12/17	10:30	-34.249024	150.230609	Wollondilly River, NSW	0.2	0.3	4 kts, W	20	700	AWFS-F18-043
5	5A	6/12/17	12:15	-34.187453	150.300165	Wollondilly River, NSW	0.2	0.4	6 kts, SW	22	700	AWFS-F18-038
5	5B	6/12/17	12:15	-34.187453	150.300165	Wollondilly River, NSW	0.2	0.4	6 kts, SW	22	600	AWFS-F18-039
5	5C	6/12/17	12:15	-34.187453	150.300165	Wollondilly River, NSW	0.2	0.4	6 kts, SW	22	600	AWFS-F18-040
9	9A	7/12/17	09:45	-33.836605	150.359458	Kedumba River, NSW	0.2	0.3	2 kts, NE	23	500	AWFS-F18-044
9	9B	7/12/17	09:45	-33.836605	150.359458	Kedumba River, NSW	0.2	0.3	2 kts, NE	23	500	AWFS-F18-045
9	9C	7/12/17	09:45	-33.836605	150.359458	Kedumba River, NSW	0.2	0.3	2 kts, NE	23	600	AWFS-F18-046
13	13A	7/12/17	12:00	-33.871051	150.255054	Kelpie Point, Coxs River, NSW	0.2	0.4	4 kts, NE	26	700	AWFS-F18-047
13	13B	7/12/17	12:00	-33.871051	150.255054	Kelpie Point, Coxs River, NSW	0.2	0.4	4 kts, NE	26	700	AWFS-F18-048
13	13C	7/12/17	12:00	-33.871051	150.255054	Kelpie Point, Coxs River, NSW	0.2	0.4	4 kts, NE	26	700	AWFS-F18-049
3	3A	8/12/17	07:30	-34.14096	150.436637	Nattai River, NSW	0.2	0.3	2 kts, NE	22	900	AWFS-F18-050
3	3B	8/12/17	07:30	-34.14096	150.436637	Nattai River, NSW	0.2	0.3	2 kts, NE	22	800	AWFS-F18-051
3	3C	8/12/17	07:30	-34.14096	150.436637	Nattai River, NSW	0.2	0.3	2 kts, NE	22	800	AWFS-F18-052
Control		8/12/17									800	AWFS-F18-053

eDNA was extracted using Qiagen Blood & Tissue DNeasy kits in the TrEnD laboratory at Curtin University in dedicated facilities (inclusive of laboratory clean rooms) suited for eDNA workflows. eDNA derived from fish was amplified using PCR (16S rRNA Fish assay), followed by sequencing on an Illumina MiSeq in the TrEnD Laboratory. Negative laboratory controls were included (and sequenced if identified as positive) to control for environmental laboratory contamination.

The 16S DNA sequences recovered were compared to the National Centre for Biotechnology Information (NCBI) database for taxonomic identification. A more detailed analysis was carried out to investigate the presence/absence of the target taxa Macquarie perch (*Macquaria australasica*) and Australian Greying (*Prototroctes maraena*).

3. Results and Discussion

The following list outlines the taxonomic assignments from each sample for which fish DNA was amplified and sequenced. Taxonomic assignments are to species, genus or family depending on a number of factors including the genetic similarity to the DNA sequences contained on the reference database (NCBI) and if the DNA database contains the DNA sequence for target species of this report and their closely related taxa. At the time of this report, the taxonomic assignments for the DNA sequences obtained from the water samples (i.e. DNA 'barcodes') are listed in the table below – the electronic file accompanying this report (and the tabs within the file) contain data on percentage similarities, closest matches and expert interpretive notes on the assignments. The environmental laboratory controls for this work were identified as negative for fish and not included in the Table.

Site 5, Replicate 5A, Wollondilly River, NSW. TrEnD AWFS038	
Taxa assignment	Common name
Eleotridae	Sleeper gobies
Philypnodon grandiceps	Flathead gudgeon
Philypnodon	Sleeper gobies
Retropinnidae	Southern Graylings & Southern Smelts
Site 5, Replicate 5B, Wollondilly River, NSW. TrEnD AWFS039	
Taxa assignment	Common name
Eleotridae	Sleeper gobies
Philypnodon grandiceps	Flathead gudgeon
Gambusia	Mosquitofish
Osmeriformes	Argentines & Smelts
Site 5, Replicate 5C, Wollondilly River, NSW. TrEnD AWFS040	
Taxa assignment	Common name
Hypseleotris	Australian carp gudgeons
Eleotridae	Sleeper gobies
Philypnodon grandiceps	Flathead gudgeon
Philypnodon	Sleeper gobies
Gambusia holbrooki	Eastern mosquitofish
Gambusia	Mosquitofish
Retropinnidae	Southern Graylings & Southern Smelts
Osmeriformes	Argentines & Smelts
Site 12, Replicate 12A, Wollondilly River, NSW. TrEnD AWFS041	
Taxa assignment	Common name
Hypseleotris	Australian carp gudgeons
Eleotridae	Sleeper gobies
Philypnodon grandiceps	Flathead gudgeon
Gambusia	Mosquitofish
Retropinnidae	Southern Graylings & Southern Smelts
Osmeriformes	Argentines & Smelts
Litoria lesueurii	Lesueur's frog
Site 12, Replicate 12B, Wollondilly River, NSW. TrEnD AWFS042	
Taxa assignment	Common name
Hypseleotris	Australian carp gudgeons
Eleotridae	Sleeper gobies
Philypnodon grandiceps	Flathead gudgeon
Retropinnidae	Southern Graylings & Southern Smelts
Osmeriformes	Argentines & Smelts

Site 12, Replicate 12C, Wollondilly River, NSW. TrEnD AWFS043	
Taxa assignment	Common name
Eleotridae	Sleeper gobies
Philypnodon grandiceps	Flathead gudgeon
Gambusia	Mosquitofish
Retropinnidae	Southern Graylings & Southern Smelts
Osmeriformes	Argentines & Smelts
Site 9, Replicate 9A, Kedumba River, NSW. TrEnD AWFS044	
Taxa assignment	Common name
Eleotridae	Sleeper gobies
Philypnodon grandiceps	Flathead gudgeon
Gambusia holbrooki	Eastern mosquitofish
Gambusia	Mosquitofish
Galaxias	Galaxias
Retropinnidae	Southern Graylings & Southern Smelts
Osmeriformes	Argentines & Smelts
Litoria citropa	Blue Mountains Tree Frog
Litoria lesueurii	Lesueur's frog
Site 9, Replicate 9B, Kedumba River, NSW. TrEnD AWFS045	
Taxa assignment	Common name
Macquaria australasica	Macquarie Perch
Hypseleotris	Australian carp gudgeons
Eleotridae	Sleeper gobies
Philypnodon grandiceps	Flathead gudgeon
Gambusia holbrooki	Eastern mosquitofish
Gambusia	Mosquitofish
Galaxias	Galaxias
Retropinnidae	Southern Graylings & Southern Smelts
Osmeriformes	Argentines & Smelts
Litoria citropa	Blue Mountains Tree Frog
Litoria lesueurii	Lesueur's frog
Site 9, Replicate 9C, Kedumba River, NSW. TrEnD AWFS046	
Taxa assignment	Common name
Anguilla australis	Short-finned eel
Eleotridae	Sleeper gobies
Philypnodon grandiceps	Flathead gudgeon
Gambusia	Mosquitofish
Galaxias	Galaxias
Retropinnidae	Southern Graylings & Southern Smelts
Osmeriformes	Argentines & Smelts
Litoria lesueurii	Lesueur's frog
Site 13, Replicate 13A, Kelpie Point, Coxs River, NSW. TrEnD AWFS047	
Taxa assignment	Common name

Macquaria australasica	Macquarie Perch
Eleotridae	Sleeper gobies
Gambusia holbrooki	Eastern mosquitofish
Gambusia	Mosquitofish
Retropinnidae	Southern Graylings & Southern Smelts
Osmeriformes	Argentines & Smelts
Litoria lesueurii	Lesueur's frog
Site 13, Replicate 13B, Kelpie Point, Coxs River, NSW. TrEnD AWFS048	
Taxa assignment	Common name
Gambusia holbrooki	Eastern mosquitofish
Gambusia	Mosquitofish
Retropinnidae	Southern Graylings & Southern Smelts
Osmeriformes	Argentines & Smelts
Litoria lesueurii	Lesueur's frog
Site 13, Replicate 13C, Kelpie Point, Coxs River, NSW. TrEnD AWFS049	
Taxa assignment	Common name
Macquaria australasica	Macquarie Perch
Eleotridae	Sleeper gobies
Gambusia	Mosquitofish
Salmonidae	Salmon
Retropinnidae	Southern Graylings & Southern Smelts
Osmeriformes	Argentines & Smelts
Litoria lesueurii	Lesueur's frog
Site 3, Replicate 3A, Nattai River, NSW. TrEnD AWFS050	
Taxa assignment	Common name
Hypseleotris	Australian carp gudgeons
Eleotridae	Sleeper gobies
Philypnodon grandiceps	Flathead gudgeon
Philypnodon	Sleeper gobies
Gambusia holbrooki	Eastern mosquitofish
Gambusia	Mosquitofish
Salmonidae	Salmon
Retropinnidae	Southern Graylings & Southern Smelts
Osmeriformes	Argentines & Smelts
Litoria lesueurii	Lesueur's frog
Site 3, Replicate 3B, Nattai River, NSW. TrEnD AWFS051	
Taxa assignment	Common name
Hypseleotris	Australian carp gudgeons
Eleotridae	Sleeper gobies
Philypnodon grandiceps	Flathead gudgeon
Philypnodon	Sleeper gobies
Gambusia	Mosquitofish
Retropinnidae	Southern Graylings & Southern Smelts
Osmeriformes	Argentines & Smelts

Litoria lesueurii	Lesueur's frog
Plumatella	Bryozoans
Site 3, Replicate 3C, Nattai River, NSW. TrEnD AWFS052	
Taxa assignment	Common name
Hypseleotris	Australian carp gudgeons
Eleotridae	Sleeper gobies
Philypnodon grandiceps	Flathead gudgeon
Philypnodon	Sleeper gobies
Retropinnidae	Southern Graylings & Southern Smelts
Osmeriformes	Argentines & Smelts
Litoria lesueurii	Lesueur's frog

4. Findings, Recommendations and Concluding remarks

The 16S rRNA fish metabarcoding assay utilised on the water samples collected by BMT WBM detected a wide variety of fish taxa as well as frog (Lesueur's frog) and Bryzoan. To our knowledge this represents the first time an eDNA based approach has been used in this river system. The taxa described are broadly consistent with the range of the species/genus/Family as described in the Atlas of Living Australia and/or FishBase. The gaps in the reference databases often prevent definitive assignments to genus and/or species at the time of this report. In some instances the species might be inferred from those know to occur in the region, although this report does not speculate in such cases.

The presence of Macquarie perch (*Macquaria australasica*) in 3 of the 15 samples indicate the method is capable of detecting a threatened species. A detailed phylogeny of eDNA barcodes with known references of Macquarie perch and other closely related taxa was conducted. The eDNA barcodes identified and Macquarie perch reference data cluster together 100% of the time at the exclusion of other fish taxa. Given our findings and analyses we classify the taxonomic assignment as being Highly Probable (the highest level of certainty for taxonomic assignment based on eDNA).

The Australian Greying (*Prototroctes maraena*) was the other species to be detected, as requested by BMT WBM. Although we detected some eDNA signatures in the water from the Retropinnidae family (of which *Prototroctes maraena* is a member) we can specifically exclude *Prototroctes maraena* a possible assignment as it was found to be 93% similar to the reference DNA sequence contained on NCBI and therefore highly unlikely to be this species. The identity of this Retropinnidae eDNA 'signature' will remain unknown until reference DNA data is available from the species detected in the study region.

Given this was the first application of eDNA in the study area, the number of replicate samples remains an unknown factor. If future studies are to be conducted using eDNA (and based on variability in the 3 replicates used here), then we would advocate that sample number is increased to ~6 replicates and a wider geographical spread of samples should be considered.

The TrEnD has focused exclusively on targeting fish DNA in this study – the possibility exists for expanding the biotic survey to targeting DNA from other taxa including birds, mammals, invertebrates and plants. The expansion of this work outside of targeting fish DNA was beyond the scope of the current work. The DNA extracted from the water samples is stored in the TrEnD laboratory and the possibility to expand the above-mentioned work at a future date can be conducted if required and requested by the clients.

5. Appendices and additional information

- An electronic file titled; BMT_WBM_eDNA fish results MArch2018.XLS is attached to this report.

- Additional information on sampling and methods are available from TrEnD upon request however the exact nature of the assays and workflow are proprietary.

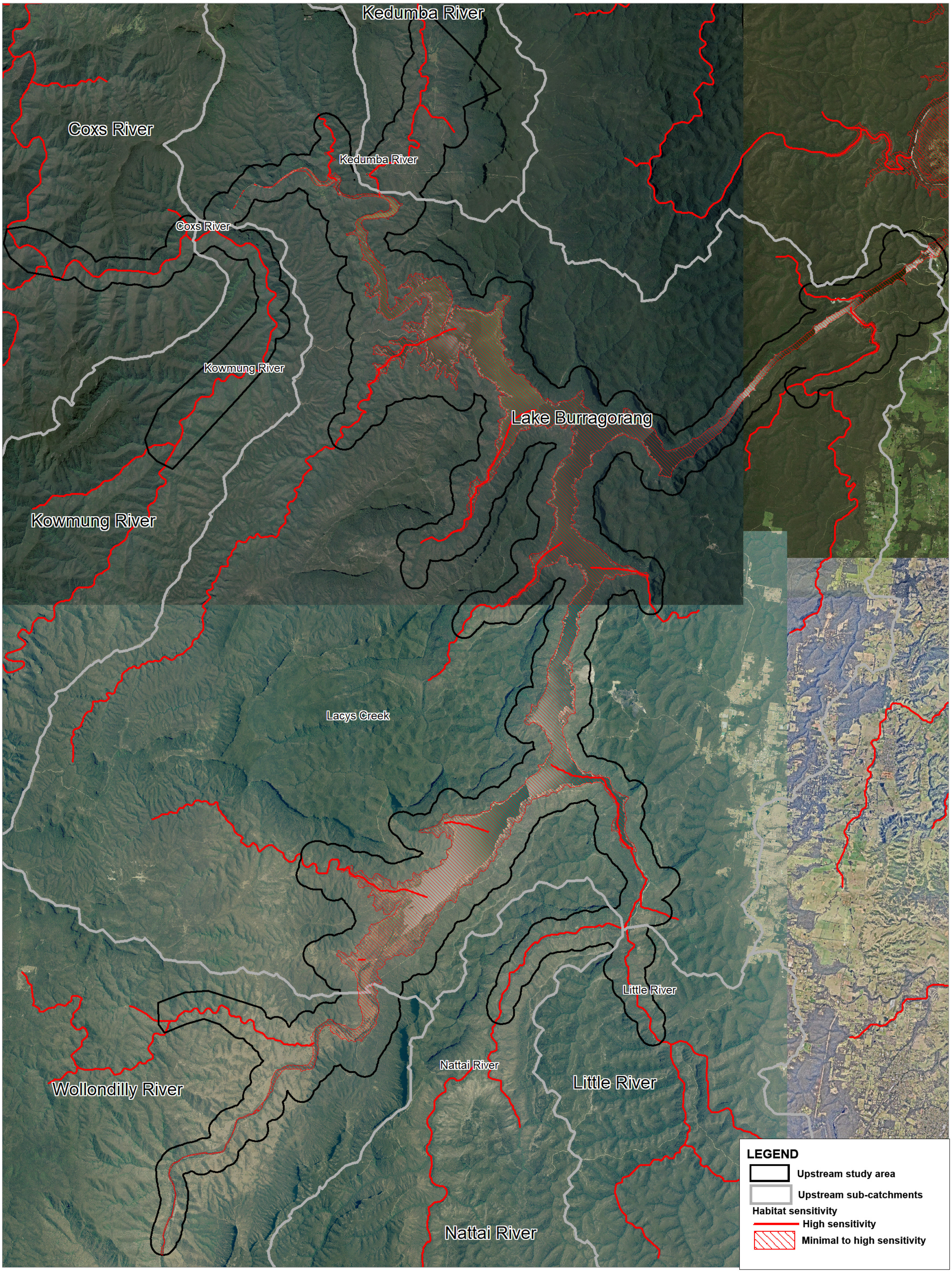
- Below is a list of acronyms, abbreviations and definitions that may apply to aspects of this report.

% value in data	Represents the percentage similarity of a DNA sequence recovered from a sample compared to reference sequences in a database (e.g. compared to DNA databases such as GenBank or references generated in-house)
(x) value in data	Represents the frequency the % value was recorded in the dataset
16S rRNA	The 16S rRNA refers to a conserved gene region of mitochondrial DNA, which codes for a subunit of the ribosome. 16S rRNA is found in all eukaryotes making it a good candidate for DNA barcoding and is used extensively to detect vertebrate taxa such as fish and mammals.
18S rRNA	The 18S rRNA refers to a conserved gene region of nuclear DNA, which codes for a subunit of the ribosome. 18S rRNA is found in all eukaryotes making it a good candidate for DNA barcoding
18S IMS reference database	Reference 18S rRNA sequences of invasive marine species that are available in DNA databases
Assay	In the context of metabarcoding an assay is a molecular test (using PCR) that is implemented to target a group of taxa within a mixed biological substrate. It is akin to using a magnet to selective enrich for needles (the target) in the context of a haystack (the total DNA from a sample).
COI	The gene region that is being used as the standard barcode for almost all animal groups is a 648 base-pair region of the mitochondrial cytochrome c oxidase 1 gene (“CO1”). COI is proving highly effective in identifying birds, butterflies, fish, flies and many other animal groups. COI is not an effective barcode region in plants because it evolves too slowly, but two gene regions in the chloroplast, matK and rbcL, have been approved as the barcode regions for plants
CO1 IMS reference database	Reference COI sequences of invasive marine species that are available in DNA databases
DNA	Deoxyribonucleic Acid (DNA) is the hereditary material that contains the genetic information of an organism
DNA metabarcoding	Is a genetic technique that simultaneously amplifies and sequences barcode regions

	(e.g. COI, 18S, 16S) of many different species in parallel
eDNA	Environmental DNA (eDNA) refers to genetic material that is recovered from an environmental substrate (e.g. water, sediment, air)
eukaryotes	An organism where cells contain a nucleus surrounded by a membrane and has the DNA bound together by proteins (histones) into chromosomes. The cells of eukaryotes also contain an endoplasmic reticulum and numerous specialised organelles not present in prokaryotes, especially mitochondria, golgi bodies, and lysosomes
Fisheries	Department of Primary Industries and Regional Development, Fisheries Division, Aquatic Biosecurity Section
GenBank	Publically available repository of genetic information. Contains the barcode information of genes that have previously been sequenced
Genome	A genome is all the genetic material of an organism. It consists of DNA (or RNA in RNA viruses). The genome includes both the genes (the coding regions) and the noncoding DNA. In eukaryotes it refers to the genomes of the nucleus, mitochondria and chloroplasts. In prokaryotes, there is a single genome (as they do not contain mitochondria or chloroplasts)
Illumina MiSeq	Next generation sequencing platform developed by the company Illumina
IMP	Introduced marine pests
IMS	Introduced marine species
Metabarcoding assay	A PCR reaction using a specific set of primers that simultaneously amplifies the same gene target from multiple species
Mitochondria	The mitochondrion (plural mitochondria) is a double membrane-bound organelle found in all eukaryotic organisms, although some cells in some organisms may lack them (e.g. Red blood cells). It contains its own genome
Mitogenomes	Refers to the mitochondrial genome
NGS	Next generation sequencing or second generation sequencing refers to massively parallel sequencing technology, as opposed to first generation sequencing or sanger sequencing where only a single template is sequenced at one time
Nucleotide	A compound consisting of a nucleoside linked to a phosphate group. Nucleotides form the basic structural unit of nucleic acids such as DNA
PCR	Polymerase chain reaction (PCR) is the technique that is used to amplify (akin to photocopying DNA) specific regions of the genome from specific groups of taxa
Primer	A short DNA strand (≈20bp in size) used in PCR to target particular groups of organisms and genes. Two of them are required for PCR (a forward and a reverse)
Primer binding site	A primer-binding site is the target region of a genome where the primer attaches to start replication. The primer binding site is on one of the two complementary strands of a double-stranded nucleotide polymer, in the strand which is to be copied, or is within a single-stranded nucleotide polymer sequence
prokaryote	Any of the typically unicellular microorganisms that lack a distinct nucleus and

	membrane-bound organelles and that are classified as a kingdom (Prokaryotae syn. Monera) or into two domains (Bacteria and Archaea)
RNA	Ribonucleic acid (RNA) is a polymeric molecule implicated in various biological roles in coding, decoding, regulation, and expression of genes
rRNA	ribosomal ribonucleic acid is the RNA component of the ribosome, and is essential for protein synthesis in all living organisms
Sequence	DNA sequencing is the process of determining the precise order of nucleotides within a DNA molecule. It includes any method or technology that is used to determine the order of the four bases—adenine, guanine, cytosine, and thymine—in a strand of DNA
Shotgun sequencing	Refers to randomly sequencing short pieces of DNA (≈150bp in size) after shearing or cutting DNA (e.g. fragmenting a genome)
TrEnD	Trace and Environmental DNA laboratory, Curtin University

Appendix C Habitat sensitivity and habitat class



Title:

Habitat sensitivity types based on the classification scheme in Table 1 of the NSW Fisheries Guidelines (2013)

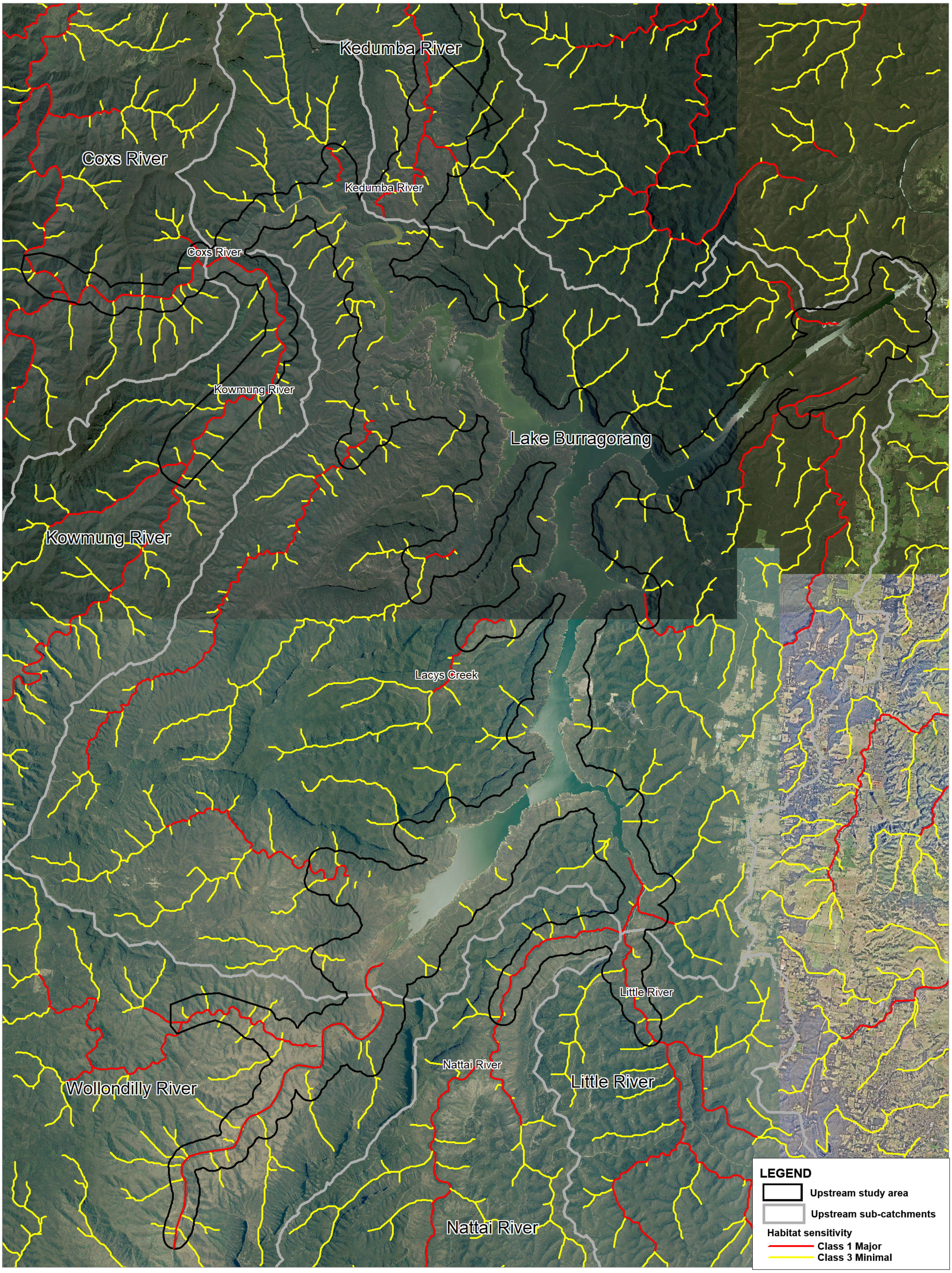
Figure: **3-26**

Rev: **A**

N

BMT
www.bmt.org

Filepath: I:\N20854_I_BH_Warragamba Dam\DRG\ECO_018_Table1HabitatSensitivity.wor



Title:

Waterway class based on the scheme in Table 2 of the NSW Fisheries Guidelines (2013)

Figure: 3-27

Rev: A

BMT endeavours to ensure that the information provided in this map is correct at the time of publication. BMT does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.

BMT
www.bmt.org

Filepath: I:\N20854_I_BH_Warragamba Dam\DRG\ECO_019_Table2WaterwayClasses.wor

Appendix D Assessments of Significance

Assessments of significance

Limit of impact assessment

As the Hawkesbury River widens as it approaches the lower estuarine areas and tidal influences begin to dominate water levels closer to the ocean, potential downstream impacts decrease with distance downstream until they become negligible. Other influences on hydrology and water quality in the downstream catchment may also be significant, such as inflows from downstream catchments (e.g., the Nepean River, Grose River, Macdonald River, and Colo River), runoff from rural and urban land uses, and discharges from sewage treatment plants.

Identification of a practicable downstream boundary for the aquatic ecology impact assessment considered both changes to downstream hydrology and to water quality.

An analysis of changes in water levels was carried out to identify where water levels were generally similar to pre and post-Project conditions. This was based on an assessment of the hydrographs at various downstream cross-sections. This identified that the change in water levels downstream would range from about 200 millimetres to 400 millimetres at Wisemans Ferry and decrease to less than 100 millimetres immediately downstream of Wisemans Ferry.

A second consideration in establishing the downstream boundary was potential changes in water quality associated with operation of the flood mitigation zone (the Project would not result in any changes in water quality in the dam during normal operations as there would be no change in the full supply level or how the dam is operated currently).

When the flood mitigation zone is capturing inflows from the Lake Burragorang catchment, there would be no change in downstream water quality. However, when captured water is being released from the flood mitigation zone after a flood event there is potential for impacts if the water quality of the captured water is worse than downstream water quality.

A detailed discussion around the downstream water quality impacts of the Project is provided in Section 27.5.4 of the EIS. The assessment examined changes in Total Nitrogen, Total Phosphorus, chlorophyll-a, and Total Suspended Solids. The assessment identified that water quality in the flood mitigation zone was generally better than the downstream receiving environment and would not have any material impact on downstream quality.

On the basis of consideration of likely downstream hydrological and water quality changes, the downstream boundary for the aquatic ecology assessment has been set at Wisemans Ferry.

NSW *Fisheries Management Act 1994*

The following threatened aquatic species were identified as having a reasonable likelihood of occurrence in the Project study area. Potential impacts on these species have been assessed through the matters listed in section 221ZV) of the FM Act (the 'seven part test):

- Adam's Emerald Dragonfly (*Archaeophya adamsi*)
- Sydney Hawk Dragonfly (*Austrocordulia leonardi*)
- Macquarie Perch (*Macquaria australasica*) and

The Blue Mountains Perch (*Macquaria sp. nov. 'hawkesbury taxon'*) was previously considered part of *Macquaria australasica* but since 1986 has been accepted as a separate taxon and is now recognised as a separate species.[1] This species is not listed under the FM Act but in light of DAWE advice, this species is being treated as endangered and has been included in the Assessment of Significance.

Commonwealth *Environment Protection and Biodiversity Conservation Act 1999*

The following threatened aquatic species were identified as having a reasonable likelihood of occurrence in the Project study area. Potential impacts on these species have been assessed through the *Matters of National Environmental Significance Significant impact guidelines 1.1* (Commonwealth of Australia 2013):

- Black Rockcod (*Epinephelus daemelii*),
- Macquarie Perch (*Macquaria australasica*)

As noted above, in light of DAWE advice regarding the Blue Mountains Perch, this species has been included in the assessment.

[1] https://www.iucnredlist.org/species/128972817/128972820

Adam's Emerald Dragonfly (*Archaeophya adamsi*), Endangered under the FM Act

Adam's Emerald Dragonfly has an aquatic larval stage that relies on a specific set of habitat requirements. It is therefore sensitive to habitat disturbance and water quality degradation. The Adam's Emerald Dragonfly prefers cool clear streams with gravely riffles and extensive riparian vegetation. Larvae of the Adams Emerald Dragonfly generally occur in small to moderate sized creeks with gravel or sandy beds, with narrow, shaded riffle zones containing moss and abundant riparian vegetation (DPI, 2013). This type of habitat occurs within the study area.

Larvae of the Adams Emerald Dragonfly generally occur in small to moderate sized creeks with gravel or sandy beds, with narrow, shaded riffle zones containing moss and abundant riparian vegetation (DPI, 2013). Such habitat conditions are present in tributary streams feeding into Lake Burragorang and within some parts of the downstream study area. The Adams Emerald Dragonfly has been recorded around streams feeding into Ku-ring-gai Chase National Park, which is in the lower reaches of the downstream study area and beyond the limit of the Project's influence at Wisemans Ferry.

Assessment of significance

(a) in the case of a threatened species, whether the proposed development or activity is likely to have an adverse effect on the life cycle of the species such that a viable local population of the species is likely to be placed at risk of extinction
Impacts resulting from the project that may relate to the Adam's Emerald Dragonfly include: ▪ Bank erosion and slumping resulting in vegetation community and habitat degradation ▪ Adverse impacts to water quality, affecting larval stages. Impacts to aquatic habitat that this species relies on during certain lifecycles stages are not anticipated during construction of the Project. The Adam's Emerald Dragonfly prefers cool, clear streams with gravel substrate riffles, and extensive riparian vegetation. Recorded sightings of this species are rare. Between 1980 and 2013 there were only two sightings of this species (DPI, 2013).These were both in the Hawkesbury estuary; one of these was in Ku-ring-gai Chase National Park in an ephemeral stream that feeds into Cowan Creek, and one in Brisbane Waters National Park in an ephemeral stream that feeds into Brisbane Waters. Prior to 1980, there were three recorded sightings of this species (DPI, 2013): one in the Blue Mountains National Park in a tributary of the Grose River, one in Dharug national Park in a tributary of the Macdonald River, and one in Ku-ring-gai Chase National Park in an ephemeral stream that feeds into Cowan Creek. While suitable habitat for this species exists throughout the study area, it is unlikely that these areas would be impacted by the Project. Potential impacts upstream of Warragamba Dam would largely be restricted to the flood mitigation zone, and then only when this is required. There is no or limited suitable habitat for the Adam's Emerald Dragonfly in the flood mitigation zone. Potential impacts at or downstream of Warragamba Dam would largely be restricted to the construction area and in the worst case, downstream to Wiseman's Ferry. However, these relate largely to flood releases and changes that would occur due to water quality. This is no different to floods that have occurred in the past. And potentially, temporary storage of flood waters in the flood mitigation zone, would contribute to settling out of sediment loads, potentially resulting in releases of water that is of better quality that that which currently occurs during flood events. It is also noted that there would also be numerous downstream sources contributing to changes in water quality.
(b) in the case of an endangered population, whether the proposed development or activity is likely to have an adverse effect on the life cycle of the species that constitutes the endangered population such that a viable local population of the species is likely to be placed at risk of extinction
Not applicable to a threatened species.

(c) in the case of an endangered ecological community or critically endangered ecological community, whether the proposed development or activity: **(i) is likely to have an adverse effect on the extent of the ecological community such that its local occurrence is likely to be placed at risk of extinction, or** **(ii) is likely to substantially and adversely modify the composition of the ecological community such that its local occurrence is likely to be placed at risk of extinction**
(i) Not applicable to a threatened species. (ii) Not applicable to a threatened species.
(d) in relation to the habitat of a threatened species, population or ecological community: **(i) the extent to which habitat is likely to be removed or modified as a result of the proposed development or activity, and** **(ii) whether an area of habitat is likely to become fragmented or isolated from other areas of habitat as a result of the proposed development or activity, and** **(iii) the importance of the habitat to be removed, modified, fragmented or isolated to the long-term survival of the threatened species, population or ecological community in the locality**
(i) The Project is not anticipated to remove or modify preferred habitat of the Adam's Emerald Dragonfly. The species prefers smaller, shallow, isolated streams. Any impacts that may occur due to the Project would be restricted to the flood mitigation zone and urbanised areas of the downstream floodplain. (ii) The Project is not likely to fragment preferred habitat of the Adam's Emerald Dragonfly. (iii) The Project is not anticipated to remove or modify preferred habitat of the Adam's Emerald Dragonfly. The species prefers smaller, shallow, isolated streams. Any impacts that may occur due to the Project would be restricted to the flood mitigation zone and urbanised areas of the downstream floodplain.
(e) whether the proposed development or activity is likely to have an adverse effect on any critical habitat (either directly or indirectly)
No critical habitat has been declared for this species
(f) whether the proposed development or activity is consistent with a Priorities Action Statement,
Recovery actions for the Adam's Emerald Dragonfly are: ▪ Advice to consent and determining authorities ▪ Collation and review existing information ▪ Community and stakeholder liaison, awareness and education ▪ Compliance / enforcement ▪ Enhance, modify or implement NRM planning processes to minimize adverse impacts on threatened species ▪ Habitat rehabilitation ▪ Research / monitoring ▪ Targeted surveys and mapping. The Project is neither consistent, nor inconsistent with these recovery actions. The Project is not anticipated to adversely impact the implementation of these recovery actions.
(g) whether the proposed development constitutes or is part of a key threatening process or is likely to result in the operation of, or increase the impact of, a key threatening process
The proposed development may contribute (either directly or indirectly) to the following key threatening processes (KTPs): ▪ Degradation of native riparian vegetation along New South Wales water courses ▪ Installation and operation of instream structures and other mechanisms that alter natural flow regimes of rivers and streams ▪ Removal of large woody debris from New South Wales rivers and streams. These processes are already in happening to various degrees within the study area.

The Project may contribute to degradation of riparian habitat, but this is likely to be restricted to the flood mitigation zone, and only when it is required. Impacts to the remaining riparian habitat in the study area are not anticipated to be different to those that have occurred in historical flood events. Several in-stream structures occur throughout the study area. The Project would not result in additional in-stream structures. The Project would not alter existing flow regimes during normal operation. Downstream flow regimes would be temporarily altered during operation of the flood mitigation zone. Flood waters stored in the flood mitigation zone would be released in a controlled manner, to minimise flood risk to life in the downstream catchment. The flow regime of the Hawkesbury-Nepean River is regulated and therefore is not natural, accordingly, this KTP is considered of limited relevance to the Project. The Project would not involve the removal of large woody debris with the possible exception of the immediate downstream area in relation to the area required for construction activities. Accordingly, the Project is not considered to contribute to or be part of this KTP.
Conclusion
The Project is not anticipated to result in modifications to suitable habitat or reduce the availability of potential breeding habitat for the Adam's Emerald Dragonfly. As such, the Project is not likely to have a significant impact on the Adam's Emerald Dragonfly.

References

DPI (2013), Adam's Emerald Dragonfly – *Archaeophya adamsi*. Port Stephens, Department of Primary Industries, Fisheries Ecosystems Unit.

Sydney Hawk Dragonfly (*Austrocordulia leonardi*), Endangered under the FM Act

The Sydney Hawk Dragonfly has an aquatic larval stage that relies on a specific set of habitat requirements. It is therefore sensitive to habitat disturbance and water quality degradation. The Sydney Hawk Dragonfly prefers cool clear streams with gravely riffles and extensive riparian vegetation. This type of habitat occurs within the study area.

Sydney Hawk Dragonfly larvae have only ever been collected from under rocks in deep and shady river pools with cooler water (DPI 2007). Such habitat conditions occur in tributary streams feeding into Lake Burragorang and within some parts of the downstream study area. The Sydney Hawk Dragonfly has been recorded in the Nepean River near Wilton, which is upstream from the confluence of the Warragamba River and Nepean River, and not within the area of the existing or Project PMF.

Assessment of significance

(a) in the case of a threatened species, whether the proposed development or activity is likely to have an adverse effect on the life cycle of the species such that a viable local population of the species is likely to be placed at risk of extinction
Impacts resulting from the project that may relate to the Sydney Hawk Dragonfly include: ▪ Bank erosion and slumping resulting in vegetation community and habitat degradation ▪ Adverse impacts to water quality, affecting larval stages. Impacts to aquatic habitat that this species relies on during certain lifecycles stages are not anticipated during construction of the Project. The Sydney Hawk Dragonfly prefers cool, clear streams with gravel substrate riffles, and extensive riparian vegetation. Recorded sightings of this species are rare. They are only known from isolated coastal areas north of Newcastle and in the ranges and national parks between Sydney and Wollongong (DPI, 2007). While suitable habitat for this species exists throughout the study area, it is unlikely that these areas would be impacted by the Project. Impacts upstream of Warragamba Dam would largely be restricted to the flood mitigation zone, and then only when this is required. There is no or limited suitable habitat for the Sydney Hawk Dragonfly in the flood mitigation zone. Impacts downstream of Warragamba Dam would largely be restricted to the construction area and in the worst case, downstream to Wiseman's Ferry. However, impacts relate largely to flood releases and changes that would occur due to these to water quality. This is no different to floods that have occurred in the past. And potentially, temporary storage of flood waters in the flood mitigation zone, would contribute to settling out of sediment loads, potentially resulting in releases of water that is of better quality that that which currently occurs during flood events. It is also noted that there would also be numerous downstream sources contributing to changes in water quality.
(b) in the case of an endangered population, whether the proposed development or activity is likely to have an adverse effect on the life cycle of the species that constitutes the endangered population such that a viable local population of the species is likely to be placed at risk of extinction
Not applicable to a threatened species.
(c) in the case of an endangered ecological community or critically endangered ecological community, whether the proposed development or activity: **(i) is likely to have an adverse effect on the extent of the ecological community such that its local occurrence is likely to be placed at risk of extinction, or** **(ii) is likely to substantially and adversely modify the composition of the ecological community such that its local occurrence is likely to be placed at risk of extinction**
(i) Not applicable to a threatened species. (ii) Not applicable to a threatened species.

(d) in relation to the habitat of a threatened species, population or ecological community: (i) the extent to which habitat is likely to be removed or modified as a result of the proposed development or activity, and (ii) whether an area of habitat is likely to become fragmented or isolated from other areas of habitat as a result of the proposed development or activity, and (iii) the importance of the habitat to be removed, modified, fragmented or isolated to the long-term survival of the threatened species, population or ecological community in the locality
(i) The Project is not anticipated to remove or modify preferred habitat of the Sydney Hawk Dragonfly. The species prefers smaller, shallow, isolated streams. Any impacts that may occur due to the Project would be restricted to the flood mitigation zone and urbanised areas of the downstream floodplain. (ii) The Project is not likely to fragment preferred habitat of the Sydney Hawk Dragonfly. (iii) The Project is not anticipated to remove or modify preferred habitat of the Sydney Hawk Dragonfly. The species prefers smaller, shallow, isolated streams. Any impacts that may occur due to the Project would be restricted to the flood mitigation zone and urbanised areas of the downstream floodplain.
(e) whether the proposed development or activity is likely to have an adverse effect on any critical habitat (either directly or indirectly)
No critical habitat has been declared for this species
(f) whether the proposed development or activity is consistent with a Priorities Action Statement,
Recovery actions for the Sydney Hawk Dragonfly include: ▪ Advice to consent and determining authorities ▪ Collation and review existing information ▪ Community and stakeholder liaison, awareness and education Compliance / enforcement ▪ Enhance, modify or implement NRM planning processes to minimize adverse impacts on threatened species ▪ Habitat rehabilitation ▪ Research / monitoring ▪ Targeted surveys and mapping. The Project is neither consistent, nor inconsistent with these recovery actions. The Project is not anticipated to adversely impact the implementation of these recovery actions.
(g) whether the proposed development constitutes or is part of a key threatening process or is likely to result in the operation of, or increase the impact of, a key threatening process
The proposed development may contribute (either directly or indirectly) to the following key threatening processes (KTPs): ▪ Degradation of native riparian vegetation along New South Wales water courses ▪ Installation and operation of instream structures and other mechanisms that alter natural flow regimes of rivers and streams ▪ Removal of large woody debris from New South Wales rivers and streams. These processes are already in happening to various degrees within the study area. The Project may contribute to degradation of riparian habitat, but this is likely to be restricted to the flood mitigation zone, and only when it is required. Impacts to the remaining riparian habitat in the study area are not anticipated to be different to those that have occurred in historical flood events. Several in-stream structures occur throughout the study area. The Project would not result in additional in-stream structures. The Project would not alter existing flow regimes during normal operations. Downstream flow regimes would be altered during flood events that result in the inundation of the flood mitigation zone. Flood waters stored in the flood mitigation zone would be released in a controlled manner, to minimise flood risk to life in the downstream catchment. The flow regime of the Hawkesbury-Nepean River is regulated and therefore is not natural, accordingly, this KTP is considered of limited relevance to the Project.

The Project would not involve the removal of large woody debris with the possible exception of the immediate downstream area in relation to the area required for construction activities. Accordingly, the Project is not considered to contribute to or be part of this KTP.
Conclusion
The Project is not anticipated to result in modifications to suitable habitat or reduce the availability of potential breeding habitat for the Sydney Hawk Dragonfly. As such, the Project is not likely to have a significant impact on the Sydney Hawk Dragonfly.

References

DPI (2007), Sydney Hawk Dragonfly: *Austrocordulia leonardi*. Port Stephens, Department of Primary Industries, Threatened Species Unit.

Macquarie Perch (*Macquaria australasica*), Endangered under the FM Act

The Macquarie Perch (*Macquaria australasica*) is known to prefer waterways with rocky substrate (Bruce *et al*., 2007). It has been recorded at several locations in the Hawkesbury-Nepean catchment. Macquarie Perch distribution within the study area is fragmented and they often occur in low numbers (Bruce *et al*., 2007; Knight, 2010). Bruce *et al*. (2007) and Knight (2010) recorded this species in 20 of 48 water bodies sampled, including the Colo River, lower Coxs River, Lake Burragorang and the Nepean River. This species was typically one of the most abundant species in locations where it was recorded (Bruce *et al*. 2007, Knight 2010).

eDNA analysis undertaken to inform this assessment suggest this species also occurs in the Kedumba River within the upstream study area.

Knight (2010) observed that all sites where Macquarie Perch (*Macquaria australasica*) occurred were in an undisturbed condition, suggesting that their distribution is limited by their sensitivity to in-stream habitat conditions.

Blue Mountains Perch (*Macquaria* sp. *nov. 'hawkesbury taxon'*)

The Blue Mountains Perch s thought to be restricted to the mid-reaches of small near pristine streams, at elevations of 35-420 m above sea level, mostly commonly at 100-175 m above sea level. It occurs in complex boulder habitats near pristine, clear streams in rugged gorges, with minimal sediment and nutrient loads, and little or no instream vegetation.

Historically the species was more widespread and has disappeared from areas such as the upper Kowmung River, Wollondilly River, and approximately 80 km of the Nepean River between the Bargo River junction and Penrith weir (Bray, 2020).

This species is not listed under the FM Act but in view of its taxonomy has been included in this assessment.

Assessment of significance

(a) in the case of a threatened species, whether the proposed development or activity is likely to have an adverse effect on the life cycle of the species such that a viable local population of the species is likely to be placed at risk of extinction
The population status of Macquarie/Blue Mountains Perch in the upstream study area is not well defined, but based known habitat associations, the Macquarie/Blue Mountains Perch is likely to prefer the upstream reaches of tributaries that flow into Lake Burragorang. These areas typically have habitat characterised by rocky substrate and good water quality, attributes that Macquarie/Blue Mountains Perch prefer. Potential impacts of the Project are limited to the flood mitigation zone, and areas downstream of this. Impacts included increase in the extent of areas under temporary inundation, and potential changes to water quality. These impacts do occur currently during flood and recession of Lake Burragorang and surrounding tributaries. The Project is not expected to reduce the area of occupancy of Macquarie/Blue Mountains Perch. Temporary inundation would occur in areas that may contain Macquarie/Blue Mountains Perch; however, Macquarie/Blue Mountains Perch is mobile and would likely be more affected by flood inflows, which would occur regardless of the Project. The Project is not likely to disrupt the breeding cycle of Macquarie/Blue Mountains Perch. Macquarie/Blue Mountains Perch spawning generally occurs during spring and early summer in shallow, fast-flowing water over gravel beds. The eggs, which are adhesive, stick to the gravel. Flood behaviour under current conditions would likely impact this to an extent however, the Project is not likely to exacerbate this.
(b) in the case of an endangered population, whether the proposed development or activity is likely to have an adverse effect on the life cycle of the species that constitutes the endangered population such that a viable local population of the species is likely to be placed at risk of extinction
Not applicable to a threatened species.
(c) in the case of an endangered ecological community or critically endangered ecological community, whether the proposed development or activity: **(i) is likely to have an adverse effect on the extent of the ecological community such that its local occurrence is likely to be placed at risk of extinction, or** **(ii) is likely to substantially and adversely modify the composition of the ecological community such that its local occurrence is likely to be placed at risk of extinction**
(i) Not applicable to a threatened species. (ii) Not applicable to a threatened species.

(d) in relation to the habitat of a threatened species, population or ecological community: **(i) the extent to which habitat is likely to be removed or modified as a result of the proposed development or activity, and** **(ii) whether an area of habitat is likely to become fragmented or isolated from other areas of habitat as a result of the proposed development or activity, and** **(iii) the importance of the habitat to be removed, modified, fragmented or isolated to the long-term survival of the threatened species, population or ecological community in the locality**
(i) The Project is not likely to modify, destroy, remove or isolate or decrease the availability or quality of habitat to the extent that the species is likely to decline. Macquarie/Blue Mountains Perch habitat gets inundated under existing flood conditions. This is not anticipated to change under the Project. (ii) The Project is not likely to lead to fragmentation of Macquarie/Blue Mountains Perch habitat. The upstream habitat for Macquarie/Blue Mountains Perch currently undergoes periods of inundation and recession of varying extents and over varying timeframes. While the Project would change areas of temporary inundation, flood and drought behaviour is not likely to be changed. (iii) The Project is not likely to modify, destroy, remove or isolate or decrease the availability or quality of habitat to the extent that the species is likely to decline. Macquarie/Blue Mountains Perch habitat gets inundated under existing flood conditions. This is not anticipated to change under the Project.
(e) whether the proposed development or activity is likely to have an adverse effect on any critical habitat (either directly or indirectly)
The Project is not likely to lead to fragmentation of Macquarie/Blue Mountains Perch habitat. The upstream habitat for Macquarie/Blue Mountains Perch currently undergoes periods of inundation and recession of varying extents and over varying timeframes. While the Project would change areas of temporary inundation, flood and drought behaviour is not likely to be changed.
(f) whether the proposed development or activity is consistent with a Priorities Action Statement
A recovery plan for the Macquarie Perch has been prepared under the EPBC Act (DoEE, 2019), and came into effect in February 2019. The objective of the plan is to ensure the recovery and ongoing viability of Macquarie Perch populations throughout the species' range (including historically translocated populations in Cataract Reservoir and the Mongarlowe and Yarra rivers). The plan defines the following six strategies to achieve this objective: ▪ Conserve existing Macquarie Perch (including historically translocated populations in Cataract Reservoir and the Mongarlowe and Yarra rivers) ▪ Protect and restore Macquarie Perch habitat ▪ Understand and address threats to Macquarie Perch populations and habitats ▪ Establish additional Macquarie Perch populations within the species' natural range ▪ Improve understanding of the biology and ecology of the Macquarie Perch and its distribution and abundance ▪ Increase participation by community groups in Macquarie Perch conservation. The Project is not anticipated to interfere substantially with the recovery of this species. The species is already subject to periodic flooding and recession.
(g) whether the proposed development constitutes or is part of a key threatening process or is likely to result in the operation of, or increase the impact of, a key threatening process
The proposed development may contribute (either directly or indirectly) to the following key threatening processes (KTPs): ▪ Degradation of native riparian vegetation along New South Wales water courses ▪ Installation and operation of instream structures and other mechanisms that alter natural flow regimes of rivers and streams ▪ Removal of large woody debris from New South Wales rivers and streams. These processes are already in happening to various degrees within the study are. The Project may lead to degradation of riparian habitat, but this is likely to be restricted to the flood mitigation zone, and only when it is required. Impacts to the remaining riparian habitat in the study area are not anticipated to be different to those that have occurred in historical flood events.

Several in-stream structures occur throughout the study area. The Project would not result in additional in-stream structures; however, existing structures would be modified. This in not likely to alter the existing flow regimes during normal operations. Downstream flow regimes would be altered during flood events that result in the inundation of the flood mitigation zone. Flood waters stored in the flood mitigation zone would be released in a controlled manner, to minimise flood risk to life in the downstream catchment. It is considered that this controlled release of floodwaters would benefit downstream aquatic habitat compared to existing flood releases from Warragamba Dam. Removal of large woody debris may occur during a flood event; however, this would occur during flood events without the Project. As such the impact of the Project on this KTP is considered negligible.
Conclusion
The Project is not anticipated to have a significant impact on the Macquarie Perch or Blue Mountains Perch.

References

Bray DJ (2020) *Macquaria sp. nov. 'hawkesbury taxon'* in Fishes of Australia, accessed 15 Oct 2020 https://fishesofaustralia.net.au/Home/species/5544#summary

Bruce A, Knight J, Creese B (2007) Survey of aquatic threatened species Macquarie Perch *(Macquaria australasica)* and Adam's emerald dragonfly *(Archaeophya adamsi)* within the Hawkesbury-Nepean catchment. Interim report to the Hawkesbury-Nepean Catchment Management Authority by the Department of Industry and Investment, Port Stephens Fisheries Centre.

DoEE (2019), *National Recovery Plan for Macquarie Perch (Macquaria australasica)*. Canberra, Department of the Environment and Energy.

Knight JT (2010) The feasibility of excluding alien redfin Perch from Macquarie Perch habitat in the Hawkesbury-Nepean catchment. Report prepared for the Hawkesbury-Nepean Catchment Authority.

Black Rockcod (*Epinephelus daemelii),* Vulnerable under the EPBC Act

As the Hawkesbury River widens as it approaches the lower estuarine areas and tidal influences begin to dominate water levels closer to the ocean, potential downstream impacts decrease with distance downstream until they become negligible. Other influences on hydrology and water quality in the downstream catchment may also be significant, such as inflows from downstream catchments (e.g., the Nepean River, Grose River, Macdonald River, and Colo River), runoff from rural and urban land uses, and discharges from sewage treatment plants.

Identification of a practicable downstream boundary for the aquatic ecology impact assessment considered both changes to downstream hydrology and to water quality .

An analysis of changes in water levels was carried out to identify where water levels were generally similar to pre and post-Project conditions. This was based on an assessment of the hydrographs at various downstream cross-sections. This identified that the change in water levels downstream would range from about 200 millimetres to 400 millimetres at Wisemans Ferry and decrease to less than 100 millimetres immediately downstream of Wisemans Ferry.

A second consideration in establishing the downstream boundary was potential changes in water quality associated with operation of the flood mitigation zone (the Project would not result in any changes in water quality in the dam during normal operations as there would be no change in the full supply level or how the dam is operated currently).

When the flood mitigation zone is capturing inflows from the Lake Burragorang catchment, there would be no change in downstream water quality. However, when captured water is being released from the flood mitigation zone after a flood event there is potential for impacts if the water quality of the captured water is worse than downstream water quality.

A detailed discussion around the downstream water quality impacts of the Project is provided in Chapter 27, Section 27.5.4 of the EIS. The assessment examined changes in Total Nitrogen, Total Phosphorus, chlorophyll-a, and Total Suspended Solids. The assessment identified that water quality in the flood mitigation zone was generally better than the downstream receiving environment and would not have any material impact on downstream quality.

On the basis of consideration of likely downstream hydrological and water quality changes, the downstream boundary for the aquatic ecology assessment has been set at Wisemans Ferry.

The Matters of National Environmental Significance: Significant impact guidelines (DoE 2013) define an ‘important population’ of a vulnerable species as being

> *a population that is necessary for a species’ long-term survival and recovery. This may include populations identified as such in recovery plans, and/or that are:*
>
> - *key source populations either for breeding or dispersal.*
> - *populations that are necessary for maintaining genetic diversity.*
> - *populations that are near the limit of the species range.*

An action is likely to have a significant impact on an endangered or critically endangered species if there is a real chance or possibility that it will: • **lead to a long-term decrease in the size of an important population of a species**
Black Rockcod occur in the far downstream study area, in the Hawkesbury River estuary. The Project is considered unlikely to impact on this species such that it would lead to a long-term decrease in the size of an important population of the species.
• **reduce the area of occupancy of an important population**
Black Rockcod occur in the far downstream study area, in the Hawkesbury River estuary. The Project is considered unlikely to impact on this species such that it would reduce the area of occupancy of an important population.
• **fragment an existing important population into two or more populations**
Black Rockcod occur in the far downstream study area, in the Hawkesbury River estuary. The Project is considered unlikely to impact on this species such that it would fragment an existing important population into two or more populations.

• **adversely affect habitat critical to the survival of a species**
Black Rockcod occur in the far downstream study area, in the Hawkesbury River estuary. The Project is considered unlikely to impact on this species such that it would adversely affect habitat critical to the survival of this species.
• **disrupt the breeding cycle of an important population**
Black Rockcod occur in the far downstream study area, in the Hawkesbury River estuary. The Project is considered unlikely to impact on this species such that it would disrupt the breeding cycle of an important population of this species.
• **modify, destroy, remove or isolate or decrease the availability or quality of habitat to the extent that the species is likely to decline**
Black Rockcod occur in the far downstream study area, in the Hawkesbury River estuary. The Project is considered unlikely to impact on this species such that it would adversely affect habitat critical to the survival of this species.
• **result in invasive species that are harmful to a vulnerable species becoming established in the vulnerable species' habitat**
Black Rockcod occur in the far downstream study area, in the Hawkesbury River estuary. The Project is considered unlikely to impact on this species such that it would result in invasive species that are harmful to this species becoming established in its habitat.
• **introduce disease that may cause the species to decline, or**
Black Rockcod occur in the far downstream study area, in the Hawkesbury River estuary. Impacts to the area are not anticipated to be major. Flood extents would be reduced. Other impacts relating to flood activity would remain unchanged to existing conditions.
• **interfere substantially with the recovery of the species.**
Black Rockcod occur in the far downstream study area, in the Hawkesbury River estuary. The Project is considered unlikely to impact on this species such that it would r interfere substantially with the recovery of this species.
Conclusion
No significant impact is anticipated for Black Rockcod.

References

Department of the Environment (DoE) (2013) Matters of National Environmental Significance: Significant impact guidelines 1.1 Environment Protection and Biodiversity Conservation Act 1999, Commonwealth of Australia.

Macquarie Perch *(Macquaria australasica)*, Endangered under the EPBC Act

Following the 2019-2020 bushfires, DAWE released a provisional list of animals requiring urgent management intervention. The list included the Blue Mountains Perch/Hawkesbury Perch (*Macquaria* sp*. nov. 'hawkesbury taxon'*) and identified it as 'endangered at the species level' under the EPBC Act. The IUCN Red List identifies this species as 'Vulnerable' (IUCN 2019). In light of this, it has been included in the following Assessment of Significance.

The Matters of National Environmental Significance: Significant impact guidelines (DoE 2013) defines a 'population' of an endangered species as being:

> *an occurrence of the species in a particular area. In relation to critically endangered, endangered or vulnerable threatened species, occurrences include but are not limited to:*
>
> - *a geographically distinct regional population, or collection of local populations, or*
> - *a population, or collection of local populations, that occurs within a particular bioregion.*

An action is likely to have a significant impact on an endangered or critically endangered species if there is a real chance or possibility that it will: • **lead to a long-term decrease in the size of a population**
The population status of Macquarie Perch and Blue Mountains Perch in the upstream study area is not well defined, but based on known habitat associations, they are likely to prefer the upstream reaches of tributaries that flow into Lake Burragorang. These areas typically have habitat characterised by rocky substrate and good water quality, attributes that both species prefer. Potential impacts of the Project are considered to be limited to the Flood Mitigation Zone. Potential impacts include an increase in the extent of areas under temporary inundation, and potential changes to water quality. These impacts currently occur during major inflow events in Lake Burragorang and surrounding tributaries. The Project is not considered likely to have a significant impact on these species such that there is a real chance or possibility that it will lead to a long-term decrease in the size of a population.
• **reduce the area of occupancy of the species**
The project is not expected to reduce the area of occupancy of Macquarie Perch and Blue Mountains Perch. Temporary inundation would occur in areas that may contain these species; however, both species are mobile and would likely be more affected by flood inflows, which would occur regardless of the Project.
• **fragment an existing population into two or more populations**
The project is not likely to lead to fragmentation of Macquarie Perch and Blue Mountains Perch habitat. The upstream habitat for these species currently undergoes periods of inundation and recession of varying extents and over varying timeframes. While the Project would extend areas of temporary inundation, flood and drought behaviour is not likely to be changed.
• **adversely affect habitat critical to the survival of a species**
The project is not likely to lead to fragmentation of Macquarie Perch and Blue Mountains Perch habitat. The upstream habitat for these species currently undergoes periods of inundation and recession of varying extents and over varying timeframes. While the Project would extend areas of temporary inundation, flood and drought behaviour is not likely to be changed.

• disrupt the breeding cycle of a population
The Project is not likely to disrupt the breeding cycle of Macquarie Perch or Blue Mountains Perch. Macquarie Perch spawning generally occurs during spring and early summer in shallow, fast-flowing water over gravel beds. The eggs, which are adhesive, stick to the gravel. Existing flood behaviour likely impact this to an extent however, the Project is not likely to exacerbate this. The spawning habitat preference of the Blue Mountains Perch species is unknown, but is likely to be over rocky substrate (IUCN 2019). As for the Macquarie Perch, these habitats are likely to already be affected by inflow events which would not change with the Project.
• modify, destroy, remove or isolate or decrease the availability or quality of habitat to the extent that the species is likely to decline
The Project is not likely to modify, destroy, remove or isolate or decrease the availability or quality of habitat to the extent that these species are likely to decline. Their habitat gets inundated under existing flood conditions, and including temporary changes to water quality such as increased turbidity. This is not anticipated to change under the Project.
• result in invasive species that are harmful to an endangered or critically endangered species becoming established in the endangered or critically endangered species' habitat
Invasive species harmful to these species already exist in the upstream study area. The Project is not anticipated to change the distribution of these species.
• introduce disease that may cause the species to decline
The disease Epizootic Haematopoietic Necrosis Virus (EHNV) represents a serious threat to both species. Potential carriers for EHNV include redfin and rainbow trout (DoEE, 2018). Invasive species harmful to the Macquarie Perch and Blue Mountains Perch already exist in the upstream study area. The Project is not anticipated to change the distribution of these species.
• interfere substantially with the recovery of the species.
The Project is not anticipated to interfere substantially with the recovery of these species. Both species are already subject to periodic flooding and recession.
Conclusion
No significant impact is anticipated for Macquarie Perch or the Blue Mountains Perch.

References

Department of the Environment (DoE) (2013) Matters of National Environmental Significance: Significant impact guidelines 1.1 Environment Protection and Biodiversity Conservation Act 1999, Commonwealth of Australia.

Department of the Environment and Energy (DoEE) (2018) *National Recovery Plan for Macquarie Perch (Macquaria australasica)*, DoEE/NSW Dept of Primary Industries

Department of Sustainability, Environment, Water, Population and Communities (2011) Draft referral guidelines for the endangered Macquarie Perch, *Macquaria australasica*.

IUCN (2019) Red List, Blue Mountains Perch *Macquaria sp. nov. 'Hawkesbury'* (https://www.iucnredlist.org/species/128972817/128972820)

Brisbane	Level 8, 200 Creek Street, Brisbane QLD 4000 PO Box 203, Spring Hill QLD 4004 Tel +61 7 3831 6744 Fax +61 7 3832 3627 Email brisbane@bmtglobal.com Web www.bmt.org
Denver	8200 S. Akron Street, #B120 Centennial, Denver Colorado 80112 USA Tel +1 303 792 9814 Fax +1 303 792 9742 Email denver@bmtglobal.com Web www.bmt.org
London	International House, 1st Floor St Katharine's Way, London E1W 1UN Tel +44 20 8090 1566 Fax +44 20 8943 5347 Email london@bmtglobal.com Web www.bmt.org
Melbourne	Level 5, 99 King Street, Melbourne 3000 Tel +61 3 8620 6100 Fax +61 3 8620 6105 Email melbourne@bmtglobal.com Web www.bmt.org
Newcastle	126 Belford Street, Broadmeadow 2292 PO Box 266, Broadmeadow NSW 2292 Tel +61 2 4940 8882 Fax +61 2 4940 8887 Email newcastle@bmtglobal.com Web www.bmt.org
Northern Rivers	5/20 Byron Street, Bangalow 2479 Tel +61 2 6687 0466 Fax +61 2 66870422 Email northernrivers@bmtglobal.com Web www.bmt.org
Perth	Level 4, 20 Parkland Road, Osborne, WA 6017 PO Box 2305, Churchlands, WA 6918 Tel +61 8 6163 4900 Email perth@bmtglobal.com Web www.bmt.org
Sydney	Suite G2, 13-15 Smail Street, Ultimo, Sydney, NSW, 2007 PO Box 1181, Broadway NSW 2007 Tel +61 2 8960 7755 Fax +61 2 8960 7745 Email sydney@bmtglobal.com Web www.bmt.org
Vancouver	Suite 401, 611 Alexander Street Vancouver, British Columbia V6A 1E1 Canada Tel +1 604 683 5777 Fax +1 604 608 3232 Email vancouver@bmtglobal.com Web www.bmt.org