Appendix K
Surface water quality and aquatic ecology assessment report

Billabong Creek Regulators Surface Water Quality and Aquatic Ecology Assessment

Document no: DE19-823-YCM2-DE-EN-RPT-0003
Version: 3-0

NSW Department of Climate Change, Energy, the Environment and Water

Billabong Creek Regulators EIS

Billabong Creek Regulators
Surface Water Quality and Aquatic Ecology Assessment

Client name: NSW Department of Climate Change, Energy, the Environment and Water

Project name: Billabong Creek Regulators EIS

Client reference:

Project no: IW238424

Document no: DE19-823-YCM2-DE-EN-RPT-0003

Version: 3-0

Prepared by: James Shelley and Kate Byrnes

Date: 13/08/2024

File name: DE19-823-YCM2-DE-EN-RPT-0003-BillabongEIS-AquaEcol-RevB

Document history and status

Version	Date	Description	Author	Checked	Reviewed	Approved
1-0	31/5/24	DRAFT	James Shelley and Kate Byrnes	Jean-Michel Benier,		
2-0	21/6/24	DRAFT	James Shelley and Kate Byrnes	Jean-Michel Benier	Mike Luger, Tony Paul	
3-0	13/8/24	FINAL report	James Shelley and Kate Byrnes	Jean-Michel Benier	Mike Luger	D Chubb

Distribution of copies

Version	Issue approved	Date issued	Issued to	Comments

Jacobs Group (Australia) Pty Limited

Floor 13, 452 Flinders Street
Melbourne, VIC 3000
PO Box 312, Flinders Lane
Melbourne, VIC 8009
Australia

T +61 3 8668 3000
F +61 3 8668 3001
[Website]

Executive summary

The NSW Department of Climate Change, Energy, the Environment and Water (DCCEEW) proposes to replace two existing weirs along Billabong Creek with new regulators. The two existing weirs to be demolished are Hartwood Weir and Wanganella Weir. DCCEEW is seeking approval from the NSW Minister for Planning under the NSW *Environmental Planning and Assessment Act 1979* (EP&A Act) for the proposal. This report has been prepared on behalf of DCCEEW for the proposal to support the environmental impact statement (EIS) and responds to the Secretary's Environmental Assessment Requirements (SEARs) for surface water quality and aquatic ecology.

The assessment presented in this report has included a review of relevant legislation, policy and guidelines related to surface water and aquatic ecology, as well as consideration of existing conditions through desktop assessment and field observations. The report builds on findings from the *Billabong Creek Regulators Hydrology Assessment* (Jacobs, 2024a) and the *Billabong Creek Regulators Geomorphology Assessment* (Jacobs, 2024b) prepared for the proposal, which are addressed in separate reports.

Methodology

The surface water quality and aquatic ecology impact assessment for the construction and operation of the proposal has been prepared based on a review and analysis of available aquatic fauna and water quality data, relevant literature and database searches, management plans and background reports, concept and detailed design, applicable legislation, policies and guidelines and a site visit comprising of aquatic habitat and waterway conditions assessment, environmental DNA (eDNA) sampling and water quality sampling.

Existing environment

The proposal is located on Billabong Creek, which is part of the Yanco Creek System in south-west New South Wales and forms part of the Murray-Darling Basin (MDB). The Yanco Creek System is a complex braided system of interconnecting creeks and anabranches with the main branches being Yanco, Colombo, Billabong and Forest Creeks.

Billabong Creek is a significant waterway that travels over 300 kilometres in a westerly direction and drains a catchment of approximately 791 square kilometres. Billabong Creek can be divided into three reaches based on its hydrology, ecology and geomorphology. The upper reach of Billabong Creek is unregulated and flows most of the time due to catchment rainfall. The mid Billabong Creek extends from the Colombo Creek confluence to the Yanco Creek confluence and is free-flowing upstream of Jerilderie Town Weir. Mid Billabong Creek is regulated downstream of Jerilderie by numerous weirs. The Lower Billabong Creek extends from the Yanco Creek confluence to where Billabong Creek discharges into the Edward River at Moulamein and is heavily regulated due to numerous weirs. Hartwood Weir is located on the mid Billabong Creek and Wanganella Weir is located on the lower Billabong Creek.

The proposal lies wholly within the bounds of the 'aquatic ecological community in the natural drainage system of the lower Murray River catchment', also known as the 'Lower Murray River aquatic ecological community'. The desktop review identified that Billabong Creek was predicted habitat for a number of listed threatened species and populations. However, upon further review of literature and assessment of the waterway conditions in the field surrounding the proposal study area, it was determined that only three species namely Murray Cod, Silver Perch and Freshwater Catfish are likely to be present. These three species have high conservation significance and are listed under one or both of the FM Act and the EPBC Act.

Analysis of existing water quality data and grab samples collected during the site visit assessed the key indicators of pH, electrical conductivity, dissolved oxygen, turbidity and nutrients. Generally, pH and electrical conductivity were below the basin plan and Australian and New Zealand Guidelines (ANZG) (2018) recommended guideline values for the protection of nominated water quality objectives. Dissolved oxygen levels were variable, with non-compliance more commonly associated with dissolved oxygen levels below the lower guideline values. Turbidity levels were consistently high in Billabong Creek and increased with distance downstream. Where nutrient data was available, it also showed elevated concentrations that exceeded the guidelines.

Construction impacts

Construction of the proposal would involve a range of activities including vegetation clearing, earthworks, concrete works, establishment of construction compounds and instream works including construction and dewatering of cofferdams, streambed excavation and demolition of existing structures. It was determined that without management, that impacts to aquatic ecology and water quality could occur through several impact pathways. Potential direct and indirect impact pathways that were identified included:

- Direct harm or mortality of aquatic fauna from contact with equipment and machinery.
- Direct harm or mortality of aquatic fauna from noise and vibration during instream works. Noise and vibration may also result in behavioural changes for species.
- Direct loss or degradation of instream habitat through changes to water quality and water regime such as sedimentation (i.e. infilling habitat features or smothering aquatic vegetation), removal of vegetation increased light levels and temperature) and accidental spills and leaks resulting in release of oils and fuels.
- Loss of connectivity and impeded fish passage from temporary barriers associated with instream work areas (dry work areas), potentially leading to decreased productivity and spawning due to reduced ability to migrate up and downstream.
- Temporary barriers to aquatic fauna passage from instream work areas (dry work areas), leading to behavioural changes for species such as movement across land by freshwater turtles, Platypus, and Rakali (water-rat) which could present an increased risk of predation.
- Reduced water quality, particularly increased turbidity which may lead to direct harm or mortality of aquatic species from clogging fish gills, reduced visibility for fish and other aquatic biota, or reduced light penetration through the water column which may limit growth of aquatic macrophytes.
- Reduced water quality, particularly increased nutrient loading released from mobilised sediments potentially leading to increased risk of algal blooms. Algal blooms could subsequently lead to direct impacts to aquatic fauna from clogging fish gills or lead to fish kills in areas of anoxic water following decomposition of algae.
- Reduced water quality, particularly increased pH from mobilisation of extremely alkaline concrete waste products (i.e., concrete slurries, concrete dust or washout water) may directly harm or kill aquatic species which cannot tolerate changes to pH.
- Proliferation of weeds, pest species or pathogens that can tolerate poor water quality and subsequently result in further degradation of water quality and habitat.

With the implementation of safeguards and management measures it was determined that the risk rating for these impact pathways was between ‘medium’ and ‘very low’, but mostly ‘low’ and ‘very low’. As such it is expected that the water quality objectives and aquatic ecosystem values in the study area (including threatened species and key fish habitat) would be protected during construction.

Operational impacts

During operation, the proposal is expected to improve native fish populations and the delivery of environmental water by reestablishing river connectivity and fish passage so that fish can complete their life cycles and avoid predation – a common occurrence below weirs and barriers to fish passage. Although the proposal would result in considerable benefits to the native aquatic fauna communities within Billabong Creek, there are also some potential adverse impacts associated with the replacement regulators and proposed Yanco Creek System Operations Plan. The potential broad impacts pathway categories identified for the operation of the proposal included:

- Loss of connectivity and impeded passage for native aquatic species due to deterioration of fish passage over time, and fragmentation of terrestrial habitat for turtles, Platypus and Rakali.
- Degradation of aquatic habitat through water quality (operation of new regulators results in increased erosion and sedimentation and accidental spills during maintenance) or water regime changes (changed flow conditions are unsuitable for aquatic species).
- Proliferation of aquatic pest species and spread of aquatic weeds.
- Direct impacts to aquatic habitat or species related to the operation of vehicles as part of operation and maintenance activities.

It is important to note that most of these impacts are already evident to varying degrees at the existing Hartwood and Wanganella Weirs.

The design of the replacement new regulators for the proposal would allow for improved control of environmental flows and fish passage that would result in improved connectivity for native aquatic species, relative to current conditions. Hydraulic and hydrological modelling indicates that operation of the new regulators will result in relatively minor changes to flow and velocity regardless of the operating flow setting (maximum or minimum) that are unlikely to negatively impact the native aquatic community. With the implementation of management measures and additional safeguards, the risk rating derived for the risk pathways were 'low' and 'very low' in all instances.

Cumulative effects

Positive and negative cumulative effects may arise from construction and operation of the replacement new regulators for the proposal. During construction, with the implementation of safeguards and management measures, the risks to water quality and aquatic ecology were mostly considered 'low' to 'very low', and at most 'medium', as such there are not expected to be any cumulative impacts.

Cumulative impacts to hydraulic and hydrological nature of the study area due to operation of the proposal were considered, accounting for the new regulators and the closely associated Forest Creek Return Flows Project. On the whole it was determined that there would be no cumulative impacts for mid or lower Billabong Creek following implementation of these projects.

A potential positive cumulative effect of the proposal is an increase in fish passage due to the incorporation of fishways into the proposed regulators. While these structures are expected to facilitate upstream fish movement by at least ~14km above the Wanganella Regulator and ~16km above the Heartwood Regulator, the potential benefits for fish communities are lessened by the presence of other existing instream structures (e.g. farm dams and weirs) that present barriers to fish movement.

Summary

Based on the assessment of the existing water quality and aquatic environments, the design of the new regulators, and the proposed safeguards and management practices, it was concluded that water quality objectives and aquatic ecosystem values within the study area would be adequately protected during both construction and operation of the proposal.

Important note about this report

The 3Rivers Joint Venture (3Rivers), a joint venture between Jacobs Group (Australia) Pty Limited and GHD Pty Ltd has been engaged to provide certain Engineering and Approvals Services for the NSW Sustainable Diversion Limit Adjustment Mechanism (SDLAM) program in accordance with the Agreement between 3Rivers and the NSW Department of Climate Change, Energy, the Environment and Water (DCCEEW) (the client).

The sole purpose of this report and the associated services performed by Jacobs is to review the potential environmental effects associated with the construction and operation of the Billabong Creek Regulators in accordance with the scope of services set out in the contract between 3Rivers and the Client. That scope of services, as described in this report, was developed with the Client.

In preparing this report, Jacobs has relied upon, and presumed accurate, any information (or confirmation of the absence thereof) provided by the Client and/or from other sources. Except as otherwise stated in the report, Jacobs has not attempted to verify the accuracy or completeness of any such information. If the information is subsequently determined to be false, inaccurate or incomplete then it is possible that our observations and conclusions as expressed in this report may change.

Jacobs derived the data in this report from information sourced from the Client (if any) and/or available in the public domain at the time or times outlined in this report. The passage of time, manifestation of latent conditions or impacts of future events may require further examination of the project and subsequent data analysis, and re-evaluation of the data, findings, observations and conclusions expressed in this report. Jacobs has prepared this report in accordance with the usual care and thoroughness of the consulting profession, for the sole purpose described above and by reference to applicable standards, guidelines, procedures and practices at the date of issue of this report. For the reasons outlined above, however, no other warranty or guarantee, whether expressed or implied, is made as to the data, observations and findings expressed in this report, to the extent permitted by law.

This report should be read in full and no excerpts are to be taken as representative of the findings. No responsibility is accepted by Jacobs for use of any part of this report in any other context.

This assessment has been prepared in the timeframe and on the basis of the project description prepared by the client and within the limits of the budget approved for the work.

This report has been prepared on behalf of, and for the exclusive use of, the Client, and is subject to, and issued in accordance with, the provisions of the contract between 3Rivers and the Client. Jacobs accepts no liability or responsibility whatsoever for, or in respect of, any use of, or reliance upon, this report by any third party

Contents

Appendices

Tables

Figures

Glossary

Term	Description
Anabranch	A section of a river or stream that diverts from the main channel of the watercourse and rejoins downstream.
Clearing area	This is the area required to construct the proposed infrastructure. Within this area it is assumed that all vegetation would be removed, including trees and ground cover vegetation. Borrow pits also include a clearing area.
Commonwealth Environmental Water Holder	The Commonwealth Environmental Water Holder is a statutory position established under the *Water Act 2007* (Cth) responsible for managing the Commonwealth's environmental water holdings. These water holdings are used to protect or restore environmental assets of the Murray-Darling Basin.
Construction activity zone	The area surrounding and including the 'clearing area' that would be used for construction purposes e.g., laydown, site sheds, parking. It is assumed topsoil will need to be removed / cleared, with some re-grading to create level areas with grubbing and clearing of small shrubs/grasses. Trimming of trees may be required. Tree removal would not occur in portions of the CAZ outside of a clearing area.
Cumulative impacts	The combined impacts of the proposal on a matter with other relevant future projects.
Disturbance area	The disturbance area includes all locations where the proposal directly impacts the land surface or water body. This includes clearing areas, construction activity zones, access tracks and power supply routes.
Entitlement	The volume of water authorised to be taken and used by an irrigator or water authority; includes bulk entitlements, environmental entitlements, water rights, sales water and surface-water and groundwater licenses.
Environmental flow	Any river flow pattern provided with the intention of maintaining or improving river health.
Fish passage	The ability of fish or other aquatic species to move through an aquatic system.
Fishway	Structures placed on or around constructed barriers (such as dams or weirs) to give fish the opportunity to move past the barrier.
The proposal	The construction and operation of the two regulators and supporting infrastructure.
The proposal site	The footprint that would be directly affected by construction and the location of operational infrastructure.
Regulator	A gated structure used to actively manage or control the amount of water that flows from one location to another.
Regulated	A water system in which water is stored or flow levels are controlled through the use of structures such as dams and weirs.
Sustainable diversion limit adjustment mechanism	A mechanism under the Murray-Darling Basin Plan that allows the sustainable diversion limit to be adjusted under certain circumstances.
Study area	The area investigated for this assessment which includes the proposal site and surrounding area, with the potential to be directly or indirectly affected by the proposal.

Weir	A low barrier or dam that is built across a watercourse and is designed to store water, control or alter the flow of water in a creek

Abbreviations

Abbreviations	Definitions
% sat	Per cent saturation
°C	Degrees Celsius
µS/cm	Micro Siemens per centimetre
ALA	Atlas of Living Australia
ANZECC	Australian and New Zealand Environment and Conservation Council
ANZG	Australian and New Zealand Guidelines
ARI	Average Recurrence Interval
ARMCANZ	Agriculture and Resource Management Council of Australia and New Zealand
BF	Base Flow
BLASTN	Nucleotide Basic Local Alignment Search Tool
BOD	Biological Oxygen Demand
BOM	Bureau Of Meteorology
CE	Critically Endangered
CEMP	Construction Environmental Management Plan
CSU	Charles Stuart University
CSWMP	Construction Soil and Water Management Plan
CtF	Cease-to-Flow
Cth	Commonwealth
CUM	Cumulative
NSW DCCEEW	NSW Department of Climate Change, Energy, the Environment and Water
DEC	Former NSW Department of Environment and Conservation
DECC	Former NSW Department of Environment and Climate Change
DECCW	Former NSW Department of Environment, Climate Change, and Water
DGV	Default Guideline Value
DO	Dissolved Oxygen
DPI	NSW Department of Primary Industries
DPIE	Former NSW Department of Planning, Industry and Environment
DS	Downstream
DSEWPAC	Former Cth Department of Sustainability, Environment, Water, Population and Communities
E	Endangered
EC	Electrical Conductivity
eDNA	Environmental DNA
EEC	Endangered Ecological Community

Abbreviations	Definitions
EHNV	Epizootic Haematopoietic Necrosis Virus
EIA	Environmental Impact Assessment
EIS	Environmental Impact Statement
En. Pop.	Endangered Population
EP&A Act	NSW Environmental Planning and Assessment Act 1979
EPA	NSW Environment Protection Authority
EPBC Act	Cth Environment Protection and Biodiversity Conservation Act 1999
ESCP	Erosion and Sediment Control Plan
EWR	Environmental Water Requirements
FM Act	NSW Fisheries Management Act 1994
GDE	Groundwater-Dependent Ecosystems
GL	Gigalitre
GL/yr	Gigalitre per year
ICNG	Interim Construction Noise Guideline
KFH	Key Fish Habitat
KTP	Key Threatening Process
LGA	Local Government Area
LTWP	Long-Term Watering Plan
m/s	Metres per second
m^2	Square metres
MDB	Murray-Darling Basin
MDBA	Murray-Darling Basin Authority
mg/L	Milligrams per Litre
ML	Megalitres
ML/d	Megalitres per day
MLTWP	Murrumbidgee Long-Term Watering Plan
MNES	Matters of National Environmental Significance
MPN/100 mL	Most Probable Number per 100 millilitres
NATA	National Association of Testing Authorities
NHMRC	National Health and Medical Research Council
NMCRT	National Murray Cod Recovery Team
NRMMC	National Resource Management Ministerial Council
NTU	Nephelometric Turbidity Unit
NWQMS	National Water Quality Management Strategy
OTU	Operational Taxonomic Unit

Abbreviations	Definitions
PMST	Protected Matters Search Tool
POEO Act	NSW Protection of the Environment Operation Act 1997
PU	Planning Unit
RCE	Riparian Channel and Environment
SCADA	Supervisory Control and Data Acquisition
SDLAM	Sustainable Diversion Limit Adjustment Mechanism
SEAR	Secretary's Environmental Assessment Requirement
SF	Small Fresh
SPRAT	Species Profile and Threats Database
SSI	State Significant Infrastructure
TP	Total Phosphorus
TSS	Total Suspended Solids
VLF	Very Low Flow
VU	Vulnerable
WAL	Water Access Licence
WM Act	NSW Water Management Act 2000
WQMP	Water Quality Management Plan
WQO	Water Quality Objective
WRP	Water Resource Plan
WSP	Water Sharing Plan

1. Introduction

1.1 Overview

NSW Department of Climate Change, Energy, the Environment and Water (NSW DCCEEW) is proposing to replace two existing weirs along Billabong Creek with new regulators (the proposal). The two existing weirs to be demolished are Hartwood Weir and Wanganella Weir. These structures are situated on Billabong Creek within the Yanco Creek System in south-west NSW (refer **Figure 1-1**).

These weirs were built in the early 20th century and have been used to regulate flows through Billabong Creek, create weirs pools for irrigation and, in the case of Wanganella Weir, provide town water supply. The weirs are currently in states of declining condition and functionality and are barriers to the movement of fish through the creek. Their condition limits their ability to regulate flows through the Yanco Creek System and leads to inefficiencies in how water is delivered to the environment and irrigators.

The new regulators would be fully automated and remotely operated meaning that operators could control the delivery of water more efficiently. The proposal is needed to improve the operator's ability to deliver the right amount of water to the right place at the right time. The new regulators would also feature fishways to support fish movement past the new structures.

The proposal is subject to environmental and planning approvals in accordance with the *NSW Environmental Planning and Assessment Act 1979* (EP&A Act) and the *Commonwealth Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act). The proposal is State significant infrastructure (SSI), and the NSW Minister for Planning and Public Spaces is the approval authority. An environmental impact statement (EIS) is required to accompany the application for approval of the proposal.

1.2 Purpose and scope of this report

This report has been prepared by Jacobs as part of the EIS for the proposal. The EIS has been prepared to accompany the application for approval of the proposal and addresses the Secretary's Environmental Assessment Requirements (the SEARs), issued on 17 October 2024.

The purpose of this report is to assess potential surface water quality and aquatic ecology effects associated with the construction and operation of the proposed regulators for the proposal, and where required, identify feasible and reasonable mitigation and management measures. This report:

- Provides a summary of key legislation, policies and procedures relevant to surface water quality and aquatic ecology
- Describes the existing environments with respect to water quality and aquatic ecology, including characteristics of the catchment, flows, water quality and aquatic biodiversity that are expected to occur within the study area
- Assesses the impact of constructing and operating the proposal on surface water quality and aquatic ecology
- Recommends measures to mitigate and manage the potential impacts identified.

1.3 Structure of the Report

The report is structured as follows:

- Section 1 – provides an introduction to the proposal and the assessment
- Section 2 – Provides the legislative and policy framework relevant to the proposal
- Section 3 – describes the methodology and approach for the assessment

- Section 4 – describes the existing environment
- Section 5 – identifies the various potential impact pathways resulting from construction and operation of the proposal
- Section 6 – provides mitigation measures for the impacts identified
- Section 7 – presents the findings of the risk assessment
- Section 8 – provides the aquatic biodiversity offset strategy Summary of the proposal
- Section 9 – presents the key findings of the assessment and conclusion.

1.4 Summary of the proposal

1.4.1 Location

The proposal is located on Billabong Creek, which is part of the Yanco Creek System in south-west New South Wales (NSW). The Yanco Creek System forms a part of the Murray-Darling Basin (MDB). An overview of the location of the proposal is shown in **Figure 1-1**.

The proposal is located within the local government area (LGA) of Edward River.

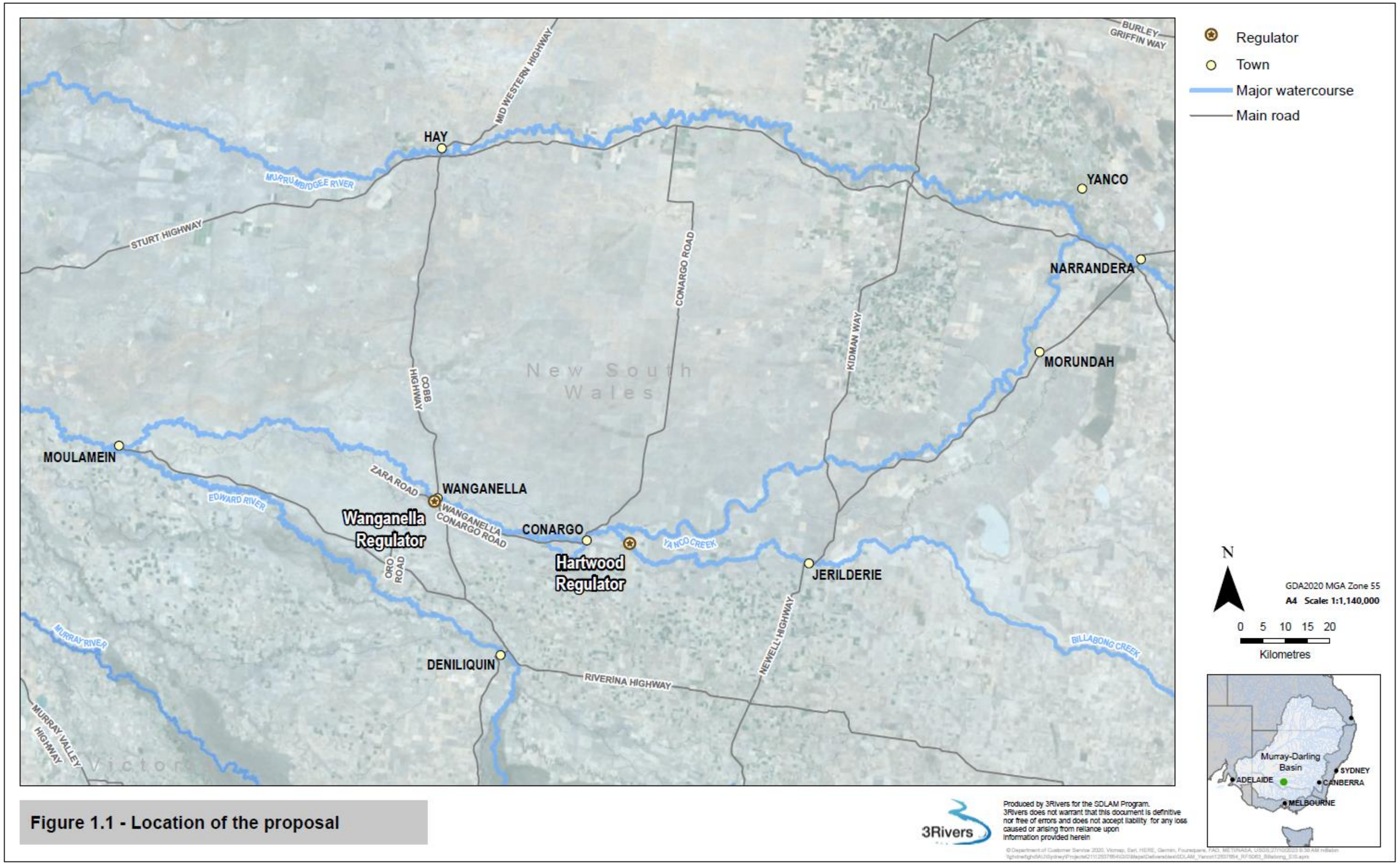


Figure 1-1 Location of the proposal

1.4.2 Key features of the proposal

As discussed in **Section 1.1**, the proposal involves replacing two existing weirs along Billabong Creek with new regulators including fishways.

The core structure of the two regulators is similar and would include:

- Concrete piers with maintenance bulkhead slots
- Automated layflat gates across the crest of the structure to assist with flow management and downstream fish passage
- A low turbulence 'keyhole' type vertical slot fishway with allowances for variable headwater to provide upstream fish passage
- Automated sidewinder gates within the vertical slot fishway to allow for variable headwater conditions
- Fixed concrete crests on the opposite side of the gates to the vertical slot fishway
- Concrete apron downstream of the structure
- Concrete wingwalls upstream and downstream of the structure
- Access from a trafficable deck for maintenance (Hartwood Regulator only)
- Pedestrian walkway access part way across Wanganella Regulator structure to facilitate housing of gate actuators and for maintenance
- Walkway grating over gates to facilitate operations and maintenance
- Crushed rock maintenance pads, access and turnaround areas adjacent to the structure
- Rip rap and rock beaching upstream and downstream of structure for erosion protection
- Control house
- Sheet pile cut-off walls beneath the structure
- Fencing of the structures to prevent public access
- Supervisory Control and Data Acquisition (SCADA) control system.

An indicative layout of a regulator is shown in **Figure 1-2**. This example is of a five gate regulator with a fish passage and trafficable deck for maintenance vehicles.

Figure 1-2 Indicative layout of a regulator

The proposal would also involve the following elements:

- Power supply to the regulators would be provided by a mix of underground and overhead electricity cables connecting the structures to the grid.
- Access to the regulators would require permanent tracks for maintenance and some additional tracks to support construction only.
- The existing Forest Creek block bank, associated with the Hartwood Regulator, would be replaced with a similar earthen structure to the existing. This would include two concrete sills to define the upstream and downstream top of bank and armoured with rock beaching and crushed rock for erosion protection.
- A flood bypass channel would be constructed to reduce potential upstream flooding impacts from the Wanganella Regulator. The channel would enable flood waters to drain between the billabongs in the Wanganella Reserve during flood events. It would be 85 metres long, around 40 metres wide and 1.7 metres deep and located north of the Wanganella Tip. Once completed, the channel sides and base would be naturalised and vegetated with appropriate local native species.
- An existing borrow pit on lot 56 / DP756322 near Hartwood Weir would be extended to provide material for the construction of Hartwood Regulator and Forest Creek block bank.

The location of the existing weirs, proposed infrastructure, and the indicative proposal footprints are shown on **Figure 1-6** and **Figure 1-7**.

1.4.3 Key features of existing proposal site

1.4.3.1 Hartwood

The existing Hartwood Weir, completed in 1916, is downstream of the Billabong Creek and Forest Creek junction and can share the regulated flows between the two creeks by creating a weir pool to divert water to Forest Creek (Alluvium, 2013). A regulator at the head of Forest Creek regulates these diversions of water into that creek.

Hartwood Weir, shown in **Figure 1-3**, now largely operates as a fixed crest weir with a concrete apron and abutments. The weir contains manual drop boards that would have been used historically to regulate flows past the weir and are now only removed in high flows.

The extent of the existing weir pool at the median (50th%ile) water surface level, upstream of the structure, is around 16.5 kilometres.

WaterNSW owns the land on which Hartwood Weir is located. Downstream of this land includes both private and Crown land. Land on the right bank (eastern side) of the creek is privately-owned agricultural land. Billabong Creek around the weir is a Crown Waterway. The land on the left bank (western side) is Crown land.

Figure 1-3 Hartwood Weir

1.4.3.2 Wanganella

Wanganella Weir shown in **Figure 1-4**, is located on Billabong Creek and contains eleven drop board bays to regulate flows, however the drop boards are no longer in place as they were removed in the 1980s. It now operates as a fixed crest weir with a concrete apron and abutments. The weir was constructed for the Wanganella village water supply. The extent of the weir pool at the median (50th%ile) water surface level upstream of the structure is around 13 kilometres.

Wanganella village is located around 1 km north of the site The site is part of the Wanganella Recreation Reserve, known to local residents as Wanganella Common. It is understood to be managed by Edward River Council. Billabong Creek at this location is a Crown Waterway. Existing access to the site is from the Cobb Highway on the western side of the Creek. Zara Road is located on the eastern side of the creek but there is no formed access track on this side.

Figure 1-4 Wanganella Weir

1.4.4 Timing

Construction of the proposal is anticipated to start in 2025 and be completed by 2026. The construction period is anticipated to be around 18 months. Construction would pause during periods of high flow.

1.5 Construction activities

The construction method would be similar for each respective regulator location, and at a high-level construction will be undertaken in two stages (see **Figure 1-5**):

- Stage 1: Fishway and Lay Flat Gates, and
- Stage 2: Fixed Crest Weir.

Generally, site establishment works would occur, then the structures would be installed and finally the site would be rehabilitated.

Key activities of the main construction components are outlined in **Table 1-1**. Points of note include:

- A permanent sheet pile wall would be installed on the upstream face of the regulators, most likely using a vibratory hammer.
- A blinding layer made of a lean mix concrete and an in-situ concrete slab would be poured on top of the hardstand.

- Other required in-situ concrete slabs would be constructed using industry standard form, reinforce and pour methods. Required in-situ concrete walls and beams would be fabricated onsite on the hardstand area and installed using the crane.
- The prefabricated baffles, grates handrails and walkways, lay-flat gate unit and all other steelwork would be installed using the crawler crane.

Table 1-1 Indicative activities for construction components of the proposal

Phase	Activities
Fishway and layflat gates	▪ construct hardstands for the compound, laydown areas and crane pad(s) ▪ install site facilities and mobilise plant ▪ demolish small section of existing weir to allow cofferdam through structure ▪ install all the temporary cofferdams around new structures and old weirs separately and dewater work zones ▪ prepare subgrade and initial earthworks including any remediation if required ▪ install permanent sheet pile wall ▪ form, reinforce and pour all slabs (fixed crest structure, stilling pool, apron and fishway) ▪ form, reinforce and pour all walls (gates and fishway) ▪ install scour protection and finalise backfill of new structure ▪ demolish existing weir including reshaping of creek bed ▪ install and commission layflat gates and fishway furniture ▪ flood cofferdam and remove the sheet piles around the new structure only.
Fixed crest structure	▪ install temporary sheet pile cofferdam for the fixed crest weir section and seal against the new structure (at this point the new gates would be operational) ▪ remove the cofferdam around the existing weir and reinstall around the other side of the existing weir ▪ dewater the two new work zones ▪ prepare subgrade and initial earthworks including any remediation if required ▪ install remaining permanent sheet pile wall ▪ form, reinforce and pour remaining slabs (fixed crest structure, stilling pool and apron) ▪ form, reinforce and pour remaining walls (fixed crest structure) ▪ install scour protection and finalise backfill of other side ▪ demolish other side of the existing weir including reshaping of creek bed ▪ flood both cofferdams and remove the sheet pile ▪ rehabilitate work areas and demobilise from site.

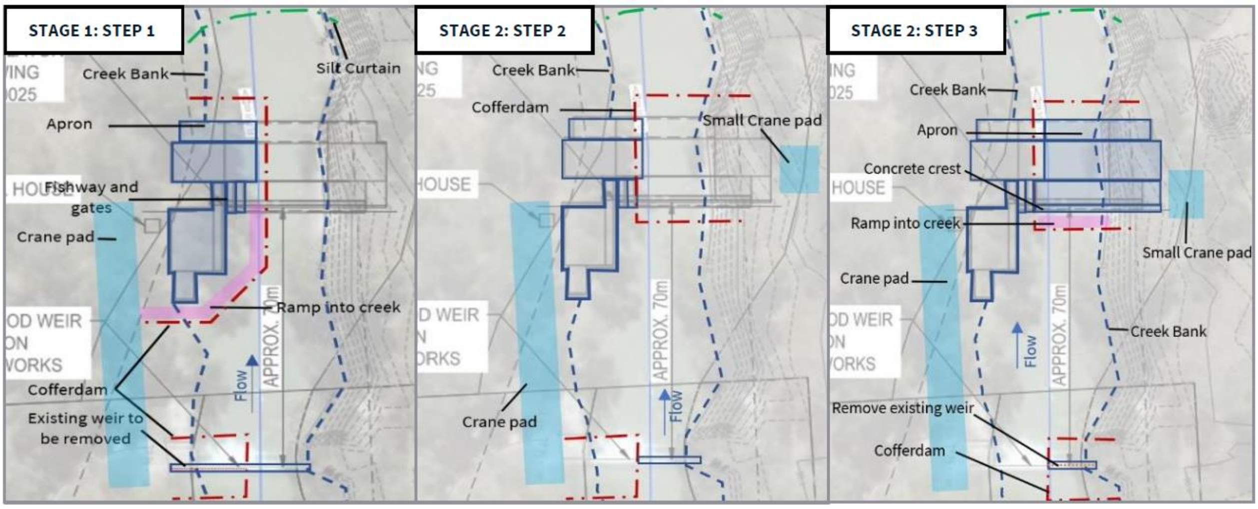


Figure 1-5 Construction staging for regulators

1.5.1.1 Site establishment

Site establishment would include vegetation removal, access track upgrades, establishment of construction activity zones and hardstand areas.

Vegetation removal would be required as a part of site establishment, including for the establishment of:

- access tracks
- crane pad(s)
- crane's slew zones
- borrow pit.

In the clearance areas tree removal would be required, but minimised where possible. Within the construction activity zones, grubbing of surface vegetation may be required, but tree removal would not occur.

Compound and laydown areas would be established to support construction. Access tracks would also be upgraded, where required.

A hardstand area would be constructed within the proposal site at the main works area at each site. The hardstands would facilitate the establishment of site facilities, laydown areas and parking segregation for both light vehicles and heavy plant. These hardstand areas would be cleared and grubbed and overlaid with a layer of crushed rock road base to create the hardstand.

1.5.1.2 Sediment and erosion controls

A floating silt curtain would be installed downstream of each work area to capture potential silt or debris mobilised from construction activities to minimise turbidity within the creek. In addition, silt fencing would be installed along the toe of the batters to minimise the transport of sediment in runoff from disturbed areas entering in the creek. Jute matting would also be placed on the batter to help reduce sediment transportation.

1.5.1.3 Cofferdams

Only partial cofferdams will be put in place at any given point during the construction process to enable continuous stream flow and fish passage (**Section 5.2.1.1.1**). Once each partial cofferdam is installed, the construction zone would be dewatered in accordance with the water management method described in **Section 1.5.2.4**. Sheet piles would be installed using a vibratory hammer attached to a crawler crane to construct a cofferdam at the existing weir and new regulator sites. A boat would be used to position the sheet piles and check if the sheets are interlocked correctly.

A small temporary cofferdam would also be installed in an existing irrigation channel south of Hartwood Weir to enable construction of a culvert for the access track.

1.5.2 Working platform

The creek bed would then be cleared of debris and silt. The structure footprint would be proof rolled to create a solid working platform. The working platform would generally consist of crushed rock road base for minor sections and ballast for larger sections that need to be bridged. A capping layer of road base would then be placed on the entire work area. The working platform would then be proof-rolled again and detailed excavation would occur around the location of the permanent sheet piles and stilling pool.

1.5.2.1 Removal of the existing weirs

The existing weirs would be removed using an excavator and a rock breaker once dewatered. Earthworks would be carried out to the proposed design levels and the creek reshaped.

1.5.2.2 Site rehabilitation

The site would be rehabilitated and restored to previous conditions, as much as possible.

1.5.2.3 Earthworks source and quantity of materials

The proposal would involve earthworks for the following:

- clearing the creek bed of debris and silt
- installation of cofferdams
- demolition of existing structures.

Excavated spoil would be reused for backfilling where possible. Surplus material that cannot be used on-site or on other projects would be classified in accordance with the *NSW EPA Waste Classification Guidelines* (EPA, 2014) and disposed of at an approved materials recycling or waste disposal facility. The volume of material to be excavated to allow access to the existing weirs (1m upstream and 1m downstream) for demolition is estimated to be 20m^3 for Hartwood and 30m^3 for Wanganella.

The amount of water that would be required during construction is unknown at this stage. Water would be used for concrete pouring, compaction of work areas and access roads, and dust suppression. Water would be obtained from Billabong Creek.

1.5.2.4 Water management

Construction of the proposal would be designed to enable water to be flowing through part of the creek bed throughout construction. To achieve this, in creek construction needs to be undertaken in two phases; half of the creek needs to remain unobstructed to maintain continuous flow of water while construction is undertaken on the other side. Cofferdams, sumps and pumps would be used to separate and dewater the half of the creek undergoing construction.

As part of the access track upgrades at Hartwood Weir, a new culvert would be installed within an existing irrigation channel to provide a crossing point for vehicles. A temporary water diversion would be required to maintain flow for irrigators. This would be achieved through either pumping or providing a diversion trench and pipes under the access track.

1.5.2.4.1 Sumps

Residual water in construction areas would be managed using temporary sumps. Sumps would be installed into dug holes of a few metres. The number and depth of sumps would depend on the ground conditions and amount of water ingress. The sumps involve excavating a hole to a depth of a few metres, followed by the placement of steel drum barrel with perforation and wrapped in geofabric. The area surrounding the sumps would then be backfilled with screenings to the surface. A pump would be placed in each sump to remove the incoming water. Small channels around the perimeter of the construction zone may also be used to direct surface water into the sumps. The pump would be suitably sized to exceed the ingress of water.

1.5.2.4.2 Dewatering

Once a cofferdam is installed the construction area would be dewatered using multiple pumps that would be operational for several days until all the water is removed. Water pumped out of the construction areas would be discharged downstream of the construction area but upstream of the silt curtain to manage sedimentation. De-sludging of existing unsuitable material would be removed from within the cofferdam using excavators and dump trucks.

1.5.3 Operation

The proposal would be operated in accordance with the operating requirements established with the new asset owner and developed in consultation with key stakeholders. These operating requirements are known as the Yanco Creek System Operations Plan (DPIE, 2022a). The plan would take into account the regulation requirements at each regulator, as well as constraints such as limits to rates of rise and fall to accommodate fish breeding requirements.

The proposed regulators would provide greater control of water levels which would be operated to meet environmental and water supply objectives.

1.5.3.1 General operating principle of the regulators

1.5.3.1.1 Hartwood Regulator

The proposed general operating principles of Hartwood Regulator are as follows:

- Use primarily to maintain a regulator pool height sufficient to deliver normal regulated flow requirements (including managed environmental flows) into Forest Creek
- Use to create a pumping pool for seven irrigation pumps within the regulator pool and to provide re-regulation capacity of flows in the Billabong Creek. Some stock and/or domestic pumps extract water from the weir pool
- Open fully the regulator gates during moderate to large unregulated flow events at every possible opportunity to enable unrestricted fish passage opportunities
- Share equitably any adverse outcomes across water access licence holders during unexpected supply shortfalls
- Optimise regulator pool operations to minimise the risk of adverse environmental outcomes
- Distribute flows across each of the regulator gates to maximise the effectiveness of the vertical slot fishway.

1.5.3.1.2 Wanganella Regulator

The proposed general operating principles of Wanganella Regulator are as follows:

- Use primarily to create a pumping pool for Wanganella's town water supply and one irrigation pump and to provide re-regulation capacity of flows in Billabong Creek
- Use to create a pumping pool for stock and/or domestic pumps that extract water from the regulator pool, and at higher storage levels provide irrigation pump benefits from the regulator pool
- Open fully regulator gates during moderate to large uncontrolled flow events at every possible opportunity to enable unrestricted fish passage opportunities
- Share equitably any adverse outcomes across water access licence holders during unexpected supply shortfalls
- Optimise regulator pool operations to minimise the risk of adverse environmental outcomes
- Distribute flows across each of the regulator gates to maximise the effectiveness of the vertical slot fishway.

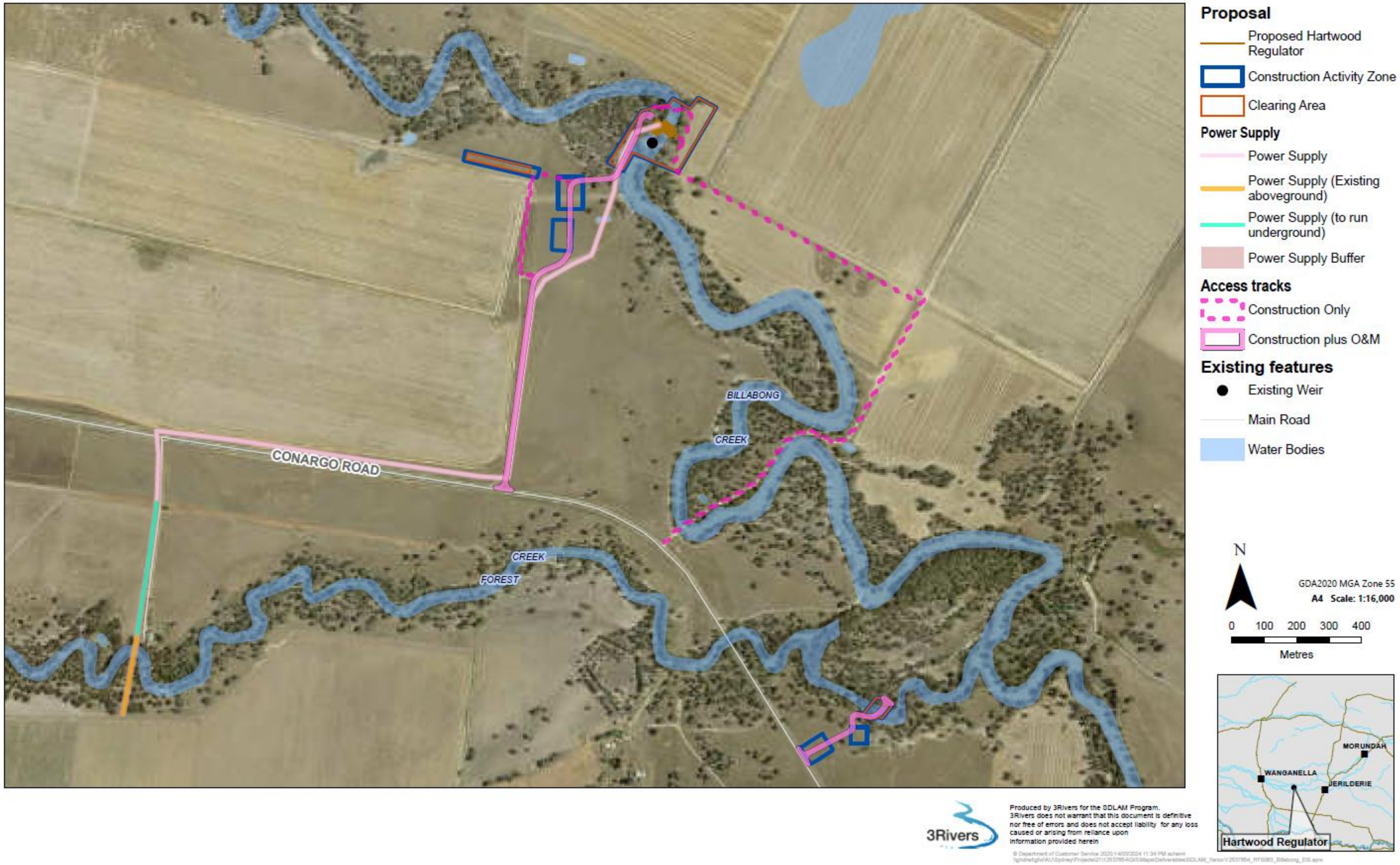


Figure 1-6 Location of Hartwood Regulator and proposed works.

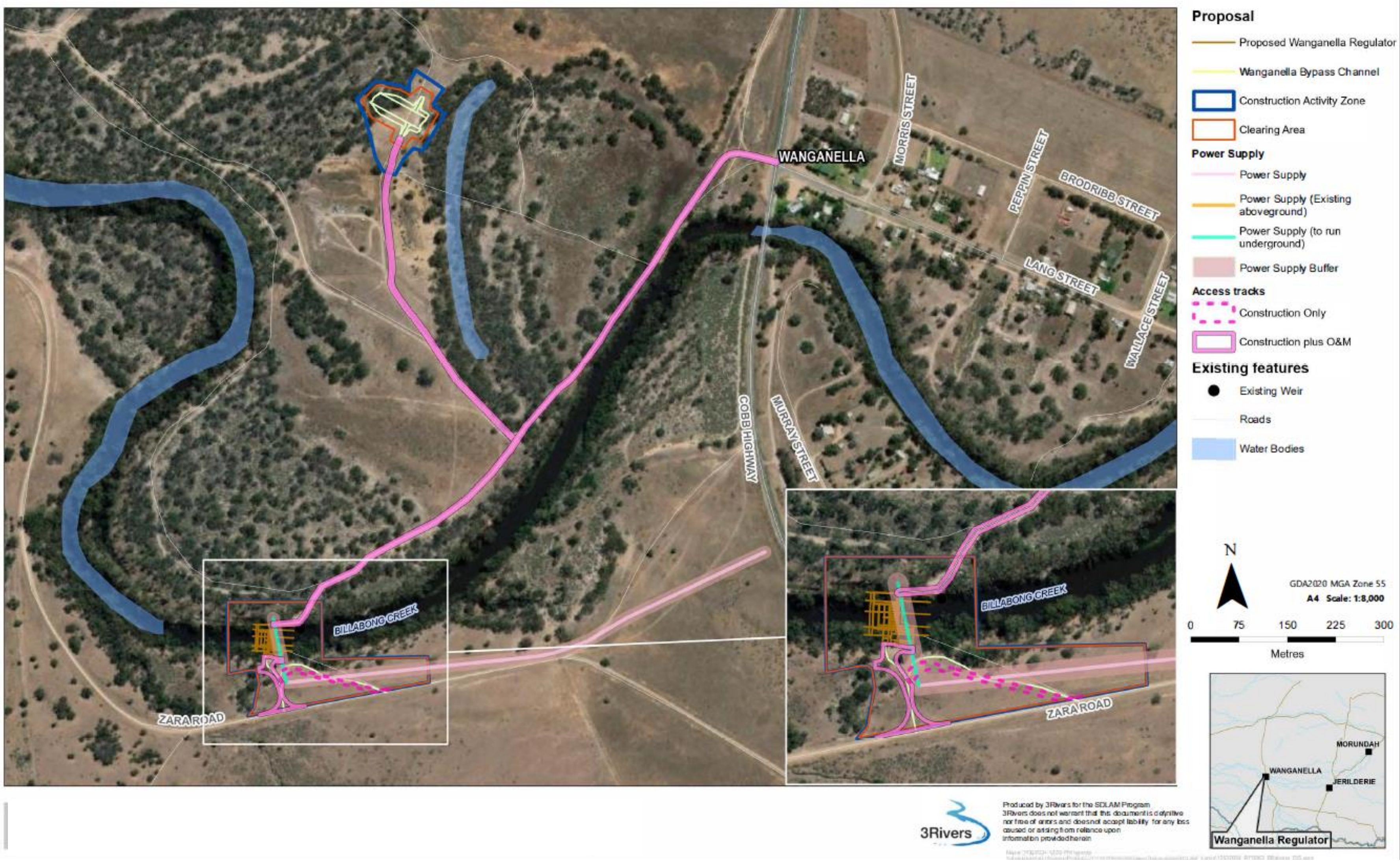


Figure 1-7 Location of Wanganella Regulator and proposed works.

1.6 Secretary's environmental assessment requirements

This surface water quality and aquatic ecology assessment has been prepared to address the Secretary's Environmental Assessment Requirements (SEARs). **Table 1-2** outlines the requirements relevant to this assessment. The assessment also considers issues raised by the NSW DCCEEW - Water Assessment Group and DPI Fisheries as part of the project's stakeholder engagement process.

Table 1-2. Relevant SEARs

Requirements	Where addressed in this report
Water	
3. Include a thorough description of the existing environmental conditions and hydrological regime to the extent of project influence up and down stream, including:	
H) Water quality baseline data for the water resources likely to be impacted by the development. This should include relevant physical and chemical parameters such as temperature, electrical conductivity (EC), pH, turbidity, nutrients and dissolved oxygen as well as any available major ion and toxicant data.	Sources of existing surface water quality data are provided in **Section 3.1.2.2** A summary of the desktop review of surface water quality monitoring data is provided in **Sections 4.11.1** to **4.11.7** with site specific water quality presented in **Table 4-10**
4. Include a thorough assessment of the hydrological impacts of the project in comparison with existing hydrological conditions, to the extent of project influence up and downstream, including:	
H) Identification and impact assessment of all works/activities located on waterfront land including an assessment against *Guidelines for Controlled Activities on Waterfront Land (NRAR 2018).*	**Section 2.1.2.10** discusses the legislative requirements for works on waterfront land. Potential impacts to waterfront land is provided in **Section 5.2.1.5** and mitigation measures relevant to waterfront land are provided in **Table 6-1.**
L) An assessment of the impact of the project on water savings under the Sustainable Diversion Limit Adjustment Mechanism (SDLAM) framework, and in consideration of the Murray-Darling Basin including environmental flow requirements and environmental watering.	SDLAM projects are designed to deliver better environmental outcomes without the need for additional water recovery, through infrastructure, changing rules to deliver water to high value environmental sites and changing the way rivers are managed. The YCMP is part of the SDLAM acceleration program which will deliver up to 45GL of the outstanding amount needed to reach the 605GL target required by the Basin Plan each year (NSW DCCEEW, 2024a). The MDBA (2020) identified that supply and constraint projects are complex projects that together make a substantial contribution to the overall sustainable diversion limit adjustment. These projects include the modernising of water delivery infrastructure in Yanco Creek to improve the operation of Yanco Creek and its environmental outcomes. The MDBA made an estimate of the volumetric contribution of projects to the SDLAM offset, using two methods to develop an estimated range

	of potential supply contributions for supply projects. The estimated contribution range for the YCMP is that it will deliver between seven and 16GL of water savings per year (MDBA, 2020).
M) Changes to environmental water availability, both regulated/licensed and unregulated/rules-based sources of such water, specifically: i). assessment of impacts to the volume, reliability and effectiveness of Planned Environmental in the catchment downstream of the proposed works. ii). Assessment of impact to volume reliability, effectiveness of Planned Environmental Water assets in the catchment downstream of the works. iii). Any water substitution effects of the removal of surplus or tributary flows from the catchment that may then require held or discretionary planned environmental water to make up the shortfall.	The impact of the Project on flows downstream of the new regulators is discussed in **Section 5.2.2.2.1** and also in the *Billabong Creek Regulators Hydrology Assessment* (Jacobs, 2024a). The proposed new regulators include automated lay flat gates to assist with flow management. The regulators would provide greater control of water levels and be operated in accordance with the Yanco Creek System Operating Plan (DPIE, 2020a) to meet environmental and water supply objectives.
5. Include a thorough assessment of the water quality impacts of the project during construction and operation, to the extent of project influence up and down stream, including:	
A) The ambient *NSW Water Quality and River Flow Objectives (NSW WQO)* and environmental values for the river, including the indicators and associated trigger values or criteria for the identified environmental values.	NSW Water Quality Objectives relevant to the proposal are discussed in **Section 2.1.2.5.** Nominated environmental values for the receiving waterways relevant to the proposal are provided in **Section 3.1.2.1**. Relevant indicators and associated default guideline values or criteria for the identified environmental values (referred to as Water Quality Objectives in this assessment) are provided in **Table 3-1**.
B) The rainfall event that the water quality protection measures will be designed to manage.	Water quality protection measures will be designed and sized in accordance with the *Managing Urban Stormwater - Soils and Construction* as documented in **Table 6-1.**
C) The significance of any identified impacts including consideration of the relevant ambient water quality outcomes.	Existing surface water quality of receiving waterways is described in **Section 4.11**. Identified impacts to surface water quality from construction are discussed in **Section 5.2.1**. Identified impacts to surface water quality from operation are discussed in **Section 5.2.2.** **Section 7.3** details the influence of the proposal on meeting water quality objectives.
D) How construction and operation of the project will, to the extent that the project can influence, ensure that: i). where the NSW WQOs for receiving waters are currently met, they will continue to be protected and	The NSW WQOs refer to the ANZG (2018) and other guidelines to assess compliance as detailed in **Section 7.3.** Existing surface water quality and compliance with relevant targets is discussed in **Section 4.11**.

ii). Where the NSW WQOs are currently not met, activities will work toward their achievement over time.	Water quality controls and management measures to protect water quality will be designed and implemented as part of the Construction Environmental Management Plan (CEMP) as detailed in **Table 6-1**. The proposal's influence on meeting objectives during construction and operation is discussed in **Section 7.3**.
E) Identify proposed monitoring locations, monitoring frequency and indicators of surface and groundwater quality.	A surface water quality and groundwater quality monitoring program will be developed as part of the Construction Soil and Water Management Plan as detailed in **Table 6-1**.
6. The EIS must also include:	
F) Details of any environmental flow regimes which will be impacted by the implementation of the proposal.	Existing environmental flow regimes are provided **Section 4.7.3.** Changes to the regimes from implementation of the Proposal are discussed in **Section 5.2.2.2.1.** Overall, the design and operation of the replacement new regulators would allow for improved control of environmental flows
Flooding	
14. The EIS must assess the impacts on the proposed development on flood behaviour, to the extent of project influence up and down stream, including:	
F) Whether there will be adverse effect to beneficial inundation of the floodplain environment on, adjacent to, upstream or downstream of the site.	**Section 5.3** and the *Billabong Creek Regulators Hydrology Assessment* (Jacobs, 2024a) presents the finding that there will be no or negligible adverse effects in the frequency of inundation of the floodplain and that overall there would be an increase in unimpeded riverine habitat.
Biodiversity (aquatic ecology)	
3. Include a thorough description of the existing environmental conditions and hydrological regime to the extent of project influence up and downstream, including:	
F) Instream ecosystems, assets and functions associated with all upstream and downstream river that will see altered flow.	Aquatic habitats are discussed in **Section 4.9**.
K) An assessment of any direct or indirect impacts to any Ramsar listed wetlands in the vicinity of the project.	Wetlands are described in Section 4.6. Potential impacts to wetlands are discussed in **Sections 5.2.1.2.1** and **5.2.2.2.1**.
19. Assessment of biodiversity impacts must include the following:	
H) Assessment of terrestrial, riparian and floodplain biodiversity and ecology that addresses all direct, indirect, and prescribed impacts of the project on flora and fauna, threatened species, populations, and	Aquatic receptors are discussed in **Section 4.10** and impacts to aquatic receptors are discussed in **Section 5.2.** GDEs are described in **Section 4.8** and impacts to GDEs are discussed in **Section 5.2.1.4**.

communities for the construction and operation of the project, including flow dependent and groundwater dependent ecosystems.	
I) An aquatic ecological assessment prepared in accordance with the Policy and Guidelines for Fish Habitat Conservation and Management (2013), addressing all direct and indirect impacts of the project and associated works on Key Fish Habitat and associated flora and fauna including threatened species, populations, and communities during construction and operation for the life of the assets.	**Table 4-1** summarises the findings of the aquatic habitat field assessment. Impacts to aquatic receptors are discussed in **Section 5.2.**
J) An assessment of impacts during construction and operation of the project and associated works on river hydrology, hydraulics (lotic and lentic flow profiles), geomorphology, and water quality and associated impacts on flow-dependent ecological communities.	Impacts to water bodies and flow-dependent ecological communities are discussed in **Section 5.2**
K) Assessment of impacts of changes to the extent of project influence up and downstream. This must be informed by the flooding assessment required by these SEARs.	The operation of the regulators will not have a significant impact on the flood characteristics and floodplain behaviour of the study area. The changes that may be experienced are due to altering the location and level of the weir pool control (including proposed operating rules). As such changes directly upstream and downstream of the regulator could occur. Operating flows (maximum and minimum) through the new regulators and the influence this may have on aquatic habitats (lentic and lotic) is discussed in **Section 5.2.2.2.1.**
L) Detailed assessment, design, construction, operation and monitoring of suitable fishways at each of the proposed regulators, and any works on instream structures associated with the proposal including additional regulator modifications and block banks, to ensure the safe and effective upstream and downstream movement of native fish 30mm to 1000mm across all flow ranges.	In accordance with the relevant Fisheries policy and guidelines the design of the fishway and construction activities is provided in **Section 1.4.2** and **Section 1.5** respectively. The assessment of impacts from construction and operation of the structures and associated fishways ss provided in **Section 5.2.1** and **Section 5.2.2** respectively. As discussed in **Section 5.2.2.1.1**, the proposed fishways for both Hartwood and Wanganella have been designed to allow for effective upstream passage of native fish from 30mm (small bodied) to 850mm (large bodied) – this being representative of the local native fish fauna Fish passage management during construction and operation is detailed in **Table 6-1.**
M) An Aquatic Biodiversity Offsets Strategy that is adequately funded to mitigate and manage impacts of the Billabong Creek Environmental Water Regulators project during construction and subsequent operation, focusing on protecting and improving the biodiversity	**Section 5.2.2.1.1** details our response to this SEAR. A project specific offset strategy commensurate with the risk and impact to Key Fish Habitat (KFH) features is subject to ongoing negotiations between DCCEEW and NSW DPI Fisheries, so the purpose of this section is to outline

and conservation values of Billabong Creek, its biota, and associated riparian zones in the medium to long term.	considerations relevant to the strategy as they relate to the proposal construction and operation. To support development of an offset strategy NSW DPI Fisheries has recently completed an aquatic habitat mapping investigation of Billabong Creek, upstream and downstream of the proposed Hartwood and Wanganella regulators. Furthermore, impacts to hydraulic fish habitat have been quantitatively estimated in this report. Predominantly these findings, and potentially other factors raised in this report, will be used to develop an appropriate aquatic biodiversity strategy for the proposal.

1.7 Definition of areas addressed in this EIS

For the purposes of the assessment the areas to be addressed have been defined as follows:

- proposal footprint – the area that would be directly disturbed by construction and the location of operational infrastructure. The disturbance area would include clearing areas, construction activity zones, access tracks and power supply corridors.
- study area – the area that was subject to environmental impact assessment which includes the proposal footprint and the reach of Billabong Creek with the potential to be impacted by the proposal, being from Jerilderie to the Darlot flow gauge (near the town of Moulamein) as shown in **Figure 1-8**.
- area of investigation – the area of investigation covered by this surface water quality and aquatic ecology assessment is the entire Yanco Creek System starting from Yanco Weir and finishing at the Darlot flow gauge. This encompasses a broader area than that anticipated to be impacted by the new regulators (i.e. Billabong Creek from Jerilderie to the Darlot flow gauge), because the impacts of the new regulators have been assessed within the context of associated system wide operational changes as per the Yanco Creek System Operations Plan (DPIE 2022a).

The areas to be addressed include the following Planning Units (PU) of the Murrumbidgee River catchment as defined in the Murrumbidgee Long Term Water Plan (DPIE, 2020b):

- PU10: Upper Yanco Creek - The Upper Yanco Creek PU is situated within the Murrumbidgee Western Water Source. Flows into the Yanco Creek System go through the Yanco offtake cutting. Flows are controlled by altering the height of Yanco Weir on the Murrumbidgee River downstream of the cutting.
- PU11: Colombo & Billabong Creeks - The Colombo & Billabong Creeks PU is situated within the Murrumbidgee Western Water Source and Lower Billabong Anabranch Water Source. It begins where Colombo Creek bifurcates from Yanco Creek near Morundah. The division of flows between Colombo Creek and Lower Yanco Creek is controlled by Tarabah Weir. Colombo Creek flows into Billabong Creek upstream of Jerilderie. Upstream of this junction, Billabong Creek is unregulated. The PU ends where Lower Yanco Creek joins Billaong Creek.
- PU12: Lower Yanco Creek to Lower Billabong Creek - The Lower Yanco Creek to Lower Billabong Creek PU is situated within the Murrumbidgee Western Water Source. It begins where Colombo Creek bifurcates from Yanco Creek near Morundah. The division of flows between Colombo Creek and Lower Yanco Creek is controlled by Tarabah Weir. The PU ends where Lower Yanco Creek joins Billabong Creek.
- PU13: Lower Billabong and Intersecting Streams - The Lower Billabong and Intersecting Streams PU is situated within the Lower Billabong Anabranch Water Source.

Figure 1-8 Study area for the aquatic and water quality assessment.

1.8 Assumptions

The opinions, conclusions and any recommendations in this report are based on the assumptions described in this report. The assumptions have been made using the usual standard of care and skill to be expected of the consulting professions and disclaims liability arising from any of the assumptions being incorrect. These assumptions include:

- The presence of threatened species and communities have been assumed based on available survey records, database searches, predicted threatened species mapping and modelled preferred habitat. These records were also supplemented by some Environmental DNA (eDNA) sampling as part of this proposal.
- This report is based on desktop assessment supported by site-specific information from other sources. A visual habitat assessment was also undertaken by aquatic ecologists.
- The impact assessment was undertaken with reference to the detailed design, the *Billabong Creek Regulators Hydrology Assessment* (Jacobs, 2024a), *Billabong Creek Regulators Geomorphology Assessment* (Jacobs, 2024b), the *Billabong Creek Regulators Groundwater Assessment* (Jacobs, 2024c), *Yanco Creek Modernisation Hydraulic Modelling Technical Report – Piccaninny Weir to Wanganella Weir Study Area (*3Rivers, 2024a) and *Yanco Creek Modernisation Hydraulic Modelling Technical Report – Hartwood Weir to Piccaninny Weir Study Area (*3Rivers, 2024b).

2. Assessment approach and methodology

2.1 Legislative and policy context to the assessment

This section summarises the legislation, guidelines and/or policies driving the approach to the surface water quality and aquatic ecology assessment.

The SEARs requirements relevant to surface water quality and aquatic ecology and where these have been addressed in this report, are discussed in **Section 1.6**.

2.1.1 Commonwealth legislation

2.1.1.1 Environment Protection and Biodiversity Conservation Act 1999

The *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) protects Matters of National Environmental Significance (MNES). Under the EPBC Act, an action requires approval from the Minister for the Environment and Water if the action has, will have, or is likely to have, a significant impact on MNES. The MNES categories applicable to this assessment are aquatic threatened species and ecological communities, Ramsar-listed wetlands and Nationally Important Wetlands.

The following aquatic species MNES are predicted (based on habitat suitability) or known to occur in the study area and may be impacted:

- Murray Cod (*Maccullochella peelii*) – listed as Vulnerable
- Silver Perch (*Bidyanus bidyanus*) – listed as Endangered
- Flathead Galaxias (*Galaxias rostratus*) – listed as Critically Endangered
- Macquarie Perch (*Macquaria australasica*) – listed as Endangered
- Trout Cod (*Maccullochella macquariensis*) – listed as Endangered
- Murray Hardyhead (*Craterocephalus fluviatilis*) – listed as Endangered.

Whilst the proposal is not directly located within a Ramsar-listed wetland, the Protected Matters Search Tool (PMST) (DCCEEW, 2023) returned six wetlands of International Importance (Ramsar) within the locality (10 kilometre radius) (refer **Table 2-1**). As the proposal works are only confined to small areas and due to the distance from Ramsar Sites, activities are not expected to have significant or long last impact on these MNES within the meaning of the EPBC Act.

Table 2-1 Wetland of International Importance (Ramsar) within the locality (PMST)

Wetland of International Importance	Proximity to Proposal footprint (kilometres)
NSW Central Murray State Forest	Within 10km of Ramsar Site
Fivebough and Tuckerbil Swamps	Within 10km of Ramsar Site
Hattah-Kulkyne Lakes	200-300km upstream from Ramsar Site
Riverland	300-400km upstream from Ramsar Site
Banrock Station Wetland Complex	400-500km upstream from Ramsar Site
The Coorang, and Lakes Alexandrina and Albert Wetland	400-500km upstream from Ramsar Site

Assessment of significance for species which are known or likely to occur within the study area has been completed as part of this assessment.

Where a proposal is likely to have a significant impact on a MNES, the proposal is referred to the Commonwealth Minister for the Environment and Water. The referral process involves a decision on whether or not the proposal is a 'controlled action'. When a proposal is declared a controlled action, approval from the Minister is required under the EPBC Act.

2.1.1.2 Water Act

The Water Act 2007 provides the legislative framework for ensuring that the Murray-Darling Basin – Australia's largest water resource – is managed in the national interest. The Act establishes the Murray-Darling Basin Authority (MDBA) as an independent authority that has functions and powers, including enforcement powers, to ensure that Murray-Darling Basin water resources are managed in an integrated and sustainable way. The Act aims to:

- Improve water security for all uses of water resources in the Basin
- Promote the use and management of the Basin's water resources in a way that optimises economic, social and environmental outcomes
- Ensure the return to environmentally sustainable levels of extraction for water resources that are overallocated or overused
- Protect, restore and provide for the environment of the Basin
- Maximise the economic returns to the Australian community from the use and management of the Basin's water resources
- Implement relevant international agreements to address threats to the Basin's water resources
- Ensure that the management of the Basin's water resources takes into account the broader management of natural resources in the Basin
- Achieve efficient and cost-effective water management and administrative practices in relation to the Basin's water resources
- To provide for the collection, collation, analysis and dissemination of information about:
  - Australia's water resource
  - The use and management of water in Australia.

Components of the Act of relevance to this assessment include:

- The Murray Darling Basin Authority (MDBA), which is the regulatory body responsible for overseeing water resource planning in the Murray-Darling Basin as a whole
- The Basin Plan which is a strategic plan for the integrated and sustainable management of water resources in the Murray-Darling Basin (discussed further in **Section 2.1.2.7**).

The Water Act 2007 established a Commonwealth Environmental Water Holder (CEWH) which is responsible for managing the Commonwealth environmental water holdings to protect and restore environmental assets of the Murray-Darling Basin. The CEWH must manage the Commonwealth environmental water holdings in accordance with the Murray-Darling Basins environmental water plan. CEWH has identified their current (2023-24) environmental demand priorities in the Murrumbidgee River Valley to be:

- build ecological condition and resilience of plants throughout the region
- support foraging areas for juvenile waterbirds in the mid- and lower Murrumbidgee wetlands
- promote native fish spawning and movement.

See: Current priorities – Murrumbidgee River Valley - DCCEEW

2.1.1.3 State (NSW) legislation

2.1.1.4 Fisheries Management Act 1994

The *Fisheries Management Act 1994* (FM Act) provides for the conservation, protection and management of fisheries, aquatic systems and habitats in NSW. The FM Act is administered by the Department of Primary Industries - Fisheries (DPI Fisheries) and establishes mechanisms for:

- The listing of threatened species, populations and ecological communities or key threatening processes (KTPs); and
- The declaration of critical habitat.

Issuing permits for certain works on 'water land';

- Requiring the provision of fishways in the construction of weirs; and
- Consideration and assessment of threatened species impacts in the development assessment process.

Sections of the FM Act which are applicable to this assessment are discussed below.

Threatened species and Communities.

Part 7A, Division 12 of the FM Act relates to the environmental assessment of a development under Part 5 of the EP&A Act. Of relevance to this assessment, the following threatened aquatic species, populations and ecological communities which are listed under Schedule 4, 4A and 5 of the FM Act are predicted to occur in the study area:

- Murray Cod (*Maccullochella peelii*) – Vulnerable
- Silver Perch (*Bidyanus bidyanus*) – Vulnerable
- Flathead Galaxias (*Galaxias rostratus*) – Critically Endangered
- Macquarie Perch (*Macquaria australasica*) – Endangered
- Trout Cod (*Maccullochella macquariensis*) – Endangered
- Murray Hardyhead (*Craterocephalus fluviatilis*) – Critically Endangered
- Freshwater Catfish (*Tandanus tandanus)* – Endangered population in the Murray-Darling Basin.
- Murray Crayfish (*Euastacus armatus*) – Vulnerable.

An assessment of likelihood of occurrence has been undertaken for these threatened species and is documented in **Section 4.10.3.**

Impacts to critical habitat

Whilst the study area is known to support threatened aquatic species, no areas have been declared to be 'Critical habitat', in accordance with Part 7A, Division 3 of the FM Act.

Protection of fish habitats

Part 7 of the FM Act relates to the protection of aquatic habitats, including providing management of dredging and reclamation works within permanently or intermittently flowing watercourses, as well as the temporary or permanent blockage of fish passage within a watercourse. The 'Fisheries NSW Policy and Guidelines for Fish Habitat Conservation and Management' provided the framework used in this assessment (details provided in **Section 2.1.2.1**).

Provision of a fishway

A public authority that proposes to construct, alter or modify a structure on a waterway is subject to the provisions of section 218(5) of the FM Act, which requires that the Minister be notified of the proposal and allows for the Minister to request that the works include a suitable fishway or fish by-pass. Each of the proposed sites would include fishways that would provide for upstream and downstream fish passage and NSW DCCEEW has consulted with DPI Fisheries throughout the development the proposal.

This assessment is based on the available concept designs of the proposed fishways. The fishways are subject to further design development in the detailed design phase of the proposal. NSW DCCEEW would continue to engage with NSW Fisheries during the development of the fishway designs and seek their agreement on the suitability of the final designs.

Key threatening processes (KTPs)

Part 7A of the FM Act states that a threatening process is eligible to be listed as a key threatening process (KTP) if, in the opinion of the Fisheries Scientific Committee:

- It adversely affects threated species or ecological communities
- It could cause species or ecological communities that are not threatened to become threatened.

Schedule 6 of the FM Act outlines the KTPs related to aquatic species and ecological communities. Of the KTPs listed, the proposal is expected to involve the following:

- Installation and operation of instream structure and other mechanisms that alter natural flow regimes of rivers and streams
- Degradation of native riparian vegetation along NSW watercourses
- Removal of large woody debris from NSW rivers and streams.

Potential impacts due to KTPs are discussed further in **Section 7.4**.

2.1.1.5 Water Management Act 2000

The *Water Management Act 2000 (WM Act)* is the primary legislation for the management of water in NSW. The WM Act contains provisions for water management plans and the allocation of water. Management plans cover both surface and groundwater sources.

Water Sharing Plans (WSPs) apply within the study area and are shown in **Table 2-2**. Water sharing plans establish the rules for the sharing of water in a particular water source between water users and the environment and rules for the trading of water in a particular water source.

With respect to groundwater in the study area, the uppermost groundwater source and WSP is shown in **Table 2-2**. This groundwater source consists of unconsolidated alluvial sediments to a depth of 40 metres or to the bottom of the Shepparton Formation, whichever is deeper. Additional groundwater sources and WSPs underly the upper most groundwater source and WSP. However, these deeper groundwater sources and WSPs are not applicable as proposal works are not proposed at depths of greater than a few metres below ground level and are unlikely to influence these deeper groundwater systems.

Table 2-2 WSPs and water sources in the study area

Water type	Water Sharing Plan	Water Source of Management Area
Surface water	Water Sharing Plan for the Murrumbidgee Unregulated River Water Sources 2012	Lower Billabong Anabranch Water Source
	Water Sharing Plan for the Murrumbidgee Regulated River Water Sources 2016	Murrumbidgee Regulated River Water Source

Water type	Water Sharing Plan	Water Source of Management Area
Groundwater	Murray Alluvial Groundwater Sources 2020	Lower Murray Shallow Groundwater Source
	Murrumbidgee Alluvial Groundwater Sources 2020	Lower Murrumbidgee Shallow Groundwater Source

Water Sharing Plan for the Murrumbidgee Unregulated River Water Sources 2012

Billabong Creek upstream of Colombo Creek is subject to the Water Sharing Plan for the Murrumbidgee Unregulated River Water Source (Murrumbidgee WSP) and relates to those waterways that whilst contributing water, do not receive regulated flow. The key elements of the Murrumbidgee WSP that are relevant to the proposal are described in this section based on the statutory instrument itself.

The Murrumbidgee WSP has several objectives; the objectives most relevant to the proposal include:

- To protect, preserve, maintain and enhance the important river flow dependent and high priority groundwater dependent ecosystems of these water sources
- Manage these water sources to ensure equitable sharing between users
- Contribute to the maintenance of water quality
- Adaptively manage these water sources.

In accordance with sections 20 and 21 of the WM Act, the Murrumbidgee Unregulated River WSP applies a range of strategies to achieve these objectives including establishing performance indicators and environmental water rules, identifying water requirements for basic landholder rights and requirements for access licences, establishing rules for granting and amending of access licences and approvals and rules that place limits of the availability of water for extraction and circumstances under which water may be extracted, establishing rules for the operation of water allocation accounts.

The Murrumbidgee Unregulated WSP covers a number of water sources of which the proposal is located within the Lower Billabong anabranch water source. The Lower Billabong Anabranch water source falls within the Unregulated Murrumbidgee Gogeldrie to Weimby Extraction Management Unit which provides the limit for the amount of water that can be extracted within a specified time period.

Water Sharing Plan for the Murrumbidgee Regulated River Water Sources 2016

The Murrumbidgee Regulated River WSP applies to the Murrumbidgee below Burrinjuck Dam and Blowing Dam to the Yanco/Billabong Creek system and as such, Billabong Creek downstream of its confluence with Colombo Creek is also subject to this WSP. The broad environmental objective of this plan is to protect and contribute to the enhancement of ecological condition of the water source and its water-dependent ecosystems. More specifically, the targeted objectives are:

- To protect and contribute to the enhancement of:
  - The recorded distribution or extent and population structure of target ecological populations
  - The longitudinal and lateral connectivity within and between water sources to support target ecological processes
  - Water quality within target ranges for the water source to support water-dependent ecosystems and ecosystem functions.
- To support environmental watering in the water course and contribute to maintaining or enhancing ecological condition in streams, riparian zones, dependent wetlands and floodplains.

The WSP applies a range of strategies to achieve these objectives including establishing and maintaining compliance with an annual extraction limit and long-term average sustainable diversion limit; reserving a share of water to partially mitigate alterations to natural flow regime in the water source, to maintain connectivity between water sources, to support environmental watering and to contribute to the management of critical environmental and water quality events in downstream connected water sources.

Minimum daily flows (end of system flows) are specified in part 6, division 2 clause 30 the Water Sharing Plan to maintain connectivity within the River Murray. The WSP requires that a minimum daily flow of 50ML/d must be maintained in Billabong Creek at Darlot gauge throughout the year.

2.1.1.6 Water (Accredited Water Resource Plan – Murrumbidgee) Instrument 2024 and Murrumbidgee Water Resource Plan, 2024

The *Water (Accredited Water Resource Plan – Murrumbidgee) Instrument* (2024), made under section 63 of the *Water Act 2007* came into effect on 22 February 2024 and governs the management of use of water resources in the Murrumbidgee Region. Under this instrument the Murrumbidgee Water Resource Plan (WRP) was accredited as being consistent with the Basin Plan and commenced on 29 February 2024, and is the prevailing management plan for the surface water resources in the Murrumbidgee water resource plan area. The Murrumbidgee WRP sets out arrangements for water sharing within the sustainable diversion limits for the WRP area, establishes rules to meet environmental and water quality objectives and considers the need to manage and/or mitigate potential and emerging risks to water resources. The WRP also identifies Indigenous objectives and outcomes for water resources arrangement based on the values and uses associated with those water resources (MDBA, 2024).

2.1.2 Policy and guidelines

2.1.2.1 Policy and Guidelines for Fish Habitat Conservation and Management 2013

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

- Background information on aquatic habitats and fisheries resources in NSW
- An outline of the legislative requirements relevant to planning and development which may affect fisheries or aquatic habitat in NSW
- General policies and classification schemes for the protection and management of fish habitats and an outline of the information that NSW Fisheries requires to be included in development proposals that affect habitat
- Specific policies and guidelines aimed at maintaining and enhancing the free passage of fish through instream structures and barriers
- Specific policies and guidelines for foreshore works and waterfront developments
- Specific policies and guidelines for the management of other activities that affect watercourses.

The aquatic habitat assessment has taken into account the requirements of these guidelines.

2.1.2.2 Why do Fish Need to Cross the Road: Fish Passage Requirements for Waterway Crossings

The NSW DPI guideline *Why do Fish Need to Cross the Road? Fish Passage Requirements for Waterway Crossings* (Fairfull and Witheridge, 2003) provides practical guidelines for the planning, design, construction and maintenance of waterway crossings aimed at minimising impacts on fish passage and aquatic ecology in general. It should be used in conjunction with the *Policy and Guidelines for Fish Habitat Conservation and Management* (DPI, 2013) by outlining potential impacts of instream structures and design specifications/recommendations for crossings to avoid erecting barriers to fish passage. The aquatic habitat assessment has taken into account the requirements of these guidelines in relation to permanent structure detailed in the proposal.

2.1.2.3 National Water Quality Management Strategy

The National Water Quality Management Strategy (Australian Government, 2018) (NWQMS) was formulated with the objective of achieving sustainable use of the nation's water resources by protecting and enhancing water quality whilst maintaining economic and social development.

The NWQMS contains guidelines for setting water quality objectives to sustain current or likely future environmental values for water resources. The *Australian and New Zealand Guidelines for Fresh and Marine Water Quality* (ANZG, 2018) are part of the NWQMS and are relevant to the proposal as discussed in **Section 2.1.2.4.**

2.1.2.4 Australian and New Zealand Water Quality Guidelines for Fresh and Marine Water Quality

The Australian and New Zealand Environment and Conservation Council (ANZECC/ARMCANZ) published the *Australian and New Zealand Guidelines for Fresh and Marine Water Quality* (ANZECC/ARMCANZ, 2000) to provide benchmarks against which to assess the existing water quality of waterways. The guidelines were updated in 2018 to incorporate new science and knowledge developed over the past 20 years (ANZG, 2018).

The ANZG (2018) *National Water Quality Guidelines for Fresh and Marine Water Quality* (referred to herein as the ANZG (2018) Water Quality Guidelines) have been applied with guidance from the *Using the ANZECC Guidelines and Water Quality Objectives in NSW* (DEC, 2006) booklet to understand the current health of the waterways in the study area and the ability to support nominated water quality objectives, particularly the protection of aquatic ecosystems. The ANZG (2018) Water Quality Guidelines provide default guideline values which have been considered when describing the existing water quality and key indicators of concern. However, many of the guideline values are still in a draft form.

The ANZG (2018) Water Quality Guidelines have been derived to apply to the ambient waters that receive flows and runoff and protect the water quality objectives they support.

2.1.2.5 NSW Water Quality and River Flow Objectives

The NSW Water Quality Objectives (WQOs) (DECCW, 2006) are the agreed long-term goals for NSW's surface water, as determined by the then Department of the Environment, Climate Change and Water (now Department of Planning and Environment). They set out:

- The community's values and uses (i.e. healthy aquatic ecosystem, water suitable for recreation or drinking water etc) for our waterways (rivers, creeks, lakes and estuaries); and
- A range of water quality indicators to assess whether the current condition of the waterway supports these values and uses.

The WQOs identify environmental values for NSW waters and the ANZG (2018) guidelines provide the technical guidelines to assess the water quality needed to protect these values.

The proposal falls within the Murray River Catchment. Different WQOs have been set for areas within this catchment based on land use and the nature of its watercourses and their flows. Billabong Creek is located within the study area and receives controlled flows from the Murrumbidgee River and has been categorised as "controlled river with altered flow pattern (regulated creeks)". There are a number of nominated water quality objectives for protection for this category including:

- Aquatic ecosystems
- Visual amenity
- Secondary contact recreation
- Primary contact recreation
- Livestock water supply
- Irrigation water supply
- Homestead water supply
- Aquatic foods (cooked).

The water quality targets for protection of these WQOs are provided in **Table 3-1**.

2.1.2.6 Guidelines for Managing Risks in Recreational Waters

The *Guidelines for Managing Risks in Recreational Water* (NHMRC, 2008) aim to protect the health of humans from threats posed by the recreational use of coastal, estuarine, and fresh waters.

The guidelines provide recommended values for indicators that may pose a risk to human health. These indicators are relevant for waterways that are being used for recreation but have the potential to be polluted. These guidelines are applicable to this assessment because the waterways in proximity of the proposal site have been nominated the environmental values of 'Primary contact recreation' and 'Secondary contact recreation'.

2.1.2.7 The Basin Plan

The Basin Plan (MDBA, 2012) is the overarching, strategic plan for the integrated and sustainable management of water resources in the Murray-Darling Basin. During the development of the Murray-Darling Basin Plan, basin ministers requested the ability for less water recovery in the southern Basin if projects could be delivered that would achieve equal environmental outcomes. This is called the Sustainable Diversion Limit Adjustment Mechanisms (SDLAM). The Basin Plan sets environmentally sustainable limits on surface water and groundwater use in the MDB. In order to implement new limits, the Australian Government is recovering water to protect and restore the rivers, wetland and floodplains of the MDB and this recovered water becomes part of the Commonwealth's Environmental Water Holdings.

The Basin Plan provides a coordinated approach to managing Basin water resources across Queensland, NSW, ACT, Victoria and South Australia. In NSW, the plan came into effect following the signing of an Intergovernmental Agreement and a National Partnership Agreement in 2014. The NSW DCCEEW is responsible for the development of valley-based plans in NSW, including long-term water plans and water resource plans. These plans are relevant to this proposal and have been considered for this assessment. These are described below.

Murrumbidgee Long-term Water Plan

The Murrumbidgee Long-Term Water Plan (LTWP) is one of nine plans developed to cover the NSW portion of the Murray-Darling Basin. The Murrumbidgee LTWP is in two parts – Part A, which presents a catchment-scale description of the flow regimes required to maintain or improve environmental outcomes in the

Murrumbidgee (NSW DPIE, 2020a); and Part B, which describes the flow regimes required to maintain or improve environmental outcomes in the Murrumbidgee at a planning unit scale (NSW DPIE, 2020b).

To address variation along the Murrumbidgee River, the Murrumbidgee Long-Term Water Plan divides the river into 14 planning units, which correspond to the 14 management zones in the WSP. The proposal spans across a number of planning units, with the proposed Hartwood Regulator located within the relevant planning units (PU) of Colombo and Billabong Creeks (PU11) and the proposed Wanganella Regulator located within the Lower Billabong and Intersecting Streams (PU13).

Murrumbidgee Surface Water Resource Plan

Under the Murray-Darling Basin Plan, there is a requirement to develop water quality management plans for each Water Resource Plan (WRP) area within the Murray-Darling Basin with the purpose of providing a framework to protect, enhance and restore water quality that is suitable for a range of outcomes. The proposal falls within the Murrumbidgee Water Resource Plan area which comprises water between the banks of the Murrumbidgee River, from Burrinjuck Dam and Blowering Dam downstream to the confluence of the River Murray. It also includes the Lowbidgee and Yanco Creek, Colombo Creek, and lower sections of Billabong Creek.

The WRP includes the regulated river systems, unregulated rivers flowing into the regulated river systems, unregulated effluent creeks flowing out of the regulated river system onto the plains, and water captured through farm dams.

Water Quality Management Plan for the Murrumbidgee Surface Water Resource Plan Area

The Murrumbidgee Surface Water Resource Plan applies to the Yanco Creek System and was accredited as being consistent with the Basin Plan in February 2024.

The Water Quality Management Plan (WQMP) for the Murrumbidgee Surface WRP area (DPE, 2020) supports the Murrumbidgee WRP and LTWP. The plan provides a framework to protect, enhance and restore water quality that is fit for purpose for a range of outcomes including to:

- Fulfill First Nation peoples spiritual, cultural customary and economic values;
- Protect and improve ecological processes and healthy aquatic ecosystems;
- Provide essential recreational amenities for rural communities; and
- Assist agricultural enterprises to be productive and profitable.

The WQMP sets out water quality targets for water-dependent ecosystems in Water Quality Target Application Zones in the Murrumbidgee Water Resource Plan Area. Billabong Creek is currently classified as Central Lowland, Murray water quality zone, however NSW DPIE (2020c) identified Billabong Creek to be more like the Central Murrumbidgee River in nature than the Central Murray River. The NSW DPIE recommended that Billabong Creek be included in the Murrumbidgee Valley Lowland Zone (A3) rather than the Central Murray (Upper, Middle) zone (CMum) and that water quality targets for the Murrumbidgee lowland zone (A3) may be more applicable (NSW DPIE, 2020c).

The water quality targets for aquatic ecosystems in the WQMP were developed following methods outlined in the ANZG (2018) Water Quality Guidelines (described in **Section 3.1.2**). Some water quality targets outlined in the WQMP correspond with default guideline values (DGVs) nominated in the ANZG (2018) Water Quality Guidelines – in particular toxicant concentrations. Where ANZG (2018) DGVs differ from the water quality targets outlined in the WQMP, the WQMP water quality targets were adopted for this assessment.

The WQMP also sets out water quality targets for recreational water. The targets have been adapted from the *Guidelines for Managing Risks in Recreational Water* (NHMRC, 2008) as described in **Section 2.1.2.6**.

2.1.2.8 Approved Methods for Sampling and Analysis of Water Pollutants in NSW

The *Approved Methods for Sampling and Analysis of Water Pollutants in NSW* (NSW EPA, 2022) is a guideline which lists the sampling and analysis methods that are approved for use when complying with a requirement of the Protection of the Environment Operations (POEO) Act 1997 The process for determining the sampling and analysis methods to be used are outlined in these guidelines.

2.1.2.9 Managing Urban Stormwater: Soils and Construction

Managing Urban Stormwater, Soils and Construction, Volume 1 (Landcom, 2004), commonly referred to as the 'Blue Book', outlines the basic principles for stormwater management during construction. It provides guidance on design and construction of sediment and erosion control measures to protect downstream water quality, thereby improving the health, ecology and amenity of rivers and streams.

2.1.2.10 Guidelines for controlled activities on waterfront land

Works carried out on waterfront land are regulated by the WM Act as controlled activities. The WM Act defines where an approval is required for controlled activities. Guidelines are provided for works requiring approval.

The Guideline for instream work on waterfront land (DPI, 2022) addresses the assessment requirements for the design and construction of works within a watercourse or on waterfront land i.e. the bed of any river, lake or estuary, and the land within 40 metres of the highest bank of the river, the shore of the lake or the mean high-water mark of the estuary. Instream works include modifications or enhancements to the watercourse, channel realignment, bed control structures, pipe laying and cable trenching and the carrying out of any other activity that affects the quality or flow of water in the water source.

The guidelines include assessment requirements associated with the aims and objectives for instream works, considerations for the design and construction of instream works, information provision for assessment and maintenance period provisions. As the project would involve construction of new regulators and fishways within the river channel and ancillary road/facility within 40 metres of riverbanks the proposal would meet the definition of a controlled activity under the WM Act.

Section 41 of the Water Management (General) Regulation 2018 provides that a public authority is exempt from requiring activity approval to carry out a controlled activity in, on or under water from land. Furthermore, in accordance with section 5.23 of the EP&A Act, an activity approval (including a controlled activity approval) under section 91 of the WM Act is not required for SSI. However, the guidelines have been considered in this assessment.

2.1.2.11 Survey Guidelines for Australia's Threatened Fish

The *Survey Guidelines for Australia's Threatened Fish* (DSEWPAC, 2011) provide guidance on what should be considered when planning and undertaking species surveys for threatened fishes. The guidelines particularly focused on species listed under the EPBC Act, however, also apply to most state listed threatened species. The individual taxa (species or subspecies) accounts provide a guide to the survey methods and effort (where available) that are appropriate for assessing whether those listed taxa occur at or near a specified site. The survey guidelines have been considered when assessing the suitability of existing surveys in assessing species presence in the system.

2.1.2.12 NSW Weirs Policy

The NSW Weirs Policy provides a framework for the review of weirs across the state and establishes the goal and principles for the ongoing approval and management of weirs, including making formal allocations to the environment based on the best scientific information available (DPI, 1991). The goal of the NSW Weirs Policy is to halt and, where possible, reduce and remediate the environmental impacts of weirs. The NSW Weirs Policy has three components, the first "*Approvals for new or expanded weirs*" relates to the approval to build a new, or expand an existing weir, the second "*Weir review program*" is a review of all existing weirs and the third "*Provision of fishways*" addresses the consideration of weirs that have a significant impact on the movement of fish.

The '*Weir Review Program*' component was first implemented following the then NSW Fisheries and Department of Land and Water Conservation initial weir review program in 1999. This review evaluated the impact of licenced dams and weirs on fish passage for the purpose of identifying sites for remediation. Both the Hartwood Weir and Wanganella Town Weir were identified in this initial review (NSW DPI, 2006). Hartwood Weir was identified for remediation as its acts as a barrier to fish passage during most flow conditions as the weir does not drown out and the area is recognised as key habitat for important fish species including threatened fish species and endangered ecological communities. Wanganella Town Weir was identified for remediation as it acts as a barrier to fish during low flow conditions (although does drown out several times a year). Similarly, Hartwood weir is recognised as key habitat for important fish species and the site is crucial for fish recruitment and migration (NSW DPI, 2006).

This assessment considers the first and third components of the policy including the limited ability of the existing weirs to regulate flows through the Yanco Creek System leading to inefficiencies in how water is delivered to the environment and irrigators and demonstrated that it is necessary to seek approval for a new or expanded weir. The new regulators which are described in **Section 1.4** have been designed with consideration to the factors outlined in the NSW weirs policy component three, including provision of automated lay flat gates to allow for movement of fish downstream and provide for a low turbulence 'keyhole' type vertical slot fishway with allowances for variable headwater to provide upstream fish passage.

3. Methodology

This section outlines the methods used to assess the effect of the proposal on surface water quality and aquatic ecology from construction works and the operation of the new replacement regulators for the proposal. The assessment is based on a review of relevant literature and hydrological and hydraulic modelling of flows in the Yanco Creek System.

3.1.1 Desktop assessment of aquatic fauna

A desktop assessment was undertaken to identify aquatic species with the potential to occur within the study area. The review considered published records, the results of eDNA sampling done as part of this EIS, predicted occurrences of aquatic species, and habitat distribution models.

3.1.1.1 Databased searches

The following databases were used, with the search being carried out with a buffer of 10 km around the proposal study area:

- Protected Matters Search Tool (PMST) for species and communities listed under the Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act), maintained by Commonwealth DCCEEW
- NSW DPI threatened species distribution maps
- Atlas of Living Australia (ALA)
- The Australian Platypus Monitoring Network, an initiative of the Australian Platypus Conservancy
- TurtleSAT, a community-focused freshwater turtle mapping initiative.

3.1.1.2 Literature review and previous ecological assessments

The following ecological assessments and information associated with the proposal were also reviewed to inform the desktop assessment:

- Gilligan, D. (2005). Fish communities of the Murrumbidgee catchment: Status and trends. NSW Department of Primary Industries – Fisheries Final Report Series No. 75.
- Sharpe, C., Stuart, I. and Vilizzi, L (2013). Billabong, Yanco and Colombo Creek Fish Baseline Project 2012-13. Final Report, for Murray Catchment Management Authority by CPS Environmental Research, Irymple Victoria. July 2013.
- Sharpe, C. and Stuart, I. (2015). The Distribution of Trout cod in Yanco and Colombo Creeks. Final Report for Murray Local Land Services by CPS Enviro and Kingfisher Research, Irymple Victoria.
- Sharpe, C. (2018). Trout cod in Yanco Creek; Patterns of spawning, recruitment and population status in 2017/18. Final Report for Murray Local Land Services by CPS Enviro, Irymple Victoria.
- Walcott, A., Wolfenden, B., Hall, A. & Wassens, S. (2018). Yanco-Billabong Creek Broad-scale Wetland Monitoring Project: Frog communities of the Yanco-Billabong creek system. Final Report prepared for Murray Local Land Services. Institute of Land Water and Society, Charles Sturt University, Albury.
- McNeil, D, G. and Griffiths, J. (2021). Platypus in the Yanco Creek: Understanding Distribution and Population Status. Report to the Yanco Creek and Tributaries Advisory Council, Jerilderie, NSW.
- Stuart, I. (2022). Yanco Creek fish movement model. Unpublished Client Report. Arthur Rylah Institute for Environmental Research, Victoria Department of Environment, Land, Water, and Planning, Heidelberg.
- Charles Sturt University (2022). Data from a 2022 aquatic and terrestrial fauna survey of the Yanco-Billabong System (unpublished).

3.1.2 Desktop assessment of water quality

The desktop assessment of surface water quality included:

- Undertaking a desktop review and analysis to understand the existing environment and identify the potential surface water quality risks of the proposal
- Sites visits and water quality monitoring to support and enhance the findings of the desktop analysis and refine the understanding of potential surface water quality risks
- Classifying sensitive receiving environments and identifying environmental values relevant to the proposal.

3.1.2.1 Site classification

Sensitive receiving environments

Sensitive receiving environments are environments that have a high conservation or community value or support ecosystem/human uses of water that are particularly sensitive to pollution or degradation of water quality. Billabong Creek within the study area, and the nearby connected Colombo Creek and Forest Creek, have been identified as a sensitive receiving environment (Type 1 – Highly Sensitive Key Fish Habitat) because the waterways are known to support threatened species listed under the EPBC Act and FM Act.

Water quality objectives

Water quality objectives for the Murray River Catchment have been nominated in both the Basin Plan and DECCW (2006) *Water quality and River flow objectives* and contribute towards maintaining appropriate water quality, including salinity for environmental, social, cultural and economic activities. The Murrumbidgee Surface WRP together with the ANZG (2018) provide water quality target indicators as a guideline for meeting water quality objectives. The objectives and indicators are provided in **Table 3-1.** Water quality data will be compared to water quality targets to determine if nominated water quality objectives are currently being met in the Project. An assessment of the impact the construction and operation of the project may have on meeting water quality targets will also be undertaken.

Table 3-1 Water quality objectives for Billabong Creek, associated indicators and nominated water quality targets

Water quality objective	Indicator	Target	Source
Aquatic ecosystems - maintaining or improving the ecological condition of waterbodies and their riparian zones over the long term	Total phosphorus	0.05mg/L (Streams, rivers lakes and wetlands)	Murray Darling Basin Plan (2012)
	Total nitrogen	0.6mg/L (Streams, rivers lakes and wetlands)	Murray Darling Basin Plan (2012)
	Chlorophyll-*a*	5µg/L	ANZG (2018)
	Turbidity	35NTU (River and streams)	Murray Darling Basin Plan (2012)
	Salinity (electrical conductivity)	$95^{th\%ile}$ 580[1]µS/cm Median (50^{th}%ile) 162 µS/cm	End of Valley Target, Schedule B, Appendix 1 of the Commonwealth *Water Act* (2007)
	Temperature	Between the 20^{th} and 80^{th} percentile of natural monthly water temperature	Murray Darling Basin Plan (2012)

Water quality objective	Indicator	Target	Source
	Dissolved oxygen	80-110 percent saturation (Streams, rivers lakes and wetlands)	Murray Darling Basin Plan (2012)
	pH	6.5-8 (Streams, rivers lakes and wetlands)	Murray Darling Basin Plan (2012)
	Toxicants	Toxicants mush not exceed the 95th percentile value for t aquatic ecosystems	ANZG (2018); Murray Darling Basin Plan (2012)
Visual amenity – aesthetic qualities of waters	Visual clarity and colour	Natural visual clarity should not be reduced by more than 20%. Natural hue of water should not be changed by more than 10 points on the Munsell Scale. The natural reflectance of the water should not be changed by more than 50%.	NHMRC (2008)
	Surface films and debris	Oils and petrochemicals should not be noticeable as a visible film on the water, nor should they be detectable by odour. Waters should be free from floating debris and matter	NHMRC (2008)
	Nuisance organisms	Macrophytes, phytoplankton scums, filamentous algal mats, blue-green algae, sewage fungus and leeches should not be present in unsightly amounts	NHMRC (2008)
Secondary contact recreation - maintaining or improving water quality for activities such as boating and wading, where there is a low probability of water being swallowed	Faecal coliforms, enterococci, algae and blue-green algae	As per the National Health and Medical Research Council (NHMRC) (2008) Guidelines for managing risks in recreational water. Secondary contact recreation – maintaining or improving water quality for activities such as boating and wading, where there is a low probability of water being swallowed	NHMRC (2008)
	Nuisance organisms	As per the visual amenity guidelines Large numbers of midges and aquatic worms are undesirable.	NHMRC (2008)
	Chemical contaminants	Waters containing chemicals that are either toxic or irritating to the skin or mucous membranes are unsuitable for recreation Toxic substances should not exceed values in Table 9.3 of NHMRC (2008) guidelines	NHMRC (2008)
	Visual clarity and colour	As per the visual amenity guidelines	NHMRC (2008)
	Surface films	As per the visual amenity guidelines	NHMRC (2008)
Primary contact recreation - maintaining or	Blue-green algae (cyanobacteria)	$\geq$ 10 µg/L total microcystins; or $\geq$ 50000 cells/mL toxic Microcystis aeruginosa; or biovolume equivalent of $\geq$ 4 mm^3/L for the combined total of all cyanobacteria where	Water Resource plan (NSW DPIE, 2020c)

Water quality objective	Indicator	Target	Source
improving water quality for activities such as swimming where there is a high probability of water being swallowed		a known toxin producer is dominant in the total biovolume; or ≥ 10 mm^3/L for total biovolume of all cyanobacterial material where known toxins are not present; or Cyanobacterial scums consistently present	
	Protozoans	Pathogenic free-living protozoans should be absent from bodies of fresh water	NHMRC (2008)
	Chemical contaminants	Waters containing chemicals that are either toxic or irritating to the skin or mucous membranes are unsuitable for recreation Toxic substances should not exceed values in Table 9.3 of NHMRC (2008) guidelines	NHMRC (2008)
	Visual clarity and colour	As per the visual amenity guidelines	NHMRC (2008)
	Temperature	15°-35°C for prolonged exposure	NHMRC (2008)
Irrigation water supply - protecting the quality of waters applied to crops and pasture	Algae and blue-green algae	An increasing risk to livestock health is likely when cell counts of microcystins exceed 11500 cells/mL and/or concentrations of microcystins exceed 2.3 µg/L expressed as microcystin-LR toxicity equivalents.	ANZECC/ARMCANZ (2000)
	Salinity (electrical conductivity)	95th percentile over 10 year period less than 833µS/cm	Murray Darling Basin Plan (2012)
	Thermotolerant coliforms (faecal coliforms)	Drinking water for livestock should contain less than 100 thermotolerant coliforms per 100 mL (median value)	ANZECC/ARMCANZ (2000)
	Chemical contaminants	Refer to Table 4.3.2 of ANZECC Guidelines (ANZECC/ARMCANZ, 2000) for heavy metals and metalloids in livestock drinking water. Refer to Australian Drinking Water Guidelines (NHMRC and NRMMC, 2018) for information regarding pesticides and other organic contaminants, using criteria for raw drinking water.	ANZECC/ARMCANZ (2000) NHMRC and NRMMC (2018)
Aquatic foods (cooked) - refers to protecting water quality so that it is suitable for production of	Algae and blue-green algae	No guideline is directly applicable, but toxins present in blue-green algae may accumulate in other aquatic organisms	ANZECC/ARMCANZ (2000)
	Faecal coliforms	*Guideline in water for shellfish:* The median faecal coliform concentration should not exceed 14 MPN/100mL; with no more than 10% of the samples exceeding 43 MPN/100 mL.	ANZECC/ARMCANZ (2000)

Water quality objective	Indicator	Target	Source
aquatic foods for human consumption and aquaculture activities		*Standard in edible tissue:* Fish destined for human consumption should not exceed a limit of 2.3 MPN *E Coli* /g of flesh with a standard plate count of 100,000 organisms /g.	
	Toxicants (as applied to aquaculture activities	Metals: Copper: less than 5µgm/L. Mercury: less than 1µgm/L. Zinc: less than 5µgm/L. Organochlorines: Chlordane: less than 0.004µgm/L (saltwater production) PCB's: less than 2µgm/L	ANZECC/ARMCANZ (2000)
	Physico-chemical indicators (as applied to aquaculture activities	Suspended solids: less than 40 micrograms per litre (freshwater) Temperature: less than 2 degrees Celsius change over one hour.	ANZECC/ARMCANZ (2000)

3.1.2.2 Existing water quality data analysis

Water quality data used in this report to establish existing water quality has been sourced from monitoring undertaken by Charles Sturt University (CSU) as part of the Yanco Creek System environmental monitoring, real time monitoring data collected at WaterNSW gauges and the water quality index scores calculated used data collected under the NSW State water quality assessment and monitoring program (NSW DPI, 2019). In addition to the data received by CSU, literature reviews which generally included a broader range of water quality indicators were also used to describe existing water quality. Additional in-situ physico-chemical water quality data was also collected for this assessment (refer **Table 3-3**).

Table 3-2 provides details of the CSU water quality monitoring location, frequency of monitoring and parameters measured. The locations of existing water quality monitoring sites are shown on **Figure 3-2a-c**.

Table 3-2 CSU Monitoring location descriptions, sampling dates and parameters

Monitoring location name	Location description	Dates sampled range	Parameters monitored
RHY	Rhyola wetland	Dec 2021	Temperature, electrical conductivity, dissolved oxygen, pH and turbidity
RHY2	Billabong Creek, Rhyola	Oct 2021, Feb 2022, Apr 2022	Temperature, electrical conductivity, dissolved oxygen, pH and turbidity
RHY3	Forest Anabranch, Rhyola	Feb 2022, Apr 2022	Temperature, electrical conductivity, dissolved oxygen, pH and turbidity

Monitoring location name	Location description	Dates sampled range	Parameters monitored
WSP	Wanganella Swamp wetland	Oct 2021, Dec 2021, Feb 2022, Apr 2022, Sep 2022, Jan 2023, Mar 2023	Temperature, electrical conductivity, dissolved oxygen, pH and turbidity
WSP2	Forest Creek, Wanganella	Oct 2021, Dec 2021, Feb 2022, Sep 2022, Jan 2023, Mar 2023	Temperature, electrical conductivity, dissolved oxygen, pH and turbidity
WSP3	8 Mile Creek, Wanganella	Apr 2022, Apr 2023	Temperature, electrical conductivity, dissolved oxygen, pH and turbidity
HRT	Hartwood wetland	Sep 2022, Jan 2023, Mar 2023, Apr 2023	Temperature, electrical conductivity, dissolved oxygen, pH and turbidity
HRT2	Billabong Creek, Hartwood	Sep 2022, Jan 2023, Mar 2023, Apr 2023	Temperature, electrical conductivity, dissolved oxygen, pH and turbidity

The NSW Water Quality Index (WaQI) tool was developed for presenting technical water quality data in a simple and consistent way by comparing water quality parameters against their appropriate water quality targets and calculating a score between 1 to 100 (NSW DPI, 2019). **Figure 3-1** shows the NSW WaQI scoring categories.

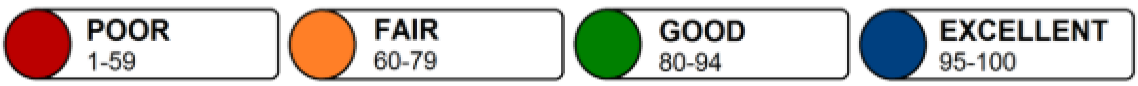
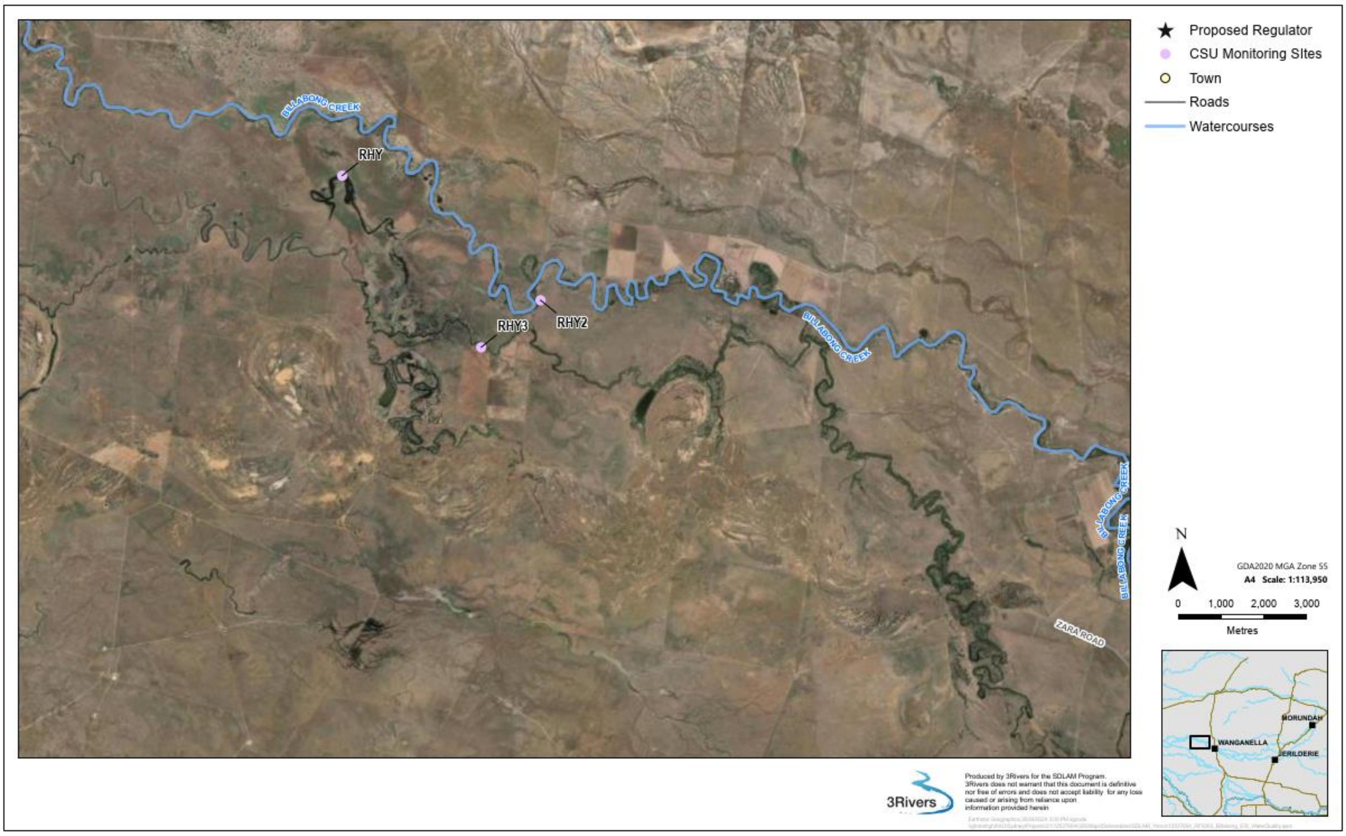


Figure 3-1 NSW Water quality index (WaQI) scoring categories (Source NSW DPI, 2019)

The methodology for determining existing water quality conditions have included:

- Collating water quality data;
- Calculating summary statistics for each site including number of samples, mean, median, 95th percentile, maximum and minimum value; and
- Reporting the median historical data and mean sampled data in comparison with applicable Murrumbidgee Water Quality Targets, DECCW (2006) WQOs and ANZG (2018) DGVs.


Proposed Regulator
CSU Monitoring SItes
Town
Roads
Watercourses
BILLABONG CREEK
RHY
RHY3
RHY2
BILLABONG CREEK
BILLABONG CREEK
ZARA ROAD
N
GDA2020 MGA Zone 55
A4 Scale: 1:113,950
0 1,000 2,000 3,000
Metres
MORUNDAH
WANGANELLA
JERILDERIE
3Rivers
Produced by 3Rivers for the SDLAM Program.
3Rivers does not warrant that this document is definitive
nor free of errors and does not accept liability for any loss
caused or arising from reliance upon
information provided herein

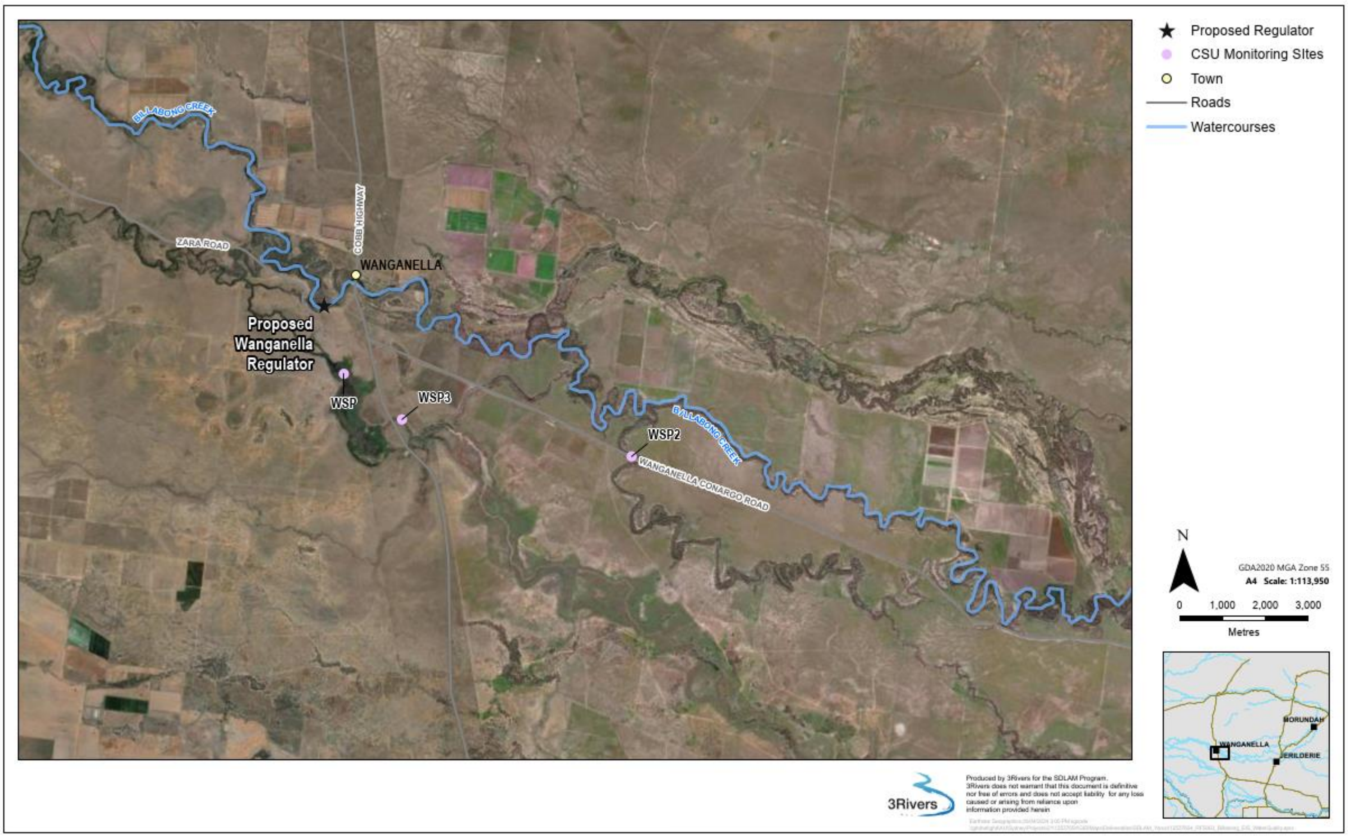

Proposed Regulator
CSU Monitoring SItes
Town
Roads
Watercourses
BILLABONG CREEK
ZARA ROAD
COBB HIGHWAY
WANGANELLA
Proposed
Wanganella
Regulator
WSP
WSP3
WSP2
BILLABONG CREEK
WANGANELLA CONARGO ROAD
N
GDA2020 MGA Zone 55
A4 Scale: 1:113,950
0 1,000 2,000 3,000
Metres
MORUNDAH
WANGANELLA
JERILDERIE
3Rivers
Produced by 3Rivers for the SDLAM Program.
3Rivers does not warrant that this document is definitive
nor free of errors and does not accept liability for any loss
caused or arising from reliance upon
information provided herein

Figure 3-2a-c Charles Sturt University water quality monitoring locations

3.1.3 Site investigations

Site investigations of the study area were undertaken by Jacobs aquatic ecologists between 5 March 2023 and 8 March 2023 which comprised of a visual assessment of aquatic habitat and waterway conditions and an eDNA survey targeting fish communities. The purpose of site investigations was to assess aquatic ecosystems and environmental values of waterways in the study area, adding more targeted, on-ground information to the desktop analysis to help refine the understanding of potential impacts from the proposal. The survey area at each assessment site included the site location and 100m upstream and downstream, the condition of the waterway including the water quality, bank stability, aesthetic value as well as aquatic and riparian habitat quality were assessed, with the location of each site recorded and photographs taken. Assessment sites are listed in **Table 3-3** and shown on **Figure 3-3**.

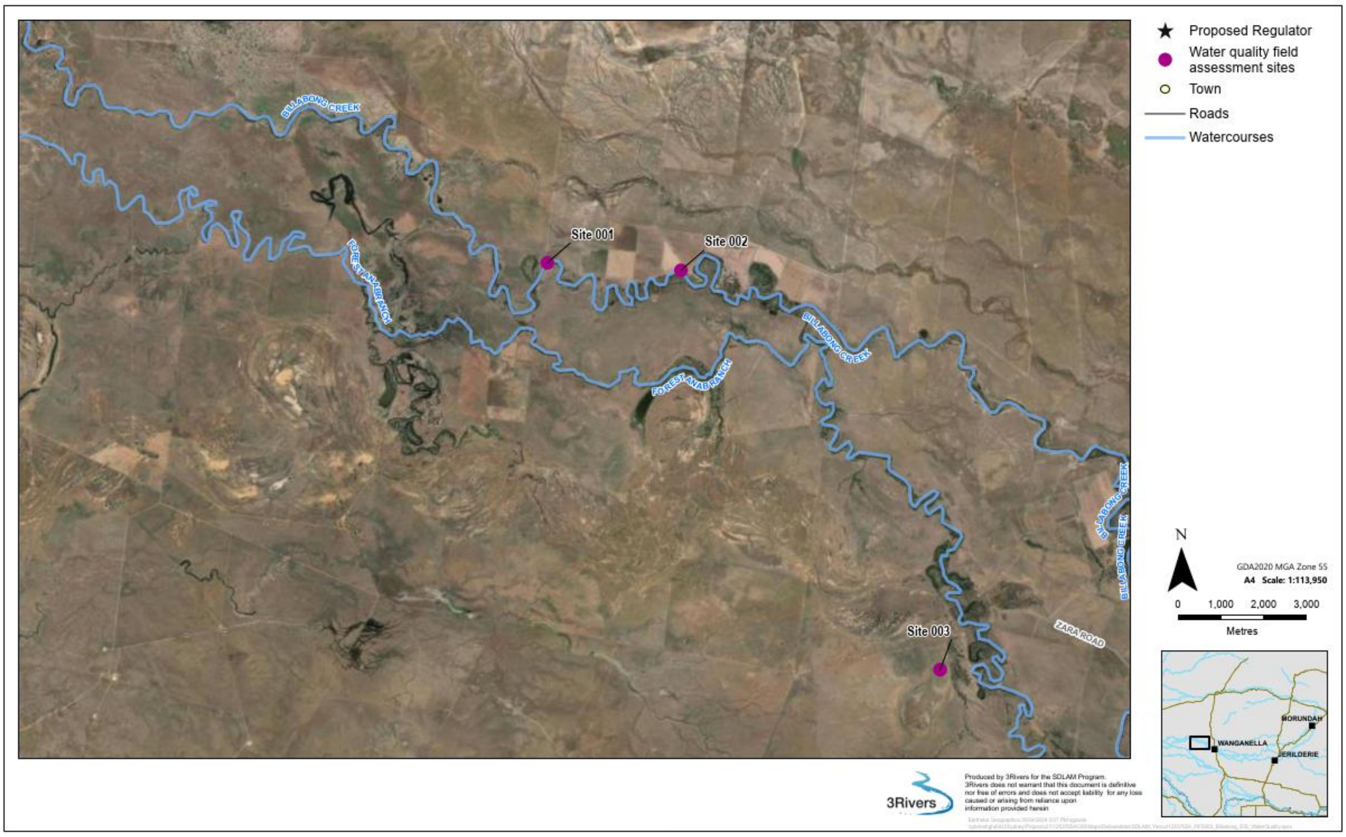
Table 3-3 List of assessment sites visited in the field. Sites are listed from most downstream to the most upstream

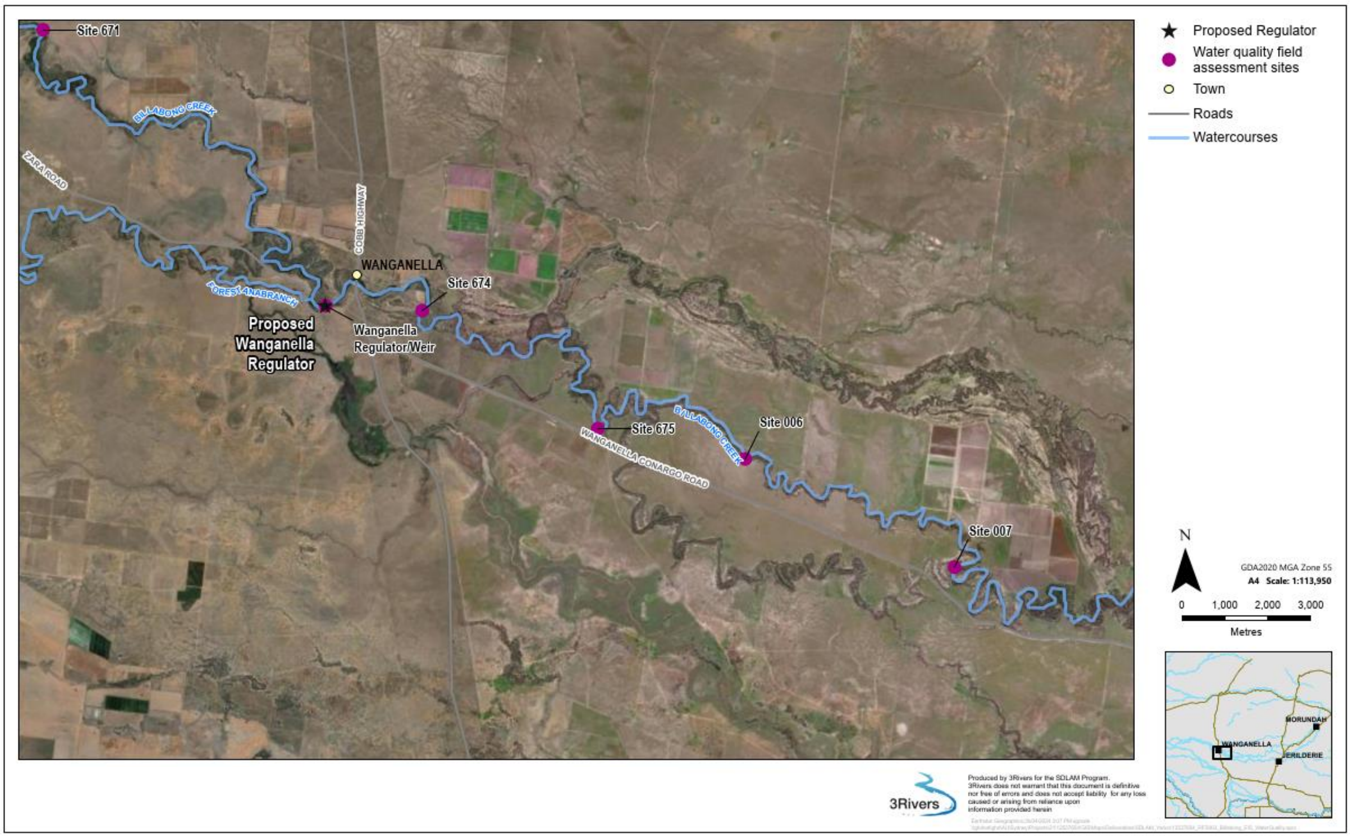
Assessment Site	Location	Latitude/Longitude	Date visited	Assessment undertaken
Site 001	Caroonboon Weir immediately downstream	-35.09925 144.58791	8/3/23	Habitat assessment, hydrological assessment, in-situ water quality, grab samples[1]
Site 002	Billabong Creek ~8km upstream of Caroonboon Weir	-35.10149 144.62202	8/3/23	Habitat assessment, hydrological

Assessment Site	Location	Latitude/Longitude	Date visited	Assessment undertaken
				assessment, in-situ water quality
Site 003	Billabong Creek ~15km upstream of Caroonboon Weir	-35.18661 144.68589	8/3/23	Habitat assessment, hydrological assessment, in-situ water quality
Site 671	Billabong Creek ~17km d/s of Wanganella Regulator/Weir	-35.15855 145.73692	7/3/23	Habitat assessment, hydrological assessment, in-situ water quality
Wanganella Regulator/Weir	Wanganella Regulator/Weir and immediately upstream	-35.21773 144.80742	7/3/23	Habitat assessment, hydrological assessment, in-situ water quality, grab samples[1], eDNA
Site 674	Billabong Creek ~3.5km upstream of the regulator/weir	-35.21919 144.83202	7/3/23	Habitat assessment, hydrological assessment, in-situ water quality
Site 675	Billabong Creek ~13km upstream of the regulator/weir	-35.24472 144.87619	7/3/23	Habitat assessment, hydrological assessment, in-situ water quality
Site 006	Billabong Creek off Wanganella-Conargo Rd	-35.25173 144.91368	7/3/23	Habitat assessment, hydrological assessment, in-situ water quality
Site 007	Billabong Creek near Flood Creek confluence	-35.27534 144.96657	7/3/23	Habitat assessment, hydrological assessment, in-situ water quality
Site 022	Billabong Creek at Morrison Rd	-35.30799 145.16587	6/3/23	Habitat assessment, hydrological assessment, in-situ water quality, eDNA
Hartwood Regulator/Weir	Hartwood Regulator/Weir and immediately upstream	-35.31108 145.28653	6/3/23	Habitat assessment, hydrological assessment, in-situ water quality, grab samples[1], eDNA

Assessment Site	Location	Latitude/Longitude	Date visited	Assessment undertaken
Site 026	Hartwood Regulator/Weir immediately d/s	-35.31041 145.28723	6/3/23	Habitat assessment, hydrological assessment, in-situ water quality
Site 028	Billabong Creek immediately d/s of Forest Creek offtake	-35.32313 145.29386	6/3/23	Habitat assessment, hydrological assessment, in-situ water quality
Site 029	Billabong Creek @ irrigation channel off Conargo Rd u/s or Hartwood Regulator/Weir	-35.33485 145.30605	6/3/23	Habitat assessment, hydrological assessment, in-situ water quality
Site 030	Billabong Creek @ bridge crossing off Conargo Rd u/s Hartwood Weir	-35.34708 145.32484	5/3/23	Habitat assessment, hydrological assessment, in-situ water quality

[1] grab samples were analysed for nutrients, total metals, organochlorine pesticides, organophosphorus pesticides Phenoxyacetic Acid Herbicides, suspended solids, total organic carbon, chlorophyll-a





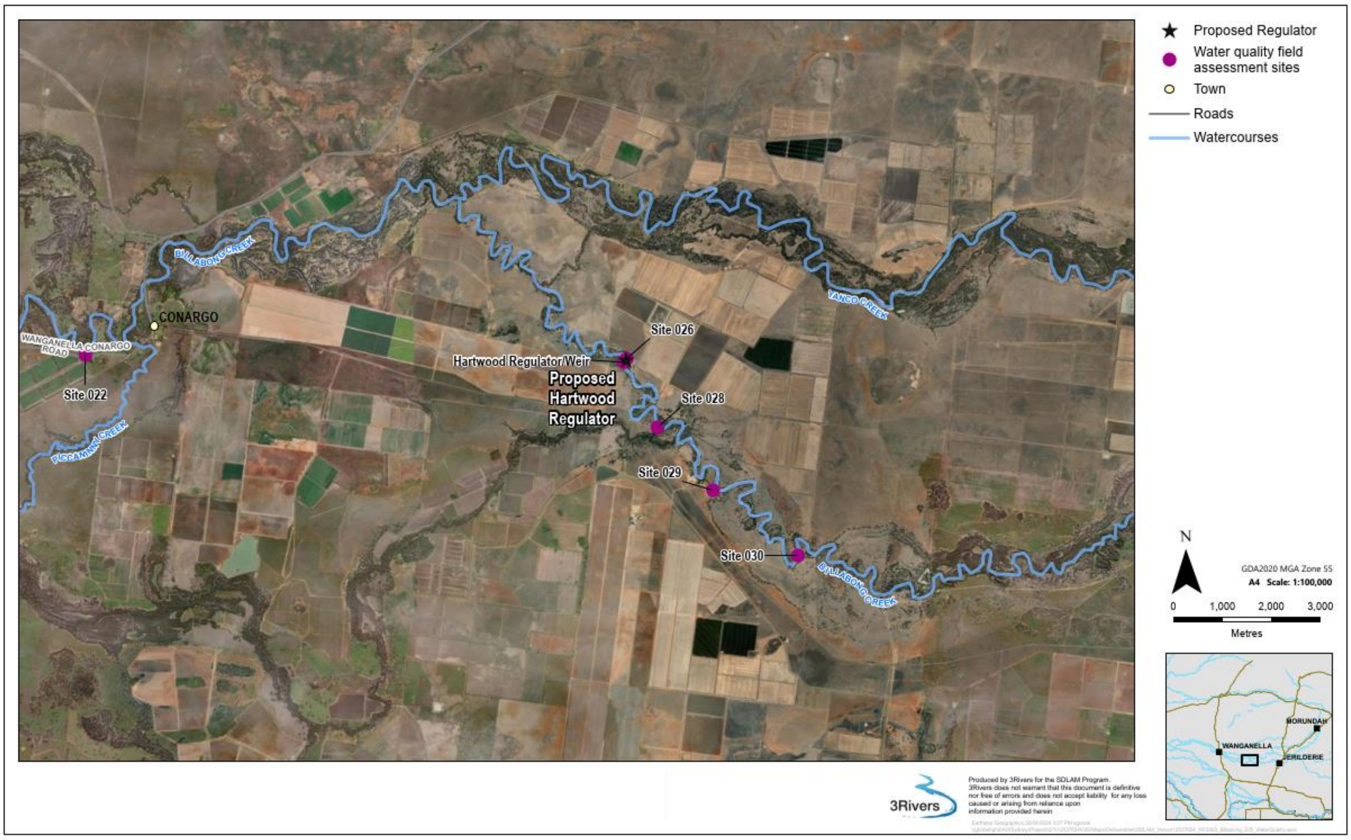


Figure 3-3a-c Aquatic habitat and water quality sites assessed in the field

3.1.3.1 Environmental DNA (eDNA) – fish

Environmental DNA was used to help characterise the fish community in the proposal footprint. All samples were analysed by EnviroDNA Pty Ltd. Two samples were collected at each of three sites on Billabong Creek, including in the Hartwood and Wanganella weir pools and the stretch of river between them.

While the use of eDNA to detect EPBC-listed fish species is not included in the Survey Guidelines for Australia's threatened fish (DSEWPAC 2011), it has been used for the Basin Plan environmental outcomes monitoring in NSW. The purpose of our survey was to complement the existing data and to collect site specific fish community data.

The timing of sample collection (early Autumn) was considered appropriate as the streams were running at base flow and fish communities would be expected to be experiencing a post-breeding season peak. While the sample replication was low, the surveys were only considered as supplementary to the existing comprehensive surveys outlined above and the results were not used to imply the absence of a species.

Environmental DNA sampling has been shown to be a highly sensitive method for detect fish species in the MDB, including EPBC listed species which have the potential to be present within the study area (Bylemans *et al.,* 2018; Hinlo *et al.,* 2018). For example, Hinlo *et al.* (2018) detected a greater number of fish species using eDNA when compared to traditional (i.e., electrofishing/trapping) sampling methods. This included the detection of EPBC-listed Silver Perch, which were not collected using traditional methods during the study. The use of eDNA has been shown to increase detectability of cryptic/hard to capture fish species. For example, Stoessel *et al.* (2023) found that eDNA sampling was more effective in detecting Southern Purple Spotted Gudgeon (*Mogurnda adspersa*) than traditional survey methods in the Reedy Lakes.

As a tool for fish community characterisation at the scale of this proposal, the technique is considered a valid addition to prescribed methods and appropriate for the purposes of an impact assessment.

Sample collection method

Samples were filtered through a 1.2μm syringe filter on site to reduce DNA degradation that may occur during transport of water (Yamanaka *et al*., 2016). A preservative (approx. 0.5mL 10xTris-EDTA) was added to the filters after filtering to minimise DNA degradation. Clean sampling protocols were employed to minimise contamination including new sampling equipment at each site, not entering water, and taking care not to transfer soil, water, or vegetation between sites, using single-use gloves and plasticware. Filters were stored out of sunlight and refrigerated while being transported to the EnviroDNA laboratory for processing.

Laboratory analysis method

Fish biodiversity assessments were performed on a subset of samples using a universal 'fish' assay targeting a small region of the 12S mitochondrial DNA (McColl-Gausden *et al.,* 2021). Library construction involved two rounds of PCR whereby the first round employed gene-specific primers to amplify the target region and the second round incorporated sequencing adapters and unique barcodes for each sample-amplicon combination included in the library. Negative controls were also included during library construction. Negative controls consisted of the extraction negative as well as PCR negatives where nuclease-free water was used in place of DNA during both rounds of PCR. Sequencing was carried out on an Illumina iSeq 100 machine.

Following quality control filtering to remove primer sequences, truncated reads and low-frequency reads, DNA sequences were clustered into Operational Taxonomic Units (OTUs) on the basis of sequence similarity. Taxonomic assignment was performed with VSEARCH software (Rognes *et al.,* 2016) whereby each cluster was assigned a species identity using a threshold of 95% by comparing against a reference sequence database. Where a species could not be assigned (i.e., reference database was deficient and/or taxa were poorly characterised), taxonomic assignments were manually vetted by first obtaining a list of possible species through BLASTN searches against the public repository Genbank (www.ncbi.nlm.nih.gov), then eliminating species on the basis of their geographic distribution using information from the Atlas of Living

Australia (ALA). In cases where a sample could not be adequately resolved to a single species (e.g. due to shared haplotypes between closely related species), either a list of multiple species was included, or it was assigned to the lowest taxonomic rank without further classification.

Sample collection sites were located at the downstream end of Wanganella and Hartwood weir pools, and the stretch of creek between, so they are considered to have detected fish communities in the upstream weir pools. The sites assessed are presented in **Table 3-3**.

3.1.3.2 Habitat assessment

Aquatic habitat condition was assessed in accordance with sampling design and methods as detailed in the *Aquatic Ecology in Environmental Impact Assessment – EIA Guideline* (NSW DoP, 2003). Geomorphic and aquatic habitat conditions were assessed together with hydrological characteristics. The assessment also considered the requirements of the *Policy and Guidelines for Fish Habitat Conservation and Management* (DPI, 2013) and *Why do Fish Need to Cross the Road? Fish Passage Requirements for Waterway Crossings* (Fairfull and Witheridge, 2003), so that the assessment site may be classified into KFH 'Type' (DPI, 2013) and waterway 'Class' (Fairfull and Witheridge, 2003).

The criteria the assessment was undertaken against broadly included:

- Microhabitat type (percent) (eg pool, riffle, run, glide, backwater)
- Type and class of water way in accordance with NSW DPI (2013) and Fairfull and Witheridge (2003)
- Connectivity to other waterways, wetlands
- Presence of refuge areas; presence of spawning areas
- Substrate type
- Presence/absence of aquatic vegetation and riparian vegetation and type
- Presence of barriers to fish passage
- Presence/absence of visible signs of erosion
- Presence/absence of snags
- Presence of aquatic fauna and habitat for key species.

Riparian habitat quality was assessed using a modified version of the Riparian Channel and Environment (RCE) inventory method (Peterson, 1992; Chessman *et al.*, 1997). This method involves evaluation and scoring of the characteristics of the riparian zone, the condition of the riverbanks, channel and bed of the waterway, and degree of disturbance evident at the site. The RCE method provides an objective method of assessing aquatic habitat and facilitates comparisons between locations and potential changes through time. It presents a simplified description of the aquatic habitats and does not fully represent its complex and changing nature. The scores which should be used as a generalised assessment only, range between 52 (maximum score) which indicates a stream with little or no obvious physical disruptions and 13 (lowest score) which indicates a heavily channelled stream without any riparian vegetation. The criteria and values used when applying the RCE method is provided in **Appendix A**. The inventory has equal weighting for each of the indices and therefore certain elements and differences in the habitat of each site may be masked.

In conjunction with assessing aquatic habitat, hydrological characteristics, water quality and waterway condition were assessed to gain an understanding of where nominated environmental values are currently being achieved. This included undertaking in-situ water quality monitoring (pH, turbidity, conductivity, dissolved oxygen, temperature) with a calibrated Hanna HI 9829 water quality meter and grab samples for analysis by a certified and National Association of Testing Authorities (NATA) accredited laboratory (i.e. Australian Laboratory Services). In-situ water quality parameters recorded include temperature, pH, electrical conductivity, turbidity and dissolved oxygen. Grab samples were collected and analysed for total suspended solids, total organic carbon, total metals, nutrients, pesticides, herbicides and chlorophyll-a.

3.1.4 Likelihood of occurrence assessment for threatened species and threatening processes

The database and literature review were used to identify rare or threatened species and threatened communities potentially occurring with the study area (i.e., using a 10 km buffer). Potential effects on these species were considered for both construction and operation stages.

The likelihood of occurrence assessment was used to determine the likelihood of each species' presence within the study area based on the dates and number of previous records of each species and consideration of the habitat present (e.g. regulated riverine habitat). The criteria used for evaluating likelihood of occurrence for each species is presented in **Table 3-4**.

Table 3-4 Likelihood assessment criteria for threatened species

Likelihood	Criteria
Present	Species recorded within study area based on historical records within the last 30 years.
Possible	Potentially suitable habitat occurs within the study area and species' known range encompasses the study area. Species recorded historically in the study area but not regularly observed within the last 30 years. This category is mainly informed by NSW DPI threatened species distribution models.
Unlikely	Species' known range encompasses the study area, but suitable habitat does not occur within the study area or occurs within the study area, but with generally low quality and quantity. Species recorded historically in the study area but not within the last 30 years.
Highly Unlikely	No historical records of the species and/or no suitable habitat in the study area.

Further to this, an assessment was undertaken of the relevance and likelihood of key threatening processes listed under the FM Act and the EPBC Act to occur in the study area. Only those threatening processes that were deemed relevant to the proposal (i.e. the likelihood was moderate, high, or present) were assessed. The criteria used for evaluating likelihood of threatening processes occurring are presented in **Table 3-5.**

Table 3-5 Likelihood assessment criteria for listed threatening processes

Likelihood	Criteria
Present	Threatening process directly observed or recently recorded within the study area, or the study area supports suitable conditions that are likely to encourage and/or exacerbate threatening process.
High	The study area supports suitable conditions that are likely to encourage and/or exacerbate threatening processes.
Moderate	The study area supports suitable conditions that could encourage or exacerbate threatening process.
Low	Threatening process not recorded in the study area, and/or the study area supports conditions that are unlikely to encourage or exacerbate threatening processes.

3.1.5 Risk Assessment

Risk assessments were conducted to:

- Identify and describe the key risks and effect pathways, resulting from the construction and operation of the proposal, that have the potential to negatively impact on the environment and/or local communities
- Evaluate the significance of potential adverse effects

- Develop measures to avoid or limit the adverse effects to acceptable levels.

The level of effort directed at investigating and managing potential adverse effects has been based on the evaluated risk ratings, with greater effort directed to matters that pose a higher risk. The environmental performance objective adopted for the risk assessment is to avoid and minimise impacts on State and Commonwealth listed aquatic species and communities, and aquatic ecosystem health. Risks to aquatic ecology values were assessed using the likelihood and consequence scales that are described in **Table 3-6** and **Table 3-7**. The level of effort directed at investigating and managing potential adverse effects has been based on the evaluated risk ratings outlined in **Table 3-8**.

Table 3-6 Risk likelihood criteria used to evaluate key risk associated with the construction and operation of the proposal

Likelihood of an effect	Description
Almost certain	The event is expected to occur in most circumstances
Likely	The event will probably occur in most circumstances
Possible	The event could occur
Unlikely	The event could occur but not expected
Rare	The event may occur only in exceptional circumstances

Table 3-7 Consequence criteria used to evaluate key risks associated with the construction and operation of the proposal

Consequence	Adverse effects on threatened aquatic species and aquatic ecosystem health
Severe	Long-term and possible permanent impact on threatened aquatic fauna or their habitat beyond the construction footprint or maximum inundation areas.
Major	Long-term and possible permanent decrease in aquatic ecosystem health beyond the construction footprint or maximum inundation areas.
Moderate	Substantial but reversible change to threatened aquatic fauna or their habitat outside the construction footprint or maximum inundation areas, or reduced breeding capacity for greater than one season.
Minor	Measurable decrease in aquatic ecosystem health within or beyond construction footprint or maximum inundation areas
Negligible	Measurable but reversible change to threatened aquatic fauna populations or their habitat within construction footprint or maximum inundation areas, or reduced breeding capacity for one season.

Table 3-8 Risk Rating matrix derived from likelihood and consequence assessments

	Consequence					
Likelihood	**Rating**	Severe	Major	Moderate	Minor	Negligible
	Almost certain	Extreme	Extreme	Very High	High	Medium
	Likely	Extreme	Very High	High	Medium	Low
	Possible	Very High	High	Medium	Medium	Low
	Unlikely	High	Medium	Medium	Low	Very Low
	Rare	Medium	Low	Low	Very Low	Very Low

3.1.6 Cumulative impact assessment

The potential for cumulative impacts has been included as part of relevant technical assessments of the EIS and have been summarised in **Section 5.3**. The cumulative impacts assessment considered the potential impacts to current surface water quality and aquatic ecology associated with the new replacement regulators for the proposal and the Forest Creek Return Flows project. The cumulative impact assessment has been undertaken with consideration of the Cumulative Impact Assessment Guidelines for State Significant Projects (DPIE, 2022b).

4. Existing Environment

4.1 Catchment overview

4.1.1 The Murray-Darling Basin

The MDB is located in the interior south-east of Australia and is the country's largest river system by area. The MDB holds great environmental, cultural, and economic significance, supporting 16 internationally significant wetlands, at least 35 endangered species, more than 40 Aboriginal First Nations, and an agricultural region that produces around one-third of the national food supply. From its headwaters along the Great Dividing Range, it drains predominantly in a south-west direction into the Great Australian Bight in South Australia. The MDB spans most of NSW, Victoria, and the Australian Capital Territory, and the lower third of Queensland and the south-eastern corner of South Australia.

The two longest rivers in the Murray-Darling Basin are the Murrumbidgee and the Murray rivers. These rivers run roughly parallel to each other for much of their length, and before they reach their confluence, they are connected by the Yanco Creek System, a distributary that runs between them. The Yanco Creek System is the focus of this proposal.

4.1.2 Yanco Creek System

The Yanco Creek System generally flows south-west from the Murrumbidgee River ~14 km downstream of Narrandera until it joins the Edward River, part of the Murray River basin, at Moulamein. Along its path the Yanco Creek System passes from the traditional lands of the Wiradjuri people, and through Bangerang, Barapa-Barapa and Wemba-Wemba traditional country.

The Yanco Creek System is a complex, braided system of interconnecting creeks and anabranches. The main branches of the system are Yanco, Colombo, Billabong and Forest Creeks.

There is a long history of European settlement and agriculture in the catchment, starting in the 1840s. At this time, the Murrumbidgee River would only have connected to Yanco Creek during flooding (flows >40 GL at the Murrumbidgee-Yanco junction) and/or when there was substantial runoff and flows in the upper catchment of Billabong Creek (Molino Stewart, 1999). Yanco Creek was regularly reduced to waterholes during the summer dry period. To increase the water supply to Yanco Creek, in order to expand irrigated agriculture in the catchment, Yanco Weir was constructed in 1928 to permanently divert water from the Murrumbidgee into Yanco Creek. It follows that the hydrology of the Yanco Creek System changed immensely due to the construction of the Yanco Weir, and furthermore due to the increasing degree of water extraction and regulation (by means of 30 re-regulating weirs) throughout its reaches. Of particular note is that flows through the system are maintained at artificially high levels during dry periods when irrigation demand is highest, so natural wet-dry cycles have been effectively removed throughout much of the system.

The Yanco Creek System contains a number of environmental assets that are supported by the hydrological behaviour of the creek system. These include a wide range of floodplain wetlands such as the Wanganella Swamp, riparian and wetland vegetation communities, the nationally threatened Trout Cod, and important populations Murray Cod and Freshwater Catfish that are declining in the broader Murry-Darling Basin. The Olive Perchlet (*Ambassis agassizii*) and Southern Pygmy Perch (*Nannoperca australis*), which are each listed as threatened in the MDB, are thought to have gone extinct from the Yanco Creek System.

4.1.3 Mid to Lower Billabong Creek

Billabong Creek is an important source of water for the surrounding areas. The majority of land adjacent to the water course is used for dryland grazing and cropping. The majority of irrigation water licences in the creek are general security, stock and domestic, and supplementary licences used for seasonal crops.

Billabong Creek also provides water supply for local water utility, and in the case Wanganella Weir, town water supply (Cooling & Gippel, 2018).

Billabong Creek has been broadly divided into three reaches on the basis of hydrology, ecology and geomorphology. This division has been adopted in this assessment (as well as the assessment of other SDLAM projects in the system), and includes; upper Billabong Creek (an unregulated reach), mid Billabong Creek (reach 4), and lower Billabong Creek (reach 5) (Alluvium, 2013). The Hartwood weir component of the proposal is located within the mid Billabong Creek while the Wanganella weir component of the proposal is located in the lower Billabong Creek.

The mid Billabong Creek extends from the Colombo Creek confluence to the Yanco Creek confluence. Flow is augmented by regulated water entering from Colombo Creek, but the watercourse remains free-flowing upstream of the Jerilderie Town Weir. Weirs below Jerilderie include Algudgerie Weir, McCaughey Institute Weir, Hartwood Homestead Weir, Road Paddock Weir, Lower Woolshed Weir, and Hartwood Weir.

Flows are diverted from mid Billabong Creek upstream of Hartwood Weir into Forest Creek, via the Forest Creek offtake, for irrigation purposes and to contribute to environmental watering of three wetlands that are considered key environmental assets of the Yanco Creek System: Wanganella Swamp, Rhyola Lake and Rhyola Swamp. Since May 2011, environmental water deliveries into Forest Creek have targeted Wanganella Swamp and swamp health remains a key objective for environmental watering (Commonwealth of Australia, 2022).

Lower Billabong Creek extends from the Yanco Creek confluence to where Billabong Creek discharges into the Edward River at Moulamein. The reach contains several weirs including Boonoke Homestead Weir, Piccaninny Weir, Tracey's Weir, Chinamans Weir, Four Mile Weir - Boonoke, Wanganella Homestead Weir, Wanganella Town Weir, Caroonboon Weir and Windouran Weir.

Billabong Creek is deep in the mid and lower reaches, with steep (1 to 2m high) banks. Instream habitat is characterised by deep pools connected by shallow runs, and the creek is interrupted at points by the large weir pools mentioned above. Large woody debris is present on the banks and in the channel. Aquatic plants are present on benches in the channel. River Red Gum closely line the channel, but Black Box Woodland is the dominant vegetation along the watercourse (Cooling & Gippel 2018).

4.2 Climate

The climate is semi-arid, characterised by hot, dry summers and cool, wet winters. The highest rainfall months tend to be May and September. Summer rainfall tends to occur mainly from localised thunderstorms with more consistent rain occurring in winter. Annual rainfall decreases from east to west. Within the Billabong Yanco System rainfall ranges from 442.7 mm at Urana to 356.8 mm at Moulamein (Bureau of Meteorology, http://www.bom.gov.au/).

4.3 Geology

The main geological features of the study area are the Cenozoic alluvial deposits associated with the Murrumbidgee River and other rivers, including sediments of the underlying riverine plains in the lower catchment of the Murray basin. These deposits occur within creeks and rivers as a result of weathering of Palaeozoic bedrock. The sedimentary deposits in the study area represent different time periods of deposition and include the Shepparton Formation (uppermost layer), Calivil Formation and Renmark Group (lowermost layer) (DPIE, 2019). The sediments of the Shepparton formation not only result from prior stream and drainage depression deposition but are also influenced by a high clay content due to aeolian material deposited over riverine sediments and by localised aeolian sand hill formation.

4.4 Soils

The system is almost entirely embedded in ancestral sediments with many instances of ancestral river channels throughout. Soil distribution patterns reflect the depositional characteristics of the prior and ancestral streams, as such there are broadly two types of soils in the study area, red brown earths that are generally associated with ancestral river deposits and grey-brown clays associated with the floodplain of the Murrumbidgee River and associated creek systems (Forest Creek Working Group, 2000). Red brown earths are moderately fertile loamy clay soils with hard setting topsoils that that have a high potential for wind erosion and scalding. Red soils have moderate infiltration rates. Grey and brown clays soils are moderately deep that tend to crack when they dry out but are less susceptible to erosion due to their compact nature. The grey clays are common on flooded and poorly drained floodplains whereas brown clays occur on higher less frequently flooded ground (Alluvium, 2013).

4.5 Topography

The maximum elevation of Billabong Creek catchment is around 517m above sea level in its headwaters (at Majors Creek), dropping to 100m at Hartwood Weir where Billabong Creek is diverted down Forest Creek, dropping down to 74m at Moulamein in the Lower Billabong Creek reach near the downstream end of the study area.

4.6 Wetlands and lakes

In Yanco Creek system, the most diverse and significant floodplain wetlands occur in Forest Creek. For instance, lower Forest Creek supports regionally important Wanganella Swamp and Rhyola Swamp. Wanganella and Rhyola swamps are important habitat and breeding sites for bird species (Turner *et al.,* 2021). These areas receive water from Billabong Creek that is diverted into Forest Creek before flowing through Eight Mile Creek and Forest Anabranch respectively. Environmental water deliveries have targeted both swamps to ensure their health (Commonwealth of Australia, 2022).

In addition to these large floodplain wetlands, the Yanco Creek system supports many smaller floodplain depressions and billabongs, and it is these types of wetland that are most within the study area (**Figure 4-1**). The overall ecological resilience of the Yanco Creek System is largely dependent on the maintenance these wetlands, which requires maintenance of hydrological connections with stream channels under different hydrological regimes (e.g. through environmental watering) and the management of stock grazing on wetland plants (Alluvium, 2013; Walcott *et al.,* 2018).

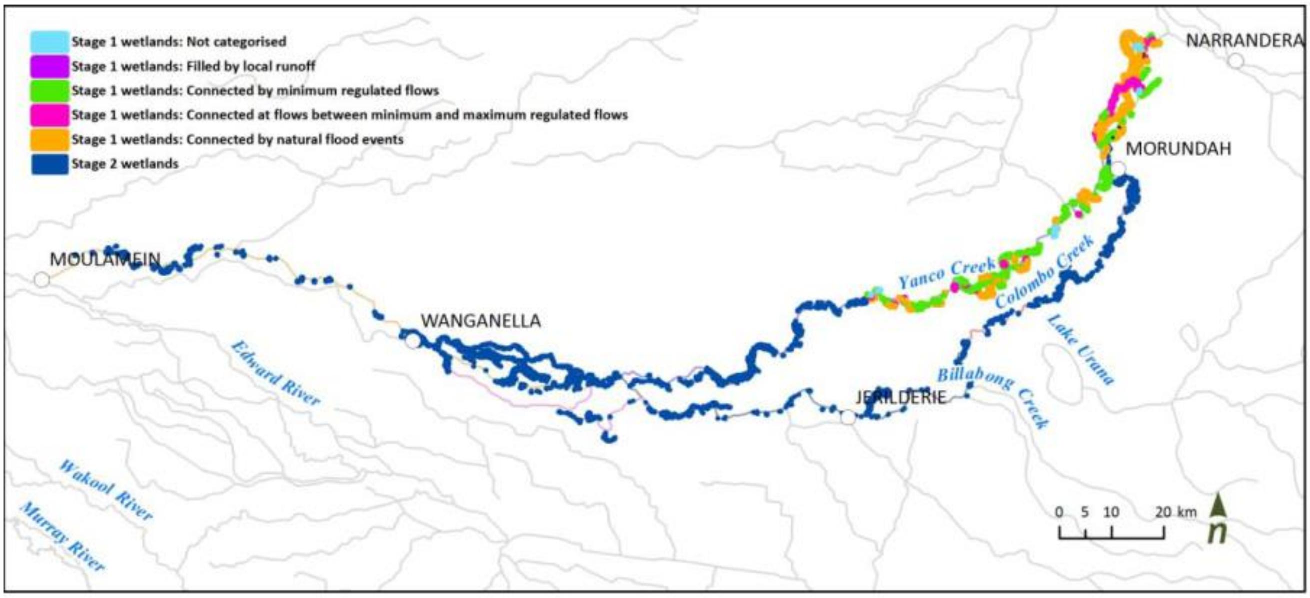


Figure 4-1 Wetlands mapped in the Yanco Creek System (Source: Alluvium 2013)

4.7 Hydrology and water delivery

The description of existing hydrological conditions, changes in hydrology from pre-development conditions and finding of the modelled existing hydrological regime of the proposal study area, and broader Yanco Creek System, are summarised from the *Billabong Creek Regulators Hydrology Assessment Jacobs* (2024a).

4.7.1 Existing hydrological conditions

Prior to European settlement, Yanco Creek was a high-level effluent creek and it is believed that the Murrumbidgee River only connected to the creek during flows of around 40,000 ML/day or greater (NSW DPI 2015). Pre-development, flows into Yanco Creek occurred 1 in 2 years with a duration of less than 10% of the time (Alluvium 2013). Billabong Creek, which has its own local catchment, contributed smaller but more frequent flows to the system (Alluvium, 2013). Unregulated flows enter from the Billabong Creek catchment and other tributaries. Drainage flows and regulated flows enter from adjacent irrigation areas (Cooling and Gippel, 2018).

WaterNSW manages the Yanco System to deliver around 110 GL annually to 423 water licensees and provide town water supply to Morundah, Urana, Oaklands, Jerilderie, Conargo and Wanganella (DPI Water, 2017; NSW, DPIE 2019a). Under typical conditions, the Water Sharing Plan for the Murrumbidgee Regulated River Water Source (NSW Government, 2020) limits regulated flow in upper Yanco Creek to 1,400 ML/day (at offtake) to prevent excessive losses from overbank flows. A minimum diversion of 500 ML/d is usually provided year-round for stock and domestic requirements (SKM, 2011). A minimum daily flow of 50 ML/d at Darlot is provided to maintain connectivity with the Edward River. Outfall drains (i.e. irrigation escapes) are used to supplement water supply and overcome capacity constraints - water may be provided from the Coleambally Irrigation Area to Yanco Creek and from the Murray Irrigation District to Billabong Creek and Forest Creek.

Billabong Creek is an unregulated tributary of the Yanco Creek System which drains a catchment of 791 km^2, the headwaters of which are in the western slopes of the Great Dividing Range near Holbrook (Cooling and Gippel, 2018). The upper portions of Billabong Creek are unregulated (Alluvium, 2013). Billabong Creek is joined by Colombo Creek west of Urana and continues to flow in a westerly direction toward Jerilderie, before converging with Yanco Creek upstream of Conargo. The watercourse continues as Billabong Creek and flows west to join the Edward River at Moulamein. Billabong Creek drains a catchment of approximately 791 square kilometres (Cooling and Gippel, 2018). Billabong Creek can be broadly divided into three reaches on the basis of hydrology, ecology and geomorphology (Alluvium, 2013; Cooling and Gippel, 2018).

The upper Billabong Creek is the unregulated portion of the creek extending from its headwaters near Holbrook to its confluence with Colombo Creek. This reach of Billabong Creek also receives inflows from Cocketgedong Creek. The upper Billabong Creek flows the majority of the time due to catchment rainfall.

The mid Billabong Creek extends from the Colombo Creek confluence to the Yanco Creek confluence. Flow in this reach is supplemented by water from Colombo Creek and becomes part of a regulated water source receiving water from the major dams on the Murrumbidgee River (Alluvium, 2013; Cooling and Gippel, 2018). The mid Billabong Creek has a broad channel with deep pools separated by shallower runs and benches at a variety of elevations in the channel. Mid Billabong Creek has several distributaries (also referred to as anabranches and paleochannels) that divert from the main channel and re-join it upstream of Moulamein. There are a number of weirs in mid Billabong Creek below Jerilderie, including Hartwood Weir. Hartwood Weir raises the Billabong Creek level so that water enters Forest creek via the Forest Creek offtake when flow exceeds 100 ML/d.

The lower Billabong Creek is from below the Yanco Creek confluence to the Edward River confluence at Moulamein and is part of a regulated water source. There are numerous weirs along this stretch of Billabong creek including Boonoke Homestead Weir, Piccaninny Weir, Tracey's Weir, Chinamans Weir, Four Mile Weir - Boonoke, Wanganella Homestead Weir, Wanganella Town Weir, Caroonboon Weir and Windouran Weir. The channel in the lower Billabong Creek is deep with steep one- to two-metre-high banks and has deep pools connected by shallow runs. Forest Creek is a notable anabranch of Billabong Creek. Forest Creek diverges from Billabong Creek upstream of the Yanco Creek confluence, near Hartwood Weir.

4.7.2 Hydrological change from pre-development

Mid Billabong Creek (Jerilderie to downstream of Hartwood Weir) - summarises the modelled mean annual water balance represents a high degree of hydrological alteration to cease-to-flow, low flow and baseflow and freshes flow categories from pre-development (NSW DPIE, 2020b). The frequency with which cease-to-flow now occurs has decreased by greater than 50% from pre-development, while low flow and baseflow and freshes flows have increased by greater than 50%. By comparison, there is only a low degree of hydrological alteration (i.e. less than 20% increase in frequency) from pre-development for high and infrequent flows - 1.5ARI, 2.5ARI and 5ARI (NSW DPIE, 2020b).

Lower Billabong and Intersecting Streams (downstream of Hartwood Weir to Moulamein) - The current hydrology of lower Billabong Creek and intersecting streams, from downstream of Hartwood Weir to Moulamein (and therefore inclusive of Wanganella and Darlot), represents a high degree of hydrological alteration from pre-development for cease-to-flow, low flow and baseflow and freshes (NSW DPIE 2020b). The frequency with which cease-to-flow now occurs has decreased by greater than 50% from pre-development, while the frequency of low flow and baseflow and freshes flows has increased by greater than 50%. For high and infrequent flows there has been a medium degree of hydrological change from pre-development for 1.5ARI (20-50% increase in frequency), and low hydrological change for 2.5ARI (<20% increase) and 5ARI (<20% decrease) events (NSW DPIE, 2020b).

4.7.3 Modelled existing hydrological regime

For the purpose of assessing the potential hydrological effects of the new regulators for the proposal an eWater Source model was developed by NSW DCCEEW for the Murrumbidgee River downstream of Burrinjuck and Blowering Dams to Balranald Weir. This Source model is the best available estimate of how this complex system interacts and behaves under a range of different scenarios. The Base Murrumbidgee Source Model has been calibrated to historical data, for the period 1/07/1895 – 30/06/2020. The modelled Base Case scenario is comparable to current hydrological conditions and is representative of existing weirs and other structures, flow constraints, minimum environmental flow provisions, environmental flow provisions and irrigation escape flows applicable to these reaches under the modelled Base Case scenario.

Under modelled Base Case scenario, the total annual flows (GL/year) throughout the Yanco Creek System can be seen to be highly variable, primarily associated with unregulated flows through Yanco Offtake and the unregulated upper Billabong Creek catchment passing through the system. Major changes in flows across the Yanco Creek System can be attributed to the distribution of flows between connected waterways, with some changes between these attributed to consumptive extractions, irrigation escape inflows and evaporation losses.

Mean monthly flows display a typical temperate seasonal pattern, with generally higher flows during winter-spring and lower flows during summer-autumn periods, which is generally consistent with pre-developed conditions. High variability in averaged daily flow volumes is particularly evident from December to April which is likely in response to modelled irrigation, consumptive and environmental demands during periods of lower flow.

The flow size analysis indicates overbank flows (small and large) occur infrequently under existing conditions and that cease-to-flow and very low flows (Yanco and Colombo Creeks) no longer occur. The relative proportion of large and small freshes and baseflow is not considered to be significantly dissimilar between any of the reaches within the system. Overall, flows downstream of Hartwood Weir are lower than at other locations within mid and lower Billabong Creek, as a result of diversion of flows to Forest Creek through the Forest Creek Offtake. Correspondingly, baseflow occurs across a greater proportion (majority of flows) of modelled flows downstream of Hartwood Weir. In contrast, small freshes occur across a greater proportion of the flow regime at Wanganella and Darlot due to additional flow contribution from lower Yanco.

4.8 Groundwater Dependent Ecosystems (GDEs)

The Bureau of Meteorology's GDE Atlas (BOM, 2024) depicts aquatic and terrestrial ecosystems that are dependent on the surface expression of groundwater, including all groundwater-fed surface water bodies such as wetlands, rivers, and springs, and any fringing vegetation.

The GDE Atlas was reviewed to investigate the potential for GDEs to exist within the study area. Four potential aquatic GDEs are identified within 500m of the existing Wanganella weir, with two within 100m. Two aquatic GDEs are identified within 500m of the existing Hartwood weir, both of which are within 100m.

4.9 Aquatic habitat

4.9.1 Aquatic habitat assessment

An aquatic habitat assessment was undertaken at 12 sites, starting at ~47 km below Wanganella Weir and ending near the top of the Hartwood Weir pool, to characterise the aquatic environment of Billabong Creek within the proposal construction and operational footprints.

Surveys have shown that Murray Cod (Vulnerable under the EPBC Act) and Silver Perch (Endangered under the EPBC Act) are widespread in the middle and lower reaches of Billabong Creek, so all sites have been classified 'Type 1 – Highly Sensitive KFH' (DPI, 2013). The purpose of the site assessment was to characterise the aquatic habitat features of the waterway and assess against aquatic habitat criteria outlined in the Policy and Guidelines for Fish Habitat Conservation and Management (2013). **Table 4-1** summarises the findings of the aquatic habitat assessment undertaken at each survey site (see **Figure 3-3** for aquatic habitat assessment site locations).

4.9.1.1 Detailed aquatic habitat mapping

DPI Fisheries has undertaken a detailed aquatic habitat mapping of the Billabong Creek upstream and downstream of the proposed Hartwood and Wanganella regulators (DPI, 2024). The results of the DPI Fisheries detailed aquatic habitat mapping identified aquatic habitat condition (within the study area for the survey) is in reasonable condition. Habitat mapping identified positive habitat value features included:

- 9,250 large woody habitat (LWH) features
- 679 rootballs
- 103 wetland entry/exit points
- 88 potential drought refuges covering 11.1 ha
- 847 benches covering 1,375.8 ha
- 10 macrophyte species covering 15.9 ha of which Broadleaf Cumbungi (*Typha orientalis)* was the most prevalent macrophyte species particularly at Hartwood Weir and Sedges (*Juncus* spp.) in the vicinity of Wanganella Weir.

4.9.1.2 Overview of aquatic and riparian habitat

Waterway dependent vegetation

For the purpose of this general description of waterway dependant vegetation, the communities are often discussed in terms of broad taxonomic associations, such as Black Box woodlands, River Red Gum woodlands or forests (the difference between forest and woodland depends mostly on canopy cover and tree size and density), but greater detail is provided where possible.

There is very little submerged aquatic vegetation in the Billabong Creek system. Submerged taxa such as *Vallisneria* and *Potamogeton* are common in inland rivers of New South Wales and would be expected to be present in Billabong Creek as well. It seems likely that such aquatic vegetation has been lost, with the expansion of carp and changes in stream hydrology being likely causes of decline.

Floating species such as *Azolla* sp., Water Primrose (*Ludwigia peploides*), and Water Couch (*Paspalum distichum*) are sparsely distributed and occupy shallow margins or islands. A priority weed species, Sagittaria (*Sagittaria platyphylla*), has also been recorded near Heartwood Weir albeit in very low abundance.

Emergent species (Sedges [*Carex* spp.], Flat-sedges [*Cyperus* spp.], Spikerush [*Eleocharis* spp.], Rushes [*Juncus* spp.], Common Reed (*Phragmites australis*), Broadleaf Cumbungi (*Typha orientalis*)) are present along the riverbanks and on benches or in shallow water in the stream margins. Common Reed and Cumbungi are relatively common, although the others appear to have restricted distributions. This is probably as a result of relatively unchanging water levels in many of the waterways. Emergent taxa commonly grow best when water levels fluctuate on a seasonal basis, with high water levels in winter and spring and low water levels in summer. Constantly high-water levels, especially when the water is enriched with plant nutrients such as phosphorus, differentially encourage the growth of Cumbungi (*Typha* spp.), and this process was evident at several sites in the study area.

Billabong Creek still supports a band of riparian vegetation along its banks and higher benches. River Red Gum (*Eucalyptus camaldulensis*) dominates those parts that are inundated more frequently, while Black Box (*Eucalyptus largiflorens*) becomes more common on slightly higher ground that receives less frequent and shorter inundation. The density of trees and canopy cover vary for River Red Gum stands, from sparse woodland in drier sites to, more rarely, a dense forest with larger trees and more canopy cover in wetter sites. In a few locations, River Cooba (*Acacia stenophylla*) is present as a canopy-forming tree. Flooding is important for this species in order to maintain adult trees and potentially helps in recruitment. While native species tend to dominate the riparian zone, up to 15 exotic species have been recorded across the study area (NSW DPI 2024). Most prominent among these are Lippia (*Phyla canescens*), Willows (*Salix* spp.) and African Boxthorn (*Lycium ferocissimum*).

The width of the riparian zone varies greatly over the study area, from over a kilometre in some locations to narrow bands only a tree or two wide in others. This variation is largely the result of (1) changing geomorphology, resulting in differences in the width of the floodplain and higher-level benches across the site, and (2) differences in land-management, including historic clearing and the impact of stock grazing (mostly by sheep) on the recruitment of young trees into the population. The adverse impact of stock access is strongly evident in mid Billabong Creek (Reach 4) where stock have unlimited access to the stream and its bankside vegetation in many cases.

Although the riparian zone has a canopy layer consisting of mostly either River Red Gum or Black Box, or less commonly River Cooba, there are also important understorey species present as well. In many cases, the understorey condition is limited, probably as a result of grazing pressures. In those spots where grazing does not occur, the understorey can be dense and is made up of a range of native grasses and lignum (*Muehlenbeckia florulenta*) further from the water.

Physical habitat

There is a moderate to high abundance of in-stream structural habitat (large woody habitat and rootballs) throughout mid and lower Billabong Creek. Furthermore, refuge habitat (i.e. deep, permanent pools) is relatively common, particularly in the weir pools and rarely elsewhere. Benching along the riverbank is also common, providing variability in water depth and substate for plant growth, amongst other important functions.

Table 4-1 Aquatic habitat assessment results. Key Fish Habitat (KFH) Type follows descriptions in NSW DPI (2013) and waterway Class follows descriptions of Fairfull and Witheridge (2003)

Assessment Site	Proposed work	Stream type	KFH Type Waterway Class	Relevant features	Riparian Channel and Environment (RCE) Score
Site 001	Changed volume of flows released from Wanganella Weir Pool	Perennial (Regulated)	Type 1 – Highly Sensitive KFH Class 1 – Major KFH	▪ Channel is shallow to moderately deep (~1m) and ~25m wide ▪ Fast flowing habitat for about 50m downstream of the weir ▪ Channel bank was very steep on the right (~50°) and moderately steep (~20°) of the left bank. Significant bank scouring and erosion apparent for ~40m downstream of the weir wall. ▪ Silt/mud substate ▪ Stock access ▪ Moderate density of low complexity snags ▪ At the time of inspection turbidity was low for the system (197 NTU), conductivity was (370 µm), pH was neutral (7.82), and dissolved oxygen levels were low (80.2%). ▪ The riparian zone was continuous and around 15m wide. It consisted of juvenile and mature River Red Gum (50%), Blackbox (25% riparian community), and River Cooba (25%). ▪ No aquatic vegetation ▪ Common Yabby observed	40
Site 002	Changed volume of flows released from Wanganella Weir Pool	Perennial (Regulated)	Type 1 – Highly Sensitive KFH Class 1 – Major KFH	▪ Channel is deep and ~30m wide ▪ Slow flowing, turbid weir pool ▪ Channel bank was very steep on the right (~50° and ~5m high) and moderately steep (~20° and ~2m high) of the left bank. Little evidence of erosion. ▪ Moderate to high density of snags, but few appeared to be complex ▪ Stock access	40

Assessment Site	Proposed work	Stream type	KFH Type Waterway Class	Relevant features	Riparian Channel and Environment (RCE) Score
				▪ At the time of inspection turbidity was low for the system (182 NTU), conductivity was (373 µm), pH was neutral (7.70), and dissolved oxygen levels were low (65.4%). ▪ The riparian zone was continuous and around 20-30m wide. It consisted of juvenile and mature River Red Gum (60%), Blackbox (20% riparian community), and River Cooba (30%). ▪ No aquatic vegetation ▪ Murray Cod and Carp observed.	
Site 003	Changed volume of flows released from Wanganella Weir Pool	Perennial (Regulated)	Type 1 – Highly Sensitive KFH Class 1 – Major KFH	▪ Channel is deep and ~30m wide ▪ Slow flowing, turbid weir pool ▪ Channel bank was moderately steep both banks. Little evidence of erosion. ▪ Stock access ▪ Moderate to high density of snags, but few appeared to be complex ▪ At the time of inspection turbidity was low for the system (176 NTU), conductivity was (365 µm), pH was neutral (7.78), and dissolved oxygen levels were moderately high (81.7%). ▪ The riparian zone was continuous and around 20-30m wide. It consisted of juvenile and mature River Red Gum (65%), Blackbox (25% riparian community), River Cooba (3%), grasses (2%), and herbaceous weeds (5%). ▪ No aquatic vegetation.	40
Site 671	Changed volume of flows released from Wanganella Weir Pool	Perennial (Regulated)	Type 1 – Highly Sensitive KFH Class 1 – Major KFH	▪ Channel is shallow to moderately deep (~1.5m) and ~15m wide ▪ Riffle and glide habitat with moderate flow, flowing into deep pool ▪ Channel banks are gently slopped and stepped on left bank, and relatively steep on right. Minor erosion apparent.	40

Assessment Site	Proposed work	Stream type	KFH Type Waterway Class	Relevant features	Riparian Channel and Environment (RCE) Score
				▪ Silt/mud substate ▪ Abundance of snags, including large complex snags ▪ At the time of inspection turbidity was low for the system (164 NTU), conductivity was (392 µm), pH was neutral (7.48), and dissolved oxygen levels were low (62.4%). ▪ The riparian zone consists juvenile and mature Blackbox (60% riparian community), River Red Gum (30%), and River Cooba (10%). ▪ Some sedges were also present, but no other aquatic vegetation.	
Site 673	Changed volume of flows released from Wanganella Weir Pool	Perennial (Regulated)	Type 1 – Highly Sensitive KFH Class 1 – Major KFH	▪ Channel is deep (>2m) and ~20m wide. ▪ Slow to moderate flowing pool habitat predominates. ▪ Channel banks are moderately sloped and high (~5m). Minor erosion apparent towards top of banks. ▪ Silt/mud substate dominates with some sand. ▪ Low density of snags, large or otherwise. No complex snags. ▪ At the time of inspection turbidity was low for the system (178 NTU), conductivity was (367 µm), pH was neutral (7.45), and dissolved oxygen levels were low (57.1%). ▪ Fairly intact riparian zone dominated by juvenile and mature River Red Gum (90%) with some scattered Blackbox (9% of bank) and River Cooba (1%). Understory was made up of scattered native grasses. ▪ No aquatic vegetation	40
Wanganella Weir	Changed volume of flows released from Hartwood Weir Pool	Perennial (Regulated)	Type 1 – Highly Sensitive KFH Class 1 – Major KFH	▪ Channel is deep (>2m) and ~25m wide. ▪ Slow flowing pool habitat predominates. ▪ Channel banks stable, right bank gently sloping (~15°), left bank steep sloping (~25°). ▪ Silt/mud substate dominates mixed with some sand and clay.	

Assessment Site	Proposed work	Stream type	KFH Type Waterway Class	Relevant features	Riparian Channel and Environment (RCE) Score
				▪ Moderate density of large snags, one complex snag apparent ▪ At the time of inspection turbidity was 250 NTU, conductivity 367 µm, pH was near neutral (7.38) and dissolved oxygen levels were quite low (51.0%). ▪ The riparian zone was dominated by juvenile and mature River Red Gum (90%) with some Blackbox (10%) present. Understory was made up of scattered native grasses. ▪ A small amount of Floating primrose (*Ludwigia peploides*) was present in a slow flow zone on the leeward side of an island in the middle of the channel. Emergent terrestrial grasses were also present in the fringes of the channel (dead).	
Site 674	Change in Wanganella Weir Pool	Perennial (Regulated)	Type 1 – Highly Sensitive KFH Class 1 – Major KFH	▪ Channel is deep (>2m) 25m wide. ▪ Slow flowing pool habitat predominates. ▪ Channel banks are stable, moderately sloped, stepped on the right bank, steeply sloped on the left bank. Minor erosion apparent. ▪ Silt/mud substate dominates. ▪ Low density of snags, large or otherwise. Some complex snags. ▪ At the time of inspection turbidity was 200 NTU, conductivity was 335 µm, pH was neutral (7.47), and dissolved oxygen levels were low (60.2%). ▪ The riparian zone was dominated by juvenile and mature River Red Gum (80%) with some Blackbox (20% of bank). Understory was made up of scattered native grasses. ▪ Small amount of floating macrophytes (<1% cover)	40
Site 675	Change in Wanganella Weir Pool	Perennial (Regulated)	Type 1 – Highly Sensitive KFH Class 1 – Major KFH	▪ Channel is deep (>2m) 25m wide. ▪ Slow flowing pool habitat predominates. ▪ Channel banks stable. Left bank steep (~50°) and high (~5m), right bank ~25° and 3m high. Minor erosion apparent.	40

Assessment Site	Proposed work	Stream type	KFH Type Waterway Class	Relevant features	Riparian Channel and Environment (RCE) Score
				▪ Silt/mud substate dominates. ▪ Moderate density of large snags. Some complex snags. ▪ At the time of inspection turbidity was 224 NTU, conductivity was 312 µm, pH was neutral (7.30) and dissolved oxygen levels were low (45.8%). ▪ The riparian zone was continuous and ~20m wide, made up of juvenile and mature Blackbox (43%), River Red Gum (42%), and River Cooba (15% of bank). Understory was made up of scattered native grasses. ▪ No aquatic vegetation ▪ An old, fixed crest weir was present that would likely pose a barrier to fish movement when flows are lower than the crest.	
Site 006	Change in Wanganella Weir Pool	Perennial (Regulated)	Type 1 – Highly Sensitive KFH Class 1 – Major KFH	▪ Channel is deep (>2m) and ~25m wide. ▪ Slow to moderate flowing pool habitat predominates. ▪ Channel banks stable. Right bank high steep (45°), left bank moderate sloping (15°). ▪ Silt/mud substate dominates. ▪ Moderate density of large snags, but with limited complexity ▪ At the time of inspection turbidity was 223 NTU, conductivity was 264 µm, pH was neutral (7.76), and dissolved oxygen levels were 76.2%. ▪ The riparian zone was sparse but continuous, made up of juvenile and mature River Red Gum (45%), Blackbox (35%), and River Cooba (20%). Understory was made up of scattered native grasses. ▪ No aquatic vegetation.	42

Assessment Site	Proposed work	Stream type	KFH Type Waterway Class	Relevant features	Riparian Channel and Environment (RCE) Score
Site 007	Change in Wanganella Weir Pool	Perennial (Regulated)	Type 1 – Highly Sensitive KFH Class 1 – Major KFH	▪ Channel is deep (>2m) and ~35m wide. ▪ Slow flowing pool habitat predominates. ▪ Channel banks stable. Right bank 4m high with 15° slope, left bank 4m high and 25° slope. ▪ Silt/mud substate dominates. ▪ Moderate density of large, complex snags ▪ At the time of inspection turbidity was 181 NTU, conductivity was 267 µm, pH was neutral (7.56) and dissolved oxygen levels were low at 68.3%. ▪ The riparian zone was continuous and 20-30m wide, made up of juvenile and mature River Red Gum (40%), Blackbox (35%), and River Cooba (25%). Understory was made up of scattered native grasses. ▪ Thick stands of dead Typha in the channel (10% of channel).	40
Site 022	Change in Wanganella Weir Pool	Perennial (Regulated)	Type 1 – Highly Sensitive KFH Class 1 – Major KFH	▪ Channel is deep (>2m) and ~25m wide. ▪ Slow flowing pool habitat predominates. ▪ Channel banks stable. Right bank 4m high and steep (50°), left bank 4m high and 25° slope. ▪ Silt/mud substate dominates. ▪ Moderate density of large snags, complexity unclear ▪ At the time of inspection turbidity was 258 NTU, conductivity was 312 µm, pH was neutral (8.09), and dissolved oxygen levels were low (45.7%). ▪ The riparian zone was made up of juvenile and mature River Red Gum (40%), Blackbox (35%), and River Cooba (25%). Understory was made up of scattered native grasses. ▪ <1% cover of floating macrophytes (unknown species).	42

Assessment Site	Proposed work	Stream type	KFH Type Waterway Class	Relevant features	Riparian Channel and Environment (RCE) Score
Site 026	Changed volume of flows released from Hartwood Weir Pool	Perennial (Regulated)	Type 1 – Highly Sensitive KFH Class 1 – Major KFH	▪ Channel is deep (>2m) and ~25m wide. ▪ Moderate flowing pool habitat predominates. ▪ Channel banks stable. Left and right banks steep (50°). ▪ Silt/mud substate dominates. ▪ Low density of large snags, one complex snag apparent ▪ At the time of inspection turbidity was 315 NTU, conductivity 336 µm, pH was near neutral (7.97) and dissolved oxygen levels were high relative to other sites due to mixing of water falling over the weir (82.0%). ▪ The riparian zone was made up of juvenile and mature Blackbox (50%), River Red Gum (35%), and River Cooba (15%). Understory was made up of scattered native grasses. ▪ No aquatic vegetation.	42
Hartwood Weir	Change in Hartwood Weir Pool	Perennial (Regulated)	Type 1 – Highly Sensitive KFH Class 1 – Major KFH	▪ Channel is deep (>2m) and ~45m wide. ▪ Slow flowing pool habitat predominates. ▪ Channel banks stable. Left and right banks gently sloping (10°). ▪ Silt/mud substate dominates. ▪ No large, complex snags, but many dead trees standing in the channel ▪ At the time of inspection turbidity was 321 NTU, conductivity 349 µm, pH was neutral (8.07) and dissolved oxygen levels were low (68.3%). ▪ The riparian zone was made up of juvenile and mature River Red Gum (47.5%), Blackbox (47.5%), and River Cooba (5%). Understory was made up of scattered native grasses. ▪ A near continuous strip of rushes (*Typha* sp.) on the right banks and several stands of sedges (*Cyperus* sp.) on the left bank. ▪ Hartwood Weir present at downstream end of site.	40

Assessment Site	Proposed work	Stream type	KFH Type Waterway Class	Relevant features	Riparian Channel and Environment (RCE) Score
Site 028	Change in Hartwood Weir Pool	Perennial (Regulated)	Type 1 – Highly Sensitive KFH Class 1 – Major KFH	▪ Channel is deep (>2m) and ~25m wide. ▪ Slow flowing pool habitat predominates. ▪ Left and right banks gently sloping (~10°). Some substantial erosion on left bank immediately downstream of the Forest Creek offtake. ▪ Silt/mud substate dominates. ▪ Many dead trees standing in the channel with fallen trees creating a high density of moderately complex snags. ▪ At the time of inspection turbidity was 357 NTU, conductivity 344 µm, pH was neutral (7.92) and dissolved oxygen levels were low (68.2%). ▪ The riparian zone was effectively cleared on the left bank, on the right bank it was made up of juvenile and mature River Red Gum (50%), Blackbox (48%), and River Cooba (2%). Understory was made up of scattered native grasses. ▪ A large stand of rushes (*Typha* sp.) immediately above the Forest Creek offtake and downstream on the right bank. Several small stands of sedges (*Cyperus* sp.) also present on the left bank. ▪ Forest Creek offtake present at site.	42
Site 029	Change in Hartwood Weir Pool	Perennial (Regulated)	Type 1 – Highly Sensitive KFH Class 1 – Major KFH	▪ Channel is deep (>2m) and ~45m wide. ▪ Slow flowing pool habitat predominates. ▪ Stable banks. Left bank steep (~40°), right bank more gently sloping (~15°). ▪ Silt/mud substate dominates. ▪ Many dead trees standing in the channel near the left bank, with fallen trees creating a high density of complex snags.	41

Assessment Site	Proposed work	Stream type	KFH Type Waterway Class	Relevant features	Riparian Channel and Environment (RCE) Score
				▪ At the time of inspection turbidity was 348 NTU, conductivity 357 µm, pH was neutral (8.23) and dissolved oxygen levels were low (63.3%). ▪ The riparian zone was consistent on both banks and made up of juvenile and mature River Red Gum (75%) and River Cooba (25%). Understory was made up of scattered native grasses. ▪ Several small stands of sedges (*Cyperus* sp.) also present on both banks.	
Site 030	Change in Hartwood Weir Pool	Perennial (Regulated)	Type 1 – Highly Sensitive KFH Class 1 – Major KFH	▪ Channel is deep (>2m) and ~40m wide. ▪ Slow flowing pool habitat predominates. ▪ Stable banks. Left bank steep (~40°), right bank more gently sloping (~10°). ▪ Silt/mud substate dominates. ▪ Moderate density of large, low to moderately complex snags. ▪ At the time of inspection turbidity was 337 NTU, conductivity 363 µm, pH was neutral (7.94) and dissolved oxygen levels were low (61.4%). ▪ The riparian zone was sparse on both banks and made up of juvenile and mature Blackbox (80%) and River Red Gum (20%). Understory was made up of scattered native grasses. ▪ No aquatic vegetation.	37

See **Figure 3-3** for aquatic habitat assessment site locations.

4.10 Aquatic fauna

4.10.1 Aquatic fauna assemblages

4.10.1.1 Regional fish community

The Yanco Creek System has a moderately diverse native fish community, with at least 11 species recorded in the system in recent times (i.e. since 1980; Sharpe *et al.,* 2013; **Table 4-2**). Furthermore, Southern Pygmy Perch (*Nannoperca australis*), Olive Perchlet (*Ambassis agassizii*), Murray Hardyhead (*Craterocephalus fluviatilis*) were recorded in the system before 1980 but are now thought to be locally extinct (Gilligan, 2005). The various species within the community are not necessarily distributed throughout the system as habitat and flow conditions change significantly along the system and some reaches may not be suitable. These reaches could become suitable if appropriate ecosystem management is undertaken (Sharpe *et al.*, 2013). Four species (Murray Cod, Trout Cod, Silver Perch, Freshwater Catfish) have high conservation significance and are listed under the one or both of the FM Act and the EPBC Act.

Trout Cod is listed as Endangered under the EPBC Act and as Endangered under the FM Act. Upper Yanco Creek (including upper Colombo Creek and the Murrumbidgee River near the Yanco Creek offtake) supports one of the only two remaining self-sustaining populations of Trout Cod (Sharpe & Stuart, 2015). These reaches are thought to support Trout Cod because they are some of the few remaining sites in the lowland Murray-Darling Basin which provides fast, perennial flow and dense woody debris. Such habitat has been lost elsewhere due to river regulation and removal of riparian zones.

Murray Cod (Vulnerable - EPBC Act, Vulnerable - FM Act) is distributed throughout the system (Charles Sturt University 2018, unpublished data). The species appears to be more abundant in Billabong Creek than Yanco Creek. The population includes fish of a range of ages with some adults over 700 mm and some young-of-year juveniles. Murray Cod are also stocked in the system by the Jerilderie Fishing Club (Cooling & Gippel 2018).

Silver Perch (Endangered - EPBC Act, Vulnerable - FM Act) has been observed in Billabong Creek, Colombo Creek and Forest Creek at Wanganella Swamp, but not Yanco Creek (Charles Sturt University, 2022, unpublished data). Only mature adults have been recorded and no young-of-year. This would indicate that recruitment is limited in the Yanco Creek System.

Freshwater Catfish (Endangered Population - FM Act) is likely present throughout much of the system in low numbers and few young of year were detected in the surveys reviewed here. This population is significant, and listed as endangered, as the species has suffered widespread declines in range and abundance elsewhere in the MDB (Fisheries Scientific Committee, 2008a).

Other non-threatened large and medium bodied fish species are present throughout the system including Golden Perch and Bony Herring. The most common native species are small-bodied fish such as Australian Smelt, Unspecked Hardyhead, Murray Rainbowfish, and Carp Gudgeons that are common elsewhere in the lowland areas of the Murrumbidgee River catchment (Gilligan, 2005). There have been observations of Golden Perch and the various small-bodied species within larger associated floodplain lakes, such as Wanganella Swamp, Dry Lake and Mollys Lagoon (Wassens *et al.*, 2012; Charles Sturt University, 2022, unpublished data). Such floodplain habitats are often utilised by these species for recruitment (Humphries & Walker, 2013).

A further five non-native species are also present throughout the wider Yanco Creek System. These include Carp, Gambusia, Goldfish, Redfin Perch and Oriental Weatherloach. Each of these species are also expected to utilise floodplain habitat for recruitment (Sharpe *et al.*, 2013). Regarding Carp, while they are common throughout the system, the system is not considered a Carp hotspot according to NSW DPI Fisheries (**Figure 4-2**).

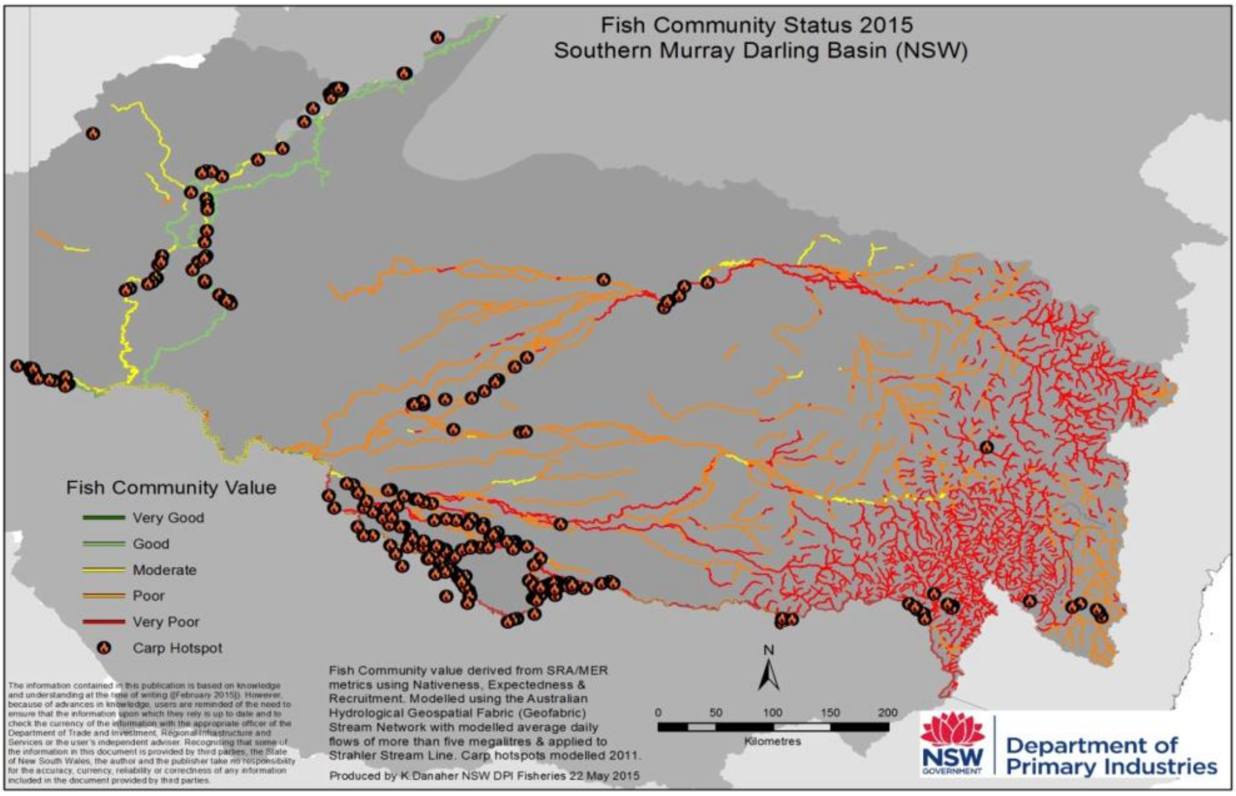


Figure 4-2 Fish Community Status for the Southern Murray-Darling Basin, highlighting condition of fish communities and Carp hotpots (Source: Ellis et al, 2016)

Table 4-2 Presence of individual fish species in each hydrological reach of the Yanco Creek System

Data sourced from † = Alluvium (2013); ‡ = Sharpe *et al.* (2013); * = McNeil & Griffiths (2021); Δ = Charles Sturt University (2022, unpublished); ¥ = 2023 field surveys. Atlas of Living Australia records (∞) are only included if they extend the distribution of a species beyond what is in the literature. Note that Southern Pygmy Perch (*Nannoperca australis*), Olive Perchlet (*Ambassis agassizii*), Murray Hardyhead (*Craterocephalus fluviatilis*) have been recorded in the catchment, but before 1980, and are thought to be extinct in the catchment (Gilligan, 2005). The unregulated upper reaches of Billabong Creek are not included due to a lack of published survey data

Common name	Scientific name	Native/ exotic	EPBC Act status	FM Act status	Reach 1 /PU10 (upper Yanco Creek)	Reach 2/PU10 (mid- Yanco Creek)	Reach 3/PU11 (Colombo Creek)	Reach 4 /PU11 (mid- Billabong Creek)	Reach 5 /PU13 (lower Billabong Creek)	Forest Creek /PU13 (Forest Creek)
Murray Cod	*Maccullochella peelii*	Native	VU		Present [† ‡]	Present [† ‡]	Present [† ‡]	Present [†‡]	Present [‡ Δ]	Present[Δ]
Trout Cod	*Maccullochella macquariensis*	Native	E	E	Present [† ‡]					
Golden Perch	*Macquaria ambigua*	Native			Present [† ‡]	Present [† ‡]	Present [‡]	Present [†‡]	Present [‡ Δ]	Present[Δ]
Silver Perch	*Bidyanus bidyanus*	Native	E	VU	Present [†]	Present [†]	Present [‡]	Present[‡]	Present [† ‡]	Present[Δ]
Murray Rainbowfish	*Melanotaenia fluviatilis*	Native			Present [† ‡]	Present [‡]	Present [‡]	Present [‡ Δ]	Present [‡ Δ]	Present[Δ]
Freshwater Catfish	*Tandanus tandanus*	Native		E pop.			Present [‡]	Present [†]	Present [†]	
Bony Herring	*Nematalosa erebi*	Native			Present [†]				Present [Δ]	Present[Δ]
Carp Gudgeon species complex	*Hypseleotris spp.*	Native			Present [† ‡]	Present [‡]	Present [† ‡]	Present [†‡] Δ	Present [†‡ Δ]	Present[Δ]

Common name	Scientific name	Native/ exotic	EPBC Act status	FM Act status	Reach 1 /PU10 (upper Yanco Creek)	Reach 2/PU10 (mid- Yanco Creek)	Reach 3/PU11 (Colombo Creek)	Reach 4 /PU11 (mid- Billabong Creek)	Reach 5 /PU13 (lower Billabong Creek)	Forest Creek /PU13 (Forest Creek)
Un-specked Hardyhead	*Craterocephalus fulvus*	Native			Present † ‡		Present ‡	Present †‡Δ		PresentΔ
Australian Smelt	*Retropinna semoni*	Native			Present † ‡	Present ‡	Present † ‡	Present †‡Δ	Present ‡	PresentΔ
Flathead Gudgeon	*Philypnodon grandiceps*	Native			Present †					
Eastern Gambusia	*Gambusia holbrooki*	Exotic			Present † ‡	Present ‡	Present †‡	Present †‡Δ	Present ‡	PresentΔ
Goldfish	*Carassius auratus*	Exotic			Present † ‡	Present ‡	Present †‡	Present †‡	Present ‡	PresentΔ
Oriental Weatherloach	*Misgurnus anguillicaudatus*	Exotic			Present †			Present Δ		PresentΔ
European Carp	*Cyprinus carpio*	Exotic			Present † ‡	Present † ‡	Present †‡	Present †‡Δ	Present †‡Δ	PresentΔ
Redfin Perch	*Perca fluviatilis*	Exotic			Present † ‡		Present †‡			PresentΔ
Broad-shelled Turtle	*Chelodina expansa*	Native				Present Δ			Present Δ	
Eastern Long-necked Turtle	*Chelodina longicollis*	Native				Present Δ			Present Δ	Present Δ
Murray River Turtle	*Emydura macquarii*	Native				Present Δ			Present Δ	Present Δ
Common Yabby	*Cherax destructor*	Native				Present ¥	Present ¥	Present ¥		

Common name	Scientific name	Native/ exotic	EPBC Act status	FM Act status	Reach 1 /PU10 (upper Yanco Creek)	Reach 2/PU10 (mid- Yanco Creek)	Reach 3/PU11 (Colombo Creek)	Reach 4 /PU11 (mid- Billabong Creek)	Reach 5 /PU13 (lower Billabong Creek)	Forest Creek /PU13 (Forest Creek)
Murray Crayfish	*Euastacus armatus*	Native		VU		Present ∞				
River Mussel	*Alathyria jacksoni*	Native							Present ¥	
Billabong Mussel	*Velesunio ambiguus*	Native							Present ¥ ∞	
Platypus	*Ornithorhynchus anatinus*	Native			Present *	Present *				
Rakali	*Hydromys chrysogaster*	Native			Present Δ	Present Δ	Present Δ	Present Δ	Present Δ	Present Δ

4.10.1.2 Macroinvertebrates

The term aquatic macroinvertebrate refers to a diverse group of non-vertebrate animals found in the river channel. This includes animals such as insects (e.g. groups such as mayflies, caddisflies, and beetles), crustacea (crayfish, yabbies, amphipods), and freshwater mussels. Macroinvertebrates form an important component of the aquatic ecosystem, mediating water quality through filtration, providing food and habitat for organisms such as fish, and playing a significant role in the biogeochemical cycling of nutrients (Arthington *et al.*, 2010).

The major determinants of the abundance and composition of the aquatic macroinvertebrate fauna are stream flows, habitat availability, food sources, and water quality. The key habitats for macroinvertebrates in lowland rivers are predominantly the benthic sediments, instream vegetation and woody debris in the channel. An additional habitat type in lowland rivers is the zone of tree roots along the edge of the channel. These roots provide shelter from high flows and predators, and trap leaves and other organic debris in which the macroinvertebrates live (Sheldon & Walker, 1998).

The major food sources for most macroinvertebrates are algae, biofilms (layers of bacteria and other micro-organisms that cover elements in the water) and terrestrial organic material (leaves, twigs etc) that fall into the stream from the riparian zone (Guo *et al.*, 2016).

4.10.1.2.1 Large-bodied macroinvertebrates

Three species of freshwater mussel (River Mussel (*Alathyria jacksoni*), Freshwater Mussel (*Alathyria condola*), and Billabong Mussel (*Velesunio ambiguous*)), one species of crayfish (Murray Crayfish (*Euastacus armatus*)), and one species of yabby (Common Yabby (*Cherax destructor*)) are known from the lower Murray River. However, there are very few records of crayfish and mussels in the Yanco Creek System.

In the published literature, Walcott *et al.* (2018) observed Common Yabby at three wetland sites, although those sites weren't defined. Furthermore, the Atlas of Living Australia shows a single observation of the Murray Crayfish in Yanco Creek ~2km above the confluence with Billabong Creek, and four observations of the Billabong Mussel from middle (near Wanganella) and unregulated upper Billabong Creek (ALA, 2023). The River Mussel and Billabong Mussel were found at Caroonboon Weir, immediately above the weir wall, during the aquatic habitat assessments conducted for this proposal. Otherwise, all of these large macroinvertebrate species have been recorded nearby in the Murrumbidgee River near Narrandera.

Aquatic surveys in the Yanco Creek System have focussed on other taxonomic groups and it is possible that crayfish and mussels have been overlooked or not recorded as incidental catch. It seems likely that their distribution in the system is not adequately described and they are more widespread.

Specific details of the habitat requirements of the freshwater mussels of the northern Murray-Darling basin are not known (Sheldon & McCasker, 2020). However, differences in the abundance and distribution of each species suggest that there are differences in their physiological adaptations that are relevant to their conservation management. For instance, River Mussels and Freshwater Mussels (*Alathyria* spp.) are restricted to the permanent channels of rivers where they require well-oxygenated conditions (Sheldon & Walker, 1989) and preferably flowing water. On the other hand, the Billabong Mussel occupies a wide range of habitats including temporary flowing creeks, backwaters and billabongs and artificial environments such as farm dams and irrigation channels (Jones, 2011). The Billabong Mussel is uncommon in major river channels where it is exposed to strong water currents, but it is well adapted to drought conditions and can burrow into the mud where it may aestivate for several years (Walker, 1981).

The presence both River Mussels and Billabong Mussels in the Caroonboon Weir pool would indicate that the conditions in weir pools are suitable to a degree for both species, although it appeared that Billabong Mussels were more abundant (one River Mussel was found compared to 15 Billabong Mussels). This conforms to expectations that weir pools would present more marginal habitat for River Mussels and Freshwater Mussels than flowing stream sections (Sheldon & McCasker, 2020). While targeted mussel surveys have not been conducted in the Yanco Creek System and their distributions may be wider, searches for mussel shells conducted as part of the aquatic habitat assessment indicate that their distribution is patchy. Factors such as flow velocity and permanency are expected to be key controls on their distribution. As freshwater mussels use fish hosts to disperse, it is also expected that barriers to fish dispersal would similarly pose barriers to mussel dispersal within the system (Hoffman *et al.*, 2017).

4.10.1.2.2 Small-bodied macroinvertebrates

No data could be found regarding the aquatic macroinvertebrate fauna for the study area. However, it is expected that communities would differ between macrohabitat types, such as between wetland and riverine habitats and between pool habitat and flowing habitat.

4.10.2 Overview of native fish behaviours and flow response

The reproductive characteristics of fishes provides a strong indication of their susceptibility to impacts on freshwater ecosystems, their likely response, and their ability to recover (Baumgartner *et al.*, 2010). As such, it can be helpful to view species in terms of their general reproductive strategy when assessing the likelihood that they would be impacted by a given change to their environment, and the trajectory and severity of any impact. With this in mind, the native fishes of the Murray-Darling Basin have been categorised into four life history modes depending on spawning style and timing and developmental intervals (Baumgartner *et al.*, 2014). These life history modes, summarised in **Table 4-3**, include (1) Long-lived apex predators; (2) Flow dependant specialists; (3) Foraging specialists; and (4) Floodplain specialists.

Long-lived apex predators such as Murray Cod and Trout Cod are not flow-dependant and rather spawn in response to increasing temperature, irrespective of flow (Rowland, 1983; Humphries, 2005). They are nesting species which require parental guarding of eggs and larvae for at least 10 days (Humphries, 2005). Young-of-year fish were historically abundant in floodplain habitats suggesting a potential preference to access nursery habitat (Anderson, 1915). These species are long-lived and spawn annually from when they mature (Anderson *et al.*, 1992). Environmental flow strategies for these species should therefore not focus solely on provision of single flows to create spawning opportunities on an annual basis but providing additional opportunities for juveniles to disperse to and from floodplain habitat (Baumgartner *et al.*, 2014).

Flow dependant specialists include Golden Perch and Silver Perch. With these species, flow pulses are needed to generate a spawning response (Mallen-Cooper & Stuart, 2003; King *et al.*, 2009). Adult fish develop ova (egg cells) in response to increasing water temperatures (Lake, 1967b; Leigh & Zampatti, 2011) but can delay spawning, potentially indefinitely, if adequate flow conditions are not met (Leigh & Zampatti, 2011). They are mobile species with both juvenile and adult fish undertaking significant migrations. Adults in particular undergo large-scale migrations in response to flow increases which are hypothesized to be linked with spawning behaviour (Reynolds, 1983). Environmental flow strategies for these species therefore need to focus on the delivery of increased flows that coincide with the Spring-Summer spawning period of these species. The species would also greatly benefit from the removal of barriers that would impede their ability to migrate.

Foraging generalist are the dominant group in the system, including Australian Smelt, Bony Herring, Murray Rainbowfish, Un-specked Hardyhead, Carp Gudgeon, Flatheaded Gudgeon, and Freshwater Catfish. For these species both large flood pulses and low-flow periods are equally important.

These species are generally resilient to prolonged low-flow conditions and appear to have more flexible spawning and recruitment strategies (Gilligan *et al.*, 2009). Adult fish move over a wide range of hydrological conditions and have been reported from fishways during periods of high or low flow (Stuart & Mallen-Cooper, 1999; Stuart *et al.*, 2008; Baumgartner *et al.*, 2010). Larvae have been observed year-round but are most abundant during increased water temperatures (Lake, 1967a; Humphries *et al.*, 1999; Humphries & Potter, 1993). Juveniles move from September to April (Spring, Summer and Autumn) between the channel and floodplain habitats regardless of hydrological conditions, as long as connectivity exists (Jones & Stuart, 2008; Lyon *et al.*, 2010). These species may spawn more than once annually, so numerous small-scale freshes that inundate spawning habitat would help benefit these species, if inundation occurs long enough for eggs to hatch. These species tend to increase in abundance during low-flow periods suggesting that they may benefit in years when environmental water is limited or not delivered at all. Taken as a whole, ideal environmental flow settings for this group may therefore focus on habitat availability, enhancing spawning conditions and connectivity through small flow increases.

Floodplain specialists include Southern Pygmy Perch, Murray Hardyhead, Olive Perchlet, and Flatheaded Galaxias. Each of these species is thought to be extinct within the system but may return either naturally or through translocation if conditions are improved to their benefit. Connectivity between main channel habitats and floodplains is a main driver behind the success of these species, with floodplains being critical as spawning and nursery habitat (McNeil *et al.*, 2008). Most floodplain species are short-lived, so even short-term interruptions to wetting and drying cycles can lead to dramatic population decline or population extinction. Given the degree of hydrological alteration across the MDB, it is unsurprising that many of these species are in decline across their range (Lintermans, 2023). Suitable environmental flow settings would include enough bankfull or floodplain inundation events to prevent wetland drying and to also provide these fish opportunities to disperse and expand distributions.

Table 4-3 Groupings of Murray-Darling native fish into four major groups based on spawning strategy and flow preferences

Species confirmed as present within the Forest Creek system are marked with an asterisk (*). Placement of Murray-Darling native fish in the four major groups defined by Baumgartner *et al.* (2014) that are based on spawning strategy and flow preferences. Information encompasses most native species that could be expected within the study region. Information sourced from Lake, 1967a; Rowland, 1983; Mallen-Cooper & Stuart, 2003; Tonkin *et al.*, 2007, 2008; Lintermans, 2023; and King *et al.*, 2010.

Group	Species	Max. life expectancy	Spawning season	Spawning temperature	Spawning method	Fecundity	Hatch time	Egg morphology
1.Long-lived apex predators	Murray Cod*	60 years	Sep-Nov	>18°C	Nesting, parental care	10,000–90,000	13 days	Sticky, demersal
	Trout Cod	25 years	Sep-Nov	>20°C	Nesting, parental care	1,000–12,000	10 days	Sticky, demersal
2.Flow dependent specialists	Golden Perch*	25 years	Oct-Apr	>20°C	Serial, no parental care	100,000–500,000	3 days	Buoyant, pelagic
	Silver Perch*	25 years	Oct-Apr	>20°C	Serial, no parental care	200,000–300,000	5 days	Buoyant, pelagic
3.Foraging generalists	Australian Smelt*	3 years	Sep-Feb	>12°C	Batch, no parental care	100–1,000	10 days	Sticky, demersal
	Bony Herring*	Unknown	Oct-Feb	>18°C	Batch, no parental care	33,000–800,000	7 days	Buoyant, pelagic
	Murray Rainbowfish*	5 years	Sep-Feb	>20°C	Batch, no parental care	35–350	7 days	Sticky, demersal
	Un-specked Hardyhead*	3 years	Sep-Apr	>18°C	Batch, no parental care	20–100	7 days	Sticky, demersal
	Carp Gudgeon species complex*	5 years	Sep-Apr	>20°C	Batch, parental care	100–2000	2 days	Sticky, demersal
	Flatheaded Gudgeon	5 years	Sep-Feb	>18°C	Batch, parental care	500–900	6 days	Sticky, demersal

Group	Species	Max. life expectancy	Spawning season	Spawning temperature	Spawning method	Fecundity	Hatch time	Egg morphology
	Freshwater Catfish*	8 years	Sep-Mar	>20°C	Nesting, parental care	10,000–50,000	7 days	Non-sticky, demersal
4. Floodplain specialists	Southern Pygmy Perch	5 years	Sep-Jan	>16°C	Serial, no parental care	100–4000	4 days	Sticky, demersal
	Murray Hardyhead	3 years	Sep-Apr	>18°C	Batch, no parental care	20–100	7 days	Sticky, demersal
	Olive Perchlet	4 years	Oct-Dec	>22°C	Batch, no parental care	200–700	7 days	Sticky, demersal
	Flatheaded Galaxias	Unknown	Aug-Sep	>11°C	Batch, no parental care	2,000–7,000	9 days	Sticky, demersal

4.10.3 Threatened aquatic species

Recent (within the last10 years) surveys in mid and lower Billabong Creek have shown that the conservation listed Silver Perch (Endangered [EPBC Act], Vulnerable [FM Act]) and Murray Cod (Vulnerable [EPBC Act]) occur in the vicinity of the study area.

Other threatened species and populations either occur in the broader Yanco Creek System or species distribution models (NSW DPIE, 2022b) suggest that there is suitable habitat, so we discuss their likelihood of occurrence in the study area in this section as well. **Table 4-4** outlines the Commonwealth and state listed aquatic species that are known to, or are predicted to, occur within the study area and provides a more precise assessment of likelihood of occurrence based on available survey evidence, database searches, and professional opinion.

Table 4-4 Likelihood of occurrence of Commonwealth and State listed threatened aquatic species within the study area

EPBC Act 1999 status: Critically endangered (CE), Endangered (E), Vulnerable (VU); FM Act 1994 status: Critically endangered (CE), Endangered (E), Vulnerable (VU), Endangered population (En. Pop.)

Common name	Species name	EPBC Act	FM Act	Distribution and preferred habitat	Likelihood of occurrence
Murray Cod	*Maccullochella peelii*	VU	-	The Murray Cod occurs naturally in the watercourses of the Murray-Darling Basin (MDB) (ACT, SA, NSW and Vic) and was formerly widespread in lower and mid altitudes of the MDB, however the species now has patchy distribution (Lintermans, 2023). Preferred habitat for both juvenile and adult Murray Cod generally consists of deep holes in low-flowing rivers, and particularly around instream rocks, woody debris, fallen trees or undercut banks which provide shelter and protection from predators (Lintermans, 2023).	Present – Recordings within the study area and species distribution models indicate that the habitat is suitable. Further assessment of the significance of potential impacts to this species is provided in **Section 7.2** and **Table 7-3.**
Silver Perch	*Bidyanus bidyanus*	E	VU	The Silver Perch was once widespread with a distribution range including most of the MDB and extending through drainage lines within western NSW. The species has experienced dramatic decline throughout the region. It is suggested that the current species distribution is likely to be limited to a portion of the mid-Murray River below Yarrawonga Weir, as well as several of its anabranches and tributaries including Edward River, an anabranch of the River Murray that flows through Deniliquin, and the Murrumbidgee River. The species are found in a wide range of habitats in the Murray-Darling system. Their preferred habitat is generally found in fast-flowing, more open sections of river but they can also be found in lowland, turbid and slow-flowing rivers (Lintermans, 2023).	Present – Recordings within the study area and species distribution models indicate that the habitat is suitable. Further assessment of the significance of potential impacts to this species is provided in **Section 7.2** and **Table 7-3.**
Flathead Galaxias	*Galaxias rostratus*	CE	CE	The Flathead Galaxias was historically known from the Southern MDB including the Macquarie, Lachlan, Murrumbidgee and Murray Rivers with patchy recordings (Lintermans, 2023).	Unlikely – No records within the study area based on survey evidence and database searches. The species has predicted distribution within the study area, however, it hasn't been recorded in 33 years and

Common name	Species name	EPBC Act	FM Act	Distribution and preferred habitat	Likelihood of occurrence
				It is generally found mid-water in still and gently moving waters of small streams, lakes, lagoons, billabongs and backwaters. Its habitat consists of coarse sand or mud substrate and aquatic vegetation (Lintermans, 2023).	Gilligan (2005) suggested that the species is likely to be extinct in the Murrumbidgee catchment. No further assessment required.
Freshwater Catfish	*Tandanus tandanus*	-	En. Pop.	The Freshwater Catfish is a non-migratory, benthic species. It is relatively sedentary, and adults typically only move within a 5 km range. They can be found in a diverse range of freshwater environments including rivers, creeks, lakes, billabongs and lagoons. They prefer clear, slow following or still waters, but can also be found in faster flowing streams with turbid waters. Substrates range from mud to gravel and rock. Freshwater Catfish are naturally distributed throughout the MDB and in east coast drainages between Clarence River (NSW) and Pioneer River (Qld). The species has declined substantially in the MDB due to a range of impacts including river regulation, invasive species, habitat degradation, cold water pollution, and fishing pressure. Only a small number of isolated populations remain in southern MDB; one of which occurs in the study area.	Present – The species has been recorded in mid-Billabong Creek, and Yanco and Colombo Creek, and it follows that the species distribution models indicate that the habitat is suitable. The species occurs in low numbers in the system. Further assessment of the significance of potential impacts to this species is provided in **Section 7.2** and **Table 7-3.**
Macquarie Perch	*Macquaria australasica*	E	E	The Macquarie Perch is a riverine species, typically found in the cool upper reaches of the MDB. In NSW, natural inland populations are isolated to the upper reaches of the Lachlan, Goulburn and Murrumbidgee Rivers. Translocated populations in NSW are found in the Mongarlowe River, Queanbeyan River upstream of the Googong Reservoir and in Cataract Dam (Lintermans, 2023). The fish prefers clear water and deep, rocky holes with abundant cover such as aquatic vegetation, large boulders, debris and overhanging banks (DPI, 2016a).	Unlikely – No records within the study area based on survey evidence or database searches. The species has predicted distribution within the Murrumbidgee River, near the study area. However, the available aquatic habitat is not preferred for this species. No further assessment required.

Common name	Species name	EPBC Act	FM Act	Distribution and preferred habitat	Likelihood of occurrence
Trout Cod	*Maccullochella macquariensis*	E	E	Often confused with the Murray Cod and only formally recognised as a separate species in 1972, the Trout Cod is endemic to the southern MDB including the Murrumbidgee, Murray and Macquarie Rivers. There are only three known self-sustaining populations left in the wild. The largest is in the River Murray below Yarrawonga and small translocated populations in Cataract Dam and upper reaches of Sevens Creek (Lintermans, 2023). The species also prefers similar habitat to the Murray Cod such as deep pools and instream cover such as large boulders, fallen trees and woody debris.	Unlikely – No records within the study area based on survey evidence or database searches, however the species has been recorded nearby in upper Yanco Creek where more suitable flow regimes prevail. Their absence from Billabong Creek is likely due to the prevailing hydrological regime (Stuart, 2022). No further assessment required.
Murray Hardyhead	*Craterocephalus fluviatilis*	E	CE	Murray Hardyhead is a small freshwater fish, native to the floodplains of the southern MDB. They were once widespread and abundant throughout their range; however the species has suffered a serious decline in abundance and distribution, and are now considered one of the most threatened vertebrate species in Australia. Murray Hardyhead is rare in NSW and only a few isolated populations occur in Victoria and South Australia (Lintermans, 2023). Murray Hardyhead preferred habitat is along the edges of wetlands and slow-flowing lowland rivers. They are often found among aquatic plants, particularly in saline waters containing few other fish species.	Unlikely – No records within the study area based on survey evidence or database searches. The species has predicted distribution within the study area, however Gilligan (2005) suggested that the species is likely to be locally extinct in the Murrumbidgee catchment. No further assessment required.
Murray Crayfish	*Euastacus armatus*	-	VU	Murray Crayfish are endemic to the southern tributaries of the MDB. They have a wide distribution but are declining due to habitat modification from construction of weirs and river regulation in particular. They prefer cool flowing water that is well oxygenated, deep pools, boulder rich streambeds, and extensive riparian vegetation (McCormack, 2012).	Possible – There is a single record from Yanco Creek, near the confluence with Billabong Creek, taken in 2019. Although the species hasn't been recorded in Billabong Creek, there is marginally suitable habitat within the study area. The lack of records suggests that it would not be common if present.

4.10.4 Other species of cultural importance and growing conservation concern

Other ecologically, commercially, and culturally important aquatic and semi-aquatic species that have been recorded in the Yanco-Billabong System in the vicinity of the study area include native fish (Golden Perch), turtles (Eastern Long-necked Turtle, Broad-shelled Turtle and Murray River Turtle), Platypus, and Rakali. While they are not listed as threatened by Commonwealth or state legislation (FM Act or EPBC Act), their general importance to the community and environment means that their presence in the study area is worth considering to ensure a robust assessment of impacts. **Table 4-5** describes these species and their likelihood of occurrence within the study area.

Table 4-5 Other important aquatic species known within the study area that could occur within the study area

Common Name	Species Name	Distribution and preferred habitat	Likelihood of occurrence
Golden Perch	*Macquaria ambigua*	Golden Perch naturally inhabit the Murray-Darling River system (except at high elevations) and exist in the internal drainage systems of Lake Eyre and the Bulloo River. The abundance of Golden Perch has dramatically decreased in the Murray-Darling due to migration obstruction and the alteration of flow regimes and temperature stratification following the construction of weirs and dams. Golden Perch have been translocated into other rivers of NSW, Queensland and the Northern Territory. They prefer warm, slow moving, turbid streams.	Present – Records within the study area. They utilize both riverine and wetland habitat within the study area.
Platypus	*Ornithorhynchus anatinus*	They are known to live in the rivers, streams and lakes of eastern Australia, from the Annan River in northern Queensland to the far south of Victoria and Tasmania. They are found in the major permanent river systems in the south of NSW, west of the Great Dividing Range, and occasionally in South Australia. Out of the water, platypuses spend most of their time in burrows which have been dug into the riverbank, with their entrances usually above water level. The animals use a number of short resting burrows (3 – 5 metres in length) as protection from predators and temperature extremes. Burrows used for nesting tend to be more elaborate, with many side branches	Unlikely – An eDNA survey of the Yanco Creek System detected the species in the upper and mid Yanco Creek, but not in Billabong Creek. No sightings recorded in databases and the habitat appears to be suboptimal, so it is considered unlikely that they species is present.
Rakali	*Hydromys chrysogaster*	This widespread species can be found in permanent water systems in Australia, New Guinea and offshore islands. Rakali live near permanent water in a diverse range of habitat that varies from fresh slow-moving streams, brackish inland lakes and creeks to wetlands,	Present - Records throughout the Yanco Creek System and in the study area.

Common Name	Species Name	Distribution and preferred habitat	Likelihood of occurrence
		rivers, estuaries and beaches on coastlines. Their home range typically comprises 1–4 km of waterways and they can travel a distance of between 200m to a kilometre in a night when foraging. They prefer low banks with flat, densely vegetated water edges, spending time when not foraging resting in hollow logs and burrows.	
Broad-Shelled Turtle	*Chelodina expansa*	Mostly found in turbid waters of depths greater than three meters. It is mostly a riverine turtle, generally inhabiting permanent streams but is also found in oxbows, ponds in floodplains, backwaters, and swamps across its distributed region. The Broad-Shelled Turtle will tend to inhabit environments that are undisturbed and have moderate vegetation cover for nest construction. The turtle has shown a preference of aquatic habitats in structured environments, where submerged logs, root systems and dead trees occur.	Present - Records throughout the Yanco Creek System. Surveys found them in lower Billabong Creek, but not in middle Billabong Creek in the vicinity of Hartwood Weir. A lack of targeted surveys means their presence close to the weir pools can't be ruled out.
Eastern Long-necked Turtle	*Chelodina longicollis*	The Eastern Long-necked Turtle is the most widespread species of freshwater turtle in Australia. It lives in slow-moving rivers, lakes and waterways across most of NSW, but is often found on land.	Present - Records throughout the Yanco Creek System. Surveys found them in lower Billabong Creek, but not in middle Billabong Creek in the vicinity of Hartwood Weir. A lack of targeted surveys means their presence close to the weir pools can't be ruled out.
Murray River turtle	*Emydura macquarii*	The Murray River turtle occurs primarily in rivers and waterbodies associated with rivers such as backwaters, oxbows, anabranches and deep, permanent waterholes on the floodplains in the Murray-Darling Basin. This species appears to avoid shallow water (Cann & Sadlier, 2017).	Present - Records throughout the Yanco Creek System. Surveys found them in lower Billabong Creek, but not in middle Billabong Creek in the vicinity of Hartwood Weir. A lack of targeted surveys means their presence close to the proposal weir pools can't be ruled out.
River Mussel	*Alathyria jacksoni*	The River Mussel is found throughout the Murray-Darling Basin. It is restricted to the permanent	Present – Recorded in lower Billabong Creek in

Common Name	Species Name	Distribution and preferred habitat	Likelihood of occurrence
		channels of rivers where they require well-oxygenated conditions, preferably in flowing water.	the Caroonboon Weir pool, but nowhere else in the system. A complete lack of surveys targeting mussels means their presence close to the proposal weir pools can't be ruled out.
Billabong Mussel	*Velesunio ambiguus*	The Billabong Mussel has a wide distribution across eastern Australia. It occupies a wide range of habitats including temporary flowing creeks, backwaters and billabongs and artificial environments such as farm dams and irrigation channels.	Present - Records in lower Billabong Creek as well as the upper unregulated reaches. A complete lack of surveys targeting mussels means their presence close to the proposal weir pools can't be ruled out.

4.10.5 Threatened ecological communities

The study area is situated wholly within the bounds of the 'aquatic ecological community in the natural drainage system of the lower Murray River catchment', also known as the 'Lower Murray River aquatic ecological community'. This effectively means that the whole fish community and its habitat is listed as Endangered under the FM Act. The Lower Murray River aquatic ecological community encompasses all natural creeks, rivers and associated lagoons, billabongs and lakes of the regulated portions of the Murray, Murrumbidgee and Tumut Rivers (refer to **Figure 4-3**).

The Lower Murray River aquatic ecological community is characterised by meandering channels and wide floodplains where flows are often heavily regulated. The land is generally flat to gently sloping. In their natural state, these lowland rivers experience extremely variable flows, ranging from floods to droughts. The river and creeks provide a wide range of habitats for fish and invertebrates, including pools, runs or riffles, backwaters and billabongs, large woody habitats and aquatic plants. The floodplains also provide a mosaic of important habitat types, including permanent and temporary wetlands (DPI, 2007).

The aquatic habitats present in the Yanco Creek System are representative of the Lower Murray River aquatic ecological community, including permanent and intermittent river channels, and intermittent to permanent wetlands. The modification of natural river flows because of river regulation (dams, weirs) was identified as the main threat to the Lower Murray River aquatic ecological community. The changed river flow regimes lead to reduced habitat quality, loss of spawning cues, and reduced opportunities for dispersal and migration.

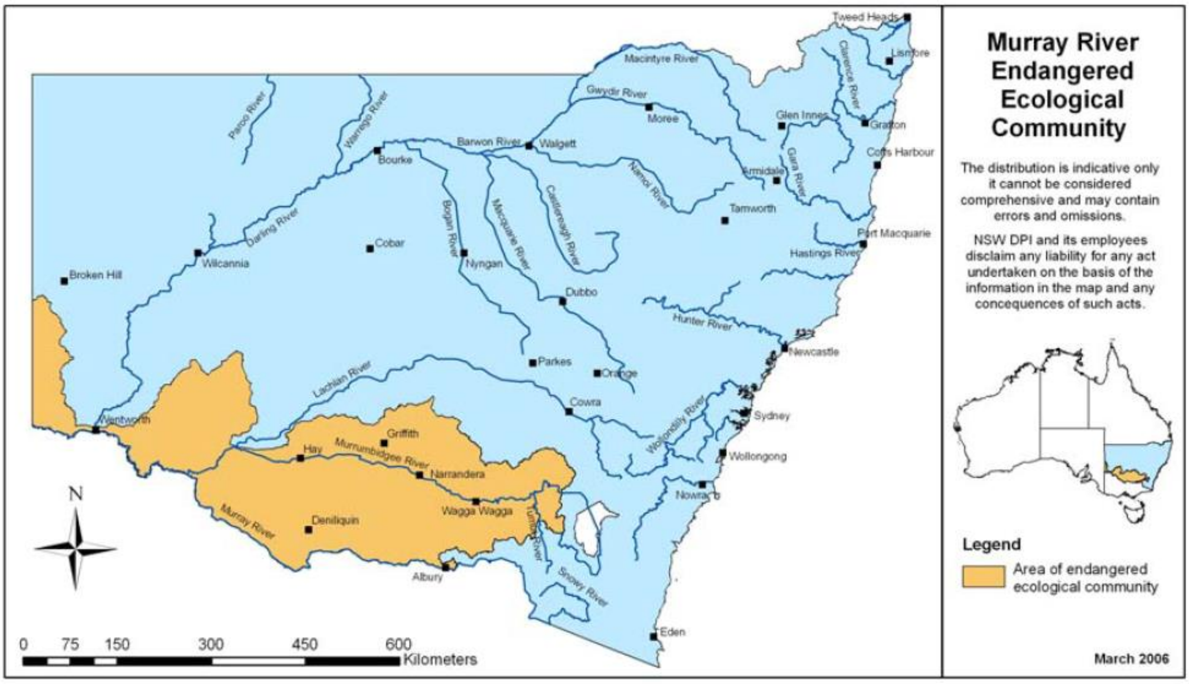


Figure 4-3 Map of the Lower Murray River aquatic ecological community (Source: DPI, 2007)

4.11 Existing water quality

A summary of the desktop review of surface water quality monitoring data is provided below.

4.11.1 Yanco Creek System Natural Resource Management Plan (Beal *et al,* 2006)

Historical water quality data was collected throughout the Yanco-Colombo system between 1993 and 2003 at five sites for a number of indicators including total suspended solids, turbidity, total phosphorus, pH, dissolved oxygen and electrical conductivity. Three sites were monitored in Yanco Creek; at offtake, at Morundah and at Bridge 321, and two sites were monitored in Colombo Creek; at Morundah and at Urana Road. At the time, monitoring identified that:

- Turbidity and total suspended solids in Yanco Creek (i.e. sediments) increased with distance downstream, but was fairly stable in Colombo Creek. Elevated turbidity was likely attributed to stream bank instability and altered flow and flooding regimes.
- Total phosphorus (TP) concentrations show similar trends to sediment increasing with distance downstream due to a large proportion of TP being bound to sediment. Total phosphorus concentration exceeded 0.05mg/L in more than 50% of the collected samples with the exception of the most upstream site in Yanko Creek which generally had lower concentrations (median ~0.03mg/L).
- pH was generally neutral, ranging between 6.5 and 8.0.
- Dissolved oxygen concentrations decreased with distance downstream, often falling below 85% saturation, which was likely attributable to low flow eutrophic conditions during the sampling period.
- Conductivity whilst variable between sites was aways within acceptable concentrations ranging between 50 and 350µS/cm.

Historical water quality data was also available at 16 sites throughout the Yanco Creek System which comprised of sites along the regulated creek system, the irrigation drains and the main tributary (upper

Billabong Creek). Data was available for the indicators salinity, nutrients, turbidity, dissolved oxygen, pesticides and biological indicators and showed that:

- Salinities are variable with higher salinity recorded during summer and/or under low flow conditions.
- Total phosphorus concentrations were elevated and exceed recommended target for protection of aquatic ecosystems.
- Yanco Creek System was relatively turbid, possibly due to bank erosion under high flows or the impact of carp and would not meet limits required for protection of nominated WQOs.
- Pesticides were generally not detected with the exception of Molinate that was recorded at some sites.
- Algal numbers were generally low, possibly due to high turbidity.

4.11.2 Water quality technical report for the Murrumbidgee surface water resource plan area (SW9) (NSW DPIE, 2020c)

The NSW Department of Planning, Industry and Environment (DPIE) have reported water quality for Billabong Creek, Colombo Creek and Forest Creek in the *Water Quality Technical report for the Murrumbidgee surface water resource plan area (SW9)* (NSW DPIE, 2020c). Whilst sites may not be in the vicinity of the proposed works, they provide an indication of current water quality in the broader catchment. Median water quality results are presented in **Table 4-6**, where bolded text denotes exceedance of target and the number in brackets is the number of samples. The calculated WaQI over the same period is also provided (NSW DOI, 2019).

Table 4-6 Median water quality for Billabong Creek and Colombo Creek between 2007 and 2015 (NSW DPIE, 2020c)

Indicator	Colombo Creek at Morundah	Billabong Creek at Walbundrie	Billabong Creek at Jerilderie	Billabong Creek at Darlot	Target
Total nitrogen (mg/L)	0.365 (94)	**0.95** (85)	**0.66** (87)	**1.0** (40)	0.6 [1]
Total phosphorus (mg/L)	0.05 (95)	**0.08** (85)	**0.08** (87)	**0.127** (40)	0.05[1]
Turbidity (NTU)	**50** (94)	34 (94)	**94** (94)	**148** (92)	35[1]
Total suspended solids (mg/L)	49 (93)	30 (86)	59 (92)	75 (91)	No guideline
Dissolved oxygen (% saturation)	95 (92)	87 (94)	80 (93)	81 (92)	80-110[1]
pH	7.2 (93)	7.7 (94)	7.1 (93)	7.1 (91)	6.5-8[1]
Electrical conductivity (µS/cm)	133 (93)	**1509** (85)	**192** (87)	**180** (91)	162 (median)[1]
WaQI Score[2]	67	36	32	27	

[1]Basin Plan water quality target

[2]WaQI score based on dissolved oxygen, turbidity, pH, total nitrogen and phosphorus results

Based on the data provided in *Water Quality Technical report for the Murrumbidgee surface water resource plan area (SW9), the* water quality of Colombo and Billabong Creek could be described as:

- Exhibiting elevated turbidity that presents a risk to aquatic ecosystems. Elevated turbidity may also impact on the visual amenity and suitability for recreation (primary and secondary) due to reduced visual clarity.
- Total nitrogen and phosphorus concentrations are elevated in Billabong Creek, the highest concentrations generally recorded at the most downstream site, i.e. Billabong Creek at Darlot. Median concentrations in Billabong Creek currently exceed the basin plan target for protection of aquatic ecosystems. The higher nutrient concentrations in Billabong Creek at Darlot is likely due to its location at the downstream extent of the Billabong Creek catchment where it receives the cumulative impacts of land use, soil disturbance and human activity upstream.
- Nutrient concentrations in Colombo Creek at Morundah were notably lower than Billabong Creek and median concentrations met the basin plan targets for protection of aquatic ecosystems for both total nitrogen and total phosphorus. There were occasions during high flow when nutrients exceeded the targets (NSW DPIE, 2020c).
- Median dissolved oxygen concentrations at all sites in Billabong Creek and in Colombo Creek fell within the recommended basin plan target of 80-110% saturation for protection of aquatic ecosystems. Low dissolved oxygen however has been recorded in Colombo Creek following flooding and the subsequent inundation of the riparian zone.
- pH is generally compliant and meets the requirements for protection of aquatic ecosystems and agricultural uses.
- Electrical conductivity concentrations in Colombo Creek are generally stable and compliant with the recommended basin plan target of a median that doesn't exceed 162µS/cm. Electrical conductivity levels in Billabong Creek were highly variable, with median concentrations at the upstream site at Walbundrie exceeding the basin target for both aquatic ecosystems and livestock and irrigation water supply. Conductivity at this site was notably higher than downstream, particular in the low flow years and possibly due to saline groundwater intrusion. The sites further downstream (at Jerilderie and Darlot) generally had lower median conductivity possibly due to flow diversions and regulated inflows from Colombo Creek which provide some dilution to the higher conductivity recorded in the upper Billabong Creek catchment (NSW DPIE, 2020c), however marginally exceeded the median target concentrations for protection of aquatic ecosystems.
- Poorer water quality (i.e. higher nutrients and turbidity is generally experienced in high flow/wetter conditions than during dry weather due to run-off inputs (NSW DPIE, 2020c).

4.11.3 Integrated Hydrological Operations Plan for the Billabong, Yanco and Colombo Creeks - Literature Review and Stakeholder Consultation

The Integrated Hydrological Operations Plan for the Billabong, Yanco and Colombo Creeks Literature Review and Stakeholder Consultation report (Cooling and Gippel, 2018) was a project undertaken to identify and address issues relevant to local communities and environments of the Yanco Billabong Region. It involved an extensive literature review and gap analysis to aid in the development of a hydrological operations plan.

Documented water quality issues of the Yanco, Billabong and Colombo Creeks within the WSP for the Murrumbidgee Regulated River Water Source include elevated turbidity, blackwater and the presence of blue-green algae (Cooling and Gippel, 2018). Turbidity in Yanco Creek is generally higher in summer due to inflows from the Billabong catchment, frequently reaching 120ppm (approximately 120mg/L suspended sediment) and has been documented to be an issue for water treatment at Jerilderie. Blackwater events occur during inundation of the floodplains in the Billabong Yanco systems or in the upstream Murrumbidgee and Billabong catchments. Blackwater events result in a decline in dissolved oxygen which can result in anoxic conditions. These changes in water quality can result in failure to meet nominated WQOs including protection of aquatic ecosystems, visual amenity, recreation, consumption of aquatic foods (cooked) and stock and domestic uses. Blue-green algal blooms occur naturally in lowland river systems but can occur more frequently due to elevated nutrient concentrations and low flows, particularly in summer (Cooling and Gippel, 2018). Similar to blackwater events, presence of blue green algae can result in failure to meet WQOs.

4.11.4 Murrumbidgee Monitoring Evaluation and Research Program: ecological responses to environmental watering

More recently, Charles Sturt University has undertaken monitoring, on behalf of the CEWH, at a number of sites in the Yanco Creek System to assess the ecological outcomes from environmental watering in the Murrumbidgee systems. Throughout the monitoring periods, the Murrumbidgee catchment received above average rainfall resulting in very high water levels in all the Yanco creek monitoring sties. The sites comprise of a wetland paired with nearby creek sites. The sites most relevant to the proposal, based on proximity to the works, are as follows. Ryhola-Billabong Creek (including wetland and anabranch), Wanganella-Forest Creek (and Wanganella Swamp wetland) and Hartwood River (and wetland). Ryhola-Billabong Creek sites (RHY, RHY2, RHY3) are located on the Forest Creek Anabranch of Billabong Creek downstream of both the proposed Wanganella and Hartwood Regulators. Wanganella Forest Creek sites (WSP, WSP2, WSP3) are located in the vicinity of the proposed Wanganella Regulator on the anabranch of Billabong Creek that diverges from the left bank of Billabong Creek upstream of the Yanco Creek confluence and rejoins Billabong Creek upstream of Moulamein. The Hartwood River sites (HRT, HRT2) are located upstream of the proposed Hartwood regulator. The wetlands are reliant on environmental watering (or high flows/flooding) to prevent drying out.

In-situ monitoring was undertaken over eight separate events in October and December 2021, and in February, April and September 2022, and in January, March and April 2023 although frequency at each site varies depending on water availability and site access. A summary of these results is provided in **Table 4-7**, with bold text denoting exceedance of relevant water quality target. Site names for the corresponding site codes are provided in **Table 3-2**. Water temperature and conductivity was within an acceptable range at all sites at the time of sampling. Turbidity levels reported exceeded the water quality target at each site, but this was possibly due to equipment deployment impacting turbidity at the time of sampling (as communicated by Charles Sturt University). Dissolved oxygen was variable with median concentrations at five of the eight sites within the recommended limits for protection of aquatic ecosystems Median pH levels between 6.5 and 8 are considered suitable for protection of aquatic ecosystems and five sites exceeded this range.

Table 4-7 Median water quality of selected sites withing the Yanco Creek Systems October 2021 -April 2023 (source: Charles Sturt University). Bold text denotes exceedance of the water quality target.

Indicator	HRT (4)[1]	HRT2 (4)[1]	WSP (7)[1]	WSP2 (6)[1]	WSP3 (2)[1]	RHY (1) [1]	RHY2 (3)[1]	RHY3 (2)[1]	Target
Temperature (°C)	21.91	18.95	25.61	23.97	19.06	24.06	21.91	25.28	No guideline
EC (µS/cm)	384	327	259	234	283	334	185	238	162 (median)[2]
DO (% sat)	**145.5**	**73.2**	105.1	84.45	108.7	105.5	91.6	**111.25**	80-110[2]
pH	**8.77**	7.47	**8.32**	7.2	**8.34**	**8.15**	7.26	**8.12**	6.5-8[2]
Turbidity (NTU)	**233.5**	**217.3**	**377.7**	**135.5**	**469.8**	**459.3**	**179.7**	**81.52**	35[2]

[1]Denotes number of monitoring events (refer **Table 3-2**)

[2]Basin plan water quality target

4.11.5 Yanco-Billabong Broad-scale Wetland Monitoring Project: Frog communities of the Yanco-Billabong creek system

As part of some broad scale frog surveys, in-situ water quality was measured at a number of wetlands in October and December 2017 in various reaches of the Yanco Creek System, the mid-Yanco, Colombo, Forest and mid and lower-Billabong Reaches. This water quality has been included in **Table 4-8** to provide an overview of water quality within the broader catchment. Water quality at the time of sampling had neutral pH ranging between 6.8 and 7.34 across the 13 sites and dissolved oxygen was variable (both high and low), however no sites exhibited anoxic conditions. Conductivity concentrations were representative of freshwater wetlands ranging between 60 to 360µS/cm, however due to the single sampling results could not be compared to the water quality target of median conductivity less than 162µS/cm. Turbidity concentrations were elevated and variable ranging between 85 and 355NTU.

Table 4-8 Water quality results from wetland sampling (Source: Walcott et al, 2018) (bolded text denotes exceedance of water quality target)

Reach	Site	Temperature (°C)	EC (µS/cm)	DO(% saturation)	pH	Turbidity
Mid-Yanco	BROO	21.59	70	108.85	7.01	**233.92**
	BUND	21.16	80	98.97	7.09	**150.5**
	WILS	26.07	150	**120.22**	7.36	**239.17**
	YANK	20.19	100	86.18	6.9	**352.33**
Colombo	CCKT	21.35	90	71.68	6.84	**100.50**
	CNNG	24.03	90	**110.35**	7.11	**85.58**
	SHEE	20.49	60	**114.23**	7.27	**207.67**
Mid-Billabong	HART	23.46	130	**113.93**	7.34	**355.5**
	WANG	20.78	180	**64.48**	6.81	**234.33**
Forest	FRT	21.51	140	95.33	7.2	**298.83**
	WANL	21.74	290	**124.15**	6.94	**107.84**
	WANU	23.28	360	109.35	7.75	**143.60**
Lower-Billabong	QUA	21.60	160	**120.73**	7.29	**229.50**

4.11.6 Murrumbidgee valley annual surface water quality report 2021-2022 and 2022-2023 (DPIE, 2022; NSW DCCEEW, 2024b)

Monthly water quality data was collected between July 2021 and June 2023 as part of the State Water Quality Assessment and monitoring program which monitors 26 sites in the Murrumbidgee Valley. A number of these sites fall within the broader study area including:

- Colombo Creek at Morundah
- Billabong Creek at Walbundrie
- Billabong Creek at Jerilderie
- Billabong Creek at Darlot.

Monitoring over this period indicated that:

- Flow during July 2021 to June 2022 and July 2022 to June 2023 was characterised by heavy rain falling across much of the catchment and subsequently resulting in regular large flow events (NSW DPIE, 2022; NSW DCCEEW ,2024b).
- Electrical conductivity levels were good and did not exceed the agriculture and salinity target of 833µS/cm. Despite compliance, conductivity in Billabong Creek at Walbundrie during 2021-22 was noticeably higher than other sites in the catchment, likely due to mobilisation of salts stored in the soils as a result of heavy rainfall and runoff (DPIE, 2022). Whilst conductivity was still high in w022 to 2023, the following year, with the higher conductivity recorded in Billabong Creek at Darlot (DCCEEW,2024).
- Median pH of Colombo and Billabong Creek ranged between 7.0 to 7.5 which is suitable for protection of aquatic ecosystems and livestock and irrigation water supply.
- Turbidity concentrations appear elevated, likely due to higher-than-normal rainfall. Median turbidity exceeded the basin plan target of 35NTU in Billabong Creek, increasing with distance downstream.
- Nutrient concentrations were elevated in Billabong Creek, with highest concentrations recorded at the upstream site at Walbundrie. Concentrations were lower downstream, possibly due to dilution from regulated flows from Yanco Creek (DPIE, 2022).
- Median dissolved oxygen levels met the target for protection of aquatic ecosystems in both 2021-2022 and 2022-2023 at the sites n Billabong Creek and Colombo Creek, although there were occasions of dissolved oxygen levels in the lower Murrumbidgee catchment dropping in response to widespread flooding of the floodplain which led to deoxygenated water being generated on the floodplain and returned back into the river (DPIE, 2022).
- Water quality of Billabong Creek at Jerilderie and Darlot was considered to be the poorest throughout the lower Murrumbidgee River catchment during both 2021-2022 and 2022-2023 recording the lowest WaQI scores, In 2021-2022 the WaQI at Jerlilderie and Darlot were 54 and 59 respectively but declined to 44 and 45 respectively in 2022-2023. Billabong Creek at Walbundrie and Colombo Creek at Morundah scored better with a WaQI of 74 and 75 in 2022-2023 (and 67 and 73 in 2021-2022). The lower WaQI scores for Billabong Creek at Jerelderie were due to high turbidity, nutrient concentrations and electrical conductivity and high nutrient concentrations and electrical conductivity at Darlot. Widespread flooding was the main driver of water quality throughout the Murrumbidgee catchment over both years and which was confirmed by the monitoring sites returning lower WaQI scores when compared the preceding (drier) sampling period of 2021-2022 (NSW DPIE, 2022; NSW DCCEEW, 2024b).

4.11.7 WaterNSW water quality data

WaterNSW monitor surface water quality in NSW via a combination of automatic digital sensor and logging devices as well as manual sampling. Loggers typically record water quality every 15 minutes, which can be summarised as hourly, daily and monthly data. Daily water quality data for a number of gauges in the Yanco-Billabong catchment was downloaded for the past 5 years (1 March 2019 – 12 March 2024). Most gauges only measure the water quality indicators electrical conductivity and temperature, however one gauge, Billabong Creek at Darlot also measures pH and turbidity. Summary statistics (median) for the past 5 years is presented in **Table 4-9** and indicates that water temperature and conductivity are fairly similar throughout the catchment. Billabong Creek at Darlot has neutral pH that complies with the target, but elevated turbidity exceeds the basin target of 35NTU.

Table 4-9 Water quality results from WaterNSW automatic gauges (2019-2024)

Site (Gauge number)	Temperature (°C)	EC (µS/cm)	pH	Turbidity (NTU)
Billabong Creek at Darlot (410134)	17.6	192	7.38	88
Billabong Creek d/s Hartwood Weir (410168)	17.9	213	Not measured	Not measured
Forest Creek at Warriston Weir (410148)	16.5	220	Not measured	Not measured
Forest Creek at Offtake (41010309)	17.9	Not measured	Not measured	Not measured

4.11.8 Site specific water quality

Proposal specific site inspections were carried out between 5 March 2023 and 8 March 2023 at nominated sites within the study area which included collecting in-situ water quality measurements that are indicative of water quality at the time of sampling. Of note, the system was receiving environmental flows typical of an autumn fresh. Otherwise, conditions were warm and dry. The results of the sampling are shown in **Table 4-10** and **Table 4-11**, where **bold** text denote results that were outside the recommended targets. Pesticides and herbicides were not detected in the grab samples at the three sites and therefore have not been reported in **Table 4-11.**

Table 4-10 Insitu Water quality results from March 2023 site visit

Site number	Location	Turbidity (NTU)	EC (µm)	pH	DO (% saturation)
Site 001	Caroonboon Weir immediately downstream	**197**	370	7.82	80.2
Site 002	Billabong Creek ~8km upstream of Caroonboon Weir	**182**	373	7.7	**65.4**
Site 003	Billabong Creek ~15km upstream of Caroonboon Weir	**176**	365	7.78	81.7
Site 671	Billabong Creek ~17km d/s of Wanganella Regulator/Weir	**164**	392	7.48	**62.4**
Wanganella Regulator/Weir	Wanganella Regulator/Weir and immediately upstream	**250**	367	7.38	**51**

Site number	Location	Turbidity (NTU)	EC (µm)	pH	DO (% saturation)
Site 674	Billabong Creek ~3.5km upstream of the regulator/weir	**178**	367	7.45	**57.1**
Site 675	Billabong Creek ~13km upstream of the regulator/weir	**200**	335	7.47	**60.2**
Site 006	Billabong Creek off Wanganella-Conargo Rd	**224**	312	7.3	**45.8**
Site 007	Billabong Creek near Flood Creek confluence	**223**	264	7.76	**76.2**
Site 022	Billabong Creek at Morrison Rd	**181**	267	7.56	**68.3**
Hartwood Regulator/Weir	Hartwood Regulator/Weir and immediately upstream	**258**	312	**8.09**	**45.7**
Site 026	Hartwood Regulator/Weir immediately d/s	**321**	349	**8.07**	**68.3**
Site 028	Billabong Creek immediately d/s of Forest Creek offtake	**315**	336	7.97	82.0
Site 029	Billabong Creek @ irrigation channel off Canargo Rd u/s or Hartwood Regulator/Weir	**357**	344	7.92	**68.2**
Site 030	Billabong Creek @ bridge crossing off Canargo Rd u/s Hartwood Weir	**348**	357	**8.23**	**63.3**

Table 4-11 Laboratory Water quality results from grab samples collected during March 2023 site visit

Indicator	**Site 001** (Caroonboon Weir immediately downstream)	**Wanganella Weir** (Wanganella Weir and immediately upstream)	**Hartwood Weir** (Hartwood Weir and immediately upstream)	**Target for protection of aquatic ecosystem**
Ammonia (mg/L)	0.01	0.01	**0.03**	0.02
Oxidised nitrogen (mg/L)	0.01	**0.12**	**0.12**	0.04
Total nitrogen (mg/L)	**1.2**	**0.7**	**0.7**	0.6
Total phosphorus (mg/L)	**0.11**	**0.08**	**0.12**	0.05
Reactive phosphorus (mg/L)	0.01	0.01	0.01	0.02
Chlorophyll-a (µg/L)	**76**	**53**	**48**	5
Total organic carbon (mg/L)	7	8	8	No guideline
Suspended solids (mg/L)	130	70	161	No guideline
Total mercury (mg/L)	Not detected	Not detected	Not detected	0.00006
Total arsenic (mg/L)	0.003	0.003	0.004	0.013
Total cadmium (mg/L)	Not detected	Not detected	0.0001	0.0002
Total chromium (mg/L)	**0.004**	**0.004**	**0.007**	0.001
Total copper (mg/L)	**0.003**	**0.003**	**0.005**	0.0014
Total lead (mg/L)	**0.004**	**0.004**	**0.006**	0.0034
Total nickel (mg/L)	0.004	0.004	0.005	0.011
Total Zinc (mg/L)	**0.01**	**0.011**	**0.012**	0.008

4.11.9 Summary

Water quality in the broader catchment and within the vicinity of the project is generally characterised as having elevated turbidity, nutrients and, at times, conductivity. The elevated turbidity (sediments) appears to be a result of erosion as increases were recorded following high rainfall events. In addition to elevated nutrients and turbidity, monitoring at the weir sites (Caroonboon, Hartwood and Wanganella weirs (refer **Table 4-11**) also shows elevated concentrations of metals but no evidence of pesticides and herbicides.

The water quality indicators of turbidity, dissolved oxygen, nutrients and some heavy metals did not meet the recommended target limits at the time of sampling in the project area, and nutrients and turbidity appear to be elevated throughout the catchment.

5. Risk assessment

5.1 Overview

The risk assessment in this section is based on the information on the aquatic fauna and habitat present in the study area (presented above). The performance objective adopted for the risk assessment is to avoid and minimise impacts on State and Commonwealth listed aquatic species, and aquatic ecosystem health. Risks and environmental delivery standards were identified and developed based on the draft construction plan outlined in **Section 1.5**. The risk assessment involves:

- Identifying effect pathways through which aquatic fauna and habitat may be impacted by the construction and operation of the proposal and rating the risk each effect pathway poses in the context of the proposal and the relative risk likelihood (i.e. likely, possible, unlikely, rare) and consequence (i.e. severe, major, moderate, minor, negligible) - these are addressed in **Section 5.2**
- Developing safeguards that are required to manage the identified risk - these are outlined in **Section 6**
- Assessing the residual risk likelihood and consequence to the aquatic ecosystem following the implementation of the safeguards and providing an overall risk rating – this is addressed in **Section 7.1**.

The assessment has investigated a broad range of effect pathways for aquatic species and their habitat that have been categorised into potential effects on animal passage, water quality and water regimes, weeds and pest species, noise and vibration, toxic substances, groundwater interactions, and direct impacts such as loss of habitat or the mortality of individuals or communities. Safeguards were developed to ensure that there is a clear, unambiguous and transparent set of controls in place to guide proposal delivery across the construction and operation phases. Key risks are defined as having an initial rating of medium or above.

In some cases, the assessment required consideration of the life histories and current distribution of aquatic fauna likely present in the study area. Threatened species descriptions are provided in **Table 4-4**. Outcomes from the assessment of effects were used to inform the significant impact criteria for MNES (**Table 7-2**). The potential effect pathways have also been assessed against State significant matters in the study area (**Table 7-3**). A summary of the potential effect pathways and associated safeguards is provided in **Table 7-1**.

5.2 Impact pathway identification and initial risk assessment

5.2.1 Construction

The proposed construction works for the Billabong Creek Regulators could potentially impact on aquatic ecological values via several effect pathways. In this section we identify these effect pathways, assign them to broad categories, and provide 'risk likelihood' and 'consequence' ratings for each effect.

5.2.1.1 Loss of connectivity and impeded passage for native aquatic species

Longitudinal connectivity is essential to the ecological integrity of river ecosystems (Pringle, 2003). However, such connectivity is significantly reduced by the construction of artificial barriers, such as culverts and block banks (Nilsson *et al.* 2005). Fragmentation of river networks by human-made barriers is recognized as a significant threat to the occurrence, abundance, and persistence of many freshwater species (Bednarek, 2001; Bourne *et al.*, 2011).

River connectivity plays an important role for aquatic fauna at both individual and population levels. For individuals, physical obstructions limit access to rearing and spawning habitat and shelter from predation and disturbances (Baras & Lucas, 2001; Liermann *et al.*, 2012). Furthermore, when populations become fragmented by barriers to dispersal, and genetic exchange is restricted, the risk of local extinction is increased, and the chance of subsequent recovery is decreased because recolonization is no longer possible (Lucas *et al.*, 2009).

Each of the proposal sites would require one or two cofferdams to be built that may present a barrier to passage of aquatic fauna. A cofferdam is a temporary, waterproof enclosure built within a body of water to allow the enclosed area to be pumped out so that work can be carried out within. In this instance the cofferdams would be constructed using sheet piling that would be driven into the riverbed.

Cofferdams would be built to (1) allow the construction of the new regulators, and (2) to allow the demolition of the existing weirs. After completion of works within the dewatered cofferdams, the area would be progressively re-filled with water, and the cofferdam would then be progressively removed by a crane.

Here we detail the potential effects of the cofferdams on passage of aquatic fauna during construction of the proposed regulators and associated fishways. The following effect pathway is discussed:

- Construction of infrastructure within a waterway requires construction of cofferdams, which results in a temporary loss of connectivity and impeded passage impacting aquatic species.

5.2.1.1.1 Construction of infrastructure within a waterway requires cofferdams and silt curtains, which results in a temporary loss of connectivity and impeded passage impacting aquatic species

The new regulator structures would be built downstream of the existing weirs. The regulators would be built, and the weirs would be removed in a staged fashion so that irrigation water is available throughout the construction phase and so that fish passage is not impeded any further than it currently is. The existing weirs already present barriers to the longitudinal movement of aquatic fauna in Billabong Creek. During Stage 1, Step 1 of construction the downstream and upstream cofferdams would prevent access to a small area of the channel, but longitudinal access would remain unchanged. During Stage 2, Step 2 the upstream cofferdam and the remaining half of the existing weir would still present a barrier to longitudinal movement, but the newly installed fishway would allow for fish passage between the existing weir and the downstream environment while the downstream cofferdam is in place. During Stage 2, Step 3 fish passage between habitat above and below the new regulator would exist past the removed section of the existing regulator and through the fishway.

Passage for aquatic fauna would remain relatively unchanged during construction given the weir already presents a barrier to movement. The cofferdams would prevent access to very little aquatic habitat. Furthermore, the habitat isn't considered to be unique or of particularly high quality (**Table 4-1**), and it is broadly available elsewhere. Finally, animals that can traverse the terrestrial environment such as Rakali, Platypus, turtles, and crayfish would still be able to navigate around the barrier if necessary. This would be facilitated by the presence of at least one low gradient of the riverbank in the vicinity of each of the works.

With all this in mind, it is considered that the initial risk likelihood of this impact pathway is 'Unlikely' and the consequence to the aquatic community 'Minor'.

5.2.1.2 Degradation of aquatic habitat through water quality or water regime changes

This section details effects to aquatic habitat during construction of the regulators and fishways, and related infrastructure such as access tracks, containment banks, crane pads, etc. The following effect pathways are discussed under this category:

- Disturbance of soil during construction of infrastructure in or adjacent to waterway corridor leads to increased erosion/sedimentation, leading to aquatic habitat degradation due to input of sediment and/or contaminants.
- Removal of vegetation leads to a decline in aquatic habitat (e.g. increased light levels and stream temperature) that negatively impacts on aquatic fauna.
- Spillage or leaks of toxic substances or litter from construction vehicles or machinery or from storage facilities enters waterbodies, leading to water quality unsuitable for aquatic species.

- Mobilisation of sediment deposited behind the existing weirs.

5.2.1.2.1 Disturbance of soil during construction of infrastructure in or adjacent to waterway corridor leads to increased erosion/sedimentation, leading to aquatic habitat degradation and reduced water quality due to input of sediment and/or contaminants

Erosion and sedimentation can result in increased turbidity and poor water clarity, impacting on visual amenity and potentially lead to smothering of benthic organisms and fish eggs, and reduced visibility for fish. Sediments may contain high concentrations of nutrients which can lead to increased risk of algal blooms and subsequently result in reduced light penetration therefore limited growth of aquatic vegetation. Algal blooms may also result in diurnal fluctuations and overall reduction of dissolved oxygen in the waterway, which may impact on aquatic organisms. In addition to nutrients, mobilised sediment may contain elevated concentrations of metals and other contaminants which can be toxic and negatively impact aquatic life.

As evaluated in the Yanco Creek Modernisation – Billabong Creek re-regulation weirs (Part 2) draft report (North, 2022), construction of the Billabong Creek regulators would involve excavation and ground disturbance in areas with soils potentially susceptible to dispersion, erosion and instability. Also, it is proposed that soil would be imported from nominated quarries or local borrow pits for use as fill material, which would be stored on site. Importation and storing of this material, as well as excavation and vehicle movements within the proposal footprints could result in destabilisation of constructed landforms and increased risk of erosion and sediment transport into the creek driven by rainfall runoff. Disturbance of the riverbed during the installation of the cofferdams is also likely to bring additional sediment into suspension, temporarily increasing turbidity in the stream.

The proposal does not intend to manage sites for large-scale flood events. Rather, it is proposed to manage for usual seasonal flow conditions and, in the event of a flood, to secure work sites and demobilise until such time as the sites are accessible and control measures can be re-established or reinstated. Standard sediment management procedures proposed in the construction plan include silt fencing and jute matting around the construction site to help reduce sediment transport into the creek. Any effects due to large-scale flooding are considered to be low based on the relatively small size of the construction footprints.

The *Billabong Creek Regulators Geomorphology Assessment* Report (Jacobs, 2024b) lists the potential construction impacts related to erosion and sedimentation as:

- Construction works and structures potentially result in bed and bank erosion or instability and subsequent effects on environmental values
- Potential effects to important wetlands and wetland habitat as a result of changes in fluvial processes
- Erosion and loss of topsoil causing water quality degradation (e.g., due to clearing of vegetation and ground disturbance, establishment/upgrade to access tracks, movement of heavy vehicles across exposed earth, stockpiling, dewatering, instream works such as streambed clearing and piling, inundation during construction activities).

An important point to note in relation to sediment impacts on aquatic communities is that streams within the Yanco Creek System currently experience elevated erosion and turbidity during flood events (Cooling & Gippel, 2018). Additionally, erosion and sedimentation would be managed via various standard water quality control measures including installation of floating silt curtains downstream of work area and silt fences and jute matting at the toe of batters to minimise the transport of silt into the creek.

Sumps would be installed to manage residual water on the construction sites within the cofferdams, with pumps installed to dewater the sumps. To ensure water pumped out of sumps is of adequate quality, pumps would be installed above the deposited sediment.

Taken as a whole, the initial risk likelihood of this impact pathway is considered to be ‘Possible’ and the consequence ‘Moderate’.

5.2.1.2.2 Removal of vegetation leads to a decline in aquatic habitat (e.g. increased light levels and stream temperature) that negatively impacts on aquatic fauna

Riparian vegetation along the stream edge acts to mediate stream temperature (Martin *et al.*, 2021), light exposure (Dignan & Bren, 2003) and nutrient and sediment input (Davies & Nelson, 1994), while also providing food for aquatic organisms in the form of leaves, debris, and falling invertebrates, and habitat in the form of large woody debris (Robison & Beschta, 1990; Wipfli, 1997; Quinn *et al.*, 2004). It follows that the removal of riparian vegetation as part of construction activities may negatively impact on these aspects of in-stream habitat and the resident aquatic community.

Vegetation removal is expected across the 'clearing area' at each of the proposal sites (see **Figure 5-1** and **Figure 5-2**). This area includes for example, the crane pad(s), crane slew zones, and borrow pit/s. Access tracks would require minimum width and height clearance for heavy machinery which may require removal and/or trimming of trees. In addition, topsoil would likely be removed/cleared and regraded in the 'construction activity zone' for construction (e.g. laydown, site sheds, parking areas) which would mean clearing of small shrubs and grasses. Tree removal for site facilities would be minimised where possible.

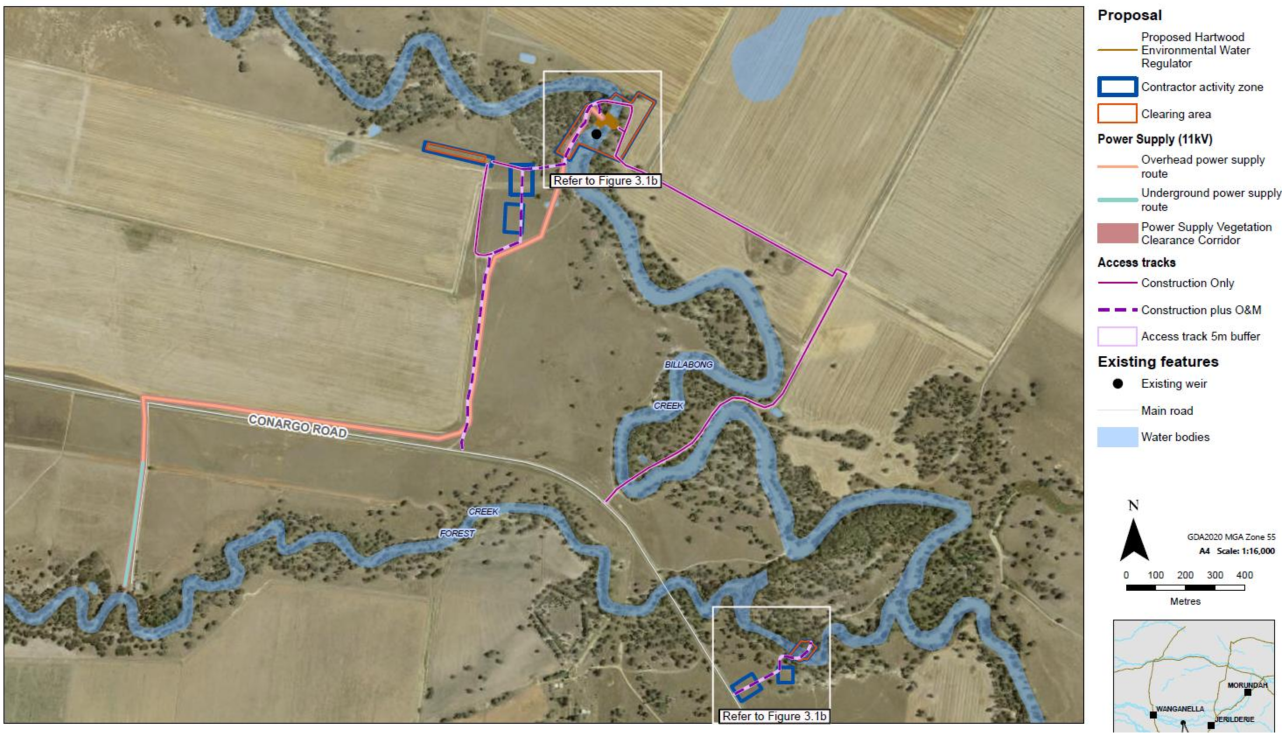


Figure 5-1 Location of Hartwood Regulator and proposed works

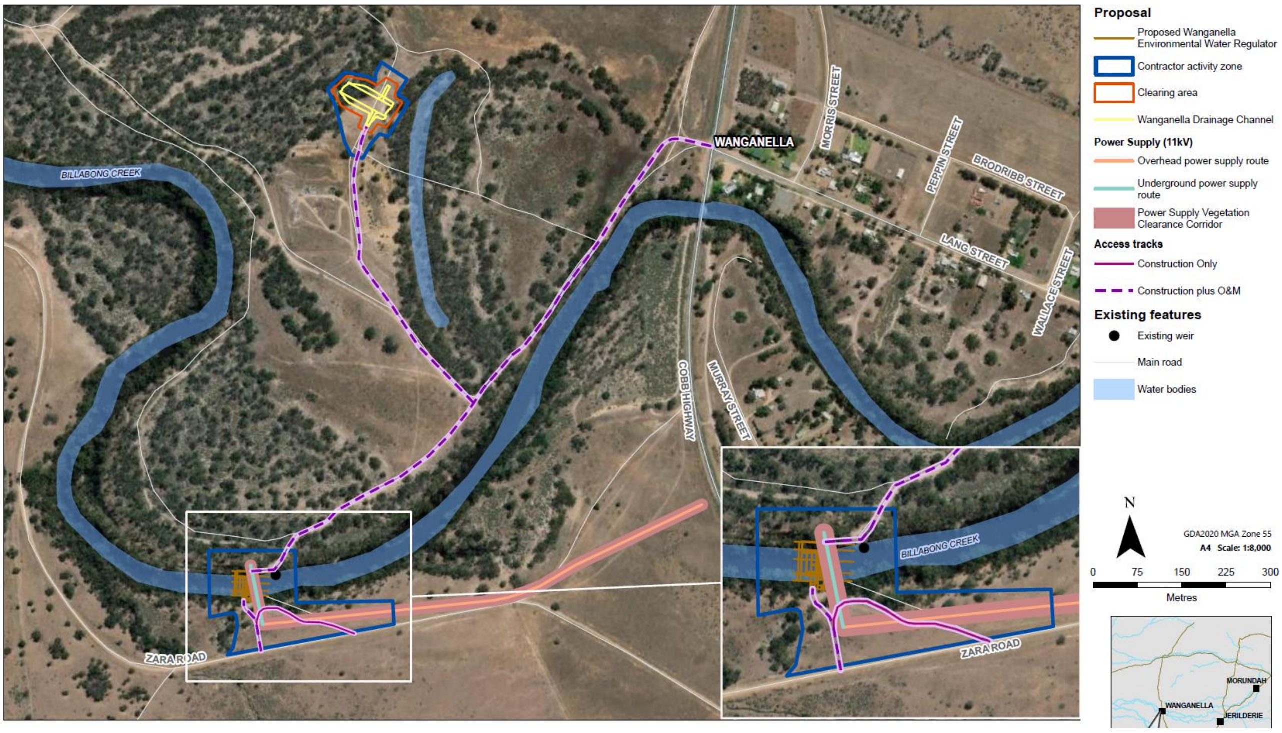


Figure 5-2 Location of Wanganella Regulator and proposed works

Efforts have been made throughout the planning and design phases for the proposed construction to avoid and minimise impacts to vegetation by utilising existing cleared/disturbed areas to build the necessary infrastructure. The construction footprint is small in relation to the riparian habitat available along Billabong Creek that is accessible to the local aquatic community. Also, the footprint contains vegetation that is already disturbed, degraded and/or modified. That said, the proposed removal and/or modification of vegetation is unlikely to have a material impact on the provision of shade, habitat, and/or food sources for the local aquatic community.

With respect to water quality, the clearing of vegetation could result in the release of tannin leachate. Cleared vegetation would be mulched and could result in the release of tannin leachate which can cause dark coloured water to be discharged into downstream waterways altering the instream pH and reducing visibility and light penetration. Tannins can also increase the biochemical oxygen demand (BOD) in the waterway which can decrease instream dissolved oxygen concentrations which can impact on aquatic ecosystems.

The initial risk likelihood of this impact pathway is considered to be 'Likely' and the consequence 'Minor'.

5.2.1.2.3 Construction works could result in the release of oils and fuels, accidental release of concrete waste and dust and litter into downstream waterbodies, leading to water quality unsuitable for aquatic species

Toxic substances can have both lethal and sublethal effects (e.g., changed physiology, reproduction and behaviour) on aquatic biota that can occur as a result of both acute (short-term) and chronic (long-term) exposure (Weis, 2014; Ucan-Marin & Dupuis, 2015). Toxicants can also impact aquatic habitat values and lead to reduced dissolved oxygen (Enujiugha & Nwanna, 2004).

There is potential for accidental spills and leaks of various toxic substances (e.g., fuels, oils and hydraulic fluids) during construction. These could include spills while refuelling, leaky and unmaintained equipment or plant, and failure of storage containers. These spills could result in the result in the release of hydrocarbons and other toxic substances into Billabong Creek then flow into aquatic ecosystems and impact aquatic biota and habitats and could affect waterway users. It should be noted that the construction sites are not large, and the various proposed elements of construction mean the amount of toxic substances that would be used at any given time is not expected to be large.

Concrete works which would be required for the construction of the new structure could result in concrete dust, concrete slurries or washout water entering downstream waters. Concrete by-products can be extremely alkaline, with a pH as much as 12, and therefore have the potential to alter the pH of the receiving water which can be harmful to aquatic life that are sensitive to changes in water quality. Additionally, concrete washout water contains high levels of chromium that can accumulate in the gills and intestines of fish.

Dust and litter could be generated from a variety of sources during the construction of the proposal including materials transport, stockpiling, concrete works, demolition of existing structures, rock crushing and use of construction sites impacting on the water quality of Billabong Creek. Mobilisation of litter and waste to the waterway could introduce gross pollutant, heavy metals and hydrocarbons into the waterway which could be harmful to aquatic life and reduce the visual amenity.

The initial risk likelihood of this impact pathway is considered to be ‘Possible’ and the consequence ‘Minor’.

5.2.1.2.4 Dewatering of the area could impact on surface water quality

Dewatering of the area within the cofferdams would be required to provide a dry worksite. Dewatering discharge could result in discharge of highly turbid water which could impact on visual amenity and aquatic ecosystems.

For the proposed Hartwood regulator there will be no effect on groundwater as the base of the structure and likely excavation depths are above the recorded groundwater level at the site. For the proposed Wanganella regulator, groundwater drawdown in the vicinity of the construction area will be limited to a maximum of approximately 0.5m with a peak possible radius of influence of 250m and a likely maximum discernible radius of effect of less than 50 m. The expected rate of dewatering is less than 0.2L/s.

Water pumped out of the construction areas would be discharged downstream of the construction area but upstream of the silt curtain to manage sedimentation. Residual water (due to rain events or groundwater intrusion) would be directed into temporary sumps which would be installed to manage the ingress of water.

The initial risk likelihood of this impact pathway is considered to be ‘Possible’ and the consequence ‘Minor’.

5.2.1.2.5 Construction works result in the disturbance of saline soils

Hydrogeological Landscape (HGL) boundaries and descriptions (NSW DCCEEW, 2024b) indicate moderate/high hazard for adjacent land salinity at Wanganella and Hartwood, and therefore saline soils have the potential to occur within the construction footprint. Saline soils may become exposed, erode or leach salt into runoff and subsequently to Billabong Creek, altering the salinity of the water which can alter instream biodiversity and ecosystem function. Saline soils would be disturbed as a result of earthworks and piling.

The initial risk likelihood of this impact pathway is considered to be ‘Possible’ and the consequence ‘Negligible’.

5.2.1.2.6 Mobilisation of sediment deposited behind the existing weir walls

The proposed removal of the existing Hartwood and Wanganella weir structures may lead to the resuspension of deposited sediment which would lead to an increase in turbidity downstream. As discussed in **Section 5.2.1.2.1**, mobilisation of sediments has the potential to result in harm to native species that are unable to tolerate changes to water quality. That said, the most substantial impacts occur from chronic sediment impacts (elevated sediment that occur over many days or weeks) rather than short, sharp impact as would be expected following the removal of the weirs (see review in Shelley *et al.,* 2023).

The Geomorphology specialist report (Jacobs, 2024b) found there is little difference in bed invert levels upstream and downstream of either existing weir, and therefore it is considered unlikely that there is significant sedimentation in channel upstream of weir. In addition, although it has been estimated that $20m^3$ and $30m^3$ of silt may have to be removed at the existing Hartwood and Wanganella weirs respectively during demolition, these works would occur within the dry work area within the cofferdam. It is therefore unlikely that the removal of the weir will lead to the suspension and transport of sediment deposited behind the existing weirs during their removal.

The initial risk likelihood of this impact pathway is considered to be 'Unlikely' and the consequence 'Negligible'.

5.2.1.3 Spread of weeds, pest species or pathogens

This section details potential effects to aquatic habitat and individuals from the introduction of weeds, pest species, or pathogens. It relates to the following effect pathways, identified in below:

- Construction activities lead to introduction of weeds or noxious species that become established in aquatic habitats, leading to conditions unsuitable for existing species.
- Construction activities lead to introduction of pathogens which directly impact existing species.

5.2.1.3.1 Construction activities lead to introduction of weeds or noxious species that become established in aquatic habitats, leading to conditions unsuitable for existing species

Invasive aquatic plants can cause severe impacts to waterways by blocking channels, restricting flows, increasing silt accumulation, degrade water quality, exacerbate flooding, and altering instream habitat (Cherry & Bosse, 2014). In addition, aquatic weed species which form dense infestations can reduce the diversity of native aquatic flora and reduce other forms of macrohabitat, which can lead to secondary impacts on aquatic invertebrates and fish (van Oosterhout, 2009; Perna *et al.*, 2012). The DPI – NSW WeedWise identifies 20 priority aquatic weed species in the Murray and Riverina regions (NSWDPI, 2022c). These weeds are those that could cause a serious negative impact on agriculture or the environment.

Invasive weeds (terrestrial and riparian) in the study area are considered in the Terrestrial Ecology section of the EIS. Aquatic weeds were characterised by a desktop assessment of database and publication records, the results of a survey of the study area conducted by NSW DPI (2024) and complimented by observations during the aquatic habitat assessments detailed in this report.

Across the study area, one specimen of priority aquatic weed species Sagittaria (*Sagittaria platyphylla*) was observed in the reach between Hartwood Weir and lower Woolshed Weir by NSW DPI (2024). No other weed species were identified, and none were observed in the construction footprint. Based on these findings the risk of spread out of the construction footprint is considered low. However, there is the potential that aquatic weeds could be introduced to the proposal footprint on machinery.

The initial risk likelihood of this impact pathway is considered to be 'Possible' and the consequence 'Minor'.

5.2.1.3.2 Construction activities lead to introduction of pathogens which directly impact existing species

Pathogens include bacterium, viruses or other microorganism that may cause illness or death. In the Murray Darling Basin, the most significant introduced pathogenic threat to aquatic communities is from Epizootic Haematopoietic Necrosis Virus (EHNV) (NSW DPIE, 2021a). Although primarily know to affect Redfin Perch and Rainbow Trout, laboratory trials indicate that it has the potential to negatively impact native fish species, including Murray-Darling Rainbowfish, Freshwater Catfish, Silver Perch, Murray Cod, Golden Perch, and Silver Perch which are found in the study area (NSW DPIE, 2021a). EHNV has been documented in the upper Murrumbidgee catchment in NSW, the Broken River catchment in Victoria and the lower Murray Darling catchment in South Australia. Any construction activity within streams which uses equipment or vehicles that have come into contact with freshwater systems where the virus is present, have the potential to transfer the virus to native fish within the study area. That said, control measures have been proposed to minimise the risk of this happening (NSW DPIE, 2021b).

The initial risk likelihood of this impact pathway is considered to be 'Unlikely' and the consequence 'Moderate'.

5.2.1.4 Impacts to Groundwater Dependent Ecosystems

As stated in Section 4.8, four potential aquatic GDEs are identified within 500m of the existing Wanganella weir, with two within 100m, and two aquatic GDEs are identified within 500m of the existing Hartwood weir, both of which are within 100m.

As identified in the Groundwater Assessment (Jacobs, 2024c) during construction for the proposed Hartwood regulator there will be no effect on groundwater as the base of the structure and likely excavation depths are above the recorded groundwater level at the site. For the proposed Wanganella regulator, groundwater drawdown in the vicinity of the construction area will be limited to a maximum of approximately 0.5m with a peak possible radius of influence of 250m and a likely maximum discernible radius of effect of less than 50m. The expected rate of dewatering is less than 0.2L/s.

The potential effect of the groundwater drawdown are considered 'unlikely' to impact aquatic GDEs in the vicinity of the proposed Wanganella regulator during construction and would have an 'Negligible' effect.

5.2.1.5 Waterfront land

As described in **Section 1.5**, construction of the new regulators at Hartwood and Wanganella weirs would require works within Billabong Creek a ninth order Strahler stream that is classified as waterfront land under the WM Act. Billabong Creek at the proposed location is a deep wide channel with stable banks. Works would involve demolition of existing weir (in stages), establishment of a temporary cofferdam, dewatering and reshaping of creek bed. During construction, flow would be maintained throughout the creek and scour protection measures would be implemented. Construction works would not impact on the bankful level (ie water level, or stage, at which a waterway is at the top of its banks and any further rise would result in water moving into the floodplain.

Whilst a controlled activity approval is not required, the design and construction activities within the watercourse and waterfront land has considered the need to maintain flow and protect water quality, stream ecology and existing riparian vegetation.

5.2.1.6 Direct impacts to aquatic habitat or species

Direct impact to aquatic habitat or species relates to the physical impact of construction activities on animals and their habitat. The following effect pathways are discussed under this category:

- Construction of infrastructure within a waterway requires a cofferdam and pumping of water, which results in accidental mortality of aquatic species within the construction site
- Construction of infrastructure and rock-beaching causes bank disturbance resulting in loss of habitat
- Construction of infrastructure in or adjacent to waterways leads to removal of large woody habitat and a loss of structural habitat for aquatic species
- Injury or death of individuals through construction activities.

5.2.1.6.1 Construction of infrastructure within a waterway requires a cofferdam and pumping of water, which results in accidental mortality of aquatic species within the construction site

During the construction of the cofferdams, there is potential for aquatic fauna to become trapped within the structure. This may also happen later if the structure is overtopped during a high flow event. In either case, when the water within the cofferdam is pumped out to create a dry worksite, any trapped animals become stranded. As water is pumped in and out of the cofferdam at the start and end of its use, it is also possible that animals would be sucked into the pumps leading to mortality.

It is unlikely turtles, rakali, platypus and large fish such as Murray Cod, Silver Perch, and Freshwater Catfish would become trapped during initial construction of the cofferdam as they are highly mobile and would be expected to avoid the construction area. Smaller fish species and juveniles are more likely to become entrapped. It is also unlikely that the flows required to overtop the cofferdam would happen regularly, if at all, given that flooding in Billabong Creek is uncommon (see *Billabong Creek Regulators Hydrology Assessment* (Jacobs, 2024a) Report) and particularly limited in the middle reaches due to the regulated nature of the system.

The initial risk likelihood of this impact pathway is considered 'Likely' and the consequence 'Negligible'.

5.2.1.6.2 Construction of infrastructure and rock-beaching causes bank disturbance resulting in loss of habitat

The construction of infrastructure for this proposal would impact on habitat on the riverbank and adjacent land where crane pads, site compounds and access roads would be constructed. Freshwater turtles, of which three species occur in the study area (i.e. have been observed in lower Billabong Creek), dig nests in the riverbank and up to several hundred meters away (Cann & Sadlier, 2017). Furthermore, Rakali dig burrows in riverbanks for the purpose of resting, breeding, and feeding (Scott & Grant, 1997). Therefore, there is a risk that construction activities and the completed structures would reduce access to these sites. Given that the construction footprint and the footprint of the completed regulators is small relative to the accessible nesting and burrowing habitat available more broadly throughout the Yanco Creek System, this is considered to be a minor concern. Destruction of existing nest sites during construction poses a risk in itself, which is discussed in **Section 5.2.1.6.4**.

The initial risk likelihood of this impact pathway is considered to be 'Possible' and the consequence 'Negligible'.

5.2.1.6.3 Construction of infrastructure in or adjacent to waterway corridor leads to removal of large woody habitat due to adjacent land or in-channel disturbance, leading to a loss of structural habitat for aquatic species

Large snags (> 3m length or 30cm in width), and many smaller snags were observed at the site during the aquatic habitat assessment. Furthermore, a detailed survey of large woody habitat and root balls across the broader study area found that it was relatively abundant and available to fish under most flow conditions, and this is unlikely to be lessened by the proposal (NSW DPI, 2024).

During construction of infrastructure, snags and woody debris may be removed if they interfere with works resulting in the loss of structural habitat for aquatic species. Other aspects of aquatic habitat (e.g. aquatic plants) may also be impacted, but the instream construction footprints are small and many large snags were observed in each of the weir pools, so the impact is considered negligible and isn't discussed further.

The initial risk likelihood of this impact pathway is considered to be 'Likely' and the consequence 'Negligible'.

5.2.1.6.4 Injury or death of fauna through construction activities

Freshwater turtles dig nests in the riverbank and up to several hundred meters away over the late-Spring to Summer period (Cann & Sadlier, 2017). The incubation period can last up to 150 days in the Eastern long-neck turtle, with juveniles hatching up until April (Kennet & Georges, 1990). Rakali also dig burrows in riverbanks for the purpose of resting, breeding, and feeding and may be found there year-round (Scott & Grant, 1997). Therefore, there is a risk that construction activities, that predominantly occur within a few hundred meters of the river, may directly impact on these species by crushing nests and burrows.

Further to this, adult turtles, and Rakali may be directly or indirectly injured from vehicle strikes. That said, older, mobile individuals are likely to avoid the noisy and disturbed construction area in most cases during the daytime. As the construction footprints are small, and the road access necessitates a slow vehicle speed, the likelihood of such impacts in the context of the proposal is unlikely.

The initial risk likelihood of this impact pathway is considered to be ‘Possible’ and the consequence ‘Negligible’.

5.2.1.6.5 Construction increases terrestrial predator abundance (e.g. feral cat, wild dog, and Red Fox) leading to greater predation pressure on freshwater turtles, Platypus, and Rakura

As freshwater turtles and Rakali are semi-aquatic and at least part of their lifecycle occurs on land, they are susceptible to predation by terrestrial predators. The Red Fox (*Vulpes vulpes*), Domestic Cat (*Felis catus*), and Domestic Dog (*Canis familiaris*) are three such predators which predate heavily on these semi-aquatic native species (Grant, 2003; Stobo-Wilson *et al.,* 2021). Both the Domestic Cat and Red Fox and are listed as Key Threatening Processes under the EPBC Act 1999. Rakali are among the mammals most often consumed by Red Fox (Stobo-Wilson *et al.,* 2021). Furthermore, predation of freshwater turtle eggs can lead to greater than 90% mortality in some areas (Cann and Sadlier, 2017).

There is potential for the abundance of these terrestrial predators to increase as a result of construction activities, as litter around the construction sites may increase food availability. There may also be increased ability and/or incentive to access the stream due to the construction of vehicle tracks. As almost all proposed access tracks and infrastructure are located in already heavily disturbed areas (e.g., along existing tracks, close to existing infrastructure) the proposal is unlikely to increase access across the study area. If general construction site hygiene rules are followed, there would not be an increase in food to attract terrestrial predators.

With this in mind, the risk likelihood of increased predation of turtles and Rakali by terrestrial predators is considered ‘Unlikely’ and the consequence ‘Minor’.

5.2.2 Operation

Potential effects to ecological values during the operation phase are expected to be associated with the following broad effect pathways.

- Loss of connectivity and impeded passage for native aquatic species
- Degradation of aquatic habitat through water quality or water regime changes
- Spread of weeds, pest species or pathogens
- Direct impacts to aquatic habitat or species.

In the same way as **Section 5.2.1**, each of these effect pathway categories is considered in detail, with an initial risk likelihood rating and a consequence rating provided for the effect.

5.2.2.1 Loss of connectivity and impeded passage for native aquatic species

This section details potential effects to aquatic fauna due to impeded passage during operation of the proposal. The following effect pathways are discussed under this category:

- The new regulators and fishways do not allow for effective fish passage in an upstream direction
- Fish passage through the new regulators and fishways declines over time
- Operation of proposal leads to fragmentation of habitat for aquatic fauna (e.g. turtles and Rakali).

5.2.2.1.1 The new regulator does not allow for fish passage and an upstream and/or downstream direction

The ability of fish to move past regulators and other barriers is dependent on the design of the structure and the biology of the species. Broadly speaking, swimming ability increases with body size, with smaller animals being the weakest swimmers (Cooper *et al.*, 2017). Also, larger fish need deeper water to navigate through than smaller fish, which can also be limiting (Reinfelds *et al.*, 2020). For a regulator to provide effective passage for aquatic species, it must be designed in such a way that considers the swimming ability of all species and size classes in the area.

The existing Hartwood and Wanganella weirs, along with other existing instream structures, have been determined to be effective barriers to fish passage within mid and lower Billabong Creek by DPI Fisheries (according to their unpublish fish passage database) during most flow conditions. That said, upstream and downstream migration could occur over the structures when they are overtopped in high flow events.

The proposed Hartwood and Wanganella regulators will include layflat gates and a plunge pool of >1m to facilitate safe passive downstream passage of native fish species, but the velocities through the regulator gates are predicted to exceed the sustained swimming capability of both small and large bodied native fish species.

The proposed fishways for both Hartwood and Wanganella have been designed to allow for effective upstream passage of native fish from 30mm (small bodied) to 850mm (large bodied) – this being representative of the local native fish fauna such as Australian Smelt (small bodied) and adult Murray Cod (large bodied). Their design ensures they will operate effectively up to the flows at which the fixed crest section of the regulator is drowned out.

The ecology and physiological requirements of the local native fish community were considered in the Yanco Creek fish movement model (Stuart, 2022), which were incorporated into the design of the Hartwood and Wanganella fishways. The fishway designs were informed by computational fluid dynamic (CFD) and physical modelling to ensure that the flow hydraulics are suitable for the fish community. Fishway design was done in consultation with NSW Fisheries representatives and using fishway expert and fish ecologist Dr Ivor Stuart to advise.

Based on the above, the initial risk likelihood of this impact pathway is considered to be 'Rare' and the consequence 'Negligible'.

5.2.2.1.2 Effectiveness of fish passage through the regulators and fishways declines over time

As discussed above, upstream fish passage past the existing Hartwood and Wanganella weirs is currently restricted during most flow conditions – upstream and downstream migration could occur over the weirs when they are overtopped.

The effectiveness of fish passage past the proposed regulators and fishways for Hartwood and Wanganella could decline over time if they are not appropriately maintained. For instance, build-up of silt and/or debris at the regulator gates or fishway entrance and exit can impact on accessibility and flow dynamics, and fish passage may subsequently be impacted.

The first point to note is that the fishways are designed to minimise the attraction and intake of debris into the structure. The key design features in this respect include:

- A 2.0m wide x 3.56m high trash screen is placed at the entry/exit gates at the top of the structure that act to deflect debris that may enter the shoot. The slots of the trash screen are 180 mm wide across the top ~2/3rds of the screen which matches the slot widths inside the fishway, so any debris that is sucked in should be able to pass right through the fishway.
- The upstream and downstream entry/exit gates are orientated parallel to the flow of the river so that debris is more likely to flow past the structure.
- A small protruding baffle (referred to as a “knife edge plate”) is placed immediately upstream of the entry/exit gates which acts to divert flow (and debris) away from the gates.
- The fishways are designed in such a way that the water velocity entering and travelling through the fishway is much less that the river flow velocity, so debris isn’t attracted into the structure.
- When the fishway is being operated within the proposed operating levels considerable depth is maintained within the structure, so small amounts of debris that may make it into the fishway are unlikely to fully block fish passage through the slots.

Despite these best efforts, it is still likely that some debris, particularly floating aquatic plant matter, will enter the structure and it may impact on fish passage if the debris is left to build up. With that in mind, an operations manager will be tasked with ongoing operation and general maintenance of the fishway which is designed in such a way that the operator will be able to remove most debris that accumulates on the trash screen or the baffles/gates inside the structure. For more substantial and less frequent maintenance tasks related to the baffles and gates, Isolation dropboards and guides are provided on the outside (upstream) face of the common exit slot which will enable the isolation and dewatering of the fishway. Operation and Maintenance manuals for the fishways are to be produced if the proposal proceeds to development.

Finally, to aid in monitoring of fish passage effectiveness, fish traps and Passive Integrated Transponder (PIT) tag monitoring stations will be located at the entry and exit points to facilitate monitoring efforts.

Bearing this in mind, the initial risk likelihood of this impact pathway is considered to be ‘unlikely’ and the consequence ‘minor’.

5.2.2.1.3 Operation of proposal leads to fragmentation of terrestrial habitat for turtles and Rakali

While species such as Murray River Turtles and Broad-shelled Turtles show a preference for remaining in the water and rarely undergo terrestrial migration (Baggiano, 2012), they are still capable of travelling hundreds of meters overland which would be sufficient to circumvent the regulators if conditions required it (Cann & Sadlier, 2017). This would increase susceptibility to predation from terrestrial animals such as foxes, but no more than under current conditions (Grant & Temple-Smith, 2003).

Turtles would be able to use the fishways, however, the slots are key-holed and the turtle would need to fit the slot widths. The lower slot is 275 mm wide, and the upper slot is 150 mm wide. During high flow events, turtles may swim upstream through wider slot openings at the top of the slots, or swim over the submerged fixed weir crest. Swimming through the open regulator gates is unlikely given predicted high velocities through the gates. Taken as a whole, some size-dependant upstream movement of turtles will be facilitated by the fishways, while larger individuals would have to walk around the structure. This would mark an improvement from current conditions, where upstream movement would be largely restricted to overland pathways.

The proposed regulators would likely present a barrier to Rakali passage, but no more than the current weirs. There are no plans to change the slope or height of the riverbanks near the structure, so the potential for overland passage for these species would be similar.

The initial risk likelihood of this impact pathway is considered to be 'unlikely' and the consequence 'negligible'.

5.2.2.2 Degradation of aquatic habitat through water regime or water quality changes

This section details potential effects to aquatic biodiversity values due to water quality or water regime changes during operation of the proposed regulators. The following effect pathways were assessed:

- Operation of proposal leads to alteration to the natural flow regimes of rivers and streams, leading to conditions unsuitable for aquatic species.
- Spillage or leaks of toxic substances or litter during maintenance of infrastructure enters waterbodies, leading to water quality unsuitable for aquatic species.
- Operation of the regulator leads to increased erosion and sedimentation which impacts on water quality and subsequently, aquatic communities.
- The regulator and semi-permanent sediment control measures degrade leading to increased erosion and sediment input into the stream network.

5.2.2.2.1 Operation of proposal leads to alteration to the natural flow regimes of rivers and streams, leading to conditions unsuitable for native aquatic species

Over time a single river can consistently provide ephemeral, seasonal, and persistent types of habitats that range from flowing, to standing water, to dry conditions. This diversity of in-channel and floodplain habitat types has promoted the evolution of aquatic communities that exploit the habitat mosaic created and maintained by flow variability. For many aquatic species, completion of their life-history requires an array of different habitat types whose availability over time is regulated by the prevailing flow regime. It follows that changes to the natural velocity, volume, timing, and frequency of flows in a river system would impact on the resident aquatic communities.

With this in mind the potential impacts of the operation of the proposed Hartwood and Wanganella regulators for the proposal has been assessed based on modelled changes in (1) the hydraulic and (2) the hydrological regimes within the proposal study area. It's noted that this section focusses on the impacts of Hartwood and Wanganella Regulators independent of other SDLAM projects in the Yanco System, while the cumulative effects of each of the relevant projects are addressed in **Section 5.3.**

Summary of hydraulic modelling findings

Modelling presented in the *Yanco Creek Modernisation: Hydraulic Modelling Technical Report – Picaninny Weir to Wanganella Weir Study Area* (3Rivers, 2024a) and *Yanco Creek Modernisation: Hydraulic Modelling Technical Report – Hartwood Weir to Picaninny Weir Study Area* (3Rivers, 2024b) helps to describe the change in the hydraulic nature of fish habitat between the base and change case scenarios, in particular changes in water velocity and water level. As such, we use these results as context for this assessment. Before interpreting the results, it is important to recognise that the hydraulic modelling accounted for several flow and operational levels and that the study area was different to that assessed here. With this in mind, it is noted that this assessment of the hydraulic modelling results focuses on:

- Results related to the Hartwood and Wanganella weir pools and immediately downstream habitats on Billabong Creek as they are directly relevant to this assessment;
- Maximum and minimum (i.e. minimum environmental base flow requirements) operational flows (as provided by WaterNSW), but not flood flows, as operational flows represent typical conditions experienced by the aquatic communities;
- Results related to flow and velocity as they best describe changes in fish habitat; and
- Minimum, maximum, and normal operating levels of the weir pools and the different target flow rates under the proposed operating plans as these scenarios provide an upper and lower limit for effects.

To summarise, the assessment looks at changes in hydraulic habitat for fish in and just below the proposed weir pools during the lowest expected operational flow and water level conditions, and the highest, thus providing lower and upper boundaries around the expected changes. A summary of the velocity characteristics at Hartwood and Wanganella Weirs in the Base Case and Change Case scenarios, and how they relate to fish habitat categories, are presented in **Table 5-1** to **Table 5-8**.

Of the operational level and flow settings modelled for the change case, the weir pools would be most commonly operated between the minimum and normal operating limit (NSW DPIE, 2022a; Jacobs, 2024a). An important consideration is that while operation levels and flow settings may fluctuate (in the Change Case), weir pool operations between the normal operating limit and the full supply level would be minimised to limit the risk of adverse environmental outcomes that result from having a deeper weir pool with slower flow that also submerges more edge habitat more often. It is noted that the exact rules that would be followed to ensure this are not yet specified.

Hartwood Regulator – Maximum operating flow

At Hartwood Regulator during maximum operating flow (500 ML/day), at the normal operating limit (95.44), it is expected that there would be a decrease in lentic habitats such as backwaters (11%), weir pools (16%), and slow flowing pool habitat (2%) relative to the Base Case. Moderate-flowing, lotic habitat is expected to increase substantially across all categories (56-83%). Fast flowing, high-quality lotic habitat is expected to experience minor decreases across each category (1-7%), although, very fast flowing, high-quality habitat is predicted to increase more substantially (13%). Overall, this represents a 9% decrease in lentic habitat, a 56% increase in moderate flowing lotic habitat, and a 3% increase in high-quality lotic habitat.

At the minimum operating level (95.28m AHD) the pattern of velocity habitat loss and gain is the same as for the normal operating limit. It is expected that there would be a decrease in lentic habitats such as backwaters (32%), weir pools (33%), and slow flowing pool habitat (13%), while moderate flowing habitat is projected to increase substantially across all categories (139-231%). Fast and very fast-flowing, high-quality habitat is expected to increase overall, despite relatively small reductions in some velocity categories. Overall, a 25% decrease in lotic habitat, a 146% increase in moderate flowing lotic habitat, and a 16% increase in high-quality lotic habitat is expected.

At the full supply level (95.74) it is expected that there would be an increase in lotic habitats such as backwaters (17%) and weir pools (25%) due to the greater depth of the weir pool. On the other hand, decreases are expected in slow flowing pool habitat (9%), and the moderate flowing habitat categories (44-59%). The results for high quality flow habitat are mixed, but an overall 6% decrease in such habitat is expected. To summarise, at the full supply level it is predicted that there would be a 10% increase in lotic habitat, a 45% decrease in moderate flowing lotic habitat, and a 6% decrease in high-quality lotic habitat.

Table 5-1 Velocity Characteristics Comparison Hartwood hydraulic modelling area at the maximum operating flow and each operating level (Full Supply Level, Normal Operating Level, Minimum Operating Level AHD)

Fish Habitat Description (Stuart, 2022)	Water Velocity (m/s)	Quality of habitat (Mallen-Cooper & Zampatti, 2018)	Area within category (m^2)						
			Base Case	Change Case					
				Full Supply Level (95.74)	Change (%)	Normal Operating Limit (95.44)	Change (%)	Minimum Operating Limit (95.28)	Change (%)
Backwater	0 – 0.05	Pool habitat (lentic)	349903	408099	**17**	312709	**-11**	237679	**-32**
Weir pool	0.05 – 0.10	Pool habitat (lentic)	264415	331479	**25**	221951	**-16**	176863	**-33**
Slow flowing	0.10 – 0.15	Slow-moving pool habitat (lentic)	356582	324532	**-9**	348214	**-2**	308814	**-13**
Moderate flowing	0.15 – 0.20	Below the threshold to maintain flowing (lotic) habitats	83939	46653	**-44**	130741	**56**	200438	**139**
Moderate flowing	0.20 – 0.25	Minimum to maintain flowing (lotic) refugia	8148	4419	**-46**	12728	**56**	25361	**211**
Moderate flowing	0.25 – 0.30	Medium quality flowing (lotic) habitat	1146	474	**-59**	2098	**83**	3794	**231**
Fast flowing	0.30- 0.35	High quality flowing (lotic) habitat	316	340	**8**	304	**-4**	496	**57**
Fast flowing	0.35 -0.40	High quality flowing (lotic) habitat	300	316	**5**	296	**-1**	294	**-2**

Fish Habitat Description (Stuart, 2022)	Water Velocity (m/s)	Quality of habitat (Mallen-Cooper & Zampatti, 2018)	Area within category (m^2)						
			Base Case	Change Case					
				Full Supply Level (95.74)	Change (%)	Normal Operating Limit (95.44)	Change (%)	Minimum Operating Limit (95.28)	Change (%)
Fast flowing	0.40 – 0.45	High quality flowing (lotic) habitat	269	287	**7**	262	**-3**	248	**-8**
Fast flowing	0.45 – 0.50	High quality flowing (lotic) habitat	272	217	**-20**	252	**-7**	250	**-8**
Very fast flowing	>0.50	High quality flowing (lotic) habitat	872	751	**-14**	985	**13**	1063	**22**
Total Area (m^2)			1066162	1117567	**5**	1030540	**-3**	955300	**-10**

Table 5-2 Summary of velocity classes from Table 5-1 into broad habitat quality categories in the Hartwood hydraulic modelling area at the maximum operating flow and each operating level (Full Supply Level, Normal Operating Level, Minimum Operating Level AHD)

Broad habitat quality class	Existing	Fully Supply	Maximum Operating level	Minimum Operating level
Lentic (low quality)	970,900	1,064,110	882,874	723,356
Moderate flow lotic (marginal and moderate quality)	93,233	51,546	145,567	229,593
Fast and very fast flow lotic (high quality)	2,029	1,911	2,099	2,351
Total	1,066,162	1,117,567	1,030,540	955,300

Hartwood Regulator – Minimum operating flow

At Hartwood Regulator during minimum operating flow (25 ML/day) and at the normal operating level (95.44), relative to the Base Case, it is expected that there would be an increase in backwater habitat (11%), but a decrease in other lentic habitats such weir pools (66%), and slow flowing pool habitat (64%). Moderate-flowing, lotic habitat is expected to decrease substantially across all categories (23-28%). Fast flowing, high-quality lotic habitat is expected to experience substantial decreases across each category (9-26%), and very fast flowing, high-quality habitat is also predicted to decline slightly (4%). Overall, this represents a 10% increase in lotic habitat, a 25% decrease in moderate flowing lotic habitat, and a 19% decrease in high-quality lotic habitat.

At the minimum operating limit (95.28) very little change in the distribution of velocity habitat is expected relative to the Base Case. The most substantial change predicted is a 62% decrease in slow-moving pool habitat, while all other categories changed by -2% to +3%. Overall, the results indicated a 2% decrease in lotic habitat, a 3% increase in moderate flowing lotic habitat, and high-quality lotic habitat would be effectively unchanged.

At the full supply level (95.74) it is expected that there would be an increase in backwater habitat (32%) and, at the other end of the spectrum, very fast flowing, high-quality habitat (31%). All other velocity categories projected substantial declines relative to existing conditions ranging between 23-86%. Overall, the results suggest there would be a 32% increase in lentic habitat, a 37% decrease in moderate flowing lotic habitat, and a 61% decrease in high-quality lotic habitat.

Table 5-3 Velocity Characteristics Comparison Hartwood hydraulic modelling area at the minimum operating flow and each operating level (Full Supply Level, Normal Operating Level, Minimum Operating Level). Operating levels are those presented in the hydraulic modelling results.

Fish Habitat Description (Stuart, 2022)	Water Velocity (m/s)	Quality of habitat (Mallen-Cooper & Zampatti, 2018)	Area within category (m^2)						
			Base Case	Change Case					
				Full Supply Level (95.74)	Change (%)	Normal Operating Limit (95.44)	Change (%)	Minimum Operating Limit (95.28)	Change (%)
Backwaters	0 – 0.05	Pool habitat (lentic)	813960	1075088	**32**	899879	**11**	802238	**-1**
Weir pool	0.05 – 0.10	Pool habitat (lentic)	2602	598	**-77**	897	**-66**	2659	**2**
Slow flowing	0.10 – 0.15	Slow-moving pool habitat (lentic)	1538	539	**-65**	551	**-64**	581	**-62**
Moderate flowing	0.15 – 0.20	Below the threshold to maintain flowing (lotic) habitats	579	443	**-23**	445	**-23**	599	**3**
Moderate flowing	0.20 – 0.25	Minimum to maintain flowing (lotic) refugia	579	378	**-35**	437	**-25**	592	**2**
Moderate flowing	0.25 – 0.30	Medium quality flowing (lotic) habitat	435	182	**-58**	314	**-28**	447	**3**
Fast flowing	0.30- 0.35	High quality flowing (lotic) habitat	290	89	**-69**	214	**-26**	289	**0**
Fast flowing	0.35 -0.40	High quality flowing (lotic) habitat	262	114	**-56**	206	**-21**	264	**1**
Fast flowing	0.40 – 0.45	High quality flowing (lotic) habitat	204	104	**-49**	160	**-22**	206	**1**

Fish Habitat Description (Stuart, 2022)	Water Velocity (m/s)	Quality of habitat (Mallen-Cooper & Zampatti, 2018)	Area within category (m^2)						
			Base Case	Change Case					
				Full Supply Level (95.74)	Change (%)	Normal Operating Limit (95.44)	Change (%)	Minimum Operating Limit (95.28)	Change (%)
Fast flowing	0.45 – 0.50	High quality flowing (lotic) habitat	118	61	**-48**	107	**-9**	117	**-1**
Very fast flowing	>0.50	High quality flowing (lotic) habitat	113	16	**-86**	109	**-4**	114	**1**
		Total Area (m^2)	820680	1077612	**31**	903319	**10**	808106	**-2**

Table 5-4 Summary of velocity classes from Table 5-3 into broad habitat quality categories in the Hartwood hydraulic modelling area at the minimum operating flow and each operating level (Full Supply Level, Normal Operating Level, Minimum Operating Level AHD)

Broad habitat quality category	Existing	Fully Supply	Maximum Operating level	Minimum Operating level
Lentic (low quality)	818100	1076225	901327	805478
Moderate flow lotic (marginal and moderate quality)	1593	1003	1196	1638
Fast and very fast flow lotic (high quality)	987	384	796	990
Total	820680	1077612	903319	808106

Wanganella Regulator – Maximum operating flow

At Wanganella Weir during maximum operating flow (400 ML/day), at the normal operating limit (80.54), the results indicate there would be little change in the distribution of velocity defined habitat, with negligible changes (<1%) in lotic, moderate flowing, and fast flowing lotic habitat overall.

Similarly, at the minimum operating limit (80.20), negligible overall changes (<1%) were predicted for lotic, moderate flowing, and fast flowing lotic habitat.

Conversely, at full supply level (81.65) the results indicate there would be increases in every category. In particular, very large increases in backwater (440%) and weir pool habitat (229%) are predicted. Overall, the results suggest a 119% increase in lotic habitat, a 30% increase in moderate flowing lotic habitat, and a 12% increase in high-quality lotic habitat.

Table 5-5 Velocity Characteristics Comparison Wanganella hydraulic modelling area at the maximum operating flow and each operating level (Full Supply Level, Normal Operating Level, Minimum Operating Level). Operating levels are those presented in the hydraulic modelling results.

Fish Habitat Description (Stuart, 2022)	Water Velocity (m/s)	Quality of habitat (Mallen-Cooper & Zampatti, 2018)	Area within category (m^2)						
			Base Case	Change Case					
				Full Supply Level (81.65)	Change (%)	Normal Operating Limit (80.95)	Change (%)	Minimum Operating Limit (80.71)	Change (%)
Backwaters	0 – 0.05	Pool habitat (lentic)	2965	16006	**440**	2970	**0**	2963	**0**
Weir pool	0.05 – 0.10	Pool habitat (lentic)	8167	26910	**229**	7956	**-3**	7943	**-3**
Slow flowing	0.10 – 0.15	Slow-moving pool habitat (lentic)	28227	43216	**53**	28613	**1**	28516	**1**
Moderate flowing	0.15 – 0.20	Below the threshold to maintain flowing (lotic) habitats.	32106	44460	**38**	31559	**-2**	31606	**-2**
Moderate flowing	0.20 – 0.25	Minimum to maintain flowing (lotic) refugia	40300	51878	**29**	40177	**0**	40158	**0**
Moderate flowing	0.25 – 0.30	Medium quality flowing (lotic) habitat	40798	50379	**23**	41390	**1**	41374	**1**
Fast flowing	0.30- 0.35	High quality flowing (lotic) habitat	41524	47982	**16**	41483	**0**	41469	**0**

Fish Habitat Description (Stuart, 2022)	Water Velocity (m/s)	Quality of habitat (Mallen-Cooper & Zampatti, 2018)	Area within category (m^2)						
			Base Case	Change Case					
				Full Supply Level (81.65)	Change (%)	Normal Operating Limit (80.95)	Change (%)	Minimum Operating Limit (80.71)	Change (%)
Fast flowing	0.35 -0.40	High quality flowing (lotic) habitat	37931	43146	**14**	37987	**0**	37977	**0**
Fast flowing	0.40 – 0.45	High quality flowing (lotic) habitat	32877	35625	**8**	32832	**0**	32823	**0**
Fast flowing	0.45 – 0.50	High quality flowing (lotic) habitat	26243	29923	**14**	26315	**0**	26305	**0**
Very fast flowing	>0.50	High quality flowing (lotic) habitat	111887	123855	**11**	111931	**0**	111890	**0**
		Total Area (m^2)	403025	513380	**27**	403213	**0**	403024	**0**

Table 5-6 Summary of velocity classes from Table 5-5 into broad habitat quality categories in the Wanganella hydraulic modelling area at the maximum operating flow and each operating level (Full Supply Level, Normal Operating Level, Minimum Operating Level AHD)

Broad habitat quality class	Existing	Fully Supply	Maximum Operating level	Minimum Operating level
Lentic (low quality)	39359	86132	39539	39422
Moderate flow lotic (marginal and moderate quality)	113204	146717	113126	113138
Fast and very fast flow lotic (high quality)	250462	280531	250548	250464
Total	403025	513380	403213	403024

Wanganella Regulator – Minimum operating flow

At Wanganella Weir during minimum operating flow (30 ML/day), at the normal operating limit (80.95), the modelling results suggest there would be modest increases across all categories (4-12%). These changes translate to a 9% increase in lentic habitat, a 6% increase in moderate flowing lotic habitat, and a 7% increase in high-quality lotic habitat.

At the minimum operating limit (80.71), negligible overall changes (<1%) were predicted for lotic, moderate flowing, and fast flowing lotic habitat.

On the other hand, at full supply level (81.65), substantial increases were observed across all categories which resulted in a 117% increase in lentic habitat, 41% increase in moderate flowing lotic habitat, and a 32% increase in fast flowing lotic habitat.

Table 5-7 Velocity Characteristics Comparison Wanganella hydraulic modelling area at the minimum operating flow and each operating level (Full Supply Level, Normal Operating Level, Minimum Operating Level)

Fish Habitat Description (Stuart, 2022)	Water Velocity (m/s)	Quality of habitat (Mallen-Cooper & Zampatti, 2018)	Area within category (m^2)						
			Base Case	Change Case					
				Full Supply Level (95.74)	Change (%)	Normal Operating Limit (95.44)	Change (%)	Minimum Operating Limit (95.28)	Change (%)
Backwaters	0 – 0.05	Pool habitat (lentic)	6948	36789	**429**	7767	**12**	6937	**0**
Weir pool	0.05 – 0.10	Pool habitat (lentic)	23914	49922	**109**	25195	**5**	22924	**-4**
Slow flowing	0.10 – 0.15	Slow-moving pool habitat (lentic)	40055	67496	**69**	44545	**11**	41101	**3**
Moderate flowing	0.15 – 0.20	Below the threshold to maintain flowing (lotic) habitats.	39949	58005	**45**	41705	**4**	39334	**-2**
Moderate flowing	0.20 – 0.25	Minimum to maintain flowing (lotic) refugia	40515	55011	**36**	43220	**7**	40768	**1**
Moderate flowing	0.25 – 0.30	Medium quality flowing (lotic) habitat	31364	44759	**43**	33316	**6**	31496	**0**
Fast flowing	0.30- 0.35	High quality flowing (lotic) habitat	27142	36060	**33**	29448	**8**	27316	**1**
Fast flowing	0.35 - 0.40	High quality flowing (lotic) habitat	23016	29707	**29**	24122	**5**	23036	**0**

Fish Habitat Description (Stuart, 2022)	**Water Velocity (m/s)**		**Quality of habitat (Mallen-Cooper & Zampatti, 2018)**		**Area within category (m^2)**				
			Base Case	**Change Case**					
				Full Supply Level (95.74)	**Change (%)**	**Normal Operating Limit (95.44)**	**Change (%)**	**Minimum Operating Limit (95.28)**	**Change (%)**
Fast flowing	0.40 – 0.45	High quality flowing (lotic) habitat	15309	20248	**32**	16614	**9**	15287	**0**
Fast flowing	0.45 – 0.50	High quality flowing (lotic) habitat	12943	17158	**33**	13746	**6**	13006	**0**
Very fast flowing	>0.50	High quality flowing (lotic) habitat	55441	73679	**33**	59547	**7**	55373	**0**
		Total Area (m^2)	316596	488834	**54**	339225	**7**	316578	**0**

Table 5-8 Summary of velocity classes from Table 5-7 into broad habitat quality categories in the Wanganella hydraulic modelling area at the minimum operating flow and each operating level (Full Supply Level, Normal Operating Level, Minimum Operating Level AHD)

Broad habitat quality class	Existing	Fully Supply	Maximum Operating level	Minimum Operating level
Lentic (low quality)	70917	154207	77507	70962
Moderate flow lotic (marginal and moderate quality)	111828	157775	118241	111598
Fast and very fast flow lotic (high quality)	133851	176852	143477	134018
Total	316596	488834	339225	316578

Hydraulic impact overview

Changes in the hydraulics (flow, water level, velocity) within the Hartwood and Wanganella weir pools are not expected to negatively impact on aquatic communities. At the Hartwood Weir site, when operational flows are at the upper limit (i.e. maximum operating flow), the proposal would likely lead to an increase in moderate and high-quality velocity habitat and a decrease in low-quality lentic habitat more of the time, when the regulator is operated between the minimum and normal operating limits. When operational flows are at the lower limit and the regulator is being operated between the minimum and normal operating limits, all velocity classes are expected to remain relatively similar or decrease relative to the Base Case which is understandable given the overall reduction in the size of the weir pool. Deeper weir pool depths during maximum and minimum operating flows at full supply level are expected to lead to an increase in low-quality lentic habitat and a reduction in moderate and high-quality lotic habitat, although these regulator settings would be minimised to reduce any potential impacts and are not expected to occur often or for long (NSW DPIE, 2022a).

At Wanganella Weir the various settings are expected to either result in no change to the distribution of velocity habitat, or increases in all major types (e.g. lentic, moderate flowing, fast flowing). Importantly, the settings where increases in lentic habitat are expected are planned to be short-term to reduce any negative environmental effects such as overwatering of aquatic plants in the littoral zone of the pool.

Finally, in reality the operating flows will fluctuate between the minimum and maximum limits used for the models and the changes in hydraulic habitat would likely be more benign more of the time.

Overview of hydrological modelling findings

In this section we assess the potential impact of hydrological change on aquatic communities in the context of predicted changes to the flow regime (flow duration, seasonality, variability, and volume) that are described fully in the *Billabong Creek Regulators Hydrology Assessment* (Jacobs, 2024a).

The results of the *Billabong Creek Regulators Hydrology Assessment* Report (Jacobs, 2024a) indicated little change in total flow volumes in the study area. The seasonal pattern of flows was also effectively unchanged, with the most notable changes in monthly flow volumes being declines at sites below Hartwood Regulator between summer and mid-winter (up to 47.2% over summer) and minor increases between late winter and spring (up to 7%).

Differences in daily flows (i.e. flow variability) between the base and change case scenarios was most pronounced during summer and autumn (typically ranging between ±5-20%), with very little change in the prevailing flow variability expected over winter and spring.

Flow duration curves were developed to provide insight into the availability and variability of flow over time. Furthermore, flows were assigned to flow categories defined in the LTWP that serve various ecological functions (i.e. smaller than very low flows, very low flows, baseflows, small and large freshes, wetland connection flows, small and large overbank flows) and comparisons were made between the duration of flows in each flow category between the base and change case scenarios. Overall, the results showed very little change in the duration of flows in the different categories. Most notably, it is predicted that 'smaller than very low flows' would be of lower volume and slightly more common below the proposed Hartwood and Wanganella Regulators.

Hydrological impact overview

Taken as a whole, operation of the new regulators is not expected to change the flow regime in Billabong Creek substantially or in a way that would impact on the resident fish and other aquatic communities. The modelling is based on a considerable flow dataset (126 years) for the study area and the potential impact on aquatic communities is assessed based on a strong understanding of the flow requirements of the most flow sensitive members of the local aquatic community (NSW DPIE, 2020c; NSW DCCEEW, 2024c).

Environmental water requirements (EWRs)

The Murrumbidgee Long Term Water Plan (LTWP) (NSW DPIE 2020b) describes the environmental water requirements (EWRs) (including volume, frequency, timing and duration) needed to sustain and improve the health and/or extent of priority environmental assets such as threatened fish species and ecosystem functions. Furthermore, the Murray-Darling Basin Authority (MDBA) developed an analytical program (i.e. the Environmental Water Requirement (EWR) Tool) to assesses the occurrence of flow conditions over time that meet or partially meet those EWRs (NSW DCCEEW, 2024c).

As part of the *Billabong Creek Regulators Hydrology Assessment* (Jacobs, 2024a) for this EIS, the EWR Tool was applied to two mean daily flow datasets for flow gauge sites in the study area between the town of Jerilderie (upstream of Hartwood Weir) and the location of Darlot (downstream of Wanganella Weir); the 'base case' dataset and 'change case' datasets (see *Billabong Creek Regulators Hydrology Assessment* (Jacobs, 2024a) report for details). The two datasets are defined as follows:

- Base Case – describes current flow conditions with the two existing weirs along Billabong Creek at Hartwood and Wanganella (no new regulators) as well as current operations (before implementation of the proposed Yanco Creek System Operations Plan).
- Change Case – describes flow conditions and how they are potentially impacted by the components of the SDLAM project that are subject to the EIS process, specifically, the replacement of the Hartwood and Wanganella Weirs along Billabong Creek with new reregulation structures and the new operating rules associated with those structures (as described in the Yanco Creek System Operations Plan).

The hydrology assessment adopted a framework to assess the degree of change in EWR attainment when operating under the Base Case, Change Case and Cumulative Change Case scenarios. **Table 5-9** describes the different EWR categories and the respective colour coding for interpretation of results.

The results of the EWR Tool indicated that, very minor changes in the frequency of EWR attainment are expected between the base and change case scenarios (refer **Table 5-10**). The largest increase in the frequency of EWR attainment was 14% and the largest decrease was 4%. Regardless, for the most part, no EWR changed EWR attainment category, with the exception of PU12 and PU11 which due to increased frequency of EWR attainment changed from 'medium' rating under base case to 'low' rating under change case for some EWRs. Higher flows are generally not affected by the new structures as they drown out the weirs.

Table 5-9 Hydrologic alteration and EWR attainment categories adopted for the operational impact assessment (*Modified from Murrumbidgee Water Resource Plan Risk Assessment (DPIE Water, 2019)*)

Rating	Description for hydrologic alteration categories	Description for EWR attainment categories	Colour coding
Low (L)	Less than 20% difference (+/-) in key flow regime characteristics when compared to Base Case scenario conditions	100-80% achievement of required frequency as per the EWRs	Low
Medium (M)	20-50% difference (+/-) in key flow regime characteristics when compared to Base Case scenario conditions	80-50% achievement of required frequency as per the EWRs	Medium
High (H)	More than 50% difference (+/-) from Base Case scenario conditions	< 50% achievement of required frequency as per the EWRs	High
N/A	No risk outcome available	No risk outcome available	N/A

Conclusions regarding the overall impact of projected hydraulic and hydrological change on native aquatic species

Changes in the hydraulics (flow, water level, velocity) within the Hartwood and Wanganella weir pools are not expected to negatively impact on aquatic communities, the flow regime in Billabong Creek is not expected to change substantially or in a way that would impact on the resident fish and other aquatic communities, and very minor changes in the frequency of EWR attainment are predicted. With that in mind the initial risk likelihood of this impact pathway is considered to be 'rare' and the potential consequence is 'moderate'.

Table 5-10 Environmental Water Requirement (EWR) Tool results for Base Case and Change Case scenarios indicating the frequency of EWR attainment. Results are presented as % of years in the input time series (1 July 1895 to 30 June 2022) that an EWR is achieved

EWR	EWR Code	PU12 (Lower Yanco Creek to Lower Billabong Creek)		PU11 (Columbo Creek at Morundah to Billabong Creek upstream of Jerilderie)		PU11 (Billabong Creek at Jerilderie to downstream Hartwood Weir)		PU13 (Lower Billabong and Intersecting Streams)	
		Base	Change	Base	Change	Base	Change	Base	Change
Cease-to-flow	CF1	100	100	100	100	100	99	100	99
Very low flow	VF1_a	100	100	100	100	100	100	100	100
	VF1_b	100	100	100	99	100	99	100	100
Baseflow	BF1_a	32	46	100	100	100	100	100	100
	BF1_b	96	97	100	99	99	99	100	100
Native Fish Nesting Support	NestS1_mc	32	35	61	61			69	76
	NestS1_tcmc	27	28	53	57			57	63
Small fresh (pulse)	SF1_P	76	81	77	86			90	95
	SF1_S	85	88	90	92			92	96
	SF2	55	60	89	93			100	100
Large fresh (pulse)	LF1_P	77	83	80	87			85	85
	LF1_S	100	100	100	100			100	100
	LF2	100	100	100	100			100	100
Wetland connection flow	W-LF4_P							67	68
	W-LF4_S							70	71
	W-LF5							96	96
	W-LF6_P	100	100	100	100			100	100

EWR	EWR Code	PU12 (Lower Yanco Creek to Lower Billabong Creek)		PU11 (Columbo Creek at Morundah to Billabong Creek upstream of Jerilderie)		PU11 (Billabong Creek at Jerilderie to downstream Hartwood Weir)		PU13 (Lower Billabong and Intersecting Streams)	
	W-LF6_S	100	100	100	100			100	100
	W-LF7	71	71	73	73			86	87
	W-LF8	100	100	100	100			100	100
Floodplain connection flow	OB-L1							88	92
	OB-L1_P	92	92	92	88				
	OB-L1_S	100	100	100	100				
	OB-S1							72	70
	OB-S2	90	90					98	96
	OB-S2_P			86	86				
	OB-S2_S			100	100				
	Average Score	82	84	91	92	100	99	90	91

Note that the green, yellow and red shading represents high, medium and low degree of EWR attainment as per **Table 5-9.**

Planning units are as per the Murrumbidgee Long Term Watering Plan and as detailed in **Section 1.7**.

5.2.2.2.2 Spillage or leaks of toxic substances or litter during maintenance of infrastructure enter waterbodies, leading to water quality unsuitable for aquatic species

Maintenance activities would be required at both Hartwood and Wanganella Regulators during operation. In a similar way to the construction phase, this can result in the release of potentially harmful chemicals and other substances in the environment accidentally during operation from leaks of vehicle oils, lubricants and hydraulic fluids and other accidental spills from maintenance vehicles. Spills and leaks could potentially be transported to downstream waterway and could result in increased toxicant concentrations which may be toxic to aquatic species.

Whilst there is potential for minor impacts, maintenance activities would be carried out in accordance with the operation management procedures to be developed which would aim to ensure protection of the environment. As the maintenance needs of these structures are few and there is likely little requirement for vehicles and machinery, so the likelihood and consequence of such an impact is naturally low.

The initial risk likelihood of this impact pathway is considered to be 'Unlikely' and the consequence 'Minor'.

5.2.2.2.3 Operation and maintenance of the regulator leads to increased erosion and sedimentation that impacts on water quality and subsequently, aquatic communities

Changes in stream hydrology around the new regulator structures may lead to increases in velocity and shear stress that change the local processes of erosion, sediment transport and deposition. The potential risks highlighted in the *Billabong Creek Regulators Geomorphology Assessment* (Jacobs, 2024b) include:

- Potentially resulting in bed and bank erosion or deposition in pools
- Bank slumping and loss of riparian vegetation
- Increased sediment load and turbidity.

The *Billabong Creek Regulators* G*eomorphology Assessment* (Jacobs, 2024b) reviewed the hydraulic modelling results for each of the regulators and determined that, in general, there is no appreciable change in velocity and shear stress values for existing and proposed conditions for the majority of Billabong Creek. They identified the areas of Billabong Creek with the highest risk of channel instability and erosion (relative to existing conditions) are those immediately downstream from the proposed regulators. It is expected that this risk would be mediated as part of the regulator designs which include stilling pools/armouring of channel banks that facilitate energy dissipation of flows and protect the banks from erosion.

Whilst unsealed roads would be resurfaced with crushed rock they are still subject to erosion by stormwater. As such the use of unsealed roads for operation and maintenance activities has the potential to impact on water quality from mobilisation of sediment. As discussed in **Section 5.2.1.2.1**, mobilisation of sediments has the potential to result in harm to native species that are unable to tolerate changes to water quality. Indirect impacts from sediment deposition in instream environmental include:

- Deposition of sediment within aquatic habitat such as deep pools
- A decrease in trophic interactions due to decreased visibility
- Reduced light penetration which can limit growth of aquatic vegetation
- Algal blooms which could result in areas having little to no oxygen where aquatic life cannot survive. Algal blooms may also negatively impact aquatic life by blocking out sunlight and clogging fish gills.
- Potential loss of habitat or reduced suitability of habitat for native fauna that are sensitive to changes in water quality.

While there is potential for these impacts to occur from large amounts of sediment entering waterways the length of unsealed roads, existing access routes are unsealed and the low frequency of which they would be used for maintenance activities would not result in significant additional volumes of sediment mobilising to waterways. As such, impacts would be negligible and managed through standards maintenance operational procedures.

The initial risk likelihood of this impact pathway is considered to be 'Unlikely' and the consequence 'Minor'.

5.2.2.2.4 The regulator and semi-permanent sediment control measures degrade leading to increase erosion and sediment input into the stream network

There is the potential that the area around where the proposed regulators are installed may erode at a rate that causes turbidity levels to increase beyond current levels during regularly experienced flow conditions. Similarly, semi-permanent erosion controls (e.g. silt barriers) along the creek bed and bank may degrade, leading to increases in turbidity downstream. The risk of this occurring has been addressed in the design phase, but damage and degradation of structures may lead to an increase in the risk. That said, the relatively small bank area impacted by the regulator structures, and the small construction footprints, mean that the erodible area is naturally limited and any increased erosion would be proportionate.

The initial risk likelihood of this impact pathway is considered to be 'Unlikely' and the consequence 'Negligible'.

5.2.2.3 Spread of weeds, pest species or pathogens

This section details potential effects on aquatic fauna due to the spread of weeds, pest species or pathogens during operation of the proposal. The following effect pathways are discussed under this category:

- Operation of proposal creates more favourable habitat and water quality conditions for breeding or dispersal of invasive aquatic fauna (e.g. Carp), resulting in an increased population throughout Billabong Creek or in adjoining waterways.
- Operation of proposal creates conditions that are conducive to the proliferation of invasive terrestrial and/or aquatic plant species in Billabong Creek or receiving waterways.

5.2.2.3.1 Operation of proposal benefits exotic fishes (e.g. European Carp)

The exotic fish species present in the catchment (i.e. Common Carp, Goldfish, Redfin Perch, Eastern Gambusia and Oriental Weatherloach) are habitat generalists with broad physiological tolerances that are far less sensitive to flow modification (Lintermans, 2023). Rather, they show a preference for benign habitat conditions, so tend to correlate positively with river regulation which diminishes natural variability in aquatic habitat, such as that driven by seasonal wet-dry cycles (Beesley *et al.*, 2011). Exotic species in turn negatively impact on native fish populations, mainly through competition for resources, modification of the environment, and predation (Barrett *et al.* 2014; Koehn *et al.* 2016). Complicating the issue, exotic species are also unlikely to be negatively impacted by the return of more natural flow regimes and hydraulic condition, so a reversal in their population numbers should not be expected (Todd *et al.* 2024).

Modelled potential hydraulic and hydrological regime changes with operation of the proposed regulators are presented in **Section 5.2.2.2.1**. Based on these results, the changes in the hydraulics (flow, water level, velocity) within the Hartwood and Wanganella weir pools are not expected to significantly benefit exotic fishes (e.g. European Carp). In addition, operation of the new regulators is not expected to change the flow regime in Billabong Creek substantially or in a way that would be expected to significantly benefit exotic fishes (e.g. European Carp).

At Wanganella Weir no significant change in the proportion of velocity habitat is expected during the most common regulator setting where flows are at maximum operating flow and the pool is operating between the minimum and normal operating limits. All other settings are expected to either result in no change to the distribution of velocity habitat, or increases in all major types (e.g. lentic, moderate flowing, fast flowing). Importantly, the settings where increases in lentic habitat are expected are planned to be short-term to minimise any negative impact on native aquatic fauna.

Given these findings, the initial risk likelihood of this impact pathway is considered to be 'Unlikely' and the consequence 'Minor'. It is important to bear in mind that the only perceived negative impact may be in Hartwood weir pool during minimum operating flows.

5.2.2.3.2 Operation of the proposal alters habitat conditions in a way that benefits invasive aquatic plant species in Billabong Creek and receiving waterways

Native and exotic aquatic plants as components of freshwater ecosystems provide a number of ecosystem services by creating habitat for fish and aquatic invertebrates, facilitating nutrient cycling, maintaining water quality and controlling erosion (Dugdale *et al.*, 2013). But when aquatic plants (even native) become overabundant they can cause detrimental impacts by degrading water quality, slowing water velocity, exacerbating siltation or flooding, and reducing species diversity (Dugdale *et al.*, 2013). In addition, invasive aquatic weed species which form dense infestations can reduce the diversity of aquatic flora, which can have secondary impacts on aquatic fauna, such as fish (van Oosterhout, 2009). The impacts of aquatic weed species present a serious threat to the long-term functioning of freshwater aquatic ecosystems and, if left unmanaged, may result in significant habitat alteration (Barnett & Veitch, 2007; Yarrow *et al.*, 2009).

As discuss in **Section 5.2.1.3**, one specimen of the weed species Sagittaria (*Sagittaria platyphylla*) has been identified between Hartwood Weir and Lower Woolshed Weir, but no other priority weed species have been identified in the study area. Otherwise, within the Hartwood and Wanganella weir pools the still to slow flowing conditions have led to the proliferation of tall native semi-aquatic species such as Cumbungi that have formed dense stands in the slow, shallow pool margins.

The prevailing aquatic plant community in a given area is the product of the current physical, hydrological and hydraulic conditions (e.g. shading from trees, depth, velocity) and interactions with morphological, physiological and life history characteristics of the plants as well as a potential dispersal vectors (Capon *et al.*, 2009). While current conditions don't seem to encourage prolific aquatic plant growth, it follows that the introduction of new plant species and/or changes in stream habitat and connectivity may create new conditions that alter the aquatic plant community and potentially facilitate the establishment and spread of weeds like Sagittaria.

With that in mind, the hydrological modelling results, and the outputs of the EWR tool presented in the Hydrology Assessment report (Jacobs, 2024a) suggest that there would be little change to the hydrological nature of the study area (**Table 5-10**). Furthermore, hydraulic modelling in the Hartwood and Wanganella weir pools presented in the hydrology assessment (Jacobs, 2024a) indicated only very minor increases in the area flooded by the pools under any or the operating scenarios, so very little new habitat for aquatic plants would become available. The mapped area of newly wetted habitat during normal operating levels at maximum and minimum operating flows are presented in **Figure 5-3** and **Figure 5-4** as an example.

In addition, although hydraulic modelling indicates that there will potentially be an increase in lentic habitat within the weir pools for the proposed regulators, the overall change in habitat conditions is unlikely to be substantial enough to greatly increase the risk of new aquatic weed establishment and/or proliferation of resident species.

Further to this, the removal of riparian vegetation at the proposed new regulator sites to facilitate construction may increase the level of light the creek is exposed to, creating more suitable conditions for aquatic vegetation growth. However, the construction plan is expected to effectively minimise the removal of large trees, and the construction footprints are inherently small in relation to the overall Yanco Creek System, so a substantial increase in light that would greatly improve conditions for aquatic plants is considered unlikely.

Given the above, the risk likelihood of an on aquatic biodiversity values is considered 'Unlikely' and the consequence 'Moderate'.

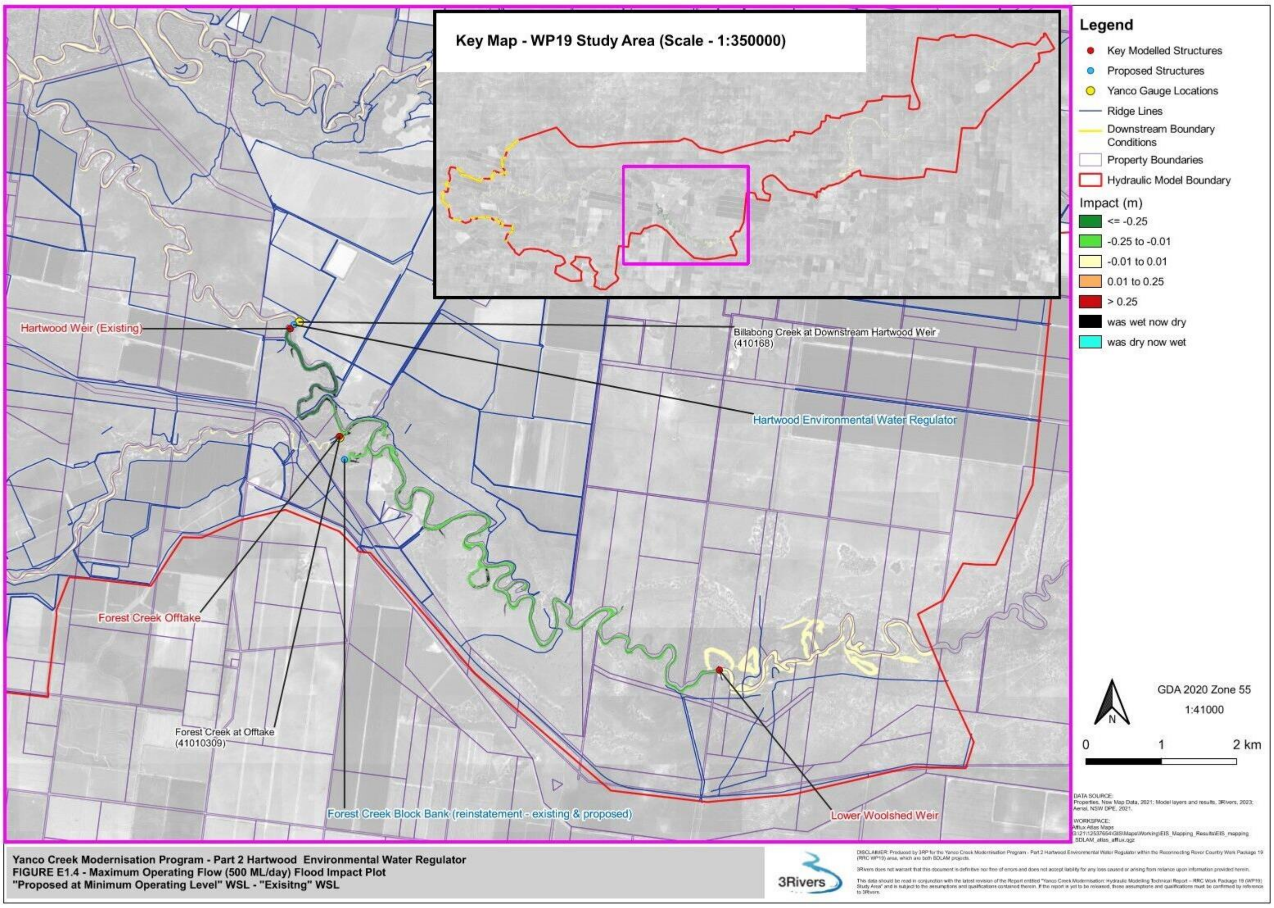


Figure 5-3 Afflux (i.e. change in Water Surface Level) results above the existing Hartwood Weir during maximum operating flows (500 ML/day) when control is set to normal operating level (taken from the *Yanco Creek Modernisation: Hydraulic Modelling Technical Report – Hartwood Weir to Picaninny Weir Study Area (3Rivers, 2024b)*). This map is presented as an example of commonly experienced conditions under the proposed operating plan (see the *Hydraulic Modelling Technical Report – Hartwood Weir to Picaninny Weir Study Area (3Rivers, 2024b)* for full results).

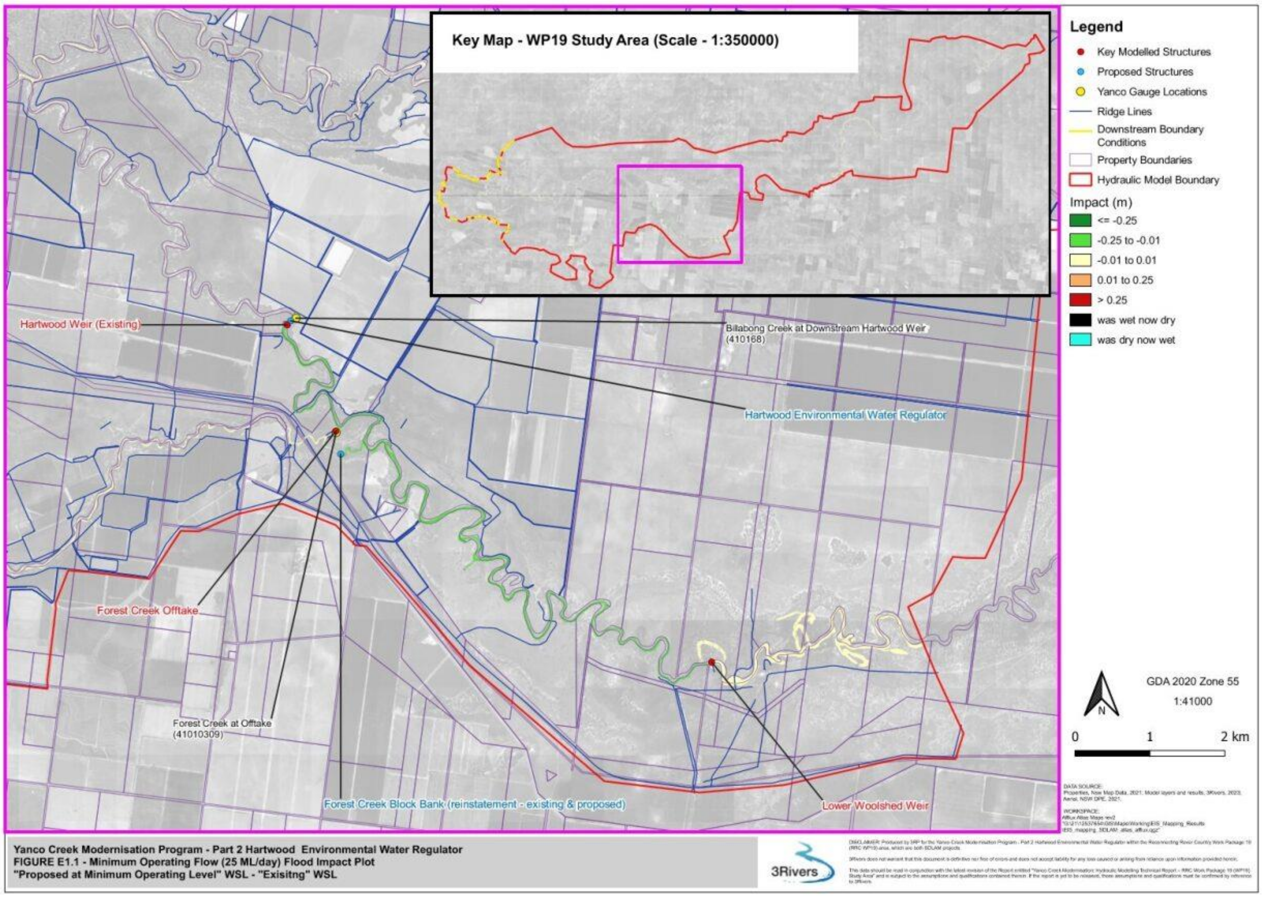


Figure 5-4 Afflux results above the existing Hartwood Weir during minimum operating flows (25ML/day) when control is set to normal operating level (taken from the *Yanco Creek Modernisation: Hydraulic Modelling Technical Report – Hartwood Weir to Picaninny Weir Study Area (3Rivers, 2024b)*). This map is presented as an example of commonly experienced conditions under the proposed operating plan (see the *Yanco Creek Modernisation: Hydraulic Modelling Technical Report – Hartwood Weir to Picaninny Weir Study Area (3Rivers, 2024b)* for full results).

5.2.2.4 Direct impacts to aquatic habitat or species

This section details potential effects due to direct impact to aquatic habitat during operation of the proposal. The effect pathways discussed under this category was:

- Vehicle collisions lead to mortality of turtles and Rakali during operation of the proposal.

5.2.2.4.1 Vehicle collisions lead to mortality of turtles and Rakali during operation of proposal

During operation of the proposal, turtles and Rakali may be directly injured and/or killed through vehicle impacts. However, given that most main vehicle access tracks currently exist, and maintenance of the structure is unlikely to require regular site visits, the risk likelihood and consequence of this impact is naturally low.

The initial risk likelihood of this impact pathway is considered to be 'Unlikely' and the consequence 'Negligible'.

5.3 Cumulative impact assessment

Cumulative impacts are defined as an impact on the environment which results from the incremental impact of the action when added to other past, present, and reasonably foreseeable future actions. Cumulative impacts can result from individually minor but collectively significant actions taking place over a period of time. The overall effect of cumulative impacts could be positive or negative, depending on the nature of the proposal and its surroundings, other relevant projects within proximity of the proposal (or hydrologically linked), as well as the nearby communities and environment. In this instance, the closely situated Forest Creek Return Flows project includes several proposals that are considered in this cumulative assessment (Forest Creek Return Regulator, Wilsons Anabranch Offtake, and Wanganella Swamp Regulators).

Construction Phase

All threat pathways identified for the construction phases were rated as having 'Rare' or 'Unlikely' likelihood of occurrence following implementation of the proposed safeguards described in **Section 6**. As such, they are unlikely to contribute significantly to negative cumulative effects in the system. That said, we note the following:

- The clearance areas where trees would be removed are small
- Any impacts on water quality and physical habitat are likely to be largely confined to an area close to the construction footprint and be temporary in nature (less than a year)
- Direct impacts to threatened species are very unlikely if the proposed safeguards are followed
- The spread of weeds into the area is a constant risk but should be adequately mitigated by the safeguards implemented.

Operation Phase

Cumulative effects of the proposed hydrological and hydraulic alteration were assessed in the relevant reports. The *Yanco Creek Modernisations Hydraulic Modelling Technical Reports – Picaninny Weir to Wanganella Weir Study Area* (3Rivers, 2024a) and the *Hartwood Weir to Picaninny Weir Study Area* (3Rivers, 2024b) assessed (1) the impact of Hartwood Regulator with and without the works related to the Forest Creek Return Regulator and Wilsons Anabranch Offtake, and (2) the impact of Wanganella Regulator with and without the works related to the Wanganella Swamp Regulators, for select scenarios. The results found that the works related to this proposal are effectively independent of the other works, with no significant changes are expected.

The *Billabong Creek Regulators Hydrology Assessment* (Jacobs, 2024a) modelled the hydrological impacts (adverse and beneficial) associated with cumulative impacts of the proposal and the Forest Creek Return Flows project. The most relevant results here are those related to the achievement of Environmental Watering Requirements within the study area for native fishes, which was assessed using the EWR support tool and results presented in **Table 5-11.**

The key EWR results for Mid Billabong Creek (Jerilderie to downstream of Hartwood Weir; PU11 410014 and 410016) are as follows:

- Generally no reduction in the frequency with which the specific flow or inundation regime EWRs are achieved in the cumulative case compared to the base case. Where decreases are predicted these are minor (≤ 4%). Increases are of up to 10% are predicted for some EWRs within the study area.
- The frequency with which all of the specified EWR categories are modelled to be achieved represents no or a low degree of hydrological alteration to the specific flow or inundation regime needed to support key ecological values and related MLTWP objectives in this reach.

The key EWR results for lower Billabong and Intersecting Streams (downstream of Hartwood Weir to Moulamein; PU13) are as follows:

- No or negligible (≤ 1%) reduction in the frequency with which the specific flow or inundation regime EWRs are achieved in the cumulative case compared to the base case with the exception of Wetland Connection Flow W-LF7 which has a predicted reduction of 23%.
- Increases in the frequency of Large Overbank Floodplain Connection OB-L1 (+8%), Wetland Connection flow EWRs (W-LF4_P 'preferred seasonal timing' and W-LF4_S 'any time that is considered satisfactory'; +1-2%), Small Freshes SF1 (+2-5%), and Native Fish Nesting Support NestS1 (+7-8%).
- The predicted frequency of attaining NestS1_tcmc, and NestS1_mc, would still represent a medium degree of hydrological alteration for these flow categories following implementation of the SDLAM projects.

A potential cumulative benefit of the proposal is an increase in fish passage due to the construction of fishways in the Hartwood and Wanganella Regulator and fishway structures. While these structures are expected to facilitate upstream fish movement, the potential benefits for fish communities are lessened by the presence of other existing instream structures (e.g. farm dams and weirs) that also present barriers to fish movement. NSW DPI compiled a database of instream structures throughout the Billabong-Yanco system and assessed whether they present barriers to fish movement under typically encountered flow conditions. Using Google Earth and this database we measured the stream distance (along the stream centre line) between each of these structures to provide an indication of how much habitat would become available to fish populations downstream of Hartwood and Wanganella Weirs once the proposed fishways are constructed. We also included all intervening fish barriers to provide broader context to the assessment. Listed in an upstream direction from the site of the proposed Wanganella Regulator to the first barrier encountered upstream of the proposed Hartwood Regulator, these barriers include:

Caroonboon Weir $\rightarrow^{46.90km}$ **Wanganella Regulator (no barrier)** $\rightarrow^{13.81km}$ 4 Mile Dam $\rightarrow^{15.80km}$ Chinamans Dam $\rightarrow^{17.30km}$ Tracey's Weir $\rightarrow^{9.42km}$ Piccaninny Weir $\rightarrow^{9.34km}$ Boonoke Homestead Weir $\rightarrow^{34.19km}$ **Hartwood Regulator (no barrier)** $\rightarrow^{16.30km}$ Lower Woolshed Dam

The results indicate that ~47km of unimpeded riverine habitat between Caroonboon Weir and the existing Wanganella Weir would be extended by ~14km, up to 4 Mile Dam, following the construction of the Wanganella Regulator and fishway. This is a considerable improvement, although the broader benefits of the increased habitat connectivity would be localised and are expected to have little overall benefit to populations at the level of the Billabong-Yanco system which are still fragmented by several other barriers.

It is noted that while 4 Mile Dam, Chinamans Dam, and Tracey's Weir pose barriers to fish movement, they are smaller structures than Wanganella or Picaninny weir. They would be likely be drowned out when flows are high allowing for a greater degree of upstream and downstream fish movement. 4 Mile Dam for instance would be drowned out when the Wanganella Regulator pool is operated at full supply level (NSW DPI 2024). So, connectivity may be improved as far as Picaninny Weir under certain flow conditions, but populations between these structures are still considered fragmented.

The fishway at the proposed Hartwood Regulator would connect ~34km of Billabong Creek, and a further 53km of stream habitat in lower Yanco Creek, with ~16km of stream habitat up to Lower Woolshed Weir. We note that there would also be an increase in high-quality, fast flow habitat above Hartwood Regulator that would provide important habitat for flow-sensitive species such as Silver Perch. Again, this would mark a considerable improvement, but the benefits would be localised and are expected to have modest overall benefit to populations at the level of the Billabong-Yanco system.

Table 5-11 Cumulative change case EWR attainment score results. Note that PU10 (Upper Yanco Creek) is included in this cumulative assessment of the broader potential impacts of the various proposals in the Yanco Creek System. However, PU10 was not included in the impact assessment for the Billabong Creek Regulators alone as it is outside the study area (see Table 5-9).

Category	EWR	PU10 (Upper Yanco Creek)		PU12 (Lower Yanco Creek to Lower Billabong Creek)		PU11 (Colombo Creek at Morundah to Billabong Creek upstream of Jerilderie)		PU11 (Billabong Creek at Jerilderie to downstream Hartwood Weir)		PU13 (Lower Billabong and Intersecting Streams)	
		Base	Cumulative Change	Base	Cumulative Change	Base	Cumulative Change	Base	Cumulative Change	Base	Cumulative Change
Cease-to-flow (CtF)	CF1	100	100	100	100	100	100	100	100	100	99
Very low flow (VLF)	VF1_a	100	100	100	100	100	100	100	100	100	100
	VF1_b	100	100	100	100	100	99	100	99	100	100
Baseflow (BF)	BF1_a	68	100	32	42	100	100	100	100	100	100
	BF1_b	100	100	96	97	100	99	99	99	100	100
Native Fish Nesting Support	NestS1_mc	47	52	32	37	61	65			69	76
	NestS1_tcmc	36	40	27	29	53	60			57	65
Small fresh (pulse) (SF)	SF1_P	72	79	76	82	77	86			90	94
	SF1_S	84	87	85	90	90	93			92	96
	SF2	100	100	55	59	89	97			100	100
Large fresh (pulse) (LF)	LF1_P	76	81	77	81	80	87			85	85
	LF1_S	97	100	100	100	100	100			100	100
	LF2	98	100	100	100	100	100			100	100
	W-LF4_P									67	68

Category	EWR	PU10 (Upper Yanco Creek)		PU12 (Lower Yanco Creek to Lower Billabong Creek)		PU11 (Colombo Creek at Morundah to Billabong Creek upstream of Jerilderie)		PU11 (Billabong Creek at Jerilderie to downstream Hartwood Weir)		PU13 (Lower Billabong and Intersecting Streams)	
		Base	Cumulative Change	Base	Cumulative Change	Base	Cumulative Change	Base	Cumulative Change	Base	Cumulative Change
Wetland connection flow (Wetland-LF)	W-LF4_S									70	72
	W-LF5									96	98
	W-LF6_P	100	100	100	100	100	100			100	100
	W-LF6_S	100	100	100	100	100	100			86	100
	W-LF7	90	89	71	70	73	73			100	87
	W-LF8	100	100	100	100	100	100			100	100
Floodplain connection flow (OB)	OB-L1									88	96
	OB-L1_P	88	88	92	92	92	88				
	OB-L1_S	100	100	100	100	100	100				
	OB-S1									72	70
	OB-S2			90	90					98	98
	OB-S2_P	70	70			86	86				
	OB-S2_S	88	88			100	100				

Note that the green, yellow and red shading represents high, medium and low degree of EWR attainment as per **Table 5-9**.

6. Mitigation and management of impacts

This section identifies measures that could be taken to lower the likelihood and consequence of the identified potential risks/ impacts occurring because of the proposal construction and operation.

Impacts to aquatic ecology due to construction are largely related to entrapment of animals due to cofferdam construction, mobilisation of poor-quality runoff and erosion/sedimentation, and the spread of aquatic weeds/pest species. The contractor would prepare a construction environmental management plan (CEMP) that describes how activities undertaken during the construction phase of the proposal will be managed to avoid or mitigate environmental impacts, and how those environmental management requirements will be implemented. A biodiversity management plan would be prepared as a sub-plan to the CEMP and would identify aquatic habitat that needs to be protected, outline a procedure for salvaging any aquatic fauna species that are at risk from dewatering, and outline all other biodiversity focused safeguards related to the establishment of instream construction work sites or other aspects of the works. Further to this, erosion and sediment controls would be identified and developed for the new and existing weir sites, which would be detailed in a construction soil and water management plan (CSWMP) as part of the CEMP.

Some of the most prominent risks during operation of the proposal relate to fish passage through the new regulators and changes in stream hydraulics and hydrology. However, these risks have been accounted for in the proposal design phase, so they don’t require specific safeguards given that no significant risk was identified in the initial risk assessment (**Section 5**).

Where impacts cannot be avoided, measures to minimise or manage impacts to aquatic ecology should be implemented. Recommendations for safeguards are detailed in **Table 6-1.**

Table 6-1 Surface water quality and aquatic ecology safeguards to address identified effect pathways

ID	Impact	Environmental Standard	Responsibility	Timing
MM1	General - CEMP	Preparation of a CEMP to outline the measures to manage water quality impacts associated the construction works is recommended. If risks are to be minimised, it is recommended the CEMP include, but not be limited to, the following: ▪ Measures to minimise/manage erosion and sediment transport within the disturbance area and off site with consideration of contingencies for moderate to high rainfall events. ▪ Measures to manage stockpiles, including locations and sediment controls and stabilisation. ▪ Detail procedures to capture, contain and dispose of concrete waste. ▪ Measures to manage saline soils. ▪ Measures to manage water (including dewatering) and groundwater ingress from construction, including water collection protocols, and water quality standards to be achieved for release to downstream environment. This should be included in a dewatering management plan that would be prepared as a subplan to the CEMP. ▪ Staging of works to consider and respond to forecast high flows and heavy rainfall events. ▪ Management of the spread of weeds and pests. ▪ Management of spills and leaks. Measures to ensure all waterway crossings will be constructed in accordance with the Guidelines for Controlled Activities on Waterfront Land – riparian corridors (NRAR, 2018), Guidelines for watercourse crossings on waterfront land (DPI, 2012), Guidelines for riparian corridors on waterfront land (DPI, 2012) and Why Do Fish Need to Cross the Road? Fish Passage Requirements for Waterway Crossings (DPI, 2003).	Construction contractor	Prior to construction
MM2	Erosion and sediment management during construction	Implement site specific control measures to manage potential erosion or sedimentation impacts including, but not be limited to: ▪ Floating silt fences for instream works. ▪ Minimise the duration of works within the watercourse as far as practicable. ▪ Minimise clearance of vegetation and retain existing vegetation as much as possible.	Construction contractor	Prior to construction

ID	Impact	Environmental Standard	Responsibility	Timing
		▪ Develop a site erosion and sediment control methodology with consideration of contingencies for moderate to high flows during instream works. ▪ Wherever possible, prefabricate instream structural elements prior to instream installation. ▪ Install sediment controls around stockpiles to contain coarse soil and sediment, as applicable to prevent sedimentation of watercourses. ▪ Placement of stockpiles away from the watercourse (at least 20m from creek channels) and covering them when not in use to prevent sediment runoff. ▪ Stabilise exposed soil where applicable with the appropriate structural materials and media for the construction activities (e.g., stabilisation matting, rock armour or vegetation). ▪ Undertake water quality monitoring downstream of the study area during construction, to assess the effectiveness of silt fences, so they can be fixed if necessary. ▪ Erosion and sediment controls established prior to commencement of vegetation clearing or earthworks. ▪ These controls to be documented in the CEMP. ▪ A construction Erosion and Sediment Control Plan (ESCP) will be prepared as part of the CSWMP and will detail the specific erosion and sediment control measures to be implemented within the proposal are, in accordance with the principles and requirements of *Managing Urban Stormwater – Soils and Construction, Volumes 1* (Landcom, 2004) and 2C (DECC, 2008), (known as the Blue Book).		
MM3	Spills or leaks during construction	Site specific controls to be developed to manage the risk of accidental spills or leaks of fuels, oils and chemicals (such as hydraulic oils), or concrete, during construction. These controls are to be documented in the CEMP and would include: ▪ Emergency spill response procedure in accordance with NSW DCCEEW incident management protocols.	Construction contractor	Prior to construction

ID	Impact	Environmental Standard	Responsibility	Timing
		▪ Site specific controls to reduce the risk of the release of potentially harmful chemicals from spills or leaks entering waterways. ▪ Storage of hazardous materials such as oils, chemical and refuelling activities in bunded areas within contractor's temporary work areas. ▪ Bunded receptacles for concrete waste including concrete slurries and washout water provided at the work sites to capture, contain and appropriately dispose of any concrete waste at a suitably licenced waste facility. These will be located as far from waterways as feasible.		
MM4	Concrete works management	To avoid ingress of concrete waste material into downstream watercourse, the CEMP would outline procedures to capture, contain and appropriately dispose of any concrete waste. Concrete structures would be pre-fabricated prior to installation instream, where practicable.	Construction contractor	Construction
MM5	Water quality monitoring	To detect and manage the degradation of water quality due to construction activities, a water quality monitoring program will be designed and implemented and appended to the CSWMP. As a minimum water quality monitoring would include: ▪ Water quality monitoring upstream and downstream of the proposal site prior to and during construction. In particular, monitoring of dissolved oxygen to ensure suitable saturation levels and turbidity to determine effectiveness of erosion and sediment controls. ▪ Any groundwater that enters excavations within the works sites will be tested and, if suitable, pumped into nearby waterways or otherwise transferred into a treatment pond and treated before being discharged into nearby waterways. The CEMP will include water quality criteria for any water to be discharged into nearby waterways.	Construction contractor	Construction
MM6	Fish passage management during construction	Minimise the duration of fish passage restrictions (e.g. cofferdams).	Construction contractor	Construction
MM7	Weed and pathogen management	Develop and implement a weed and pathogen control plan that includes the following requirements and measures to mitigate spread:	Construction contractor	Construction

ID	Impact	Environmental Standard	Responsibility	Timing
		▪ Vehicle, personnel, material and equipment hygiene protocols (including measures required to prevent the spread or transmission of Chytrid Fungus as per Hygiene protocols for the control of diseases in Australian frogs (Murray *et al.,* 2011). ▪ Weed, pest animal and pathogen management and monitoring and reporting requirements during the construction period. ▪ Weed and pathogen management and monitoring and reporting requirements should be documented. Measures must be auditable and linked to management outcomes. ▪ Identify any listed weeds (identified in NSW WeedWise) that have been found in the construction area as part of the ecological assessment and assess the risk of additional spread prior to relocating topsoil. Implement measures to manage this risk when clearing, grading, and reinstatement activities. ▪ To a reasonable extent when conducting clearing and grading activities, check that vehicles and plant equipment are free of soil (dust/clods) and vegetation prior to entry and exit from the construction area. ▪ Evaluate disturbed areas post-construction and implement rehabilitation in accordance with the appropriate safeguards. ▪ To avoid and minimise spread of weeds and pathogens, all vehicles and plant undertaking construction works directly in the watercourse must be cleaned and free of debris prior to entering a waterway, and on exit if working between multiple waterways.		
MM8	Aquatic habitat disturbance minimisation	▪ Limit disturbance to riparian vegetation and snags to the assessed clearing areas and avoid complete removal wherever possible. ▪ Any large woody debris and snags (>3m long or 30 cm wide) that have to be removed from the construction footprint should be moved to a suitable location upstream or downstream of the site in consultation with a qualified ecologist.	Construction contractor	Construction
MM9	Reinstatement	▪ Disturbed areas will be revegetated with endemic riparian and floodplain species (replacing like for like) to be undertaken as soon as practical, progressive reinstatement. ▪ Rehabilitation at construction sites to include replacing topsoil from the site stockpile.	Construction contractor	Construction

ID	Impact	Environmental Standard	Responsibility	Timing
MM10	Pest control	Food waste accumulated on site will be stored in inaccessible bins and disposed off-site regularly so that the waste doesn't attract predatory pests such as cats and foxes.	Construction contractor	Construction
MM11	Fauna Management	Implement the following fauna management procedures during construction including: ▪ Prepare a dewatering plan for cofferdams to avoid potential impacts to aquatic fauna such as fish stranding. ▪ As a requirement of the dewatering plan, native aquatic fauna entrained within the cofferdams will be captured and relocated to a nearby suitable habitat by qualified aquatic ecologists. ▪ Development and implementation of handling and salvage protocols for terrestrial and aquatic fauna during construction, including requirements for legislative permits and authorisation requirements of wildlife handlers. This will include procedures for pre-clearing, clearing surveys and procedures should fauna or nests/burrows be found during these surveys and removal is required. The protocols will include details of requirements, including wildlife handler/ecologist/NSW DPI permits. All fencing must be fauna friendly to minimise risk of injury from collision and include provision of egress points, for example: ▪ Temporary to exclude construction: High visibility string of bunting or plastic mesh (not transparent) attached to star pickets with plastic caps (or weighted posts that avoid ground penetration in culturally sensitive areas). ▪ Temporary to exclude wildlife (e.g. from open trenches): Fencing stays located inside the exclusion area, or with high visibility mesh to guide wildlife away from obstructions and potential traps. Shade cloth or other suitable deterrent attached to the lower 50 cm of the outside of the exclusion zone and weighted to the ground. ▪ No barbed or razor wire will be used. ▪ Trench management, including avoiding open trenches overnight where practicable. Where trenches cannot be closed, check trenches at the start and end of each day (i.e., dawn/dusk), and consider feasibility of measures (e.g., ramps) to aid animal escape.	Construction contractor	Construction

ID	Impact	Environmental Standard	Responsibility	Timing
		Implement measures to minimise noise, vibration and lighting impacts on known threatened fauna species and habitat, including: ▪ Avoid unnecessary light spill across a broader area than required to avoid attracting insects and subsequently their predators (bats and birds). ▪ Avoiding night works during periods of high insect/bird/bat activity (October to March) as far as reasonably practical, so as to minimise disturbance to fauna communication, foraging and other behaviours that depend on sound and darkness.		
MM12	Hydrology	Once the proposal structures have been in operation through an appropriate operational cycle, the Yanco Creek System Operations Plan will be updated taking into account system monitoring results, identified operating risks and ecological response.	WaterNSW	Operation
MM13	Erosion and sediment control during operation	▪ Erosion and sediment controls, including semi-permanent controls along the creek bed and bank as required, will be maintained post construction until disturbed areas are stabilised. ▪ Undertake two post-construction visual assessments of regulators over 2 years to identify and assess any erosion caused by the structures, so it can be addressed if required.	WaterNSW	Operation
MM14	Spills or leaks during operation	Site environmental management, inclusive of spill response measures, will be in accordance with broader WaterNSW operation and maintenance and environmental management procedures for operations.	WaterNSW	Operation
MM15	Fish passage management during operation	▪ Develop and adhere to fishway maintenance protocols in line with NSW DPI – Fisheries advice. ▪ Conduct fishway monitoring in line with advice from NSW DPI - Fisheries at each regulator once the construction is complete to ensure they are operating as anticipated.	WaterNSW	Operation
MM16	Water quality management downstream of the new regulators	To assess changes in water quality following the construction of the proposal and implementation of the Yanco Creek System Operations Plan, develop and conduct a water quality monitoring program for Billabong Creek, downstream of Wanganella and Hartwood Regulators. This may be incorporated into existing catchment-based monitoring programs at long-term monitoring locations, if not already covered.	WaterNSW	Operation

ID	Impact	Environmental Standard	Responsibility	Timing
MM17	Fauna management during operation	▪ All operation personnel would be informed of environmental responsibility with respect to the protection of aquatic and terrestrial fauna and their habitat. ▪ All vehicles driven by operation personnel would be required to remain on designated tracks and not drive through water.	WaterNSW	Operation

7. Assessment results

This assessment of results section contains the residual risk assessment, describes potential impacts on Matters of National and State environmental significance, and reports on the likely impact of the proposal on NSW water quality objectives and on threatening processes.

7.1 Residual risk assessment

Section 5.2.1 and **5.2.2** identify the potential impact pathways resulting from construction and operation of the proposed Hartwood and Wanganella Regulators. Then, in **Section 6**, a number of measures to mitigate the risk posed by these impact pathways are identified. This section provides an assessment of the residual risk for the impact pathways are expected to pose, following the implementation of the safeguards, and final risk rating. The results are provided in **Table 7-1**.

In short, all impact pathways had a Residual Risk Likelihood of 'Unlikely' or less, and a Risk Rating of 'Medium' or lower and. That is to say, if project management and planning proceeds as described and the safeguards are implemented during construction and operation, the proposal is likely to have no more than an "acceptable" negative impact on surface water quality or the aquatic communities.

Table 7-1 Effect pathways and proposed mitigation measures for the Billabong Creek Regulators

Effect pathway	Unmitigated risks			Safeguards	Residual risks		
	Likelihood	Consequence	Risk rating		Likelihood	Consequence	Risk rating
Phase: Construction							
Loss of connectivity and impeded passage for native aquatic species							
Construction of infrastructure within a waterway requires cofferdams, which results in a temporary loss of connectivity and impeded passage impacting aquatic species.	Unlikely	Minor	Low	Fish passage management has been considered adequately in the construction plan. The implementation of MM6 (Fish passage management during construction) will minimise any temporary loss of connectivity.	Rare	Minor	Very Low
Degradation of aquatic habitat through water quality or water regime changes							
Disturbance of soil during construction of infrastructure in or adjacent to waterway corridor leads to increased erosion/sedimentation, leading to aquatic habitat degradation and reduced water quality due to input of sediment and/or contaminants	Possible	Moderate	Medium	MM2 (Erosion and sedimentation control), MM8 (Aquatic habitat disturbance minimisation), MM 9 (Reinstatement) and MM5 (Water Quality Monitoring) will be implemented with a range of measures which would avoid or minimise the potential for erosion and sedimentation.	Unlikely	Moderate	Medium
Removal of vegetation leads to a decline in aquatic habitat (e.g. increased light levels and stream temperature) that negatively impacts on aquatic fauna.	Likely	Minor	Medium	MM2 (Erosion and sedimentation control) and MM8 (Aquatic habitat disturbance minimisation) include measures to minimise clearance of vegetation, retain existing vegetation wherever possible, revegetate impacted areas, and retain and reinstate instream woody structure (i.e. snags). Additionally, reinstatement (MM9 –	Unlikely	Minor	Low

Effect pathway	Unmitigated risks			Safeguards	Residual risks		
	Likelihood	Consequence	Risk rating		Likelihood	Consequence	Risk rating
				Reinstatement) would provide for bank stabilisation to mitigate the impact on disturbed soil. The Construction Environmental Management Plan (CEMP) (MM1) will include procedures for the disposal, stockpiling and reuse of cleared vegetation to minimise risk of tannin leachate into Billabong Creek.			
Construction works could result in the release of oils and fuels, accidental release of concrete waste and dust and litter into downstream waterbodies, leading to water quality unsuitable for aquatic species	Possible	Minor	Medium	Effects will be mitigated by developing a standard CEMP (MM1 – General CEMP) in line with the relevant guidelines and MM3 (Accidental spills or leaks management), which includes management measures for resource use and waste (excluding soils) to be developed and implemented to appropriately manage litter, construction and demolition wastes, and organic waste during construction and operation in accordance with the EPA waste management hierarchy and management options. The risk to water quality from concrete works will be managed by using pre-fabricated structures where possible as per MM4 (Concrete works management). Standard safeguards to reduce the likelihood of spills and leaks include	Unlikely	Minor	Low

Effect pathway	Unmitigated risks			Safeguards	Residual risks		
	Likelihood	Consequence	Risk rating		Likelihood	Consequence	Risk rating
				locating refuelling and storage areas away from watercourses, regular maintenance and inspection of vehicles and equipment, providing adequate spill kits and appropriate storage of toxic substances including drip trays and bunding as appropriate.			
Dewatering of the area could impact on surface water quality	Possible	Minor	Medium	To minimise the impact on surface water quality from dewatering during construction a dewatering management plan will be prepared and appended to the CEMP as per MM1 (General CEMP). This plan will detail the procedures for dewatering and water quality criteria to be achieved prior to water from the cofferdam being discharged downstream.	Unlikely	Minor	Low
Construction works result in the disturbance of saline soils	Possible	Negligible	Low	Requirements for managing the disturbance of saline soils will be outlined in the CEMP as per MM 1 (General CEMP). It will include implementation of water quality controls to ensure there is minimal runoff from exposed areas and stockpiles.	Unlikely	Negligible	Very Low
Mobilisation of sediment deposited behind the existing weir walls	Unlikely	Negligible	Very Low	To minimise the impact of sediment mobilisation on water quality and aquatic ecology, appropriate measures will be outlined in the CEMP as per MM1 (General CEMP), including procedures to secure	Rare	Negligible	Very Low

Effect pathway	Unmitigated risks			Safeguards	Residual risks		
	Likelihood	Consequence	Risk rating		Likelihood	Consequence	Risk rating
				instream works sites and prevent water pollution when high flows occur and erosion and sediment control measures will be implemented as per MM2.			
Spread of weeds, pest species or pathogens							
Construction activities lead to introduction of weeds or noxious species that become established in aquatic habitats, leading to conditions unsuitable for existing species	Possible	Minor	Medium	During construction the transfer and establishment of weeds and pathogens in aquatic habitats will be reduced by implementing MM12 (Weeds and pathogen management). This includes a provision for all vehicles and plant equipment to be washed down prior to entering waterways and monitoring of weeds to be completed during the construction phase. There is a high level of certainty that these measures would be effective based on standard hygiene protocols and monitoring programs.	Unlikely	Minor	Low
Construction activities lead to introduction of pathogens which directly impact existing species.	Unlikely	Moderate	Medium	MM7 (Weed and pathogen management) includes provisions for vehicle, personnel, material and equipment hygiene protocols. In particular, all vehicles and plant undertaking construction works directly in the watercourse must be cleaned and free of debris prior to entrance of each waterway and on exit if working between multiple waterways	Rare	Moderate	Low

Effect pathway	Unmitigated risks			Safeguards	Residual risks		
	Likelihood	Consequence	Risk rating		Likelihood	Consequence	Risk rating
Impacts to Groundwater Dependent Ecosystems	Unlikely	Negligible	Very Low	None required	Unlikely	Negligible	Very Low
Direct impacts to aquatic habitat or species							
Construction of infrastructure within a waterway requires a cofferdam and pumping of water, which results in accidental mortality of aquatic species within the construction site	Likely	Negligible	Low	MM11 (Aquatic fauna management) includes provisions for the development of a dewatering plan which includes a requirement for the removal and relocation of native aquatic fauna entrained within the cofferdams by a qualified aquatic ecologist.	Unlikely	Negligible	Very Low
Construction of infrastructure causes bank disturbance resulting in loss of habitat.	Possible	Negligible	Low	To minimise bank disturbance and loss of habitat, MM13 (Erosion and sediment control) dictates the implementation of semi-permanent controls along the creek bed and banks, which are to be maintained post construction until disturbed areas are stabilised. In addition, MM9 (Reinstatement) will be implemented to allow for rehabilitation of riverbanks in terms of log reinstatement and targeted revegetation.	Unlikely	Negligible	Very Low
Construction of infrastructure in or adjacent to waterway corridor leads to removal of large woody habitat due to adjacent land or in-channel	Likely	Negligible	Low	Snags and woody debris will be returned to the waterway post construction (MM8 - Aquatic habitat disturbance minimisation), so the loss of this aquatic habitat would	Rare	Negligible	Very Low

Effect pathway	Unmitigated risks			Safeguards	Residual risks		
	Likelihood	Consequence	Risk rating		Likelihood	Consequence	Risk rating
disturbance, leading to a loss of structural habitat for aquatic species.				only be localised and restricted to the short construction period.			
Injury or death of fauna through construction activities.	Possible	Negligible	Low	MM11 (Aquatic fauna management) includes requirements for the removal of aquatic fauna from the water, in the construction area, prior to construction. It also includes provisions for excluding animals from the construction site and any open trenches through fencing. Finally, MM 10 (Pest control) includes a provision for safely storing and removing food waste from the construction.	Unlikely	Negligible	Very Low
Construction increases terrestrial predator abundance (e.g. feral cat, wild dog, and Red Fox) leading to greater predation pressure on freshwater turtles and Rakali	Unlikely	Minor	Low	MM10 (Pest Control) includes a provision for storing food waste accumulated on site in inaccessible bins and disposing off-site regularly so that the waste doesn't attract predatory pests such as cats and foxes.	Rare	Minor	Very Low
Phase: Operation							
Loss of connectivity and impeded passage for native aquatic species							
The new regulator does not allow for fish passage in an upstream or downstream direction	Rare	Negligible	Very Low	No safeguards have been proposed as fish passage design has been addressed in the design phase.	Rare	Negligible	Very Low
Fish passage through the of regulator declines over time due to environmental impacts	Unlikely	Minor	Low	The safeguard for this effect (MM15 - Fish passage management during operation) is to annually inspect the structure and ensure that silt or vegetation build up or	Rare	Minor	Very Low

Effect pathway	Unmitigated risks			Safeguards	Residual risks		
	Likelihood	Consequence	Risk rating		Likelihood	Consequence	Risk rating
				blockages are removed. Furthermore, once the regulator structures have been in operation through an appropriate operational cycle, the Yanco Creek System Operations Plan will be updated taking into account system monitoring results, identified operating risks and ecological response. This presents an opportunity to assess the performance and impact of the structures over time (MM12 – Hydrology).			
Operation of proposal leads to fragmentation of terrestrial habitat for turtles and Rakali	Unlikely	Negligible	Very Low	No safeguards have been proposed as in the worst-case scenario passage for these species will be no worse than under current conditions and these species can travel short distances overland to navigate around the structures.	Unlikely	Negligible	Very Low
Degradation of aquatic habitat through water quality or water regime changes							
Operation of proposal leads to alteration of the natural flow regimes of rivers and streams, leading to conditions unsuitable for native aquatic species	Rare	Moderate	Low	While the changes to the hydrological regime and the subsequent impact on aquatic communities has been addressed in the operations plan and changed conditions are not expected to negatively impact aquatic communities, it would be prudent to conduct water quality monitoring following construction to ascertain whether there are any unforeseen impacts. As such, MM16 (Water quality	Rare	Moderate	Low

Effect pathway	Unmitigated risks			Safeguards	Residual risks		
	Likelihood	Consequence	Risk rating		Likelihood	Consequence	Risk rating
				management downstream of the new regulators) includes a provision for a water quality monitoring program which may be incorporated into existing catchment-based monitoring programs if not already covered.			
Spillage or leaks of toxic substances or litter during maintenance of infrastructure enter waterbodies, leading to water quality unsuitable for aquatic species	Unlikely	Minor	Low	Site environmental management, inclusive of spill response measures, will be in accordance with broader WaterNSW operation and maintenance, and environmental management procedures for operations (MM3 – Accidental spills and leaks; MM4 – concrete works).	Rare	Minor	Very Low
Operation and maintenance of the regulator leads to increased erosion and sedimentation that impacts on water quality and subsequently, aquatic communities	Unlikely	Minor	Low	The structures have been designed to limit scour and erosion downstream. Additional risk for operation and maintenance of the regulators will be managed through implementation of operational safeguards and management measures MM13 (Erosion and sediment control) and MM14 (Spills and or leak during operation).	Rare	Minor	Very Low
The regulator and semi-permanent sediment control measures degrade leading to increase erosion and sediment input into the stream network	Unlikely	Negligible	Very Low	The risk of erosion from these structures has been addressed in the design phase, but damage and degradation may lead to increased erosion risk. As such, MM13 (Erosion and sediment control) includes provisions for (1) the maintenance of semi-	Rare	Negligible	Very Low

Effect pathway	Unmitigated risks			Safeguards	Residual risks		
	Likelihood	Consequence	Risk rating		Likelihood	Consequence	Risk rating
				permanent erosion control structures, and (2) annual assessment of the regulator structures in the two years following construction to identify any problematic points of erosion so that they can be addressed.			
Spread of weeds, pest species or pathogens							
Operation of proposal alters hydraulic and hydrological conditions in a way that benefits exotic fishes (e.g. European Carp)	Unlikely	Minor	Low	No safeguards have been proposed as changes to the hydrological regime and the subsequent impact on aquatic habitat and communities has been addressed in the operations plan. The changed conditions are expected to benefit native fish over invasive species.	Unlikely	Minor	Low
Operation of the proposal alters habitat conditions in a way that benefits invasive aquatic plant species in Billabong Creek and receiving waterways	Unlikely	Moderate	Medium	The hydraulic modelling suggested some improved conditions for aquatic plant species, but the changes were not considered significant enough to have a negative implication for the aquatic community.	Rare	Moderate	Low
Direct impacts to aquatic habitat or species							
Vehicle collisions lead to mortality of turtles and Rakali during operation of proposal	Unlikely	Negligible	Very Low	The following measures outlined in MM17 (Fauna management during operation) would be implemented to minimise the effect on turtles and rakali:	Rare	Negligible	Very Low

Effect pathway	Unmitigated risks			Safeguards	Residual risks		
	Likelihood	Consequence	Risk rating		Likelihood	Consequence	Risk rating
				All operation personnel would be informed of environmental responsibility with respect to the protection of aquatic fauna and their habitat. All vehicles will be required to remain on designated tracks and not drive through water, where possible, and avoid established no-go sensitive areas.			

7.2 Matters of National and State environmental significance

The following section assesses how the effect pathways discussed above (summarised in **Table 7-1**) could specifically impact on matters of national environmental significance (MNES) under the EPBC Act, and threatened species and communities under the FM Act, identified as being present or likely to be present in the study area. The two types of MNES identified in the study area are Vulnerable (Murray Cod) and Endangered (Silver Perch) species. Further to this, the Freshwater Catfish population in the Yanco Creek System is considered threatened (FM Act), and the entire study area is representative of the Lower Murray River aquatic ecological community which means that the whole fish and invertebrate community is listed as Endangered under the FM Act.

The significant impact criteria for these MNES are outlined by DotE (2013) and summarised here in **Table 7-2**. These criteria provide a clear framework for the impact assessment and, while they are developed specifically for MNES, the same has been used to assess potential impacts to State significant species and communities in the absence of a State specific framework. As the risk pathways that may affect the aquatic community are considered as a whole in the section above, there is considerable overlap when assessing the risk to MNES specifically. Each of the criteria are addressed in **Table 7-3** where we provide a significant impact assessment for the construction and operation phases of the proposal including expected or potential impacts, safeguards and residual impacts expected following implementation of safeguards. The risk posed to the MNES is considered under the assumption that the safeguards outlined in **Table 6-1** are implemented as in the section above. For species listed as Vulnerable, the term 'important population' is used in a number of the significant impact criteria. However, the precise definition of important population is not clearly defined. For the purpose of this assessment, we consider 'important populations' of a species to be populations which are defined as strongholds within relevant Species Profile and Threats Database (SPRAT) profiles (Report (environment.gov.au)), or by recovery plans for the target species.

To summarise the results of the MNES significant impact assessment, all effect pathways from construction and operation of the proposal were judged to pose a low to insignificant risk of impact to the national and State listed species, populations, and communities following adoption of the proposed safeguards.

Table 7-2 EPBC Significant Impact Criteria

Criteria	Critically Endangered and Endangered Species	Vulnerable Species
A	Lead to a long-term decrease in the size of a population	Lead to a long-term decrease in the size of an important population of a species
B	Reduce the area of occupancy of the species	Reduce the area of occupancy of an important population
C	Fragment an existing population into two or more populations	Fragment an existing important population into two or more populations
D	Adversely affect habitat critical to the survival of a species	Adversely affect habitat critical to the survival of a species
E	Disrupt the breeding cycle of a population	Disrupt the breeding cycle of an important population
F	Modify, destroy, remove, isolate or decrease the availability or quality of habitat to the extent that the species is likely to decline	Modify, destroy, remove or isolate or decrease the availability or quality of habitat to the extent that the species is likely to decline
G	Result in harmful invasive species becoming established in the endangered or critically endangered species' habitat	Result in invasive species that are harmful to a vulnerable species becoming established in the vulnerable species' habitat

Criteria	Critically Endangered and Endangered Species	Vulnerable Species
H	Introduce disease that may cause the species to decline	Introduce disease that may cause the species to decline
I	Interfere with the recovery of the species	Interfere with the recovery of the species

Adapted from Commonwealth Significant Impact Guidelines 1.1 Matters of National Environmental Significance DotE (2013).

Table 7-3 Significant Impact Assessment for MNES and State listed species and communities identified as 'present' or 'likely to occur' in the Billabong Creek Regulators study area

EPBC significant impact criteria A to I (**Table 7-2**) are considered. Note that both the species treated here are present within the study area. VU = Vulnerable, E = Endangered, CE = Critically Endangered.

MNES name	EPBC Act / FM Act	Expected or Potential Impact	Safeguards	Significant Impact Assessment (following safeguards) against relevant significant impact criteria
Construction Phase				
Murray Cod **Silver Perch** **Freshwater Catfish** **Murray Crayfish** **Lowland Murray River Drainage System Endangered Ecological Community**	VU / Not listed E / VU Not listed / E population Not listed / VU Not listed / E community	Minor impacts are possible (risk ratings are Medium or lower) through some impact pathways (e.g., temporary changes in water quality and loss of small areas of potential habitat), but they are not considered significant under the EPBC Act.	MM1 – General CEMP MM2 – Erosion and sediment control during construction MM3 – Spills and leaks during construction MM4 – Concrete works MM5 – Water quality monitoring MM6 – Fish passage management during construction MM7 – Weed and pathogen management MM8 – Aquatic habitat disturbance	Significant impacts are considered unlikely. A, B, C: No important Murray Cod or Silver Perch populations have been identified in the study area, so the operation of the proposal would not impact on one. Regardless, it is unlikely that the construction phase of the proposal would lead to a decrease in the size, area of occupancy, or connectivity of Murray Cod and Silver Perch populations. The construction footprint is small and the impacts on downstream water quality are considered minor and temporary if the listed safeguards are followed. Furthermore, the potential for a temporary loss of connectivity is considered minor as fish passage would be maintained throughout the construction process and the construction period is short (less than 13 months) relative to the life-span of these species. If the species were to become entrapped within cofferdams, safeguards are in place to have them safely removed. D: It is unlikely that habitat critical to survival of Murray Cod or Silver Perch would be adversely impacted by the proposed construction. This is by virtue of the small construction footprint and the proposed safeguards. Potential water quality impacts which would affect critical habitat include erosion and sedimentation. Safeguards have been proposed for each of these broad impacts, which would minimise the likelihood or consequence of an impact to the species. E: As the construction areas are small, the physical habitat (e.g. snags) that may be impacted on is limited and the construction works would occur over a

MNES name	EPBC Act / FM Act	Expected or Potential Impact	Safeguards	Significant Impact Assessment (following safeguards) against relevant significant impact criteria
			MM9 – Reinstatement MM10 – Pest control MM11 – Fauna management	short timeframe. Safeguards to prevent downstream water quality impacts would also help mitigate any impact to breeding populations within lower Billabong Creek, Edward, and Murray rivers. F: Construction would not destroy, remove, isolate, or decrease the availability or quality of habitat to the extent that the species is likely to decline. The construction footprint is small and relatively unintrusive and the construction activities are temporary. The regulators themselves occupy a similar area to the existing weir structures, and the associated fishways would facilitate upstream fish movement, increasing connectivity for fish. Furthermore, safeguards are in place to reinstate any large woody habitat removed, and to rehabilitate impacted banks and riparian vegetation. G: The construction phase of the proposal is unlikely to lead to an increase in invasive species as the safeguards in place would minimise the risk of any new species being introduced during construction and the construction activities themselves would not improve habitat for exotic species. H: Introduction of disease during the construction phase is unlikely if proposed hygiene protocols in the safeguards are implemented. I: The National Murray Cod Recovery Team (NMCRT) (2010) lists threats to Murray Cod, which include habitat degradation, lowered water quality, barriers, and alien species. The construction phase of the proposal is unlikely to exacerbate any of the listed threats if proposed safeguards are implemented, thus the potential for recovery of the species is unchanged. Key threats to Silver Perch relevant to the construction phase are provided by Koehn *et al.* (2020). These include barriers to longitudinal connectivity, decreased water quality and being sucked into pumps. Each of these risks are adequately accounted for in the construction plan and safeguards proposed as part of the construction phase, and the proposal is unlikely to exacerbate any of the listed threats.

MNES name	EPBC Act / FM Act	Expected or Potential Impact	Safeguards	Significant Impact Assessment (following safeguards) against relevant significant impact criteria
Operation Phase				
Murray Cod **Silver Perch** **Freshwater Catfish** **Murray Crayfish** **Lowland Murray River Drainage System Endangered Ecological Community**	VU / Not listed E / VU Not listed / En population Not listed / VU Not listed / En community	Safeguards, in addition to the proposal operation and construction plans, are expected to effectively minimise the risk likelihood of any potential impacts during operation (no identified risks had residual risk likelihoods greater than Unlikely or risk ratings greater than Medium). As such adhering to these plans and safeguards would adequately minimise the risk of any impact on conservation listed fishes within the proposal area and in downstream reaches.	MM12 – Hydrology MM13 – Erosion and sedimentation during operation MM14 – Spills and leaks during operation MM15 – Fish passage management during operation MM16 – Water quality management downstream of new regulators MM17 – Fauna management during operation	Significant impacts are considered unlikely. A, B, C: No important Murray Cod or Silver Perch populations have been identified in the study area, so the operation of the proposal would not impact on one. Potential water quality impacts include erosion and sedimentation. Safeguards have been proposed for these broad impacts, which would minimise the likelihood or consequence of an impact to the species from operation of the proposal. There is the potential that the proposal could change the stream hydrology and hydraulics in such a way that would impact on these species or remove critical habitat, but the modelling results suggests that any such impacts would be negligible. Rather, the proposal would more often lead to slight improvements in regard to the hydrological and hydraulic nature of fish habitat. D: It is unlikely that habitat critical to survival of Murray Cod or Silver Perch would be adversely impacted. This is by virtue of the minimal change to aspects of stream hydrology and hydraulics that are critical to these fish communities. In particular, lotic (flowing) habitat would be preserved during the standard operating limits of the regulators, and in some cases increased. Some reductions in lotic habitat area are predicted to occur at Hartwood Regulator during maximum operating flows at the full supply level, and during minimum operating flows between the normal operating limit and full supply level, although these conditions would be minimised under the operating plan to reduce any negative impact to the aquatic community. Potential water quality impacts which would affect critical habitat include changes to geomorphological values leading to erosion and sedimentation. Safeguards have been proposed for each of these broad impacts, which would minimise the likelihood and/or consequence of an impact to the species.

MNES name	EPBC Act / FM Act	Expected or Potential Impact	Safeguards	Significant Impact Assessment (following safeguards) against relevant significant impact criteria
				E: Hydrological and hydraulic modelling indicates that elements of the flow regime that are critical to spawning in Murray Cod and Silver Perch, and other flow sensitive species would be largely unchanged and, in some aspects, improved by the proposal. Temperature is also a strong spawning que for Murray Cod, but stream temperature is no expected to be changed by operation of the proposal. Negligible long-term impacts on water quality are also projected if safeguards are followed. Furthermore, no significant change to the physical habitat available to these species (e.g. snag removal) is expected. Therefore, breeding success in the study area and downstream in Billabong Creek and the Edward and Murray rivers is unlikely to be impacted by operation of the proposal. F: Operation would not destroy, remove, isolate or decrease the availability or quality of habitat to the extent that the species is likely to decline. The fishways associated with the regulators would facilitate upstream fish movement, increasing connectivity for fish. Hydrological and hydraulic alteration is not predicted to negatively impact on habitat quality for the aquatic community. Furthermore, long-term impacts on water quality are not expected if safeguards are followed. G: The operation phase of the proposal is unlikely to lead to an increase in invasive species. First, the regional invasive species community are already present in the study area and can already access the site freely from upstream areas. Second, while the new fishways would likely increase exotic fish passage the difference is negligible as migration isn't critical to the life history stage of the exotic species and they can breed in the available habitat without migration. Third, the proposal is not expected to greatly increase suitable habitat for invasive species. Rather, it is expected to reduce the availability of lentic habitat more often, which is preferred by the exotic fish community.

MNES name	EPBC Act / FM Act	Expected or Potential Impact	Safeguards	Significant Impact Assessment (following safeguards) against relevant significant impact criteria
				H: Introduction of disease during the operation phase is unlikely. While fish passage would likely improve due to the installation of the regulator, there has not been any evidence to suggest that fish communities in the surrounding area are carrying novel diseases, or that they are disproportionately impacted by disease. I: NMCRT (2010) lists threats to Murray Cod, which include habitat degradation, lowered water quality, barriers, and alien species. Silver Perch are sensitive to a similar range of threats (Koehn *et al.* 2020). The operations phase of the proposal is unlikely to exacerbate any of the listed threats if proposed safeguards are implemented. Physical habitat (flowing habitat, woody debris, riparian cover) is not projected to decline due to operation of the proposal, water quality is not expected to be impacted upon by operation, and it is likely that fish passage would improve overall due to the installation of the new regulators. Thus, the potential for recovery of these species is unchanged.

7.3 Impact on NSW water quality objectives

In accordance with SEAR 5 (D), an assessment of the impacts of the construction and operation of the proposal has been undertaken in accordance with relevant guidelines for nominated water quality objectives. A brief summary of the current water quality with respect to each WQO and a qualitative assessment of the potential impacts that the proposal may have on meeting these objectives during construction and operation is provided in **Table 7-4.**

Table 7-4 Surface water quality objectives and potential impacts during construction and operation

Water quality objective	Indicators	Proposal related impacts during construction and operation
Aquatic ecosystems: *Maintaining or improving the ecological condition of waterbodies and their riparian zones over the long term*	▪ Total phosphorus ▪ Total nitrogen ▪ Chlorophyll-a ▪ Turbidity ▪ Electrical conductivity ▪ Dissolved oxygen ▪ pH ▪ Chemical contaminants or toxicants	Current water quality data for Billabong Creek at various locations does not achieve this WQO due to elevated nutrients and turbidity, occasional low dissolved oxygen and elevated electrical conductivity that were outside acceptable ranges. Construction Construction of the proposal presents a number of risks to the surface water quality of Billabong Creek including potential sediment laden runoff entering the creek from construction compounds, stockpiles and laydown areas in proximity to the waterway, accidental leaks or spills of hydrocarbons and instream work associated with decommissioning of the existing weir and construction of the new structure. These risks could impact on the key indicators that are necessary for protection of aquatic ecosystems and which are currently not meeting the relevant trigger values. Key indicators that have the potential to be impacted would be turbidity and suspended solids which could temporarily exceed background concentrations and/or the trigger value. Nutrient concentrations in soils in the area are influenced by land use, soil disturbance and human activity upstream and mobilisation of sediments in the waterways could result in increased concentrations of nutrients and toxicants if bound to the soil particles. Further increases in nutrient concentrations which are already elevated in Billabong Creek and increase with distance downstream could result in increased risk of algal blooms and eutrophication and in turn impact on dissolved oxygen levels. Currently, electrical conductivity generally complies with the WRP Target although construction presents a temporary risk of further increases due to disturbance of saline soils which could alter the salinity of water. Changes in salinity could alter instream biodiversity and ecosystem function. In order to manage risks to water quality and protect this WQO, a variety of management measures will be applied including silt curtains, sediment fences, sumps and regular water quality monitoring to manage sediment and saline water. Whilst this WQO is currently not being met the implementation of management measures would ensure that construction of the

Water quality objective	Indicators	Proposal related impacts during construction and operation
		proposal would not impact on achieving the water quality objective "protection of aquatic ecosystems" of Billabong Creek in the future. Operation Operation of the proposal presents a risk to surface water quality of Billabong Creek including mobilisation of sediment and additional source of pollution from accidental spills. When the regulators become operational, there is a risk of scour which can contribute sediment to the waterway. Sediment may also enter the waterways from runoff from unsealed access tracks used to access the structures for maintenance and operation. Mobilisation of sediment may result in increased turbidity and nutrients such that they do not meet recommended guideline trigger values for protection of aquatic ecosystems. Additionally, there is a risk of toxicants entering the water from accidental leaks and spills which may also exceed recommend guideline values. The design has provided sedimentation controls such as rock beaching and geotextile layers to prevent scouring of Billabong Creek upstream and downstream of the regulators. Additionally spills and leaks will be managed in accordance with the operation and management procedures. As such, the operation of the new Hartwood and Wanganella Regulators is not expected to impact on achieving the WQO for the protection of aquatic ecosystems.
Visual amenity: *To maintain the aesthetic quality of water*	▪ Visual clarity and colour ▪ Surface films and debris ▪ Nuisance organisms	Whilst data is limited, the WQO 'visual amenity' is likely not being met in Billabong Creek due to elevated turbidity levels and occasions of algal blooms/blackwater events. Construction Construction of the proposal could impact on achieving the water quality objective visual amenity if turbidity levels increased which in turn would result in poor water clarity. Increases in turbidity could results from release of highly turbid water during dewatering of the cofferdams, or from erosion and sedimentation. Visual amenity may also be impacted if dust or litter is mobilised during construction. Environmental management measures will be implemented to manage sediment, dust and litter and accidental spills to ensure that the aesthetic quality of Billabong Creek at each site would not be reduced and that there would be no impact to achieving this WQO during construction of the proposal. Operation Visual amenity may be impacted due to sedimentation (due to runoff from unsealed access tracks and scour of the new structure) which may result in poor visual clarity. Increased sediment loads downstream of the new structure will be mitigated via scour protection. Other water quality risks associated with maintenance

Water quality objective	Indicators	Proposal related impacts during construction and operation
		activities will be managed via the operation and management procedures. Therefore, it is not expected that the operation of the proposal would impact on the long-term achievement of the WQO visual amenity for Billabong Creek.
Secondary contact recreation: *Maintaining or improving water quality of activities such as boating and wading, where there is a low probability of water being swallowed*	▪ Enterococci ▪ Algae and blue-green algae ▪ Chemical contaminants	Based on existing literature regarding algal alerts in Billabong Creek, harmful algal numbers appear to be low and therefore it is assumed that the WQO secondary contact recreation is currently being achieved. <u>Construction</u> As mentioned previously, construction of the proposal if it increases sediment and nutrients may result in an increased risk of algal blooms which can impact on suitability for recreation. Additionally, increased sediment may contain elevated concentrations of metals and toxicants that are hazardous to human health. Whilst not routinely monitored, enterococci and other pathogens may be present in Billabong Creek in elevated numbers from upstream sources (e.g. agricultural runoff) and may pose a risk to recreational suitability. However, construction of the proposal is not expected to introduce pathogens into Billabong Creek. Whilst there may be occasions of poor water quality during construction (eg following rainfall) with the implementation of management measures, the quality of water is not expected to deteriorate such that the existing water quality would not meet the NHMRC (2008) guidelines. Therefore, construction of the proposal would ensure that secondary contact recreation in Billabong Creek continues to be achieved. <u>Operation</u> The operation of the regulators is not expected to contribute pathogens to Billabong Creek. Additionally accidental leaks and spills if they occur can also contribute contaminants to the waterway. With the implementation of appropriate operational management measures to manage accident spills, it is not expected that the operation of the new structures would impact on secondary contact recreation and this WQO would continue to be protected.
Primary contact recreation: *Maintaining or improving water quality of activities such as swimming in which there is high probability of water being swallowed*	▪ Cyanobacterial biovolume ▪ Toxic cyanobacterial biovolume ▪ Potentially toxic cyanobacteria ▪ Enterococci	Based on existing literature regarding algal alerts in Billabong Creek, harmful algal numbers appear to be low and therefore it is assumed that the WQO primary contact recreation is currently being achieved. <u>Construction</u> As mentioned previously, construction of the proposal if is increases sediment and nutrients may result in an increased risk of algal blooms which can impact on suitability for recreation. Additionally, increased sediment may contain elevated concentrations of metals and toxicants that are hazardous to human health.

Water quality objective	Indicators	Proposal related impacts during construction and operation
	▪ Protozoan	Whilst not routinely monitored, enterococci and other pathogens may be present in Billabong Creek in elevated numbers from upstream sources (eg agricultural runoff, livestock and wildlife in riparian areas) and may pose a risk to recreational suitability. However, construction of the proposal is not expected to introduce pathogens into Billabong Creek. Whilst there may be occasions of poor water quality during construction (e.g. following rainfall) with the implementation of management measures, the quality of water is not expected to deteriorate such that the existing water quality would not meet the NHMRC (2008) guidelines. Therefore, construction of the proposal would ensure that primary contact recreation in Billabong Creek continues to be achieved. <u>Operation</u> The operation of the regulators is not expected to contribute pathogens to Billabong Creek. Additionally accidental leaks and spills if they occur can also contribute contaminants to the waterway. With the implementation of appropriate operational management measures to manage accident spills, it is not expected that the operation of the new structures would impact on primary contact recreation and this WQO would continue to be protected.
Livestock water supply: *Protecting water quality to maximise the production of healthy livestock.*	▪ Algae and blue-green algae ▪ Salinity (electrical conductivity) ▪ Thermotolerant coliforms (faecal coliforms) ▪ Chemical contaminants	Data for a limited number of indicators infer that the WQO 'Livestock water supply' is currently being achieved with limited algal alerts and salinity that is generally within acceptable ranges for protection of the WQO. <u>Construction</u> The construction of the proposal has the potential to increase salinity due to disturbance of saline soils. Construction also presents a risk of algal blooms if nutrient concentrations increase as a result of increased sediments. Contaminants may also be introduced via accidental spills or bound to sediment laden runoff. Construction is not expected to introduce thermotolerant coliforms. Appropriate mitigation measures will be implemented to manage these risks such that concentrations of key water quality indicators continue to meet relevant guideline criteria and that this WQO continues to be met. <u>Operation</u> As mentioned previously, the operation of the new regulators would not result in an increase in pathogens. With the implemented of operational management measures to manage accidental spills and leaks, an increase in chemical contaminants is also unlikely. Therefore, the operation of the new regulators are not expected to impact on achieving the WQO of Livestock water supply in Billabong Creek.

Water quality objective	Indicators	Proposal related impacts during construction and operation
Irrigation water supply: *Protecting the quality of waters applied to crops and pastures.*	▪ Algae and blue-green algae ▪ Salinity (electrical conductivity) ▪ Thermotolerant coliforms (faecal coliforms) ▪ Heavy metals and metalloids ▪	Data for a limited number of indicators infer that the WQO 'Irrigation water supply' is generally being achieved as salinity and algal counts are generally within acceptable ranges. <u>Construction</u> The construction of the proposal has the potential to increase salinity due to disturbance of saline soils. Construction also presents a risk of algal blooms if nutrient concentrations increase as a result of increased sediments. Contaminants may also be introduced via accidental spills or bound to sediment laden runoff. Construction is not expected to introduce thermotolerant coliforms. Appropriate mitigation measures will be implemented to manage these risks such that concentrations of key water quality indicators continue to meet relevant guideline criteria and that the WQO continues to be met. <u>Operation</u> The operation of the new regulators would not result in an increase in pathogens. With the implemented of operational management measures to manage accidental spills and leaks, an increase in chemical contaminants is also unlikely. Therefore the operation of the new regulators are not expected to impact on achieving the WQO of Livestock water supply in Billabong Creek.
Homestead water supply: *Protecting water quality for domestic use in homesteads, including drinking, cooking and bathing*	▪ Blue-green algae ▪ Turbidity ▪ Total dissolved solids ▪ Faecal coliforms ▪ pH ▪ Chemical contaminants	Based on existing water quality, protection of the WQO 'homestead water supply' is only partially met due to variable turbidity which exceeds the limit of 5NTU. Other indicators where data were available fell within the recommended limits. <u>Construction</u> Construction of the proposal could impact on achieving the water quality if turbidity levels increased which could occur from the release of highly turbid water during dewatering of the cofferdams, from instream works or from erosion and sedimentation. The construction of the proposal has the potential to increase salinity due to disturbance of saline soils. Construction also presents a risk of algal blooms if nutrient concentrations increase as a result of increased sediments. Contaminants may also be introduced via accidental spills or bound to sediment laden runoff. Construction is not expected to introduce thermotolerant coliforms. Appropriate mitigation measures will be implemented to manage these risks such that concentrations of key water quality indicators continue meet relevant guideline criteria and that the WQO continues to be met for those indicators currently being achieved and works towards achieving the guidelines for those indicators not currently meeting the required limits. <u>Operation</u>

Water quality objective	Indicators	Proposal related impacts during construction and operation
		The operation of the new regulators is not expected to introduce key toxicants or pathogens into Billabong Creek nor is it likely to increase the occurrence of algal blooms. Therefore, the operation of the proposal would not impact on achieving the WQO homestead water supply.
Aquatic foods (cooked): *Protection of water quality so that is suitable for the production of aquatic foods for human consumption and aquaculture activities*	▪ Algae and Blue-green algae ▪ Faecal coliforms ▪ Toxicants ▪ Physio-chemical indicators	Lack of water quality data for key indicators required for the protection of aquatic foods (cooked) cannot confirm if this WQO is currently being met. <u>Construction</u> The construction of the proposal as the potential to temporarily increase concentrations of physio-chemical indicators including suspended solids such that they may exceed guidelines for protection of the WQO. Increases in suspended solids may result in increased nutrients which present a risk for an increase in the occurrence of algal blooms or toxicants which can increase the toxicity of water. This can then result in water quality that is unsuitable for the production of aquatic foods that are safe to consume. Installation of silt curtains, sediment fences and sumps and other mitigation measures will reduce this risk of increased sediments. Therefore, with implementation of management measures, the construction of the proposal is unlikely to have a significant impact on aquatic food values. <u>Operation</u> The operation of the new regulators is not expected to introduce key toxicants or pathogens into Billabong Creek such that they would impact on the suitability for consumption of aquatic foods (cooked).

7.4 Threatening processes

With regards to aquatic ecology values, five potentially threatening processes listed under the EPBC Act may apply to the study area.

These threatening processes are listed in **Table 7-5** along with an appraisal of their likelihood of occurrence, consequence during construction and operation of the proposal. In short, if the proposed safeguards are followed, none of the processes that are likely to be exacerbated by the proposal.

Table 7-5 Key threatening processes related to the proposal

Residual risk likelihood of threatening process being exacerbated			
Listed threatening process	**Construction**	**Operation**	**Reasoning/Mitigation**
Fisheries Management Act 1994			
Installation and operation of instream structures and other mechanisms that alter natural flow regimes of rivers and streams	**Consequence**: Major **Likelihood**: Rare **Risk Rating**: Low	**Consequence**: Major **Likelihood**: Unlikely **Risk Rating**: Medium	During construction, flows will be maintained along the channel during the construction period. A degree of flow alteration will be caused by the construction of the cofferdams, but the impacts would likely be localised and short-lived (less than a year). Fish passage would be maintained in and out of the area. As such, the likelihood of construction impacting significantly on the natural flow regime in a way that would cause harm to the aquatic community is considered Unlikely. The Yanco Creek System is highly regulated which has resulted in the decline of the resident fish community (Sharpe *et al.*, 2013). With that in mind, operation of the proposal is not expected to lead to changes in stream hydrology that will negatively impact of the aquatic community. Rather, some minor benefits may result. The risk likelihood of operation exacerbating impacts on the natural flow regime in the study area is considered Unlikely.
Degradation of native riparian vegetation along NSW water courses	**Consequence**: Minor **Likelihood**: Unlikely **Risk Rating**: Low	**Consequence**: Minor **Likelihood**: Rare **Risk Rating**: Low	Construction of the new regulator is expected to require the removal of some native vegetation, including large trees. Vegetation removal may be associated with construction of infrastructure, access track widening, stockpiles and borrow pits, site offices, parking, etc. There is also potential for construction works to increase dust pollution, impacting vegetation growth by reducing photosynthesis. Efforts have been made throughout the planning and design phases for the proposed construction to avoid and minimise impacts to vegetation by utilising existing cleared/disturbed areas and tracks to build the necessary infrastructure. Impacts to biodiversity values are expected to be limited as most areas of native vegetation that are proposed to be impacted are adjacent to existing vehicle tracks and areas of previous human disturbance. As such the construction footprint already contains existing disturbed, degraded and/or modified low quality vegetation. Impacts can be mitigated through a range of approaches including minimising the removal of mature trees, retaining vegetation where possible along drainage lines and waterways, and reinstating vegetation as soon as possible (MM 9). As such, the residual risk likelihood of proposal construction exacerbating impacts on native riparian vegetation is considered Unlikely. Operation of the proposal is not expected to lead to the degradation of native riparian vegetation. No further vegetation clearing would be necessary. With this in mind, the residual likelihood of proposal operation exacerbating impacts on native riparian vegetation is considered Rare.

Introduction of fish to waters within a river catchment outside their natural range	**Consequence:** Major **Likelihood:** Rare **Risk Rating:** Low	**Consequence:** Major **Likelihood:** Rare **Risk Rating:** Low	The Action Statement related to this threatening process (Fisheries Scientific Committee, 2008b) states this is the '*Deliberate or accidental introduction of live fish into public or private waters within a Victorian river catchment in which the taxon to which the fish belongs cannot reliably be inferred to have been present prior to the year 1770 AD*'. We take it that this also relates to NSW river catchments. The Yanco Creek System has the complete compliment of invasive fish species known from the lowland rivers of the MDB, so the increase in fish passage afforded by the proposal would not increase the risk of introduction of exotic species. Regardless, any risk of accidental introduction of exotic fish to the proposal site would be addressed by (MM7) that requires all equipment to be cleaned before accessing the proposal site. The residual likelihood of this proposal exacerbating this threatening process is 'rare' for both construction and operation.
Removal of large woody debris from NSW rivers and streams	**Consequence:** Minor **Likelihood:** Rare **Risk Rating:** Low	**Consequence:** Minor **Likelihood:** Rare **Risk Rating:** Low	During construction of infrastructure, snags and other large woody debris may be removed and relocated if they interfere with works resulting in the loss of structural habitat for aquatic species. Some large woody debris was observable in the construction footprints during aquatic habitat surveys related to this proposal and it was also common in the surrounding area. However, any snags and large woody debris that are removed would be returned to the waterway in a nearby location resulting in no net loss of habitat (MM8). It is expected that any impacted aquatic fauna would simply relocate to other woody debris present in the area. Taken as a whole, the proposal construction will at worst only remove large woody debris temporarily before relocating it, so the residual likelihood of this threatening process being exacerbated is Rare. No impacts to the contribution of large woody debris to waterways are expected during operation and the residual likelihood of this threatening process being exacerbated is Rare.
Hook and line fishing in areas important for the survival of threatened fish species	**Consequence:** Negligible **Likelihood:** Rare **Risk Rating:** Low	**Consequence:** Negligible **Likelihood:** Rare **Risk Rating:** Low	It is highly unlikely that proposal construction and operation would change this. As such the residual likelihood of this threatening process being exacerbated is 'rare'.
Environment Protection and Biodiversity Conservation Act 1999			
Land clearance	**Consequence:** Minor	**Consequence:** Minor	Construction would involve the removal of some native vegetation, likely including large trees. Vegetation removal would be associated with the widening and extending existing access tracks (2.805 km of track works at Hartwood Weir and 1.478 km at Wanganella Weir), and the construction of stockpiles and borrow pits, site offices, parking, etc. Efforts have been made throughout the planning and design phases for the proposed construction to avoid and minimise impacts to

	Likelihood: Unlikely **Risk Rating**: Low	**Likelihood**: Rare **Risk Rating**: Low	vegetation by utilising existing cleared/disturbed areas and tracks to build the necessary infrastructure. Impacts to biodiversity values are expected to be limited as most areas of native vegetation that are proposed to be impacted are adjacent to existing vehicle tracks and areas of previous human disturbance. As such the construction footprint already contains existing disturbed, degraded and/or modified vegetation. Impacts can be mitigated through a range of approaches including minimising the removal of mature trees, limiting the pruning of trees, retaining vegetation where possible along drainage lines and waterways, and reinstating vegetation as soon as possible (MM9). In summary, some vegetation would likely be disturbed (removed or pruned). However, the study area has an existing access track and cleared areas, the proposal footprint would be small, the vegetation is already disturbed, and impacted areas will be rehabilitated. As such, the residual likelihood of an impact during construction is Unlikely. During operation there is no projected risk of land clearance, so the residual risk is considered Rare.
Loss and degradation of native plant and animal habitat by invasion of escaped garden plants, including aquatic plants	**Consequence**: Major **Likelihood**: Unlikely **Risk Rating**: Medium	**Consequence**: Major **Likelihood**: Rare **Risk Rating**: Low	Construction activities may lead to introduction of weeds that become established in aquatic habitats, leading to conditions unsuitable for the local aquatic flora and fauna. Management of weeds prior to and post-construction would be outlined in a weed and pathogen control plan within the CEMP. During construction, strict measures would be put in place to mitigate the spread of weeds to the study area (MM7). As such, the residual likelihood of an impact during construction is Unlikely. During operation, maintenance vehicles may introduce weeds, but would not enter the water. Furthermore, MM7 would still apply and weed monitoring would take place during the construction period to help identify and eliminate any weeds. So, the residual likelihood of an impact during operation is Rare.
Novel biota and their impact on biodiversity	**Consequence**: Major **Likelihood**: Rare **Risk Rating**: Low	**Consequence**: Major **Likelihood**: Rare **Risk Rating**: Low	The construction and operation of the proposal is not projected to cause significant changes in stream hydrology or habitat that would lead to an increase in suitability for novel (exotic) biota. Little new habitat would be inundated either. The system already contains a full complement of exotic fish species that occur in lowland Murray River streams. The risk of spread of exotic species due to the construction and operation of the proposal is also considered Rare. As such the residual likelihood of an impact during construction and operation is Rare.
Predation by European Red Fox and feral cats	**Consequence**: Minor **Likelihood**: Unlikely **Risk Rating**: Low	**Consequence**: Minor **Likelihood**: Rare **Risk Rating**: Low	Poor waste and garbage management around construction sites might attract invasive predators (e.g. foxes and cats), and any increased access for vehicles to the proposal footprint may also provide better access predators. Increased abundance of these species increases the risk of predation on native fauna such as Platypus, Rakali, and turtles. That said, most of the proposed access tracks and infrastructure are in already heavily disturbed areas. The proposal is considered Unlikely to increase fox and cat access to the study area and MM10 includes a provision for sealing rubbish in bins during the day and removing it from the site at the end of each day so that it does not attract animals. Operation of the

			proposal is also considered Unlikely to impact on predation by Red Fox or feral cats in any way. As such the residual likelihood of an impact during construction and operation is Rare.

8. Aquatic Biodiversity Offset Strategy

The SEARS include a requirement that an Aquatic Biodiversity Offsets Strategy is adequately funded to mitigate and manage impacts of the Billabong Creek Environmental Water Regulators project during construction and subsequent operation, focusing on protecting and improving the biodiversity and conservation values of Billabong Creek, its biota, and associated riparian zones in the medium to long term.

A project specific offset strategy commensurate with the risk and impact to Key Fish Habitat (KFH) features is subject to ongoing negotiations between DCCEEW and NSW DPI Fisheries, so the purpose of this section is to outline considerations relevant to the strategy as they related to the proposal construction and operation.

The key guidelines are the *NSW Biodiversity Offsets Policy for Major Projects* (State of NSW and Office of Environment and Heritage, 2014) (FBA) which provide a standard method for determining offsets for areas where there is a predicted loss of biodiversity, including aquatic biodiversity. While the FBA broadly outlines the approach, the guidelines refer to the *Policy and Guidelines for Fish Habitat Conservation and Management* (DPI, 2013a) as the primary document that details the process to be followed with respect to aquatic biodiversity offsets. The FBA states that:

"to meet aquatic biodiversity offset requirements, the NSW policy and guidelines (DPI, 2013) will classify the habitat types being offset. It will then apply a ratio and dollar value to determine the total dollar value of the offset required to be implemented by the proponent via on-ground protection or rehabilitation works, or placed into the aquatic biodiversity offset fund. The proponent will have the opportunity to reduce this cost through direct negotiation with Fisheries NSW, subject to meeting the minimum overall offset ratio requirements".

According to the NSW policy and guidelines (DPI, 2013), aquatic biodiversity offsets relate to waterways that have been identified as KFH by NSW KFH Mapping (DPI, 2021a). In the NSW policy and guidelines (DPI, 2013) this is stated as *"NSW DPI will focus the application of the FM Act, FM Regulations and the NSW Policy and Guidelines for Fish Habitat Conservation and Management on KFH (as defined in the guidelines)"*. The NSW policy and guidelines (DPI, 2013) further clarify that *"NSW DPI enforces a 'no net loss' of KFH habitat policy as a permit condition or condition of consent. This may require proponents to conduct habitat rehabilitation and/or provide environmental compensation. A monetary bond or payment may be required to be lodged with NSW DPI to ensure the works are completed in accordance with the permit conditions"*. The guidelines also indicate that mitigation and compensation "*may include re-establishing habitat that has been removed or otherwise damaged, re-instating fish passage along waterways (removing barriers or building fishways) and improving water quality*".

The general principle which should be applied to the offset strategy is:

"…proponents should, as a first priority, aim to avoid impacts upon key fish habitats. Where avoidance is impossible or impractical, proponents should then aim to minimise impacts. Any remaining impacts should then be offset with compensatory works".

Section 3.3.3.2 of the NSW policy and guidelines (DPI, 2013) provides guidance for calculating monetary offsets, where it is stated that *"NSW DPI calculates habitat compensation on a minimum 2:1 basis for all key fish habitat (TYPE 1-3) to help redress other indirect impacts of development.*

The calculation of aquatic biodiversity offsets is based on a current (July 2024) rate of $114.40 per square metre to meet the 2:1 habitat offset requirement.

As the project area is classified as 'Type 1- Highly Sensitive Key Fish Habitat' it requires an aquatic habitat offset strategy including monetary offsets to be proposed in accordance with the N*SW policy and guidelines* (DPI, 2013). To help achieve this requirement NSW DPI Fisheries has recently completed an aquatic habitat mapping investigation of Billabong Creek, upstream and downstream of the proposed Hartwood and

Wanganella regulators. The aim was to better quantify the KFH features and potential impacts / changes to them due to the proposal to aid in offset calculations.

Furthermore, the potential impacts to hydraulic fish habitat have been quantitatively estimated in this report. Potential changes in the timing, duration and frequency of modelled surface water levels within the weir pools for the Hartwood and Wanganella regulators have been assessed in the Billabong Creek Regulators Hydrology Assessment (Jacobs (2024a) and are summarised below.

These findings, and potentially other factors raised in this report, can be used to develop an appropriate aquatic biodiversity strategy for the proposal. In the sections below we describe the findings of these reports and this impact assessment as they relate to the offset strategy.

8.1 Changes to Key Fish Habitat

8.1.1 Construction impacts

The construction works associated with the proposed regulators and removal of the existing weirs may result in minor and temporary loss of KFH due to direct disturbance of streambeds, clearance of vegetation and removal of woody debris on the streambed and on the banks.

To minimise potential loss of KFH in the proposal footprint, the construction methodology proposes the following standard practices:

- To minimise downstream impacts to water quality from sedimentation, erosion and sediment controls will be established prior to any construction and a floating silt curtain would be placed downstream of the construction area in each. The impact assessment considers these standard practices to be sufficient within the context of the proposal.
- To allow continuous fish passage through the construction area, construction of the regulators and associated fishways will be carried out in two stages with the cofferdams have only ever spanning about half the width of the waterway at any one time. Also, the fishway will be constructed as part of the first stage so that fish passage will be allowed during stage two when the regulator is being constructed. The silt curtains are not considered to be a risk to fish passage as the will only obstruct the top portion of the water column. At completion, fish passage would be improved as the new fishways and regulators would allow fish passage.
- Prior to construction of instream structures, habitat features (i.e. large woody debris) that are within the instream construction area which are able to be relocated would be moved to areas upstream or downstream, in consultation with a qualified ecologist. Riparian vegetation would subsequently be reinstated in the construction footprint area after construction. Further, it is anticipated that by replacing the existing weirs fish regulator/fishways structures, tens of kilometres of additional aquatic habitat will become available to downstream fish communities.

Provided these standard practices are maintained throughout the construction phase, temporary loss of KFH is not expected to result in any long-term degradation of KFH. Accordingly, an aquatic biodiversity offset is not proposed for temporary loss of KFH.

8.1.2 Operational impacts

8.1.2.1 Regulator and fishway footprint

There will be a permanent loss of stream habitat where the regulator/fishways will be constructed. The final design for the proposed Hartwood regulator indicates that the total area of the structures (including the regulator, embankment, and fishway) is expected to be approximately 2,550m^2. Wanganella regulator is in the detailed design phase and a final design has not been reached yet, but the expected footprint is estimated to be 4,450m^2. As stated in Section 1.6 of the DPI (2013a) policy and guidelines, "…mitigation and compensation for key fish habitat loss may include re-instating fish passage along waterways (including building fishways)" therefore it is considered reasonable to exclude the 1,150m^2 (Hartwood) and 1,225m^2 (Wanganella) area that encompasses the fishway structures from the offset calculation.

8.1.2.2 Changes to hydraulic habitat

Key features of the proposed new regulator structures that relate to changes in hydraulic habitat include: (1) area to be constructed closely downstream (<100m) of the current weirs, (2) the new regulator designs include increasing the maximum weir pool heights by 0.46m (Hartwood) and 1.35m (Wanganella), and (3) by using regulators rather than the current fixed crest weirs, the weir pools will be operated at a range of levels (full supply, normal, and minimum operating limit) during different flows (maximum and minimum operating flows) depending on operational and environmental needs (settings). These changes will impact on the weir pool area, depth, and hydraulic (velocity) habitat available, depending on the operational setting. Understandably, the hydraulic changes are expected to be most prominent when the proposed weir pools are operated at full supply level.

Upstream (weir pool)

At Hartwood, upstream of the proposed regulator during maximum operating flows the pool weir pool is estimated to increase in approximate area (relative to the Hartwood Weir maximum operating flow base case) at the full supply level (+51,590 m^2) and decrease in area at the normal operating limit (-35,620 m^2) and minimum operating limit (-110,860 m^2). During minimum operating flows the pool weir pool is estimated to increase in area (relative to the Hartwood Weir minimum operating flow base case) at the full supply level (+256,930 m^2) and the normal operating limit (+82,640 m^2) and is expected to decrease at minimum operating limit (-12,570 m^2).

Changes in modelled monthly averaged water surface levels within the Hartwood Regulator weir pool are predicted to occur with operation of the Hartwood Regulator compared to existing conditions (i.e. the existing Hartwood weir). Compared to existing conditions, the water surface level in the Hartwood Regulator weir pool is predicted to be marginally higher (median 22 mm higher) in the irrigation season and median 3 mm lower in the non-irrigation season. Monthly average water surface levels for the Hartwood Regulator are modelled to exceed the median (50th%ile) water surface level of the existing Hartwood weir in 58 months during the 22-year times series (270 months total) compared to 48 months for existing conditions. The maximum number of consecutive months where water surface levels exceed the median (50th%ile) water surface level of the existing weir is predicted to be 12 months for Hartwood Regulator, compared to 8 consecutive months for the existing Hartwood weir. Operation of the Hartwood Regulator to achieve the proposed weir pool target levels will result in surface water levels within the weir pool of the regulator being higher than the median (50th%ile) water surface level of the existing Hartwood weir less frequently (-3.5%).

At Wanganella, upstream of the proposed regulator during maximum operating flows the pool weir pool is estimated to increase in approximate area (relative to the Wanganella Weir maximum operating flow base case) at the full supply level (+110,350 m^2) and normal operating limit (+190 m^2) and remain effectively the same at the minimum operating limit (-1 m^2). During minimum operating flows the weir pool is estimated to increase in area (relative to the Wanganella Weir minimum operating flow base case) at the full supply level (+172,240 m^2) and the normal operating limit (+22,630 m^2) and is expected to remain effectively the same at minimum operating limit (-20 m^2).

Changes in modelled monthly averaged water surface levels within the Wanganella Regulator weir pool are predicted to occur with operation of the Wanganella Regulator compared to existing conditions (i.e. the existing Wanganella weir). Compared to existing conditions, the water surface level in the Wanganella Regulator weir pool is predicted to be median 65 mm higher in the irrigation season and median 43 mm lower in the non-irrigation season. Monthly average water surface levels for the Wanganella Regulator are modelled to exceed the median (50th%ile) water surface level of the existing Wanganella weir in 161 months compared to 71 months for existing conditions, during the 22-year times series. There is no predicted change in the maximum number of consecutive months where water surface levels exceed the median

(50th%ile) water surface level of the existing weir (12 months) for Wanganella Regulator compared to existing conditions. Operation of the Wanganella Regulator to achieve the proposed weir pool target levels will result in surface water levels within the weir pool of the regulator being higher than the median (50th%ile) water surface level of the existing Wanganella weir +33.5% more frequently.

As discussed in **Section 5.2.2.2.1**, these changes are not expected to reduce the quality of flowing habitat in either weir pool (i.e. Hartwood or Wanganella) during the most common regulator setting where flows are at maximum operating flow and the pool is operating between the minimum and normal operating limits. However, at Hartwood there is expected to be a decrease in medium and high-quality flowing habitat, and a subsequent increase in low-quality lentic habitat, during maximum operating flows at full supply level, and during minimum operating flows between the normal operating limit and full supply level. At Wanganella during the less common flow and operating limit settings, either no change to the distribution of velocity habitat is expected, or increases in both low, moderate and high-quality flow habitat. An important consideration of the offset calculations should be that the regulator settings that lead to decreases in moderate and high-quality flow habitat (e.g. maximum operating level where the weir pool is deepest and slowest) would be minimised to reduce any potential impacts and are not expected to occur often or for long (NSW DPIE, 2022a).

Downstream

The hydraulic modelling results presented in 3Rivers (2024a and 2024b) indicated no change is expected in the water surface level downstream of either of the proposed regulators during all flow and proposed operating level settings. That said, a significant increase in water surface level is expected between the proposed and existing regulators as the new regulators lie slightly downstream of the current weirs, so some stream is proposed to become weir pool.

8.1.2.3 Changes to other key fish habitat features

NSW DPI (2024) conducted a survey if KFH features within and immediately below the proposed regulators. The report considered inundation dynamics upstream of the proposed new regulators under the proposed full supply levels only (presumably at maximum operating flows), so inundation dynamics under other operating scenarios, where the water level is lower, must be assumed. NSW DPI (2024) surveyed the following key fish habitat features which we discuss in this section:

- In-stream structural habitat (Rootballs and large woody habitat (LWH))
- In-channel benches
- Refuge pools
- Vegetation (Aquatic macrophytes and riparian vegetation)
- Floodplain wetlands (and access to them from the mainstream)
- Barriers to fish passage
- Stream bed substrate
- Aquatic macrophytes
- Refuge pools (≥ 2m deep)
- Riffle habitat.

Upstream (weir pool)

As the Hartwood and Wanganella weir pool heights and areas are expected to increase at the full supply level relative to the current levels, there is expected to be a net gain in LWH, rootballs, submerged wetland entry/exits, and inundated in-channel benches upstream of the proposed regulators. No impacts were expected for the other surveyed habitat features (e.g. refuge pools, vegetation, riffles). They also note that 4

Mile Dam, which poses a fish barrier within the Wanganella weir pool, will be drowned out at this regulator setting, providing connectivity up to Chinamans Dam.

Accurately assessing the loss or gain of key habitat features under other operational settings (that weren't addressed in NSW DPI (2024)) is difficult, but we make some general observations here. At Hartwood, the weir pool area is also expected to be greater than the current pool during minimum operating flows at the full supply level and the normal operating limit, so gains in the habitat features identified in the report (i.e. LWH, rootballs, submerged wetland entry/exits, and inundated in-channel benches upstream of the proposed regulators) would also be expected. However, the pool area would be smaller than the current pool during maximum operating flows at the normal operating limit and minimum operating limit (which are planned to occur most of the time).

At Wanganella, the weir pool area is expected to be approximately the same at the normal operating limit and minimum operating limit, so no net loss of the habitat features that are sensitive to changes in weir pool height (i.e. LWH, rootballs, submerged wetland entry/exits, and inundated in-channel benches upstream of the proposed regulators) is expected and possibly slight gains will be made. During minimum operating flows the weir pool area is expected to be greater than the current pool during the normal operating limit, and effectively the same at minimum operating limit, meaning that there will be either net gain in these key fish habitat features or no tangible net loss.

Downstream

Where the downstream boundary of the weir pools are shifted further downstream to the proposed regulator sites, NSW DPI Fisheries (2024) highlight a range of key habitat features that will be gained within the upstream weir pool, but lost from the downstream section. Given that streambank habitat features will still remain, this is not considered a net loss. Otherwise, 3Rivers (2024a and 2024b) indicated no change is expected in the water surface level downstream of either of the proposed regulators during all flow and proposed operating level scenarios, so no net loss of these key fish habitat features are expected due to the proposal.

9. Key findings and conclusions

9.1 Existing conditions

The mid Billabong Creek extends from the Colombo Creek confluence to the Yanco Creek confluence and is free-flowing upstream of Jerilderie Town Weir. Mid Billabong Creek is regulated downstream of Jerilderie by numerous weirs. The Lower Billabong Creek extends from the Yanco Creek confluence to where Billabong Creek discharges into the Edward River at Moulamein and is heavily regulated due to numerous weirs. Hartwood Weir is located on the mid Billabong Creek and Wanganella Weir is located on the lower Billabong Creek.

Billabong Creek within the study area is 'Type 1 – Highly Sensitive Key Fish Habitat' (Department of Planning, Industry and Environment, 2022b) and it supports a diverse assemblage of native and introduced aquatic species. The aquatic community as a whole is listed as endangered under the FM Act, and the Freshwater Catfish population in the Yanco Creek System is listed as an 'Endangered population' under the same Act. Furthermore, Murray Cod (Vulnerable - EPBC) and Silver Perch (Endangered – EPBC, Vulnerable -FM Act) have State and Federal conservation listings.

The desktop review identified that Billabong Creek was predicted habitat for a number of listed threatened species and populations. However, upon further review of literature and assessment of the waterway conditions in the field surrounding the proposal study area, it was determined that only three species namely Murray Cod, Silver Perch and Freshwater Catfish are likely to be present and these species have high conservation significance and are listed under one or both of the FM Act and the EPBC Act.

Analysis of existing water quality data and grab samples collected during the site visit assessed the key indicators of pH, electrical conductivity, dissolved oxygen, turbidity and nutrients. Generally, pH and electrical conductivity were below the basin plan and Australian and New Zealand Guidelines (ANZG) (2018) recommend guideline values for the protection of nominated water quality objectives. Dissolved oxygen levels were variable, with non-compliance more commonly associated with dissolved oxygen levels below the lower guideline values. Turbidity levels were consistently high in Billabong Creek and increased with distance downstream. Where nutrient data was available, it also showed elevated concentrations that exceeded the guidelines.

9.2 Key findings

9.2.1 Construction

Construction of the proposal would involve a range of activities including vegetation clearing, earthworks, concrete works, establishment of construction compound and instream works including construction and dewatering of cofferdams, streambed excavation and demolition of existing structures.

Potential adverse effects of the proposal during construction of the proposed regulators relate to loss of connectivity and impeded passage for native aquatic species, degradation of aquatic habitat through water quality or water regime changes, spread of weeds, pest species or pathogens, impacts to Groundwater Dependent Ecosystems and direct impacts to aquatic habitat or species.

With the implementation of safeguards and management measures it was determined that the risk of these impacts occurring changed from possible and likely to unlikely and rare for works in the study area. As such it is expected that the water quality objectives and aquatic ecosystem values in the study area (including threatened species and key fish habitat) would be protected during construction.

9.2.2 Operation

During operation, the proposal is expected to improve native fish populations and the delivery of environmental water by reestablishing river connectivity and fish passage so that fish can complete their life cycles and avoid predation – a common occurrence below weirs and barriers to fish passage. Although the proposal would result in considerable benefits to the native aquatic fauna communities within Billabong Creek, there are also some potential adverse impacts associated with the replacement new regulators and proposed Yanco Creek System Operations Plan.

Potential adverse effects of the proposal during operation of the proposed regulators relate to loss of connectivity and impeded passage for native aquatic species, degradation of aquatic habitat through water quality or water regime changes, spread of weeds, pest species or pathogens and direct impacts to aquatic habitat or species. With respect to the potential adverse impacts identified, it is important to note that these impacts are already evident at the existing Hartwood and Wanganella Weirs.

The design of the replacement new regulators for the proposal would provide for improved flow and fish passage that would result in improved connectivity for native fish, relative to current conditions. Operation of the new regulators would result in minor changes to flow and velocity which is dependent on the operating flow (maximum or minimum). This has the potential to result in changes to aquatic habitat, such as quality and size of lentic and lotic habitat. Any potential changes are expected to be short term and managed via regulator settings. As such with the implementation of safeguards and management measures, the likelihood of these impacts occurring are expected to be unlikely during operation.

9.2.3 Cumulative

Positive and negative cumulative impacts may arise from construction and operation of the replacement new regulators for the proposal. During construction, with the implementation of safeguards and management measures, the risk to water quality and aquatic ecology were considered unlikely, as such there are not expected to be any cumulative impacts.

Cumulative impacts from operation of the proposal could result from alteration of the hydraulic regime from the new regulators together with other projects in the area (i.e. the Forest Creek Return Flows Project), and the achievement of Environmental Watering Requirements. Generally there would be no cumulative impacts for mid Billabong Creek, but there would be a medium degree of hydrological alteration for the Lower Billabong Creek following implementation of SDLAM projects.

A potential cumulative benefit of the proposal is an increase in fish passage due to the construction of fishways in the Wanganella and Hartwood Regulator and fishway structures. While these structures are expected to facilitate upstream fish movement, the potential benefits for fish communities are lessened by the presence of other existing instream structures (e.g. farm dams and weirs) that also present barriers to fish movement.

9.3 Conclusions

It is anticipated that the construction and operation of the proposed new regulators would not result in significant adverse effects to aquatic habitat or fish passage in the study area. Similarly, it is considered unlikely that the aquatic community, including conservation listed species, would be negatively impacted by the proposal. All potential effect pathways included in this assessment were assessed as having medium or low residual risk ratings if proposed standard safeguards are adopted.

Overall, on the basis of the assessment of the existing water quality and aquatic environments, the design of the replacement new regulators and with the implementation of the recommended safeguards and management, the assessment concluded that water quality objectives and aquatic ecosystem values within the study area would be adequately protected during both construction and operation of the proposal. It appears that the major risks associated with water quality and physical habitat impacts, changes in hydrology, hydraulics, and fish passage were carefully considered in the design phase.

Overall, the proposal is predicted to present an improvement in fish passage (mainly in an upstream direction) within mid and lower Billabong Creek, and result in modest improvements to the hydrological and hydraulic conditions within the study area in relation to aquatic community health.

10. References

3Rivers (2024a). *Yanco Creek Modernisation: Hydraulic Modelling Technical Report – Piccaninny Weir to Wanganella Weir Study Area.*

3Rivers (2024b). *Yanco Creek Modernisation: Hydraulic Modelling Technical Report – Hartwood Weir to Piccaninny Weir to Study Area.*

Alluvium (2013) Yanco Creek System environmental flow study. Leeton: Alluvium Consulting

Anderson, H. K. (1915) Rescue operations on the Murrumbidgee River. Royal Zoological Society of NSW, 1, 157–160

Anderson, J. R., Morison, A. K., & Ray, D. (1992). Age and growth of Murray cod, *Maccullochella peeli* (Perciformes : Percichthyidae), in the lower Murray-Darling Basin, using thin-sectioned otoliths. In 'Age Determination and Growth in Fish and Other Aquatic Animals'. Australian Journal of Marine and Freshwater Research 43, 983-1013.

ANZECC/ARMCANZ, 2000. *National Water Quality Management Strategy Australian and New Zealand Guidelines for Fresh and Marine Water Quality*. Australian and New Zealand Environment and Conservation Council, Agriculture and Resource Management Council of Australia and New Zealand, October 2000.

ANZG, 2018. *Australian and New Zealand Guidelines for Fresh and Marine Water Quality*. Australian and New Zealand Governments and Australian state and territory governments. Canberra ACT, Australia, 2018. Available at www.waterquality.gov.au/anz-guidelines.

Arthington, A. H., Naiman, R. J., Mcclain, M. E., & Nilsson, C. (2010) Preserving the biodiversity and ecological services of rivers: new challenges and research opportunities. Freshwater Biology, 55(1), 1-16.

Atlas of Living Australia (2023). http://www.ala.org.au. Accessed 3/2/2024.

Australian Government (2018) Charter: National Water Quality Management Strategy, Department of Agriculture and Water Resources, Canberra, March. CC BY 3.0.

Baggiano, O. (2012). The Murray-Darling Turtles: Gene Flow and Population Persistence in Dryland Rivers (Ph. D. Thesis). Griffith University, Australia.

Baras, E., & Lucas, M. C. (2001). Impacts of man's modifications of river hydrology on the migration of freshwater fishes: a mechanistic perspective. International Journal of Ecohydrology & Hydrobiology, 1(3), 291-304.

Barnett, B., and Veitch, V., 2007, New life in Lagoon Creek, National Wetlands Update, *Wetlands Australia, Australian Government*, Volume 1, No.15

Baumgartner, L. J., Boys, C. A., Stuart, I. G., & Zampatti, B. P. (2010). Evaluating migratory fish behaviour and fishway performance: testing a combined assessment methodology. Australian Journal of Zoology, 58(3), 154-164.

Baumgartner, L. J., Conallin, J., Wooden, I., Campbell, B., Gee, R., Robinson, W. A., & Mallen-Cooper, M. (2014). Using flow guilds of freshwater fish in an adaptive management framework to simplify environmental flow delivery for semi-arid riverine systems. Fish and Fisheries, 15(3), 410-427.

Beal, P., Furness, L., Parrett, J. and Scriven, R. (2006). The Yanco Creek System Natural Resource Management Plan. Stage 1. Written for the Yanco Creek and Tributaries Advisory Council

Bednarek, A. T. (2001). Undamming rivers: a review of the ecological impacts of dam removal. Environmental Management, 27, 803-814.

Beesley, L., Price, A., King, A., Gawne, B., Nielsen, D., Koehn, J., ... & Hladyz, S. (2011) Watering floodplain wetlands in the Murray–Darling Basin for native fish. Waterlines report, National Water Commission, Canberra.

Bourne, C. M., Kehler, D. G., Wiersma, Y. F., & Cote, D. (2011). Barriers to fish passage and barriers to fish passage assessments: the impact of assessment methods and assumptions on barrier identification and quantification of watershed connectivity. Aquatic Ecology, 45, 389-403.

Bylemans, J., Gleeson, D. M., Lintermans, M., Hardy, C. M., Beitzel, M., Gilligan, D. M., & Furlan, E. M. (2018). Monitoring riverine fish communities through eDNA metabarcoding: Determining optimal sampling strategies along an altitudinal and biodiversity gradient. Metabarcoding and Metagenomics, 2, 1-12.

Cann, J., & Sadlier, R. A. (2017). Freshwater Turtles of Australia. CSIRO Publishing, Melbourne.

Capon, S. J., James, C. S., Williams, L., & Quinn, G. P. (2009) Responses to flooding and drying in seedlings of a common Australian desert floodplain shrub: *Muehlenbeckia florulenta* Meisn.(Tangled Lignum). Environmental and Experimental Botany, 66(2), 178-185.

Charles Sturt University (2022) unpublished data from a 2022 aquatic and terrestrial fauna survey of the Yanco-Billabong System.

Cherry, H., & Bosse, P. (2014). Across borders and basins: reducing the risk of aquatic weed spread in Australia's Murray-Darling River system. ed. M. Baker pp. 263-266. In Proceedings of the 19th Australasian Weeds Conference.

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

Commonwealth of Australia (2022) Commonwealth Environmental Water Office Water Management Plan 2022–23, Canberra. CC BY 4.0.

Cooling, M.P. and Gippel, C.J. (2018). Integrated Hydrological Operations Plan for the Billabong, Yanco and Colombo Creeks – Literature Review and Stakeholder Consultation. Ecological Associates report FL001-1-F prepared for Murray Local Land Services, Albury.

Cooper, A. R., Infante, D. M., Daniel, W. M., Wehrly, K. E., Wang, L., & Brenden, T. O. (2017). Assessment of dam effects on streams and fish assemblages of the conterminous USA. Science of the Total Environment, 586, 879-889.

Davies, P. E., & Nelson, M. (1994) Relationships between riparian buffer widths and the effects of logging on stream habitat, invertebrate community composition and fish abundance. Marine and Freshwater Research, 45(7), 1289-1305.

DEC, 2006. *Using the ANZECC Guidelines and Water Quality Objectives in NSW,* Department of Environment and Conservation, ISBN 1-74137-9180, June 2006.

DECCW, 2006. *NSW Water Quality and River Flow Objectives for the Murray River Catchment*. Department of Environment, Climate Change and Water, 2006.

DCCEEW (2023) *Protected Matters Search Tool*. Australian Government – Department of Agriculture, Water and the Environment. Available at: http://www.environment.gov.au/webgis-framework/apps/pmst/pmst.jsf

DECC (2008) *Managing Urban Stormwater Soils and Construction: Volume 2C Unsealed Roads.* Department of Environment and Climate Change.

DECC (2009) *Interim Construction Noise Guideline* (ICNG). NSW Environment Protection Authority.

Dignan, P., & Bren, L. (2003). A study of the effect of logging on the understorey light environment in riparian buffer strips in a south-east Australian forest. Forest Ecology and Management, 172(2-3), 161-172.

DoTE (2013) Matters of National Environmental Significance - Significant impact guidelines 1.1 - Environment Protection and Biodiversity Conservation Act 1999. Department of the Environment. Australian Government, Canberra.

DPI (2007) *Endangered ecological communities in NSW: Lower Murray River aquatic ecological community*. NSW Department of Primary Industries – Fisheries.

DPI (2013) *Policy and Guidelines for Fish Habitat Conservation and Management*. NSW Department of Primary Industries – Fisheries.

DPI (2024) Hartwood and Wanganella Weir Replacement Project – Detailed Aquatic Habitat Mapping. NSW Department of Primary Industries – Fisheries.

DPE (2020) *The Water Quality Management Plan (WQMP) for the Murrumbidgee WRP Area SW9*. New South Wales Department of Planning and Environment.

DPIE (2020a) *Murrumbidgee Long-Term Water Plan Part A: Murrumbidgee catchment*. New South Wales Department of Planning, Industry and Environment.

DPIE (2020b) *Murrumbidgee Long-Term Water Plan Part B: Murrumbidgee planning units*. New South Wales Department of Planning, Industry and Environment.

DPIE (2020c) *Water Quality Technical Report for the Murrumbidgee surface water resource plan area (SW9).* NSW Department of Planning, Industry and Environment.

DPIE (2022a). Murrumbidgee valley annual surface water quality report: 2021-2022. New South Wales Department of Planning and Environment.

DPIE (2022b). Cumulative Impact Assessment Guidelines for State Significant Projects. New South Wales Department of Planning and Environment.

DSEWPAC (2011) Survey guidelines for Australia's threatened fish - Guidelines for detecting fish listed as threatened under the Environment Protection and Biodiversity Conservation Act 1999. Australian Government, Department of Sustainability, Environment, Water, Population and Communities.

Ellis, I., Cheshire, K., Townsend, A., Copeland, C. Danaher, K., & Webb, L. (2016) Fish and Flows in the Murray River Catchment- A review of environmental water requirements for native fish in the Murray River Catchment. NSW Department of Primary Industries, Queanbeyan.

Enujiugha, V. N., & Nwanna, L. C. (2004). Short Communication - Aquatic Oil Pollution Impact Indicators. Journal of Applied Sciences and Environmental Management, 8, 71–75.

EPA (2014) NSW EPA Waste Classification Guidelines. New South Wales Environmental Protection Agency, Sydney.

Fairfull and Witheridge (2003) Why do fish Need to Cross the Road? Fish Passage Requirements for Watercourse Crossings. Department of Primary Industries – Fisheries, 2003.

Fisheries Scientific Committee (2008a) Final Determination - The *Tandanus tandanus* – EelTailed Catfish in the Murray/Darling Basin as an endangered population. New South Wales Government, Parramatta.

Fisheries Scientific Committee (2008b) Recommendation - key threatening process: Introduction of fish to fresh waters within a river catchment outside their natural range. New South Wales Government, Parramatta.

Forest Creek Working Group (2000) Management Plan for the Forest Creek System including Forest Creek, and Eight Mile Creek the Forest Anabranch Stage 1 (Draft).

Gilligan, D. (2005) Fish communities of the Murrumbidgee catchment: Status and trends. NSW Department of Primary Industries – Fisheries. Final Report Series No. 75. New South Wales Government, Parramatta.

Gilligan, D. M., Vey, A., & Asmus, M. (2009) Identifying drought refuges in the Wakool system and assessing status of fish populations and water quality before, during and after the provision of environmental, stock and domestic flows. Department of Primary Industries. New South Wales Government, Parramatta.

Grant, T. R., & Temple-Smith, P. D. (2003). Conservation of the Platypus, *Ornithorhynchus anatinus*: threats and challenges. Aquatic Ecosystem Health & Management, 6(1), 5-18.

Guo, F., Kainz, M. J., Valdez, D., Sheldon, F., & Bunn, S. E. (2016) High-quality algae attached to leaf litter boost invertebrate shredder growth. Freshwater Science, 35(4), 1213-1221.

Hinlo, R., Lintermans, M., Gleeson, D., Broadhurst, B., & Furlan, E. (2018). Performance of eDNA assays to detect and quantify an elusive benthic fish in upland streams. Biological Invasions, 20(11), 3079-3093.

Hoffman, J. R., Willoughby, J. R., Swanson, B. J., Pangle, K. L., & Zanatta, D. T. (2017) Detection of barriers to dispersal is masked by long lifespans and large population sizes. Ecology and Evolution, 7(22), 9613-9623.

Hopf, J., Davis, S., Graham, K., Stratford, D., & Durr, P. A. (2023). Linking demographic and habitat suitability modelling identifies the environmental determinants of successfully controlling invasive common carp (Cyprinus carpio) in south-eastern Australia. Biological Invasions, 1-20.

Humphries, P., & Potter, I. C. (1993) Relationship between the habitat and diet of three species of atherinids and three species of gobies in a temperate Australian estuary. Marine Biology, 116, 193-204.

Humphries, P., King, A. J., & Koehn, J. D. (1999) Fish, flows and flood plains: links between freshwater fishes and their environment in the Murray-Darling River system, Australia. Environmental Biology of Fishes, 56, 129-151.

Humphries, P. (2005) Spawning time and early life history of Murray cod, *Maccullochella peelii* (Mitchell) in an Australian river. Environmental Biology of Fishes, 72, 393-407.

Humphries, P., & Walker, K. (Eds.). (2013) Ecology of Australian freshwater fishes. CSIRO publishing.

Jacobs (2024a). Billabong Creek Regulators Hydrology Assessment. Draft.

Jacobs (2024b). Billabong Creek Regulators Geomorphology Assessment. Draft.

Jacobs (2024c). Billabong Creek Regulators Groundwater Assessment. Draft.

Jones, M. J., & Stuart, I. G. (2008) Regulated floodplains–a trap for unwary fish. Fisheries Management and Ecology, 15(1), 71-79.

Jones, H. A. (2011) Crustaceans and molluscs. In Rogers, K & Ralph, TJ (Eds). Floodplain Wetland Biota in the Murray-Darling Basin: Water and Habitat Requirements. CSIRO Publishing, Melbourne, Pp. 275-310

Kennett, R. M., & Georges, A. (1990) Habitat utilization and its relationship to growth and reproduction of the eastern long-necked turtle, *Chelodina longicollis* (Testudinata: Chelidae), from Australia. Herpetologica, 22-33.

King, A. J., Tonkin, Z., & Mahoney, J. (2009) Environmental flow enhances native fish spawning and recruitment in the Murray River, Australia. River Research and Applications, 25(10), 1205-1218.

King, A. J., Ward, K. A., O'Connor, P., Green, D., Tonkin, Z., & Mahoney, J. (2010) Adaptive management of an environmental watering event to enhance native fish spawning and recruitment. Freshwater Biology, 55(1), 17-31.

Lake, J. S. (1967a) Rearing experiments with five species of Australian freshwater fishes. I. Inducement to spawning. Marine and Freshwater Research, 18(2), 137-154.

Lake, J. S. (1967b) Rearing experiments with five species of Australian freshwater fishes. II. Morphogenesis and ontogeny. Marine and Freshwater Research, 18, 155–176.

Landcom (2004) Managing Urban Stormwater: Soil and Construction. Volume 1, 4th Edition, New South Wales Government, Parramatta.

Leigh, S. J., & Zampatti, B. (2011) Movement and spawning of Murray Cod (*Maccullochella peelii*) and golden perch (*Macquaria ambigua*) in response to a small-scale flow manipulation in the Chowilla Anabranch system. SARDI publication No (p. 52). F2010/000646-1.

Liermann, C. R., Nilsson, C., Robertson, J., & Ng, R. Y. (2012). Implications of dam obstruction for global freshwater fish diversity. BioScience, 62(6), 539-548.

Lintermans, M. (2023). Fishes of the Murray-Darling Basin: an introductory guide 2nd Ed. Canberra: Australian River Restoration Centre.

Lucas, M. C., Bubb, D. H., Jang, M. H., Ha, K., & Masters, J. E. (2009). Availability of and access to critical habitats in regulated rivers: Effects of low‐head barriers on threatened lampreys. Freshwater Biology, 54(3), 621-634.

Lyon, J., Stuart, I., Ramsey, D., & O'Mahony, J. (2010). The effect of water level on lateral movements of fish between river and off-channel habitats and implications for management. Marine and Freshwater Research, 61(3), 271-278.

Mallen-Cooper, M., & Stuart, I. G. (2003). Age, growth and non‐flood recruitment of two potamodromous fishes in a large semi-arid/temperate river system. River Research and Applications, 19(7), 697-719.

Martin, F. M., Janssen, P., Bergès, L., Dupont, B., & Evette, A. (2021). Higher structural connectivity and resistance against invasions of soil bioengineering over hard-engineering for riverbank stabilisation. Wetlands Ecology and Management, 29(1), 27-39.

McCormack, R. B. (2012). *A guide to Australia's spiny freshwater crayfish*. CSIRO PUBLISHING.

McNeil, D.G., Wilson, P., Hartwell, D., & Pellizari, M. (2008) Olive Perchlet (Ambassis agassizii) in the Lachlan River: Population status and sustainability in the Lake Brewster region. A Report submitted to the Lachlan Catchment Management Authority. 66 pp.

MDBA (2012). Basin Plan 2012. Murray Darling Basin Authority. Available at: https://www.legislation.gov.au/Details/F2018C00451.

MDBA (2020). *Annual Progress Report 2020: Sustainable Diversion Limit Adjustment Mechanism.* Murray-Darling Basin Authority, Canberra.

MDBA (2024) *Water Resource Plan assessment report.* Murray -Darling Basin Authority, Canberra, 2024

Murray, K., Skerratt, L., Marantelli, G., Berger, L., Hunter, D., Mahony, M., & Hines, H. (2011). Hygiene protocols for the control of diseases in Australian frogs: report for the Australian Government Department of Sustainability, Environment, Water, Population and Communities.

NHMRC (2008). Guidelines for Managing Risks in Recreational Water. National Health and Medical Research Council. Australian Government, Canberra.

NHMRC and NRMMC (2018). Australian Drinking Water Guidelines. National Health and Medical Research Council and Natural Resource Management Ministerial Council. Australian Government, Canberra.

NSW DCCEEW (2024a). *Sustainable Diversion Limit Adjustment Mechanism* at https://water.dpie.nsw.gov.au/our-work/water-infrastructure-nsw/sdlam. Accessed 19 July 2024.

NSW DCCEEW (2024b) *Murrumbidgee valley annual surface water quality report: 2022-2023.* NSW Department of Climate Change, Energy, the Environment and Water.

NSW DCCEEW (2024c) Hydrogeological Landscapes of New South Wales and the Australian Capital Territory. Available at: Hydrogeological Landscapes of New South Wales and the Australian Capital Territory | Dataset | SEED (nsw.gov.au)

NSWDoP (2003) Aquatic Ecology in Environmental Impact Assessment – EIA Guideline. NSW Department of Planning. New South Wales Government, Sydney.

NSWDPIE (2021a). Epizootic Haematopoietic Necrosis Virus (EHNV). Available at: https://www.dpi.nsw.gov.au/fishing/aquatic-biosecurity/aquatic-industries/wildfish-shellfish/ehnv [accessed 26 November 2022]. Department of Planning, Industry and Environment. New South Wales Government, Parramatta.

NSWDPIE (2021b). Make 'clean' part of your routine. Available at: Make 'clean' part of your routine (nsw.gov.au). [accessed 18 May 2023]. Department of Planning, Industry and Environment. New South Wales Government, Parramatta.

NSWDPIE (2022a). Yanco Creek System operations plan: Yanco Creek Modernisation Project. Department of Planning, Industry and Environment. New South Wales Government, Parramatta.

NSWDPIE (2022b) Fisheries NSW Spatial Data Portal. Geocortex Viewer for HTML5 (nsw.gov.au) [Accessed 15/12/22]. Department of Planning, Industry and Environment. New South Wales Government, Parramatta.

NSWDPI (2022c). NSW Weedwise. Available at: https://weeds.dpi.nsw.gov.au/ [accessed 15th November 2022]. Department of Planning, Industry and Environment. New South Wales Government, Parramatta.

NSWDPI (2006). *Reducing the Impact of Weirs on Aquatic Habitat - New South Wales Detailed Weir River. Murray CMA regions*. Report to the New South Wales Environmental Trust. NSW Department of Primary Industries, Flemington, NSW.

NSWEPA (2022) Approved Methods for Sampling and Analysis of Water Pollutants in NSW. NSW Environmental Protection Agency. New South Wales Government, Parramatta.

Perna, C. N., Cappo, M., Pusey, B. J., Burrows, D. W., & Pearson, R. G. (2012) Removal of aquatic weeds greatly enhances fish community richness and diversity: an example from the Burdekin River floodplain, tropical Australia. River Research and Applications, 28(8), 1093-1104.

Peterson, R.C., 1992. *The RCE: a Riparian, Channel, and Environmental Inventory for small streams in the agricultural landscape*. Freshwater Biology, Volume 27, pp. 295 – 306.

Pringle, C. (2003) The need for a more predictive understanding of hydrologic connectivity. Aquatic Conservation: Marine and Freshwater Ecosystems, 13(6), 467-471.

Quinn, J. M., Boothroyd, I. K., & Smith, B. J. (2004) Riparian buffers mitigate effects of pine plantation logging on New Zealand streams: 2. Invertebrate communities. Forest Ecology and Management, 191(1-3), 129-146.

Reinfelds, I. V., Keenan, H., & Walsh, C. T. (2020) Fish passage modelling for environmental flows: Hawkesbury - Nepean River, NSW, Australia. River Research and Applications, 36(4), 595-606.

Reynolds, L. F. (1983) Migration patterns of five fish species in the Murray-Darling River system. Marine and Freshwater Research, 34(6), 857-871.

Robison, E. G., & Beschta, R. L. (1990). Identifying trees in riparian areas that can provide coarse woody debris to streams. Forest Science, 36(3), 790-801.

Rowland, S. J. (1983) Spawning of the Australian freshwater fish Murray cod, *Maccullochella peeli* (Mitchell), in earthen ponds. Journal of Fish Biology, 23(5), 525-534.

Scott, A. C., & Grant, T. (1997) Impacts of water management in the Murray-Darling Basin on the platypus (*Ornithorhynchus anatinus*) and the water rat (*Hydromys chrysogaster*) (Vol. 26). Canberra: CSIRO Land and Water.

Sharpe, C., Stuart, I., & Vilizzi, L. (2013) Billabong, Yanco and Colombo Creek Fish Baseline Project 2012-13. Final Report, for Murray Catchment Management Authority by CPS Environmental Research, Irymple Victoria.

Sharpe, C., & Stuart, I. (2015) The Distribution of Trout cod in Yanco and Colombo Creeks. Final Report for Murray Local Land Services by CPS Enviro and Kingfisher Research, Irymple Victoria.

Sheldon, F., & Walker, K. F. (1998) Spatial distribution of littoral invertebrates in the lower Murray–Darling River system, Australia. Marine and Freshwater Research, 49(2), 171-182.

Sheldon, F., & McCasker, N. (2020) Habitat and flow requirements of freshwater mussels in the northern Murray-Darling Basin. Australian Rivers Institute report to the Commonwealth Environmental Water Office.

Shelley, J.J., Freeman, M., Raadik, T.A., Lyon, J.P., Nyman, P., Noske, P.J., Lane, P.N.J., Garnick, S., & Fitzpatrick, B. (2023). A review of literature relevant to buffer width prescriptions in southeast Australia: Managing the risk of forestry derived sediment impacts on aquatic communities. Arthur Rylah Institute for Environmental Research Technical Report Series. Department of Environment, Land, Water and Planning, Heidelberg, Victoria.

Stoessel, D. J., Raadik, T. A., Adams, M., Shelley, J. J., Hately, T. J., Iervasi, D., ... & Murphy, N. (2024). Environmental DNA as a detection tool for small-bodied, cryptic, threatened fish in a highly turbid freshwater lake system. Wildlife Research, 51(1), WR23027.

Stuart, I. G., & Mallen-Cooper, M. (1999). An assessment of the effectiveness of a vertical-slot fishway for non-salmonid fish at a tidal barrier on a large tropical/subtropical river. Regulated Rivers: Research & Management: An International Journal Devoted to River Research and Management, 15(6), 575-590.

Stuart, I. G., Zampatti, B. P., & Baumgartner, L. J. (2008). Can a low-gradient vertical-slot fishway provide passage for a lowland river fish community?. Marine and Freshwater Research, 59(4), 332-346.

Todd, C. R., Koehn, J. D., Stuart, I. G., Wootton, H. F., Zampatti, B. P., Thwaites, L., ... & Bice, C. (2024). Modelling the response of common carp (Cyprinus carpio) to natural and managed flows using a stochastic population model. Biological Invasions, 1-20.

Tonkin, Z., King, A., Mahoney, J., & Morrongiello, J. (2007). Diel and spatial drifting patterns of silver perch Bidyanus bidyanus eggs in an Australian lowland river. Journal of Fish Biology, 70(1), 313-317.

Tonkin, Z., King, A.J., & Mahoney, J. (2008) Effects of flooding on recruitment and dispersal of the Southern Pygmy Perch (*Nannoperca australis*) at a Murray River floodplain wetland. Ecological Management & Restoration, 9, 196–201

Ucan-Marin, F., & Dupuis, A. (2015). A literature review on the aquatic toxicology of petroleum oil: An overview of oil properties and effects to aquatic biota. Fisheries and Oceans Canada Canadian Science Advisory Secretariat, Ottawa.

van Oosterhout, E. (2009). Cabomba control manual: current management and control options for Cabomba (*Cabomba caroliniana*) in Australia. NSW Department of Primary Industries. New South Wales Government, Parramatta.

Walker K.F. (1981) Ecology of freshwater mussels in the River Murray. Australian Water Resource Council Technical Paper 63, 119 pp.

Walcott, A., Wolfenden, B., Hall, A. & Wassens, S. (2018). Yanco-Billabong Creek Broad-scale Wetland Monitoring Project: Frog communities of the Yanco-Billabong creek system. Final Report prepared for Murray Local Land Services. Institute of Land Water and Society, Charles Sturt University, Albury

Wassens, S., Watts, R. J., Spencer, J. A., Howitt, J., McCasker, N. A., Griese, V., Burns, A., Croft, R., Zander, A., Amos, C., & Hall, A. (2012). Monitoring of ecosystem responses to the delivery of environmental water in the Murrumbidgee system. Institute for Land, Water and Society, Charles Sturt University, Report 2.

WaterNSW (2024). Real time water data. Available at: https://realtimedata.waternsw.com.au/

Weis, J. S. (2014). Delayed Behavioural Effects of Early Life Toxicant Exposures in Aquatic Biota. Toxics, 2, 165–187.

Wipfli, M. S. (1997). Terrestrial invertebrates as salmonid prey and nitrogen sources in streams: contrasting old-growth and young-growth riparian forests in southeastern Alaska, USA. Canadian Journal of Fisheries and Aquatic Sciences, 54(6), 1259-1269.

Yarrow, M., Marin, V. H., Finlayson, C., Tironi, A., Delgado, L. E., & Fischer, F. (2009). The ecology of *Egeria densa* Planchon (Liliopsida: Alismatales): a wetland ecosystem engineer?. Revista chilena de historia natural, 82(2), 299-313.

Appendix A. Riparian Channel and Environmental Inventory (Source: Chessman *et al*, 1997)

	Description and Category	Value		Description and Category	Value
1	**Land us pattern beyond the immedate riparian zone**		**8**	**Riffle / pool sequence**	
	Undisturbed native vegetation	4		Frequent alternation of riffle and pools	4
	Mixed native vegetation and pasture/exotics	3		Longpools with infrequent short riffles	3
	Mainly pasture, crops or pine plantation	2		Natural channel without riffle / pool sequence	2
	Urban	1		Artificial channel; no riffle / pool sequence	1
2	**Width of riparian strip of woody vegetation**		**9**	**Retention devices in stream**	
	More than 30 m	4		Many large boulders and/or debris dams	4
	Between 5 and 30 m	3		Rocks / logs present; limited damning effect	3
	Less than 5 m	2		Rocks / logs present, but unstable, no damming	2
	No woody vegetation	1		Stream with few or no rocks / logs	1
3	**Completeness of riparian strip of woody vegetation**		**10**	**Channel sediment accumulations**	
	Riparian strip without breaks in vegetation	4		Little or no accumulation of loose sediments	4
	Breaks at intervals of more than 50 m	3		Some gravel bars but little sand or silt	3
	Breaks at intervals of 10 - 50 m	2		Bars of sand and silt common	2
	Breaks at intervals of less than 10 m	1		Braiding by loose sediment	1
4	**Vegetation of riparian zone within 10 m of channel**		**11**	**Stream bottom**	
	Native tree and shrub species	4		Mainly clean stones with onvious interstices	4
	Mixed native and exotic trees and shrubs	3		Mainly stones with some cover of algae / silt	3
	Exotic trees and shrubs	2		Bottom heavily silted but stable	2
	Exotic grasses / weeds only	1		Bottom mainly loose and mobile sediment	1
5	**Stream bank structure**		**12**	**Stream detritus**	
	Banks fully stabilised by trees, shrubs etc	4		Mainly unsilted wood, bark, leaves	4
	Banks firm but held mainly by grass and herbs	3		Some wood, leave etc. with much fine detritus	3
	Banks loose, partly held by sparse grass etc	2		Mainly fine detritus mixed with sediment	2
	Banks unstable, mainly loose sand or soil	1		Little or no organic detritus	1
6	**Bank undercutting**		**13**	**Aquatic vegetation**	
	None, or restricted by tree roots	4		Little or no macrophyte or algal growth	4
	Only on curves and constrictions	3		Substantial algal growth; few macrophytes	3
	Frequent along all parts of stream	2		Substantial macrophyte growth; little algae	2
	Severe, bank collapses common	1		Substantial macrophyte and algal growth	1
7	**Channel form**				
	Deep: width / depth ratio less than 7:1	4			
	Medium: width / depth ratio 8:1 to 15:1	3			
	Shallow: width / depth ratio greater than 15:1	2			
	Artificial: concrete or excavated channel	1			