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Environmental Impact Statement – Chapter 15: Flooding and hydrology

Warragamba Dam Raising

Reference No. 30012078
Prepared for WaterNSW
10 September 2021

SMEC INTERNAL REF. 30012078

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15 Flooding and hydrology

This chapter provides an assessment of flooding and hydrology during construction and operation of the Warragamba Dam Raising. The relevant Secretary's Environmental Assessment Requirements (SEARs) are shown in Table 15-1.

Table 15-1. Secretary's Environmental Assessment Requirements: Hydrology and flooding

Desired performance outcomes	Secretary's Environmental Assessment Requirements	Where addressed
8. Flooding Desired performance outcome: 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 15.2 Section 15.6, Section 15.7
	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:	Section 15.5 Section 15.6 Section 15.7 Section 15.8 Section 15.9 Section 15.10
	(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	Section 15.5 Section 15.6 Section 15.7 Section 15.8
	(b) quantify the benefits of reducing flood affectation to developments, land, properties, assets and infrastructure	Section 15.7 Chapter 21: Socio-economic, land use and property
	(c) consistency (or inconsistency) with applicable Council floodplain risk management plans	Section 15.4 Section 15.7 Chapter 21: Socio-economic, land use and property
	(d) compatibility with the flood hazard of the land	Section 15.4 Section 15.7
	(e) compatibility with the hydraulic functions of flow conveyance in flood ways and storage areas of the land	Section 15.4 Section 15.7
	(f) downstream velocity and scour potential	Section 15.7 Chapter 22: Soils
	(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 15.4 Section 15.7

Desired performance outcomes	Secretary's Environmental Assessment Requirements	Where addressed
	(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.	Section 15.7 Chapter 21: Socio-economic, land use and property
	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 15.2 Section 15.4 Section 15.6 Section 15.7
	(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 1 in 100 year flood with the range of climate change scenarios recommended in Australian Rainfall and Runoff 2016.	Section 15.8
	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 15.4 Section 15.8
	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.	Section 15.4 Section 15.5 Section 15.6 Section 15.7 Section 15.8 Section 15.9
	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.	Section 15.7 Chapter 21: Socio-economic, land use and property
20. Water - Hydrology Long term impacts on surface water and groundwater hydrology (including drawdown, flow rates and volumes) are minimised.	1. The Proponent must consider potential alternatives for managing flood waters and justify the selection having regard to the relative environmental impacts.	Chapter 4: Project development and alternatives
The environmental values of nearby, connected and	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	Section 0 Section 15.14

Desired performance outcomes	Secretary's Environmental Assessment Requirements	Where addressed
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.	by the project, including stream orders, as per the FBA. Mapping must include upstream and downstream tributaries that may potentially be impacted, including:	Chapter 8: Biodiversity upstream Chapter 9: Downstream ecological assessment Chapter 10: Biodiversity construction area Chapter 11: Aquatic ecology Chapter 22: Soils Chapter 26: Waste Chapter 27: Water quality
	(a) the extent of regional flood up to the probable maximum flood	Section 15.6 Section 15.7
	(b) flood planning area, the area below the flood planning level (area below the 100 year ARI plus freeboard)	Section 15.6 Section 15.7
	(c) hydraulic categorisation (floodways and flood storage areas)	Section 15.4 Section 15.7
	(d) hazard categorisation. The extent of mapping/modelling used needs to be identified and rationalised.	Section 15.4 Section 15.7
	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 0
	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 15.5 Section 15.6 Section 15.7
	(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 and velocities), aquatic connectivity and access to habitat for spawning and refuge	Section 15.4 Section 15.5 Section 15.6 Section 15.7 Chapter 8: Biodiversity upstream Chapter 9: Downstream ecological assessment Chapter 10: Biodiversity construction area Chapter 11: Aquatic ecology

Desired performance outcomes	Secretary's Environmental Assessment Requirements	Where addressed
	(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	Chapter 8: Biodiversity Upstream Chapter 9: Downstream ecological assessment Chapter 10: Biodiversity construction area Chapter 11: Aquatic ecology Chapter 22: Soils
	(c) changes to environmental water availability and flows, both regulated/licensed and unregulated/rules-based sources	Section 15.7 Chapter 11: Aquatic ecology
	(d) direct or indirect increases in erosion, siltation, destruction of riparian vegetation or a reduction in the stability of river banks or watercourses	Section 15.7 Chapter 8: Biodiversity upstream Chapter 9: Downstream ecological assessment Chapter 22: Soils
	(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	Section 15.5 Section 15.6 Section 15.7 Chapters 22: Soils Chapter 26: Waste
	(f) water take (direct or passive) from all surface and groundwater sources with estimates of annual volumes during construction and operation.	Section 15.5 Section 15.6 Section 15.7
	5. The Proponent must identify any requirements for baseline monitoring of hydrological attributes.	Section 15.12
	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 15.8
	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	Section 15.5 Section 15.6 Section 15.7

Desired performance outcomes	Secretary's Environmental Assessment Requirements	Where addressed
	would include an assessment of environmental availability, both regulated and unregulated use, licenced and rules-based sources of such water.	Chapter 21: Socio-economic, land use and property
	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 15.6 Section 15.7 Chapter 8: Upstream biodiversity Chapter 9: Downstream ecological assessment Chapter 27: Water quality

1 This chapter specifically addresses SEARs 8 and 20, in addition to those general requirements of the SEARs applicable to all chapters and as identified as such in Chapter 1 (Section 1.5, Table 1-1).

The flooding and hydrology assessment is supported by detailed investigations, which have been documented in:

- Flooding and hydrology assessment report (BMT Eastern Australia Pty Ltd 2019, Appendix H1)
- Flood risk analysis (WMAwater 2020, Appendix H2).

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

15.1 Project overview

15.1.1 Project description

Warragamba Dam and its reservoir, Lake Burragorang, operate for the supply of potable water to the Sydney region. The dam provides water to the Prospect water filtration plant, which supplies treated water to approximately 80 percent of Sydney's population. Water from the dam is also supplied to the townships of Warragamba, Penrith, and the Lower Blue Mountains through smaller filtration plants at Warragamba and Orchard Hills. Water is also released into the Warragamba River to provide a secure water supply to the population of North Richmond and as environmental flows. Current operations comprise:

- fixed low flow releases of 22 megalitres per day in winter and 30 megalitres per day in summer, of which five megalitres per day 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 inflows cause the storage levels to rise above full supply level (FSL) the dam is operated per H14 rules or protocol. The H14 rules are 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 flood mitigation to reduce the significant existing risk to life and property in the Hawkesbury-Nepean Valley downstream of the dam. This would be achieved through raising the level of the central spillway crest by around 12 metres and the auxiliary spillway crest by around 14 metres above the existing full supply level (FSL) for temporary storage of inflows. The spillway crest levels and outlets control the extent and duration of the temporary upstream inundation. There would be no change to the existing maximum volume of water stored for water supply.

The Project would delay downstream flooding, which would reduce current downstream flood peaks and increase the time taken for downstream water levels to recede. The dam would be subject to the following operational regimes, depending on the water level:

Normal operations

Current operations would apply when the reservoir level is at or lower than the FSL, which is when the water level in the dam is at or below 116.7 metres Australian Height Datum (mAHD).

Flood operations

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

Operational objectives in order of priority are to:

- maintain the structural integrity of the dam
- minimise risk to life
- maintain Sydney's water supply
- minimise downstream impact of flooding to properties
- minimise environmental impact
- minimise social impact.

15.1.2 Project location and study area

The Hawkesbury-Nepean River drains a catchment of 22,000 square kilometres from the Great Dividing Range to the Pacific Ocean at Broken Bay. Warragamba Dam is located approximately 65 kilometres west of Sydney in a narrow gorge at the start of the Warragamba River, 3.3 kilometres before it joins the Nepean River. The Nepean River then becomes the Hawkesbury River at the junction of the Grose River at Yarramundi. The entire river is called the Hawkesbury-Nepean River. The area downstream of the dam supports several major population centres including the towns of Wallacia, Penrith, Richmond and Windsor.

The topography of the Hawkesbury-Nepean Valley varies from rugged and mountainous terrain, which covers nearly half of the area, to floodplains. The latter accounts for only a small percentage of the total area but contains most of the urban development. The catchment is generally aligned south to north, rising to 600 mAHD near the Avon River, 750 mAHD at the head of the Wollondilly River and about 1,200 mAHD on the Great Dividing Range at the head of the Kowmung River.

Warragamba Dam controls approximately 40 percent of the total area of the Hawkesbury-Nepean River catchment to the ocean and about 70 percent of the catchment at Windsor. There are four other major dams in the catchment upstream of Sackville on the Nepean River (Nepean, Avon, Cordeaux and Cataract dams). The total area controlled by other dams are a small proportion of the total catchment and have minimal impact on floods.

The Project study area comprises:

- upstream: area within the Project probable maximum flood (PMF) extent
- downstream: area within the current PMF (note that the downstream Project PMF area would be less than that for the current PMF).

The Hawkesbury-Nepean and surrounding major catchments are shown on Figure 15-1. The catchment area and study area relevant to the Project are shown on Figure 15-2.

Figure 15-1. Regional catchments

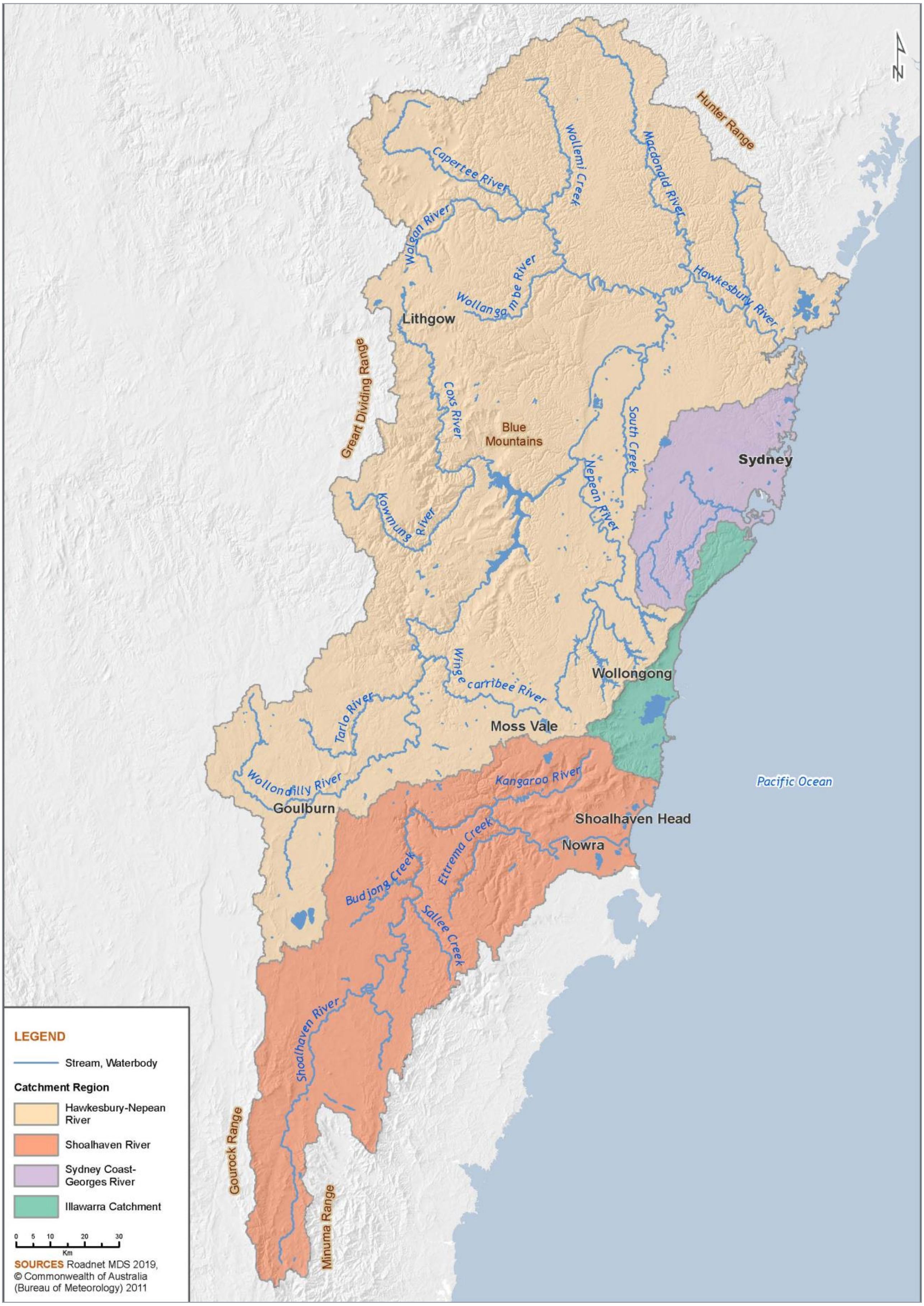
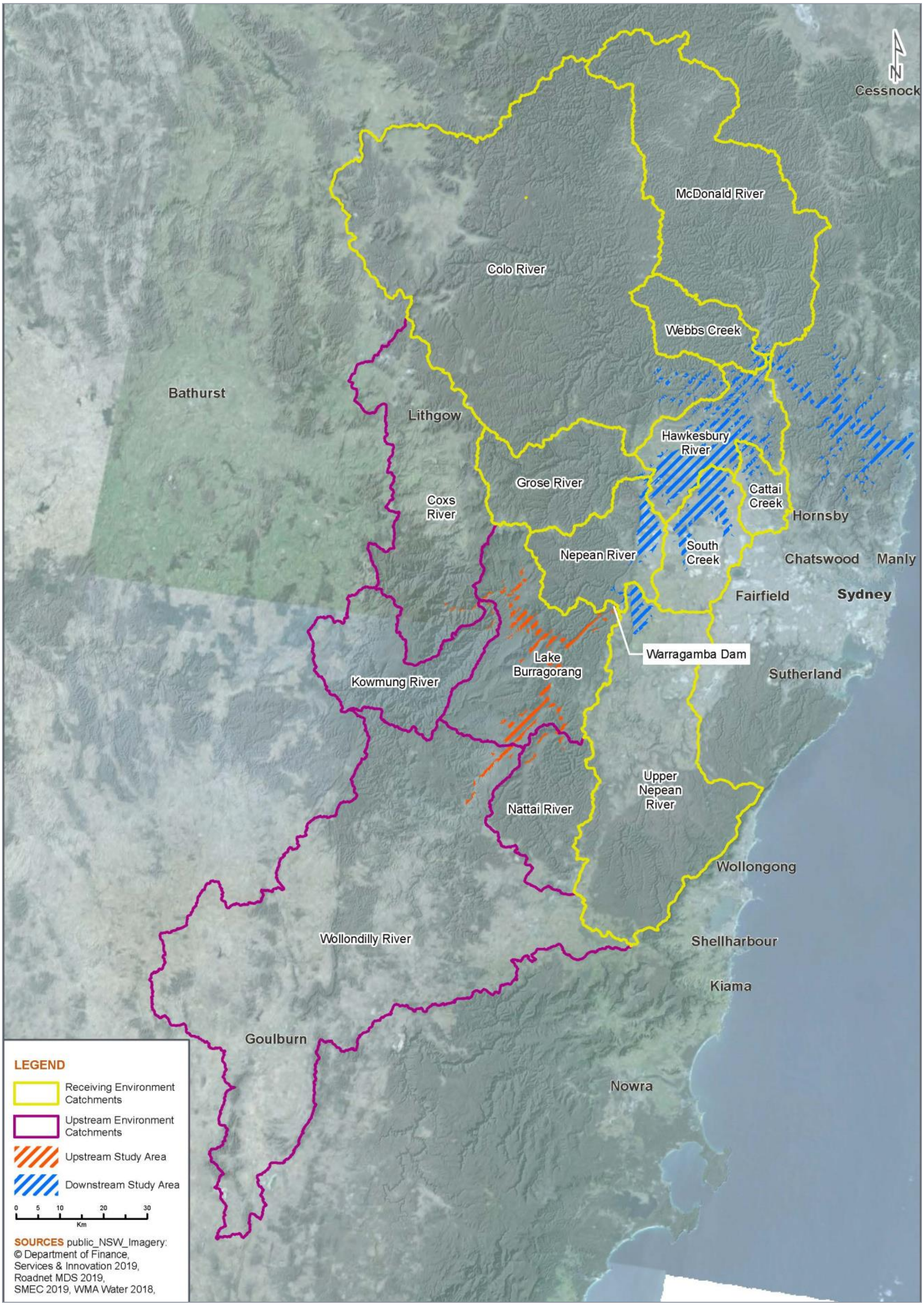


Figure 15-2. Catchment study area



15.2 Methodology

15.2.1 Studies and terminology

15.2.1.1 Flood studies

There has been ongoing flood modelling in the Hawkesbury-Nepean Valley for about 40 years. Flood modelling was carried out for the *Hawkesbury-Nepean Valley Flood Risk Management Strategy 2016-2036 (*Infrastructure NSW 2017*)* and further updated for the *Hawkesbury-Nepean Valley Regional Flood Study* (WMAwater 2019). The most recent study assesses flood behaviour of the main Hawkesbury-Nepean River from Bents Basin near Wallacia and Warragamba Dam to Brooklyn Bridge in Broken Bay, backwater flooding associated with main river flooding and effects of climate change.

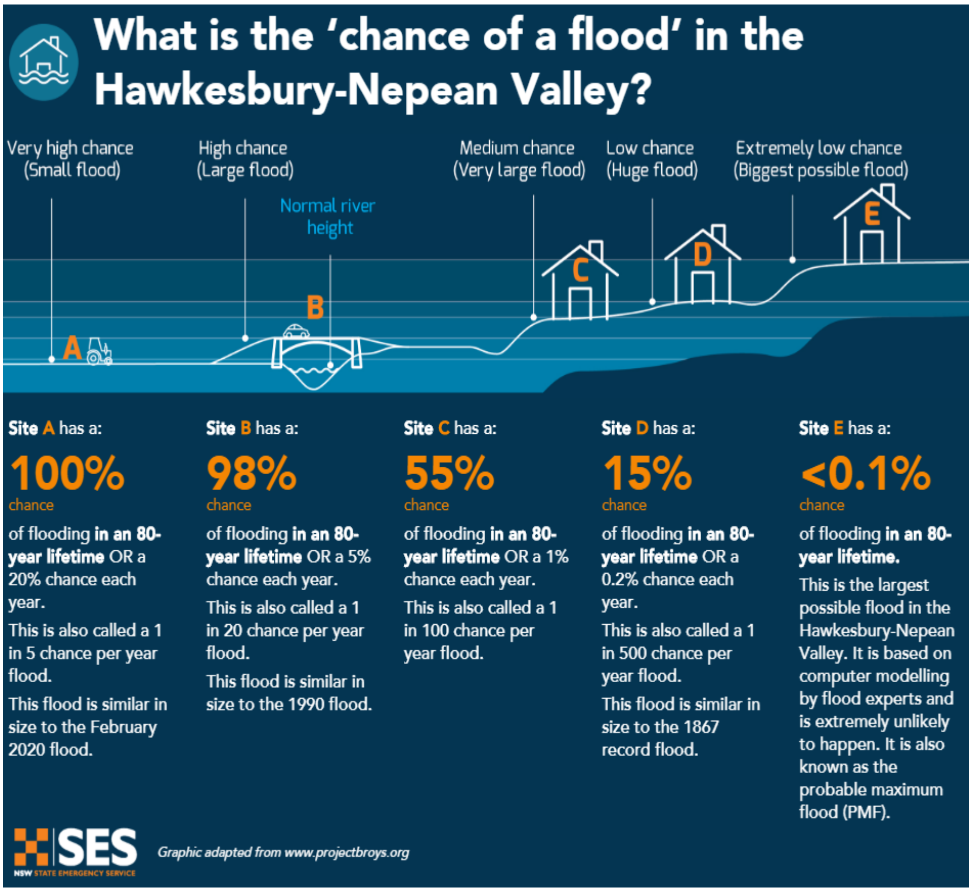
Further assessment was undertaken to assess flooding characteristics upstream and downstream of Warragamba Dam with various dam wall raising scenarios and other alternatives considered for flood mitigation (Infrastructure NSW 2018). More detailed modelling of the downstream impacts of the Project to address specific flood events outlined in the SEARs (see Table 15-1; SEARs 8 (2h) and (3a)) have also been undertaken (Appendix H2: WMAwater 2020). Study parameters and results are included in Appendix H1 (Flooding and hydrology assessment report, Section 2).

15.2.1.2 Terminology

The annual exceedance probability (AEP) is the probability of an event being equalled or exceeded within a given year. The AEP may be expressed as either a percentage (%) or 1 in 'x' chance in a year event. For example, a one percent AEP event or 1 in 100 chance in a year event has a one percent chance of the event being equalled or exceeded in any given year.

Average Recurrence Interval (ARI) is an alternate terminology representing the average time-period (years) between occurrences equalling or exceeding a given value.

Design flood terminology is summarised in Table 15-2. This and other EIS chapters use the 1 in x chance in a year terminology, which is also consistent with State Emergency Services (SES) definitions (see adjoining SES graphic). Technical reports may use other terminology, which is consistent with industry standards such as the national guideline document: *Australian Rainfall and Runoff – A guide to flood estimation* (Geoscience Australia 2019).



Ref: State Emergency Service (SES): Flood definitions
https://www.ses.nsw.gov.au/hawkesbury-nepean-floods

The maximum flood level that can possibly occur is the Probable Maximum Flood (PMF) and is the largest flood that could conceivably occur at a location, usually estimated from probable maximum precipitation, and where applicable, snow melt, coupled with the worst flood producing catchment conditions. The PMF is a hypothetical flood estimate relevant to a specific catchment whose magnitude is such that there is negligible chance of it being exceeded. It represents a notional upper limit of flood magnitude and no attempt is made to assign a probability of exceedance to such an event (AR&R 2019). In other words, the PMF is so unlikely it is impossible to estimate the chance of it occurring. The PMF is used for dam safety and emergency planning purposes and has an extremely low probability of occurrence of happening.

Table 15-2. Design flood terminology

AEP[1]	1 in x chance in a year[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 (rounded to 10)	9.5 years	As for the 0.2% AEP flood but with a 10% probability or 9.5 year return period.
20%	4.5 (rounded to 5)	4.5 years	As for the 0.2% AEP flood but with a 20% probability or 4.5 year return period.

Notes:
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 is not necessarily the same as an extreme flood.

15.2.2 Flood modelling

15.2.2.1 Flood model

Flood modelling is discussed in Appendix H1 (Flooding and hydrology assessment report, Section 2.3), which describes the assessment methodology, data requirements and selection of computer simulation models. A summary is provided below.

Hydrological model

The hydrological model simulates the rate at which rainfall runs off the catchment, which is dependent on:

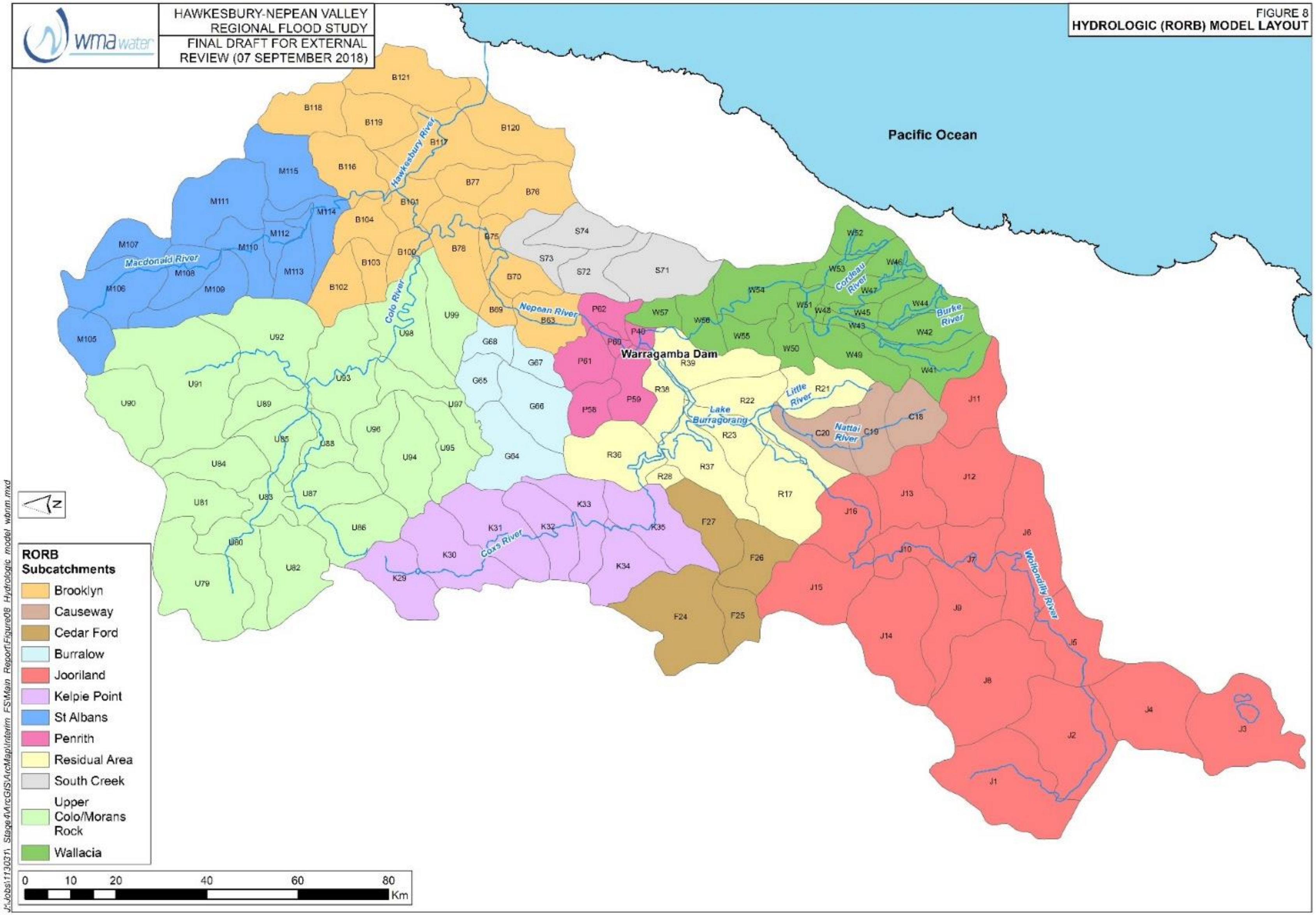
- the catchment slope, area, vegetation, urbanisation, and other characteristics
- variations in the distribution, intensity, and amount of rainfall
- moisture conditions (dryness/wetness) of the catchment.

The interactive runoff and streamflow routing program RORB was used for hydrological modelling with the catchment divided into 121 sub-areas as shown in Figure 15-3. 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 ungauged catchments in the downstream valley.

A special sub-routine, DAMROU, was added to the RORB program to model flows through Lake Burragorang, which incorporates 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).

Outputs from the hydrological model are a series of flow hydrographs at selected locations, which are used by the hydraulic model to simulate the passage of various size floods through the river channels and floodplain to produce water levels and velocities. A modelling report was prepared that provided details of the data used, model development, and calibration and verification of the model (WMAwater 2019).

Figure 15-3. Hydrological model sub-catchments



Source: Appendix H1, Figure 2-1

Hydraulic model

Hydraulic modelling of flood flows was done using the following models:

- *Upstream*: An existing MIKE 11 one-dimensional hydraulic model, which was originally developed in the 1990s to assess flow behaviour prior to the dam construction. The MIKE 11 model was used to assist in the calibration of the RORB model between the dam and the inflow gauges.
- *Downstream*: A quasi two-dimensional RUBICON model (hydrodynamic model software used to quantify the hydraulic aspects of flood behaviour) was used, which covered a river length of 360 kilometres and was calibrated and verified against ten historical flood events. A quasi calibration was also undertaken using the TUFLOW model. Modelling has been extensively reviewed and endorsed by numerous Australian and international experts (WMAwater 2019).

Modelling data and calibration

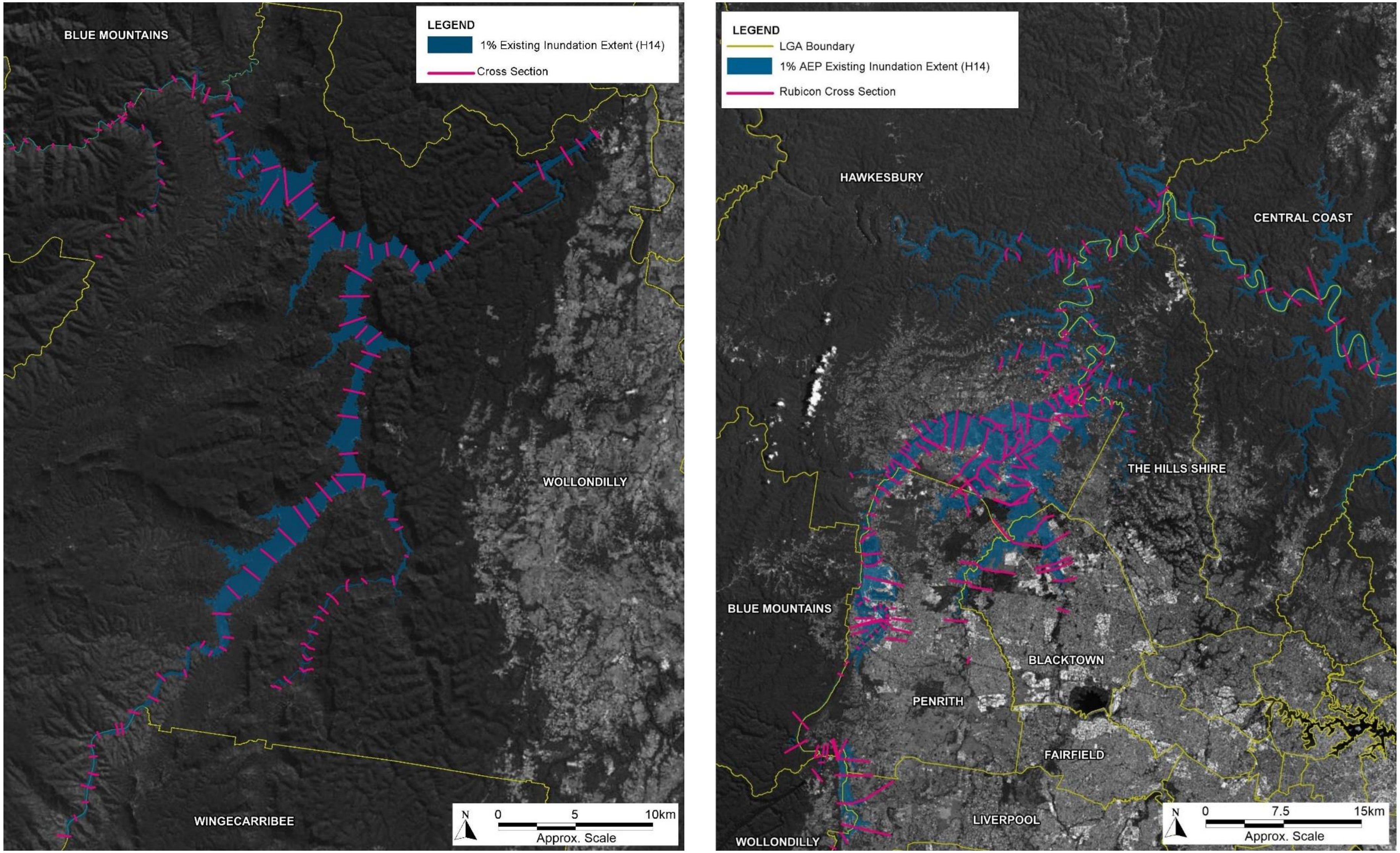
Data used in the modelling and location of data monitoring stations are discussed in Appendix H1 (Flooding and hydrology assessment report, Section 2.3) and includes the following:

- *Model cross sections*: Model cross sections are generally located approximately one to two kilometres apart and the modelled branches extend up to where gauged inflows are recorded. Cross sections are shown on Figure 15-4.
- *Rainfall data*: A comprehensive rainfall monitoring network has been installed in the catchment and in 1998 there were 93 pluviographs (real-time rainfall monitoring) and 376 daily rainfall gauges. For each calibration event a spatial pattern was created across the catchment. Temporal rainfall patterns were taken from available pluviographs for each event.
- *Stream flows*: There are over 100 stream gauging stations in the catchment. Ten representative gauging stations were chosen for use as calibration locations or for model verification.
- *Terrain*: A merged digital elevation model (DEM) was created across the catchment and was used to give an overview of the catchment and for calculation of the average slope of sub-catchments.
- *Dam operations and inflows*: WaterNSW supplied a daily time-series of Lake Burragorang lake levels from 1960 to 2017, and hourly time-series of releases for the period covering the calibration events.

Model calibration included:

- increasing the number of model sub-areas
- calibrating the model at additional locations within the catchment
- inclusion of baseflows
- The TUFLOW model was used to calibrate the model 10 historical events including a range of representative events. The model is 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.

Figure 15-4. Hydraulic model cross sections



Source: Appendix H1, Figures 2-2 and 2.1

15.2.2.2 Modelled options and events

Every flood is different due to the variability in various factors including:

- **rainfall intensity and frequency:** the number of times, during a specified period of years, that rainfall of a certain magnitude or greater occurs
- **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 storm burst
- **dam drawdown:** the level of Warragamba Dam before the start of an event
- **relative timings of dam inflows:** when water flows from rivers and streams to the dam
- **tides:** tidal influences in the Hawkesbury River.

> **Monte Carlo simulation** performs risk analysis by building models of possible results by substituting a range of values—a probability distribution—for any factor that has inherent uncertainty. It then calculates results over and over, each time using a different set of random values from the probability functions.

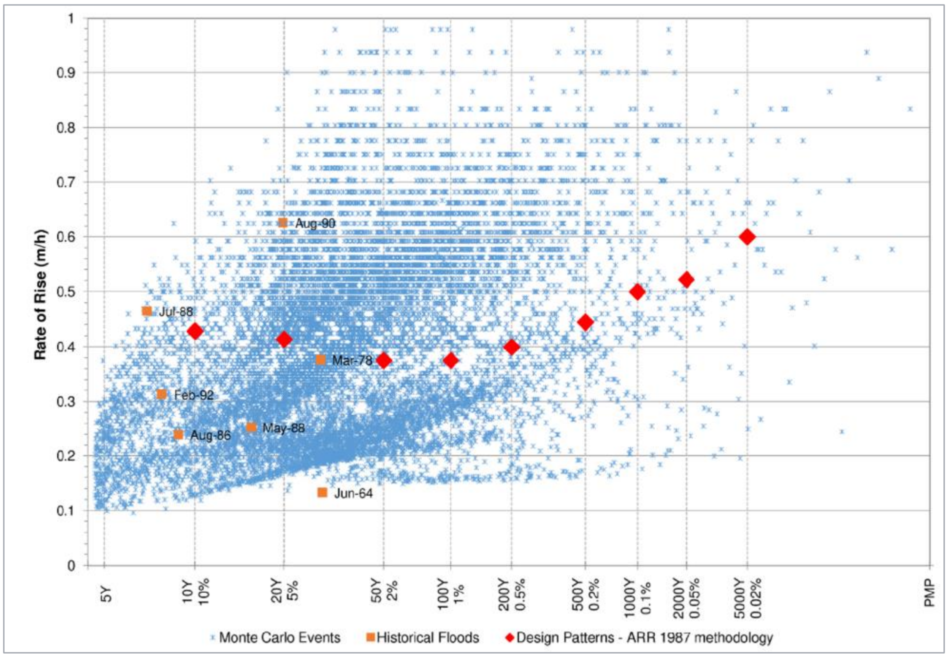
To account for this variability, a Monte Carlo approach to modelling was undertaken. This involved varying the above factors, modelling the different scenarios and then statistically analysing the hydrographs. The flood modelling framework and use of the Monte Carlo analysis considers antecedent conditions as a variable in the assessment of flooding conditions for existing and Project scenarios. Accordingly, the variability in both wet and dry conditions at the onset of flood producing rainfall is incorporated in the probabilistic estimation of the timing and response of surface water flows to rainfall, and subsequent estimation of peak flood levels and inundation extents. About 20,000 model runs were undertaken to capture the potential variability in flood events and flood events along the whole flood frequency curve were generated. A detailed description of the Monte Carlo approach to flood modelling is contained in Appendix H1 (Flooding and hydrology assessment report, Section 2.4).

The Monte Carlo approach recognises that any design flood characteristic (e.g. 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. The model outputs for a particular flood is therefore represented by an 'envelope' of events, which cover a wide range of flood durations and affected areas. This EIS has conservatively adopted the largest modelled event, which is a 'worst case' approach, and the actual impacts are likely to be less.

The hydraulic model is based on a series of discrete cross sections (refer Figure 15-4 and Figure 15-6) 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 time-step. Time-series of water levels, flow rates and flow velocities can be generated for each simulated event, and peak values for each parameter identified.

A slightly different approach was adopted for the upstream area. The MIKE11 model was not used to discretely simulate each of the Monte Carlo design flood scenarios, but rather was used to extract rating curves (flow-height relationships) under different dam raising scenarios. 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 raised dam option.

To confirm the Monte Carlo framework was accurately replicating observed flood behaviour, 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).*

As required by SEAR 8(3a), the following flooding events were assessed with and without dam raising:

- 1 in 5 chance in a year
- 1 in 10 chance in a year
- 1 in 20 chance in a year
- 1 in 100 chance in a year
- PMF

In addition, this assessment also examined the 1 in 200 and 1 in 500 chance in a year events for impact discussion and as required by SEAR 8(3b) to assess potential climate change impacts. Climate change is also addressed in Chapter 14 (Climate change risk). 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 flood events specified in the SEARs.

15.2.3 Truncation of flood extents

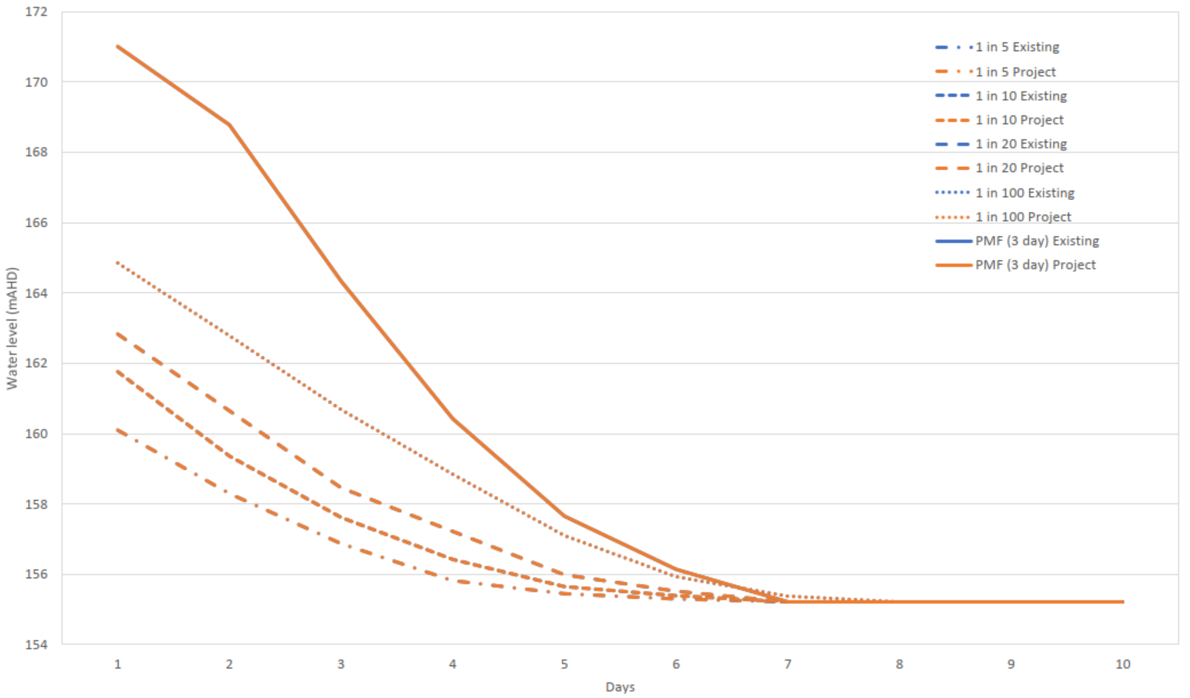
Modelling of flood extents was extended further upstream than the cross-sections at which differences between the existing and with Project flooding impacts occurred, and included areas impacted by existing local catchment flooding. Two factors were considered for assessing existing and Project affected areas:

- depth of flooding (which is effectively extent)
- duration of flooding; this can vary depending on tributary and topographical characteristics.

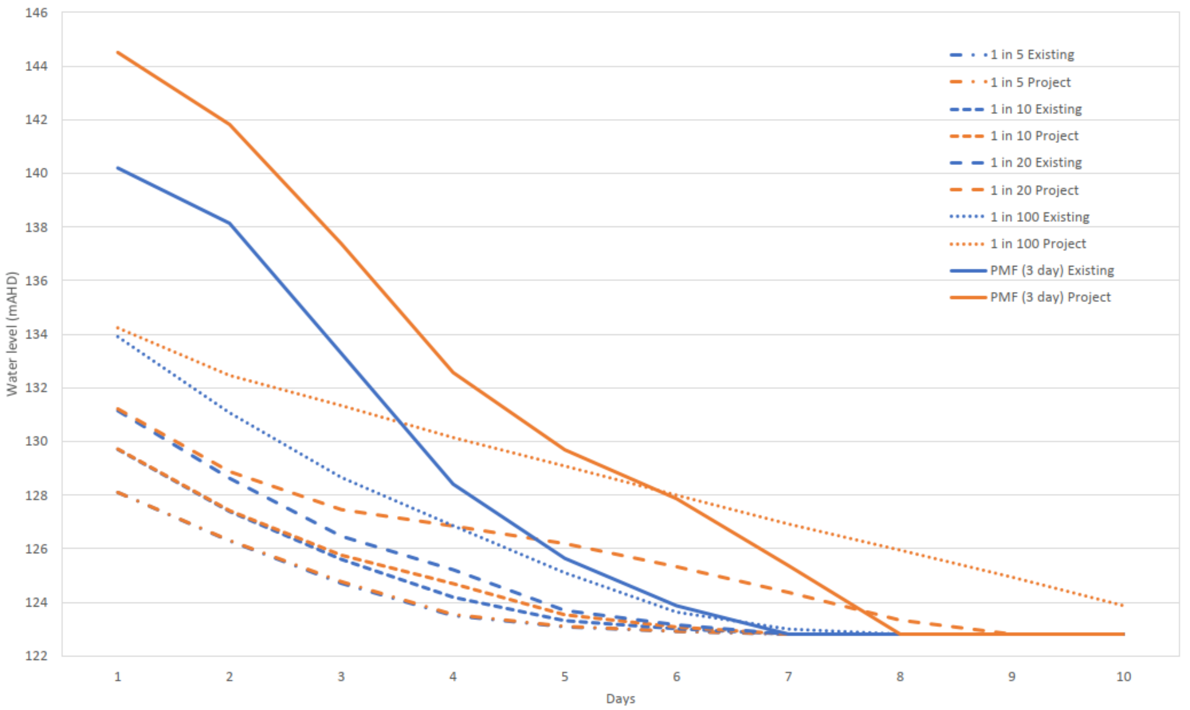
Depth-duration curves for modelled cross sections were used to identify tributary cross-sections at which there were no longer any differences between the existing and Project flood events. The modelled layers were truncated, or abbreviated, at these cross sections. For example, Figure 15-5 shows the modelled depth-duration curves for the SEARs events at an upstream cross section (WOLLONDILLY_US_0) on the Wollondilly River, which shows no material differences between the existing and Project curves at this location. A cross section (WOLLONDILLY_3380) about 10 kilometres further downstream shows considerable divergence between existing and Project flood events.

Figure 15-5. Depth–duration curve examples to show modelling truncation extent of Project influence

Depth-duration curves for SEARs events at WOLLONDILLY_US_0: ***No change***



Depth-duration curves for SEARs events at WOLLONDILLY_3380: ***Existing/Project divergence***



15.3 Existing environment

15.3.1 Upstream catchment

15.3.1.1 Catchment characteristics

The upstream environment includes the reservoir formed by Warragamba Dam (Lake Burragorang) and its tributaries, which are shown on Figure 15-6. The catchment covers an area of approximately 9,050 square kilometres and includes State Conservation Areas, National Parks and areas of the Greater Blue Mountains World Heritage Area (GBMWHA). The catchment extends to the south near Lake Bathurst, where rainfall is comparatively low, and drains to Mulwaree Ponds near Goulburn and then to the Wollondilly River, which flows north-east to Lake Burragorang. A major tributary of the Wollondilly River is the Wingecarribee River, which rises in an area of high rainfall near Bowral to the east.

The other main tributary of Lake Burragorang is the Coxs River, which extends as far north as Ben Bullen and flows north of Lake Burragorang along the western edge of the Great Dividing Range. The Coxs River has been dammed and the mid reaches of the catchment cleared to supply water and land for power generation, coal mining and agriculture. Other important but smaller waterways include the Kowmung River, Kedumba River and Nattai River, which generally drain heavily vegetated areas within the National Parks.

Geology comprises massive beds of quartz-rich sandstones containing smaller beds of slate and siltstone. Consequently, the rivers in the upstream environment are characterised by steep and high cliffs with minimal floodplain areas. Topography varies dramatically across the catchment, with typical elevations ranging between 90 mAHD and 180 mAHD near the dam, and up to around 1200 mAHD at the head of the Kowmung River. The narrow stretch of lake immediately upstream of the dam is characterised by almost vertical sandstone walls and benches, while the main lake and its tributaries are bordered by sandstone escarpments and associated colluvial slopes. Most of the catchment falls within these colluvial sloping landscapes that vary from steep to gently sloping. Terrain around the Wollondilly River and Nattai River typically consists of alluvial flats and rolling hills, while terrain around the Coxs River and Kowmung River is steep with talus and scree slopes.

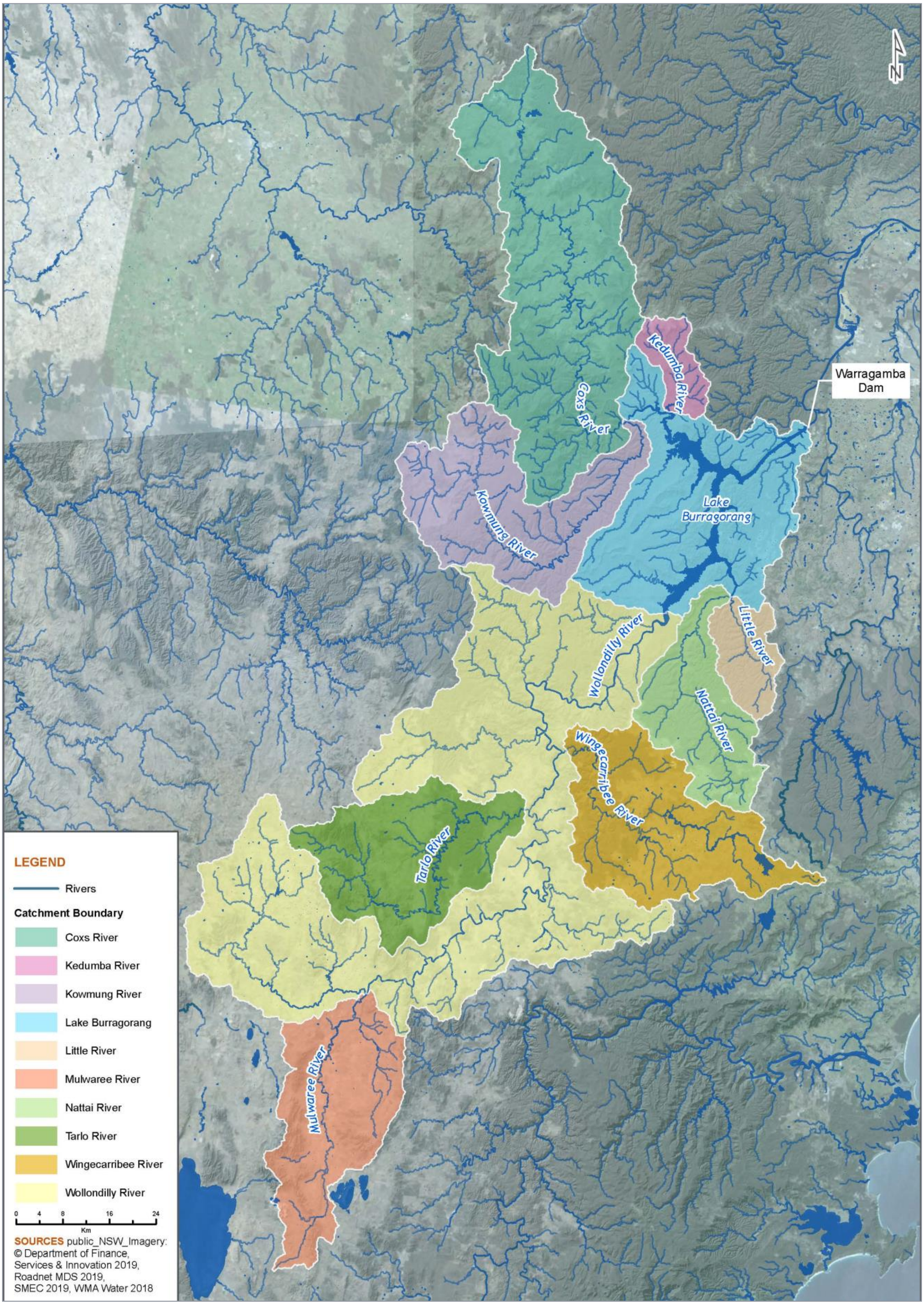
Natural vegetation is typically associated with dry sclerophyll forest of shrubby sub-formation, as well as areas of wet sclerophyll forest, dry rainforest, warm temperate rainforest, grassy woodlands and forested wetlands. In the upper catchment land uses include agricultural activities and towns, including Wallerawang, Lithgow and Katoomba in the north; and Goulburn, Bowral and Mittagong in the south.

Average yearly rainfall throughout the catchment varies from 542 millimetres at Warragamba, 863 millimetres at Oakdale (Wollondilly River) in the south and 970 millimetres at Oberon in the north-west (representative of Coxs River catchment). The highest rainfall generally occurs in the warmer months, with the highest falls occurring in February.

A previous investigation (GHD 2013b) found that 57 percent of stream reaches within the wider catchment were either in good condition or in a protected area. A section of the Kowmung River was declared a Wild River (Department of Environment and Conservation (DEC) 2005b) under the *National Parks and Wildlife Act 1974.* The Kowmung River flows through Kanangra-Boyd National Park, Blue Mountains National Park, and the Warragamba Special Areas before it enters Lake Burragorang.

One wetland (Lake Burragorang) has been identified within the development site (Department of Environment, Climate Change and Water (DECCW) 2010g). No Ramsar wetlands occur within 10 kilometres of the study area.

Figure 15-6. Upstream catchment

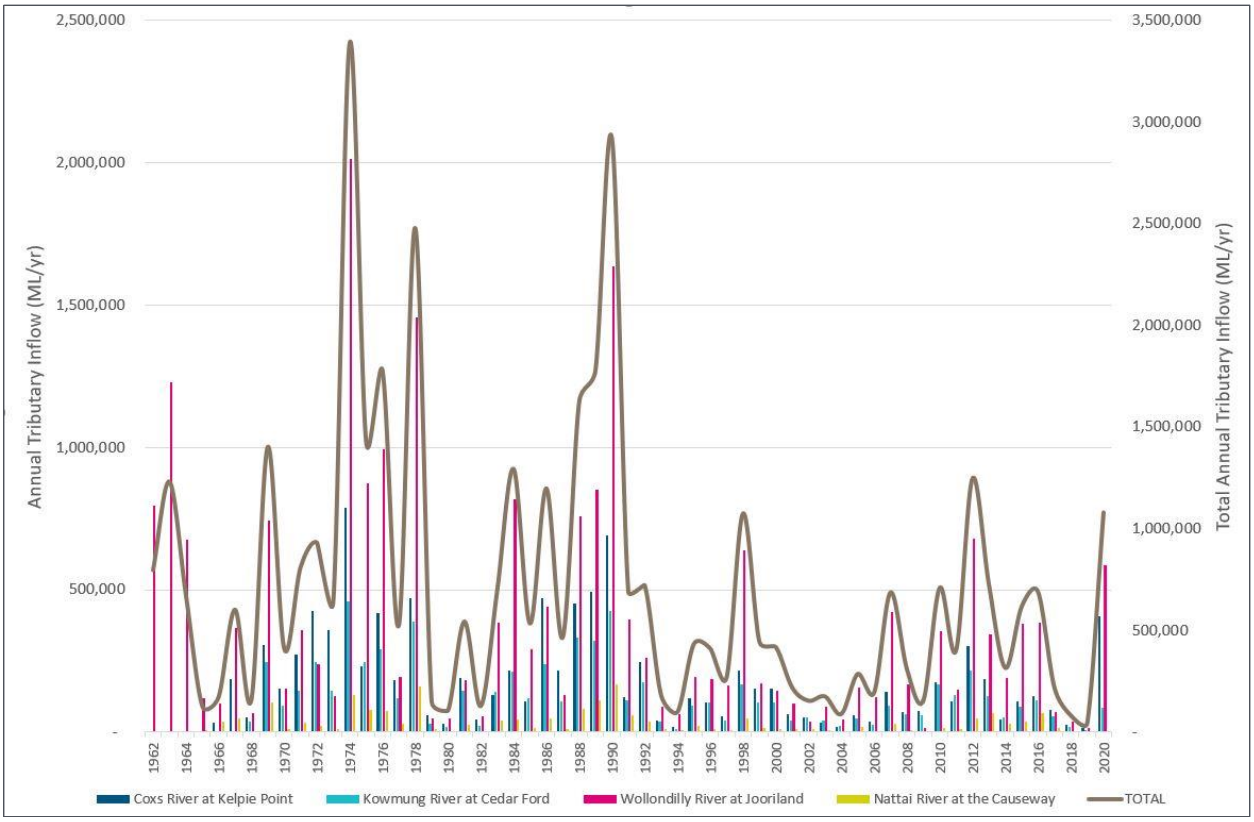


15.3.1.2 Hydrology

Lake Burragorang is 52 kilometres long, has 354 kilometres of foreshore and covers a waterway area of approximately 75 square kilometres. Warragamba Dam is situated in a steep, narrow gorge. Before the dam was built the gorge carried the Warragamba River from the junction of the Wollondilly and Coxs Rivers down to the Nepean River below Wallacia. The total length of the Warragamba River was 22 kilometres, though since the creation of Lake Burragorang it is now 3.5 kilometres long.

Major tributaries have differing flow characteristics due to variable rainfall across the upstream catchment. WaterNSW records streamflow into Lake Burragorang for the Wollondilly River, Nattai River, Coxs River (upstream of Kowmung River confluence) and Kowmung River. Annual tributary inflows and combined total inflow to Lake Burragorang between 196–2016 are shown in Figure 15-7. Total inflows to the reservoir have varied considerably since construction of Warragamba Dam, ranging from over 3,390,000 megalitres in 1974 to a low of 87,000 megalitres in 2004.

Figure 15-7. Annual tributary inflows into Lake Burragorang

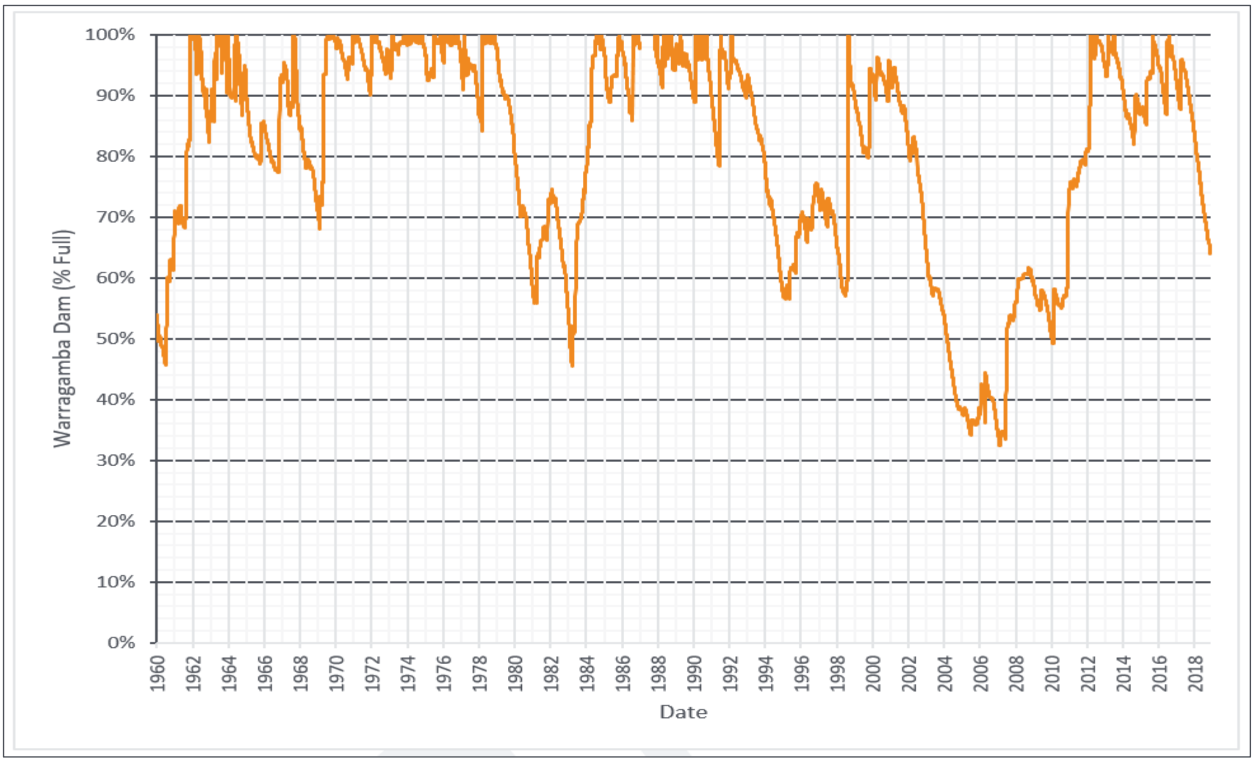


Note: During the period 2003 to 2007 the Wollondilly River inflows include transfers from the Shoalhaven.
Source: Appendix H1, Figure 3-7

Historic dam levels are shown in Figure 15-8. Since 1960 the dam storage level has been above 80 percent full for most of the time, however the level has dropped to less than 60 percent full on several occasions, and in the early 2000s the dam water level dropped below 40 percent. The dam was about 60 percent capacity in late 2018. The dam has also exceeded 100 percent capacity and spilled on numerous occasions during the 1960s and 1970s. Recent dam spills occurred in 2012, 2013 and 2015.

Lake Burragorang has altered hydrological and sediment transport regimes between the upstream catchment and downstream rivers and floodplain. The lake functions as a sediment 'sink' and reduces downstream sediment loads.

Figure 15-8. Historic dam levels



Source: Appendix H1, Figure 3-11

15.3.1.3 Warragamba Dam

Water supply development began in the Hawkesbury-Nepean catchment in the early 1880s with the construction of diversion weirs on the Nepean and Cataract Rivers. The four dams on the upper Nepean were completed between 1907 and 1935.

The Warragamba River was identified as a potential source of water supply to Sydney as early as 1845. Serious consideration was given to its use in the early twentieth century, but no work was undertaken until 1937. Construction of Warragamba Weir, one kilometre downstream of the dam site, began in that year as part of an emergency scheme prompted by the record drought. Pumping from the river started in 1940 and continued until February 1959.

Work on the construction of Warragamba Dam commenced in the late 1940s and was completed in 1960. The dam is of concrete gravity construction, 142 metres high and 351 metres wide. It holds back some 2,027 gigalitres of water.

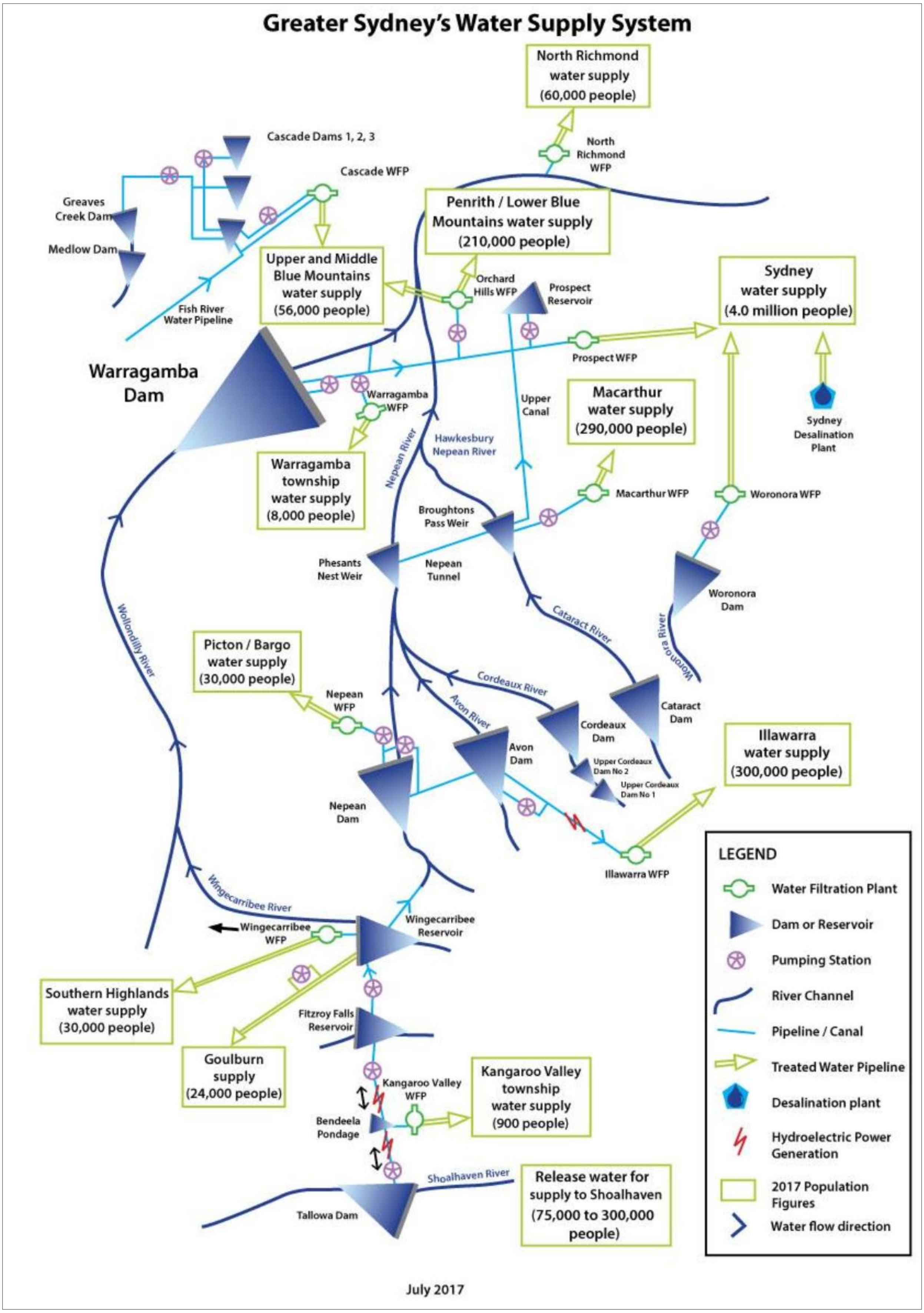
The dam's primary spillway has four radial gates and a drum gate. Construction of a secondary fuse plug spillway began in 1998 and was completed in 2002.

15.3.1.4 Dam operations

The water supply system for Greater Sydney is an integrated network of dams, pipelines, canals, tunnels, the desalination plant and rivers (Figure 15-9).

The system includes Warragamba Dam and the pipelines that connect the dam to the Warragamba, Orchard Hills, and Prospect water filtration plants (WFPs), along with the Prospect Reservoir. The water supply system yield is estimated at 570 gigalitres per year (WaterNSW 2015b) and Warragamba Dam provides up to 80 percent of Sydney's water demands.

Figure 15-9. Greater Sydney water supply system

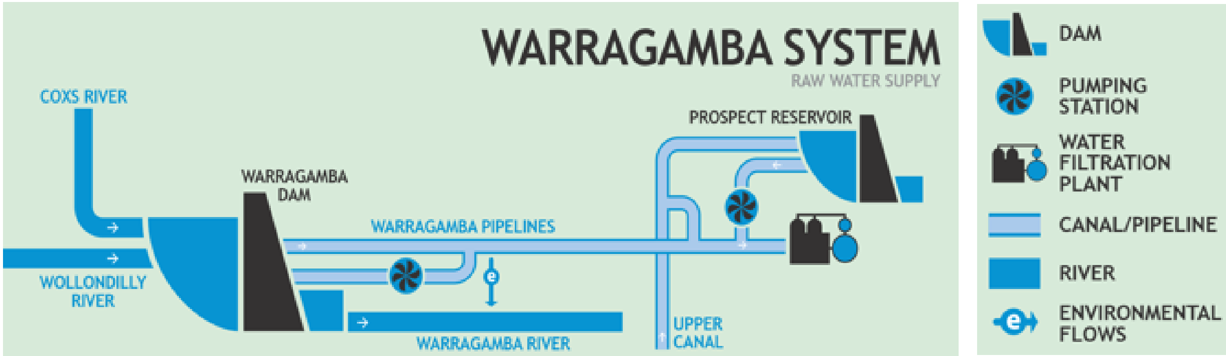


Source: Appendix H1, Figure 3-9.

Dam operations are shown on Figure 15-10 and compromise:

- *fixed low flow releases*: typically 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. There is no drawdown of the dam prior to a flood (that is, a pre-release of water).

Figure 15-10. Warragamba water supply system and dam gate operations



Warragamba water supply system

How the gates on Warragamba Dam work (Source: WaterNSW Website)

Source: Appendix H1, Figure 3-10

Monthly flows into and out of Warragamba Dam are summarised in Figure 15-11, which shows that unregulated river flows into Warragamba Dam are notably higher than regulated river flows released downstream of the dam. The highest flows occur during the winter months. This is expected due to the dam being used as water supply infrastructure.

Lake Burragorang is typically maintained at or below FSL, with gates automatically releasing water once storage levels rise above the FSL (WaterNSW 2016). Warragamba dam operates under the H14 protocol, whereby the gates are opened automatically in sequence as the storage level rises above the FSL (see Figure 15-10). The central drum gate is the first to be opened and is used to discharge smaller floods, while the four radial gates are only opened for larger floods. The primary objectives of the Warragamba Dam gate opening procedures are to ensure that:

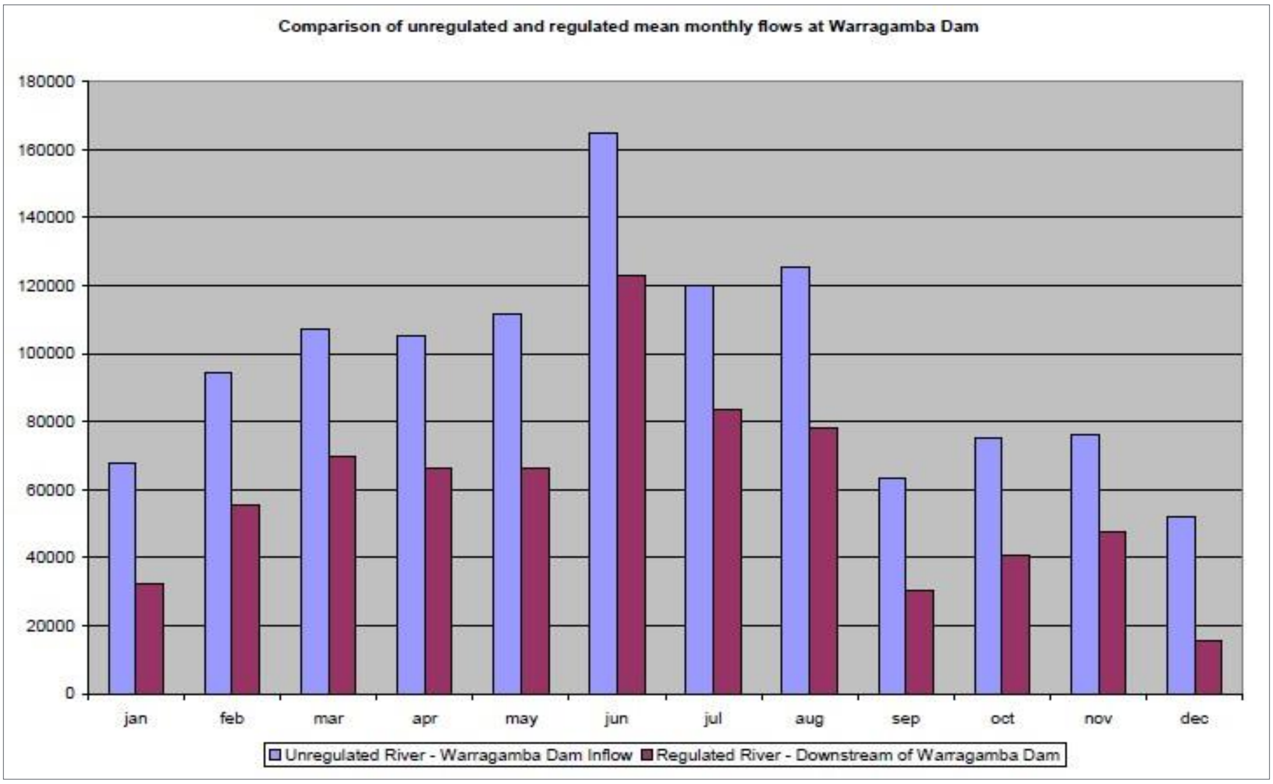
- the gates are opened quickly enough to prevent inflows overtopping and damaging the gates
- the gates are closed quickly enough to ensure the reservoir level is returned to the FSL at the end of a flood.

There is no drawdown of the dam prior to a flood (that is, a pre-release of water) and currently no FMZ above FSL dedicated to storing inflows. Daily base flow releases (or riparian releases) also occur from the dam, which are typically between 20 megalitres and 30 megalitres per day. Water released to each end-use (riparian, Warragamba WFP, Orchard Hills WFP, Prospect WFP, Prospect Reservoir) from 2006 – 2017 is shown on Figure 15-12. For the period August 2016 to August 2017, average end use flows were:

- Prospect WFP: 1,047 megalitres per day
- Orchard Hills WFP: 66 megalitres per day
- Riparian releases: 26 megalitres per day
- Prospect Reservoir: 16 megalitres per day
- Warragamba WFP: 3 megalitres per day.

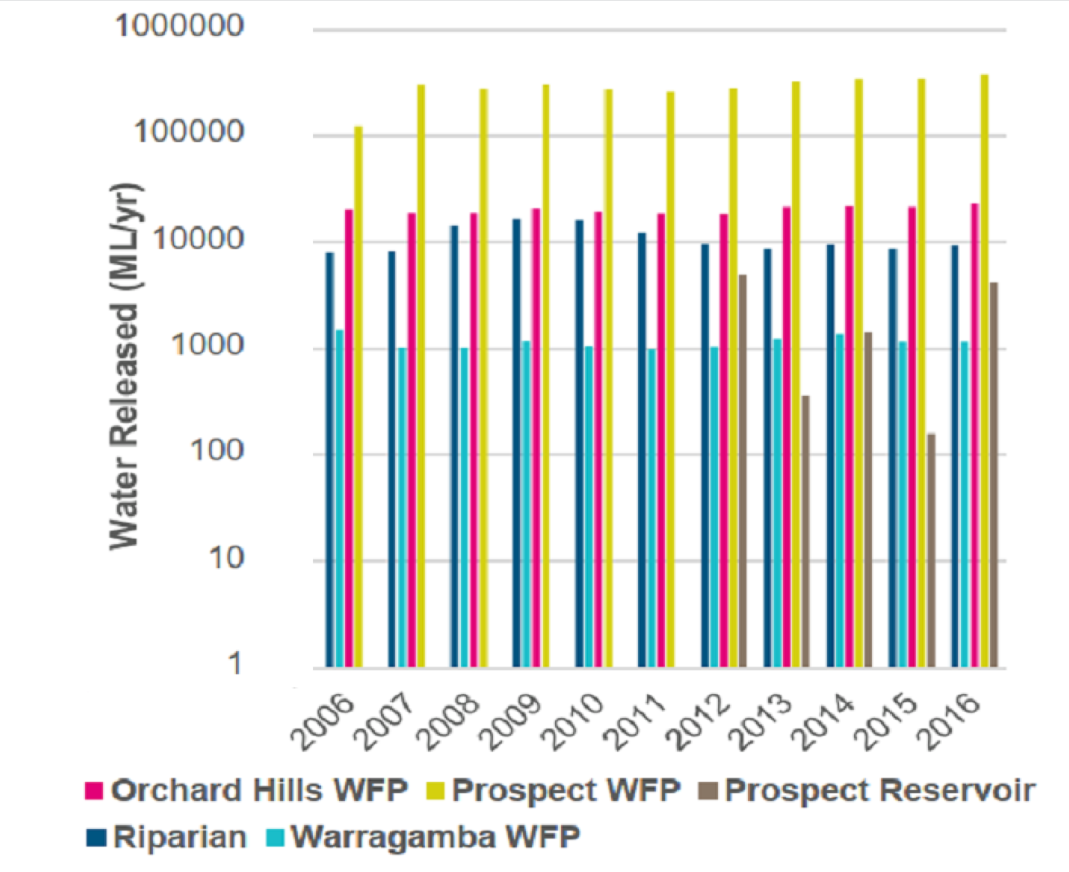
Most of the water released from Warragamba Dam goes to the Prospect WFP followed by the Orchard Hills WFP. The Prospect Reservoir and riparian release flows remain consistent across the year with occasional spikes. Warragamba WFP takes considerably less water than any other use.

Figure 15-11. Mean monthly flows



Source: Appendix H1, Figure 3-5

Figure 15-12. Annual water released to each end-use



Source: Appendix H1, Figure 3-13

15.3.1.5 Average annual water balance: upstream catchment

A water balance is discussed in Appendix H1 (Flooding and hydrology assessment report, Section 3.1.1.10) and summarised in Table 15-3. This shows:

- tributary inflows to Lake Burragorang including the Coxs, Kowmung, Wollondilly and Nattai Rivers. The Wollondilly River is the largest individual inflow into Lake Burragorang supply accounting for approximately 36 percent of the reservoir's annual inflow
- outflow from Warragamba Dam
- diversions from the Warragamba Dam outflow including raw water supply to Warragamba, Orchard Hills and Prospect WFPs, and Prospect Reservoir. The largest demand on dam storage is from the Prospect WFP, which accounts for approximately 50% of the raw water supply.
- 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.

Table 15-3. Upstream water balance

Flow or Discharge	Mean Annual Flow (2020 Demand)		Data Source / Comments
	GL	%	
Warragamba Dam inflows	**765**	**100**	
- *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
Warragamba Dam outflows	**765**	**100**	
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	
- *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

15.3.2 Downstream catchment

15.3.2.1 Catchment characteristics

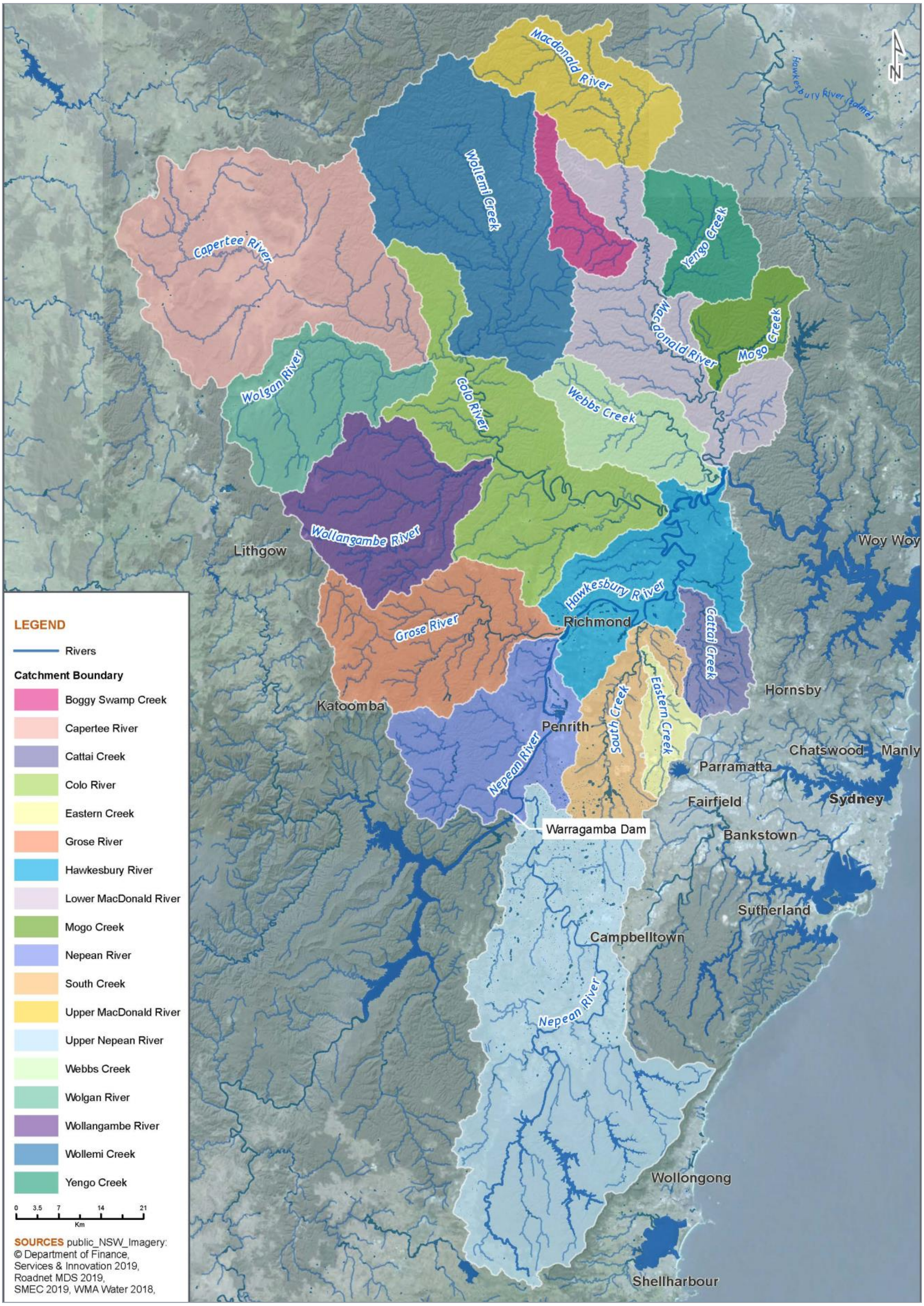
The downstream catchment and waterways are shown on Figure 15-13. The downstream environment includes the freshwater and estuarine reaches of the river system between the dam wall and Brooklyn. Also included are local waterways/creeks, riparian zone and floodplain and wetland/lagoon waterbodies adjacent to the main rivers.

The Sydney Basin dominates the area with the Narrabeen group and Hawkesbury sandstone subgroups covering most of the region. Topography of the Hawkesbury-Nepean Valley varies from flat floodplains to mountainous terrain that covers almost 50 percent of the catchment. Floodplains account for a small percentage of the total catchment area, however they contain most of the urban development. Almost one million people reside in the Hawkesbury-Nepean catchment with most of these living in the lower catchment. Approximately 134,000 people live in the probable maximum flood extent of the Hawkesbury-Nepean River (Infrastructure NSW 2017).

The mean annual rainfall varies considerably across the catchment, ranging from 1,306 millimetres at Mt Irvine in the Blue Mountains, to 628 millimetres at Sackville in the lower catchment. The highest rainfall generally occurs in the warmer months, with the highest falls occurring in February.

National parks occur within the downstream catchment and are mostly located on the western and northern borders of the study area and within the sub-catchments of the Grose, Colo, and Macdonald Rivers. A large urban area is centred around Penrith on the eastern side of the Hawkesbury-Nepean River, with numerous smaller urban areas along the length of the river to Pitt Town. Between these centres are agricultural areas, which occur on both sides of the Hawkesbury-Nepean River and in the sub-catchments of South Creek and Cattai Creek.

Figure 15-13. Downstream catchment



River reaches downstream of Warragamba Dam have been significantly modified since pre-European settlement. The impact of urbanisation along the river and land use changes across the floodplain have altered geomorphic features and river flow characteristics. 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. Further downstream, between Cattai and Wisemans Ferry, the floodplain is narrow (typically less than 400 metres wide) and mostly non-existent where the river channel is bedrock-controlled and characterised by steep sandstone gorges. River geomorphology is discussed in Appendix N2 (Geomorphology assessment report).

15.3.2.2 Hydrology

Downstream waterways and wetlands are shown on Figure 15-14. The Nepean catchment at its junction with the Warragamba River is approximately 20 percent of the size of the upstream Warragamba catchment, however the river drains a region of high rainfall along the top of the Illawarra escarpment and its contribution to downstream flows is significant. During high rainfall, substantial flows from the Warragamba catchment into the Nepean River and the narrow Fairlight Gorge causes existing upstream flows in the river to back up and cause localised flooding in the floodplain at Wallacia.

Downstream of the junction, the Nepean River flows through a narrow gorge until it emerges into more open country immediately upstream of Penrith. Floodplain elevation near Penrith, including Emu Plains and the Penrith Lakes Scheme, is relatively high and does not convey floodwaters until floods almost reach the magnitude of a 1 in 100 chance in a year event. However, once water starts flowing over the flood plain, downstream flows are partially restricted by the Castlereagh Gorge, which is located just upstream of the Grose River junction.

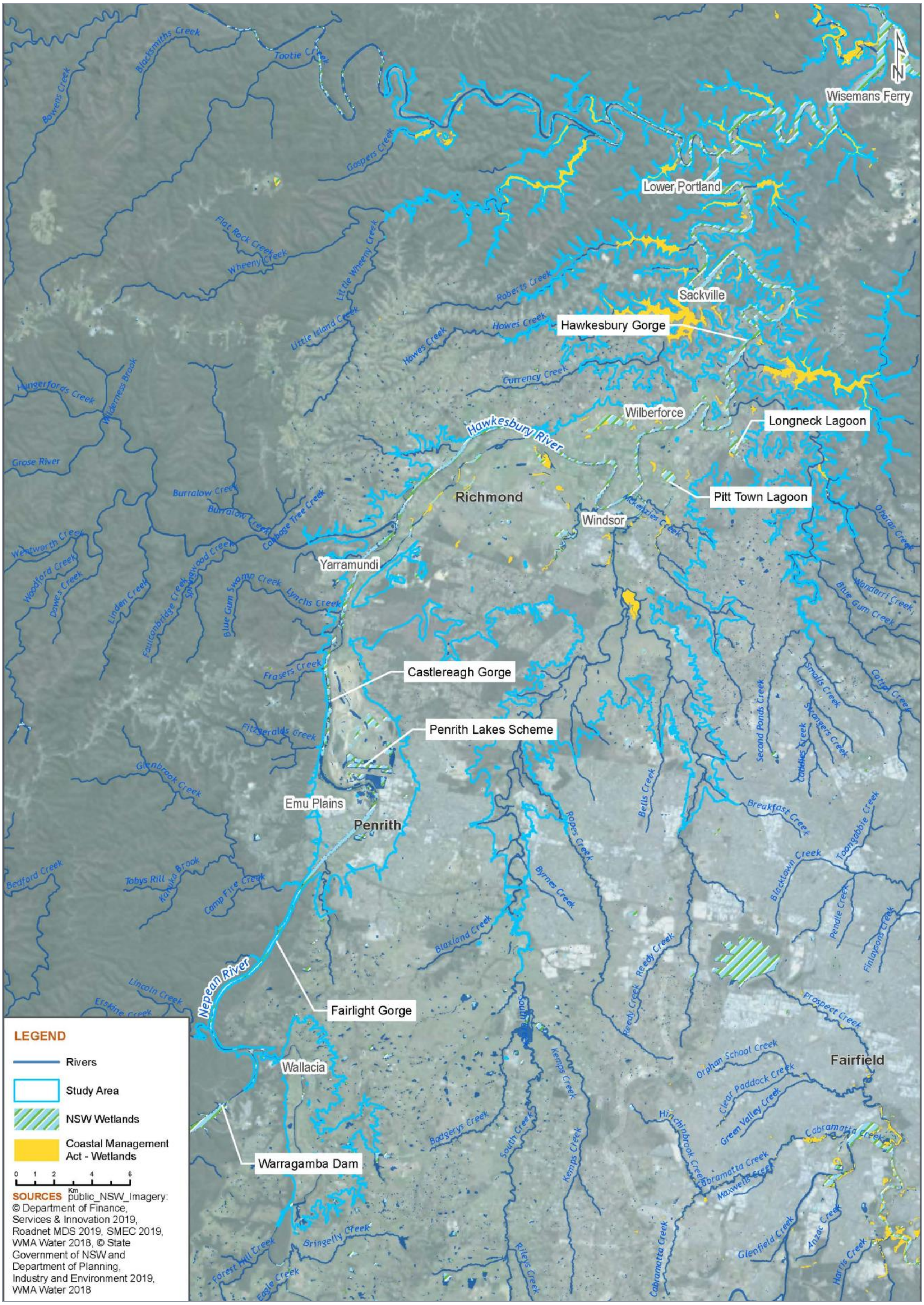
Downstream of Penrith the Grose River joins the Hawkesbury-Nepean River and flows through the Richmond/Windsor lowlands. These are extensive floodplains inundated by minor and moderate flooding (see Section 15.4.6 for definitions of flood size). The main towns in the area, Richmond and Windsor, are in the most part elevated above smaller floods but are seriously affected by floods above the 1 in 50 chance in a year event.

South Creek joins the river just below Windsor, and although the creek is not a major contributor to flood flows it has a large floodplain that is inundated by backwater from the Hawkesbury River. Below Wilberforce, Cattai Creek joins the river prior to it entering the Hawkesbury gorge, which extends for over 100 kilometres to the ocean at Broken Bay. Other major tributaries to join the Hawkesbury-Nepean River are the Colo River at Lower Portland and Macdonald River at Wisemans Ferry. The gorge at Sackville presents a significant constriction to flood flow, causing flooding of the Windsor and Richmond areas. This restriction results in a substantial difference of approximately nine metres between the 1 in 100 chance in a year flood level and the PMF, which compares to approximately two metres for other rivers in NSW.

Streamflow gauging stations at Wallacia and Penrith have been operational on the Hawkesbury-Nepean River system for over 70 years. Dry weather flow characteristics have been heavily influenced by abstractions for irrigation and water supply as well as wastewater treatment plant discharges. Flow duration curves for major tributaries are provided in Appendix H1 (Flooding and hydrology assessment report, Figure 3-8) and show that downstream rivers (excluding Glenbrook Creek) have flows of 100 megalitres per day or more for at least 10 percent of the time, while most tributaries ‘cease to flow’ on occasion.

The tidal limit of the Hawkesbury River occurs near Yarramundi, approximately 140 kilometres upstream of the river mouth. 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.

Figure 15-14. Downstream waterways and wetlands



15.3.2.3 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 regarding 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 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. Regarding 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 approximately 50 floodplain wetlands that 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 (Figure 15-14). Important wetlands include Pitt Town Lagoon and Longneck Lagoon,

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

which 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. There are no Ramsar listed wetlands, however some wetlands north of Agnes Banks are listed under State Environmental Policy (Coastal Management) 2018.

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

Groundwater dependent ecosystems (GDEs) have been classified to a corresponding vegetation type and mapped by the Bureau of Meteorology and Kuginis *et al.* in the Groundwater Dependent Ecosystems Atlas (BoM 2019). Sixty-two vegetation types were identified and classified according to their groundwater dependency potential, groundwater management area, position in the landscape and bioregion. This classification has been provided in Appendix F2 (Downstream ecological assessment, Section 5.3).

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 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.

15.3.2.4 River water users, extractions, and management

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

Major water users in the downstream 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. There are currently 43 licenced extraction bores within the Hawkesbury alluvium with a combined extraction rate of 1.172 gigalitres per annum. (NSW Water Register - WaterNSW)

Water extraction volumes are addressed in Appendix H1 (Flooding and hydrology assessment report, Section 3.1.2.6), which shows that the Colo River and Upper Hawkesbury (Cattai to Colo) water management zones, and the Penrith Lakes development corporation have the largest water licence shares.

15.3.2.5 Infrastructure and built environment

The natural hydrology and hydraulics of the Hawkesbury-Nepean catchment and river have been significantly altered by urban development, dam construction, water extractions, water discharges, weirs and water diversions. These are summarised as follows:

- *Urban waterways*: The Hawkesbury-Nepean River receives stormwater runoff from highly modified urban creek catchments such as South Creek and Eastern Creek. These waterways drain significant portions of the Greater Western Sydney suburbs including Blacktown, Rooty Hill, St Marys and Quakers Hill, and join with the Hawkesbury River near Windsor.
- *Farm dams, irrigation channels and groundwater bores*: Farm dams are common throughout the catchment with major clusters around the Mulgoa, South, Cosgrove, Currency and Douglas Creek catchments, and in the North Richmond area. Irrigation channels occur across the floodplain and are used to supply river water to irrigated agricultural areas. There are also numerous groundwater bores near the river from Orchard Hills to Wisemans Ferry.

- *Weirs and weir pools*: Numerous weirs have been constructed in the Hawkesbury-Nepean River and its tributaries. Fourteen of the larger weirs are described in Appendix H1 (Flooding and hydrology assessment report, Section 3.1.2.7) and include Penrith Weir, which creates a significant weir pool upstream of Penrith, and Emu Plains, and two water supply diversion weirs, Broughtons Pass and Pheasants Nest, which are in the Upper Nepean catchment near Wilton and Appin. Artificial lakes such as Shaws Lakes and Penrith Lakes can also influence river flow conditions.
- *Fishways:* 10 weirs have been modified to incorporate fishways, which comprise a series of interconnected pools and resting areas for fish to move unimpeded along the river.
- *Pumping stations, raw water pipeline, and canals:* Sydney Water currently operates four wastewater treatment plants and eight water filtration plants within the Hawkesbury-Nepean catchment. There are also an estimated 50,000 on-site wastewater treatment systems within the catchment.
- *Water abstractions:* The main water abstractions are for potable water supply (Richmond WRP) 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 water filtration plants and Prospect Reservoir via the Warragamba Pipeline.

15.3.2.6 Average annual water balance: downstream catchment

A water balance is discussed in Appendix H1 (Flooding and hydrology assessment report, Section 3.1.2.8) and summarised in Table 15-4.

Table 15-4. Downstream water balance

Flow or Discharge	Mean Annual Flow (2020 Demand)		Data Source / Comments
	GL	%	
Surface water inflows	**1,978**	**100**	
- 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	**68**	**100**	
- *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 water balance shows:

- tributary inflows to the Hawkesbury-Nepean River System including the Warragamba/Nepean, Grose, Colo and McDonald Rivers, and South and Cattai Creeks. The average annual inflow was estimated to be 1,978 gigalitres of which approximately 28 percent is supplied by the catchment upstream of Penrith Weir. The Colo River is the largest tributary by volume flowing into the Hawkesbury-Nepean river system below the Hawkesbury-Nepean junction, supplying almost 27 percent of flows to the system, while the Grose and Macdonald Rivers each contribute approximately 12 and 15 percent of flow respectively. A relatively small percentage of the flow is derived from STP discharges.
- the average annual total outflow from surface waters was estimated to be 69.8 gigalitres with approximately 11 percent delivered to the North Richmond water filtration plant, 60 percent to meet irrigation demands along the river, and 29 percent to industrial demands.
- The licenced groundwater extraction rate is 1.172 gigalitres per annum, which is less than two percent of the total quantity of water extracted from the Hawkesbury-Nepean system.
- assumed difference between inflows and extractions (1,909 gigalitres) is accounted for by outflows to Broken Bay.

15.4 Existing flooding

15.4.1 Historical flooding in the Hawkesbury-Nepean valley

The Hawkesbury-Nepean Valley has one of the most significant flood risk exposures within Australia. The risk to property and life due to flood exposure is well known and has been the subject of numerous studies, including the Hawkesbury-Nepean Valley Flood Risk Management Strategy (Infrastructure NSW 2017), which was prepared on behalf of the NSW State Government. Additional flood modelling was undertaken as part of the Project assessment and outcomes are presented in Appendix H1 (Flooding and hydrology assessment report, Section 3.2).

Since records began in the 1790s, there have been about 130 moderate to major floods in the valley. The largest flood in living memory was in November 1961 (approximately 1 in 50 chance in a year flood), when the water reached 15.7 metres above normal river height at Windsor. The largest flood on record was in 1867 (close to a 1 in 500 chance in a year flood), and reached 19.7 metres above normal river height at Windsor, causing massive damage and loss of life (Hawkesbury-Nepean Valley Regional Flood Study 2019). Palaeoflood investigations examined deposits from floods in Fairlight Gorge near the junction of the Nepean and Warragamba Rivers (Saynor *et al*. 1993). Analysis of minerals and radiocarbon dating found that a flood at least eight metres higher than the 1867 flood had occurred in the Holocene (approximately within the last 10,000 years).

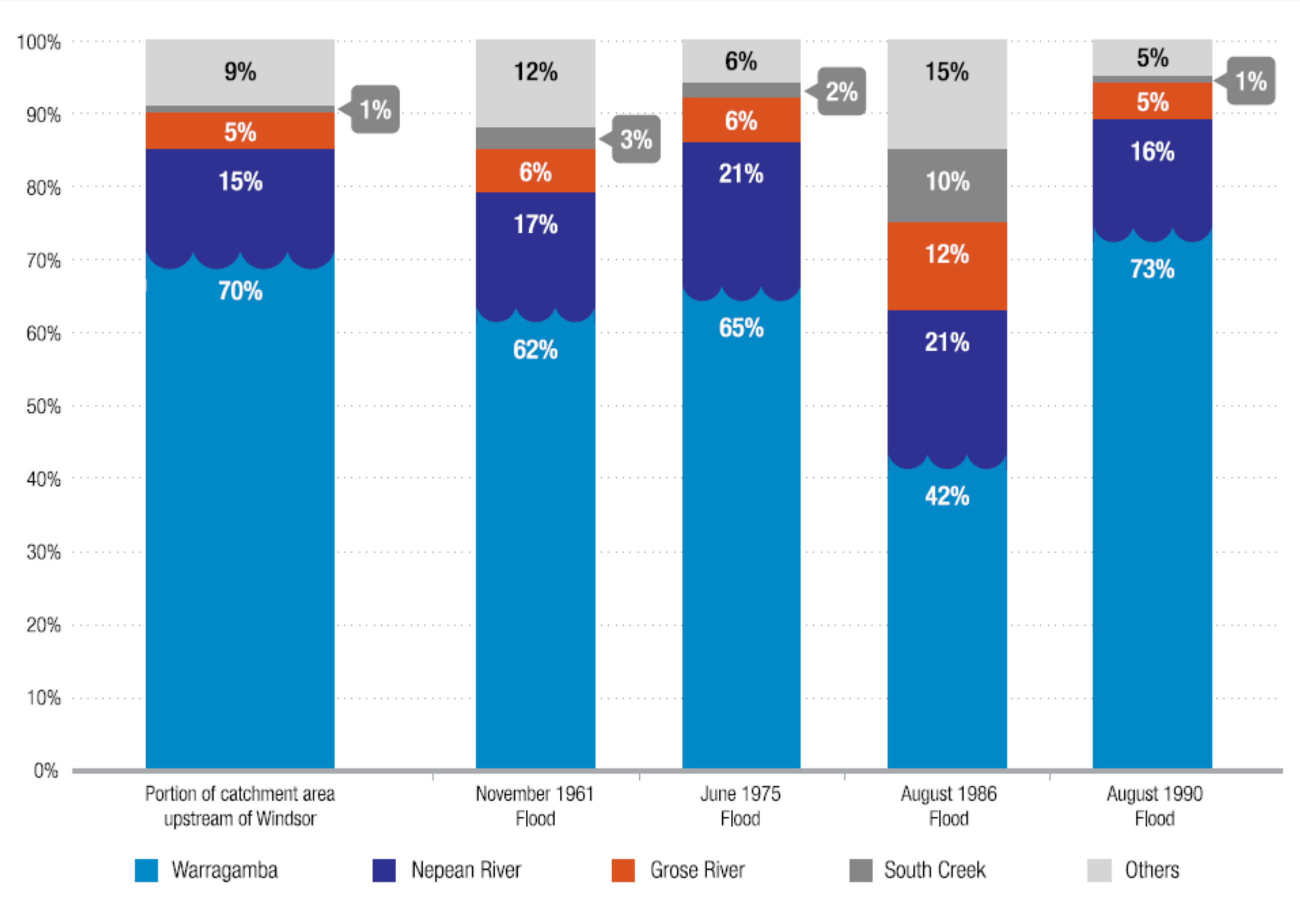
The period from 1901 to 1948 had fewer and smaller floods compared to the 1857–1900 period. However, the period from 1949 to 1992 had more frequent and larger floods, despite the completion of Warragamba Dam for water supply in 1960. Six of the top nine flood events in the continuous period of record (1893–present) occurred in the last 50 years. While 1867 is the highest-ranking event, 1961 is the highest in the continuous record. No moderate or major floods (using NSW SES categories: see Section 15.4.6) have been observed at Windsor in the 27 years since 1992.

Of interest is a recent significant rainfall event that occurred in February 2020. Downstream flooding was estimated to be about a 1 in 5 chance in a year event. At the time Warragamba 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.

Floods are highly variable with each flood behaving differently depending on rainfall distribution and the storage level in Warragamba Dam. The Warragamba Dam catchment provides the greatest contribution of high flows causing significant flooding in the Hawkesbury-Nepean Valley. The relative contributions of different river catchments for a range of historical floods are shown in Figure 15-15.

Figure 15-16 shows the extent and depth of flooding for the 1 in 500 chance per year flood, which is similar to the worst flood on record (1867 flood). Monte Carlo modelling results are summarised in Section 15.4.3.

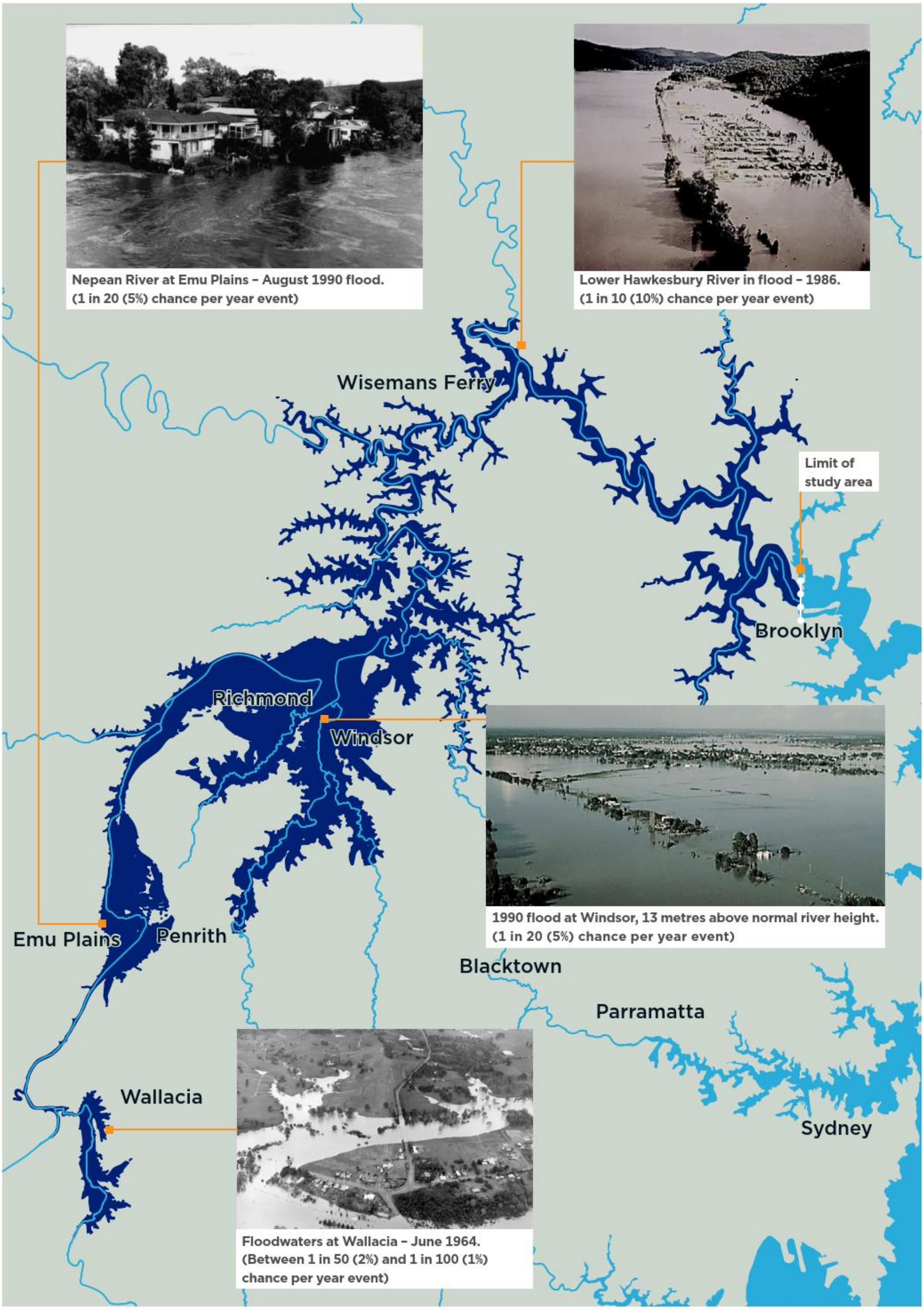
Figure 15-15. Relative contribution of different river catchments in a range of floods in the Hawkesbury-Nepean Valley



Source: Flood Strategy (Infrastructure NSW 2017)

Note*:* The August 1986 flood event was smaller than a 1 in 20 chance per year flood, with Warragamba Dam contributing only 42% of the total volume at Windsor. This is because Warragamba Dam storage level was relatively low and captured a large portion of the incoming flows thus delaying the downstream flows. If Warragamba Dam had been full, the Warragamba Catchment would have contributed 57% of the volume at Windsor.

Figure 15-16. Hawkesbury-Nepean River flood extent for a 1 in 500 chance per year flood



Source: Hawkesbury-Nepean Valley Regional Flood Study Overview, 2019

15.4.2 Upstream catchment

Flooding in the upstream catchment is characterised by backwater inundation with inflows building on the upstream side of the dam wall. The water level builds until the outflow exceeds the inflow, at which time the water level recedes to the FSL. The extent and duration of inundation is dependent upon the magnitude of the flood producing rainfall event and the dam release rate. Monte Carlo flood modelling results (see Section 15.2.2) at the dam wall are shown in Table 15-5. Existing peak flood levels may be higher in the upper tributary reaches.

The inundation extent is controlled by the peak flood level at the dam wall and the topography across the upstream catchment. Steep terrain extends upstream from the dam wall for at least 20 kilometres, so that the extent of land inundated changes at a relatively small rate with increasing magnitude floods. However, the rate of change and inundated area increases as terrain flattens about where the Wollondilly River and Coxs River enter the lake. Maps of different flood events are provided in Section 15.14.1 (Figure 15-50 to Figure 15-56). Additional information, including flood depth – duration graphs at different catchment locations, is provided in Section 15.6.3.

Water levels in Lake Burragorang remain elevated for a period of approximately three to five days depending on the size of the event (see Table 15-5). Although lake levels remain elevated for a period of days, the period of inundation for specific locations will vary depending on their location in the catchment.

Flood storage areas are characterised by deep, low velocity inflows, although higher velocities would be expected where major tributaries discharge into the lake.

Table 15-5. Existing upstream peak water level at dam wall

Flood event (1 in X chance in a year)	Water level[1] (mAHD)	Approximate days above FSL
5	117.4	2.8
10	118.0	3.4
20	118.6	4.0
100	121.5	4.0
200	122.9	4.1
500	124.6	4.5
PMF (3 day)	131.2	4.2

1. Based on Monte Carlo flood modelling (see Section 15.2.2)

15.4.3 Downstream catchment

15.4.3.1 Flood characteristics

Floodwaters flowing into the Hawkesbury-Nepean Valley come from several different river catchments (refer Figure 15-2). The largest of these is the Warragamba River catchment, which drains into Lake Burragorang and represents approximately 80 percent of the catchment at Penrith and 70 percent of the catchment at Windsor.

Further inflows downstream of the dam originate from the Nepean River (up to 37 percent), the Grose River (up to 11 percent), South and Eastern Creeks (up to 7 seven percent), and other tributaries (up to 12 percent). While floods can occur without contribution from the Warragamba catchment, larger floods (above the 1 in 100 chance in a year flood event) would include significant floodwater inflows from the Warragamba River catchment. However, each flood event is unique due to the timing of rainfall across the Hawkesbury-Nepean Valley catchment.

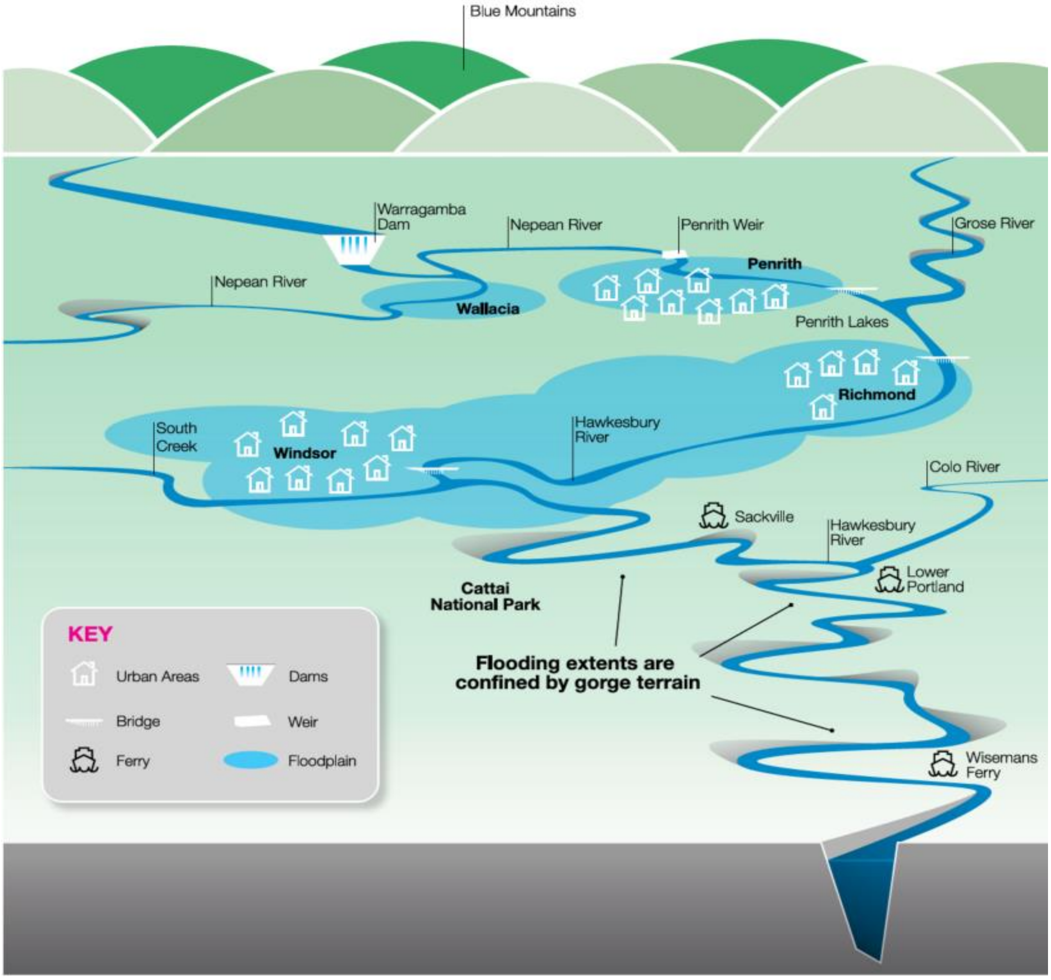
The inundation extent is controlled by the topography across the floodplain, with floodwaters primarily contained within the channel and highly incised valley floor for some reaches, and widespread inundation in other sections of the floodplain.

There are also significant step changes in inundation extents between flood events; for example 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, while near the regional localities of Penrith, Windsor, and Richmond the floodplain is notably flatter and wider, and flood inundation extends over a greater area.

Flooding within the Hawkesbury-Nepean Valley has been described as a 'bathtub' effect (Infrastructure NSW 2017), whereby floodwaters are constrained by river channel chokepoints to form three main floodplains around Wallacia, Penrith/Emu Plains, and Richmond/Windsor (including backwater flooding in South Creek and Eastern Creek). Downstream from the Richmond/Windsor floodplain, the river winds its way through around 100 kilometres of confined, sandstone gorges to Brooklyn. Along this stretch, numerous small floodplains form in the narrow areas between the river and the steep valley sides.

Flooding in the valley is described in a video prepared by the State Emergency Services[2] (SES), which describes how flooding is controlled by three choke points. A summary of the video is provided on Figure 15-17.

Figure 15-17. Flooding in the Hawkesbury-Nepean Valley



Source: INSW (2017)

Wallacia choke point: Located downstream of Wallacia near the junction of the Nepean and Warragamba rivers. This causes flood waters to back up around Wallacia. The highest recorded flood was 20 metres above normal river levels.
Castlereagh choke point: Located downstream of Penrith, this chokepoint causes floodwaters to spread over a large floodplain encompassing Penrith and Emu Plains. The highest recorded flood was 12 metres above normal river levels.
Sackville gorges choke point: Located downstream of Windsor, this chokepoint causes floodwaters to spread over a large floodplain encompassing Windsor and Richmond. The highest recorded flood was 19 metres above normal river levels.

[2] https://www.ses.nsw.gov.au/hawkesbury-nepean-floods

15.4.3.2 Flood modelling

Flood modelling was undertaken for existing conditions to determine the extent and impacts of a range of flood events including those greater than a 1 in 100 chance in a year event. The rate of rise of floodwaters is a function of the dam outflow and local topography.

The water level time-series at selected locations within the catchment corresponding to modelled cross sections are presented in Appendix H1 (Flooding and hydrology assessment report, Section 3.2.2.4). Simulated peak velocities for the range of design events corresponding to modelled cross sections are presented in Appendix H1 (Flooding and hydrology assessment report, Section 3.2.2.5). Peak flow velocities are relatively consistent across the floodplain, with minimal variation in flow velocity with increasing event magnitude.

Flood extents for the 1 in 5 chance in a year, 1 in 100 chance in a year and PMF events are shown on Figure 15-18 (flood maps of all SEARs flood events are provided in Section 15.14.2), while Figure 15-19 and Figure 15-20 show flood depths for the 1 in 100 chance in a year and PMF events respectively (flood depths for all SEARs flood events are provided in Appendix H2 – Flood risk analysis). Representative depths at specified cross sections, such as bridge locations, are shown in Table 15-7.

High-level Monte Carlo modelling results are summarised in Table 15-6 (*Hawkesbury-Nepean Valley Regional Flood Study,* WMAwater 2019). Further discussion for SEARs flood events are discussed below.

Table 15-6. Monte Carlo modelling results in key areas

Wallacia While the Wallacia floodplain is relatively small, it has the potential for the deepest flooding in the valley. The Nepean and Warragamba rivers meet downstream of Wallacia, and floodwaters can back up behind the narrow gorges between Wallacia and Penrith. In a 1 in 20 chance per year event, floodwaters inundate low lying parts of Wallacia and Park Road, the main evacuation route to the east, is cut. In a 1 in 500 chance per year event, floodwaters would cut all major evacuation routes. In the rarest and most unlikely flood (PMF), the village of Wallacia would be completely inundated.
Penrith/Emu Plains During a 1 in 100 (chance per year flood, the floodwaters would remain mostly within the banks of the Nepean River. However, there would be flooding in Emu Plains on the southern side of the railway embankment, and up the Peachtree and Boundary creeks in Penrith. The study shows that for a 1 in 500 (chance per year event, much of Emu Plains would be inundated and floodwaters would extend east to Woodriff Street in Penrith. In the most extreme flood (PMF), large areas of Penrith would be inundated. Floodwaters would extend as far as two kilometres along the Great Western Highway east of the Victoria Bridge. The flood extent would include Emu Heights to the west of the Nepean River. For this floodplain, higher resolution flood modelling and mapping is available from Penrith City Council's Nepean River Flood Study (2018).
Richmond/Windsor The Richmond/Windsor floodplain is the most flood-affected area within the valley. Even in a relatively frequent 1 in 5 (20%) chance per year event, there is extensive flooding of low-lying river flats between Richmond and Pitt Town. In the 1 in 100 chance per year event, the flood extent increases substantially. McGraths Hill would be completely submerged, Pitt Town would become a flood island, as would be parts of Windsor and South Windsor. A key evacuation route, Windsor Road, would be inundated as far as Vineyard Railway Station (six kilometres from Windsor Bridge). In an event similar to the record 1867 flood, Windsor would be completely isolated, Jim Anderson Bridge roadway would be around two metres under water, and the floodwater would extend up to 20 kilometres at its widest. Very little land would remain above floodwater in the Richmond/Windsor floodplain in an extremely rare PMF.
South Creek and Eastern Creek Floodwaters from the Hawkesbury River can back up into South Creek and Eastern Creek causing flooding in adjacent suburbs. In a 1 in 100 chance per year event, floodwaters would inundate properties in parts of Windsor Downs, Berkshire Park, Shanes Park and Llandilo. The Richmond Road evacuation route would be cut at South Creek Bridge. Along Eastern Creek, backwater flooding would impact properties at Vineyard, Riverstone and Schofields. If the worst flood on record happened today, the backwater effects would be higher and extend further, impacting more properties including in parts of Marsden Park.
Lower Hawkesbury River Downstream of Cattai Creek near Ebenezer, the main Hawkesbury River enters gorge country which continues for many kilometres all the way to Brooklyn. Along these gorges, narrow floodplains form between the riverbank and the valley sides. Due to the steep gorges, roads in the Lower Hawkesbury are often close to the river and are cut by relatively small floods. Tide levels have some minor impacts on flooding, especially downstream from Wisemans Ferry, and especially for frequent floods such as the 1 in 5 chance per year event.

1 in 5 chance in a year flood event

- **Wallacia**: Minor overbank flooding at some locations on the river and increased overbank flooding along many of the tributaries flowing into this section of the river.
- **Penrith**: Some over bank flooding in the Penrith Lakes area and at some locations west of the river near Emu Plains. No developed areas would be affected.
- **Windsor and Richmond**: Substantial overbank flooding along South Creek and its tributaries. Residential areas in North Richmond, Richmond, Windsor, and the North West Growth Centres would generally be flood free. Bridge crossings at Windsor and Richmond would be underwater and impassable.

1 in 10 chance in a year flood event

- **Wallacia**: Some overbank flooding along the river and increased overbank flooding along many of the tributaries flowing into this section of the river.
- **Penrith**: Some over bank flooding in the Penrith Lake area and at some locations west of the river near Emu Plains. No developed areas would be affected.
- **Windsor and Richmond**: Substantial overbank flooding along South Creek and its tributaries. Residential areas in North Richmond, Richmond, Windsor and the North-West Growth Centres would generally be flood free. Some increased flooding in Riverstone. Bridge crossings at Windsor and Richmond would be underwater and impassable.

1 in 20 chance in a year flood event

- **Wallacia**: Overbank flooding along both sides of the river and substantial overbank flooding along many of the tributaries flowing into this section of the river.
- **Penrith**: Some over bank flooding in the Penrith Lake area and at some locations west of the river near Emu Plains. Some residential areas of Emu Plains may experience flooding.
- **Windsor and Richmond**: Substantial overbank flooding along South Creek and its tributaries. Residential areas in North Richmond, Richmond, most of Windsor and the North-West Growth Centres would be flood free. Some increased flooding in South Windsor and Riverstone. Bridge crossings at Windsor and Richmond would be underwater and impassable.

1 in 100 chance in a year flood event

- **Wallacia**: Flooding generally confined to a 7.5 kilometre section of the Nepean River, typically either side of the river channel with minor backwater flooding of minor tributaries to the east of the river. Wallacia town centre would not be affected by flooding; however, all connecting roads would be flooded.
- **Penrith, Emu Plains and Penrith Lakes**: Some residential areas in Emu Plains would be flooded, however most flooding would be restricted to undeveloped, former sand mining and rural areas. Some industrial facilities and public infrastructure (for example Emu Plains Correctional Centre and Penrith Sewage Treatment Plant) may be impacted by flooding. There would be minor flooding of the Penrith town centre, however most of the town centre would not be affected.
- **Richmond and North Richmond town centres**: Generally, remain flood free, however the fringe areas of both towns may experience some flooding. North Richmond is likely to be isolated. The Bells Line of Road to the north of the town would be inundated and the Richmond Bridge over the Hawkesbury River and Kurrajong Road completely submerged.
- **Other**: Apart from the central area of Windsor, substantial areas of Wilberforce, South Windsor, Mulgrave, Pitt Town and McGraths Hill would be flooded. The depth of flooding would generally be greater than 17 metres and there would be significant flooding of properties and public infrastructure. Back water flooding would also occur along South Creek and its tributaries potentially impacting Riverstone and Windsor Downs.

1 in 200 chance in a year flood event

- **Wallacia**: Flooding generally confined to a 7.5 kilometre section of the Nepean River, typically either side of the river channel with minor backwater flooding of minor tributaries to the east of the river. The eastern side of the Wallacia town centre would be affected by flooding and all connecting roads would be flooded.
- **Penrith, Emu Plains and Penrith Lakes**: Extensive residential areas in Emu Plains and Emu Plain Heights would be flooded. Industrial facilities and public infrastructure (for example, Emu Plains Correctional Centre and Penrith

Sewage Treatment Plant) would be impacted by flooding. There would be minor flooding of the Penrith town centre, however most of the town centre would not be affected.

- **Richmond and North Richmond town centres**: Generally, remain flood free, however the fringe areas of both towns may experience some flooding. North Richmond is likely to be isolated. The Bells Line of Road to the north of the town would be inundated and the Richmond Bridge over the Hawkesbury River and Kurrajong Road completely submerged.
- **Other**: Apart from the central area of Windsor, substantial areas of Wilberforce, South Windsor, Mulgrave, Pitt Town and McGraths Hill would be flooded. Back water flooding would also occur along South Creek and its tributaries potentially impacting Riverstone and Windsor Downs.

1 in 500 chance in a year flood event

- **Wallacia**: About 25 percent of Wallacia would be affected by flooding and all connecting roads would be flooded.
- **Penrith**: About 50 percent of Emu Plains and Emu Plains Heights would be flooded. Smaller areas of Leonay, Regentville and Jamisontown would also be flooded. All river front land and about a third of the Penrith town centre would be flooded. Large areas of industrial development in Penrith would also be flooded.
- **North Richmond**: Generally remains flood free, however some fringing residential areas and the industrial area would be flooded. North Richmond is likely to be isolated. The Bells Line of Road to the north of the town would be inundated and the Richmond Bridge over the Hawkesbury River and Kurrajong Road completely submerged.
- **Richmond**: About a third of the residential area would be flooded and a flood island consisting of east Richmond would form. About 80 percent of RAAF Base Richmond would be underwater.
- **Windsor**: About 50 percent of Windsor would be flooded and the remaining unflooded areas would be surrounded by flood waters (that is, would form a flood island), making evacuation via road impossible.
- **Other**: All or most of Mulgrave, McGraths Hill, Blighs Park and Pitt Town would be flooded. Unflooded areas in Pitt Town would be surrounded by flood waters (that is, would form a flood island), making evacuation via road impossible.
- **Back water flooding**: This would also occur along South Creek and its tributaries flooding large areas of Londonderry, Schofields, Marsden Park, Riverstone, and Windsor Downs.

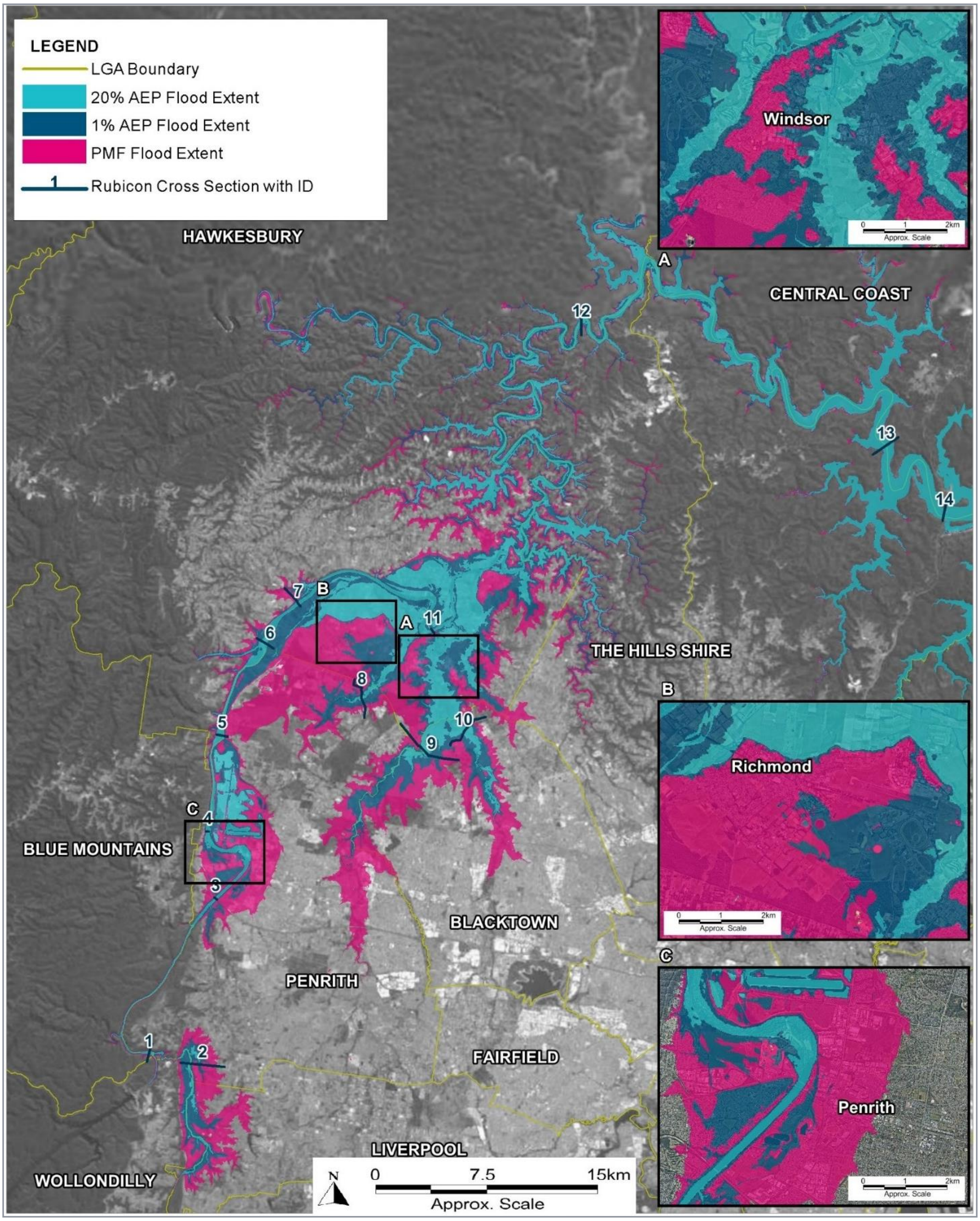
PMF event

- **Wallacia**: The town would be completely inundated and there would be considerable flood damage. The flooded area would be approximately double that flooded in the 1 in 100 chance in a year event.
- **Leonay, Emu Heights, and Emu Plains residential areas**: All these areas would be flooded. On the eastern side of the river, the Penrith town centre and some adjacent residential areas, industrial zones and public infrastructure would also be inundated.
- **Richmond and Agnes Banks and large areas of Londonderry and North Richmond**: All these areas would be flooded.
- **Wilberforce, Windsor, Bligh Park and McGraths Hill**: All these areas would be flooded. The depth of flooding would be approximately 24 metres and there would be significant damage to properties and public infrastructure.
- **South Creek**: Backwater flooding would occur along South Creek and its tributaries, and inundate Berkshire Park, Shanes Park, Ropes Crossing and parts of St Marys and Werrington.
- **Eastern Creek**: Flooding would occur on areas in North-West Growth Centres along Eastern Creek including Vineyard, Schofields, Riverstone, Marsden Park, Colebee, and Quakers Hill.

Table 15-7. Downstream peak flood levels at river cross sections

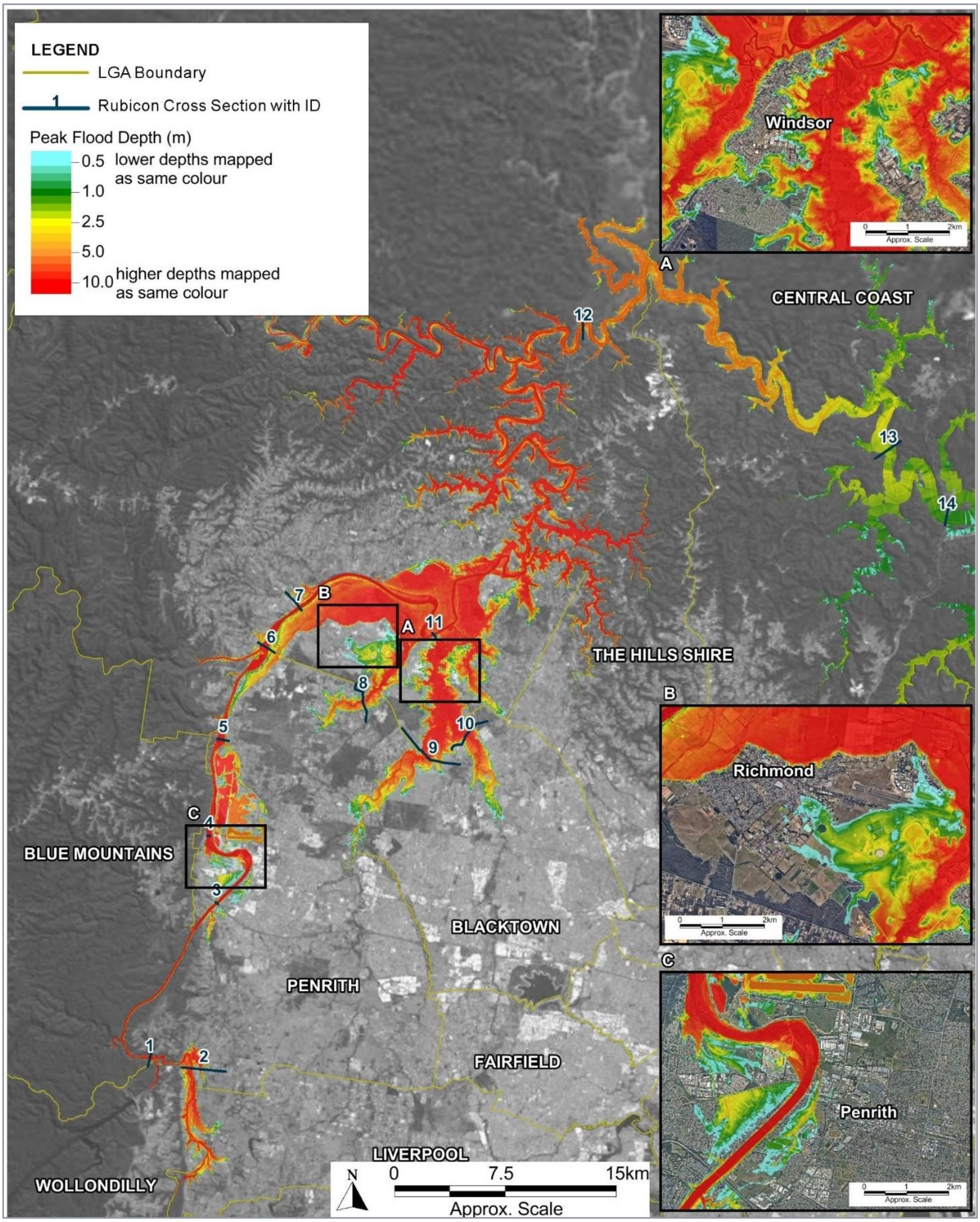
Cross section (see Figure 15-18 to Figure 15-20)		Name	Flood event (1 in x chance in a year), (mAHD)						
			5 Yr	10 Yr	20 Yr	100 Yr	200 Yr	500 Yr	PMF
1	JUNCTION3	Nepean River – Downstream of confluence with Warragamba River	28.3	33.0	37.4	42.7	44.7	47.3	65.7
2	BLAXCROSS	Nepean River – Blaxland Crossing bridge	35.1	37.2	39.4	44.6	46.5	48.9	66.3
3	F4BRIDGE	Nepean River – M4 Motorway bridges	20.6	22.7	24.9	27.6	28.4	29.0	34.9
4	BONNIEVALE	Nepean River – Downstream of Penrith Weir	14.9	17.8	20.5	23.5	24.3	25.3	32.5
5	MILLDAM 1	Nepean River – At Castlereagh	12.9	15.6	18.0	20.4	21.4	22.7	31.4
6	YMUNDI 1	Hawkesbury River – Downstream of Grose River confluence	12.0	14.5	16.4	18.2	19.1	20.3	27.1
7	NORTHRICH 1	Hawkesbury River – At North Richmond	11.4	13.7	15.4	17.5	18.6	19.8	26.8
8	LDERRY	South Creek – At Londonderry	10.1	12.0	13.8	17.4	18.4	19.6	26.7
9	RICH WALK	South Creek – At Richmond Road Bridge	9.8	11.9	13.7	17.3	18.3	19.6	26.7
10	POWERLINE	Eastern Creek – At Mulgrave	9.8	11.9	13.7	17.3	18.3	19.6	26.7
11	WINDSORBR	Hawkesbury River – Windsor Bridge	9.9	11.9	13.7	17.3	18.3	19.6	26.7
12	HALFMOON	Hawkes River – Downstream of Wisemans Ferry	3.7	5.1	6.5	9.1	10.1	11.5	17.2
13	PUMPKINPT	Hawkesbury River - Berowra Creek confluence	1.7	1.8	1.9	2.3	2.6	3.1	5.9
14	PEAT1	Hawkesbury River – M1 Motorway Bridges	1.5	1.6	1.6	1.7	1.7	1.7	2.0

Figure 15-18. Downstream existing peak flood extent for the 1 in 5 chance in a year, 1 in 100 chance in a year and PMF events



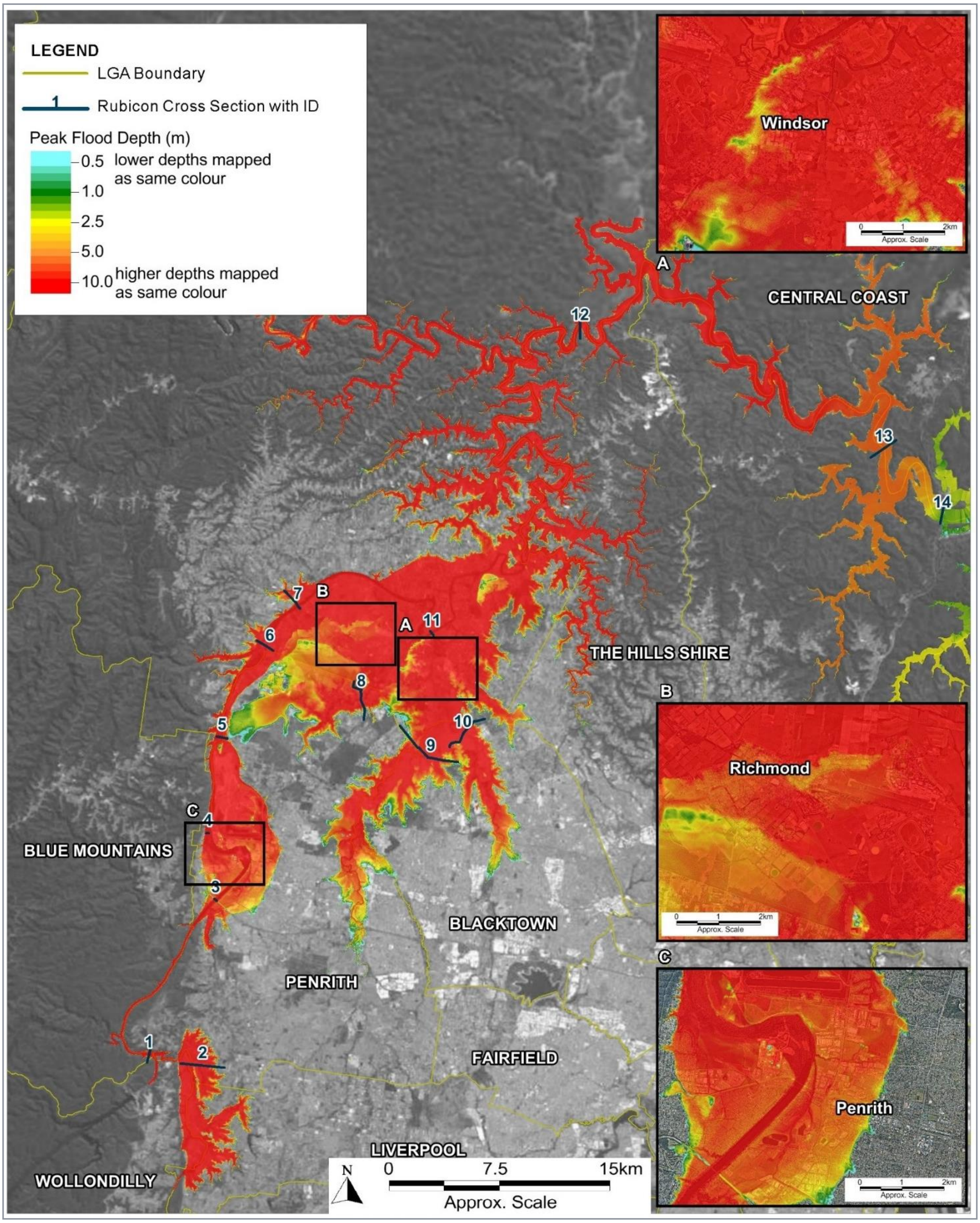
Source: Appendix H1, Figure 3-25

Figure 15-19. Downstream existing peak flood depth for the 1 in 100 chance in a year event



Source: Appendix H1, Figure 3-26

Figure 15-20. Downstream existing peak flood depth for the PMF



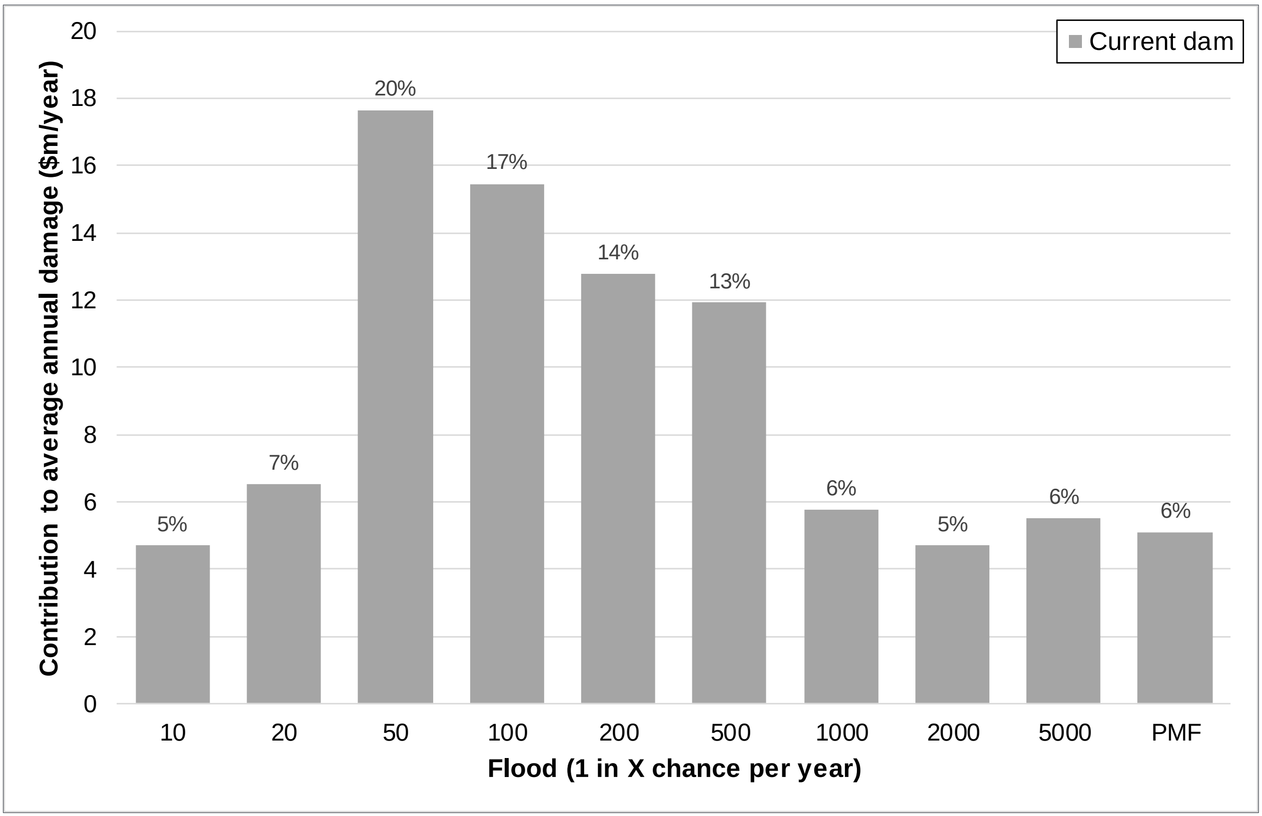
Source: Appendix H1, Figure 3-27

15.4.4 Flood damages and number of residential properties affected by flooding

Floods between the current 1 in 50 and 1 in 500 chance in a year events contribute about two-thirds of calculated current average annual damages, which is shown in Figure 15-21 (Infrastructure NSW 2019). More frequent (smaller) flood events contribute about 12 percent of current average annual damages. Significant flood impacts to dwellings occur from around the 1 in 50 chance in a year event. This is because the 1 in 100 chance per year flood planning level was previously lower (as flooding modelling and understanding was less advanced), allowing houses to be built at a level lower than would be permissible today. For example, in the 1990s the 1 in 100 chance in a year flood planning level at Windsor was 16.0 mAHD compared to the current 1 in 100-year chance per year level of 17.3 mAHD.

The numbers of affected residential properties for a range of flood events in 2018 are shown in Table 15-8.

Figure 15-21. Contribution of flood events to average annual flood damages in the Hawkesbury-Nepean Valley



Source: Infrastructure NSW 2019
Note: Base case, 2015 development; PMF = probable maximum flood

Table 15-8. *Number of affected residences for a range of flood events in 2018*

Flood Size	2018 (existing risk)		
	Existing (2018) properties	Existing (2018) manufactured homes	
1 in 5	160	570	730
1 in 10	370	1300	1,670
1 in 20	1,000	1,500	2,500
1 in 50	3,100	1,700	4,800
1 in 100	5,900	1,700	7,600
1 in 200	8,200	1,800	10,000
1 in 500	13,700	1,800	15,500
1 in 1,000	17,700	1,900	19,600
1 in 2,000	21,700	1,900	23,600
1 in 5,000	24,300	1,900	26,200
PMF	34,800	1,900	36,700

15.4.5 Flood function and flood hazard

Flood function and hazard modelling is provided in Appendix H2 (Flood risk analysis) and summarised as follows.

15.4.5.1 Floodplain conveyance and storage

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 development constraints within the floodplain. The *Floodplain Development Manual* (Department of Infrastructure, Planning and Natural Resources (DIPNR) 2005) defines the following hydraulic categories:

- **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. These are divided into primary (relative high velocities greater than 0.5 metres per second) and secondary (lower velocities) floodways.
- **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 metres and/or would cause the peak discharge to increase by more than 10 percent.
- **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.

Flood function maps for the 1 in 100 and 1 in 500 chance in a year floods are shown on Figure 15-23. and Figure 15-24., and summarised below. More detailed maps are provided in Appendix H2 (Flood risk analysis).

1 in 100 AEP Event (Appendix H2: Figures 32 to 35)

- **Primary floodway:** The primary floodway is generally located within the main river channel. At Wallacia and Penrith, the primary floodway does not extend beyond the low-lying overbank areas. On the Windsor floodplain, the primary floodway extends beyond the banks of Rickabys Creek and South Creek in small areas, but does not intersect existing residential or industrial development.
- **Secondary floodway:** At Penrith, nearly all the flow is contained in the river while in the Windsor area, a significant amount of the flow is conveyed down the Richmond lowlands as relatively deep, low velocity flow. At Penrith, approximately 99 per cent of the flow is contained within the river at a level just below the level required for major break outs at Penrith and Emu Plains to occur. The area north of Windsor, which contains a large area of farmland, conveys a significant amount of the flow. Downstream of Gronos Point, the floodway is largely confined to the river and adjoining low lying floodplain. The overbank in the Wallacia area is a floodway.

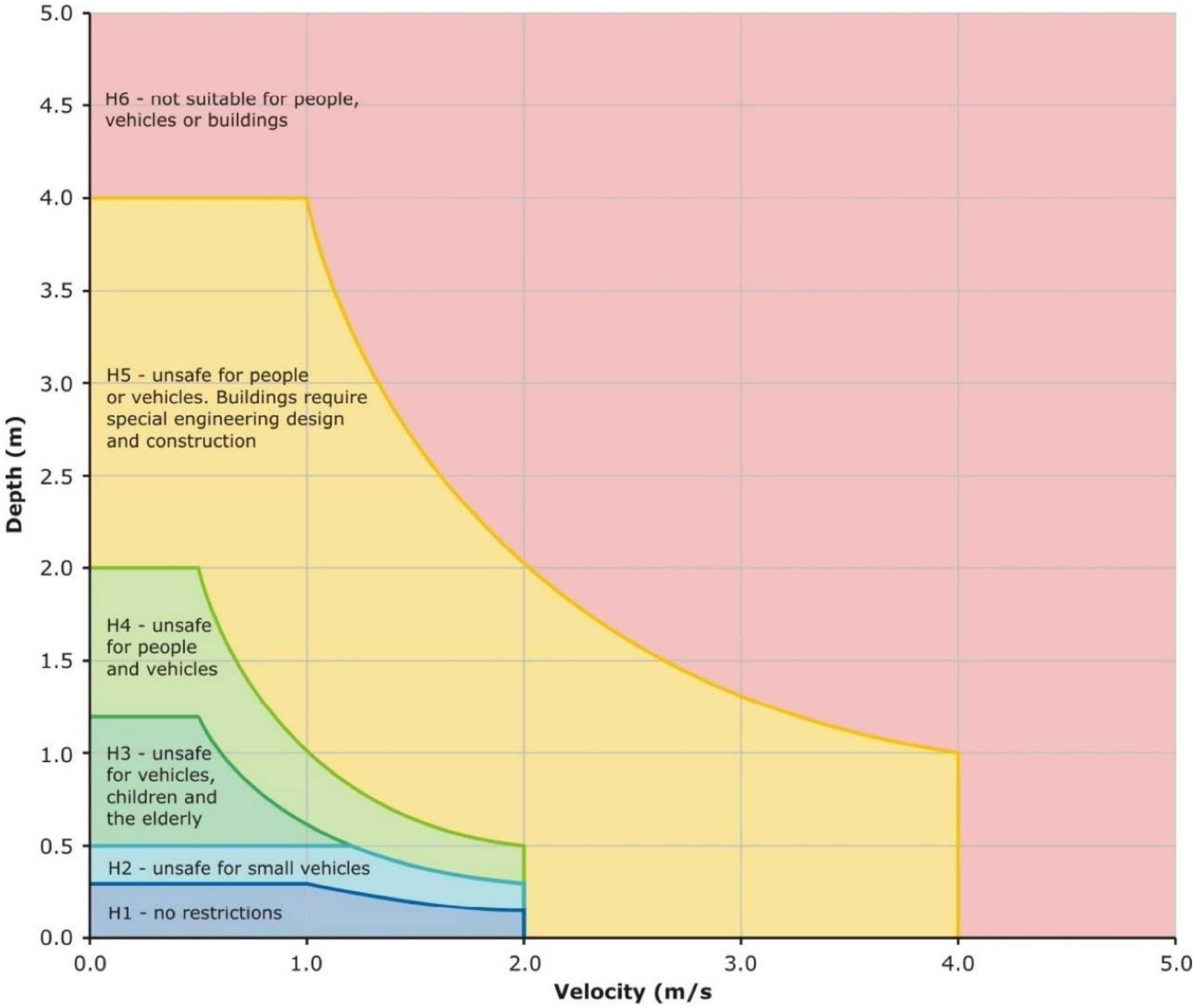
1 in 500 AEP Event (Appendix H2: Figures 36 to 39)

- **Primary floodway:** There is little change in the primary floodway, however the primary floodway now extends further into the Windsor floodplain, particularly around the suburbs of Mulgrave, South Windsor, and Bligh Park. The modelling showed no additional primary floodways developing.
- **Secondary floodway:** An additional floodway breaks out along Nepean Street, Emu Plains before joining Lapstone Creek and returning to the Nepean River floodway. The secondary floodway also widens at Wilberforce, north of Windsor, allowing for an additional floodway to develop, connecting to Currency Creek. Downstream of Sackville, there are only minor differences from the 1 in 100 chance in a year flood event.

15.4.5.2 Hazard classification

Flood hazard (or hazard categorisation) is determined from the predicted flood depth and velocity. 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. The National Flood Risk Advisory Group (Australian Institute for Disaster Resilience (AIDR) 2017b) recommends a composite six-tiered hazard classification, which is shown on Figure 15-22 and further described in Table 15-9.

Figure 15-22. Combined flood hazard curves



Source: Australian Disaster Resilience Handbook (2017) - Guideline 7-3 Flood Hazard

15.4.5.3 Flood hazard modelling

Flood hazard modelling for a range of flood events is provided in Appendix H2 (Flood risk analysis), which includes detailed flood hazard maps for Richmond-Windsor, Penrith and Wallacia. Flood conditions and hazard classifications are summarised in Table 15-9, while example flood hazard maps for the 1 in 20 and 1 in 100 chance in a year floods are shown on Figure 15-23. and Figure 15-24.

Table 15-9. Flood hazard modelling – existing conditions (Appendix H2: WMAwater 2020)

Category	Constraint to people/vehicles	Building constraints
H1	Generally safe for people, vehicles and buildings	No constraints
H2	Unsafe for small vehicles	No constraints
H2	Unsafe for vehicles, children and the elderly	No constraints
H4	Unsafe for vehicles and people	No constraints
H5	Unsafe for vehicles and people	All buildings vulnerable to structural damage. Some less robust building types vulnerable to failure.
H6	Unsafe for vehicles and people	All building types considered vulnerable to failure

Flood event 1 in X chance in a year	Existing conditions
5	*Flood hazard maps: Appendix H2: Figure 4 to Figure 7* ▪ Most of the flooded area is classified as unsafe for vehicles and people (H4 to H6), however most of the flow is contained within its banks. ▪ Wallacia and Penrith areas mostly consist of a H6 classification; however, this is mostly contained to the immediate channel vicinity. ▪ Less hazardous areas occur on the Windsor floodplain, where water overflowing from the banks is classified as H1 to H4. Upstream of Wisemans Ferry, most of the overbank areas are classified as a H1 to H4 hazard.
20	*Flood hazard maps: Appendix H2: Figure 8 to Figure 11* ▪ Most of the floodplain is considered unsafe for vehicles and people and is classified as H5. Some areas classified as H6. ▪ Most of the flow is contained within the river banks upstream of Yarramundi. Significant overbank flooding occurs on the Windsor floodplain, with most of the flood extent in this area classified as H6. ▪ Significant overbank flow occurs between Richmond to Pitt Town and is predominantly classified between H5. Some areas classified as H6 with less hazardous classifications visible on the edges of the floodplain. ▪ Most of the flood extent around Wallacia and Penrith is classified as H6.
100	*Flood hazard maps: Appendix H2: Figure 12 to Figure 15* ▪ Most of the floodplain is considered unsafe for vehicles and people, with buildings requiring special engineering design and construction or buildings being vulnerable to failure (H5 to H6 flood hazard classification). ▪ All but the very edges of the flood extent at Wallacia is classified as H6. ▪ At Penrith, overbank flow occurs and is classified H1 to H5. ▪ Richmond and Windsor are mostly inundated and is largely given a H6 classification other than patches at Pitt Town Road and between Hawkesbury Valley Way and Blacktown Road.
200	*Flood hazard maps: Appendix H2: Figure 16 to Figure 19* ▪ Similar to the 1 in 100 chance in a year flood hazard. ▪ Upstream of Pitt Town, almost all the floodplain is considered unsafe for vehicles and people, with building types being vulnerable to failure (H5 to H6). ▪ A small increase in the extent of flooding and consequent increase in H6 classification extent is observed in the breakout of Rickabys Creek near Blacktown Road.

Flood event 1 in X chance in a year	Existing conditions
	▪ The flooded area between Hawkesbury Valley Way and Blacktown Road is now largely H5. Additionally, an increase in H1 to H2 hazard classification is visible in Penrith and Emu Plains as more flow paths join up and the extent of flooding increases. ▪ Apart from an increase in the width of the floodway and consequent H6 hazard, little change in hazard classification is observed in Wallacia from the 1 in 100 chance in a year flood.
500	*Flood hazard maps: Appendix H2: Figure 20 to Figure 23* ▪ Most of the floodplain is considered unsafe for vehicles and people, with all building types considered vulnerable to failure (H6). ▪ Larger breakouts occur in Penrith from Lapstone Creek, Peach Tree Creek, and Mulgoa Creek but are mostly classified as safe for people, larger vehicles and buildings (H1 to H2). ▪ The Richmond to Windsor Region is mostly given a H6 flood hazard classification, however breakouts that occur near Blacktown Road are classified as less hazardous (H1 to H4). ▪ As with the 1 in 200 chance in a year flood, Wallacia remains mostly unsafe for vehicles and people with all building types considered vulnerable to failure (H6).
2000	*Flood hazard maps: Appendix H2: Figure 24 to Figure 27* ▪ Except for Penrith, most of the floodplain is considered unsafe for vehicles and people, with all building types considered vulnerable to failure (H6). ▪ A large breakout occurs directly south of Penrith Lakes at the sharp bend in the Nepean River. This area is predominantly classified as H2 and H5, with the edges of the floodplain considered generally safe for people, vehicles and buildings (H1).
PMF	*Flood hazard maps: Appendix H2: Figure 28 to Figure 31* Most of the floodplain is considered unsafe for vehicles and people with all building types considered vulnerable to failure (H6). At the very edges of the floodplain and some areas around Emu Plains are subject to lower hazard categories.

Figure 15-23. Existing hydraulic categorisation: 1 in 100 chance in a year flood (Appendix H2, Figure 32)

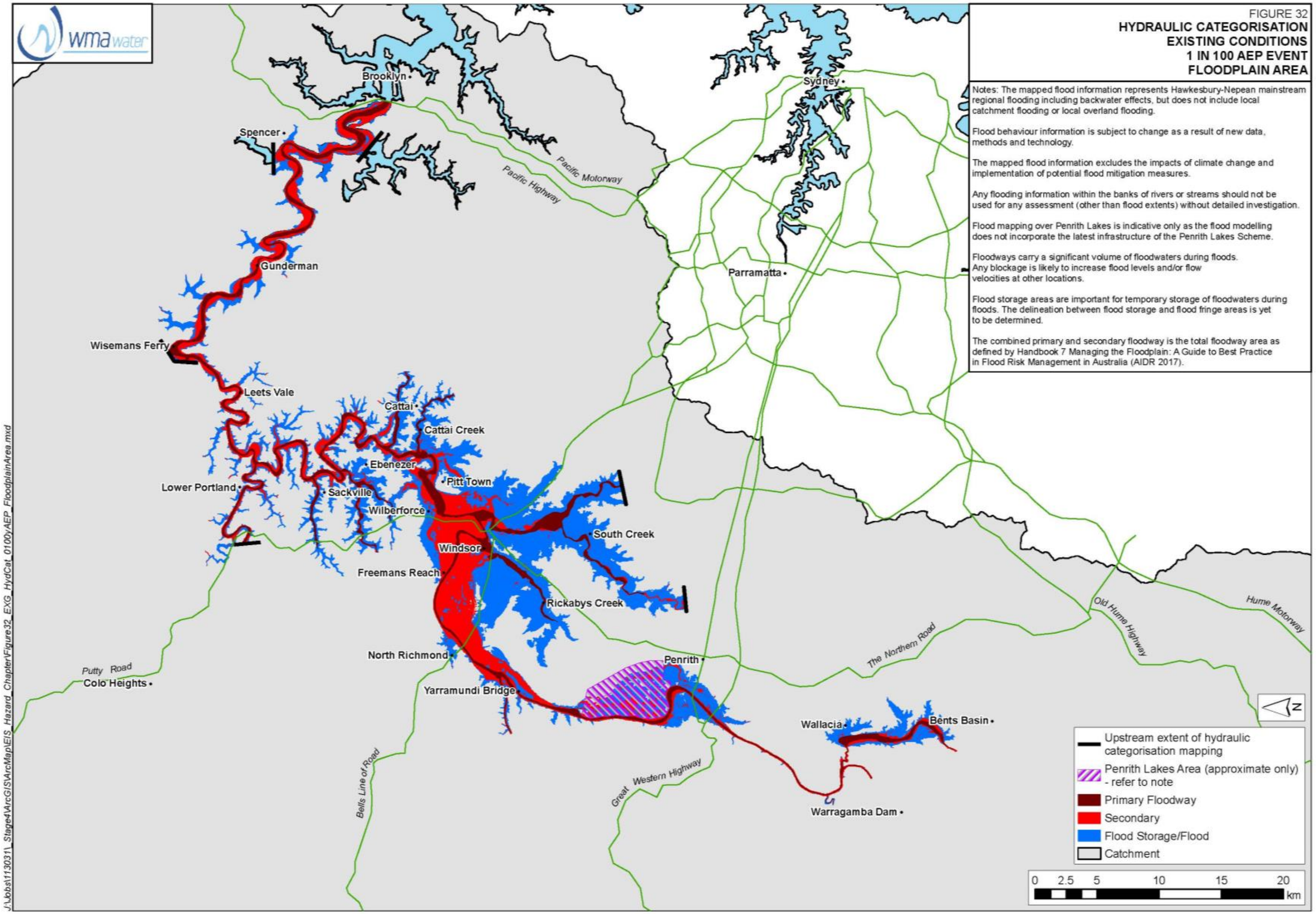


Figure 15-24. Existing hydraulic categorisation: 1 in 500 chance in a year flood (Appendix H2, Figure 36)

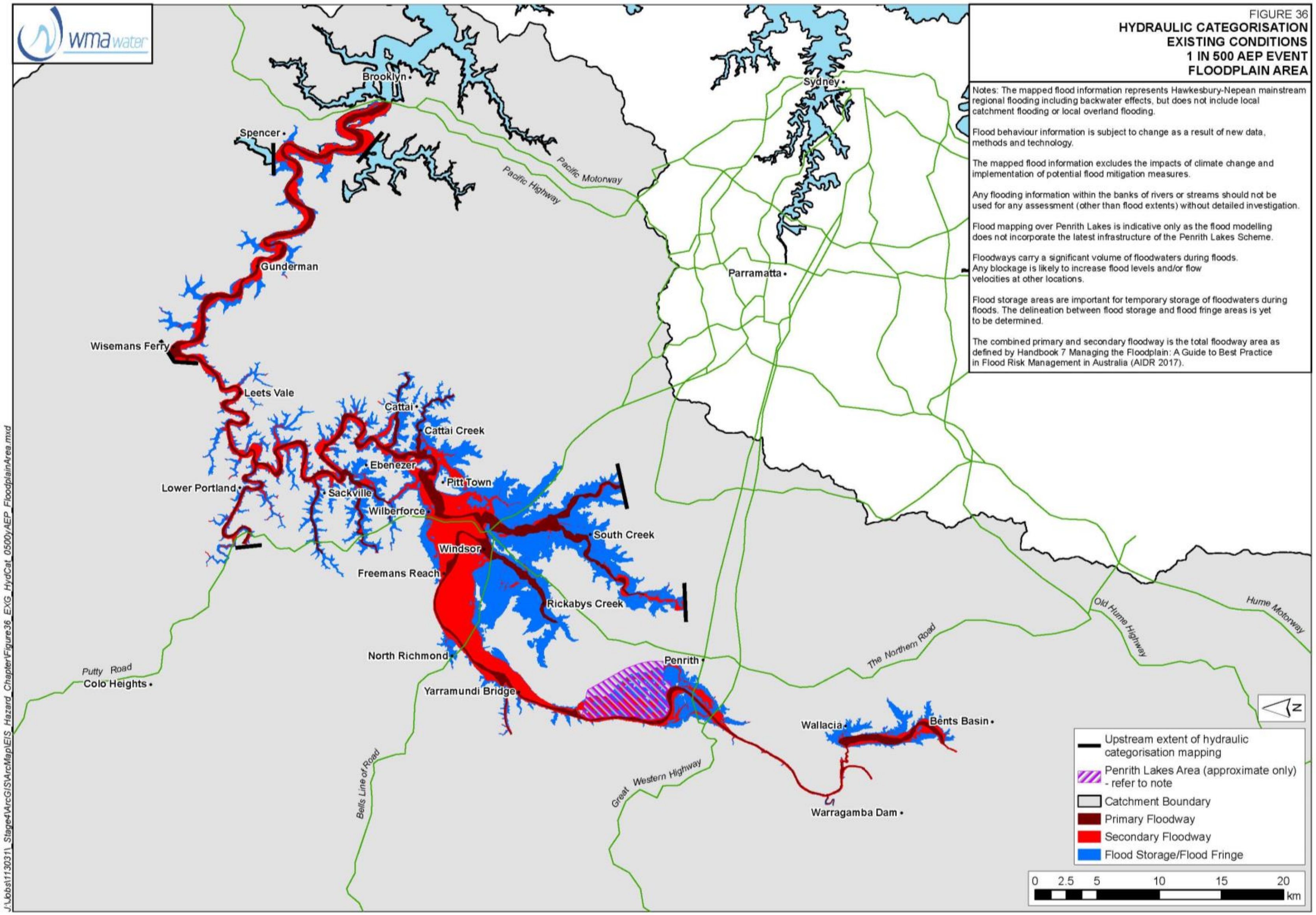
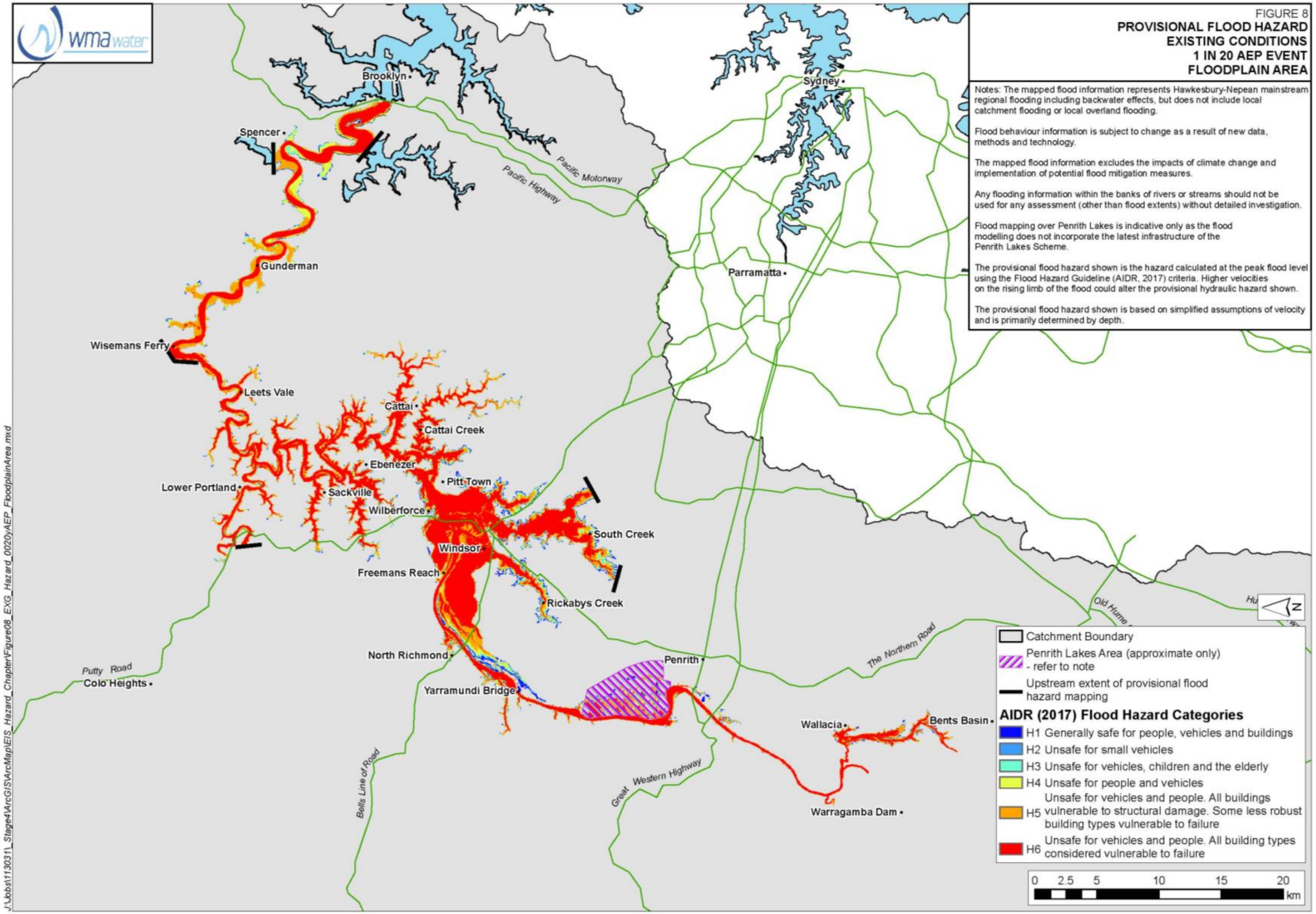


Figure 15-25. Existing flood hazard mapping: 1 in 20 chance in a year event (Appendix H2, Figure 8) 1 of 2



Existing flood hazard mapping: 1 in 20 chance in a year event (Appendix H2, Figure 9) 2 of 2

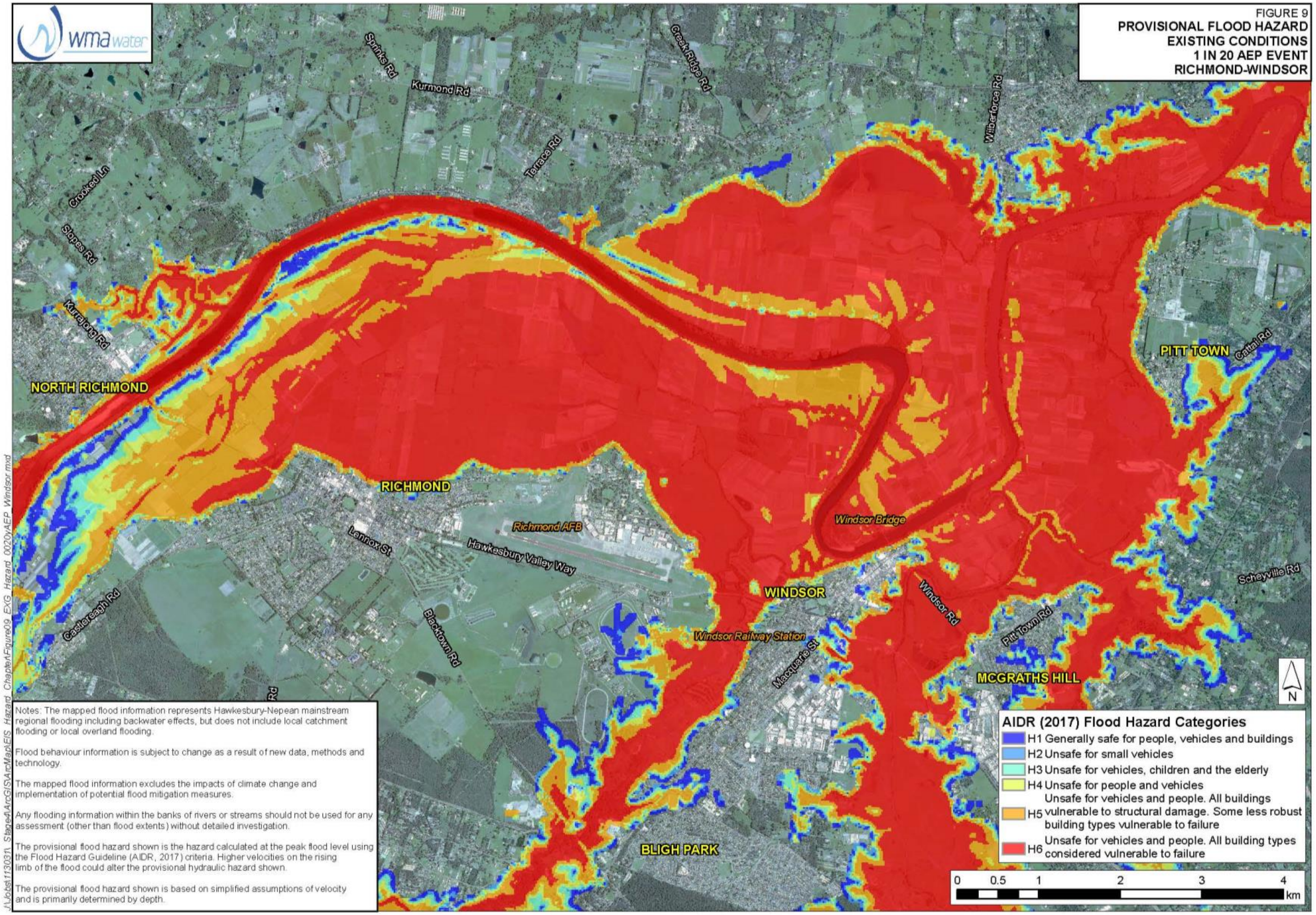
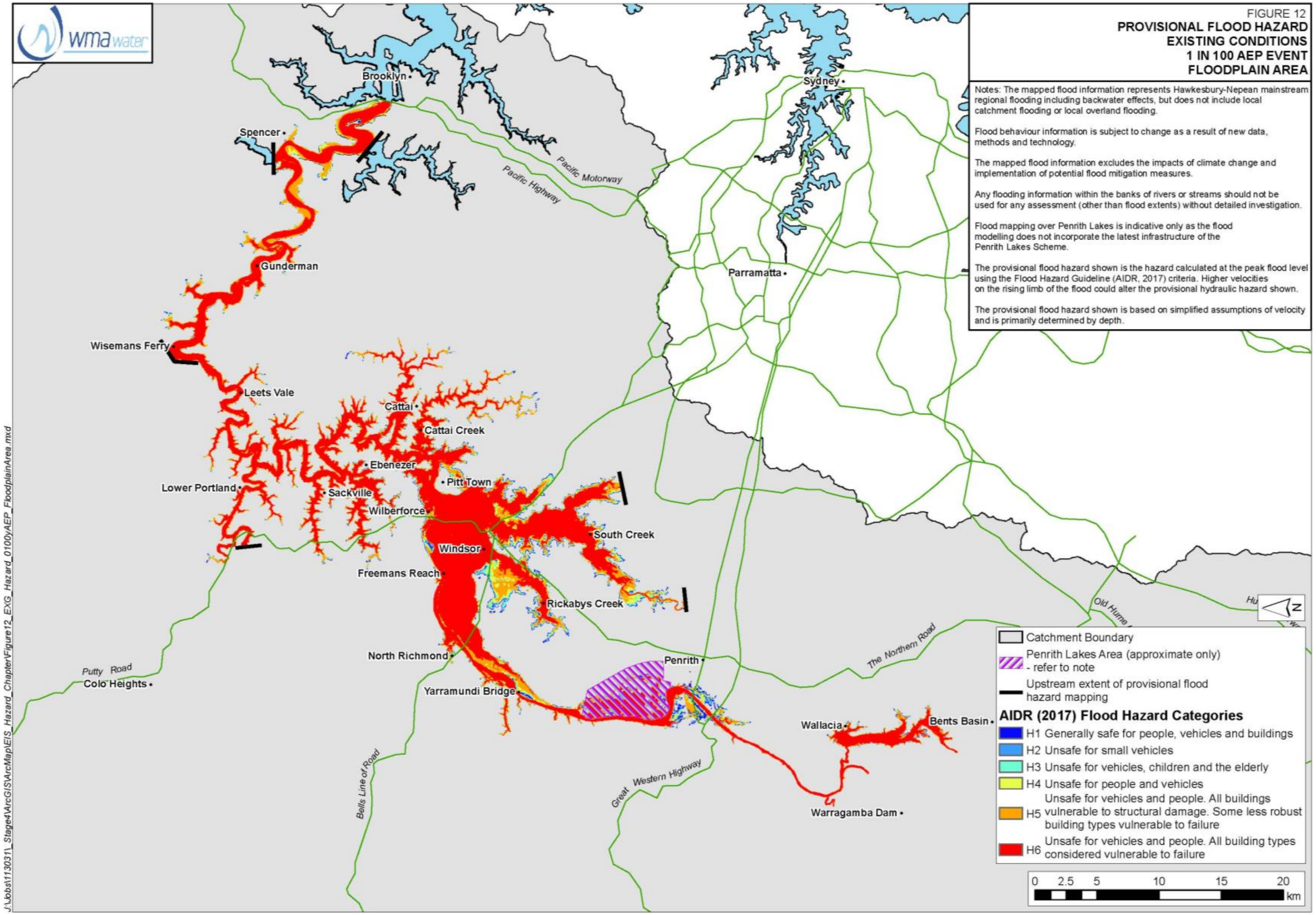
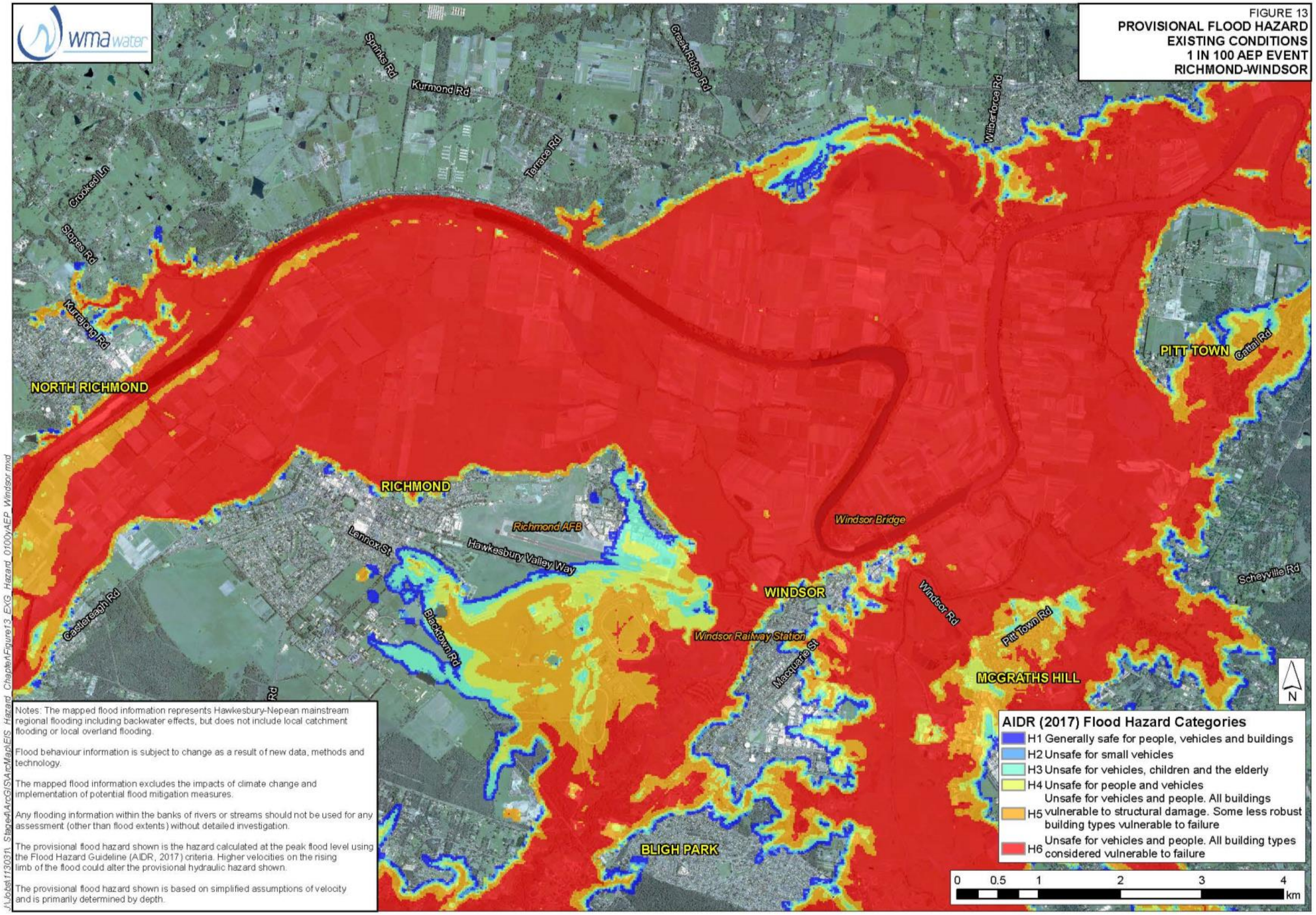


Figure 15-26. Existing flood hazard mapping: 1 in 100 chance in a year event (Appendix H2, Figure 12) 1 of 2



Existing flood hazard mapping: 1 in 100 chance in a year event (Appendix H2, Figure 13) 2 of 2



15.4.6 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) (NSW SES 2015). The Flood Plan covers the areas from Wallacia to Spencer and there are several 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) would likely need to play a part, as well as people at risk of flood impacts. Other agencies are to assist the NSW SES in accordance with arrangements laid down in the Hawkesbury-Nepean Flood Plan and Local Flood Sub Plans.

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

- **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 at which the routes are cut are shown in Figure 15-27. Currently, there is insufficient road capacity to safely evacuate the whole population within the Bureau of Meteorology target flood forecast time (BoM 2015), with multiple communities relying on common, constrained and congested road links as their means of evacuation.

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 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 15-10. In summary:

- for a 1 in 100 chance in a year flood (similar to the 2011 Brisbane flood); 55,000 people would have required evacuation in 2018

- for a 1 in 500 chance in a year flood (similar to the 1867 Hawkesbury-Nepean valley flood); 88,000 people would have required evacuation in 2018.

Table 15-10. Number of people requiring evacuation (2018)

Flood size 1 in X chance in a year	Residents Existing risk (2018)					Employees Existing risk (2018)			Total people considered in evacuation planning (2018)
	Residents in dwellings in flooded areas (2018)	Residents in manufactured homes in flooded areas (2018)	Total residents in flooded areas (2018)	Residents in isolated dwellings (2018)	Total residents considered in evacuation planning	Employees who work in flooded areas but live outside the floodplain	Employees isolated on High Flood Islands who live outside the floodplain	Total employees considered in evacuation planning who live outside floodplain	
100	15,800	3,900	19,800	23,400	43,100	9,600	2,200	11,900	55,000
500	34,900	4,000	39,000	22,200	61,200	23,700	2,900	26,600	88,000
PMF	86,900	4,200	91,000	12,900	104,000	48,100	300	48,400	152,000

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. 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.

These are discussed as follows:

15.4.6.1 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.

The SES preference is to evacuate high flood islands and high trapped perimeters, as these areas would likely have no utilities and resupply is not certain given the likely inclement weather conditions.

15.4.6.2 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.

15.4.6.3 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 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.

15.4.6.4 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 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 evacuation by vehicle fails.

15.4.6.5 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.

15.4.6.6 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.

Flood evacuation routes and the flood level (mAHD) at which the routes are cut are shown on Figure 15-27.

The different sectors within the Hawkesbury-Nepean, their flood classification and specific evacuation characteristics are summarised in Table 15-11.

Figure 15-27. Hawkesbury-Nepean Valley flood evacuation routes and flood level (mAHD) at which routes are cut

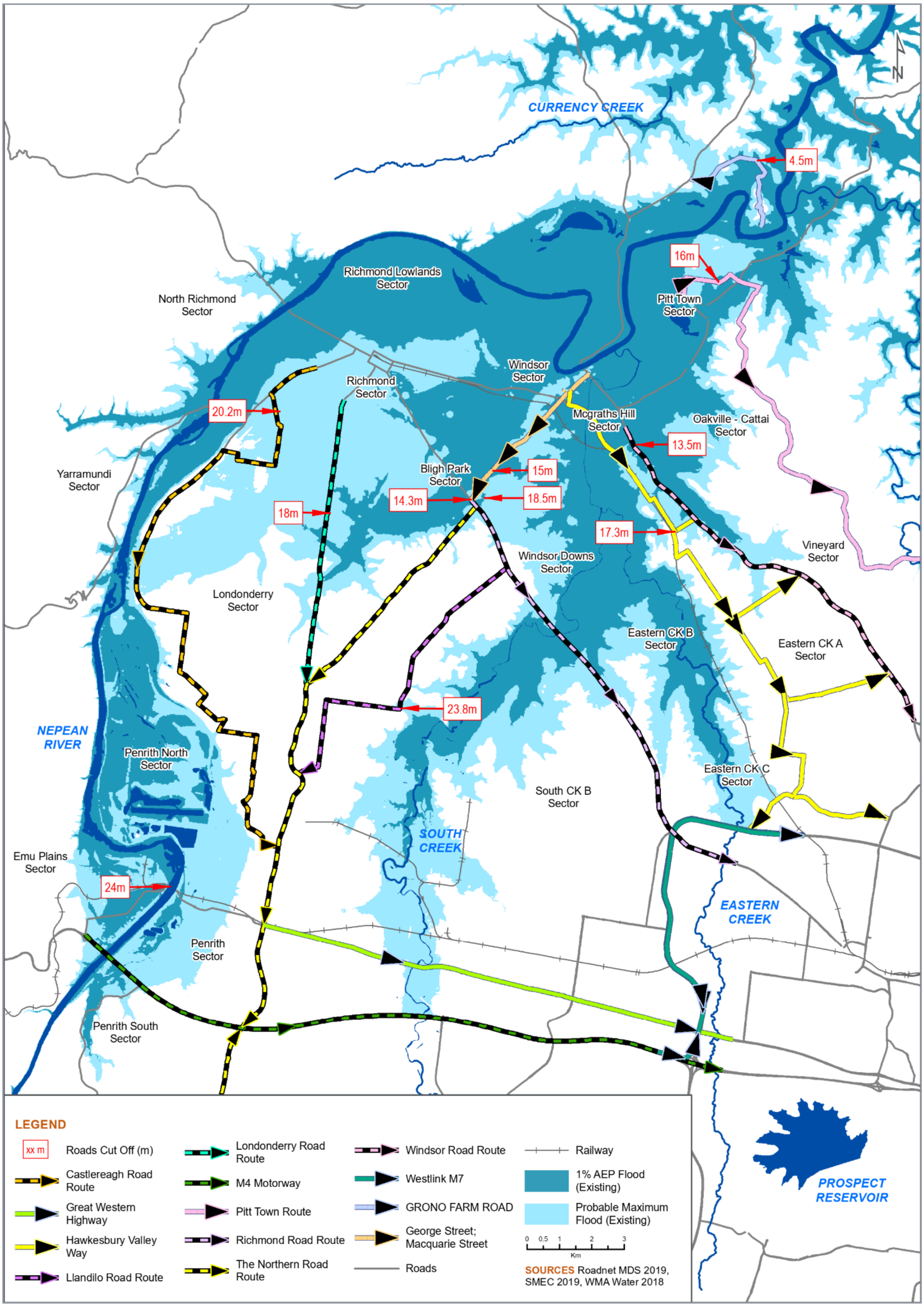


Table 15-11. Flooding classification and evacuation characteristics by area

Area (sector/sub-sector)	Flood classification	Loss of road access (mAHD)	Submersion height (mAHD)	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/Ebenezer	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 6.2 m (Windsor gauge) in Pitt Town Bottoms. Around 60 dwellings in Pitt Town would be flooded by 13.7 m.
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.
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.

Area (sector/sub-sector)	Flood classification	Loss of road access (mAHD)	Submersion height (mAHD)	Comments
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 several properties near the Nepean River which can be flooded in larger events.
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.

15.4.7 Flood management plans

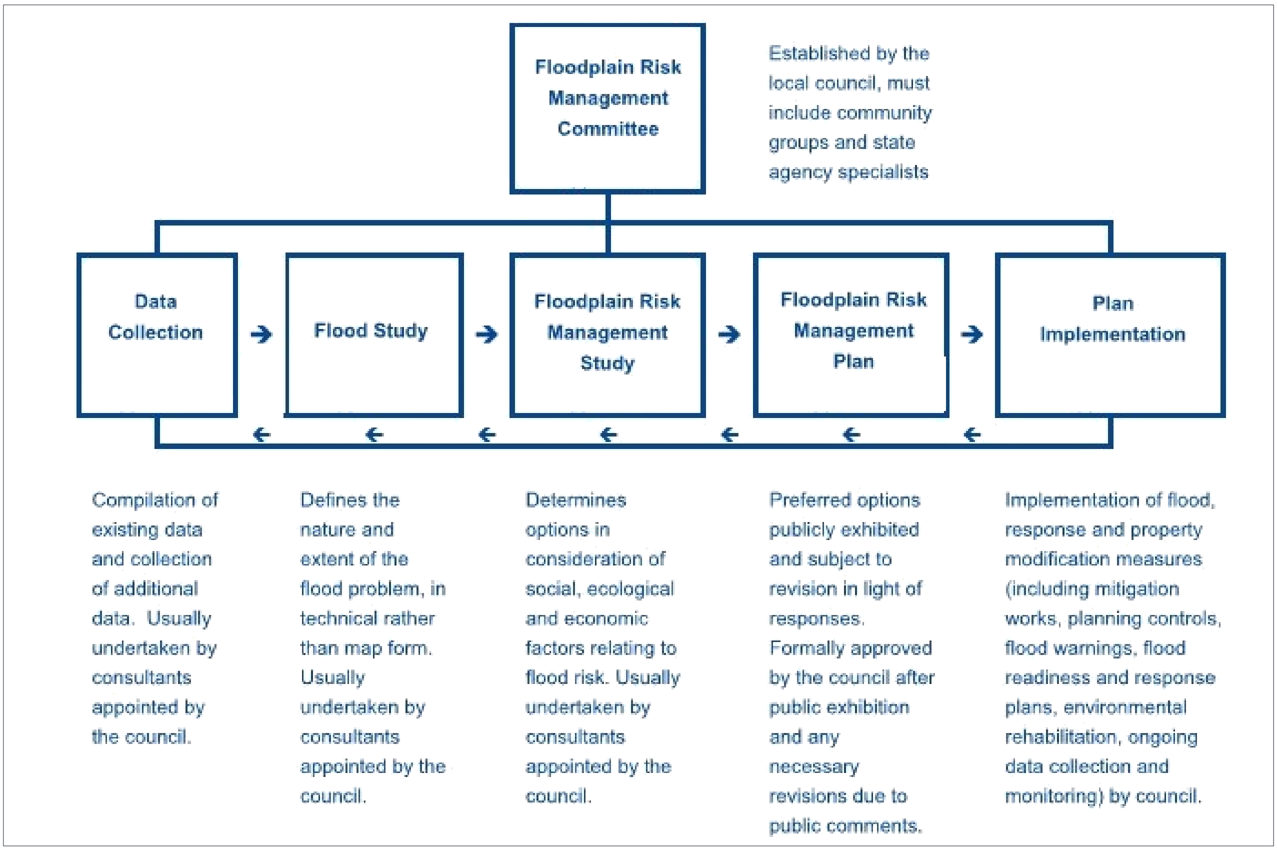
Local governments are required to prepare Floodplain Risk Management Plans based upon guidance in the *Floodplain Development Manual* (DIPNR 2005) and the *Flood Prone Land Policy*. The primary objective of the Flood Prone Land Policy is to reduce the impacts of flooding and flood liability on individual owners of flood prone property, and to reduce private and public losses resulting from floods.

The application of the Flood Prone Land Policy and the steps in preparing and implementing a Floodplain Risk Management Plan are detailed in Figure 15-28. 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 is not permitted
- flood warning, readiness and response planning
- environmental programs which may reduce flooding (for example, wetland restoration)
- monitoring and data collection programs.

Resilient Valley, Resilient Communities – Hawkesbury-Nepean Valley Flood Risk Management Strategy (Flood Strategy) (Infrastructure NSW 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.

Figure 15-28. Floodplain risk management plan process



Source: Appendix H1, Figure 3-38

Relevant flood studies and floodplain risk management strategies that have been prepared since 1995 are shown in Table 15-12. 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 LGAs 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 15-12. Relevant flood studies and floodplain risk management strategies

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	City of Gosford Council (now Central Coast 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
Draft South Creek Floodplain Risk Management Strategy and Plan	Dec-2019	Penrith City Council
Hawkesbury-Nepean Valley Regional Flood Study	2019	WMAwater

15.5 Construction impacts

15.5.1 Overview

Construction would be undertaken over a four to five-year period. Potential impacts relate to increased flooding impacts, reduced downstream flows, increased stormwater runoff and water demands. Potential impacts are discussed as follows.

15.5.2 Flooding impacts

Construction areas would be directly exposed to dam spills and flooding resulting in potential impacts to worker safety, construction works and scheduling, plant and equipment, erosion and sedimentation, and water quality. Debris may potentially wash downstream causing environmental and safety impacts.

Preliminary flood management options for construction have been developed and include:

- **Lowering the FSL by five metres:** This would provide about 20 percent of the existing dam capacity for flood mitigation, which would protect construction works up to the 1 in 20 chance in a year rain event and allow sufficient time to move plant and equipment, and secure the construction area. A similar level of flood mitigation would be provided to downstream flood prone areas.
- **Coffer dams:** Protective coffer dams would be constructed upstream of the auxiliary spillway works and downstream of the dam wall works.
- **Temporary spillway gates:** These would be used during the construction of the new central spillway.
- **Construction staging:** Construction of the central and auxiliary spillway works would be staged to ensure that one spillway is always able to pass floodwaters.

A construction flood management plan would be developed as part of construction planning. 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. The requirements of Dams Safety NSW will also be addressed.

15.5.3 Construction emergency management

There would be no change in downstream flooding and evacuation management during construction of the Project. The existing Flood Plan would continue to be the primary management plan for downstream evacuation, which is discussed in Section 15.9. Evacuation requirements and planning at the construction site would be detailed in the Construction Flood Management Plan.

15.5.4 Reduced downstream flows

Existing downstream flows would be maintained by diverting water through the dam construction site at controlled locations.

15.5.5 Stormwater runoff

Construction would result in additional temporary hardstand areas including site offices, workshops, car and truck parking, plant and equipment storages, concrete batch plant facilities, water treatment plant and access roads. Stormwater runoff would increase from these areas; however, this would be temporary and relatively small, and there would be minor impact on river flows. Appropriate drainage infrastructure would be addressed during detailed design and be installed prior to the commencement of construction works.

15.5.6 Water demands

About 183 megalitres of water is required for construction water uses over the construction period. This amounts to approximately 0.11 megalitres per day. This water would be generally sourced from the potable water supply. 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.

15.6 Upstream Project impacts

15.6.1 Overview

The Project would involve raising the dam wall and spillways to create a dedicated FMZ, with a depth of around 12 metres above FSL. The FMZ works by capturing inflows during rainfall events and then releasing the captured water at a controlled rate once the rainfall event is over. The replacement of the drum and radial gates on the central spillway, and fuseplugs on the auxiliary spillway, with fixed spillways temporarily holds back more water during large flood events. This results in a reduction in downstream peak flows and flooding extents. However, the total volume of water discharged downstream does not change and there would be changes in the extent, duration and frequency of temporary inundation upstream of the dam wall. These changes will vary significantly throughout the upstream catchment, and would depend on distance from the dam wall, and site specific topographical and hydrological conditions.

Rainfall events that do not increase Lake Burragorang levels above the FSL would have no impact on hydrology and flood behaviour. Activation of the FMZ would only occur when rainfall increases dam water levels above the FSL.

15.6.2 Extent of Project impacted area

As discussed in Section 15.2.2, 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 kilometres, 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 15-13 and shown on flood maps provided in Section 15.14.1 (Figure 15-50 to Figure 15-56).

Table 15-13. Changes to flood extents

Event (1 in x chance in a year)	Flood affected area (ha)		Area change due to Project	
	Existing	Project	Area (ha)	%
5	560	843	283	51
10	754	1,589	835	111
20	926	2,313	1,387	150
100	998	2,910	1,912	192
PMF	2,934	5,280	2,346	80

15.6.3 Changes to flood levels and duration of temporary inundation

Modelling included development of depth-duration curves at various cross sections within the lake and along major tributaries[3]. 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.

Flood depth-duration curves were examined for a selection of locations as shown on Figure 15-29. 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. This is discussed in Section 15.2.3. Further downstream, cross sections were analysed to assess changes to Project depth – duration characteristics.

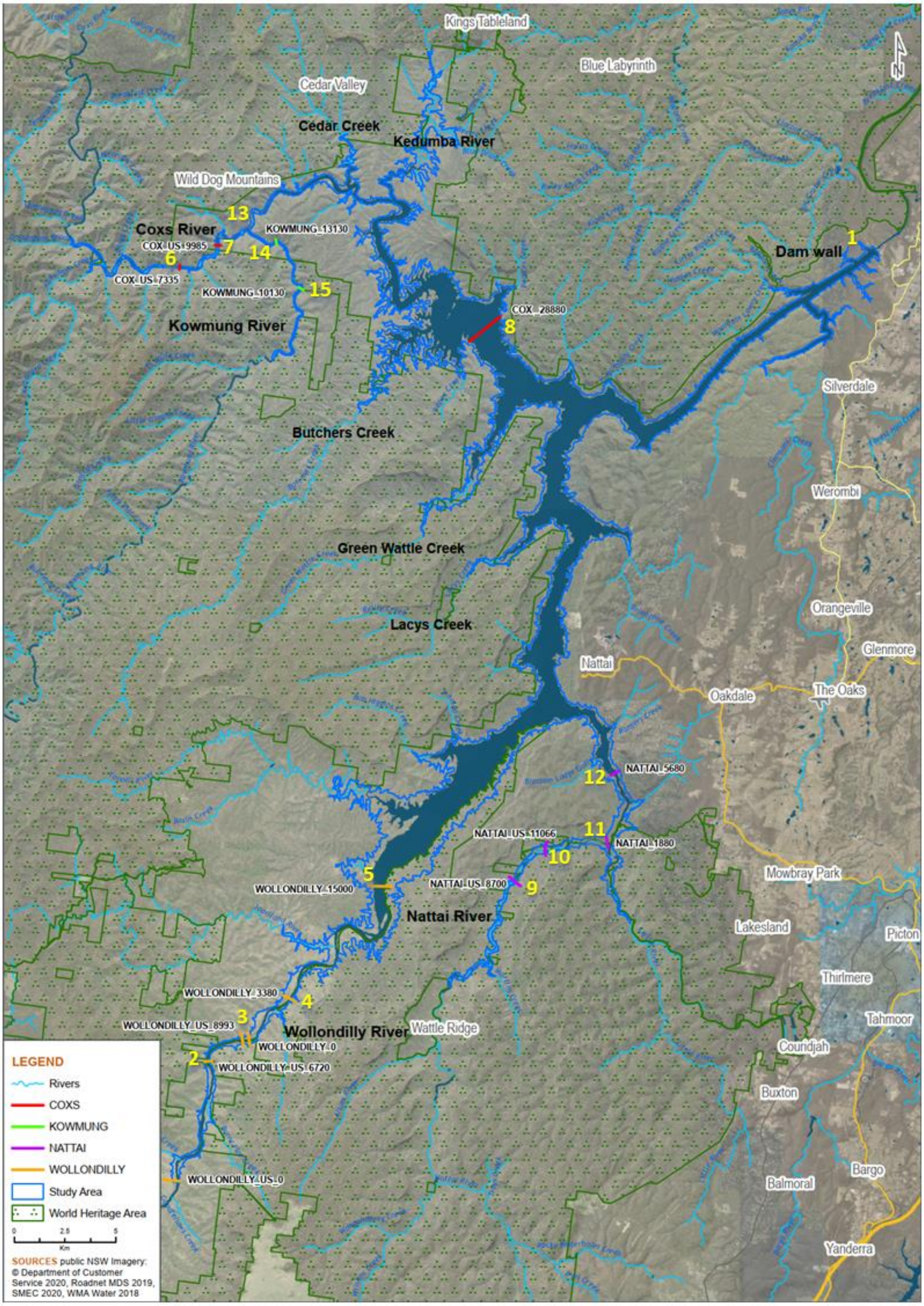
Cross section locations (which are cross referenced to modelled cross section names) are:

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

Results of the analyses are discussed below.

[3] It should be noted that the figures for the incremental depths and durations are based on representative hydrographs from the Monte Carlo analysis.

Figure 15-29. Upstream locations for depth-duration and flood frequency analyses



15.6.3.1 Dam wall

Predicted changes at the dam wall are shown on Figure 15-30 and summarised in Table 15-14.

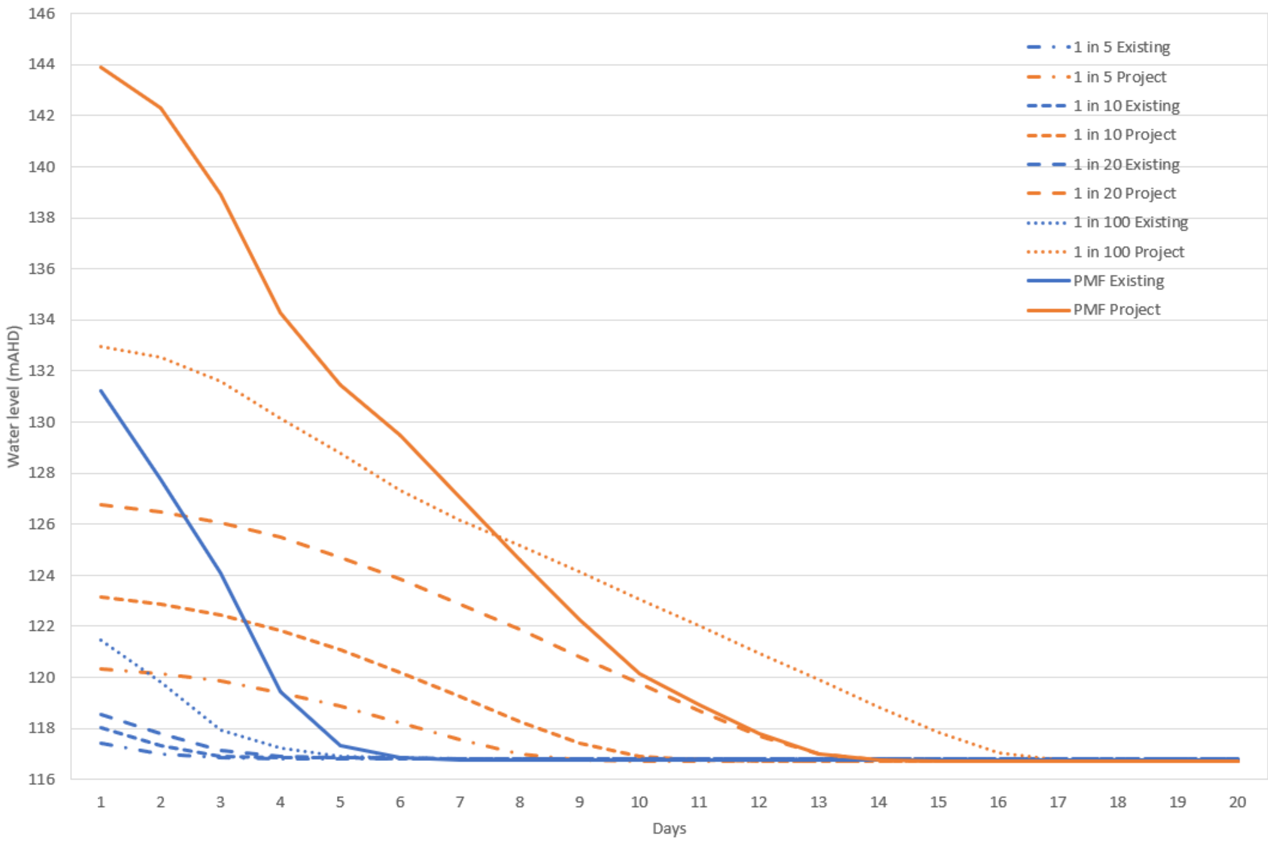
Changes to the duration of upstream inundation at the dam wall would be up to about five days for the relatively more frequent 1 in 5 chance in a year flood, and up to about 11 days for a rarer 1 in 100 chance in a year flood event.

Table 15-14. Dam wall: Changes to temporary inundation levels and durations

Event (1 in x chance in a year)	Existing			Project			
	Level (mAHD)	Depth (m)	Inundation* (days)	Level (mAHD)	Depth (m)	Increase in inundation (days)	Total inundation (days)
5	117.4	0.7	2.8	120.3	2.9	4.6	7.4
10	118.0	1.3	3.4	123.1	5.1	6	9.4
20	118.6	1.9	4.0	126.8	8.2	8.6	12.6
100	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	11.2

* 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 15-30. Dam wall: Depth-duration curves



15.6.3.2 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_8993) represents the approximate location of the Project for the 1 in 100 chance in a year 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 shown on Figure 15-31 and summarised in Table 15-15. 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:

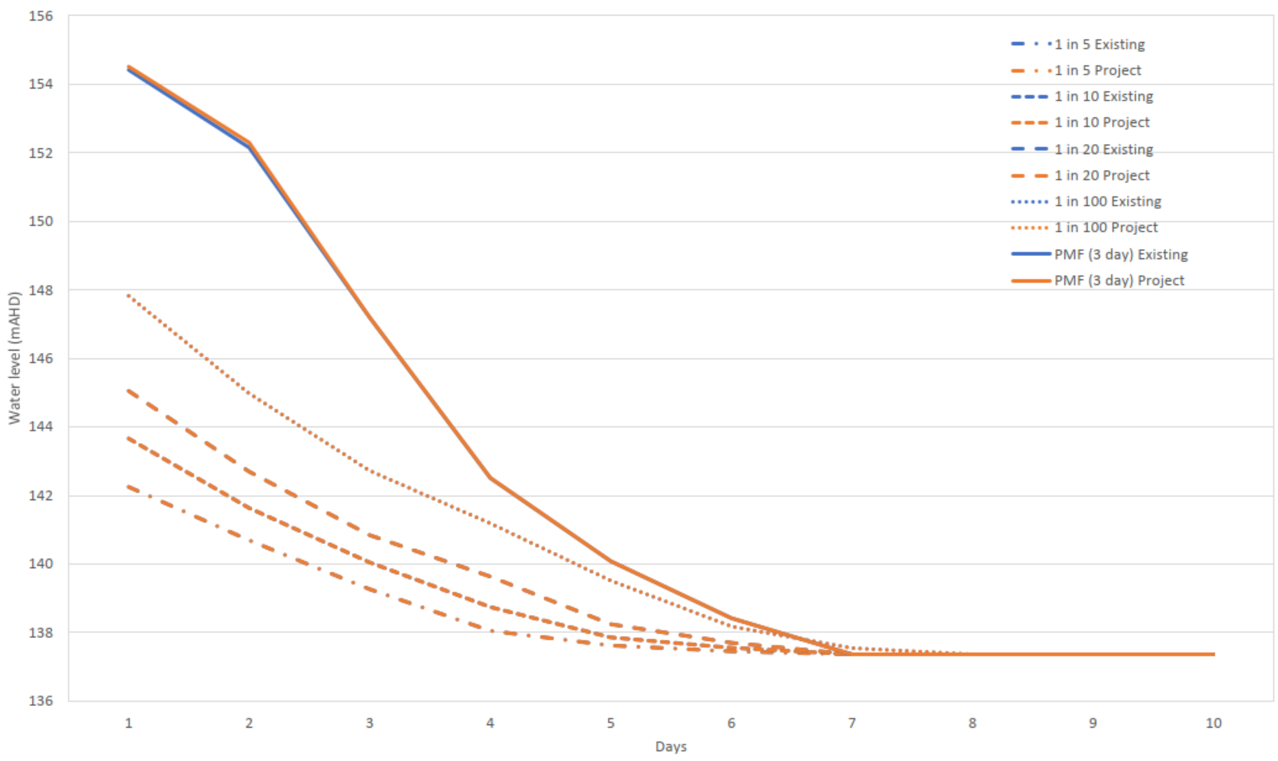
- increases in the depth and duration of temporary inundation are generally less than half a metre and half a day respectively for the two upstream most cross-sections for all SEARs events, the exception being the PMF event for Location 3 (WOLLONDILLY_US_8993) where the increase in depth is about 1.1 metres
- at Location 4 (WOLLONDILLY_3380), increases in depth are less than half a metre for all events up to the 1 in 100 chance in a year event; 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 in 10 chance in a year event, then increasing up to 3.6 days for the 1 in 100 chance in a year 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 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 15-15. Upstream changes in temporary inundation depth and duration

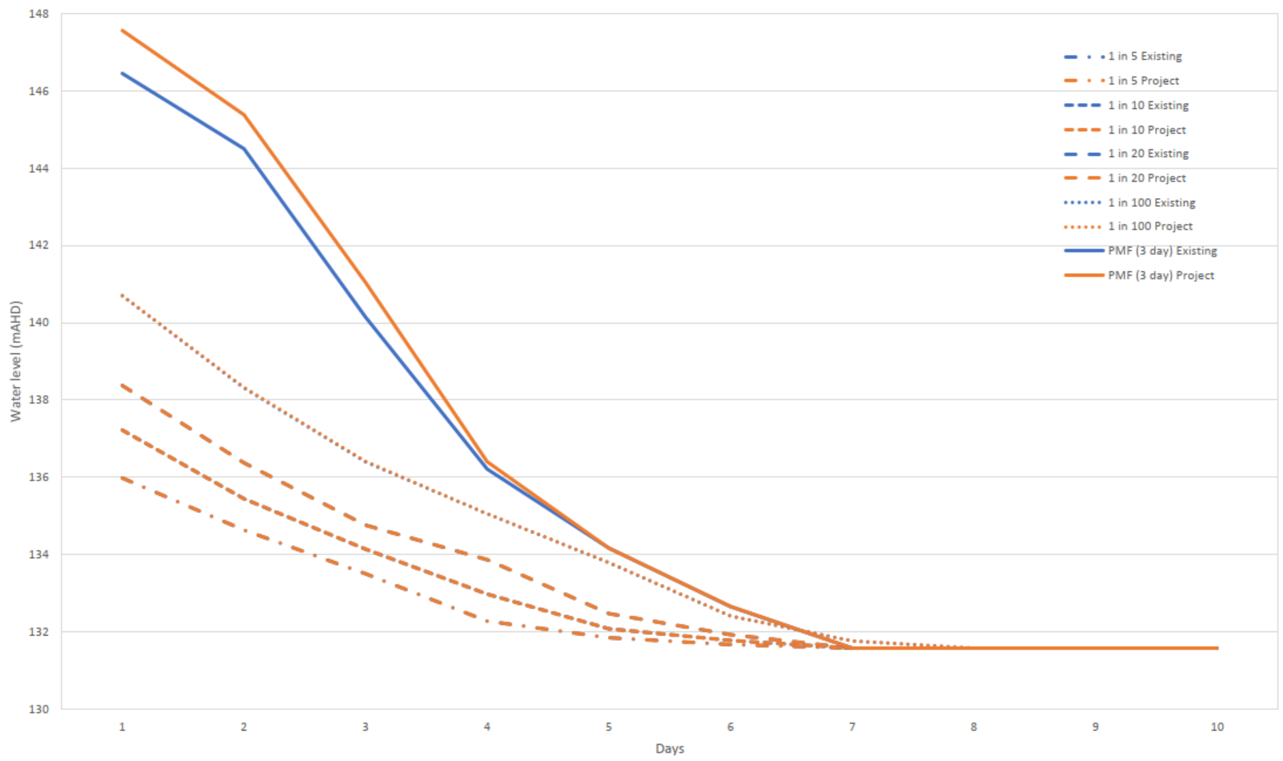
Location (refer Figure 15-31)	Flood event (1 in x chance in a year) E = existing; P = Project									
	1 in 5		1 in 10		1 in 20		1 in 100		PMF	
	E	P	E	P	E	P	E	P	E	P
Location 2: WOLLONDILLY_US_6720										
Depth (m)	4.4	<0.5	6.2	<0.5	9.0	<0.5	10.0	<0.5	17.1	<0.5
Duration (days)	5.9	<0.5	5.4	<0.5	6.2	<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 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 15-31. Wollondilly River: Depth-duration curves

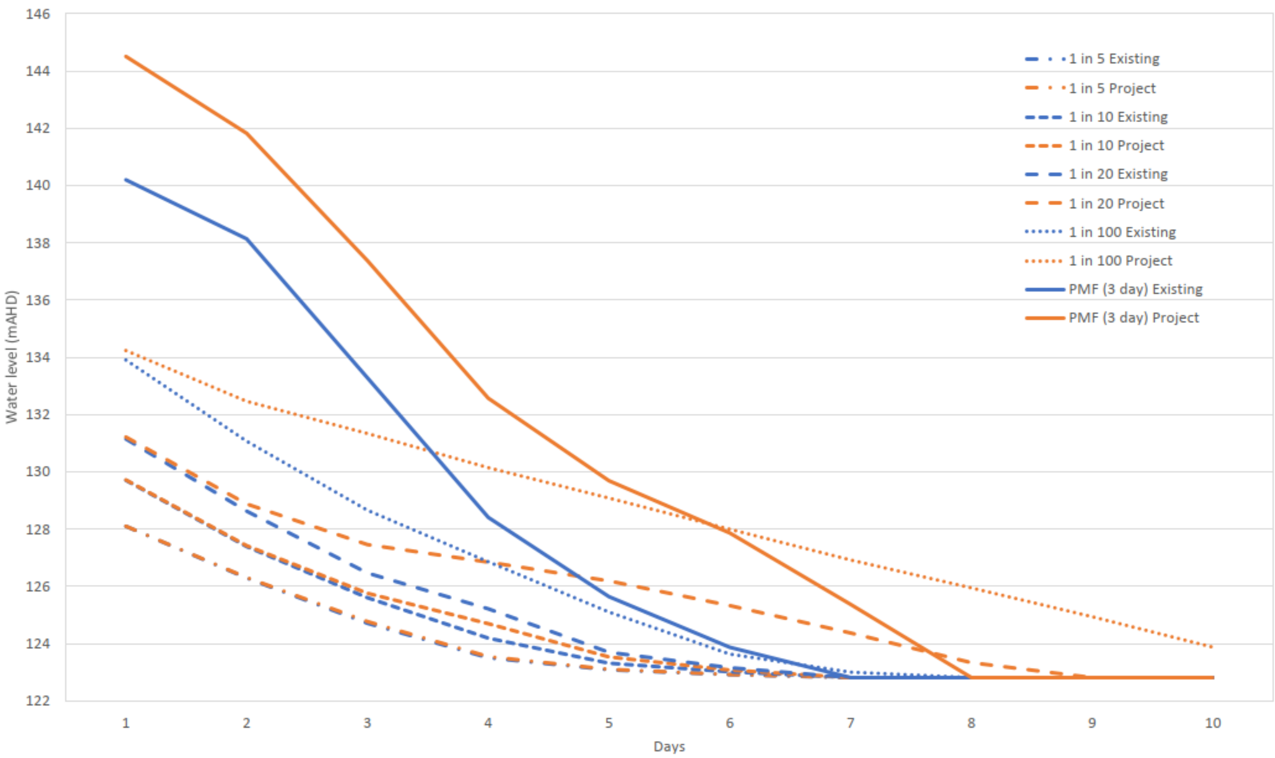
Location 2: WOLLONDILLY_US_6720



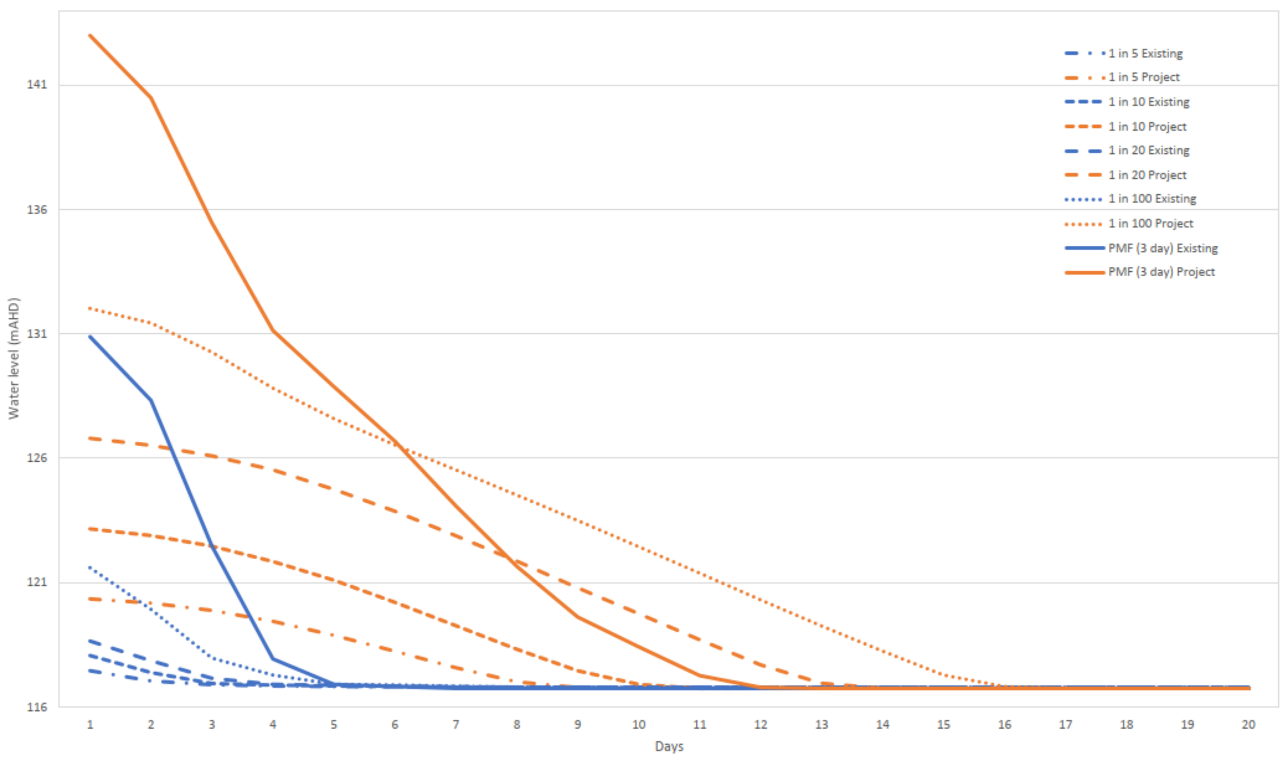
Location 3: WOLLONDILLY_US_8993



Location 4: WOLLONDILLY_3380



Location 5: WOLLONDILLY_15000



15.6.3.3 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 in 100 chance in a year 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 shown on Figure 15-32 and summarised in Table 15-19. 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:

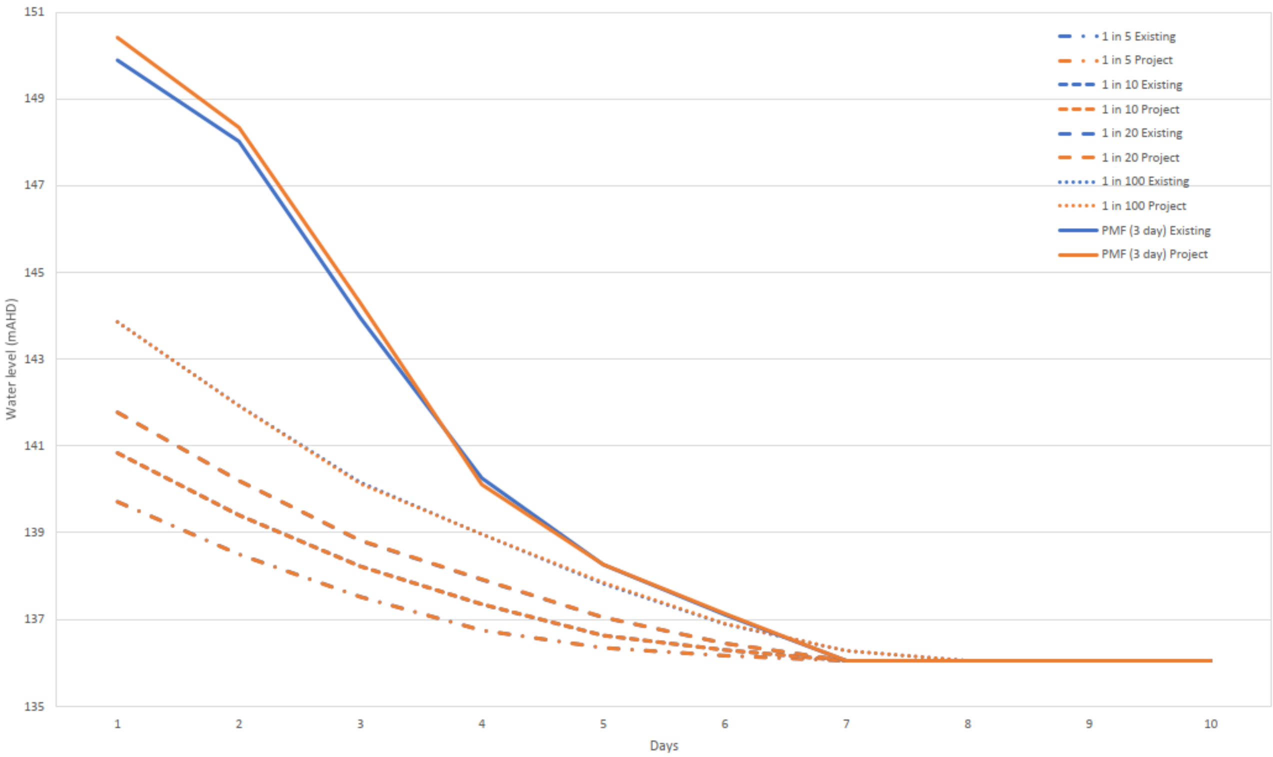
- increases in the depth and duration of temporary inundation are half a metre (for the PMF event) or less and half a day respectively for Location 6 (COX_US_7335) for all events
- increases in the depth of temporary inundation for Location 7 (COX_US_9985) are half a metre or less up to the 1 in 100 chance in year 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 1 in 20 chance in a year event; this increases slightly to 0.7 days for the 1 in 100 chance in a year 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 15-16. Coxs River: Upstream changes in temporary inundation depth and duration

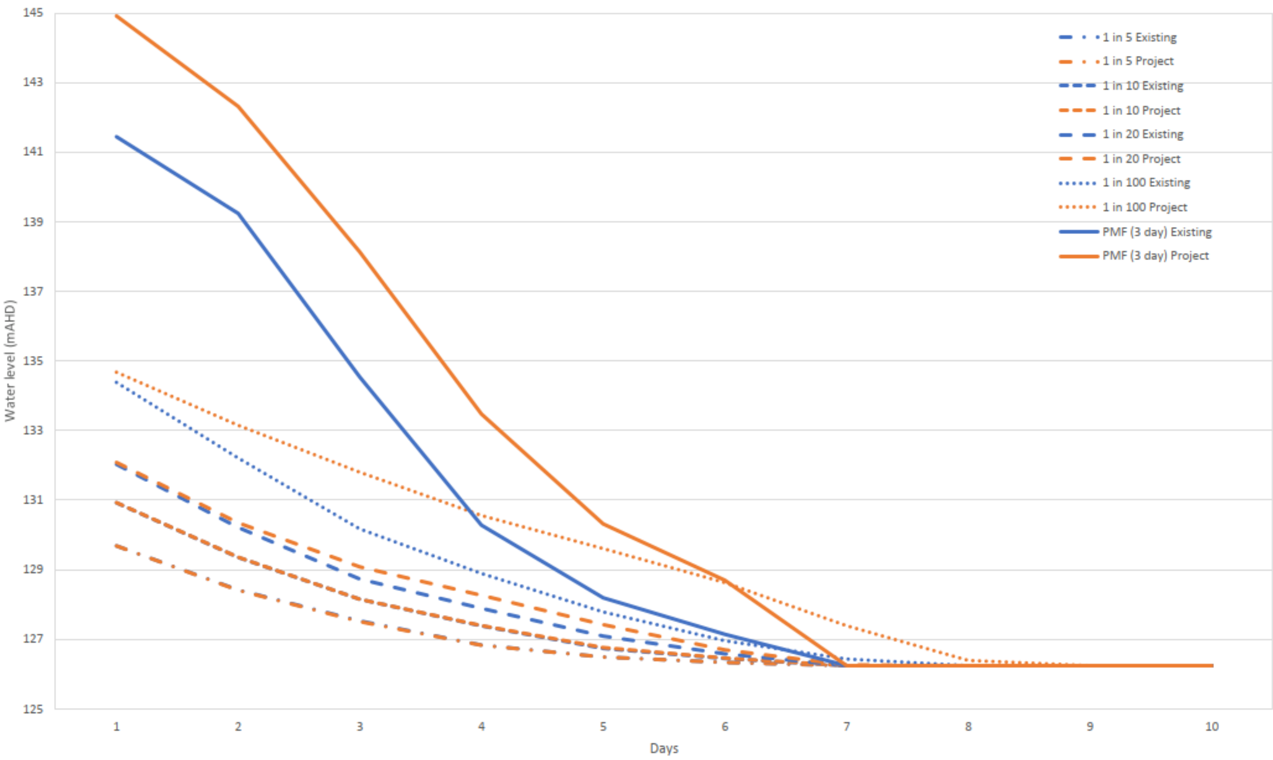
Location (refer Figure 15-32)	Flood event (1 in x chance in a year) E = existing; P = Project									
	1 in 5		1 in 10		1 in 20		1 in 100		PMF	
	E	P	E	P	E	P	E	P	E	P
Location 6: COX_US_7335										
Depth (m)	2.4	<0.5	4.6	<0.5	5.3	<0.5	6.7	<0.5	13.8	0.5
Duration (days)	5.8	<0.5	5.4	<0.5	6.2	<0.5	5.3	<0.5	5.3	<0.5
Location 7: COX_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										
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 15-32. *Coxs River: Depth-duration curves*

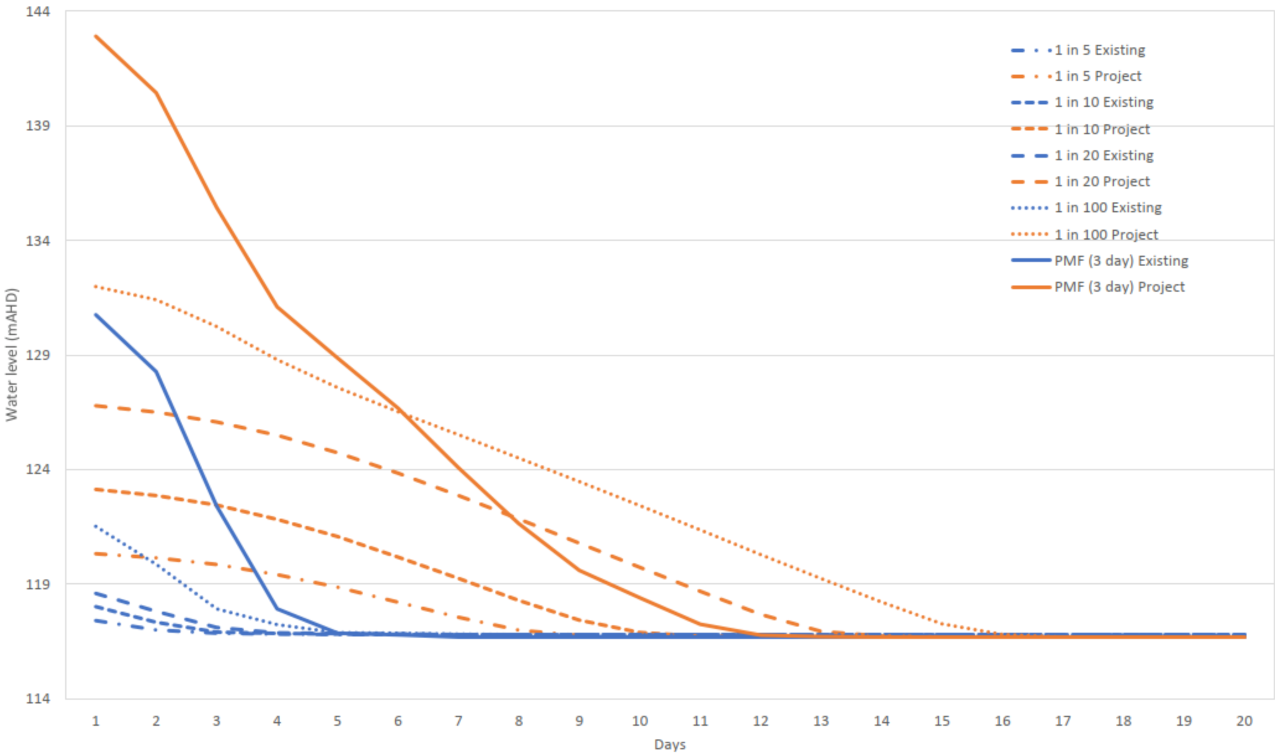
Location 6: COXS_US_7335



Location 7: COXS_US_9985



Location 8: COXS_28880



15.6.3.4 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 in 100 chance in a year 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 shown on Figure 15-33 and summarised in Table 15-17. 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:

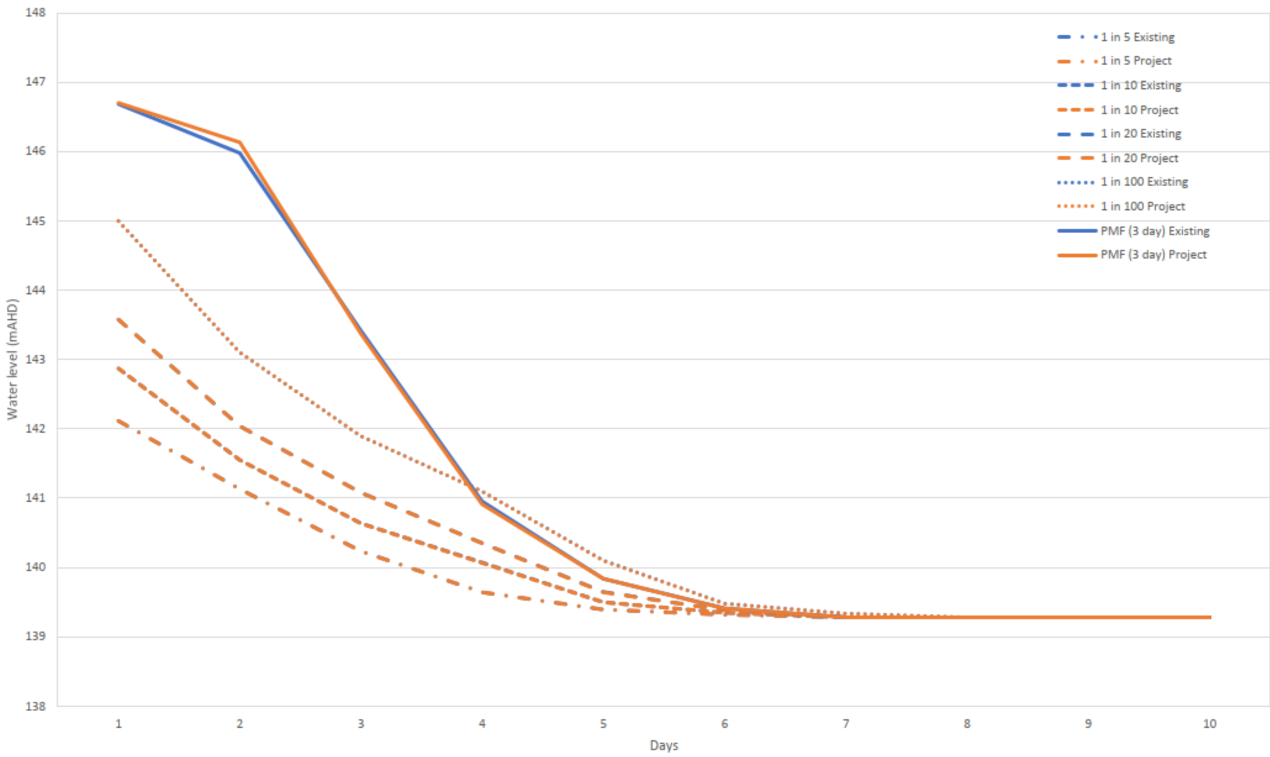
- increases in the depth and duration of temporary inundation for cross-sections NATTAI_US_8700 and NATTAI_US_11066 are less than half a metre and half a day respectively for all events with the exception of the PMF event for NATTAI_US_11066 which would increase by about 7.8 metres
- increases in the depth and duration of temporary inundation are more noticeable at cross-section NATTAI_1880, particularly for the 1 in 20 chance in a year and larger 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 1 in 20 chance in a year and larger flood events.

Table 15-17. Nattai River: Upstream changes in temporary inundation depth and duration

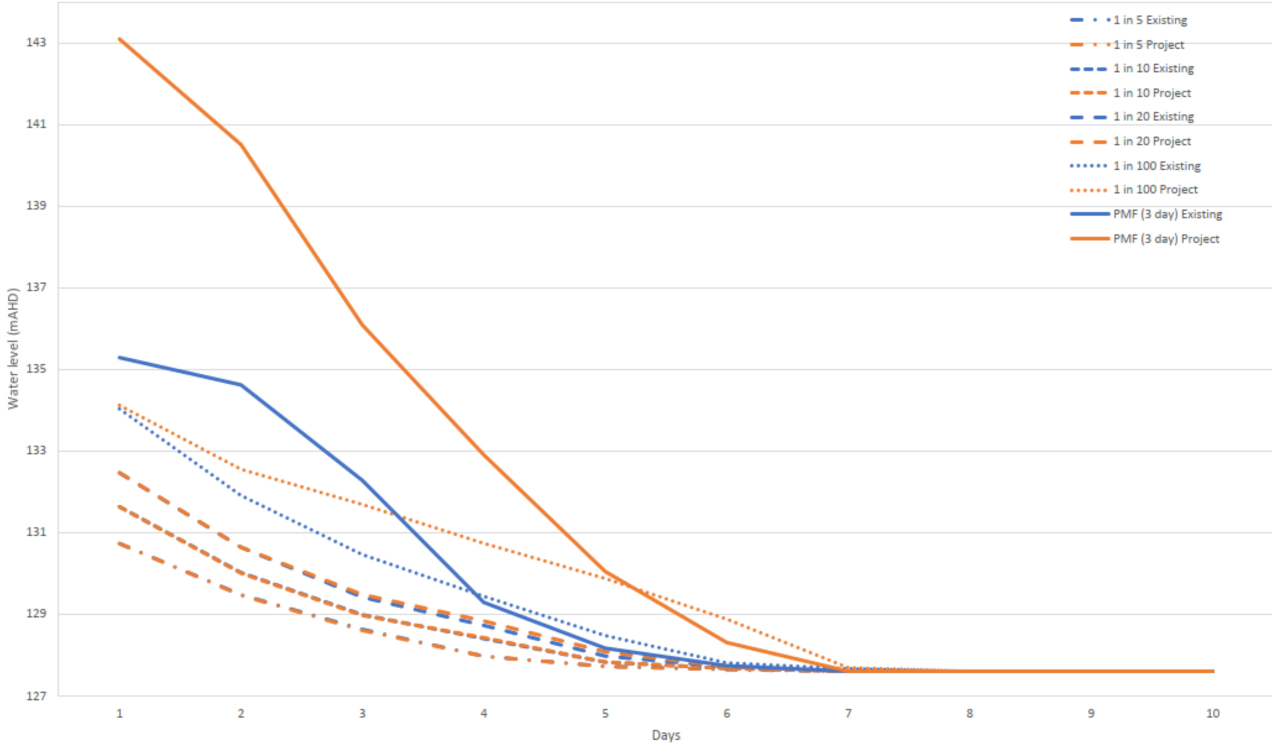
Location (refer Figure 15-33)	Flood event (1 in x chance in a year) E = existing; P = Project									
	1 in 5		1 in 10		1 in 20		1 in 100		PMF	
	E	P	E	P	E	P	E	P	E	P
Location 9: NATTAI_US_8700										
Depth (m)	3.4	<0.5	3.7	<0.5	4.3	<0.5	4.3	<0.5	7.4	<0.5
Duration (days)	5.9	<0.5	5.4	<0.5	6.2	<0.5	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										
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 15-33. Nattai River: Depth-duration curves

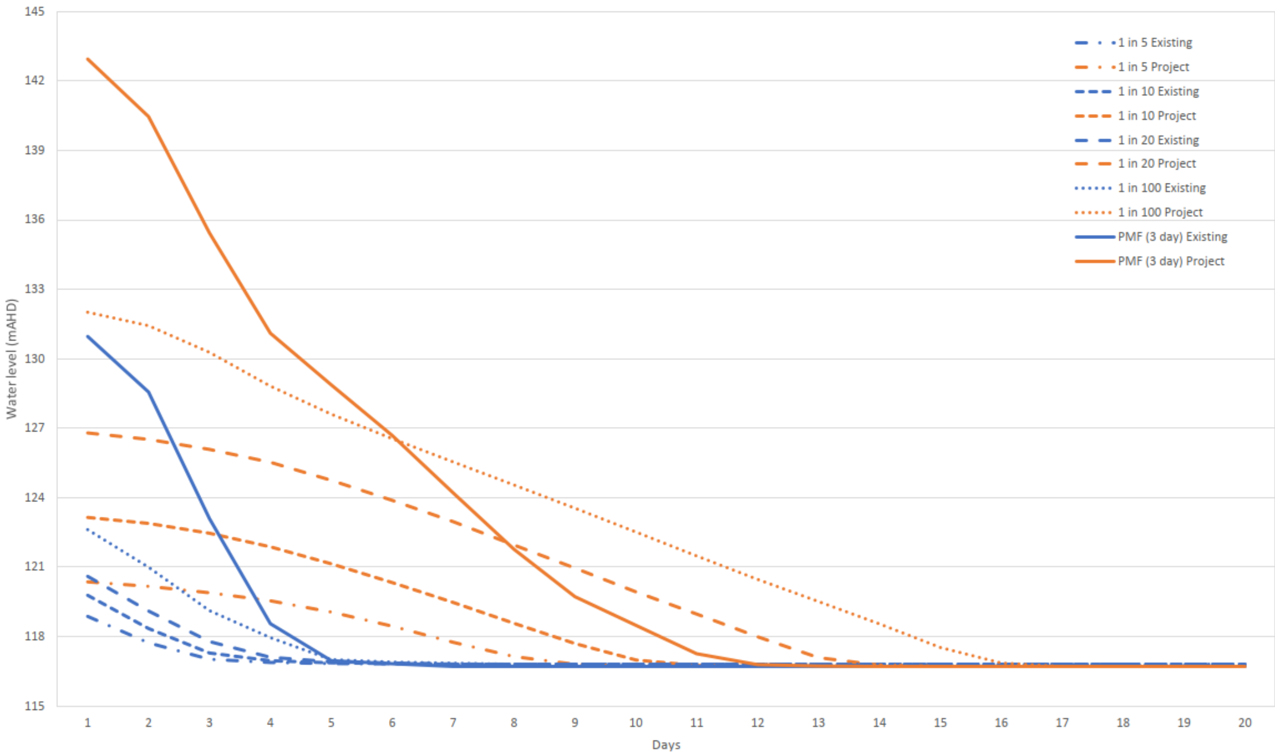
Location 9: NATTAI_US_8700



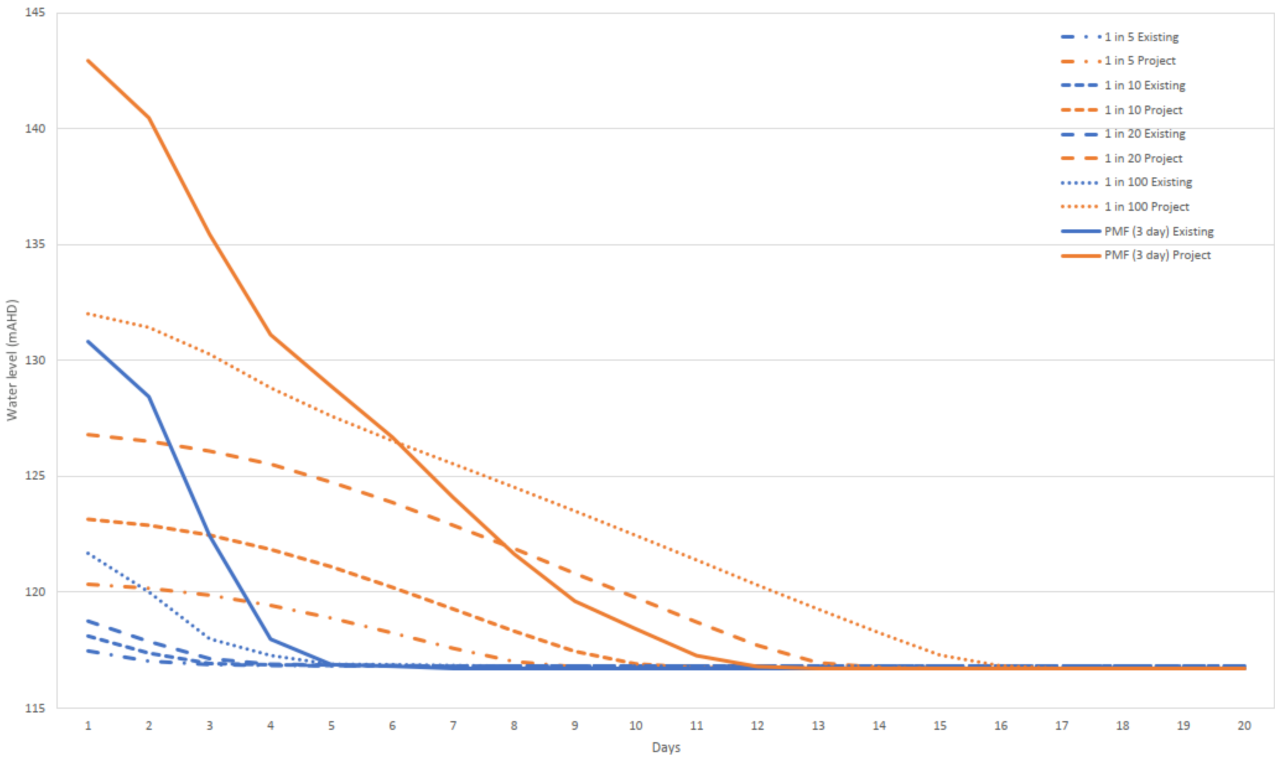
Location 10: NATTAI_US_11066



Location 11: NATTAI_1880



Location 12: NATTAI_5680



15.6.3.5 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 in 100 chance in a year event.

Predicted changes along the Wollondilly River are shown on Figure 15-34 and summarised in Table 15-18. 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:

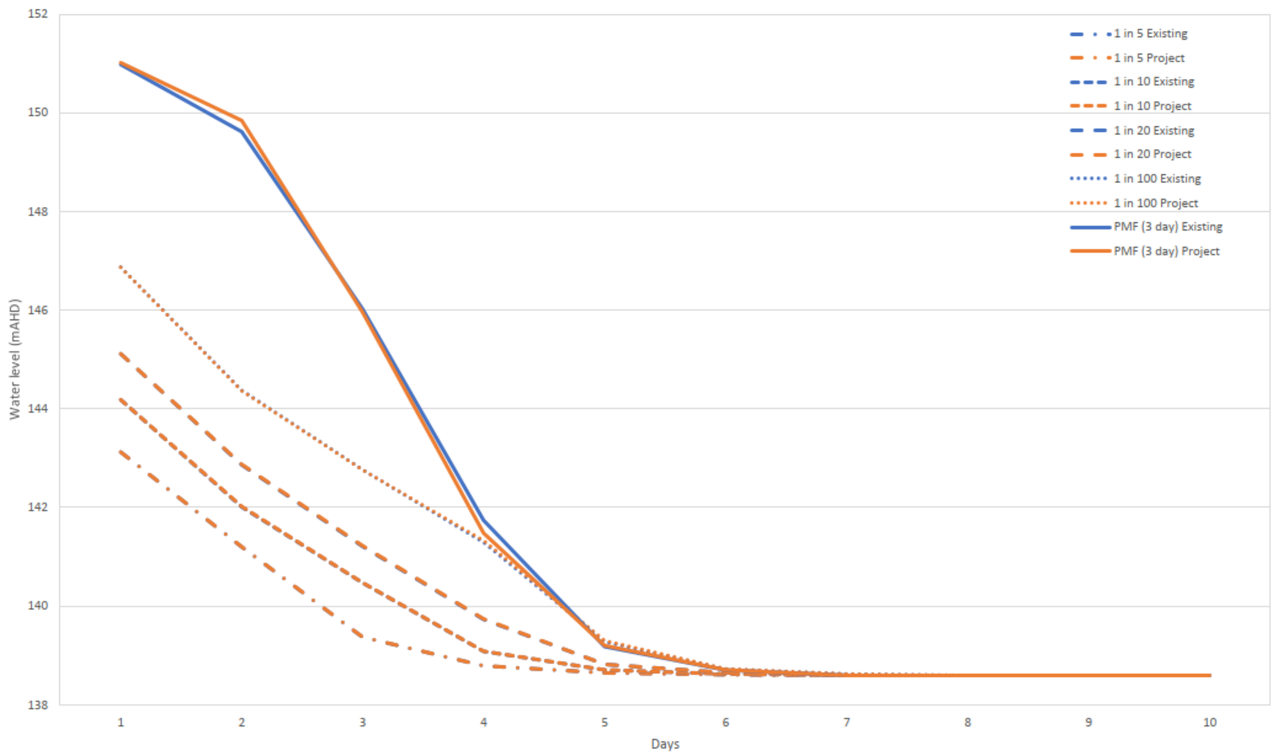
- increases in the depth and duration of temporary inundation for cross-section Location 14 (KOWMUNG_10130) are less than half a metre and half a day respectively for all events
- increases in the depth of temporary inundation for Location 15 (KOWMUNG_13130) are less than half a metre up to the 1 in 100 chance in a year event, and about 4.3 metres for the PMF event
- increases in the duration of temporary inundation for Location 15 (KOWMUNG_13130) are less than half a day up to the 1 in 20 chance in a year event, increasing slightly – up to two days – for the larger events.

Table 15-18. Kowmung River: Upstream changes in temporary inundation depth and duration

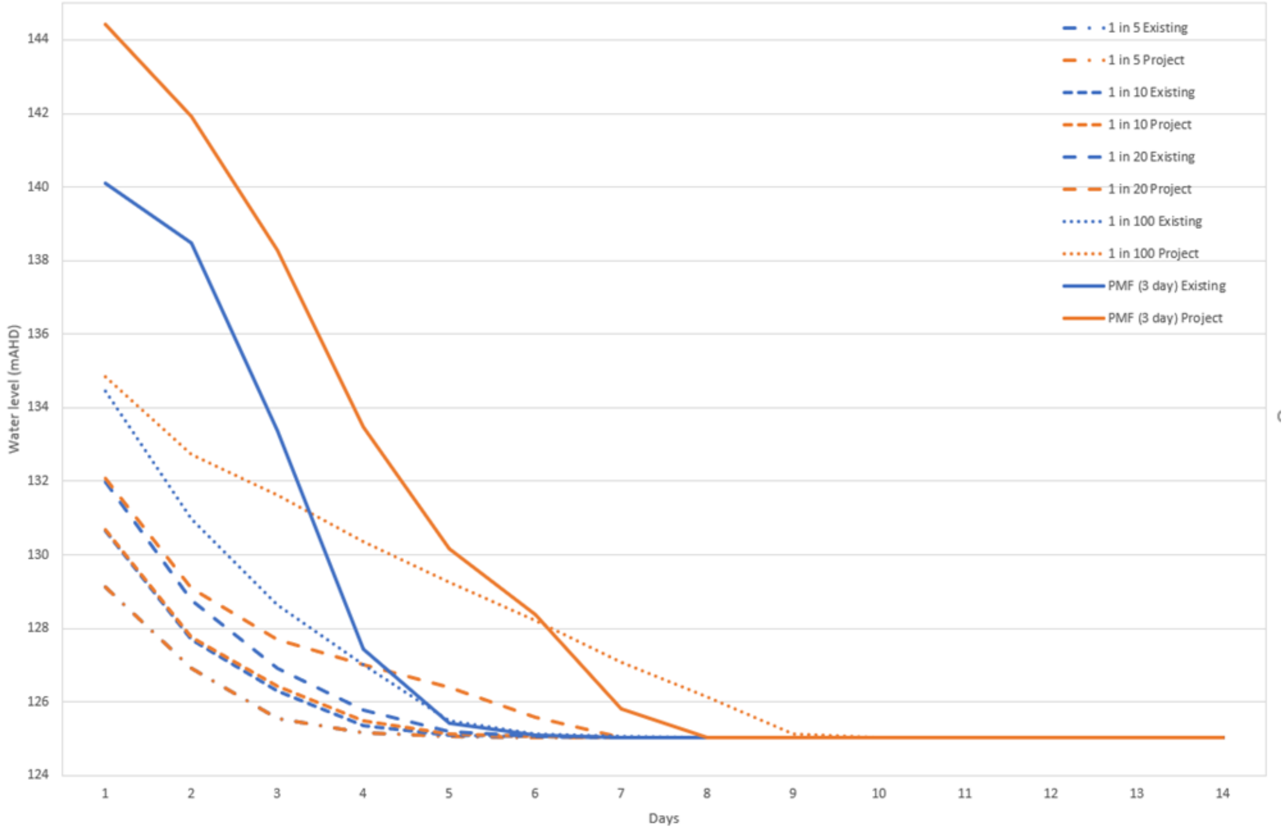
Location (refer Figure 15-34)	Flood event (1 in x chance in a year) E = existing; P = Project									
	1 in 5		1 in 10		1 in 20		1 in 100		PMF	
	E[1]	P[2]	E	P	E	P	E	P	E	P
Location 15: KOWMUNG_10130										
Depth (m)	3.8	<0.5	4.9	<0.5	6.8	<0.5	7.4	<0.5	12.4	<0.5
Duration (days)	5.9	<0.5	5.4	<0.5	6.1	<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	1.3	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										
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 15-34. Kowmung River: Upstream changes in temporary inundation depth and duration

Location 15: KOWMUNG_10130



Location 14: KOWMUNG_13130



15.6.4 Changes to flood frequencies

A frequency analysis of the peak flood levels in Lake Burragorang at the dam wall under both existing case and with Project scenarios is presented on Figure 15-35 . The frequency analysis shows the increase in peak flood levels for all events considered.

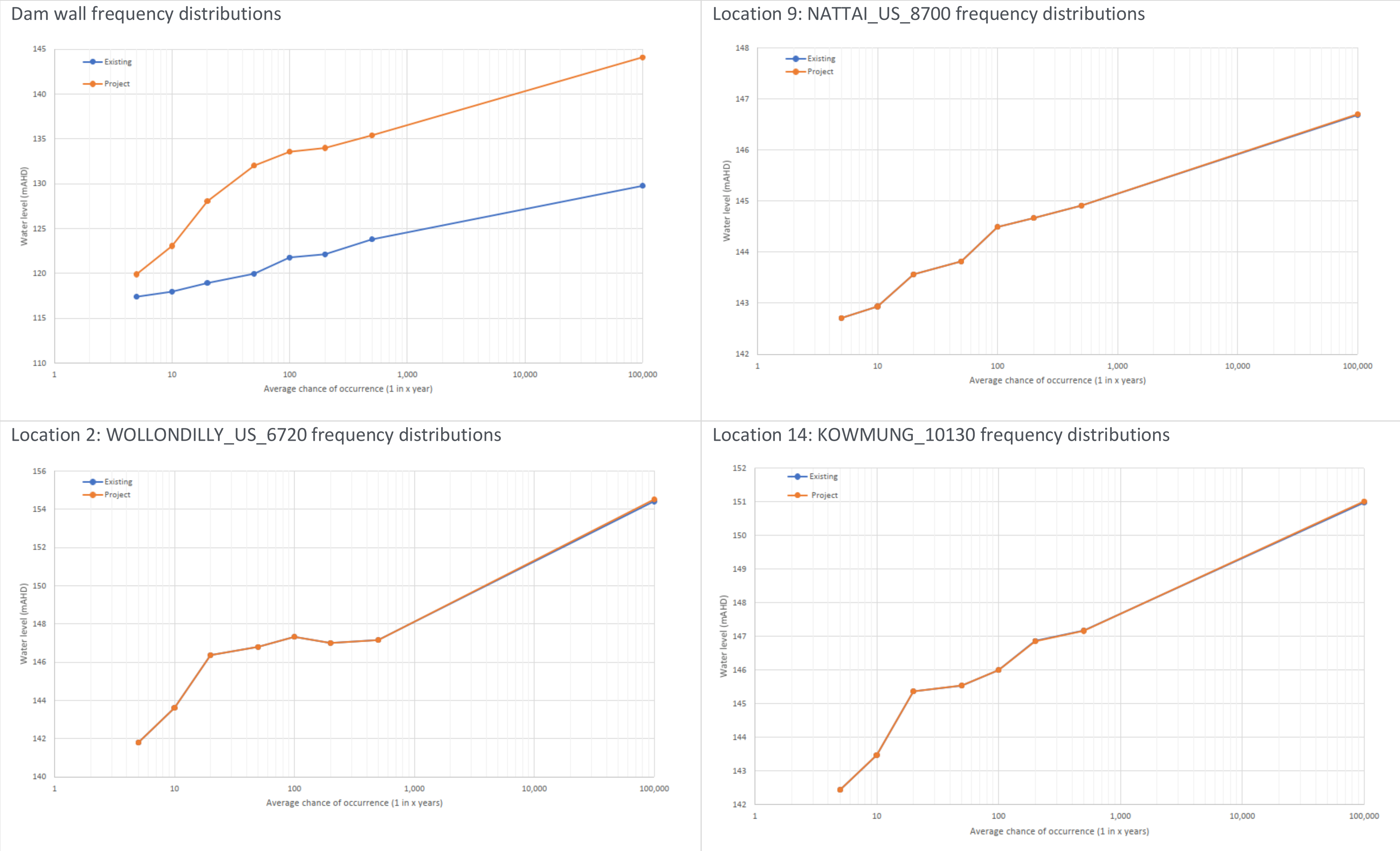
The frequency analysis shows a change in the shape of the frequency curve, with a change in grade occurring between the 1 in 20 chance in a year event to the 1 in 100 chance in a year event. This shows that the relative impact during these smaller order design events is higher than that of the rarer events (that is, greater than the 1 in 100 chance in a year 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 1 in about 50 chance in a year event under existing conditions would be equivalent to about a 1 in 5 chance in a year 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).

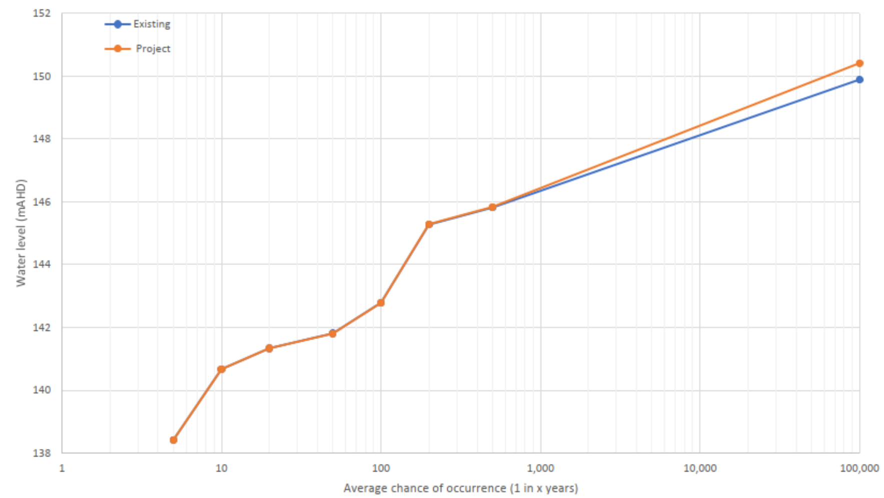
However, the pattern of the leftward shift with the Project flood frequency curve is not uniform across the upstream catchment and is substantially less further up the catchment. The frequency analysis shows that for the Wollondilly River and Nattai River there is effectively no material change in flood 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.

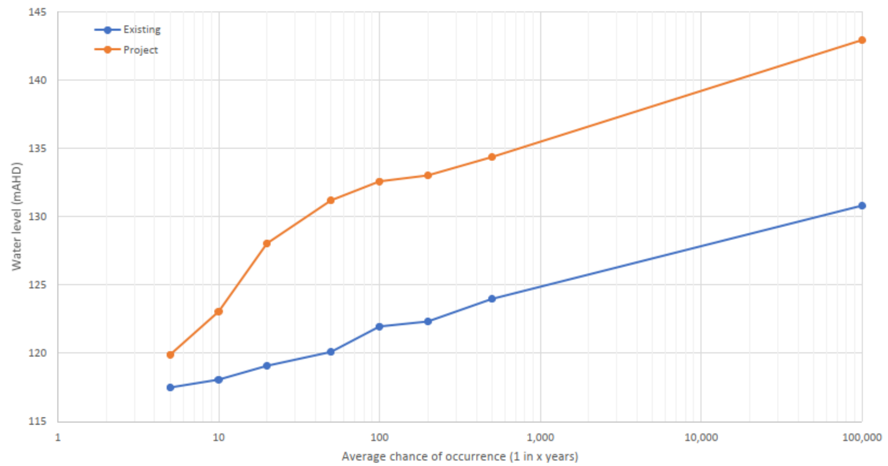
Figure 15-35. Upstream flood frequency distributions: existing and with Project scenarios



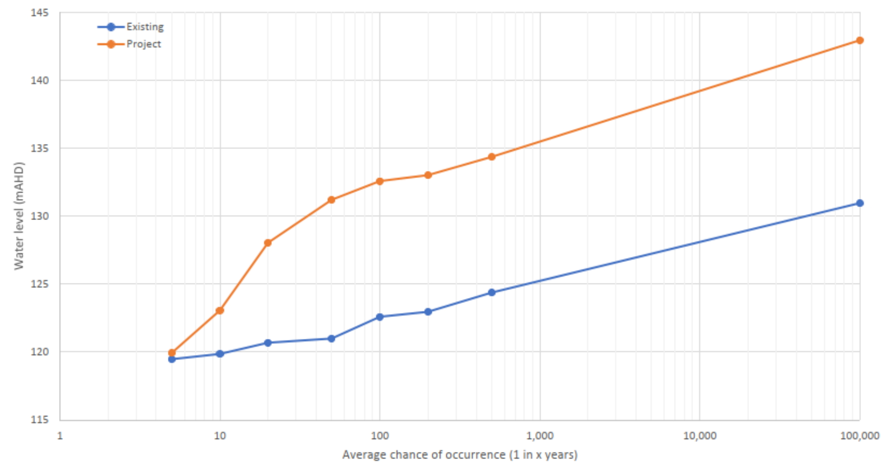
Location 6: COX_US_7335 frequency distributions



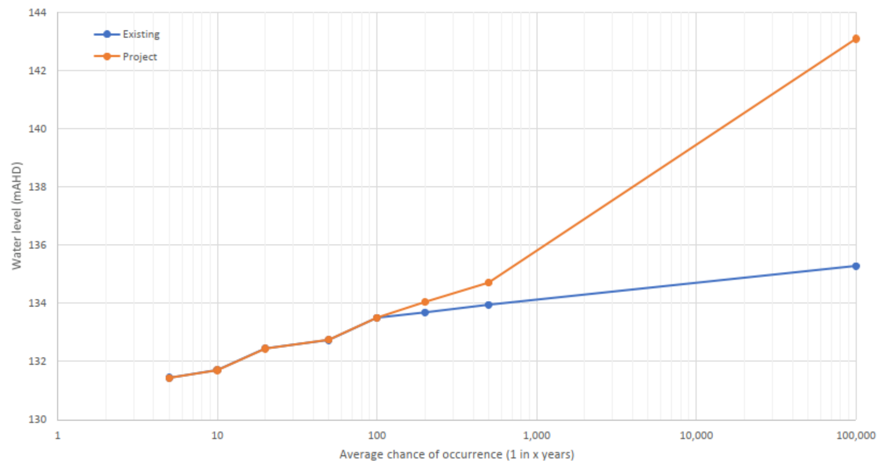
Location 9: NATTAI_5680 frequency distributions



Location 11: NATTAI_1880 frequency distributions



Location 10: NATTAI_11066 frequency distributions



15.6.5 Summary of potential upstream impacts

- The FMZ would provide capacity to capture temporarily around 1,000 gigalitres of water during a flood event. The rate of discharge would be relatively constant at around 100 gigalitres per day. For large floods, the spill rate over the dam may be substantially lower than the existing situation. As downstream flood levels would be higher, there is the opportunity to discharge water from the FMZ at a higher rate without increasing the extent of flooding (termed piggy back releases – see Section 15.8.5). Generally, these higher discharge rates would occur for about two days before the FMZ discharge is reduced to a constant 100 gigalitres per day
- Steep terrain extends upstream from the dam wall for at least 20 kilometres, and any change to flood extent would be contained to a relatively small area. However, the rate of change and inundated area increases as terrain flattens about where the Wollondilly River and Coxs River enter Lake Burragorang.
- 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 in nature. While the above discussion of the PMF event is provided for completeness (and to comply with the SEARs), more weight should be given to the flood events with a relatively greater chance of occurrence.

  For upstream locations, approximating the limit of the Project PMF event, the analysis shows:
  - increases in depth with the Project for all events up to the PMF event would be half a metre or less
  - increases in duration of temporary inundation for all events up to the PMF event for all locations would be less than half a day.

  For locations approximating the limit of the 1 in 100 chance in a year event, the analysis shows:
  - increases in the depth of temporary inundation with the Project for all events up to the 1 in 100 chance in a year event would be half a metre or less
  - increases in depth with the Project for the PMF event range from 1.1 metres for the Wollondilly River up to 7.8 metres for the Nattai River
  - increases in duration of temporary inundation for all events up to the PMF event for the Nattai River and Wollondilly River would be less than half a day
  - increases in temporary inundation for the Kowmung River would be less than half a day up to the 1 in 5 and 1 in 10 chance in a year events, about 1.3 days for the 1 in 20 chance in a year event, about two days for the 1 in 100 chance in a year event, and about 1.1 days for the PMF event
  - increases in temporary inundation for the Coxs River would be less than half a day for up to the 1 in 20 chance in a year event, and then slightly over half a day up to the PMF event

  There is an increasing influence of the Project moving downstream with the increase in temporary depth and duration of temporary inundation with locations within Lake Burragorang generally reflecting the pattern of changes in depth and duration of temporary inundation for the same flood events at the dam wall.
- 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.
- There would be an overall decrease in flood velocities, both in the tributaries and within Lake Burragorang.
- Flood extent and depths would increase around Lake Burragorang, which would increase the potential for flood hazards. The area around the lake is predominantly forested with restricted access, and consequently potential hazard impacts would not be significant. Access to the catchment would be closed during a major flood event.
- Potential impacts on protected areas are discussed in Chapter 20 (Protected and sensitive lands). A section of the Kowmung River is a declared Wild River, as noted in Section 15.4.2. The Project may result in additional areas of temporary inundation of the lower extent of the Kowmung River where it enters Lake Burragorang. This portion of the Kowmung River is within the Warragamba Special Area and is not considered in the extent of the wild rivers declared area. Therefore, no declared Wild Rivers would be impacted by the Project.
- the biodiversity assessment (Appendix F1) for the upstream study area identified the presence of Camden White Gum (*Eucalyptus benthamii*). This species is listed as vulnerable under both NSW and Commonwealth environmental legislation. The assessment noted that the species occurs on the alluvial flats of the Kedumba and Nepean Rivers and their tributaries, and requires a combination of deep alluvial sands and a flooding regime that permits seedling establishment. It also noted that while the species has some tolerance to temporary inundation,

based on a CSIRO (2019) study that identified the species could tolerate temporary inundation for up to six weeks to a depth of about 30 centimetres, tolerance of partial or complete submergence of the canopy was unknown. The assessment also noted that inundation to depths greater than 30 centimetres may result in mortality to affected individuals including soil-stored seed bank through flood stress.

There is an existing water monitoring station on the Kedumba River (212016, Kedumba River @ Crossing, period of record is from 1 June 1990 to present). This site is located outside of the upsteam study area. The utility of this site in informing assessment of potential impacts on this species and in development of appropriate management responses under the proposed adaptive management plan may need to be investigated, which may also involve consideration of establishing a site further downstream on the Kedumba River within the study area.

- Specific impacts are addressed in the relevant EIS chapters and relate to biodiversity (Chapter 8 – Biodiversity upstream), Aboriginal heritage (Chapter 18 – Aboriginal cultural heritage), water quality (Chapter 27 Water – quality) and soils (Chapter 22 – Soils).

The SEARs (Number 20 Clause 8) requires specific assessment of the impact of the recession of flood waters following a PMF. As noted, the PMF is a hypothetical flood or combination of floods, which represent an extreme scenario and is highly unlikely to occur in nature. Potential impacts are:

- compared to the existing situation, the Project would result in an increase of 12.7 metres in peak flood levels and an additional seven-day inundation period at the dam wall. This would significantly decrease with distance upstream
- a relatively rapid rise in flood levels, followed by a similarly rapid decrease until about four days after the start of the event. The rate of decrease in flood levels would reduce as the piggy back discharges would cease and be replaced with a steady state discharge from the FMZ
- a steady state discharge of around 100 gigalitres per day would continue for another four to five days until the FMZ had emptied. The steady state discharge period from the PMF is lower than other events as a greater volume of water is discharged via piggy-back discharges during a PMF compared to other events
- impacts on biodiversity from the PMF are described in Chapter 8 (Biodiversity upstream).

15.7 Downstream Project impacts

15.7.1 Overview

The FMZ would delay and attenuate the progression of inflows coming from the upstream Warragamba catchment, which in turn would reduce the severity of regional flood events impacting on the downstream Hawkesbury-Nepean Valley. While the Project would significantly reduce flood risk, it would not eliminate it completely. Flooding from other catchments such as the Nepean, Grose, Colo and South Creek can also contribute significantly to downstream flooding.

Rainfall events that do not increase Lake Burragorang levels above the FSL would have no impact on hydrology and flood behaviour. Activation of the FMZ would only occur when rainfall increases dam water levels above the FSL. The FMZ would provide capacity to capture temporarily around 1,000 gigalitres of water during a flood event.

The Project would result in a range of flood mitigation benefits to the Hawkesbury-Nepean Valley including:

- a reduction in flooding extents across all flood events especially in the Penrith, Windsor, Richmond and South Creek areas. This would result in lower flood damages and social impacts from flooding
- there would be a more predictable rise in floodwaters and evacuation routes would remain open for longer. This would reduce the risk of loss of human life during floods.

However, there are potential negative impacts that need to be considered including:

- the impacts of water discharge from the FMZ after a rainfall event. This may result in environmental, social, and economic impacts as water levels and velocities downstream of the dam would be higher for a longer period than the existing situation
- environmental impacts from the reduction in flooding extents and peak water velocities, especially for sensitive features such as wetlands.

15.7.2 Project changes to flood characteristics

15.7.2.1 Reduction to peak dam outflows and flood levels

Existing and Project outflow scenarios are provided in Table 15-19, while changes to flood levels at representative river cross sections are provided in Table 15-20.

Flood hydrographs near the dam wall for various rainfall events are shown on Figure 15-36. This shows the discharge (outflow) hydrographs from Warragamba Dam for the 1 in 20 and 1 in 100 chance in a year events for existing and with Project. As can be seen, the FMZ substantially reduces the peak of the hydrographs but this is offset by an extended period where downstream flows remain above normal levels until the FMZ is emptied.

Table 15-19. Peak dam outflows for existing and Project scenarios for a range of flood events

Flood event (1 in x chance in a year)	Existing scenario (m^3/s)	Project scenario (m^3/s)	Peak outflow change at dam wall (m^3/s)
5	2,271	810	-1,461
10	4,430	1,160*	-3,270
20	6,860	1,160*	-5,700
100	9,660	3,800	-5,860
200	11,061	5,943	-5,118
500	13,019	8,862	-4,157
PMF	40,950	36,390	-4,560

* Discharge rate of flood mitigation zone (100 gigalitres per day)

Figure 15-36. Discharge hydrographs from Warragamba Dam: 1 in 20 and 1 in 100 chance in a year flood

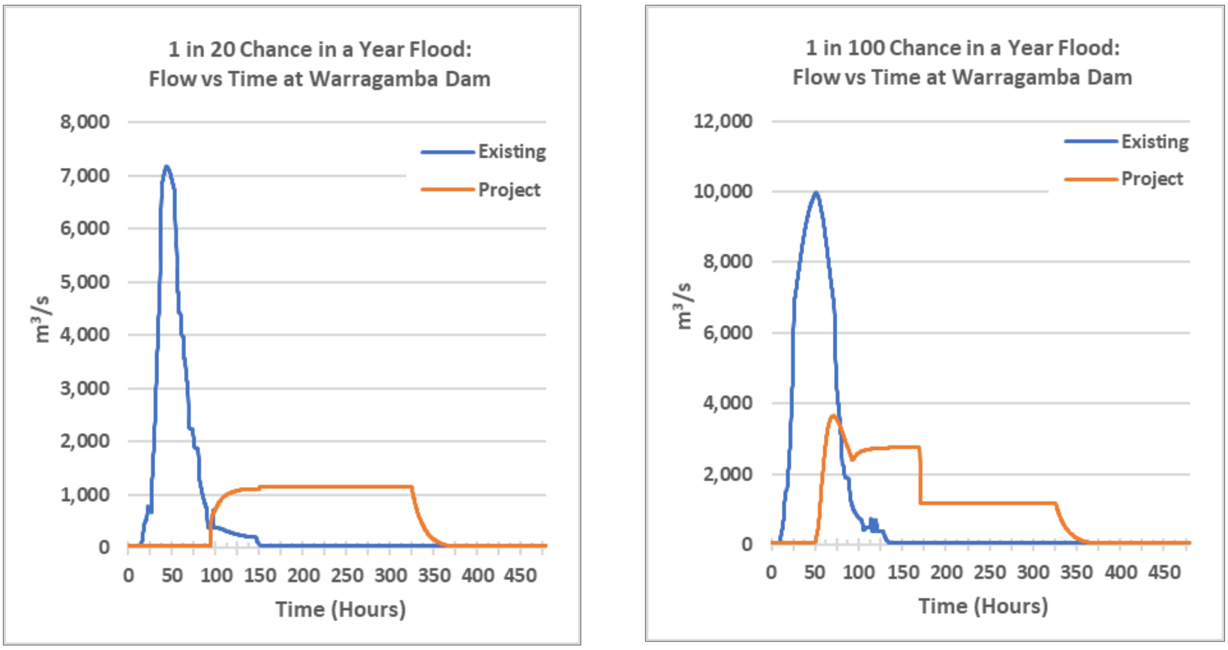


Table 15-20. Project changes to flood levels at river cross sections

Cross section (see section 15.14.2 – flood maps)	Location	Flood event (1 in x chance in a year), (mAHD)						
		1 in 5	1 in 10	1 in 20	1 in 100	1 in 200	1 in 500	PMF
JUNCTION3	Nepean River – downstream of confluence with Warragamba River	-6.6	-9.2	-11.4	-9.1	-7.3	-5.4	-2.9
BLAXCROSS	Nepean River – Blaxland Crossing bridge	-0.2	-0.1	-0.5	-2.6	-3.2	-3.4	-2.8
F4BRIDGE	Nepean River – M4 Motorway bridges	-2.7	-3.9	-5.3	-4.7	-3.5	-1.8	-1.3
BONNIEVALE	Nepean River – downstream of Penrith Weir	-3.9	-5.3	-6.7	-5.2	-3.6	-2.2	-1.5
MILLDAM 1	Nepean River – at Castlereagh	-3.5	-4.6	-5.7	-4.3	-3.2	-2.7	-1.6
YMUNDI 1	Hawkesbury River – downstream of Grose River confluence	-3.1	-4	-4.7	-3.2	-2.5	-2.6	-1.6
NORTHRICH 1	Hawkesbury River – at North Richmond	-2.9	-3.7	-4.2	-3.1	-2.9	-2.8	-1.7
LDERRY	South Creek – at Londonderry	-0.8	-2.3	-3.2	-4.1	-3.6	-2.8	-1.6
RICH WALK	South Creek – at Richmond Road Bridge	-2.1	-2.9	-3.5	-4.1	-3.6	-2.9	-1.7
POWERLINE	Eastern Creek – at Mulgrave	-2.2	-2.9	-3.5	-4.1	-3.6	-2.9	-1.7
WINDSORBR	Hawkesbury River – Windsor Bridge	-2.4	-3	-3.5	-4.1	-3.6	-2.9	-1.7
HALFMOON	Hawkesbury River – downstream of Wisemans Ferry	-0.6	-1	-1.3	-1.2	-1.2	-1.3	-1.6
PUMPKINPT	Hawkesbury River - Berowra Creek confluence	0	0	0	-0.2	-0.3	-0.4	-1
PEAT1	Hawkesbury River – M1 Motorway Bridges	0	0	0	0	0	0	-0.1

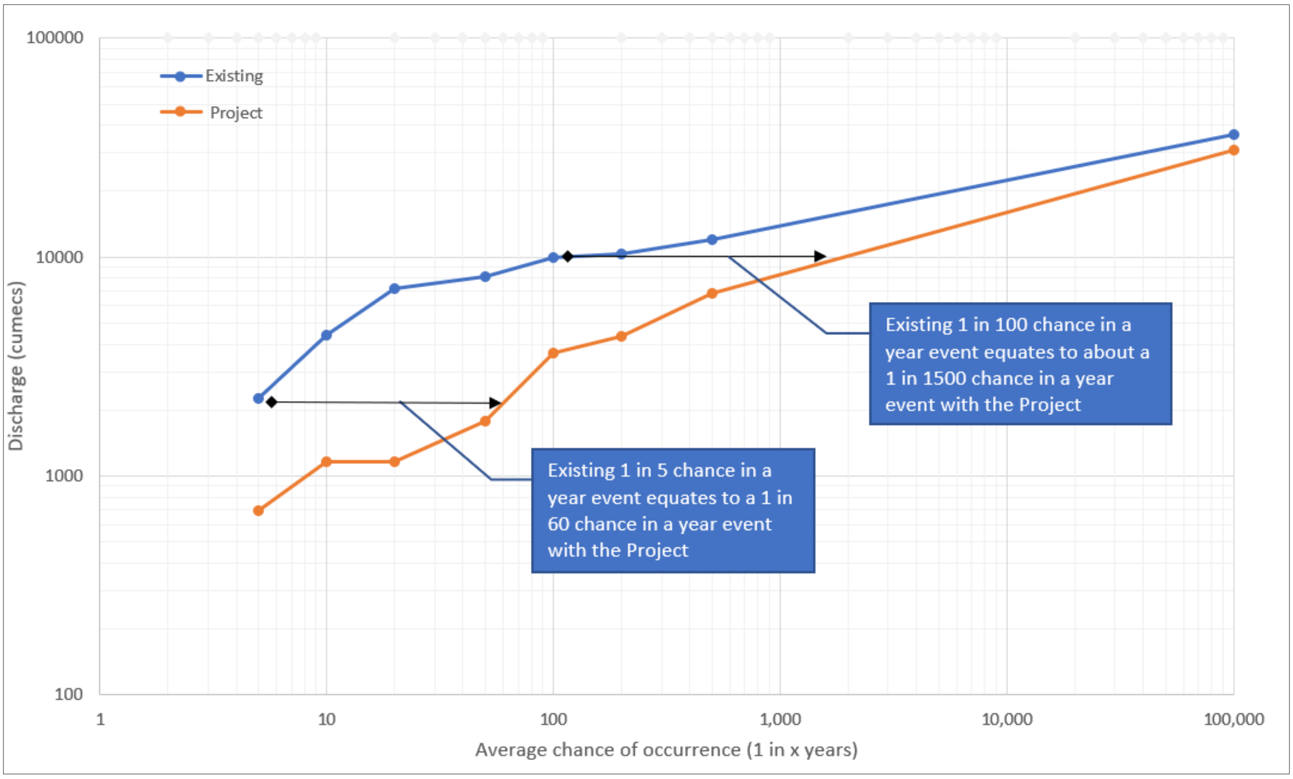
15.7.2.2 Reduction in frequency of flooding

A frequency distribution of dam outflows is shown on Figure 15-37. This shows:

- A reduction in magnitude for an outflow event of a specific chance of occurrent; for example, a 1 in 5 chance in a year outflow event reduces from about 2,260 m^3/s (cubic metres per second or cumecs) to about 690 m^3/s while the 1 in 100 chance in a year outflow event reduces from about 9,970 m^3/s to about 3,650 m^3/s.
- An overall shift to the right for the Project flood frequency curve representing a lesser chance of occurrence for an outflow event of a specific magnitude.

As illustrated in Figure 15-37, the existing 1 in 5 chance in a year outflow event becomes a relatively less frequent event with the Project, having about a 1 in 60 chance in a year of occurring. Similarly, the existing 1 in 100 chance in a year outflow event becomes a rarer 1 in 1,500 chance in a year outflow event.

Figure 15-37. Frequency distribution of dam outflows for existing and Project scenarios



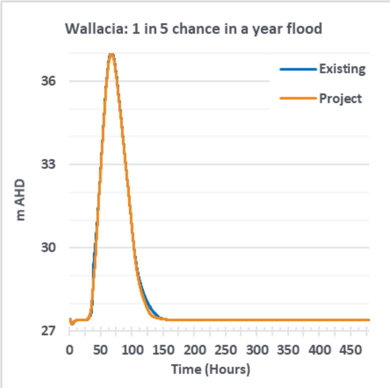
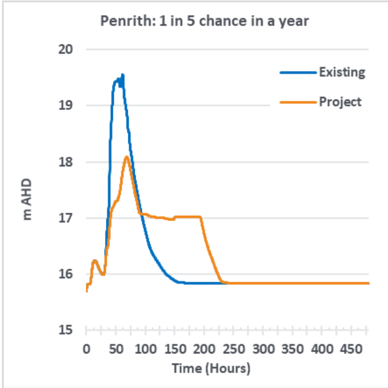
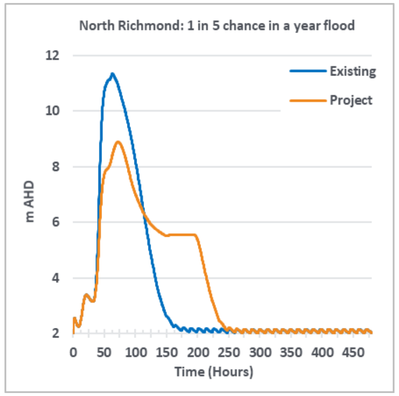
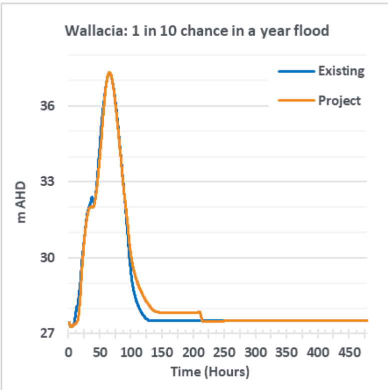
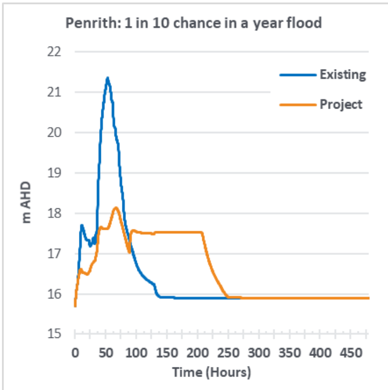
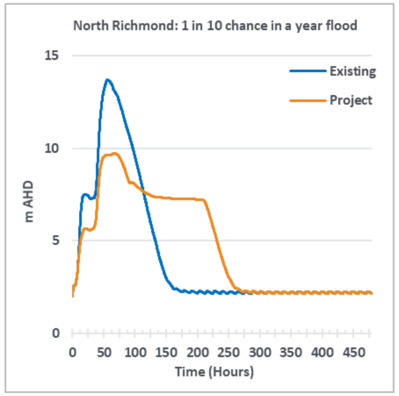
15.7.2.3 Reduction to flood extents

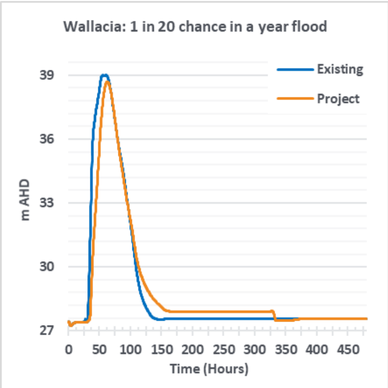
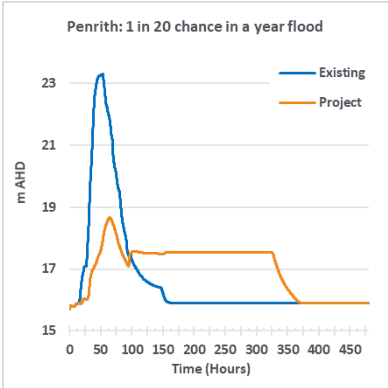
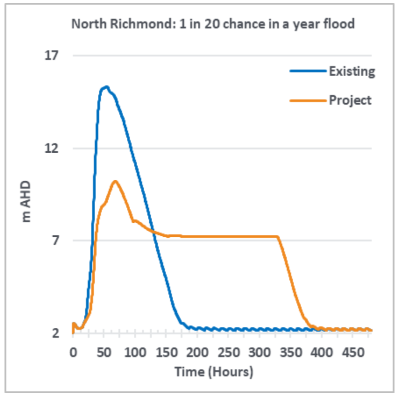
Project flood extents for various downstream flood scenarios are provided in Section 15.12.2 (Figure 15-57 to Figure 15-91) and summarised in Table 15-21. Major town flooding, flood level changes and flood frequencies are also discussed.

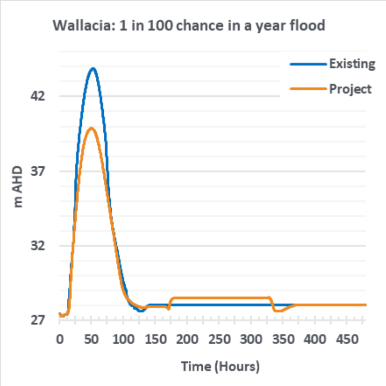
Model results show that the Project would reduce peak outflow rates and flood levels for all flood scenarios. Flood levels are substantially reduced for floods up to the 1 in 1,000 chance in a year event, however there is a relatively small reduction for the PMF event. The discharge of the FMZ following a major flood event would result in some sections of the floodplain being subjected to longer periods of inundation (see Section 15.8).

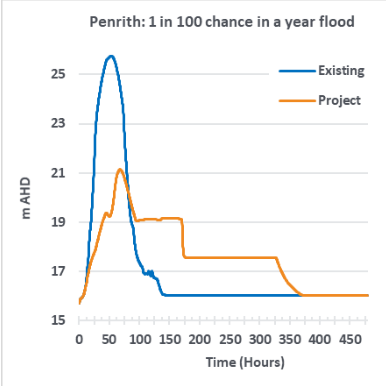
Generally, the benefits of the Project in the reduction of flood extents and the impacts from the FMZ discharge extend downstream to Wisemans Ferry. While the benefits and impacts of the Project may still be detectable downstream of Wisemans Ferry, the changes in water levels would be minor and be substantially below the tidal range in the marine influenced section of the Hawkesbury River.

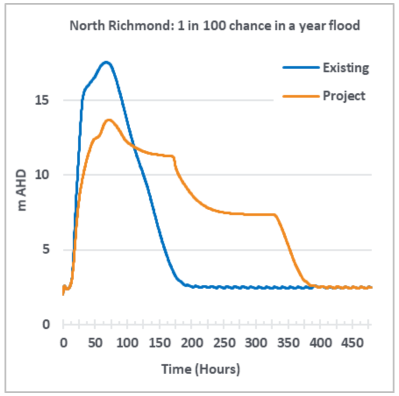
Table 15-21. Summary change in flood extents

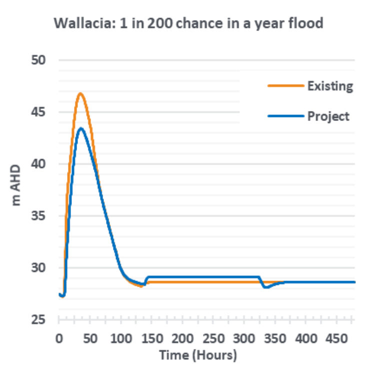
Wallacia area	Penrith area	Windsor, Richmond South Creek areas
	1 in 5 chance in a year	
 The Project would result in minimal change in existing flooding extents. However, existing flooding does not result in substantial damage or impacts	 There would be minor changes in flood extents due to the Project. However, even under existing conditions, flood impacts in the Penrith area are relatively minor and no developed land is impacted.	 The Project would substantially reduce overbank flooding. Similarly, the Project would reduce upstream flooding along South Creek and its tributaries, and in Riverstone.
	1 in 10 chance in a year	
	 There would be minor changes in flood extents due to the Project. However, even under existing conditions	 The Project would substantially reduce overbank flooding. Similarly, the Project would reduce upstream

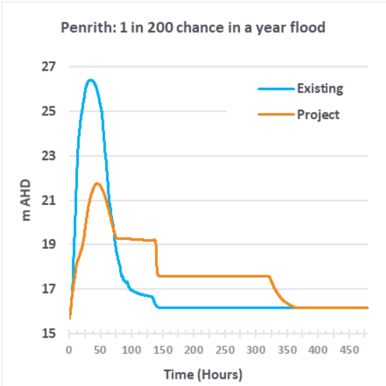
<table>
<tr><th>Wallacia area</th><th>Penrith area</th><th>Windsor, Richmond South Creek areas</th></tr>
<tr><td>The Project would result in minimal change to existing flooding extents. However, existing flooding does not result in substantial damage or impacts</td><td>flood impacts in the Penrith area are relatively minor and no developed land is impacted</td><td>flooding along South Creek and its tributaries, and in Riverstone.</td></tr>
<tr><th colspan="3">1 in 20 chance in a year</th></tr>
<tr><td>
</td><td>
</td><td>
</td></tr>
<tr><td>The Project would result in a minimal change in existing flooding extents. However, existing flooding does not result in substantial damage or impacts</td><td>There would only be minor changes in flood extents due to the Project. Small areas in Emu Plains Heights that were impacted by flooding in existing conditions would not be impacted by flooding with the Project</td><td>The Project would reduce overbank flooding; however substantial areas of overbank flooding would remain. The Project would reduce flooding of fringes of residential areas in Wilberforce, Pitt Town, South Windsor, and McGraths Hill. Similarly, the Project would reduce lateral and upstream flooding along South Creek, Riverstone, and Vineyard.</td></tr>
</table>

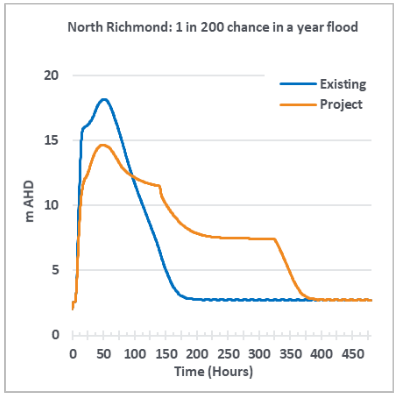
<table>
<tr><th>Wallacia area</th><th>Penrith area</th><th>Windsor, Richmond South Creek areas</th></tr>
<tr><th colspan="3">1 in 100 chance in a year</th></tr>
<tr>
<td>


The Project would result in minimal change in existing flooding extents, although some low-lying development areas would be better protected.
</td>
<td>


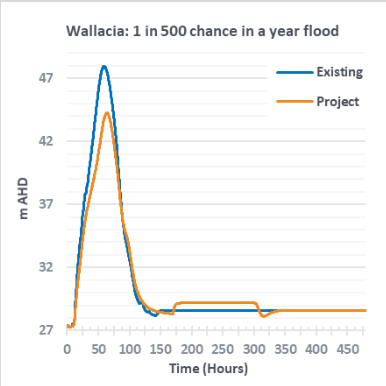
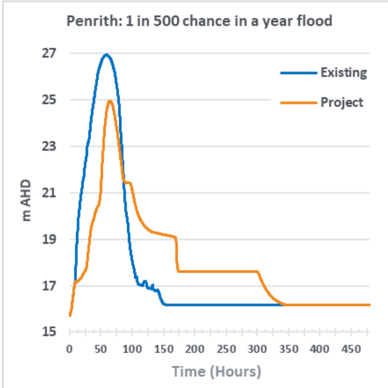
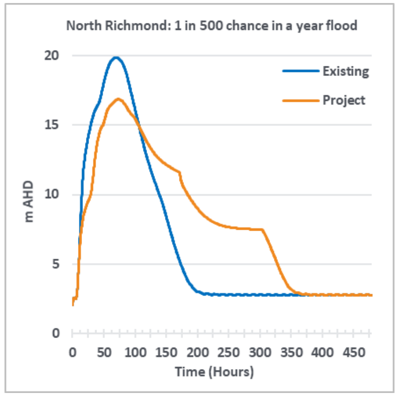
The Project would substantially reduce flood extents in Emu Plains Heights and Emu Plains. The Project would prevent flooding near the Penrith town centre.
</td>
<td>


The Project would reduce urban flooding in Pitt Town, Bligh Park, South Windsor, and Windsor. Clarendon and McGraths Hill, which would be totally flooded under existing conditions, would be largely flood-free with the Project. The Project would substantially reduce flooding in Riverstone, Vineyard and Schofields.
</td>
</tr>
<tr><th colspan="3">1 in 200 chance in a year</th></tr>
<tr>
<td>


</td>
<td>


</td>
<td>


</td>
</tr>
</table>

Wallacia area	Penrith area	Windsor, Richmond South Creek areas
The Project would result in a minor reduction from existing flooding extents, particularly along the eastern side on Wallacia and agricultural land to the south.	The Project would substantially reduce flood extents in Emu Plains Heights and Emu Plains. Large areas of Emu Plains and Emu Plains Heights would remain flood-free whereas under existing conditions they would have been flooded. The Project would prevent flooding near the Penrith town centre.	The Project would reduce urban flooding in Pitt Town, Bligh Park, South Windsor and Windsor. Clarendon, Mulgrave and McGraths Hill, which would be totally flooded under existing conditions, would have some areas that would be flood free with the Project. The Project would result in a minor reduction in flooding extents in Riverstone, Vineyard and Schofields.
1 in 500 chance in a year		
 The Project would result in a minor reduction from existing flooding extents, particularly along the eastern side on Wallacia and agricultural land to the south.	 The Project would substantially reduce flood extents in Emu Plains Heights while only a minor reduction of flooding extents would occur in Emu Plains. The Project would prevent substantial areas of flooding in the Penrith town centre and Jamisontown.	 The Project would have a minor reduction in flooding extents in Pitt Town, South Windsor, Windsor, Mulgrave, and Oakdale. The Project would result in a major reduction of flooding extents in Richmond, Bligh Park and Londonderry. Clarendon, Mulgrave, and McGraths Hill would be totally flooded. The Project would result in a minor reduction in flooding extents in Riverstone, Vineyard and Schofields.
PMF		
The existing PMF flood extent is discussed in Section 15.5.3. Most of the main population centres would be flooded, with a maximum flood depth of approximately 24 metres around Wilberforce, Windsor, Bligh Park and McGraths Hill. The Project would result in relatively minor changes in flooding extents compared with existing conditions. However, in many locations the reductions in flooding extents would be in urban areas where even a minor reduction in flooding would result in substantially less damage to residential, commercial, public buildings and infrastructure.		

Flood characteristics for major towns are discussed below:

Wallacia

Change in flood levels are shown on Figure 15-38 and summarised in Table 15-22. Most of the flooding at Wallacia is caused by upstream Nepean River catchment flows rather than discharges from Warragamba Dam. However, the discharge from Warragamba Dam into the Nepean River may result in flood waters from upstream backing up and flooding Wallacia. The Project's biggest benefit for flooding in Wallacia would occur when the Project's around 100 gigalitres per day release rate from Warragamba Dam is lower than the existing situation. This would allow more water from the upstream Nepean River catchment to flow downstream rather than backing up and flooding Wallacia. This effect is most notable for floods greater than a 1 in 100 chance in a year event.

Figure 15-38. Wallacia: Flood frequency plot

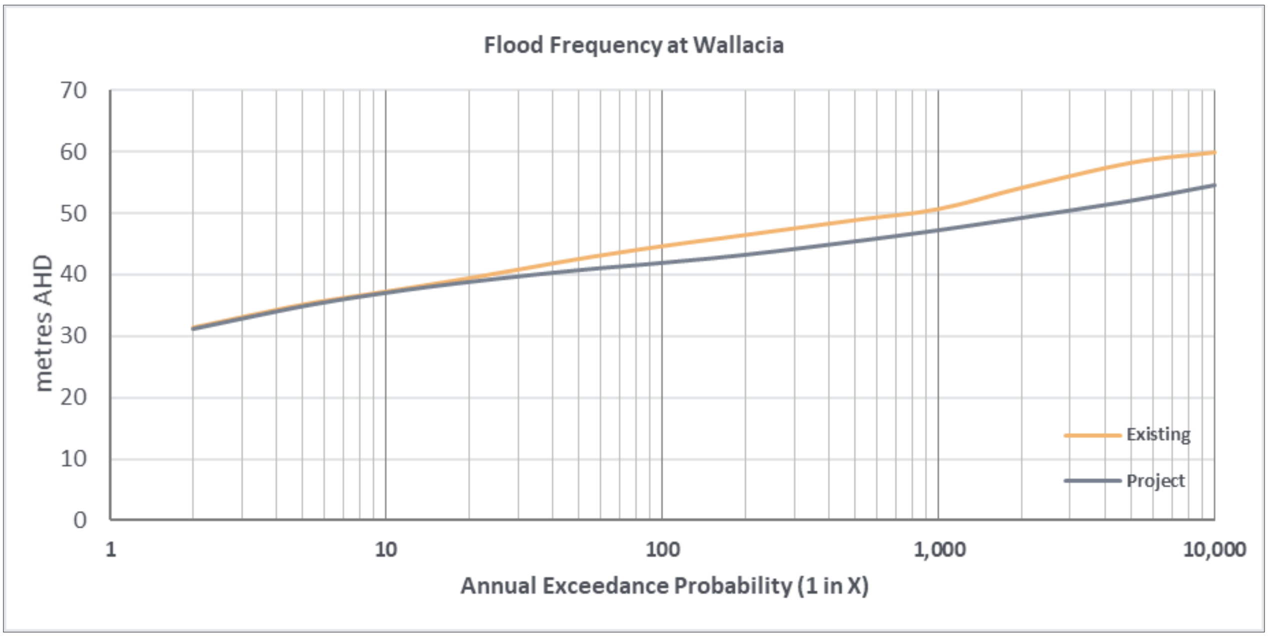


Table 15-22. Change in flood levels at Wallacia due to the Project (Blaxland Crossing Bridge cross-section)

Flood Event (1 in X chance in a year)	Existing Conditions (mAHD)	With Project (and 100 GL/day discharge) (mAHD)	Change in flood levels (m)	Flood map figure (Section 15.12.2)
5	35.1	34.9	-0.2	Figure 15-58
10	37.2	37.1	-0.1	Figure 15-63
20	39.4	38.9	-0.5	Figure 15-68
100	44.6	42.0	-2.6	Figure 15-73
200	46.5	43.3	-3.2	Figure 15-78
500	48.9	45.5	-3.4	Figure 15-83
PMF	66.3	63.5	-2.8	Figure 15-88

Penrith

Change in flood levels are shown on Figure 15-39 and summarised in Table 15-23. In the Penrith area, most flood impacts and flooding of urban areas would occur once flood levels exceed the existing 1 in 100 chance in a year flood level of about 25.8 metres. With the Project, the flood level in the 1 in 500 chance in a year flood would be lower than 25.8 metres.

Figure 15-39. Penrith: Flood frequency plot

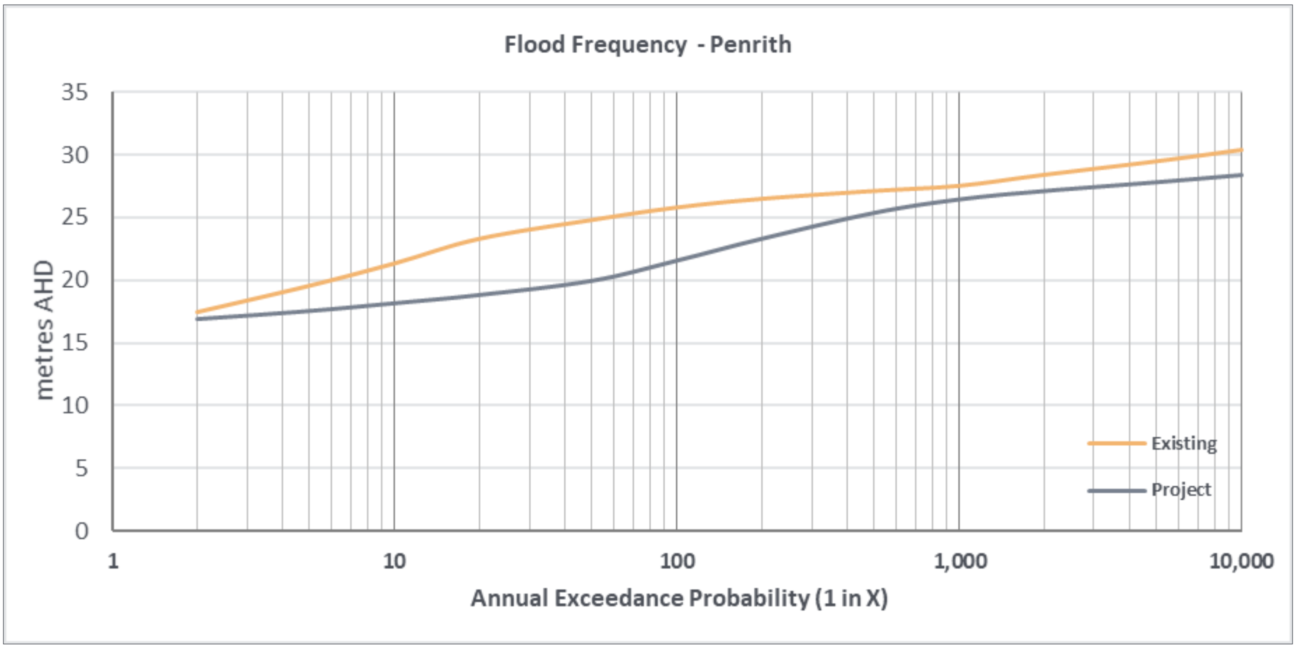


Table 15-23. Change in flood levels at Penrith due to the Project (Victoria Bridge cross-section)

Flood Event (1 in X chance in a year)	Existing Conditions (mAHD)	With Project (and 100 GL/day discharge) (mAHD)	Change in flood levels (m)	Flood map figure (Section 15.12.2)
5	19.6	17.5	-2.1	Figure 15-59
10	21.3	18.2	-3.1	Figure 15-64
20	23.3	18.8	-4.5	Figure 15-69
100	25.8	21.6	-4.2	Figure 15-74
200	26.5	23.3	-3.2	Figure 15-79
500	27.1	25.4	-1.7	Figure 15-84
PMF	32.7	31.4	-1.3	Figure 15-89

Windsor

Change in flood levels are shown in the flood frequency plot below and summarised in Table 15-24. In the Windsor area, substantial flooding of urban areas generally occurs between the 1 in 20 chance in a year flood and the 1 in 100 chance in a year flood in existing conditions. For the same period, the Project would reduce flooding by 3.5 metres and 4.1 metres respectively.

Figure 15-40. Windsor: Flood frequency plot

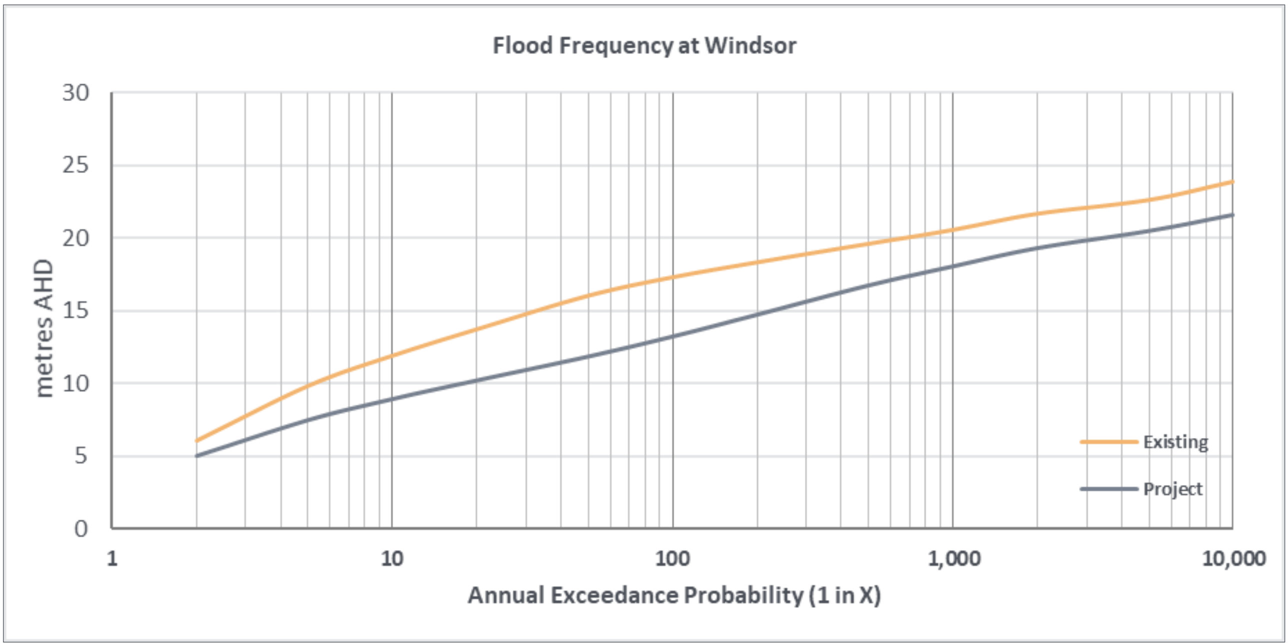


Table 15-24. Change in flood levels at Windsor due to the Project (Windsor Bridge cross-section)

Flood Event (1 in X chance in a year)	Existing Conditions (mAHD)	With Project (and 100 GL/day discharge) (mAHD)	Change in flood levels (m)	Flood map figure (Section 15.12.2)
5	9.9	7.4	-2.5	Figure 15-60
10	11.9	8.9	-3.0	Figure 15-65
20	13.7	10.2	-3.5	Figure 15-70
100	17.3	13.2	-4.1	Figure 15-75
200	18.3	14.7	-3.6	Figure 15-80
500	19.6	16.8	-2.60	Figure 15-85
PMF	26.7	25.7	-1.0	Figure 15-90

North Richmond

Change in flood levels are shown on Figure 15-41 and summarised in Table 15-25. In the North Richmond area, substantial flooding of urban areas generally occurs between the 1 in 5 chance in a year flood and the 1 in 100 chance in a year flood in existing conditions. For the same period, the Project would reduce flooding by 2.9 metres and 3.1 metres respectively. The largest decrease would occur for a 1 in 20 chance in a year flood (4.2 metres).

Figure 15-41. North Richmond: Flood frequency plot

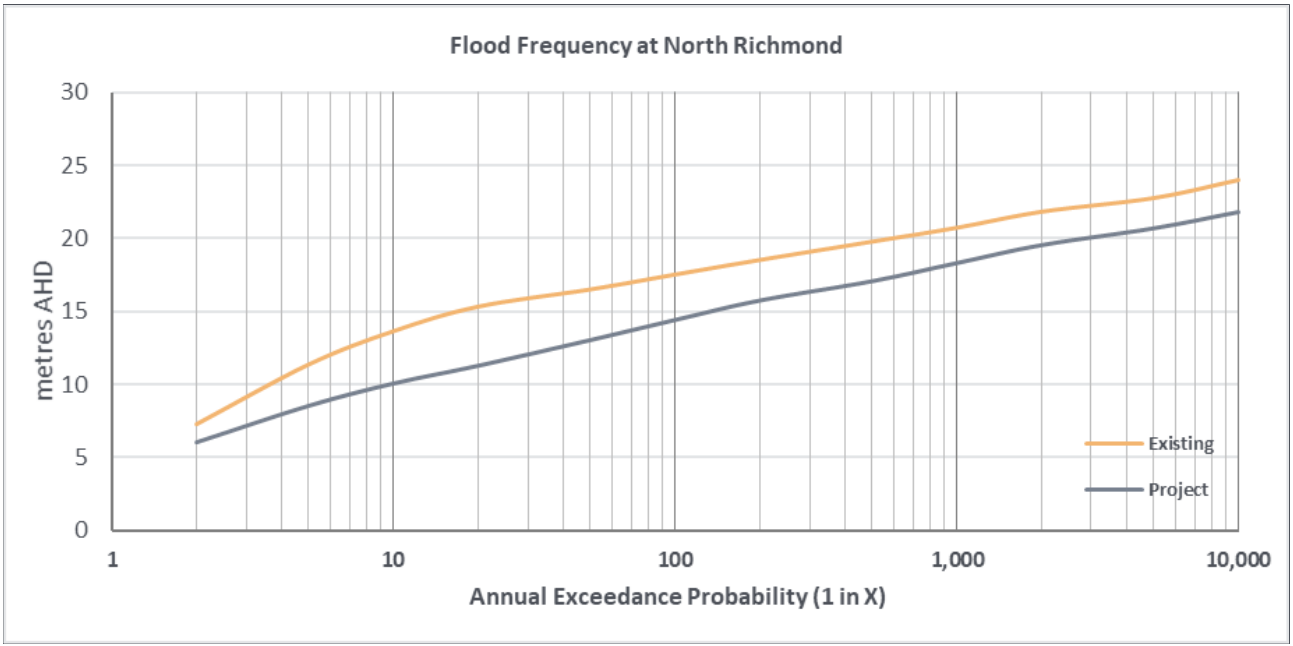


Table 15-25. Change in flood levels at North Richmond due to the Project (North Richmond cross-section)

Flood Event (1 in X chance in a year)	Existing Conditions (mAHD)	With Project (and 100 GL/day discharge) (mAHD)	Change in flood levels (m)	Flood map figure (Section 15.12.2)
5	11.4	8.5	-2.9	Figure 15-60
10	13.7	10.0	-3.7	Figure 15-65
20	15.4	11.2	-4.2	Figure 15-70
100	17.5	14.4	-3.1	Figure 15-75
200	18.6	15.7	-2.9	Figure 15-80
500	19.8	17.0	-2.8	Figure 15-85
PMF	26.8	25.1	-1.7	Figure 15-90

15.7.2.4 Impacts of the PMF

The SEARs (20.8) requires specific assessment of the impact of the recession of flood waters following a PMF. As noted previously, the PMF is a hypothetical flood or combination of floods, which represent an extreme scenario and is highly unlikely to occur in nature.

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 downstream existing and Project PMF impacts is relatively small.

Potential impacts are:

- the flood peak with the Project would be delayed slightly. This would have minimal benefit as the whole valley would be an inland sea and most of the NSW population would likely be at risk from the extreme storm event. However, there would be some benefit in a delay in the onset of flooding.
- the flood peak level with the Project would be marginally lower, which would vary throughout the downstream catchment
- The period of higher flows and higher levels would be slightly longer with the Project due to piggy back discharges (see Section 15.8.5) from the FMZ. Generally, the longer period of higher discharges would be for one to two days but would be below the peak flood level recorded during the event

- After piggy backing of discharges from the FMZ has ceased, a steady state discharge of around 100 gigalitres per day would continue for another four to five days until the FMZ is emptied. This same steady state discharge of 100 gigalitres per day would occur after all flood events with the discharge of the FMZ. The steady state discharge period from the PMF is lower than other events as a greater volume of water would be discharged via piggy back discharges during a PMF compared to other events
- The impacts on biodiversity would be negligible for the PMF as there is only a small change in flooding extents between the existing and Project PMF. The impacts of the Project on downstream biodiversity are discussed in Chapter 9 (Downstream ecological assessment).

15.7.3 Changes in evacuation planning

In addition to reducing the peak flood levels and associated flood extents, the Project would alter the period of inundation and rate of rise of floodwaters. The benefits to evacuation come from the reduction in flood peak reducing the number of people to evacuate for a given flood event.

Table 15-26 provides information on the additional time before closure of key road bridges for a range of flood events. There are other key evacuation routes that are not shown in the table, however, a similar increase in the number of hours before closure could be expected for all key evacuation routes. As well as an increase in hours available for evacuation, some key road bridges would remain open in certain events due to the Project (e.g. Jim Anderson Bridge, which is the key evacuation route from Windsor, would remain open for events up to the 1 in 500 chance in a year event).

The Project and other components of the Flood Strategy would require the existing Flood Plan to be revised to reflect the multiple changes in flood risk management for the Hawkesbury-Nepean Valley. In relation to evacuation this would include:

- improved flood awareness and preparedness of the community (Flood Strategy)
- improved flood signage (Flood Strategy)
- improved forecasting of floods (Flood Strategy)
- local road improvements (Flood Strategy)
- revised evacuation traffic modelling (Flood Strategy)
- improved information on dam releases including FMZ discharges (Project)
- reduction in the frequency, extent, duration, and depth of downstream flooding (Project)
- increases in low level flooding due to the discharge of the FMZ (Project)
- changes in bridge closure times (Project)
- changes in the time to closure of key evacuation routes (Project)

The Project and other components of the Flood Strategy would:

- reduce the number of people requiring evacuation
- allow a greater number of people to be evacuated
- increase the certainty and efficiency of evacuations.

As shown in Section 15.7.9 (Table 15-28), a substantially lower number of residential properties would be affected by flooding due to the Project and, therefore, the number of people requiring evacuation for flood events up to the 1 in 1,000 chance in a year event would also be lower with the Project.

The State emergency services (SES) and local councils, as well as other government agencies involved in evacuation planning and implementation were involved in the Taskforce that developed the Flood Strategy. Many other components of the Flood Strategy have already been initiated (for example, revised evacuation modelling) and have involved the SES and local councils as well as other government agencies involved in evacuation planning and implementation. Infrastructure NSW has undertaken ongoing consultation and involvement of the SES, local councils and other government agencies involved in evacuation planning and implementation during the development of the Project.

The Flood Plan and local flood plans would be reviewed and updated once the detailed design and operational protocols of the Project have been finalised. It would also consider any other changes to flood risk management and evacuation from other components of the Flood Strategy. This is discussed further in Section 15.9.

Table 15-26. Number of hours before a river crossing is closed for existing conditions and with the Project

Location	Hours before a river crossing is closed for different flood events Red shading = increase in time to closure; Green shading = decrease in time to closure									
	1 in 5 chance in a year (hours to closure)		1 in 10 chance in a year (hours to closure)		1 in 20 chance in a year (hours to closure)		1 in 100 chance in a year (hours to closure)		PMF (hours to closure)	
	Existing	Project	Existing	Project	Existing	Project	Existing	Project	Existing	Project
Cattai Creek Road Bridge	8 (3-22)	10 (4-23)	8 (2-14)	8 (3-19)	6 (2-13)	7 (3-17)	5 (2-11)	6 (3-14)	6	3
Yarramundi Road Bridge	3 (1-17)	6 (3-21)	3 (1-9)	5 (3-17)	2 (1-5)	4 (2-14)	2 (1-4)	4 (2-10)	1	3
Windsor Road Bridge (New)	Not closed	Not closed	Not closed	Not closed	30 (21-45)	Not closed	21 (15-34)	39 (29-54)	8	14
North Richmond Road Bridge	4 (3-17)	17 (6-27)	5 (3-19)	11 (5-22)	3 (2-12)	9 (4-20)	3 (2-10)	6 (4-19)	2	5
Richmond - Blacktown Road Bridge	Not closed	Not closed	Not closed	Not closed	46 (35-64)	Not closed	38 (26-55)	59 (43-75)	20	28
Jim Anderson Bridge	Not closed	Not closed	Not closed	Not closed	Not closed	Not closed	29 (21-41)	Not closed	18	24
Victoria Road Bridge	Not closed	Not closed	Not closed	Not closed	Not closed	Not closed	Not closed	Not closed	53	64
M4 Motorway Bridge - Nepean River (west)	Not closed	Not closed	Not closed	Not closed	Not closed	Not closed	Not closed	Not closed	Not closed	Not closed
M4 Motorway Bridge - Nepean River (east)	Not closed	Not closed	Not closed	Not closed	Not closed	Not closed	Not closed	Not closed	81	110
M4 Motorway - South Creek	Not closed	Not closed	Not closed	Not closed	Not closed	Not closed	Not closed	Not closed	69	93
Great Western Highway - South Creek	Not closed	Not closed	Not closed	Not closed	Not closed	Not closed	Not closed	Not closed	7	8
Blaxland Crossing Road Bridge (Wallacia)	15 (11-29)	15 (12-29)	12 (8-26)	13 (9-26)	10 (5-19)	11 (8-20)	8 (3-15)	10 (7-18)	7	8

Note: Range is 10th to 90th percentile. Hours to closure indicated in brackets

15.7.4 Flood velocity

Large Project inflow events would comprise of similar velocity distributions to the existing conditions. However, due to the increased attenuation and management of flood waters associated with the Project, the maximum period of peak flood velocities would be reduced, which would result in an associated reduction of flood hazard.

Velocity duration curves at four downstream locations are provided in Appendix H1 (Flooding and hydrology assessment report, Section 4.2.3.4). This shows that for some events, including emptying of the FMZ at a steady release rate of 100 gigalitres per day, there would be an increase in the duration of sustained bank-full velocities. The impact of changes in scour potential and impacts on bank stability are discussed in Chapter 22 (Soils).

15.7.5 Floodplain conveyance and storage

The Project would not directly impact on downstream floodplain connectivity, conveyance or flood storage areas as the Project does not involve construction in or modification of the topography of the floodplain. There may be some minor indirect geomorphological impacts associated with the Project (see Appendix N2 - Geomorphology assessment report), however these impacts would not substantially alter local or regional flood conveyance and storage areas.

Flood function maps for the 1 in 100 and 1 in 500 chance in a year floods are shown in Figure 15-42. and Figure 15-43., and summarised below. More detailed maps are provided in Appendix H2 (Flood risk analysis). Operation of the FMZ is discussed in Section 15.7.10.

1 in 100 AEP Event (Appendix H2: Figures 68 to 71)

- **Primary floodway:** The primary floodway is generally located within the main river channel. Similar to existing conditions at Wallacia and Penrith, the primary floodway does not extend beyond the low-lying overbank areas. There is a slightly smaller breakout at the Rickabys Creek confluence with the main river at Windsor in comparison with the existing scenario. The primary floodway extends beyond the banks of Rickabys Creek and South Creek in small areas, but does not intersect existing residential or industrial development. Additionally, there is a smaller breakout of the Hawkesbury River at Pitt Town.
- **Secondary floodway:** At Penrith, as with the existing scenario, nearly all the 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. The overbank in the Wallacia area remains as a floodway under the raised dam scenario.

1 in 500 AEP Event (Appendix H2: Figures 72 to 75)

- **Primary floodway:** There is little change in the primary floodway in comparison to the 1 in 100 chance in a year flood under existing conditions. The calculation and assessment of a primary floodway did not result in any additional primary floodways developing from the 1 in 100 chance in a year flood.
- **Secondary floodway:** The secondary floodway breaks out from the Hawkesbury River banks at the Richmond Lowlands. However, unlike the existing scenario, it does not completely cover the whole floodplain and there is no development of additional floodways at Emu Plains and Penrith. The flowpath across Pitt Town also remains relatively narrow in comparison to the secondary flowpath under existing conditions. Furthermore, Currency Creek does not connect to the Hawkesbury River at Wilberforce, north of Windsor, under the raised dam conditions. Downstream of Sackville, there are only minor differences from the floodways of the 1 in 100 chance in a year flood.

Figure 15-42. Dam raising hydraulic categorisation: 1 in 100 chance in a year flood (Appendix H2, Figure 68)

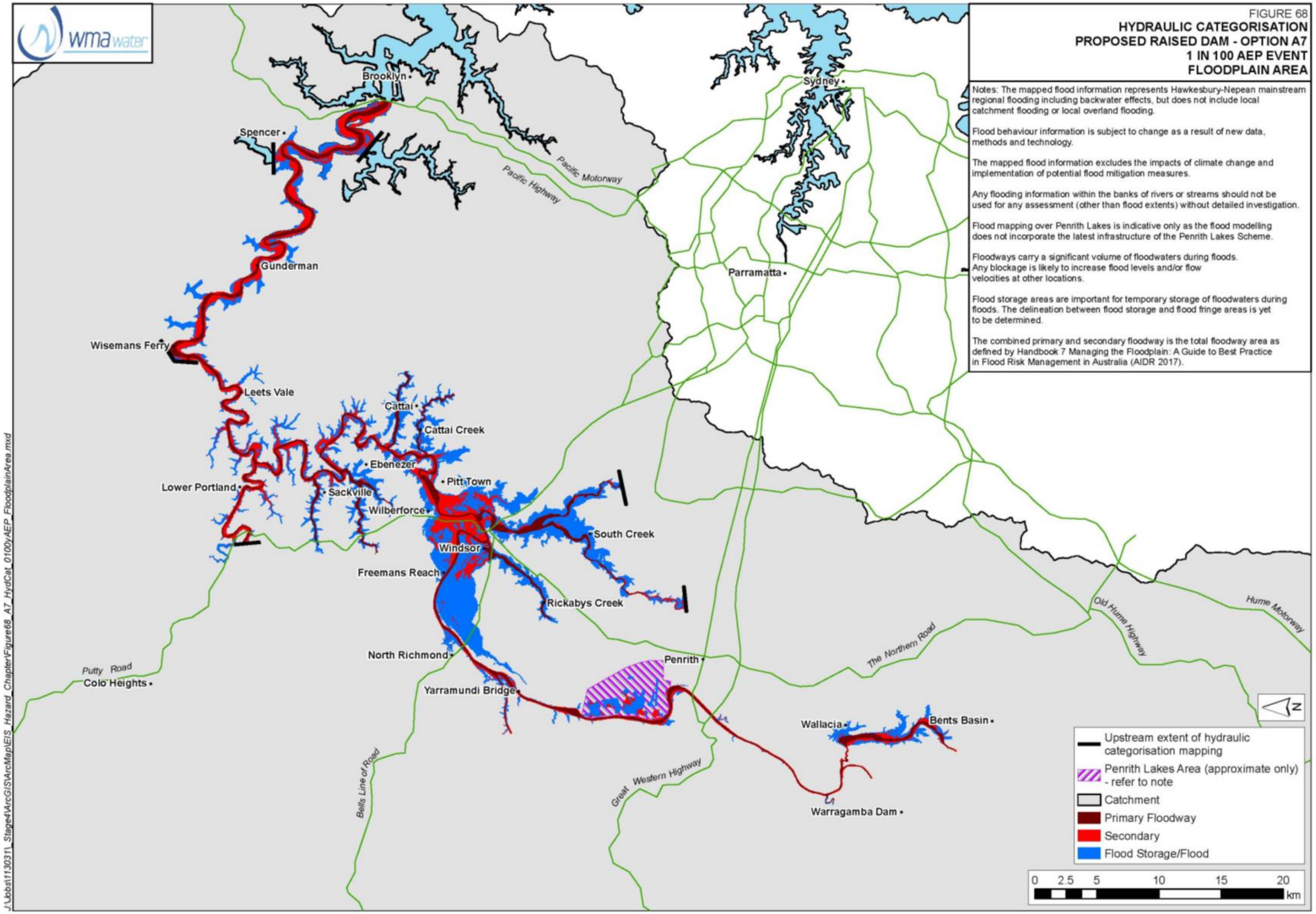
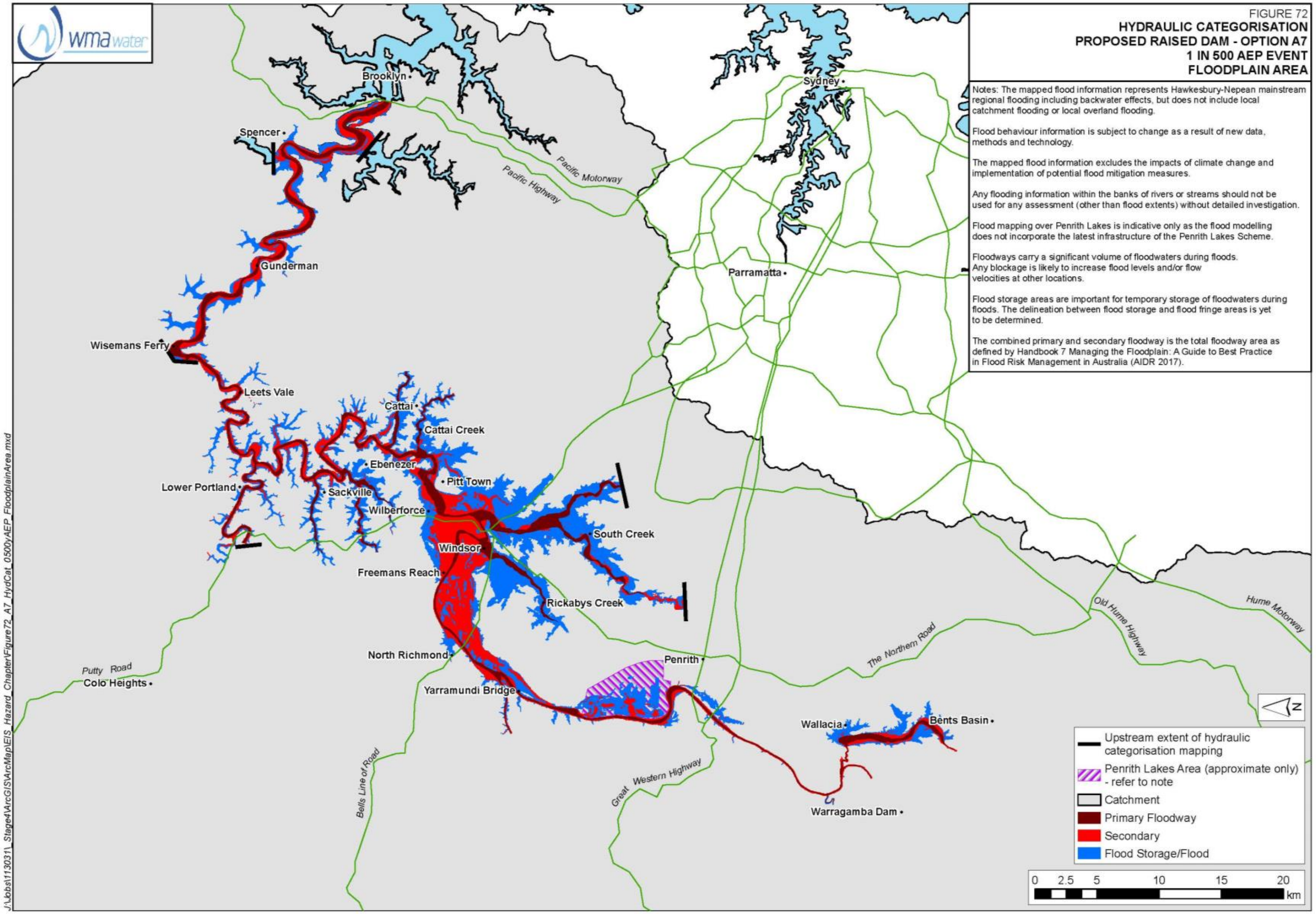


Figure 15-43. Dam raising hydraulic categorisation: 1 in 500 chance in a year flood (Appendix H2, Figure 72)



15.7.6 Flood hazard

The Project would reduce the frequency, extent and depth of floods, and consequently current flood hazards would be reduced.

Flood hazard modelling for a range of flood events is provided in Appendix H2 (Flood risk analysis), which includes detailed flood hazard maps for Richmond-Windsor, Penrith and Wallacia. Flood conditions and hazard classifications for a range of flood events are summarised in Table 15-28, while example flood hazard maps for the 1 in 20 and 1 in 100 chance in a year floods are shown on Figure 15-44. and Figure 15-45..

Operation of the FMZ is discussed in Section 15.7.10.

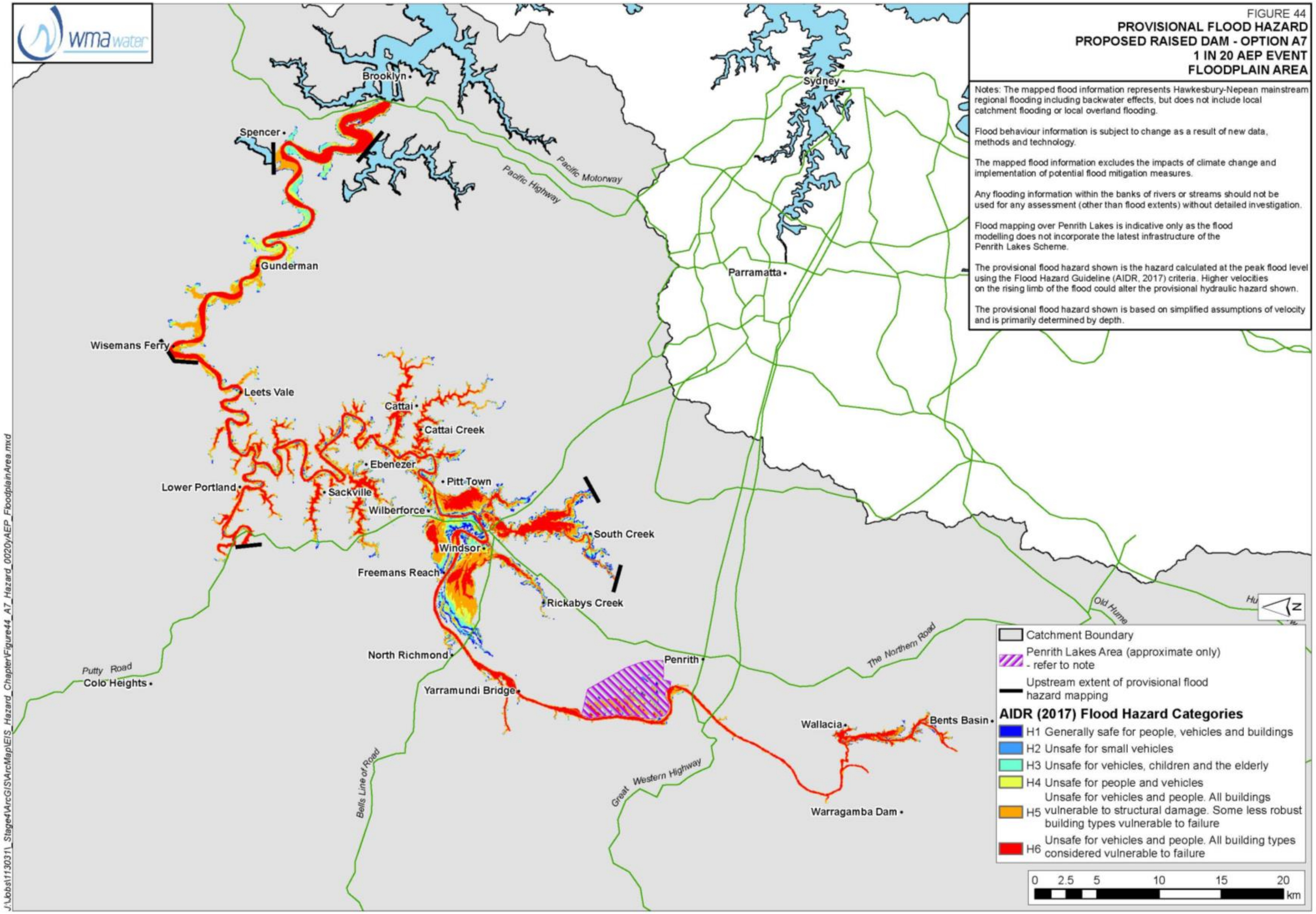
Table 15-27. Flood hazard modelling – existing conditions (Appendix H2)

Category	Constraint to people/vehicles	Building constraints
H1	Generally safe for people, vehicles and buildings	No constraints
H2	Unsafe for small vehicles	No constraints
H2	Unsafe for vehicles, children and the elderly	No constraints
H4	Unsafe for vehicles and people	No constraints
H5	Unsafe for vehicles and people	All buildings vulnerable to structural damage. Some less robust building types vulnerable to failure.
H6	Unsafe for vehicles and people	All building types considered vulnerable to failure

Flood event 1 in x chance in a year	Dam raising
5	*Flood hazard maps: Appendix H2: Figure 40 to Figure 43* ▪ Most of the floodplain is classified as unsafe for vehicles and people (H4 to H6). Similar to existing conditions, most of the flow for this event is contained within the river banks. ▪ The tributaries upstream of Wisemans Ferry experience a decrease in hazard categorisation from an overall H1 to H4 in the existing case to H1 to H2 under the raised dam conditions. ▪ The Windsor floodplain experiences a large decrease in the extent of the H5 and H6 hazard classifications. ▪ The flow is contained to the river at Penrith and there is little change in the hazard between the raised dam and existing conditions. This is also true for Wallacia.
20	*Flood hazard maps: Appendix H2: Figure 44 to Figure 47* ▪ Most of the floodplain at Windsor is considered unsafe for vehicles, people and buildings and is classified as H5 to H6 under existing conditions. For the raised dam there is considerable hazard reduction, with some areas no longer flooded or now classified H1 to H2. ▪ At Penrith, there is minimal change in flood extent as the flow is within banks. For the raised dam the hazard at the bend in the Hawkesbury River downstream of Victoria Bridge is reduced from H6 to H5 on the western bank. ▪ Less regional flooding occurs in Peach Tree Creek, School House Creek, and Mulgoa Creek under a raised dam and there is reduced hazard in these areas. ▪ Reduced flooding in the breakouts from Rickabys Creek and Cooley Creek would lead to a reduction in hazard in these areas. ▪ No change is observed in Wallacia and immediately downstream of the dam between the raised dam and existing conditions
100	*Flood hazard maps: Appendix H2: Figure 48 to Figure 51* ▪ Most of the floodplain is considered unsafe for vehicles and people, with buildings requiring special engineering design and construction or buildings being vulnerable to failure (H5 to H6). This is similar to the existing case but the extent is reduced. ▪ Upstream of Spencer, the hazard classification for the tributaries is reduced from mostly H5 to H4. Unlike existing conditions, the Richmond Lowlands are not all classified as a H6 hazard under a raised dam. ▪ Rickabys Creek is yet to break out towards Blacktown Road in comparison to existing conditions, and hazard in this area is reduced. Additionally, Mckenzies Creek, South Creek and Rickabys Creek remain as three separate flowpaths under the raised dam scenario and do not join up.

Flood event 1 in x chance in a year	Dam raising
	▪ Similarly, there is yet to be any major breakout from the Nepean River in Penrith under the raised dam conditions. No measurable change is observed in hazard at Wallacia and immediately downstream of the dam.
200	*Flood hazard maps: Appendix H2: Figure 52 to Figure 55* ▪ Under both existing and raised dam conditions most of the floodplain is considered unsafe for vehicles and people, with most building types considered vulnerable to failure (H5 to H6). ▪ Most of the flood hazard differences between the raised dam and existing conditions are between Pitt Town and Penrith. ▪ The hazard near North Richmond, Rickabys Creek and Cooleys Creek is reduced under raised dam conditions. Additionally, the breakout from Rickabys Creek towards Blacktown Road and the joining of the flowpath across Pitt Town Bottoms does not occur in the raised dam scenario. ▪ No change is observed in Wallacia and immediately downstream of the dam.
500	*Flood hazard maps: Appendix H2: Figure 56 to Figure 59* ▪ Similar to existing conditions, the Windsor floodplain is predominantly classified as a H6 hazard under the raised dam conditions. ▪ The Rickabys Creek breakout towards Blacktown Road is mostly classified as H1 to H5 hazard in comparison to H4 to H6 under existing conditions. ▪ Under the raised dam conditions the flow path across Emu Plains is yet to merge back into the main river and the Boundary Creek breakout does not occur, thereby reducing the hazard in these areas. Similar to the raised dam conditions in the 1 in 200 AEP event, flooding within Penrith and Emu Plains is significantly reduced with lower hazards in areas still flooded. ▪ No significant change is observed in Wallacia.
2,000	*Flood hazard maps: Appendix H2: Figure 60 to Figure 63* ▪ Except for Penrith, most of the floodplain is considered unsafe for vehicles and people, with all building types considered vulnerable to failure (H6), which is similar to existing conditions. ▪ Aside from the Rickabys Creek breakout towards Blacktown Road not joining up with the main river under a raised dam scenario, the overall trend of flood hazard classification between the raised dam and existing scenarios is the same. Under the raised dam conditions, the extent of H1 to H2 is greater in comparison to the existing scenario. ▪ The hazard in Penrith and Emu plains is significantly reduced in a raised dam scenario. Furthermore, the Boundary Creek breakout does not merge with the Penrith Lakes floodplain in the raised dam scenario leading to reduced hazard to this area. ▪ No change is observed in Wallacia.
PMF	*Flood hazard maps: Appendix H2: Figure 64 to Figure 67* ▪ Like the flood hazard classification under existing conditions, most the floodplain is considered unsafe for vehicles and people with all building types considered vulnerable to failure (H6) with a raised dam. ▪ While in the existing scenario the flowpath from Rickabys Creek towards Devlin Road converges back with the Nepean River; this is not the case under the raised dam option.

Figure 15-44. Dam raising flood hazard mapping: 1 in 20 chance in a year event (Appendix H2, Figure 44) 1 of 2



Dam raising flood hazard mapping for Richmond-Windsor: 1 in 20 chance in a year event (Appendix H2, Figure 45) 2 of 2

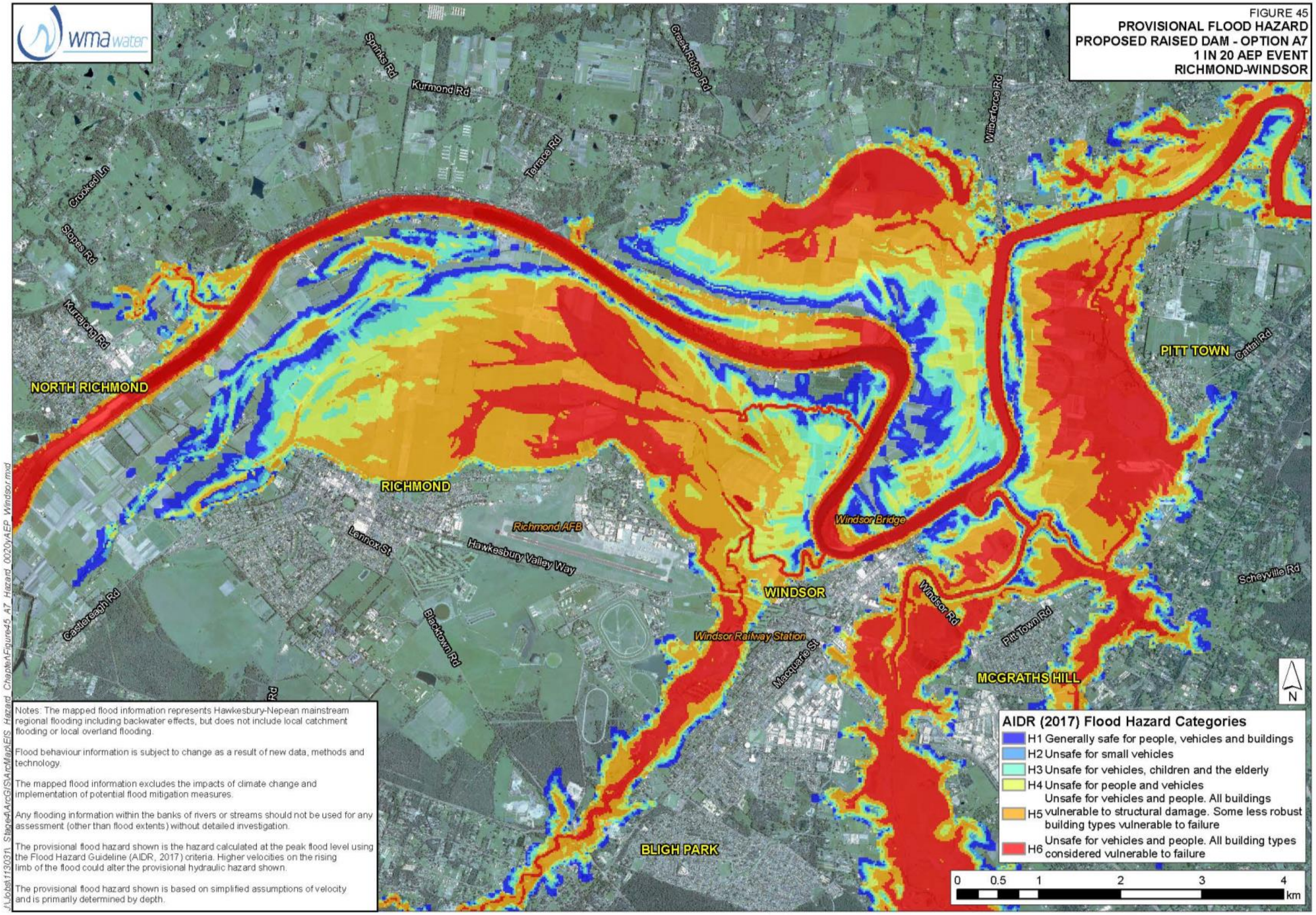
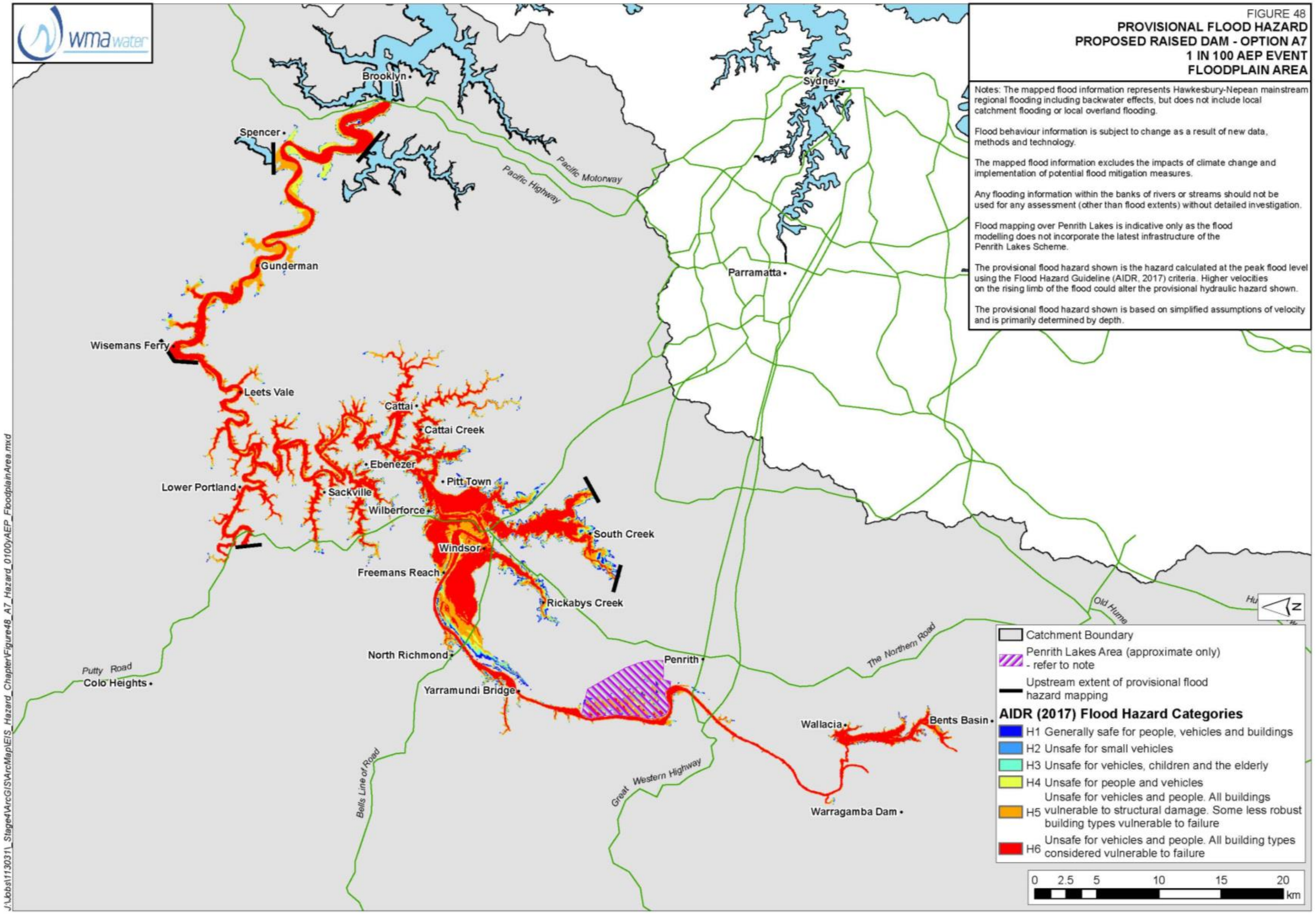
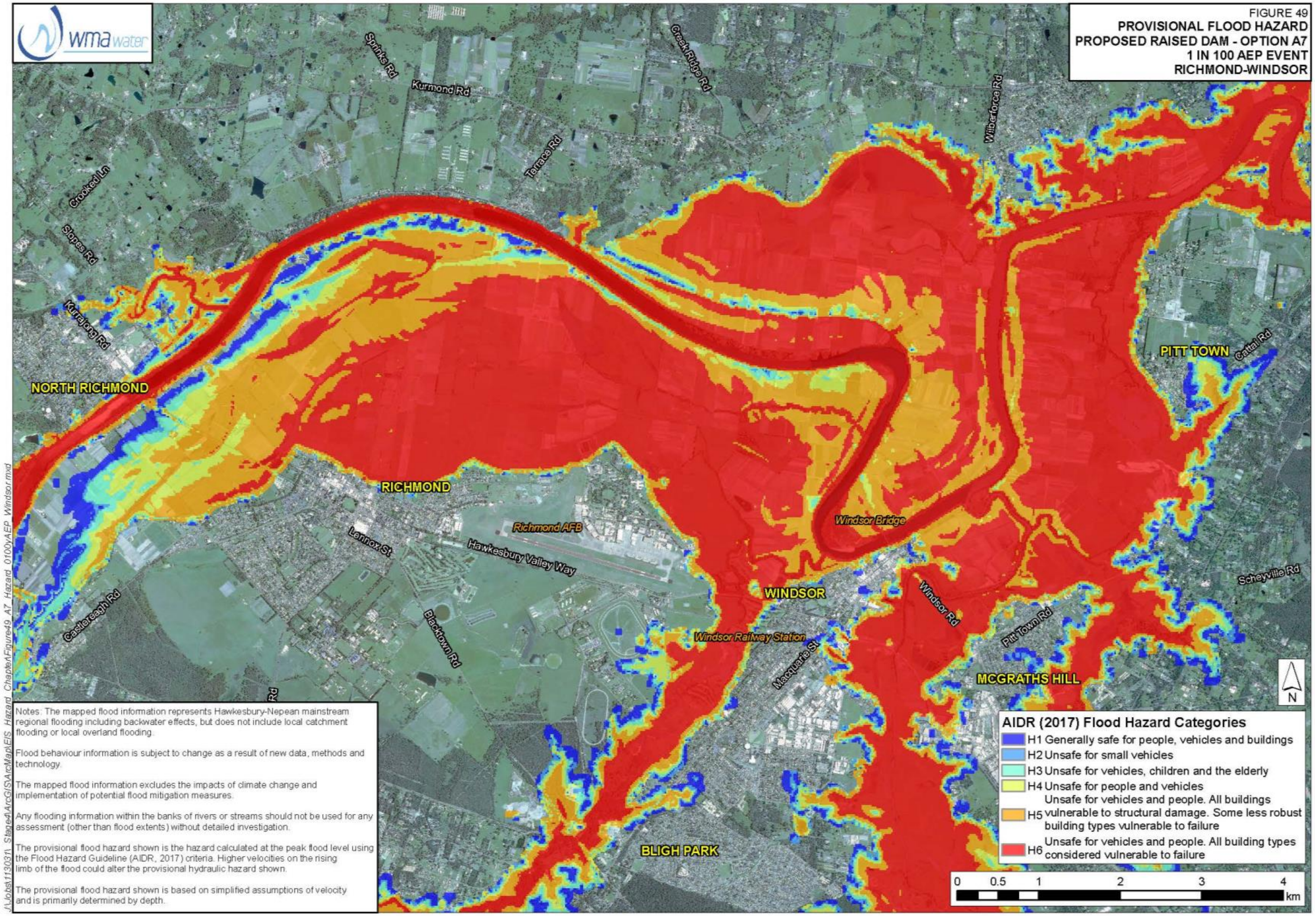


Figure 15-45. Existing flood hazard mapping: 1 in 100 chance in a year event (Appendix H2, Figure 48) 1 of 2



Existing flood hazard mapping for Richmond-Windsor: 1 in 100 chance in a year event (Appendix H2, Figure 49) 2 of 2



15.7.7 Groundwater

Groundwater and wetlands within the Hawkesbury-Nepean floodplain are discussed in Section 15.3.2.3. Important wetlands in the Project study area are:

- 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 (see Section 15.4.1). 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).

15.7.8 Other hydrological impacts

Due to the increased attenuation and management of flood waters due to the Project, the frequency with which the Hawkesbury and Nepean River experiences out-of-bank flows and inundation of floodplain wetlands would be reduced. Potential negative impacts include:

- FMZ discharges would result in longer periods of low level flooding and flood hazard, and flood function mapping would need to be updated to reflect this additional impact
- increases in soil erosion and sediment transport may occur because of alterations to flood flows and velocities. Erosion modelling suggests that during operations, the risk of increased soil erosion and sediment transport includes:
  - no areas of extreme erosion or sediment transport risk
  - a reduction the number of areas rated high-risk of erosion and sediment transport (from four existing sites, to one post-construction of the raised dam)
  - an increase in the number of areas rated medium-risk of erosion and sediment transport; however, this is a result of the reduction in high risk areas.

  There would be unavoidable geomorphological impact on bank erosion in the system; however, the impacts associated with elevated sediment deposition in the upstream zone and on floodplains in the downstream zone when flows are backed was assessed to be low. Constraining flows within the downstream channel would lead to a net reduction in overbank flows in the downstream rivers, leading to a reduced likelihood of sediment deposition. There would be a transition towards deposition conditions during flood storage events (upstream) and Flood Mitigation Zone discharges (downstream). The long-term effect of these events; however, appear to be short-lived and covering a limited spatial scale. This is addressed in Appendix N2 (Geomorphology assessment report)

- existing wetland habitats that are dependent on a specific long-term flooding regime may be impacted due to the reduction in frequency of flooding. This is addressed in Chapter 9 (Downstream ecological assessment)
- agricultural land uses that currently benefit from the nutrients and sediments deposited on the floodplain by periodic inundation. Whilst a reduced frequency of flooding may provide a reduced risk of crop damage in agricultural areas, the reduction of the long-term exposure to flood inundation may result in degradation of land value for some agricultural purposes. Generally, turf growing, market gardens and other similar agricultural enterprises would not be affected by land degradation as they regularly apply fertilisers and other soil conditioners, and do not rely on flooding. However, passive agricultural enterprises such as grazing may rely on regular flooding to replenish nutrients and other soil characteristics. This is addressed in Chapter 21 (Socio-economic, land use and property)
- 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 any changes 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.

15.7.9 Changes in the number of residential properties affected by flooding

The number of residential properties affected by flooding with and without the Project in 2018 is shown in Table 15-28. The number of affected residential properties reduce by around 50 to 68 percent for floods up to about the 1 in 1,000 chance in a year event, and then reduces to about 11 percent up to the PMF. 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 15-28. Number of residences affected by flooding with and without dam raising (2018)

Flood event 1 in x chance in a year	Existing dam	Dam raising		
			Change	
	2018	2018	Number	%
5	730	370	-360	-49
10	1,670	820	-850	-51
20	2,500	1,480	-1,020	-41
50	4,800	1,980	-2,820	-59
100	7,600	2,420	-5,180	-68
200	10,000	3,500	-6,500	-65
500	15,500	5,900	-9,600	-62
1,000	19,600	9,600	-10,000	-51
2,000	23,600	15,100	-8,500	-36
5,000	26,200	20,100	-6,100	-23
PMF	36,700	32,800	-3,900	-11

15.7.9.1 Economic costs of flooding

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. Economic impacts are addressed in Chapter 21 (Socio-economic, land use and property).

15.7.10 Summary of potential downstream impacts

- The FMZ would delay and attenuate the progression of inflows coming from the upstream Warragamba catchment, which in turn would reduce the severity of regional flood events impacting on the downstream Hawkesbury-Nepean Valley. Flooding from other catchments such as the Nepean, Grose, Colo and South Creek can also contribute significantly to downstream flooding. Project changes include:
  - reduction to peak dam outflows and flood levels
  - reduction in frequency of flooding
  - reduction to flood extents.
- The Project would result in a range of flood mitigation benefits to the Hawkesbury-Nepean Valley including:
  - a reduction in flooding extents across all flood events especially in the Penrith, Windsor, Richmond and South Creek areas. This would result in lower flood damages and social impacts from flooding. The benefits to evacuation come from the reduction in flood peak reducing the number of people to evacuate for a given flood event
  - there would be a more predictable rise in floodwaters and evacuation routes would remain open for longer. This would reduce the risk of loss of human life during floods
  - substantially lower number of residential properties would be affected by flooding
  - estimated flood damages are significantly lower.
- Flood velocities would generally be the same but for a shorter duration for larger flood events. However, during emptying of the FMZ there would be an increase in the duration of sustained bank-full velocities.
- Downstream floodplain connectivity, conveyance or flood storage areas would not be significantly impacted as the Project does not involve construction in or modification of the floodplain.
- Flood hazards would be reduced as the Project would reduce the frequency, extent and depth of floods.
- Groundwater resources are primarily influenced by local rainfall and flooding and would not be significantly impacted by the Project.
- Potential negative impacts include:
  - discharge of the FMZ would result in longer periods of low level flooding and flood hazard, disruption to transport and businesses as well as an increase in the risk of bank erosion: see Chapter 21 (Socio-economic, land use and property), Chapter 24 (Transport and traffic) and Chapter 22 (Soils)
  - existing wetland and flood plain habitats that are dependent on a specific long-term flooding regime may be impacted due to the reduction in frequency of flooding: see Chapter 9 (Downstream biodiversity assessment report)
  - agricultural land uses that currently benefit from the nutrients and sediments deposited on the floodplain may be impacted by reduced periods of inundation; see Chapter 21 (Socio-economic, land use and property)

15.8 Operation of the flood management zone

15.8.1 Operational protocols

Current Warragamba Dam flood operating protocols are based around capturing water until the FSL is reached. When water storage levels rise above FSL, the gates progressively open in accordance with the H14 operating rules (see section 15.3.1.4). Under these rules the gates do not fully open until the upstream storage level is 1.83 metres above the Full Supply Level, which corresponds to around a 1 in 20 chance in a year inflow event.

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 done by WaterNSW (2017). These are shown on Figure 15-46 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.

15.8.2 Normal storage operations

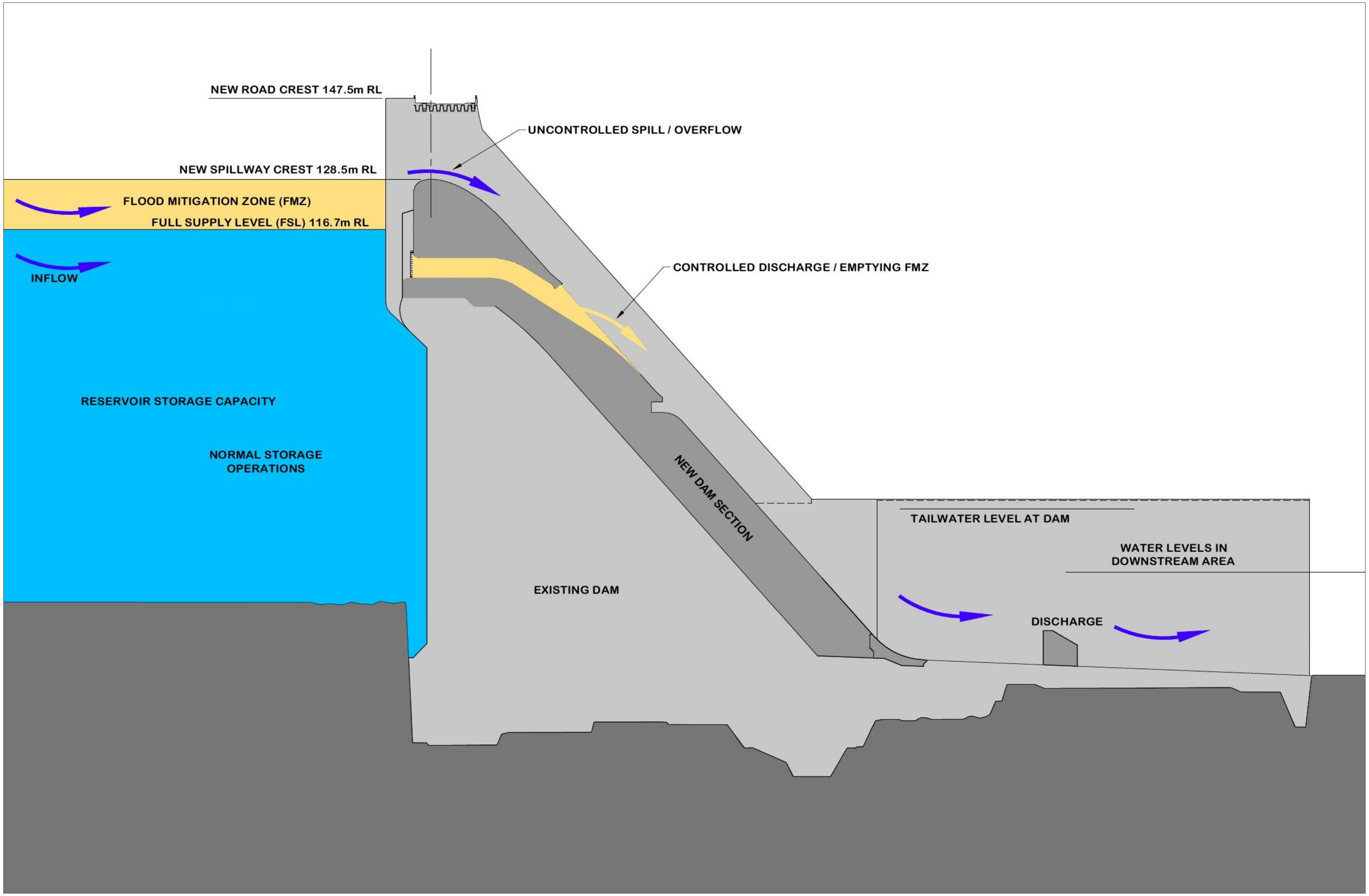
Normal storage operations for the modified dam would generally be the same as current operations. Inflows would be captured up until the FSL is reached, after which either FMZ maintenance or FMZ operation procedures would be implemented.

The only difference is that variable environmental flow releases would occur during normal operations. The Project includes provision for environmental flow infrastructure, however a separate approval is required for environmental flow releases. Further assessment would therefore be undertaken to determine the optimal environmental flow release regime based on environmental benefits and costs.

15.8.3 FMZ maintenance

Minor rainfall events and associated inflows may result in small increases in the dam water level, which in turn may exceed the FSL. Once the water level in the dam reaches a nominated level above the FSL (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 FSL. 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 environment flow release regime adopted.

Figure 15-46. Preliminary operational protocols for the raised dam



15.8.4 Discharge during flood events

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

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

Flood function and flood hazard are discussed in Section 15.8.6. Potential flood impacts on traffic and bridge closures are discussed in Chapter 24 (Transport and traffic).

15.8.5 Discharge after a flood event

15.8.5.1 Piggy back 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 'piggy back' 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 inflows behind the dam wall, thus reducing the downstream peak flood levels. Flood mitigation zone 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.

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

In the event of a second forecast significant flood inflow, it would be possible to empty the whole of the FMZ with piggy-backing within 3-4 days. This would allow FMZ capacity to mitigate further downstream flooding.

15.8.5.2 Constant discharge

A constant FMZ discharge rate of around 100 gigalitres per day was assessed against a range of environmental, social, and economic factors (Table 15-29). Two 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 Water Filtration Plant.

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 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 around 100 gigalitres per day may allow the new Windsor Bridge and possibly Richmond Bridge to be cleared of flood debris, checked and reopened, depending upon flows from the other catchments. The bridges do not open as soon as the water recedes.

The North Richmond water filtration plant 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 15-29. Potential impacts of prolonged 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.
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.

Area of concern: Increase in downstream river levels (above normal)	100 GL/day flow rate in the river
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.

15.8.6 Flood function and flood hazard

A steady state flow of 100 gigalitres per day was modelled to represent sustained releases from the dam. Most of the flow is contained within the river and creek banks, except for Sackville, Cattai, Pitt Town, South Creek, Rickabys Creek and the Windsor floodplain. Flood function (hydraulic categorisation) and hazard (hazard categorisation) modelling is provided in Appendix H2 (Flood risk analysis).

15.8.6.1 Floodplain conveyance and storage

A flood function map for the steady discharge of 100 gigalitres per day is shown on Figure 15-47 and summarised below. More detailed maps are provided in Appendix H2 (Flood risk analysis, Figures 80 to 83).

- **Primary floodway:** 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.
- **Secondary floodway:** 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.

15.8.6.2 Flood hazard

Flood hazard maps for the steady state release of 100 gigalitres per day are shown on Figure 15-48 and summarised below. More detailed maps are provided in Appendix H2 (Flood risk analysis, Figures 76 to 79).

Only the Hawkesbury/Nepean River and its confluences, within their banks, are classified as a H6 hazard (Unsafe for vehicles and people; all building types considered vulnerable to failure). Where overbank areas are flooded, they are mostly given a H1 to H2 classification (representing a relatively low hazard). However, the hazard classification near major creeks, such as Rickabys Creek, South Creek, and Little Cattai Creek, is H4 (Unsafe for vehicles and people) to H5 (Unsafe for vehicles and people; All buildings vulnerable to structural damage; Some less robust building types vulnerable to failure). In the Wallacia region, most of the main stream is contained within its bank and is mostly classified as a H5 hazard with some regions of H4 and H6 present.

Figure 15-47. Dam raising hydraulic categorisation: 100 gigalitres per day (Appendix H2, Figure 76)

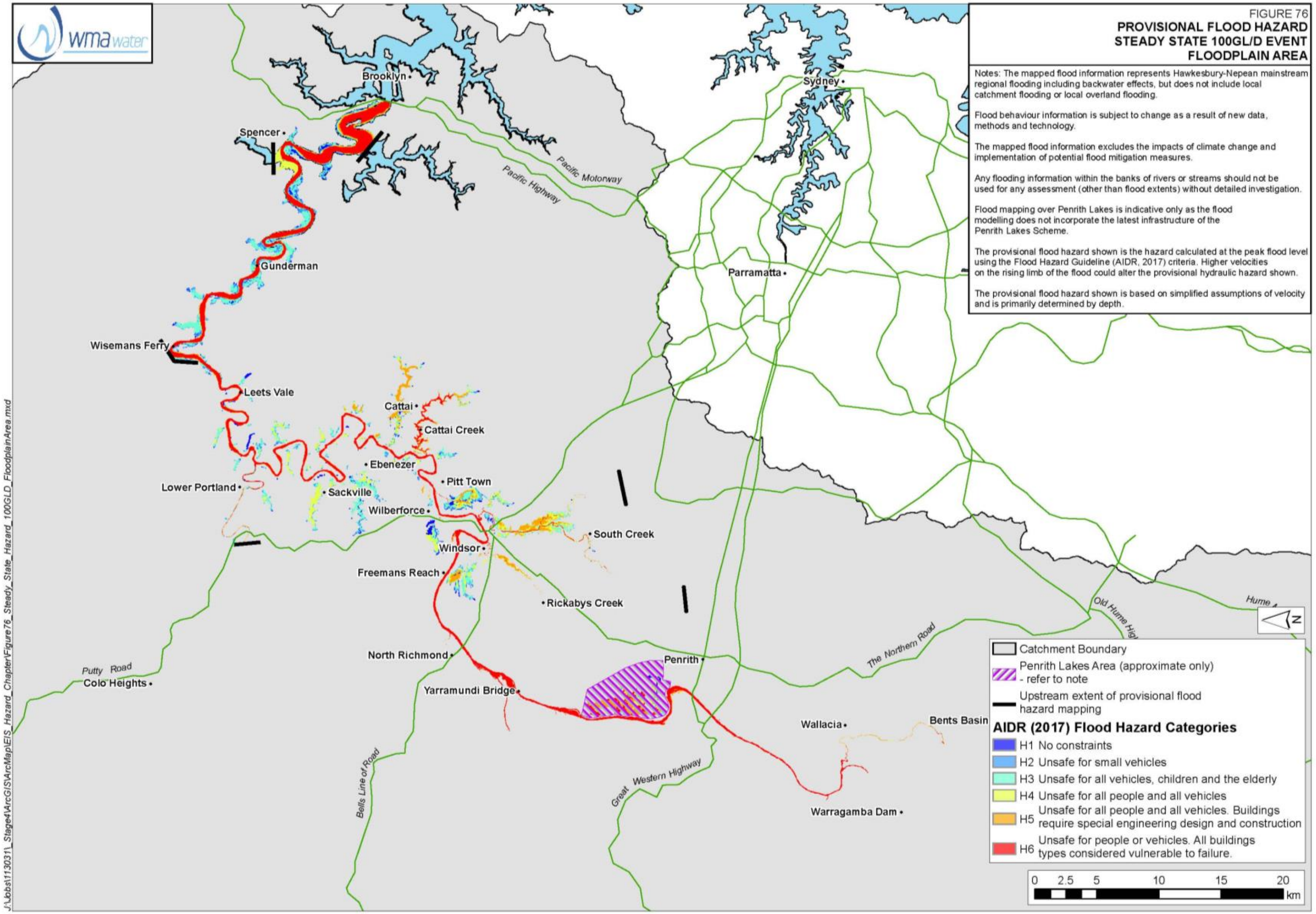
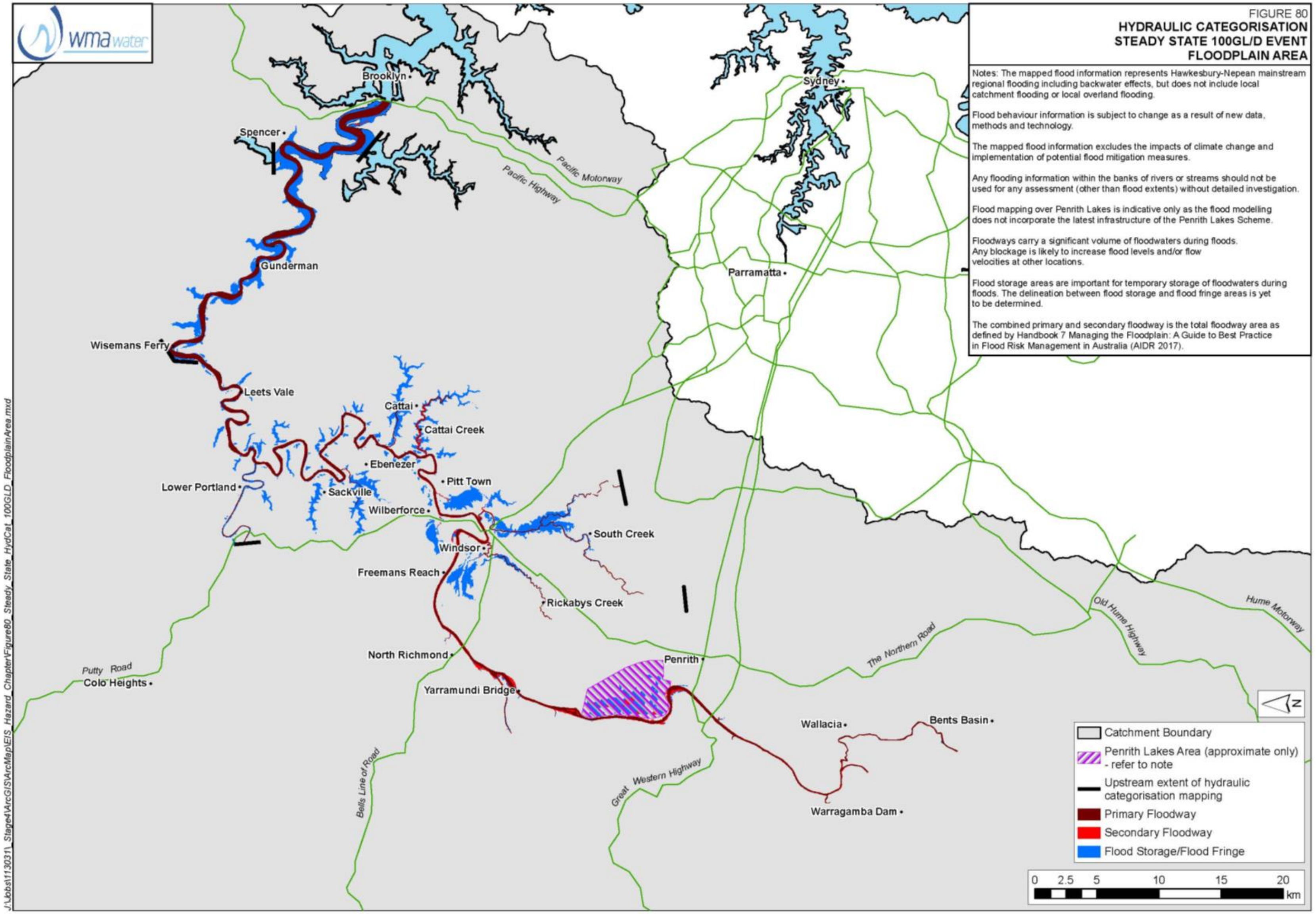
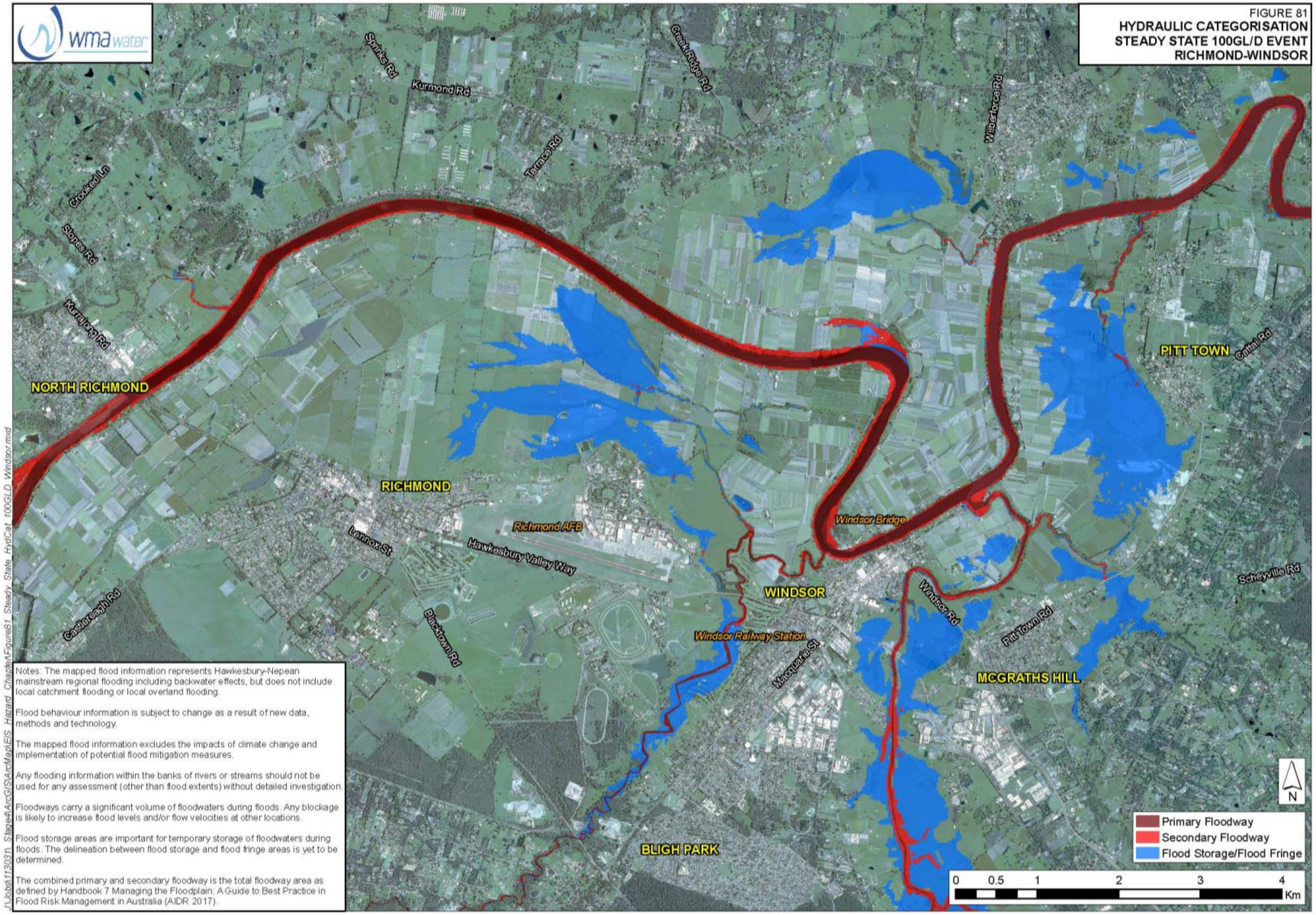


Figure 15-48. Dam raising flood hazard mapping: 100 gigalitres per day (Appendix H2, Figure 76) - Figure 1 of 2



Dam raising flood hazard mapping for Richmond-Windsor: 100 gigalitres per day (Appendix H2, Figure 81) - Figure 2 of 2



15.9 Emergency management arrangements for flooding

The Warragamba Dam Raising proposal is only one workstream of the broader Flood Strategy that also includes a workstream 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 Resilience NSW[4] 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 Resilience NSW 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 Valley.

The resultant actions 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 (NSW SES)
- periodically review and update the Valley recovery strategy (Hawkesbury-Nepean Valley Flood Recovery Strategy) (Resilience NSW)
- to plan for recovery from catastrophic events by developing NSW recovery arrangements for catastrophic disasters using the Valley as a case study. To date three exercises based on catastrophic flooding in the Hawkesbury-Nepean Valley (led by Resilience NSW) 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 Resilience NSW). An exercise to test changes needed with a flood mitigation dam in operation was carried out in April 2019, involving SES, Resilience NSW, WaterNSW and the Bureau of Meteorology. 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 (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 is also part of the multi-agency Flood Strategy Program Delivery Group (PDG), which was formed in April 2017. The PDG monitors progress and advises the Infrastructure NSW 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, Resilience NSW, Transport for NSW, and WaterNSW. Activities have included:

- the PDG 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 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

[4] Resilience NSW was established on 6 April 2020 and was formerly the Office for Emergency Management.

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

Council officers have been nominated who can act as ongoing points of contact with the Infrastructure NSW 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.

15.10 Climate change

Climate change is addressed in Chapter 14 (Climate change risk) and Appendix H1 (Flooding and hydrology assessment report). 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. It is likely that climate change would cause the overall frequency of this weather system to change, which may increase rainfall variability and intensity across the Hawkesbury Nepean catchment, and cause changes to flood regimes and dam operational protocols. Specifically, 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.

Appendix H1 (Flooding and hydrology assessment report, Section 4.2.6) presents assessment of four different emission scenarios:

- 4.9 percent increase in rainfall (high emissions by 2030)
- 9.1 percent increase in rainfall (low emissions by 2090)
- 13.9 percent increase in rainfall (medium emissions by 2090)
- 18.6 percent 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 in 100 chance in a year event with different increases in rainfall are presented in Table 15-30.

The increase in rainfall due to climate change would result in an increase in downstream flooding with the existing dam and a deterioration in Project flood mitigation capacity. For example, if rainfall increased by 9.1 percent, the current 1 in 100 chance in a year flood level at Penrith would change to a 1 in 65 chance in a year event. With the Project the current 1 in 100 chance in a year flood level would be experienced in a 1 in 508 chance in a year event, which would decrease to a 1 in 302 chance in a year event.

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

To be resilient to the future impacts of climate change and maintain the downstream benefits, the Project includes an additional three metres in the abutment height.

Table 15-30. Change in probability of a 1 in 100 chance in a year event by 2090: Existing dam and raised dam

Location	Dam scenario	Current average climate to 2016 (1 in X chance per year)	Future probability of 1 in 100 chance in a year event with different increases in rainfall by 2090			
			4.9%	9.1%	13.9%	18.6%
PENRITH	Existing Dam	100	78	65	54	46
	Project	508	377	302	238	184
WINDSOR	Existing Dam	100	80	65	54	44
	Project	589	421	335	256	197

15.11 Water user impacts

Capture of overland floodplain waters (floodplain harvesting) is not used in the Hawkesbury-Nepean river system to extract water for agriculture, but 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 smaller events, with lower flows during the flood event and higher flows post-flood event due the capture and discharge operations of the FMZ. Potential impacts on water users 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 FSL of Warragamba Dam would not change and all water captured in the FMZ would be discharged.

The water quality assessment undertaken for the Project (see Chapter 27 – Water quality) 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 have no significant change.

15.12 Environmental management measures

Management measures detailed in Table 15-31 have been developed to avoid, minimise or manage potential risks identified in Section 15.6, Section 15.7, Section 15.8 and Section 15.9. Management measures have been incorporated in the Environmental Management measures in Chapter 29 (EIS synthesis, Project justification and conclusion).

Table 15-31. Management measures

Impact	ID	Environmental management measure	Timing	Responsibility
Impacts during construction	HF1	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. Construction activities will be sequenced in accordance with Dams Safety NSW guidelines to ensure dam safety during construction. A Dam Safety Emergency Plan will also be prepared in accordance with the requirements of Dams Safety NSW.	Pre-construction	WaterNSW Construction contractor
Impacts from operation of FMZ	HF2	A detailed operational protocol for the operation of the FMZ will be developed in consultation with relevant downstream and upstream stakeholders.	Pre-construction	WaterNSW
Monitoring	HF3	Investigate water monitoring systems to reflect Project changes in operational protocols.	Pre-operation	WaterNSW

Impact	ID	Environmental management measure	Timing	Responsibility
		Investigate additional monitoring station downstream of the Kedumba River (see Section 15.7.3.9)		

15.13 Risk assessment

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

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

The likelihood and consequence matrix is shown on Figure 15-49.

Once the consequence and likelihood of an impact are assessed, the risk matrix provides an associated ranking of risk significance: **Low**; **Medium**; **High** or **Extreme,** as shown in Table 15-32**.** The residual risk was determined after the application of proposed mitigation measures.

The risk analysis for potential flooding and hydrology impacts is provided in Table 15-33. This includes the residual risk of the potential impact after the implementation of mitigation measures.

Table 15-32. Risk ranking definitions

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

Figure 15-49. Risk matrix

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

Risk Definition (see Table 15-32)	Low	Medium	High	Extreme

Table 15-33. Flooding and hydrology risk analysis

Flooding and hydrology								
Key impacts	Risk before mitigation			Mitigation and management	Risk after mitigation			Residual risk
	L	C	R		L	C	R	
Construction								
▪ construction areas would be directly exposed to dam spills and flooding resulting in potential impacts to worker safety, construction works and scheduling, plant and equipment, erosion and sedimentation, and water quality ▪ debris may potentially wash downstream causing environmental and safety impacts ▪ reduced downstream flows ▪ stormwater runoff ▪ water demands.	b	D	22	H1	d	C	11	Flooding is an "extreme" risk because of the high likelihood that the construction area would be flooded, which could have serious environmental and health and safety consequences. Similarly, debris and potential pollutants washing downstream could create a significant environmental and safety hazards. Mitigation measures include installation of infrastructure and management measures to manage flows, which would significantly reduce the likelihood that flood damage would occur. The consequences of flood damages would also be reduced by implementing rapid response management measures to contain potential impacts. Successful implementation of mitigation will reduce this issue to a Medium residual risk.
Operation: Upstream								
▪ increase area of inundation ▪ increase duration of inundation ▪ relative impact during smaller order flood events is higher than that of the rarer events.	a	E	25	H2, H3	a	C	20	The Project would increase the upstream extent and durations of temporary inundation, which may impact on biodiversity and indigenous heritage values, as well as increasing potential for soil and water quality degradation. There is uncertainty around potential environmental impacts due to the lack of scientific information and the relative infrequency of impact from the rarer flood events. The consequences are a potential loss of environmental qualities that are of regional, national, and international significance.

Flooding and hydrology								
Key impacts	Risk before mitigation			Mitigation and management	Risk after mitigation			Residual risk
	L	C	R		L	C	R	
								Mitigation includes an operational protocol that aims to minimise upstream flooding durations, as well as specific biodiversity, water quality and soil management plans, and a comprehensive monitoring and offset strategy (see Chapter 8). The likelihood of increased upstream flooding remains; however, the consequences can be managed to reduce potential impacts. However, the residual risk remains high and it will be important that adequate resources are available to ensure successful implementation of mitigation measures.
Operation: Downstream								
Water discharge from the FMZ after a rainfall event may result in environmental, social and economic impacts as minor flooding would occur for a longer duration than the existing situation. This may result in minor flooding and disruption of bridge access, drinking water supply and river related commercial and recreational activities	a	C	**20**	H2, H3	b	B	**12**	The purpose of the Project is to alleviate potential for downstream flooding and reduce impacts related to safety, property damage and socio-economic aspects. There are therefore significant benefits, particularly for reducing floods up to about the 1 in 1,000 chance a year flood event. The major recipients of these benefits are the large urban centres of Windsor, Richmond and Penrith. However, without mitigation there is a possibility of poorly managed flood discharges, which could worsen smaller flood events. The Warragamba Dam Raising proposal is only one workstream of the broader Hawkesbury-Nepean Valley flood recovery management strategy (HNVFRMS - Flood Strategy) that also includes a workstream for a comprehensive plan to improve emergency management response and recovery in the Hawkesbury-Nepean Valley (the valley). This workstream plan is to cover implementing changes to the state emergency plan and to respond to the changed operations with a

Flooding and hydrology								
Key impacts	Risk before mitigation			Mitigation and management	Risk after mitigation			Residual risk
	L	C	R		L	C	R	
								flood mitigation dam in operation. Implementation of approved flood operation procedures would lower the likelihood for poorly managed dam discharges and increase community awareness about dam operations and flood characteristics. Improving community preparedness would also reduce the adverse consequences, resulting in a Medium residual risk.

15.14 Flood mapping with Project

15.14.1 Upstream flood mapping with Project

Flood mapping showing Project changes to existing upstream flood extents are provided in the following sections. Mapping includes flood extents for SEARs events (namely the 1 in 5, 10, 20 and 100 chance in a year events, and the PMF), as well as the 1 in 200 and 500 chance in a year events

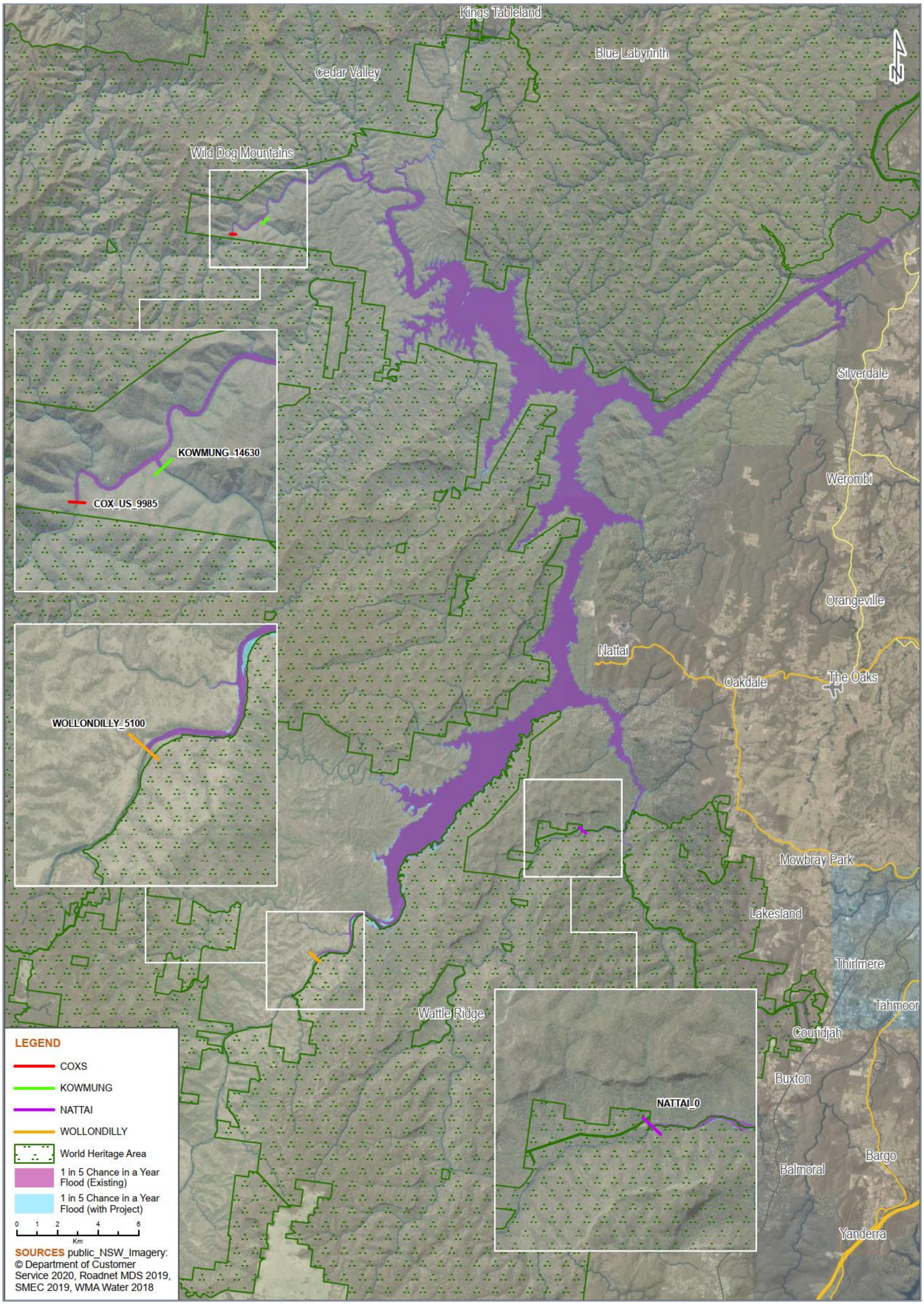
Changes to temporary inundation levels and duration at the dam wall, as well as Figure references are provided in Table 15-34.

Table 15-34. Changes to temporary inundation levels and duration at dam wall and figure references

Flood event (1 in x chance in a year)	Existing		Project				Figure reference
	Maximum upstream flood level (mAHD)	Average upstream inundation above FSL (days)	Maximum upstream flood level (mAHD)	Increase in maximum flood levels (m)	Change to average upstream inundation above FSL (days)		
					Change	Total	
5	117.4	1	120.3	2.9	6.5	7.5	Figure 15-50
10	118.0	2.8	123.1	5.1	7.8	10.6	Figure 15-51
20	118.6	3.0	126.8	8.2	9.5	12.5	Figure 15-52
100	121.5	4.2	132.0	10.5	10.6	14.8	Figure 15-53
200	122.9	4.1	133.2	10.3	9.0	13.1	Figure 15-54
500	124.6	4.5	134.6	10.0	9.2	13.7	Figure 15-55
PMF	131.2	4.8	143.9	12.3	7.2	12	Figure 15-56

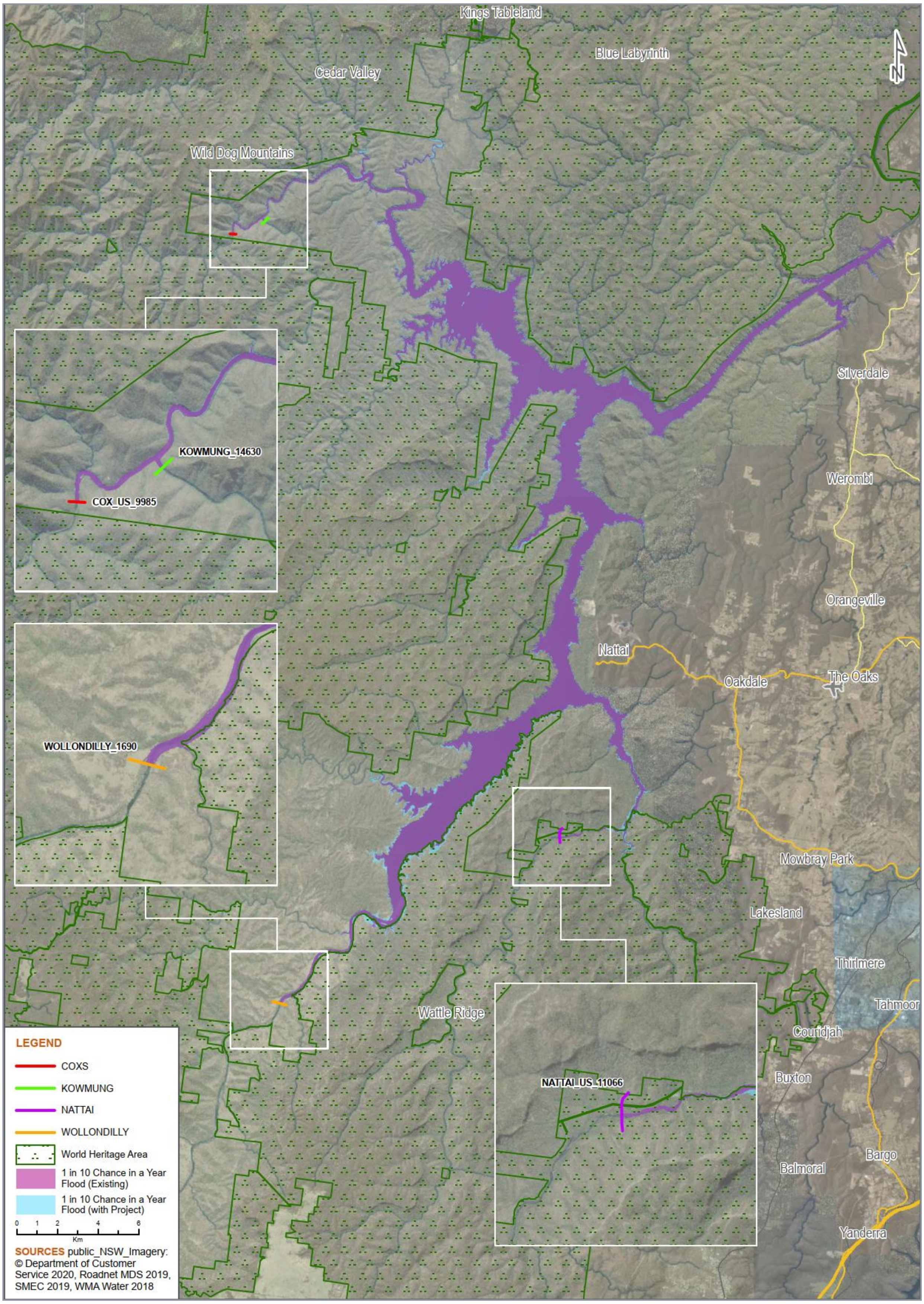
15.14.1.1 Upstream: 1 in 5 chance in a year

Figure 15-50. Upstream flood extent: 1 in 5 chance in a year event



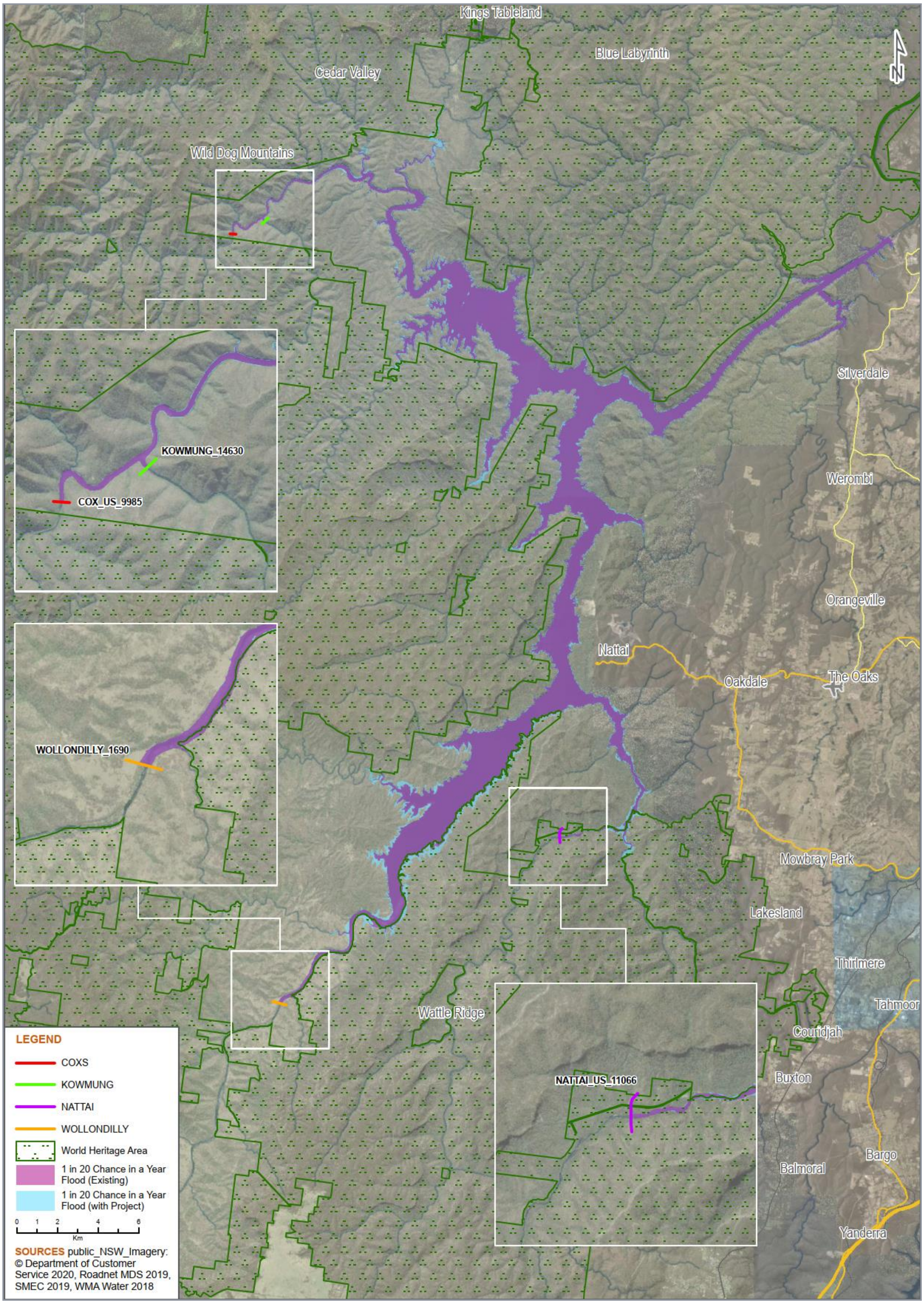
15.14.1.2 Upstream: 1 in 10 chance in a year

Figure 15-51. Upstream flood extent: 1 in 10 chance in a year event



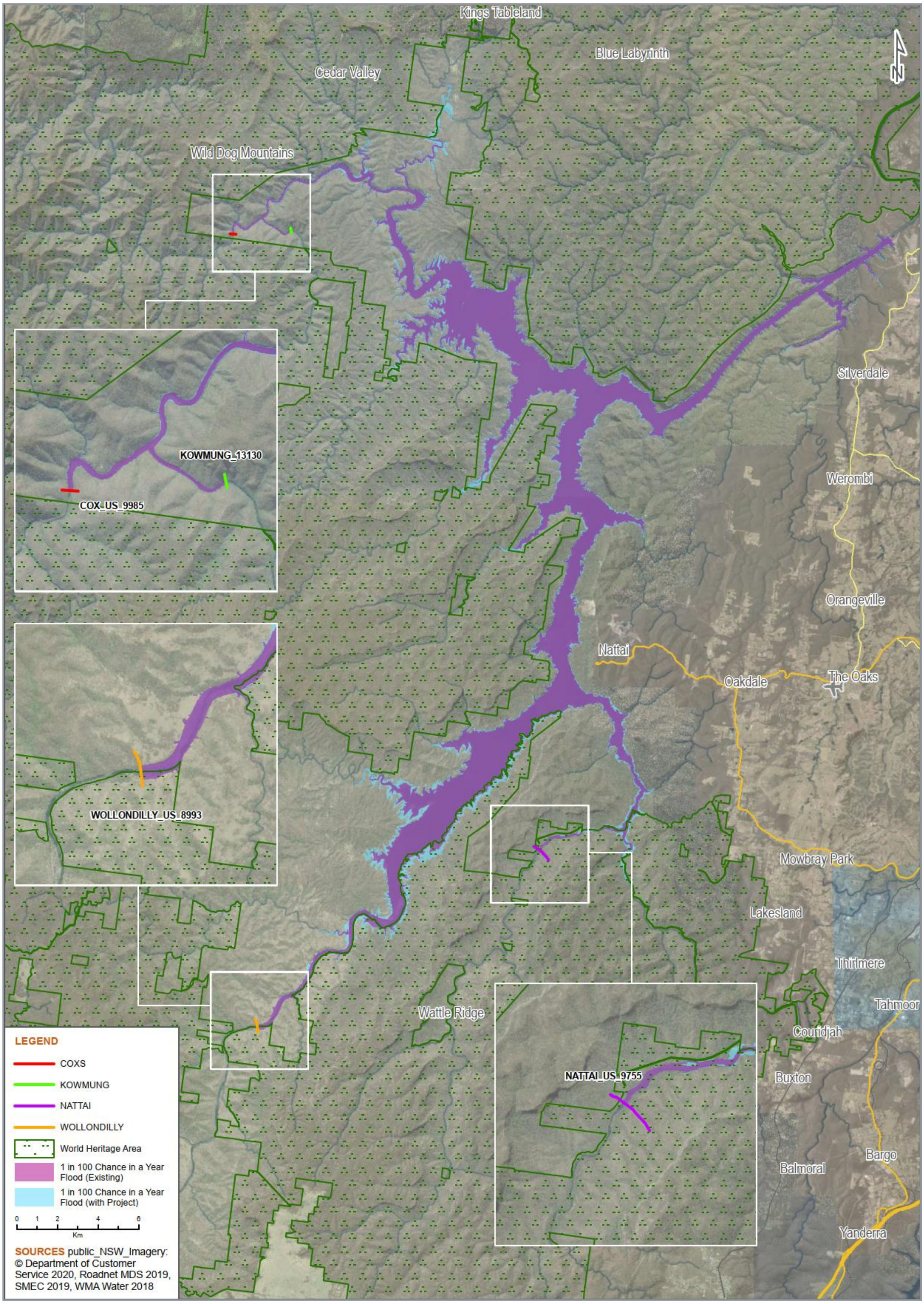
15.14.1.3 Upstream: 1 in 20 chance in a year

Figure 15-52. Upstream flood extent: 1 in 20 chance in a year event



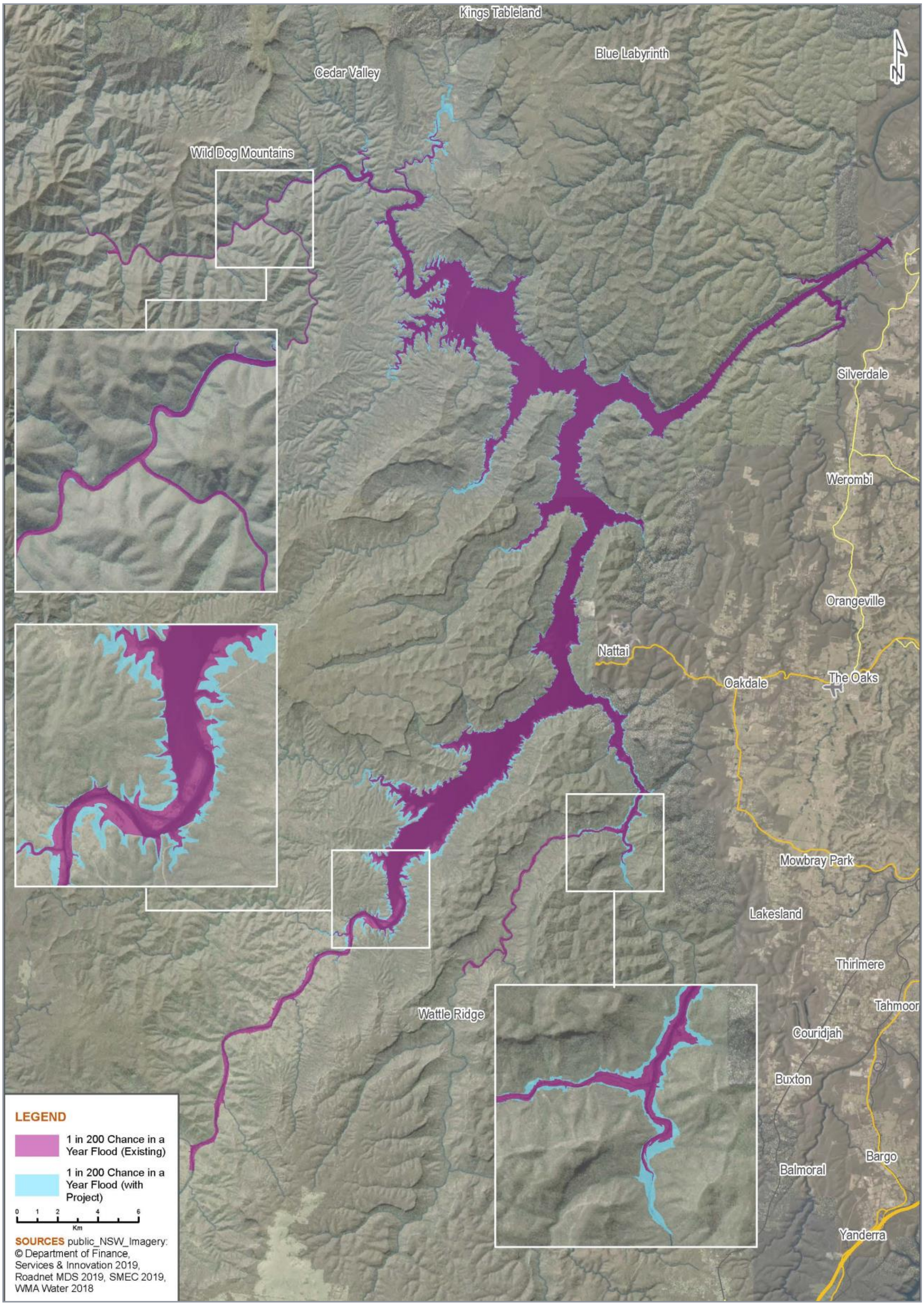
15.14.1.4 Upstream: 1 in 100 chance in a year

Figure 15-53. Upstream flood extent: 1 in 100 chance in a year event



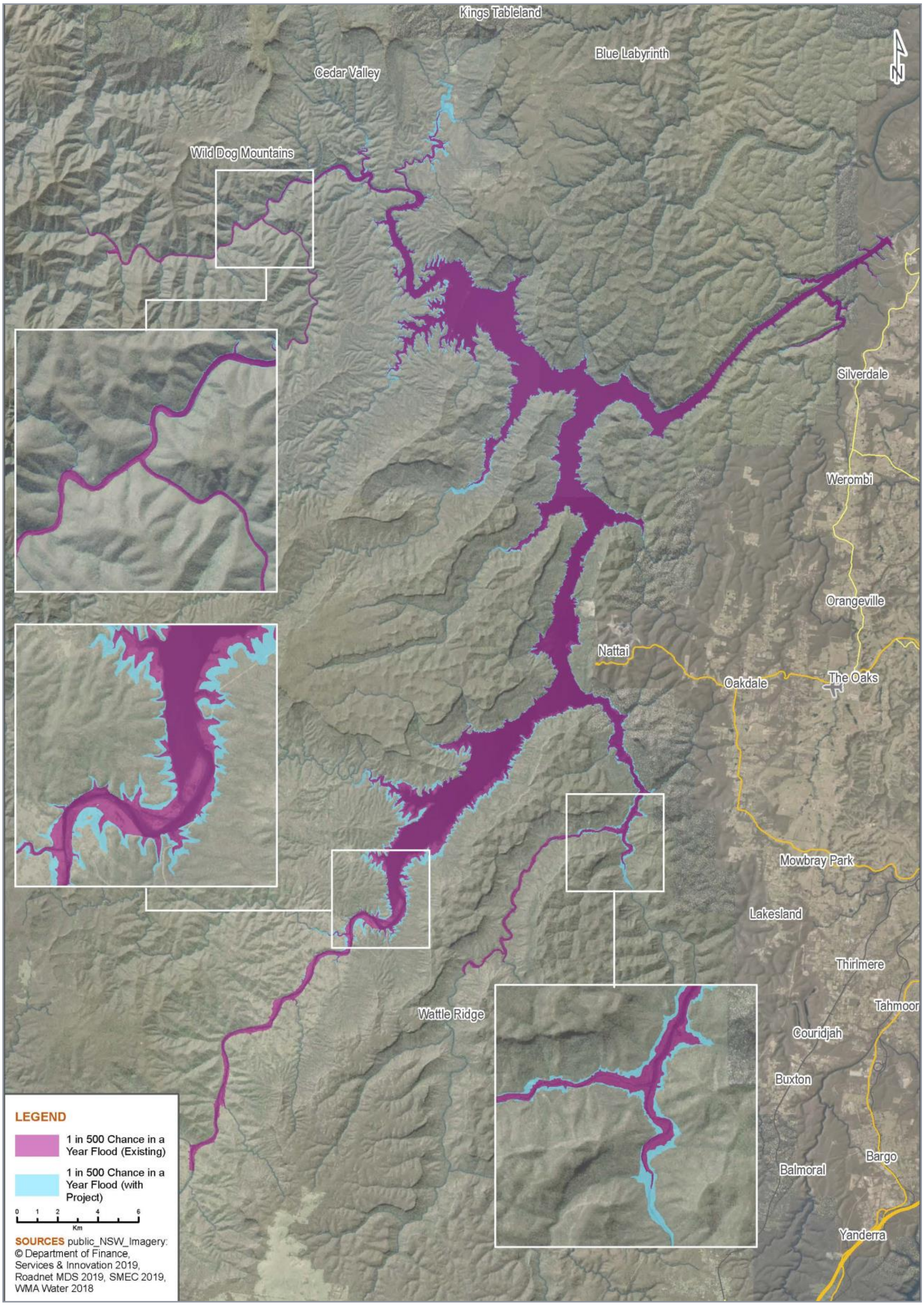
15.14.1.5 Upstream: 1 in 200 chance in a year

Figure 15-54. Upstream flood extent: 1 in 200 chance in a year event



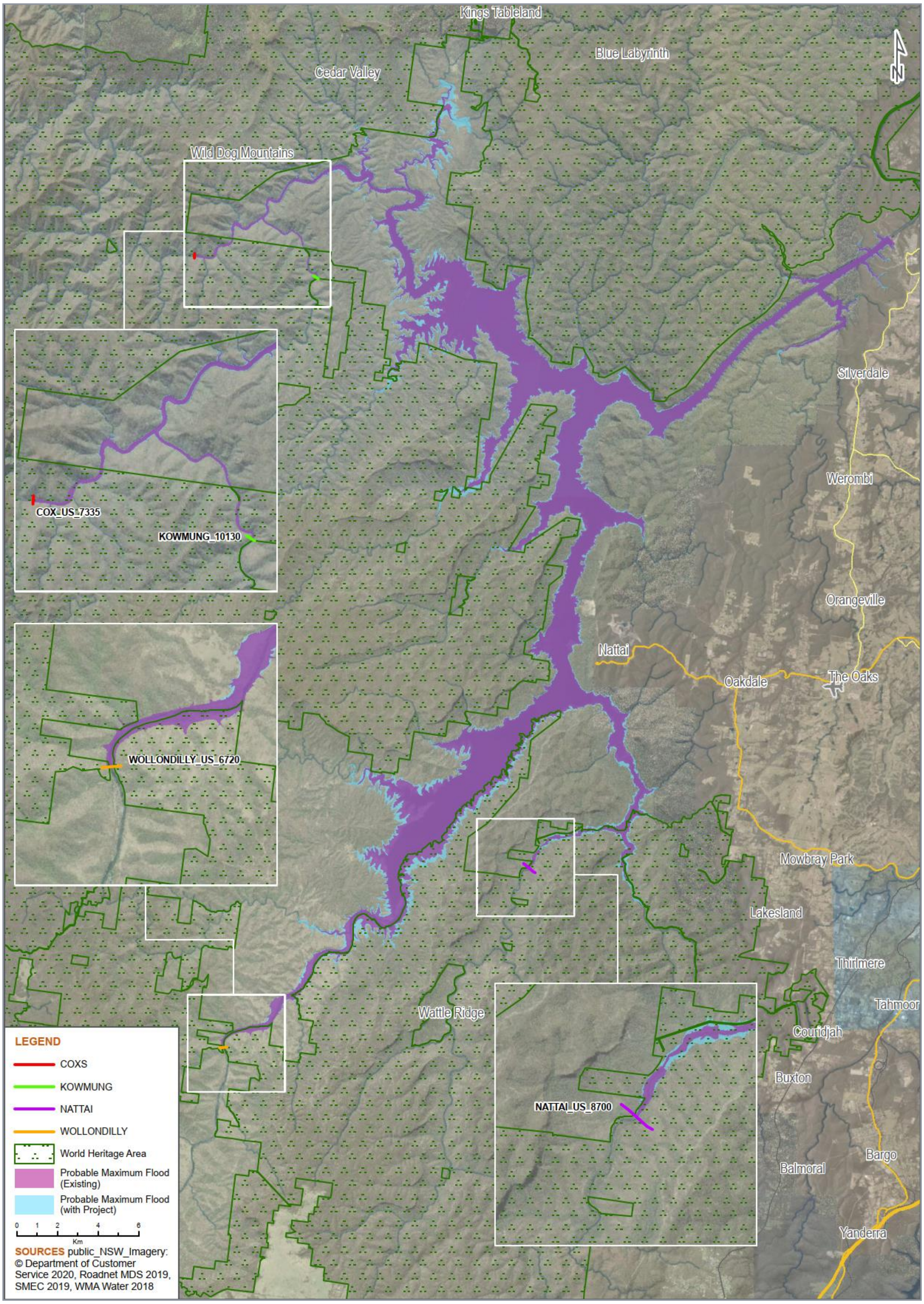
15.14.1.6 Upstream: 1 in 500 chance in a year

Figure 15-55. Upstream flood extent: 1 in 500 chance in a year event



15.14.1.7 Upstream: PMF

Figure 15-56. Upstream flood extent: PMF event



15.14.2 Downstream flood mapping with Project

Flood mapping showing Project changes to existing downstream flood extents are provided in the following sections. Mapping includes:

- downstream flood extents for SEARs events (namely the one in 5, 10, 20 and 100 chance in a year events, and the PMF), as well as the 1 in 200 and 500 chance in a year events.
- large scale maps for Wallacia, Penrith, Richmond/Windsor and South Creek

Peak dam outflows for flood extents and Figure references are provided in Table 15-35. Flood level changes at representative downstream river locations are given in Table 15-36.

Table 15-35. Peak dam outflows and Figure reference

Flood event (1 in x chance in a year)	Existing scenario (m^3/s)	Project scenario (m^3/s)	Peak outflow change (m^3/s)	Figure reference				
				Catchment	Wallacia	Penrith	Richmond/ Windsor	South Creek
5	2,271	810	-1,461	Figure 15-57	Figure 15-58	Figure 15-59	Figure 15-60	Figure 15-61
10	4,430	1,160*	-3,270	Figure 15-62	Figure 15-63	Figure 15-64	Figure 15-65	Figure 15-66
20	6,860	1,160*	-5,700	Figure 15-67	Figure 15-68	Figure 15-69	Figure 15-70	Figure 15-71
100	9,660	3,800	-5,860	Figure 15-72	Figure 15-73	Figure 15-74	Figure 15-75	Figure 15-76
200	11,061	5,943	-5,118	Figure 15-77	Figure 15-78	Figure 15-79	Figure 15-80	Figure 15-81
500	13,019	8,862	-4,157	Figure 15-82	Figure 15-83	Figure 15-84	Figure 15-85	Figure 15-86
PMF	40,950	36,390	-4,560	Figure 15-87	Figure 15-88	Figure 15-89	Figure 15-90	Figure 15-91

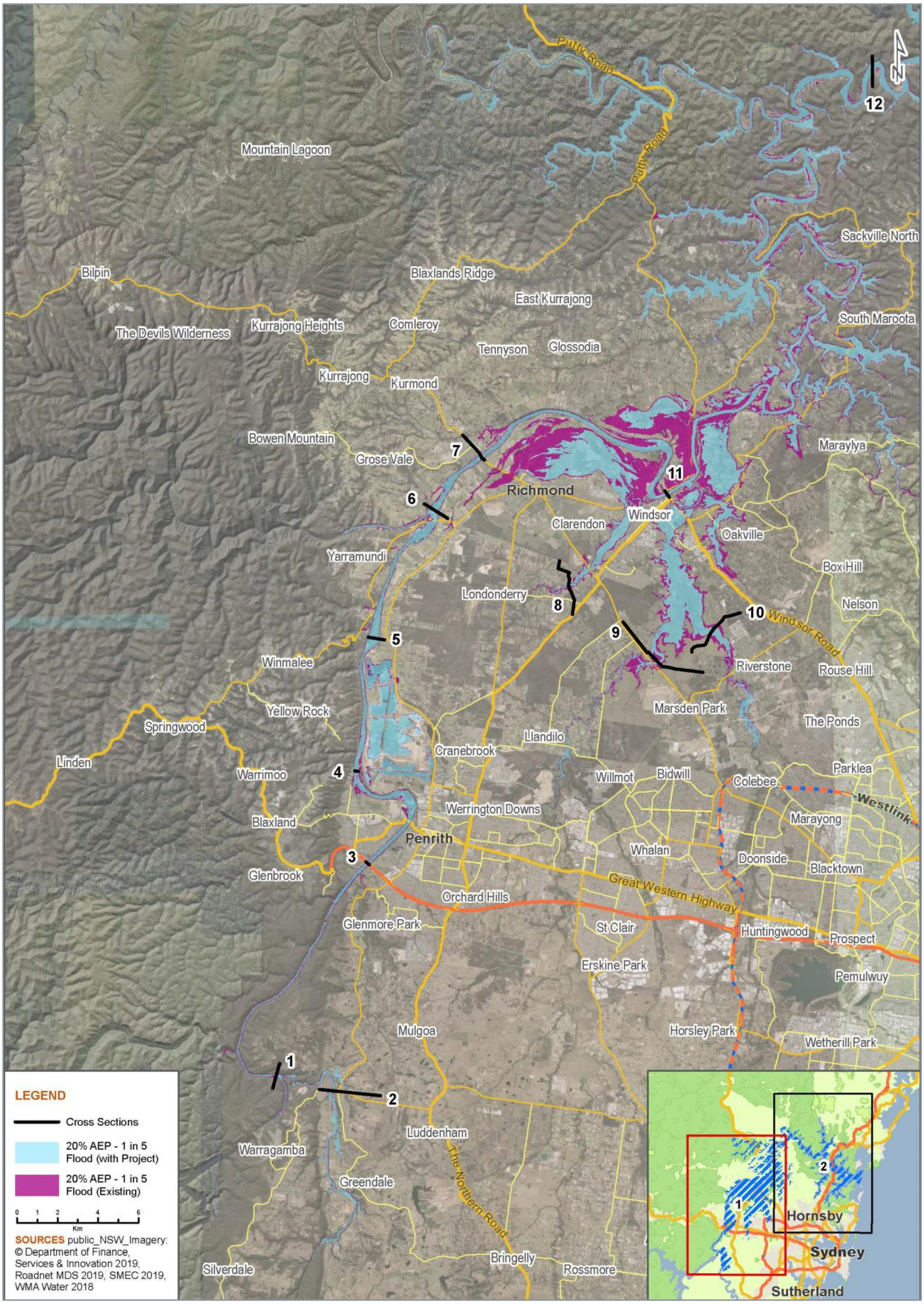
*Discharge rate of flood mitigation zone (100 Gigalitres per day)

Table 15-36. Project change in flood levels at river cross sections

Cross section name (see Figure 15-57 to Figure 15-91)		Flood event (1 in x chance in a year): change in level (m)						
		5 (metres)	10 (metres)	20 (metres)	100 (metres)	200 (metres)	500 (metres)	PMF (metres)
1	JUNCTION3	-6.7	-9.2	-11.3	-7.3	-5.7	-4.1	-5.5
2	BLAXCROSS	-0.1	-0.1	-0.5	-2.6	-2.9	-2.8	-4.6
3	F4BRIDGE	-2.6	-3.9	-5.2	-3.7	-2.7	-1.2	-1.6
4	BONNIEVALE	-3.8	-5.3	-6.6	-4.2	-2.8	-1.6	-2.2
5	MILLDAM1	-3.5	-4.6	-5.6	-3.3	-2.6	-2.2	-2.5
6	YMUNDI1	-3.1	-4.0	-4.6	-2.5	-2.1	-2.1	-1.9
7	NORTHRICH1	-2.9	-3.6	-4.0	-2.6	-2.5	-2.3	-2.0
8	LDERRY	-0.8	-2.3	-3.2	-3.7	-3.1	-2.3	-2.0
9	RICHWALK	-2.1	-2.9	-3.4	-3.7	-3.1	-2.4	-2.0
10	POWERLINE	-2.2	-2.9	-3.4	-3.7	-3.1	-2.4	-2.0
11	WINDSORBR	-2.4	-3.0	-3.4	-3.7	-3.1	-2.4	-2.0
12	HALFMOON	-0.5	-0.9	-1.3	-1.2	-1.2	-1.3	-1.2
13	PUMPKINPT	0.0	0.0	0.0	-0.2	-0.3	-0.4	-0.6
14	PEAT1	0.0	0.0	0.0	0.0	0.0	0.0	0.0

15.14.2.1 Downstream: 1 in 5 chance in a year

Figure 15-57. Downstream flood extent: 1 in 5 chance in a year event



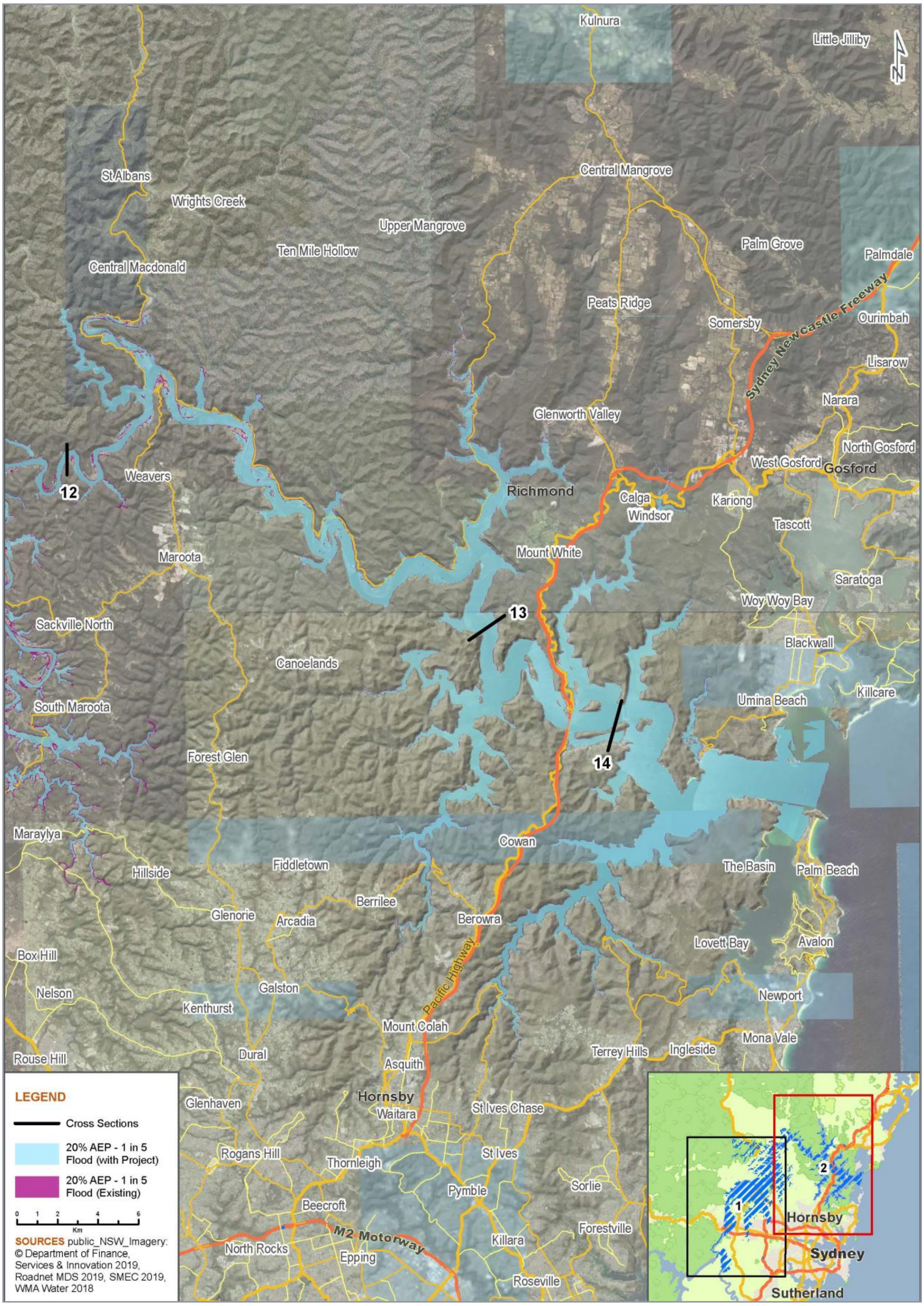

Kulnura
Little Jilliby
St Albans
Wrights Creek
Central Mangrove
Upper Mangrove
Ten Mile Hollow
Palm Grove
Palmdale
Central Macdonald
Peats Ridge
Somersby
Ourimbah
Sydney Newcastle Freeway
Lisarow
Narara
Glenworth Valley
North Gosford
West Gosford
Gosford
12
Weavers
Richmond
Calga
Windsor
Kariong
Tascott
Maroota
Mount White
Saratoga
Woy Woy Bay
13
Sackville North
Blackwall
Canoelands
Killcare
Umina Beach
South Maroota
14
Forest Glen
Cowan
Maraylya
Fiddletown
The Basin
Palm Beach
Hillside
Berrilee
Glenorie
Arcadia
Berowra
Lovett Bay
Avalon
Box Hill
Pacific Highway
Galston
Newport
Nelson
Kenthurst
Mount Colah
Mona Vale
Rouse Hill
Dural
Terrey Hills
Ingleside
Asquith
LEGEND
Cross Sections
20% AEP - 1 in 5 Flood (with Project)
20% AEP - 1 in 5 Flood (Existing)
0 1 2 4 6
Km
SOURCES public_NSW_Imagery: © Department of Finance, Services & Innovation 2019, Roadnet MDS 2019, SMEC 2019, WMA Water 2018
Glenhaven
Hornsby
Waitara
St Ives Chase
Rogans Hill
Thornleigh
St Ives
Pymble
Sorlie
Beecroft
Forestville
M2 Motorway
North Rocks
Epping
Killara
Roseville
1
2
Hornsby
Sydney
Sutherland

Figure 15-58. Wallacia: 1 in 5 chance in a year event

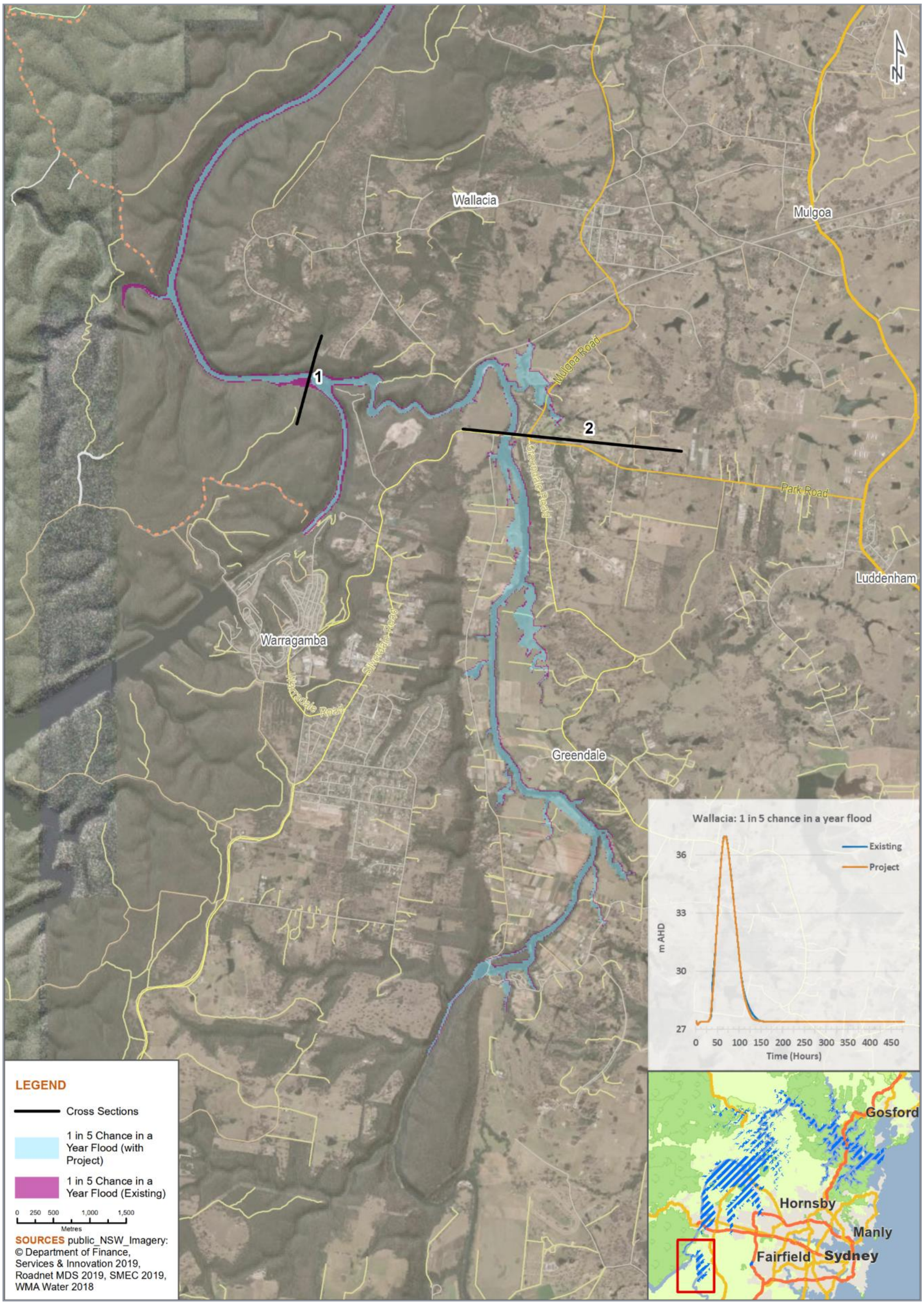


Figure 15-59. Penrith: 1 in 5 chance in a year event

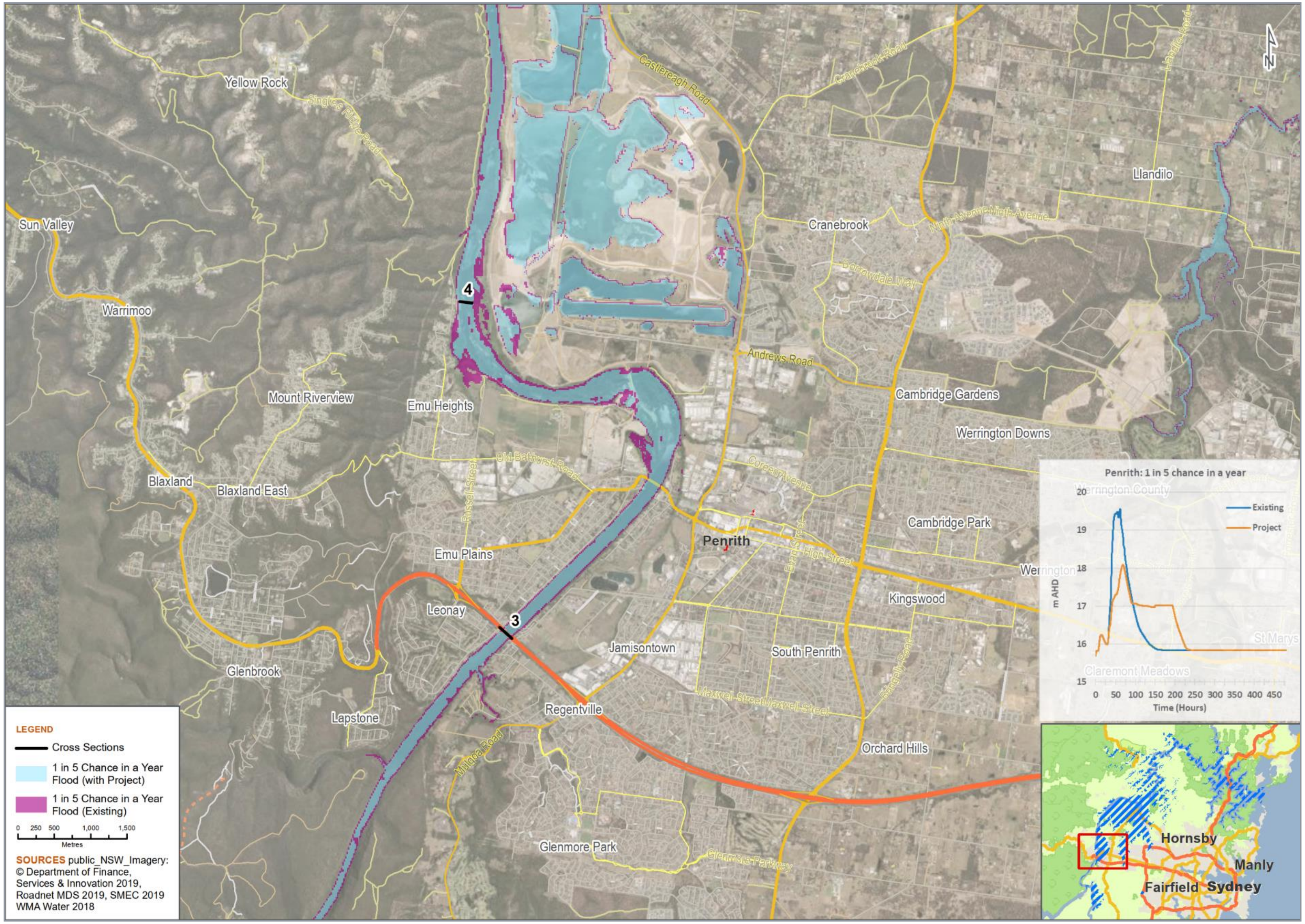


Figure 15-60. Richmond/Windsor: 1 in 5 chance in a year event

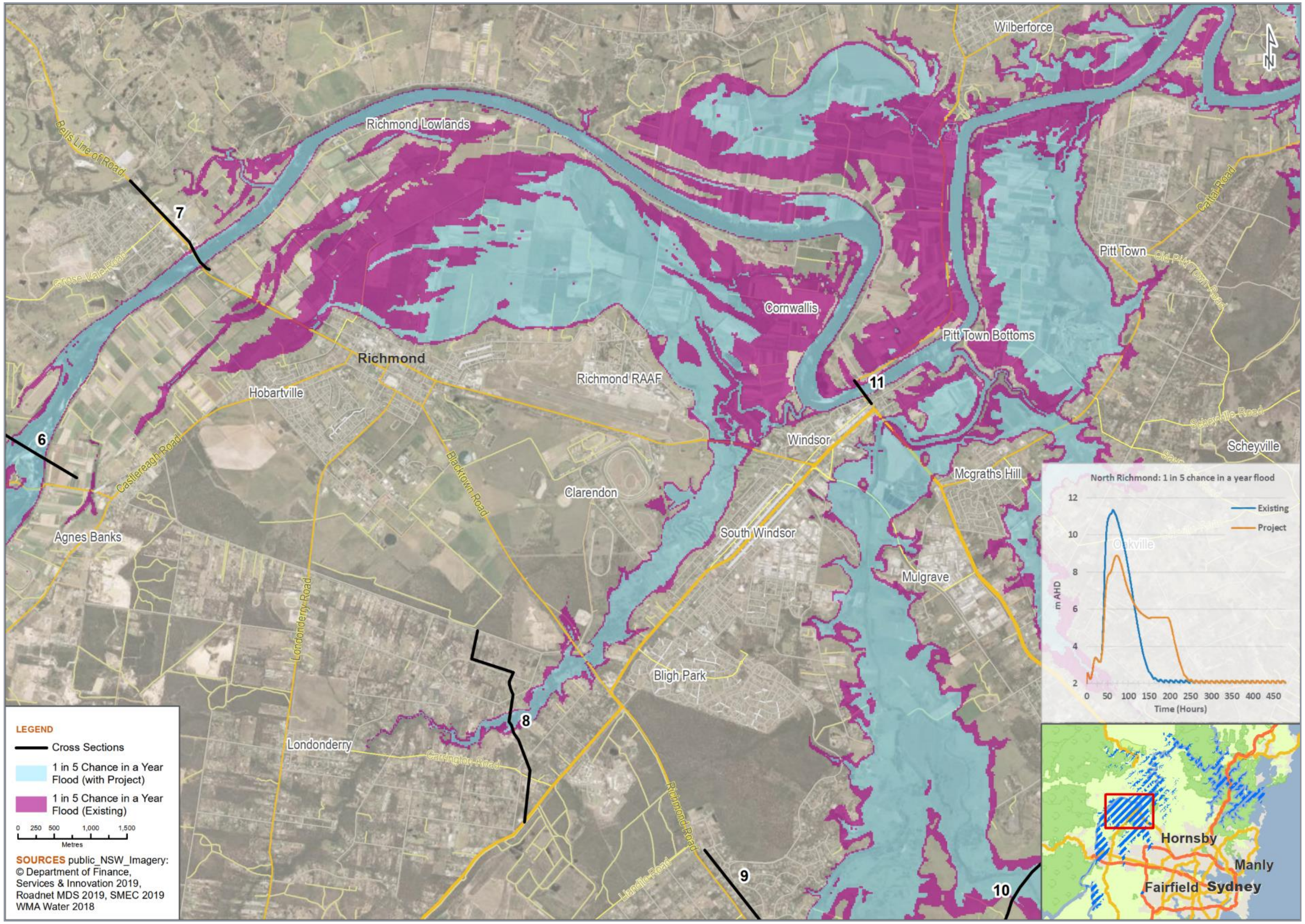
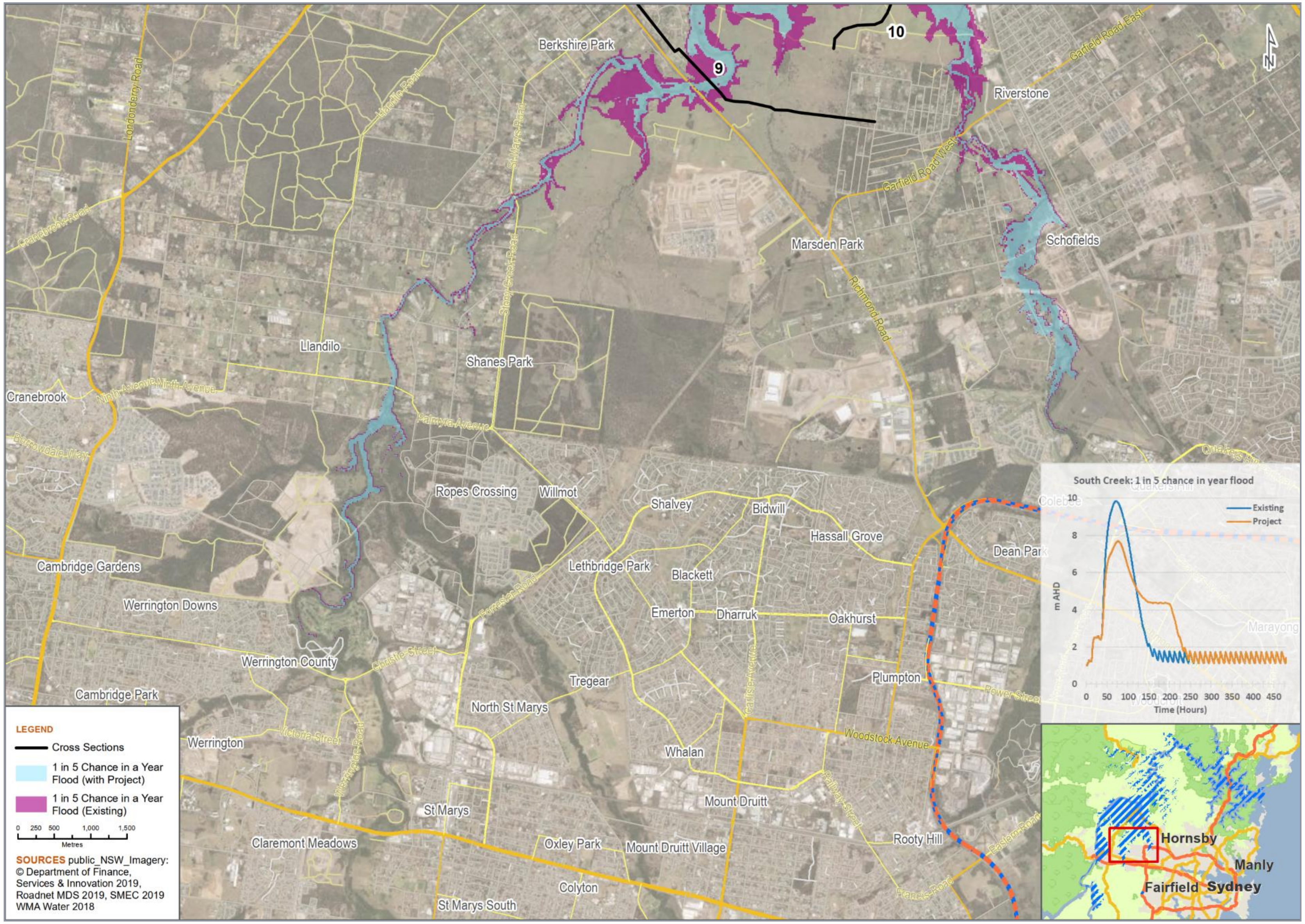
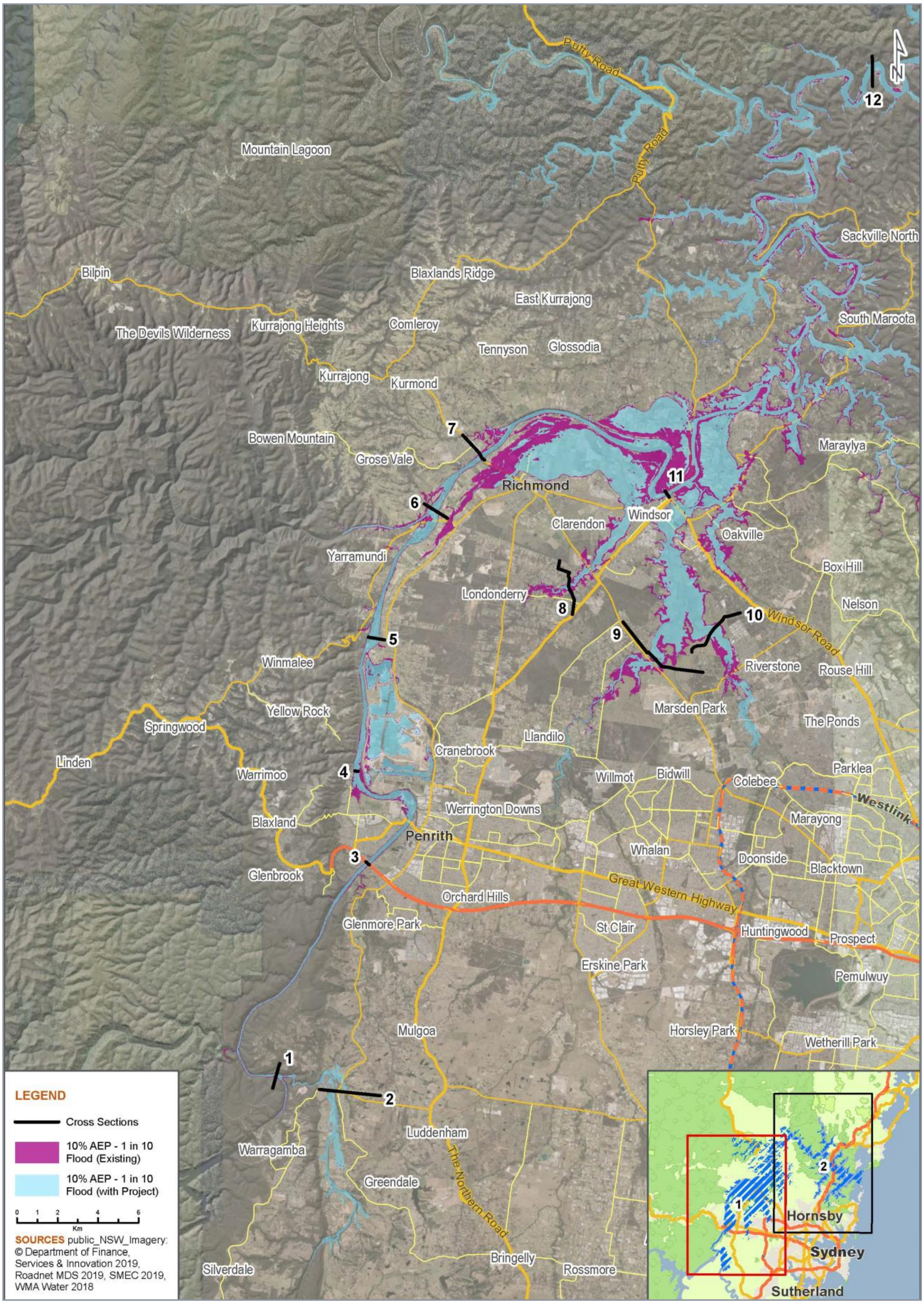


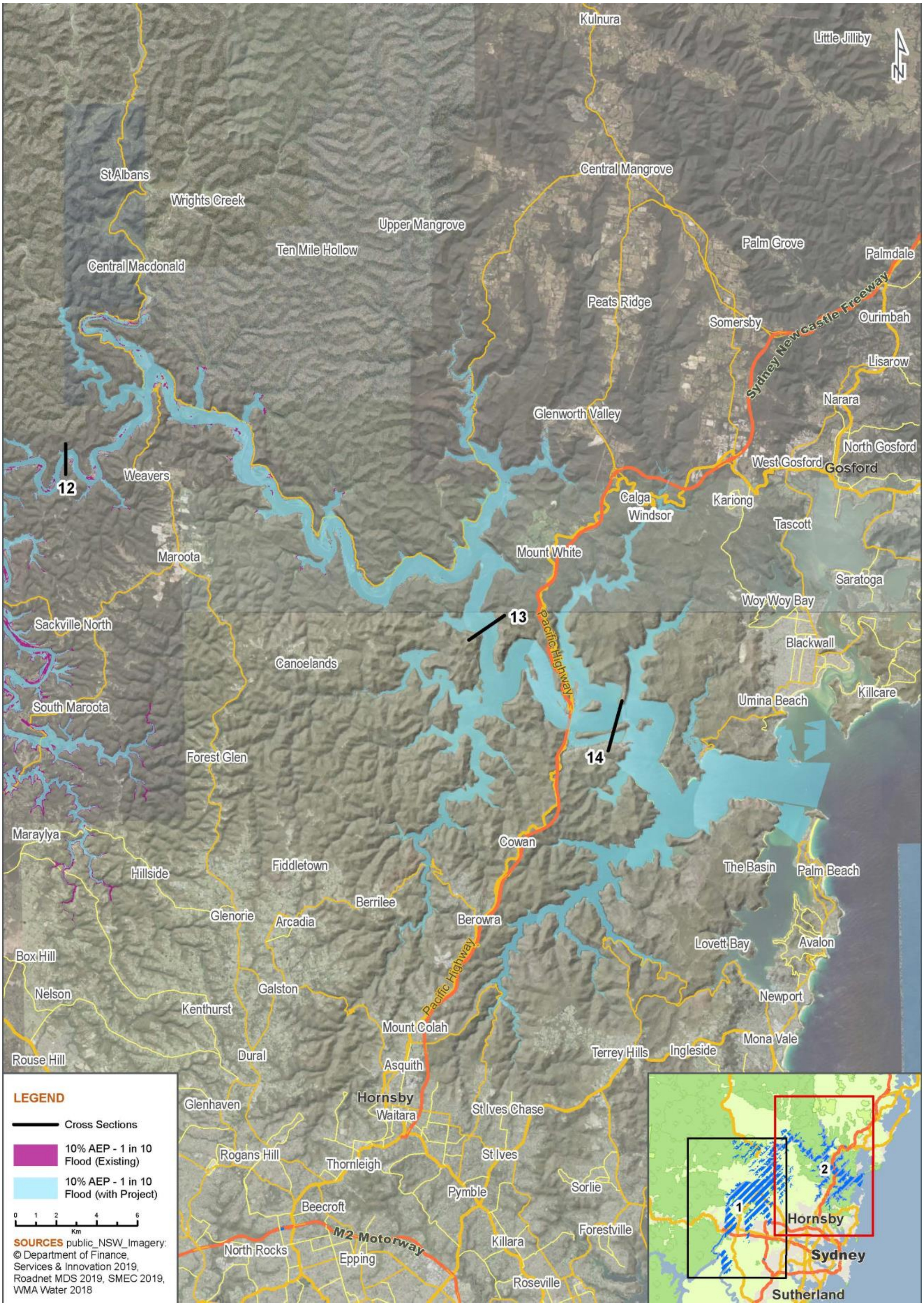
Figure 15-61. South Creek: 1 in 5 chance in a year event



15.14.2.2 Downstream: 1 in 10 year chance in a year

Figure 15-62. Downstream flood extent: 1 in 10 chance in a year event




Kulnura
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Peats Ridge
Sydney Newcastle Freeway
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Pacific Highway
Blackwall
Canoelands
Killcare
Umina Beach
South Maroota
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Forest Glen
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Palm Beach
Hillside
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Kenthurst
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Mona Vale
Rouse Hill
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Terrey Hills
Ingleside
Asquith
Hornsby
Glenhaven
Waitara
St Ives Chase
Rogans Hill
Thornleigh
St Ives
Sorlie
Pymble
Beecroft
M2 Motorway
Forestville
North Rocks
Epping
Killara
Roseville
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Sydney
Sutherland
LEGEND
Cross Sections
10% AEP - 1 in 10 Flood (Existing)
10% AEP - 1 in 10 Flood (with Project)
0 1 2 4 6
Km
SOURCES public_NSW_Imagery: © Department of Finance, Services & Innovation 2019, Roadnet MDS 2019, SMEC 2019, WMA Water 2018

Figure 15-63. Wallacia: 1 in 10 chance in a year event

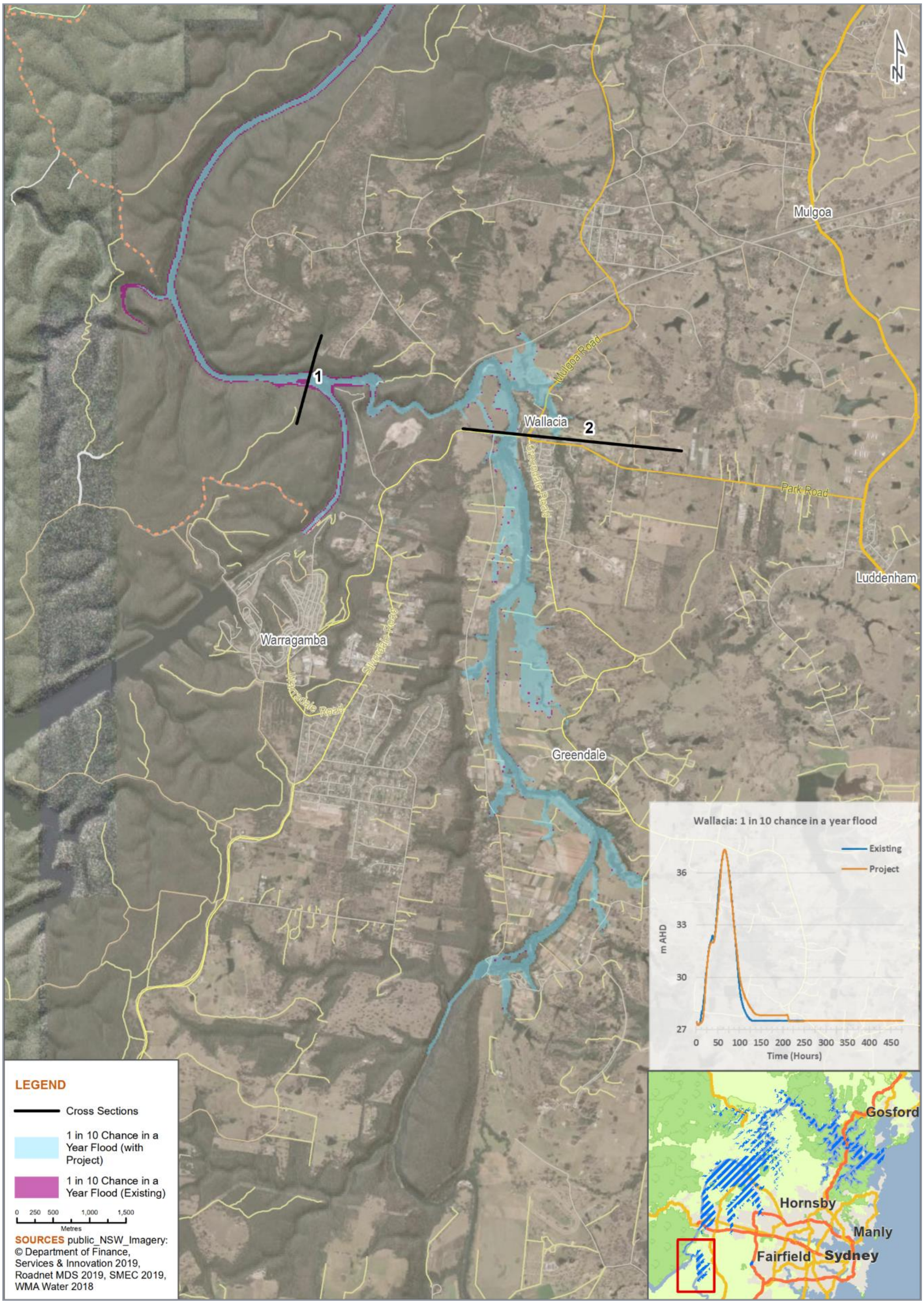


Figure 15-64. Penrith: 1 in 10 chance in a year event

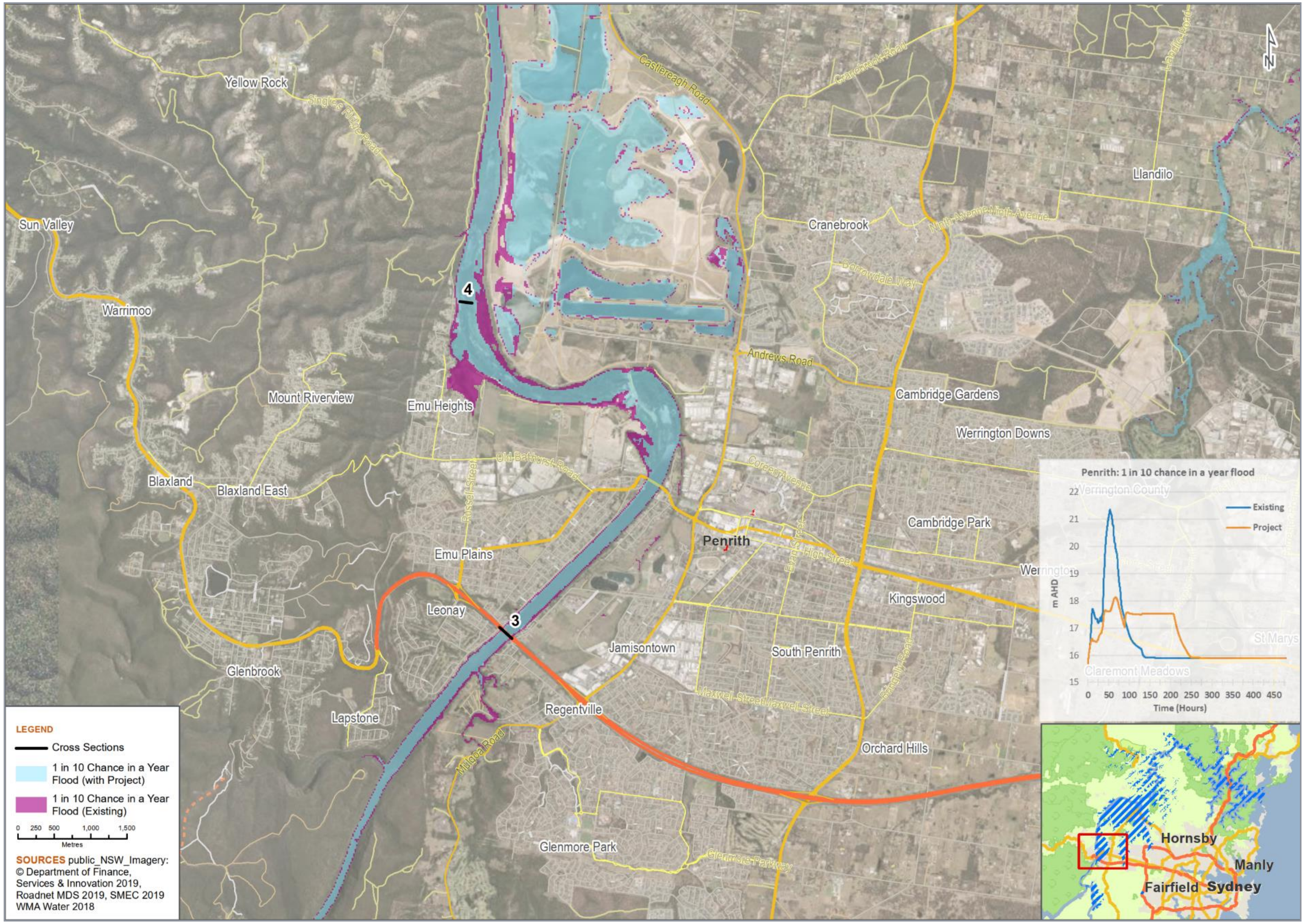


Figure 15-65. Richmond/Windsor: 1 in 10 chance in a year event

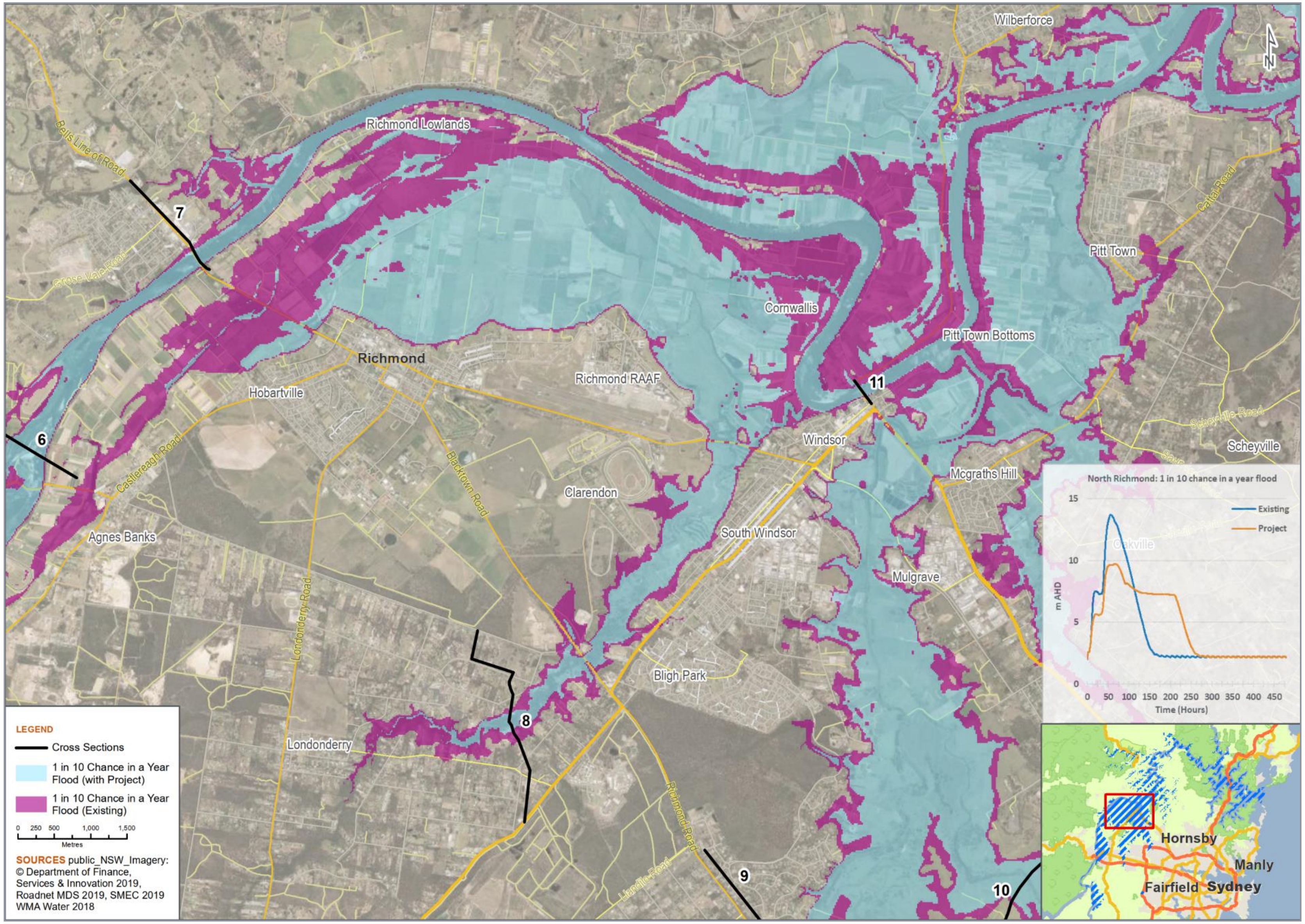
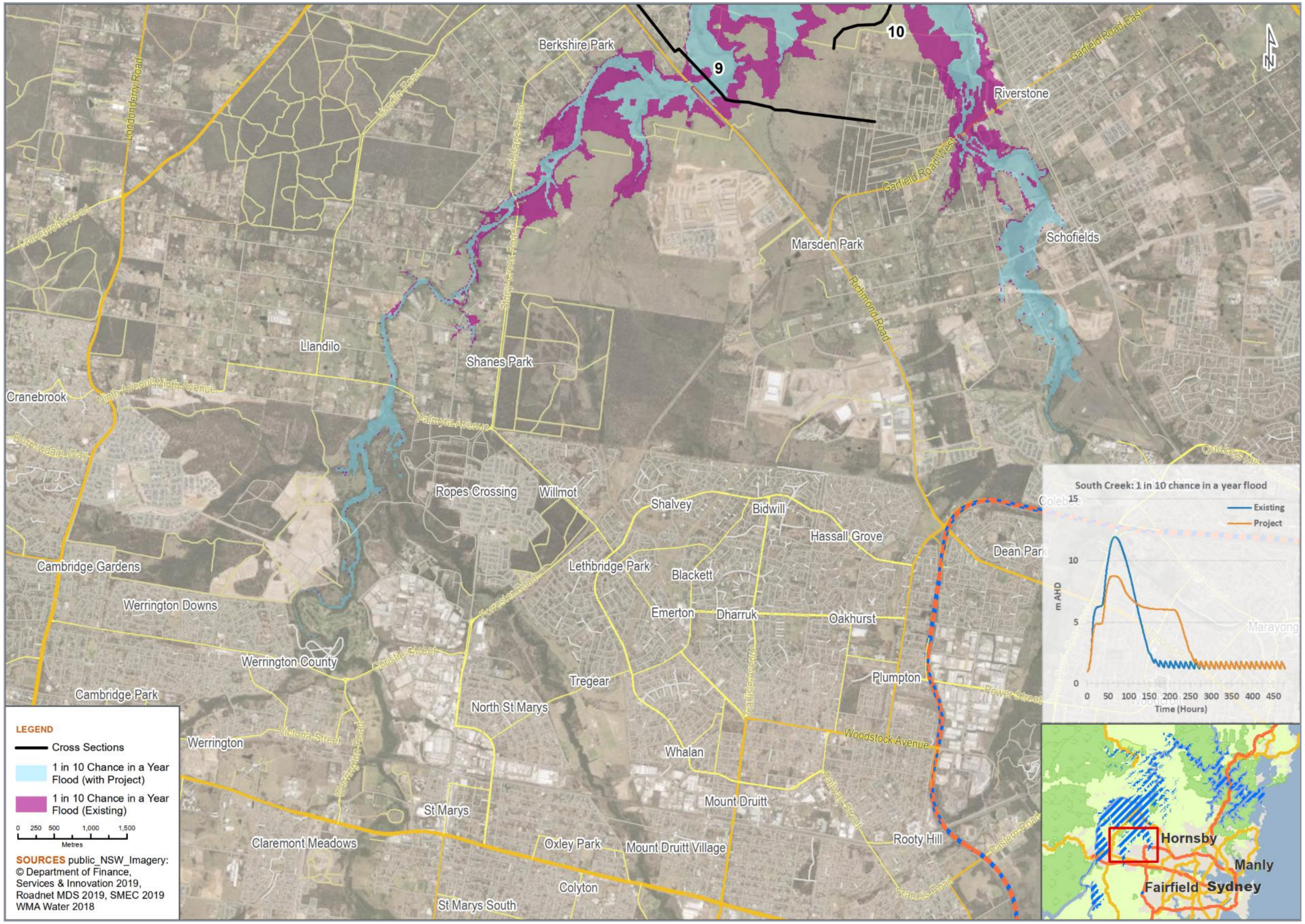
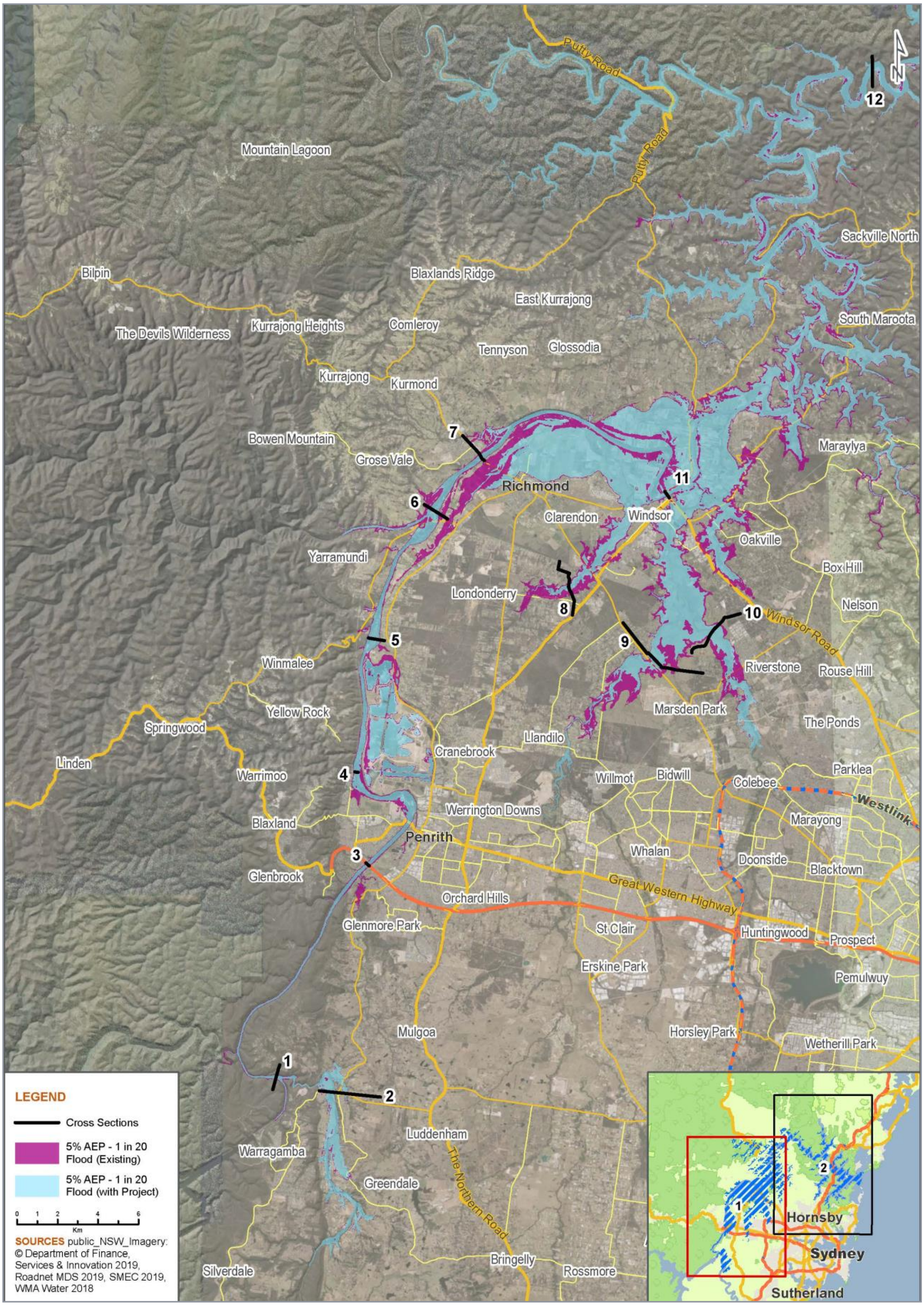


Figure 15-66. South Creek: 1 in 10 chance in a year event



15.14.2.3 Downstream: 1 in 20 chance in a year

Figure 15-67. Downstream flood extent: 1 in 20 chance in a year event



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Blackwall
Pacific Highway
Canoelands
Killcare
Umina Beach
South Maroota
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Arcadia
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Lovett Bay
Avalon
Box Hill
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Mount Colah
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Terrey Hills
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Rouse Hill
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Glenhaven
St Ives Chase
Waitara
Rogans Hill
Thornleigh
St Ives
Sorlie
Pymble
Beecroft
Forestville
M2 Motorway
North Rocks
Killara
Epping
Roseville
LEGEND
Cross Sections
5% AEP - 1 in 20 Flood (Existing)
5% AEP - 1 in 20 Flood (with Project)
0 1 2 4 6
Km
SOURCES public_NSW_Imagery: © Department of Finance, Services & Innovation 2019, Roadnet MDS 2019, SMEC 2019, WMA Water 2018
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Sydney
Sutherland

Figure 15-68. Wallacia: 1 in 20 chance in a year event

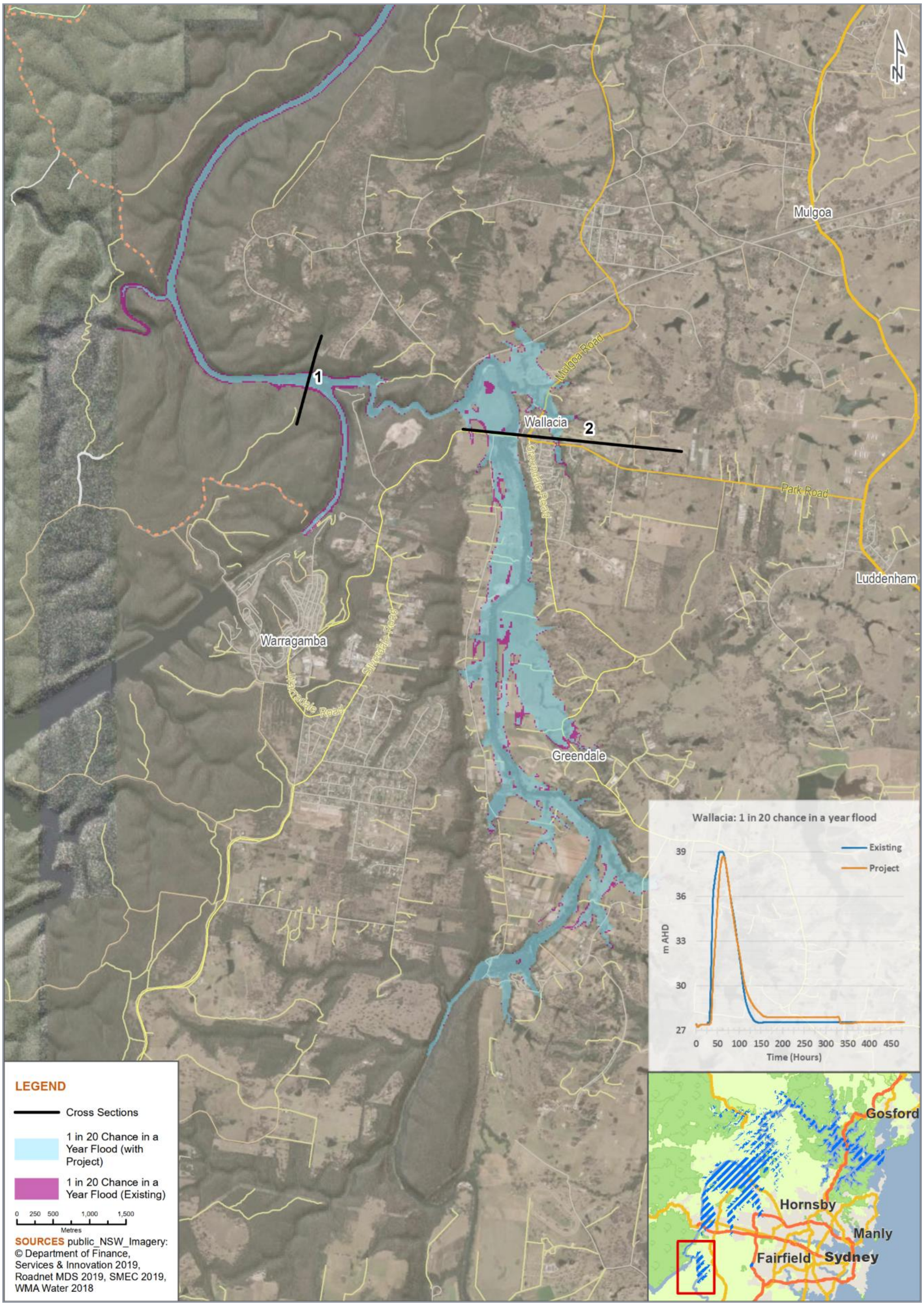


Figure 15-69. Penrith: 1 in 20 chance in a year event

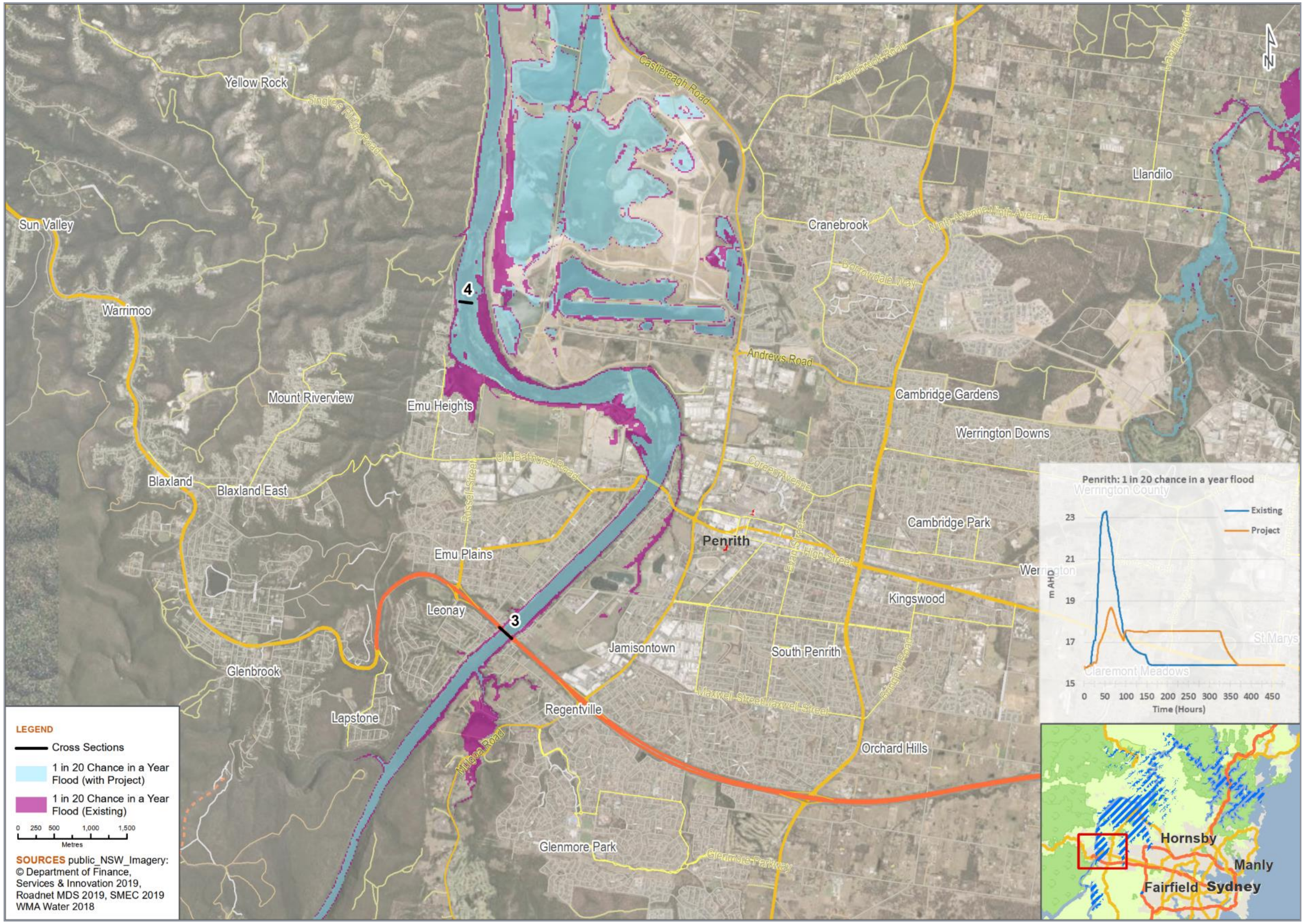


Figure 15-70. Richmond/Windsor: 1 in 20 chance in a year event

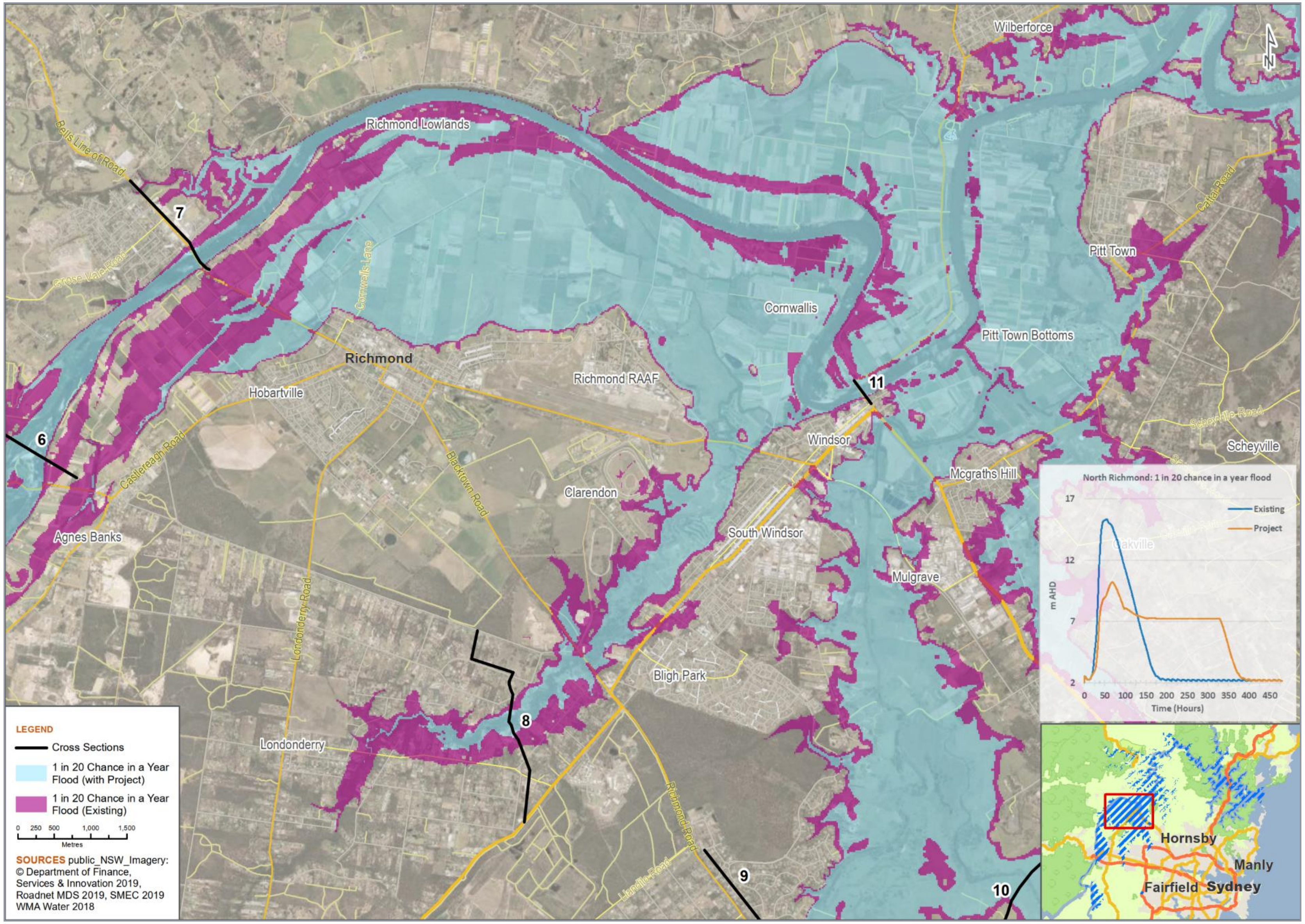
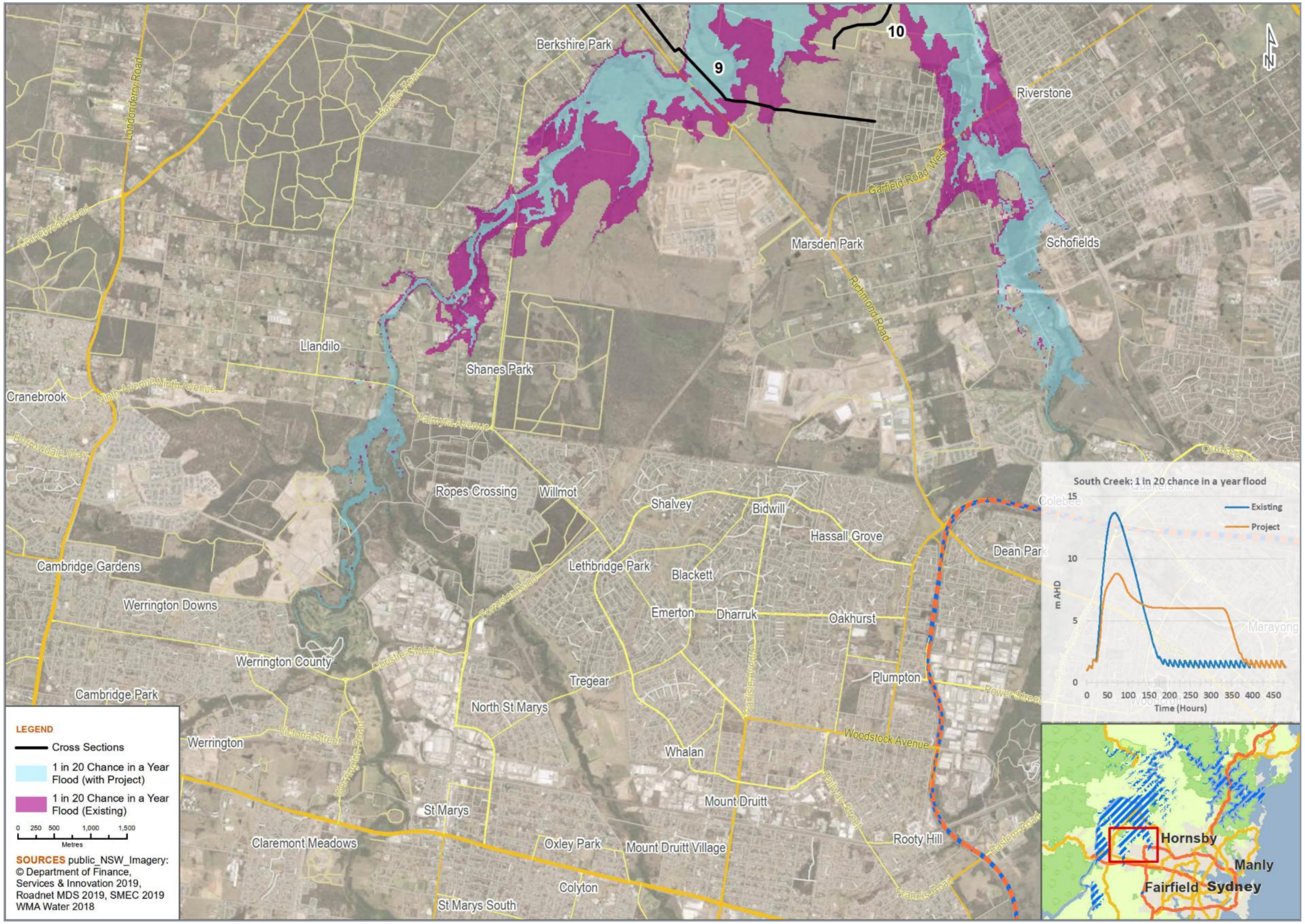
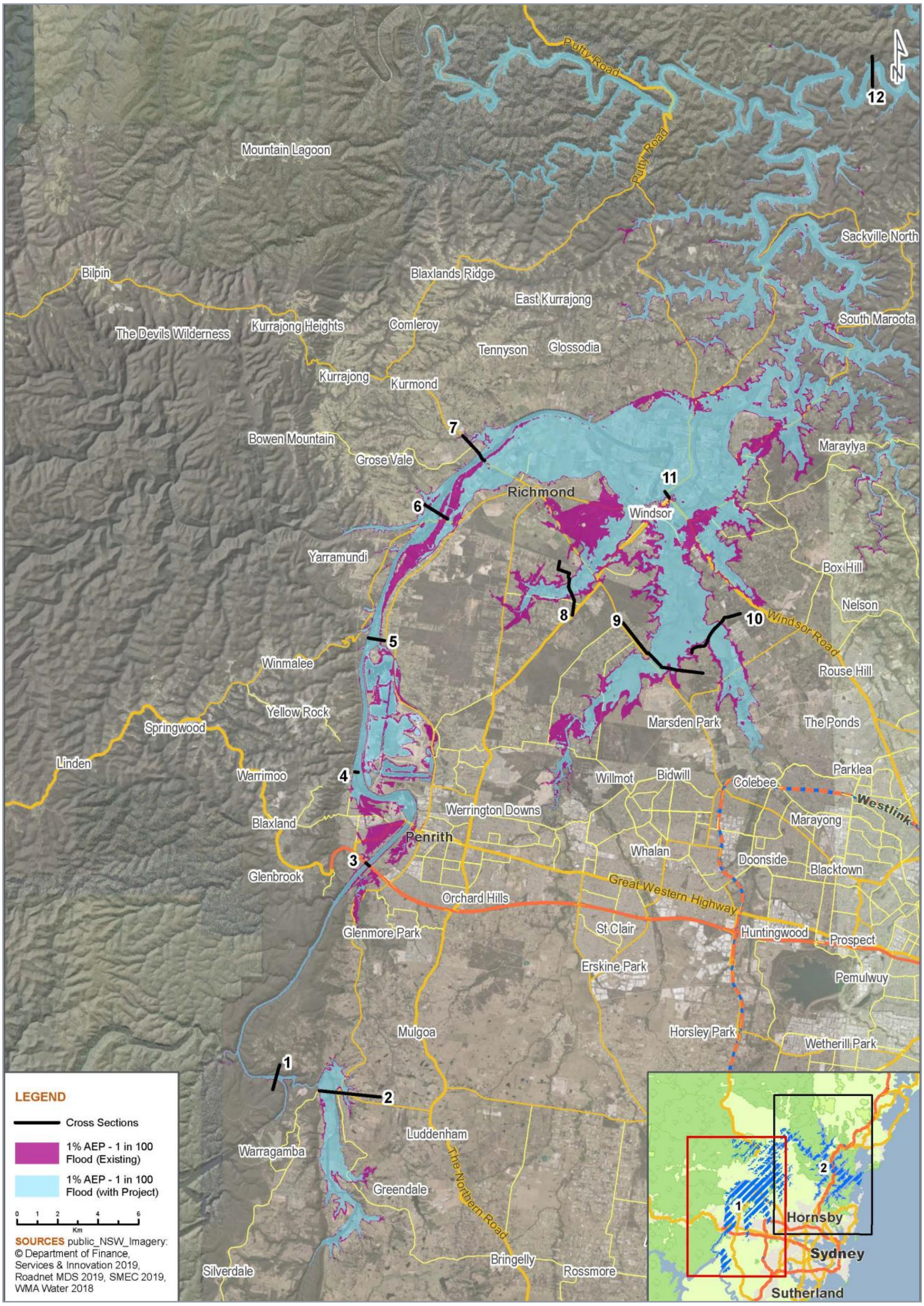


Figure 15-71. South Creek: 1 in 20 chance in a year event



15.14.2.4 Downstream: 1 in 100 chance in a year

Figure 15-72. Downstream flood extent: 1 in 100 chance in a year event




Kulnura
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Woy Woy Bay
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Pacific Highway
Blackwall
Canoelands
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Arcadia
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Lovett Bay
Avalon
Box Hill
Nelson
Galston
Newport
Kenthurst
Mount Colah
Mona Vale
Rouse Hill
Dural
Terrey Hills
Ingleside
Asquith
LEGEND
Cross Sections
1% AEP - 1 in 100 Flood (Existing)
1% AEP - 1 in 100 Flood (with Project)
0 1 2 4 6
Km
SOURCES public_NSW_Imagery: © Department of Finance, Services & Innovation 2019, Roadnet MDS 2019, SMEC 2019, WMA Water 2018
Glenhaven
Hornsby
Waitara
St Ives Chase
Rogans Hill
Thornleigh
St Ives
Pymble
Sorlie
Beecroft
Forestville
M2 Motorway
North Rocks
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Figure 15-73. Wallacia: 1 in 100 chance in a year event

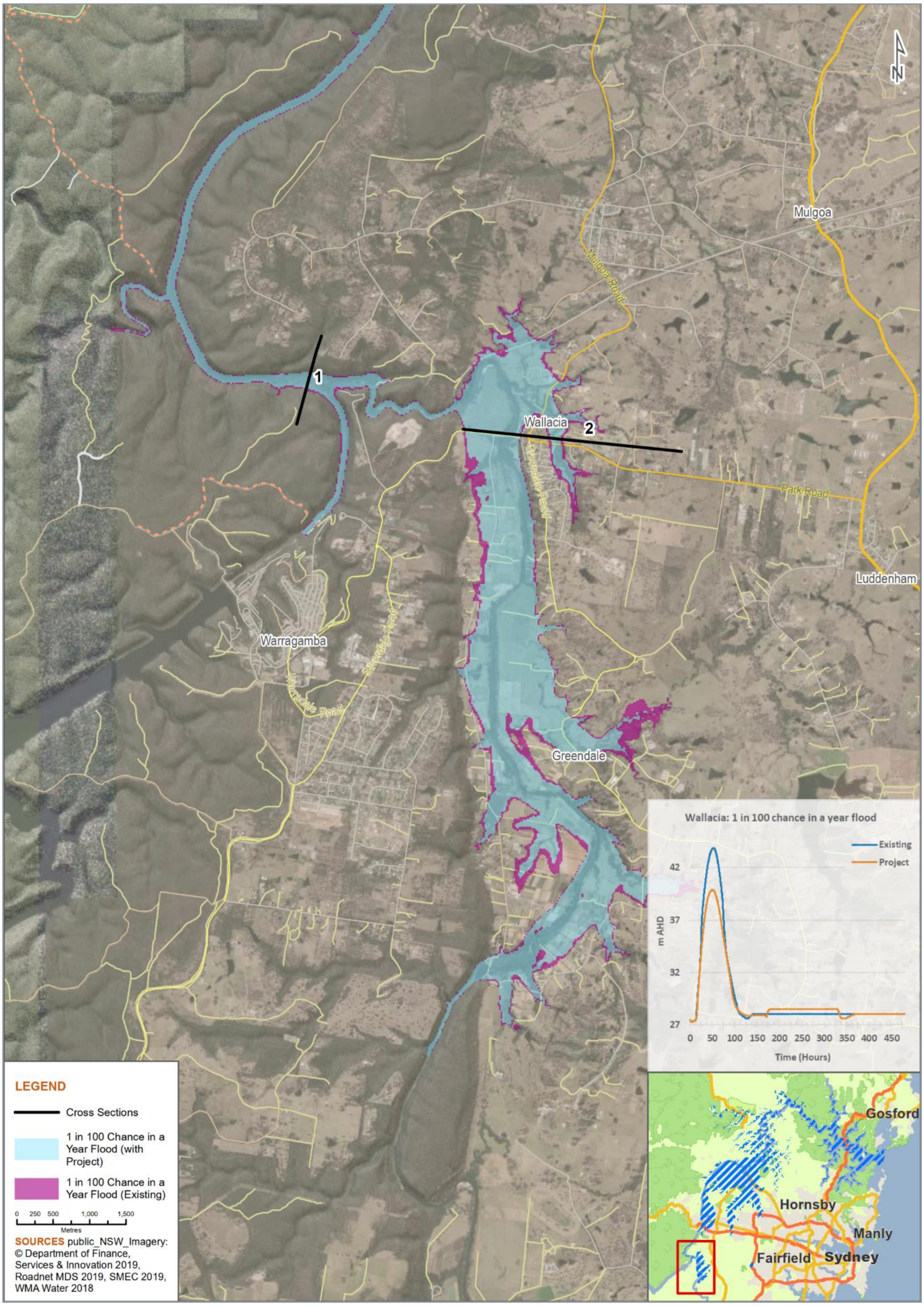


Figure 15-74. Penrith: 1 in 100 chance in a year event

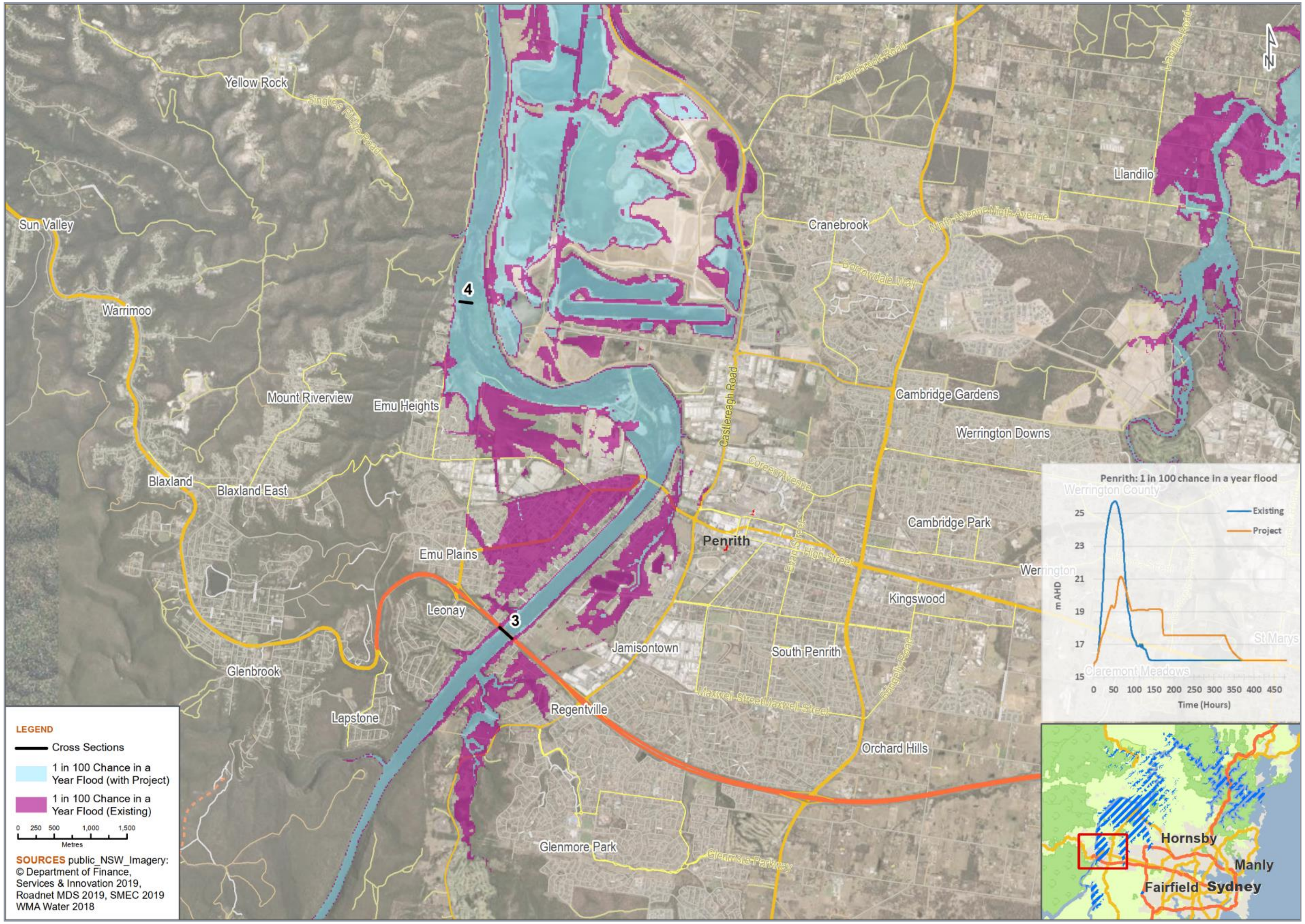


Figure 15-75. Richmond/Windsor: 1 in 100 chance in a year event

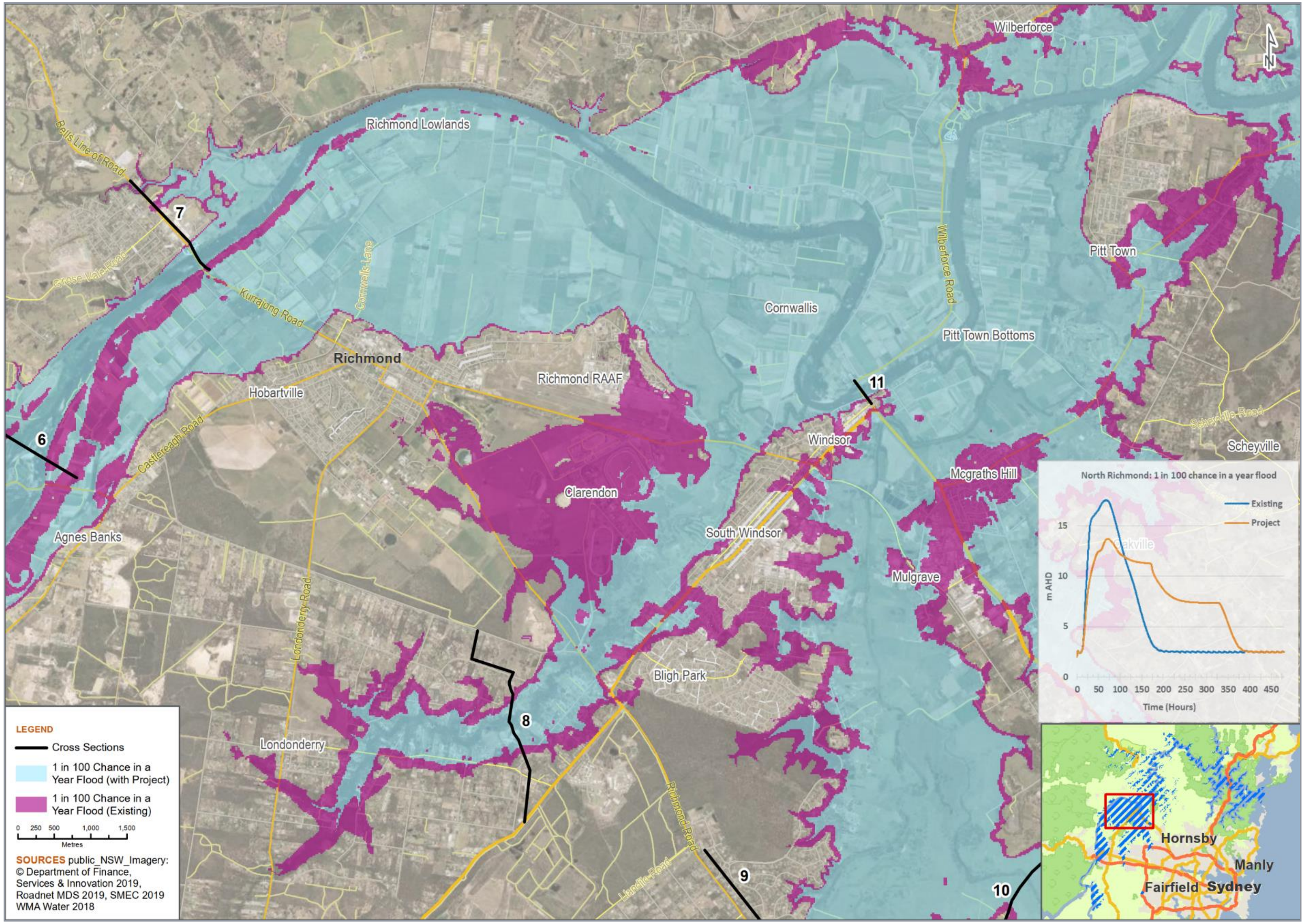
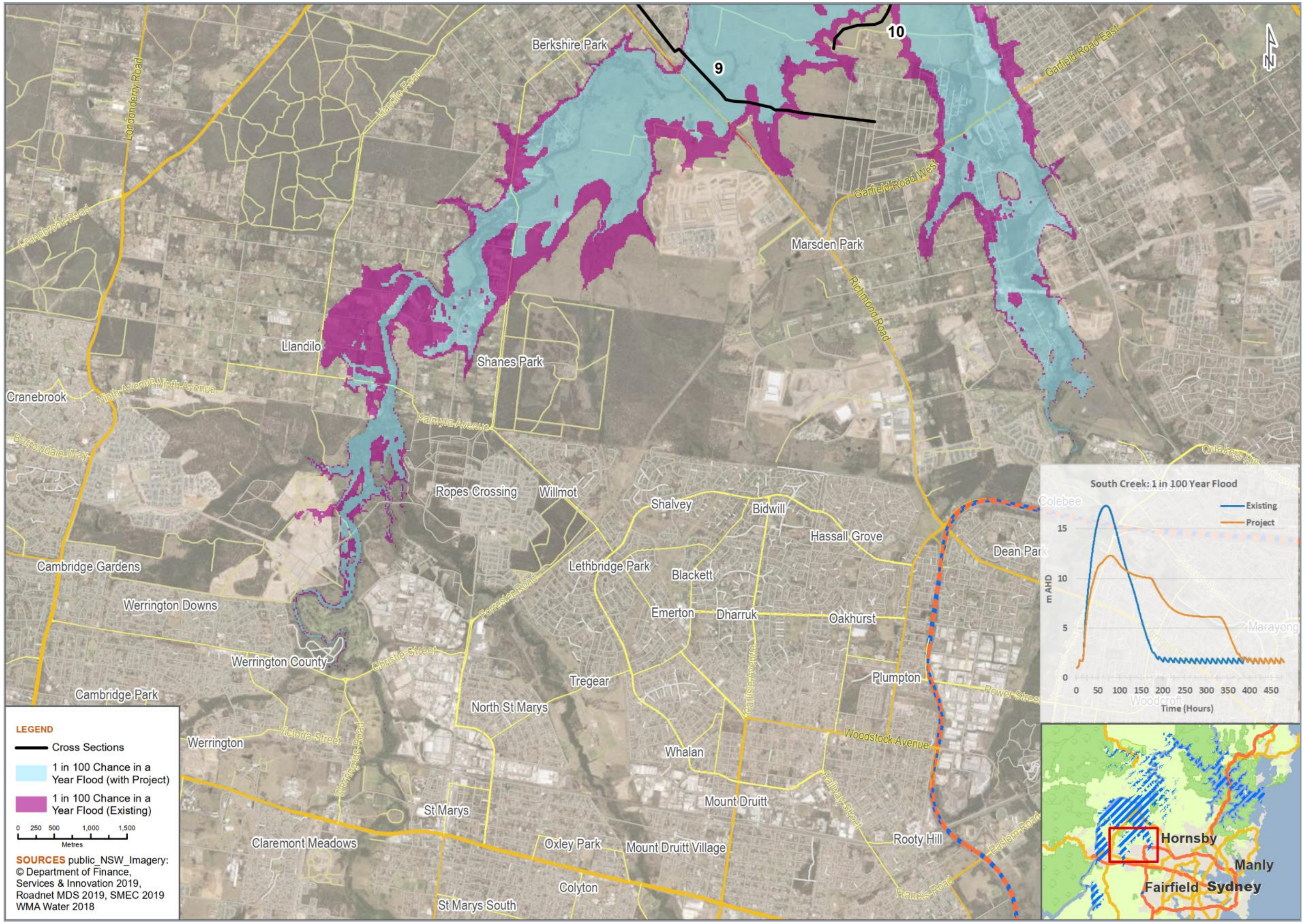
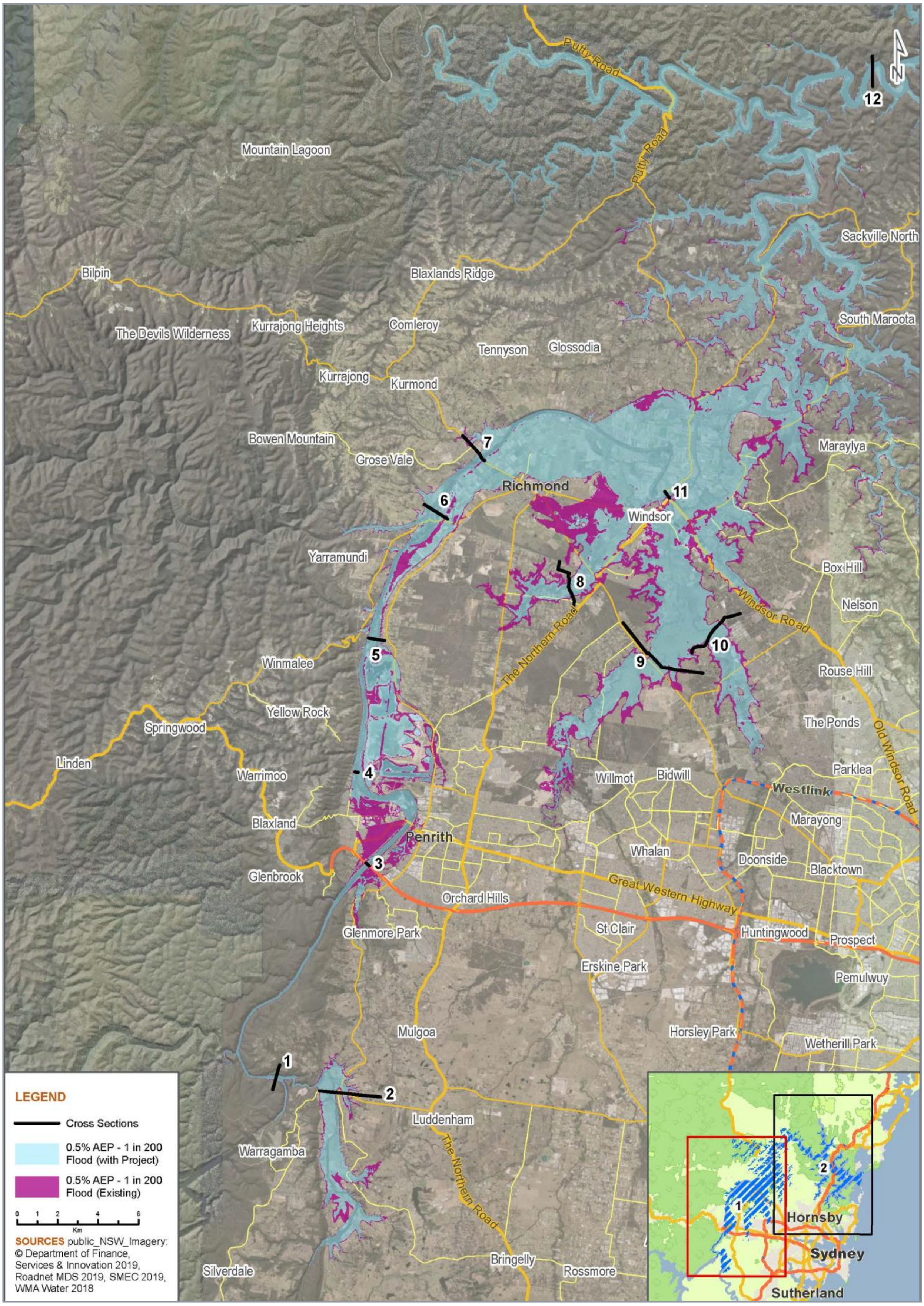


Figure 15-76. South Creek: 1 in 100 chance in a year event



15.14.2.5 Downstream: 1 in 200 chance in a year

Figure 15-77. Downstream flood extent: 1 in 200 chance in a year event




Kulnura
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Box Hill
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Newport
Kenthurst
Mount Colah
Mona Vale
Rouse Hill
Dural
Asquith
Terrey Hills
Ingleside
LEGEND
Cross Sections
0.5% AEP - 1 in 200 Flood (with Project)
0.5% AEP - 1 in 200 Flood (Existing)
0 1 2 4 6
Km
SOURCES public_NSW_Imagery: © Department of Finance, Services & Innovation 2019, Roadnet MDS 2019, SMEC 2019, WMA Water 2018
Glenhaven
Hornsby
Waitara
St Ives Chase
Rogans Hill
Thornleigh
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Pymble
Sorlie
Beecroft
Forestville
M2 Motorway
North Rocks
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Sutherland

Figure 15-78. Wallacia: 1 in 200 chance in a year event

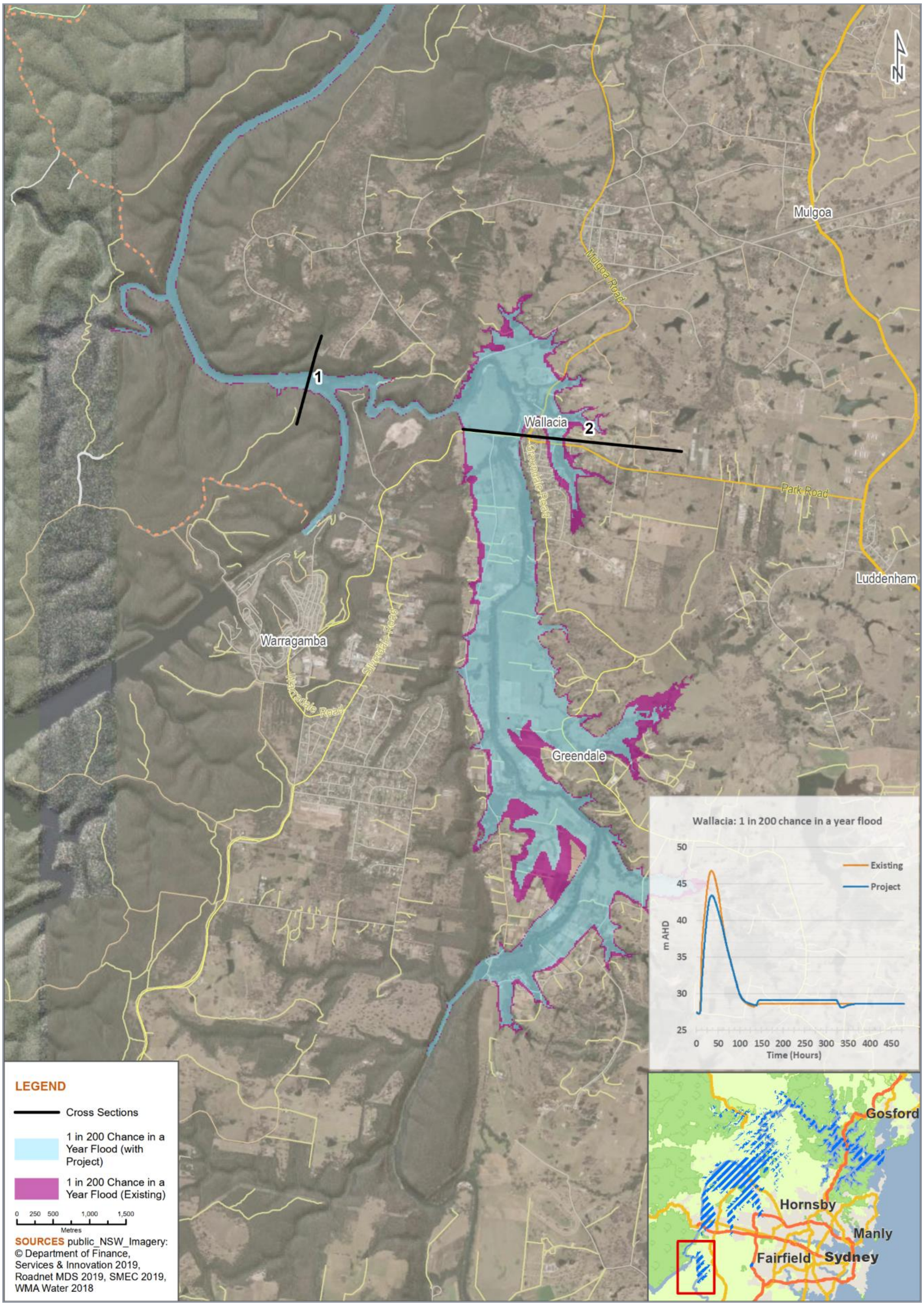


Figure 15-79. Penrith: 1 in 200 chance in a year event

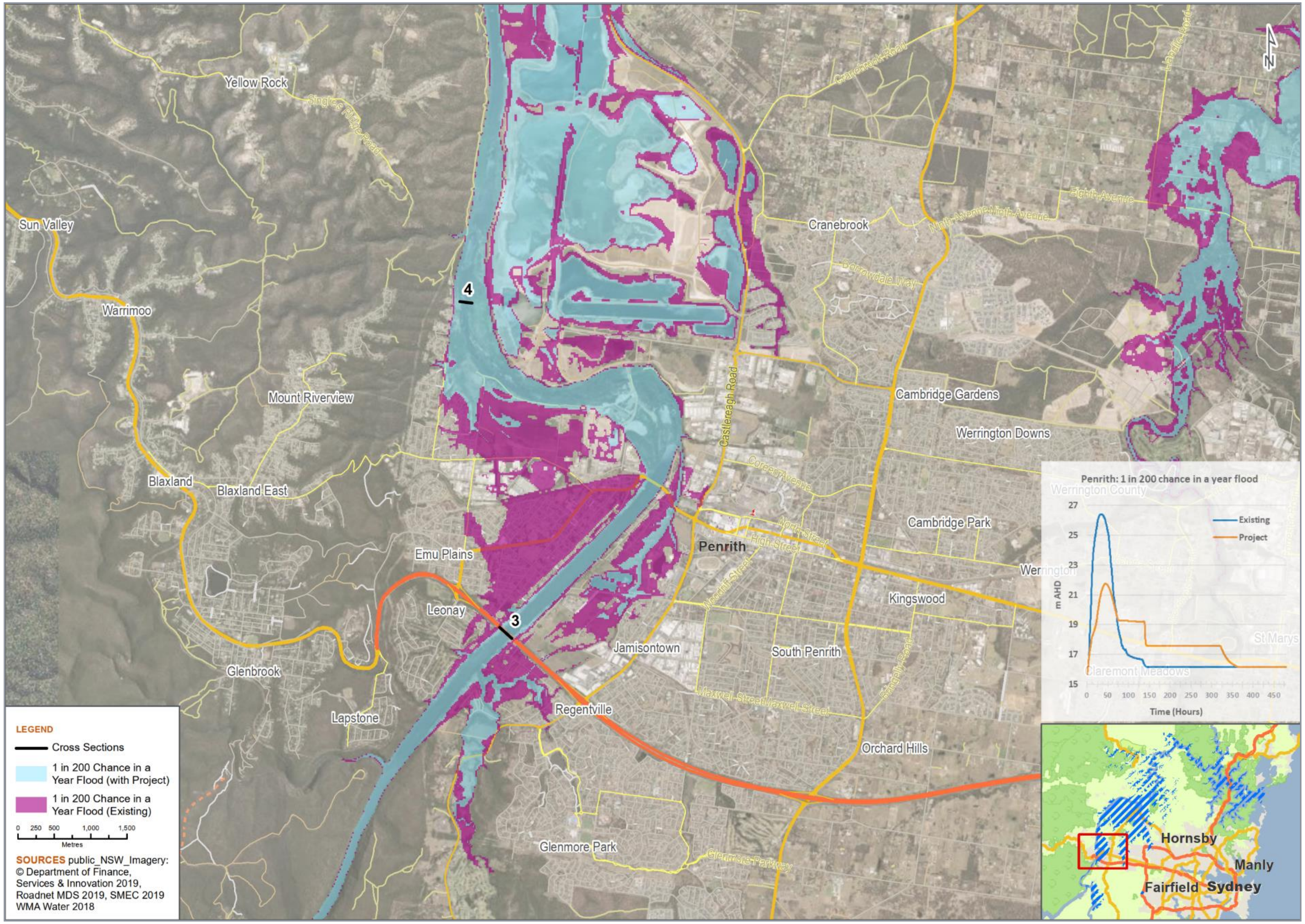


Figure 15-80. Richmond/Windsor: 1 in 200 chance in a year event

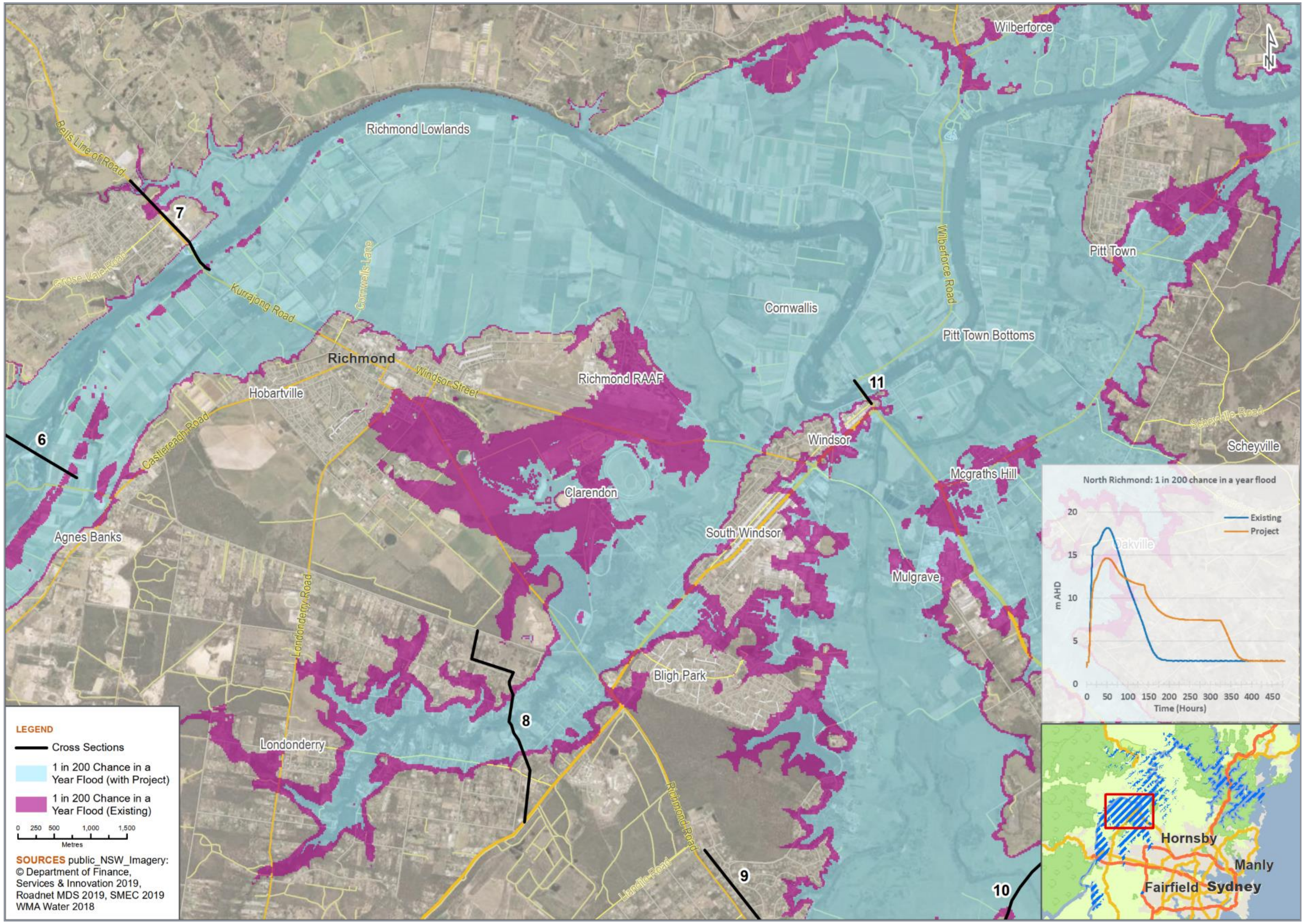
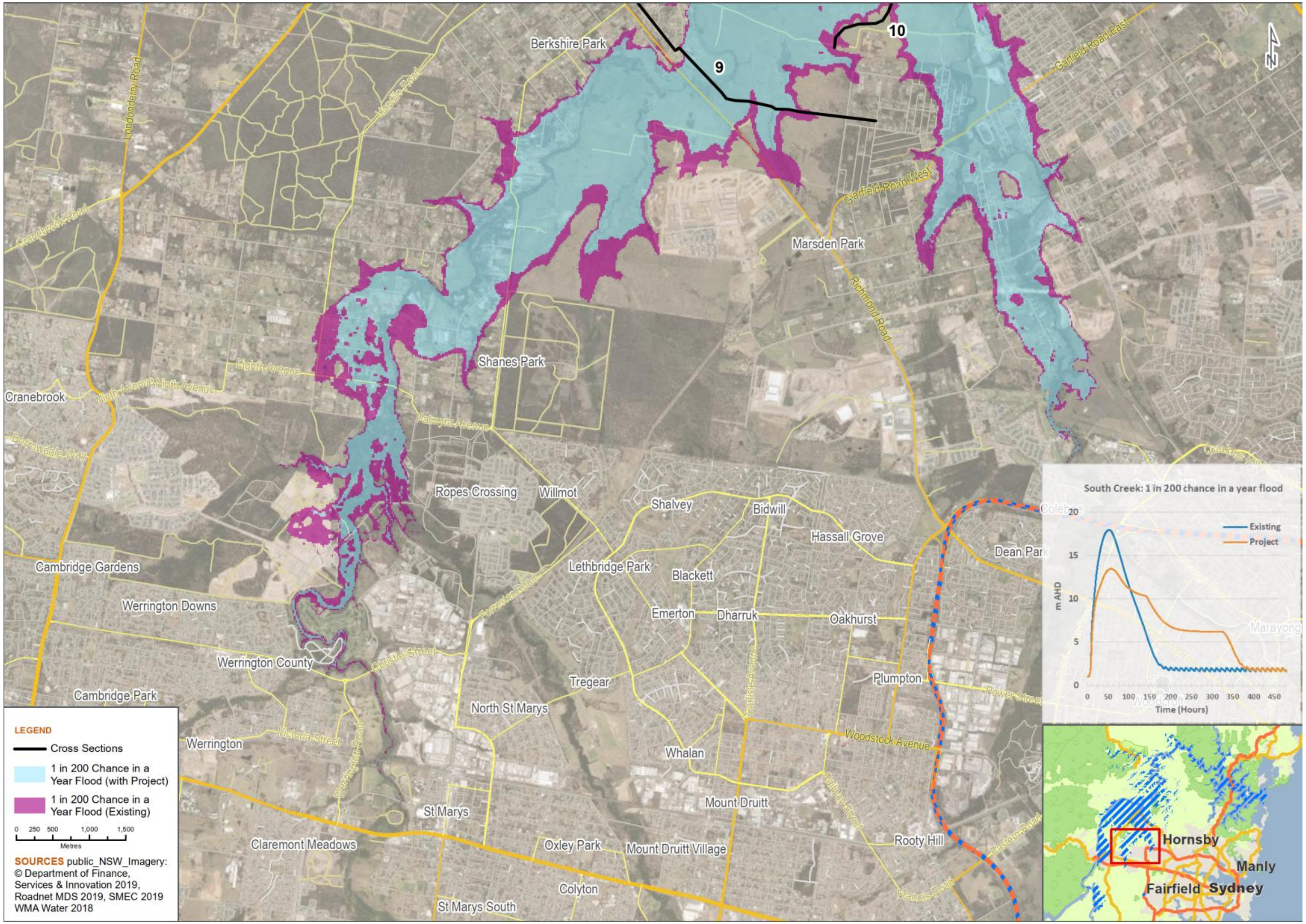
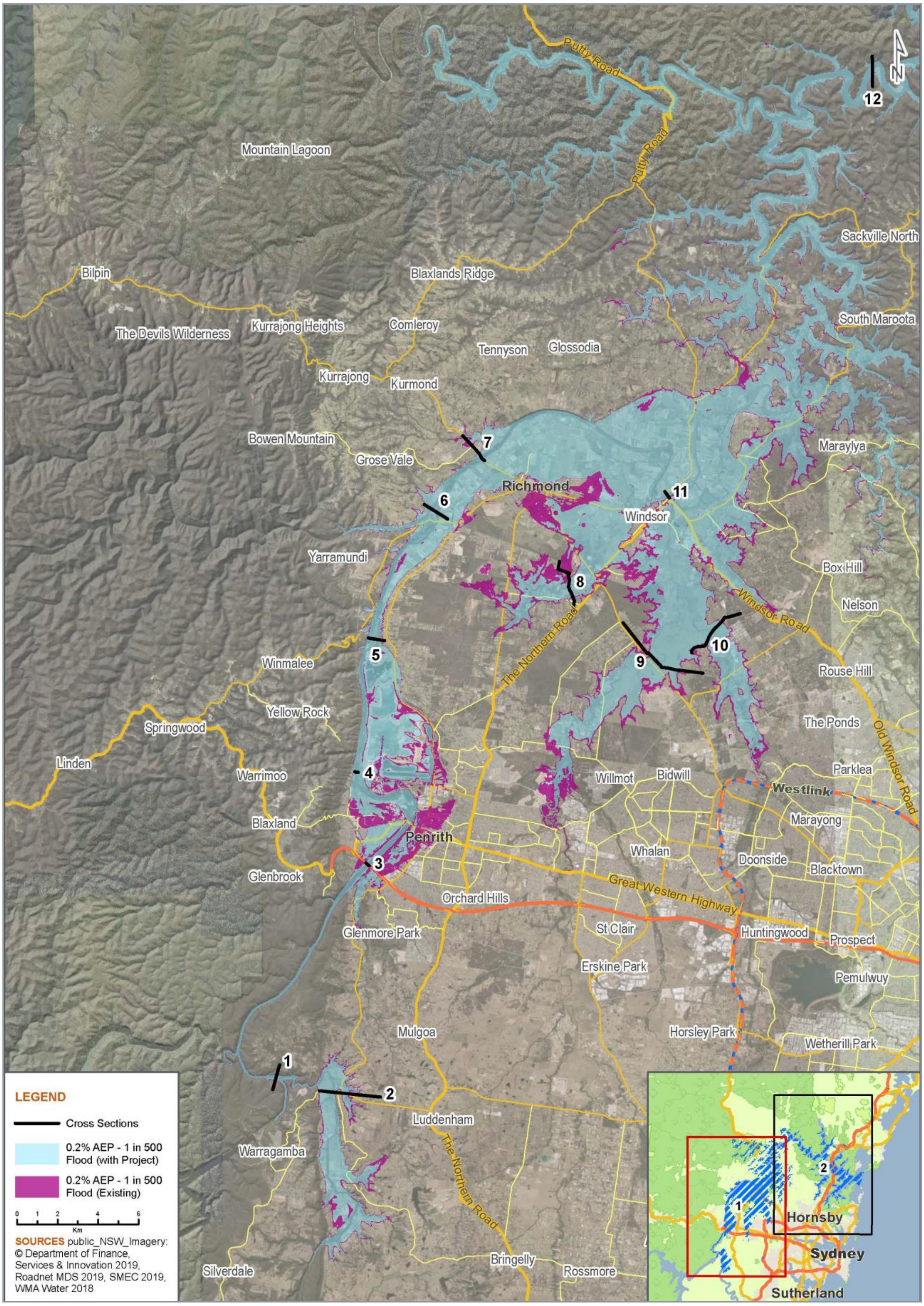


Figure 15-81. South Creek: 1 in 200 chance in a year event



15.14.2.6 Downstream: 1 in 500 chance in a year

Figure 15-82. Downstream flood extent: 1 in 500 chance in a year event



Kulnura
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Woy Woy Bay
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Sackville North
Canoelands
Killcare
Umina Beach
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Forest Glen
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Maraylya
Cowan
The Basin
Palm Beach
Hillside
Fiddletown
Glenorie
Arcadia
Berrilee
Berowra
Lovett Bay
Avalon
Box Hill
Pacific Highway
Nelson
Galston
Kenthurst
Newport
Mount Colah
Mona Vale
Rouse Hill
Dural
Terrey Hills
Ingleside
Asquith
LEGEND
Cross Sections
0.2% AEP - 1 in 500 Flood (with Project)
0.2% AEP - 1 in 500 Flood (Existing)
0 1 2 4 6
Km
SOURCES public_NSW_Imagery: © Department of Finance, Services & Innovation 2019, Roadnet MDS 2019, SMEC 2019, WMA Water 2018
Glenhaven
Hornsby
Waitara
St Ives Chase
Rogans Hill
Thornleigh
St Ives
Pymble
Sorlie
Beecroft
M2 Motorway
Forestville
North Rocks
Epping
Killara
Roseville
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Hornsby
Sydney
Sutherland

Figure 15-83. Wallacia: 1 in 500 chance in a year event

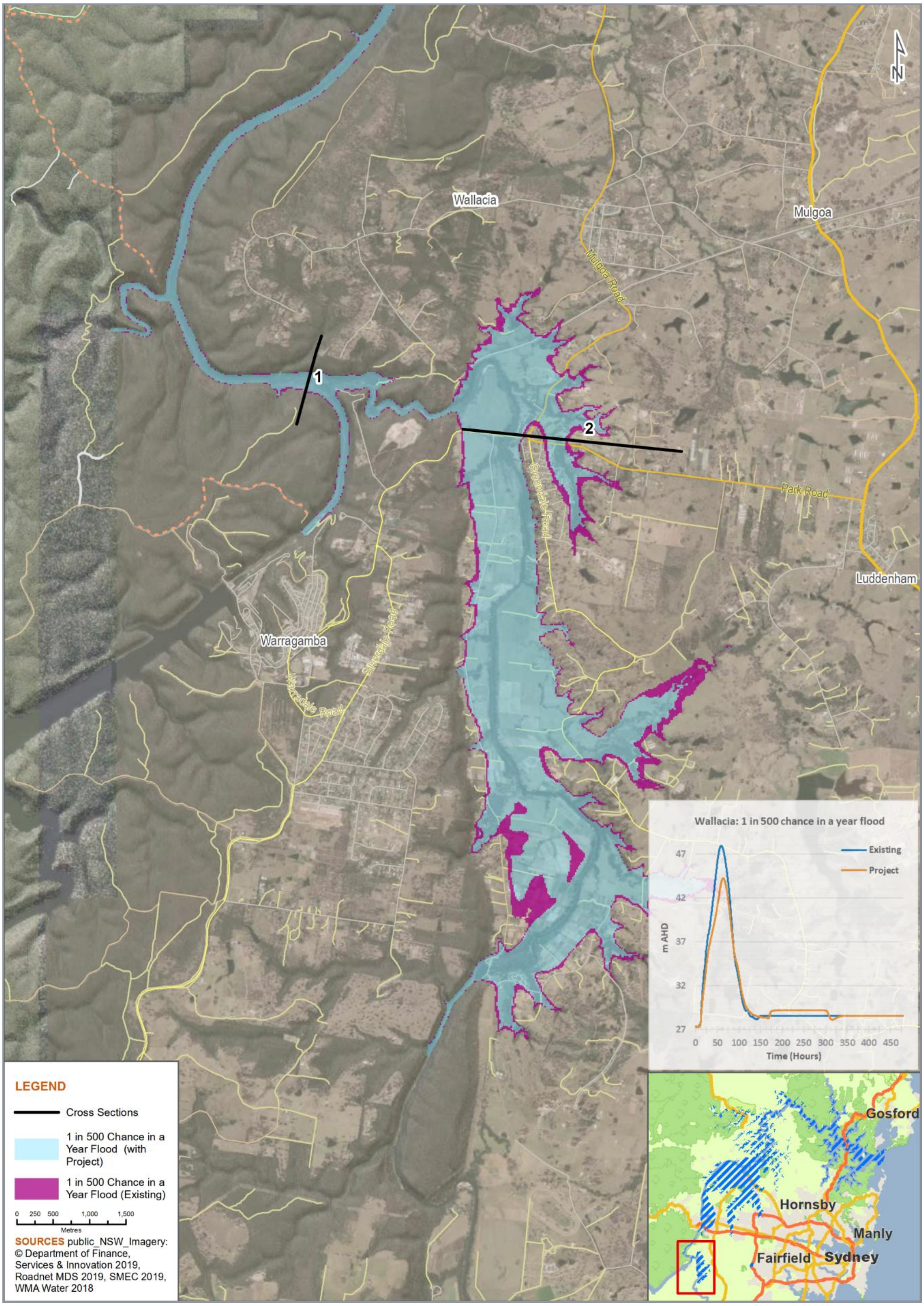


Figure 15-84. Penrith: 1 in 500 chance in a year event

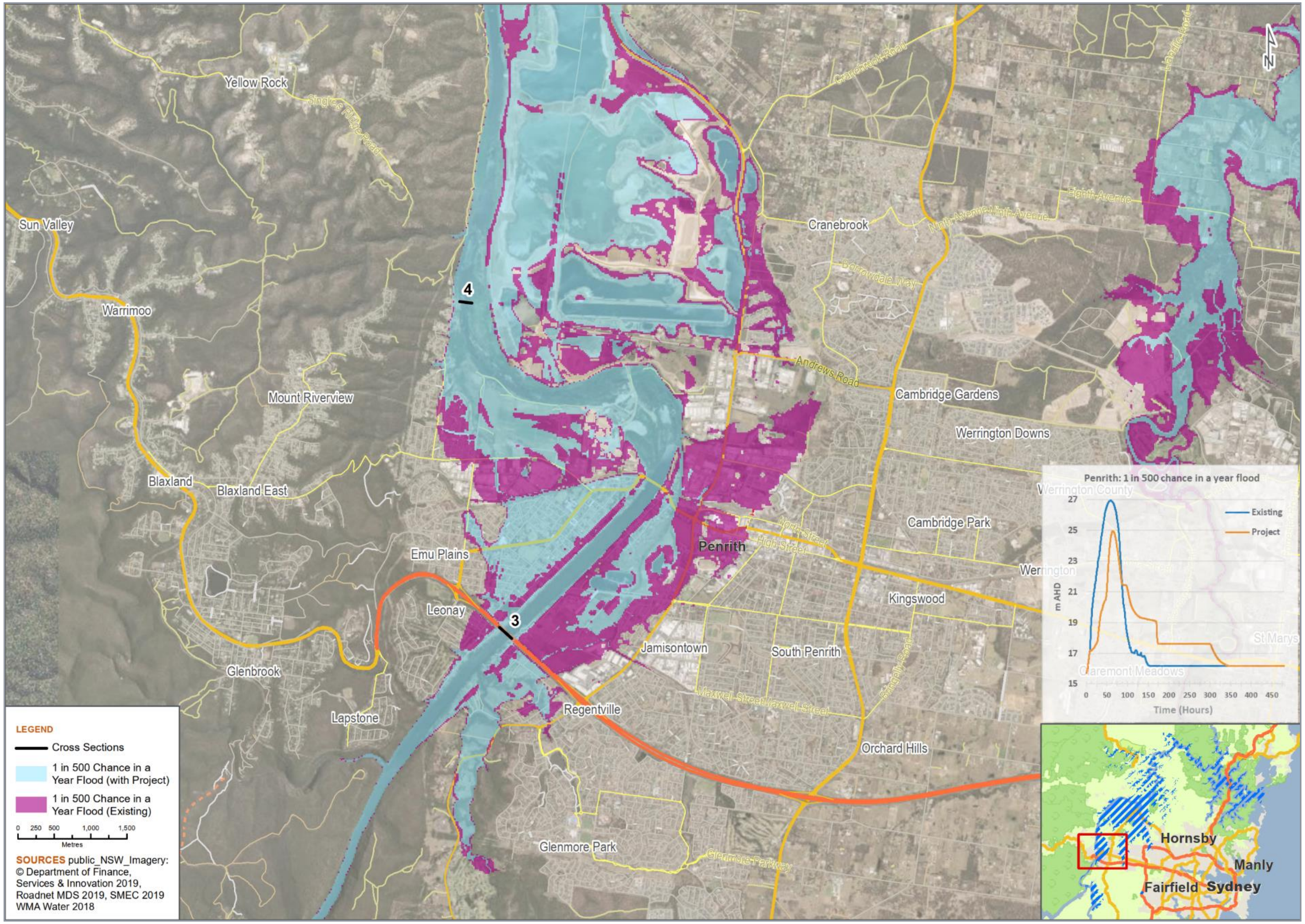


Figure 15-85. Richmond/Windsor: 1 in 500 chance in a year event

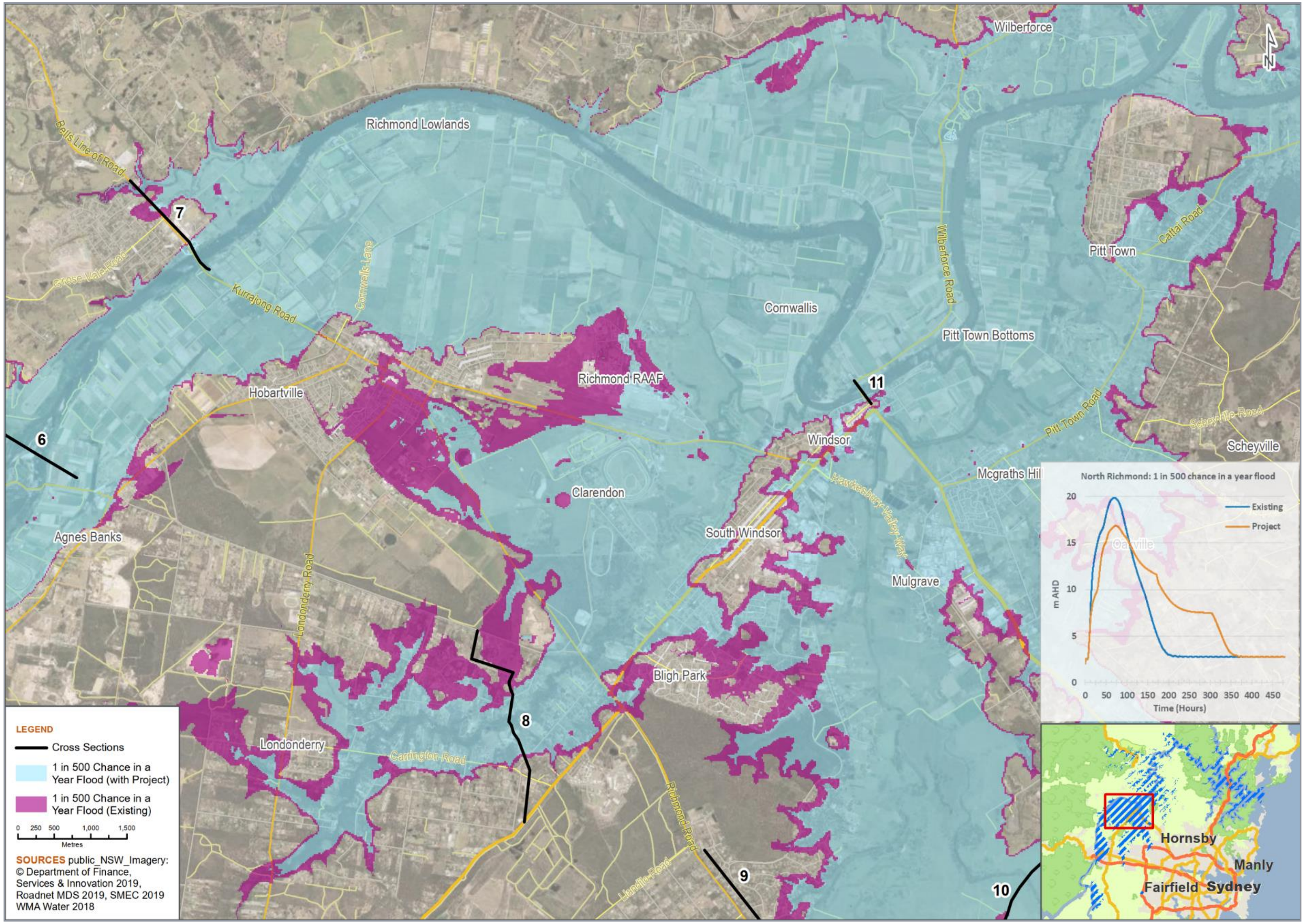
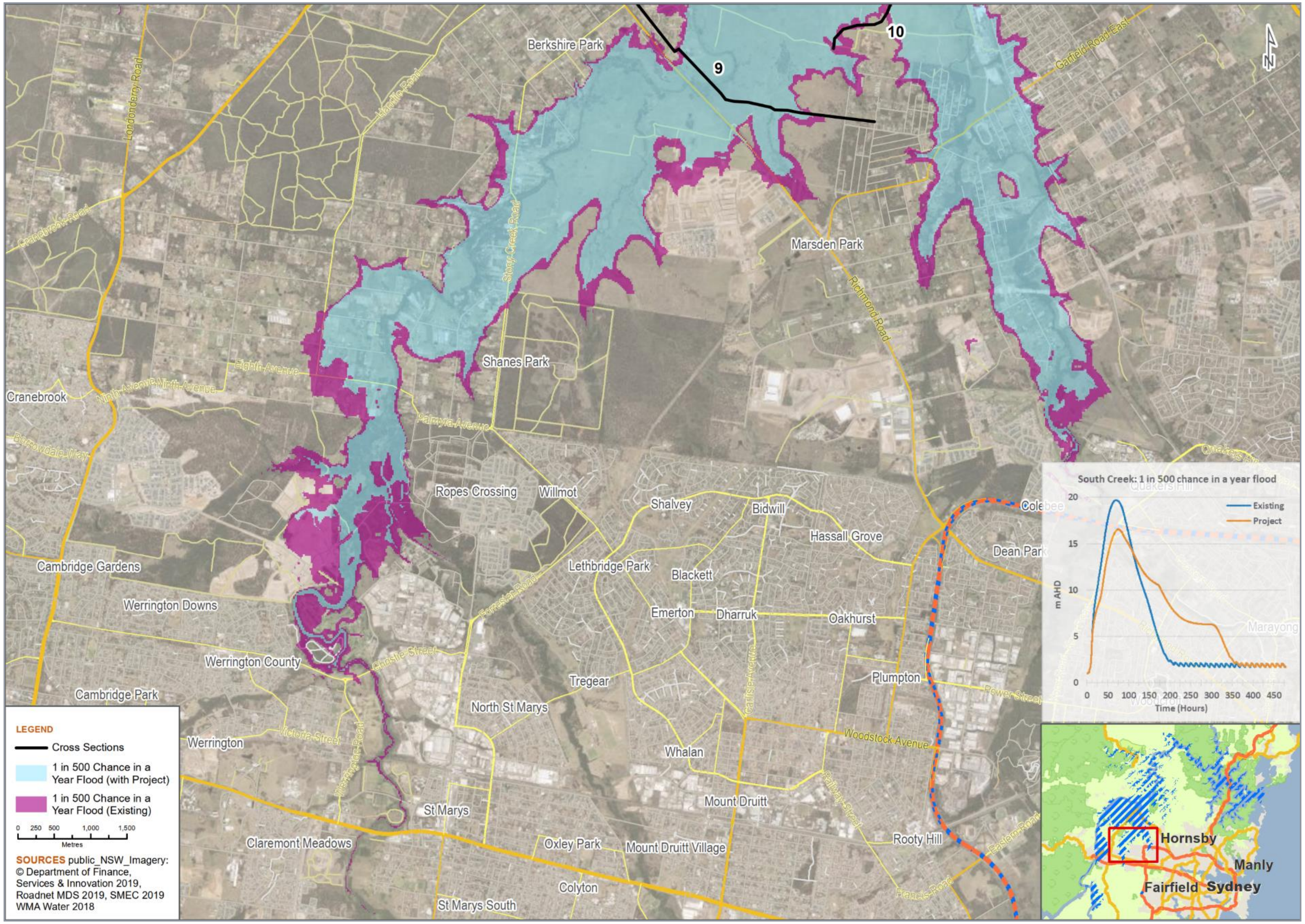
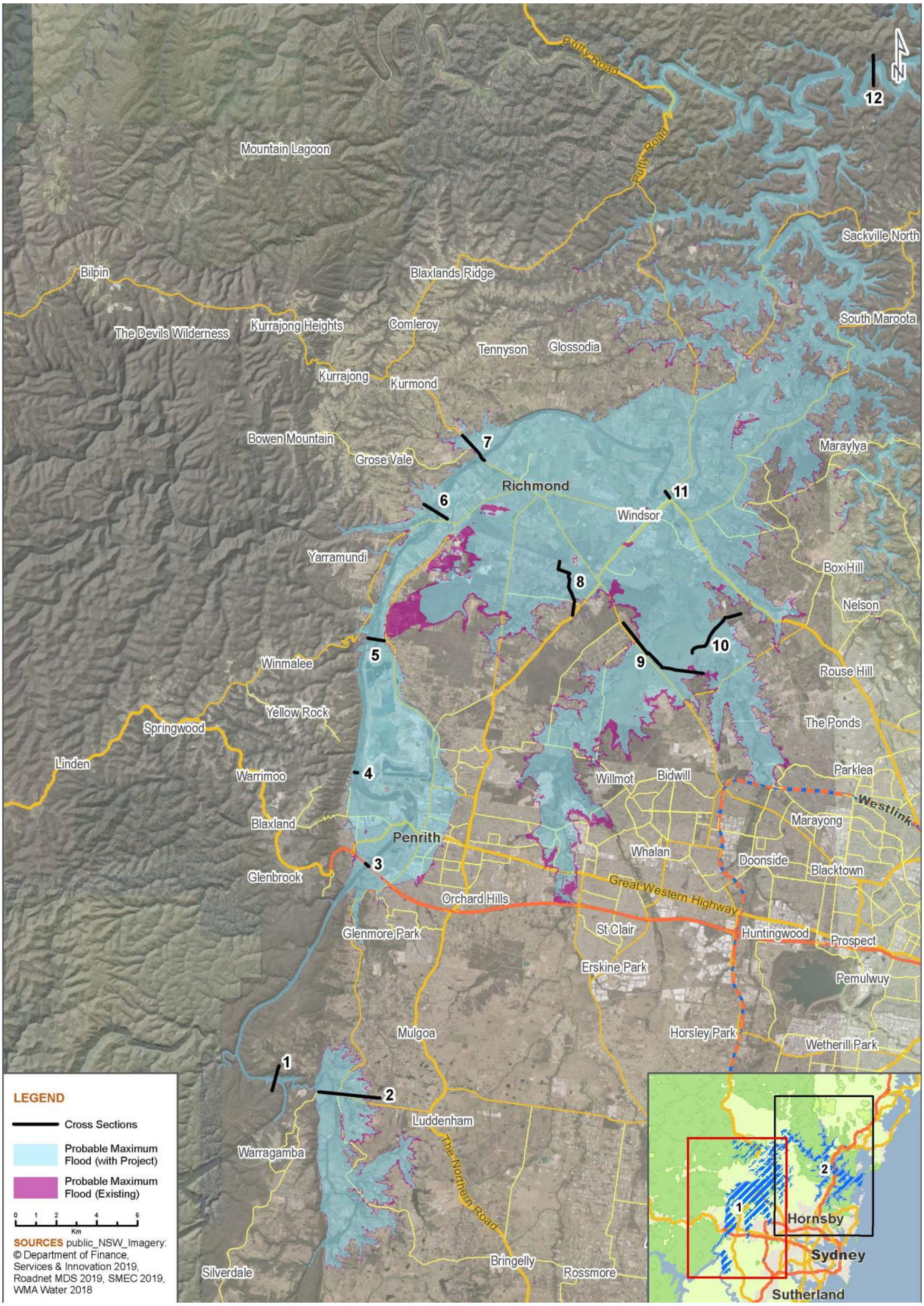


Figure 15-86. South Creek: 1 in 500 chance in a year event



15.14.2.7 Downstream: PMF

Figure 15-87. Downstream flood extent: PMF




Kulnura
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The Basin
Palm Beach
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Avalon
Box Hill
Galston
Nelson
Newport
Kenthurst
Mount Colah
Mona Vale
Terrey Hills
Ingleside
Dural
Rouse Hill
Asquith
LEGEND
Cross Sections
Probable Maximum Flood (with Project)
Probable Maximum Flood (Existing)
0 1 2 4 6
Km
SOURCES public_NSW_Imagery: © Department of Finance, Services & Innovation 2019, Roadnet MDS 2019, SMEC 2019, WMA Water 2018
Glenhaven
Hornsby
Waitara
St Ives Chase
Rogans Hill
Thornleigh
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Pymble
Sorlie
Beecroft
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North Rocks
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Figure 15-88. Wallacia: PMF

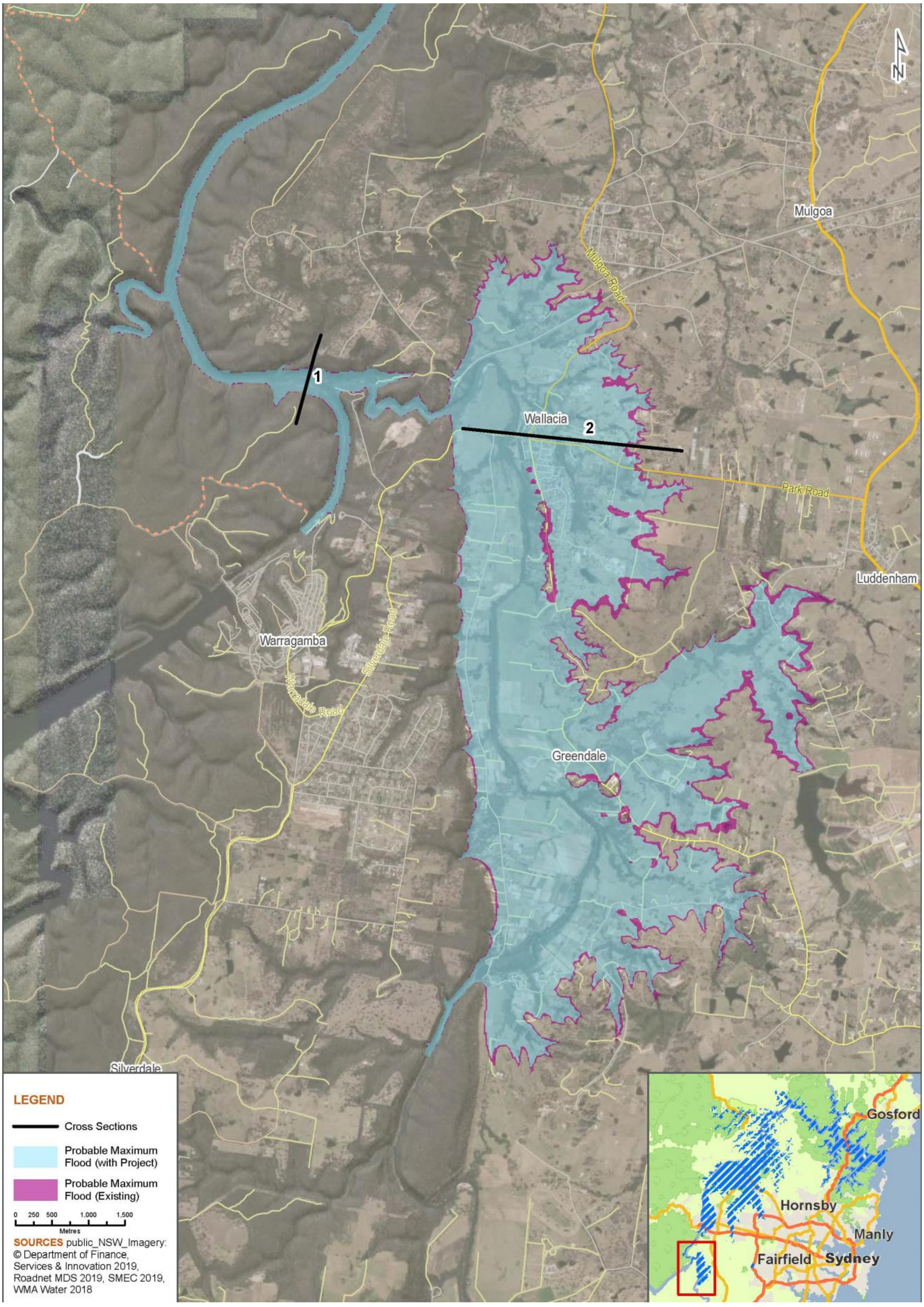


Figure 15-89. Penrith: PMF

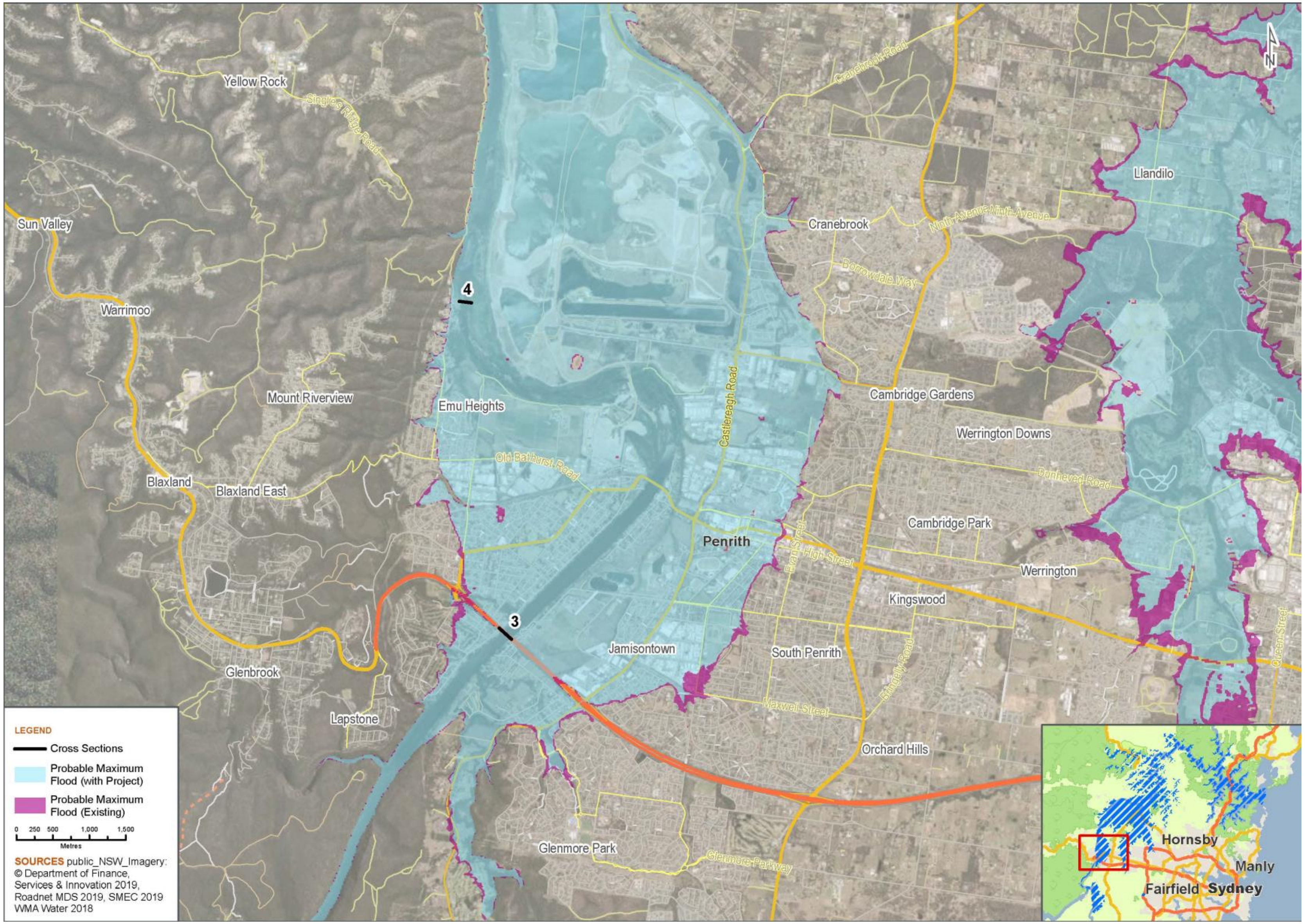


Figure 15-90. Richmond/Windsor: PMF

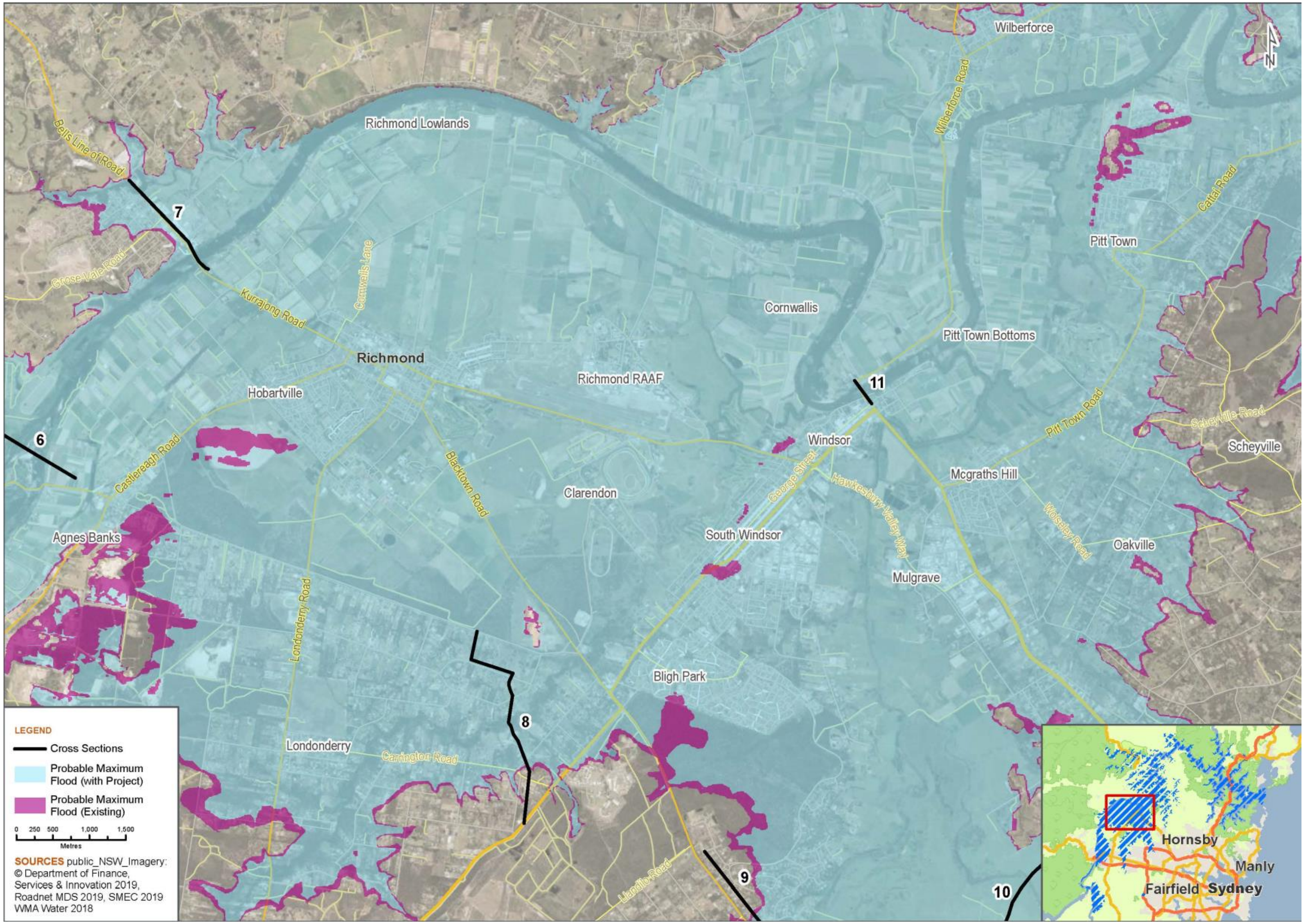
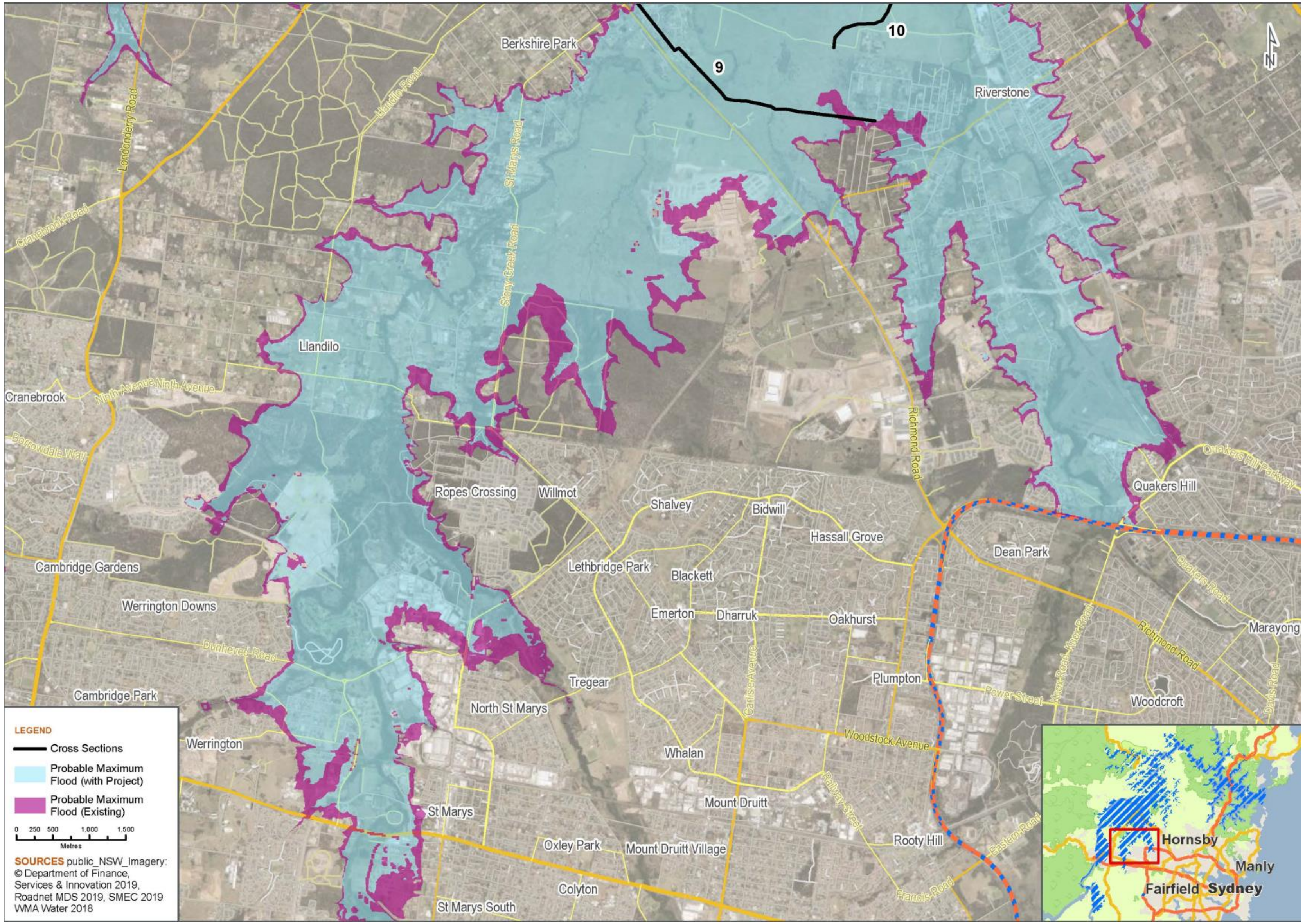


Figure 15-91. South Creek: PMF



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