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Environmental Impact Statement – Chapter 11: Aquatic ecology

Warragamba Dam Raising

Reference No. 30012078
Prepared for WaterNSW
10 September 2021

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11 Aquatic ecology

This Chapter provides an assessment of aquatic ecology during construction and operation of the Warragamba Dam Raising (the Project). The relevant Secretary's Environmental Assessment Requirements (SEARs) are shown in Table 11-1.

Table 11-1. Secretary's Environmental Assessment Requirements: Aquatic ecology

Desired performance outcomes	Secretary's Environmental Assessment Requirements[1]	Where addressed
6. Biodiversity Desired performance outcomes: 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.	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*.	Section 11.1 Section 11.4 Section 11.5
	2. The proponent must assess the downstream impacts on threatened biodiversity, native vegetation and habitats resulting from any changes to hydrology and environmental flows.	Section 11.5
	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.	Section 11.6
	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).	Section 11.4 Section 11.5

1. This chapter specifically addresses SEAR 6 in addition to those general requirements of the SEARs applicable to all chapters and as identified as such in Chapter 1 (Section 1.5, Table 1-1).

The aquatic assessment is supported by detailed investigations, which have been documented in Chapter 27 of the EIS (Water quality) and Appendix Q (Water quality statistical analysis). Also relevant are:

- Biodiversity – Upstream (Chapter 8)
- Downstream Ecological Assessment (Chapter 9)
- Matters of National Environmental Significance – Biodiversity (Chapter 12).

The proposed management and mitigation measures in Section 11.7 of this this chapter are collated in Chapter 29 (EIS synthesis, Project justification and conclusion).

11.1 Legislation and policies

Legislation relevant to the Project is discussed in Chapter 2 (Statutory and planning framework). Legislation, guidelines, specifications, and policy documents relevant to aquatic ecology are outlined in Table 11-2.

Table 11-2. Legislation, guidelines, specifications, and policies documents relevant to aquatic ecology

Legislation, guidelines, specification, or policy document	Where addressed
Environment Protection and Biodiversity Conservation Act 1999	Section 11.1.1
Fisheries Management Act 1994	Section 11.1.2
Threatened Species Conservation Act 1995	Section 11.1.3
Policy and Guidelines for Fish Habitat Conservation and Management (2013 update) (Fairfull 2013)	Section 11.1.4
Why do Fish Need to Cross the Road? Fish Passage Requirements for Waterways Crossings (Fairfull and Witheridge 2003)	Section 11.1.4
Aquatic Ecology in Environmental Impact Assessment – EIA Guideline Series (Lincoln Smith 2003)	Section 11.1.4
NSW Biodiversity Offsets Policy for Major Projects (Office of Environment and Heritage (2014b)	Section 11.1.4
Significant Impact Guidelines 1.1 – Matters of National Environmental Significance (Department of the Environment 2013)	Section 11.1.1 Section 11.1.4
Draft Referral Guidelines for the Endangered Macquarie perch, Macquaria australasica (Department of Sustainability, Environment, Water, Population and Communities 2011)	Section 11.1.1 Section 11.1.4

11.1.1 Environment Protection and Biodiversity Conservation Act 1999

The Project was referred to the then Commonwealth Department of the Environment and Energy (DoEE) by WaterNSW and subsequently determined to be a controlled action under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act). The referral was accompanied by a preliminary consideration of relevant matters of national environmental significance (MNES), principally those relating to biodiversity and heritage. The MNES under the EPBC Act relevant to aquatic ecology that could be potentially impacted are listed threatened species and communities (discussed further in Section 11.3.5).

The EPBC Act has been addressed regarding relevant Commonwealth guidelines and Attachment A to the SEARs.

One of the key assessment priorities for the Project under the EPBC Act is to determine whether there would be significant impacts to relevant MNES. In this regard, the Significant Impact Guidelines 1.1 – Matters of National Environmental Significance (DoE 2013) provide criteria for determining whether an activity would have a significant impact on MNES.

The *Draft Referral Guidelines for the Endangered Macquarie Perch, Macquaria australasica* (DSEWPaC 2011) provide information on impacting processes and mitigation specific to the Macquarie perch, and have been considered in this chapter.

11.1.2 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 FM 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 FM 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.

These triggers for assessment apply to the Project due to potential impacts on the Macquarie perch (*Macquaria australasica*), which is listed as endangered under the FM Act, 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.

The Department of Primary Industries was consulted with regard to matters falling under section 218 of the FM Act. It advised 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.

The Department of Primary Industries 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 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.

11.1.3 Threatened Species Conservation Act 1995

The *Threatened Species Conservation Act 1995* (TSC Act) was repealed when the *Biodiversity Conservation Act 2016* commenced on 25 August 2017. However, transitional arrangements allow SSI projects to be considered under previous legislation if the SEARs were issued before 25 August 2017. The initial SEARs for the Project were issued on 30 June 2017 and accordingly the TSC Act still applies.

The TSC Act provides for the identification, conservation and recovery of threatened species and their populations and communities. It also provides for designation of key threatening processes that could adversely affect threatened species, populations or ecological communities, or cause species, populations or ecological communities that are not threatened to become threatened.

11.1.4 Other legislation and policy relevant to fish and fish habitat conservation and management

Policy and Guidelines for Fish Habitat Conservation and Management (2013 Update)

This Policy supplements the assessment and management processes of the NSW Biodiversity Offset Policy for Major Projects (OEH 2014c) and Framework for Biodiversity Assessment (FBA) (OEH 2014a) as they relate directly to fisheries values. The document provides policies related to fish habitat management for specific work types, and guidelines for aligning project management with these policies. Of relevance to the Project are provisions for management of riparian habitat, in-stream structures and fish passage barriers, and temperature.

The policy and guidelines set out requirements associated with general fish habitat conservation and management, and barriers to fish passage, and provides requirements for development applications for these types of works as triggered under the FM Act. Importantly, an assessment of waterways and aquatic habitat values is required to support an application, including categorisation based on waterway class and habitat type. This is based primarily on desktop data, supplemented where necessary by a site assessment(s).

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

Why do fish need to cross the road? Fish passage requirements for waterways crossings

Fish passage is critical to the survival of Australian native fish, as approximately 70% of coastal species in south-eastern Australia migrate to complete their lifecycle. This guideline aims to minimise impacts on fish passage and general aquatic wildlife by providing practical guidance for the planning, design, construction, and maintenance of waterway crossings, particularly with regard to barriers to fish passage.

Warragamba Dam is an existing barrier to fish passage and there would be no material change to this with regard to the Project. As such, this guideline is of limited relevance to the Project (and relevant matters are already captured through the *Policy and Guidelines for Fish Habitat Conservation and Management (2013 Update)* (Fairfull 2013)).

Aquatic ecology in environmental impact assessment – EIA Guideline series

These guidelines outline considerations with regard to assessment of impacts to aquatic ecology as part of an environmental impact assessment (EIAs). 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 assessment.

NSW Biodiversity Offset Policy for Major Projects

This policy was introduced to standardise biodiversity assessment and offsetting for major project approvals in NSW. The policy applies to projects identified as State Significant Development (SSD) and State Significant Infrastructure (SSI) under the EP&A Act and works in conjunction with the *Biodiversity Conservation Act 2016* and FM Act.

The scope of the NSW Biodiversity Offset Policy for Major Projects is limited to projects with impacts to vegetation (for example, clearing) and is therefore mainly directed towards terrestrial biodiversity. With regard to aquatic biodiversity, the Policy notes (pp 13-14)

> *Impacts on water environments are more complex as they often require consideration of additional factors including water flow, connectivity of aquatic habitats, water pollution, downstream impacts, impacts on other aquatic users and geomorphology of the area.*
>
> *For aquatic biodiversity, the policy and FBA refers to the Fisheries NSW policy and guidelines for guidance on addressing aquatic impacts and offsetting.*
>
> *It is recognised that wetlands and saline vegetation can contain components of both aquatic and terrestrial biodiversity. To ensure there is clarity as to what guidelines need to be used to address these impacts, the following applies:*

- *saline wetland vegetation formations must be assessed according to the Fisheries NSW policy and guidelines. This includes plant community types such as coastal saltmarsh, mangroves and seagrasses.*
- *all other (non-saline) wetlands and riparian vegetation will be assessed under the FBA.*

The aquatic ecology assessment (Appendix F4) has been prepared with regard to relevant matters under the Policy. A separate biodiversity offset strategy has been prepared for the entire Project (refer Chapter 13).

11.2 Aquatic impact assessment methodology

The key objective of this assessment was to identify and assess aquatic ecological impacts related to the Project. Given the variable extent and quality of information available on baseline values and potential project impacts, a risk-based impact assessment approach was adopted for the assessment.

This accords with the *Aquatic Ecology in Environmental Impact Assessment – EIA Guideline Series* (Lincoln Smith 2003), and involves the following:

- description of the environmental values of the area specifically related to hydrology and flooding that may be affected by the Project (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.

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.

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 impact 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. This notwithstanding, consideration has still been given to relevant matters further downstream related to aquatic ecology.

11.3 Existing environment

The Hawkesbury-Nepean catchment is one of the largest coastal basins in NSW covering an area of about 21,400 square kilometres, stretching from Lithgow to Goulburn and the Illawarra escarpment up to Gosford (Figure 11-1). A summary of existing aquatic ecology relevant to the study environments (upstream and downstream/receiving) is provided below.

11.3.1 Upstream

The major sub-catchments that drain into Lake Burragorang include the Wollondilly River and Coxs River systems, which collectively cover an area of 9,050 square kilometres. Minor sub-catchments that drain into Lake Burragorang include the Nattai River, Kowmung River, Wingecarribee River, and Mulwaree River (Figure 11-2).

11.3.1.1 Rivers and creeks

The catchment upstream of Warragamba Dam accounts for about 40 percent of the total area of the Hawkesbury-Nepean River catchment. Lake Burragorang, the lake created by Warragamba Dam, receives inflow from several major rivers including the Wollondilly River to the south, Coxs River and Kowmung River to the west, and Nattai River, and Little River to the east. These major rivers each have individual sub-catchments comprising numerous lower order tributaries. Stream order classifications for the upstream study area are shown on Figure 11-3.

11.3.1.2 Declared wild rivers

Wild rivers are rivers that are in near-pristine condition in terms of animal and plant life and water flow and are free of the unnatural rates of siltation or bank erosion that affect many of Australia's waterways (OEH 2015). Wild rivers are declared under the *National Parks and Wildlife Act 1974* and managed to ensure restoration (where possible) and maintenance of the natural biological, hydrological, and geomorphological processes associated with wild rivers and their catchments. There is one declared wild river within the upstream catchment: the Kowmung River. The section of the Kowmung River that is declared as a wild river is outside of the flood mitigation zone. Wild rivers are discussed further in Chapter 20 (Protected and sensitive lands).

Figure 11-1. Hawkesbury-Nepean catchment

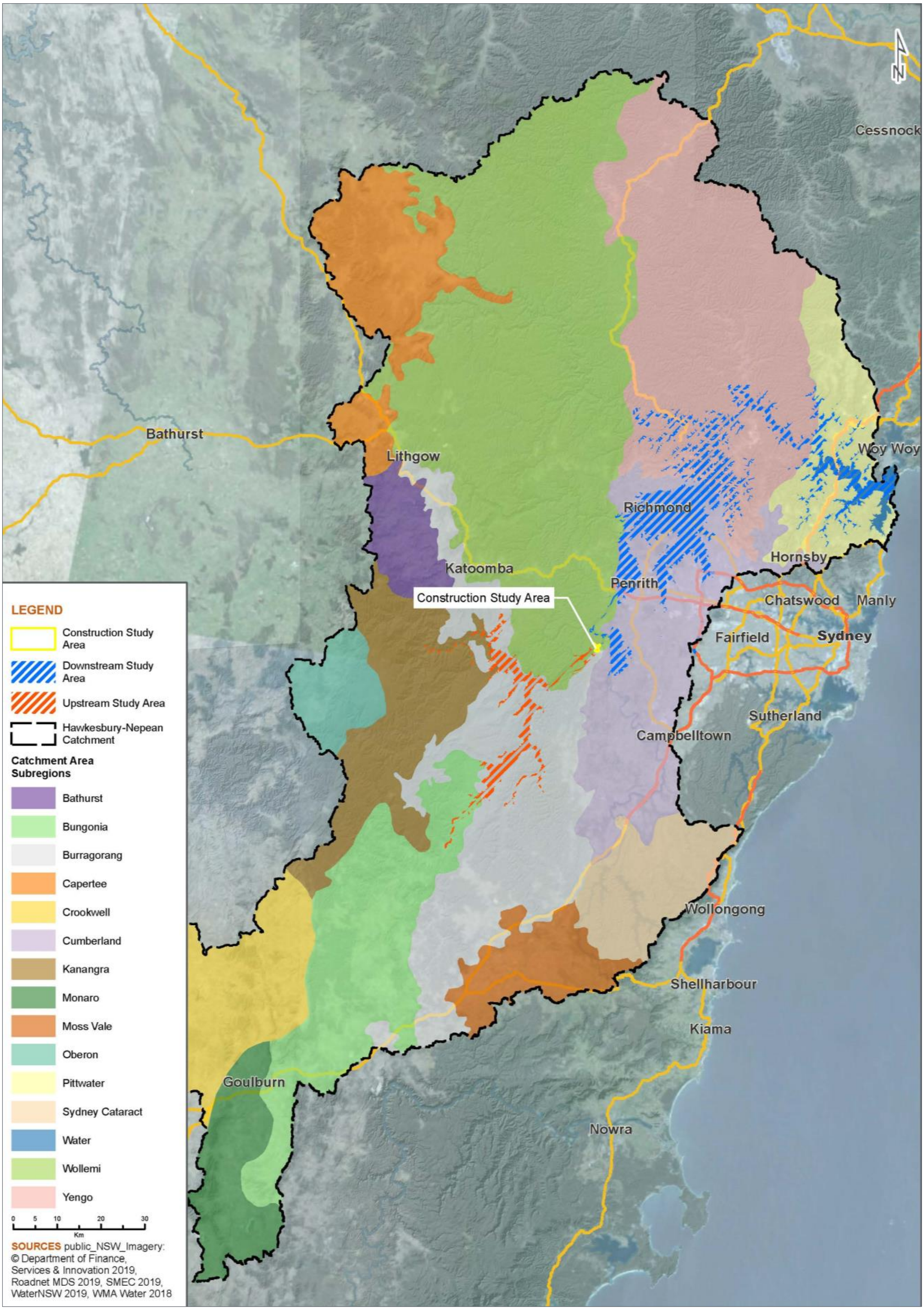


Figure 11-2. Upstream sub-catchments and major rivers

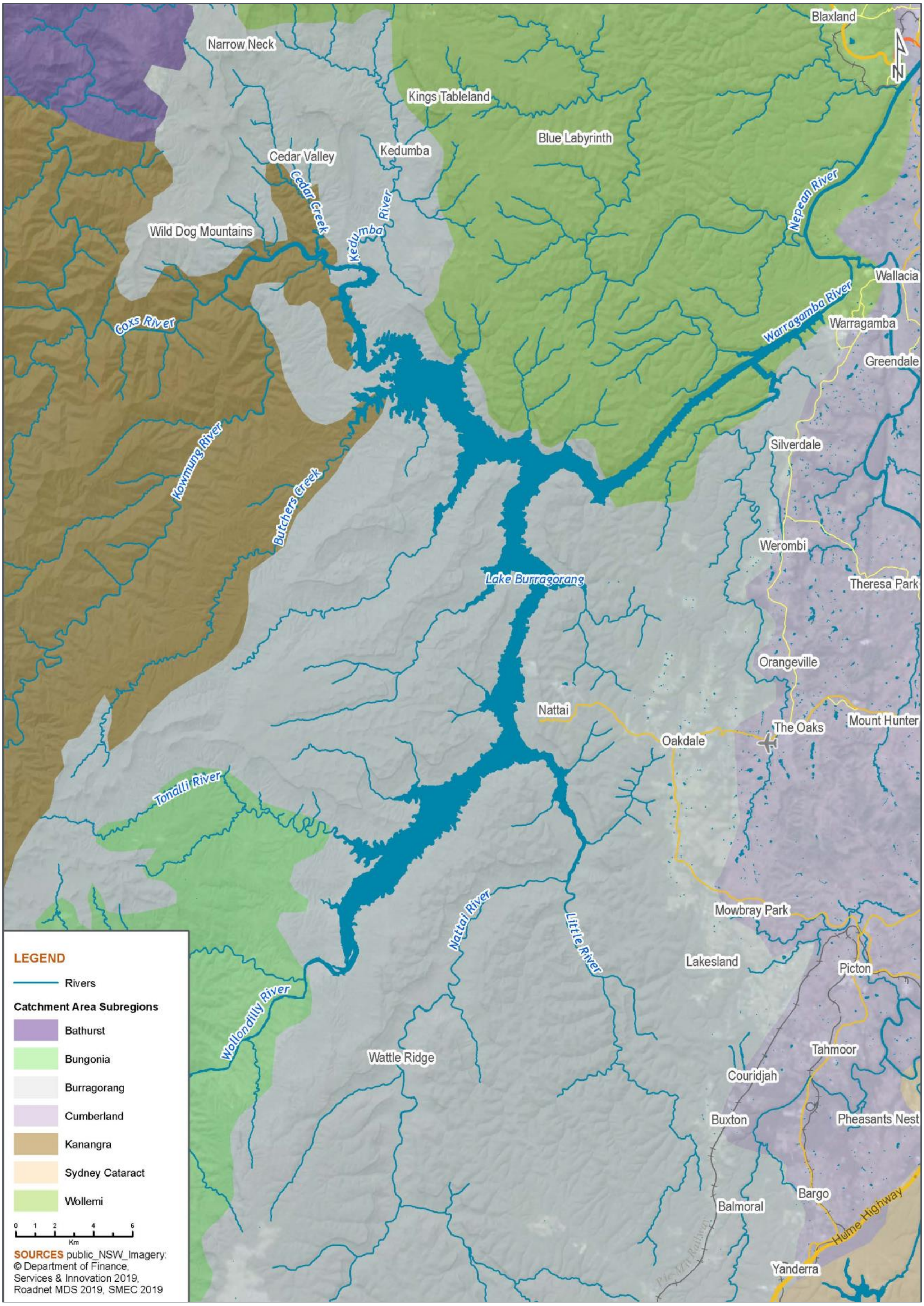


Figure 11-3. Stream order classifications – upstream study area

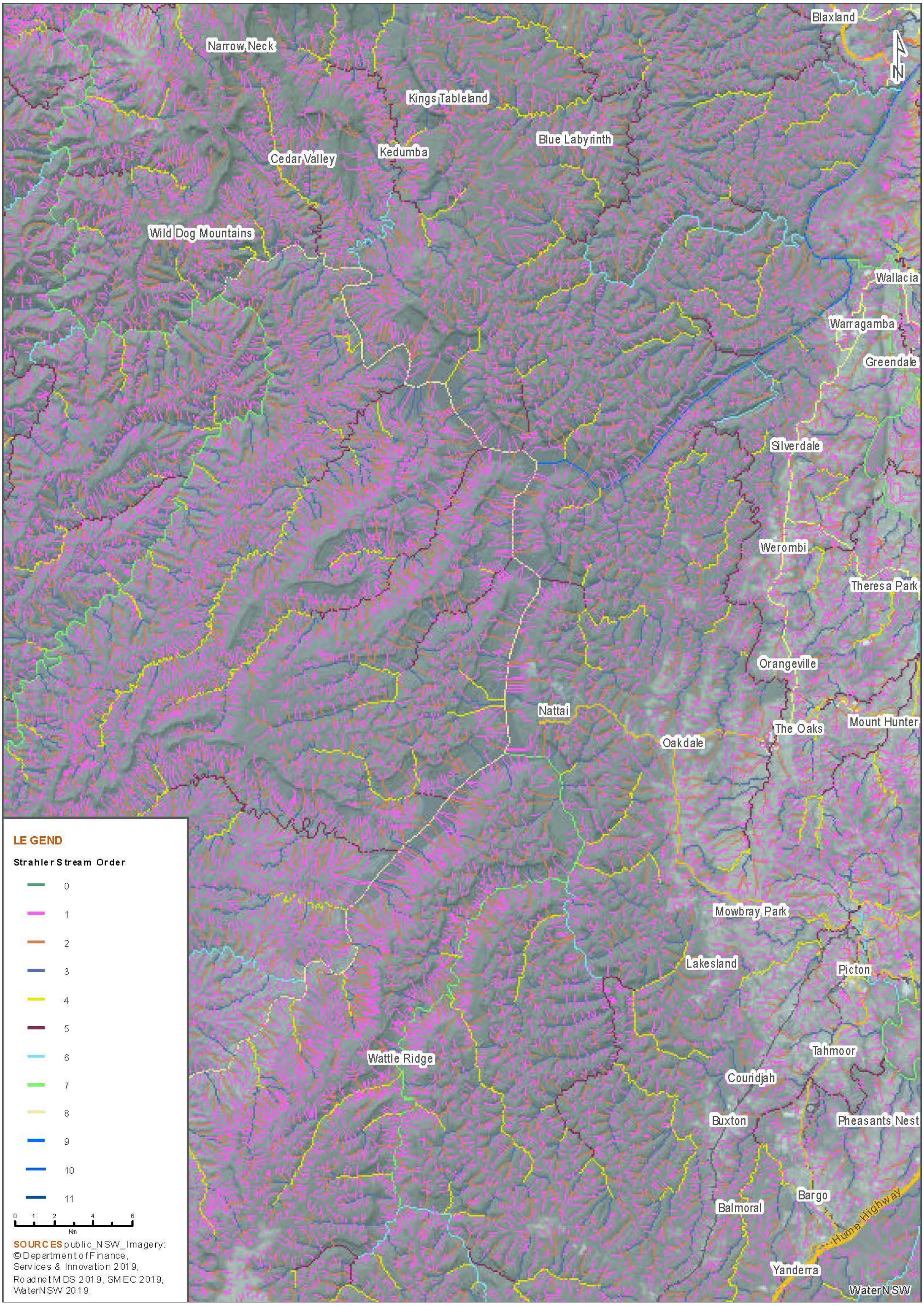
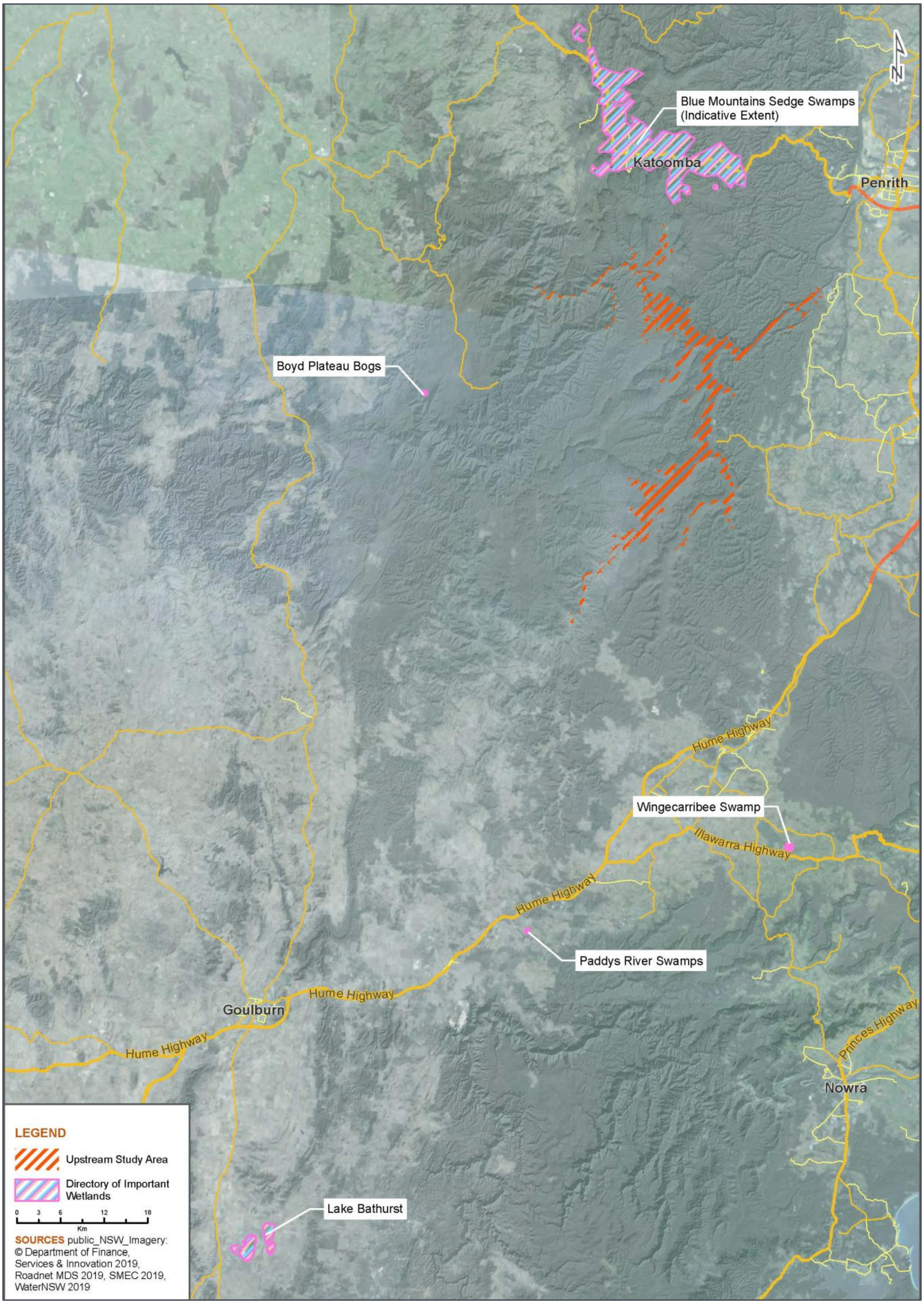


Figure 11-4. DIWA listed wetlands in the Hawkesbury-Nepean catchment



11.3.1.3 Wetlands

Wetland is a broad term used to describe bodies of water such as swamps, marshes, billabongs, and lakes. Wetlands 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. Wetlands are important transitional ecosystems between aquatic and terrestrial environments. They have important hydrological value playing a role in water storage and flood mitigation.

The Convention on Wetlands of International Importance (Ramsar Convention) commits contracting parties, including Australia, to designate wetlands that meet the Ramsar criteria, and include the conservation and wise use of wetlands in relevant national policy. There are no known Ramsar-listed wetlands in the study area.

The Directory of Important Wetlands in Australia (DIWA) identifies five wetlands within the upstream catchment:

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

The Blue Mountains sedge swamps are the closest DIWA wetlands 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 Project flood mitigation zone or the probable maximum flood (PMF) extent.

The Boyd Plateau Bogs area about 38 kilometres 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.

DIWA-listed wetlands within or near the upstream catchment area shown in Figure 11-4.

11.3.1.4 Lake Burragorang

Lake Burragorang covers a total waterway area of about 75 square kilometres and has a total operating capacity of 2,027 gigalitres, making it one of the largest water supply dams in the world. The lake is 52 kilometres in length, has 354 kilometres of foreshore at full supply level, with a maximum depth of 105 metres and receives an annual average rainfall total of 840 millimetres (WaterNSW n.d.b).

The current geomorphological condition at the lake is characterised by significantly altered hydrological and sediment transport regimes between the upstream catchment and downstream rivers and floodplain. Lake Burragorang is a significant sink for upstream sediment loads that would otherwise provide the river downstream its normal sediment load.

11.3.1.5 Aquatic flora

No comprehensive aquatic flora surveys have previously been undertaken in the reaches upstream of the Warragamba River confluence with the Nepean River, including the upstream study area. Qualitative aquatic macrophyte surveys were undertaken to inform this assessment through interrogation of aerial photograph and site inspections at Coxs River, Kedumba River, Wollondilly River, Nattai River, and Little River.

Surveys are presented in Appendix F4 (see Appendix A to Appendix F4) and show:

- 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.). 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 (less than ten percent
- green filamentous algae were abundant at sites with low riparian cover

- 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.

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.

11.3.1.6 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.

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 WaterNSW, 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 has shown a general trend of decline at many of the sites in the catchment
- the number of monitoring sites deemed to be within the AUSRIVAS referenced condition category has shown significant variation over the monitoring period
- there was improvement in sub-catchment macroinvertebrate conditions at some sites in 2013-2016 compared to previous years monitoring results
- the Lower Coxs River sub-catchment had the largest proportion of sites in reference condition compared to other sub-catchments monitored. Most sub-catchments adjacent to the upstream study area demonstrated consistent macroinvertebrate assemblage condition ranging between ‘similar to’ and ‘better than’ reference conditions
- monitoring sites in the Nattai River, Little River, lower Wollondilly River and Kedumba Rivers were typically below reference condition. Of these, the Kedumba River sub-catchment is subject to high stress – urban runoff and sewage discharges – demonstrated by high pathogen and nutrient loads
- the Upper Coxs River sub-catchment had the highest percentage of sites in the ‘severely impaired’ or ‘extremely impaired’ conditions categories
- the Kowmung River and Lake Burragorang typically had the highest percentage of samples in the similar to reference or richer than reference condition category.

11.3.1.7 Fish

Based on a review of available information and relevant studies, at least 27 species of freshwater fish are known to occur within the upstream study area (Knight 2010; GHD 2013; Alluvium Consulting Australia 2017). Of these, 20 species are native to Australia and the remainder are introduced species.

No detailed targeted extractive surveys of the 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 with 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 (for example, e-fishing, netting, trapping) were not feasible to undertake. Hence, non-destructive sampling methods were used. This rapid assessment agreed with previous studies.

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 (eight), Upper Coxs River (seven) and Wollondilly River (six). Low species diversity (less than five species) was found at all other sub-catchments. The Australian smelt (*Retropinna semoni*) and Flathead gudgeon (*Philypnodon grandiceps*) were the most widely distributed species recorded in the study area.

Table 11-3 summarises the freshwater fish species recorded in the study area sourced from DPI (2006), Knight (2010), and BMT WBM (2014).

Table 11-3. Freshwater fish species recorded in the Hawkesbury-Nepean River

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, Hallett & Beatty 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 ~700 m including rapids.	UE, DE

Scientific name	Common name	Origin	Migration pattern	Habitat requirements	Known/likely occurrence in study area [1]
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
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

Scientific name	Common name	Origin	Migration pattern	Habitat requirements	Known/likely occurrence in study area [1]
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 slow-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 ~600 m 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

11.3.2 Downstream

11.3.2.1 Rivers, creeks, and tidal limits

The five main rivers within the downstream study area are the Hawkesbury River, Nepean River, Grose River, Colo River, and the Macdonald River. The four major creeks within the downstream study area are Erskine Creek, Webbs Creek, South Creek, and Cattai Creek (refer Figure 11-5).

Directly below Warragamba Dam, the dam pool is located in an incised, steep sided 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 and extensive macrophyte beds are present in places.

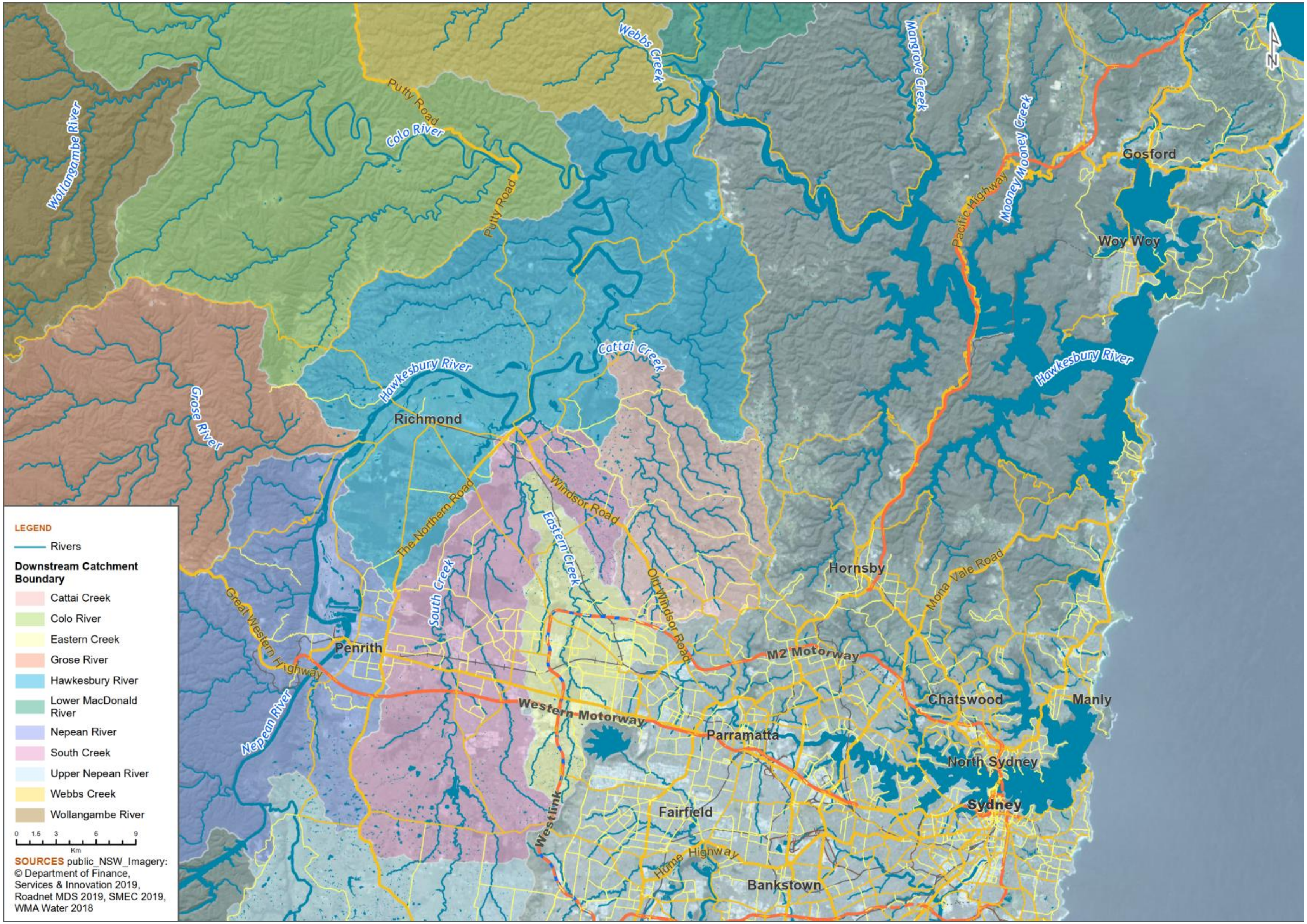
The tidal limit of the Hawkesbury River occurs near Yarramundi, approximately 140 kilometres upstream of the river mouth (Department of Natural Resources 2006; Krogh, Wright and Miller 2009). Near the tidal limit, the Hawkesbury River receives tributary inflows from the Grose River (at Yarramundi) and the Nepean River (further upstream of Yarramundi), and experiences moderate freshwater tidal influence (Gruber, Ferguson and Haine 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 Marys, and Quakers Hill.

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 modified 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 condition (GHD 2013). Several waterways were identified as poor 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 regulate river flow and create a series of segmented weir ponds rather than a free-flowing river. An example of this is Penrith Weir, which creates a significant weir pool upstream of Penrith and Emu Plains. Artificial lakes (for example, 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.

Figure 11-5. Downstream subcatchments and major rivers



11.3.2.2 Declared wild rivers

There are two declared wild rivers within the downstream catchment: the Colo River and the Grose River. Potential impacts to these rivers as a result of operation of the project are discussed further in Chapter 20 (Protected and sensitive lands).

11.3.2.3 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 vary in size from 0.3-208 hectares in the downstream reaches of the Hawkesbury-Nepean catchment (Smith & Smith 1996). Only about 50 of these wetlands are associated with the Hawkesbury-Nepean River downstream of Pheasants Nest and Broughtons Pass Weirs to the confluence of the Colo River. Most 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:

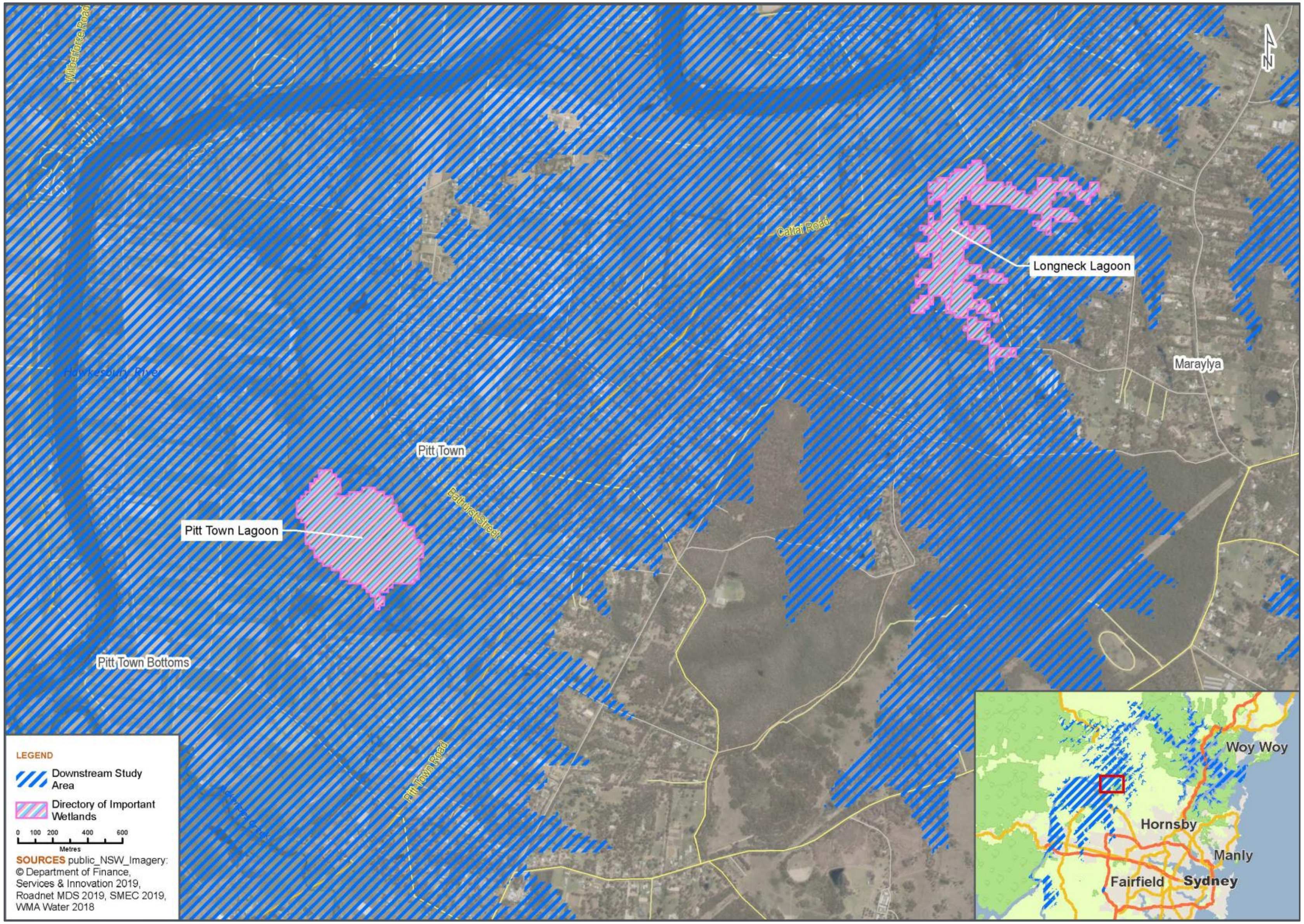
- DIWA listed wetlands (Figure 11-6):
  - Pitt Town Lagoon (NSW087)
  - Longneck Lagoon (NSW083)
- coastal wetlands located within the downstream study area or its sub-catchments.

There are no Ramsar wetlands in the downstream study area or its sub-catchments.

Pitt Town Lagoon and Longneck Lagoon are examples of the threatened 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 Appendix F2 (Downstream ecological assessment). Both these wetlands would continue to experience flooding in the 1 in 5 chance in a year and larger events; accordingly the Project is not anticipated to have a material impact on these wetlands.

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 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. In turn, this has reduced the ability of many downstream wetlands to be flushed by flows, either from their own catchments or from the river. The result is 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 11-6. DIWA listed wetlands – downstream



11.3.2.4 Aquatic flora

Downstream aquatic environments support many native and introduced (exotic) macrophyte species (Table 11-4). Historical changes to flow, geomorphological and water quality processes have resulted in habitat conditions that favour the proliferation of several aquatic macrophyte species, including problematic species introduced and native species (DPI 2014b). None of the aquatic flora species in Table 11-4 are listed as threatened species under the TSC Act.

Table 11-4. Aquatic macrophyte species in the Hawkesbury-Nepean catchment (DPI 2014b; Roberts, Church & Cummins 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 (Taylor-Wood 2003).
Senegal tea	*Gymnocoronis spilanthoides*	Exotic, Class 1, *National Environmental Alert List NSW Noxious Weeds Act 1993* (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
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, Weeds of National Significance (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.

11.3.2.5 Aquatic macroinvertebrates

Upstream

Regular macroinvertebrate monitoring in upstream environments has been undertaken by the Sydney Catchment Authority since 2001. The most recent audit addresses the period 1 July 2013 to 30 June 2016, and is documented in *2016 Audit of the Sydney Drinking Water Catchment* (Alluvium Consulting Australia 2017). The audit was documented in three volumes as follows:

- Volume 1 – Catchment Overview and Concepts, Audit Method, Key Findings and Recommendations
- Volume 2 – Detailed Analysis of Each Indicator
- Volume 3 – Supporting Technical Data and Detailed Information.

The audit was carried out by a team of specialist auditors with Dr Ian Wright of Western Sydney University having the role of 'Indicator specialist – Macroinvertebrates; Water quality'. A full list of the audit specialists is provided in Section 1.1 of Volume 2.

The audit report notes that the methodology adopted for the 2016 Audit was based on the internationally accepted Pressure-State-Response framework used for State of the Environment Reporting in Australia. The audit team reviewed multiple sources of evidence to determine the condition and trends of indicators relevant to water quality, water availability, biodiversity and habitats, land use and human settlements, and then current responses by government authorities to those conditions. The detailed analysis provided for macroinvertebrate health was considered sufficient to inform the assessment for the Project.

The audit used aquatic macroinvertebrates as an indicator of catchment health (together with various other complementary catchment health indicators). The AUSRIVAS (Australian River Assessment System) methodology was used to conduct sampling, assessment and reporting of aquatic macroinvertebrates. This compared observed macroinvertebrate results collected from sampling sites with modelled data that compared those results with predicted results (expected) for macroinvertebrate data in regional models based on collection from undisturbed reference sites (Alluvium Consulting Australia 2017).

The audit findings noted:

- macroinvertebrate health showed a general trend of decline at many of the sites in the catchment as demonstrated by monitoring results:
  - from between 2001 and 2009 which suggested that about 28 percent of monitoring sites were in significant to severe ecological impairment
  - from between 2001 and 2013 which suggested that about 50 percent of monitoring sites were in significant to severe ecological impairment
- monitoring results from between 2013 and 2016 suggested that the declining trend had stabilised with some monitoring sites showing slight improvement in ecological impairment, specifically the Lower Coxs River and Wollondilly River sub-catchments
- the number of monitoring sites within the reference condition category showed significant variation over the monitoring period as follows:
  - 13 percent of monitoring sites were within the reference condition category in 2010
  - 40 percent of monitoring sites were within the reference condition category in 2011
  - 28 percent of monitoring sites were within the reference condition category in 2013
  - 45 percent of monitoring sites were within the reference condition category between 2013 and 2016
  - The long-term average of monitoring sites within the reference condition category was 52 percent.
- the Lower Coxs River sub-catchment had the largest proportion 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 conditions except for monitoring sites in the Nattai River, Little River, lower Wollondilly River and Kedumba River; of these the Kedumba River sub-catchment was subject to the highest stress, urban runoff and sewage discharges, reflected by high pathogen and nutrient loads
- for 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 similar to reference or richer than

reference conditions. 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

- for 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 or greater to reference conditions.

Downstream

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

- the macroinvertebrate community was dominated by members of the phylum Arthropoda, for which Diptera (flies/midges), Coleoptera (beetles), Acarina (mites), Odonata (dragon/damsel flies), Trichoptera (caddisflies) were the most abundant orders
- 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
- sixteen (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
- sixty-nine (69) species of 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 *Centroptilum* 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
- members of the order Hemiptera comprised 23 species recorded from 12 families. Note this does not account for families present in lentic environments, which would add substantially to this number. Water boatman, *Micronecta batilla* (Corixidae) was the most abundant and is common throughout lowland rivers in south-eastern Australia
- the region is rich in Odonata, which favour wetlands and slow-flowing rivers and creek habitats. Thirty-five species from 11 families were recorded. The downstream study area is in the known distribution of numerous additional species
- 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 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

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.

Macroinvertebrate monitoring in the downstream study area (DECC 2009; DPI 2012), indicated that:

- macroinvertebrate assemblages were varied 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 at monitoring sites downstream of Yarramundi had lower taxonomic richness 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.

11.3.2.6 Fish

Freshwater fish species recorded in the downstream study area are summarised in Table 11-3 (see Section 11.4.1.7). Fish survey data (DPI 2016) for various downstream river reaches showed the following:

- **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.
- **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*).
- **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*).
- **Hawkesbury River from Grose River to Wilberforce** (which includes the freshwater/estuarine interface): 24 fish species have been recorded since 1994, comprised of 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.
- **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 dominated species.

11.3.3 Recreational and commercially important species

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 occur throughout the downstream study area. This species has been historically stocked in the Nepean River at Penrith and the Penrith Lakes system (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 Coxs River catchment at Lake Lyell.

11.3.4 Exotic, noxious, and pest species

11.3.4.1 Weed species

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 is the numerically dominant aquatic macrophyte species in many downstream areas (Roberts, Church and Cummins 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, Church and Cummins 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 (Healthy Rivers Commission (HRC) 1998; Hunt & 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 weed's potential to spread up the river and invade macrophyte beds that are relatively free of exotic species.

11.3.4.2 Fish species

Seven exotic fish species are known to occur in the Warragamba catchment, four of which are classified as noxious species under the FM Act. 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. For example, redfin perch (*Perca fluviatilis*) 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 which the threatened Macquarie perch is highly susceptible (Knight 2010). 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. It is anticipated that this species would move further downstream and invade Lake Burragorang. Once established in the lake, this species is likely to disperse up other tributaries, many of which are inhabited by Macquarie perch, posing a significant threat to perch populations.

11.3.5 Threatened species

11.3.5.1 Macroinvertebrates

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

Larvae of the Adam's 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. Adam's 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.

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 PMF.

11.3.5.2 Fish species

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 taxon'*), is likely present within the study area. While not officially listed as threatened under the EPBC

Act, the Blue Mountains perch 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.

Table 11-5 provides a summary of potential threatened species occurring in the study area, with detailed descriptions provided below for the species that are known or likely to occur – Macquarie perch (*Macquaria australasica*), Australia grayling (*Prototroctes maraena*) and black rockcod (*Epinephelus daemelii*).

Table 11-5. Threatened fish species known to or possibly occurring in the Hawkesbury-Nepean catchment

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 listing	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 19^{th} century in the Coxs Nepean and Wollondilly rivers. Stock in Cataract Dam and several water storages (Rowland 1989)
Bidyanus bidyanus	Silver perch	VU	NL	Similar to Murray cod, lowland turbid stream. Species is not found in cool, fast-flowing upland rivers of Murray-Darling Basin	No
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

11.4 Construction 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.

Earthworks would be required during construction of the Project. These would largely be undertaken in proximity to the existing dam, the existing spillway, the existing weir pool, and areas required for construction of the site compound and concrete batching plants. 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 environmental flows infrastructure
- other infrastructure elements.

These activities would involve excavation and stockpiling, clearing of vegetation, construction of temporary and permanent infrastructure. Collectively, these activities would require clearing of about 22.5 hectares of vegetation. 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 and 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 (for example, 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.

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 2002).

Impacts to water quality are assessed in Chapter 27 (Water quality). 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 conditions, these are expected to return to baseline concentrations rapidly and within a short distance of the construction study area.

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. 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 macroinvertebrate 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 viral encephalopathy and retinopathy (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).

Temporary and permanent 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 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
- 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 and indirect effects from and impacts to water quality. Impacts to water quality and aquatic ecology are discussed Chapter 27 (Water quality) and in Appendix F4 (Section 4.1.1) respectively.

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.

11.5 Assessment of potential operational impacts

Activities undertaken during operation of the flood mitigation zone that may result in impacts to aquatic environments and ecology include:

- use of the flood mitigation zone (potential upstream impacts)
- operation of (that is, release of water from) the flood mitigation zone (potential downstream impacts).

11.5.1 Upstream

Operation of the flood mitigation zone would result in a temporary increase in upstream water levels resulting in the temporary inundation of areas above full supply level (FSL). The depth (and duration) of temporary inundation would depend on a range of factors including the magnitude of the inflow event and the water level of Lake Burragorang at the time of the inflow event. The following discussion assumes Lake Burragorang is at the FSL, representing a conservative position for the assessment.

Areas affected by temporary inundation, including the upstream impact area, are principally around the perimeter of Lake Burragorang. The influence of the Project diminishes substantially moving up the catchment away from Lake Burragorang.

Inundation of the flood mitigation zone (including the upstream impact area) may result in impacts to aquatic ecology associated with:

- decay of vegetation, which has the potential to have short-to-medium term impact on water quality through the decomposition of organic matter as inundation takes place. This could increase nutrient loads and organic matter concentrations, which may cause algal blooms
- geomorphic changes, including increase in bank and in-stream erosion, causing an increase in sedimentation and turbidity
- creating additional temporary aquatic habitat which may become fragmented and isolated during operation (release of water) from the flood mitigation zone, potentially stranding aquatic fauna
- promotion of weed and exotic vegetation species growth in the flood mitigation zone.

Potential impacts on water quality associated with inundation of the flood mitigation zone are addressed in the water quality working paper.

Dewatering of the flood mitigation zone would occur over several days. The topography of much of the flood mitigation zone is gently sloping, and therefore water regress is unlikely to occur at a rate that would result in isolation of aquatic fauna species.

Lake Burragorang supports a range of native and introduced fish species, almost all of which do not have an obligatory marine phase. This includes the threatened Macquarie perch (*Macquaria australasica*) and the priority listed Blue Mountains perch (*Macquaria* sp. *nov. 'hawkesbury taxon'*), which migrate exclusively in freshwaters. The *Draft referral guidelines for the endangered Macquarie perch, Macquaria australasica* (DSEWPaC 2011) identify impacts considered to represent a high risk of impact to this species. These include disruption to riffle maintenance flows – which could occur during periods of temporary inundation. The likelihood of the other identified impacts is considered low.

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. The potential for this may temporarily increase during periods of inundation when lower flow velocities could be expected. However, flow velocities would be expected to increase as the flood mitigation zone is drawn done, and return to a similar state prior to inundation.

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 metres above sea level, mostly commonly at 100-175 metres 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 would be inundated during operation of the flood mitigation zone.

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. 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. 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.

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. 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 Appendix F4, Section 4.2). 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.

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

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 (see Appendix N2 – Geomorphology assessment report). Stream bed habitat in these areas is not considered suitable for Macquarie perch, and therefore impacts to this species are not anticipated.

The geomorphology assessment also concluded that the proposal would be unlikely to increase velocities in rivers in the upstream study area. Conversely, velocities are predicted to decrease and the depositional regime in dry season for the rivers would not change from the existing case. However, the assessment could not establish quantitatively if 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 transport/bedload transport to one of deposition.

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 and 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 would 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).

11.5.2 Downstream

Operation of the Project with the flood mitigation zone would still result in flooding of downstream environments; however, the extent of flooding relative to existing conditions would reduce. The operation of the Project (that is, during a flood event) would impact water levels, potentially contributing to ecological impacts and benefits, and geomorphic impacts in downstream environments. However, these need to be viewed in the context that floods have occurred 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. As noted, in Section 11.2, the downstream influence of the Project is essentially minimal beyond Wisemans Ferry.

In terms of obstruction of fish passage, it is unlikely that operation of the flood mitigation zone would increase the key threatening process – installation and operation of instream structures and other mechanisms that alter natural flow regimes of rivers and streams – downstream of the dam. Warragamba Dam does not have a fishway and, along with several weirs downstream from the dam, presents an impassable barrier to many fish species. A notable exception to this is Anguilla eels, which move from downstream environments 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 to 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 Project would not create any further obstruction to fish passage.

The Project includes the provision of infrastructure for environmental flows, or e-flows, but operation of the dam in this regard does not form part of the Project, nor part of 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.

Similarly, during operation of the flood mitigation zone, release 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, 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.

However, all floods pose a threat to 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 that may be released from the flood mitigation zone. These therefore need to be considered in the context of how the inundation of the flood mitigation zone may change the quality of water stored within the flood mitigation zone and Lake Burragorang prior to its release. These potential changes in water quality within the flood mitigation zone are discussed in detail in Chapter 27 (Water Quality). In short, the operation of the flood mitigation zone may lead to temporary increases in turbidity and sedimentation, nutrients (for example, through decay of inundated vegetation) and heavy metals (for example, liberated from eroded sediments).

Downstream of the dam, the operational release of floodwaters stored in the flood mitigation zone may increase the rate of bank erosion in the Penrith and Windsor area of the Nepean and Hawkesbury Rivers. This in turn could increase turbidity and sedimentation. Increased turbidity can contribute to reduced light penetration through the water column leading to reduced photosynthetic activity in aquatic plants. Increased sedimentation, specifically with regard to bedload, can lead to smothering of aquatic habitats (Department of Primary Industries 2013).

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 will be impacted during a flood event. 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. 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 that reaches upstream of Yarramundi. Still it would be important to continue to monitor macroinvertebrate assemblages over time, and particularly post-flood event to understand potential impacts.

With regard to threatened fish species, the following is noted:

- Australia grayling (*Prototroctes maraena*): there is no known distribution of this species in the study area. As such, the Project would not impact on this species
- Black rockcod (*Epinephelus daemelii*): this species occurs in caves, gutters and rocky reefs in near shore environments, with juveniles potentially also occurring in estuaries. These habitats do not occur in the construction area nor in the area affected by operation of the flood mitigation zone (that is, above Wisemans Ferry). As such, the Project is not expected to impact on this species.

The Sydney Hawk dragonfly (*Austrocordulia leonardi*) is listed as endangered under the FM Act. It spends most of its life underwater as an aquatic larva, before metamorphosing and emerging from the water as an adult. The species has specific habitat requirements and has only ever been collected from deep and shady river pools with cooler water (DPI 2007). The Adam's emerald dragonfly (*Archaeophya adamsi*) may have potential to occur in the downstream study area based on one record from Bedford Creek in the Lower Blue Mountains (which is outside of the downstream study area). The Project would generally reduce the extent of downstream flooding and is therefore not expected to impact habitat utilised by these two species.

Cold water stress is not anticipated to be an impact from operation of the flood mitigation zone. Water stored in large dams can become thermally stratified 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, and therefore cold-water pollution should not be an issue.

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 controlled to a degree. Modelling of flood velocities indicates that Project flood waters at a given location and flow rate would comprise similar velocity distributions to the 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 of flood hazard. When the flood mitigation zone is emptied, the Project would result in an increase in the duration of sustained bank-full velocities associated with the steady release rate of 100 gigalitres a day (see Chapter 15 - Flooding and hydrology). Operation of the flood mitigation zone results 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 geomorphic assessment concluded that during operation of the Project the largest/least frequent flood events are less likely (compared to existing scenarios) to cause bank erosion. However, the intermediate/more frequent (for example, one in 20 chance in a year) discharges from the flood mitigation zone may cause significant erosion risks. The rate of bank erosion in the Penrith and Windsor area of the Nepean and Hawkesbury Rivers may increase significantly with the Project, and to a lesser extent in 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 one in 20 chance in a year flood flows have a combination of high stream power and intermediate duration here, resulting in higher bank erosion potential.

Increased bank erosion could contribute to increased sediment loads being delivered to the waterway, both as suspended load and bedload. Increased sediments in the waterway could result in reduced light penetration, excessive sediment deposition, smothering of aquatic habitats (such as riffle zones), and increased amounts of toxic materials entering the food chain.

Impacts to geomorphic processes may also have consequent direct impacts to water quality, which in turn would have impacts on aquatic ecology. Water quality impacts are assessed separately in Chapter 27.

11.6 Summary of potential impacts to threatened species

Table 11-6 summarises the potential impacts to threatened species known or potentially occurring in the study area.

Table 11-6. Summary of potential impacts to known or potential threatened species

Species name	Potential construction impacts	Potential operational impacts	Occurrence
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.	Areas within the flood mitigation zone that in potentially support preferred habitat of the Macquarie perch are not anticipated to be subject to significant changes. 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 habitat of the Macquarie perch (i.e., rocky substrates) being altered through sediment deposition is low.	Upstream Downstream
Blue Mountains perch (*Macquaria sp. nov. 'hawkesbury taxon'*)	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.	Upstream Downstream
Australia grayling (*Prototroctes maraena*)	No known distribution within the study area. Construction impacts not anticipated to change to existing threats.	No known distribution within the study area. Operational impacts not anticipated to change to existing threats.	Known distribution does not overlap study area

Species name	Potential construction impacts	Potential operational impacts	Occurrence
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. These areas do not exist in the area of potential construction impact.	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.	Downstream estuary environment
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.	Upstream Downstream
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.	Downstream

Assessments of significance have been prepared for the species listed in Table 11-6 and are provided in Appendix F4 (Aquatic ecology assessment report). These concluded that the Project would not significantly impact any of these species.

11.7 Environmental management measures

Safeguards and management measures have been developed to avoid, minimise or manage potential impacts. Relevant management and mitigation measures are detailed in Table 11-7. These mitigation and management measures have been incorporated into the consolidated list of environmental management measures in Chapter 29.

Safeguards and management measures to protect water quality are detailed in Chapter 27 (Water quality) and Chapter 22 (Soils). These would also mitigate risks to aquatic ecology from the Project.

Table 11-7. Safeguards and management measures

Impact		Environmental management measure	Responsibility	Timing
Obstruction to fish passage	AE1	Access to the existing eel passageway would be maintained. Should construction activities require modification to the eel passageway, works should be carried outside of the period when likely to be used by juvenile eels.	Construction contractor	Pre-construction Construction
Obstruction to fish passage	AE2	Where required, temporary in stream structures would be constructed in accordance with the NSW DPI policy guideline and would be inserted during low-flow periods with management plans being submitted to NSW DPI detailing how high flow events would be managed. Dewatering of temporary in-stream structure would address the following matters: ▪ NSW DPI would be notified seven days prior to any dewatering activities to assess the need for potential fish rescue activities and to make appropriate arrangements for this. A separate s37 permit may be required from NSW DPI to relocate fish ▪ water is to be pumped a minimum of 30 metres away from the waterway and should preferentially not re-enter the waterway. If water is to re-enter the waterway, water quality would be managed in accordance with the approved water quality criteria for construction of the Project.	Construction contractor	Construction
Water quality	AE3	Water quality would be managed in accordance with the approved water quality criteria for construction of the Project.	Construction contractor	Construction
Erosion and bank stability	AE4	Scour protection and other bank stability mechanisms would be installed in the Warragamba River below the dam to minimise erosion and destabilisation of streambanks.	Design contractor Construction contractor	Pre-construction Construction
Aquatic habitat impacts	AE5	Aquatic habitat would be protected in accordance with Section 3.3.2 Standard precautions and mitigation measures of the *Policy and guidelines for fish habitat conservation and management (2013 update)* (Fairfull 2013).	Construction contractor	Pre-construction Construction
Aquatic habitat impacts	AE6	Existing monitoring programs would be reviewed and revised as required to effectively monitor potential impacts of the Project. The review would include consultation with DPI Fisheries.	WaterNSW	Pre-construction Construction Operation
Threatened species	AE7	Relevant safeguards and management measures detailed in the Draft referral guidelines for the endangered Macquarie perch, *Macquaria australasica* (DSEWPaC 2011) would be implemented as required.	Construction contractor	Construction

11.8 Risk assessment

An environmental risk analysis was carried out in accordance with the SEARs, using the methodology provided in Appendix C (Risk assessment procedure) of this EIS. A Project risk matrix was developed and risk ranking evaluated by considering:

- the likelihood (L) of an impact occurring
- the severity or consequence (C) of the impact in a biophysical and/or socio-economic context, with consideration of:
  - whether the impact would be in breach of regulatory or policy requirements
  - the sensitivity of receptors
  - duration of impact, that is, whether the impact is permanent or temporary
  - the areal extent of the impact and/or the magnitude of the impact on receptors.

The likelihood and consequence matrix is shown on Figure 11-7.

Once the consequence and likelihood of an impact are assessed, the risk matrix provides an associated ranking of risk significance: **Low**; **Medium**; **High** or **Extreme,** as shown in Table 11-8**.** The residual risk was determined after the application of proposed mitigation measures.

The risk analysis for potential aquatic ecology impacts is provided in Table 11-9. This includes the residual risk of the potential impact after the implementation of mitigation measures.

Table 11-8. Risk ranking definitions

Risk definitions	
Extreme 21 – 25	Widespread and diverse primary and secondary impacts with significant long-term effects on the environment, livelihood and quality of life. Those affected will have irreparable impacts on livelihoods and quality of life.
High 15 – 20	Significant resources and/or Project modification would be required to manage potential environmental damage. These risks can be accommodated in a project of this size, however comprehensive and effective monitoring measures would need to be employed such that Project activities are halted and/or appropriately moderated. Those impacted may be able to adapt to change and regain their livelihoods and quality of life with a degree of difficulty.
Medium 9 – 14	Risk is tolerable if mitigation measures are in place, however management procedures will need to ensure necessary actions are quickly taken in response to perceived or actual environmental damage. Those impacted will be able to adapt to changes.
Low 1 – 8	Ongoing monitoring is required however resources allocation and responses would have low priority compared to higher ranked risks. Those impacted will be able to adapt to change with relative ease.

Figure 11-7. Risk matrix

		Consequence				
		Negligible	**Minor**	**Medium**	**Major**	**Extreme**
	LEGAL	No legal consequences	No legal consequences	Incident potentially causing breach of licence conditions	Breach of licence conditions	Breach of licence conditions resulting in shutdown of Project operations.
	SOCIO-ECONOMIC	Impacts that are practically indistinguishable from the social baseline, or consist of solely localised or temporary/short-term effects with no consequences on livelihoods and quality of life.	Short-term or temporary impacts with limited consequences on livelihoods and quality of life. Those affected will be able to adapt to the changes with relative ease and regain their pre-impact livelihoods and quality of life.	Primary and secondary impacts with moderate effects on livelihoods and quality of life. Will be able to adapt to the changes with some difficulty and regain their pre-impact livelihoods and quality of life.	Widespread and diverse primary and secondary impacts with significant long-term effects on livelihoods and quality of life. Those affected may be able to adapt to changes with a degree of difficulty and regain their pre-impact livelihoods and quality of life.	Widespread and diverse primary and secondary impacts with irreparable impacts on livelihoods and quality of life and no possibility to restore livelihoods.
	HEALTH	No health consequences	Accident or illness with little or no impact on ability to function. Medical treatment required is limited or unnecessary.	Accident or illness leading to mild to moderate functional impairment requiring medical treatment.	Accident or illness leading to permanent disability or requiring a high level of medical treatment or management.	Accident, serious illness or chronic exposure resulting in fatality.
	ENVIRONMENT	Localised (on-site), short-term impact on habitat, species or environmental media	Localised or widespread medium-term impact to habitat, species or environmental media	Localised degradation of sensitive habitat or widespread long-term impacts on habitat, species or environmental media. Possible contribution to cumulative impacts.	Widespread and long-term changes to sensitive habitat, species diversity or abundance or environmental media. Temporary loss of ecosystem function at landscape scale. Moderate contribution to cumulative impacts.	Loss of a nationally or internationally recognised threatened species or vegetation community. Permanent loss of ecosystem function on a landscape scale. Major contribution to cumulative effects
		A - negligible	**B** - minor	**C** - medium	**D** - major	**E** - extreme
Expected to occur during the Project or beyond the Project	**a** - expected	**13**	**14**	**20**	**24**	**25**
May occur during the Project or beyond the Project	**b** - may	**8**	**12**	**19**	**22**	**23**
Possible under exceptional circumstances	**c** - possible	**6**	**7**	**11**	**18**	**21**
Unlikely to occur during the Project	**d** - unlikely	**4**	**5**	**10**	**16**	**17**
Rare or previously unknown to occur	**e** - rare	**1**	**2**	**3**	**9**	**15**

Risk Definition (see Table 11-8)	**Low**	**Medium**	**High**	**Extreme**

Table 11-9. Aquatic ecology: risk assessment

Key impacts	Risk before mitigation			Mitigation and Management	Risk after mitigation			Residual risk
	L	C	R		L	C	R	
Construction								
Impacts associated with: ▪ obstruction to fish passage ▪ erosion and bank stability ▪ removal of aquatic habitat ▪ aquatic habitat impacts ▪ waste discharges	b	D	**22**	AE1, AE2, AE3, AE4, AE6	c	C	**11**	There is an Extreme risk of impacting water quality and aquatic ecology due to uncontrolled management of wastes, materials and construction activities. This would result in degradation of downstream aquatic habitats. Mitigation measures are well developed and can be readily applied to manage site activities and the risk of environmental harm can be significantly reduced to a Medium residual risk. However, sufficient resources would be required to ensure mitigation measures are appropriately implemented, including quickly responding to a potential incident.
Operation								
Upstream Flood inundation causing changes to aquatic habitats and water quality	b	C	**19**	AE5	b	B	**12**	Rapid inundation of the FMZ may result in reduced water quality and aquatic habitat modification, however, changes to current inundation extent and durations are not expected to significantly impact on the aquatic environment. Implementing catchment management measures to reduce water quality impacts (see Chapter 27 – Water quality) and managing dam discharges would reduce potential consequences, resulting in a Medium residual risk.
Downstream Changes to dam discharges and flood regimes including: ▪ reduction in inundation extent and increase time for floods to reside ▪ water quality changes ▪ habitat modification	b	C	**19**	AE5	b	B	**12**	Downstream water quality and aquatic habitats may be influenced by changes to flow regimes and there is a High risk due to local degradation of environmental qualities. Mitigation includes operational protocols to regulate flood and environmental flows, which would reduce this to a Medium risk. This risk is likely to be further reduced as the benefits of more regulated environmental flows become entrenched.

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