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Environmental Impact Statement – Chapter 27: Water quality

Warragamba Dam Raising

Reference No. 30012078
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27 Water quality

This chapter provides an assessment of water quality impacts during construction and operation of the Project. The relevant Secretary's Environmental Assessment Requirements (SEARs) for water quality and where they are addressed are shown in Table 27-1.

Table 27-1. Secretary's Environmental Assessment Requirements: Water quality

Desired performance outcomes	Secretary's Environmental Assessment Requirements	Where addressed
21. Water – Quality The Project is designed, constructed and operated to protect the NSW Water Quality Objectives where they are currently being achieved, and contribute towards achievement of the Water Quality Objectives over time where they are currently not being achieved, including downstream of the Project to the extent of the Project impact including estuarine and marine waters (if applicable). The Project should not adversely affect drinking water quality.	1. The Proponent must: (a) state the ambient NSW Water Quality Objectives (NSW WQO) and environmental values for the receiving waters relevant to the Project, including the indicators and associated trigger values or criteria for the identified environmental values	Section 27.2
	(b) identify and estimate the quality and quantity of all pollutants that may be introduced into the water cycle by source and discharge point and describe the nature and degree of impact that any discharge(s) may have on the receiving environment, including consideration of all pollutants that pose a risk of nontrivial harm to human health and the environment	Section 27.3 Section 27.4 Section 27.5
	(c) identify the rainfall event that the water quality protection measures will be designed to cope with	Section 27.4
	(d) assess the significance of any identified impacts including consideration of the relevant ambient water quality outcomes	Section 27.4 Section 27.5
	(e) assess cumulative water quality and connective flow impacts on upstream and downstream areas and provide mitigation measures	Section 27.5 Section 27.6
	(f) demonstrate how construction and operation of the Project will, to the extent that the Project can influence, ensure that: ▪ where the NSW WQOs for receiving waters are currently being met they will continue to be protected ▪ where the NSW WQOs are not currently being met, activities will work toward their achievement over time ▪ identify how potential concrete, dust and other by products of the construction phase will be managed during construction activities, to ensure that water quality is maintained throughout the works. Mitigation measures should be discussed for stormwater and	Section 27.5 Section 27.5 Section 27.4

Desired performance outcomes	Secretary's Environmental Assessment Requirements	Where addressed
	wastewater management during and after construction	
	(g) justify, if required, why the WQOs cannot be maintained or achieved over time	Section 27.4 Section 27.5
	(h) demonstrate that all practical measures to avoid or minimise water pollution and protect human health and the environment from harm are investigated and implemented	Section 27.4 Section 27.6
	(i) identify sensitive receiving environments (which may include estuarine and marine waters downstream) and develop a strategy to avoid or minimise impacts on these environments	Aquatic ecology assessment report (Appendix F4) Biodiversity assessment report – upstream (Appendix F1) Downstream ecological assessment (Appendix F2) Sensitive environments are identified and assessed in Appendices F4, F1 and F2.
	(j) identify sensitive upstream environments that become 'receivers' during times of flood and may become inundated. Develop a strategy to avoid or minimise impacts on these environments.	Aquatic ecology assessment report (Appendix F4) Biodiversity assessment report – upstream (Appendix F1) Sensitive upstream environments are identified and assessed in Appendices F4 and F1.

1. This chapter specifically addresses SEAR 21 in addition to those general requirements of the SEARs applicable to all chapters and as identified as such in Chapter 1 (Section 1.5, Table 1-1).

The water quality assessment is supported by additional information provided in the water quality statistical analysis (SMEC 2020, Appendix Q).

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

27.1 Background

The objectives of the water quality assessment are to demonstrate that the Project is designed, constructed and operated to protect the NSW Water Quality Objectives (WQO) (Department of Environment, Climate Change and Water (DECCW) 2006) and the raw water supply for drinking water purposes agreement guidelines (WaterNSW). This water quality assessment identifies:

- the NSW WQO and drinking water quality requirements for upstream of the dam wall
- the NSW WQO for downstream of the dam wall
- the impacts of the operation of Project
  - upstream of the dam wall
  - downstream of the dam wall, including the benefits of the environmental flows
- the risk mitigation strategies to protect the receiving waters from construction impacts

- mitigation measures.

Water quality is influenced by flow and catchment land uses, and therefore this section should be read in conjunction with Chapter 15 (Flooding and hydrology) and Chapter 22 (Soils).

Warragamba Dam does not currently have the appropriate infrastructure to allow the controlled release of environmental flows into the Warragamba River and the Hawkesbury-Nepean River. WaterNSW is also seeking approval for the installation of environmental flow infrastructure at Warragamba Dam.

Approval for the operation of the environmental flow infrastructure is not being sought as part of this EIS and would be subject to a separate approval process. However, assessment of different environmental flow regimes has been undertaken as part of the *2017 Metropolitan Water Plan* (Metropolitan Water Directorate 2017). The water quality benefits from environmental flows been have been considered in determining future background downstream water quality to provide a conservative assessment of the potential impacts of the Project.

27.2 Assessment methodology

27.2.1 Overall framework

The NSW Environment Protection Authority (EPA) requires risk-based management of construction and operational impacts on the receiving waters (Dela-Cruz, Pik and Wearne 2017). A risk-based assessment framework has been developed by the EPA to provide a structured approach to considering the potential impacts of land use change on a waterway and to identify appropriate management responses to ensure that desired uses of a waterway can be met.

The methodology described in the risk-based framework approach has been used to assess the risk to the receiving waters and develop mitigation strategies. The steps of the assessment are detailed in Figure 27-1.

This chapter describes the context of the proposed development and assesses the impact through an effects-based assessment. Measures to mitigate the effects of the development are described and provided to inform the design and implementation of the strategies during later phases of the Project. Specific methodologies to address potential impacts on water quality upstream and downstream of the dam and during construction are presented in the following sections.

27.2.2 Methodology for the assessment of potential construction impacts

A risk-based approach was undertaken for assessing the potential impacts of construction on water quality. This involved:

- identifying construction activities that may have a risk to water quality
- identifying guidelines, requirements and other mitigation measures that reduce the risk of any construction related water quality impacts.

More detailed assessment of risks and mitigation measures would be undertaken during the detailed construction planning.

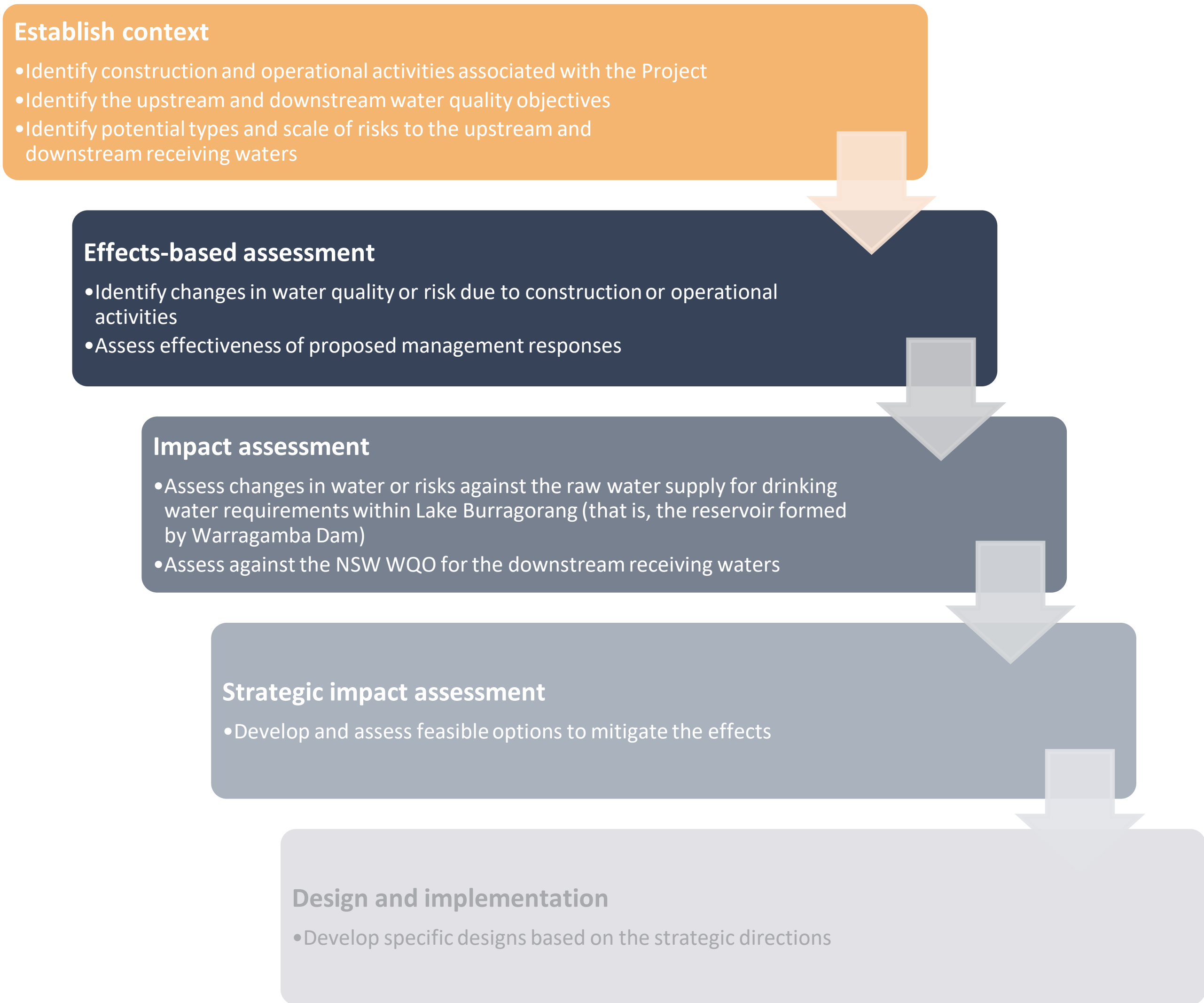
27.2.3 Methodology for the assessment of potential upstream impacts

The operation of the flood mitigation zone (FMZ) would result in an increase in the extent and duration of temporary inundation of the upstream catchment. These catchment areas contain landscapes, vegetation and soils which do not currently experience inundation and consequently there would be the potential for changes in water quality while they are inundated. In the longer term, repeated occurrences of inundation may permanently alter the landscapes, vegetation and soils which may give arise to additional impacts such as erosion. However, both the frequency and period of temporary inundation of new catchment areas would be very low in comparison to the permanent full supply level (FSL) – and therefore any water quality impacts would generally be short-term.

Due to the infrequent and variable nature of temporary inundation, a qualitative risk assessment-based approach has been used to identify risks, impacts and the potential mitigation measures. This involved:

- identifying specific risks to water quality in Lake Burragorang. Risks were focused on the raw water supply for drinking water purposes rather than the ecological functions, however it is recognised that these are inter-related
- reviewing relevant current water quality data, operational characteristics of the water supply system and other scientific information
- assessing potential impacts of each risk

Figure 27-1. Flow chart of the risk assessment approach recommended by the EPA



Source: Dela-Cruz, Pik and Wearne 2017

- undertaking an initial risk assessment
- identifying current and potential mitigation measures
- undertaking a residual risk assessment.

Risk assessments were undertaken using a 5x5 risk assessment matrix which is presented in Appendix C.

27.2.4 Methodology for the assessment of potential downstream impacts from the discharge of FMZ

Water quality modelling for the downstream Hawkesbury-Nepean River was available including consideration of environmental flow releases. A review of upstream data found that there were suitable inflow events that could be representative of the FMZ water quality. To assess potential downstream water quality impacts from the discharge of the FMZ, the following process was undertaken:

- identification of surrogate inflow events that would be similar to the capture of the flood inflows by the FMZ
- collate and analyse appropriate water quality data from the specific events to estimate water quality in the FMZ
- compare predicted water quality of the FMZ with downstream water quality from Hawkesbury-Nepean modelling to identify any impacts in relation to water quality objectives
- identify any mitigation measures.

The first three stages of the above process are described in the following sections. Mitigation measures are discussed in Section 27.7.

27.2.4.1 Selection of surrogate events

Historical daily storage data from Warragamba Dam (sourced from WaterNSW) was examined to identify surrogate events that would mimic the filling of the FMZ before discharge (refer Figure 15-10). The data collected between 1960 (dam opening) and 1985 were excluded as during this period there is limited inflow and water quality data. Dam storage level data was screened from 1985 to 2018 to identify events for potential surrogates.

A suitable wet weather surrogate event to assess the impact of the filling of the FMZ would have the following features:

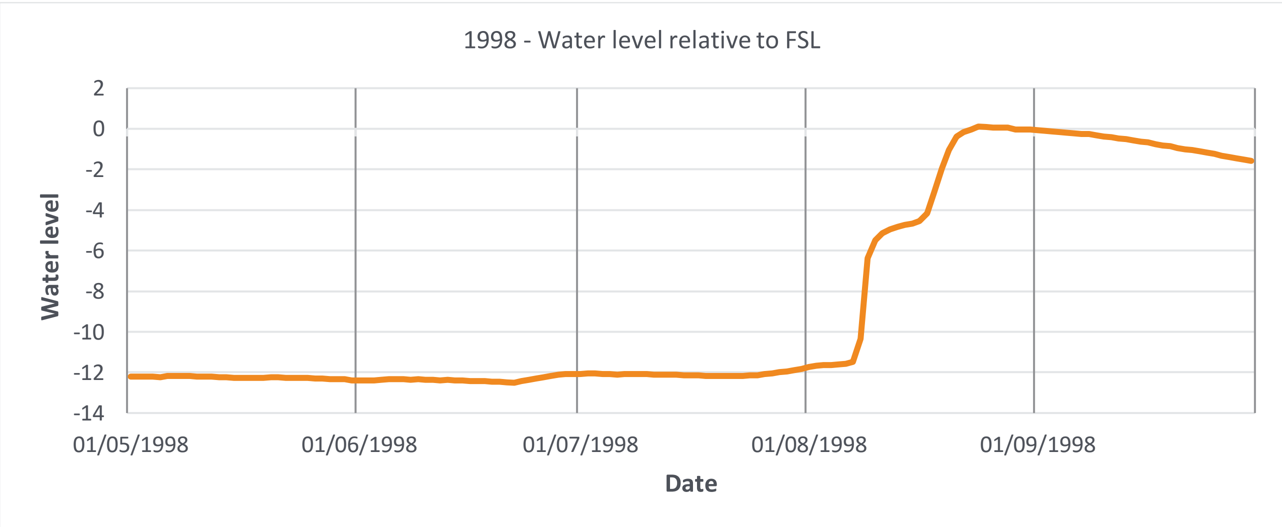
- the water level in the dam would be at least 12-16 metres below FSL which is similar to the depth of the FMZ when full
- the event would result in the filling of the dam to FSL (or just above FSL) with minimal or no spilling
- appropriate water quality data was available.

It should be noted that this is a conservative assessment as the landscape beneath FSL is devoid of vegetation and generally consists of bare earth or deposited sediment – which may contribute higher levels of turbidity and nutrients during filling, compared to the FMZ which would not be devoid of vegetation.

In reviewing historical water quality and inflow data, there were very few events which met the criteria for a suitable surrogate event. There were no suitable events in the 1980s.

Based on the criteria, the August 1998 and March 2012 events were found to be good representative surrogates. Prior to the August 1998 event the dam had not spilled for six years and prior to the early 2012 event the dam had not spilled for 14 years, which resulted in significant regrowth of vegetation in areas below FSL. In 1998, the water level of the dam was about 12 metres below FSL when a significant rainfall event started around 7 August 1998 (see Figure 27-2). This initial rainfall event resulted in the dam reaching about 4.5 metres below FSL. A second rainfall event started on about 15 August 1998 and raised the dam levels to about 0.1 metres above FSL, which resulted in a very minor spill.

Figure 27-2. Change in storage water level at the dam wall for 1998 event (1 May 1998 – 30 September 1998)

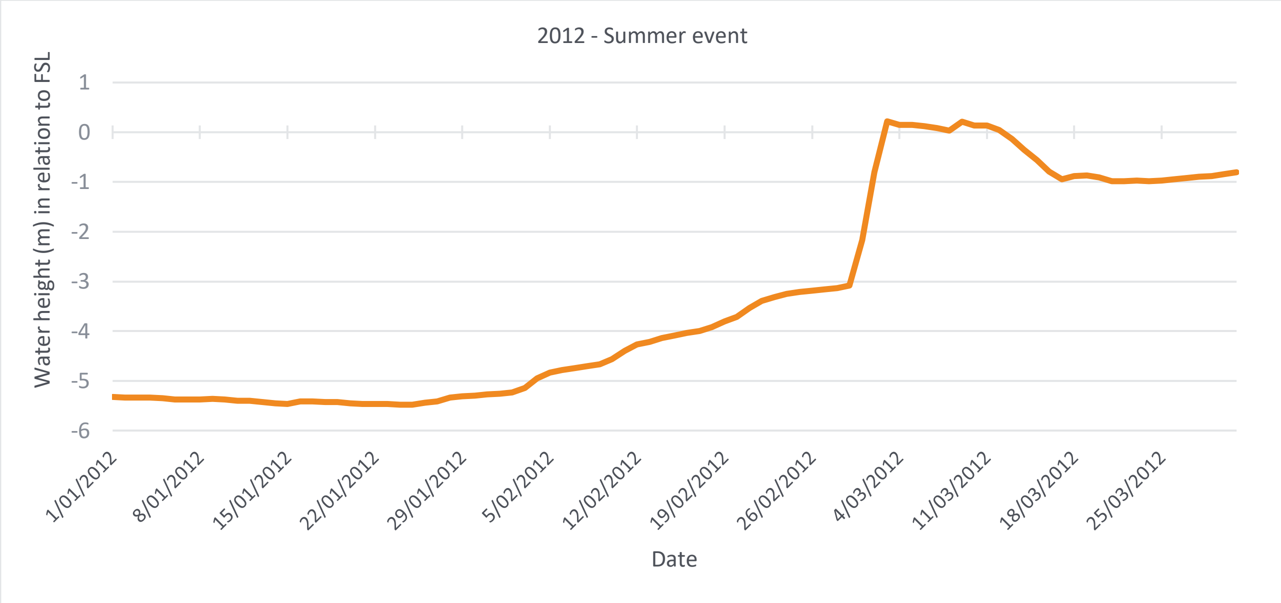


Source: WaterNSW

Most significant flood events (80 to 90 percent) are associated East Coast lows which generally only form and deliver substantial rainfall in winter. As the 1998 event involved an increase in water level of 12+ metres in a short period of time and occurred in the winter months, it is the most suitable surrogate and representative event to mimic the filling and resultant water quality in the FMZ.

As noted above most significant flood events occur in winter, however, there is the potential for a significant event to occur during warmer months. To assess the potential impacts on water quality especially in the main reservoir during summer, a summer surrogate event was also identified and assessed. The candidate events for assessment were further limited due to the lack of significant events in summer months (as noted above most significant rainfall events occur in winter). In February 2012, there were several smaller rainfall events early in the month which resulted in the water levels increasing from about six metres below FSL to about three metres below FSL (refer Figure 27-3). At the end of the month there was a more significant rainfall event which resulted in the dam spilling for about nine days.

Figure 27-3. Change in storage water level at the dam wall for 2012 event (1 January 2012 – 31 March 2012)



Source: WaterNSW

27.2.4.2 Surrogate event water quality

Station DWA2 is located about 500 metres upstream of the dam wall and is considered representative of the water quality flowing over the spillway. Sampling was undertaken at multiple depths within the water column with the average of water quality measurements taken from 0 to 18 metres selected as a representative baseline value. This is because the proposed FMZ is about 14 metres at the dam wall, and 0 to 18 metres would be representative of the water quality likely to be discharged from the FMZ. It is assumed for the purposes of the analysis that the thermocline would not influence the FMZ and that therefore an average would suitably represent the system. It is noted, however, that there is a potential seasonal influence on the location of the thermocline. To confirm this assumption further modelling would be required for the dam during detailed design.

The post-event water quality data was defined as around two weeks following the flood event as this is a representative period to empty the FMZ. For the 1998 winter event, post-event data was collected from 24 August to 7 September 1998. For the 2012 summer event, post-event data was sampled from 14 March to 27 March 2012. Data for all events is presented in Appendix Q.

In comparing the post event water quality for both events to 'normal' conditions the sudden increase in water levels and inundation of landscape below FSL results in (see Appendix Q):

- significantly increased total nitrogen concentrations
- significantly increased total phosphorus concentrations for the summer event
- increased turbidity.

Sources of increased turbidity and nutrients would be direct runoff from the area below FSL - which is largely devoid of vegetation due to permanent inundation for protracted periods of time - and inflows from the major tributaries. Table 27-2 is a summary of post-winter event water quality data, which has been assessed against the ANZECC 2000 water quality guidelines, downstream NSW WQO and the pre-event water quality.

The 1998 post event is statistically different for phosphorus indicating that the sudden increase in water level can result in increased concentrations of phosphorus. This would also influence the FMZ discharges and any sudden increase in water levels could result in increased total phosphorus levels.

Table 27-2. Pre and post-event water quality – 1998 (Mean of 0 to 18 metres depth – Site DWA2)

Parameter	Units	Pre-event 1998	Post event 1998	ANZECC 2000 guidelines	Downstream main river NSW WQO
Chlorophyll-a	µg/L	1.47	1.94	5	15
Total Nitrogen	mg/L	0.25	0.37	0.35	0.5
Total Phosphorus	mg/L	0.004	0.008	0.010	0.030
pH	Lab/Field	7.25	7.3	6.5-8.0	6.5
Turbidity Lab/Field	NTU	0.95	1.9	1 to 20	None

The only water quality parameter that exceeded ANZECC guidelines for the 1998 event was post event total nitrogen. Total phosphorous and turbidity doubled from the pre to the post-event, but did not exceed the ANZECC guidelines.

Apart from the deep-water sites, turbidity and nutrient concentrations were below the NSW WQOs. Changes in turbidity and nutrient concentrations in the surface water layer was minimal or negligible and did not increase with depth at DWA2. This is because in winter months the inflows are generally colder than the surface water of the stratified lake water column and generally enter the deeper sections of Lake Burragorang at the bottom of the water column. This observation has been validated by modelling undertaken by WaterNSW using its lake water quality and hydrological model.

However, the water quality in deeper section of the water column worsens and increases in pollutant concentrations are more substantial and often exceed the guidelines (see Appendix Q). This suggests that:

- sediment laden catchment inflows flow into the lower water column in the deeper sections of Lake Burragorang rather than along the surface in cooler months
- catchment inflows flow into the lower water column which result in the resuspension of settled sediments on the bed of the lake
- a combination of the two effects described above.

Generally, water quality in the top 18 to 24 metres of the water column remains good and within acceptable criteria and similar to the water quality before the rainfall event.

In terms of the 2012 summer event, post the rainfall event turbidity in the upper column (0-18 metres) at site in the main reservoir (DWA2) was 6.2 NTU. As a result, during a flood event, these flows could be at FSL, if water is in the FMZ.

Table 27-3. Pre and post event water quality – 2012 (Mean of 0 to 18 metres depth – Site DWA2)

Parameter	Units	Pre-event summer (2012)	Post-summer event (2012)	ANZECC 2000 guidelines	Downstream main river NSW WQO
Chlorophyll-a	µg/L	2.71	2.44	5	15
Total Nitrogen	mg/L	0.40	0.40	0.35	0.5
Total Phosphorus	mg/L	0.02	0.02	0.010	0.030
pH	Lab/Field	7.1	7.2	6.5-8.0	6.5
Turbidity Lab/Field	NTU	6.2	7.0	1 to 20	None

27.2.4.3 Water quality modelling

The NSW Government Hawkesbury-Nepean Hydrodynamic Water Quality Model is supported by the EPA and can be used to (Sydney Water 2016):

- compare relative changes in water quality and flow under different management options
- determine whether it is likely that scenarios could achieve water quality targets

- assess the compounding impacts of changing land-use and growth
- assess the flow recurrence intervals and flow regimes in the catchment.

The Hawkesbury-Nepean Hydrodynamic Water Quality Model was used in this assessment to determine if:

- the changes in flow regime have an impact on the downstream receiving waters
- the changes in discharge water quality from the FMZ have an impact on the downstream receiving waters.

The sites that were considered were those downstream of Warragamba Dam (see Figure 27-4).

Existing modelled scenarios from Hawkesbury-Nepean Hydrodynamic Water Quality Model were reviewed with the following six scenarios found to be relevant to the Project and were used in the assessment:

- Scenario 5: Current discharges from Warragamba dam, 2011 land-use and 2011 discharges from WWTP
- Scenario 7: Current discharges from Warragamba dam, 2030 land-use and 2030 discharges from WWTP
- Scenario 15: Current discharges from Warragamba Dam, 2050 land-use and 2050 discharges from WWTP
- Scenario 41: 90/10 Environmental flows from Warragamba Dam, 2011 land-use and 2011 discharges from WWTP
- Scenario 43: 90/10 Environmental flows from Warragamba Dam, 2030 land-use and 2030 discharges from WWTP
- Scenario 51: 90/10 Environmental flows from Warragamba Dam, 2050 land-use and 2050 discharges from WWTP.

27.2.5 Water quality standards for receiving environments

27.2.5.1 Key assessment considerations

The three key risks to water quality from the Project have been identified as:

- impacts during construction from erosion and sedimentation after rainfall and runoff/flood flows through the active construction site. Diffuse (for example, runoff from construction areas) and point (for example, wastewater from concrete batch plants) source pollution management during construction would comply with relevant guidelines, policies, and legislative requirements. Detailed management plans to manage various water quality risks would be prepared post-approval during the detailed construction planning phase. Water quality protection criteria and general risks and impacts during construction are discussed in Section 27.4.2. Ultimately any discharge criteria would be specified in an Environmental Protection Licence (EPL) for construction of the Project
- impacts on water quality in Lake Burragorang during the operation of the FMZ, which may have impacts on the raw water supply for drinking water purposes. These potential impacts are mainly from the increased extent and duration of temporary inundation of the upstream catchment. Due to the infrequent and variable nature of temporary inundation, a qualitative risk assessment-based approach has been used to identify risks, impacts and the potential mitigation measures including the measures currently in place to ensure raw water supply for drinking water purposes during flood events
- impacts of the discharge of the FMZ on downstream water quality. As the discharge of the FMZ may extend into periods when downstream water quality would have recovered after a flood event, there could be potential impacts if the water quality of the FMZ was poorer than downstream. A quantitative assessment using surrogate dam inflow events and downstream receiving water modelling has been used to assess potential impacts.

SEAR 21(b) requires the assessment of water quality to 'identify and estimate the quality and quantity of all pollutants' which consists of an assessment of any change in pollutant loads due to the Project. Warragamba Dam would only have a minor contribution to downstream pollutant loads as:

- most inflows to the dam are captured rather than being discharged downstream. The only time that the dam contributes to downstream pollutant loads would be when the dam spills which is relatively rare occurrence
- a significant proportion (about 50 percent) of the Lake Burragorang catchment is forested and protected within National Parks and State Conservation Areas. Forested areas generate lower levels of pollutants than other land uses

Figure 27-4. Model domain and output points of the NSW Government Hawkesbury Nepean Hydrodynamic Water Quality Model

Source: HN Toolkit Help Files 2017

Note: Tuflow sites are locations on the main river where water quality was modelled

Source sites are locations where water quality was used to generate pollutant loads from tributaries for use in the main river modelling

- Lake Burragorang acts as a large treatment basin for any inflows. Suspended sediments (to which pollutants are generally attached) either are entrained in the bottom waters or sediment as cold inflows enter the base of the water column or settle due to the lower water velocity in the lake.

The operation of the Project would not result in any significant change in the volume of water discharged from Warragamba Dam and no significant change in the water quality or pollutants in the dam is envisaged. The FMZ is only fully utilised during flood inflow events greater than 1 in 20 years. Operational experience is that the pollutants coming into the lake varies considerably during these flood events depending on the intensity and distribution of the rainfall and antecedent conditions of the catchment such as vegetation cover, drought or normal conditions, and recent bushfire events. The infrequent and variable operation of the FMZ and the difficulty in quantifying changes in upstream catchments also presents limitations in assessing any changes in pollutant loads. Consequently, no meaningful load assessment of pollutants was able to be undertaken. However, pollutant load data from the previous studies and the geomorphology assessment (Appendix N2) has been presented.

Heavy metal and other non-trivial pollutants in the Lake Burragorang are at low concentrations (or absent), below any relevant criteria and are not expected to change significantly with the operation of the Project.

27.2.5.2 Upstream

Within Lake Burragorang, the primary water quality objectives are based upon the Raw Water Supply Agreement between WaterNSW and Sydney Water (Independent Pricing and Regulatory Tribunal of New South Wales (IPART NSW) 2013) and are detailed in Table 27-4.

Table 27-4. Raw water supply for drinking water agreement standards to the Prospect, Warragamba and Orchard Hills Water Filtration Plants

Parameter	Units	Minimum	Maximum
Turbidity	NTU	-	40
True Colour @ 400 nm	Colour Units	-	60
Iron (total)	mg/L	-	3.50
Manganese	mg/L	-	1.40
Aluminium	mg/L	-	2.60
Hardness	mg/L as $CaCO_3$	25.0	70.0
Alkalinity	mg/L as $CaCO_3$	15	60
Algae	Algal Standard Units	-	2,000 – Warragamba/Orchard Hills 1,000 or 500 (if NTU>10 and CU >30) - Prospect

As part of WaterNSW's operating licence 2017-2022, it must:

> *With respect to Declared Catchment Areas, Water NSW must maintain a Water Quality Management System that is consistent with either:*
>
> *a) the Australian Drinking Water Guidelines; or*
> *b) if NSW Health were to specify any amendment or addition to the Australian Drinking Water Guidelines that applies to Water NSW, the Australian Drinking Water Guidelines as amended or added to by NSW Health; or*
> *c) any other requirements specified or approved by NSW Health or IPART.* (IPART 2017, p. 5)

27.2.5.3 Downstream

The spilling of the dam and the discharge of the FMZ drain into the Warragamba River and the Hawkesbury-Nepean River. As detailed in Chapter 15, the river has many uses, including recreation, aquatic agriculture, raw water supply for drinking water purposes and irrigation. In addition, both Sydney Water and Hawkesbury City Council discharge their wastewater treatment plants (WWTP) directly or indirectly into the river. Historically, the Hawkesbury-Nepean River downstream of the dam has experienced large algae blooms and excessive aquatic weed growth because of high nutrient concentrations from the discharge of treated wastewater from inland WWTPs and runoff from agricultural and urban areas in the catchment. Recent mitigation strategies and upgrades at the WWTPs have resulted in significant reductions in receiving water phosphorus and nitrogen concentrations.

The NSW WQOs are the agreed environmental values and long-term goals for NSW surface waters. The NSW WQOs set out the community's values and uses for rivers, creeks, estuaries and lakes and outline a range of water quality indicators to help assess whether the waterway's current condition supports those values.

The 2007-2016 *Hawkesbury-Nepean River Catchment Action Plan* (CAP) outlined the agreed environmental values for the catchment which were based on community aspirations and the Hawkesbury-Nepean Catchment Management Authority (HNCMA) 2008. The environmental values for the Hawkesbury-Nepean catchment are given in Table 27-5 and vary between land uses and locations in the catchment.

Table 27-5. Environmental values for the water in the Hawkesbury-Nepean Catchment

Location	Aquatic ecosystem	Recreational water			Raw water supply for drinking purposes	Primary industry		
		Primary Contact	Secondary Contact	Visual use		Irrigation and general use	Livestock drinking	Human consumption of aquatic foods
Above dams	✓	✓	✓	✓	✓	✓	✓	✓
Below dams								
Mixed use rural	✓	✓	✓	✓	✓	✓	-	-
Forested	✓	✓	✓	✓	✓	✓	✓	✓
Urban	✓	-	✓	✓	-	-	-	-
Brackish and estuarine	✓	✓	✓	✓	✓	-	-	-
Ocean	✓	✓	✓	✓	-	-	-	✓

Source: HNCMA 2008

WQOs recognise and aim to protect the community's environmental values and uses for ambient waters. The NSW WQOs were endorsed for rivers and estuaries by the NSW Government in 1999 after extensive community consultation. They were developed for each catchment in NSW in accordance with the framework outlined in the Australian National Guidelines for Managing Water Quality (Australian and New Zealand Environment and Conservation Council (ANZECC) and the Agricultural and Resource Management Council of Australia and New Zealand (ARMCANZ) 2000). The current WQO guidelines that apply to the Hawkesbury-Nepean River are set in the Healthy Rivers Commission (HRC) and supplemented by the ANZECC guidelines (2000). The combination of the two are included in Table 27-6.

Table 27-6. Healthy Rivers Commission and ANZECC (2000) water quality targets for the downstream Hawkesbury-Nepean River and as used in the Hawkesbury-Nepean Analysis Toolkit

Parameter	Unit	Estuarine	Mixed	Main river
Total Nitrogen (TN)	mg/L	0.4	0.7	0.5
Oxidised Nitrogen (NO_x)	mg/L	0.015	0.04	0.04
Ammonium (NH_4)	mg/L	0.015	0.02	0.02
Total Phosphorus (TP)	mg/L	0.03	0.035	0.03
Faecal coliforms	cfu/100 mL	150	150	150
Enterococci	cfu/100 mL	35	35	35
Dissolved Oxygen (DO)	mg/L	6.5	6.5	6.5
Conductivity	microS/cm	2,200	2,200	350
Dissolved Oxygen Saturation (DO)	%	80	85	85
Nitrate (NO_3)	mg/L	0.015	0.04	0.04
Chlorophyll-a	µg/L	7	7	15
Blue Green Algae	µg/L	2.3	2.3	2.3

Source: Sydney Water (2018)

Benchmarks for water quality downstream of WaterNSW’s dams and weirs are derived from ANZECC lowland rivers ecosystem types (WNSW 2016) and include:

- turbidity: this is a measure of suspended particulates in the water. High turbidity can result in reduced light penetration, smothering of aquatic ecosystems when particulates settle, clogging of fish gills and difficulties in treating raw water supply for drinking water purposes
- nutrients (phosphorus and nitrogen): high concentrations of these plant nutrients can cause algal blooms and the excessive growth of macro-algae
- chlorophyll: this is a measure of the amount micro-algae in the water column. Excessive concentrations of micro-algae can cause eutrophication, smothering, problems in drinking water treatment and if the microalgae are cyanobacteria (blue/green algae), human health risks.

27.3 Existing environment

27.3.1 Warragamba Dam construction area

According to soil landscape mapping for NSW, soils adjacent to dam wall are from the Narrabeen Group including Wentworth Clay, Burralow Formation and Banks Wall Sandstone subgroups. The Narrabeen Group and Hawkesbury Sandstone soils properties for erosion and sediment control are shown in Table 27-7.

Table 27-7. Soil properties relevant to the proposal area

Parameter	Narrabeen	Hawkesbury sandstone
Soil Hydrologic Group	Group A	Group D
USCS (Unified Soil Classification System) class	SP (SC)	SM
K-factor	0.006-0.007	0.024—0.025
Sediment Type	Type C	Type C, D or F

Source: Managing Urban Stormwater: Soils and Construction Landcom 2004

Acid sulfate soils are not known to be in close proximity of areas to be disturbed for construction or within the upstream study area. Some areas within the proposed construction zone have been identified as having past contamination issues or incomplete documentation following remediation. However, these areas are unlikely to be directly disturbed for construction of the Project. Overall, the likelihood of encountering widespread contamination during construction zone has been assessed as low (see Chapter 22 and Appendix N1).

Areas near the receiving waters (within 40 metres) and on the steeper slopes above 10 percent are considered high erosion hazard.

27.3.2 Upstream environment

27.3.2.1 Overview

The upstream environment includes Lake Burragorang (that is, the reservoir formed by Warragamba Dam) and its tributaries. The Warragamba Dam catchment covers an area of some 9,050 square kilometres and encompasses a variety of land use types. Lake Burragorang collects water from the catchments of the Kedumba, Kowmung, Nattai, Wollondilly, and Coxs Rivers (Figure 27-5) and is the largest raw water supply for drinking water purposes dam in Australia.

The Hawkesbury-Nepean catchment rises to 750 metres above sea level at the head of the Wollondilly River and over 1,300 metres on the Great Dividing Range at the head of the Tuglow River (WMAwater 2013). Numerous towns are located within the upstream catchment, the largest towns to the north being Wallerawang, Lithgow and Katoomba and in the south the main population centres are Goulburn, Bowral and Mittagong.

Land use

Warragamba Dam is situated in a narrow gorge on the Warragamba River about 65 kilometres west of the Sydney CBD. The township of Warragamba is located to the east of the dam wall and it is the only residential area near the dam wall and proposed construction area. Excluding the township of Warragamba, the area surrounding the dam wall is native bushland with a range of access roads and fire trails leading to the dam and nearby areas. The Warragamba Dam Visitors Centre is the closest building to the dam wall itself.

The landscape upstream of the dam is recognised as a nationally significant wilderness area that provides habitat for many threatened and critically endangered terrestrial flora and fauna species. The area surrounding Lake Burragorang is predominantly undisturbed bushland with minimal fire trails and access points. Public access to the upstream catchment is generally not permitted, with the only publicly-accessible point being Burragorang lookout and picnic area (National Parks and Wildlife Service (NSW NPWS) n.d., last viewed 28 September 2017). The upstream environment is well known for its natural beauty, pristine condition and environmental significance as part of the Greater Blue Mountains World Heritage Area (GBMWHA). More than one-quarter of the Warragamba Dam catchment is covered by the Warragamba Special Area, a 'no entry' area that extends for three kilometres from the Lake Burragorang FSL (WaterNSW n.d.a, last viewed 4 October 2017).

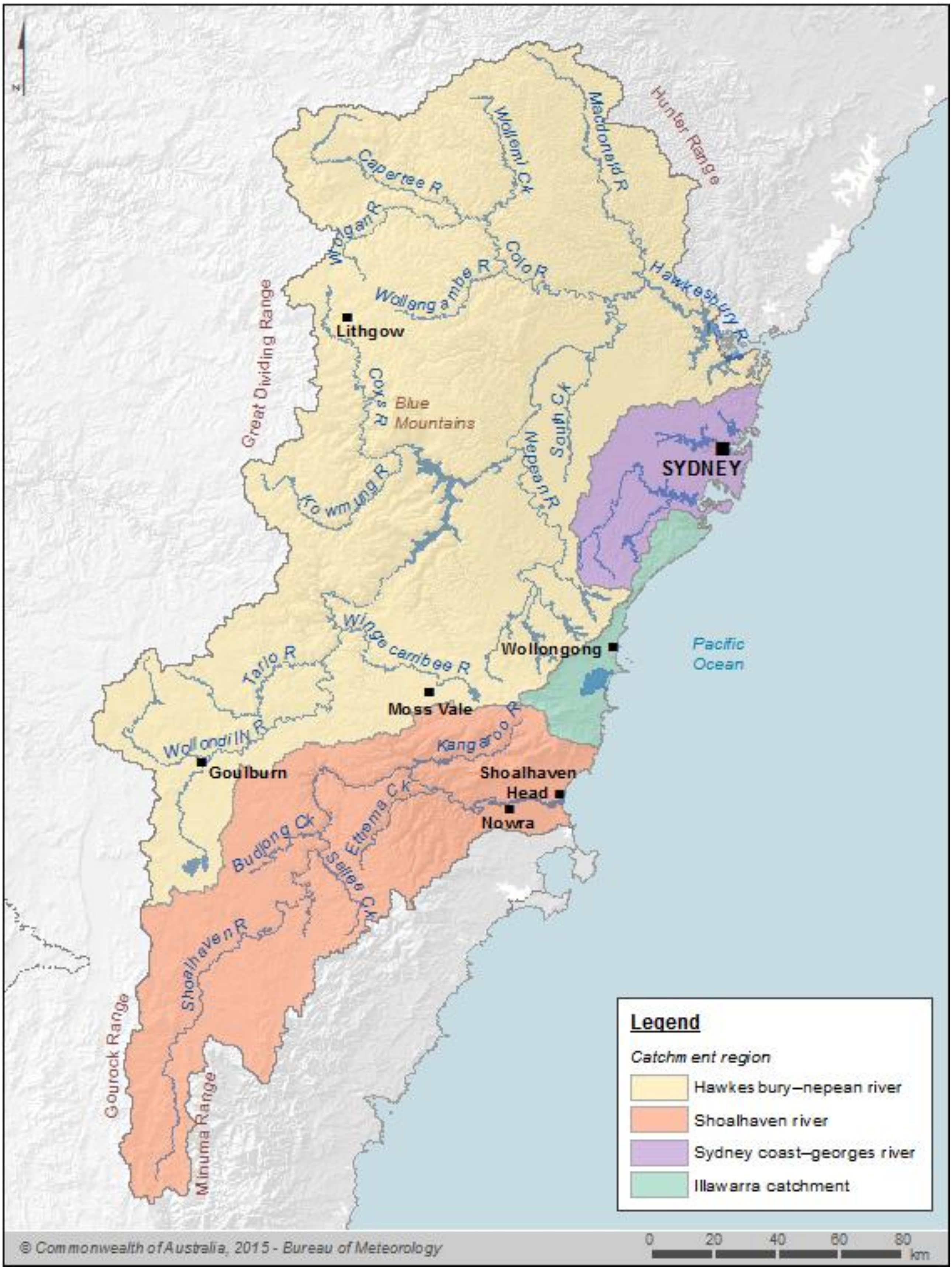
Whilst the area surrounding Lake Burragorang is predominantly National Parks, State Conservation Areas and Special Areas, the upstream catchment is not. Many of the tributaries of Lake Burragorang originate in areas dominated by grazing and agricultural land uses. Cattle and sheep grazing is the largest single land use within the Warragamba Dam catchment whilst the region also supports dairies, horse studs, piggeries and poultry production as well as canola and cereal crops (WaterNSW n.d.a). Mining and tourism are also operating in the catchment.

There are several urban areas and townships in the south-west and south of the upper catchment including Tarago, Goulburn, Taralga, Moss Vale and Bowral. There are also towns to the north including Katoomba and Lithgow. There are small pockets of business, commercial and light industry associated with these urban areas and several coal-fired power stations located in the north of the catchment area. There are also forested areas in the upstream catchment such as Belanglo State Forest and Tarlo River National Park.

Rivers and creeks

Warragamba Dam controls approximately 40 percent of the total area of the Hawkesbury-Nepean River catchment to the ocean at Broken Bay, but 70 percent of the catchment upstream of Penrith and 60 percent of the catchment upstream of Windsor. Numerous rivers and creeks drain to Lake Burragorang providing the source of freshwater for the lake. The key tributaries and main inflows to Lake Burragorang are the Wollondilly River in the south, the Coxs and Kowmung rivers in the west and the Nattai and Little rivers in the east (WMAwater 2013). The stream order of rivers and creeks in the upstream catchment varies from 1st order to 7th order. The main tributaries entering Lake Burragorang are classified as 5th order streams or greater.

Figure 27-5. Contextual map of the Sydney region



Source: Bureau of Meteorology (BoM) n.d., accessed 13 October 2017

GHD (2013b) undertook mapping of river types in the Hawkesbury-Nepean Catchment, and assessed their condition, fragility and recovery potential in accordance with the River Styles® framework. The geomorphic condition was categorised as good, moderate or poor based on, for example, ecological diversity, the presence of catchment controls, vegetation coverage and overall geomorphic stability.

The River Styles® assessment found that most of the rivers and creeks that flow directly into Lake Burragorang are in good condition. Some sections of waterways were identified as poor condition, including where Cedar Creek and the Tonalli River join Lake Burragorang, and numerous other upstream creeks were assessed as having a moderate geomorphic condition (GHD 2013b). Good condition reaches are largely associated with Confined Valley Setting (CVS) river styles, with almost 80 percent of confined river styles in the catchment assessed as in good condition. These waterways exist mainly in undisturbed areas in the upper to middle regions of the upstream (catchment) environment. The association of these waterways with good geomorphic condition is that they are resilient and are in rugged landscapes that are not subject to intense land disturbances such as grazing, land clearing, agriculture or any kind of development, which is the case for much of the upstream catchment area. These findings were confirmed by the geomorphology assessment undertaken for the EIS (Appendix N2).

In 2000, the CSIRO produced a report assessing the condition of the lower Coxs River under the existing flow regime. This report summarised and analysed data previously collected between 1962-1990 and 1998-1999 at two sites on Lake Lyell, five sites on the Coxs River below Lake Lyell and six sites on tributaries of the Coxs River (below Lake Lyell) (Young *et al.* 2000).

Young *et al.* (2000) found that while there was no downstream trend in water quality, the best water quality occurred at Kelpie Point and in the river's headwaters. Nutrient concentrations and faecal coliform counts were found to vary across the downstream reach of the Coxs River, which is likely due to differing tributary inflow quality based on the level of natural vegetation disruption in each catchment. Overall, nutrient concentrations and faecal coliform counts were high compared with those in near-natural Blue Mountains streams, with faecal coliform levels exceeding the ANZECC guideline limit for primary contact recreation. Additionally, they found that the total phosphorus levels recorded at Kelpie Point were elevated enough to cause the high levels of algal growth observed in the river. The high nutrient concentrations were recorded during high flows and were attributed to agricultural land uses and WWTP discharges.

Young *et al.* (2000) found that the pH range across all sites in the river was considered safe for aquatic life although some higher values were noted, which was likely due to elevated algal growth at the time of assessment. Turbidity, conductivity and suspended particulate matter were found to vary temporally and spatially and were indicative of a disturbed catchment. Sites downstream of catchment disturbance, such as sites downstream of urbanisation, generally had poorer water quality (Young *et al*. 2000). The study also noted that trace metal concentrations in the river sediments were generally low; however, widespread contamination from insecticide residues, petroleum hydrocarbons and polycyclic aromatic hydrocarbons was found.

Declared wild rivers

Wild rivers are rivers that are in near-pristine condition in terms of animal and plant life and water flow and are free of the unnatural rates of siltation or bank erosion that affect many of Australia's waterways (Office of Environment and Heritage (OEH) 2015).

Within the upstream environment, a section of the Kowmung River is a declared wild river under the *National Parks and Wildlife Act 1974* (NPW Act). Under the NPW Act, wild rivers are to be managed to ensure restoration (where possible) and maintenance of the natural biological, hydrological and geomorphological processes associated with wild rivers and their catchments.

Most of the 80-kilometre stretch of the Kowmung River lies within Kanangra-Boyd National Park, with the lower reaches of the river occurring within the Blue Mountains National Park. About 500 metres of the declared wild river section of Kowmung River would potentially be impacted by the Project is assessed in Chapter 20 (Protected and sensitive lands).

Wetlands

Wetlands are important transitional ecosystems between aquatic and terrestrial environments. They have important hydrological value playing a role in water storage and flood mitigation. Within the upstream environment there are no known Ramsar or State Environment Protection Policy (Coastal Management) listed wetlands. However, the Directory of Important Wetlands in Australia (the Directory) identifies several wetlands within the catchment: Boyd Plateau

Bogs, Lowbidgee Floodplain, Wingecarribee Swamp and Thirlmere Lakes, which are all located more than 50 kilometres from Lake Burragorang.

Boyd Plateau Bogs is small wetland that drains to Kowmung River within the Kanangra-Boyd National Park more than 60 kilometres upstream of the Coxs River. Lowbidgee Floodplain is situated near Belanglo State Forest, more than 100 kilometres upstream of the Wollondilly River which also drains to Lake Burragorang. Wingecarribee Swamp lies in a gently sloping upper catchment valley of Wingecarribee River near the town of Robertson (over 100 kilometres upstream of the Wollondilly River). The swamp is the largest and one of the best examples of a montane peatland in NSW. The Thirlmere Lakes situated near Camden Park drain to the Nepean River, although are only noted here due to their relative proximity to the dam and upstream study area.

None of these wetlands would be impacted by the Project.

Lake Burragorang

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

The current geomorphological condition at the dam is characterised by significantly altered hydrological and sediment transport regimes between the upstream catchment and downstream rivers and floodplain as summarised below:

- the Dam impounds Warragamba River creating the reservoir/freshwater storage known as Lake Burragorang
- lake Burragorang is a sink for upstream sediment loads that would otherwise provide the river downstream its normal sediment load
- the interruption of normal downstream sediment transport by the dam results in ‘clear water’ erosion to the channel downstream of the dam, whereby sediment that is naturally scoured and transported from this downstream reach is not replaced by inflowing sediment from upstream
- dam operation alters the natural hydrological regime of the river downstream of the dam (reduced baseflows and reduced peak flows) which impacts sediment transport processes, bank stability, and the availability of hydraulic habitat (the temporal and spatial distribution of suitable depth and velocity, as determined by river morphology and hydrological regime) (Sammut and Erskine 1995; Warner 1995; Brizga and Finlayson 2000; Erskine and Green 2000).

27.3.2.2 Long-term trends in water quality

Since its inception in 2015, WaterNSW has and continues to undertake extensive water quality monitoring within its catchments, storages and rivers. Prior to 2015, the Sydney Catchment Authority undertook similar water quality monitoring within the upstream environment of the Project.

Each year WaterNSW publishes a report describing the results of the water quality monitoring undertaken for the previous 12-month period. The report is provided to meet WaterNSW statutory obligations under the operating licence however it also provides useful water quality information to the public.

The key water quality findings documented in reports issued between 2006 and 2019 are summarised in Table 27-8. The reports are publicly available on the WaterNSW website. The table also inlcudes unpublished information for 2019-2020.

Ongoing water quality monitoring is conducted in compliance with the Water Monitoring Program 2015-2020. There are three key components to the Water Monitoring Program 2015-2020 including:

- routine and compliance monitoring – aims to ensure raw water supply for drinking water purposes is supplied to customers meets the standards set by the Australian Drinking Water Guidelines
- targeted or investigative monitoring – includes hot spot monitoring locations such as below sewage treatment plants, event-based monitoring in response to rainfall or other events and incident monitoring requiring immediate risk assessment such as for algal blooms
- monitoring catchment solutions to reduce pollution – monitoring of known pollution sources to assess the expected outcomes of funded works to control pollution loads.

The 2017-18 round of water quality monitoring typically took 12 samples at each catchment site for each parameter across the year, with more frequent sampling in the Lake Burragorang sites. There is a total of 19 catchment sites and nine Lake Burragorang sites and the locations are shown in Figure 27-6. The parameters tested for at each of the locations include:

- physico-chemical
- nutrients
- metals
- cyanobacteria
- pathogens
- health related physical chemical (Lake Burragorang sites only)
- cryptosporidium and giardia.

As demonstrated by the key findings across the past 10 years, water quality across the catchment and Lake Burragorang itself is variable and often influenced by inflow events and catchment land use activities such as power stations, agriculture and mining. Key water quality parameters that regularly fell outside ANZECC 2000 guideline values included eutrophication indicators such as nitrogen and chlorophyll-*a*.

The catchments that experience urban and agricultural land uses such as the Wollondilly River tributary catchments typically had poorer water quality as a result of increased nutrient loads, compared to protected catchments (that is, catchment within National Parks or State Conservation Areas). Conversely, the rivers with catchments protected in national parks such as Kowmung, Kedumba and Little River generally exhibit better water quality due to the predominantly undisturbed nature of their catchments.

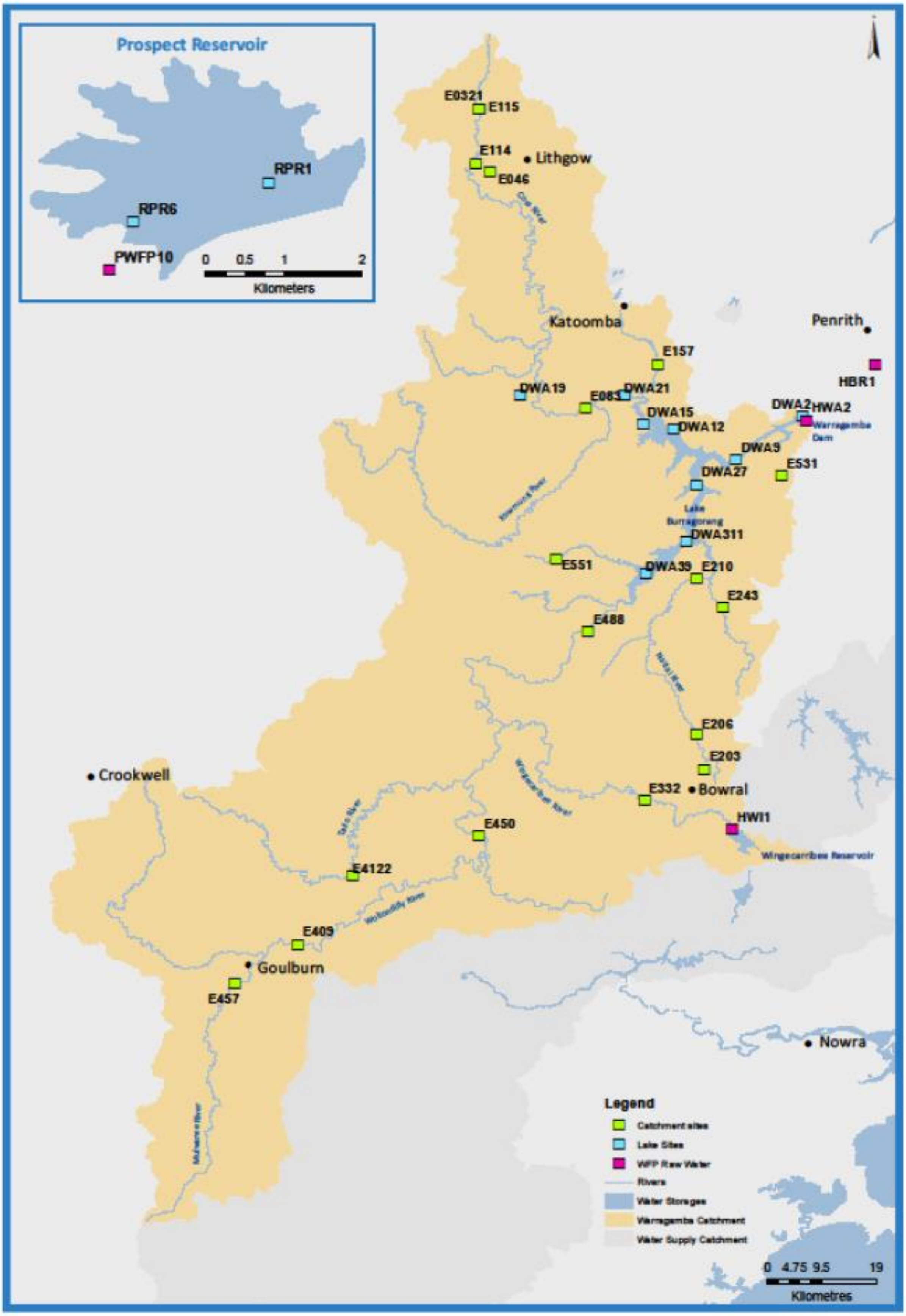
Variance in water quality parameters can occur from year to year based on events such as major incidents and rainfall, and between monitoring sites depending on local sub-catchment inputs. Significant inflow events have occurred on several occasions over the past 10 years often resulting in elevated nutrients, turbidity and colour in local creeks/rivers and the lake waterbody.

One such natural event that led to greatly increased loads of sediment and nutrients entering Lake Burragorang was the severe bushfires which occurred in 2001. Wilkinson *et al*. (2007) conducted a four-year study using tracers to assess the impact of sediment and nutrient delivery into Lake Burragorang following this bushfire. Based on the data collected, Wilkinson *et al*. (2007) concluded that:

- the 2001 fires and subsequent rainfall triggered widespread erosion of hillslopes with post-fire sediment yields from the burnt area to the river network approximately six times the pre-fire levels
- the post-fire sediment was predominantly sourced from surface erosion rather than erosion of sub-surface material and contained considerably more (several times more) phosphorus than pre-fire sources
- over a four-year period, the sediment yields to the river network declined towards pre-fire levels. The post-fire pulse in delivery of phosphorus was somewhat shorter than four years
- after fire, individual runoff events can transport one to two orders of magnitude more sediment and nutrients than during pre-fire events and thus the risk of algae blooms may be elevated after post-fire runoff events.

Similar impacts are anticipated with regard to the 2019-2020 bushfire (refer Table 27-8).

Figure 27-6. Warragamba system water quality monitoring sites



Source: WaterNSW 2018
Note: Not all sites listed in Table 27-9 are shown on this map

Table 27-8. Summary of annual water quality reports from 2006 to 2020

Report year	Key findings and outcomes
2006-2007	**Hydrology and rainfall** Average dam level: 37 percent capacity Significant inflow event: June 2007 **Catchments** ▪ aesthetic guidelines were met for all sites except one site on the Wollondilly River which exceeded the turbidity guidelines in 15 percent of the samples taken ▪ elevated nutrients concentrations were observed at some sites and dissolved oxygen levels was low at a several sites ▪ cryptosporidium was detected at several Warragamba tributary sites. Giardia was also detected at two sites. **Lake Burragorang** ▪ water quality across the lake was typical with numerous sites recording nitrogen, phosphorus and dissolved oxygen levels outside of the ANZECC guidelines. **Major incidents** ▪ a major incident was declared in late June 2007 due to elevated levels of turbidity in Lake Burragorang. The incident did not result in any deterioration of water supplied for treatment but required careful management to maintain the quality of raw water supply for drinking water purposes.
2007-2008	**Hydrology and rainfall** Average dam level:56 percent capacity. Significant inflow events: August 2007, December 2007, February 2008. **Catchments** ▪ all sites generally had low turbidity and remained within the aesthetic and recreational guidelines 75-100 percent of the time ▪ nutrient concentrations exceeded guideline values reasonably frequently (particularly total nitrogen). The increased nutrients were associated with prolonged algal blooms near Warragamba Dam **Lake Burragorang** ▪ the incidence of the *E. coli* varied between sites in Lake Burragorang although bacteria was detected on at least 25 percent of sampling occasions ▪ dissolved oxygen levels were low, potentially associated with algal bloom activity ▪ total nitrogen concentrations in the Lake increased compared to 2006/2007 sampling results, with all sites exceeding guidelines more frequently.

Report year	Key findings and outcomes
	Major incidents As a result of ongoing drought conditions, inflows to the lake remained below average in the seven years before 2007. Nutrient build up occurred in catchment lands over that time and was exacerbated by a large bushfire in the Barkers Creek area of the Warragamba Special Area in November 2006. A series of significant rainfall events were recorded across the catchments in June 2007, creating cold water inflows that increased total storage levels by around 20 percent. Subsequently a blue-green algae incident occurred.
2008-2009	**Hydrology and rainfall** Average dam level: 59 percent capacity. Significant inflow event: May 2009. **Catchments** ▪ significant decrease in nutrient concentrations compared to previous years, particularly in Lake Burragorang ▪ bacterial indicators remained within guidelines for most sites. **Lake Burragorang** ▪ pH was high ▪ dissolved oxygen levels increased and nutrient concentrations decreased compared to 2007/08 ▪ *E. coli* was detected near than dam wall frequently. **Major incidents** ▪ none in Lake Burragorang.
2009-2010	**Hydrology and rainfall** Average dam level: 55 percent capacity Significant inflow event: February 2010 **Catchments** ▪ emerging heavy metal and salinity issues were recorded in the Coxs River catchment possibility due to point source pollution inputs from power stations, past mining and other land uses. ▪ nutrient concentrations exceeded guidelines more frequently than in 2008/09. **Lake Burragorang** ▪ pH values were generally within guideline range ▪ dissolved oxygen levels generally improved compared to previous years' sampling results, with increases observed at most sites ▪ very high *E. coli* levels were recorded in December 2009 and January 2010, however generally low and below guideline across all sites at other times

Report year	Key findings and outcomes
	Major incidents ▪ heavy rainfall and significant inflows to Lake Burragorang in February 2010. Elevated nutrient concentrations were observed shortly after.
2010-2011	**Hydrology and rainfall** Average dam level: 67 percent capacity. Significant inflow event: December 2010. **Catchments** ▪ nutrients, chlorophyll-*a* and total aluminium concentrations exceeded guidelines across several sites for most of the sampling occasions ▪ pH and turbidity were generally within guideline ranges at most sites. **Lake Burragorang** ▪ water quality across most parameters was reasonably good – pH, turbidity and dissolved oxygen levels were generally within ANZECC guideline ranges ▪ nutrient concentrations were generally low except for increased nutrient concentrations following wet weather events ▪ bacteriological water quality of Lake Burragorang was very good with very few detections of key bacterial indicators. **Major incidents** ▪ large inflow event to Lake Burragorang in December 2010.
2011-2012	**Hydrology and rainfall** Average dam level: 86 percent capacity Significant inflow events: March 2012, April 2012, June 2012 **Catchments** ▪ Nutrients and chlorophyll-*a* concentrations regularly exceeded ANZECC guideline levels. **Lake Burragorang** ▪ lake Burragorang experienced significant inflows during the year with Warragamba Dam spilling for the first time in 14 years in March 2012. Despite this there were no issues with turbidity ▪ nutrients concentrations were elevated for most of the year due to inflows and this resulted in elevated chlorophyll-*a* concentrations ▪ no cyanobacterial exceedances were observed. **Major incidents** ▪ there was a sediment dam failure/breach at a quarry adjacent to the Coxs River. The sediment dam is an OEH-licensed discharge point for the quarry. Monitoring and investigations downstream showed that this had no adverse effects to water quality entering Lake Burragorang.

Report year	Key findings and outcomes
2012-2013	**Hydrology and rainfall** Average dam level: 97 percent capacity. Significant inflow events: February 2013, June/July 2013. **Catchments** ▪ nutrients, chlorophyll-*a* and dissolved oxygen levels regularly exceeded ANZECC guidelines, particularly in the river catchments which are not in National Parks ▪ satisfactory cyanobacteria levels. **Lake Burragorang** ▪ large inflows brought moderately increased turbidity, elevated nutrient concentrations and elevated true colour. However, turbidity remained within ANZECC guideline levels. **Major incidents** ▪ there were no major water quality incidents.
2013-2014	**Hydrology and rainfall** Average dam level: 90 percent capacity. Significant inflow event: June/July 2013. **Catchments** ▪ nutrients and chlorophyll-*a* concentrations regularly exceeded ANZECC guidelines. The Kowmung, Kedumba and Little rivers (whose catchments are contained in National Parks) reported lower values than agriculture dominated catchments such as Wollondilly River ▪ all sites were well below algal guidelines. **Lake Burragorang** ▪ nutrient concentrations peaked in August 2013 following significant inflows in June-July 2013 ▪ algal activity was moderate, chlorophyll-*a* concentrations were around the seasonal average and toxins (microcystin) remained below the detectable limit ▪ true colour levels were above historical averages, but below 2012/13 levels. **Major incidents** ▪ there were no major water quality incidents.

Report year	Key findings and outcomes
2014-2015	**Hydrology and Rainfall** Average dam level: 88 percent capacity. Significant inflow event: August 2014. **Catchments** ▪ nutrients (nitrogen and phosphorus) and chlorophyll-*a* concentrations regularly exceeded the ANZECC guidelines across the Warragamba catchments. Rivers with catchments that are protected in National Parks returned much better values than agriculture dominated catchments ▪ a statistically significant increase in dissolved oxygen levels was identified at several catchment sites, resulting in a substantial improvement in ANZECC compliance for the upstream environment. **Lake Burragorang** ▪ increased total nitrogen concentrations were observed at all Lake Burragorang storage sites with results exceeding the ANZECC guidelines ▪ nutrient concentrations peaked at the end of August 2014 corresponding to a significant inflow event. A second smaller event caused a smaller increase in nutrients in May 2015 ▪ algal activity was moderate across 2014/15 and followed the typical seasonal pattern ▪ chlorophyll-*a* peak concentrations improved slightly compared to recent years ▪ toxins (microcystin) remained below the limit of detection ▪ true colour continued to slowly improve (from its peak in 2013), with a small increase in September 2014 associated with the August inflow event. **Major incidents** ▪ there were no major water quality incidents.
2015-2016	**Hydrology and rainfall** Average dam level: 94 percent capacity. Significant inflow event: June 2016. **Catchments** ▪ Nitrogen, phosphorus and chlorophyll-*a* concentrations exceeded ANZECC guidelines (rivers with catchments within National Parks had lower concentrations than agricultural catchments). **Lake Burragorang** ▪ significant inflow event in June 2016 delivered increased nutrients, turbidity and elevated colour ▪ algal activity moderate with a typical seasonal pattern ▪ toxins (microcystin) remained below the limit of detection ▪ true colour peaked throughout the year in response to inflow events.

Report year	Key findings and outcomes
	Major incidents Significant wet weather event in June 2016 resulted in poor quality surface water quality in Lake Burragorang including increased turbidity.
2016-2017	**Hydrology and Rainfall** Average dam level: 96 percent capacity. Significant inflow event: March 2017. **Catchments** ▪ consistent with recent years, nitrogen, phosphorus and chlorophyll-a concentrations exceeded ANZECC guidelines (rivers with catchments within National Parks had lower concentrations than agricultural catchments). **Lake Burragorang** ▪ below average inflows led to water quality generally of good quality ▪ residual water quality effects of June 2016 inflow had improved. No further effects noted from 2017 inflow ▪ algal activity moderate with a typical seasonal pattern ▪ toxins (microcystin) remained below the limit of detection ▪ true colour increased slightly due to March inflow event but reduced relative to the previous year **Major incidents** ▪ there were no major water quality incidents.
2017-2018	**Hydrology and Rainfall** Average dam level: 81 percent capacity. Significant inflow event: no significant inflows for the year. **Catchments** ▪ consistent with recent years, nitrogen, phosphorus and chlorophyll-a concentrations exceeded ANZECC guidelines (rivers with catchments within National Parks had lower concentrations than agricultural catchments) ▪ conductivity increased due to low flow in some upper parts of the catchment. **Lake Burragorang** ▪ below average inflows led to water quality generally of good quality ▪ nitrogen exceeded guidelines more frequently at all Lake Burragorang sites than in 2016-17 ▪ phosphorus and chlorophyll-a declined due to declining water levels ▪ aluminium concentrations declined from previous years

Report year	Key findings and outcomes
	▪ toxins (microcystin) remained below the limit of detection ▪ true colour declined due to reduced inflows. **Major Incidents** ▪ there were no major water quality incidents.
2018-2019	**Hydrology and Rainfall** Average dam level: 60 percent capacity. Significant inflow event: no significant inflows for the year. **Catchments** ▪ consistent with recent years, nitrogen and chlorophyll-a concentrations exceeded ANZECC guidelines (rivers with catchments within National Parks had lower concentrations than agricultural catchments) ▪ due to the drought, a general decrease in phosphorus exceedences was observed. **Lake Burragorang** ▪ below average inflows led to water quality generally of good quality ▪ turbidity remains low ▪ total phosphorus and aluminium increased due to declining water levels ▪ cyanobacterial levels remained low ▪ true colour declined due to few inflows. **Major Incidents** ▪ there were no major water quality incidents.
2019-2020	**Hydrology and rainfall** Average dam level: lake level rose from 19.34 m below FSL on 7 February to 5.34 m below FSL on 19 February equating to a volume increase of about 778 GL. Significant inflow event: February 2020. **Catchments** ▪ prior to the February rainfall, nitrogen, phosphorus and chlorophyll-a concentrations exceeded ANZECC guidelines (rivers with catchments within National Parks had lower concentrations than agricultural catchments) due to the drought ▪ approximately 80% of the Warragamba catchment was impacted by a major bushfire event December 2019 through January 2020 ▪ february rainfall on bushfire impacted areas have led to significant export of sediment, nutrients, metals and organics to stream.

Report year	Key findings and outcomes
	Lake Burragorang ▪ prior to the bushfire rainfall event, algal activity was moderate across 2019/20 and followed the typical seasonal pattern ▪ chlorophyll-a peak concentrations were low ▪ toxins (microcystin) remained below the limit of detection ▪ *E. coli* levels remained low ▪ runoff from bushfire impacted areas has led to significant increases in nutrients, metals, organics with the majority of impacts outside the Gorge area ▪ sediment and organics have impacted water quality at the dam wall ▪ due to increased oxygen demand caused by elevated organics from the bushfire impacted runoff, manganese and iron levels have increased throughout the storage ▪ post bushfire, algal levels have increased in the upper lake due to increased nutrient availability. **Major incidents** As a result of ongoing drought conditions, inflows to the lake remained below average in the two years before 2019. Nutrient build up occurred in catchment lands over that time and was exacerbated by the largest bushfire on record across the Warragamba Catchment for the period December 2019 through January 2020. A significant rainfall event was recorded across the catchment in February 2020, creating inflows that increased the total storage level by around 40 percent. This resulted in a poor quality surface water layer in Lake Burragorang including increased turbidity.

27.3.2.3 Snapshot of existing water quality conditions

The most recent WaterNSW *Annual Water Quality Monitoring Report* details the results of the 2018-2019 water quality monitoring period (WaterNSW 2020).

Water quality in Lake Burragorang's river catchments during this monitoring period showed similar characteristics to previous years, with catchments dominated by agricultural and urban land uses regularly exceeding ANZECC benchmarks. Monitoring sites in the Mulwaree, Wingecarribee, Wollondilly and upper Coxs catchments most frequently exceeded benchmarks, particularly for nutrient loads and conductivity.

During this period, water monitoring undertaken across the catchments that flow into Lake Burragorang regularly returned elevated nitrogen, phosphorus and chlorophyll-*a* values which exceed the ANZECC guidelines. The agricultural and urban land-use dominated catchments including Wollondilly, Mulwaree and Wingecarribee Rivers had notably poorer water quality than rivers with catchments in National Parks. Poorer water quality was particularly evident at sites downstream of sewage treatment plants such as those on the Gibbergunyah and Farmers Creeks.

The percentage of water quality monitoring results that fell outside the recommended ANZECC guideline values are shown for each site in Table 27-9 (see Figure 27-6 for sample locations). These show:

- with the exception of two sites in the catchment, turbidity met guideline values across all of the monitoring sites in the catchment and within Lake Burragorang
- total nitrogen exceeded the guideline values most of the time across the catchment monitoring sites with the exception of Little River
- total nitrogen concentrations measured at lake sites were lower than most catchment sites
- chlorophyll-a results vary across all sites however most of the Wollondilly River and tributaries recorded higher concentrations generally reflecting elevated nutrient levels
- with the exception of two sites, dissolved oxygen levels were outside the recommended guideline range with three sites on the Wollondilly River exceeding the recommended guideline 50 percent of the time
- little River, Kedumba River, and Kowmung River had generally better water quality than other catchment rivers
- water quality across Lake Burragorang was similar between sites.

There was a major inflow event in February 2020 due to significant rainfall that occurred across the Warragamba catchment, and which increased the total storage level by around 40 percent. In the two years prior to 2019, inflows to Lake Burragorang had remained below average due to ongoing drought conditions. During this period, nutrient build up occurred in catchment lands, and was exacerbated by the bushfire event that occurred across the catchment from December 2019 through to late January 2020. The February 2020 inflow event resulted in a poor quality surface water layer in Lake Burragorang including increased turbidity.

Table 27-9. Warragamba system water quality parameters percentage of samples outside benchmarks

Key:	
(green)	Within guideline range
(yellow)	<25% of samples exceeded guidelines
(orange)	25-50% of samples exceeded guidelines
(red)	>50% of samples exceeded guidelines

Site	Site code	Dissolved oxygen	pH	Turbidity	Total nitrogen	Total phosphorus	Chlorophyll-a
Coxs River D/S Lake Lyell	E0114	42	92	8	100	100	25
Coxs River U/S Lake Lyell	E0115	25	100	0	100	75	75
Coxs River at Lithgow	E0321	17	83	25	92	25	0
Farmers Creek Mt Walker	E046	0	17	0	100	75	58
Coxs River at Kelpie Point	E083	17	58	0	50	33	25
Kowmung River at Cedar Ford	E130	33	8	0	25	17	8
Kedumba River at Maxwells Crossing	E157	17	0	0	50	8	8
Gibbergunyah Creek	E203	17	0	0	100	92	42
Nattai River at The Crags	E206	8	8	0	100	17	0
Nattai River at Smallwoods Crossing	E210	50	0	0	33	8	25
Little River at Fireroad W41	E243	25	0	0	0	8	0
Wingecarribee River at Berrima	E332	58	0	0	100	58	58
Wollondilly River at Murrays Flat	E409	67	17	0	100	83	83
Wollondilly River at Upper Tarlo	E4122	100	0	0	100	58	83
Wollondilly River at Golden Valley	E450	33	17	0	92	8	67
Mulwaree River at Towers Weir	E457	42	67	0	100	100	58
Wollondilly River at Jooriland	E488	8	92	0	92	17	58
Werriberri Creek at Werombi	E531	100	50	0	17	33	17

Site	Site code	Dissolved oxygen	pH	Turbidity	Total nitrogen	Total phosphorus	Chlorophyll-a
Lake Burragorang at 9km D/S of DWA15	DWA12	31	46	0	8	19	0
Lake Burragorang at 4km U/S of Butchers Creek	DWA15	33	50	0	0	17	17
Lake Burragorang at Kedumba River Arm	DWA19	33	0	0	67	33	100
Lake Burragorang at 500m U/S of Dam Wall	DWA2	23	65	0	12	12	0
Lake Burragorang at Coxs River Arm 37km U/S of Dam	DWA21	33	0	0	0	0	67
Lake Burragorang at Wollondilly River Arm 23km U/S of Dam	DWA27	27	54	0	8	8	0
Lake Burragorang at Wollondilly River Arm U/S of Nattai River	DWA311	17	50	0	0	17	17
Lake Burragorang at Wollondilly River Arm 40km from Dam	DWA39	0	33	0	0	0	33
Lake Burragorang at 14km U/S of Dam Wall	DWA9	27	46	0	12	12	0

Source: WaterNSW 2020

Note: Data from routine samples were extracted from the WaterNSW water quality database. The data were filtered so that only composite samples from 0-6 metres and samples taken between 0 metres and 6 metres remained. On each sampling date, the mean of the data was taken and compared to the relevant guideline value for each analyte. The number of guideline exceedances was calculated as a percentage of the total samples taken in the reporting year.

27.3.2.4 Pollutant loads

There is limited available information on pollutant loads from the upstream catchment. Two catchments of predominantly pristine bushland in the Warragamba area, were monitored over the period from late 1997 to early 2001 (Hollinger and Cornish 2001). The results from the monitoring are presented in Table 27-10 and indicate that pollutant loads from these forested catchments are low in comparison to other land uses.

Table 27-10. Summary of pollutant loads from Reedy Creek and Little River

Location/parameter	Monthly flow-weighted concentration range (mg/l)	Export rate (kg/ha/year)
Reedy Creek		
Total nitrogen	0.03-1.57	1.1
Total phosphorus	0.001-0.090	0.07
Little River		
Total nitrogen	0.01-2.14	0.2
Total phosphorus	0.00-0.048	0.01

For the geomorphology assessment (see Appendix N2), suspended sediment loads were estimated from the major tributaries of Lake Burragorang (refer Table 27-11). The Wollondilly River had the highest contribution of suspended sediments loads primarily from agricultural catchments to the west of the dam. The Coxs River, which has a similar size catchment to the Wollondilly River, only contributed about 10 percent as much sediment compared to the Wollondilly River. The Nattai River's sediment load was negligible and reflects its forested and protected catchment.

Table 27-11. Estimated suspended sediment loads from the major tributaries of Lake Burragorang

River	Suspended sediment load (tonnes/annum)	Catchment area (km^2)	Catchment factored load (tonnes/annum/km^2)
Coxs	54,822	2,630	21
Nattai	154	446	0.3
Wollondilly	496,983	2,699	184

The geomorphology assessment (see Appendix N2) included estimated suspended sediment loads from a 2006 study which varied substantially from those in Table 27-11. No specific reasons were provided for the variance other than to noted the uncertainty associated with such estimates. It was further noted that the lack of agreement did not affect the outcome of the assessment as the estimates were not used in further analysis.

27.3.3 Downstream environment

27.3.3.1 Overview

The downstream environment (that is, downstream of the dam) includes the freshwater and estuarine reaches of the river system between the Warragamba River directly downstream of the dam wall and Wisemans Ferry. The downstream environment does not include the reach of the Nepean River upstream of its junction with the Warragamba River. Although the discharges from the current Warragamba Dam during large flood events can cause reverse flows up the Nepean River to Wallacia, these events are generally less than a day and are almost entirely eliminated with the Project. For this reason the temporary water quality impact of the Project on the normally upstream section of the Nepean River has not been assessed. The downstream environment also includes the local waterways/creeks, riparian zone, floodplain, and wetland/lagoon waterbodies adjacent to the main rivers.

The downstream catchment comprises the Hawkesbury-Nepean Valley which has diverse topography which varies from floodplains to mountainous terrain which covers almost 50 percent of the catchment. While the floodplains only account for a small percentage of the total catchment area, they contain most of the urban development (WMAwater 2013). The downstream environment that the Hawkesbury-Nepean River passes through include several historically notable population centres including Penrith, Richmond, Windsor, McGraths Hill, Wilberforce, and Pitt Town.

Land use

There is a wide variety of land use types within the Project downstream environment which can impact the water quality of creeks, lakes, wetlands, and rivers. Like the upstream environment, several national park areas including the GBMWHA are located within the downstream environment. These areas are typically located on the western and northern borders of the study region where major rivers including the Grose, Colo, and Macdonald Rivers flow toward the Hawkesbury-Nepean River.

On the eastern side of the Hawkesbury-Nepean River there is a large urban area around Penrith, with numerous smaller urban areas along the length of the river to Pitt Town. Between these town centres, agriculture is a dominant land use (and is a key economic industry for the region) on both sides of the Hawkesbury-Nepean River and in the sub-catchments of South Creek and Cattai Creek (DECCW 2010f).

The *Lower Hawkesbury-Nepean River Nutrient Management Strategy* (DECCW 2010c) compiled and assessed the latest (2009) land use mapping for some areas of the Hawkesbury-Nepean River catchment. The land use categories identified include:

- urban environment (50,000 hectares) – urban built environment such as houses, parks, roads, car parks, utilities, commercial and industrial facilities
- rural residential (44,000 hectares) – rural residential and associated uses such as small acre farms.
- grazing (136,000 hectares) – livestock grazing of modified pastures and natural vegetation, such as cattle, sheep, horses, and alpacas
- intensive horticulture (7,100 ha) – intensive cropping practices such as flower, vegetable and fruit tree market gardens
- intensive animal production (6,400 ha) – farms with high intensity animal practices such as poultry, dairy and piggeries
- non-intensive agriculture/cropping (5,500 ha) – non-intensive agriculture and cropping such as turf, silage and hay production
- other diffuse sources (40,000 ha) – including mining, waste treatment and disposal and a range of facilities.

Each of these major land use categories have varying levels of impact on water quality of the receiving environment (Department of Environment and Climate Change (DECC) 2009c).

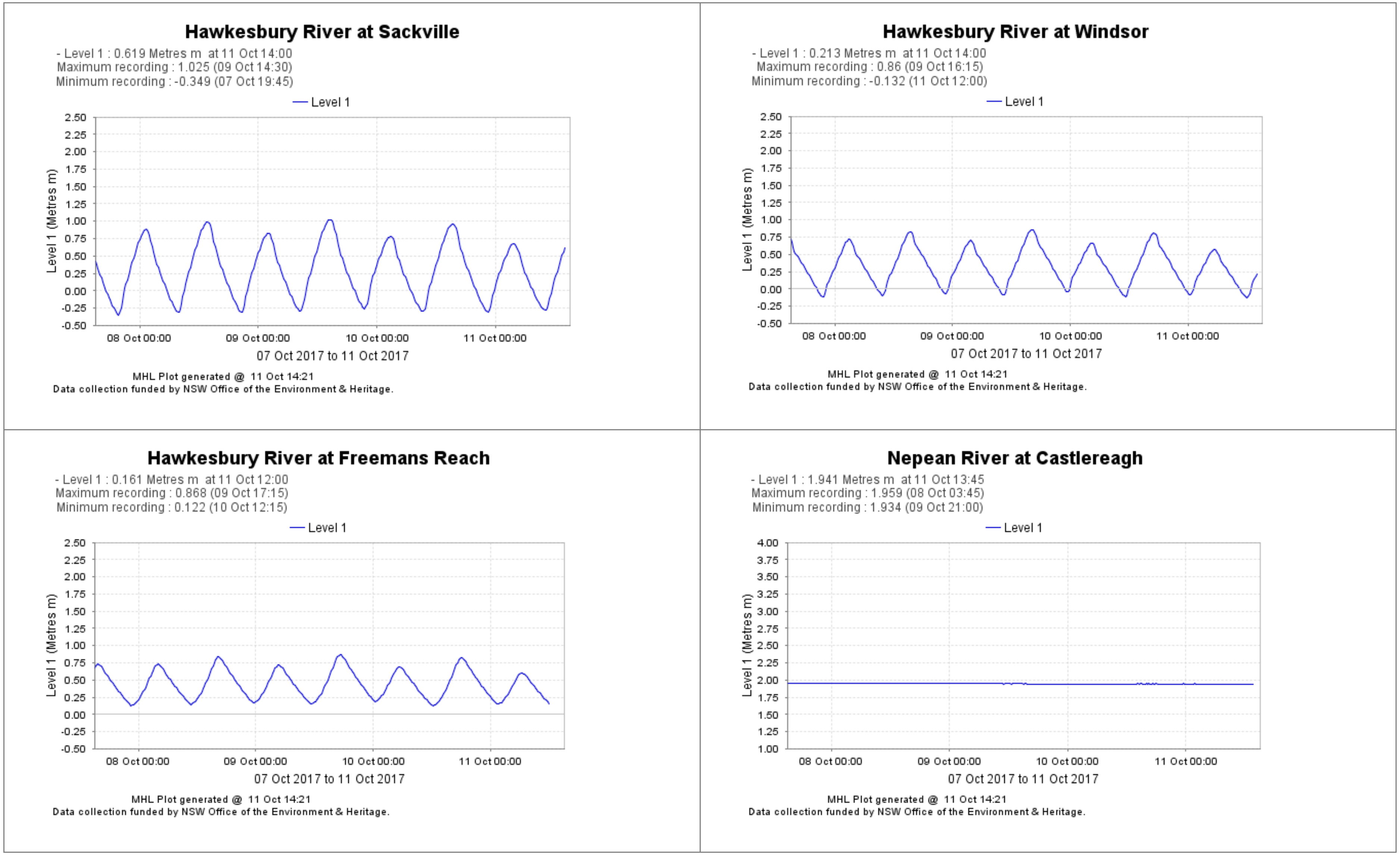
Rivers, creeks, and tidal limits

With distance upstream from the mouth the Hawkesbury River, the tidal influence on water levels decrease (see Figure 27-7). The tidal limit of the Hawkesbury River occurs near Yarramundi, approximately 140 kilometres upstream of the river mouth (Department of Natural Resources 2006; Krogh, Wright and Miller *et al*. 2009). The Yarramundi to Windsor reach is wide, shallow and freshwater dominated with moderate tidal influence. Near the tidal limit, the Hawkesbury River receives tributary inflows from the Grose River (at Yarramundi) and the Nepean River (further upstream of Yarramundi), and experiences moderate freshwater tidal influence (Gruber, Ferguson and Haine *et al.* 2010). There is no tidal influence at Castlereagh as demonstrated by the constant river water level which is controlled by the river bed a short distance downstream. Tidal flows vary the water level at Sackville, Windsor and Freemans Reach by a maximum of approximately 1.3 metres, 1 metre and 0.7 metres, respectively. At Windsor, high and low tide are 5 hours and 15 minutes and 5 hours and 30 minutes behind Fort Denison, respectively. At the downstream extent of the downstream environment (Wisemans Ferry), high tide is 2 hours and 15 minutes after the recorded high tide at Fort Denison.

Many of the river reaches and tributaries downstream of Warragamba Dam have been significantly modified since European settlement which in turn has resulted in poorer water quality. River and tributary modifications include:

- removal of riparian native vegetation
- invasion of weeds
- dredging and realignment of waterways
- increased erosion and siltation of waterway banks
- changes in hydrological regimes
- construction of instream and bank structures (for example, bridges, weirs).

Figure 27-7. Water level on the Hawkesbury-Nepean River 7-10 October 2017



Source: Manly Hydraulics Laboratory 2006

The geomorphology assessment contains more detailed information (Appendix N2) on the morphology of the main river channel and tributaries.

Downstream of the Warragamba and Hawkesbury-Nepean Rivers junction, the Hawkesbury-Nepean River continues to flow through a narrow gorge until just before it reaches Penrith, where it emerges at the head of the floodplain.

Downstream of Penrith, the Nepean River terminates at the junction with the Grose River. These two rivers flow into the Hawkesbury River which flows through the Richmond/Windsor lowlands. South Creek joins the Hawkesbury River downstream of Windsor but is not a major contributor to flood flows however it has a large floodplain which is inundated by backwater from the Hawkesbury-Nepean (WMAwater 2013). Major contributions of stormwater runoff from the highly modified urban creek catchments, namely South Creek and Eastern Creek occur in this reach. These two urban creeks drain significant portions of Greater Western Sydney suburbs including Blacktown, Rooty Hill, St Marys and Quakers Hill and join with the Hawkesbury River near Windsor.

Between Yarramundi and Windsor, the Hawkesbury River is wide and shallow with numerous shoals restricting navigability. This segment of river is also notably straighter than the other downstream river reaches and includes numerous lagoons and wetlands across the floodplain and lowlands. The channel form and bank stability of the upper estuary at this location are largely influenced by the persistent low flows in the main stream of the Hawkesbury River (Kimmerikong 2005). The altered flow regime affects sediment and bank dynamics, which is readily observed as bank slumping and erosion within this reach of the study area (BMT WBM 2013). Water quality in this reach of the downstream environment is predominantly influenced by agricultural and pastoral runoff from the Richmond Lowlands where orchards, small farms, equine studs, and turf farms are common. This reach of the Hawkesbury River also receives runoff from smaller urban centres such as the townships of North Richmond.

The reach between Windsor and Sackville is wide and deep and has the poorest water quality of the downstream environment with Cattai Creek and South Creek delivering flows that are frequently high in nutrients, low in dissolved oxygen and of a higher salinity than the incoming tidal flows (at this location). Bank erosion is prevalent and native riparian vegetation is sparse. Below Wilberforce, Cattai Creek joins the Hawkesbury River prior to it entering the Hawkesbury gorge which extends for over 100 km to the ocean at Broken Bay (WMAwater 2013). While the river passes through this gorge, the Hawkesbury-Nepean's largest tributary in the downstream environment, the Colo River, emerges and joins the river along with several other minor tributaries. The McDonald River also merges with the Hawkesbury River at Wisemans Ferry.

Between Cattai and Wisemans Ferry, the floodplain is narrow (typically less than 400 metres wide) and essentially non-existent where the river channel is bedrock-controlled (that is, steep sandstone gorge). Between Sackville and Wisemans Ferry the river is wide and deep in this reach although the surrounding terrain steepens. The banks are often sheer sandstone cliffs with well-established native vegetation. Inflows from the Colo River deliver clean fresh water to this reach. Water quality in this reach of the downstream environment is influenced by regular (twice daily) tidal flushing. The land use surrounding this reach of the Hawkesbury River is predominantly rural and forested areas with minimum urban development. Runoff in this area typically flows to the Hawkesbury River from heavily vegetated areas.

The Hawkesbury River widens as it approaches the lower estuarine areas near Wisemans Ferry and tidal influences begin to dominate water levels closer to the ocean. Water quality is influenced by inflows from downstream catchments (for example the Nepean River, Grose River, Macdonald River, and Colo River), runoff from rural and urban land uses, and discharges from sewage treatment plants.

Declared wild rivers

Under the NPW Act, wild rivers are to be managed to ensure restoration (where possible) and maintenance of the natural biological, hydrological and geomorphological processes associated with wild rivers and their catchments. Within the downstream environment there are two declared wild river systems, the Colo River and the Grose River, both of which are major tributaries of the Hawkesbury River.

The Colo River which flows through the GBMWHA consists of four subcatchments, namely Colo, Wolgan, Capertee and Wollemi which largely fall within the Blue Mountains and Wollemi National Parks. These are large and relatively undisturbed catchments and are important in controlling flood mitigation, water supply and water quality in the Hawkesbury-Nepean catchment. Historically, impacts from mining occurred in the headwaters of Wollangambie Creek which lies within the Colo subcatchment. However, it is likely that the biological condition of the river improves downstream from the colliery (OEH 2015).

The Grose River also flows through the Blue Mountains National Park but has a history of grazing, logging and mining within the catchment. The grazing and logging that took place within the catchment has left no remaining major impacts and the mine which was located at the headwaters of the Grose River once impacted the waterway but is no longer operational.

Wetlands, lagoons and groundwater dependent ecosystems

The Hawkesbury-Nepean region contains several wetland types including upland lakes and wetlands, coastal swamps and coastal floodplains. Wetlands included within the Directory are present in the downstream environment of the Project and include Pitt Town Lagoon and Longneck Lagoon. Both of these wetlands are examples of the Endangered Ecological Communities (EEC) Freshwater Wetlands on Coastal Floodplains of the New South Wales North Coast, Sydney Basin and South East Corner Bioregions. These two floodplain lagoons are located south of the Hawkesbury River, with Pitt Town Lagoon located off Bardenarang Gully, and Longneck Lagoon located off Longneck Creek near the suburb of Pitt Town.

According to the Hawkesbury-Nepean State of the Catchments (SOC) 2010 report, overall wetlands in the region are in very poor condition (DECCW 2010h). In general, there is limited information and data on the condition of wetlands in NSW however, the SOC 2010 report identified the overall condition, indicators of pressure and pressure rating experienced by Hawkesbury-Nepean wetlands. Those wetlands listed in the SOC 2010 report within the downstream environment are detailed in Table 27-12. As shown in Table 27-12, the existing altered hydrology has resulted in a moderate disturbance to both wetlands.

Table 27-12. Condition, indicators of pressure and pressure rating

Downstream wetland	Condition	Pressure	Indicators of pressure
Longneck Lagoon Upland freshwater lake	Very Poor	High	Catchment Disturbance: High Hydrological Disturbance: Moderate Habitat Disturbance: High
Pitt Town Lagoon Coastal floodplain swamp	Very Poor	High	Catchment Disturbance: High Hydrological Disturbance: Moderate Habitat Disturbance: Moderate

Source: DECCW 2010h

Infrastructure and built environment

The natural hydrology and hydraulics of the Hawkesbury-Nepean catchment and river have been greatly altered by human modifications which has resulted in detrimental effects on many river-dependant ecosystems (Department of Primary Industries (DPI) 2014b). Key alterations to hydrology include urban development, dam construction, water extractions, water discharges, weirs and water diversions. The alterations and subsequent changes to hydrology also impact on the water quality of the Hawkesbury-Nepean River system.

Urban waterways and stormwater runoff water quality

The Hawkesbury-Nepean River receives major contributions of stormwater runoff from the highly modified urban creek catchments, namely South Creek and Eastern Creek. These waterways drain significant portions of Greater Western Sydney suburbs including Blacktown, Rooty Hill, St Marys and Quakers Hill and join with the Hawkesbury River near Windsor.

Pollutant build-up and wash off in urban areas can present significant sources of nutrients and sediment being transported into the Hawkesbury-Nepean River. This is particularly relevant to the South Creek catchment which has been identified as the most degraded sub-catchment of the Hawkesbury-Nepean River (DECCW 2010c). The vegetation clearing and increasing urbanisation in this area has increased runoff changing the hydrology of the area but also contributing to poor water quality of the streams.

Diffuse pollution sources such as stormwater runoff is often more difficult to quantify and manage than point sources; however, diffuse sources such as urban (and agricultural) runoff have just as great if not greater effect on water quality (Rae 2007). Land use and vegetation cover strongly influence the nutrient loads from diffuse sources of pollution, with increased levels of land disturbance and modification resulting in higher nutrient loads (Rae 2007).

Discharges from WWTPs

One of the main anthropogenic discharges into the Hawkesbury-Nepean River system is discharges from WWTPs. Whilst point source discharges typically contribute a lower portion of the total nutrient load to the Hawkesbury-Nepean River than diffuse sources, under dry weather conditions point sources contribute most of the nutrient loads as they typically have constant discharges all year round (DECCW 2010c).

Sydney Water operates 15 WWTPs that are licensed to discharge into the lower Hawkesbury-Nepean catchment, whilst Hawkesbury City Council has two WWTPs. Sydney Water monitors the impacts of the WWTP discharges and reports annually to the NSW Environmental Protection Authority (EPA). Results from the most recent published monitoring data (2014-15) indicates that key nutrients, dissolved oxygen, pH and chlorophyll-a increased from previous years at most monitoring sites. This was attributed to the increased rainfall across the year leading to higher runoff, wastewater overflows and discharge of partially treated wastewater due to WWTPs reaching their capacity (Sydney Water 2015).

Weirs and weir pools

The only currently maintained weir on the Nepean River downstream of the junction with the Warragamba River is the Penrith Weir, located approximately 22 kilometres downstream of Warragamba Dam. Historically three or possibly four weirs were constructed across the Nepean River with diversions to power water mills, but these are no longer maintained. The environmental impact of weirs (and dams) is widely recognised as one of the key contributors to riverine degradation (DPI 2006). Weirs alter natural hydrology and sedimentation processes and create still water environments. Weirs impact on channel geomorphology and water quality by trapping sediments from the upstream environment and storing them in the freshwater pool created by the weir, thus disrupting the natural sediment balance. The sedimentation that occurs in the weir pool also affects aquatic organisms and their habitats.

Muzirwa *et al.* (2015) conducted an analysis of Hawkesbury-Nepean River water quality monitoring data collected by WaterNSW. The analysis concluded that, of the sites examined, the site at Penrith Weir (along with another site at North Richmond) were the most polluted parts of the river with respect to TN, TP, *E. Coli* and algae levels. This result indicates that the river has been notably impacted by urban and industrial developments along its urban corridor near Penrith. While the weir itself is not directly causing this poor water quality, it may be responsible for the high nutrients loads building up in the weir pool.

Water uses

The Hawkesbury-Nepean River is utilised by many different individuals, groups, businesses and industries. Major water users in this catchment include Sydney Water Corporation, local councils, irrigated agriculture, tourism, commercial fishing and oyster farming. The Hawkesbury-Nepean is also utilised by the community for recreational purposes such as swimming, recreational fishing, water skiing, etc. Sydney Water supplies water to most homes and businesses within the greater metropolitan area (DPI 2017a).

Water is extracted by Sydney Water to use for water supply purposes at the North Richmond WFP. Cyanobacteria are recognised as a serious water quality problem within Australia regarding both raw water supply for drinking water purposes and recreational water use. Previously, prolonged low flows in the Hawkesbury River between Windsor and Wisemans Ferry have been associated with blue-green algal blooms (Krogh, Wright and Miller 2009).

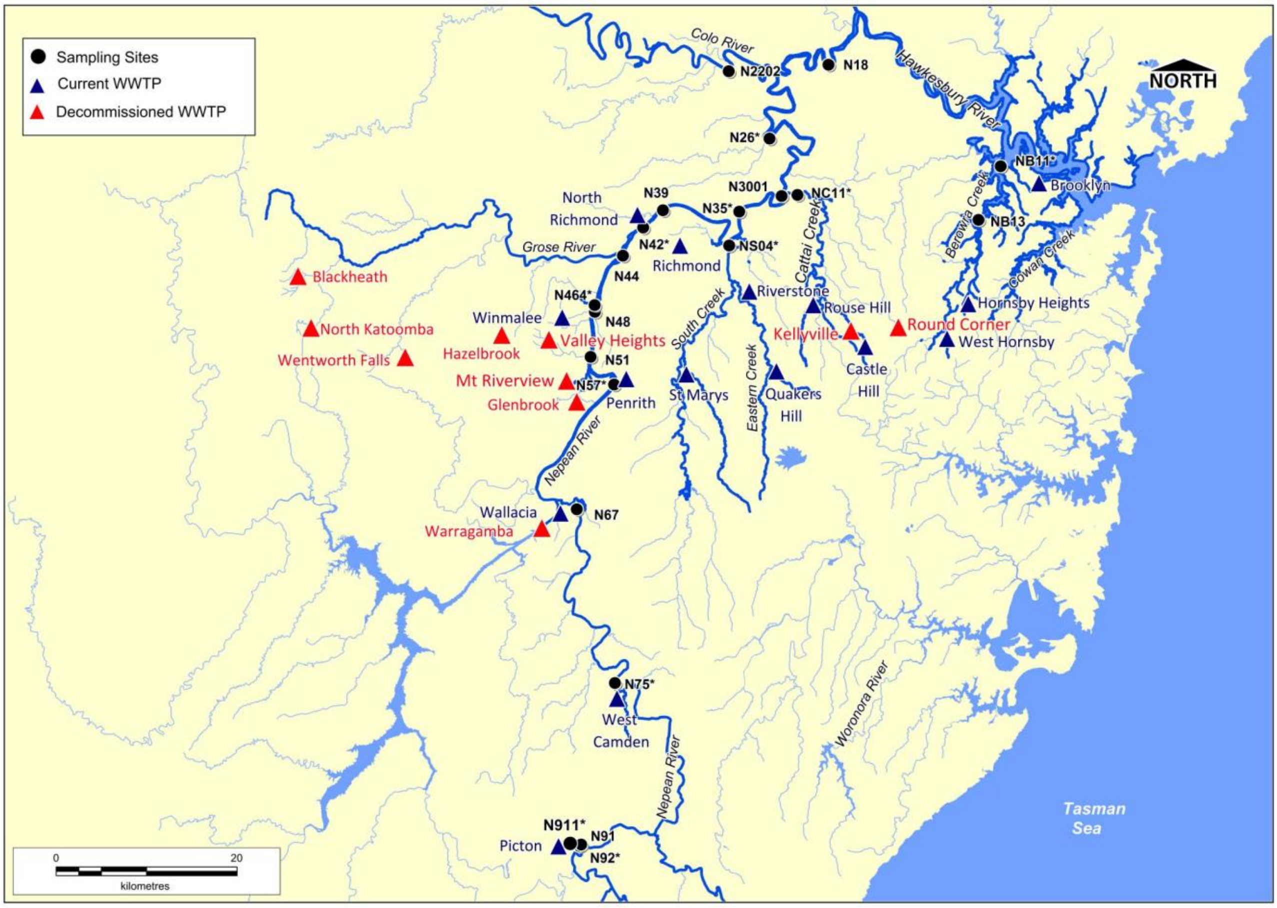
Large volumes of water are also extracted from the Hawkesbury and Nepean Rivers for irrigation purposes.

As previously outlined, treated wastewater is also discharged into the Hawkesbury-Nepean River and its tributaries which impacts on water quality, often increasing nutrient levels downstream of discharge points.

27.3.3.2 Downstream environment water quality conditions

Sydney Water undertakes water quality monitoring of the Hawkesbury-Nepean River and some of its tributaries for its Sewage Treatment System Impact Monitoring Program. Results from its Interpretive Report 2016-17 (Sydney Water 2018b) are summarised in the following sections. The sites monitored and the locations of WWTPs are shown in Figure 27-8.

Figure 27-8. Key water quality monitoring sites monitored by Sydney Water as part of its Sewage Treatment System Impact Monitoring Program



Source: Sydney Water 2018b

Trend analysis was undertaken for key water quality parameters at key sites to identify statistically significant long-term trends in water quality. Details of the methodology used to undertake the trend analysis can be found in the Interpretive Report 2016-17 (Sydney Water 2018b). A summary of the trend analysis is presented in Table 27-13. The long-term nutrient load reduction from Sydney Waters WWTPs as well as other government initiatives to reduce diffuse run-off to the river, is reflected in reduced nutrient concentrations in the downstream river and its tributaries (Sydney Water 2018). Total nitrogen and total phosphorus have decreased significantly over the long-term in the order of 13 percent to 72 percent at most monitoring sites. Localised long-term increasing trends in total phosphorus concentrations were identified in the Nepean River at Penrith Weir and Hawkesbury River at Leets Vale.

Despite the significant long-term reduction in nutrient concentrations, chlorophyll-a, a key indicator of algal biomass, showed little change at most monitoring sites. A long-term decreasing trend in chlorophyll-a was identified at two sites (Winmalee Lagoon outflow and Hawkesbury River at Sackville Ferry), while a significant increasing trend was detected at the Nepean River at Penrith Weir and the Hawkesbury River at Leets Vale. These sites also showed increasing trends in total phosphorus.

Blue-green algal biomass significantly decreased in the lower Hawkesbury-River at Sackville Ferry where frequent algal blooms have historically occurred.

Significant changes in other water quality parameters were also identified including:

- Seven sites showed a significant long-term decline in pH
- Long-term water clarity improved as indicated by decreased turbidity at 10 sites.

Table 27-13. Summary of long-term water quality trends from upstream to downstream sites along the Hawkesbury-Nepean River and tributaries

Site	Chlorophyll-a	Blue green algal biovolume	Total nitrogen	Total phosphorus	pH	Dissolved oxygen saturation	Turbidity
N67: Nepean River at Wallacia Bridge							
N57: Nepean River at Penrith Weir							
N51: Nepean River at Fitzgerald Creek							
N48: Nepean River at Penrith Weir							
N464: Winmalee Lagoon							
N44: Nepean River at Yarramundi Bridge							
N42: Hawkesbury River at North Richmond							
N39: Hawkesbury River at Freemans Reach							
NS04: South Creek near Hawkesbury River							
N35: Hawkesbury River at Wilberforce							
NC11: Cattai Creek							
N26: Hawkesbury River at Sackville							
N18: Hawkesbury River at Leets Vale							

Key

	insufficient data or not a key site
	insignificant trend for parameter
	significant decreasing trend for parameter
	significant increasing trend for parameter

Source: Sydney Water 2018b

Water quality in the Hawkesbury-Nepean River varies widely as the river morphology and other conditions change along the 180 kilometres from Maldon Weir, downstream to Leets Vale. Several tributaries join or confluence with the river along this large distance, carrying a diverse range of inflows from different localised catchments. Among these, four tributaries (including one lagoon) are monitored by Sydney Water where WWTPs are discharging.

The water quality at the upstream reference site at Maldon Weir was good for many of the parameters monitored as it receives flows from protected drinking water catchments and environmental flow releases from upstream water storages. The water quality changes with distance downstream and the river widens and it receives nutrient rich pollutants from urbanised catchments, diffuse runoff from agriculture, plus continuous discharge from multiple WWTPs. The quality of the lower Hawkesbury River, below Windsor and downstream of the South Creek confluence is comparatively poor with very high levels of nutrients, chlorophyll-a and algae. In the estuary, the water quality is variable due to tidal flushing from the ocean.

The median values for water quality parameters for 2016-17 data for key sites monitored along the Hawkesbury-Nepean River are presented in Table 27-14. Chlorophyll-a concentrations progressively increased with distance downstream, including the tributaries sites. The highest median chlorophyll-a concentrations (≥10 µg/L) were observed in the lower Hawkesbury River at Wilberforce (N35), and the Sackville Ferry (N26). The second highest median chlorophyll-a levels were recorded further downstream at Leets Vale (N18). Median chlorophyll-a concentrations exceeded the recommended site-specific HRC (1998) objective at these sites. Blue-green algal abundance was evident in the lower Hawkesbury River sites, as well as limited occurrences in South and Cattai creeks.

The nutrient concentrations in South Creek (NS04) were poor, with both total nitrogen and total phosphorus median concentrations exceeding the site-specific HRC (1998) objective. The median total nitrogen concentration at Cattai Creek (NC11) also exceeded the HRC objective. These sites drain large semi-urban catchments and receive continuous discharge from WWTPs. The median total nitrogen concentrations also exceeded the HRC objective at Wallacia Bridge (N67). Typically, high nutrient concentrations (nitrogen and phosphorus), were evident in the Hawkesbury River downstream of the South Creek. The median total phosphorus concentrations exceeded the HRC objective at Wilberforce (N35) and Leets Vale (N18), while the median total nitrogen concentration was the only nutrient to exceed the HRC objective at Wilberforce (N35).

Physico-chemical parameters indicated poor water quality in South and Cattai creeks. The highest median turbidity and lowest median dissolved oxygen saturation were also associated with these sites (NS04 and NC11).

Table 27-14. Median water quality values for 2016-2017 at sites in the Hawkesbury-Nepean River and tributaries

Site	Chlorophyll-a (µ g/L)	Blue-green algal biovolume (mm^3/L)	Total nitrogen (mg/L)	Total phosphorus (mg/L)	pH	Dissolved oxygen saturation (%)	Turbidity (NTU)
N67: Nepean River at Wallacia Bridge	4.3	0.005	0.91	0.019	7.1	90.9	9.3
N57: Nepean River at Penrith Weir	5.6	0.042	0.50	0.014	7.5	99.1	4.5
N51: Nepean River at Fitzgerald Creek	3.2	0.010	0.52	0.015	7.6	99.9	5.0
N48: Nepean River at Penrith Weir	6.9	0.050	0.56	0.018	7.6	97.6	3.7
N464: Winmalee Lagoon	3.9	0.025	0.84	0.022	7.6	98.5	4.1
N44: Nepean River at Yarramundi Bridge	5.4	0.108	0.56	0.020	7.6	95.4	6.3
N42: Hawkesbury River at North Richmond	7.2	0.015	0.52	0.020	7.4	97.6	7.6
N39: Hawkesbury River at Freemans Reach	6.1	0.069	0.53	0.019	7.3	98.3	6.3
NS04: South Creek near Hawkesbury River	5.8	0.002	2.53	0.111	7.4	72.0	53.0
N35: Hawkesbury River at Wilberforce	10.1	0.039	0.74	0.043	7.4	84.9	14.0
NC11: Cattai Creek	4.1	0.033	1.49	0.043	7.1	61.0	21.5
N26: Hawkesbury River at Sackville	10.0	0.078	0.62	0.033	7.5	88.5	13.0
N18: Hawkesbury River at Leets Vale	7.9	0.018	0.65	0.044	7.3	81.5	17.5

Key

(red)	Non-compliance with HRC objectives

Source: Sydney Water 2018b

27.4 Assessment of potential construction impacts

27.4.1 Construction activities

The construction footprint of the Project covers an area of about 100 hectares and includes:

- concrete batch plants
- materials storage areas
- vegetation clearing (about 22 hectares)
- demolition and construction activities associated with the dam raising.

The potential impacts on water quality of these activities are discussed in the following sections. Typical management and mitigation measures to minimise risks to water quality are also discussed for specific activities.

27.4.1.1 Concrete batch plants

Potential water quality impacts from this activity include:

- wastewater from concrete batching process – generally the volume of wastewater generated would be small and wastewater would be able to be incorporated into the concrete batching process. Water quality risks from this activity would be minor
- runoff from the concrete batch plant sites – the surface of the concrete batch plants sites would contain spilled concrete and materials used in the manufacture of concrete. Runoff from the site may have high suspended solids loads and high pH. Water quality risks from this activity would be high if not managed appropriately
- concrete materials storage – runoff from areas used to store materials used in the production of concrete may have high suspended solids loads and high pH. Water quality risks from this activity would be high if not managed appropriately.

The concrete batch plants sites would be constructed to have a dedicated drainage system, which would drain to treatment facilities (for example, either a treatment pond or water treatment plant). Runoff would be appropriately treated and either discharged or reused where possible.

27.4.1.2 Material storage areas

Potential water quality impacts include:

- runoff from material storage areas – the surface of the material storage areas would contain soil, dust, and other particulate material. Runoff from the site may have high suspended solids loads and other particulate pollutants. Water quality risks from this activity would be high if not managed appropriately
- hazardous good storage – hazardous goods such as oils, fuels and chemicals used in equipment and for construction may be stored in material storage areas. Potential risks to water quality include contaminated runoff from storage areas and leaks and spills of hazardous goods.

The material storage areas would be constructed so that runoff would drain to water quality treatment ponds. Runoff would be appropriately treated and either discharged or reused where possible.

Hazardous goods would be stored and handled in accordance with appropriate guidelines, policies, and legislation. This would include bunding of storage areas, spill management procedures, appropriate training and capture and treatment of any contaminated water.

27.4.1.3 Vegetation clearing

Potential water quality impacts from this activity include:

- runoff from cleared areas – runoff from and erosion of exposed soils may have high suspended solids loads and other particulate pollutants. Water quality risks from this activity would be high if not managed appropriately
- runoff from stockpiles of mulched vegetation – runoff from stockpiles of mulched vegetation may contain high levels of tannins which may lower dissolved oxygen and discolour receiving waters.

Appropriate erosion and sedimentation control measures for cleared areas would be designed, installed, and operated in accordance with *Managing Urban Stormwater: Soils and Construction* (Landcom 2004).

Mulch stockpiles would be managed in accordance with *Management of Tannins from Vegetation Mulch* (Roads and Maritime Service (RMS) 2012).

27.4.1.4 Demolition and construction activities associated with the dam raising

Potential water quality impacts from these activities include:

- generation of concrete dust and concrete slurry from demolition and preparation activities – The amount of concrete dust generated from demolition activities would be relatively minor however would still need to be managed. Concrete dust and slurry would be generated from hydro-blasting of the dam wall and significant quantities would be generated. Concrete dust and slurry from the site may have high suspended solids loads and high pH. Water quality risks from these wastes would be high if not managed appropriately

- runoff from construction area – runoff from the construction area may contain concrete dust, soil, oil/fuels, and other pollutants. Water quality risks from this activity would be high if not managed appropriately.

The construction contractor would be required to develop a detailed construction soil and water management plan to manage these activities. Specific management and mitigation activities would depend upon the construction staging, construction methodology, land availability and other factors, which have yet to be fully determined.

The dissipater pond at the base of the dam would require draining to enable the dam wall to be thickened. This would require the construction of a coffer dam downstream of the dissipater pond which would prevent water from the Warragamba River from flowing back into the dissipater pond. This would effectively create a large area where ponds could be located to capture any runoff from the dam wall construction and the hydro-blasting. Similarly, a second coffer dam would be required downstream of the auxiliary spillway to allow the installation of erosion protection downstream of the auxiliary spillway. This would also provide an area to capture any runoff from the auxiliary spillway construction area.

27.4.2 Water quality protection criteria

Erosion and sedimentation impacts during construction would be managed in accordance with *Managing Urban Stormwater: Soils and construction, Volume 1* (Landcom 2004) – the Blue Book for diffuse source pollution. Point source pollution from the concrete batch plant and other sources would be subject to an EPL issued under the *Protection of the Environment Operations Act 1997* and any point sources will need to meet the NSW WQO for the receiving waters or for raw water supply for drinking purposes water guidelines.

Warragamba Dam is Sydney's major water supply source. Protecting the water quality in the dam during construction is therefore important. As noted in the sections above runoff from construction areas and other activities may pose a risk to water quality if not appropriately managed.

Where possible construction water discharges would be re-directed to downstream of the dam, however this may not be feasible or possible in all locations and for all activities. Consequently, any water quality protection criteria for discharges to the dam would reflect the 'sensitive' use of water in the dam. Water quality protection criteria would include suitable design criteria for mitigation measures to capture and treat runoff from construction areas as well discharge criteria.

A 90^{th} percentile 5-day rainfall event would be the basis for mitigation measures to capture and treat runoff from construction areas (Landcom 2004). This is equivalent to approximately 48 millimetres of rainfall. Appropriate discharge criteria would be 25 mg/L of total suspended solids, a pH of 6.5 to 8 and no visible oil and grease. However, the final discharge criteria would need to be developed and approved by the EPA and WaterNSW.

27.5 Assessment of operational impacts

27.5.1 Risks during operation

Potential impacts to the water quality in Lake Burragorang due to the Project would only occur during large flood events and when the water levels exceed FSL and the FMZ is operational.

Potential changes in downstream water quality due to the Project could occur when the FMZ is being discharged. It should be noted, however, that rainfall events giving rise to the need to operate the FMZ will be of a magnitude likely to result in increased flows in other catchments discharging to the Hawkesbury-Nepean River below Warragamba Dam, and in turn, affecting receiving water quality (as currently occurs). The key potential operational impacts on water quality are described in Table 27-15.

Table 27-15. Mechanisms affecting operational water quality

Mechanism	Potential impact
Upstream environment	
Increased temporary storage of flood waters before release	Increased extent and duration of temporary inundation of upstream catchment. Potential water quality risks identified and assessed include: ▪ increased natural organic matter concentrations ▪ increased pathogens concentrations ▪ increased turbidity ▪ increased nutrient concentrations ▪ changes in hydrology which could cause water quality impacts.
Downstream environment	
Discharge of the FMZ	Temporary changes in water quality due to an extended period of discharge from the FMZ

27.5.2 Operation of Warragamba Dam

27.5.2.1 Normal operations

During non-flood periods the dam and water supply operations would continue to operate as they do currently. The only difference with the Project is that the current daily fixed volume releases would be replaced by a variable volume environmental flow release.

During normal operations, water is held in the dam for a substantial period and any suspended particulate matter would generally settle. The dam also has a multi-level offtake for raw water supply for drinking water purposes and therefore water can be selected from the required location within the water column to meet raw water supply for drinking water purposes' quality requirements.

The Project would not result in any changes in water quality in the dam during normal operations as there would be no change in FSL or how the dam is operated currently.

27.5.2.2 Flood operations

Flooding and hydrology is discussed in Chapter 15 and Appendix H1. Operation of the FMZ would occur during significant rainfall events and when the water level in the dam is above FSL. Generally, the FMZ would capture all flood inflows up to a 1 in 20 to 1 in 40 chance in a year flood event. The timeframe to empty the FMZ when full would be around two weeks.

The most effective way of discharging the FMZ in a manner that restores the availability of the FMZ as soon as practical while minimising additional flooding impacts is to 'piggy back' discharges after the peak flood level has been reached. The maximum discharge rate through the new outlet conduits would be 230 gigalitres per day. This is equivalent to a 1 in 5 chance in a year flood event on the Richmond-Windsor floodplain, and consequently piggybacking at this rate would be suitable for any downstream flood greater that a 1 in 5 chance in a year flood event. For smaller floods events, the discharge rate would need to be reduced to reflect peak flood levels.

Piggy backing of discharges would generally occur for two to three days after the peak of a flood event, after which a constant discharge rate of around 100 gigalitres per day (1,160 cubic metres per second) would be implemented. For smaller flood events (1 in 20 chance in a year and lower), piggy backing would not be possible and a constant discharge would need to be adopted.

27.5.2.3 Current management systems

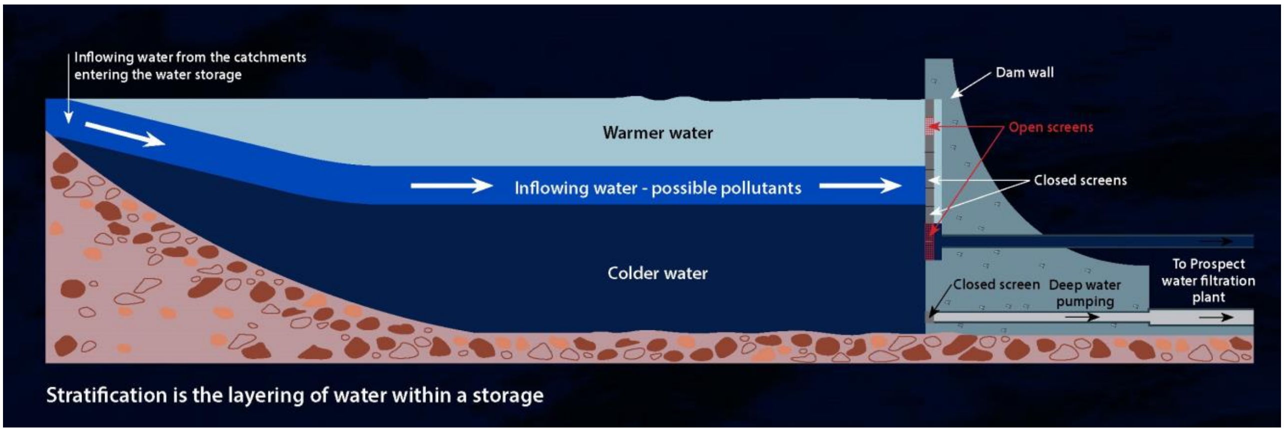
To manage water quality in the dam and specifically raw water supply for drinking water purposes, there are existing management and monitoring systems that would be updated to reflect the modified operations and impacts of the Project. These include:

- water quality monitoring – extensive regular and event-based monitoring of water quality in Lake Burragorang is undertaken including monitoring of raw water supply for drinking water purposes guideline parameters, nutrients, pathogens, algae and other pollutants which either pose a risk to water quality or human health. This monitoring contributes to understanding of processes that may affect dam water quality as well providing up to date water quality information which can be used to select appropriate quality water for raw water supply for drinking purposes. Regular monitoring is supplemented by issue specific monitoring. For example, the pathogen monitoring program aims to gain a better understanding of the pathogen risk at times when it is expected to be the greatest challenge to water treatment. To achieve this, pathogen monitoring during heavy rain events is increased. The increased wet weather dataset and additional knowledge on Cryptosporidium infectivity and human pathogenicity will enable reliable risk assessments to be conducted for the Sydney water supply for drinking water purposes

- Sydney Catchment Aquatic Real-time Information Support System (SCARISS) – A real-time monitoring system consisting of thermistors chains in 6 locations, inflow gauging and water quality monitoring stations and weather stations is used to provide essential information to which can used to select appropriate quality water for the supply of raw water supply for drinking water purposes from the multi-level offtake at the dam wall. This information is input into the Sydney Catchment Aquatic Real-time Management System (SCARMS)
- SCARMS is a real-time decision support tool that can use real-time and historical data for reservoir management and to inform the selection of appropriate quality water for raw water supply for drinking water purposes from the multi-level offtake at the dam wall. Three different models have been integrated in the decision support tool three different models including one-dimensional hydrodynamics model (DYRESM), three-dimensional hydrodynamics model (ELCOM) and an aquatic ecological model (CAEDYM). The integration of the validated models, databases and a graphical user interface into a decision support system provides a tool for reservoir managers to improve understanding of water quality processes and to aid in short-term operational strategies and long-term management policies
- regional raw water supply for drinking water purposes system – There is an extensive system of dams, weirs, canals, pipelines, and tunnels which supply raw water supply for drinking water purposes to various water filtration plants in the Sydney, Illawarra and Shoalhaven regions. If the water quality in Lake Burragorang is not suitable as raw water supply for drinking water purposes, alternative sources can temporarily supply Prospect Water Filtration Plant including the Upper Nepean dams, Shoalhaven dams and Prospect Reservoir. However, Warragamba and Orchard Hills filtration plants would still rely on water from Lake Burragorang.

  Management of raw water supply for drinking water purposes at Warragamba Dam is shown in Figure 27-9. When the flood inflows are colder than the water in Lake Burragorang, they sink to the bottom of the lake and the water supply outlet screens are raised to avoid lower quality flood inflows. Conversely when the flood inflows are warmer than the water in the lake, the outlets are lowered to avoid the lower quality flood inflows.

Figure 27-9. Management of raw water supply for drinking water purposes at Warragamba Dam



27.5.3 Upstream water quality impacts

27.5.3.1 Introduction

The four key risks to water quality in Lake Burragorang are:

- increased natural organic matter, which could result in treatability issues and disinfection by-products
- increased turbidity from erosion
- increased nutrient concentrations resulting in algal blooms (aesthetics, taste and odour, toxins)

- increased pathogens concentrations.

These are further discussed and considered in the following sections; the risk assessment is presented in Table 27-16.

27.5.3.2 Increased natural organic matter which could result in disinfection by-products

At the water filtration plants chlorine is added to water supplied from Lake Burragorang to disinfect the water to meet Australian drinking water standards. Disinfection by-products were first discovered in the early 1970s, with the identification of chloroform and other trihalomethanes (THMs) in drinking water (Bellar, Lichtenberg and Kroner 1974; Rook 1974).

Trihalomethanes are a group of four chemicals—chloroform, bromodichloromethane, dibromochloromethane and bromoform—formed, along with other disinfection by-products, when chlorine or other disinfectants used to control microbial contaminants in drinking water react with natural organic matter (NOM) and inorganic matter in water. While trihalomethanes are potentially carcinogenic to animals and can produce maternal and foetal toxicity at high doses, the doses required to produce these effects are very high and much higher than typically is recorded in drinking water (National Health and Medical Research Council (NHMRC) and National Resource Management Ministerial Council (NRMMC) 2018).

The Australian Drinking Water Guidelines (ADWG) set a guideline value for total THMs of 250 µg/L in 1996 (National Health and Medical Research Council (NHMRC) and Agricultural and Resource Management Council of Australia and New Zealand (ARMCANZ) 1996). The guidelines also state that

> *Trihalomethane concentrations fluctuating occasionally (for a day or two annually) up to 1 mg/L are unlikely to pose a significant health risk. Action to reduce THMs is encouraged, but must not compromise disinfection, as nondisinfected water poses significantly greater risk than THMs.*

The levels of THMs in treated drinking water are dependent upon many factors, however, the two key factors are:

- concentration of NOM in raw water supply for drinking water purposes
- drinking water treatment processes.

Natural organic matter is a broad term for the complex mixture of thousands of organic compounds found in water. It can consist of both dissolved and particulate forms. However as raw water supply for drinking water purposes treatment generally involves filtration before chlorination and particulate matter would be largely removed, the dissolved forms of NOM would generally generate THMs. Generally dissolved NOMs are measured using dissolved organic carbon (DOC) as a surrogate.

Natural organic matter can be generated through a number of typical biological processes and for Lake Burragorang the most likely sources are:

- directly leached from soil
- decay of submerged vegetation
- runoff from catchment
- algal blooms.

Dissolved organic carbon concentrations in Lake Burragorang are generally low (4 to 6 mg/L). However higher concentrations have been recorded in surface waters when algal blooms are occurring.

The Project would result in an increase in the temporary inundation of vegetated areas and soil landscapes that potentially could result in an increase in NOMs. While it is likely that there would be an immediate short-term increase in NOM concentrations due to the liberation of highly soluble and available NOMs in the soil and vegetation experiencing temporary inundation, this would be a short term infrequent minor increase and would not result in a significantly increased risk of human health risks.

Significant increase in human health risk is not anticipated due to the:

- infrequent operation of the FMZ – The FMZ would operate infrequently. While flood levels for various flood events have been presented in Chapter 15 (Flooding and hydrology), these are worst case scenarios and assume that the dam is at FSL when a rainfall event occurs. In reality, the dam is rarely at FSL and consequently the frequency and extent of temporary inundation would be substantially less than that suggested by the frequency of different flood events

Table 27-16. Upstream water quality risk assessment

Summary of risk	Factors to consider	Overall impacts and risk without mitigation	Mitigation measures	Residual risk with mitigation measures
Increased generation of NOM in dam water from inundated vegetation and soils – which in turn may increase concentration of trihalomethanes in chlorinated drinking water. Trihalomethanes have been suggested to cause cancer	▪ cancer risk from THMs in drinking water not clear ▪ existing NOM concentrations low ▪ the generation of NOM from soils and vegetation is determined by period of inundation. The frequency and duration of inundation with the Project is low ▪ threshold period for establishment of microbiological communities and significant NOM generation 15+ days ▪ non-deciduous woody vegetation has a low rate of generation of NOM.	**Likely Impacts** – Small increases in NOM concentrations in raw water supply for drinking water purposes after operation of FMZ **Risk Assessment** Consequence – Health major Likelihood – Rare *Overall risk – Medium*	▪ monitoring ▪ sourcing raw water supply for drinking water purposes from other dams ▪ adjusting treatment processes at WFPs ▪ use of multi-level offtake.	Consequence – Health negligible Likelihood – Rare *Overall risk – Low*
Increased erosion of inundated areas resulting in increased turbidity and raw water supply for drinking water quality issues	▪ the majority of sediment and nutrient loads originate from upstream catchment ▪ the frequency and duration of inundation with the Project is low allowing vegetation to regenerate or colonise between events ▪ existing turbidity is low.	**Likely Impacts** – Increases in water turbidity due to erosion **Risk Assessment** Consequence – Legal Medium (Breach of raw water supply for drinking water purposes agreements) Likelihood – May occur *Overall risk – High*	▪ implementation of the National Parks EMP ▪ continued implementation of other erosion management programs in the upper catchment ▪ use of the multi-level offtake ▪ sourcing raw water supply for drinking water purposes from other dams ▪ adjusting processes at water treatment plants.	Consequence – Legal Minor (Breach of raw water supply for drinking water purposes agreements) Likelihood – Possible under exceptional circumstances *Overall risk – Low*
Leaching of nutrients from inundation of soils and eutrophication/water quality issues	▪ the leaching of nutrients from soils is determined by period of inundation. The frequency and duration of inundation with the Project is low	**Likely Impacts** – Small increases in soluble nitrogen concentrations	▪ implementation of the National Parks EMP ▪ use of the multi-level offtake	Consequence – Environment Minor (algal bloom) Likelihood – Unlikely

Summary of risk	Factors to consider	Overall impacts and risk without mitigation	Mitigation measures	Residual risk with mitigation measures
	▪ threshold period for establishment of microbiological communities and significant phosphorus generation 20+ days ▪ soils in catchment generally nutrient poor.	**Risk Assessment** Consequence – Environment Minor (algal bloom) Likelihood – May occur *Overall risk – Medium*	▪ sourcing raw water supply for drinking water purposes from other dams ▪ adjusting processes at Water Treatment Plants.	*Overall risk – Low*
Increased concentrations of pathogens in dam water leading to increased human health risks	▪ pathogen levels are very low in the dam and generally below detectable levels ▪ the frequency and duration of inundation with the Project is low ▪ native animal faeces have low levels of pathogens ▪ existing feral animal control programs.	**Likely Impacts** – Small increases in pathogen concentrations **Risk Assessment** Consequence – Health Medium Likelihood – Possible *Overall risk – Medium*	▪ implementation of the National Parks EMP ▪ use of the multi-level offtake ▪ sourcing raw water supply for drinking water purposes from other dams ▪ adjusting processes at water treatment plants	**Risk Assessment** Consequence – Health Medium Likelihood – Rare *Overall risk – Low*
Discharge of the FMZ when algal bloom present in dam	▪ would occur anyway under existing operations of dam ▪ algal blooms are relatively infrequent ▪ algal blooms generally occur sometime after inflow events, which is generally beyond the two-week window for emptying the FMZ.	**Likely Impacts** – No change from existing conditions	None.	No change from existing risk

- short and variable duration of flooding – There would be an increase in the area and duration of vegetation and soils temporarily inundated. The duration of temporary inundation would vary significantly across the landscape (that is, relative to the height above FSL and the size of the event) and could range from hours to around two weeks. For example, if a 1 in 20 chance in a year event was to occur and the dam was at FSL , the maximum water level would be around RL 126.8 metres. Vegetation and soils at this level would only experience temporary inundation for hours, whereas vegetation and soils at RL 122 metres to FSL would experience temporary inundation for between seven and 12 days. The quantity of NOM generated is directly related to the duration of inundation of vegetation and soils – so therefore while the extent of inundation may be large – the duration of inundation for large areas of vegetation and soils may be relatively short – reducing the quantity of NOM generated
- time required to establish microbial communities which generate NOM – Based on numerous scientific studies (Gunnison *et al* 1985) there appears to be a threshold inundation period for the generation of NOM from the decay of submerged terrestrial plant species. Microbial processes are an essential part of accelerating the decay of vegetation – and these take a period of time to establish. As for vegetation, microbial processes determine the rate of the release of NOM from soils. Studies on the release of NOM from soils similar to Warragamba have indicated that about 20 days inundation are required to establish microbial communities, which cause a high rate of release of NOM. As soils would be inundated for less than 20 days for all events, it is unlikely that the Project would result in significant releases of NOM from soils (Gunnison *et al*. 1985)
- low decay rate of woody species – In Australian Eucalypt plant communities the majority of carbon (>90 percent) is found within the eucalypt tree components. Hard woods have a very low decay rate when submersed and therefore do not release large quantities of NOM in short periods of time. Eucalypts are also non-deciduous, and they do not generate the same level of leaf litter as deciduous trees. Leaves decay more rapidly to produce NOM. Trees and other woody vegetation would remain in situ when the FMZ is being emptied and therefore there would not be a significant additional long-term source of NOM in the lake.

The Prospect WFP is not specifically designed and operated to remove NOMs or reduce the production of THMs because raw water NOM concentrations are low. Concentrations of THMs in treated drinking water produced by Prospect WFP range between 0.041 (10^{th} percentile) and 0.124 mg/L (90^{th} percentile) (Office of NSW Chief Scientist and Engineer 2014), which are below the ADWG guideline value of 0.25 mg/L – and 1 mg/L for short periods. Despite the WFP not being designed or operated specifically to remove NOMs, some processes specific to the WFP such as flocculation with a combination of ferric chloride and aluminium polymers, can reduce NOM concentrations. The sand filter medium at Prospect WFP would also remove some NOMs, however the effectiveness of NOM removal by sand is low in comparison to Granulated Activated Carbon, for example.

If NOM levels were to increase, there are a number of potential mitigation measures such as:

- monitoring of DOC concentrations in the raw water supply for drinking water purposes to identify any increases in DOC levels so that adaptive management can be implemented
- when NOM levels are high in Lake Burragorang, consider adjusting the blend of water being provided to Prospect WFP so a greater proportion of water is supplied from storages with lower NOM levels
- adjusting treatment processes at WFPs to increase the removals of NOMs – this could include increased dosing with ferric chloride, reducing chlorination and increasing chloramination (which does not produce THMs).

27.5.3.3 Increased turbidity from erosion

A potential risk on the lake water quality from the Project would be an increase in erosion leading to increased turbidity of raw water supply for drinking water purposes and sedimentation of the reservoir. Temporary inundation would result in the loss of some vegetation (depending on the type, frequency and depth of inundation) which in turn could increase the erosion of soils. While some increased erosion is expected, the impact would unlikely to be significant as:

- as described above temporary inundation events would be relatively uncommon and would have a variable duration across the landscape. While there would be a loss of vegetation especially near FSL where vegetation would experience the greatest duration of inundation, there would also be the opportunity for the regeneration of vegetation as the flood events are relatively uncommon. The vegetation that regenerates may not be the same plant community type as originally present, however, would still provide protection against erosion. For example, there is evidence that more flood tolerant Casuarina species are colonising areas around FSL

- existing upstream catchment sources of sediment are significant and would continue to contribute most of the sediment load to the dam. The Wollondilly River particularly contributes high sediment loads to Lake Burragorang as its catchment is mostly cleared (about 50 percent), contains eroded landscapes impacted by agricultural activities and contributes the highest proportion of flow to Lake Burragorang
- while water is held in the FMZ, some sediment would settle to the bottom, reducing sediment concentrations in the water column.

Mitigation measures to minimise any increased erosion and turbidity impacts on drinking water supplies include:

- implementation of the National Parks environment management plan (EMP) – which would have as one its objectives erosion control and revegetation of areas impacted by the operation of the FMZ
- continued implementation of other erosion management programs in the upper catchment areas such as the WaterNSW Grazing and Erosion Program
- use of the multi-level offtake to withdraw water with lower turbidity within the water column
- sourcing raw water supply for drinking water purposes from other dams when the FMZ at Warragamba Dam is in operation or sediment levels are high
- adjusting processes at water filtration plants to increase the removal of particulates in raw water supply for drinking water purposes.

27.5.3.4 Increased nutrient concentrations

A potential risk on the lake water quality from the Project would be an increase in nutrient concentrations (nitrogen and phosphorus) leading to more frequent and larger algal blooms.

Algal blooms are relatively infrequent in Lake Burragorang and there have only been two significant algal blooms recorded in the past 30 years. Both algal blooms have occurred following an inflow event when the water level has substantially risen. The majority of nutrient inputs into the lake are from the tributaries rather from localised catchment runoff.

The two potential sources of increased nutrients from the Project are from soils/vegetation that are temporarily inundated and from increased erosion as nutrients are often attached to soil particles. Increased erosion is discussed in Section 27.5.3.3, and there is not expected to be a significant increase in erosion.

The temporary inundation of soils – and to a lesser extent vegetation may result in a short-term increase in some nutrients – particularly soluble forms of nitrogen. Soluble nitrogen generally would not be in a form that is immediately available for use by algae (for example, amino acids), however further decay or oxidation/reduction of the soluble nitrogen compounds could make the nitrogen available. Generally, the Australian environment and soils are phosphorus poor – and any phosphorus would attach to particulates and in a form that is unavailable to algae. Microbial processes that would liberate phosphorus from inundated soils would take in excess of 20 days to establish (Gunniston 1985), which is greater than the maximum temporary inundation period.

As noted previously the operation of the FMZ would be relatively uncommon – so at worst there would be potentially short term increases in nitrogen levels before normal low dry weather concentrations are established. However, there would be an increased risk of algal blooms depending on when the rainfall event occurred, with higher risk periods when the dam is low or in summer months.

Mitigation measures to minimise any algal blooms impacts on drinking water supplies include:

- use of the multi-level offtake to withdraw water from lower in the water column as algal blooms only occur in surface layers
- sourcing raw water for drinking water purposes from other dams when algal blooms occur
- adjusting processes at Water Filtration Plants to increase the removal of algae in raw water supply for drinking water purposes.

27.5.3.5 Increased pathogen concentrations

Potential pathogens from catchment runoff include *Giardia*, *Cryptosporidium* and *E. coli*. The levels of these pathogens in Lake Burragorang are low and generally below the limit of detection. The Project may result in the increased mobilisation of pathogens in animals' faeces during temporary inundation events. While there is likely to be additional mobilisation of pathogens when animal faeces are inundated, this risk to drinking water supplies would be low as:

- native animals have a very low level of pathogens in their faeces

- while there are some pest species in the catchment – there are existing feral animal control programs, and these would be reviewed and enhanced as part of the National Parks EMP
- infrequent operation of the FMZ.

Mitigation measures to minimise any increased pathogens levels on drinking water supplies include:

- use of the multi-level offtake to withdraw water from locations in the water column where pathogen concentrations are low
- sourcing raw water supply for drinking water purposes from other dams when the FMZ is in operation
- adjusting processes at Water Filtration Plants to increase the removal of pathogens in raw water supply for drinking water purposes.

27.5.3.6 Changes in pollutant loads

The Project is not expected to result in any significant changes in pollutant loads in Lake Burragorang as most pollutants would still originate from upstream catchment areas particularly from the Wollondilly River.

27.5.4 Downstream impacts from operation of the FMZ

27.5.4.1 Flows

The discharge from the FMZ should not impact downstream water quality The proposed environmental flows and their impacts have been modelled in the Hawkesbury-Nepean Hydrodynamic Water Quality model. The scenario model uses a period from 1984 to 1994 as it provides a representative sample of very low flows to flood flows across the Hawkesbury-Nepean catchment. The model is a continuous flow model designed to determine the daily changes in water quality in response to flows, contaminants, and in-stream processes over a period of a decade. As this daily timestep model was not designed to model intra-day changes such as spills and flood inflows, flow increases greater than 3.4 gigalitres per day were smoothed to keep the model stable. This smoothing does not impact the results of the modelling as it takes several days for flows to impact the overall river water quality and the flood peaks would have passed before the commencement of the discharge of the FMZ. Figure 27-10 shows the modelled discharges from Warragamba Dam under current conditions, overlayed with estimated FMZ discharges and smoothing dates.

Based on the current preliminary operating rules, the proposed discharges of 100 gigalitres per day from the FMZ could continue for around two weeks after a flood event has ceased. Equivalent flows were identified from the Hawkesbury Nepean Hydrodynamic Water Quality model. The 1984 and 1989 events, which were around a 1 in 10 chance in a year flood inflow (see Appendix H1) and have a similar flow rate, were selected for comparison on flow impacts.

Figure 27-11 shows the 1984 flood event and illustrates that the flow regime from the Project would increase flows during the regression of flows. However, the Project would result in the reduction of the high flows for smaller flood events. Figure 27-12 shows the 1989 event, which clearly shows an impact on the rising limb of the flood event. Both figures also clearly show that the existing higher flushing flows will be reduced to moderate flows due to the FMZ (as defined in DPE 2018) which would reduce the frequency of flushing of the river downstream.

Sufficiently high flows at Penrith Weir and through to Yarramundi can result in the removal of nuisance algal growth in this reach of the river. Algal biomass removal requires flows of 3 gigalitres per day (DPE 2018) and as the discharge from the FMZ would be about 100 gigalitres per day, algal biomass removal would occur.

Figure 27-10. Modelled flows and estimated dam discharges during FMZ operation (data based on Hawkesbury-Nepean Hydrodynamic Water Quality model)

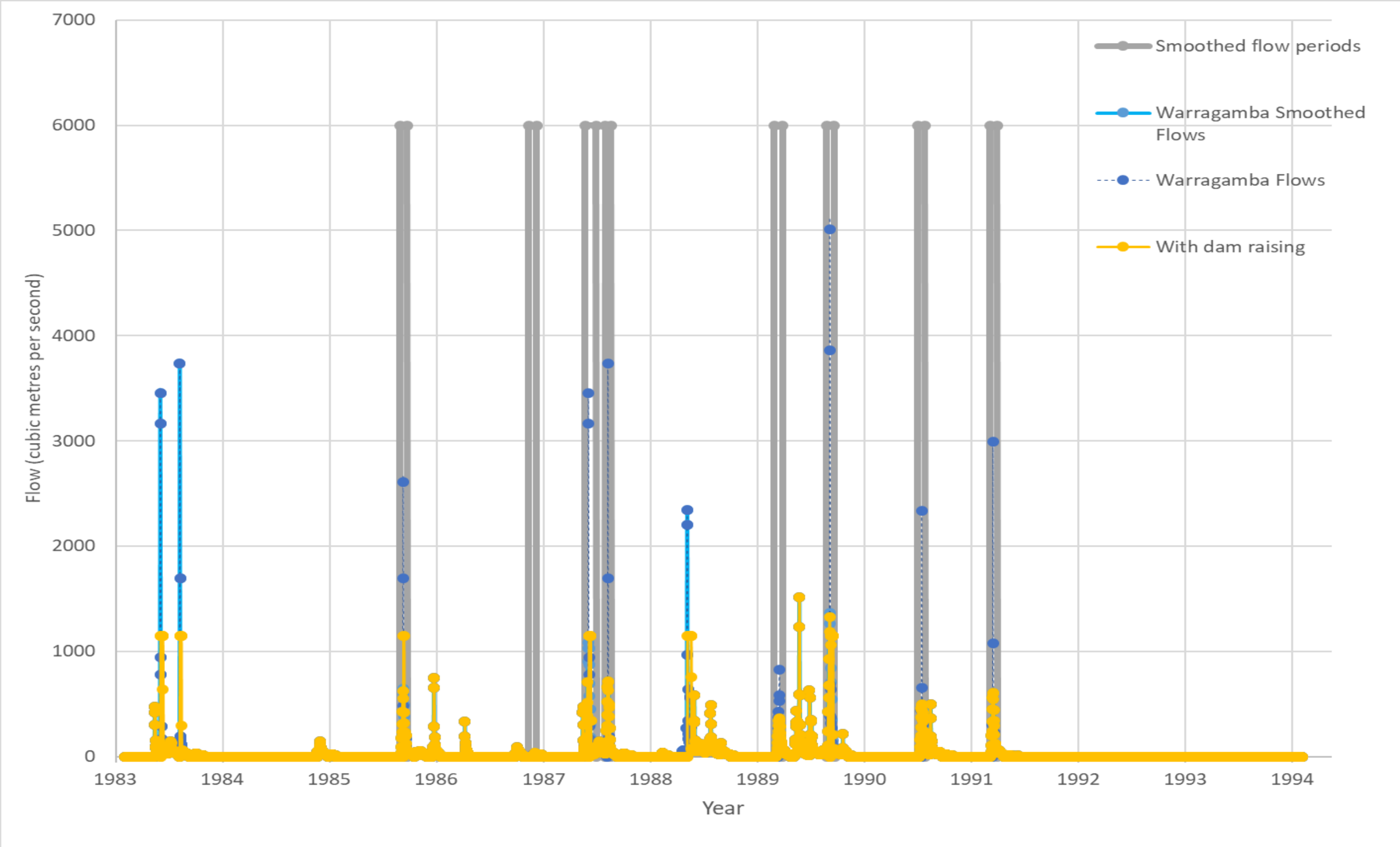


Figure 27-11. The 1984 flood event in relation to existing and Project dam outflows (based on the data from the Hawkesbury-Nepean Hydrodynamic Water Quality model)

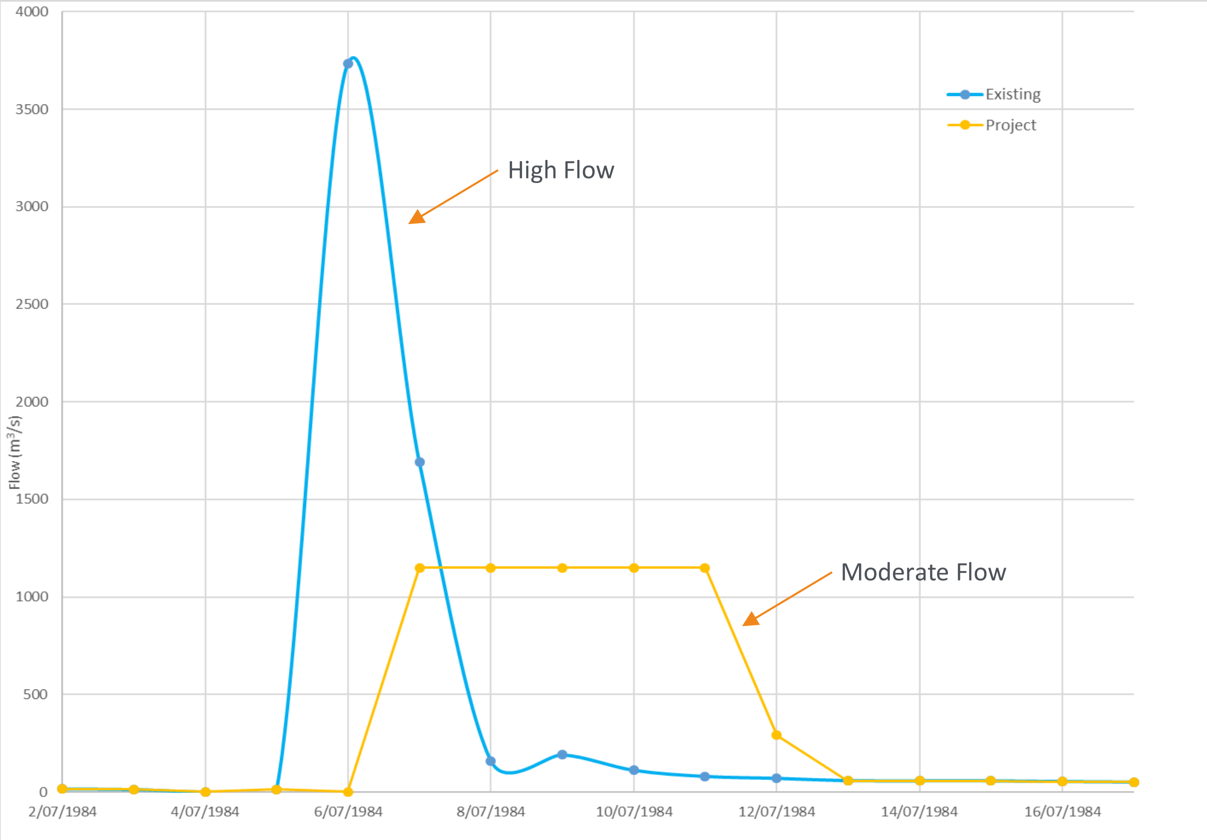
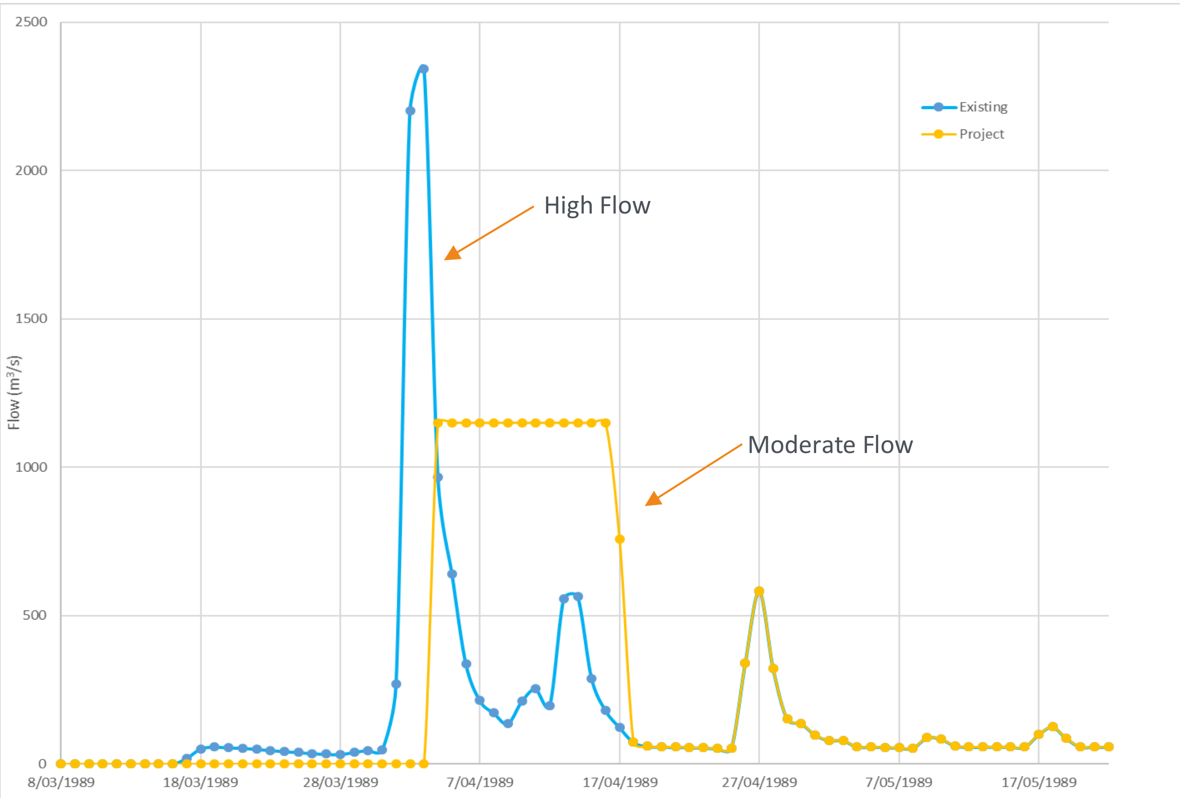


Figure 27-12. The 1989 flood event in relation to the existing and Project dam outflows (based on the data from the Hawkesbury-Nepean Hydrodynamic Water Quality model)



27.5.4.2 Water quality

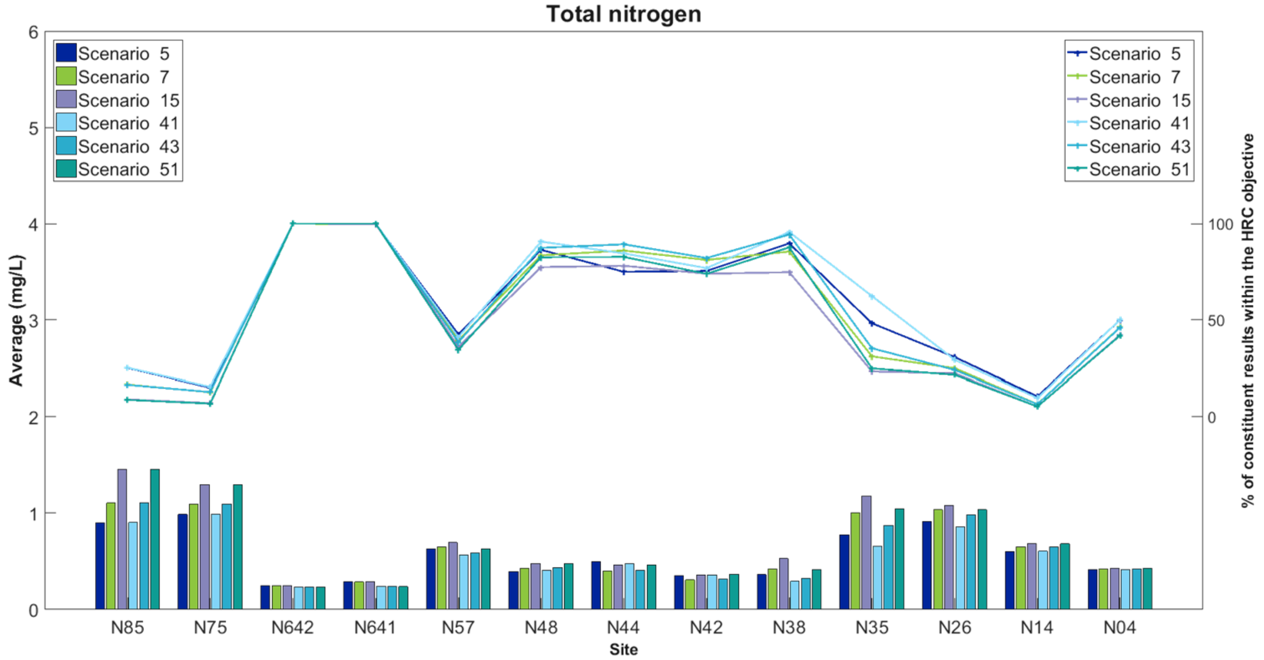
With the operation of the FMZ, the near surface section of the water column would be discharged once the downstream peak flood level had been reached. Based upon the 1998 and 2012 events, the water quality of the discharge from the FMZ would have a:

- total nitrogen concentration ranging between 0.37 milligrams per litre and 0.40 milligrams per litre
- total phosphorus concentration ranging 0.008 milligrams per litre and 0.02 milligrams per litre
- chlorophyll-a concentration ranging between 1.9 milligrams per litre and 2.4 milligrams per litre
- turbidity of about 1.5 NTU.

The modelled scenarios presented in the following figures are detailed in Section 27.2.4.3.

The total nitrogen concentration of the FMZ discharge water (see Figure 27-13) is substantially lower than the total nitrogen concentration at Penrith Weir (N57) and Yarramundi (N44) for all flow scenarios. Therefore, the discharge of the FMZ would have no impact on the downstream total nitrogen concentrations in the Hawkesbury-Nepean receiving waters. The total nitrogen concentration of the FMZ discharge is also lower than the relevant NSW WQO for downstream waters.

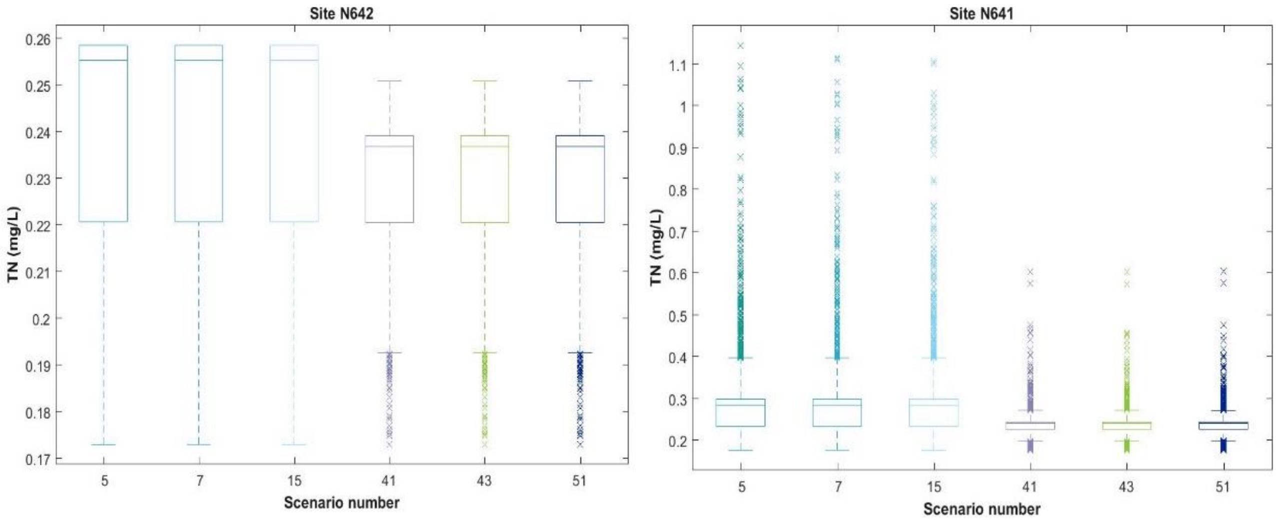
Figure 27-13. Average total nitrogen concentrations along the Hawkesbury Nepean river as modelled in the Hawkesbury-Nepean Hydrodynamic Water Quality model (Sydney Water 2019)



Source: Sydney Water 2019

Directly downstream of the dam wall at Sites N642 and N641 in the Warragamba River, the mean total nitrogen concentrations of the FMZ discharge are within the error bounds of the expected total nitrogen concentrations at these sites, however the mean value is higher. The impact of environmental flows on site N642 and N641 is significant and therefore any changes in discharge profile from the dam should be modelled during the design phase to ensure the improvements downstream of the dam are not adversely impacted. It is highly unlikely that the changes in discharge profile will show any impact on the downstream concentrations.

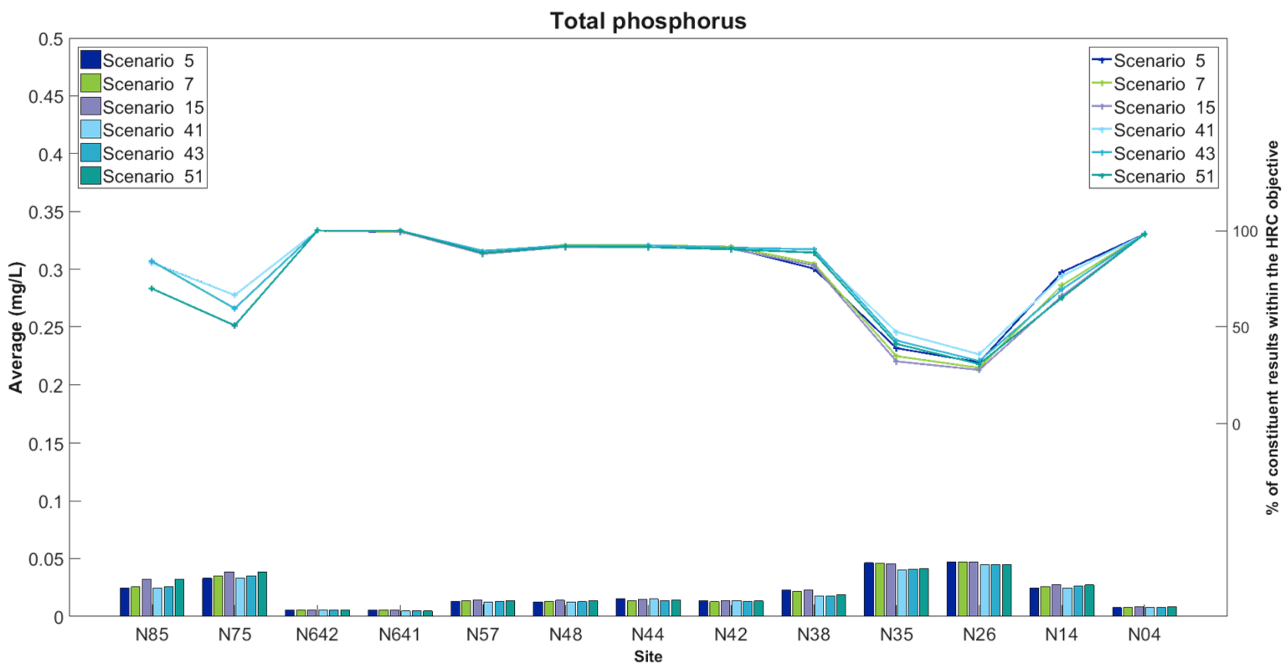
Figure 27-14. Distribution of total nitrogen concentrations at site N642 and N641 as modelled in the Hawkesbury-Nepean Hydrodynamic Water Quality model



Source: Sydney Water 2019

The total phosphorus concentration of the FMZ discharge water (see Figure 27-15) is substantially lower than the total phosphorus concentration at Penrith Weir (N57) and Yarramundi (N44) for all flow scenarios. Therefore, the discharge of the FMZ would have no impact on the downstream total phosphorus concentrations in the Hawkesbury-Nepean receiving waters. The total phosphorus concentration of the FMZ discharge is also lower than the relevant NSW WQO for downstream waters.

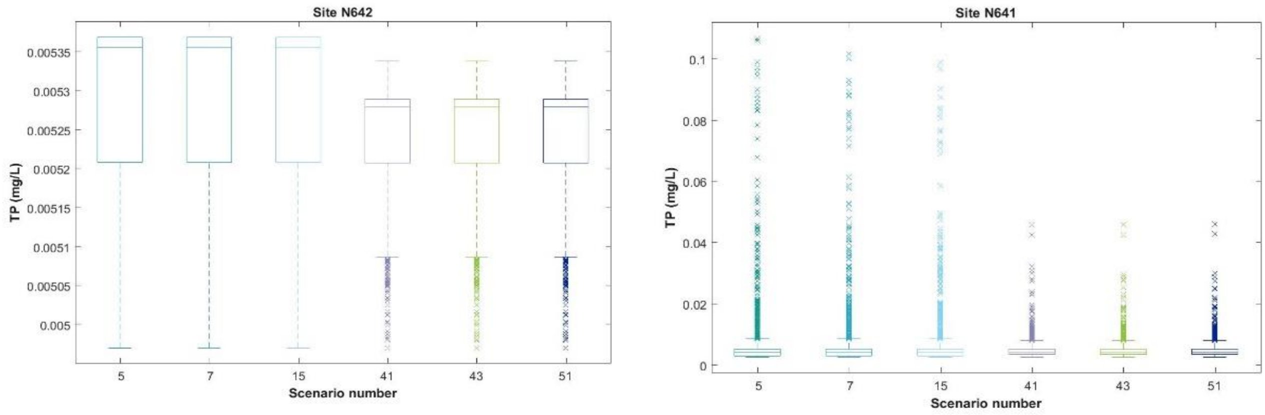
Figure 27-15. Average total phosphorus concentrations along the Hawkesbury Nepean river as modelled in the Hawkesbury-Nepean Hydrodynamic Water Quality model (Sydney Water 2019)



Source: Sydney Water 2019

Directly downstream of the dam wall at sites N642 and N641 in the Warragamba River, the average total phosphorus concentrations of the FMZ discharge are within the errors bounds of the expected total phosphorus concentrations at these sites, however the mean value is higher (see Figure 27-16). The impact of environmental flows on Sites N642 and N641 is significant and that therefore any changes in discharge profile from the dam should be modelled during the design phase to ensure the improvements downstream of the dam are not adversely impacted. It is highly unlikely that the changes in discharge profile will show any impact on the downstream concentrations.

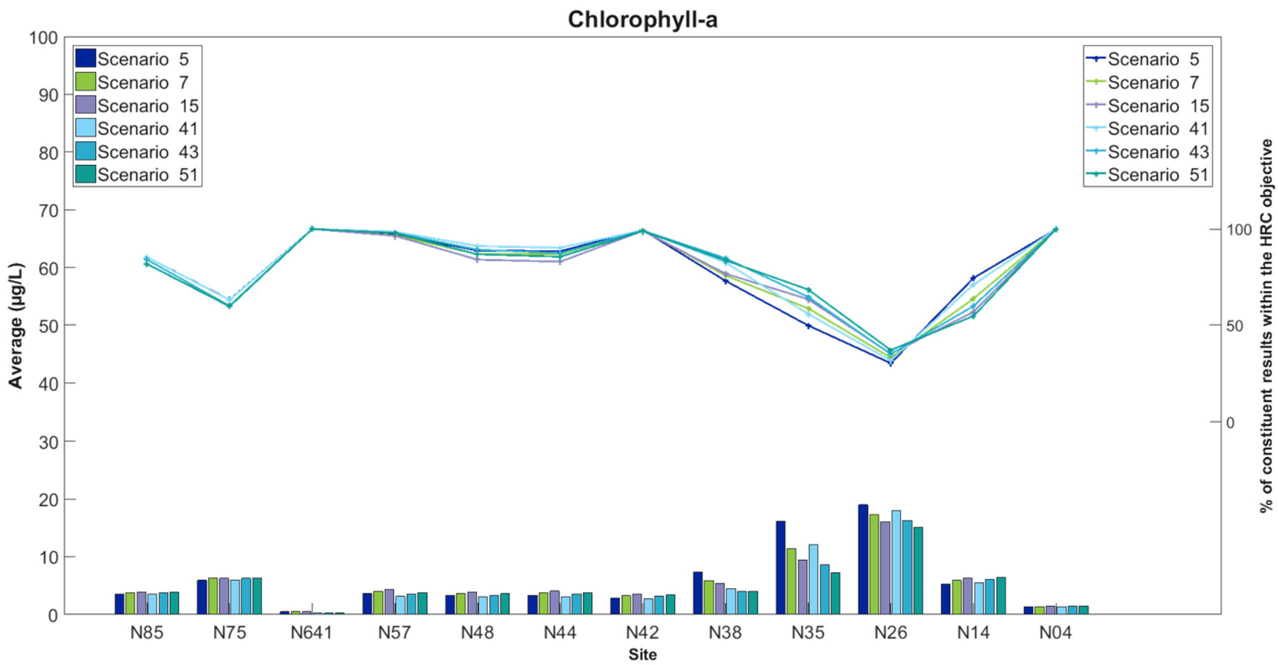
Figure 27-16. Distribution of total phosphorus concentrations at sites N642 and N641 as modelled in the Hawkesbury-Nepean Hydrodynamic Water Quality model



Source: Sydney Water 2019

The environmental flows have a significant impact on the chlorophyll-a concentrations throughout the river profile as shown in Figure 27-17. The chlorophyll-a concentration in the FMZ discharge are much lower in comparison to downstream concentrations and potentially could further reduce chlorophyll-a concentrations downstream of the dam. The chlorophyll-a concentration of the FMZ discharge is also lower than the relevant NSW WQO for downstream waters.

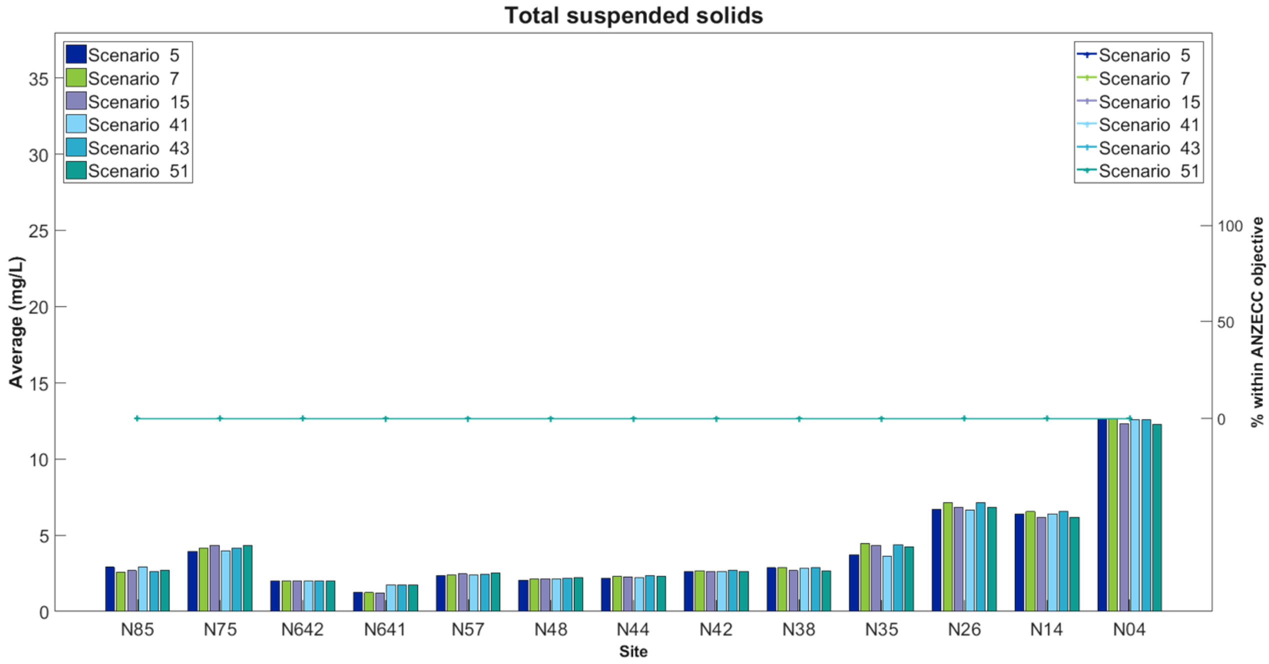
Figure 27-17. Average chlorophyll-a concentrations along the Hawkesbury Nepean river as modelled in the Hawkesbury-Nepean Hydrodynamic Water Quality model



Source: Sydney Water 2019

The turbidity of the FMZ discharges would be low. Turbidity is not modelled in the Hawkesbury-Nepean Hydrodynamic Water Quality model, but total suspended solids is modelled. An approximate conversion between turbidity and total suspended solids is 0.88 NTU equalling 1.00 mg/L of total suspended solids. A turbidity level of 1.5 NTU in the FMZ would be equivalent to 1.70 mg/L of total suspended solids, which is well below the predicted concentrations in the downstream receiving waters (see Figure 27-18). Therefore, the FMZ discharge would have no impact on the downstream total suspended concentrations in the Hawkesbury-Nepean receiving waters. It should also be noted that post flood event turbidity levels in downstream receiving waters are likely to be high. The turbidity of the FMZ discharge is also lower than the relevant ANZECC 2000 guideline for downstream waters.

Figure 27-18. Average total suspended solids concentrations along the Hawkesbury Nepean river as modelled in the Hawkesbury-Nepean Hydrodynamic Water Quality model



Source: Sydney Water 2019

In summary, there would be negligible impacts on the downstream environment from the changes in water quality from the FMZ discharges. As well as not causing the exceedance of WQOs objectives downstream, the FMZ would only be operational relatively infrequently. Overall there would no material cumulative impacts from the operation of the Project.

27.6 Environmental management measures

Management measures detailed in Table 27-17 have been developed to avoid, minimise or manage potential risks. Management measures have been incorporated in the environmental management measures in Chapter 29 (EIS synthesis, Project justification and conclusion).

Table 27-17. Management measures

Impact	ID	Environmental management measure	Timing	Responsibility
General water quality impacts	WQ1	Continuation, monitoring and, where necessary, modification of water quality management measures to address operational impacts of the Project. These include: ▪ monitoring DOC levels in the raw water supply for drinking water purposes to identify any increases in DOC levels so that adaptive management can be implemented via the SCRAMS ▪ sourcing raw drinking water from other dams when the FMZ at Warragamba Dam is in operation or NOM levels are high. ▪ when NOM levels are high in Lake Burragorang, consider adjusting the blend of water being provided to Prospect WFP so a greater proportion of water is supplied from storages with lower NOM levels. ▪ adjusting treatment processes at WTPs to increase the removals of NOMs – this could include increased doing with ferric chloride, reducing chlorination and increasing chloramination (which does not produce THMs) ▪ implementation of the National Parks EMP – which would have as one its objectives erosion control and revegetation of areas impacted by the operation of the FMZ ▪ continued implementation of other erosion management programs in the upper catchment areas such as WaterNSW Grazing and Erosion Program ▪ sourcing raw water supply for drinking water purposes from other dams when sediment levels are high. ▪ sourcing raw water supply for drinking water purposes from other dams when algal blooms occur ▪ use of the multi-level offtake to withdraw water from less turbid locations in the water column ▪ use of the multi-level offtake to withdraw water from lower in the water column as algal blooms only occur in surface layers ▪ use of the multi-level offtake to withdraw water from locations in the water column where pathogen concentrations are low ▪ adjusting processes at Water Filtration Plants to increase the removal of algae in raw water supply for drinking water purposes ▪ adjusting processes at Water Filtration Plants to increase the removal of pathogens in raw water supply for drinking water purposes ▪ adjusting processes at water filtration plants to increase the removal of particulates in raw water supply for drinking water purposes.	Existing and ongoing	WaterNSW
Sedimentation and erosion control, vegetation	WQ2	The construction environmental management plan will include management measures for minimising water quality impacts from (as relevant): ▪ process water management	Construction	WaterNSW Construction contractor

Impact	ID	Environmental management measure	Timing	Responsibility
clearing, management of hazardous material and other water quality risks		▪ concrete batching plants ▪ controlled blasting activities ▪ hydro-blasting activities ▪ underwater excavations ▪ dewatering activities (such as the dissipation pool) and any water diversions ▪ use of epoxy resins ▪ discharge of concrete cooling pumping system ▪ use of sediment basins and water treatment plants ▪ road and bridge upgrades (including piling). ▪ material storage areas ▪ demolition and other construction activities. Vegetation clearing: ▪ erosion and sedimentation control measures to be designed, installed, and operated in accordance with *Managing Urban Stormwater: Soils and Construction* (Landcom 2004) ▪ mulch stockpiles would be managed in accordance with *Management of Tannins from Vegetation Mulch* (Roads and Maritime Service (RMS) 2012). Other water quality management measures are identified in the following chapters: ▪ Soils (Chapter 22, Section 22.10): S8, S9 ▪ Flooding and hydrology (Chapter 15, Section 15.10): H1.		
Construction water quality impacts	WQ3	A construction water quality monitoring program will be developed	Construction	WaterNSW Construction contractor
Water quality impacts on raw water for drinking water purposes	WQ4	While the risks to the quality of raw water supply for drinking water purposes have been assessed to be low, further monitoring is recommended to confirm the risk assessment and enhance adaptive responses to any changes in water quality due to the Project.	Pre-operation	WaterNSW
Quality of raw water for	WQ5	The SCARMS and SCARISS will be updated to include the raised dam, new outlets, and operation of the FMZ.	Pre-operation	WaterNSW

Impact	ID	Environmental management measure	Timing	Responsibility
drinking water impacts				
Catchment impacts	WQ6	The Catchment to Customer Risk Assessment will be reviewed and updated to reflect any new or changed risks to the quality of raw water supply for drinking water purposes from the operation of the FMZ. Implementation of the EMP as required under the Water NSW Act.	Pre-operation	WaterNSW

27.7 Risk assessment

An environmental risk assessment was carried out in accordance with the SEARs, using the methodology provided in Appendix C. A Project risk matrix was developed and risk ranking evaluated by considering:

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

The likelihood and consequence matrix is shown on Figure 27-19.

Once the consequence and likelihood of an impact are assessed, the risk matrix provides an associated ranking of risk significance: **Low**; **Medium**; **High** or **Extreme,** as shown in Table 27-18**.** The residual risk was determined after the application of proposed mitigation measures.

The risk analysis for potential water quality impacts is provided on Figure 27-19. This includes the residual risk of the potential impact after the implementation of mitigation measures.

Table 27-18. Risk ranking definitions

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

Figure 27-19. Risk matrix

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

Risk Definition (see Table 27-18	**Low**	**Medium**	**High**	**Extreme**

Table 27-19. Water quality risk analysis

WATER QUALITY								
Key impacts	Risk before mitigation			Mitigation and management	Risk after mitigation			Residual risk
	L	C	R		L	C	R	
Construction								
Contaminated runoff from construction activities: ▪ two batching plants ▪ two laydown and material storage areas ▪ vegetation clearing ▪ demolition and construction activities ▪ waste management ▪ soil erosion ▪ dewatering.	b	D	22	Mitigation measures for Soils (Chapter 22) and Flooding and hydrology (Chapter 15), WQ1	c	C	11	There is an Extreme risk of impacting water quality due to uncontrolled management of wastes, materials, and construction activities. This would result in breaches of licence conditions and degradation of downstream environments. Mitigation measures are well developed and can be readily applied to manage site activities and the risk of environmental harm can be significantly reduced to a Medium residual risk. However, sufficient resources will be required to ensure mitigation measures are appropriately implemented, including quickly responding to a potential incident.
Operation								
Upstream ▪ Flood inundation causing vegetation clearing and soil erosion. ▪ Changed water quality regime. *Downstream* ▪ Decreased inundation duration of downstream environments. ▪ Reduced flushing of the river from spill events. ▪ Modified flow regimes downstream.	b	C	**19**	WQ2, WQ3, WQ4, WQ5, WQ6	c	C	**11**	Rapid filling of the FMZ may result in reduced water quality, however this was assessed as being relatively minor and no significant upstream water quality changes would occur. Downstream water quality may be influenced by changes to flow regimes and there is a High risk due to potential breaches of water quality criteria or local degradation of environmental qualities. Mitigation includes operational protocols to regulate flood and environmental flows, which will reduce this to a Medium risk. This risk is likely to be further reduced as the benefits of more regulated environmental flows become entrenched.

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