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Environmental Impact Statement – Appendix H1: Flooding and Hydrology Assesment Report

Warragamba Dam Raising

Reference No. 30012078
Prepared for WaterNSW
10 September 2021

SMEC INTERNAL REF. 30012078

Executive Summary

Background

The Hawkesbury-Nepean Flood Risk Management Strategy 2016-2036 comprises a mix of infrastructure, non-infrastructure and policy measures that contribute to preventing or mitigating floods, more coordinated and strategic planning in preparing for floods, including increasing ability to evacuate, and responding to and recovering from floods in the Hawkesbury-Nepean Valley.

The preferred infrastructure option from the Hawkesbury-Nepean Flood Risk Management Strategy involves (INSW, 2016):

'introducing a flood mitigation function at Warragamba Dam by raising the dam wall by around 14 metres to reduce average annual flood damages to assets and social amenity and the risk to life'.

The raising of the dam also provides the opportunity to construct infrastructure to allow a new variable environmental flows regime (herein referred to as e-flows) from the dam.

After the submission of a Preliminary Environmental Assessment (PEA) for the proposed dam raising works, the NSW Department of Planning and Environment (DPE) issued Secretary's Environmental Assessment Requirements (SEARs) to be addressed by the Warragamba Dam Raising Environmental Impact Statement (EIS). The EIS is required to inform planning assessments under the *Environmental Planning and Assessment Act 1979* (EP&A Act) and inform a Final business case for Government consideration of whether to progress to phase 2 - implementing the raising of Warragamba Dam wall - subject environmental to planning and approvals.

Additionally, an impact assessment is also required to inform an approval by the Commonwealth Department of the Environment and Energy (DoEE) under the *Environment Protection and Biodiversity Conservation Act 1999* (Cth) (EPBC Act). As there is an Assessment Bilateral Agreement in place between the Commonwealth and NSW Government, the SEARs for the EIS also cover EPBC Act matters.

This Flooding and Hydrology Assessment has been prepared to provide technical guidance and inform the broader EIS that is being prepared for the proposed dam raising Project. A separate technical assessment has been prepared for the proposed e-flows regime and therefore this is not considered in detail in this report.

Potential Flooding and Hydrology Impacts

The study area encompasses the following locations:

- The **construction area** includes the area on and around the existing dam, including the dam wall itself, a central drum gate and spillway, four radial gates and auxiliary spillway as well as auxiliary access roads and dam site buildings.
- The **operation area** includes the areas upstream and downstream of the dam that could be affected by the future operation of the dam with a raised dam wall and operated for flood mitigation as well as water supply.

Hydrology and flooding impacts during the construction phase of the Project may occur during or because of the following activities:

- reduced flow levels and volumes downstream of the dam including changes to water availability and flows for both regulated and unregulated users and the environment
- stormwater runoff from construction and site storage areas
- stormwater and wastewater management
- water take (direct or passive) from surface and groundwater sources
- major flood event occurring during the construction phase

Note that there are only adverse hydrological impacts during construction (no beneficial impacts).

In the operation phase, during small (flood producing) rainfall events when the flood mitigation zone (FMZ) is not used (for example, the lake level below Full Supply Level (FSL)), the Project would have no impact on upstream hydrology and flood behaviour. Potential adverse impacts of the Project on hydrology and flooding would therefore be limited to less frequent rainfall events that result in the Flood Mitigation Zone being activated (that is, when the lake water increases over FSL). Potential impacts during the operational phase of the Project may include:

- increases in flood extents and lake levels in the upstream environment resulting from the FMZ being activated (used to temporarily store flood waters)
- increased flood levels and inundation extent along tributaries of the lake
- changes to flood flow regime (timing, magnitude and duration) downstream of the dam
- changes to erosional processes and river morphology downstream of the dam
- decrease in overbank flood events connecting with wetlands downstream of the dam.

The beneficial impacts related to hydrology are primarily linked to environmental benefits whilst flood impacts are primarily linked to social and economic values. The beneficial impacts of hydrology (primarily linked to surface and groundwater dependent ecosystems, for example, wetlands and floodplain lagoons) and beneficial impacts of flooding are discussed in the following sections. Beneficial impacts on hydrology and flooding during the operational phase of the Project may occur during or because of the following activities:

- reduced peak flood flows, levels, extents, velocity and scour potential in the downstream environment
- increase warning time for evacuation in downstream environment
- reduced risk to life and infrastructure damage due to the mitigation of floods
- changes to the environmental flow regime in the downstream environment.

Management measures

Safeguards and management measures have been developed to avoid, minimise or manage potential risks identified in this report. Relevant management and mitigation measures are presented in Table 1.

Table 1 Safeguards and management measures

Impact	Environmental management measure	Responsibility	Timing
Impacts during construction	A Construction Flood Management Plan will be developed to minimise any changes in hydrology up and downstream of the dam and minimise risks to the construction site. A Dam Safety Emergency Plan will also be prepared in accordance with the requirements of Dams Safety NSW.	WaterNSW Construction Contractor	Pre-construction
Impacts from operation of FMZ	A detailed operational protocol for the operation of the FMZ will be developed in consultation with relevant downstream and upstream stakeholders.	WaterNSW	Operation
Monitoring	Investigate water monitoring systems to reflect Project changes in operational protocols. Investigate additional monitoring station downstream of the Kedumba River.	WaterNSW	Pre-operation

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1 Introduction

1.1 Background

The potential for significant flooding of the Hawkesbury-Nepean Valley was known by the local Aboriginal community before the first settlement of the area in the late 1790s. In the very early years of European settlement the risk of flooding was recognised and a series of proclamations that warned of the risk of flooding were issued.

During the 1980s and 1990s updated flood investigation techniques and paleo flood evidence emerged that floods significantly larger than any historically recorded could occur in the Hawkesbury-Nepean Valley. Further investigations into flood mitigation were undertaken and culminated in 1995 in a proposal and associated EIS to raise Warragamba Dam by 23 metres for flood mitigation. The 23 metre dam raising proposal did not proceed and the EIS was withdrawn by the NSW Government at the time. In the late 1990s, major upgrades of Warragamba Dam were undertaken to prevent dam failure during extreme flooding events in order to protect Sydney's water supply and to prevent catastrophic downstream floods from dam failure. However, these works only dealt with dam safety issues and did not address the major flood risks to the people and businesses in the Hawkesbury-Nepean Valley and the NSW economy as a whole.

In 2011, an approximately 1 in 100 chance in a year flood impacted Brisbane, resulting in significant damage, economic costs and social disruption. The substantial impacts of the 2011 Brisbane flood led the NSW Government to recommence investigations into flood mitigation options for the Hawkesbury-Nepean Valley through the Hawkesbury-Nepean Valley Flood Management Review

The Stage One review found that the current flood management and planning arrangements were insufficient in mitigating the flood risk and no single mitigation option could address all the flood risk present in the Hawkesbury-Nepean Valley. The raising of Warragamba Dam to create a flood mitigation zone (FMZ) was found to be the most effective infrastructure measure that could have a major influence on flood levels during those events when most damages occur.

In May 2014, the NSW Government established the Hawkesbury-Nepean Flood Management Taskforce to lead Stage Two of the Review. As part of Stage Two, a more detailed cost-benefit analysis of specific flood mitigation infrastructure options was undertaken. To help inform the cost-benefit analysis, a high level environmental, social and cultural-heritage impact assessment was undertaken of various flood mitigation options.

Following on from these studies, the Hawkesbury-Nepean Flood Management Taskforce has since proposed the Hawkesbury-Nepean Flood Risk Management Strategy 2016-2036 (Infrastructure NSW 2017) to reduce flood risk to life and potential impacts on the economy and social amenity from riverine flooding in an integrated and effective manner.

The Hawkesbury-Nepean Flood Risk Management Strategy 2016-2036 comprises a mix of infrastructure, non-infrastructure and policy measures that contribute to preventing or mitigating floods, more coordinated and strategic planning in preparing for floods, including increasing ability to evacuate, and responding to and recovering from floods in the Hawkesbury-Nepean Valley.

The preferred infrastructure option from the Hawkesbury-Nepean Flood Risk Management Strategy involves (INSW, 2016):

‘introducing a flood mitigation function at Warragamba Dam by raising the dam wall by around 14 metres to reduce average annual flood damages to assets and social amenity and the risk to life’.

The raising of the dam also provides the opportunity to construct infrastructure to allow a new variable environmental flows regime (herein referred to as e-flows) from the dam.

After the submission of a Preliminary Environmental Assessment (PEA) for the proposed dam raising works, the then NSW Department of Planning and Environment (DPE) issued Secretary’s Environmental Assessment Requirements (SEARs) to be addressed by the Warragamba Dam Raising Environmental Impact Statement (EIS). The EIS is required to inform planning assessments under the *Environmental Planning and Assessment Act 1979* (EP&A Act) and inform a Final business case for Government consideration of whether to progress to phase 2 - implementing the raising of Warragamba Dam wall - subject environmental to planning and approvals.

Additionally, an impact assessment is also required to inform an approval by the Commonwealth Department of the Environment and Energy (DoEE) under the *Environment Protection and Biodiversity Conservation Act 1999* (Cth) (EPBC Act). As there is an Assessment Bilateral Agreement in place between the Commonwealth and NSW Government, the SEARs for the EIS also cover EPBC Act matters.

This Flooding and Hydrology Assessment has been prepared to provide technical guidance and inform the broader EIS that is being prepared for the proposed dam raising Project. A separate technical assessment has been prepared for the proposed e-flows regime and therefore this is not considered in detail in this report.

1.2 Scope of assessment

The scope of this assessment includes:

- changes in flooding – both upstream and downstream
- changes in other hydrological characteristics of waterways - both upstream and downstream
- impacts on water users
- impacts of climate change.

1.3 Project description

1.3.1 Overview

Warragamba Dam and the Lake Burragorang reservoir are situated in a narrow gorge on the Warragamba River about 65 km west of the Sydney central business district (CBD). Created by damming Warragamba River and flooding the Burragorang Valley, Lake Burragorang is four times the size of Sydney Harbour and is currently managed as a water supply dam (WaterNSW, 2017).

Water from the dam flows by gravity through two pipelines (27 km in length) to the Prospect Water Filtration Plant located 15 km west of Sydney's CBD. Water treated at this plant supplies water for around 80% of Sydney's population. Water from the dam is also supplied to the townships of Warragamba, Penrith and the Lower Blue Mountains through filtration plants at both Warragamba and Orchard Hills. A deep-water pumping station is located at Warragamba Dam to enable continued supply if the water level falls below the outlets during extended dry periods. Water is also released into the Warragamba River to provide a secure water supply to the population of North Richmond and as e-flows (albeit limited at this stage) to maintain downstream river health and provide community benefits (WaterNSW, 2016a).

Since the completion of construction of the original dam in 1960, the flow contribution from Warragamba Dam to the Warragamba River and subsequently the Hawkesbury-Nepean River has varied. The current regime is limited to the following releases:

- fixed low flow releases (22 megalitres/day in winter and 30 megalitres/day in summer, 5 megalitres/day of which is for the dilution of sewage treatment plant (STP) outfalls)
- operational releases
- flows during heavy rainfall when the dam has filled, and water flows over the spillway.

Currently when the inflows cause the storage levels to rise above full supply level the dam is operated according to H14 rules or protocol. H14 is designed to incrementally open the drum and radial gates to minimise rapid increases in the rate of rise of downstream flooding.

Warragamba Dam Raising is a project to provide capacity to facilitate flood mitigation by increasing the crest levels of the central spillway by approximately 12m and increasing the dam abutments (including access road) by 17m which includes approximately 3m to be resilient to the future impacts of climate change. The Project would:

- enable the dam to capture and temporarily hold back inflows from the Lake Burragorang catchment behind the wall
- provide capacity to facilitate flood mitigation by increasing the crest levels of the central spillway by approximately 12 metres above the full supply level and increasing the dam abutments (including access road) by 17 metres, which includes approximately three metres to be resilient to the future impacts of climate change
- provide infrastructure to allow for environmental flows to be released from Warragamba Dam.

The Project would include the following main activities and elements:

- demolition or removal of parts of the existing Warragamba Dam, including the existing drum and radial gates, to allow for the new works
- thickening and raising of the dam abutments
- thickening and raising of the central spillway
- new gates or slots for discharge of water from the dam
- modifications to the auxiliary spillway

- other infrastructure and elements including new roads, bridges and ancillary facilities
- environmental flows infrastructure
- operation of the dam for flood mitigation.

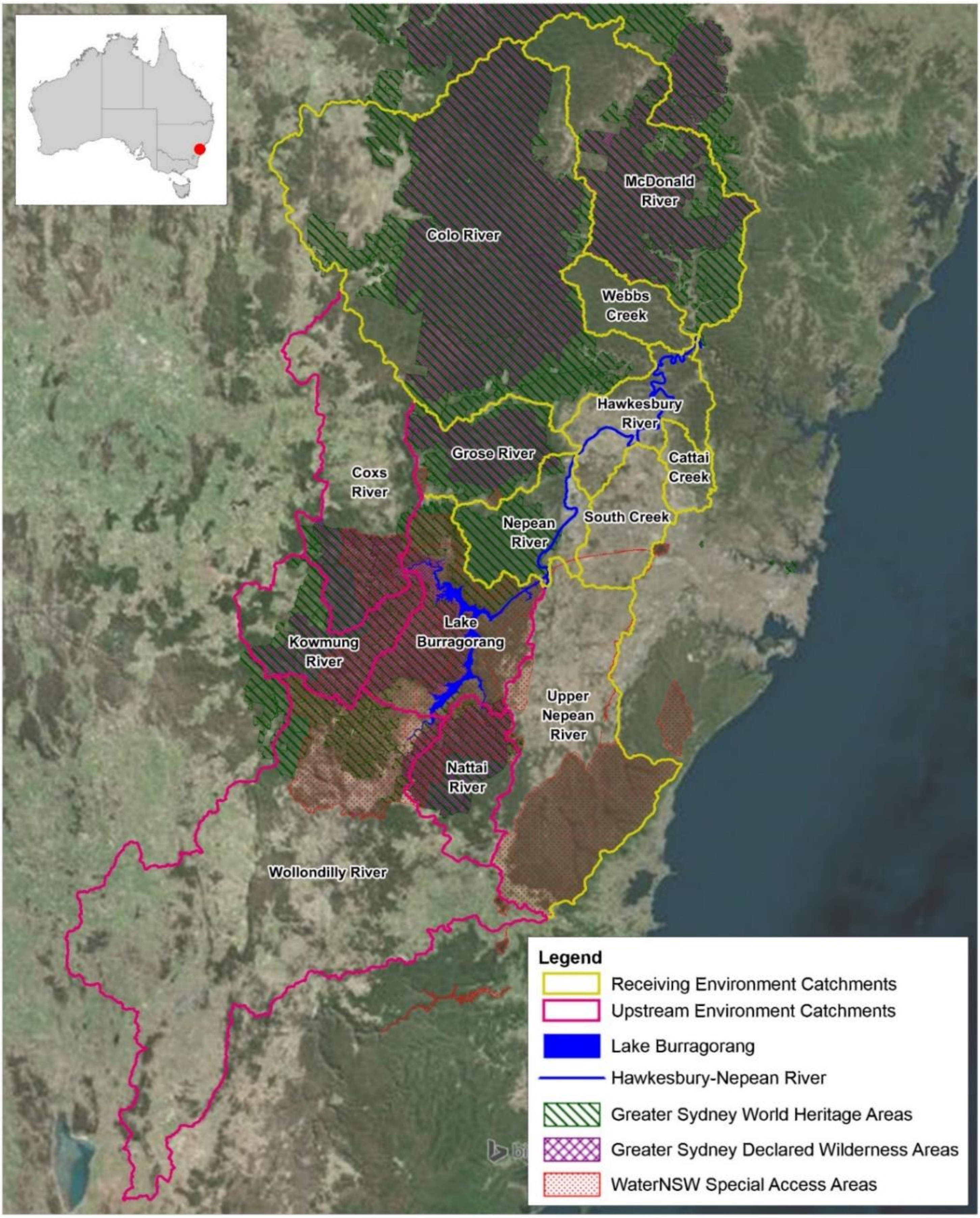
The Project site is shown in Figure 1-1.

The study area encompasses the following locations:

- The **construction area** includes the area on and around the existing dam, including the dam wall itself, a central drum gate and spillway, four radial gates and auxiliary spillway as well as auxiliary access roads and dam site buildings.
- The **operation area** includes the areas upstream and downstream of the dam that could be affected by the future operation of the dam with a raised dam wall and operated for flood mitigation as well as water supply.

Upstream of the dam, the **upstream environments** include Lake Burragorang (that is, the reservoir formed by Warragamba Dam) and its tributaries and areas of the Blue Mountains National Park, Burragorang State Conservation Area, Nattai National Park, Nattai State Conservation Area and Yerranderie State Conservation Area. Most of the Blue Mountains National Park is also in the Greater Blue Mountains World Heritage Area (GBMWHA) and some small areas of the GBMWHA would be impacted by increased temporary inundation.

Downstream of the dam, the **downstream environment** (receiving environment), includes the freshwater and estuarine reaches of the river system and its tributaries between Warragamba Dam where it joins the Nepean River near Wallacia (not including the reach of the Nepean River upstream of Wallacia) and Wisemans Ferry as well as the adjacent riparian zone, floodplain and wetland/lagoon waterbodies. During flood events, there are backwater flooding impacts along South Creek which flows into the Hawkesbury River downstream of Windsor and consequently South Creek has been included in the Operational Study Area.



Title:
Project Locality and Impact Areas

Figure: 1-1

Rev: A

BMT WBM endeavours to ensure that the information provided in this map is correct at the time of publication. BMT WBM does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.

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Approx. Scale

BMT
www.bmt.org

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1.3.2 Construction activities

A preliminary construction program is presented in Figure 1-2 with the Project likely to be completed between four to five years from commencement. Note that abutment and central spillway works are required to be largely completed before the new auxiliary spillway crest can be completed to allow water to be discharged via the auxiliary spillway if a major flood occurs during construction

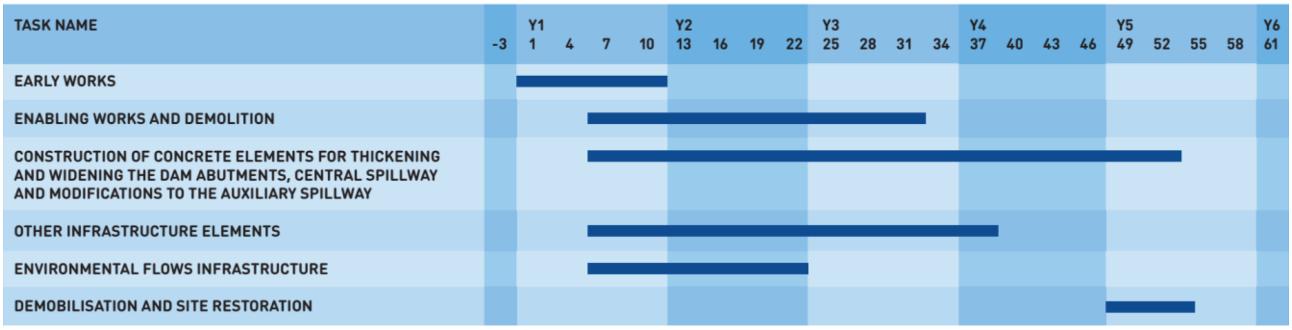


Figure 1-2 Preliminary construction program

During construction, several auxiliary construction facilities will also be required to support the dam raising. These include concrete batching facilities (to avoid the need to transport concrete to the site), a boat ramp providing access for water-based construction, main site office and facilities, access road to dam wall base, and material laydown and storage areas. The footprint of this infrastructure (the **construction area**), including areas that will require clearing, are shown in Figure 1-3.

Construction activities will be facilitated by dewatering and reservoir lowering across the Project site. While the exact sequencing and extent of activities requires finalisation, this dewatering is anticipated to consist of the following (Stantec & GHD, 2018):

- initial lowering of the reservoir level to Reduced level (RL – metres above mean sea level) 111.72 m using central spillway gates
- dewatering on work areas using cofferdams and caissons
- diversion of water from the central spillway to the auxiliary spillway, facilitated by changes to fuse plug embankment material.

The dewatering process will be managed to ensure no increase to flood or environmental risks downstream. Additionally, changes to spilling processes during construction will be closely monitored and managed to ensure discharge capacity is maintained at a suitable level to respond to flooding events.

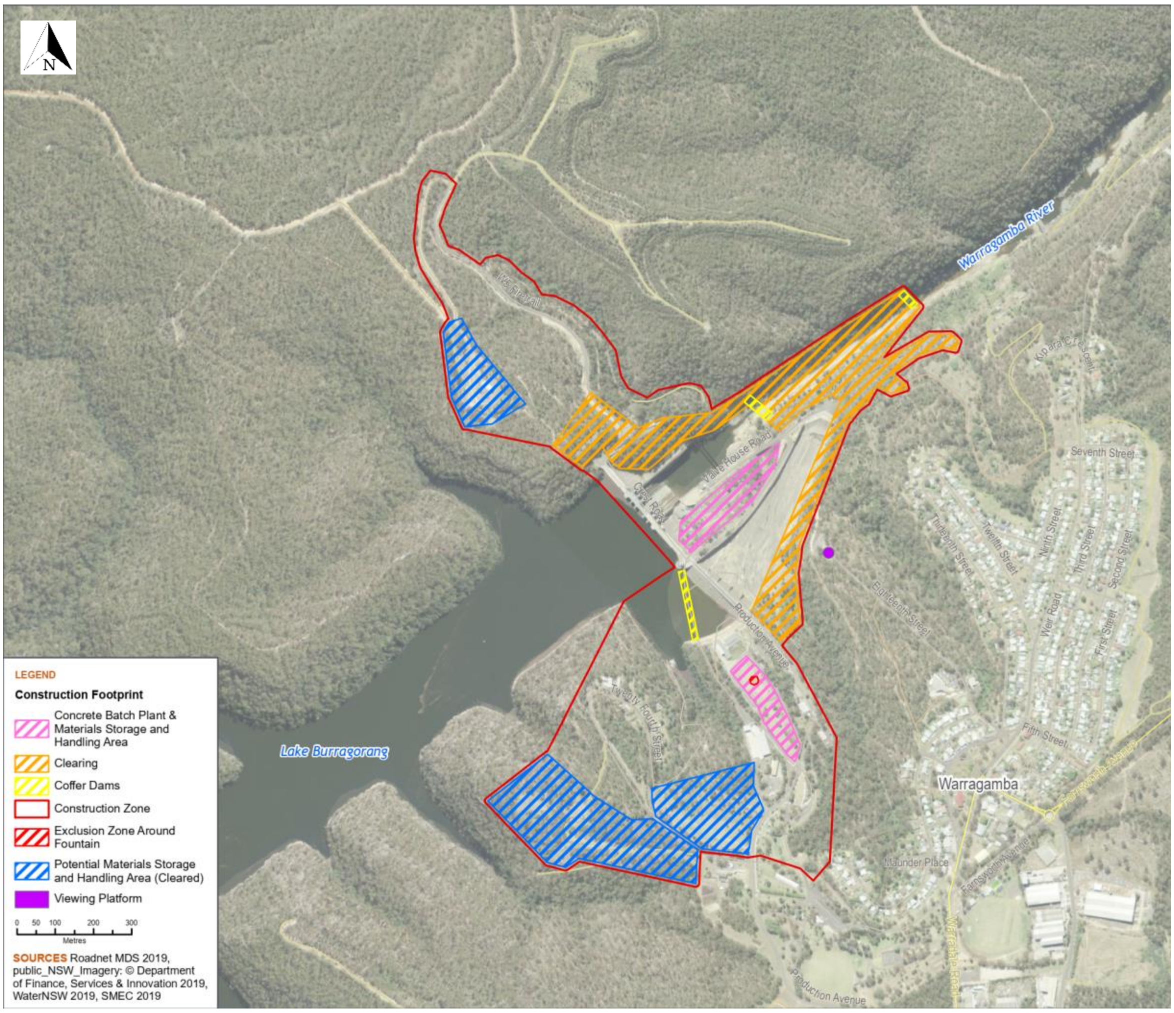


Figure 1-3 Project construction area

1.3.3 Operation activities

Following the construction works, Warragamba Dam will continue to operate as a water supply dam as well as a flood mitigation dam. However, the raising will create a new FMZ that operates above the existing full supply level (FSL). The dam will be subject to two operational regimes, depending on water level:

(1) normal operations, with e-flows as required

(2) flood operations (subject to agreed protocols).

Normal operations will apply wherever the dam lake level is at or lower than the FSL or RL116.72 m. This replicates the existing operations of the dam (without the wall raising) but will include operational releases associated with maintaining e-flows.

Flood operations would apply when the water level is higher than the full supply level. The FMZ would provide capacity to capture temporarily around 1,000 gigalitres of water during a flood. For larger floods the FMZ would be filled and uncontrolled discharge would occur over the central spillway, and potentially, auxiliary spillway of the dam.

When inflows are falling, the FMZ will be emptied to ensure capacity for any subsequent events. The rate of discharge from the FMZ would be determined based on several factors:

- ensuring the FMZ is emptied in sufficient time to capture a subsequent flood event
- minimising the duration of upstream catchment inundation
- not causing any increase in the extent of flooding downstream of the dam
- the need to keep downstream bridge river crossings open.

There will be two different emptying protocols:

(1) Minor flood releases – releases of inflows captured from a 5% to 2.5% AEP event or at the tail end of larger floods. The rate of discharge of these releases will be identified based on potential flooding risks downstream, noting that as the dam raising will reduce the immediate exposure of downstream areas to these flood events, the subsequent release from the dam will need to be restricted to avoid increases in these reduced downstream flooding extents. Typically, discharges would be at 1,150 m^3/s (around 100 GL/day) but would not occur until after the peak of the flooding downstream has passed.

(2) Major flood releases – releases for significant flood events. As the FMZ is designed to contain a 5% to 2.5% AEP event above FSL, any event above this will cause spilling to downstream areas, albeit at a lower level. During this scenario there is an opportunity to increase the rate of discharge from the FMZ at a higher rate than for minor flood releases without increasing the extent of downstream flooding (that is, piggyback releases). This can typically occur for the first two days before the FMZ discharge rate would then be reduced to the same rate as for minor flood releases (that is, 1,150 m^3/s).

For all events, the dam raising will cause a substantial reduction in the flow rate of spills over the dam. This will reduce flood levels and delay the downstream peak.

The extent and duration of inundation is important to defining potential impacts on environmental values. The approximate change to upstream lake surface area based on recent hydrosurvey data of Lake Burragorang (data provided by INSW, 19 February 2015) is summarised in Table 1-1. The Warragamba Dam Raising is expected to temporarily increase the existing impoundment area within the upstream reservoir from approximately 75 km^2 to up to 94 km^2.

Table 1-1 Estimated upstream water level and inundation extent based on 2014 Lake Burragorang hydrosurvey

Dam condition	Maximum water level at dam wall (RL m)	Lake surface area (km^2)	Change to lake surface area relative to existing (%)
Existing crest level	116.72	75.1	-
Proposed raised dam wall (~12 m)	128.45	93.7	+25

1.4 Environmental assessment requirements

The Project has been deemed State Significant Infrastructure (SSI) under the EP&A Act. The Secretary of the NSW DPE has issued SEARs for the Project, which set the terms of reference for an EIS under the EP&A Act and identifies desired performance outcomes. The SEARs relevant to this technical assessment are present in Table 1-2.

Table 1-2 SEARs addressed by this report

SEAR	Requirement	Where addressed
8. Flooding The Project minimises adverse impacts on existing flooding characteristics. Construction and operation of the Project avoids or minimises the risk of, and adverse impacts from, infrastructure flooding, flooding hazards, or dam failure.	1. The Proponent must quantify what flood events can be mitigated by the dam.	Section 4.2.3
	2. The Proponent must assess and model the impacts on flood behaviour during construction and operation for a full range of flood events up to the probable maximum flood (accounting for sea level rise and storm intensity due to climate change) including: (a) any detrimental increases in the potential flood affectation of other developments, land, properties, assets and infrastructure. This may include redirection of flow, flow velocities, flood levels, hazards and hydraulic categories;	Construction – Section 4.1 Operation – Section 4.2
	(b) quantify the benefits of reducing flood affectation to developments, land, properties, assets and infrastructure;	Chapter 4 of EIS Socio-economic Impact Assessment
	(c) consistency (or inconsistency) with applicable Council floodplain risk management plans;	Section 4.2.3
	(d) compatibility with the flood hazard of the land;	Section 4.2.3
	(e) compatibility with the hydraulic functions of flow conveyance in flood ways and storage areas of the land;	Section 4.2.3
	(f) downstream velocity and scour potential;	Section 4.2.3
	(g) impacts the development may have upon existing community emergency management arrangements for flooding. These matters must be discussed with the State Emergency Services (SES) and relevant Councils; and	Section 4.2.3
	(h) any impacts the development may have on the social and economic costs to the community as consequence of flooding. Specifically, events at a minimum must be assessed for the 1 in 5 year, 1 in 10 year, 1 in 20 year, 1 in 100 year and the probable maximum flood. Modelling should include flood characteristics such as extent, level, velocity, and rate of rise at a minimum. Discussion and an assessment of the flood management zone also needs to be included.	Chapter 4 of EIS Socio-economic Impact Assessment
	3. The Proponent must model the effect of the proposed project on the flood behaviour of the broader catchment under the following scenarios: (a) Current flood behaviour for a range of design events as identified in point 2 above;	Section 4.2.3
	(b) The 1 in 200 and 1 in 500 year flood events as proxies for assessing sensitivity to an increase in rainfall intensity of flood producing rainfall events due to climate change or modelling of the	Section 4.2.4

SEAR	Requirement	Where addressed
	1 in 100 year flood with the range of climate change scenarios recommended in Australian Rainfall and Runoff 2016.	
	4. The Proponent must identify and address any impacts the Project may have upon existing emergency management arrangements for flooding. These matters are to be discussed with the SES and relevant councils downstream and upstream of the Dam.	Section 4.2.3
	5. The assessment must discuss emergency management, evacuation and access, and contingency measures for the construction and operational stages of the Project considering the full range or flood risk including the probable maximum flood. These matters are required to be discussed with the SES and relevant councils.	Construction – Section 4.1 Operation - Section 4.2.4
	6. Discussion in the assessment of the consequences of flooding on social and economic costs to the community and in the broader catchment, including up to the probable maximum flood level.	Chapter 4 of EIS Socio-economic Impact Assessment
20. Water - Hydrology Long term impacts on surface water and groundwater hydrology (including drawdown, flow rates and volumes) are minimised. The environmental values of nearby, connected and affected water sources, groundwater and dependent ecological systems including estuarine and marine water (if applicable) are maintained (where values are achieved) or improved and maintained (where values are not achieved). Sustainable use of water resources.	1. The Proponent must consider potential alternatives for managing flood waters and justify the selection having regard to the relative environmental impacts.	Chapter 4 of EIS and Chapter 30 of EIS
	2. The Proponent must describe (and map) the existing hydrological regime for any surface and groundwater resource (including reliance by users and for ecological purposes) likely to be impacted by the Project, including stream orders, as per the FBA. Mapping must include upstream and downstream tributaries that may potentially be impacted, including: (a) the extent of regional flood up to the probable maximum flood;	Section 3.1 and Section 3.2
	(b) flood planning area, the area below the flood planning level (area below the 100 year ARI plus freeboard);	Section 3.2
	(c) hydraulic categorisation (floodways and flood storage areas); and	Section 3.2
	(d) hazard categorisation. The extent of mapping/modelling used needs to be identified and rationalised.	Section 3.2
	3. The Proponent must prepare a detailed water balance for ground and surface water including the intake and discharge locations, where relevant, volume, frequency and duration of flooding events (1 in 5 year, 1 in 10 year, 1 in 20 year, 1 in 100 year, and probable maximum flood) and at times of non-flood.	Section 4
	4. The Proponent must assess (and model if appropriate) the impact of the construction and operation of the Project and any ancillary facilities (both built elements and discharges) on surface and groundwater hydrology in accordance with the current guidelines, including:	Section 4
	(a) natural processes within rivers, wetlands, estuaries, marine waters and floodplains that affect the health of the fluvial, riparian, estuarine or marine system and landscape health (such as modified discharge volumes, durations	Section 4.3 Aquatic Ecology Assessment Report

SEAR	Requirement	Where addressed
	and velocities), aquatic connectivity and access to habitat for spawning and refuge;	
	(b) impacts from any permanent and temporary interruption of groundwater flow, including the extent of drawdown, barriers to flows, implications for groundwater dependent surface flows, ecosystems and species, groundwater users and the potential for settlement;	Downstream Biodiversity Assessment Report
	(c) changes to environmental water availability and flows, both regulated/licensed and unregulated/rules-based sources;	Section 4.3
	(d) direct or indirect increases in erosion, siltation, destruction of riparian vegetation or a reduction in the stability of river banks or watercourses;	Soils and Contamination Report
	(e) minimising the effects of proposed stormwater and wastewater management during construction and operation on natural hydrological attributes (such as volumes, flow rates, management methods and re-use options) and on the conveyance capacity of existing stormwater systems where discharges are proposed through such systems; and	Section 4.2 and 4.3
	(f) water take (direct or passive) from all surface and groundwater sources with estimates of annual volumes during construction and operation.	Section 4.1 and Section 4.4
	5. The Proponent must identify any requirements for baseline monitoring of hydrological attributes.	Section 5
	6. The Proponent must detail a framework for managing water releases from the dam that are capable of meeting the objectives of the Project (in terms of flood mitigation), ensures impacts to upstream and downstream areas and ecosystems are minimised. The framework shall include consideration of the potential rates of rise and fall in the river, timing of water releases. These shall include consideration of antecedent, conditions within the river, flooding impacts, and transparent and translucent flows.	Section 1.3.3
	7. The Proponent must assess the potential impact on groundwater and surface water users, details of how existing water rights will be protected, including with respect to availability, quantity and quality of the water, noting the interjurisdictional users within the potentially impacted area. This would include an assessment of environmental availability, both regulated and unregulated use, licenced and rules-based sources of such water.	Section 4.3
	8. The Proponent must consider and discuss the rate at which flood waters would potentially recede following a probable maximum flood event, the impact on vegetation both upstream and downstream from the flood and the impact on water quality over time as flood waters are released from the dam throughout the catchment. Geomorphology and river management should be taken into account.	Section 4.2.3

2 Existing flood information

The Hawkesbury-Nepean Valley has one of the most significant flood risk exposures within Australia (Bewsher Consulting, 2012). The risk to life and risk to property due to flood exposure in the Hawkesbury-Nepean Valley is well known and has been the subject of numerous studies, including the Hawkesbury-Nepean Valley Flood Risk Management Strategy (Infrastructure NSW 2017) prepared on behalf of the NSW State Government.

The flood data presented in this report has been provided by WMAWater for INSW from studies undertaken as part of the ongoing floodplain risk management in the Hawkesbury-Nepean. No additional modelling has been undertaken by BMT or SMEC in preparation of this report, with existing modelling results provided by WMAWater considered fit for purpose.

2.1 Adopted terminology

Australian rainfall and runoff – A guide to flood estimation (ARR) (Geoscience Australia, 2019) is a national guideline document, data and software suite that can be used for the estimation of design flood characteristics in Australia. ARR 2019 recommends the use of Annual Exceedance Probability (AEP) to describe flood probabilities or frequency. Annual Exceedance Probability (AEP) is the probability of an event being equalled or exceeded within a year. AEP may be expressed as either a percentage (%) or 1 in X. Floodplain management typically uses the percentage form of terminology. Therefore a 1% AEP event or 1 in 100 AEP has a one per cent chance of being equalled or exceeded in any year. This report uses the terminology of 1% AEP. Average Recurrence Interval (ARI) is an alternate terminology representing the average time period (years) between occurrences equalling or exceeding a given value. Refer to Table 2-1 for a definition of AEP and the ARI equivalent.

Table 2-1 Design flood terminology

AEP[1]	1 in X[2]	ARI[3]	Comments
Extreme Flood / PMF[4]			A hypothetical flood or combination of floods, which represent an extreme scenario.
0.2%	500	500 years	A hypothetical flood or combination of floods with a 0.2% probability of occurring in any given year or likely to occur on average once every 500 years
0.5%	200	200 years	As for the 0.2% AEP flood but with a 0.5% probability or 200 year return period.
1%	100	100 years	As for the 0.2% AEP flood but with a 1% probability or 100 year return period.
5%	20	20 years	As for the 0.2% AEP flood but with a 5% probability or 20 year return period.
10%	9.5	9.5 years	As for the 0.2% AEP flood but with a 10% probability or 9.5 year return period.
20%	4.5	4.5 years	As for the 0.2% AEP flood but with a 20% probability or 4.5 year return period.

1 Annual Exceedance Probability (%)
2 1 in X - annual probability of occurrence
3 Average Recurrence Interval (years) approximate interval years provided in table with AEP = 1-exp(-1/ARI)
4 A PMF (Probable Maximum Flood) is not necessarily the same as an Extreme Flood.

A Probable Maximum Flood (PMF) is an estimate that represents the maximum flood magnitude possible in a catchment which is not assigned a likelihood of occurring.

2.2 Previous studies

The Hawkesbury-Nepean Valley Regional Flood Study (WMAWater, 2019) represents the contemporary flood study for the Hawkesbury-Nepean Valley. The Regional Flood Study builds upon previous modelling and analysis developed as part of the flood study completed by WMAWater as a component of the Warragamba Dam Auxiliary Spillway Environmental Impact Study (ERM Mitchell McCotter, 1996).

The Regional Flood Study is a technical document describing the flood behaviour of the main Hawkesbury-Nepean River from Bents Basin near Wallacia and Warragamba Dam downstream to Brooklyn Bridge. The mainstream river flooding behaviour was assessed for existing conditions and under projected climate change scenarios. It does not include local catchment flooding or local overland flow inundation or the proposed raising of Warragamba Dam.

As part of the Warragamba Dam raising Project, WMAwater was engaged by WaterNSW to undertake modelling of the increase in duration of temporary inundation during large inflow events upstream.

2.3 Models

A summary of the numerical models developed for the Regional Flood Study is provided below.

Hydrological Model

The hydrological model simulates the rate at which rainfall runs off the catchment. The amount of rainfall runoff from the catchment is dependent on:

- the catchment slope, area, vegetation, urbanisation and other characteristics
- variations in the distribution, intensity and amount of rainfall
- the antecedent moisture conditions (dryness/wetness) of the catchment.

The software product RORB has been used for the hydrological modelling. In the adopted model layout, the catchment was sub-divided into a network of sub-catchments inter-connected by channel reaches representing the creeks and rivers. The model layout consists of 121 sub-areas defining the total catchment area as shown Figure 2-1. It is based on design rainfall inputs that reflect current best practice.

A special sub-routine, DAMROU, was added to the RORB program to model flow through the Lake Burragorang Reservoir taking account of the gate operations at the dam. The subroutine was modified as part of the Regional Flood Study to also include simulation of the fuse plug operation on the auxiliary spillway (WMAWater, 2019).

The model was calibrated to available streamflow and rainfall data, mainly at stations upstream of the dam, and the calibration parameters used to estimate suitable parameters in catchments in the downstream valley.

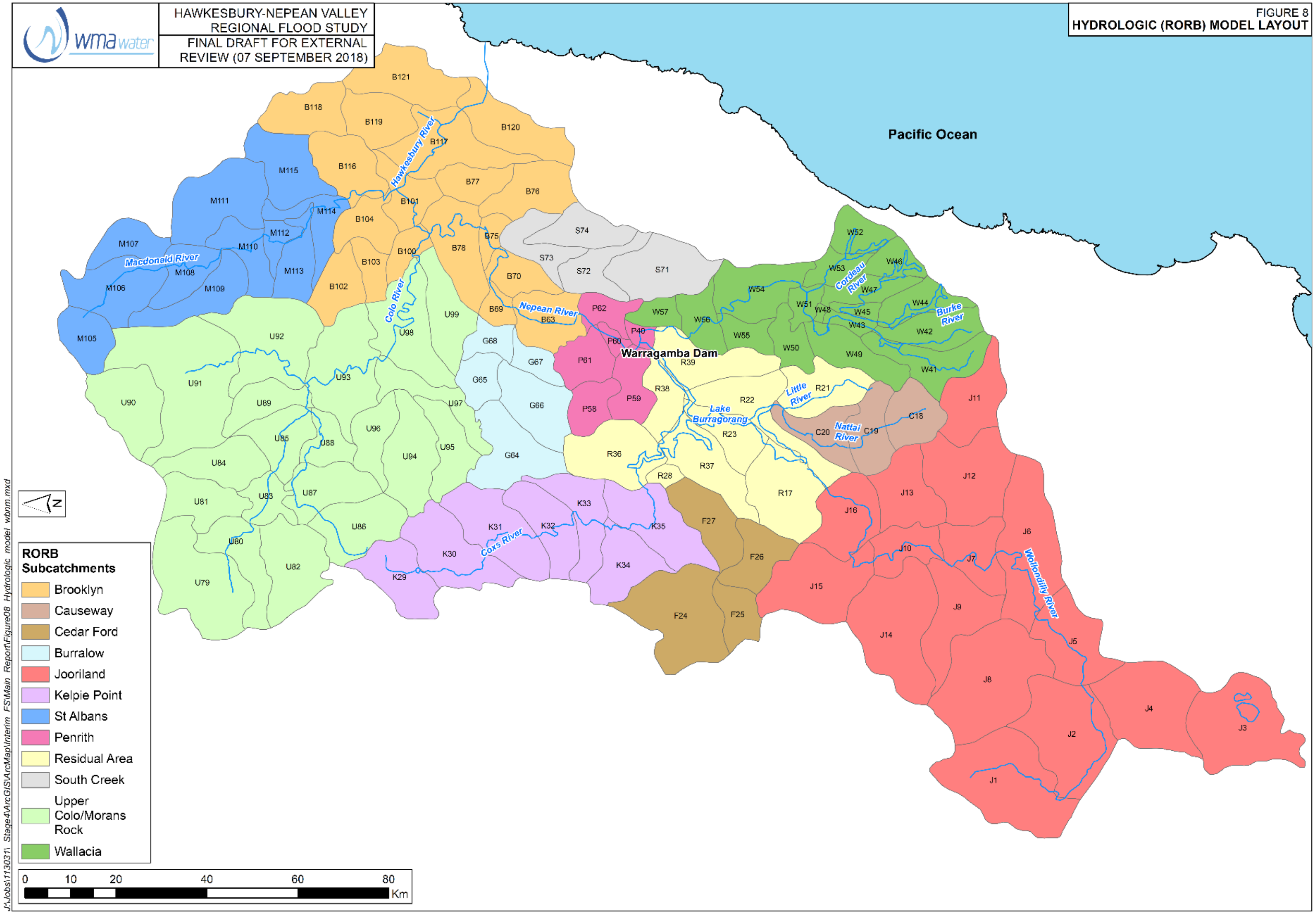


Figure 2-1 RORB hydrological model layout (WMAWater, 2018)

The output from the hydrological model is a series of flow hydrographs at selected locations such as at the boundaries of the hydraulic model. These hydrographs are used by the hydraulic model to simulate the passage of the flood through the catchment.

Upstream Environment Hydraulic Model

As part of the Warragamba Dam Raising Project, WMAWater has utilised an existing MIKE11 one-dimensional hydraulic model obtained from WaterNSW. The MIKE11 model was used to assist in the calibration of the RORB model between the dam and the inflow gauges.

The extent of the MIKE11 model is shown in Figure 2-2. Cross sections are generally located approximately 1 km to 2 km apart and the modelled branches extend up to where gauged inflows are recorded:

- Nattai River – extends to 'The Causeway', approximately 10.8 km upstream of the junction with the Wollondilly River (approximately 48 km from Warragamba Dam)
- Wollondilly River – extends to Jooriland, approximately 48 km upstream of the junction with the Coxs River (approximately 67 km from Warragamba Dam)
- Kowmung River – extends to 'Cedar Ford', approximately 15 km upstream of the junction with the Coxs River (approximately 70 km from Warragamba Dam)
- Coxs River – extends to 'Kelpie Point', approximately 36 km upstream of the junction with the Wollondilly River (approximately 55 km from Warragamba Dam)

Downstream Environment Hydraulic Model

The distance from Warragamba Dam to the ocean is approximately 200 kilometres and includes:

- narrow incised valleys (from Warragamba to Penrith)
- deep river channels that can convey a 1 in 50 AEP flood (Penrith)
- wide floodplains with a large flood range (Windsor)
- a choked river valley that transitions into a drowned river valley (downstream of Windsor to the ocean).

Model selection is detailed in The Hawkesbury-Nepean Valley Regional Flood Study (WMAWater, 2019). The flood study reviewed the two-dimensional model TUFLOW HPC (Heavily Parallelised Compute), however it was concluded that modelling of the entire valley was not possible due to topographical constraints such as the gorge upstream of Penrith. While the Hawkesbury-Nepean floodplain is challenging for two-dimensional models, the quasi two-dimensional model developed in earlier studies (RUBICON) can be run fast enough (5,000 times faster than the two-dimensional model) that it can be used in a Monte Carlo environment (refer to Section 2.4).

A quasi two-dimensional hydraulic model using RUBICON modelling software was therefore developed for the floodplain area downstream of Warragamba Dam. The extent and layout of the RUBICON model is shown in Figure 2-3 covering a total river length of 360 kilometres. With regard to the RUBICON model, the following is noted:

- on the Nepean River, the model extends upstream to Camden although it is noted accurate modelling begins below Bents Basin
- the Warragamba River is modelled from the dam (which is represented by a point inflow) to the Warragamba Junction
- South Creek and Eastern Creek are both modelled by a series of branches which extend upstream as far as the M4 Motorway and Richmond Road respectively
- the Colo River is modelled up to the gauging station at Morans Rock
- the downstream model boundary is at a line between Barrenjoey and Box Heads at the entrance to Broken Bay.

Model calibration included:

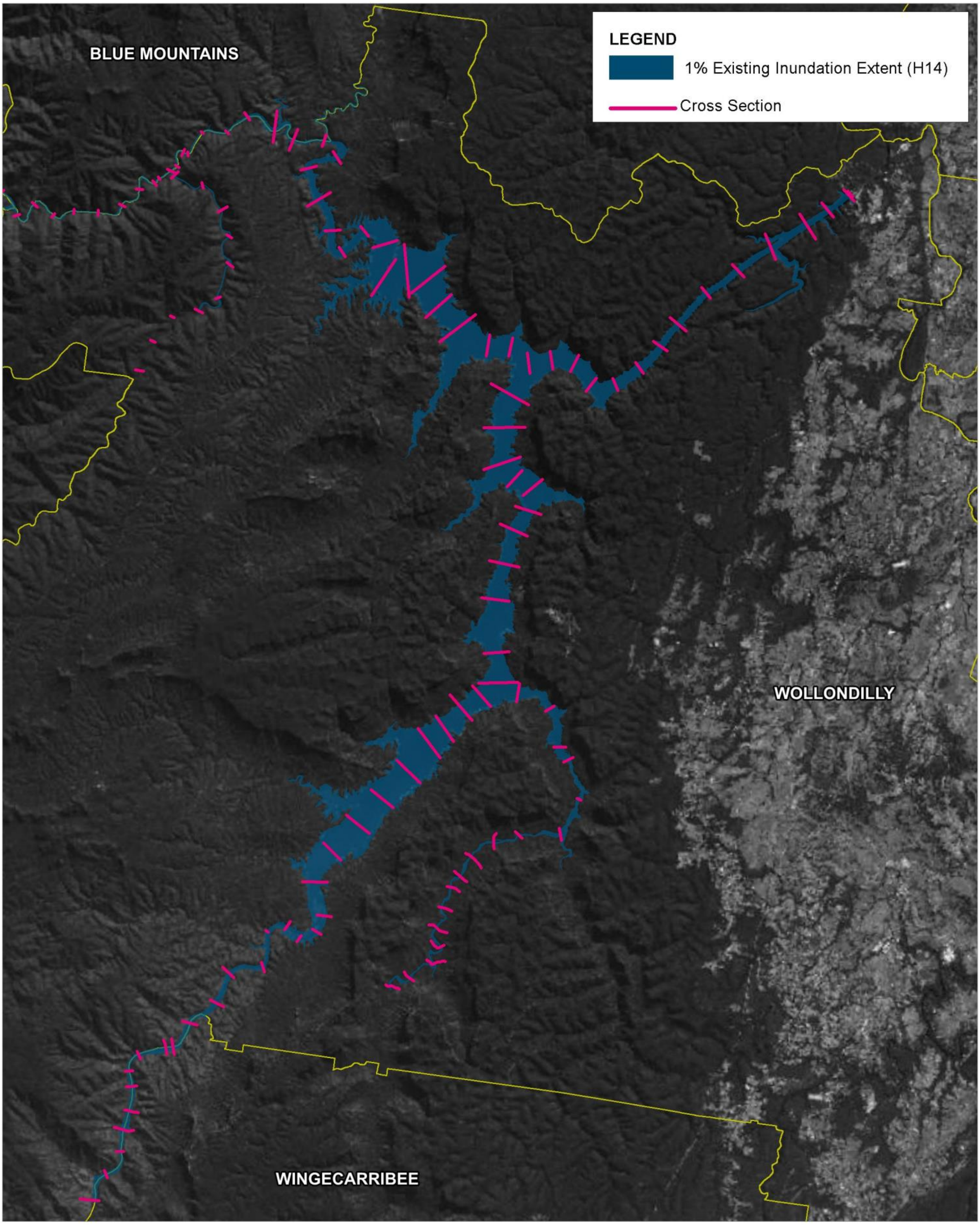
- increasing the number of model sub-areas
- calibrating the model at additional locations within the catchment
- inclusion of baseflows

A quasi calibration was also undertaken using the TUFLOW model, which was run for 10 historical events including a range of representative events. Model development included:

- initial calibration to obtain model stability and reasonable fits to observed data. The model was calibrated to 1961, June 1964, June 1975, March 1978, Aug 1986, April/May 1988 and August 1990 events.
- review by Mr A Verwey, co-author of the RUBICON program (with outcomes presented in Hawkesbury-Nepean Hydraulic Model, 1989)
- fine tuning of the model using flood events of March 1978, August 1986 and April/May 1988 (particularly around Windsor and Penrith)
- comparison to the flood of August 1990 (which occurred during the model's development).

The TUFLOW model was used to calibrate 10 historical events including a range of representative events. The historical events were November 1961, June 1964, June 1975, March 1978, August 1986, October 1987, April/May 1988, July 1988, April 1989 and August 1990. The model was considered suitable to give a general indication of the velocity distribution for the 1 in 100 AEP for the purposes of determining flood hazard and hydraulic categories. Further refinement and detailed bathymetry are required before this model is suitable for detailed modelling.

The modelling reproduces observed events well, reproduces flood frequency analysis at dam, Penrith and Windsor and other key variables like rates of rise and duration of inundation. This provides a high level of certainty in the results.



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Upstream Environment - Model Cross Sections

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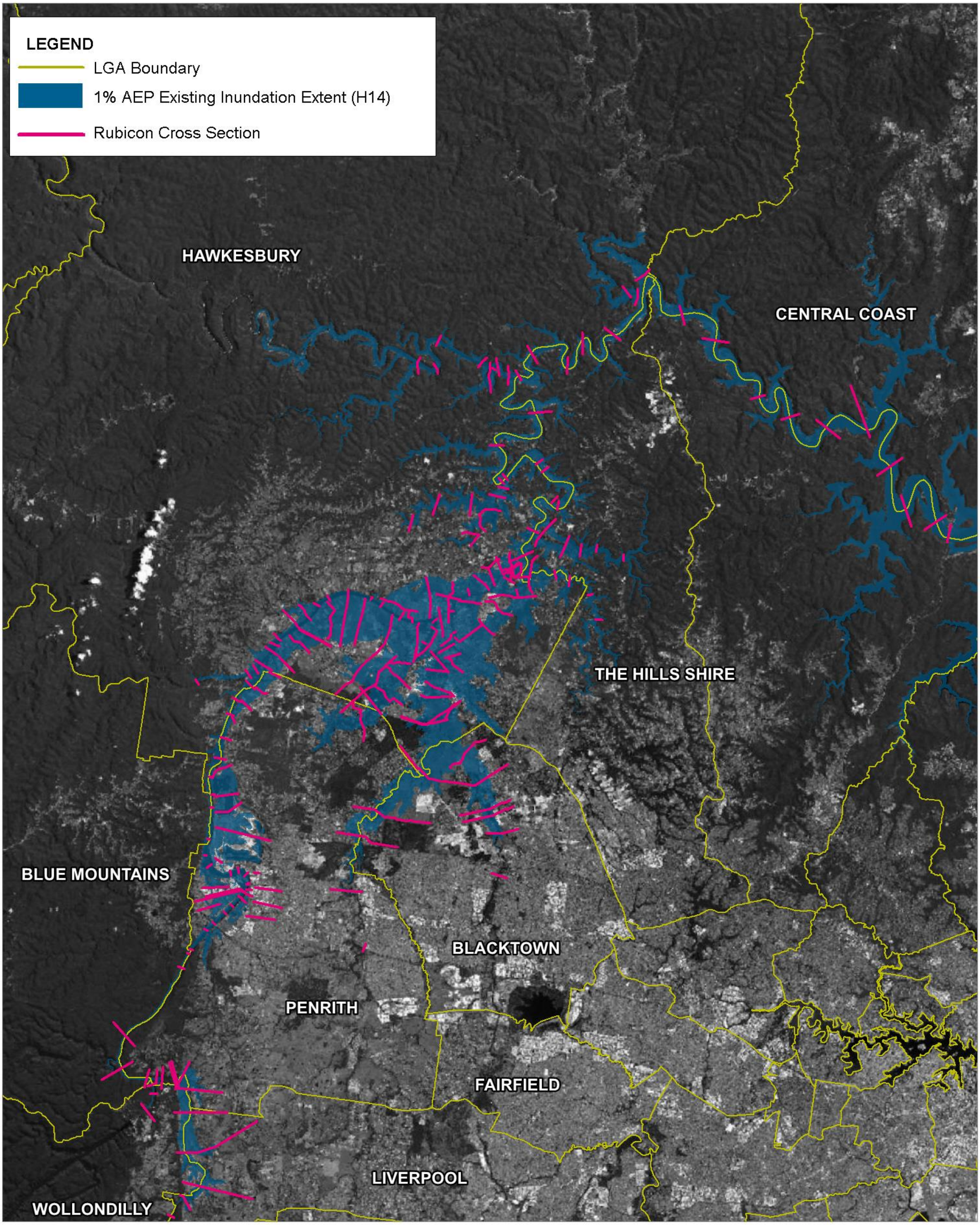

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2.4 Design flood estimation

Most traditional rainfall-based flood estimation techniques are based on the design event approach, in which all parameter values and inputs other than rainfall are treated as fixed values. The application of these traditional methods generally involves the implicit assumption that the annual exceedance probability (AEP) of the flood is the same as its causative rainfall. Monte Carlo simulation offers an alternative to the design event method. This approach recognises that any design flood characteristics (for example, peak flow) could result from a variety of combinations of flood producing factors, rather than from a single combination. The approach mimics “mother nature” in that the influence of all probability distributed inputs are explicitly considered, thereby providing a more realistic representation of the flood generation processes. (AR&R, 2019).

Monte Carlo modelling incorporates the simulation of a large number of flood events using combinations of various input parameters. Input parameter values are randomly selected from pre-defined probability distributions for each variable to provide a combination representing a single possible event.

WMAWater (2018) notes the variability in each of the following key input variables was estimated from observed events, and a Monte Carlo framework was established to model flood events based on randomly sampling each variable from within the range of possible inputs:

- rainfall intensity and frequency – catchment average rainfall
- spatial pattern of rainfall – where in the catchment rain falls
- temporal pattern of rainfall – when in the event rain falls
- initial loss – rain ‘lost’ at the beginning of an event through infiltration into the soil
- pre-burst rainfall – rain that occurs before the most intense burst of the storm
- dam drawdown – the level of Warragamba Dam before the start of an event
- relative timings of tributary inflows
- tides.

The modelling framework and use of the Monte Carlo analysis for the Regional Flood Study is depicted in Figure 2-4. The variables from the Monte Carlo analysis were fed to the hydrological model, and the resultant flows, together with the other variables including relative timings of tributary inflows, tides and other variables, were fed into the hydraulic model.

The MIKE11 and RUBICON models are a 1-dimensional (1-D) hydraulic model, which is based on a series of discrete cross sections (refer Figure 2-2 and Figure 2-3) that assumes a uniform water level across the section perpendicular to the direction of flow. The model outputs include a water level, flow rate and cross-section average flow velocity for each cross section for each model timestep. From these outputs, timeseries of water levels, flow rates and flow velocities can be generated for each event, and peak values for each parameter identified, for each event simulated.

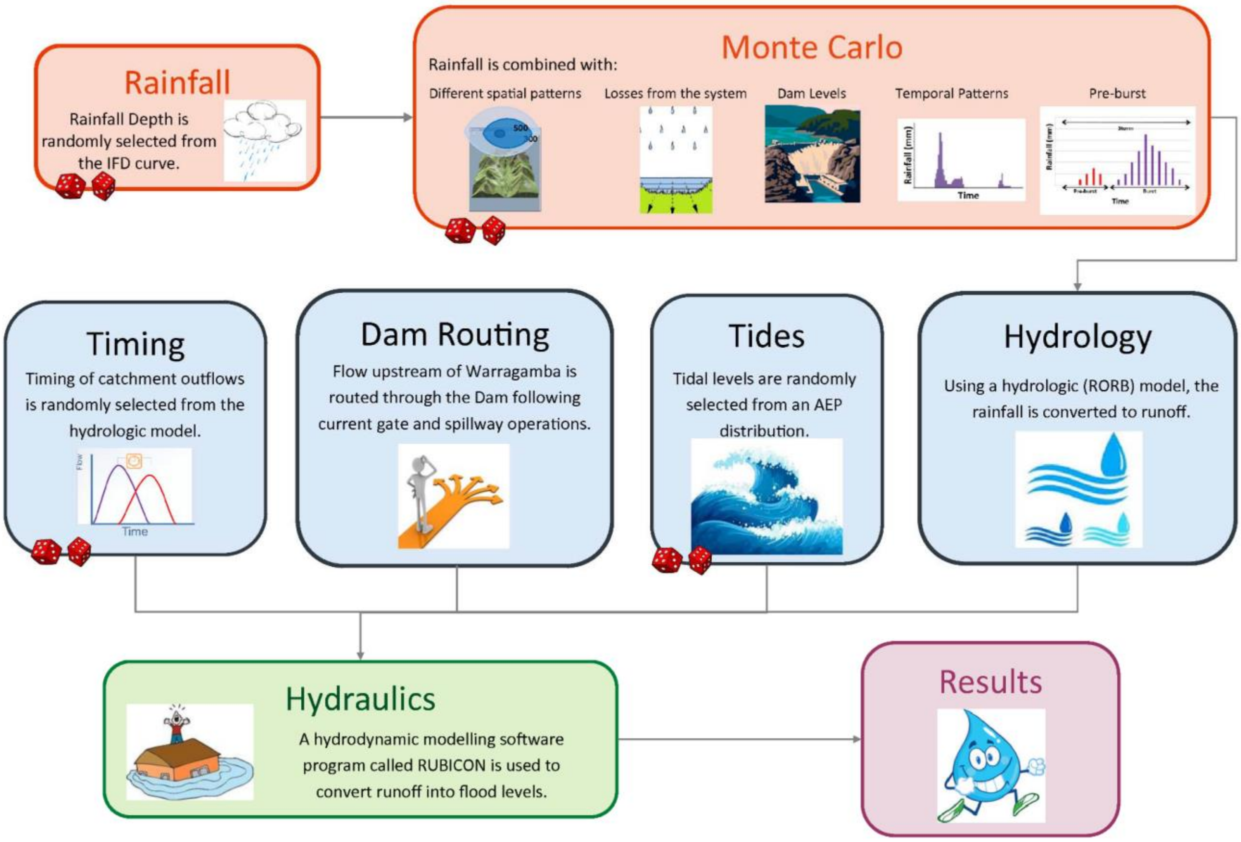
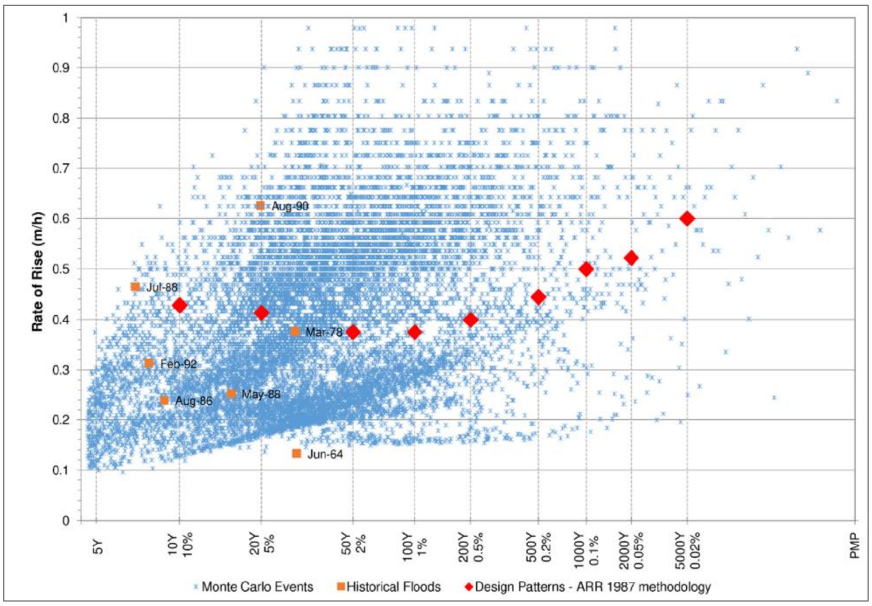


Figure 2-4 Monte Carlo framework flowchart (WMAWater, 2018)

A slightly different analysis approach was adopted for the upstream area. The MIKE11 model was not used to discretely simulate each of the Monte Carlo design flood scenarios. Rather, the MIKE11 model was used to extract rating curves (flow-height relationships) under different dam raising scenarios. These rating curves were used to calculate level hydrographs from flow inputs (from the RORB model) at all cross-sections for the 20,000 Monte Carlo runs of the existing dam and the raised dam option. These level hydrographs were used to obtain estimates of inundation times upstream of the dam and to give an indication of the change in inundation time between the existing dam and the 14m raised dam option.

To confirm the Monte Carlo framework was accurately replicating observed flood behaviour, a number of flood characteristics of the modelled events were compared to the observed events. The rate of rise between 4 and 10 metres at Windsor was extracted and compared with Monte Carlo results, as shown on the adjoining diagram. The limited time series data available for some historic events (either through gauge fault or only three-hour data being available) mean that some events plot at the edges of the modelled event range. The flood study provides a discussion of model limitations, including that some sites (generally upstream) do not contain observed hydrographs (e.g. Nattai River at causeway and Kowmung River at Cedar Ford), while the gauge at Jooriland was found to be overestimating flows. However generally a good representation of observed rate of rise is achieved by the Monte Carlo modelling.



Rate of rise between four and 10 metres versus frequency at Windsor
(Hawkesbury Nepean Flood Study, 2019; Diagram 7).

2.5 Limitations and next steps

The flood study identified limitations with the following aspects:

- limited in-bank bathymetry for developing maps of flood depths and provisional flood hazard mapping. Results presented within channel should be confirmed using detailed survey and modelling
- the complex nature of the catchments upstream and downstream of the study area
- the accuracy of bridge, weir and other structure data
- the effect on flood behaviour of development and existing structures outside the project boundary were modelled with the best available information
- the assessment of climate change was based upon the best available information at the time of writing
- environmental flows are not included in the model
- the accuracy of the resultant flood levels is generally considered to be +/- 200mm. However, levels at Wallacia are likely to be more uncertain than this.

A roughly calibrated two-dimensional model was established for the purposes of providing velocity distributions for flood hazard and hydraulic categorisation of the floodplain. The development of GPU style models means that it is now possible to model the 200 kilometres stretch of river covered by the RUBICON model in two dimensions. However, given the size of the floodplain it is still only possible to develop a model with a grid cell size in the order of 20 metres with reasonable run times that will not inhibit a study program. The use of too fine a grid cell size, while providing more detailed mapping will mean that run times will be in the order of weeks and calibration will rely heavily on the modeller's skill and educated guesses. A consistent set of detailed bathymetry of the river is required to inform the two-dimensional model.

The current study provides boundary conditions that can be used in the development of more detailed flood models. These more detailed models may be two-dimensional models with fine grids that will better represent the local flood behaviour.

3 Baseline characterisation – existing environment

3.1 Hydrology

Hydrology is the study of surface and groundwater occurrence, distribution, movement and properties and their relationship with the environment within each phase of the hydrologic (water) cycle. The water cycle describes the continuous movement of water on, above or below the Earth, and begins with the evaporation of water from the surface of the ocean which is transported around the globe until it returns to the surface as precipitation.

Once the water reaches the ground, one of two processes may occur i) some of the water may evaporate back into the atmosphere or ii) the water may penetrate the surface and become groundwater. Groundwater either seeps its way to into the oceans, rivers, and streams, or is released back into the atmosphere through transpiration. The balance of water that remains on the earth's surface is runoff, which empties into lakes, rivers and creeks and is carried back to the oceans, where the cycle begins again.

Typically, in river systems with high water use such as the Hawkesbury-Nepean, their natural patterns of river flows are greatly altered due to the presence of dams, weirs and other river regulation activities. Many of the rivers and creeks of the upstream environment are largely in a pristine and natural state with minimal changes to flow regimes. The downstream environment flow regimes have been greatly altered from natural conditions due to the construction and operation of Warragamba Dam, along with numerous other dams and reservoirs, weirs, water extraction and supply systems which are part of the Greater Sydney water supply system (WaterNSW, 2017c).

The construction of dams and weirs is necessary to store water however it changes the natural pattern of river flows downstream. Water transfers between catchments for either the potable water network supply or irrigation can alter the total volume of water within a river and additionally vary the seasonality of high and low flows (Varley, 2002). Extraction of water for agriculture industry and urban use reduces the total volume of water in rivers and creeks while wastewater treatment plants (WWTP) and agricultural discharge provide point source inflows to the system. Land clearing and urban development modify the run-off rates in catchments which often leads to increased peak flows but reduced or shorter duration river flows from rainfall events (Puckridge et al., 1998). Each of these processes is occurring within the Hawkesbury-Nepean Catchment and will impact upon the hydrology of the rivers and creeks.

The key hydrological attributes of the upstream environment and downstream environment and their extents is shown in Figure 3-2 and Figure 3-3 respectively, and discussed further in Section 3.1.1 and Section 3.1.2.

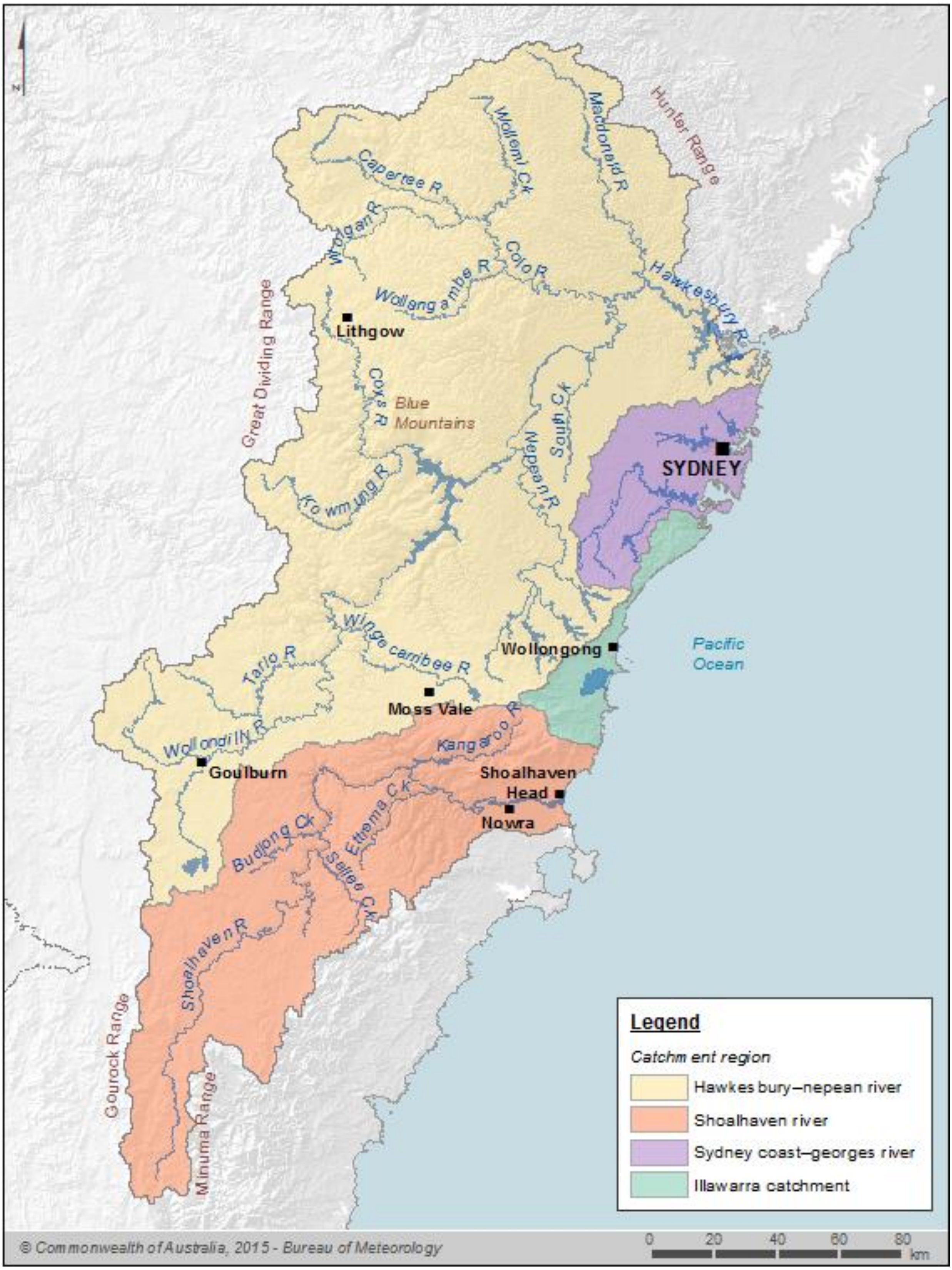
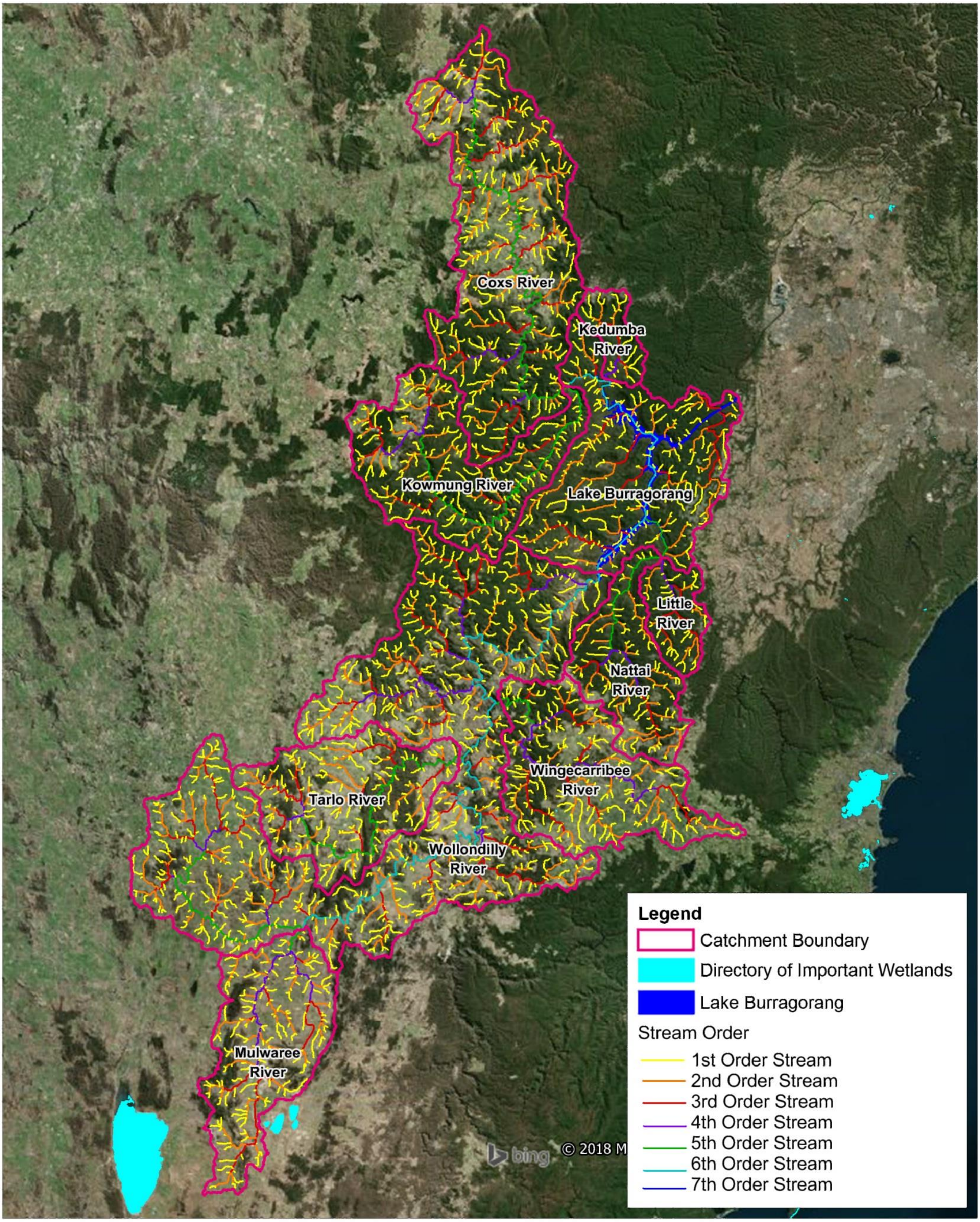


Figure 3-1 Contextual map of the Sydney Region (Source: BoM, 2017a)



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Upstream Environment Hydrological Attributes

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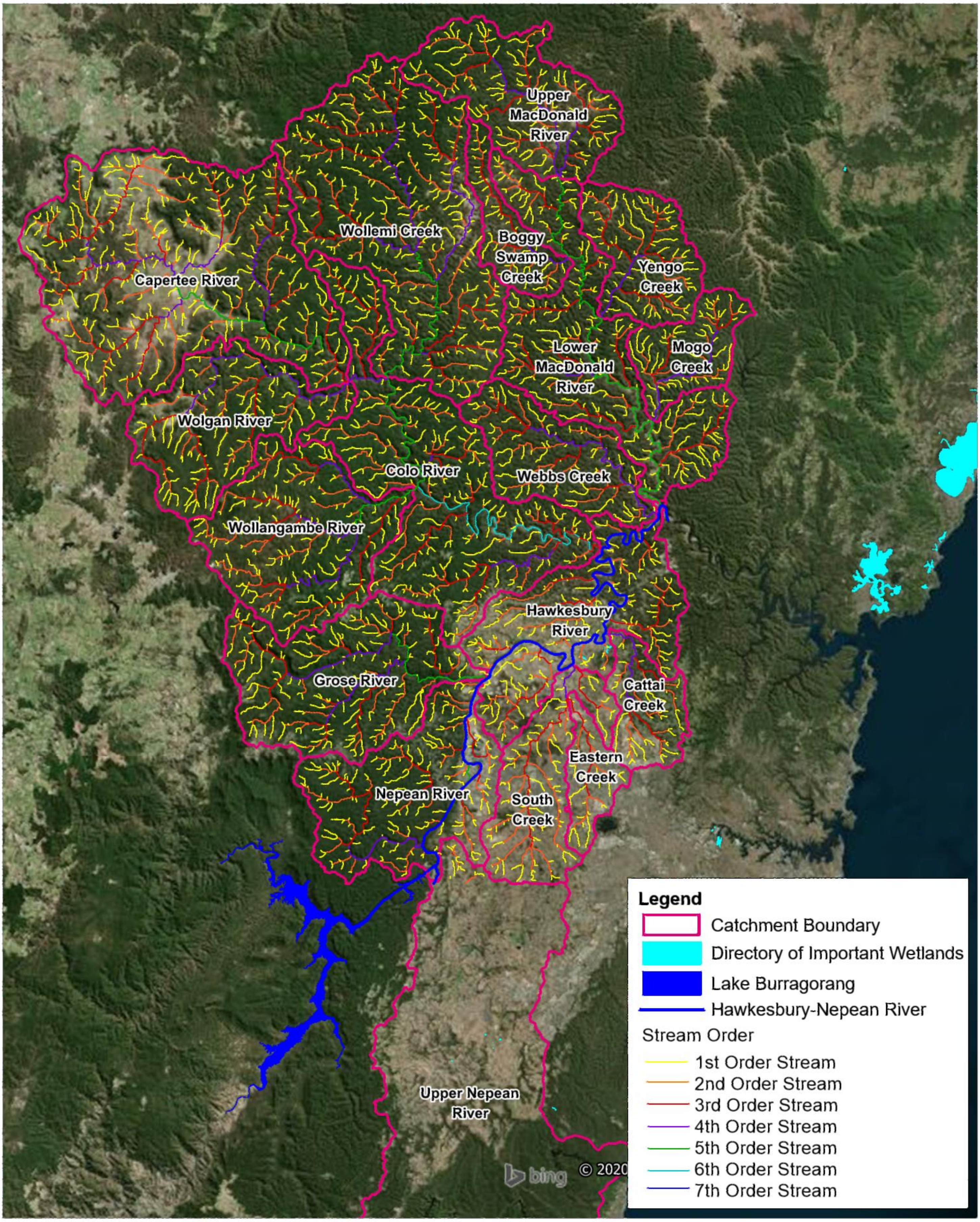

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3.1.1 Upstream environment

3.1.1.1 Overview

The upstream environment includes Lake Burragorang (that is, the reservoir formed by Warragamba Dam) and its tributaries. The catchment of Lake Burragorang includes a number of State Conservation Areas, National Parks and the broader Greater Blue Mountains World Heritage Area (GBMWHA). The Warragamba Dam catchment covers an area of some 9 050 km^2 and encompasses a variety of land use types. Lake Burragorang collects water from the catchments of the Nattai River, Kedumba River, Kowmung River, Wollondilly River and Coxs River and is the largest raw water supply in Australia.

The Hawkesbury-Nepean catchment rises to 750 metres above sea level at the head of the Wollondilly River and over 1 200 metres on the Great Dividing Range at the head of the Kowmung River (WMA Water, 2013). Numerous towns are located within the upstream environment, the largest towns to the north being Wallerawang, Lithgow and Katoomba and in the south the main population centres are Goulburn, Bowral and Mittagong.

3.1.1.2 Climate

The Tasman Sea to the east and the Blue Mountains in the west strongly influence the climate of the upstream environment. In spring and summer prevailing winds originate from the north-east while in autumn and winter they originate from the south-west. Diurnal and seasonal temperature ranges across the upstream and downstream environments are known to vary considerably. The upstream environment experiences mild to hot summers, with the average maximum January temperatures approaching 26°C and 23°C at Moss Vale (south) and Katoomba (west) respectively. Winter temperatures are cool to mild with the average maximum July temperature in Katoomba being 9°C with frosts common at higher altitudes (Sydney Water, 1991 in GHD, 2013).

3.1.1.3 Geology

The upstream environment has varying geology with the headwaters of Hawkesbury-Nepean River lying over Hawkesbury sandstone. This geological formation consists of massive beds of quartz-rich sandstones containing smaller beds of slate and siltstone. Consequently, the rivers in the upstream environment are characterised by steep, high cliffs with minimal floodplain areas (Markich and Brown, 1998). The south-western region of the upstream environment has several geological formations as shown in Figure 3-4.

The Sydney Basin is an elongated basin between three ford belts, the Lachlan and Thomson Ford Belts in the west and the New England Ford Belt in the east. There are two main geological features that comprise the Hawkesbury-Nepean catchment, namely the Sydney basin which occupies 74% of the catchment, and the Lachlan Ford Belt which occupies 26% of the catchment. A majority of the Sydney Basin lies on the Lachlan Ford Belt (GHD, 2013).

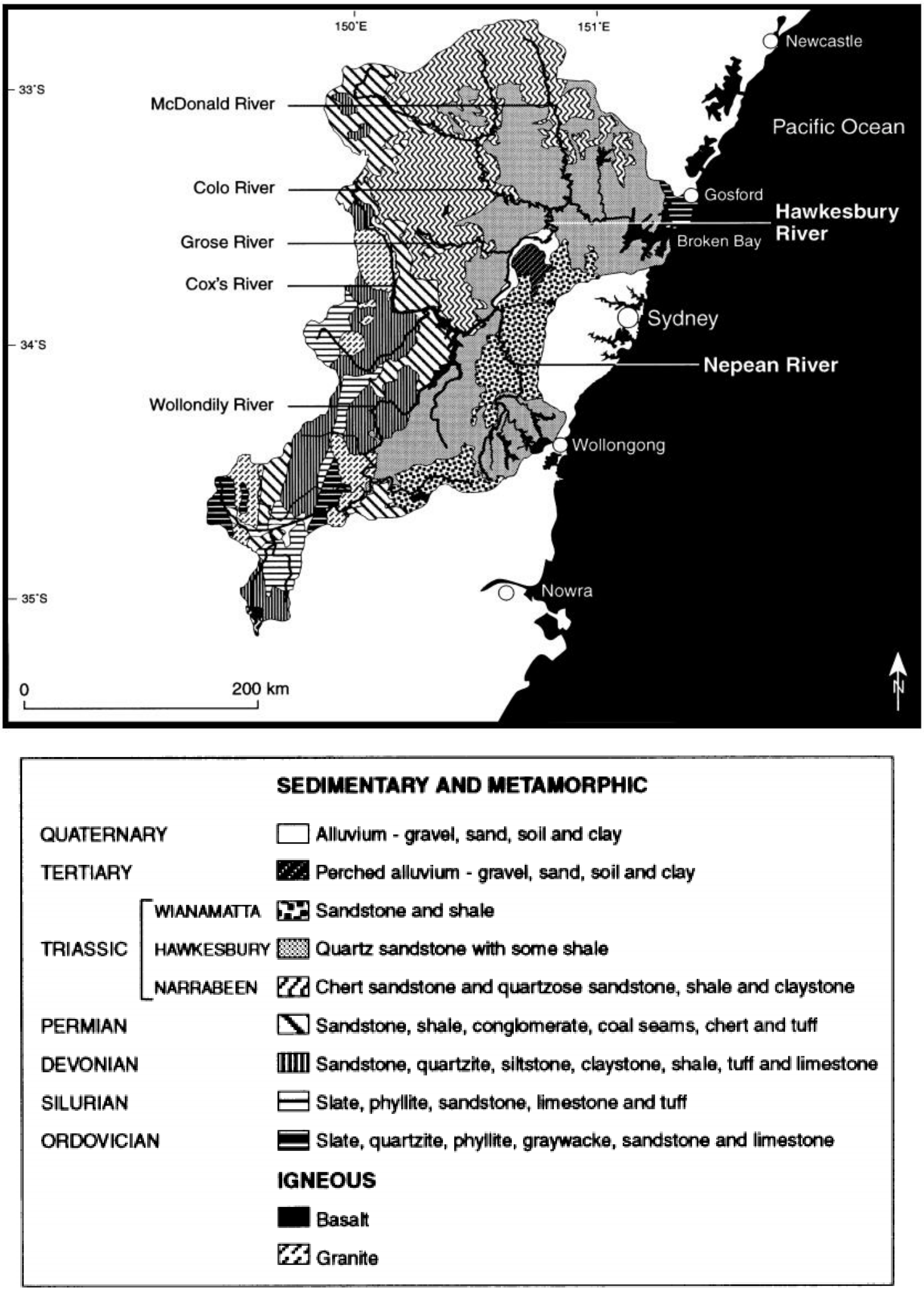


Figure 3-4 Location and geology of the Hawkesbury-Nepean River catchment (Source: Markich and Brown, 1998)

The Lachlan Fold Belt located in the south-west of the upstream environment is a complex array of sedimentary, volcanic and igneous rocks which have been subjected to various degrees of faulting, folding and intrusion resulting in deformation and metamorphism (GHS, 2013). Most of the Hawkesbury-Nepean River catchment is sandstone (64%) with a small portion of shale (10%) and a belt of metamorphic and igneous rocks (26%) in the upper catchment to the south-west (Markich and Brown, 1998). Within the catchment there are three main geological formations, the Narrabeen Group, Hawkesbury sandstone and Wianamatta Group as shown in Figure 3-4.

3.1.1.4 Land Use

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

The landscape upstream of the dam is recognised as a nationally significant wilderness area that provides habitat for many threatened and critically endangered terrestrial flora and fauna. The area is surrounding Lake Burragorang is predominately undisturbed bushland with minimal fire trails and access points. Public access to the upstream Burragorang SCA is generally not permitted with the only publicly-accessible point being Burragorang lookout and picnic area (NPWS, 2015). The upstream environment is well known for its natural beauty, pristine condition and environmental significance as part of the GBMWHA. More than one-quarter of the Warragamba Dam catchment is covered by the Warragamba Special Area (WaterNSW, 2017a).

Whilst the areas surrounding Lake Burragorang (and potentially impacted by the Project) are predominately national parks, state conservation areas and SCA special areas, the upstream areas of the catchment are not. The upper catchment where many of the tributaries of Lake Burragorang originate is dominated by grazing and agricultural land uses. Livestock grazing is the largest single land use within the Warragamba Dam catchment whilst the region also supports dairies, horse studs, piggeries and poultry production as well as canola and cereal crops (WaterNSW, 2017a).

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

3.1.1.5 Rivers and creeks

Overview

Warragamba Dam controls approximately 40% of the total area of the Hawkesbury-Nepean River catchment to the ocean and around 70% of total flows of the Hawkesbury-Nepean River catchment. Numerous rivers and creeks drain to Lake Burragorang providing the source of freshwater for the reservoir. The key tributaries and main inflows to Lake Burragorang are the Wollondilly River in the south, the Coxs and Kowmung Rivers in the west and the Nattai and Little Rivers in the east (WMA Water, 2013).

The quantity of surface water or catchment yield provided to Lake Burragorang from the Wollondilly and Coxs River catchments are significantly influenced by the climatic conditions, land use and extraction activities undertaken in the upper catchment which extends beyond Goulburn in the south and Lithgow to the West (WaterNSW and NSW OEH, 2015).

SMEC (2002) reported on WATNET modelling of monthly flows into and out of Warragamba Dam as summarised in Figure 3-5 and Figure 3-6. These figures show that the unregulated river flows into Warragamba Dam are notably higher than the regulated river flows released downstream of the dam. This is expected due to the dam being used as key water supply infrastructure.

Existing Condition and Geomorphic Features

A recent assessment by GHD (2013) of the Hawkesbury-Nepean Catchment Management Authority region was undertaken to determine and map the river types present across the and assess the condition, fragility and recover potential in accordance with the River Styles® framework. The geomorphic condition was categorised as good, moderate or poor based on, for example, ecological diversity, the presence of catchment controls, vegetation coverage and overall geomorphic stability. The assessment found that most of the rivers and creeks that flow directly into Lake Burragorang are in good condition. Some sections of waterways were identified as poor condition, including where Cedar Creek and the Tonalli River where they join Lake Burragorang, and numerous others upstream creeks in a moderate geomorphic condition (GHD, 2013).

GHD (2013) explains that good condition reaches are largely associated with Confined Valley Setting (CVS) river styles, with almost 80% of confined river styles in good condition. These waterways exist mainly in undisturbed areas in the upper to middle regions of the upstream (catchment) environment. The association of these waterways with good geomorphic condition is that they are resilient and are in rugged landscapes that are not subject to intense land disturbances such as grazing, land clearing, agriculture or any kind of development, which is the case for much of the upstream catchment area.

The stream order of rivers and creeks in the upstream catchment varies from 1st order to 7th order as shown previously in Figure 3-2. The main tributaries entering Lake Burragorang are classified as 5th order streams or greater.

Declared Wild Rivers

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

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

Most of the 80-kilometre stretch of the Kowmung River lies within Kanangra-Boyd National Park, with the lower reaches of the river (~15 km) occurring within the Blue Mountains National Park.

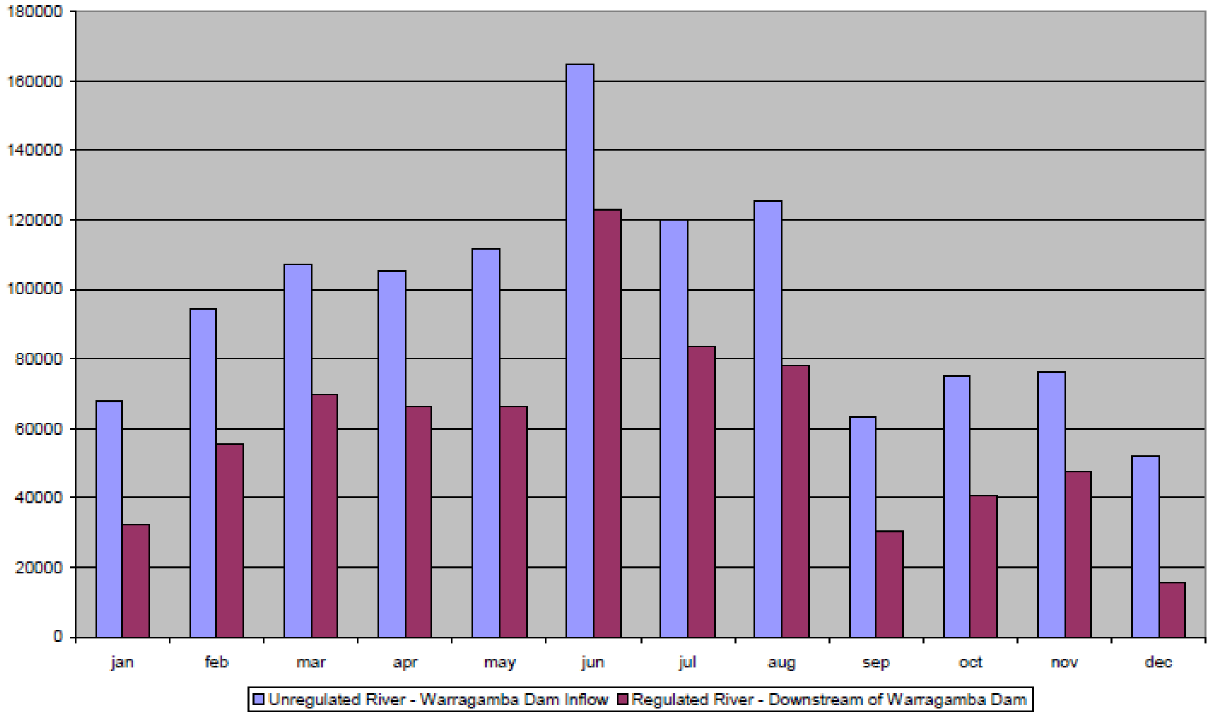


Figure 3-5 Comparison of unregulated and regulated mean monthly flows at Warragamba Dam (Source: SMEC, 2002)

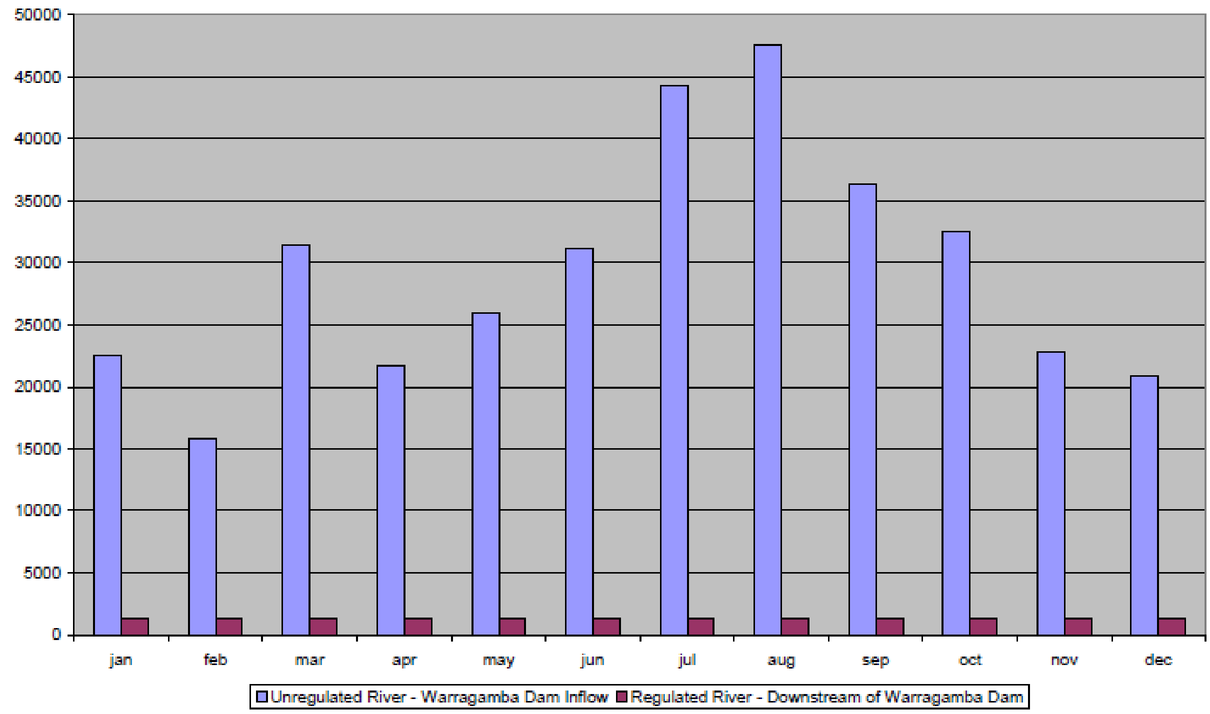


Figure 3-6 Comparison of unregulated and regulated median monthly flows at Warragamba Dam (Source: SMEC, 2002)

3.1.1.6 Rainfall and streamflow

Rainfall

Analysis of long-term rainfall data sourced from the Bureau of Meteorology (BoM) for the upstream environment shows that the mean annual rainfall varies considerably between stations across the catchment. Although the wettest months are consistent across the catchment with January and February recording the greatest rainfall and July typically being the driest month (Table 3-1).

The greatest rainfall totals across the upstream environment consistently occurs between November and March, however the variability between stations can be high. For example, during 2015, Katoomba received 1 499 mm of rainfall, while Jenolan Caves less than 30 km away received 972 mm (35% less than Katoomba).

Table 3-1 Rainfall statistics for the upstream environment (Source: BoM)

Location	BOM Station (year opened)	Mean annual rainfall (mm)	Mean monthly rainfall (mm)	Mean wettest month	Mean rainfall for wettest month (mm)	Driest month	Mean rainfall for driest month (mm)	Driest year	Total rainfall for driest year (mm)	Wettest year	Total rainfall for wettest year (mm)
Wombeyan Caves	63093 (1942)	835	70	Jan	90	Jul	54	1,944	265	1963	1,478
Richlands (Bouverie)	70124 (1959)	1,018	85	Jan	102	Jul	69	1,982	484	1978	1,500
Gurnang State Forest (Oberon)	63033 (1933)	1,009	84	Jun	97	Mar	68	1,944	476	1950	1,787
Katoomba (Murri St)	63039 (1885)	1,403	117	Feb	175	Sept	72	1,944	618	1950	2,783
Oakdale (Cooyong Park)	68125 (1963)	891	74	Feb	128	Jul	33	1,982	535	1964	1,188
Wollondilly (River View)	70325 (1973)	696	58	Feb	78	Jul	41	2,004	408	1978	1,122
Greenstead - Wingecarribee River	68215 (1954)	544	45	Feb	63	Jul	29	2,003	337	2012	683

The headwaters of the Cox and Nattai Rivers in the upstream environment receive high rainfall totals (annual rainfall averages of around 1 000 mm). Most of the remaining upstream environment is located within a rain shadow where average annual rainfall is typically within a lower range, that is, between 650 mm to 750 mm (Sydney Water, 1991 in GHD, 2013).

Although the driest years varied between stations, the year 1944 was identified as the driest year at three rainfall stations, and the year 1982 being another one of the driest years at another two stations. The wettest years also varied but both 1978 and 1950 were recorded as the wettest year at two rainfall stations each.

Streamflow

In Australia, rivers naturally have variable flows (Gippel, 2001 in NSW DPI, 2014). Rivers on the east coast are subject to Drought-Dominated Regimes (DDRs) followed by Flood-Dominated Regimes (FDRs) that can last for decades (Varley, 2002 in NSW DPI, 2014). FDRs are the periods of time when frequent flood events occur, in addition to typically higher river flows (Sammut and Erskine, 1995 in NSW DPI, 2014). DDRs are the opposite and refer to periods when there is a reduction in the number and severity of floods as well as lower river flows in general. During an FDR, flood magnitudes can be doubled with flood frequencies up to four times greater than for DDRs (Warner, 1987 in NSW DPI, 2014).

WaterNSW records streamflow into Lake Burragorang for its major tributaries including Wollondilly River, Nattai River, Coxs River (upstream of Kowmung River confluence) and Kowmung River. The annual inflows for these tributaries (and their combined total inflow to Lake Burragorang) between 1962 to 2016 are shown in Figure 3-7. During the period 2003 to 2007 the Wollondilly River inflows include transfers from the Shoalhaven.

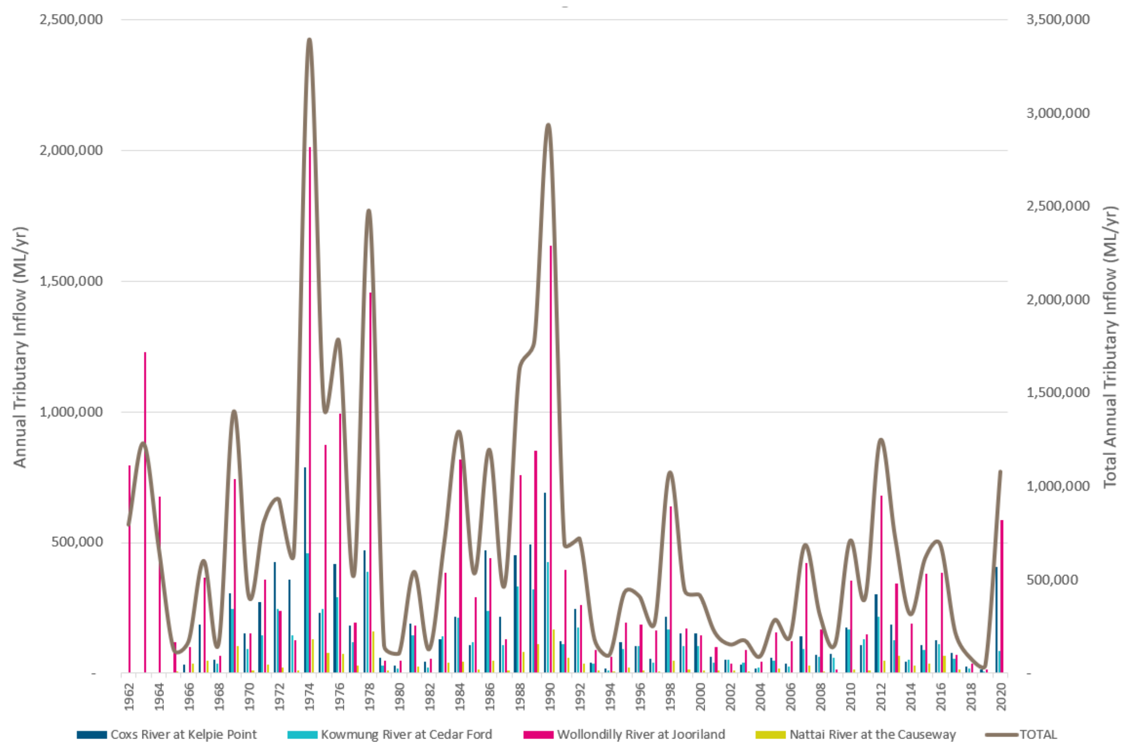


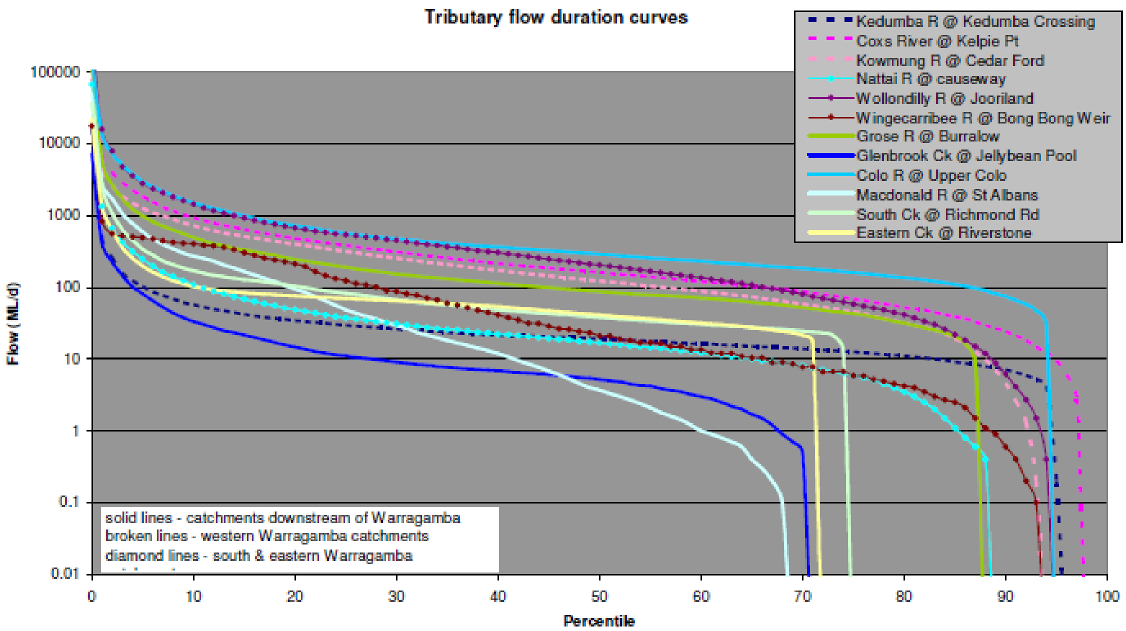
Figure 3-7 Historical streamflow records for Lake Burragorang tributaries (Source: WaterNSW)

As expected, total inflows to the reservoir from these four main tributaries have varied considerably since construction of Warragamba Dam, ranging from over 3 390 GL in 1974 to only 87 GL in 2004. Wollondilly River provides the largest flow into Lake Burragorang on average accounting for over 50% of the inflows from the four rivers documented in Figure 3-7.

Due to the variable rainfall across the upstream catchment, the major tributaries of Lake Burragorang have differing flow characteristics. For modelling, two sets of information are required to provide streamflow data: a record of water levels at a given site over the duration of a flood event (a stage hydrograph) and a relationship between height and flow at the site (a rating curve). Putting these together produces a time varying record of flow (a flow hydrograph, often called simply a hydrograph).

Flow duration curves for major tributaries of the Hawkesbury-Nepean River as produced by NSW Office of Water (2014) are provided in Figure 3-8. This figure shows flows into Lake Burragorang from the western rivers (broken lines) and from the eastern/southern rivers (diamond lines) along with tributaries in the downstream environment.

Figure 3-8 shows that the Lake Burragorang tributaries to the west, including the Coxs and Kowmung Rivers, have similar flow duration curves and these are comparable to the Wollondilly River to the south. A key feature of all rivers shown by the flow duration curves is that they all run dry (cease to flow) on occasion (even when accounting for missing data).



Note – record length and percent missing data for tributary gauging stations

Site	Years	% missing	Site	Years	% missing
Kedumba R @ Kedumba Crossing	1990-2013	5	Grose R @ Burralow	1987-2013	10
Coxs R @ Kelpie Point	1967-2013	1	Glenbrook Ck @ Jellybean Pool	1990-2013	22
Kowmung R @ Cedar Ford	1967-2013	4	Colo R @ Upper Colo	1976-2013	1
Natai R @ causeway	1967-2013	1	Macdonald R @ St Albans	1990-2013	27
Wollondilly R @ Jooriland	1967-2013	2	South Ck @ Richmond Rd	1982-2013	19
Wingecarribee R @ Bong Bong Weir	1990-2013	2	Eastern Ck @ Riverstone	1982-2013	16

Figure 3-8 Flow duration curves for major tributaries of the upstream environment (Source: NSW Office of Water, 2014)

3.1.1.7 Wetlands and groundwater dependant ecosystems

Wetlands are important transitional ecosystems between aquatic and terrestrial environments. They have important hydrological value playing a role in water storage and flood mitigation. Within the upstream environment there are no known Ramsar or SEPP 14 listed wetlands. However, the

Directory of Important Wetlands in Australia (the Directory) lists present wetlands. The Directory describes 851 wetlands across Australia that have qualified as nationally important with 178 of these occurring within NSW.

The wetlands within the upstream environment designated by the Directory include Boyd Plateau Bogs, Lowbidgee Floodplain, Wingecarribee Swamp and Thirlmere Lakes, which are all located more than 50 km from Lake Burragorang.

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

The Independent Expert Panel on Environmental Flows for the Hawkesbury Nepean, Shoalhaven and Woronora Catchments published a literature review in 2002 on the identified knowledge gaps concerning the Hawkesbury-Nepean River system. They identified that the knowledge related to the hydrology and ecology of individual wetlands is poor. This in turn making it very difficult to evaluate their current condition, level of significance for flora and fauna, impacts from flow reduction and/or anthropogenic factors and potential benefits from environmental flows. Additionally, the literature review noted that it is not known which wetlands are (and were) directly or indirectly influenced by flows in the Hawkesbury-Nepean River.

3.1.1.8 Lake Burragorang

Lake Burragorang covers a total waterway area of about 75 km^2 and has a total operating capacity of 2 069 GL, making it one of the largest water supply dams in the world. The lake is 52 km in length and has 354 km of foreshore. The lake has a maximum depth of 105 metres and receives an annual average rainfall total of 840 mm (WaterNSW, 2015).

River regulation to conserve water for other purposes, in the form of dams and weirs, can greatly reduce natural flows and sediment yields to downstream environments. For Warragamba Dam, there is a change to the average annual volume of water due to pumping / diversion of water from the reservoir. Other changes include sediment trapping upstream of the dam and altered hydrographs for downstream river reaches (Sammut and Erskine, 1995; Warner, 2014).

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

- the Dam impounds Warragamba River creating the reservoir / freshwater storage known as Lake Burragorang
- Lake Burragorang is a significant sink for upstream sediment loads that would otherwise provide the river downstream its normal sediment load

- the interruption of normal downstream sediment transport by the dam results in 'clear water' erosion to the channel downstream of the dam, whereby sediment that is naturally scoured and transported from this downstream reach is not replaced by inflowing sediment from upstream
- dam operation alters the natural hydrological regime of the river downstream of the dam (reduced baseflows and reduced peak flows) which impacts sediment transport processes, bank stability, and the availability of hydraulic habitat (the temporal and spatial distribution of suitable depth and velocity, as determined by river morphology and hydrological regime) (Sammut and Erskine, 1995; Warner, 1995; Brizga and Finlayson, 2000; Erskine and Green, 2000).

While geomorphology of the Hawkesbury-Nepean River is highly modified from its natural (pre-dam) condition, it has been more than 55 years since the construction and opening of Warragamba Dam. Although the channel morphological conditions upstream and downstream of the dam are still adjusting to regulated flow regimes, they provide the physical foundations for valuable aquatic and terrestrial habitat with broad environmental value. WaterNSW (2015) report that Lake Burragorang supports an abundance of aquatic flora and fauna including macroinvertebrates, molluscs, fish, reptiles and mammals.

3.1.1.9 Water storage and system supply network

WaterNSW supplies raw water to be treated and distributed to its Greater Sydney customers. The water supply system for Greater Sydney is an integrated network of dams, pipelines, canals, tunnels, rivers and a desalination plant that have been designed and are operated to optimise overall water supply outcomes (WaterNSW, 2018).

In 2015, the Greater Sydney water supply system yield was estimated at 570 GL/yr (WaterNSW, 2018). The Warragamba system is a key component of the water supply system as shown in Figure 3-9. The system includes Warragamba Dam and the pipelines that connect the dam to the Warragamba, Orchard Hills and Prospect Water Filtration Plants along with the Prospect Reservoir.

Dam Operation

The existing Warragamba Dam impounds the Warragamba River creating the freshwater reservoir or storage known as Lake Burragorang. Lake Burragorang is four times the size of Sydney Harbour and is currently managed as a water supply dam (WaterNSW, 2015).

The Warragamba water supply system is illustrated schematically in Figure 3-10.

Water from the dam flows by gravity through two pipelines (27 kilometres in length) to the Prospect water filtration plant (WFP) located 15 km west of Sydney's CBD. Water treated at this plant supplies water for a large portion of Sydney's population. Water from the dam is also supplied to Warragamba, Penrith and the Lower Blue Mountains through filtration plants at both Warragamba and Orchard Hills. A deep-water pumping station is located at Warragamba Dam to enable continued supply if the water level falls below the outlets during a severe drought.

Water is also released into the Warragamba River to provide a secure water supply to the people of North Richmond and as environmental flows (albeit limited at this stage) to keep the river healthy and provide community benefits (WaterNSW, 2016).

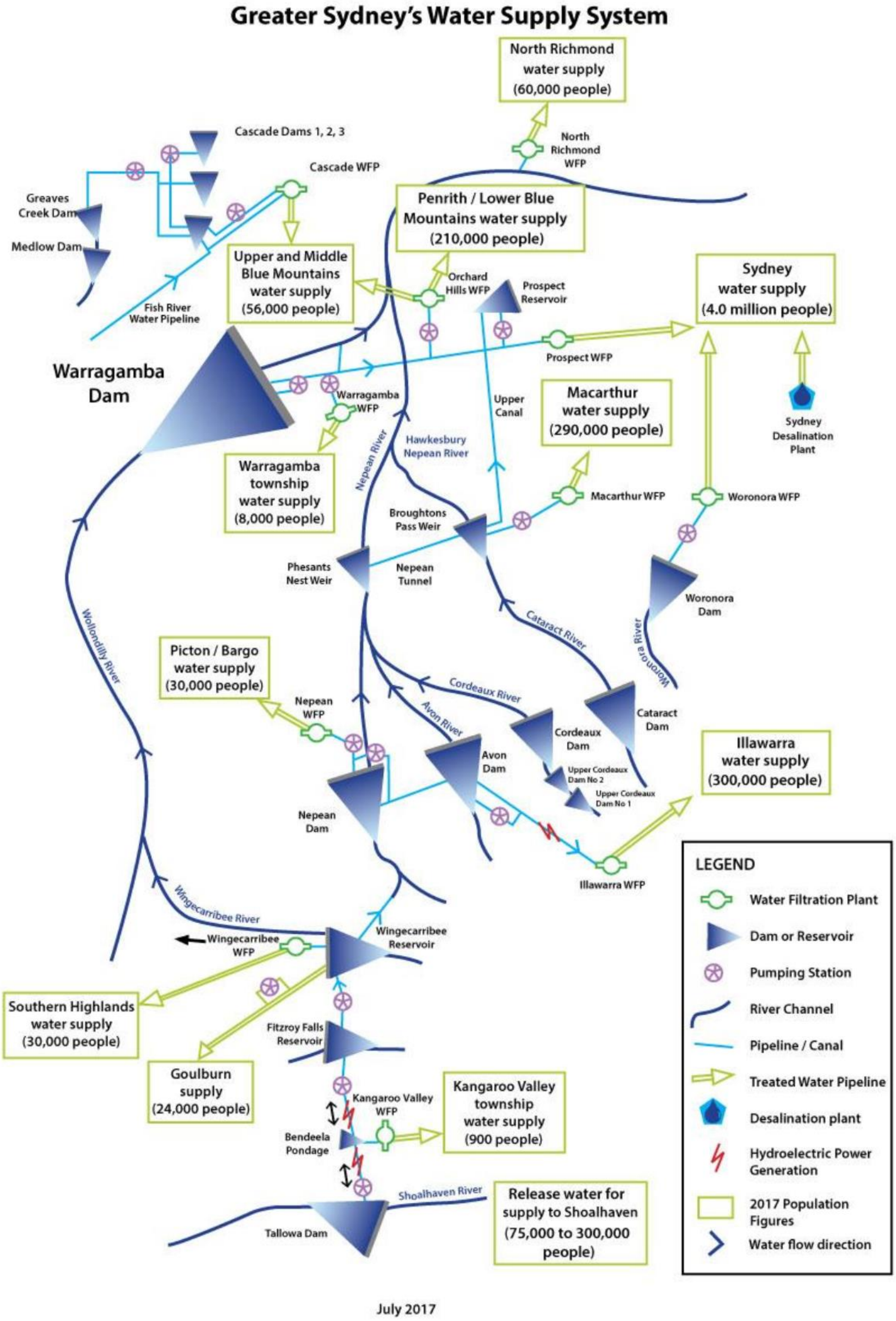


Figure 3-9 Greater Sydney Water Supply System (Source: WaterNSW, 2018)

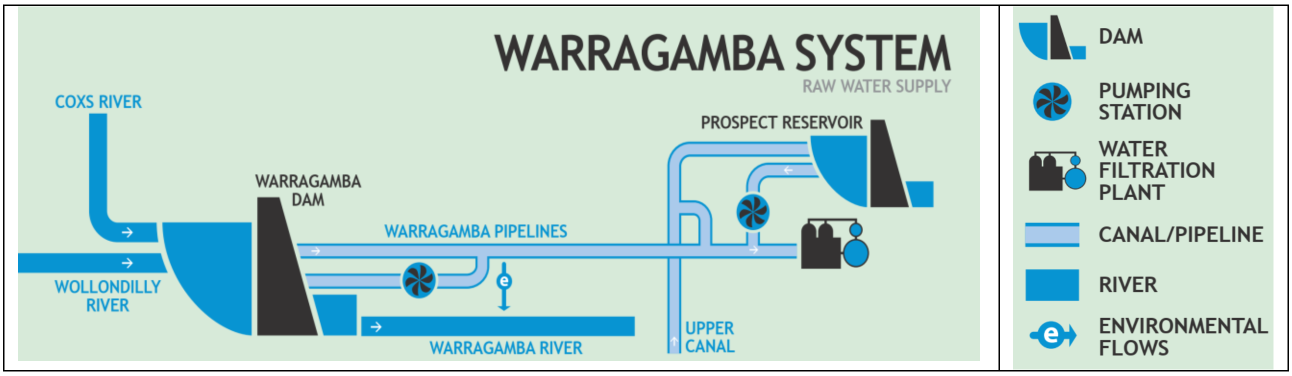


Figure 3-10 Warragamba Water Supply System (Source: WaterNSW)

Water Use

Warragamba Dam is primarily a water supply dam supplying bulk water to three WFPs. When the dam is full it holds more than 2.6 million megalitres of water. More than 80% of Sydney's water comes from Warragamba Dam. The best quality water from the dam is selected and drawn through screens at three outlets in the upstream face of the dam. After flowing by gravity to the valve house, pipelines feed the raw water to the various WFPs. From there, the treated and filtered water is distributed to households, businesses and other users across Sydney. SMEC (2002) reported that the three WFPs have a combined median day demand of 1 295 megalitres and a maximum day demand of 2 417 megalitres. The pipeline has a capacity of 2 600 megalitres/day, which is sufficient to meet maximum day demand (SMEC, 2002). The North Richmond WFP is operated by Sydney Water and draws water directly from the Hawkesbury-Nepean River. The fixed low flow or riparian release is sufficient to meet the demands of the Richmond WFP (SMEC, 2002).

Warragamba Dam has previously been utilised for power generation. The Warragamba hydro-electric power station is a 50-megawatt station which generates green power when there is a high level of water in the lake. The hydro-electric power station was commissioned in 1960 and was last used in 1998. It is currently decommissioned.

Dam Releases and Spills

Since the construction of the dam in 1960, the flow contribution from Warragamba Dam to the Warragamba River and subsequently the Hawkesbury-Nepean River has been limited to the following releases:

- fixed low flow releases: 22 megalitres per day in winter and 30 megalitres per day in summer
- operational releases: The best quality water from the dam is selected and drawn through screens at three inlets in the upstream face of the dam. After flowing by gravity to the valve house, pipelines feed the raw water to the various treatment plants and then distributed to users across Sydney. The North Richmond WFP is operated by Sydney Water and draws water directly from the Hawkesbury-Nepean River. Operational releases my also occur during maintenance and upgrade works
- flood flows: These occur when water levels in the dam exceed the full supply level, the gates are opened, and water flows over the dam spillway. There is no drawdown of the dam prior to a flood (that is, a pre-release of water).

While Warragamba Dam has greatly changed the natural hydrological regime of the river downstream of the dam (reduced base flows and reduced peak flows), it has been nearly 60 years since the construction and opening of Warragamba Dam, and as such the current dam operation characterise existing (baseline) environmental conditions for the Lake Burragorang storage area and downstream catchment.

The key waterbodies located at the dam wall which require consideration and assessment are Lake Burragorang and the Warragamba River which receives flows from the lake as either spills or fixed flow releases. Figure 3-11 shows the historical percentage full level for Warragamba Dam from 1960 to 2017, and during this period, the storage level has been above the 80% full level for most of the time. However, over the past 57 years, the dam level has dropped to less than 60% full on several occasions (approximately every 10 to 20 years, for example, early 1980s, mid 1990's and early to late 2000's). In the early 2000's the dam water level dropped below 40% full. This was the first occurrence of the dam level being below 40% capacity since it commenced operation in 1960. The dam has also exceeded 100% capacity and spilled on numerous occasions during the 1960's and 1970's. The dam spilled in 2012 for the first time in 14 years, with other recent notable dam spills occurring again in 2013 and 2015.

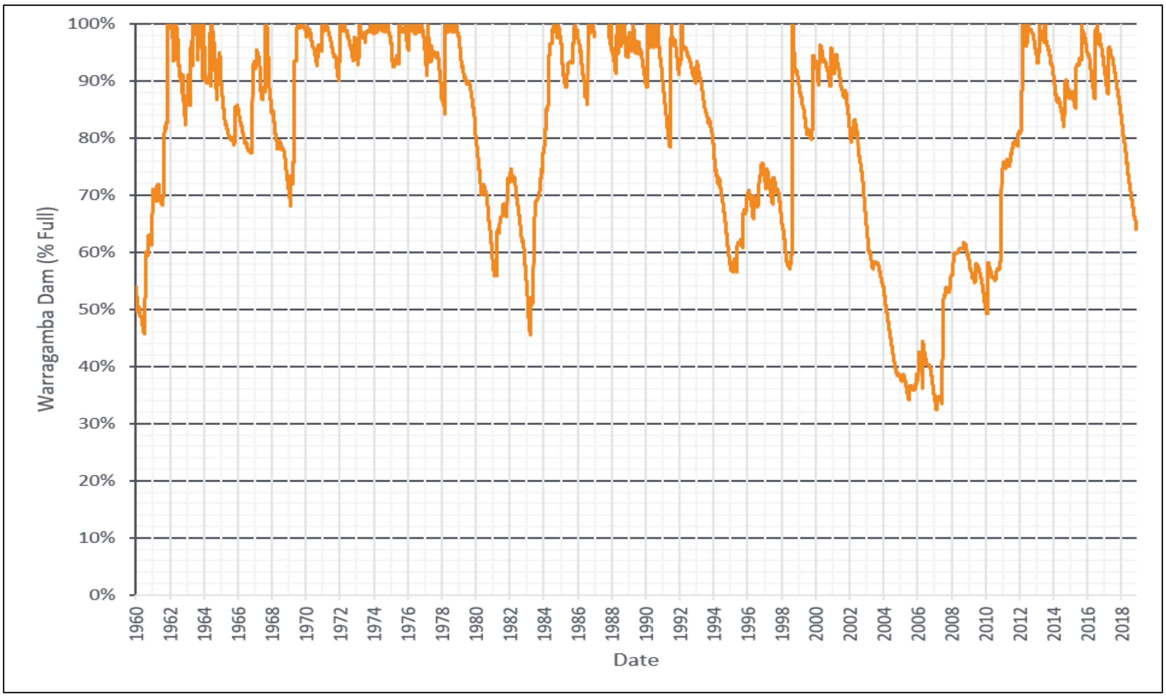


Figure 3-11 Warragamba Dam historical levels – Percentage Full (Source: WaterNSW)

Dam Operation

Lake Burragorang is typically maintained at or below the Full Supply Level (FSL), with gates automatically releasing water once storage levels rise above the FSL (WaterNSW, 2016). Warragamba dam operates under a "H14 protocol" (see Figure 3-12) where the gates are opened automatically in sequence as the storage level rises above the FSL. The drum gate is the first to be opened and is used to discharge smaller floods, while the radial gates are only opened for larger floods.

The primary objectives of the Warragamba Dam gate opening procedures are to ensure that:

- the gates are opened quickly enough to prevent inflows overtopping and damaging the gates
- the gates are closed quickly enough to ensure the reservoir level is returned to the FSL at the end of a flood.

There is no drawdown of the dam prior to a flood (that is, a pre-release of water) and no FMZ above FSL dedicated to storing inflows. Daily base flow releases (or riparian releases) also occur from the dam (typically between 20 megalitres and 30 megalitres per day) though this is not an e-flow by design. The releases from the dam have been recorded by WaterNSW and the yearly total sum of water released to each end-use (riparian, Warragamba WFP, Orchard Hills WFP, Prospect WFP, Prospect Reservoir) from 2006 – 2016 is shown in Figure 3-13.

Figure 3-12 How the gates on Warragamba Dam work (Source: WaterNSW Website)

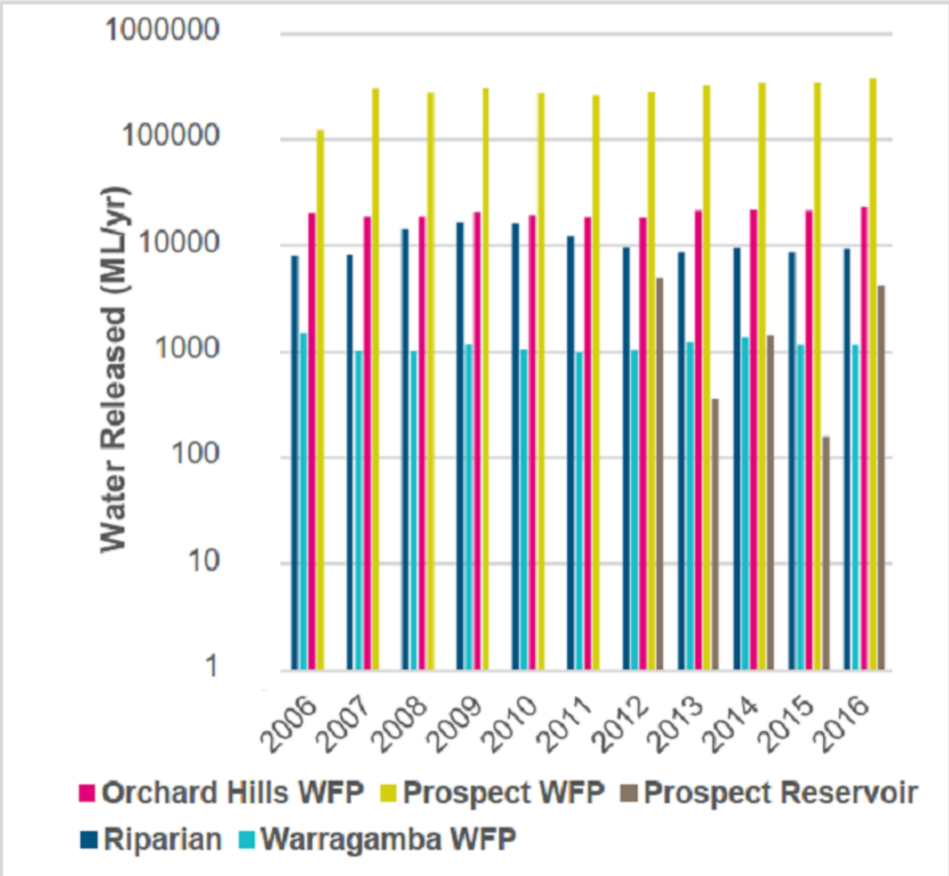


Figure 3-13 Annual total water released to each end-use (Source: WaterNSW)

The Prospect WFP uses the most water from Warragamba Dam, with it drawing considerably more water than any other end use. Each of the outflows has been relatively consistent in recent years, except for Prospect Reservoir which varies year to year. The releases from the dam to various uses over a typical year (August 2016 to July 2017) are shown in Figure 3-14 and Figure 3-15.

Figure 3-14 Warragamba Dam releases to Prospect WFP and Prospect Reservoir (Source: WaterNSW)

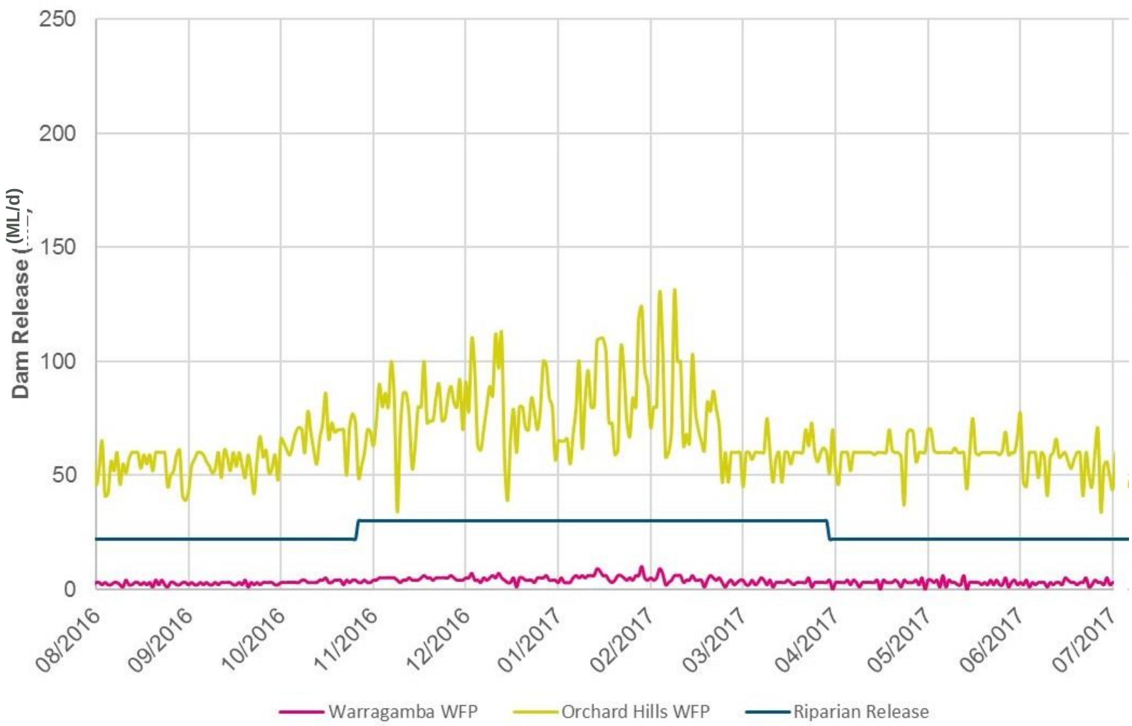


Figure 3-15 Warragamba Dam releases to Warragamba WFP, Orchard Hills and the riparian release (Source: WaterNSW)

On average across the period August 2016 to August 2017, each end-use consumed the following:

- Prospect WFP – 1 047 megalitres/d
- Orchard Hills WFP – 66 megalitres/d
- Riparian releases – 26 megalitres/d
- Prospect Reservoir – 16 megalitres/d
- Warragamba WFP – 3 megalitres/d.

These figures show that most of water released from Warragamba Dam goes to the Prospect WFP followed by the Orchard Hills WFP. The Prospect Reservoir and riparian release flows remain consistent across the year with occasional spikes. Warragamba WFP takes considerably less water than any other use.

3.1.1.10 Average annual water balance

The following presents an average annual water balance of the existing hydrology of the upstream environment. The water balance is summarised in Table 3-2.

Table 3-2 Existing upstream environment water balance

Flow or Discharge	Mean Annual Flow (2020 Demand)		Data Source / Comments
Upstream Inflows			
Warragamba Dam Inflows	765	100	A sum of the individual inflows listed below
Coxs River	161	21	Tributary Flow Monitoring Data from WaterNSW. Average value based on total annual flows for 1980 to 2020
Kowmung River	114	15	
Wollondilly River	273	36	
Nattai River	31	4	
Other Tributaries	186	24	Assumed based on an average area weighted flow of the gauged catchments to account for the total ungauged catchment inflows
Downstream Outflows			
Warragamba Dam Outflow	273	36	WaterNSW outflow monitoring data. Average value based on total annual flows for 1980 to 2020
Diversions			
Warragamba WFP	1.2	0.2	Data from WaterNSW Greater Sydney Operations Report (April 2020)
Orchard Hills WFP	22.9	3	
Prospect WFP	396	52	

Flow or Discharge	Mean Annual Flow (2020 Demand)		Data Source / Comments
Prospect Reservoir	2.2	0.3	WaterNSW outflow monitoring data. Average value based on total annual flows for 2012 to 2016
Unaccounted Losses			
Unknown	*70*	*8.5*	A combination of evaporation losses, assumed non-gauged inflows and uncertainties with using annual average data

The flows included in the upstream environment water balance include:

- inflows to Lake Burragorang from major tributaries including the Coxs, Kowmung, Wollondilly and Nattai Rivers along with other tributaries
- outflow from Warragamba Dam
- diversions from the Warragamba Dam outflow including supply to Warragamba, Orchard Hills and Prospect WFP and Prospect Reservoir.

The tabulated flows represent indicative mean annual flows for the existing condition. It is acknowledged and should be noted that actual flows fluctuate with time that is, daily and yearly variations.

The Wollondilly River is the largest individual inflow into Lake Burragorang supply accounting for approximately 36% of the reservoir's annual inflow. These flows will vary year on year and will change in response to seasonal variations and longer-term climatic conditions. Flood and drought cycles, which can persist for long periods are evident throughout the historic flow records (as previously shown in Figure 3-7).

The largest demand on dam storage is from the Prospect WFP, to which over 50% of the supply water is delivered. Around 36% of the Warragamba dam water is either release or spills into the downstream environment.

The difference between the upstream inflows and downstream outflows (i.e. unaccounted losses) is assumed to be accounted for by losses associated with evaporation, infiltration into soil and vegetation, and uncertainties with using annual average data.

3.1.2 Downstream environment

The downstream environment includes the freshwater and estuarine reaches of the river system between the Warragamba River directly downstream of the dam wall and Wisemans Ferry. The downstream environment does not include the reach of the Nepean River upstream of its junction with the Warragamba River. The downstream environment also includes the local waterways/creeks, riparian zone, floodplain and wetland/lagoon waterbodies adjacent to the main rivers.

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

Like the upstream environment, the climate of the receiving environment is influenced by both the Tasman Sea and the Blue Mountains. Summers in the area are mild to hot and winters are cool to mild, with average maximum temperatures at Richmond approaching 30°C in January and 17°C in July (see Section 3.1.1.2).

The key geological features outlined for the upstream environment in Section 3.1.1.3 also apply to the receiving environment. The Sydney Basin dominates the area with the Narrabeen Group and Hawkesbury sandstone subgroups covering most of the downstream environment (as shown previously in Figure 3-4). The Narrabeen Group, which is widespread in the northern and western region of the catchment consists of a variety of sandstone types, conglomerates and shales. The Hawkesbury sandstone that overlays the Narrabeen Group in the north-eastern region of the catchment consists of massive beds of quartz-rich sandstones which contain smaller beds of siltstone and slate (Markich and Brown, 1998).

3.1.2.1 Land use

There is a wide variety of land use types within the Project downstream environment. Almost one million people currently reside in the Hawkesbury-Nepean catchment with most of these living in the lower catchment area and the population is expected to increase significantly in the future (HNCMA, 2008 in DECCW, 2010b). Therefore, urban land use is expected to increase in the future which will in turn lead to increased stormwater and runoff (as well as other impacts such as noise pollution, water pollution, sedimentation, nutrient pollution, degradation of riparian vegetation, habitat loss) across the receiving environment.

The Lower Hawkesbury-Nepean River Nutrient Management Strategy (DECCW, 2010b) compiled and assessed land use mapping for the area. The land use categories identified include:

- **urban environment** (50,000 ha) – urban built environments such as houses, parks, roads, car parks, utilities, commercial and industrial facilities
- **rural residential** (44,000 ha) – rural residential and associated uses such as small acre farms
- **grazing** (136,000 ha) – livestock grazing of modified pastures and natural vegetation, such as cattle, sheep, horses and alpacas
- **intensive horticulture** (7100 ha) – intensive cropping practices such as flower, vegetable and fruit tree market gardens
- **intensive animal production** (6400 ha) – farms with high intensity animal practices such as poultry, dairy and piggeries
- **non-intensive agriculture/cropping** (5500 ha) – non-intensive agriculture and cropping such as turf, silage and hay production
- **other diffuse sources** (40,000 ha) – including mining, waste treatment and disposal and a range of facilities.

Note: the area figures reported above are for the entire lower Hawkesbury-Nepean catchment, not the receiving environment area for the Project.

Like the upstream environment, numerous national park areas are located downstream of Warragamba Dam. These park areas are typically located on the western and northern borders of the study region where major rivers including the Grose, Colo and Macdonald Rivers flow towards the Hawkesbury-Nepean River. On the eastern side of the Hawkesbury-Nepean River there is a large urban area around Penrith, with numerous smaller urban areas along the length of the river to Pitt Town. Between these town centres, agricultural land use is a dominant land use (and is a key economic industry for the region) on both sides of the Hawkesbury-Nepean River and in the sub-catchments of South Creek and Cattai Creek (DECCW, 2010b).

3.1.2.2 Rivers and creeks

Overview

At the junction of the Warragamba and Hawkesbury-Nepean Rivers, the Hawkesbury-Nepean catchment is only 20% of the size of the Warragamba catchment. However, the Hawkesbury-Nepean River drains a region of very high rainfall along the top of the Illawarra Escarpment and thus its contribution to downstream flows is typically greater than the simple portion of the catchment area may suggest (WMA Water, 2013).

Downstream of the Warragamba and Hawkesbury-Nepean Rivers junction, the Hawkesbury-Nepean River continues to flow through a narrow gorge until just before it reaches Penrith, where it emerges at the head of the floodplain. Downstream of Penrith, the Grose River joins the Hawkesbury-Nepean River and flows through the Richmond/Windsor lowlands. The Grose River is one of the Hawkesbury-Nepean Rivers largest tributaries in the downstream environment. South Creek joins the Hawkesbury River downstream of Windsor but is not a major contributor to flood flows however it has a large floodplain which is inundated by backwater from the Hawkesbury-Nepean (WMAwater, 2013).

Below Wilberforce, Cattai Creek joins the river prior to it entering the Hawkesbury gorge which extends for over 100 km to the ocean at Broken Bay (WMA Water, 2013). While the river passes through this gorge, the Hawkesbury-Nepean’s largest tributary in the downstream environment, the Colo River, emerges and joins the river along with several other minor tributaries. The McDonald River also merges with the Hawkesbury River at Wisemans Ferry. There are numerous other tributaries downstream of Wisemans Ferry, but these are located beyond the study extent for the Project.

Existing Condition and Geomorphic Features

The condition of river reaches downstream of Warragamba Dam has been significantly modified since pre-European settlement. There is a realisation that human impacts from changes in the catchment and in the channel certainly modify pre-existing processes and, in some cases, dominate them. Thus, regimes can be altered without a change in climate, simply by anthropogenic activity in the catchment, often accelerating erosion and increasing runoff (Warner, 1984; Warner, 1991; Warner, 1994a; Warner, 1994b; Warner, 2002a; Warner, 2014). The impact of construction along the river and land use change across the floodplain has altered river flow conditions and geomorphic features within the existing downstream environment. The impact of infrastructure and the building environment is discussed further in Section 3.1.2.8.

The River Styles® assessment by GHD (2013) concluded that the Hawkesbury-Nepean River was primarily in moderate geomorphic condition with the river reaches closest to Warragamba Dam in good condition. Most of the other waterways within the downstream study site were of moderate condition with some sections in a good condition. A few sections of waterway were identified as poor condition, in particular, parts of the Grose River, Cooley Creek, Claremount Creek, McKenzies Creek, Greens Creek, and Webbs Creek.

Between Yarramundi and Windsor, the Hawkesbury River is wide and shallow with numerous shoals restricting navigability. This segment of river is also notably straighter than the other downstream river reaches and includes numerous lagoons and wetlands across the floodplain and lowlands. The channel form and bank stability of the upper estuary at this location are largely influenced by the persistent low flows in the main stream of the Hawkesbury River (Kimmerikong, 2005). The altered flow regime affects sediment and bank dynamics, which is readily observed as bank slumping and erosion within this reach of the study area (BMT WBM, 2014).

Further downstream, between Cattai and Wisemans Ferry, the floodplain is narrow (typically less than 400 metres wide) and essentially non-existent where the river channel is bedrock-controlled (that is, steep sandstone gorge).

Declared Wild Rivers

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

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

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

3.1.2.3 Rainfall and streamflow

Rainfall

Analysis of long-term rainfall data sourced from BoM for the downstream environment of the Project shows that the mean annual rainfall varies considerably between stations across the area. However, the wettest and driest months are consistent across the catchment with February generally recording the greatest rainfall and July recording the lowest rainfall (see Table 3-3).

Peak rainfall totals across the downstream environment stations consistently occurs between November and March, however the variability between locations can be high. For example, Kurrajong Heights received 1 379 mm of rainfall across 2015, while Richmond RAAF less than 20 km away received 1 018 mm. The Grose River, for example, drains a high rainfall area in the Blue Mountains where mean annual rainfall exceeds 1 400 mm.

The years 1944, 1979, 1994 and 2006 were identified as the driest years at two different stations each. The wettest years also varied between stations but both the year 1963 and 1990 were recorded as the wettest year at two stations each.

Table 3-3 Rainfall statistics for the downstream environment (BoM)

Location	BOM Station (opened)	Mean annual rainfall (mm)	Mean monthly rainfall (mm)	Mean wettest month	Mean rainfall for wettest month (mm)	Driest month	Mean rainfall for driest month (mm)	Driest year	Total rainfall for driest year (mm)	Wettest year	Total rainfall for wettest year (mm)
Glen Alice	61334 (1970)	631	53	Jan	79	Jul	35	1982	285	1978	996.2
Glenbrook Bowling Club	63185 (1963)	982	82	Feb	139	Jul	36	1979	544	1963	1,652
Castlereagh (Road)	67002 (1939)	836	70	Feb	113	Jul	34	1944	227	1950	1,678
Winmalee (Pentlands Dr)	63286 (1985)	1,019	85	Feb	168	Jul	39	1994	636	1990	1,644
Kurrajong Heights	63043 (1866)	1,249	104	Feb	172	Aug	53	1944	473	1870	2,840
Mt Irvine (Booralee)	63285 (1986)	1,306	109	Feb	164	Jul	50	1994	787	1990	1,887
Colo Heights (Mount Pines)	61211 (1962)	1,029	86	Feb	140	Jul	37	1979	524	1963	1,676
Richmond RAAF	67105 (1993)	741	62	Feb	116	Jul	28	2006	491	2007	1,051
Sackville	63280 (1980)	628	52	Feb	101	Aug	22	2006	419	2010	895
Wisemans Ferry (Old PO)	61119 (1903)	865	72	Feb	103	Sep	48	1906	437	1988	1,498

Streamflow

Streamflow gauging stations have been operational on the Hawkesbury-Nepean River system for over 70 years (Wallacia and Penrith). Normally, this would be a sufficient period to provide good estimates of mean annual flows at these locations, however due to the ever-increasing abstractions for irrigation and water supply in addition to the increasing STP discharges, river flows have been continuously impacted (DPI, 2014). Thus, flow behaviour and mean annual flow volumes have constantly changed (or been altered) during this time making it difficult to characterise the 'normal' streamflow behaviour or condition in the downstream environment.

Nonetheless, flow duration curves for major tributaries of the Hawkesbury-Nepean River as produced by NSW Office of Water (2014) (shown previously in Figure 3-8) provide a good overview of flow volume and occurrence. The flow duration curves show that the rivers in the downstream environment downstream of the dam (solid lines) have 'cease to flow' periods on occasion. These downstream rivers (excluding Glenbrook Creek) have flows of 100 megalitres/d or more at least 10% of the time.

3.1.2.4 Tidal limit

The tidal limit of the Hawkesbury River occurs near Yarramundi, approximately 140 km upstream of the river mouth (Department of Natural Resources, 2006; Krogh et al., 2009). The Yarramundi to Windsor reach is wide, shallow and freshwater dominated with moderate tidal influence. Near the tidal limit, the Hawkesbury River receives tributary inflows from the Grose River (at Yarramundi) and the Nepean River (further upstream of Yarramundi), and experiences moderate freshwater tidal influence (Gruber et al., 2010).

Water level recording stations are located across the length of the Hawkesbury-Nepean River system as shown in Figure 3-16. Example river levels recorded at locations along the Hawkesbury River (see Figure 3-17) demonstrate the attenuation of the tides with increasing distance upstream. There is no tidal influence at Castlereagh as demonstrated by the constant river water level which is controlled by the river bed a short distance downstream near Yarramundi (that is, the tidal limit).

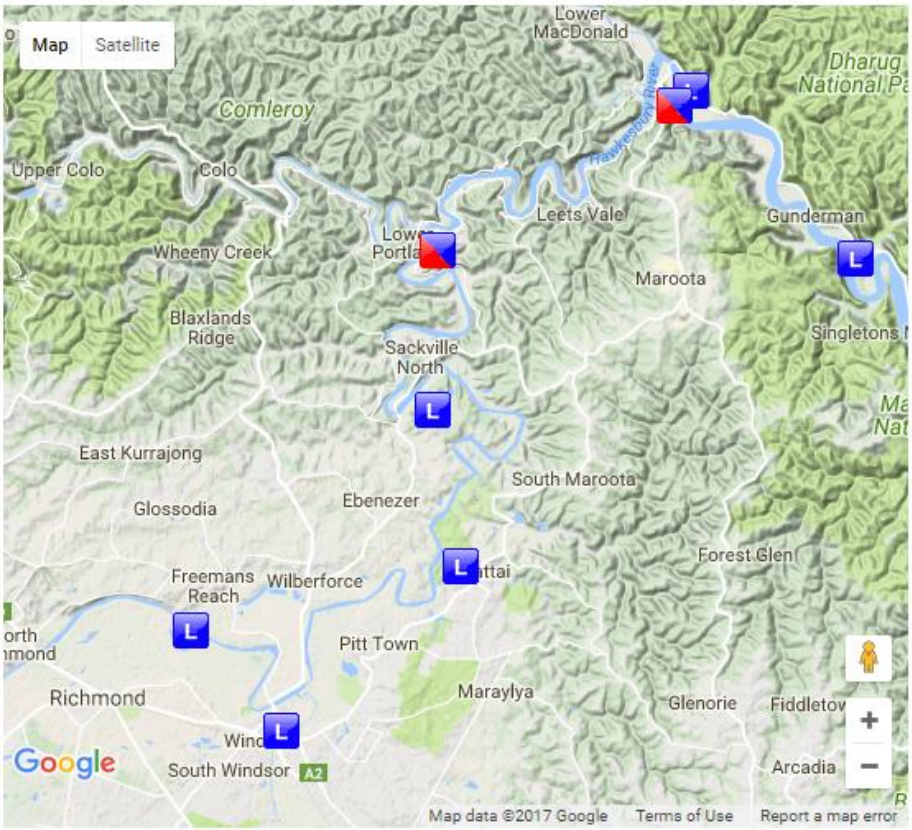
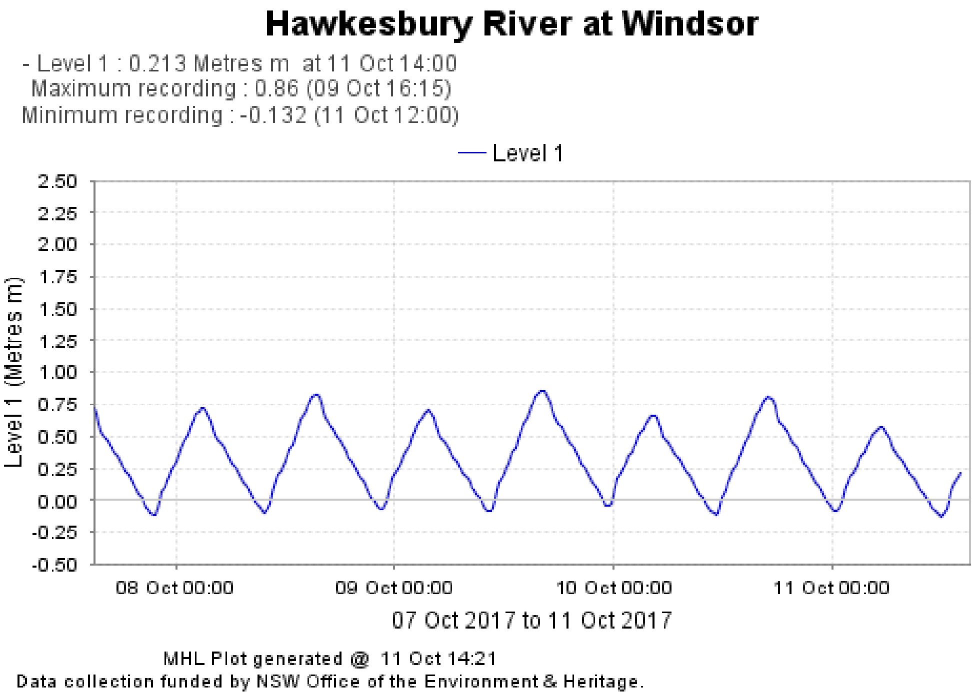


Figure 3-16 Water level recording stations (Source: Manly Hydraulics Laboratory)



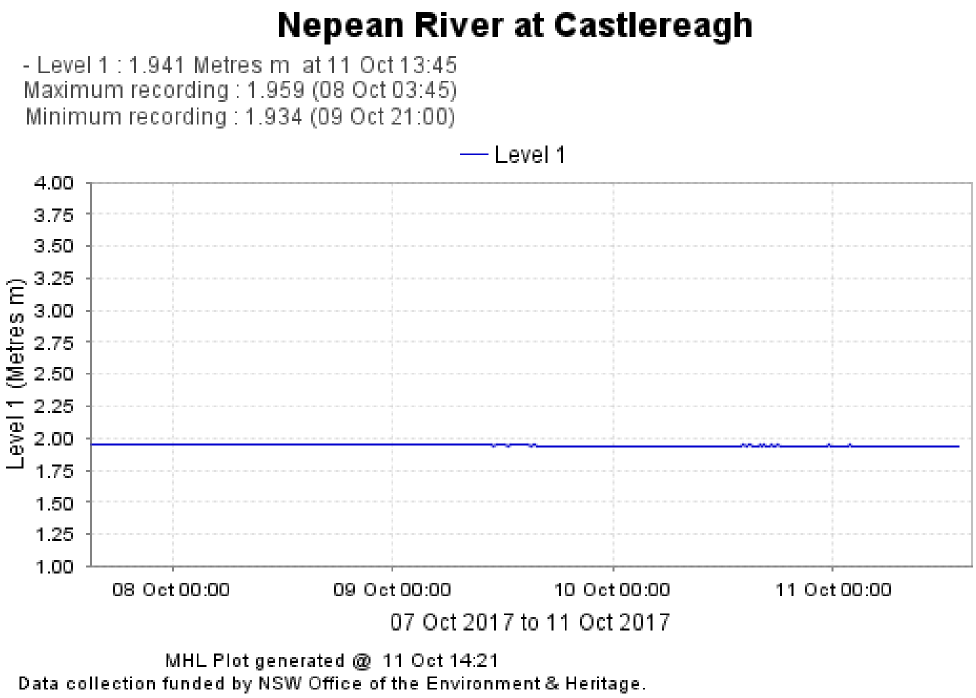


Figure 3-17 Water level on Hawkesbury-Nepean River 7-10 October 2017 (Source: Manly Hydraulics Laboratory)

At Wisemans Ferry high tide is 2 hours and 15 minutes after the recorded high tide at Fort Denison. With distance along the estuary from its entrance at Broken Bay, the tide continues to lag the ocean, low tides are increased slightly, and high tides are amplified. At Windsor, high and low tide are 5 hours and 15 minutes and 5 hours and 30 minutes behind Fort Denison, respectively.

The river between Windsor and Sackville is wide and deep and highly utilised for water-skiing and wakeboarding. This reach has the poorest water quality with Cattai Creek and South Creek delivering flows that are frequently high in nutrients, low in dissolved oxygen and of a higher salinity than the incoming tidal flows (in this location). Bank erosion is prevalent and native riparian vegetation is sparse.

Between Sackville and Wisemans Ferry the river is wide and deep in this reach although the surrounding terrain steepens. The banks are often sheer sandstone cliffs with well-established native vegetation. Inflows from the Colo River deliver clean fresh water to this reach.

3.1.2.5 Wetlands and lagoons

Overview

The Hawkesbury-Nepean region contains several wetland types including upland lakes and wetlands, coastal swamps and coastal floodplains including flood lakes, backswamps, ponded tributaries and creek swamps (ERM Mitchell McCotter, 1995). Floodplain wetlands are diverse and provide important habitat for migratory water birds, and although predominantly invaded by carp at present, they have some potential for native fish habitat (BMT WBM, 2014).

Important Wetlands

Wetlands included within the Directory are present in the downstream environment of the Project and include Pitt Town Lagoon and Longneck Lagoon. Both wetlands are examples of the Endangered Ecological Communities (EEC) Freshwater Wetlands on Coastal Floodplains of the New South Wales North Coast, Sydney Basin and South East Corner Bioregions. These two floodplain lagoons are located south of the Hawkesbury River, with Pitt Town Lagoon located off Bardenarang Gully, and Longneck Lagoon located off Longneck Creek near the suburb of Pitt Town. There are no Ramsar listed wetlands, however some wetlands north of Agnes Banks are listed under State Environmental Policy (Coastal Management) 2018. The location of notable wetlands in the downstream environment are shown in Figure 3-3 and discussed further below.

Wetland Distribution

Several studies have been undertaken within the Hawkesbury-Nepean catchment to map wetlands (Adam and Stricker, 1989; Smith and Smith, 1994; Stricker and Wall, 1995), including the most recent by Smith and Smith (1996) who identified 495 wetlands or wetland clusters of regional conservation significance that varied in size from 0.3 ha to 208 ha.

Of the total wetlands, 50 floodplain wetlands are associated with the Hawkesbury-Nepean River downstream of Pheasants Nest and Broughtons Pass Weirs to the confluence of the Colo River, with the majority found between Richmond and Wisemans Ferry (Hawkesbury-Nepean River Management Forum, 2002). Taylor-Wood and Warner (2003) identified 47 wetlands that are likely to depend on flows from the Hawkesbury-Nepean River, many of which are in very poor condition.

Several other floodplain wetlands exist on the Richmond Lowlands (Hawkesbury-Nepean River Management Forum, 2004) in various tenure, including Irwins Swamp, Yarramundi Lagoon, Bakers and Triangle Lane Lagoons (both in private ownership), and Pughs and Bushells Lagoons spanning both public and private property.

Wetland Condition and Pressures

According to the Hawkesbury-Nepean State of the Catchments (SOC) 2010 report, overall wetlands in the region are in very poor condition (DECCW, 2010a). The SOC 2010 report identified the overall condition, indicators of pressure and pressure rating experienced by Hawkesbury-Nepean wetlands. Those wetlands listed within the downstream environment are detailed in Table 3-4. As shown in Table 3-4, altered hydrology is already having a moderate disturbance on both wetlands.

Wetland and Floodplain Connectivity

Many of these wetlands now rely on water from their own catchments as the construction of levy banks and other flood mitigation devices has reduced (and in some cases removed) their connectivity to the Hawkesbury-Nepean River (Taylor-Wood and Warner, 2003). The lack of connectivity between the wetlands and rivers has decreased wetland flushing resulting in nutrient and sediment build-up and wetlands becoming smaller, shallower and prone to invasion by weed species (Taylor-Wood and Warner, 2003).

Flood frequency dependency of floodplain wetlands is not clear. However, since the construction of Warragamba Dam and other flood mitigation measures, flood frequency and magnitudes have reduced, limiting the connectivity of the river and wetlands.

Table 3-4 Condition, indicators of pressure and pressure rating (Source: DECCW, 2010a)

Downstream environment wetland	Condition	Pressure	Indicators of pressure
Longneck Lagoon Upland freshwater lake	Very poor	High	• Catchment disturbance: high • Hydrological disturbance: moderate • Habitat disturbance: high
Pitt Town Lagoon Coastal floodplain swamp	Very poor	High	• Catchment disturbance: high • Hydrological disturbance: moderate • Habitat disturbance: moderate

3.1.2.6 Groundwater and groundwater dependent ecosystems (GDEs)

Two of the thirteen groundwater management areas (GWMAs) identified in the State of the Catchments 2010 report for the Hawkesbury-Nepean region[1] are relevant to the Project, these being the Hawkesbury Alluvium (alluvial GWMA) and the Sydney Basin–Central (porous rock GWMA).

Herron et al. (2018) note the following with regard to the hydrogeological characteristics of the Sydney Basin bioregion:

The alluvial deposits of the Hawkesbury River, extending downstream of Warragamba Dam to the township of Spencer, are referred to as the Hawkesbury Alluvium Groundwater Source. Alluvial

[1] https://www.environment.nsw.gov.au/soc/sydneymetro.htm

deposits are broadest in the Windsor to Wilberforce area with most bores drilled in thinner alluvia of minor tributaries. … The Hawkesbury alluvium is a significant alluvial groundwater system with reasonable levels of storage.

The main hydrogeological unit in the Sydney Basin–Central area is the Wianamatta Group. Two other hydrogeological units in this area are Quaternary-Cenozoic and Hawkesbury Sandstone. With regard to the Wianamatta Group, Herron et al. (2018) note:

The Wianamatta Group consists of three units: the Ashfield Shale, the Minchinbury Sandstone and the Bringelly Shale, with the Minchinbury Sandstone of negligible thickness (McNally, 2004). This group has a maximum thickness in western Sydney of up to 300 m, but with more typical thicknesses in the range of 100 to 150 m. The Wianamatta Group occurs as scattered remnant areas in the Southern Highlands, with major outcrops predominantly over the Cumberland Plain south-west of Richmond.

In western Sydney, two aquifer systems are associated with the shale formations of the Wianamatta Group. The upper aquifer system comprises residual soils and colluvium derived from the shales, floodplain alluvium and the weathered saprolite, and typically has a depth of 3 to 10 m. Hydraulic conductivities show a large variability and range between 0.01 and 10-5 m/day, with the higher end suggesting the presence of open fractures in weathered shales or ferricrete bands. The lower aquifer system occurs below the base of the weathering and comprises fine-grained mudrocks. This aquifer shows some degree of fracturing thus allowing some groundwater flows. Despite its low transmissivities, McNally (2004) refers to this system as an aquifer because it discharges small volumes of saline water to the surface. Hydraulic conductivities range between 0.001 and 10-8 m/day, with the lower end reflecting the intrinsic impermeability of the unfractured shale.

Both aquifers show limited storage and low bore yields, typically less than 0.1 ML/day (McNally, 2004; Parsons Brinckerhoff, 2013). Water-bearing fractures are widely spaced and sometimes poorly interconnected. This results in boreholes being dry when first drilled, then slowly filling with water over several weeks, causing substantial head and salinity variations in piezometers. Water within fractures is generally brackish to saline, especially in low relief areas, with typical values in the range of 5,000 to 50,000 mg/L TDS (McNally, 2004).

The nature of groundwater recharge in the Sydney Basis is described as follows in Herron et al. (2018):

The dominant recharge mechanism in the geological Sydney Basin is likely to be infiltration of rainfall and runoff through alluvial deposits in valleys, particularly where they are incised into weathered Hawkesbury Sandstone (Parsons Brinckerhoff, 2011). Similarly, recharge through infiltration takes place where the underlying units of the Narrabeen Group outcrop. … Recharge for deeper sandstone aquifers comes mainly from infiltration of rainfall over outcropping areas and through inter-aquifer leakage (SCA, 2012). In the Southern Coalfields, the deeper aquifers occurring in the Bulgo and Scarborough sandstones (Narrabeen Group) outcrop in the valleys of the Cordeaux and Avon reservoirs and thus recharge is expected at times of higher water level (SCA, 2012).

and

On a local scale, topography controls the groundwater flow near the ground surface in alluvial and shallow aquifers. In these systems, groundwater flow is likely to be localised and limited in extent, *with occurrence of perched aquifers controlled by the presence of fine-grained materials. In general, these systems are responsive to rainfall and streamflow (SCA, 2012). On a regional scale, … groundwater flows for the geological Sydney Basin [are] controlled by the basin geometry, topography and major hydraulic boundaries.*

There are currently 43 licenced extraction wells within the Hawkesbury – Nepean basin, with a combined extraction rate of 1.172 gigalitres per annum.

Appendix 4 to the background document for the Water Sharing Plan for the Greater Metropolitan Region Groundwater Sources (NSW Office of Water, 2011) lists identified high priority Groundwater dependent ecosystems (GDEs) in the Greater Metropolitan Region. Of these, the following are relevant to the assessment:

- Pitt Town Lagoon (associated with the Hawkesbury Alluvium groundwater source)
- Long Swamp (associated with the Sydney Basin Central groundwater source)
- Longneck Lagoon (associated with the Sydney Basin Central groundwater source)
- O'Hares Creek (associated with the Sydney Basin Central groundwater source).

Downstream GDEs are considered to have limited reliance upon flows from the Warragamba catchment with regard to their ongoing viability. Periodic inundation of floodplain areas under flood conditions represents only a minor contribution to groundwater, particularly compared with the contribution of infiltration from direct rainfall in the catchment. The recent flood in February 2020 demonstrated the extent of local flooding without flow contribution from the Warragamba Dam catchment.

3.1.2.7 River water users, extractions and management

Water users

The Hawkesbury-Nepean River is utilised by many different individuals, groups, businesses and industries. Major water users in this catchment include Sydney Water Corporation, local councils, industry (for example, major utility use, mining, agriculture, dairies), commercial (for example, fishing, livestock, aquaculture, irrigation) and tourism/recreation (for example, public use of waterways for swimming, fishing etc).

Sydney Water supplies water to most homes and businesses within the greater metropolitan area (NSW DPI Water, 2017).

Water sharing plan

To preserve water resources in river and groundwater systems for the long term, it is critical to balance the competing needs of the environment and water users. Water sharing plans establish rules for sharing water between the environmental needs of the river or aquifer, water users, and also between different types of water use such as town supply, rural domestic supply, stock watering, industry and irrigation (NSW DPI Water, 2017).

Water sharing plans in the Hawkesbury-Nepean catchment include:

- Central Coast Unregulated

- Greater Metropolitan Region Groundwater
- Greater Metropolitan Region Unregulated River
- Kulnura Mangrove Mountain Groundwater.

The *Water Sharing Plan for the Greater Metropolitan Region Unregulated River Water Sources 2011* (Water Sharing Plan) is a detailed legal instrument that includes rules for protecting the environment, extractions, managing licence holders' water accounts and water trading in the Water Sharing Plan area (NSW DPI, 2016). The Water Sharing Plan commenced on July 1, 2011 and encompasses the Hawkesbury-Nepean River.

River extractions and drinking water supply

Numerous water users are affected by the Water Sharing Plan. The environment benefits from having water reserved for the fundamental health of the river and ecosystems that depend on it. Commercial water users need to be licensed to extract water from the Hawkesbury-Nepean River with commercial water users including irrigation, mining, manufacturing, power generation, diaries, tourism facilities and aquaculture.

Extraction management units are used for managing long-term average annual extractions. The downstream environment of the Project covers two extraction management units:

- Upper Nepean and Upstream Warragamba Management Unit
- Hawkesbury and Lower Nepean Rivers Management Unit.

Requirements for water are defined under Part 5, Division 3 of the Water Sharing Plan as licensed share components in megalitres per annum (ML/a), while limits to the availability of water are defined under Part 7. The Water Sharing Plan requirements for water extraction for relevant water users is provided in Table 3-5.

As discussed, a large volume of water is designated as major utility use for the Hawkesbury-Nepean catchment in the Water Sharing Plan. This is expected as Warragamba Dam supplies potable water to most of Sydney's population of 5.5 million. Water is also drawn from the Hawkesbury-Nepean to provide potable water to the North Richmond WFP.

Sydney Water is licenced to take 20 075 megalitres of water from the Hawkesbury-Nepean River every year for the North Richmond WFP. The WFP draws raw water directly from the river at North Richmond and then treats and distributes potable water to homes and businesses.

Table 3-5 Water sharing plan requirements for water extraction

Share components of access licences	Water source (ML/year)
	Hawkesbury and Lower Nepean Rivers
Domestic and stock access	1,498.5
Local water utility access	974
Major utility access	26,075 *6,000 for WaterNSW* *20,075 for Sydney Water*

Irrigation

The Hawkesbury-Nepean River system supports a multimillion-dollar agriculture industry. Irrigated agriculture occurs in pockets adjacent to both the main river and its tributaries, most notably South Creek. Irrigation has occurred in the catchment since the nineteenth century; however, it has undergone changes due to the growth and evolution of farming practices along with the desire to grow 'in demand crops' which have higher water demands. The irrigation demand in the downstream environment is highly responsive to climatic conditions with water requirements notably higher during periods of drought.

The Hawkesbury-Nepean River is classed as an unregulated river, meaning that the dams are not used to store and release water for irrigation purposes. Rather, irrigators downstream of Warragamba Dam only have access to residual flows that enter the system downstream of the dam or excess flows that are released from the dam. The discharge of STPs particularly in the South Creek catchment also contribute substantial flows in dry weather.

The Water Sharing Plan caps the total irrigation extraction volume in the Upper Nepean and Upstream Warragamba extraction management unit at 11 GL per annum. The annual Hawkesbury and Lower Nepean management unit extraction is capped at 71 GL per annum (DPI, 2014).

Under the *Water Management Act 2000* extraction of water for basic landholder rights does not require a license. Otherwise, a water access licence is required to extract river water for irrigation purposes. This includes extracting water for domestic and stock purposes from a water source fronting a landholder's property, which under the current Water Sharing Plan is capped at 25.4 megalitres/day in the Hawkesbury and Lower Nepean Rivers water source and 21 megalitres/day for the Upper Nepean and Upstream Warragamba water source.

The current licensed volumes are summarised in Table 3-6. It can be seen that the Colo River and Upper Hawkesbury (Cattai to Colo) water management zones have the largest water licence shares in the downstream environment.

In terms of total water usage, irrigation is a relatively small portion of the mean annual flow and the Water Sharing Plan ensures that irrigation cannot exceed set levels during low flow drought periods.

Table 3-6 Current water access licenced volumes for water management zones in the downstream environment excluding major utilities (Source: DPI, 2014)

Water management zone	All licences		Unregulated licences	
	Number	Shares ML/yr	Number	Shares ML/yr
Lower Nepean (Wallacia to Grose River)	34	949	67	6,490
Yarramundi Lagoon	3	7	34	2,413
Grose River	28	242	33	1,323
South Creek	32	290	180	8,351
Upper Hawkesbury (Grose to Cattai)	27	566	241	29,956
Cattai Creek	18	116	51	1,458
Upper Hawkesbury (Cattai to Colo)	33	355	65	3,705

Water management zone	All licences		Unregulated licences	
	Number	Shares ML/yr	Number	Shares ML/yr
Colo River	56	1,374	78	2,475
Lower Hawkesbury (Colo to Macdonald)	12	74	11	315
Macdonald River	3	9	9	321

Other extractions

Numerous commercial operations exist in the downstream environment of the Project that abstract water directly from the Hawkesbury-Nepean River. Commercial operations include sand and gravel quarries, cement works, Penrith Lakes and the 'Panthers World of Entertainment' complex. Commercial abstractions represent a very small proportion of the total mean annual flow.

Penrith Lakes is a 1,935-hectare site located on the eastern bank of the Nepean River downstream of Penrith Weir. The site is a former sand and gravel quarry that is being transformed into a system of lakes, parklands and residential development.

The *Water Management (General) Amendment (Licences) Regulation 2017* under the *Water Management Act 2000* allows for a new category of water access licence (the Penrith Lakes Scheme access licence), and to declare that type of water access licence to be a specific purpose access licence (initial fill of the lakes that form part of the Scheme), for the purposes of the *Water Management Act 2000*.

The draft vision plan for Penrith Lakes (NSW Public Works, 2014) states that the creation and maintenance of nearly 700 ha of lake requires a water supply to match the evaporation losses from the lakes' surface. The Nepean River is to be the source of water to fill the lakes which is contingent on the water access licence and the development consent being issued by the NSW Government. Any water drawn from the Nepean River is subject to strict development conditions on the Penrith Lakes Development Corporation, which only permit pumping from the river during medium to high river flows and not during periods of drought or 'low flow'.

The Nepean River top up water scheme has 16.4 GL of available water to pump from the Nepean River annually under the current high flow licence based on average river flow conditions (AECOM, 2014). On average, the net water extracted from the river (the difference between what is extracted from the Nepean River and what is discharged back to the Nepean River) would be approximately 2.5 GL/yr (Cardno, cited in AECOM 2014).

To maintain adequate environmental river flows in addition to maintaining the optimum Penrith Lakes Scheme operating levels the following pumping rules were proposed for the operational phase of the development (AECOM, 2014):

- pumping can commence from the Nepean River to the lakes when the total river flow exceeds 500 megalitres/day
- pumping must cease when the total Nepean River flow drops below 350 megalitres/day
- the maximum pumping rate is 86.4 megalitres/day (or 1.0 m^3/s)

- environmental flows cannot be pumped. When pumping occurs, the remaining flow in the Nepean River must exceed the environmental flows.

3.1.2.8 Infrastructure and built environment

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

Urban waterways

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

Farm dams, irrigation channels and groundwater bores

Farm dams are typically private dams that are used to intercept catchment runoff that would otherwise have contributed to streamflow. There are numerous farm dams located within the Hawkesbury-Nepean catchment and specifically the downstream environment of the Project. Farm dams are important resources providing water to stock, irrigation and gardens along with habitat for wildlife and fire management and protection.

Analysis of aerial photography indicates that there are large clusters of farm dams in the following downstream environment locations:

- Mulgoa Creek catchment – Mulgoa area upstream of Penrith
- South and Cosgrove Creek catchments – Luddenham and Badgery's Creek area
- North Richmond area
- Currency Creek catchment – Wilberforce and Ebenezer area
- Douglas Creek catchment – Maroota area.

Irrigation channels exist across the floodplain which are used to supply river water to irrigated agricultural areas. These are man-made and artificial and divert water from streamflow to be used for irrigation.

Existing groundwater bores (water supply) are shown in Figure 3-18. There are numerous groundwater bores located throughout the downstream environment from Orchard Hills up to Wisemans Ferry.

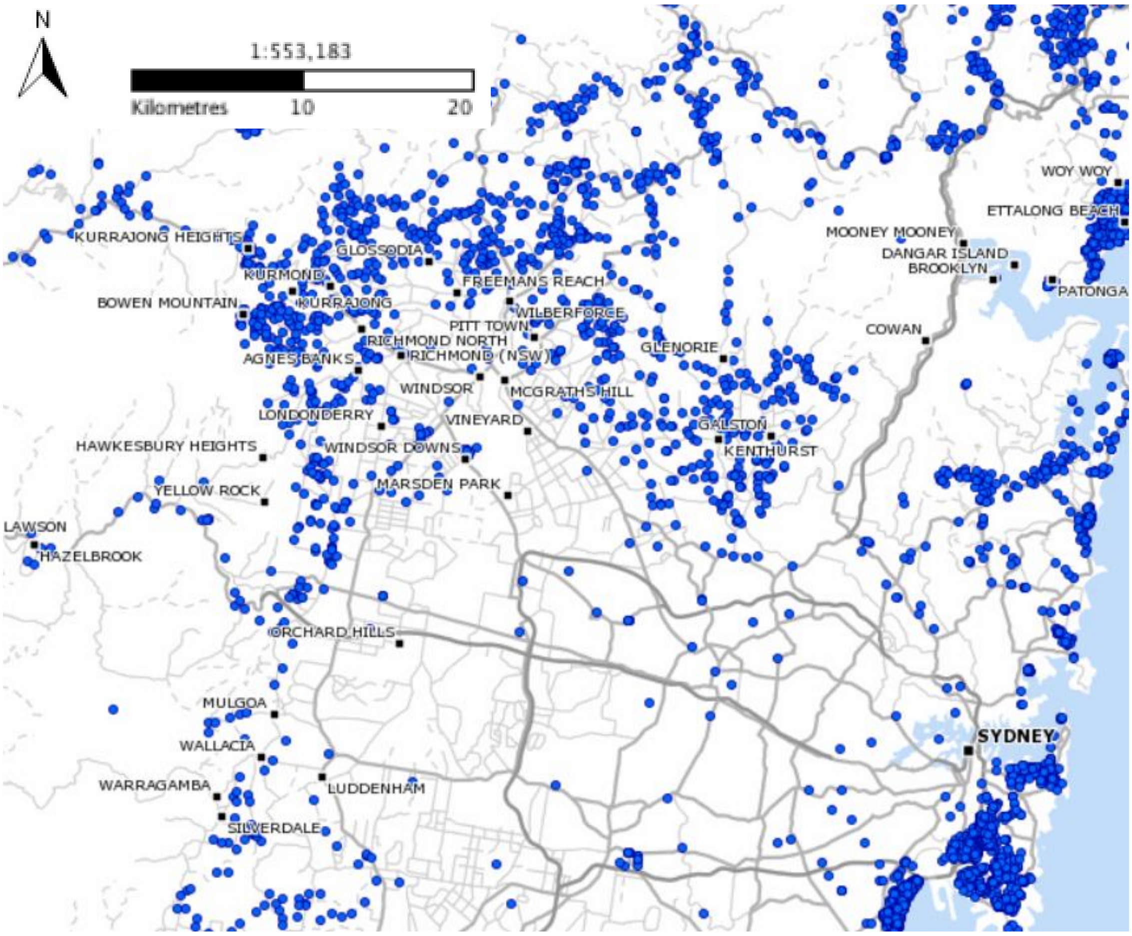


Figure 3-18 Groundwater bores in the downstream environment (Source: BoM, 2017b)

Weirs and weir pools

A weir is a ‘mini dam’ built across a river to control or divert water flow to larger dams, supply networks, or for irrigation. The construction of weirs along the Hawkesbury-Nepean River significantly regulates the river flow and creates a series of segmented weir ponds rather than a freely flowing river. Over the last 100 years, numerous weirs have been constructed in the Hawkesbury-Nepean River and its tributaries. These include:

- Pheasants Nest Diversion Weir
- Broughtons Pass Diversion Weir
- Maldon Weir
- Douglas Park Weir
- Menangle Weir
- Bergins Weir
- Thurns Weir
- Camden Weir
- Sharpes Weir
- Cobbity Weir
- Mount Hunter Rivulet Weir
- Theresa Park Weir
- Wallacia Weir
- Penrith Weir.

The location of the above weirs is shown in Figure 3-19.

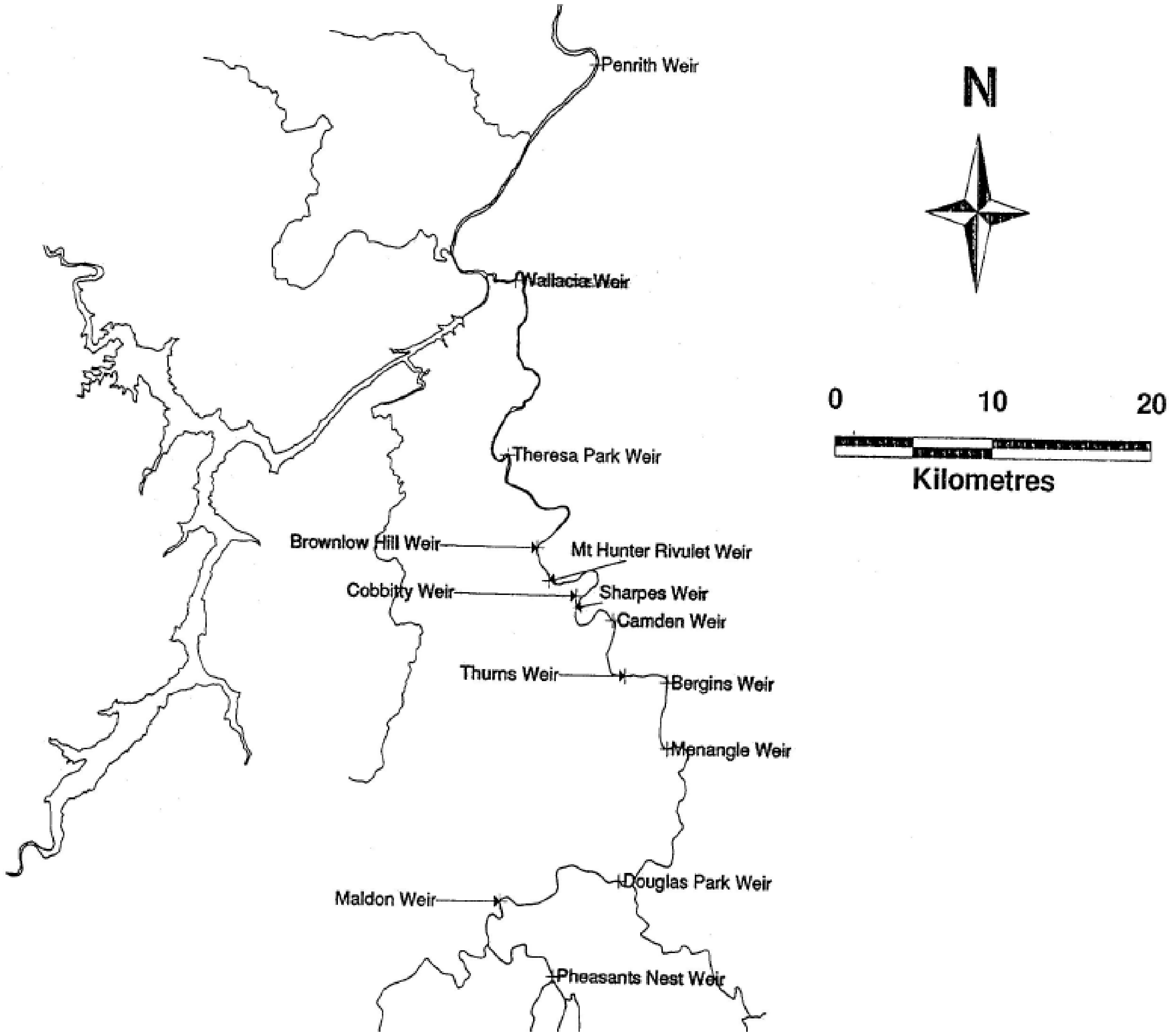


Figure 3-19 Weir location map (Source: Wilson, 2002)

Penrith Weir is one such example (in the downstream environment of the Project) which creates a significant weir pool upstream of Penrith and Emu Plains. Penrith Weir was originally constructed in 1908 and is today listed on the State Heritage Register. The channel at the weir is approximately 120 m wide increasing to 200 m wide at the Victoria Bridge downstream. Upstream the channel varies from 130 to 150 m wide however has varied notably since 1900 (Warner, 2002b).

The two water supply diversion weirs – Broughtons Pass and Pheasants Nest located in the Upper Nepean catchment near Wilton and Appin are managed by WaterNSW. These were constructed in 1888 and today remain an integral part of the water supply system.

Warner (2002c) determined approximate mean weir pool widths, surface areas and evaporation levels, as shown in Table 3-7.

Downstream of Penrith, the construction of artificial lakes (for example, Shaws Lakes and Penrith Lakes) also has some influence on local river flow conditions with various floodplain connections established between shallow offline lake storages during floods, and non-flood periods such as the pumping from Nepean River as part of the operational phase of the Penrith Lakes Scheme.

Table 3-7 Weir pool lengths, mean widths, surface areas and approximate evaporation[2] (Source: Warner, 2002c)

Weir pool	Distance[1] (km)	Mean Width[2] (m)	Area (m^2)	Evaporation[3] (ML)
Menangle	12.4	40.8	506,730	507
Camden	4.5	42.0	187,320	187
Sharpes	4.1	45.5	187,460	187
Cobbitty	4.2	49.3	206,850	207
Mt Hunter	2.5	38.0	95,760	96
Brownlow H	1.6	43.0	69,000	69
Teresa Park	approx. 10.0	45.0	450,000	450
Bents Basin	3.3	18.6	81,600	82
Wallacia	11.0	27.4	301,400	301
Wallacia-Warra Junc.	2.2	34.8	76,500	77
WarraDam to Nep Junc.	3.4	24.7	84,000	84
Junction to Penrith	18.4	96.4	1,773,950	1,774

Fishways

New fishways were installed at 10 weirs on the river as part of a project to upgrade weirs in 2009 to prepare the weirs for the environmental flows from upstream dams. The fishways installed comprise of a series of interconnected pools and resting areas for fish which gradually swim up a slope to get to the upper level of the weir. The vertical-slot design used is proven to be effective with native fish in Australia.

Monitoring of fish in the river carried out by the NSW DPI indicate the fishways are benefiting all fish in the river and highlight positive improvements for the river's overall fish community. Surveys at 20 sites along the river before and after the completion of the new fishways confirm that fish as small as 25-30 mm in length (for example Australian smelt and Cox's gudgeons) as well as larger fish (including Australian bass and Freshwater mullet (60 mm to 400 mm long) and Long-finned eels up to 1200 mm in length) are all using and benefiting from the fishways (WaterNSW, 2017b).

Pumping stations, raw water pipeline and canals

The Upper Nepean Scheme completed in 1888 centred around two weirs collecting river water which was gravity fed along a series of tunnels, canals and aqueducts to a large reservoir in Sydney's west.

[1] Distance is the length of weir pool surveyed.
[2] Mean width was based on measuring the width on topographic maps to the nearest 0.1mm every 5 km in most pools, elsewhere the distance was every 200m.
[3] Evaporation assumed on average to be about 1m/yr.

As Sydney's population grew additional water supply was required, four new dams were built on the Upper Nepean to supplement the scheme's supply – the Cataract Dam, Cordeaux Dam, Avon Dam and Nepean Dam. A schematic of the Nepean System is shown in Figure 3-20.

The main features of the Upper Nepean Scheme continue to operate today (excluding the lower canal). In 2008 a Raw Water Pumping Station was built at Prospect Reservoir to provide greater flexibility to the water supply. It was one of four deep water pump stations constructed during the last drought.

Return flows from STP discharges

One of the key anthropogenic water inputs to the Hawkesbury-Nepean River is point source STP discharges. Sydney Water currently operate 15 STPs and Water Recycling Plants (WRPs) within the Hawkesbury-Nepean catchment. Of these, 12 are in the downstream environment of the Project and are outlined in Table 3-8.

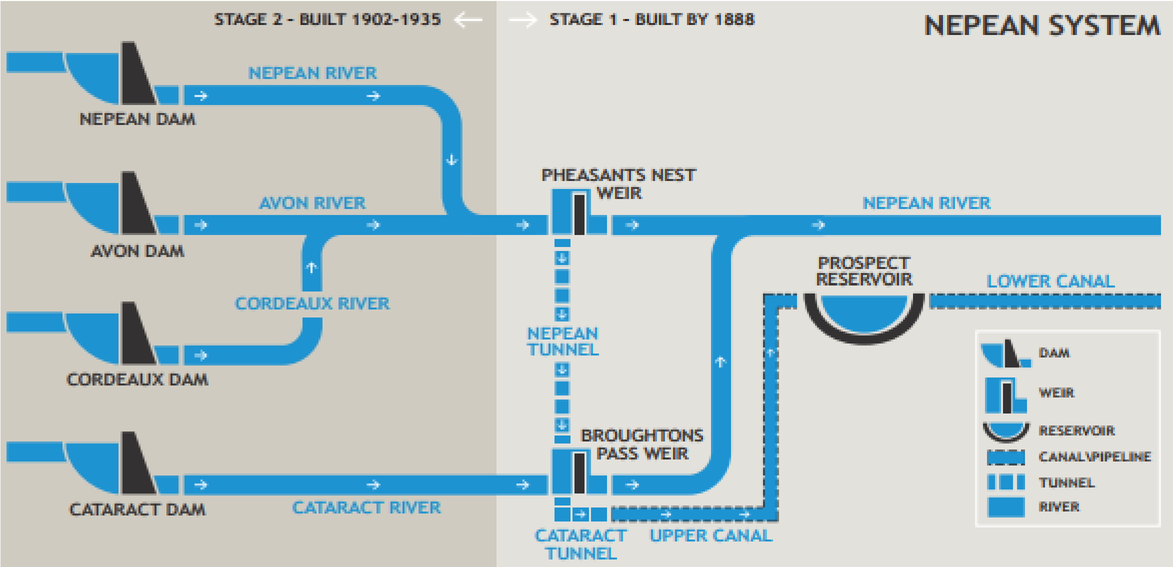


Figure 3-20 Nepean water supply system (Source: WaterNSW, 2013)

In addition to the central plants listed above, there are also estimated to be around 50,000 on-site systems in the lower Hawkesbury-Nepean catchment (DECC, 2009 in DPI, 2014).

Abstractions and diversions

The main abstractions from the Hawkesbury-Nepean River in the downstream environment of the Project are for potable water supply (Richmond WFP) and irrigation purposes. There are no significant diversions of water in the downstream environment, rather these occur upstream on the Nepean River and directly from Warragamba Dam to the WFPs and Prospect Reservoir via the Warragamba Pipeline.

Table 3-8 Water recycling and wastewater treatment plant discharge locations and volumes (Source: DPI, 2014; Sydney Water, 2017)

Plant	Discharges to creek / river	Volume discharged ML/d	Volume discharged ML/a
Wastewater Treatment Plants			
Wallacia	Warragamba River	0.6	219
Winmalee	Unnamed Creek (Nepean)	16.5	6,022.5
North Richmond	Redbank Creek (Hawkesbury)	0.9	328.5
Riverstone	South Creek	1.8	657
Water Recycling Plants			
Penrith*	Boundary Creek (Excess only)	23.1	8,431.5
Richmond	Rickabys Creek (Excess only)	2.2	803
St Marys*	South Creek (Excess only)	39.2	14,308
Quakers Hill*	South Creek (Excess only)	35.4	12,921
Castle Hill	Cattai Creek	6.5	2,372.5
Rouse Hill	Second Ponds to Cattai Creek	15.3	5,584.5
South Windsor	South Creek (overflows only)		0
McGraths Hill	South Creek		200

* St Marys Advanced Water Treatment Plant receives flow from St Marys, Quakers Hill and Penrith WRP to produce highly treated water discharged to Boundary Creek under Western Sydney Replacement Flows Recycled Water Scheme. The plant discharges an average of 42 ML/d to the Hawkesbury-Nepean River.

3.1.2.9 Average annual water balance

The following presents an average annual water balance of the downstream catchment. The water balance is summarised in Table 3-9.

The tabulated flows show indicative mean annual flow conditions. Actual flows fluctuate with time, that is, daily and yearly variations. Overall, the average annual inflow to the Hawkesbury-Nepean System across the downstream environment study area is approximately 1978 GL per year, with 28% of this being supplied by the catchment upstream of the Penrith Weir.

The Colo River is the largest tributary by volume flowing into the Hawkesbury River, supplying almost 27% of flows to the system. The Grose and McDonald Rivers contribute approximately 12% and 15% of flow, respectively. These flows vary year on year and will change in response to seasonal variations and longer-term climatic conditions. Flood and drought cycles, which can persist for long periods are evident throughout the historic flow records.

Table 3-9 Existing downstream environment water balance

Flow or Discharge	Mean Annual Flow (2020 Demand)		Data Source / Comments
	GL	%	
Surface water inflows			
Total river flow upstream of Penrith Weir	555	28%	Tributary Flow Monitoring Data from WaterNSW. Average value based on total annual flows for 1980 to 2020
Grose River	234	12%	
South Creek	30	1.5%	
Colo River	340	17%	
McDonald River	286	15%	Assumed based on an average area weighted flow of the gauged catchments to account for the total ungauged catchment inflows
Cattai Creek	28	1.4%	
Other tributary inflows	491	25%	
STP discharges into river	13.6	0.7%	From online Sydney Water daily discharge data
Surface water extractions			
North Richmond WFP	6.1	9%	Data from WaterNSW Greater Sydney Operations Report (April 2020)
Irrigation demands	41.9	62%	Data from SMEC (2002).
Industrial irrigation demands	20.0	29%	
Groundwater extraction	**1.2**	**100**	**Data from NSW Water Register - WaterNSW**

The flows included in the water balance include:

- inflows to the Hawkesbury-Nepean River System from major tributaries including the Warragamba/Nepean, Grose, Colo and McDonald Rivers and South and Cattai Creeks along with other local tributaries
- inflows to the rivers from STP discharges
- outflow from the rivers for irrigation
- outflows from the rivers for water supply to North Richmond WFP
- licenced groundwater extraction rate of 1.172 gigalitres per annum, which is less than two percent of the total quantity of water extracted from the Hawkesbury-Nepean system
- assumed the difference between inflows and extractions is accounted for by outflows to Broken Bay.

3.2 Flooding

The Hawkesbury-Nepean Valley has one of the most significant flood risk exposures within Australia (Bewsher Consulting, 2012). The risk to property and risk to life due to flood exposure in the Hawkesbury-Nepean Valley is well known and has been the subject of numerous studies, including the Hawkesbury-Nepean Valley Flood Risk Management Strategy prepared on behalf of the NSW State Government.

All the flood behaviour presented in this report is based on previous investigations and reports. (refer to assumptions and limitations).

A Monte Carlo approach to modelling was undertaken, as discussed in Section 2.4. As required by SEAR #8(3a), the following flooding events were assessed with and without dam raising:

- 20% AEP (approx. 1 in 5 chance in a year)
- 10% AEP (1 in 10 chance in a year)
- 5% AEP (1 in 20 chance in a year)
- 1% AEP (1 in 100 chance in a year)
- PMF (probable maximum flood).

The specific flood events used in the EIS assessment have been selected from the range of Monte Carlo flood events, as representative events for each of the AEPs specified in the SEARs. In addition, this assessment also examined the 0.5% AEP (1 in 200) and 0.2% AEP (1 in 500) chance in a year events as required by the SEAR #8(3b) to assess potential climate change impacts.

3.2.1 Upstream environments

3.2.1.1 Overview

Flooding in the upstream environment is effectively backwater inundation, with inflows building on the upstream side of the dam wall. The water level builds until the outflow exceeds the inflow after which time the water level in the upstream environment will begin to fall. Water levels will continue to fall until the lake level drops to the weir crest level. Spills from the dam via the weir crest will then cease. The extent and duration of inundation in the upstream environment is dependent upon the magnitude of the flood producing rainfall event and the release rate from the dam.

3.2.1.2 Flood levels and extent

A frequency analysis of the peak flood levels in Lake Burragorang under existing conditions is presented in Figure 3-21, with peak flood levels in Lake Burragorang for all design events considered presented in Table 3-10. The existing peak inundation extents for the 20% AEP, 1% AEP and Extreme Flood events are shown in Figure 3-22.

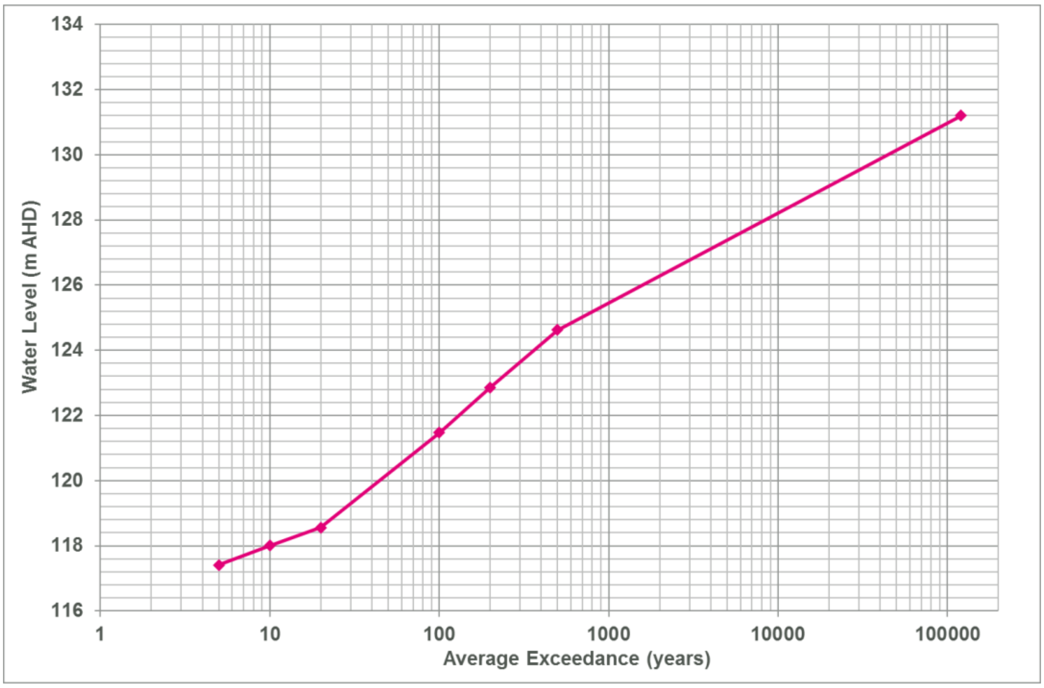


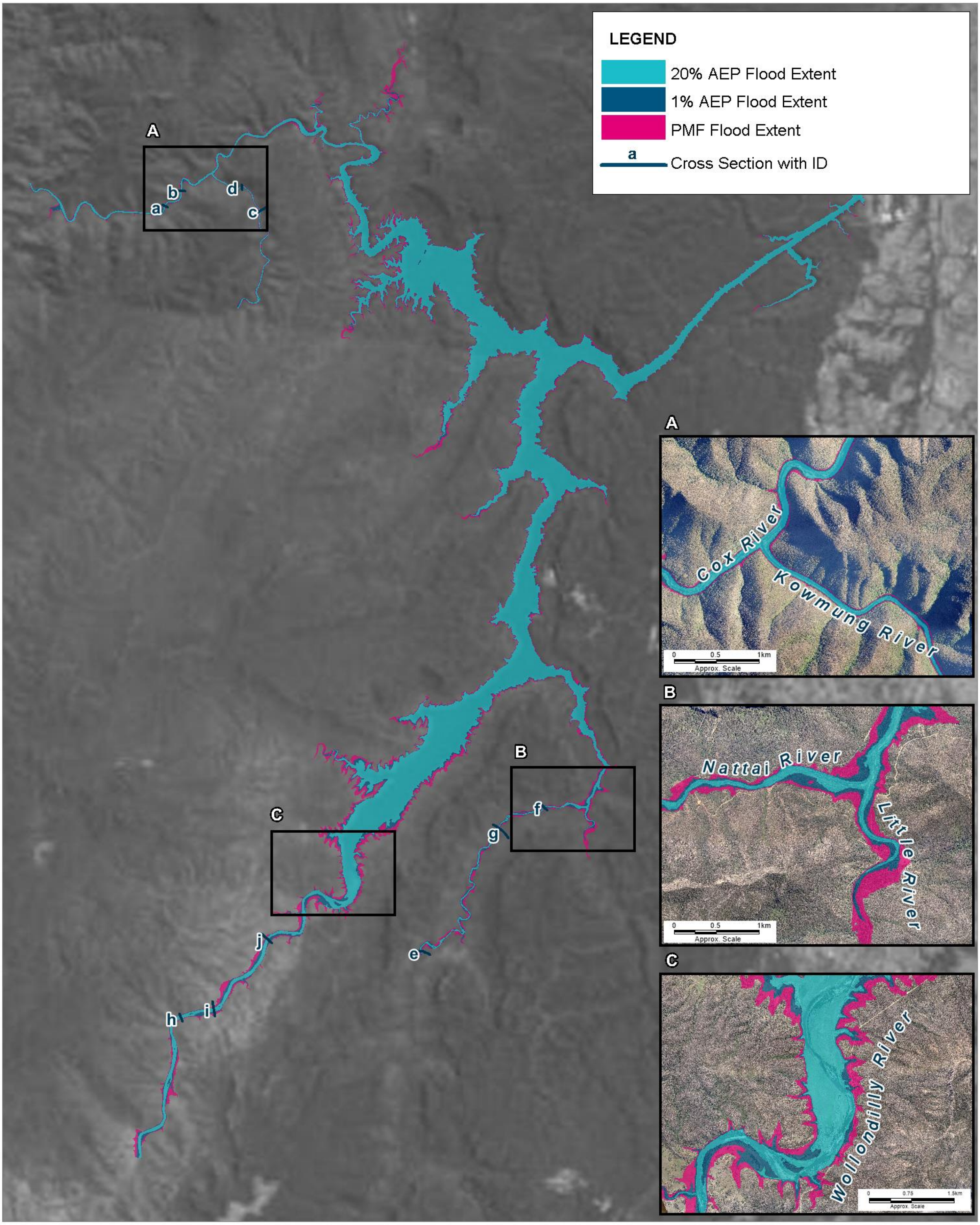
Figure 3-21 Upstream environment peak flood levels for existing scenario

Table 3-10 Upstream environment peak flood levels for existing scenario (at dam wall)

Size of Flood	Existing scenario
5yr (20% AEP)	117.4
10yr (10% AEP)	118.0
20yr (5% AEP)	118.6
100yr (1% AEP)	121.5
200yr (0.5% AEP)	122.9
500yr (0.2% AEP)	124.6
PMF	131.2

As evident in Figure 3-21 and Table 3-10, the step increase in flood levels for the 20% AEP event to the 5% AEP event is consistent with 0.6 m increases in peak flood levels between design events. However, the step change between design events then increases, with a 2.9 m difference between the 20% AEP and 1% AEP event. The highest step change occurs between the 0.2% AEP and PMF event, with a 6.6 m increase in the peak flood level.

As seen in Figure 3-22, the inundation extent is controlled by the peak flood level at the dam wall and the topography across the upstream catchment. Examples of the varying inundation extent in relation to topography is shown in the local inset figures. Areas with steep terrain have limited increases in flood extent between increasing event magnitude when compared to the areas with flatter terrain. The steep valley terrain surrounding Lake Burragorang, which extends from the dam wall upstream for at least 20 km, results in the peak flood level inundation increases with increasing event magnitude being contained to a small total land area.



Title:

Upstream Peak Flood Extent - Existing Scenario (H14) 20% AEP, 1% AEP and PMF

Figure: 3-22

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BMT endeavours to ensure that the information provided in this map is correct at the time of publication. BMT does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.

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Further upstream where key tributaries such as the Wollondilly River and Coxs River enter Lake Burragorang, there is notably flatter terrain. As a result, the increase in peak flood level inundation extent with increasing event magnitude encompasses a larger total area (as topographical elevation increases more gradually).

3.2.1.3 Period of inundation and rate of rise

The rate of rise of inflows and period of inundation in the upstream environment is directly linked to the rate of inflows entering Lake Burragorang from the upstream tributaries and the outflow rates from the dam. The timeseries (that is, hydrograph) of combined inflows into Lake Burragorang, selected from the Monte Carlo modelling to be representative of each design event considered are presented in Figure 3-23. The corresponding water level timeseries in Lake Burragorang for each of the selected representative design events considered are presented in Figure 3-24.

For the representative design flood events, flows enter Lake Burragorang from the contributing catchments for a period of approximately 100-hours (~4-days).

The representative water level timeseries presented in Figure 3-24 show that levels in Lake Burragorang remain elevated for a period of approximately 100 hours (~4-days). It is important to note that although lake levels remain elevated for a period of days, the period of inundation for particular locations will vary significantly depending on their location in the upstream environment (that is, local topography and ground elevation).

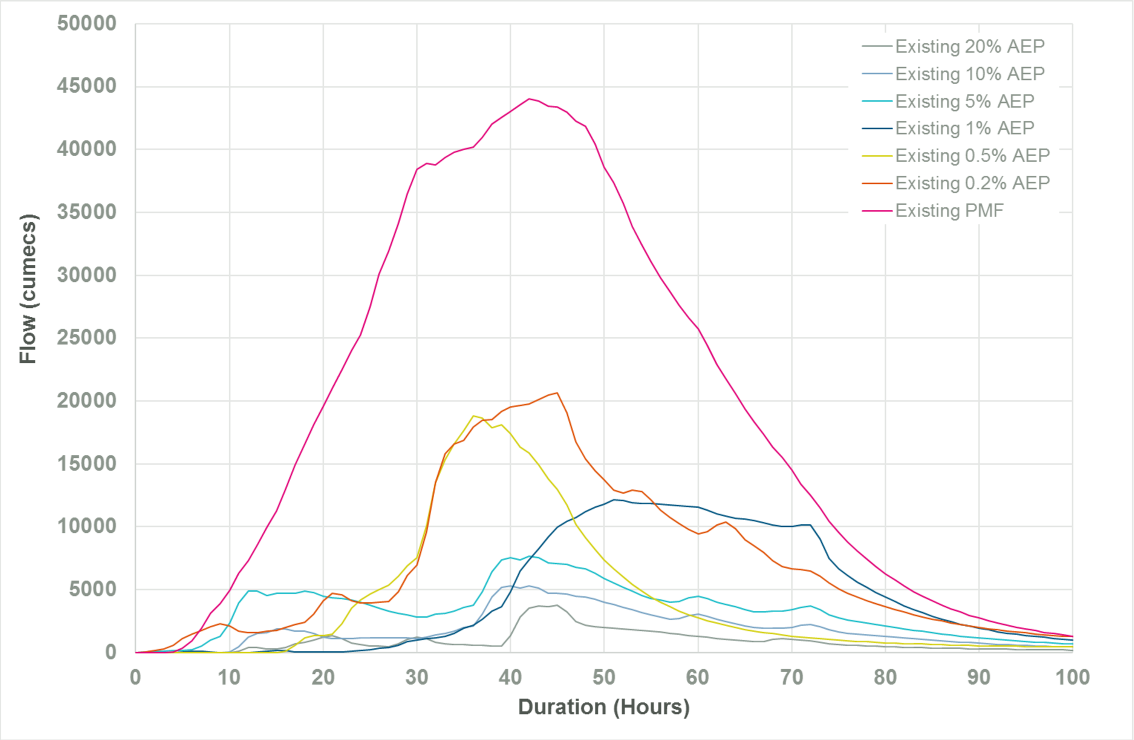


Figure 3-23 Lake Burragorang inflow hydrograph

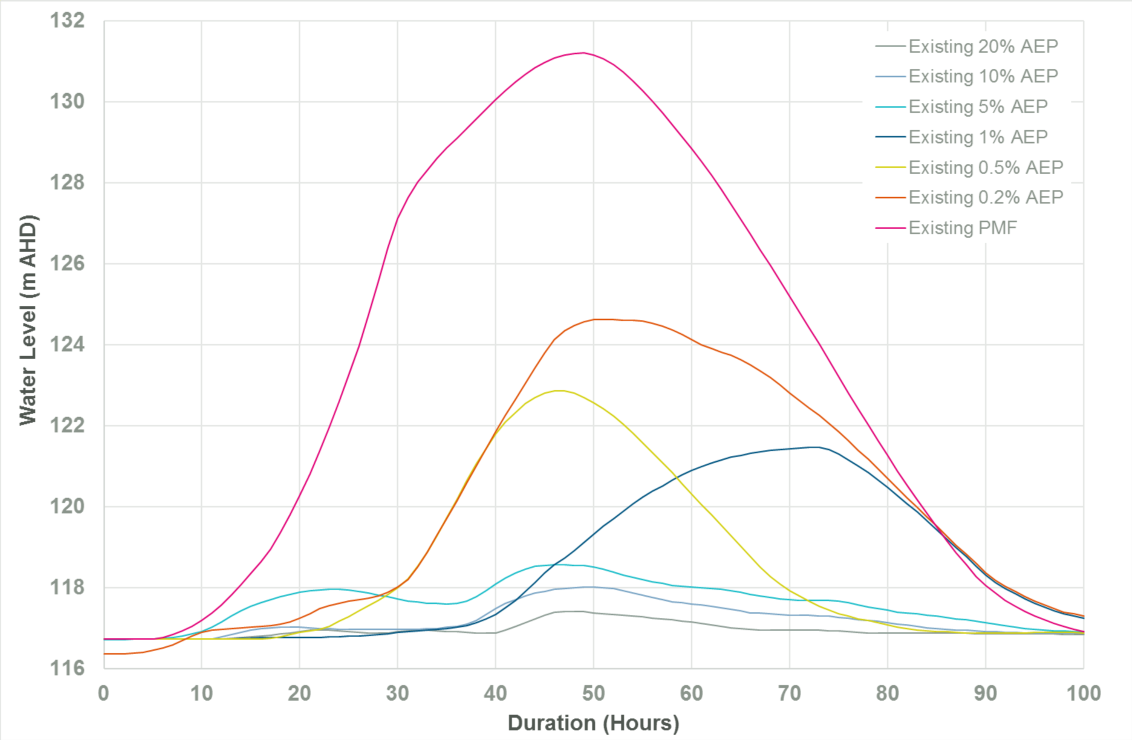


Figure 3-24 Lake Burragorang water level timeseries

3.2.1.4 Flood velocity

Flooding in the upstream environment is backwater in nature, with Lake Burragorang acting as a flood storage. Flood storage areas are characterised by deep, low velocity inflows. However, there are localised areas of higher velocities where the major tributaries discharge into Lake Burragorang.

3.2.2 Downstream environment

3.2.2.1 Overview

As previously stated, the Hawkesbury-Nepean Valley (that is, downstream environment) has one of the most significant flood risk exposures within Australia (Bewsher Consulting, 2012). Flooding in the downstream environment is driven by mainstream flooding of the Hawkesbury-Nepean River and its tributaries, with potential for widespread inundation across the valley/floodplain.

3.2.2.2 Flood levels and extent

The existing peak inundation extents for the 20% AEP, 1% AEP and PMF events are shown in Figure 3-25. The corresponding peak flood levels at selected locations corresponding to modelled cross sections are presented in Table 3-11. The peak flood depths across the downstream environment for the 1% AEP and Extreme Flood events are shown in Figure 3-26 and Figure 3-27 respectively.

Table 3-11 Downstream environment peak flood levels for existing scenario (RL m)

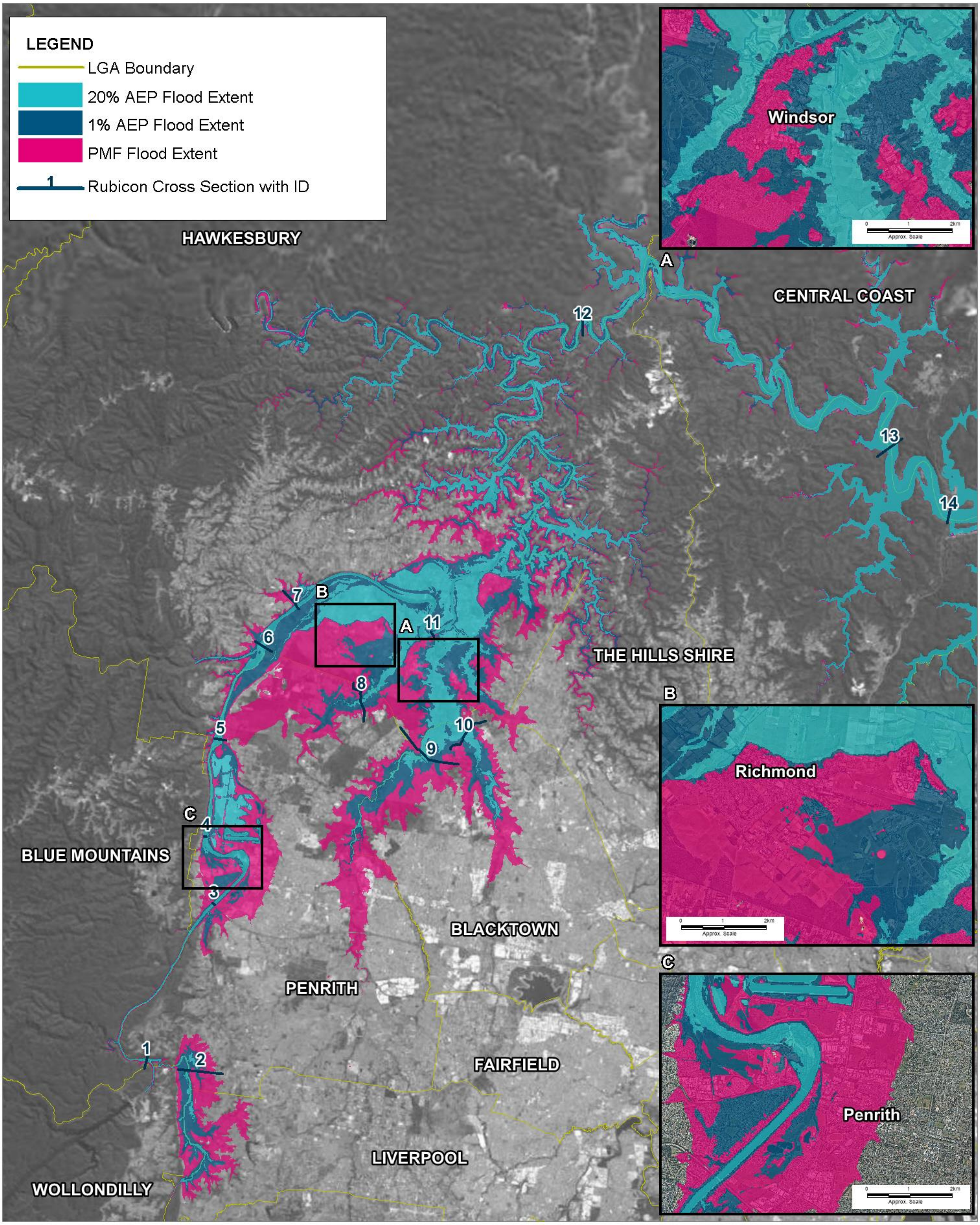
ID*	Cross section name	20% AEP	10% AEP	5% AEP	1% AEP	0.5% AEP	0.2% AEP	PMF
1	JUNCTION3	28.3	33.0	37.4	42.7	44.7	47.3	65.7
2	BLAXCROSS	35.1	37.2	39.4	44.6	46.5	48.9	66.3
3	F4BRIDGE	20.6	22.7	24.9	27.6	28.4	29.0	34.9
4	BONNIEVALE	14.9	17.8	20.5	23.5	24.3	25.3	32.5
5	MILLDAM1	12.9	15.6	18.0	20.4	21.4	22.7	31.4
6	YMUNDI1	12.0	14.5	16.4	18.2	19.1	20.3	27.1
7	NORTHRICH1	11.4	13.7	15.4	17.5	18.6	19.8	26.8
8	LDERRY	10.1	12.0	13.8	17.4	18.4	19.6	26.7
9	RICHWALK	9.8	11.9	13.7	17.3	18.3	19.6	26.7
10	POWERLINE	9.8	11.9	13.7	17.3	18.3	19.6	26.7
11	WINDSORBR	9.9	11.9	13.7	17.3	18.3	19.6	26.7
12	HALFMOON	3.7	5.1	6.5	9.1	10.1	11.5	17.2
13	PUMPKINPT	1.7	1.8	1.9	2.3	2.6	3.1	5.9
14	PEAT1	1.5	1.6	1.6	1.7	1.7	1.7	2.0

* Refer to Figure 3-25 for location of cross sections

As shown in Figure 3-25 - Figure 3-27, the inundation extent is controlled by the topography across the floodplain, with floodwaters primarily contained within channels and highly incised valley floor for some reaches, and widespread inundation in other sections of the floodplain. There are also significant step changes in inundation extents between certain design events that are also controlled by local topography. Examples of the varying inundation extent in relation to topography is shown in Figure 3-25. The reach of the Nepean River from the dam wall to immediately upstream of Penrith is characterised by steep terrain with a highly incised channel, resulting in a narrow flood extent with floodwaters primarily contained within channel. In comparison, near the regional localities of Penrith, Windsor and Richmond where the floodplain is notably flatter and wider, the flood inundation extends over a greater area.

3.2.2.3 Number of residential properties affected by flooding

The number of affected residential properties in 2018 for a range of flood events are shown in Table 3-12. In 2018, the number of affected residential properties in the 1% AEP and 0.2% AEP events was 7,600 and 17,000, respectively.



Title:

Downstream Environment Peak Flood Extent Existing Scenario - 20% AEP, 1% AEP, PMF

Figure: 3-25

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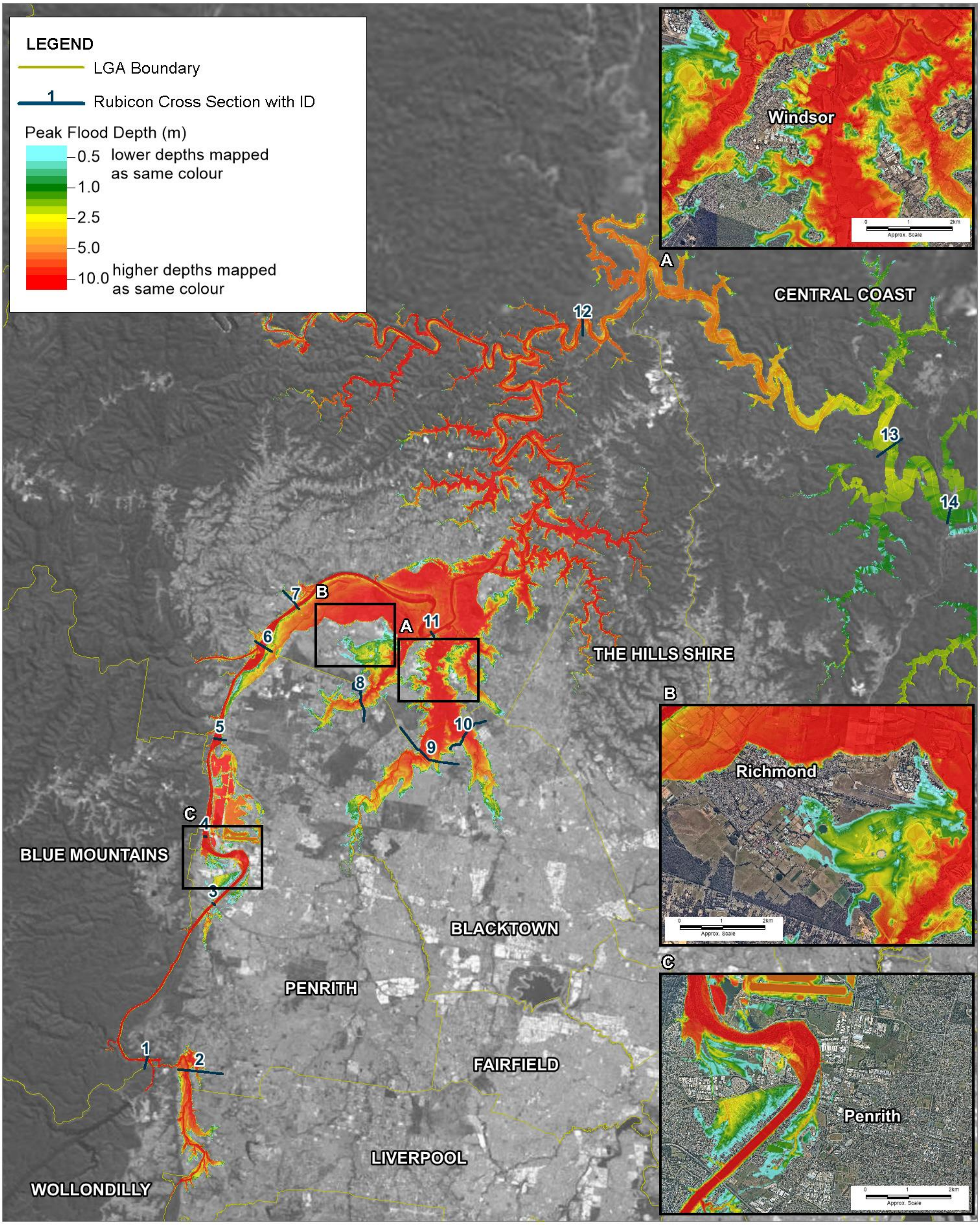

Title:

Downstream Environment Peak Flood Depth Existing Scenario (H14) - 1% AEP

Figure: 3-26

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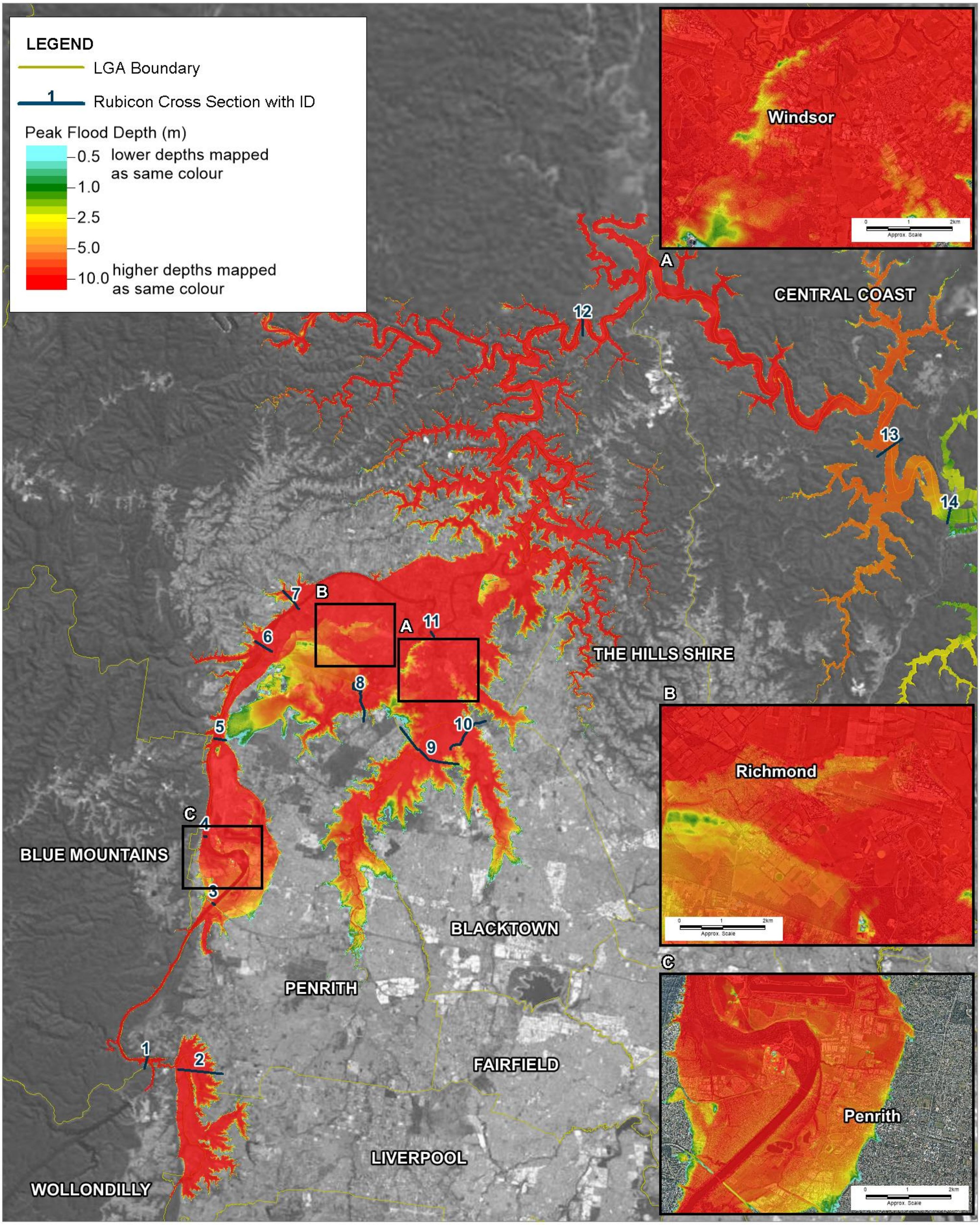

Title:

Downstream Environment Peak Flood Depth Existing Scenario (H14) - Extreme Flood

Figure: 3-27

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Table 3-12 Number of affected residential properties in 2018 for a range of flood events

Size of Flood	2018 (existing risk)		
	Existing (2018) properties	Existing (2018) manufactured homes	Total existing (2018) risk
20% AEP	160	570	730
10% AEP	370	1,300	1,700
5% AEP	1,000	1,500	2,500
2% AEP	3,100	1,700	4,800
1% AEP	5,900	1,700	7,600
0.5% AEP	9,200	1,800	11,000
0.2% AEP	15,200	1,800	17,000
0.1% AEP	19,600	1,900	21,500
0.05% AEP	24,100	1,900	26,000
0.02% AEP	27,200	1,900	29,100
PMF	39,100	1,900	41,000

3.2.2.4 Period of inundation and rate of rise

Whilst there are several factors contributing to flooding across the downstream environment, the primary contribution is outflows from Warragamba Dam. As such, the period of inundation and rate of rise of floodwaters is directly linked to outflows from Warragamba Dam. Timeseries of outflows from Warragamba Dam under existing operating conditions, selected from the Monte Carlo modelling to be representative of each design event considered are presented in Figure 3-28.

The rate of rise of floodwaters in the downstream environment is a function of the dam outflow and local topography. The water level timeseries at selected locations within the catchment corresponding to modelled cross sections, selected from the Monte Carlo modelling to be representative of a 1% AEP design event condition, are presented in Figure 3-29. The rate of rise differs depending on the distance downstream of Warragamba Dam. The duration of inundation will also vary depending on the location within the downstream environment, with water levels typically returning to standard/pre-response levels within six to eight days after the initial flood release.

3.2.2.5 Flood velocity

Simulated peak cross-section average velocities for the range of design events to be considered for selected locations corresponding to modelled cross sections are presented in Table 3-13 (refer to Figure 2-3 for cross section locations). It is evident that the peak cross-section average velocities are relatively consistent across the floodplain, with minimal variation in velocity with increasing event magnitude.

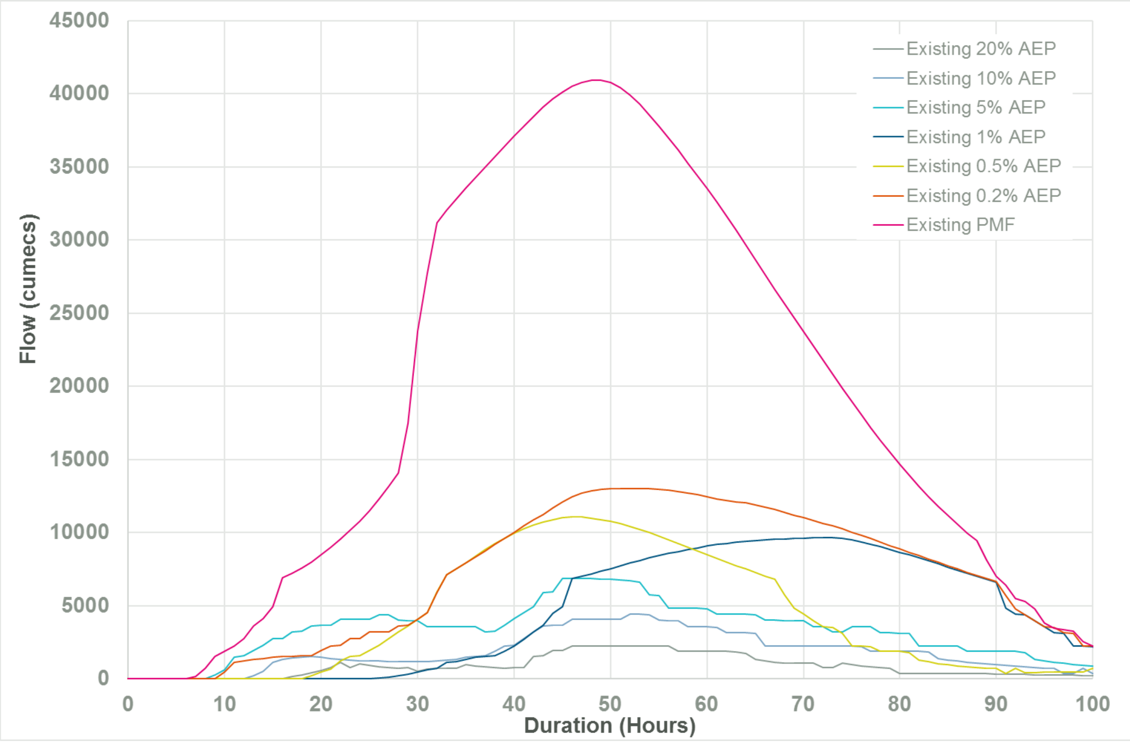

Figure 3-28 Warragamba Dam outflow hydrographs

Table 3-13 Downstream environment peak cross-section average flood velocities for existing scenario (m/s)

ID	Cross section name	20% AEP	10% AEP	5% AEP	1% AEP	0.5% AEP	0.2% AEP	PMF
1	JUNCTION3	1.2	1.2	1.2	1.2	1.2	1.2	1.3
2	BLAXCROSS	1.2	1.3	1.5	1.7	1.7	1.6	1.4
3	F4BRIDGE	1.1	1.1	1.1	1.1	1.1	1.1	1.1
4	BONNIEVALE	1.3	1.4	1.3	1.3	1.3	1.3	1.2
5	MILLDAM1	1.2	1.1	1.1	1.1	1.1	1.1	1.1
6	YMUNDI1	1.0	1.0	1.1	1.1	1.1	1.2	1.2
7	NORTHRICH1	1.1	1.1	1.2	1.2	1.2	1.3	1.6
8	LDERRY	No data	No data	No data	No data	No data	No data	No data
9	RICHWALK	No data	No data	No data	No data	No data	No data	No data
10	POWERLINE	No data	No data	No data	No data	No data	No data	No data
11	WINDSORBR	1.1	1.2	1.2	1.2	1.3	1.3	1.3
12	HALFMOON	1.2	1.2	1.3	1.3	1.3	1.3	1.2
13	PUMPKINPT	0.9	0.9	0.9	1.0	1.0	1.0	1.0

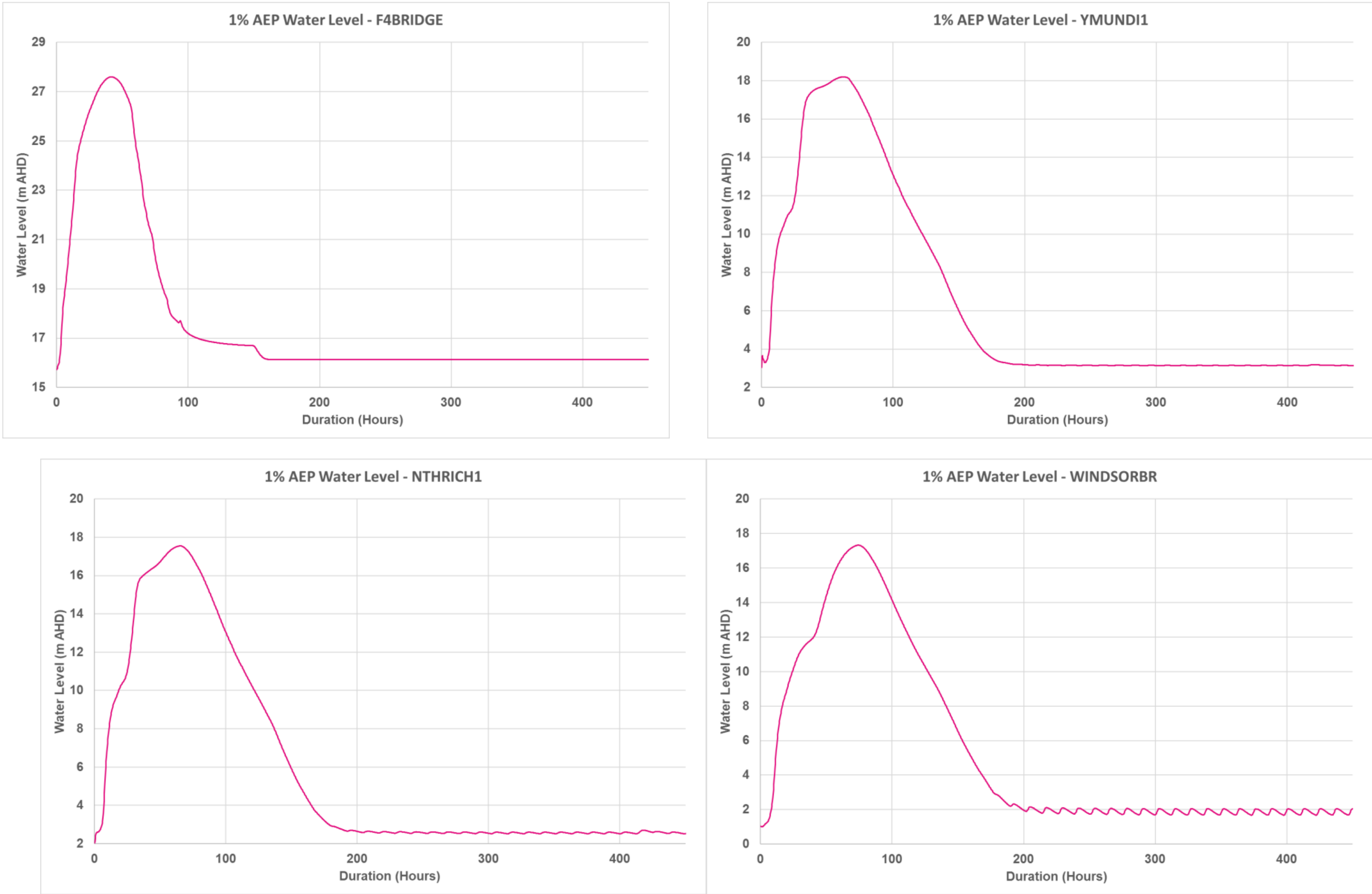

Figure 3-29 1% AEP water level timeseries

3.2.2.6 Flood hazard

The National Flood Risk Advisory Group (AIDF, 2017) considers a holistic approach to consider flood hazards to people, vehicles and structures. It recommends a composite six-tiered hazard classification, reproduced in Figure 3-30. The six hazard classifications are summarised in Table 3-14.

The flood hazard level is determined based on the predicted flood depth and velocity. This is conveniently done through the analysis of flood model results. A high flood depth will cause a hazardous situation while a low depth may only cause an inconvenience. High flood velocities are dangerous and may cause structural damage while low velocities generally have no major threat.

Flood hazard mapping in accordance with this methodology has been produced for the downstream environment as part of the Hawkesbury-Nepean Valley Regional Flood Study (WMAWater, 2019). Mapping for the 1% AEP flood event has been reproduced in Figure 3-31 to Figure 3-33. Similar hazard mapping for the 20% AEP, 5% AEP, 0.5% AEP, 0.2% AEP, 0,05% AEP and PMF events is included in WMAWater (2020) (refer to Appendix H3).

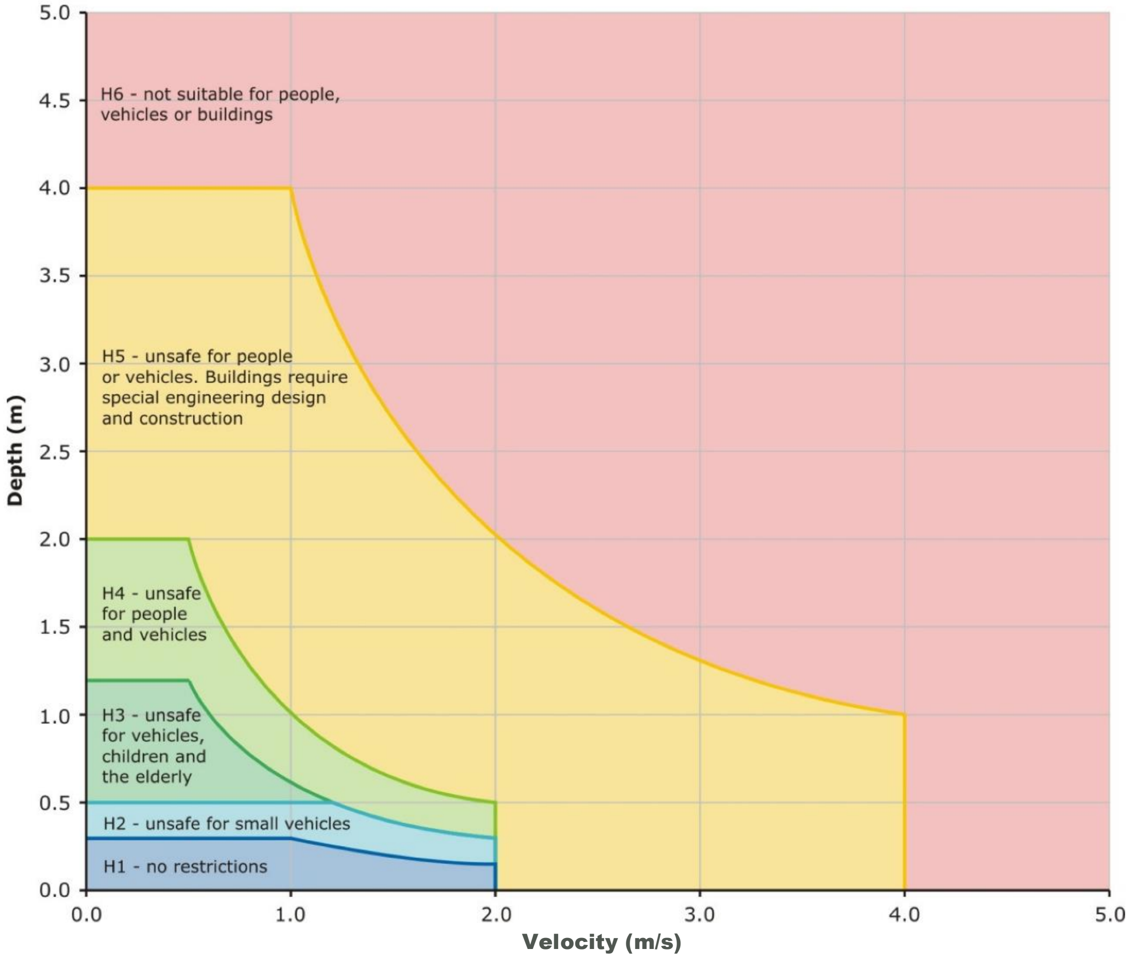

Figure 3-30 Combined flood hazard curves

Table 3-14 Combined flood hazard curves – vulnerability thresholds

Hazard classification	Description
H1	Relatively benign flow conditions. No vulnerability constraints.
H2	Unsafe for small vehicles.
H3	Unsafe for all vehicles, children and the elderly.
H4	Unsafe for all people and vehicles.
H5	Unsafe for all people and all vehicles. Buildings require special engineering design and construction.
H6	Unconditionally dangerous. Not suitable for any type of development or evacuation access. All building types considered vulnerable to failure.

3.2.2.7 Flood function

The flood function (or hydraulic categorisation) of a floodplain helps describe the nature of flooding in a spatial context and from a flood planning perspective can determine what can and can't be developed in areas of the floodplain. The hydraulic categories as defined in the NSW Floodplain Development Manual (DIPNR, 2005) are:

- **Floodway** - Areas that convey a significant portion of the flow. These are areas that, even if partially blocked, would cause a significant increase in flood levels or a significant redistribution of flood flows, which may adversely affect other areas.
- **Flood storage** - Areas that are important in the temporary storage of the floodwater during the passage of the flood. If the area is substantially removed by levees or fill it will result in elevated water levels and/or elevated discharges. Flood storage areas, if completely blocked would cause peak flood levels to increase by 0.1 m and/or would cause the peak discharge to increase by more than 10%.
- **Flood fringe** - Remaining area of flood prone land, after floodway and flood storage areas have been defined. Blockage or filling of this area will not have any significant effect on the flood pattern or flood levels.

There are no prescriptive methods for determining what parts of the floodplain constitute floodways, flood storages and flood fringes. Descriptions of these terms within the NSW Floodplain Development Manual are essentially qualitative in nature. Flood function mapping has been produced for the downstream environment as part of the Hawkesbury-Nepean Valley Regional Flood Study (WMAWater, 2019) as shown in Figure 3-34 to Figure 3-36 adopting the following general classification criteria. Similar flood function mapping for the 0.2% AEP event is included in WMAWater (2020).

Primary Floodway

The primary floodway was defined as the area that conveys 80 per cent of the flow width defined above and where velocities are greater than 0.5 m/s.

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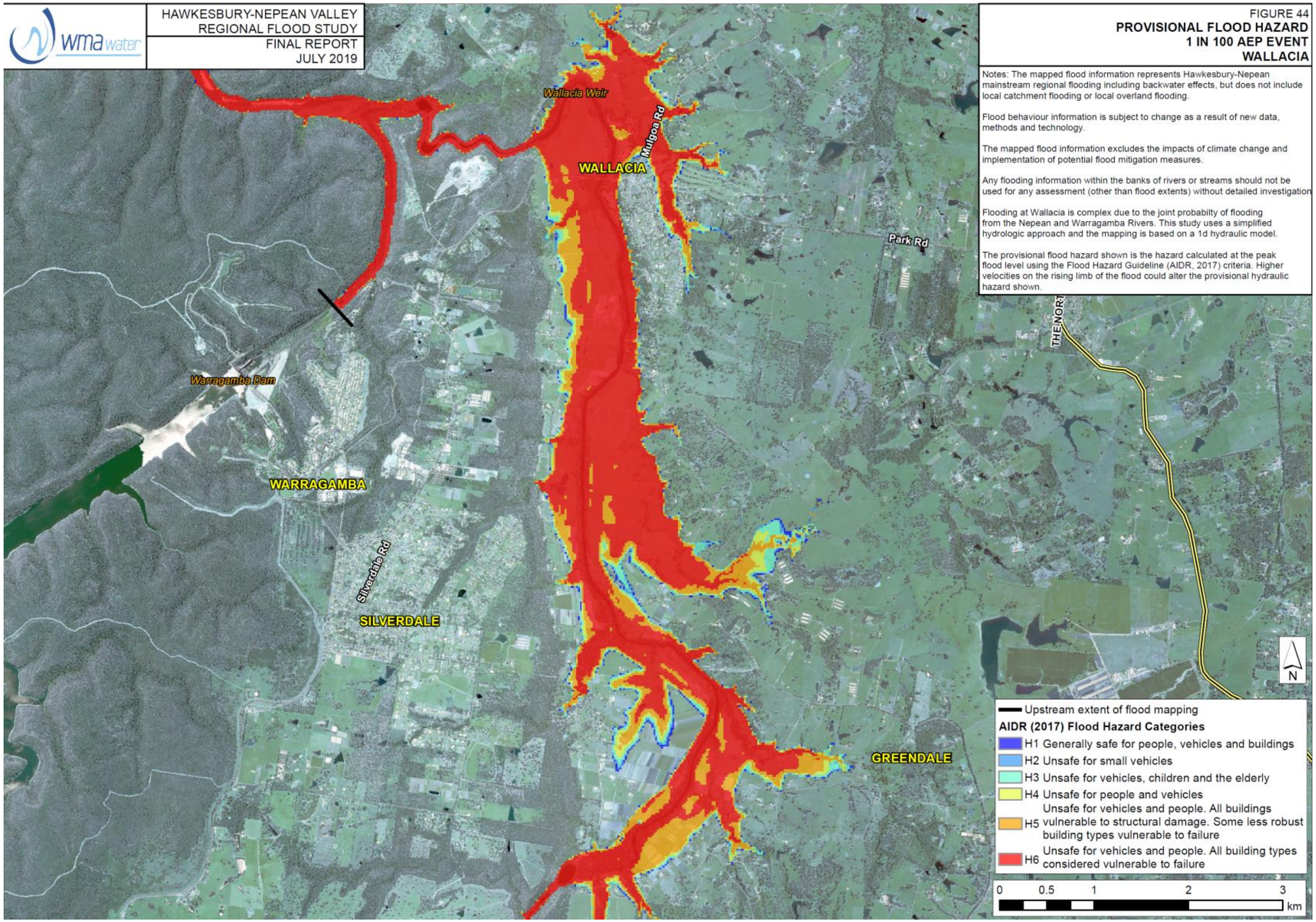


Figure 3-31 Existing 1% AEP flood hazard mapping – Wallacia (Source WMAWater 2019)

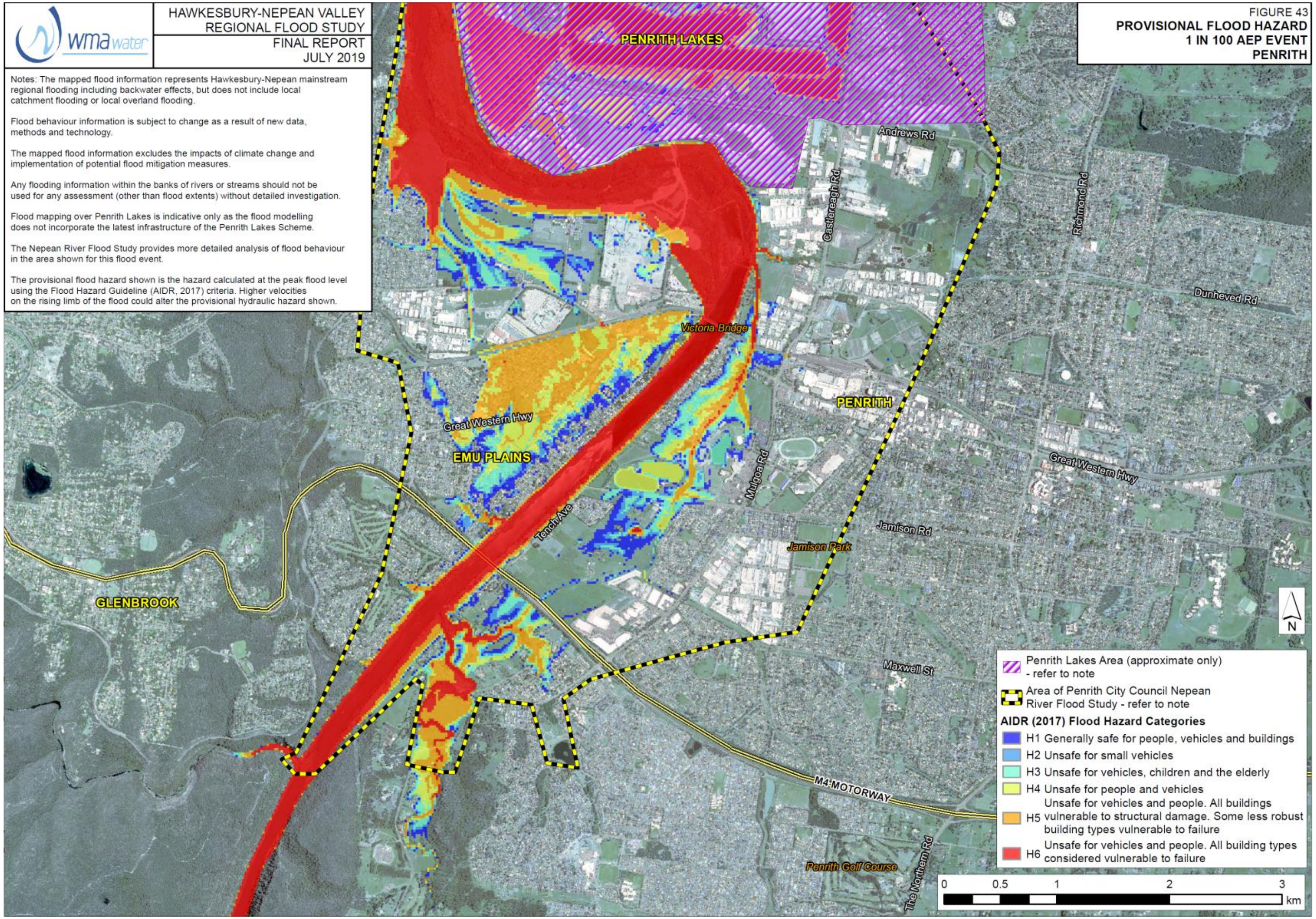


Figure 3-32 Existing 1% AEP flood hazard mapping – Penrith (Source WMAWater 2019)

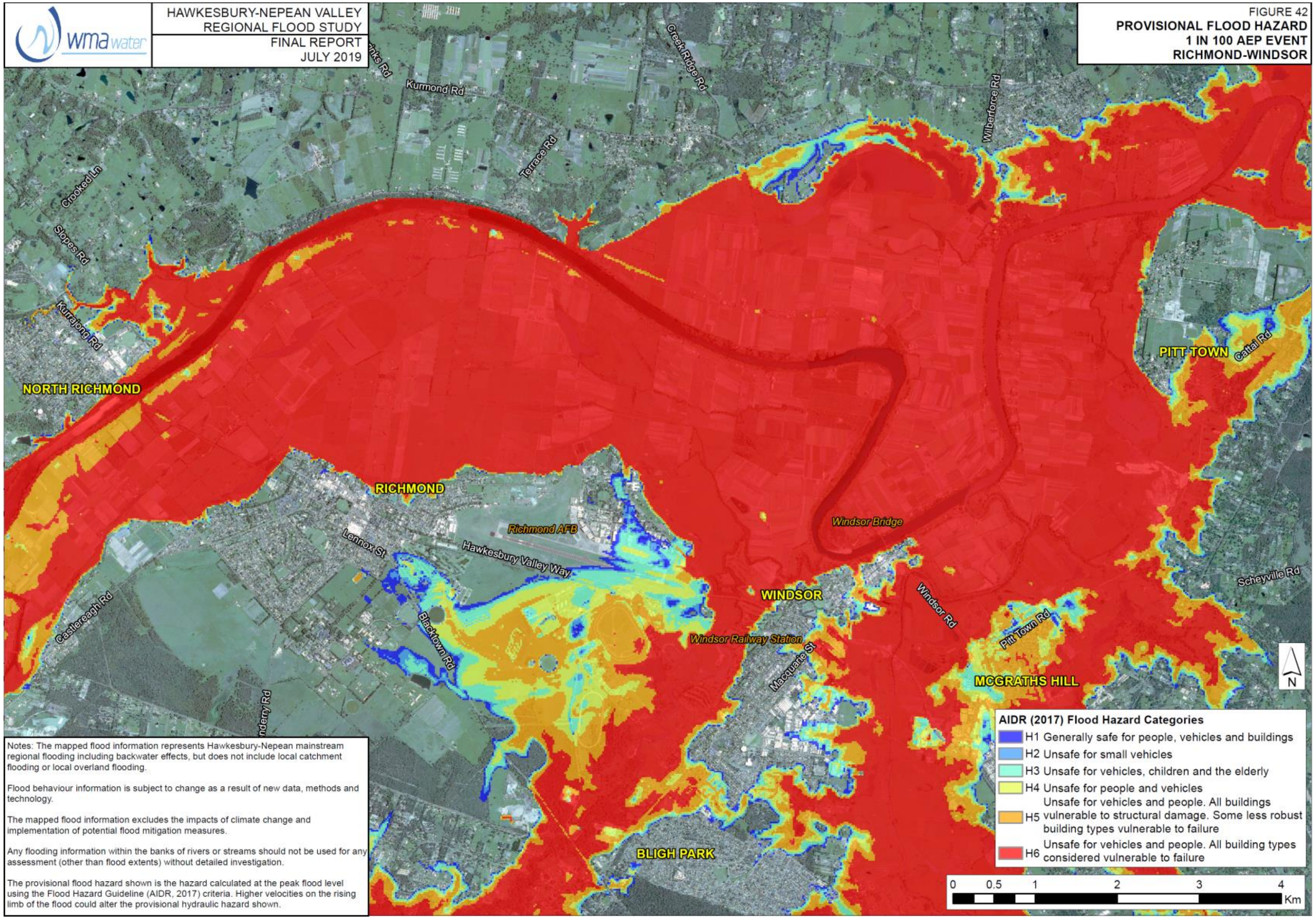


Figure 3-33 Existing 1% AEP flood hazard mapping – Windsor (Source WMAWater 2019)

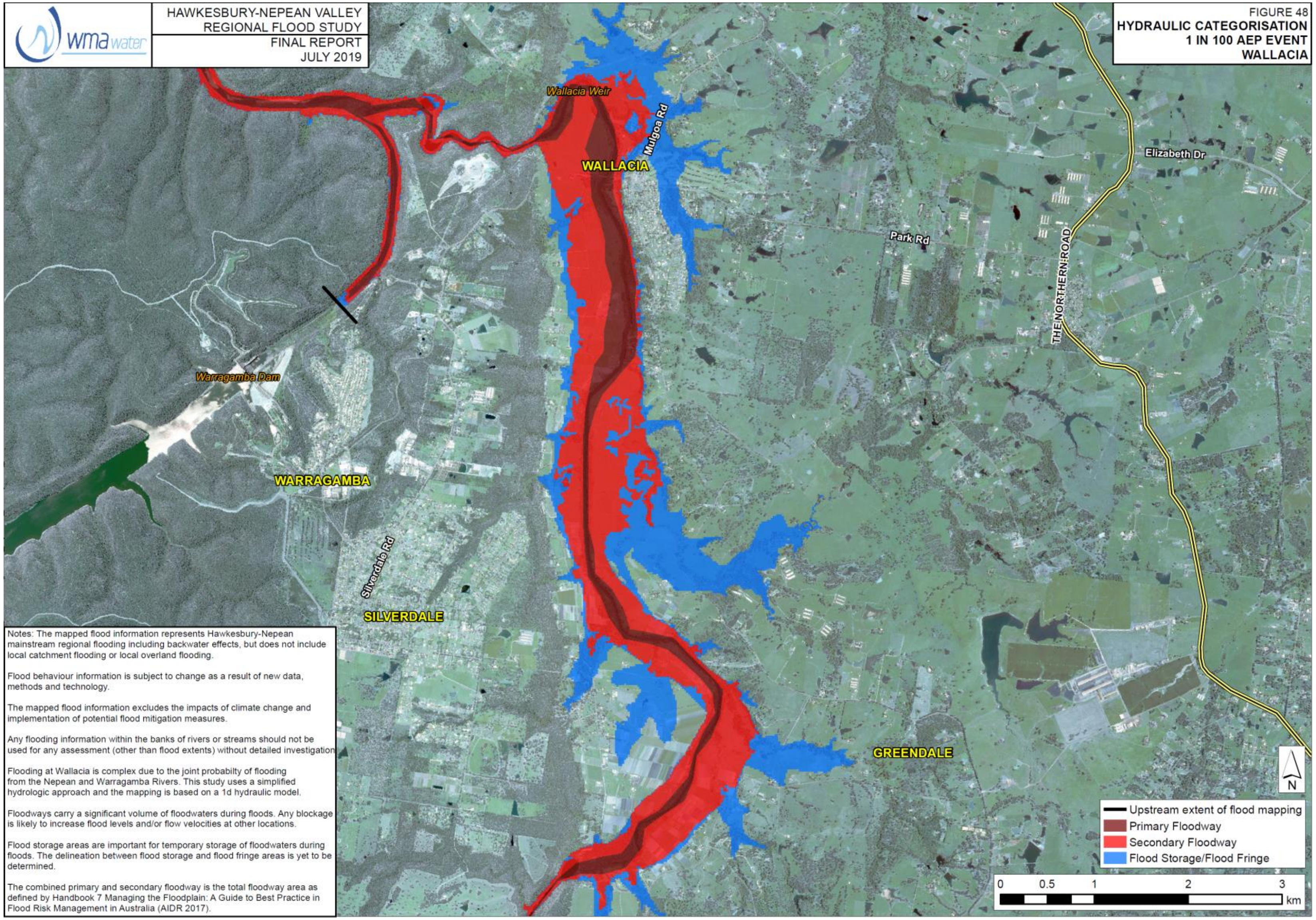


Figure 3-34 Existing 1% AEP flood function mapping – Wallacia (Source WMAWater 2019)

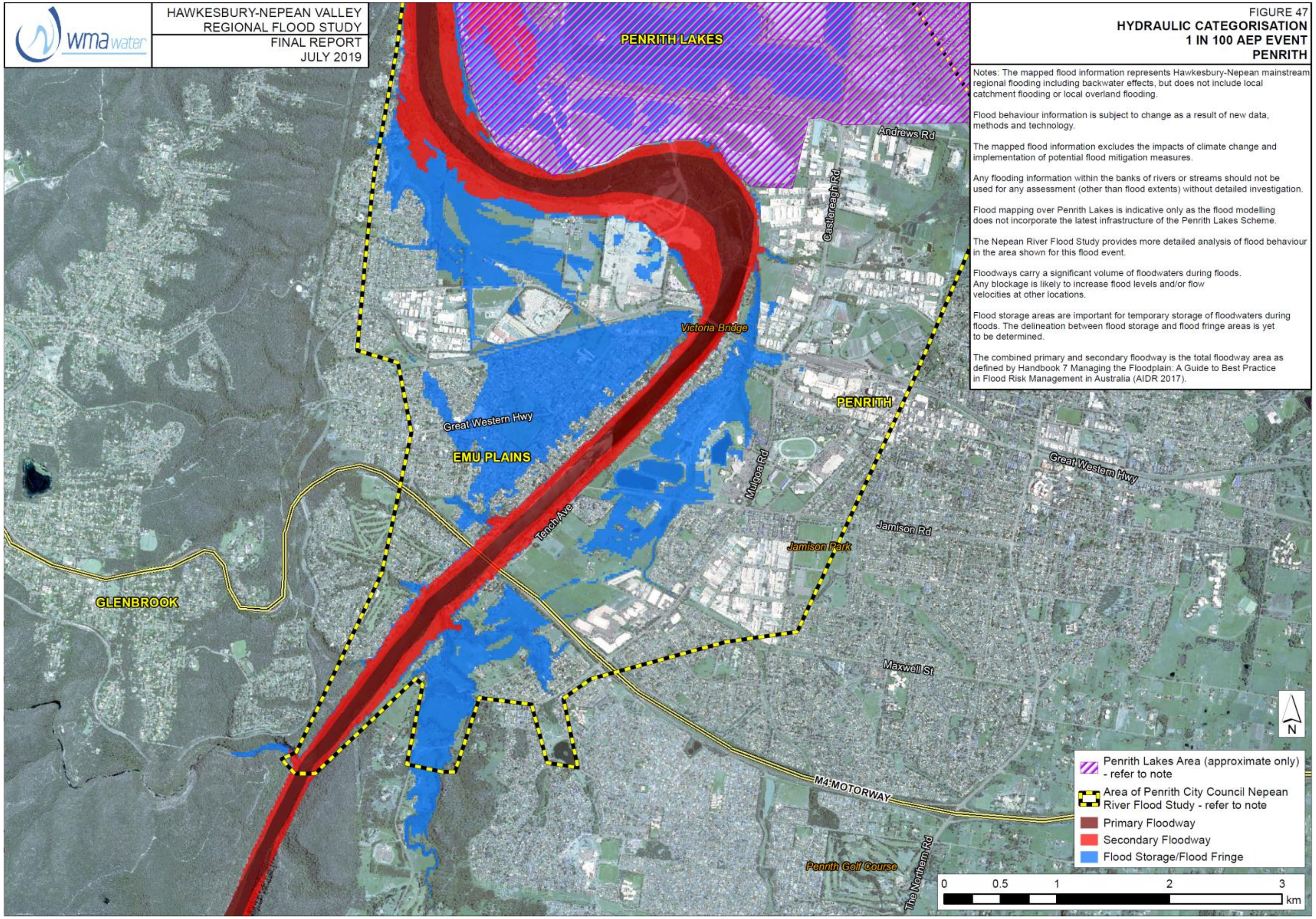


Figure 3-35 Existing 1% AEP flood function mapping – Penrith (Source WMAWater, 2019)

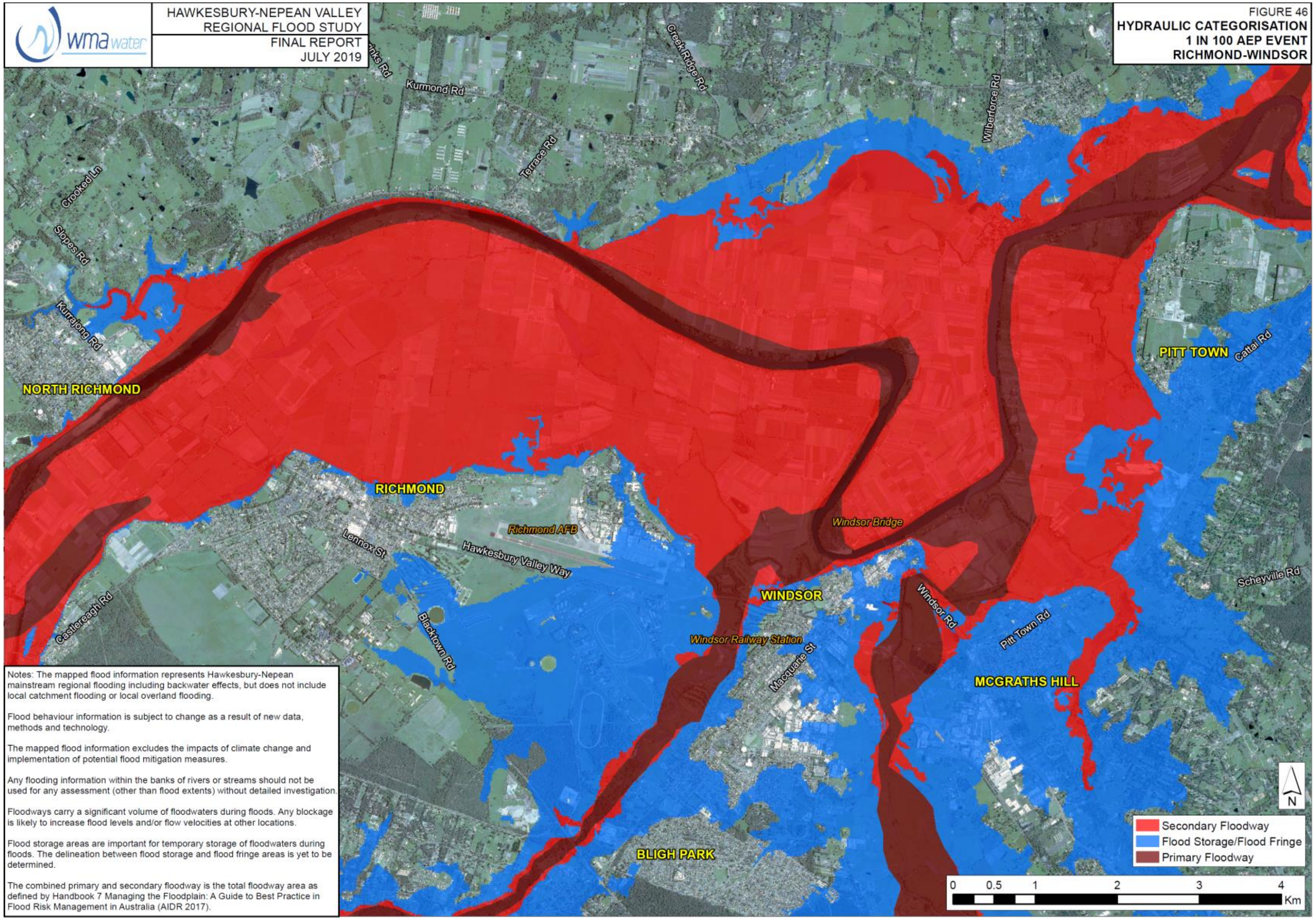


Figure 3-36 Existing 1% AEP flood function mapping – Windsor (Source WMAWater 2019)

3.3 Flood evacuation

Detailed planning for the evacuation of flood affected areas has been undertaken by the NSW Government and NSW State Emergency Service (SES) and is detailed in the Hawkesbury Nepean Flood Plan (Flood Plan) (SES 2015). The Flood Plan covers the areas from Wallacia to Spencer and there are a number of subordinate local flood plans including:

- Hawkesbury City Local Flood Plan
- Penrith City Local Flood Plan
- Blacktown City Local Flood Plan
- The Hills Shire Local Flood Plan
- Hornsby Shire Local Flood Plan
- Gosford City Local Flood Plan.

The NSW SES is the combat agency for dealing with floods, however, the nature of the flood threat within the Hawkesbury-Nepean Valley is such that many other agencies and organisations (including non-government agencies) will likely need to play a part, as will the people at risk of flood impacts. Other agencies are to assist the NSW SES in accordance with arrangements laid down in this Hawkesbury-Nepean Flood Plan and Local Flood Sub Plans.

The Flood Plan also defines three levels of flooding which is used for warnings, evacuations and the initiation of other management activities: These three levels are:

- **Minor flooding**: Flooding which causes inconvenience. Low-lying areas next to watercourses are inundated. Minor roads may be closed and low-level bridges submerged. In urban areas inundation may affect some backyards and buildings below the floor level as well as bicycle and pedestrian paths. In rural areas removal of stock and equipment may be required.
- **Moderate flooding**: Flooding which inundates low-lying areas, requiring removal of stock and/or evacuation of some houses. Main traffic routes may be flooded. In addition to the effects of minor flooding, the area of inundation is more substantial. Main traffic routes may be affected. Some buildings may be affected above the floor level. Evacuation of flood affected areas may be required. In rural areas removal of stock is required.
- **Major flooding**: Flooding which causes inundation of extensive rural areas, with properties, villages and towns isolated and/or appreciable urban areas flooded. Evacuation of flood affected areas may be required. Utility services may be impacted.

Evacuating people from flood affected areas is the primary method of reducing the risk to life during a flood event. In the Hawkesbury-Nepean Valley, the SES identifies mass self-evacuation by private motor vehicles as the primary method for evacuation, as other transport options are highly vulnerable to floods or have limited capacity. The major regional evacuation road route flood levels (RL m) at which the routes are cut are shown in Figure 3-37. Currently, there is insufficient road capacity to safely evacuate the whole population within the Bureau of Meteorology target flood forecast time (BoM NSW SLS 2015), with multiple communities relying on common, constrained and congested road links as their means of evacuation.

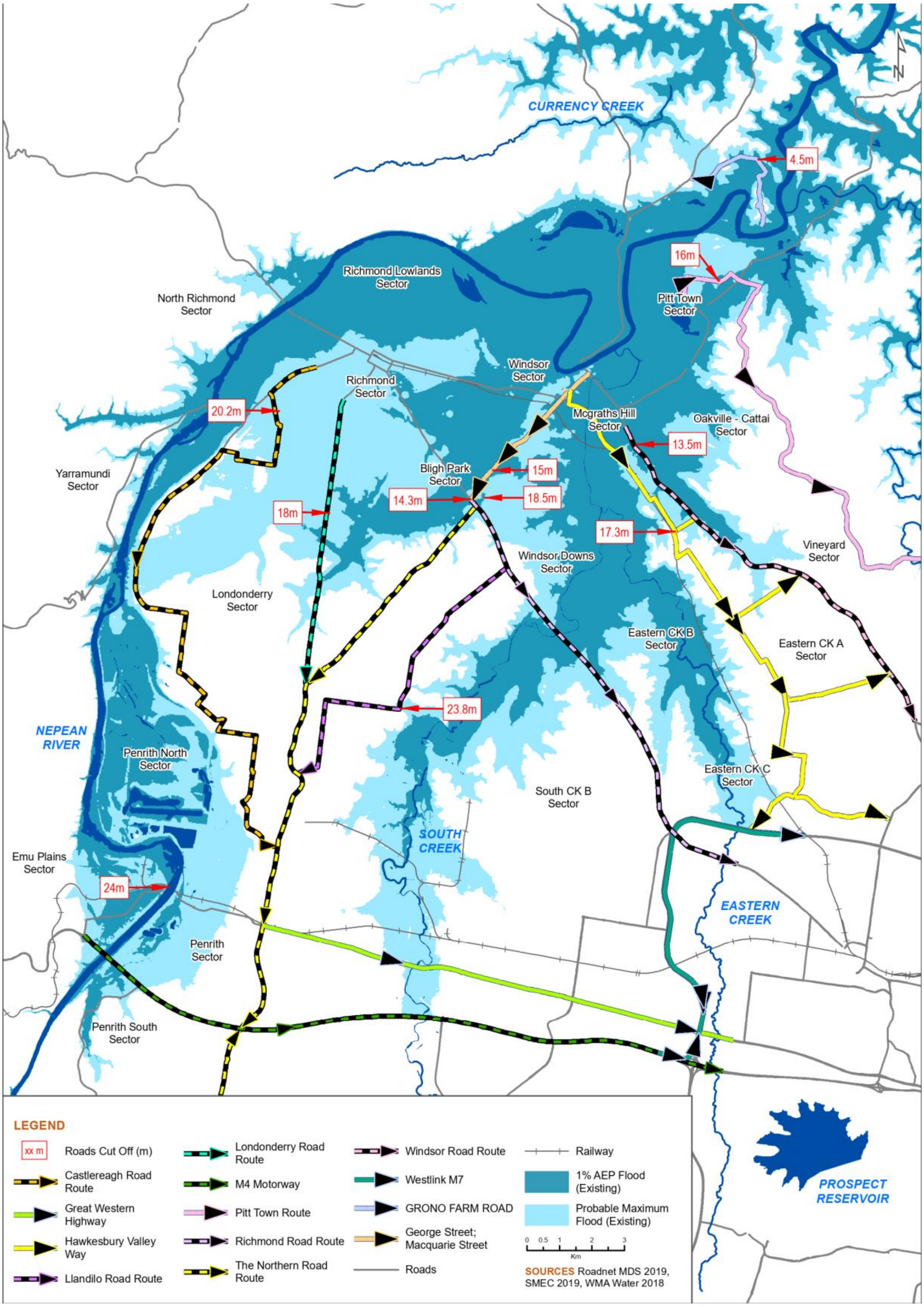


Figure 3-37 Hawkesbury-Nepean Valley flood evacuation routes and the flood level (RL m) at which the routes are cut

The undulating topography of the Hawkesbury-Nepean Valley results in many key evacuation routes becoming flooded at low points long before population centres are inundated, creating flood islands. Many of the significant urban centres such as McGraths Hill, Windsor, Richmond and Bligh Park are located on flood islands, which can become fully submerged in large flood events.

Reliable and timely flood forecasts and warnings are critical for evacuation. Currently the Bureau of Meteorology has advised that it can provide up to 15-hour flood level predictions for large flood events. However, the SES requires more than 15 hours to evacuate some flood islands in the Hawkesbury-Nepean Valley during large flood events. This could force the SES to make evacuation orders based on uncertain flood prediction. If the flood exceeds the prediction, lives could be at risk. Alternatively, if the flood does not reach the predicted level, large numbers of people could be evacuated unnecessarily, which could mean people may be reluctant to follow future evacuation orders.

The total number of people requiring evacuation during a major flood event consists of residents and workers within the directly flood affected areas and those potentially isolated on flood islands. The number of residents and workers requiring evacuation in 2018 is shown in Table 3-15.

For a flood similar to the 2012 Brisbane floods (1% AEP event), 55,000 people would have required evacuation in 2018.

For a 0.2% AEP flood that occurred in the Hawkesbury-Nepean valley in 1867, 94,000 people would have required evacuation in 2018.

Table 3-15 Number of people requiring evacuation (2018)

Size of Flood	Residents in the floodplain	Residents isolated on flood Islands	Total residents requiring evacuation	Workers in the floodplain	Workers isolated on flood Islands	Total workers requiring evacuation	Total people involved in evacuation planning
1% AEP	19,800	23,400	43,100	9,600	2,200	11,900	**55,000**
0.2% AEP	42,300	24,900	67,100	23,700	2,900	26,600	**94,000**
PMF	99,900	13,100	113,000	48,100	300	48,400	**161,000**

The Hawkesbury-Nepean Valley has been divided into sectors based upon flood risk and evacuation requirements. Flood risk has been categorised by an area's flooding experience, and topographical, access and other constraints. Classification provides an indication of the relative vulnerability of the community in flood emergency response There are six different classifications of flood affected areas that determine evacuation and other responses when floods occur. These are:

(1) High flood islands.

(2) Low flood islands.

(3) Areas with trapped perimeters (both high and low).

(4) Areas with overland escape routes.

(5) Areas with rising road access.

(6) Areas indirectly impacted by flooding.

High flood island

A high flood island is higher than the limit of flooding (that is, above the PMF). It would be surrounded by flood water but there would be still enough land available to provide a flood free area for remaining people. This flood free area may not be enough to adequately cater for the population as some properties may be flooded. The area would require resupply by boat or air if not evacuated before the road access is lost. Evacuation would have to take place before isolation occurs if adequate support and essential services are not available, or if houses are flooded.

Low flood island

A low flood island is lower than the limit of flooding (that is, below the PMF). If flood water continues to rise after it is isolated, the island would eventually be completely flooded with all properties inundated. People left stranded may be at considerable risk unless rescued. Evacuation must be completed before roads are inundated.

Areas with trapped perimeters

These are like flood islands in that they are inhabited or potentially habitable areas of higher ground. They exist at the fringe of the floodplain where the only practical road or overland access is through flood prone land and the access becomes unusable during a flood event. In some cases, normal access to the area is by boat but flood conditions may prevent usual boat access. The ability to retreat to higher ground does not exist due to topography or impassable structures.

Trapped perimeter areas are further classified according to what can happen after the evacuation route is cut as follows:

- *High trapped perimeters*: These are inhabited areas above the PMF but the only access road/s is across flood-prone land. Road access may be closed during a flood. The area would require resupply by boat or air if not evacuated before the road is cut. Evacuation would have to take place before isolation occurs if adequate support and essential services are not available, or if houses are flooded.
- *Low trapped perimeters:* The inhabited area is lower than the limit of flooding (that is, below the PMF) or does not have enough land to cope with the number of people in the area. During a flood event the area is isolated by floodwater and property may be inundated. If flood water continues to rise after the area is isolated, it will eventually be completely covered.

Areas with overland escape routes

These are inhabited areas on flood prone ridges jutting into the floodplain or on the valley side. The access road/s cross lower lying flood prone land. Evacuation can take place by road only until access roads are closed by flood water. Escape from rising flood waters would be possible by walking overland to higher ground. Anyone not able to walk out would need to be reached by using boats and aircraft. If people cannot get out before inundation, rescue would most likely be from rooftops. Pedestrian evacuation as a primary evacuation strategy must never be relied upon and is only a back-up strategy if vehicular evacuation fails.

Areas with rising road access

These are inhabited areas on flood prone ridges jutting into the floodplain or on the valley side with access road/s rising steadily uphill and away from the rising flood waters. Evacuation can take place by vehicle or on foot along the road as flood waters advance. People would not be trapped unless they delay their evacuation. For example, people living in two-storey homes may initially decide to stay but reconsider after water surrounds them. These communities contain low-lying areas from which people would be progressively evacuated to higher ground as the level of inundation increases. This inundation could be caused either by direct flooding from the river system or by localised flooding from creeks.

Indirectly affected areas

There will be areas outside the limit of flooding that would not be inundated and would not lose road access. However, they may be indirectly affected because of flood damaged infrastructure such as loss of transport links, electricity supply, water supply, sewerage or telecommunications services. They may require resupply or in the worst case, evacuation.

The different sectors within the Hawkesbury-Nepean, their flood classification and specific evacuation characteristics are summarised in Table 3-16 and discussed below.

Table 3-16 Flooding classification and evacuation characteristics by area

Area (sector/sub-sector)	Flood classification	Loss of road access (RL m)	Submersion height (RL m)	Comments
Richmond/Windsor/Wilberforce				
Wilberforce/ Gronos Point	High flood island	Around 6.5 to 6.75 (at Windsor)	>PMF	Becomes isolated early during a flood at 5.1 m locally, which is equivalent to around 6.5 m to 6.75 m at the Windsor gauge. Some small flood free areas during a PMF.
Richmond Lowlands	Low flood island	10.86	Not applicable	Properties begin to be flooded by 12.5 m at Richmond gauge with most of the surrounding agricultural areas also flooded.
McGraths Hill	Low flood island	13.5	16.0 to 18	Some properties (around 50) are flooded in a 1 in 20 chance in a year event (13.7 m at Windsor), with nearly all properties (around 913) flooded in a 1 in 100 chance in a year event (17.3 m at Windsor).
Yarramundi	Trapped perimeter	15.1 to 15.5	>PMF	Becomes isolated in less than a 1 in 100 chance in a year event. Some properties flooded in 1 in 50 chance in a year event, with around 35 flooded in a PMF.
Wilberforce/Ebeneze r	High flood island	15.5	>PMF	Isolations begin from 9.6 m, with properties flooded from 11.1 m. During a PMF around 50% (528) of properties would be flooded and 50% isolated.
Pitt Town and Pitt Town Bottoms	Low flood island*	16	>PMF	*There is a very small area of land which remains flood free during a PMF. Some isolations begin from 6.2m (Windsor gauge) in Pitt Town Bottoms. Around 60 dwellings in Pitt Town would be flooded by 13.7m.
Windsor	Low flood island	17.3 (14m*)	26.0	Some properties flooded from 11.1 m, with around 110 properties flooded in a 1 in 20 chance in a year event (13.7 m) and over 800 properties in a PMF. *The Windsor North area also becomes a flood island at 14 m and is submerged at 22.3 m.
Bligh Park	Low flood island	18.5 (17.2**)	25.0 (>PMF)	Around 60 properties would be flooded in a 1 in 100 chance in a year event (17.3 m) and 2,285 in a PMF. There is some opportunity for overland escape into Windsor Downs Nature Reserve. **Internal road closures occur prior to 18.5 m from 17.2 m.

Area (sector/sub-sector)	Flood classification	Loss of road access (RL m)	Submersion height (RL m)	Comments
RAAF Base Richmond	Low flood island	20.1	20.4	Flooding begins at around 16.4 m at North Richmond gauge. 19.3 m low point on Windsor St, Richmond affects late evacuations.
Richmond	Low flood island	20.2	23.6	Some properties affected from 15.3 m at Richmond gauge, with most unaffected until above the 1 in 100 chance in a year event (17.5 m at Richmond gauge). Around 450 flooded in a PMF.
Windsor Downs	Low flood island	23.8 (16.7 -19 internal roads cut)	26.4 (PMF)	About 30 properties are flooded by 17.3 m A (1 in 100 chance in a year event), 260 by 21.9 m, and 290 in a PMF. Some opportunity to escape by foot to the Windsor Downs Nature Reserve.
Lower Hawkesbury				
Singletons Mill	Trapped perimeter	Various locations from 1.2		Properties will become isolated during smaller flood events but may be flooded during larger events.
Gunderman	Trapped perimeter	1.2 to 2		Wisemans Ferry Road becomes cut in some places between Wisemans Ferry and Spencer.
Macdonald River	Trapped perimeter	1.5 to 1.9		Cut at St Albans Road (1.5 m) and Settlers Road (1.9 m) causing isolations. Also isolated by ferry closures. Significant number of properties flooded in a 1 in 100 chance in a year event.
Lower Reaches	Trapped perimeter	1.5 to 4		River Road cut in some places from 1.5 m. Some caravan parks will become isolated and flood affected during a 1 in 5 chance in a year event.
Webbs Creek	Trapped perimeter	2.05 and 2.28		Webbs Creek Road and Chaseling Roads are cut due to flooding and Webbs Creek Ferry closes isolating properties and caravan parks.
Emu Plains/Penrith/Castlereagh				
Penrith/Peach Tree Creek West	Low flood island	22.1 at Penrith		Road cut at Ladbury Avenue. Some possibility to leave by overland route through Tench Reserve, but this way out also gets cut at Jamison Rd close to Anakai Drive at 23.6 m.
Penrith/North Penrith	Low flood island	22.3 at Penrith		This contains industrial/commercial areas.
Penrith/Regentville	Low flood island	23.2 at Penrith		Cut at Factory Road isolating a number of properties near the Nepean River which can be flooded in larger events.

Area (sector/sub-sector)	Flood classification	Loss of road access (RL m)	Submersion height (RL m)	Comments
Emu Plains/Emu Heights	Trapped perimeter	23.8 at Penrith	>PMF	Properties become isolated when Wedmore Road close to Alma Crescent is cut.
Emu Plains/East	Low flood island	25.7 at Penrith	28	River Road is initially cut at Jamison Creek, then along its entire length.
Emu Plains/Central West	Low flood island	25.7 at Penrith	31	This area becomes isolated around a 1 in 100 chance in a year event (26 m or 11.9 m at the Penrith gauge).
Emu Plains/Leonay	Trapped perimeter	34.35 locally		Road evacuation route cut on Leonay Parade at Knapsack Creek culvert.
Wallacia/Bents Basin	Trapped perimeter	33.9 locally		Bents Basin Road is cut at Baines Ck early during flooding isolating the area. Properties may be flooded during larger flood events.
Wallacia (WA1) (15) and (23)	High flood island	61.3 locally	>PMF	The Park Road Evacuation Route is cut at 39.8 m. The alternative route is through a private property on a dirt track. Many properties would be flood affected in a PMF.

3.4 Flood management plans

Local governments are required to prepare Floodplain Risk Management Plans based upon guidance in the Floodplain Development Manual (DIPNR 2005) and the Flood Prone Land Policy.

The primary objective of the Flood Prone Land Policy is to reduce the impacts of flooding and flood liability on individual owners of flood prone property, and to reduce private and public losses resulting from floods, utilising ecologically positive methods wherever possible. That is:

- a merit based approached shall be adopted for all development decisions in the floodplain to take into account social, economic and ecological factors, as well as flooding consideration
- both mainstream and overland flooding shall be addressed, using the merit approach, in the preparation of and implementation by councils of strategically generated flood plain risk management plans
- the impact of flooding and flood liability in existing developed areas identified in floodplain risk management plans shall be reduced by flood mitigation works and measures, including on-going emergency management measures, the raising of houses where appropriate and by development controls
- the potential for flood losses in all areas proposed for development shall be contained by the application of ecologically sensitive planning and development controls.

Resilient Valley, Resilient Communities – Hawkesbury-Nepean Valley Flood Risk Management Strategy (Flood Strategy) (INSW 2017) was guided by the Floodplain Development Manual (DIPNR 2005) and the Flood Prone Land Policy. It contains the key outputs required for a regional Floodplain Risk Management Plan.

The application of the Flood Prone Land Policy and the steps in preparing and implementing a Floodplain Risk Management Plan is detailed in Figure 3-38. The key outputs from the Floodplain Risk Management Plan are:

- local mitigation measures to reduce flooding impact (for example, levees)
- planning Controls – which are generally flood levels below which flood sensitive development in not permitted
- flood warning, readiness and response planning
- environmental programs which may reduce flooding (for example, wetland restoration)
- monitoring and date collection programs.

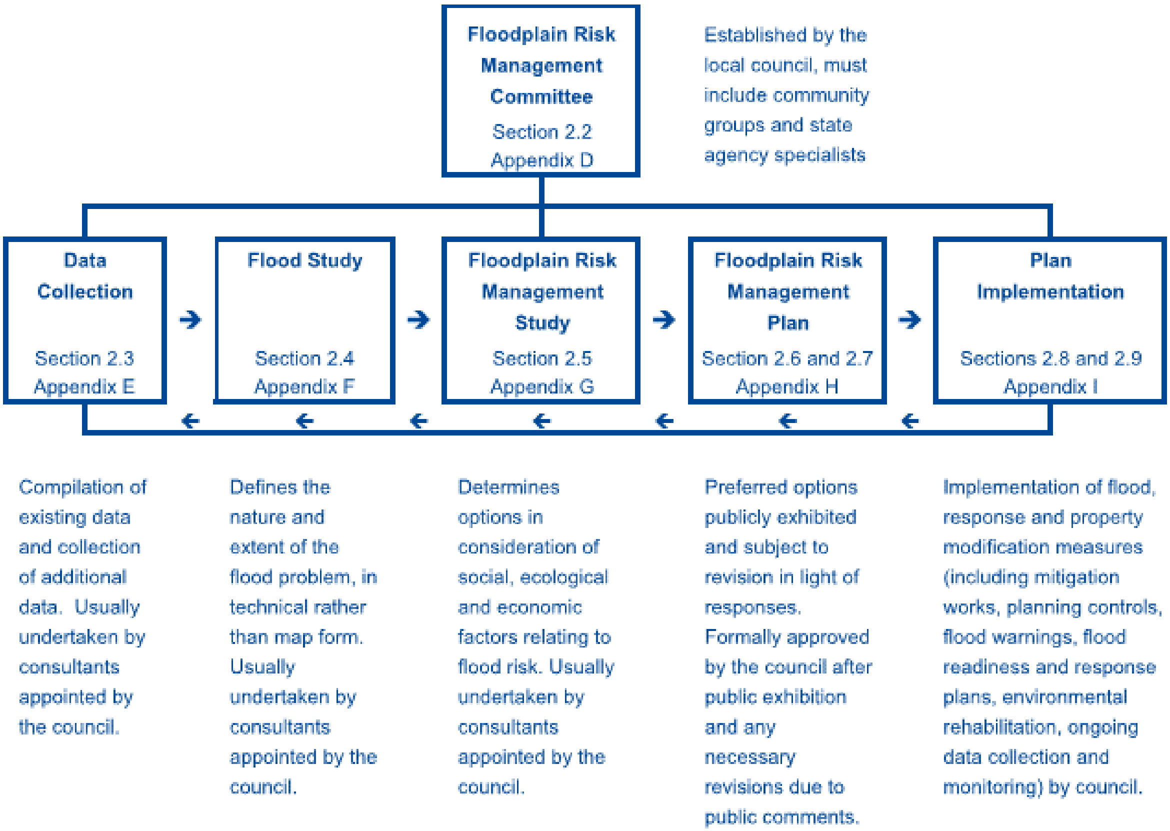


Figure 3-38 Floodplain risk management plan process

Relevant flood studies and floodplain risk management strategies that have been prepared since 1995 are shown in Table 3-17. Some flood studies of the major tributaries of the Hawkesbury–Nepean River have been prepared. Apart from the Liverpool LGA, Hawkesbury LGA and Blue Mountains LGA, no other LGA's downstream have prepared a floodplain risk management plan and strategy for areas impacted by flooding from the Hawkesbury- Nepean and its tributaries.

The South Creek Floodplain Risk Management Study and Plan prepared by Liverpool Council is outside the area of impact of backwater flooding impacts from the Hawkesbury–Nepean River. The Lapstone, South Glenbrook and South Blaxland Floodplain Risk Management Study and Plan prepared by Blue Mountains Council is also outside the influence of flooding from the Hawkesbury-Nepean and its tributaries.

Table 3-17 *Relevant flood studies and floodplain risk management strategies in the upstream and downstream study areas*

Study name	Date	Client organisation
Upper Nepean River Flood Study	Sep-1995	NSW Department of Land and Water Conservation, Wollondilly, Campbelltown, Camden, Liverpool and Penrith Councils
Lower Hawkesbury River Flood Study (final draft)	Apr-1997	NSW Department of Land and Water Conservation
Achieving a Hawkesbury-Nepean Floodplain Management Strategy	Nov-1997	NSW Government
Upper Nepean River Floodplain Risk Management Study and Plan - Floodplain Management Study	Apr-2001	Camden Council
Lower Macdonald River Flood Study	Aug-2004	Hawkesbury City Council
Hawkesbury-Nepean Floodplain Management Strategy Implementation	Oct-2004	NSW Government
South Creek Floodplain Risk Management Study and Plan (Vols 1 and 2)	Dec-2004	Liverpool City Council
Hawkesbury Floodplain Risk Management Study & Plan	Dec-2012	Hawkesbury City Council
Torkington Creek, Londonderry, Flood Investigations	Jan-2013	Penrith City Council
Brisbane River Foreshore Flood Study	Jul-2013	Gosford Council
Eastern Creek Hydrologic and Hydraulic Assessment	Dec-2014	Blacktown City Council
Updated South Creek Flood Study (Vols 1 and 2)	Jan-2015	Penrith City Council
Nepean River Flood Study	Apr-2015	Camden Council
Lapstone, South Glenbrook and South Blaxland Floodplain Risk Management Study and Plan	Jun-2015	Blue Mountains City Council
St Marys Byrnes Creek Overland Flow Flood Study – Final Report	Nov-2015	Penrith City Council
Nattai River Floodplain Risk Management Study and Plan	Sep-2016	Wingecarribee Shire Council
Nepean River Flood Study	Nov-2018	Penrith City Council
Hawkesbury-Nepean Regional Flood Study	Jul 2019	Infrastructure NSW
Draft South Creek Floodplain Risk Management Strategy and Plan	Dec-2019	Penrith City Council

4 Environmental assessment

4.1 Construction phase

The following section outlines an environment assessment of potential impacts of the Project on hydrology and flooding during the construction phase.

4.1.1 Potential impacts

Hydrology and flooding impacts during the construction phase of the Project may occur during or because of the following activities:

- reduced flow levels and volumes downstream of the dam including changes to water availability and flows for both regulated and unregulated users and the environment
- stormwater runoff from construction and site storage areas
- stormwater and wastewater management
- water take (direct or passive) from surface and groundwater sources
- major flood event occurring during the construction phase.

Note that there are only adverse hydrological impacts during construction (no beneficial impacts).

4.1.1.1 Reduced flows/releases to downstream environment

The existing flows/releases to the downstream Warragamba River and the water supply network or WFPs will be maintained throughout the construction process. Warragamba Dam is Sydney's largest drinking water supply dam and as such it is crucial that this supply is maintained during construction of the Project.

A reduction in flow levels and volumes downstream of the dam (and releases to WFPs) during construction is considered unlikely as flows will be diverted around the dam construction site, maintaining the water access of existing downstream users as well as downstream environmental flows. This can be achieved through the provision of temporary works such as a diversion channel and auxiliary spillway, the details of which should be developed as the design progresses towards construction.

4.1.1.2 Stormwater runoff from construction area

During the construction phase of the Project, there is expected to be additional hardstand areas built to house the facilities and plant material needed in the construction process. Additional hardstand areas may include site offices, workshops, car and truck parking, plant and equipment storages, concrete batch plant facilities, a water treatment plant and access roads to the dam construction itself.

The additional hardstand area will lead to slight increases in stormwater runoff however the impact of this increased volume and speed of runoff on the overall hydrology of the area is expected to be a negligible or minor impact. The change to runoff at the dam wall is anticipated to be minor compared to the total flow volume in the river (and the volume of dam releases).

4.1.1.3 Stormwater and wastewater management

There is a requirement for stormwater and wastewater management during construction to mitigate potential impacts on natural hydrological attributes (such as volumes, flow rates, management methods and re-use options) and on the conveyance capacity of existing stormwater systems where discharges are proposed through such systems. Appropriate management plans should be developed as the design progresses towards construction.

4.1.1.4 Water take from surface water and groundwater sources

About 183 megalitres of water is required for construction water uses over the construction period. This amounts to approximately 0.11 megalitres per day, which would be generally sourced from the dam where possible. This is equivalent to less than about 0.01 percent of the current daily water supply demands (about 1,200 megalitres). There would be minimal impact on dam water storage or daily supply.

4.1.1.5 Flood event during construction phase

During the four to five year construction phase, the dam raising works, associated equipment and personnel will be exposed to existing flood risks. Flood events themselves cannot be minimised or influenced by mitigation measures however the impact of the flood can be mitigated through the construction design program and management of flood waters if an event is to occur.

The Warragamba Dam catchment is large with multiple different major rivers extending from different locations. In addition to the diversion of flood waters through the auxiliary spillway, the nature of the catchment should enable adequate flood warning time to protect personnel, plant and equipment from the effects of flooding.

A preliminary flood management plan has been developed as part of the Project development phase to assess temporary works and flood management requirements that would need to be considered during the construction of the Project. The preliminary flood management plan included:

- lowering the FSL of the dam by 5 metres during the construction period
- constructing a coffer dam upstream of the auxiliary spillway to protect construction works in the spillway
- use of temporary coffers during the construction of the new central spillway
- staging the construction of the central and auxiliary spillway works to ensure that one spillway is always able to pass floodwaters.

A Construction Flood Management Plan will be developed to minimise any changes in hydrology up and downstream of the dam and minimise risks to the construction site.. The plan will detail the measures and any impacts of construction flood management. Construction flood management measures will be designed and implemented to maintain the existing flood performance of the dam. A Dam Safety Emergency Plan will also be prepared in accordance with the requirements of Dams Safety NSW.

Changes to the upstream and downstream flooding are expected to be negligible during the construction phase of the Project.

4.2 Operation phase

The following section outlines an environment assessment of potential impacts of the Project on hydrology and flooding during the operational phase.

4.2.1 Overview

During small (flood producing) rainfall events when the flood mitigation zone (FMZ) is not used (for example, the lake level below FSL), the Project would have no impact on upstream hydrology and flood behaviour. Potential adverse impacts of the Project on hydrology and flooding would therefore be limited to less frequent rainfall events that result in the FMZ being activated (that is, when the lake water increases over FSL). Potential impacts during the operational phase of the Project may include:

- increases in flood extents and lake levels in the upstream environment resulting from the FMZ being activated (used to temporarily store flood waters)
- increased flood levels and inundation extent along tributaries of the lake
- changes to flood flow regime (timing, magnitude and duration) in the downstream environment
- changes to erosional processes and river morphology in the downstream environment
- bank erosion impact caused by prolonged FMZ flows
- decrease in overbank flood events connecting with wetlands in the downstream environment.

The beneficial impacts related to hydrology are primarily linked to environmental benefits whilst flood impacts are primarily linked to social and economic values. The beneficial impacts of hydrology (primarily linked to surface and groundwater dependent ecosystems, for example, wetlands and floodplain lagoons) and beneficial impacts of flooding are discussed in the following sections. Beneficial impacts on hydrology and flooding during the operational phase of the Project may occur during or because of the following activities:

- reduced peak flood flows, levels, extents, velocity and scour potential in the downstream environment
- delay the downstream flood peak within the weather event
- reduced risk to life and infrastructure damage due to the mitigation of floods
- changes to the environmental flow regime in the downstream environment.

4.2.2 Upstream environments

4.2.2.1 Extent of Project impacted area

Project flood extents are based on flood modelling and assessing the limits of potential Project changes. Key aspects are:

- the inundation extent upstream of Warragamba Dam is controlled by the peak flood level at the dam wall and the topography across the upstream catchment. Areas with steep terrain would have minor increases in flood extent compared to areas with flatter terrain. The steep valley terrain surrounding Lake Burragorang, which extends from the dam wall upstream for at least 20 km, results in the peak flood level inundation extent being contained to a small total land area.

- the terrain is notably flatter further upstream where the Wollondilly River and Coxs River enter Lake Burragorang. Therefore, the increase in peak flood level inundation extent from the existing to Project scenario encompasses a larger total area (as elevation increases more gradually).

Approximate changes to the SEARs flood extents for the Project study area are summarised in Table 4-1, with the 1% AEP event presented in Figure 4-1.

Table 4-1 Changes to flood extents

Event	Existing flood affected area (ha)	Project flood affected area (ha)	Increase in flooded area (ha)	Increase in flooded area (%)
20% AEP	560	843	283	51
10% AEP	754	1589	835	111
5% AEP	926	2313	1387	150
1% AEP	998	2910	1912	192
PMF	2934	5280	2346	80

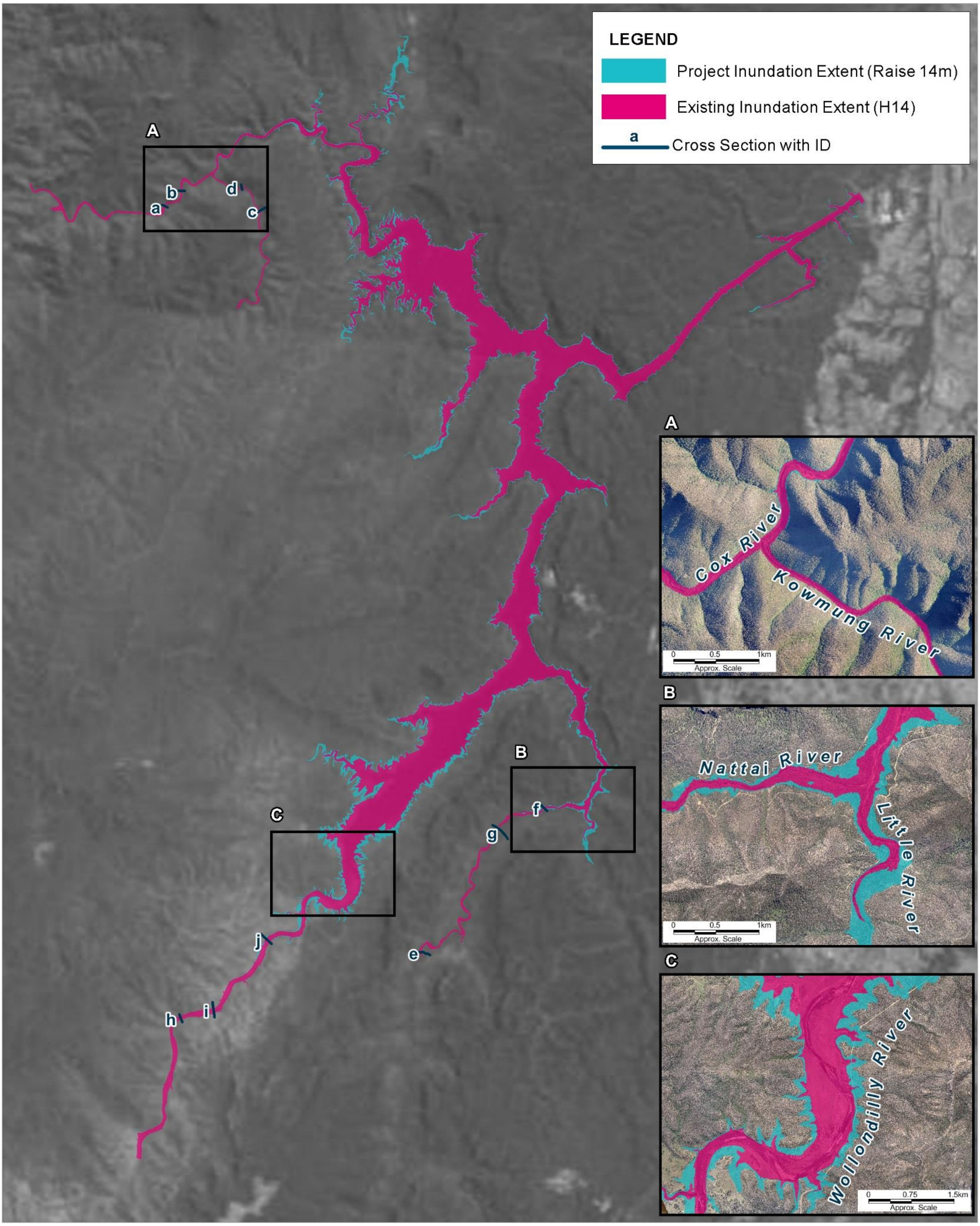
4.2.2.2 Flood levels and inundation duration

Modelling included the development of depth-duration curves at various cross sections within the lake and along major tributaries. These curves show the amount of time that water levels are at or above a specific elevation and are of use in comparing different flood events at a specific location or, in this case, comparing flood events of a specific chance of occurrence for the existing situation and the Project. It should be noted that the figures for the incremental depths and durations are based on representative hydrographs from the Monte Carlo analysis.

Flood depth-duration curves were examined for a selection of locations as shown in Table 4-1. For each of the main tributaries cross sections were selected to show the upstream limit of the Project influence, which is where contributions from the local catchments begin to decline and the contribution to flooding by the Project for the PMF event begins to dominate. Further downstream cross sections were analysed to assess changes to Project depth – duration characteristics. Cross section locations (which are cross referenced to modelled cross section names) are shown in Figure 4-2 and include:

- dam wall (Location 1). The dam wall shows the greatest influence of the Project
- Wollondilly River (Locations 2, 3, 4 and 5). The lower Location 5 is close to the main body of Lake Burragorang
- Coxs River (Locations 6, 7, 8 and 13). The lower Location 8 is close to the main body of Lake Burragorang
- Nattai River (Locations 9, 10, 11 and 12)
- Kowmung River (Locations 14 and 15)

The results of the analyses are discussed below.



Title:

1% AEP Upstream Peak Flood Extents Existing and Project Scenarios

Figure: 4-1

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Approx. Scale

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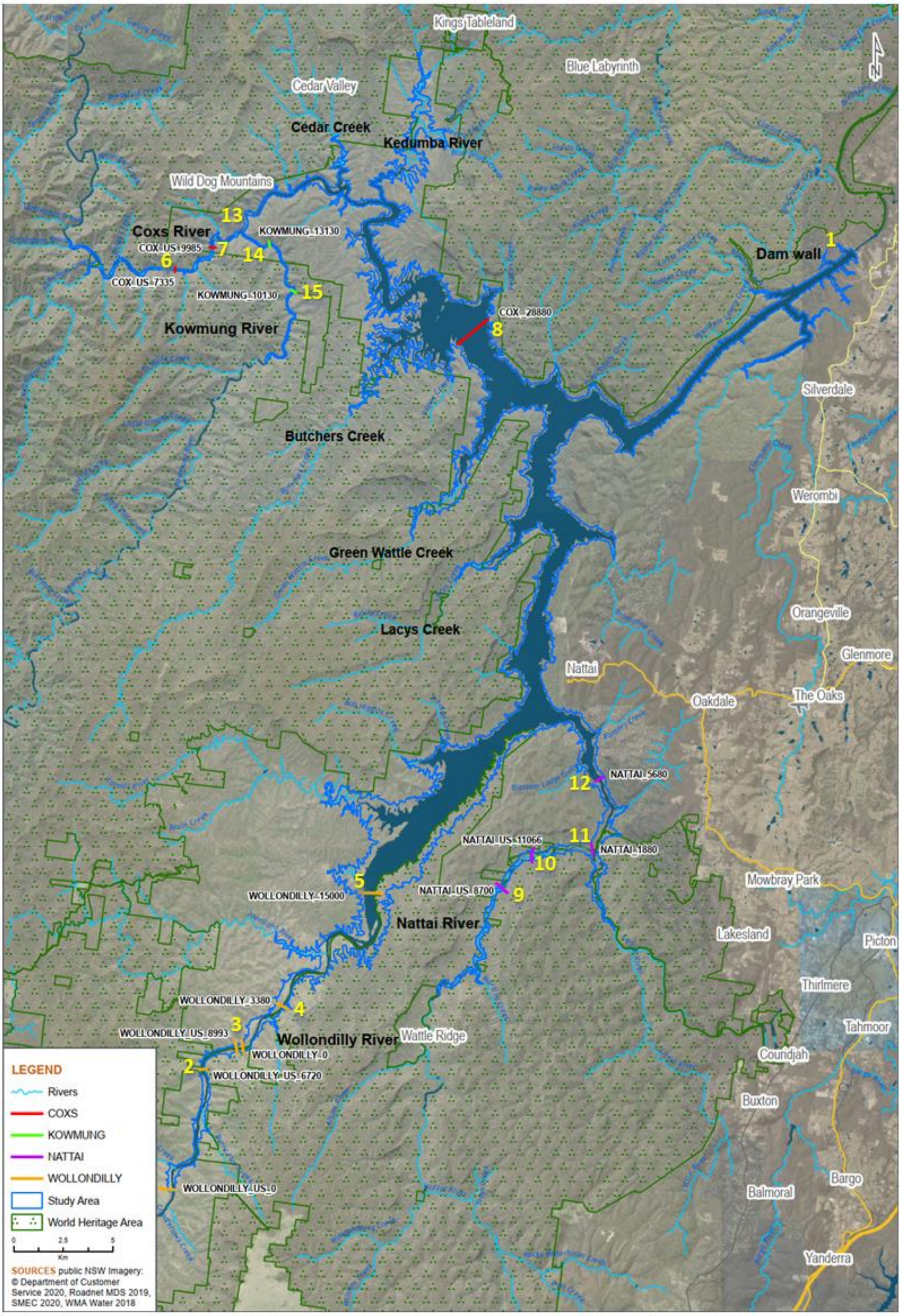


Figure 4-2 Upstream locations for depth-duration and flood frequency analyses

Dam Wall

Predicted changes at the dam wall are presented in Figure 4-3 and summarised in Table 4-2.

Changes to the duration of upstream inundation at the dam wall would be up to about five days for the relatively more frequent 20% AEP flood and up to about 11 days for a rarer 1% AEP flood event.

Table 4-2 Dam wall: Changes to temporary inundation levels and durations

Event	Existing			Project			
	Level (m AHD)	Depth (m)	Inundation (days)	Level (m AHD)	Depth (m)	Inundation increase (days)	Total Inundation (days)
20% AEP	117.4	0.7	2.8	120.3	2.9	4.6	7.4
10% AEP	118.0	1.3	3.4	123.1	5.1	6.0	9.4
5% AEP	118.6	1.9	4.0	126.8	8.2	8.6	12.6
1% AEP	121.5	4.8	4.0	132.0	10.5	10.8	14.8
PMF	131.2	14.5	4.2	143.9	12.7	7.0	11.2

Note: Duration of temporary inundation has been calculated as when the rising limb of the hydrograph exceeds FSL (116.7 metres) and the falling limb of the hydrograph reaches FSL.

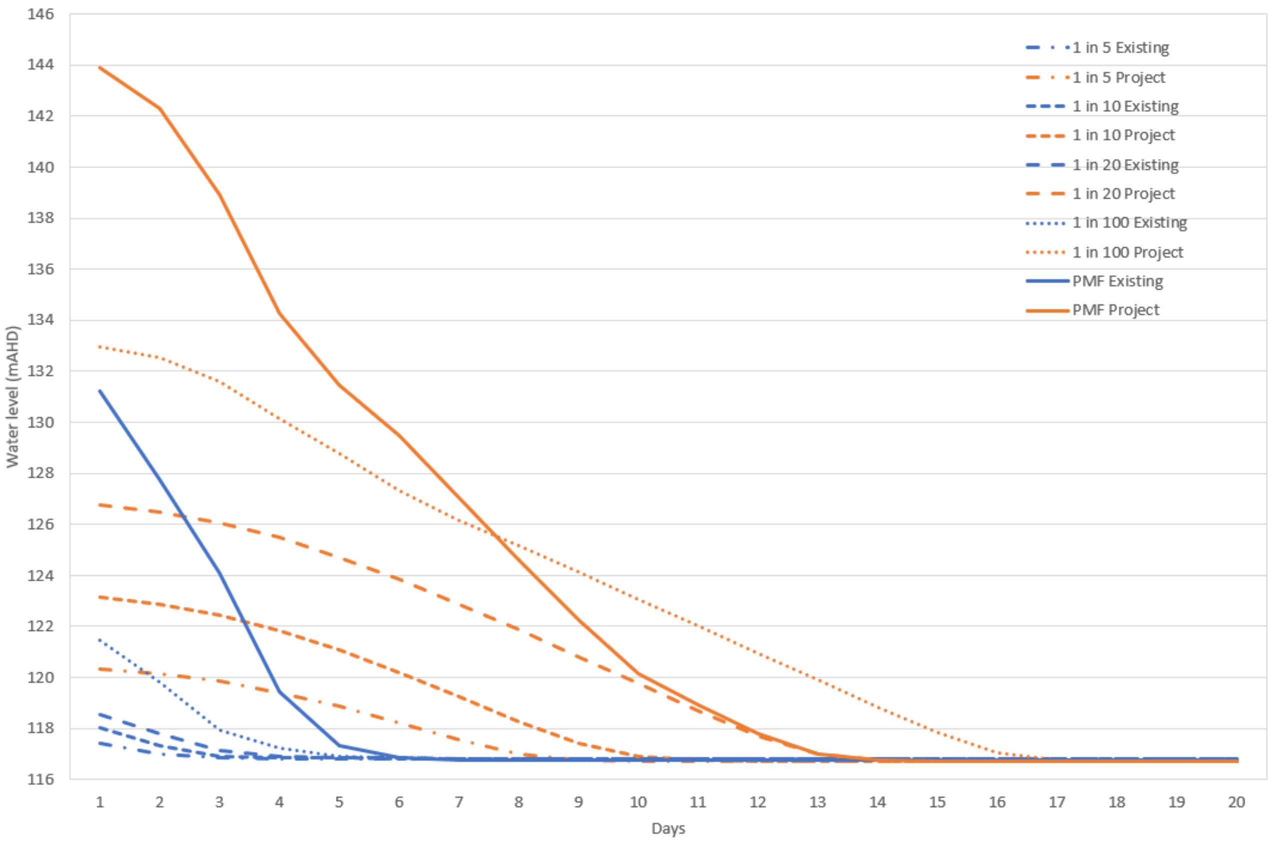


Figure 4-3 Dam wall: Depth-duration curves

Wollondilly River

The Wollondilly River is one of the two main arms of Lake Burragorang (the other being the Coxs River). Depth-duration curves were examined for four cross-sections on the Wollondilly River as follows:

- Location 2 (WOLLONDILLY_US_6720) represents the approximate location of the Project PMF event, and the limit of Project influence on the Wollondilly River
- Location 3 (WOLLONDILLY_US_8933) represents the approximate location of the Project for the 1% AEP event
- Locations 4 and 5 (WOLLONDILLY_3380 and WOLLONDILLY_15000) are two further downstream cross-sections, the latter located within Lake Burragorang.

Predicted changes along the Wollondilly River are presented in Figure 4-4 to Figure 4-7 and summarised in Table 4-3. The table also includes the results for the dam wall to facilitate a comparison with the situation at the downstream-most location in the upstream study area. Analysis shows the following:

- increases in the depth and duration of temporary inundation are generally less than half a metre and half a day respectively for the two upstream most cross-sections for all SEARs events, the exception being the PMF event for Location 3 (WOLLONDILLY_US_8993) where the increase in depth is about 1.1 metres
- at Location 4 (WOLLONDILLY_3380) increases in depth are less than half a metre for all events up to the 1% AEP; for the PMF event the increase in depth is about 4.3 metres
- at Location 4 (WOLLONDILLY_3380) increases in temporary inundation are less than half a day up to the 1% AEP event, then increasing up to 3.6 days for the 1% AEP event
- at Location 5 (WOLLONDILLY_15000) there is a clear increase in depths and durations for temporary inundation for all SEARs events, these broadly mirroring those at the dam wall for respective flood events
- an increasing influence of the Project moving downstream with the increase in temporary depth and duration of temporary inundation within Lake Burragorang generally reflecting that at the dam wall.

Table 4-3 Wollondilly River: Upstream changes in temporary inundation depth and duration

Event	Flood Event (E = existing, P = Project)									
	20% AEP		10% AEP		5% AEP		1% AEP		PMF	
	E	P	E	P	E	P	E	P	E	P
Location 2: WOLLONDILLY_US_6720										
Depth (m)	4.4	<0.5	6.2	<0.5	9.0	<0.5	10.0	<0.5	17.1	<0.5
Duration (days)	5.9	<0.5	5.4	<0.5	6.2	<0.5	5.2	<0.5	5.2	<0.5
Location 3: WOLLONDILLY_US_8993										
Depth (m)	4.0	<0.5	5.6	<0.5	7.9	<0.5	8.7	<0.5	14.9	1.1
Duration (days)	5.9	<0.5	5.4	<0.5	6.2	<0.5	5.2	<0.5	5.2	<0.5
Location 4: WOLLONDILLY_3380										
Depth (m)	4.7	<0.5	6.8	<0.5	9.6	<0.5	10.6	<0.5	17.4	4.3
Duration (days)	5.9	<0.5	5.4	<0.5	6.2	3.2	5.2	3.6	5.2	1.9
Location 5: WOLLONDILLY_15000										
Depth (m)	0.7	2.5	1.3	5.0	2.3	9.0	5.2	10.7	5.2	10.7
Duration (days)	6.8	2.4	6.4	3.8	7.2	8.0	6.8	8.3	6.4	8.3
Location 4: Dam wall (comparison)										
Depth (m)	0.7	2.9	1.3	5.1	1.9	8.2	4.8	10.5	14.5	12.7
Duration (days)	2.8	4.6	3.4	6.0	4.0	8.6	4.0	10.8	4.2	7.0

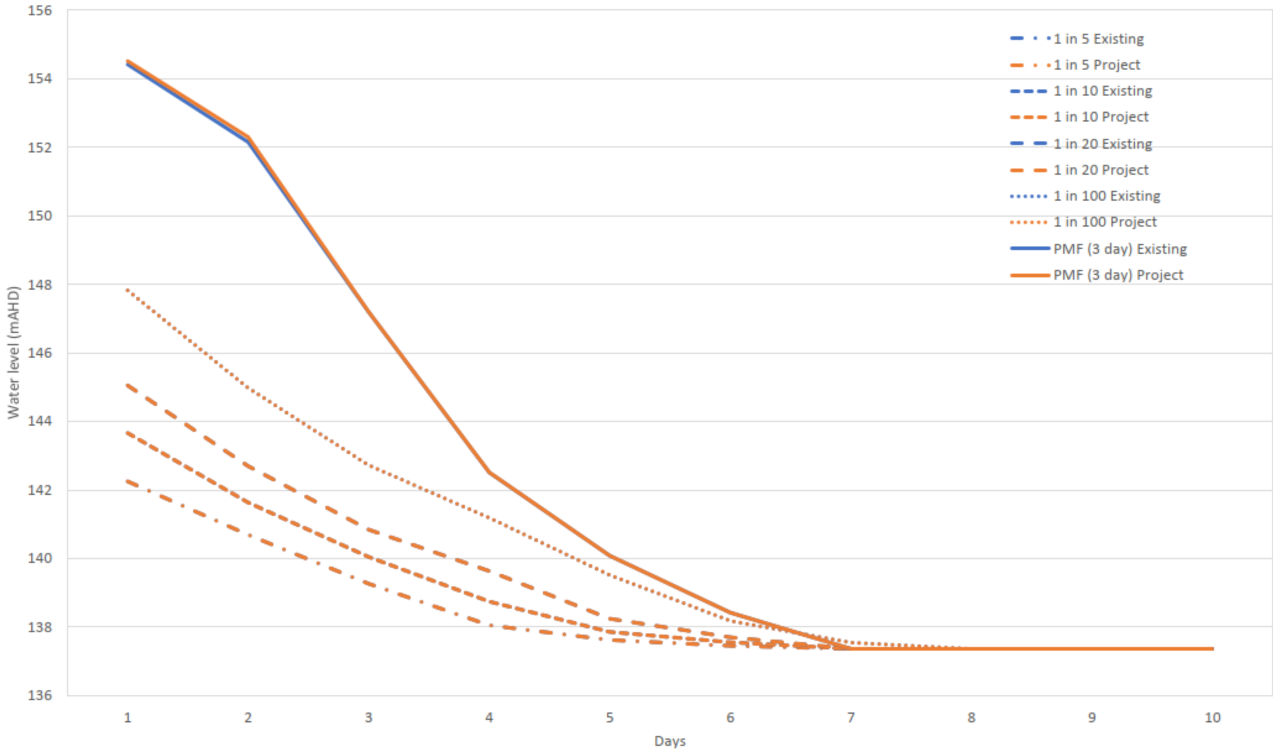


Figure 4-4 WOLLONDILLY_US_6720 depth-duration curves

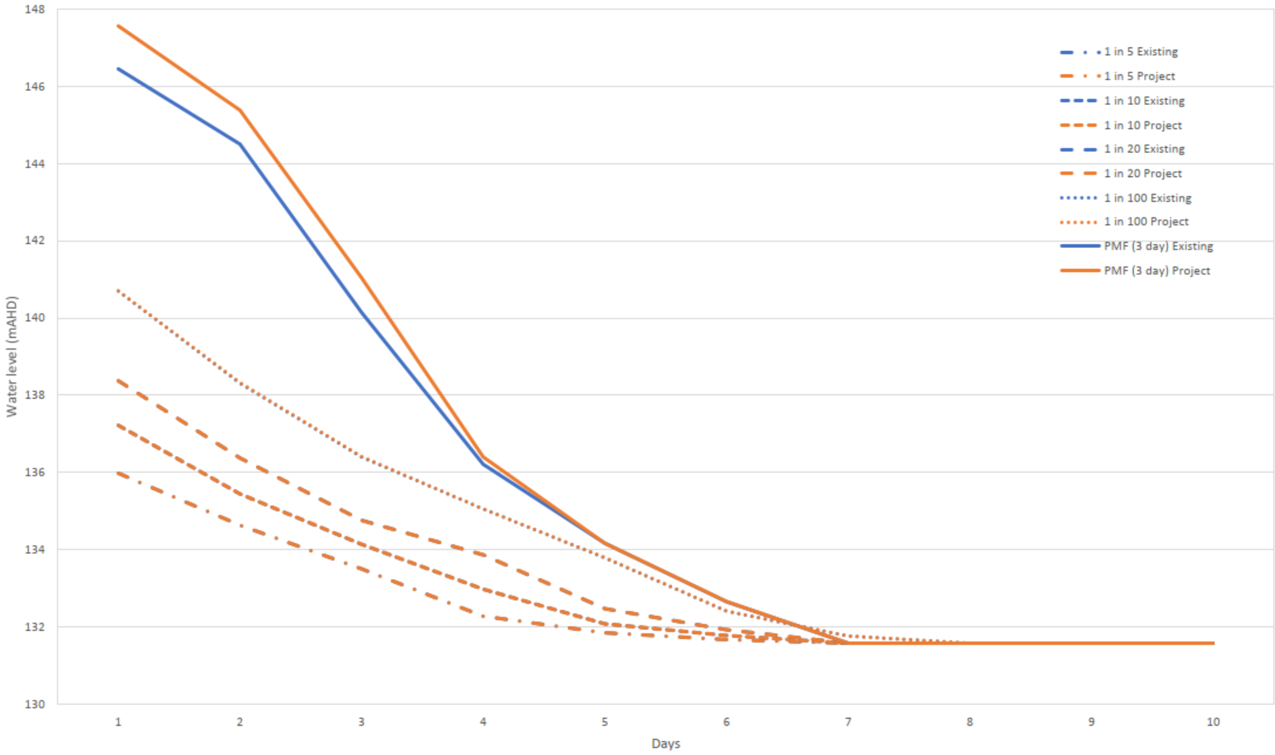


Figure 4-5 WOLLONDILLY_US_8933 depth-duration curves

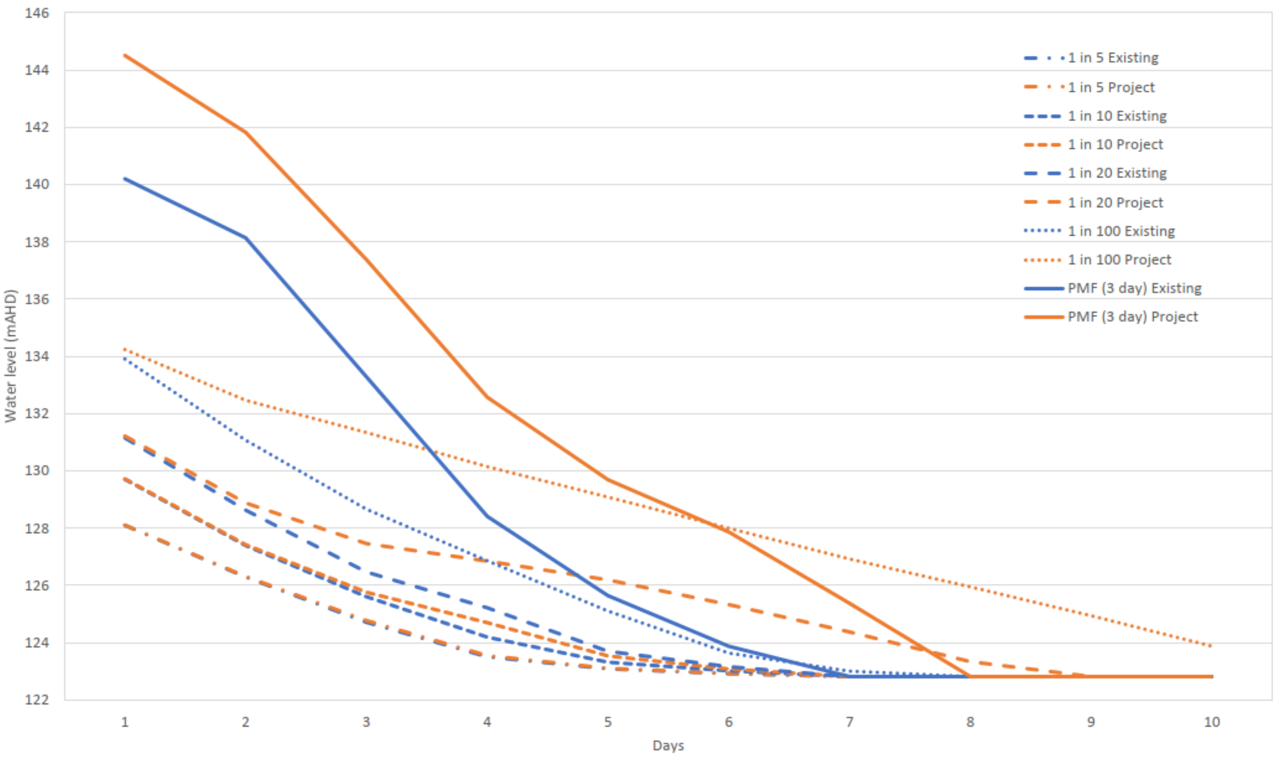


Figure 4-6 WOLLONDILLY_3380 depth-duration curves

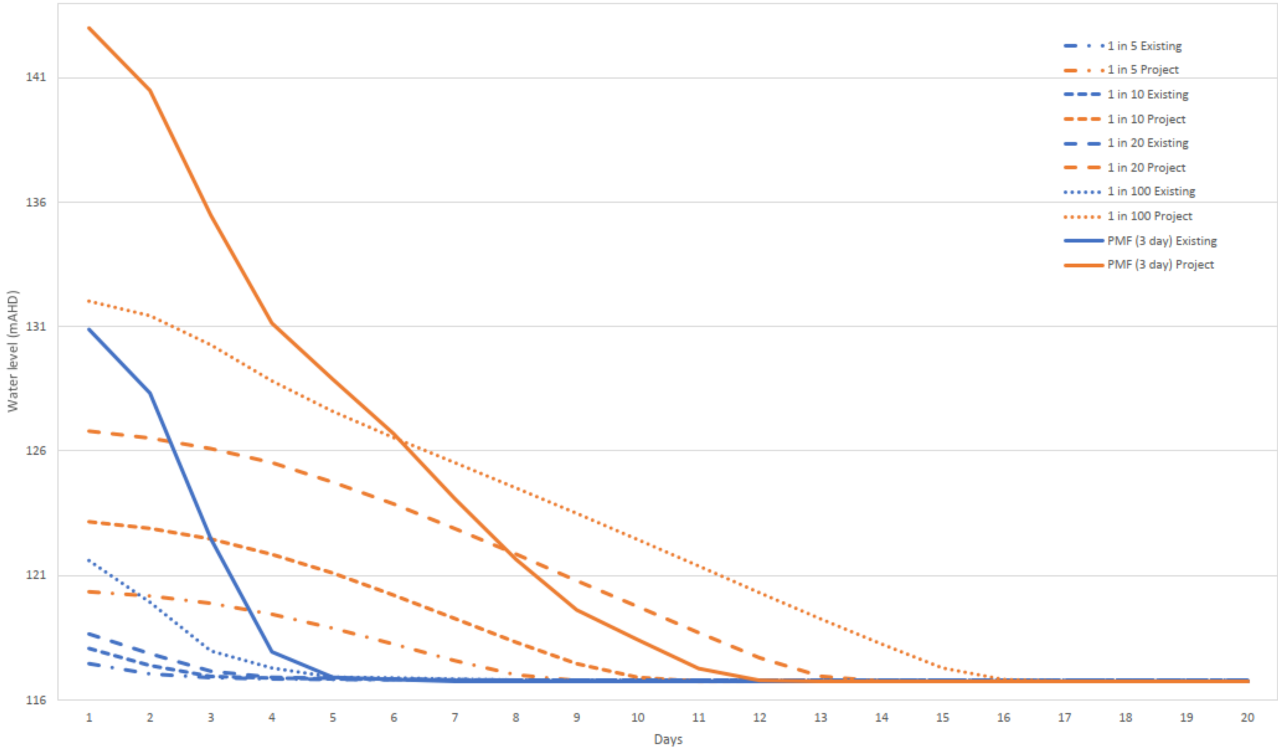


Figure 4-7 WOLLONDILLY_15000 depth-duration curves

Coxs River

Depth-duration curves were examined for three cross-sections on the Coxs River as follows:

- Location 6 (COX_US_7335) represents the approximate location of the Project PMF event and the limit of Project influence on the Coxs River
- Location 7 (COX_US_9985) represents the approximate location of the Project for the 1% AEP event and is about 2.5 kilometres downstream of COX_US_7335
- Location 8 (COXS_28800) is further downstream located within Lake Burragorang.

Predicted changes along the Coxs River are presented in Figure 4-8 to Figure 4-10 and summarised in Table 4-4. The table also includes the results for the dam wall to facilitate a comparison with the situation at the downstream-most location in the upstream study area. Analysis shows the following:

- increases in the depth and duration of temporary inundation are half a metre (for the PMF event) or less and half a day respectively for Location 6 (COX_US_7335) for all events
- increases in the depth of temporary inundation for Location 7 (COX_US_9985) are half a metre or less up to the 1% AEP event and about 3.5 metres for the PMF event
- increases in the duration of temporary inundation for Location 7 (COX_US_9985) are less than half a day up to the 5% AEP event; this increases slightly to 0.7 days for the 1% AEP event and the PMF event

- at Location 8 (COXS_28800), there is a clear increase in depths and durations for temporary inundation for all SEARs events, these broadly mirroring the those at the dam wall for respective flood events
- an increasing influence of the Project moving downstream with the increase in temporary depth and duration of temporary inundation within Lake Burragorang generally reflecting that at the dam wall.

Table 4-4 Coxs River: Upstream changes in temporary inundation depth and duration

Event	Flood Event (E = existing, P = Project)									
	20% AEP		10% AEP		5% AEP		1% AEP		PMF	
	E	P	E	P	E	P	E	P	E	P
Location 6: COXS_US_7335										
Depth (m)	2.4	<0.5	4.6	<0.5	5.3	<0.5	6.7	<0.5	13.8	<0.5
Duration (days)	5.8	<0.5	5.4	<0.5	6.2	<0.5	5.3	<0.5	5.3	<0.5
Location 7: COXS_US_9985										
Depth (m)	2.1	<0.5	4.5	<0.5	5.3	<0.5	6.9	0.5	15.2	3.5
Duration (days)	5.8	<0.5	5.4	<0.5	6.2	<0.5	5.1	0.7	5.3	0.7
Location 8: COXS_28800										
Depth (m)	0.7	2.5	1.3	5.1	2.2	9.1	5.1	10.8	14.0	12.2
Duration (days)	6.8	2.4	6.4	3.8	7.2	8.0	6.4	8.3	5.3	6.4
Location 1: Dam wall (comparison)										
Depth (m)	0.7	2.9	1.3	5.1	1.9	8.2	4.8	10.5	14.5	12.7
Duration (days)	2.8	4.6	3.4	6.0	4.0	8.6	4.0	10.8	4.2	7.0

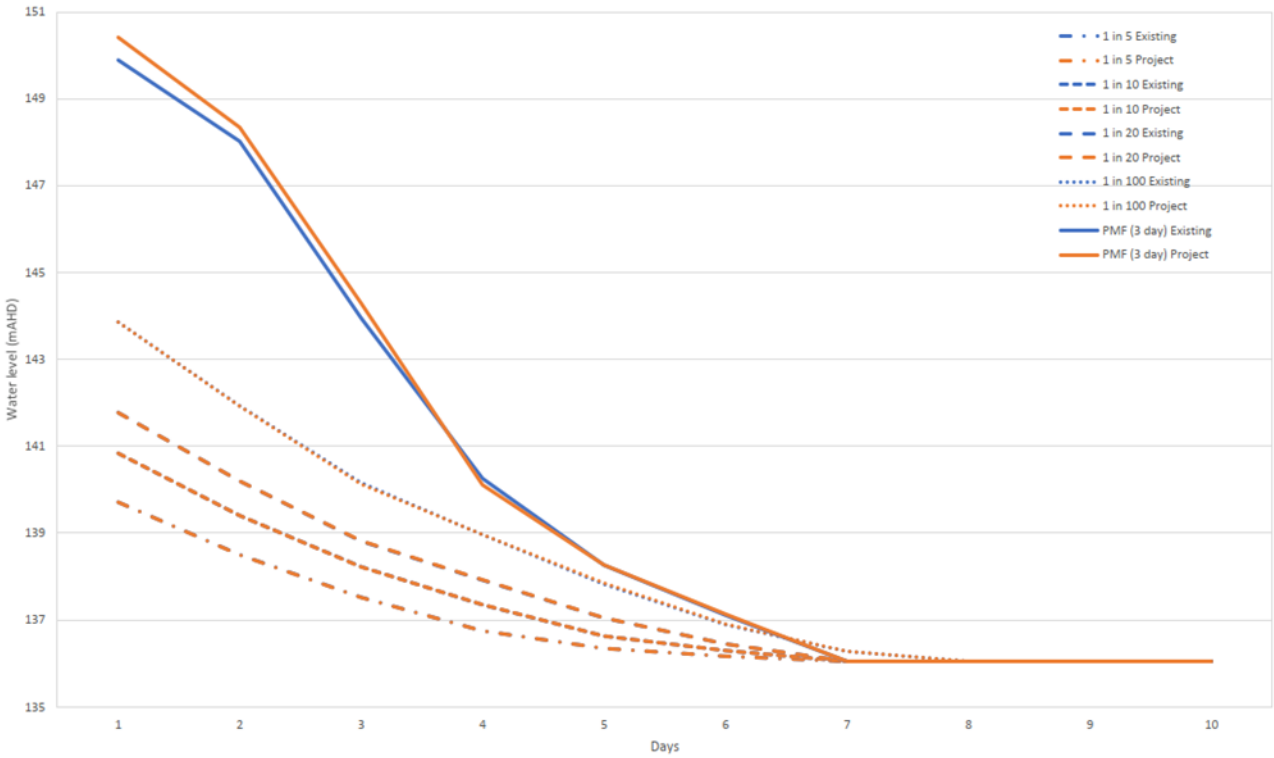


Figure 4-8 COXS_US_7335 depth-duration curves

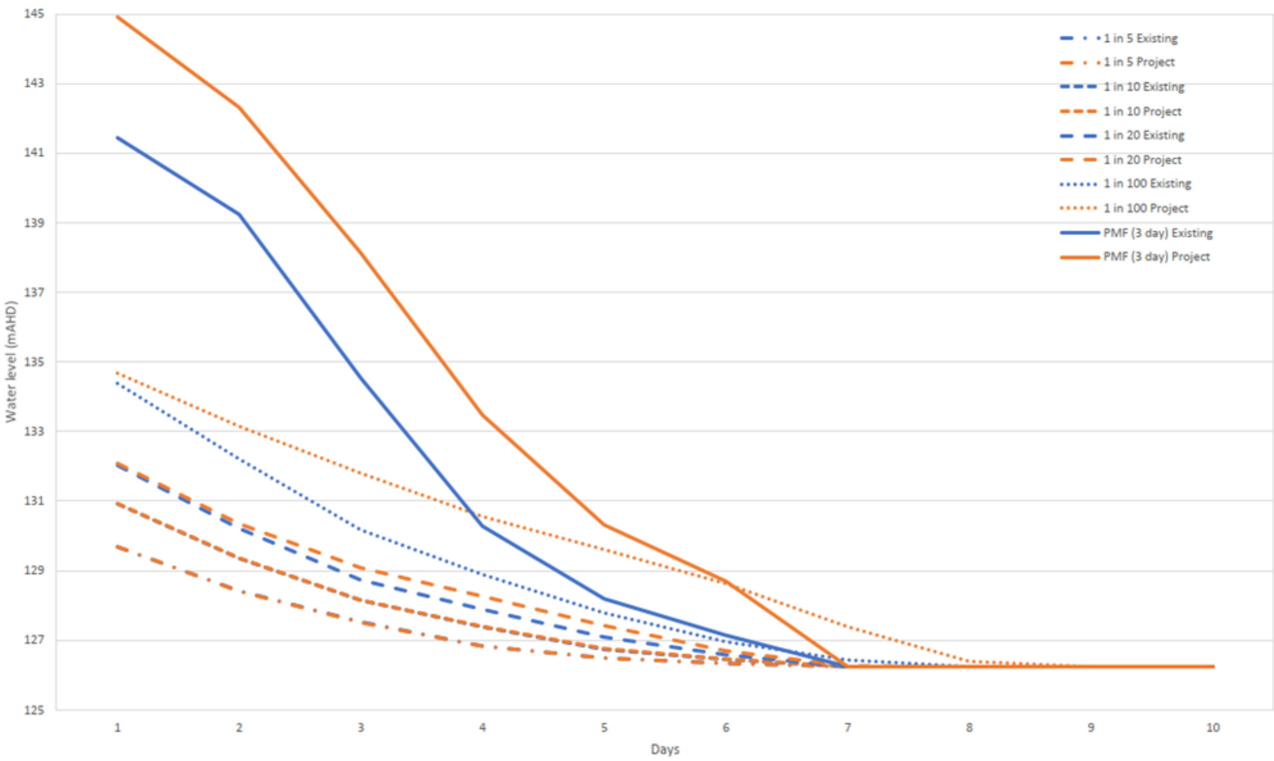


Figure 4-9 COXS_US_9985 depth-duration curves

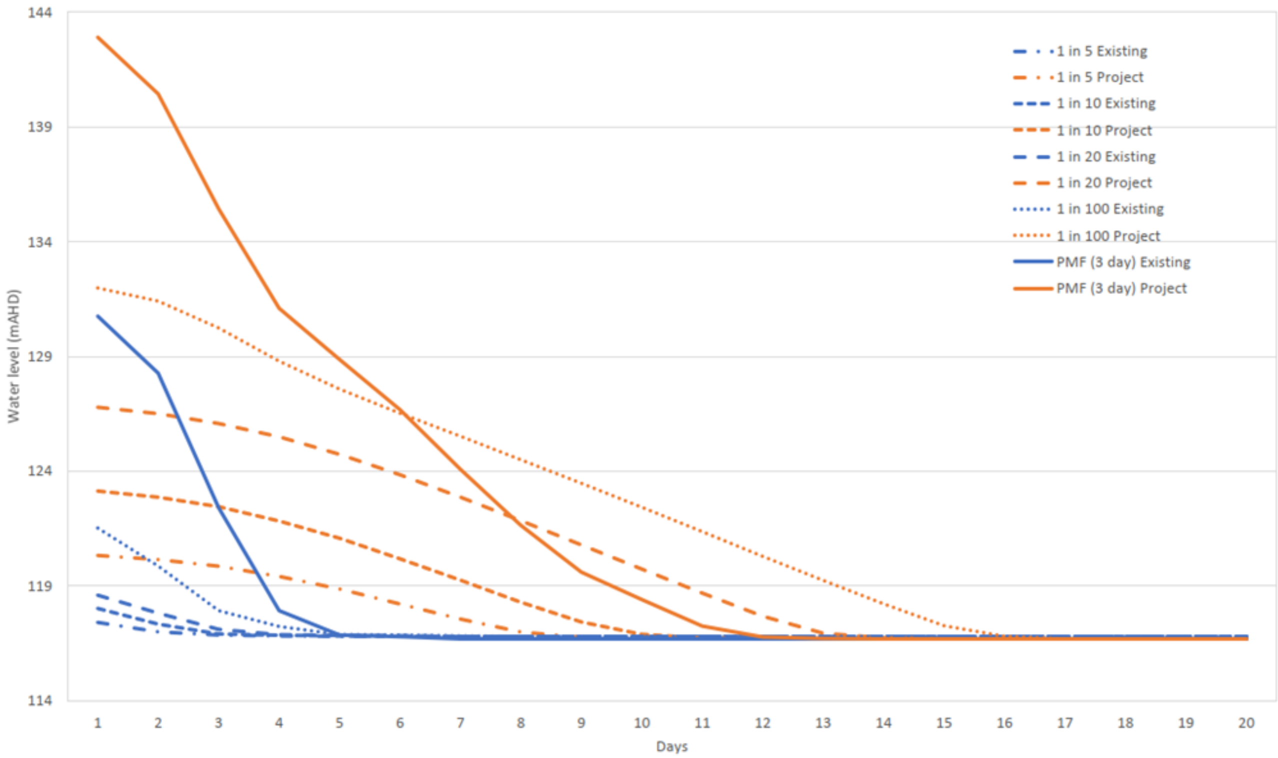


Figure 4-10 COXS_28880 depth-duration curves

Nattai River

Depth-duration curves were examined for four cross-sections on the Nattai River as follows:

- Location 9 (NATTAI_US_8700) represents the approximate location of the Project PMF event and the limit of Project influence on the Nattai River
- Location 10 (NATTAI_US_11066) is about 2.4 kilometres downstream of NATTAI_US_8700 and represents the approximate location of the Project for the 1% AEP event
- Location 11 (NATTAI_1880) is about 2.6 kilometres downstream of cross-section NATTAI_US_11066
- Location 12 (NATTAI_5680) is a further 3.8 kilometres downstream and is where the Nattai River broadens out into Lake Burragorang.

Predicted changes along the Nattai River are presented in Figure 4-11 to Figure 4-14 and summarised in Table 4-5. The table also includes the results for the dam wall to facilitate a comparison with the situation at the downstream-most location in the upstream study area. Analysis shows the following:

- Increases in the depth and duration of temporary inundation for cross-sections NATTAI_US_8700 and NATTAI_US_11066 are less than half a metre and half a day respectively for all events with the exception of the PMF event for NATTAI_US_11066, which would increase by about 7.8 metres

- Increases in the depth and duration of temporary inundation are more noticeable at cross-section NATTAI_1880, particularly for the 5% AEP and rarer events
- At NATTAI_5680, there is also a clear increase in depths and durations for temporary inundation for all SEARs events, these broadly mirroring the those at the dam wall for the respective 5% AEP and rarer flood events.

Table 4-5 Nattai River: Upstream changes in temporary inundation depth and duration

Event	Flood Event (E = existing, P = Project)									
	20% AEP		10% AEP		5% AEP		1% AEP		PMF	
	E	P	E	P	E	P	E	P	E	P
Location 9: NATTAI_US_8700										
Depth (m)	3.4	<0.5	3.7	<0.5	4.3	<0.5	4.3	<0.5	7.4	<0.5
Duration (days)	5.9	<0.5	5.4	<0.5	6.2	<0.5	6.2	<0.5	5.1	<0.5
Location 10: NATTAI_US_11066										
Depth (m)	3.8	<0.5	4.1	<0.5	4.8	<0.5	5.9	<0.5	7.7	7.8
Duration (days)	5.9	<0.5	5.4	<0.5	6.2	<0.5	5.2	<0.5	5.1	<0.5
Location 11: NATTAI_1880										
Depth (m)	2.8	0.5	3.1	3.2	4.0	7.4	5.9	10.0	14.2	12.0
Duration (days)	6.8	2.4	6.4	3.8	6.7	8.0	6.4	8.3	5.3	6.4
Location 12: NATTAI_5680										
Depth (m)	0.8	2.4	1.3	5.0	2.4	9.0	5.2	10.6	14.1	12.1
Duration (days)	6.8	2.4	6.4	3.8	7.2	8.0	6.4	8.3	5.3	6.4
Location 1: Dam wall (comparison)										
Depth (m)	0.7	2.9	1.3	5.1	1.9	8.2	4.8	10.5	14.5	12.7
Duration (days)	2.8	4.6	3.4	6.0	4.0	8.6	4.0	10.8	4.2	7.0

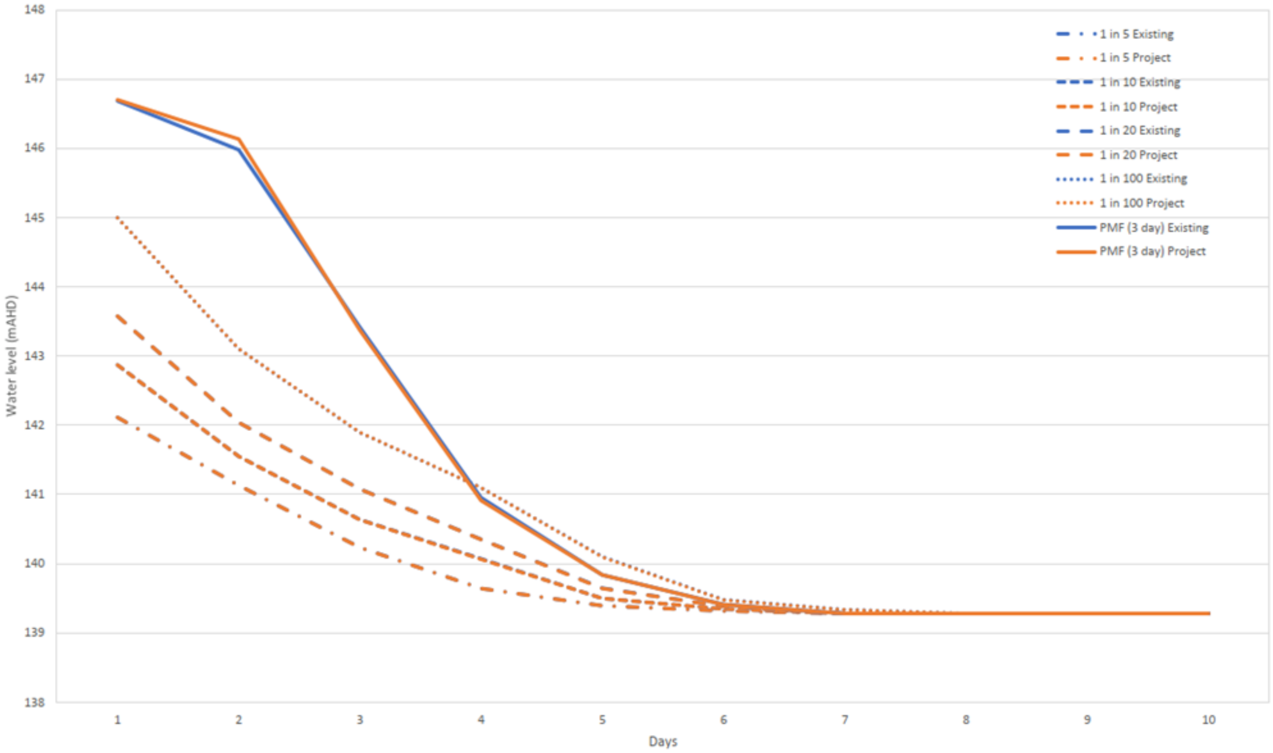


Figure 4-11 NATTAI_US_8700 depth-duration curves

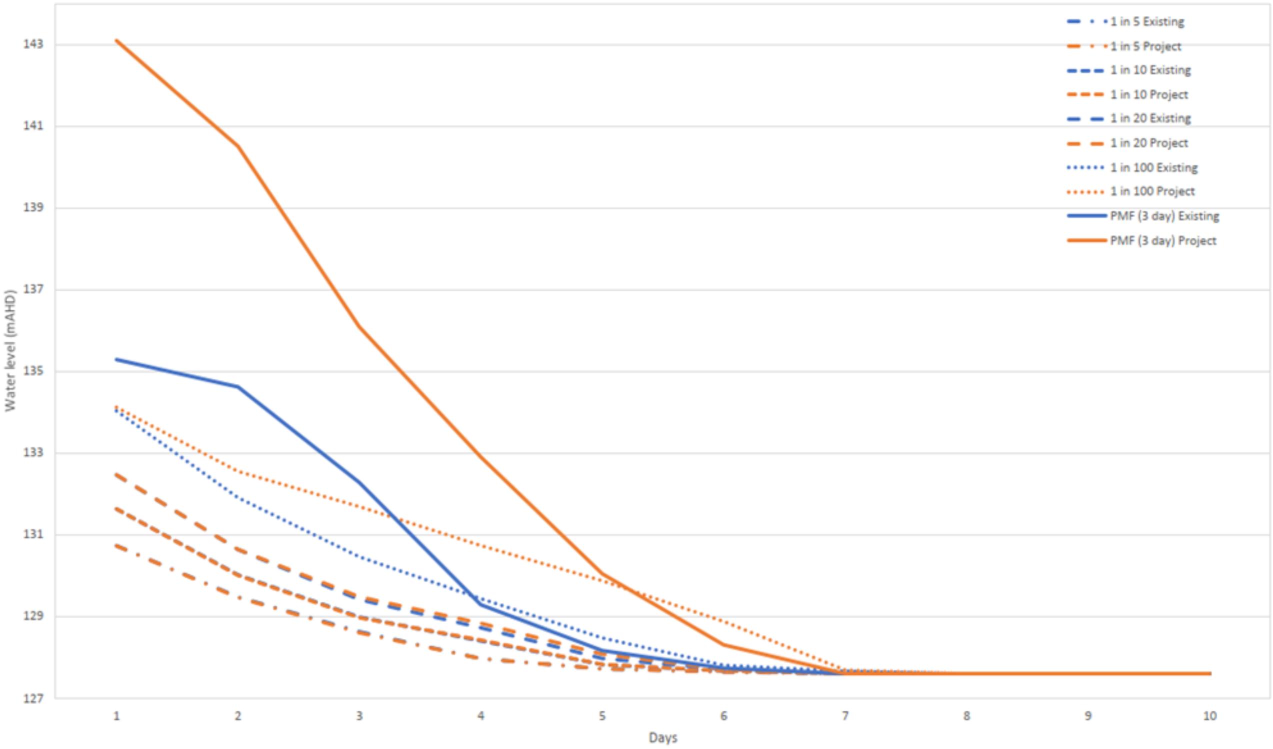


Figure 4-12 NATTAI_US_11066 depth-duration curves

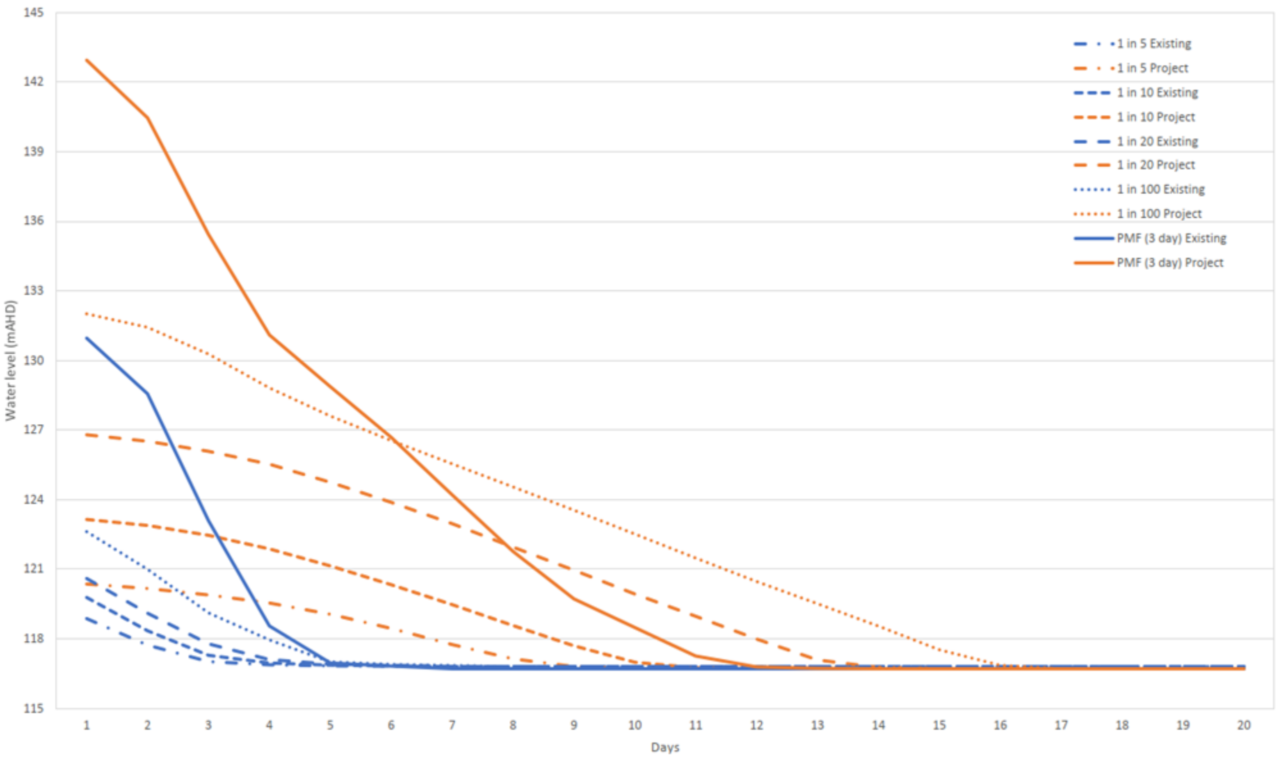


Figure 4-13 NATTAI_1880 depth-duration curves

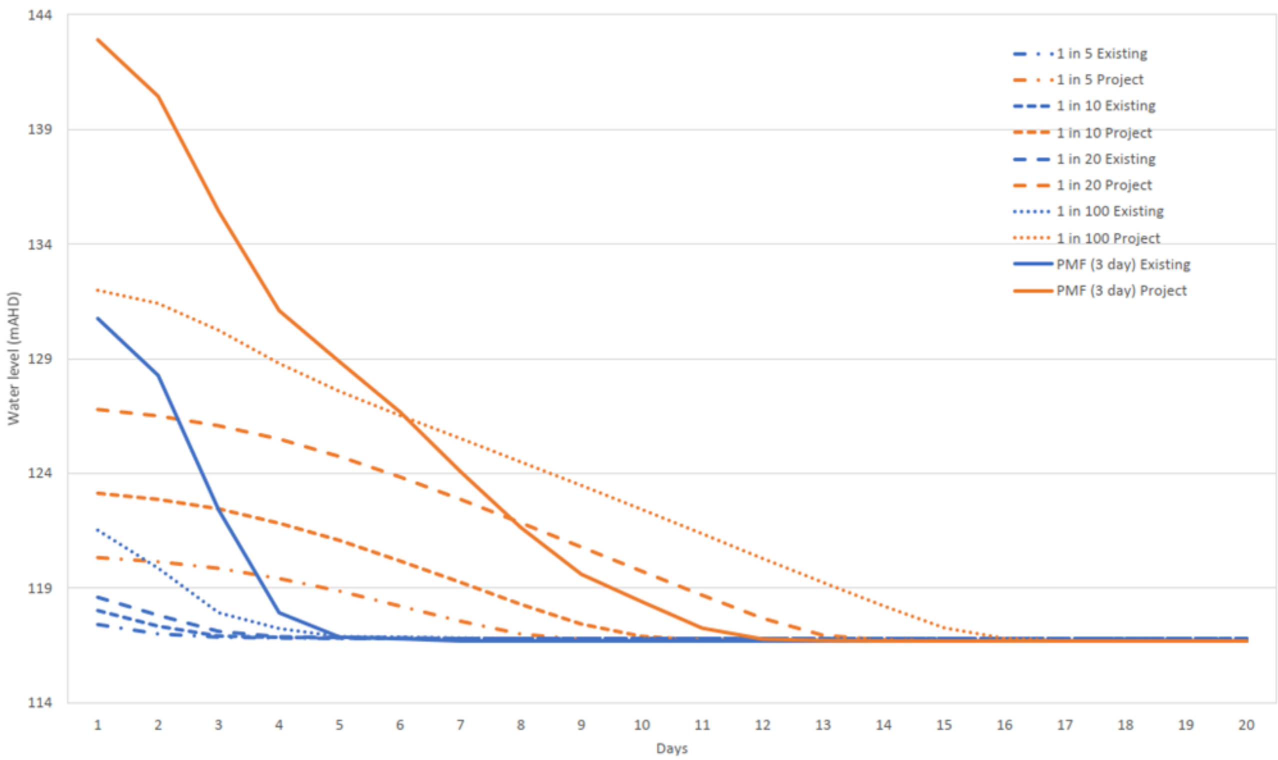


Figure 4-14 NATTAI_5680 depth-duration curves

Kowmung River

The Kowmung River joins the Coxs River above Location 13 (COX_1475). Depth-duration curves were examined for two cross-sections on the Kowmung River as follows:

- Location 15 (KOWMUNG_10130) represents the approximate location of the Project PMF event, and the limit of Project influence on the Kowmung River
- Location 14 (KOWMUNG_13130) is about three kilometres further downstream and represents the approximate location of the Project for the 1% AEP event.

Predicted changes along the Wollondilly River are presented in Figure 4-15 and Figure 4-16 and summarised in Table 4-6. The table also includes the results for the dam wall to facilitate a comparison with the situation at the downstream-most location in the upstream study area. Analysis shows the following:

- increases in the depth and duration of temporary inundation for cross-section Location 15 (KOWMUNG_10130) are less than half a metre and half a day respectively for all events
- increases in the depth of temporary inundation for Location 14 (KOWMUNG_13130) are less than half a metre up to the 1% AEP event, and about 4.3 metres for the PMF event
- increases in the duration of temporary inundation for Location 14 (KOWMUNG_13130) are less than half a day up to the 5% AEP event, increasing slightly – up to two days – for the rarer events.

Table 4-6 Kowmung River: Upstream changes in temporary inundation depth and duration

Event	Flood Event (E = existing, P = Project)									
	20% AEP		10% AEP		5% AEP		1% AEP		PMF	
	E	P	E	P	E	P	E	P	E	P
Location 15: KOWMUNG_10130										
Depth (m)	3.8	<0.5	4.9	<0.5	6.8	<0.5	7.4	<0.5	12.4	<0.5
Duration (days)	5.9	<0.5	5.4	<0.5	6.1	<0.5	5.1	<0.5	5.2	<0.5
Location 14: KOWMUNG_13130										
Depth (m)	4.1	<0.5	5.6	<0.5	7.0	<0.5	9.4	<0.5	15.1	4.3
Duration (days)	5.9	<0.5	5.4	<0.5	6.1	<0.5	5.3	2.0	5.2	1.0
Location 8: COXS_28800										
Depth (m)	0.7	2.5	1.3	5.1	2.2	9.1	5.1	10.8	14.0	12.2
Duration (days)	6.8	2.4	6.4	3.8	7.2	8.0	6.4	8.3	5.3	6.4
Location 1: Dam wall (comparison)										
Depth (m)	0.7	2.9	1.3	5.1	1.9	8.2	4.8	10.5	14.5	12.7
Duration (days)	2.8	4.6	3.4	6.0	4.0	8.6	4.0	10.8	4.2	7.0

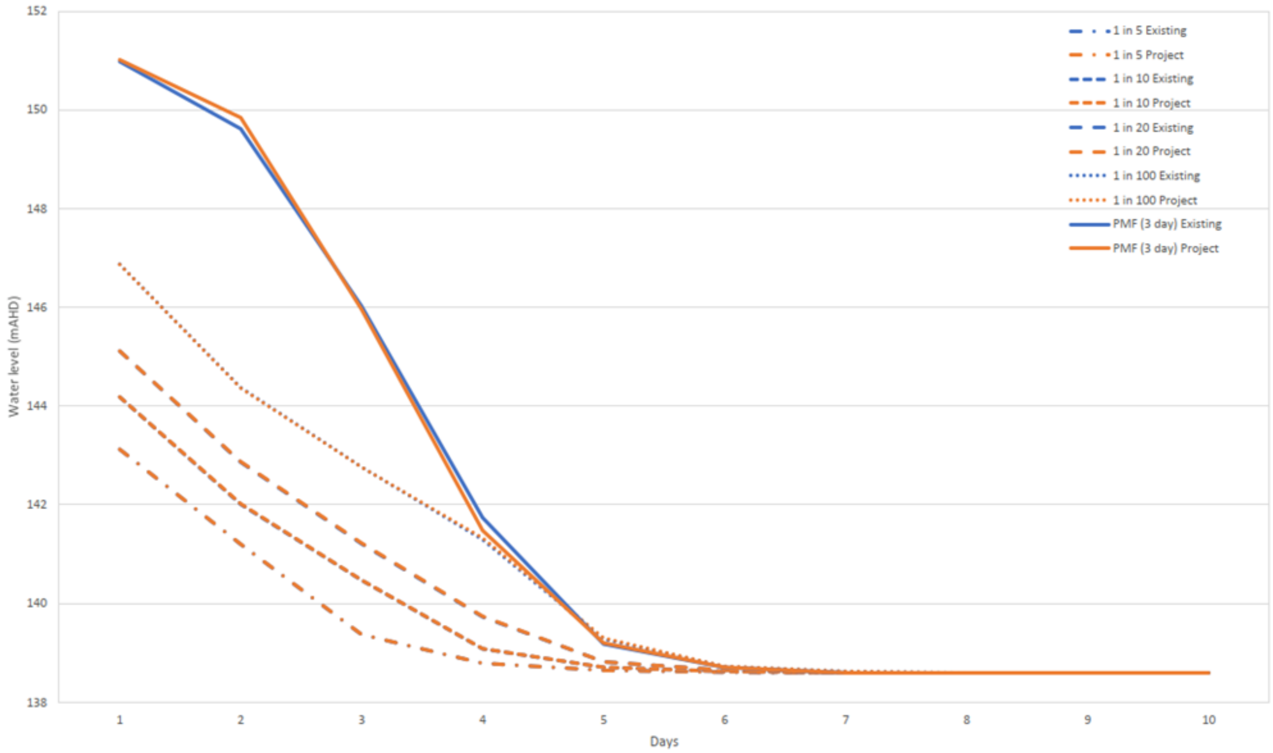


Figure 4-15 KOWMUNG_10130 depth-duration curves

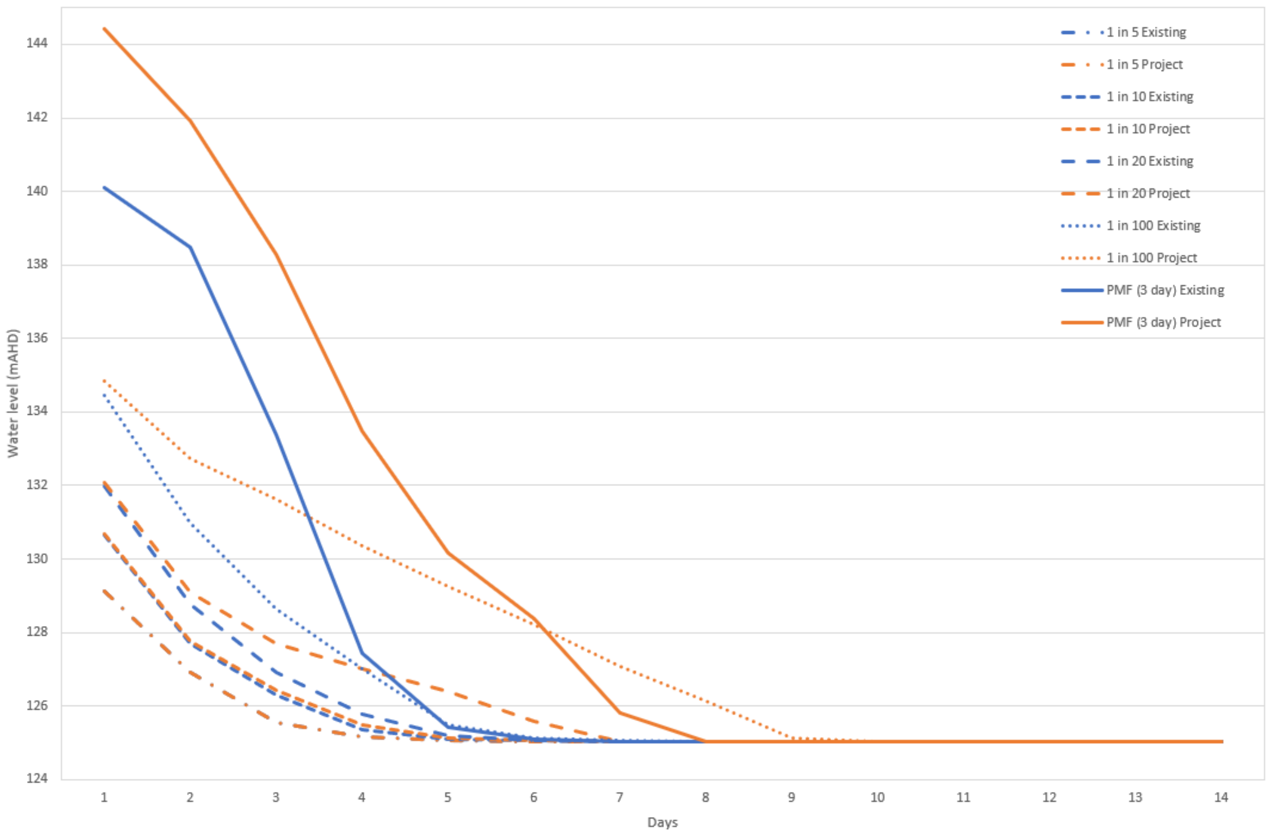


Figure 4-16 KOWMUNG_13130 depth-duration curves

4.2.2.3 Changes to flood frequencies

A frequency analysis of the peak flood levels in Lake Burragorang at the dam wall under both the existing case and with Project scenarios is presented in Figure 4-17 and shows the increase in peak flood levels for all events considered.

The frequency analysis shows a change in the shape of the frequency curve, with a change in grade occurring between the 5% AEP event to the 1% AEP event. This illustrates that the relative impact during these smaller order design events is higher than that of the rarer events (that is, rarer than the 1% AEP event).

The frequency analysis also shows a leftward shift in the frequency of flood events, with an increase in the frequency of all events of a specified magnitude. For example, a 2% AEP event under existing conditions would be equivalent to about a 20% AEP event with the Project (that is, a water level that currently occurs on average about once every 50 years would occur on average once every five-years with the Project).

However, the pattern of the leftward shift with the Project flood frequency curve is not uniform across the upstream catchment and is substantially less further up the catchment. The frequency analysis shows that for the Wollondilly River and Nattai River there is effectively no material change in flood frequencies. For the Kowmung River, the flood frequency curves start to diverge at about the 1 in 50 chance in a year event. The current 1 in 100 chance in a year event would occur on average about once every 85 years with the Project. For the Coxs River, the curves start to diverge between the 1 in 10 chance in a year and the 1 in 20 chance in a year events. The current 1 in 100 chance in a year event would occur on average about once every 70 years with the Project.

The convergence of the flood frequency curves (reducing leftward shift) with distance up the catchment is better illustrated at Location 12 (NATTAI_5680), Location 11 (NATTAI_1880) and Location 10 (NATTAI_11066). The pattern of the flood frequency curves at Location 12 (NATTAI_5680) is similar to the curves for the dam wall with the flood frequency curves progressively converging moving up the Nattai River.

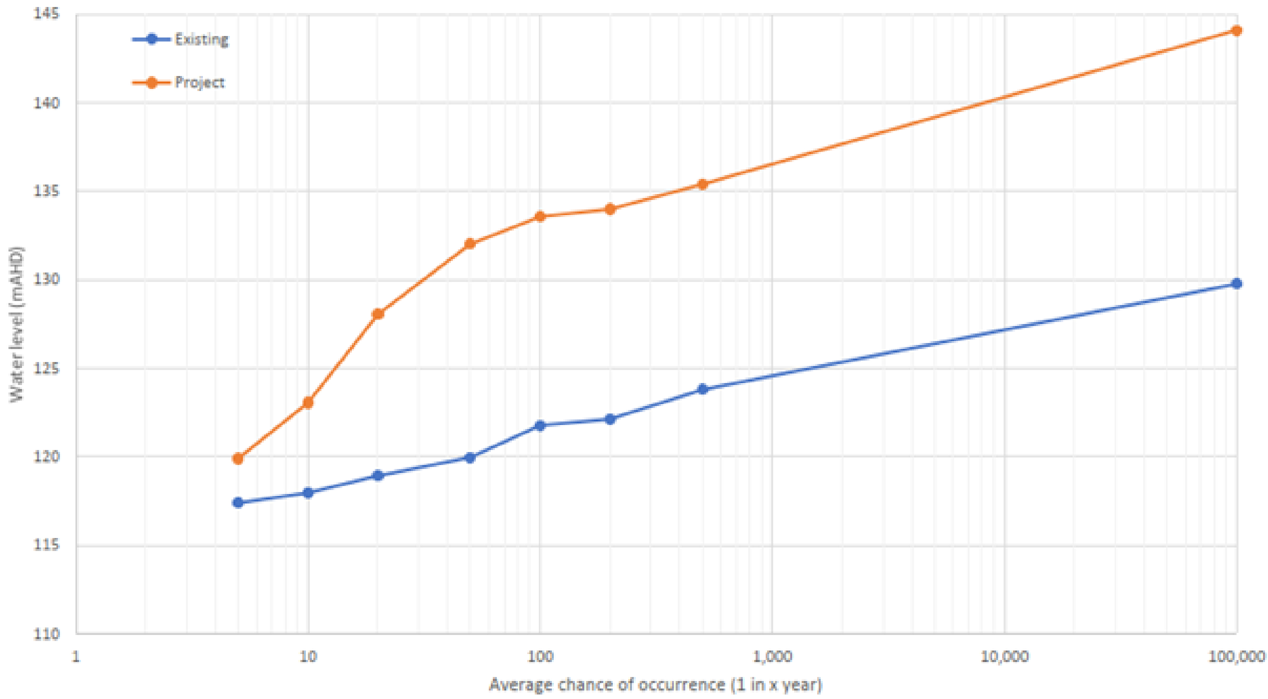


Figure 4-17 Dam wall frequency distribution

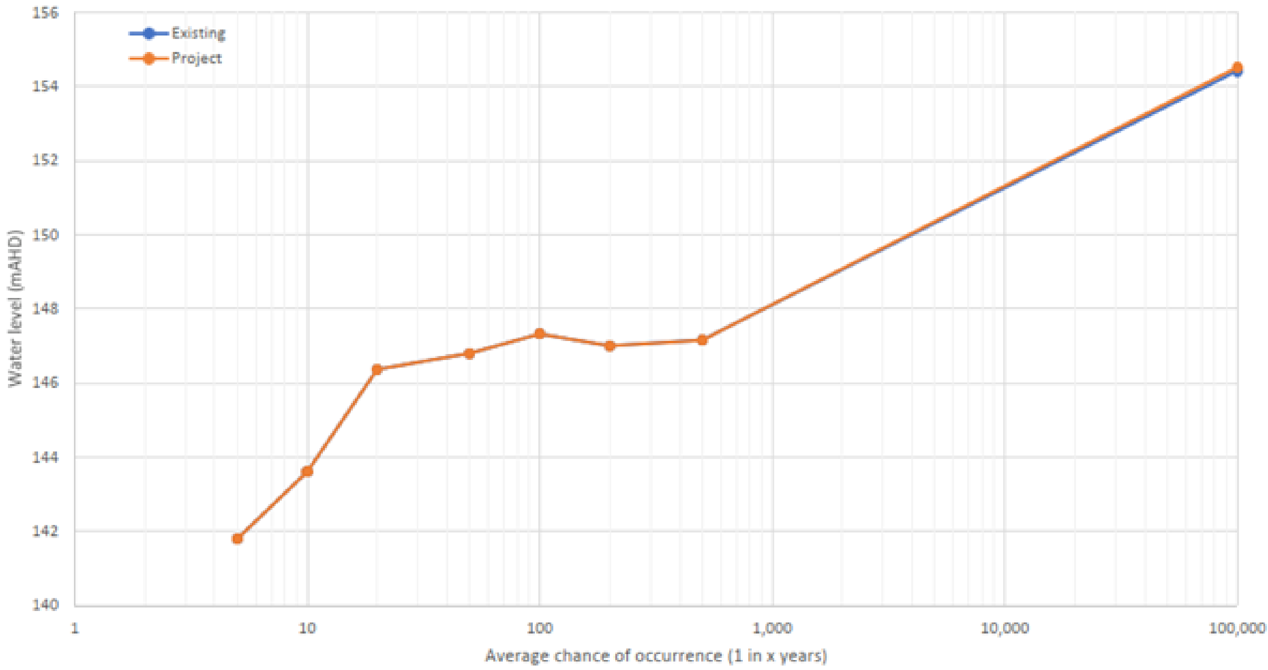


Figure 4-18 WOLLONDILLY_US_6720 frequency distribution

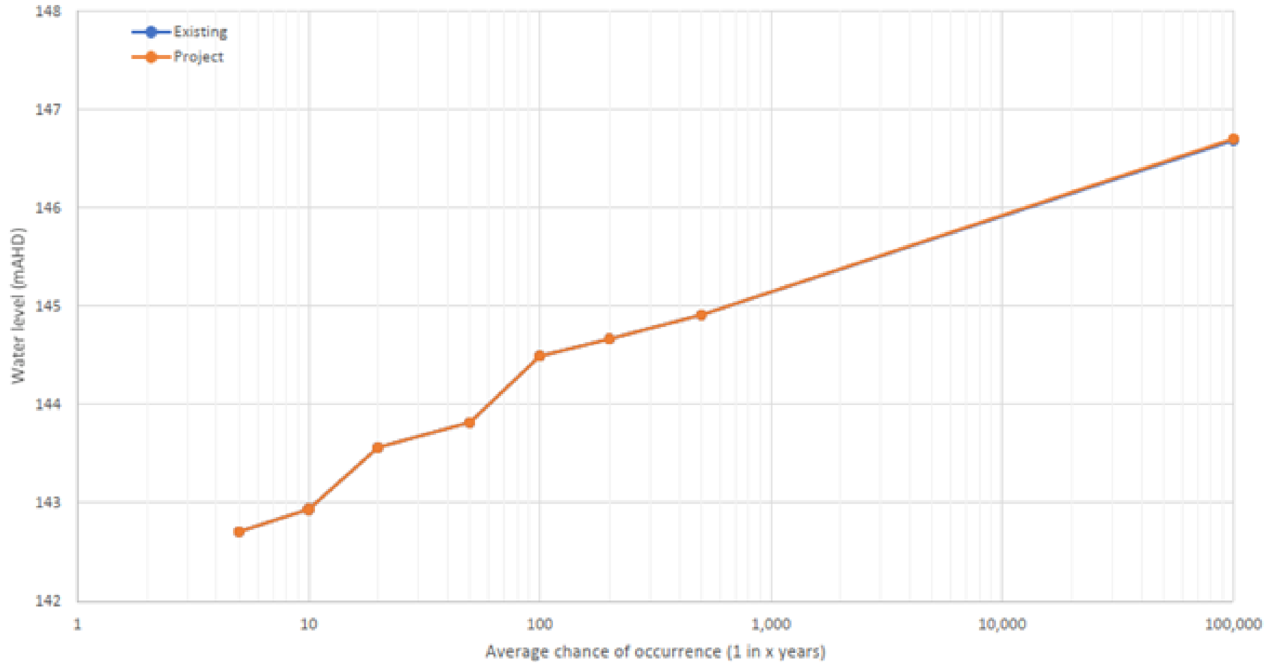


Figure 4-19 NATTAI_US_8700 frequency distribution

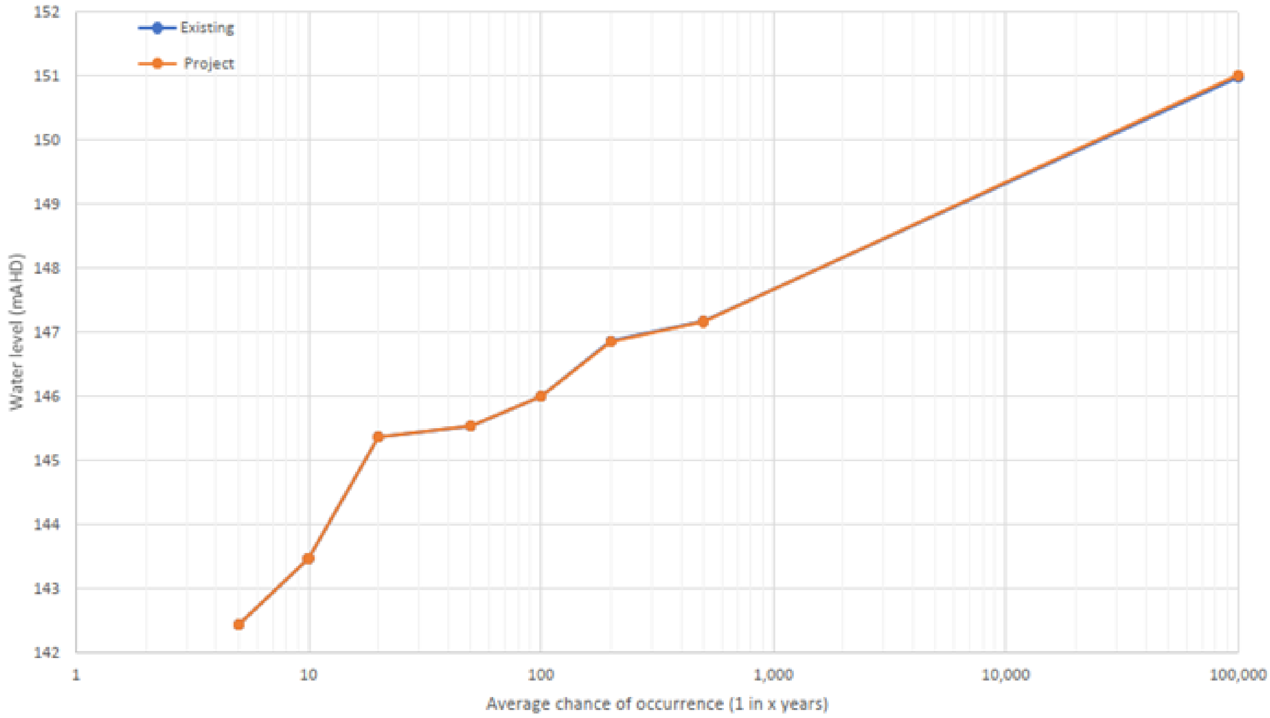


Figure 4-20 KOWMUNG_10130 frequency distribution

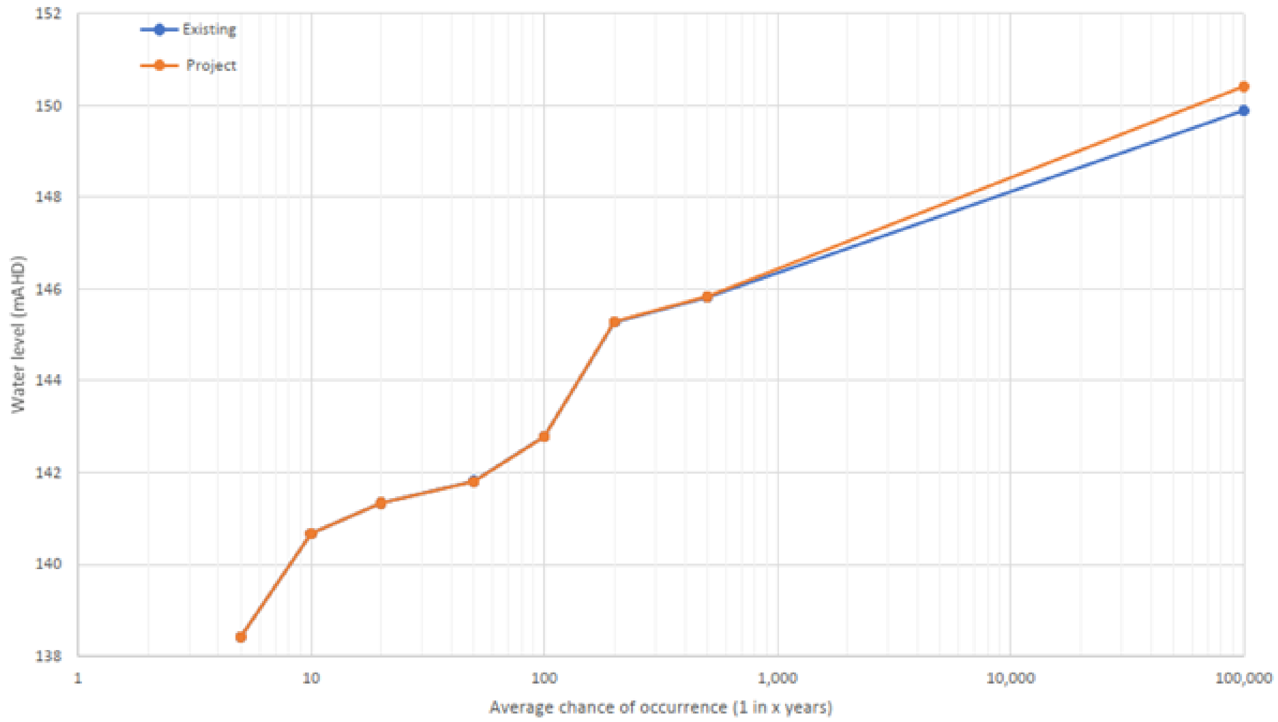


Figure 4-21 COXS_US_7335 frequency distribution

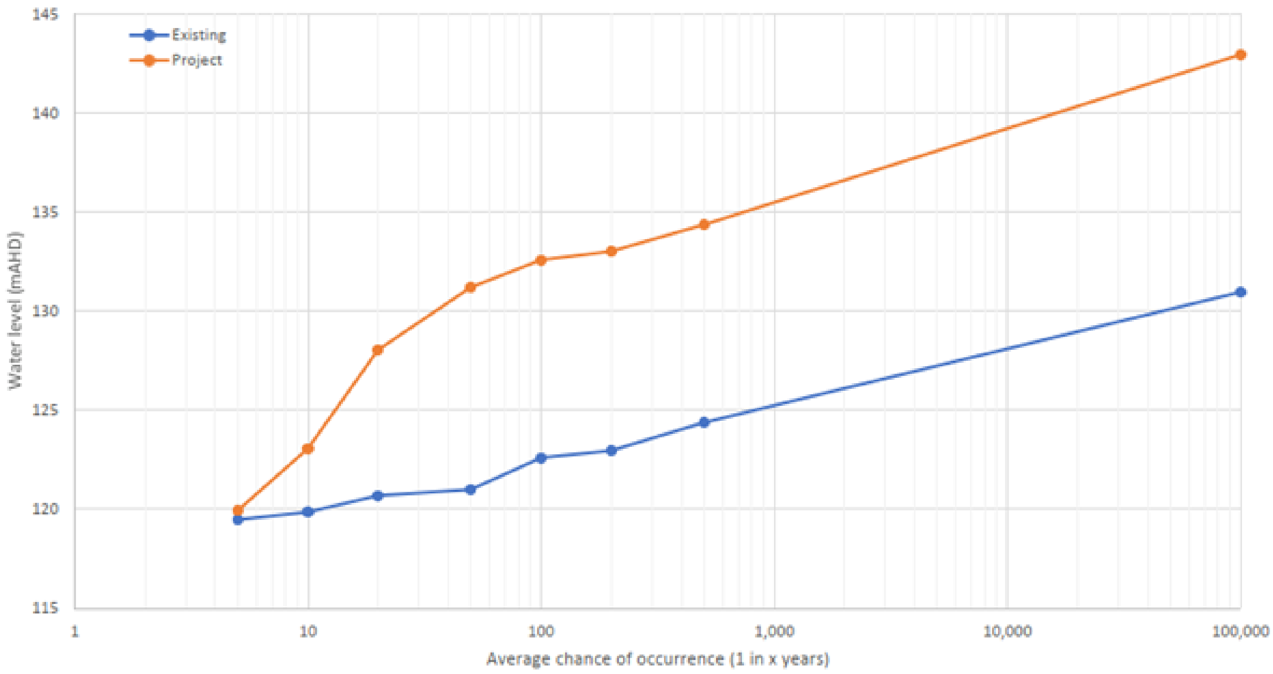


Figure 4-22 NATTAI_1880 frequency distribution

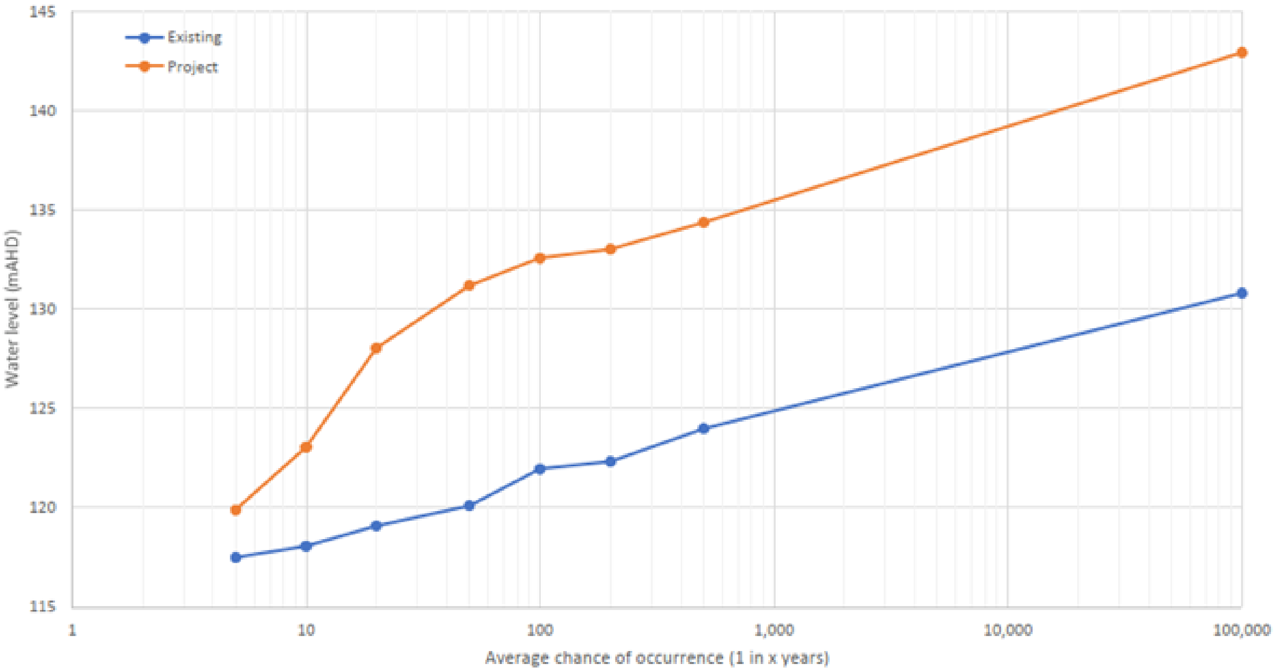


Figure 4-23 NATTAI_5680 frequency distribution

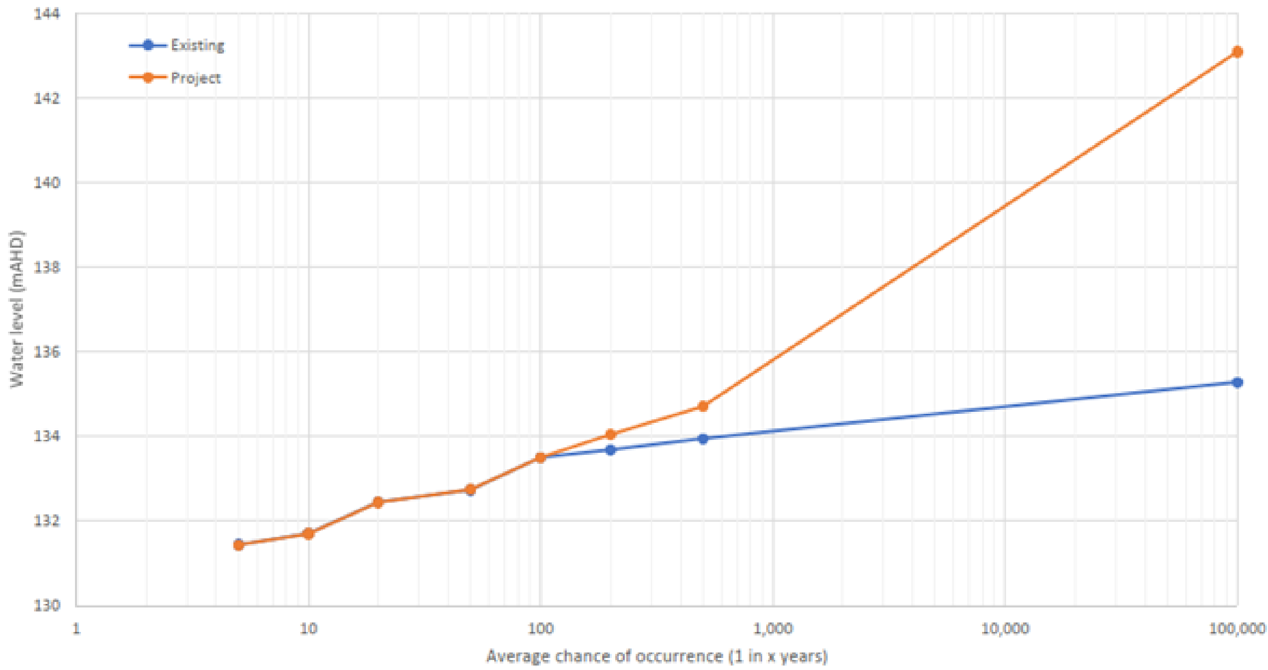


Figure 4-24 NATTAI_11066 frequency distribution

4.2.2.4 Flood velocity

The existing and future Lake Burragorang extents act as a relatively low convective flood storage area. The velocities associated with incoming flood flows from tributary watercourses are dissipated as they enter the lake environment. Velocities through Lake Burragorang will be governed by the discharges through the Warragamba Dam, related to the varying operation phases.

The impacts of the Project on flood velocities in the upstream environment will effectively be limited to the areas identified as being subject to increased inundation extent. Flood velocities within the extended upstream lake surface will be reduced as they interface with the lake water body.

Velocity profiles for the tributaries of Lake Burragorang demonstrate an overall decrease in velocity due to the Project.

4.2.2.5 Flood hazard and flood function

The flood hazard of Lake Burragorang is dominated by high hazard associated with the large depths of water. The flood hazard reduces around the lake foreshore as the topography rises and the water depths decrease. The overall nature of flood hazard in the upstream environment will not change due to the Project. However, the spatial distribution of higher hazards will be increased around the Lake Burragorang foreshore in direct correlation to the increased flood depths. The upstream environment within the impacted area around Lake Burragorang is predominantly forested and is part of the restricted access Special Areas surrounding the lake. However, there are fire trails, bush walking tracks and other similar infrastructure in the Special Areas that may be impacted by the Project. While the use of these is restricted and the actual number of people using this infrastructure is small, there is the potential for increased flood hazards on these uses. There are also a small number of private properties in the Lake Burragorang catchment which are potentially impacted by the Project. This is assessed in the EIS – Chapter 21 – Socio-economic, Property and Land Use.

The flood function of Lake Burragorang is predominantly one of flood storage, becoming a floodway when flood flows are being discharged through Warragamba Dam. Due to the steep topography surrounding the lake foreshore, areas of flood fringe are minimal. The overall nature of flood function in the upstream environment will not change due to the Project. However, the spatial distribution of flood storage will be increased around the Lake Burragorang foreshore in direct correlation to the increased flood depths. The upstream environment within the impacted area around Lake Burragorang is predominantly forested and as such, the areas of increased flood storage are expected to be compatible with the current land use.

4.2.3 Downstream environment

4.2.3.1 Flood flows, levels, and extent

The principal benefits from the Project are associated with the mitigation of flood impacts within the downstream Hawkesbury-Nepean Valley. The FMZ would delay and attenuate the progression of floodwaters coming from the upstream environment. This in turn reduces the severity of regional flood events impacting the highly populated downstream environment.

The Project will significantly reduce flood risk in the downstream environment, but not eliminate it completely. It is not reasonable to build a dam high enough to capture such extreme, rare floods from the upstream environment (that is, Warragamba catchment). Also, flooding from other catchments such as the Nepean, Grose, Colo and South Creek can contribute to downstream flooding, albeit generally smaller volumes compared to the Warragamba catchment.

Nonetheless, the Project will provide mitigation benefits by delaying and reducing the flood peak for all flood events, protecting lives and reducing damages.

The benefits discussed above are all linked to the outflow from Warragamba Dam. A frequency analysis of outflows from Warragamba Dam under both existing scenario and Project scenario is shown in Figure 4-25, with peak flows presented in Table 4-7. The timeseries of dam outflows, selected from the Monte Carlo modelling to be representative of a 5% and a 1% AEP event under both existing scenario and Project scenario are shown in Figure 4-26.

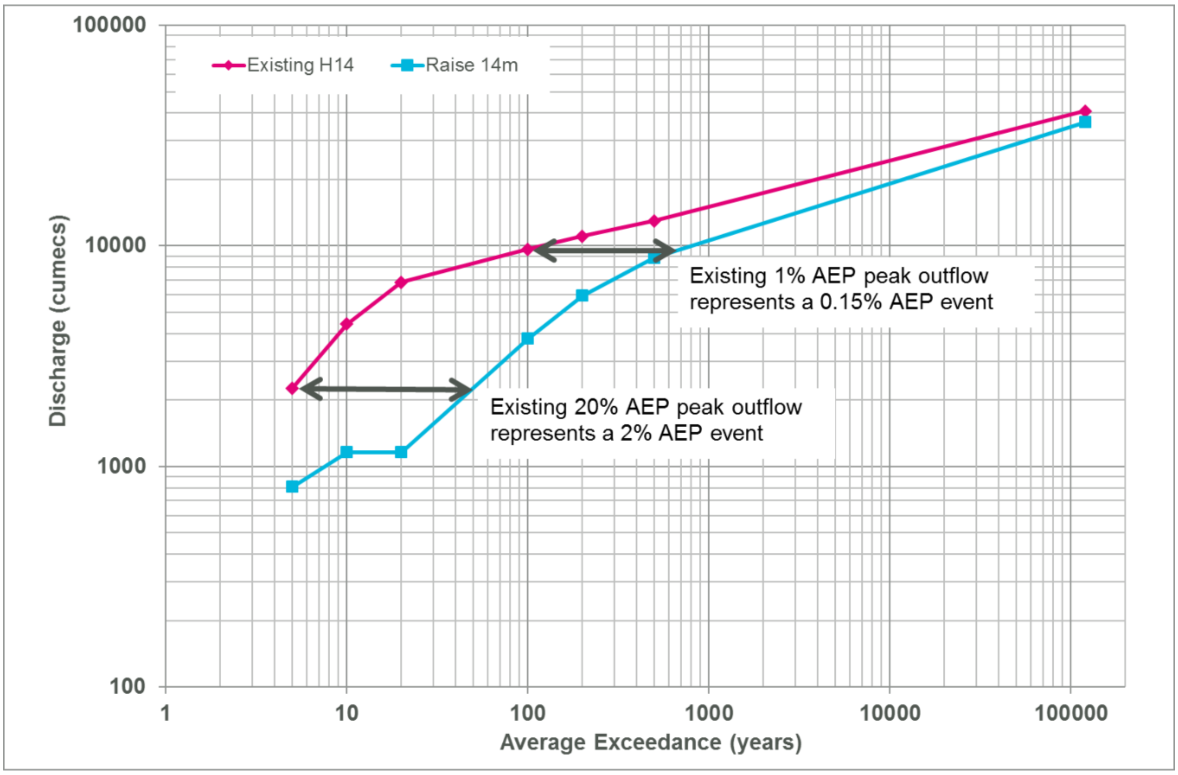


Figure 4-25 Frequency distribution of dam outflows for existing and project scenarios

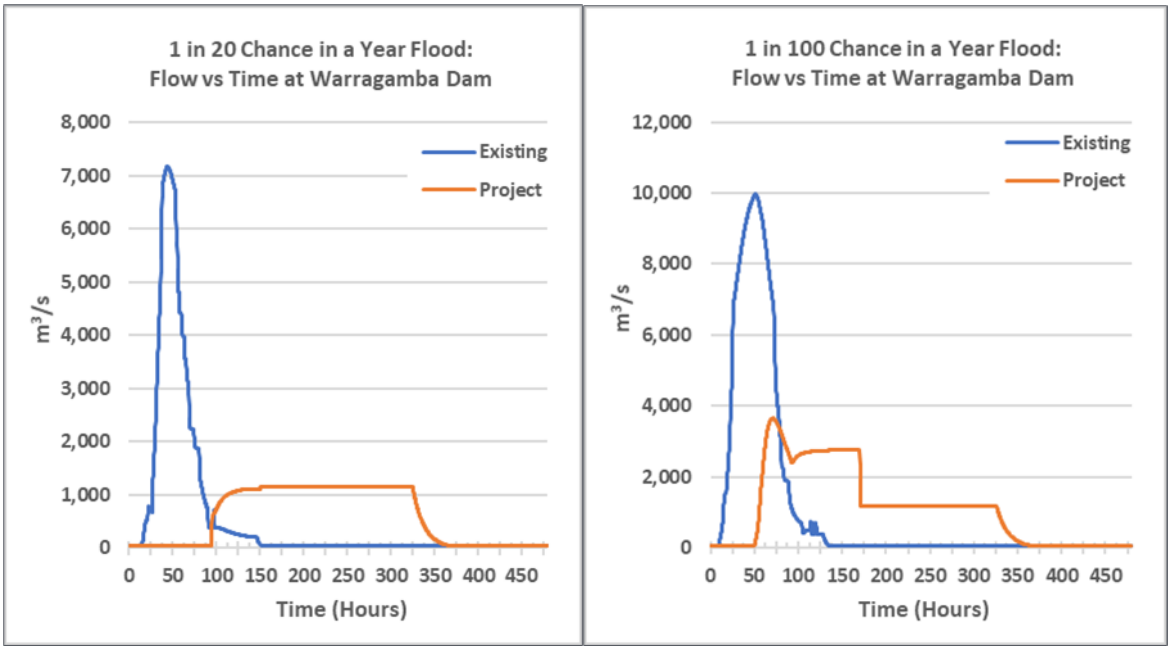


Figure 4-26 Discharge hydrographs from Warragamba Dam for 5% AEP and 1% AEP floods

Table 4-7 Peak dam outflows for existing and project scenarios

Event	Existing Scenario (m^3/s)	Project Scenario (m^3/s)	Peak Outflow Change at Dam Wall (m^3/s)
20% AEP	2,271	810	-1,461
10% AEP	4,430	1,160*	-3,270
5% AEP	6,860	1,160*	-5,700
1% AEP	9,660	3,800	-5,860
0.5% AEP	11,061	5,943	-5,118
0.2% AEP	13,019	8,862	-4,157
PMF	40,950	36,390	-4,560

*Discharge rate of FMZ (100 Gigalitres per day)

Overall, the results show a reduction in peak outflow rates from the existing scenario to Project scenario for all events considered. This is to be expected as the primary aim of the Project is to capture and store flood waters in the upstream environment to delay the release of floodwaters to the downstream environment.

Directly linked to the reduction in peak outflow from Warragamba Dam is the reduction in peak flood levels and extents in the downstream environment. Simulated peak flood levels at the selected locations corresponding to modelled cross sections are shown in Table 4-8. The change in inundation extent for the 20% AEP, 1% AEP and PMF are shown in Figure 4-27, Figure 4-28 and Figure 4-29 respectively.

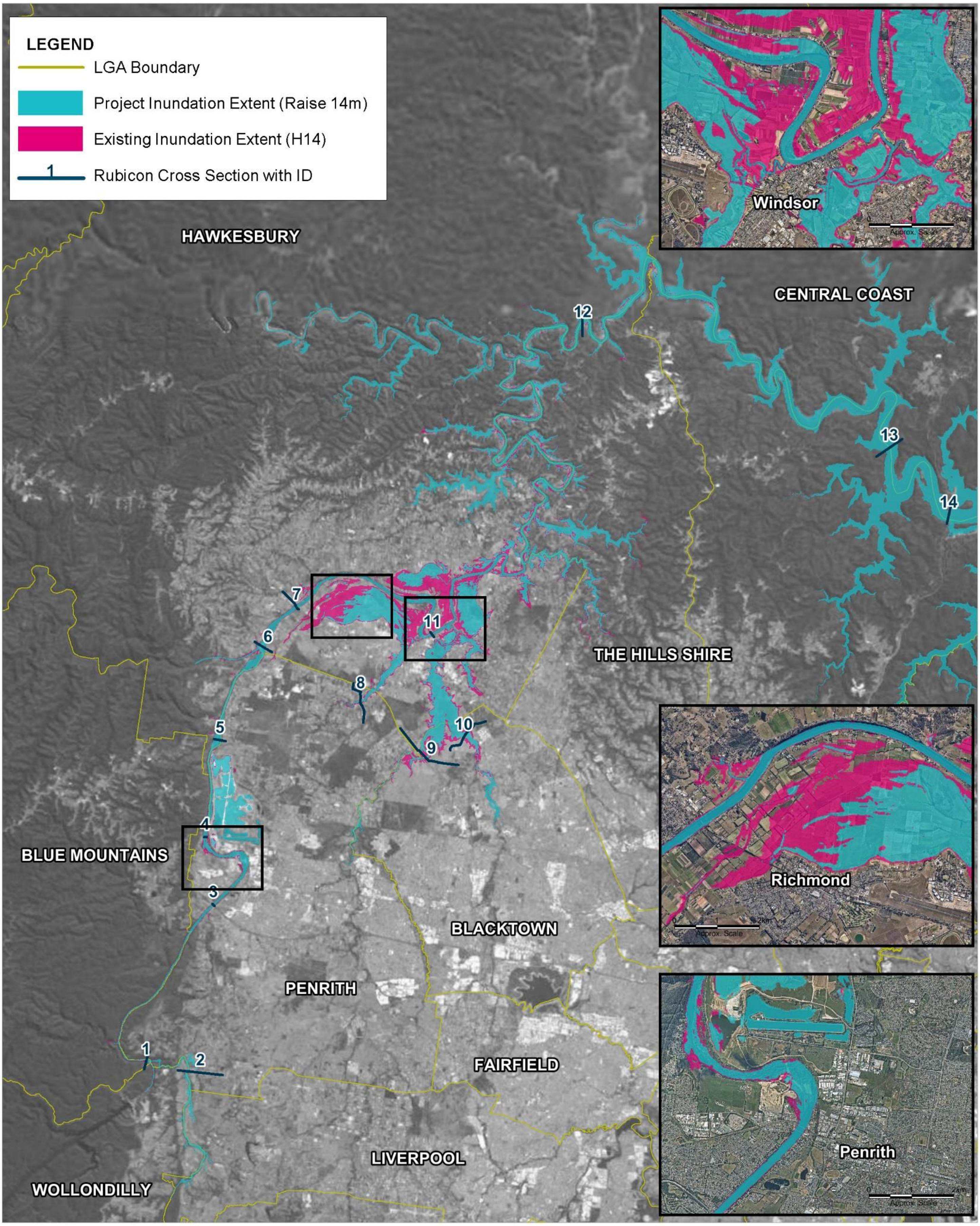
Table 4-8 Change in peak flood levels – Project scenario minus existing scenario

ID	Cross Section Name	5yr (20% AEP)	10yr (10% AEP)	20yr (5% AEP)	100yr (1% AEP)	200yr (0.5% AEP)	500yr (0.2% AEP)	PMF
1	JUNCTION3	-6.6	-9.2	-11.4	-9.1	-7.3	-5.4	-2.9
2	BLAXCROSS	-0.2	-0.1	-0.5	-2.6	-3.2	-3.4	-2.8
3	F4BRIDGE	-2.7	-3.9	-5.3	-4.7	-3.5	-1.8	-1.3
4	BONNIEVALE	-3.9	-5.3	-6.7	-5.2	-3.6	-2.2	-1.5
5	MILLDAM1	-3.5	-4.6	-5.7	-4.3	-3.2	-2.7	-1.6
6	YMUNDI1	-3.1	-4	-4.7	-3.2	-2.5	-2.6	-1.6
7	NORTHRICH1	-2.9	-3.7	-4.2	-3.1	-2.9	-2.8	-1.7
8	LDERRY	-0.8	-2.3	-3.2	-4.1	-3.6	-2.8	-1.6
9	RICHWALK	-2.1	-2.9	-3.5	-4.1	-3.6	-2.9	-1.7
10	POWERLINE	-2.2	-2.9	-3.5	-4.1	-3.6	-2.9	-1.7
11	WINDSORBR	-2.5	-3	-3.5	-4.1	-3.6	-2.8	-1
12	HALFMOON	-0.6	-1	-1.3	-1.2	-1.2	-1.3	-1.6
13	PUMPKINPT	0	0	0	-0.2	-0.3	-0.4	-1
14	PEAT1	0	0	0	0	0	0	-0.1

Overall, the results show a decrease in all peak flood levels and inundation extents from the existing scenario to Project scenario. The flood extents shown in Figure 4-27 and Figure 4-28 demonstrate the substantial area of land which is protected from inundation due to the Project for the 5% AEP and 1% AEP events, respectively. The relative reduction in peak flood extents is not as apparent for the PMF event as shown in Figure 4-29.

The principal benefits from the Project are reduction in peak flood levels and associated flood extents in the downstream Hawkesbury-Nepean Valley. However, the discharge of the FMZ following a major flood event will result in some sections of the floodplain being subjected to periods of prolonged inundation.

The dam outflow hydrographs under both the existing scenario and Project scenario are presented in Figure 4-26 for the 5% and 1% AEP events. Following the immediate release of floodwaters off the back of the main flood peak dam releases are maintained at a steady state of 1,157 m^3/s for up to 10 days. The flood extent corresponding to this steady release rate is presented in Figure 4-30.



Title:

Change in Peak Flood Extent
20% AEP

Figure: 4-27

Rev: A

BMT endeavours to ensure that the information provided in this map is correct at the time of publication. BMT does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.

N

0 7.5 15km

Approx. Scale

BMT

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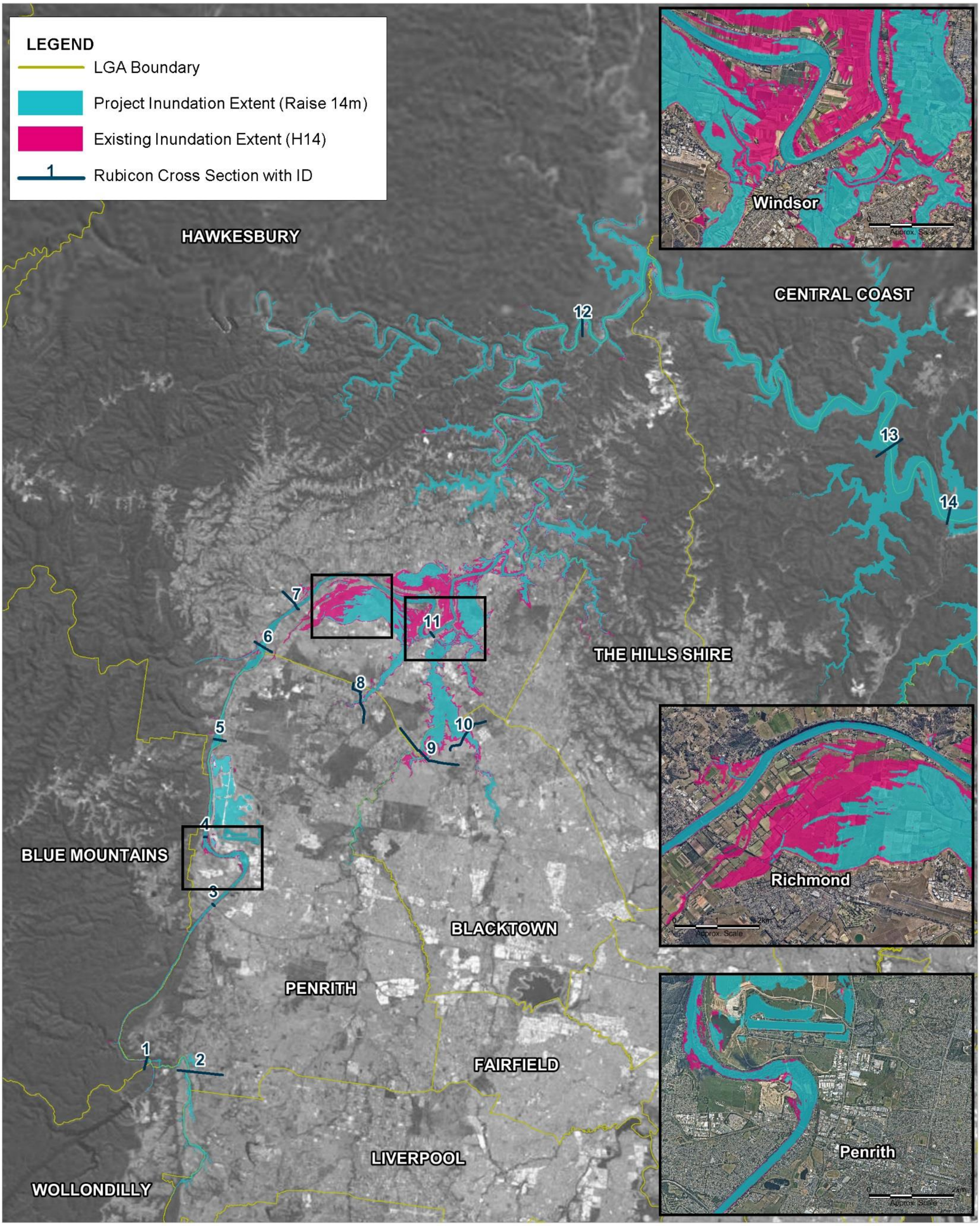

Title:

Change in Peak Flood Extent 20% AEP

Figure: 4-28

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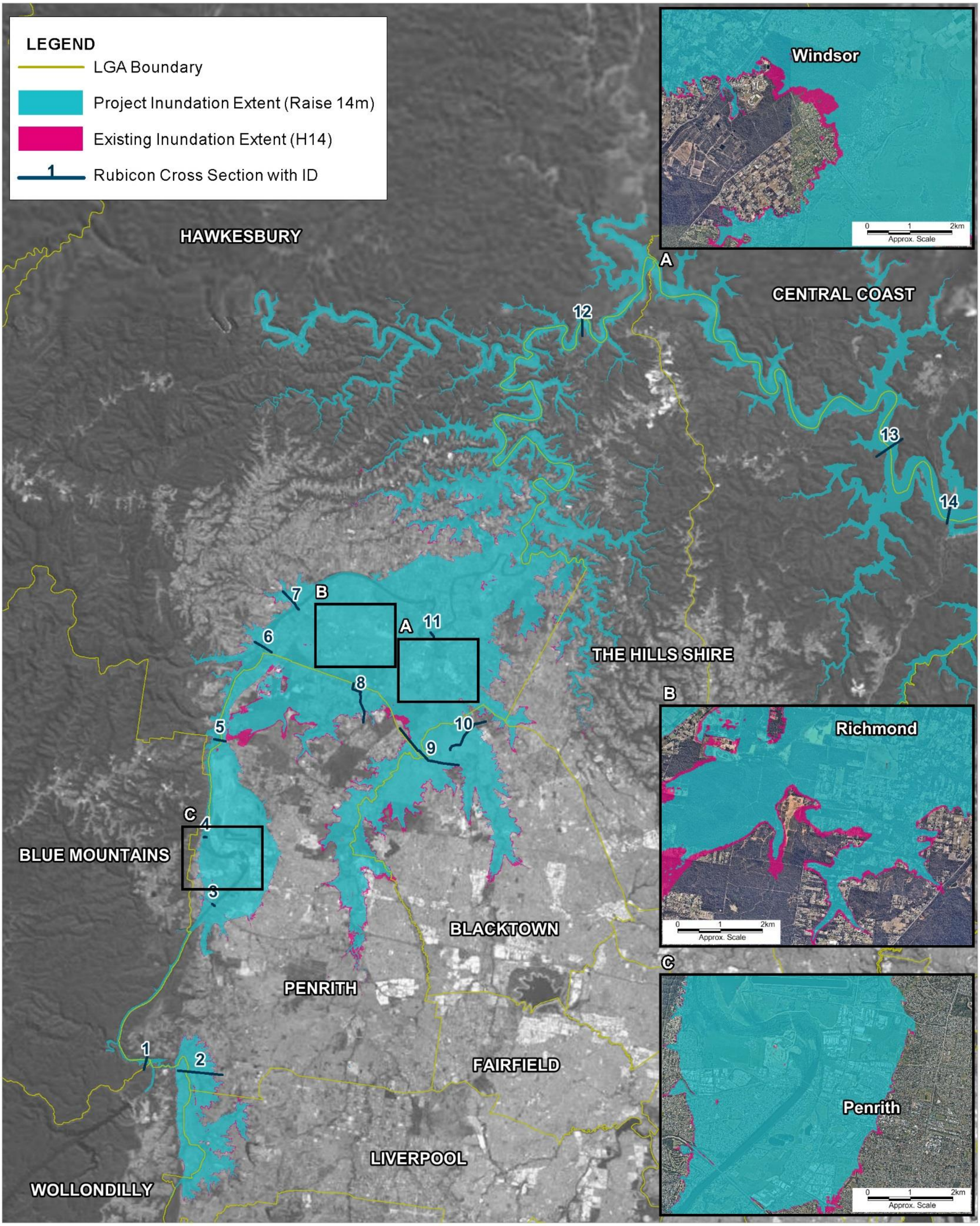

Title:

Receiving Environment Peak Flood Extents
Existing and Project Scenarios - Extreme Flood

Figure: 4-29

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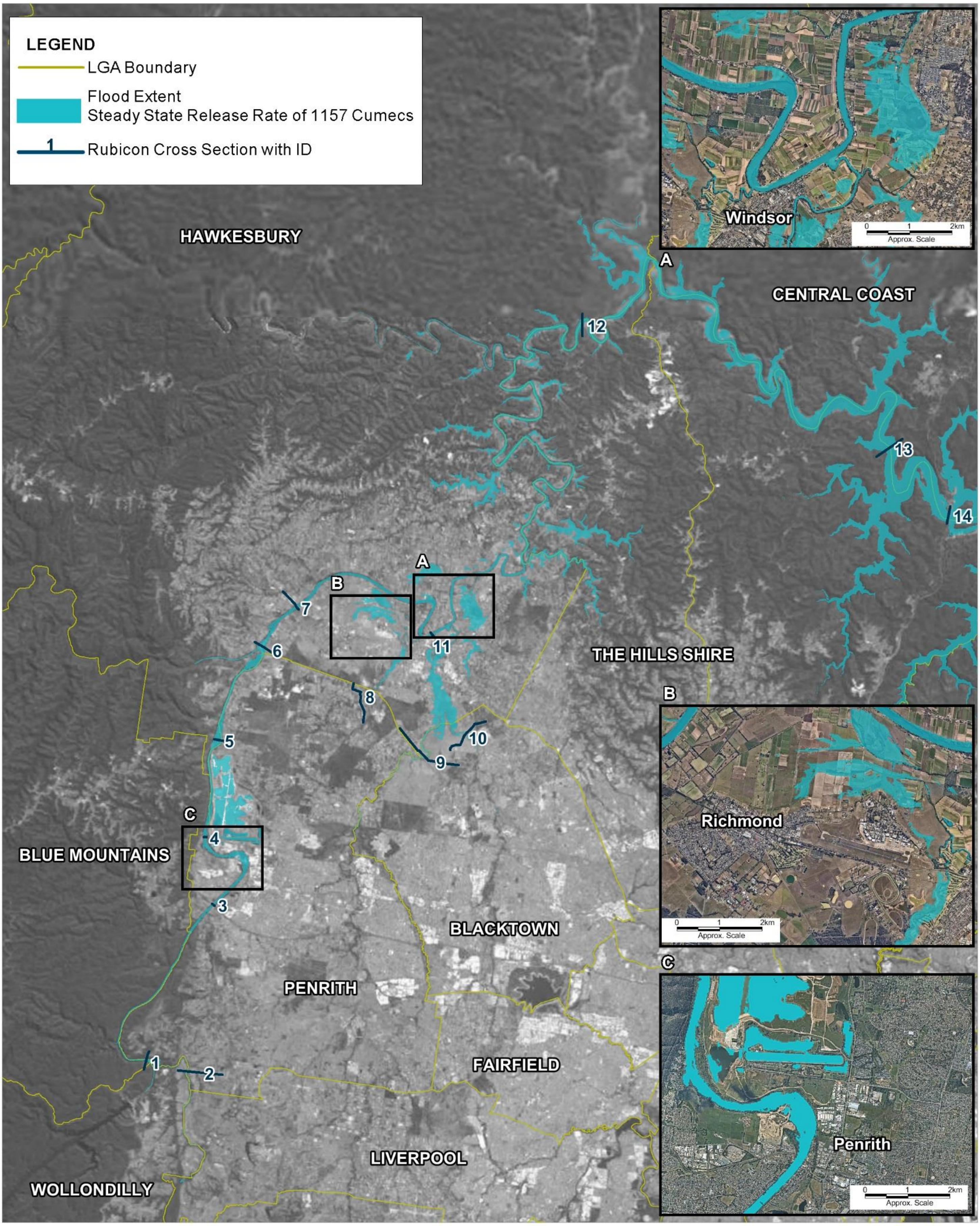

Title:

Receiving Environment Flood Extent Steady Release Rate - 1157 Cumecs

Figure: 4-30

Rev: A

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4.2.3.2 Period of inundation and rate of rise

In addition to reducing the peak flood levels and associated flood extents, a raised dam wall will alter the period of inundation and rate of rise of floodwaters, allowing more certainty of time for people to evacuate, protecting lives and reducing damages.

Figure 4-31 shows the distribution of the delay (in hours) between existing and with Project flood peaks for the 300 highest flood events from the Monte Carlo analysis (refer Section 2.4 for specific details of the Monte Carlo methodology) that reach a height of 17.3 mAHD at Windsor. This height is a key level in the downstream road network with regard to flood evacuation as 17.3 mAHD is the level at which access across the Jim Anderson Bridge is cut, and is also the 1 in 100 year default flood planning level in the Richmond/Windsor floodplain.

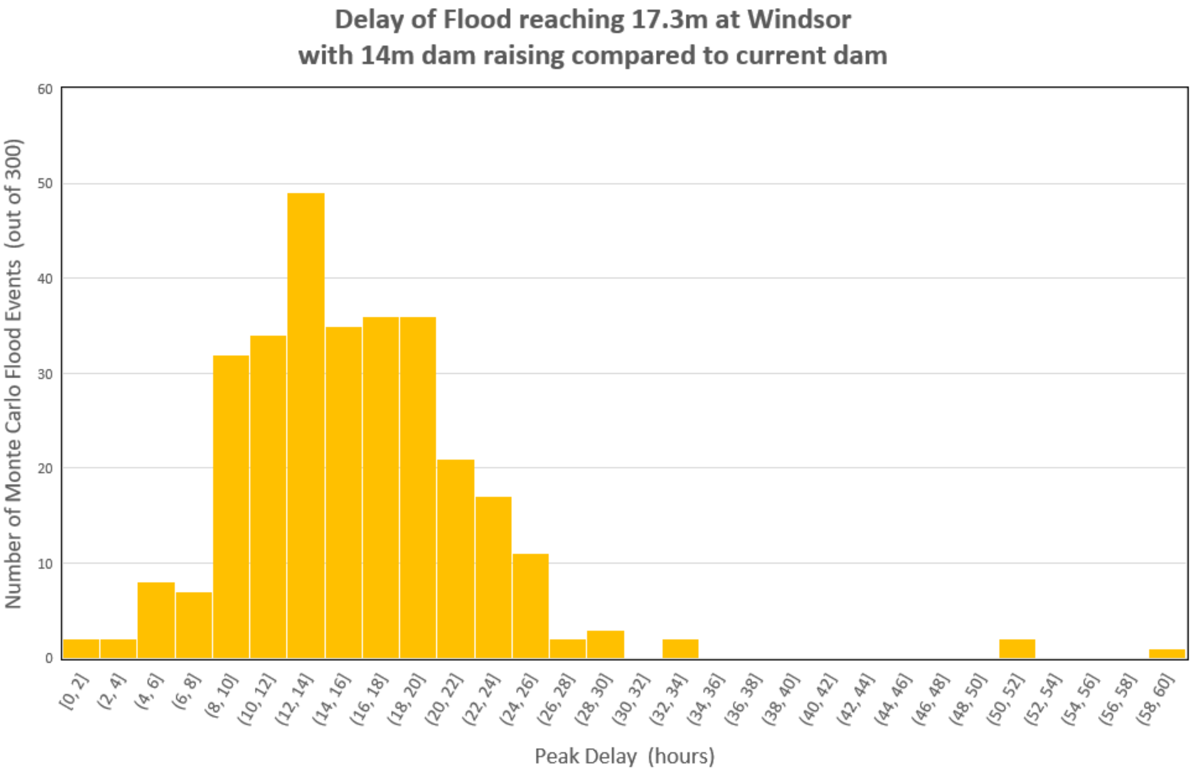

Figure 4-31 Distribution of delays in flood event peaks from monte Carlo analysis at Windsor

Figure 4-31 shows:

- The delay in floods reaching 17.3m AHD between existing and with Project modelled flood events ranges from less than two hours up to 60 hours
- 97 percent of the modelled flood events have a delay in flooding reaching 17.3m AHD between four hours and 30 hours
- 74 percent of the modelled flood events have a delay between eight hours and 20 hours.

A generally similar pattern in the distribution of delays in modelled flood levels and peaks occurs for other downstream locations.

With respect to existing community emergency management arrangements for flooding, there will be a reduction in the frequency of events resulting in overtopping of key transport corridors and a corresponding reduction in the need for evacuations.

In connection with the reduction in peak water level and increase in available warning time is the increased period of raised water levels as the volume of water held within Lake Burragorang is progressively released (as shown in Figure 4-32 and Figure 4-33). These drawdown release rates have been designed to enable the key bridge crossing locations to be reopened as soon as practical after a flood event (if they were overtopped or closed).

SEARs #20 Clause 8 requested specific assessment of the impact of the recession of flood waters following a PMF. The impact of the Project on downstream PMF flood extents and durations is minimal as the Project would only capture a very small proportion of inflows – and consequently the difference between the existing and with Project PMF impacts is small downstream.

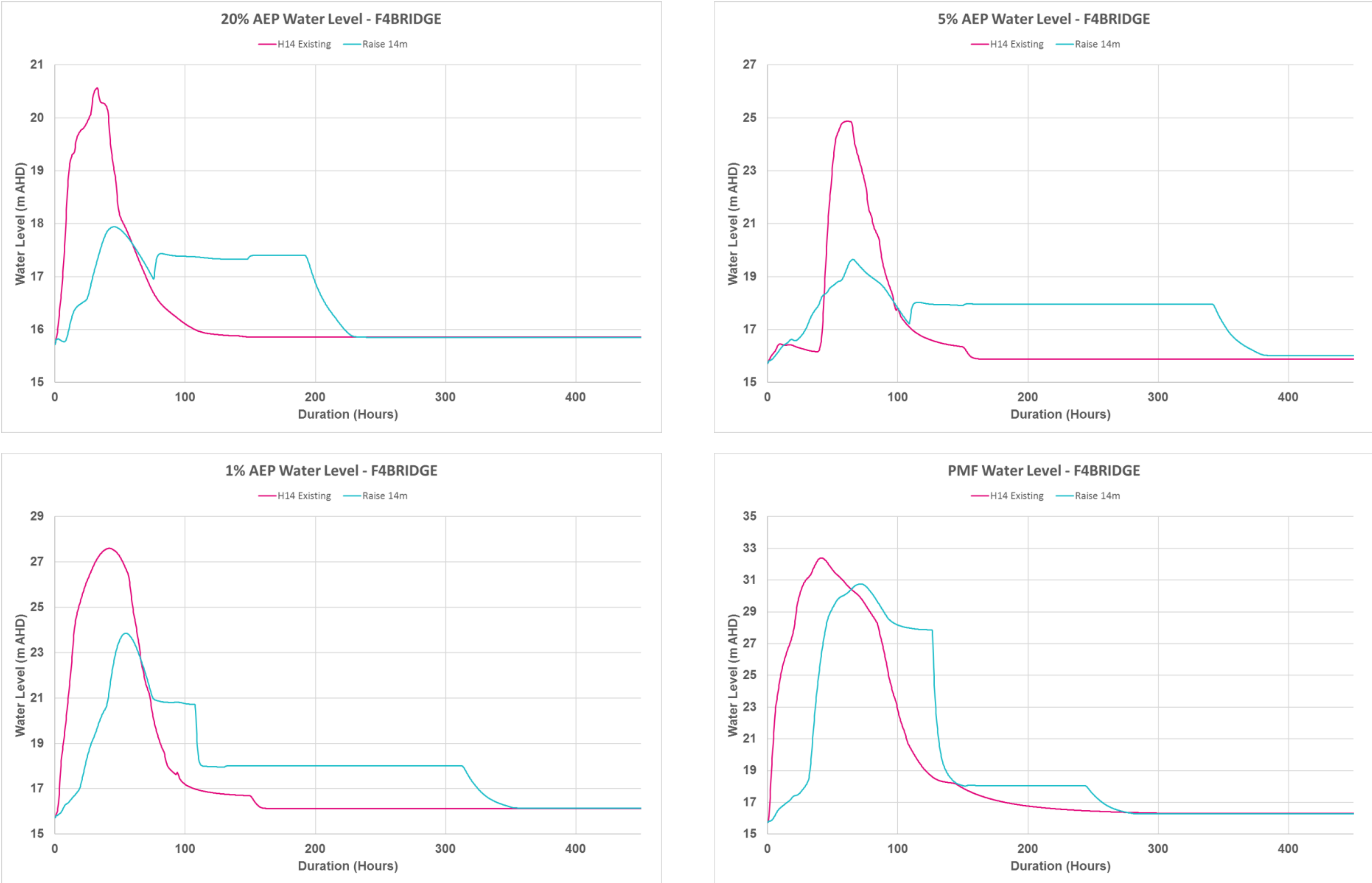

Figure 4-32 Water level timeseries – Selected Monte Carlo flood events at F4BRIDGE Cross Section

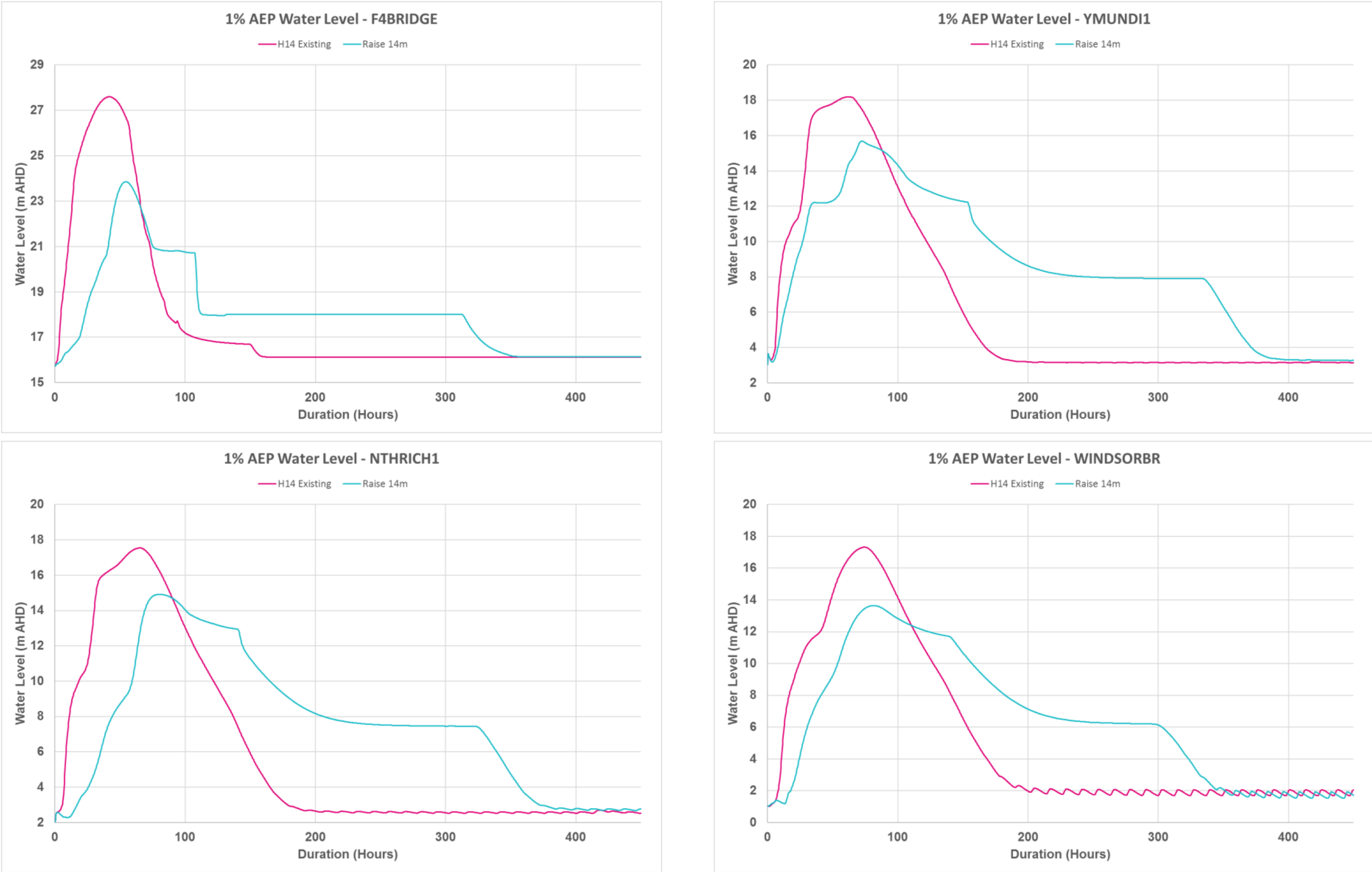

Figure 4-33 1% AEP water level timeseries

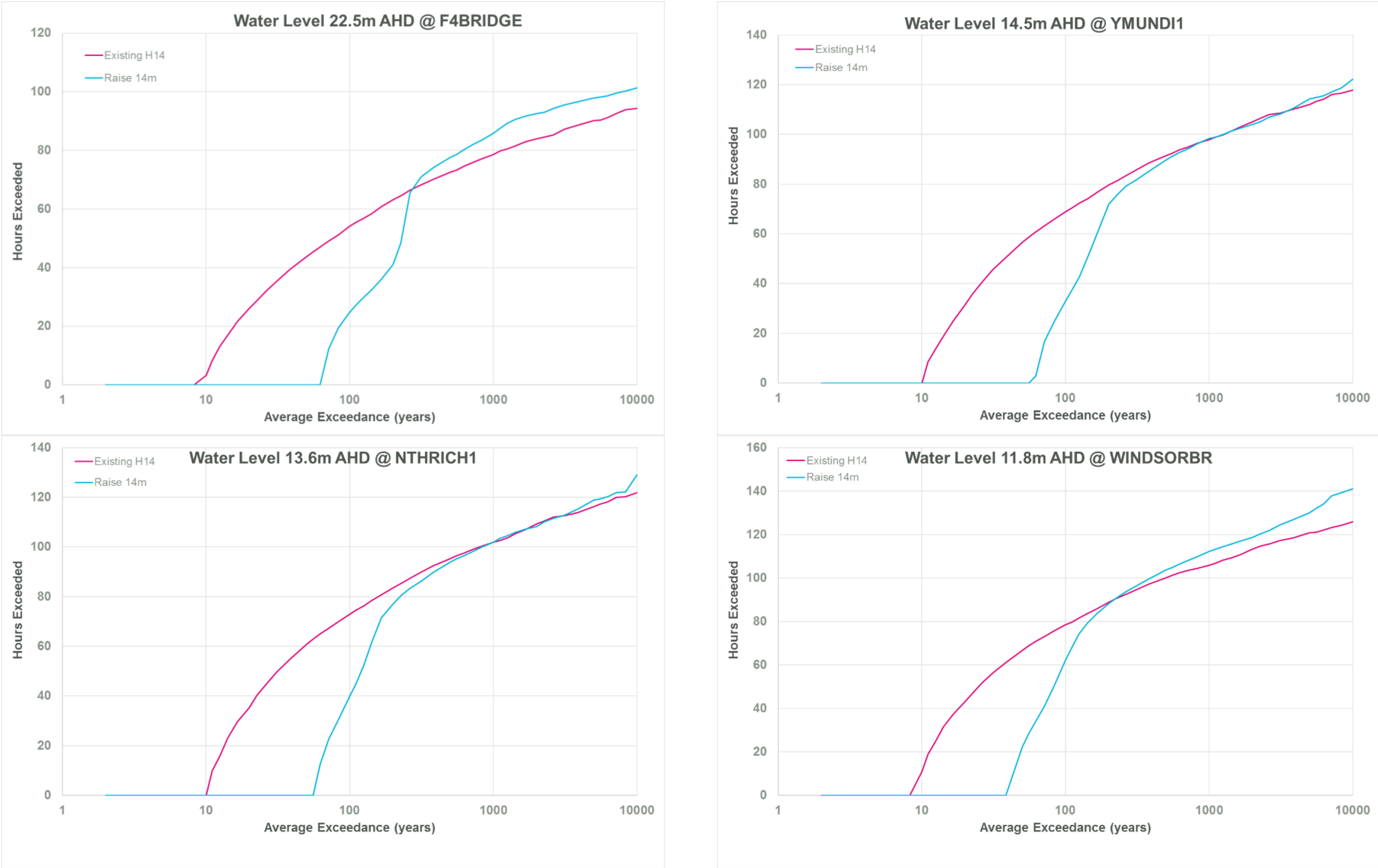

Figure 4-34 Water level duration curves

Figure 4-32 provides an example of a typical PMF hydrograph in the downstream waters. The PMF event is used principally as an input to design and, given the scale of the catchment of Lake Burragorang, is highly unlikely to occur. While discussion of the PMF event is included for completeness (and to comply with the SEARs), more weight should be given to the flood events with a relatively greater chance of occurrence.

The changes between the existing PMF and with Project would include:

- the flood peak level with the Project would be lower – this would vary throughout the downstream catchment
- the period of higher flows and higher levels would be slightly longer with the Project due to piggyback discharges from the FMZ. Generally, the longer period of higher discharges would be for one to two days but would be below the peak flood discharge during the event
- after piggybacking of discharges from the FMZ had ceased, a steady state discharge of around 100 GL/day would continue for another four to five days until the FMZ had emptied. This same steady state discharge of around 100 GL/day would occur after all flood events with the discharge of the FMZ. The steady state discharge period from the PMF is actually lower than other events as a greater volume of water is able to be discharged via piggyback discharges during a PMF compared to other events.

Compared to other smaller events, the impact of the Project on PMF flooding is relatively minor. Impacts on vegetation are assessed in the Downstream Biodiversity Assessment Report. Impacts on water quality are assessed on the Water Quality Assessment Report. Impacts on Geomorphology are assessed in the Soils and Contamination Report.

4.2.3.3 Flood velocity

The overall range of flood velocities currently experienced within the downstream environment will not be impacted by the Project. Flood waters at a given location and flow rate will comprise similar velocity distributions to the existing conditions. However, due to the increased attenuation and management of flood waters associated with the Project, the frequency with which the downstream environment is exposed to the current peak flood velocity distributions will be reduced. As presented in Table 4-7, the existing 10% AEP peak flows will be experienced less frequently than a 1% AEP following the dam raising. Similarly, the existing 1% AEP flood conditions will be experienced less frequently than a 0.2% AEP. The overall reduction in the frequency of peak flood velocities will result in an associated reduction of flood hazard and hence public risk expose in the downstream environment.

In addition to the overall reduction in peak flood velocities, there will also be a change in the nature of in-bank velocities in the downstream environment. The magnitude of in-bank velocities of the Hawkesbury and Nepean Rivers within the study area will not be impacted by the Project, that is, at any given location and flow rate the water column will comprise similar velocity distributions to the existing conditions. However, due to the increased attenuation and management of flood waters associated with the Project, the frequency with which the Hawkesbury and Nepean Rivers within the study area experience bank-full flows will be reduced. Conversely, when the FMZ is emptied, the

Project will result in an increase in the duration of sustained bank-full velocities associated with the steady release rate discussed in Section 4.2.3.1.

Figure 4-35 presents velocity duration curves at four selected locations for a threshold velocity of 1.5 m/s. Although the probabilities of sustained velocity durations are unique for each location, there is a general consistency in the expected impact from the Project. Raising the height of Warragamba Dam and the associated increased control of flood flow releases typically reduces the expected duration of sustained flood velocities. However, depending on the characteristics of individual flood events, in some circumstances (albeit of a relatively rarer occurrence) the duration of sustained velocity is expected to be significantly increased.

Environmental assessment

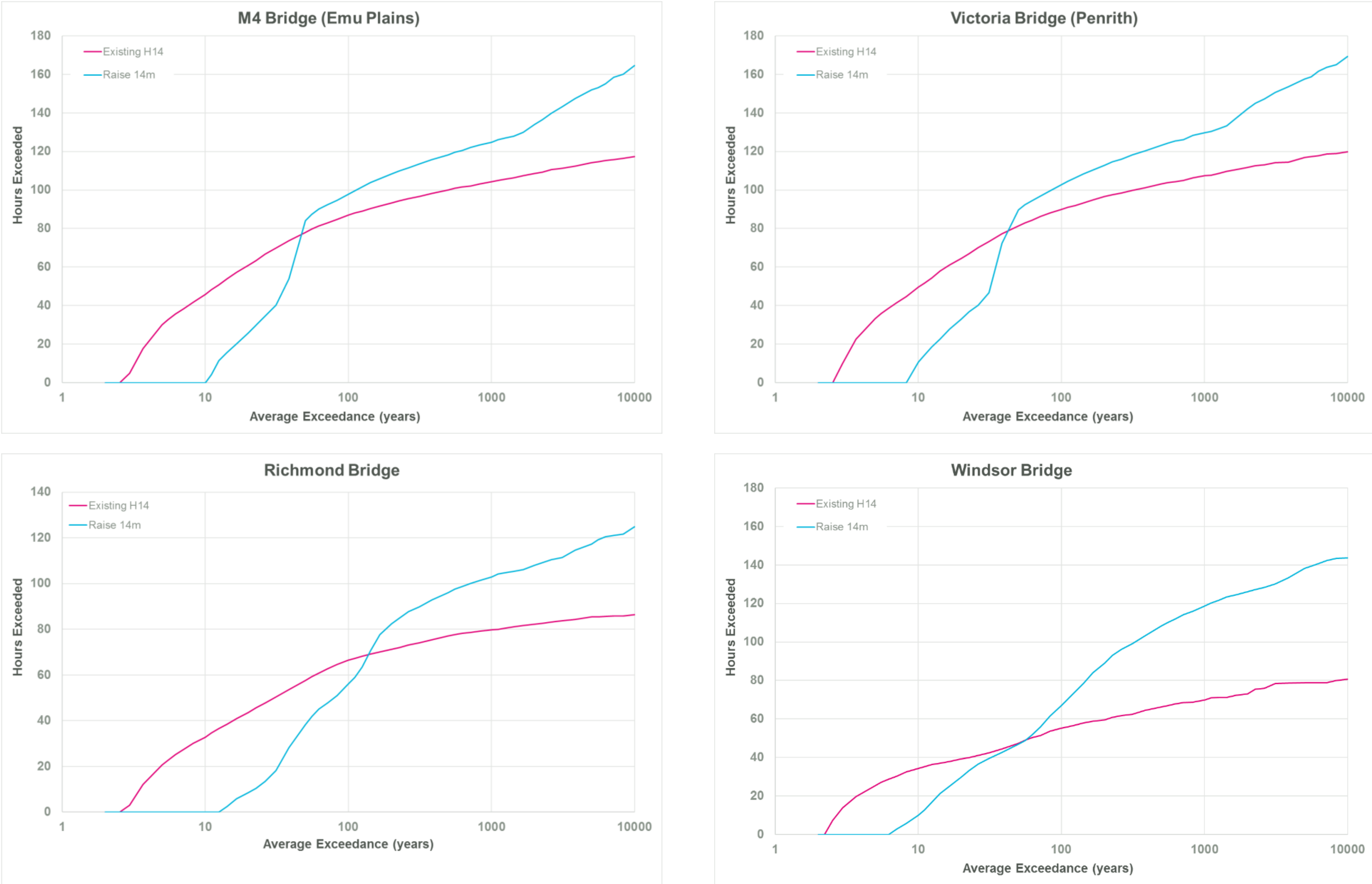

Figure 4-35 1.5 m/s flood velocity duration curves

4.2.3.4 Flood hazard and flood function

The overall range of flood hazards currently experienced downstream of the dam will not be impacted by the Project. Flood waters at a given location and flow rate will comprise similar hazard distributions to the existing conditions. However, due to the increased attenuation and management of flood waters associated with the Project, the frequency with which the downstream area is exposed to the current flood hazard distributions will be reduced. As presented in Table 4-7, the existing 10% AEP peak flows will be experienced less frequently than a 1% AEP following the dam raising. Similarly, the existing 1% AEP peak flows will be experienced less frequently than a 0.2% AEP. The overall reduction in the frequency of peak flood flows will generally result in an associated reduction of flood hazard and hence public risk exposure in the downstream area.

Flood hazard mapping for existing conditions for the 1% AEP flood event has been provided in Figure 3-31 to Figure 3-33. Corresponding 1% AEP hazard mapping for the Dam raising is provided in Figure 4-36 to Figure 4-38. Similar hazard mapping for the 20% AEP, 5% AEP, 0.5% AEP, 0.2% AEP, 0.05% AEP and PMF events is included in WMAWater (2020).

Due to the extreme flood depths that occur under existing conditions in the Hawkesbury Nepean Valley much of the floodplain is classified unsafe for vehicles and people and all building types considered vulnerable to failure (H6). While the raised dam significantly reduces flood depths it is not enough to significantly alter the hazard classification (due to the nature of the classification scheme) as the depths are still enough to classify the floodplain as H6 (WMAWater, 2020).

Similarly, overall flood function classification downstream of the dam will not be significantly impacted by the Project. Flood waters at a given location and flow rate will constitute a similar function to the existing conditions. However, due to the increased attenuation and management of flood waters associated with the Project, the frequency with which floodways and flood storages within the downstream environment are activated will be reduced. For example, a floodway that is currently activated at around a 10% AEP threshold may become activated at a reduced frequency of a 1% AEP or rarer.

Flood function mapping for existing conditions for the 1% AEP flood event has been provided in Figure 3-34 to Figure 3-36. Corresponding 1% AEP flood function mapping for the Dam raising is provided in Figure 4-39 to Figure 4-44. Similar flood function mapping for the 20% AEP, 5% AEP, 0.5% AEP, 0.2% AEP, 0,05% AEP and PMF events is included in WMAWater (2020).

In the 1% AEP event, the primary floodway is generally located within the main river channel. Similar to the primary floodway under the existing conditions, at Wallacia and Penrith, the primary floodway does not extend beyond the low-lying overbank areas.

At Penrith, as with the existing scenario, nearly all of the 1% AEP flow is contained in the river. However, while the floodway extents are similar between the raised dam and existing scenarios, there is minimal flood storage and flood fringe in Penrith under the raised dam conditions in comparison to the existing case.

In the Windsor area, there is a large reduction in the secondary floodway for the raised dam scenario. The secondary floodway is mostly confined to the banks of the Hawkesbury Nepean River from the Richmond Lowlands to Yarramundi Bridge. Additionally, the secondary floodway does not consistently cover the area between Richmond and Pitt Town on the Windsor floodplain, unlike the secondary floodway in the existing conditions scenario. The extent of flood storage and flood fringe in the Windsor floodplain as well as on Rickabys Creek and South Creek confluences are much greater in the existing scenario than in the raised dam scenario (WWAWater 2020).

Flood function mapping has been provided for a constant discharge (steady-state) scenario of 100 GL/D to represent sustained releases from the dam (refer to Figure 4-42 to Figure 4-44). Similar flood function mapping for the 0.2% AEP event is included in WMAWater (2020).

In the steady sate event, the primary floodway does not extend beyond any low-lying overbank areas and is completely contained within the river channels. At Penrith and Windsor, most of the secondary floodway is contained in the river. In Wallacia, the secondary floodway is completely contained within the banks. Under the steady state conditions, no flow is conveyed down the Richmond Lowlands in the Windsor region. Accordingly, a sustained discharge under the release scenarios of the order of 100GL/d does not activate any significant floodway area outside of the general channel extents.

The impact of the Dam raising is in general to reduce flood hazard and extents of floodway categorisations. Where the is no significant change in flood characteristics of depth and velocity, the existing categorisations are retained, i.e., no worsening of existing conditions as a result of the Project.

As the Flood Risk Management practice in NSW has traditionally been to map flood hazards and flood function at specific flood event magnitudes/rarities (for example, 1% AEP) rather than for specific flood flow conditions, impacted authorities may consider revising their flood hazard and flood function mapping in response to the impacts of the Project.

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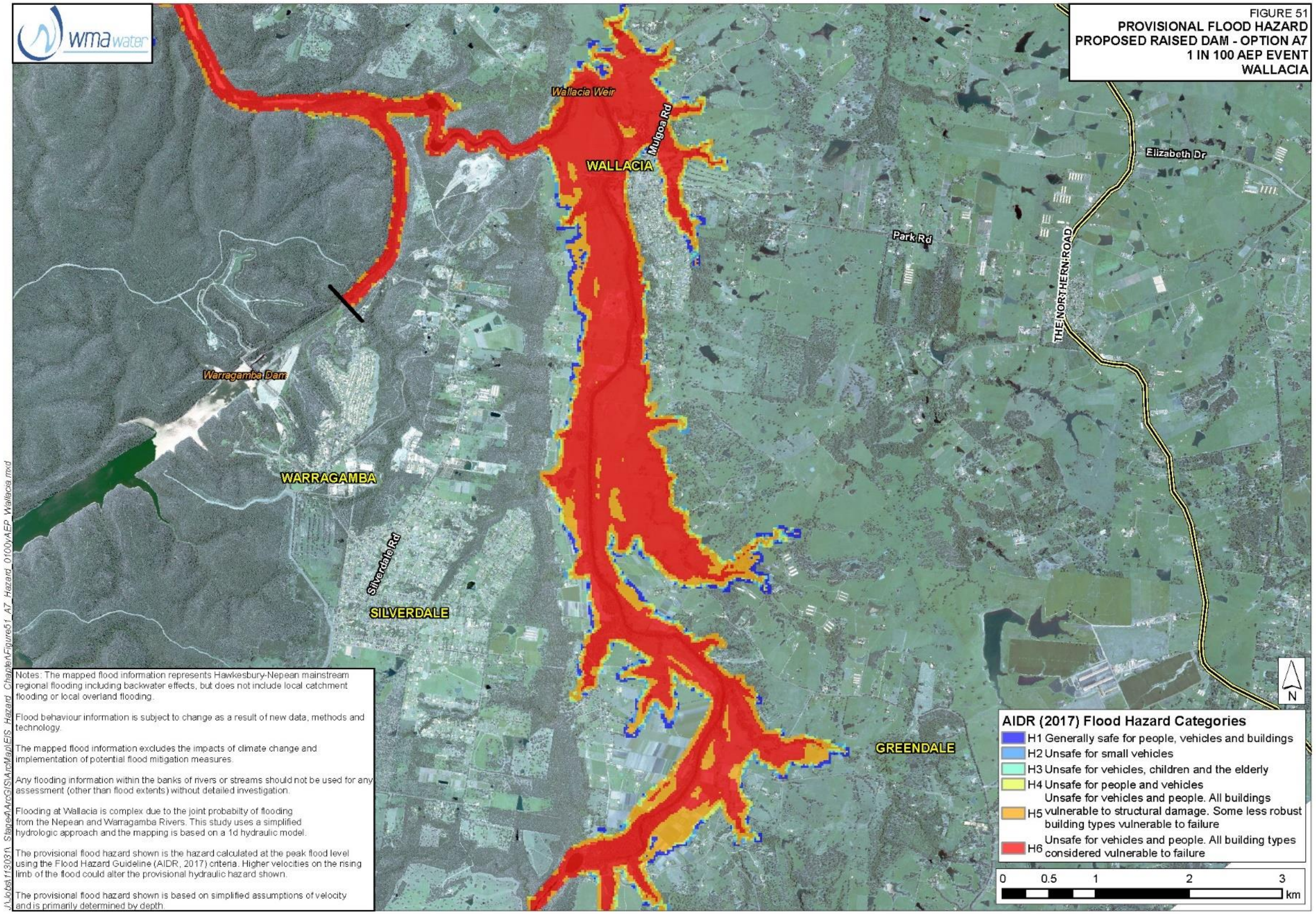

Figure 4-36 Raised Dam 1% AEP flood hazard mapping – Wallacia (Source WMAWater 2020)

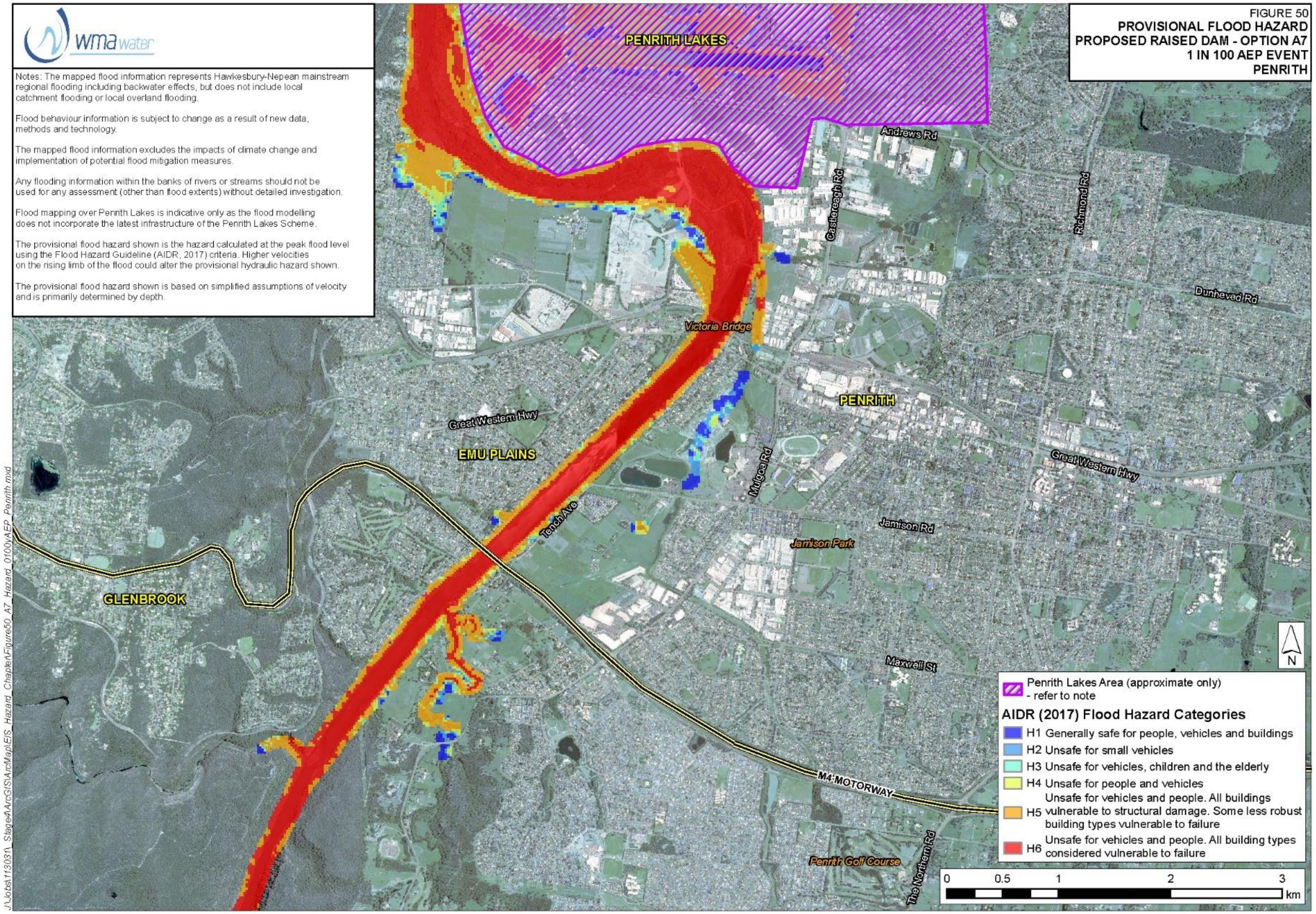

Figure 4-37 Raised Dam 1% AEP flood hazard mapping – Penrith (Source WMAWater 2020)

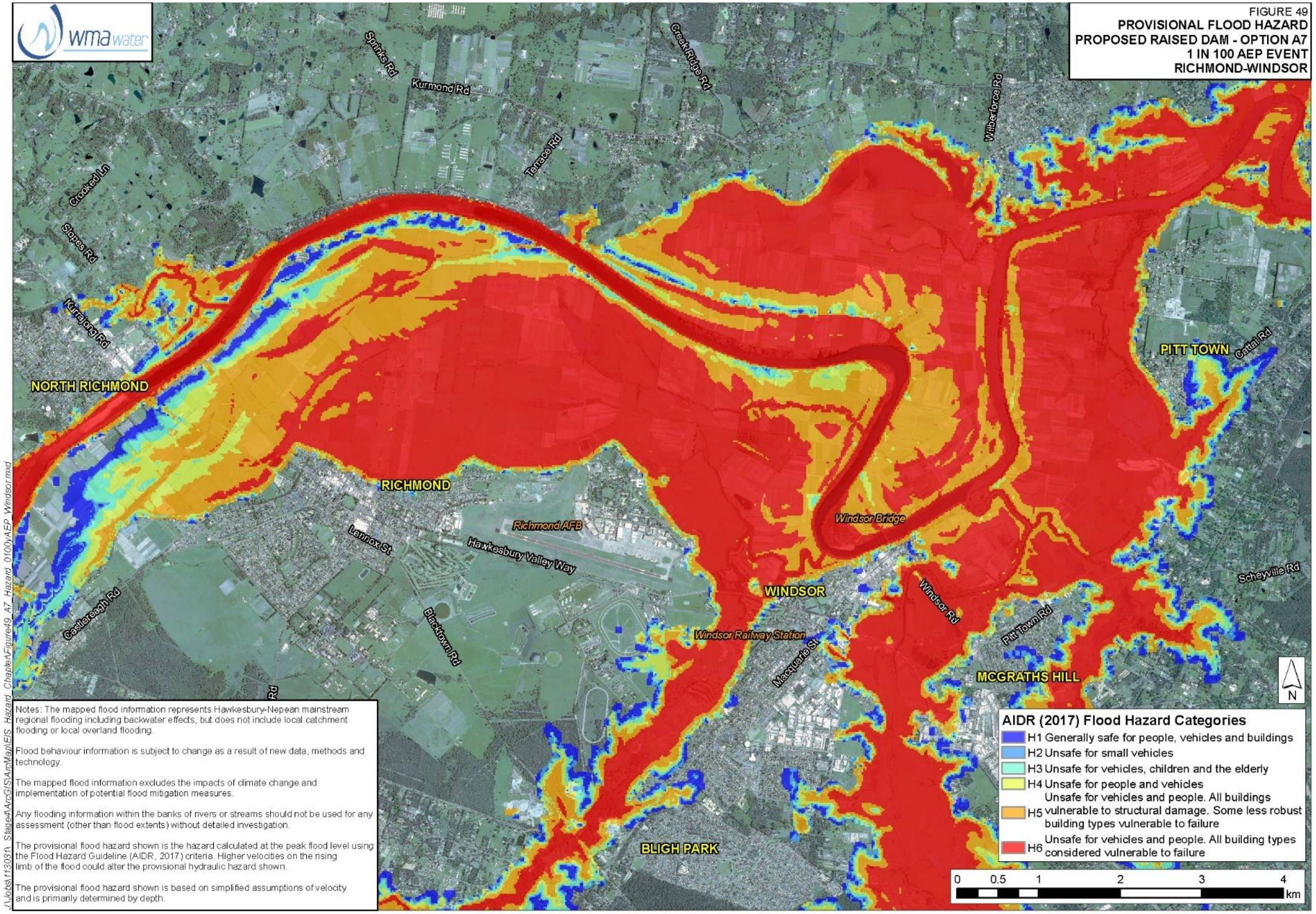

Figure 4-38 Raised Dam 1% AEP flood hazard mapping – Windsor/Richmond (Source WMAWater 2020)

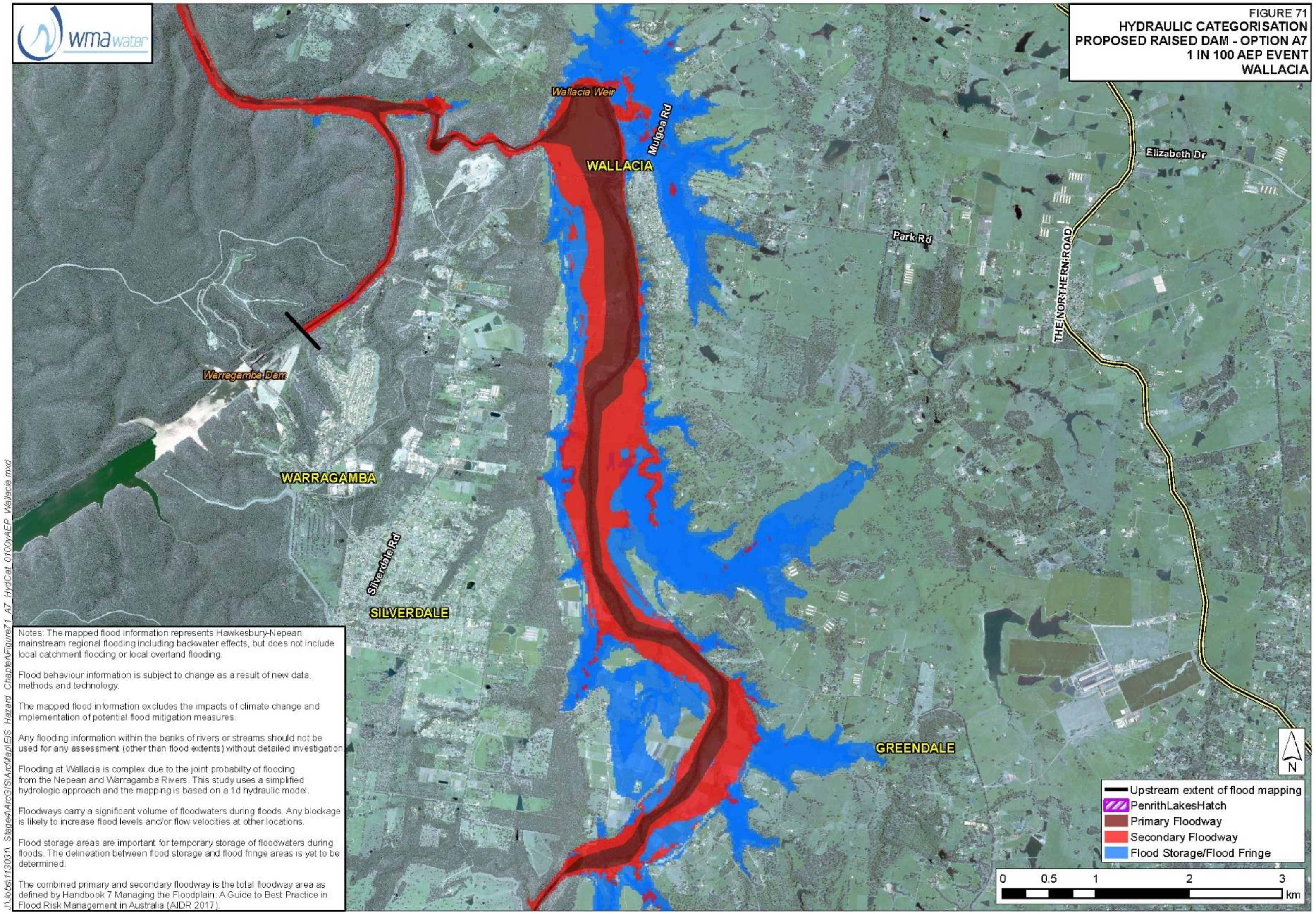

Figure 4-39 Raised Dam 1% AEP flood function mapping – Wallacia (Source WMAWater 2020)

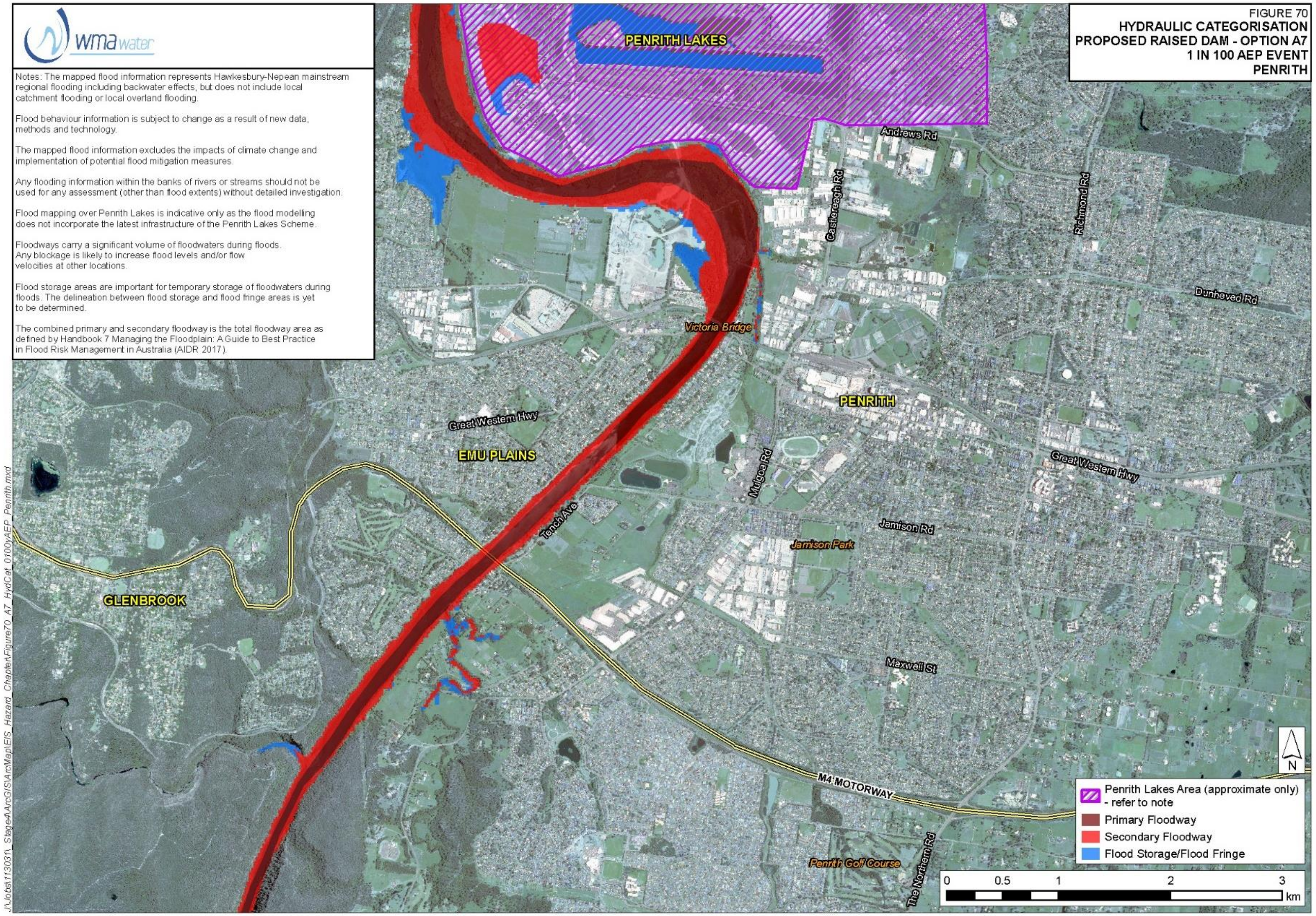

Figure 4-40 Raised Dam 1% AEP flood function mapping – Penrith (Source WMAWater, 2020)

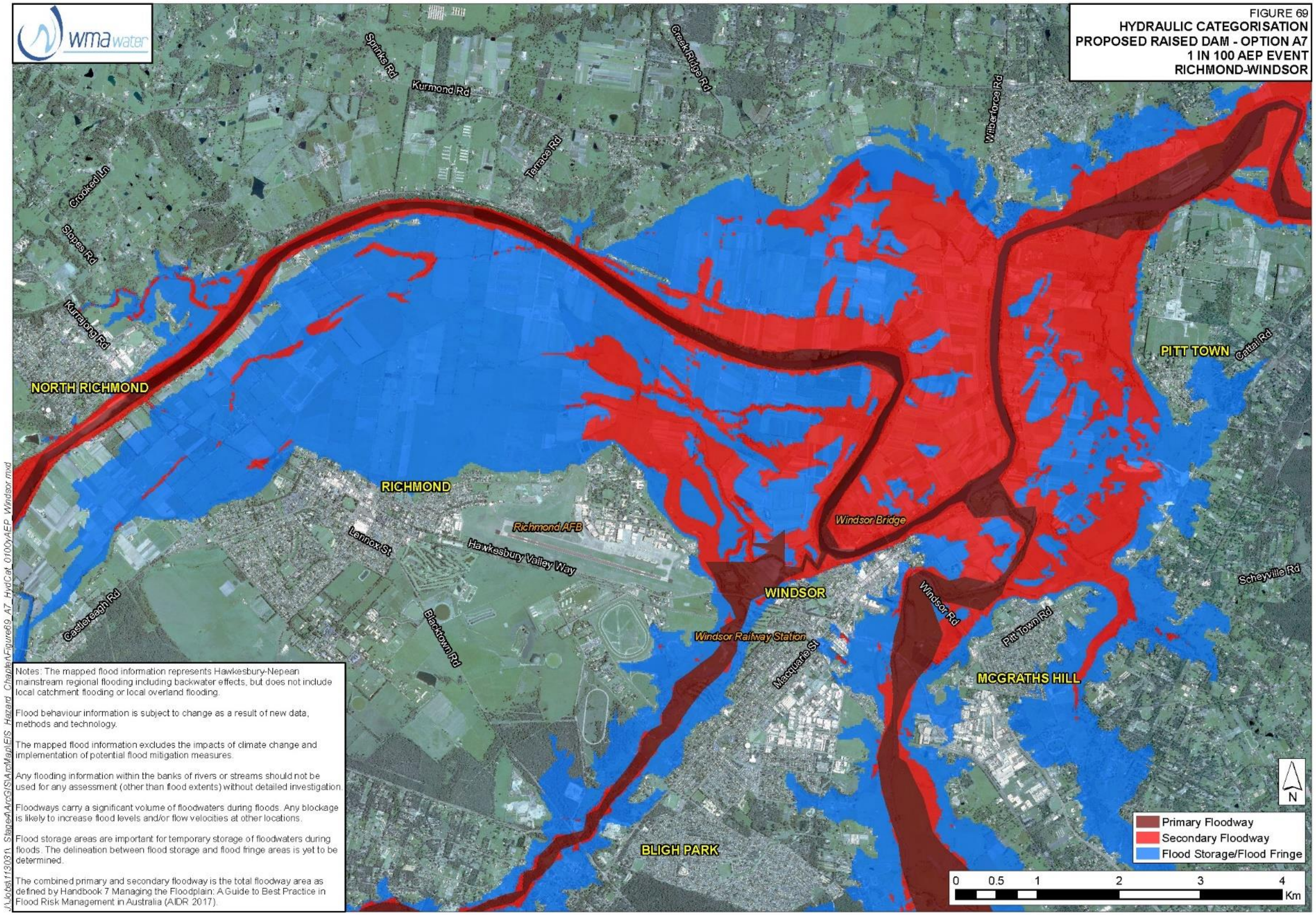

Figure 4-41 Raised Dam 1% AEP flood function mapping – Windsor/Richmond (Source WMAWater, 2020)

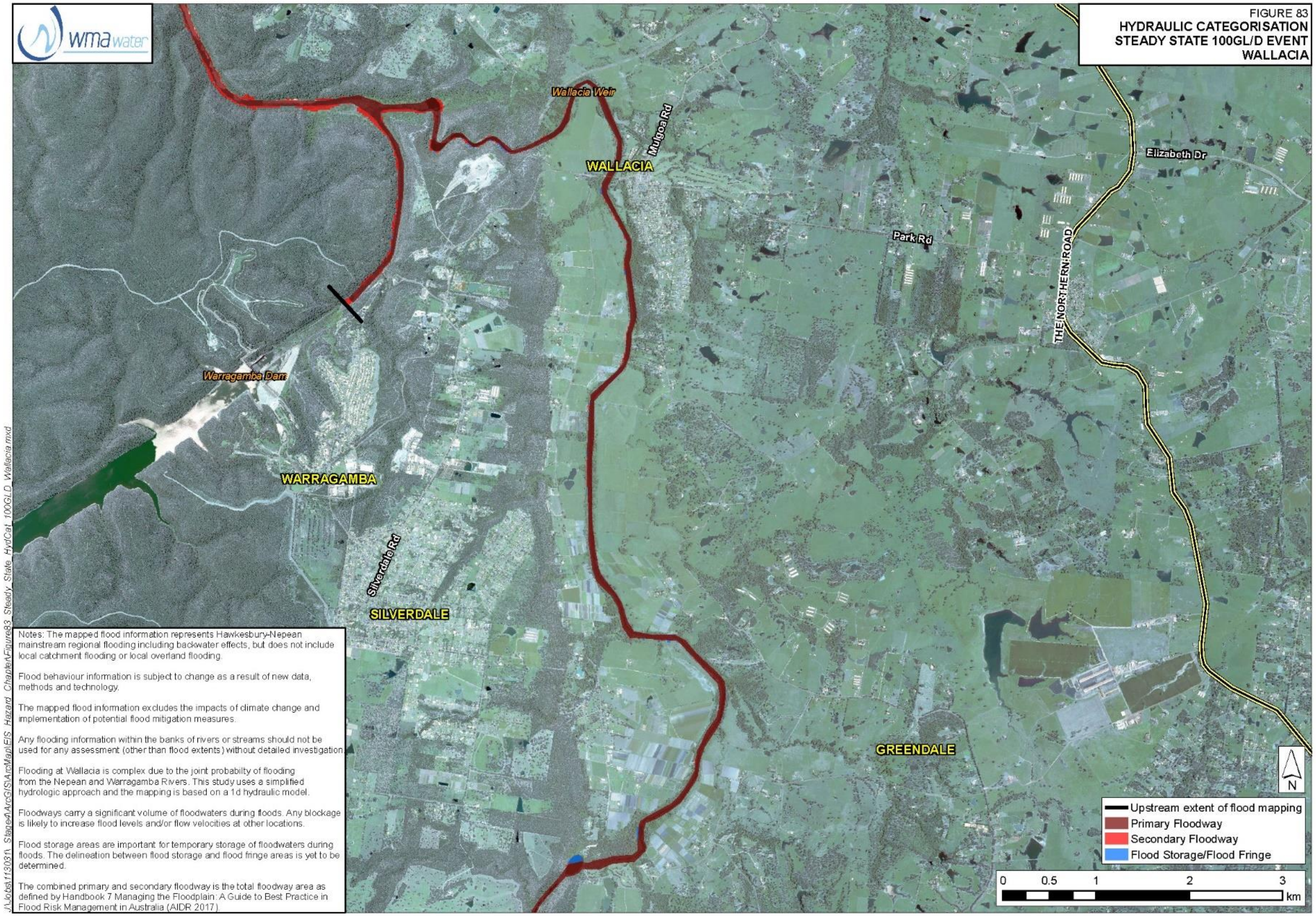

Figure 4-42 Raised Dam 100GL/D flood function mapping – Wallacia (Source WMAWater 2020)

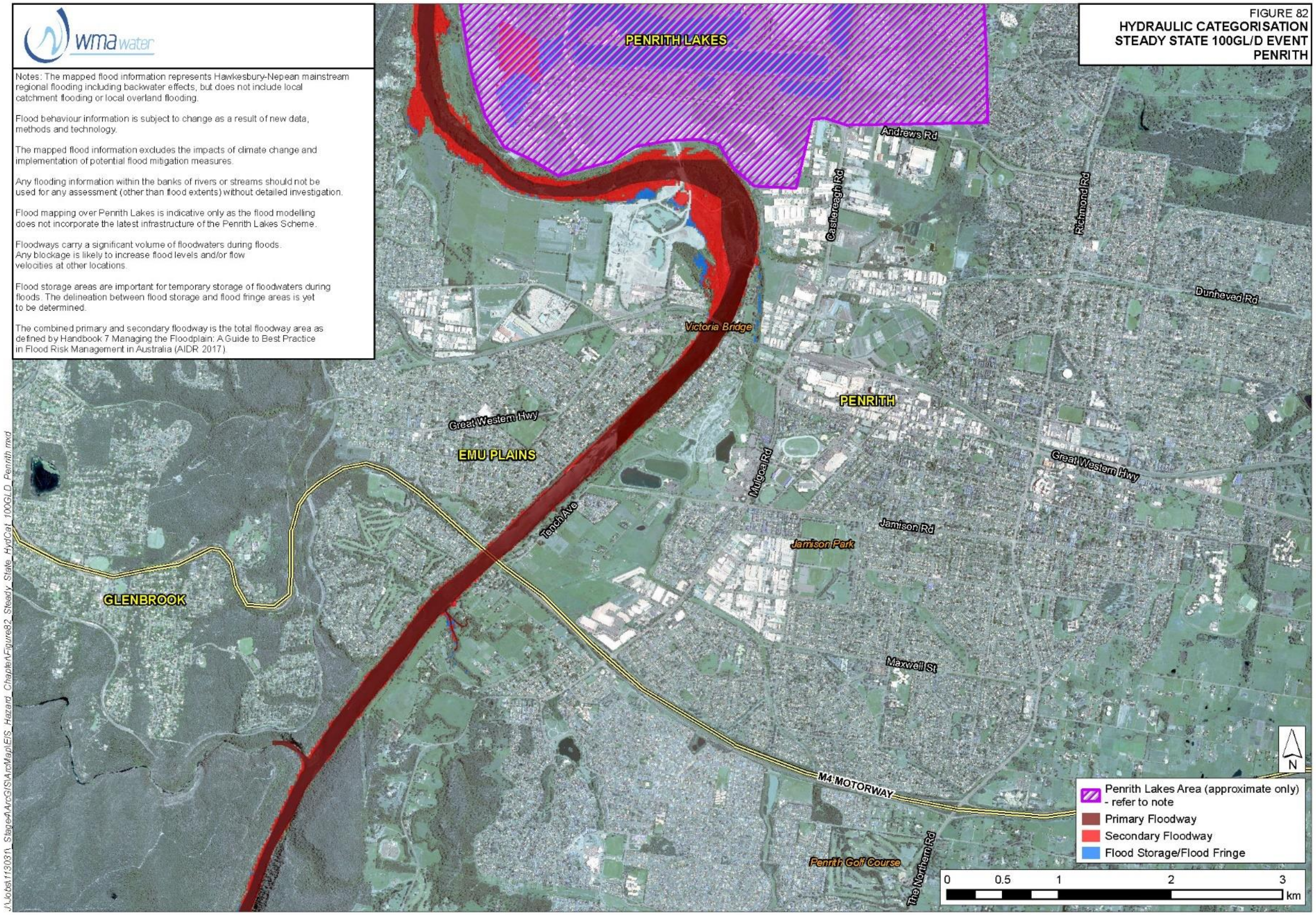

Figure 4-43 Raised Dam 100GL/D flood function mapping – Penrith (Source WMAWater, 2020)

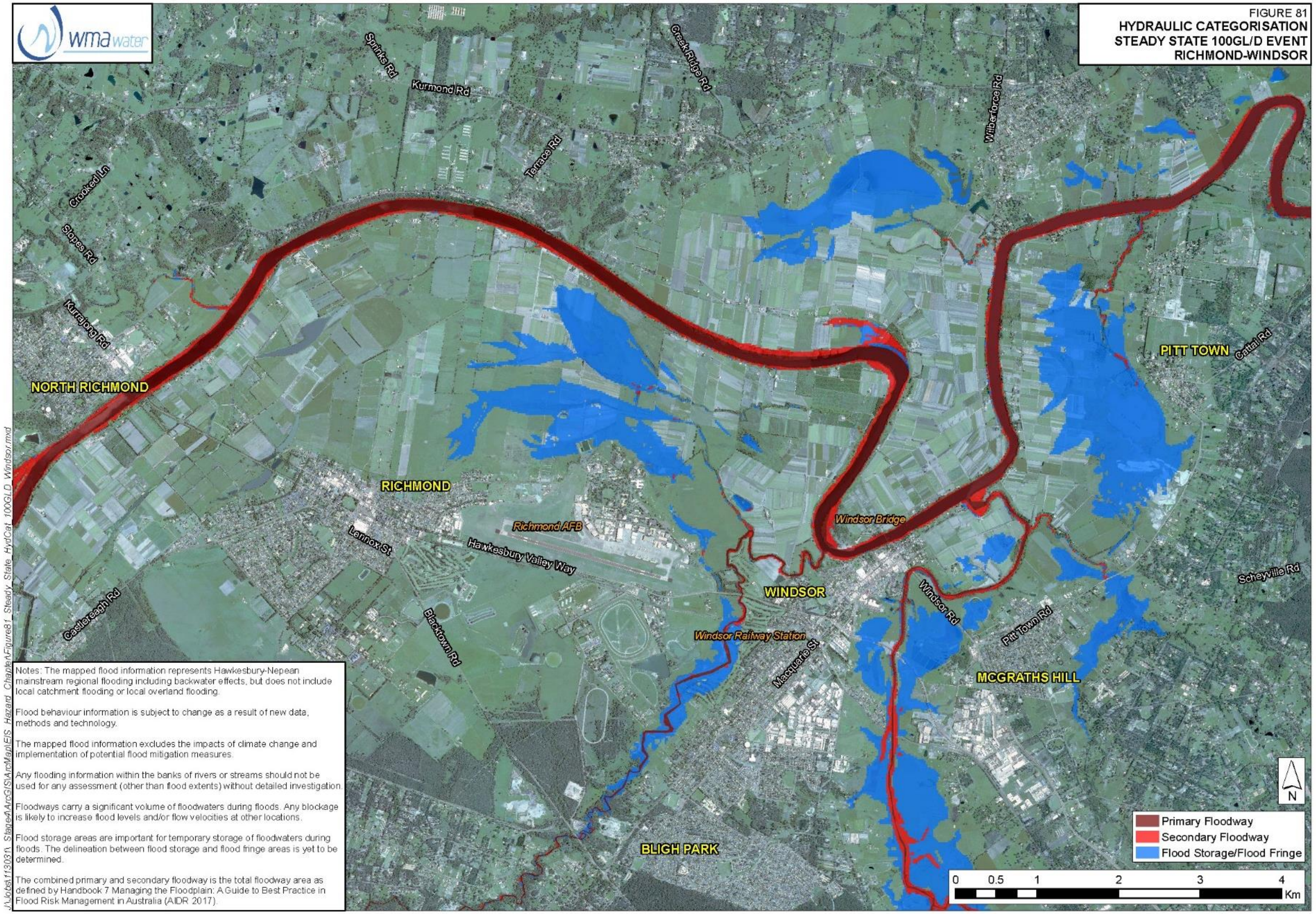

Figure 4-44 Raised Dam 100GL/D flood function mapping – Windsor/Richmond (Source WMAWater, 2020)

4.2.3.5 Groundwater

Groundwater and wetlands within the Hawkesbury-Nepean floodplain are discussed in Sections 3.1.2.6 and 3.1.2.7. Important wetlands in the study area include:

- Pitt Town Lagoon (associated with the Hawkesbury Alluvium groundwater source)
- Long Swamp (associated with the Sydney Basin Central groundwater source)
- Longneck Lagoon (associated with the Sydney Basin Central groundwater source)
- O'Hares Creek (associated with the Sydney Basin Central groundwater source).

There are currently 43 licenced extraction wells within the Hawkesbury – Nepean basin, with a combined extraction rate of 1.172 gigalitres per annum. The dominant aquifer recharge mechanism is likely to be infiltration of rainfall and runoff throughout the wider catchment (Herron et al. 2018).

Potential Project impacts on groundwater resources are discussed below:

- The Project has no impact on rainfall distribution or physical changes to the channel and floodplain that provides for direct recharge of groundwater systems via infiltration.
- Periodic inundation of floodplain areas under flood conditions represents only a minor contribution to groundwater, particularly compared with the contribution of infiltration from direct rainfall in the catchment. Further, local flooding from downstream tributaries such as the Nepean River, South Creek, Cattai Creek, Grose River and Colo River will not change due to the Project. The recent flood in February 2020 demonstrated the extent of local flooding without flow contribution from the Warragamba dam catchment. For this February 2020 event, downstream flooding was estimated to be about a 1 in 5 chance in a year event. At the time dam capacity was less than 50 percent full, and all upstream inflow was trapped by the dam, with no spill. Downstream flooding was therefore wholly a result of local flooding, with no contribution from the Warragamba dam catchment. This characterises the importance of local downstream flooding in contributing to existing landforms, biodiversity and groundwater characteristics. Changes in the frequency of floodplain inundation achieved by the flood mitigation objective of the Project would therefore have minimal impact on the groundwater system.
- The NSW Government's 2017 Metropolitan Water Plan (Metropolitan Water Directorate 2017) proposes variable environmental flows from Warragamba Dam to improve the health of the Hawkesbury-Nepean River. The plan aims to mimic as much as possible the natural flow of the river. Accordingly, there is expected to be minimal impact on surface water and groundwater interaction at low-flow regimes, including connectivity to flow dependent ecosystems.
- The Project will not impact on current groundwater extraction rates or current groundwater users.
- There will be minimal impacts on groundwater dependent ecosystems (GDEs), such as wetlands. This is addressed in Appendix F2 (Downstream ecological assessment).

4.2.3.6 Flood emergency response

The Project is only one workstream of the broader Hawkesbury-Nepean Valley Flood Risk Management Strategy that also includes for a comprehensive plan to improve emergency management response and recovery in the Hawkesbury-Nepean Valley. This workstream plan is to cover implementing changes to the state emergency plan and to respond to the changed operations with a flood mitigation dam in operation.

The NSW SES and the NSW Office for Emergency Management (OEM) are core members of the Taskforce team that developed the Flood Strategy. The NSW SES provided detailed analysis of the impact of options, and their advice regarding timing of evacuation and evacuation routes as a key input in the evacuation assessments.

The NSW SES and the OEM already maintain flood risk response and recovery plans for the Hawkesbury-Nepean Valley and are responsible for providing the deliverables for the Flood Strategy workstream: “Best Practice Emergency Response and Recovery”.

The testing of the plans and ensuring that the necessary capabilities are maintained is critical for continuous improvement. Ensuring that these arrangements are adequate, understood and well-rehearsed is important given the likely prolonged and highly complex nature of response and recovery in the Hawkesbury-Nepean Valley.

The resultant action to be undertaken are:

- periodically review and update the emergency response plan (Hawkesbury-Nepean Flood Plan) to account for the latest information on flood risk and integrate with recovery arrangements (conducted by NSW SES)
- periodically review and update the Hawkesbury-Nepean Valley recovery strategy (Hawkesbury-Nepean Valley Flood Recovery Strategy) (conducted by OEM)
- to plan for recovery from catastrophic events by developing NSW recovery arrangements for catastrophic disasters using the Hawkesbury-Nepean Valley as a case study. To date three exercises based on catastrophic flooding in the Hawkesbury-Nepean Valley (led by OEM) were held between 18 June and 3 July 2019 and included a mass evacuation exercise involving 200 volunteers on 26 June 2019
- test and rehearse emergency response and recovery plans and arrangements with regular exercises (NSW SES and OEM). An exercise to test changes needed with a flood mitigation dam in operation was carried out in April 2019, involving SES, OEM, WaterNSW and BoM. The objectives were to test draft operating protocols/rules and understand how proposed new arrangements affect risks to SES, Councils, other agencies and the community
- improve and maintain rescue capability (Conducted by NSW SES).

SES is advising and providing the major input into evacuation strategies and detail of evacuation routes to enable further modelling of evacuation times for existing conditions and for mitigation options. SES are part of the multi-agency Flood Strategy Program Delivery Group (PDG) that monitors progress and advises the INSW Program Director on the Warragamba Dam Raising Project and other Flood Strategy workstreams. Other agency members of the PDG include Premiers and Cabinet, NSW Treasury, Department of Planning, Industry and Environment, OEM, Transport for NSW, and WaterNSW. The PDG was formed in April 2017 and has held 21 meetings to December 2019.

Separate briefings and consultation with the SES Commissioner and other senior SES executives have occurred on four occasions since mid-2017.

Regional councils have an important role in many aspects of flood risk management, including land use, road and emergency planning, response and recovery, and providing information for local communities. In recognition of this ongoing role affected local councils were consulted in the Taskforce phase.

Implementation of the current Flood Strategy Phase One is being underpinned by a governance structure that includes a Local Government Advisory Group (LGAG).

The LGAG is chaired by a senior representative from the Department of Planning, Industry and Environment and meets quarterly. Councils represented are Penrith, Hawkesbury City, Blue Mountains City, Wollondilly, Blacktown City, Hornsby City, Liverpool City, The Hills Shire, Central Coast. Each LGAG meeting includes an update on the Warragamba Dam Raising Project and an opportunity for discussion. There have been six LGAG meetings held commencing in November 2017.

In addition, there have been a series of briefings and presentations to individual councils:

- Hawkesbury City - July 2017, May 2018
- Penrith October 2016, July 2017
- Wollondilly July 2017, August 2019
- Blacktown City May 2018
- Blue Mountains City May 2018
- The Hills Shire June 2018
- Hornsby November 2018
- Wingecarribee August 2018
- Liverpool City May 2018.

Council officers have been nominated who can act as ongoing points of contact with INSW Directorate to provide input to specific areas including flood risk management, land use planning communications and engagement, data and GIS, and roads and asset management.

4.2.3.7 Social and economic impacts

The overall social and economic impacts of the Project are expected to be beneficial, as a principal outcome is a wholesale reduction in flood risk exposure within the downstream environment. A reduced frequency and magnitude of flooding will result in a lessening of flood damages associated with impacted property. The risk to life within the downstream environment will also be reduced from both a lower exposure to flood hazards and improvements in flood emergency response reliability. However, there will be some negative impacts that require consideration, including:

- potential -albeit infrequent occurrence of prolonged road and bridge closures
- potential reduction in the long-term benefits of periodic flood inundation for agricultural land

- potential reduction in wetland health if adversely impacted by the changed long-term flooding regime.

The Socio-Economic, Land Use and Property Assessment provides more information on the socio-economic impacts of the Project.

Changes in the number of residential properties affected by flooding

The number of residential properties in 2018 affected by flooding with and without the Project is shown in Table 4-9. The largest reduction in the number of residential properties affected by flooding due the Project is between the 1 in 50 and 1 in 1000 chance in a year events when only about a third as many properties are flooded compared to the existing situation. The reduction in the number of properties flooded in the PMF due to the Project is relatively low in comparison to other events and it is not feasible or cost effective to raise the dam to provide substantial flood mitigation for this extremely rare event.

Table 4-9 Number of residential properties affected by flooding for a range of flood events with and without dam raising (2018)

Flood event (yr)	Existing dam	Dam raising	Change	
			Number	%
1 in 5	730	370	-360	-49
1 in 10	1,670	820	-850	-51
1 in 20	2,500	1,480	-1,020	-41
1 in 50	4,800	1,980	-2,820	-59
1 in 100	7,600	2,420	-5,180	-68
1 in 200	10,000	3,500	-6,500	-65
1 in 500	15,500	5,900	-9,600	-62
1 in 1,000	19,600	9,600	-10,000	-51
1 in 2,000	23,600	15,100	-8,500	-36
1 in 5,000	26,200	20,100	-6,100	-23
PMF	36,700	32,800	-3,900	-11

Economic Cost

The economic cost to the community, business and the NSW Government includes damages to residential properties, pubic infrastructure, commercial properties, assets and other structures. Damage costs would mostly be due to flooding impacts on private residences however, commercial properties and public infrastructure would also be damaged and require repair.

With the Project, the flood damage estimates would typically be reduced by approximately 74 to 80 percent for floods up to about the 1 in 200 chance in a year event, reducing to approximately 50 percent for a 1 in 2,000 year chance in a year event.

4.2.4 Operation of the flood management zone

Current Warragamba Dam flood operating protocols are based around capturing water until the full supply level is reached and then discharging any excess water to protect the dam from overtopping and damage.

Raising the dam wall and creation of the FMZ would require modification of the operational rules of dam releases. An initial assessment and development of preliminary operating protocols was completed by WaterNSW (2017). These are shown on Figure 4-45 and summarised below. Final operational protocols will be further developed in conjunction with detailed design of the dam and in consultation with stakeholders responsible for flood management and emergency response in the downstream floodplain.

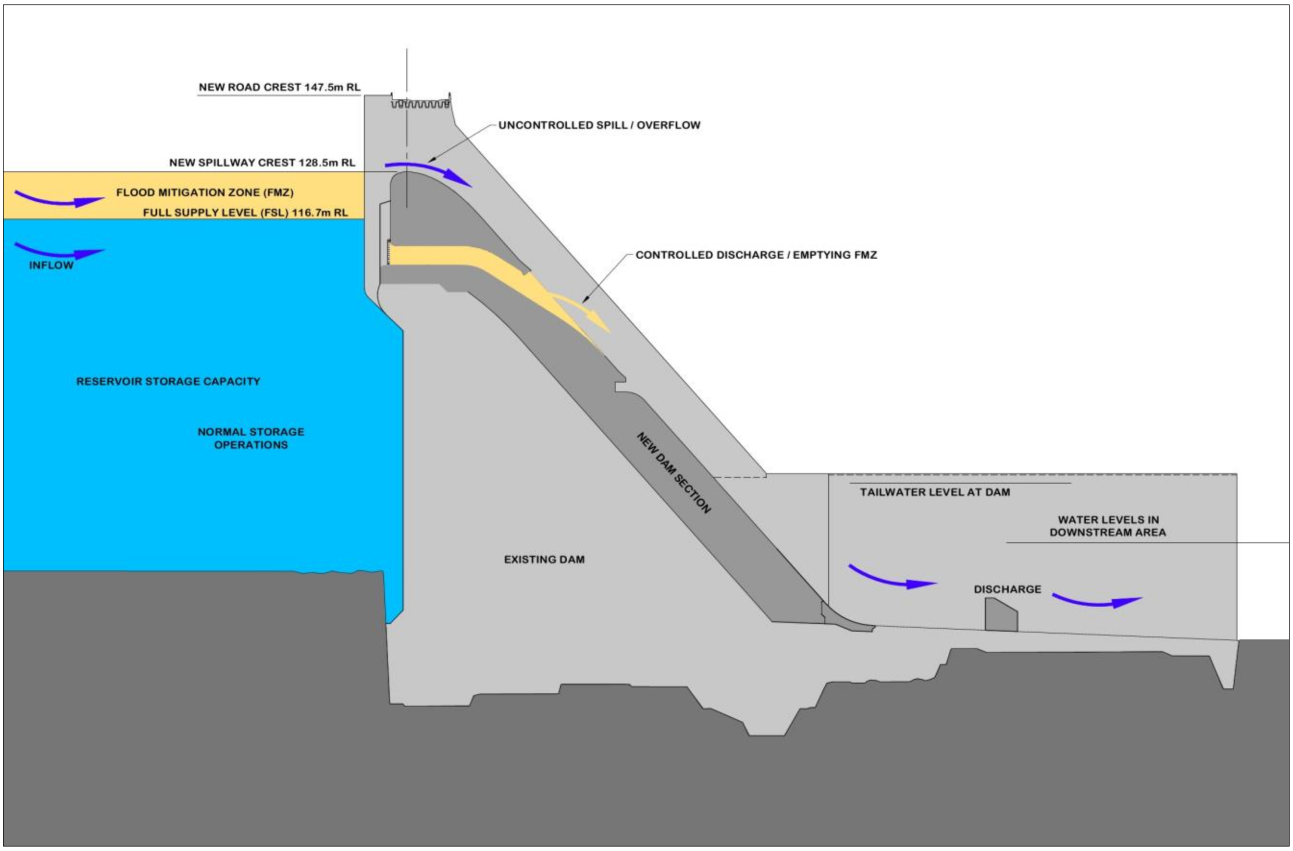

Figure 4-45 Potential operational phases for operation of Project

4.2.4.1 Normal storage operations

Normal storage operations for the modified dam would generally be the same as current operations. Inflows would be captured up until the full supply levels is reached after which either FMZ maintenance or FMZ operation procedures would be implemented.

The only difference is that variable e-flows would occur during normal operations. Currently a scaled 90/10 e-flows is proposed (see Appendix H2), however further assessment would be undertaken to determine the optimal e-flows regime based on environmental benefits and costs.

4.2.4.2 FMZ maintenance

Minor rainfall events and associated inflows may result in small increases in the dam water level, which in turn may exceed the full supply level. Once the water level in the dam reaches a nominated level above the full supply level (and no significant rainfall is predicted), the FMZ maintenance protocols would be implemented. These include discharging approximately 48 gigalitres of water via the conduits until the dam water level drops to the full supply level. While this could be undertaken in a single day with minimal downstream impacts, the discharge rate would be determined by several factors including downstream water levels and the predicted short-term rainfall forecast. The need for maintenance discharges may be minimal depending on the e-flows regime adopted.

4.2.4.3 FMZ operation

Operation of the FMZ would occur during significant rainfall events and when the water level in the dam is above the full supply level. For most rainfall events the dam would capture all flood inflows until uncontrolled spilling occurs.

4.2.4.4 FMZ discharge

The timing and rate of water discharge from the FMZ would vary depending on several factors including:

- during inflow events: Minimise flood extents, maintain evacuation routes and minimise other flooding impacts
- after an inflow event: Restore flood mitigation capacity as quickly as possible while minimising additional flood impacts
- upstream catchment: Minimise the inundation time and impacts on the upstream catchment.

The timing and rate of discharge during inflow events would be determined on a case-by-case basis. Generally, the discharge of water from the FMZ during an inflow event would only occur:

- when there was a reliable prediction of significant future rainfall
- when the discharge would not cause unacceptable downstream flooding impacts.

Piggyback discharges

The most effective way of discharging the FMZ in a manner that restores the availability of the FMZ as soon as practical while minimising additional flooding impacts is to “piggyback” discharges after the peak flood level has been reached. Local catchment flooding causes the river to rise, in addition to any overflows from the dam. The FMZ holds upstream floodwaters behind the dam wall, thus reducing the downstream peak flood levels. FMZ releases are made after the flood at the downstream location has peaked; with a slight delay and a temporary fall in river levels whilst downstream peak is confirmed. The FMZ is then discharged at a rate that does not cause the river to exceed the previous flood level peak and is gradually reduced in stages. Therefore, the FMZ releases would not impact anywhere that had not already been affected by the preceding flood.

The maximum discharge rate through the new outlet conduits would be 230 gigalitres per day. This is equivalent to a 1 in 5 chance in a year flood event on the Richmond-Windsor floodplain, and consequently piggybacking at this rate would be suitable for any downstream flood greater that a 1 in 5 chance in a year flood event. For smaller floods events, the discharge rate would need to be reduced to reflect peak flood levels.

Piggybacking of discharges would generally occur for only two to three days after the peak of a flood event, after which a constant discharge rate of about 100 gigalitres per day would be implemented. For smaller flood events (1 in 20 chance in a year and lower), piggybacking would not be possible, and a constant discharge would need to be adopted.

Constant discharge

A constant FMZ discharge rate of 100 gigalitres per day was assessed against a range of environmental, social, and economic factors (Table 4-10). Two of the key factors for the discharge rate would be impacts on the three regional bridges crossing the Hawkesbury-Nepean River at Yarramundi, Richmond, and Windsor, and impacts on the North Richmond WFP.

The three bridges provide access to and from the north of the river and are the primary routes for communities north of the river to access the Sydney metropolitan area and major social infrastructure. Alternative routes involve considerable travel (100+ kilometres) and are not viable options for extended periods of time. Roads and Maritime Services (RMS) has indicated that the closure of Yarramundi Bridge would occur at a flow rate of around 80 gigalitres per day, Richmond Bridge at a flow rate of around 90 gigalitres per day, and the new Windsor Bridge and approaches at around 100 gigalitres per day. Consequently, a constant discharge rate of about 100 gigalitres per day may allow the new Windsor Bridge to reopen and possibly Richmond Bridge, depending upon flows from the other catchment. The existing Windsor Bridge would be closed at 100 gigalitres per day release rates from Warragamba Dam.

The North Richmond WFP supplies drinking water to 60,000 people in Richmond, Windsor, and surrounds. It draws water directly from the Hawkesbury-Nepean River and has issues treating raw water when the river water is too turbid, which typically occurs when river flow increases to approximately 60 gigalitres per day. Major water mains are also located on the Richmond and Windsor river crossings. When these bridges are closed because of flooding the water mains on the bridges are isolated to protect the water supply system from damage and leakage. Typically, there would be sufficient drinking water in the system to supply customers for two to three days, however for extended periods of water main isolation, water supply issues may occur. However, water quality of the FMZ would be higher than typical wet weather water quality in the Hawkesbury-Nepean River. This is because at Richmond the flood water would also contain runoff from urban and agricultural areas within the downstream catchment, which would be more polluted than the runoff from the heavily vegetated Warragamba catchment. Once the constant discharge of the higher quality water from the FMZ has commenced the more polluted runoff from the other catchment areas would have ceased and therefore it is expected that water quality around Richmond would remain suitable for drinking water extraction.

Table 4-10 Potential impacts of 100 gigalitres per day discharge rate

Area of concern: Increase in downstream river levels (above normal)	100 GL/day flow rate in the river
Penrith	+2.5 m
Richmond	+6.8 m
Windsor	+5.5 m
Sackville	+2.1 m
Backwater flooding	40% of creeks between Yarramundi and Lower Portland visibly affected.
Overbank flooding	None.
Irrigation	A significant number of irrigation pumps would not be able to be replaced to their typical dry weather location.
Agriculture	Some grazing lands and turf farms affected. Minimal impact on other agricultural uses.
Commercial fishing	Catchability of some species will alter (positive and negative) because of habitat and water quality changes, and downstream movement of the saline wedge. However, this impact would rarely occur and be short-lived.
River dependent businesses	River based tourism operators would be unable to operate for between one to three weeks. However, this impact would rarely occur and would need to be balanced with the significant reduction in peak flooding.
Other businesses	No direct impact on land-based tourism or accommodation however, businesses that support river dependent businesses would likely be affected.
Regional bridges	Yarramundi and possibly Richmond Bridges closed. The new Windsor Bridge possibly open.
Vehicle ferries	Vehicle ferries may close. The Sackville ferry would be most affected; however, Wisemans Creek ferries may be open.
Floodplain road network	Only the two bridges over Cattai Creek are affected.
Richmond-Windsor drinking water supply	Water quality impacts possibly manageable. Two to three days' supply available after delivery system shut down.
Local sewerage systems	Not affected.
Residential housing	Not affected.
River access and amenity	Wharves, jetties, and pontoons unusable upstream of Sackville. Boat ramps generally unusable. Mud sediment and debris deposition may be an issue.
Recreational river use and safety	Water velocity and debris loading hazardous. Swimming and non-motor boating not recommended upstream of Lower Portland. Motor boating not recommended upstream of Sackville North. Access to fishing spots may be restricted.
Caravan and water ski parks	Facilities and park access not affected. However, debris loading and some river access restrictions may be increased.

Area of concern: Increase in downstream river levels (above normal)	100 GL/day flow rate in the river
Land based recreation	Some parts of the lower section of the Great River Walk are closed. Two urban parks and two nature reserves are affected. One polo field is closed.
River water quality	It is expected that the higher FMZ releases would generally have a positive effect on water quality due to their “flushing” of the river and destratification of the deeper pools, particularly in the upper reaches.
Aquatic macrophytes and weeds	Likely to remove or relocate rooted weeds. Flushing effects can be beneficial in removing floating weeds. Floating weed mats can cause infrastructure damage downstream.
Riparian vegetation	Riparian vegetation may benefit from higher flows in the river.
Riverbank erosion and protection	Medium flows are likely to result in some erosion. Older structures may degrade or collapse.
Fish and fish passage	It is expected that increased flows in the river of 40 GL/ day would have a positive impact on fish and fish passage as natural barriers would be removed. Further investigation is required to confirm that these release rates are not disadvantageous (that is, too high) for fish and fish passage.
Wetlands	Marginal benefit.
Natural and European heritage	None.
Aboriginal heritage	None.

4.2.5 Stormwater impacts and other operational requirements

The Project would result in a minor increase in the impervious areas of dam infrastructure. However, as the increase in impervious area would be small, the activities associated with the dam are generally non-polluting and the downstream environment has sufficient capacity and no local flood sensitive receivers, any change in the quality or quantity of stormwater would have negligible impact.

Apart from environmental flow releases, the Project would not require additional water for operations compared to the existing situation.

4.2.6 Climate change

WMA Water (WMA Water, 2017) were commissioned by INSW to investigate potential impacts of climate change in relation to the Project. The outcomes of their assessment are summarised below.

The impact of climate change on flood producing rainfall is quite complex and there is still considerable uncertainty around exactly how a warming climate will influence flood behaviour. Warmer temperatures increase the moisture carrying capacity of the atmosphere and theoretically will lead to higher rainfall, but the causes of rare floods are more complex. Nearly all major floods in the Hawkesbury Nepean are caused by an east coast low, an intense low pressure weather system that can occur on average several times each year off the eastern coast of Australia. The overall frequency of this weather system and how often they impact the Hawkesbury Nepean is also likely to change along with how dry catchments are and the dam levels prior to a flood. It is also likely that climate change will cause proportionally higher increases in rainfall in locations where the terrain orographically enhances rainfall. While there is some uncertainty about how climate change will affect rainfall, the Project climate change assessment used work by CSIRO, BoM and the NSW NARCLIM project.

4.2.6.1 Climate cycles – ENSO and IPO

The flood record on the east coast of Australia exhibits periods of a decade or longer timescale that are flood or drought dominated. This was first recognised by Erskine and Warner in 1988.

Short term climate variability on the east coast of Australia is characterised by the inter-annual El Nino/Southern Oscillation (ENSO). There is a marked increase in flood risk in Eastern Australia during the La Nina phase. The El Nino phase typically contains few major floods (Trenberth, 2011).

There is also considerable evidence that longer term processes have a major impact on flood risk. The Inter-decadal Pacific Oscillation (IPO) is a pattern of Pacific Ocean temperature variation that shifts phase at a timescale typically lasting 15-30 years. On the east coast of Australia there is a considerable increase in flood risk during an IPO negative period (Micevshi et al, 2006). The three largest recent flood events in the Hawkesbury-Nepean system (1867, 1864 and 1961) all occurred in IPO negative periods.

Understanding the influence of ENSO and IPO and how the IPO modulates individual ENSO events is very important to understanding how changes to the broader climate will affect flood risk. While there is a well-understood relationship between IPO negative periods and flooding, the interaction is quite complex. The El Nino phase and IPO negative phase result in higher than average rainfall and this has a two-fold effect, as not only does the probability of flood producing rainfall increase, but more importantly this rainfall is more likely to occur during a period when the catchment is considerably wetter than average. Wet antecedent conditions are well documented as having a strong influence on the resulting flood magnitude as much more of the rainfall becomes runoff.

ENSO and IPO have a large impact on dam levels before a major flood event as dam level behaves in a similar way to soil wetness but with a much longer memory, with dam levels being much higher during wet periods. In the Hawkesbury Nepean there is a strong multidecadal wet dry cycle that partially aligns with the IPO cycle.

4.2.6.2 Potential impacts

There is strong evidence that increases in global temperatures will lead to an increase in the intensity of rare rainfall, and that extreme flooding globally has increased over the 20th century (Trenberth, 2011). Global warming has been observed for several decades and has been linked to changes in key parts of the hydrologic cycle including changes in rainfall behaviour, rainfall intensity, soil moisture and runoff (Bates et al, 2008).

Climate change can alter flood behaviour in the Hawkesbury-Nepean by changing:

- probability of long duration rainfall intensities

- storm type and frequency
- rainfall spatial and temporal patterns
- antecedent conditions
- dam levels prior to flood producing rainfall.

The interaction of these characteristics makes predicting the impact of climate change on flood behaviour complex.

4.2.6.3 Assessment of potential impacts of climate change

The best available information on climate change is based on research projects by Commonwealth Science and Industrial Research Organisation (CSIRO) and others as part of ARR (Engineers Australia, 2014). This work recommends an interim approach based on simple temperature scaling using temperature projections from the CSIRO future climates tool (CCinA REF). Scaling based on temperature is recommended as climate models are much more reliable at producing temperature estimates than rainfall, and an ensemble of climate models can be used to estimate annual mean surface temperature. Several Representative Climate Pathways (RCP) were assessed – and these were based upon different emissions scenarios and the resultant increases in temperatures and rainfalls in the future years. The four scenarios assessed were:

- 4.9 % increase in rainfall (high emissions by 2030)
- 9.1% increase in rainfall (low emissions by 2090)
- 13.9% increase in rainfall (medium emissions by 2090)
- 18.6% increase in rainfall (high emissions by 2090).

The selection of these specific emission scenarios complied with the approach recommended in Australian Rainfall and Runoff 2016 (and the latest 2019 version).

The changes in the probability of a 1% AEP event with different increases in rainfall are presented in Table 4-11. For example, if rainfall intensities increased by 18.6%, the existing 1% AEP rainfall would have a probability equivalent to a 2.27% AEP event. The probability of a 1% AEP event increases substantially even for small increases in rainfall – and provides further justification for the Project.

Table 4-11 Change in probability of a 1% AEP event by 2090 (ratio compared to current climate)

Location	Equivalent probability of 1% AEP event with different increases in rainfall			
	+4.9%	+9.1%	+13.9%	+18.6%
Windsor	1.26	1.53	1.86	2.27
Penrith	1.28	1.55	1.86	2.20

4.2.6.4 Climate change impacts on the Project

The increase in rainfall due to climate change would result in an increase in flooding downstream with the existing dam and a deterioration in the flood mitigation capacity of the dam with the Project.

Table 4-12 shows both effects and also shows results from creating a range of larger FMZs than proposed by the Project. For example, with the existing dam a current 1% AEP flood level, would change to a 1.53% AEP if rainfall was to increase by 9.1%. With the Project, the current 1% AEP flood level would only be experienced in a 0.17% AEP flood event at Windsor and a 0.2% AEP flood event at Penrith. If rainfall was to increase by 9.1%, the flood events at which the current 1% AEP flood level would be experienced would increase in frequency to a 0.3% AEP event at Windsor and a 0.33% AEP event at Penrith.

This demonstrates the increased flood risk and the deterioration in Project flood mitigation capacity due to climate change. If rainfall was to increase by 9.1 percent, the Project FMZ would need to be raised by three meters by 2090 to have about the same flood mitigation capacity as the Project FMZ under existing rainfall conditions.

Table 4-12 Change in probability (Year ARI) – Existing dam and raised dam by 2090

Location	Dam scenario	Current climate	Future probability of 100 year ARI event with different increases in rainfall by 2090			
			4.9%	9.1%	13.9%	18.6%
Penrith	Existing dam	100	78	65	54	46
	14m FMZ	508	377	302	238	184
	15m FMZ	622	465	361	283	224
	16m FMZ	759	577	443	337	268
	17m FMZ	945	708	553	415	320
	18m FMZ	1206	NA	665	NA	NA
	19m FMZ	1486	NA	811	NA	NA
	20m FMZ	1701	NA	997	NA	NA
Windsor	Existing dam	100	80	65	54	44
	14m FMZ	589	421	335	256	197
	15m FMZ	731	496	388	298	236
	16m FMZ	808	607	458	348	277
	17m FMZ	954	750	552	404	321
	18m FMZ	1100	NA	665	NA	NA
	19m FMZ	1311	NA	745	NA	NA
	20m FMZ	1486	NA	853	NA	NA

NA= Not assessed

4.3 Impacts on water users

4.3.1 Environmental flows

The Project includes the installation of environmental flow infrastructure; however, the environmental flow releases would be subject to a separate approvals under the Water Management Act 2000. Changes to the Water Sharing Plan for the Greater Metropolitan Region Unregulated River Water Sources 2011 would also be required. Environmental flow releases from Warragamba Dam would be greater than the volume of water currently released from the dam – and would likely be protected from extraction by other water users. Overall, the environmental flow releases would not affect the water availability for other water users.

4.3.2 Flood operations

Capture of overland floodplain waters (floodplain harvesting) is not used in the Hawkesbury-Nepean river system to extract water for agriculture – rather water is pumped directly from the river or tributaries. Therefore, the reduction in flood extents would not change the availability of water for water users. There would be a change in the discharge regime of water from Warragamba Dam especially for the smaller events (that is, less than 1% AEP) with lower flows during the flood event and higher flows post-flood event due the capture and discharge operations of the FMZ. A more constant and stable flow regime would potentially increase the availability of water for water users; however, this benefit would be relatively minimal given the already highly regulated nature of the river.

There would be no change in the quantity of water discharged into the Hawkesbury-Nepean River due to the Project flood operations as the Full Supply Level of Warragamba Dam would not change and all water captured in the FMZ would be discharged.

The water quality assessment undertaken for the Project indicates that the discharge of the FMZ would not have any significant impacts on water quality and water quality would either be slightly improved or demonstrate no change.

4.4 Water balance

Detailed water balance modelling was not considered necessary as the Project would only temporarily capture and then release flood waters that is, the volume of water discharged by Warragamba Dam during and post a flood event would not change with the Project. This would also occur relatively infrequently, for example between 1998 and 2018, the FMZ would have only been operational seven times for a total period of 52 days (1.2% of the time period).

5 Conclusion and recommendations

Safeguards and management measures have been developed to avoid, minimise or manage potential risks identified in this report. Relevant management and mitigation measures have been detailed below in Table 5-1.

Table 5-1 Safeguards and management measures

Impact	Environmental management measure	Responsibility	Timing
Impacts during construction	A Construction Flood Management Plan will be developed to minimise any changes in hydrology up and downstream of the dam and minimise risks to the construction site. A Dam Safety Emergency Plan will also be prepared in accordance with the requirements of Dams Safety NSW.	WaterNSW Construction Contractor	Pre-construction
Impacts from operation of FMZ	A detailed operational protocol for the operation of the FMZ will be developed in consultation with relevant downstream and upstream stakeholders.	WaterNSW	Operation
Monitoring	Investigate water monitoring systems to reflect Project changes in operational protocols. Investigate additional monitoring station downstream of the Kedumba River.	WaterNSW	Pre-operation

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