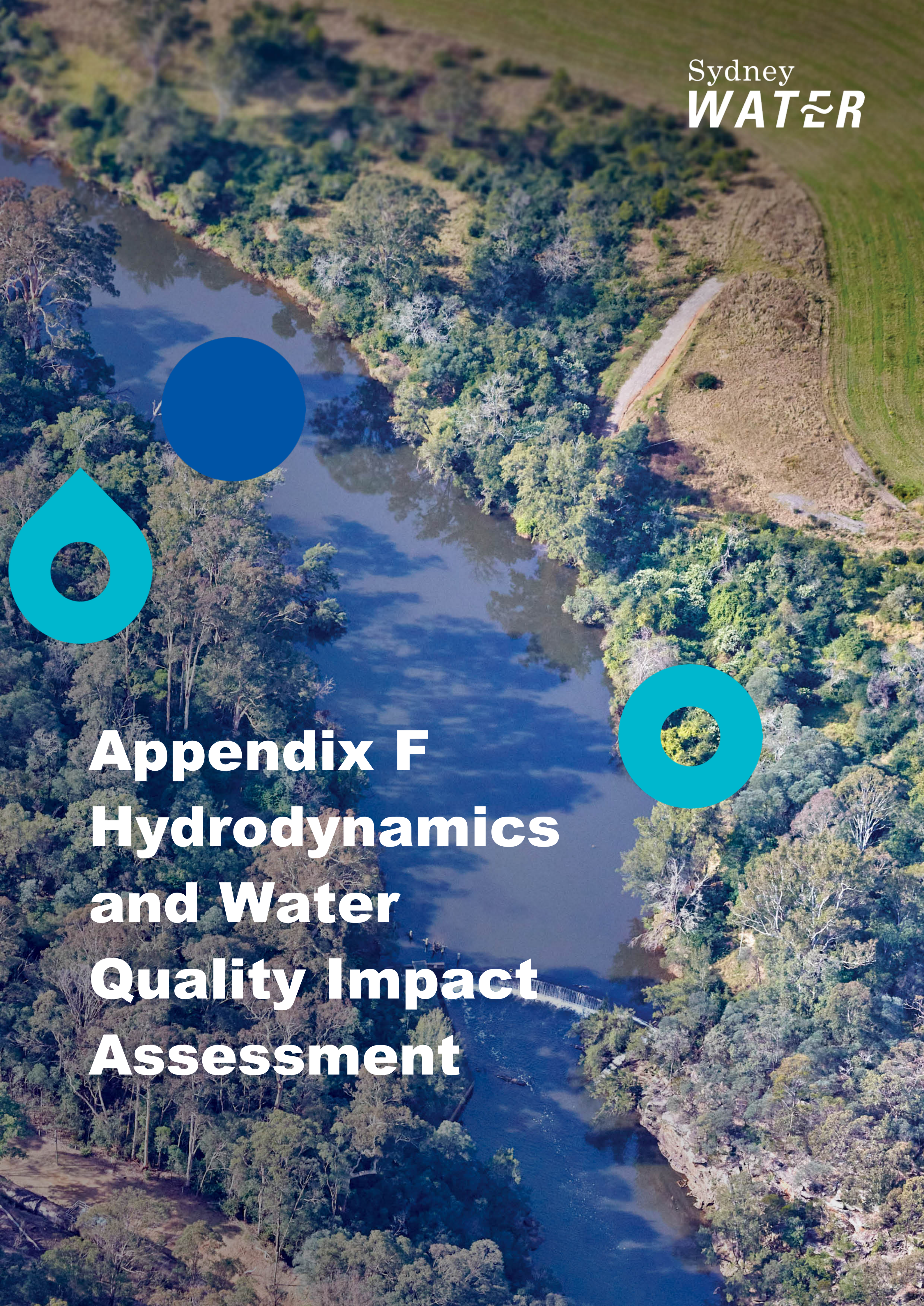


Sydney WATER

Appendix F Hydrodynamics and Water Quality Impact Assessment

aurecon ARUP

Upper South Creek AWRC EIS

Hydrodynamic and Water Quality Impact Assessment

Executive Summary

The objective of the Hydrodynamic and Water Quality Impact Assessment has been to assess and address potential impacts of how the releases of treated water from the operation of the Upper South Creek Advanced Water Recycling Centre (AWRC) (the project) may impact the hydrodynamics and water quality in the receiving waters of the Hawkesbury Nepean River and South Creek. The assessment has been developed to address the requirements of project specific Secretary's Environmental Assessment Requirements (SEARs) and in accordance with relevant legislation, policy and guidelines.

The project includes releases of treated water to the Nepean River (upstream of Wallacia Weir), wet weather releases to South Creek (upstream of Kemps Creek), and also the potential for releases to the Warragamba River (downstream of the dam wall). The Nepean River and South Creek have varying water quality conditions associated with pressures from urban and industrial development, agricultural practices, land use changes, point source discharges as well as numerous, competing demands for water. The water quality in South Creek also deteriorates under extended dry weather conditions, when the flows in the creek can slow and become segregated into separated pools.

Project specific waterway objectives for the Nepean and Warragamba rivers and South Creek were developed which include numerical criteria sourced from existing guidelines and policies. Predicted impacts of the releases of treated water from the AWRC were assessed against these waterway objectives using numerical outputs from Water Quality Response Models (WQRMs).

The WQRMs simulate the hydrodynamics and an extended suite of water quality processes within the receiving waterways. The models were developed for the Hawkesbury Nepean River, South Creek and major tributaries using a number of software applications and were based on a range of datasets including rainfall, land use, topography, channel bathymetry and release data from wastewater treatment plants (WWTPs). The WQRMs were calibrated and validated against an extensive record of hydrodynamic and water quality monitoring data recorded at various locations along the Hawkesbury Nepean River, South Creek and their major tributaries. The WQRMs performed well across the selected calibration and validation periods and also across the range of parameters that have been assessed. The calibrated WQRMs informed the development of CORMIX models which were used to assess near field impacts, such as toxicity, in the immediate vicinity of the proposed AWRC release points.

The WQRMs and CORMIX models have been developed in line with industry standards and are considered fit for purpose in the application of assessing predicted impacts of the Upper South Creek AWRC. In line with all similar studies, the modelling should however be considered as a representative approximation to the real world and not without accepted levels of uncertainty. It should therefore be understood that each model is based on a series of assumptions, and also dependent on the accuracy of, and sensitivity to, its input data. The model results should therefore be interpreted as indicative of impacts, responses and trends in the receiving waters and not as absolutes.

A suite of scenarios was developed to allow simulation of a range of conditions that could be expected during the operational life of the AWRC. This included releases of treated water from the AWRC associated with a treatment and release strategy specifically developed for the project, as well as expected changes in other catchment conditions such as land use, population growth, and proposed stormwater management strategies for the Western Parkland City.

The following scenarios were assessed for representative dry and wet climatic years so as to address the question of how wet and dry conditions affect impacts from the AWRC releases:

- Baseline scenario. Represents current (circa 2020) conditions

- Background scenario. Represents catchment and waterway conditions expected in future years without the inclusion of the treated water releases from the AWRC
- Impact scenario. Represents catchment and waterway conditions expected in future years with the inclusion of various release strategies of the treated water from the AWRC

Two future operational stages of the AWRC (Stage 1 and Future stages) were assessed for the background and impact scenarios. Key assumptions regarding the modelling of the AWRC's operation included:

- The scenarios assumed the AWRC is operating at full capacity i.e. 50 ML/d in 2036 and 100 ML/d in 2056. Prior to reaching these operating levels, the extent of the impacts on the receiving water, whether they be beneficial or detrimental, are likely to be proportionally reduced.
- Similarly, the scenarios assume no allowance for beneficial reuse. Therefore the volume of treated water generated by the AWRC is released to the waterways and no percentage is supplied for recycling purposes.

The model results indicate that the impacts on water quality in South Creek from the wet weather releases are considered to present a low risk of affecting long term ambient water quality and/or ecosystem health. This risk classification is predominantly a result of the treatment and release strategy that is proposed for the AWRC, and has been based on interpretation of both the predicted consequences and likelihood of the impacts from the wet weather releases.

For the Nepean River, the model results indicate the impacts on water quality downstream of the release point to be predominantly positive. Predicted improvements in river water quality generally consisted of lower concentrations of nutrients and pathogens, as well as higher levels of dissolved oxygen. These reductions in downstream ambient concentrations in turn demonstrated the potential for improved localised compliance with relevant waterway objectives, as well as a potential reduction in the risk of algal blooms.

Further downstream of the initial footprint (~20 km), the impacts were predicted to be either negligible or predicted not to present negative effects on the river water quality and/or ecosystem health.

The positive/neutral nature of these impacts is principally attributed to the comparatively low release volumes, the quality of the treated water being released as well as the increases in ambient flows, flushing and dilution.

As a high-level summary, Figures 1 and 2 present an overview of the predicted impacts on key water quality parameters from the operation of Stage 1 of the AWRC. These figures summarise the modelling results for key parameters covered by both the Hawkesbury Nepean and South Creek WQRMs, for both the dry and wet years respectively, and at several locations downstream of the AWRC releases. The colour coded matrices provide an indication of predicted compliance with waterway objectives, based on the annual median model results for the baseline, background and impact scenarios. Cells shaded in green indicate that waterway objectives are predicted to be achieved based on the annual median concentration at this location. Cells shaded in red indicate that the annual median concentration is predicted to exceed the waterway objectives.

For the background and impact scenarios, a trend is also shown as up or down, or unchanged relative to baseline and background scenarios respectively. In this analysis, a trend was defined as a change in annual medians of greater than five percent.

As noted previously, these results should not be interpreted as absolute values that can be achieved and do not guarantee that waterway objectives will or will not be achieved, but rather provide an indication of change as a result of the releases, and also as a result of cumulative impacts from the surrounding catchment.

A second, alternative release strategy was also assessed with respect to the Nepean River releases. This strategy effectively split the flows from the AWRC between release points in the Nepean River (again upstream of Wallacia Weir) and the Warragamba River (downstream of the dam wall), with the Warragamba releases replicating the current WaterNSW Warragamba Dam release regime, and only consisting of advanced treated water. Residual flows of treated water from the AWRC are then released into the Wallacia Weir pool as per the Nepean release scenarios. On the occasions where advanced treated water was not available from the AWRC, releases to the Warragamba were halted and it was assumed that releases from the dam would be resumed.

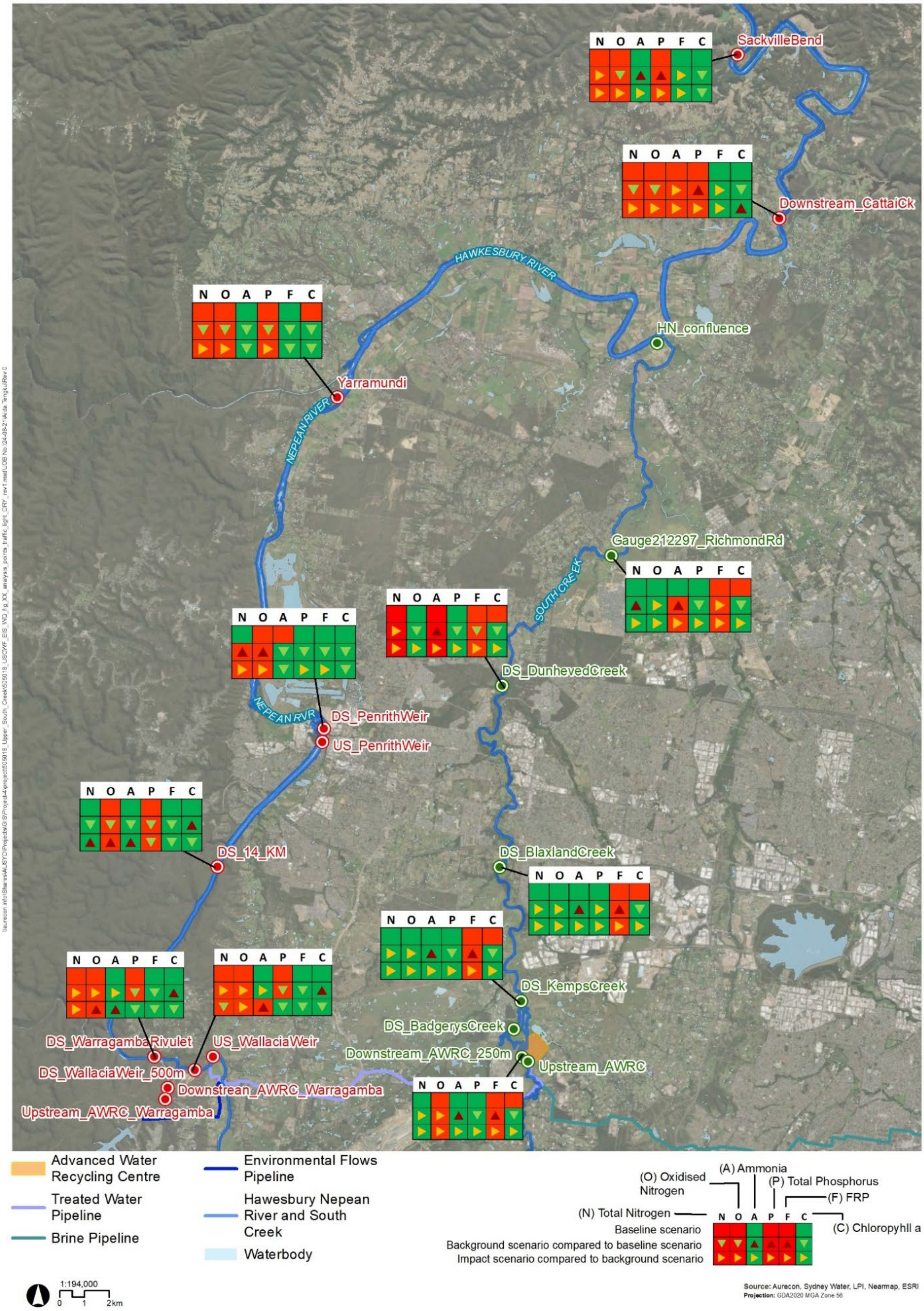
With many similarities to the Nepean release scenarios, the modelling indicated that the releases would generally improve water quality in the downstream river reaches. Some localised occurrences of additional algal growth in the Warragamba River were predicted, although these impacts were relatively minor and localised in nature.

In addition to these assessments relating to hydrodynamics and water quality, impacts from the AWRC releases were also evaluated within the Sydney drinking water catchment with respect to the Neutral or Beneficial Effect (NorBE) guidelines, as well as with respect to sensitive environments within the wider river and creek system. From these assessments, the impacts from the AWRC releases were concluded to be either beneficial and/or not to present negative effects on relevant water quality indicators.

Near field impact assessments were also undertaken with respect to the potential for toxicity in the releases to South Creek and the Nepean River. From analysis of the treatment applied under various weather conditions, it was determined the risk from toxicants in the releases would be limited to severe wet weather conditions when flows from the AWRC would be greater than 3 x ADWF (average dry weather flow). Under these conditions, tertiary treated water would be released to the Nepean River, while elevated proportions of primary treated water would be released to South Creek. Based on the characteristics of the release conditions, it was concluded that the potential for toxicity and environmental harm arising from these release events should be considered to be low, and no mixing zones are to be proposed for the Nepean River or South Creek.

With respect to the existing regulatory framework to manage nutrient load inputs in the river system, the total predicted nutrient loads for 2036 and 2056 have been determined to be below the framework limits for each subzone. The additional loads from the AWRC releases are therefore considered consistent with the Environment Protection Authority's (EPA) framework.

The primary form of mitigation and management of environmental impacts on the receiving waterways is through the implementation of the AWRC treatment and release strategy. A comprehensive monitoring program is proposed for the post-commissioning operational phase of the AWRC to monitor the potential for impacts on ambient water quality from the operation of the AWRC.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HAWKESBURY RIVER
HN_confluence
Yarramundi
NEPEAN RIVER
Gauge212297_RichmondRd
SOUTH CREEK
DS_DunhevedCreek
DS_PenrithWeir
US_PenrithWeir
NEPEAN RVR
DS_14_KM
DS_BlaxlandCreek
DS_KempsCreek
DS_BadgerysCreek
Downstream_AWRC_250m
Upstream_AWRC
DS_WarragambaRivulet
US_WallaciaWeir
DS_WallaciaWeir_500m
Downstream_AWRC_Warragamba
Upstream_AWRC_Warragamba
N O A P F C
Advanced Water Recycling Centre
Treated Water Pipeline
Brine Pipeline
Environmental Flows Pipeline
Hawesbury Nepean River and South Creek
Waterbody
(O) Oxidised Nitrogen
(A) Ammonia
(P) Total Phosphorus
(F) FRP
(N) Total Nitrogen
(C) Chloropyhll a
Baseline scenario
Background scenario compared to baseline scenario
Impact scenario compared to background scenario
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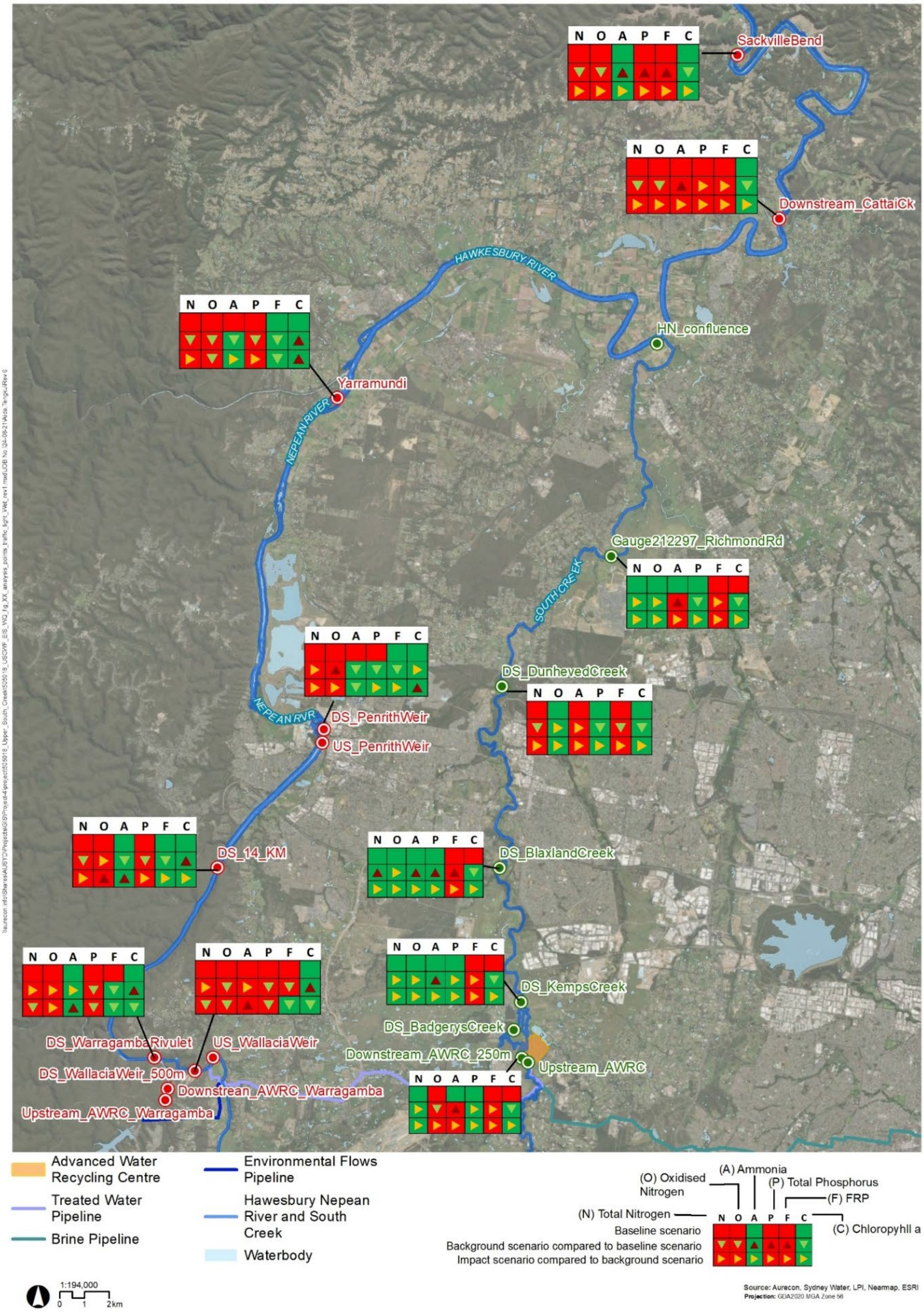
0 1 2km
Source: Aurecon, Sydney Water, LPI, Nearmap, ESRI
Projection: GDA2020 MGA Zone 56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SOUTH CREEK
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NEPEAN RVR
DS_PenrithWeir
US_PenrithWeir
DS_14_KM
DS_BlaxlandCreek
DS_KempsCreek
DS_BadgerysCreek
Downstream_AWRC_250m
Upstream_AWRC
DS_WarragambaRivulet
US_WallaciaWeir
DS_WallaciaWeir_500m
Downstream_AWRC_Warragamba
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Source: Aurecon, Sydney Water, LPI, Nearmap, ESRI
Projection: GDA2020 MGA Zone 56

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		Signature			
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		Name	Ed Beling, Kaushal Kumandur, Steph Kermode	Ed Beling	Paul Dunne
		Signature			

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Alluvium	Catchment modelling
eWater	Catchment modelling
Ecological Australia	Catchment modelling

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Glossary and Abbreviations

Term	Abbreviation	Definition
Adopted middle thread distance	AMTD	The distance, measured along the middle of a watercourse that a specific point is from the watercourse's mouth or junction with the main watercourse.
Advanced treated	-	Wastewater treatment process which involves using reverse osmosis membrane technology to produce highly treated recycled water.
Advanced Water Recycling Centre	AWRC	Proposed centre for treatment of the wastewater prior to reuse applications or release to waterways. The AWRC includes liquids treatment, advanced water treatment, solids treatment, odour treatment, and residuals management.
Ancillary infrastructure	-	Permanent infrastructure to support the operation of the AWRC and may include a range of assets such as access roads and provision of utilities such as power.
Australian and New Zealand Guidelines for Fresh and Marine Water Quality (2018)	ANZG	Guidelines (2018 online version) to provide a framework and supporting guidance for the management, assessment and monitoring of water quality for natural and semi-natural water resources in Australia and New Zealand.
Australian and New Zealand Guidelines for Fresh and Marine Water Quality (2000)	ANZECC	Guidelines (2000 version) to provide a framework and supporting guidance for the management, assessment and monitoring of water quality for natural and semi-natural water resources in Australia and New Zealand.
Average Dry Weather Flow	ADWF	Average Dry Weather Flow consists of average daily wastewater flows. ADWF is the average flow that occurs on a daily basis with no evident reaction to rainfall.
Background scenario	-	Represents catchment and waterway conditions expected in future years, including conditions relating to land use, WWTP and WRP releases, extractions, etc.
Baseline scenario	-	Represents current (circa 2020) waterway and catchment conditions relating to land use, WWTP and WRP releases, extractions, etc.
Brine	-	Brine is a by-product of the reverse osmosis technology applied in the AWRC treatment process.
Brine pipeline	-	A pipeline to transport brine from the AWRC to Lansdowne, in south-west Sydney, where it connects to the Malabar wastewater network
Business as Usual	BaU	The execution of standard functional operations. Also indicative of no change of approach in terms of future management or policy.
Colony-forming unit	cfu	Unit used in microbiology to estimate the number of viable bacteria or fungal cells in a sample
Courant–Friedrichs–Lewy	CFL	A condition in numerical equation solving which states that a time step larger than a computable quantity should not be taken.

Term	Abbreviation	Definition
Cooperative Research Centre	CRC	Cooperative Research Centres (CRC) form part of an Australian government initiative that supports Australian industries' ability to compete and produce.
CORMIX	-	Numerical software for the analysis of near field mixing of wastewater in watercourses.
Default guideline values	DGV	Water quality guideline values in line with the ANZG (2018) guidelines. Previously referred to as trigger values in the ANZECC (2000) guidelines.
Department of Environment and Climate Change	DECC	Former department in the NSW government with responsibility for protecting and caring for the environment and developing and coordinating programs to address the impacts of climate change.
Department of Environment, Climate Change and Water	DECCW	Former department in NSW government with responsibility for protecting and caring for the environment, managing water resources and developing and coordinating programs to address the impacts of climate change.
Department of Planning, Industry and Environment	DPIE	DPIE is a NSW government department responsible for effective and sustainable planning, and the development of industry to support growth in NSW.
Dissolved Oxygen	DO	The oxygen level present in water, expressed as either percentage saturation, or as a concentration.
Dry year	-	A representative dry climatic year. Selected as 2013/14 in this study.
Effluent Knowledge and Management System	EKAMS	Sydney Water web-based system for accessing operational data and licencing reports.
Environment Protection Authority	EPA	The EPA is the primary environmental regulator for NSW with a mandate to reduce pollution and waste, protect human health, and prevent degradation of the environment.
Environment Protection Licence	EPL	Licences to the owners or operators of various industrial premises under the Protection of the Environment Operations Act 1997. Licence conditions relate to pollution prevention and monitoring, and cleaner production through recycling, reuse and implementation of best practice.
Environmental flows	-	Environmental flows refer to water released from a dam, weir or other source to sustain healthy waterways and ecosystem health downstream. Releases from the AWRC may be used to supplement or replace flows that are currently being released to the Nepean and Warragamba rivers.
Environmental Impact Statement	EIS	An Environmental Impact Statement is a publicly available document that provides information on a project, including its environmental impacts and mitigation measures, and is used to inform development consent decisions
Environmental values	EVs	ANZG (2018) defines a community/environmental value as a particular value or use of the environment that is important for a

Term	Abbreviation	Definition
		healthy ecosystem or for public benefit, health, safety or welfare, and requires protection from the effects of stressors. In the ANZG (2018) guidelines, the following values are recognised: aquatic ecosystems. cultural and spiritual values, drinking water, industrial water, primary industries, recreational water and aesthetics.
Ephemeral	-	Creeks which generally only flow during or after precipitation and runoff.
Filterable reactive phosphorus	FRP	Filterable reactive phosphorus
Geographical Information System	GIS	A framework for gathering, managing, and analysing spatial data.
Grams per litre	g/L	Unit for measuring a concentration as a quantity in a volume of liquid.
Hawkesbury Nepean	HN	The Hawkesbury Nepean River system, which incorporates the main watercourses of the Hawkesbury River and Nepean River, as well as their tributaries
Hawkesbury River		The Hawkesbury River extends upstream to near Yarramundi, and the confluence with the Grose River, where it becomes the Nepean River.
Healthy Rivers Commission	HRC	The HRC was established in 1995 by the NSW Government to make recommendations on suitable objectives for water quality, flows and other goals central to achieving ecologically sustainable development in a realistic time frame.
Hornsby Shire Council	HSC	Hornsby Shire Council.
Impact scenario	-	Represents catchment and waterway conditions expected in future years including the releases of treated water from the AWRC.
Improved water quality	-	Improved water quality is classified as changes in ambient conditions that support the protection or enhancement of applicable environmental values and objectives. In the context of this assessment, this may relate to maintenance/achievement of one or more of the following effects:
Insignificant/minor impacts	-	In the context of this assessment, these impacts are classified as being recognisable as short term, or temporary, or of limited magnitude in nature and only predicted at a local scale.
Kilograms	Kg	Unit for measuring weight.
Kilometre	Km	Unit for measuring length.
Kilometre squared	km^2	Unit for measuring area.
Local Government Area	LGA	Local Government Area.
MATLAB	-	Software program used for iterative analysis and design processes with a programming language that expresses matrix and array mathematics directly.

Term	Abbreviation	Definition
Megalitres	ML	Unit for measuring volume.
Megalitres per day	ML/d	Unit for measuring volumetric rate of flow.
Micro Siemens per centimetre	µS/cm	Unit for measurement of electrical conductivity
Milligrams per litre	Mg/l	Unit for measuring a concentration as a quantity in a volume of liquid.
Millimetres	mm	Unit for measuring length.
Model for Urban Sewers	MOUSE	Numerical modelling software that models collection system for urban wastewater and stormwater.
National Water Quality Management Strategy	NWQMS	Australian wide strategy for water quality management and the provision of information and tools to help water resource managers, planning and management agencies, regulatory agencies and community groups manage and protect water resources.
Nepean River	NR	The Nepean River extends down to near Yarramundi, and the confluence with the Grose River, where it becomes the Hawkesbury River.
Nephelometric Turbidity Unit	NTU	Unit for measuring turbidity.
Non-ephemeral	-	Creeks which flow continuously all year.
Office of Environment and Heritage	OEH	The NSW OEH is a former division of the Government of New South Wales between April 2011 and July 2019. The NSW OEH was responsible for the care and protection of the environment and heritage, which includes the natural environment, Aboriginal country, culture and heritage, and built heritage in New South Wales.
Primary treated	-	Wastewater that is screened but bypass secondary and tertiary treatment processes at the AWRC prior to release to the environment. The bypasses occur during more severe wet weather events.
Project	-	The construction and operation of the Upper South Creek Advance Water Recycling Centre, pipelines and all ancillary infrastructure.
Regional Environmental Health Values	REHV	Regional Environmental Health Values as defined by Hornsby Shire Council.
Reverse Osmosis	RO	A wastewater treatment technology where a solution is forced under pressure through a semi-permeable membrane separating pure water from dissolved salts.
Secretary's Environmental Assessment Requirements	SEARs	These are issued by the Secretary of the NSW DPIE for projects declared by the Minister of Planning as State Significant Infrastructure. These SEARS provide the technical requirements for the impact assessment.

Term	Abbreviation	Definition
Sewage Treatment System Impact Monitoring Program	STSIMP	Sydney Water commenced the STSIMP commenced in 2008 to satisfy monitoring requirements within their Environment Protection Licence. The STSIMP aims to monitor the environment within Sydney Water's area of operations to determine general trends in water quality over time, monitor Sydney Water's performance and to determine where Sydney Water's contribution to water quality may pose a risk to environmental ecosystems and human health. The results are reported to the NSW EPA every year.
Sinclair Knight Merz	SKM	SKM was an Australian company specialising in strategic consulting, engineering and project delivery. SKM was purchased by Jacobs in 2013.
Source	-	Numerical modelling software for the analysis of catchment processes including water quantity, quality and environmental management.
South Creek	SC	South Creek, also known as Wianamatta South Creek
South West Growth Area	SWGA	The South West Growth Area consists of 18 precincts that are planned to accommodate about 200,000 new homes over the next 10 years.
State Significant Infrastructure	SSI	Projects specified as State Significant Infrastructure are high priority projects that are deemed essential for economic, social or environmental reasons.
Tertiary treated	-	Wastewater treatment process which consists of three stages to treat wastewater prior to reuse applications or release to the environment. The stages commonly include filtration, biological and chemical processes as well as disinfection.
The Aquatic Ecodynamics Modelling Library	AED2	Community-driven library of modules and algorithms for simulation of "aquatic ecodynamics" - water quality, aquatic biogeochemistry, biotic habitat and aquatic ecosystem dynamics
Total Nitrogen	TN	Total nitrogen
Total Phosphorus	TP	Total phosphorus
Total Suspended Solids	TSS	Total suspended solids/sediment
Treated water pipeline	-	The pipelines that will convey the treated from the AWRC to the release points in the Nepean and Warragamba rivers.
TUFLOW FV	-	A finite volume numerical modelling software that simulates hydrodynamic, and advection/dispersion processes in oceans, coastal waters, estuaries and rivers.
University of New South Wales	UNSW	University of New South Wales.
University of Western Australia	UWA	University of Western Australia
Upper South Creek	USC	The sub-catchment in which the AWRC will be located. The wider South Creek flows into the Hawkesbury River and then subsequently out to the Pacific Ocean.

Term	Abbreviation	Definition
Wastewater Treatment Plant	WWTP	A facility in which a series of treatment processes (e.g. physical, chemical and biological) are used to treat wastewater and convert it into a form that can be recycled or returned to the environment.
Wastewater	-	The used water from baths, showers and washing machines (‘greywater’) and toilets (‘blackwater’) and enters into the sewerage system.
Water Quality Objectives	WQO	Water Quality Objectives are parameter based goals for water quality management. They effectively define what the water quality should be to protect the environmental values for a waterway.
Waterway objectives	-	The waterway objectives are specific to this project and have been developed in accordance with the Risk-based Framework for Considering Waterway Health Outcomes in Strategic Land-use Planning Decisions (OEH, 2017). The numerical criteria are sourced from existing guidelines and objectives relating to relevant waterway values such as aquatic ecosystems, drinking water, primary industries, recreation and aesthetics.
Water Quality Response Model	WQRM	Combination of numerical models used to simulate hydrodynamic and water quality responses in waterways.
Water Recycling Plant	WRP	A facility in which a series of treatment processes (e.g. physical, chemical and biological) are used to treat wastewater and convert it into highly treated recycled water which can be used for non-potable use, such as irrigation, or returned to the environment.
Western Sydney Aerotropolis Growth Area	WSAGA	The WSAGA consists of several precincts in Western Sydney surrounding the new Western Sydney International Airport.
Wet weather overflows	-	During heavy rainfall the wastewater system can be impacted due inflow and infiltration into the wastewater collection system. The system can become overloaded and wastewater can ‘overflow’ from pipes and other network structures.
Wet weather releases	-	During heavy rainfall, the AWRC can be impacted due elevated volumes of influent from inflow and infiltration into the upstream wastewater collection system. Under more severe events, the AWRC can become overloaded and a primary treated bypass stream will be released to South Creek.
Wet year	-	A representative wet climatic year. Selected as 2014/15 in this study.
Year	yr	Year

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1 Introduction

1.1 Background

This hydrodynamic and water quality assessment has been developed to support and inform the Environmental Impact Statement (EIS) for the Upper South Creek Advanced Water Recycling Centre (AWRC). Sydney Water is planning to build and operate the AWRC to service significant future development in the South West and Western Sydney Aerotropolis Growth Areas.

This report consequently provides an assessment of how the releases of treated water from the AWRC may impact the hydrodynamics and water quality in the receiving waters of South Creek and the Hawkesbury Nepean River system during its operation. Two future operational stages of the AWRC have been evaluated along with cumulative impacts of other expected changes in the surrounding catchments.

As the project has been declared as State Significant Infrastructure, the Secretary of the Department of Planning, Industry and Environment (DPIE) has issued project specific Secretary's Environmental Assessment Requirements (SEARs). The assessment has therefore been developed to address these requirements and in accordance with relevant legislation, policy and guidelines.

1.2 Project description

The proposed development will include the Water Recycling Centre as well as associated treated water, environmental flows and brine pipelines. An overview of the location of the proposed infrastructure is provided in Figure 1-1. Further details regarding the project are provided below.

Advanced Water Recycling Centre

- a wastewater treatment plant with the capacity to treat up to 50 ML of wastewater per day, with an ultimate capacity of up to 100 ML per day
- the AWRC will produce both advanced and tertiary treated water suitable for a range of uses including recycling, environmental flows and to minimise environmental impacts on receiving waterways
- brine will also be generated as a by-product of the reverse osmosis treatment process

Treated water and brine pipelines

- a pipeline approximately 17 km long from the AWRC to the Nepean River at Wallacia Weir, for the release of advanced and tertiary treated water
- infrastructure from the AWRC to South Creek to release excess treated water during wet weather events
- (potentially) a pipeline approximately five kilometres long from the main treated water pipeline at Wallacia to a location between the Warragamba Dam and Warragamba Weir, to release advanced treated water to the Warragamba River
- a pipeline about 24 km long that transfers brine from the AWRC to Lansdowne, in south-west Sydney, where it connects to the existing Malabar wastewater network

Sydney Water is planning to deliver the project in stages, with Stage 1 comprising:

- building and operating the AWRC to treat an average dry weather flow of up to 50 ML per day.

- building all pipelines to their ultimate capacity, but only operating them to transport and release volumes produced by the Stage 1 AWRC

The timing and scale of the future stages will be phased to respond to drivers including population growth rate and the most efficient way for Sydney Water to optimise its wastewater systems.

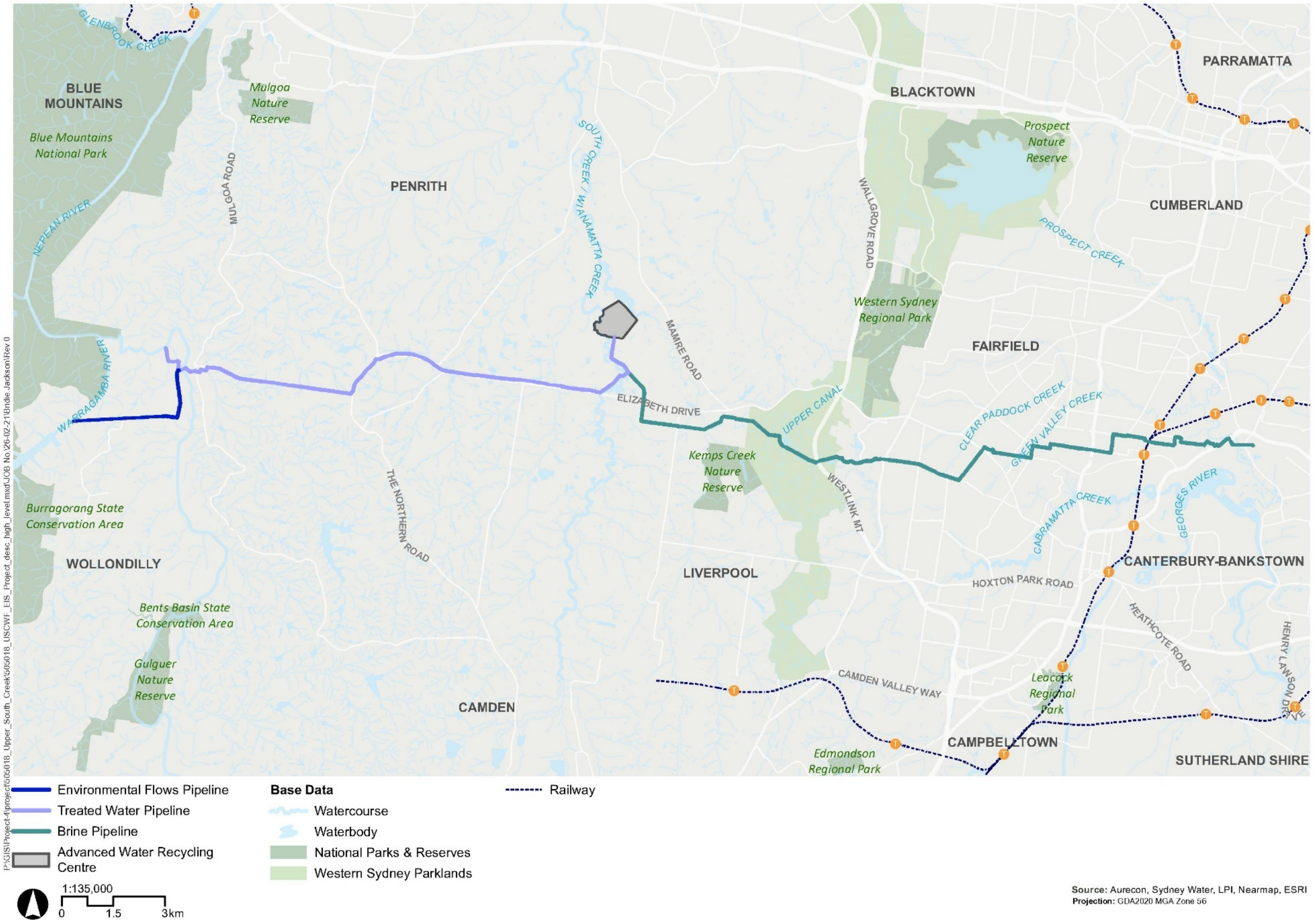


Figure 1-1 Project overview

1.3 Study objectives

The primary objective of this study is to provide a scientifically robust assessment of the hydrodynamic and water quality impacts that may be realised as a result of the releases of treated water from the proposed AWRC.

The objective is achieved by answering the following key impact assessment questions regarding the operational phases of the AWRC:

1. How do the hydrodynamics and water quality conditions change downstream of the release points, compared with current[1] and background[2] conditions, due to the proposed AWRC releases?
2. What differences are there to question 1 if some flows are released to the Warragamba River, including assessment of any changes to conditions in the Warragamba River?
3. How does the operational size of the AWRC and the corresponding release volumes affect results for questions 1 and 2?
4. How do different treatment levels (in upstream and downstream wastewater treatment plants) affect the impacts?
5. How do assumptions about stormwater management in new urban development areas affect the impacts?
6. How do wet and dry climatic conditions affect the impacts?

The assessment supports and informs the EIS directly through addressing these questions, but also indirectly through the provision of results and interpretation to other specialist studies relating to the potential water environment impacts, including the aquatic ecology impact assessment and the eco-hydraulic and geomorphology assessment. These studies and an overview of the extent of their associated considerations are presented in Figure 1-2.

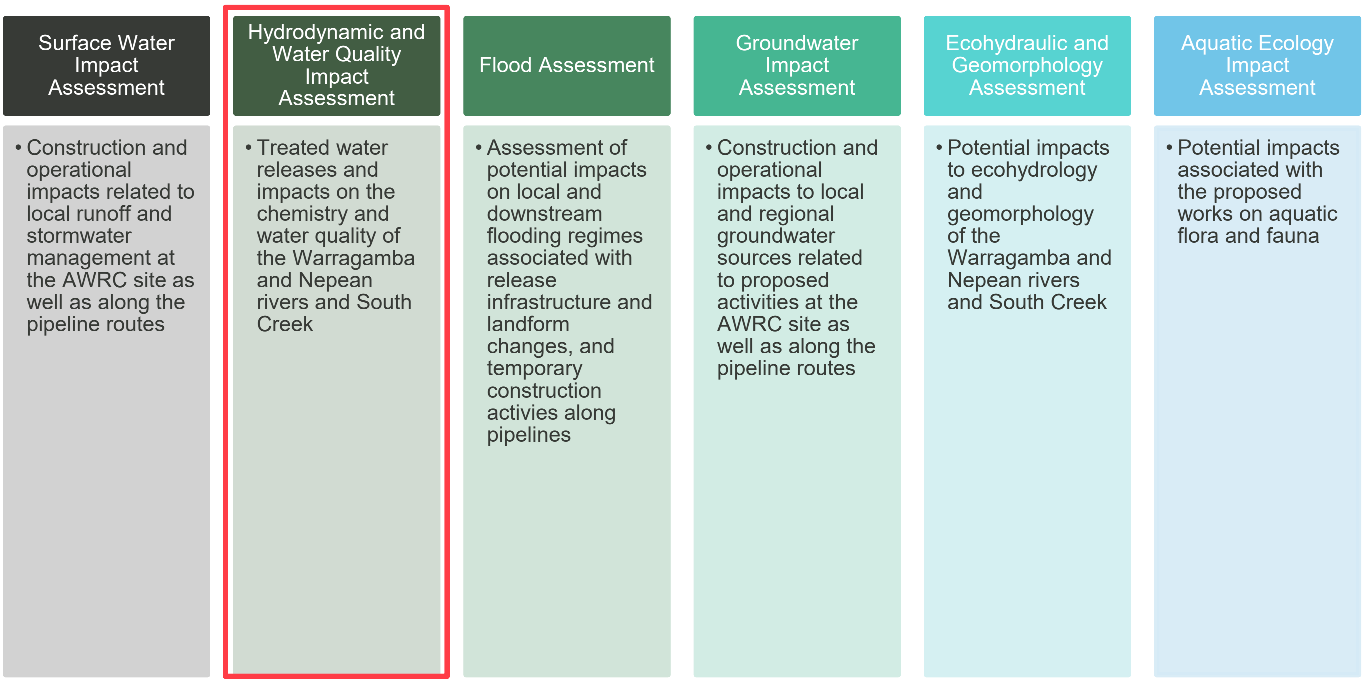


Figure 1-2 Specific water cycle impacts addressed by each study in this EIS

[1] Conditions are assumed representative of current (circa 2020) waterway and catchment conditions including land use, populations, extractions, etc.
[2] Conditions are assumed representative of future (circa 2036 and 2056) waterway and catchment conditions including land use, populations, extractions, etc.

1.4 Report structure

The following structure has been adopted for this report:

- Section 1: Introduction
- Section 2: Legislation and policy context (including applicable national, state and local legislative requirements)
- Section 3: SEARs (including specific clauses relevant to the hydrodynamic and water quality assessment)
- Section 4: Methodology (including details on the software applied, modelling approach, analytical methods, assumptions and limitations)
- Section 5: Existing environment (including a description of all relevant receiving waterways)
- Section 6: Impact assessments (including evaluation of impacts of relevant release scenarios covering a range of plant capacities, climatic conditions, time horizons, etc.)
- Section 7: Mitigation and monitoring measures
- Section 8: Conclusions

2 Legislation, policy and guidelines

2.1 Legislation and policy context

This section summarises the current legislative requirements, policies and guidelines that are considered most relevant to the hydrodynamic and water quality elements of the project. The entries within Table 2-1 are ordered from a national level through to state and local levels.

Table 2-1 Legislation and policy context

Legislation and Policy relevant to the technical study	Brief description of legislation, salient parts and intent	How legislation/policy is relevant to the study
National Water Quality Management Strategy (NWQMS)	The purpose of the NWQMS is to protect the nation's water resources by maintaining and improving water quality, while supporting dependent aquatic and terrestrial ecosystems, agricultural and urban communities, and industry. The NWQMS therefore provides a nationally consistent approach to water quality management and the provision of information and tools to help water resource managers, planning and management agencies, regulatory agencies and community groups manage and protect water resources. The main policy objective of the NWQMS is to achieve sustainable use of water resources, by protecting and enhancing their quality, while maintaining economic and social development.	Key outcomes of relevance from the NWQMS include the ANZG (2018) and ANZECC (2000) guidelines. These guidelines are discussed below.
Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZG, 2018)	Mandated step-by-step guidance on the management of water quality for natural and semi-natural water resources in Australia and New Zealand. Includes stronger emphasis on weight of evidence and desire for inclusion of conceptual models. This 2018 revision of the national water quality guidelines is presented as an online platform, to improve usability and facilitate updates as new information becomes available.	In the absence of site-specific guideline values, the ANZG (2018) provides direction on default guideline values (DGVs) for a range of stressors relevant to different community values, such as aquatic ecosystems, human health, and primary industries. The ANZG (2018) outline required targets and thresholds for relevant water quality indicators in the receiving waterways that are applicable to the project. Development of the waterway objectives for this project have therefore

Legislation and Policy relevant to the technical study	Brief description of legislation, salient parts and intent	How legislation/policy is relevant to the study
		considered these guidelines in conjunction with the ANZECC (2000) and NHMRC (2008) discussed below.
Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC, 2000)	The ANZECC (2000) Water Quality Guidelines provide a framework for conserving ambient water quality in rivers, lakes, estuaries and marine waters and list a range of environmental values assigned to that waterbody. The guidelines provide recommended trigger values (now known as default guideline values) for various levels of protection which have been considered when describing the existing water quality and key indicators of concern.	In addition to the ANZG (2018), the ANZECC (2000) provide detailed guidance on required targets and thresholds for relevant water quality indicators in the receiving waters. These guidelines, along with the ANZG (2018) and NHMRC (2008) documents formed a significant dataset in the development of the waterway objectives for the project.
Guidelines for Managing Risks in Recreational Water (National Health and Medical Research Council, 2008)	These guidelines represent non-mandatory standards designed to protect the health of humans from threats posed by the recreational use of coastal, estuarine and fresh waters. This includes natural and artificial hazards. They form part of the NWQMS and can be used at a state level as a tool to: • assure the safe management of recreational water environments, so that as many people as possible can benefit from using the water • develop legislation and standards appropriate for local conditions and circumstances	These guidelines identify suitable water quality indicators and targets for the assessment of recreational water quality. The standards were consequently included in the development of the project specific waterway objectives presented in Section 2.2.
Australian Drinking Water Guidelines 6, Version 3.5 (National Health and Medical Research Council, 2011, updated March 2021)	The Australian Drinking Water Guidelines (ADWG) are intended to provide a framework for good management of drinking water supplies that, if implemented, will assure safety at point of use. The guidelines have been developed after consideration of the best available scientific evidence. They are designed to provide an authoritative reference on what defines safe, good quality water, how it can be achieved and how it can be assured. They are concerned both with safety from a health point of view and with aesthetic quality.	The ADWG identify guideline values which are the concentration or measure of a water quality characteristic relating to the safety and aesthetic quality of drinking water for consumers. Where relevant, these guidelines were also considered in the development of the project specific waterway objectives.
Using the ANZECC Guidelines and Water Quality Objectives in NSW (DECCW, 2006)	This document was developed to provide additional guidance on the principles behind the ANZECC (2000) guidelines and how to apply these in a NSW context.	Guidance from this booklet provides additional understanding with respect to the current health of the waterways in the vicinity of the project and the ability to

Legislation and Policy relevant to the technical study	Brief description of legislation, salient parts and intent	How legislation/policy is relevant to the study
		support nominated environmental values, particularly the protection of aquatic ecosystems.
NSW Water Quality and River Flow Objectives (DECCW, 2006)	Agreed state-level environmental values and long-term goals for NSW surface waters which stipulate community values and uses, as well as water quality indicators to assess waterway condition.	For the Hawkesbury Nepean catchment, these objectives reference the Healthy Rivers Commission (HRC) as interim environmental objectives. However, the HRC guidelines (referenced below) are now considered superseded by ANZG (2018), ANZECC (2000) and relevant site-specific guidelines.
Healthy Rivers Commission (HRC, 1998)	The HRC was established in 1995 by the NSW Government to make recommendations on suitable objectives for water quality, flows and other goals central to achieving ecologically sustainable development in a realistic time frame.	The HRC Inquiry established environmental values for the Hawkesbury Nepean catchment, however these have been superseded by the ANZG (2018) and ANZECC (2000) guidelines as part of the National Water Quality Management Strategy (NWQMS), listed previously. The HRC guidelines however provide additional clarification on environmental values that are to be protected.
NSW Water Management Act (NSW Government, 2000)	The objects of the Water Management Act are to provide for the sustainable and integrated management of the water sources of the state by protecting, enhancing and restoring water resources.	Consideration of the project against the overarching water management principles promoted under the Water Management Act.
Protection of the Environment Operations Act (NSW Government, 1997)	The Protection of the Environment Operations Act 1997 is the key piece of environment protection legislation administered by the Environment Protection Authority (EPA). The Act enables the Government to set out explicit protection of the environment policies. The EPA also issues environment protection licences to the owners or operators of various industrial premises under the Act. Sydney Water's wastewater treatment plants all operate under environmental protection licences issued by the EPA.	It is anticipated that, if approved, the AWRC will operate under the provisions of a new environment protection licence issued and administered by the EPA. Such a licence will specify environmental performance requirements, taking into account factors such as the likely impact of the activity on the environment including the receiving waterways.
Risk-based framework for considering waterway health outcomes in strategic land use planning decisions (OEH, 2017)	The Risk Based Framework brings together existing principles and guidelines recommended in the NWQMS, which the federal, state and territory governments have adopted for managing water quality.	The development of the project waterway objectives followed the principles of the risk-based framework. The framework was also applied in the development of water quality and flow objectives for South Creek. These

Legislation and Policy relevant to the technical study	Brief description of legislation, salient parts and intent	How legislation/policy is relevant to the study
	The purpose of the Risk Based Framework is to: • ensure the community's environmental values and uses for our waterways are integrated into strategic land use planning decisions • identify relevant objectives for the waterway that support the community's environmental values and uses, and can be used to set benchmarks for design and best practice • identify areas or zones in waterways that require protection • identify areas in the catchment where management responses cost-effectively reduce the impacts of land use activities on our waterways • support management of land use developments to achieve reasonable environmental performance levels that are sustainable, practical, and socially and economically viable.	objectives have consequently been included alongside ANZG (2018) and ANZECC (2000) guidelines for the assessment of hydrology and water quality in the South Creek catchment.
State Environmental Planning Policy (Sydney Drinking Water Catchment) (DPIE, 2011)	The State Environmental Planning Policy (Sydney Drinking Water Catchment) 2011, has three main aims: • to provide for healthy water catchments that will deliver high quality water and permit development that is compatible with that goal • to ensure that consent authorities only allow proposed developments that have a neutral or beneficial effect on water quality • to support water quality objectives in the Sydney drinking water catchment.	The SEPP defines the boundaries of the Sydney Drinking Water Catchment (SDWC). The Warragamba River release point and part of the treated water pipeline is within the SDWC boundary, despite being downstream of Warragamba Dam and its catchment. As required by SEARs 2(c), an assessment of whether the project will achieve a neutral or beneficial effect (NorBE) on water quality within the declared SDWC is therefore required. This is further discussed in Section 6.3.1 with reference to the *Neutral or Beneficial Effect on Water Quality Assessment Guideline* (SCA, 2015).
Sydney Regional Environment Plan No. 20 – Hawkesbury-Nepean River (DPIE, 1997)	The purpose of the Sydney Regional Environment Plan No. 20 – Hawkesbury-Nepean River (SREP20) is to protect the environment of the Hawkesbury-Nepean River system by ensuring that the impacts of future land uses are considered in a regional context. It covers environmentally sensitive areas, water quality and quantity and development that has the potential to impact on the river environment.	The AWRC site and the largest portion of the pipeline alignments are located within the Nepean and South Creek catchments which ultimately drains to the Hawkesbury River. The Local Government Areas (LGAs) of Penrith, Liverpool, Wollondilly and Fairfield are identified as four of the 15 LGAs to which the SREP20 – Hawkesbury-Nepean River applies and specific planning

Legislation and Policy relevant to the technical study	Brief description of legislation, salient parts and intent	How legislation/policy is relevant to the study
		policies and recommended strategies for consideration in this project are detailed in Clause 6.
Regulating nutrients from sewage treatment plants in the Lower Hawkesbury Nepean River catchment (EPA, 2019)	The EPA has developed a regulatory framework to manage nutrient load inputs to the Hawkesbury Nepean River from wastewater treatment plants. The objective is to meet the community's environmental values for the river and provide wastewater treatment plant operators with alternatives to meet those nutrient loads. The framework includes limits on nutrient concentrations, interim caps on nutrient loads and a framework for nutrient trading and offsets.	The framework divides the river system into different zones and proposes separate load limits for Total Nitrogen and Total Phosphorus within each zone. Releases from the AWRC to the Nepean and Warragamba rivers are within Yarramundi subzone 2. Releases to South Creek are within Sackville subzone 2. The framework has been applied to Sydney Water's existing Environment Protection Licences (EPLs) and similarly would be applied to the AWRC's EPL. Sydney Water is therefore designing the project to be consistent with the framework with additional loads from the AWRC releases in alignment with the framework's limits.
Metropolitan Water Plan (Department of Industry, Skills and Regional Development, 2017).	The Metropolitan Water Plan aims to ensure Sydney's water needs will be met so it can withstand drought and support a growing population. The plan considers how to optimise existing water supplies, develop water efficiency and conservation programs, manage drought, and where to source new water supply options if required. The plan has four key outcomes: • Outcome 1 – our water supply is secure and affordable • Outcome 2 – our water supply system is resilient to stresses and shocks • Outcome 3 – our urban communities are more liveable and resilient • Outcome 4 – rivers downstream from dams are healthy. With reference to outcome 4, the plan was developed in consultation with community and industry stakeholders. A strong expectation was found for the Hawkesbury-Nepean to be a healthy and productive river downstream of the water supply dams, to support amenity, water quality and	The plan recognises the benefits of, and commits to improve, river health by releasing water from Warragamba Dam, which would otherwise supply drinking water for Sydney. Treated water produced by the AWRC can potentially contribute to this approach through releases to Nepean or Warragamba River. These potential environmental flow releases have been considered in the modelling as part of the project.

Legislation and Policy relevant to the technical study	Brief description of legislation, salient parts and intent	How legislation/policy is relevant to the study
	the health of fish communities, and to enable boating and other recreational activities.	
Greater Sydney Water Strategy (DPIE, in development)	The Greater Sydney Water Strategy is currently being developed by DPIE. This 20-year strategy will replace the 2017 Metropolitan Water Plan and reflect the government's objectives and desired outcomes for integrated water cycle management. The government is concerned with water security, enhancing and enabling economic growth, liveability and community wellbeing, environmental sustainability and improvement. The strategy is expected to be finalised in 2021.	Sydney Water has been engaging with DPIE as the strategy develops which has illustrated that the project objectives align to the strategy's direction. Sydney Water will continue to work closely with DPIE as the Greater Sydney Water Strategy is developed to ensure alignment of our relevant activities, including the project.
Approved Methods for the Sampling and Analysis of Water Pollutants in NSW (DECC, 2008)	This document lists the sampling and analysis methods to be used when complying with a requirement by, or under, the NSW environment protection legislation, or a licence or notice under that legislation, to test for the presence or concentration of matter in water and the volume, depth and flow of water or wastewater. The environment protection legislation includes, among other legislation, the Protection of the Environment Operations Act (1997) and regulations under it.	The application of these methods is prescribed as one of the relevant environmental planning instruments, policies, guidelines and plans within the project specific SEARS.

2.2 Waterway values and objectives

Table 2-2 presents a summary of the waterway objectives for the Nepean and Warragamba rivers and South Creek. The objectives are specific to this project and were developed in accordance with the *Risk-based Framework for Considering Waterway Health Outcomes in Strategic Land-use Planning Decisions*, published by the NSW Office of Environment and Heritage (OEH, 2017). The numerical criteria are sourced from existing guidelines and objectives as notated in the table. Predicted impacts from the project will be assessed against these waterway objectives.

The Risk-based Framework defines waterway objectives as consisting of:

- community's environmental values and uses of the water
- indicator(s) and corresponding numerical criteria to assess whether the waterway will support a particular environmental value or use.

The values and uses adopted for the Nepean and Warragamba rivers and South Creek are listed below:

- aquatic ecosystems
- recreation and aesthetics
- primary industries
- drinking water (Nepean River only).

Management goals and numerical criteria for each of these values and uses have been informed by the following guidelines:

- Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC, 2000 and ANZG, 2018)
- Guidelines for managing risks in recreational water (NHMRC, 2008)
- Australian Drinking Water Guidelines 2011, Version 3.5 Updated August 2018 (NHMRC, NRMMC, 2011)

Draft water quality and flow objectives have also been developed by DPIE as part of the precinct planning work for the Aerotropolis (NSW government, 2020). These draft objectives include performance criteria that have been included in the project objectives for South Creek.

Table 2-2 Waterway objectives for Nepean and Warragamba rivers and South Creek

Values and uses & associated management goals	Indicator	Numerical criteria/metric	
		Nepean and Warragamba rivers	South Creek (values in brackets/blue text are DPIE criteria).
1. Aquatic Ecosystems *Management goal: Protect, maintain and restore the ecological condition of aquatic systems and their riparian zones overtime.*	Total nitrogen (TN)	0.35 mg/L[1]	0.35 mg/L[1] (1.72 mg/L)[2]
	Total phosphorus (TP)	0.025 mg/L[1]	0.025 mg/L[1] (0.14 mg/L)[2]
	Oxidised nitrogen (NOx)	0.040 mg/L[1]	0.040 mg/L[1] (0.66 mg/L)[2]
	Ammonium (NH_4^+)	0.020 mg/L[1]	0.020 mg/L[1] (0.08 mg/L)[2]
	Filterable reactive phosphorus (FRP)	0.020 mg/L[1]	0.020 mg/L[1]
	Chlorophyll *a* (Chl *a*)	0.003 mg/L[1]	0.003 mg/L[1]
	Dissolved oxygen (DO)	85 - 110 % Saturation[1]	85 - 110 % Saturation[1] (43 - 75 % Saturation, 8 mg/L)[2]
	pH	6.5 - 8.0[1]	6.5 - 8.0[1] (6.2 - 7.6)[2]
	Conductivity / Salinity	125 - 2200 µS/cm[1] Equivalent to Salinity of 0.09 -1.5 g/L[1]	125 - 2200 µS/cm[1] Equivalent to Salinity of 0.09 -1.5 g/L[1] (1103 µS/cm Equivalent to Salinity of 0.75 g/L)[2]
	Toxicants	Refer to Table 2-3 and ANZG/ANZECC guidelines[1,3]	Refer to Table 2-3 and ANZG/ANZECC guidelines[1,3]
	Turbidity	6 - 50 NTU[1] TSS < 40 mg/L[1]	6 - 50 NTU[1] TSS < 40 mg/L[1] (50 NTU)[2] (TSS < 30 - 37 mg/L)[2,6]

Values and uses & associated management goals	Indicator	Numerical criteria/metric	
		Nepean and Warragamba rivers	**South Creek (values in brackets/blue text are DPIE criteria).**
2. Recreation & Aesthetics *Management Goal: Maintain or improve water quality for recreational activities such as swimming, boating and fishing.*	Enterococci	Primary contact: 95th percentile for intestinal enterococci/100 mL ≤ 40[4] Secondary contact: 95th percentile for intestinal enterococci/100 mL > 40 and ≤ 200[4]	
	Cyanobacteria risk index	No overall increase in (cyanobacteria) risk under any scenario, as determined by the length of period with index values consistently above 0.8.	
Management Goal: Maintain or improve the aesthetic qualities of the waterways	Visual clarity and colour	Surface waters should be free from substances that produce undesirable colour, odour, tasting or foaming.[1]	
	Surface films and debris	Surface waters should be free from floating debris, oil, grease and other objectionable matter[1]	
	Nuisance organisms	Surface waters should be free from undesirable aquatic life, such as algal blooms, or dense growths of attached plants or insects[1].	
3. Irrigation and livestock drinking *Management Goal: Protect the quality of water used for a broad range of irrigation activities and livestock drinking*	As per Water Quality metrics, under Aquatic Ecosystems		
	Human Pathogens	Thermotolerant Coliforms <10 cfu/100 mL[1]	
	Cyanobacteria	No overall increase in (cyanobacteria) risk under any scenario, as determined by the length of period with index values consistently above 0.8.	
4. Protection of Raw Drinking Water Supplies *Management Goal: Maintain or improve the quality of raw drinking water extracted downstream*	As per Water Quality metrics, under Aquatic Ecosystems		Not applicable to South Creek.
	Microorganisms	E. Coli < 1cfu/100mL Enterococci <1cfu/100mL	Not applicable to South Creek.
		Viruses, protozoa and helminths[3,5] - Absent	
		Cyanobacteria risk index. Criteria: No overall increase in risk under any scenario.	
	Toxicants	Refer to Table 2-3 and ANZECC guidelines[1,3]	

Table notes:

1. *Indicators and metrics adopted from ANZG (2018) and ANZECC (2000) default guideline values (DGVs) are for slightly disturbed lowland river ecosystems in south-east Australia*
2. *These metrics are performance criteria presented in the Draft Aerotropolis Precinct Plan (Western Sydney Planning Partnership, November 2020).*
3. *Refer to the EIS for more information on how these indicators were identified and assessed.*
4. *Guidelines for managing risks in recreational water (NHMRC, 2008)*
5. *Australian Drinking Water Guidelines 6 V3.6 (NHMRC, NRMMC 2011)*
6. *Objective of 30 mg/L conservatively adopted in analysis*

Table 2-3 Relevant toxicant DGVs

Indicator	Adopted DGV
Total Ammonia as N	0.90* mg/L
Nitrate as N	2.40** mg/L
Total Chlorine	0.003* mg/L
Aluminium	0.055* mg/L
Copper	0.0014* mg/L
Zinc	0.008* mg/L
Manganese	0.100*** mg/L

Table notes:

* *DGV for the protection of aquatic ecosystems (95% protection as typically recommended for slightly to moderately disturbed ecosystems) – refer ANZECC (2000) Table 3.4.1 and ANZG (2018)*

** *For Nitrate, the updated ANZG (2018) state that the ANZECC (2000) DGV of 0.7 mg/L was erroneous and recommends the use of the guideline values published in the NIWA report "Updating nitrate toxicity effects on freshwater aquatic species" (2013).*

*** *DGV for recreational purposes – refer NHMRC (2008) The ANZG (2018) DGV for the protection of aquatic ecosystems is significantly higher with a value of 1.9 mg/L.*

3 Relevant SEARs

As the project has been declared State Significant Infrastructure, project specific Secretary's Environmental Assessment Requirements (SEARs) have been issued by DPIE. The intention of these requirements is to assess the impacts of the project on the biophysical and socio-economic environment, including a description of how the project has aimed to avoid, minimise and mitigate environmental impacts.

The SEARS clauses that are directly relevant to the hydrodynamic and water quality assessment have been identified and are presented in Table 3-1. In addition to these clauses Table 3 2 provides a summary of additional issues raised by government agencies and councils during consultation on the EIS.

Table 3-1 Project SEARs relevant to the hydrodynamic and water quality assessment

SEARs Section	SEARs clause number and matter to be addressed by study	Report section where addressed
General	(g) an assessment of the likely impacts of the project on the biophysical and socio-economic environment, focusing on the specific issues identified below and any other significant issues identified, including:	Sections 6.1, 6.2, 6.3 and 8
	i. a description of the existing environment likely to be affected by the project using relevant and adequate data.	Section 5
	ii. an assessment of the potential impacts of the project, including any cumulative impacts, and taking into consideration relevant guidelines, policies, plans and industry codes of practice.	Sections 2, 6.1, 6.2, 6.3 and 8
	iii. a description and details of how the project has been designed to avoid, minimise and offset impacts (through design, or construction or operation methodologies).	Section 7
	iv. a description of how any residual impacts will be managed or offset, and the approach and effectiveness of these measures.	Section 7
Key Issues - Water	1. Describe background conditions for any water resource likely to be affected by the development, including:	
	a) existing surface and groundwater.	Section 5
	b) hydrology, including volume, frequency and quality of discharges at proposed intake and discharge locations.	Section 4.6.3.5.1
	c) Water Quality Objectives (as endorsed by the NSW Government (www.environment.nsw.gov.au/ieo/index.htm) including groundwater as appropriate that represent the community's uses and values for the receiving waters.	Section 2.2
	d) indicators and trigger values/criteria for the environmental values identified at (c) in accordance with the ANZECC (2000) Guidelines for Fresh and Marine Water Quality and/or local objectives, criteria or targets endorsed by the NSW Government.	Section 2.2
Key Issues - Water	2. Assess the impacts of the development on water quality, including:	
	a) the nature and degree of impact on receiving waters for both surface and groundwater, demonstrating how the development protects the Water Quality Objectives where they are currently being achieved, and contributes towards achievement of the Water Quality Objectives over time where they are currently not	Sections 6.1 and 6.2, 6.3, 7 and 7.3

SEARs Section	SEARs clause number and matter to be addressed by study	Report section where addressed
	being achieved. This should include an assessment of the mitigating effects of proposed stormwater and wastewater management during and after construction. b) identification of proposed monitoring of water quality. c) if the proposal will achieve a neutral or beneficial effect (NorBE) on water quality within the declared Sydney Drinking Water Catchment (SDWC).	Section 7.2 Section 6.3.1
Key Issues - Water	3. Assess the impact of the development on hydrology, including: b) effects to downstream rivers, wetlands, estuaries, marine waters and floodplain areas. d) impacts to natural processes and functions within rivers, wetlands, estuaries and floodplains that affect river system and landscape health such as nutrient flow, aquatic connectivity and access to habitat for spawning and refuge (e.g. river benches). f) mitigating effects of proposed stormwater and wastewater management during and after construction on hydrological attributes such as volumes, flow rates, management methods and re-use options. g) identification of proposed monitoring of hydrological attributes.	Section 6.1 Sections 6.1, 6.2 and 6.3 Section 7.1 Section 7.2 (further details provided in the Aquatic Ecology and the Ecohydraulic and Geomorphology assessments
Key Issues - Water	4. Map: e) proposed intake and discharge locations.	Section 4.6.3.1.3 / Figure 4-4
Key Issues - Water	5. Demonstrate that the project is consistent with the Environment Protection Authority's (EPA) framework for regulating nutrient discharges in effluent from STPs discharging to the lower Hawkesbury Nepean River (EPA 2019) including: b) specify the location of discharge points, including but not limited to the Nepean River, Warragamba River and South Creek release location(s) for dry and wet weather justifying why the location was selected over other potential discharge points, including discussion of waterway characteristics at each point (eg depth, salinity, hydrodynamics) and consideration of the relative water quality risks.	Section 6.3.3 Sections 4.6.3.1.3, 5, 6.1 and 6.2
Key Issues - Water	6. Provide a detailed analysis of discharges into Warragamba River including e-flow needs going back 20 years. This analysis needs to consider: b) how the discharge will affect the health of the river	Sections 4.6.3.5.1 and 6.1.3
Key Issues - Water	7. Consult/coordinate with the Department of Planning, Industry and Environment (and Planning Partnership Office) in respect to environmental impacts on the South Creek catchment and the Wianamatta South Creek program. This includes: c) assess the potential impacts on the quantity and quality of surface and groundwater resources along South Creek, including the implications of dry and wet weather flows from the project.	Sections 6.1 and 6.2 regarding impacts on quantity and quality of surface water in South Creek
Key Issues - Crown Lands	65. An assessment of project impacts on Crown Land Waterways, including: d) the impact of the treated water pipeline on South Creek, Badgerys Creek, Oaky Creek, Cosgroves Creek, Nepean River, Megaritys Creek.	Sections 6.1 and 6.2 regarding impacts on South Creek and the Nepean River.

Table 3-2 Summary of additional issues raised during agency consultation

Agency	Issue raised	Report section where addressed
Wollondilly Council	Concern that Bents Basin is a high recreational area, and that the discharge must support these activities and not promote algal blooms.	Section 6.3.2
EPA	(d) 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 discharge(s) may have on the receiving environment, including consideration of all pollutants that pose a risk of non-trivial harm to human health and the environment.	Section 4.6.3.5.1 Sections 6.1, 6.2 and 6.3
EPA	(k) provide details of the likely frequency and volume of overflows and the load of pollutants that would be discharged during those events.	Sections 4.6.3.5.5, 6.1.1.2, 6.1.2.2, 6.1.3.2
EPA	(l) assess the significance of any identified impacts including consideration of the relevant ambient water quality outcomes.	Sections 6.1 and 6.2
EPA	(n) include the results of water quality modelling and analysis including descriptions of water quality impacts under the full range of operating scenarios, including average or typical through to worst case for each discharge point during wet and dry weather.	Sections 6.1 and 6.2
EPA	(o) if a mixing zone is proposed, demonstrate that the NSW WQOs will be met at the edge of the near-field mixing zone.	Section 6.2
EPA	(p) justify, if required, why the relevant NSW WQOs cannot be maintained or achieved over time.	Sections 6.1 and 6.2
EPA	(q) demonstrate that all practical measures to avoid or minimise water pollution and protect human health and the environment from harm are investigated and implemented	Sections 6 and 7
EPA	(r) identify sensitive receiving environments (which may include estuarine and marine waters downstream) and develop a strategy to avoid or minimise impacts on these environments	Sections 5.4, 6 and 7
EPA	(s) provide details of measures to minimise and mitigate potential impacts of discharges on the receiving waterway such as optimising the location, depth and mode (eg diffuser) of discharge to maximise dilution, mixing and dispersion.	Section 7
EPA	(t) identify proposed water quality monitoring locations, monitoring frequency and indicators of water quality, including groundwater quality	Section 7.2

4 Assessment methodology

4.1 Overview

This section outlines the methodology that was adopted in the assessment to adequately address the SEARs as well as other relevant, previously discussed, technical and legislative requirements. As a high-level overview, the following sequence of tasks was undertaken as part of the assessment methodology:

- site inspections
- data compilation and review
- software selection and model configuration
- model development, calibration and validation
- scenario testing and impact assessment
- analysis and interpretation

Details regarding these tasks are presented in the sub-sections below.

4.2 Site inspections

Site visits were undertaken in October 2019. These included the following visual inspections of the release sites and the receiving waterways:

- South Creek. Land based inspections upstream and in the vicinity of the proposed AWRC, as well as at various locations downstream of the proposed release point.
- Nepean River. Boat based inspections from the Penrith boat ramp up to the navigable extents of the Nepean River and the Warragamba River.

Both inspections coincided with an extended period of dry weather and corresponding low flow conditions within the waterways.

4.3 Data compilation and review

An extensive suite of publicly available datasets, and information specific to the project was compiled and reviewed as part of the assessment. A summary of these tasks are presented below:

The initial phase provided for the development, calibration and validation of the hydrodynamic and water quality models. Descriptions of the underlying datasets included in this development phase are presented in the model calibration report. Details provided include the source of the data, its application and where relevant, the resolution and various other key attributes relating to each dataset. The model calibration report can be supplied by Sydney Water upon request.

The subsequent phase of data compilation and review tasks primarily focussed on information relevant to the characterisation of the existing environment as well as for the development of model scenarios that would be needed in the impact assessment. Key datasets therefore included:

- previous studies relating to hydrodynamic and water quality conditions of the Hawkesbury Nepean River, South Creek and their tributaries
- water quality monitoring data collected within the receiving waterways
- land use data for the catchments as forecast for future time horizons

- monitoring data from relevant wastewater treatment plants (WWTPs) and water recycling plants (WRPs) located within the catchments including flow rates and water quality relating to the treated water releases
- wet weather overflow data predicted for future conditions
- irrigation and water filtration extraction data for future conditions

4.4 Software selection

The Water Quality Response Models (WQRMs) used in the impact assessment were built on application of the finite volume hydrodynamic modelling software, TUFLOW FV, which was dynamically coupled with the Aquatic Ecodynamics Modelling library, AED2. Further details regarding these software packages as well as other relevant modelling tools are presented below.

4.4.1 TUFLOW FV

The TUFLOW FV (version 2019.01.008 Single Precision Build) hydrodynamic modelling software, developed by BMT Commercial Australia Pty Ltd, was adopted for the WQRM. The software uses a flexible mesh (finite volume) approach to resolve the variations in water level, flow, horizontal salinity distribution and vertical density stratification in response to tides, inflows and surface thermodynamics.

Model meshes can consist of a combination of triangular and quadrilateral elements of different sizes. Such mesh structures are well suited to simulating areas of complex riverine and estuarine morphometry. The resolution of the meshes can be easily adapted to accommodate areas of waterway where the hydrodynamics are either considered complex or where there are specific zones of interest.

The model meshes can then be applied as either two dimensional (2D) or three dimensional (3D). Further options exist for the vertical mesh discretisation including sigma or z coordinate systems, or a hybrid of the two, allowing for multiple surface Lagrangian layers to respond to water elevation changes.

The finite volume numerical scheme solves the conservative integral form of the non-linear shallow water equations in addition to the advection and transport of scalar constituents such as salinity and temperature. The timestep, typically in the order of minutes, varies throughout a simulation and is selected by taking into account physical and numerical convergence and stability considerations. The appropriate timestep is calculated by TUFLOW FV such that Courant–Friedrichs–Lewy (CFL) constraints imposed by the flow characteristics are obeyed.

4.4.2 AED2

The AED2 water quality modelling library (libfvaed2 1.0.0 and libaed2 1.3.0), developed by the University of Western Australia (UWA), is coupled with the TUFLOW FV model. The library is organised as a series of independent water quality modules that can be interconnected.

The core conceptualisation of the model is configured to capture the dynamics of oxygen, carbon, nutrients (including inorganic and organic fractions) and primary productivity as presented in Figure 4-1. Individual phytoplankton groups are simulated with chlorophyll *a* also included as a primary indicator of phytoplankton abundance and biomass. Other indicators of waterway health (e.g. species habitat, hypoxia or nuisance algal bloom risk) can also be output and summarised. The water quality properties are updated dynamically in response to changes in water conditions brought about by weather and flow events.

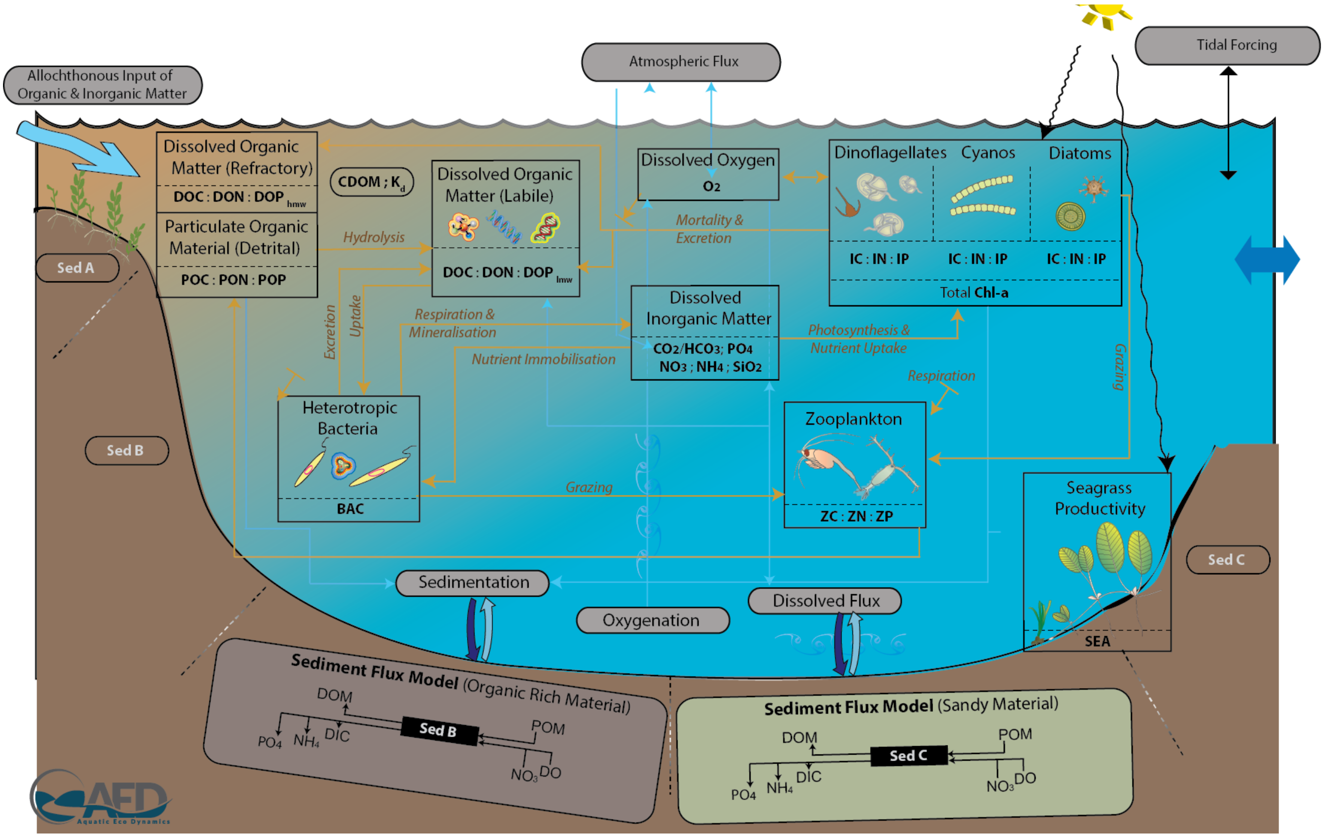


Figure 4-1 AED2 conceptual model

4.4.3 CORMIX

The CORMIX software (version 12.0GT) is a US EPA supported mixing zone model and decision support system, commonly used for environmental impact assessments of treated wastewater releases. The software consists of a series of algorithms for the analysis of near field mixing of wastewater in receiving waterways, with an emphasis on steady-state analysis for the prediction of plume geometry and dilution characteristics.

The CORMIX models developed for the EIS used boundary condition data from the WQRMs as well as relevant monitoring data to define the initial dilution and mixing characteristics and profiles within South Creek and the Nepean River. The models were then applied to assess near field impacts, such as toxicity, in the immediate vicinity of the release points.

4.4.4 Other modelling tools

TUFLOW FV and AED2 were the primary software packages used to simulate the hydrodynamics and an extended suite of water quality processes within the receiving waterways. However, a number of other modelling tools were also applied in the development of the WQRMs, as well as the impact assessment modelling, as listed below.

- Source models. Catchment processes were modelled using an integrated river basin water resources modelling software known as Source. The Source catchment models were developed to generate daily timestep data on catchment runoff flows and pollutant export loads for key water quality constituents including nutrients, sediment and pathogens. Scenarios were run using Source for existing and predicted future catchment conditions.

- MOUSE models. MOUSE, short for MOdel for Urban SEwers, is used by Sydney Water for modelling its wastewater network systems. The MOUSE models were used to generate data on wet weather overflows, including spill volumes at each overflow location. Scenarios were run using MOUSE for existing and predicted future network conditions. The timestep for these models can be defined by the user.
- WWTP/WRP models. Daily timestep models were developed within Microsoft Excel to allow the generation of daily timestep timeseries of flow and water quality for each of the treated water releases. Scenarios were run using these spreadsheet models for existing conditions as well as predicted future release conditions. As a general rule, data from Sydney Water's Effluent Knowledge and Management System (EKAMS) was used as the base dataset with interpolation and modifications to flow rates and water quality applied as required to simulate future conditions, such as population growth, treatment upgrades, network transfers, etc.

4.5 Model configuration

Figure 4-2 presents a high-level overview of the interfaces for the various models used in the impact assessment. In summary:

- Timeseries data from the WWTP/WRP models were incorporated either in the Source catchment model or directly into the WQRM, depending on their location in the catchment. WWTPs and WRPs located in the upper reaches of the catchments were included in the Source catchment model. However, those with release points located adjacent to the Hawkesbury Nepean River or South Creek were included as point sources within the WQRMs.
- Timeseries wet weather overflow data from the MOUSE models were incorporated directly into relevant sub-catchments within the Source catchment models.
- Surface water extractions were represented in the Source catchment model or within the WQRMs depending on their location.
- Results from the Source catchment models were processed using MATLAB to develop boundary conditions for the WQRMs.
- Results from the WQRMs were processed and used to develop the necessary boundary conditions for the CORMIX model scenarios.

Separate WQRM and Source catchment models were developed for South Creek and the Hawkesbury Nepean River system. Upstream, the extents of these models were governed by a number of key catchment features. More specifically, rainfall runoff from several catchments is regulated by dams including the Nepean, Avon, Cordeaux, Cataract, Warragamba and Mangrove Creek dams. The catchments upstream of these dams were therefore not included in the models and the timeseries data on these regulated flows were included directly in the WQRMs. Downstream, the limit of the Hawkesbury Nepean WQRM is represented as an open ocean boundary that runs from Barrenjoey Head to Box Head. The extents of the WQRM meshes are presented in Figure 4-3.

To allow for integration of the two separate WQRMs, an interface was developed to allow changes in the flows and water quality originating from South Creek to be simulated in the downstream waters of the Hawkesbury Nepean River. The interface was consequently located at the tidal limit of South Creek with results from the South Creek WQRM scenarios extracted at this location and then formatted as boundary conditions for the Hawkesbury Nepean WQRM.

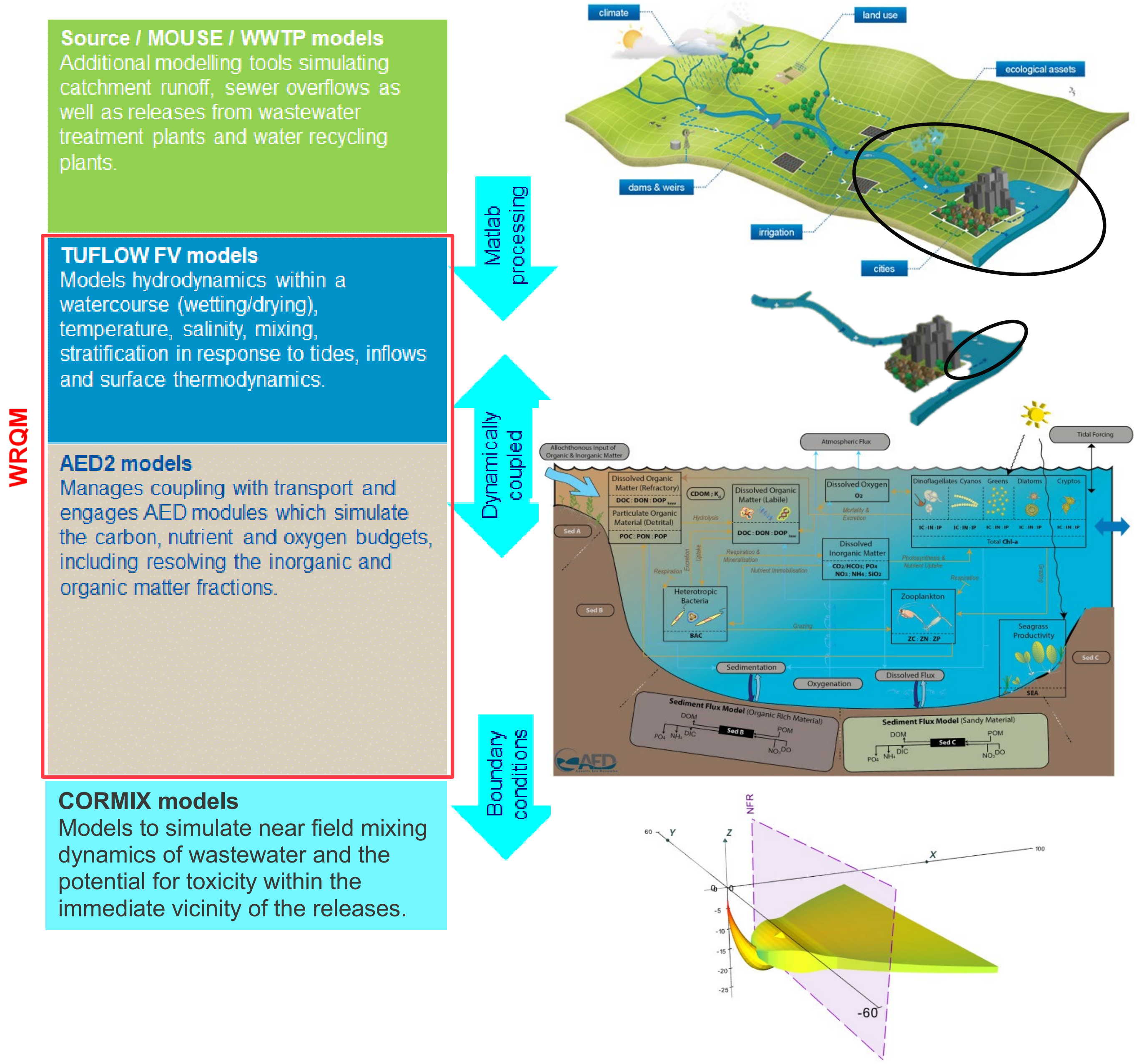


Figure 4-2 Primary model interfaces (Image sources: eWater, University of Western Australia and MixZon)

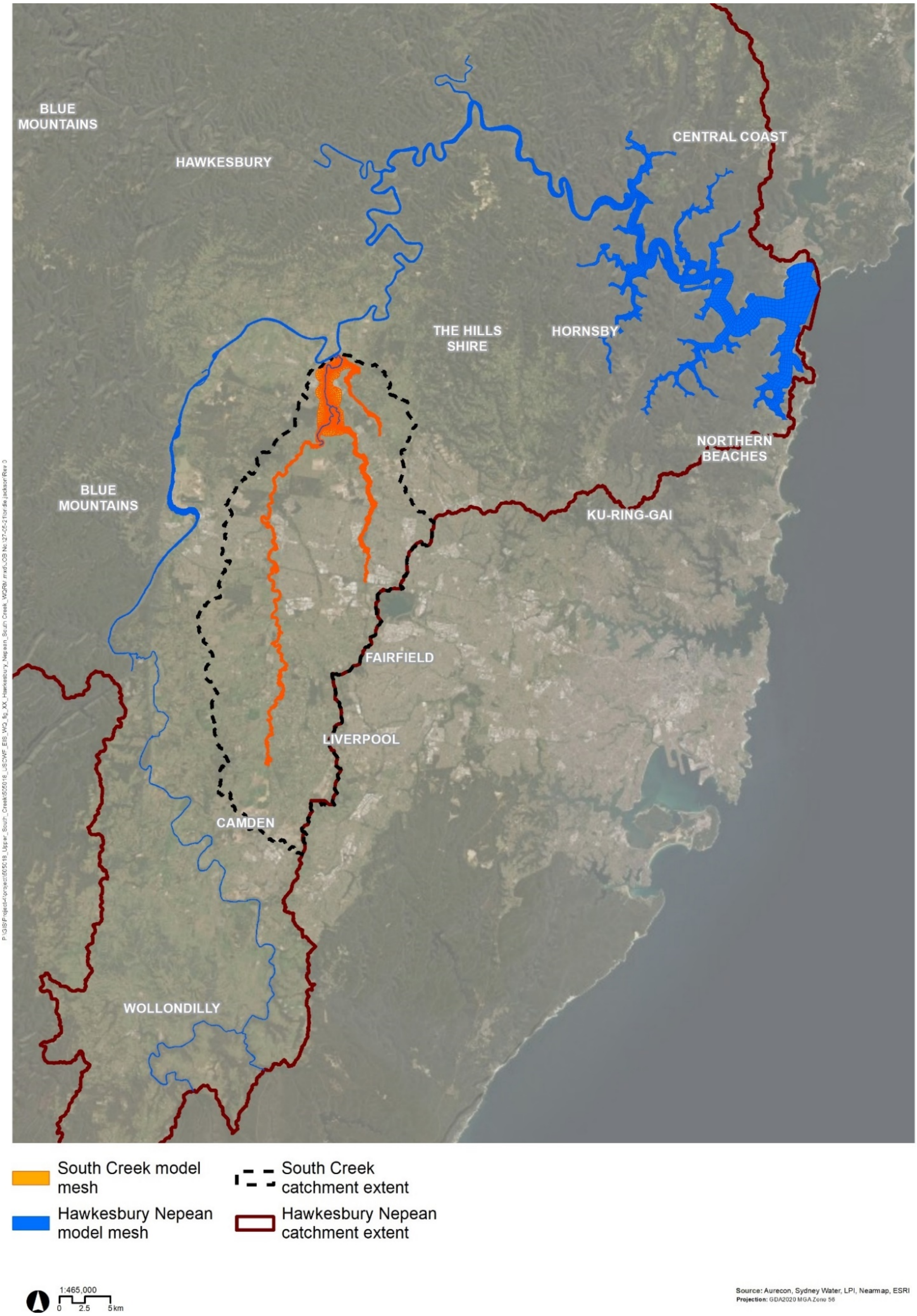


Figure 4-3 Extent of the Hawkesbury Nepean and South Creek WQRMs

4.6 Hydrodynamic and water quality modelling

4.6.1 Model development, calibration and validation

The WQRMs that have been applied in the EIS to simulate hydrodynamic and water quality impacts, represent a significant upgrade on the models developed as part of the *Water Quality Modelling of the Hawkesbury Nepean River System* (SKM, 2014). A fundamental focus of the upgrade was to ensure the modelling system has the capacity to realistically evaluate far field hydrodynamic and water quality impacts from the Upper South Creek AWRC. In addition to the upgrade of the existing Hawkesbury Nepean WQRM, the new WQRM of South Creek was developed exclusively to allow simulation of the finer scale details of the sub-catchments within the South West and Western Sydney Aerotropolis growth areas.

In summary, the model development tasks included:

- updates to the modelling software versioning to apply latest advances in modelling hardware and software
- updates of various model datasets and model elements, including the development of a new model mesh representing South Creek, updates to WWTP/WRP data and extending all boundary condition datasets to cover more recent time periods through to 2018
- updates to the catchment inflows through application of updated Source catchment models
- review of biogeochemical and sediment parameter descriptions, units and assigned values based on local evidence, or otherwise relevant literature

The WQRMs were calibrated and validated for the following years based on an assessment of each year's representative climatic conditions and an audit/comprehensive review of available hydrodynamic and water quality monitoring data:

- Calibration: 2017-2018 was selected due to the extensive and comprehensive datasets available
- Validation: 2013-2014 and 2014-2015 were selected as representative dry and wet years based on a review of climatic data (refer Section 4.6.3.3 for further details)

The monitoring data included output from regular sampling programs (e.g. monthly at fixed sites), high-frequency data at fixed locations, and ad-hoc transect data with high spatial resolution along the river gradient. The data was made available from the following sources: Sydney Water, DPIE, WaterNSW Blacktown City Council and Hornsby Shire Council.

Calibration and validation of the two WQRMs focussed on comparing the model predictions against the water quality and hydrodynamic monitoring data. Adjustments were made to model variables until an acceptable fit between predicted and observed data was achieved. The core suite of hydrodynamic and water quality parameters calibrated and validated within the WQRMs included flow, salinity, temperature, dissolved oxygen, suspended solids, nutrients (including inorganic and organic fractions), primary productivity and pathogens.

A range of plotting tools was used for the comparison of model predictions against monitoring data including an innovative zonal analysis approach, which involved data aggregation within predefined zones of the waterways. Transect analysis was also applied to demonstrate the longitudinal variation in different water quality attributes. These plots were integrated over either monthly, seasonal, or annual timeframes, allowing assessment of the large-scale trends along the river or creek, with less emphasis on the high-frequency variability brought about by day-to-day conditions.

The WQRMs performed well across the range of calibration and validation periods and also across the range of parameters that have been assessed. The WQRMs were considered to be a significant enhancement on the model developed by SKM in 2014, and have been independently reviewed by the University of New South Wales (UNSW) Water Research Laboratory. The models are consequently considered fit for purpose in the application of assessing impacts of the Upper South Creek AWRC.

4.6.2 Scenario testing approach

A suite of scenarios was developed to allow simulation of a range of conditions that could be expected during the operational life of the AWRC. Therefore, in addition to the releases of treated water from the AWRC on their own, expected changes in other catchment conditions such as land use, population growth, and stormwater management, were also considered in the scenarios. Through consideration and simulation of these other expected changes in the catchments, the cumulative impacts in the receiving waters for selected future time horizons could be assessed.

To apply these changes in the models, the boundary conditions were systematically adjusted so as to represent the relevant settings for each of the scenarios. As part of this process, the Source catchment models were used to generate catchment inflow boundaries for the future scenarios and to reflect changes in land use, WWTP/WRP upgrades, wet weather overflows, extractions and alternative stormwater management strategies. The WQRMs were then also adjusted to represent the remaining scenario elements including the AWRC treated water releases to South Creek, to the Nepean River, and if relevant, to the Warragamba River.

The potential influence of climatic conditions on the cumulative impacts was also evaluated for each scenario through the adoption of an extended simulation period that included both representative high and low rainfall years.

Further details regarding the application of the scenario conditions and any relevant assumptions are presented below in Section 4.6.3.

4.6.3 Scenario descriptions

4.6.3.1 Scenario types

In addition to scenarios that simulated the release of treated water from the AWRC, the suite of scenarios also included a series of background and baseline scenarios that were used for comparative purposes and allowed for targeted assessment of the impacts from just the release of the treated water.

The different types of scenarios are described below.

4.6.3.1.1 Baseline scenarios

The baseline scenarios represent current (circa 2020) conditions. The land use applied in these scenarios are representative of the year 2017. All other inputs (WWTPs/WRPs, extractions, etc) are also considered representative of current catchment conditions.

4.6.3.1.2 Background scenarios

The background scenarios simulate catchment and waterway conditions expected in future years. The time horizons selected correspond with the provisional staging timelines for the AWRC, but without inclusion of the treated water releases from the AWRC.

While the completion dates of the different stages are not yet confirmed, the following provisional time horizons were selected for these background scenarios:

- 2036 selected as representative of Stage 1 of the AWRC
- 2056 selected as representative of Future stages of the AWRC

The following boundary conditions were modified in these scenarios to be representative of these time horizons:

- catchment inflows and water quality assuming future land use mapping including variations in stormwater management strategies (refer Sections 4.6.3.5.2 and 4.6.3.5.3)
- point source inflows and treated water quality from other WWTPs and WRPs including variations in treatment levels for selected plants (refer Section 4.6.3.5.4)
- inflows and water quality from emergency release structures (refer Section 4.6.3.5.5)
- extractions for irrigations and other purposes (refer section 4.6.3.5.6)
- inflows and water quality for the headwaters including Warragamba Dam (refer Section 4.6.3.5.7)

4.6.3.1.3 Impact scenarios

The impact scenarios were developed to allow for targeted evaluation of the impacts from the treated water releases from the AWRC. Each impact scenario corresponds with one of the background scenarios but with inclusion of relevant releases of the treated water from the AWRC. These scenarios therefore included both time horizons and AWRC capacities as well as variations in the other boundary conditions listed above in Section 4.6.3.1.2.

With respect to the release points from the AWRC, one or more of the following three sites were included in the scenarios depending on the scenario conditions to be simulated:

- South Creek in the vicinity of the AWRC for the release of wet weather flows
- The Nepean River upstream of the Wallacia Weir for the release of advanced and tertiary treated water
- The Warragamba River downstream of the Warragamba Dam wall for the release of advanced treated water

The locations of these release points are presented in Figure 4-4. Further details regarding the quantity and quality of these treated water releases are provided in Section 4.6.3.5.1 below.

Matrices of the relevant scenario conditions applied to South Creek and the Hawkesbury Nepean River are presented below in Section 4.6.3.2.

4.6.3.1.4 Advanced treatment shutdown scenarios

In addition to the impact scenarios representing normal operating conditions for the AWRC, additional scenarios were also developed to simulate the potential shutdown of the advanced treatment process to mitigate the risk of brine overflows. Further details regarding these conditions are discussed below.

Brine produced from the AWRC is to be transferred to the Northern Georges River Submain (NGRS) within the Malabar System. Under normal operation, it is intended for brine to be transferred to a storage tank, then transferred from the tank to the NGRS at specified rates.

In wet weather, when the brine transfer to the NGRS needs to stop due to capacity constraints, the brine storage tank will hold the brine for the majority of wet weather events. However, when the storage tank reaches capacity, the advanced treatment process will become inhibited and will be temporarily switched off so brine does not continue to be produced. The brine pumps will also be inhibited when capacity constraints are detected in NGRS network. These measures will avoid brine being released to local waterways. These scenarios simulate inclusion of these modified release conditions.

Modelling of the wastewater system suggests this is likely to be happen about six times in 10 years in 2026, and up to 15 times in 10 years when the AWRC is operating at 50 ML/day (Stage 1). By 2036 however, upgrades to the Malabar wastewater system will increase its capacity so brine storage at the AWRC is unlikely to be required.

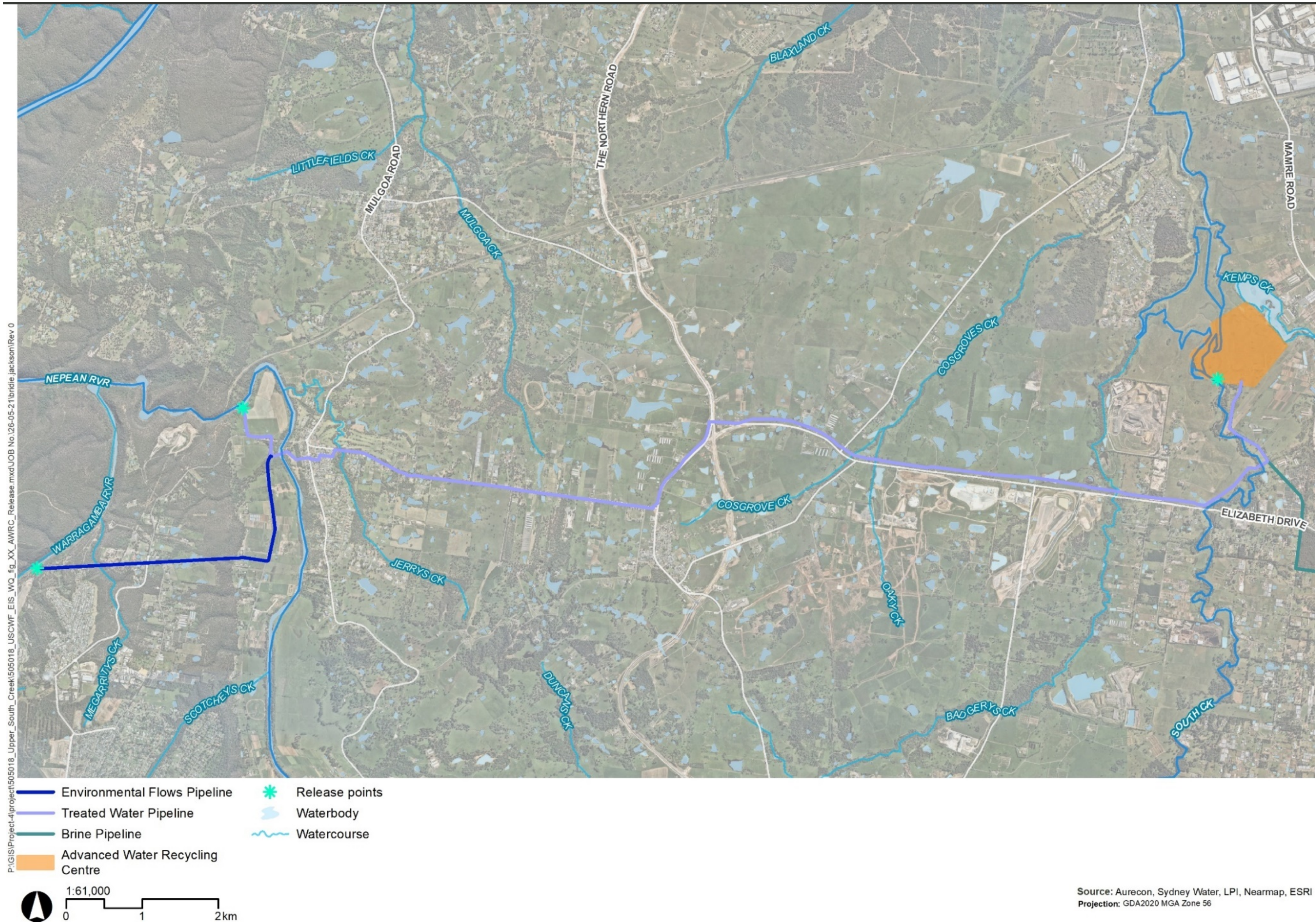


Figure 4-4 Location of the AWRC treated water release points

4.6.3.2 Scenario matrices

4.6.3.2.1 South Creek

Table 4-1 presents a matrix for the scenario conditions that were run for the South Creek WQRM.

The following comments are provided as context:

- The baseline scenario (SC00) represents current conditions (circa 2020) in terms of all catchment conditions e.g. land use, WWTP/WRP releases, extractions, etc.
- There are four background scenarios (SC01 to SC04) to incorporate the two future time horizons as well as the two different stormwater management strategies: "Business as Usual (BaU)" and "Parkland" (refer to Section 4.6.3.5.3).
- Similarly, the first four impact scenarios (SC05 to SC08) incorporate the two future time horizons, and the corresponding AWRC capacities, as well as both stormwater management strategies. These scenarios represent expected normal operational conditions for the AWRC.
- The final impact scenario (SC09) simulates the impact of shutting down the AWRC advanced treatment process to avoid the risk of overflows from the brine transfer pipeline, during wet weather events. This scenario therefore includes release conditions from the AWRC when these temporary shutdowns occur. Refer to Section 4.6.3.1.4 for further details.
- The treatment standards for the other WWTPs/WRPs in the South Creek catchment align with Sydney Water's asset renewal and upgrade strategy.

Table 4-1 South Creek scenario conditions

Scenario number	Time horizon	AWRC capacity (ML/d)	Release point(s)	Stormwater management
Baseline scenario				
SC00	Current (2017)	N/A	N/A	BaU
Background scenarios				
SC01	2036	0	N/A	BaU
SC02	2036	0	N/A	Parkland
SC03	2056	0	N/A	BaU
SC04	2056	0	N/A	Parkland
Impact scenarios				
SC05	2036	50	South Creek	Parkland
SC06	2056	100	South Creek	Parkland
SC07	2036	50	South Creek	BaU
SC08	2056	100	South Creek	BaU
SC09	2036	50 / advanced treatment shutdown	South Creek	BaU

4.6.3.2.2 Hawkesbury Nepean River

Table 4-2 presents a matrix for the scenario conditions that were run for the Hawkesbury Nepean WQRM. The following comments are provided as context:

- The baseline scenario (HN00) represents current conditions (circa 2020) in terms of all catchment conditions e.g. land use, WWTP/WRP releases, extractions, etc.
- There are four background scenarios (HN01 to HN04) to incorporate the two future time horizons as well as the high and low loading options for selected treatment plants that release treated water to the Hawkesbury Nepean River. Please refer to Section 4.6.3.5.4 for further details regarding the other treatment plants.
- The first four impact scenarios (HN05 to HN08) correspond to the aforementioned background scenarios (HN01 to HN04) with inclusion of treated water releases from the AWRC to the Nepean River release point.
- The second batch of four scenarios (HN13 to HN16) replicate scenarios HN05 to HN08 but with inclusion of treated water releases from the AWRC to both the Nepean River and Warragamba River release points. These scenarios represent the provision of treated water releases from the AWRC to the Warragamba River, supplementing or completely substituting the current WaterNSW release regime from the Warragamba Dam storage (refer to Section 4.6.3.5.7 for further details).
- Only advanced treated water is released to the Warragamba River, whereas releases to the Nepean River may include advanced treated water during dry conditions and during wet weather, either a blend of advanced and tertiary treated water or tertiary treated water. Please refer to Section 4.6.3.5.1 for further details.
- In addition to the releases in the Nepean and Warragamba rivers, the Hawkesbury Nepean WQRM scenarios also simulated flows and loads originating from the corresponding South Creek release scenarios. Details regarding which South Creek scenario was applied at the South Creek boundary are included in Table 4-1
- Due to comparatively low levels of growth and development in the wider Hawkesbury Nepean catchment, only one option is included regarding stormwater management that may be applied outside of the South Creek sub-catchment. This corresponds to a BaU level of stormwater management intervention.
- The final impact scenario (HN17) simulates the impact of shutting down the AWRC advanced treatment process to avoid the risk of brine overflows if the brine pipeline reaches capacity, during wet weather events. This scenario therefore includes release conditions from the AWRC when these temporary shutdowns occur. Refer to Section 4.6.3.1.4 for further details.
- Scenarios HN09 to HN12 represented alternative release conditions that were not considered relevant to the final EIS. These scenarios have therefore not been included in Table 4-2, or subsequent analysis.

Table 4-2 Hawkesbury Nepean River scenario conditions

Scenario number	Time horizon	AWRC capacity (ML/d)	Release point(s)	Treatment plants	South Creek scenario
Baseline scenario					
HN00	Current (2017)	N/A	N/A	Current	SC00
Background scenarios					
HN01	2036	0	N/A	Low loading	SC02
HN02	2056	0	N/A	Low loading	SC04

Scenario number	Time horizon	AWRC capacity (ML/d)	Release point(s)	Treatment plants	South Creek scenario
HN03	2036	0	N/A	High loading	SC02
HN04	2056	0	N/A	High loading	SC04
Impact scenarios					
HN05	2036	50	Nepean	Low loading	SC05
HN06	2056	100	Nepean	Low loading	SC06
HN07	2036	50	Nepean	High loading	SC05
HN08	2056	100	Nepean	High loading	SC06
HN13	2036	50	Nepean / Warragamba	Low loading	SC05
HN14	2056	100	Nepean / Warragamba	Low loading	SC06
HN15	2036	50	Nepean / Warragamba	High loading	SC05
HN16	2056	100	Nepean / Warragamba	High loading	SC06
HN17	2036	50	Nepean	High loading	SC09

4.6.3.3 Scenario comparisons

For the analysis of the scenario results, the results from each impact scenario are plotted against a background scenario as well as the baseline scenario. To allow assessment of the impacts from the AWRC releases on their own, the background scenario selected in this analysis represents the same catchment conditions as that of the impact scenario, except for the AWRC releases.

Table 4-3 presents the background and baseline scenarios numbers that have been used for comparison against each impact scenario.

Table 4-3 Scenario comparisons applied in results analysis

Impact scenario number	Background scenario number	Baseline scenario number
South creek scenarios		
SC05	SC02	SC00
SC06	SC04	SC00
SC07	SC01	SC00
SC08	SC03	SC00
SC09	SC01	SC00
South creek scenarios		
HN05	HN01	HN00
HN06	HN02	HN00
HN07	HN03	HN00
HN08	HN04	HN00

Impact scenario number	Background scenario number	Baseline scenario number
HN13	HN01	HN00
HN14	HN02	HN00
HN15	HN03	HN00
HN16	HN04	HN00
HN17	HN03	

4.6.3.4 Scenario duration and representative climatic conditions

All the scenarios were run over a duration of two years and two months. This simulation duration incorporated the following time periods and climatic conditions:

- 1st May 2013 to 30th June 2013 – a two month 'warm up/conditioning' period to allow the models to adjust to new loading conditions
- 1st July 2013 to 30th June 2014 – a representative dry climatic year (~510 mm/year)
- 1st July 2014 to 30th June 2015 – a representative wet climatic year (~1060 mm/year)

Simulation of the two climatic years was undertaken to address the principal question of how do wet and dry conditions affect impacts from the AWRC releases. The assessment of impacts on water quality under such different climatic conditions are commonly undertaken in an EIS as different catchment influences, such as point and diffuse sources, may become more predominant under wet or dry conditions. Similarly, different release options, such as wet weather or all-weather release strategies, will also have differing levels of influence.

The two representative climatic years were selected based on decile analysis of rainfall over a 25-year period from 1994 through to 2019. Records from the following meteorological stations were analysed: Penrith, Richmond and South Creek. The median rainfall for this period varied between 710 and 800 mm/year across the three stations. Refer to Figure 4-5 for a representation of the South Creek rainfall data.

The WQRMs were initialised at the start of the simulation period using initial condition files that provided spatial distribution for each parameter throughout the waterways, derived from the analysis of field monitoring data.

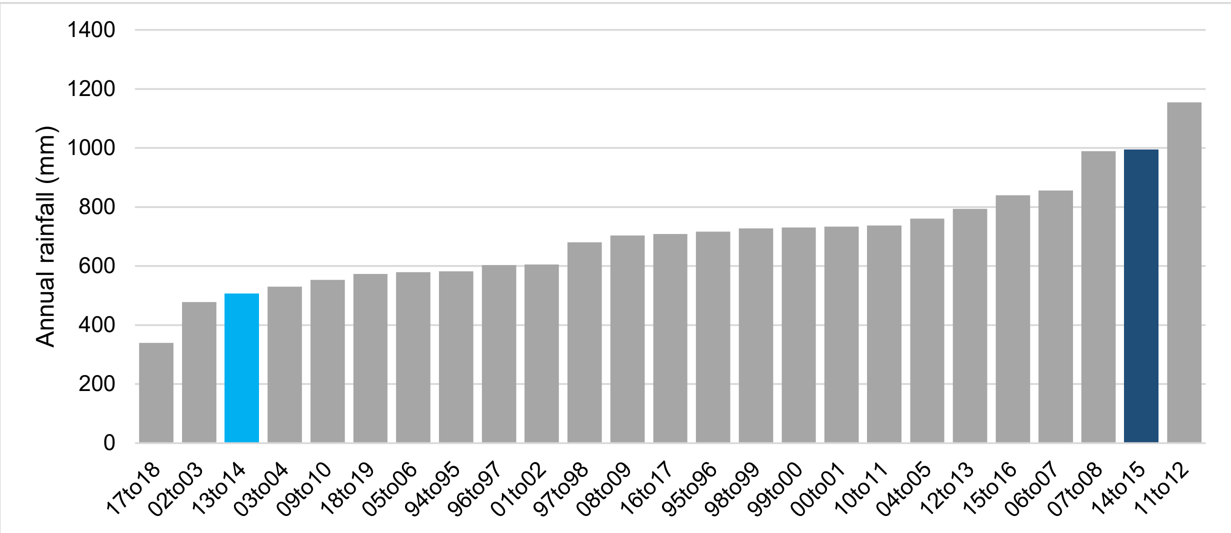


Figure 4-5 Annual rainfall data from 1994 to 2019

4.6.3.5 Scenario datasets

4.6.3.5.1 AWRC releases

Proposed release strategies

Two variations in release strategy are currently being considered for the AWRC as summarised below:

- Nepean River release strategy
  - releases of treated water to the Nepean River under all weather conditions
  - no releases to the Warragamba River
  - releases to South Creek under moderate to severe wet weather conditions
- Nepean River and Warragamba River release strategy
  - releases of treated water to the Nepean River under all weather conditions
  - releases to the Warragamba River to supplement or completely substitute the current WaterNSW release regime from the Warragamba Dam (when advanced treated water is available)
  - releases to South Creek under moderate to severe wet weather conditions

With respect to these release strategies, the following points are noted regarding the Nepean and Warragamba releases:

- The Metropolitan Water Plan for Sydney (Department of Industry, Skills and Regional Development, 2017) recommends the release of environmental flows from the Warragamba Dam. Currently, releases from the dam are for the purposes of diluting flows from Wallacia WWTP and also to provide for drinking water extraction at the downstream Richmond Water Filtration Plant (WFP). The Plan recommends a new variable flow regime and further work to refine this is currently underway by DPIE.
- Sydney Water is currently consulting with DPIE if the project can contribute to waterway health benefits by releasing treated water solely to the Nepean River at Wallacia Weir, thereby avoiding the significant cost of building the pipeline to the Warragamba River. On this basis, the modelling has assessed both release strategies, so as to align with the main options being discussed with DPIE. This will provide flexibility while cross-government discussions and cost-benefit analysis occurs.

Proposed treatment and release streams

A high-level schematic diagram of the AWRC treatment and release system is presented in Figure 4-6. From this system, there are three potential wastewater release streams that flow to the receiving waters of the Nepean and Warragamba rivers and South Creek. The level of treatment provided to each stream varies depending on the level of flow passing through the AWRC. The level of flow is measured in factors of Average Dry Weather Flow (ADWF).

In summary:

- During dry weather (<1.3 x ADWF), releases to the Nepean River (and the Warragamba River if applicable) will consist only of advanced treated water. No releases to South Creek will occur.
- During mild wet conditions (1.3 to 1.7 x ADWF), releases to the Nepean River will consist of a blend of advanced and tertiary treated water. If applicable, the provision of releases to the

Warragamba River will cease as unblended advanced treated water will not be available. No releases to South Creek will occur.

- During moderate wet conditions (1.7 to 3 x ADWF), releases to the Nepean River will consist of either a blend of advanced and tertiary treated water, or unblended tertiary treated water, dependent on the availability of advanced treated water. Once the treated water pipeline reaches capacity, releases of advanced treated water to South Creek will occur. There is again no availability of advanced treated water for releases to the Warragamba River.
- During severe wet conditions (>3 x ADWF), releases to the Nepean River consist only of tertiary treated water. Releases to South Creek will consist of a blend of primary and advanced treated water. There is again no availability of advanced treated water for releases to the Warragamba River.

The levels of treatment provided to each release stream are also presented in Table 4-4 for the Nepean River release scenarios and in Table 4-5 for the combined Nepean River and Warragamba River release scenarios. Table 4-6 presents the estimated release volumes for each waterway under each different flow conditions, and for both wet and dry years.

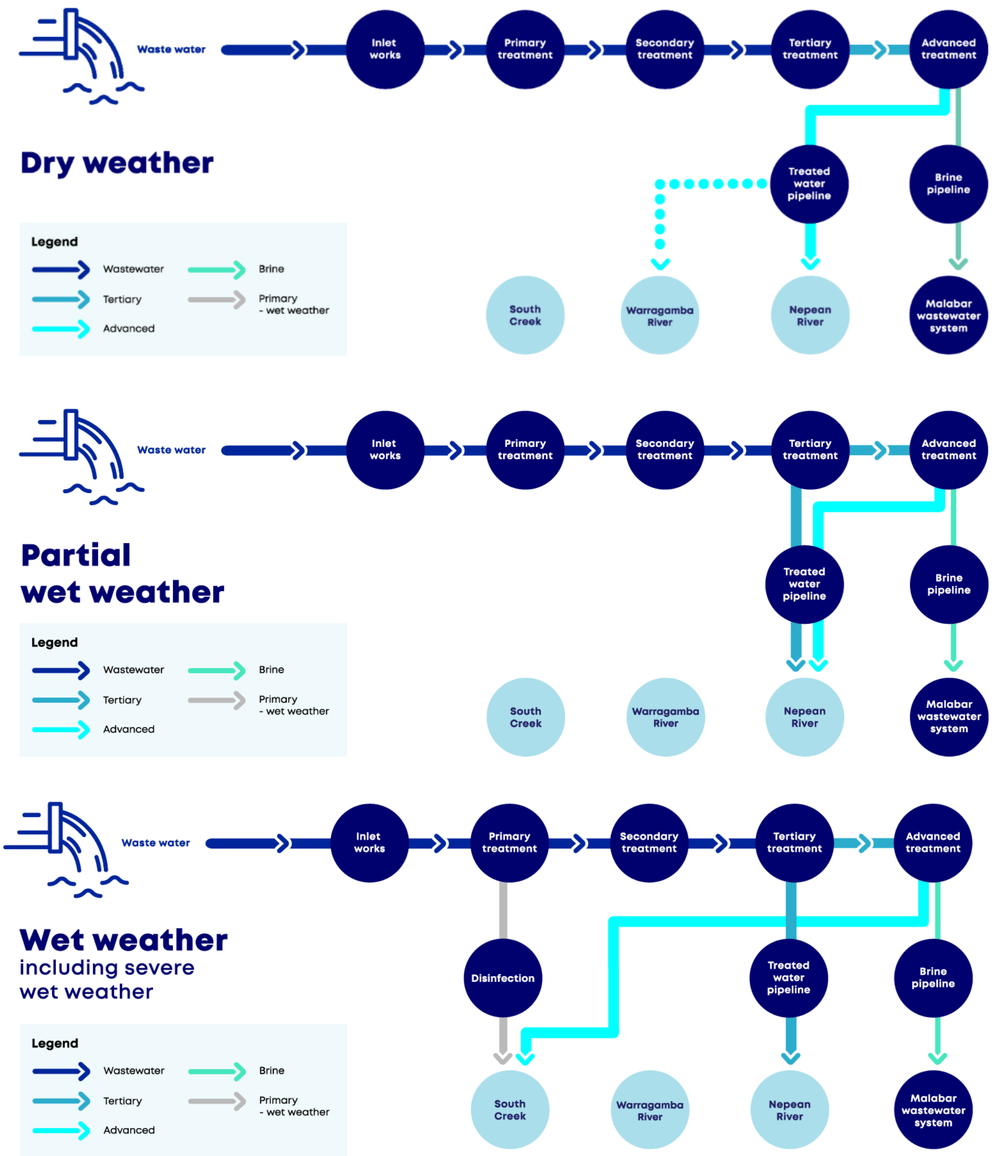


Figure 4-6 Schematic diagram of the AWRC treatment and release system

Table 4-4 Treatment conditions for the AWRC release streams – Nepean River release scenarios

Level of influent flow at AWRC	South Creek release	Nepean release	Warragamba release
< 1.3 x ADWF	No release	Advanced treated	N/A
1.3 – 1.7 x ADWF	No release	Advanced/Tertiary treated	N/A
1.7 – 3 x ADWF	Advanced treated	Advanced/Tertiary treated, or Tertiary treated*	N/A
> 3 x ADWF	Advanced/Primary treated	Tertiary treated	N/A

Table notes:

* *Treatment level dependent on availability of advanced treated water, which is preferentially released to South Creek.*

Table 4-5 Treatment conditions for the AWRC release streams – Nepean River and Warragamba River release scenarios

Flow	South Creek release	Nepean release	Warragamba release
< 1.3 x ADWF	No release	Advanced treated	Advanced treated
1.3 – 1.7 x ADWF	No release	Advanced/Tertiary treated	No release
1.7 – 3 x ADWF	Advanced treated	Advanced/Tertiary treated, or Tertiary treated*	No release
> 3 x ADWF	Advanced/Primary treated	Tertiary treated	No release

Table notes:

* *Treatment level dependent on availability of advanced treated water, which is preferentially released to South Creek*

Table 4-6 Estimated release volumes

Release condition	Release volume (ML/year)	
	Wet year	Dry year
Flows less than 1.3 x ADWF		
Advanced treated water only to Nepean and Warragamba rivers	14,364	14,193
Flows between 1.3 and 1.7 x ADWF		
Advanced treated water only to Nepean and Warragamba rivers	1,638	702
Advanced/tertiary treated blend to Nepean and Warragamba rivers	1,825	818
Tertiary treated water only to Nepean and Warragamba rivers	187	116
Flows between 1.7 and 3.0 x ADWF		
Advanced treated water to South Creek	179	14
Advanced treated water only to Nepean and Warragamba rivers	523	162
Advanced/tertiary blend to Nepean and Warragamba rivers	1,008	255
Tertiary treated water only to Nepean and Warragamba rivers	*485*	*93*
Flows above 3.0 x ADWF		
Advanced treated water to South Creek	351	0
Advanced/primary blend to South Creek	557	0
Primary treated water only to South Creek	206	0
Tertiary treated water only to Nepean and Warragamba rivers	510	0

Release stream preferences

Under the wet weather flow conditions, the preference is to minimise releases to South Creek. However, once incoming flows increase above 1.7 x ADWF, and the treated water pipeline reaches capacity, advanced treated releases will be incrementally diverted to South Creek up until the incoming flows reach 3.0 x ADWF. As the incoming flows to the AWRC increase, the advanced treated releases to Nepean River will reduce, being replaced by tertiary treated water.

If the Nepean River and Warragamba River release strategy is implemented, releases of advanced treated water to the Warragamba River will be prioritised, so as to effectively replicate the seasonal variations of the existing WaterNSW release regime from the Warragamba Dam. When advanced treated water is being released to the Warragamba River, all residual flows are to be released to the Nepean River within the Wallacia Weir pool. Similarly, when there is limited or no availability of advanced treated water from the AWRC, and consequently no provision for releases to the Warragamba River, all flows from the AWRC are released to the Nepean River.

Treated water quality

The anticipated treatment performance of the AWRC was derived from various sources including monitoring data from similar treatment plants operated by Sydney Water. Further details are provided below.

- Advanced treated - based on analysis of advanced treated water quality data from the St Marys AWTP
- Tertiary treated - based on treated water quality data as adopted from Final Effluent Water Quality Analysis USC AWRC (Sydney Water, 2020), assuming expected MBR performance (scenario 1) and no chlorination
- Primary treated – based on wet weather quality data assuming raw sewage and wet weather overflow monitoring data and standard removals from Primary treatment in wet weather conditions

The median water quality concentrations assumed for the three release streams is presented in Table 4-7.

Table 4-7 Assumed treated water quality for the AWRC release streams

Parameter	Units	Median concentrations		
		Advanced treated water	Tertiary treated water	Primary treated water
Total nitrogen	mg/L	0.35	2.5	18.0
Total phosphorus	mg/L	0.009	1.0	1.0
Oxidised nitrogen	mg/L	0.12	1.8	0
Ammonia	mg/L	0.03	0.2	15.0
Filterable reactive phosphorus	mg/L	0.006	0.660	0.660
Chlorophyll *a*	µg/L	0	0	0
Dissolved oxygen	mg/L	9.2	5.9	0
Suspended solids	mg/L	0	1	35
Salinity	mg/L	0.03	0.75	0.15
Enterococci	cfu/100mL	0	0	7400

While Table 4-7 presents the median expected concentrations for the release streams, it was acknowledged that there would be variability in the treatment processes and consequently the concentrations of the AWRC releases over time. To provide a representation of the expected daily variability, modifications to the boundary condition timeseries for the AWRC releases were made to allow for expected ranges in each water quality parameter.

Proposed AWRC staging and time horizons

While the completion dates of the different operational stages of the AWRC are not yet confirmed, the following provisional staging and time horizons have been adopted in the scenarios.

- 2036 selected as representative of Stage 1 of the AWRC
- 2056 selected as representative of Future stages of the AWRC

Flow estimates

Flow estimates for the duration of the scenario simulation period are presented as timeseries in the following sections for each release point and for each time horizon. The daily flow estimates presented in these figures align with the release strategy discussed above.

South Creek releases

Releases to South Creek only occur during moderate to severe wet weather conditions. These wet weather releases are limited in their temporal extent and can vary significantly in volume. During the representative dry year and assuming a 50 ML/d AWRC capacity (2036), there is a limited number (~2 events over 3 days) of very minor releases of <0.07 m^3/s (6 ML/d) predicted. The releases increase in frequency and volume during the wet year, with ~6 events predicted over 14 days, and with magnitudes of up to 1.5 m^3/s (130 ML/d).

For the 100 ML/d capacity AWRC (2056), the number and duration of the events remain similar to the 50 ML/d scenarios, but the magnitude of releases approximately doubles in line with the capacity of the plant. In a dry year, the releases are predicted below 0.15 m^3/s (12 ML/d), and during the wet year, the more frequent releases increase in magnitude up to 3 m^3/s (260 ML/d).

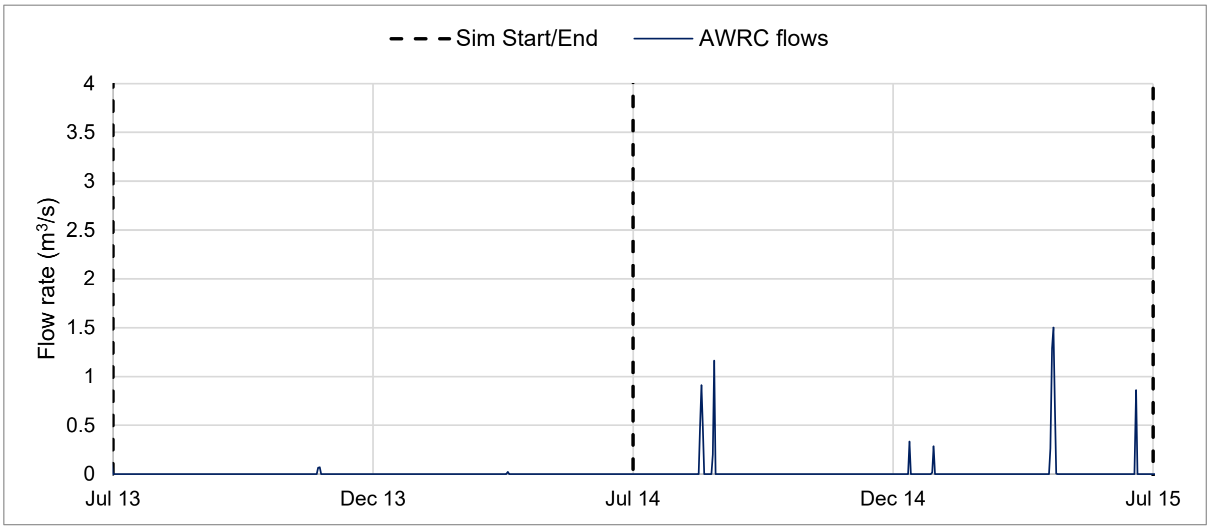


Figure 4-7 Assumed wet weather releases to South Creek (2036)

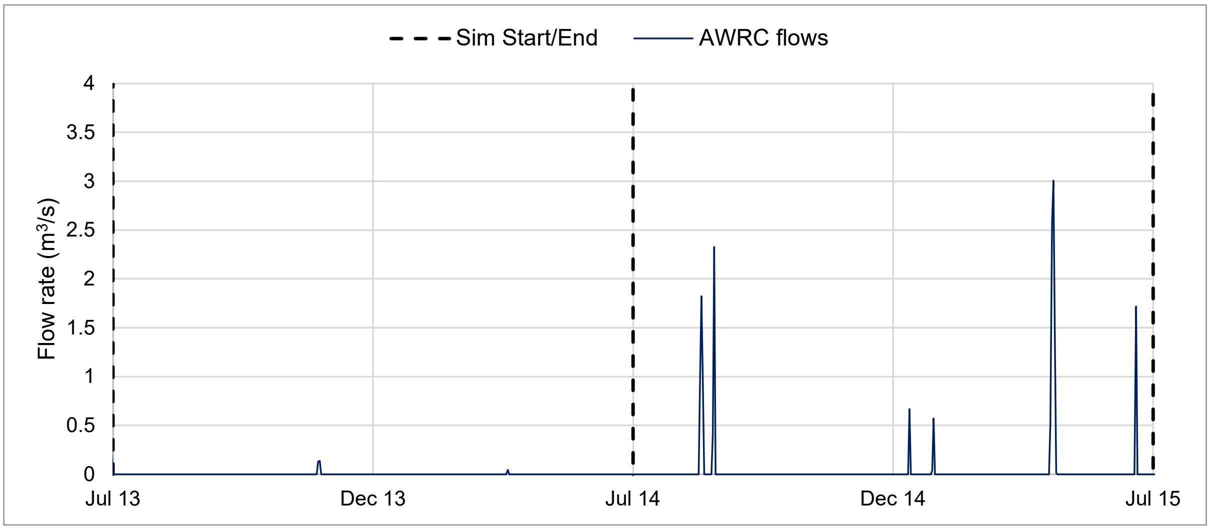


Figure 4-8 Assumed wet weather releases to South Creek (2056)

Nepean River releases (Nepean River release scenarios)

For the Nepean releases, a median daily volume of ~0.50 to 0.55 m^3/s (or 43 to 47 ML/d) is estimated for the 50 ML/d AWRC capacity scenarios. The release rates are marginally below the plant capacity due to generation of the brine waste stream.

For the 100 ML/d AWRC capacity scenarios, the volumes effectively increase by a factor of two.

Peak daily release rates are estimated to be ~1 m^3/s (86 ML/d) and ~2 m^3/s (172 ML/d) respectively for the two AWRC capacities.

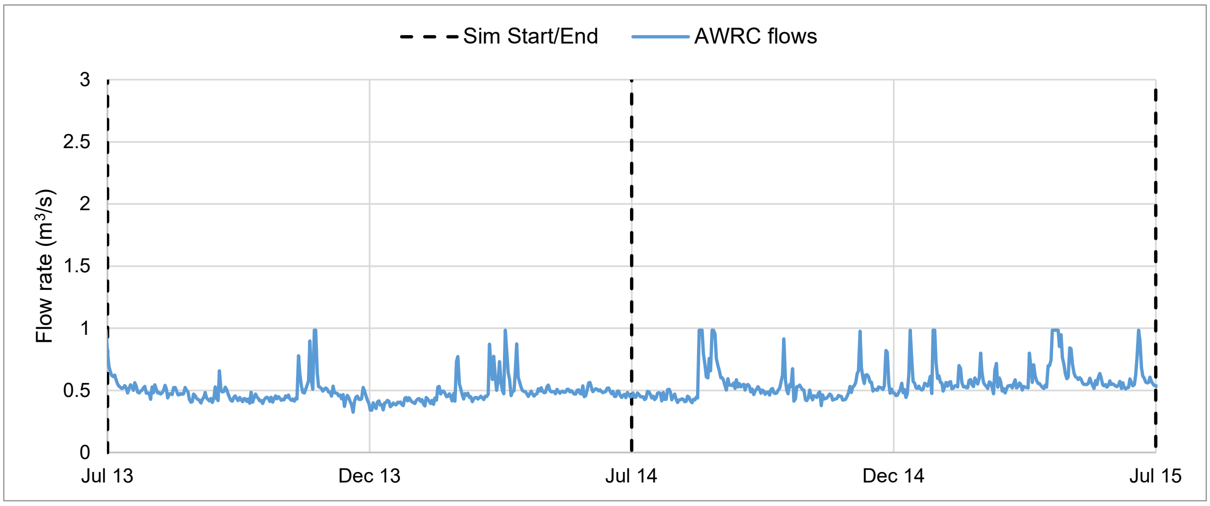


Figure 4-9 Assumed releases to the Nepean River (Nepean River release scenarios, 2036)

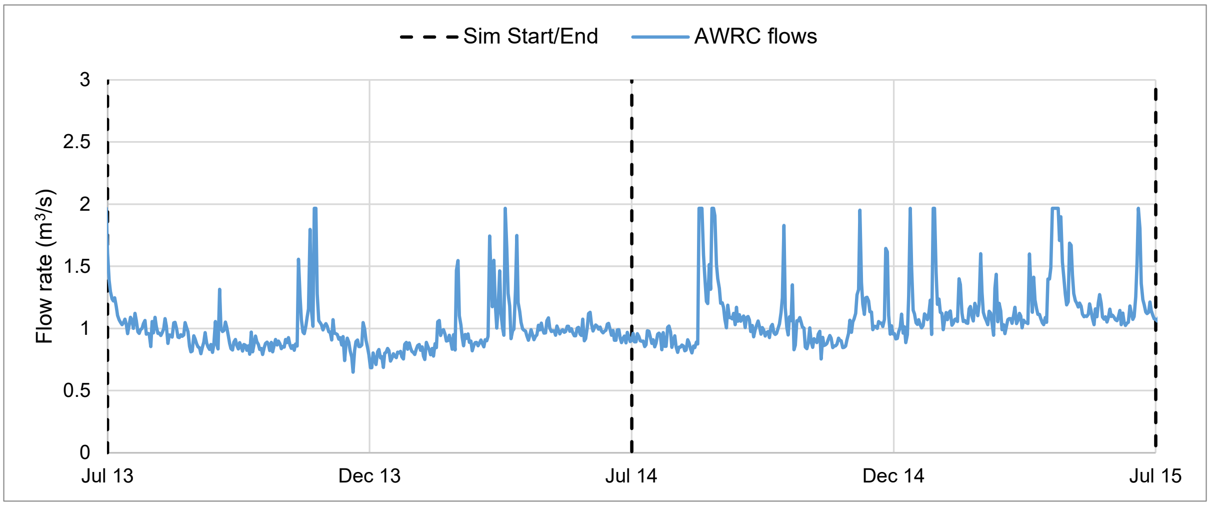


Figure 4-10 Assumed releases to the Nepean River (Nepean River release scenarios, 2056)

Nepean River releases (Nepean River and Warragamba River release scenarios)

With introduction of releases to the Warragamba River, the median release rate drops to ~0.22 m³/s (or ~19 ML/d) for the 50 ML/d AWRC capacity scenarios, increasing by greater than a factor of three to 0.71 m³/s (or 62 ML/d) for the 100 ML/d AWRC capacity scenarios.

The peak daily release rates however remain similar in magnitude to those for the Nepean River release strategy, as it is only the dry weather release conditions that are modified between the two strategies. During wet weather conditions (>1.3 x ADWF), releases to the Nepean River are therefore the same as the Nepean River release scenarios.

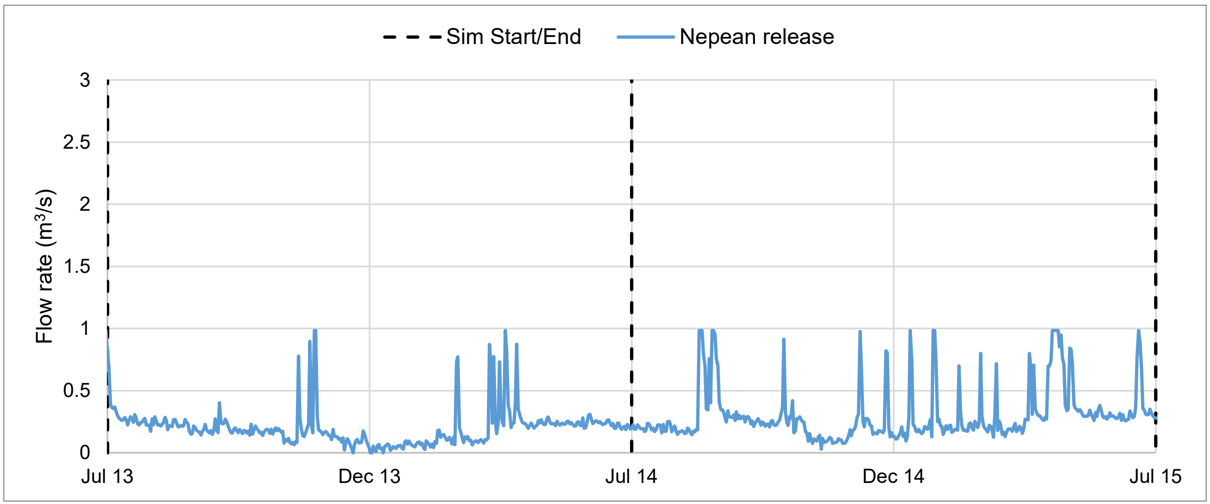


Figure 4-11 Assumed releases to the Nepean River (Nepean River and Warragamba River release scenarios, 2036)

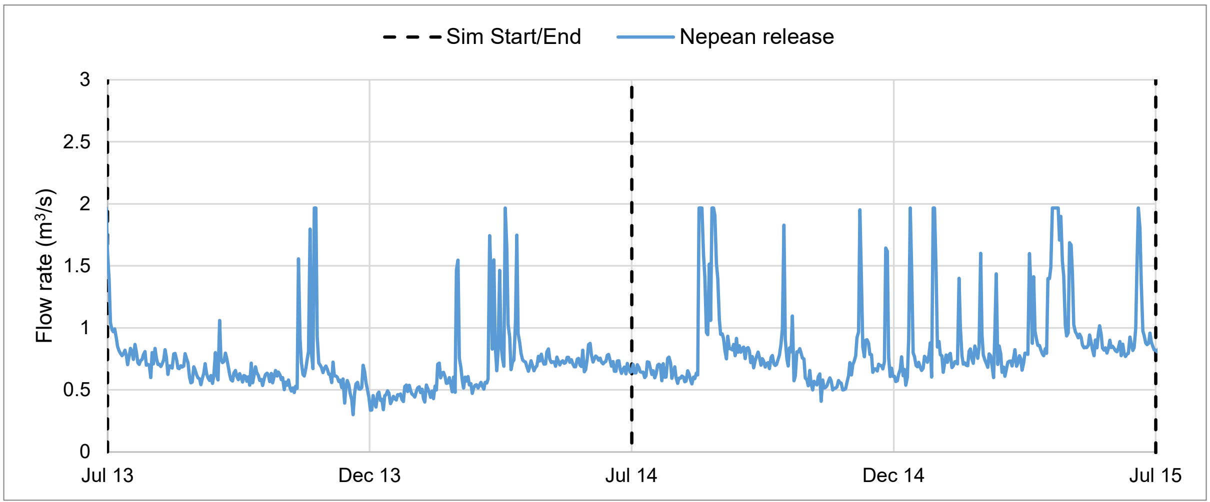


Figure 4-12 Assumed releases to the Nepean River (Nepean River and Warragamba River release scenarios, 2056)

Warragamba River releases (Nepean River and Warragamba River release scenarios)

For modelling purposes, the AWRC releases to the Warragamba River effectively replicate the current seasonal variations of the existing WaterNSW release regime from the Warragamba Dam (refer Section 4.6.3.5.1). The only exception is when there is limited or no availability of advanced treated water from the AWRC, and consequently no provision for these flows from the AWRC. Under these infrequent circumstances, the modelling has assumed releases from the Warragamba Dam will be reinstated to maintain the required level of flows in the river. A variable release environmental flow regime was not considered, given that it is yet to be finalised by DPIE.

It is also noted that there are insignificant differences in the release rates provided by the AWRC under both the 50 and 100 ML/d capacities. This is due to similar patterns in the aforementioned availability of advanced treated water between the two scenario conditions.

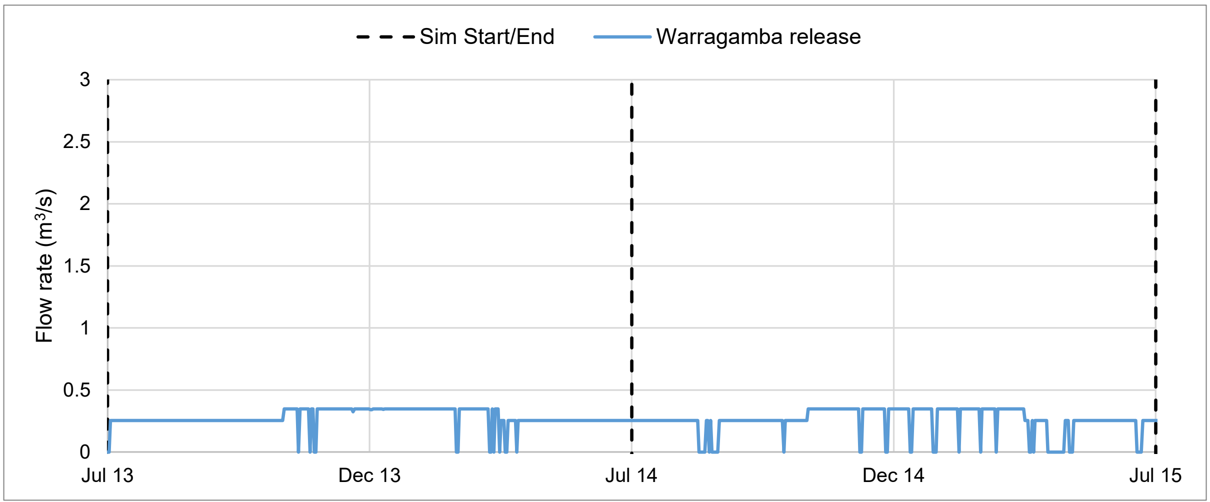


Figure 4-13 Assumed releases to the Warragamba River (Nepean River and Warragamba River release scenarios, 2036)

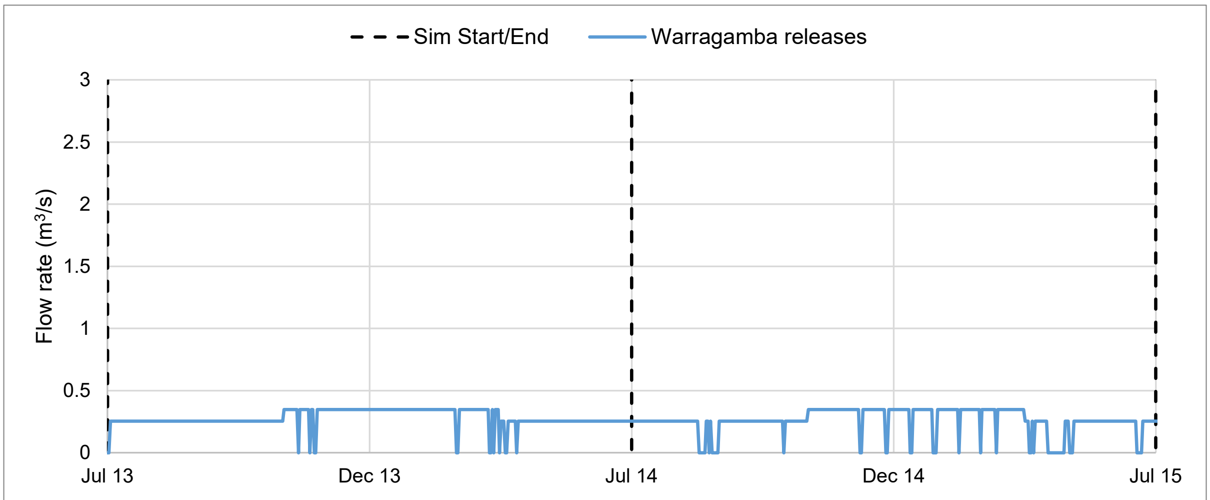


Figure 4-14 Assumed releases to the Warragamba River (Nepean River and Warragamba River release scenarios, 2056)

4.6.3.5.2 Land use

As previously discussed, land use layers were developed for three distinct time horizons: 2017, 2036 and 2056. These layers represented a key input layer in the Source modelling that was undertaken to simulate the catchment flows and loads for each of the scenarios.

The 2017 land use layer was generated using base data from OEH. The land use distribution was then modified and cross checked with Sydney Water Hydra Lot coverage, Google Earth images, land zoning from Local Environmental Plans, and other data layers available from the OEH. Land use categories applied in this layer included: High Density Urban, Urban, Peri-Urban, Commercial, Industrial, Environmental Living, Cropping, Agriculture, Grazing, Infrastructure/Utilities, Forest, Airport, Mining, Open Space and Developable land.

The 2036 and 2056 layers were subsequently developed through GIS analysis of the 2017 layer and consolidated growth forecast geospatial data prepared by Sydney Water. For the South Creek catchment additional information was used to inform the 2036 and 2056 land use layers including typology metrics data prepared by Cox Architect for Infrastructure NSW (iNSW) and draft information from the Western Sydney Aerotropolis (Initial Precincts) Stormwater and Water Cycle Management Study Interim Report (Sydney Water, 2020a).

Further details on the generation of land use data and how the data was used within the Source catchment modelling are provided in Appendix A.

4.6.3.5.3 Stormwater management

South Creek catchment

Within the South Creek catchment, the following two stormwater management strategies have been considered in the scenarios.

- Parkland – This level of management is assumed to be representative of the Western Parkland City stormwater strategy as outlined in the Western Sydney Aerotropolis (Initial Precincts) Stormwater and Water Cycle Management Study Interim Report
- Business as Usual (BaU) – This approach is assumed to be consistent with current stormwater management practices applied within the Greater Sydney region

At the time of undertaking this analysis, specific stormwater management measures had not been identified for the Western Sydney Aerotropolis. Stormwater management measures have been represented in the model through reduced imperviousness for BaU and Parklands urban forms as discussed in Appendix A. These two urban forms are intended to represent ‘bookends’ of what can be expected in terms of urban land use forms for stormwater management strategies. The Parklands approach demonstrates the potential reduction in imperviousness possible when more compact urban forms are delivered to support the Western Parkland City vision of a greener and cooler landscape for Western Sydney than current urban forms being delivered under BAU.

Further details on the generation of land use data and how the data was used within the Source catchment model are provided in Appendix A.

Hawkesbury Nepean catchment

Within the Hawkesbury Nepean catchment but outside of these South Creek growth areas discussed above, there is expected to be relatively lower levels of development and growth in the catchment. Outside of the South Creek catchment boundary, a BaU level of stormwater management has therefore been applied within the scenarios.

4.6.3.5.4 Other treated wastewater releases

Throughout the scenarios, the boundary conditions for the other relevant WWTPs and WRPs were developed using spreadsheet models so their flows and treated water quality could be representative of the relevant time horizons (2020, 2036 or 2056).

With respect to the release volumes, the daily flows from monitoring data were adjusted in line with expected population growth, assumed rates of reuse, network transfers, as well as any forecasted changes in inflow and infiltration to the sewerage system.

With respect to quality of the treated water releases, concentrations of the key contaminants were adjusted in line with any planned upgrades that have been agreed with the EPA. Variability in water quality parameters was also included in line with historical monitoring data or forecasted performance of the WWTPs and WRPs.

The location of the other treatment plants is presented in Figure 4-15.

South Creek catchment

Within the South Creek catchment, the five plants that release treated water to the creek are St Marys WRP, Quakers Hill WRP, Riverstone WWTP, South Windsor WWTP and McGraths Hill WWTP. The assumed treatment standards are presented in Table 4-8.

Hawkesbury Nepean catchment

Within the wider Hawkesbury Nepean catchment, there are an additional 13 treatment plants including the St Marys Advanced Water Treatment Plant (AWTP). For five of these plants, variations in treatment standards (high and low loading conditions) have been considered within the scenarios. These five plants are Penrith WRP, Picton WRP, West Camden WRP, Wilton WRP and Winmalee WWTP. The assumed treatment standards are also presented in Table 4-8.

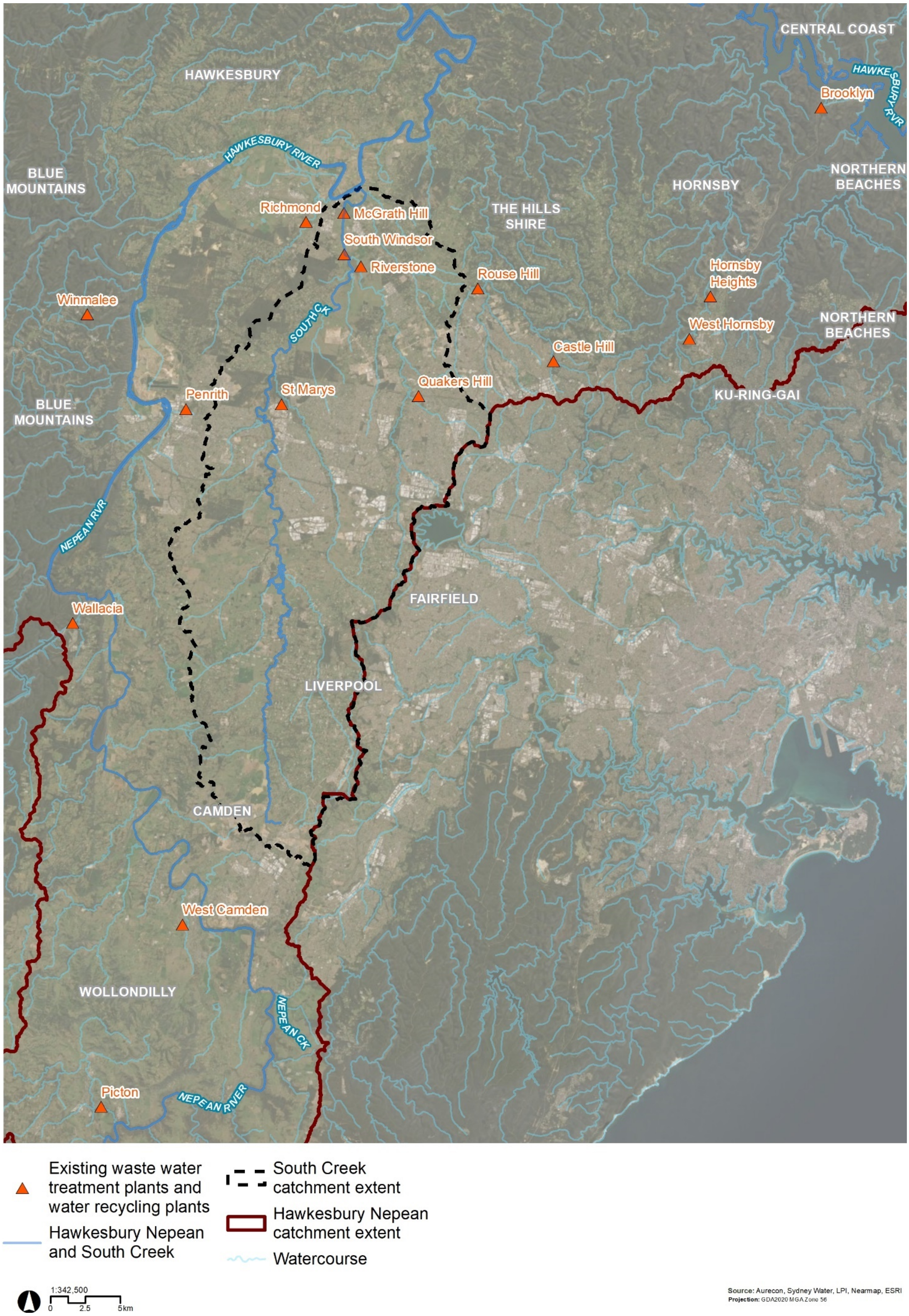


Figure 4-15 Location of the other WWTPs and WRPs

Table 4-8 Assumed treatment standards for other WWTPs and WRPs for baseline and future scenarios

Name	Median concentrations					
	TN 2020 (mg/L)	TN 2036 (mg/L)	TN 2056 (mg/L)	TP 2020 (mg/L)	TP 2036 (mg/L)	TP 2056 (mg/L)
South Creek						
St Marys	3.2	2.5[5]	2.5[5]	0.02	0.04[5]	0.04[5]
Quakers Hill	5.0	1.6[1,5]	0.35[1,5]	0.07	0.03[1,5]	0.01[1,5]
Riverstone	1.5	3.0[2]	3.0[2]	0.02	0.05[2]	0.05[2]
South Windsor[6]	5.8	2.5[2]	2.5[2]	0.20	0.04[2]	0.04[2]
McGrath Hill[6]	3.6	2.5[2]	2.5[2]	1.10	0.04[2]	0.04[2]
Hawkesbury Nepean						
Penrith (low)	4.5	0.73[1,5]	0.40[1,5]	0.070	0.014[1,5]	0.010[1,5]
Penrith (high)	4.5	0.71[1,5]	0.36[1,5]	0.070	0.014[1,5]	0.009[1,5]
Winmalee (low)	6.7	2.5[2]	2.5[2]	0.14	0.04[2]	0.04[2]
Winmalee (high)	6.7	3.0[2]	3.0[2]	0.14	0.05[2]	0.05[2]
Picton (low)	5.0	3.0[2]	3.0[2]	0.02	0.05[2]	0.05[2]
Picton (high)	5.0	3.0[2]	3.0[2]	0.02	0.05[2]	0.05[2]
Wilton[3] (low)	N/A	2.5	2.5	N/A	0.05	0.05
Wilton[3] (high)	N/A	2.5	2.5	N/A	0.05	0.05
West Camden (low)	7.8	2.5[2]	2.5[2]	0.03	0.03[2]	0.03[2]
West Camden (high)	7.8	3.0[2]	3.0[2]	0.03	0.04[2]	0.04[2]
St Marys AWTP	0.28	0.35	0.35	<0.005	0.009	0.009
Brooklyn	3.4	3.4	3.40	0.03	0.03	0.03
Castle Hill	17.0	5.0[2]	5.0[2]	0.12	0.10[2]	0.10[2]
Hornsby heights	3.6	4.0	4.0	0.04	0.05	0.05
North Richmond[4]	6.0	N/A	N/A	0.11	N/A	N/A
Richmond	6.0	4.0[2]	4.0[2]	0.03	0.04[2]	0.04[2]
Rouse Hill	6.0	4.5[2]	4.5[2]	0.01	0.05[2]	0.05[2]
Wallacia	4.0	5.0	5.0	0.02	0.05	0.05
West Hornsby	4.0	4.0	4.0	0.05	0.05	0.05

Table notes:

[1] *Penrith and Quakers Hill treated water represents a blend of advanced and tertiary treated water*

[2] *Water quality assuming planned upgrade (capacity and/or treatment) to WWTP/WRP*

[3] *Wilton represents a new WRP*

[4] *North Richmond WWTP to close with diversion to Richmond WRP*

[5] *Increased flows to St Marys AWTP*

[6] *WWTP operated by Hawkesbury City Council*

(low) signifies low loading as discussed previously in Section 4.6.3.5.4

(high) signifies high loading as discussed previously in Section 4.6.3.5.4

Treatment bypasses

Analysis was undertaken regarding the potential for treatment bypasses at the other WRPs and WWTPs in South Creek and in the wider Hawkesbury Nepean catchment. From assessment of the process configurations and capacities, the following treatment plants have been considered to have the potential for full treatment bypasses (including bypass of disinfection): St Marys WRP, Castle Hill WWTP, Rouse Hill WRP, West Hornsby WWTP, Winmalee WWTP and McGraths Hill WWTP.

All other WWTPs and WRPs were assumed to maintain treatment during wet weather, however their treatment performance may be less effective at these times and this has been represented in the relevant model boundary conditions, based on historical monitoring data.

4.6.3.5.5 Emergency relief structures

Wet weather overflows from the wastewater system are considered as significant point sources of untreated wastewater which make their way into waterways, generally during wet weather events. Timeseries of overflow release rates were simulated using the MOUSE software platform for both the existing network as well as a future network scenario that was considered representative of expected development in the catchments.

The resulting datasets formed inputs to the Source catchment model discussed previously in Sections 4. Water quality constituent generation rates associated with these overflows were developed based on analysis of untreated wastewater quality and the level of dilution expected within the networks.

4.6.3.5.6 Extractions

Extractions for irrigators and other water users have been incorporated into the Source catchment model for all the respective tributaries and from upper sub-catchments. Similar types of extractions from the main water bodies of the Hawkesbury Nepean River and South Creek are incorporated directly within the WQRMs.

For the future scenarios, extractions were adapted for loss of agricultural land as predicted by the respective land use layers for 2036 and 2056. In this way, a 20% reduction in agricultural land with a sub-catchment would equate to a 20% reduction in daily irrigation demand at a corresponding extraction point in the Hawkesbury Nepean River or in South Creek.

4.6.3.5.7 Headwaters

Headwaters were assumed consistent with current conditions with the exception of scenarios HN13 to HN16. For these four impact scenarios, the releases from the Warragamba Dam were adjusted to account for releases introduced from the AWRC to the Warragamba River. For example, if there was a sufficient volume of advanced treated water available from the AWRC on any one day, and this was released at the Warragamba River release point, the releases from the dam would either not be included or they would be modified to supplement the AWRC releases so the requisite release volume was met.

4.6.4 Analysis and interpretation

4.6.4.1 Approach

The assessment of impacts consistently involved comparison of results from the following scenario types:

- an impact scenario representing releases from the AWRC at a future operational phase and relevant time horizon
- a background scenario representing the same catchment conditions as the impact scenario but without the AWRC releases
- a baseline scenario representing current (circa 2020) catchment conditions, again without AWRC releases

Further details and descriptions regarding the scenario types are presented in Section 4.6.3.1.

In addition to this comparative analysis, relevant waterway objectives were also included in the plotting of the results. As discussed in Section 2.2, these objectives include guideline values from a range of relevant legislation and guidelines, including ANZG (2018), ANZECC (2000), NHMRC (2008), etc.

4.6.4.2 Parameters

The impacts were assessed for a range of hydrodynamic and water quality parameters necessary to assess the relevant waterway objectives (refer Section 2.2) and address the SEARs requirements (refer Section 2.2). These parameters are listed below:

- Hydrodynamics
  - Flow and flow duration
  - Water level
- Water quality
  - Nitrogen (including ammonia, oxidised nitrogen, total nitrogen)
  - Phosphorus (including filterable reactive phosphorus, total phosphorus)
  - Chlorophyll *a* (adopted as primary indicator of phytoplankton abundance and biomass)
  - Salinity
  - Temperature
  - Total suspended solids
  - Dissolved oxygen (including concentration and saturation)
  - Pathogens (including enterococci and E. coli)
  - Cyanobacteria risk

Near field impacts relating to toxicants (e.g. ammonia, nitrate, chlorine, metals, etc) that may be present in the releases were assessed separately using CORMIX models. These models and the assessment approach adopted are described in Section 4.7.

4.6.4.3 Formats

The impacts from the AWRC release scenarios were assessed from upstream of the releases to the full downstream spatial extent of the WQRMs using three different formats.

- Longitudinal profiles of annual median concentrations
- Time series plots of daily concentrations
- Box and whisker plots of daily concentrations

As discussed previously, the assessment approach involved comparison of results from the following scenario types:

- an impact scenario representing releases from the AWRC at a future operational phase and relevant time horizon
- a background scenario representing the same catchment conditions as the impact scenario but without the AWRC releases
- a baseline scenario representing current (circa 2020) catchment conditions, again without AWRC releases

These three scenario types are therefore included in each of the formats discussed below.

4.6.4.3.1 Longitudinal profiles

Longitudinal profile plots of the annual median concentrations for the baseline, background and impact scenarios were prepared along the spatial extent of the modelled waterways of the Hawkesbury Nepean River and South Creek. Where applicable, the longitudinal plots also included the relevant waterway objectives for each parameter (refer to Section 2.2). For the South Creek profiles, the waterway objectives also included the local values developed by EES/DPIE. The waterway objectives are of particular relevance to the annual median results as they represent the appropriate statistical measure for comparison to these guideline values.

Kilometre markers with a distance relative to the AWRC release points are included on the x-axis of these profiles along with the locations of key geographic markers, such as tributary confluence points. The longitudinal profiles present the predicted annual median values for the relevant simulated climatic year and were prepared for each of the water quality parameters with the exception of cyanobacteria risk, which was presented as a separate format (refer Section 4.6.4.3.3).

A sample profile longitudinal annual median plot is presented in Figure 4-16.

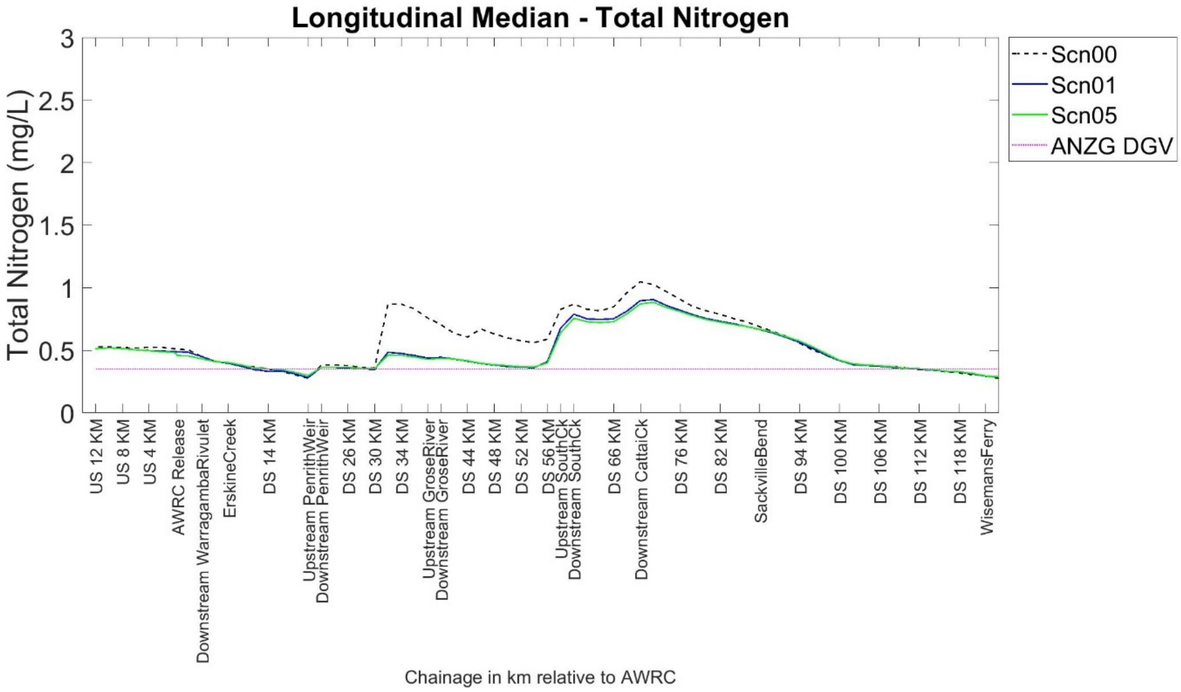


Figure 4-16 Example longitudinal annual median profile plot

4.6.4.3.2 Timeseries and box plots

Timeseries plots showing the baseline, background and impact scenario results were prepared at selected analysis sites in the receiving waterways. The dates presented in these plots are representative of 'model dates' and are consistent with the scenario durations and representative climatic years discussed in Section 4.6.3.4.

The analysis sites were selected to provide a representative picture of the impacts as you travel downstream from the proposed release points in the receiving waterways. These sites of interest are presented in Figure 4-17 and Figure 4-18 for the Hawkesbury Nepean River and South Creek respectively.

The timeseries data was also converted into box and whisker plots to allow for further evaluation of the impacts and variability of the results. In addition to the results from the different scenario types, both the timeseries and box and whisker plots also included the relevant waterway objectives for each parameter, where applicable.

Examples of the timeseries and box and whiskers plots are presented in Figure 4-19 and Figure 4-20 respectively.

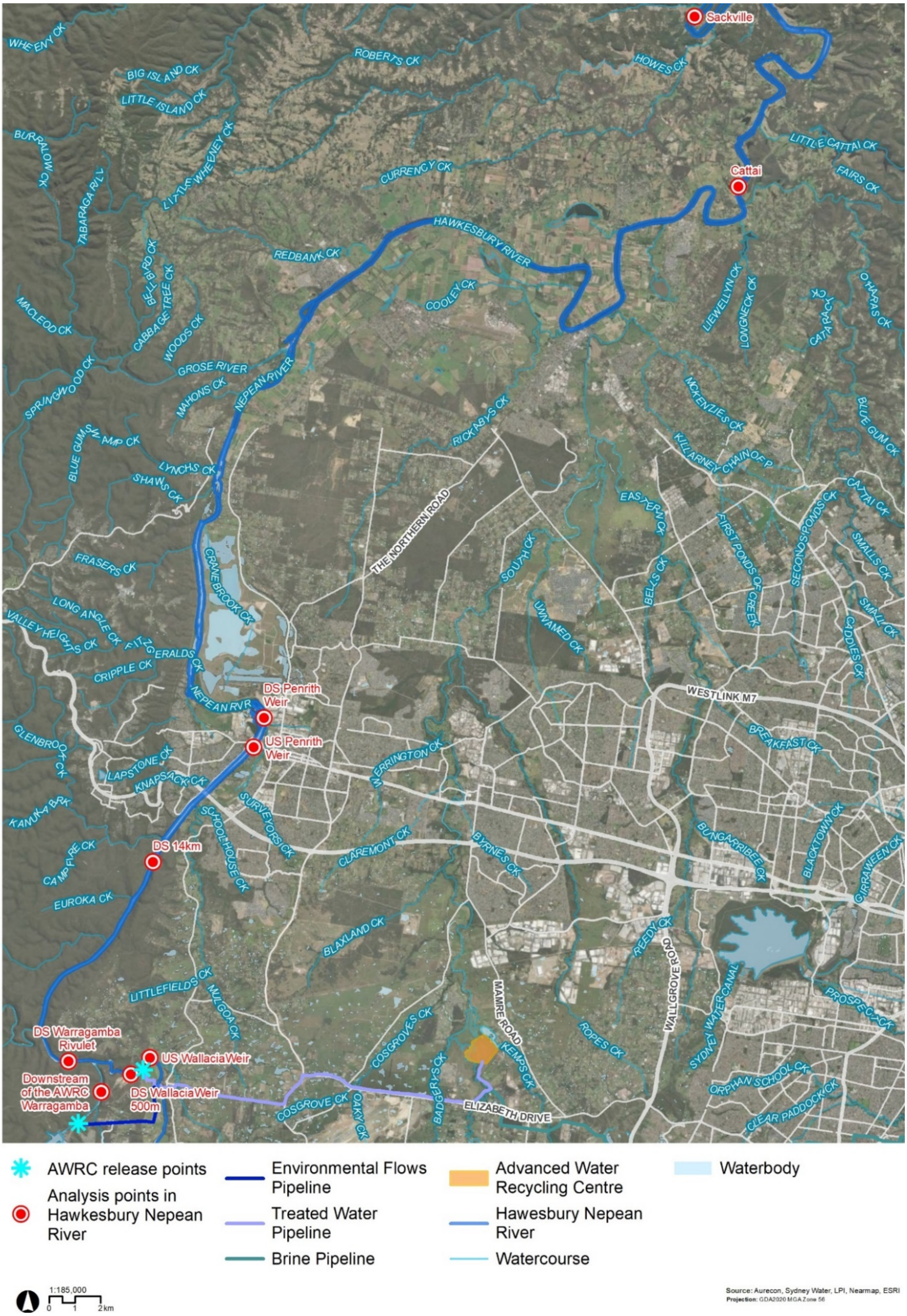


Figure 4-17 Analysis sites for reporting timeseries and box plot results on the Hawkesbury Nepean River

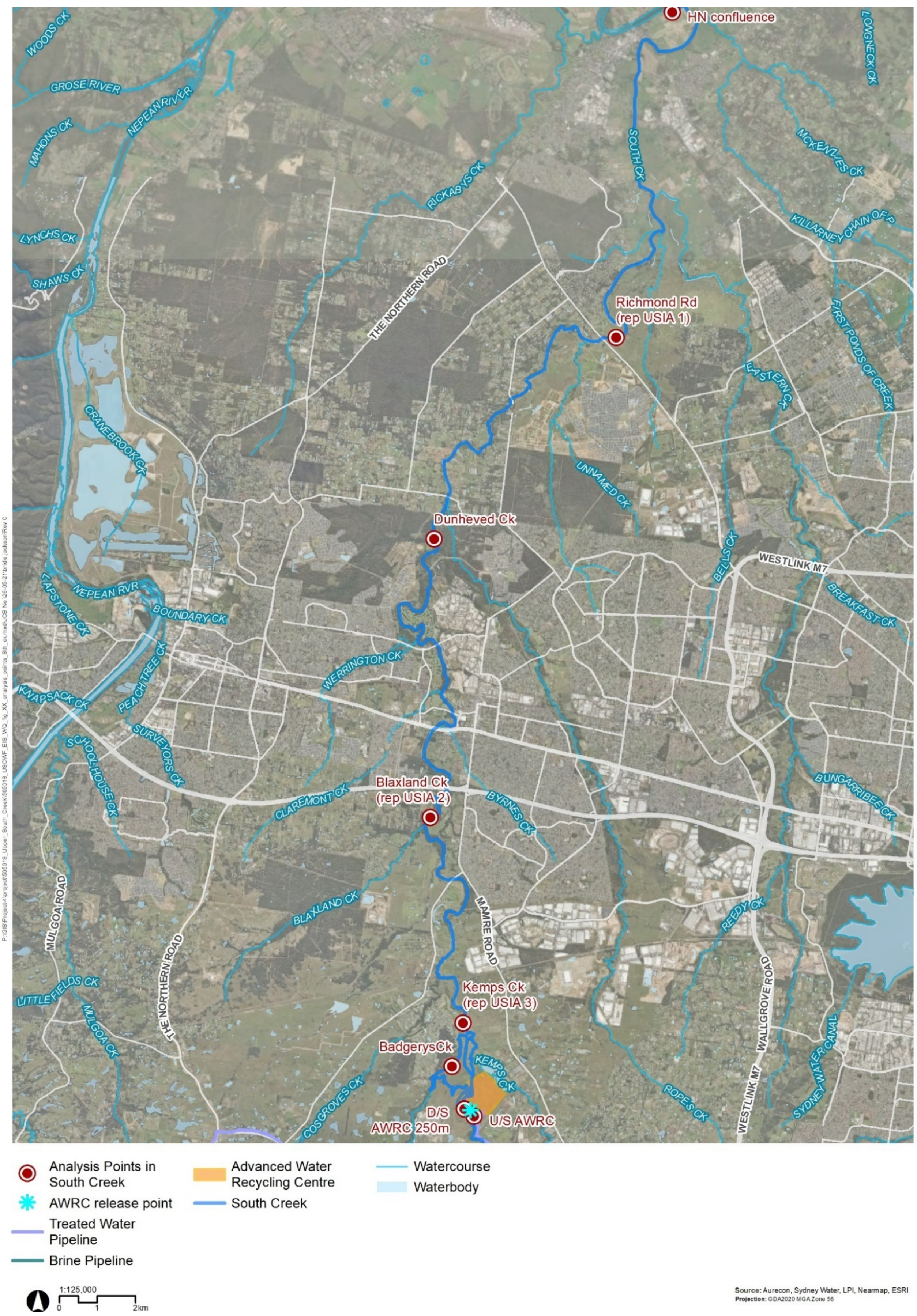


Figure 4-18 Analysis sites for reporting timeseries and box plot results in South Creek

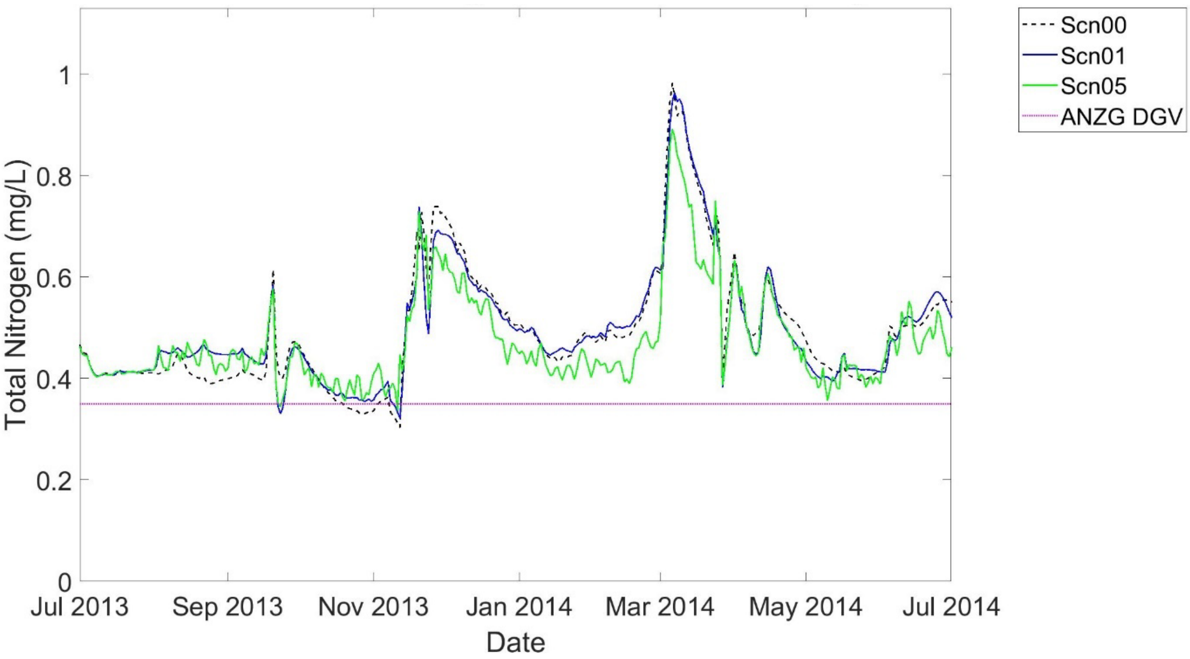


Figure 4-19 Example timeseries plot

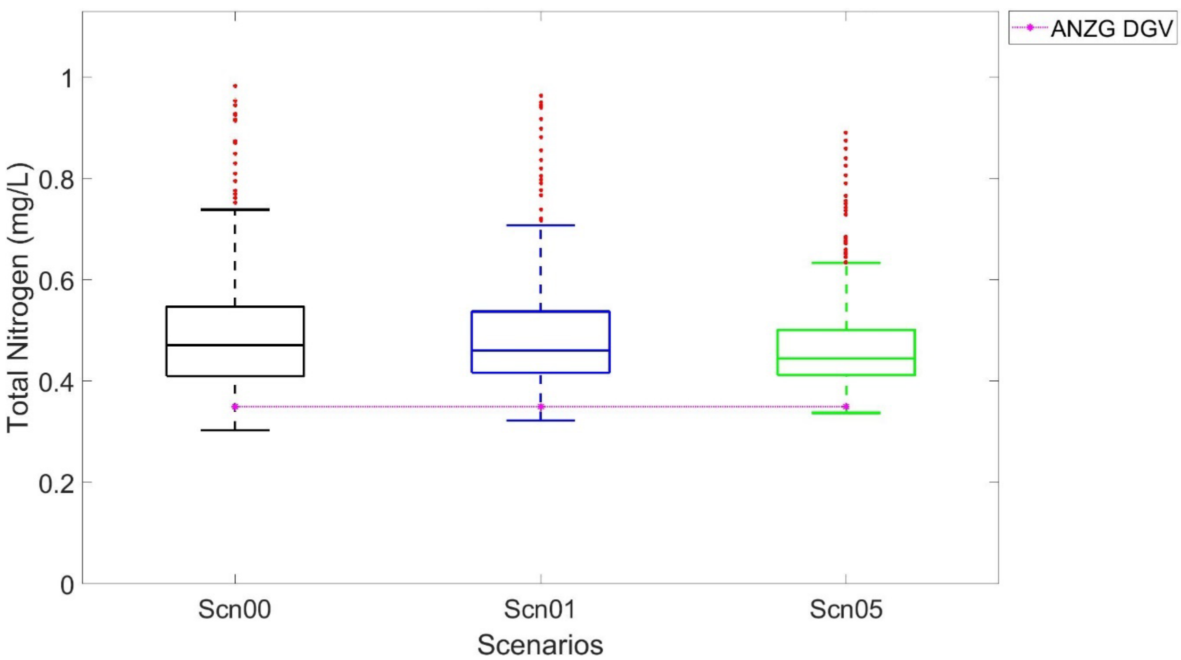


Figure 4-20 Example box and whiskers plot

4.6.4.3.3 Cyanobacteria risk index

The cyanobacteria risk index is derived from analysis of the primary factors that are considered conducive to cyanobacteria growth including the following: temperature, salinity, oxidised nitrogen, ammonia, filterable reactive phosphorus, depth and velocity.

The equation, and supporting equations, used to calculate the risk index is presented below:

$$CR = fT \times (\min(fN, fP)) \times fS \times fV$$

Where:

CR = Cyanobacteria risk factor between 0 and 1

fT = function of temperature

fN = function of Nitrogen

fP = function of Phosphorus

fS = function of Salinity

fV = function of stratification or velocity

$$fT = v^{(ModTemp-20)} - v^{(k \times (ModTemp-a))} + b$$

Where:
v = 1.08

k = 4.1102

a = 35.0623

b = 0.1071

ModTemp = Modelled water temperature in degree C

$$fN = \frac{(ModNOx + ModAmm)}{(KN + ModNOx + ModAmm)}$$

Where:
ModNOx = Modelled NOx in mmol/m^3

ModAmm = Modelled Ammonia in mmol/m^3

KN = 4 mmol/m^3

$$fP = \frac{ModFRP}{KP + ModFRP}$$

Where:
*ModFR*P = Modelled FRP in mmol/m^3

KP = 0.15 mmol/m^3

$$fS = \frac{KS}{KS + ModSal}$$

Where:
KS = 5 g/L

ModSal = Modelled Salinity in g/L *(if ModSal < 2.5 g/L, then fS = 1)*

$$fV = \frac{KV}{KV + ModV}$$

Where:

ModV = Modelled velocity in m/s If ModV < 0.05 m/s then fV = 0

KV = 0.5

$$ModV = (ModVx^2 + ModVy^2)^{0.5}$$

Timeseries output of the risk indices for the impact, background and baseline scenarios were plotted for selected analysis zones downstream of the release points. The boundaries of these zones are presented in Figure 4-20.

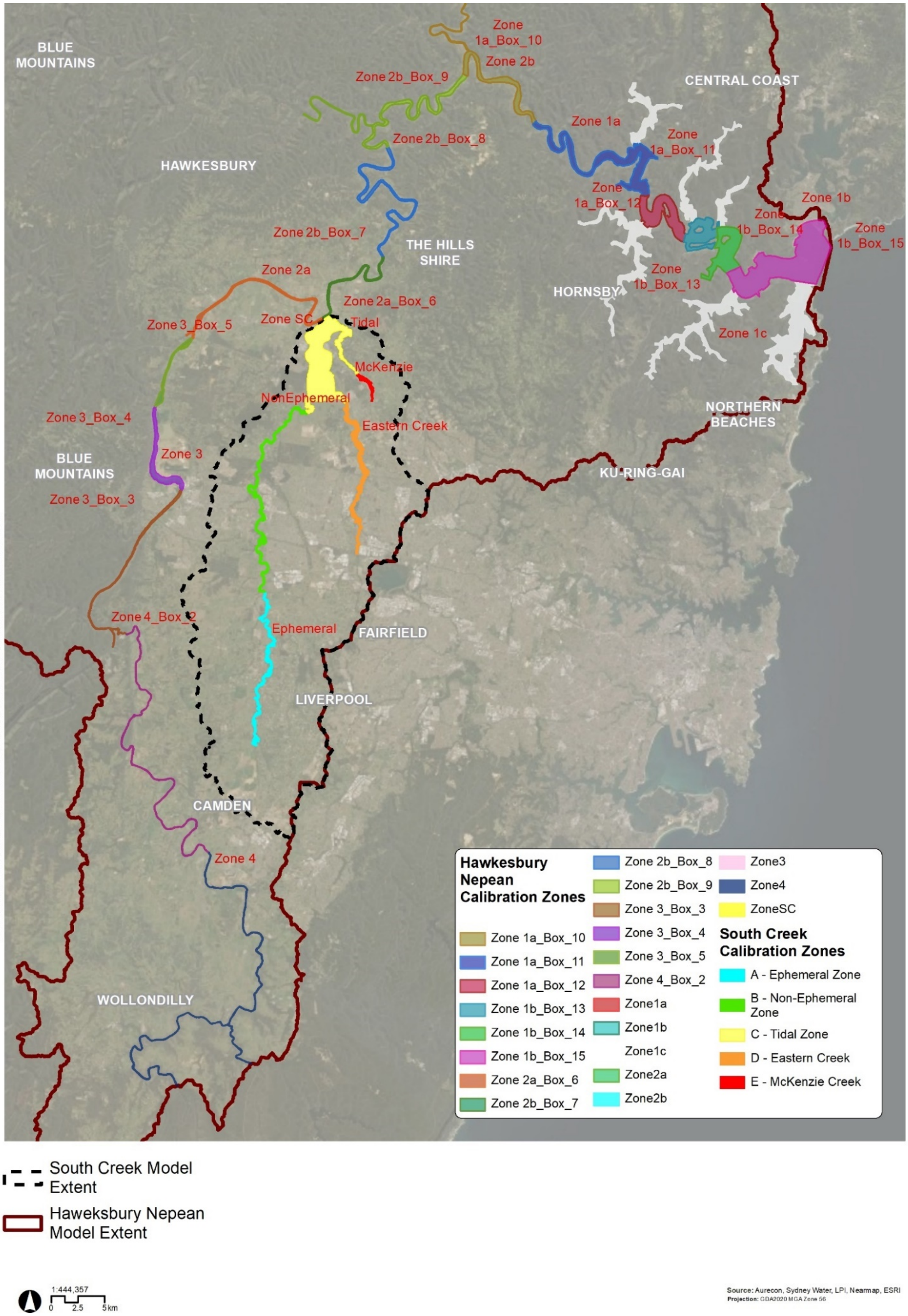


Figure 4-21 Zonal analysis boundaries

From an interpretative perspective, values over 0.6 to 0.8 were considered to represent a greater risk of cyanobacteria growth if they were predicted over a sustained continuous period e.g. a month. An example of a cyanobacteria risk index plot is presented in Figure 4-22.

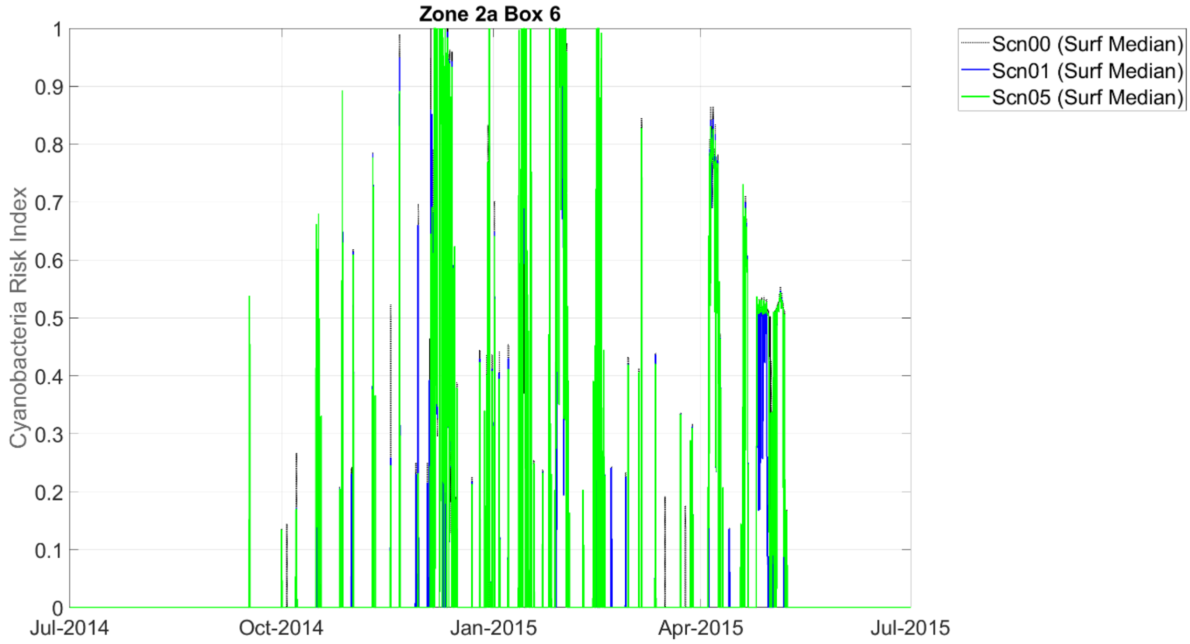


Figure 4-22 Example Cyanobacteria risk index plot

4.7 Near field and toxicity modelling

4.7.1 Scenario testing approach

The modelling and impact assessments followed the stepped approach outlined below:

- analysis of proposed release conditions for the South Creek and Nepean River releases to determine conditions that may present a risk of toxicity
- analysis of the characteristics and hydrodynamics of the waterways in the immediate vicinity of the release points at the time of the releases of interest
- evaluation of the dilution requirements for each toxicant of concern based on the expected release concentrations, background ambient concentrations and the relevant guideline values
- near field modelling of the initial dilution and mixing processes for the releases with consideration of the expected range of release rates and ambient flow conditions
- assessment of the size and configuration of mixing zones, if required, in line with the ANZG (2018) and ANZECC (2000) technical guidelines (refer to Section 4.7.4.3.2)
- In line with the NSW Guide to Licensing (DECC, 2009), appropriate measures are to be made to consult with DECC as soon as possible, if a mixing zone is to be proposed.

Consistent with Appendix 1 of Volume 2 of the ANZECC (2000) guidelines, the mixing zone and near field assessments have been restricted to soluble, non-bioaccumulatory toxicants.

4.7.2 Model development

With an emphasis on the steady-state simulation of plume geometries and initial dilution characteristics, the CORMIX software applied in the near field impact assessments consists of a series of algorithms for the analysis and prediction of near field mixing. To inform the application of these algorithms, a suite of datasets was acquired so the AWRC treated water releases could be simulated realistically in the near field.

The datasets included the following fundamental groups:

- Release conditions including size, release depth and configuration of the release infrastructure, flow rates, water density and contaminant concentrations.
- Ambient conditions of the receiving waters including details of bathymetry, flow rates, background contaminant concentrations and ambient density.

A summary of these datasets is provided below with further detail regarding the scenario conditions and assumptions included in Section 6.2.

4.7.2.1 Release conditions

The potential for near field impacts will generally occur infrequently and only during severe wet weather events. More specifically, the conditions that may present a higher potential toxicity risk are expected to occur when AWRC influent rates rise above 3 x ADWF. Such events are predicted to be very infrequent i.e. two to three times per year but frequencies may actually vary between zero and six events per year.

Under these conditions, the releases to South Creek will include higher proportions of primary treated water. Consequently, there is potential for these releases to include elevated levels of contaminants that could present a risk of toxicity to the waters in the immediate vicinity of the release point.

Under the same conditions, the releases to the Nepean River will consist solely of tertiary treated water, again introducing a higher potential risk of toxicity. It is noted that tertiary treated releases to the Nepean River may also occur below the 3 x ADWF threshold, there is however a greater likelihood that these releases will be diluted with advanced treated water, and therefore present a lower risk of toxicity in the receiving waters.

The release conditions at both the South Creek and Nepean River release points were consequently derived from analysis of the WQRM scenario boundary conditions when they correlated with the higher influent flows. Additional characterisation of the release conditions was undertaken through analysis of relevant monitoring data as well as the reference design drawings of the release infrastructure.

Further details relating to the derivation of the release conditions are provided below and in Section 6.2.

- Release quantity - The expected release rates of treated water were determined from analysis of the boundary conditions for the AWRC releases as assumed in the WQRM scenarios. The ranges of these release rates are presented below in Table 4-9 and Table 4-10.
- Release quality - The maximum expected concentrations of the selected contaminants were determined from analysis of treated water quality data as listed below. The concentrations derived from this analysis are presented below in Table 4-11 and Table 4-12:
  - advanced treated water quality data from the St Marys AWTP
  - tertiary treated water quality data as adopted from Final Effluent Water Quality Analysis USC AWRC (Sydney Water, 2020) assuming expected MBR performance (scenario 1) and no chlorination
  - wet weather quality data assuming raw sewage and wet weather overflow monitoring data

In line with the analysis approach presented in Section 7.4.4.2 of the ANZECC (2000) guidelines, the 95th percentile concentrations of the toxicants were calculated in the above analysis. Adoption of this percentile allows for removal of outliers in the monitoring data, and provides for a reasonable representation of the maximum levels expected in the release streams.

4.7.2.1.1 Toxicants of concern

The toxicants typically found in wastewater include inorganic chemicals, metals/metalloids, pesticides, residual disinfectants and pharmaceuticals (DES, 2021). The risk of toxicity from these contaminants can initially be undertaken through analysis of the maximum end-of-pipe concentrations and comparison to toxicant trigger values in section 3.4 of the ANZECC (2000) guidelines, or the ANZG (2018) toxicant DGVs.

Therefore, as a first step to determine the likely presence and potential concentrations of toxicants in the release streams, analysis was undertaken as part of the review of micropollutant concentrations in other wastewater treatment plants (refer Appendix B). The following parameters were identified based on this analysis which reviewed the anticipated quality of the treated water, at each release point, during severe wet weather events (>3 x ADWF).

South Creek

Toxicants including:

- Total Ammonia as N
- Nitrate as N
- Total Chlorine

The Nepean River

Metals including:

- Aluminium
- Copper
- Zinc
- Manganese

The Warragamba River

No contaminants were assessed as applicable due to the release of advanced treated water only. No near field modelling of the Warragamba River was therefore undertaken.

4.7.2.2 Ambient conditions

The ambient conditions assumed for the South Creek and Nepean River receiving waterways were derived as follows:

- Bathymetry - Bathymetric and topographic data in the vicinity of the proposed release points was acquired from available survey data used in the development of the WQRM models. The sources of this data were as follows:
  - South Creek: LiDAR data collected in 2011 by Land and Property Information
  - Nepean River: Cross sectional data collected prior to 2012 by Sydney Water Hydrometric Services Group and the Sydney Catchment Authority (SCA)

- Hydrology - Representative flow rates upstream of the release points in South Creek and the Nepean River were determined from analysis of the WQRM model hydrodynamic results. The flows for each waterway were extracted from locations upstream of the proposed release points. The ranges of these flows are presented in Table 4-9 and Table 4-10. The scenarios used to determine these flow rates were as follows:
  - South Creek: Scenarios SC02 and SC04 representing background Parkland conditions for the 2036 and 2056 time horizons respectively
  - Nepean River: Scenarios HN01 and HN02 representing background Low Loading conditions for the 2036 and 2056 time horizons respectively
- Background concentrations for the selected contaminants of concern were determined from median analysis of instream monitoring data. Table 4-11 and Table 4-12. The data used for this analysis were as follows:
  - 22 samples from March 2020 to June 2021 at site NS45
  - 36 samples from June 2020 to June 2021 at sites N66A and N66B for Aluminium (18 events x 2 sites)
  - 6 samples from June 2020 to June 2021 at sites N66A and N66B for Copper, Manganese and Zinc (3 events x 2 sites)

4.7.3 Scenario descriptions

A suite of scenario conditions was developed to allow simulation of a range of releases that could present a risk of toxicity to the waters in the immediate vicinity of the release points. The scenario conditions tested in the CORMIX modelling were therefore defined based on the expected ranges of these potentially harmful release conditions, as well as the ambient hydrological conditions expected in the receiving waterways at the time of the releases.

These ranges were determined through aforementioned analysis of the WQRM scenario conditions, monitoring data and the reference designs. Table 4-9 and Table 4-10 present a summary of the ranges of the expected release and ambient flow conditions.

With respect to water quality of the releases and the receiving waters, representative values for the relevant toxicants are presented in Table 4-11 and Table 4-12 for South Creek and the Nepean River respectively.

Table 4-9 CORMIX scenario flow conditions (2036/AWRC Stage 1)

Scenario condition	South Creek	Nepean River
Release conditions		
Lower release limit (m^3/s)	0.73	0.98
Upper release limit (m^3/s)	1.50	0.98
Ambient conditions		
Lower flow range (m^3/s)	10.1	15.4
Upper flow range (m^3/s)	33.5	153.1

Table 4-10 CORMIX scenario flow conditions (2056/AWRC Future Stages)

Scenario condition	South Creek	Nepean River
Release conditions		
Lower release limit (m^3/s)	1.46	1.97
Upper release limit (m^3/s)	3.01	1.97
Ambient conditions		
Lower flow range (m^3/s)	11.3	15.5
Upper flow range (m^3/s)	38.2	153.2

Table 4-11 CORMIX scenario water quality conditions (South Creek)

Contaminant	Toxicant DGV	Treated water quality	Background water quality
Total Ammonia as N (mg/L)	1.75*	6.00#	0.05^
Nitrate as N (mg/L)	2.40**	0.20#	0.91^
Total Chlorine (mg/L)	0.003** / 0.007***	0.025#	0.00^^

Table notes:

^ *Background concentration derived from median analysis of 22 sampling events from March 2020 to June 2021 at a site upstream of the proposed release point (site NS45).*

^^ *Assumed to be zero due to their limited persistence in water.*

Treated water quality – refer to Section 4.7.2.1 for sources.

* *Toxicant DGV for the protection of aquatic ecosystems (95% protection) as typically recommended for slightly to moderately disturbed ecosystems – refer ANZECC (2000). Modifications to the DGV have been made in line with ANZECC (2000) based on a median ambient pH of 7.4, which was determined from monitoring data collected from March 2020 to June 2021, at site NS45.*

** *Toxicant DGV for the protection of aquatic ecosystems (95% protection) – refer ANZECC (2000)/ANZG (2018).*

*** *Guideline Value (GV) derived for chlorine in freshwater by Batley et al. (2021).*

Table 4-12 CORMIX scenario water quality conditions (Nepean River)

Contaminant	Toxicant DGV	Treated water quality	Background water quality
Aluminium (mg/L)	0.055*	0.340#	0.010^
Copper (mg/L)	0.0014*	0.005#	0.001^
Zinc (mg/L)	0.008*	0.050#	0.003^
Manganese (mg/L)	0.100**	0.134#	0.067^

Table notes:

^ *The background concentrations were derived from median analysis of sampling events from June 2020 to June 2021 at sites upstream of the release point (sites N66A and N66B). 36 samples for Aluminium. 6 samples for Copper, Manganese and Zinc. All results represent filtered concentrations.*

Treated water quality – refer to Section 4.7.2.1 for sources.

* *DGV for the protection of aquatic ecosystems (95% protection) as typically recommended for slightly to moderately disturbed ecosystems – refer ANZECC (2000). Aluminium DGV specified for pH >6.5. No modifications or corrections to these DGVs have been applied regarding bioavailability and/or toxicity modifying factors such as pH, hardness, alkalinity or organic carbon.*

*** DGV for the recreational purposes – refer NHMRC (2008). The ANZG (2018) DGV for the protection of aquatic ecosystems is significantly higher with a value of 1.9 mg/L. No modifications or corrections to the NHMRC (2008) DGV has been applied.*

4.7.4 Analysis and interpretation

4.7.4.1 Approach

As outlined above in Section 4.7.1, the near field assessments followed a stepped approach of comparing modelling results for initial dilution and mixing against the dilution requirements for each contaminant of concern. From this analysis the size and configuration of any applicable mixing zone could be evaluated.

The following sections outline the parameters analysed, the format of the analysis and also the regulatory criteria relevant to mixing zones in ANZG (2018) and ANZECC (2000).

4.7.4.2 Formats

4.7.4.2.1 Dilution requirements

The dilution requirements have been presented in tabular format for each contaminant and for each release location. These dilution factors were determined from the assumed maximum (95th percentile) treated water concentrations, the background ambient concentrations and the relevant guideline values. These dilution factors effectively represent the level of dilution required in the vicinity of the release point to reach each toxicant DGV (or alternative guideline value). The factors therefore represent the level of dilution required at the boundary of a regulatory mixing zone.

The equation used to calculate these factors is presented below:

$$Dilution\ Factor = \frac{(C_{AWRC} - C_{Back})}{(C_{DGV} - C_{Back})}$$

Where:

C_{AWRC} is the concentration of the AWRC treated water releases

C_{DGV} is the relevant Default Guideline Value

C_{Back} is the ambient background concentration

4.7.4.2.2 Dilution profiles

Dilution profiles were plotted against distance downstream of the release points. An example of these profiles is presented in Figure 4-23.

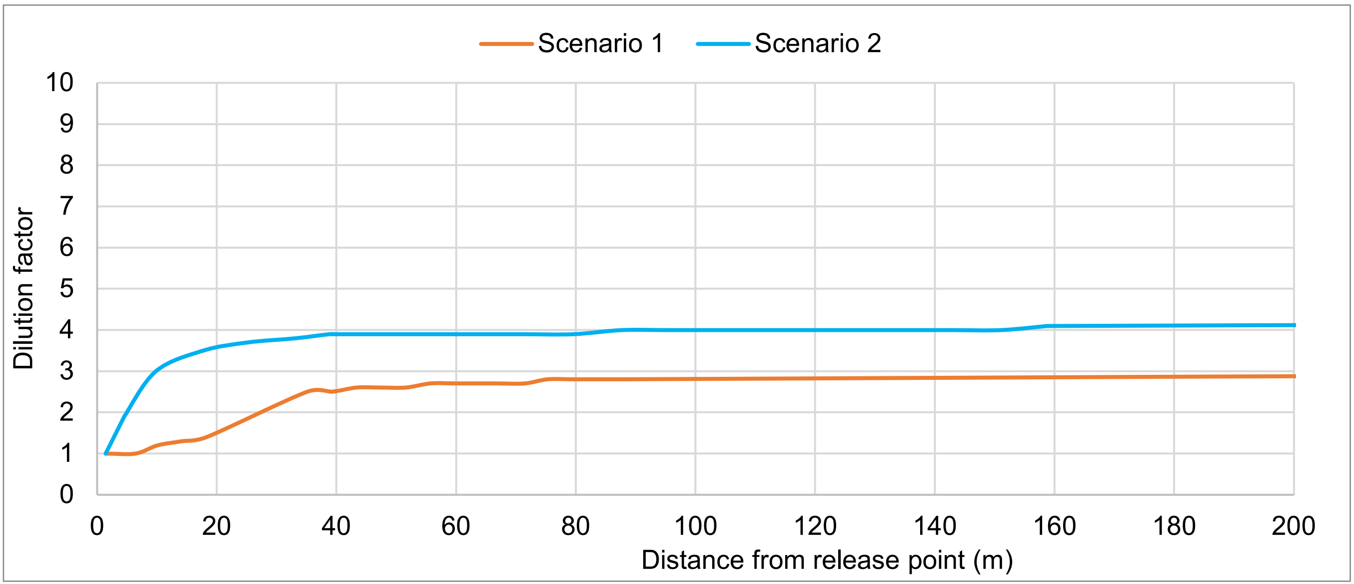


Figure 4-23 Example dilution profile

4.7.4.2.3 Mixing zone and plume analysis

Where applicable, the predicted size and configuration of the relevant mixing zones have been presented in tabular format. These results represent the predicted dimensions of a mixing zone where sufficient dilution has been realised to achieve concentrations on the zone boundary equal to the applicable toxicant DGV.

4.7.4.3 Mixing zone criteria

4.7.4.3.1 Background

In the absence of NSW specific technical guidelines and assessment criteria relating to regulatory mixing zones, the assessment criteria adopted for this study has followed the principles and procedures presented in the ANZECC (2000) water quality guidelines, specifically Appendix 1 of Volume 2 which acts as a key information source regarding mixing zones.

From the guidelines, mixing zones are defined as: "*An explicitly defined area around an effluent discharge where effluent concentrations may exceed guideline values and therefore result in certain environmental values not being protected*."

The size of the mixing zone is generally considered to be site specific. The application of a mixing zone in licensing discharges is not mandatory, but where it is proposed, ANZECC (2000), and other state-based guidelines may provide guidance on their application. This includes directions on: the size of a mixing zone; its configuration; applicability to water uses or water types or release types; and, the applicability with respect to toxic substances.

4.7.4.3.2 ANZG (2018) and ANZECC (2000) guidelines

In the revised ANZG (2018), the following definition is provided: "*We can define a mixing zone as an explicitly defined area around an effluent discharge where some, or all, water quality objectives may not be met. Under some circumstances, it is an accepted practice to apply the concept of a mixing zone. As a consequence, some community values of the water body may not be protected. The size of a mixing zone, and the environmental conditions within it, are important concerns, particularly because degraded areas around effluent discharges compromise community values.*"

As previously mentioned, Appendix 1 of Volume 2 of the ANZECC (2000) guidelines provides a primary information source and is not updated in ANZG (2018). The following key aspects are presented from this Appendix.

Nature and difficulties of mixing zones

- Mixing zones are generally designated to manage the controlled discharge of soluble, non-bioaccumulatory toxicants whose impacts on local biota are primarily related to their concentration. The use of mixing zones is not appropriate for managing the discharge of nutrients, bioaccumulatory or particulate substances.
- The boundary of the mixing zone is usually defined in terms of the concentrations of indicator species in the effluent. Where these are statistically indistinguishable from ambient water concentrations, the mixing zone is presumed to have ended.
- Simple models for mixing zones assume a smooth gradient of concentration from the source to the boundary. Where stratification is likely (due to differences in density between the effluent and the receiving water) models used in predicting the size of the mixing zone must take this into account.
- Mixing zones are areas of water, albeit usually small, where prudent environmental safeguards may need to be suspended. For sedentary species acutely sensitive to effluent components, the mixing zone may become a sacrificial zone from which ecological recovery is slow when effluent release is stopped.
- Mixing zones may inhibit fish migration in small rivers, particularly during low river flow conditions.

Management of mixing zones

- Before a mixing zone is permitted, every effort should be made to reduce the amount and concentration of liquid waste by applying the waste hierarchy: avoid, reduce, reuse, recycle, treat, dispose. In applying the hierarchy, best practice should be used as benchmarks throughout the planning process.
- A mixing zone should have a maximum agreed size and should have corresponding effective discharge controls. The point of discharge should be chosen to minimise the size and impact of the mixing zone. If considerations of the effluent quality and receiving water characteristics indicate that high initial dilutions are required, then a diffuser at the point of discharge may be the best option.
- Where mixing zones occur, management should ensure that impacts are effectively contained within the agreed zone, and that the size of the mixing zone is sufficiently small so as not to compromise the agreed and designated values and uses of the ecosystem as a whole.
- In keeping with the philosophy of continual improvement, efforts should be made to reduce the size of mixing zones over time.
- Human health considerations would not normally be relevant in the allocation of mixing zone permits, because a licence to release effluent would be unlikely to be issued where the Environmental Values for the mixing zone include protection of fish, crustacea and shellfish for human consumption.
- Similarly, recreational use inside a mixing zone would not usually be prudent unless the effluent was known to be benign.

- Mixing-zone management is influenced by a number of considerations. In locations of high environmental significance, severe restrictions may be placed on the creation of mixing zones, if they are allowed at all.
- Depending on the stringency of the environmental requirements being suspended, some or all of the following restrictions, and their extent, may be applied to achieve best practice in mixing zone management:
  - Treatment and toxicity testing.
  - Temporal restrictions: release may only be permitted under specified hydrological conditions. For example, discharge to marine or estuarine environments may only be when certain tidal conditions are met. For fluvial systems, threshold streamflow discharge may be required for release. A requirement may also be made for the effluent release to be pulsed, with extended periods of no release to maximise the possibility of ecological recovery.
  - Mixing zone size: the zone must be as small as practical in accordance with the waste management hierarchy, and either alone, or in combination with other mixing zones, should not occupy a significant proportion of the receiving waters. This may allow migrating species to avoid the contaminated zone.
  - Mixing zones not applicable to certain waters: mixing zones should not generally be designated in waters which have values or characteristics which are not compatible with the existence of a plume of water which does not meet ambient management goals. For example: (a) primary contact recreation areas; (b) areas of significant value for spawning or nursery; (c) are close to areas used for aquaculture; (d) are close to potable water supply intakes; (e) are of outstanding ecological or scientific importance; (f) have high conservation ecosystem values; or (g) where the mixing zone plume is likely to hug the shoreline.
  - Emission limits: emission discharge limits should be set such that, within the mixing zone, the emission does not cause either: (a) objectionable odours; (b) objectionable discoloration; (c) visible floating foam, oils, grease, scum, litter or other objectionable matter; acute toxicity to fish or other aquatic vertebrates; (e) significant irreversible harm within the mixing zone; (f) a barrier to the migration of aquatic organisms; or (g) the growth of undesirable aquatic life or dominance of nuisance species (algal blooms, for example).
  - Monitoring programs: monitoring may be mandatory.

4.7.4.3.3 Primary considerations

For the purposes of this assessment, mixing zones have therefore been determined as the areas of the receiving waterways where the relevant ANZG (2018)/ANZECC (2000) toxicant DGVs are exceeded. In line with the analysis approach presented in Section 7.4.4.2 of the ANZECC (2000) guidelines, the 95th percentile treated water concentrations of the toxicants are assumed. Adoption of this percentile allows for removal of outliers in the monitoring data, and provides for a reasonable representation of the maximum levels expected in the release streams.

In the absence of NSW specific technical guidelines and assessment criteria relating to regulatory mixing zones, primary considerations as presented in the Queensland Government Technical Guideline have been adopted in the modelling assessments. These guidelines are considered to follow the principles and procedures presented in the ANZECC (2000) water quality guidelines.

Specifically, the following lateral and longitudinal dimensions of the mixing zones and potential interaction with banks and shorelines have been used as the principal three criteria to determine whether the zones may be consistent or not with the principles of the ANZG (2018)/ANZECC (2000) guidelines.

- the maximum lateral dimension should be the lesser of 50 m diameter or 30% of the waterway width
- the maximum longitudinal dimension should be the lesser of 300 m or three stream widths

4.8 Assumptions and limitations

The hydrodynamic and water quality modelling has been undertaken in line with accepted industry standard practices and the WQRMs have been independently reviewed for the purposes of this EIS. With recognition of the findings documented in Section 4 of the calibration report, the WQRM models are considered fit for purpose in their application for the impact assessment undertaken for the AWRC EIS.

However, in line with all similar impact assessment studies, the modelling undertaken for the EIS should be considered as a representative approximation to the real world and not without accepted levels of uncertainty. It should therefore be understood that each model is based on a series of assumptions, and also dependent on the accuracy of its input data. The model results should therefore be interpreted as indicative of impacts, responses and trends in the receiving waters and not absolutes.

Further discussion regarding the levels of uncertainty and model limitations are presented in the calibration report. Sensitivity analysis relating to the boundary conditions, and other model parameterisation, has also been undertaken as part of the calibration process and this is also presented in the calibration report. The model calibration report can be supplied by Sydney Water upon request.

In addition to the limitations discussed in the calibration report, an underprediction of flows at the Wallacia Weir was identified in the WQRM results during analysis of the WQRM scenarios. More specifically, it was observed that the modelled baseline and background flows deviated from the gauge data, from the 30th percentile to the tail end of the flow duration curve. Sensitivity analysis was undertaken to establish the influence of this issue with respect to the water quality impacts predicted by the WQRM. The results from the analysis indicated that the WQRM results for the impact scenarios could be considered as conservative and potentially over predicting the impacts of the AWRC releases. Refer to Section 6.1.2.6 for further details.

With respect to CORMIX, while the software is internationally recognised as a leading and proven hydrodynamic modelling software package, the aforementioned caveats also apply. The developers, MixZon Inc. also advise users regarding its accuracy and limitations, and that it should not be considered as exact science. MixZon Inc. provide guidance that extensive comparison with field and laboratory data has shown that CORMIX predictions on dilutions and concentrations (with associated plume geometries) are reliable for the majority of cases and are accurate to within about ± 50% (standard deviation).

5 Existing environment

The project includes releases of treated water to the Nepean River (upstream of Wallacia Weir), wet weather releases to South Creek (upstream of Kemps Creek), and also the potential for releases to the Warragamba River (downstream of the dam wall).

The following sections present an overview of the existing hydrodynamic and water quality conditions within these proposed receiving waterways. From review of relevant monitoring data and findings from previous studies, descriptions are presented with respect to the surrounding catchments, the waterways, relevant pressures, load estimates and also the water quality conditions that currently exist in the water courses.

5.1 Data sources

5.1.1 Previous studies

The following studies have been included as references to the description of the existing environment.

- Sydney Water publications including Sewage Treatment System Impact Monitoring Program (STSIMP) annual data reports, environmental performance annual reports and the interpretative report 2016-17 (Sydney Water, 2018)
- Department of Environment and Climate Change Hawkesbury-Nepean River Environmental Monitoring Program – Final technical report (DECC, 2009a)
- Department of Environment and Climate Change Lower Hawkesbury-Nepean River nutrient management strategy (DECC, 2009b)
- Hornsby Shire Council Waterway Health Review 1995-2017 (HSC, 2019)
- CRC for Irrigation Futures report, Water Management in South Creek Catchment: Current state, issues and challenges (CRC, 2007)
- SKM report, Water Quality Modelling of the Hawkesbury Nepean River System (SKM, 2014)
- Alluvium report, South Creek Source Model Calibration (Alluvium, 2019)

5.1.2 Monitoring datasets

The following datasets and sources were also assessed for characterisation of the existing environment.

- Sydney Water - routine streamflow/gauge and water quality monitoring data, upstream/downstream water quality monitoring of WWTP/WRP releases as well as wet and dry weather intensive sampling
- DPIE/EES - transect and buoy water quality data
- WaterNSW - routine streamflow/gauge and water quality monitoring data
- Hornsby Shire Council - routine water quality monitoring (sonde and monthly nutrients)

The location of the monitoring sites relevant to these programs are presented in Figure 5-1.

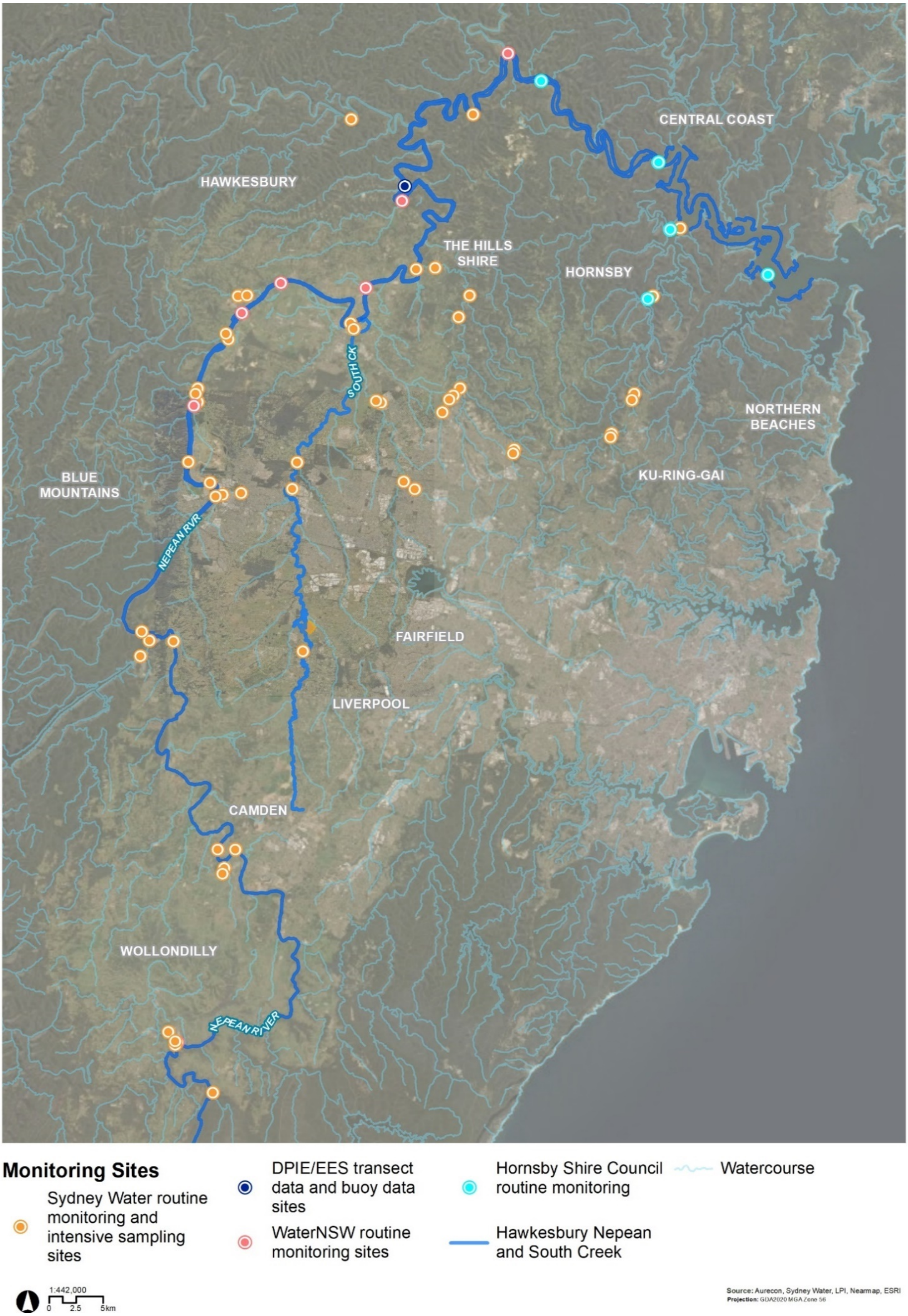


Figure 5-1 Location of monitoring sites

5.2 South Creek

5.2.1 Catchment description

The South Creek catchment covers an area of 628 km^2, sitting within the lower region of the Cumberland Plain. The creek starts its journey in Narellan, north west of Campbelltown and then flows generally in a south to north direction through a gently undulating landscape until reaching its confluence with the Hawkesbury River, near Windsor.

From source to mouth, the creek flows through or forms the boundary of many suburbs including Bringelly, Badgerys Creek, Kemps Creek, Orchard Hills, St Marys, Dunheved, Riverstone, Windsor and McGraths Hill.

Land use within the catchment currently consists of a mix of rural farms, remnant native forest and urban areas (Alluvium, 2019). Rural activities include cattle and sheep grazing, market gardening and intensive agriculture such as poultry farming. As part of the development of the Source model, grazing was evaluated to be the dominant land use of the existing catchment, occupying approximately 39% of the area, while Peri Urban and Urban accounted for approximately 21% and 16% of the region respectively. Land uses for South Creek are presented in Figure 5-23.

5.2.2 Waterway description

5.2.2.1 Overview

From its origins, the creek descends approximately 94 m over its 70 kms course to the Hawkesbury River. The creek is joined by seventeen major tributaries including Badgerys Creek, Kemps Creek, Ropes Creek, Eastern Creek and McKenzies Creek. These tributaries and the course of South Creek are presented in Figure 5-2.

Regarding its flow regime, the creek can generally be separated into three waterway types: ephemeral, non-ephemeral and tidal. The ephemeral zone is generally considered to end at the confluence with Kemps Creek, however under extended dry weather conditions, the creek can slow and become segregated into separate pools all the way down to the Dunheved reach.

5.2.2.2 Flow modification from dams and weirs

While there are no instream weirs or other flow controlling structures in the main body of South Creek, there are a significant number of farm dams within the catchment that are used for irrigation purposes, stock watering, etc. Other retaining structures are also found on some of the creek’s tributaries e.g. Kemps Creek. These dams and weirs can provide significant modification to flows from surrounding sub-catchments and consequently flows within South Creek.

5.2.2.3 Environmental flows

There is currently no provision of environmental flows in the catchment.

Figure 5-2 South Creek and its tributaries

5.2.2.4 Replacement flows

The Replacement Flows Project commenced operation in October 2010. Treated water from St Marys, Quakers Hill and Penrith wastewater treatment plants is treated via reverse osmosis technology at the St Marys AWTP. The advanced treated water is then pumped to Penrith where up to 50 ML/day is released into the Nepean River via Boundary Creek.

This project was designed to replace 18 billion litres of drinking water being released from Warragamba Dam each year by replacing the environmental releases with the advanced treated recycled water from the plant. The process used at St Marys AWTP treats wastewater to an extremely high standard greatly reducing nutrient loads as well as a variety of other contaminants.

The St Marys and Quakers Hill wastewater treatment plants are located within the South Creek catchment. Currently the St Marys WRP transfers ~18 ML/d to the AWTP but this is estimated to increase to ~20 ML/d by 2036. Similarly, the Quakers Hill WWTP transfers ~10 ML/d to the AWTP and this is estimated to increase to 12 ML/d by 2036.

5.2.2.5 Flooding

Two major flood events occurred in the South Creek catchment in the 1980s. The August 1986 flood and the April 1988 flood are two of the largest floods to have occurred in the catchment since European settlement. The 1988 flood was in the order of a 100 year recurrence flood within South Creek. The creek was also significantly affected recently by the 2021 New South Wales floods.

Flooding of South Creek typically occurs as a result of local catchment runoff breaking out of the main channel and spilling across the adjoining floodplain. However, impacts can also be experienced by flood conditions in the Hawkesbury River when river levels rise.

5.2.2.6 Tidal influence

The tidal influence extends up to near Richmond Road, approximately 14 km AMTD from the confluence with the Hawkesbury River.

5.2.3 Pressures and water management issues

Principal pressures and water management challenges for South Creek include intensive urban and industrial development, agricultural practices, land use change and clearing, as well as numerous, competing demands for water.

Specific water management issues within the catchment include:

- water quality: elevated contaminant levels, excess nutrients, algae and aquatic weed growth
- development: land use change including growth of urban, commercial and industrial areas
- agriculture: practices that affect downstream waterways including fertiliser use, riparian zone reduction
- increasing demand for water: growing urban population and industry growth as well as extractions for agricultural practices
- water accounting: the need to meter and regulate licence holders to account for water extraction
- point sources: increases in pollutant loads from treated wastewater due to population growth. This includes the existing treatment plants of St Marys, Quakers Hill, Riverstone, South Windsor and McGrath Hill.

In terms of future pressures, the South Creek catchment will see the most significant level of development within the wider Hawkesbury Nepean catchment. The South West and Western Sydney Aerotropolis Growth Areas are primarily located within the South Creek catchment boundary.

As with the wider Hawkesbury Nepean region, the increasing urbanisation of the catchment is expected to result in significant changes in land use and commensurate point and diffuse sources of pollution.

5.2.4 Load analysis

Analysis of total nitrogen and total phosphorus loads to the river has been undertaken to allow comparison of the contributions from various sub-catchments and treatment plants under current conditions (circa 2020). The loads were estimated through analysis of the model boundary conditions, discussed previously in Section 4.6.

The load analyses presented in the figures below, extend from upstream of Lowes Creek to the confluence with the Hawkesbury River. Figure 5-3 and Figure 5-4 present the cumulative analysis from upstream to downstream for all loads (including WWTPs and WRPs).

From these graphs, the influence of the major tributaries, such as Kemps Creek, Dunheved Creek, Eastern Creek, etc can be observed (refer to Figure 5-2 regarding location of tributaries). To a lesser extent, the influence of some of the larger treatment plants can also be seen. Differences in load magnitude between the dry and wet years is also notable.

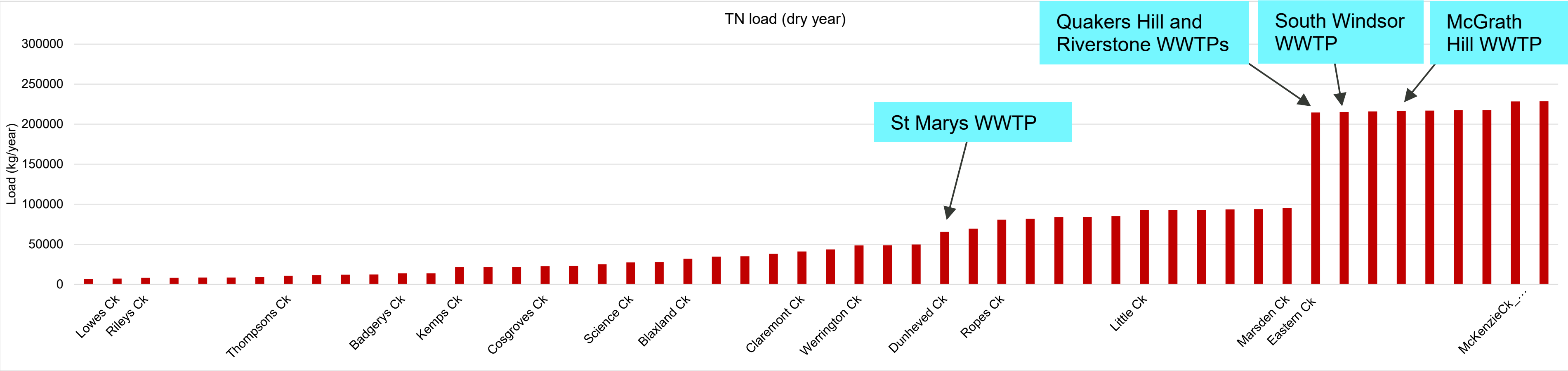


Figure 5-3 Total Nitrogen cumulative catchment loads for South Creek (dry year)

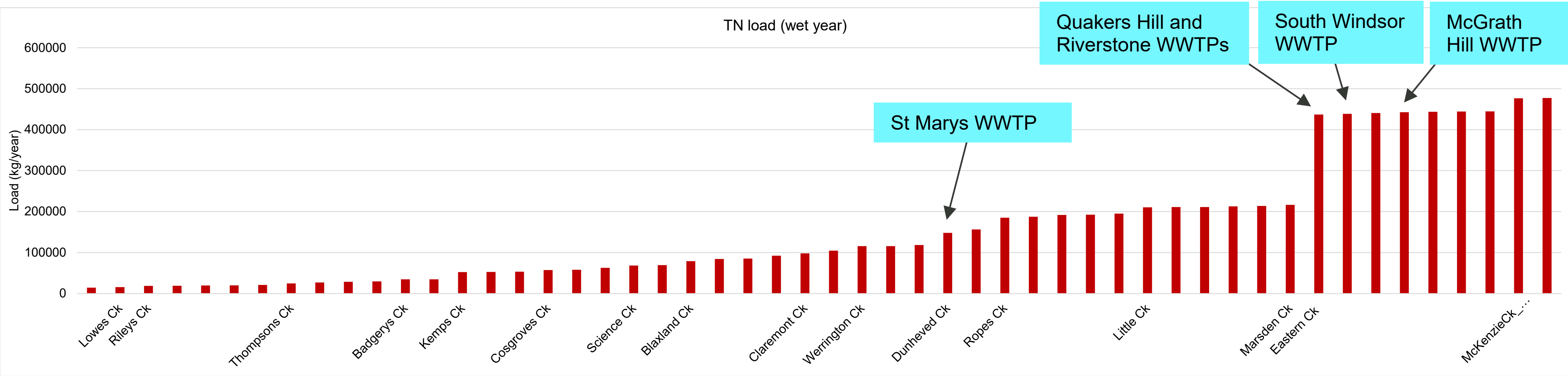


Figure 5-4 Total Nitrogen cumulative catchment loads for South Creek (wet year)

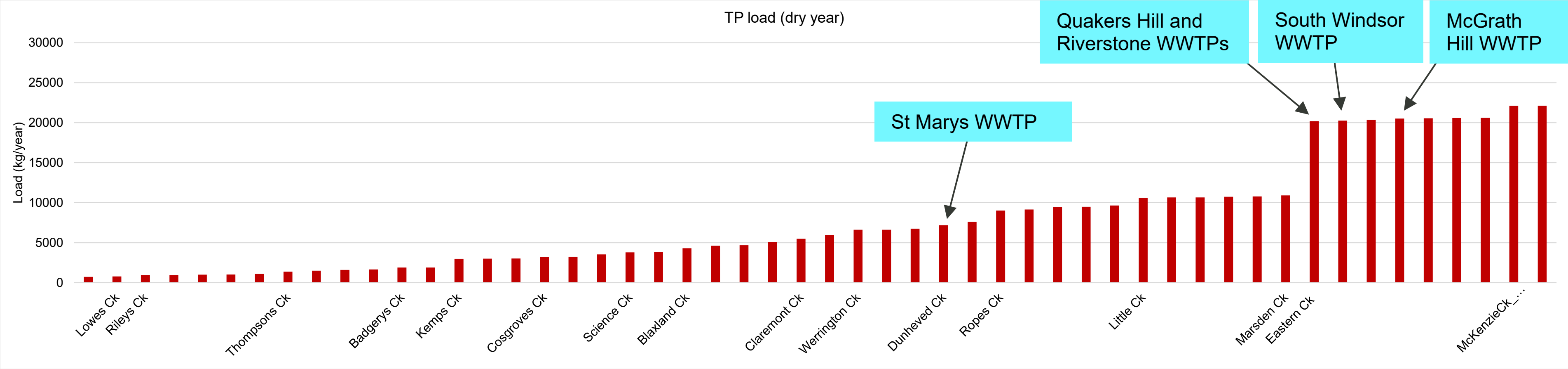


Figure 5-5 Total Phosphorus cumulative catchment loads for South Creek (dry year)

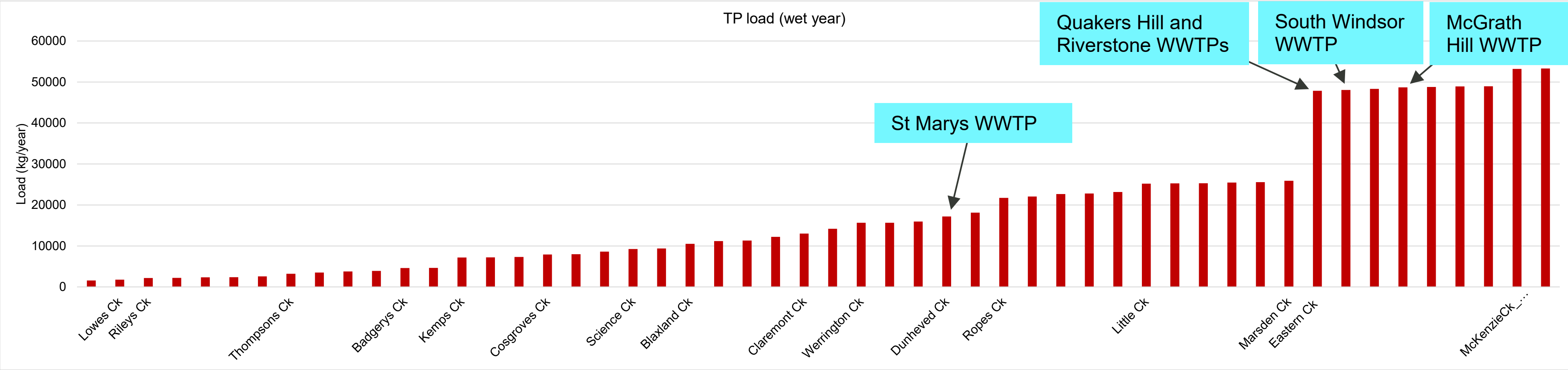


Figure 5-6 Total Phosphorus cumulative catchment loads for South Creek (wet year)

5.2.5 Water quality

The following sections present the findings of recent studies and analysis into the water quality of South Creek, predominantly focussing on the primary water quality processes of concern, namely nutrients, and algal growth. Discussion regarding existing conditions for ecosystem flora and fauna, including aquatic weeds and macrophytes, is included in the Aquatic Ecology Impact Assessment.

5.2.5.1 Nutrients

South Creek has been identified as a significant influence on the water quality of the Hawkesbury River. Despite significant focus on the health of the creek and its influence on the Hawkesbury River, there is relatively limited monitoring data available for the waterway. Data is extremely limited in the upper catchment and also relatively infrequent and variable in the more downstream reaches.

Extracts from relevant monitoring datasets are presented in Figures 5-7 to 5-16 below for total nitrogen, ammonia, nitrate, total phosphorus and phosphate. Due to the number of individual measurement points and the diversity of data sources, this data has been grouped into zones that correlate with the non-ephemeral and tidal reaches of the creek. Figures 5-7 to 5-11 present data for the non-ephemeral reaches, and Figures 5-12 to 5-16 present data for the tidal reaches.

The non-ephemeral data for both total nitrogen and total phosphorus indicates potential compliance, on a median basis, with the EES waterway objectives for South Creek, but not with the more stringent ANZG derived objective. The data from the tidal reaches demonstrates a general increase in nutrient concentrations towards the lower sections of the creek, with potential non-compliance with both the EES and the ANZG waterway objectives for total nitrogen.

With respect to the more bioavailable forms of nitrogen, potential compliance with the EES derived waterway objective is demonstrated in the ammonia data for the non-ephemeral sections. Concentrations are however above the ANZG derived objective for these reaches. Further downstream, concentrations again increase in the tidal section of the creek, potentially above both sets of waterway objectives when considering annual medians. From a toxicity perspective, the data indicates no potential for toxicity as the peaks remain below the toxicant DGV for Total Ammonia.

For nitrate, the data presented includes a significant range of concentrations with peaks up to 3 mg/L. This indicates potential non-compliance with both the EES and ANZG derived waterway objectives on a median basis, and also with respect to the concentration spikes relative to the adopted toxicant DGV of 2.4 mg/L (refer Section 2.2).

With respect to the more bioavailable forms of phosphorus, data limitations make it difficult to assess compliance but on a median basis, concentrations in the ephemeral reaches may potentially remain below both the ANZG and EES waterway objectives. In the tidal reaches, concentrations again are shown to rise and generally lie above the objective.

Seasonal trends are not easily identifiable with the data indicating conditions are more generally event driven than seasonally characterised. Table 5-1 presents seasonal statistical analysis for the data collected at monitoring site NS26, upstream of Dunheved Creek. While significantly downstream of the proposed location for the AWRC, this represents the closest long-term dataset (2005 to 2013) for South Creek. The analysis indicates some potential for higher concentrations of total and oxidised nitrogen in the cooler months between April and September.

Table 5-1 Statistical analysis of nutrient monitoring data at NS26 (upstream of Dunheved Creek)

Percentile	Total Nitrogen (mg/L)		Ammonia (mg/L)		Oxidised Nitrogen (mg/L)		Total Phosphorus (mg/L)		FRP (mg/L)	
Season	Oct - Mar	Apr - Sep	Oct - Mar	Apr - Sep	Oct - Mar	Apr - Sep	Oct - Mar	Apr - Sep	Oct - Mar	Apr - Sep
10th percentile	0.66	0.59	0.01	0.01	0.01	0.05	0.05	0.04	0.02	0.01
Median	1.03	1.13	0.06	0.05	0.13	0.34	0.11	0.08	0.03	0.02
90th percentile	2.20	2.95	0.14	0.10	0.84	1.83	0.23	0.22	0.09	0.05

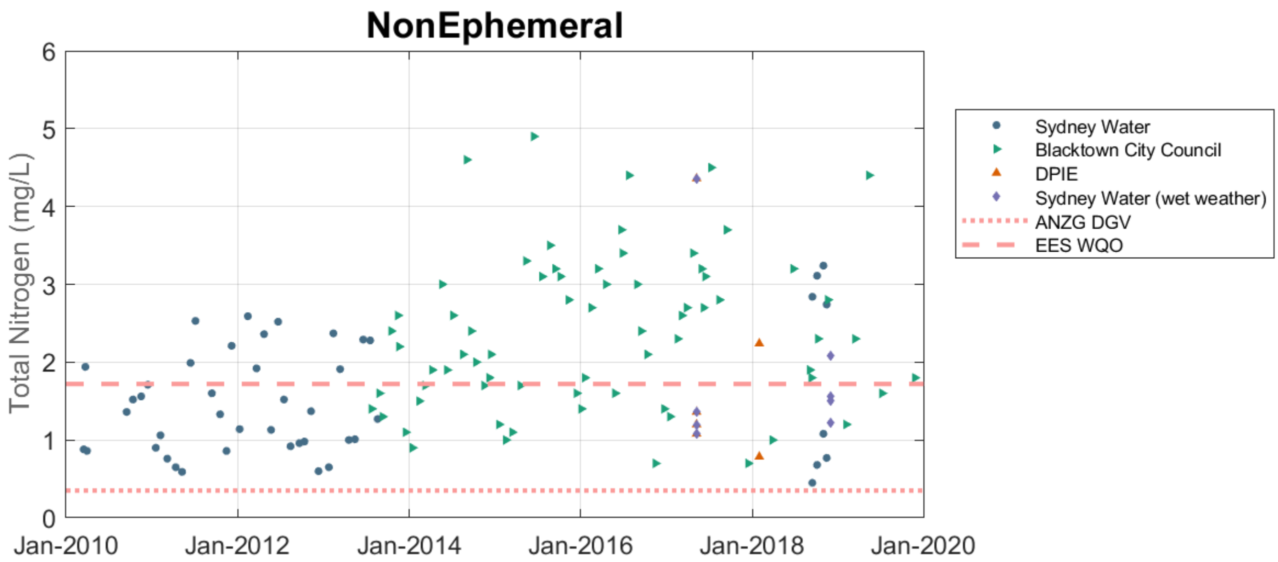


Figure 5-7 Total Nitrogen monitoring data for non-ephemeral reaches of South Creek

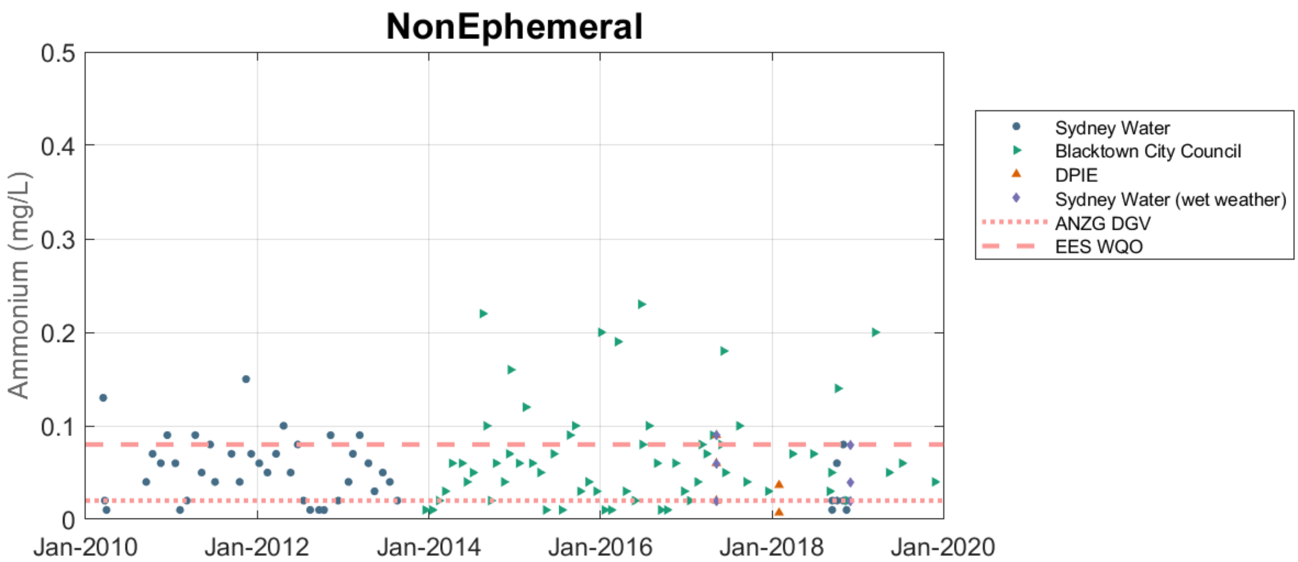


Figure 5-8 Ammonia monitoring data for non-ephemeral reaches of South Creek

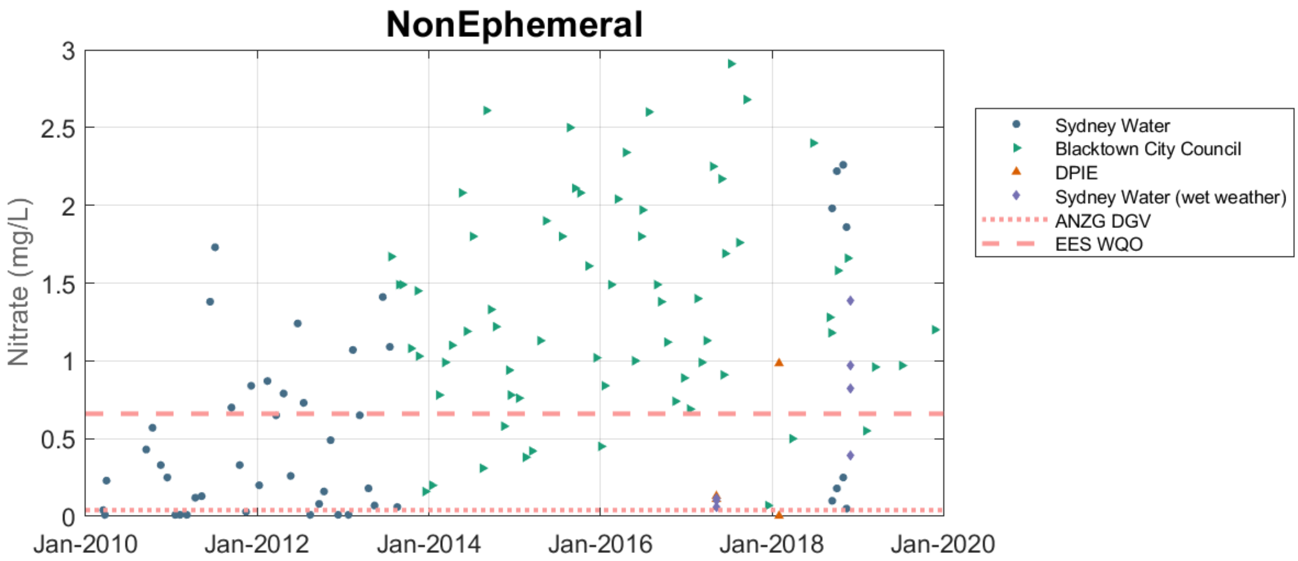


Figure 5-9 Nitrate monitoring data for non-ephemeral reaches of South Creek

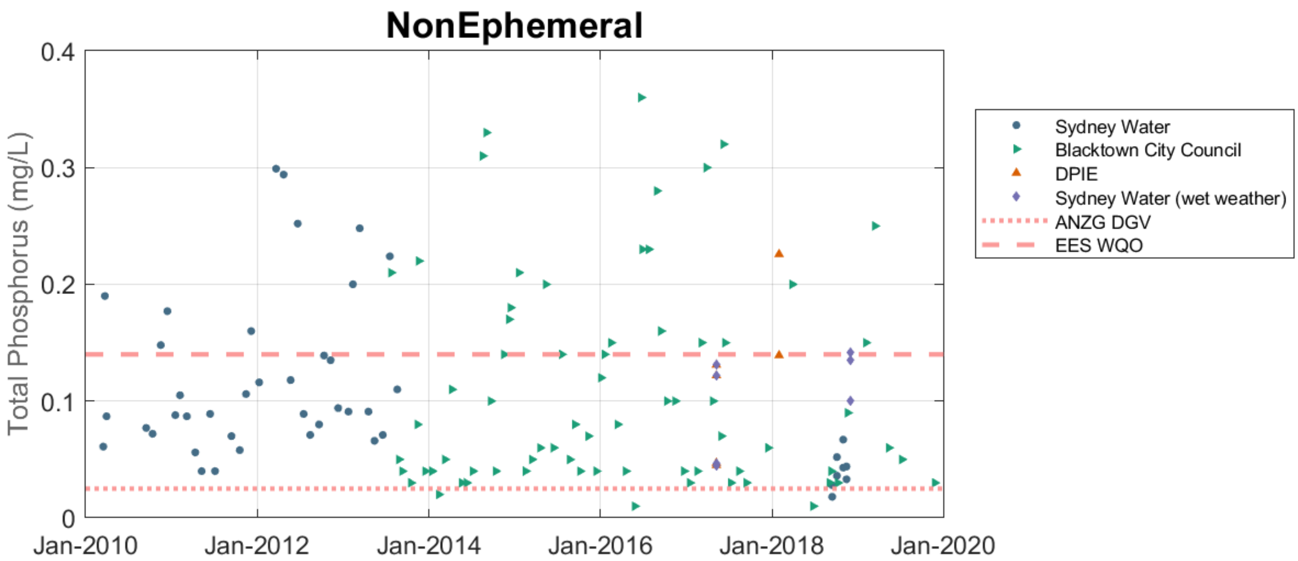


Figure 5-10 Total Phosphorus monitoring data for non-ephemeral reaches of South Creek

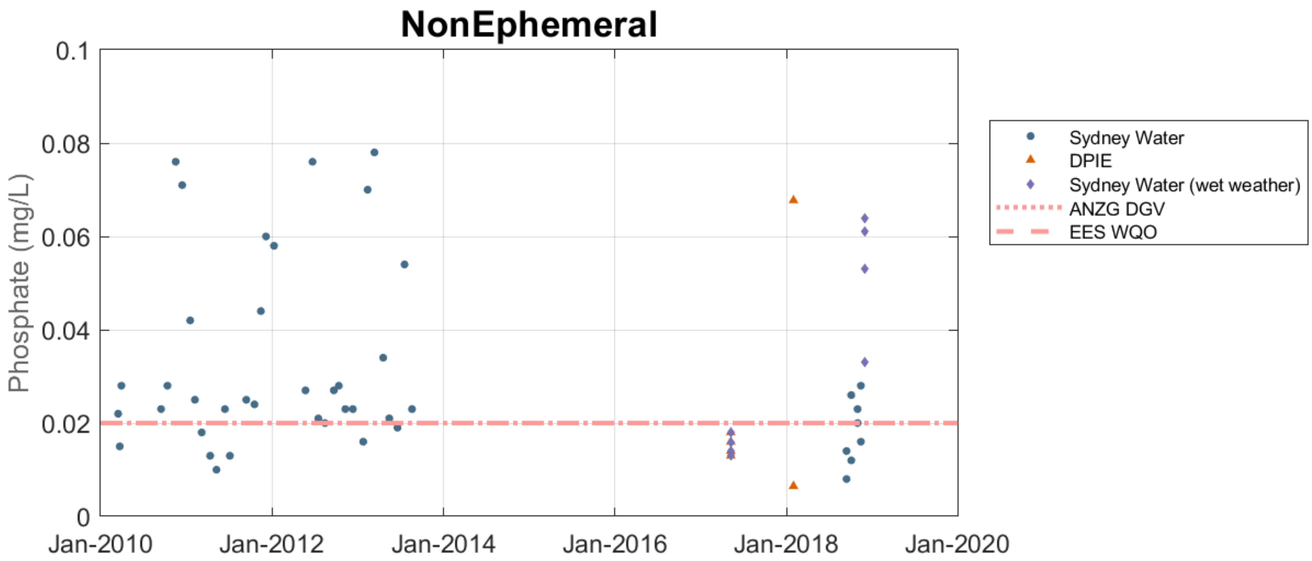


Figure 5-11 Phosphate monitoring data for non-ephemeral reaches of South Creek

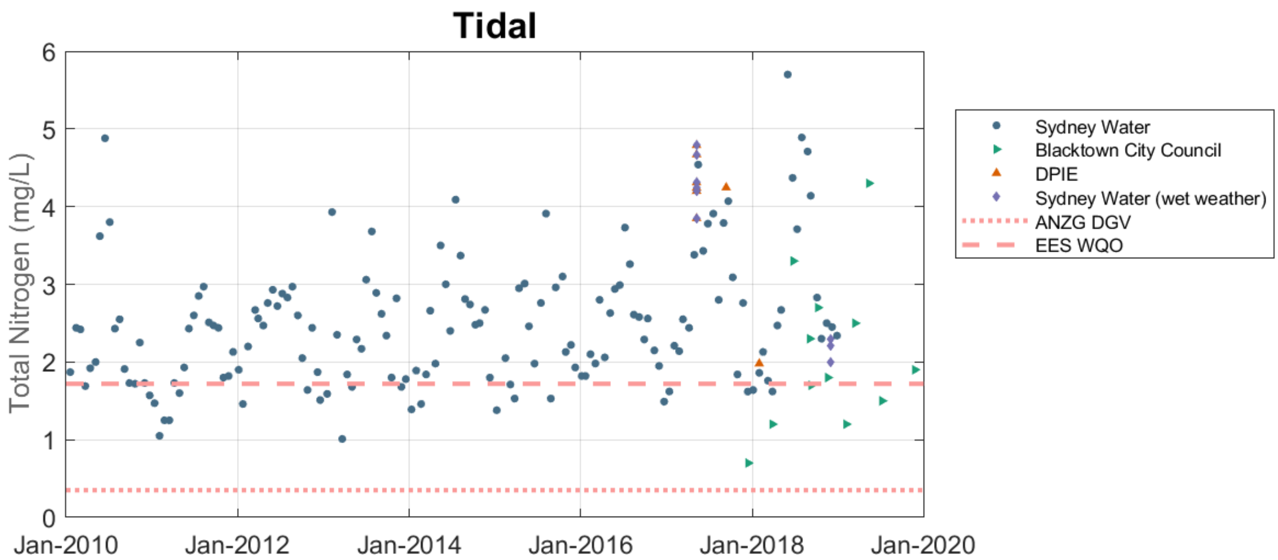


Figure 5-12 Total Nitrogen monitoring data for tidal reaches of South Creek

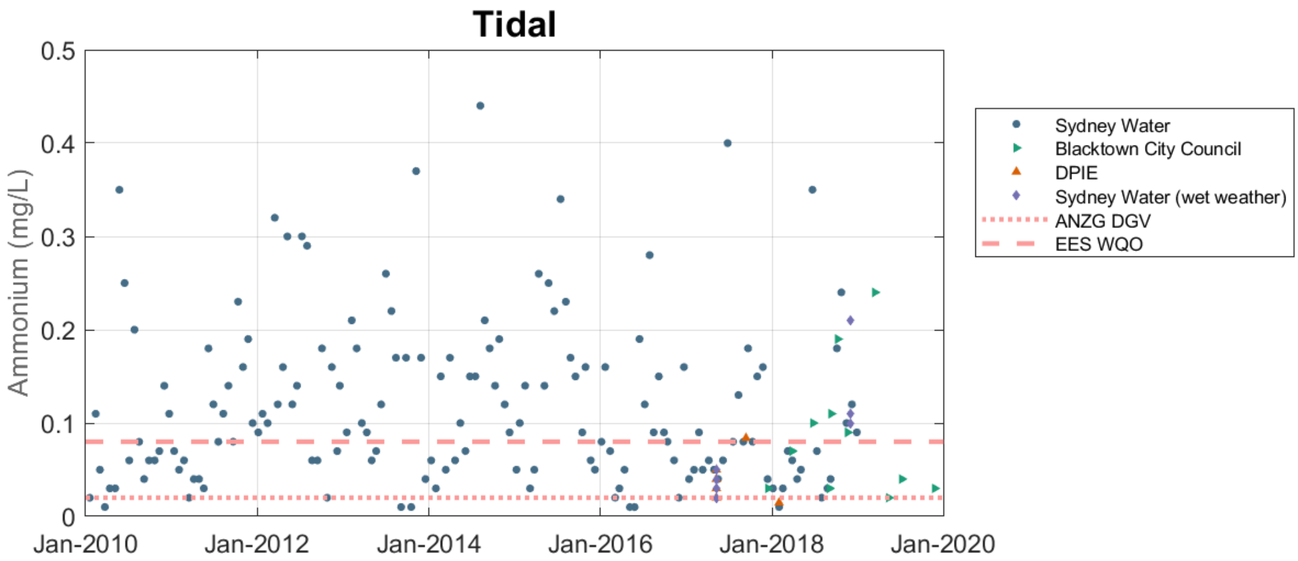


Figure 5-13 Ammonia monitoring data for tidal reaches of South Creek

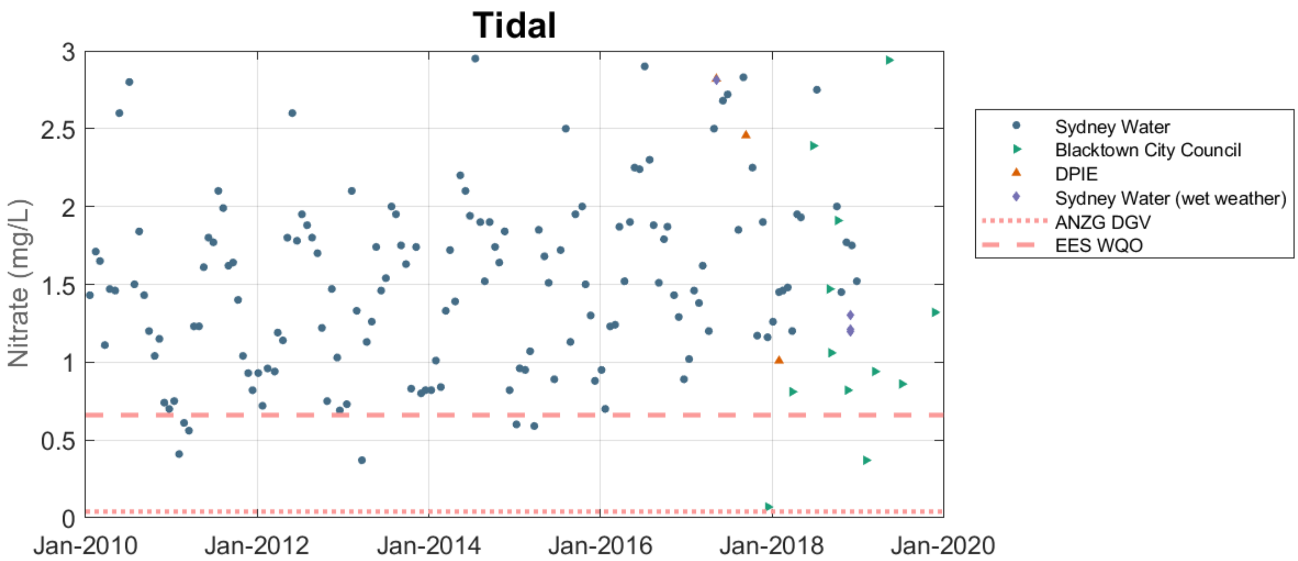


Figure 5-14 Nitrate monitoring data for tidal reaches of South Creek

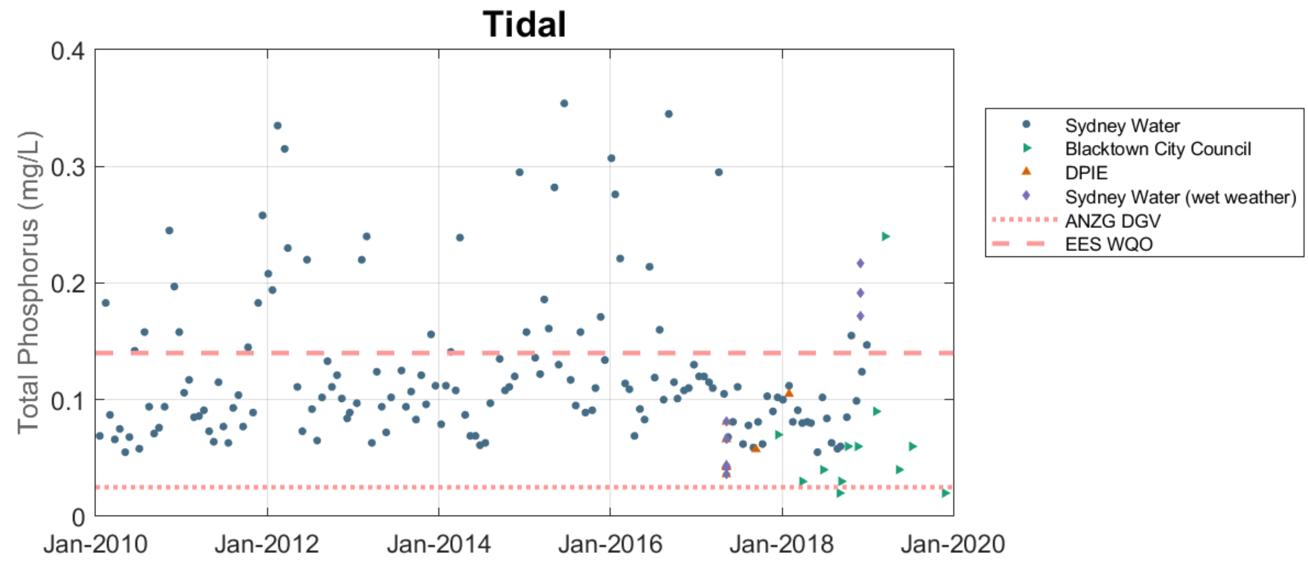


Figure 5-15 Total Phosphorus monitoring data for tidal reaches of South Creek

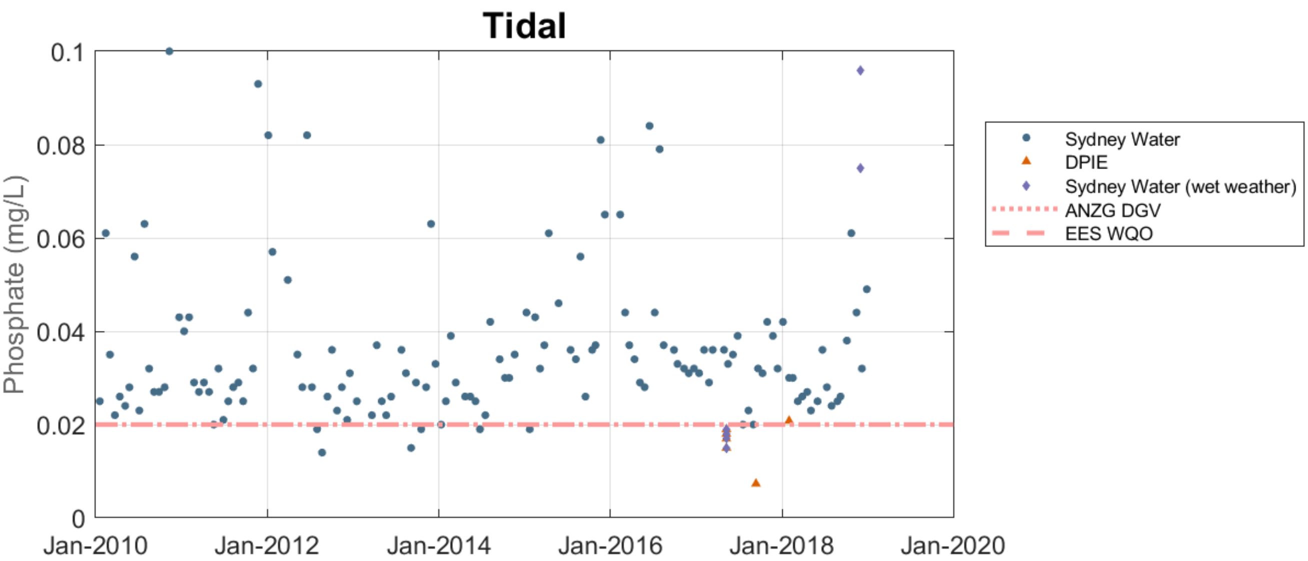


Figure 5-16 Phosphate monitoring data for tidal reaches of South Creek

The Sydney Water STSIMP interpretative report (2018) provided further context with respect to nutrient loads to the creek and also ambient water quality.

The report identified that the population in the South Creek catchment had increased by 45% between 1992 and 2017, but despite this growth, total nitrogen and phosphorus loads had significantly reduced by 86% and 92% respectively due to upgrades to the WWTPs/WRPs. Despite these reductions, it was also noted that nutrient loads have trended upwards between 2011 and 2017 due to a combination of population growth (~2.2% per year) and more frequent storm events. With the increasing wastewater inflows requiring treatment, WWTP efficiency was also reduced resulting in increased nutrient concentrations in releases and ultimately in nutrient loads to the creek.

With respect to impacts from South Creek on the lower Hawkesbury River, the STSIMP interpretative report identified that below Windsor and downstream of the confluence, water quality is comparatively poor with very high levels of nutrients, chlorophyll *a* and algae. Trend analysis performed on flow-adjusted data at the confluence, however indicated that there have been significant decreases in total nitrogen (73%), dissolved inorganic nitrogen (79%), total phosphorus (59%), filterable phosphorus (75%) and turbidity (29%) in the 25 years from 1992 to 2017.

Further investigations were therefore undertaken in the form of step trend analysis, evaluating two different periods before and after the WWTP upgrades at Quakers Hill, St Marys and Riverstone in 2011. This analysis indicated that "*Nutrient concentrations decreased across the board at South Creek (NS04) in the historical period from 1992 to 2011. All four parameters (total nitrogen: 80%, dissolved inorganic nitrogen: 85%, total phosphorus: 73% and filterable total phosphorus: 83%) exhibited significantly decreasing trends during this period between 1992 to 2011. However, no significant trends were found in these parameters for the short-term recent period after completion of upgrade works in 2011. This confirms that although significant nutrient reduction was achieved at South Creek by 2011, the nutrient level stabilised after that point".*

With respect to interpretative analysis from earlier studies, the 2009 technical report by the DECC concluded that long-term median total nitrogen levels were also strongly linked to areas under the influence of WWTP releases, increasing initially downstream of South Creek and Eastern Creek.

The CRC for Irrigation Futures (2007) undertook an extensive assessment of historical monitoring data in the creek and drew the following conclusions:

- The major water quality issues in South Creek are related to high nutrient concentrations derived from both point and diffuse pollution sources and subsequent algal and aquatic weed growth.
- The St Marys, Quakers Hill and Riverstone WWTPs historically contributed significant nutrient loads to the Hawkesbury, downstream of the junction with South Creek. Upgrades to these plants have reduced the levels of nitrogen and phosphorus considerably, although modelling demonstrated that even the highest level of nutrient removal at these facilities would not reduce nutrient levels sufficiently to meet ANZECC (2000) guidelines for a substantial proportion of the time.
- It has been established that diffuse sources such as urban and agricultural runoff have just as great if not greater effect on water quality. Estimates derived after the WWTP upgrades indicate that around 56% of the pollutant load of total nitrogen and 64% of total phosphorus in the South Creek catchment was contributed by agriculture compared to 27% and 9% from WWTPs (EPA, 2002).
- A more detailed breakdown of the estimated sources of phosphorus in the South Creek catchment indicate that 44% was derived from agricultural runoff, 28% from urban runoff, 18% from unused or cleared land, 9% from WWTPs and 1% from natural runoff (EPA, 2003). As urban development replaces agricultural land in the catchment, urban runoff is likely to become the dominant degrading factor in the future (DEC, 2004).
- Although each of the remedial actions that have been undertaken in South Creek catchment in relation to water quality have been able to demonstrate improvements, it seems that collectively these actions have not been able to keep pace with continuing population growth and urbanisation. The net effect of water quality in South Creek catchment can be clearly seen in the impacts that inflows have on the water quality in the Hawkesbury-Nepean River downstream of the confluence.

5.2.5.2 Algae

The higher concentrations in nutrients and particularly bioavailable species provide for favourable conditions in algal growth during extended dry weather periods. The figures below present the timeseries of monitoring data for chlorophyll *a* in the non-ephemeral and tidal sections of the creek.

The data for the non-ephemeral reaches indicates the potential for non-compliance with both the ANZG and EES waterway objectives. With increases in algal growth within the tidal reaches, further non-compliances with these objectives can be observed in lower sections of the creek.

Seasonal trends are again not easily definable with Table 5-2 presenting seasonal statistical analysis for the data collected at monitoring site NS26, upstream of Dunheved Creek.

Table 5-2 Statistical analysis of Chlorophyll *a* monitoring data at NS26 (upstream of Dunheved Creek)

Percentile	Total Chlorophyll a (µg/L)	
Season	Oct - Mar	Apr - Sep
10th percentile	4.1	2.6
Median	9.4	10.2
90th percentile	39.9	37.9

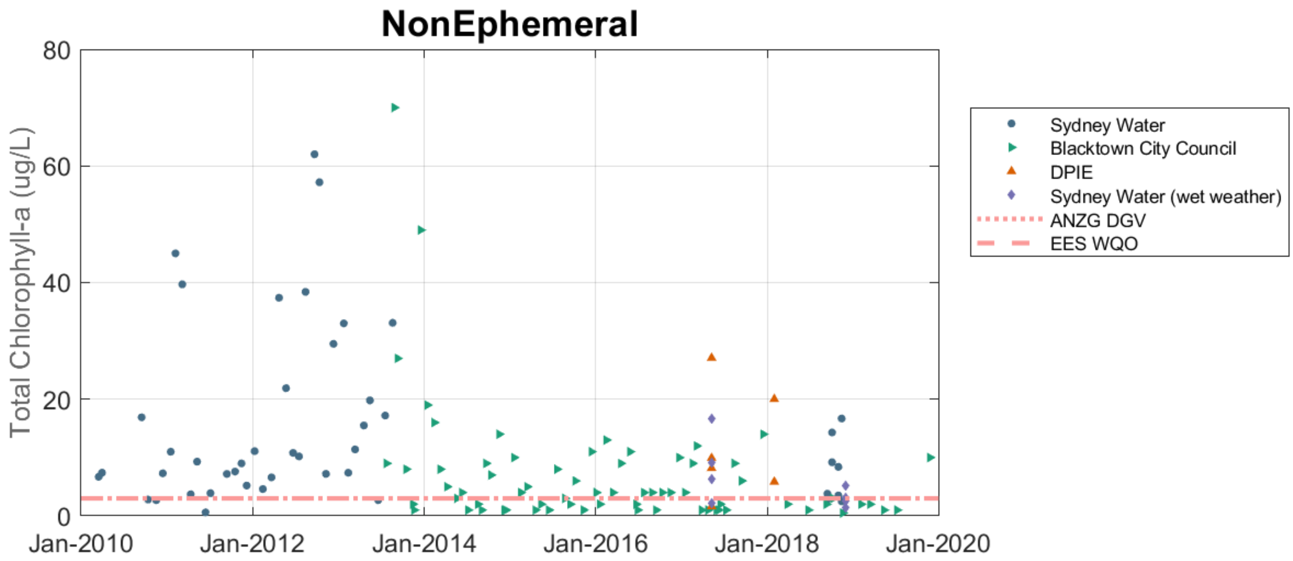


Figure 5-17 Chlorophyll *a* monitoring data for non-ephemeral reaches of South Creek

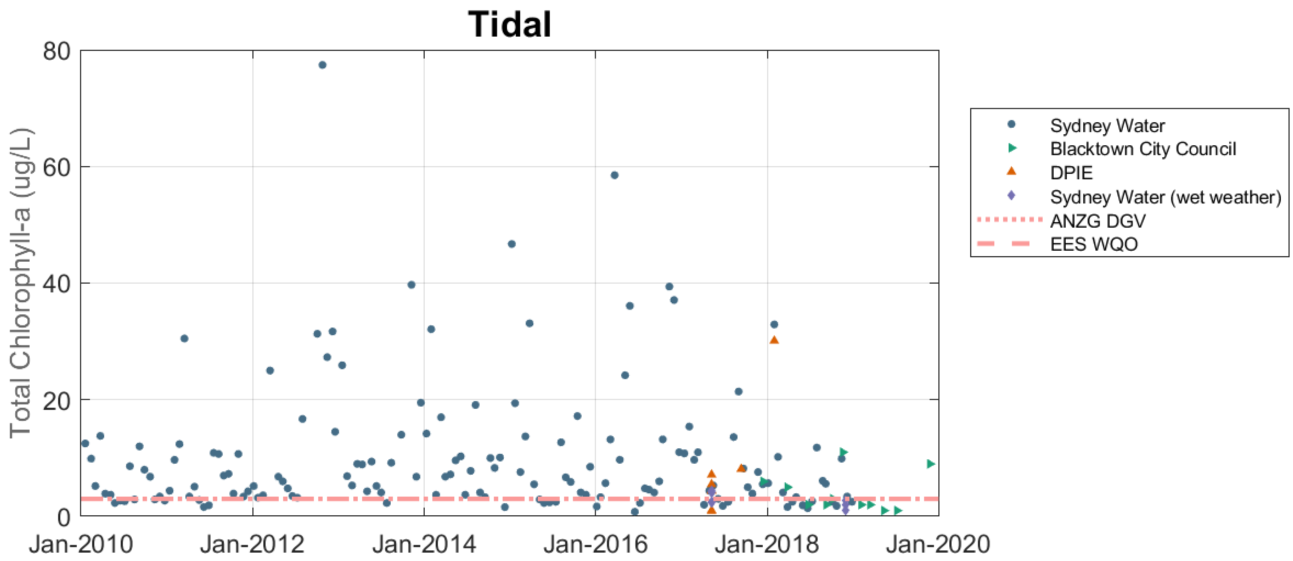


Figure 5-18 Chlorophyll *a* monitoring data for tidal reaches of South Creek

The Sydney Water STSIMP interpretative report (2018) provided further context with respect to algal growth in the creek. The following key findings were drawn:

- There is relatively limited algal data, however a significantly increasing trend in the total algal biovolume (254%) was observed over the long-term from 1996 to 2017.
- This in turn has impacts on the water quality of the lower Hawkesbury River, below Windsor. Downstream of the confluence, the quality is comparatively poor with very high levels of nutrients, chlorophyll *a* and algae.
- Further step trend analysis was undertaken with respect to chlorophyll *a*, for the periods before and after the WWTP upgrades (including the commissioning of the St Marys AWTP). The findings were as follows:
  - Despite limitations in data availability, the analysis revealed a significantly increasing trend in total algal biovolume but also a significantly decreasing trend in blue-green algal biovolume prior to the upgrades.
  - During the period from 2011 to 2017, no significant trends were identified for chlorophyll *a* and/or algae.

A recent modelling study on the Hawkesbury Nepean River and South Creek found a clear response with reduced chlorophyll *a* at South Creek with increased flow, irrespective of whether the increased flow was from high quality recycled water or tertiary treated wastewater (Sydney Water, 2015). Consistent with the findings from this report, flow and other catchment factors were found to be the main drivers for algal abundance.

5.2.5.3 Other water quality indicators

5.2.5.3.1 Salinity

Figure 5-19 and Figure 5-20 present monitoring data for the non-ephemeral and tidal reaches of South Creek. Concentrations generally vary between minimum levels of 0.1 g/L up to a maximum of ~0.75 g/L, which correlates with the EES derived waterway objective. There are potential signs of seasonal trends in both the non-ephemeral and tidal reach data, but the variations are likely to be more significantly influenced by rainfall runoff events in the catchment and when the monitoring was undertaken relative to these events.

Due to the variability and temporal limitations in the datasets, it is not viable to establish any longer term trends.

Also of note, the tidal reaches include monitoring sites near the confluence with the Hawkesbury River, indicating that although the river is tidal, the water is fresh and upstream of the salinity wedge. Further discussion regarding tidal influences in the Hawkesbury River is provided in Section 5.3.2.6.

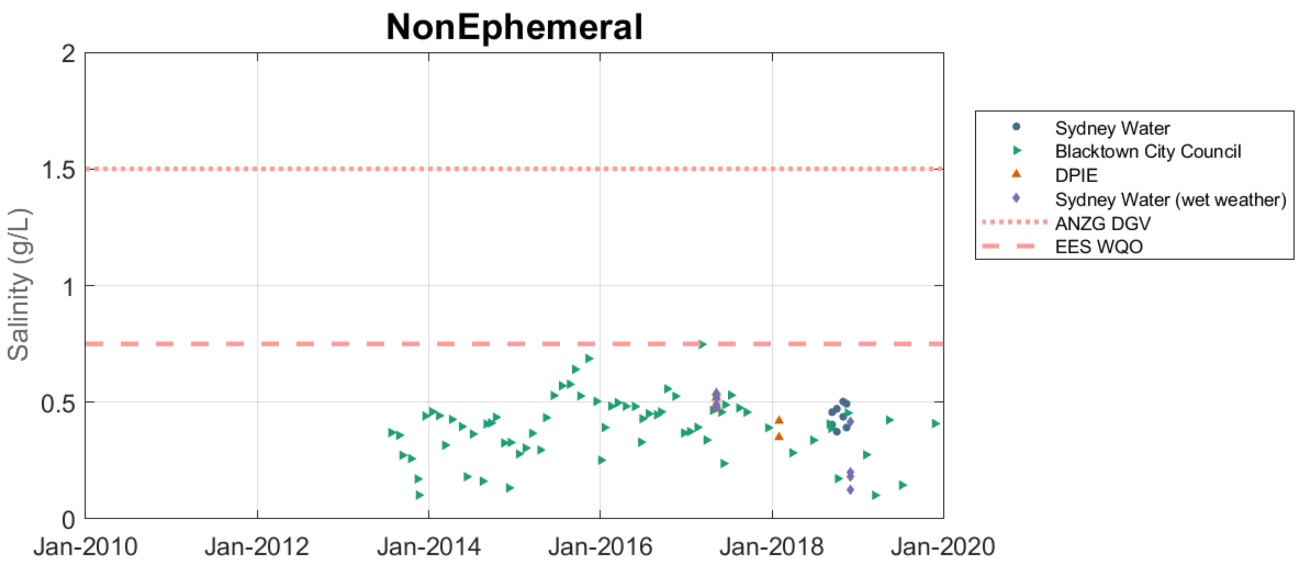


Figure 5-19 Salinity monitoring data for non-ephemeral reaches of South Creek

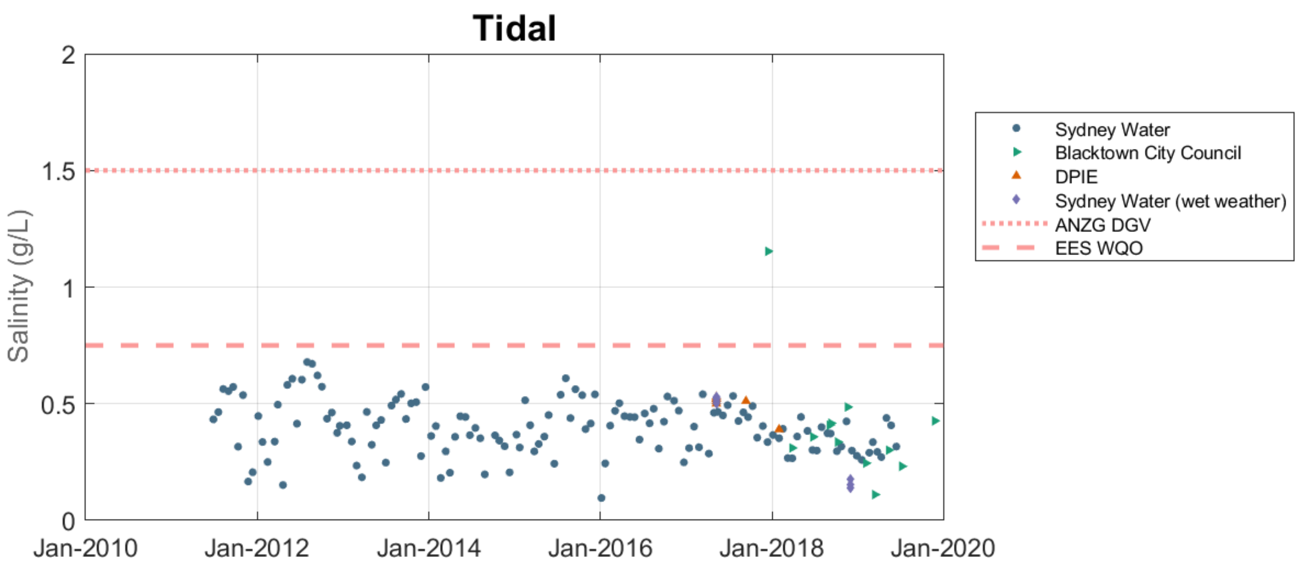


Figure 5-20 Salinity monitoring data tidal reaches of South Creek

The CRC for Irrigation Futures (2007) also discusses salinity and how it can arise as a result of environmental change brought about by natural processes or human impacts. The report states that in Western Sydney, salinity is an existing process that has been exacerbated by the dramatic changes that have occurred in the way water is cycled through the environment (Sinclair et al. 2004).

The nature of the emerging problem of salinity in South Creek catchment was first established in 1997 (Dias & Thomas, 1997) when 7% of the catchment was found to show signs of being affected by soil salinity and 30% was found to have the potential to become salt affected. The work of Dias & Thomas highlighted the issues regarding the rising water table and salinity.

As a result of ongoing research activities, salinity issues including dryland and urban salinity, that are present in South Creek catchment, have been recognised as significant and worsening problems across much of Australia. This has resulted in a range of government initiatives aimed at developing prevention and remediation strategies.

5.2.5.3.2 Total Suspended Solids

Figure 5-21 and Figure 5-22 present monitoring data for total suspended solids the non-ephemeral and tidal reaches of South Creek. The datasets are relatively limited, particularly within the tidal section of the creek.

Concentrations are expected to be heavily dependent on rainfall and runoff events, ranging from minimum levels of below 5 mg/L up to concentrations of ~100 mg/L, collected during targeted wet weather monitoring.

The EES and ANZG waterway objectives applicable to South Creek are 30 mg/L and 40 mg/L respectively. Therefore, despite significant spikes that are expected during wet weather, the non-ephemeral reaches appear to be compliant with both sets of objectives. Insufficient data is available to assess compliance in the tidal reaches of the creek.

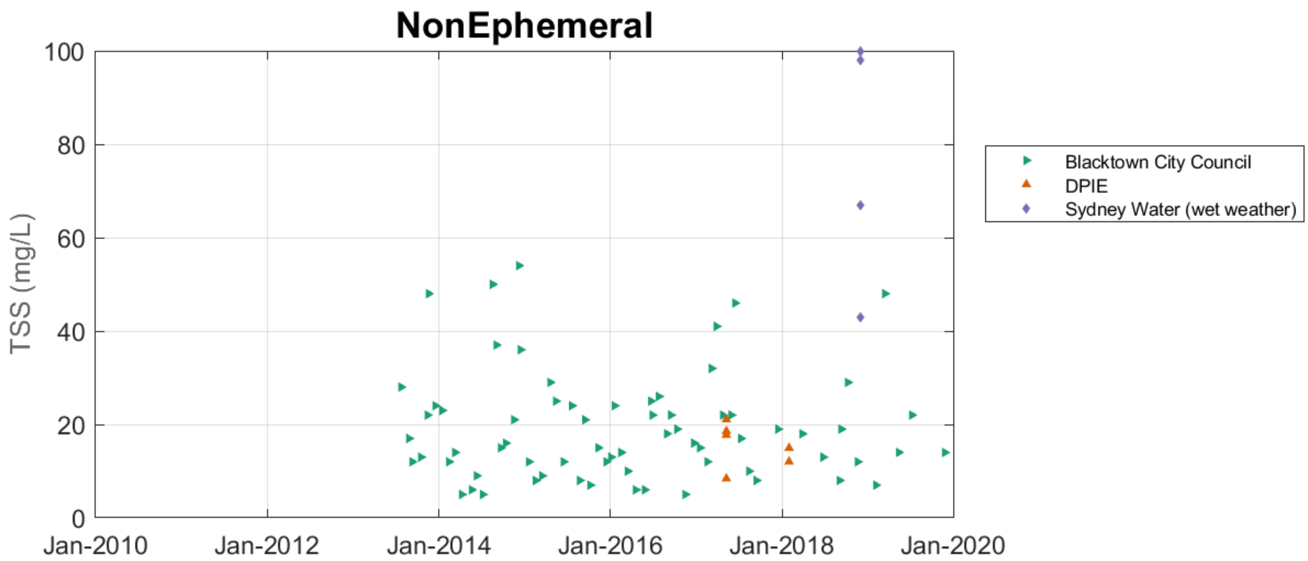


Figure 5-21 TSS monitoring data for non-ephemeral reaches of South Creek

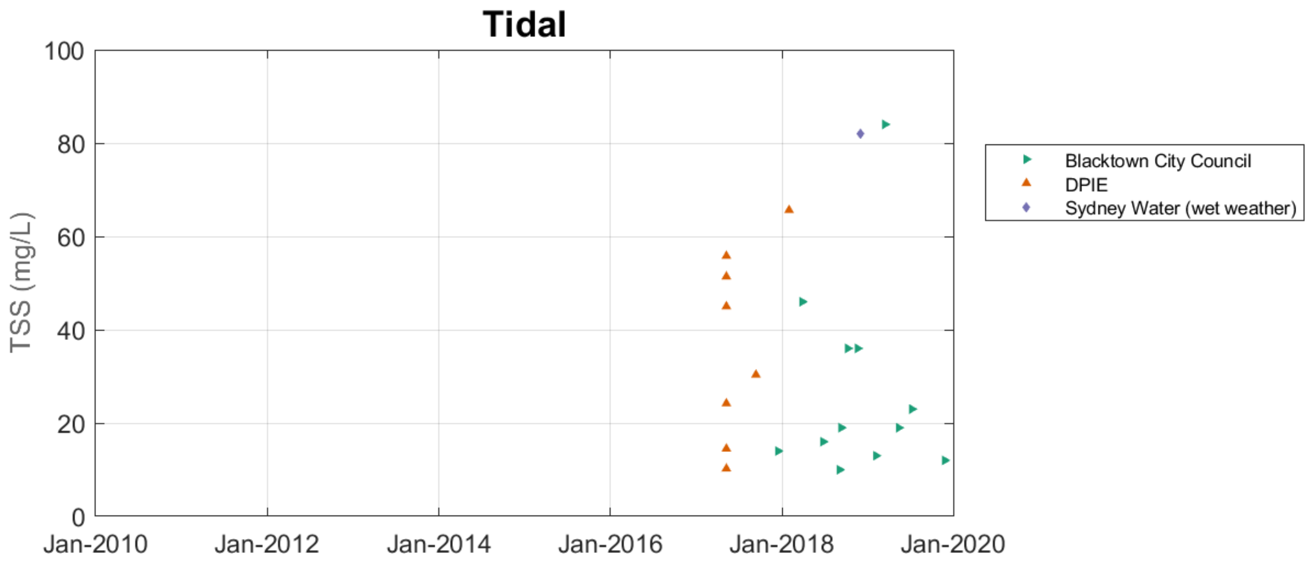


Figure 5-22 TSS monitoring data for tidal reaches of South Creek

5.2.5.3.3 Toxicants

Only limited monitoring data was identified with respect to toxicants, particularly in the ephemeral reaches near the proposed AWRC and its release point. While restricted to sampling from March 2020, the baseline monitoring program (Sydney Water, 2020d) does however provide some indication of potential concentrations for selected toxicants within the creek. Table 5-3 presents statistical analysis for data collected from March 2020 to June 2021 at monitoring site NS45, approximately 3.8 km upstream of the proposed AWRC release point (refer Figure 7-1). With the exception of chlorine, which is not monitored, the analysis focuses on the suite of toxicants previously identified in Section 4.7.2.1.1.

From this limited dataset, it can be observed that there is potential for elevated concentrations above the relevant toxicant DGVs for nitrate, copper and manganese.

Table 5-3 Statistical analysis of toxicant monitoring data at NS45 (baseline monitoring site upstream of the AWRC)

Percentile	Ammonia (mg/L)	Nitrate (mg/L)	Aluminium (mg/L)	Copper (mg/L)	Manganese (mg/L)	Zinc (mg/L)
Minimum	0.01	0.01	0.003	0.0020	0.165	0.002
10^{th} percentile	0.01	0.07	0.003	ID	ID	ID
Median	0.05	0.91	0.003	0.0021	0.241	0.002
90^{th} percentile	0.12	2.09	0.009	ID	ID	ID
95^{th} percentile	0.13	3.63	0.010	ID	ID	ID
Maximum	0.29	4.05	0.012	0.0032	0.317	0.007
Number of samples	22	22	22	3	3	3
Toxicant DGV	1.75*	2.40**	0.055**	0.0014**	0.100***	0.008**

Table notes:

* *Toxicant DGV for the protection of aquatic ecosystems (95% protection) as typically recommended for slightly to moderately disturbed ecosystems – refer ANZECC (2000). Modifications to the DGV have been made in line with ANZECC (2000) based on a median ambient pH of 7.4, which was determined from monitoring data collected from March 2020 to June 2021, at a site upstream of the proposed release point (site NS45).*

** *Toxicant DGV for the protection of aquatic ecosystems (95% protection) as typically recommended for slightly to moderately disturbed ecosystems – refer ANZECC (2000)/ANZG (2018). Aluminium DGV specified for pH >6.5.*

*** *DGV for the recreational purposes – refer NHMRC (2008). The ANZG (2018) DGV for the protection of aquatic ecosystems is significantly higher with a value of 1.9 mg/L.*

ID Insufficient data for analysis

Monitoring results for Aluminium, Copper, Manganese and Zinc represent filtered concentrations.

5.3 Hawkesbury Nepean River

5.3.1 Catchment description

The Hawkesbury Nepean catchment represents one of the largest coastal basins in NSW. With an area of approximately 21,400 km^2, over 70% of the catchment consists of mountainous terrain, with about 10% of flat terrain. A further 10% of the total catchment comprises of undulating plateau type country and is termed the south terrain. The maximum elevation is about 1,290 m above sea level.

Land use data (circa 2017) indicates that, downstream of the Warragamba Dam, the catchment is predominantly forest (76%), followed by grazing (13%), urban (3%), peri-urban (6%), horticulture (<1%) and cropping (<1%). A map of land use distribution (2017) is presented in Figure 5-23.

Major towns that are located along the river system include Penrith, Gosford, Goulburn, Camden, Lithgow, Richmond, Windsor, Moss Vale, Mittagong and Bowral.

5.3.2 Waterway description

5.3.2.1 Overview of the river system

The main rivers and tributaries include the Nepean, Hawkesbury, Avon, Cataract, Colo, Cordeaux, Coxs, Grose, MacDonald, Wollondilly, Warragamba and Wingecarribee rivers. There are also a significant number of contributing creeks including Berowra, Bundanoon, Cascade, Cattai, Colo, Cowan, Sooley, South and Mooney Mooney creeks.

The headwaters of the Nepean River rise near Robertson, about 100 kilometres south of Sydney before flowing north through an unpopulated catchment area and later past the town of Camden and the city of Penrith. Near Wallacia it is joined by the dammed Warragamba River; and north of Penrith, near Yarramundi, at its confluence with the Grose River, the Nepean River becomes the Hawkesbury River. It then continues on a meandering course for ~140 km, combining with the significant tributaries of South Creek, Cattai Creek, Colo Creek and MacDonald River before reaching the ocean between Barrenjoey and Box Head. Figure 5-24 presents a map of the main river system and its tributaries.

5.3.2.2 Flow modification from dams and weirs

Flows within the river system are heavily modified and controlled by major dams, as well as a series of weirs which also retain river flows. The river system represents the main water supply for Sydney's population, with the Warragamba Dam providing approximately 80% of the water to the Greater Sydney metropolitan area and the lower Blue Mountains region. Other key water storages include the Nepean, Avon, Mangrove Creek, Cataract and Cordeaux dams. The Broughtons Pass and Pheasants Nest water supply diversion weirs located near Wilton and Appin also form major retention structures on the Cataract and Nepean rivers. The area upstream of the water supply storage dams is estimated to be approximately 10,000 km^2, which is just less than half of the total catchment area (SKM, 2014). The location of the major dams and weirs is presented in Figure 5-15.

In addition to potable water supply, there is also an extensive network of extractions from the river and its tributaries to supply water for the region's significant agricultural production. Figure 5-26 presents the indicative location of these extractions. In the absence of reliable metered data for this network, extraction rates were derived from the Hawkesbury-Nepean IQQM model developed originally by the NSW Office of Water.

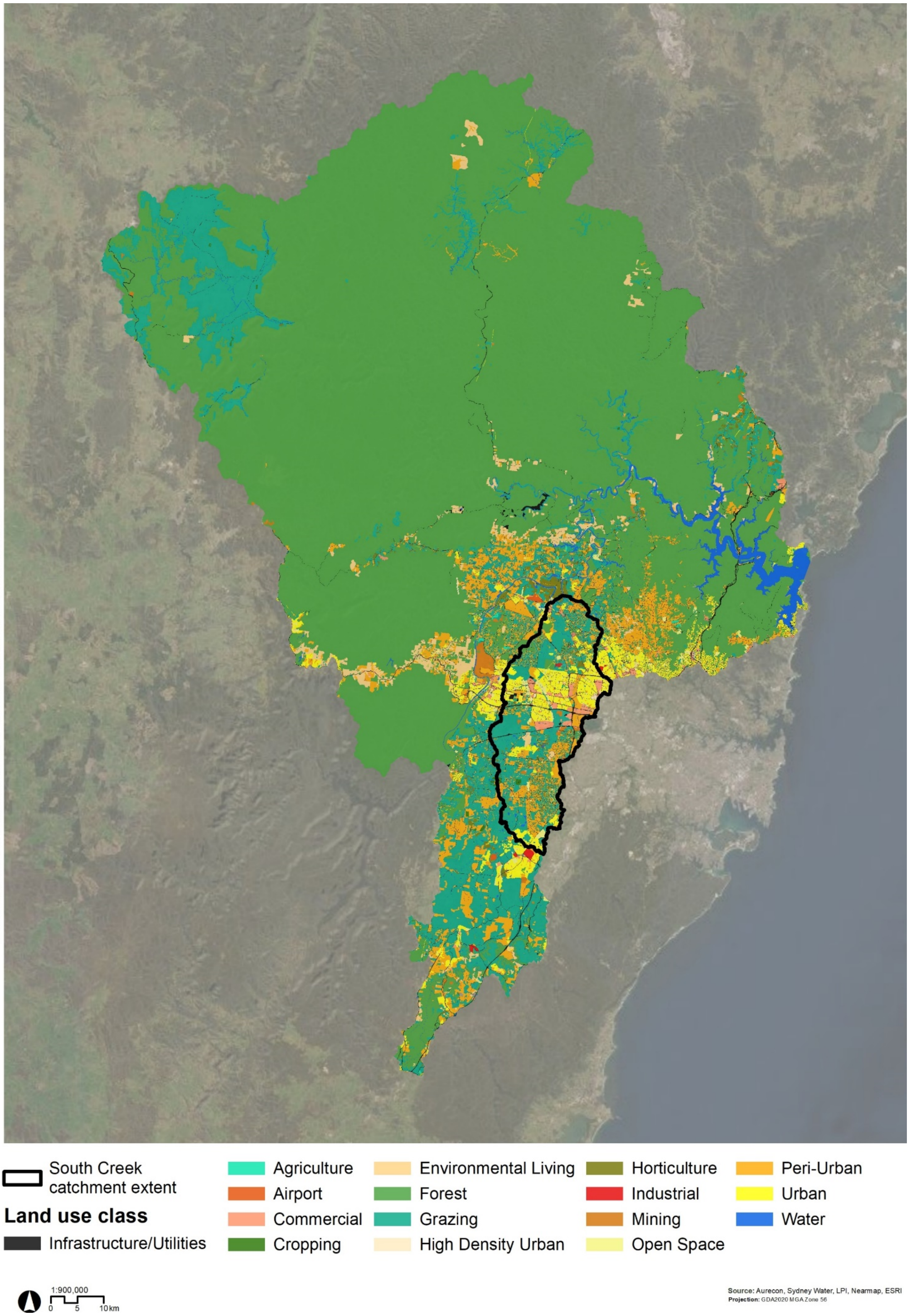


Figure 5-23 Distribution of land use in the Hawkesbury Nepean and South Creek catchments

Figure 5-24 The Hawkesbury Nepean River and its tributaries

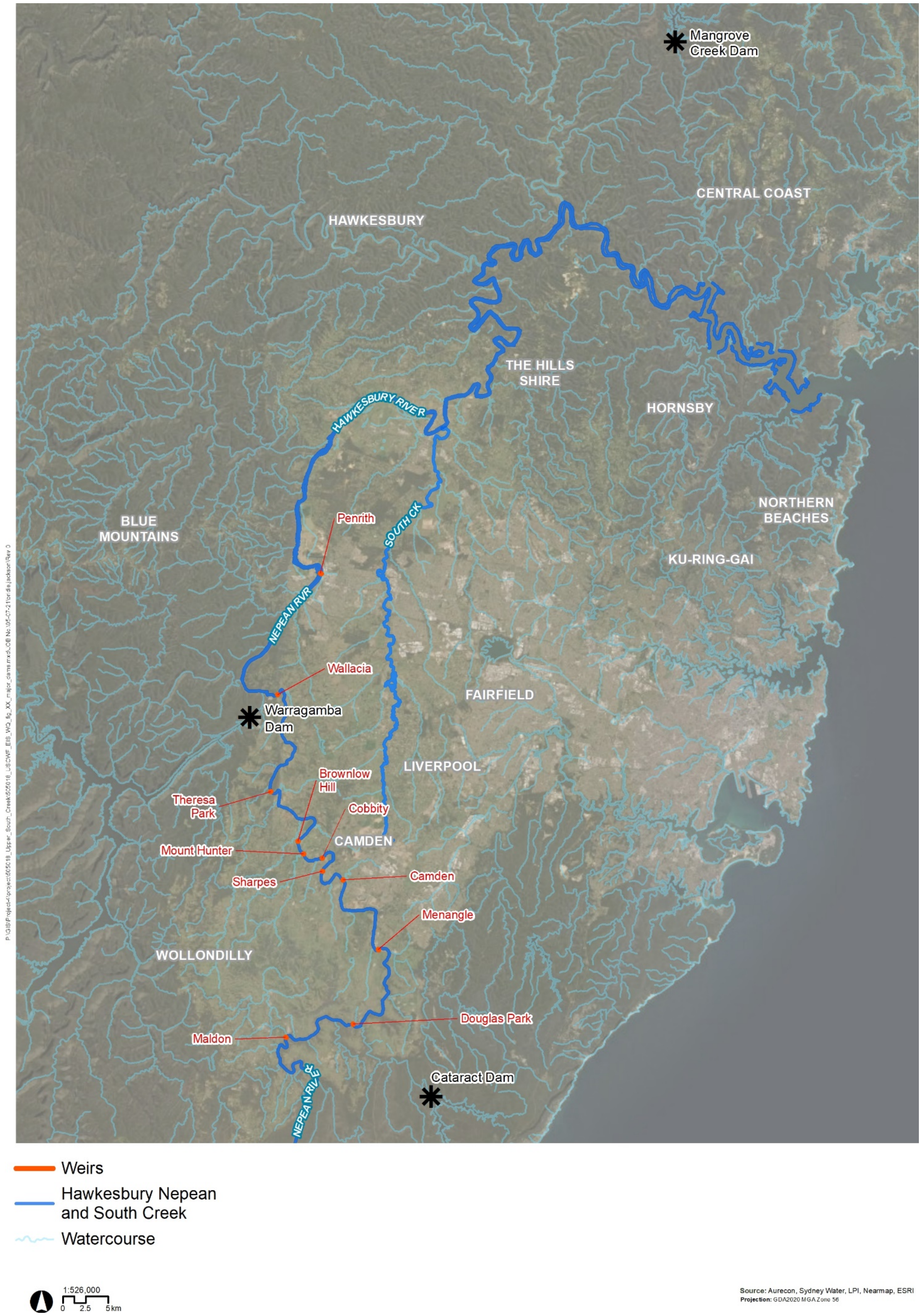


Figure 5-25 Major dams and weirs within the Hawkesbury Nepean River

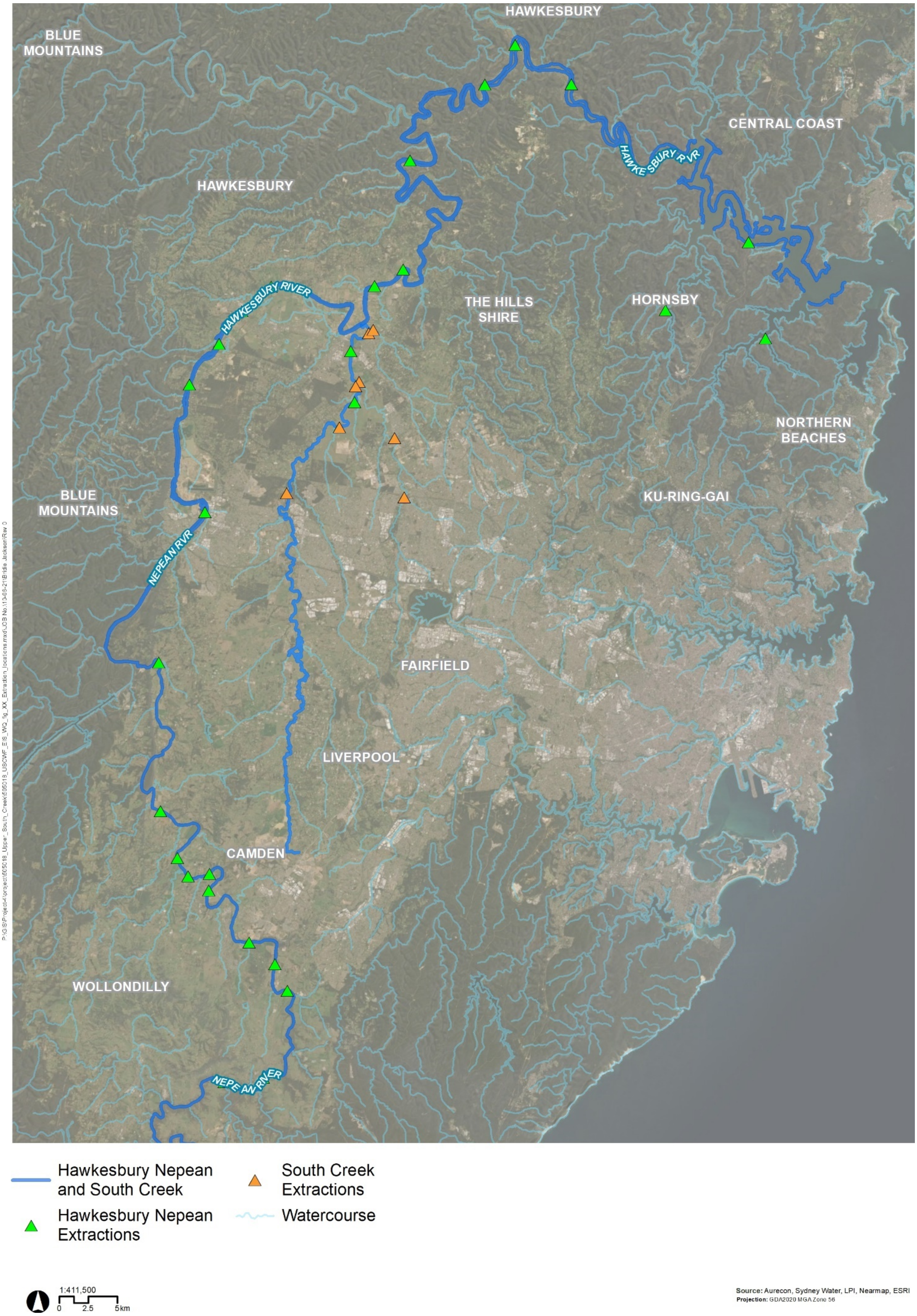


Figure 5-26 Extraction locations within the Hawkesbury Nepean River and South Creek

5.3.2.3 Warragamba Dam releases and environmental flows

To counteract the presence of the weirs and dams, as well as significant levels of water demand, releases from the Warragamba Dam and environmental flow releases from the Upper Nepean system have been introduced to provide for the following:

- Protection of aquatic ecosystems and reduction of aquatic weeds and frequency of algal blooms
- Improvement in river health including conditions for native fauna and river-dependent plants that rely on different flows to trigger migration and breeding
- Protection of river condition for recreation such as boating and swimming

Of particular relevance are the following two release regimes that are managed by WaterNSW.

5.3.2.3.1 The Warragamba River system

Five megalitres of water is released each day from Warragamba Dam into the downstream Warragamba River to dilute effluent releases from the Wallacia WWTP. Another 17 ML/d of water is released in winter, increasing to 25 ML/d in summer. These additional flows effectively replace water extracted at Sydney Water's North Richmond Water Filtration Plant (WFP). These releases are specified in the Water Sharing Plan for the Greater Metropolitan Region.

5.3.2.3.2 Upper Nepean system

Daily variable flows from the Upper Nepean dams and water supply weirs for environmental purposes were introduced from July 2010. At times of low flow, all inflows to the Upper Nepean dams and water supply weirs are released to the downstream river. Daily variable inflows of up to 20.1 ML are released from the Nepean Dam, up to 6.8 ML from the Avon Dam, up to 4.5 ML from the Cordeaux Dam and up to 14.5 ML from the Cataract Dam. These releases are passed through Pheasants Nest and Broughtons Pass weirs to the downstream river. Inflows from the catchments between the dams and weirs are also released from the weirs, including up to 4.4 ML from the Pheasants Nest Weir and up to 4.5 ML from the Broughtons Pass Weir. At times of higher flow, an additional 20 % of inflows to each dam and water supply weir are released to the downstream rivers.

5.3.2.4 Replacement flows

As discussed previously in Section 5.2.2.4, treated water from St Marys, Quakers Hill and Penrith wastewater treatment plants is treated via reverse osmosis technology at the St Marys AWTP. The advanced treated water is then pumped to Penrith where up to 50 ML/day is released into the Nepean River via Boundary Creek.

Currently the Penrith WRP transfers ~12 ML/d to the AWTP but this is estimated to increase to 18 ML/d by 2036. Details regarding the transfer rates for St Marys WRP and the Quakers Hill WWTP are provided in Section 5.2.2.4.

5.3.2.5 Flooding

The Hawkesbury Nepean catchment is susceptible to extensive flooding. The most significant historical events include 1867, 1900, 1914, 1925, 1933, 1961, 1974, 1978, 1986, 1988, 1990, and most recently during the 2021 New South Wales floods. These events have commonly resulted in inundation and damage to towns, agricultural land and residences.

In the 1950s, the increased magnitude and frequency of flooding at that time imposed a demand for some protection of flood plains. There was consequently a notable change from a drought-dominated regime to a flood-dominated regime in the Hawkesbury-Nepean catchment.

The Warragamba Dam was completed in 1960 and has assisted in reducing flood levels in the Penrith area. In 1982, a Flood Plain Management Study for the Hawkesbury-Nepean Valley was released. It called for liaison between local councils and relevant state government authorities in order to reduce flood losses, improve the environment of flood plain areas and collect information and promote research in the area of flood mitigation. Further studies into flood management have been completed over the years including most recently, the Hawkesbury-Nepean Valley Regional Flood Study in 2019.

5.3.2.6 Tidal influence

Tidal influence in the river, exhibited in the form of flow reversal and tidal amplitudes, extends up to near Yarramundi and the confluence with the Grose River. However, while the tidal influence extends to this location, salinities remain fresh to brackish for a significant distance downstream. Higher salinities (> 5 g/L) are not typically observed until approximately 60 km upstream from the estuary mouth, near Wisemans Ferry.

5.3.3 Pressures and water management issues

The Hawkesbury Nepean River faces similar challenges that are common to many coastal river systems on the east coast of Australia. Key pressures and water management challenges include intensive urban and industrial development, agricultural practices, land use change and clearing, significant alteration of the natural river flow, point sources including treated wastewater releases, as well as numerous, competing demands for water.

Specific water management issues within the catchment include:

- water quality: elevated contaminant levels, excess nutrients, algae and weed growth
- development: land use change including growth of urban, commercial and industrial areas
- agriculture: practices that affect downstream waterways including fertiliser use, riparian zone reduction
- environmental water: sufficient flows and freshes to maintain river health
- increasing demand for water: growing urban population and industry growth as well as extractions for agricultural practices
- water accounting: the need to meter and regulate licence holders to account for water extraction
- point sources: increases in pollutant loads from treated wastewater due to population growth

In terms of future pressures, continued and significant urban growth in the catchment and other parts of Sydney is expected to place increasing demand on the river's resources. It is planned that a large proportion of Sydney's urban growth will occur in the South West and Western Sydney Aerotropolis growth areas, which are primarily located within the catchment of South Creek, although some of this urban growth will extend into other parts of the overall Hawkesbury Nepean catchment.

The increasing urbanisation of the catchment is expected to not only result in a significant increase in demand for potable water but will also potentially result in changes in land use and commensurate point and diffuse sources of pollution.

5.3.4 Load analysis

Analysis of total nitrogen and total phosphorus loads has been undertaken to allow comparison of the contributions from various sub-catchments and treatment plants under current conditions (circa 2020). The loads were estimated through analysis of the model boundary conditions, discussed previously in Section 4.6 for both the representative wet and dry years.

The load analyses presented in the figures below, extend from upstream of Wallacia Weir to downstream of the Berowra Creek confluence. Figure 5-27 and Figure 5-28 present the cumulative analysis from upstream to downstream for all loads (including WWTPs and WRPs).

From these graphs, the influence of the major tributaries, such as Grose River, South Creek, Cattai Creek, etc can be observed (refer to Figure 5-24 regarding location of tributaries). To a lesser extent, the influence of some of the larger treatment plants can also be seen. The differences in load magnitude between the dry and wet years is also notable.

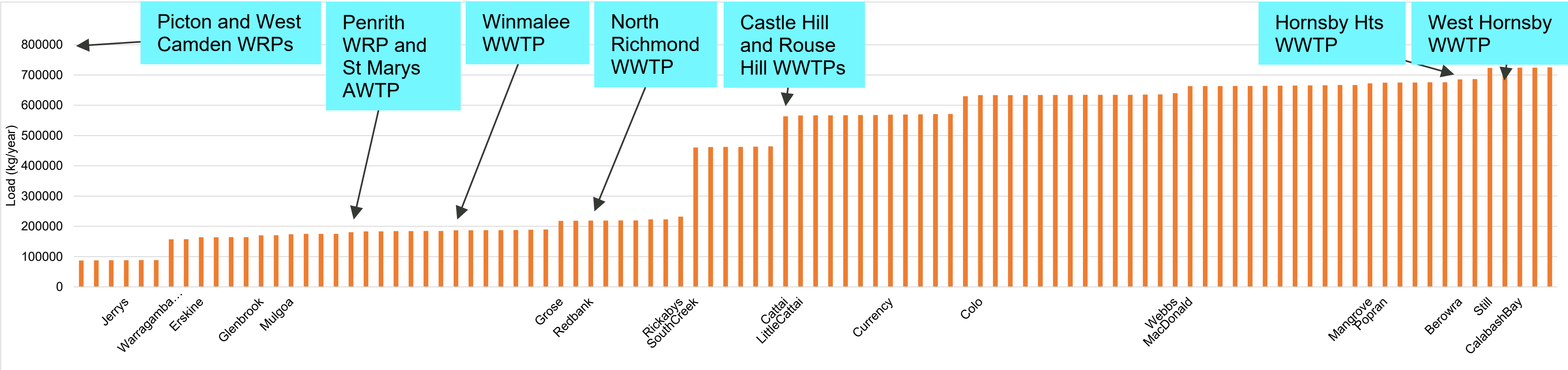


Figure 5-27 Total Nitrogen cumulative catchment loads for the Hawkesbury Nepean River (dry year)

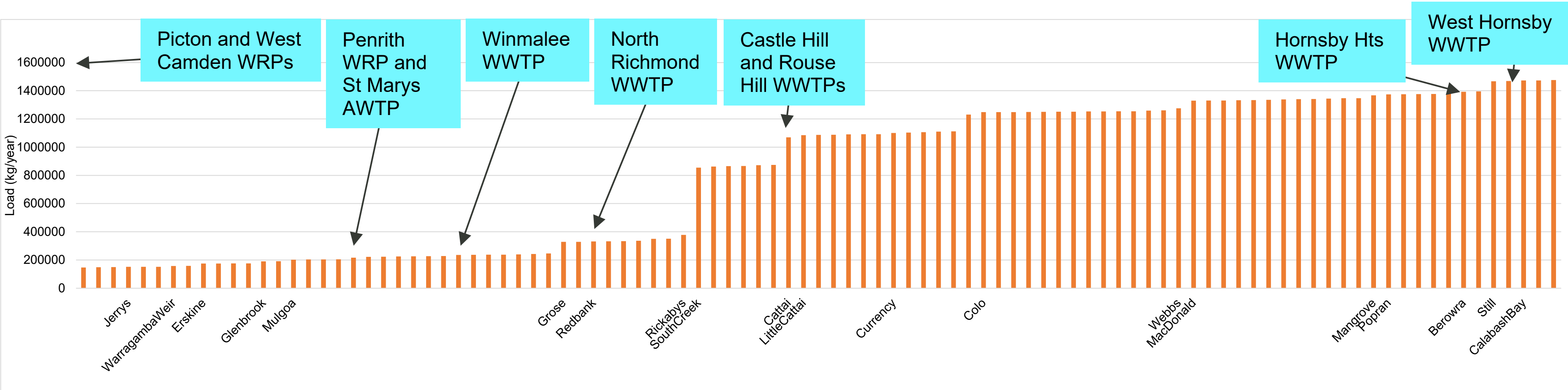


Figure 5-28 Total Nitrogen cumulative catchment loads for the Hawkesbury Nepean River (wet year)

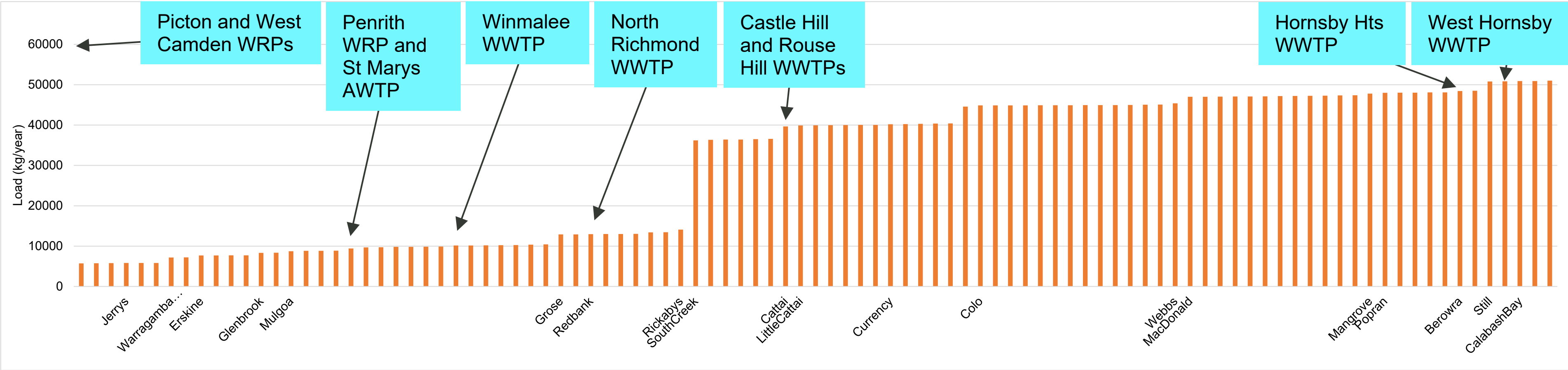


Figure 5-29 Total Phosphorus cumulative catchment loads for the Hawkesbury Nepean River (dry year)

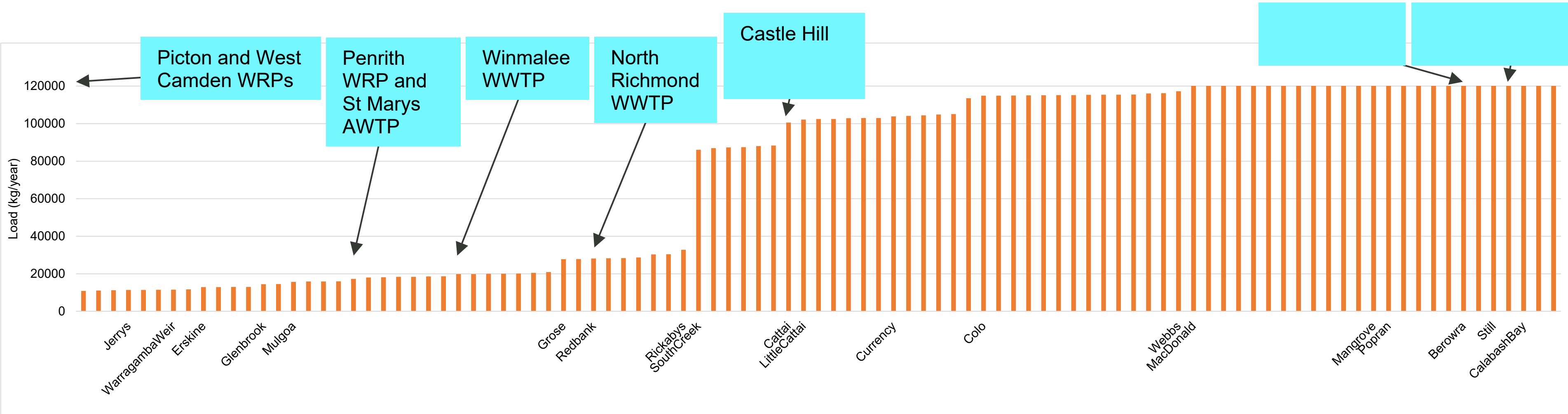


Figure 5-30 Total Phosphorus cumulative catchment loads for the Hawkesbury Nepean River (wet year)

5.3.5 Water quality

The Hawkesbury Nepean represents a complex river system with an extensive range of water quality conditions. Depending on location, the instream water quality can be affected by a range of different factors including, but not limited to:

- diffuse catchment runoff
- modified hydrology from introduction weirs and dams
- high and low flow conditions due to climatic variations in rainfall
- water extractions for either potable, industrial or agricultural purposes
- point sources such as treated water from wastewater treatment plants
- fluxes of nutrients from sediment
- eutrophication and nuisance algal growth

The following sections present the findings of recent studies and analysis into the water quality of the river, predominantly focussing on the primary water quality processes of concern, namely nutrients and algal growth. Discussion regarding existing conditions for ecosystem flora and fauna, including aquatic weeds and macrophytes, is included in the Aquatic Ecology Impact Assessment.

5.3.5.1 Nutrients

To provide an understanding of how nutrient levels generally vary along the length of the river, and also under different climatic years, the figures below present ambient monitoring data for both total nitrogen and total phosphorus. The data is displayed in box and whisker format along the river from the mouth (0 km), up to 250 km adopted middle thread distance (AMTD). Figure 5-31 and Figure 5-32 present total nitrogen for the representative dry and wet years respectively. Similarly, Figure 5-37 and Figure 5-38 present total phosphorus for the representative dry and wet years.

As a general rule, nutrient levels increase from the mouth to a peak near or downstream of 120 km AMTD, which corresponds to the confluence with South Creek. Concentrations then generally reduce and are more consistent with distance upstream. A minor peak is however observed around 140 km AMTD which is near Yarramundi, the confluence with the Grose River and also downstream of Winmalee WWTP.

Nitrogen levels in the river between Penrith Weir (~160 km AMTD) and Bents Basin (~190 km AMTD) are generally elevated and above the ANZG derived waterway objective of 0.35 mg/L for both the wet and dry years. Conversely, total phosphorus concentrations appear consistently below the objective of 0.025 mg/L, with an apparent low point in values around 170 km AMTD (~7 km downstream of the confluence with the Warragamba River).

With respect to the more bioavailable inorganic forms of nitrogen, ammonia concentrations are generally shown to be compliant, except in wetter conditions downstream of the South Creek confluence and also near West Camden. Conversely, nitrate levels are generally recorded above the ANZG waterway objective except for the initial 20 km from the estuary mouth. From a toxicity perspective, the data indicates no potential for toxicity as the peaks of ammonia and nitrate remain below the toxicant DGVs discussed in Section 2.2.

With respect to phosphate, the data indicates compliance with the waterway objective for both climatic years. Peaks in concentrations are again shown downstream of the confluence with South Creek.

As an indication of conditions in the vicinity of the proposed AWRC releases, Figures 5-41 to 5-45 present long-term timeseries monitoring data for the key nutrient indicators at site N67, located upstream of the Wallacia Weir. Seasonal trends are identifiable to some degree, particularly for total and oxidised nitrogen. The analysis indicates some potential for higher concentrations of these nitrogen indicators in the cooler months between April and September. Table 5-1 presents seasonal statistical analysis for the data collected at site N67 between April 2008 and December 2018.

Table 5-4 Statistical analysis of nutrient monitoring data at NS67 (upstream of Wallacia Weir)

Percentile	Total Nitrogen (mg/L)		Ammonia (mg/L)		Oxidised Nitrogen (mg/L)		Total Phosphorus (mg/L)		FRP (mg/L)	
Season	Oct - Mar	Apr - Sep	Oct - Mar	Apr - Sep	Oct - Mar	Apr - Sep	Oct - Mar	Apr - Sep	Oct - Mar	Apr - Sep
10th percentile	0.38	0.45	0.005	0.005	0.020	0.180	0.015	0.013	0.005	0.004
Median	0.54	0.72	0.010	0.010	0.170	0.410	0.021	0.019	0.007	0.006
90th percentile	0.94	1.04	0.030	0.030	0.455	0.730	0.057	0.033	0.017	0.011

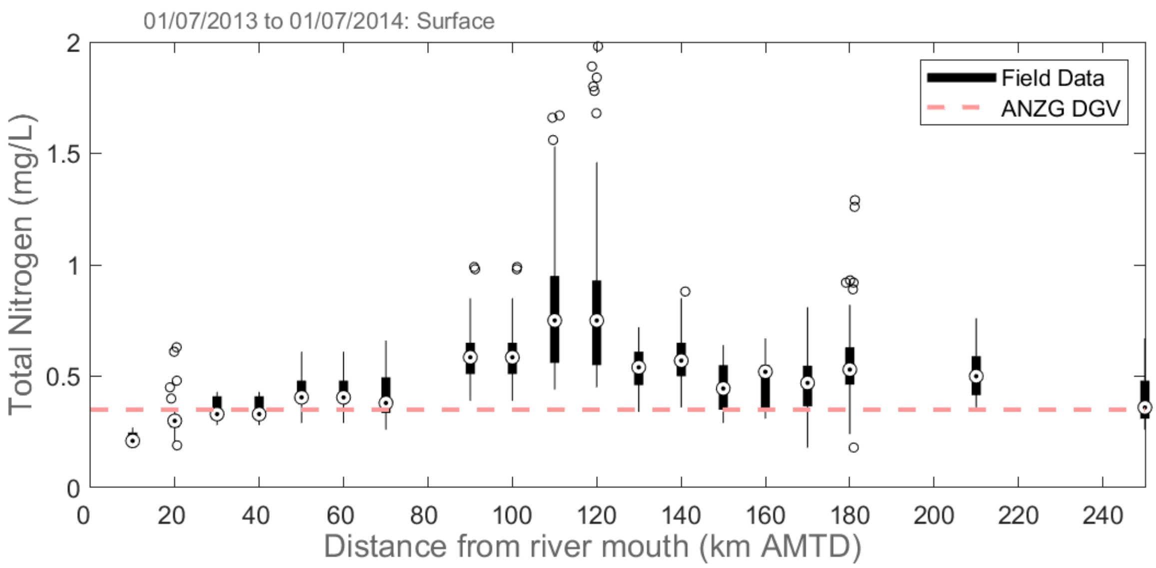


Figure 5-31 Longitudinal transect plots of Total Nitrogen monitoring data (dry year)

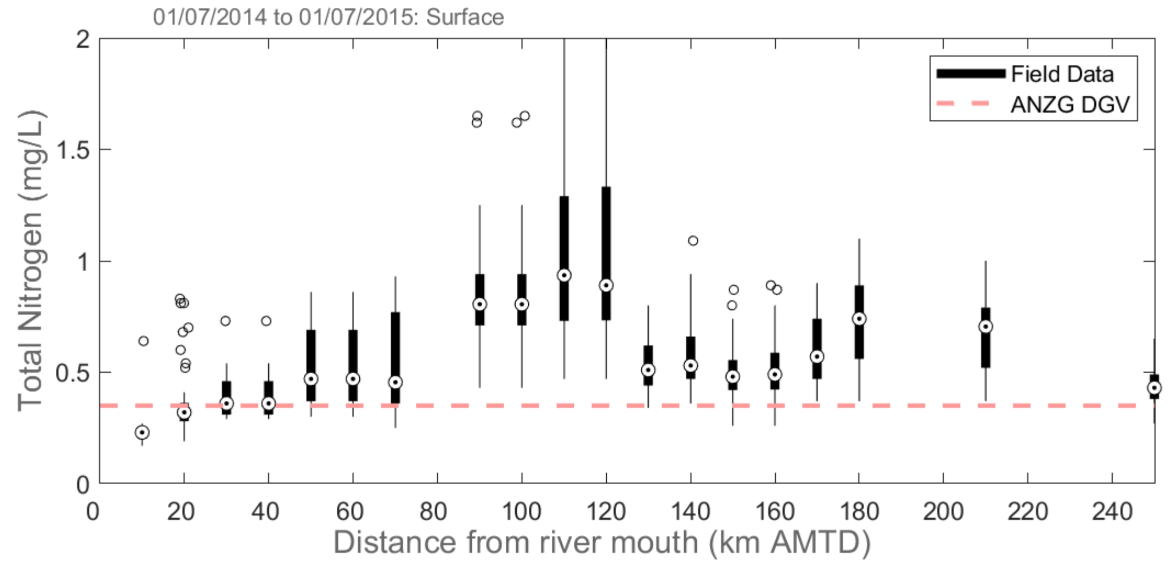


Figure 5-32 Longitudinal transect plots of Total Nitrogen monitoring data (wet year)

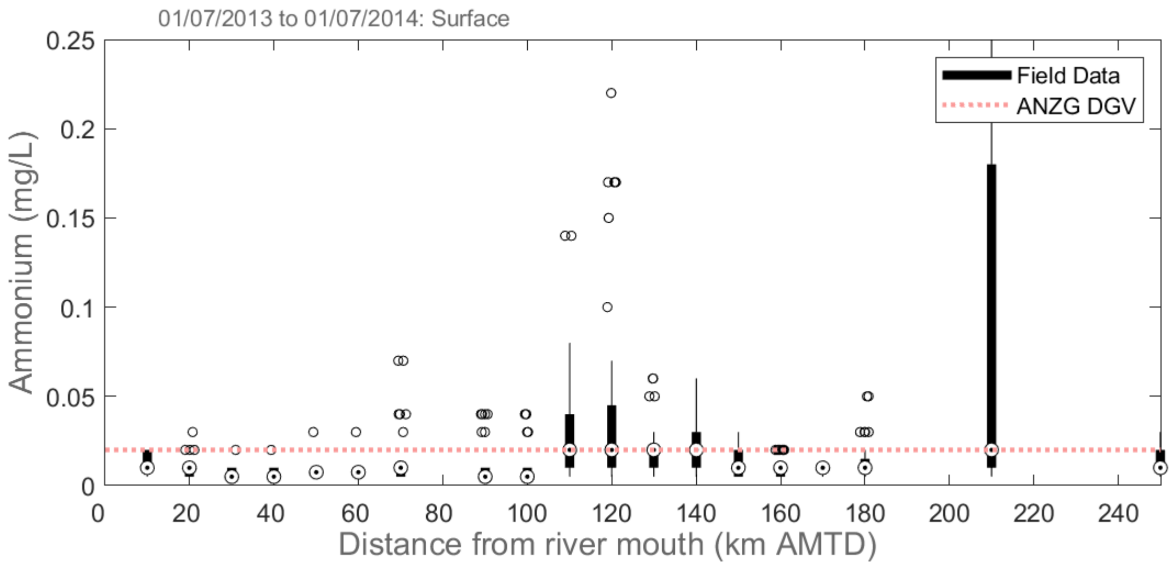


Figure 5-33 Longitudinal transect plots of Ammonia monitoring data (dry year)

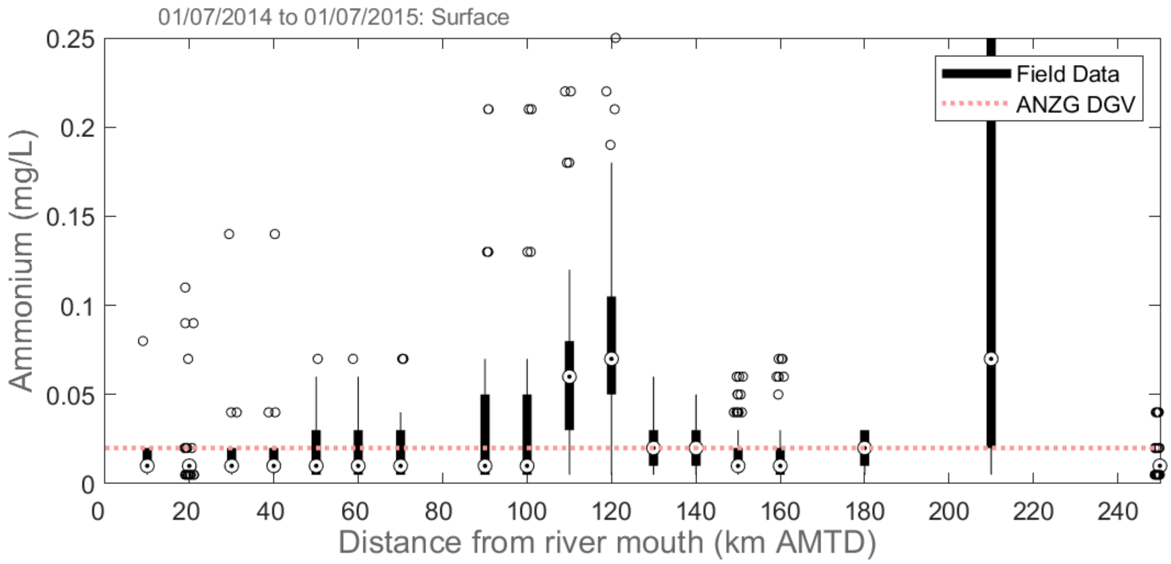


Figure 5-34 Longitudinal transect plots of Ammonia monitoring data (wet year)

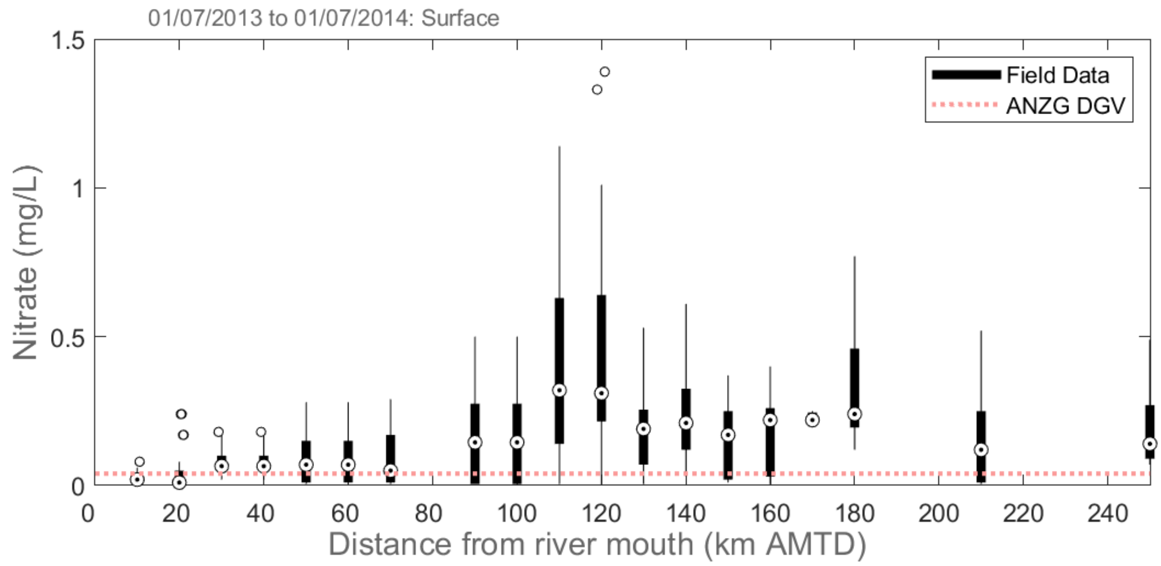


Figure 5-35 Longitudinal transect plots of Nitrate monitoring data (dry year)

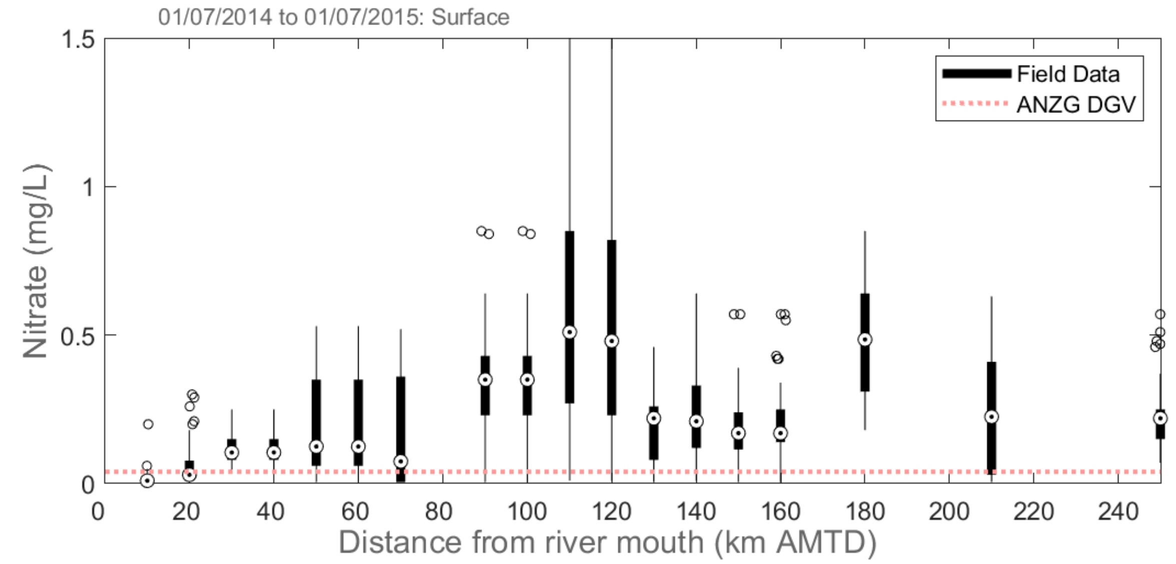


Figure 5-36 Longitudinal transect plots of Nitrate monitoring data (wet year)

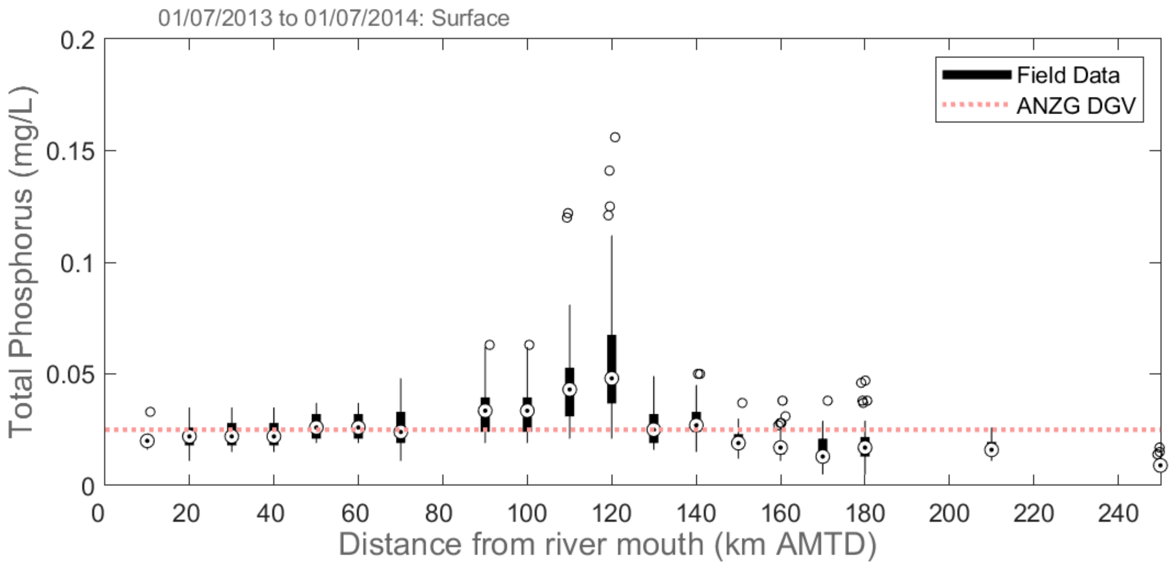


Figure 5-37 Longitudinal transect plots of Total Phosphorus monitoring data (dry year)

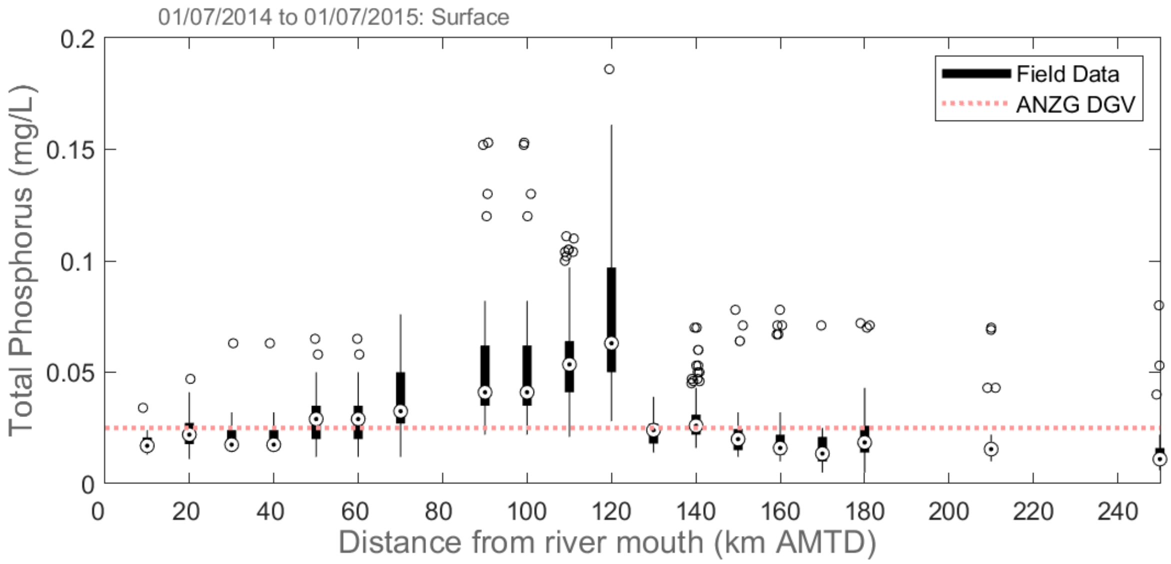


Figure 5-38 Longitudinal transect plots of Total Phosphorus monitoring data (wet year)

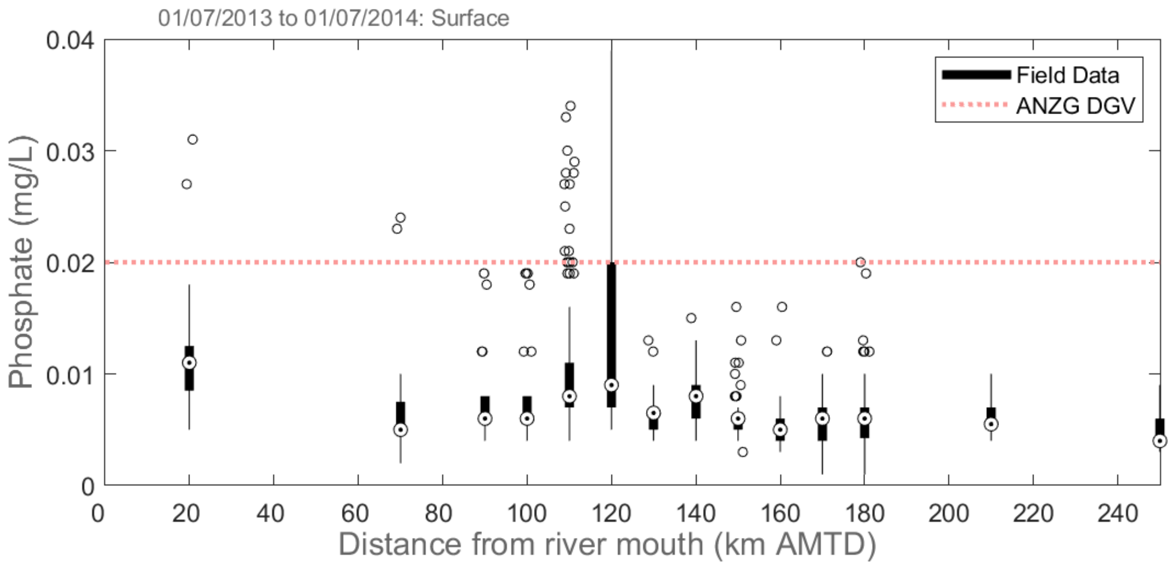


Figure 5-39 Longitudinal transect plots of Phosphate monitoring data (dry year)

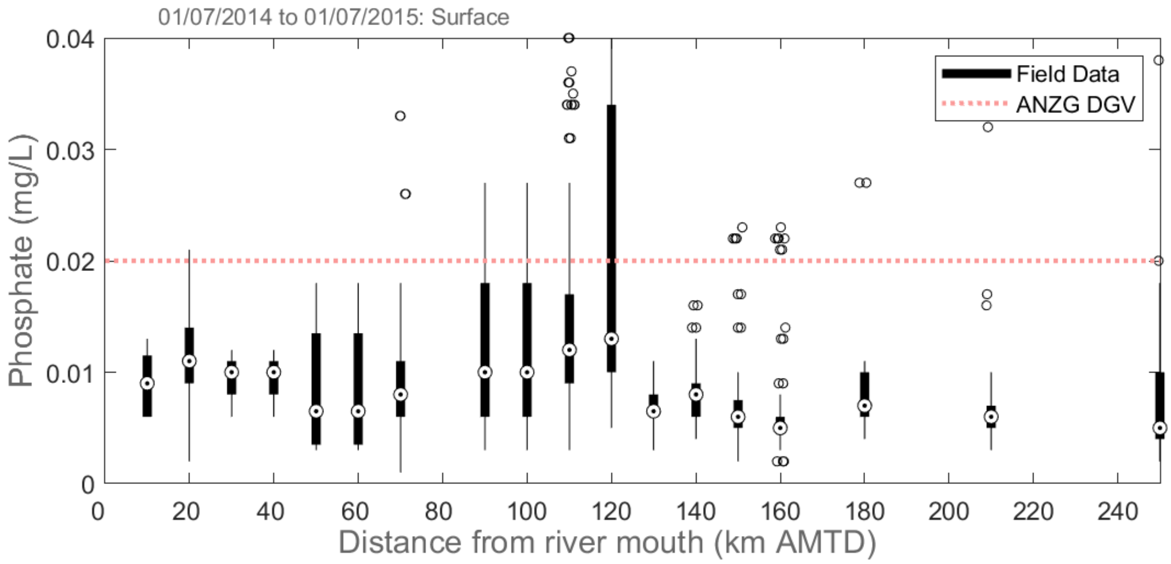


Figure 5-40 Longitudinal transect plots of Phosphate monitoring data (wet year)

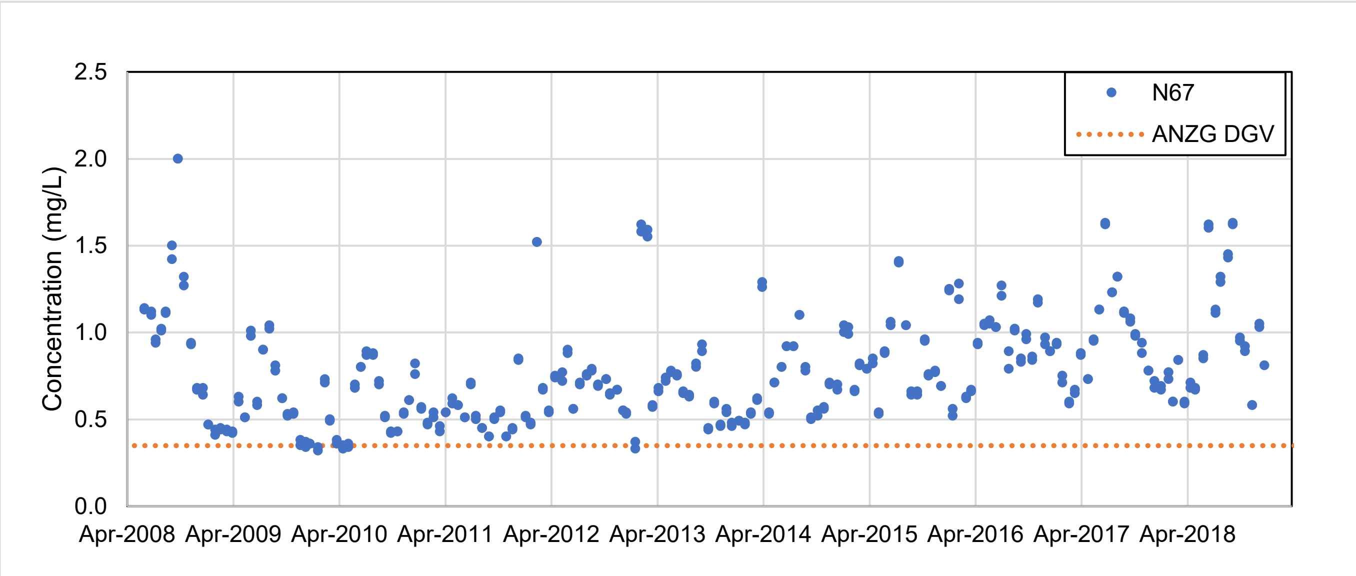


Figure 5-41 Total Nitrogen monitoring data for site N67 (upstream of Wallacia Weir)

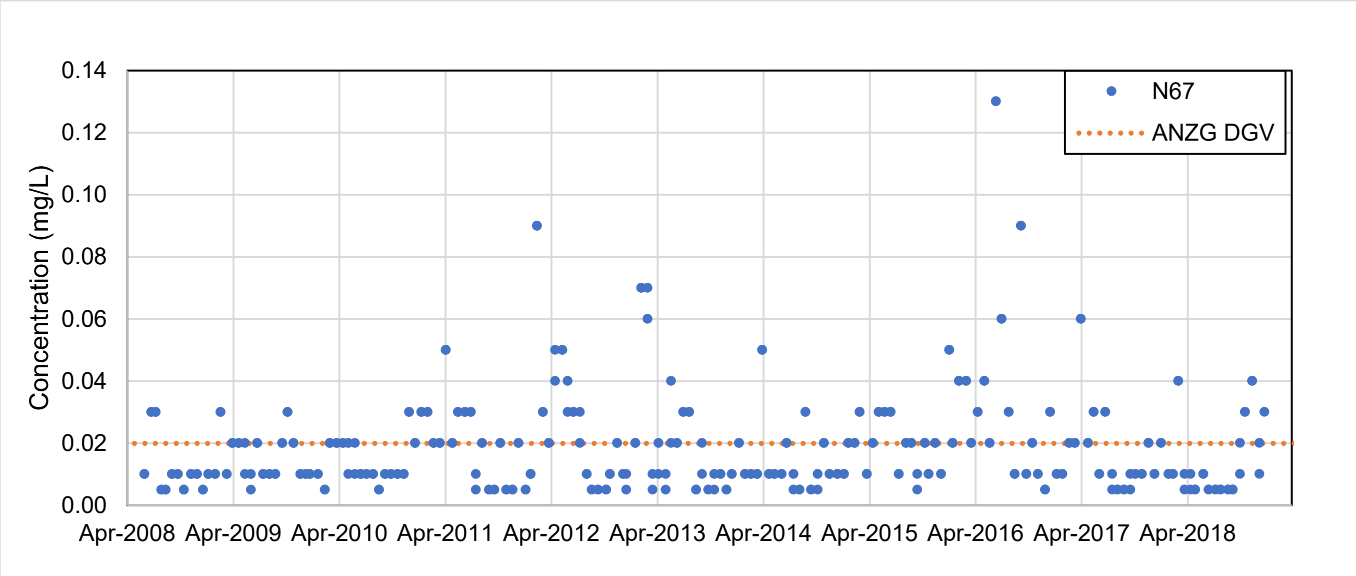


Figure 5-42 Ammonia monitoring data for site N67 (upstream of Wallacia Weir)

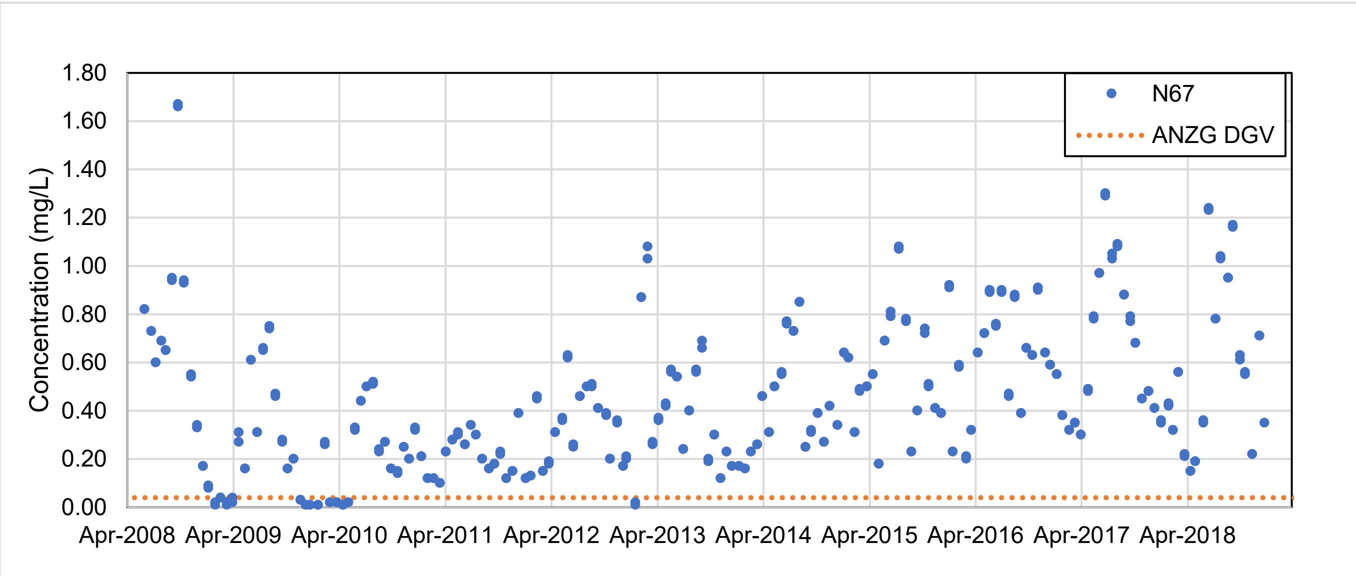


Figure 5-43 Oxidised Nitrogen monitoring data for site N67 (upstream of Wallacia Weir)

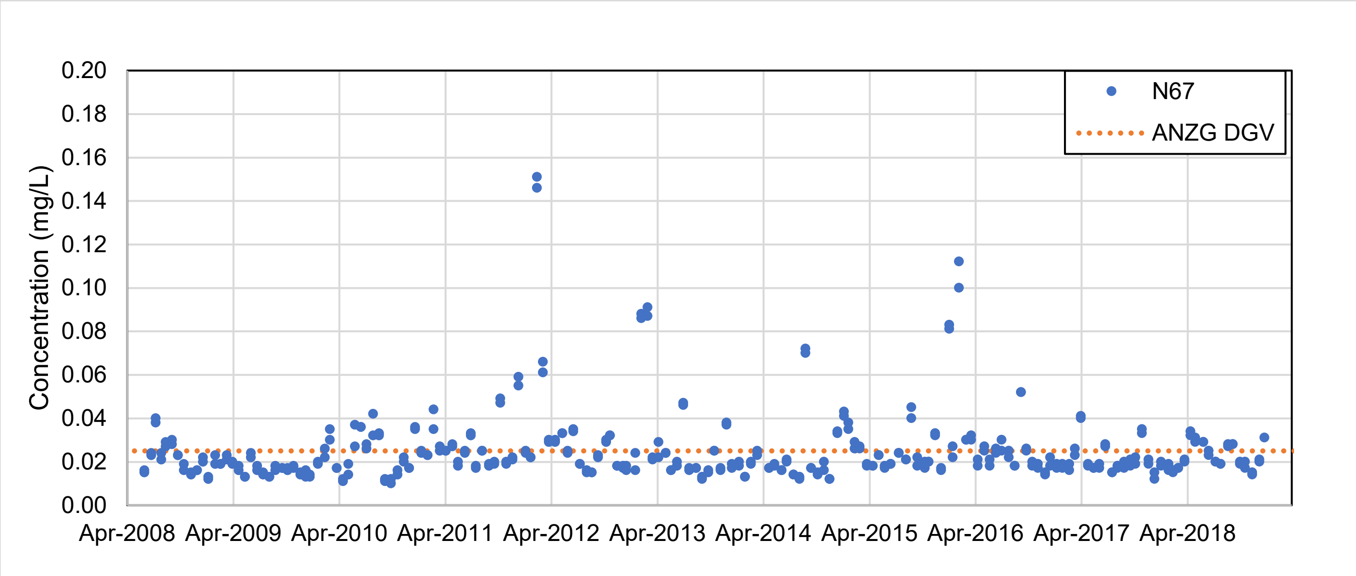


Figure 5-44 Total Phosphorus monitoring data for site N67 (upstream of Wallacia Weir)

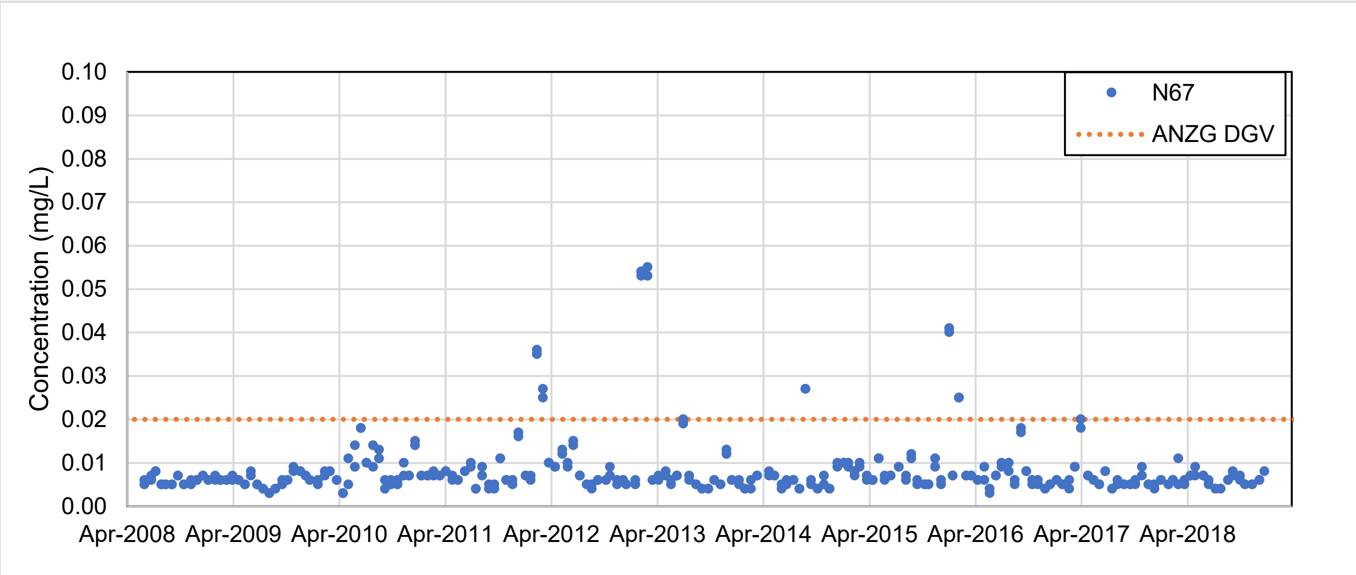


Figure 5-45 Phosphate monitoring data for site N67 (upstream of Wallacia Weir)

With respect to interpretative analysis from previously published studies, the 2009 technical report by DECC (2009a) provided the following conclusions based on analysis of monitoring data:

- Phosphorus levels (both total and filterable) have generally been declining throughout most of the river system, although phosphorus levels downstream of Penrith STP often remain elevated compared with other sites.
- Long-term median total phosphorus levels are considered to be strongly linked to areas under the influence of WWTP releases, particularly between Lapstone Creek and Cattai Creek.
- Nitrogen levels have also declined at many sites throughout the river system, with the exception of Sharpes Weir (downstream of Camden WRP) and Wallacia Bridge. Despite many decreasing trends in nitrogen concentrations at other sites, nitrogen levels often remain well above ANZG (2018) DGVs throughout the river system.
- Long-term median total nitrogen levels are also strongly linked to areas under the influence of WWTP releases, increasing initially downstream of West Camden STP, with peaks at Winmalee Creek, Lapstone Creek and South and Eastern creeks.

In the more recent STSIMP interpretative report by Sydney Water (2018), the following findings regarding nutrient loads and waterway conditions were drawn:

- Nutrient loads (both nitrogen and phosphorus) released to the river and its tributaries have considerably decreased over the long-term (1992 to 2017). This decrease was a result of improvements in wastewater treatment processes, as well as decommissioning of older WWTPs.
- Since 2011, there has however been an increase in the total nitrogen load released from the WWTPs. As with South Creek, this increase is thought to be a result of population growth increasing the overall volume of inflow, as well as reducing the efficiency of nitrogen removal in the treatment process resulting in increased nitrogen concentration in the releases. Despite the increasing trend, loads remain well within the current Environment Protection Licence load limits and well below pre-1992 figures.
- Since 2011, there has been an increase in total nitrogen and dissolved inorganic nitrogen concentrations at approximately half the instream monitoring sites, while phosphorus concentrations remained static or decreased.
- The nutrient loads released to the freshwater section of the river from Sydney Water's WWTPs in 2016-2017 amounted to approximately 885 kg/day and 9 kg/day, respectively. This was estimated to be ~ 28% and 2% of the total nitrogen and total phosphorus loads from all agricultural activities.
- The water quality of the river system varied considerably between the upstream and downstream reaches with indications that the modified flow regimes, as well as loading conditions, represent a key influence.
- Generally, the water quality deteriorated with increased distance downstream where the river widens and receives nutrient rich runoff from urbanised catchments and releases from multiple WWTPs. In particular, the water quality of the lower Hawkesbury River and the South Creek confluence was comparatively poorer, with elevated concentrations of nutrients, chlorophyll *a* and algal biomass.

Further downstream in the Hornsby local government area (LGA), the following range of conclusions have been drawn by the Natural Resources Branch of Hornsby Shire Council (HSC, 2019):

- Estuarine sites in the lower Hawkesbury River are exhibiting impacts from pressures that extend well beyond the Hornsby LGA, particularly with regards to increasing nutrient concentrations. Within the Hawkesbury River estuary, results indicate that total nitrogen concentrations are significantly increasing at all of the sampling sites located in the main arm of the river. Significant increases in total phosphorus are also of concern at sites located in Milsons Passage and south of Dangar Island.
- Whilst nutrient levels towards the mouth of the estuary are relatively low, sites further upstream already experience elevated nutrient levels that exceed the Regional Environmental Health Values (REHVs).
- Amongst the estuarine sites, elevated nutrient concentrations are of particular concern in Berowra Creek and within the main arm of the river. These elevated levels may lead to an increase in algal blooms and impact on the recreational and commercial use of the estuary.
- The most significant long-term improvements in water quality have occurred downstream of the West Hornsby and Hornsby Heights WWTPs in Berowra and Calna Creeks respectively.

5.3.5.2 Algae

To demonstrate the range of primary productivity and algal growth, Figure 5-46 and Figure 5-47 present longitudinal profiles of monitoring data for chlorophyll *a,* for the representative dry and wet years respectively. While there are the expected seasonal variations in productivity, concentrations generally follow similar patterns to those shown in nutrients, with the most significant growth downstream of South Creek (120 km AMTD) as well as Sackville (80 km AMTD).

Between Penrith Weir (~160 km AMTD) and Bents Basin (~190 km AMTD), chlorophyll *a* concentrations are relatively low but still generally above the ANZG derived waterway objective. Correlating with the total phosphorus monitoring data, an apparent low point in values is seen around ~7 km downstream of the confluence with the Warragamba River, particularly in the wet year.

With respect to conditions in the vicinity of the AWRC releases, Figure 5-48 presents long-term timeseries monitoring data for chlorophyll *a* at site N67, located upstream of the Wallacia Weir. Seasonal trends are not easily definable with Table 5-5 presenting statistical analysis for the data collected at site N67, between April 2008 and December 2018.

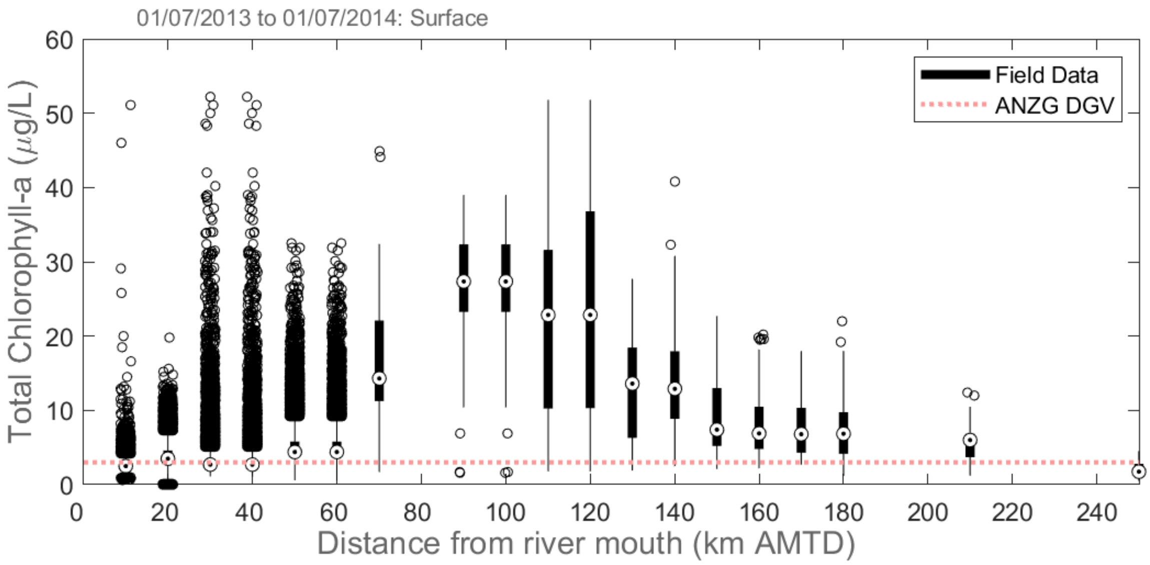


Figure 5-46 Longitudinal transect plots for Total Chlorophyll *a* (dry year)

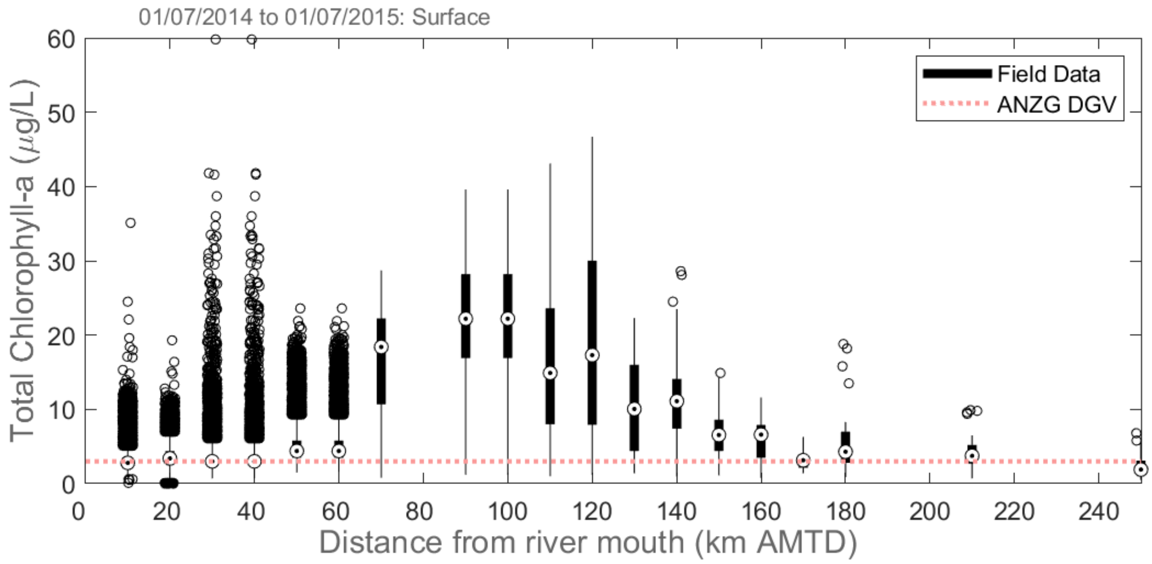


Figure 5-47 Longitudinal transect plots for Total Chlorophyll *a* (wet year)

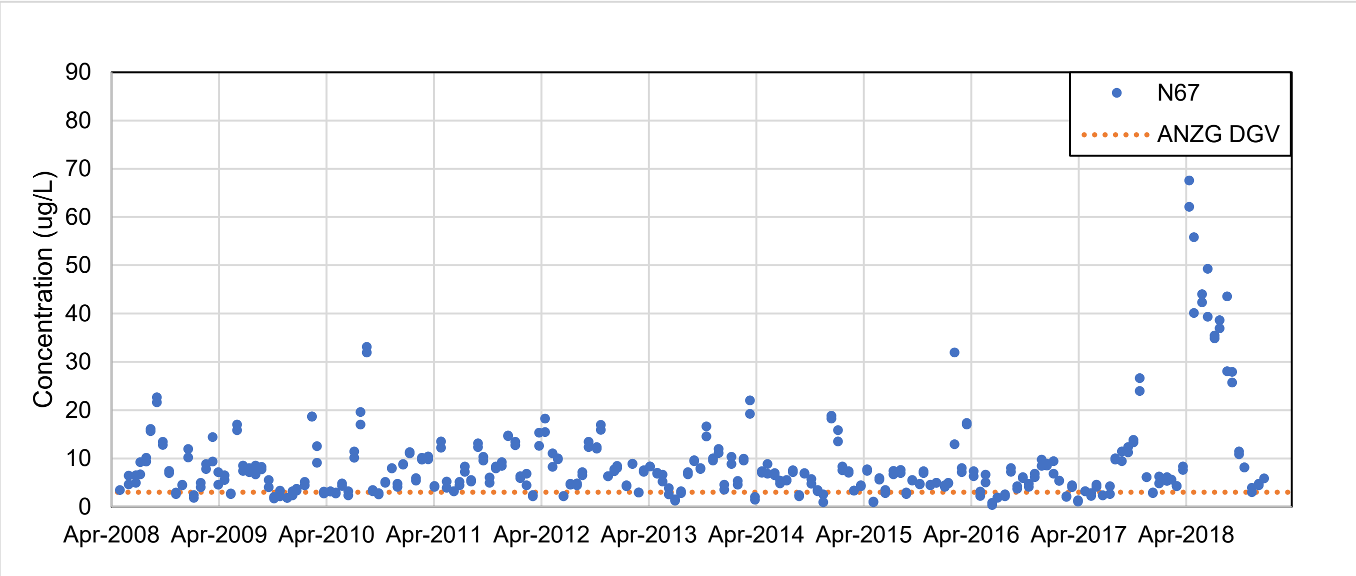


Figure 5-48 Total Chlorophyll *a* monitoring data for site N67 (upstream of Wallacia Weir)

Table 5-5 Statistical analysis of Chlorophyll *a* monitoring data at site N67 (upstream of Wallacia Weir)

Percentile	Total Chlorophyll a (μg/L)	
Season	Oct - Mar	Apr - Sep
10th percentile	2	3
Median	7	7
90th percentile	14	15

Several studies have also documented the presence and impacts of algal blooms as summarised below.

The STSIMP interpretative report (Sydney Water, 2018) commented that phosphorus was generally considered the key nutrient responsible for potentially toxic blue-green algal blooms in the lower Hawkesbury River.

The Hawkesbury Nepean River Environmental Monitoring Program technical report (DECC, 2009a) stated that: "*Chlorophyll-a levels have mostly declined or remained stable at most sites. Cyanobacterial cell counts have largely remained stable, although some slight increases are suggested*".

The report however also commented that many areas in the Hawkesbury-Nepean can be described as being stressed, and some areas can probably best be described as being eutrophic. Large amounts of water are diverted for water supply and irrigation, and nutrient levels are often high. Outbreaks of algal blooms are therefore common.

5.3.5.3 Other water quality indicators

5.3.5.3.1 Salinity

Figure 5-49 and Figure 5-50 present longitudinal profiles of monitoring data for salinity in the representative dry and wet years respectively. The transects show the significant gradient of salinity concentrations as conditions change from oceanic to freshwater. The transition to freshwater occurs around 70 to 80 km inland from the river mouth, but this distance can vary depending on the season. In both years, concentrations are compliant with the ANZG derived freshwater waterway objective upstream of the salinity wedge, located near Wisemans Ferry.

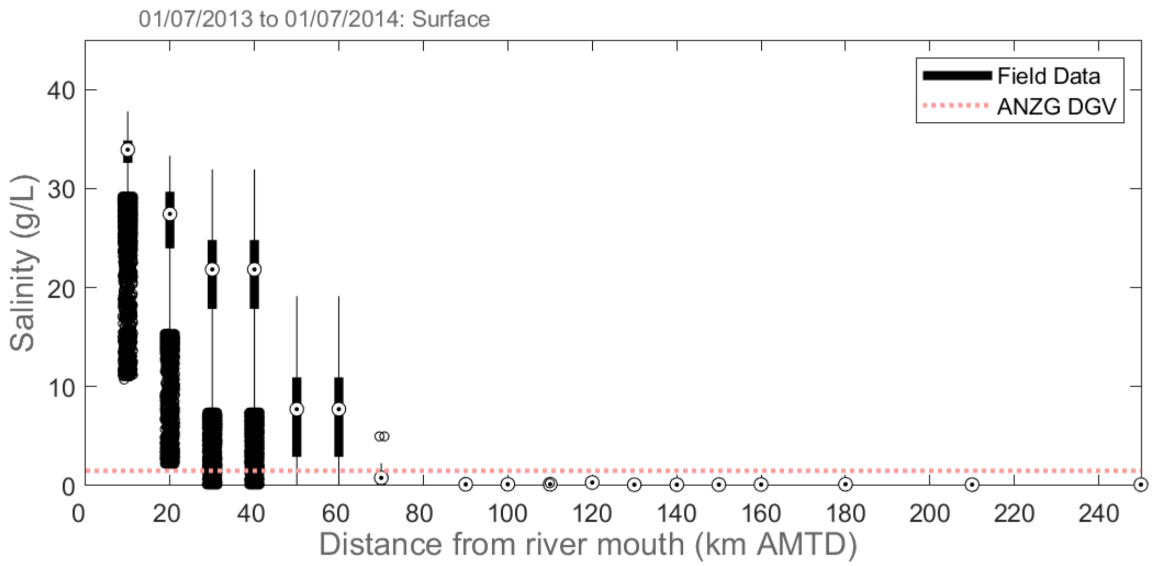


Figure 5-49 Longitudinal transect plots for Salinity (dry year)

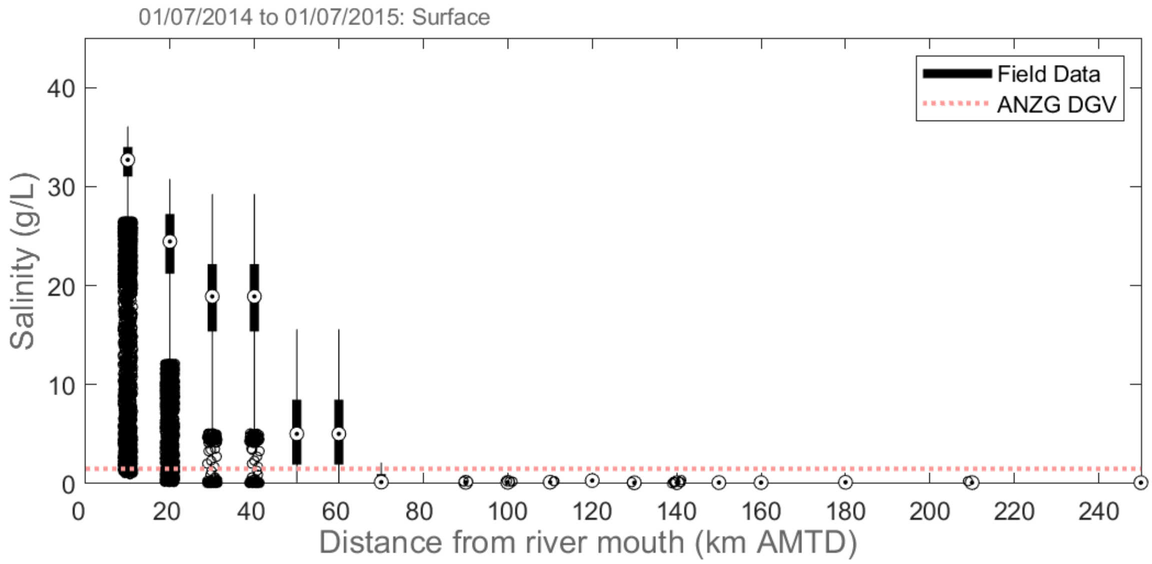


Figure 5-50 Longitudinal transect plots for Salinity (wet year)

5.3.5.3.2 Total Suspended Solids

Relatively limited datasets were identified with respect to suspended solids in the Hawkesbury Nepean River, particularly for the 2014-15 wet year. While limited in extent, the available data does indicate compliance against the ANZG derived waterway objective (40 mg/L). With respect to the reach between Penrith Weir (~160 km AMTD) and Bents Basin (~190 km AMTD), TSS levels were relatively low with maximum concentrations recorded up to ~20 mg/L.

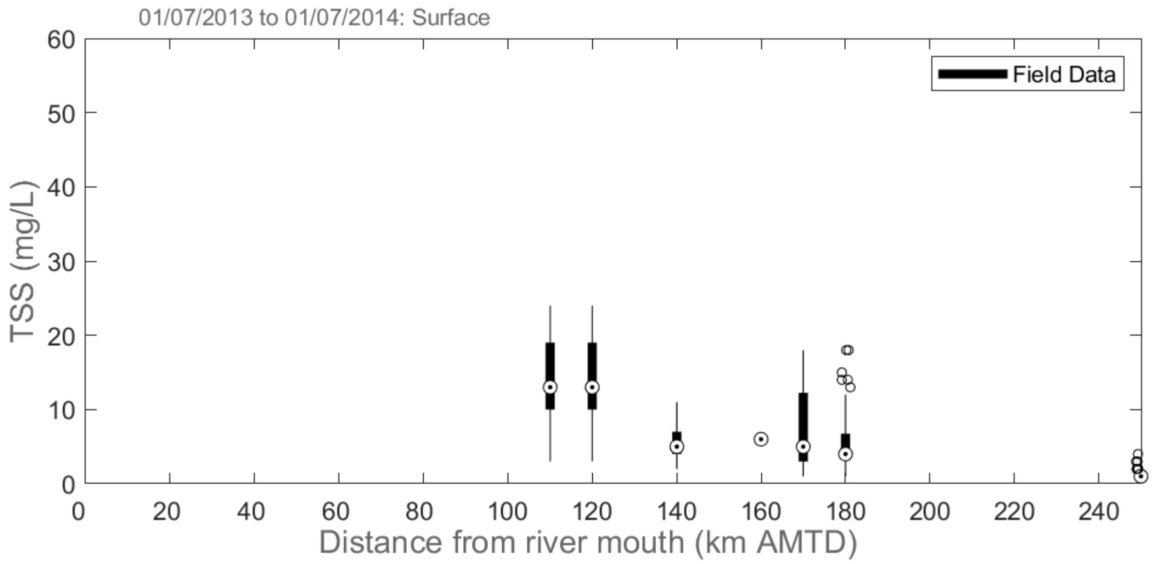


Figure 5-51 Longitudinal transect plots for TSS (dry year)

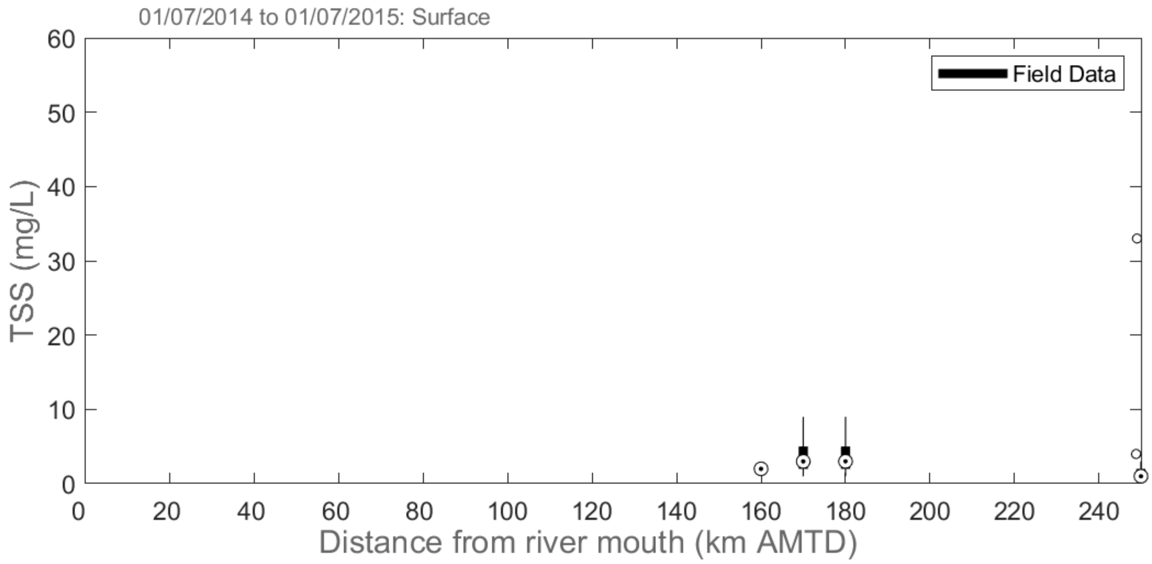


Figure 5-52 Longitudinal transect plots for TSS (wet year)

5.3.5.3.3 Toxicants

With respect to toxicants, only limited monitoring data was identified, particularly in the reaches near Wallacia Weir and the proposed AWRC release point. While restricted to sampling from June 2020, the baseline monitoring program (Sydney Water, 2020d) provides some indication of potential concentrations for selected toxicants within the river. Table 5-6 presents statistical analysis for data collected from June 2020 to June 2021 at monitoring sites N66A and N66B, located upstream of the proposed AWRC release point (refer Figure 7-2). With the exception of chlorine, which is not monitored, the analysis focuses on the suite of toxicants previously identified in Section 4.7.2.1.1.

From this limited dataset, it can be observed that there is potential for elevated concentrations above the relevant toxicant DGVs for manganese.

Table 5-6 Statistical analysis of toxicant monitoring data at NS66A and N66B (baseline monitoring sites upstream of the AWRC)

Percentile	Ammonia (mg/L)	Nitrate (mg/L)	Aluminium (mg/L)	Copper (mg/L)	Manganese (mg/L)	Zinc (mg/L)
Minimum	0.01	0.21	0.003	0.0008	0.037	0.002
10th percentile	0.01	0.46	0.006	ID	ID	ID
Median	0.02	0.67	0.010	0.0009	0.067	0.003
90th percentile	0.14	1.46	0.031	ID	ID	ID
95th percentile	0.21	1.51	0.035	ID	ID	ID
Maximum	0.28	1.53	0.042	0.0012	0.105	0.003
Number of samples	36	36	36	6	6	6
Toxicant DGV	1.75*	2.40**	0.055**	0.0014**	0.100***	0.008**

Table notes:

* *Toxicant DGV for the protection of aquatic ecosystems (95% protection) as typically recommended for slightly to moderately disturbed ecosystems – refer ANZECC (2000). Modifications to the DGV have been made in line with ANZECC (2000) based on a median ambient pH of 7.4, which was determined from monitoring data collected from June 2020 to June 2021, at a sites upstream of the proposed release point (sites N66A and N66B).*

** Toxicant DGV for the protection of aquatic ecosystems (95% protection) as typically recommended for slightly to moderately disturbed ecosystems – refer ANZECC (2000)/ANZG (2018). Aluminium DGV specified for pH >6.5.

*** DGV for the recreational purposes – refer NHMRC (2008). The ANZG (2018) DGV for the protection of aquatic ecosystems is significantly higher with a value of 1.9 mg/L.

ID Insufficient data for analysis

Monitoring results for Aluminium, Copper, Manganese and Zinc represent filtered concentrations.

5.4 Sensitive environments

Evaluation of sensitive environments within the Hawkesbury Nepean River system was undertaken as part of the following assessments: the Health Impact Assessment, the Social Impact Assessment and the Aquatic Ecology Impact Assessment.

As outlined below, two Matters of National Environmental Significance (MNES) were identified within the study area, downstream of the Wallacia Weir release point. Other than these MNES, some areas used for recreational activities were also recognised, but no other specific environmental sensitivities were identified as part of the assessments.

5.4.1 MNES

The Warragamba River and the Nepean River (from downstream of the confluence with Warragamba River to Lynch Creek, downstream of Penrith Weir) are mapped as critical habitat for the Macquarie Perch (Macquaria australasica). The Macquarie Perch is listed as endangered under the *Environment Protection and Biodiversity Conservation (EPBC) Act 1999* and the *NSW Fisheries Management Act 1994.*

Also of note, a section of the reach between the Wallacia Weir and Penrith Weir also flows through the Blue Mountains World Heritage Area, which is also considered as a MNES.

5.4.2 Non-MNES environmental sensitivities

In the absence of any other specific non-MNES sensitive environments being identified as part of the EIS, the sensitivity of the river has been discussed in a more general sense, and in line with relevant legislation, policy and guidelines.

Under the section relating to regulatory priority and risk, the EPA website[3] states that: "*For water, sensitivity of the environment is highly dependent on the receiving water-type, the state of the catchment and the pollutants discharged. For example, inland rivers are highly sensitive to discharges of phosphorous, while open oceans are not as sensitive; discharges into potable (drinkable) water supplies pose a higher risk to human health than those to other types of receiving waters.*"

In addition to this, the *State Regional Environmental Plan No. 20 - Hawkesbury Nepean River*, defines environmentally sensitive areas as follows: *"environmentally sensitive areas are areas where environmental characteristics mean that the potential impacts of land use are greater than elsewhere in the catchment. Environmentally sensitive areas identified by the Hawkesbury-Nepean Environmental Strategy in the Hawkesbury-Nepean catchment are: the river; riparian land; escarpments and other scenic areas; conservation area sub-catchments; national parks and nature reserves; wetlands; other significant floral and faunal habitats and corridors; acid sulphate soils and potential acid sulphate soils".*

[3] https://www.epa.nsw.gov.au/licensing-and-regulation/licensing/environment-protection-licences/risk-based-licensing/regulatory-priority-and-risk

Therefore, for the purposes of this study, the overall sensitivity of the river has been discussed in a broader sense, and with respect to water type. This discussion is presented within the existing environment section (Section 5), and in a similar manner, impacts on the waterways are discussed in Section 6.

5.4.3 Recreational activities

There are many locations along the Hawkesbury Nepean River system that are used for swimming and other recreational purposes. These locations include the following:

- Maldon Weir
- Bents Basin
- Wallacia Weir
- Nortons Basin
- Penrith Weir
- Blaxlands Cross Reserve
- Yarramundi Reserve
- Menangle Bridge
- Windsor Beach
- Cattai National Park

Recreational areas were also identified on South Creek downstream of the proposed AWRC site. These areas include the following:

- Samuel Marsden Reserve, Orchard Hills
- The Kingsway
- Wianamatta Regional Park
- Governor Phillip Park

For the purposes of this assessment, impacts on applicable waterway values have been assessed at the following primary sites, downstream of the Nepean release point: Wallacia Weir and Penrith Weir. This assessment is presented in Section 6.3.2. Sites downstream of the South Creek release point were not included in this assessment due to the episodic nature of the wet weather releases and also due to these sites not being recognised for use in primary recreational contact activities.

6 Impact assessments

6.1 Hydrodynamic and water quality assessment

The following sections present the findings of the hydrodynamic and water quality assessments. These assessments have been structured as follows:

- South Creek releases
- Nepean River releases
- Nepean River and Warragamba River releases

Within each assessment, the following sub-sections are also presented:

- Load analysis
- Scenario results
- Interpretation - background scenarios
- Interpretation - impact scenarios

Further details on the modelling and assessment approach are provided in Section 4.6.

6.1.1 South Creek releases

6.1.1.1 Scenario conditions

As discussed in Section 4.6.3.3, the results from each AWRC impact scenario are plotted against a corresponding background scenario as well as a baseline scenario. This approach allows for analysis of the impacts from the AWRC releases on their own, in relation to the catchment conditions that are expected for the selected time horizon, and also relative to current conditions. Further details regarding these scenario types are provided in Section 4.6.3.

Table 6-1 presents a summary of the key conditions relating to the South Creek release scenarios. Further details relating to these impact scenarios, and also the relevant background and baseline scenarios, can be found in Section 4.6.3.

Table 6-1 Summary of scenario conditions – South Creek release scenarios

Scenario number	Time horizon	AWRC capacity (ML/d)	Stormwater management strategy	Relevant background scenario
SC05	2036	50	Parkland	SC02
SC06	2056	100	Parkland	SC04
SC07	2036	50	BaU	SC01
SC08	2056	100	BaU	SC03
SC09	2036	50 / advanced treatment shutdown	BaU	SC01

6.1.1.2 Load analysis

Analysis of estimated total nitrogen and total phosphorus loads to South Creek has been undertaken to allow comparison of the contributions from various sub-catchments and treatment plants under current (circa 2020) conditions, and also for the impact scenarios discussed in Section 4.6.3.

The loads were estimated through analysis of the model boundary conditions for each scenario, and for both the representative wet and dry years independently.

The load analyses presented in the figures below, extend from upstream of Lowes Creek to the confluence with the Hawkesbury River. Figure 6-1 and Figure 6-2 present the cumulative analysis of total nitrogen loads from upstream to downstream for all the catchment loads (including WWTPs and WRPs). From left to right, each new set of columns/bars represents the cumulative load with the addition of the load from a new boundary in the model.

Figure 6-3 and Figure 6-4 present the assumed loads for the individual WWTPs and WRPs. Please note that the y-axis limits differ between the cumulative and WWTP/WRP analyses. Figures 6-5 to 6-8 present similar outputs for total phosphorus loads.

Load estimates for the background scenarios were not included as they replicated the impact scenario conditions except for the addition of the AWRC loads. Load estimates for the advanced treatment shutdown scenario (SC09) were also not included as there were only minor differences in the AWRC nutrient loading between SC09 and the corresponding non-shutdown scenario, SC07. The differences between these scenarios was estimated to be less than ~200 kg/year TN and ~100 kg/year TP.

From these graphs, the influence of the major tributaries, such as Kemps Creek, Dunheved Creek, Eastern Creek, etc can be observed (refer to Figure 5-2 regarding location of tributaries). To a lesser extent, the influence of some of the larger treatment plants on nutrient loads can also be seen. The differences in load magnitude between the dry and wet years is also notable.

From analysis of the WWTP/WRP bar graphs (Figures 6-3, 6-4, 6-7 and 6-8), planned upgrades to some of the existing treatment plants can be seen. The most significant being Quakers Hill and South Windsor.

The contributions of the AWRC loads are estimated to be as follows:

- Total nitrogen:
  - Dry year: ~0.002% (2036) to ~0.005% (2056)
  - Wet year: ~0.6% (2036) to ~1.1% (2056)
- Total phosphorus
  - Dry year: <0.001% (2036 and 2056)
  - Wet year: ~0.3% (2036) to ~0.4% (2056)

Further information regarding expected future nutrient loads, and how these address the requirements of the EPA’s regulatory framework to manage nutrient load inputs are presented in Section 6.3.3.

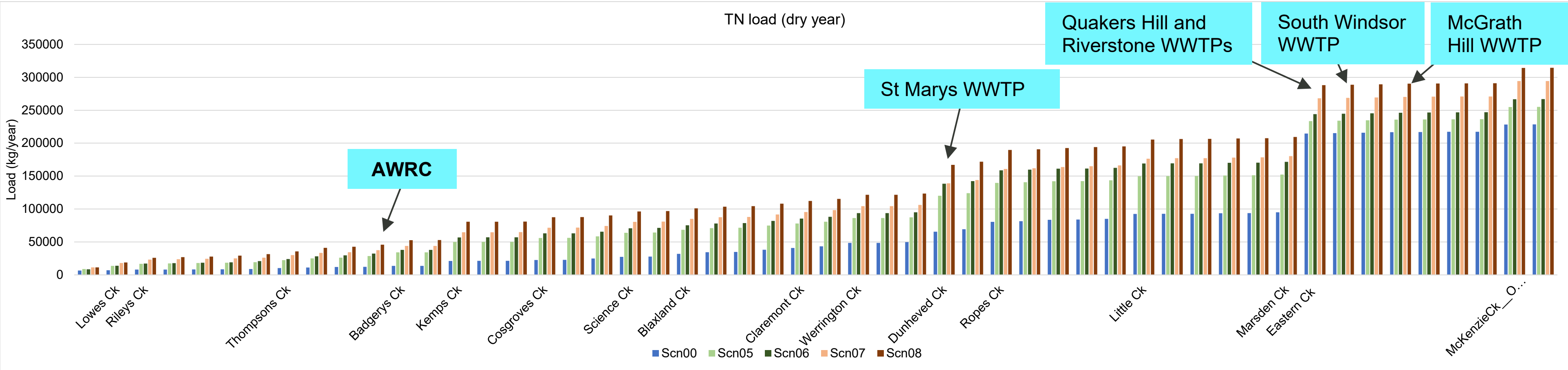


Figure 6-1 South Creek Total Nitrogen cumulative catchment loads (dry year)

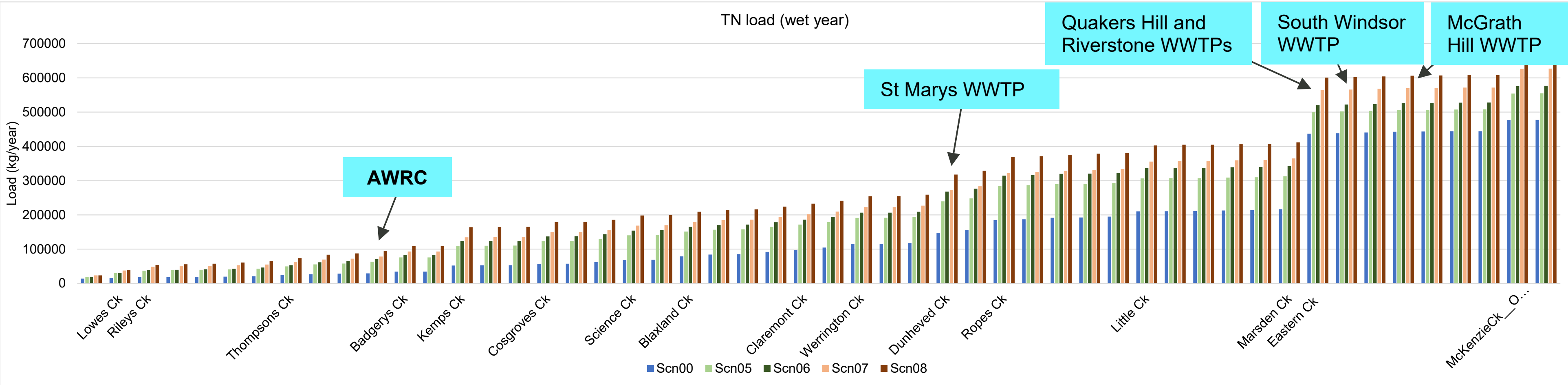


Figure 6-2 South Creek Total Nitrogen cumulative catchment loads (wet year)

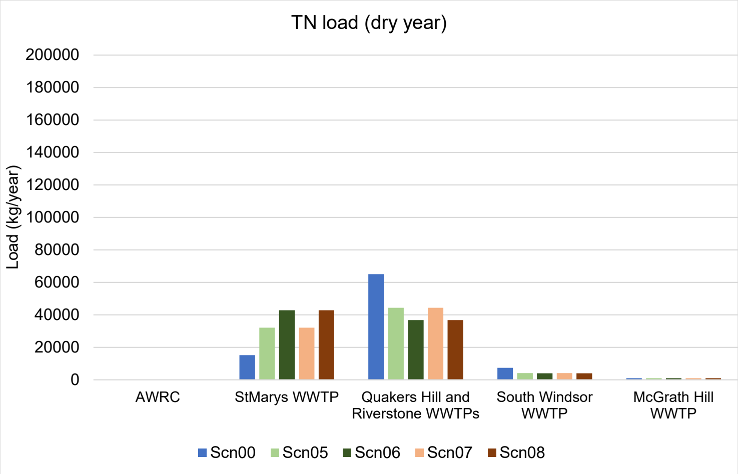


Figure 6-3 South Creek Total Nitrogen WWTP/WRP loads (dry year)

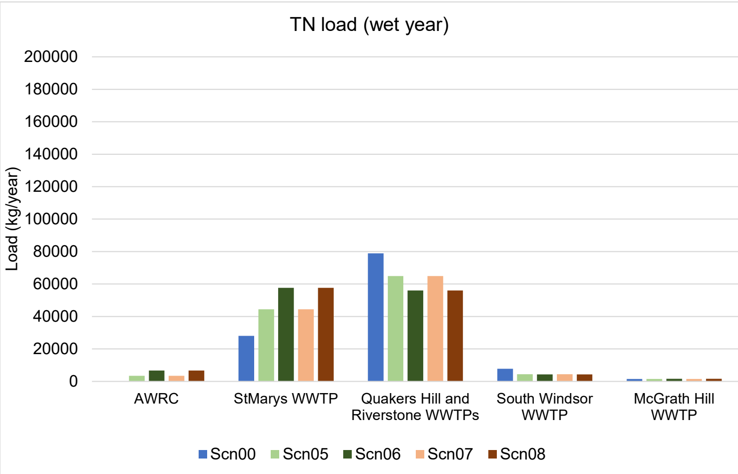


Figure 6-4 South Creek Total Nitrogen WWTP/WRP loads (wet year)

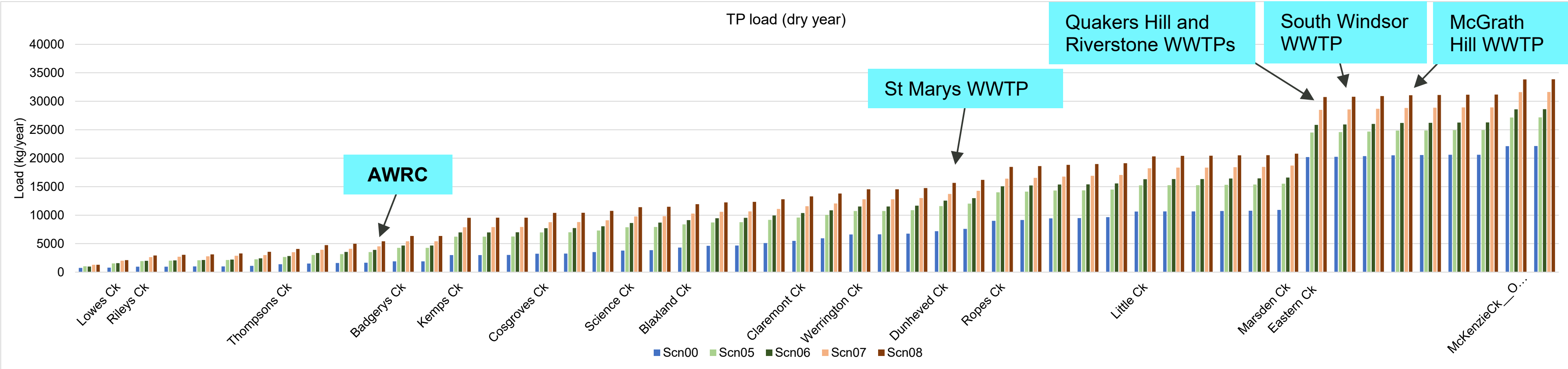


Figure 6-5 South Creek Total Phosphorus cumulative catchment loads (dry year)

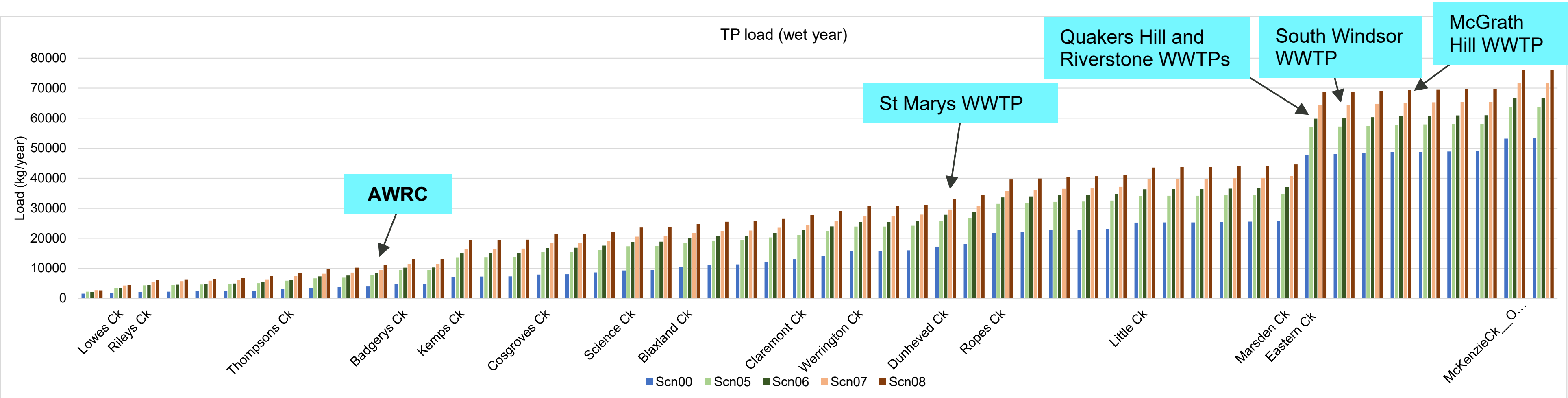


Figure 6-6 South Creek Total Phosphorus cumulative catchment loads (wet year)

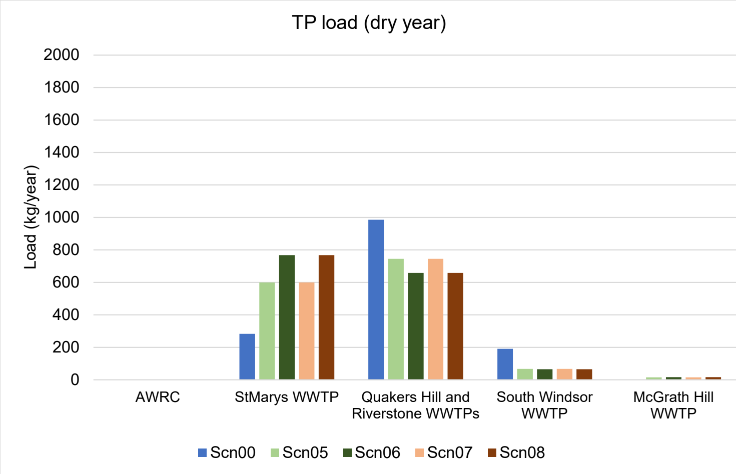


Figure 6-7 South Creek Total Phosphorus WWTP/WRP loads (dry year)

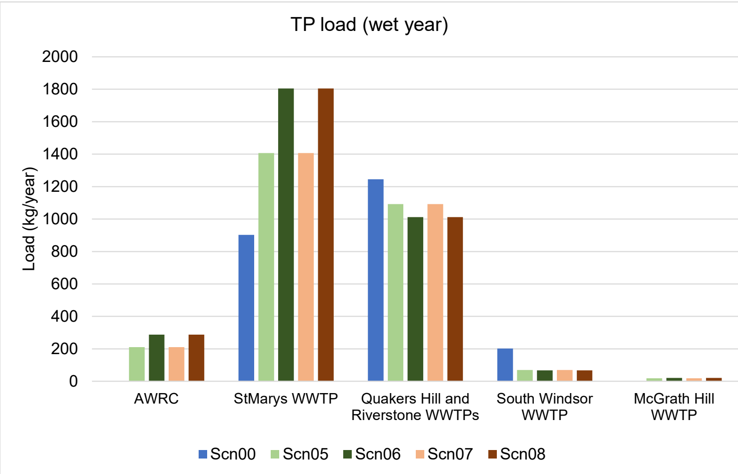


Figure 6-8 South Creek Total Phosphorus WWTP/WRP loads (wet year)

6.1.1.3 Scenario results

A significant level of model output has been generated for the purposes of the hydrodynamic and water quality assessment. For South Creek, this includes the following formats for 14 primary water quality parameters and two hydrodynamic indicators.

- Box and whisker plots
- Timeseries plots
- Longitudinal profile plots

For each of the impact scenarios, this dataset has been output at eight primary sites of interest for both the representative dry and wet year.

As discussed in Section 4.6.3.3, the results from each impact scenario are plotted against a corresponding background scenario as well as a baseline scenario. This approach allows for analysis of the impacts from the AWRC releases on their own, in relation to the catchment conditions that are expected for the selected time horizon, and also relative to current conditions. Further details regarding the formats used to present the results, and the location of the analysis sites, are discussed in Section 4.6.4.

For brevity, a selection of relevant scenario results has been included in the following sections to aid interpretation. A full set of results for scenario SC05 (2036 AWRC releases/Parkland stormwater management) has also been included in Appendix C1 for reference. As identified below in Section 6.1.1.5, scenario SC05 was considered to be representative of the potential impacts for Stage 1 operation of the AWRC project. As discussed in Section 4.6.3.3, the results for scenario SC05 are compared to background scenario SC02, and baseline scenario SC00.

Results for the other scenarios can be supplied by Sydney Water upon request.

6.1.1.4 Interpretation – background scenarios

6.1.1.4.1 General

The following general comments are provided with respect to the results from the background scenarios (circa 2036 and 2056) relative to baseline conditions (circa 2020):

- In many of the modelled scenarios, the differences in water quality between the background scenarios (SC01 to SC04) and the baseline scenario (SC00) were predicted to be more significant than the differences between the impact and background scenarios.
- Many of the differences predicted for the background scenarios (future conditions, circa 2036 and 2056) reflect potential improvements in water quality conditions relative to the baseline scenario (current conditions, circa 2020). Therefore, the future, more-developed catchment of South Creek in some cases is predicted to generate improved water quality for some parameters relative to current undeveloped conditions.
- The following general conclusions are provided from analysis of these scenarios:
  - The flow regime is a key factor in the water quality within the creek, particularly with respect to nutrient levels and phytoplankton biomass. Under the 2020 baseline scenario conditions, the WQRM realistically represents the development of segregated reaches under sustained dry weather periods. This results in isolated, stagnant water pools that do not flow and join until there is a pulse of inflows from the upstream catchments. Within these pools, some nutrients become more concentrated, potentially affected by nutrient fluxes from the sediment. Primary

productivity is also promoted under these conditions as shown in results for chlorophyll *a,* as well as individual phytoplankton groups. Phytoplankton biomass is observed to increase in the early dry periods, then remaining in high biomass until catchment flows enter the creek and flush the isolated waters and reduce the biomass.

- During the future background scenario conditions, the flow regime is significantly modified in terms of both base flows and event peaks, due to the more impermeable land uses assumed in the future developed topologies that represent the growth areas. Under these modified conditions, the modelling predicts lower concentrations in some parameters in some of the upper and middle reaches of the creek due to higher flows and increased connectivity throughout the creek. Consequently, the previously predicted sediment fluxes and algal blooms become less prevalent. The temperature conditions are also affected and play a part in the changed water quality conditions. These effects are predicted for both the Parkland and BaU scenarios. Figure 6-9, Figure 6-10 and Figure 6-11 present the longitudinal profiles of predicted total phosphorus, chlorophyll a and temperature respectively for both a 2036 Parkland background scenario (SC05) and the baseline scenario (SC00).
- Therefore, despite the potential increases in inflow concentrations and loads of nutrients from the catchments in the future scenarios, the water quality is in fact predicted to improve for some indicators such as chlorophyll *a*. The predicted effects are seen in both the timeseries and longitudinal annual median profiles.

- The influence of the existing WWTPs/WRPs are also seen in the future background scenarios with marked differences in total and inorganic nutrient indicators in the lower sections of the creek. In particular, the planned upgrades to Quakers Hill, McGraths Hill and South Windsor WWTPs are seen to result in significant changes in the results, particularly visible in the longitudinal profiles (refer to Figure 6-12). The releases from St Marys WRP also result in an increase in nutrients throughout the scenarios.

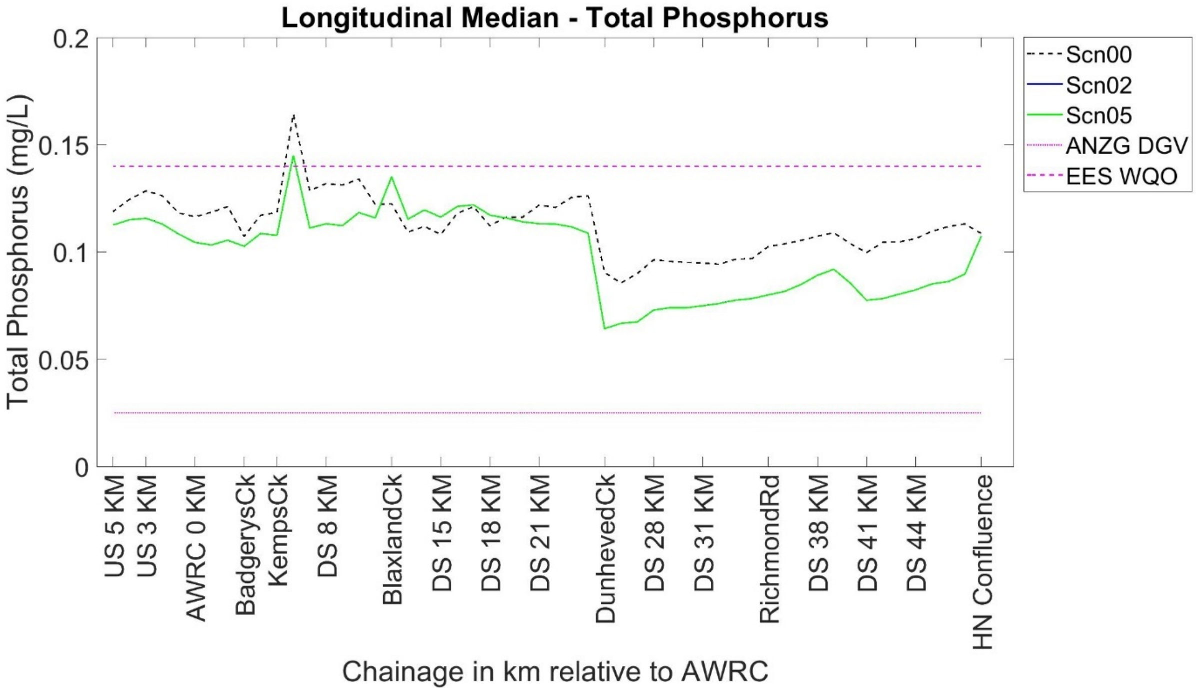


Figure 6-9 Longitudinal profile of predicted annual median Total Phosphorus concentrations (2036 releases/dry year)

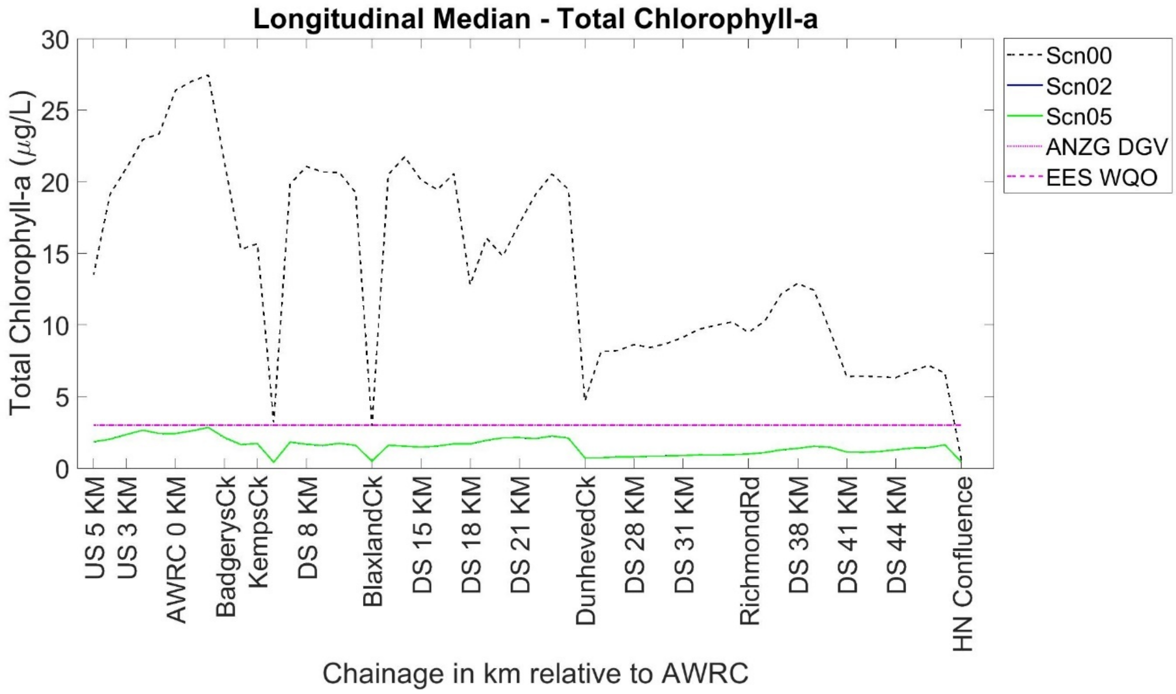


Figure 6-10 Longitudinal profile of predicted annual median Chlorophyll *a* concentrations (2036 releases/dry year)

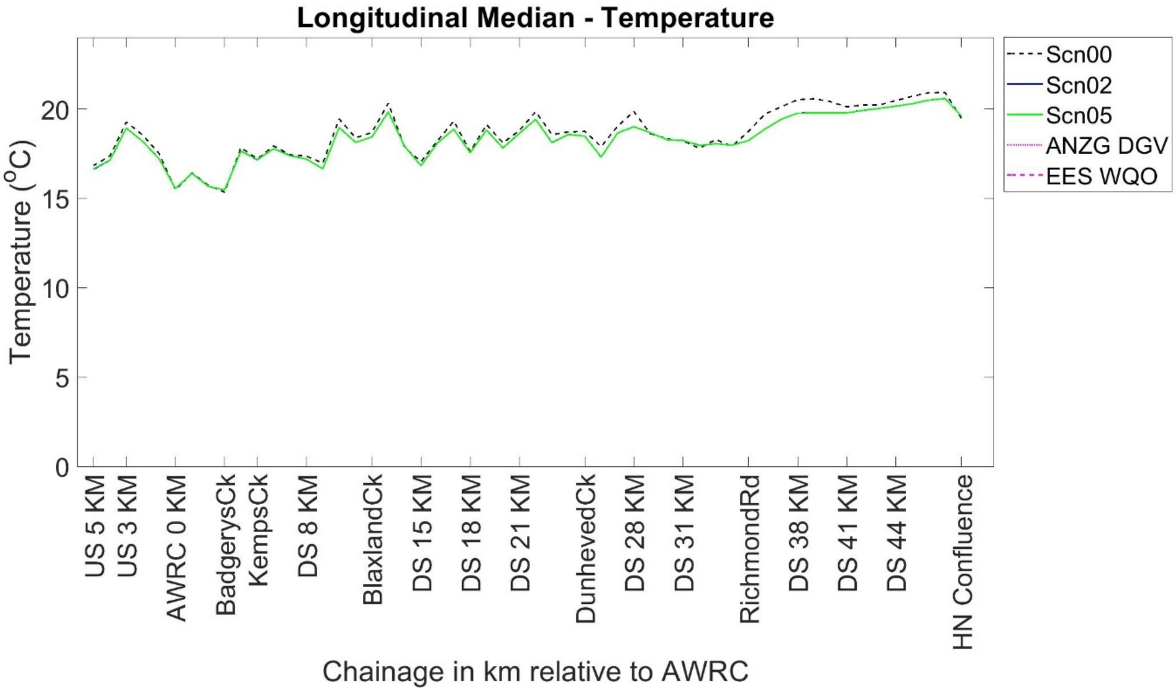


Figure 6-11 Longitudinal profile of predicted annual median Temperatures (2036 releases/dry year)

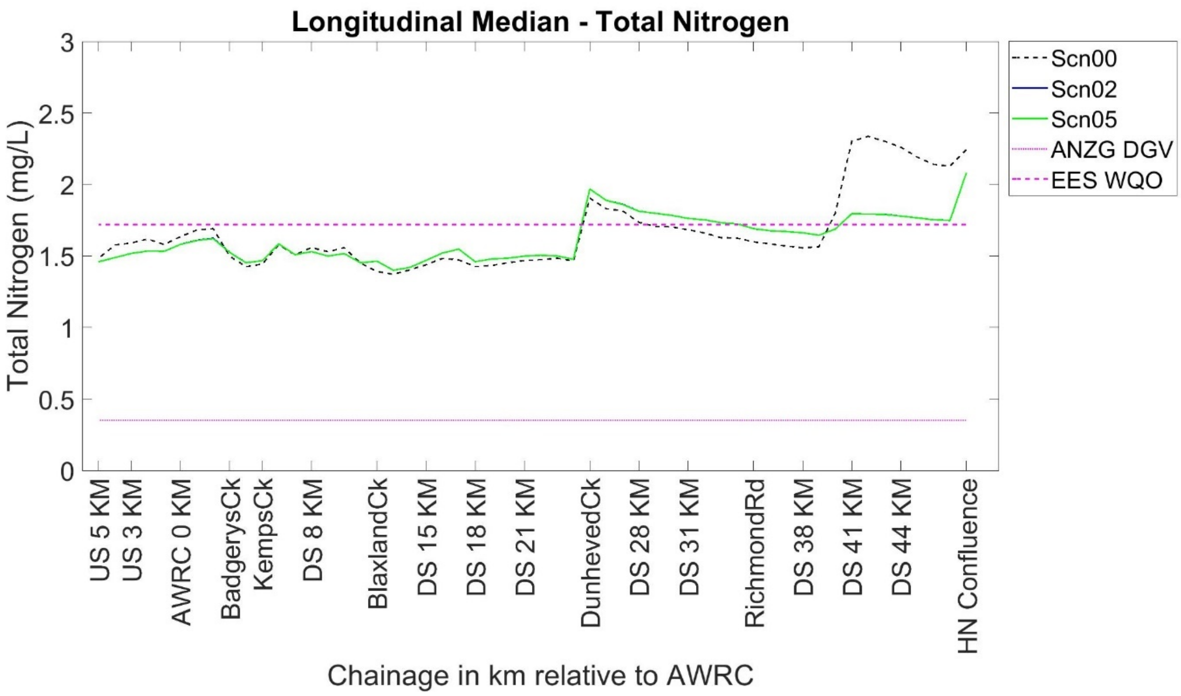


Figure 6-12 Longitudinal profile of predicted annual median Total Nitrogen concentrations (2036 releases/dry year)

6.1.1.5 Interpretation – impact scenarios

6.1.1.5.1 General

With implementation of the treatment and release strategy discussed in Section 4.6.3.5.1, the predicted residual impacts from the AWRC releases are considered to present a low risk of affecting long term ambient water quality and/or ecosystem health.

The following supporting comments are provided with respect to the results from the Upper South Creek AWRC impact scenarios relative to corresponding background conditions (circa 2036 and 2056):

- The timing of all release events generally correlates to increased flows in the creek. This indicates that typically rainfall in the AWRC wastewater catchments also corresponds with rainfall in the upper catchment of South Creek.
- The release events therefore generally occur not only when there are higher flows in the creek but also when elevated levels of contaminants (such as nutrients and sediment) and generally deteriorated water quality are experienced due to runoff originating from the surrounding catchments.
- For the 50 ML/d scenarios, there are a limited number (~2 events over 3 days) of very minor releases (< 0.07 m^3/s or 6 ML/d) during the dry year. During the wet year, more frequent (~6 events over 14 days) releases of greater magnitude (up to 1.5 m^3/s or 130 ML/d) are simulated.
- As shown in the hydrodynamic analysis below, there is the potential for releases from the AWRC to commence while creek flows are still increasing due to the rainfall in the upper catchment. This can lead to short-lived periods where there is less dilution in the creek and higher proportions of AWRC release relative to the overall creek flows.
- The relative magnitudes of the releases can, for some of the water quality parameters, have a significant influence on relative impacts in the creek. Not only do the releases increase in the more severe wet weather events, but the treatment level is also very much affected with more primary treated water being released as part of the blended/shandied releases. The releases can therefore in some instances actually provide a degree of dilution if they represent advanced treated water, but in other more severe wet weather circumstances, concentrations in the creek can increase temporarily due to higher proportions of primary treated water in the AWRC releases.
- Under the 2056 (Future stages) scenarios, the impacts are generally greater relative to those predicted under the 2036 (Stage 1) scenarios due to the proportional increases in volumes released.
- All impacts are mostly short lived with concentrations generally returning to background levels within a day due to the higher flow regimes (and consequently low residence times) that are experienced during moderate to severe wet weather in the ephemeral and non-ephemeral sections of the creek.
- Where applicable waterway objectives exist, analysis of the impacts on annual median profiles indicate there is no change to the level of compliance compared to the background scenario for any of the water quality parameters considered in the assessment. This applies to both the EES and ANZG derived waterway objectives.
- While the impacts are generally of similar magnitude, the impacts predicted for the scenarios that represented the Parkland stormwater management strategy were marginally greater than the scenarios that represented the BaU stormwater management strategy. Therefore, interpretation of the results has primarily focussed on the Parkland impact scenarios SC05 (circa 2036) and

SC06 (circa 2056), as well as the corresponding background scenarios, SC02 and SC04. Additional commentary is provided, where required, on how the BaU stormwater scenario results compare.

- With respect to the advanced treatment shutdown scenario (SC09), there is effectively only one event in the wet year where the treated water releases present significant changes in both release volume and water quality. This event occurs in late April 2015 and corresponds to a three-day wet weather event, with a total rainfall of up to 170 mm, and a peak daily total of ~85 mm/day in the upper South Creek catchment. Flows within the creek are predicted to rise to ~3,000 ML/day during this event. Due to the need to shut down the AWRC advanced treatment (reverse osmosis), wet weather releases to South Creek are extended by one day and the release volumes are also increased on two other days during the release event. The treated water quality in the releases are also modified due to the shut down. Results away from this date, replicate the comparable impact scenario, SC07. There are no events of this kind in the dry year.

6.1.1.5.2 Hydrodynamics

The following sub-sections present findings of the predicted hydrodynamic impacts from the AWRC releases with respect to flow conditions and contributions of flows from the AWRC. The findings are drawn from analysis of the results from the impact scenarios and the corresponding background conditions (circa 2036 and 2056). Further assessment of the hydrodynamic impacts, including analysis of water depth/level, velocity, wetted perimeter and erosion potential, is presented in the Ecohydraulic and Geomorphology Assessment.

Dry year

- The limited number of releases predicted in the dry year generate relatively minor increases in the downstream peak flow volumes. At a location 250 m downstream, the releases assumed for the 2036 impact scenario (SC05) are predicted to account for ~10% of the total flow at the start of the more severe wet weather event, reducing to less than 0.5% as the creek flows increase. Further downstream near Blaxland Creek (~12 km downstream of the releases), the predicted contributions are reduced to less than 4% of the total creek flow at the start of these larger wet weather event, reducing to less than 0.4% as the creek flows again increase. Figure 6-13 presents the predicted flow timeseries immediately downstream of the AWRC release point for the 2036 dry year release scenario assuming Parkland stormwater management.
- As discussed above, several of the AWRC release events are predicted to commence before flows in the creek have become more established. The creek flows are therefore sometimes predicted to temporarily be relatively low compared to the magnitude of the treated water releases from the AWRC. This leads to a reduced level of dilution and potentially lower levels of initial mixing. While this may be a product of the daily time steps used in the Source catchment and the modelling of the AWRC releases, the timing of the releases is an important aspect that should be managed if possible, so as to allow for sufficient dilution and mixing in the creek.
- Under the 2056 release scenario (SC06), the release volumes approximately double but the catchment is also further developed with more impermeable area, therefore the percentage contributions to total creek flow from the AWRC do not increase proportionally. The maximum contributions to total creek flow by the AWRC releases are predicted to increase to ~17% and ~5% respectively at the downstream locations (250 m and Blaxland Creek).

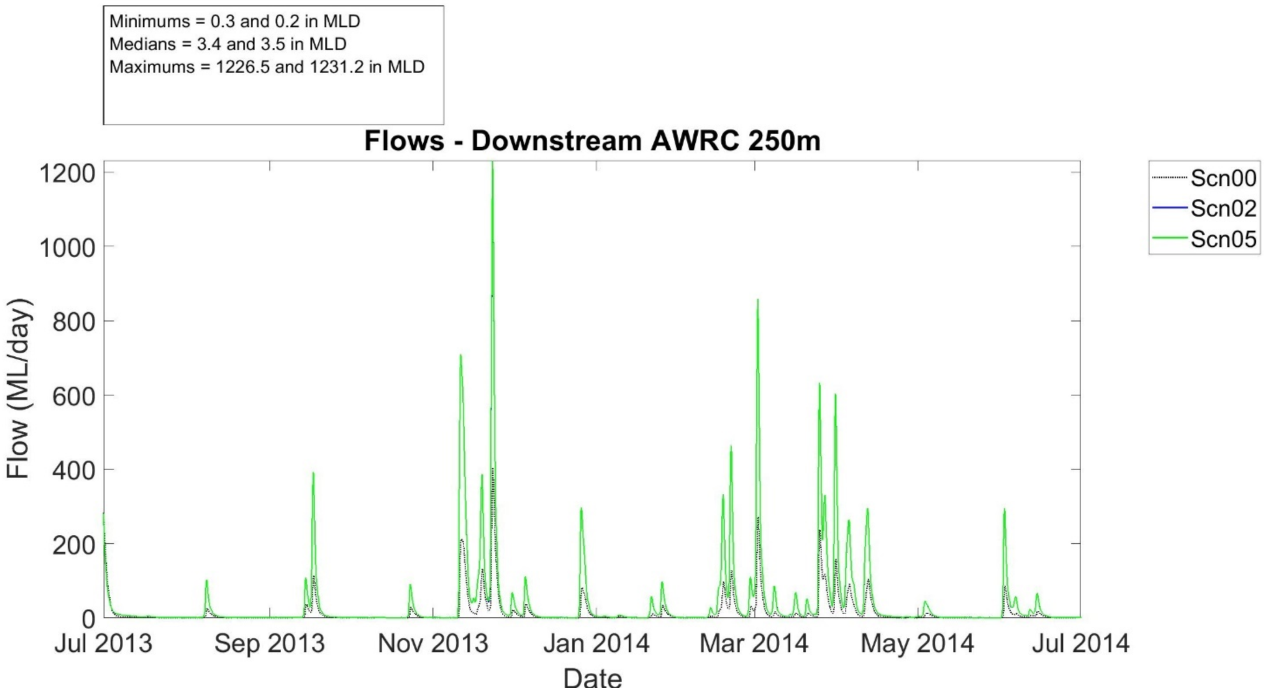


Figure 6-13 Timeseries of predicted flows 250 m downstream of AWRC release point (2036 releases/dry year)

Wet year

- Similar patterns are observed in the wet year, with the occasional spike in the relative contribution of the AWRC release to overall creek flow, at the start of some release events. The relative contribution from the AWRC treated water releases then generally declines as flows within the creek increase. During the wet weather release events (circa 2036), the average contribution of the AWRC releases downstream of the release point, lies between 4% and 7% of the total creek flows. The percentage contribution can however also account for up to 40% to 50% when the creek flows are relatively low, and the AWRC releases commence.
- Further downstream (~12 km) near Blaxland Creek, the releases on average account for 2%, up to a maximum of ~10% of the total creek flow.
- Under the 2056 release scenario (SC06), the percentage contributions to total creek flow again do not increase proportionally with release volumes due to ongoing land use changes. The average contributions to total creek flow are predicted to increase to ~11% and ~5% respectively at the aforementioned downstream locations (250 m and Blaxland Creek).

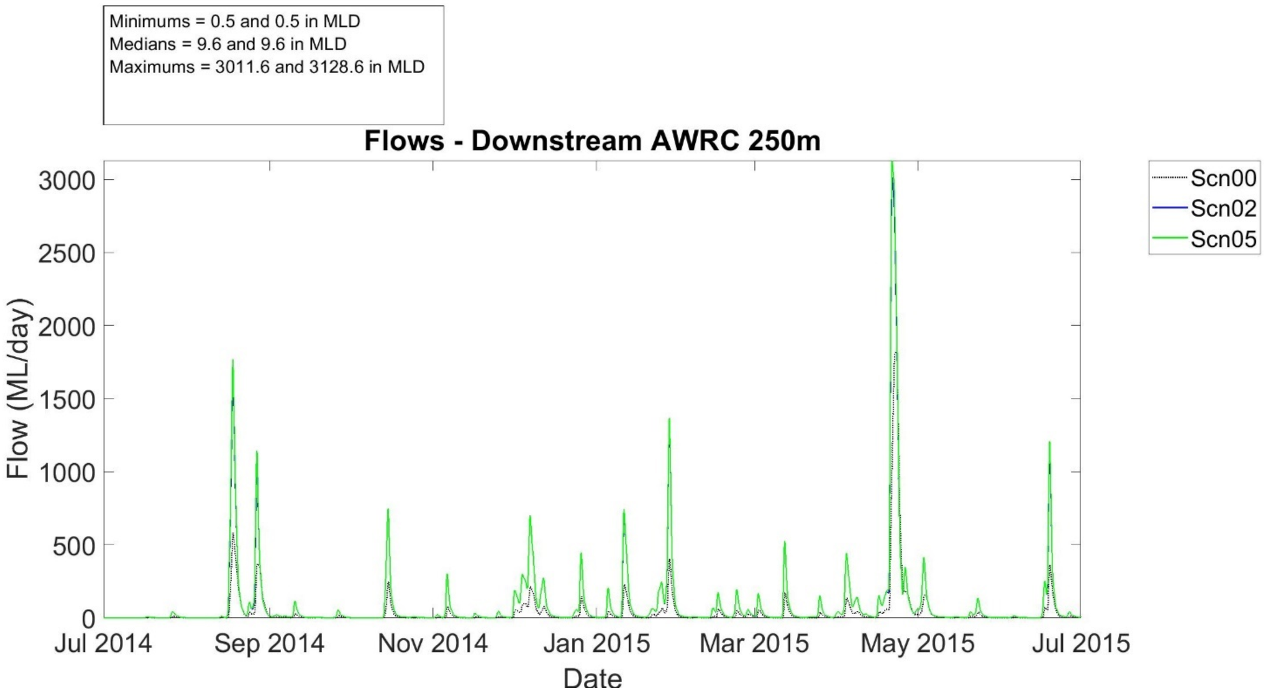


Figure 6-14 Timeseries of predicted flows 250 m downstream of AWRC release point (2036 releases/wet year)

BaU vs Parkland scenarios

Under BaU stormwater conditions (scenarios SC07 and SC08), the relative flow contributions from the AWRC releases are predicted to be lower. This is due to the higher background flows in the creek, resulting from less stormwater mitigation in the catchment.

In a dry year, the maximum downstream contribution from the AWRC releases falls to 8% (2036) and 12% (2056), compared to 10% and 17% for the corresponding Parkland scenarios.

In a wet year, the average contribution of the AWRC releases downstream of the release point, reduces to ~9% for the 2056 impact scenario (SC08), relative to 11% for the corresponding Parkland scenario (SC06).

Advanced treatment shutdown scenarios

The flows downstream of AWRC release point are predicted to be the similar for the shutdown scenario (SC09) as for the comparable 2036 BaU scenario (SC07), as the release volumes from the AWRC do not change significantly.

6.1.1.5.3 Water quality

The following sub-sections present findings of the predicted impacts on water quality from the AWRC releases, relative to the corresponding background conditions (circa 2036 and 2056).

Nitrogen

Dry year

- The limited number of releases during the dry year are predicted to generate negligible changes in the primary nitrogen indicators: ammonia, oxidised nitrogen and total nitrogen. Timeseries results indicate the short-term variations are either minor or not identifiable downstream of Kemps Creek.

- Importantly in a dry year all impacts represent beneficial reductions in total nitrogen in the creek due to the low concentrations in the advanced treated water being released, and the elevated nutrient levels and deteriorated water quality flowing in the creek from the upstream catchment.
- For the Parkland 2036 scenario (SC05), predicted daily total nitrogen concentrations decrease by up to a maximum of ~0.2 mg/L, 250 m downstream of the release (refer to Figure 6-15), reducing to less than 0.025 mg/L immediately downstream of Kemps Creek. These predicted variations increase marginally to ~0.3 mg/L and <0.06 mg/L respectively for the Parkland 2056 scenario (SC06).

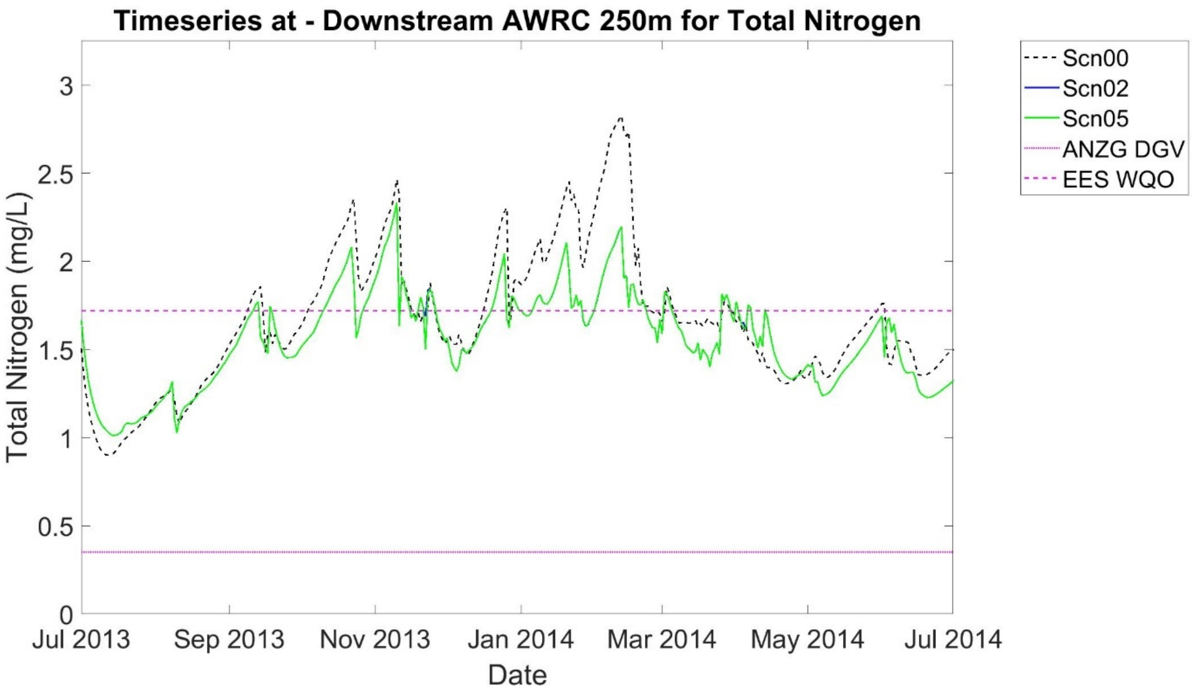


Figure 6-15 Timeseries of predicted Total Nitrogen concentrations 250 m downstream of AWRC release point (2036 releases/dry year)

Wet year

- During the wet year, the nature of the impacts varies considerably as a result of the different levels of treatment provided to the AWRC water releases over different rainfall conditions. The impacts in the creek include a mixture of reduced creek concentrations (dilution) and increased wet weather spikes (higher loading). The dilutions are due to the low concentrations of nitrogen in the advanced treated water releases during mild/moderate wet weather events, as seen in the dry year. Conversely, the higher loading is a result of elevated nutrient concentrations expected in the treated water releases during the release events that correspond to more severe wet weather, due to a lower proportion of advanced treated water relative to more primary treated water.
- Under the 2036 Parkland scenario (SC05), variations in wet weather concentrations, as a result of the AWRC releases, are predicted to extend further downstream within the creek, relative to the dry year. The most extreme increase in daily total nitrogen concentrations is predicted to be up to ~0.9 mg/L, 250 m downstream of the release (refer to Figure 6-16), reducing to less than 0.35 mg/L immediately downstream of Kemps Creek, and below 0.1 mg/L immediately downstream of Dunheved Creek. The impacts are again predicted to be short lived and return to the background conditions within a day of the releases.

- While the concentrations predicted downstream of the release point are predicted to peak above the EES waterway objective in Figure 6-16, it is predicted on a median basis, the concentrations will be remain compliant with the objective.
- With respect to the more bioavailable and inorganic forms of nitrogen, peaks in ammonia and oxidised nitrogen (refer Figure 6-17 and Figure 6-18) are also predicted above the waterway objective but on a median basis, the results are predicted to be close to, or below the guideline value. From a toxicity perspective, these results also indicate a low risk of toxicity as the predicted peaks in concentrations of ammonia and oxidised nitrogen remain below the toxicant DGVs discussed in Section 2.2, noting that the modified DGV for Total Ammonia is assumed to be 1.75 mg/L (refer Section 6.2.1.3.1 and Table 6-4).
- Under the higher AWRC capacity simulated in the 2056 Parkland scenario (SC06), the most extreme increase in total nitrogen concentrations is predicted to be ~1.4 mg/L, 250 m downstream of the release, reducing to less than 0.6 mg/L downstream of Kemps Creek, and ~0.14 mg/L immediately downstream of Dunheved Creek. The impacts are again still predicted to be short lived and return to background conditions within a day.

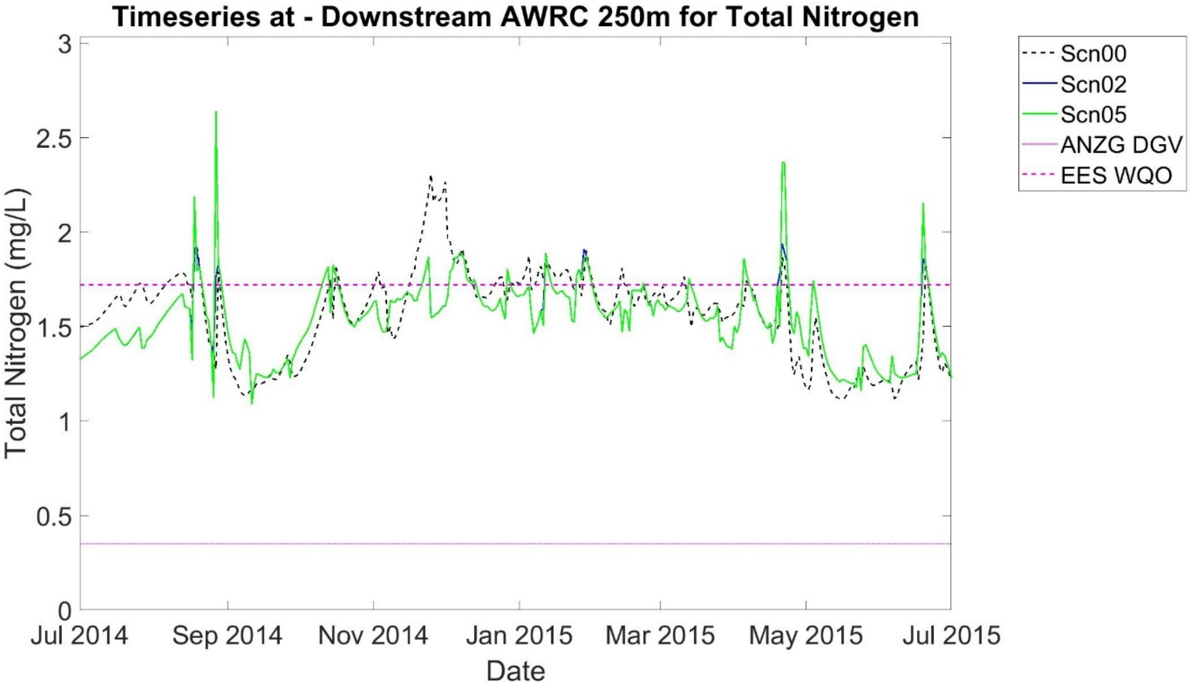


Figure 6-16 Timeseries of predicted Total Nitrogen concentrations 250 m downstream of AWRC release point (2036 releases/wet year)

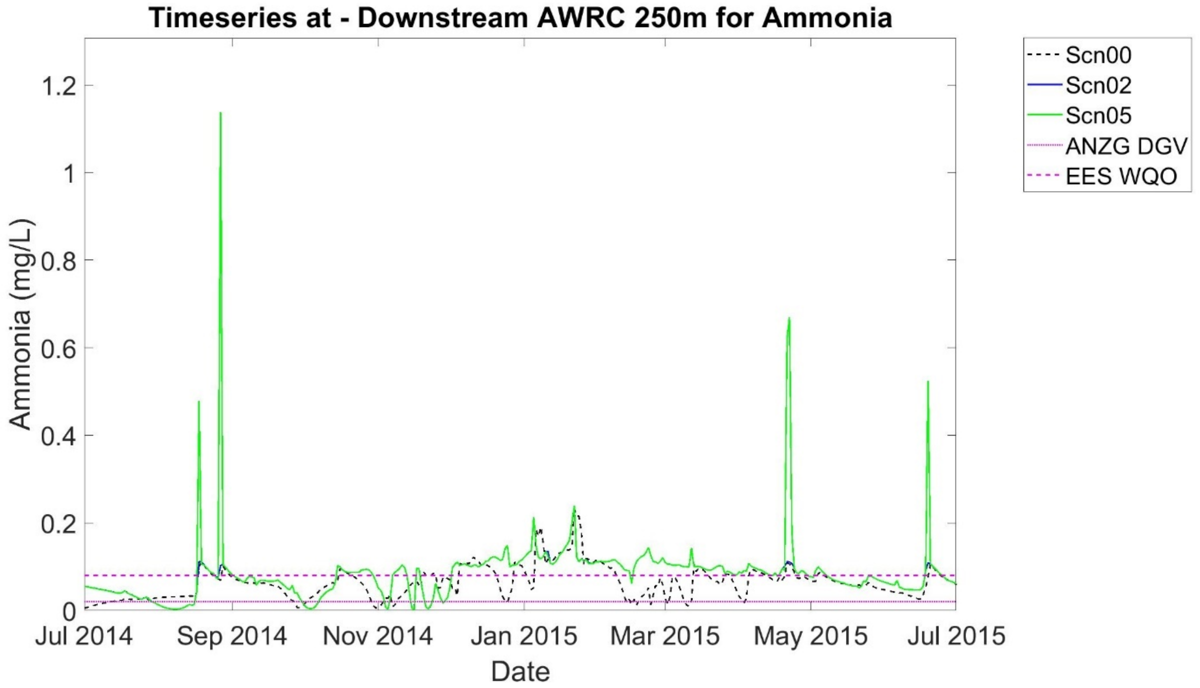


Figure 6-17 Timeseries of predicted Ammonia concentrations 250 m downstream of AWRC release point (2036 releases/wet year)

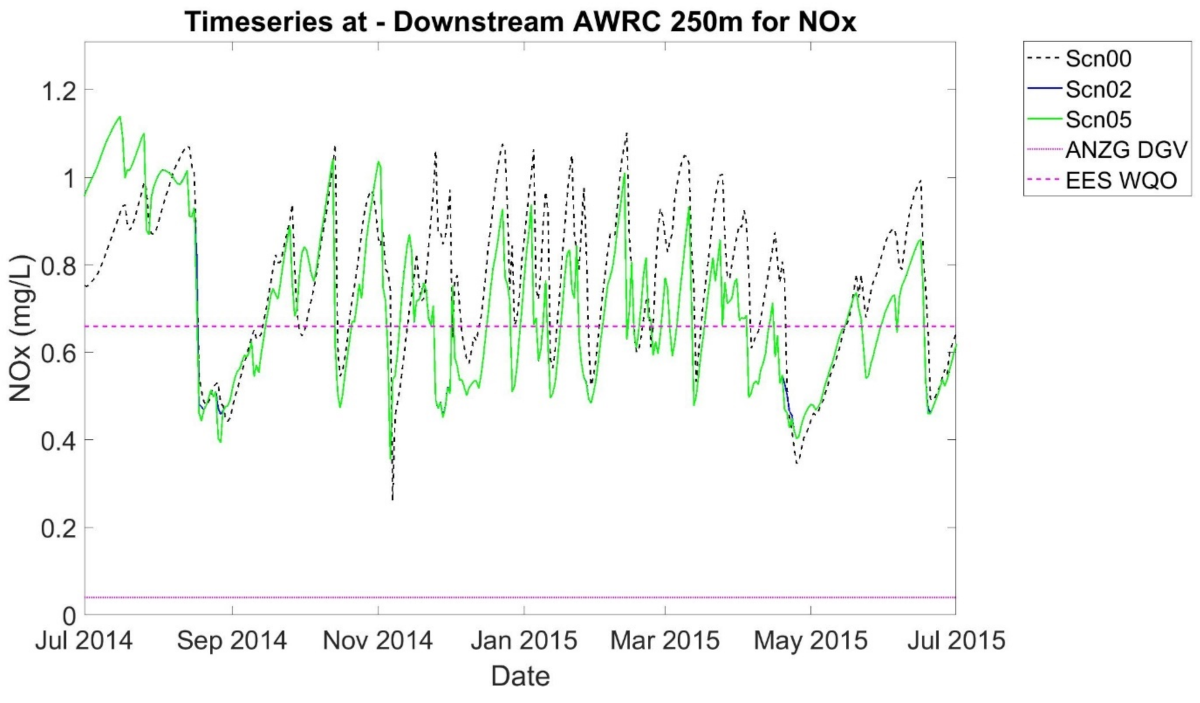


Figure 6-18 Timeseries of predicted Oxidised Nitrogen concentrations 250 m downstream of AWRC release point (2036 releases/wet year)

BaU vs Parkland scenarios

- Similar patterns in impacts were predicted for the comparative BaU stormwater scenarios (SC07 and SC08) with the corresponding reductions in total nitrogen predicted to be up to ~80% of those predicted for the Parkland scenarios (SC05 and SC06).

Advanced treatment shutdown scenarios

- For the advanced treatment shutdown scenario (SC09), there were little or no changes to the level of impact predicted relative to continuous and normal operation of the AWRC. With respect to total nitrogen, the most extreme increase in daily total nitrogen concentrations was predicted to remain unchanged from the equivalent non-shutdown scenario (SC07) i.e. 0.8 to 0.9 mg/L, 250 m downstream of the release, reducing to ~0.3 mg/L immediately downstream of Kemps Creek.
- The impacts are again predicted to be short lived and return to the background conditions within a day of the releases ceasing.

Compliance

- The impacts from introduction of the AWRC releases are predicted to have negligible influence on the annual median nitrogen concentrations. The predicted levels of compliance against the project waterway objectives are therefore identical to the background scenario for all nitrogen indicators.
- For both wet and dry years, the predicted annual median profiles for the 2036 release conditions (SC05) present only marginal or undiscernible changes in all nitrogen indicators with compliance with the EES waterway objective predicted for total nitrogen upstream of the St Marys/Dunheved reach (refer to Figure 6-17 and 6-18).
- For ammonia, compliance with the EES waterway objective is generally predicted downstream to the Dunheved reach, for the 2036 scenario (SC05), under both wet and dry years (refer to Figure 6-19 and Figure 6-20).
- For oxidised nitrogen, compliance with the EES waterway objective is predicted downstream to the tidal section of the creek, for the 2036 scenario (SC05), under both wet and dry years (refer the Figure 6-23 and Figure 6-24).
- For all nitrogen indicators, compliance with the relatively more stringent ANZG guidelines is predicted to be limited or not achievable.

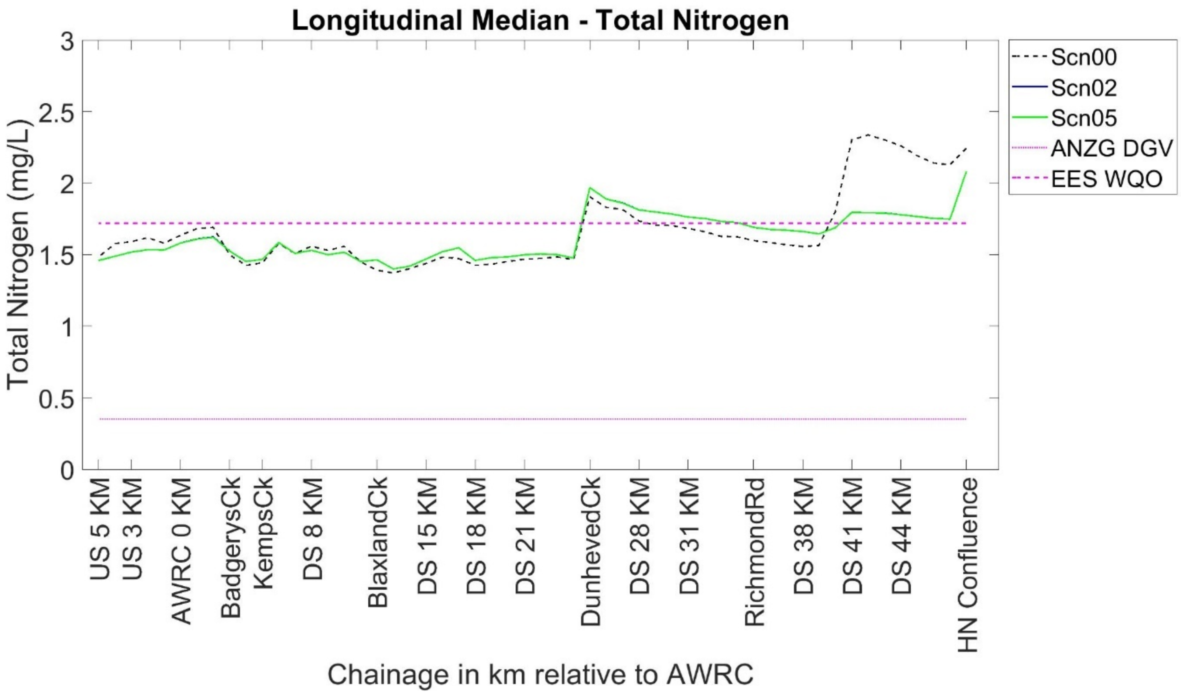


Figure 6-19 Longitudinal profile of predicted annual median Total Nitrogen concentrations (2036 releases/dry year)

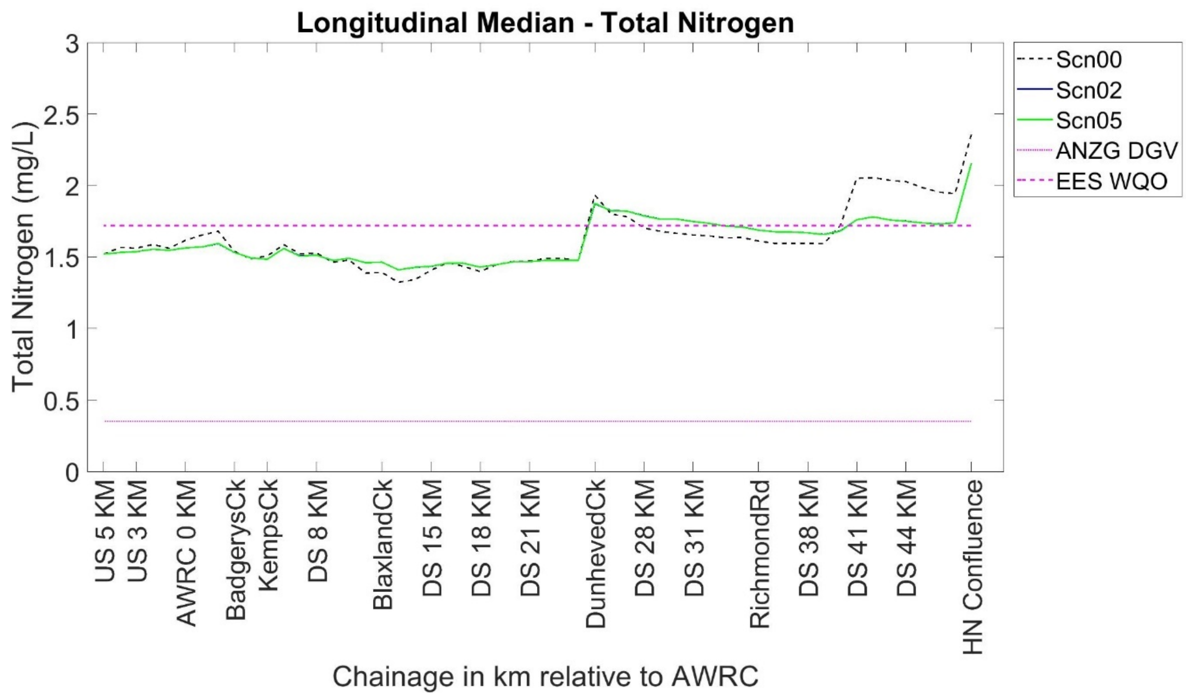


Figure 6-20 Longitudinal profile of predicted annual median Total Nitrogen concentrations (2036 releases/wet year)

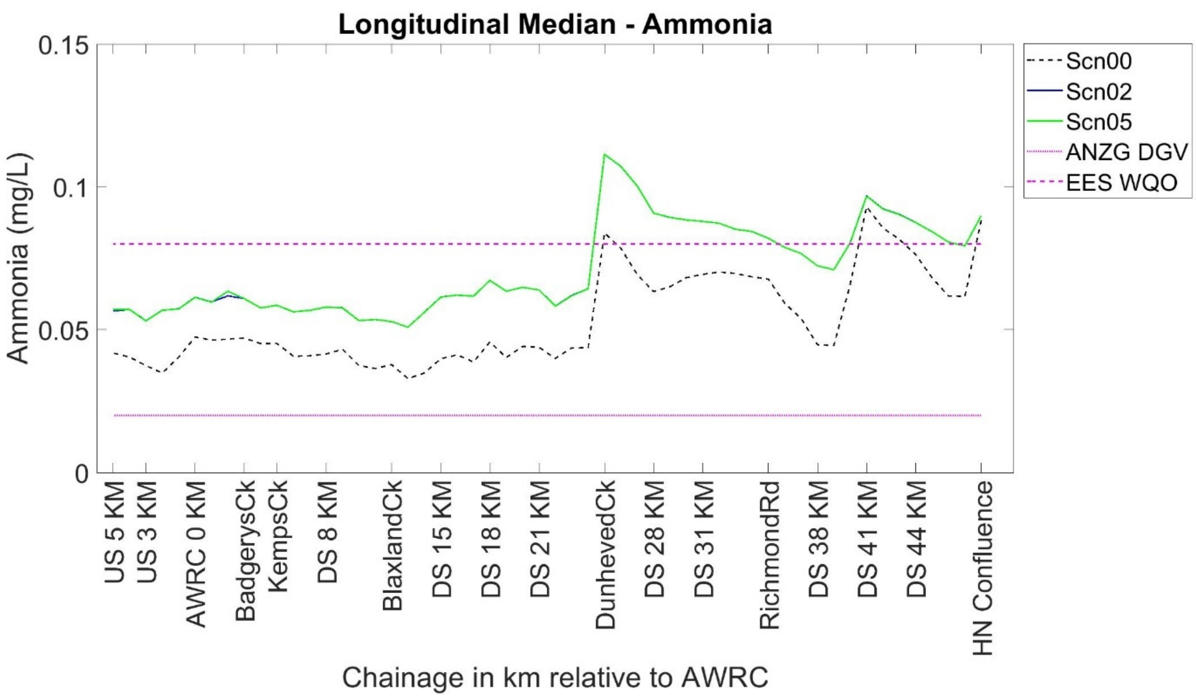


Figure 6-21 Longitudinal profile of predicted annual median Ammonia concentrations (2036 releases/dry year)

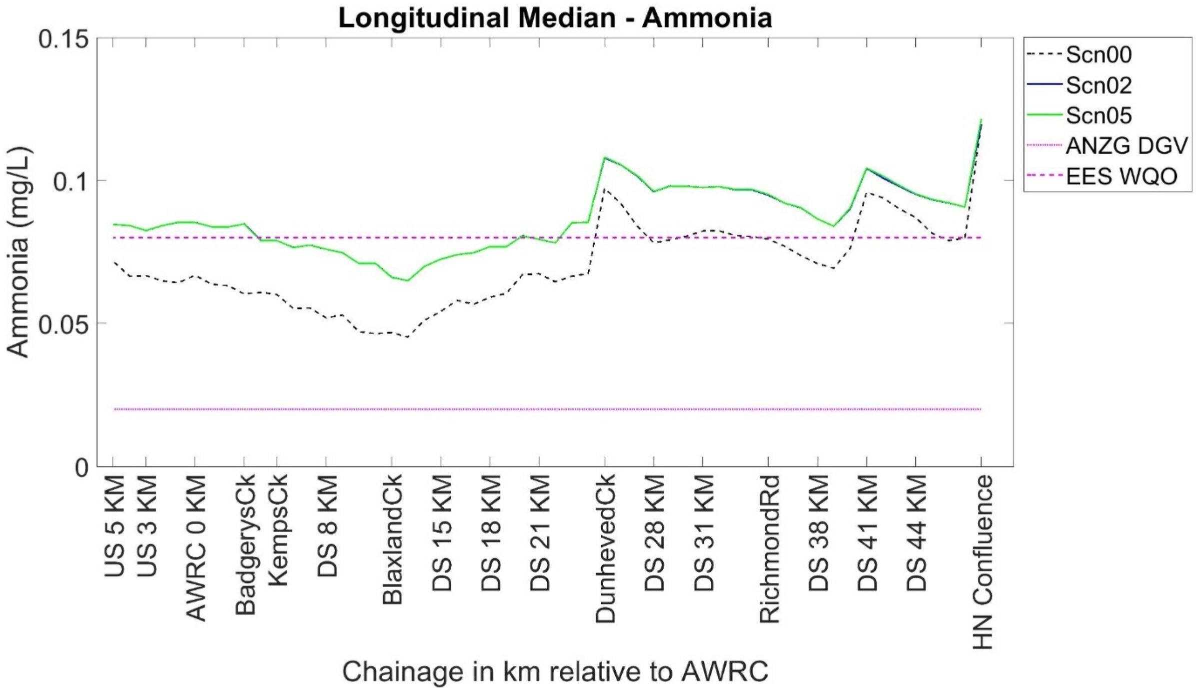


Figure 6-22 Longitudinal profile of predicted annual median Ammonia concentrations (2036 releases/wet year)

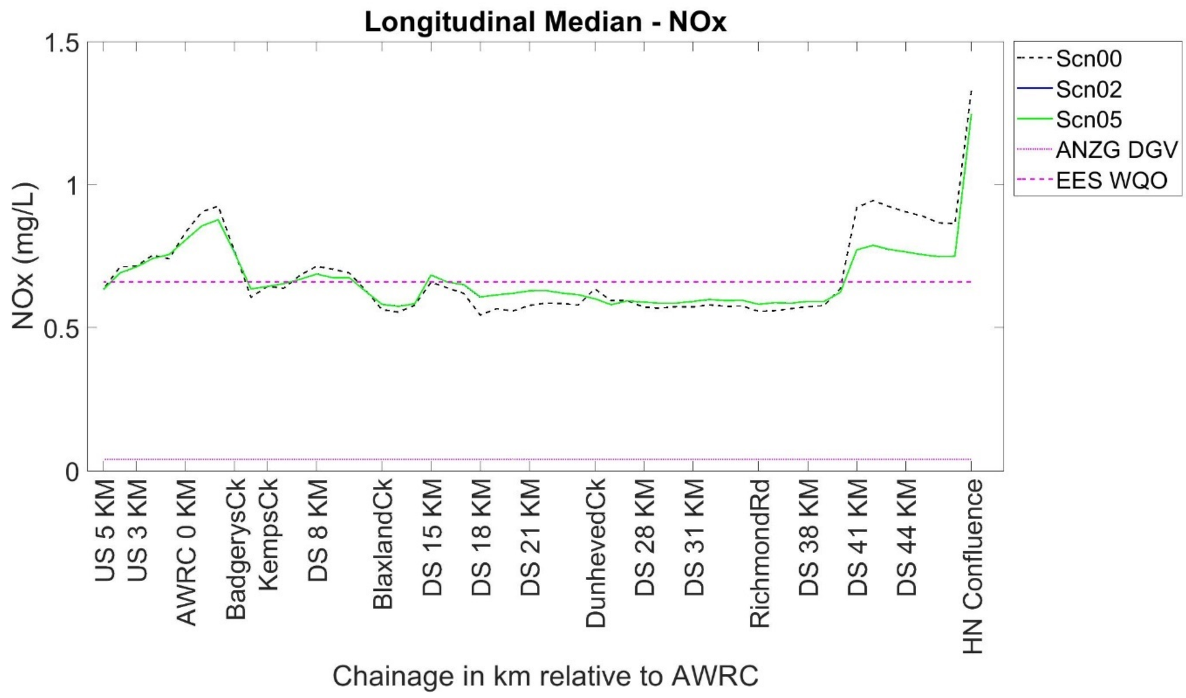


Figure 6-23 Longitudinal profile of predicted annual median Oxidised Nitrogen concentrations (2036 releases/dry year)

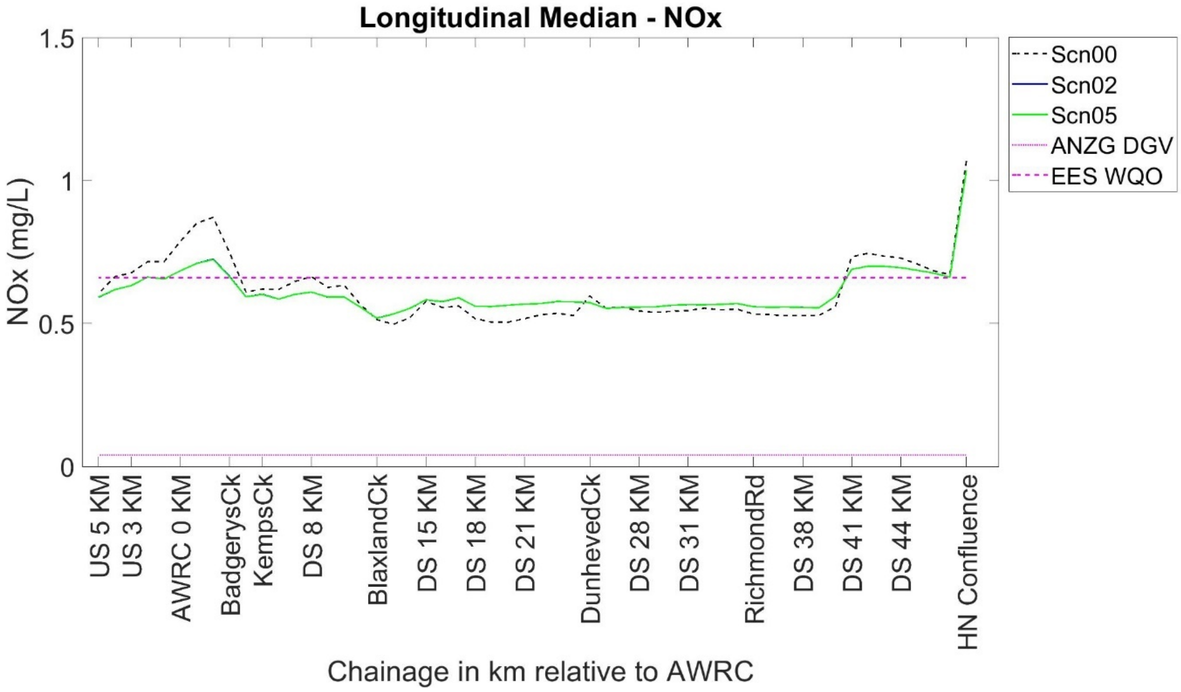


Figure 6-24 Longitudinal profile of predicted annual median Oxidised Nitrogen concentrations (2036 releases/wet year)

Phosphorus

Dry year

- Similar trends to nitrogen were predicted for all the scenarios with lower downstream concentrations of phosphorus predicted in the creek due to dilution from the advanced treated water releases. For the 2036 Parkland scenario (SC05), a maximum reduction of ~0.02 mg/L in total phosphorus daily concentrations was predicted 250 m downstream of the release point during the most significant release (refer to Figure 6-25). Immediately downstream of Kemps Creek, the reduction in phosphorus concentrations was predicted to be an order of magnitude lower than those predicted at the 250 m downstream location.
- Under the 2056 Parkland scenario (SC06), a ~0.04 mg/L reduction in daily phosphorus concentrations was predicted, at the site 250 m downstream of the release point. This indicates the potential for greater dilutions within the creek with the increased volumes of advanced treated water being released.
- Similar to the nitrogen analysis, while the concentrations predicted downstream of the release point are predicted to peak above the EES waterway objective in Figure 6-25, it is predicted on a median basis, the concentrations will be remain compliant with the objective.
- The impacts from the release events are predicted to be short lived and return to the background conditions within a day.

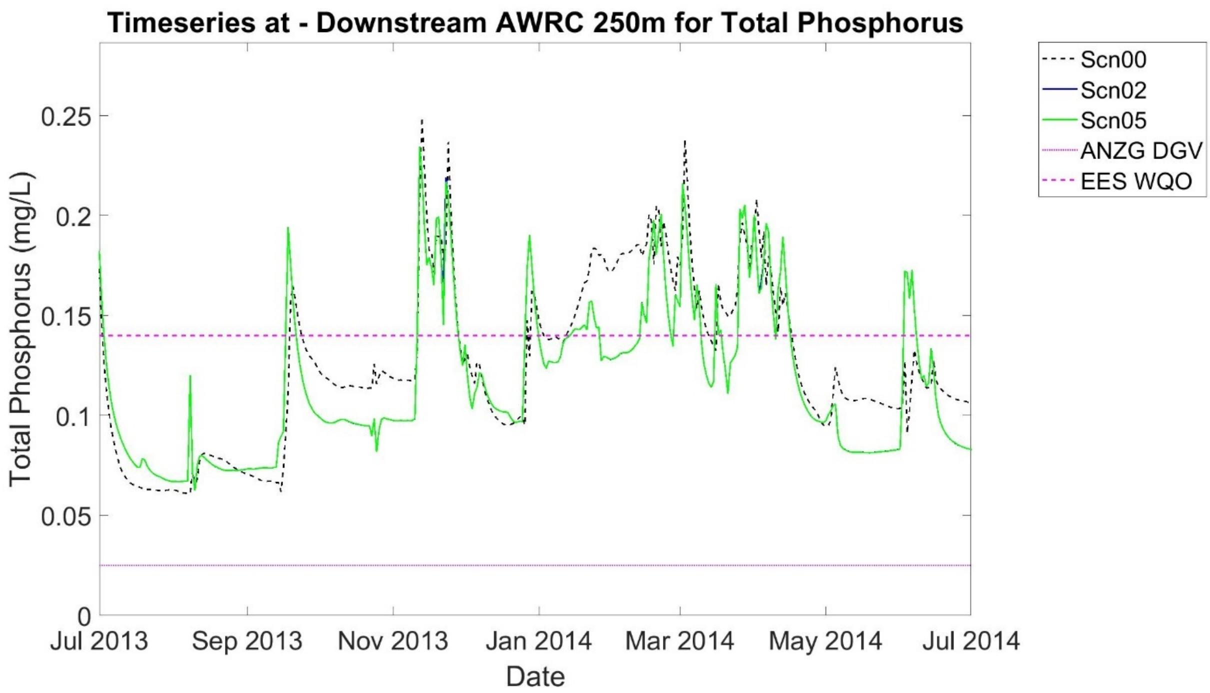


Figure 6-25 Timeseries of predicted Total Phosphorus concentrations 250 m downstream of AWRC release point (2036 releases/dry year)

Wet year

- Impacts again varied between dilution and higher loading as a result of the level of treatment and the corresponding differential between the concentrations in the treated water releases and the water in the creek. Under the Parkland 2036 scenario (SC05), the maximum increases in daily concentrations of total phosphorus and FRP, 250 m downstream of the releases, were predicted to be ~0.04 mg/L for both indicators (refer to Figure 6-26). The relative impacts were predicted to be reduced with distance from the release point, with concentrations of both total phosphorus and FRP reducing by ~0.15 mg/L downstream of the Kemps Creek confluence (refer to Figure 6-27).
- Under the 2056 release scenario (SC06), the modelling results indicate a range of impacts for total phosphorus with increases of downstream concentrations of up to ~0.02 mg/L and maximum reductions of ~0.06 mg/L (refer to Figure 6-28). For FRP, the range of impacts extends from increases of ~0.06 mg/L to reductions of 0.015 mg/L (refer to Figure 6-29).
- The impacts are again predicted to be short lived and return to the background conditions within a day of the releases ceasing.

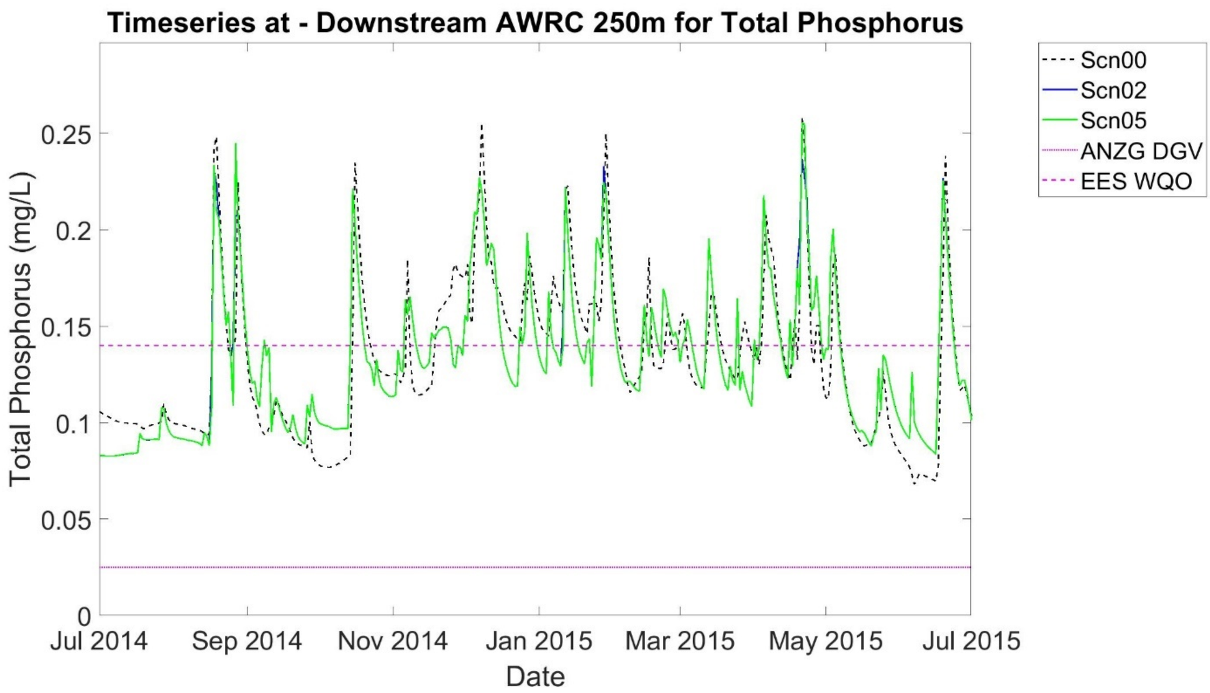


Figure 6-26 Timeseries of predicted Total Phosphorus concentrations 250 m downstream of AWRC release point (2036 releases/wet year

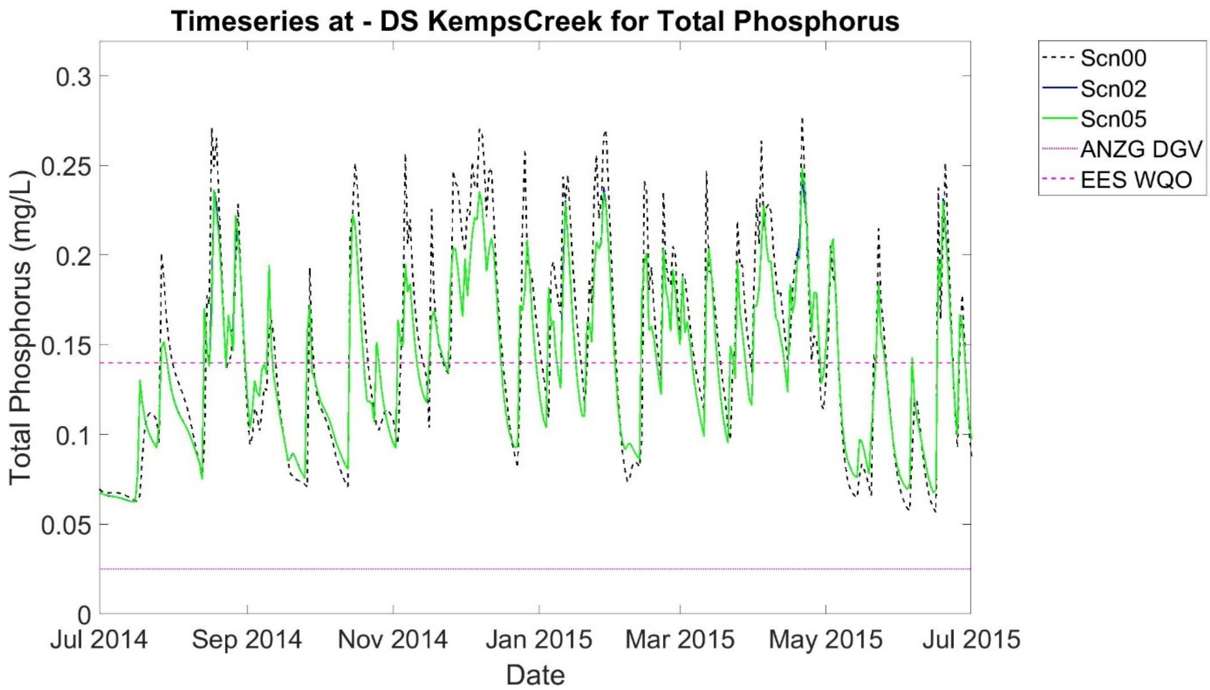


Figure 6-27 Timeseries of predicted Total Phosphorus concentrations downstream of the Kemps Creek confluence (2036 releases/wet year

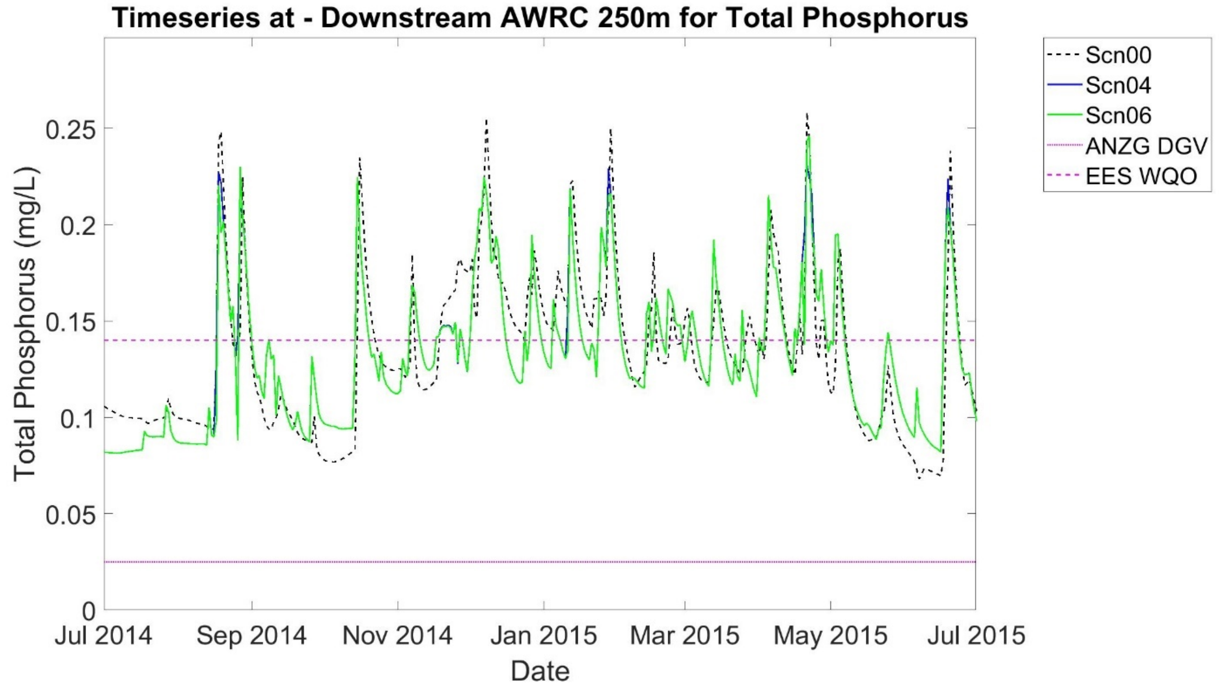


Figure 6-28 Timeseries of predicted Total Phosphorus concentrations 250 m downstream of AWRC release point (2056 releases/wet year)

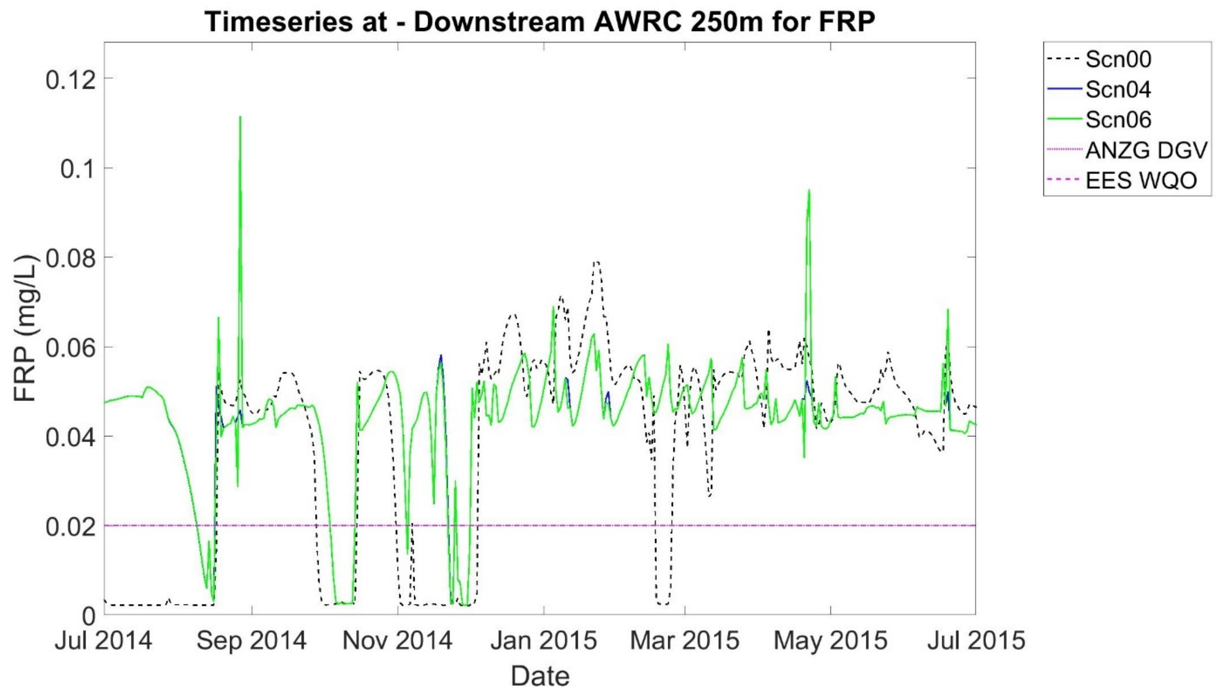


Figure 6-29 Timeseries of predicted FRP concentrations 250 m downstream of AWRC release point (2056 releases/wet year)

BaU vs Parkland scenarios

- Similar patterns in impacts were predicted for the comparative BaU stormwater scenarios (SC07 and SC08) with the corresponding reductions in total phosphorus predicted to be 70% to 80% of those predicted for the Parkland scenarios (SC05 and SC06).

Advanced treatment shutdown scenarios

- Minor changes to the level of impact were predicted under the advanced treatment shutdown scenario (SC09). During the April 2015 event that simulated a shutdown of the AWRC advanced treatment process, daily total phosphorus concentrations were predicted to increase temporarily, relative to background, by ~0.05 mg/L, 250 m downstream of the release point. This was relative to 0.03 mg/L to 0.04 mg/L that was predicted without the shutdown (scenario SC07). Immediately downstream of Kemps Creek, the impacts were of a similar magnitude to the equivalent non-shutdown scenario.
- For FRP, the impacts relative to the non-shutdown scenario were also predicted to be minor with an increase of downstream daily concentrations from ~0.03 mg/L to ~0.035 mg/L, relative to the corresponding non-shutdown scenario (SC07).

Compliance

- Annual medians are predicted to remain essentially unmodified under the proposed release scenarios during both wet and dry years.
- Annual median concentrations for total phosphorus are generally predicted to be compliant with the EES waterway objective downstream of the AWRC release point, but not with the ANZG objective. Refer to Figure 6-30 and Figure 6-31 for the dry and wet year circa 2036 (SC05) analysis.
- For FRP, zero compliance is predicted for either the EES or ANZG objectives, replicating the background scenario. Refer to Figure 6-32 for the dry year circa 2036 (SC05) analysis.

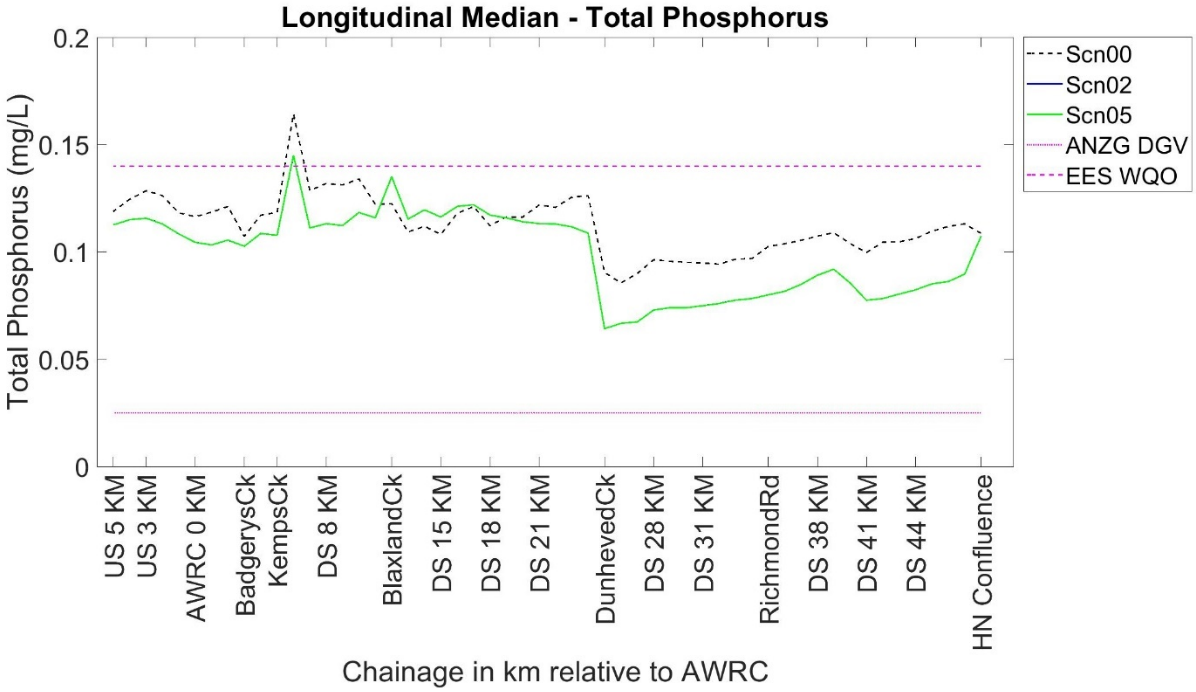


Figure 6-30 Longitudinal profile of predicted annual median Total Phosphorus concentrations (2036 releases/dry year)

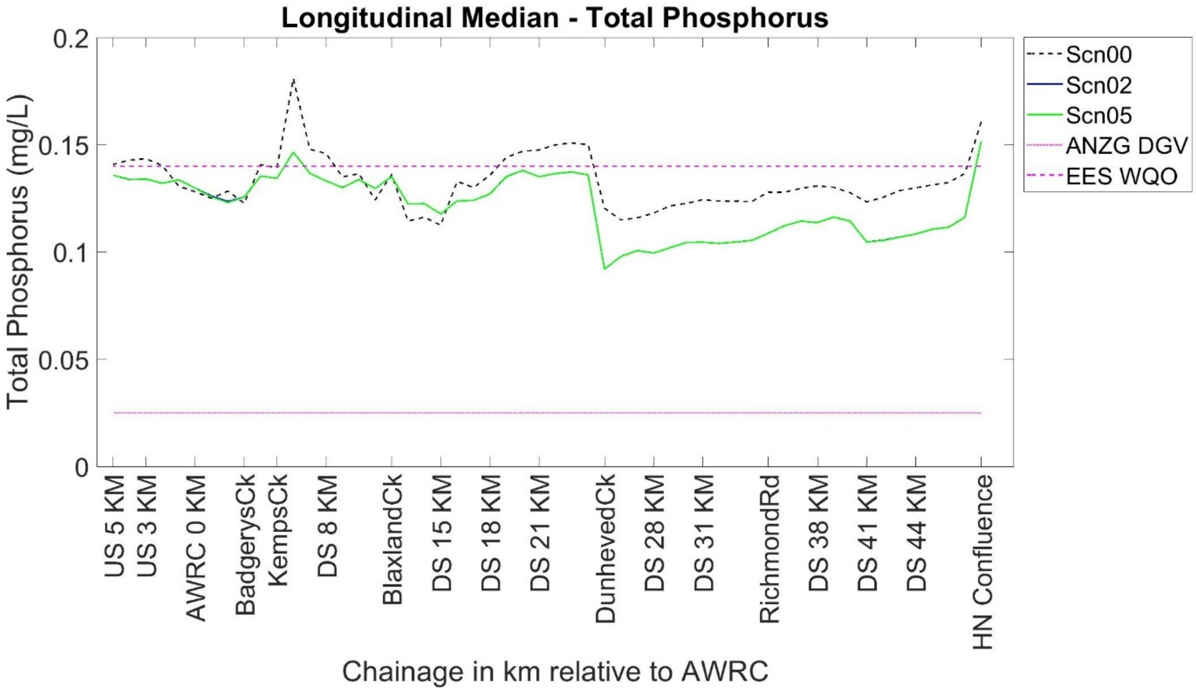


Figure 6-31 Longitudinal profile of predicted annual median Total Phosphorus concentrations (2036 releases/wet year)

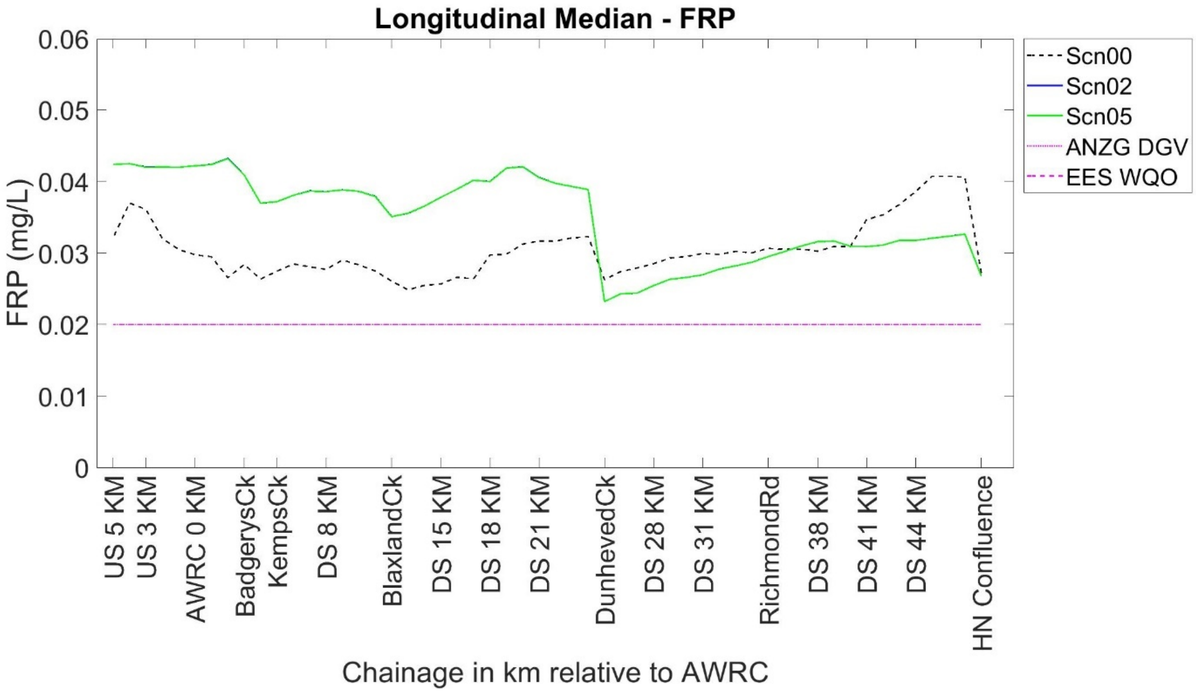


Figure 6-32 Longitudinal profile of predicted annual median FRP concentrations (2036 releases/dry year)

Chlorophyll *a*

- Under both 2036 impact scenario conditions (SC05 and SC07), no discernible change in chlorophyll *a* is predicted in either the daily time series or the annual median concentration profiles, indicating there is no expected modification to primary productivity or algal growth as a result of the AWRC releases. This is considered a result of the releases occurring in times of wet weather with rapid flushing of the creek (refer to Figure 6-33).
- In addition to the flushing dynamics, the changes in nutrient loading to the creek assumed in 2036 and 2056 are also marginal, with any additional nutrient loads occurring away from sustained dry periods when conditions that favour eutrophication are more prominent.
- For both 2056 impact scenarios (SC06 and SC08), very minor and short-term reductions in daily chlorophyll *a* concentrations were predicted in the time series downstream of the AWRC following the larger releases, but generally the results indicate there is no expected modification to primary productivity or algal growth. This indicates that during some of the AWRC release events, dilution is predicted to occur due to the relative differences in concentrations between the creek and the AWRC treated water.
- No additional growth was predicted as a result of the shutdown of the AWRC advanced treatment process.
- No modifications to the annual median profiles are predicted compared to the background scenario. Compliance is predicted with both the EES and ANZG derived waterway objectives. Refer to Figure 6-34 for the 2036 (SC05) dry year analysis.

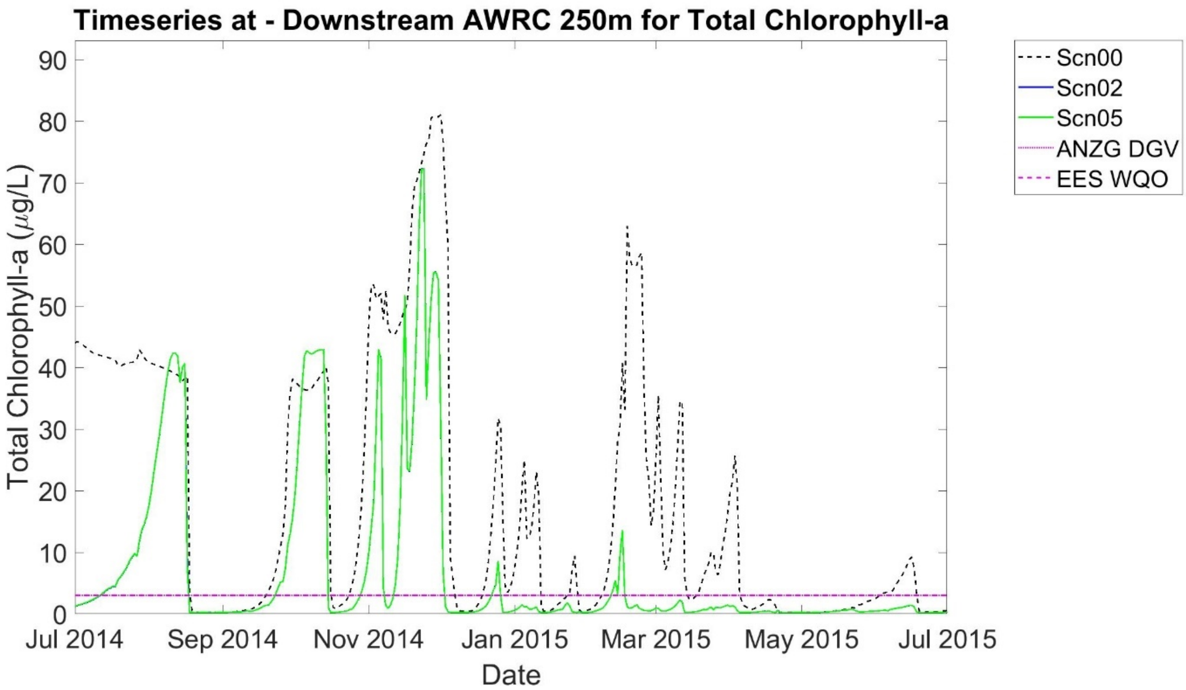


Figure 6-33 Timeseries of predicted Chlorophyll *a* concentrations 250 m downstream of AWRC release point (2036 releases/wet year)

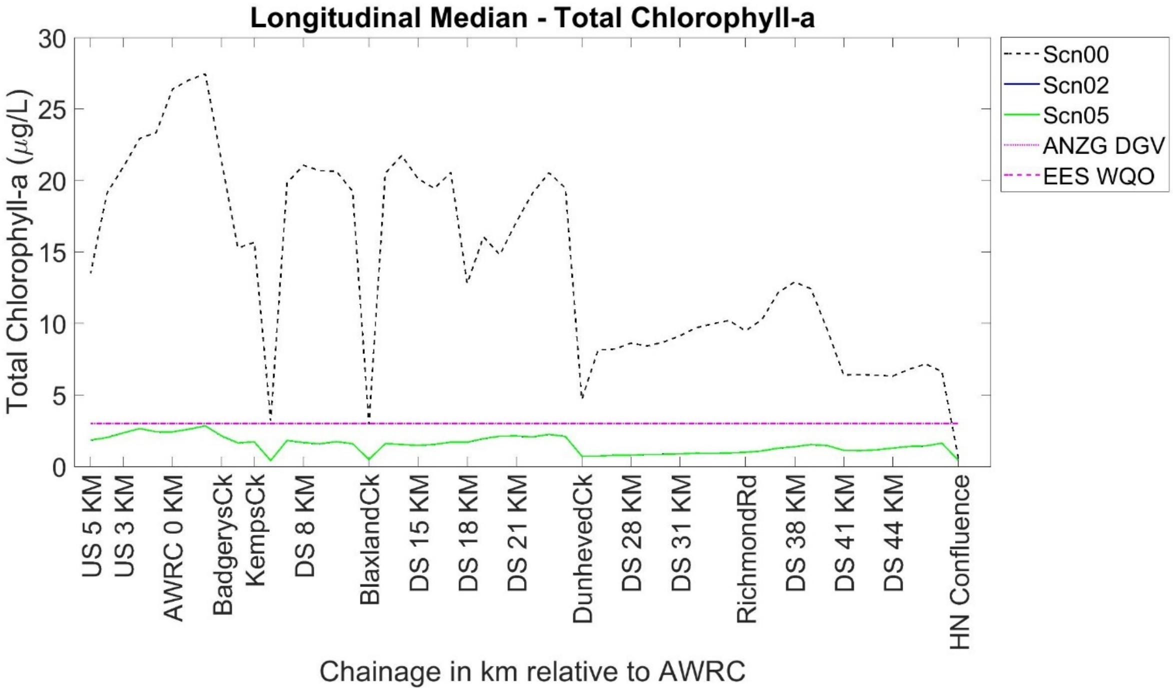


Figure 6-34 Longitudinal profile of predicted annual median Chlorophyll *a* concentrations (2036 releases/dry year)

Salinity

- For the 2036 impact scenario conditions (SC05 and SC07), minor (<0.05 g/L), infrequent and short-lived reductions in daily concentrations of salinity in the creek are predicted immediately downstream due to the lower salinity in the AWRC treated water (~0.1 g/L), relative to the assumed salinity in the creek (0.3 to 0.4 g/L) (refer to Figure 6-35).
- For the 2056 impact scenario (SC06 and SC08), the downstream reductions in salinity are predicted to increase up to ~0.07 g/L due to the higher volumes of treated water being released.
- No changes were predicted as a result of the shutdown of the AWRC advanced treatment process.
- No notable change in annual median profiles were predicted for either the wet or dry year, with compliance predicted against both EES and ANZG waterway objectives throughout the creek. Refer to Figure 6-36 for the 2036 (SC05) dry year analysis.

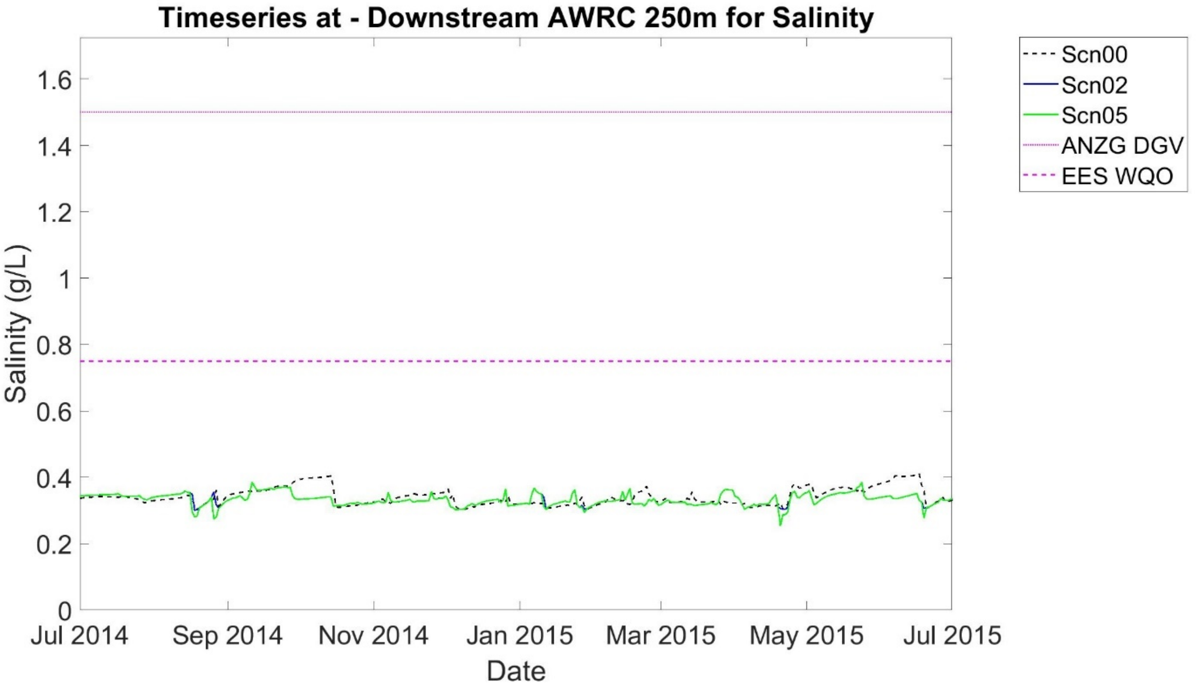


Figure 6-35 Timeseries of predicted Salinity concentrations 250 m downstream of AWRC release point (2036 releases/wet year)

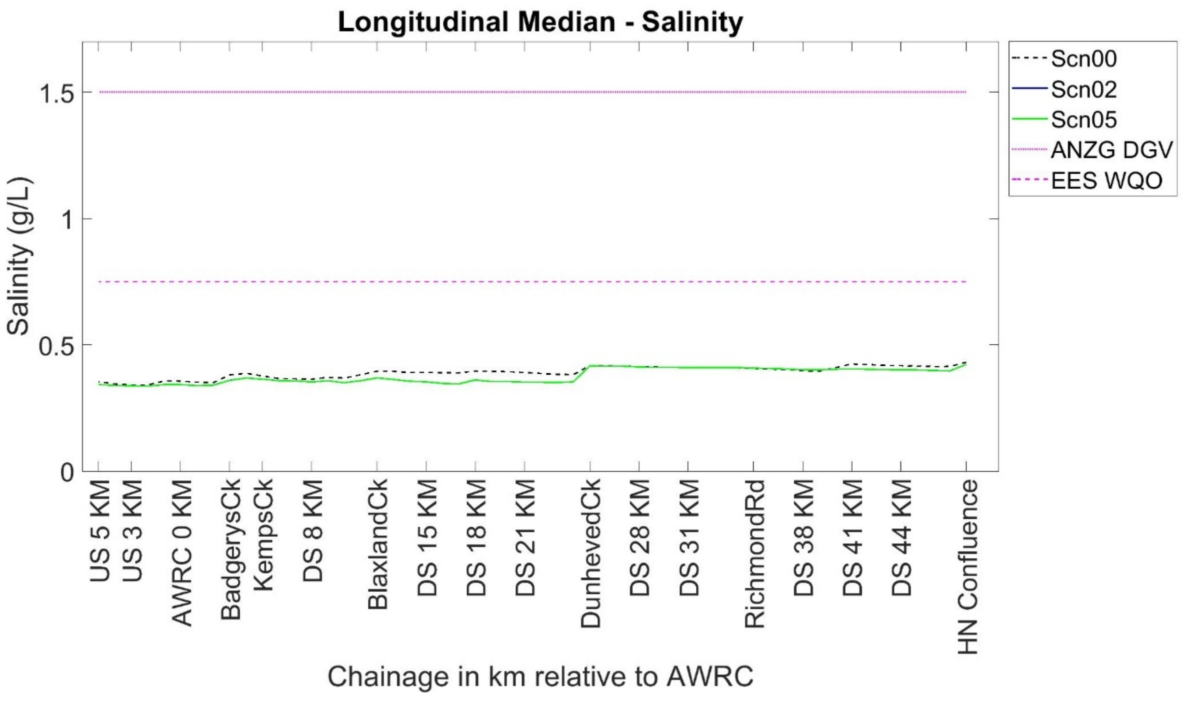


Figure 6-36 Longitudinal profile of predicted annual median Salinity concentrations (2036 releases/dry year)

Total Suspended Solids

- For the 2036 impact scenarios (SC05 and SC07), minor (<15 mg/L), infrequent and short-lived reductions in daily concentrations of suspended solids in the creek are predicted downstream of the releases. This is due to the lower TSS concentrations in the treated water (<15 mg/L) relative to the creek concentrations in wet weather (>80 g/L).

- On larger events, some evidence is shown that the more significant releases may generate more erosion and/or resuspension. Increases in TSS are predicted of a similar magnitude to the reductions discussed above. These impacts are again short term due to the release event length and significant creek flushing (refer to Figure 6-37).
- For the 2056 scenarios, the reductions (and increases) are both <20 mg/L relative to background conditions.
- For the advanced treatment shutdown scenario (SC09), the level of impact remained unchanged relative to the equivalent non-shutdown scenario (SC07).
- No notable change in annual median profiles were predicted for either time horizon or for either plant capacity. Refer to Figure 6-38 for the 2036 wet year analysis. The annual median concentrations are predicted to be compliant with both the EES waterway objective (30 g/L) and ANZG waterway objective (40 g/L).

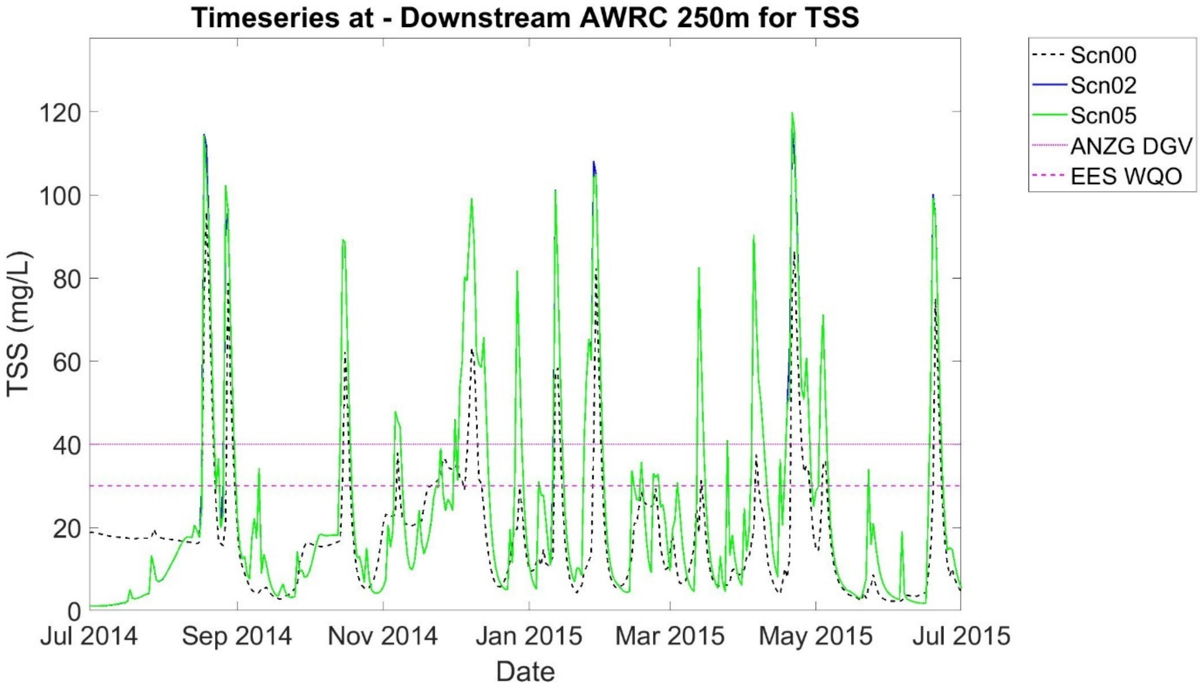


Figure 6-37 Timeseries of predicted TSS concentrations 250 m downstream of AWRC release point (2036 releases/wet year)

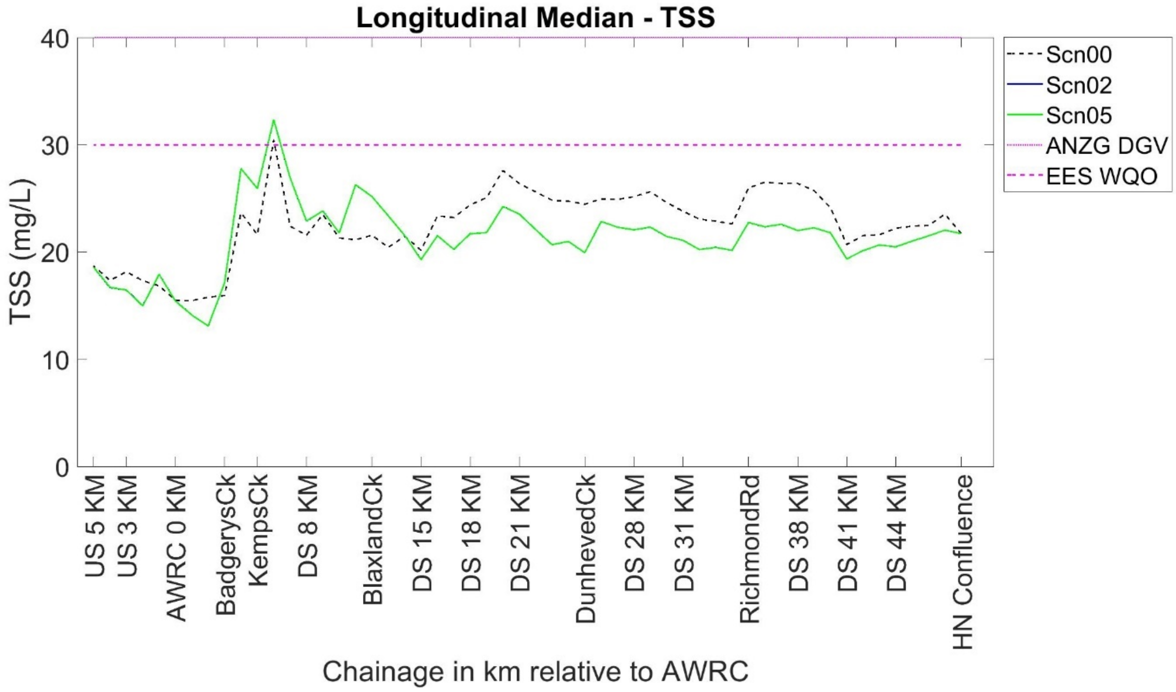


Figure 6-38 Longitudinal profile of predicted annual median TSS concentrations (2036 releases/wet year)

Dissolved oxygen

- For all the impact scenarios, minor beneficial increases (<~1.5 mg/L or ~15%) in daily dissolved oxygen levels were predicted 250 m downstream of the release point as a result of the AWRC wet weather releases. These increases were assumed to be the result of higher concentration in the treated water releases relative to the lower creek concentrations. The increases are short-lived with concentrations returning to background levels within a day of the release event ceasing (refer to Figure 6-39). While these temporary increases are predicted throughout the downstream creek system to some extent, their magnitudes progressively reduce with distance travelled from the release point.
- For the advanced treatment shutdown scenario (SC09), the level of impact remained unchanged relative to the equivalent non-shutdown scenario (SC07).
- With respect to compliance, annual median concentrations remain predominantly unmodified with the addition of the AWRC releases. Saturation levels are predicted to be generally compliant with the EES waterway objectives (43% to 75%), but not the ANZG objectives (85% to 11%). Refer to Figure 6-40 for the 2036 (SC05) dry year analysis.

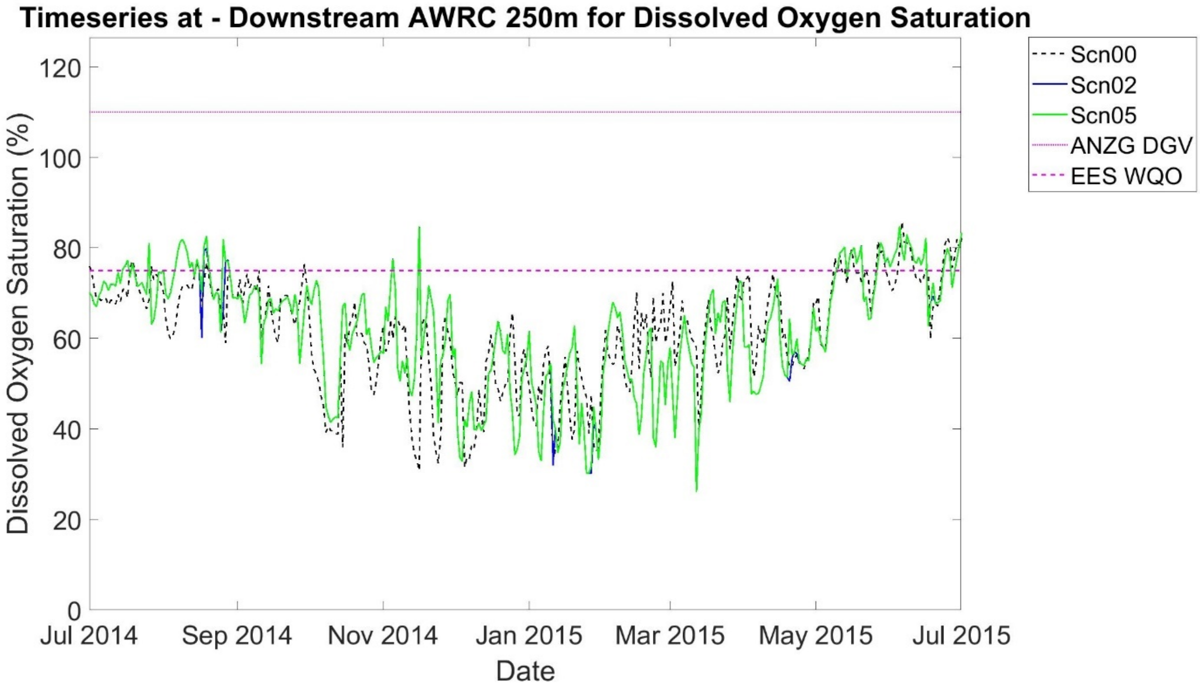


Figure 6-39 Timeseries of predicted DO concentrations 250 m downstream of AWRC release point (2036 releases/wet year)

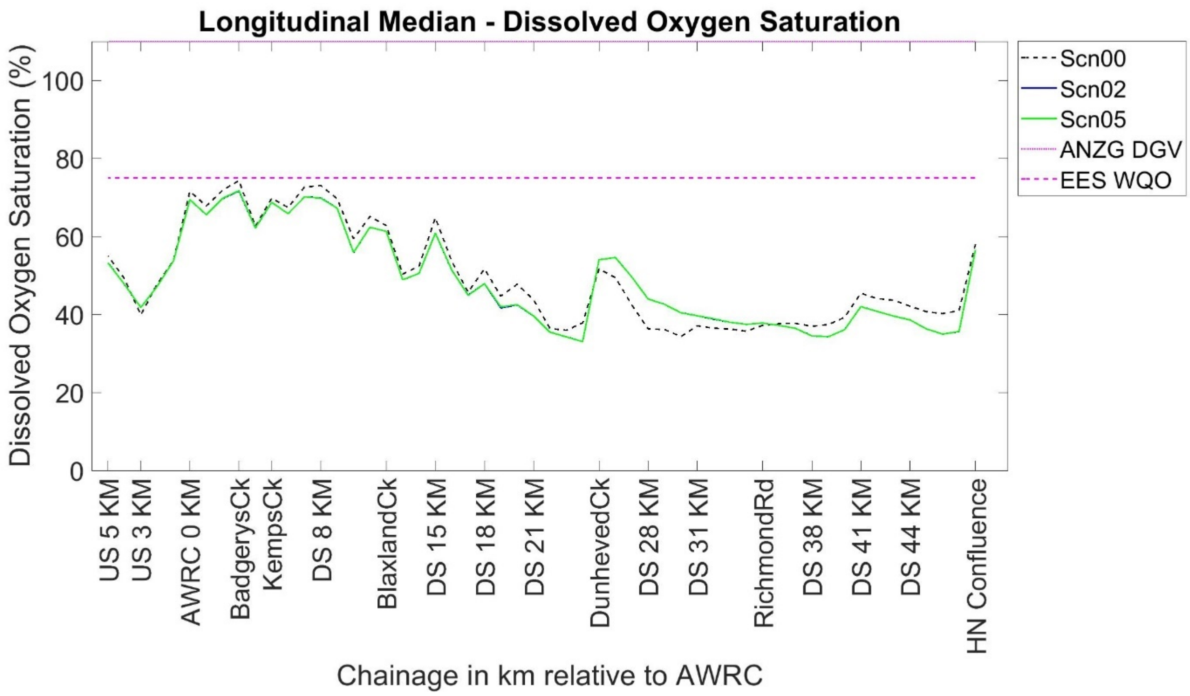


Figure 6-40 Longitudinal profile of predicted annual median DO concentrations (2036 releases/wet year)

Enterococci (primary pathogenic indicator)

Dry year

- During the dry year for the 2036 Parkland impact scenario (SC05), dilution is provided to the creek concentrations of enterococci as all releases are predicted to be advanced treated and the assumed release concentrations are ~1 cfu/100mL. Daily creek concentrations are predicted to be reduced by up to ~130 cfu/100mL at a site 250 m downstream of the releases. The reductions in creek concentrations are predicted to be higher (220 cfu/100mL) under 2056 conditions (SC06) due to increased volumes of advanced treated water being released.

Wet year

- During the wet year, impacts again vary between dilution and higher loading as a result of the differential between the concentrations in the treated water releases and the creek. During the more minor events (<3 x ADWF), the releases are assumed to have negligible pathogenic content (~1 cfu/100mL), but in the larger events, concentrations in the treated water releases are assumed up to 5,000 cfu/100mL, due to the blend of advanced treated and primary treated water.
- For the 2036 Parkland scenario (SC05), increases in daily enterococci concentrations are predicted up to ~400 cfu/100mL during the more severe wet weather events. However, reductions of ~250 cfu/100mL are also predicted when advanced treated water is released (refer to Figure 6-41).
- For the 2056 Parkland scenario (SC06), increases in daily enterococci concentrations are predicted up to ~600 cfu/100mL, alongside reductions of ~400 cfu/100mL during the release of advanced treated water.
- The impacts of both dilution and higher loading are again predicted to be short lived with concentrations returning to background conditions within a day of releases ceasing.
- For the advanced treatment shutdown scenario (SC09), the level of impact remained unchanged relative to the equivalent non-shutdown scenario (SC07).

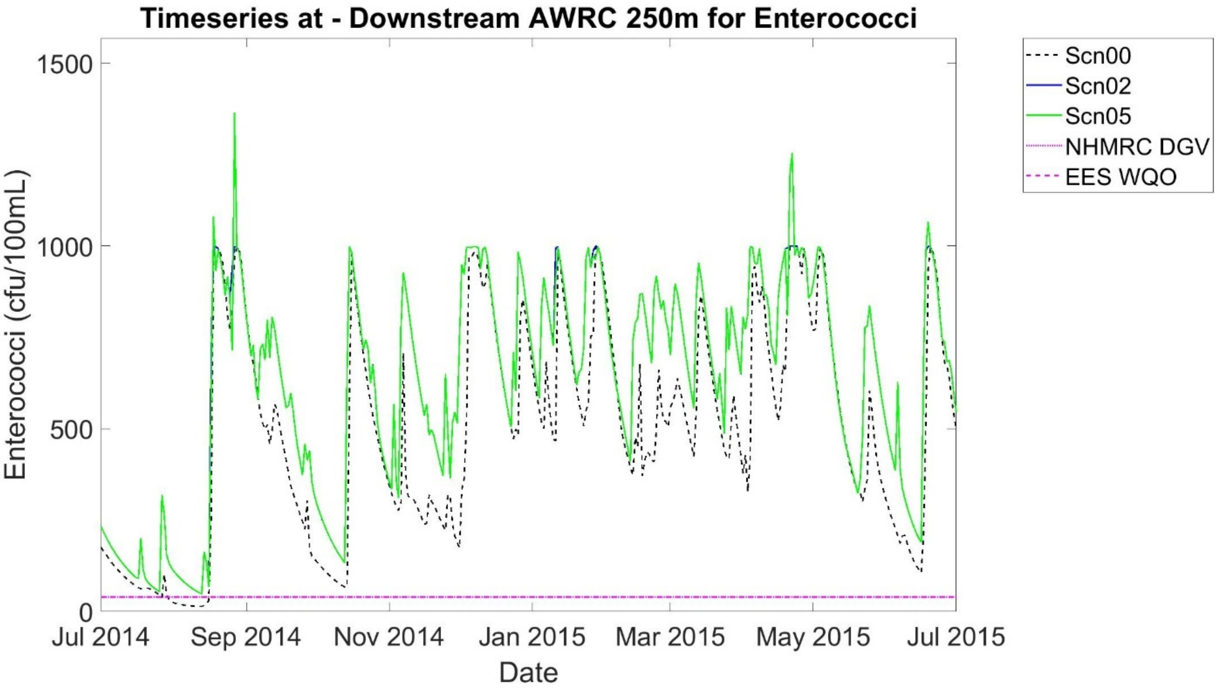


Figure 6-41 Timeseries of predicted Enterococci concentrations 250 m downstream of AWRC release point (2036 releases/wet year)

BaU vs Parkland scenarios

- Relative to the impacts predicted for the Parkland scenarios, the BaU impacts were approximately 15 to 25% lower in magnitude. Refer to Figure 6-42 for the 2036 BaU scenario (SC07), comparable to the 2036 Parkland scenario (SC05) results (Figure 6-41).

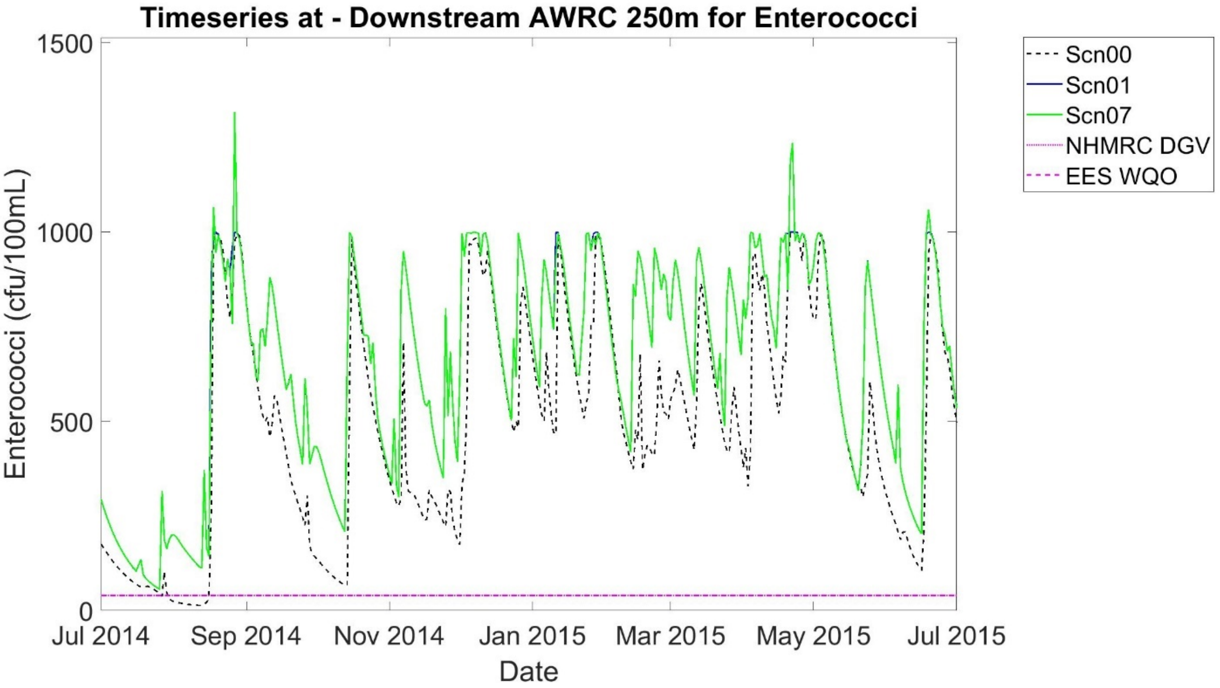


Figure 6-42 Timeseries of predicted Enterococci concentrations 250 m downstream of AWRC release point (2036 releases/wet year/BaU stormwater management)

Compliance

- Minor or negligible influence on the annual median profiles was predicted as a result of the AWRC releases (SC05), relative to the background scenario (SC02). Both the baseline and background scenario median concentrations are however predicted to be significantly above the NHMRC (2008) 95th percentile guideline value of 40 cfu/100mL. Refer to Figure 6-43 and Figure 6-44 for the predicted annual median profiles for the SC05 (circa 2036) dry year and wet year respectively.

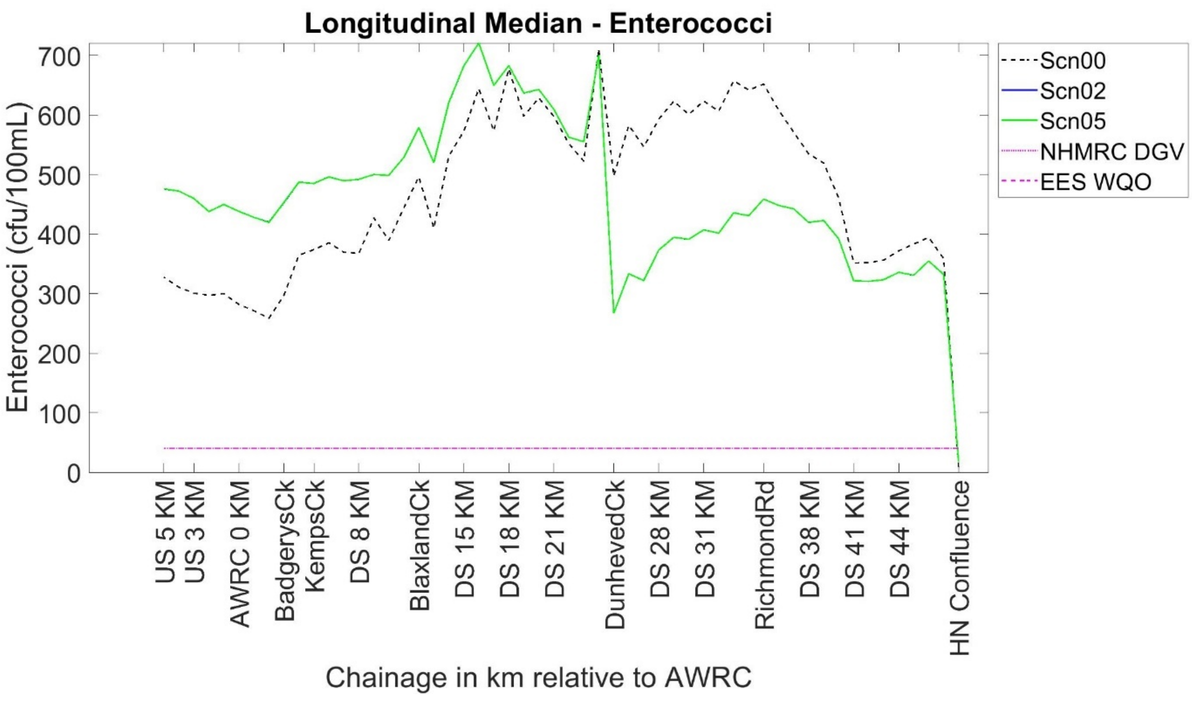


Figure 6-43 Longitudinal profile of predicted annual median Enterococci concentrations (2036 releases/dry year)

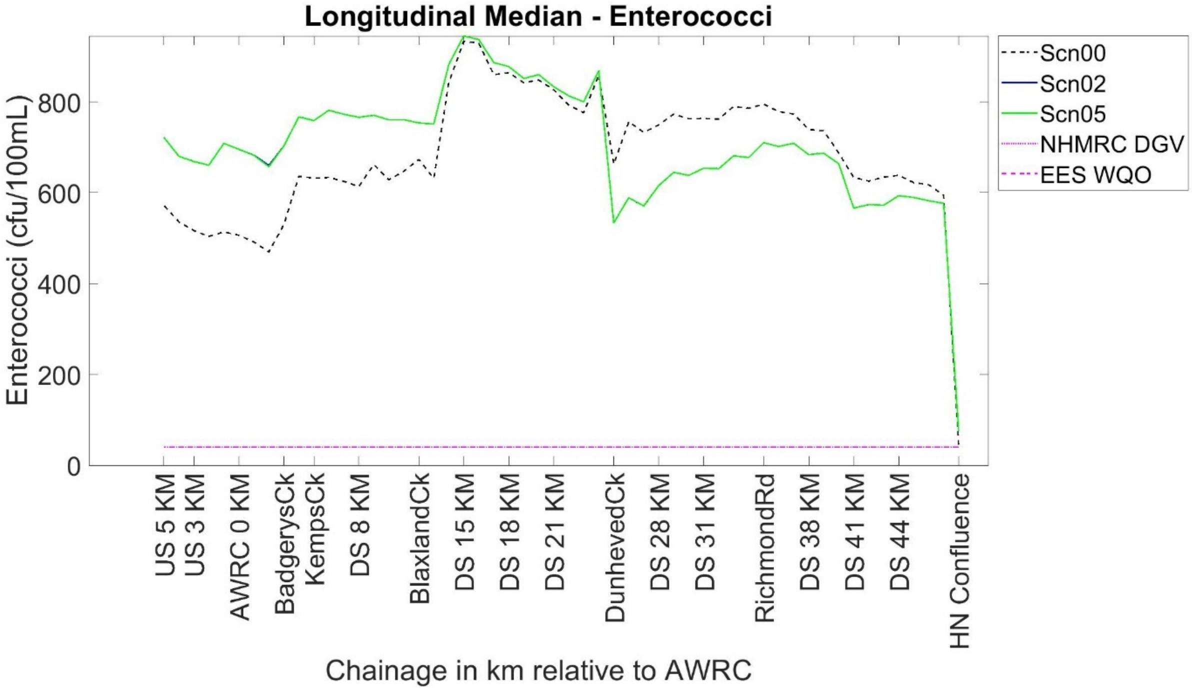


Figure 6-44 Longitudinal profile of predicted annual median Enterococci concentrations (2036 releases/wet year)

E. coli

Dry year

- Similar to enterococci, the releases from the AWRC during more minor events (<3 x ADWF) are assumed to have negligible pathogenic content (~1 cfu/100mL), but in the larger events, concentrations in the treated water releases are assumed to be significant, up to potentially over 80,000 cfu/100mL.
- Therefore, during a dry year, the minor release events present temporary dilution to the creek concentrations. Daily creek concentrations are predicted to be reduced by up to ~120 cfu/100mL at a site 250 m downstream of the release point. The reductions in creek concentrations are predicted to be higher (~200 cfu/100mL) under 2056 conditions (SC06) due to increased volumes of advanced treated water being released.

Wet year

- During a wet year, impacts again are predicted to vary between dilution and higher loading as a result of the differential between the concentrations in the treated water releases and the creek. However due to the more significant concentrations in the primary treated water, the influence of the more severe wet weather events is greater than the dilution effects provided by the more minor events. This is demonstrated in the 2036 Parkland scenario (SC05), where increases in daily E. coli concentrations are predicted up to ~9,300 cfu/100mL during the more severe wet weather events. In comparison, reductions of only ~210 cfu/100mL are predicted when advanced treated water is released during the more minor wet weather events.

- For the 2056 Parkland scenario (SC06), increases in daily E. coli concentrations are predicted up to ~15,000 cfu/100mL, alongside reductions of ~350 cfu/100mL during the release of advanced treated water.
- Under both the 2036 and 2056 scenarios, the impacts are again predicted to be short lived with concentrations returning to background conditions within a day of releases ceasing.

Compliance

- With respect to compliance, it is noted that there is no applicable waterway objective for South Creek. Regardless, there is predicted to be negligible influence on the annual median profiles as a result of the AWRC releases, relative to the background scenarios. This applies to both the 2036 and 2056 impact scenarios.

Cyanobacteria risk

- The risk index is derived from conditions that are considered conducive to cyanobacteria growth. Contributing factors include temperature, salinity, oxidised nitrogen, ammonia, FRP, depth and velocity. The risk is also calculated on a reach basis which includes analysis of model results across a zone or sub-zone box as discussed in Section 4.6.4.3.3.
- No change to the overall risk index was predicted between any of the impact scenarios and the corresponding background scenarios. Similar to the interpretation of the chlorophyll *a* results, this was considered a result of the releases occurring in times of wet weather with rapid flushing of the creek as well as any additional nutrient loads occurring away from sustained dry periods when conditions that favour cyanobacteria growth are more prominent.
- The changes in nutrient loading to the creek assumed in 2036 or 2056 are also marginal, with some AWRC release events providing dilution to the elevated nitrogen and phosphorus concentrations in the creek. Figure 6-45 and Figure 6-46 respectively present the predicted indices for the 2036 dry and wet year impact scenario.

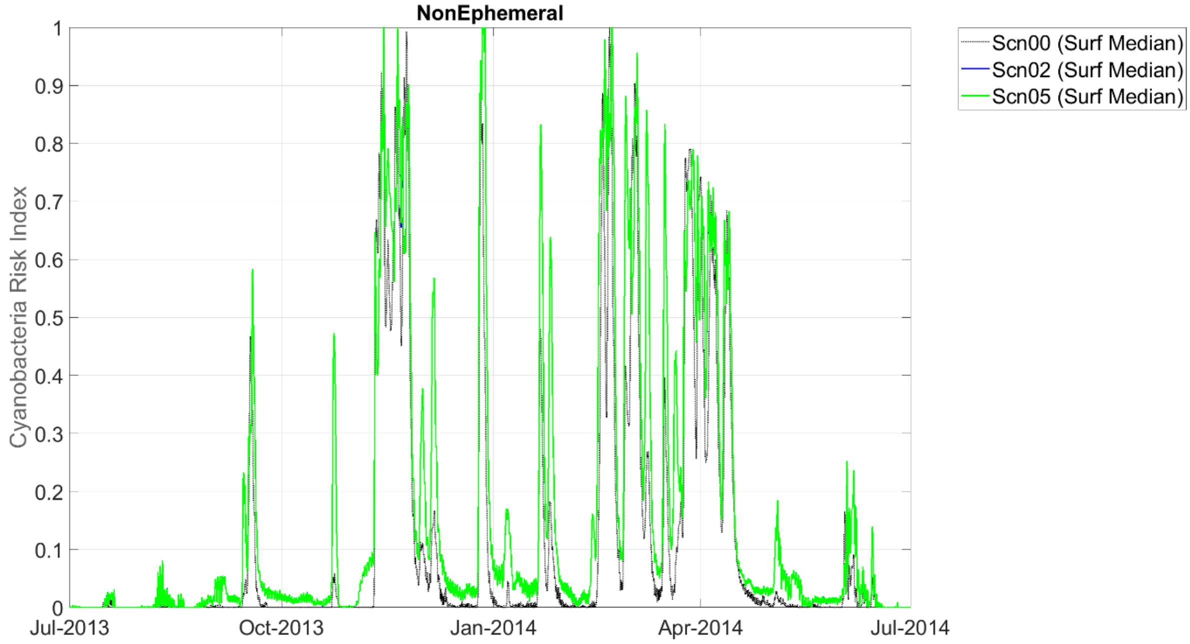


Figure 6-45 Timeseries of predicted Cyanobacteria risk in the non-ephemeral reaches of South Creek (2036 releases/dry year)

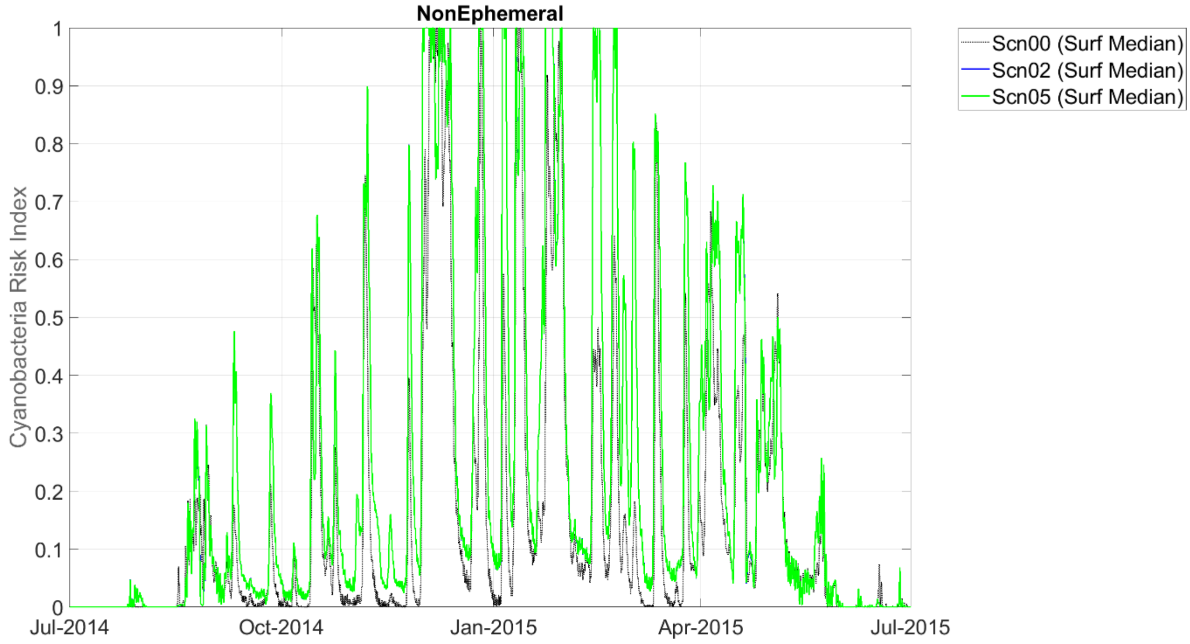


Figure 6-46 Timeseries of predicted Cyanobacteria risk in the non-ephemeral reaches of South Creek (2036 releases/wet year)

6.1.2 Nepean River releases

6.1.2.1 Scenario conditions

As discussed previously, the results from each AWRC impact scenario are plotted against a corresponding background scenario as well as baseline conditions. This approach allows for analysis of the impacts from the AWRC releases on their own, in relation to the catchment conditions that are expected for the selected time horizon, and also relative to current conditions. Further details regarding these scenario types are provided in Section 4.6.3.

Table 6-2 presents a summary of the key conditions relating to the South Creek release scenarios. Further details relating to these impact scenarios, and also the relevant background and baseline scenarios, can be found in Section 4.6.3.

Table 6-2 Summary of scenario conditions - Nepean River release scenarios

Scenario number	Time horizon	AWRC capacity (ML/d)	Treatment plant loading	Relevant background scenario
HN06	2036	50	Low loading	HN01
HN07	2056	100	Low loading	HN02
HN08	2036	50	High loading	HN03
HN06	2056	100	High loading	HN04
HN17	2036	50 / advanced treatment shutdown	High loading	HN03

6.1.2.2 Load analysis

Analysis of estimated total nitrogen and total phosphorus loads flowing to the Hawkesbury Nepean River has been undertaken to allow comparison of the contributions from various sub-catchments and treatment plants under current conditions, and also for the impact scenarios discussed in Section 4.6.3. The loads were estimated through analysis of the model boundary conditions for each scenario, and for both the representative wet and dry years independently.

The load analyses presented in the figures below, extend from upstream of Wallacia Weir to downstream of the Berowra Creek confluence. Figure 6-47 and Figure 6-48 present the cumulative analysis of total nitrogen loads from upstream to downstream for all catchment loads (including WWTPs and WRPs). From left to right, each new set of columns/bars represents the cumulative nutrient load with the addition of a new boundary in the model.

Figure 6-49 and Figure 6-50 present the assumed loads for the WWTPs and WRPs individually. Please note that the y-axis limits differ between the cumulative and WWTP/WRP analyses. Figures 6-51 to 6-54 present similar datasets for total phosphorus loads.

Load estimates for the background scenarios were not included as they replicated the impact scenario conditions except for the addition of the AWRC loads. Load estimates for the advanced treatment shutdown scenario (HN17) were also not included as there were only minor differences in the AWRC nutrient loading between HN17 and the corresponding non-shutdown scenario, HN07. The differences between these scenarios was estimated to be less than ~500 kg/year TN and ~200 kg/year TP.

From these graphs, the influence of the major tributaries, such as Grose River, South Creek, Cattai Creek, etc can be observed (refer to Figure 5-24 regarding location of tributaries). To a lesser extent, the influence of some of the larger treatment plants can also be seen. The differences in load magnitude between the dry and wet years is also notable.

From analysis of the WWTP/WRP bar graphs (Figures 6-47, 6-48, 6-51 and 6-52), planned upgrades to some of the existing treatment plants can be seen. The most significant being upgrades to Winmalee and Castle Hill. The decommissioning of North Richmond and the introduction of the Wilton WRP can also be identified in these graphs.

The contributions of the AWRC loads (combined Nepean River and South Creek releases) are estimated to be as follows:

- Total nitrogen:
  - Dry year: ~0.9% (2036) to ~1.7% (2056)
  - Wet year: ~0.8% (2036) to ~1.6% (2056)
- Total phosphorus
  - Dry year: ~0.6% (2036) to ~1.2% (2056)
  - Wet year: ~1.0% (2036) to ~2.6% (2056)

Further information regarding expected future nutrient loads, and how these address the requirements of the EPA's regulatory framework to manage nutrient load inputs are presented in Section 6.3.3.

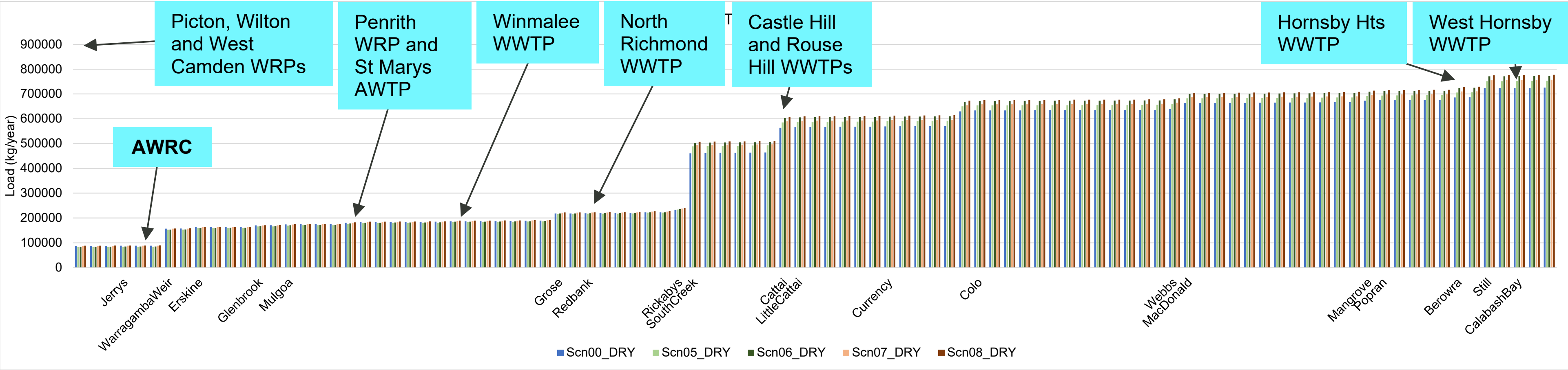


Figure 6-47 Hawkesbury Nepean Total Nitrogen cumulative catchment loads (dry year)

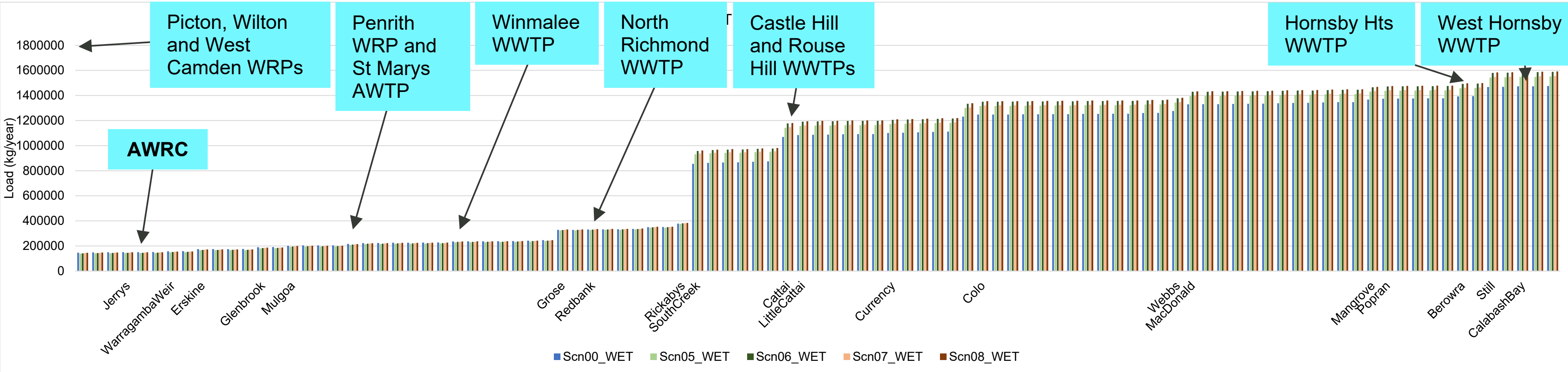


Figure 6-48 Hawkesbury Nepean Total Nitrogen cumulative catchment loads (wet year)

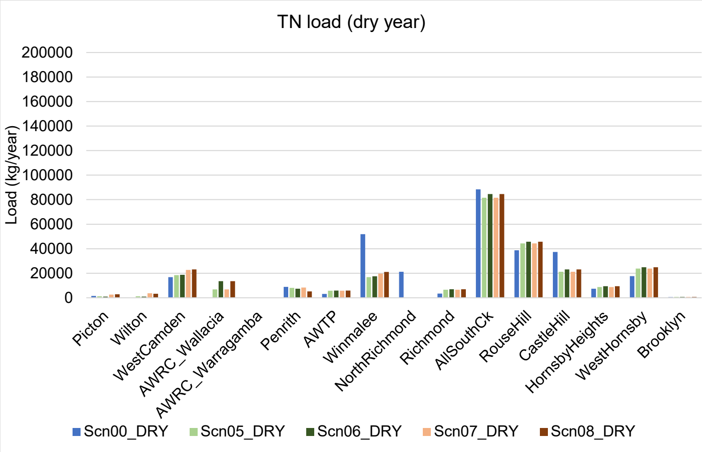


Figure 6-49 Hawkesbury Nepean Total Nitrogen WWTP/WRP loads (dry year)

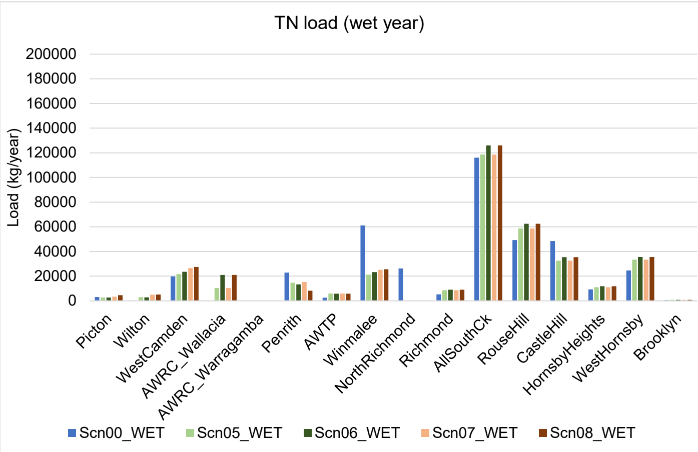


Figure 6-50 Hawkesbury Nepean Total Nitrogen WWTP/WRP loads (wet year)

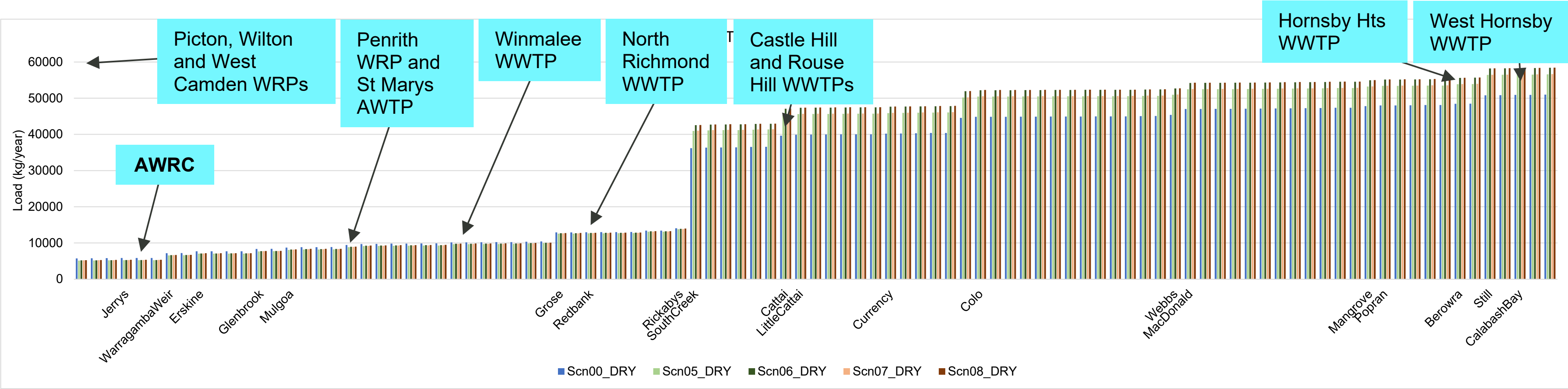


Figure 6-51 Hawkesbury Nepean Total Phosphorus cumulative catchment loads (dry year)

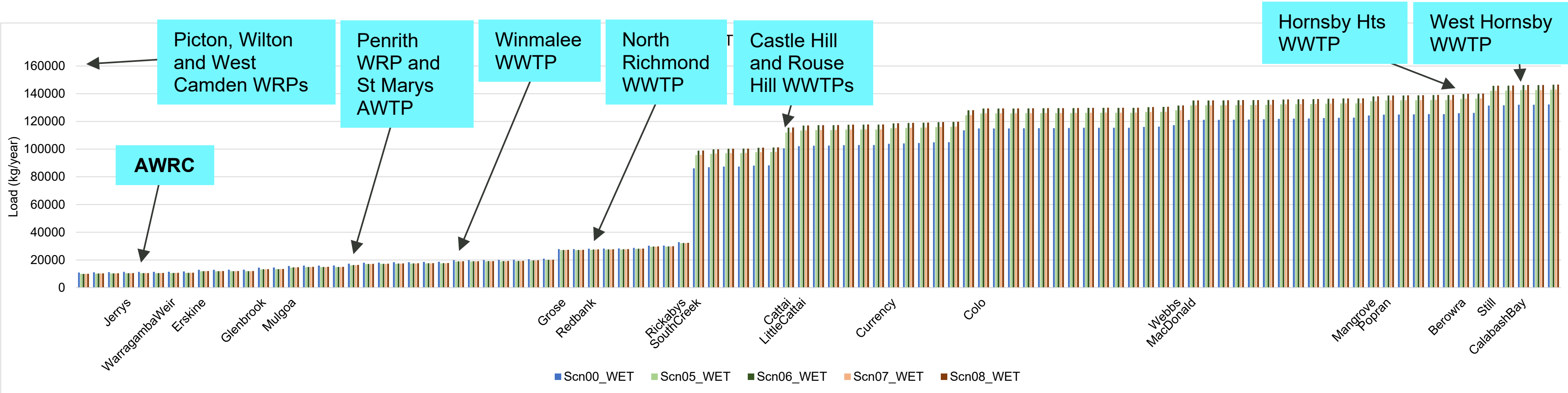


Figure 6-52 Hawkesbury Nepean Total Phosphorus cumulative catchment loads (wet year)

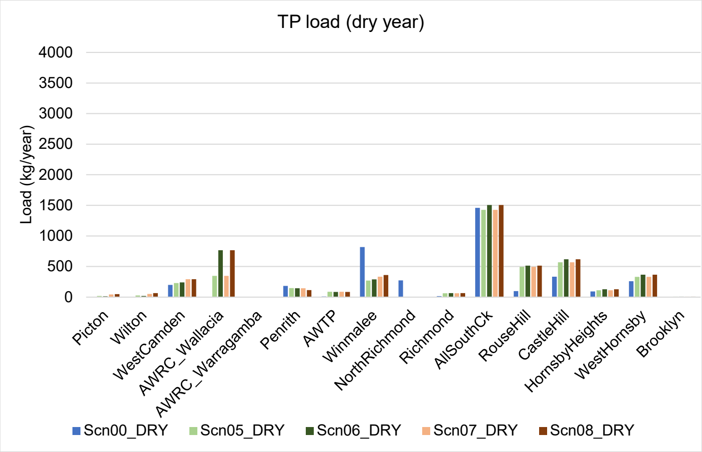


Figure 6-53 Hawkesbury Nepean Total Phosphorus WWTP/WRP loads (dry year)

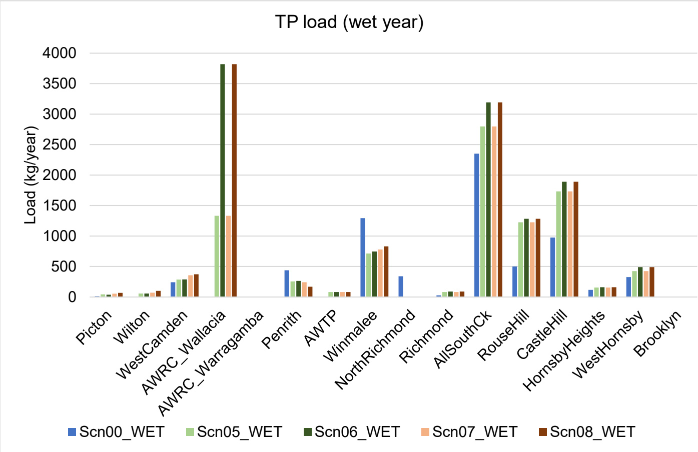


Figure 6-54 Hawkesbury Nepean Total Phosphorus WWTP/WRP loads (wet year)

6.1.2.3 Scenario results

A significant level of model output has been generated for the purposes of the hydrodynamic and water quality assessment. For the Nepean River scenarios, this includes the following formats for 14 primary water quality indicators as well as two hydrodynamic indicators.

- Box and whisker plots
- Timeseries plots

For each of the impact scenarios, this dataset has been output at eight primary sites of interest for both the representative dry and wet year.

As discussed in Section 4.6.3.3, the results from each impact scenario are plotted against a comparative background scenario as well as a baseline scenario. This approach allows for analysis of the impacts from the AWRC releases on their own, in relation to the catchment conditions that are expected for the selected time horizon, and also relative to current conditions. Further details regarding the formats used to present the results, and the location of the analysis sites, are discussed in Section 4.6.4.

For brevity, a selection of relevant scenario results has been included in the following sections to aid interpretation. A full set of results for scenario HN05 (2036 AWRC releases/low WWTP loading) has also been included in Appendix C2 for reference. As identified below in Section 6.1.2.5, scenario HN05 was considered to be representative of the potential impacts for Stage 1 operation of the AWRC project. As discussed in Section 4.6.3.3, the results for scenario HN05 are compared to background scenario HN01, and baseline scenario HN00.

Results for the other scenarios can be supplied by Sydney Water upon request.

6.1.2.4 Interpretation – background scenarios

The following general comments are provided with respect to the results from the background scenarios (future catchment conditions) relative to the baseline scenario (current conditions):

- In common with the South Creek modelling, the differences between the background scenarios (circa 2036 and 2056) and baseline scenarios (circa 2020) are commonly predicted to be more significant than the differences between the impact and background scenarios. In addition to changes in the assumed catchment loads, these changes are again likely to be a result of modifications in the flow regime, in terms of both base flows and event peaks. In the Nepean River, the flow conditions may be affected by introduction of more impermeable land uses and/or higher releases from existing WWTPs/WRPs due to population growth.
- The increase in impermeable land and also the increases in releases from the WWTPs/WRPs is also predicted to result in a marginal shift in the salinity wedge downstream of Sackville Bend (refer Figure 6-90 and Figure 6-91). The increase in flows extending freshwater conditions further downstream relative to baseline (circa 2020) conditions.
- The changes in the inflows and the nutrient loads under future conditions are also shown to have a potentially complex impact on the water quality and subsequently biogeochemical environment in the Hawkesbury Nepean River system. This complexity is increased by the presence of the weirs and how releases from these structures may vary with changing flow dynamics.

- The wet years generally showed higher annual median nutrient and enterococci concentrations than the dry year in both the background and baseline scenarios. Both the background and baseline scenarios presented similar temporal variations in the water quality variables (e.g. same timing of high concentration events), though the magnitudes of variations are different between the two scenario types.
- In general, the annual median concentrations of total nitrogen, total phosphorus and enterococci are close to, or above the relevant waterway objective downstream to approximately Wisemans Ferry, in both the background and baseline scenarios. Under the background conditions, variations are predicted across different reaches of the river, although this does not impact on the overall trend of compliance.
- The influence of the existing WWTPs/WRPs is also seen in the future scenarios with marked differences in total and inorganic nutrient indicators in several reaches. In particular, the effects of the planned upgrades to the Winmalee WWTP (~30 km downstream of the Wallacia release point) and Penrith WRP (~20 km downstream), and the decommissioning of the North Richmond WWTP (~46km downstream), are seen in the results for the future scenarios, generally observed as reductions in the concentrations of many nutrient species.

6.1.2.5 Interpretation – impact scenarios

6.1.2.5.1 General

The residual impacts on the Nepean River from the AWRC releases are predicted to be predominantly beneficial and positive in nature. The modelling indicates that with implementation of the AWRC treatment and release strategy, many improvements in water quality are expected downstream of Wallacia Weir release point.

The following supporting comments are provided with respect to the results from the Upper South Creek AWRC impact scenarios relative to corresponding background conditions (circa 2036 and 2056):

- In both the dry and wet years, the AWRC release scenarios showed on average a relative improvement in water quality in downstream reaches of the Nepean River, compared to the background conditions. The predicted improvements were generally due to the low concentrations of contaminants in the treated water releases and the resulting dilution of the river water.
- Reductions in median nutrient concentrations and improvements in dissolved oxygen levels were observed within a footprint downstream of the AWRC releases. For the 2036 impact scenarios, the footprints generally extended ~15 km from Wallacia Weir, and ~20 km from the South Creek confluence. For the 2056 impact scenarios, these footprints increased to ~20 km, and ~30 km respectively. Outside of these areas of influence, other reaches exhibited similar water quality to the baseline and background conditions in terms of both temporal variations and statistical distributions of all water quality variables.
- The predicted impacts are slightly different between the simulated wet and dry years, with the wet year results indicating higher annual median nutrient and pathogen concentrations than the dry year results. However, the predicted influence of the AWRC releases on water quality between the wet and dry years is generally consistent, and the differences in the levels of impact are relatively minor, compared to the inter-annual differences that occur naturally between these climatic and hydrological conditions.

- Several spikes in nutrient concentrations are predicted downstream of Wallacia Weir and the AWRC release point. These spikes correlate with more severe wet weather conditions and consequently when releases from the AWRC include higher levels, and up to 100%, of tertiary treated water. These events are however relatively short-lived, and the nutrient concentrations drop quickly to levels lower than the background simulation within a few days.
- In general, the annual median profiles of background nutrient levels and enterococci concentrations were close to, or above, the relevant waterway objectives in most reaches of the Nepean River. The introduction of the AWRC releases, in both the wet and dry years, showed potential for improved localised compliance with the relevant waterway objectives.
- The predicted chlorophyll *a* concentrations and risk of algal blooms is generally improved due to reduced nutrient levels and improved flushing under dry conditions, but small changes in water clarity and temperature mean that overall the median algal biomass is likely to be similar between the impact and background conditions that were simulated.
- With respect to the other treatment plants, scenarios HN07 and HN08 represent higher loading from the following five WWTPs and WRPs, relative to scenarios HN05 and HN06: West Camden WRP, Picton WRP, Wilton WRP, Penrith WRP and Winmalee WWTP. The first three of these plants are upstream of the proposed AWRC release point in Wallacia Weir. In general, the simulation of the higher loading conditions raised the background concentrations of nutrients in the river. The following general comments are also provided with respect to the higher loading scenarios:
  - The predicted cumulative impacts of higher WWTP loading exhibited slight increases in the annual median nitrogen, phosphorus and chlorophyll *a* concentrations in the Nepean River, compared to the comparable low loading scenarios.
  - The increase of nutrient concentrations was notable mostly in the upstream sections of the Nepean River, although the increases were relatively small when compared to their annual variations (generally <10%).
  - No notable differences in salinity, TSS, dissolved oxygen and pathogens were observed between the loading variations.
  - The differences between the loading variations were relatively small and the modelling predicted no change in compliance with the relevant waterway objectives.
- For the purposes of this report, Section 6.1.2.5.3 has focussed on the low loading scenarios (HN05 and HN06) so as to present potentially more significant impacts from the AWRC releases against lower background conditions. Additional commentary has been provided, where relevant, with respect to the results for the higher loading scenarios.
- With respect to the advanced treatment shutdown scenario (HN17), similar to the South Creek modelling, there is only one event in the wet year where the treated water releases present significant changes in both release volume and water quality. This event occurs in late April 2015, and for the Nepean releases, extends into early May. As discussed previously in Section 6.1.1.5.1, this event corresponds to a three-day wet weather event. Flows within the weir pool are predicted to rise up to ~14,000 ML/day during this event. Due to the need to switch off the AWRC advanced treatment (reverse osmosis), treated water releases to the Nepean River increase in volume over a period of three days (by between 3 and 6.5 ML/d), and with higher nutrient concentrations (up to 3 mg/L total nitrogen and 0.9 mg/L total phosphorus) also expected over this period. Additional commentary regarding this event has been provided where relevant.

6.1.2.5.2 Hydrodynamics

The following sub-sections present findings of the predicted hydrodynamic impacts from the AWRC releases with respect to flow conditions and contributions of flows from the AWRC. The findings are drawn from analysis of the results from the impact scenarios (HN05 and HN06) and the corresponding background conditions (HN01 and HN02).

No further analysis of the 'high loading' impact scenarios (HN07 and HN08) was undertaken as these variations in loading from the existing WWTPs/WRPs only related to treatment performance and water quality, and not release volumes.

Further assessment of the hydrodynamic impacts, including analysis of water depth/level, velocity, wetted perimeter and erosion potential, is presented in the Ecohydraulic and Geomorphology Assessment.

Dry year

- During dry weather, the 2036 AWRC release impact scenario (HN05) assumes a median release of just below 50 ML/d. Releases are below the plant capacity due to generation of the brine waste stream. The release point is upstream of the Wallacia Weir wall in the weir pool storage area. As a result of the AWRC releases, the water levels in the weir pool are consistently higher than the background conditions (i.e. without the AWRC releases). This is shown in the timeseries presented in Figure 6-55. The AWRC therefore fills the weir pool and consistently overtops the weir. This influence on water levels occurs despite extractions (for irrigation purposes) within the weir pool that are estimated to be on average ~4 ML/d.
- Immediately downstream of the weir, median flows in the river are therefore significantly increased. For the 2036 AWRC release impact scenario (HN05), an increase in median flow rates of ~48% is predicted relative to the background conditions (HN01), as a result of the introduction of the AWRC releases. Refer to Figure 6-56 for all flows, and Figure 6-57 for base flows. The increases in river flow are also predicted further downstream but the contribution of the AWRC gradually becomes less significant due to the contributions from tributaries. During an extended dry period, the increases are predicted to drop to ~37% of the background flows at Penrith and to 12% at Yarramundi.
- During wet weather events, the AWRC contributions to the overall river flow become relatively negligible due to the significant runoff from the upstream catchment. During severe wet weather events, the AWRC releases may contribute to only ~1% increase in flows downstream of the Wallacia Weir due to the influx of catchment runoff that dwarf the AWRC release volumes.
- For the 2056 AWRC release scenario (HN06), dry weather flows to the Wallacia Weir pool are predicted to increase up to just below a median of 100 ML/d. Water levels in the weir pool are again predicted to remain high and allow for consistent flows over the weir. Under these conditions, flows immediately downstream of the weir are predicted to increase by, on a median basis, a factor of two relative to background conditions (HN02). Refer to Figure 6-58 for all flows, and Figure 6-59 for base flows.

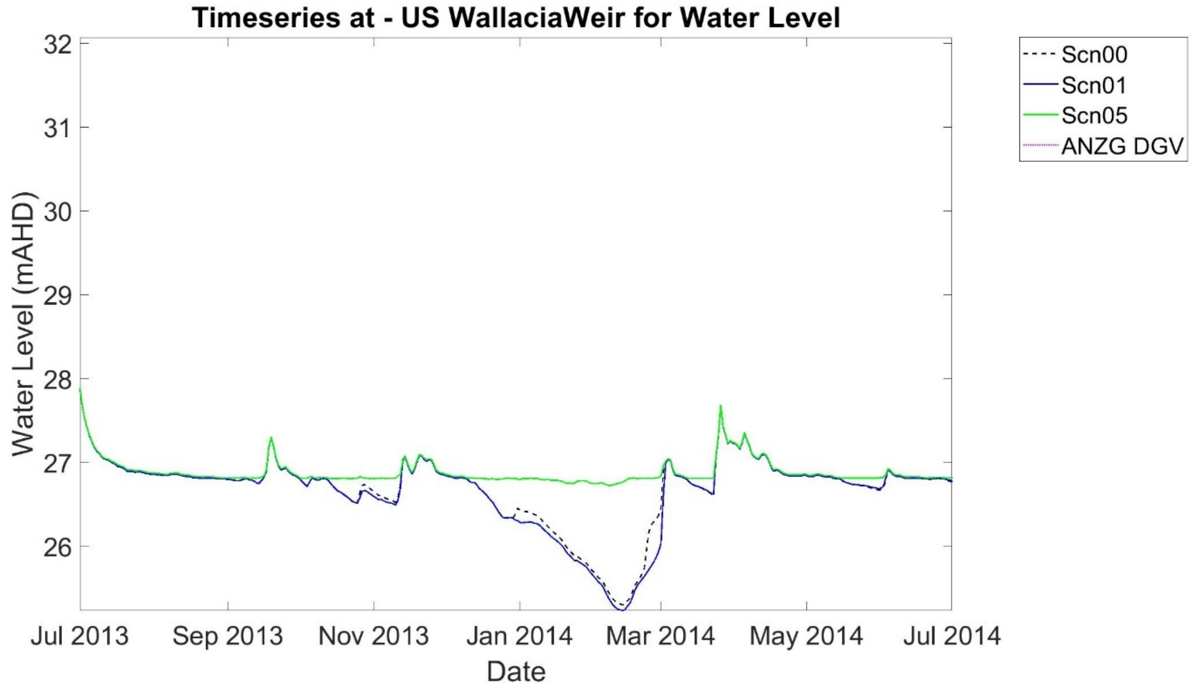


Figure 6-55 Timeseries of predicted water level upstream of Wallacia Weir (2036 releases/dry year)

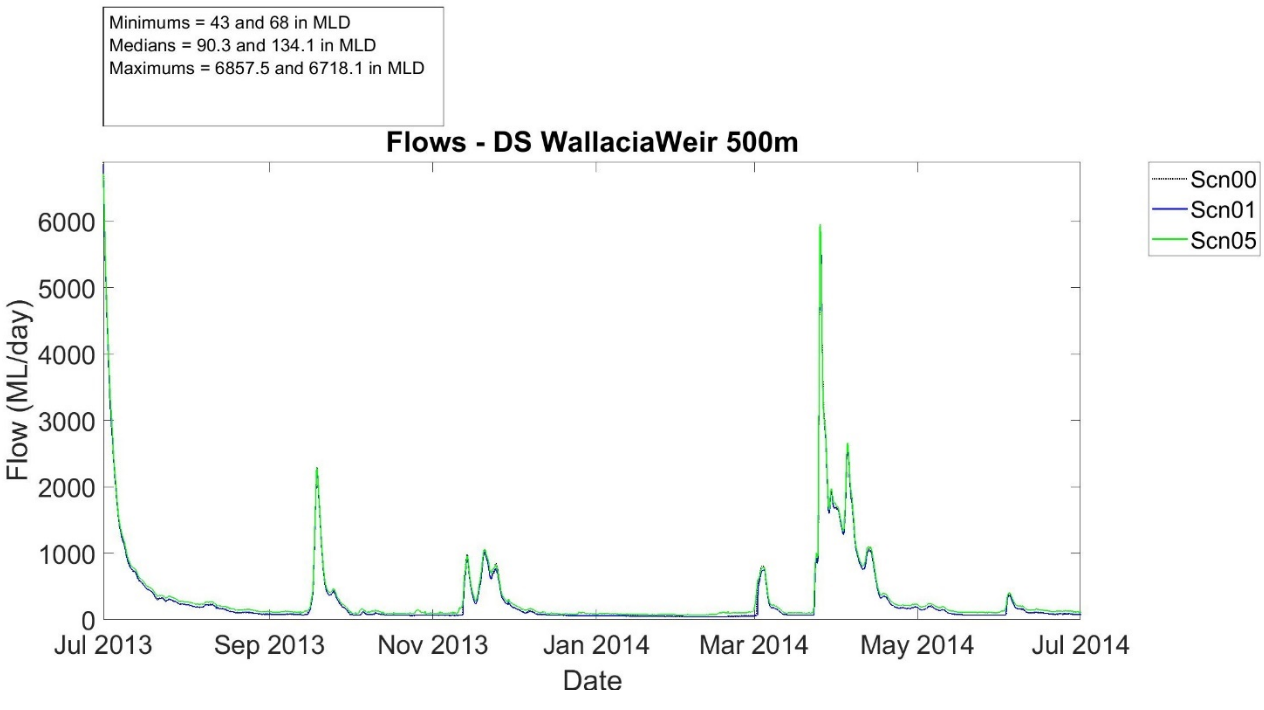


Figure 6-56 Timeseries of predicted river flow 500m downstream of Wallacia Weir (2036 releases/dry year)

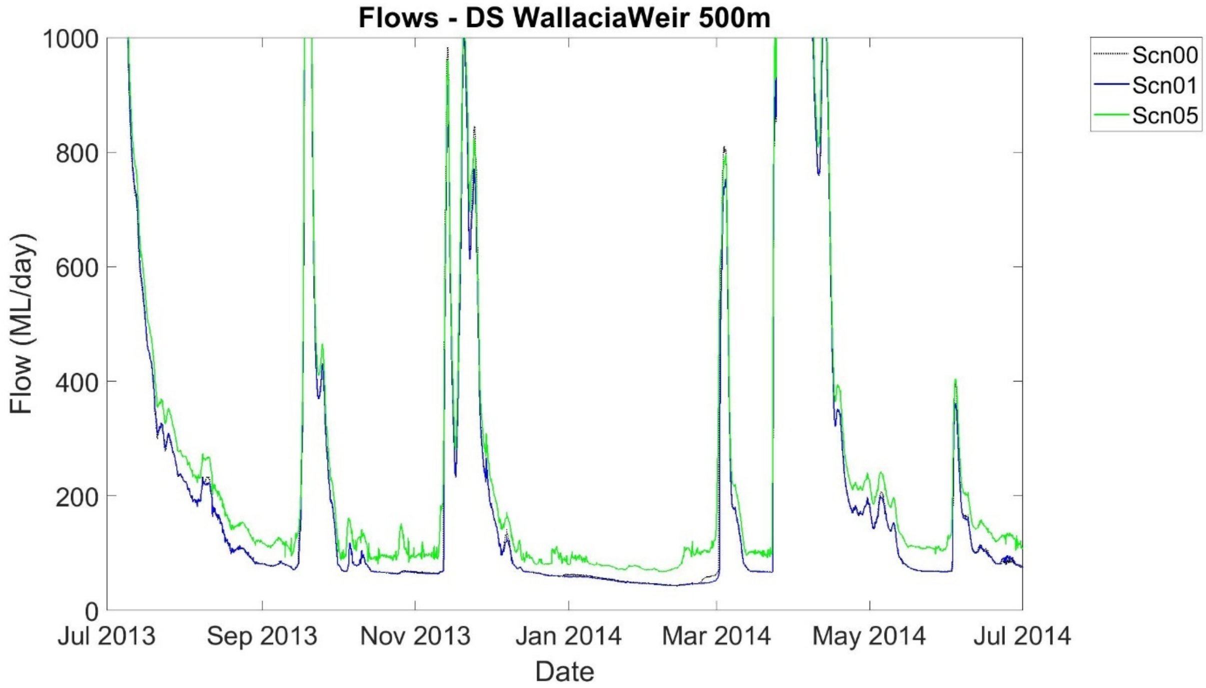


Figure 6-57 Timeseries of predicted river flow 500m downstream of Wallacia Weir (2036 releases/dry year/base flows)

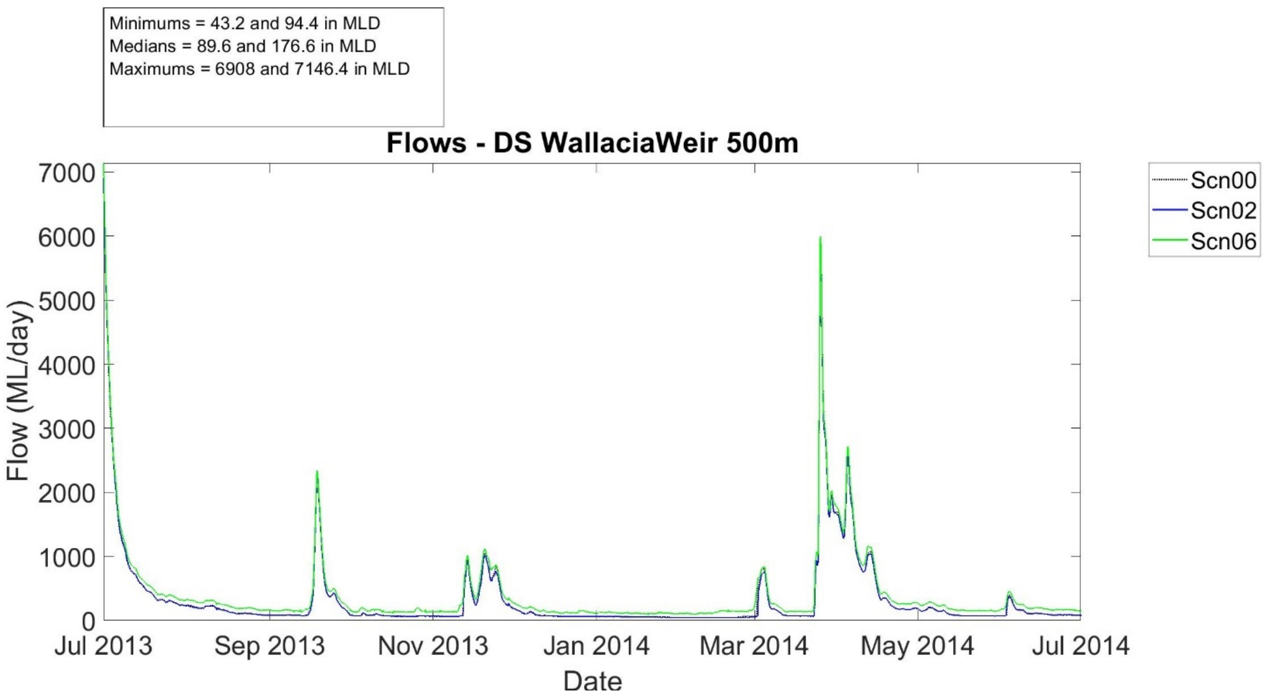


Figure 6-58 Timeseries of predicted river flow 500m downstream of Wallacia Weir (2056 releases/dry year)

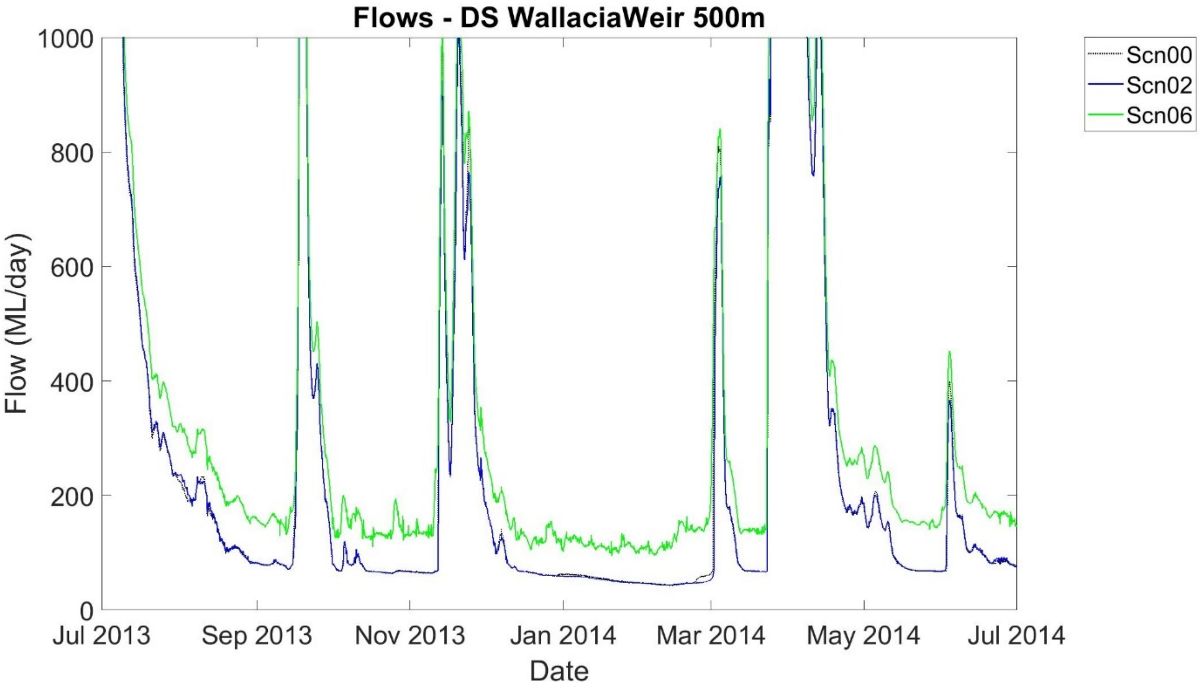


Figure 6-59 Timeseries of predicted river flow 500m downstream of Wallacia Weir (2056 releases/dry year/base flows)

Wet year

During the wet year (HN05, circa 2036), flows downstream of the Wallacia Weir are again heavily influenced by the introduction of the AWRC releases. On a median basis, across the wet year, the flows are predicted to increase by ~30% at this location (refer to Figure 6-60 for all flows, and Figure 6-61 for base flows).

Under the 2056 release conditions (HN06), the downstream flows again increase with the annual median rising by just over 50% to 275 ML/d (refer to Figure 6-62).

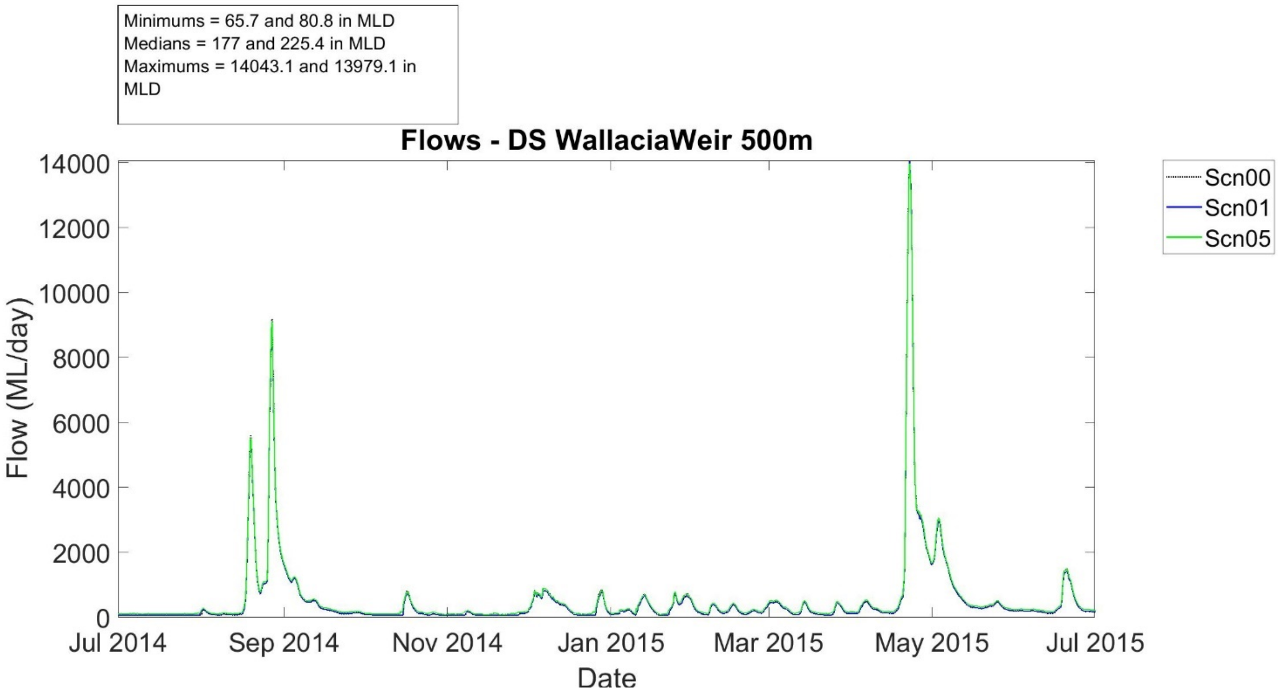


Figure 6-60 Timeseries of predicted river flow 500m downstream of Wallacia Weir (2036 releases/wet year)

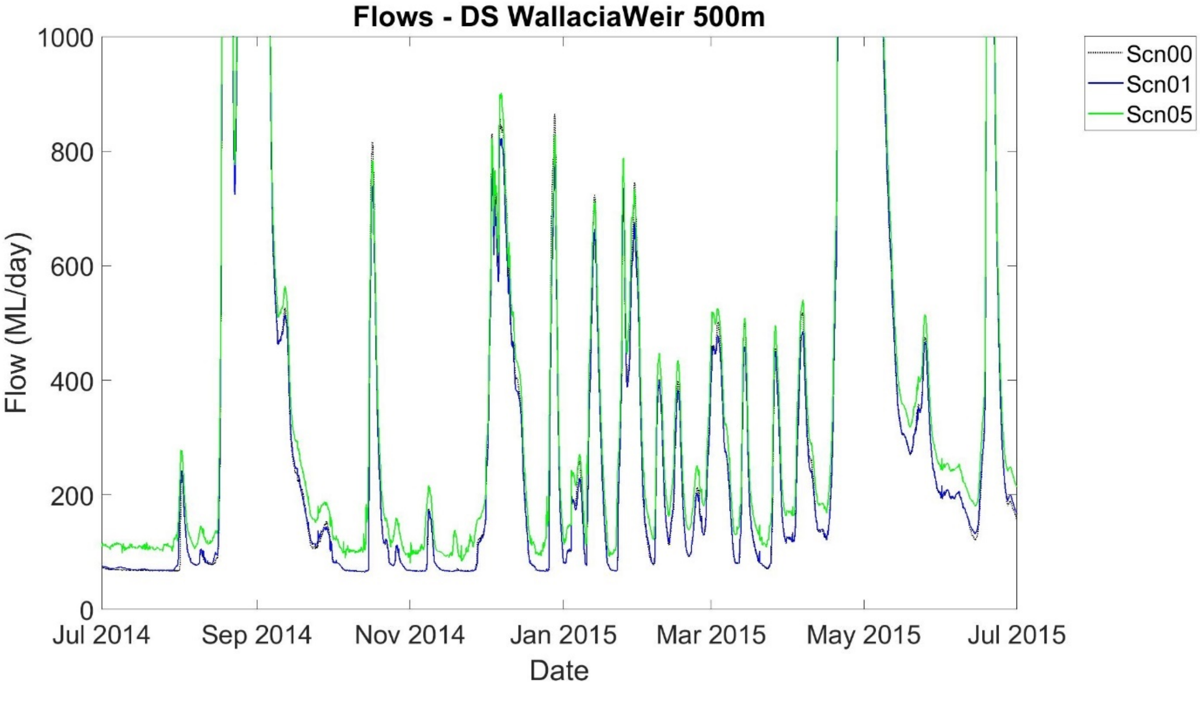


Figure 6-61 Timeseries of predicted river flow 500m downstream of Wallacia Weir (2036 releases/wet year/base flows)

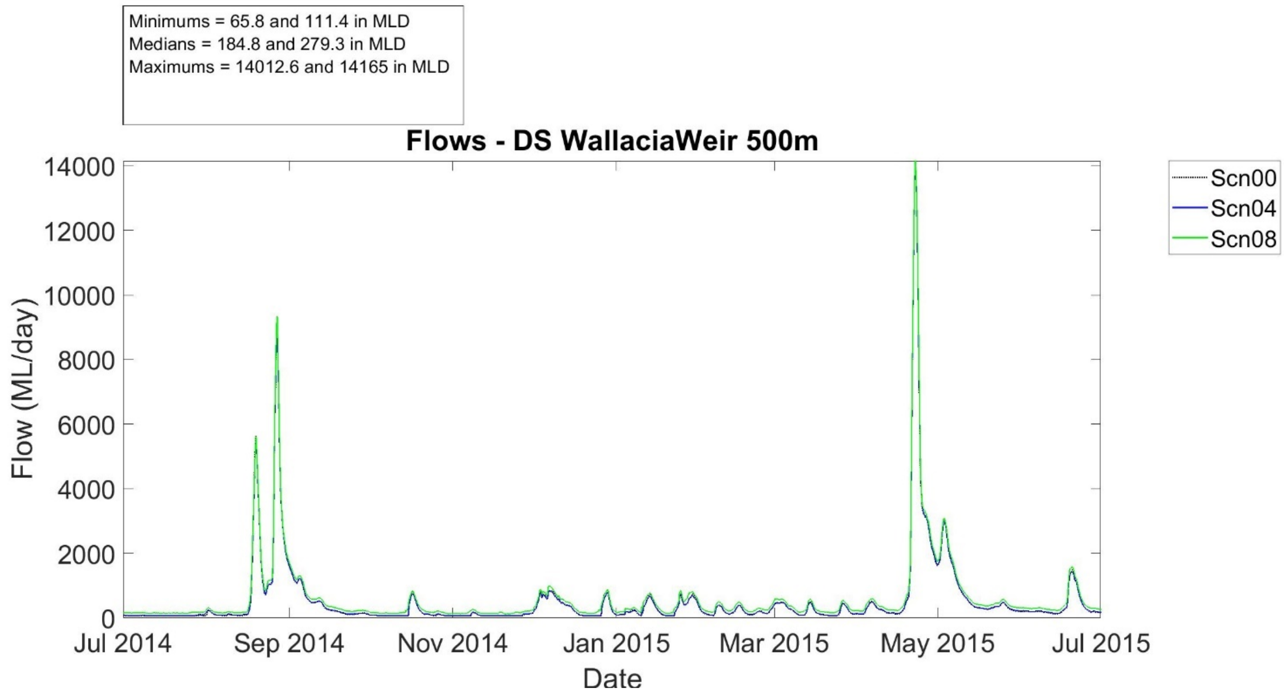


Figure 6-62 Timeseries of predicted river flow 500m downstream of Wallacia Weir (2056 releases/wet year)

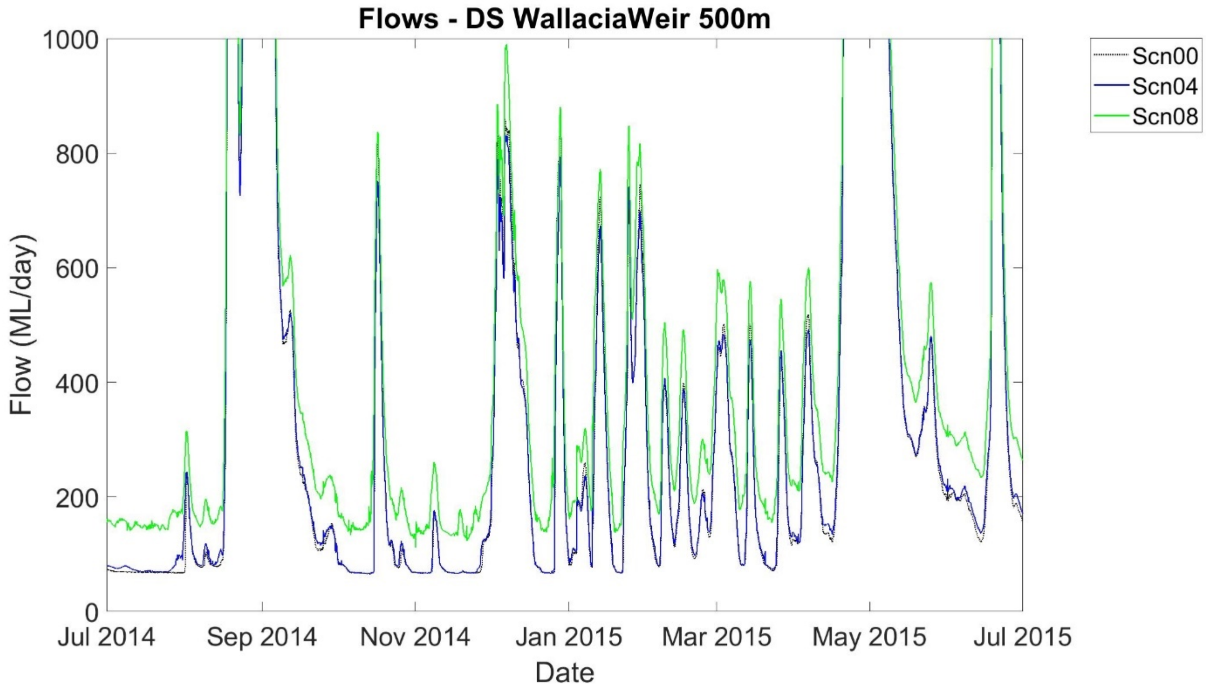


Figure 6-63 Timeseries of predicted river flow 500m downstream of Wallacia Weir (2056 releases/wet year/base flows)

Advanced treatment shutdown scenarios

No notable changes in the flow conditions were predicted as a result of the shutdown of the AWRC advanced treatment process. The additional flows (3 to 6.5 ML/d) are minor relative to the magnitude of the treated water releases, the volume of water in the weir pool and the upstream flows in the Nepean River during wet weather.

6.1.2.5.3 Water quality

The following sub-sections present findings of the predicted impacts on water quality from the AWRC releases, relative to the corresponding background conditions (circa 2036 and 2056).

Nitrogen

Dry year

- The annual median total nitrogen concentrations were predicted to be comparatively lower in the reaches immediately downstream of the AWRC release point, and also in the reaches between South Creek to Cattai Creek. For the 2036 impact scenario (HN05), reductions in median concentrations were predicted in the range ~0.02 to ~0.03 mg/L (refer to Figure 6-64), increasing to ~0.03 to ~0.04 mg/L for the 2056 impact scenario (HN06). These reductions are due to increased dilution of the river water with the lower concentrations of the advanced treated water from the AWRC releases.
- The predicted reductions in total nitrogen concentrations are also shown in the timeseries analysis for HN05 (2036 conditions). The median concentrations at a location 500 m below the Wallacia Weir wall were predicted to reduce by ~0.03 mg/L, with the predicted peak daily concentration also decreasing by ~0.12 mg/L (refer to Figure 6-65). Reductions in total nitrogen concentrations are also predicted immediately downstream of the confluence with the Warragamba River where median and peak concentrations are estimated to be ~0.02 mg/L and ~0.07 mg/L below the background conditions (HN01). Refer to Figure 6-66.
- Whilst the total nitrogen concentrations are predicted to be lower, the dissolved inorganic forms of nitrogen (ammonia and oxidised nitrogen) were predicted to be marginally higher under the impact scenario (HN05) in the vicinity of the AWRC releases, reflecting the composition of the treated water. Refer to Figures 6-67 to 6-70. Despite the marginal increases in ammonia and oxidised nitrogen, peaks in daily concentrations remained well below the toxicant DGVs discussed in Section 2.2.
- Other sites, away from the immediate downstream footprints of Wallacia Weir and the South Creek confluence, correlated with the results for the background scenarios, in terms of both temporal variations and statistical distributions of all nitrogen species.

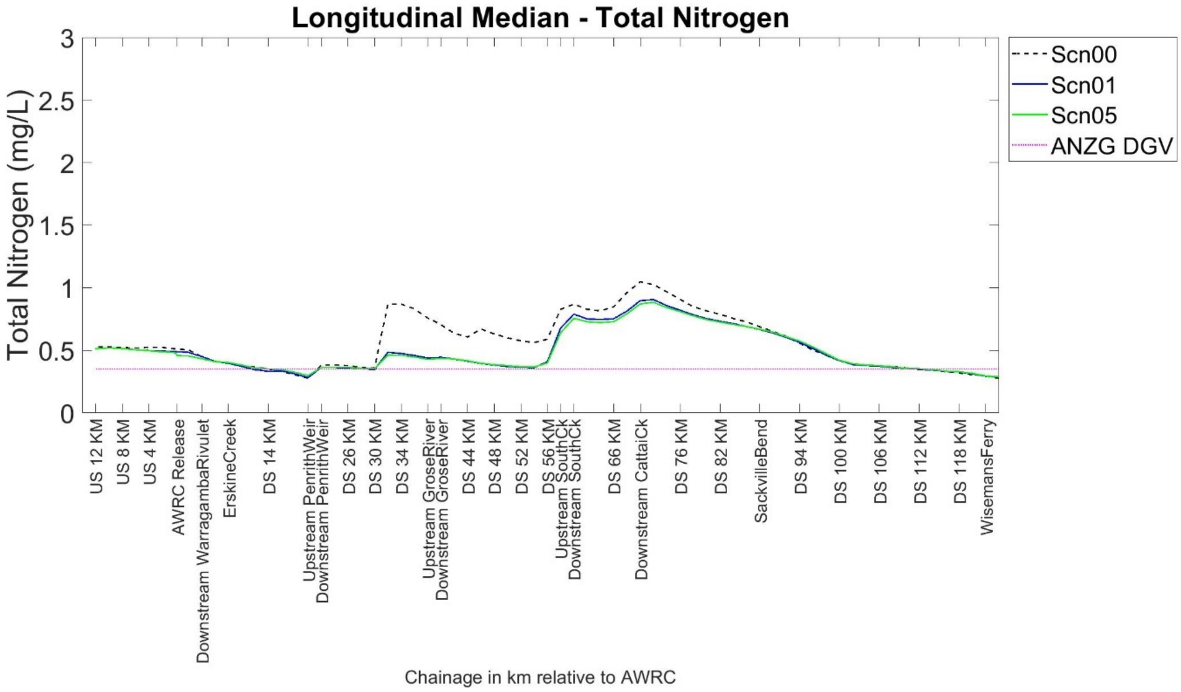


Figure 6-64 Longitudinal profile of predicted annual median Total Nitrogen concentrations (2036 releases/dry year)

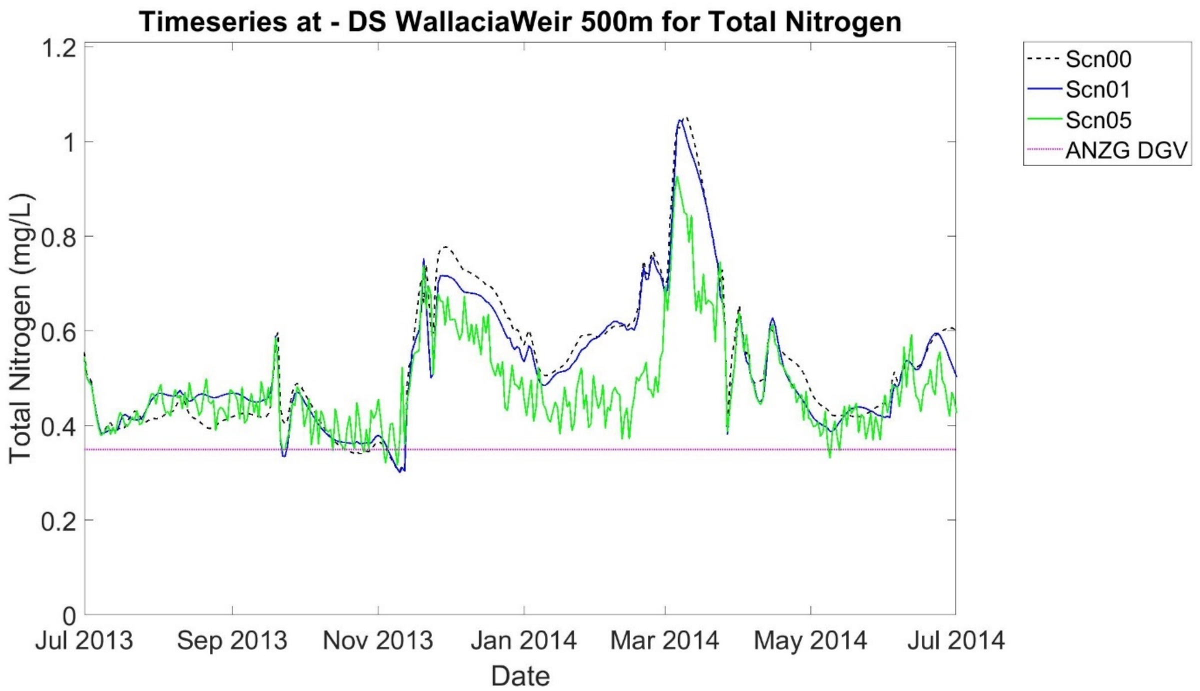


Figure 6-65 Timeseries of predicted Total Nitrogen concentrations 500 m downstream of Wallacia Weir (2036 releases/dry year)

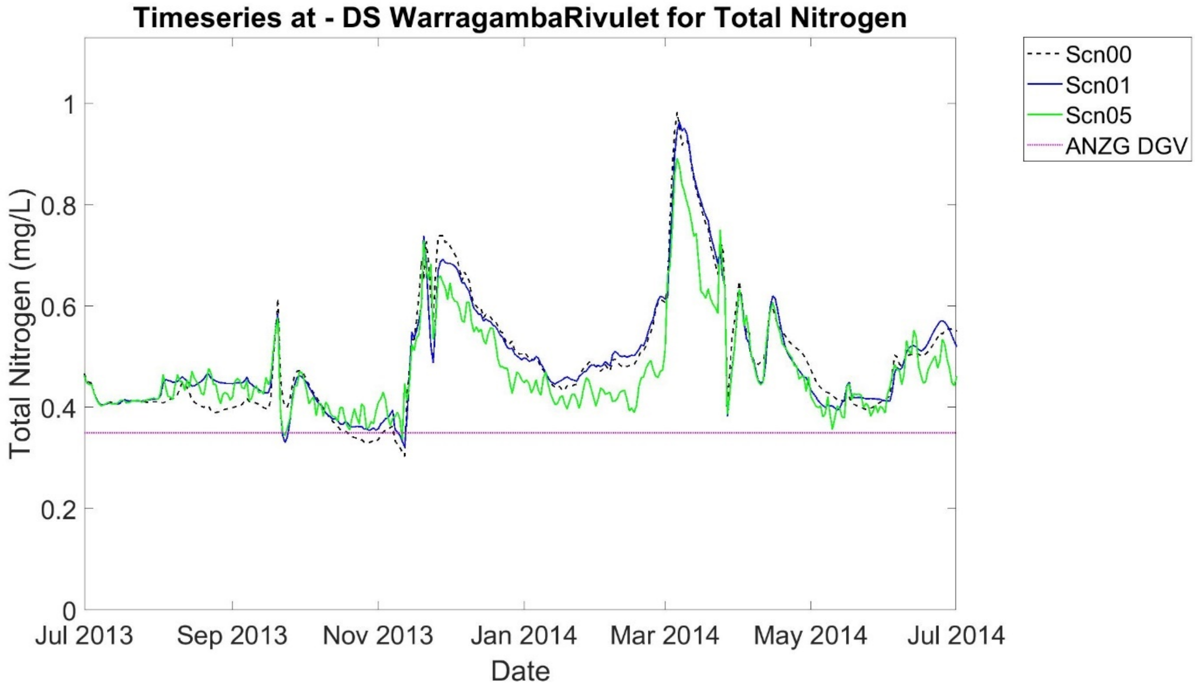


Figure 6-66 Timeseries of predicted Total Nitrogen concentrations downstream of the Warragamba confluence (2036 releases/dry year)

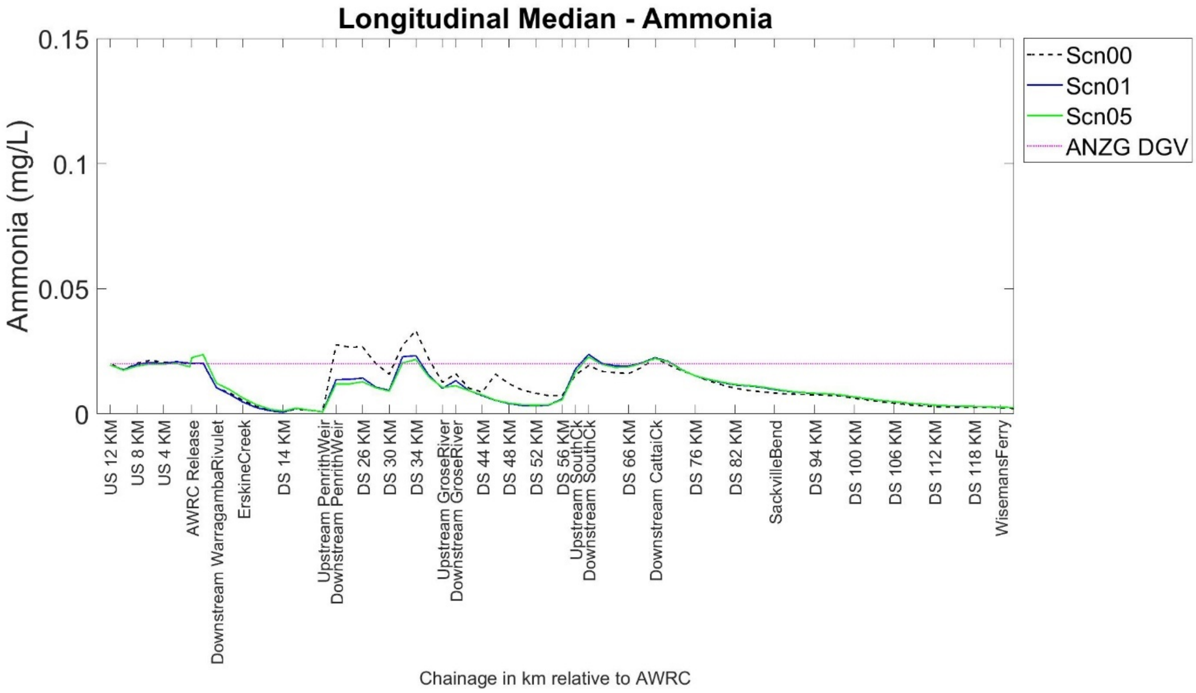


Figure 6-67 Longitudinal profile of predicted annual median Ammonia concentrations (2036 releases/dry year)

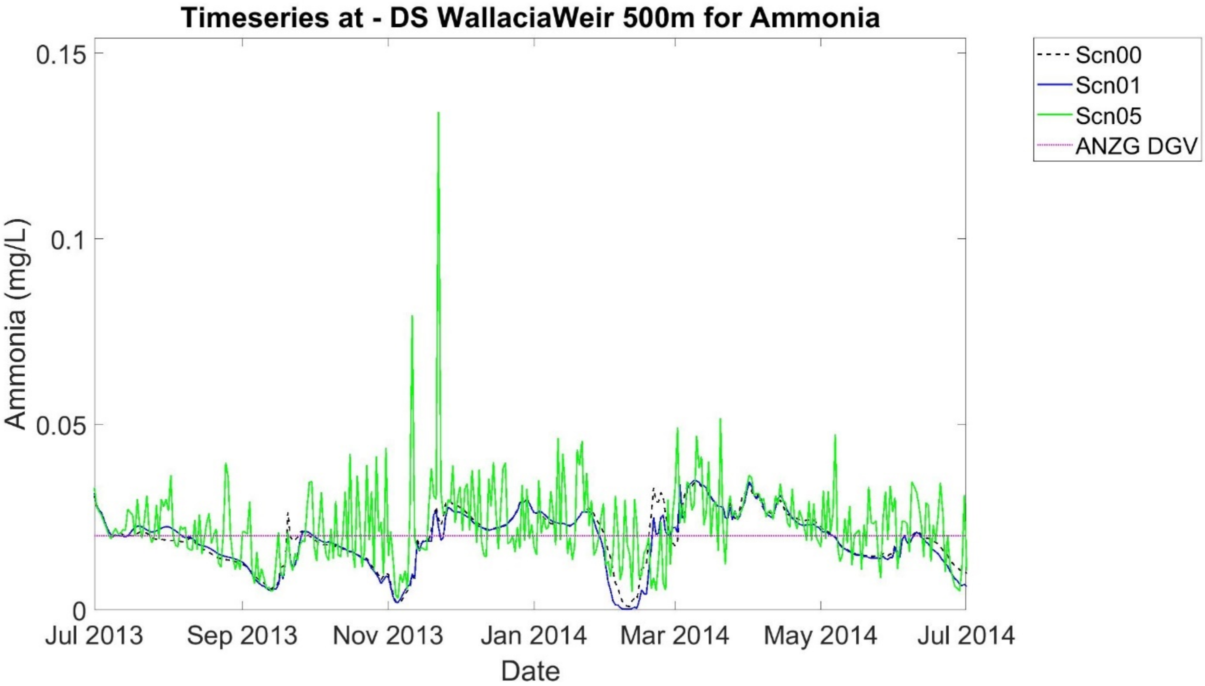


Figure 6-68 Timeseries of predicted Ammonia concentrations 500 m downstream of Wallacia Weir (2036 releases/dry year)

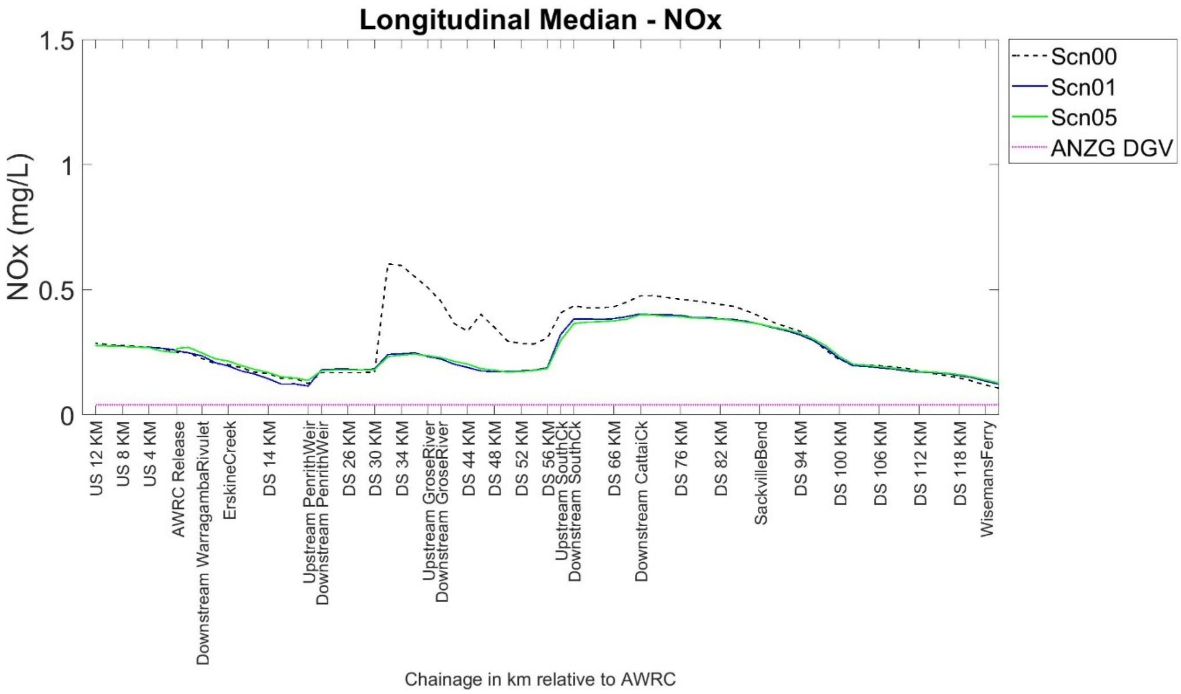


Figure 6-69 Longitudinal profile of predicted annual median Oxidised Nitrogen concentrations (2036 releases/dry year)

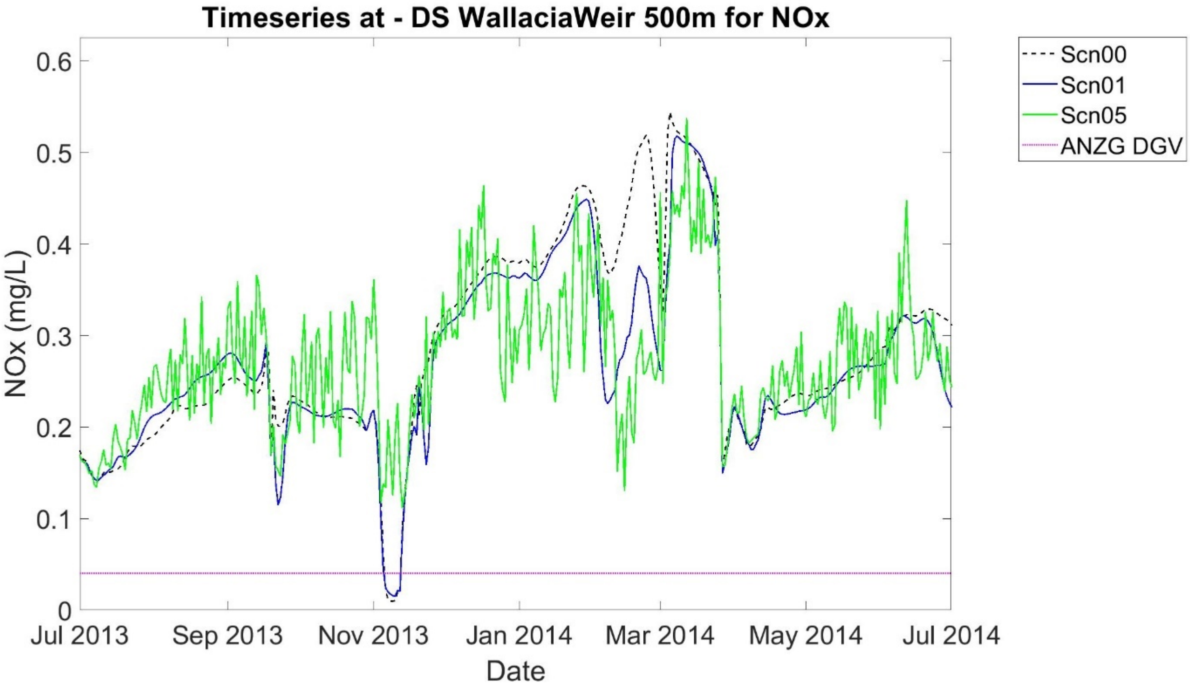


Figure 6-70 Timeseries of predicted Oxidised Nitrogen concentrations 500 m downstream of Wallacia Weir (2036 releases/dry year)

Wet year

- The transect patterns of annual median total nitrogen profiles along the river during wet year conditions are generally predicted to be similar to that in the dry year, although the annual median total nitrogen concentrations are incrementally higher due to increased catchment loads (refer to Figure 6-71).
- Downstream of the Wallacia Weir, the total nitrogen concentrations were generally predicted to be lower than the background scenario (HN01), with median concentrations ~0.06 mg/L lower than background conditions for the simulated 2036 conditions (HN05). However periodic spikes of higher nitrogen concentrations were also predicted, associated with the episodic release of tertiary treated water from the AWRC (refer to Figure 6-72). During the wet year, increases in concentrations were predicted up to ~0.7 mg/L higher than background conditions, with the introduction of the AWRC releases. These increases are however relatively short-lived, with concentrations returning quickly to levels equivalent, or lower, than background conditions within a few days.
- Due to the composition of the treated water releases, similar trends were also predicted for ammonia and oxidised nitrogen as shown in Figure 6-73 and Figure 6-74 respectively, with temporary spikes in concentrations correlating with the release of tertiary treated water. Despite the temporary increases in the more bioavailable forms of nitrogen, peaks in daily concentrations remained well below the toxicant DGVs discussed in Section 2.2.

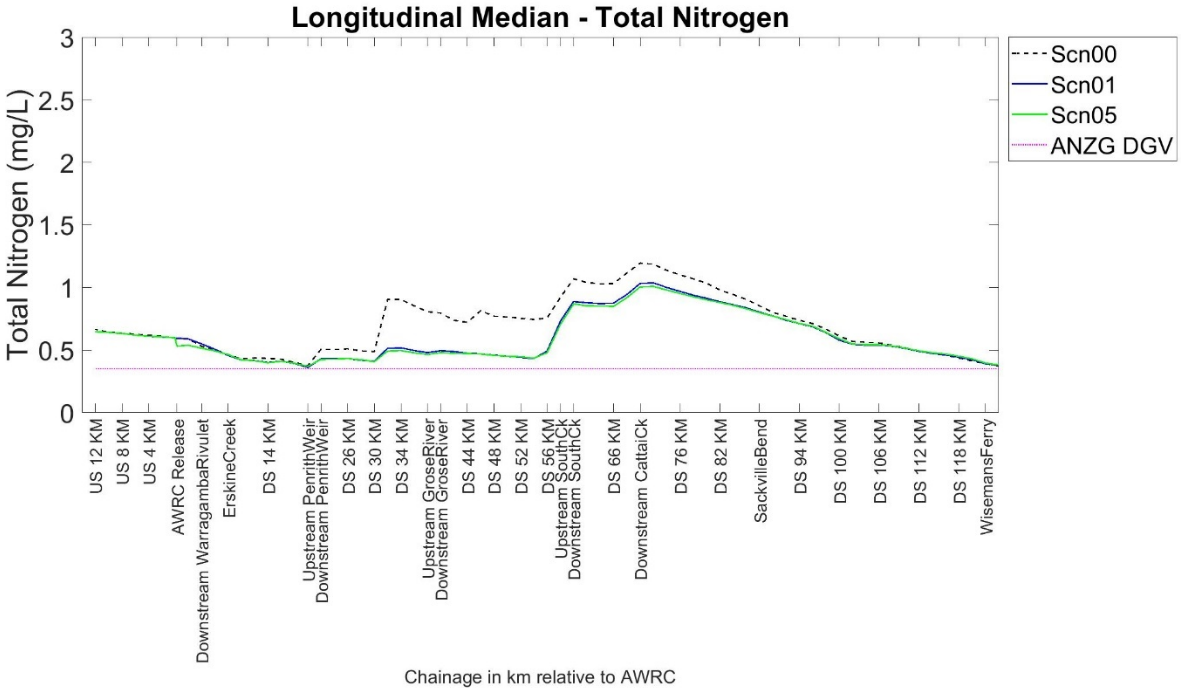


Figure 6-71 Longitudinal profile of predicted annual median Total Nitrogen concentrations (2036 releases/wet year)

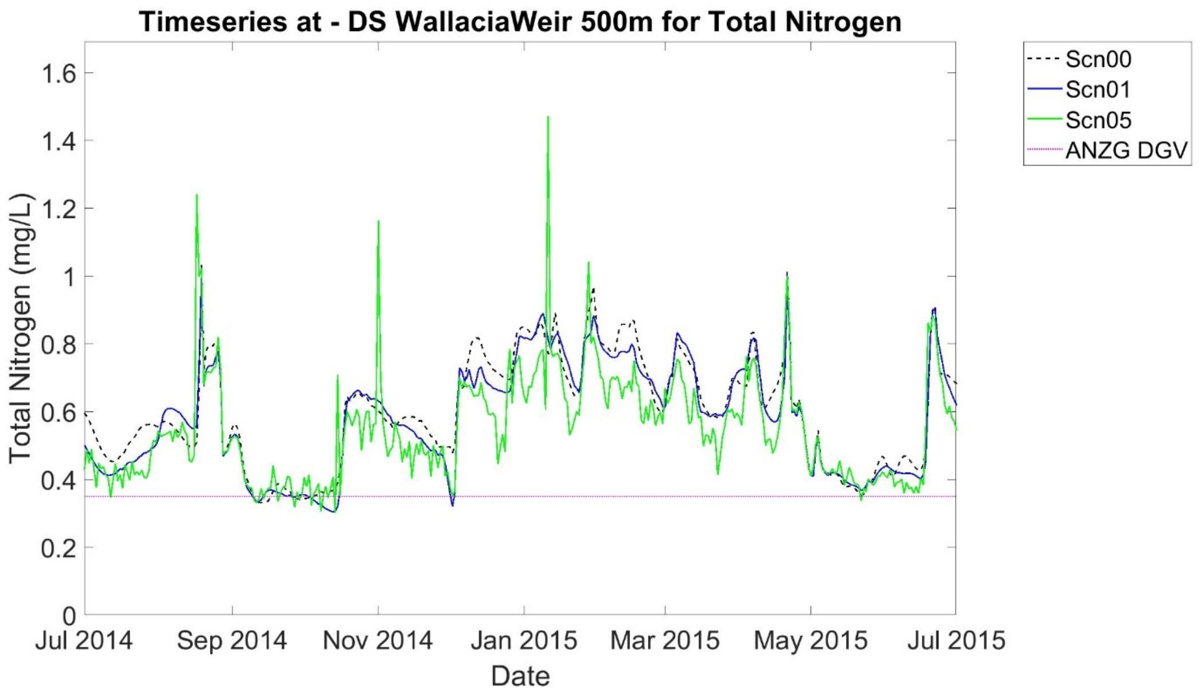


Figure 6-72 Timeseries of predicted Total Nitrogen concentrations 500 m downstream of Wallacia Weir (2036 releases/wet year)

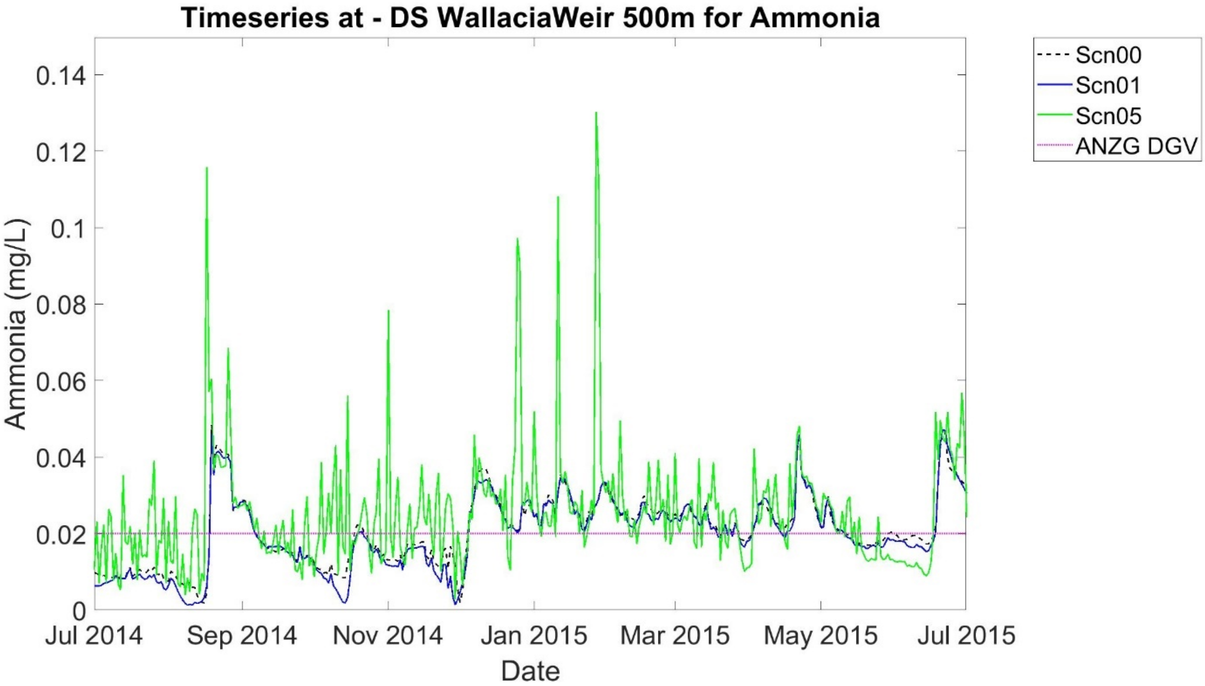


Figure 6-73 Timeseries of predicted Ammonia concentrations 500m downstream of Wallacia Weir (2036 releases/wet year)

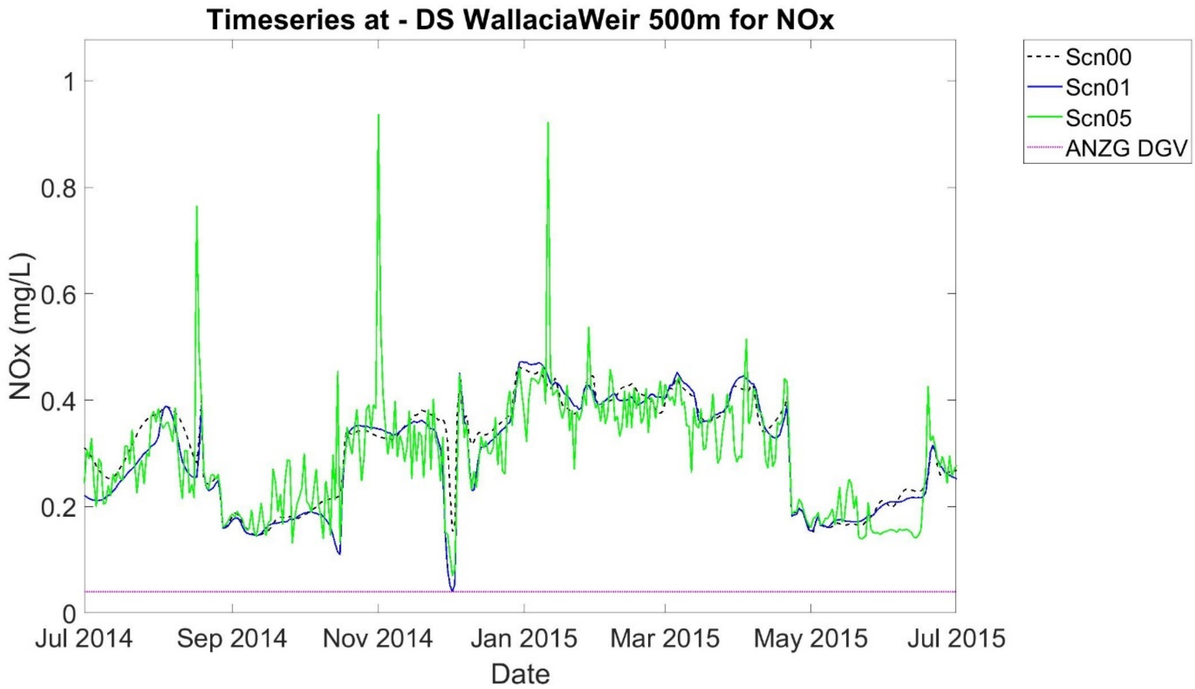


Figure 6-74 Timeseries of predicted Oxidised Nitrogen concentrations 500m downstream of Wallacia Weir (2036 releases/wet year)

High loading vs low loading background

- Minor increases in total nitrogen were predicted in the Nepean River, with the highest median increase of ~0.06 mg/L relative to the 2036 lower loading dry year scenario. The most significant impact of the additional loading was predicted in the upper reaches of the river, upstream of Penrith weir. These increases were due to modified release conditions assumed for the West Camden WRP, Picton WRP, and the new Wilton WRP. Figure 6-75 presents the longitudinal profile of predicted annual median total nitrogen concentrations for the high loading scenario (HN07). This can be compared to the corresponding lower loading results in Figure 6-64.

- Minor increases were also predicted for ammonia and oxidised nitrogen median concentrations with the highest increases in the 2036 dry year (~0.002 mg/L and ~0.025 mg/L respectively), again predicted upstream of Penrith.

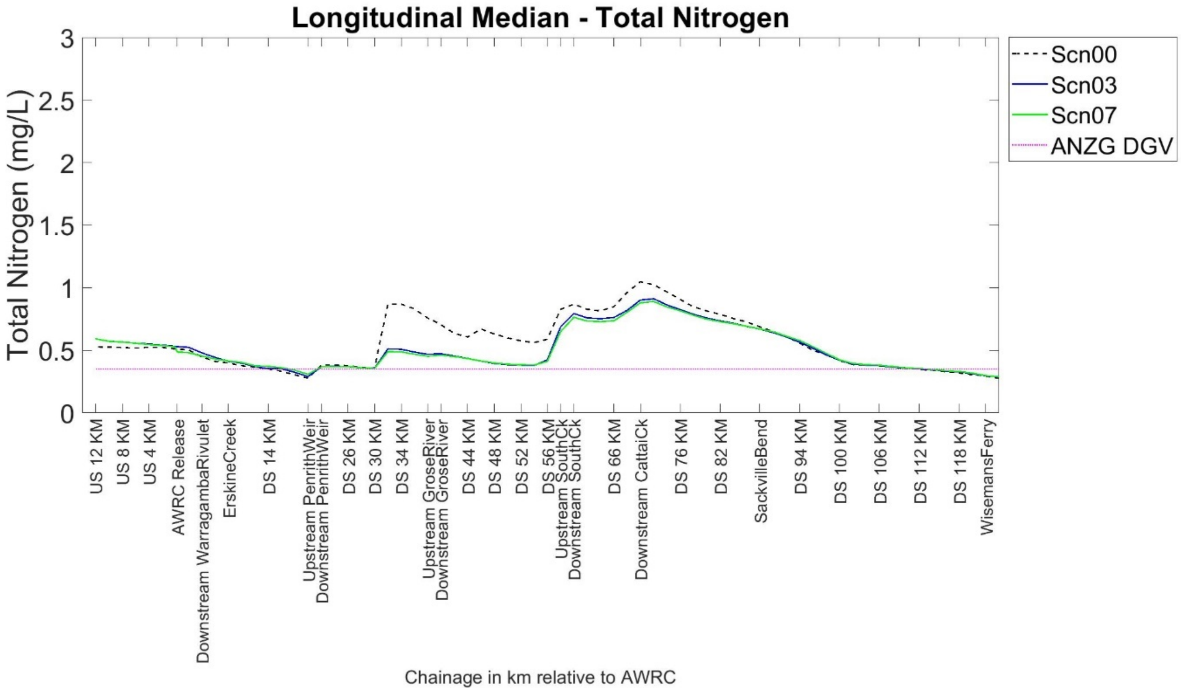


Figure 6-75 Longitudinal profile of predicted annual median Total Nitrogen concentrations (2036 releases/dry year/higher loading)

Advanced treatment shutdown scenarios

- No significant changes in the downstream concentrations of any of the nitrogen indicators were observed as a result of the shutdown of the AWRC advanced treatment process. The conclusions regarding impacts therefore also remain unchanged between the shutdown and the non-shutdown scenarios.

Compliance

- In both the dry and wet years (refer to Figure 6-64 and Figure 6-71), the predicted annual median profiles for total nitrogen were predicted to be generally above the relevant waterway objective throughout the river system. The highest annual median concentrations were found in the region around the Cattai Creek where the total nitrogen concentration reached ~1.0 mg/L in the wet year. Treated water releases from the AWRC assisted in reducing total nitrogen concentration in the vicinity, and downstream of the releases, but the annual median concentrations remained above the relevant waterway objective as per the background scenarios.
- For the more bioavailable forms, annual median concentrations of ammonia were predicted to have a higher level of compliance (refer to Figure 6-67). Conversely, zero compliance was predicted for oxidised nitrogen (refer to Figure 6-69).
- Importantly, the introduction of the AWRC releases did not affect the general level of compliance predicted for any of the nitrogen indicators.

Phosphorus

Dry year

- The annual median profiles of phosphorus (total phosphorus and FRP) showed similar transect patterns to total nitrogen. Median phosphorus concentrations in the reaches of the Nepean River being marginally lower (<0.005 mg/L of total phosphorus and FRP on average in 2036) than background conditions through introduction of the AWRC releases. These reductions were due to the dilution effect of the AWRC treated water that generally reduced mean concentrations downstream of the releases. Refer to Figure 6-76 and Figure 6-77.
- Downstream of Wallacia Weir, daily concentrations of total phosphorus and FRP were predicted to be generally lower than background conditions but with the periodic and relatively short-lived spikes correlating with the introduction of tertiary treated water into the AWRC releases (refer to Figure 6-78 and Figure 6-79). For total phosphorus, predicted median concentrations are reduced by ~0.005 mg/L at this location, but with increases in daily concentrations up to 0.06 mg/L. The increases in concentration These increases were predicted to return quickly to levels equivalent, or typically lower, than background conditions within a few days.
- Further afield, outside of the region of influence, the results of the impact scenario generally correlated with background and baseline conditions, in terms of temporal variations and statistical distributions of all phosphorus indicators.

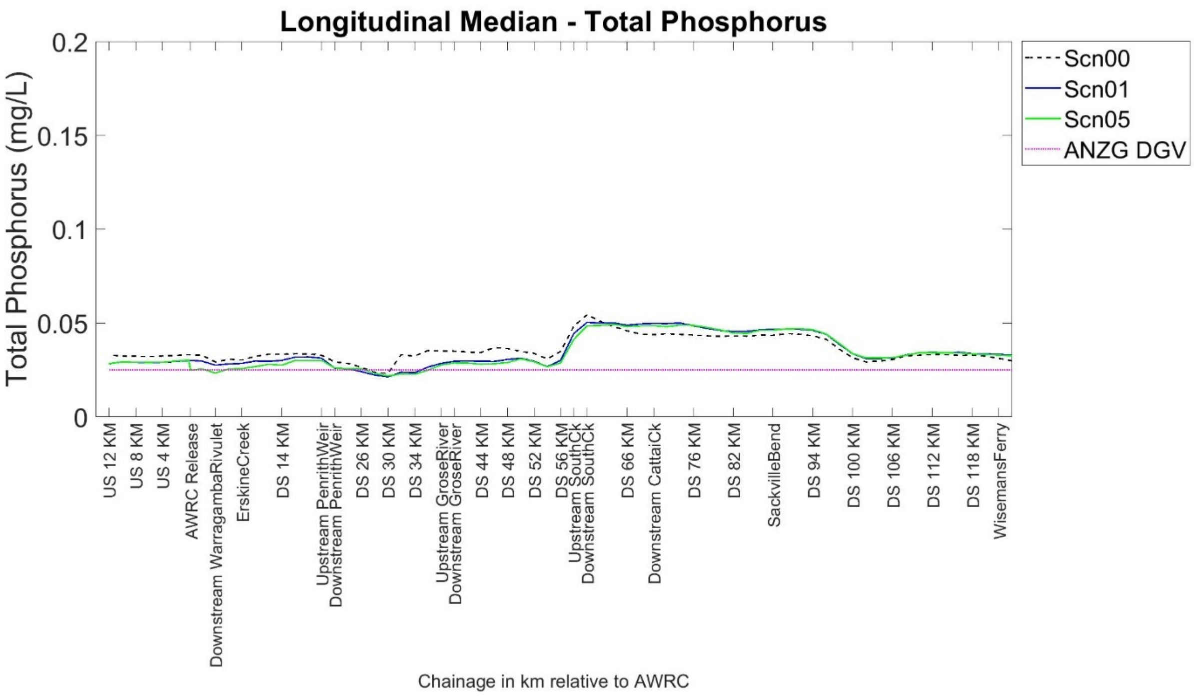


Figure 6-76 Longitudinal profile of predicted annual median Total Phosphorus concentrations (2036 releases/dry year)

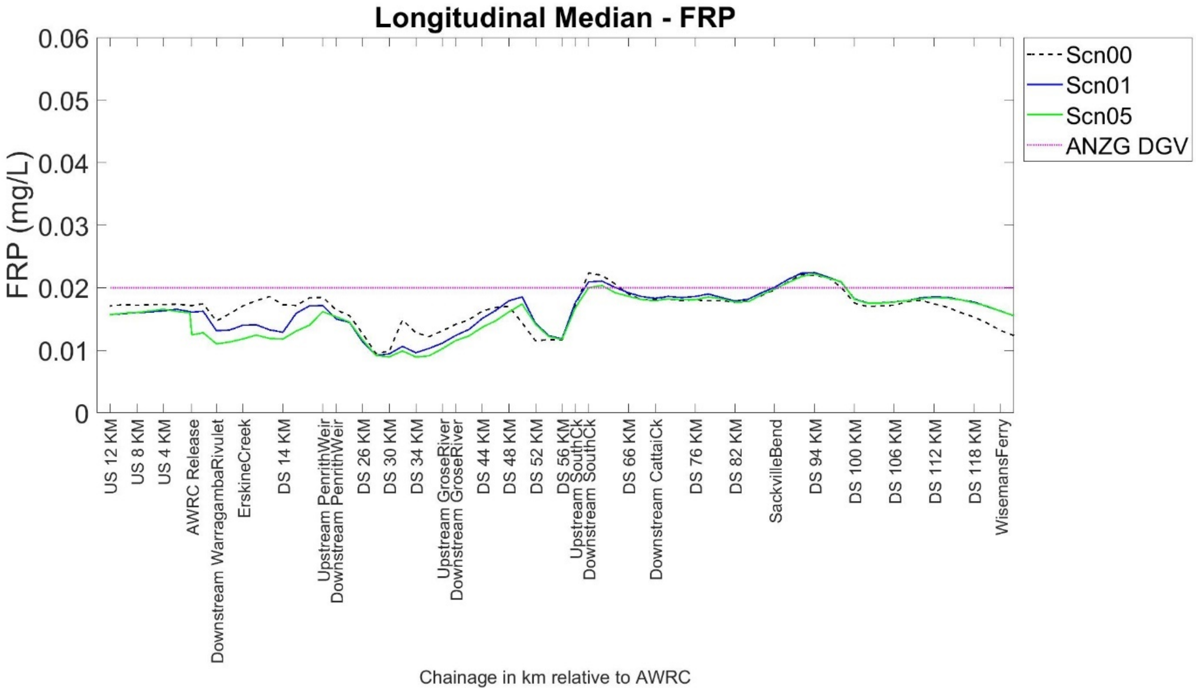


Figure 6-77 Longitudinal profile of predicted annual median FRP concentrations (2036 releases/dry year)

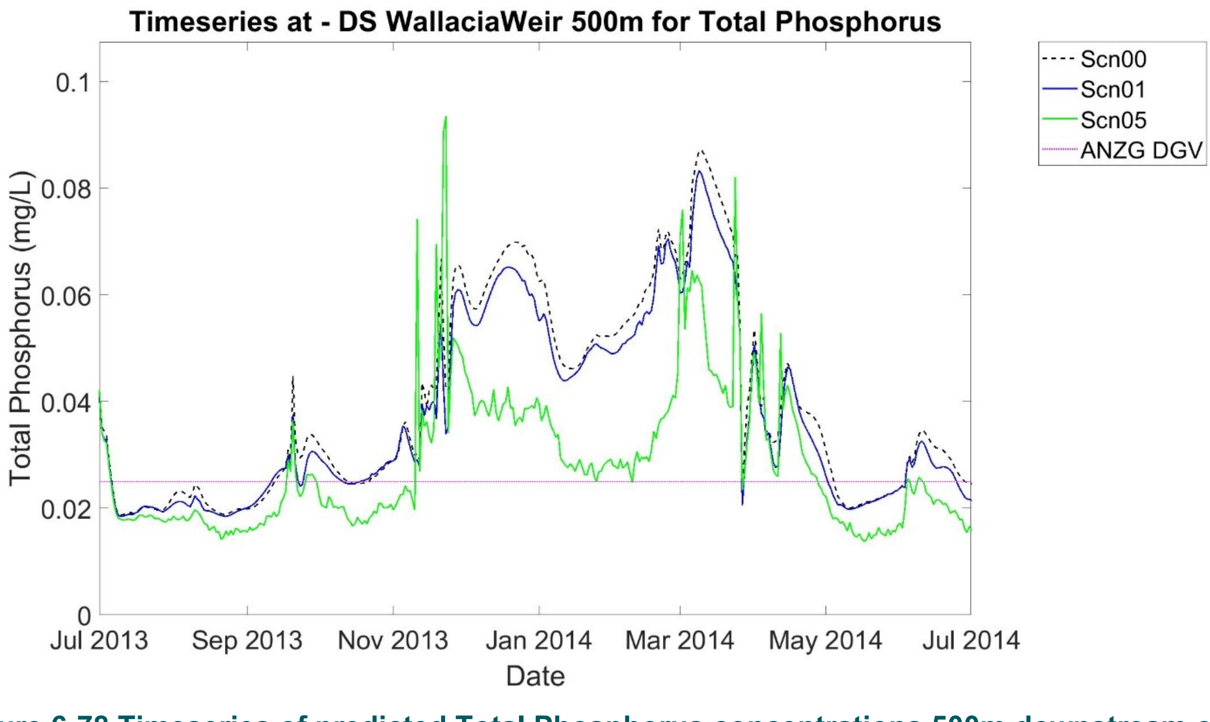


Figure 6-78 Timeseries of predicted Total Phosphorus concentrations 500m downstream of Wallacia Weir (2036 releases/dry year)

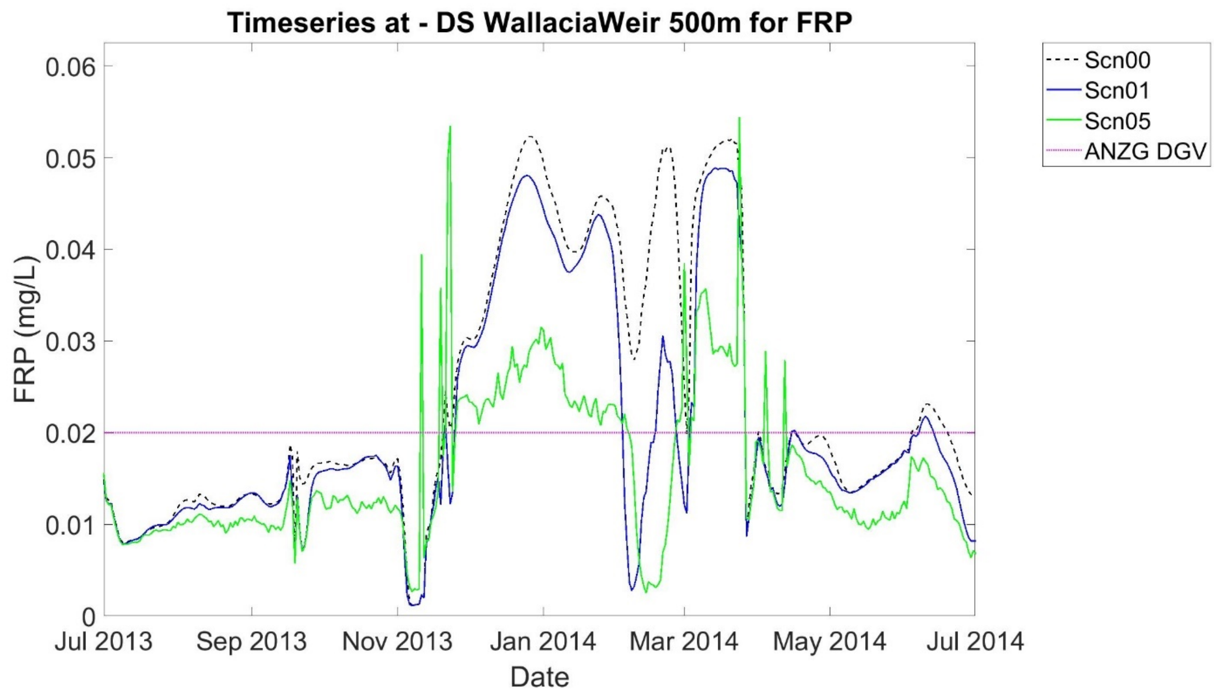


Figure 6-79 Timeseries of predicted FRP concentrations 500m downstream of Wallacia Weir (2036 releases/dry year)

Wet year

- The transect patterns of predicted annual median phosphorus concentrations in the wet year are similar to that of the dry year, except the concentrations in the wet year are again incrementally higher than that in the dry year due to the elevated loading from the catchment (refer to Figure 6-80). With introduction of the AWRC releases (circa 2036), reductions in annual median values were predicted up to 0.01 mg/L downstream of the Wallacia Weir releases. Further reductions were predicted in the vicinity and downstream of the confluence with South Creek.
- Immediately downstream of the Wallacia Weir, the phosphorus concentrations were generally predicted to be lower than the background scenario (HN01), with annual median concentrations of total phosphorus ~0.01 mg/L lower than background conditions for the simulated 2036 conditions (HN05). However periodic spikes of higher nutrient concentrations were again predicted, associated with the episodic release of tertiary treated water from the AWRC (refer to Figure 6-81 and Figure 6-82). With the introduction of the tertiary treated water, increases in daily concentrations of up to ~0.27 mg/L (total phosphorus) and 0.19 mg/L (FRP) were predicted, relative to background conditions.
- Immediately downstream of the confluence with the Warragamba River, these spikes in concentrations were reduced in magnitude with maximum predicted increases of 0.13 mg/L in total phosphorus, and 0.09 mg/L in FRP.
- As discussed previously, these spikes correlate with releases from the AWRC when there are higher proportions (up to 100%) of tertiary treated water being released into the Wallacia Weir pool. On average however, the total phosphorus and FRP concentrations were predicted to be generally lower than background conditions, and the spikes were short-lived with concentrations returning to background conditions, or below, within a day or two of the wet weather events.

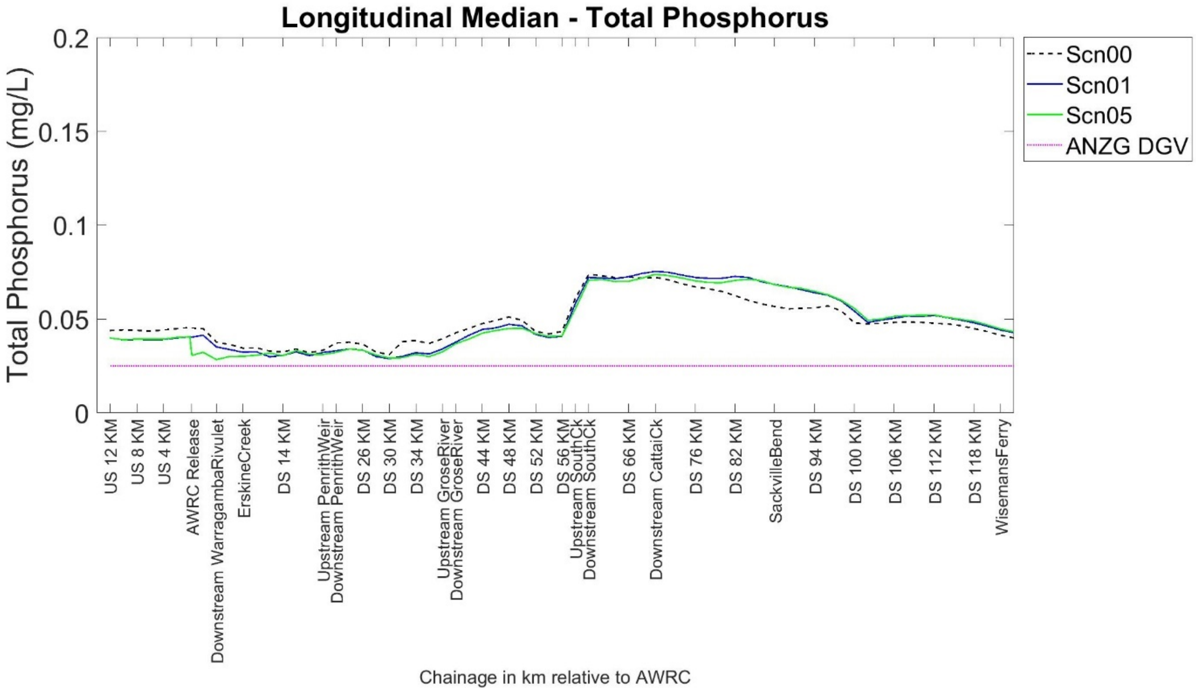


Figure 6-80 Longitudinal profile of predicted annual median Total Phosphorus concentrations (2056 releases/wet year)

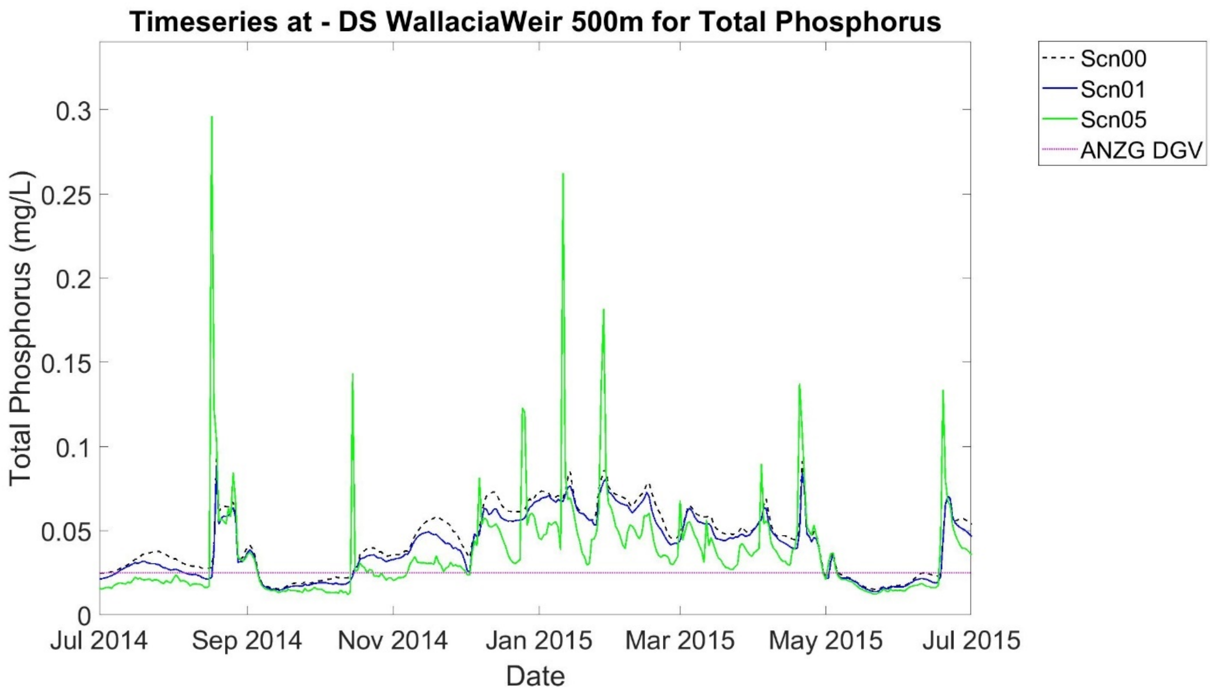


Figure 6-81 Timeseries of predicted Total Phosphorus concentrations 500m downstream of Wallacia Weir (2036 releases/wet year)

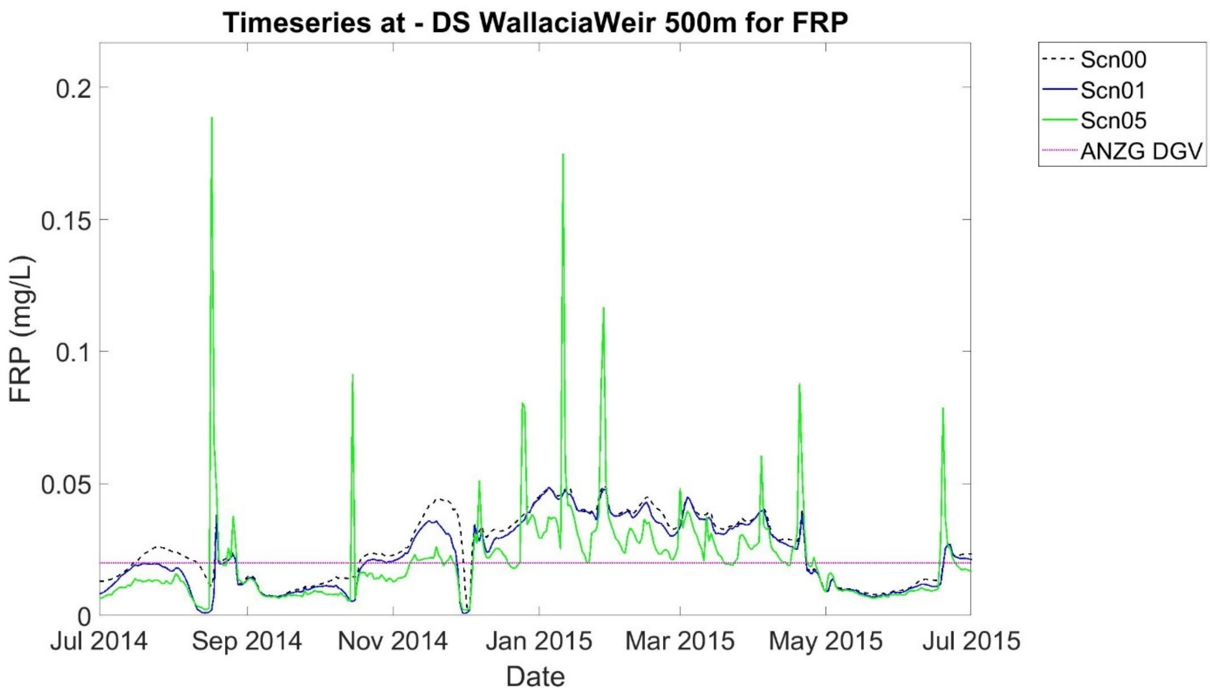


Figure 6-82 Timeseries of predicted FRP concentrations 500m downstream of Wallacia Weir (2056 releases/wet year)

High loading vs low loading background

- Minor increases in total phosphorus were predicted in the Nepean River under the higher loading scenarios (HN07 and HN08), with the highest ‘dry year’ annual median increase of ~0.001 mg/L relative to the 2036 lower loading scenario.
- The largest increases relative to the low loading scenarios were again predicted in the higher reaches of the river. Similar patterns and minor relative increases in annual median concentrations were also predicted for FRP (<0.001 mg/L).

Advanced treatment shutdown scenarios

- Minor temporary changes in the downstream concentrations of FRP and total phosphorus (~0.02 mg/L) were predicted as a result of the shutdown of the AWRC advanced treatment process. However, the conclusions regarding impacts remain valid as these increases are lower than the more severe wet weather events and the corresponding impacts of tertiary treated water.

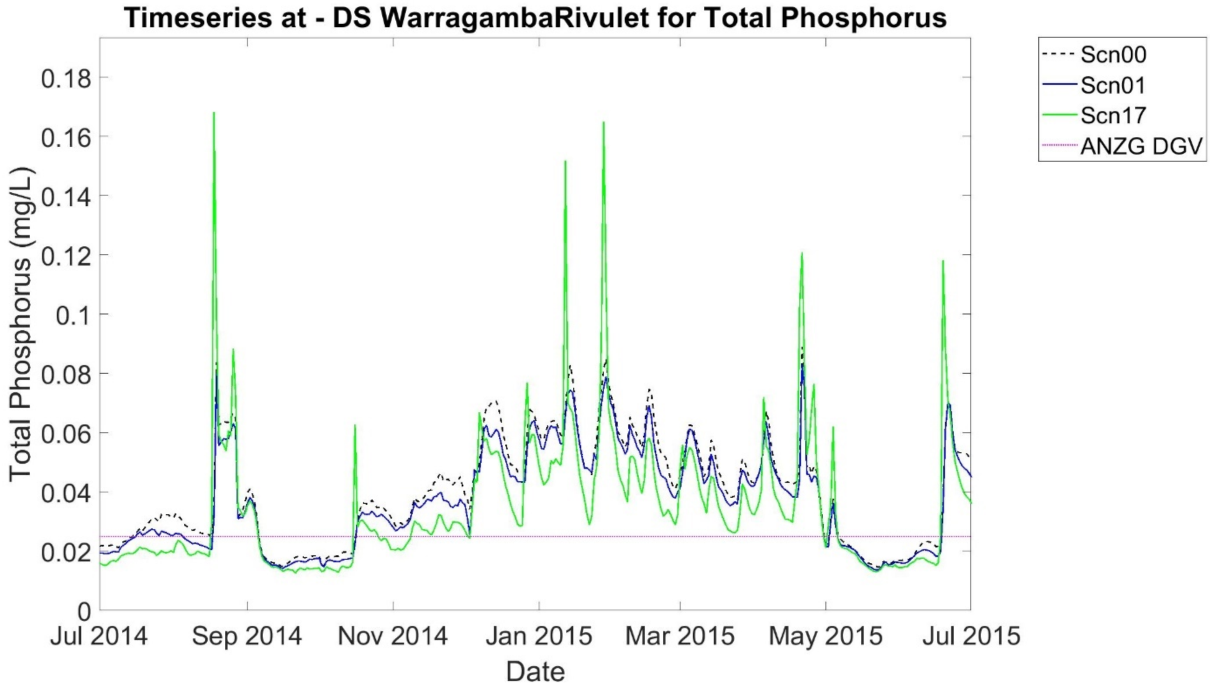


Figure 6-83 Timeseries of predicted Total Phosphorus concentrations downstream of the Warragamba confluence (2036 releases/wet year/advanced treatment shutdown)

Compliance

- In both the dry and wet years, the longitudinal profiles of annual median total phosphorus concentrations are predicted to be generally close to, or above the relevant waterway objective downstream to Wisemans Ferry (refer to Figure 6-76 and Figure 6-80). Based on the modelling results, the introduction of the AWRC releases may have the potential to slightly aid compliance with the objective within, and downstream of Wallacia Weir, particularly under drier conditions.
- The FRP annual median concentration were predicted to be generally below the waterway objective downstream to Wisemans Ferry in the dry year (refer to Figure 6-77); whilst in the wet year (refer to Figure 6-84), annual median concentrations were above the objective in the region between the South Creek confluence to approximately Wisemans Ferry. Similarly to total phosphorus, the introduction of the AWRC releases may have the potential to slightly aid compliance with the objective.

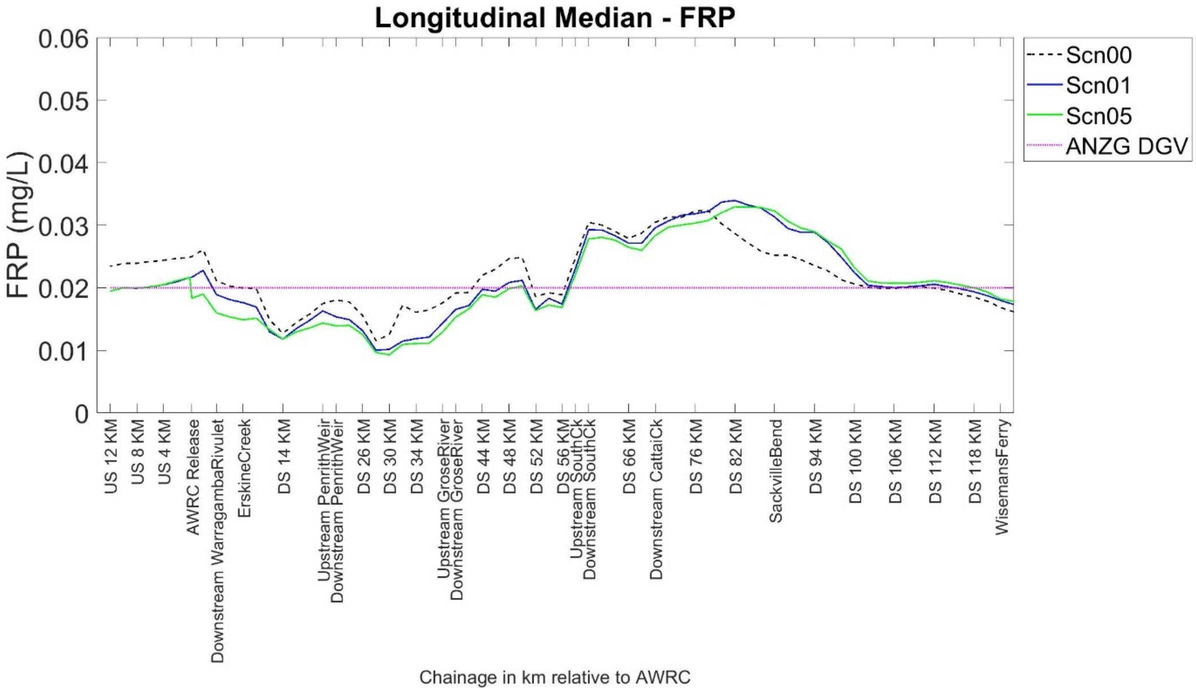


Figure 6-84 Longitudinal profile of predicted annual median FRP concentrations (2036 releases/wet year)

Chlorophyll *a*

- The difference of predicted chlorophyll *a* concentration between the impact and background scenarios is marginal when looking at the annual median profiles along the river. The predicted annual median profiles also showed concentrations lower than the relevant waterway objective from the upstream reach of the Nepean River down to Wisemans Ferry. Refer to Figure 6-85 and Figure 6-86 for the dry and wet year 2036 impact scenario profiles. Importantly, the level of compliance with the waterway objectives was predicted to remain unmodified with the introduction of the AWRC releases.
- Elevated chlorophyll *a* concentrations, above the waterway objective were however often observed in time periods when the inflow rates were low and the river was less well flushed. The chlorophyll *a* concentration tended to increase during dry periods and would exceed the waterway objective quickly in these times. This risk was however not significantly changed in the impact scenario, relative to the background conditions.
- The timing of algal blooms was slightly different between the impact and background scenarios due to the changes in the flow regimes and biogeochemical environment. In the reaches downstream of the AWRC release, a build-up of chlorophyll *a* concentration generally occurred earlier in the background scenario relative to the impact scenario. Higher chlorophyll *a* concentrations were also typically predicted in the background scenario than when the AWRC releases were introduced. Refer to Figure 6-87.
- Only minor increases of annual median concentrations were predicted for the higher loading scenarios (Refer to Figure 6-88). This is considered as a response to the marginal increase in nutrients from the upstream WWTPs/WRPs. Figure 6-88 can be compared against the low loading version in Figure 6-85.

Advanced treatment shutdown scenarios

- No changes in the downstream concentrations of chlorophyll *a* were observed as a result of the shutdown of the AWRC advanced treatment process. Despite the increased load from the AWRC as a result of the shutdown, these increases were relatively minor and biomass growth remained low.

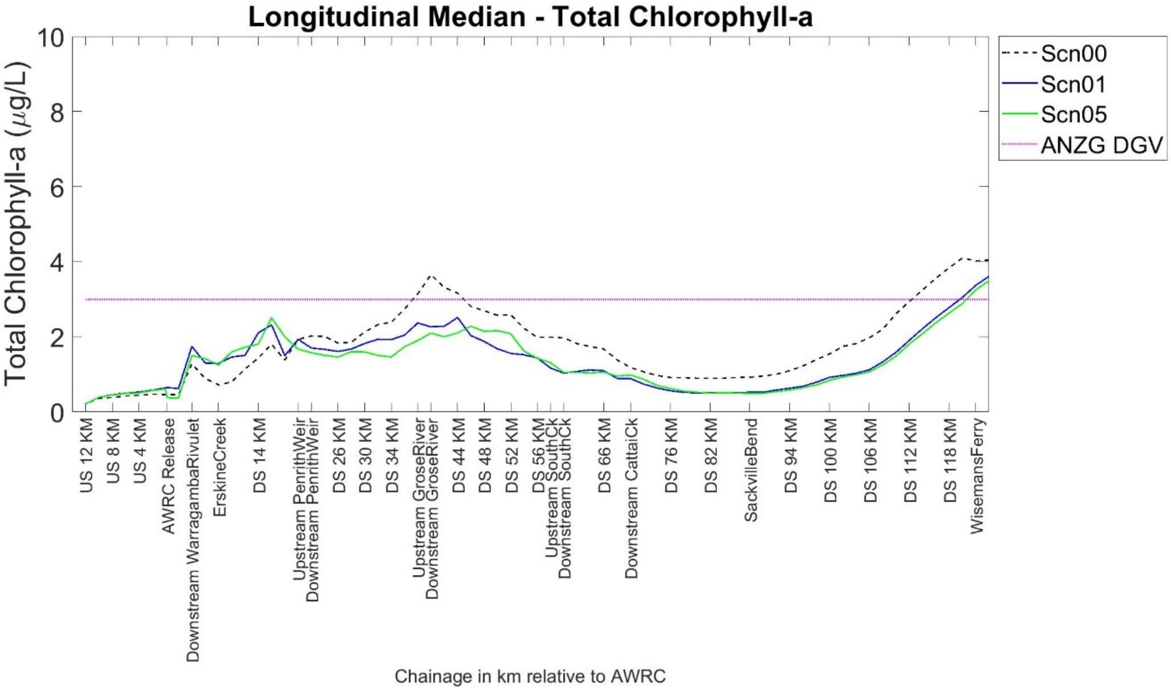


Figure 6-85 Longitudinal profile of predicted annual median Chlorophyll *a* concentrations (2036 releases/dry year)

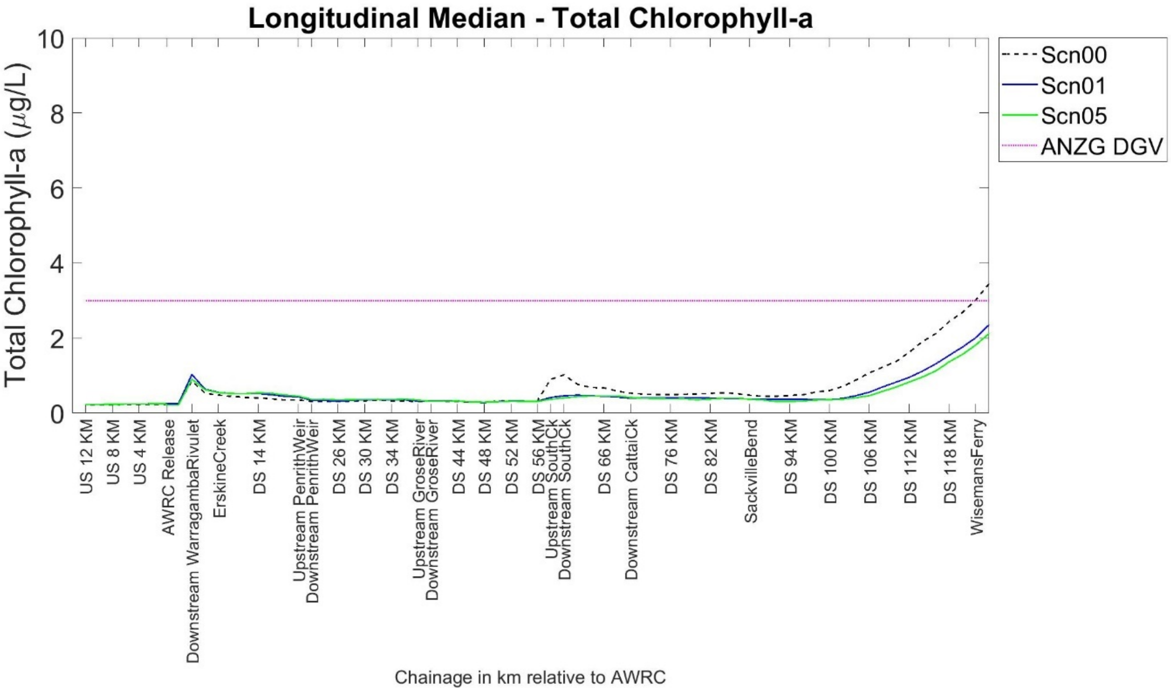


Figure 6-86 Longitudinal profile of predicted annual median Chlorophyll *a* concentrations (2036 releases/wet year)

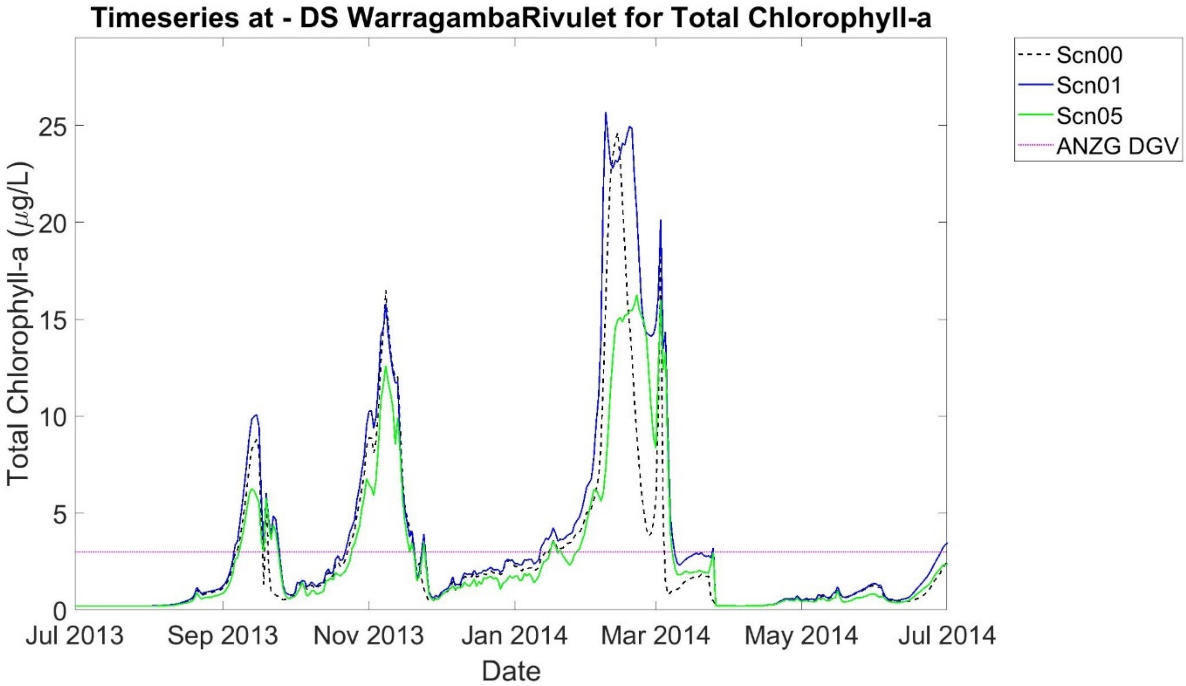


Figure 6-87 Timeseries of predicted Chlorophyll *a* concentrations downstream of the Warragamba River confluence (2036 releases/dry year)

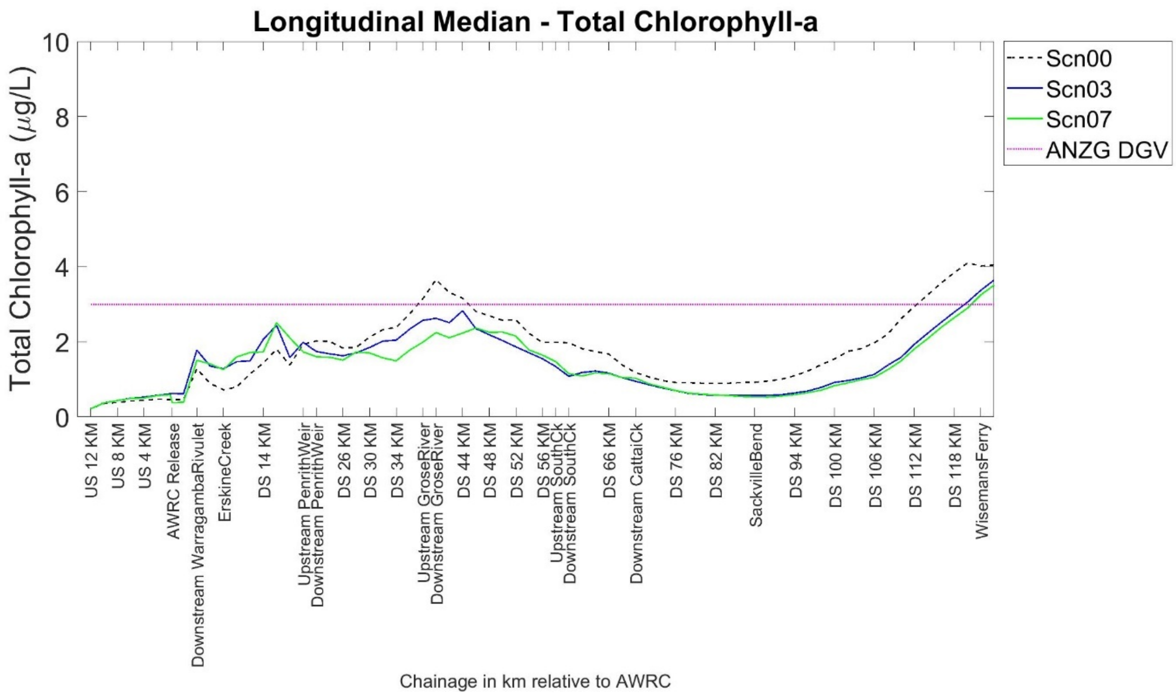


Figure 6-88 Longitudinal profile of predicted annual median Chlorophyll *a* concentrations (2036 releases/dry year/high loading)

Salinity

- Minor reductions (<0.05 g/L) in salinity were predicted with the introduction of the AWRC releases relative to the background conditions. These reductions were most evident in the regions around, and downstream of, the release point and due to the lower salinities in the treated water relative to the ambient river salinity. Refer to Figure 6-89 for predicted salinity concentrations below the Wallacia Weir.

- No significant differences in annual median profiles, or compliance with waterway objectives, were predicted for either the dry or wet years.
- No notable differences in salinity were observed between the low and high loading scenarios.
- No additional impacts were predicted as a result of the shutdown of the AWRC advanced treatment process in the advanced treatment shutdown scenario.
- Figure 6-90 and Figure 6-91 respectively present the longitudinal profiles of annual median salinity concentrations for the 2036 dry and wet year impact scenarios.

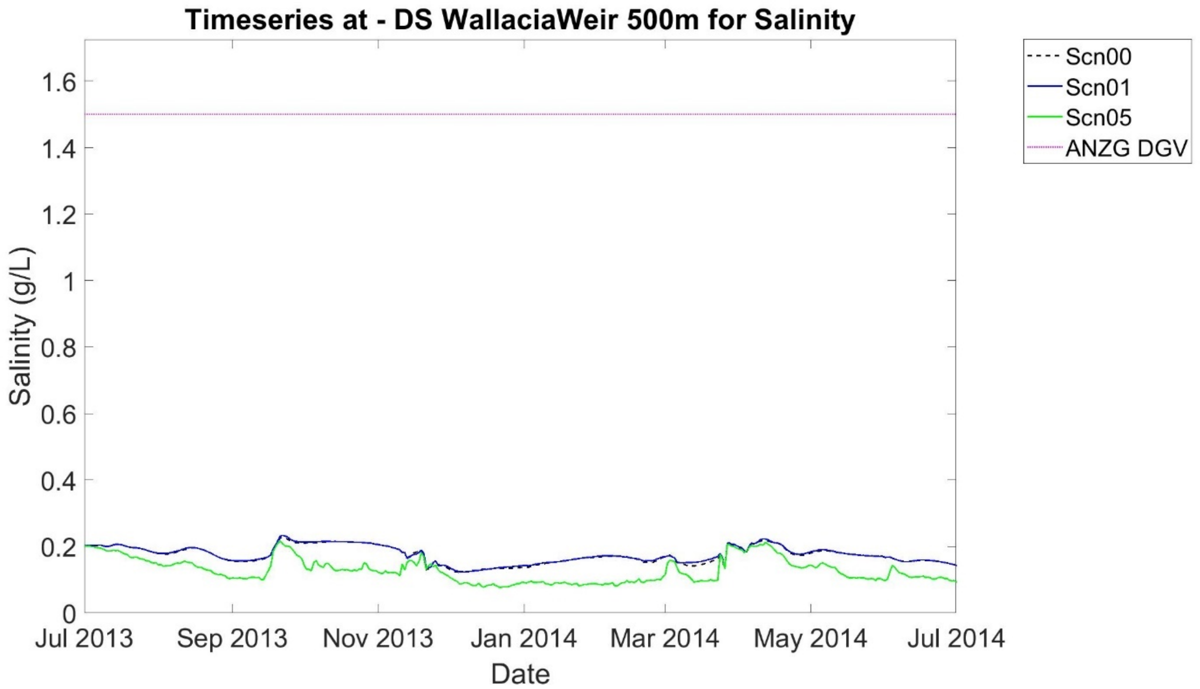


Figure 6-89 Timeseries of predicted Salinity concentrations 500m downstream of Wallacia Weir (2036 releases/dry year)

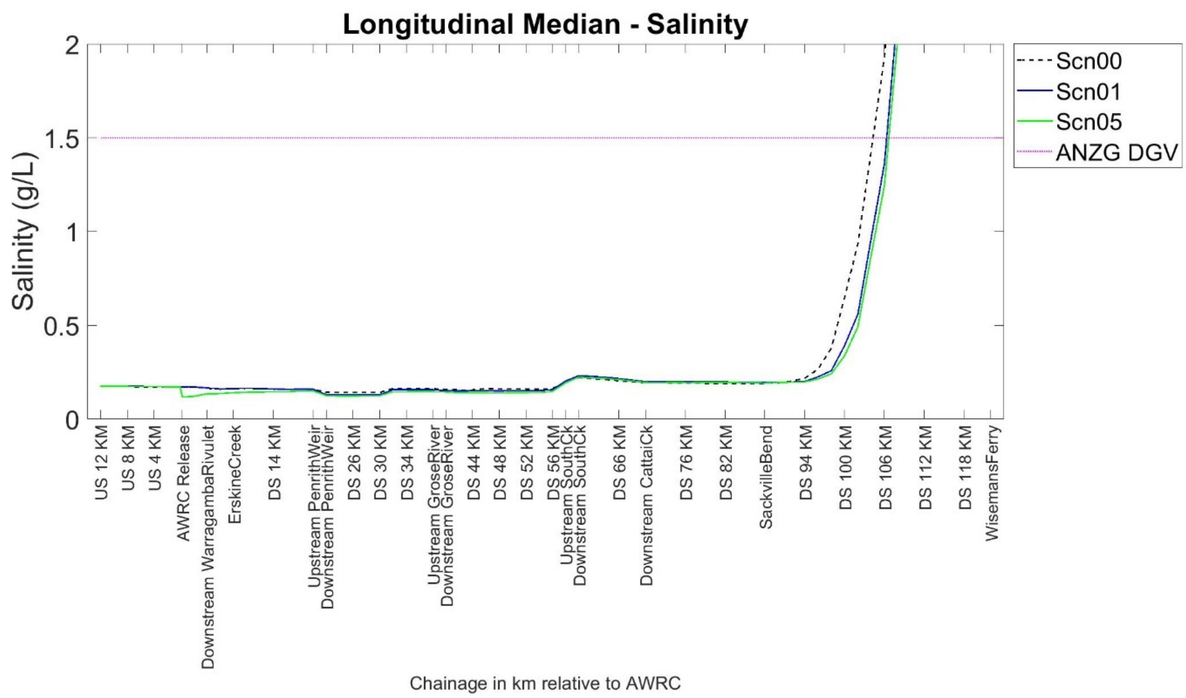


Figure 6-90 Longitudinal profile of predicted annual median salinity concentrations (2036 releases/dry year)

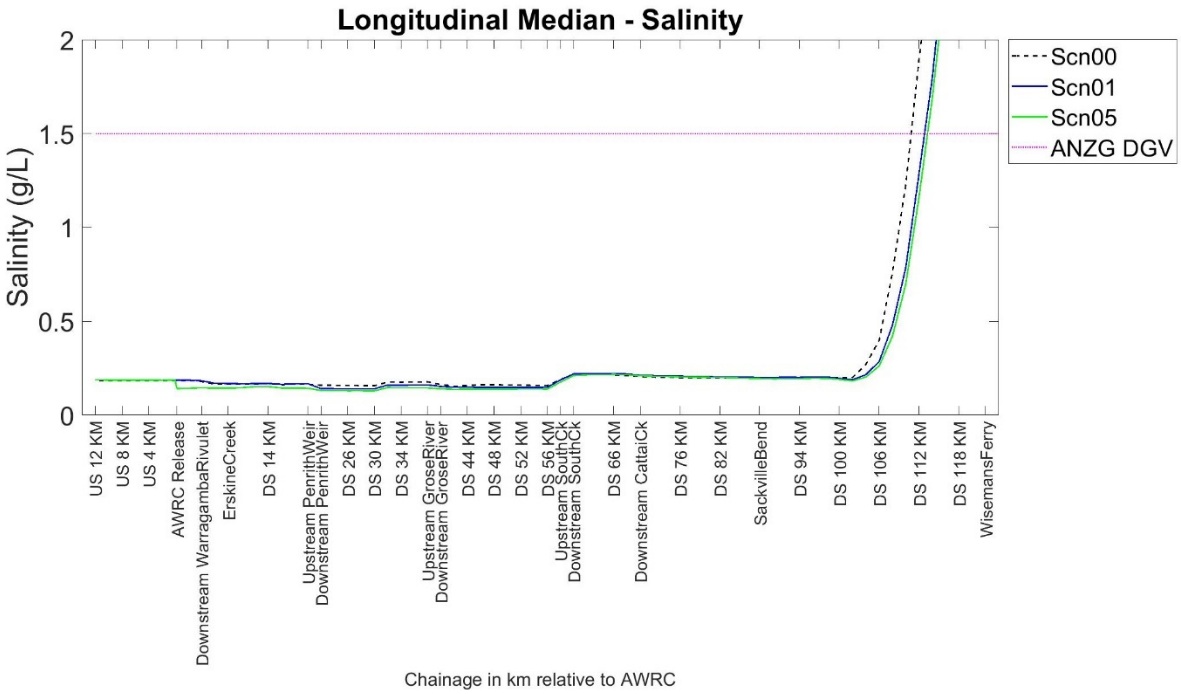


Figure 6-91 Longitudinal profile of predicted annual median salinity concentrations (2036 releases/wet year)

Total Suspended Solids

- Reductions in median and daily TSS concentrations were predicted in the downstream reaches of Wallacia Weir, as a result of the low concentrations in the AWRC releases. Refer to Figure 6-92.
- No notable differences in TSS concentrations were observed between the low and high loading scenarios.
- No additional impacts were predicted as a result of the shutdown of the AWRC advanced treatment process in the advanced treatment shutdown scenario.
- Annual median concentrations were however predicted to be marginally higher (<~5 mg/L) than background conditions in the region between Penrith Weir and Grose River (refer to Figure 6-93 and Figure 6-94). These minor differences were likely due to increased transportation of high TSS water to further downstream due to the modified flow regime.

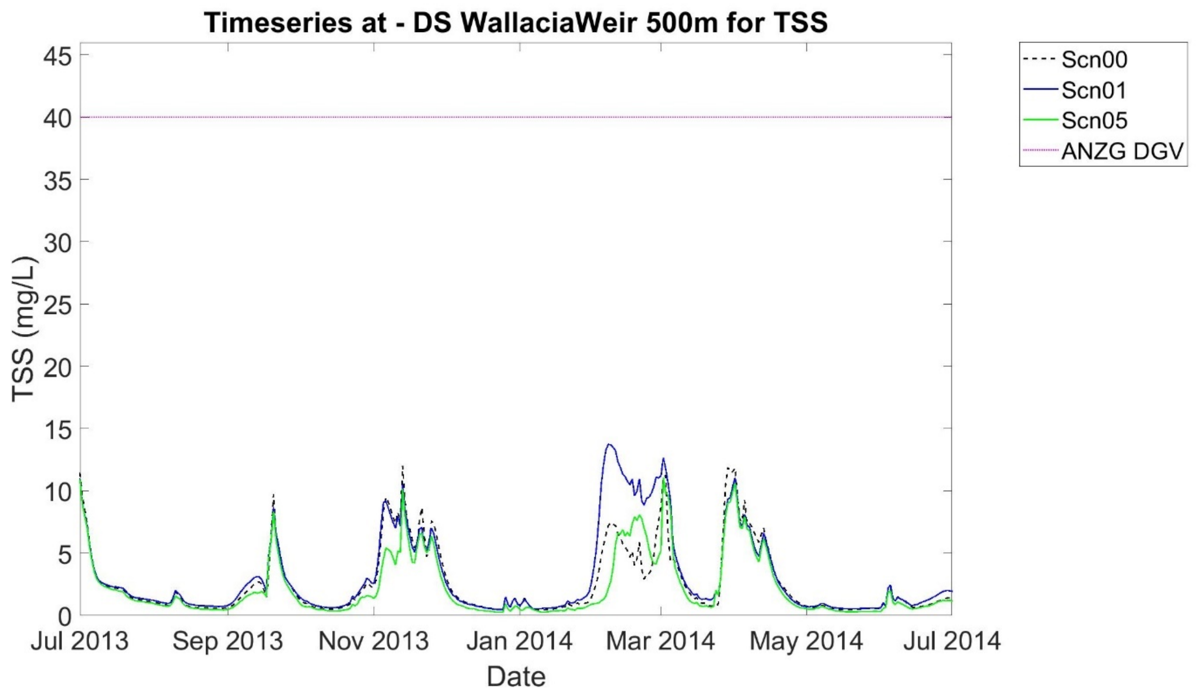


Figure 6-92 Timeseries of predicted TSS concentrations 500m downstream of Wallacia Weir (2036 releases/dry year)

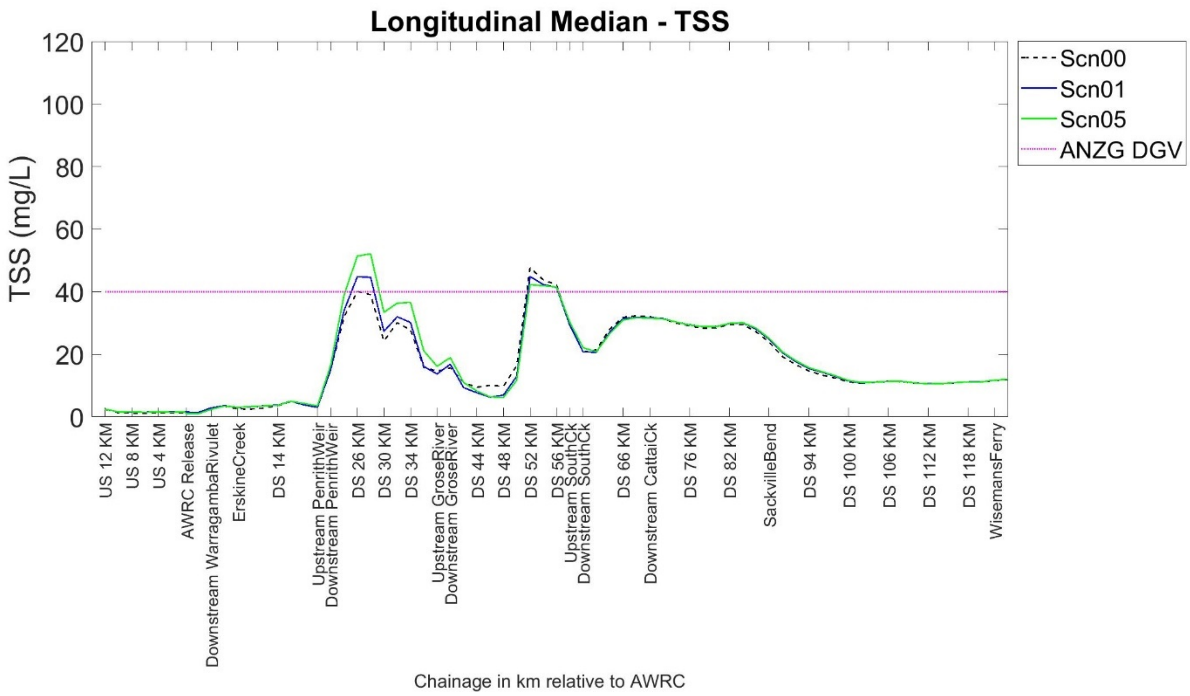


Figure 6-93 Longitudinal profile of predicted annual median TSS concentrations (2036 releases/dry year)

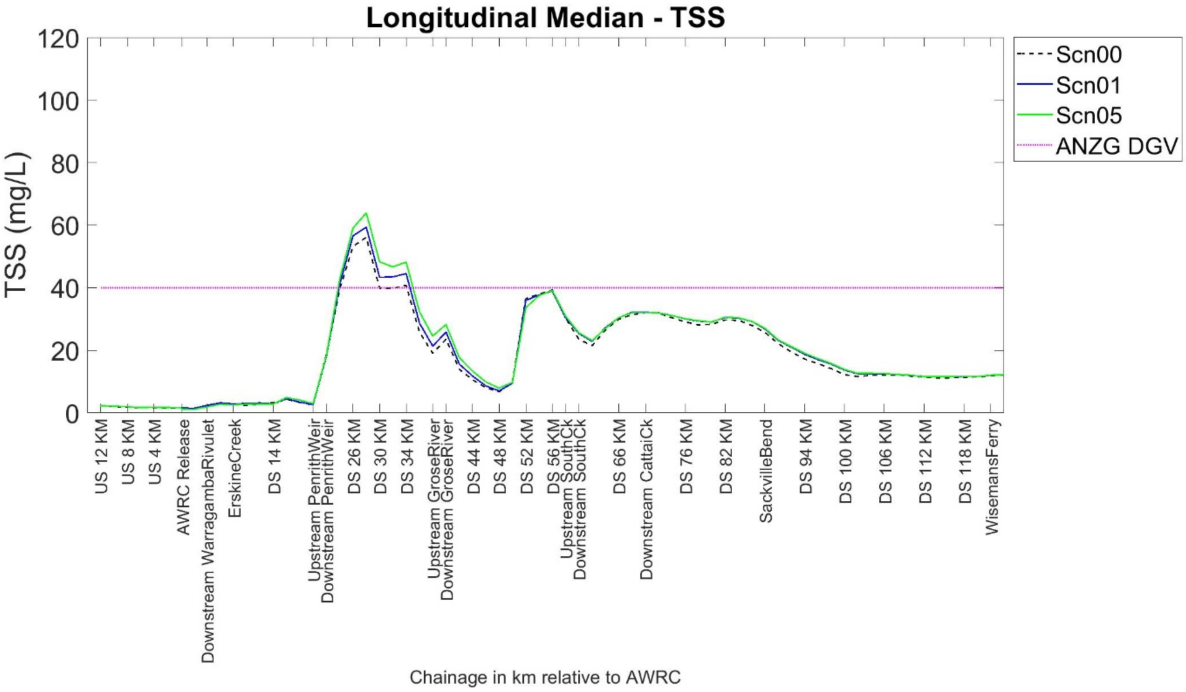


Figure 6-94 Longitudinal profile of predicted annual median TSS concentrations (2036 releases/wet year)

Dissolved oxygen

- Notable improvements in dissolved oxygen were predicted with the introduction of the AWRC releases (refer to Figure 6-95). These improvements were observed around and downstream of the AWRC releases, where oxygen sags (difference below saturation) were reduced in both the dry and wet years. Further downstream, sites showed similar responses to background conditions in terms of temporal variations and statistical distributions of dissolved oxygen.
- The longitudinal profile plots for 2036 dry year and wet year simulations are presented in Figure 6-96 and Figure 6-97, showing the impact of the oxygen rich treated water releases. The potential to improve compliance with the waterway objective is predicted with the introduction of the AWRC treated water releases.
- No notable differences in dissolved oxygen were observed between the low and high loading scenarios.
- No additional impacts were predicted as a result of the shutdown of the AWRC advanced treatment process in the advanced treatment shutdown scenario (HN17).

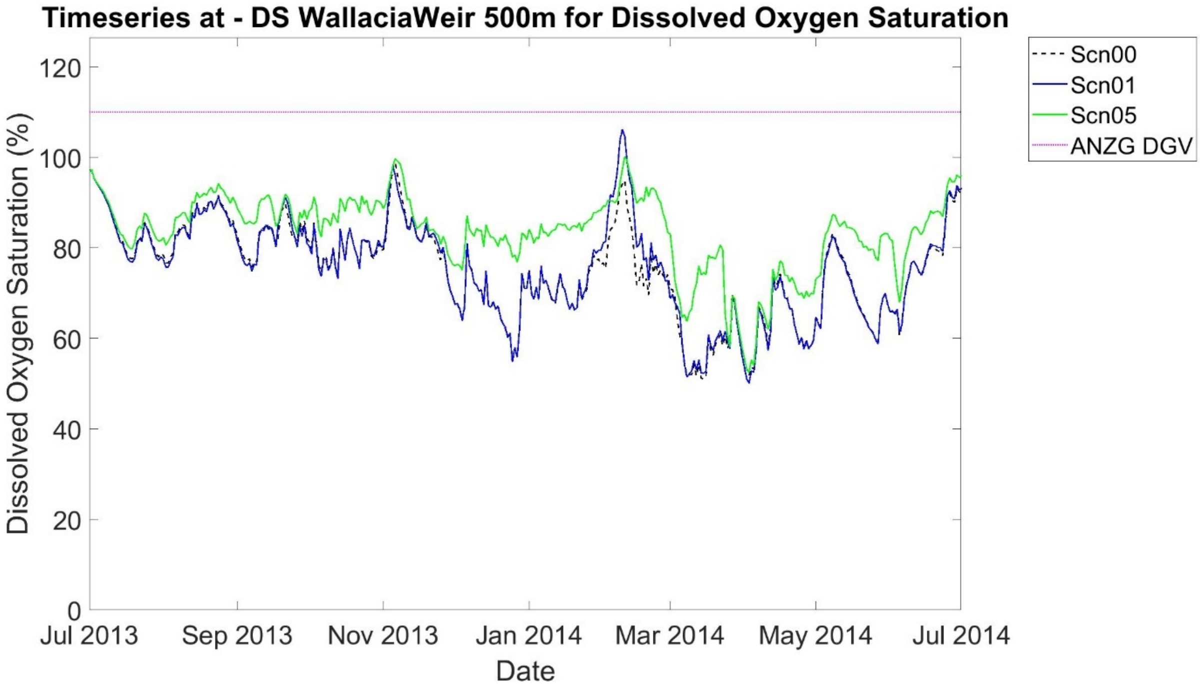


Figure 6-95 Timeseries of predicted TSS concentrations 500m downstream of Wallacia Weir (2036 releases/dry year)

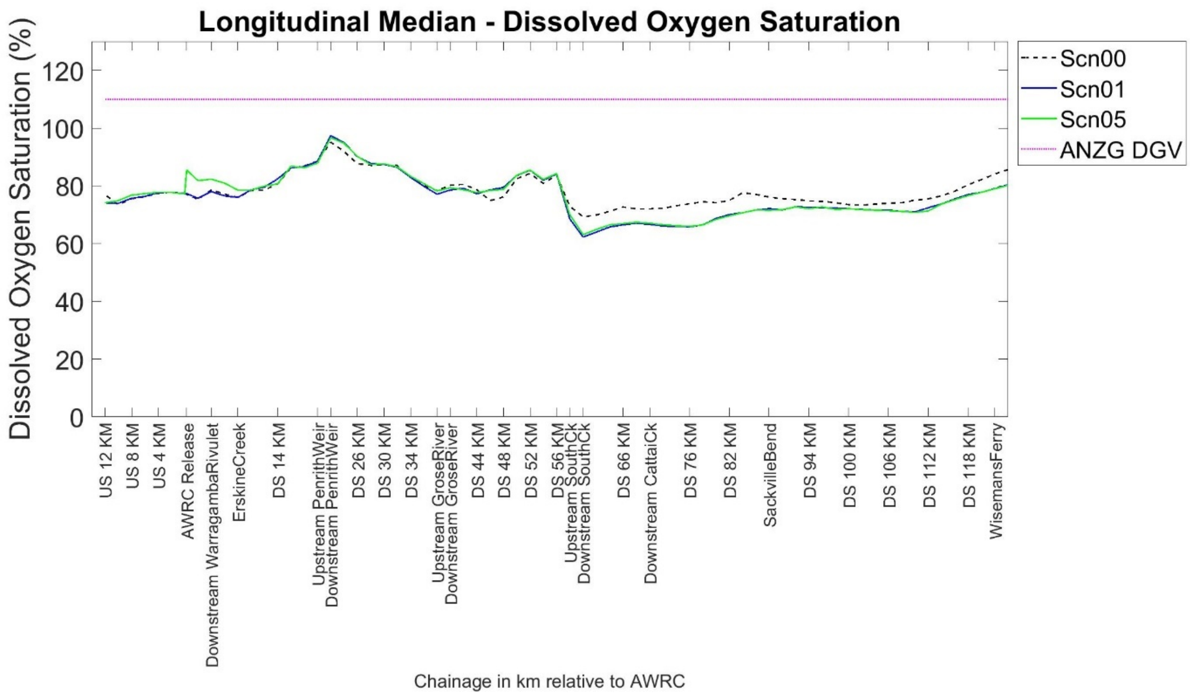


Figure 6-96 Longitudinal profile of predicted annual median DO concentrations (2036 releases/dry year)

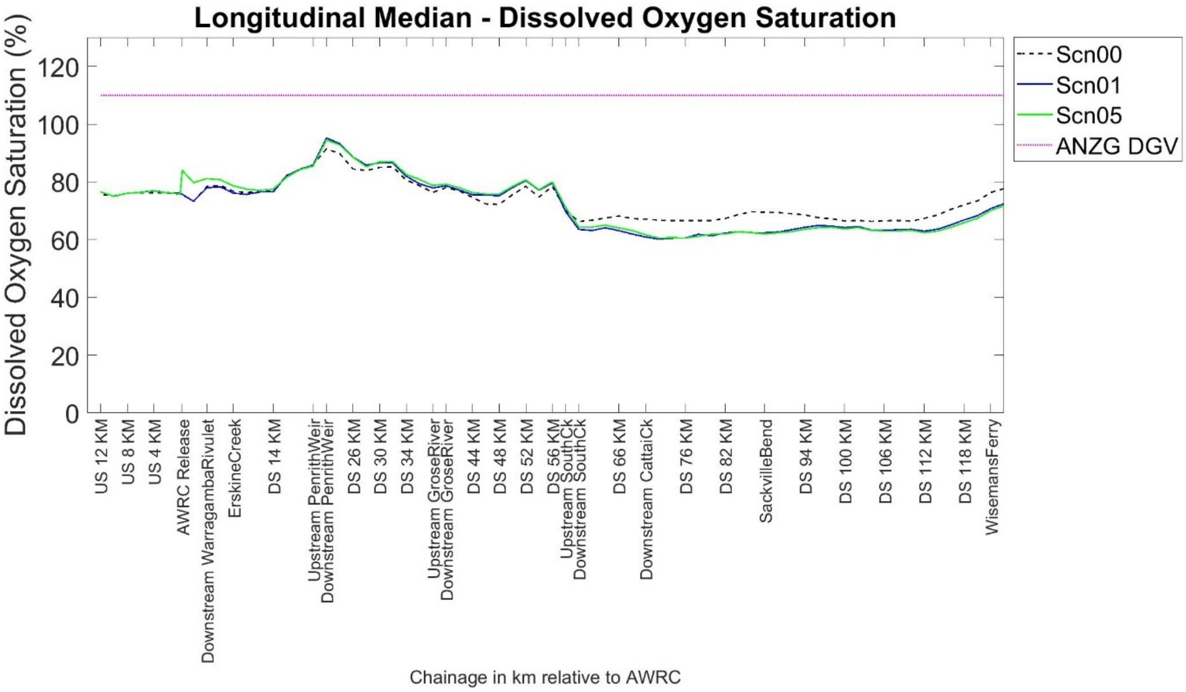


Figure 6-97 Longitudinal profile of predicted annual median DO concentrations (2036 releases/wet year)

Enterococci (primary pathogenic indicator)

- Under the impact scenario, enterococci concentrations were predicted to be marginally lower in the reaches within and downstream of Wallacia Weir (refer to Figure 6-98). Reductions were also predicted near, and downstream of the South Creek confluence. Other sites showed similar concentrations to background in terms of temporal variations and statistical distributions.
- Similar trends in enterococci were observed between the low and high loading scenarios.
- No additional impacts were predicted as a result of the shutdown of the AWRC advanced treatment process in the advanced treatment shutdown scenario.
- The NHMRC (2008) guidelines state a 95th percentile for intestinal enterococci ≤ 40 cfu/100 mL. While this is not statistically comparable to the annual median concentrations plotted in Figure 6-99 and Figure 6-100, the following comments are provided:
  - In the dry year, the longitudinal profiles of annual median enterococci concentration were predicted to be close to, or above the NHMRC (2008) guideline value downstream to Sackville Bend.
  - In the wet year, the median concentrations are above the NHMRC (2008) 95th percentile guideline value from upstream of the releases and down to Wisemans Ferry.
  - With the introduction of the AWRC releases, the potential to lower pathogenic concentrations is predicted. Therefore compliance with waterway objectives may also be aided.

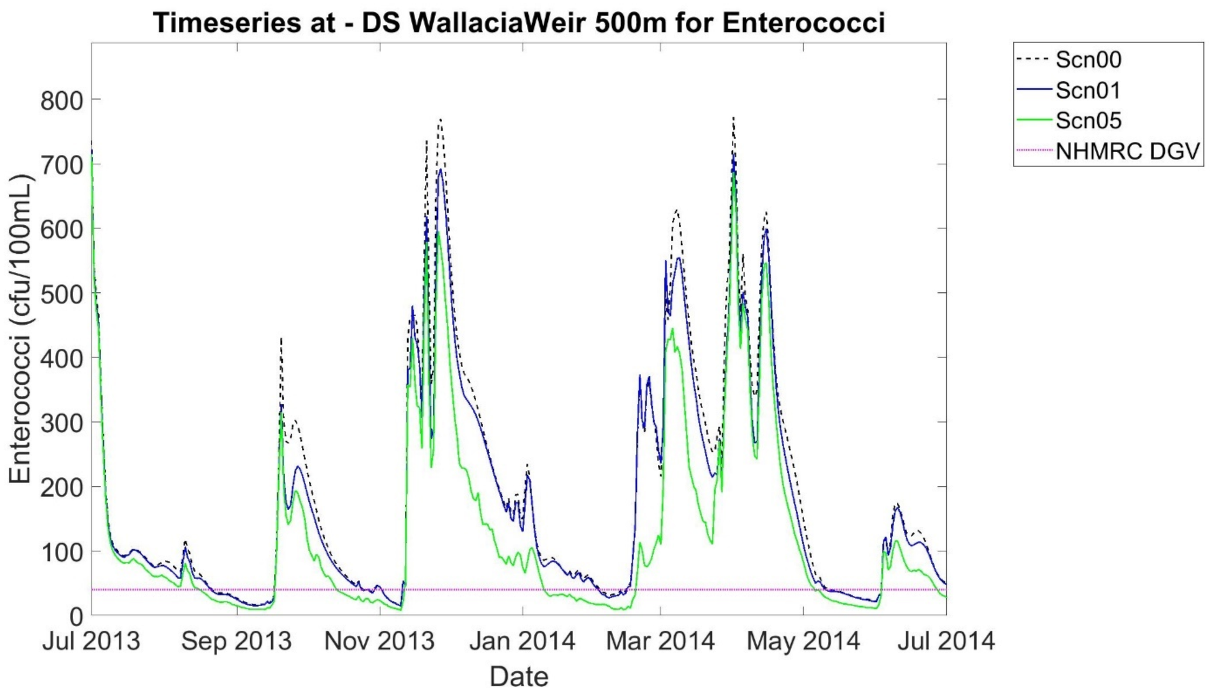


Figure 6-98 Timeseries of predicted Enterococci concentrations 500m downstream of Wallacia Weir (2036 releases/dry year)

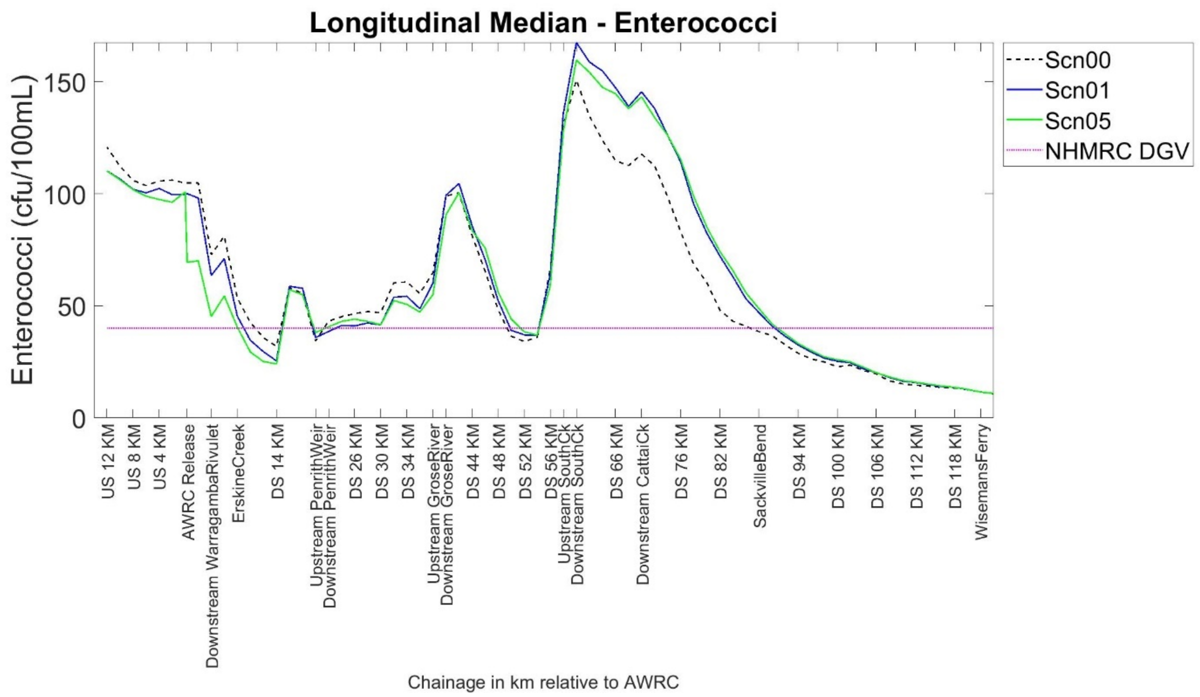


Figure 6-99 Longitudinal profile of predicted annual median Enterococci concentrations (2036 releases/dry year)

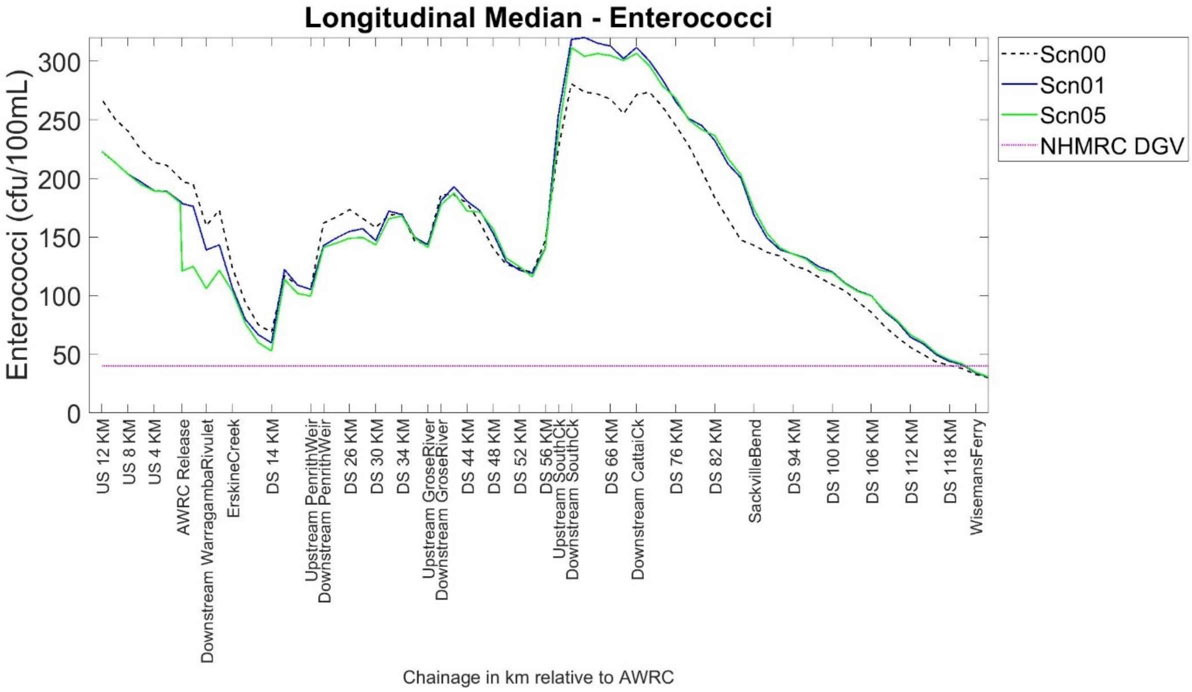


Figure 6-100 Longitudinal profile of predicted annual median Enterococci concentrations (2036 releases/wet year)

E. coli

- Similar to the trends shown for enterococci, lower concentrations of E. coli were predicted in the reaches within and downstream of Wallacia Weir. Downstream of the weir, annual median concentrations were predicted to reduce by up to 30 cfu/100mL and daily concentrations by over 200 cfu/100mL. Reductions were also predicted near, and downstream of the South Creek confluence. Similar trends were observed between the low and high loading scenarios.
- The Australian Drinking Water Guidelines (NHMRC, NRMMC 2011) state a E. coli objective of 1 cfu/100 mL. Under all scenarios, concentration throughout the river system were predicted to be significantly in excess of this objective. However, it is noted that with the introduction of the AWRC releases, the potential to lower pathogenic concentrations in the river is consistently predicted.

Cyanobacteria risk

- The risk index is derived from conditions that are considered conducive to cyanobacteria growth. Contributing factors include temperature, salinity, oxidised nitrogen, ammonia, FRP, depth and velocity. The risk is also calculated on a reach basis which includes analysis of model results across a zone or sub-zone box as discussed in Section 4.6.4.3.3.
- The timeseries results indicate minor changes but no increased risk relative to the background scenarios. Slightly warmer temperature near the AWRC release in winter can increase risk slightly at this time, but in summer when blooms are likely, the AWRC also has a cooling effect on the river water. Along with small changes to water clarity and nutrient availability there is likely to be some change to biomass, but no material change in risk.
- Figure 6-101 presents the risk timeseries for zone 3, located downstream of Wallacia Weir.

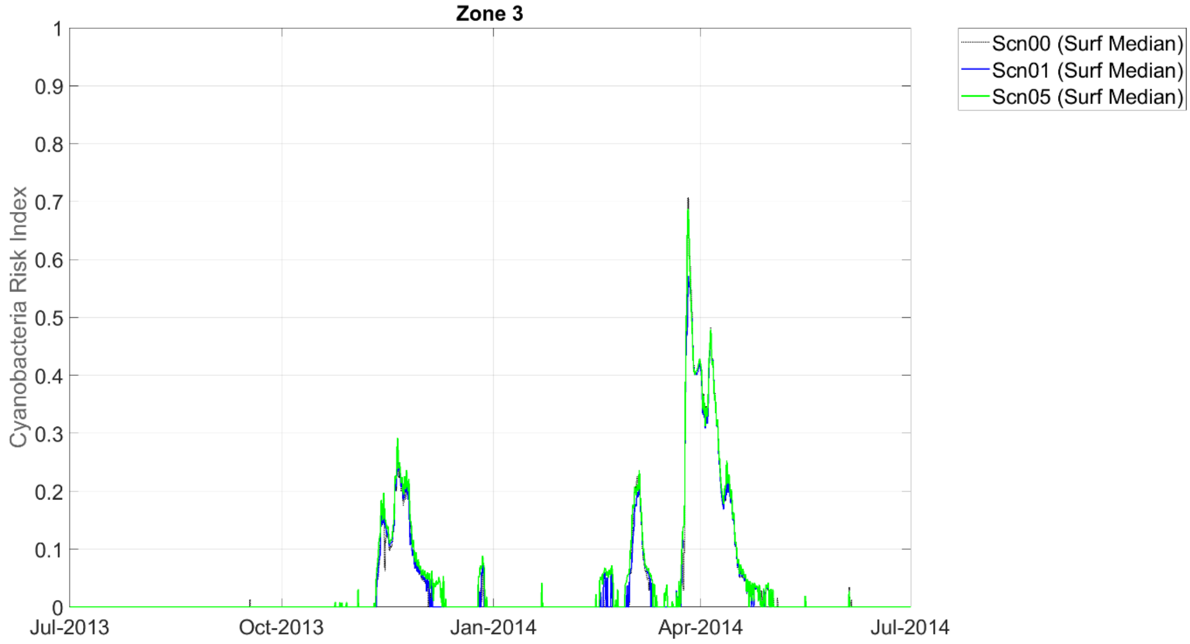


Figure 6-101 Timeseries of predicted Cyanobacteria risk indices for Zone 3 (2036 releases/dry year)

6.1.2.6 Sensitivity analysis – impact scenarios

During analysis of the WQRM scenarios, an underprediction of flows at the Wallacia Weir was identified relative to gauge data (gauge 212202). For the scenario period 2013 to 2015, it was observed that the modelled baseline and background flows deviated from the gauge data, from the 30th percentile to the tail end of the flow duration curve (refer Figure 6-102).

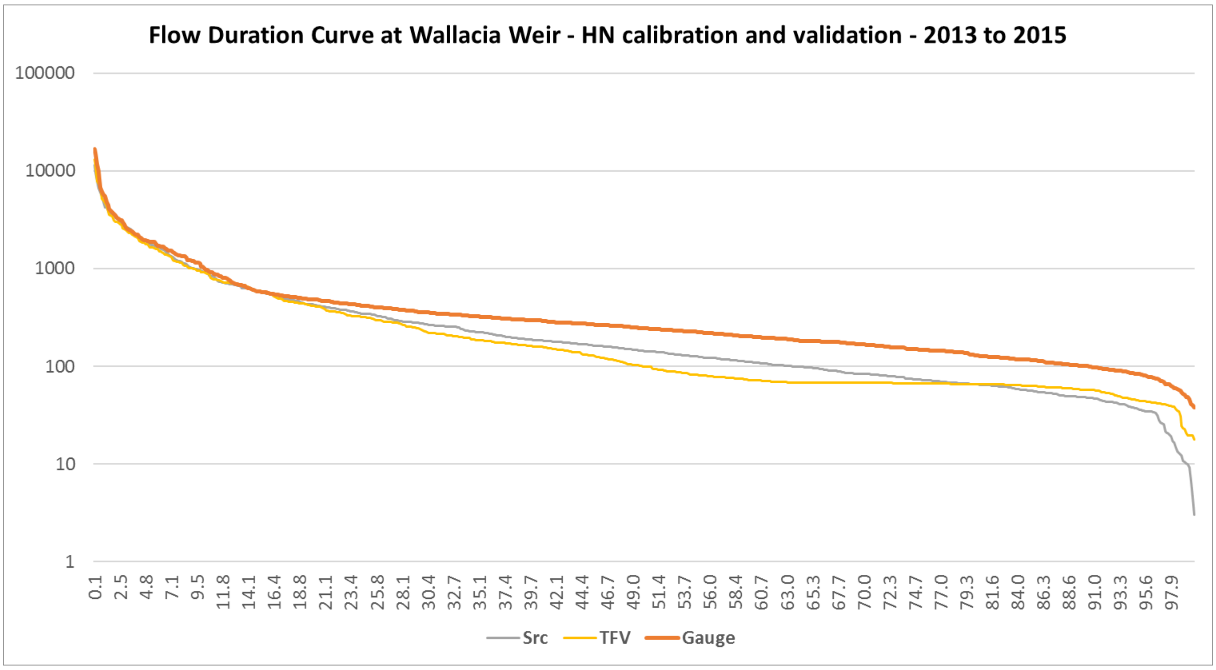


Figure 6-102 Flow duration curve at Wallacia Weir – Original scenarios HN05, HN01 and HN00

The discrepancy was assessed to be a result of an underprediction of flows from the Source catchment model which is used to generate boundary conditions for the WQRM hydrodynamic model. While calibration and validation of the Source model demonstrated close correlation with the gauge data over a 20-year simulation, the model underestimated the flow volumes, particularly base flows, for the 2013-15 scenario period.

The discrepancy in the WQRM results is also potentially exacerbated by the inclusion of extractions within the model upstream of Wallacia Weir.

To determine the effects of this underprediction on water quality, sensitivity runs were undertaken with increased flows added upstream of the Wallacia Weir pool. The approach adopted for the sensitivity analysis is discussed below.

6.1.2.6.1 Methodology

The approach adopted for the sensitivity runs included introduction of an inflow equal to the underprediction of the model to see the impacts on water quality if the modelled flows were closer to gauged data.

Firstly, a timeseries of observed gauge data and modelled flows at Wallacia weir was collated. The difference between the modelled and observed flows was calculated. Three of the Nepean River release scenarios were selected for this exercise, namely scenarios HN05, HN01 and HN00.

The additional flows were then introduced as a new inflow in the sensitivity scenarios at a point roughly 12 km upstream of the proposed release point at Wallacia Weir. The water quality input for this inflow was set to match the modelled water quality in the river at that location for the relevant scenario, thereby not changing the downstream concentration once the inflow was introduced.

The three sensitivity scenarios for this exercise were named Scenario 33 (HN33), Scenario 34 (HN34) and Scenario 35 (HN35). Where, HN33 is equivalent to HN00 from the original suite of scenarios, HN34 is equivalent to HN01, and HN35 is the equivalent of HN05. All other settings in the sensitivity scenarios were kept identical to the original scenarios with the new inflow being the only modification.

6.1.2.6.2 Results and interpretation

The implications on the flow duration curves is evident and has the desired effect on the sensitivity scenario results with a close correlation between predicted flow frequency distributions (refer Figure 6-103 and Figure 6-104) and the aforementioned gauge data.

With respect to water quality, analysis was undertaken with respect to total nitrogen and total phosphorus downstream of the Wallacia Weir. Figure 6-105 and Figure 6-106 present the dry year results for total nitrogen for the original scenarios and the sensitivity scenarios respectively. Similarly, Figure 6-107 and Figure 6-108 present the dry year results for total phosphorus, firstly for the original scenarios and then the sensitivity scenarios.

In general, the results indicate a dampening influence on the water quality impacts from the addition of the inflows. This is expected to be a result of additional dilution and dispersion arising from higher volumes of flow in the receiving waters. Of particular note is the reduction in the wet weather spikes in phosphorus that were identified in Section 6.1.2.5.3. This is also shown in the time series results for the wet year (refer Figure 6-109 and Figure 6-110).

Based on the sensitivity analysis, it is concluded that the WQRM results for the original scenarios can be considered as conservative and potentially over predicting the impacts of the AWRC releases.

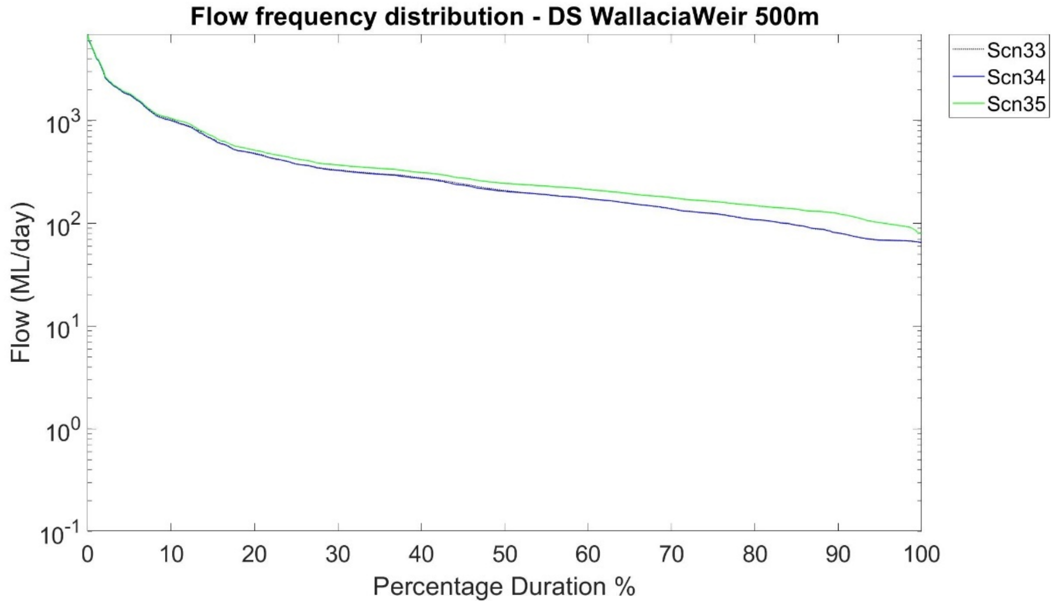


Figure 6-103 Flow duration curve downstream of Wallacia Weir – Sensitivity scenarios HN35, HN34 and HN33 (Dry year)

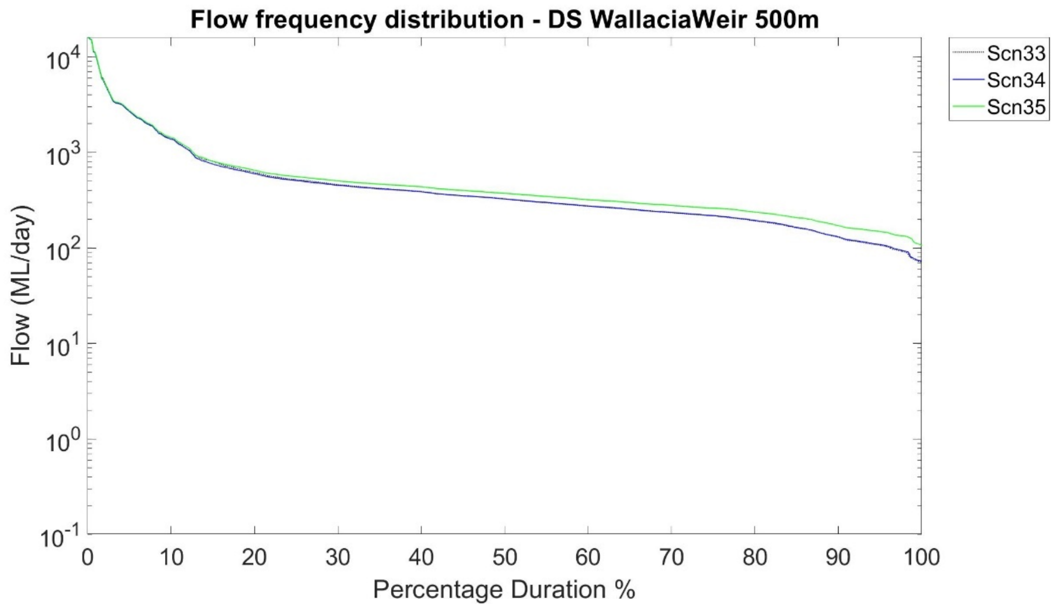


Figure 6-104 Flow duration curve downstream of Wallacia Weir – Sensitivity scenarios HN35, HN34 and HN33 (Wet year)

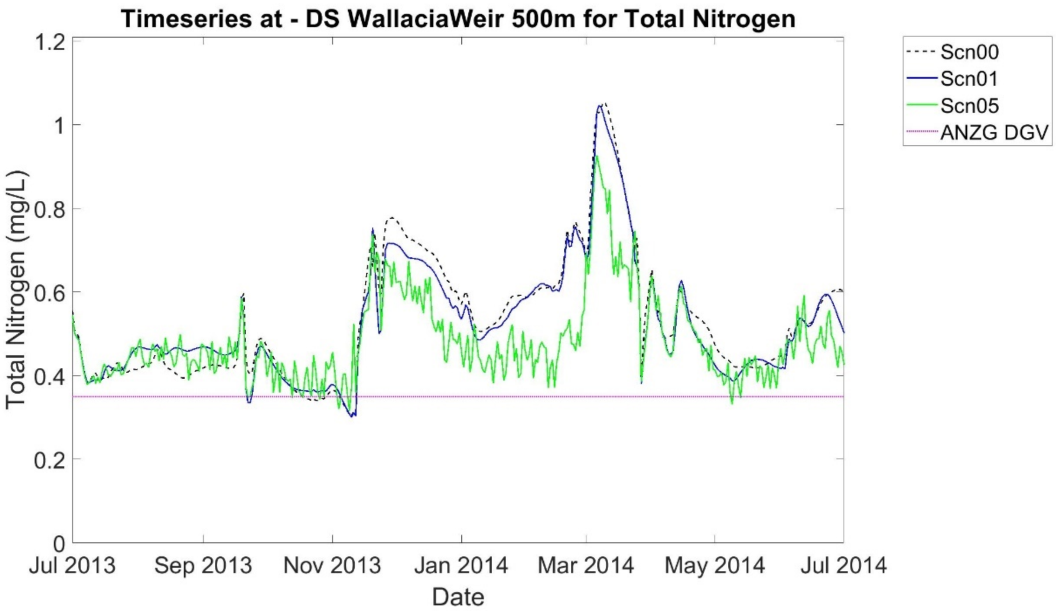


Figure 6-105 Timeseries of predicted Total Nitrogen concentrations 500m downstream of Wallacia Weir (2036 releases/dry year) - Original scenarios HN05, HN01 and HN00

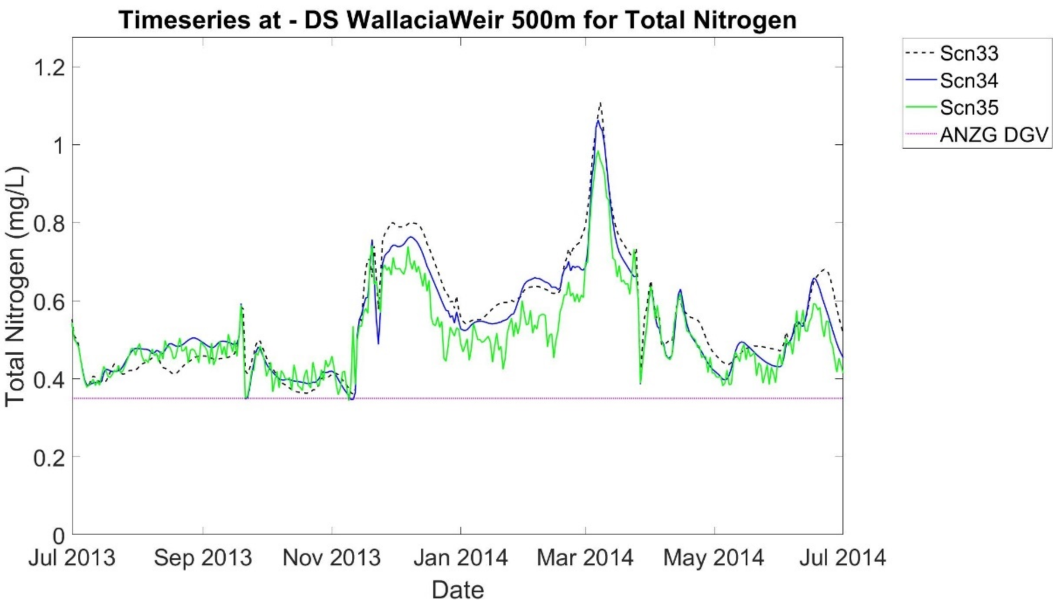


Figure 6-106 Timeseries of predicted Total Nitrogen concentrations 500m downstream of Wallacia Weir (2036 releases/dry year) - Sensitivity scenarios HN35, HN34 and HN33

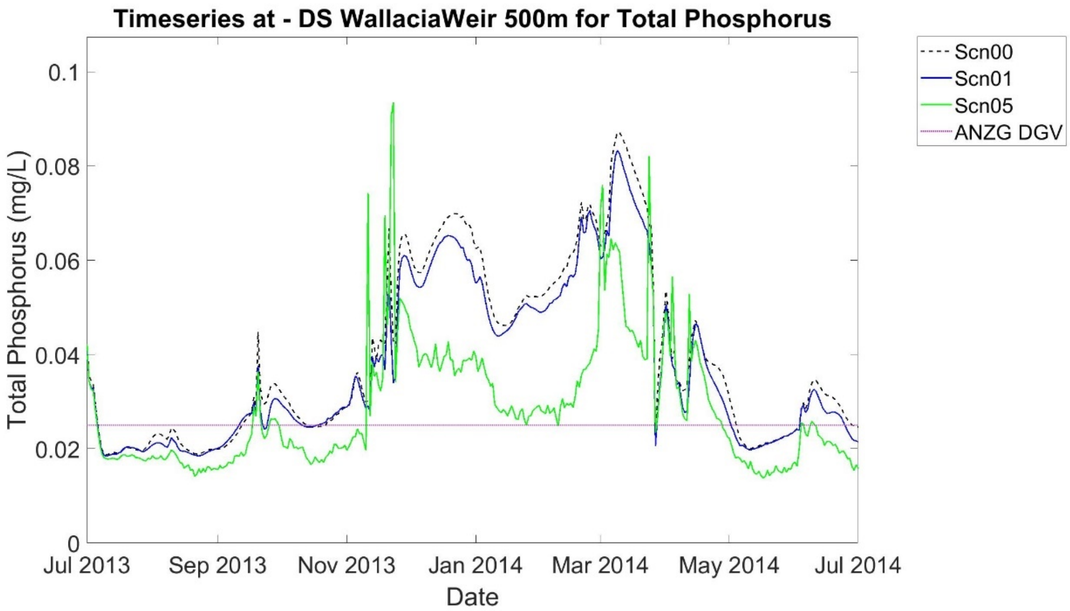


Figure 6-107 Timeseries of predicted Total Phosphorus concentrations 500m downstream of Wallacia Weir (2036 releases/dry year) - Original scenarios HN05, HN01 and HN00

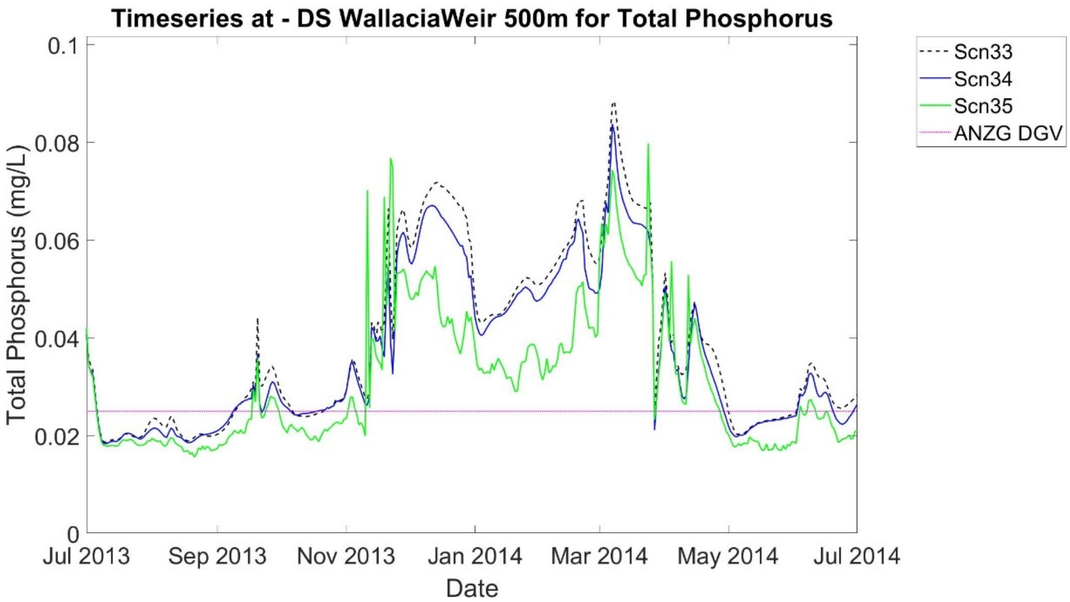


Figure 6-108 Timeseries of predicted Total Phosphorus concentrations 500m downstream of Wallacia Weir (2036 releases/dry year) - Sensitivity scenarios HN35, HN34 and HN33

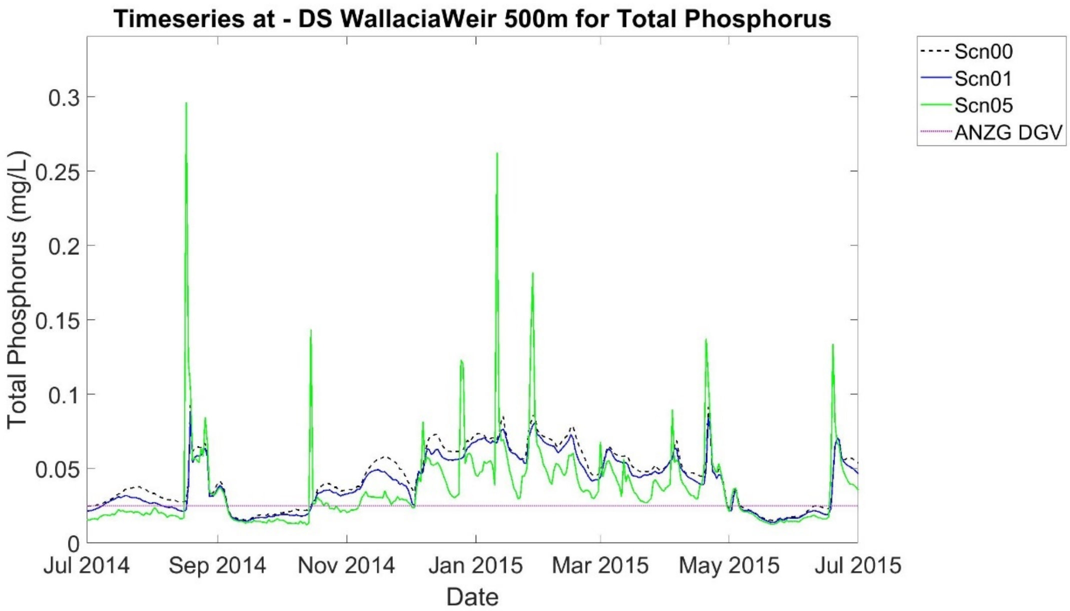


Figure 6-109 Timeseries of predicted Total Phosphorus concentrations 500m downstream of Wallacia Weir (2036 releases/wet year) - Original scenarios HN05, HN01 and HN00

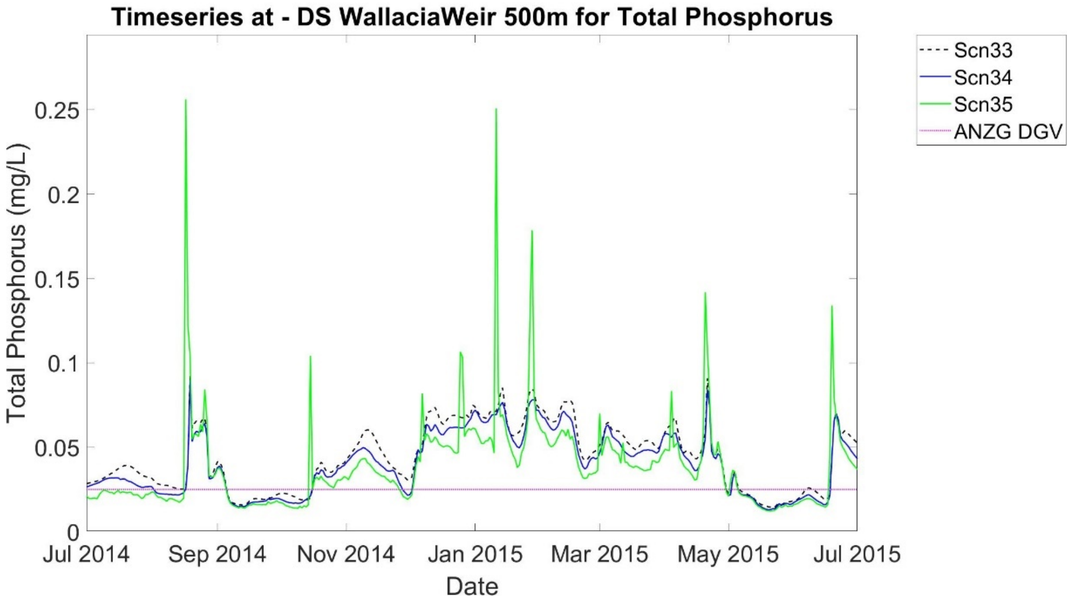


Figure 6-110 Timeseries of predicted Total Phosphorus concentrations 500m downstream of Wallacia Weir (2036 releases/wet year) - Sensitivity scenarios HN35, HN34 and HN33

6.1.3 Nepean River and Warragamba River releases

6.1.3.1 Scenario conditions

As discussed in previous sections, the results from each AWRC impact scenario are plotted against a corresponding background scenario as well as a baseline scenario. This approach allows for analysis of the impacts from the AWRC releases on their own, in relation to the catchment conditions that are expected for the selected time horizon, and also relative to current conditions. Further details regarding these scenario types are provided in Section 4.6.3.

Table 6-3 presents a summary of the key conditions relating to the South Creek release scenarios. Further details relating to these impact scenarios, and also the relevant background and baseline scenarios, can be found in Section 4.6.3.

Table 6-3 Summary of scenario conditions - Nepean River and Warragamba River release scenarios

Scenario number	Time horizon	AWRC capacity (ML/d)	Treatment plant loading	Relevant background scenario
HN13	2036	50	Low loading	HN01
HN14	2056	100	Low loading	HN02
HN15	2036	50	High loading	HN03
HN16	2056	100	High loading	HN04

6.1.3.2 Load analysis

Analysis of total nitrogen and total phosphorus loads flowing to the Hawkesbury Nepean River has been undertaken for the Nepean River and Warragamba River release impact scenarios. Due to the similarities in the scenario conditions, the cumulative analyses are comparable to those presented in Section 6.1.2.2 and have therefore not been repeated. The only difference in the analyses being the splitting of AWRC loads to the Warragamba River and Nepean River (refer Figures 6-111 to 6-114).

The load contributions from the AWRC also remain as per the analysis presented in Section 6.1.2.2.

Further information regarding expected future nutrient loads, and how these address the requirements of the EPA's regulatory framework to manage nutrient load inputs are presented in Section 6.3.3.

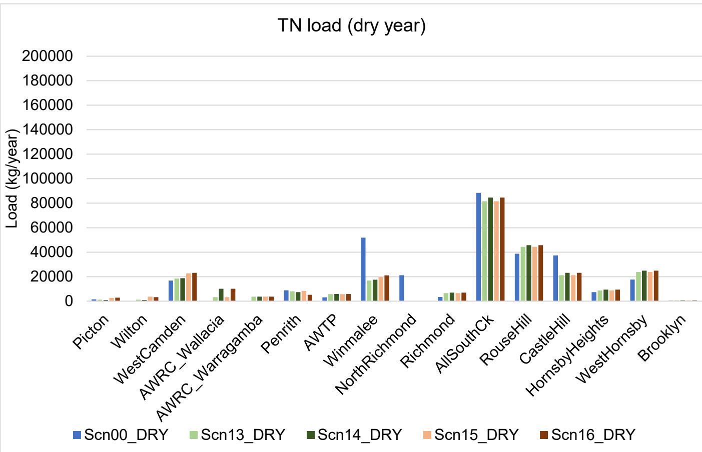


Figure 6-111 Hawkesbury Nepean Total Nitrogen WWTP/WRP loads (dry year)

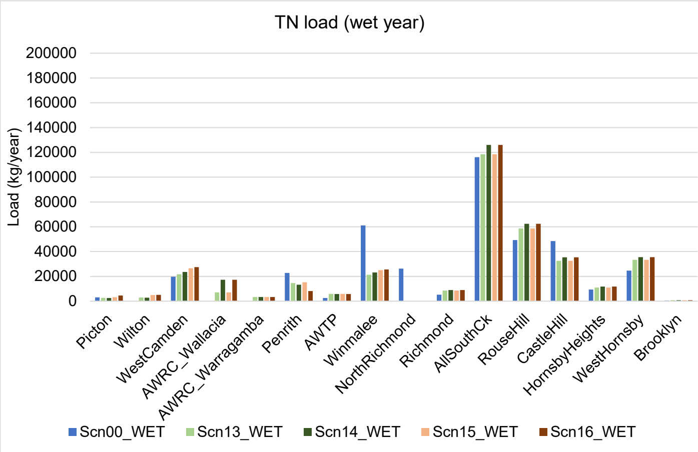


Figure 6-112 Hawkesbury Nepean Total Nitrogen WWTP/WRP loads (wet year)

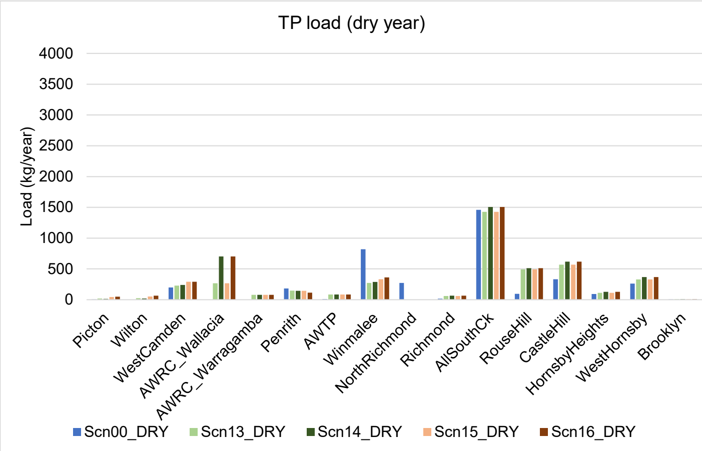


Figure 6-113 Hawkesbury Nepean Total Phosphorus WWTP/WRP loads (dry year)

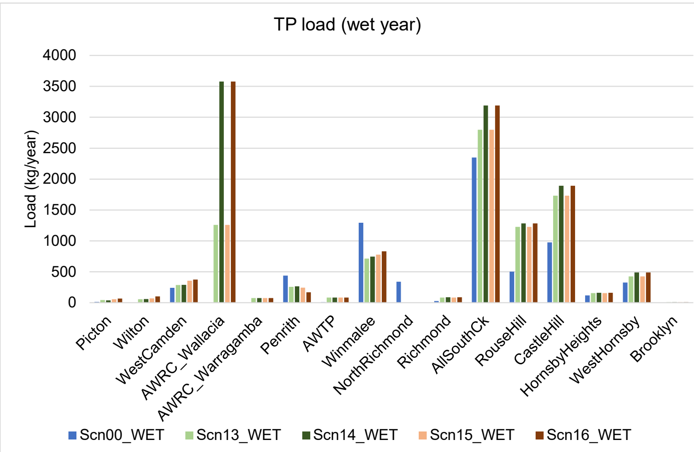


Figure 6-114 Hawkesbury Nepean Total Phosphorus WWTP/WRP loads (wet year)

6.1.3.3 Scenario results

For brevity, a selection of relevant scenario results has been included in the following sections to aid interpretation.

A full set of results for scenario HN13 (2036 AWRC releases/low WWTP loading) has also been included in Appendix C3 for reference. Scenario HN13 was considered to be representative of the potential impacts for Stage 1 operation of the AWRC project.

Results for the other scenarios can be supplied by Sydney Water upon request.

6.1.3.4 Interpretation – background scenarios

The following general comments are provided with respect to the results from the background scenarios (future catchment conditions) relative to the baseline scenario (current conditions):

- Water quality in the Warragamba River is heavily influenced by the dam releases and releases from the Wallacia WWTP. Similar to the Nepean River, forecast population growth in the catchment is predicted to result in changes to water quality.
- Under 2036 conditions, the modelling identified that the most significant impacts on water quality in the Warragamba River related to nutrients and pathogens. Concentrations were predicted to increase measurably across all indicators relevant to these two water quality groups, principally as a result of forecast increases in concentrations and loads from the Wallacia WWTP.
- With respect to conditions within the Nepean River, please refer to Section 6.1.2.4 as the findings from the background scenarios are consistent with the Nepean release scenarios.

6.1.3.5 Interpretation – impact scenarios

For the purposes of this assessment, the interpretation has focussed on relative impacts between the Nepean River and Warragamba River release scenario (HN13) relative to the corresponding background scenario (HN01). Also, where applicable, comparisons are made against the Nepean River release scenario (HN05). Both scenarios HN05 and HN13 are representative of 2036 conditions with Stage 1 of the AWRC operational (50 ML/d), and with low loading from the upstream WWTPs/WRPs.

6.1.3.5.1 General

The following general comments are provided with respect to the results from the Upper South Creek AWRC impact scenarios relative to corresponding background conditions (circa 2036 and 2056):

- The Nepean River and Warragamba River release scenarios effectively split the flows from the AWRC between release points in the Nepean and Warragamba rivers, with the Warragamba releases effectively replicating the current WaterNSW Warragamba Dam release regime, and only consisting of advanced treated water. In circumstances when advanced treated water from the AWRC is unavailable, releases from the Warragamba Dam would be reinstated to maintain the required level of releases to the river. Residual flows of AWRC treated water are released into the Wallacia Weir pool as per the Nepean release scenarios.
- It could be assumed that the impacts from this “flow splitting” would only be seen upstream of the confluence of the Warragamba and Nepean rivers. However, due to the complexity of the river system and the presence of the flow retaining structures, this is not the case as discussed below:

- The impacts from the Nepean River and Warragamba River release scenarios were generally greatest near the proposed release points in the two rivers. However, minor differences in the water quality at other sites in the Nepean River were also observed against the comparable Nepean release scenario. While these differences were predicted to be smaller in magnitude, this indicates the change in release configuration may also change the fate and effect of pollutants and processes further downstream.
- There are several weir structures around the region of the AWRC releases. These structures will affect the water retention and flushing within the river, and changes in the release regime will also affect how water is controlled by these structures. For example, at the site upstream of Wallacia Weir, the water level significantly decreased in HN13 in the period January to March 2014 (refer to Figure 6-115 and Figure 6-116 below). When the water level was lower than the weir height, the residual AWRC releases were retained and therefore the flushing effects to downstream was reduced.

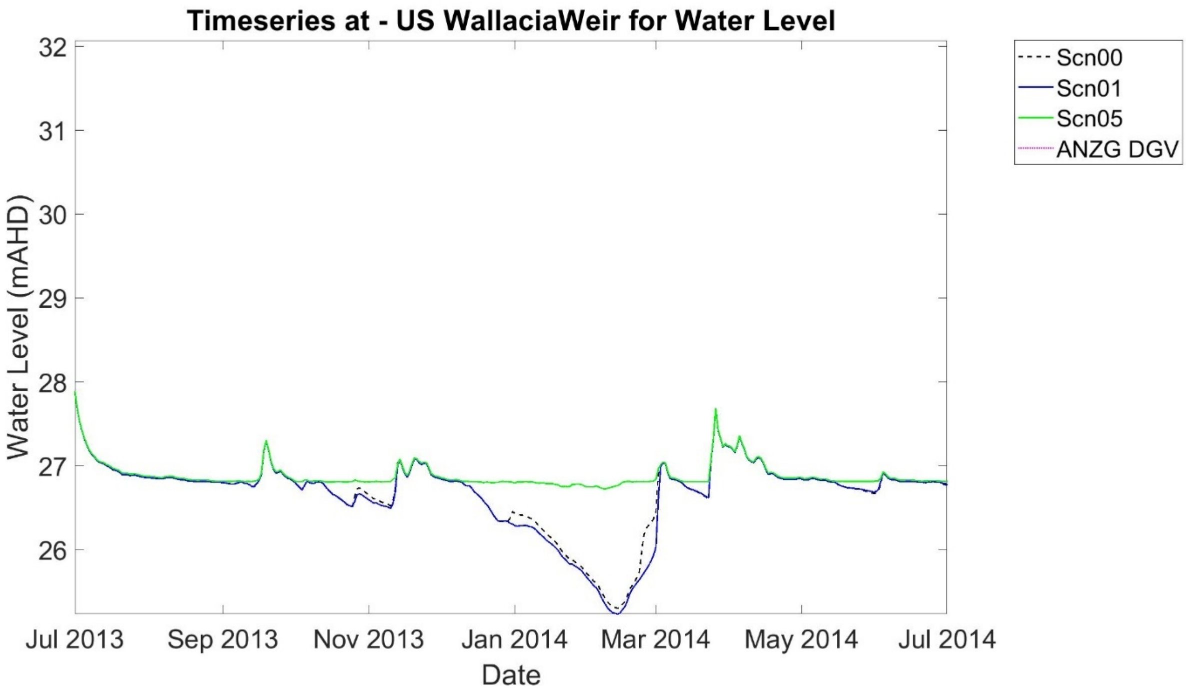


Figure 6-115 Timeseries of predicted water level in Wallacia Weir pool for a Nepean release scenario (2036/dry year)

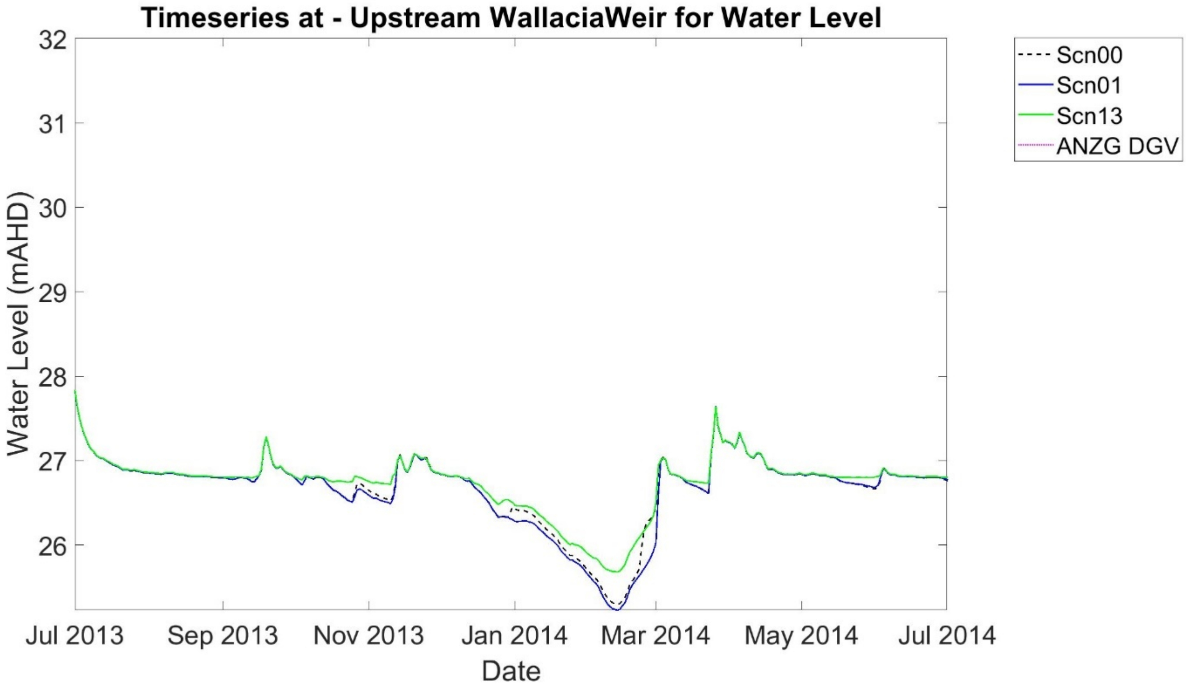


Figure 6-116 Timeseries of predicted water level in Wallacia Weir pool for Nepean River and Warragamba River release scenario HN05 (2036/dry year)

6.1.3.5.2 Hydrodynamics

As discussed above, the introduction of releases to the Warragamba River has an influence on the flows into, and from the Wallacia Weir pool. Figures 6-117 to 6-120 present the timeseries of predicted flow downstream of Wallacia Weir for the dry year and wet year respectively.

Under the assumed 2036 Stage 1 conditions, the flows are significantly reduced relative to the Nepean River release scenarios. In contrast to the Nepean release scenarios, the results in Figure 6-116 indicate there will be periods, under dry weather conditions, where the water level will drop below the weir level.

Consequently, in the dry year, the predicted median flows downstream of the weir reduce by ~20% relative to the Nepean release scenarios, and in the wet year, the median flows reduce by ~10%.

Further downstream, the changes in flow regime are still predicted but to a lesser degree. Figure 6-121 and Figure 6-122 present the predicted flows downstream of the Penrith Weir for the impact scenario (HN13) and the background scenario (HN01).

Looking ahead at the 2056 Nepean River and Warragamba River release scenario (HN06), the increase in residual flows to the Wallacia release point allows for the water levels in the weir pool to again retain the level of the weir wall.

With respect to the flow conditions in the Warragamba River, these are assumed to be largely unmodified as the AWRC releases effectively replace the existing WaterNSW release regime from the Warragamba Dam. On the infrequent occasions when advanced treated water is unavailable from the AWRC, it is simulated that the releases from the dam would be temporarily reinstated.

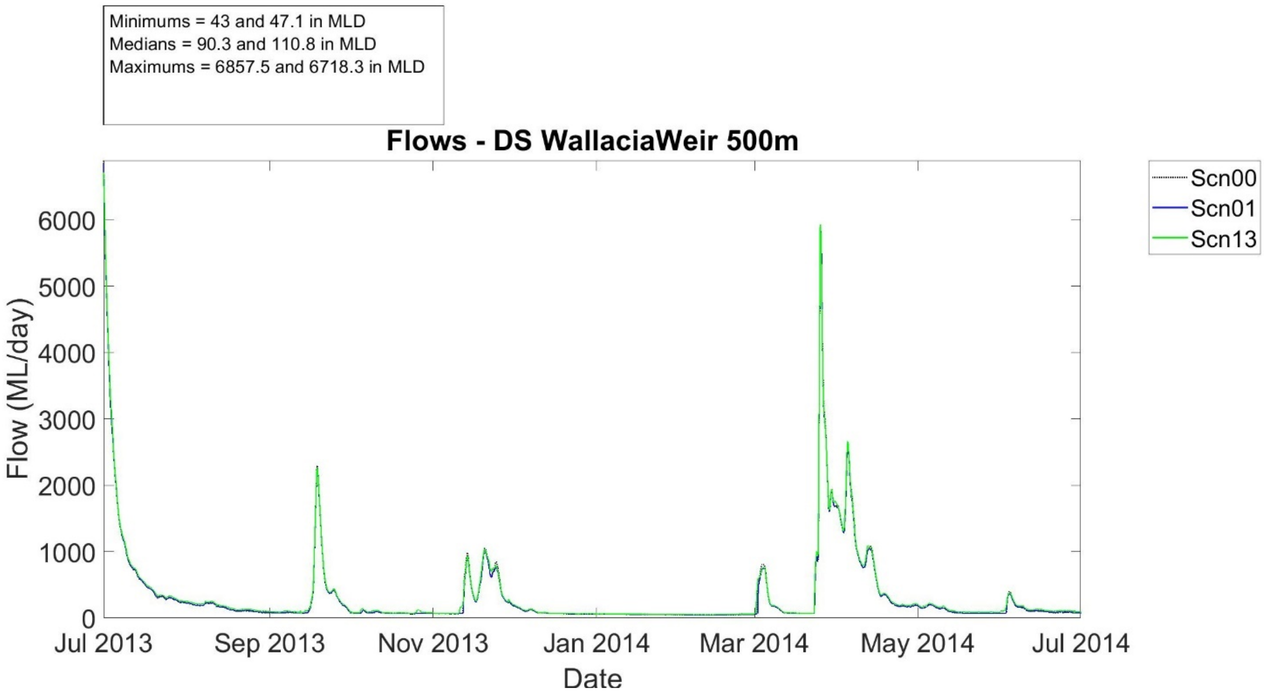


Figure 6-117 Timeseries of predicted river flow 500m downstream of Wallacia Weir (2036 releases/dry year)

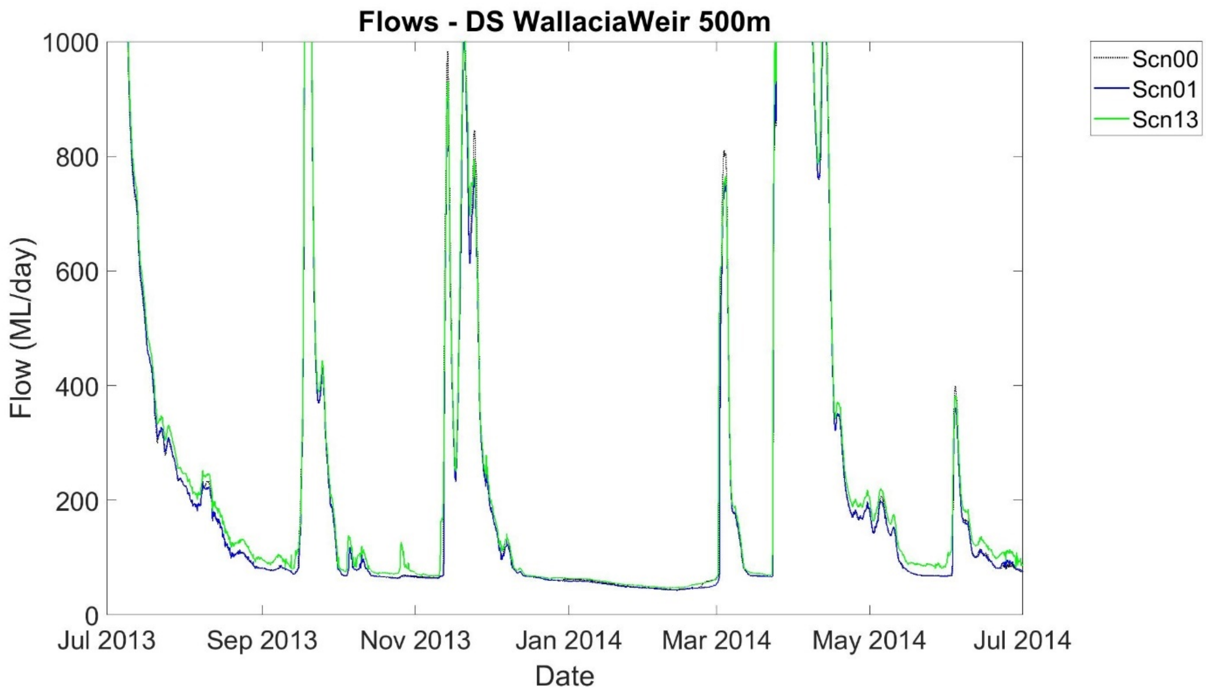


Figure 6-118 Timeseries of predicted river flow 500m downstream of Wallacia Weir (2036 releases/dry year/base flows)

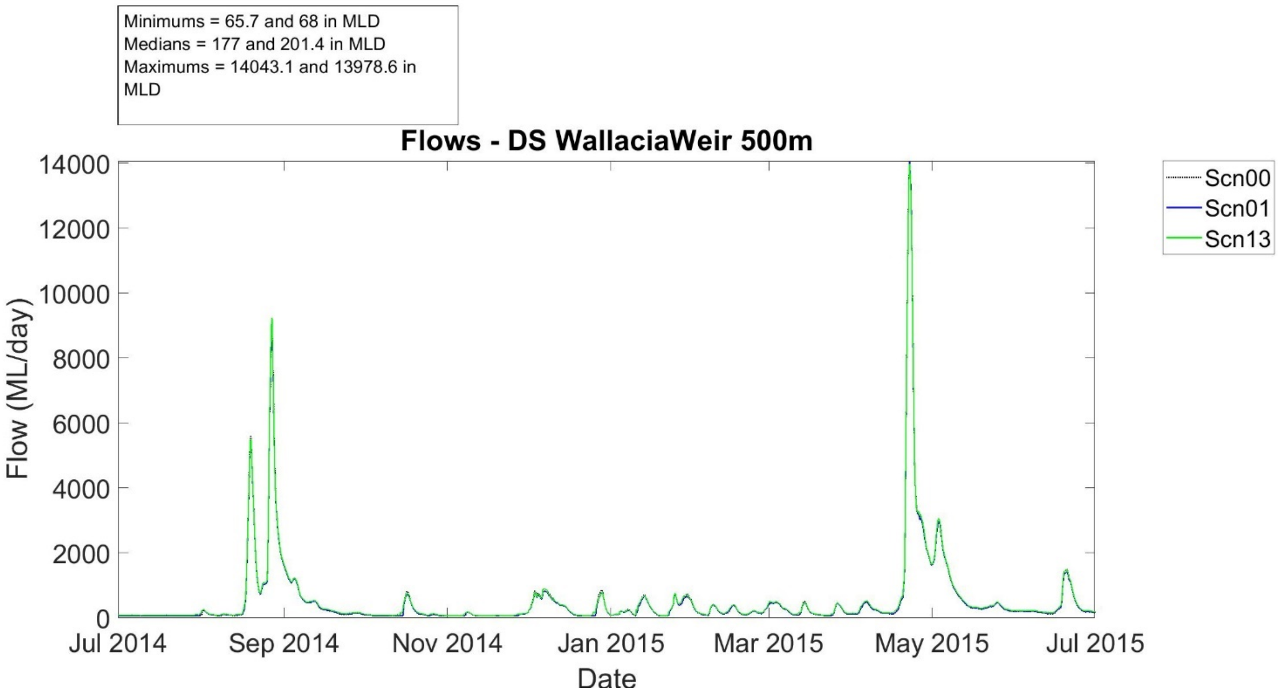


Figure 6-119 Timeseries of predicted river flow 500m downstream of Wallacia Weir (2036 releases/wet year)

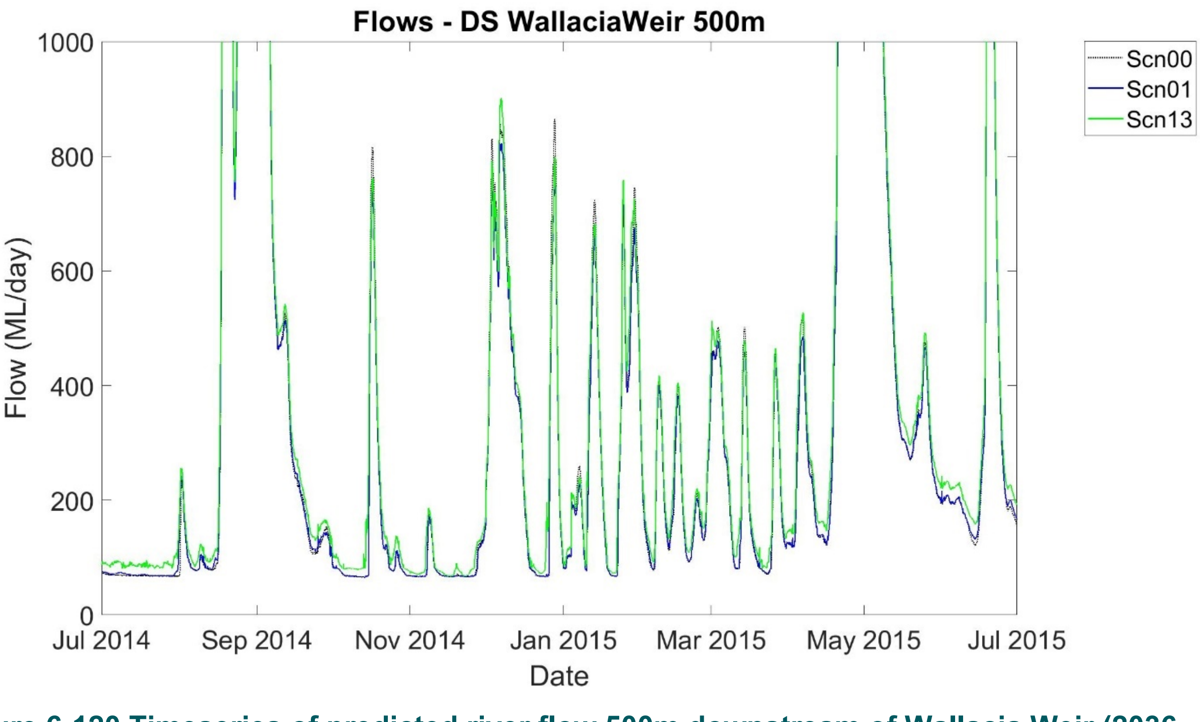


Figure 6-120 Timeseries of predicted river flow 500m downstream of Wallacia Weir (2036 releases/wet year/base flows)

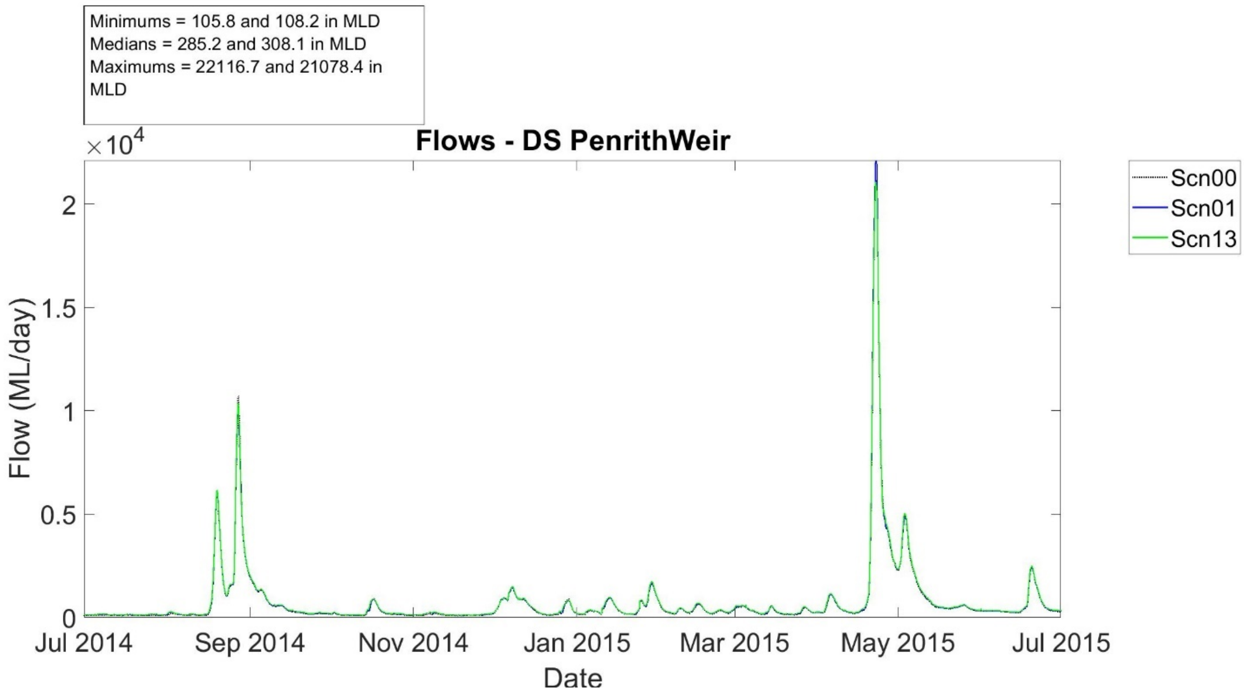


Figure 6-121 Timeseries of predicted river flow downstream of Penrith Weir (2036 releases/wet year)

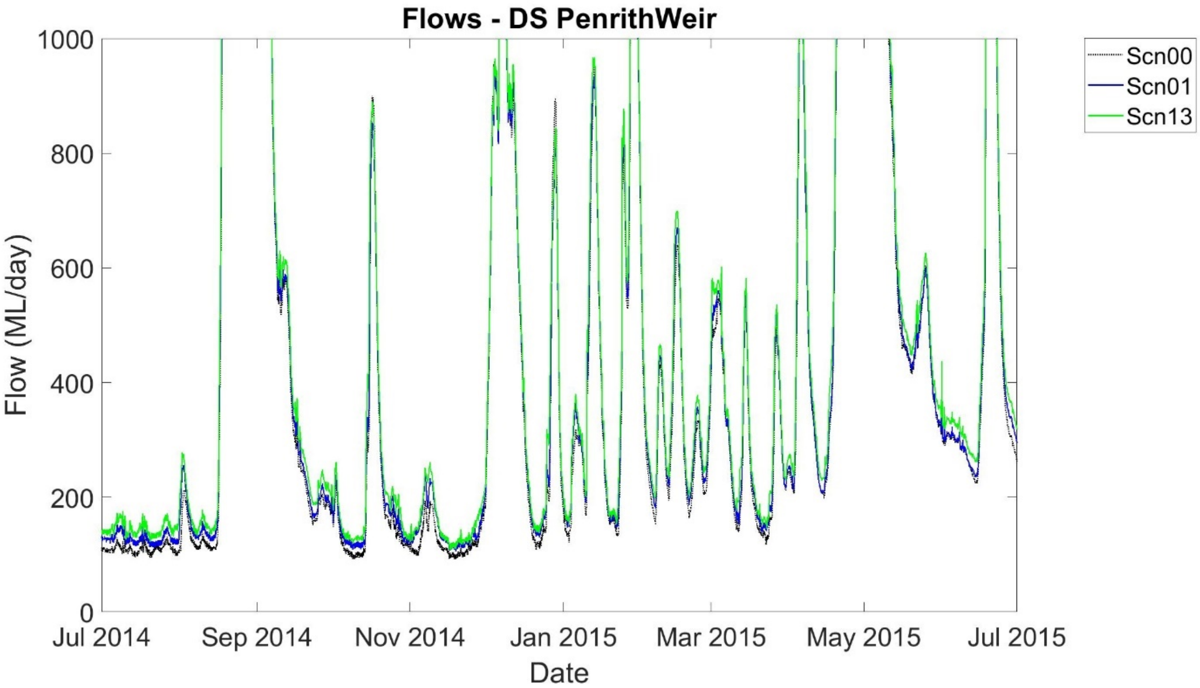


Figure 6-122 Timeseries of predicted river flow downstream of Penrith Weir (2036 releases/wet year/base flows)

6.1.3.5.3 Water quality

The following sub-sections present findings of the predicted impacts on water quality from the AWRC releases, relative to the corresponding background conditions (circa 2036 and 2056).

Nitrogen

- Minor changes to the total nitrogen response were predicted in the Warragamba River downstream of the AWRC release point, although the general magnitude remained similar, or marginally reduced relative to the background conditions. The speciation of the nitrogen downstream of the releases was predicted to be modified with more bioavailable forms (ammonia and oxidised nitrogen) relative to the background conditions. Figure 6-123 and Figure 6-124 present timeseries results for total nitrogen for the dry year and wet year respectively.
- Similarly, immediately downstream of the confluence of the two rivers, the nitrogen signal remained relatively consistent to the background conditions. Some minor spikes are predicted due to the wet weather release conditions from the AWRC that include some tertiary treated water. The speciation of the nitrogen was again predicted to be modified relative to the background due to the AWRC releases. Figure 6-125 and Figure 6-126 present timeseries results for total nitrogen for the dry year and wet year.
- With respect to annual median concentrations, the profiles remained generally similar to the Nepean release scenarios (refer to Figure 6-127, Figure 6-128 and Figure 6-129 for the wet year profiles for ammonia, oxidised nitrogen and total nitrogen). The following comments are therefore consistent with the Nepean release scenarios.
  - Treated water releases from the AWRC assisted in reducing total nitrogen concentration in the vicinity of their releases, but the annual median concentrations remained above the project waterway objective as per the background scenario.
  - For the more bioavailable forms, annual median concentrations of ammonia were predicted to have a higher level of compliance. Conversely, zero compliance was predicted for oxidised nitrogen. Importantly, the introduction of the AWRC releases did not affect the general level of compliance predicted for any of the nitrogen indicators.

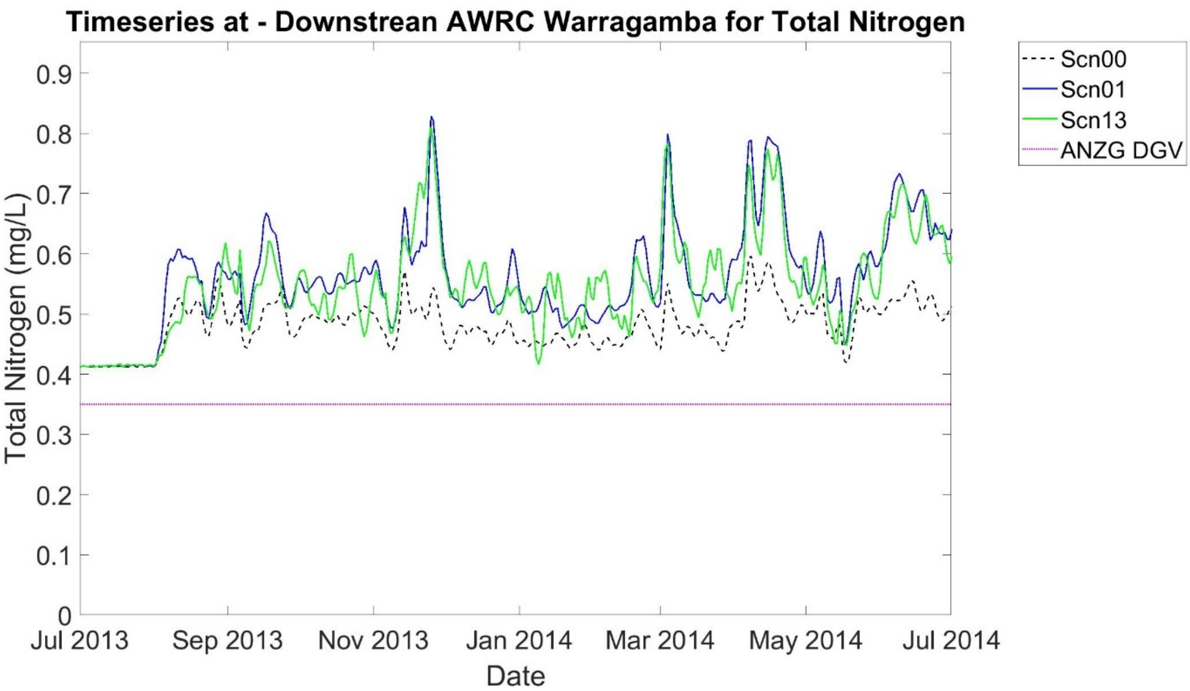


Figure 6-123 Timeseries of predicted Total Nitrogen concentrations downstream of the AWRC Warragamba release point (2036 releases/dry year)

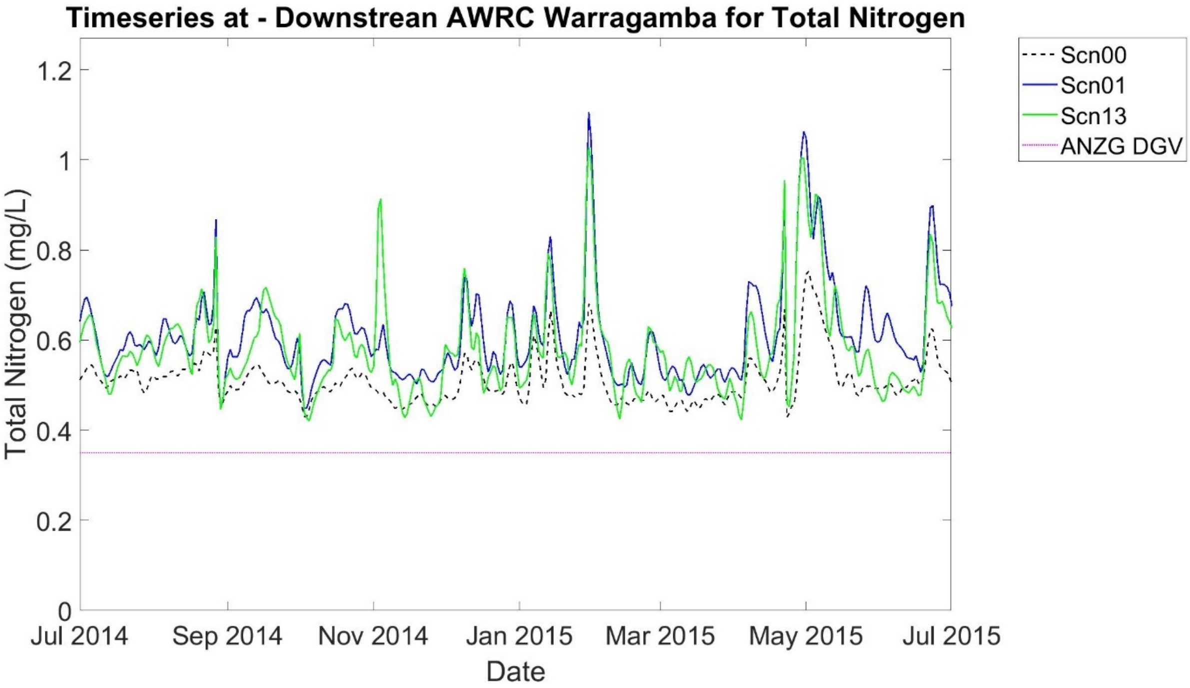


Figure 6-124 Timeseries of predicted Total Nitrogen concentrations downstream of the AWRC Warragamba release point (2036 releases/wet year)

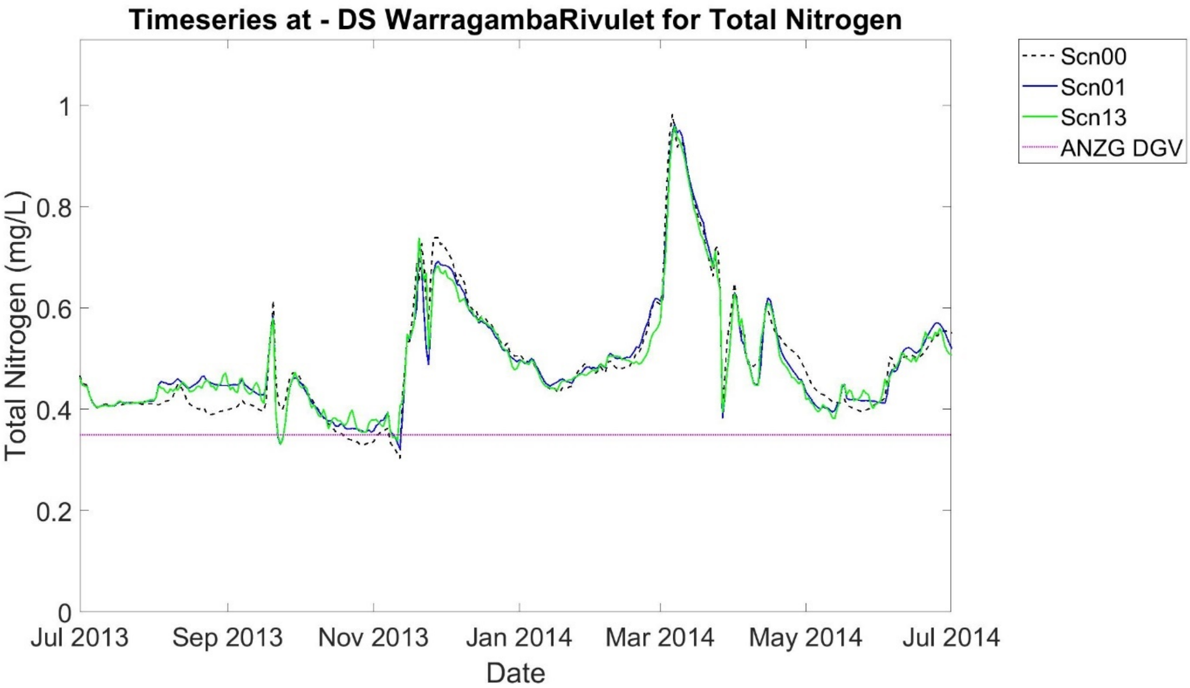


Figure 6-125 Timeseries of predicted Total Nitrogen concentrations downstream of the Warragamba River confluence (2036 releases/dry year)

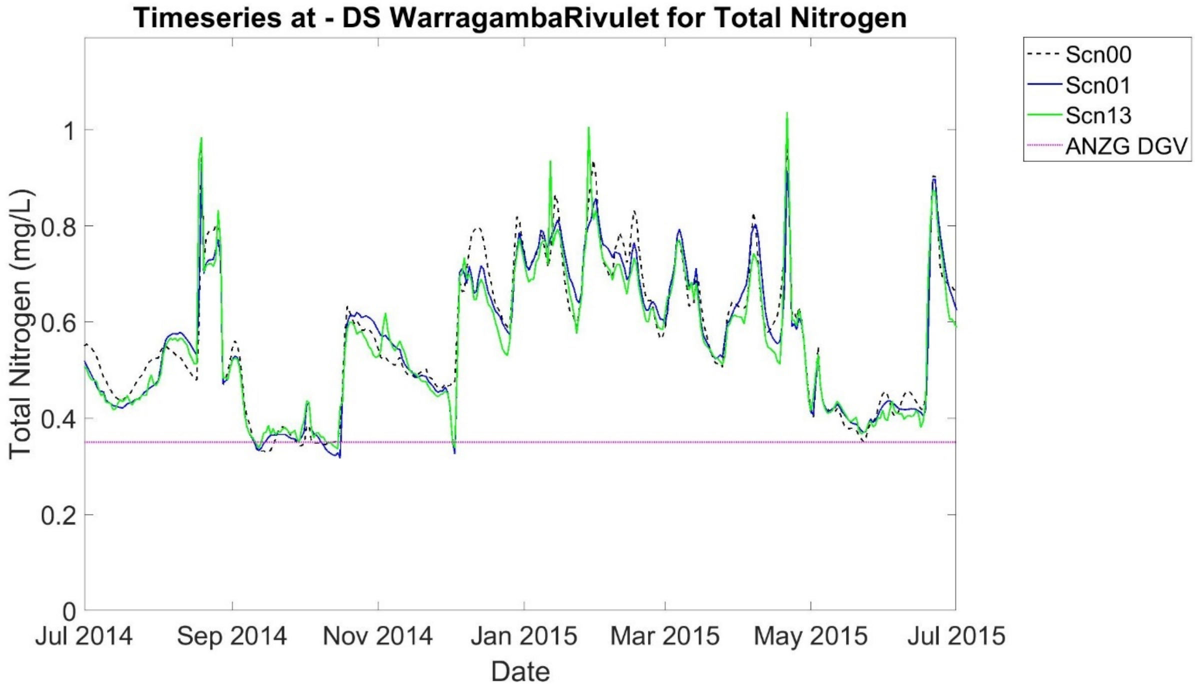


Figure 6-126 Timeseries of predicted Total Nitrogen concentrations downstream of the Warragamba River confluence (2036 releases/dry year)

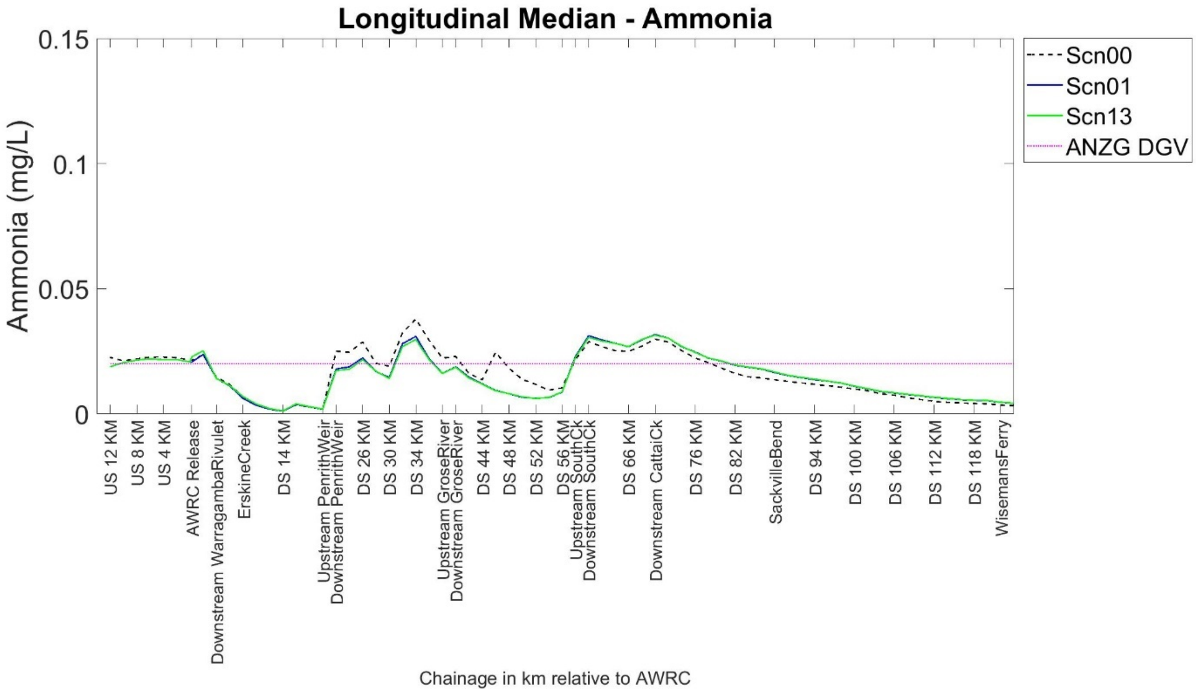


Figure 6-127 Longitudinal profile of predicted annual median Ammonia concentrations (2036 releases/wet year)

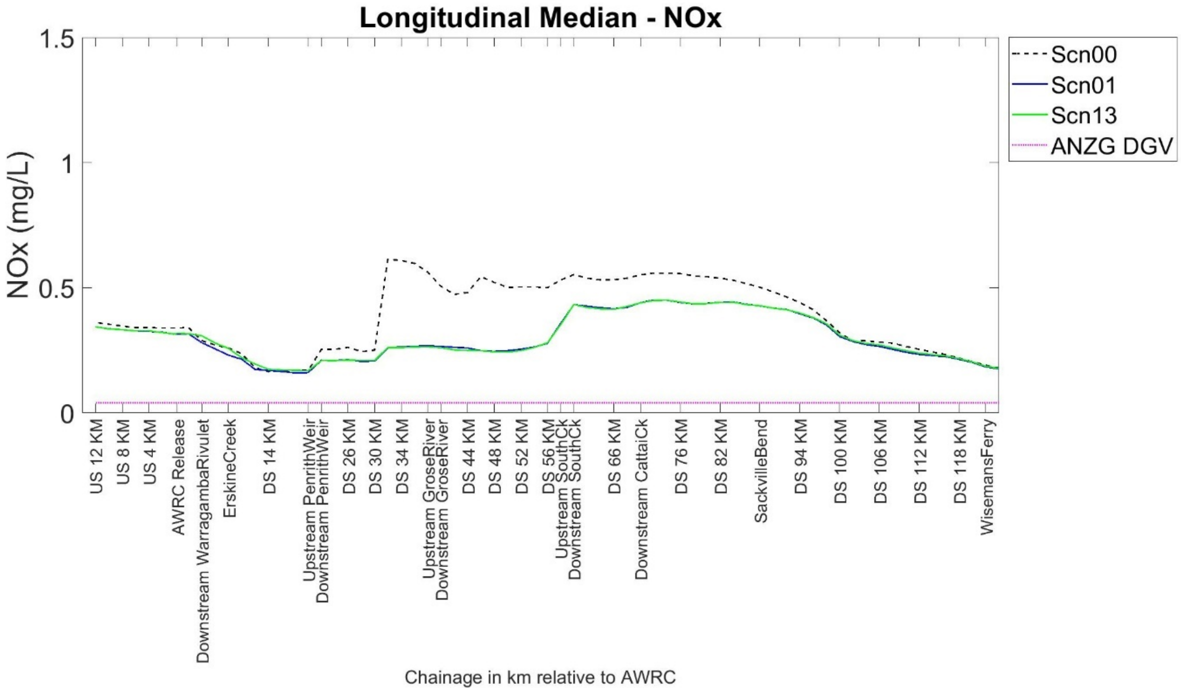


Figure 6-128 Longitudinal profile of predicted annual median Oxidised Nitrogen concentrations (2036 releases/wet year)

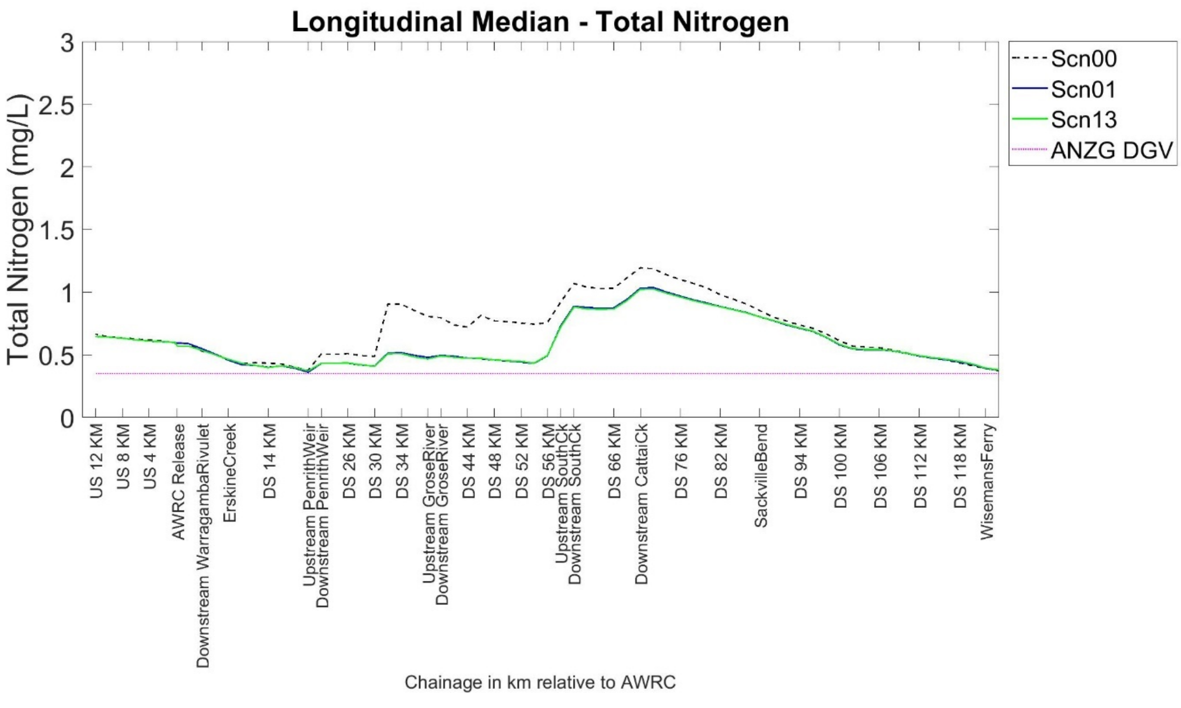


Figure 6-129 Longitudinal profile of predicted annual median Total Nitrogen concentrations (2036 releases/wet year)

Phosphorus

- In line with the findings for nitrogen, changes to the phosphorus profile are predicted downstream of the AWRC releases in the Warragamba River. Increases in concentrations of total phosphorus are predicted along with increased levels of FRP due to the introduction of the advanced treated water. As the AWRC releases are predicted to be relatively consistent (refer Section 4.6.3.5.1), the relatively minor fluctuations shown throughout the year in the concentrations for both parameters are a result of other influences such as localised catchment inflows, releases from the Wallacia WWTP as well as infrequent releases from the Warragamba Dam. Figure 6-130 and Figure 6-131 present timeseries results for FRP and total phosphorus respectively for the wet year analysis.
- Figure 6-132 and Figure 6-133 present corresponding timeseries results for FRP and total phosphorus immediately downstream of the confluence of the Warragamba and the Nepean River. At this location, the results start to resemble those seen in the Nepean release scenarios with generally lower phosphorus concentrations but with spikes that correlate with wet weather release conditions from the AWRC.
- In terms of annual median concentrations, the profiles remained generally similar to the Nepean release scenarios (refer to Figure 6-134 and Figure 6-135 for the wet year profiles for FRP and total phosphorus). The following comments are therefore consistent with the Nepean release scenarios.
  - In both the dry and wet years, the longitudinal profiles of annual median total phosphorus concentrations are predicted to be generally close to, or above the relevant waterway objective downstream to Wisemans Ferry.
  - The FRP concentration were predicted to be generally below the relevant waterway objective downstream to Wisemans Ferry in the dry year; whilst in the wet year annual median concentrations were above the waterway objective in the region between the South Creek confluence to approximately Wisemans Ferry.

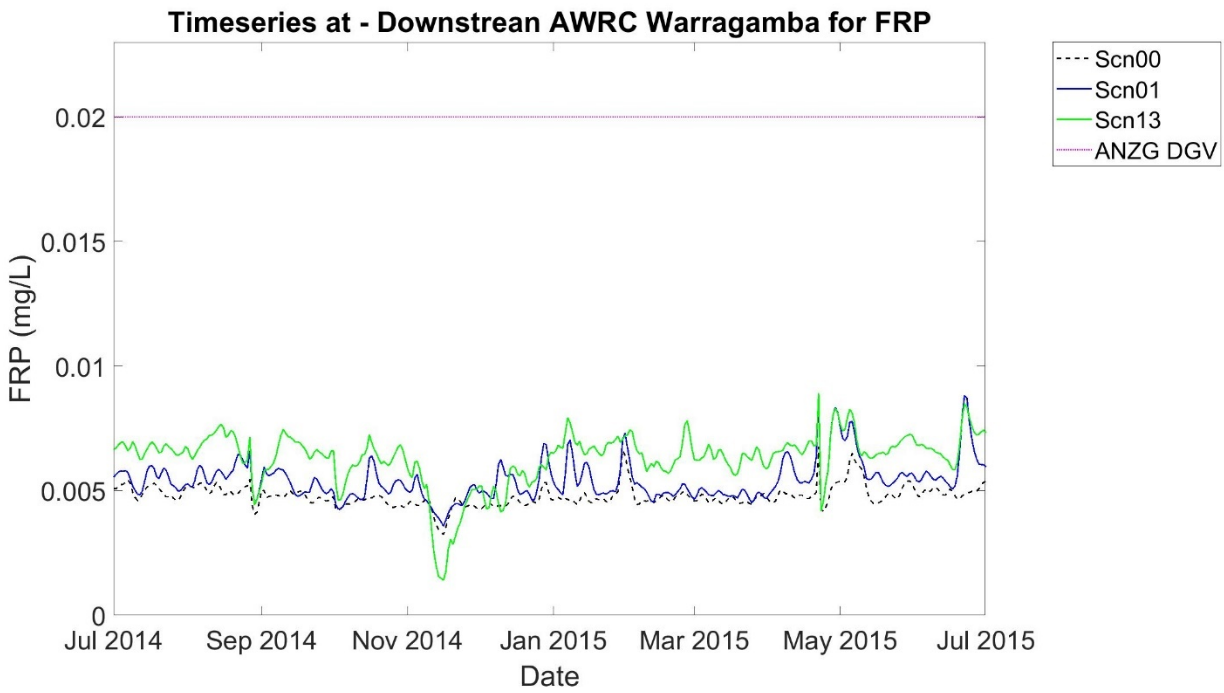


Figure 6-130 Timeseries of predicted FRP concentrations downstream of the AWRC Warragamba release point (2036 releases/wet year)

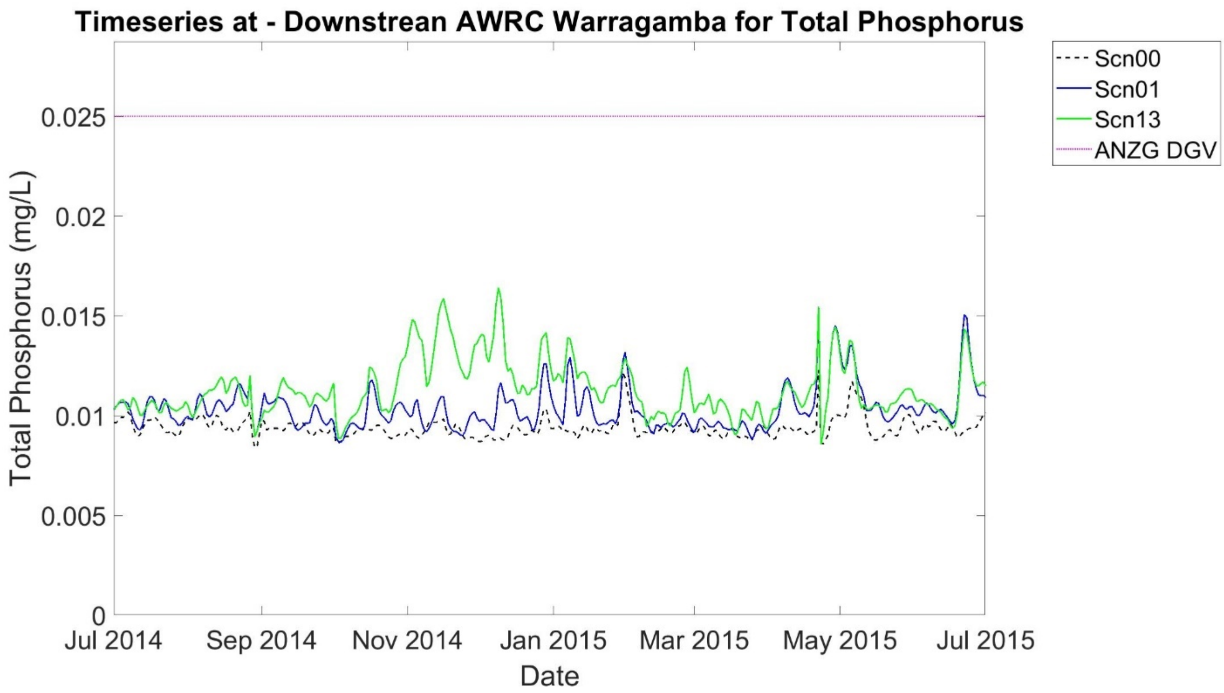


Figure 6-131 Timeseries of predicted Total Phosphorus concentrations downstream of the AWRC Warragamba release point (2036 releases/wet year)

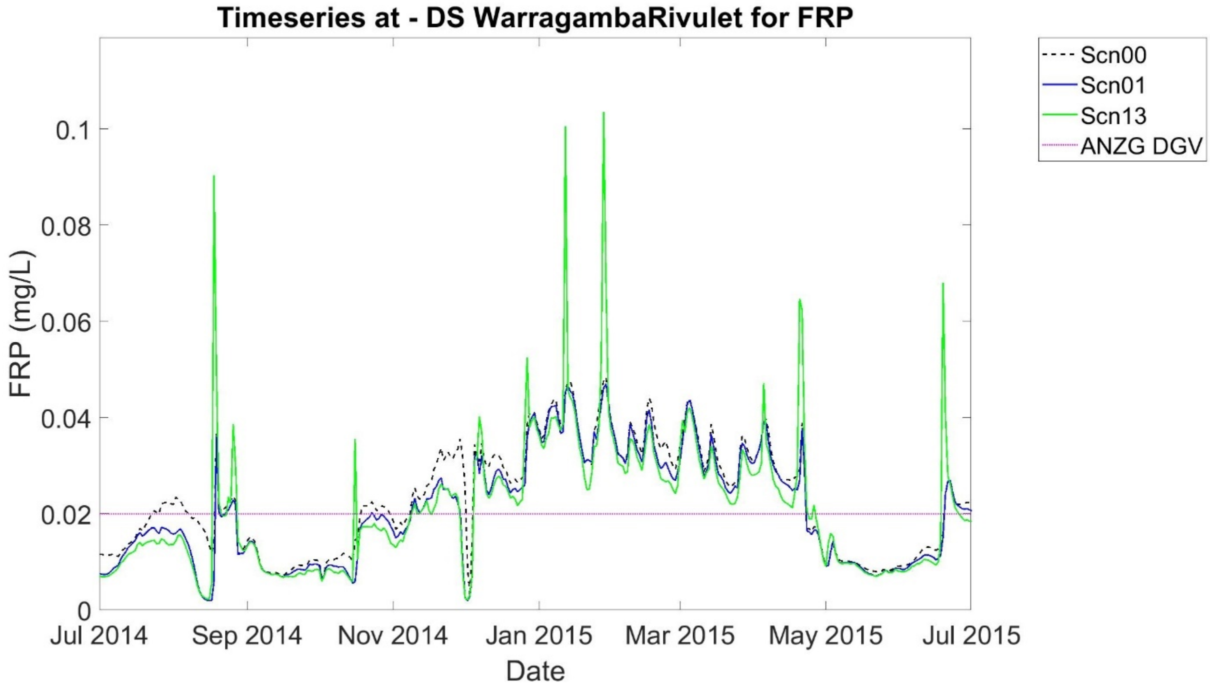


Figure 6-132 Timeseries of predicted FRP concentrations downstream of the Warragamba River confluence (2036 releases/wet year)

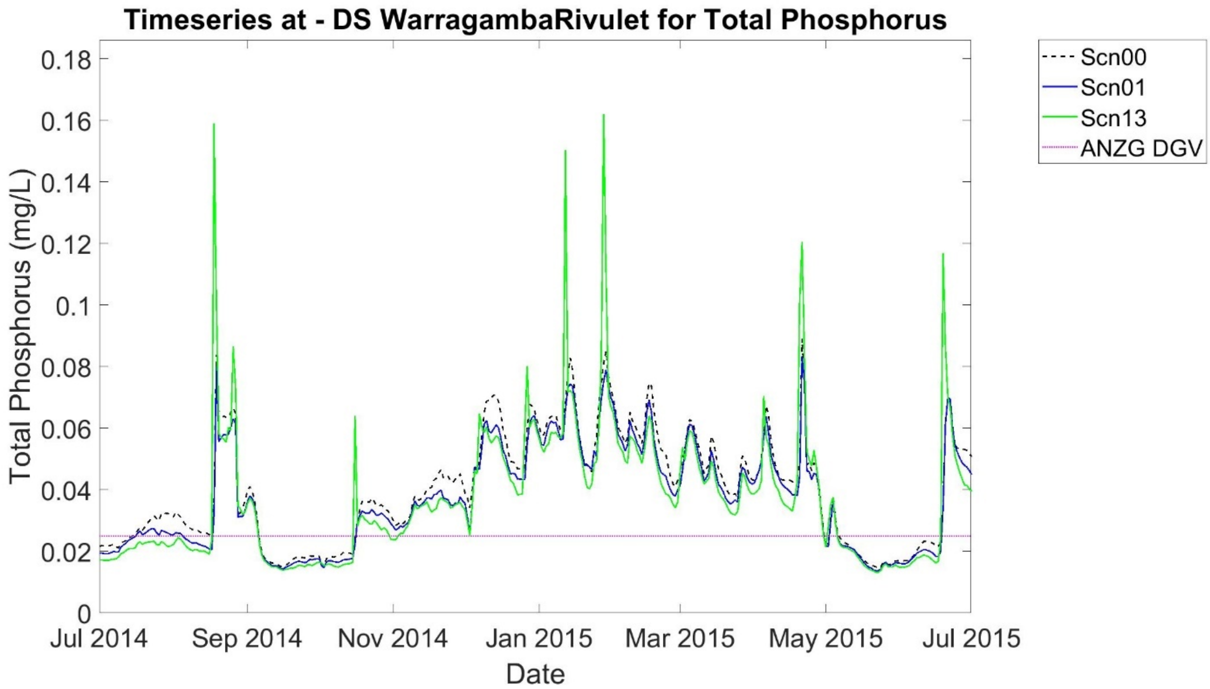


Figure 6-133 Timeseries of predicted Total Phosphorus concentrations downstream of the Warragamba River confluence (2036 releases/wet year)

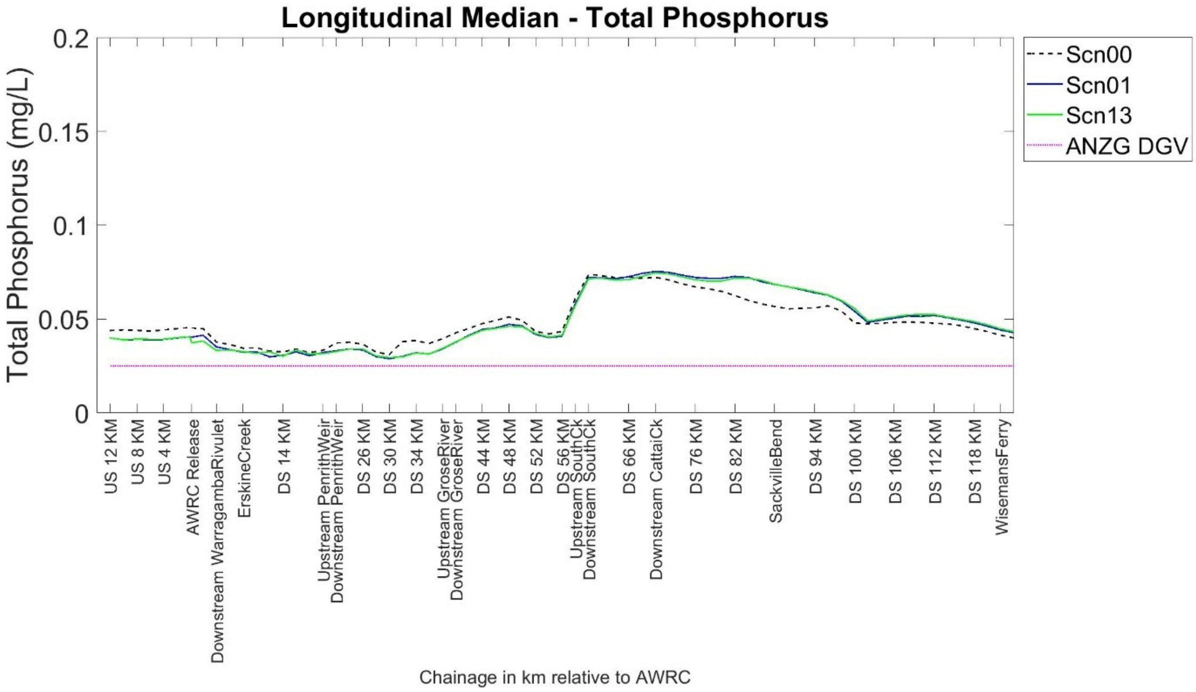


Figure 6-134 Longitudinal profile of predicted annual median Total Phosphorus concentrations (2036 releases/wet year)

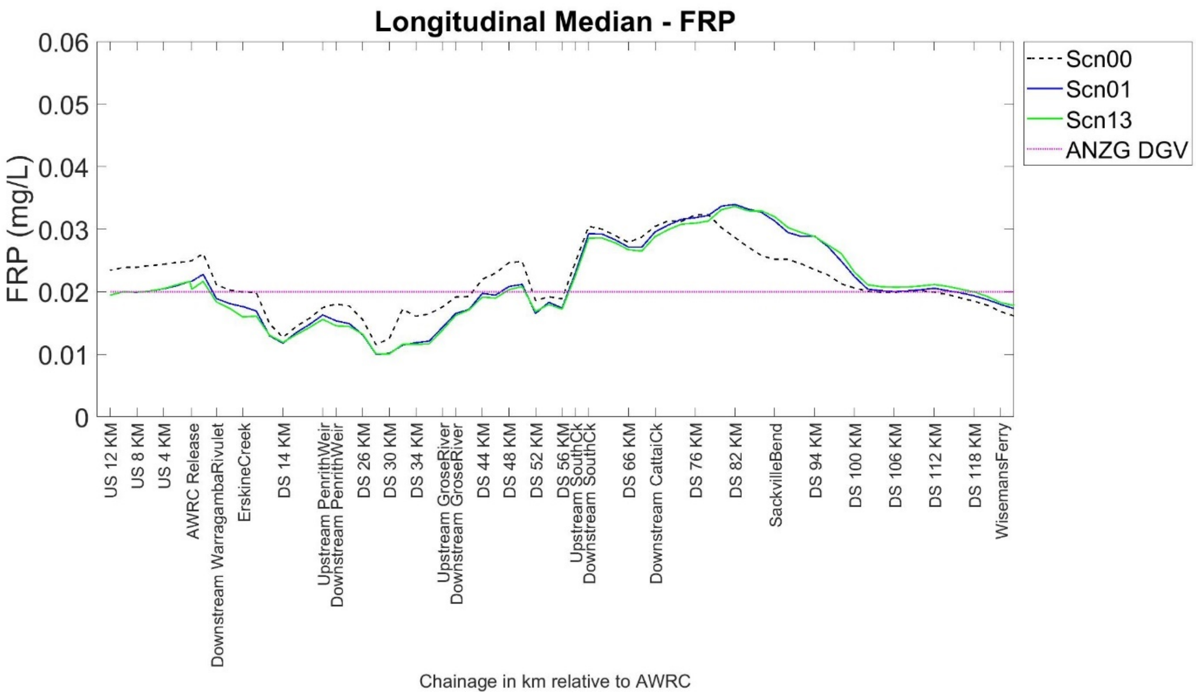


Figure 6-135 Longitudinal profile of predicted annual median FRP concentrations (2036 releases/wet year)

Chlorophyll *a*

- Under the Nepean River and Warragamba River release scenarios, there is predicted to be higher levels of chlorophyll a within the Warragamba River, downstream of the AWRC release point (refer to Figure 6-136 and Figure 6-137). While not major blooms, they are considered to be the result of increased, and more inorganic forms of the nutrient loads, particularly bioavailable phosphorus and to a lesser extent nitrogen. The lower levels of suspended solids may also contribute to the predicted growth.

- These increases in primary productivity are however not seen immediately downstream of the confluence with the Nepean River, as shown in Figure 6-138 and Figure 6-139.
- Regarding annual median analysis, while there were minor differences, the profiles (refer to Figure 6-140 and Figure 6-141) presented similar magnitudes and responses to those presented for the Nepean release scenarios.

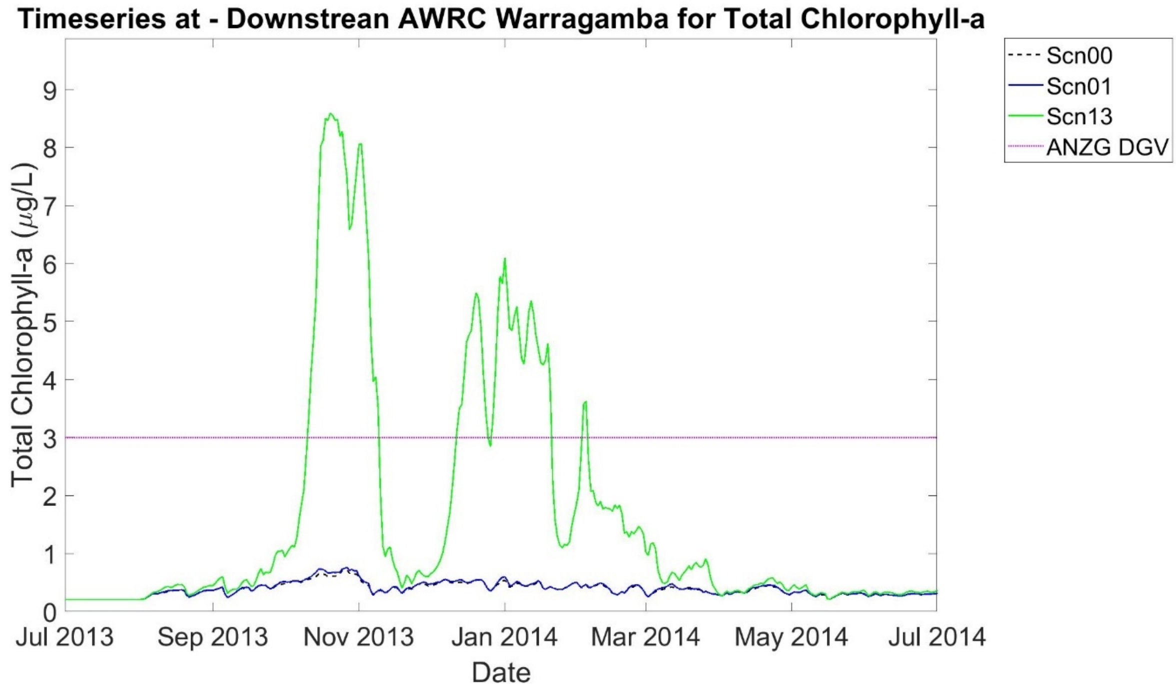


Figure 6-136 Timeseries of predicted Chlorophyll *a* concentrations downstream of the AWRC Warragamba release point (2036 releases/dry year)

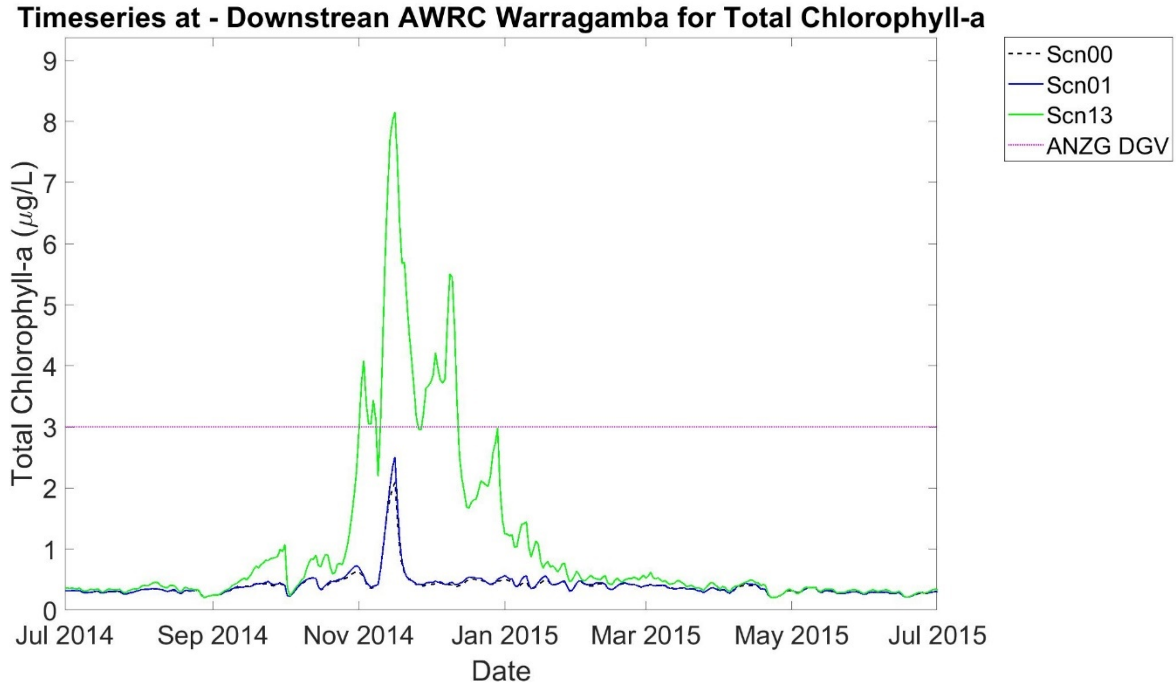


Figure 6-137 Timeseries of predicted Chlorophyll *a* concentrations downstream of the AWRC Warragamba release point (2036 releases/wet year)

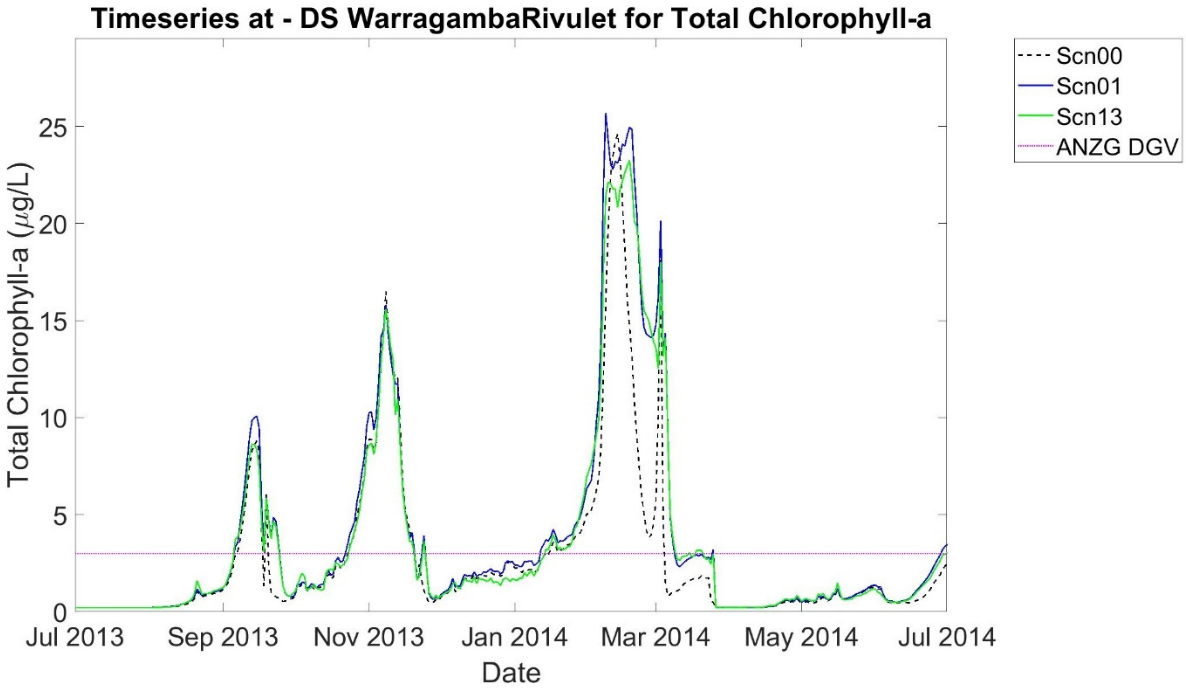


Figure 6-138 Timeseries of predicted Chlorophyll *a* concentrations downstream of the Warragamba River confluence (2036 releases/dry year)

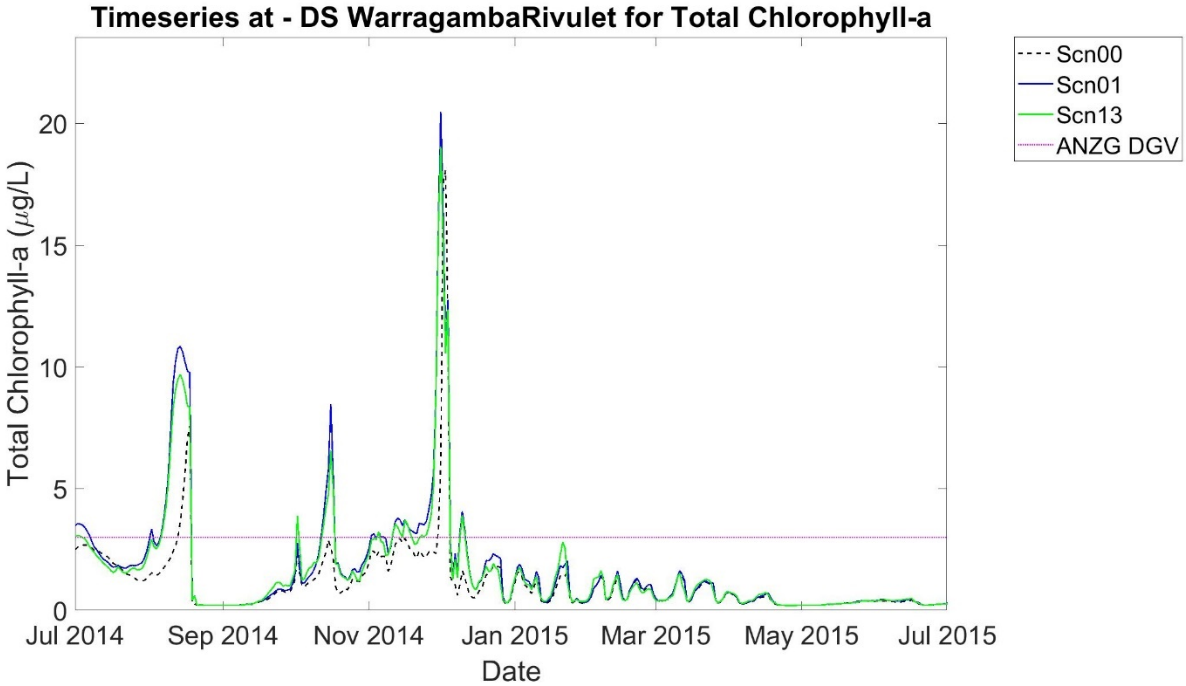


Figure 6-139 Timeseries of predicted Chlorophyll *a* concentrations downstream of the Warragamba River confluence (2036 releases/wet year)

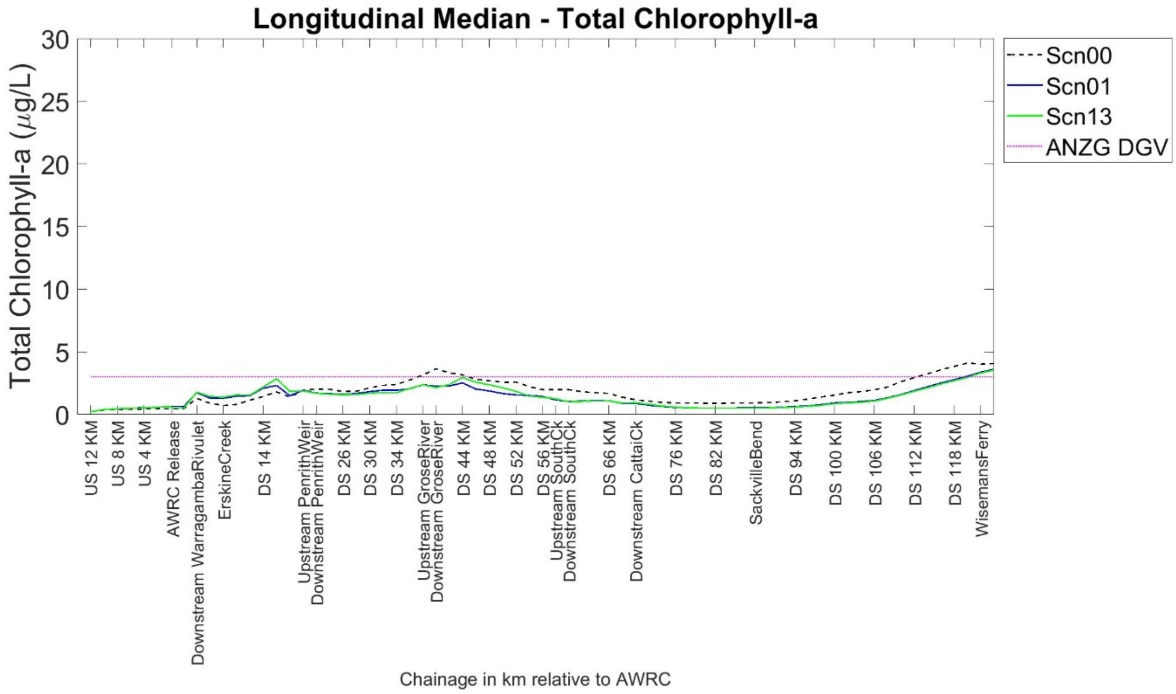


Figure 6-140 Longitudinal profile of predicted annual median Chlorophyll *a* concentrations (2036 releases/dry year)

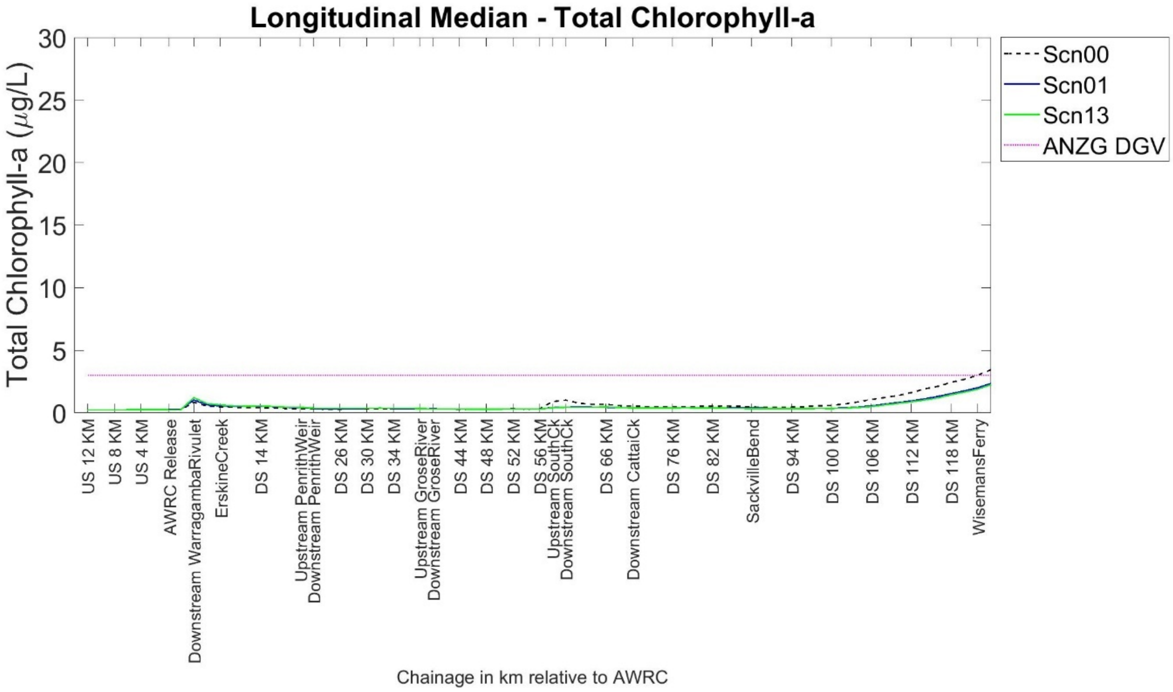


Figure 6-141 Longitudinal profile of predicted annual median Chlorophyll *a* concentrations (2036 releases/wet year)

Salinity

Salinities in the Warragamba River are predicted to be lower as a result of the AWRC releases (refer to Figure 6-142). The resulting modified conditions are reduced immediately downstream of the confluence with the Nepean River (refer to Figure 6-143).

The annual median concentrations are predicted to remain similar to the Nepean release results with reductions in the reaches immediately downstream of the release points (refer to Figure 6-144)

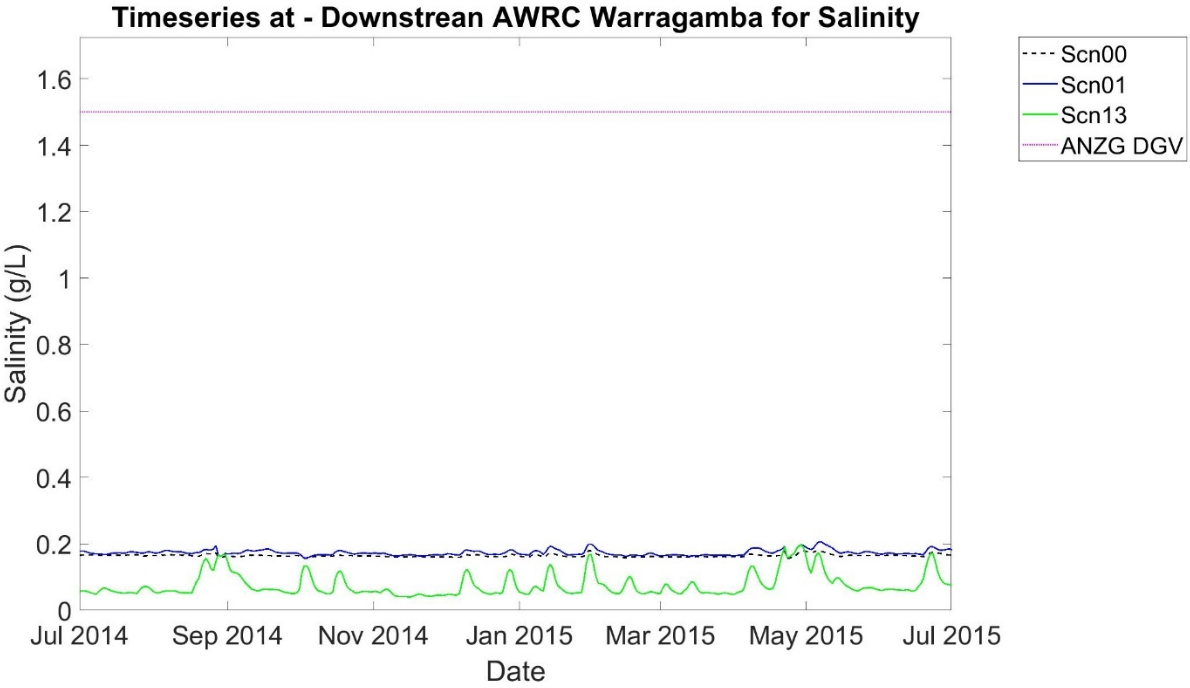


Figure 6-142 Timeseries of predicted Salinity concentrations downstream of the Warragamba AWRC release point (2036 releases/wet year)

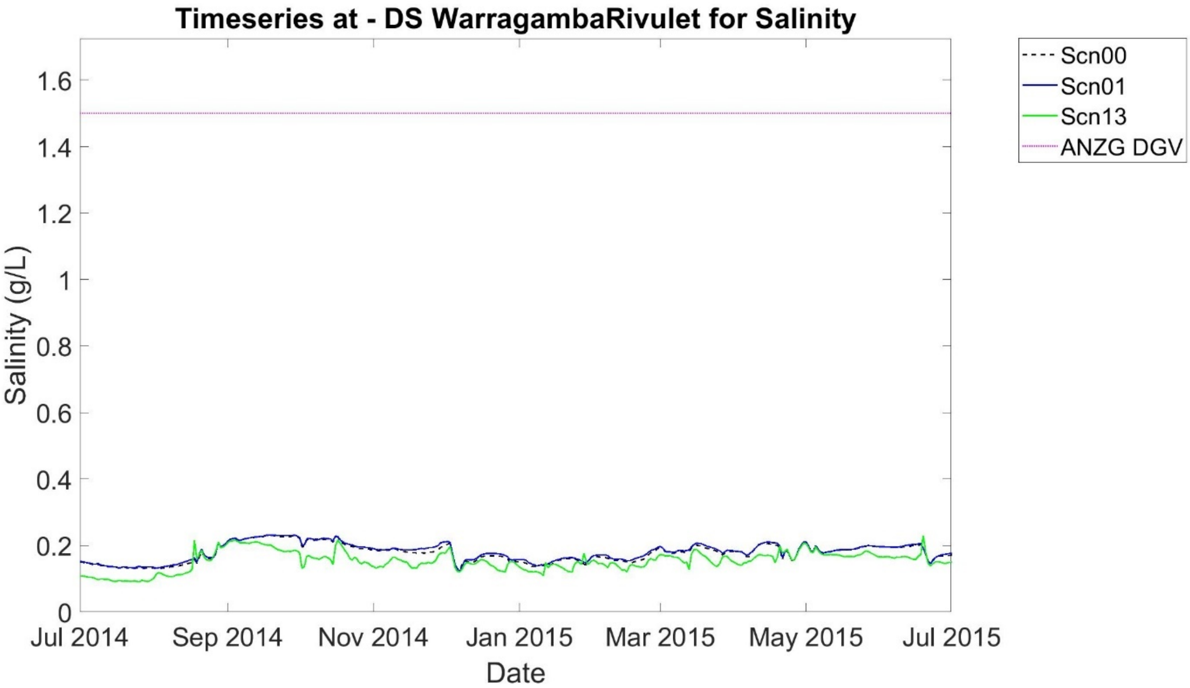


Figure 6-143 Timeseries of predicted Salinity concentrations downstream of the Warragamba River confluence (2036 releases/wet year)

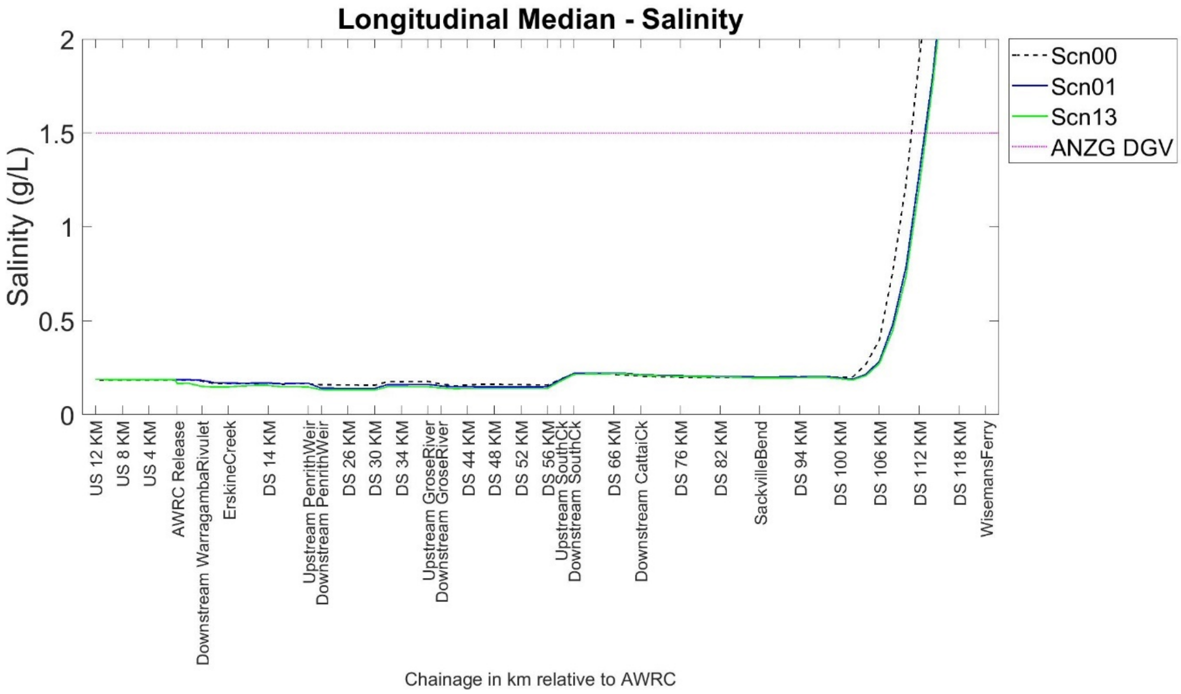


Figure 6-144 Longitudinal profile of predicted annual median Salinity concentrations (2036 releases/wet year)

Total Suspended Solids

Concentrations of suspended solids in the Warragamba River are predicted to be reduced as a result of the AWRC releases (refer to Figure 6-145). This reduction may also contribute to the aforementioned increase in primary productivity in the Warragamba River.

The resulting modified conditions are reduced immediately downstream of the confluence with the Nepean River (refer to Figure 6-146). The annual median profiles replicate those predicted for the Nepean release scenarios.

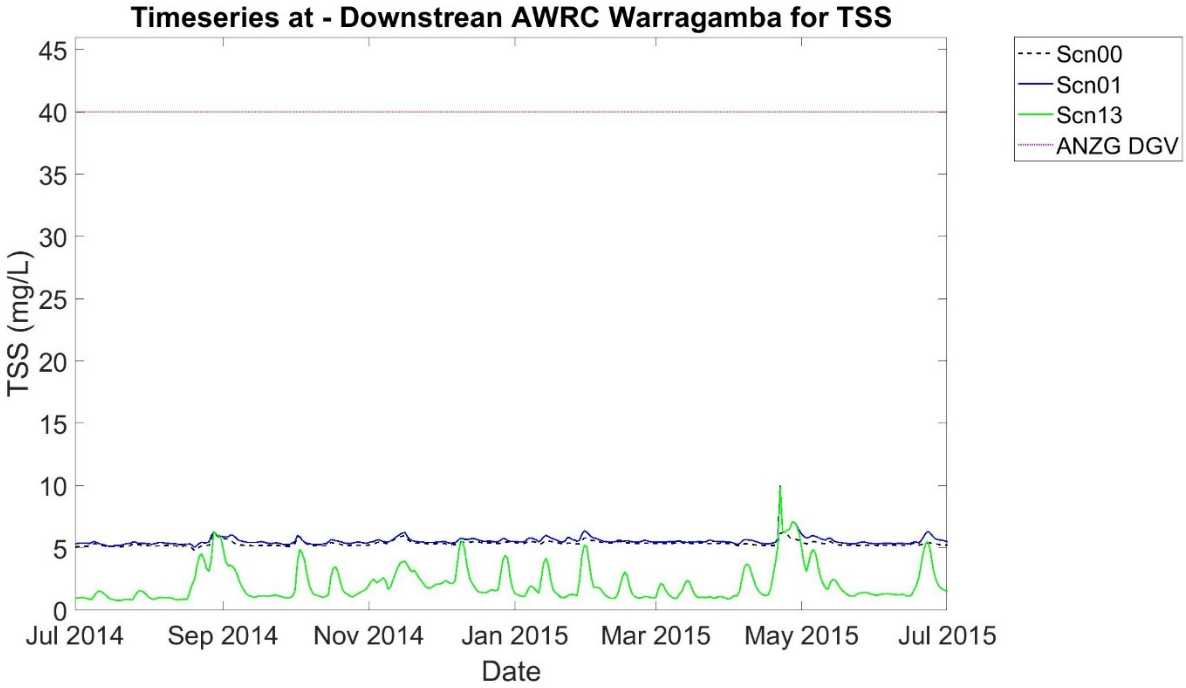


Figure 6-145 Timeseries of predicted TSS concentrations downstream of the Warragamba AWRC release point (2036 releases/wet year)

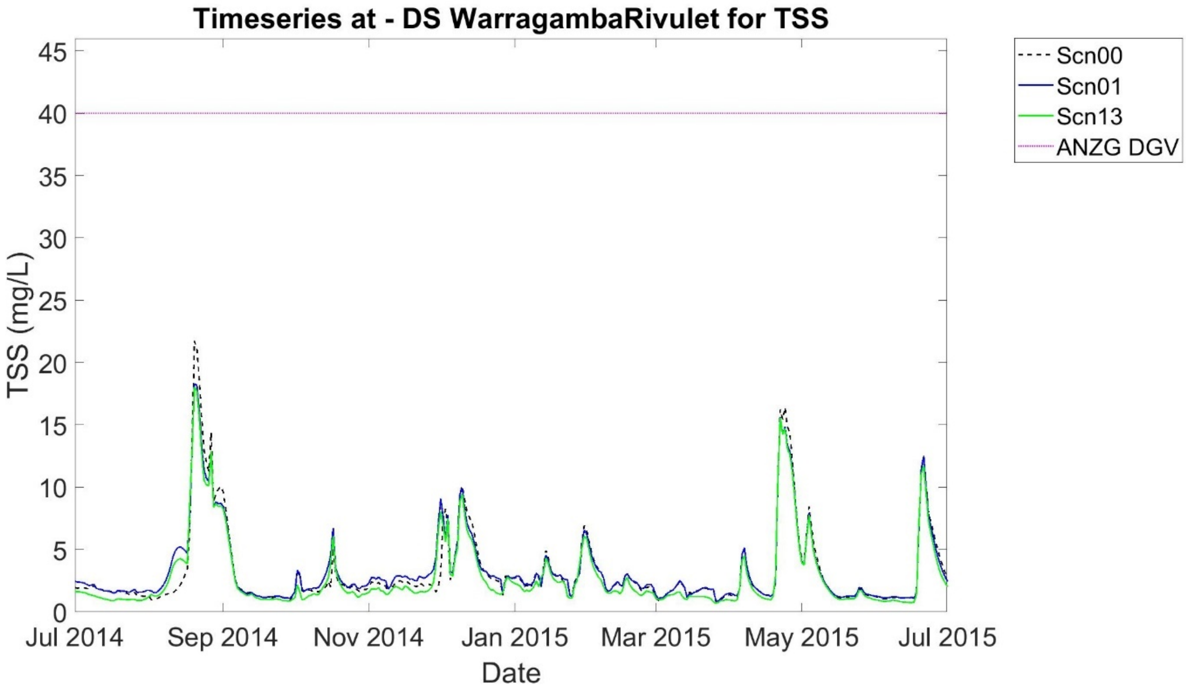


Figure 6-146 Timeseries of predicted TSS concentrations downstream of the Warragamba River confluence (2036 releases/wet year)

Dissolved oxygen

- Significant increases in dissolved oxygen were predicted in the Warragamba River with the introduction of the AWRC releases. Further downstream at the confluence with the Nepean River, the increases were generally dampened by the effects of mixing and the convergence of water from the Nepean River.

- No notable differences in the annual median concentrations were predicted between the Nepean River and Warragamba River release scenarios and the Nepean release scenarios.

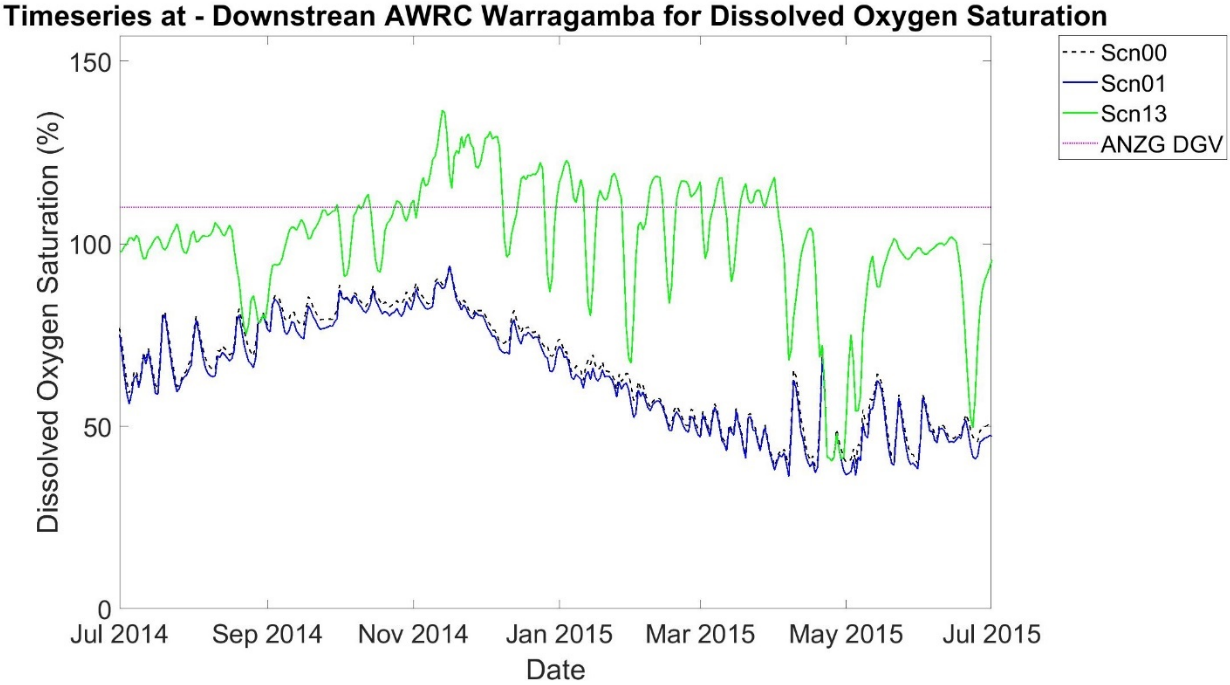


Figure 6-147 Timeseries of predicted DO concentrations downstream of the Warragamba AWRC release point (2036 releases/wet year)

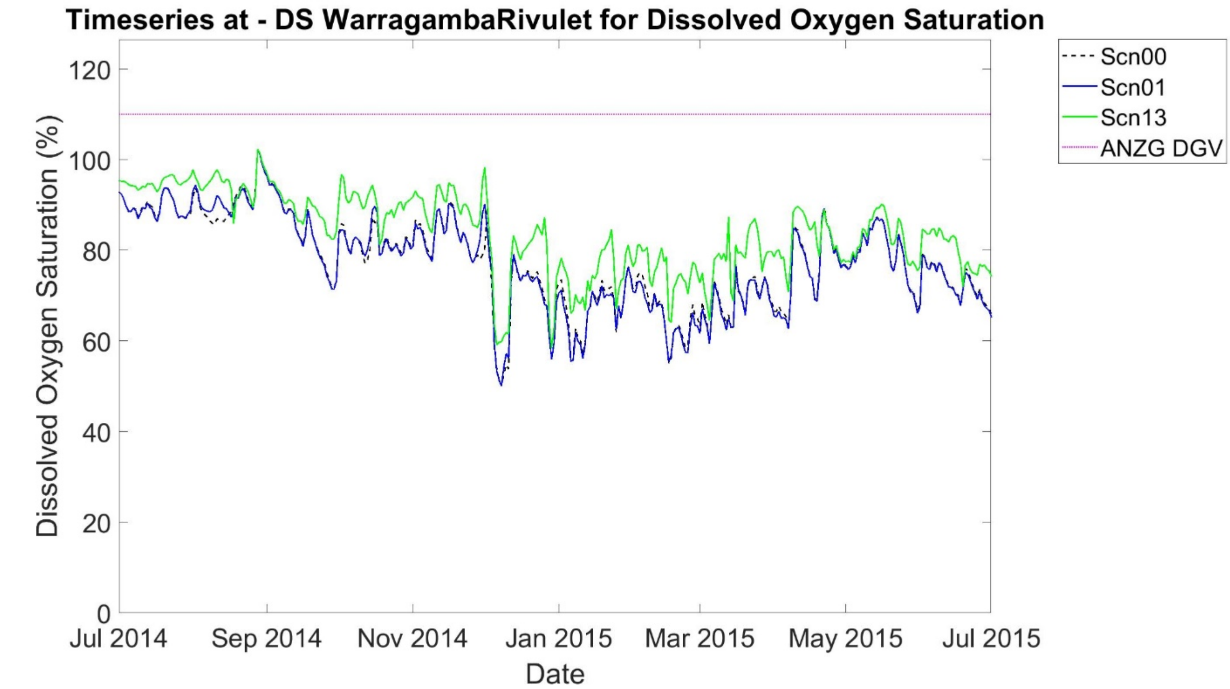


Figure 6-148 Timeseries of predicted DO concentrations downstream of the Warragamba River confluence (2036 releases/wet year)

Enterococci and E. coli (Enterococci analysed as primary pathogenic indicator)

- Due to the low pathogenic content of the AWRC treated water releases, dilution of the enterococci concentrations was predicted downstream of the AWRC Warragamba release point (refer to Figure 6-149 and Figure 6-150).
- No significant change in the annual median concentration profiles were predicted between the Nepean River and Warragamba River release scenarios and the Nepean release scenarios

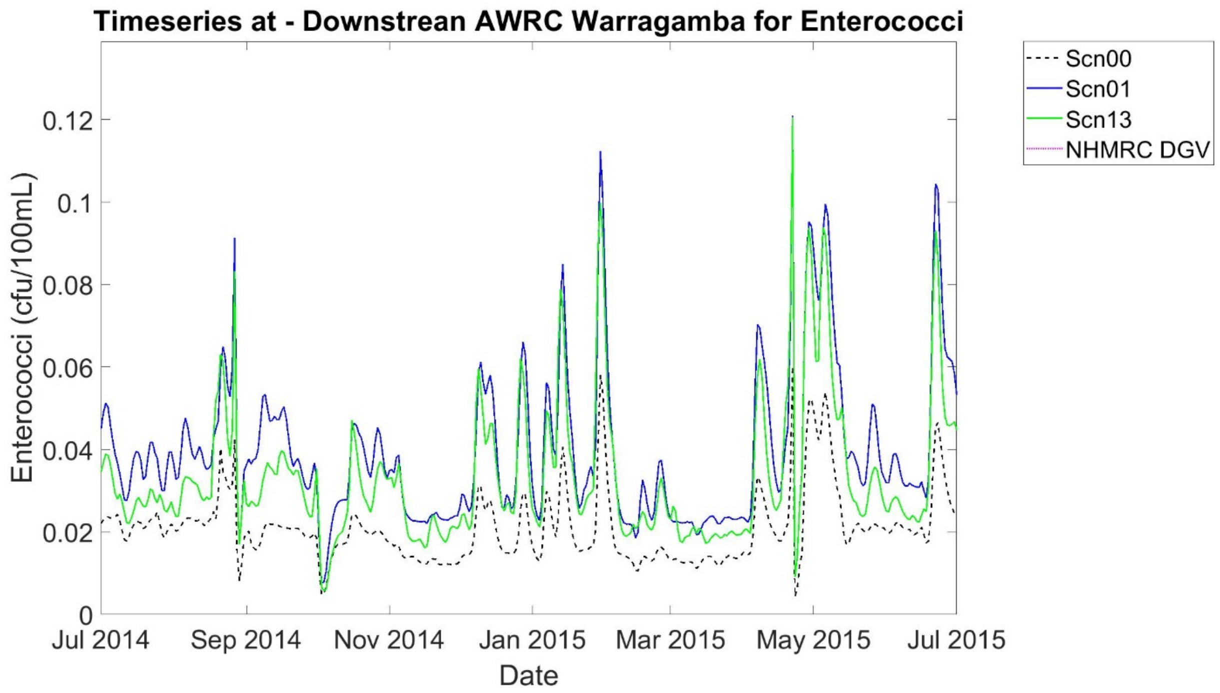


Figure 6-149 Timeseries of predicted Enterococci concentrations downstream of the Warragamba AWRC release point (2036 releases/wet year)

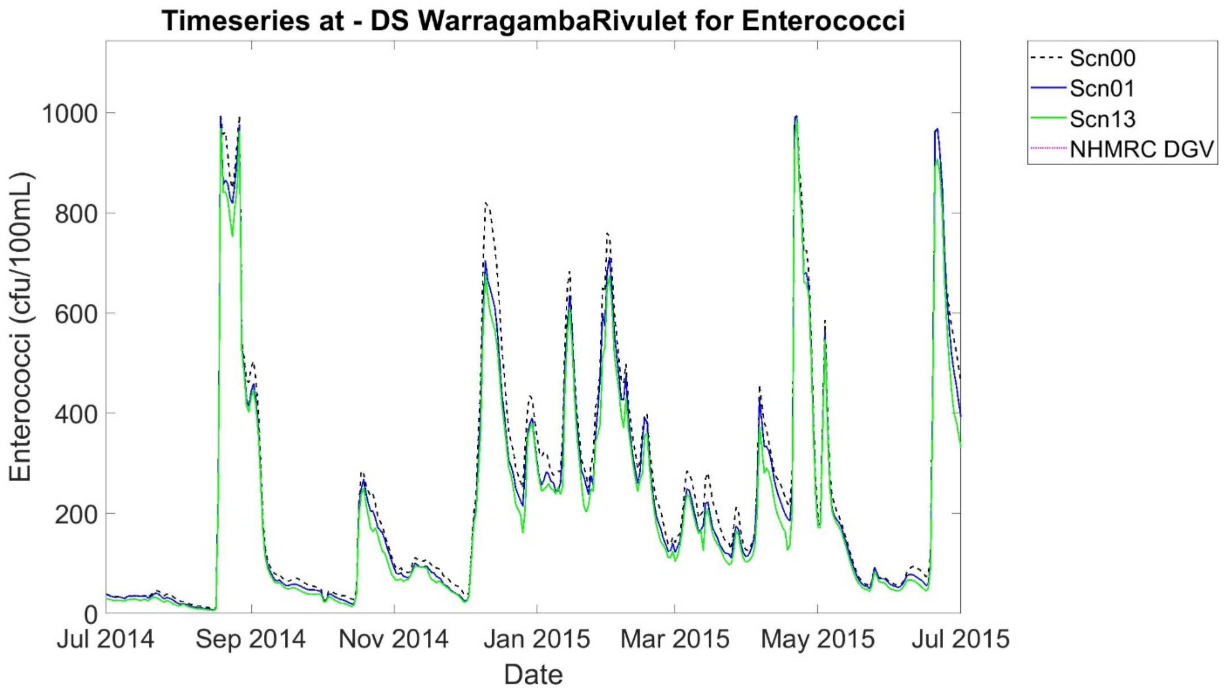


Figure 6-150 Timeseries of predicted Enterococci concentrations downstream of the Warragamba River confluence (2036 releases/wet year)

Cyanobacteria risk

- The risk index is calculated on a reach basis which includes analysis of model results across a zone or sub-zone box (refer to Section 4.6.4.3.3), and while the WQRM predicted potential localised increases in algal growth within the Warragamba River, the predicted cyanobacteria risk index indicates only minor differences across the downstream reaches, relative to both the background scenario and the equivalent Nepean River release scenario. Figure 6-151 presents the predicted risk index timeseries for Zone 3, located downstream of Wallacia Weir.
- The index results therefore indicate no increased risk in the downstream reaches based on the conditions that are considered conducive to growth of cyanobacteria. Slightly warmer temperature near the AWRC releases in winter can increase risk slightly at this time, but in summer when blooms are likely, the AWRC also has a cooling effect on the river water. Along with small changes to water clarity and nutrient availability there is likely to be some change to biomass, but no material change in risk.

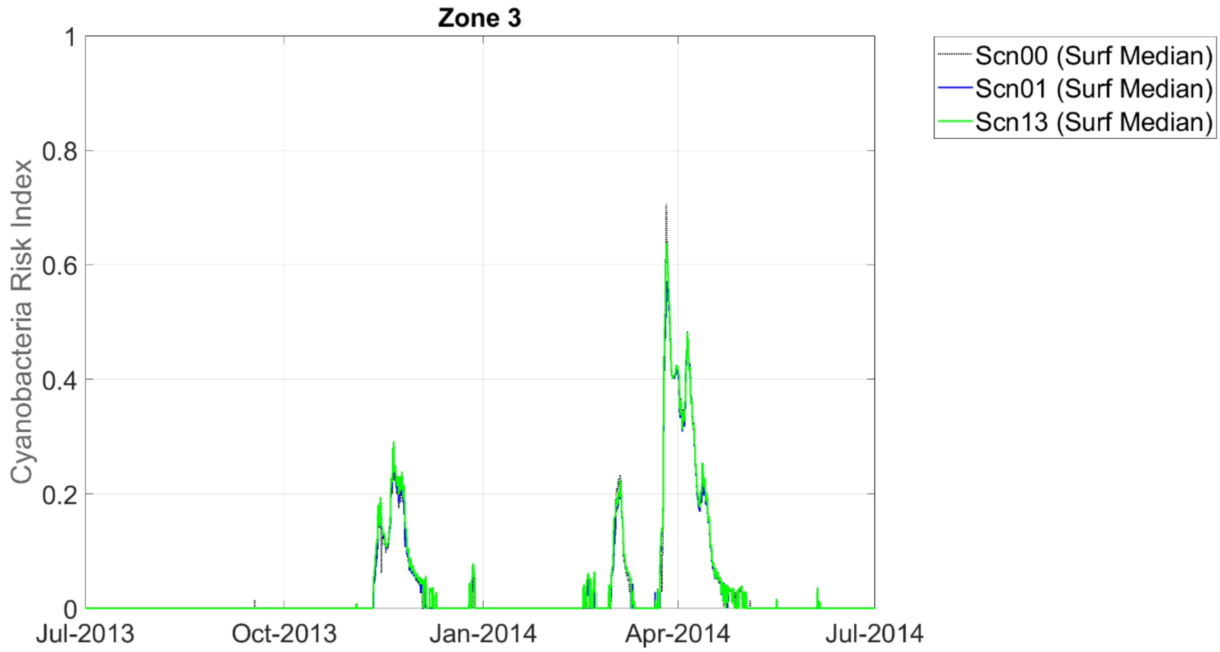


Figure 6-151 Timeseries of predicted Cyanobacteria risk indices for Zone 3 (2036 releases/dry year)

6.2 Near field and toxicity assessment

6.2.1 South Creek releases

6.2.1.1 Release conditions

The proposed release infrastructure for South Creek consists of an open shallow (~1 m deep) channel with a 2.5 m wide base and 1:5 gradient sides. The channel meets the creek at an angle of ~30^{o}. The proposed invert level at the end of the channel is ~36.1 m AHD.

At the release location, the creek can be generally described as ephemeral with minimal or no flow during extended dry weather periods. However, during the release events, flows within the creek are predicted to be significantly elevated due to rainfall and runoff in the upstream sub-catchments (refer Sections 4.7.3 and 6.1.1.5).

The releases to the creek commence when there is an influent flow rate of greater than 1.7 x ADWF to the AWRC. However, as discussed in Section 4.6.3.5.1, only advanced treated water is released until a flow threshold of 3 x ADWF is reached. Above this threshold, a blend of primary treated and advanced treated water will be released to the creek. This near field assessment has focussed on the events that include primary treated water as these are the releases that have the potential to include higher levels of some toxicants.

Over the extended simulation period analysed in the WQRM modelling, six days were identified where influent and release rates from the AWRC exceeded 3 x ADWF. Each of these events were simulated to allow an understanding of the range of dilution and mixing characteristics that could be expected in the creek. Section 4.7.3 presents the range of release and ambient boundary conditions that were assumed in the CORMIX modelling.

Cross sectional profiles of the creek at the release point were derived from bathymetric and topographic data used in the development of the WQRM (refer Section 4.7.2). In summary, the creek profile is shallow with an extended width of ~45 m and a depth of ~3.5 m. The invert level of the creek near the release point is ~33.5 m AHD. Water depths in the creek were extracted from the WQRM results for the times of the release events.

The differences between the 2036 and 2056 scenarios include the magnitude of the release volumes as well as the flows within the creek, as a result of the changes in assumed land use for the two time horizons. For all scenarios, the Parkland stormwater management strategy was assumed with respect to flows predicted within the creek.

6.2.1.2 Dilution profiles

The predicted dilution profiles for the release events are presented in Figure 6-152 and Figure 6-153 for the 2036 (Stage 1) and 2056 (Future stages) scenarios respectively. Under these scenario conditions, the modelling predicted a range of near field mixing conditions as discussed below:

- Near field mixing is relatively limited due to the weak release conditions provided by the open bank channel constructed on the creek bank
  - For the 2036 scenarios, the predicted dilution factors vary from ~2 to ~6, at 100 m distance from the release
  - For the 2056 scenarios, the predicted dilution factors vary from ~3 to ~4.5, 100 m distance from the release

- Under lower release volumes, the plume commonly becomes rapidly deflected
- The potential for bank attachment is predicted downstream of the release channel
- Near field mixing converts to ambient mixing generally within 12 m and 45 m of the release point
- The release velocity has potential to be less than the ambient velocity and results in wake flow conditions
- Under lower creek flow conditions, the plume may extend across the width of the creek and interact with the opposite bank

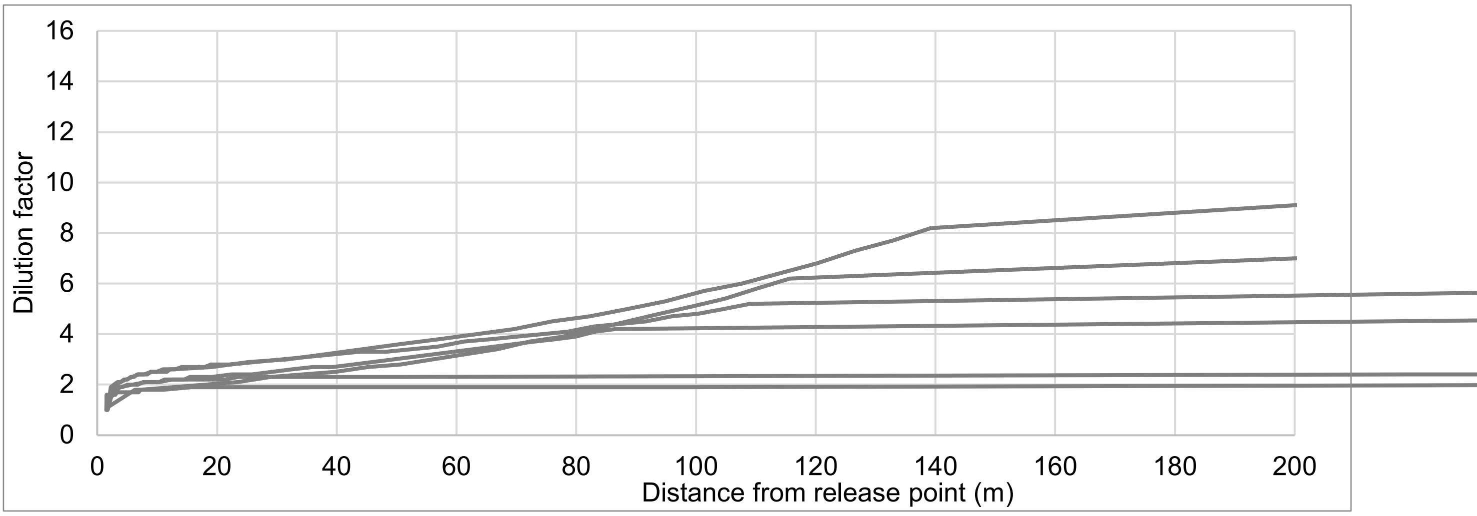


Figure 6-152 Predicted dilution profile for South Creek (2036 releases)

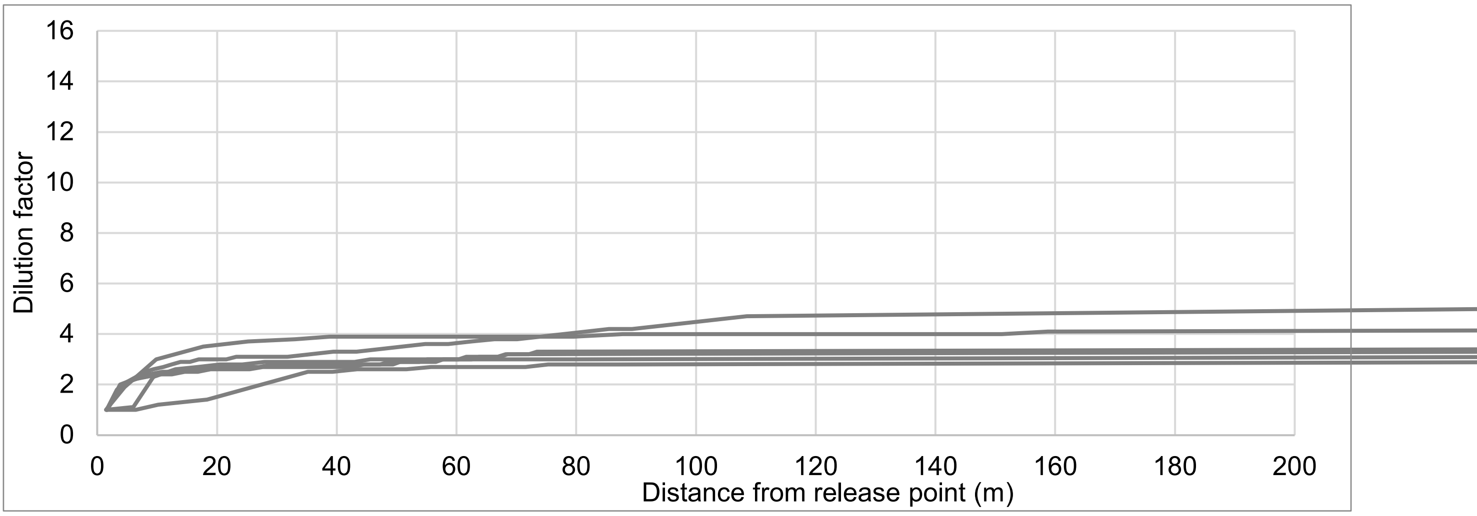


Figure 6-153 Predicted dilution profile for South Creek (2056 releases)

6.2.1.3 Toxicity and mixing zone analysis

6.2.1.3.1 Dilution requirements

The dilution requirements are presented in Table 6-4 for each contaminant of concern identified for South Creek in Section 4.7.2.1.1, i.e. Ammonia, Nitrate and Chlorine. These dilution factors were determined from the assumed maximum treated water concentrations, background ambient concentrations and the relevant toxicant guideline values. The equation used to calculate these factors is included in Section 4.7.4.2.1.

The dilution factors effectively represent the level of dilution required in the vicinity of the release point to reach each of the DGVs. These factors therefore represent the level of dilution required at the boundary of a mixing zone.

From this analysis, the following comments and conclusions are drawn:

- For Total Ammonia:
  - The treated water released under more severe wet weather release events (>3 x ADWF) is assessed to be potentially toxic to aquatic organisms as the maximum end-of-pipe concentration is above the DGV.
  - A dilution factor of 3.5 is required to reach the adopted DGV.
- For Total Chlorine:
  - The treated water released under the more severe wet weather events is assessed to be potentially toxic to aquatic organisms as the maximum end-of-pipe concentration is above the relevant guideline values.
  - A dilution factor of 8.3 and 3.6 is required to respectively reach the relevant ANZG (2018) toxicant DGV and a recently updated guideline value for total chlorine by Batley et al. (2021).
- For Nitrate, the treated water released under more severe wet weather events is assessed to be not toxic to aquatic organisms as the maximum end-of-pipe concentrations are below the relevant toxicant DGV presented in the ANZG (2018) guidelines.

Table 6-4 Dilution requirements – South Creek releases

Contaminant	ANZG (2018) toxicant DGV (mg/L)	Treated water quality (mg/L)	Background water quality (mg/L)	Dilution required
Total Ammonia as N	1.75*	6.00#	0.05^	3.5
Nitrate as N	2.40**	0.20#	0.91^	<1
Total Chlorine	0.003**	0.025#	0.00^^	8.3
Total Chlorine	0.007***	0.025#	0.00^^	3.6

Table notes:

* *Toxicant DGV for the protection of aquatic ecosystems (95% protection) as typically recommended for slightly to moderately disturbed ecosystems – refer ANZECC (2000). Modifications to the DGV have been made in line with ANZECC (2000) based on a median ambient pH of 7.4, which was determined from monitoring data collected from March 2020 to June 2021, at a site upstream of the proposed release point (site NS45).*

** *Toxicant DGV for the protection of aquatic ecosystems (95% protection) – refer ANZECC (2000)/ANZG (2018).*

*** *GV derived for chlorine in freshwater by Batley et al. (2021).*

^ *Background concentration derived from median analysis of 22 sampling events from March 2020 to June 2021 at site NS45.*

^^ *Assumed to be zero due to their limited persistence in water.*

\# *Treated water quality – refer to Section 4.7.2.1 for sources.*

6.2.1.3.2 Mixing zone analysis

Ammonia

For Total Ammonia, the dilution profiles predicted from the CORMIX modelling (refer Figure 6-152 and Figure 6-153) indicate that the dilution requirement of 3.5 (refer to Table 6-4) is potentially met on four of the simulated release events (circa 2036). While the dilution factors are predicted to be achieved on these events, the lateral and/or longitudinal extents of the mixing zones exceed the primary considerations discussed in Section 4.7.4.3.3.

Under the majority of the scenario conditions, the modelling also predicts the potential for extensive bank attachment downstream of the release point.

Total Chlorine

The dilution profiles predicted from the CORMIX modelling indicate that the ANZG DGV derived dilution requirement of 8.3 (refer to Table 6-4) is only met on one of the simulated release events (circa 2036). However, the lateral and longitudinal extents of the mixing zone again exceed the primary considerations discussed in Section 4.7.4.3.3.

With consideration of the Batley et al. derived dilution requirement, the CORMIX modelling indicates that the dilution requirement of 3.6 is potentially achieved on four of the simulated release events (circa 2036). Again, however the lateral and/or longitudinal extents of the mixing zones exceed the primary considerations discussed in Section 4.7.4.3.3.

Under the majority of the scenario conditions, the modelling also predicts the potential for extensive bank attachment downstream of the release point.

6.2.1.3.3 Interpretation – South Creek near field impacts

While the near field modelling has predicted that the primary mixing zone criteria (refer Section 4.7.4.3.3) cannot generally be achieved for the relevant severe wet weather release events, the potential for toxicity and environmental harm arising from these releases is considered to be low due to the factors listed below. As a result of this analysis, no mixing zones are proposed for the AWRC releases to South Creek.

- Temporally, the events are very infrequent. On average the more severe 3 x ADWF events are predicted to occur two to three times per year but frequencies may vary between zero and six events per year.
- The release events are also typically short lived with durations ranging from less than one day to intermittently over three days.
- The releases correlate with conditions of significant flow within the creek and corresponding low residence times.
- Mixing zones are generally only considered in terms of management of continuous releases of treated wastewater, where releases may present a risk of harm to fish migration or harm to sedentary species. Consequently, mixing zone modelling is generally focussed on periods of extended dry weather e.g. in the Queensland Government Technical Guideline, the minimum consecutive seven day average flow with a 10-year recurrence interval is recommended as a guide to minimum dilution conditions in non-tidal streams.

- Application of ANZG (2018) toxicant DGVs in the near field impact assessments could be considered as very conservative as the DGVs are applicable to chronic exposure situations. Therefore, these guideline values are deemed more relevant to exposure durations of greater than three days. No applicable shorter-term toxicity-based guidance values are available under the ANZG (2018) and ANZECC (2000) guidelines.

Alternative release structures may improve mixing and dilution of releases in the waterways. Potential modifications could include the provision of piped release infrastructure located in the creek so that the releases of treated water would be submerged, and the infrastructure protected, during higher creek flows and at the times of the expected AWRC releases. Such a design may assist in increasing initial mixing and dilution in the vicinity of the release point. It may further reduce the risk of attachment of the plume to the creek banks (refer to Section 7.3.1).

6.2.2 Nepean River releases

6.2.2.1 Release conditions

The proposed release infrastructure for the Nepean River consists of a headwall design with an energy dissipation structure consisting of baffle blocks. The apron of the structure is ~5.4 m at its widest aperture. The invert level of the apron is 26.74m AHD which is just above the level of the Wallacia Weir wall (26.6 m AHD), located ~50 m downstream.

The release location is therefore within the Wallacia Weir pool. Currently, water levels fluctuate with river flow, and the weir overtops during sustained wet weather and elevated runoff from the upstream catchments. With the introduction of the AWRC releases, the modelling indicates that water levels in the weir pool will become more consistent (refer Section 6.1.2.5.2).

While treated water releases from the AWRC are planned to be continuous, the near field assessment has focussed on the events that include significant levels of tertiary treated water, as these are the events that have the potential to include higher levels of some metals.

Similar to the South Creek analysis, over the extended simulation period analysed in the WQRM modelling, six days were identified when the presence of tertiary treated water in the releases would present the potential for elevated metal concentrations. Each of these events were simulated to allow an understanding of the range of dilution and mixing characteristics that could be expected in the weir pool. Section 4.7.3 presents the range of release and ambient boundary conditions that were assumed in the modelling.

Cross sectional profiles of the river at the release point were again derived from bathymetric and data used in the development of the WQRM (refer Section 4.7.2). In summary, the river profile near the release point has an extended width of ~40 m and an average bed elevation of ~24.4 m AHD. Water depths in the weir pool were extracted from the WQRM results for the times of the release events.

Similar to the South Creek modelling, the differences between the 2036 and 2056 scenarios include the magnitude of the release volumes as well as the flows within the river. The upstream river conditions vary as a result of the changes in assumed land use for the two time horizons, as well as changes in flows from the upstream WWTPs/WRPs.

6.2.2.2 Dilution profiles

The predicted dilution profiles for the release events are presented in Figure 6-154 and Figure 6-155 for the 2036 (Stage 1) and 2056 (Future stages) scenarios respectively. The near field mixing analysis is restricted to ~50 m as this is the distance from the release point to the weir wall.

Under these scenario conditions, the near field modelling predicted a range of near field mixing conditions as discussed below:

- Near field mixing is relatively limited due to the relatively weak release conditions provided by the headwall structure to be constructed high on the river bank
  - For the 2036 scenarios, the predicted dilution factors vary from ~3 to ~6.5, at 50 m distance from the release
  - For the 2056 scenarios, the predicted dilution factors vary from ~2.5 to ~4.5, 50 m distance from the release
- Due to the elevated water levels in the weir pool during the release events, the apron of the headwall becomes submerged during all the scenarios.
- Under lower release volumes, the plume commonly becomes rapidly deflected. The potential for bank attachment and recirculation dynamics is predicted immediately downstream of the release point.
- The release velocity has potential to be less than the ambient velocity and may result in wake flow conditions. There is therefore no release momentum induced mixing.
- In the absence of sufficient momentum in the releases, ambient buoyant mixing generally becomes dominant within the first few metres.
- Under lower river flow conditions, the plume is predicted to extend across the width of the weir pool and interact with the opposite river bank.

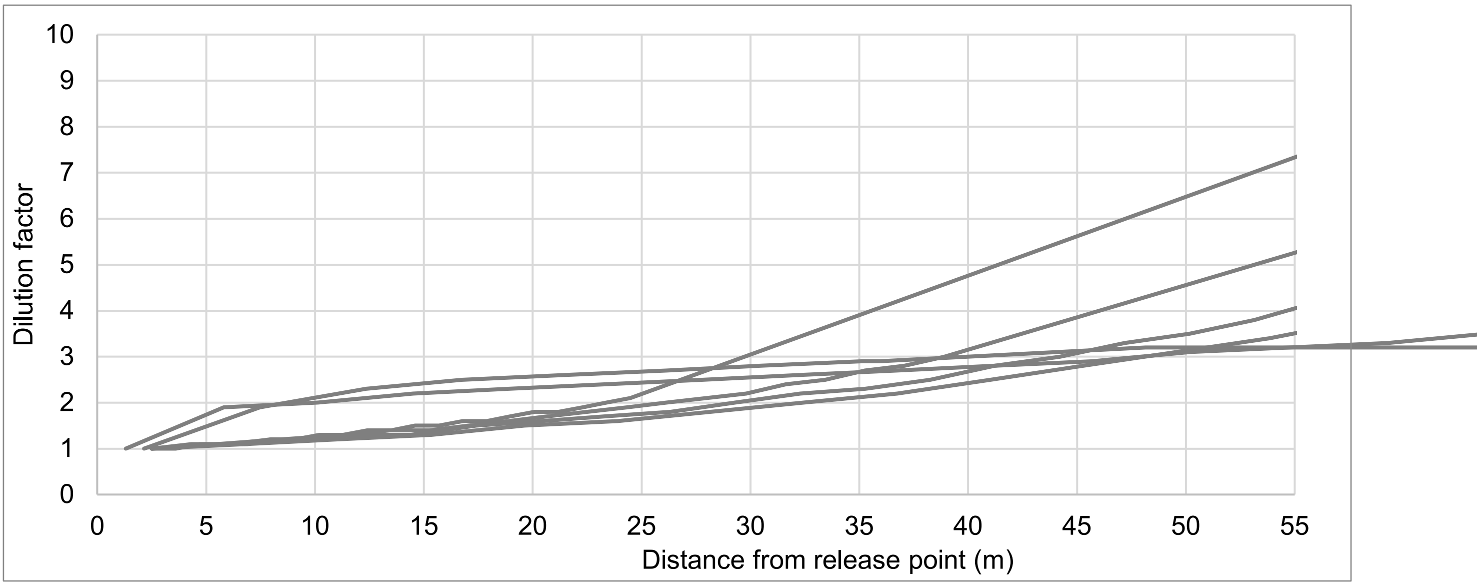


Figure 6-154 Predicted dilution profile for the Nepean River (2036 releases)

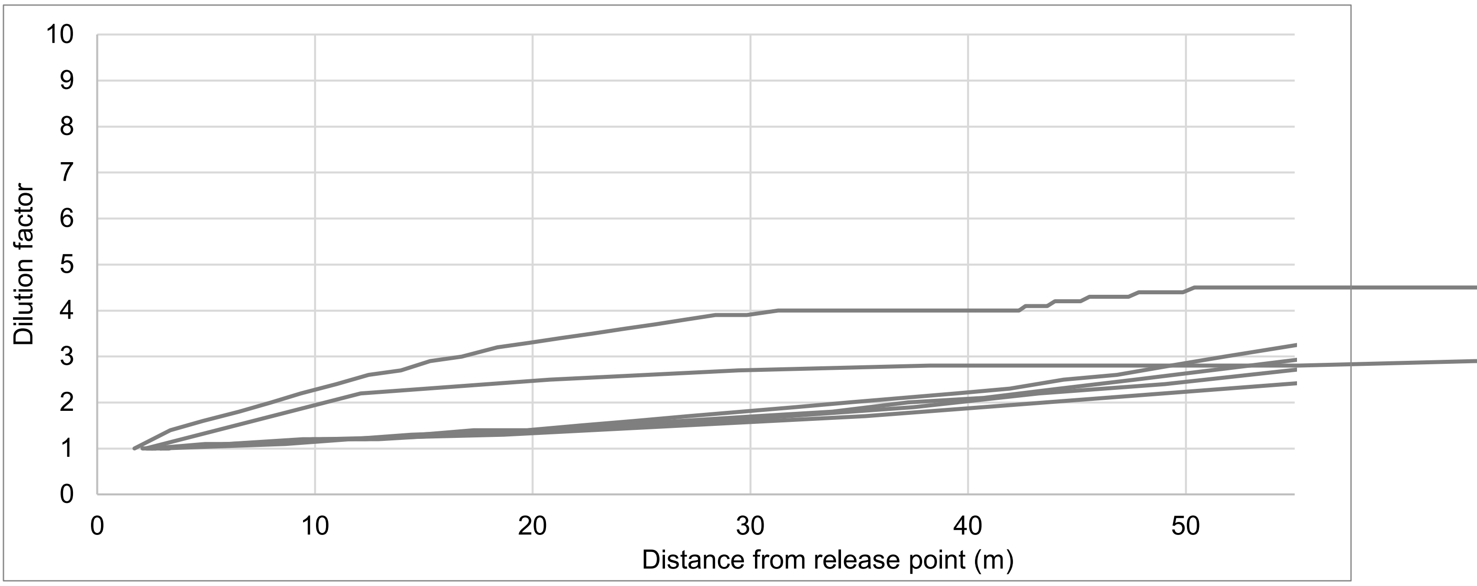


Figure 6-155 Predicted dilution profile for the Nepean River (2056 releases)

6.2.2.3 Toxicity and mixing zone analysis

6.2.2.3.1 Dilution requirements

The dilution requirements are presented in Table 6-5 for each contaminant of concern identified for the Nepean River in Section 4.7.2.1.1, i.e. Aluminium, Copper, Manganese and Zinc. These dilution factors were determined from the assumed maximum treated water concentrations, available background ambient concentration data and the relevant ANZG (2018) toxicant DGVs. The equation used to calculate these factors is included in Section 4.7.4.2.1.

The dilution factors effectively represent the level of dilution required in the vicinity of the release point to reach each of the DGVs. These factors therefore represent the level of dilution required at the boundary of a mixing zone.

From this analysis, the following comments and conclusions are drawn:

- For Aluminium, Copper and Zinc:
  - The treated water released under more severe wet weather release events (>3 x ADWF) is assessed to be potentially toxic to aquatic organisms as the maximum end-of-pipe concentrations are above the toxicant DGVs.
  - Dilution factors of 7.3, 10.3 and 9.5 are required to reach the adopted DGVs for Aluminium, Copper and Zinc respectively.
- For Manganese:
  - The treated water released under more severe wet weather release events (>3 x ADWF) is assessed to be a potential risk for recreational purposes as the maximum end-of-pipe concentration is marginally above the adopted DGV.
  - A dilution factors of 2.0 is required to reach the adopted DGV.

Table 6-5 Dilution requirements – Nepean River releases

Contaminant	ANZG (2018) DGV (mg/L)	Treated water quality (mg/L)	Background water quality (mg/L)	Dilution required
Aluminium	0.055*	0.340#	0.010^	7.3
Copper	0.0014*	0.005#	0.001^	10.3
Zinc	0.008*	0.050#	0.003^	9.5
Manganese	0.100**	0.134#	0.067^	2.0

Table notes:

* *DGV for the protection of aquatic ecosystems (95% protection) as typically recommended for slightly to moderately disturbed ecosystems – refer ANZECC (2000). Aluminium DGV specified for pH >6.5. No modifications or corrections to these DGVs have been applied regarding bioavailability and/or toxicity modifying factors such as pH, hardness, alkalinity or organic carbon.*

** *DGV for the recreational purposes – refer NHMRC (2008). The ANZG (2018) DGV for the protection of aquatic ecosystems is significantly higher with a value of 1.9 mg/L. No modifications or corrections to the NHMRC (2008) DGV has been applied.*

^ *The background concentrations were derived from median analysis of sampling events from June 2020 to June 2021 at sites upstream of the release point (sites N66A and N66B). 36 samples for Aluminium. 6 samples for Copper, Manganese and Zinc. All results represent filtered concentrations.*

\# *Treated water quality – refer to Section 4.7.2.1 for sources*

6.2.2.3.2 Mixing zone analysis

Aluminium, Copper and Zinc

The dilution profiles predicted from the CORMIX modelling indicate that the dilution requirements presented in Table 6-5 are not achieved in the near field or in the reach between the release point and the Wallacia Weir.

Under the majority of the scenario conditions, the modelling also predicts the potential for extensive bank attachment downstream of the release point.

Manganese

The dilution profiles predicted from the CORMIX modelling indicate that the dilution requirements for Manganese may be achieved in the reach between the release point and the Wallacia Weir. The dimensions of the mixing zone are predicted to vary significantly across the range of scenarios.

For the 2036 scenarios, the zones are predicted to vary longitudinally from 8 m to 32 m with half widths of between 3 m and 7 m.

The modelling again predicts the potential for extensive bank attachment downstream of the release point.

6.2.2.3.3 Interpretation – Nepean River near field impacts

While the near field modelling has predicted that the primary mixing zone criteria (refer Section 4.7.4.3.3) cannot be achieved for the majority of the metals during the relevant severe wet weather release events, the potential for toxicity and environmental harm arising from these releases is considered to be low due to the same factors discussed in Section 6.2.1.3.3, and provided below. As a result of this analysis, no mixing zones are proposed for the AWRC releases to the Nepean River.

- Temporally, the events are very infrequent. On average the more severe 3 x ADWF events are predicted to occur two to three times per year.
- The release events are also typically short lived with durations ranging from less than one day to intermittently over three days.
- The releases correlate with conditions of significant flow within the river. Low residence times within the weir pool and the downstream reaches are therefore expected during these release events.
- Mixing zones are generally only considered in terms of management of continuous releases of treated wastewater, where releases may present a risk of harm to fish migration or harm to sedentary species. Consequently, mixing zone modelling is generally focussed on periods of extended dry weather.
- Application of ANZG (2018) toxicant DGVs in the near field impact assessments could be considered as very conservative as the DGVs are applicable to chronic exposure situations. Therefore, these DGVs are deemed more relevant to exposure durations of greater than three days. No applicable shorter-term toxicity based guidance values are available under the ANZG (2018) and ANZECC (2000) guidelines.

Alternative release structures may improve mixing and dilution of releases in the waterways. Similar to South Creek, potential modifications could include the provision of submerged piped release infrastructure located within the weir pool. Such a design may assist in increasing initial mixing and dilution in the vicinity of the release point. It may further reduce the risk of attachment of the plume to the river banks (refer to Section 7.3.1).

6.3 Supplementary assessments

6.3.1 NorBE assessment

6.3.1.1 Background and assessment criteria

The proposed location of the environmental flows pipeline and the Warragamba River release point lie within the declared Sydney Drinking Water Catchment (SDWC). Refer to Figure 6-156.

SEARS item 2c requires an assessment of the impacts in line with the following: "*if the proposal will achieve a neutral or beneficial effect (NorBE) on water quality within the declared Sydney Drinking Water Catchment (SDWC)*."

The NorBE guidelines (SCA, 2015) state that:

A neutral or beneficial effect on water quality is satisfied if the development:

a) has no identifiable potential impact on water quality, or

b) will contain any water quality impact on the development site and prevent it from reaching any watercourse, waterbody or drainage depression on the site, or

c) will transfer any water quality impact outside the site where it is treated and disposed of to standards approved by the consent authority.

6.3.1.2 Analysis

As shown in Figure 6-156, the SDWC extends to the Warragamba weir, which is ~1.2 km downstream of the Warragamba Dam wall. While there are no extractions for potable or other purposes within this reach, it does officially lie within the SDWC boundary.

The impacts on this reach have not been assessed with the WQRM as the model boundary starts below the weir and does not extend to the dam wall. Therefore, analysis of the potential impacts from the operation of the proposed AWRC releases have been undertaken through analysis of monitoring data as well as an assessment of the expected change in water quality that may result from the introduction of the AWRC releases.

6.3.1.2.1 Monitoring data

The *Warragamba environmental flows options assessment report 4* published by DPI in 2013 presented a summary of the characteristics and water quality conditions for sub-reach 19a, which extends from the dam wall to Megarritys Creek. This creek joins the river ~480 m downstream of the weir and in the vicinity of the existing WaterNSW release point.

Sub-reach 19a, generally receives very limited inflows from the surrounding catchments but infrequently can also receive major flows in the event of Warragamba Dam spilling. Flushing of this reach, particularly upstream of the weir, is therefore limited due to the presence of Warragamba Dam, particularly during dry weather.

The DPI report states that there was limited recent water quality data available for this reach. However, historic data at the Warragamba weir monitoring site (N642) collected during the 1980s indicated occasional algal blooms. Other measures of water quality were generally acceptable at that time although elevated levels of nitrogen were observed (median total nitrogen level of 0.85 mg/L and a median oxidised nitrogen level of 0.43 mg/L).

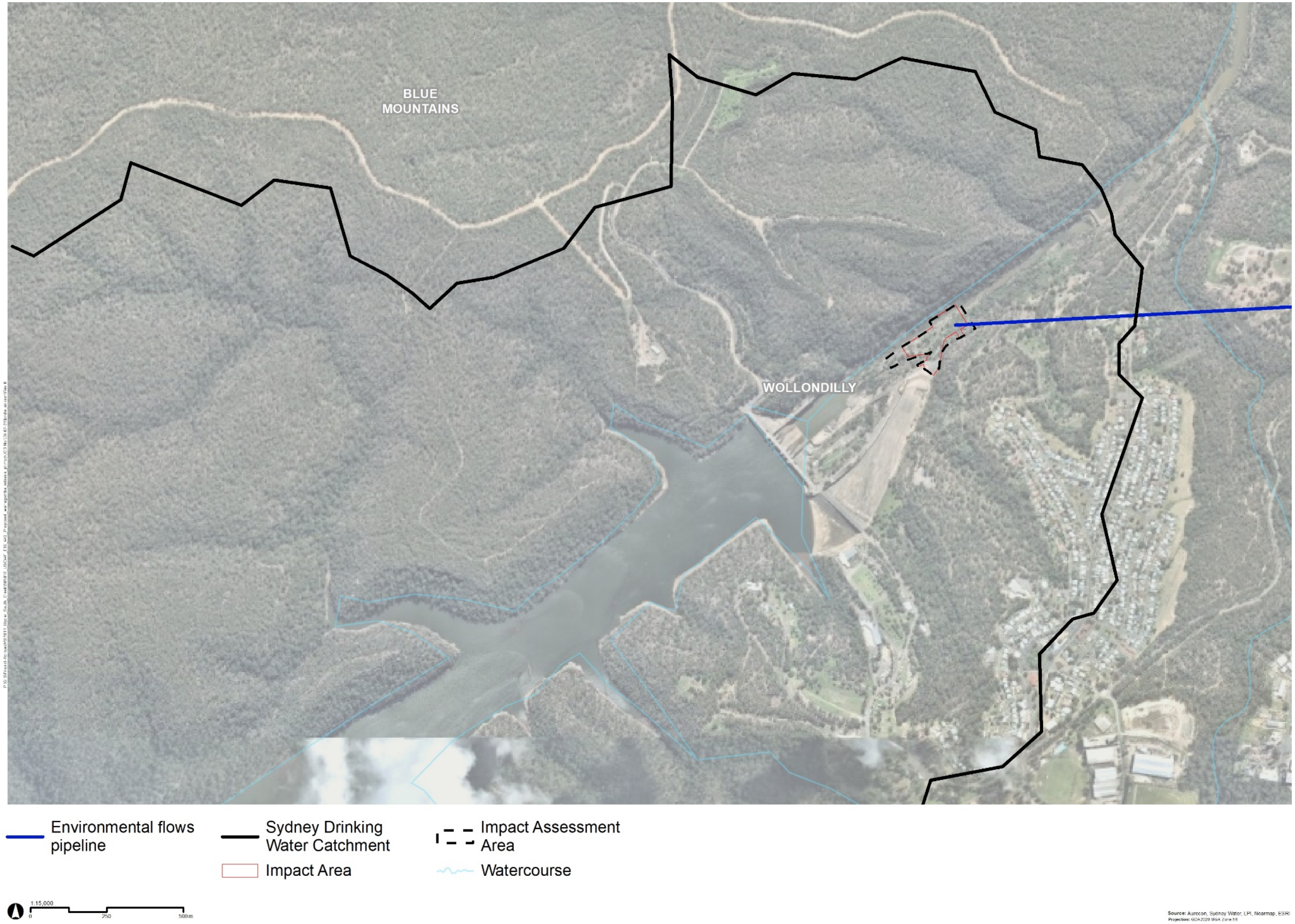


Figure 6-156 Location of the proposed Warragamba release point relative to the SDWC boundary

The report also states that more recent data suggests that conductivity and levels of total and oxidised nitrogen have decreased, potentially due to the closure of the old Warragamba WWTP. However, other than during spill events from Warragamba Dam there remains limited flow in this section, derived primarily from the small catchments draining to this section of the river and seepage from Warragamba Dam wall. High levels of iron bacteria have been noted in this reach, indicating iron-rich groundwater is reaching the surface.

Analysis of monitoring data from 2018 at site N642 indicates more recent increases in total nitrogen, oxidised nitrogen, total phosphorus and chlorophyll *a*. Refer Figures 6-157 to 6-160 below. Many of the datapoints indicate non-compliance with the project waterway objectives.

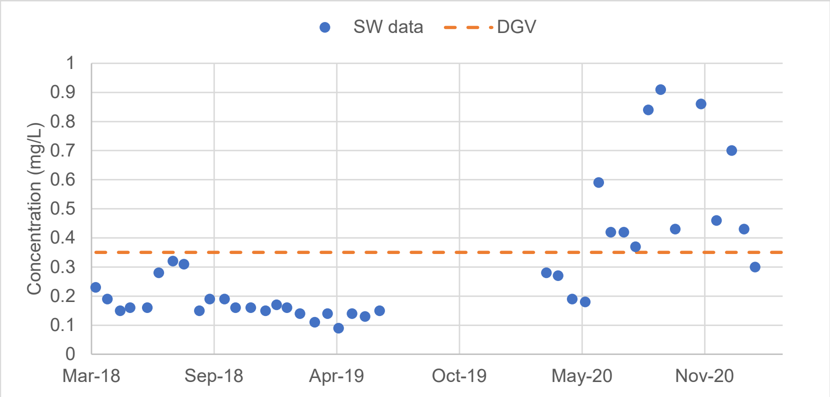


Figure 6-157 Monitoring data at site N642 – Total Nitrogen

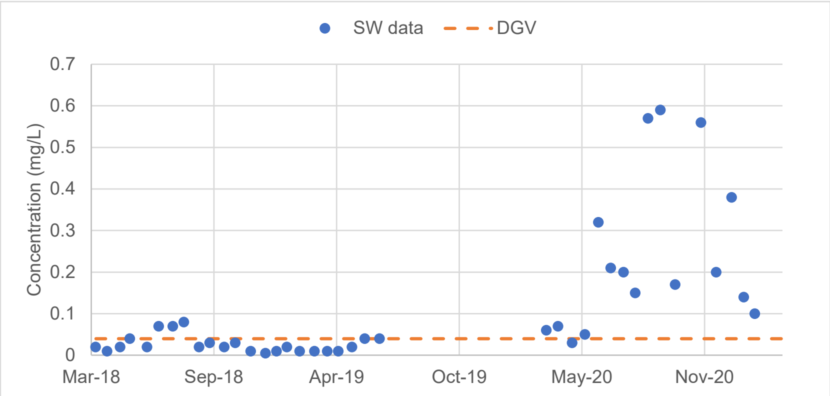


Figure 6-158 Monitoring data at site N642 – Oxidised Nitrogen

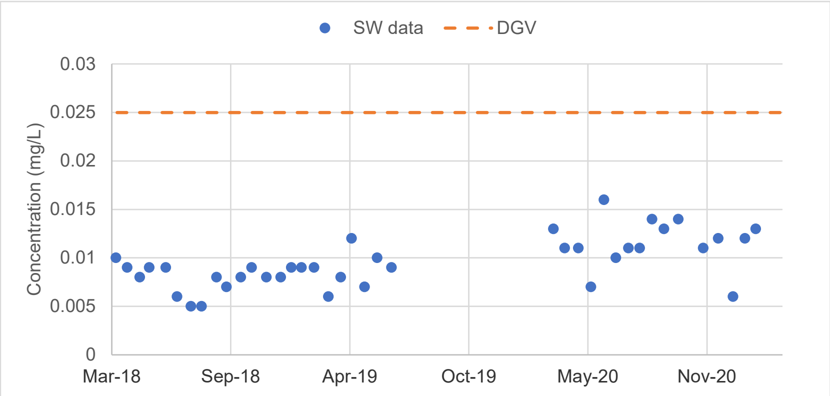


Figure 6-159 Monitoring data at site N642 – Total Phosphorus

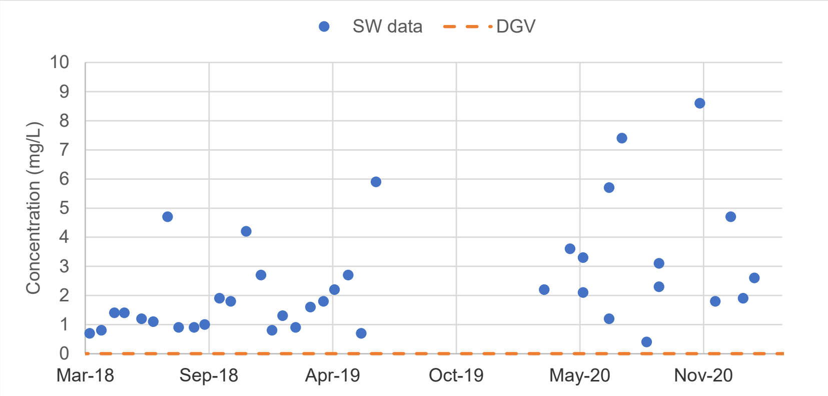


Figure 6-160 Monitoring data at site N642 – Chlorophyll *a*

6.3.1.2.2 Impacts from AWRC releases

Introduction of a consistent source of advanced treated water at the head of this poorly flushed reach is expected to be beneficial to the local water quality conditions. Due to the nature and limited extents of the reach (1.2 km length and 10 to 50 m width), it has been assumed that the water quality will generally correlate with that of the treated water being released (refer Section 4.6.3.5.1 and Table 4-7). As a result of the release rates, the introduced flow regime is also expected to improve water quality conditions by improving flushing times. Impacts from groundwater and/or seepage from the dam wall are also likely to be mitigated due to the significant inflows and reduced residence times.

Based on these assumptions, the following key conclusions are drawn:

- it is expected that there would be an improvement in water quality within this section of the river within the SWDC
- while the reach lies within the SDWC boundary, it lies downstream of the Warragamba dam wall and there are no extractions for potable or other purposes
- If the environmental flows pipeline is not built and no treated water flows are released to the Warragamba River, the project would have no impact on the SDWC.

6.3.2 Sensitive environments

As discussed in Section 5.4, two MNES were identified within the study area, namely habitat for the Macquarie Perch (Macquaria australasica), and also a section of the river that runs through the Blue Mountains World Heritage Area. No other specific sensitive environments were identified other than those relating to recreational activities.

With respect to the MNES, the potential impacts on these environmental matters is addressed in the Aquatic Ecology Impact Assessment.

With respect to the recreational areas, impacts on two sites were evaluated downstream of the Nepean release point using output from the WQRMs. The sites selected for this analysis were Wallacia Weir and Penrith Weir.

The assessment has focussed on enterococci as a primary pathogenic indicator, and has also focussed on the Stage 1 releases under low loading from the other WWTP/WRPs (scenario HN05).

Figures 6-161 and 6-162 present the corresponding results for upstream of Wallacia Weir (dry and wet years respectively). Similarly, Figures 6-163 and 6-164 present the results for upstream of Wallacia Weir for both dry and wet years.

Under all scenarios, locations and climatic conditions, the impacts from the AWRC are predicted to have minimal or no impact on enterococci concentrations. This is due to the level of treatment, including reverse osmosis and disinfection that is provided to the AWRC releases.

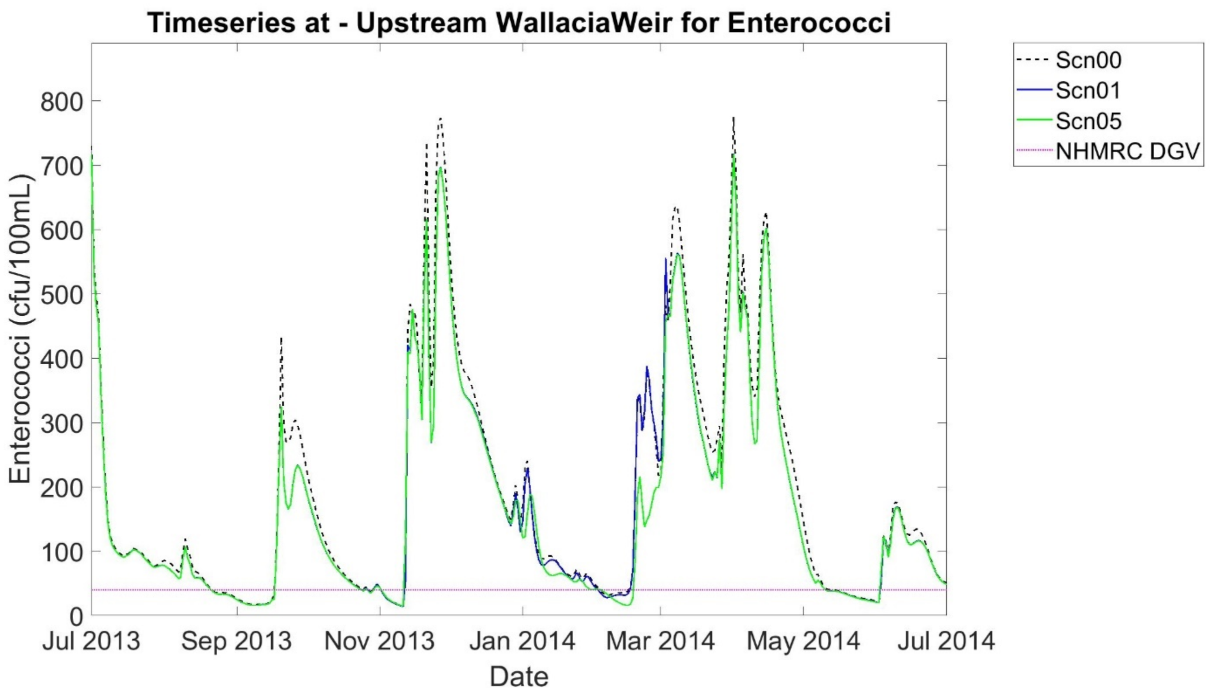


Figure 6-161 Timeseries of predicted Enterococci concentrations upstream of Wallacia Weir (2036 releases/dry year)

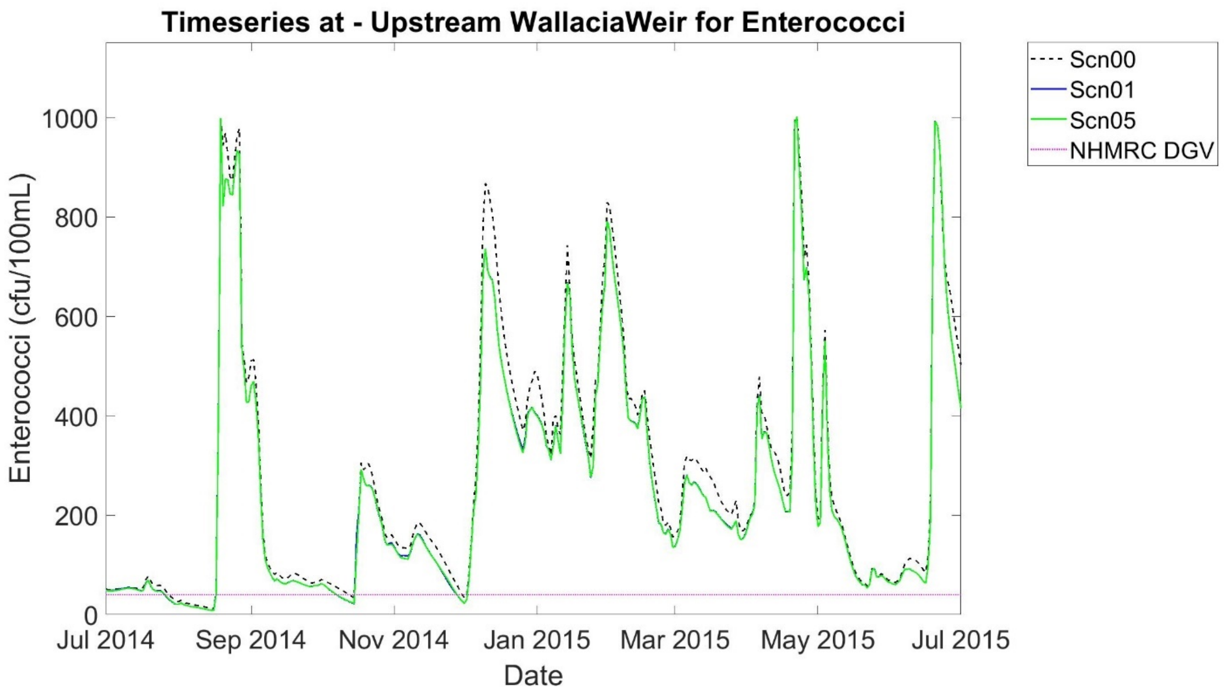


Figure 6-162 Timeseries of predicted Enterococci concentrations upstream of Wallacia Weir (2036 releases/wet year)

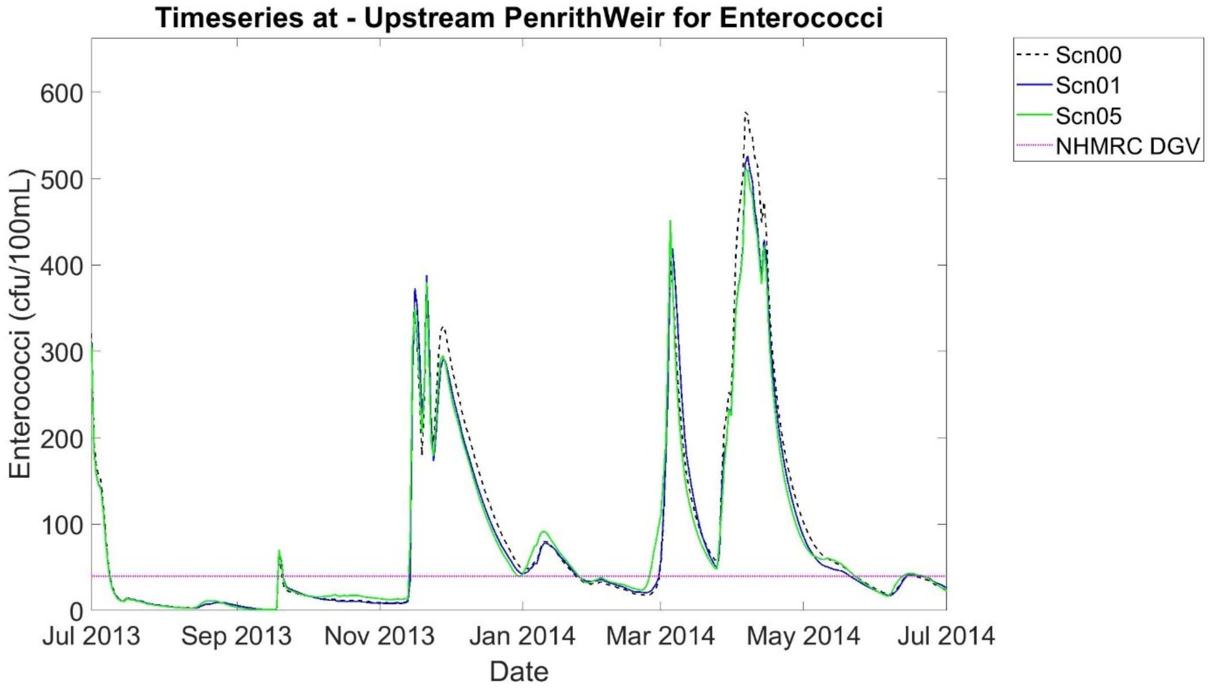


Figure 6-163 Timeseries of predicted Enterococci concentrations upstream of Penrith Weir (2036 releases/dry year)

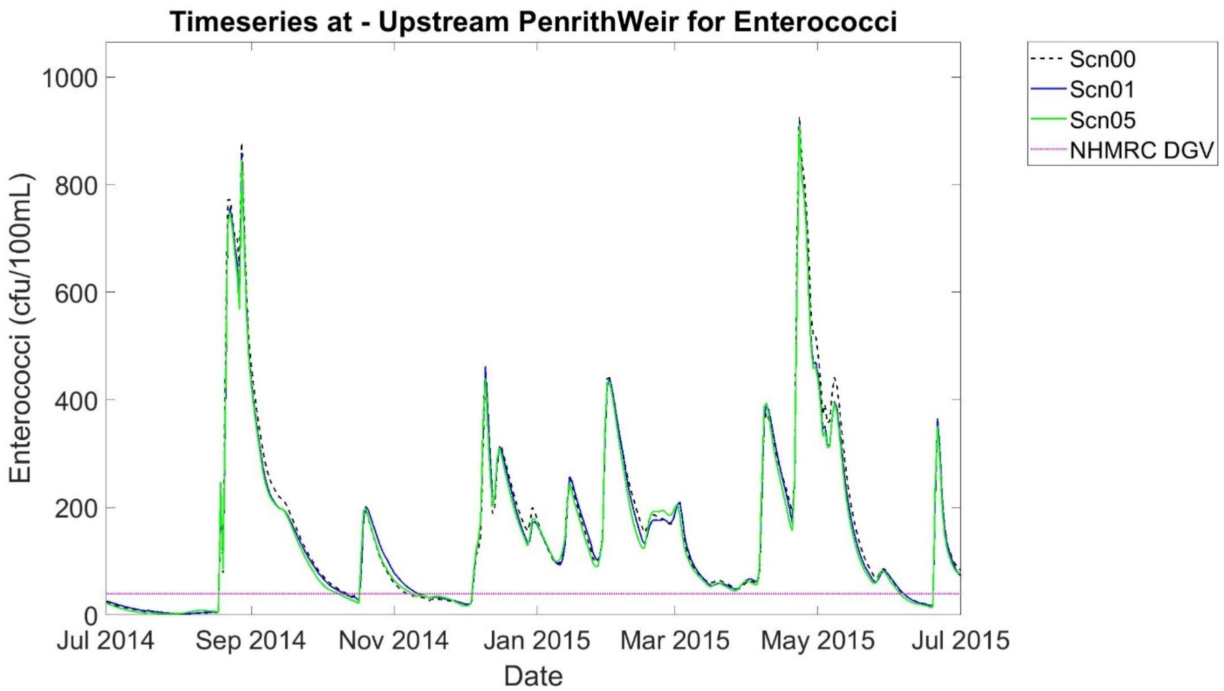


Figure 6-164 Timeseries of predicted Enterococci concentrations upstream of Penrith Weir (2036 releases/wet year)

6.3.3 Regulatory framework to manage nutrient load inputs

The EPA has developed a regulatory framework to manage nutrient load inputs to the Hawkesbury Nepean River from wastewater treatment plants (EPA, 2019). The objective is to meet the community's environmental values for the river and provide wastewater treatment plant operators with alternatives to meet those nutrient loads. The framework has been applied to Sydney Water's existing Environment

Protection Licences (EPLs) and would be applied to the project's EPL. It includes limits on nutrient concentrations, interim caps on nutrient loads and a framework for nutrient trading and offsets.

The framework divides the river system into different zones, and proposes separate limits on nutrient concentrations and/or caps on nutrient loads within each zone. With respect to the AWRC project, releases to the Nepean and Warragamba rivers are within Yarramundi subzone 2. Releases to South Creek are within Sackville subzone 2.

The Framework includes three options for the management of wastewater flows in the Upper South Creek catchment. The project best represents Option 2, which involves no discharge to South Creek, but some to the Nepean River. Load limits are therefore provided for Option 2, however no concentration limits are specified.

A summary of the predicted future loads for existing treatment plants within the subzones, and with inclusion of the proposed AWRC loads, is provided in Table 6-6 and Table 6-7. The estimates include future growth predictions and planned upgrades at treatment plants. The proposed initial WWTP/WRP load limits (2024-2028) from the framework are also included.

Total predicted nutrient loads for 2036 and 2056 have been determined to be below the framework limits for each subzone. The additional loads from the AWRC releases are therefore considered consistent with the EPA's framework.

Table 6-6 Estimated nutrient loads within Yarramundi Subzone 2

WWTP/WRP	2036 -TN (kg/yr)	2056 – TN (kg/yr)	2036 -TP (kg/yr)	2056 -TP (kg/yr)
Penrith	11,749	6,765	199	203
Wallacia	2,563	2,675	26	26
Winmalee	19,090	20,267	489	518
St Marys AWTP	5,810	5,856	84	84
AWRC	8,538	17,172	383	1,673
Total Estimated Load	**47,749**	**52,735**	**1,180**	**2,504**
Load limit	**55,300**	**55,300**	**3,450**	**3,450**

Table 6-7 Estimated nutrient loads within Sackville Subzone 2

WWTP/WRP	2036 -TN (kg/yr)	2056 – TN (kg/yr)	2036 -TP (kg/yr)	2056 -TP (kg/yr)
St Marys	37,911	50,793	991	1,283
Riverstone	33,344	37,991	759	641
Quakers Hill	21,613	7,517	350	165
AWRC	1,686	3,362	105	211
Total Estimated Load	**94,554**	**99,664**	**2,205**	**2,301**
Load limit	**126,100**	**126,100**	**2,710**	**2,710**

Notes on Tables 6-6 and 6-7

- *Load limits taken from Table 7, Regulating nutrients from sewage treatment plants in the Lower Hawkesbury Nepean River catchment (EPA, 2019).*
- *Load limit for Sackville excludes loads from McGraths Hill and South Windsor (non-Sydney Water facilities).*

7 Mitigation and monitoring measures

7.1 Proposed treatment and release strategy

The primary form of mitigation and management of environmental impacts on the receiving waterways is through the implementation of the AWRC treatment and release strategy. As outlined below, and in more detail in Section 4.6.3.5.1, the proposed strategy allows for the release of suitably treated water that is considered appropriate to the conditions expected in the receiving waterways

The proposed AWRC release strategy comprises of the following climatically driven release conditions:

- During dry weather (<1.3 x ADWF), releases to the Nepean River (and the Warragamba River if applicable) will consist only of advanced treated water. No releases to South Creek will occur.
- During mild wet conditions (1.3 to 1.7 x ADWF), releases to the Nepean River will consist of a blend of advanced and tertiary treated water. If applicable, the provision of releases to the Warragamba River will cease as unblended advanced treated water will not be available. No releases to South Creek will occur.
- During moderate wet conditions (1.7 to 3 x ADWF), releases to the Nepean River will consist of either a blend of advanced and tertiary treated water, or unblended tertiary treated water, dependent on the availability of advanced treated water. Once the treated water pipeline reaches capacity, releases of advanced treated water to South Creek will occur. There is again no availability of advanced treated water for releases to the Warragamba River.
- During severe wet conditions (>3 x ADWF), releases to the Nepean River consist only of tertiary treated water. Releases to South Creek will consist of a blend of primary and advanced treated water. There is again no availability of advanced treated water for releases to the Warragamba River.

Therefore, under dry weather operating conditions only advanced treated water will be released. This high level of reverse osmosis treatment has been demonstrated in the modelling to generally result in improvements in downstream water quality.

During wetter conditions, the treated water releases in the Nepean River consist of a combination of advanced treated water and tertiary treated water being released from the AWRC. The levels of contaminants in these releases are therefore still considered to be very low. Conditions within the river are predicted to be modified during these releases with higher flows and potentially deteriorated water quality.

In the more severe and infrequent wet weather events, the releases to the Nepean River will represent tertiary treated water. The levels of contaminants in these releases are therefore still considered to be low and treated to industry standards. Conditions within the river are predicted to be further modified during these releases with more extreme higher flows and deteriorated water quality.

For South Creek, releases will only occur under moderate to severe wet weather conditions. The level of treatment for these releases will vary depending on the intensity of the rainfall. During moderate conditions, only advanced treated water will be released. During more severe wet weather, when more substantial flows in the creek are expected, a blend of advanced and primary treated water will be released.

Finally, if releases from the AWRC were to be implemented in the Warragamba River, these releases would only consist of advanced treated water so as to maintain downstream levels of dilution and improved water quality.

7.2 Monitoring requirements

Monitoring of the treated water releases, and also within the receiving waterways, are key to determining the potential for impacts on ambient water quality from operation of the AWRC. More specifically, the monitoring will allow for the following:

- Monitoring of treated water in the different release streams will allow for assessment of the performance of the AWRC over a range of operating conditions. It will also identify any risks from elevated levels of contaminants.
- Monitoring in the waterways will allow for evaluation of impacts on the receiving waters relative to upstream/ background site conditions.

The following sections present provisional details regarding the monitoring programs for the post-commissioning operational phase of the AWRC. It is however proposed that the location, type and frequency of the monitoring programs will be developed in consultation with the EPA.

All monitoring is to follow Sydney Water's standard sampling and laboratory procedures and also align with the Approved Methods for the Sampling and Analysis of Water Pollutants in NSW (DECC, 2008). The application of these DECC (2008) methods is prescribed within the project specific SEARs.

7.2.1 South Creek

Based on the findings of the impact assessments, the following monitoring requirements are proposed.

7.2.1.1 Treated water

The following monitoring activities for the treated water are recommended prior to its release to South Creek.

7.2.1.1.1 Timing and frequency

Monitoring of the water quality of the wet weather release stream should be triggered when releases to South Creek commence. Sampling of the release stream should be undertaken daily during the occurrence of any release longer than 2 hours.

Hourly monitoring of the release volumes should also be undertaken during a release event, using a suitable calibrated flow meter.

7.2.1.1.2 Location

A suitable location within the AWRC for monitoring of water quality should be identified. The location should allow for monitoring of representative samples from the final AWRC release stream i.e. accounting for blending of primary treated and advanced treated water streams.

Similarly, the flow meter should be suitably located to allow for monitoring of the final release stream flowing to South Creek.

7.2.1.1.3 Analysis

The proposed water quality analysis of the final release stream is to include a suite of parameters which is considered appropriate to the release stream and the receiving environment. Provisionally it is proposed to adopt the same suite of analytes as approved in the EPL monitoring program for Sydney Water's St Marys AWTP and Penrith WRP.

All parameters are to be analysed by Sydney Water's Laboratory Services laboratories, or an alternative NATA accredited laboratory.

7.2.1.1.4 Reporting protocols

Reporting protocols would be in accordance with Sydney Water's standard laboratory procedures and would be reported to the EPA as required by the provisions of the EPL.

7.2.1.2 Ambient monitoring

Due to the infrequent and weather driven nature of the releases, an event-based monitoring program is recommended for the receiving waters of South Creek.

7.2.1.2.1 Timing and frequency

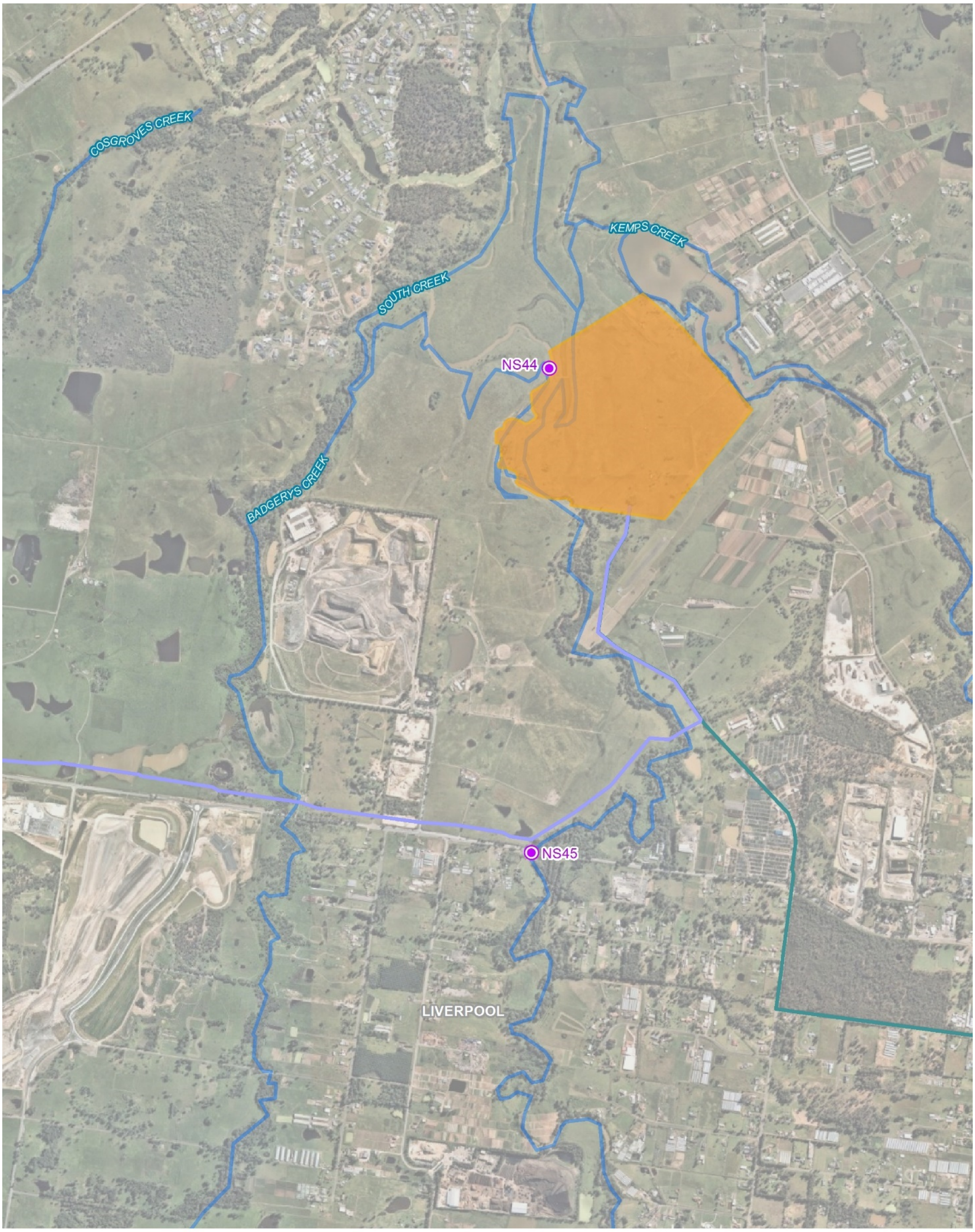
The timing of sampling should be undertaken so as to target release events from the AWRC to the creek. Provisionally it is recommended that sampling occurs daily during the occurrence of any release longer than 2 hours. Sampling should also be undertaken on the day following cessation of releases to the creek.

As these events will be weather dependent and difficult to forecast, modelling may allow determination of trigger rainfall conditions that are expected to initiate releases to South Creek. Procedures should also be developed that allow for early notification of expected rainfall events that may exceed the modelled trigger conditions. Such early notification will allow for prompt mobilisation of sampling teams with prepared sampling equipment.

7.2.1.2.2 Locations

Two sampling locations are provisionally proposed for the monitoring program as shown in Figure 7-1. This will include sites upstream and downstream of the creek release point. The upstream location will act as a background site with the downstream site used to determine the level of any impacts from the releases. Provisionally, it is proposed that the existing baseline monitoring locations of NS45 and NS44 should be retained as the upstream and downstream sites respectively.

Further details regarding the baseline monitoring can be found in the *Upper South Creek Advanced Water Recycling Centre - Baseline Monitoring Program 2020-23* (Sydney Water, 2020d).



- Monitoring sites
- Advanced Water Recycling Centre
- Treated Water Pipeline
- Brine Pipeline
- Watercourse

1:25,000
0 250 500 m

Source: Aurecon, Sydney Water, LPI, Nearmap, ESRI
Projection: GDA2020 MGA Zone 56

Figure 7-1 Proposed monitoring locations on South Creek

7.2.1.2.3 Wet weather sampling procedures

The key concerns relating to event-based monitoring, particularly wet weather sampling, relates to the safety of the personnel undertaking the sampling as the creek is likely to be in high flow conditions and also potentially in significant flood. For these reasons, sampling is only recommended from sites with safe land access. No boat based sampling is proposed. Sampling should be undertaken using one of the following methodologies (to be confirmed for each sampling site):

- An extendable rod and bottle that allows for a sample to be extracted from the creek at a distance safely away from the bank edge, and in faster flows.
- A rope and weighted bottle arrangement (e.g. Van Dorn Sampler) for sampling from bridges (or other structures) to allow for the sample to be extracted from the water surface or at a specified depth.
- A drone-based collection system for remote sampling from a selected point within the creek away from the creek banks.

For every sampling event, duplicate receiving water quality samples are to be undertaken, in line with EPA approved STSIMP protocols, to account for local variability in the waterway conditions.

Field observations such as visual indications of pollution, odour and any other important general comments will be noted at each site. A qualitative flow rate within the river will also be recorded.

7.2.1.2.4 Sampling protocols

All water quality sampling will be conducted in accordance with Sydney Water’s quality management system and health and safety plans and procedures.

7.2.1.2.5 Sampling depths.

All water samples to be collected from the surface or within a depth of 0.5 m.

7.2.1.2.6 Analysis

Analysis of the water quality within the creek is to include a suite of parameters which is considered appropriate to the release stream and the receiving environment. Provisionally it is proposed to adopt the same suite of analytes as approved in the current EPL and STSIMP for St Marys AWTP and Penrith WRP.

All parameters to be analysed by Sydney Water’s Laboratory Services laboratories or an alternative NATA accredited Laboratory.

No in-situ profiling or measurements to be undertaken due to safety risks.

7.2.1.2.7 Reporting protocols

Reporting protocols would be in accordance with Sydney Water’s standard laboratory procedures and would be reported to the EPA as required by the provisions of the EPL and STSIMP.

7.2.2 Nepean River and Warragamba River

Based on the findings of the impact assessments, the following monitoring requirements are recommended for the Nepean River. Similarly, if releases to the Warragamba River are also to be included in the AWRC release strategy, these requirements are to apply to both rivers.

7.2.2.1 Treated water

The following monitoring activities for the treated water is recommended prior to release.

7.2.2.1.1 Frequency

Analysis of water quality in the final release stream(s) should be undertaken in line with the requirements of the EPL monitoring program for Sydney Water's St Marys AWTP and Penrith WRP.

Additional sampling and analysis of the water quality in the release streams is also recommended on a daily basis during the more moderate to severe wet weather events that introduce tertiary treated water to the releases.

Daily monitoring of the release volumes should also be undertaken using a suitable calibrated flow meter.

7.2.2.1.2 Location

Suitable locations within the AWRC for monitoring of water quality should be identified. The locations should allow for monitoring of representative samples from the final AWRC release streams i.e. accounting for blending of tertiary treated and advanced treated water streams. If releases from the AWRC to the Warragamba River are implemented, monitoring should also include all relevant release streams.

Flow metering should also be suitably located to allow for monitoring of the final release streams.

7.2.2.1.3 Analysis

The proposed water quality analysis of the final release stream is to include a suite of parameters which is considered appropriate to the release stream and the receiving environment. Provisionally it is proposed to adopt the same suite of analytes as approved in the EPL monitoring program for Sydney Water's St Marys AWTP and Penrith WRP.

All parameters to be analysed by Sydney Water's Laboratory Services laboratories, or an alternative NATA accredited Laboratory.

7.2.2.1.4 Reporting protocols

Reporting protocols would be in accordance with Sydney Water's standard laboratory procedures and would be reported to the EPA as required by the provisions of the EPL.

7.2.2.2 Ambient monitoring

It is proposed that the existing STSIMP is extended to include the following monitoring requirements.

7.2.2.2.1 Frequency

The sampling frequency will be every three weeks, matching the current STSIMP. In line with this program, the frequency may vary between 17 to 25 days to allow sampling on different days of the week and to match with the STSIMP sampling runs.

7.2.2.2.2 Locations

Two sampling locations are provisionally proposed for monitoring of the Nepean River. This will include one site upstream and one site downstream of the release point. The upstream location will act as a background site with the downstream site used to determine the level of any impacts from the releases. Provisionally, it is proposed that the existing baseline monitoring locations of N66A or N67 be retained as the upstream site, and N66 or N66B be retained as the downstream site (refer to Figure 7-2). The location of these monitoring sites will be finalised in consultation with the EPA and also with consideration of access requirements and the results from the baseline monitoring program.

A further two sampling locations are proposed for monitoring of the Warragamba River if releases from the AWRC are to be introduced to this river. Provisionally the baseline monitoring location N642 may be retained as the downstream monitoring site. A new sampling location would be required upstream of the Warragamba River release point.

Further details regarding the baseline monitoring can be found in the *Upper South Creek Advanced Water Recycling Centre - Baseline Monitoring Program 2020-23* (Sydney Water, 2020d).

7.2.2.2.3 Sampling procedures

Sampling will occur regardless of weather conditions. For every sampling event, duplicate receiving water quality samples are to be undertaken, in line with EPA approved STSIMP protocols, to account for local variability in the waterway conditions.

Field-based parameters (such as temperature, dissolved oxygen, pH, conductivity, turbidity) will be recorded on one of the samples.

Field observations such as visual indications of pollution, odour and any other important general comments will be noted at each site. A qualitative flow rate within the river will also be recorded.

7.2.2.2.4 Sampling protocols

All water quality sampling to be conducted in accordance with Sydney Water's quality management system and health and safety plans and procedures.

7.2.2.2.5 Sampling depths.

All water samples to be collected from the surface or within a depth of 0.5 metres of the surface.

7.2.2.2.6 Analysis

Analysis of the water quality within the river(s) is to include a suite of parameters which is considered appropriate to the release stream and the receiving environment. Provisionally it is proposed to adopt the same suite of analytes as approved in the current EPL and STSIMP for St Marys AWTP and Penrith WRP.

All parameters to be analysed by Sydney Water's Laboratory Services laboratories or an alternative NATA accredited Laboratory.

7.2.2.2.7 Reporting protocols

Reporting protocols would be in accordance with Sydney Water's standard laboratory procedures and would be reported to the EPA as required by the provisions of the EPL and STSIMP.

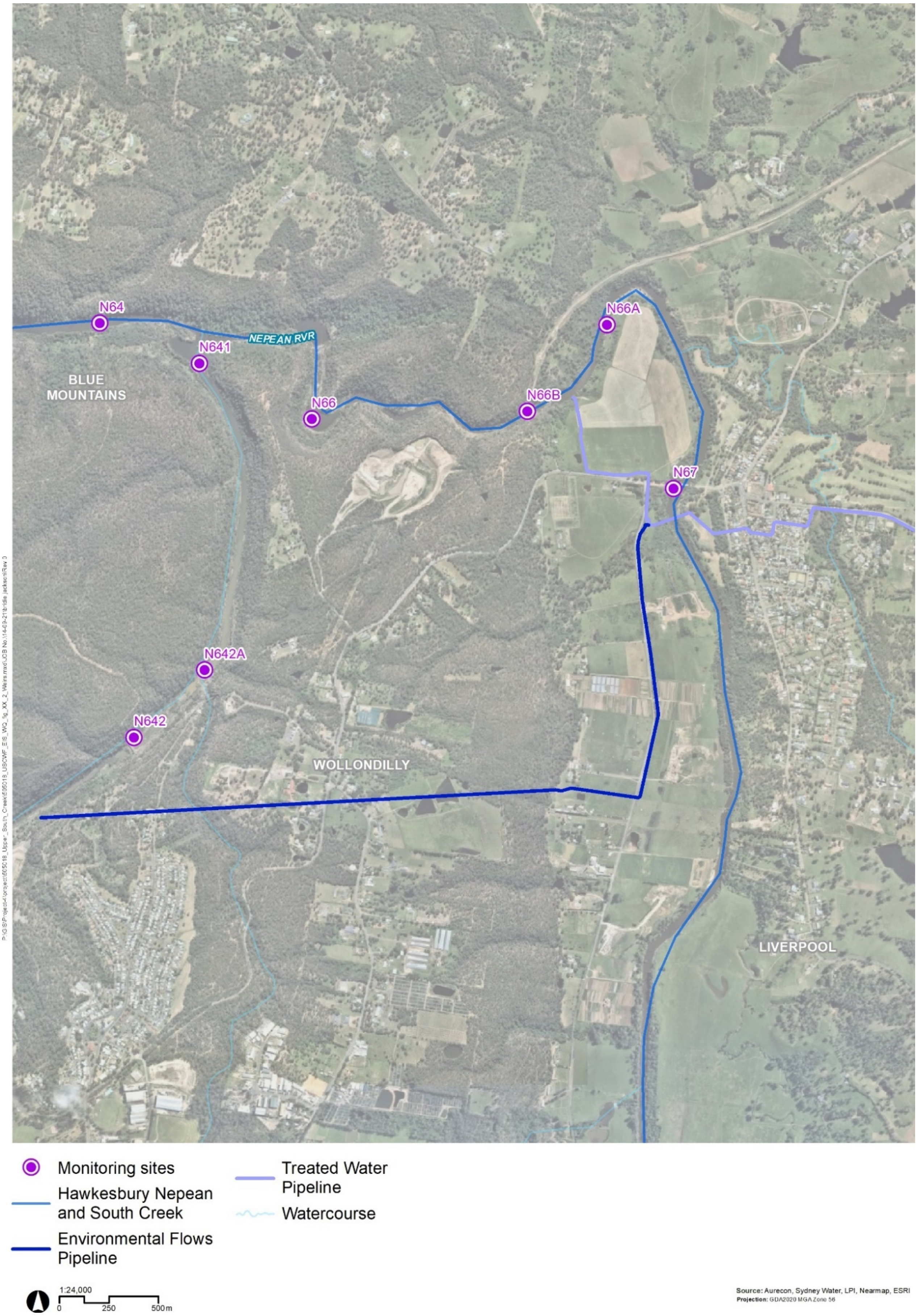


Figure 7-2 Proposed monitoring locations on the Nepean and Warragamba rivers

7.3 Additional mitigation recommendations

7.3.1 Release infrastructure

Alternative release structures may improve mixing and dilution of the releases in the waterways. Potential modifications could include the provision of piped release infrastructure located in the creek and/or rivers so that the release ports would be submerged during the release of treated water from the AWRC. Such designs may assist in increasing initial mixing and initial dilution in the vicinity of the release points. It may further reduce the risk of attachment of the plume to creek/river banks.

It is therefore recommended that opportunities to improve mixing and dilution of releases be considered during detailed design. The feasibility/acceptance of alternative options would need to be assessed against a number of key considerations including (but not limited to) engineering requirements, operations and maintenance risk, geomorphology and energy dissipation requirements.

7.3.2 South Creek release conditions

The impact assessment has identified the risk of wet weather releases to South Creek commencing from the AWRC when flows within the creek are relatively low, and/or are still increasing as a result of rainfall runoff in the upstream catchment (refer to Section 6.1.1.5.2).

Some mitigation to this risk is already provided in the release strategy discussed above as the smaller (potentially less broadly distributed) wet weather events will generate releases of only advanced treated water to the creek. Due to the level of treatment, these releases are predicted to have either a negligible or potentially a short term beneficial environmental impact even if creek flows are minimal. Conversely, when there are larger rainfall events, it is more likely that the rainfall will be more broadly distributed and the releases will be subject to greater dilution from elevated creek flows.

While it was also identified that the risk of relatively low creek flows may be a result of the daily time steps used in both the Source catchment and the AWRC modelling, the timing of releases is an important aspect that should be investigated further and, if viable, managed so as to allow for sufficient dilution and mixing in the creek.

It is therefore recommended that additional sub-daily modelling is undertaken to investigate the likelihood/frequency of scenarios where treated water releases to South Creek could occur when creek flows are low and/or are still increasing in response to rainfall. If necessary and where feasible, opportunities and management strategies should also be identified to minimise the risk of environmental harm from AWRC releases while flows in South Creek become sufficiently established to allow for adequate dilution and mixing.

8 Conclusions

This report presents the findings of a hydrodynamic and water quality impact assessment that has been developed to support and inform the EIS for the Upper South Creek AWRC. The report consequently provides analysis of how the releases of treated water from the AWRC may potentially impact the hydrodynamics and water quality in the receiving waters of South Creek and the Hawkesbury Nepean River system during its operation.

Two future operational stages of the AWRC (Stage 1 and Future stages) have been evaluated along with cumulative impacts of other expected changes in the surrounding catchments. Key assumptions regarding the modelling of the AWRC's operation include:

- The scenarios assumed the AWRC is operating at full capacity i.e. 50 ML/d in 2036 and 100 ML/d in 2056. Prior to reaching these operating levels, the extent of the impacts on the receiving water, whether they be beneficial or detrimental, are likely to be proportionally reduced.
- Similarly, the scenarios assume no allowance for beneficial reuse. Therefore the volume of treated water generated by the AWRC is released to the waterways and no percentage is supplied for recycling purposes.

The modelling has also assumed the adoption of a treatment and release strategy specifically developed for the AWRC. The strategy allows for the release of treated water to the waterways of South Creek and the Hawkesbury Nepean River, with consideration of the sensitivities and characteristics of each waterway. The adoption of the treatment and release strategy forms the key mitigation measure for the avoidance of environmental harm from the AWRC releases. Extensive monitoring is also proposed with respect to the release streams and the downstream waters.

Also key to the modelling has been the simulation of future conditions in the catchments and the river and creek systems. Background scenarios representative of future time horizons have taken account of changes in land use, population growth, etc. The modelling therefore allows for assessment of cumulative loads on the waterways as well as assessment of the impacts from the AWRC relative to expected future conditions.

Details regarding the residual impacts on the individual waterways, relative to expected future background conditions, are presented in the summaries below.

8.1 South Creek

Based on the modelling undertaken, the environmental impacts on South Creek from the wet weather releases are considered to present a low risk of affecting long term ambient water quality and/or ecosystem health. This classification is predominantly a result of the treatment and release strategy that is proposed for the AWRC, and has been based on the following factors:

The consequences of the releases being limited due to:

- the advanced treatment applied to minor and moderate wet weather releases (up to 3 x ADWF) that have the potential to result in improved water quality conditions (dilution) downstream within the creek
- the timing in wet weather that coincides with increased catchment runoff and flows within the creek, aiding dilution and mixing

- the limited release durations and low residence times in the creek due to the higher flow regimes, meaning impacts would generally be short lived with concentrations generally returning to background levels within a day of releases ceasing
- the low potential for increasing the risk of algal blooms as the releases occur in times of wet weather with rapid flushing of the creek, and away from extended dry periods when eutrophication is most likely
- the limited increases in overall catchment loads with the most significant contributions of 0.6% TN and 0.3% TP predicted for a wet rainfall year, under the assumed 2036 plant capacity

The likelihood of the impacts is also assumed to be limited due to:

- the low release frequency with release events expected to only occur under more severe rainfall conditions, provisionally estimated to range over 3 to 14 days per year
- the very low frequency of releases that includes primary treated water, provisionally expected to occur two to three times per year but frequencies may vary between zero and six events per year

Importantly, the impacts of the AWRC releases were compared against baseline conditions (circa 2020) and corresponding background conditions (circa 2036 and 2056) as well as against the relevant waterway objectives. This analysis allowed for an understanding of the cumulative impacts from future catchment conditions as well as residual impacts from just the AWRC releases.

From assessment of the future catchment ‘background’ conditions, without inclusion of the AWRC releases, many changes were predicted in the water quality of the creek, including:

- The expected development in the catchment of South Creek in some cases is predicted to generate improved water quality for some parameters relative to current undeveloped conditions. This is predominantly due to the modified flow regime which is a key factor in the water quality within the creek, particularly with respect to nutrient levels and algal biomass.
- Under the 2020 baseline scenario conditions, the WQRM realistically represents the development of segregated reaches under sustained dry weather periods. This results in isolated, stagnant water pools that are potentially affected by nutrient fluxes from the sediment as well as considerable algal growth.
- Under the future ‘developed’ scenarios, the flow regime is significantly modified in terms of both base flows and event peaks, due to the more impermeable land uses assumed in the future developed topologies that represent the growth areas. Under these modified conditions, the modelling predicts lower concentrations in some parameters due to the higher flows and increased connectivity throughout the creek.
- Therefore, despite the potential increases in inflow concentrations and loads of nutrients from the catchments under future land use conditions, the water quality is in fact predicted to improve for some indicators such as chlorophyll a.
- The influence of the other WWTPs/WRPs within the catchment are also seen in the future background scenarios with marked differences in total and inorganic nutrient indicators in the lower sections of the creek. In particular, the planned upgrades to Quakers Hill, McGraths Hill and South Windsor WWTPs are seen to result in significant changes in water quality.

With respect to the potential impacts from the AWRC releases, the assessment identified the following findings:

- Where applicable waterway objectives exist, analysis of the impacts from the AWRC releases on annual median profiles indicate there is no change to the level of compliance compared to the background scenario for any of the water quality parameters considered in the assessment. This applies to both the EES and ANZG derived waterway objectives.
- The magnitudes of the AWRC releases can have a significant influence on relative impacts in the creek. Not only do the release volumes increase in the more severe wet weather events, but the treatment level is also affected. Under mild to moderate wet weather events (< 3 x ADWF), the releases provide a degree of dilution as they comprise only of advanced treated water. Conversely, under more severe wet weather conditions, the releases represent higher levels of primary treated water and can therefore contribute to short-lived increases in creek concentrations of some contaminants.
- Releases from the AWRC are infrequent and only occur during more severe wet weather events. Modelling of the releases indicate the frequency to range from 2 to 6 release events per year depending on rainfall. At the time of these releases, the residence time in South Creek is also predicted to be low due to the elevated flows in the creek resulting from the wet weather conditions.
- All impacts from the releases are predicted to be short lived with concentrations generally returning to background levels within a day due to the higher flow regimes (and consequently low residence times) that are experienced in the ephemeral and non-ephemeral sections of the creek at the time of the wet weather releases.
- From analysis of the Stage 1 nutrient loads, it was estimated that the AWRC releases accounted for <0.01% of the total nitrogen load for the South Creek catchment in a dry year, increasing to 0.5% in a wet year. Similarly, the AWRC accounted for up to 0.3% of the total phosphorus loads in a wet year.
- While the impacts are generally of similar magnitude, the impacts predicted for the scenarios that represented the Parkland stormwater management strategy were marginally greater than the scenarios that represented the BaU stormwater management strategy.
- With respect to events where the AWRC advanced treatment (reverse osmosis) process needs to be shut down to avoid brine overflows, these events were determined to be very infrequent e.g. about six times in 10 years in 2026, and up to 15 times in 10 years when the AWRC is operating at 50 ML/day. Due to this low frequency, only one occurrence was predicted in the representative wet year. The relative impacts on creek water quality from the shutdown event were predicted to be insignificant.
- Under the 2056 (Future stages) scenarios, the impacts were generally predicted to be greater relative to those predicted under the 2036 (Stage 1) scenarios, however there remained a demonstratable low risk of affecting long term ambient water quality in South Creek. The spatial extent of impacts downstream also remained largely unaffected.
- As a consequence of the above findings, the relative impacts on water quality from the AWRC releases were concluded to be very minor relative to the cumulative impacts from the surrounding catchment.

8.2 Nepean River

For the Nepean River, the impacts on water quality from the treated water releases immediately downstream of the release point were predicted to be predominantly positive. Further downstream of the initial footprint (~20 km), the impacts were predicted to be either negligible, or predicted not to present negative effects on the river water quality and/or ecosystem health. The positive/neutral nature of these impacts are principally a result of the comparatively low release volumes, and the high quality of the treated water being released within the Wallacia Weir pool.

Similar to the South Creek assessment, the impacts of the AWRC releases have been compared against baseline conditions (circa 2020) and corresponding background conditions (circa 2036 and 2056) as well as against the relevant waterway objectives. The analysis therefore allowed for an understanding of the cumulative impacts from future catchment conditions as well as residual impacts from just the AWRC releases.

From assessment of the future catchment 'background' conditions, without inclusion of the AWRC releases, the following conclusions were drawn:

- In common with the South Creek modelling, the differences between the background scenarios (circa 2036 and 2056) and the baseline scenario (circa 2020) were again influenced heavily by modifications in the flow regime, in terms of both base flows and event peaks.
- The increase in impermeable land and also the increases in releases from the other WWTPs/WRPs is predicted to result in a marginal shift in the salinity wedge downstream of Sackville Bend
- The changes in the inflows and the nutrient loads under future conditions are shown to have a potentially complex impact on the water quality and subsequently biogeochemical environment in the Hawkesbury Nepean River system. This complexity is increased by the presence of the weirs and how releases from these structures may vary with changing flow dynamics.
- In general, the annual median concentrations of total nitrogen, total phosphorus and enterococci are close to, or above the relevant waterway objective downstream to approximately Wisemans Ferry, in both the background and baseline scenarios. Under the background conditions, variations are predicted across different reaches of the river, although this does not impact on the overall trend of compliance.
- In common with the South Creek modelling, the influence of the existing WWTPs/WRPs is also seen in the future scenarios with marked differences in total and inorganic nutrient indicators in several reaches. In particular, the effects of the planned upgrades to the Winmalee WWTP and Penrith WRP, and the decommissioning of the North Richmond WWTP, can be observed in the results for the future scenarios, generally seen as reductions in the concentrations of many nutrient species.

With respect to the potential impacts from the AWRC releases, the assessment identified the following findings:

- Based on the modelling undertaken, the introduction of the AWRC releases provided for many improvements in the water quality of the Nepean River. As discussed in more detail below, these improvements in river water quality generally consisted of lower concentrations of nutrients and pathogens, as well as higher levels of dissolved oxygen in the reaches downstream of the releases.

- With the introduction of the AWRC releases, water levels within the Wallacia Weir pool were predicted to increase, and despite anticipated rates of extraction, allow for a more consistent flow regime in the Nepean River downstream of the weir.
- The improvements in water quality in the reaches immediately downstream of the releases included reductions in nutrient concentrations as well as increases in dissolved oxygen levels. These reductions in downstream ambient concentrations in turn demonstrated the potential for improved localised compliance with relevant waterway objectives, as well as a potential reduction in the risk of algal blooms. The footprints of these improvements extended to 15 to 20 km (from the Wallacia release point), and 20 to 30 km (from the South Creek confluence).
- Further downstream of these initial footprints, the impacts were predicted to be either negligible, or predicted not to present negative effects on the river water quality and/or ecosystem health.
- The chlorophyll *a* concentrations and risk of algal blooms was also generally improved due to reduced nutrient concentrations and improved flushing under dry conditions, but small changes in water clarity and temperature mean that overall the median algal biomass is likely to be similar to background conditions despite the introduction of the AWRC releases.
- During more severe wet weather, higher concentrations of nutrients were introduced in the AWRC releases due to the higher content of tertiary treated water. These ‘spikes’ presented localised downstream effects but were short-lived, and the nutrient concentrations were predicted to drop quickly to levels lower than the background simulation within a few days. As discussed above for South Creek, the frequency of these more severe weather events was determined to be relatively low.
- The predicted influence of the AWRC releases on water quality between the wet and dry years is generally consistent, and the differences in the levels of impact were predicted to be relatively minor, particularly when compared to the inter-annual differences that occur naturally between these climatic and hydrological conditions.
- From analysis of the Stage 1 nutrient loads, it was estimated that the AWRC releases accounted for <1% of the total nitrogen load in the wider Hawkesbury Nepean catchment for the representative wet and dry years. Similarly, the AWRC accounted for approximately 0.6% of the total phosphorus load in the dry year, increasing to 1% in the wet year.
- With respect to the advanced treatment shutdown scenario, similar to the South Creek modelling, there was only one event in the wet year where a shutdown of the advanced treatment (reverse osmosis) process was predicted. The consequences to the Nepean River releases included changes to daily release volumes and water quality. The relative impacts from this event were however again predicted to be insignificant.
- Impacts were generally predicted to be greater for the 2056 releases relative to 2036 conditions, with greater reductions in annual medians for some parameters (total nitrogen, total phosphorus, FRP, salinity, enterococci) and increases to others (oxidised nitrogen and ammonia). Higher spikes in concentrations were also predicted during wet weather events when tertiary treated water is released. Overall, the AWRC releases under the assumed 2056 conditions continued to demonstrate a relative improvement in water quality in downstream reaches of the Nepean River, relative to the background conditions.
- Based on analysis of predicted annual median concentrations, the footprint downstream of the weir increased to ~20 km under 2056 conditions relative to ~15 km under 2036 conditions. Similarly, the footprint downstream of the South Creek confluence increased to ~30 km under 2056 conditions relative to ~20 km under 2036 conditions.

- As a high-level summary, across the range of climatic years that were analysed, the impacts on water quality in the reaches downstream of the release point were predicted to be predominantly positive, particularly when compared to the circa 2036 and 2056 background conditions. The positive nature of these impacts is principally attributed to the comparatively low release volumes, the quality of the treated water being released as well as the increases in ambient flows, flushing and dilution from the advanced treated water being released.

8.3 Warragamba River

The Nepean River and Warragamba River release scenarios effectively split the flows from the AWRC between release points in the Nepean and Warragamba rivers, with the Warragamba releases replicating the current WaterNSW release regime from the Warragamba Dam, and only consisting of advanced treated water. Residual flows of treated water from the AWRC are then released into the Wallacia Weir pool as per the Nepean release scenarios.

With many similarities to the Nepean release scenarios, the modelling indicates that this alternative release strategy would generally improve water quality in the downstream river reaches. The following findings were also identified:

- Due to the complexity of the river system and the presence of several weir structures, impacts on the hydrodynamics and water quality varied from the previously discussed Nepean release scenarios, extending beyond the confluence point of the Warragamba and Nepean rivers.
- Through changing the release regime to accommodate the releases to the Warragamba River, water levels in the Wallacia Weir pool were frequently reduced relative to those predicted for the Nepean release scenarios. Consequently, during Stage 1, flows were significantly reduced downstream of Wallacia Weir relative to those predicted for the Nepean release scenarios.
- With introduction of the AWRC releases, increases in some nutrient species were predicted within the downstream reaches of the Warragamba River, upstream of the confluence with the Nepean River. Combined with lower suspended solids, a potential risk of increased algal growth was identified from the modelling. The magnitude of the blooms was however not predicted to be significant and this growth in biomass was not seen immediately downstream of the confluence with the Nepean River.
- Improvements in other aspects of water quality were predicted within the downstream reaches of the Warragamba River with reduced levels of turbidity and pathogens. Dissolved oxygen levels were also predicted to improve as a result of the AWRC releases.
- Regardless of the changed flow conditions, the differences between the Nepean River and Warragamba River release scenarios and the Nepean release scenarios were relatively small and did not change the predicted level of compliance with relevant project waterway objectives.
- Under 2056 release conditions, impacts within the Warragamba River are predicted to be similar to the 2036 scenario. This is due to the same strategy and similar release conditions being applied for both scenarios.

8.4 Near field impacts

Near field impact assessments were undertaken with respect to the potential for toxicity in the releases to South Creek and the Nepean River. From analysis of the treatment applied under various weather conditions, it was determined the risk from toxicants in the releases would be limited to severe wet weather conditions when flows from the AWRC would be greater than 3 x ADWF. Under these conditions, tertiary treated water would be released to the Nepean River and elevated proportions of primary treated water would be released to South Creek.

Through application of CORMIX modelling, it was determined that the primary mixing zone criteria could typically not be achieved for the relevant severe wet weather release events in either the creek or the river. This applied to both 2036 and 2056 conditions, although it was predicted that the potential for higher dilutions to be realised in the near field was generally lower under 2056 conditions.

Despite these modelling outcomes, it was concluded that the potential for toxicity and environmental harm arising from the AWRC releases was considered to be low due to the characteristics of the release conditions. These characteristics included:

- Temporally, the events are very infrequent. On average the more severe 3 x ADWF events are predicted to occur two to three times per year but frequencies may vary between zero and six events per year.
- The release events are also typically short lived with durations ranging from less than one day to intermittently over three days.
- The releases correlate with conditions of significant flow and corresponding low residence times.
- Mixing zones are generally only considered in terms of management of continuous releases of treated wastewater, where releases may present a risk of harm to fish migration or harm to sedentary species.
- Application of ANZG (2018) toxicant DGVs in the near field impact assessments could be considered as very conservative as the DGVs are applicable to chronic exposure situations. Therefore, these guideline values are deemed more relevant to exposure durations of greater than three days. No applicable shorter-term toxicity-based guidance values are available under the ANZG (2018) and ANZECC (2000) guidelines.

As noted in Section 7.3.1, alternative release structures may improve mixing and dilution of releases in the waterways. Potential modifications could include the provision of piped release infrastructure located in the creek and/or rivers so that the release ports would be submerged during the release of treated water from the AWRC. Such designs may assist in increasing initial mixing and dilution in the vicinity of the release point. It may further reduce the risk of attachment of the plume to creek/river banks. It is therefore recommended that opportunities to improve mixing and dilution of releases be considered during detailed design.

8.5 NorBE assessment

An assessment against the NorBE guidelines (SCA, 2015) was undertaken as the proposed location of the environmental flows pipeline and the Warragamba River release point lie within the declared Sydney Drinking Water Catchment.

The assessment concluded that introduction of a consistent source of advanced treated water at the head of the river reach below Warragamba Dam would be potentially beneficial in terms of water quality. This reach is currently inadequately flushed and frequently exhibits poor water quality conditions.

Due to the nature and limited extents of the reach (1.2 km length and 10 to 50 m width), it is expected that the water quality will generally correlate with that of the advanced treated water being released. As a result of the release rates, the introduced flow regime is also expected to improve water quality conditions by improving flushing times. Impacts from groundwater and/or seepage from the dam wall are also likely to be mitigated due to the significant inflows and reduced residence times.

Based on these findings, the following key conclusions were drawn:

- it is expected that there would be an improvement in water quality within this section of the river within the SWDC
- while the reach lies within the SDWC boundary, it lies downstream of the Warragamba dam wall and there are no extractions for potable or other purposes
- If the environmental flows pipeline is not built and no treated water flows are released to the Warragamba River, the project would have no impact on the SDWC

8.6 Sensitive environments

Two Matters of National Environmental Significance were identified within the study area, namely habitat for the Macquarie Perch (Macquaria australasica), and also the Blue Mountains World Heritage Area. Based on the findings of the Aquatic Ecology Impact Assessment, the proposed action is not likely to have a significant impact on the matters of national environmental significance

No other specific sensitive environments were identified, except those relating to recreational activities. Therefore, for the purposes of this study, impacts on two of the primary recreational sites were evaluated, namely Wallacia Weir and Penrith Weir.

Based on the results of the modelling, the impacts from the AWRC were predicted to have minimal or no impact on pathogenic concentrations at these two sites. This was determined to be a result of the level of treatment, including reverse osmosis and disinfection that is provided to the AWRC releases.

8.7 Regulatory framework to manage nutrient load inputs

Total predicted nutrient loads for 2036 and 2056 have been determined to be below the framework limits for each subzone. The additional loads from the AWRC releases are therefore considered consistent with the EPA’s framework.

8.8 Mitigation and monitoring measures

As discussed previously, the adoption of the AWRC treatment and release strategy forms the key mitigation measure for the avoidance of environmental harm from the AWRC releases. In addition to the implementation of this strategy, Section 7 presents recommendations regarding monitoring of the release streams as well as ambient monitoring at sites upstream and downstream of the proposed release points. Further recommendations are also provided with respect to release conditions for South Creek and the potential for modifications to the release infrastructure.

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