Appendix G Ecohydrology and Geomorphology Impact Assessment

Upper South Creek Advanced Water Recycling Centre

Ecohydrology and Geomorphology Impact Assessment

Report for Sydney Water

September 2021

Executive Summary

Sydney Water is planning to build and operate the Upper South Creek Advanced Water Recycling Centre (AWRC) to service the South West and Western Sydney Aerotropolis Growth Areas. This report has been prepared to support the AWRC Environmental Impact Statement (EIS). The objective of this study is to provide an assessment of how the releases of treated water from the AWRC during operation may impact on the ecohydraulics (instream water conditions that relate to habitat) and geomorphology (physical form and function) in the receiving waters of South Creek and the Hawkesbury Nepean River system. Note that these two aspects of waterways are often considered under the overarching term of 'ecohydrology' – the study linking biotic response to flow regimes.

The main aspects covered in this report are:

- Potential geomorphic impacts of treated water releases from the Project on the ecohydraulics and geomorphology of the Nepean River downstream of the AWRC release location at Wallacia Weir.
- Potential geomorphic impacts of the treated water releases (impact scenarios) to the Nepean River relative to baseline and background flow scenarios, as provided by Sydney Water. The baseline scenario represents current conditions, background scenarios incorporate the cumulative impacts of other expected changes in the surrounding catchments (i.e., land use) independent of the AWRC project, and impact scenarios include the Stage 1 and Ultimate treated water release conditions associated with the AWRC.
- Potential geomorphic impacts of wet weather releases from the AWRC to South Creek relative to baseline and background scenarios as provided by Sydney Water. The baseline scenario represents current conditions, background scenarios incorporate the cumulative impacts of other expected changes in the surrounding catchments (i.e., land use) independent of the AWRC project, and impact scenarios include the Stage 1 and Ultimate wet weather release conditions associated with the AWRC.

There are limited formal metrics or thresholds for geomorphology and ecohydraulics to apply to an assessment for an EIS. Based on the requirements of the SEARS, this study has developed two types of assessments, one is based on ecohydraulic modelling and the other is based on hydrologic metrics.

- **Ecohydraulic modelling** relies on hydraulic modelling and metrics that describe characteristics of flow or the channel of relevance to biota. Several criteria were identified as relevant to these systems and relate to both morphology (this report) and ecology (Aquatic Ecology Impact Assessment report). They provide surrogates for 'habitat' available to biota and enable the indication of change based on hydrologic scenarios. The four hydraulic metrics focused on in this study are water surface elevation, wetted perimeter, velocity, and shear stress.
- **Hydrologic metrics** can be used to demonstrate changes in the hydrologic regime for different scenarios. As with hydraulic metrics (mentioned above) the hydrologic metrics must be relevant to biota. To ensure this is the case we drew upon an approach developed for the Western Sydney region, the Urban Stream Flow Impact Assessment (USIA) method (Vietz et al., 2018, Kermode et al 2020). Specific flow-related metrics relate biotic condition and response to the character of the flow regime, as previously

applied to the South Creek catchment (Vietz et al., 2018, Kermode et al 2020). The hydrologic metrics are assessed in terms of the relative difference between baseline, background, and impact scenarios. For the Nepean River, the absolute values were not used due issues with the hydrologic model underrepresenting baseflow conditions. Further details on this issue are provided in the Hydrodynamic and Water Quality Impact Assessment report (Aurecon Arup, 2021). All data and values were used in the South Creek analysis.

This report does not delve into biotic response to ecohydraulic or geomorphic changes. Considering the physically based nature of the outputs provided in this report (i.e., velocity, depth) requires interpretation by ecologists of the thresholds of change on biota (part of this EIS process). Ultimately, as evident in the Impact Assessment (Section 6), the relative changes between baseline and future scenarios often provide clear evidence of the scale of the impact.

Overall, this report found that the predicted geomorphological impacts along the Nepean River and Warragamba River would be minor and of low risk, during both the construction and operation phases. These results were consistent across the flow regime based on a detailed analysis of hydraulic metrics under median flow (50th percentile), low flow (90th percentile) and high flow (10th percentile) conditions.

Given the low impact to geomorphic conditions along the Nepean River as a result of the treated water releases at Wallacia Weir no additional mitigation measures are recommended except for on-going monitoring of bank stability and change upstream of Wallacia Weir. Should the monitoring indicate an increase in erosion along this reach then modification of flows releases, or further bank stabilisation measures should be considered.

Results for the ultimate AWRC release (100 ML/d) were very similar to Stage 1 (50 ML/d), with the most significant difference being the further increase in water levels upstream of Wallacia Weir. The additional increase in water surface elevation as a result of the higher AWRC release, may result in the potential for additional impacts on bank erosion in the reach upstream of Wallacia Weir. This may require additional mitigation measures to be investigated, such as targeted bank protection. These changes will be identified through the on-going monitoring program

In South Creek, this study has assessed the geomorphic impact of wet weather releases from the AWRC. The analysis indicates the impacts are low and no additional mitigation measures are proposed to address these wet weather flow impacts. It is important to note that excess stormwater runoff as a result of urbanisation creates significantly greater implications for streamflow patterns that may lead to geomorphic degradation (erosion) and loss of habitat. Mitigation measures associated with stormwater flows or flooding are addressed in the Surface Water and Flooding Impact Assessment reports.

Construction of waterway crossings for pipelines and release structure outlet infrastructure must consider geomorphic impacts such as disturbance of soils and vegetation and liberation of sediments. However, impacts of both trenchless and trenching operations for pipeline crossings can be mitigated with the range of standard measures. Given appropriate application of measures, operation of infrastructure will not impact on geomorphic or ecohydraulic conditions. On-going bank and channel erosion monitoring is also recommended during operation of the AWRC at each treated water release location and on South Creek at the Warragamba Pipeline crossing. Any monitoring at the Warragamba Pipeline crossing of South Creek should be scoped and agreed with WaterNSW.

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Glossary and Abbreviations

Term	Abbreviation	Definition
Advanced Water Recycling Centre	AWRC	Proposed centre for treatment of the wastewater prior to reuse applications or release, which includes liquids treatment, advanced water treatment, solids treatment, odour treatment, and residuals management
Annual Exceedance Probability	AEP	The Annual Exceedance Probability is a measure of the frequency of a rainfall or flood event. It is the probability that a given event will be exceeded in any one year.A one per cent event is a rainfall event with a one per cent chance of being exceeded in magnitude in any year.
Australian Height Datum	AHD	A common reference level used in Australia which is approximately equivalent to the height above sea level in meters.
Average Dry Weather Flow	ADWF	ADWF consists of average daily wastewater flows. ADWF is the average flow that occurs on a daily basis with no evident reaction to rainfall
Average Recurrence Interval	ARI	The Average Recurrence Interval, like the Annual Exceedance Probability, is a measure of the frequency of a rainfall or flood event. For example, a 100-year average recurrence interval event occurs or is exceeded on average once every 100 years.
Bed erosion threshold	-	This is the ratio of the shear stress of the flow on the bed of the waterway to the critical erosion shear stress of the bed sediment.
Bed load movement	-	The movement of sediment particles along the surface of a waterway. Bed load transport occurs when the shear stress on the bed exceeds the critical shear stress for the sediment.
Brine pipeline	-	A pipeline to transport brine (concentrated wastewater). Brine water is a by-product of reverse osmosis in the wastewater treatmentprocess.
Ecohydraulics		Instream water conditions that relate to habitat, such as velocity, shear stress and wetted perimeter.
Ecohydrology		The study linking biotic response to flow regimes. The ecohydraulics and geomorphology aspects of this are often considered under the overarching term of 'ecohydrology'.
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 developmentconsent decisions
Environmental flows		Environmental flows refer to water released from a dam or weir tosustain healthy rivers. Environmental Flows from the AWRC may be used, supplement or replace flows that would have been released from Warragamba Dam.
Environmental Values	EVs	Environmental Values for water are the qualities that make it suitablefor supporting aquatic ecosystems and human water uses. These qualities need to be protected from the effects of habitat alteration, waste releases, contaminated run-off and changed flows to ensure healthy aquatic ecosystems and waterways that are safe for community use.
Freshes	-	Flow greater than the median flow for the period of interest.

Geomorphology		The study of the physical form and function of features on the earths surface and their relation to its geological structures.
Horizontal Directional Drilling	HDD	Horizontal directional drilling is a minimal impact trenchless method of installing underground utilities such as pipes in a relatively shallow arcor radius along a prescribed underground path using a surface- launched drilling rig.
Mean Annual Runoff Volume	MARV	The average volume of stormwater runoff or stream flow occurring over a year
Probable Maximum Flood	PMF	The probable maximum flood is the maximum flood which can theoretically occur based on the worst combination of the probable maximum precipitation and flood-producing catchment conditions that are reasonably possible at a given location.
Project	-	The construction and operation of the Upper South Creek AdvancedWater Recycling Centre (AWRC), pipelines and all ancillary infrastructure
Release of water	-	To release water into a creek, river or the ocean
Secretary's Environmental Assessment Requirements	SEARs	These are issued by the Secretary of the NSW Department of Planning, Industry and Environment for projects that require an EIS. These SEARS provide the technical requirements for the impact assessment of each potential key issue.
Shear stress	-	Shear stress is a measure of the force of friction from the flow acting on the bed of the waterway. Bed load movement and sediment transport are a function of the shear stress.
Treated water pipeline	-	The pipeline that will convey the treated water to the release location.
Upper South Creek	USC	The catchment in which the AWRC will be located. South Creek releases to the Nepean River which flows directly into the Hawkesbury River and then releases out to the Pacific Ocean
Waterway Objectives	WWO	Defined as consisting of the community's environmental values and uses of the water and indicator(s) and corresponding numerical criteria to assess whether the waterway will support a particular environmental value or use.
Water surface elevation	WSE	The surface of the water in m AHD along the waterway
Wetted Perimeter	-	The length of the cross-sectional area that is "wet", i.e., in contact with the flow.
Zero flows	-	Also known as "cease to flow", which is where there is no surface flow in the waterway.

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1. Introduction

1.1. Background

This Ecohydraulics and Geomorphology impact assessment has been developed to support the Environmental Impact Statement (EIS) for the Upper South Creek Advanced Water Recycling Centre (AWRC) along with the treated water pipeline, environmental flows pipeline, brine pipeline and ancillary infrastructure (collectively referred to as 'the Project'). The AWRC will be located in the suburb of Kemps Creek in the Western Sydney Aerotropolis, NSW, with pipelines traversing Western Sydney from the Nepean River in the west, to the Georges River, Cabramatta in the east (Figure 1).

This report provides an assessment of how the releases of treated water from the AWRC during operation may impact the ecohydraulics (instream water conditions that relate to habitat) and geomorphology (physical form and function) in the receiving waters of South Creek and the Hawkesbury Nepean River system. Note that these two aspects of waterways are often considered under the overarching term of 'ecohydrology' – the study linking biotic response to flow regimes.

This report draws upon an understanding of the current flow regimes in the Nepean River and South Creek as well as future scenarios (background and impact scenarios) for hydrologic regimes as provided by Sydney Water. These future scenarios consider the AWRC releases as well as the cumulative impacts of other expected changes in the surrounding catchments (i.e., land use).

As the project is considered 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.

This report is one of several that assess impacts of the Project on receiving waters as shown in Figure 2 (Section 1.3).

1.2. Project Description

Sydney Water is planning to build and operate new wastewater infrastructure to service the South West and Western Sydney Aerotropolis Growth Areas. The proposed development will include a wastewater treatment plant in Western Sydney, known as the Upper South Creek Advanced Water Recycling Centre. Together, this Water Recycling Centre and the associated treated water and brine pipelines, will be known as the 'project'. An overview of the location of the proposed infrastructure is provided in Figure 1. Further details of each component of 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 ultimate capacity of up to 100 ML per day

- the AWRC will produce both advanced and high-quality treated water suitable for a range of uses including recycling, environmental flows and to minimise environmental impacts on receiving waterways.

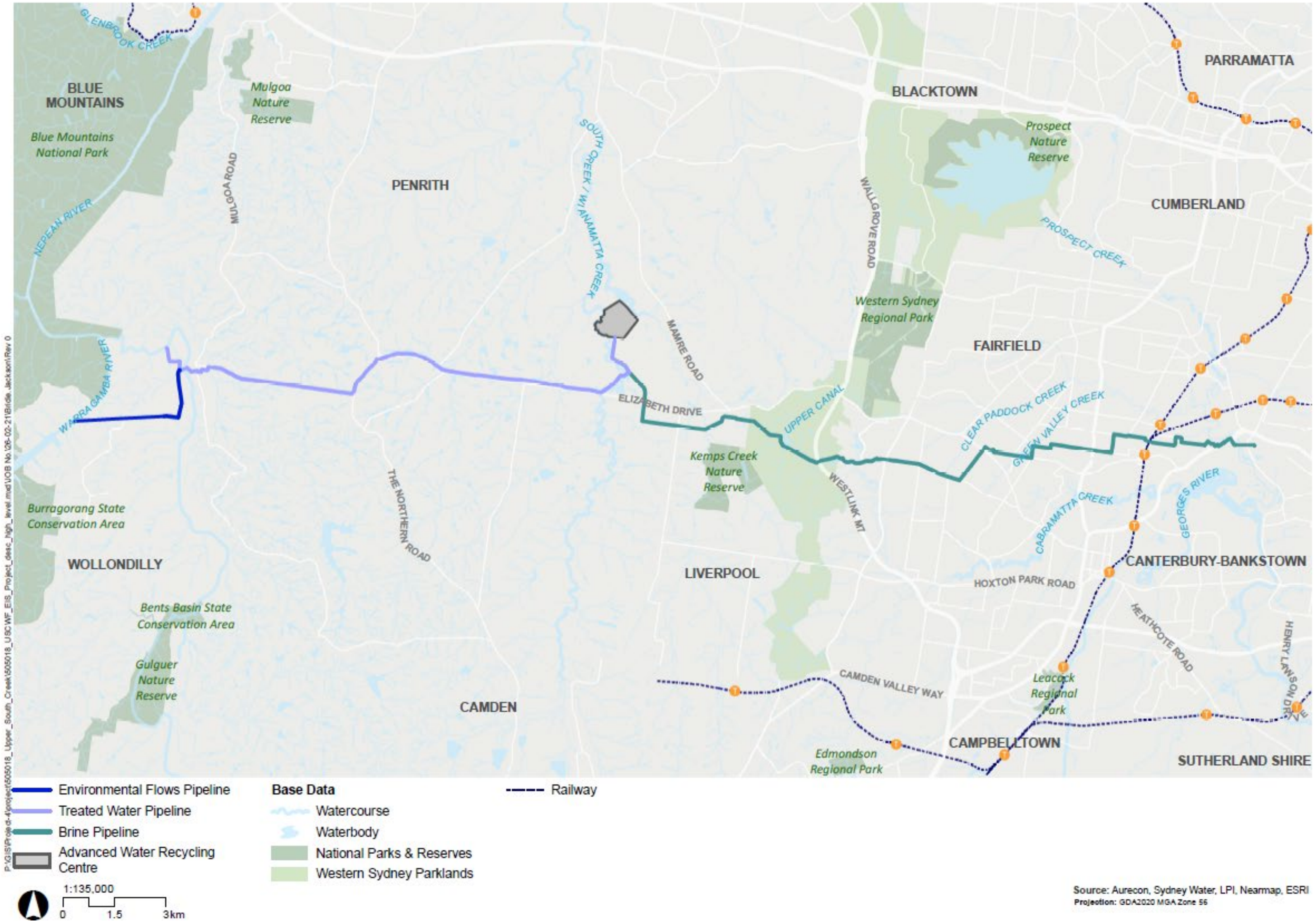
Treated water and brine pipelines

- a pipeline about 17 km long from the Advanced Water Recycling Centre to the Nepean River at Wallacia Weir, for the release of treated water.
- infrastructure from the Advanced Water Recycling Centre to South Creek to release excess treated water and wet weather flows.
- a pipeline about five kilometres long from the main treated water pipeline at Wallacia to a location between the Warragamba Dam and Warragamba Weir, to release high-quality treated water to the Warragamba River as environmental flows.
- a pipeline about 24 km long that transfers brine from the Advanced Water Recycling Centre to Lansdowne, in south-west Sydney, where it connects to Sydney Water's existing Malabar wastewater network

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

- building and operating the Advanced Water Recycling Centre to treat an average dry weather flow of up to 50ML per day
- building all pipelines to their ultimate capacity, but only operating them to transport and release volumes produced by the Stage 1 Advanced Water Recycling Centre

The timing and scale of 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.


BLUE MOUNTAINS
Blue Mountains National Park
Mulgoa Nature Reserve
PENRITH
BLACKTOWN
PARRAMATTA
Prospect Nature Reserve
CUMBERLAND
FAIRFIELD
Western Sydney Regional Park
Kemps Creek Nature Reserve
LIVERPOOL
CANTERBURY-BANKSTOWN
Burragorang State Conservation Area
WOLLONDILLY
Bents Basin State Conservation Area
Gulguer Nature Reserve
CAMDEN
CAMPBELLTOWN
Edmondson Regional Park
Leacock Regional Park
SUTHERLAND SHIRE
ELIZABETH DRIVE
THE NORTHERN ROAD
MULGOA ROAD
WALLGROVE ROAD
MAMRE ROAD
WESTLINK M7
HOXTON PARK ROAD
CAMDEN VALLEY WAY
HEATHCOTE ROAD
SOUTH CREEK / WIANAMATTA CREEK
NEPEAN RIVER
WARRAGAMBA RIVER
GLENBROOK CREEK
PROSPECT CREEK
UPPER CANAL
CLEAR PADDOCK CREEK
GREEN VALLEY CREEK
CABRAMATTA CREEK
GEORGES RIVER
Environmental Flows Pipeline
Treated Water Pipeline
Brine Pipeline
Advanced Water Recycling Centre
Base Data
Watercourse
Waterbody
National Parks & Reserves
Western Sydney Parklands
Railway
1:135,000
0 1.5 3km
Source: Aurecon, Sydney Water, LPI, Nearmap, ESRI
Projection: GDA2020 MGA Zone 56

1.3. **Study Objectives**

The objective of the Ecohydraulic and Geomorphology Impact Assessment is to assess and address environmental impacts associated with the releases of treated water from the proposed AWRC. This assessment supports and informs the EIS directly as well as indirectly through the provision of results and interpretation to other specialist studies such as the aquatic/riparian ecosystem, the surface water and flooding impact assessments.

To meet the objectives above, this assessment has sought to address the following key questions:

- How does flow change downstream from release points, compared with current conditions, as a result of the AWRC releases?
- How does the size of the AWRC release (i.e., 50 or 100 ML/day) impact hydrology and geomorphology when considered against current conditions?
- What changes can be expected with respect to geomorphology under the different scenarios proposed?
- Are there any construction impacts on geomorphology of the waterways?
- Are there any impacts on WaterNSW infrastructure because of the proposed releases?

The assessment covers sections of South Creek at and downstream of the AWRC site associated with the proposed treated water and wet weather release location, as well as the Nepean River upstream and downstream of the proposed treated water release at Wallacia Weir, and the Warragamba River at and downstream of the proposed environmental flow release location. South Creek at the Warragamba pipeline crossing has also been included to address concerns in relation to WaterNSW infrastructure.

A reference design for the Project has been developed which informs the various impact assessments. Several studies have been undertaken in parallel to cover various aspects relating to the potential water environment impacts. These studies and the extent of each study's considerations are indicated in Figure 2.

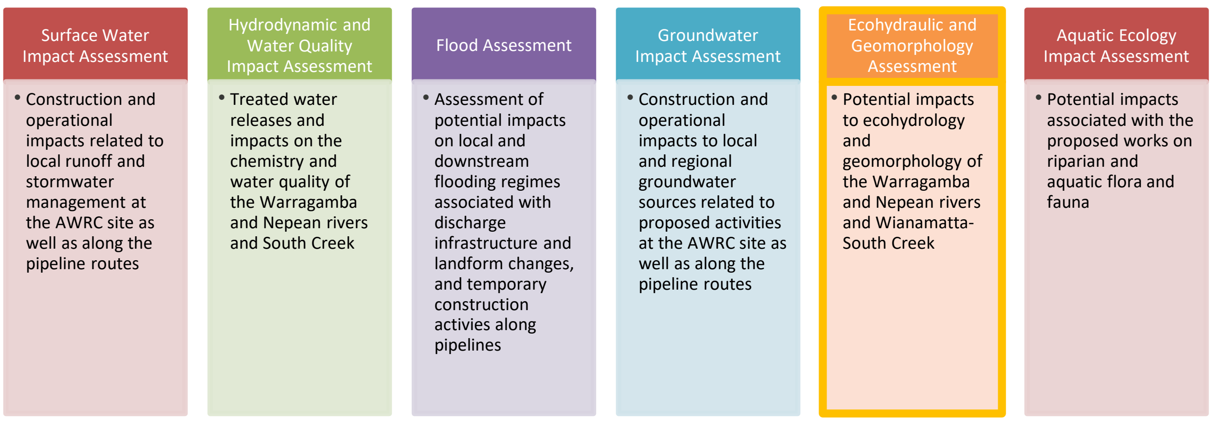


Figure 2 Specific water related impacts addressed by each study in this EIS. The focus of this document is in yellow.

1.4. **Report Structure**

The following structure has been adopted for this report:

- Section 1: Introduction
- Section 2: Legislation and policy context
- Section 3: SEARs (including specific clauses relevant to the ecohydraulics and geomorphic assessment)
- Section 4: Methodology (including details of the approach applied and assumptions and limitations)
- Section 5: Existing environment (aspects relevant to the ecohydraulics and geomorphic assessment)
- Section 6: Impact assessments (including evaluation of the relevant release scenarios)
- Section 7: Mitigation and monitoring measures
- Section 8: Conclusions

2. Legislation, Policy and Guidelines

2.1. Relevant Legislation and Policy

This section summarises the current legislative requirements and guidelines that are considered most relevant to ecohydraulic and geomorphological considerations for the Project.

Table 1 Legislation and policy documentation

Legislation/Policy	Brief description and intent	Relevance
NSW Water Management Act (2000)	The objects of the Water Management Act (WMA) 2000 are to provide for the sustainable and integrated management of the water sources of the state for the benefit of both present and future generations. In NSW, the regulator and policy maker for water resource management develops natural resource management policy frameworks, strategies and plans related to water management. DPIE Water and NRAR are accountable for water sharing plans (WSPs), which define the rules for sharing the water resources of each regulated river valley between consumptive users and the environment. WSPs are made under the Water Management Act 2000.	Consideration of the Project against the objects, water management principles and the requirement for a Water Access Licence under the Water Management Act, 2000.
Department of Agriculture and Water Resources (2018): National Water Quality Management Strategy (NWQMS)	The NWQMS (ANZECC and ARMCANZ 2000) provides a nationally consistent approach to water quality management and the information and tools to help waterresource managers, planning and management agencies, regulatory agencies andcommunity groups manage and protect their 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 economicand social development.	Key outcomes of relevance from the NWQMS include the ANZG (2018) and ANZECC and ARMCANZ (2000) guidelines. These guidelines are discussed below.

Legislation/Policy	Brief description and intent	Relevance
Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZG, 2018)	The Water Quality Guidelines provide authoritative guidance on the management ofwater quality for natural and semi-natural water resources in Australia and New Zealand. The 2018 revision of the 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's give directions to default guideline values(DGVs) for a range of stressors relevant to different community values, such as aquatic ecosystems, human health, and primary industries. As regional physical and chemical stressor default guideline values are not yet provided for the Project's ecoregion and local jurisdictions have not yet derived finer scale guideline values, these guidelines direct back to the regional DGVs provided in the ANZECC & ARMCANZ (2000) guidelines (see below).
Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC, 2000)	The ANZECC 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 ANZECC Water Quality Guidelines provide recommended trigger values for various levels of protection which have been considered when describing the existing water quality and key indicators of concern. The level of protection applied in this assessment when assessing ambient water quality is for slightly to moderately disturbed ecosystems.	The ANZECC Water Quality Guidelines provide recommended trigger values for various levels of protection which have been considered when describing the existing water quality and key indicators of concern. The level of protection applied in this assessment when assessing ambient water quality is for slightly disturbed ecosystems in NSW Lowland Rivers.
Using the ANZECC Guidelines and Water Quality Objectives in NSW (DECCW, 2006)	The ANZECC guidelines document is a large one, containing detailed scientific information and instructions for a vast array of water-quality issues. The booklet was developed to explain the principles behind the ANZECC guidelines and how to apply them.	The ANZECC Water Quality Guidelines have been applied with guidance from this booklet to understand the current health of the waterways in the vicinity of the Project and the ability to 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

Legislation/Policy	Brief description and intent	Relevance
Healthy Rivers Commission (HRC) Inquiry	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 and ANZECC 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.
Risk-based framework for considering waterway health outcomes in strategic land use planning decisions (NSW Office of Environment and Heritage, 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 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	DPIE has established water quality and flow objectives for Wianamatta South Creek through the application of the Risk Based Framework. These objectives have been included alongside ANZG/ANZECC guidelines for the assessment of water quality, hydrology and flow in the South Creek catchment.
Sydney Regional Environmental Plan No. 20 – Hawkesbury-Nepean River (No 2-1997)	The purpose of the Sydney Regional Environment Plan No. 20 – Hawkesbury-Nepean River – (No2-1997) (NSW) (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 controls 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 policies and recommended strategies for consideration in this project are detailed in Clause 6 of SREP 20.

Legislation/Policy	Brief description and intent	Relevance
Water Sharing Plan for the Greater Metropolitan Unregulated River Water Sources (NSW Office of Water 2011a)	Defines licensed volumes and management rules for access to river water. Rules apply to defined geographic areas and include, but are not limited to, the management of long-term average annual water use, daily access to water and trading rules. Extraction management units are used for managing long-term average annual extractions. The Hawkesbury-Nepean catchment has two extraction management units: • The Upper Nepean and Upstream Warragamba Management Unit (Upper Water Source) • The Hawkesbury and Lower Nepean Rivers Management Unit (Lower Water Source);	The project is located in the Hawkesbury and Lower Nepean Rivers Management Unit (Lower Water Source). Water sharing arrangements affect the hydrologic characteristics of the system and therefore are a consideration when developing the various scenarios against which the AWRC impacts are assessed against.

2.2. Waterway Objectives

2.2.1. Nepean River, Warragamba River and Wianamatta-South Creek

The waterway objectives for the Nepean and Warragamba Rivers and Wianamatta-South Creek are detailed in the Hydrodynamics and Water Quality Impact Assessment report. These 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* (OEH, 2017).

The NSW Department of Planning, Industry and Environment (DPIE) have drafted numerical objectives to preserve the hydrologic condition of Wianamatta-South Creek (and its tributaries) to inform the planning of the Western Parkland City. The criteria were developed to support the vision for Wianamatta-South Creek (and its tributaries): *"To become a cool green corridor through the Western Parkland City and be the core element of liveability and amenity for the residents. This vision relies on urban planners to explicitly keep water in the landscape by integrating waterways into the design of the city and residential neighbourhoods, and for the waterways to be healthy so they can provide the essential* services and functions expected of a cool green corridor."

Flows objectives for waterways and water dependent ecosystems (WDEs) have been developed by applying the Risk Based Framework, as cited in the Western Sydney Aerotropolis Interim Report (Sydney Water, 2020). These are published NSW government objectives, and there was no further information available to justify the values or approach. It was therefore out of project scope to analyse the suitability of these measures in protecting waterways. The values are summarised in Table 2.

Table 2 Wianamatta-South Creek waterway health (flow) objectives

Flow Variable	Unit	Performance Criteria	
		1-2 Order Streams	≥ 3rd Order Streams
Median Daily Flow Volume	L/ha	71.8 ± 22.0	1096.0 ± 157.3
Mean Daily Flow Volume	L/ha	2351.1 ± 604.6	5542.2 ± 320.9
High Spell ≥ 90th Percentile Flow Volume	L/ha	2048.4 ± 739.2	10,091.7 ± 769.7
High Spell - Frequency	number/y	6.9 ± 0.4	19.2 ± 1.0
High Spell - Average Duration	days/y	6.1 ± 0.4	2.2 ± 0.2
Freshes ≥ 75th and ≤ 90th Percentile Flow Volume	L/ha	327.1 to 2048.4	2642.9 to 10091.7
Freshes - Frequency	number/y	4.0 ± 0.9	24.6 ± 0.7
Freshes - Average Duration	days/y	38.2 ± 5.8	2.5 ± 0.1
Cease to Flow	proportion of time/y	0.34 ± 0.04	0.03 ± 0.007
Cease to Flow – Duration	days/y	36.8 ± 6	6 ± 1.1

The Surface Water Impact Assessment report (Appendix A) provides some further information as to how these objectives were derived. They note that *"flows from drainage areas with mixed land uses were considered the (tipping) point at which health, ecological and biodiversity of water dependent ecosystems declined. The flow characteristics for these waterways have been established as the waterway flow objectives for performance outcomes on third order waterways and greater. This includes the reach of Wianamatta-South Creek that is adjacent to the AWRC."*

3. **Relevant SEARs**

The Project is State Significant Infrastructure (SSI) and the Secretary of the Department of Planning, Industry and Environment has issued project specific environmental assessment requirements (SEARs). These SEARs provide the technical requirements for the impact assessment of each potential key issue, including the desired performance outcome, requirements, and current guidelines.

The SEARs clauses that are directly relevant to the ecohydraulics and geomorphology assessment have been identified and are presented in Table 3. The aspects covered in this report are highlighted in **bold**. In addition to these clauses, Table 4 provides a summary of additional issues raised by government agencies and councils during consultation on the EIS.

Where the clauses are also addressed within the Hydrodynamic and Water Quality (HWQ), Surface Water (SW), Flooding (F) and Aquatic Ecology Impact Assessment (AE) reports this is noted in the tables.

Table 3 Project SEARs relevant to the ecohydraulics and geomorphic assessments

Requirement	SEARs clause number and matter to be addressed by the study	Addressed in Section
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: i. a description of the existing environment likely to be affected by the project using relevant and adequate data. 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. iv. a description of how any residual impacts will be managed or offset, and the approach and effectiveness of these measures.	Section 2, 5, 6 & 7 HWQ SW ARE F
Key Issues - Water	1. Describe background conditions for any water resource likely to be affected by the development, including: a) existing surface. b) **hydrology**, including volume, **frequency** and quality of releases at proposed intake and release locations.	Section 5 HWQ SW AE
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 & 7 HWQ SW AE
Key Issues - Water	5. Demonstrate that the project is consistent with the Environment Protection Authority's (EPA) framework for regulating nutrient releases in effluent from STPs discharging to the lower Hawkesbury Nepean River (EPA 2019) including: b) specify the **location of release 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	Section 6 HWQ SW AE

Requirement	SEARs clause number and matter to be addressed by the study	Addressed in Section
	potential release points, including discussion of waterway characteristics at each point (e.g. depth, salinity, hydrodynamics) and consideration of the relative water quality risks.	
Key Issues - Water	6. Provide a detailed analysis of releases into Warragamba River including e-flow needs going back 20 years. This analysis needs to consider: b) **how the release** will affect the health of the river	Section 6 HWQ AE
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.	Section 6 HWQ SW AE F
Key Issues - Flooding	31. Modelling must consider and document: j) impacts to South Creek under all scenarios, specifically where **South Creek and the Warragamba Pipelines intersect**. k) Consideration of backflow impacts l) assessment of the hydrological flows into South Creek from both wet and potential dry weather flows, including consideration of **the effects on downstream receiving environments, specifically the Warragamba Pipelines infrastructure (footings etc).**	Section 6 Appendix D F
Key Issues - flooding	32. The EIS must assess the impact on the proposed development on flood behaviour, including: (g) whether there will be direct or indirect increase in erosion, siltation, destruction of riparian vegetation or a reduction in the stability of riverbanks or watercourses.	Section 6 F
Key Issues - Crown Land	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.** **e) the impact of the brine pipeline on Kemps Creek, Clear Paddock Creek, Green Valley Creek and Prospect Creek**. f) An assessment of the potential impacts of released ‘treated water’ flows on **stream banks** and riparian areas within the downstream creek systems, including South Creek.	Section 6 & 7 HWQ SW AE F

Table 4 Summary of additional issues raised during agency consultation

Agency	Issue raised	Addressed in Section
Fairfield City Council	Construction methodology of the brine pipeline: Details of how the project proposes to reinstate the creek bed and banks, and what measures would be implemented to ensure **creek bed and bank stability** after construction is complete shall be provided	Section 6 & 7 AE
WaterNSW	Treated water releases into South Creek could potentially have major impacts on the structural integrity (foundations) of the Warragamba Pipelines. This represents a major risk to WaterNSW as these pipelines provide 80% of Sydney’s drinking water. -**A hydrological assessment should 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 USCAWR**C.	Section 6 Appendix D SW F

Agency	Issue raised	Addressed in Section
WaterNSW	The EIS should include an assessment of the risks to the integrity and security of WaterNSW lands, assets and infrastructure that may result from the proposal, and the proposed measures to mitigate against those risks, including (but not limited to) consideration of: **- the effect the development will have on Warragamba Pipeline footings, through potential changed flow regimes and increased flood impact, and** **- potential direct or indirect increase of erosion or sediment deposition in the pipelines corridor and at the treated water release points.**	Section 6 Appendix D F
WaterNSW	The EIS should include an assessment on the impacts to the Warragamba and Nepean Rivers and South Creek, downstream of release points, such as scour, and - consider the environmental sensitivity of the lands surrounding the two (2) **treated water release points, as being steep and or highly erodible**	Section 6 AE SW F

4. Assessment Methodology

4.1. Overview

The focus of this assessment is on the streamflow impacts, specifically ecohydraulics and geomorphology, of releases from the AWRC. The methodology for this assessment draws upon hydrologic and hydraulic changes under a range of scenarios to assess impacts on 'habitat' or geomorphic character of the waterways.

Hydrologic and hydraulic modelling and analysis was informed by hydrologic scenarios developed for this project, provided by Sydney Water, and described in detail in the Hydrodynamic and Water Quality Assessment. These scenarios are discussed in Section 4.2.

Results from these assessments have then been utilised through the provision of results and interpretation to other specialist studies such as the Aquatic Ecology Impact Assessment.

In addition to streamflow impacts the team was asked to comment on the ecohydraulic or geomorphic implications of releases on NSW Water infrastructure. This high-level assessment was undertaken without field inspection (impacted by COVID-19 restrictions) and builds on similar reports and available information. The methodology and details of the assessment are provided as a separate standalone document in Appendix D.

4.2. Scenario Descriptions

4.2.1. Hydrologic scenarios

A suite of scenarios was developed as part of the Hydrodynamic and Water Quality assessment. These scenarios incorporate a range of conditions that could be expected during the operational life of the AWRC. In addition to scenarios that simulated the release of treated water from the AWRC, the scenarios also included a series of background and baseline scenarios that were used for comparative purposes to assess the hydrologic impacts from release of the treated water.

The scenarios include:

- **Baseline scenarios:** These scenarios represent current (circa 2020) conditions, including landuse and all other inputs considered representative of current catchment conditions
- **Background scenarios:** These 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 releases of treated water from the AWRC. Landuse changes, extractions and other inflows under future conditions are accommodated within these scenarios.
- **Impact scenarios:** These scenarios were developed to allow for targeted evaluation of the impacts from the treated water releases from the AWRC. Each scenario therefore corresponds with one of the background scenarios but with inclusion of relevant releases of the treated water from the AWRC. This includes:
    - South Creek in the vicinity of the AWRC for the release of wet weather flows.

- The release of treated water to the Nepean River upstream of the Wallacia Weir during dry and wet weather.
- Release of treated water into the Warragamba River downstream of the Warragamba Dam wall for scenarios where the release of advanced quality water was assumed for the purposes of environmental flows.

Table 5 provides an overview description of the scenarios developed for the assessment of impacts on Nepean River, Warragamba River and South Creek. A detailed description of the scenarios and their development is provided in the Hydrodynamic and Water Quality Assessment report (Aurecon Arup, 2021).

The specific scenarios assessed during this study are referenced in Table 6 and Table 7. Modelled outputs for all the scenarios listed have been analysed. For the Nepean River, the scenarios of main interest to the impact assessment are HN00 (Baseline), and HN05 and HN07 (50 ML/d AWRC release scenarios). The background scenarios (HN01 to HN04) have been analysed from a hydrologic basis to allow the impact from the treated water releases to be put in context with potential overall changes in hydrology across the catchment. The scenarios which include the Warragamba environmental flow release are not discussed separately as the differences to the main release scenario results are limited. However, the full analysis results are provided in Appendix C.

As described further in Section 4.9, it was identified during the analysis for this report that the scenario results for the Nepean River did not adequately describe the baseflow conditions in the river and that the absolute values could not be used for our analysis. We have therefore focussed on the relative differences between the different scenarios and inferred potential impacts associated with the AWRC releases. We have assumed errors in the flow estimates are consistent across all the scenarios modelled. The issues identified in the scenario modelling are described further in the Water Quality and Hydrodynamics Impact Assessment report.

For South Creek, the scenarios of main interest to the impact assessment are SC00 (Baseline), and SC05 and SC07 (50 ML/d AWRC release scenarios). As noted for the Nepean River scenarios, the background scenarios (SC01 to SC04) have been analysed from a hydrologic basis to allow the impact from the treated water releases to be put in context with potential overall changes in hydrology across the catchment. Based on advice provided by Sydney Water we have assumed the South Creek results are sufficiently accurate for our analysis.

Table 5 Description of scenarios developed for the assessment of impacts on South Creek and Nepean River (provided by Sydney Water).

Category	Input	Description	Scenario variations
General	Climatic conditions	Two representative climatic years were selected based on statistical analysis of rainfall over a 25-year period from 1994 to 2019, including: • July 2013 to June 2014 – a representative dry climatic year (about 510 mm of rainfall) • July 2014 to June 2015 - a representative wet climatic year (about 1060 mm of rainfall)	Wet year Dry year
	Land use	Land use layers were developed for the catchment model to represent current and future land use. This information was used to calculate stormwater flows.	Current (2017) 2036 2056
	Stormwater management	Two stormwater management strategies have been considered in the South Creek catchment, including: • Parkland – This level of management is assumed to be representative of the Western Parkland City stormwater strategy as outlined in the WSAGA and SWGA Sub-Regional Plan. • Business as Usual (BaU) – This approach is assumed to be in line with stormwater management practices that are currently applied in the region. Within the Hawkesbury Nepean catchment but outside of the South Creek growth areas, there is expected to be relatively lower levels of development and growth in the catchment. In this catchment, a BaU level of stormwater management has been applied.	Parkland (South Creek only) Business as Usual (BaU) - South Creek and Nepean River
AWRC releases	Operating capacity	Impact scenarios considered the operating capacity for both Stage 1 and future stages.	0 ML/day (2036 and 2056) 50 ML/day (2036) 100 ML/day (2056)

	Location, timing and quality of AWRC releases	Flows will be released to South Creek during wet weather only. For releases to the Nepean and Warragamba Rivers, two variations have been considered: • All flows to Nepean River. • Advanced treated releases to the Warragamba River to replicate the existing environmental flows regime (22ML/day in autumn/winter and 30ML/day in spring/summer) and remaining or tertiary treated flows to the Nepean River.	Hawkesbury Nepean only: All flows to Nepean River Environmental flows to Warragamba River, remaining to Nepean River
Releases from other treatment plants	Release volumes	Releases from other WWTPs and WRPs within the Hawkesbury Nepean and South Creek catchment were adjusted in the models to be representative of the relevant time horizons (2020, 2036 or 2056) based on expected population growth, assumed rates of reuse, network transfers, as well as any forecasted changes in inflow and infiltration to the sewerage system.	2020 2036 2056
	Quality	Concentrations of the key contaminants in the releases were adjusted in line with any planned upgrades. Variability in water quality parameters was also included in line with historical monitoring data or forecasted performance of the WWTPs and WRPs (including treatment bypasses or reduction of treatment performance during wet weather). Within the South Creek catchment, the five plants that release treated water to the creek consist of are St Marys WRP, Quakers Hill WRP, Riverstone WWTP, South Windsor WWTP and McGraths Hill WWTP. No variations in loading conditions were assumed for these WWTPs and WRPs in the scenarios. Within the wider Hawkesbury Nepean catchment, there are an additional 13 treatment plants. Five of these plants have low and high nutrient loading conditions that are independently considered in the scenarios, to represent potential variations in treatment. These five consist of are Penrith WRP, Picton WRP, West Camden WRP, Wilton WRP and Winmalee WWTP.	Hawkesbury Nepean only: Low nutrient loading High nutrient loading
Other inflows/outflows	Emergency relief structures	Wet weather overflows from the wastewater system are considered as significant point sources of untreated wastewater during wet weather events.	2020 2036 2056

		Timeseries of overflow release rates were simulated for both the existing network as well as a future network scenario that was considered representative of expected development in the catchments. Water quality was based on analysis of untreated wastewater quality and the level of dilution expected within the networks.	
	Extractions	Extractions for irrigators and other water users have been incorporated into the models. For the future scenarios, extractions were adapted for loss of agricultural land as predicted by the respective land use layers for 2036 and 2056.	2020 2036 2056

Table 6 Summary of scenarios modelled for the Nepean and Warragamba Rivers (scenarios of main interest are highlighted in red)

Scenario Number	Land Use	AWRC capacity (ML/d)	Release Point	Treatment Plants
Baseline scenario				
HN00	Current (2017)	N/A	N/A	Current
Background scenarios				
HN01	2036	0	N/A	Low Loading
HN02	2036	0	N/A	Low Loading
HN03	2056	0	N/A	Low Loading
HN04	2056	0	N/A	Low Loading
Impact scenarios				
HN05	2036	50	Nepean	Low Loading
HN06	2056	100	Nepean	Low Loading
HN07	2036	50	Nepean	High Loading
HN08	2056	100	Nepean	High Loading
HN13	2036	50	Nepean/Warragamba	Low Loading
HN14	2056	100	Nepean/Warragamba	Low Loading
HN15	2036	50	Nepean/Warragamba	High Loading
HN16	2056	100	Nepean/Warragamba	High Loading

Table 7 Summary of scenarios modelled for South Creek (scenarios of main interest are highlighted in red)

Scenario Number	Land Use	AWRC capacity (ML/d)	Release Point	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

4.2.2. Ecohydraulic scenarios

The ecohydraulic scenarios were developed based on an assessment of the current flow regime within the Nepean River. Gauge flow data from Nepean River monitoring sites at Wallacia Weir and Penrith Weir was analysed and presented as flow duration curves. Specific flow metrics such as the 10th, 50th and 90th percentile flow values were then defined from the results. These results set the baseline conditions for the ecohydraulic and geomorphic analysis (Table 8 and Figure 3).

A series of flow increments were then selected covering a range of typical non-flood river flows, from 25 ML/d to 1,000 ML/d. These flows represent a representative range of flows in the Nepean River at the AWRC release site which could be expected to occur at the same time as a treated water release of 50 ML/d (Stage 1) and up to 100 ML/d (ultimate capacity) as proposed.

For reporting purposes, the ecohydraulic scenarios have focussed on the 50th percentile flow (i.e., median) conditions for the 50 ML/d release (Stage 1). Additional results are provided in Appendix B and are also discussed in Section 6.

Table 8 Summary of ecohydraulic scenarios conditions

Scenario	Percentile flow (ML/d)		
	10th	50th	90th
Baseline (gauged flows 2010 to 2021)	782	229	78
+50 ML/d release	832	279	128
+100 ML/d release	882	329	178

Specific ecohydraulic scenarios were not included in the assessment for South Creek as the scope of work was focussed on the analysis of hydrologic scenarios, as detailed in the following section. As the AWRC is only undertaking wet weather releases to South Creek (i.e., more infrequent events) the relevant flood impacts (flow events > 10-year ARI) on the waterway are assessed in the Flooding Impact Assessment report. A hydraulic model was not developed for South Creek (other than at the Warragamba Pipeline location to support the assessment of impacts on WaterNSW infrastructure) so geomorphic risk was interpreted using hydrologic indices.

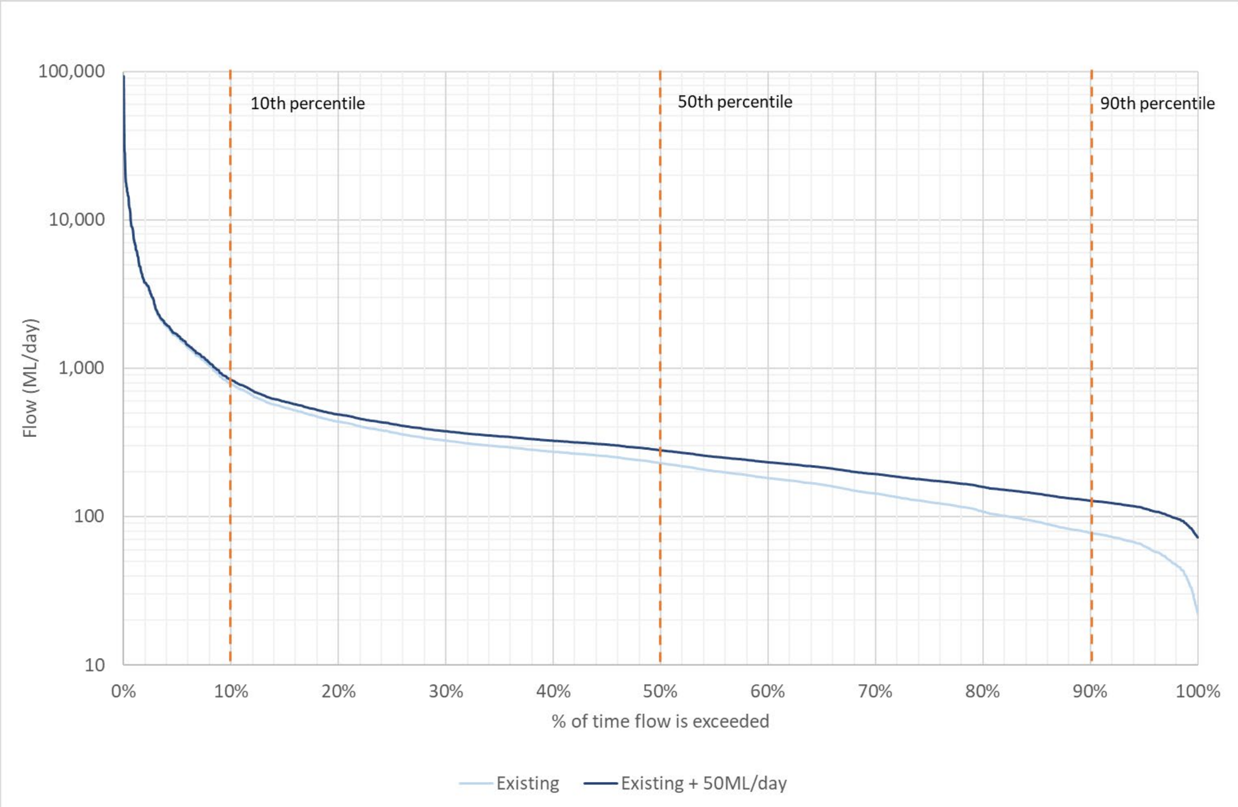


Figure 3 Flow duration curve for the Nepean River at Wallacia Weir, based on gauged flows (2010 to 2021[1]), showing the percentile flow increments used for the results analysis.

4.3. Reach Delineation

For this analysis, sections of each waterway have been delineated as assessment reaches based on their typical geomorphic conditions and taking into account the proposed treated water release locations (Figure 4 and Figure 5). In the initial stages of the study additional reaches further downstream in the Nepean River were included and demonstrated no influence from AWRC flow inputs, so these are not presented in the results.

For South Creek, the initial assessment tested a range of different flow releases were assessed and results are reported as far downstream as Richmond Road. Again, the initial assessment demonstrated no influence from AWRC flow inputs further downstream.

For a more detailed description of the physical characteristics of these reaches see Section 5.

[1] The flow duration curve is based on the period 2010 to 2021 due to changes in the flow conditions in the Nepean River since 2010. This is discussed further in Section 5.1.

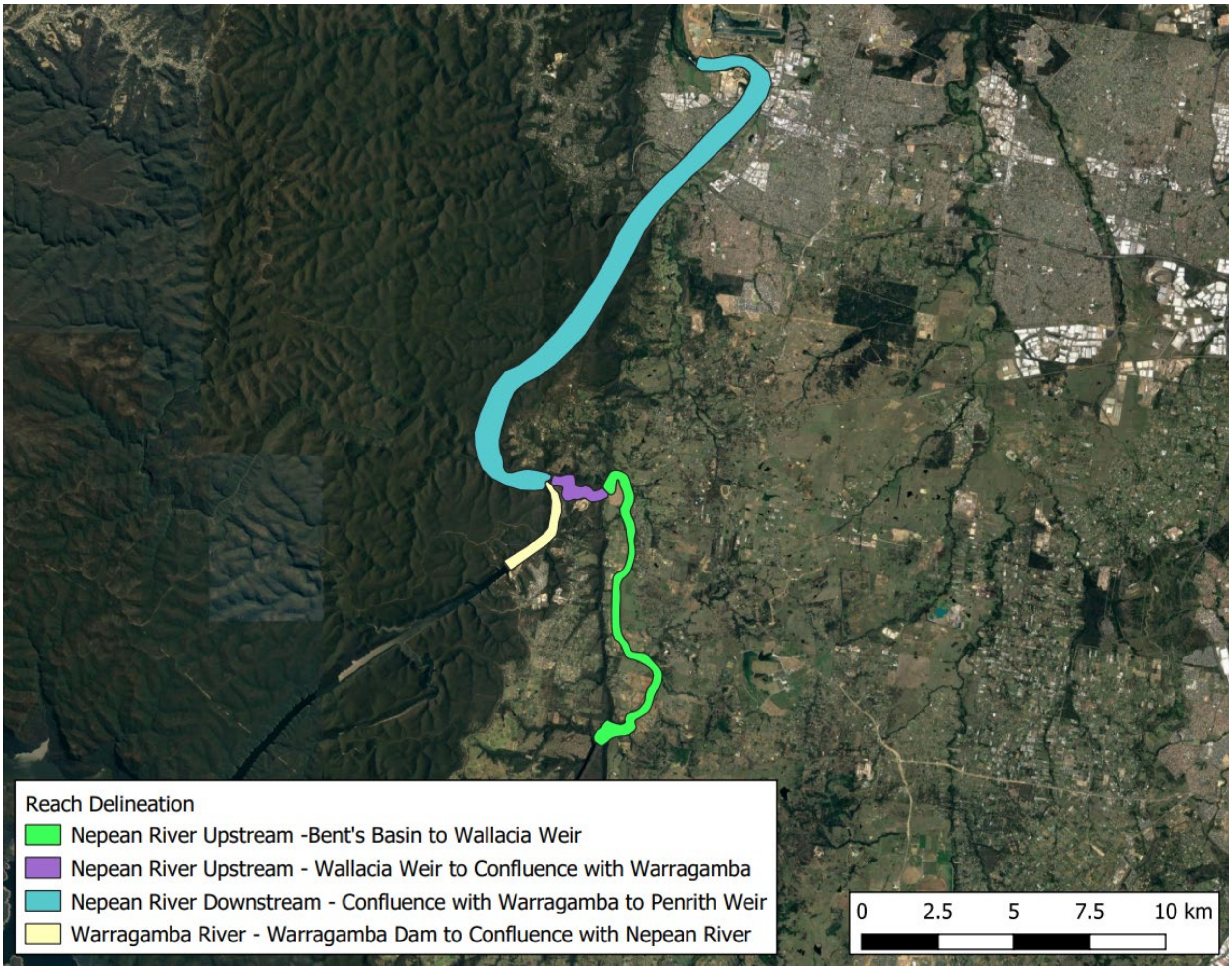


Figure 4. Nepean River and Warragamba River Reach delineation map

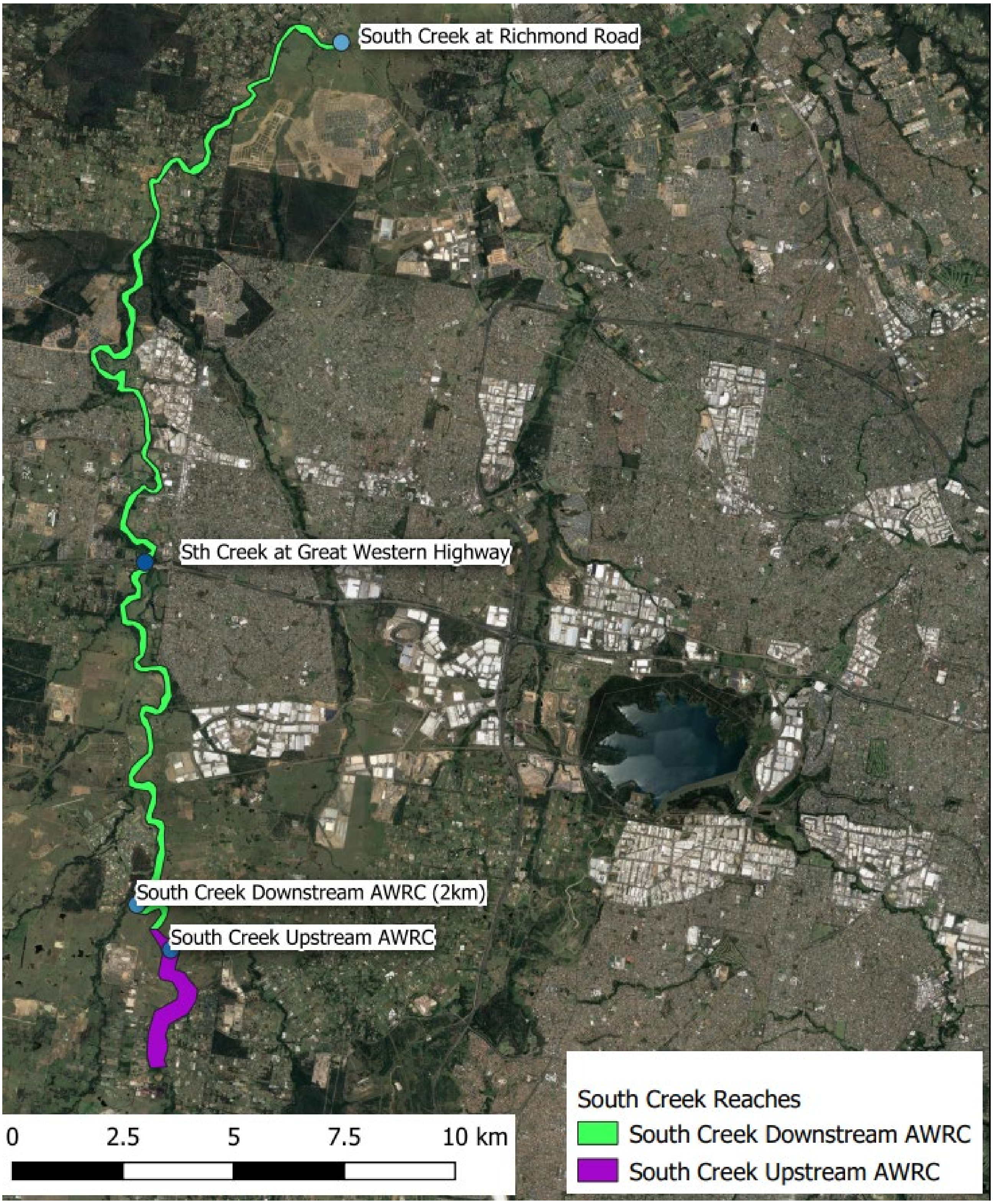


Figure 5 South Creek Reach Delineation Map.

4.4. **Desktop Review**

A suite of publicly available datasets, and information specific to the project, was compiled and reviewed as part of the assessment. Report 3 of the Environmental Flows Options Assessment: Geomorphology by DPI (2014) provided the most thorough geomorphic investigation for the Nepean River.

Modelled hydrodynamic outputs (mainly flow time series) from the Hydrodynamic and Water Quality Assessment were provided by Aurecon Arup during the impact assessment phase of the study as a key input to the hydrologic scenario analysis.

Additional bathymetric data to assist with the hydraulic modelling tasks was also supplied by Sydney Water during the study and used for modelling as described further in this report. Data is described further in Appendix A.

4.5. **Field Inspection**

Two field inspections were undertaken as part of this EIS:

1. Nepean and Warragamba Rivers for a half day boat trip on October 22nd, 2019, by Dr Geoff Vietz (in conjunction with Sydney Water and Intrawater staff).

The purpose of this inspection was to gain a clear understanding of the character of the reach (Figure 6), the geomorphic and hydrologic condition, and to identify features or reaches requiring detailed modelling.

2. Nepean River, Warragamba River and South Creek on 5th February 2020 by AUAV, who undertook drone aerial imagery capture of specific sites of WaterNSW Infrastructure in lieu of field visits due to COVID-19 restrictions.

The purpose of this inspection was to gain a clear understanding of geomorphic and hydrologic condition of the waterways at locations where WaterNSW infrastructure are located, for example the Warragamba Pipeline crossing at South Creek is shown below.

The original intention of the second site visit was also to allow more detailed assessment of key locations and in particular the bed and bank materials. However, due to COVID-19 restrictions in place during that period it was not possible to complete the works in person.

Access to all the aerial imagery captured during the visit is available via the following website: https://pano.auav.com.au/Streamology/2021_02_05_WarragambaPanos/

Figure 6 Photographs taken during field visit on the Nepean River.

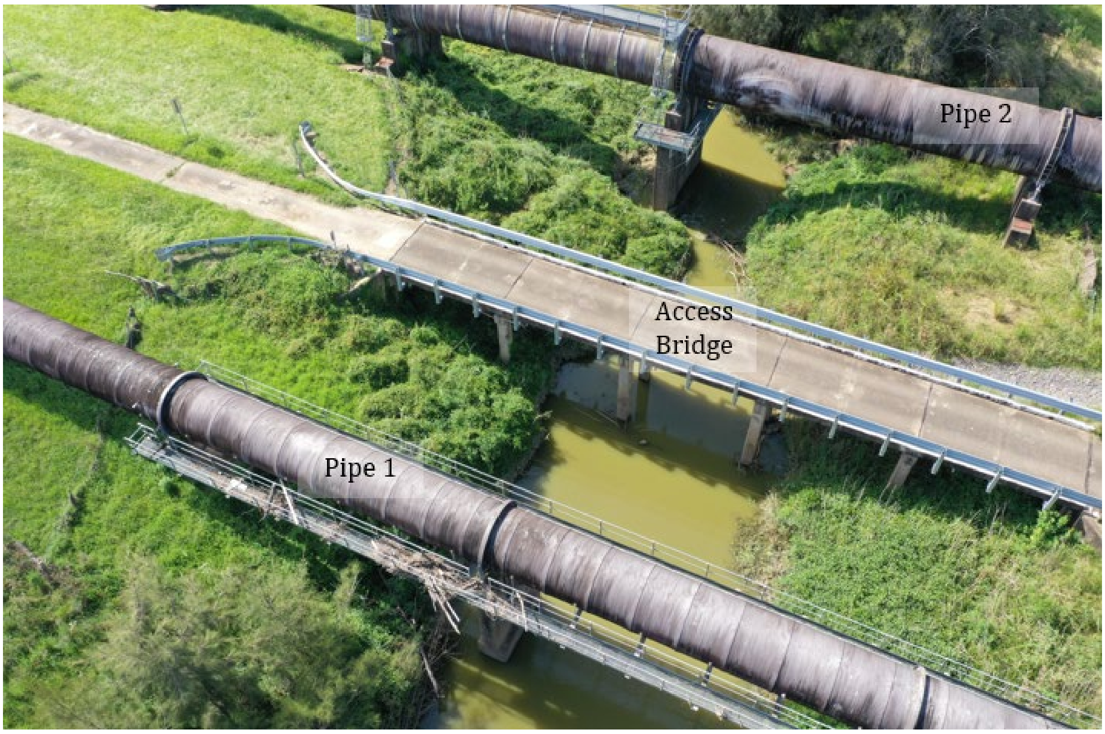


Figure 7 Aerial image captured of Warragamba Pipeline Crossing - South Creek (05/02/21).

4.6. **Hydrologic and Hydraulic Modelling**

Hydrologic and hydraulic modelling was undertaken to support this assessment.

4.6.1. **Hydrologic modelling**

Gauged flow data analysis

The gauged flow time series data for gauges on the Nepean River and South Creek was extracted from the WaterNSW Data Portal then imported into the software package River Analysis Package (RAP) by eWater.

Various hydrologic metrics as detailed in Section 4.2.1 were extracted from the data. In addition to the hydrologic metrics, the flow duration curves for each location were generated in the software.

Scenario modelling

The hydrologic modelling involved applying time series analysis tools to selected outputs from hydrodynamic and water quality model (see Hydrodynamic and Water Quality Impact Assessment report for specific model details) for the scenarios described in Section 4.2.

Flow, velocity, and water depth information was extracted from the hydrodynamic and water quality model at a range of locations across South Creek and the Nepean River systems. This information covered the two-year (2013-15) simulation period. Only the flow data was analysed in this assessment.

The time series data was then imported into the software package RAP by eWater along with a spreadsheet-based analysis model and the various hydrologic metrics detailed in Table 10 were analysed.

4.6.2. **Hydraulic modelling**

Hydraulic modelling was completed using the industry standard modelling package HEC-RAS for sections of the Nepean River and South Creek. A 1D model was created for the broader Nepean River from Bents Basin to approximately 4.2 km downstream of the Penrith Weir (chainage 0), while local 2D models were setup at the following locations, as shown in Figure 8:

- A section of the Nepean River downstream of Wallacia Weir to just downstream of the Warragamba River confluence.
- A section of the Nepean River within the Blue Mountains World Heritage Site.
- South Creek at the Warragamba Pipeline location.

The 1D model was used to simulate a range of flow conditions in the Nepean River based on the gauged flow information. The flow adopted for the modelling were focussed on non-flood flow conditions. From these simulations, hydraulic conditions such as water surface elevation, wetted perimeter, velocity, and shear stress were extracted for every model cross-section.

The Nepean River 2D model results were used to simulate specific flow conditions (e.g. a flow of 229 ML/d) to provide greater spatial resolution of the flow velocities and shear stress within the 2D model extent. This information was provided to the aquatic ecology team to inform their assessments. The selection of sites for the 2D modelling was completed by STreamology and CT

Environmental. The Nepean River 2D model that covers from Wallacia Weir to downstream of the Warragamba confluence was extended to include the Warragamba River from the confluence upstream as far as Megarritys Creek. This extended model was used to test the influence of environmental flow releases on hydraulic metrics in the Nepean River. The results indicated negligible influence due to the small magnitude of the environmental flow releases (maximum of 30 ML/d) and the constrained low flow connection between the rivers at the junction, Figure 9. Downstream of the junction the conditions in the Nepean River are also controlled by Penrith Weir which further reduces any influences.

Under high flow (flood) conditions a broader flow connection occurs as the Warragamba River breaks across a low bench (Figure 9), but these flow conditions are not affected by the proposed treated water releases. Due to the longer run times of the extended model and the limited advantages of the additional detail it was not adopted for the final assessment.

The South Creek 2D modelling was used to support the assessment of impacts on WaterNSW Infrastructure summarised in Section 6.6. The 2D model extent was selected based on the location of the infrastructure.

These hydraulic models used for this analysis were developed at a higher local spatial resolution compared to the detailed TUFLOW FV 2D model utilised in the Hydrodynamic and Water Quality Impact Assessment and the simulations were targeted to different analysis requirements. This assessment was targeted at specific waterway reaches. It was also not possible to use the TUFLOW FV model within the timelines required for this assessment.

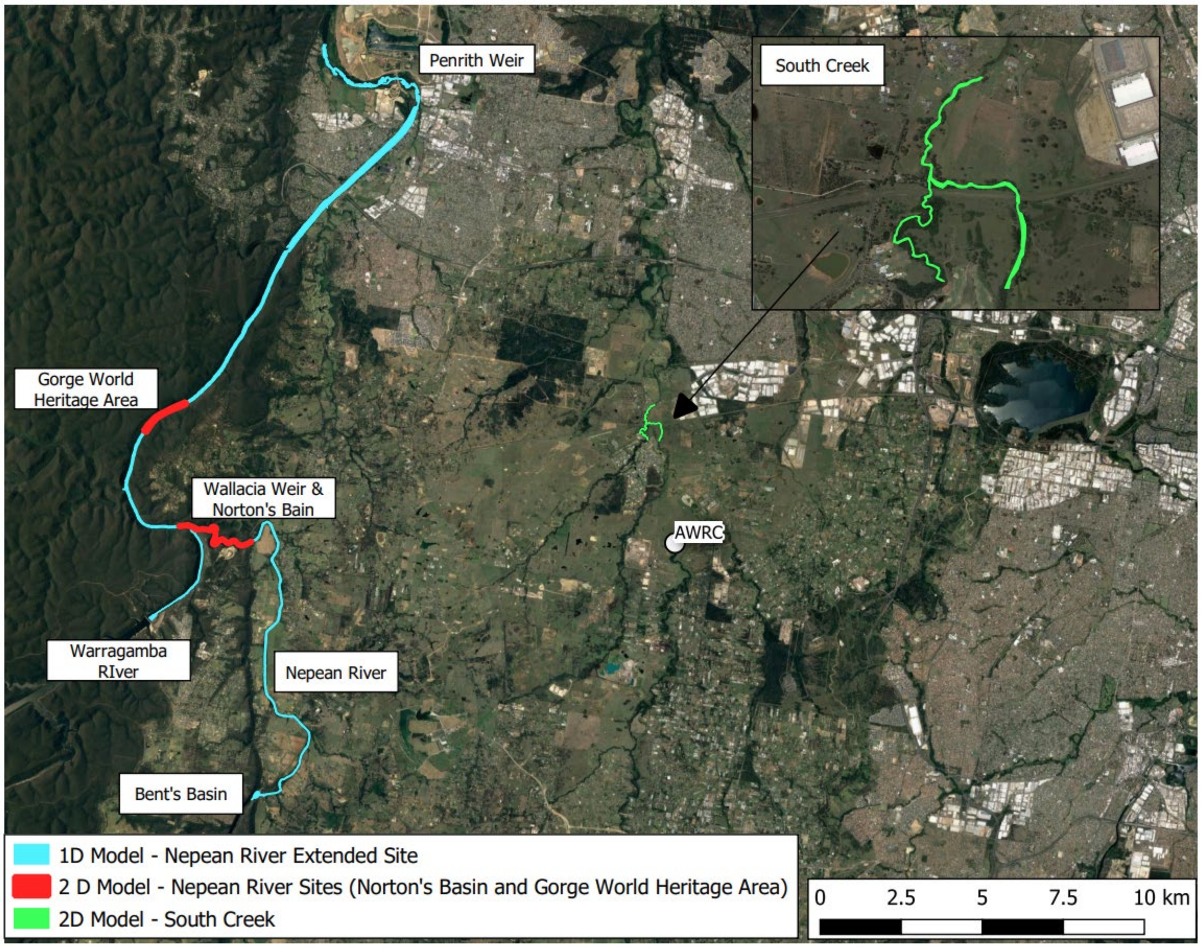


Figure 8 Overview of hydraulic model extents.

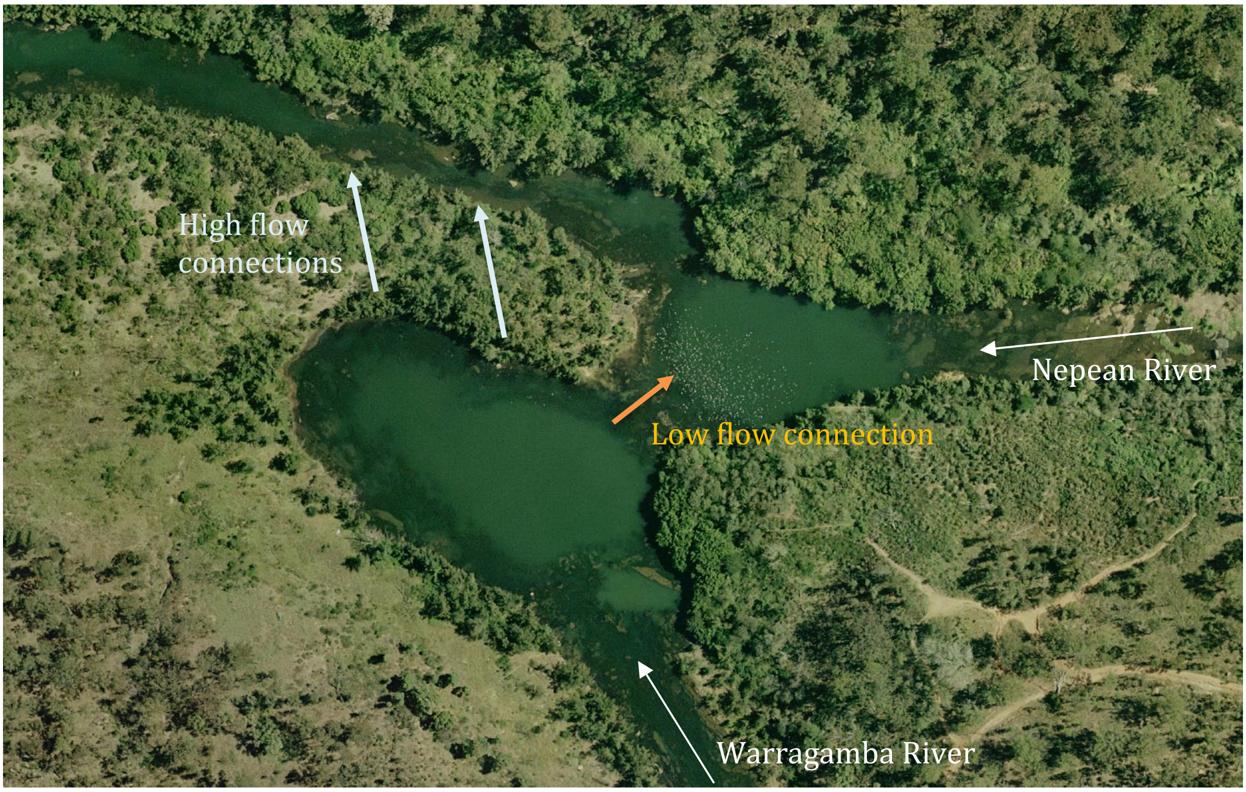


Figure 9 Warragamba and Nepean River junction showing the low flow and high flow pathways (MetroMaps 15/01/2005); adapted from DPIE (2014)

4.7. **Identification of Assessment Metrics**

There are limited formal metrics or thresholds for geomorphology and ecohydraulics to apply to an assessment for an EIS. Based on the requirements of the SEARS, we have therefore developed two types of assessments, one is based on ecohydraulic modelling and the other is based on hydrologic metrics.

Ecohydraulic modelling relies on hydraulic modelling (see previous section) and metrics that describe characteristics of flow or the channel of relevance to biota. The criteria in Table 9 were identified as relevant to these systems and relate to both morphology (this report) and ecology (Aquatic Ecology Impact Assessment report). They provide surrogates for 'habitat' available to biota and as indicators of change based on hydrologic scenarios. The values for each metric required to support ecological values are discussed further in the Aquatic Ecology Impact Assessment report.

The four hydraulic metrics focused on in this study are captured within Table 9. Riverbank stability and bed stability are the two geomorphic impacts that are described by the metrics.

Hydrologic metrics can be used to demonstrate changes in the hydrologic regime for different scenarios from which geomorphic responses can be inferred. As with hydraulic metrics (mentioned above) the hydrologic metrics must be relevant to biota. To ensure this is the case we draw upon an approach developed for the Western Sydney region, the Urban Stream Flow Impact Assessment (USIA) method (Vietz et al., 2018, Kermode et al 2020). Specific flow-related metrics relate biotic condition and response to the character of the flow regime, as previously applied to areas within the South Creek catchment (Vietz et al., 2018, Kermode et al 2020). These metrics are identified in Table 9 and described in further detail, along with complementary hydrologic variables considered in the USIA method, in Table 10. These metrics are similar to those described in the flow objectives, Table 2 but with a greater focus on geomorphic indicators such as zero flows (referred to as Cease to Flow in Table 2).

This report does not delve into ecological response to ecohydraulic or geomorphic changes. This requires interpretation by ecologists of the thresholds of change on biota and is discussed further in the Aquatic Ecology Impact Assessment report.

Table 9 Assessment metrics and the potential geomorphic and ecological impacts (relevant to the SEARS) that may be assessed against this metric (refer to the Glossary for definitions of the metrics)

	Metric	*Riverbank stability*	*Bed stability*	*Riparian vegetation*	*Aquatic connectivity*	*Fish habitat and spawning*	*Wetland inundation*	*Relevance*
Hydraulic metrics	Water surface elevation (m)	✓		✓	✓	✓	✓	Ecologically or geomorphically relevant. This changes the extent of inundation of bank and floodplain features
	Wetted perimeter (m)			✓		✓	✓	Ecologically relevant. Provides an understanding of the extent of the inundation on the cross-sectional surface of the channel
	Velocity (m/s)	✓	✓	✓	✓	✓		Ecologically or geomorphically relevant. Can be used to consider both ecological and geomorphic impacts
	Bed shear stress (N/m^2)		✓					Geomorphically relevant. Dependent on sediment/ substrate
Hydrologic metrics	Zero flow (days or % time) *				✓	✓		Ecologically relevant. For intermittent streams
	Freshes (number, % time and duration) *	✓	✓	✓	✓	✓	✓	Ecologically or geomorphically relevant only if above thresholds, such as thresholds of erosion or durations above which vegetation inundation prevents recovery
	Bed Erosion threshold (N/m^2) */**		✓			✓		Ecologically or geomorphically relevant. Dependant on sediment calibre, e.g. sands, gravels

*See Table 10 below for USIA metric descriptions and complementary hydrologic variables
**Bank erosion threshold not assessed due to lack of bank sediment data

Table 10 Flow components and associated metrics used by the Urban Streamflow Impact Assessment (USIA) method (Vietz et al. 2018). These metrics characterise hydrologic regimes and are selected for their relevance to geomorphic or ecological associations (e.g. freshes can relate to disturbance of the bed and fish migration cues).

Flow Component	Flow Metric
Flow Dynamics (Non-Zero Flows)	Maximum (ML/d)
	Minimum (ML/d)
	Mean (ML/d)
	Mean Annual Flow Volume (ML)
	Median (ML/d)
	Std Deviation (ML/d)
Zero Flow (Cease to Flow)	Average Zero Flow Duration (days)
	% of Time with Zero Flow
Freshes	# of Fresh Events (> 3 x Median Flow)/year
	% of Time Over Fresh Event
	Average Fresh Duration (days)
Erosion Threshold	% of Time > Bed Mobilisation Threshold

4.8. Impact Assessment

The impact assessment relates to ecohydraulic and geomorphic conditions in the Nepean River, Warragamba River and South Creek which may be affected by the proposed treated water releases. To define the impacts of the treated water releases on ecohydraulic and geomorphology a risk-based approach has been applied where likelihood and consequence are defined in the following sections.

The risk assessment methodology adopted is based on principles outlined in ISO 31000:2018 Risk Management. Risk Treatment is considered within Section 7 - Mitigation and Monitoring Measures.

4.8.1. Likelihood of potential impacts

For this ecohydraulic and geomorphic analysis likelihood is a function of the geomorphic or hydraulic sensitivity of the waterway reach to the given hydraulic metric (i.e., changes in water surface elevation, wetted perimeter, velocity, or shear stress). The sensitivity to a given parameter relates to the hydraulic or geomorphic conditions and is based on the review of literature and data on geomorphic conditions within the reaches assessed, available field data and expert opinion utilising the field work and existing condition information. The likelihood ratings are outlined in Table 11.

Table 11 Likelihood Descriptions (based on River Styles geomorphic sensitivity)

Likelihood	Description
Almost certain	The reach is extremely sensitive, has low resilience/adaptive capacity
Likely	The reach is moderate to highly sensitive, and it has low to moderate resilience/adaptive capacity.
Possible	The reach is moderately sensitive and has moderate resilience/adaptive capacity.
Unlikely	The reach has moderate to low sensitivity to change and has good resilience/adaptive capacity.
Very Unlikely	The reach is insensitive to change and has high resilience/adaptive capacity

4.8.2. Consequence of impacts

The consequence of impacts is defined in Table 12. There are five categories i.e., insignificant, low, moderate, high, and very high. As with the likelihood assessment, the consequences of impacts category has been determined based on the review of literature and data on geomorphic conditions within the reaches assessed, available field data and expert opinion utilising the field work and existing condition information.

Table 12 Consequence Categories

Consequence rating	Description
Insignificant	Minimal change to the existing situation, including impacts which are beneath levels of detection, impacts that are within the normal bounds of natural variation. Recovery periods associated with these impacts are within 3 to 12 months.
Minor	These impacts are recognisable, but acceptable within the decision-making process.

Consequence rating	Description
	They are still important in the determination of environmental management requirements. These impacts tend to be shorter, or temporary (recovery periods of greater than 12 months and up to 2 years are likely) and at the local scale.
Moderate	These impacts are relevant to decision making, particularly for the determination of environmental management requirements. These impacts tend to range from short to long term (recovery periods of 2 to 10 years are likely) and occur over medium scale areas or focussed within a localised area. The impacts are of local or regional significance.
High	These impacts are central to the decision-making process. They tend to be permanent or otherwise medium term to long term (recovery periods of 10 to 25 years are likely) and can occur over medium or large-scale areas. The impacts may be of State and National significance.
Very High	These impacts are critical to the decision-making process. They tend to be permanent, or irreversible (recovery unlikely within management timeframes > 25 years) and can occur over large-scale areas. The impacts are of National significance.

4.8.3. Risk of potential impacts

The risk of potential impacts is a function of the likelihood and the consequence, Table 13.

Table 13 Risk assessment matrix

Likelihood	Consequence				
	Insignificant	Minor	Moderate	High	Very High
Very Unlikely	Low	Low	Low	Medium	Medium
Unlikely	Low	Low	Medium	Medium	Medium
Possible	Low	Medium	Medium	Medium	High
Likely	Medium	Medium	Medium	High	Very High
Almost Certain	Medium	Medium	High	Very High	Very High

4.9. WaterNSW Infrastructure Assessment

Separate to the main impact assessment, in order to address issues raised by WaterNSW with regards to the AWRC project impacts on their infrastructure a separate tailored impact assessment has been completed (Appendix D). The work assesses the geomorphic implications and risks of the AWRC releases specifically on WaterNSW infrastructure.

Consideration was given to:

- The effect on Warragamba Pipeline footings, through potential changed flow regimes and increased flood impacts, and
- Potential direct or indirect increases of erosion or sediment deposition in the pipeline corridors and at the treated water release points.

The following WaterNSW infrastructure was included:

- Nepean River:
    - Wallacia Weir

- Warragamba Pipeline Crossing. The pipeline is underground about 170m downstream of Wallacia Weir
  - Penrith Weir
- Warragamba River:
  - Warragamba Weir. Located about 550m downstream of environmental flow release location.
- South Creek
  - Warragamba pipeline

4.10. Assumptions and Limitations

The following assumptions and limitations of this assessment are noted below:

- **Hydrologic gauge data input**. The ecohydraulic scenarios are based on analysis of gauged flow data in the Nepean River covering the period 2010 to 2021. Usually, the longest available data period is used to characterise the flow regime however due to significant changes in the flow regime of the Nepean River post 2010 (as described in the following existing conditions assessment) it was considered that only flow conditions since these changes should be used to describe current conditions.
- **Hydrologic scenario data input**. The hydrologic scenario data provided by Aurecon Arup for the purposes of the hydrologic modelling was assumed to be true and correct. The hydrologic data is a primary input that greatly affects the modelled results on which the impact assessment is based. During a review of the data provided it was identified that there were some discrepancies between the flow regime for the Nepean River as described by the gauged flows and that in the modelled scenarios. It was therefore agreed with Sydney Water that the analysis of hydrologic scenarios for the Nepean River would focus on the relative difference between the scenario modelling results rather than the absolute values. We have therefore assumed that the errors in the hydrologic modelling provided by Aurecon Arup are consistent across all the scenarios. Further discussion of the discrepancies is provided in the Hydrodynamics and Water Quality Impact Assessment report.
- **Hydrologic data representativeness**. The period of modelled hydrologic data provided is 2010 to 2021. With dry periods and wet periods considered to be the years 13/14 and 14/15, respectively. An understanding of the representativeness of this data leading into future conditions (including climate change) will affect the implications identified in this study. Further discussion of the simulation period selected is provided in the Hydrodynamics and Water Quality Impact Assessment report
- **Hydraulic model accuracy.** Models are only as useful as their accuracy dictates. The hydraulic models have undergone initial verification based on available field observations. Given the significant hydraulic control the Wallacia Weir and Penrith Weir provide within this system the model setup focussed on representing water levels at these locations accurately. The model is considered fit for purpose for "typical" flow (around the 50% percentile flow); However, it is likely to be less accurate under higher or flood flow conditions (<10% percentile flows) due to the increased engagement of floodplain areas and the lack of schematisation of floodplain storage in the model.

- **Channel topography accuracy.** The hydraulic modelling is based on bathymetric and topographic data supplied by Sydney Water. These datasets influence the way in which hydrology is translated into hydraulics such as depths, velocity etc. We assume these datasets are representative of the channel topography (both above and below water level).
- **Bed sediments.** The sediments on the bed of the channels are used to assess the thresholds of motion as they relate to shear stress, i.e., at what flows the bed is eroded. Adequate bed sediment data was not available for the Nepean River and bed sediments used were based on visual inspection from a boat. For South Creek bed sediments were digitally assessed (Wolman Count) during field inspections by Streamology staff.
- **Risk assessment.** There are no specific geomorphic likelihood or consequence definition that are widely agreed for risk assessment purposes and such assessments typically involve a significant level of expert interpretation. It is acknowledged that the expert opinion informing the risk assessment detailed in this report was based on the technical expertise of the senior staff within Streamology and was not tested with a broader expert group although we did utilise relevant literature, data, and field work to inform these expert opinions. Justifications for decisions have been provided in Section 6.

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 the potential for advanced treated water releases to the Warragamba River (downstream of the dam wall).

The following sections present an overview of the hydrology and geomorphology conditions that currently exist within these receiving waterways. The focus is in defining the current flow regime within these waterways to allow the assessment of impacts in Section 6.

5.1. Hydrology

Most of the Project lies within the Lower Nepean River Management Zone of the Hawkesbury-Nepean Catchment, of which a large percentage of the catchment is protected in both national parks and water catchment reserves. However, the AWRC and associated pipelines are predominately located within the South Creek sub-catchment, which has experienced land clearing and urbanisation (Aurecon Arup, 2021). Land clearing is often responsible for altering the physical form and hydrological regime of waterways.

5.1.1. Nepean River & Warragamba River

Nepean River and Warragamba River Catchment Description

The Hawkesbury-Nepean catchment is critical to metropolitan Sydney by providing drinking water, agricultural water and fisheries produce as well as recreation and tourism opportunities (Aurecon Arup, 2021). It is one of the largest coastal basins in NSW with a footprint of 21,400km^2 (NSW DPI, 2017).

The catchment has seen significant human impacts, as detailed in NSW DPI (2014), "*human modification of the Hawkesbury–Nepean catchment and river has greatly altered the natural hydrology and hydraulics, resulting in detrimental effects on many river-dependant ecosystems. Farming began in the catchment in 1794, with land clearing and farm dam construction the initial forms of hydrologic alteration. An increasing urban population and increasing contamination of near city sources of water and a series of droughts saw the construction of large dams in the catchment from the 1880s (Beasley 1988).*"

There has also been modification to the Nepean River channel. This includes significant sediment extraction from the channel downstream of the Warragamba River to Penrith Weir. Erskine (1998) reported that some 30.6 million tonnes of sand and gravel were extracted from the active channel between Glenbrook Creek and Wilberforce from 1952–72.

A summary of the hydrologic conditions relevant to each of the assessment reaches is provided in Table 14.

Table 14 Description of hydrologic condition in reaches of the Nepean and Warragamba Rivers relevant to this EIS (extracted from DPI, 2014)

Reach	Hydrologic Description
Nepean River Upstream – Bent's Basin to Wallacia Weir	The flows from the Upper Nepean have been greatly reduced by the construction of the Upper Nepean scheme and altered by the series of weirs between Menangle and Wallacia
Nepean River from Wallacia Weir to the confluence with the Warragamba River	Flows in this reach are the same as for the upstream reach. There are no additional inflows except for the Warragamba River at the junction. Inflows from the Warragamba River include environmental flow releases, as described below.
Warragamba River from the dam to the junction with the Nepean River	The entire Warragamba River catchment is 9050 km^2, with most of the catchment upstream of Warragamba Dam. Warragamba Dam is the major impact on the hydrology. Above this reach, all flows except flood flows (which result in dam spills) are held behind the Dam. Current inflows to the reach between the dam and Megarritys Creek are a combination of flood flows that spill from the dam, groundwater and dam seepage, local catchment runoff and water releases during maintenance at the dam. WaterNSW currently releases 5ML/day from Warragamba Dam to dilute treated water released from the Wallacia wastewater treatment plant into the Warragamba River. Another 17 ML/d is released in winter, increasing to 25 ML/d in summer for drinking water extraction at Richmond. The flows are currently released from the water supply pipe as it crosses Megarritys Creek, downstream of the weir (approximately 1.7km downstream of the dam.
Nepean River Downstream - from Warragamba River to Penrith Weir	This reach receives water from two main sources —the Warragamba River and the Nepean River upstream of the confluence with the Warragamba River. This reach is within the Penrith weir pool and so is dominated by the stable water levels and physical effects common to other weir pools, such as long residence times and persistent stratification.

Flow Analysis

There are two stream flow gauges located within the Nepean River area of interest: Wallacia Weir on the Nepean River (212202) and at the downstream at Penrith (212201) (Table 15).

Table 15 Stream flow gauges within the Nepean River catchment (listed upstream to downstream).

Gauge Number	*Location*	*Waterway*	*Monitoring Period*
212202	Nepean River at Wallacia	Nepean River	1962-2021
212201	Nepean River at Penrith	Nepean River	1969-2021

Wallacia Weir

Data from the Wallacia Weir gauge site is presented in Figure 10. This shows that low to no flow conditions only occur in the Nepean River at this site a small proportion of the time (approximately 5% of the time <10ML/d).

The analysis also shows that summer flows are typically lower than other periods. Higher flows (<20% exceedance) are more frequent during Autumn and Winter.

In June 2010, additional dam releases on the Nepean River system were mandated to supplement environmental flow requirements. Prior to this, flows in the Nepean were substantially lower, with a median flow of only approximately 10 ML/day - in comparison to 229 ML/day after June 2010. Therefore, the period 2010 to 2021 is considered most representative of the current flow regime in the river.

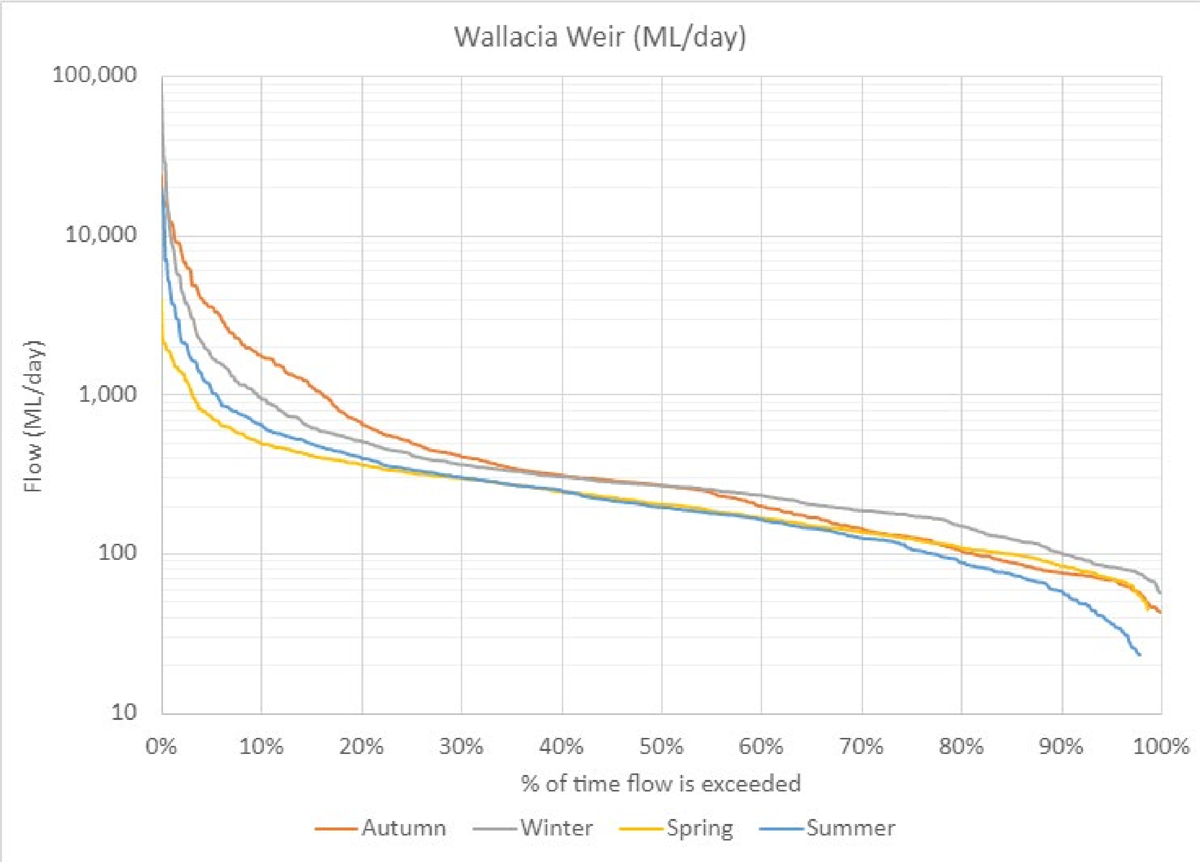


Figure 10 Flow duration curve for the Nepean River at Wallacia Weir (2010 to 2021)

Penrith Weir

The flow data show no cease to flow periods at this location, Figure 11. The Nepean River at the Penrith Weir has a minimum flow of approximately 50 ML/d (0.6 m^3/s), with summer flows typically lower than other periods. Higher flows (<20% exceedance) are more frequent during Autumn and Winter. The median flow at Penrith Weir is 275 ML/d.

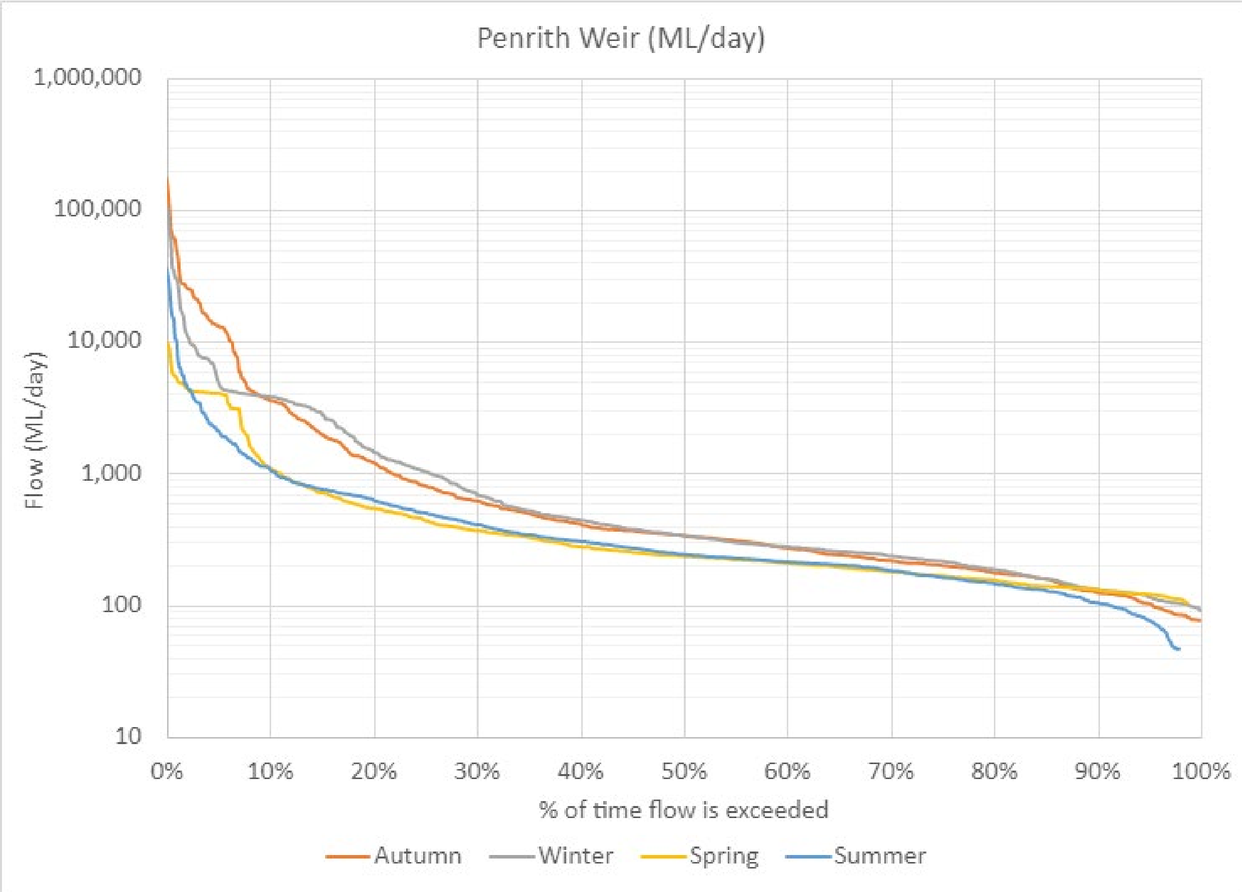


Figure 11 Flow duration curve on the Nepean River at Penrith Weir (2010 to 2021)

Warragamba River

There are two gauges on the Warragamba River relevant to the proposed environmental flow release location:

- Gauge 212241 is located at the Warragamba Weir
- Gauge 212243 is located at the Warragamba Dam

Only water storage level is recorded at the dam gauge site.

Table 16 Stream flow gauging on Warragamba River (listed upstream to downstream).

Gauge Number	Location	Waterway	Monitoring Start Date
212241	Warragamba River at Warragamba Weir	Warragamba River	28/11/1980
212243	Warragamba River at Warragamba Dam	Warragamba River	27/05/1977

As can be seen from Figure 12, there has been a significant reduction in flows in the Warragamba River downstream of the dam since the early 1990’s. Figure 13 shows that approximate 22% of the time flows are <5 ML/d.

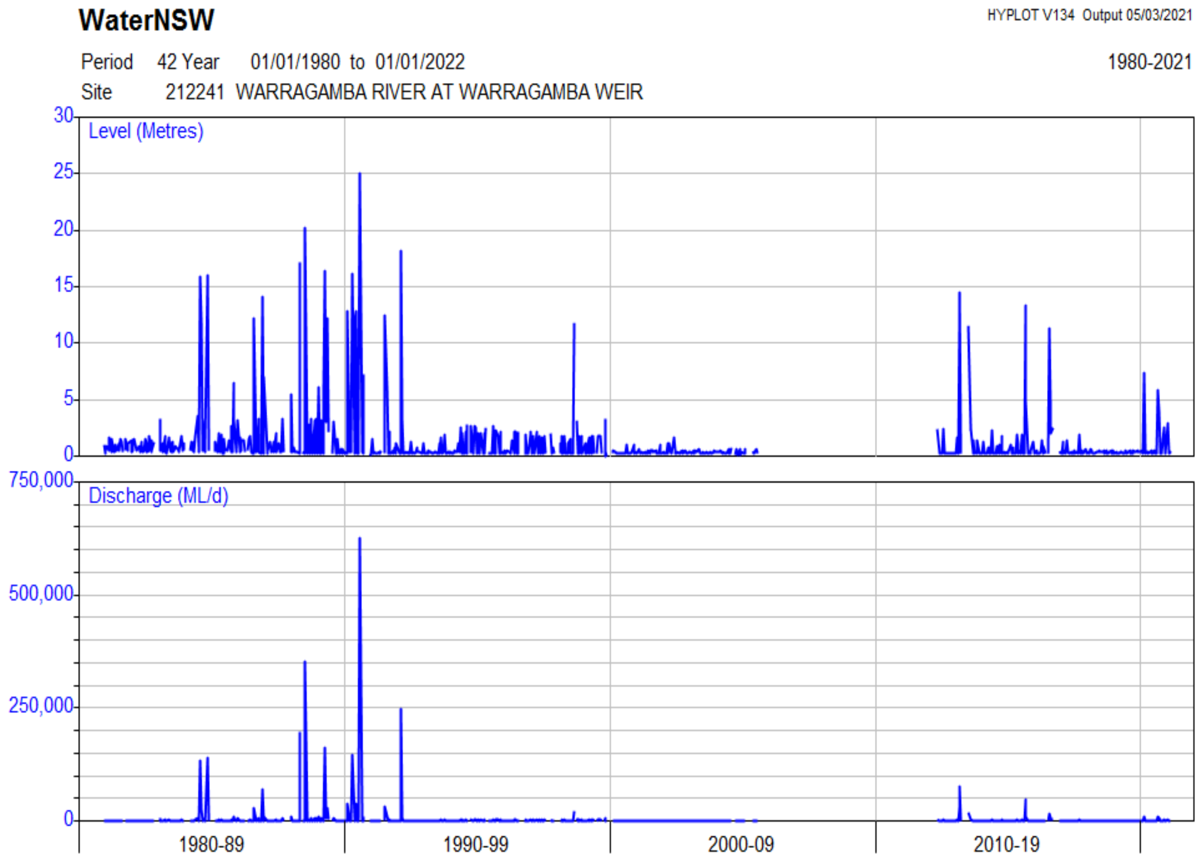


Figure 12 Flow and water level record at site 212241 (Warragamba River at Weir)

Figure 13 Flow duration curve on the Warragamba River at Warragamba Weir (1980 to 2021)

Water releases from the dam

WaterNSW currently releases 5ML/day from Warragamba Dam to dilute treated water released from the Wallacia wastewater treatment plant into the Warragamba River. Another 17 ML/d is released in winter, increasing to 25 ML/d in summer for drinking water extraction at Richmond. The flows are currently released from the water supply pipe as it crosses Megarritys Creek, downstream of the weir (approximately 1.7km downstream of the dam).

5.1.2. South Creek

South Creek and Kemps Creek Catchment Description

The origin of the South Creek catchment is located around Oran Park, flowing generally north, and joined by other tributaries including Badgerys Creek and Kemps Creek near the AWRC site. It reaches the confluence with the Hawkesbury River near Windsor. The South Creek sub-catchment covers approximately 620 km^2. The channel width and flow velocity of South Creek varies significantly within the stretch of the creek directly adjacent to the AWRC site.

The hydrology of the South Creek catchment has been significantly altered due to a decrease in pervious surfaces as a result of land clearance and urbanisation. The Hawkesbury River is the ultimate downstream receiving environment and is located about 29 km from the AWRC at the closest point.

Kemps Creek is a tributary of South Creek, located near the AWRC site. The creek flows through a predominately semi-rural setting, although urbanisation has increased in recent years. The catchment experiences flooding issues due to its limited channel capacity and hydraulic capacity (culverts, bridges) (Liverpool City Council, 2003). This has resulted in dams and channels being excavated, as well as works to widen the channel to mitigate flood events. Land use within the Kemps Creek sub-catchment largely includes agriculture (grazing, market gardens, poultry), residential, commercial, and extractive industries. Kemps Creek has a catchment area of approximately 59 km^2, (Aurecon Arup, 2021).

A summary of the hydrologic conditions relevant to each of the assessment reaches is provided in Table 17.

Table 17 Description of hydrologic condition in reaches of South Creek relevant to this EIS

Reach	Hydrologic Description
South Creek upstream of the AWRC	Hydrology has been significantly altered due to land use change and urbanisation, however the flow regime in this reach of South Creek remains intermittent in nature.
South Creek downstream of the AWRC	Kemps Creek and Badgerys Creek join South Creek immediately downstream of the AWRC site. This significantly increases flows in South Creek and the creek becomes more perennial in nature downstream.

Flow Analysis

There are two stream flow gauges located within the Wianamatta-South Creek catchment.

- Gauge 21320 is located approximately 1.7 km upstream of the AWRC site, near the Elizabeth Drive crossing
- Gauge 212048 is located approximately 14.3km downstream of the site, near the Great Western Highway crossing

Table 18 Stream flow gauges within the South Creek catchment.

Gauge Number	*Location*	*Waterway*	*Monitoring Period*
212320	South Creek at Elizabeth Drive	South Creek	1970-2021
212048	South Creek at Great Western Highway	South Creek	1986-2021

A comparison of flow duration curves at the two gauges is included in Figure 14.

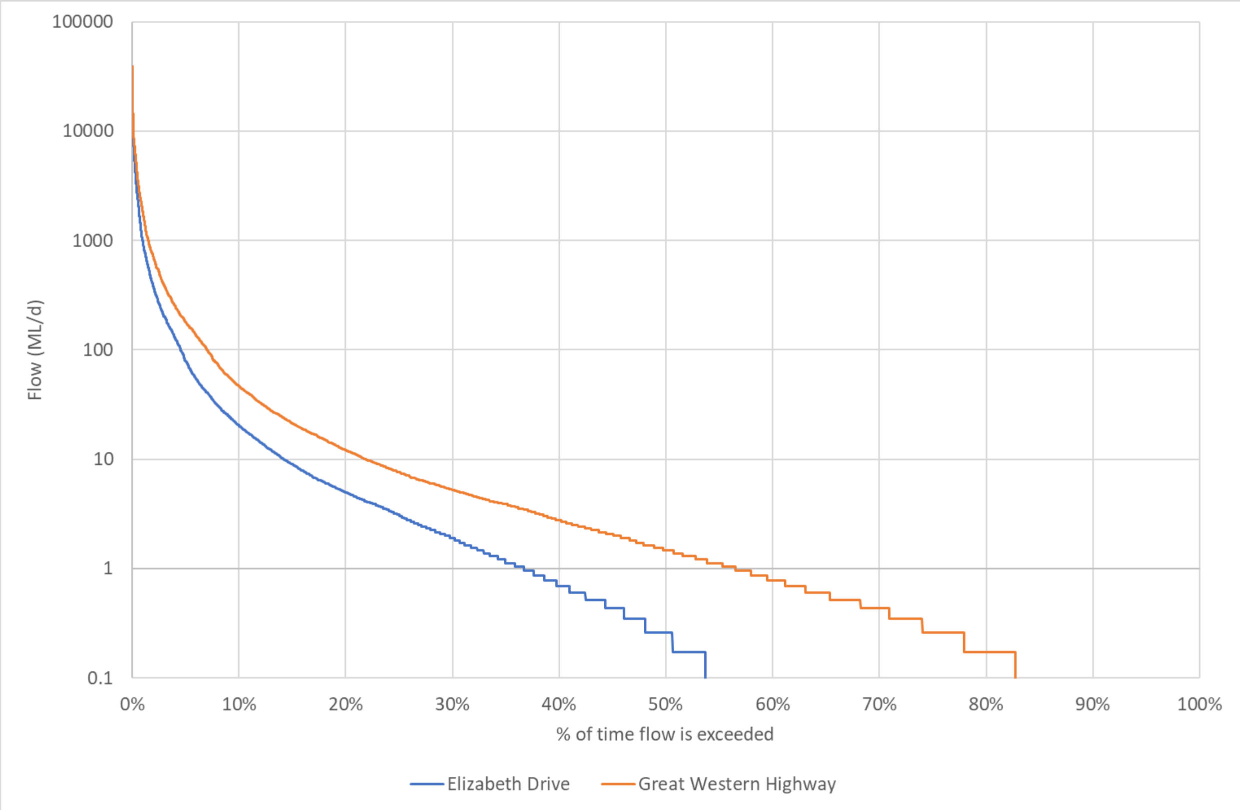


Figure 14 Comparison of flow duration curves between the two South Creek Gauges (212048 and 212320) – full monitoring period analysed. Note that zero values cannot be plotted on the log scale vertical axis.

The flow duration curves for each site show that at the more upstream site (Elizabeth Drive) there is a significant proportion of the time with very low flows (approximately 46% of the time <0.01ML/d), while by the time the flows reach the downstream site this has reduced to around 16% of the time. The median flow at Elizabeth Drive is 0.26 ML/d while this rises to 7.6 ML/d by the Great Western Highway site.

Several tributaries join South Creek downstream of Elizabeth Drive which contribute additional flows to the waterway. Overall, the waterway is currently more intermittent in nature than the Nepean River.

5.2. **Geomorphology**

5.2.1. **Nepean River & Warragamba River**

A reach-by-reach description of the geomorphology of the Nepean River and Warragamba River is provided by DPIE NSW (2014) based on an extensive desktop and field investigation. This report provides an overview of existing geomorphic character of these rivers based on information in DPIE NSW (2014) and other information gathered for this assessment. The work included a detailed literature review of information relevant to the reaches of the river below the Wallacia Weir that are being considered by this report. There have been no significant geomorphic changes to the Nepean River and Warragamba River since this report was published and therefore the information is reflective of current geomorphic conditions.

A review of locations with similar impacts, such as release of treated water to natural watercourses, revealed that the hydraulic conditions at each site were unique and sufficiently different to the conditions assessed for the AWRC that extrapolation of results from other systems to this one would be of limited value.

The Nepean and Warragamba Rivers are large systems with extensive catchment areas, leading to high Strahler orders (stream size). The Nepean River is a Strahler of 7 to the Warragamba confluence (Figure 15). The Warragamba River is a Strahler of 9. The Nepean River downstream is then labelled as a Strahler 9. The Strahler Order increases only when two streams of the same Order join. Otherwise, the highest stream Order applies downstream.

In NSW, the River Styles Framework (Brierley et al, 2005) is used to characterise geomorphic river types, their behaviour, condition, and recovery potential. The River Styles present in the study area include the Gorge style (Nepean River – Wallacia Weir to Norton's Basin and Warragamba River – Dam to Nepean River confluence), planform controlled, low sinuosity (Nepean River – Norton's Basin to upstream margin of backwater from Penrith Weir), and 'water storage' for the Nepean River downstream of Warragamba River confluence (Figure 16 and Table 19). These river style types demonstrate reaches that are often, and sometimes continuously, bedrock controlled (laterally and vertically) with a coarse-grained bed sediment. The Nepean River upstream of Wallacia Weir (alluvial low sinuosity) is a less bedrock-controlled waterway. Insights on physical and geomorphic characteristics, from the one-day field inspection and background review, are provided in Table 20.

The Nepean River is predominantly backwater controlled, with a low hydraulic gradient, i.e., slow flowing nature. This is particularly due to the hydraulic controls of Penrith Weir and Wallacia Weir. The section from Wallacia Weir to Norton's Basin is significantly steeper, which greatly increases hydraulic diversity (Figure 17).

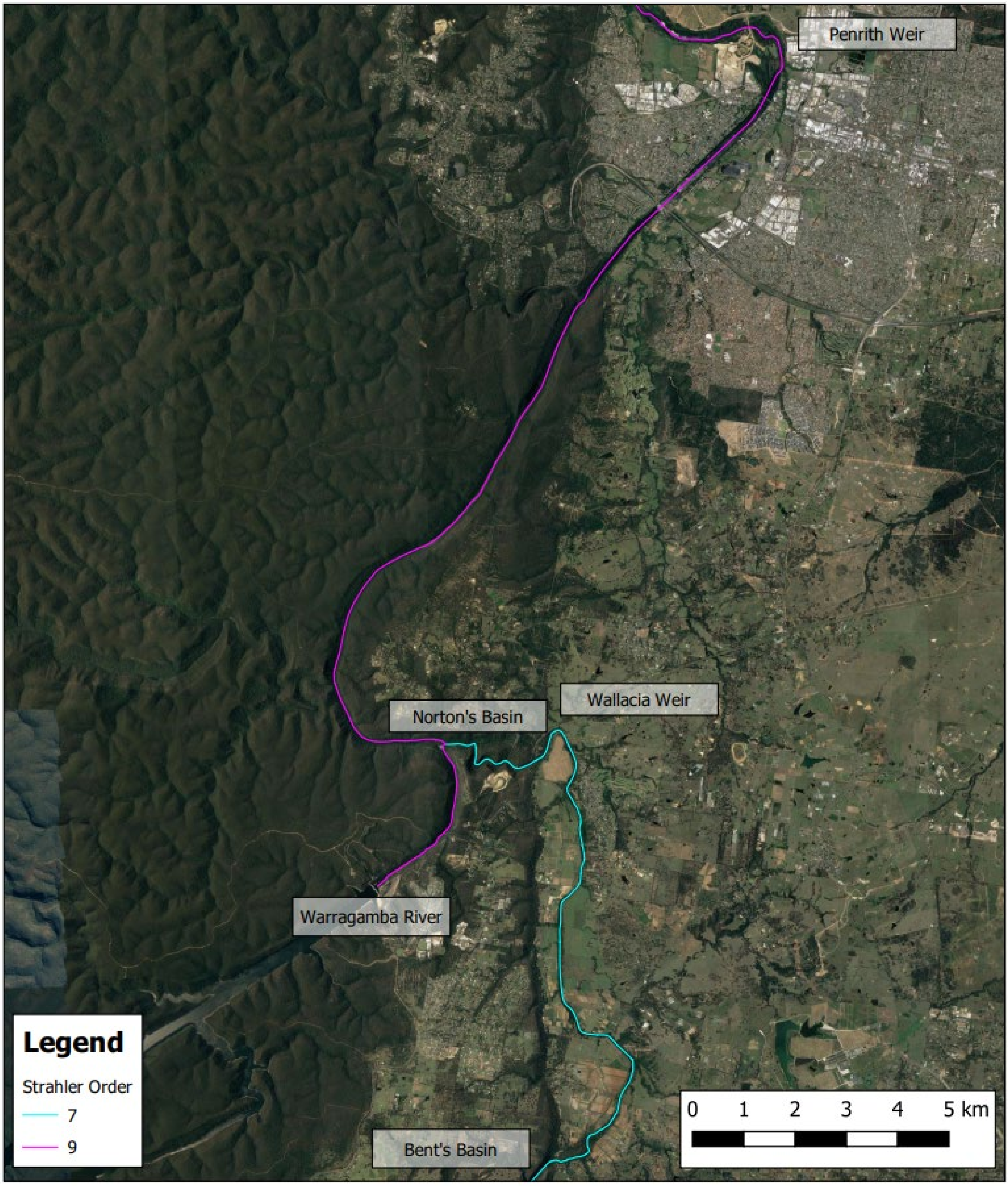


Figure 15 Strahler order (stream size) classification for Nepean and Warragamba Rivers within focal area (DPIE 2014).

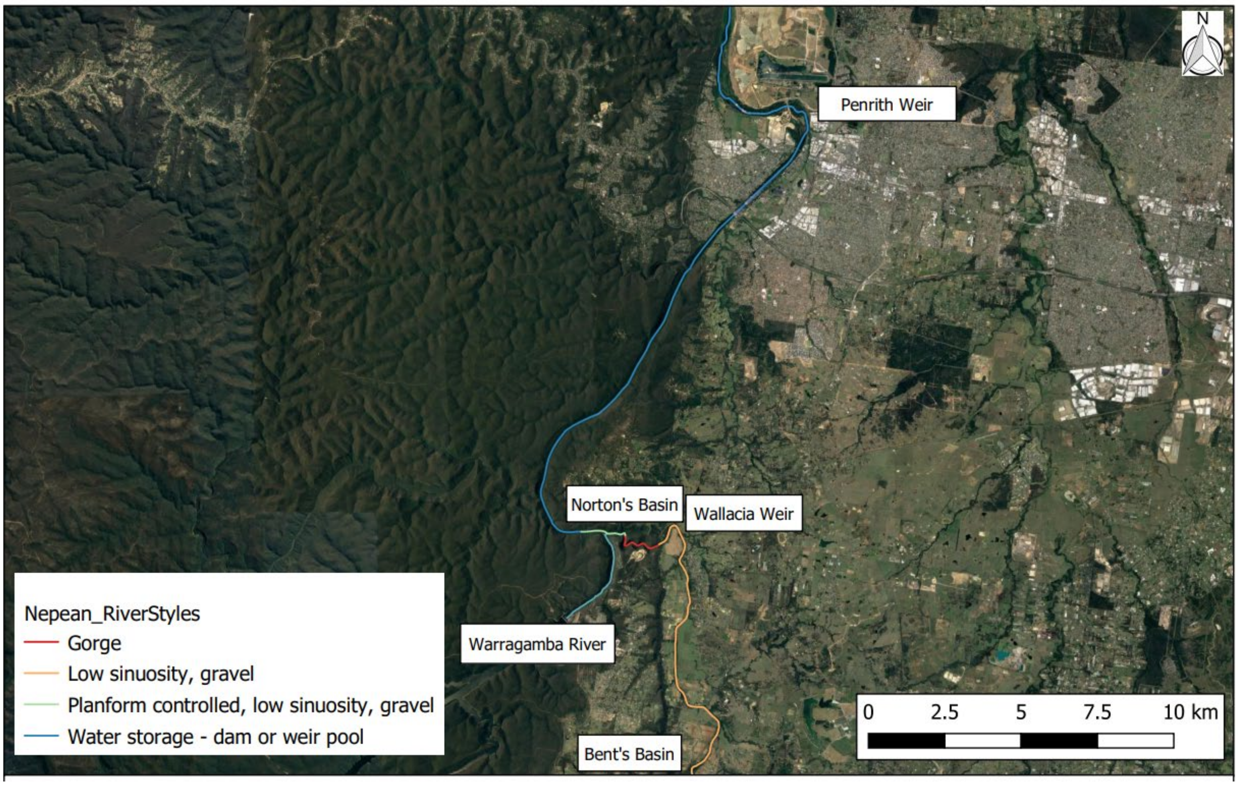


Figure 16 River styles classification for Nepean and Warragamba Rivers within focal area from Bent's Basin to Penrith Weir. Note that despite Wallacia Weir creating a weir pool it is not considered under River Styles to be a 'Water storage'.

Table 19 River Styles defined for the Nepean and Warragamba Rivers and reaches assigned (based on the River Styles assignment by Department of Land and Water Conservation (DLWC) using (Brierley & Fryirs, 2000))

River Style	Assigned Description (DLWC 2000)	Assigned reach in formal River Styles assessment (refer Figure 16)	Interpretation for this study
Gorge	Single, confined with no floodplain. Bedrock-imposed configuration; may contain straight or highly sinuous reaches. Channel zone often alternating sequences of steep stepped sections (with boulder bars, falls, cascades) and lower-slope sections with pools and rapids. Slackwater deposits. Similar to Headwater but has side slope cliffs	Nepean River – Wallacia Weir to Norton's Basin Warragamba River – Dam to Nepean River confluence	These reaches conform with the Gorge style.
Alluvial, low sinuosity, gravel	Single channel with highly variable sinuosity and continuous floodplains along both valley margins. Channel zone contains pools and LWD riffles, small fine grained point bars and midchannel bars (if any), occasional benches, chute channels, and islands Floodplain zone is continuous floodplains with levees, palaeochannels, many recent oxbows (billabongs) and back swamps. Often higher floodplain level or terraces.	Nepean River - Upstream Wallacia Weir	Key characteristic here is mobile banks, migrating channel and increasing sinuosity.
Planform controlled, low	Single, planform controlled (only 10% to 50% of channel length or apex of bend abuts valley margin). Low sinuosity or straight.	Nepean River – Norton's Basin to upstream margin	Key characteristics here are the

River Style	Assigned Description (DLWC 2000)	Assigned reach in formal River Styles assessment (refer Figure 16)	Interpretation for this study
sinuosity, gravel	Occasional short reaches with 2 channels separated by islands. Channel zone: lateral bars, islands in wider sections of channel, irregular riffles, may have elongate pools, benches Floodplain zone: flood channels, palaeochannels, terraces, wetlands.	of backwater from Penrith Weir	bedrock controls and low sinuosity.
Water storage - dam or weir pool	Backwater controlled storage.	Nepean River – Penrith Weir backwater	This reach would have previously been more so a 'Planform controlled, low sinuosity, sand/gravel' type. Inundation from the backwater obscures the style.

Table 20 Summary of reach, character, physical condition, and sensitivity to change. Note that information is based on the River Styles dataset (NSW DPIE online), DPI NSW (2014) and field inspection by Geoff Vietz

Reach desc.	*Character*	*Physical condition*
Warragamba River (Dam to confluence)	• Cobble bed river • Bedrock controlled • Moderate sinuosity • 22 to 30 ML/d baseflow	• Likely to be sediment starvation due to storage, but otherwise good condition with bedrock controls on vertical (bed) and lateral (gorge) migration. • River styles notes the reach to be in moderate condition and low sensitivity to change
Nepean River – upstream Wallacia Weir	• Alluvial • Likely sand and gravel • Low hydraulic diversity	• Condition not described in DPIE (2014) nor inspected. • River styles notes the reach to be in moderate condition and moderately sensitive to change.
Nepean River - Wallacia Weir to Warragamba confluence	• Bedrock controlled • Likely gravel, cobble and boulder bed • High hydraulic diversity • High recreational value to due to waterholes	• Good condition with significant bedrock controls • River styles notes the reach to have low sensitivity to change
Nepean River downstream Warragamba confluence to Penrith Weir	• Bedrock controlled • Likely gravel, cobble and boulder bed • Low to moderate sinuosity	• Good condition down to Glenbrook Creek • Degraded condition downstream Glenbrook Creek due to gravel extraction. • River styles notes the reach to have low sensitivity to change

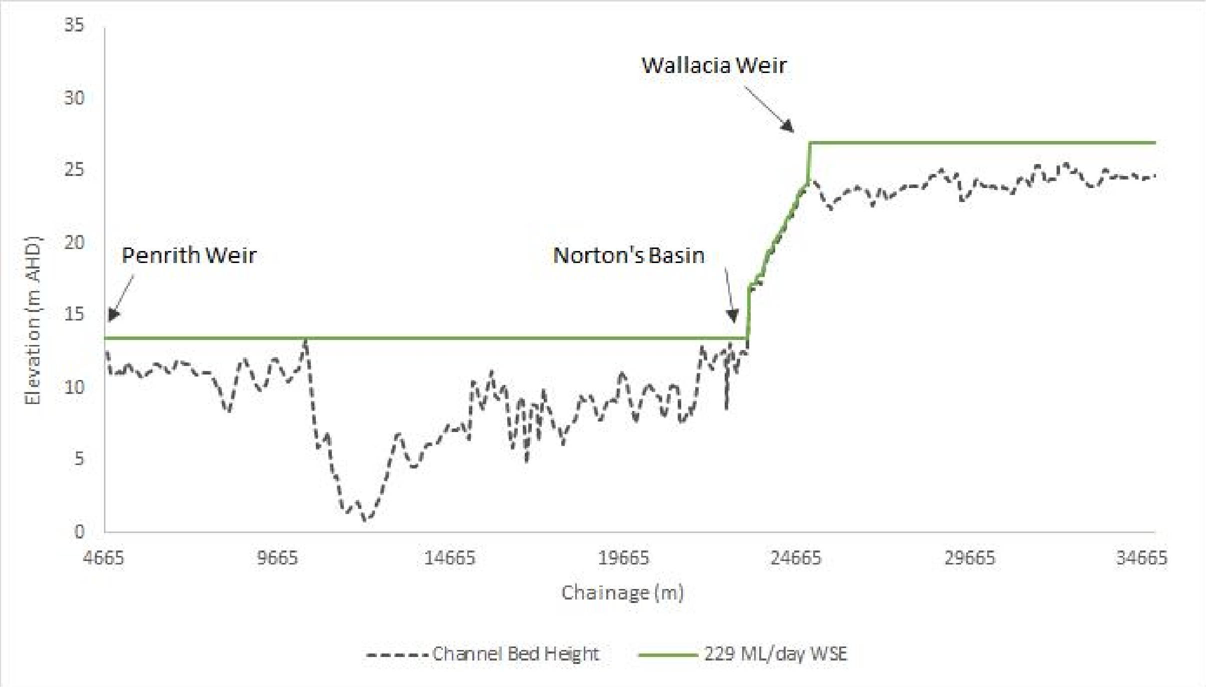


Figure 17 Water level profile along the Nepean River calculated from bathymetric and LiDAR water surface data. A flow of 229 ML/d is approximately the 50th percentile (median) flow condition.

5.2.2. South Creek

A reach-by-reach description of the existing geomorphic character of South Creek is provided in this report based on information in the NSW River Styles Database (NSW DPIE online), information from previous work undertaken on South Creek for the Urban Stream Flow Impact Assessment (USIA) project (Vietz et al., 2018, Kermode et al 2020) and additional information gathered for this assessment.

South Creek at and downstream of the proposed AWRC site including the Warragamba Pipeline crossing is a laterally unconfined waterway in a valley setting with a cohesive and continuous planform floodplain. It has a low degree of sinuosity and is characterised by fine grained bed materials in a matrix that varies between uncemented coarse matrix and cemented fines.

Bank matrix composition through this section of South Creek consists of fines with limited coarse materials and marginally dispersive conditions (Table 21). There are several informal obstructions throughout this section of creek that have preserved remnant chain of ponds function through weir pool effects, however, the original physical form of chain of ponds in this region has been lost long ago.

South Creek in this region is characterised by several large billabongs and observable anabranches as a result of the low gradient of the system, and several meander bends have steep outside banks and shallow inside banks.

The Strahler Order and River Styles characteristics for South Creek are shown in Figure 18 and Figure 19.

The condition of South Creek at and downstream of the AWRC site is poor based on the high extent and severity of erosion, and the quality of riparian vegetation (as it affects bank stability and character). The South Creek channel, however, also maintains various important geomorphic features such as fine-grained benches, and gravel bars. The condition of South Creek is related to historical land clearing, and most recently degradation as a result of urban stormwater (as described in Vietz and Clarke 2020). Upstream of the AWRC site South Creek is considered highly sensitive to change, while only moderately so downstream (NSE DPIE online).

Borelog information (GHD, 2020) at locations adjacent to South Creek indicated the soils consist of topsoil, overlying alluvial (clay) with weathered rock (siltstone/sandstone) at depth (5-7m).

A summary of the geomorphic character of this location is provided in Table 22.

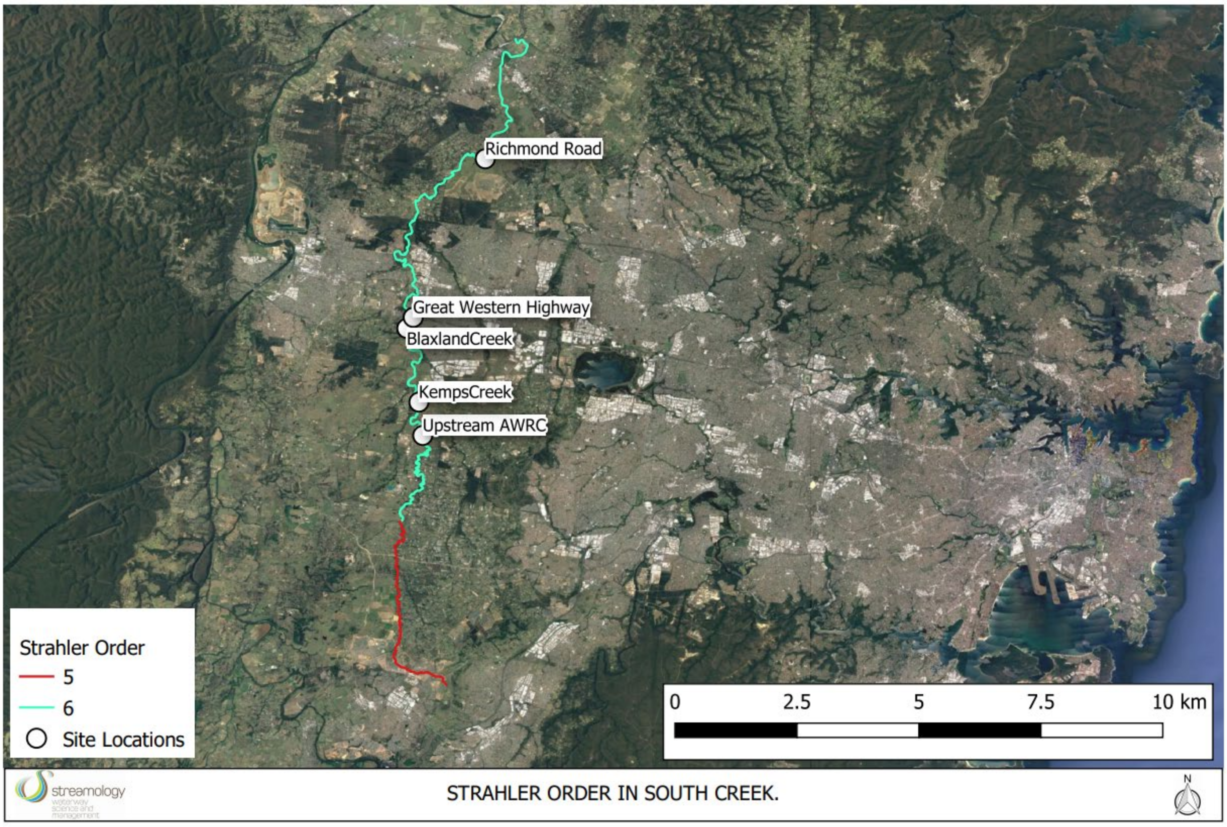


Figure 18 Strahler order (stream size) classification for South Creek within focal area (DPIE 2014).

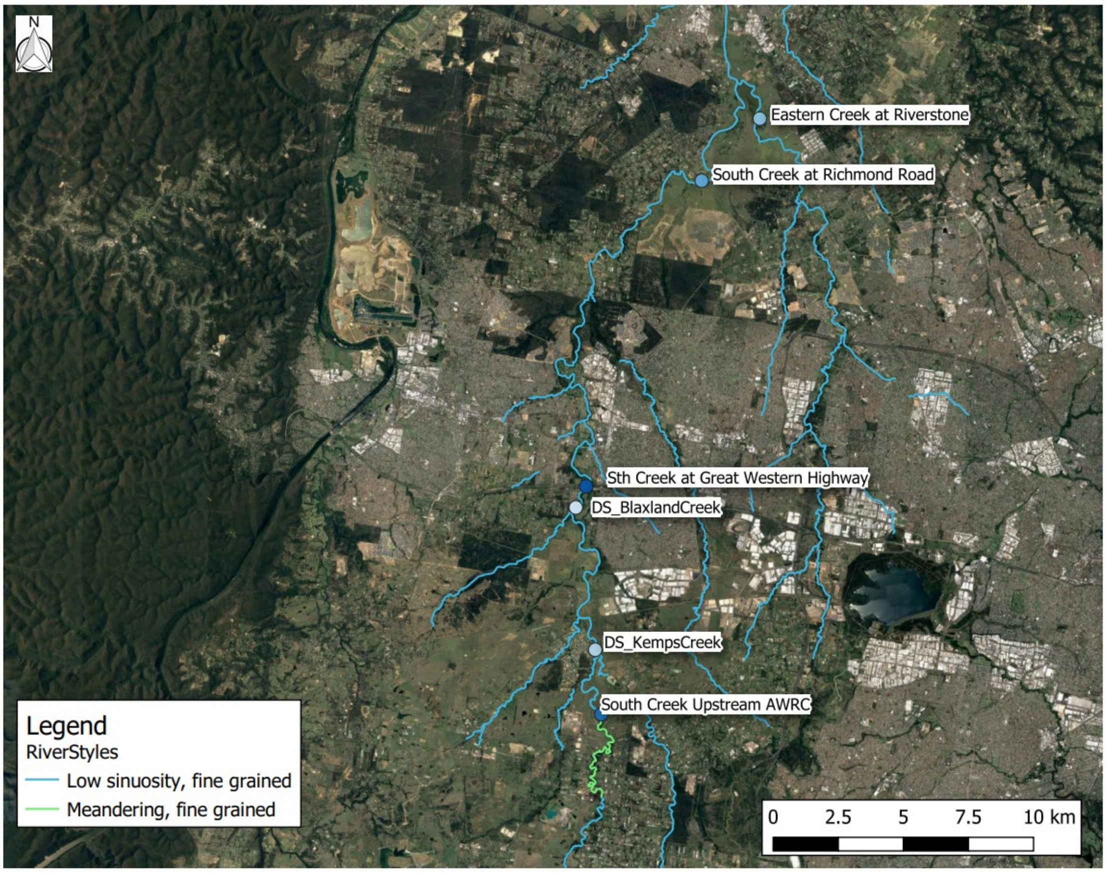


Figure 19 River styles classification for South Creek within focal area upstream and downstream of the AWRC.

Table 21 Indicative bed and bank material in South Creek (data collected during USIA project, Vietz et al, 2019). Note that the diversity of bed sediments throughout the site have not been comprehensively assessed.

Imagery of Bed and Bank	Analysis
	**Bed** Gravels - Median matrix = 2.4 mm Well graded Matrix varies between uncemented coarse matrix and cemented fines
	**Bank** Bank matrix composition silt/clay (<1mm) Marginally dispersive conditions – observable and tested during field visit.

Table 22 Summary of reach, character, physical condition, and sensitivity to change. Note that information is based on the River Styles dataset (NSW DPIE online), and limited field data from the South Creek catchment in general collected for the USIA project (Vietz et al, 2019). The character and physical condition have been inferred from this information by the project team.

Reach desc	Character	Physical Condition
South Creek from u/s of AWRC	• Alluvial • Gravels on the bed with silty/clay banks • Low sinuosity	• Highly degraded, moderate recovery potential. • Channel modifications with bed and bank structures • River styles note that the waterway is highly sensitive to change
South Creek downstream of the AWRC	• Alluvial • Gravels on the bed with silty/clay banks • Low sinuosity	• Highly degraded, moderate recovery potential. • Channel modifications with bed and bank structures • River styles note that the waterway is moderately sensitive to change

6. Impact assessment

6.1. Nepean River & Warragamba River

6.1.1. Overview of hydrologic results

The results of the hydrologic scenario analysis along the Nepean River upstream and downstream of the AWRC release location show limited change in many of the hydrologic metrics assessed.

The overall geomorphic risk associated with changes to hydrologic metrics is quantified by comparison of the background and impacts scenarios compared to baseline conditions (summarised in Table 23, drawing upon more detailed assessments in Table 24). The analysis indicates negligible differences between the background and impacts scenarios given the limited predicted land use change in the Nepean River catchment upstream of the release site. The main hydrologic change is the median flow, yet the analysis indicates this has a negligible influence on the other characteristics of the flow regime.

The likelihood and consequence of geomorphic impacts is based on interpreting how these hydrologic metrics will drive geomorphic change, such as erosion or deposition. Given the limited linkage between median flow changes in this realm, and geomorphic change, the overall impact of the AWRC release by itself on the geomorphic condition of the Nepean River above baseline or background is low. This has been considered for the three main reaches of the Nepean River and its tributary the Warragamba River, Table 23.

Table 23 Summary of potential geomorphic risks associated with background (HN01-HN04) and impact (HN05-HN16) hydrologic scenarios compared to baseline conditions (HN00).

Scenarios		Upstream Wallacia Weir	Wallacia Weir to Warragamba River	Warragamba River confluence to Penrith Weir
Background (HN01-HN04)	Likelihood	Unlikely	Unlikely	Unlikely
	Consequence	Minor	Minor	Minor
	Risk	Low	Low	Low
Impact (HN05-HN16)	Likelihood	Unlikely	Unlikely	Unlikely
	Consequence	Minor	Minor	Minor
	Risk	Low	Low	Low

To support the risk assessment, Table 24 summarises the results of the hydrologic metric assessment (USIA approach) for each of the reaches defined previously, with full results provided in Appendix C. The results are described in terms of the changes from the baseline conditions only for the background (non AWRC release) scenarios, while the impact (with AWRC release) scenarios are compared to baseline and background conditions.

Table 24 Overview of possible catchment impacts for modelled background and impact scenarios based on analysis of the change in hydrologic metrics compared to baseline conditions (HN00).

Scenario	Description	Possible Catchment Impacts for different reaches of the Nepean River		
		Upstream Wallacia Weir	Wallacia Weir to Warragamba River	Warragamba River confluence to Penrith Weir
HN00	**Baseline**	-	-	-
HN01 - HN04	**Background** - Future landuse, various stormwater approaches, No AWRC Release	• Data suggests no increase in mean annual flows with future land use compared to baseline • Undetectable change in median flows • No change in zero flows (maintains perenniality) • Minor increase (undetectable) change in the duration of time flows are above 'fresh' levels • No flows above bed erosion (no change from baseline)	• Data suggests undetectable change in mean annual flows with future land use compared to baseline • Undetectable change in median flows • No change in zero flows (maintains perenniality) • Undetectable change in freshes • No increase in flows above bed erosion threshold	• Data suggests undetectable change in mean annual flows with future land use compared to baseline • Undetectable change in median flows • No increase in zero flows • Undetectable change in freshes • No increase in flows above bed erosion threshold
HN05 - HN16	**Impact** - Future land use, future stormwater approaches and AWRC releases	• Data suggests no increase in mean annual flows with future land use compared to baseline. • Undetectable change in median flows • No change in zero flows (maintains perenniality) • Minor increase (undetectable) change in the duration of time flows are above 'fresh' levels • No flows above bed erosion (no change from baseline)	• Data suggests undetectable change in mean annual flows with land use and release changes compared to baseline, as shown for background scenarios • Moderate increase in median flows based on current modelling, compared to baseline and background • No change in zero flows (maintains perenniality) same as background and baseline • Likely low change in % time above fresh (positive and negative) compared to baseline and background • No increase in flows above bed erosion threshold, same as background	• Data suggests undetectable change in mean annual flows with land use and release changes compared to baseline and background • Moderate increase in median flows based on current modelling, compared to baseline and background • No increase in zero flows, same as background and baseline • Likely low change in % time above fresh (positive and negative) compared to baseline and background • No increase in flows above bed erosion threshold, same as background

6.1.2. **Overview of ecohydraulic results**

The hydraulic metrics (water surface elevation, wetted perimeter, velocity, and shear stress) are specific to the morphology of the river which varies along each of the reach. To assess the impact of the AWRC releases on the channel morphology we have therefore focussed on how the hydraulic metrics vary between the baseline ecohydraulic scenario and the Stage 1 (50 ML/d) AWRC release conditions.

The following series of figures show the modelled results for the hydraulic metrics and provide an indication of the overall trends along the river. General commentary is provided on the potential impacts of the releases on changes to these metrics and therefore the geomorphology of the river. While the figures present the results under the 50th percentile flow conditions (median flow), additional results for the 90th percentile (low flow) and 10th percentile (high flow) conditions are presented in Appendix B. Commentary on these low and high flow results is included.

Results for median flow conditions with the ultimate (100 ML/d) AWRC release are also provided in Appendix B and commentary included in the relevant sections. These conditions represent the maximum impact of the AWRC project, given that releases will be lower in the early stages. The releases will increase over time but may also be reduced by extractions for recycled water.

More detailed reach by reach results and analysis is presented within the subsequent sections with further commentary about the resultant impacts of these changes on morphological conditions in the rivers.

Figure 20 presents an outline of the Nepean River that was modelled, along with key locations which are referred to in the results.

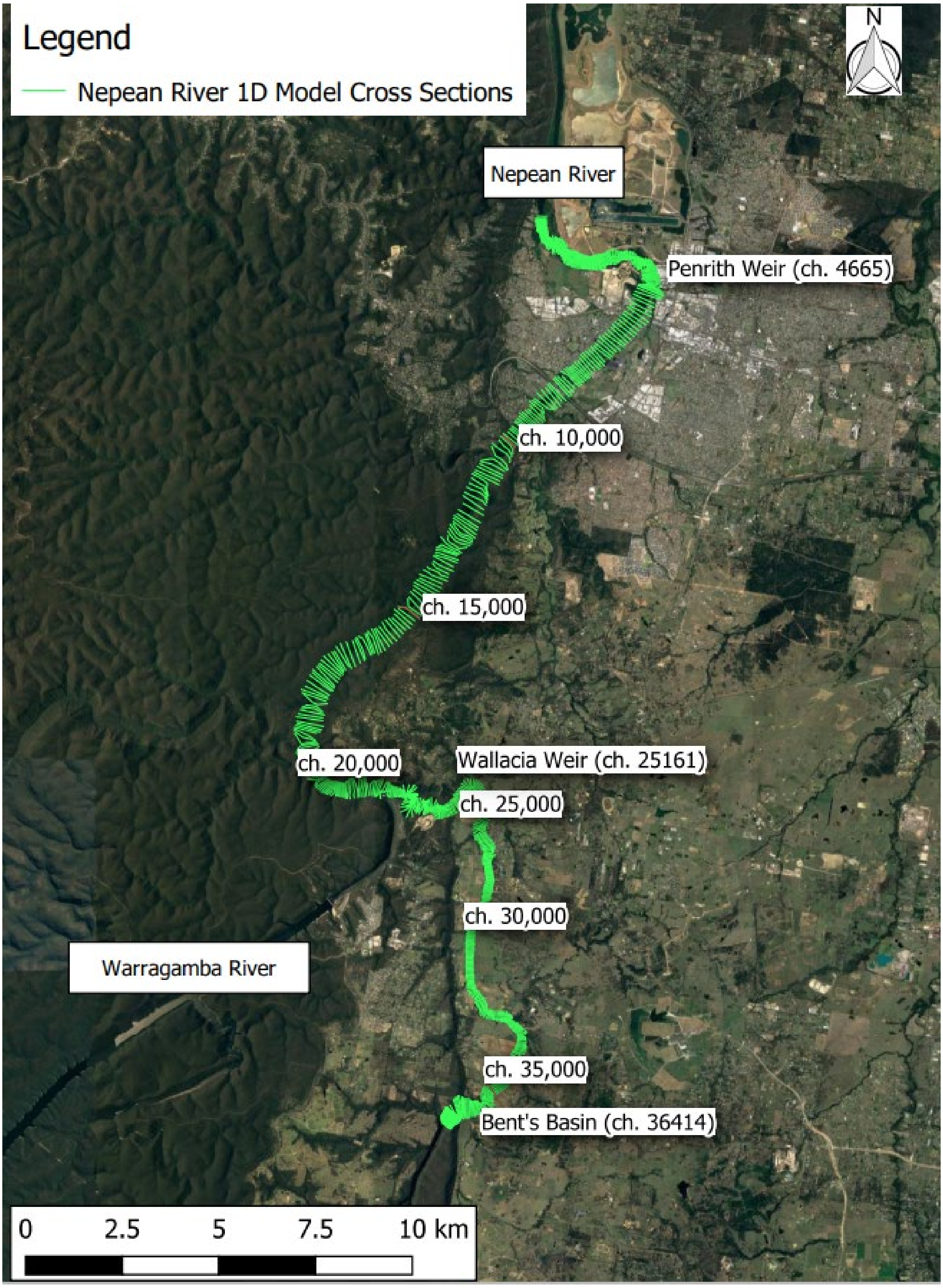


Figure 20 Extent of Nepean River 1D Model, annotated with chainage (ch.) at key locations. Chainage is measured downstream to upstream.

Water Surface Elevation

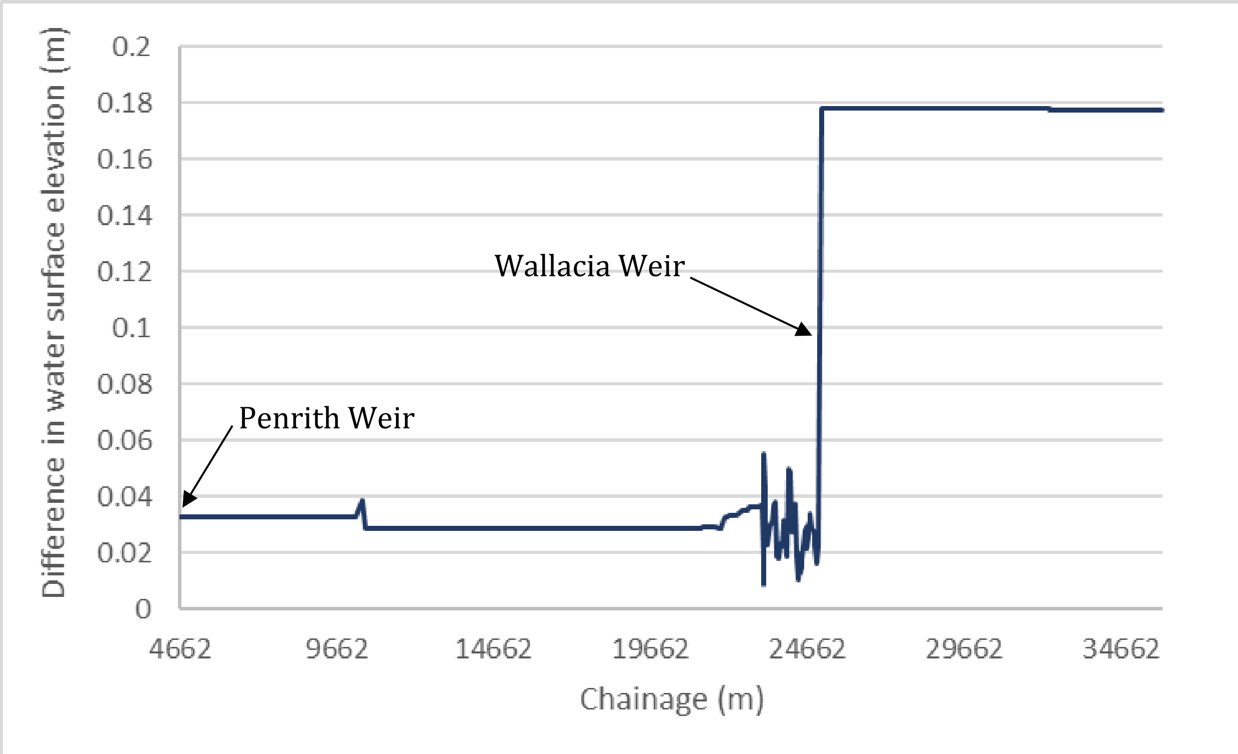


Figure 21 Difference in water surface elevation between baseline conditions and scenario with the release of 50 ML/day from the AWRC along the Nepean River between Bent's Basin (chainage 36,000) and Penrith Weir (chainage 4662m).

Figure 21 shows that changes in the water surface elevation are limit to predominantly areas upstream of Wallacia Weir, with an increase in around 0.18m for the full extent of the Wallacia weir pool under median flow conditions. The weir is a hydraulic control, meaning that upstream water levels are controlled by the flow at the weir. With the increase in flow as a result of the treated water release there is a corresponding increase in the water level upstream of the weir. Downstream of the weir the changes are minor (average <3cm) with slightly higher (up to 5cm) increases that are localised to small sections of channel.

Under low flow conditions (90th percentile flows) the results indicated a greater increase in water surface elevation within the Penrith Weir pool compared to upstream of Wallacia Weir. However, the maximum increases were less than 0.1m.

Under high flow conditions (10th percentile flows) the effects of the AWRC release are less noticeable. While the differences in water surface elevation occur at the same locations as for other flows, the magnitude of the differences is significantly reduced. The maximum increases are < 0.02m.

The effect of seasonal changes in flow conditions were considered within the assessment, however the trends and magnitude of changes are the same as for those flow conditions reported and so have not been specifically included.

Under the ultimate development condition (100 ML/d AWRC release) there is a further increase in water surface elevation upstream of Wallacia Weir, however the results downstream are very similar to the 50 ML/d release results.

Wetted Perimeter

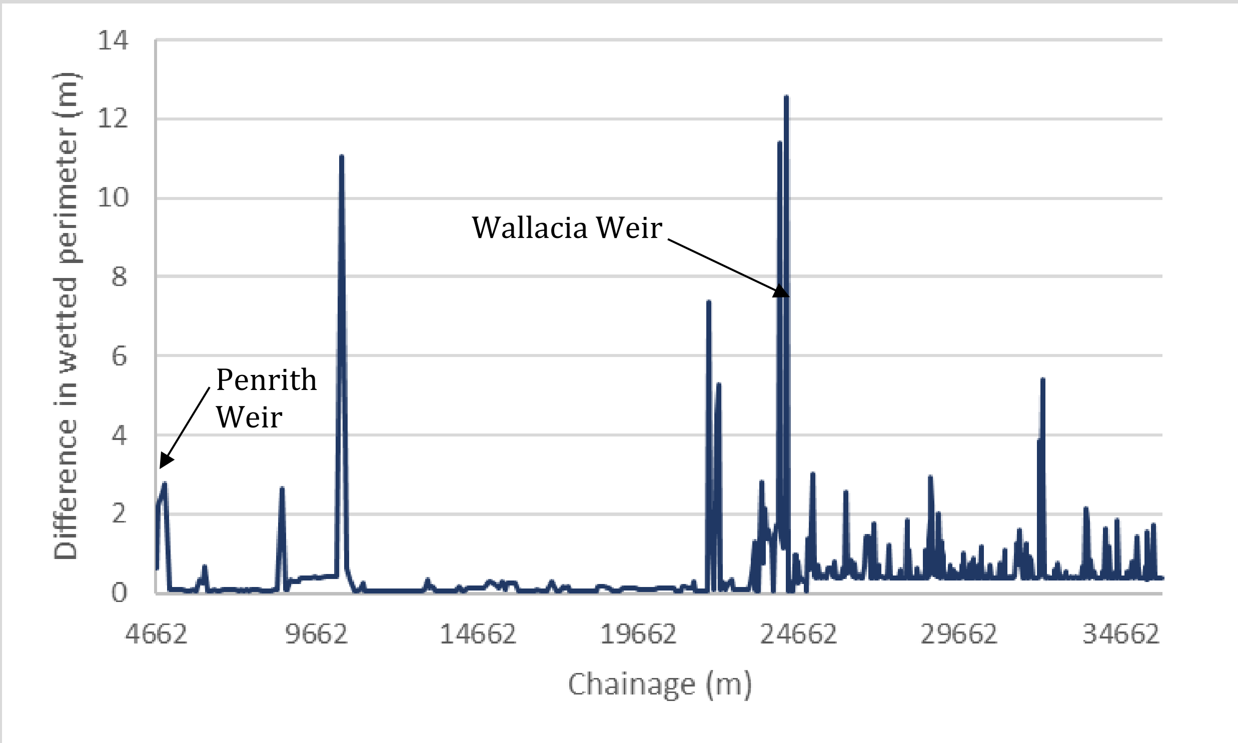


Figure 22 Difference in wetted perimeter between baseline conditions and scenario with the 50 ML/d release from the AWRC along the Nepean River between Bent's Basin (chainage 36,000) and Penrith Weir (chainage 4662m).

The metric wetted perimeter is more sensitive to changes in flow regime than water surface elevation, as shown Figure 22. A slightly increase in surface water elevation may inundate a bench or engage a wider cross-section which is reflected in larger changes in wetted perimeter. Generally, the changes in wetted perimeter are minor (<2m), however there are more significant increases in localised sections of channel. These are discussed further in the following sections.

Under low flow conditions (90th percentile flows) the results are similar to the median flow case, with localised increases in wetted perimeter predominantly noticeable in the reach downstream of Wallacia Weir to the Warragamba River confluence. The increases are the result of the same processes as occur under median flow conditions and the magnitude of the changes are approximately the same.

Under high flow conditions (10th percentile flows) the difference in wetted perimeter is less noticeable, although the changes do occur at the same locations as for the median and low flow conditions.

Under the ultimate development condition (100 ML/d AWRC release) the results are again very similar in terms of the location of the localised differences and their magnitude.

It should be noted that under all the flow conditions described here the flows remain within channel and so changes in wetter perimeter are limited to wetting of in-channel bars and benches. There is no engagement of the floodplain or additional overbank flow as a result of the releases.

Velocity

The difference in velocity is shown in Figure 23. There are negligible changes (<0.01m/s) along most of the river. However, through the steeper reach from Wallacia Weir to the Warragamba River confluence the increase in velocity is around 0.05m/s (which is still minor). There is a localised increase of around 0.24m/s under these median flow conditions and this is discussed further in the following sections.

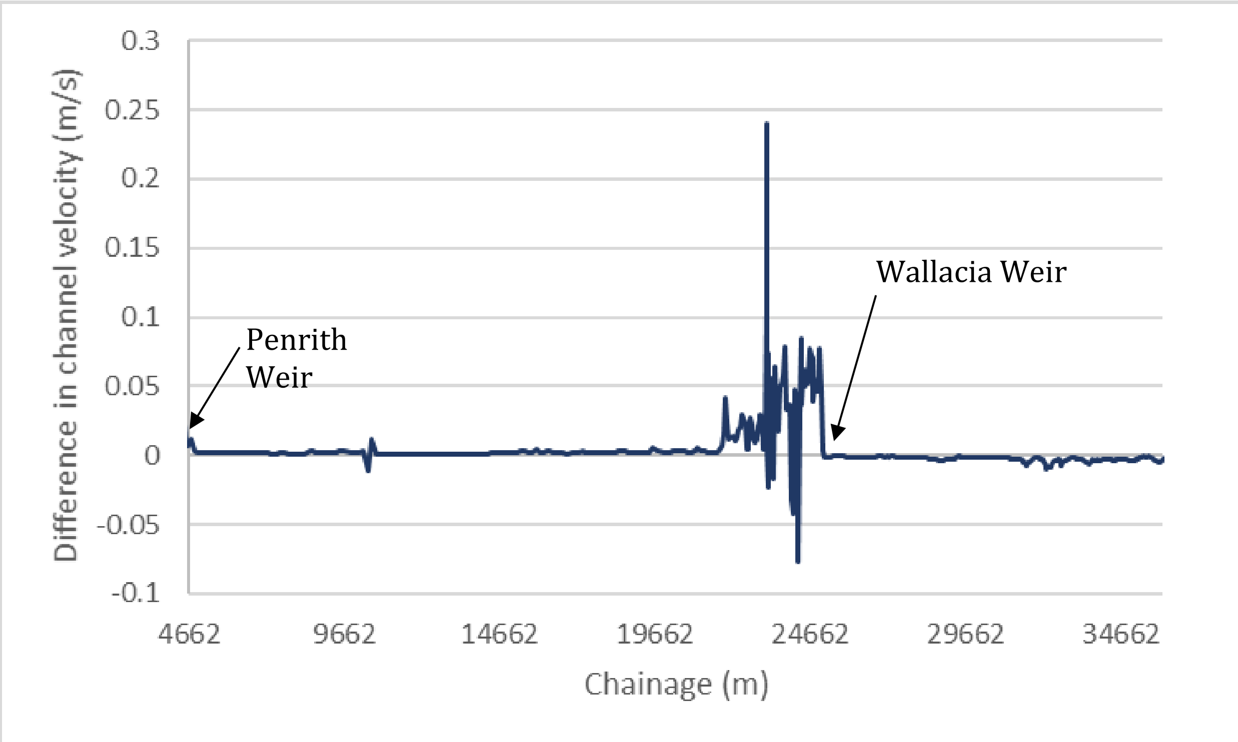


Figure 23 Difference in velocity in channel velocity between baseline conditions and scenario with the 50 ML/day release from the AWRC along the Nepean River between Bent's Basin (chainage 36,000) and Penrith Weir (chainage 4662)

Under low flow conditions (90th percentile flows) the results are similar to the median flow case, with localised increases in velocity predominantly noticeable in the reach downstream of Wallacia Weir to the Warragamba River confluence. The increases are the result of the same processes as occur under median flow conditions and the magnitude of the changes are approximately the same.

Under high flow conditions (10th percentile flows) the difference in velocity is less noticeable (<0.1m/s), although the changes do occur at the same locations as for the median and low flow conditions.

Under the ultimate development condition (100 ML/d AWRC release) the results are again very similar in terms of the location of the localised differences and their magnitude.

Shear Stress

Shear stress changes are similar to velocity, Figure 24 with negligible change along much of the river except for the reach between Wallacia Weir and the Warragamba River confluence.

However, even though the increases in this reach around 20N/m^2 in localised areas, the bedrock-controlled nature of the channel limits any impacts.

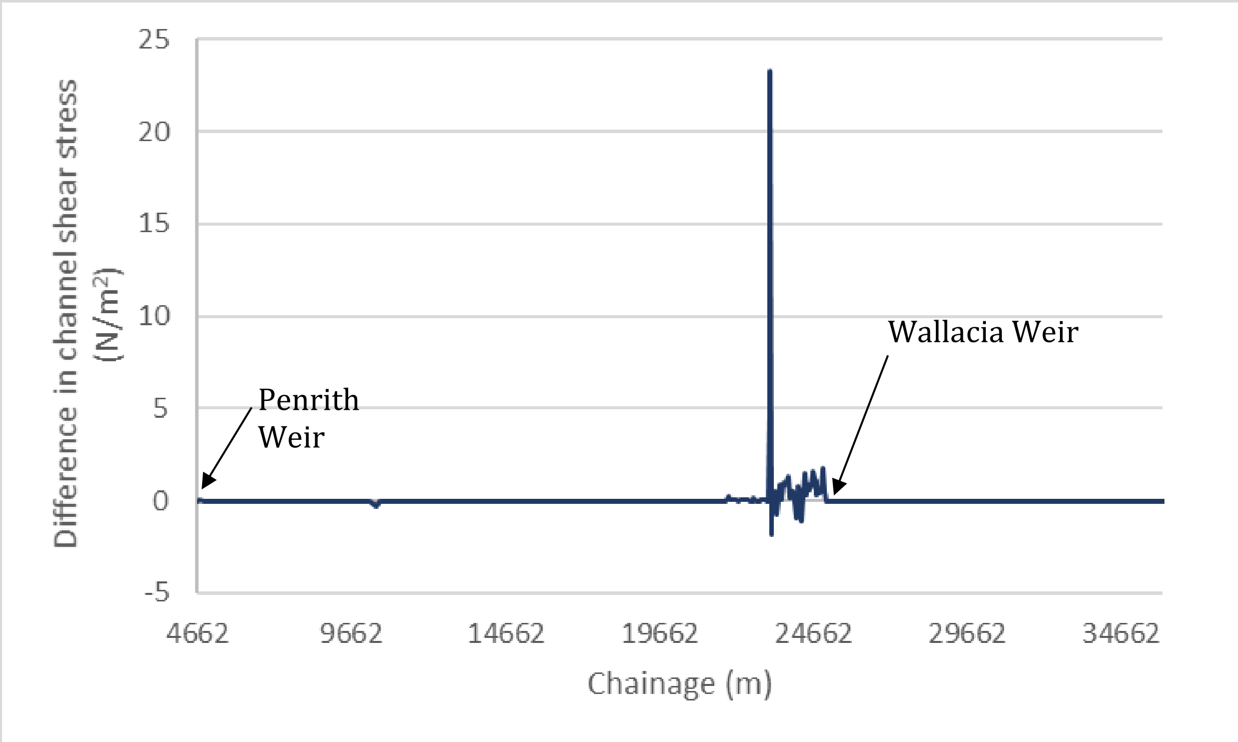


Figure 24 Difference in shear stress between baseline conditions and scenario with the 50 ML/day release from the AWRC along the Nepean River between Bent's Basin (chainage 36,000) and Penrith Weir (chainage 4662).

As for the other hydraulic metrics, under low flow conditions (90th percentile flows) the results are similar to the median flow case, with localised increases in shear stress predominantly noticeable in the reach downstream of Wallacia Weir to the Warragamba River confluence. The increases are the result of the same processes as occur under median flow conditions and the magnitude of the changes are approximately the same.

Under high flow conditions (10th percentile flows) the difference in shear stress is less noticeable (maximum <7 N/m^2), although the changes do occur at the same locations as for the median and low flow conditions.

Again, under the ultimate development condition (100 ML/d AWRC release) the results are very similar in terms of the location of the localised differences and their magnitude.

Effects of Hydraulic Controls

What is apparent from the results is that the hydraulic conditions in the river, particularly for non-flood flow conditions are controlled by the various weirs and structures present. Of specific relevance to the AWRC release are the Wallacia Weir, located immediately downstream of the release location (Figure 25); and the Penrith Weir, located a further 20 kilometres downstream (Figure 26).

Figure 25 Aerial image of Wallacia Weir - Nepean River (05/02/2021)

Figure 26 Aerial image of Penrith Weir – Nepean River (captured 05/02/21).

6.1.3. **Impacts - Nepean River Upstream Wallacia Weir**

This reach extends from Wallacia Weir upstream to around Bents Basin. The channel and floodplain are alluvial and sand deposits have been observed in the riverbanks upstream of Wallacia Weir. The weir controls water levels in this reach over much of the flow regime.

The following series of figures show the modelled results for the hydraulic metrics and provide an indication of the overall trends along this reach of the river. Commentary about the resultant impacts of these changes on morphological conditions in the reach are provided following the figures.

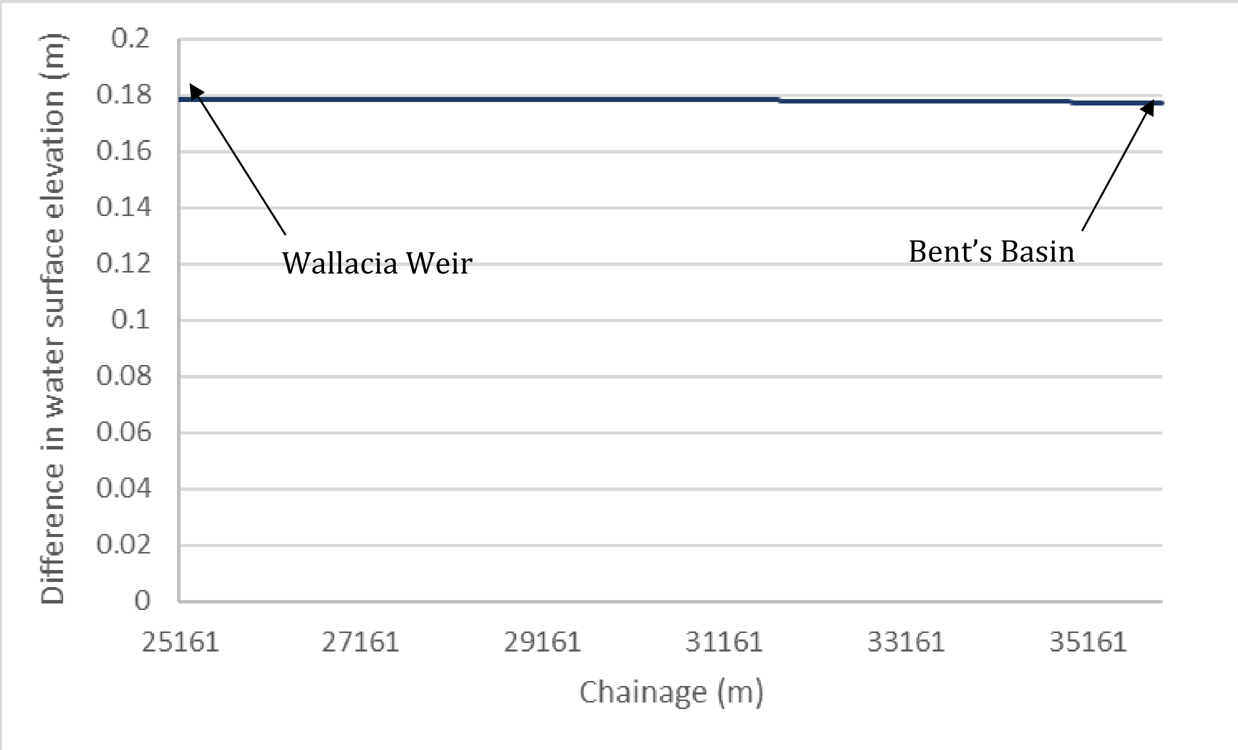


Figure 27 Difference in water surface elevation between baseline conditions and scenarios with the 50 ML/day release from the AWRC along the Nepean River between Bent's Basin (chainage 36,000) and Wallacia Weir (chainage 25161).

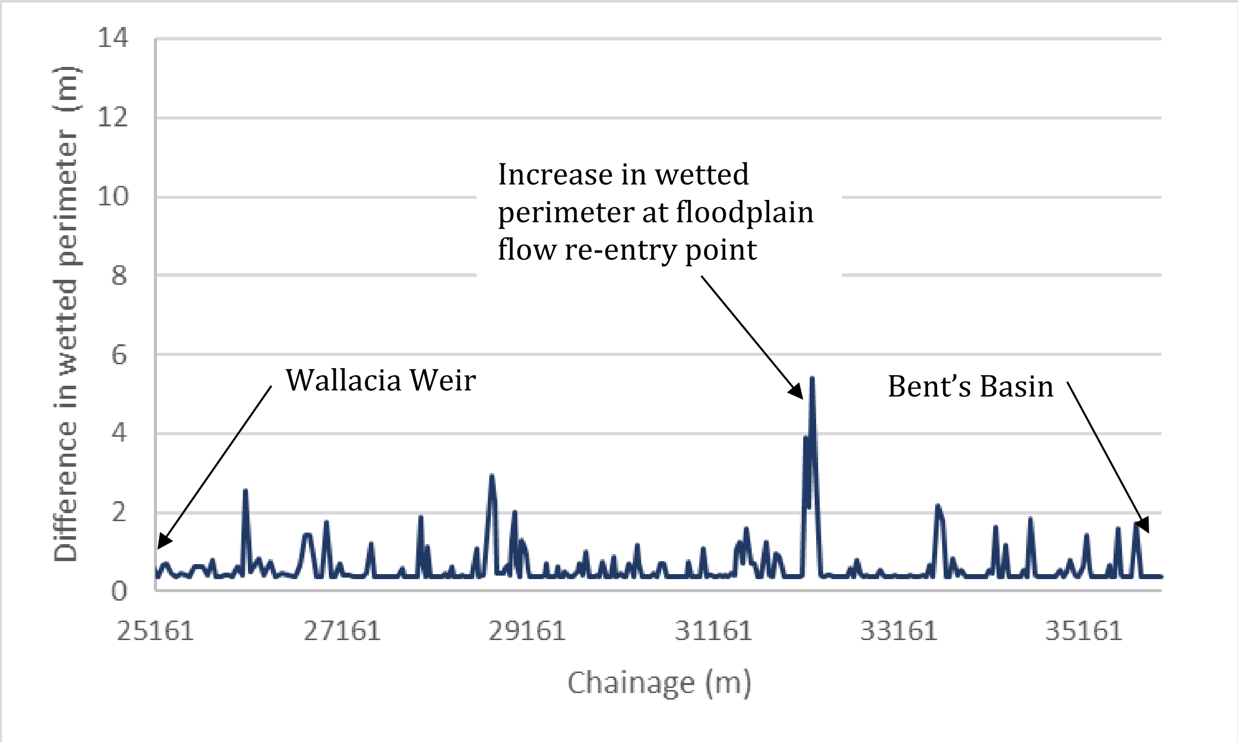


Figure 28 Difference in wetted perimeter between baseline conditions and scenarios with the 50 ML/day release from the AWRC along the Nepean River between Bent's Basin (chainage 36,000) and Wallacia Weir (chainage 25161).

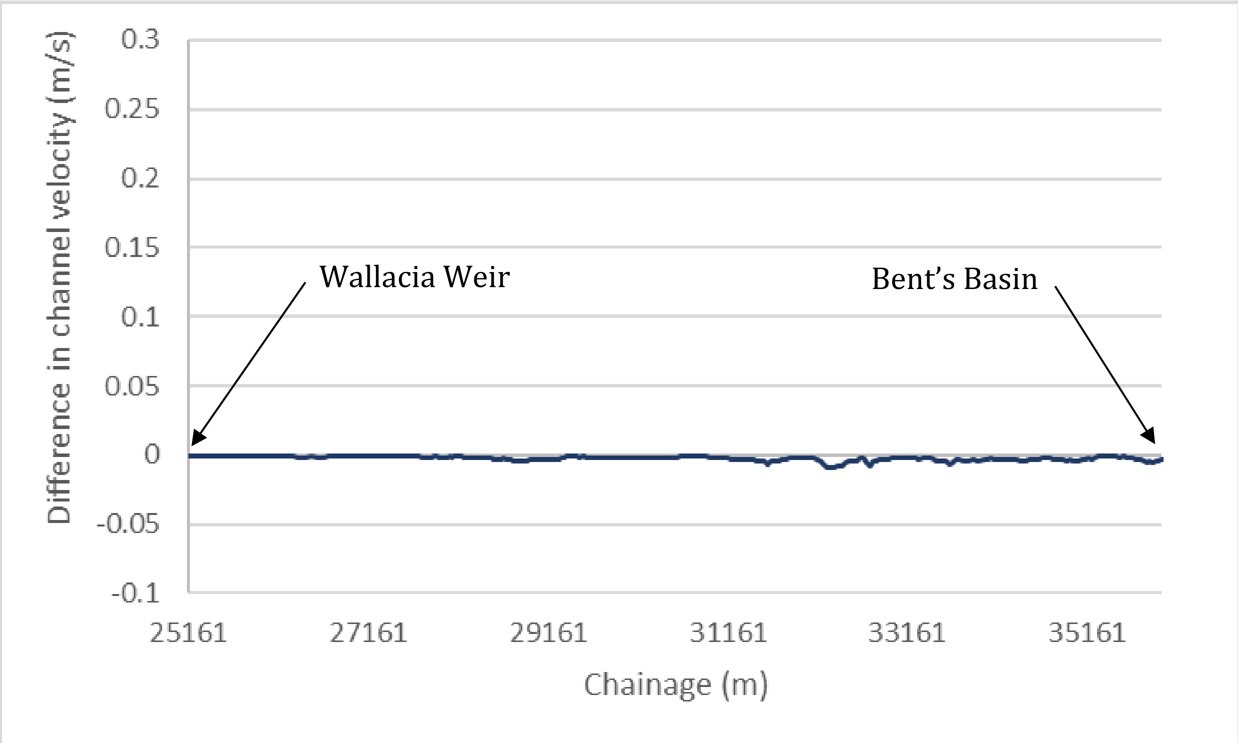


Figure 29 Difference in velocity between baseline conditions and scenarios with the 50 ML/day release from the AWRC along the Nepean River between Bent's Basin (chainage 36,000) and Wallacia Weir (chainage 25161).

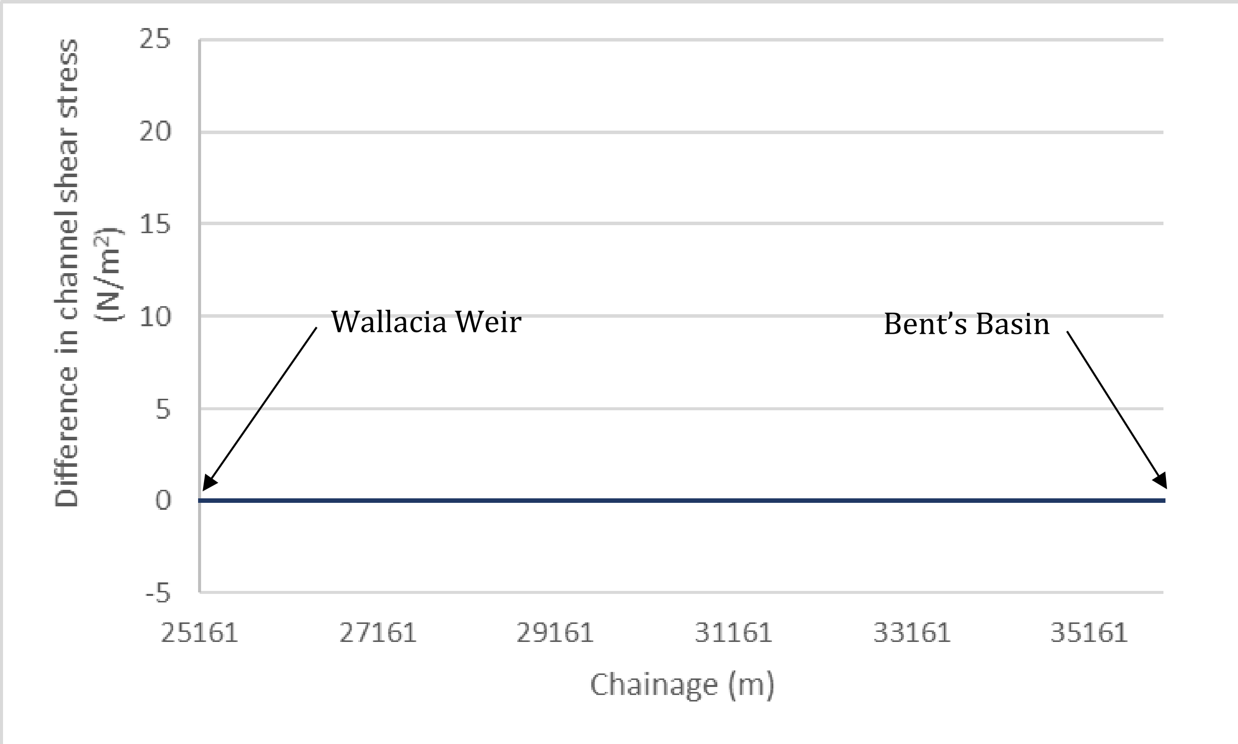


Figure 30 Difference in shear stress between baseline conditions and scenarios with the 50 ML/day release from the AWRC along the Nepean River between Bent's Basin (chainage 36,000) and Wallacia Weir (chainage 25161).

The results for surface water elevation change show the greatest difference in all the hydraulic metrics in this reach. This occurs because of the relationship between flow and water level at Wallacia Weir.

The consequences of this change in water surface elevation in the Nepean River (a change of around 18 cm extending for some 12 kilometres upstream of Wallacia Weir) are considered minor. This increase in level will influence hydraulic habitat dependent on shallow depths (e.g., vegetation or larval fish). It will also increase the inundation of bank vegetation. The implications of this will be dependent on seasonality and timing of flows at this level. The water surface elevation change is well within the channel extents and does not result in flooding or engagement of floodplain areas.

Wetted perimeter changes occur where the increase in water surface elevation engages more of the channel area, such as in-channel bars or benches. For this section of the Nepean River the largest increase in wetted perimeter occurs at a location where there appears to be a floodplain flow re-entry point, Figure 31. This is creating a small backwater area which is connected to the main channel. With the slightly higher flow conditions with the AWRC release more of the backwater becomes engaged and hence the wetted perimeter increases. However, the flows remain below bankfull and so the changes in wetted perimeter only relate to areas within the main river channel.

Given the small changes in velocity and shear stress the geomorphic implications and therefore consequences will be confined to the potential for increased erosion due to loss of vegetation, and potential for erosion (specifically notching) higher on the bank face. This applies to the full reach.

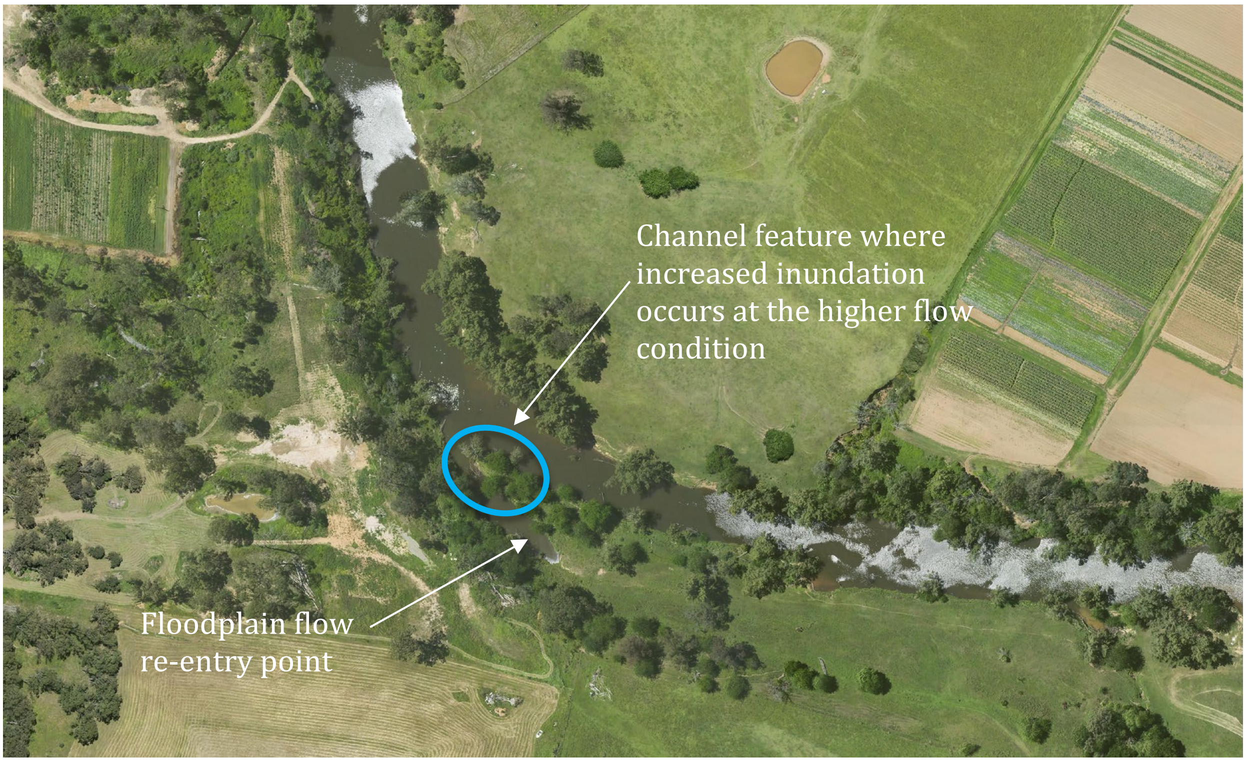


Figure 31 Location of floodplain flow re-entry point where the modelled wetted perimeter increases as a result of the AWRC release. The in-channel features are inundated to a slightly higher level.

The likelihood of geomorphic change in this reach in response to changes in hydraulic conditions is considered "unlikely" given its low to moderate geomorphic sensitivity and good resilience/adaptive capacity. The consequences are considered minor to insignificant given the small to negligible change in the hydraulic metrics. Results are summarised in Table 25.

Table 25 Summary of geomorphic impacts between baseline conditions and with the 50 ML/day release from the AWRC along the Nepean River upstream of Wallacia Weir (chainage 25161)

	Water Surface Elevation	Wetted Perimeter	Velocity	Shear Stress
Consequence	Minor	Insignificant	Insignificant	Insignificant
Likelihood	Unlikely	Unlikely	Unlikely	Unlikely
Risk	Low	Low	Low	Low

Results for the 100 M/d AWRC release (ultimate conditions) are presented in Appendix C. They show that as expected, the difference in water surface elevation upstream of Wallacia Weir is further increased with the additional treated water release, with a consistent increase of around 0.35 m. The consequence of this further increase in water surface elevation is still considered to be moderate and therefore the risk remains low. The flow conditions inclusive of the AWRC release are still well within the existing channel capacity and do not engage with the floodplain or result in overbank flows.

Given the small additional changes in velocity and shear stress the geomorphic implications will be confined to the potential for increased erosion due to loss of vegetation, and potential for erosion (specifically notching) higher on the bank face.

6.1.4. Impacts - Nepean River Wallacia Weir to Warragamba River

This reach extends from Wallacia Weir downstream to the confluence with the Warragamba River. This section is a bedrock-controlled gorge with a sequence of pool and riffle features.

The following series of figures show the modelled results for the hydraulic metrics and provide an indication of the overall trends along this reach of the river. Commentary about the resultant impacts of these changes on morphological conditions in the reach are provided following the figures.

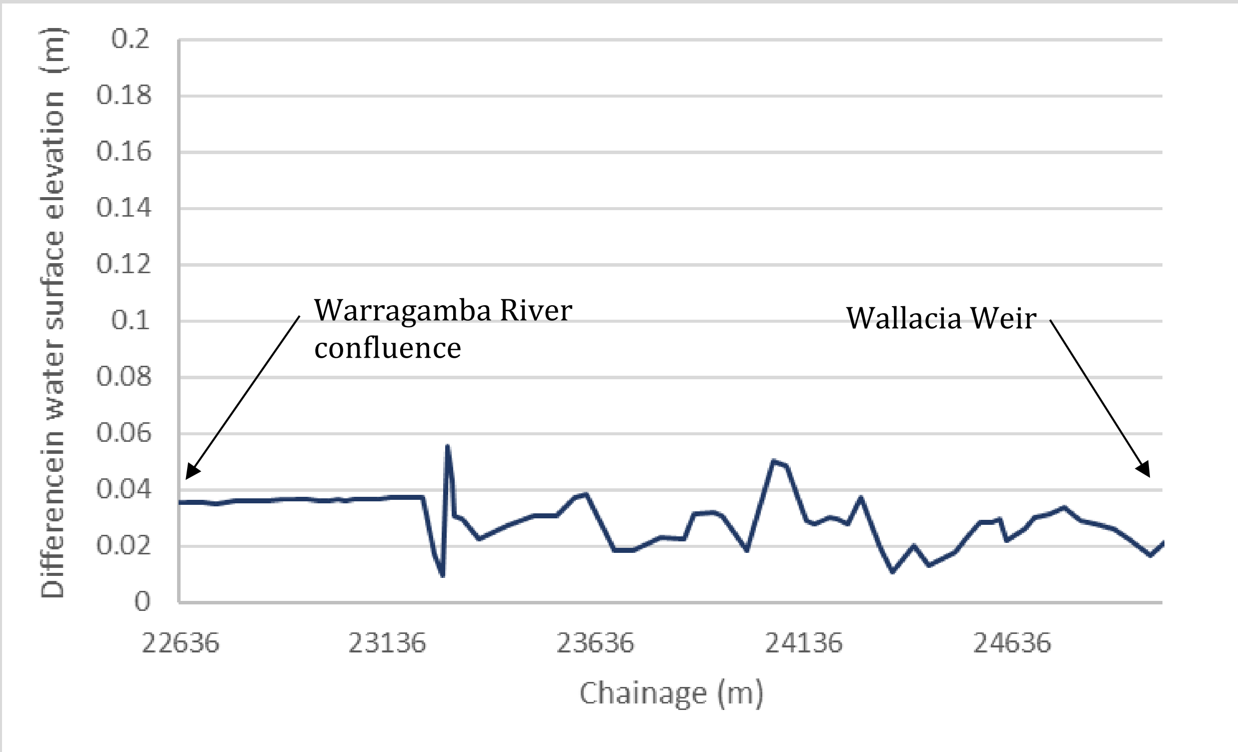


Figure 32 Difference in water surface elevation between baseline conditions and scenarios with the 50 ML/day release from the AWRC along the Nepean River between Wallacia Weir (chainage 25161) and the Warragamba River confluence (chainage 22636).

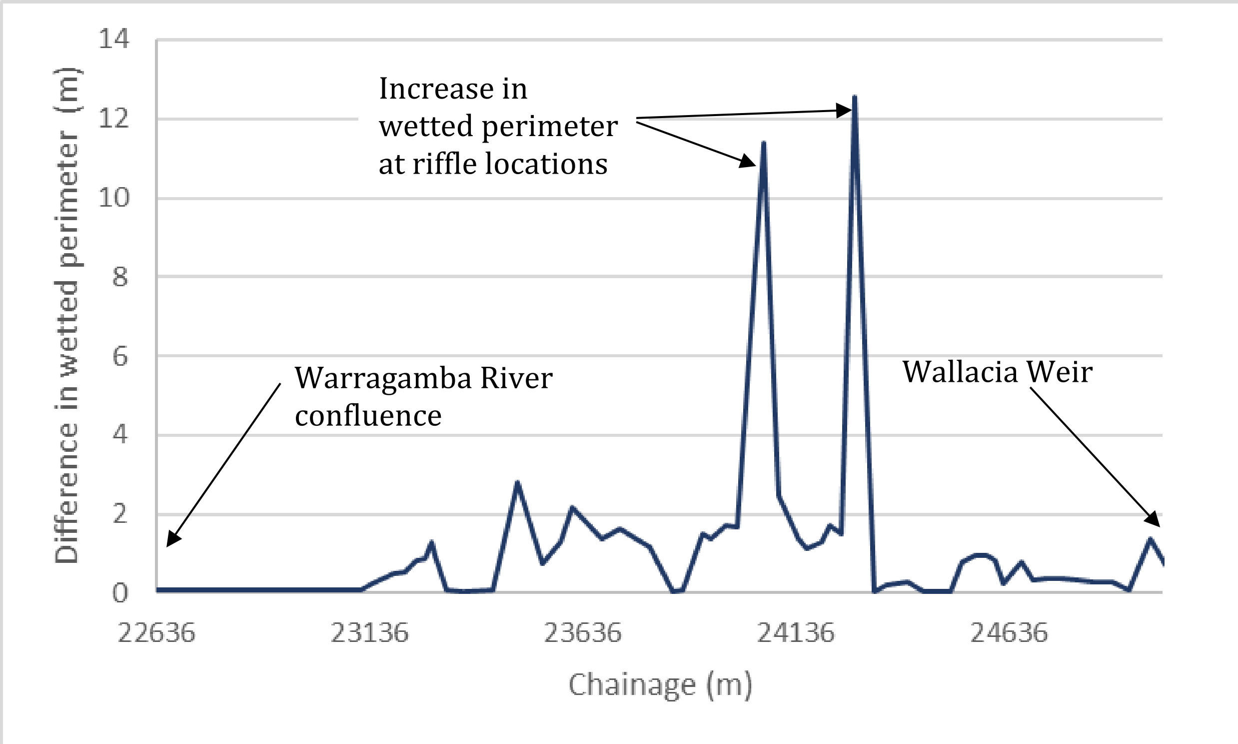


Figure 33 Difference in wetted perimeter between baseline conditions and scenarios with the 50 ML/day release from the AWRC along the Nepean River between Wallacia Weir (chainage 25161) and the Warragamba River confluence (chainage 22636).

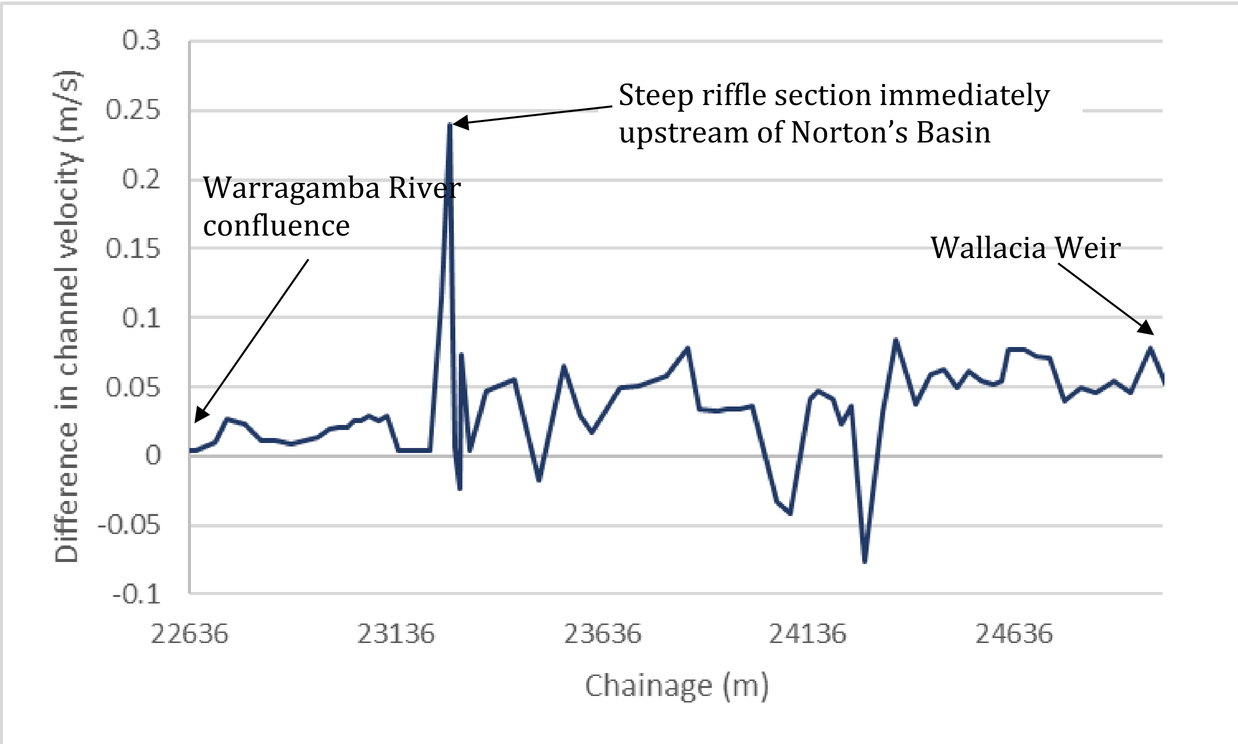


Figure 34 Difference in velocity between baseline conditions and scenarios with the 50 ML/day release from the AWRC along the Nepean River between Wallacia Weir (chainage 25161) and the Warragamba River confluence (chainage 22636).

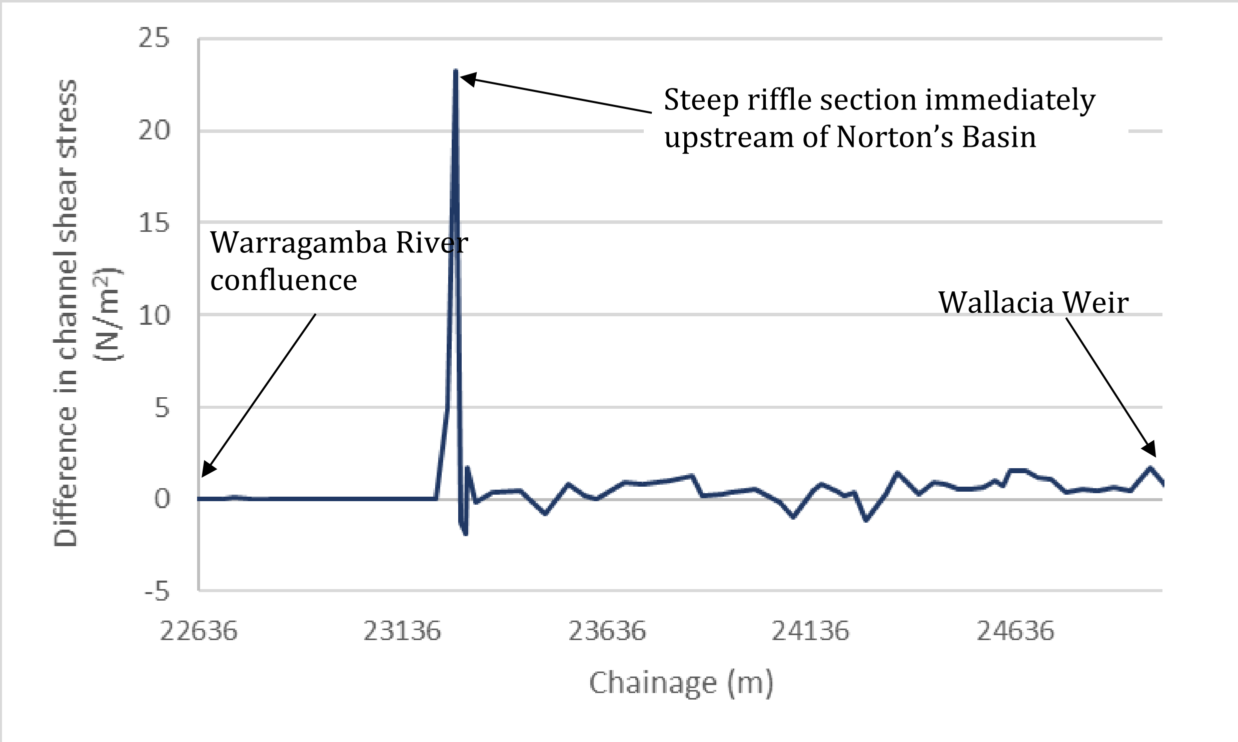


Figure 35 Difference in shear stress between baseline conditions and scenarios with the 50 ML/day release from the AWRC along the Nepean River between Wallacia Weir (chainage 25161) and the Warragamba River confluence (chainage 22636).

There are some localised increases in hydraulic metrics along this section of the river, with the change in wetted perimeter related to riffle or in-channel features which becomes more inundated at the marginally higher flow conditions, Figure 36.

There is also an increase in velocity and shear stress through the steep riffle section immediately upstream of Norton's Basin, as shown in Figure 36.

Given the small changes in the hydraulic metrics and the bedrock-controlled nature of the channel and banks the geomorphic implications are low.

Overall, the likelihood of geomorphic change in this reach in response to changes in hydraulic conditions is considered "unlikely" given its low geomorphic sensitivity and good resilience/adaptive capacity. The consequences are considered minor given the small to negligible change in the hydraulic metrics and the changes are very localised.

The results are summarised in Table 26.

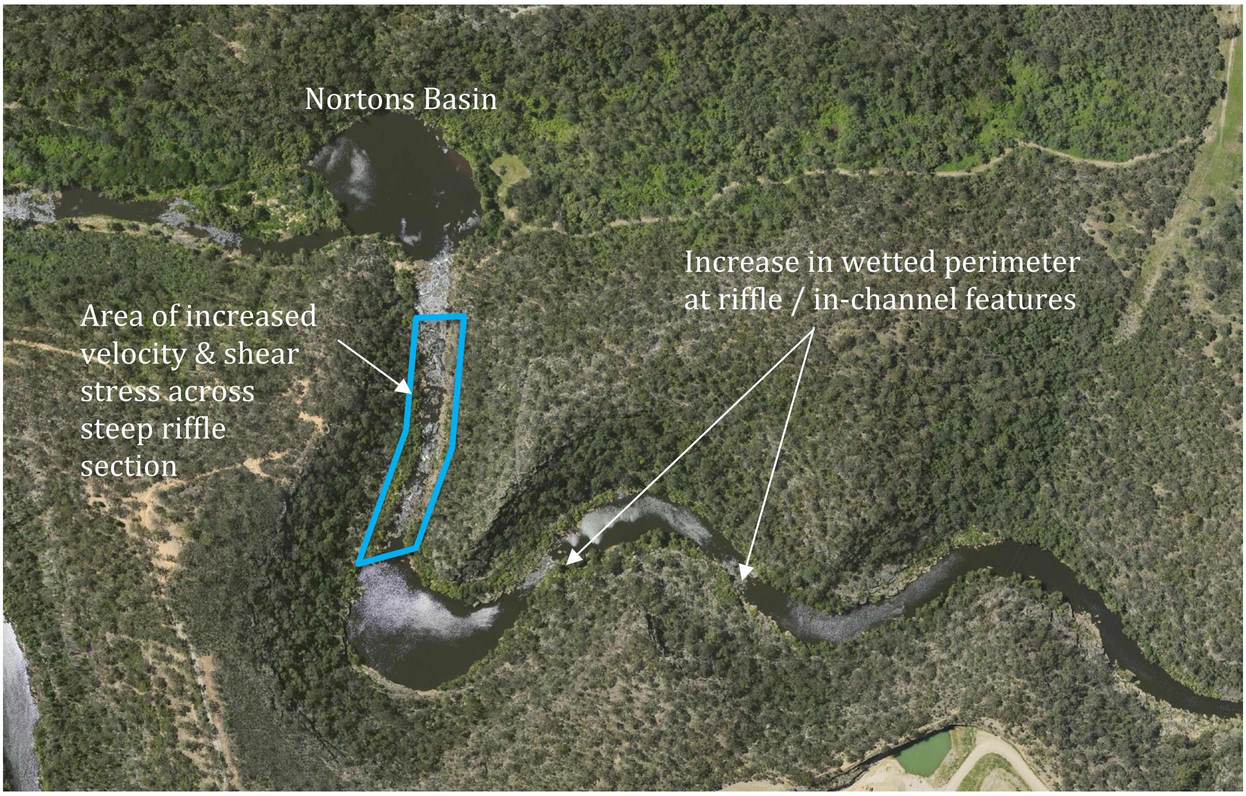


Figure 36 Locations where changes in hydraulic metrics are modelled to occur.

Table 26 Summary of geomorphic impacts between baseline conditions and with the 50 ML/day release from the AWRC along the Nepean River between Wallacia Weir (chainage 25161) and the Warragamba River confluence (chainage 22636)

	Water Surface Elevation	Wetted Perimeter	Velocity	Shear Stress
Consequence	Minor	Minor	Minor	Minor
Likelihood	Unlikely	Unlikely	Unlikely	Unlikely
Risk	Low	Low	Low	Low

6.1.5. Impacts - Nepean River Downstream Warragamba River

This reach extends from the confluence with the Warragamba River to the Penrith Weir and includes the section of the Nepean River that passes through the Blue Mountains World Heritage Area. This section is planform controlled, with low sinuosity.

The following series of figures show the modelled results for the hydraulic metrics and provide an indication of the overall trends along this reach of the river. Commentary about the resultant impacts of these changes on morphological conditions in the reach are provided following the figures.

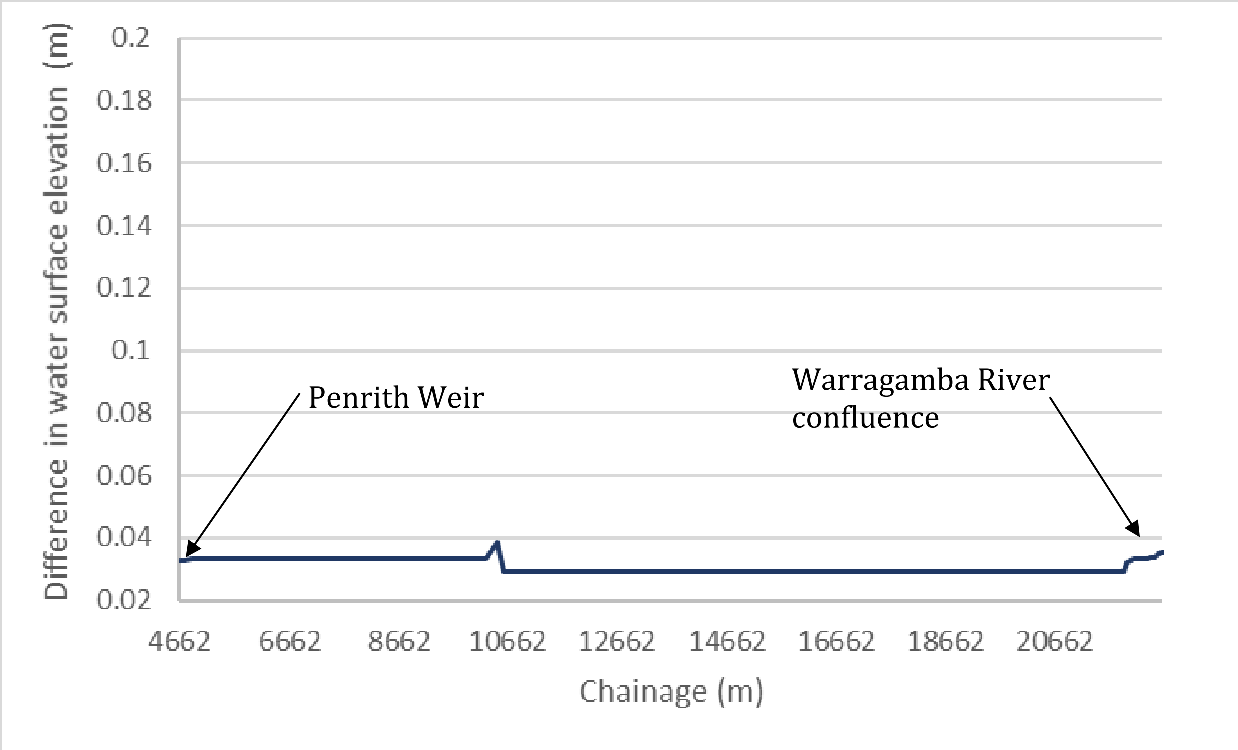


Figure 37 Difference in water surface elevation between baseline conditions and scenarios with the 50 ML/day release from the AWRC along the Nepean River between the Warragamba River confluence (chainage 22636) and Penrith Weir (chainage 4662).

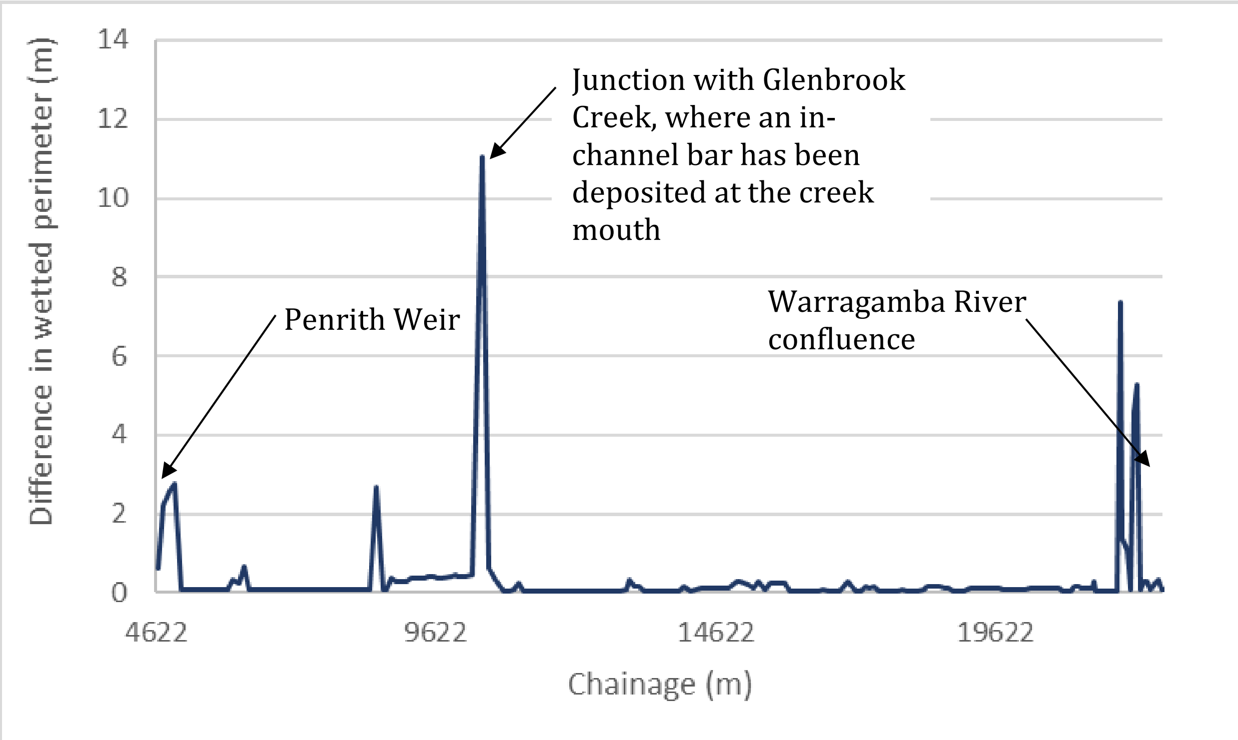


Figure 38 Difference in wetted perimeter between baseline conditions and scenarios with the 50 ML/day release from the AWRC along the Nepean River between the Warragamba River confluence (chainage 22636) and Penrith Weir (chainage 4662).

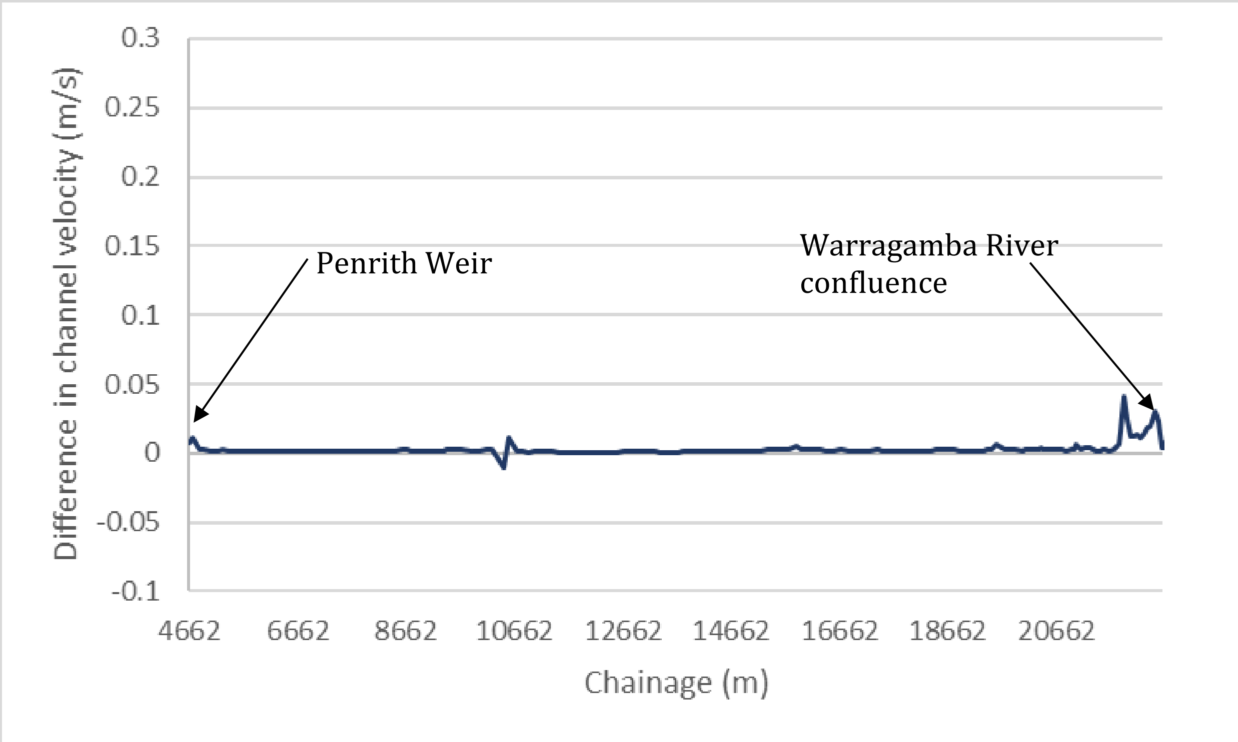


Figure 39 Difference in velocity between baseline conditions and scenarios with the 50 ML/day release from the AWRC along the Nepean River between the Warragamba River confluence (chainage 22636) and Penrith Weir (chainage 4662).

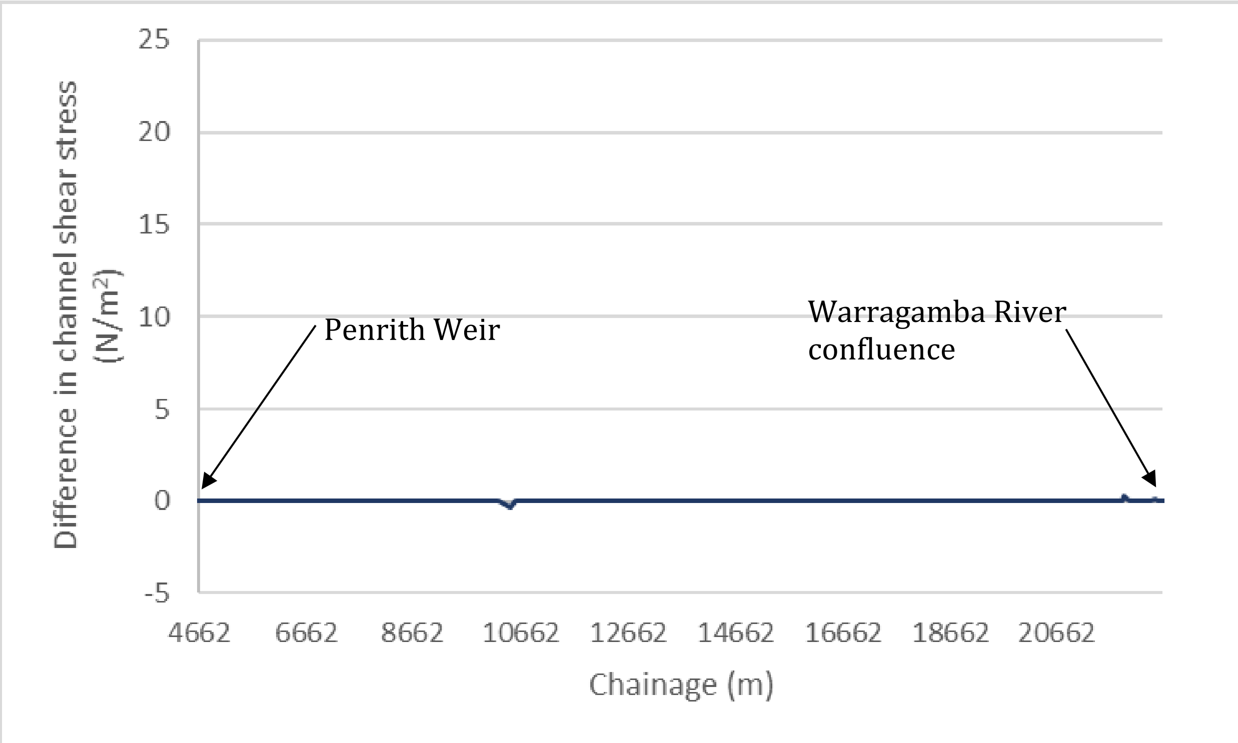


Figure 40 Difference in shear stress between baseline conditions and scenarios with the 50 ML/day release from the AWRC along the Nepean River between the Warragamba River confluence (chainage 22636) and Penrith Weir (chainage 4662).

There are localised increased in hydraulic metrics along this section of the river, with the change in wetted perimeter occurring at the junction with Glenbrook Creek (approx. chainage 10,600, as shown in Figure 41) where there is a large vegetation bar at the creek mouth. This bar becomes more engaged (i.e., the water level across the bar is slightly higher) at the marginally higher flow conditions. Due to the confined nature of the channel, the flows remain in-channel and there is no overbank flow occurring because of the release.

Given the small changes in the hydraulic metrics and the planform-controlled nature of the channel and banks the geomorphic implications are low.

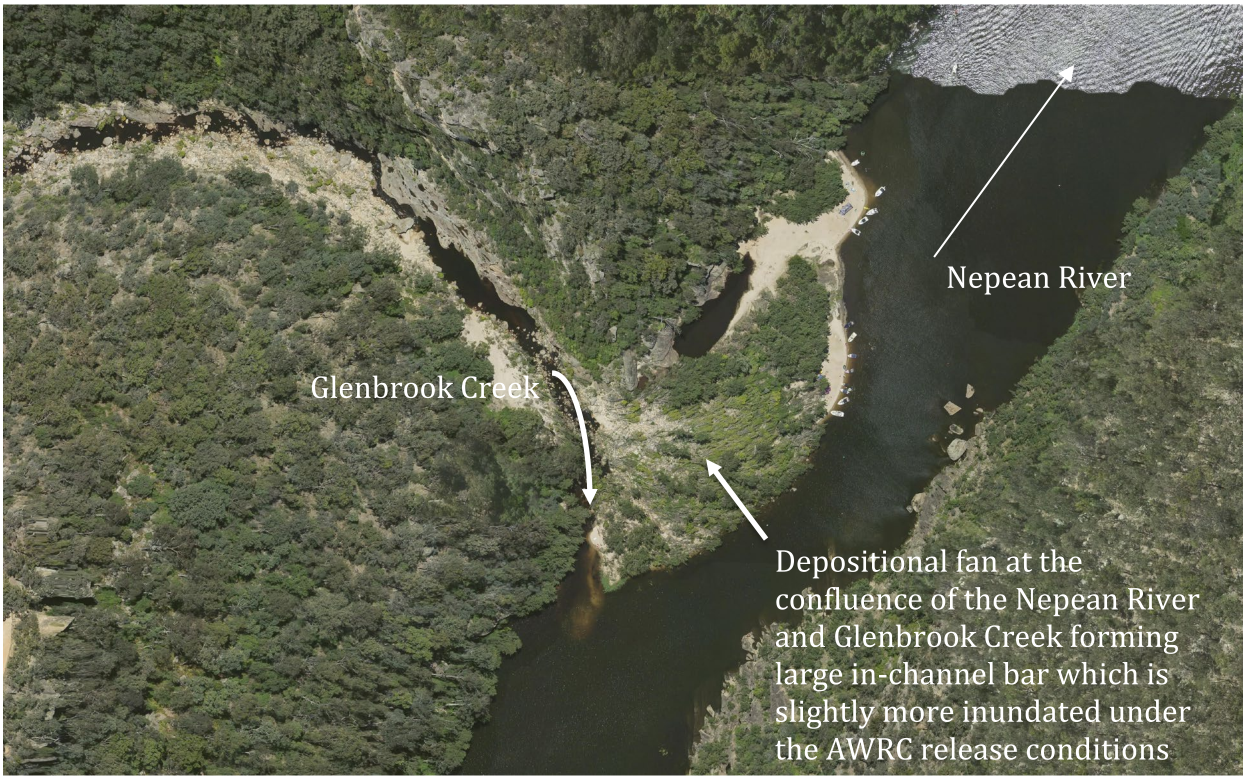


Figure 41 Location of large in-channel bar at the confluence of Glenbrook Creek and the Nepean River, where the AWRC release results in an increase in wetted perimeter and the flow level at the bar is increased.

Overall, the likelihood of geomorphic change in this reach in response to changes in hydraulic conditions is considered "unlikely" given its low geomorphic sensitivity and good resilience/adaptive capacity. The consequences are considered minor given the small to negligible change in the hydraulic metrics and the changes are very localised.

The results are summarised in Table 27.

Table 27 Summary of geomorphic impacts between baseline conditions and with the 50 ML/day release from the AWRC along the Nepean River between the Warragamba River confluence (chainage 22636) and Penrith Weir (chainage 4662).

	Water Surface Elevation	Wetted Perimeter	Velocity	Shear Stress
Consequence	Minor	Minor	Minor	Minor
Likelihood	Unlikely	Unlikely	Unlikely	Unlikely
Risk	Low	Low	Low	Low

6.1.6. **Impacts - Warragamba River**

The magnitude of environmental flows currently released into the Warragamba River are not changing because of the proposed environmental flow release associated with the AWRC proposal. The change is in relation to the location of the release, being 500m upstream of the current release location.

The Metropolitan Water Plan for Sydney (Department of Industry, Skills and Regional Development, 2017) recommends the release of environmental flows from Warragamba Dam. Currently, releases from the Warragamba are for the purposes of diluting flows from Wallacia WWTP and drinking water extraction to the Richmond Water Filtration Plant (WFP). The Plan recommends a new variable flow regime and further work to refine this is currently underway by the Department of Industry and Environment (DPIE).

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. 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. Sydney Water's releases to Warragamba River would be consistent with the current or future regime approved by DPIE. Any future impacts associated with a variable environmental flow regime would be assessed by DPIE.

6.2. **South Creek**

6.2.1. **Overview of hydrologic results**

The overall results for the hydrologic scenario analysis along South Creek downstream of the AWRC release location show limited change in many of the hydrologic metrics assessed.

Table 28 summarises the results of the hydrologic metric assessment (using the USIA type approach, metrics defined in Table 10) for reaches defined along South Creek, with full results provided in Appendix C.

The results are described in terms of the changes from the baseline conditions only for the background (non AWRC release) scenarios and impact (with AWRC wet release) scenarios.

Essentially the results show that changes to land use within the South Creek catchment are the dominant change with regards to hydrologic metrics. Land use change is likely to significantly increase flows in the creek which will result in potentially increased bed and bank erosion due to the dispersive nature of the soils in this catchment.

The effect of wet weather releases from the AWRC is a minor (<3%) increase in mean annual release and therefore limited additional impact in relation to morphological change. The most significant variable that influences the hydrologic metrics is changes to how stormwater is managed (see Table 5 for details). The "parkland" stormwater approach holds the potential to buffer the impacts of additional release from increasing urbanisation and any additional wet weather release from the AWRC.

Table 29 presents hydrologic metrics for a site 500 m downstream of the AWRC location for baseline, background, and impact scenarios (see Table 7 for a description of each scenario). Comparison the specific metrics shows that there is a significant change in flow condition between baseline and background scenarios, while the impact scenario results are similar to background conditions. The background scenario SC01 can be directly compared to impact scenario SC07 (50 ML/d AWRC release) as they include the same land use and BaU stormwater practices.

These results are indicative of the analysis for all sites along South Creek. Further tabulated results for the two reaches assessed are provide in Appendix C. Results are included for the 100 ML/d impact scenarios (SC06 and SC08), which show the same trends and relative results to background scenarios (SC03 and SC04) and seen for the 50 ML/d scenarios.

No detailed hydraulic modelling was undertaken for South Creek as part of this morphological assessment and therefore commentary on hydraulic metrics has focussed on the erosion threshold where the results are inferred from the USIA analysis previously undertaken (Vietz et al 2018). Hydraulic modelled was not included within the scope of this analysis due to the limited nature of the releases to South Creek from the AWRC and their occurrence during wet weather conditions. A detailed flood impact assessment is provided in the Flooding Impact Assessment report.

Table 28 Overview of possible catchment impacts to the modelled scenarios based on analysis of the change in hydrologic metrics compared to baseline conditions (SC00).

Scenario	Description	Possible catchment impacts for different reaches of South Creek	
		Upstream of AWRC	Downstream of AWRC
SC00	**Baseline**	-	-
SC01 - SC04	**Background** - Future landuse, various stormwater approaches, No AWRC Release	• Data suggests a significant increase in flows (mean annual and daily flow is expected to at least double in comparison to baseline flows). • Increased peak flows due to increased urbanisation and subsequent increase in impervious surfaces. • Increased mobilisation of bank and bed sediments and hence erosion. • Bank erosion due to catchments dispersive soils may result in channel widening (dispersive soils occur within the South Creek catchment but the presence in these reaches has not been verified)	• Same as for upstream reaches, but with increasing changes to flows and erosion potential.
SC05 – SC08	**Impact** - Future land use, future stormwater approaches and AWRC wet only releases	• No change compared to background scenarios.	• Minor additional increase in mean annual flow (<3%) because of wet weather releases compared to background scenarios.

Table 29 Hydrologic flow metrics for a location 500m downstream of the AWRC release on South Creek. Comparison of baseline (SC00), background (SC01 for comparison with SC07, SC02 for comparison with SC05), and impact (SC05 and SC07) scenario results

Flow Component	Flow Metrics (ML/day)	Value by Scenario				
		SC00	SC01	SC02	SC05	SC07
Flow Dynamics (Non-Zero Flows)	Maximum (ML/day)	1,827	3,304	3,011	3,128	3,422
	Minimum (ML/day)	0.37	0.42	0.88	0.88	0.52
	Mean (ML/day)	28	82	66	67	83
	Mean Annual Flow Volume (ML)	10,114	29,898	23,925	24,302	30,274
	Median (ML/day)	2	6	7	7	9
	St.Dev (ML/day)	112	246	210	219	264
Zero Flow	Average 0 Flow Duration (days)	0.1	0.2	0.1	0.1	0.2
	% Time with Zero Flow	9%	9%	3%	3%	9%
Freshes	# of Fresh Events (> 3 x Median Flow)/yr	23.5	24.0	24.5	24.5	25.0
	% of Time Over Fresh Event	33%	35%	33%	33%	35%
	Average Fresh Duration (hrs)	125	127	118	116	124
Erosion Threshold	% of Time > bank/matrix mobilisation threshold	0.8%	5.1%	3.6%	3.6%	5.2%
	% of Time > Bed mobilisation threshold	0.4%	2.2%	1.4%	1.4%	2.3%

6.2.2. Comparison to flow objectives

DPIE has used the relationship between stream flows and habitat indicators to establish several flow objectives that are critical for the protection or restoration of waterway health, ecology, and biodiversity (refer to Table 2).

Flows from drainage areas with mixed land uses were considered the (tipping) point at which health, ecology and biodiversity of water dependent ecosystems declined. The flow characteristics for these waterways have been established as the waterway flow objectives for performance outcomes on third order waterways and greater. Further details on how the waterway objectives were derived is provided in the Surface Water Impact Assessment report (Appendix A).

South Creek at the AWRC site is considered ≥ 3rd order stream and therefore hydrologic metrics immediately downstream of the site can also be compared to the relevant flow objectives performance criteria detailed in Table 2.

The comparison results (Table 30) show that the baseline, background and AWRC release scenarios do not exceed the flow performance criteria except for the cease to flow threshold. The cease to flow threshold is even exceeded under baseline conditions which reflects the on-going rapid urbanisation of the South Creek catchment. Cease to flow exceedance does improve under some of the background and impact scenarios due to a reduction in runoff from some urban sources. This change is also noted in the duration of cease to flow events, which reduce significantly under all the scenarios modelled.

The flow objectives are presented in units of ML/d rather than L/ha to allow for specific comparison to the AWRC site data. The flow objectives for freshes were not compared in the current assessment due to differences in the definition of "fresh" used. However, based on the results for freshes presented in Table 29 there is again little difference in results between background and impact scenarios for these metrics.

Note that these metrics have been calculated using flows for South Creek 500m downstream of the AWRC site and so the performance criteria noted in the table have been calculated based on the total catchment area of South Creek upstream of this location.

Table 30 Comparison of flow objectives performance criteria (see Table 2) to baseline (SC00), Background (SC01-4) and Impact (SC05-8) scenario results for key metrics approx. 500m downstream of the AWRC release to South Creek

Metric	Performance Criteria (3rd Order or greater Waterways, from Table 2)	Baseline (SC00-SC04)	Background (SC01-SC04)	Impact (SC05-SC8)
Median Daily Flow (ML/d)	67.95 ± 9.75	2.3	6 - 7	7 - 9
Mean Daily Flow (ML/d)	643.61 ± 67	27.7	66 - 99	67 - 101
Mean Annual Flow Volume (ML)	125,503	10,114	23,925 - 36,234	24,302-36,986
Cease to flow (proportion of time/year)	0.03 ± 0.007 (11 days ± 2.5)	0.09	0.03 - 0.09	0.03 - 0.09
Cease to flow - Duration (days/year)	6 ± 1.1	0.1	0.1 - 0.2	0.1 to 1.9

6.2.3. Impacts - South Creek upstream and downstream of the AWRC

The overall geomorphic risk associated with changes to hydrologic metrics occurring in the background and impacts scenarios compared to baseline conditions is summarised in Table 28. The analysis indicates limited difference between the background and impacts scenarios.

Upstream impacts are considered medium risk and reflects the highly sensitive geomorphic nature of the waterway and the on-going urbanisation of the catchment. No effects upstream of the AWRC are anticipated as a result of the proposed wet weather releases.

South Creek downstream of the AWRC is considered a moderately sensitive waterway and there is again a medium risk of geomorphic change under both background and impact scenarios.

The hydrologic analysis discussed in the preceding sections suggests that the additional impact of the wet weather AWRC releases on the geomorphic condition of South Creek downstream of the release location compared to baseline or background is likely to be negligible.

Overall, the likelihood of geomorphic change in South Creek upstream and downstream of the AWRC site in response to changes in flow conditions is considered "likely" given its moderate to high geomorphic sensitivity and low to moderate resilience/adaptive capacity. The consequences are considered moderate given the change in flow regime both under background and impact scenarios. These changes in flow regime are dominated more by catchment landuse than the additional flows from the ARWC, particularly for the upstream reach.

Table 31 Summary of potential geomorphic impacts to South Creek associated with background and impact hydrologic scenarios compared to baseline conditions.

Scenarios		Upstream of AWRC	Downstream of AWRC
Background (SC01-SC04)	Likelihood	Likely	Possible
	Consequence	Moderate	Moderate
	Risk	Medium	Medium
Impact (SC05-SC08)	Likelihood	Likely	Possible
	Consequence	Moderate	Moderate
	Risk	Medium	Medium

6.3. River Release Structure Impacts

6.3.1. Overview of release structures

The treated water and environmental flows release structures on the Nepean and Warragamba Rivers will control the release of treated water into the receiving waterways. The release structures will include the following elements:

- a concrete chamber structure set back from the waterway
- measures to dissipate the energy of the treated water flows e.g., baffle blocks, concrete rip rap (concrete slab with rocks/boulders)
- measures to prevent unauthorised access into the chamber and pipeline e.g., grated covers and fencing
- scour protection along the nearby banks of Nepean and Warragamba rivers to minimise erosion
- measures to protect the structure from flood impacts e.g., gabion wall structure

Most infrastructure is located below ground, as shown in the indicative designs for the structures in Figure 42 and Figure 43, including the incoming pipeline, manhole and concrete chamber. Above ground infrastructure includes the concrete outlet structure, handrails. and concrete rip rap.

The environmental flows release structure is located downstream of the Warragamba Dam and spillway. There is potential for the structure to be inundated when the dam releases water during a major spill event which may damage the structure. The detailed design phase of the project will include the structural detailing of the release structure and what flow velocities and inundation levels it can withstand.

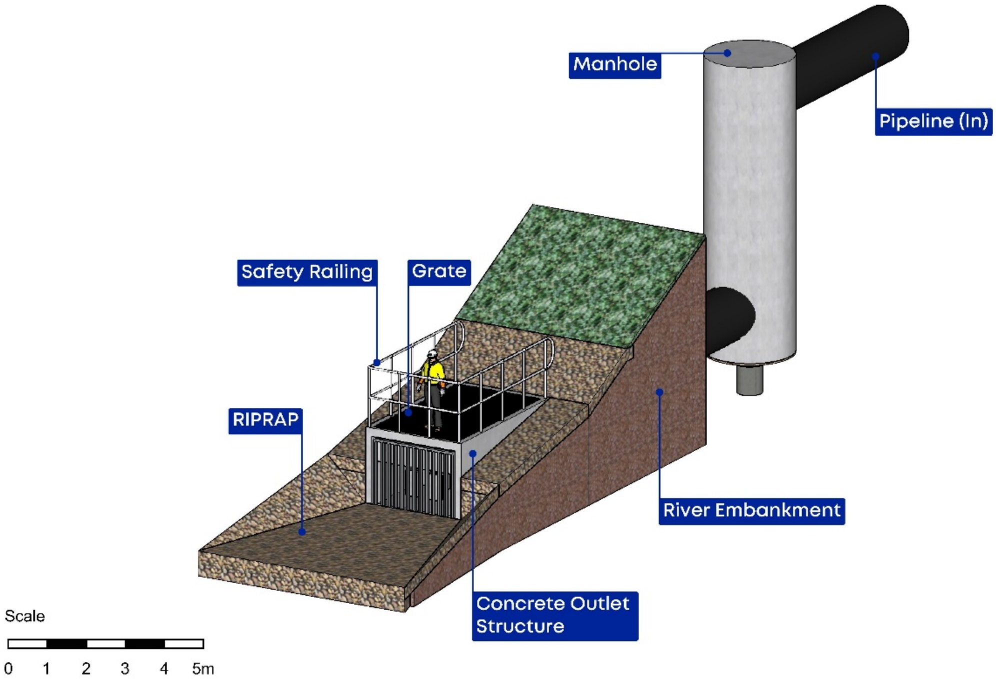


Figure 42 Indicative design of the treated water release structure (provided by Sydney Water)

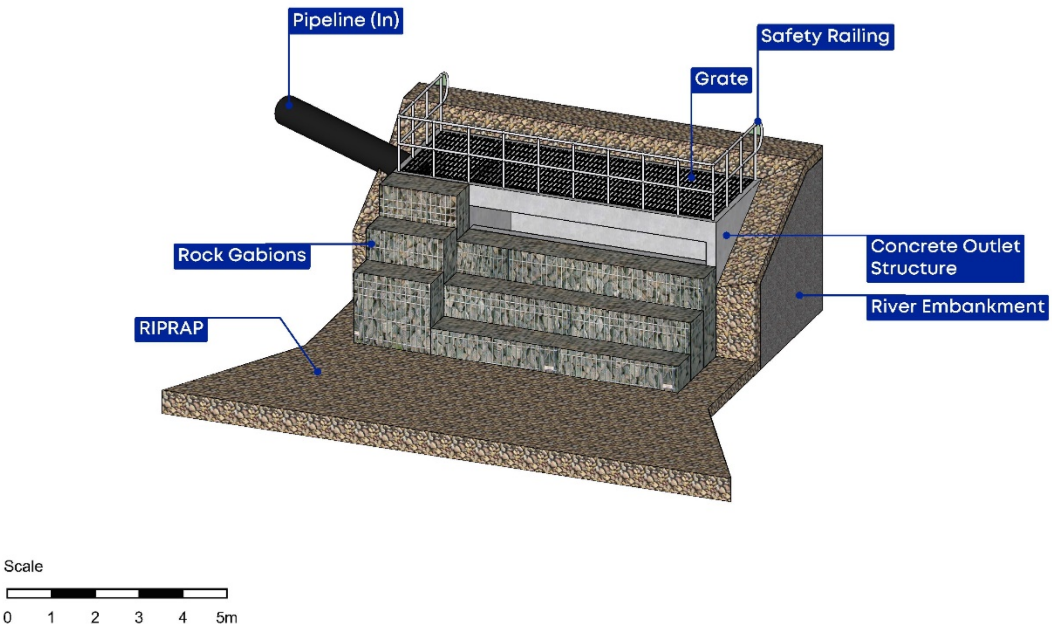


Figure 43 Indicative design of the environmental flows release structure (provided by Sydney Water)

At the AWRC on South Creek, due to the low-lying nature of the site and to ensure the discharge is above the normal creek water level, the treated water and storm water in the south shall be via a swale. The discharge in the north is likely to be a combination of the pipe and swale.

6.3.2. Construction Impacts

During the construction of release structures at the Nepean River, Warragamba River and South Creek sites, silt curtains and temporary cofferdams will be installed to segregate the construction zone from the low flow zones of the waterways and minimise the generation of sediment.

The expected duration of the cofferdam construction activities is six months. During dry weather, impacts of the construction activities are expected to be negligible. Overtopping of the coffer dams would occur during bank full discharge in the waterway, which has the potential to generate additional sediment loads to the waterway.

Considering the small footprint of the works area within the cofferdams, the volume of sediment released will have a minor impact on turbidity and silt loads in the waterway. The likelihood of a release will be further mitigated through scheduling the construction of these structures during seasons when bank full discharges are less likely (Aurecon Arup, 2021).

On-site geomorphic inspections are required prior to construction to minimise geomorphic impacts, including through understanding:

- Hydraulic conditions that may impinge on the site at a range of flows (particularly elevated flows),
- Implications of large wood debris interacting with the site,
- Surface flows (floodplain runoff) that may influence/impede construction,
- Bank stability immediately upstream and downstream of the structure, and the influence of construction barriers on this, and
- Bed stability, including the impact this has on base support for structures or construction equipment, or the geomorphic impacts that might occur.

With implementation of these measures it is expected that construction impacts will be minor.

6.3.3. Operational Impacts - Nepean River Release Structure upstream of Wallacia Weir

Figure 44 presents an overview of the Nepean River release location and structure at Wallacia Weir. The configuration of the release structure will not alter the cross-sectional area or flow conveyance capacity of the Nepean River in a detrimental way. This structure will be partly recessed into the channel wall and will not protrude into the river in such a way that would alter conveyance in the vicinity of the structure or downstream. As such, it does not result in channel constriction and does not alter the flow conditions which could contribute to erosion.

Furthermore, the release flow rates are very small (approximately 0.5 m^3/s to 3 m^3/s in dry and wet weather conditions respectively) compared to the magnitude of Nepean River flood flows at this location. In addition, the flows are impounded by the Wallacia Weir which effectively minimises flow velocities.

6.3.4. Operational Impacts - Environmental Flows Release Structure

The primary impacts with the proposed design for releases to the Warragamba River are associated with the difference in elevation from the outlet to the river. Figure 45 presents the location and layout of the outlet.

Due to the steepness of the hill beneath the outlet, some higher velocities may be experienced resulting in the erosion of the bank and or bed of the river. To counter this, it is recommended that the armouring extend sufficiently into the river to prevent erosion of the toe of the chute. The existing substrate in the vicinity of the outlet needs to be confirmed prior to construction to determine the likelihood of erosion as well as the scale of time over which erosion can be expected to occur. If non-cohesive substrate or easily eroded substrate is identified, instream works may be required for protection of the riverbed.

The design proposed directly releases flows into the existing riparian area of the Warragamba River. The detailed design considerations will include consideration of riparian planting and natural bank stabilisation measures.

Channel migration and impacts of this on fixed infrastructure are of little concern here. This section of river is bedrock controlled and is unlikely to undergo significant changes.

6.3.5. Operational Impacts - South Creek Stormwater and Wet Weather Flow Releases

At the AWRC site on South Creek, flows to the creek are managed through three on-site detention basins and two release points direct into the creek, as shown in Figure 46. These will be used to manage stormwater flows from the site as well as wet weather releases. The detention basins have been sized to detain runoff volumes associated with storms up to and including the 1% AEP flood event and the outlets are sized for the maximum release rates are less than the pre-development runoff rates for this area.

The peak wet weather flow rate from the site is expected to be 2.5 m^3/s, which includes stormwater runoff from the catchment that would otherwise be in South Creek. The wet weather flows are less than or about 1% of the South Creek flood flow rates and therefore the individual impacts of the releases are deemed to be minimal (refer to the Surface Water and Flooding Impact Assessment reports).

The southern release point is designed as a swale, comprising earth embankment and rip rap, and will include an energy dissipation structure (scour control) at the outlet to the creek. This is the main outlet. The north release is only catering for surface water from the north half of the site and is a shorter distance to the creek and therefore will be relatively simple.

The release flows must be considered relatively to catchment land use changes in flows. As identified in Section 6.2. increased stream flows in South Creek due to urban development and catchment changes are probable given increases in stormwater runoff. This will increase bank and bed erosion and these aspects should be considered within the detailed design of the release structure, i.e., not just current streamflow conditions.

Given the geomorphic sensitivity of South Creek the design must avoid unnecessary disturbance of the soils and limits removal of existing vegetation. Where dispersive soils are present the sensitivity of works must take this into consideration, as any increases in flow or saturation will lead to erosion by dispersion.

This will limit the potential for surface soil erosion and additional sediment releases to South Creek. The detailed design considerations will include consideration of riparian planting and natural bank stabilisation measures.

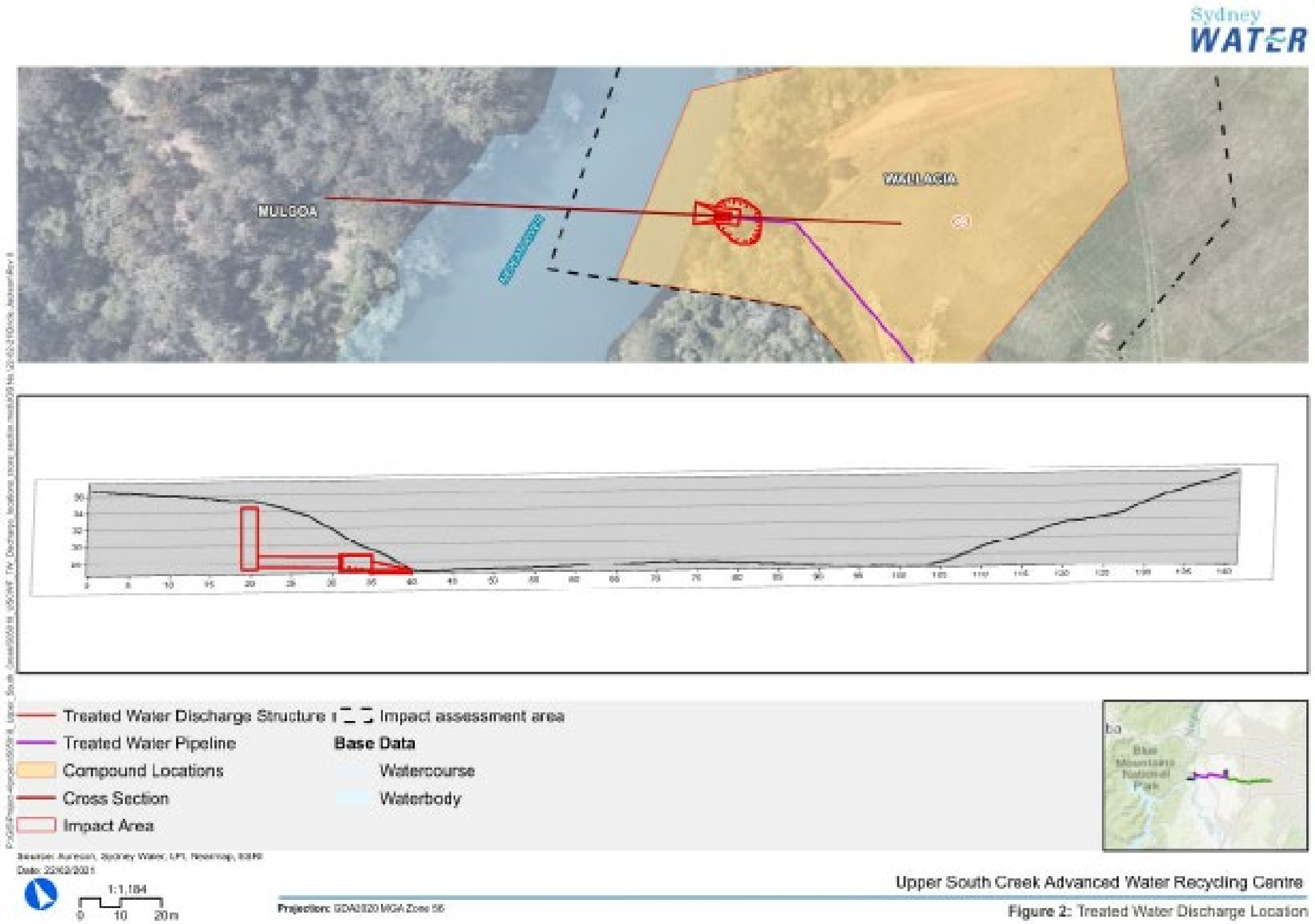


Figure 44 The Nepean River primary release location (Source: Sydney Water)

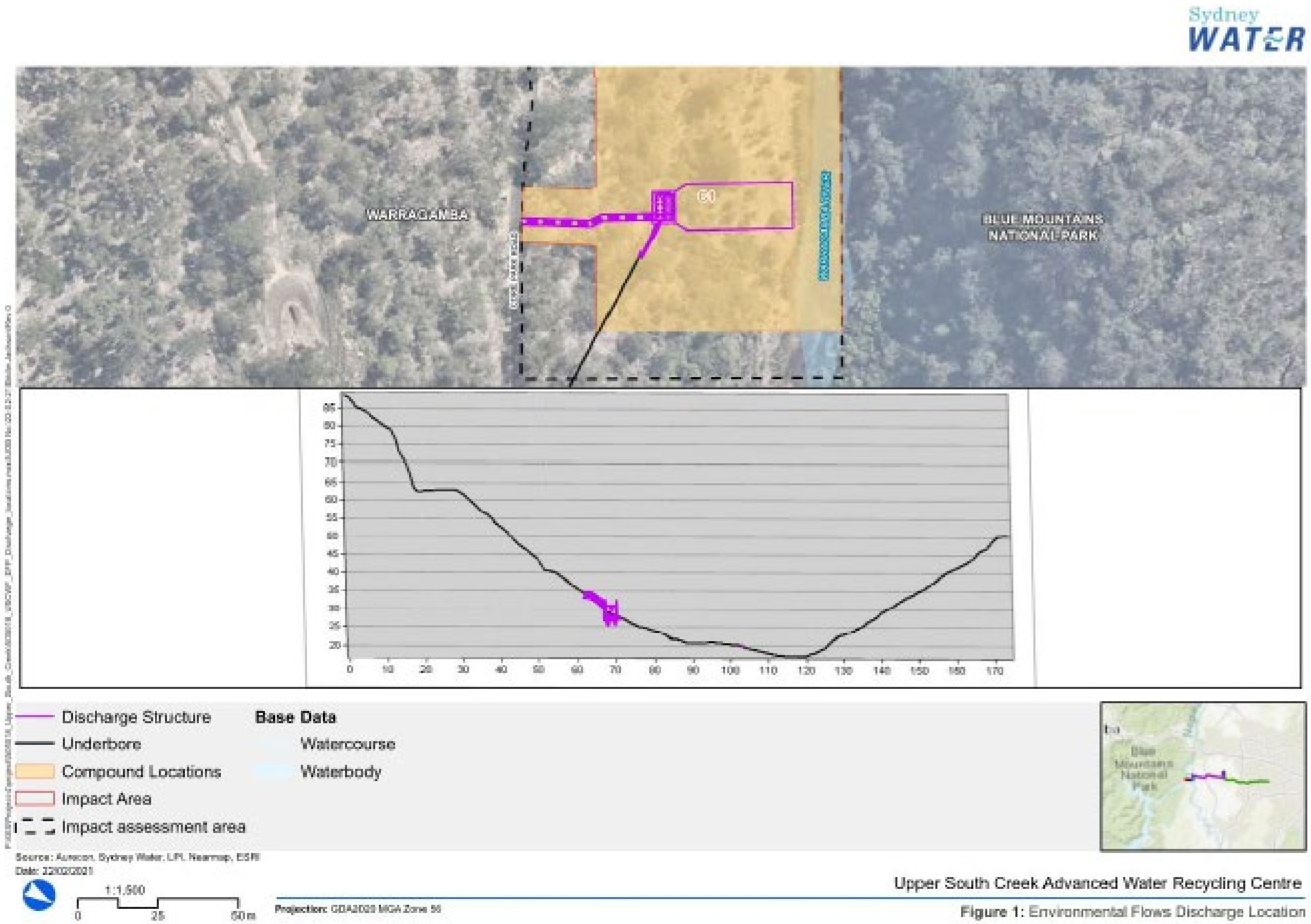


Figure 45 The environmental flows release location at Warragamba River (Source: Sydney Water)

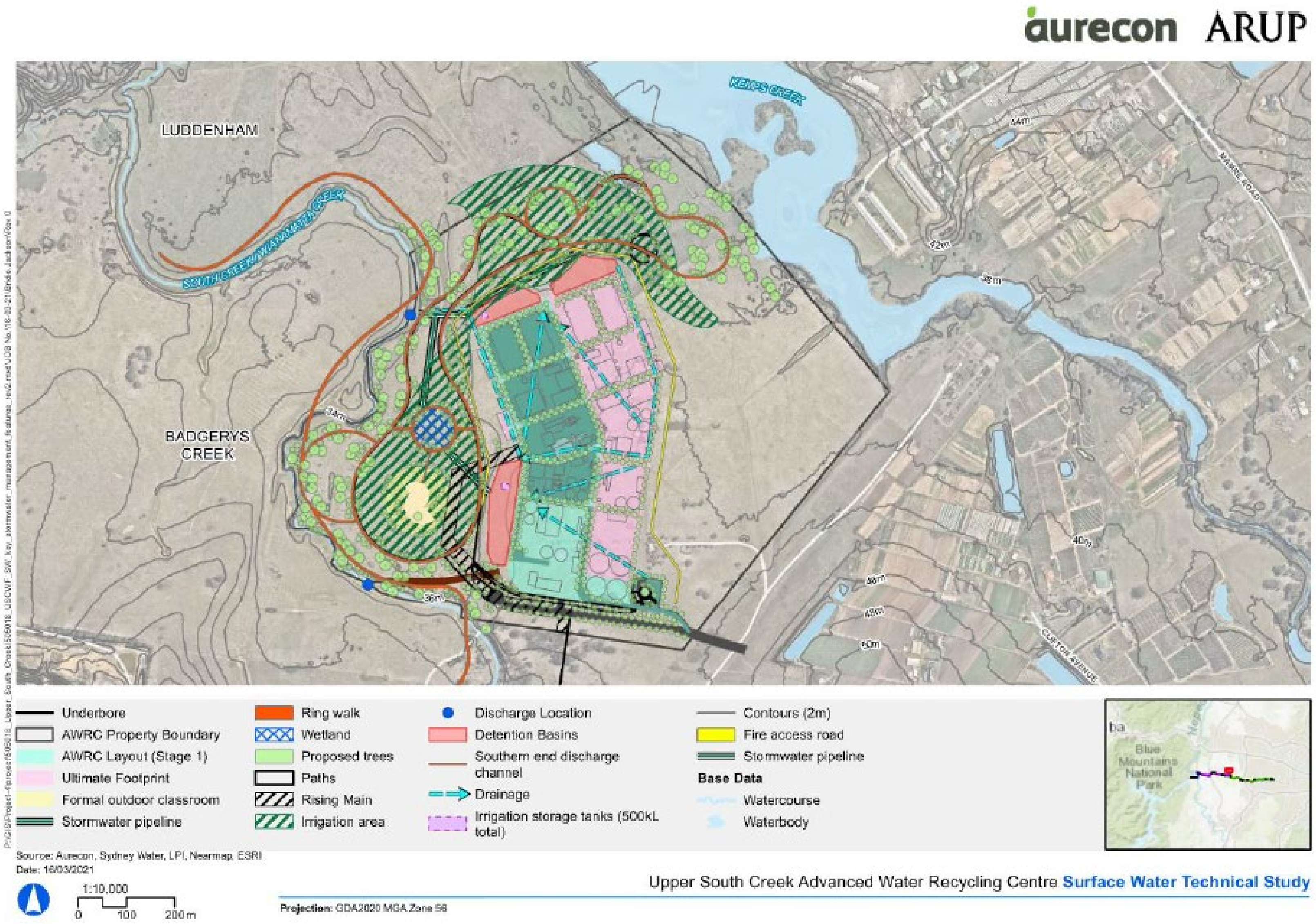


Figure 46 The AWRC layout including the release locations (Source: Aurecon Arup, Surface Water Technical Study)

6.4. **Pipeline Waterway Crossing Impacts**

6.4.1. **Construction Impacts**

The main geomorphic concern about pipeline waterway crossings will be during the construction phase. In addition to disturbance during construction, cut and cover construction (trenched) approaches for pipelines across rivers often result in localised erosion in the post-construction phase.

There are 11 main waterway crossing considered in this assessment, as summarised in Table 32 (ID 1 to 11) with a further 9 minor crossings (ID 12 to 20). The relevant River Style and geomorphic sensitivity are provided.

Table 32 Overview of main pipeline crossing locations, including construction method, river style and river sensitivity to geomorphic change (DPIE, river styles online); TWP = Treated water pipeline, EFP = environmental flow pipeline, BP = Brine pipeline; *as per River Styles assessment

ID	Waterway Name	Construction Method	Pipeline	River Style	Geomorphic Sensitivity*
1	South Creek	Open Trench	TWP	Meandering, fine grained	High
2	Badgerys Creek	Trenchless	TWP	Low sinuosity, fined grained	Moderate
3	Oaky Creek	Open Trench	TWP	Low sinuosity, fined grained	Moderate
4	Cosgroves Creek	Open Trench	TWP	Low sinuosity, fined grained	Moderate
5	Mulgoa Creek	Open Trench	TWP	Valley fill, fine grained	High
6	Jerrys Creek	Trenchless	TWP	Low sinuosity, fined grained	Moderate
7	Nepean River	Trenchless	TWP	Low sinuosity, fined grained	Moderate
8	Baines Creek	Trenchless	TWP	Low sinuosity, fined grained	Moderate
9	Baines Creek	Open Trench	EFP	Low sinuosity, fined grained	Moderate
10	Megarritys Creek	Trenchless	EFP	Gorge	Low
11	Kemps Creek	Open Trench	BP	Low sinuosity, fined grained	Moderate
12	Unnamed tributary of South Creek	Open Trench	TWP	Meandering, fine grained	High
13	Unnamed tributary of Badgery's Creek	Trenchless	TWP	Low sinuosity, fined grained	Moderate
14	Farm dams u/s of Badgery's Creek tributary	Trenchless	TWP	Low sinuosity, fined grained	Moderate
15	Farm dam & unnamed trib to Cosgroves Creek	Trenchless	TWP	Low sinuosity, fined grained	Moderate
16	Unnamed tributary to Kemps Creek	Trenched	BP	Low sinuosity, fined grained	Moderate
17	Hinchinbrook Creek	Trenched	BP	Low sinuosity, fined grained	Moderate
18	Unnamed trib to Hinchinbrook Creek	Trenched	BP	Low sinuosity, fined grained	Moderate
19	Green Valley Creek	Trenchless	BP	Low sinuosity, fined grained	Moderate
20	Prospect Creek	Trenchless	BP	Low sinuosity, fined grained	Moderate

The construction methods proposed for the different crossings include open trenching and trenchless approaches as shown in Figure 47 and Figure 48, and defined below:

- Trench pipeline crossing methods involve direct excavation to the banks and bed of a watercourse or water body. In general, the pipelines will be constructed using standard trenching methods.
- Trenchless pipeline crossing methods involve no direct excavation to the banks or bed of a watercourse or water body. Subsurface trenchless methods are designed to avoid or minimize effects to a watercourse or water body. Where existing infrastructure (above and below ground) or major watercourses are intersected, trenchless methodologies (i.e., Horizontal Directional Drilling (HDD), pipe jacking and micro-tunnelling) will be employed,

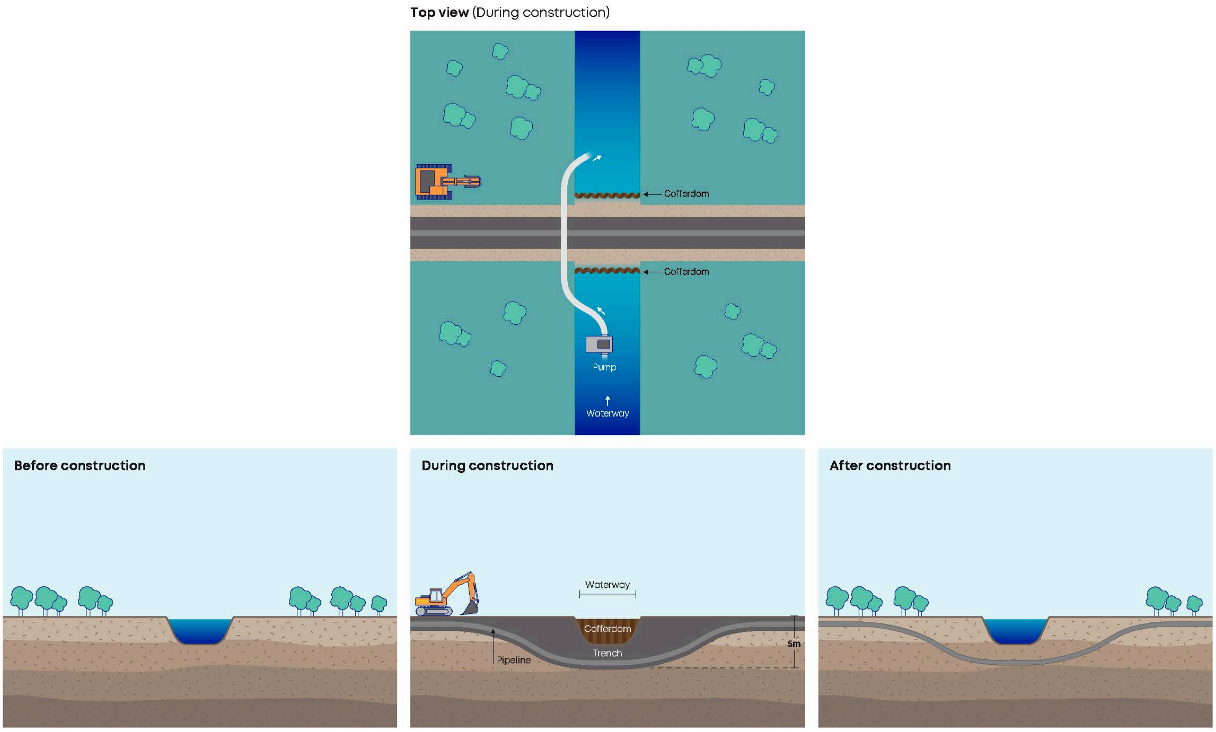


Figure 47 Illustration of trenched type pipeline crossing through waterway (image provided by Sydney Water)

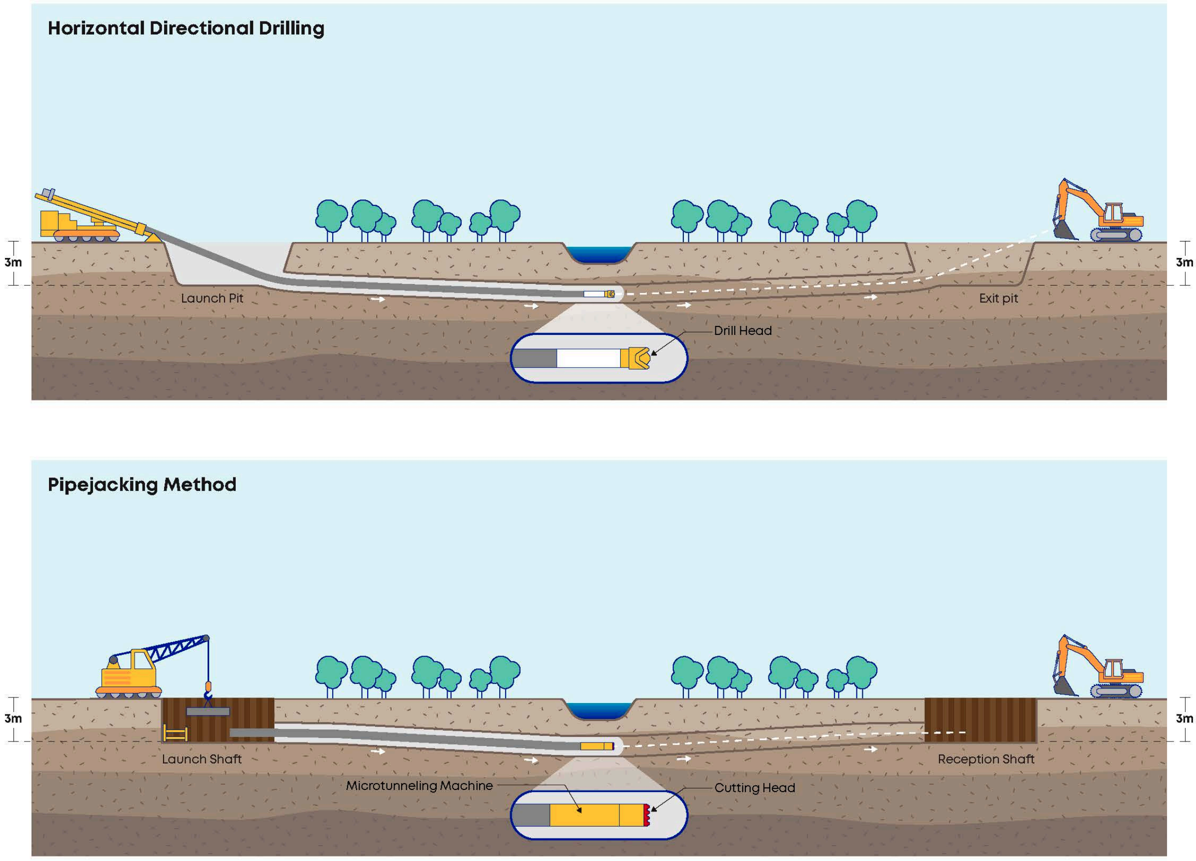


Figure 48 Illustration of tunnelling type pipeline crossings through a waterway (image provided by Sydney Water)

Potential geomorphic impacts on the waterways being crossed by the various pipelines associated with these different construction methods are summarised in Table 33. The Soils and Contamination Technical Study (Aurecon Arup, 2021) undertaken for this EIS also includes additional soil related risks.

Table 33 Potential pathways for geomorphic related impacts for pipeline waterway crossing construction and operation (Pipelines Associated Watercourse Crossings, fifth edition, online)

Potential pathway for impacts	Geomorphic impact on waterway	Type of construction	
		Trenched	Tunnelled
Vegetation clearing	Bank stability and exposed soils, increase erosion potential and change in sediment concentrations	✓	✓
Grading (ROW and construction approaches)		✓	✓
Excavation		✓	
Use of heavy equipment		✓	✓
Placement of material or structures in water	Changes in channel morphology, hydraulic and sediment concentrations	✓	
Dredging (instream excavation)	Resuspension and entrainment of sediment, changes in sediment concentrations	✓	
Changes in timing, duration, and frequency of flow	Bank and/or bed erosion, change in substrate	✓	

	composition, change in sediment concentrations		
Increases in channel erosion by dispersion	Dispersive soils known to be present in the South Creek catchment will lead to erosion given increased wetting	✓	✓

Unless mitigated, the potential pathways for geomorphic impacts identified in Table 33 can result in both short- and long-term impacts on the geomorphology of the waterways. This is particularly the case for crossings on South Creek & Mulgoa Creek (Table 32) which have high geomorphic sensitivity and where open trenching is the proposed waterway crossing construction approach. Construction and post-construction phase impacts predominantly include the potential for erosion due to removal and vegetation and disturbance of soil layers within the channel, disturbance of floodplain vegetation and sediments, and liberation of sediments and potential sediment smothering downstream (Table 33).

An additional concern with trenchless type pipeline crossings (Figure 48) is streambed slumping, or seepage flows. This is most common in unconsolidated soil types or where cracking can occur.

Mitigation options to minimise these potential geomorphic impacts are discussed in Section 7.

6.4.2. **Operational Impacts**

The pipeline infrastructure will primarily be below ground and thus potential impacts at waterway crossing locations associated with the pipelines are expected to be minimal during the operational phase. The potential operational phase impacts will be associated with maintenance activities and system malfunctions, such as leaks or bursts. The impacts are expected to be temporary and local in nature.

Mitigation options to minimise potential geomorphic impacts associated with operation of the pipelines are discussed in Section 7.

6.5. **Impacts on WaterNSW Infrastructure**

The geomorphic implications and risks of the AWRC releases specifically on WaterNSW infrastructure have been assessed (Appendix D). The work assessed risks to the integrity and security of WaterNSW lands, assets and infrastructure that may result from the treated water release to the Nepean River, the environmental flow release to the Warragamba River, and the wet weather flow release to South Creek.

A comprehensive risk assessment was completed for the following sites, as shown in Figure 49:

- Nepean River:
  - Wallacia Weir
  - Warragamba Pipeline Crossing. The pipeline is underground about 170m downstream of Wallacia Weir
  - Penrith Weir
- Warragamba River:
  - Warragamba Weir. Located about 550m downstream of environmental flow release location.

- South Creek
    - Warragamba pipeline

Overall, the results showed that geomorphic risks to WaterNSW assets on the Nepean River and Warragamba River are considered **LOW** under current conditions and with the AWRC releases.

The WaterNSW Warragamba pipeline crossing on South Creek is considered at **MEDIUM** geomorphic risk for current conditions and with the AWRC project. Wet weather flow releases do not increase the geomorphic risk to the structure.

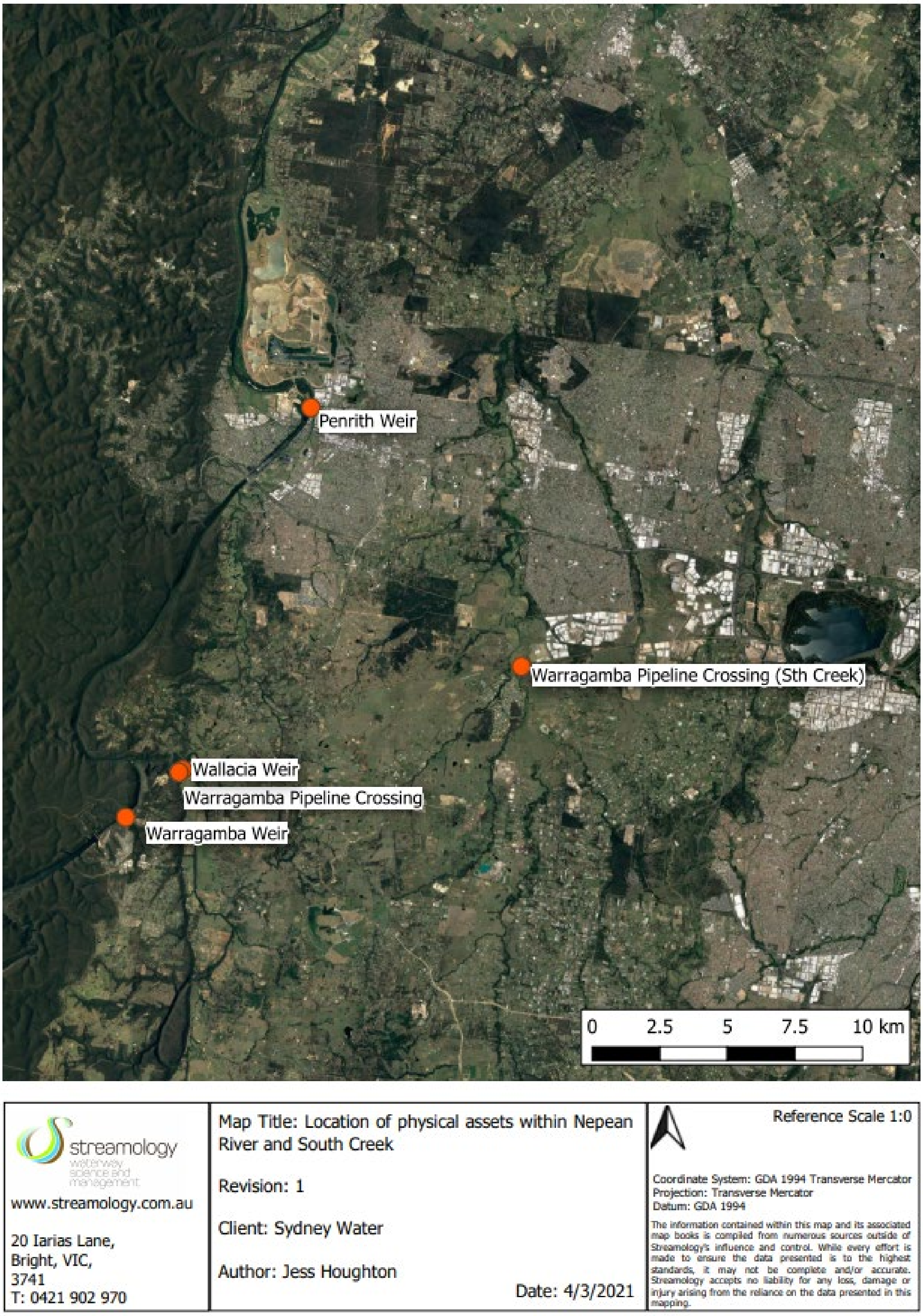


Figure 49 Location of WaterNSW assets including in this assessment within the Nepean River and South Creek

6.6. **Cumulative Impacts**

The Western Sydney Aerotropolis is being rezoned as a major growth and urban centre. This growth is the primary driver for the development of the AWRC project.

When considered in isolation, any identified project impacts were assessed as minor. These minor impacts may, however, be compounded, when the cumulative impacts of the proposed urban growth on waterways. As such the geomorphic impacts identified in Section 6 need to be considered in terms of cumulative impacts.

The major projects currently being proposed within proximity to the project are summarised in Table 34. This is also discussed in the Surface Water Impact Assessment report.

Table 34 Proposed major projects in close proximity to the AWRC project (adapted from the Surface Water Impact Assessment report)

Project	Project description, relation to current proposed AWRC project and expected residual impacts
Western Sydney Airport	The proposed Western Sydney Airport site will be located approximately 3.2 km south-west of the AWRC site, south of Elizabeth Drive. The site is primarily drained by Badgerys Creek and Cosgrove's Creek. Construction at the Western Sydney Airport site has already commenced. The Western Sydney Airport EIS surface water hydrology and geomorphology assessment (GHD, 2016b) concluded that with the implementation of a Stormwater Management Plan and Construction Environmental Management Plan, construction is unlikely to have a significant impact on downstream water quantity and that any potential impacts are likely to be localised and short term The proposed detention basin strategy would be effective at limiting the downstream impacts such that any increases in flood level would not worsen flooding to surrounding roads and dwellings, and the risks of changes in creek geomorphology would be low. Minor changes in water level are predicted immediately downstream of the airport site. Any increase in wet weather flows originating from the AWRC site will add to this minor impact.
M12 Motorway	The proposed M12 Motorway will run between the M7 Motorway at Cecil Hills and the Northern Road at Luddenham for a distance of about 16 kilometres and would be opened to traffic prior to opening of the Western Sydney Airport. The AWRC site itself is located within the extents of the M12 surface and hydrology study area. The pipelines will follow a similar alignment to the M12 along portions of their routes. Erosion and sedimentation are expected during construction of the M12 Motorway, with sediment basins located to best capture runoff before it enters the waterway. Whilst increased runoff is expected to occur during operation of the AWRC Project the implementation of appropriate runoff controls is identified in the EIS (RMS, 2019). Therefore, it is expected that there would be minor cumulative hydrological and therefore geomorphic impacts associated with the construction and operation of the AWRC Project and the M12 Motorway.
Aerotropolis initial precincts	The Western Sydney Planning Partnership (WSPP) has identified several precincts as priority precincts which will be targeted for rezoning in late 2020. These precincts all directly border the Western Sydney Airport site, they include: the Aerotropolis Core,

Project	Project description, relation to current proposed AWRC project and expected residual impacts
	Badgerys Creek, Northern Gateway, Agribusiness and adjoining areas of Wianamatta-South Creek. These precincts are primarily located within the South Creek catchment as the AWRC pipelines will transect several of them. An interim integrated water management plan for these initial precincts was released in October. The purpose of the plan is to identify measures and control mechanisms to ensure sustainable water management practices are established and consequently mitigate the cumulative hydrological and geomorphological impacts that the rapid urbanization may lead to. It sets out the draft flow objectives, defined in Table 2.
Sydney Metro – Western Sydney Airport	The proposed new railway will link St Marys to the new airport and the Western Sydney Aerotropolis (Sydney Metro, 2020). The EIS is currently being developed and expected impacts identified will need to be considered to determine the potential for compounding of impacts.
The Northern Road Upgrade – Glenmore Road to Bringelly	The project will upgrade around 35 kilometres of The Northern Road between The Old Northern Road at Narellan and Jamison Road at South Penrith. It will see The Northern Road upgraded to a minimum four-lane divided road, and up to an eight-lane divided road with dedicated bus lanes. The treated water pipeline will run alongside the Northern Road for a stretch of approximately 1.4 km. Construction works within this area could likely overlap. The road upgrades will likely result in increased local impervious areas, subsequently leading to higher peak runoff rates and therefore erosion potential. As the pipeline is expected to be below ground in this section, there are limited impacts expected post-construction and thus cumulative geomorphic impacts should be negligible.
Warragamba Dam Raising	Warragamba Dam Raising is a project to provide temporary storage capacity for large inflow events into Lake Burragorang to facilitate downstream flood mitigation and includes infrastructure to enable environmental flows. The EIS for this project is still being developed and thus potential impacts have not been assessed and published as yet. Cumulative impacts are expected to be minimal as the dam is located upstream of the environmental flows release location, and the raising is aimed at storing major flood events rather than retaining more water on a regular basis.

These proposed major projects along with the general expected future urban development in the area have the potential to increase flows, alter current watercourse geomorphology and exacerbate any impacts arising from the construction and operation of the AWRC and the release pipelines.

Major projects must be designed and delivered in accordance with current environmental legislation and incorporate sufficient control measures to mitigate associated impacts. Given the widespread expected urbanisation of the local environment, which would also include numerous small-scale developments, the cumulative impacts from these smaller developments could become a more likely source of cumulative impacts.

As the AWRC project is not expected to generate significant geomorphic impacts during construction or operation, the project would have a minor contribution to any foreseen cumulative geomorphic impacts associated with the Project and other identified projects in the vicinity.

7. Mitigation and Monitoring Measures

The following mitigation and monitoring measures relate to both the construction and operational phase of the AWRC project.

7.1. Pipeline Waterway Crossings

Geomorphic impacts, such as instream erosion, that may occur as part of the construction phase will most likely consist of acute impacts as described in Table 33. The following standard measures and mitigation should be implemented during construction and operation of the pipeline, particularly for the waterways with high geomorphic sensitivity (South Creek and Mulgoa Creek). Measures specifically direct to geomorphic impacts are detailed in the table. For additional mitigation measures to address water quality and flooding impacts refer to the Surface Water and Flooding Impact Assessment reports.

Table 35 Mitigation measures for pipeline waterways crossings during construction and operation of the pipelines with a focus on reducing geomorphic impacts to the waterways.

Mitigation Measure	Description
Planning	Building on the geotechnical investigations undertaken to date, prior to the actual works:
	• Further investigate and understand conditions that may affect disturbance of soils or vegetation on the local streambank or floodplain
	• Where not already known, further investigate the local streambed physical structure to ensure that slumping or cracking (and leaks) can be avoided
	• Dispersive soils are known to be present in the South Creek catchment and require site-specific assessment prior to construction
	• Undertake local on-ground site assessments by a qualified geomorphologist, including upstream and downstream implications, prior to the final approval for a works plan
Timing	Minimize the duration of instream, and particularly in-water work.
	Conduct instream work during periods of low flow, to further reduce the risks or to allow work in water to be isolated from flows.
	Schedule work to avoid wet, windy and rainy periods that may increase erosion and sedimentation. Provide contingency plans for forecasted periods that accommodate, or mitigate, the impacts of these potential events.
Operation of equipment	Whenever possible, operate equipment on land or from a floating barge in a manner that minimizes disturbance to the banks and bed of the water body.
	Use temporary crossing structures or other practices to cross watercourses with steep and/or highly erodible banks and beds.
	Remove all construction materials from site upon crossing completion.
	Limit machinery fording of the watercourse to a one-time event (i.e., over and back), and only if no alternative crossing method is available.

Mitigation Measure	Description
Erosion and sediment control	Installation and maintenance of effective erosion and sediment control measures before starting work to prevent sediment from entering the water body. • Regular inspection and maintenance of erosion and sediment control measures and structures during the course of construction. • Repairs to erosion and sediment control measures and structures, if damage occurs or in ineffective working conditions. • Removal of non-biodegradable erosion and sediment control materials (e.g., silt fence) once site is stabilized. Avoid the use of non-biodegradable materials.
	Implement measures for managing water flowing onto the site, as well as water being pumped or diverted from the site, such that sediment is filtered out prior to the water entering a water body.
	Implement measures for site isolation (e.g., silt boom or silt curtain) for containing suspended sediment, if in water work is required.
	Implement measures for containing and stabilizing waste material (e.g., dredging spoils, construction waste and materials, uprooted or cut aquatic plants, accumulated debris) above the top of bank and away from nearby watercourses and/or water bodies to prevent re-entry.
	Implement subsurface drainage controls, where appropriate, to maintain groundwater and surface water interactions and to maintain the stability of any reclaimed land. The type and location of subsurface drainage controls should be determined through onsite investigation with considerations for: subsurface flow potential, erodibility of backfill materials, and degree of slope.
Maintenance	Minimize the removal of natural woody debris, rocks, sand or other materials from the banks, the shoreline or the bed of the watercourse or water body below the top of bank. If material is removed from the water body or watercourse, set it aside and return it to the original location once construction activities are completed.
	Revegetate areas with surface (i.e., terrestrial) disturbance following construction works. If there is insufficient time remaining in the growing season, the site should be stabilized (e.g., cover exposed areas with erosion control blankets to keep the soil in place and prevent erosion) and vegetated.
	Revegetate streambanks and approach slopes with an appropriate native seed mix or erosion control mix.
Riparian Vegetation Removal	Where practical, design and construct approaches to the watercourse or water body such that they are perpendicular to the watercourse or water body to minimize loss or disturbance to riparian vegetation.
	Limit the clearing of riparian vegetation to a minimum; use existing trails, roads or cut lines wherever possible to avoid disturbance to the riparian vegetation and prevent soil compaction.

In addition to the general measures outlined above, the following mitigation measures are applicable to trenchless pipeline crossing method (Stantec, online):

- Establish an appropriate vegetative buffer (i.e., set-back) from the top of bank and locate all temporary workspaces outside the buffer.

- Design the alignment of the crossing to an appropriate depth below the watercourse to minimize the risk of an inadvertent release and scouring of the stream bed to the depth of the pipe.
- Determine failure-threshold criteria to indicate when a trenchless crossing method has failed, and construction works will be stopped. Examples of failure-threshold criteria may include:
  - An in-water frac-out that cannot be contained or mitigated; or
  - Streambed slumping; or
  - Schedule delays resulting from unexpected equipment failure or weather.
- Determine an alternative crossing method (i.e., contingency crossing plan) in the event the trenchless crossing method is not successful.
- Locate the entry and exit points (i.e., bell holes) back from the channel, beyond the top of bank to allow containment of any sediment or deleterious substances above the top of bank. Reclaim (i.e., backfill and pack) bell holes to pre-construction conditions

When using a trenched construction approach, the following additional mitigation measures should be implemented:

- Store materials excavated from the trench above the top of bank until the materials can be backfilled into the trench. The top 10 to 50 cm of channel substrate should be stored separately and replaced during backfilling, where practical.
- Backfill the trench with material of the same quality and gradation that was removed.
- Restore bed and banks of the watercourse or water body to their original contour and gradient; if the original gradient cannot be restored due to instability, a stable gradient should be restored.
- When using an isolated crossing method (i.e., coffer dam), this is completed while the isolation is still in place.
- If replacement rock reinforcement or armouring is required to stabilize eroding or exposed areas, ensure that appropriately sized, clean rock is used; and that rock is installed at a similar slope to maintain a uniform bank and natural stream alignment.
- Minimize in water work area where trenched crossing will be constructed.

Any residual risks associated with operation of the pipelines can be addressed through an on-going field monitoring program. Regular (6 monthly) inspections along each pipeline route including crossing locations should be undertaken.

Further pipeline related mitigation measures are also detailed in the Soils and Contamination Technical Study (Aurecon Arup, 2021).

7.2. **Nepean River and South Creek**

7.2.1. **Release structures**

Geomorphic impacts, such as instream erosion, that may occur as part of the construction phase for the release structures will most likely consist of acute impacts similar to those described in Table 33. The standard measures and mitigation, as outlined for the pipeline crossings in Table 35, should be implemented during construction of the release structures, particularly for the waterways with high geomorphic sensitivity such as South Creek.

The design of the release structures includes setbacks from the waterway, measures to dissipate energy, and scour protection along adjacent banks which mitigate potential operational impacts.

Any residual risks associated with operation of the release structures can be addressed through an on-going field monitoring program. Regular (6 monthly) inspections at each structure should be undertaken.

7.2.2. **Waterways**

Given the low impact to geomorphic conditions along the Nepean River as a result of the treated water releases at Wallacia Weir no additional mitigation measures are recommended during the operational phase except for the implementation of a program of pre-works and on-going monitoring of bank stability and change upstream of Wallacia Weir. Accelerated bank erosion will be evident (if at all) in the zone of increase, up to 18 centimetres higher in elevation up the bank relative to baseflow conditions. Should the monitoring indicate an increase in erosion along this reach then further bank stabilisation measures should be considered.

Stormwater and wet weather releases from the AWRC are proposed for South Creek and this study has only assessed the geomorphic impact of the wet weather releases. The analysis indicates the impacts are low and no additional mitigation measures are proposed to address wet weather flow impacts.

Mitigation measures associated with other impacts related to stormwater flows or flooding are addressed in the Surface Water and Flooding Impact Assessment reports.

Should future monitoring identify erosion issues, a novel approach to mitigating an increase in baseflows behind weir structures (e.g., Wallacia Weir) is to lower the weir level. This can be done in concert with an understanding of hydraulic increases to offset additional flows. The magnitude of change required is less than 18 centimetres. This suggestion serves to highlight the main impact (water level height changes) rather than serve as a recommendation (it would be recommended only in the case of evidence of severe ecological or social impacts).

7.3. **WaterNSW Infrastructure**

The results of the assessment have shown that the AWRC is not increasing geomorphic related risks to WaterNSW infrastructure. However, this report has identified an existing medium risk erosion to the long-term stability of the channel and surrounding banks at the WaterNSW pipeline crossing the Wianamatta-South Creek floodplain downstream of the AWRC South Creek release location. The concern is in the context of increased stormwater runoff resulting from the cumulative development of the upstream catchment. This is discussed further within the Surface Water Impact Assessment report (Aurecon Arup, 2021).

Mitigation measures to protect the pipelines under a cumulative development scenario are discussed further in the Surface Water and Flooding Impact Assessment reports. Mitigation measures to minimise cumulative impacts to creek flows are included in the Surface Water and Flooding Impact Assessment reports. By implementing a range of WSUD measures at the AWRC site, modelling shows the project can:

- meet draft NSW government water quality and flow objectives for South Creek and Penrith Council pollution reduction targets, and
- maintain peak flows from the AWRC site at pre-development levels

Therefore, no impacts to Warragamba Pipeline from site runoff are expected.

7.4. Monitoring Requirements

Monitoring of the receiving waterways physical form is key to determining the potential for impacts on geomorphology and managing any residual risks associated with the project. Based on the impact assessment the following requirements for on-going monitoring the physical attributes of the receiving waterways are recommended:

- **Nepean River upstream of Wallacia Weir to Bents Basin** - bank erosion and condition monitoring is required. This is recommended given the increased potential consequence for bank erosion associated with changes to the flow regime. It is recommended that baseline monitoring of bed and banks be completed prior to the commencement of releases. Following commencement of releases, the monitoring should be undertaken at 6 monthly intervals with an initial review of observed impacts after 2 years. The monitoring frequency can then be reviewed and adjusted as required, including the identification of additional monitoring sites and modification of the monitoring methods.

  Monitoring methods for the riverbed include cross sectional survey. The cross sectional must be made accurately to a fixed point, with redundancy to cope with disturbance (intentional or otherwise).

  Monitoring methods for riverbanks may include (from basic to more advanced): riverbank fixed photo-points at strategic locations, cross section surveys at strategic locations, and drone-monitoring baseline survey (topographic and imagery data) for some representative sections of each reach. It is recommended that the baseline survey include a detailed visual inspection by an experienced geomorphologist of the reach from Wallacia Weir to Bents Basin to identify priority site locations for future monitoring.

  No bank erosion monitoring is recommended for the downstream reaches.

- **Release structures -** A baseline survey is required prior to construction at each release site. Then following construction an on-going field monitoring program is required at each structure, including monitoring of the structure condition and bank conditions for at least 100m upstream and downstream. The inspections should be undertaken at 6 monthly intervals for a minimum of 2 years with further review at this time to determine the need for any on-going monitoring. Should any erosion or sedimentation issues be identified a risk assessment should be completed. This may identify the need for specific remediation measures. Field survey of any erosion sites should be added to the 6-monthly monitoring program.

- **Pipeline crossings -** A baseline survey is required prior to construction at each release site. Then following construction an on-going field monitoring program is required at each waterway crossing with emphasis on sites where open trench construction techniques were used. This monitoring should include monitoring of the waterway bed and bank conditions at the crossing location and for at least 100m upstream and downstream. The inspections should be undertaken at 6 monthly intervals, or post-event given adequate magnitude (e.g., 1 in 20-year ARI event) for a minimum of two years with further review at this time to determine the need for any on-going monitoring. Should any erosion or sedimentation issues be identified a risk assessment should be completed. This may identify the need for specific remediation measures. Field survey of any erosion sites should be added to the 6-monthly monitoring program
- **South Creek at the Warragamba Pipeline Crossing** - in conjunction with WaterNSW it is recommended that on-going bank and bed erosion and condition monitoring are undertaken for South Creek at the Warragamba Pipeline Crossing site. This would include monitoring of bed and bank condition along the channel 500 m upstream and downstream of the pipelines on an annual basis and following significant (20% AEP or larger) flood events. A baseline survey should be completed for the monitoring area and subsequent surveys can be completed on a visual basis unless impact are observed. At that time further survey (topographic and imagery) should be collected. Monitoring it recommended until such time that more detailed flood investigations and risk assessments are completed, and for 2 years after bed and bank stabilisation works are undertaken.

No additional hydrologic monitoring (i.e., flow gauging) is required as part of the on-going geomorphic monitoring.

8. Conclusions

The objective of this study has been to provide an assessment of how the releases of treated water from the AWRC during operation may impact on the ecohydraulics (instream water conditions that relate to habitat) and geomorphology (physical form and function). This has been undertaken for the receiving waters of South Creek and the Nepean River, in the Hawkesbury Nepean River system.

This report presents the findings of the ecohydraulic and geomorphic impact assessment and provides an analysis of how the releases of treated water from the AWRC may potentially impact a range of hydrologic and hydraulic metrics. These metrics are used to determine the implications on the hydraulic (potential) habitat and geomorphology of the waterways. Stage 1 of the AWRC has been the focus of the assessment, with the implications of future stages also considered.

Details regarding the impacts on the individual reaches of the waterways are presented in the summaries below.

8.1. Nepean River & Warragamba River

The following table summarises the geomorphic impacts of the proposed Stage 1 (50 ML/d) AWRC release on the Nepean River. These results are consistent across the flow regime based on a detailed analysis of hydraulic metrics under median flow (50th percentile), low flow (90th percentile) and high flow (10th percentile) conditions.

Table 36 Summary of hydraulic impacts on the Nepean River as a result of the AWRC releases

Reach	Impact of AWRC treated water releases
Nepean River upstream of Wallacia Weir	**Low** hydraulic and geomorphic impact based on predicted changes in water surface elevation, wetted perimeter, velocity, and shear stress
Nepean River from Wallacia Weir to the Warragamba River confluence	**Low** hydraulic and geomorphic impact based on predicted changes in water surface elevation, wetted perimeter, velocity, and shear stress
Nepean River downstream of Warragamba River	**Low** hydraulic and geomorphic impact based on predicted changes in water surface elevation, wetted perimeter, velocity, and shear stress
Warragamba River from the dam to the confluence	**Low** hydraulic and geomorphic impact based on predicted changes in water surface elevation, wetted perimeter, velocity, and shear stress

The ecohydraulic conditions are in the range of imperceptible with regard to physical changes in habitat conditions such as depths and velocities. Given the low impact to geomorphic conditions along the Nepean River as a result of the treated water releases at Wallacia Weir no additional mitigation measures are recommended except for on-going monitoring of bank stability and change upstream of Wallacia Weir. Should the monitoring indicate an increase in erosion along this reach then modification of flows releases, or further bank stabilisation measures should be considered.

Results for the ultimate AWRC release (100 ML/d) were very similar to Stage 1 and are consistently low (Figure 37). The most significant difference being the further increase in water levels upstream of Wallacia Weir. The additional increase in water surface elevation as a result of the higher AWRC release, may result in the potential for additional impacts on bank erosion in the reach upstream of Wallacia Weir. This may require additional mitigation measures to be investigated, such as targeted bank protection. These changes will be identified through the on-going monitoring program.

8.2. South Creek

The following table summarises the geomorphic impacts of the proposed wet weather AWRC releases on South Creek. The assessment of geomorphic risk derived from hydrologic scenario analysis takes into account the analysis of the hydrologic metrics for baseline, background and impact scenarios.

Table 37 Summary of geomorphic impacts on South Creek as a result of wet weather releases from Stage 1 of the AWRC

Reach	Impact of AWRC treated water releases
South Creek upstream of the AWRC	**Negligible** hydraulic and geomorphic impact based on predicted changes in erosion thresholds due to the wet weather releases only.
South Creek downstream of the AWRC	**Low** hydraulic and geomorphic impact based on predicted changes in erosion thresholds due to the wet weather releases only.

In South Creek, this study has assessed the geomorphic impact of wet weather releases from the AWRC. The analysis indicates the impacts are low and no additional mitigation measures are proposed to address these wet weather flow impacts. Mitigation measures associated with other impacts related to stormwater flows or flooding are addressed in the Surface Water and Flooding Impact Assessment reports.

It is recommended that bank and bed erosion and condition monitoring are undertaken for South Creek at the Warragamba Pipeline Crossing site. This should be further scoped in consultation with WaterNSW.

Implications of pipeline and outlet infrastructure construction include geomorphic impacts such as disturbance of soils and vegetation and liberation of sediments. Impacts of both trenchless and trenching operations for pipeline crossing can be mitigated with the range of standard measures proposed. Given appropriate application of measures, operation of infrastructure will not impact on geomorphic or ecohydraulic conditions.

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Appendices

Appendix A – Bathymetric Data

During the initial stages of the EIS it was identified there was a data gap in relation to detailed bathymetric data of the Nepean River. The existing data comprised of a single elevation point below the water surface and therefore the cross-section of the Nepean River below the water surface was not well resolved. This is shown in Figure A1 as the coarse bathymetry data.

This information is important for the development of the hydraulic models and aids the interpretation of the model results.

Sydney Water commissioned ALS to capture new bathymetric survey data at five locations in the Nepean River, which are summarised in Table A1 below. The survey of these sites was completed in August/September 2020.

Topographic data in the form of LiDAR data was supplied by Sydney Water.

Table A1 Summary of bathymetric survey capture extents

Site ID	Location	Reason for survey
1	Downstream of Wallacia Weir to Norton's Basin	This site consists of a steep section of waterway with prominent riffles, runs and pools located on the outside bend of the river. Preliminary 1-dimensional (1D) hydraulic modelling indicated that the ratio of riparian inundation (expressed as wetted perimeter) to depth of flow is quite high, which has implications for riparian vegetation.
2A	Norton’s Basin	Norton’s basin was included due to its high value as a local swimming hole and the ecological value it provides to local water dependent fauna.
2B	Norton’s Basin to downstream of the confluence with the Warragamba River	This site consists of shallow waterway with riffles and runs. There is visible sand substrate from aerial imagery that is potentially mobile. Preliminary hydraulic modelling for the upstream section of the site indicated that it was primarily governed by velocity due to its steepness and was prone to greater riparian inundation changes with depth.
3	Within the Blue Mountains World Heritage Area between the Warragamba confluence and Penrith Weir	Site 3 is located within the Blue Mountains World Heritage Site. It is located sufficiently downstream to include several minor tributaries to the Nepean River system. The possibility of endangered trees sensitive to long term changes in water level is also prominent through this region.
4	Downstream of Penrith Weir	Site 4 is located immediately downstream of the Penrith Weir and was selected for inclusion due to the potential presence of sand substrates and sandbars. It was also selected for inclusion in this assessment due to its distance downstream from the nominated release locations. Geographically, it represents a potentially sensitive site that is sufficiently downstream to allow the assessment of impacts to the Nepean River system as a whole.

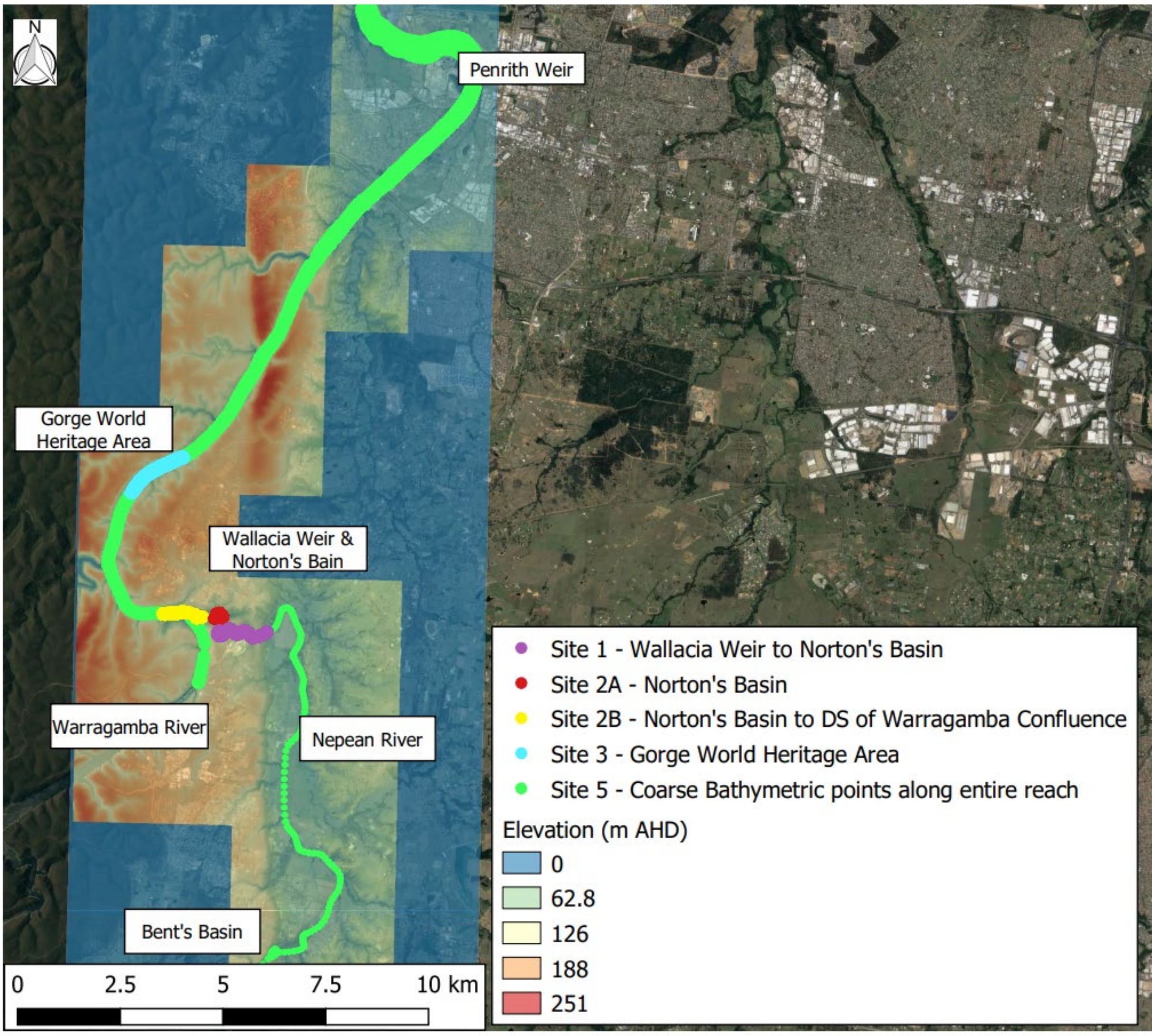

Figure A1 Summary of locations of bathymetric data within Nepean River assessment area.

Appendix B - Additional Model Results Analysis

High Release Results Analysis

The following results are presented for the ultimate development conditions results which are for an AWRC release of 100 ML/d. Modelled results are presented for the 50% ile flow. As described in Section 6, the overall trends are similar across the flow regime and therefore these results are representative of low to high flow conditions.

Water Surface Elevation (WSE)

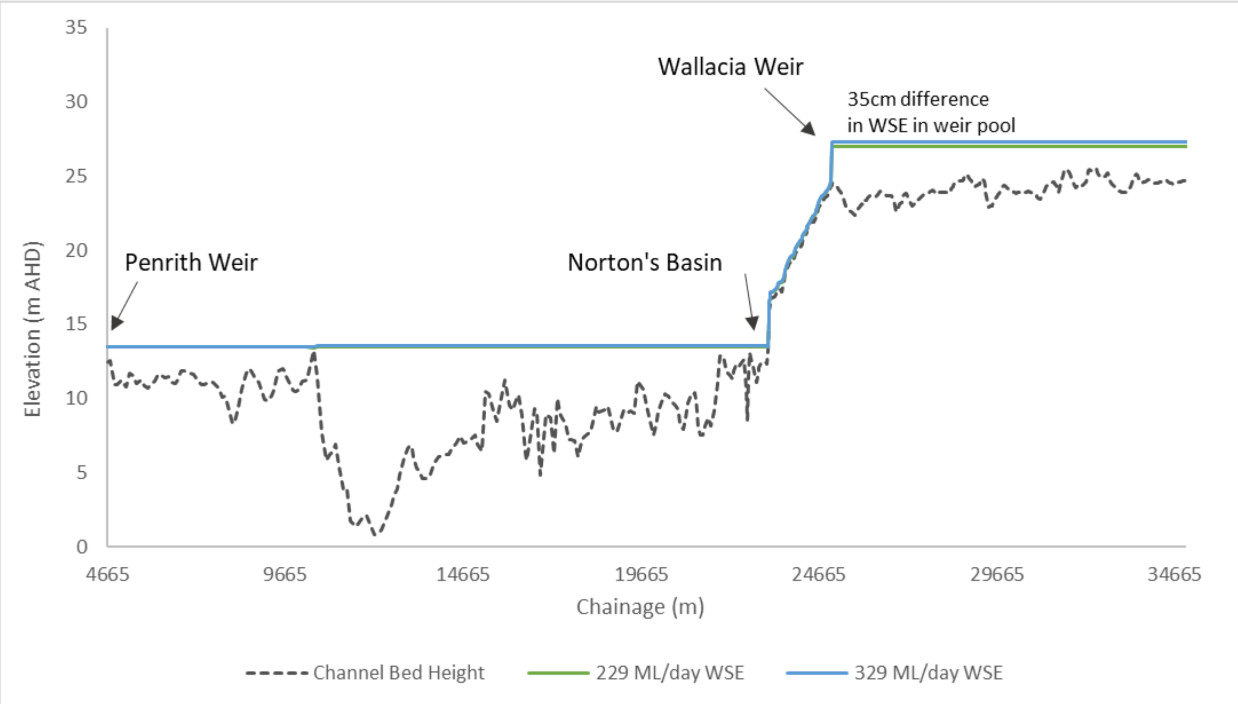

Figure B1 Comparison of water surface elevation difference between 229 ML/day and 329 ML/day flows.

The difference in water surface elevation is shown more clearly in Figure B2, where downstream of Wallacia Weir the changes in level are < 0.1 m and only occur in localised areas. However, upstream of Wallacia Weir, there is a more consistent increase in water surface elevation (of around 0.35 m) which relates directly to the increase in flows. The weir crest essentially controls the upstream weir pool level, and a higher flow will result in an increase in upstream level. The maximum level change for the 50 ML/d AWRC release is therefore around 0.18 m.

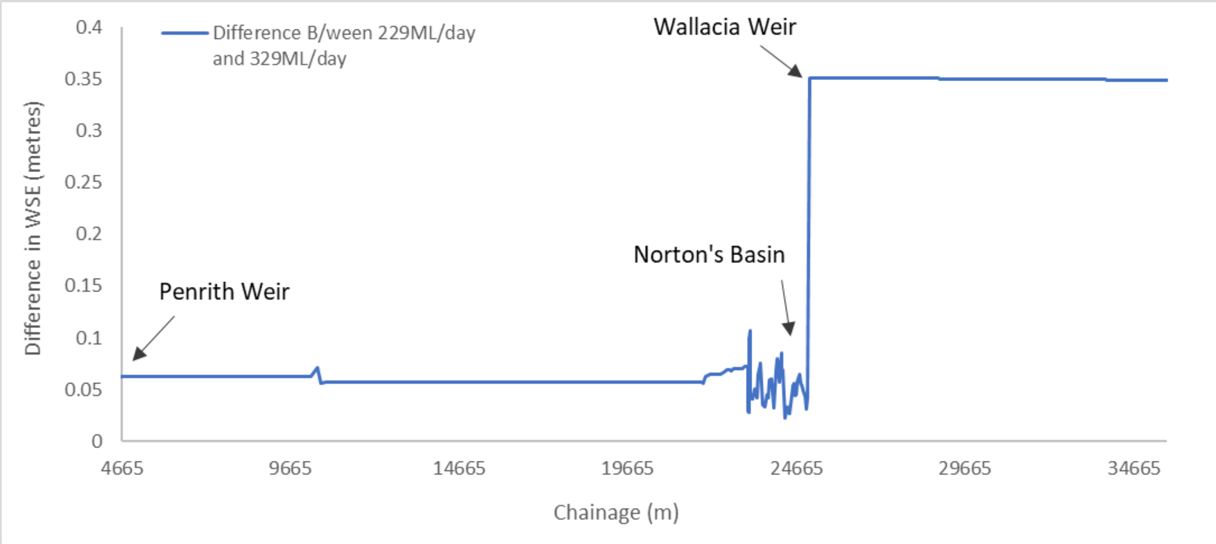

Figure B2 Difference between water surface elevation between 229 ML/day and 329 ML/day flows.

Wetted Perimeter

Wetted perimeter is a measure of the perimeter of the cross-section along a channel that is wet. Figure B3 presents the wetted perimeter results for 100 ML/d AWRC release scenarios.

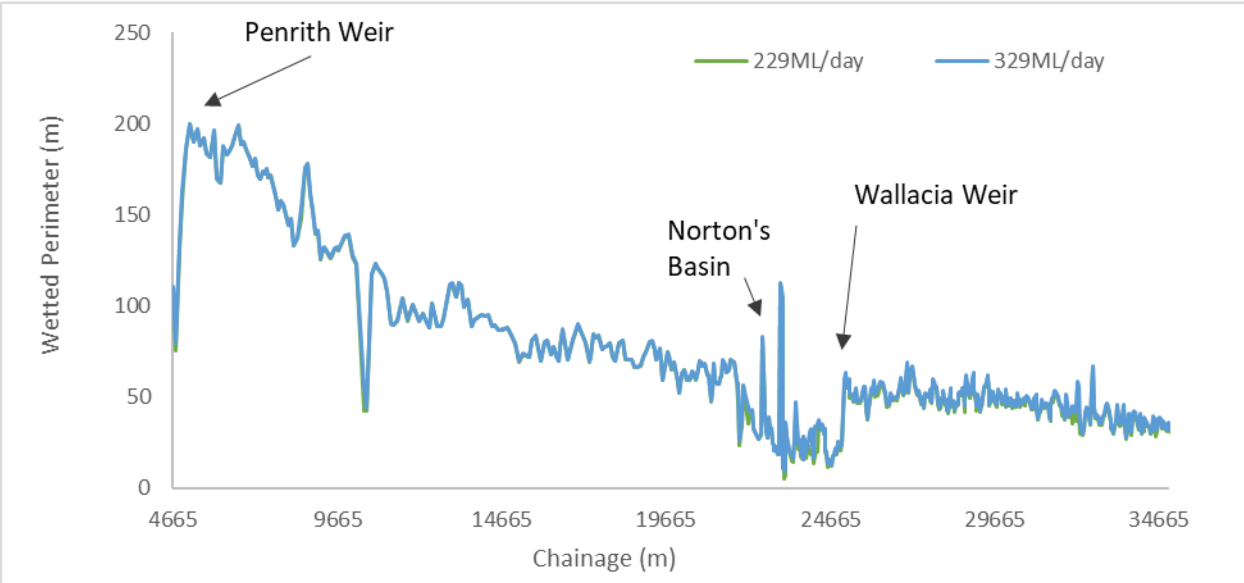

Figure B3 Comparison of wetted perimeter difference between 229 ML/day and 329 ML/day flows.

The difference in wetted perimeter is presented in Figure B4 and shows there are localised changes in wetted perimeter under the 100 ML/d AWRC release scenario. The location of these changes is the same as for the 50 ML/d case.

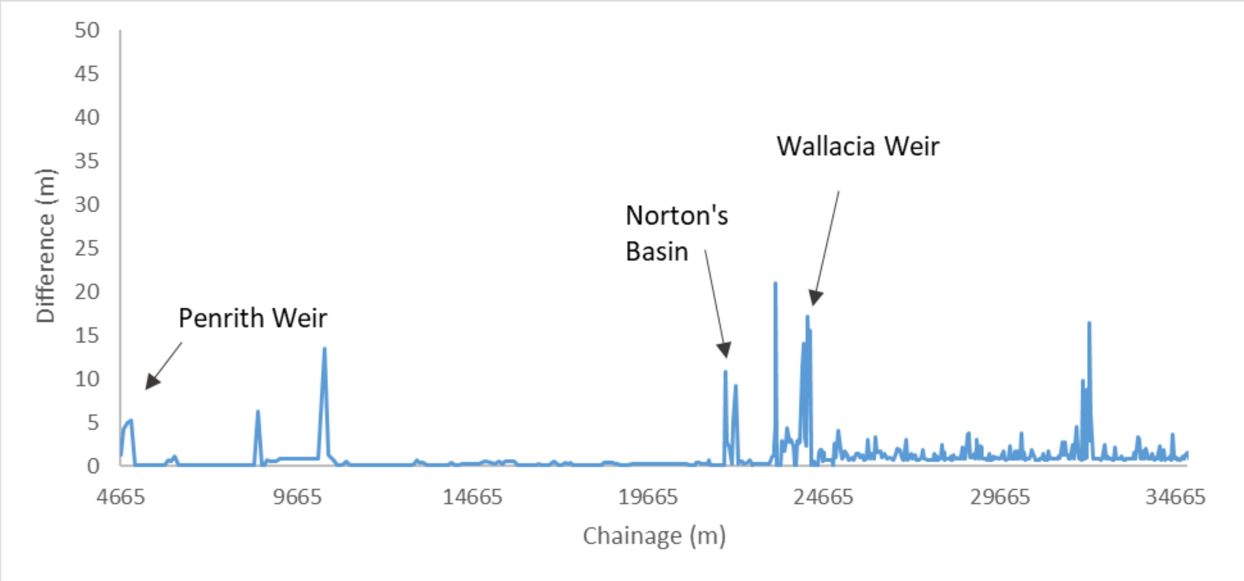

Figure B4 Difference in wetted perimeter values between 229 ML/day and 329 ML/day flows.

Overall, the mean change in wetted perimeter because of an additional 100 ML/day flow is 1.09 m. The areas with the greatest change to wetted perimeter occur in the steep section downstream of Wallacia Weir. These are locations with shallow depths, higher shear stress and higher velocity compared to adjacent sections. The location of the changes is the same as for the 50 ML/d case and are summarised in Section 6.

Channel Velocity

Velocity along a channel reflects the relationship between channel slope, width, depth, and flow.

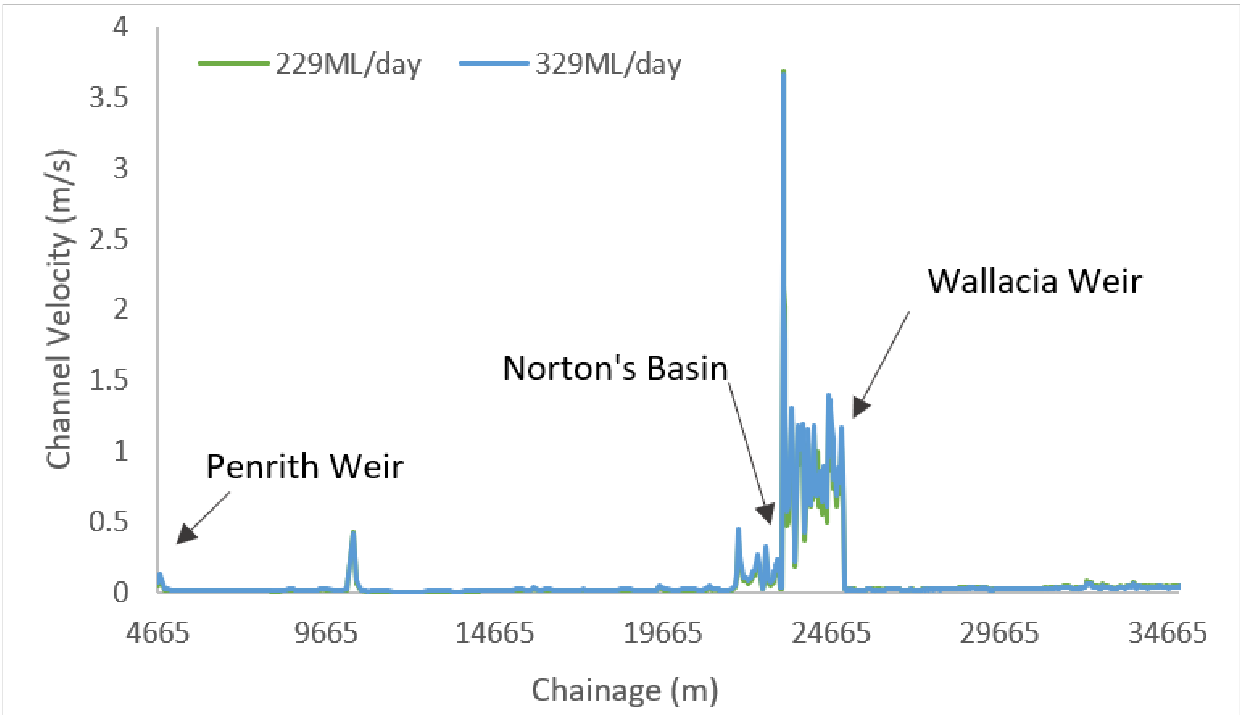

Figure B5: Comparison of velocity between 229 ML/day and 329 ML/day flows.

Higher velocities are typically reflected in the steep reach downstream of Wallacia Weir to the Warragamba River, which is not affected by the backwater from the Penrith Weir. The mean change to channel velocity along the river is only 0.01 m/s, as shown in Figure B6. Negligible change was modelled for those locations within the existing weir pools.

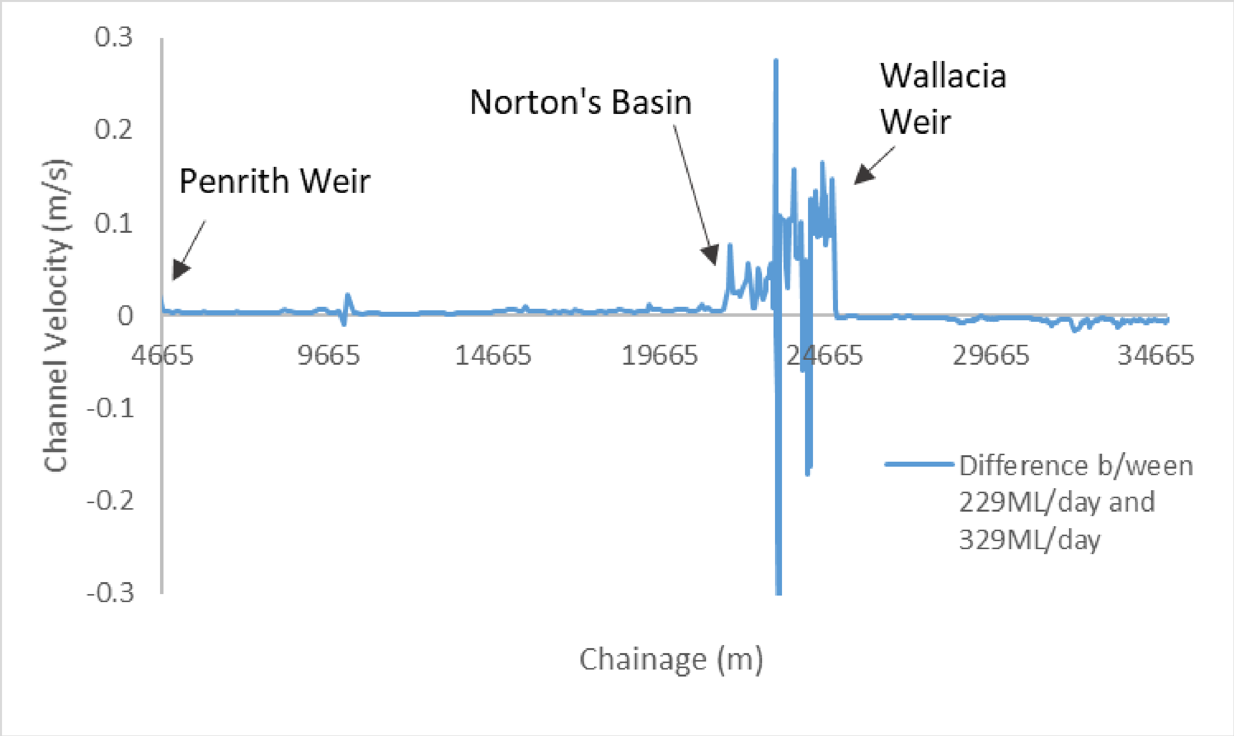

Figure B6 Difference in channel velocity between 229 ML/day and 329 ML/day flows.

Shear Stress

Shear stress along a channel reflects the relationship between channel slope, width, depth, and flow. Figure B7 and Figure B8 present the shear stress and shear stress difference results under the 50% percentile flow conditions for current conditions and assuming a 100 ML/d AWRC release.

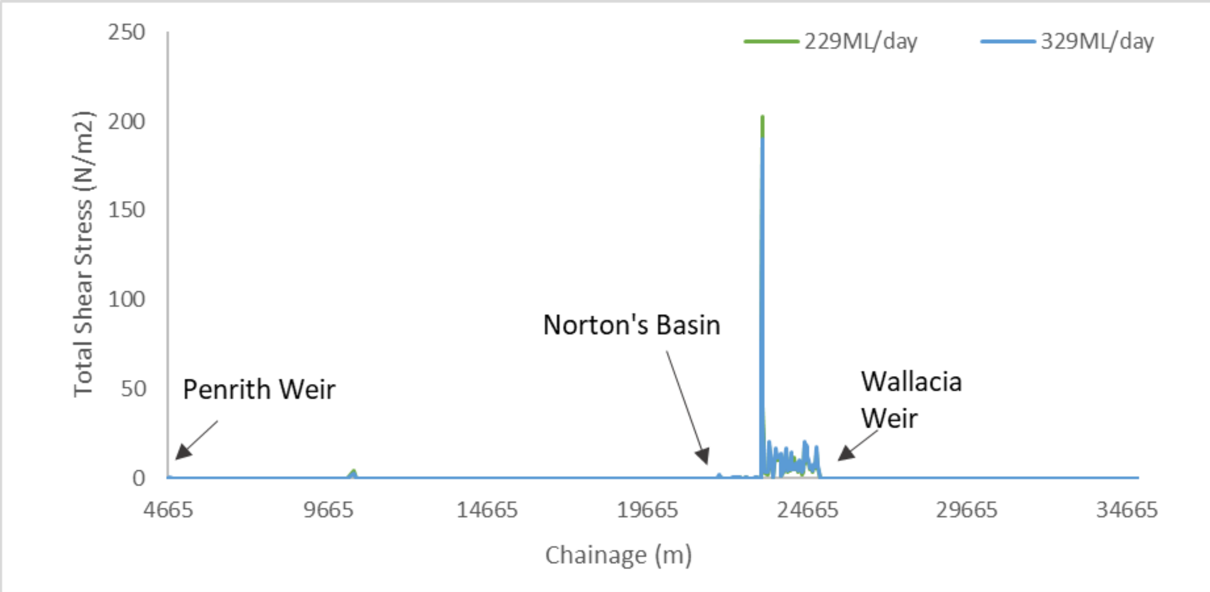

Figure B7 Comparison of channel shear stress difference between 229 ML/day and 329 ML/day flows.

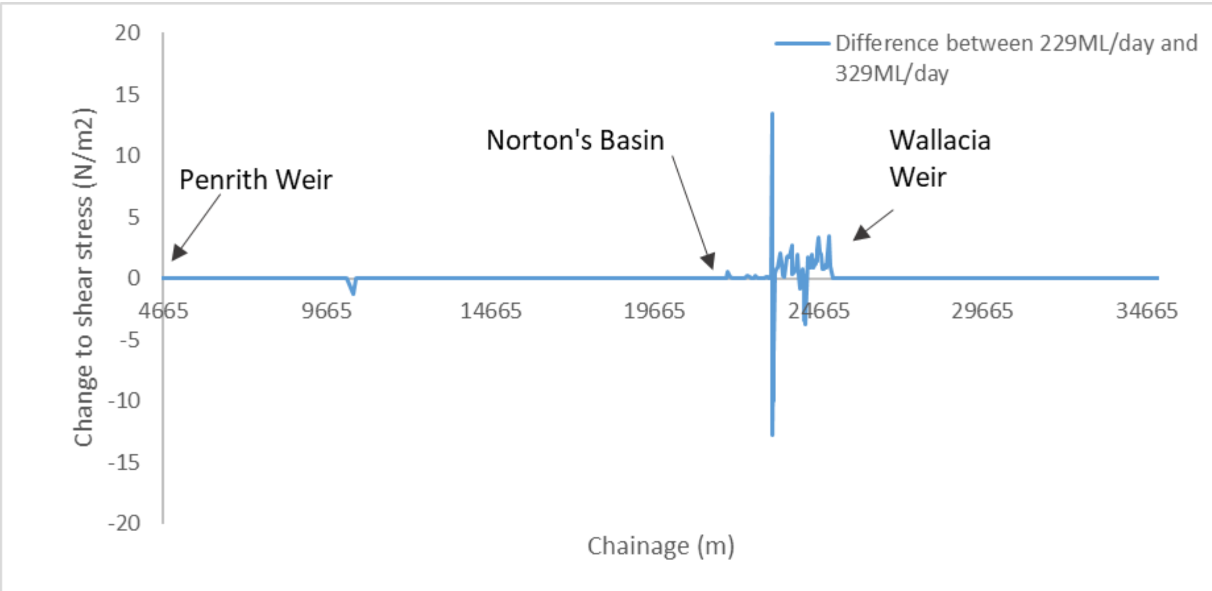

Figure B8 Difference in channel shear stress between 229 ML/day and 329 ML/day flows.

Results for 50 ML/d release, 90th percentile flows (low flow conditions)

The following low flow (90th percentile) results are presented showing the difference between baseline conditions and with the Stage 1 development (AWRC release of 50 ML/d). The 90th percentile flow under baseline conditions is 64 ML/d, while with the AWRC release these increases to 114 ML/d, except for water surface elevation where the impact is greater downstream of Wallacia Weir within the Penrith Weir pool than upstream of Wallacia Weir. However, the magnitude of change is < 0.1 m.

At these lower flow conditions, the reduction in channel cross-section at the Glenbrook Creek confluence where a large depositional sediment fan is present (approx. chainage 10,600) has an impact on the upstream water levels (in the order of 1 - 1.5 cm). The in-channel feature is effectively acting as hydraulic control under these low flows. Under high flow conditions the effect of the feature is drowned out the Penrith Weir downstream begins to dominate the water levels along the reach until the Warragamba River confluence.

The overall trends and magnitude of change are the same as for 50th percentile (median) flow results presented in Section 6.

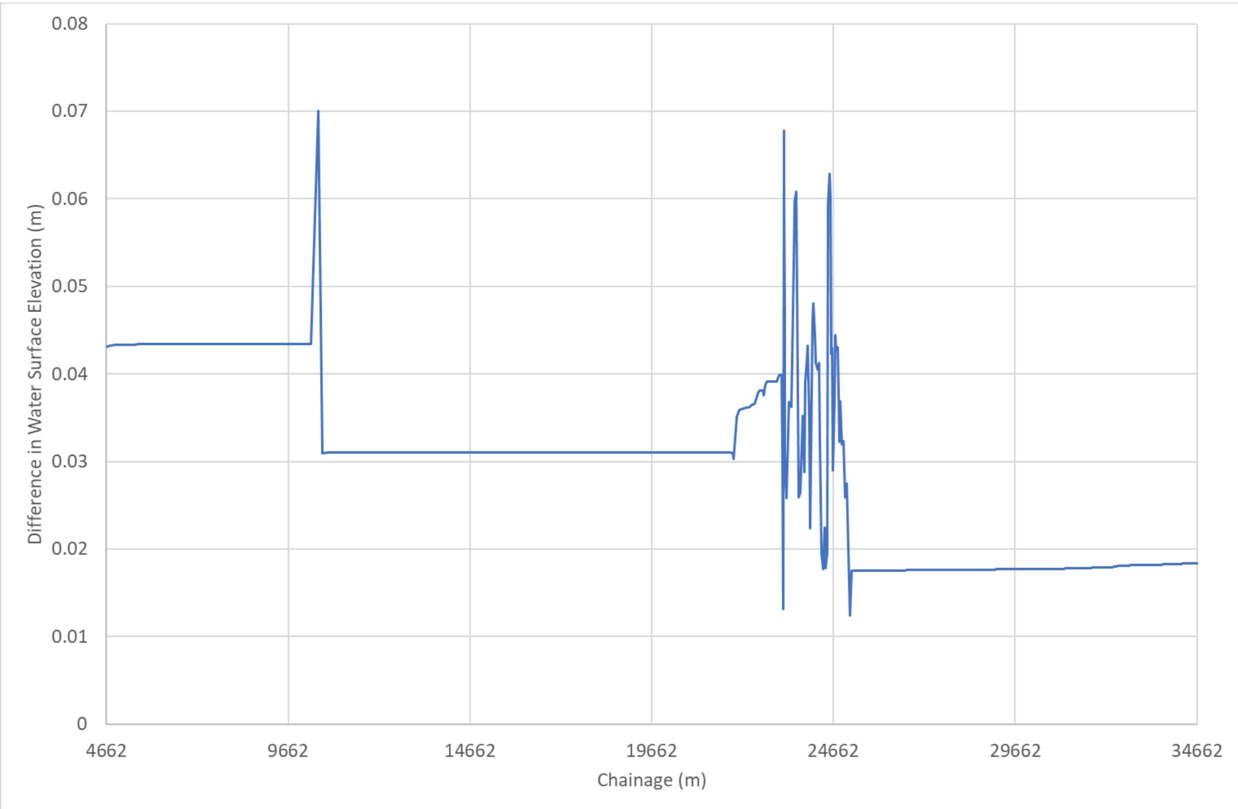

Figure B9 Difference in surface water elevation between 64 ML/day and 114 ML/day flows.

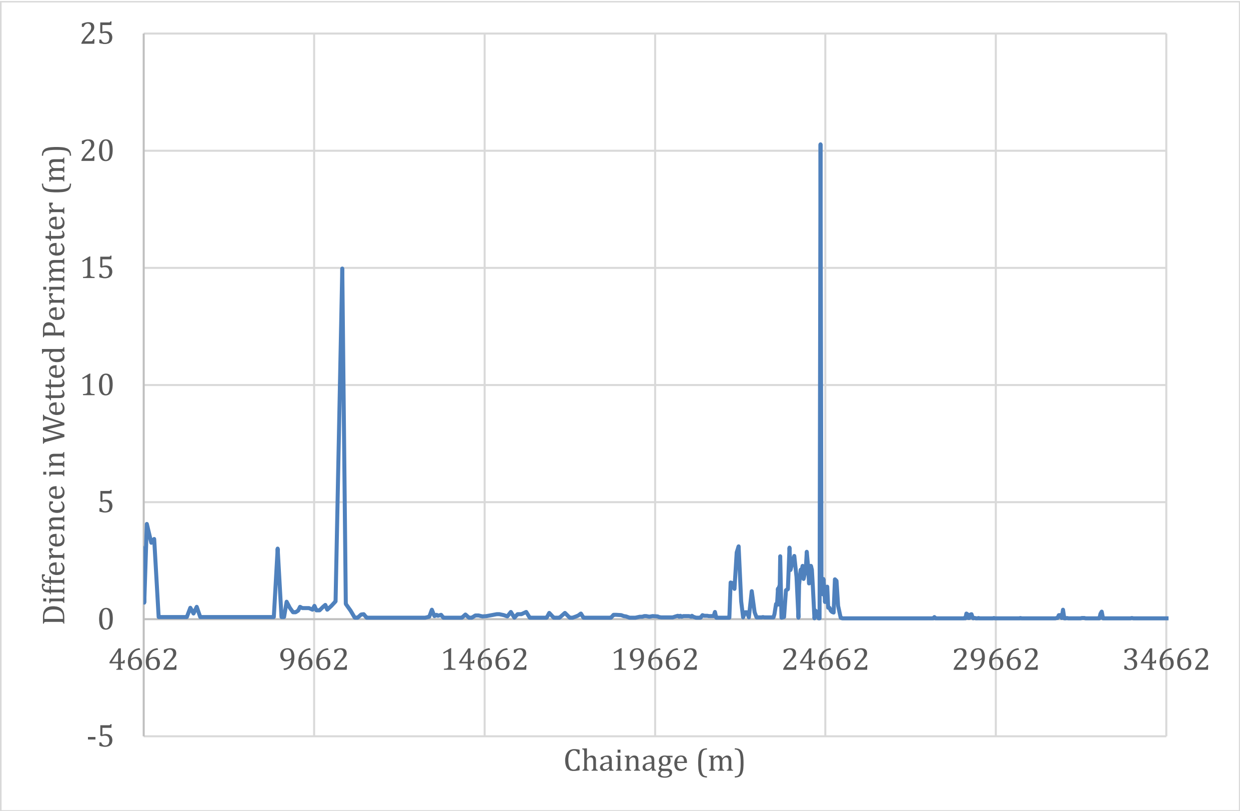

Figure B10 Difference in wetted perimeter between 64 ML/day and 114 ML/day flows.

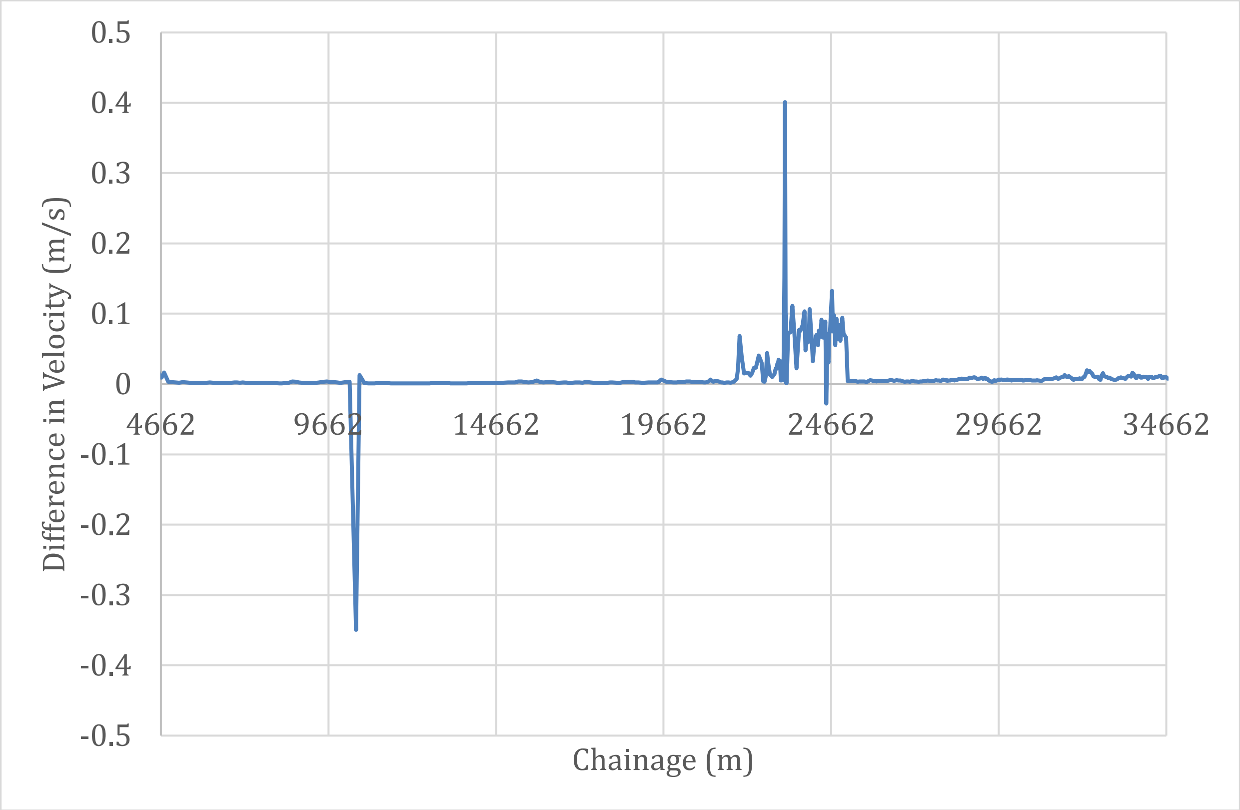

Figure B11 Difference in velocity between 64 ML/day and 114 ML/day flows.

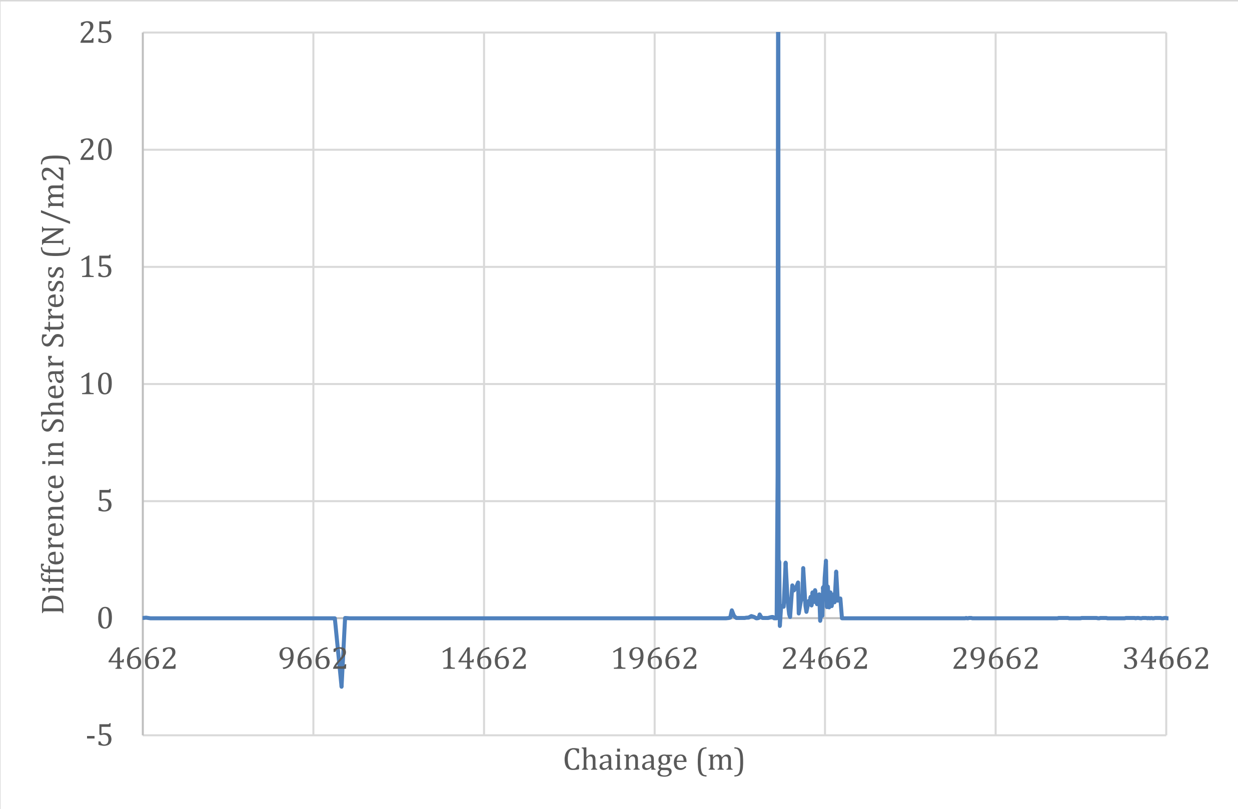

Figure B12 Difference in shear stress between 64 ML/day and 114 ML/day flows.

Results for 50 ML/d release, 10th percentile flows (high flow conditions)

The following high flow (10th percentile) results are presented showing the difference between baseline conditions and with the Stage 1 development (AWRC release of 50 ML/d). The 10th percentile flow under baseline conditions is 800 ML/d, while with the AWRC release these increases to 850 ML/d.

The overall trends are the same, however the magnitude of change in the hydraulic parameters is significantly less for these high flow conditions. Overall, the impact of the AWRC releases decreases with increasing flow magnitude above the median flow.

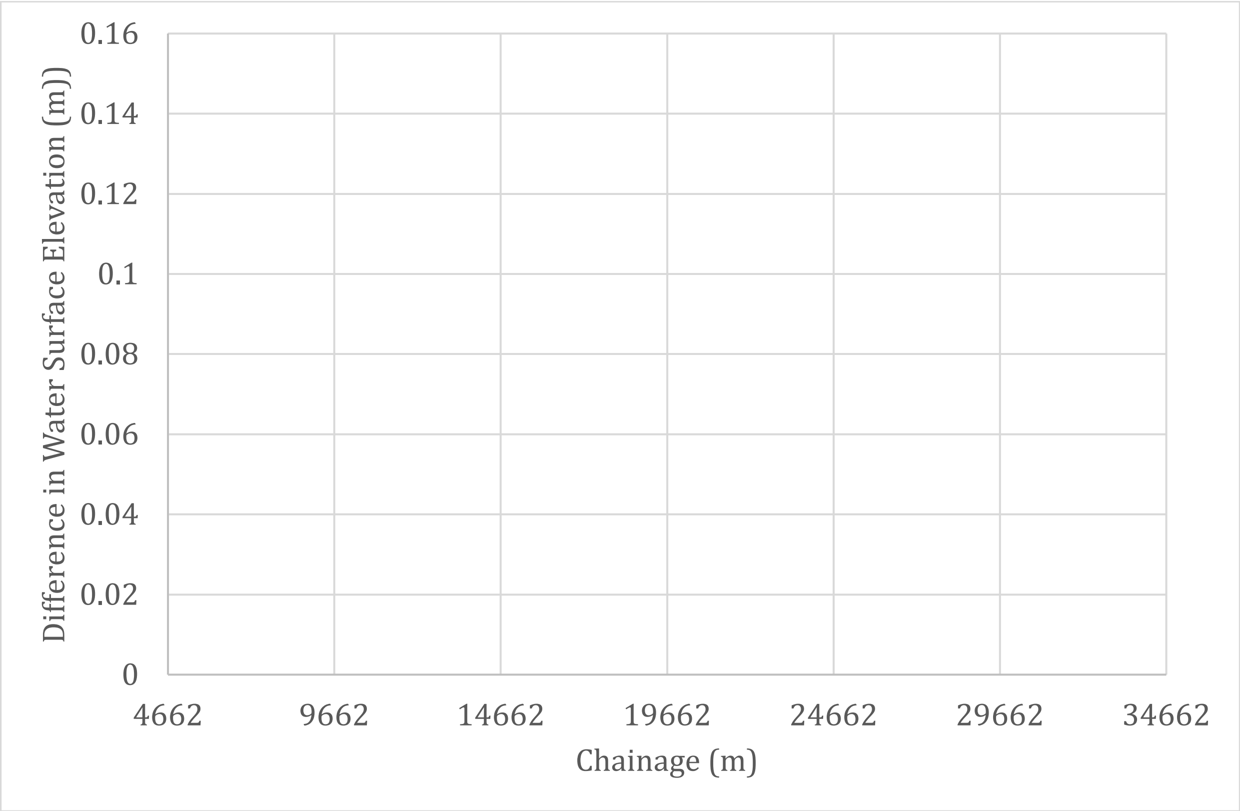

Figure B13 Difference in surface water elevation between 800 ML/day and 850 ML/day flows.

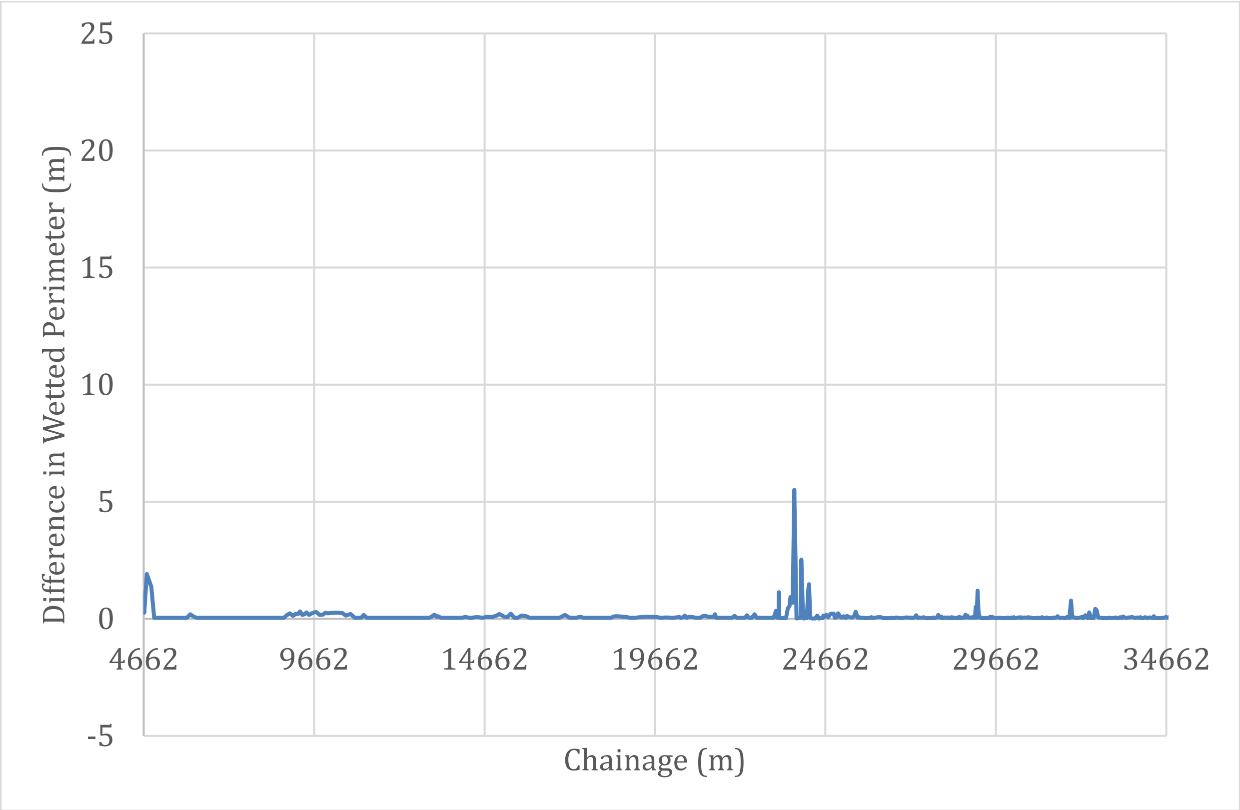

Figure B14 Difference in wetted perimeter between 800 ML/day and 850 ML/day flows.

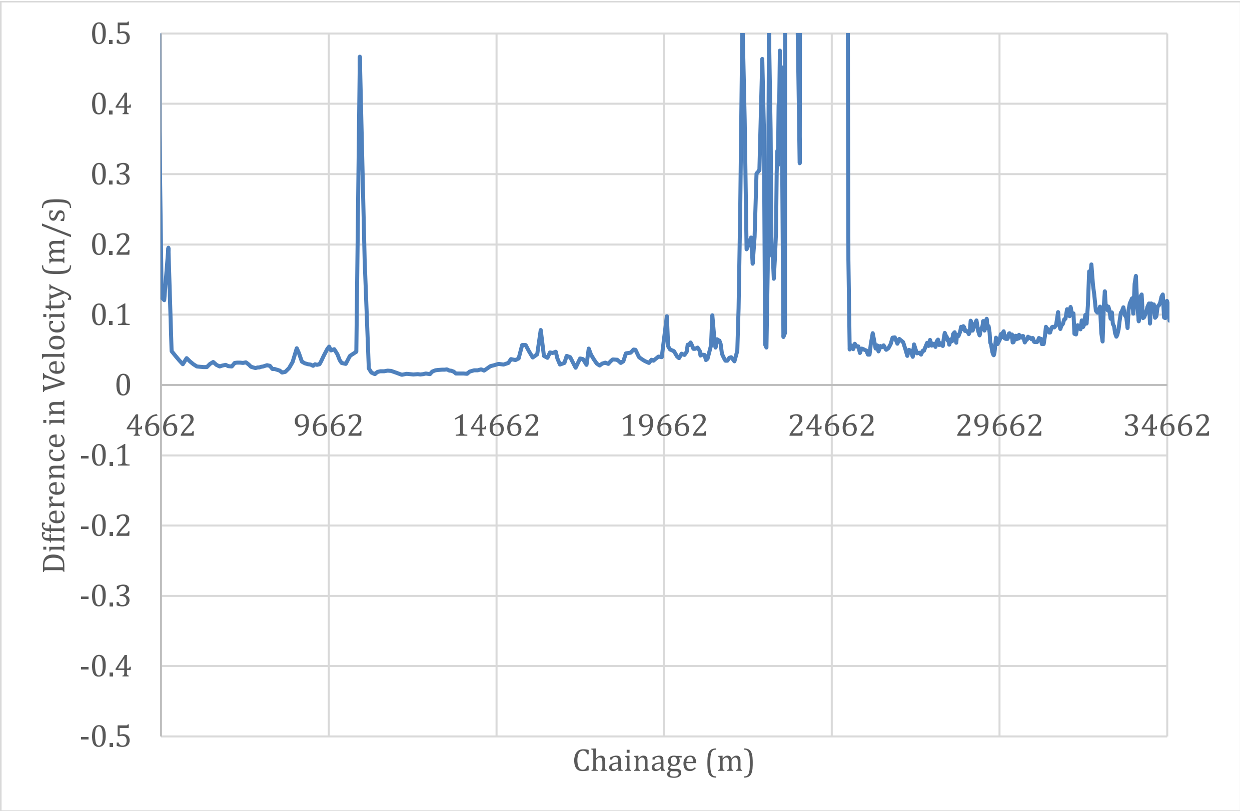

Figure B15 Difference in velocity between 800 ML/day and 850 ML/day flows.

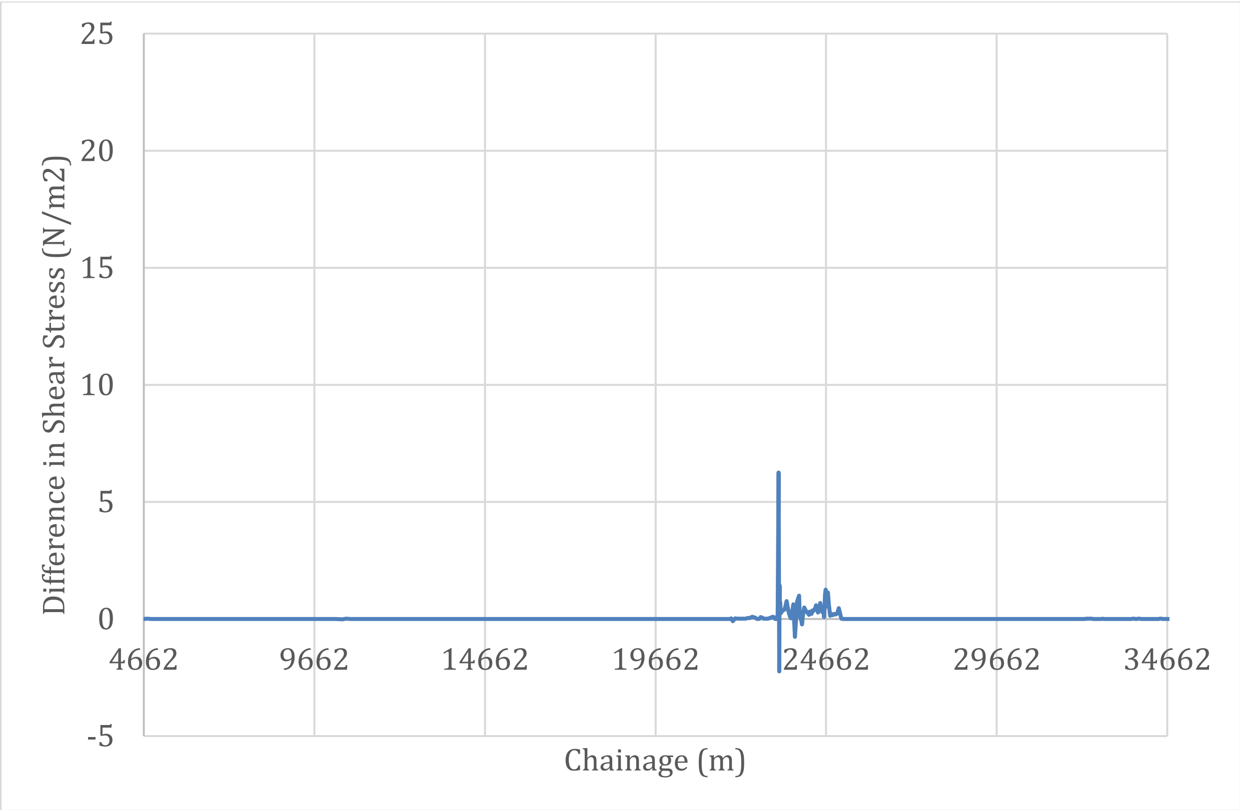

Figure B16 Difference in shear stress between 800 ML/day and 850 ML/day flows.

Appendix C - Hydrologic Scenario Analysis Results

The following tables present the detailed analysis of hydrologic metrics based on the Urban Streamflow Impact Assessment (USIA) approach, Vietz et al. (2019). These tables provide an assessment of hydrologic scenarios for varying land use and treated water releases under baseline, background future and impact future conditions. Results are provided for the Nepean River first then followed by the South Creek sites. The results cover both the wet and dry simulation periods.

The results for the Nepean River sites are provided for information only. As noted in the main report, the modelled flows do not accurately represent baseline conditions and therefore the analysis has focussed on the relative difference between the scenarios rather than the absolute values.

Table C1: Hydrologic (USIA) flow metric results for the Nepean River - upstream of Wallacia Weir

Upstream Wallacia Weir														
Flow Component	**Flow Metrics (ML/day)**	**Value by Scenario**												
		HN00	**HN01**	**HN02**	**HN03**	**HN04**	**HN05**	**HN06**	**HN07**	**HN08**	**HN13**	**HN14**	**HN15**	**HN16**
Flow Dynamics (Non-Zero Flows)	Maximum (ML/day)	14,036	13,903	14,029	13,897	14,033	13,870	14,027	14,013	14,032	13,875	13,959	14,021	14,003
	Minimum (ML/day)	43.61	42.92	43.02	44.36	44.62	30.20	25.70	30.96	27.64	6.76	26.51	22.36	28.05
	Mean (ML/day)	435	429	431	431	435	429	431	431	435	429	431	431	435
	Mean Annual Flow Volume (ML)	158,834	156,684	157,323	157,385	158,885	156,669	157,334	157,480	158,826	156,635	157,248	157,464	158,791
	Median (ML/day)	130	132	134	135	139	134	137	137	141	134	137	136	141
	St.Dev (ML/day)	1,038	1,026	1,030	1,024	1,032	1,026	1,031	1,028	1,031	1,025	1,029	1,027	1,030
Zero Flow	Average 0 Flow Duration (days)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	% Time with Zero Flow	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Freshes	# of Fresh Events (> 3 x Median Flow)/yr	10.5	10.0	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5
	% of Time Over Fresh Event	22.9%	21.9%	22.0%	22.1%	22.5%	22.0%	22.1%	22.1%	22.4%	22.0%	22.0%	22.1%	22.4%
	Average Fresh Duration (days)	7	7	8	8	7	8	7	8	7	8	8	8	7
Erosion Threshold	% of Time > bank/matrix mobilisation threshold	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	% of Time > Bed mobilisation threshold	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

Table C2: Hydrologic (USIA) flow metric results for the Nepean River - Wallacia Weir to Warragamba River

Downstream of Wallacia Weir														
Flow Component	**Flow Metrics (ML/day)**	**Value by Scenario**												
		HN00	**HN01**	**HN02**	**HN03**	**HN04**	**HN05**	**HN06**	**HN07**	**HN08**	**HN13**	**HN14**	**HN15**	**HN16**
Flow Dynamics (Non-Zero Flows)	Maximum (ML/day)	14,068	14,010	14,003	13,980	14,017	13,980	14,175	14,072	14,157	13,972	14,145	14,056	14,143
	Minimum (ML/day)	44.10	43.45	43.55	44.89	45.19	68.52	95.34	68.84	96.91	47.47	72.10	48.20	73.63
	Mean (ML/day)	435	429	431	431	435	474	521	476	525	451	498	453	502
	Mean Annual Flow Volume (ML)	158,807	156,684	157,307	157,395	158,848	173,141	190,268	173,929	191,776	164,633	181,775	165,439	183,320
	Median (ML/day)	130	132	134	135	139	181	227	182	232	155	203	158	209
	St.Dev (ML/day)	1,038	1,026	1,030	1,025	1,030	1,031	1,042	1,031	1,041	1,035	1,045	1,034	1,046
Zero Flow	Average 0 Flow Duration (days)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	% Time with Zero Flow	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Freshes	# of Fresh Events (> 3 x Median Flow)/yr	10.5	10.0	9.5	9.5	9.5	7.5	8.0	7.5	8.0	8.5	7.5	9.0	7.5
	% of Time Over Fresh Event	23.0%	21.9%	22.0%	22.1%	22.7%	18.3%	16.2%	18.2%	16.1%	20.6%	26.3%	23.6%	26.5%
	Average Fresh Duration (days)	3.8	3.8	4.0	4.0	8	8	7	8	7	4.1	0.7	0.8	0.6
Erosion Threshold	% of Time > bank/matrix mobilisation threshold	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	0%	1%
	% of Time > Bed mobilisation threshold	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%

Table C3: Hydrologic (USIA) flow metric results for the Nepean River - downstream of the Warragamba River

Heritage Reach														
Flow Component	Flow Metrics (ML/day)	Value by Scenario												
		HN00	HN01	HN02	HN03	HN04	HN05	HN06	HN07	HN08	HN13	HN14	HN15	HN16
Flow Dynamics (Non-Zero Flows)	Maximum (ML/day)	27,550	27,515	27,294	27,489	27,469	27,363	27,615	27,344	27,433	27,370	27,430	27,332	27,490
	Minimum (ML/day)	7.99	6.67	8.98	8.55	11.02	39.16	80.57	41.36	80.21	18.10	55.74	17.29	56.96
	Mean (ML/day)	748	743	743	744	748	787	834	789	838	764	811	766	815
	Mean Annual Flow Volume (ML)	273,249	271,216	271,513	271,858	273,166	287,526	304,573	288,178	306,167	278,995	296,214	279,625	297,736
	Median (ML/day)	176	176	178	178	183	222	268	225	273	198	244	200	249
	St.Dev (ML/day)	1,894	1,890	1,886	1,888	1,889	1,889	1,898	1,888	1,898	1,893	1,903	1,890	1,904
Zero Flow	Average 0 Flow Duration (days)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	% Time with Zero Flow	0.05%	0.05%	0.05%	0.05%	0.05%	0.02%	0.01%	0.02%	0.01%	0.04%	0.02%	0.04%	0.02%
Freshes	# of Fresh Events (> 3 x Median Flow)/yr	14.5	12.5	12.5	12.5	12.0	9.0	12.0	10.0	11.0	8.5	11.5	9.0	10.0
	% of Time Over Fresh Event	22.47%	22%	22%	22%	22%	24%	26%	24%	26%	23%	25%	23%	25%
	Average Fresh Duration (days)	2.9	3.5	3.3	3.3	3.2	4.0	2.7	3.5	2.9	4.4	2.8	4.1	3.4
Erosion Threshold	% of Time > bank/matrix mobilisation threshold	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	% of Time > Bed mobilisation threshold	0.71%	0.70%	0.70%	0.70%	0.70%	0.71%	0.72%	0.70%	0.72%	0.71%	0.72%	0.70%	0.72%

Table C4: Hydrologic (USIA) flow metric results for South Creek - Upstream AWRC

Upstream AWRC										
Flow Component	Flow Metrics (ML/day)	Value by Scenario								
		0	1	2	3	4	5	6	7	8
Flow Dynamics (Non-Zero Flows)	Maximum (ML/day)	1,827	3,305	3,012	4,109	3,474	3,012	3,474	3,305	4,109
	Minimum (ML/day)	0.00	0.02	0.21	0.03	0.16	0.20	0.16	0.00	0.02
	Mean (ML/day)	28	82	65	99	73	66	73	82	99
	Mean Annual Flow Volume (ML)	10,112	29,897	23,923	36,233	26,771	23,924	26,771	29,898	36,235
	Median (ML/day)	2	6	7	7	7	7	7	6	7
	St.Dev (ML/day)	112	246	210	297	235	210	235	247	297
Zero Flow	Average 0 Flow Duration (days)	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	1.1
	% Time with Zero Flow	0.33%	0.31%	0.05%	0.29%	0.06%	0.02%	0.07%	0.34%	0.29%
Freshes	# of Fresh Events (> 3 x Median Flow)/yr	23.0	24.0	24.5	24.5	24.0	24.5	24.0	24.0	24.5
	% of Time Over Fresh Event	33.28%	34.90%	32.41%	35.31%	33.04%	32.52%	33.04%	34.68%	35.29%
	Average Fresh Duration (hrs)	127	176	174	175	181	174	181	176	175
Erosion Threshold	% of Time > bank/matrix mobilisation threshold	0.0%	0.4%	0.3%	0.5%	0.3%	0.3%	0.3%	0.4%	0.5%
	% of Time > Bed mobilisation threshold	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	0.1%
Floodplain Engagement Flows	# of Bankfull or Greater Events/year	0.00	0.50	0.50	1.00	0.50	0.50	0.50	0.50	1.00
	% of Time Over Bankfull Event	0.00%	0.26%	0.23%	0.34%	0.25%	0.23%	0.25%	0.26%	0.34%

Table C5: Hydrologic (USIA) flow metric results for South Creek - 2km downstream AWRC

DS AWRC 2KM										
Flow Component	Flow Metrics (ML/day)	Value by Scenario								
		0	1	2	3	4	5	6	7	8
Flow Dynamics (Non-Zero Flows)	Maximum (ML/day)	1,827	3,305	3,012	4,110	3,475	3,129	3,709	3,422	4,344
	Minimum (ML/day)	0.05	0.04	0.24	0.05	0.20	0.25	0.17	0.03	0.01
	Mean (ML/day)	28	82	66	99	73	67	75	83	101
	Mean Annual Flow Volume (ML)	10,113	29,898	23,925	36,235	26,774	24,300	27,525	30,273	36,986
	Median (ML/day)	2	6	7	7	7	7	7	6	7
	St.Dev (ML/day)	112	246	210	297	235	217	249	253	311
Zero Flow	Average 0 Flow Duration (days)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	% Time with Zero Flow	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Freshes	# of Fresh Events (> 3 x Median Flow)/yr	23.5	24.0	24.5	25.0	24.0	24.5	24.0	24.0	25.0
	% of Time Over Fresh Event	33.47%	34.82%	32.53%	35.32%	32.89%	32.55%	32.90%	34.82%	35.33%
	Average Fresh Duration (hrs)	125	177	175	173	182	175	182	177	173
Erosion Threshold	% of Time > bank/matrix mobilisation threshold	0.8%	5.1%	3.6%	6.7%	4.2%	3.7%	4.2%	5.2%	6.8%
	% of Time > Bed mobilisation threshold	0.4%	2.2%	1.4%	3.1%	1.8%	1.4%	1.9%	2.3%	3.1%
Floodplain Engagement Flows	# of Bankfull or Greater Events/year	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	% of Time Over Bankfull Event	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%

Table C6: Hydrologic (USIA) flow metric results for South Creek - Great Western Highway

South Creek at South Western Highway										
Flow Component	Flow Metrics (ML/day)	Value by Scenario								
		0	1	2	3	4	5	6	7	8
Flow Dynamics (Non-Zero Flows)	Maximum (ML/day)	6,597	8,609	8,082	9,651	8,640	8,209	8,896	8,737	9,904
	Minimum (ML/day)	0.08	0.39	0.58	0.54	0.84	0.56	0.85	0.37	0.54
	Mean (ML/day)	69	183	149	224	174	150	176	184	226
	Mean Annual Flow Volume (ML)	25,221	66,810	54,527	81,818	63,474	54,902	64,225	67,186	82,570
	Median (ML/day)	10	17	16	22	22	16	22	17	22
	St.Dev (ML/day)	360	586	523	681	571	530	585	593	694
Zero Flow	Average 0 Flow Duration (days)	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	% Time with Zero Flow	0.01%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Freshes	# of Fresh Events (> 3 x Median Flow)/yr	21.0	26.0	26.0	22.0	24.5	26.0	24.5	26.0	22.0
	% of Time Over Fresh Event	27.92%	34.38%	32.11%	34.62%	31.97%	32.07%	31.97%	34.35%	34.62%
	Average Fresh Duration (hrs)	116	142	134	184	160	134	160	142	184
Erosion Threshold	% of Time > bank/matrix mobilisation threshold	2.6%	11.3%	9.1%	13.3%	10.4%	9.1%	10.5%	11.3%	13.3%
	% of Time > Bed mobilisation threshold	1.1%	6.2%	4.4%	8.1%	5.3%	4.4%	5.4%	6.2%	8.1%
Floodplain Engagement Flows	# of Bankfull or Greater Events/year	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	% of Time Over Bankfull Event	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%

Table C7: Hydrologic (USIA) flow metric results for South Creek - Richmond Road

South Creek at Richmond Road										
Flow Component	Flow Metrics (ML/day)	Value by Scenario								
		0	1	2	3	4	5	6	7	8
Flow Dynamics (Non-Zero Flows)	Maximum (ML/day)	9,925	14,568	13,193	15,962	14,033	13,314	14,283	14,692	16,201
	Minimum (ML/day)	0.01	23.17	25.71	36.27	39.49	25.70	39.51	23.19	36.30
	Mean (ML/day)	195	356	303	414	343	304	345	357	416
	Mean Annual Flow Volume (ML)	71,328	130,109	110,687	151,265	125,430	111,063	126,183	130,486	152,017
	Median (ML/day)	62	91	91	107	107	95	109	97	107
	St.Dev (ML/day)	622	969	843	1,079	907	863	926	995	1,093
Zero Flow	Average 0 Flow Duration (days)	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	1.1
	% Time with Zero Flow	12.33%	4.47%	3.68%	1.84%	1.32%	3.68%	1.32%	4.47%	1.83%
Freshes	# of Fresh Events (> 3 x Median Flow)/yr	41.0	49.5	48.5	52.5	59.5	48.5	59.5	49.5	52.0
	% of Time Over Fresh Event	20.75%	23.34%	21.00%	23.56%	20.78%	21.19%	20.58%	22.42%	23.56%
	Average Fresh Duration (hrs)	44	53	50	56	46	50	46	53	57
Erosion Threshold	% of Time > bank/matrix mobilisation threshold	6.8%	14.0%	11.8%	15.8%	13.1%	11.8%	13.1%	14.0%	15.8%
	% of Time > Bed mobilisation threshold	3.3%	8.3%	6.4%	9.9%	7.4%	6.4%	7.5%	8.3%	9.9%
Floodplain Engagement Flows	# of Bankfull or Greater Events/year	0.50	1.50	0.50	2.50	1.50	0.50	1.50	1.50	2.50
	% of Time Over Bankfull Event	0.48%	0.72%	0.48%	1.05%	0.61%	0.48%	0.63%	0.73%	1.07%

Table C8: Summary of hydrologic metric analysis results and implications for South Creek

Scenario	*Description*	*Possible Catchment Impacts (general)*
SC00	Baseline	• N/A
SC01	Background - 2036 Land use BAU Stormwater No Release	• Catchment is likely to experience a significant increase in flows (mean annual and daily flow is expected to at least double in comparison to baseline flows). • Channel will mobilise bank and bed sediments at a higher rate (3x increase in the percentage of time the bed is likely to experience erosion). • Catchment likely to experience greater peak flows due to increased urbanisation and subsequent increase in impervious surfaces. This reduces the time the water remains in the soil before it enters the channel. • Bank erosion due to catchments dispersive soils may result in channel widening (dispersive soils occur within the South Creek catchment but the presence in these reaches has not been verified).
SC02	Background - 2036 Land use Parkland Stormwater No Release	• Parkland stormwater management leads to reduction in mean annual and daily flows (in comparison to BAU stormwater management in scenario 1). This is likely due to the increased infiltration, transpiration and water recycling expected to occur because of the parkland stormwater management. • The application of parkland stormwater management is likely to reduce the peak flows expected in scenario 1 as a result of urbanisation by slowing the rate of runoff into the channel. This also leads to a significant reduction in the percentage of time erosion is likely to occur (in comparison to BAU stormwater management in scenario 1).
SC03	Background - 2056 Land use BAU Stormwater No Release	• Mean annual release expected to increase by >15% from scenario 1 (2036 land use) suggesting that the largest increase in urbanisation is expected to occur prior to 2036, with slower growth experienced between 2036-2056. • The significant increase in standard deviation for this scenario indicates that this scenario is likely to yield the second most variable flows, with periods of extreme low and high flow. This is indicative of a catchment that experiences large and 'flashier'

Scenario	Description	Possible Catchment Impacts (general)
		peak flows, due to the speed at which runoff enters the water way.
SC04	Background - 2056 Land use Parkland Stormwater No Release	• The impact of parkland stormwater management is sufficient to negate much of the increase in mean annual release expected due to the increasing urbanisation between 2036 and 2056 which would otherwise occur under a BAU approach to stormwater management. • The mean annual volume of release expected under this scenario remains lower than the 2036 estimation modelled under a BAU stormwater management approach, highlighting the ability for parkland stormwater management to utilise, retain and recycle significant volumes of water.
SC05	Impact - Background - 2036 Land use Parkland Stormwater Wet only release	• The addition of wet weather only release results in <5% increase to mean annual release. • The utilisation of parkland stormwater management leads to greater retention of water in the system, reducing peak flows in the catchment. • This scenario is most comparable with scenario 2 (2036 land use and parkland stormwater management), and excluding baseline conditions, experiences the second lowest mean annual release of any of the scenarios.
SC06	Impact - 2056 Land use Parkland Stormwater Wet only release	• The impact of urbanisation between the 2036 and 2056 land use results in <10% increase in mean annual release. • This will correlate to a less than 1% increase in the time that erosion occurs within the channel (in comparison to scenario 5 under a 2036 land use scenario). • The use of parkland stormwater management not only allows the reduction of peak flows, but also reduces the impact of releases during wet events, allowing the channel to potentially increase releases without triggering significant erosional thresholds.
SC07	Impact - 2036 Land use BAU Stormwater Wet only release	• This scenario is comparable with scenario 1 (2036 land use and BAU stormwater management) with the exception that this scenario also includes wet only releases. • The wet only releases, however, only add an additional 5% to mean annual release. This alone is not sufficient to alter the catchment beyond the extent that scenario 1 has already deviated from baseline conditions.
SC08	Impact - 2056 Land Use BAU Stormwater Wet only release	• This scenario yields the highest mean annual release as it is modelled based off the 3 variables likely to result in the largest flows. The combination of an urbanised catchment, BAU stormwater scenario, and addition of wet only releases is sufficient to increase all hydrologic metrics, and subsequently, the erosional capacity of the channel. This scenario is likely to yield the poorest catchment health, both geomorphically and hydrologically. • Of these three variables, it is the BAU stormwater management that reduces the capacity of the catchment to absorb the land use and hydrologic changes from the additional flows. Changing this one variable would reduce the mean annual flows by 21%.

Appendix D - WaterNSW Infrastructure Assessment

Upper South Creek Advanced Recycling Centre

WaterNSW Assets - Impact and Risk Assessment from treated water releases

Report for Sydney Water

August 2021

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contents

Glossary

Term	Definition
Advanced Water Recycling Centre (AWRC)	Proposed centre for treatment of the wastewater prior to reuse applications or discharge, which includes liquids treatment, advanced water treatment, solids treatment, odour treatment, and residuals management.
Annual Exceedance Probability (AEP)	The change of a flood of a given or larger size occurring in any one year, usually expressed as a percentage. For example, if a peak flood discharge of $500m^3/s$ has an AEP of 5% it means there is a 5% chance (that is one-in-20 chance) of a $500m^3/s$ or larger event occurring in any one year.
Australian Height Datum (AHD)	A common national surface level datum approximately corresponding to mean sea level.
Average Recurrence Interval (ARI)	The long-term average number of years between the occurrence of a flood as big as or larger than, the selected event. ARI is another way of expressing the likelihood of occurrence of a flood event.
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 Flows	Environmental flows refer to water released from a dam or weir to sustain healthy rivers. Some of the Sydney Water wastewater treatment and water recycling facilities also release treated wastewater into creeks and rivers. This can help improve conditions for native fish, frogs, birds, plants and other animals. It can also reduce the likelihood of algal blooms and enhance recreational uses. Environmental Flows from the AWRC may be used, supplement or replace flows that would have been released from Warragamba Dam.
Probable Maximum Flood (PMF)	The probable maximum flood is the maximum flood which can theoretically occur based on the worst combination of the probable maximum precipitation and flood-producing catchment conditions that are reasonably possible at a given location.
Urban Streamflow Impact Assessment (USIA)	The Urban Streamflow Impact Assessment framework explicitly links the severity of impacts to waterway values (social, ecological and geomorphic) with development scenarios and their streamflow regimes, through the use of hydrologic and hydraulic metrics.

1. Introduction

1.1. Project Description

Sydney Water is planning to build and operate new wastewater infrastructure to service the South West and Western Sydney Aerotropolis Growth Areas. The proposed development will include a wastewater treatment plant in Western Sydney, known as the Upper South Creek Advanced Water Recycling Centre. Together, this Water Recycling Centre and the associated treated water and brine pipelines, will be known as the 'project'. The main components of the project are described Table 1.

Table 1 Upper South Creek Advanced Water Recycling Centre Project Components

Component	Description
Advanced Water Recycling Centre	A wastewater treatment plant with the capacity to treat up to 50 ML of wastewater per day, with ultimate capacity of up to 100ML per day.
Treated water pipelines	A pipeline about 17 km long from the Advanced Water Recycling Centre to the Nepean River at Wallacia Weir, for the release of treated water.
	Infrastructure from the Advanced Water Recycling Centre to South Creek to release excess treated water and wet weather flows.
	A pipeline about five kilometres long from the main treated water pipeline at Wallacia to a location between the Warragamba Dam and Warragamba Weir, to release high-quality treated water to the Warragamba River as environmental flows.
Brine pipeline	A pipeline about 24 km long that transfers brine from the Advanced Water Recycling Centre to Lansdowne, in south-west Sydney, where it connects to Sydney Water's existing Malabar wastewater network

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

- building and operating the Advanced Water Recycling Centre to treat an average dry weather flow of up to 50ML per day
- building all pipelines to their ultimate capacity, but only operating them to transport and release volumes produced by the Stage 1 Advanced Water Recycling Centre

The timing and scale of 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.

1.2. Scope of work

The purpose of this study is to provide an independent assessment of risks to the integrity and security of WaterNSW lands, assets and infrastructure that may result from the project, and the proposed measures to mitigate against those risks, including consideration of:

- The effect the development will have on Warragamba Pipeline footings, through potential changed flow regimes and increased flood impacts, and
- Potential direct or indirect increases of erosion or sediment deposition in the pipeline corridors and at the treated water discharge points.

Impacts associated with drilling activities for the environmental flow pipeline and impacts to the Upper Canal from the Brine Pipeline installation (including groundwater) are assessed in other reports. This report only covers surface water impacts associated with treated water releases to waterways.

1.3. Project Approach

To understand whether there are likely to be any flow or sediment related impacts on WaterNSW infrastructure it is necessary to answer the following questions:

How will the proposed flow releases change the flow regime of each waterway compared to current conditions?

Is the change(s) sufficient to cause erosion, sedimentation or undermining of any of the assets?

Our approach to addressing these questions has been based on the following:

1. Define the current condition of the assets identified and the geomorphic and flow condition of the associated waterways:
    - **Data collation and review**, including relevant previous studies and field visits, historic aerial imagery (since 2004), available literature (including South Creek Flood Study, Nepean Regional Flood Study), design drawings (provided by WaterNSW).
    - **Collection of new aerial drone photography for each of the structures**. The drone imagery was collected on the 05/02/2021 by AUAV. This work was completed to supplement earlier fieldwork by Dr Geoff Vietz (22/10/2019) while allowing for restrictions related to COVID-19. 360-degree panoramas have been produced for each structure and can be viewed here: https://pano.auav.com.au/Streamology/2021_02_05_WarragambaPanos/ . The drone imagery was used to assist the assessment of current conditions at each site, especially through the oblique imagery of the structures themselves.
    - **Geomorphic analysis** to define the current geomorphic conditions at each site and identify any existing erosion/deposition risks to the assets.
    - **Flow regime analysis** to define the current flow regime (flow duration and flooding). This was based on the existing work for the Ecohydraulic and Geomorphic Impact Assessment and Flooding Impact Assessment reporting completed as part of the EIS with data extracted for locations relevant to each structure. Additional flood information was included from the following studies:
        - South Creek Flood Study (Worley Parsons, 2015),
        - South Creek Floodplain Risk Management Study and Plan (draft for exhibition Advisian, 2019)
        - Hawkesbury Nepean Valley Regional Flood Study (WMA Water, 2019)
        - Nepean River Flood Study (Advisian, 2018)
2. Compare the current geomorphic and flow conditions of the waterways to those with the AWRC project and quantify the magnitude of potential risks to the assets.
    - **Assessment of risks related to flooding, erosion and scour** at each location and implications for the integrity of the various structures.

This included the impacts of flooding and changes in flood conditions as well as more frequent flow conditions. Existing hydraulic models developed as part of the EIS were utilised for this assessment, as well information extracted from the various flood studies noted above. A new 2D model of South Creek at the Warragamba Pipeline crossing location was also developed to assist with the assessment.

1.4. **Report Structure**

The remainder of this report is structured as follows.

- Section 2 details each of the WaterNSW assets being assessed and their current conditions from a geomorphic and flow perspective.
- Section 3 presents the assessment of potential impacts associated with the Project.
- Section 4 presents the risk assessment for each asset, and
- Section 5 provides a summary of the assessment outcomes.

Current Conditions

2. Current Conditions of WaterNSW Assets

2.1. Overview

Sydney Water has identified the following assessment sites to be considered within this scope of work:

- Nepean River:
  - Wallacia Weir
  - Warragamba Pipeline Crossing. The pipeline is underground about 170 m downstream of Wallacia Weir
  - Penrith Weir
- Warragamba River:
  - Warragamba Weir. Located about 550 m downstream of environmental flow release location.
- South Creek
  - Warragamba pipeline

Figure 1 shows the location of each of the assets being assessed and the relevant waterway being considered, along with the location of the proposed releases from the AWRC.

In this section details of the current condition of the assets are provided in terms of:

- The structure details,
- The geomorphic condition of the waterway on which the asset it located, and
- The flow regime for the waterway considering both the flow regime and flooding.

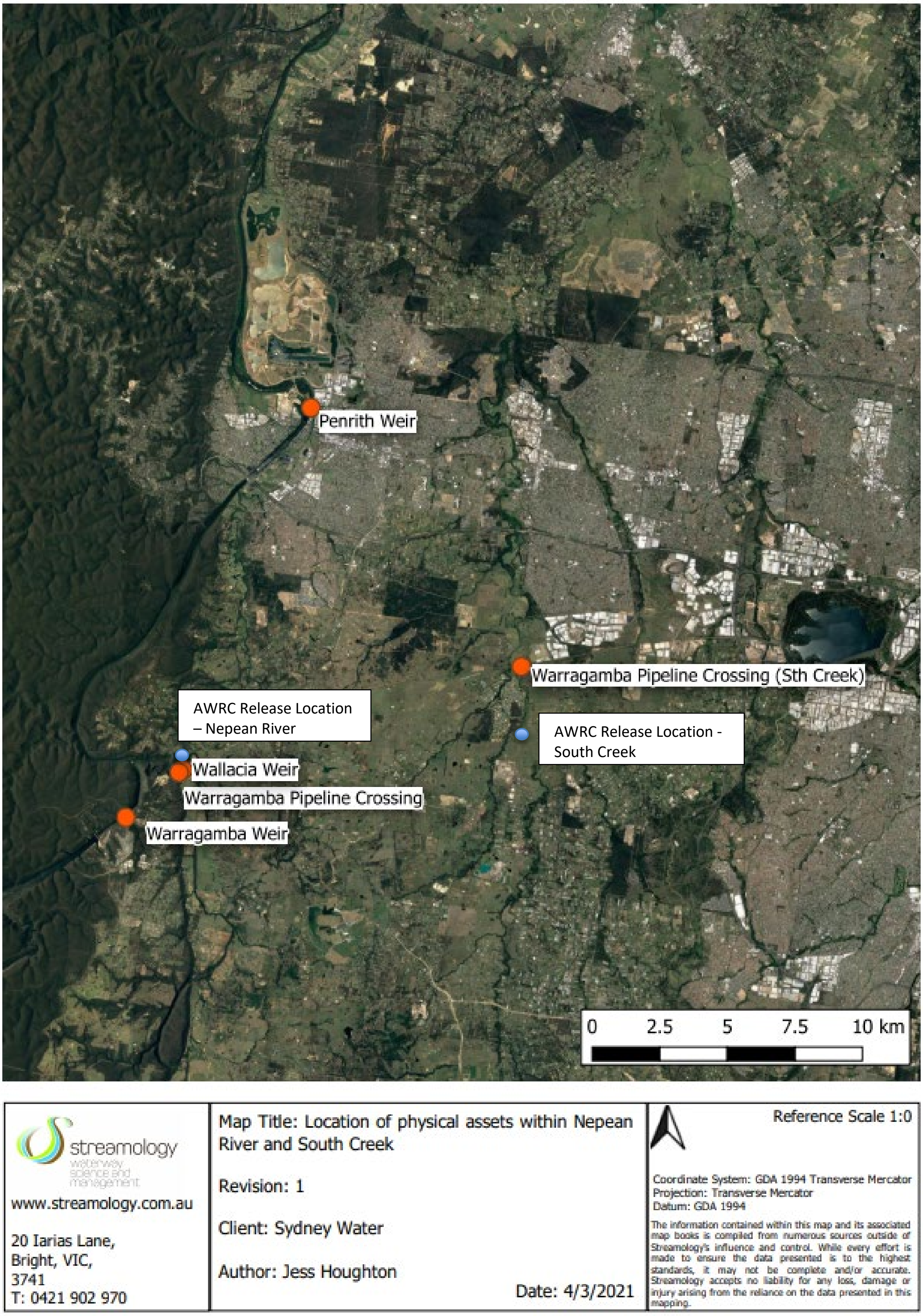


Figure 1 Location of WaterNSW assets including in this assessment within the Nepean River and South Creek

2.2. **Wallacia Weir - Nepean River**

2.2.1. **Asset Details**

Wallacia Weir is located around 2 km downstream of the township of Wallacia on the Nepean River. A timber weir was first constructed at this site in the 1800s to support a flour mill and brewery (http://www.historicalencounters.org/he/wallacia/) while the present concrete structure dates from around 1912. No details on the design or construction of the structure could be accessed.

A new fishway structure was constructed on the northern bank in 2010. Construction drawings for this work indicate it was embedded into rock material. The drawing also notes that the weir crest is at 26.7 m AHD, while the base is at 21.85 m AHD, giving a height of 4.85 m (Drawing 3001436-1708_C).

The weir is located approximately 100 m downstream of the proposed release location.

Figure 2 Wallacia weir in the 1920s (Penrith Library online)

Figure 3 Aerial image of Wallacia Weir - Nepean River (05/02/2021)

2.2.2. Geomorphic Condition

This section of the Nepean River was not defined in DPI (2014), however the section downstream of the weir structure is within a confined gorge and is bedrock controlled, with the bed material composed of cobbles and boulders.

Upstream of the weir, the river enters a more alluvial reach, as defined by Erskine (1997). A summary of the geomorphic character of this reach is provided Table 2. Sand and gravel mining has resulted in widening of the river upstream of the weir.

Figure 4 was provided by Sydney Water and shows sand on the banks of the river adjacent to the weir. The date of the image is unknown. A further image captured following the flood event in March 2021 shows deposition of sand on a point bar upstream of the weir, Figure 5.

Figure 4 Photo taken of sand deposit on the bank adjacent to Wallacia Weir (image provided by Sydney Water)

Figure 5 Aerial image of point bar upstream of Wallacia Weir with sand deposits following March 2021 flooding

Table 2 Geomorphic Character of Nepean River upstream reaches (DPI, 2014; Erskine, 1997; River Styles online, DPIE)

River	Reach	Reach desc	Character	Physical Condition
Nepean	Na	Upstream of Warragamba confluence to Wallacia Weir	• Bedrock controlled • Likely gravel, cobble and boulder bed • Moderate to high sinuosity	• likely to be good condition with significant bedrock controls • River styles notes the reach to be in good conditions and have low sensitivity to change
	Na	Wallacia Weir to Bents Basin	• Alluvial • Likely sand and gravel, with cobbles in some locations	• highly degraded condition due to sand and gravel extraction and channel modifications • River styles notes the reach to be in moderate condition and moderately sensitive to change.

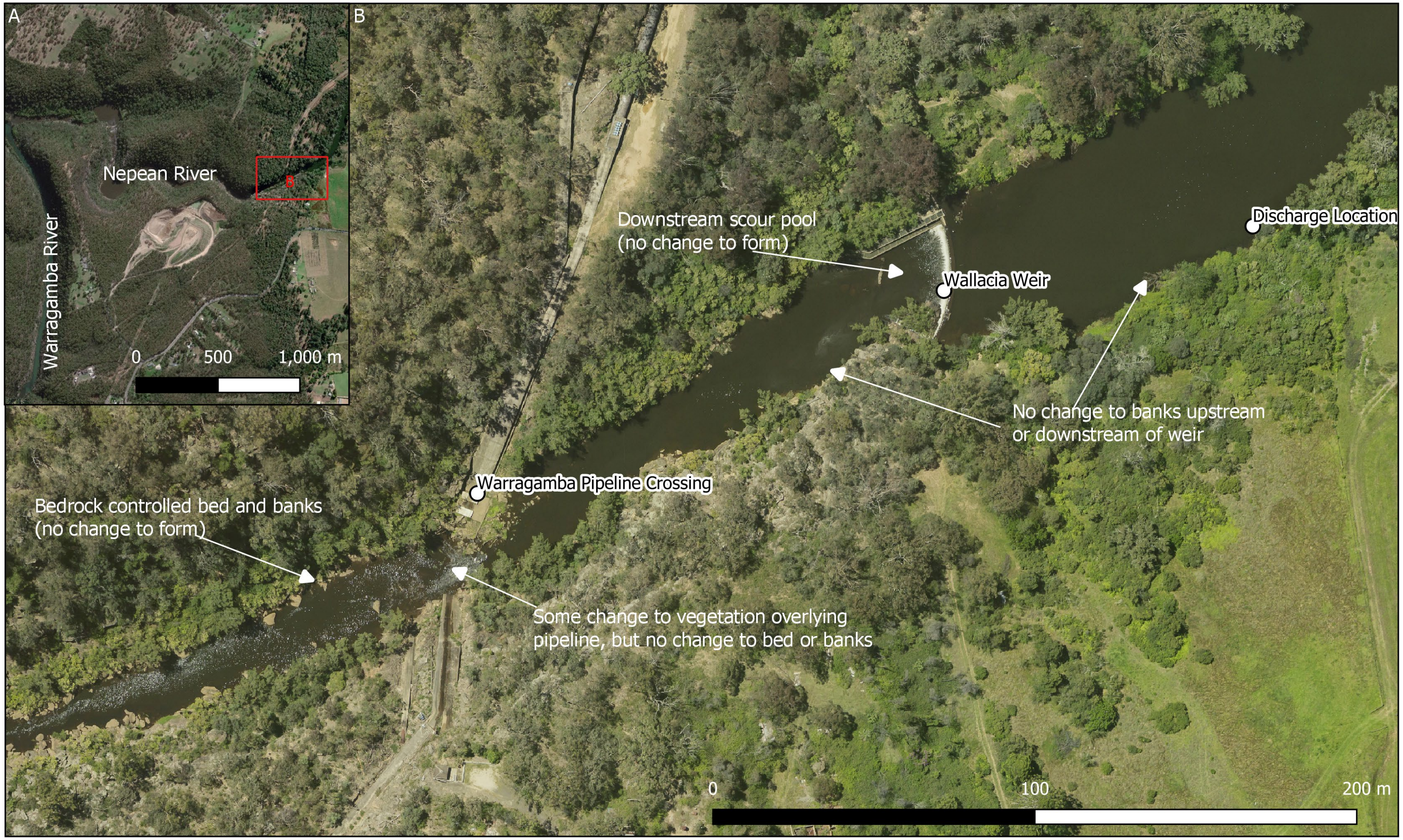
Aerial Imagery Analysis

A series of aerial images were examined to assess the current geomorphic condition of the Nepean River at and surrounding the Wallacia Weir and whether any observable change has occurred (e.g., erosion and deposition) over the period 2005-2020. The Warragamba Pipeline downstream of the weir is also included due to the proximity of the sites.

High-resolution imagery from 2005, 2007, 2011, 2014, 2018, and 2020 was reviewed. An annotated map using imagery from 6/12/2020 (selected for low flows and clear visibility of bedforms and banks) is provided in Figure 7. The analysis indicates that the channel 500 m upstream and downstream of both the weir and the pipeline is highly stable and has not undergone any visible geomorphic change since 2005. Additional review of available Google imagery (1985 to present) did not identify any further changes. Historic imagery from 1947 (NSW Historical Imagery View, NSW Spatial Services) showed the disturbance to the river in the construction period for the Warragamba Pipeline. A slightly later 1955 image (Figure 6) shows little difference to current conditions.

Some minor variation in the coverage of in-channel and riparian vegetation is apparent from year to year. This is particularly evident for images from February and March 2020 when much of the vegetation covering the Warragamba Pipeline where it crosses the river, was removed during around a 10% AEP event (1 in 10-year ARI) on the 13 and 14th February 2020.

Figure 6 Historic imagery of Nepean River at Wallacia Weir and Warragamba Pipeline Crossing (dated 1955)



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Map Title: Wallacia Weir and Warragamba Pipeline Crossing Desktop Geomorphic Assessment
Revision: RevA
Client: Sydney Water
Imagery Date (map B): 6/12/2020
Author: Thom Gower

Publication Date: 12th Jan 2021

Coordinate System: GDA 1994 Transverse Mercator
Projection: Transverse Mercator
Datum: GDA 1994

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Figure 7. Annotated map of Wallacia Weir and Warragamba Pipeline Crossing, Nepean River. Aerial imagery (map B) sourced from Metromap.com.au.

2.2.3. Flow Regime

Flow Duration

There is a stream flow gauge located at Wallacia Weir on the Nepean River (212202).

Table 3 Stream flow gauging at Wallacia Weir

Gauge Number	Location	Waterway	Monitoring Start Date
212202	Nepean River at Wallacia Weir	Nepean River	1/01/1976

In June 2010, additional dam releases on the Nepean River system were mandated to supplement environmental flow requirements. Prior to this, flows in the Nepean were substantially lower, with a median flow of only approximately 10 ML/day - in comparison to 229 ML/day after June 2010.

The flow duration curve in Figure 8 is based on the gauge data from 2010 to 2021 and shows summer flows are typically lower than other periods. Higher flows (<20% exceedance) are more frequent during Autumn and Winter.

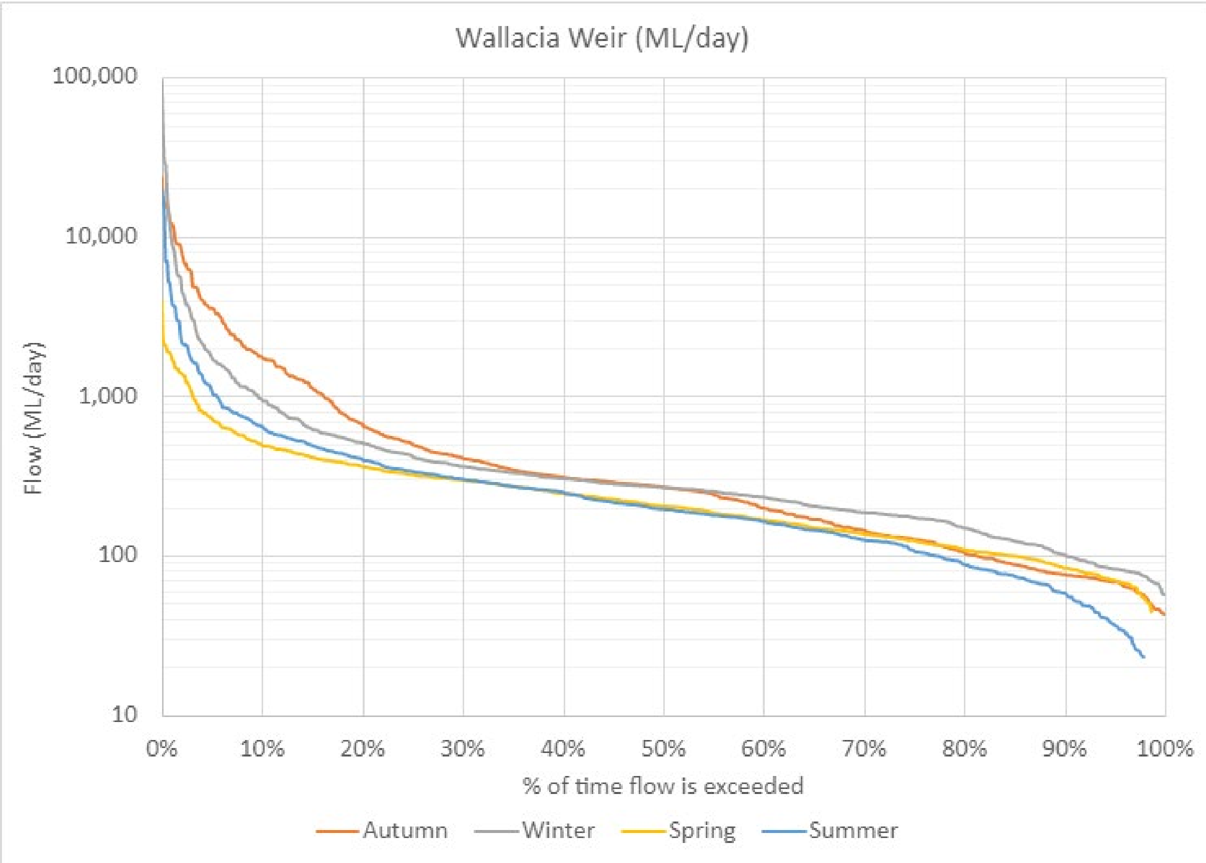


Figure 8 Flow duration curve for the Nepean River at Wallacia Weir (2010 to 2021)

Flooding

The Hawkesbury Nepean Valley Regional Flood Study (WMA Water, 2019) investigated flood levels at Wallacia (upstream of the weir) and found that the flood levels in this area vary significantly due to the constrictive effects of the Fairlight Gorge, starting immediately downstream of the Wallacia Weir site. For flood events up to a 10% AEP event, the flood extent remains restricted to low lying overbank areas. For larger events, the flood extents and depths increase significantly, Figure 10.

Flooding is also complicated at Wallacia due to the joint probability of flooding from the Nepean and Warragamba Rivers (WMA Water, 2019). Peak flood levels in the 2019 study at Wallacia Weir range from around 35m AHD for the 20% AEP event (1 in 5-year ARI) to 45 m AHD for the 1% AEP event (1 in 100-year ARI). Even a small flood in the Warragamba River can have an impact on flood levels at Wallacia.

Figure 9 shows an image of Wallacia Weir during the March 2021 flood event which affected the Nepean River and Warragamba River.

Figure 9 Aerial image of Wallacia Weir during March 2021 flood event (image captured on 26/3/2021)

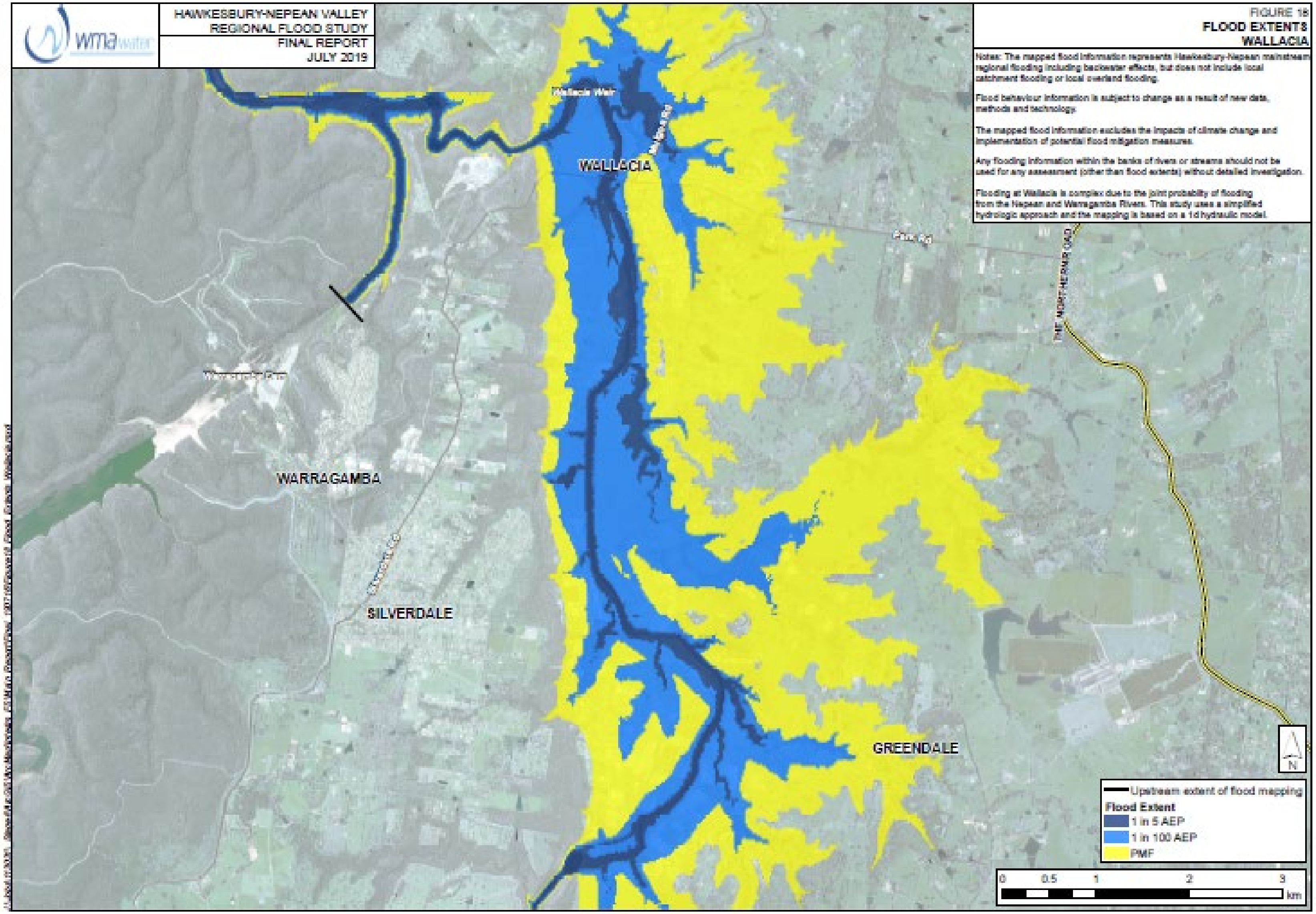


Figure 10 Flood extents at Wallacia and downstream of Warragamba Weir (WMA Water, 2019); Note that 1 in 5 AEP is 20% AEP, and a 1 in 100 AEP is a 1% AEP

2.3. **Warragamba Pipeline - Nepean River**

2.3.1. **Asset Details**

The Warragamba Pipeline crossing of the Nepean River is located approximately 160m downstream of the Wallacia Weir. At this location, the pipeline (consisting of two separate pipes within a concrete casing) has been trenched into the rock and covered with a concrete capping layer. Available drawings (Drawing No. 337 40-1) indicate that the surface of the concrete layer may be partly exposed to the flow over a short section in the centre of the channel, but the extent of the structure exposed to flows and the current condition of the concrete layer is unknown.

Figure 11 Aerial imagery captured image of Warragamba Pipeline Crossing – Nepean River (05/02/21)

FIGURE REDACTED FOR PUBLIC EXHIBITION DUE TO SENSITIVITY OF IMAGE

Figure 12 Extraction from Drawing 40-1-801 showing a cross-section of the Warragamba Pipeline adjacent to the Nepean River

2.3.2. Geomorphic Condition

This section of the Nepean River was not defined in DPI (2014); however, the pipeline section is within a confined gorge and is bedrock controlled, with the bed material composed of cobbles and boulders. The geomorphic character is summarised in Table 4.

Table 4 Geomorphic Character of Nepean River at pipeline location (based on DPI, 2014)

River	Reach	Reach desc	Character	Physical Condition
Nepean	Na	Upstream of Warragamba confluence	• Bedrock controlled • Likely gravel, cobble, and boulder bed • Moderate to high sinuosity	• likely to be good condition with significant bedrock controls • River styles notes the reach to be in good conditions and have low sensitivity to change

Aerial Imagery Analysis

As the pipeline is near the Wallacia Weir site, the analysis of aerial imagery to assess geomorphic change covered both sites and is shown in Figure 7. Essentially there has been no noticeable geomorphic change at the site in the last 20 years, however the riverbed condition at the pipeline crossing cannot be directly assessed.

2.3.3. Flow Regime

The flow regime and flood conditions for this location is essentially the same as that at the Wallacia Weir immediately upstream. At lower flows, the water level at the pipeline is controlled by the weir until the weir is drowned out. The flow is then controlled by the gorge section itself and the interaction of flows from both the Nepean and Warragamba Rivers. Flood mapping relevant to this site was presented in Figure 10.

An aerial image of the site taken during the flood event in March 2021 is presented in Figure 13. Unfortunately, an image of the site after the flood event is not available.

2.3.3. **Flow Regime**

The flow regime and flood conditions for this location is essentially the same as that at the Wallacia Weir immediately upstream. At lower flows, the water level at the pipeline is controlled by the weir until the weir is drowned out. The flow is then controlled by the gorge section itself and the interaction of flows from both the Nepean and Warragamba Rivers. Flood mapping relevant to this site was presented in Figure 10.

An aerial image of the site taken during the flood event in March 2021 is presented in Figure 13. Unfortunately, an image of the site after the flood event is not available.

Figure 13 Aerial image of the Warragamba pipeline crossing during the flood event in March 2021

2.4. **Penrith Weir - Nepean River**

2.4.1. **Asset Details**

The Penrith Weir was built in 1908, raising the water surface level by around 1.5 m above typical conditions and creating a weir pool on the Penrith River extending for around 18 km upstream. The structure has undergone various repair works since construction following damage due to flood events. However, since repair works were completed in 1970 the weir has not sustained significant damage

The main weir comprises a concrete buttressed cantilever wall with a clay puddle blanket added later upstream of the weir and covered with a concrete slab. It is founded on granite boulders in sandy clay at the right abutment and in sand on the left abutment (DPWS, 1999)

Figure 14 shows the weir from downstream looking upstream in the 1930s, while Figure 15 is an aerial image taken in February 2021.

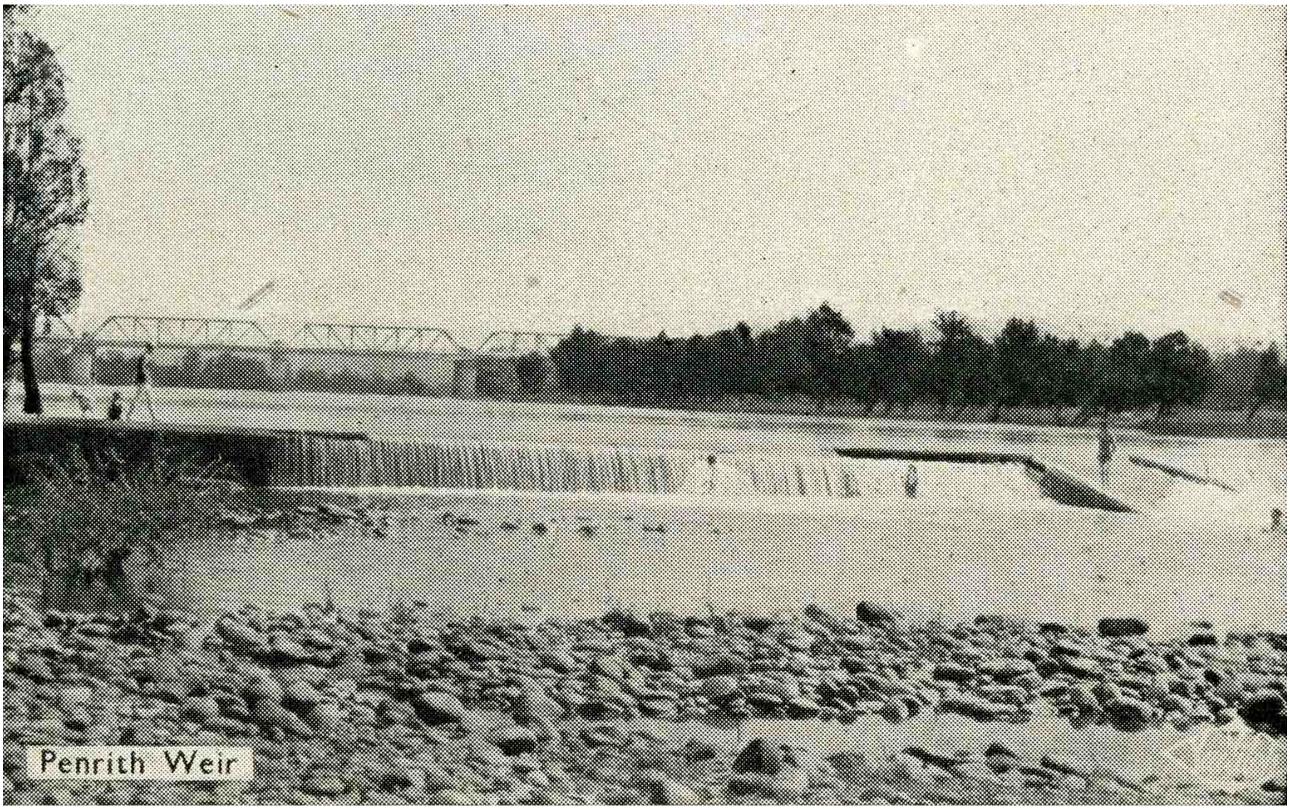


Figure 14 Penrith weir in the 1930s (Penrith Library online)

Figure 15 Aerial image of Penrith Weir – Nepean River (captured 05/02/21).

2.4.2. Geomorphic Condition

Upstream of Penrith Weir, this section of the Nepean River till the confluence with the Warragamba River is bedrock controlled with bed material likely composed of gravel and cobbles (DPI, 2014). A summary of the geomorphic character of this reach is provided in Table 5.

There has been substantial extraction of sand and gravel in this reach (Erskine, 1997). Turner & Erskine (1997) reviewed the bathymetry of the weir pool upstream of the Penrith Weir by comparing thalweg surveys in 1911, 1982 and 1996. They found only minor change had occurred since 1982, with some aggregation opposite Glenbrook Creek and slight degradation upstream of it.

Downstream of Penrith Weir is defined as a separate reach in DPI (2014) and has also been subject to significant sand and gravel extraction of both the river and floodplain in the past. This has led to enlargement and deepening of the channel. The riverbed is gravel and cobble, with sections of armoured riffles.

Table 5 Geomorphic character of the Nepean River, Reach 20-22 (DPI, 2014; River Styles online, DPIE 2021)

River	Reach	Reach desc	Character	Physical Condition
Nepean	20 & 21	Downstream Warragamba confluence to Penrith Weir	• bedrock controlled • likely gravel, cobble, and boulder bed • low to moderate sinuosity	• degraded condition due to gravel extraction • channel modifications with bed and bank structures. • The River Styles description is a weir pool, with bed rock or cohesive terrace. No condition rating is provided but it is noted to have low sensitivity to change.
	22	Penrith Weir to Grose River confluence	• Alluvial • Likely gravel and cobble bed • Low to moderate sinuosity	• highly degraded condition due to gravel extraction and channel modifications with bed and bank structures. • River Styles notes it to be in moderate condition with moderate sensitivity to change.

Aerial Imagery Comparison

A series of aerial images were examined to assess the current geomorphic condition of the Nepean River at and surrounding the Penrith Weir and whether any observable change has occurred (e.g., erosion and deposition) over the time for which imagery is available (2000-2020).

Additional historic imagery from 1943 was also used to provide an indication of long-term changes. An annotated map using imagery from 16/01/2014 (selected for low flows and clear visibility of bedforms and banks) is provided in Figure 16.

Analysis of the imagery indicates that between 1943 and 2000 the planform of the river changed, with left bank erosion leading to a wider channel upstream of the weir, and changes to instream bars downstream of the weir. However, in the last 20 years, the imagery indicates that channel 500 m upstream and downstream of the weir has been largely stable, with minimal geomorphic change. It is likely that substantial channel modifications, including construction of erosion protection and levees has limited erosion or deposition from occurring. Downstream or the weir there have been ongoing changes to mobile instream bars and islands, including stripping and regrowth of vegetation, and some movement of bars.

Figure 16. Annotated map of Penrith Weir, Nepean River. Aerial imagery (map B) sourced from Metromap.com.au.

2.4.3. Flow Regime

Flow Duration

There is a stream flow gauge located at Penrith on the Nepean River (212201). The gauge is located adjacent to the fish ladder on the weir structure.

Table 6 Stream flow gauging at Wallacia Weir

Gauge Number	Location	Waterway	Monitoring Start Date
212201	Nepean River at Penrith Weir	Nepean River	12/12/1968

The flow data records no cease to flow periods, Figure 17. The Nepean River has a minimum flow is approximately 50 ML/d (0.6 m^3/s), with summer flows typically lower than other periods. Higher flows (<20% exceedance) are more frequent during Autumn and Winter. The median flow at Penrith Weir is 275 ML/d (based on the 2010 to 2021 period).

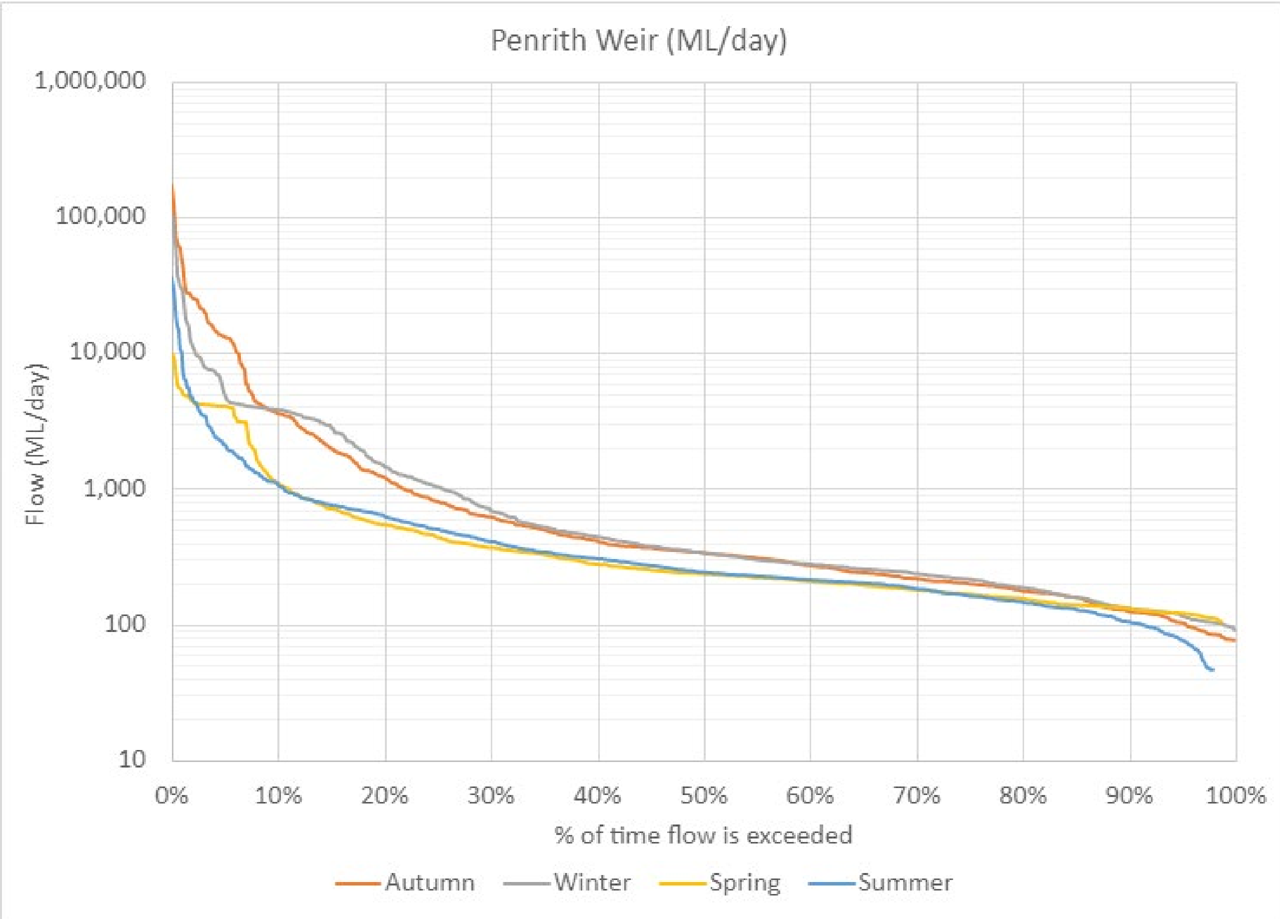


Figure 17 Flow duration curve on the Nepean River at Penrith Weir (2010 to 2021)

Flooding

Flood modelling of the Nepean River at Penrith was completed by Advisian (2018). Flood mapping was produced for a range of flood events from the 20% AEP (1 in 5-year ARI) flood. The results showed that the Victoria Bridge located approximately 550 m upstream of the weir is a significant hydraulic control and that the weir structure is completely drowned and outflanked with flows leaving the channel along the western bank immediately downstream of Victoria Bridge by the 20% AEP flood event. Upstream of the bridge the river remains largely confined to the main channel for flows up to around the 2% AEP event (Advisian, 2018; WMA Water, 2019).

Flood levels, depths and velocities were reported at the Victoria Bridge and at the mouth of Boundary Creek (immediately downstream of the weir), Table 7. The flood surface level for the 5% AEP event is shown in Figure 18 (from Advisian, 2018), while the 2% AEP, 1% AEP and PMF floods are mapped in Figure 19 (WMA Water, 2019). While similar, the methodology used in each of these studies does differ slightly which has resulted in differences in the peak flood magnitude, levels and extents for different flood events. Table 8 details a comparison of the flood magnitudes at different AEPs for each study.

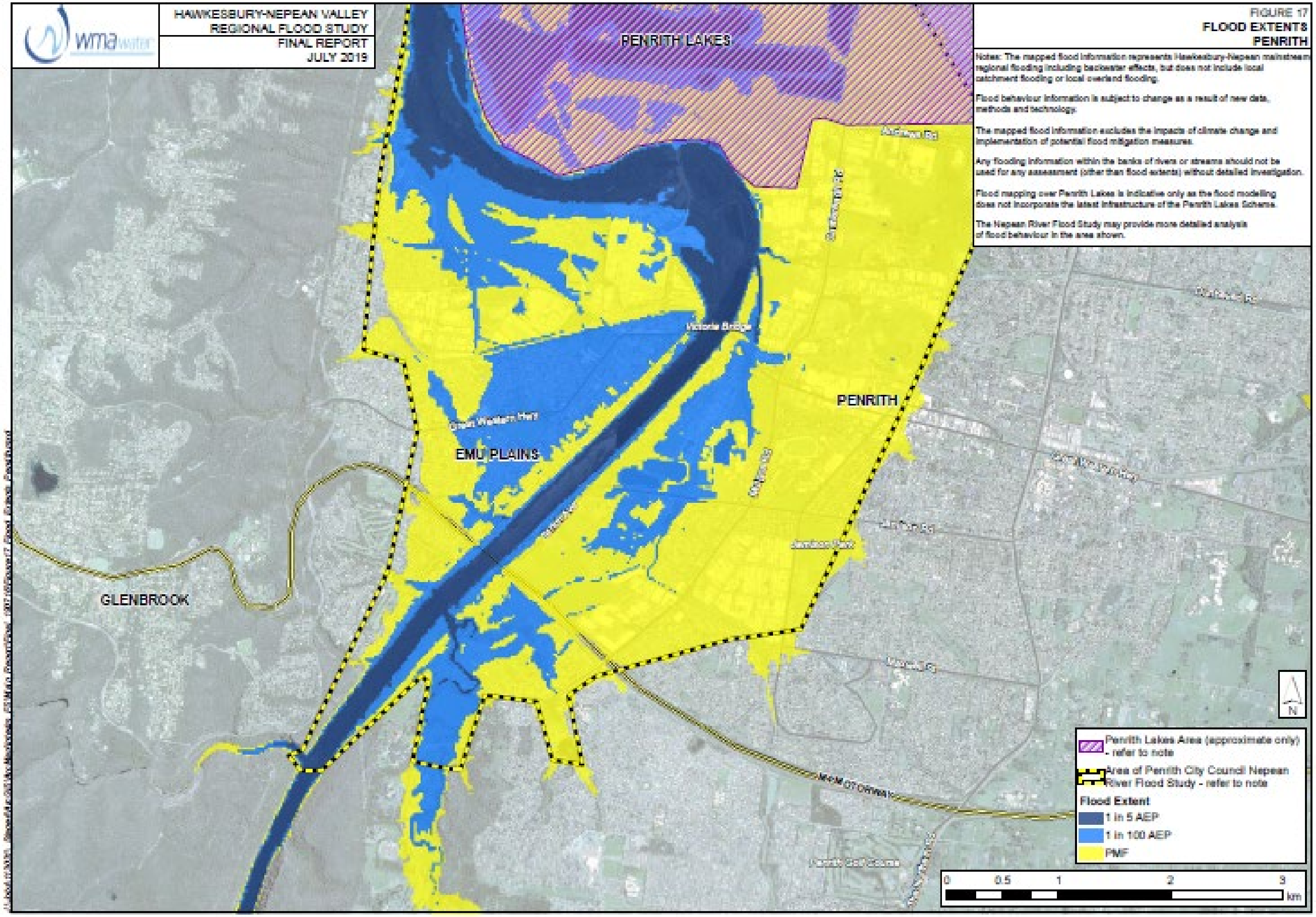
Table 7 Peak flood levels (m AHD), depths (m) and velocities (m/s) (Advisian, 2018)

Location	5% AEP	2% AEP	1% AEP
Victoria Bridge	w 23.36 d 10.32 v 3.55	w 24.97 d 11.93 v 3.86	w 26.3 d 13.25 v 4.13
Boundary Creek (mouth)	w 22.78 d 9.56 v 2.32	w 24.38 d 11.16 v 2.37	w 25.63 d 12.41 v 2.58

Table 8 Peak flood magnitude (m^3/s) at Penrith

Location	5% AEP	2% AEP	1% AEP
Advisian (2018)	8,573	11,015	13,478
WMA Water (2019)	8,500	12,400	15,600

Figure 18 Water surface level for the 5% AEP flood event (Advisian, 2019)



wmawater
HAWKESBURY-NEPEAN VALLEY
REGIONAL FLOOD STUDY
FINAL REPORT
JULY 2019
FIGURE 17
FLOOD EXTENTS
PENRITH
Notes: The mapped flood information represents Hawkesbury-Nepean mainstream regional flooding including backwater effects, but does not include local catchment flooding or local overland flooding.
Flood behaviour information is subject to change as a result of new data, methods and technology.
The mapped flood information excludes the impacts of climate change and implementation of potential flood mitigation measures.
Any flooding information within the banks of rivers or streams should not be used for any assessment (other than flood extents) without detailed investigation.
Flood mapping over Penrith Lakes is indicative only as the flood modelling does not incorporate the latest infrastructure of the Penrith Lakes Scheme.
The Nepean River Flood Study may provide more detailed analysis of flood behaviour in the area shown.
PENRITH LAKES
Victoria Bridge
PENRITH
Great Western Hwy
EMU PLAINS
GLENBROOK
Jamison Park
Penrith Lakes Area (approximate only) - refer to note
Area of Penrith City Council Nepean River Flood Study - refer to note
Flood Extent
1 in 5 AEP
1 in 100 AEP
PMF
N
0
0.5
1
2
3
km

Figure 19 Flood extent mapping in and around Penrith (WMA Water, 2019)

2.5. **Warragamba Pipeline - South Creek**

2.5.1. **Asset Details**

On South Creek the Warragamba Pipeline crosses the waterway approximately 5.3 km downstream of the proposed release location at the AWRC project site. As shown in Figure 20, the two pipelines are located either side of an access road bridge. Each pipeline and the road bridge are support by a pier(s) with at least one pier on each structure located within South Creek.

Limited information is available on the embedment depth of the piers for either pipeline. Drawing 462 40-1 from 1947 shows a total pier depth below the ground surface of approximately 4 m, noting that the minimum embedment of the pier into hard shale should be approx. 0.45 m. The total height from the base of the pier to the pipe centreline is shown as around 11.7 m.

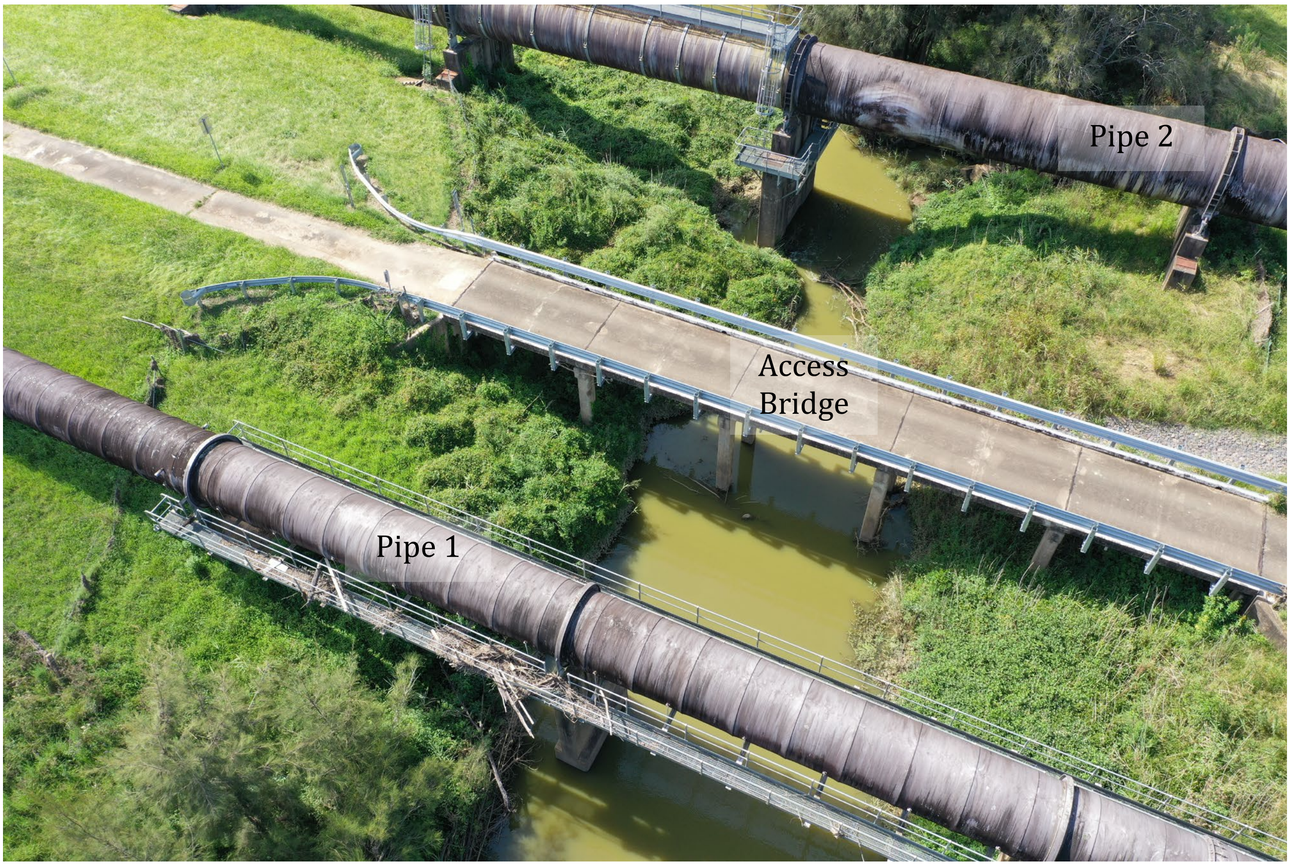


Figure 20 Aerial image captured of Warragamba Pipeline Crossing - South Creek (05/02/21)

Pipe 1 and 2 appear to have different pier designs however information was only available for one of the structures.

The grading sheet for Pipe 1 (dated 13/12/56) indicates three piers located within the South Creek cross-section, with two either side of the main flow area and the third partway up the east bank. From recent imagery, Figure 21, it appears that Pier 1 is now within the main creek flow area, while Piers 2 and 3 are in similar locations relative to the cross-sectional profile to the original drawing.

Figure 21 Pipe 1 with pier locations indicated (image capture 05/02/2021)

The grading sheet for Pipe 2 (dated 26/6/1968) shows one pier located centrally in the creek with two additional structures at the channel margins. The recent aerial imagery (Figure 22) shows the current location of the piers relative to the channel thalweg. The main channel currently flows to one side of the pier.

Figure 22 Pipe 2 with pier locations indicated (image capture 05/02/2021)

For the road access bridge between the pipelines the design drawings show two main piers located towards the outer margin of the typical flow area (Piers 2 and 3), with Piers 1 and 4 placed on the banks of the creek, Figure 23 (top). However, in the current imagery the channel appears to have widened with Pier 1 closer to the water than shown in the design (Figure 23, bottom). The depth of the piers below the original ground surface is unknown.

FIGURE REDACTED FOR PUBLIC EXHIBITION DUE TO SENSITIVITY OF IMAGE

Bridge crossing design drawing (extract from Drawing 40-1-0089)

FIGURE REDACTED FOR PUBLIC EXHIBITION DUE TO SENSITIVITY OF IMAGE

Access bridge crossing aerial image (05/02/2021)

Figure 23 Road access bridge at South Creek Crossing: top (design drawings), bottom (current conditions).

2.5.2. Geomorphic Condition

South Creek at and downstream of the proposed AWRC site including the Warragamba Pipeline crossing is a laterally unconfined waterway in a valley setting with a cohesive and continuous planform floodplain. It has a low degree of sinuosity and is characterised by fine grained bed materials in a matrix that varies between uncemented coarse matrix and cemented fines. Bank matrix composition through this section of South Creek consists of fines with limited coarse materials and marginally dispersive conditions. There are several informal obstructions throughout this section of creek that have preserved remnant chain of ponds function through weir pool effects, however, the original physical form of chain of ponds in this region has been lost long ago. South Creek in this region is characterised by several large billabongs and observable anabranches as a result of the low gradient of the system, and several meander bends have steep outside banks and shallow inside banks.

Imagery of Bed and Bank	Analysis

long ago. South Creek in this region is characterised by several large billabongs and observable anabranches as a result of the low gradient of the system, and several meander bends have steep outside banks and shallow inside banks.

Imagery of Bed and Bank	Analysis
	**Bed** Gravels - Median matrix = 2.4 mm Well graded Matrix varies between uncemented coarse matrix and cemented fines
	**Bank** Bank matrix composition silt/clay (<1mm) Marginally dispersive conditions – observable and tested during field visit.

Figure 24 Bed and bank material characteristics for South Creek relevant to the Warragamba Pipeline site

Borelog information (GHD, 2020) at locations adjacent to South Creek indicated the soils consist of topsoil, overlying alluvial (clay) with weathered rock (siltstone/sandstone) at depth (5-7m).

A summary of the geomorphic character of this location is provided Table 9.

Table 9 Geomorphic character of the South Creek in vicinity of Warragamba Pipeline

River	Reach	Reach desc	Character	Physical Condition
South Creek	na	South Creek from u/s of AWRC to Warragamba Pipeline crossing	• Alluvial • Gravels on the bed with silty/clay banks • Low sinuosity	• Highly degraded, moderate recovery potential. • Channel modifications with bed and bank structures

	• River styles note that the waterway is moderately sensitive to change

Aerial Imagery Analysis

A series of aerial images were examined to assess the current geomorphic condition of South Creek at and surrounding the Warragamba Pipeline and whether any observable change has occurred (e.g., erosion and deposition) over the time for which imagery is available (2005-2020).

An annotated map using imagery from 29/08/2020 (selected for low flows and clear visibility of bedforms and banks) is provided in Figure 26. Overall, the analysis indicates that the South Creek channel is generally stable 500 m upstream and downstream of the pipeline crossing, although there has been some movement of the channel thalweg, changes in riparian vegetation extent, and potential scouring around the piers of the various pier structures which lie within the low flow channel (Figure 25).

Figure 25 Comparison of channel planform at the crossing location between 2005 and 2020

Also shown in Figure 26, is an area of active bank erosion 70 m upstream of the crossing location where a weir structure across the channel has been outflanked. It is not known who or why the weir was constructed or its current ownership. The earliest available imagery (from 2005) indicates the weir was beginning to be outflanked at this time, with a new channel visible between the end of the weir and the left bank. Erosion continues through to 2011, before increasing significantly between 2011 and 2014, with a scour hole appearing. In 2015 the undermined weir partially fails and scouring of the left bank continues to increase through to the present.

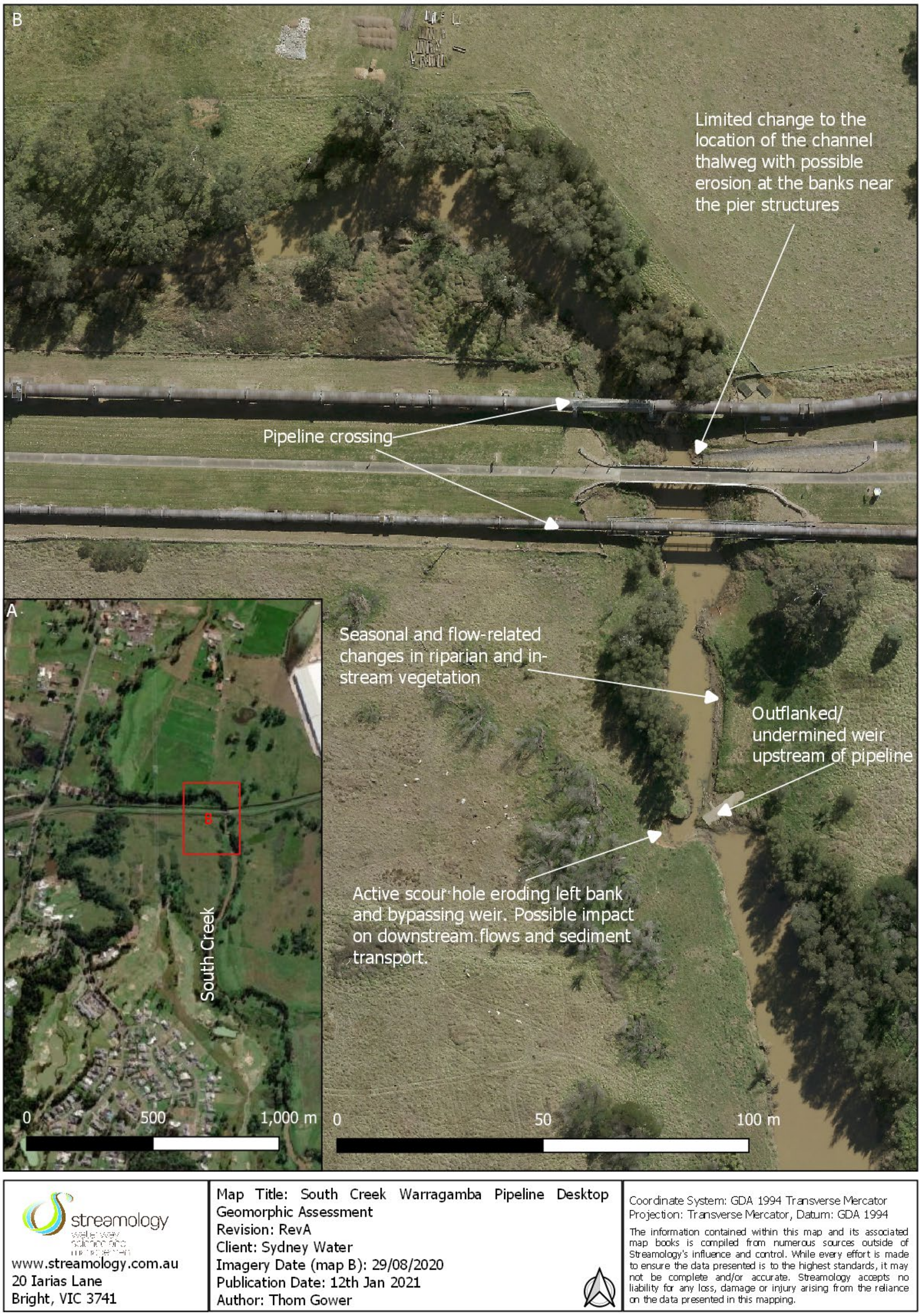


Figure 26. Annotated map of Warragamba Pipeline Crossing, South Creek. Aerial imagery (map B) sourced from Metromap.com.au.

2.5.3. Flow Regime

Flow Duration

There are multiple stream flow gauges located within the South Creek catchment. The pipeline crossing site falls between two gauges (Table 10):

- Gauge 212320 is located approximately 7 km upstream of the site, near the Elizabeth Drive crossing
- Gauge 212048 is located approximately 9.5 km downstream of the site, near the Great Western Highway crossing

Table 10 Stream flow gauging site locations on South Creek

Gauge Number	Location	Waterway	Monitoring Start Date
212320	South Creek at Elizabeth Drive	South Creek	1/06/1970
212048	South Creek at Great Western Highway	South Creek	25/02/1986

The flow duration curves for each site (Figure 27) show that at the more upstream site (Elizabeth Drive) there is a significant proportion of the time with very low to no flows (approximately 40% of the time <100 ML/d), while by the time the flows reach the downstream site this has reduced to around 5% of the time. Several tributaries join South Creek downstream of Elizabeth Drive which contribute additional flows to the waterway. Overall, the waterway is currently more intermittent in nature than the Nepean River.

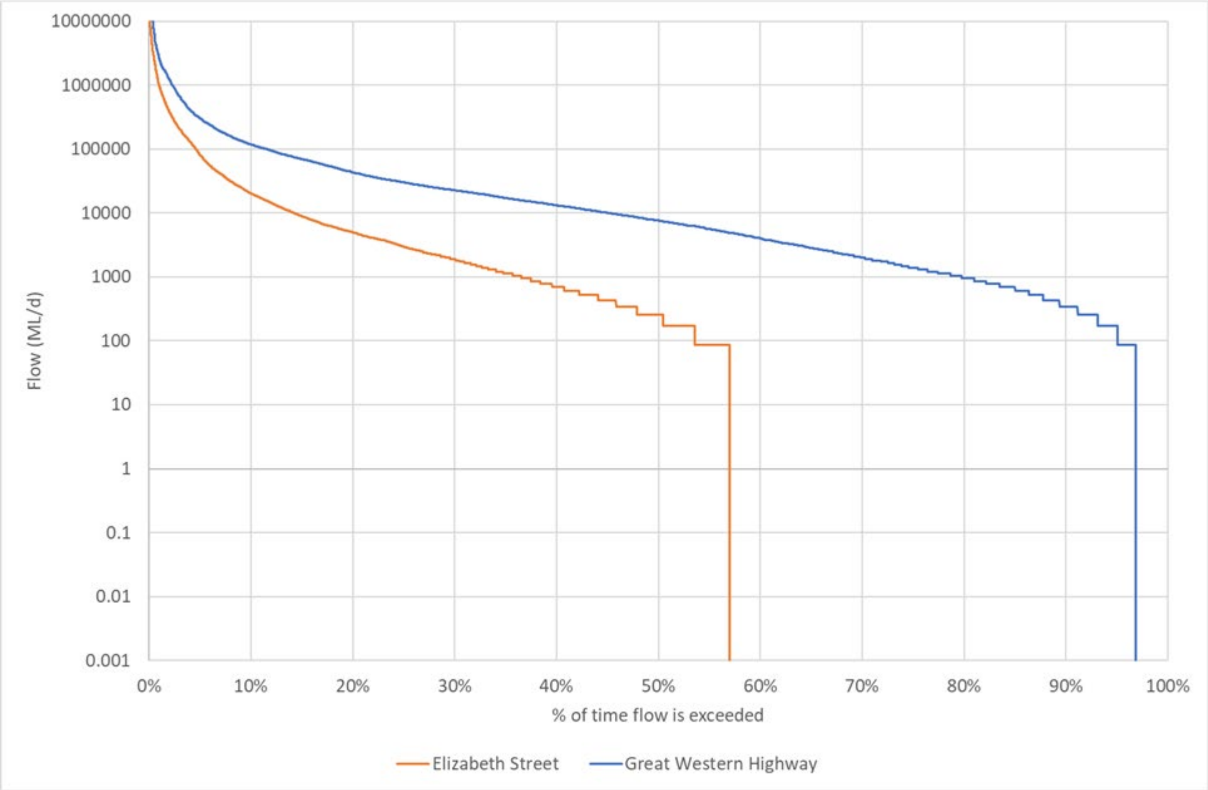


Figure 27 Flow duration curve at Gauge 212320 (South Creek at Elizabeth Drive) and Gauge 212048 (South Creek at Great Western Highway).

streamology waterway science and management www.streamology.com.au 20 Iarias Lane, Bright, VIC, 3741 T: 0421 902 970	Map Title: Location of two gauge sites used to develop duration curves for South Creek Revision: 1 Client: Sydney Water Author: Jess Houghton Date: 15/3/2021	Reference Scale 1:0 Coordinate System: GDA 1994 Transverse Mercator Projection: Transverse Mercator Datum: GDA 1994 The information contained within this map and its associated map books is compiled from numerous sources outside of Streamology's influence and control. While every effort is made to ensure the data presented is to the highest standards, it may not be complete and/or accurate. Streamology accepts no liability for any loss, damage or injury arising from the reliance on the data presented in this mapping.

Figure 28 Location of stream flow gauging stations relevant to the Warragamba Pipeline South Creek crossing

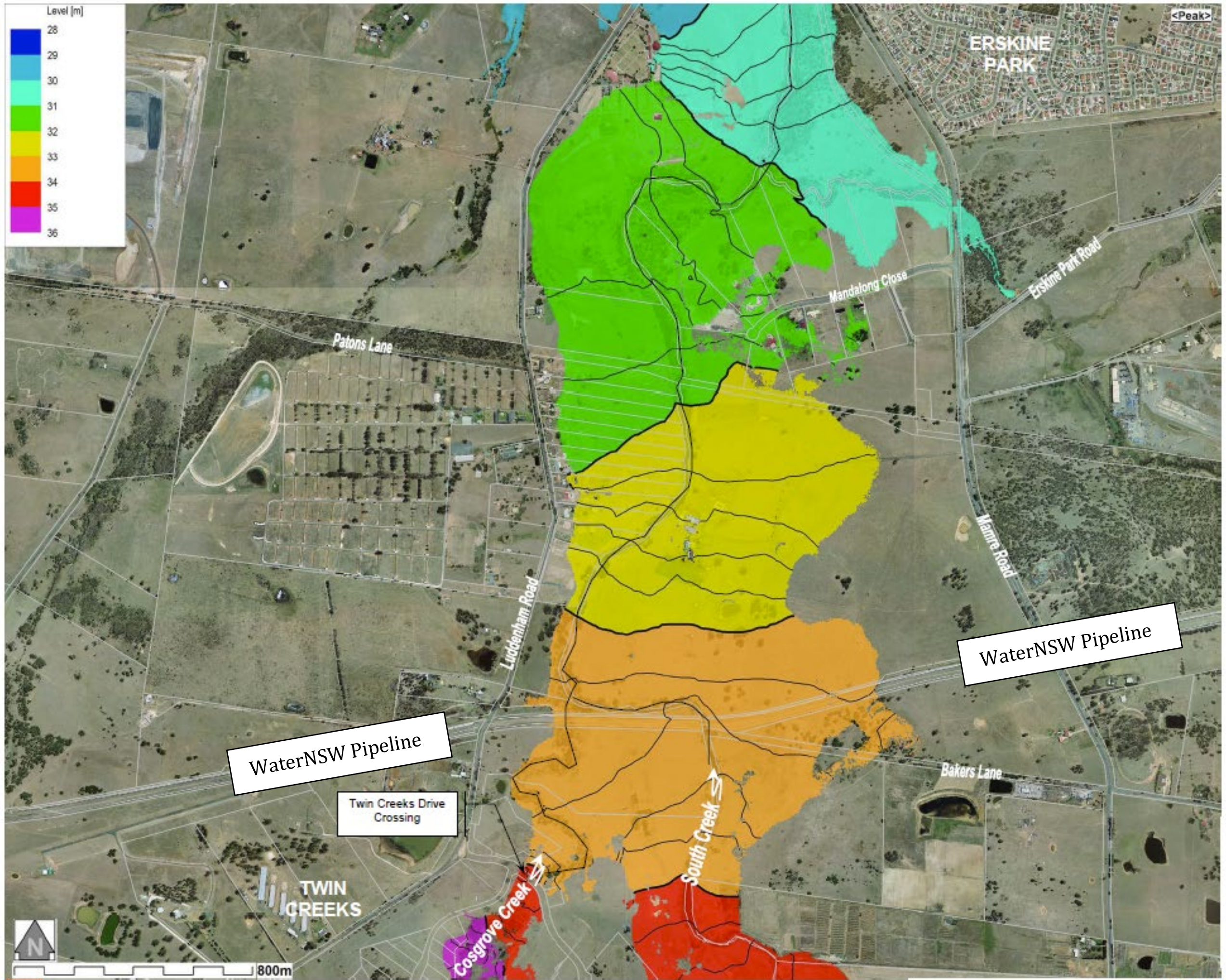
Flooding

The Updated South Creek Flood Study was completed in 2015 (Worley Parsons, 2015) and included the Warragamba Pipeline crossing location. The study modelled flood events from the 1 in 5% AEP (1 in 20-year ARI) up to the probable maximum flood (PMF). The resultant flood maps for the 5% AEP and 1% AEP flood events are shown in Figure 29 and Figure 30.

The peak flood level immediately upstream of the pipeline crossing location is estimated to be 33.8 m AHD at a flow of 1015 m^3/s for the 1% AEP event, and 33.5 m AHD at a flow of 735 m^3/s for the 5% AEP event. From the design drawings, the top surface level of the piers is at 31.4 m AHD (RL = 103' on Drawing No. 40-1-0089/0090, based on a design flood level of 103'5"). This means that the piers are overtopped for 5% AEP and larger events. Flood debris was noted on the access platform on the upstream side of Pier 1 (see Figure 22 and Figure 23) from the recent imagery which is likely the result of a flow event in February 2021 of around 565 m^3/s (approximately 1 in 8% AEP event) which confirms that the pipeline crossing is insufficient for managing flood flows without overtopping of the structures.

In the South Creek Floodplain Management Study (Advisian, 2019) it is noted that a risk assessment should be completed for the pipeline (Figure 31) due to the likely overtopping and outflanking of the structure from flooding.

FIGURE 6.26



LEGEND:

Flood Level Contour at 1 metre Interval

Flood Level Contour at 0.2 metre Interval

WorleyParsons
resources & energy

Rp6033- South Creek Flood Study
fg6033rg150113-Fig 6.26-Peak 20yr ARI Levels (5 of 17).doc

PREDICTED FLOOD LEVELS AT THE PEAK OF THE 20 YEAR RECURRENCE FLOOD [EXTENT 5 OF 17]

Figure 29 Flood map for the 5% AEP flow event (1 in 20 year), Worley Parsons (2015)

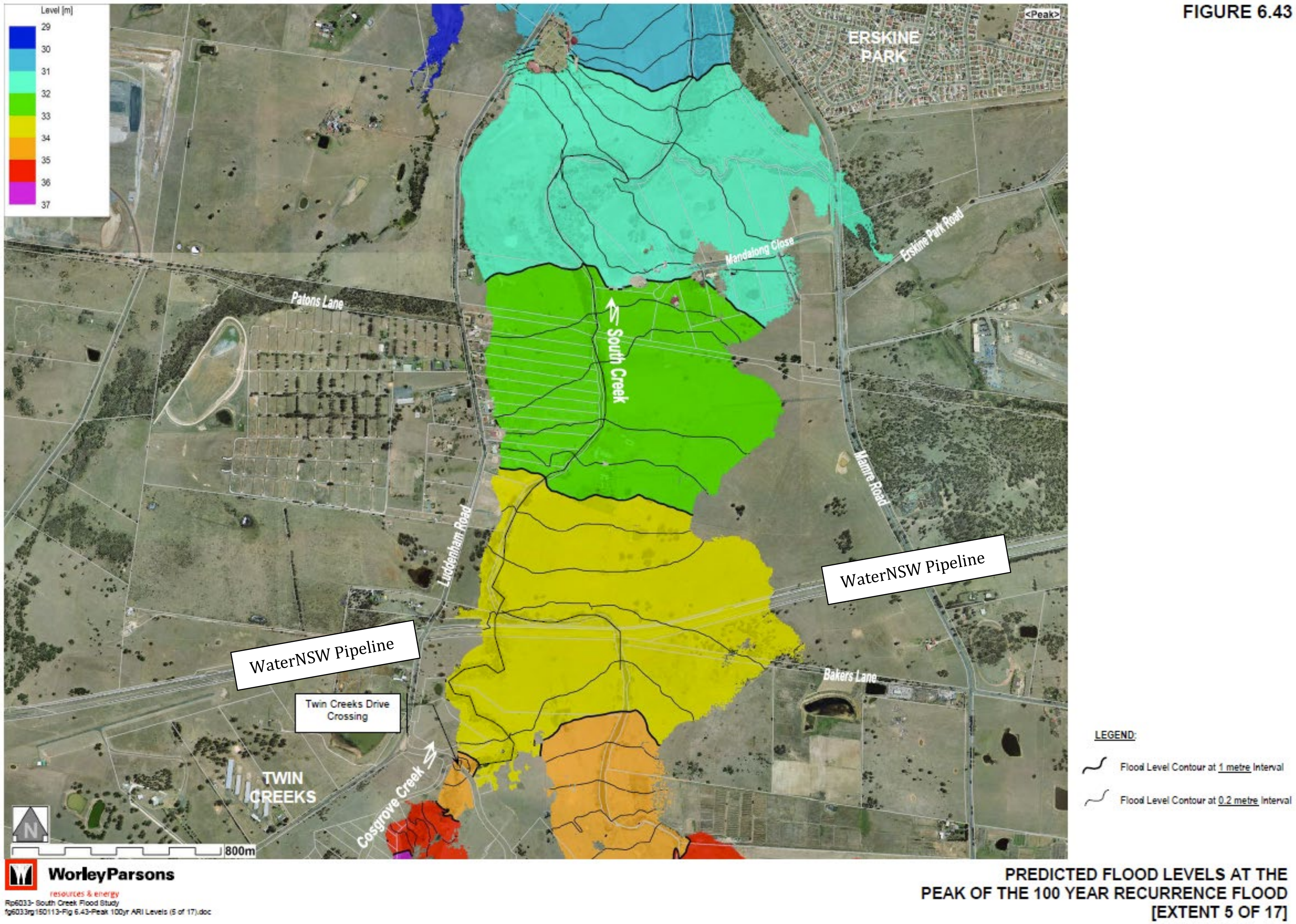
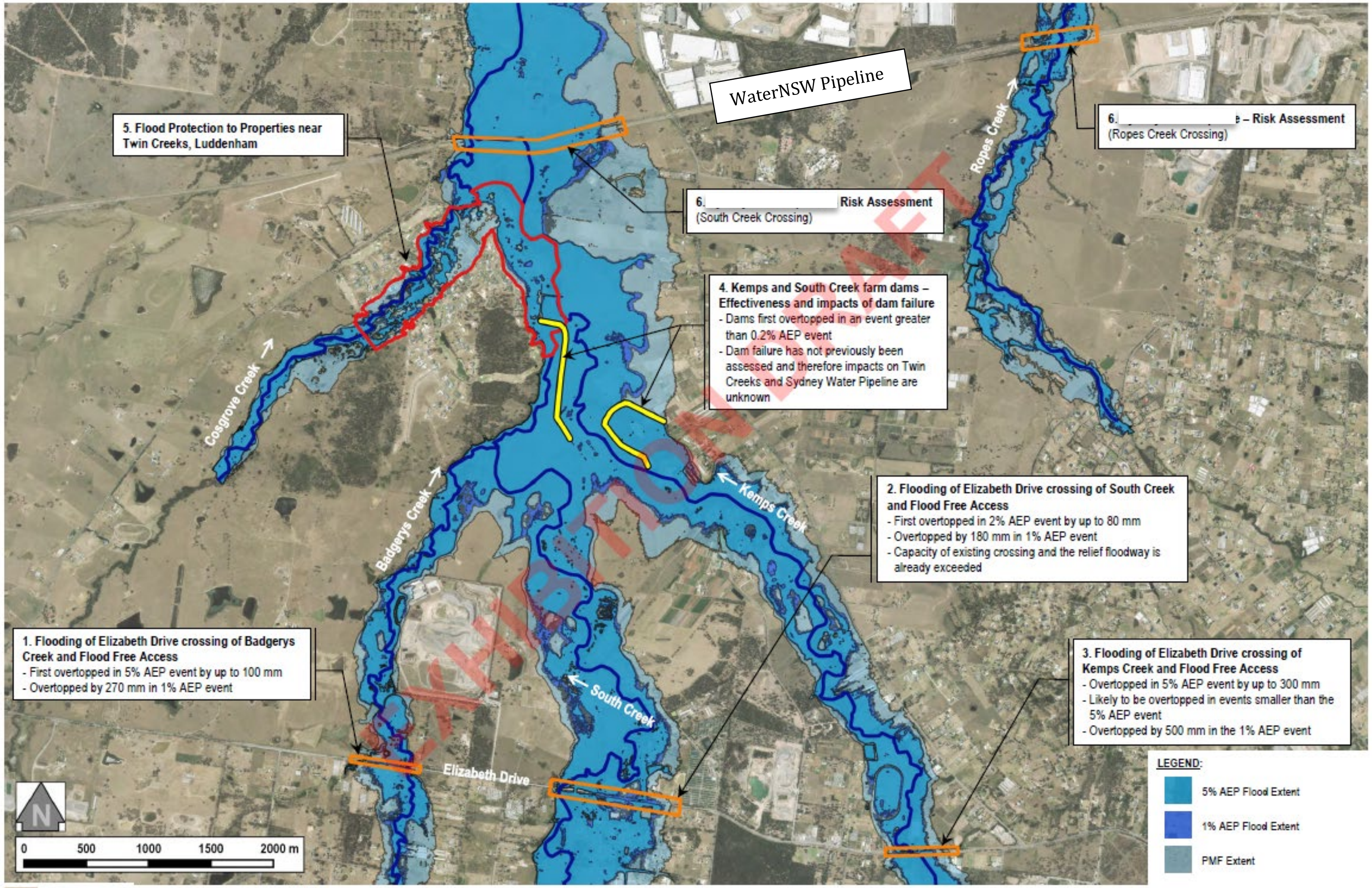


Figure 30 Flood map for the 1% AEP flow event (1 in 100 year), Worley Parsons (2015)



Advisian

WorleyParsons Group

301310-08772 – South Creek Floodplain Risk Management Study
Fig4-1_Area1_ElizDrive_SydPipeline

NOTES:

1. Flood extents are based on modelling completed as part of the South Creek Flood Study (2015).

2. Flood extents are based on a catchment flood event occurring concurrently with a Hawkesbury-Nepean River flood of the same magnitude; i.e., 1% AEP South Creek flood concurrently with a 1% AEP Hawkesbury-Nepean River flood.

FLOODPLAIN MANAGEMENT AREAS
AREA 1 – FLOODPLAIN BETWEEN ELIZABETH DRIVE AND
The Water NSW Pipeline

Figure 31 Floodplain management areas, South Creek (Advisian, 2019)

2.6. **Warragamba Weir - Warragamba River**

2.6.1. **Asset Details**

The Warragamba Weir is located around 1.25 km downstream of the Warragamba Dam and 550m downstream of the proposed environmental flow release location. This 21m high concrete gravity structure was completed in 1940 as an emergency water supply downstream of the current Warragamba Dam to supply water during the worst years of the drought (Beasely, 1988) prior to the construction of the dam upstream. The weir is no longer used for water storage and has a diversion tunnel (5.5 m wide and 4.3 m deep) on the left abutment which allows water to bypass the weir. Its current function is to control tailwater levels at the Warragamba Dam during floods.

The structure is founded on sandstone and a surveillance report from 1985 notes that the structure is in good condition (Metropolitan Water Sewerage and Drainage Board, 1985), which is supported by the recent aerial imagery capture of the site, Figure 32.

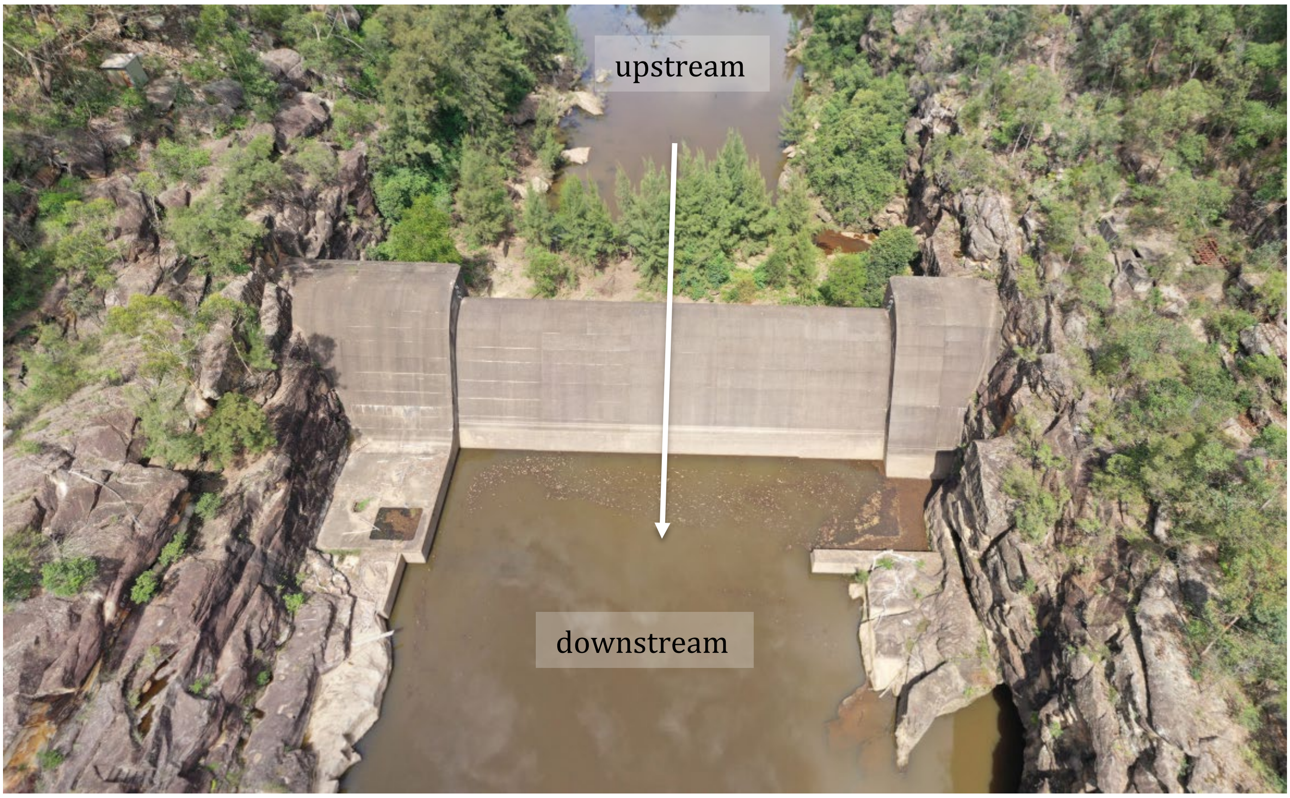


Figure 32 Aerial image of Warragamba Weir – Warragamba River (05/02/2021).

Figure 33 Diversion tunnel upstream of the Warragamba Weir

2.6.2. Geomorphic Condition

This section of the Warragamba River is in a sandstone gorge and is bedrock controlled with bed material likely composed of cobbles (DPI, 2014). Upstream of the weir, the channel is usually a series of discontinuous pools, while downstream the river enters the top end of the Penrith weir pool. Due to the lack of flood events since 2012 there had been a significant buildup of large vegetation in the channel upstream of the weir. However, since these images were captured there has been a significant flood event in the Warragamba River and informal discussions with WaterNSW staff indicates much of the vegetation and sediment build up has been removed.

A summary of the geomorphic character of this reach is provided in Table 11.

Table 11 Geomorphic Character of Warragamba River (DPI, 2014; River Styles online, DPIE 2021)

River	Reach	Reach desc	Character	Physical Condition
Warragamba	19	Warragamba Dam to Confluence	• Cobble bed river • Bedrock controlled • Moderate sinuosity • prone to thermal and saline stratification • 22 to 30 ML/d baseflow (470m downstream of weir at Megarittys Creek)	• likely to be sediment starved due to storage, but otherwise good condition with bedrock control on vertical (bed) and lateral (gorge) migration. • River styles notes the reach to be in moderate condition

	and low sensitivity to change

Aerial Imagery Analysis

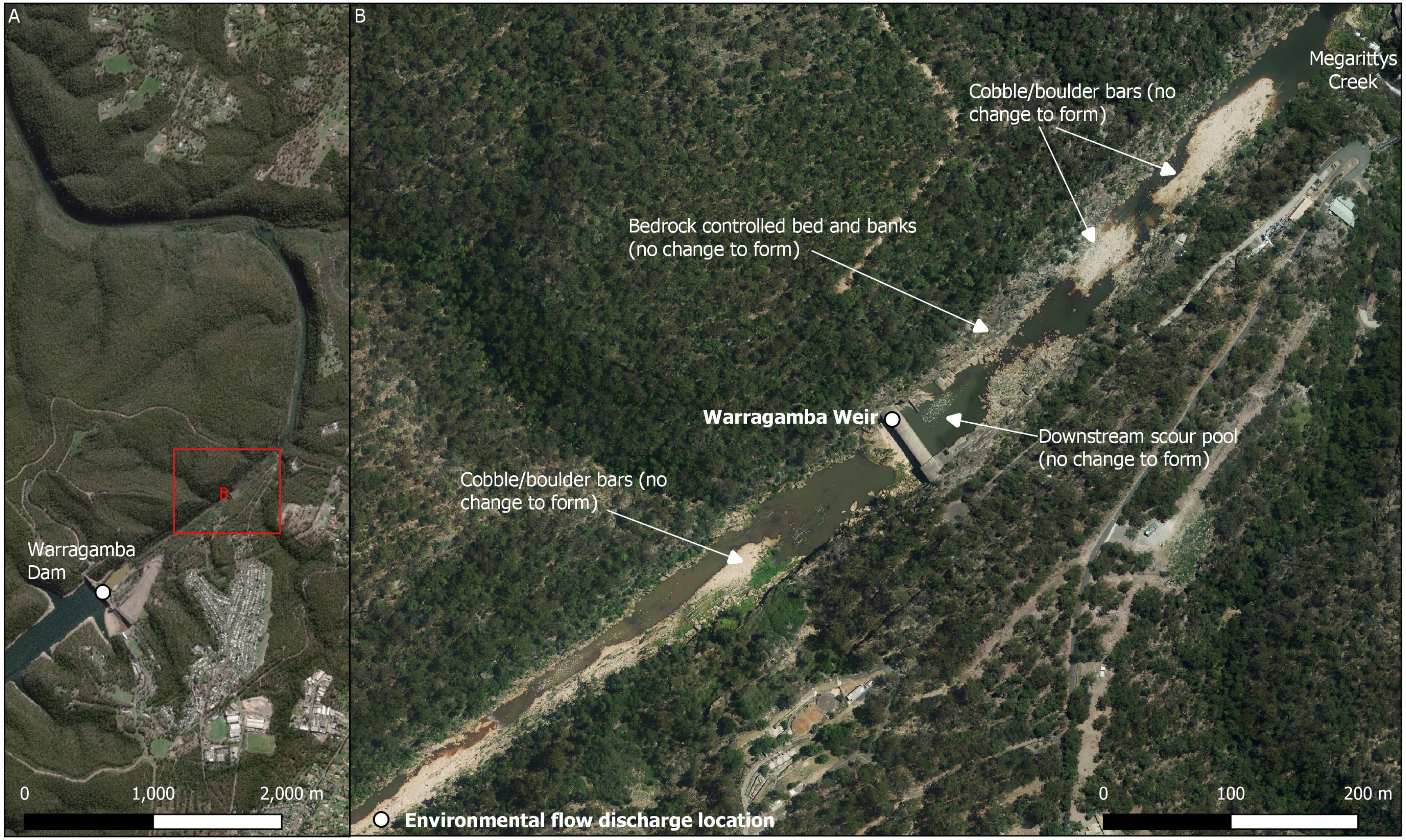
High resolution aerial imagery covering a recent 15-year period from 2005 to 2020 was examined to assess the Warragamba River for geomorphic change (e.g., erosion and deposition) in the area surrounding the Warragamba Weir. Images were available for 2005, 2007, 2011, 2014, 2018, and 2020. Additional review of available Google imagery (1985 to present) did not identify any further changes.

The analysis indicates that the channel 500 m upstream and downstream of the weir is highly stable and has not undergone any visible geomorphic change. Neither erosion or deposition of visible parts of the channel have occurred, including the banks, visible bars or the scour pool downstream of the weir. Some changes to the coverage of in-channel and riparian vegetation are apparent from year to year. The most noteworthy change occurred in 2012, when much of the in-channel and some riparian vegetation was removed during the 1 in 3-year flow event (Figure 34). This event was large enough to topple trees up to 20 m tall, yet no physical changes to the channel were observed. During flood events, the cobble substrate can be mobilised, as was observed during a flood event in 2012 (DPI, 2014).

An annotated map using imagery from 16/01/2016 (selected for low flows and clear visibility of bedforms and banks) is provided in Figure 35.

Source: Sydney Catchment Authority

Figure 34 Warragamba Weir during the March 2012 flow event (DPI, 2014)



streamology
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20 Iarias Lane
Bright, VIC 3741
T: 0421 902 970

Map Title: Warragamba Weir Desktop Geomorphic Assessment
Revision: RevA
Client: Sydney Water
Imagery Date (map B): 16/01/2016
Author: Thom Gower
Publication Date: 12th Jan 2021

Coordinate System: GDA 1994 Transverse Mercator
Projection: Transverse Mercator
Datum: GDA 1994

The information contained within this map and its associated map books is compiled from numerous sources outside of Streamology's influence and control. While every effort is made to ensure the data presented is to the highest standards, it may not be complete and/or accurate. Streamology accepts no liability for any loss, damage or injury arising from the reliance on the data presented in this mapping

Figure 35. Annotated map of Warragamba Weir, Warragamba River. Aerial imagery (map B) sourced from Metromap.com.au.

2.6.3. Flow Regime

Flow Regime

There are two gauges relevant to the Warragamba Weir site:

- Gauge 212241 is located at the Warragamba Weir
- Gauge 212243 is located at the Warragamba Dam

Table 12 Stream flow gauging on South Creek

Gauge Number	Location	Waterway	Monitoring Start Date
212241	Warragamba River at Warragamba Weir	Warragamba River	28/11/1980
212243	Warragamba River at Warragamba Dam	Warragamba River	27/05/1977

As can be seen from Figure 36, there has been a significant reduction in flows since the early 1990's. Figure 37 shows that approximate 22% of the time flows are <5 ML/d. Only water storage level is recorded at the dam gauge site.

There is a pool upstream of the weir which rarely receives inflows and consequently the water quality in this pool appears to be dominated by groundwater inflows. Groundwater impacts are considered within the Groundwater Impacts Assessment for the AWRC project.

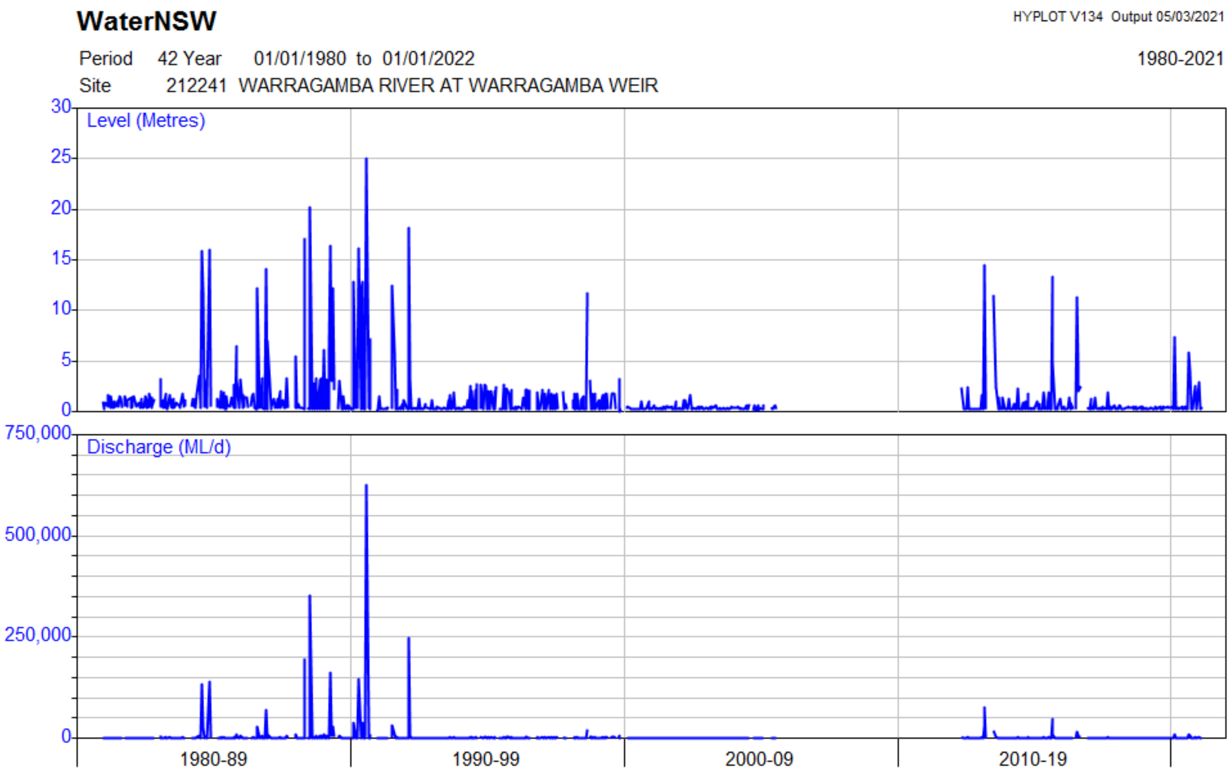

Figure 36 Flow and water level record at site 212241 (Warragamba River at Weir)

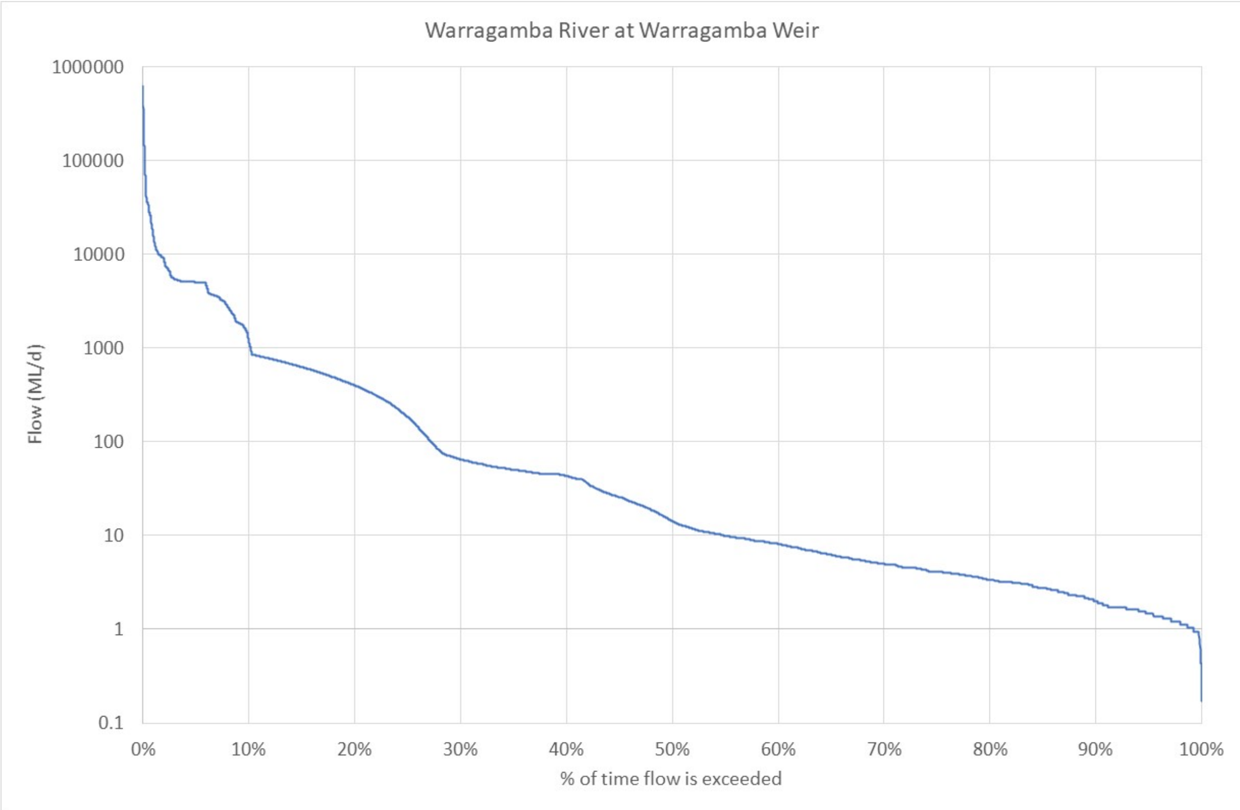

Figure 37 Flow duration curve on the Warragamba River at Warragamba Weir (1980 to 2021)

Environmental Flows

WaterNSW currently releases 5 ML/day from Warragamba Dam to dilute effluent discharge from the Wallacia sewage treatment plant into the Warragamba River. Another 17 ML/d is released in winter, increasing to 25 ML/d in summer. The flows are currently released from the water supply pipe as it crosses Megarritys Creek, downstream of the weir (approximately 1.7 km downstream of the dam).

The proposed environmental flow release location is around 500 m upstream of the Warragamba Weir.

Flooding

The river in this reach only flows when there is heavy rainfall in the immediate catchment or when the Warragamba Dam is spilling. Prior to March 2021, the most significant flow event was in February 2012 where the dam began to spill for the first time in 14 years. The weir was almost completely submerged (DPI, 2014) which had a magnitude of 1 in 6-year AEP[1]. The effects of the flood event included removal of encroaching riparian vegetation and soft sediment, however there were no impacts on the weir structure.

[1] The DPI (2014) report states the event was 1 in 3 year AEP, however a review of the flood frequency analysis for the Warragamba Weir site estimates the flow to have be around a 1 in 6 year event (BOM Water Data Online, accessed 10/03/2021).

The March 2021 flood event has been estimated at a 10% to 5% AEP event (1 in 10 to 20 year ARI) (NSW Government, 2021). WaterNSW (pers. comm) noted that vegetation and soft sediments were again removed from this reach of the Warragamba River by the flood event, however there were no impacts on the weir structure.

Table 13 Peak flood magnitude at Warragamba Dam

Location	10% AEP	5% AEP	2% AEP	1% AEP
WMA Water (2019)	5,260	7,510	10,400	12,400

3. Impact Assessment

3.1. Overview

The AWRC project proposes to release 50 ML/d of treated wastewater into the Nepean River immediately upstream of Wallacia Weir during dry weather. Additionally, treated wastewater may also be released into the Warragamba River upstream of Warragamba Weir as environmental flows. During wet weather, when flow to the AWRC is greater than 1.7 x average dry weather flow, flows will also be released to South Creek.

Within these waterways, five WaterNSW assets have been identified which could be impacted by these releases. To understand whether there are likely to be any impacts on the infrastructure it is necessary to answer the following questions:

How do the proposed flow releases change the flow regime of each waterway compared to current conditions?

Is the change(s) sufficient to cause erosion, sedimentation or undermining of any of the assets?

The following sections addresses each of these questions in turn.

3.2. Changes in Flow Regime

Changes in the flow regime of a waterway can potentially threaten the integrity of infrastructure through the following mechanisms:

- An increase in flows, particularly flood events, leading to damage to the structure through exceedance of design conditions.
- An increase or decrease in flows leading to erosion or deposition within the waterway or channel banks which affects the performance of the asset.

To assess these potential changes to the flow regime, flow duration curves have been developed for each location, considering the current conditions and proposed AWRC flow scenarios (50 ML/d release), see Figure 38, and Figure 39 Nepean River, Penrith Weir site.

The flow duration curves indicate that the flow regime at the Wallacia Weir, Warragamba Pipeline and Penrith Weir on the Nepean River are only altered for more frequent event (non-flood flows). This means that flood flow conditions are typically unaffected for these locations. The releases from the AWRC do increase the magnitude and frequency of lower flow events.

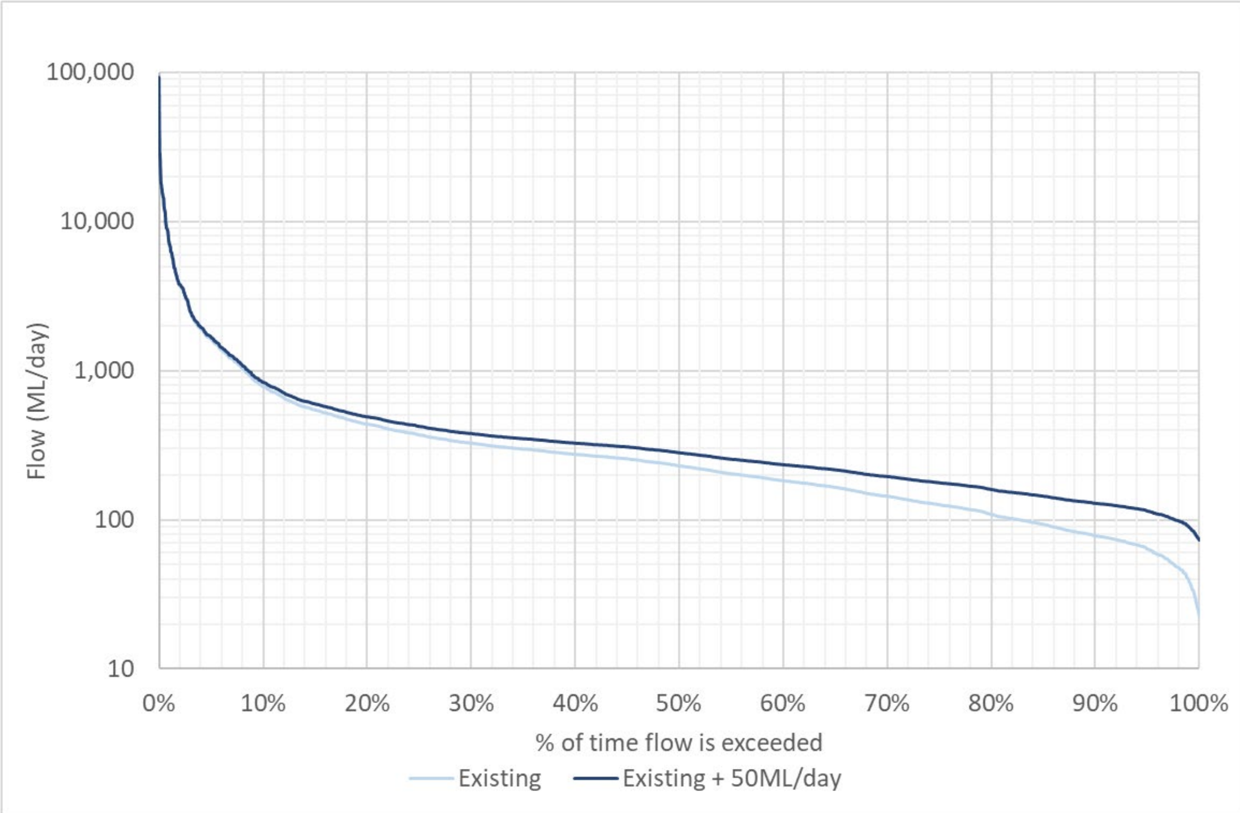

Figure 38 Nepean River, Wallacia Weir site

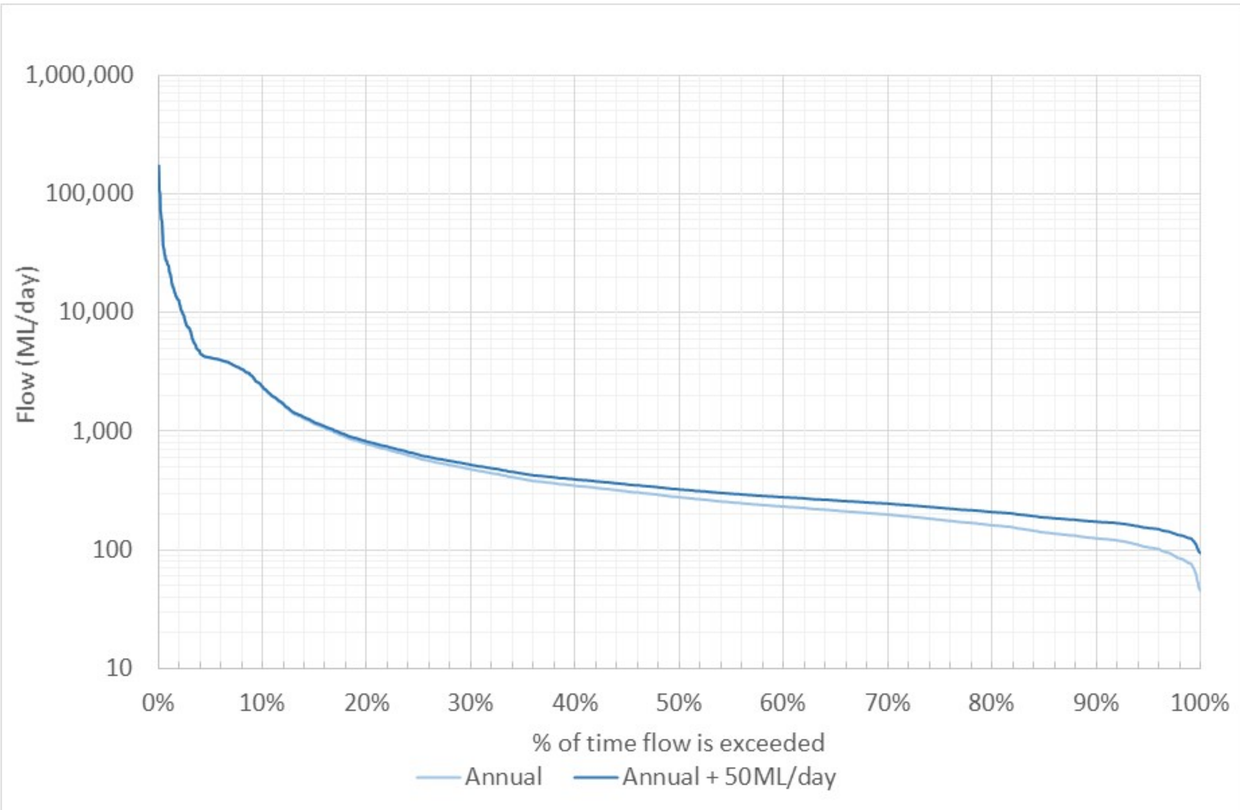

Figure 39 Nepean River, Penrith Weir site

For South Creek, the AWRC is only discharging an additional wet weather flow to the waterway. This is likely to have minimal impact on the flow duration curve for South Creek. Further analysis presented in the main Ecohydraulics and Geomorphology report.

3.3. Flooding Implications

3.3.1. Approach

The implications of flooding were assessed by undertaking a series of 2D HECRAS models for each of the asset sites. A series of flows were considered based on their annual exceedance probability (AEP). The inundation extent of the models was used to ascertain the risk to the physical assets located at each site.

3.3.2. Results

Nepean River Assets
Flood flow conditions for the Nepean River site are not likely to be affected by the AWRC release. Any increase in flood level, extent, or flow velocity because of the proposed release is likely to be negligible. Further details and flood mapping are provided in the Flooding Impact Assessment report.

Therefore, it can be expected that there will be no increase in flood impacts on the stability of the Wallacia Weir, Warragamba Pipeline, and Penrith Weir.

Warragamba Weir
Flood flow conditions for the Warragamba River at the Warragamba Weir are not likely to be affected by the AWRC environmental water release. The flows proposed for the environmental water release are currently within the capacity of the diversion tunnel and will not result in higher water levels at the weir.

Warragamba Pipeline - South Creek
Flood flows break the banks of South Creek for events with an annual exceedance probability of 10-50%, with more than 900 m of pipeline and roadway potentially inundated. The high velocities through the South Creek channel section during these flood events has the potential to scour the channel bed and banks, destabilizing or undermining the piers of each structure. The current embedment depth of the piers is unknown. However, these flow conditions are not changed by the addition of the AWRC flows and therefore there is no change in expected flooding and general scour of the channel during flood events.

3.4. Geomorphic Implications

3.4.1. Approach

Shear stress describes the pressure a flow exhibits and is calculated by considering the cross-sectional area of flow, as well as the applied force it enacts on the channel. The shear stress equation is used to provide a quantification of the level of stress that differing flows generate for a channel's bed sediments. For this analysis, the shear stress provides an indication of the likelihood of the entrainment and transportation of bed sediments around physical structures (weirs and pipeline footings). Significant transportation of bed sediments may lead to excessive scour, leaving physical assets vulnerable to collapse due to the lack of integrity surrounding their footings.

Erosion threshold is taken to be the shears stress at which sediments begin to move. Estimating this threshold value for sediments is complex and where the bed or bank material is a mixture of cohesive and non-cohesive sediment the erosion threshold will likely be site and material specific. However, based on the dominant sediment present and the median particle size it is possible to obtain an indicative estimate of the likely shear stress required to exceed the erosion threshold of the sediment. The erosion threshold value of shear stress can then be compared to the shear stress at a location in a waterway for a given flow condition.

For this assessment, given the lack of site-specific sediment data indicative estimates of critical shear stress for erosion have been adopted for different sediment classes, as summarised in Table 14.

Table 14 Sediment classification and indicative critical shear stress for erosion (based on Lagasse et al, 2012)

Sediment Classification	Particle Size Range	Critical Shear Stress (N/m^2)
Cobbles / Boulders	> 64 mm	> 20
Gravel	2 mm to 64 mm	1 to 20
Sand	0.065 mm to 2 mm	0.05 to 1
Silts	0.004 mm to 0.065 mm	Not defined
Clays	< 0.004 mm	Not defined

Critical shear stress estimates are based on the Shields curve (Shields, 1936) and procedures outlined in Lagasse et al (2012). These approaches are typically applicable for non-cohesive sediments and the critical shear stress for mobilisation of cohesive sediments is much more dependent on the material properties as well as the hydraulic conditions.

Geomorphic impacts have been assessed by comparing the estimated shear stress threshold for mobilisation of the typical bed sediment in the relevant reach of each river, Table 15, as well as the percentage of time this is exceeded. Where a range is indicated both the upper and lower limits have been assessed.

Table 15 Shear stress threshold for bed sediment movement at each location

Site	Bed Sediment Type	Shear Stress threshold for mobilisation
Wallacia Weir	Mostly pebbles, cobbles and larger	> 20 N/m^2
Penrith Weir	Gravel and cobbles	> 20 N/m^2 (upstream, where cobbles dominate) 0.05-20 N/m^2 (downstream, where sand and gravel dominate)
Warragamba Pipeline Crossing (Nepean River)	Mostly pebbles, cobbles and larger	> 20 N/m^2
Warragamba Pipeline Crossing (South Creek)	Likely gravel in a clay matrix on the bed with silty clay on the banks	0.05-20 N/m^2 (based on limits for non-cohesive materials, sands to gravel)
Warragamba Weir (Warragamba River)	Mostly pebbles, cobbles and larger	>20 N/m^2

3.4.2. Results

Penrith Weir, Nepean River

The mean shear stress in the Nepean River upstream of the Penrith Weir was assessed across a range of flow conditions. Shear stress was defined for areas that are located within the channel and within the riparian zone.

The thresholds for mobilising sandy sediments within the channel was reached at around 11,000 ML/day. Below this flow volume, only low amounts of sandy sediments are being transported. A flow of 11,000 ML/d is similar to the predicted 2% AEP flood event (1 in 50 year).

Given that much of the bed load in this reach is gravel and cobble sized material, and that this magnitude of flood event is unaffected by the additional flows from the AWRC project, no change in sediment transport is expected.

Downstream of the weir, due to deepening of the channel and excessive weed growth it has been estimated that a flow above 80,000 ML/d is required to scour the bed sediments (Warner, 2002b as report in DPI, 2014) which is well in excess of the 1% AEP event for this reach.

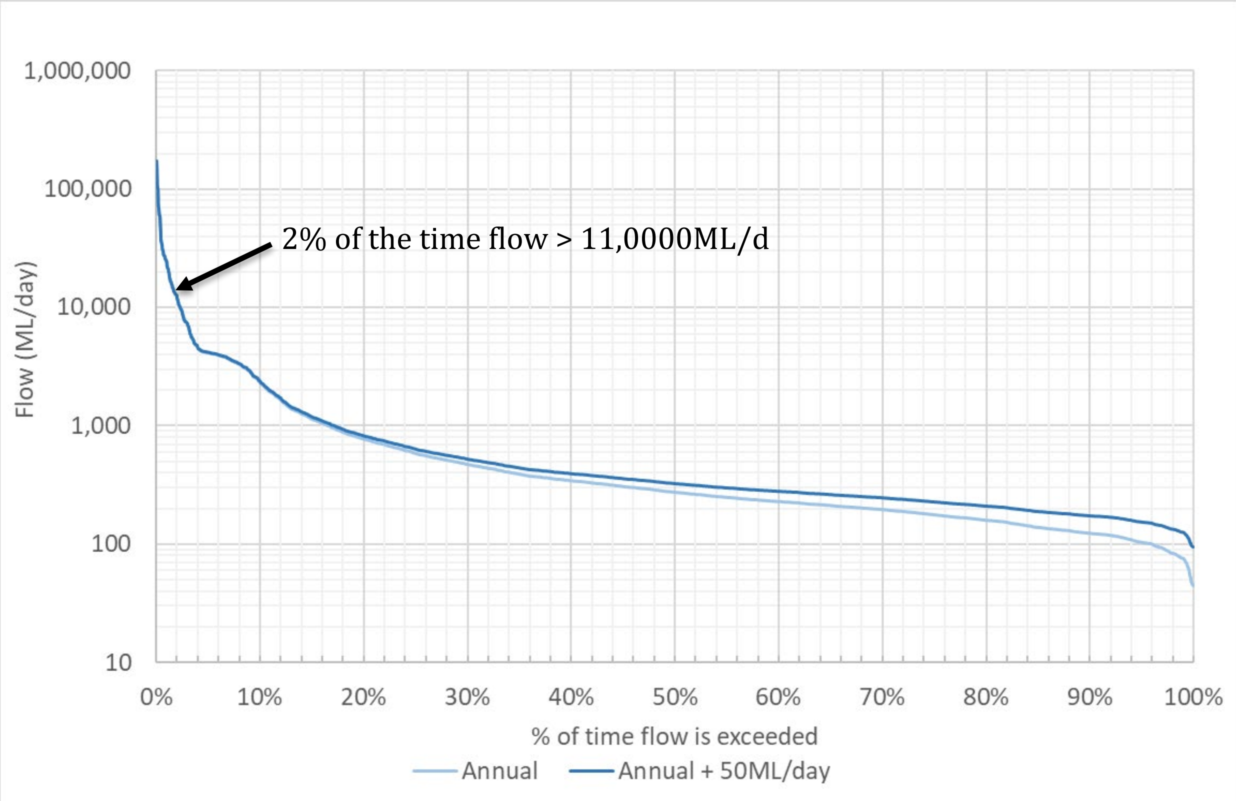

Figure 40 Flow duration curve downstream of Penrith Weir plotting 2010 flow data and annotated to include the addition of 50 ML/day to reflect the disposal from the AWRC.

Wallacia Weir & Warragamba Pipeline Assets, Nepean River

The bed and water surface profile of the reach from above Wallacia Weir to Norton's Basin downstream which encompasses the WaterNSW assets varies significantly between steep high sections to deep pools. Due to this variation in form and water level, the analysis of shear stress was segmented into sections with high velocity and sections with low velocity.

In areas with low velocity (e.g., pools and backwater zones), the bed sediments can contain more sand, whereas the in shallower areas with higher velocity (riffles), the bed sediments are generally larger (including large pebbles, cobbles, and boulders), requiring high shear stresses (>20 N/m^2) before they are mobilised.

The mean shear stress was calculated for a range of flow conditions along the reach to identify when the erosion threshold would be exceeded. The flow required to mobilise sandy bed sediments based on the mean shear stress in lower velocity areas (typically pools) was around 1,000 ML/day, and the threshold for mobilising large pebbles based on the shear stress in high velocity area (typically riffles) was 3,700 ML/day.

Estimation of flow magnitude and exceedance probability for flood events along this section of the Nepean River is complicated by the joint probability of flooding in both the Nepean River and Warragamba Rivers. So, to provide an indicative estimate of the AEP of events required to mobilise the sediment the flow duration curve was analysed to plot the percentage of time flows are expected to exceed the thresholds of 1,000 ML/day and 3,700 ML/day. This was estimated for current conditions and with the addition of flows from the AWRC (Figure 41).

Flows at the Wallacia Weir site of around 1,000 ML/day have an exceedance probability of 8%, and flows are likely to exceed 3,700 ML/day for a 2% AEP event. The influence of the 50 ML/day addition from the AWRC does not affect flows in these ranges and therefore the percentage of time sediment is likely to be mobilised is not affected. Therefore, downstream of Wallacia Weir, and at the Warragamba Pipeline crossing site there is minimal change in sediment transport characteristics due to the AWRC project.

Upstream of Wallacia Weir, the presence of the weir itself reduces flow velocities and causes sediment to settle in the weir pool. Any increase in flows will assist in maintaining limited movement of sediment through the channel and reduce deposition in the weir pool.

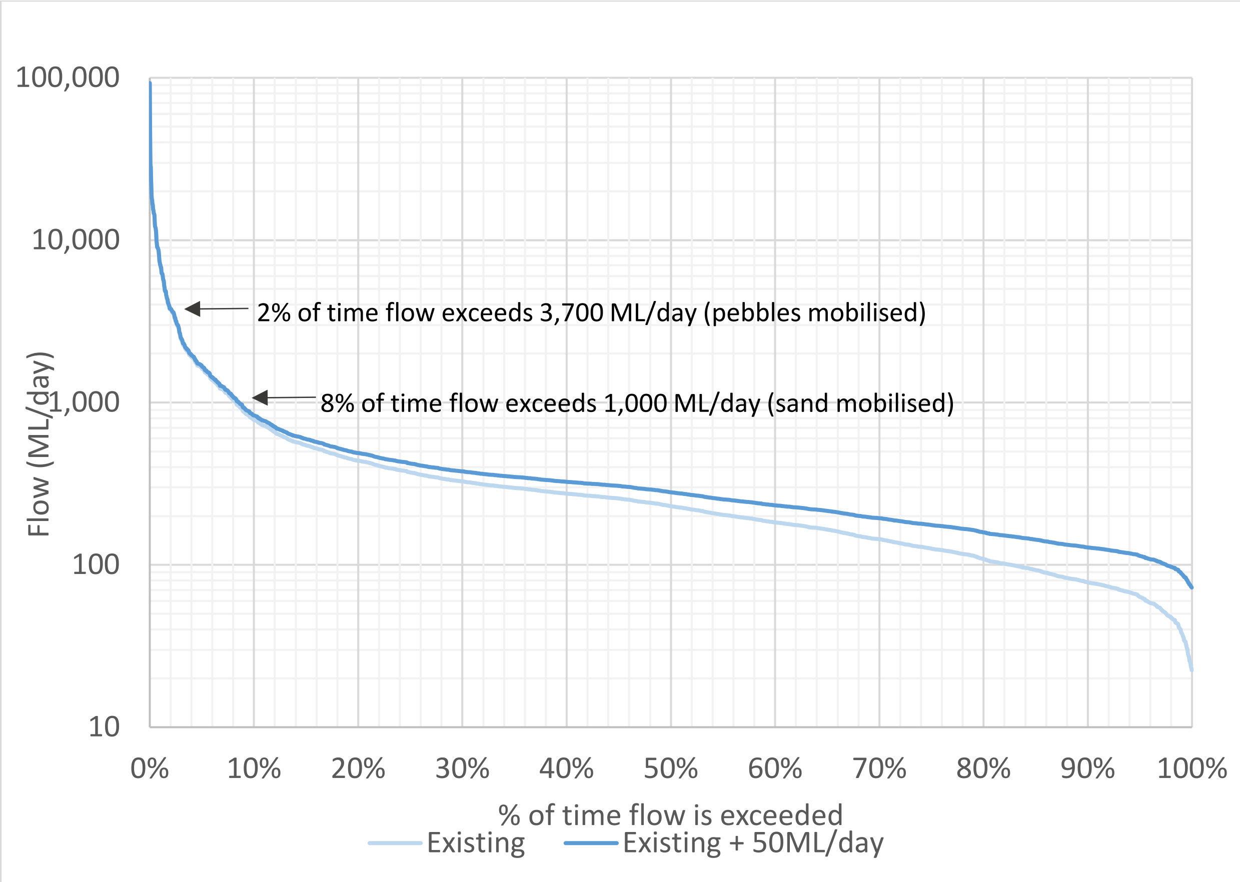

Figure 41 Flow duration curve downstream of Wallacia Weir annotated to include the addition of 50 ML/day to reflect the release from the AWRC.

Warragamba Pipeline, South Creek

The nature of the channel bed and bank materials along South Creek mean that the creek is susceptible to erosion. The bed materials contain gravels but there is also likely to be more dispersive material present.

- The channel bed and bank materials are susceptible to erosion and changes to the channel thalweg and form at the crossing have been observed.
- The failure of the weir structure upstream of the crossing has destabilized the channel and this may propagate downstream towards the structures.
- Urbanisation of the catchment is likely to be contributing to long term hydrological change. This increases the likelihood of erosion in and around the pier structures. However, the direct effects due to AWRC wet weather flows are negligible.

Figure 42 shows the modelled shear stress on the bed for different flood events under existing conditions. The modelled results indicate the shear stress at the pipeline crossing exceeds the threshold for sands and gravels in some areas of the channel for the 0.4 % AEP (2-year ARI) event, indicting the site is likely highly sensitive to erosion.

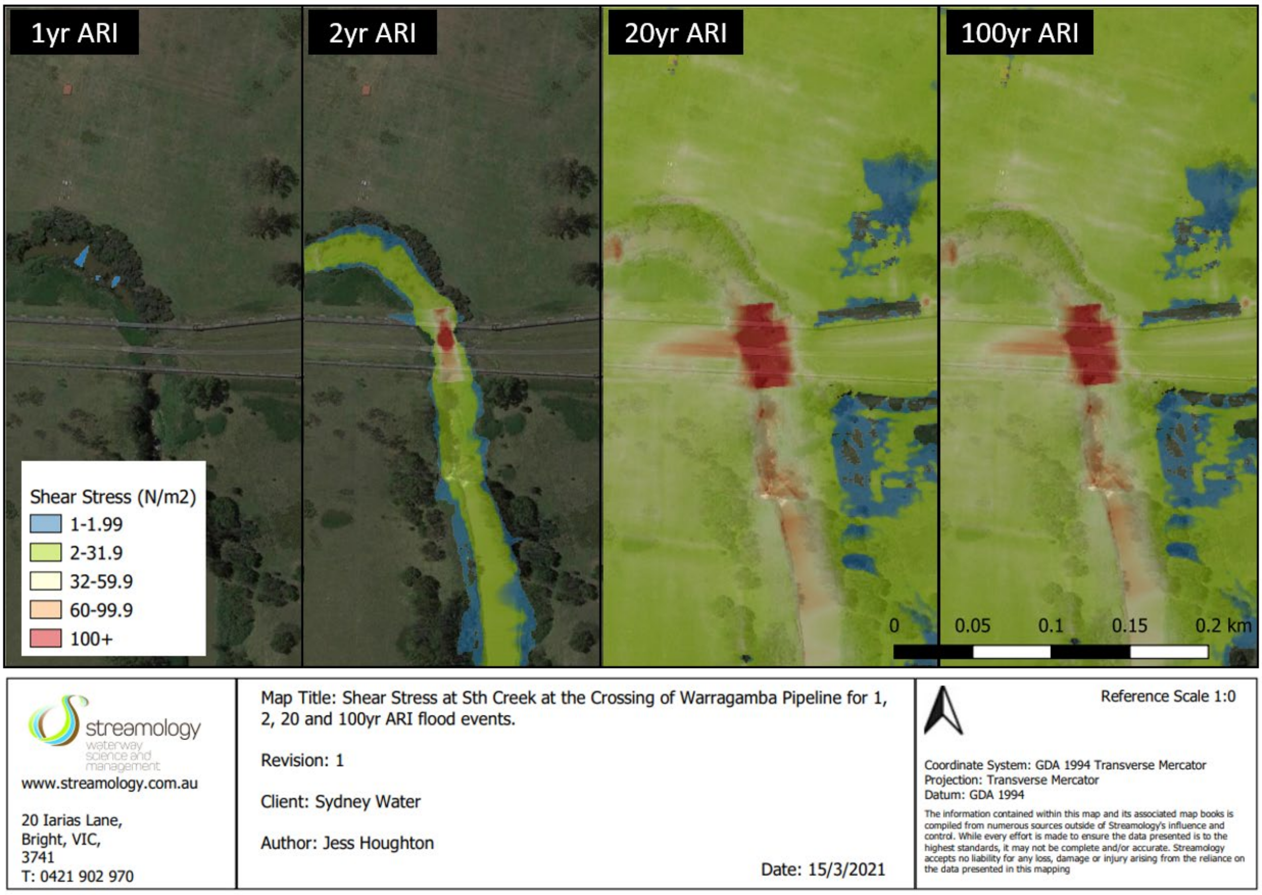

Figure 42 Shear Stress at South Creek Warragamba Pipeline Crossing for a range of flood events.

Warragamba Weir, Warragamba River

The channel of the Warragamba River downstream of the Warragamba Dam is bedrock controlled with bed material composed of cobbles and boulders. These materials require a shear stress of >20 N/m^2 before they are mobilised.

Given the similarity in the physical form of the channel along this reach to the Nepean River gorge section downstream, the threshold of 3700 ML/d for mobilising large pebbles/cobbles from the Nepean River models have been adopted for this assessment. Based on the flow duration curve for the Warragamba Weir site, a flow of this magnitude has an exceedance probability of approximately 6.8% AEP. Finer material was observed to be mobilised in the 2012 flow event.

The introduction of environmental flows from the AWRC will mobilise the finer in-channel sediments in this reach. However, DPI (2014) noted mobilization of the in-channel sediment as a benefit from the commencement of variable environmental flows released near the face of the dam. At present, the weir structure restricts this movement of sediment downstream which has led to increased deposition in the channel.

The environmental flows do not exceed the capacity of the diversion tunnel and as the tunnel is bored through the sandstone bedrock the capacity for scouring of the material as a result of low flows is negligible.

Undercutting or erosion of the abutments of the structure is not likely to occur given the condition and design of the structure and its foundations.

4. Risk Assessment

4.1. Approach

The following risk assessment addresses risks to the WaterNSW assets associated with waterway flooding, erosion, or deposition because of changes to flow regimes due to the AWRC project.

Risk management is the term applied to a logical and systematic method of establishing the context, identifying, analysing, evaluating, treating, monitoring, and communicating the risks associated with any activity, function or process in a way that will enable organisations to minimise losses and maximise opportunities (Standards Australia, 2009). Risk is identified as the product of the likelihood and consequence of an event or activity impacting on an asset.

Risk profiles have been developed by assigning a score to the consequence of flooding or flow regime change occurring for a given asset and the likelihood of the flood or flow regime change impacting the asset over a range of relevant timeframes. The risk profile for each asset is determined by applying the score to a risk matrix. The risk profile assists with the identification and analysis of priority risks for which inform mitigation strategies and measures.

Table 16 and Table 17 show, respectively, the definitions used for assigning levels of the consequences of threats, and definitions used for assigning levels of the likelihood of threats.

Consequence levels have been defined based on economic, and environmental risks. Social risk incorporates safety and reputational risks associated with damage to the assets or access to the assets. The likelihood definitions are based on the expected frequency of the flow events in a given waterway.

Table 16 Consequence Ranking (based on AGS, 2007)

Consequence	*Ranking*	*Economic*	*Environment*
Extreme	5	Significant permanent damage and/or complete loss of infrastructure and the infrastructure service. Loss of infrastructure support and translocation of services to other sites.	Permanent loss of flora or fauna (no chance of recovery) with national impact. Permanent change of channel form.
Severe	4	Extensive infrastructure damage requiring major repair. Major loss of infrastructure service.	Long term loss of flora and fauna (limited change of recovery) with regional impact. Permanent change of channel form, limited recovery.
Moderate	3	Limited infrastructure damage and loss of service. Damage recoverable by maintenance and minor repair.	Medium term loss of flora and fauna (recovery likely) with regional impact. Medium term change of channel form, some recovery.
Minor	2	Localised infrastructure service disruption. No permanent damage. Some minor restoration work required.	Short term loss of flora and fauna (strong recovery) with local impact. Minor erosion or deposition of bed and banks.
Insignificant	1	No infrastructure damage. Little change to service.	Negligible to no loss of flora and fauna (strong recovery) with local impact. Minor erosion or deposition in channel.

Table 17 Likelihood Ranking

Likelihood	*Ranking*	*Description*	*Annual Exceedance Probability*
Rare	1	Recurrent events are unlikely to occur more than once per century. Single events are not expected to occur but are possible.	< 1%
Unlikely	2	Recurrent events are expected to occur only 1-2 times per century. Single events are unlikely.	1-10%
Possible	3	Recurrent events are expected to occur every decade or so. Single events are less likely than not.	10 – 50%
Likely	4	Recurrent events are expected several times each decade. Single event more likely to occur than not	50 - 90%
Almost Certain	5	Recurrent events expected to happen several times per year. Single event highly likely.	> 90% probability

Table 18 shows the risk matrix definitions.

Table 18 Risk Assessment Matrix

Likelihood	*Consequence*				
	1 - Insignificant	2 - Minor	3 - Moderate	4 - Severe	5 - Extreme
1 - Rare	1 - Low	2 - Low	3 - Low	4 - Medium	5 - Medium
2 - Unlikely	2 - Low	4 - Low	6 - Medium	8 - Medium	10 - Medium
3 - Possible	3 - Low	6 - Medium	9 - Medium	12 - Medium	15 - High
4 - Likely	4 - Medium	8 - Medium	12 - Medium	16- High	20 - Extreme
5 - Almost Certain	5 - Medium	10 - Medium	15 - High	20 - Extreme	25 - Extreme

4.2. Results

The risk profiles for different assets are detailed in this section. The results are reported per site to reflect the different waterway and asset conditions.

4.2.1. Wallacia Weir - Nepean River

The key justifications for the risk ratings assigned to the Wallacia Weir in Table 19 are provided below.

- Flood flows <10% AEP (greater than 1 in 10-year ARI) are not changed by the addition of the AWRC flows and therefore there is no change in expected flood risk to the structure.
- Flood flows at this location are controlled by downstream water levels and the joint probability of flooding in the Nepean and Warragamba Rivers.
- The design of the structure is unknown however it is assumed the asset has been designed to accommodate flows up to around the 1% AEP event without significant damage to the structure. The risk rating therefore assumes minor damage could be expected for events larger than a 10% AEP.
- The channel is bedrock controlled and any erosion of the section downstream of the weir is only likely to result in minor changes to the channel planform. Undercutting of the structure is not likely to occur given the structures foundations.
- An increase in flows upstream of the weir may reduce deposition under low flow conditions.

Overall, the risk rating for this structure is considered **LOW**, both for current conditions and with the AWRC project.

Table 19 Risk Assessment, Wallacia Weir

Specific Impact	*Timeline*	*Likelihood*	*Consequence*	*Risk Rating*
Flows leading to damage to the structure through exceedance of design conditions	Current	Unlikely	Minor	**Low**
	With AWRC	Unlikely	Minor	**Low**
Flows leading to erosion or deposition within the waterway or channel banks which affects the performance of the asset	Current	Rare	Minor	**Low**
	With AWRC	Rare	Minor	**Low**

4.2.2. Warragamba Pipeline - Nepean River

The key justifications for the risk ratings assigned to the Warragamba Pipeline crossing of the Nepean River in Table 20 are provided below.

- Flood flows <10% AEP (greater than 1 in 10-year ARI) are not changed by the addition of the AWRC flows and therefore there is no change in expected flood risk to the structure.
- Flood flows at this location are controlled by downstream water levels and the joint probability of flooding in the Nepean and Warragamba Rivers.
- The structure (for both pipelines) is almost fully buried into the bedrock with only a small section potentially exposed to flows.
- The channel upstream and downstream is bedrock controlled and erosion of the bed or banks is unlikely.
- Undercutting of the structure is not likely to occur given the structures construction.
- The existing condition of the section of pipeline on the bed exposed to flow is unknown.

Overall, the risk rating for the pipeline crossing is considered **LOW**, both for current conditions and with the AWRC project.

Table 20 Risk Assessment, Warragamba Pipeline – Nepean River crossing

Specific Impact	*Timeline*	*Likelihood*	*Consequence*	*Risk Rating*
Flows leading to damage to the structure through exceedance of design conditions	Current	Rare	Minor	**Low**
	With AWRC	Rare	Minor	**Low**
Flows leading to erosion or deposition within the waterway or channel banks which affects the performance of the asset	Current	Rare	Minor	**Low**
	With AWRC	Rare	Minor	**Low**

4.2.3. Penrith Weir - Nepean River

The key justifications for the risk ratings assigned to the Penrith Weir in Table 21 are provided below.

- Flood flows break out across the left bank and floodplain downstream of the Victoria Bridge and the weir structure is outflanked.
- The structure has sustained flood damage during previous flood events, however no significant flood damage has occurred since repair works were completed in 1970. Since this time there has been 1 flood event with a magnitude <5% AEP (1 in 20 year). The flood magnitude of the March 2021 event has been estimated at a 1 in 1% AEP (1 in 100 year event) but no detailed hydrologic analysis is presently available to confirm this.
- Flow with an annual exceedance of <15% AEP are not changed by the addition of the AWRC flows and therefore there is no change in expected flood risk to the structure.
- Movement of sediment from upstream would likely result in deposition within the weir pool upstream of the structure, reducing the pool volume.
- Undercutting of the structure is not likely to occur given the structures' construction.
- Sediment movement under non-flood conditions is limited under current conditions and when AWRC flows are included.

Overall, the risk rating for the Penrith Weir is considered **LOW** in relation to flood impacts both for current conditions and with the AWRC project, and **LOW** for non-flood impacts associated with erosion or deposition.

Table 21 Risk Assessment, Penrith Weir

Specific Impact	*Timeline*	*Likelihood*	*Consequence*	*Risk Rating*
Flows leading to damage to the structure through exceedance of design conditions	Current	Unlikely	Minor	**Low**
	With AWRC	Unlikely	Minor	**Low**
Flows leading to erosion or deposition within the waterway or channel banks which affects the performance of the asset	Current	Rare	Minor	**Low**
	With AWRC	Rare	Minor	**Low**

4.2.4. Warragamba Pipeline - South Creek

The key justifications for the risk ratings assigned to the Warragamba Pipeline at South Creek in Table 22 are provided below. This risk applies to the two individual pipelines and the access bridge.

- Flood flows break the banks of South Creek for events with an AEP of 10-50%, with more than 900m of pipeline and roadway potentially inundated.
- High velocities through the South Creek channel section during flood events have the potential to scour the channel bed and banks, destabilizing or undermining the piers of each structure. The embedment depth of the piers is unknown.
- Flood flows are not changed by the addition of the AWRC flows and therefore there is no change in expected flooding and general scour of the channel during flood events.
- The channel bed and bank materials are susceptible to erosion and changes to the channel thalweg and form at the crossing have been observed.
- The failure of the weir structure upstream of the crossing has destabilized the channel and this may propagate downstream towards the structures.
- Enhanced long term channel degradation is unlikely to occur as a direct result of the wet weather flow releases from the AWRC.

Overall, the risk rating for the Warragamba Pipeline at South Creek is considered **MEDIUM** in relation to flood impacts both for current conditions and with the AWRC project, and **MEDIUM** for non-flood impacts associated with erosion or deposition. The risk rating is unchanged with the AWRC project.

Table 22 Risk Assessment, Warragamba Pipeline – South Creek

Specific Impact	*Timeline*	*Likelihood*	*Consequence*	*Risk Rating*
Flows leading to damage to the structure through exceedance of design conditions	Current	Possible	Severe	**Medium**
	With AWRC	Possible	Severe	**Medium**
Flows leading to erosion or deposition within the waterway or channel banks which affects the performance of the asset	Current	Possible	Severe	**Medium**
	With AWRC	Likely	Severe	**Medium**

4.2.5. **Warragamba Weir - Warragamba River**

The key justifications for the risk ratings assigned to the Warragamba Weir in Table 23 are provided below.

- Flood flows are not changed by the addition of the environmental flows and therefore there is no change in expected flood risk to the structure.
- Flood flows at this location are controlled by releases from the Warragamba Dam and the joint probability of flooding in the Nepean and Warragamba Rivers. The structure itself is currently used to dissipate flood energy.
- The structure is founded on bedrock (sandstone) and the channel upstream and downstream is bedrock controlled. Erosion of the bed or banks is unlikely. Some movement of sediment within the channel during large flood events is possible however, the presence of the dam upstream has reduced the overall supply of sediment to this section of the river.
- Undercutting or erosion of the abutments of the structure is not likely to occur given the condition and design of the structure and its foundations.
- The environmental flows do not exceed the capacity of the diversion tunnel.

Overall, the risk rating for the Warragamba Weir is considered **LOW**, both for current conditions and with the AWRC project.

Table 23 Risk Assessment, Warragamba Weir

Specific Impact	*Timeline*	*Likelihood*	*Consequence*	*Risk Rating*
Flows leading to damage to the structure through exceedance of design conditions	Current	Rare	Medium	**Low**
	With AWRC	Rare	Medium	**Low**
Flows leading to erosion or deposition within the waterway or channel banks which affects the performance of the asset	Current	Rare	Medium	**Low**
	With AWRC	Rare	Medium	**Low**

DPI (2014) noted that this section of the Warragamba River will benefit directly from the commencement of variable environmental flows released near the face of the dam. The anticipated benefits include:

- An improvement in water quality,
- Mobilisation of in channel sediment,
- An increase in wetted perimeter and a better defined, active low flow channel,
- Improved water quality through a more natural temperature regime, decrease in nutrients and metals, and increased turnover of pools.

4.3. **Mitigation Measures**

The only location where mitigation measures would be recommended to address both current and potential future erosion is the Warragamba pipeline crossing on South Creek.

The pipeline and associated infrastructure is subject to a **medium** level of flood impacts both for current conditions and with the AWRC project, and **medium** for non-flood impacts associated with erosion or deposition.

It is recommended that more detailed further flood and erosion investigations be undertaken to develop designs for appropriate erosion mitigation actions, which may likely include the installation of rock armour along the banks and bed of the river through the crossing and for a distance upstream and downstream. Any erosion protection measures must consider both the stability of the piers and abutments of the pipeline and road crossing structures. These mitigation measures are recommended based on the existing risk to the pipeline and should be undertaken by the relevant responsible authority.

5. Conclusions

The objective of this study has been to provide an assessment of risks to the integrity and security of WaterNSW lands, assets and infrastructure that may result from the AWRC project, and the proposed measures to mitigate against those risks, including consideration of:

- The effect the development will have on Warragamba Pipeline footings, through potential changed flow regimes and increased flood impacts, and
- Potential direct or indirect increases of erosion or sediment deposition in the pipeline corridors and at the treated water discharge points

This report only covers surface water impacts associated with treated water releases to waterways. Impacts associated with drilling activities for the environmental flow pipeline and impacts to the Upper Canal from the Brine Pipeline installation (including groundwater) are assessed in other reports.

The following table summarises the assessment results covering both current conditions and with the proposed AWRC releases on the Nepean River and South Creek on WaterNSW Infrastructure.

Table 24 Summary of erosion related risk rating for WaterNSW infrastructure as a result of the AWRC releases

Asset	Risk Rating for:	Current Conditions	With AWRC release
Wallacia Weir - Nepean River	Flows leading to damage to the structure through exceedance of design conditions	**Low**	**Low**
	Flows leading to erosion or deposition within the waterway or channel banks which affects the performance of the asset	**Low**	**Low**
Warragamba Pipeline - Nepean River	Flows leading to damage to the structure through exceedance of design conditions	**Low**	**Low**
	Flows leading to erosion or deposition within the waterway or channel banks which affects the performance of the asset	**Low**	**Low**
Penrith Weir - Nepean River	Flows leading to damage to the structure through exceedance of design conditions	**Low**	**Low**

Asset	Risk Rating for:	Current Conditions	With AWRC release
	Flows leading to erosion or deposition within the waterway or channel banks which affects the performance of the asset	**Low**	**Low**
Warragamba Pipeline - South Creek	Flows leading to damage to the structure through exceedance of design conditions	**Medium**	**Medium**
	Flows leading to erosion or deposition within the waterway or channel banks which affects the performance of the asset	**Medium**	**Medium**
Warragamba Weir - Warragamba River	Flows leading to damage to the structure through exceedance of design conditions	**Low**	**Low**
	Flows leading to erosion or deposition within the waterway or channel banks which affects the performance of the asset	**Low**	**Low**

*It should be noted that the risk rating is Medium under current conditions and the risk rating is unchanged with the AWRC project.

Given the low risk rating under current and with the AWRC treated water release for assets along the Nepean River no additional mitigation measures are recommended.

Given the low risk rating under current and AWRC environmental flow release conditions for assets along the Warragamba River no additional mitigation measures are recommended.

Given the medium risk rating under current and AWRC treated flow release conditions for the Warragamba Pipeline crossing of South Creek it is recommended that further investigations are undertaken to design appropriate erosion control measures. Any measures will need to consider the piers and abutments of the pipeline and road crossing structures.

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