NSW STATE EMERGENCY SERVICE

HAZARD AND RISK IN THE HAWKESBURY-NEPEAN VALLEY

Annex A

Supporting document (NSW SES Response Arrangements for Hawkesbury-Nepean Valley) to the Hawkesbury-Nepean Flood Plan

Last Update: June 2020

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VERSION LIST

The following table lists all previously versions of this Annex.

Description	Date
September 2013 as amended June 2014	June 2014
September 2015 update	Sep 2015

AMENDMENT LIST

Suggestions for amendments to this Annex should be forwarded to:

Deputy Commissioner Operations
NSW State Emergency Service
PO Box 6126, 93-99 Burrelli St, Wollongong NSW 2500

Amendments promulgated in the amendments list below have been entered in this Annex.

Amendment Number	Description	Updated by	Date

PART 1 THE FLOOD THREAT

1.1 LANDFORMS AND RIVER SYSTEMS

The Hawkesbury-Nepean catchment is around 21,400 square kilometres in size stretching from Goulburn in the south almost to Singleton in the north-west.

The Hawkesbury-Nepean River is around 470 kilometers long. It flows generally in a north easterly direction from its source near Goulburn, until eventually discharging into the Pacific Ocean north of Sydney at Broken Bay.

The Hawkesbury and Nepean rivers are actually the same river with the Nepean forming the upstream portion, and the Hawkesbury the lower half. There are a number of other large rivers and creeks that flow into the Hawkesbury-Nepean River system. The major ones include the:

- Wollondilly River
- Coxs River
- Grose River
- South Creek
- Colo River and
- Macdonald River

MAP 1 shows an overview of the Hawkesbury-Nepean Valley from Bents Basin to Broken Bay – the area covered by the Hawkesbury-Nepean Flood Plan. The area along the Nepean River upstream of Bents Basin, is covered by the Upper Nepean Flood Plan.

Major Rivers

The Nepean River has its origins in the rugged high rainfall area of the Illawarra escarpment. It is fed by smaller tributaries including the Avon, Cataract and Cordeaux rivers. The Warragamba River joins the Nepean River just downstream of Wallacia. It continues north along the base of the Blue Mountains through the open plains of Emu Plains and Penrith until it reaches the junction with the Grose River at Yarramundi. At this point it becomes known as the Hawkesbury River.

The Hawkesbury River flows generally North east from Yarramundi through the main urban and agricultural areas of Richmond and Windsor. It continues through rugged sandstone gorge country before discharging into the ocean at Broken Bay.

The Wollondilly River originates in farm land near Goulburn and is fed by smaller tributaries including the Nattai and Wingecarribee Rivers. The Wollondilly River flows through Sydney's water supply catchment area into the Warragamba River which in turn flows into Lake Burragorang. This lake is formed by the Warragamba Dam. Water that is discharged through the dam flows into the Warragamba River which joins the Nepean River below Warragamba Dam.

The Coxs River originates to the west of the Blue Mountains near the Capertee Valley. It flows in a south easterly direction, initially through farmland, then through rugged bushland valleys to the south of Blue Mountains townships. It eventually flows into Lake Burragorang.

The Warragamba River starts downstream of Warragamba Dam and joins the Nepean River 3.5 kilometres below Warragamba Dam. The Warragamba catchment is 9,051 square kilometres and makes up about 80% of the catchment to Penrith and 70% to Windsor. Most of the time only small environmental releases are made from the Warragamba Dam to the Warragamba River, but the flows can be very large when the dam spills.

The Grose River originates in the Blue Mountains and travels east through rugged World Heritage Area before joining the Nepean River at Yarramundi near Richmond. Its catchment of 650 square kilometres is a relatively small part of the total catchment and can contribute to fast rising level at North Richmond.

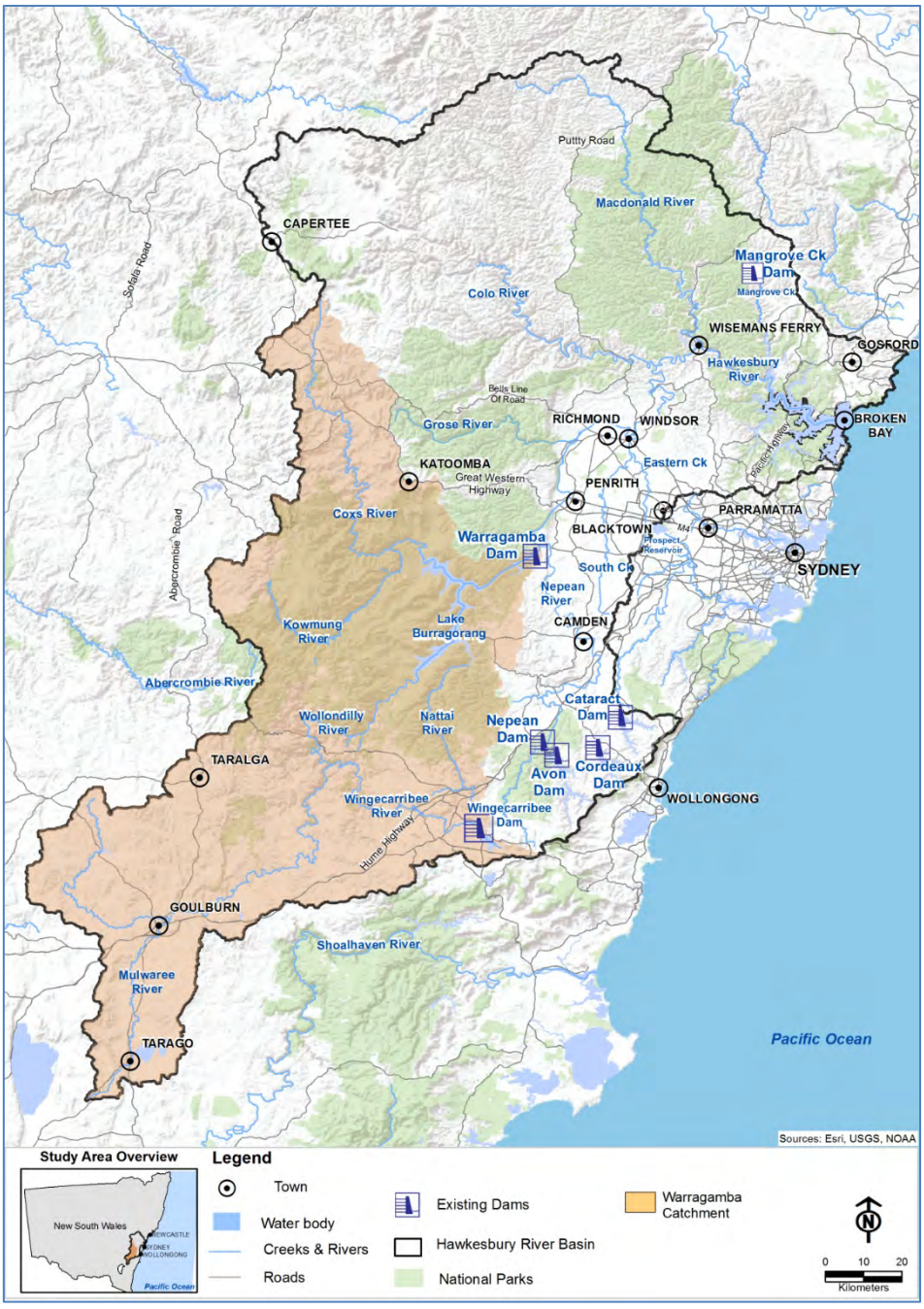
South Creek joins the Hawkesbury River at Windsor. South Creek drains a 640 square kilometre catchment in Western Sydney. It has its headwaters near Narellan and generally flows in a northerly direction. This catchment contains large urbanised areas and the site of Western Sydney Airport. Ropes and Kemps

Creek are major tributaries of South Creek. Eastern, Ropes and Kemps creeks are major tributaries of South Creek (1).

The South Creek catchment receives comparatively less rainfall than the Grose River (2).

The Colo River originates in the Blue Mountains and consists of predominantly natural rugged bushland areas. It drains an area of 4,640 square kilometres. The Colo River joins the Hawkesbury River downstream of the main urban areas around Richmond and Windsor where the landscape is predominantly steep vegetated sandstone hill slopes.

The Macdonald River originates in rugged bushland at the northern end of the catchment. It drains an area of about 1,910 square kilometres. The Macdonald River joins the Hawkesbury River near Wisemans Ferry, where the river is surrounded by steep vegetated sandstone hill slopes (3).



Map 1: Hawkesbury-Nepean River Basin (212 in the AWRC classification)

Floodplains and Gorges

Floodplains are areas of land beside rivers that can be inundated by floodwaters up to the largest possible flood extent. They are normally reasonably flat fertile areas that are made up by the sediments that have been deposited during past flood events.

Whilst flooding is a natural process bringing with it many benefits, floods can have significant impacts on people living and working on these floodplains, their property and infrastructure.

Within the Hawkesbury-Nepean Valley the major flood risk areas are located on the floodplains and tributaries between Wallacia and Spencer. There are four main identifiable floodplains within this Hawkesbury-Nepean Valley area. These are the:

- Wallacia Floodplain;
- Penrith / Emu Plains / Castlereagh Floodplain;
- Richmond / Windsor / Wilberforce Floodplain; and
- Lower Hawkesbury Floodplain

An overview of these floodplains is shown on Map 2 and are further described below.

Wallacia Floodplain

The Wallacia Floodplain is located within parts of the Penrith, Wollondilly and Liverpool local government areas and includes the township of Wallacia (Refer to Maps 2 and 3).

The Wallacia Floodplain is around 10km in length and is located between Bents Basin and Wallacia. The Nepean River runs through a very narrow sandstone gorge, known as Bents Gorge until it reaches Bent Basin State Conservation Area where the floodplain widens.

Downstream of Wallacia the Nepean River narrows again through the Nepean Gorge to a point just upstream of Emu Plains. The Warragamba River joins the Nepean River in this gorge 3.5km downstream of Warragamba Dam.

Penrith / Emu Plains / Castlereagh Floodplain

From Emu Plains to Castlereagh there is another slightly larger floodplain located within the Penrith local government area.

This floodplain extends into Emu Plains and Leonay on the western side of the river to the foothills of the Blue Mountains (refer to Maps 2 and 4).

On the eastern side of the river the floodplain extends into parts of the Penrith, and the Penrith Lakes area before constricting again near Castlereagh through the Castlereagh Gorge (4).

Richmond / Windsor / Wilberforce Floodplain

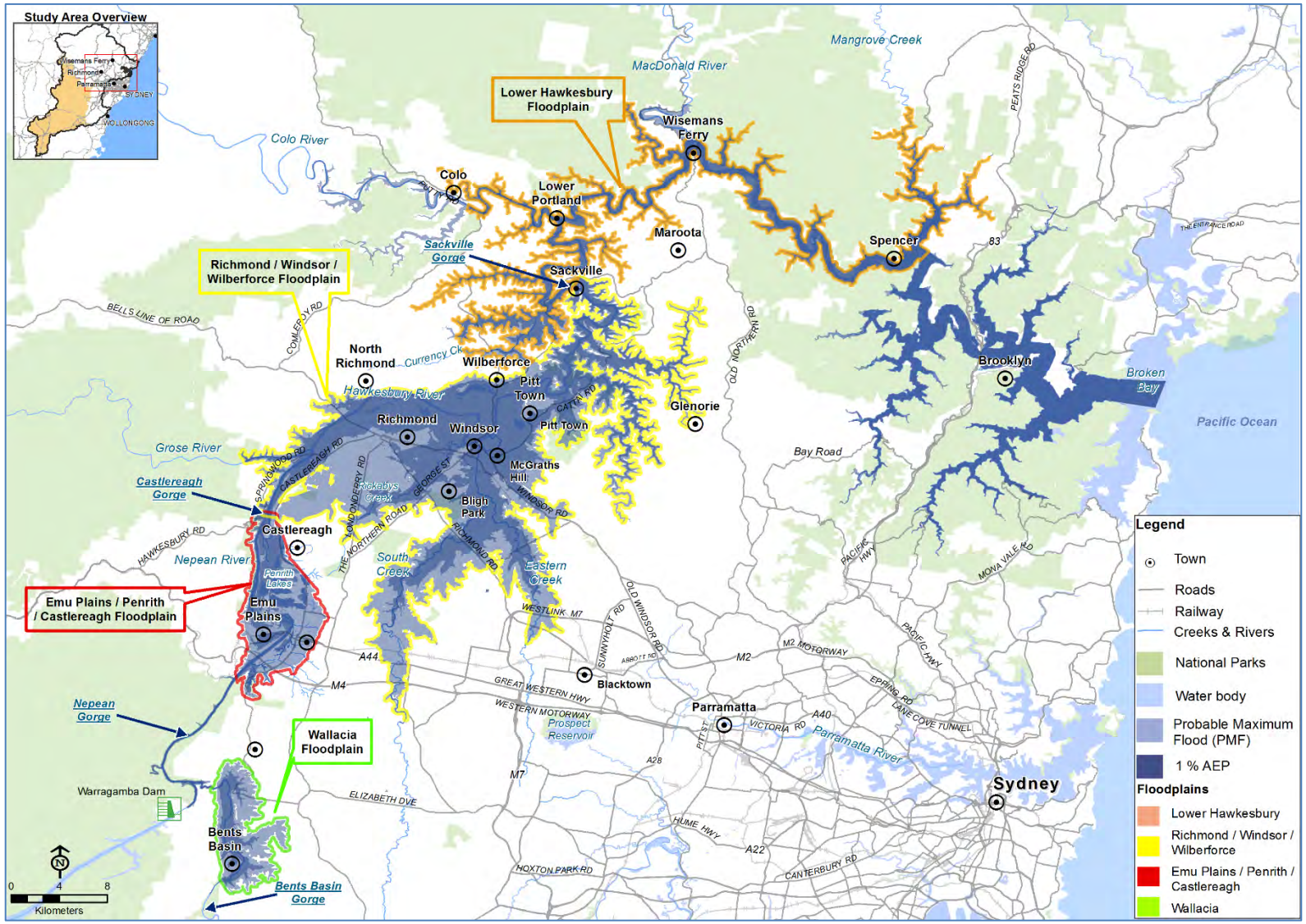
Downstream of the Castlereagh Gorge the River enters a distinct basin extending from North Richmond to Wilberforce. This is the largest of the floodplains covering parts of the Penrith, Hawkesbury, Blacktown and The Hills local government areas (refer to Maps 2 and 5). It encompasses:

- Richmond, Windsor, McGraths Hill, Bligh Park, Wilberforce, Cattai and Pitt Town;
- Rickabys Creek;
- The lower sections of South Creek (incorporating Eastern and Ropes creeks) including Marsden Park; and
- Bushells Lagoon, Wilberforce.

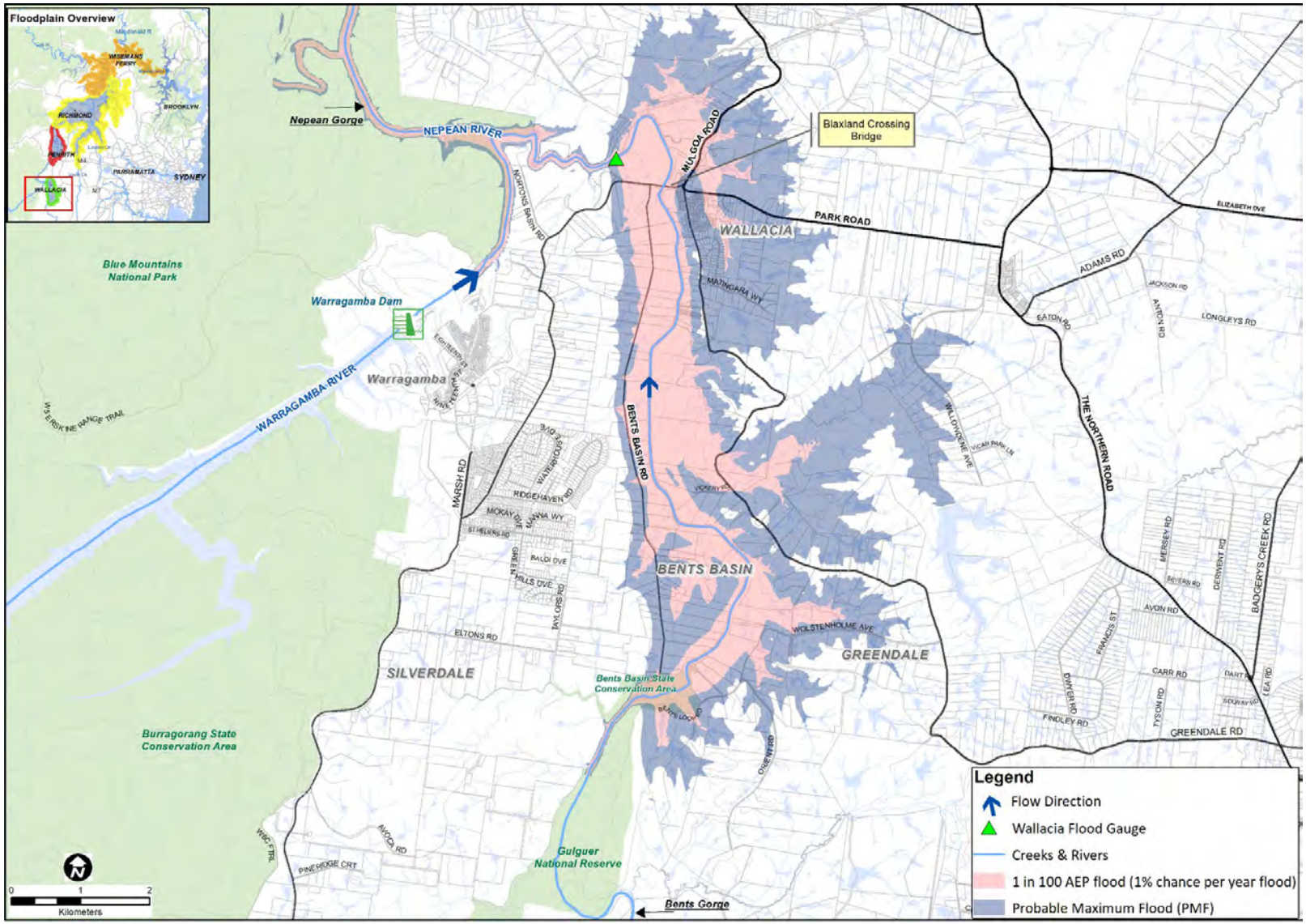
Lower Hawkesbury Floodplain

The remaining floodplain is comparatively narrow. It starts where the river constricts near Ebenezer and takes in the area downstream to Spencer (Refer to Maps 2 and 6).

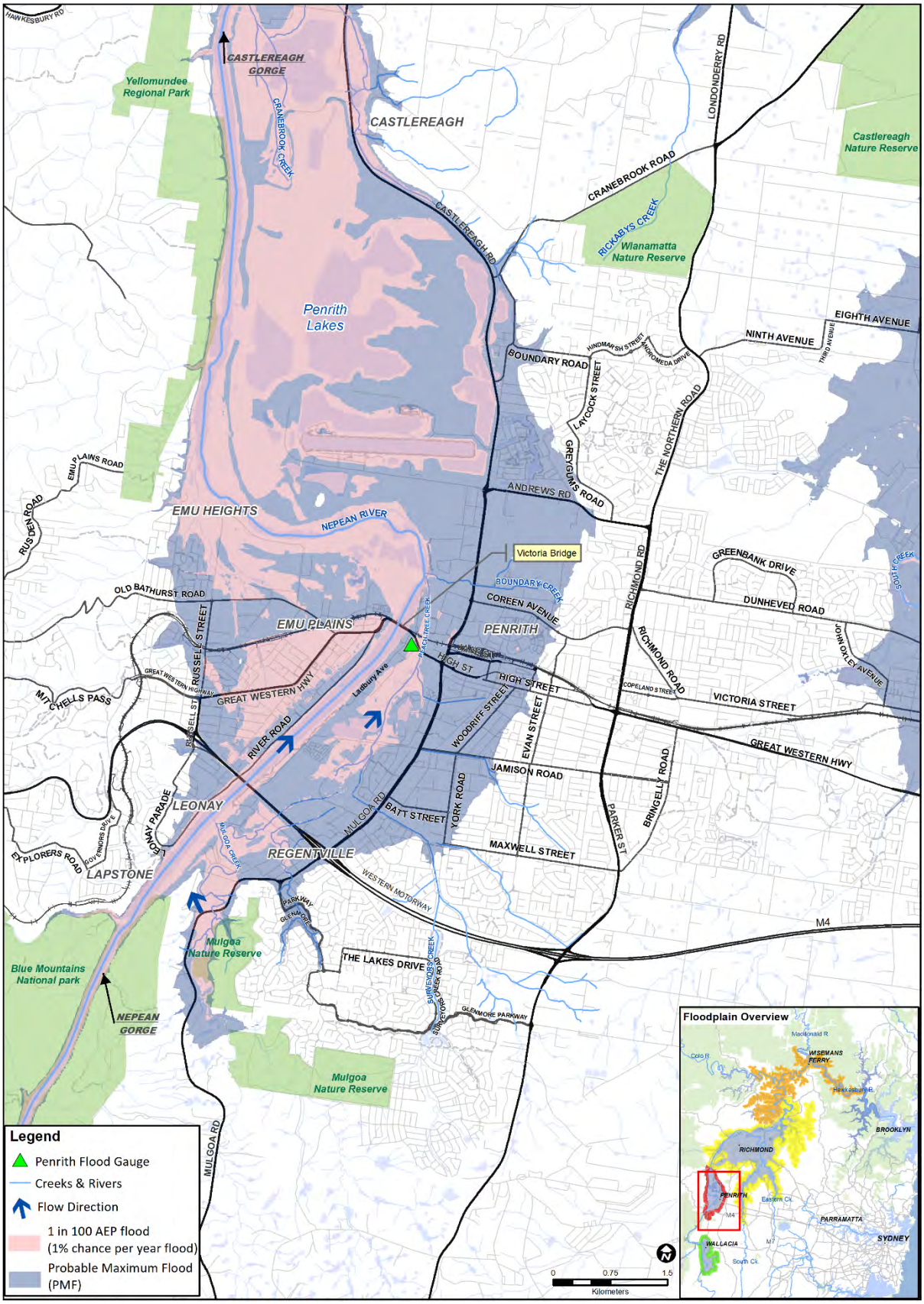
This area is generally referred to as the Lower Hawkesbury and is located within parts of The Hills, Hornsby and Central Coast local government areas.



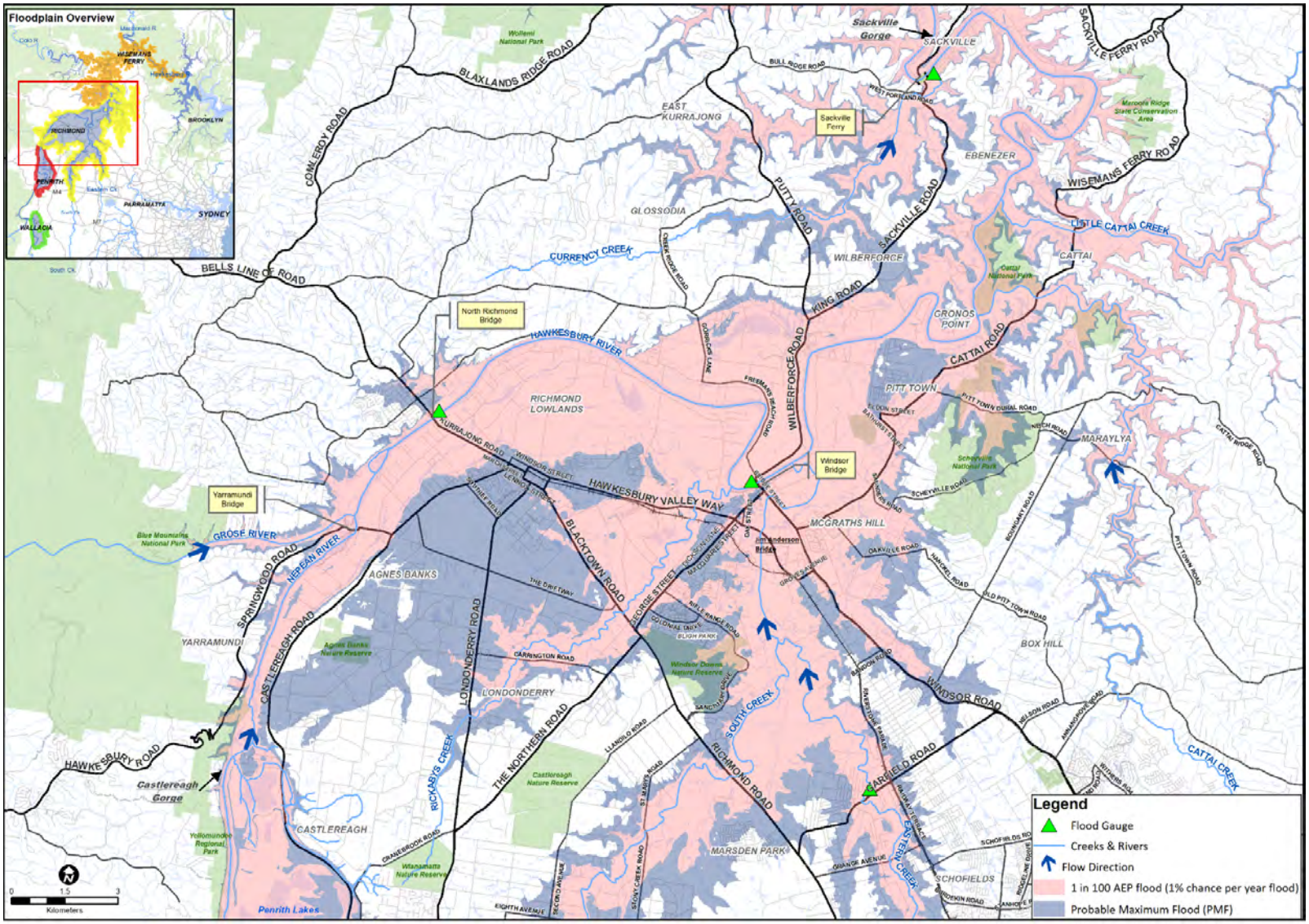
Map 2: Floodplains in the Hawkesbury-Nepean Valley



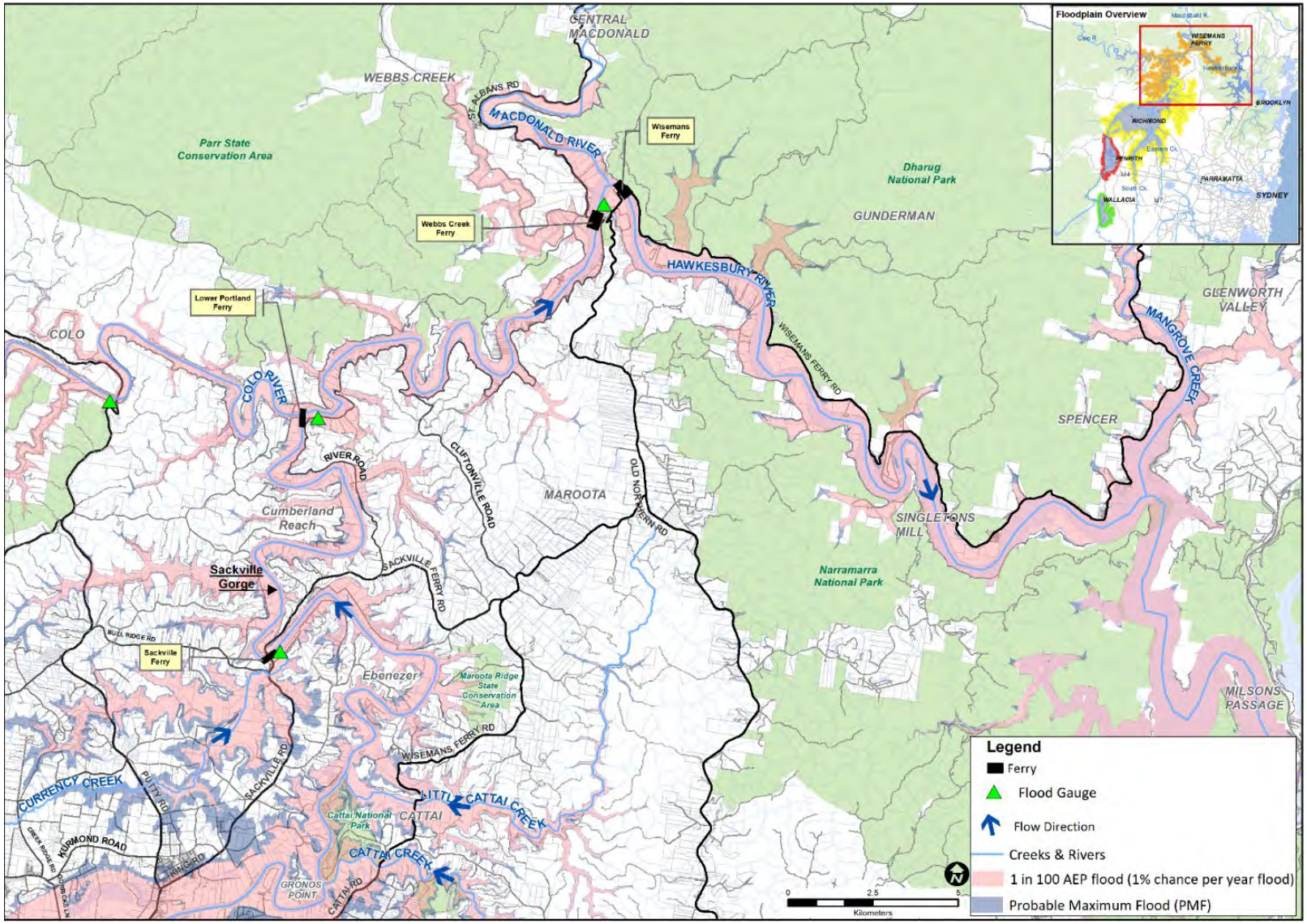
Map 3: Wallacia Floodplain



Map 4: Penrith / Emu Plains / Castlereagh Floodplain



Map 5: Richmond/ Windsor / Wilberforce Floodplain



Map 6: Lower Hawkesbury Floodplain

Below Ebenezer the River enters another narrow sandstone gorge known as Sackville Gorge which continues through to Wisemans Ferry and then on to Broken Bay, a river distance of around 100 kilometres. Unlike the upstream constrictions near Wallacia and Castlereagh, which are relatively short, this gorge consists of a long and very narrow waterway.

The Colo River and the Macdonald River join the Hawkesbury River within Sackville Gorge.

After Wisemans Ferry the gorge opens up slightly downstream to Spencer. Below Spencer the valley opens out further into the wide basin of Broken Bay where the Hawkesbury River discharges into the Pacific Ocean.

1.2 STORAGE DAMS

There are a number of water supply reservoirs on tributaries upstream of Penrith including the Warragamba, Wingecarribee, Avon, Cataract, Cordeaux and Nepean Dams. Of these, Warragamba Dam is the largest of the reservoirs with 41% percent (9000 square kilometres) of the entire Hawkesbury-Nepean catchment located upstream of this dam (5).

Mangrove Creek Dam is situated in the lower part of the catchment near the headwaters of Mangrove Creek, north west of Gosford.

Dam locations are shown on Map 1 – Hawkesbury-Nepean River Basin.

Given that their primary purpose is for water supply, these dams are managed to ensure that they are kept as full as possible and therefore have minimal flood mitigation effects.

With the exception of Warragamba Dam and Wingecarribee Dam, these dams have non-gated overflow spillways and cannot be operated as flood mitigation dams (6) (7) (8) (9) (10).

Although Warragamba Dam has gates, these are currently operated for Dam safety purposes and are not operated for flood mitigation (11).

The large storage volume of Warragamba Dam can mitigate flooding to some extent by capturing early floodwaters, but only if the rainfall occurs upstream of the dam and if not already full. Once the dam reaches full supply level, the gates are progressively opened, which can have a major contribution to downstream flood levels (11).

Dam Emergencies

Dam emergencies, particularly concerning the Warragamba and upper Nepean dams could have some downstream consequences within the area covered by this plan. However, both dams have no known structural deficiencies, have been upgraded to modern design standards and are capable of catering for extreme flood events. As such, the probability of dam failure is considered to be very low (9) (10).

Dam emergency arrangements are detailed in supporting document "Annex G Dam Emergency Arrangements" to this plan.

1.3 RIVER CONTRIBUTIONS TO FLOODING

The Warragamba catchment makes up around 70% of the catchment area located upstream of Windsor (Figure 1). Since the dam was constructed in 1960, there have been significant variations in the contribution from the Warragamba Dam catchment to flooding at Windsor ranging from between 73% to only 42% of all floodwaters (see Figure 1) (11).

There are also a number of other tributaries which contribute to flooding in the Richmond / Windsor / Wilberforce floodplain including the Nepean River, Grose River and South Creek. These catchments are smaller than the Warragamba Dam catchment however they generally respond more quickly to rainfall. Typically, their flow arrives in the floodplain before the flow from Warragamba Dam. This means that river levels can rise at Windsor regardless of what is happening upstream of Warragamba Dam (11).

The Grose River in particular drains a high rainfall area in the Blue Mountains and can have a significant effect on flooding at

Windsor. Flood flows from this tributary can result in the river level at North Richmond rising markedly before flood water arrives from upstream on the Nepean River or via Warragamba Dam. Flood flows from the Grose River alone can produce moderate to major flooding from Richmond and into the Lower Hawkesbury (12).

Similarly, the Colo River is known to have contributed significantly to flood levels in the Lower Hawkesbury (12).

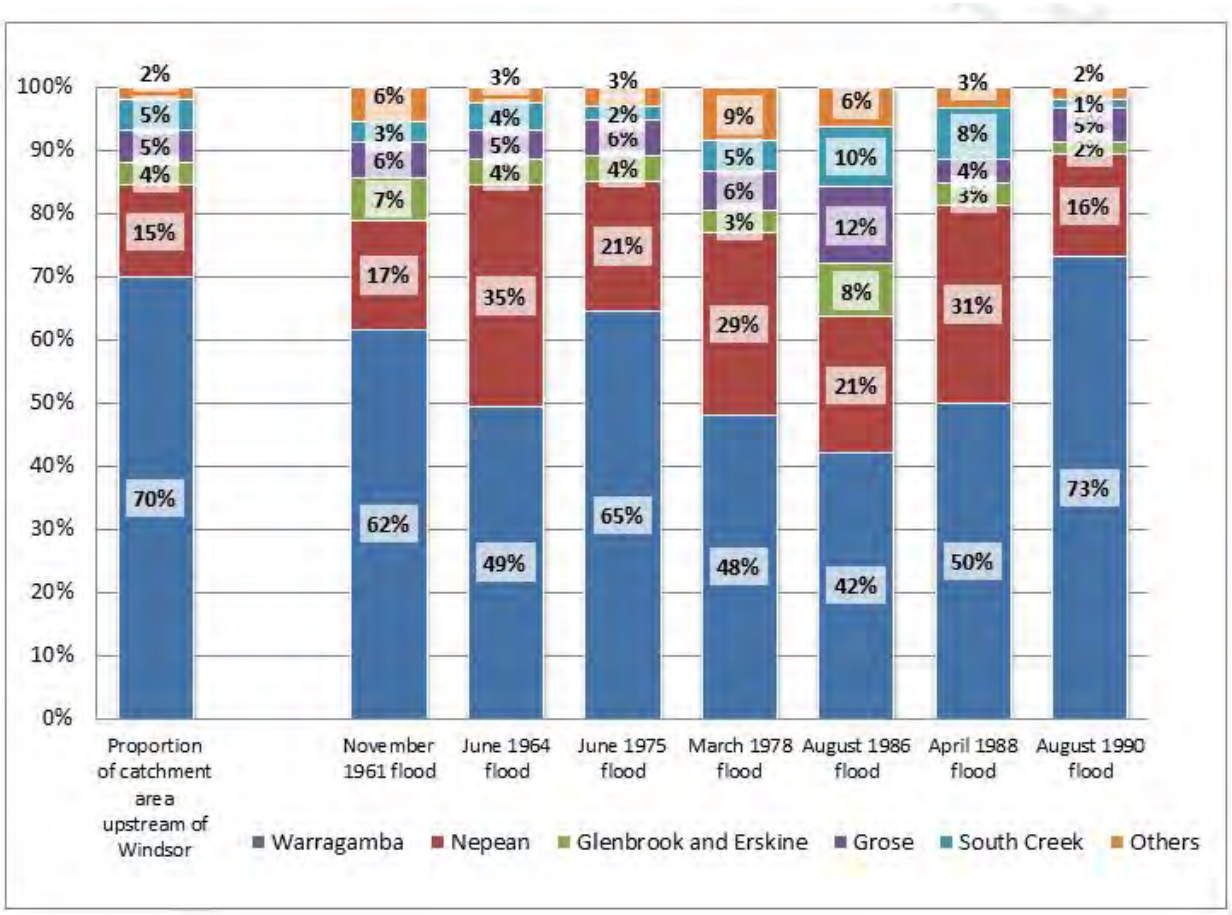


Figure 1: Sub-catchment contributions to flooding at Windsor from recent floods

(Source: WaterNSW) (11)

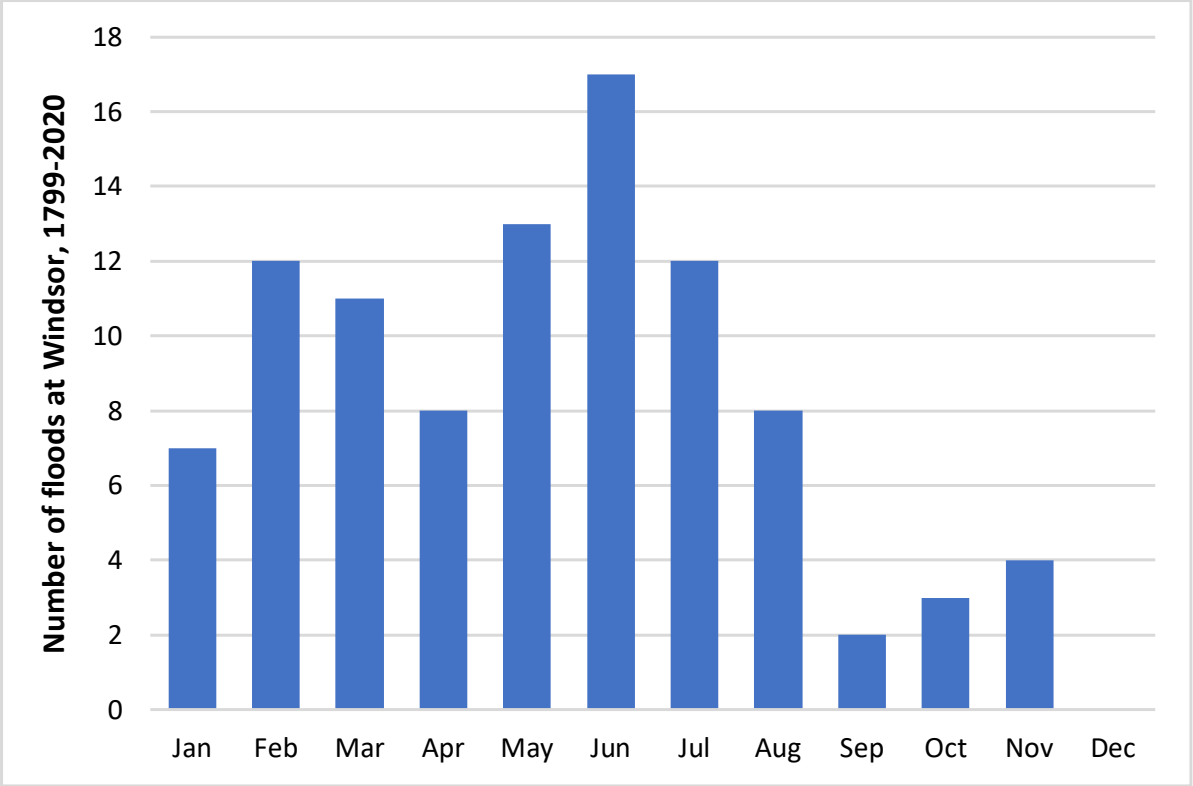


Figure 2: Seasonality of Hawkesbury-Nepean floods

Note: based on flood history at Windsor, 1799-2020 (13)

1.4 WEATHER SYSTEMS AND FLOODING

The Hawkesbury-Nepean catchment displays wide variation in rainfall distribution. The annual average rainfall for the whole catchment is approximately 1000 millimetres however the annual average rainfall over the headwaters of the Nepean is 1500 millimetres while on the southern extremity of the basin near Goulburn the figure is about 625 millimetres. The majority of the rainfall occurs in the summer months, but floods may be experienced during any part of the year.

There are many localities in the valley that have received 175 millimetres of rainfall in a 24 hour period. Falls in excess of 250 millimetres in a 24 hour period have been recorded at Katoomba, Lawson, Springwood, Penrith and Kurrajong Heights. It should be noted that these rainfall totals can often result from sustained falls of only 10-15 millimetres per hour and can produce severe floods.

The rainfall that produces severe flooding in the Hawkesbury-Nepean Valley will usually come from East Coast Low Pressure Systems. These systems develop off the state's coast, and direct moist winds onto the coast. Usually, but not exclusively, they move in a southerly direction. Once these air masses strike coastal ranges such as the Illawarra escarpment or the Great Dividing Range. The resulting uplift of air often produces very high rates of rainfall and heavy rain.

Sea conditions can also influence flooding in the lower river reaches. Along the coast, oceanic storm surges and large waves may result from East Coast Low Pressure Systems and their associated gales and storm-force winds. Such conditions may lead to coastal inundation of seawater and can delay the

floodwaters from the Hawkesbury River reaching the Pacific Ocean.

The larger floods that have occurred on the Hawkesbury-Nepean River have often been accompanied by storm surge of 0.1-0.3 metres in Broken Bay. These effects are most apparent if storm surge conditions occur during periods of spring or extreme tides.

A comparison of major Hawkesbury River floods at Windsor since 1860 to a tabulation of the weather systems causing the floods, shows that all but one of 13 major floods were associated with East Coast Low Pressure Systems. Among these were the flood of record in June 1867, and the second highest flood of record in November 1961. Major flooding in 1964, 1978, 1988 and 1990 resulted from similar weather systems (14).

Several flood-producing East Coast Low Pressure Systems may be experienced annually in New South Wales. During the 1990s for example, there were between two and five such occurrences in most years. This can result in multiple flood events on the same river system within the same year.

Climate Variability

The history of floods at Windsor since the 1790s suggests multi-decadal periods of more frequent and larger floods, interspersed by multi-decadal periods of less frequent and smaller floods. These periods have been described as flood-dominated and drought-dominated regimes, respectively. Floods still occur during the decades dominated by drier conditions and the relative infrequency of floods during those decades should not be taken to represent the total flood hazard profile.

Climate Change

Climate change is expected to affect flood behaviour within the Hawkesbury-Nepean catchment through increased severity of flood producing storms or other weather systems. Rainfall is projected to increase by 4.7% by 2030 and 9.4% by 2060 under projected medium climate change (15).

1.5 CHARACTERISTICS OF FLOODING

Bathtub Effect

The Hawkesbury-Nepean Valley has a unique feature that dramatically affects the behaviour of floods.

On a typical coastal river the valley progressively widens as it approaches the ocean outflow. However, in the Hawkesbury-Nepean the series of wide floodplains, separated by narrow sandstone gorges, causes flood waters to back up on the floodplains behind these natural 'choke points'. Water cannot escape as quickly as it enters and so it fills up like a bathtub. This is known as the 'bathtub effect' and it results in water levels that are well above those typically expected (11) (See Figure 3).

At Windsor for example, the river level could rise from a normal non-flood level of 0.7 metres up to about 26.7 metres AHD in the Probable Maximum Flood (PMF). With many house floor levels built at around 17.3m AHD this means that floodwaters can be higher than 9 metres above the floor. This is equivalent to the height of a three story building (15). (See Figure 4).

Flood Islands and Trapped Areas

Another feature of flooding within the Hawkesbury-Nepean Valley is that many roads have low points that flood and are cut off before the higher inhabited areas are inundated creating 'flood islands' (11).

As the flood rises, these flood islands are gradually inundated such that during major flood events they may be completely submerged. Those that aren't fully submerged may only have small patches of flood free land remaining.

Similarly, many areas, particularly within the gorges, can become trapped by flood waters when access roads and ferries are cut with limited means of escape due to the steep and rugged surrounding terrain.

For further information see 2.4 – Flood Emergency Response Classification of Communities.

1.6 TIMEFRAMES

Extreme floods within the Hawkesbury-Nepean Valley with the greatest depths of flooding can develop reasonably quickly. The highest possible flood level is called the Probable Maximum Flood (PMF). The time from the start of rainfall, to peak levels of a PMF can be as little as 24 hours. Historical events to date have tended to develop over 3 days or more (16) (See section 1.10 – Extreme Flooding for further details).

Rates of water level rise can be variable, with the fastest rises historically experienced in the Richmond / Windsor / Wilberforce area of almost 1 metre per hour prior to the river breaking its banks (16). Once the river breaks its banks and spreads onto the floodplain these rates of rise tend to decrease.

There is also considerable variability in flood peak times (15). For example, downstream areas may peak before upstream locations, given the bathtub effect and the timing of the downstream tributary inflows such as the Grose River and Colo River. In the February 2020 flood, inflows from the Grose River drove relatively early flooding at the North Richmond Bridge, before flows arrived from the Upper Nepean.

The rate of rise and travel times have significant implications for the evacuation of the large number of people off the floodplain. Table 1 shows the indicative flood travel times for various locations along the Hawkesbury-Nepean River.

Locations	Indicative **Travel Time**
Menangle to Camden Bridge	5 hours
Camden Bridge to Wallacia Weir	11 hours
Wallacia Weir to Penrith	2 hours*
Warragamba Dam outflow to Penrith	2-3 hours
Penrith to North Richmond	2-4 hours
North Richmond to Windsor	1-12 hours
Windsor to Sackville	3 to 11 hours
Sackville to Lower Portland	6 hours
Lower Portland to Webbs Creek (Wisemans Ferry)	6 to 11 hours

Table 1: Indicative Flow Travel Times for the Hawkesbury-Nepean River

Note: * for Warragamba-dominated floods, peaks at Penrith tend to precede peaks at Wallacia (15)

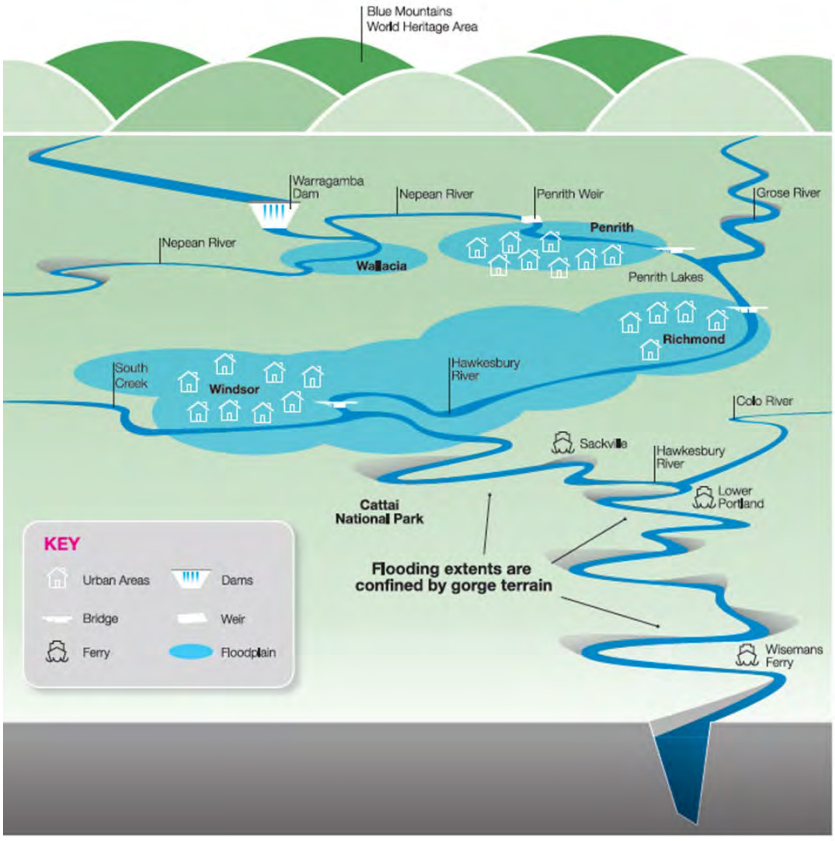


Figure 3: The 'bathtub effect' caused by some of the natural choke points in the Hawkesbury-Nepean Valley

(Source: Infrastructure NSW (17))

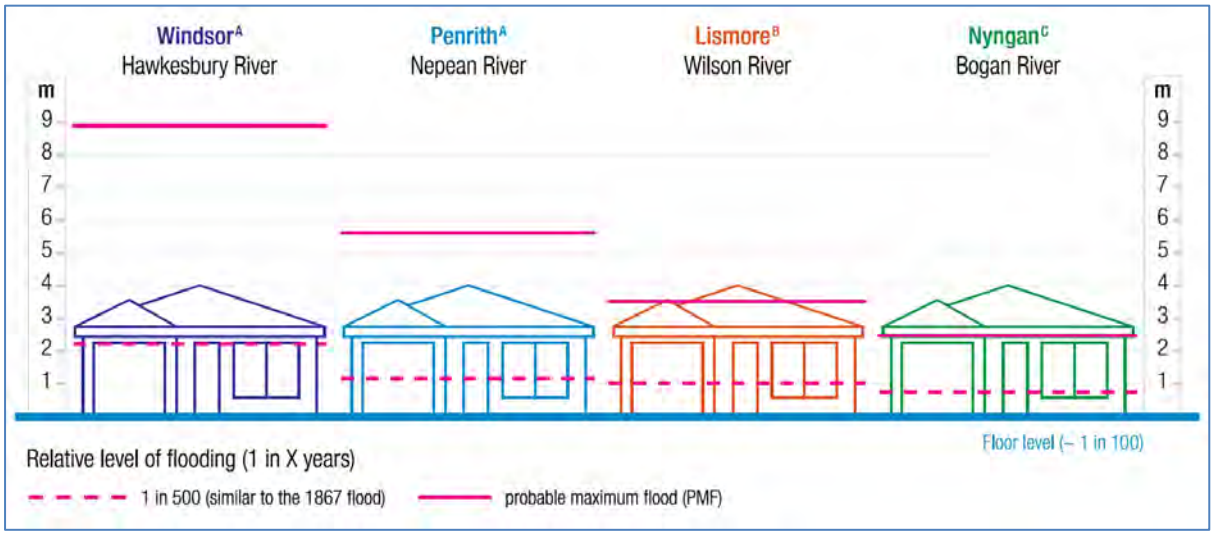


Figure 4: Comparison of the differences in flood levels and flood risk between the Hawkesbury-Nepean River and other floodplains

(Source: Infrastructure NSW (18))

A. WMAwater for the Taskforce

B. Lismore Floodplain Risk Management Plan – Glossary and Appendices (Lismore City Council, 2014)

C. Nyngan April 1990 Flood Investigation (NSW Department of Water Resources, 1990)

1.7 RIVER LEVEL GAUGING

In the monitoring of floods and the planning that takes place to deal with floods, river water levels are related to river gauging stations. These gauges measure the height of the water surface at points along a river. The Australian Bureau of Meteorology (Bureau) provides flood height predictions to several of these gauges such that people can gain an understanding of how large the flood is expected to be.

Gauge Zero

The level of a river gauge "gauge zero" is typically set at the low flow level of the stream. River heights are measured in metres above the gauge zero. For example, a river height reading of 5 metres means that the water level has risen 5 metres above its lowest level (19).

Heights within the landscape are normally measured in relation to mean sea level using Australian Height Datum (AHD). For example, the automatic flood gauge at Penrith has a gauge zero of 14.14m. This means that if the reading was 11.0m at the Penrith flood gauge this would be equivalent to a height of 25.14m AHD. The gauge at Windsor has a gauge zero of 0m. This means that if the reading was 1.0m at the Windsor gauge it would be equivalent to 1.0m AHD.

At the Victoria Bridge gauge at Penrith the gauge zero is 14.136m, therefore a reading of 10m at the gauge would be equivalent to 24.136m AHD.

Gauge Reference Area

The slope of a river channel changes along its length, with some sections flatter and others steeper. Because of these changes along the river, flood gauges are only able to be related to particular sections of the river and floodplain known as the “gauge reference area”.

Depending on what historical or modelled data is available, the consequences of flooding such as when roads will be cut, and when houses will begin to flood can be inferred from the predicted gauge height for locations within the gauge reference area.

Key Flood Gauges

The key reference flood gauges for the Hawkesbury-Nepean Valley, and for which the Bureau provides flood predictions are listed below. The designated AWRC Gauge number is shown in parentheses:

- Menangle (212904);
- Wallacia Weir (212202);
- Penrith at Victoria Bridge (212201);
- North Richmond Bridge (212902);
- Windsor PWD (212426);
- Sackville at Sackville Ferry (212406);
- Putty Road (212908);
- Lower Portland (212407);
- Webbs Creek (Wisemans Ferry) (212408).

Further details on River Level gauges in the Hawkesbury-Nepean Valley are provided in Annex B of this plan.

1.8 FLOODING OF FLOODPLAINS

Flooding of Wallacia Floodplain

Flooding in the Wallacia floodplain can be dominated by floodwaters coming from the Nepean River Catchment (typically smaller events), from the Warragamba River Catchment (larger events), or a combination of both. The narrow gorges between Wallacia and Penrith limit the rate of outflow and can cause floodwater to backup the Nepean River from the Warragamba / Nepean rivers junction to the Wallacia floodplain.

Floodwaters travel through Bents Gorge entering the Wallacia floodplain at Bents Basin (Refer to Map 3).

Once on the Wallacia Floodplain, flood waters can back up Jerrys Creek from the Nepean River surrounding the town of Wallacia to the north east and west (20). During a PMF most of Wallacia would be flooded, with only a thin

strip of land to the south of town near Greendale Road remaining flood free.

On the western side of the river, the lower lying land along Bents Basin Road can become inundated by floodwaters.

Flooding of Penrith / Emu Plains Floodplain

The upper section of the river near Penrith and Leonay has natural levee banks which help to keep flood waters contained within them to around the 1 in 100 (1%) chance per year flood event (around 11.6m at the Penrith gauge or 25.8m AHD) (15) (Refer to Map 4).

However some flooding occurs prior to the river breaking its banks where flood waters back up in local creeks including: Cranebrook Creek, Lapstone Creek, Knapsack Creek, Boundary Creek, Peach Tree Creek, Schoolhouse Creek and Mulgoa Creek (4).

Downstream of Victoria Bridge and Penrith Weir, just south of the Penrith Lakes area, the river turns sharply to the west. Floodwaters start to bypass this bend and inundate areas of Emu Plains. Flooding of the Emu Heights area is primarily caused by backwater flooding from the Nepean River, while flooding in the Penrith Lakes area develops from a combination of backwater flooding and over bank breakouts (4).

Floodwater also backs up on the southern side of the main Western Rail Line embankment in Emu Plains which is a main flow control in the floodplain (4) (21).

Floodwater can isolate parts of the communities in Emu Plains including Emu Heights, Leonay, Central and East Emu Plains, North Penrith, and the Peach Tree Creek area creating 'flood islands'. Depending on the size of the flood, these islands can gradually become completely covered by flood waters.

During large flood events floodwaters meet up on the southern and northern sides of the main Western Rail line in Emu Plains.

During a PMF most of Emu Plains, the Penrith Lakes area and parts of Penrith, extending into part of the Penrith central business district, would be flooded.

Flooding of Richmond / Windsor Floodplain

The natural constriction in the floodplain as the river enters the Sackville Gorge has a marked influence on flood behaviour upstream of this point (Refer to Map 5).

Floodwaters flow freely into the Richmond / Windsor floodplain but cannot escape at the same rate through the Sackville Gorge. As a result, water levels around Richmond and Windsor can rise to 26.7m (15) with normal river levels being about 0.5m.

Low lying farming areas including Richmond Lowlands, Cornwallis, Pitt Town Bottoms and areas along Rickabys and South Creeks are flooded first.

Depending on the size of the flood, areas that are normally hills or rises in the landscape can become surrounded by floodwaters and become isolated 'flood islands'. If floodwater continues to rise, these islands can then become completely covered by floodwater. This includes the townships of McGraths Hill, Pitt Town, Windsor, Bligh Park and parts of Richmond.

Grose River

Flood flows from this tributary can result in the river level at North Richmond rising markedly before floodwater arrives from upstream on the Hawkesbury River. There is only one rainfall and river level gauging station in the Grose Valley and no river gauge at its junction with the Hawkesbury River. The short travel time from the junction of these two rivers to North Richmond, means that warning time can be short. Flood flows from the Grose River alone can produce moderate to major flooding from Richmond and into the Lower Hawkesbury (12).

South Creek

Normally flooding of South Creek occurs as a result of local catchment runoff. However, during major flooding of the Hawkesbury-Nepean River, the lower reaches of South Creek can 'back up' South Creek from the

Hawkesbury River and flood the surrounding areas (1).

The influence of this Hawkesbury-Nepean backwater flooding on South Creek generally extends as far upstream as Mayo Road or Dunheved Road in Werrington. However during a PMF event these backwaters can extend as far upstream as the Western Motorway (M4) and main Western Rail Line (1).

Flooding of Lower Hawkesbury Floodplain

Flooding along the Hawkesbury River and its tributaries between Cattai and Broken Bay is confined within relatively deep and narrow river gorges. This results in steep flood gradients and very high flow velocities both within the river channel and the limited adjoining floodplains (15) (Refer to Map 6).

The flood behaviour of the Lower Hawkesbury River can be influenced by flooding from the Hawkesbury River upstream of Sackville combined with flooding from the major tributaries below Sackville (12).

Flooding in the lower reaches can also be influenced by the interaction of floodwater with tidal variations (5) (12).

Colo River

The Colo River can inject a large flow into the Hawkesbury River at Lower Portland. This can cause backup flooding along the Hawkesbury River towards Sackville (12).

At higher Hawkesbury River flows, the effect can be to slow down the rate of drainage from the primary floodplain which holds up flood levels in the Richmond / Windsor area (12).

Macdonald River

Flooding in the Macdonald River Valley is primarily due to surface runoff generated from the steep vegetated local catchment. However, in the lower reaches, the Macdonald River can be affected by backwater flooding from the Hawkesbury River (3).

It is believed that significant bank erosion occurred within the Macdonald River during previous flood events which caused large amounts of sand to be deposited within the river, and the river to widen. In more recent years some of this sand was flushed out of the system. Further riverbank erosion and widening is considered a possibility during future flood events (3).

1.9 FLOOD HISTORY

The Hawkesbury-Nepean Valley has experienced numerous serious floods since before the earliest days of European settlement. Floods have occurred in nearly all months of the year (Figure 2: Seasonality of Hawkesbury-Nepean floods).

The earliest European explorers noticed evidence of significant floods along the Nepean and Hawkesbury Rivers, with debris lodged in the treetops 30 to 45 feet (9.1m to 13.7m) above the normal river levels (22).

A series of floods in the early 1800's had major implications for the food supply and economy of the Sydney Colony, and led Governor Macquarie to call for the relocation of early settlements along the river to higher ground (22).

The highest recorded flood in the Hawkesbury-Nepean Valley occurred in 1867 when a height of 27.5m AHD was reached at Penrith, and 19.7m AHD at Windsor (15). This flood was also the worst that has occurred in terms of lives lost and the destruction of property and livestock. If this same flood occurred today it would reach 19.3m AHD at Windsor because the presence of Warragamba Dam has some flood mitigating effect (11).

The highest flood since Warragamba Dam was completed in 1960, and the highest in living memory, occurred in November 1961 when flood levels reached 9.75m (23.9m AHD) at Penrith and 15.0m at Windsor.

The most recent major flood (defined as being above 12.2m at Windsor) was experienced in 1990 when flood levels reached 9.3m (23.4m AHD) at Penrith and 13.5m at Windsor.

Other major floods in the valley and their heights at Windsor and Penrith are shown in Figure 5.

Despite a history of significant floods, most of the current population living within the floodplain have experienced only small flood events. The highest flood since 1992 occurred in February 2020, which reached only a minor level at Penrith (6.1m = 20.3m AHD) and moderate level at Windsor (9.3m).

There is some sedimentary evidence that floods larger than the 1867 flood occurred prior to European settlement (23).

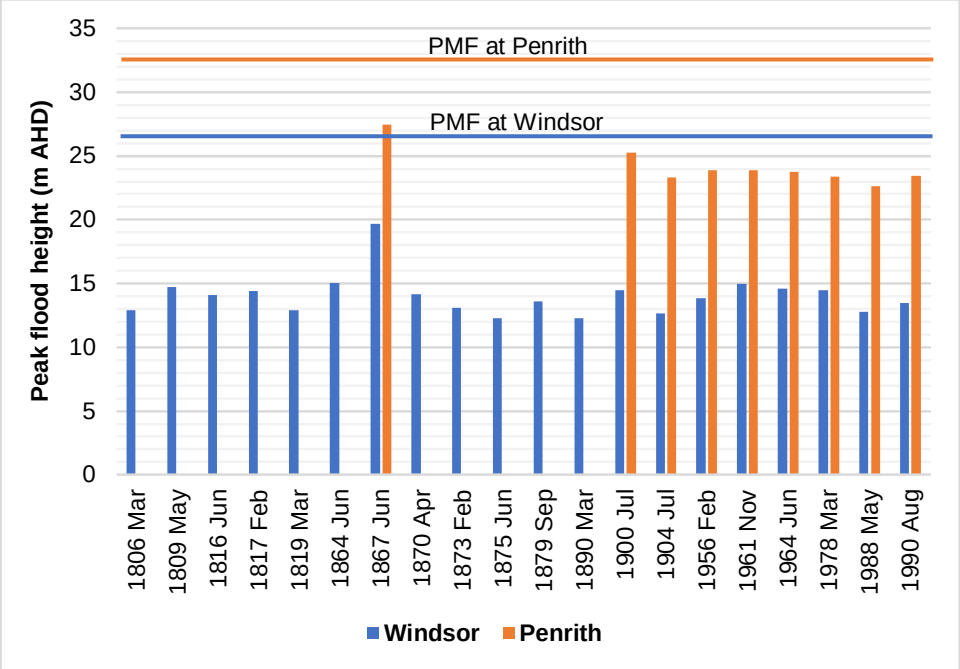


Figure 5: Hawkesbury-Nepean Flood History showing Major Floods at or above 12.2m at Windsor

Data source: (15)

Notes:

- The PMF level at Windsor is 26.7m AHD, and at Penrith is 32.8m AHD (15). (Flood levels are higher at Penrith due to it being upstream and higher in elevation).
- All readings were taken at either the Windsor Bridge gauge at Windsor or the Victoria Bridge gauge at Penrith and are in metres AHD.
- The gauge zero for the Windsor gauge is 0m, and the gauge zero for Victoria Bridge manual gauge at Penrith is 14.136m.
- All flood levels are as observed, without adjustment for Warragamba Dam, which was completed in 1960.

1.10 FLOOD MITIGATION SYSTEMS

There is currently no significant flood specific mitigation infrastructure within the Hawkesbury-Nepean Valley to reduce risk to property from a Hawkesbury-Nepean River flood (11).

A number of small flood mitigation systems have been constructed further upstream in the South Creek catchment primarily to deal with local catchment flooding in the St Marys and Werrington areas (1).

There is also a small private levee in a tributary of McKenzie's Creek near Pitt Town which appears to slightly delay water from entering the Pitt Town Bottoms area from South Creek.

A number of investigations of flood mitigation options have been undertaken for the Hawkesbury-Nepean River, including the Hawkesbury-Nepean Valley Flood Review (11) and the Taskforce Options Assessment Report (18). These have considered options to:

- Store or capture flood waters (e.g. flood mitigation dam, modification of Warragamba Dam Gate operations).
- Drain or divert water away from the valley (e.g. diversions and dredging).
- Provide local protection up to a certain level (e.g. levees).

Investigations into these flood mitigation solutions have found that there is no simple or significant solution or single infrastructure option that can eliminate all of the flood risks in the Hawkesbury-Nepean Valley.

1.11 FLOOD FREQUENCY/SIZE

Floods that are frequent are smaller; floods that are rarer are larger. The frequency and size of floods at six key flood warning gauges is described in Table 2. These results are derived from detailed flood investigations.

The size of floods is often described as a flood level (or height) at a river gauge (see Section 1.8).

The frequency of floods is expressed as an **Annual Exceedance Probability (AEP)**. This is the chance of a flood of a given or larger size occurring in any one year. AEP may be expressed as either a percentage (%) or 1 in X. For example, the peak level corresponding to a 5% AEP (or 1 in 20 AEP) flood has a 5% chance (that is, a one-in-20 chance) of being reached or exceeded in any one year. This is the preferred way to express flood probabilities.

Periods of both more frequent and more severe flooding than have been seen in recent times must be expected in the future.

It is expected that with climate change, flood levels for the 1% (1 in 100) AEP event at Windsor would rise by 0.7m (for a 9.1% increase in rainfall in 2071). Another way of looking at it is that the current 1% (1 in 100) AEP chance level will occur more frequently and would become a 1 in 65 AEP event (15).

Table 2: Hawkesbury-Nepean flood levels for different probabilities at various flood warning gauges

Frequency (AEP)		Wallacia Weir		Penrith (at Victoria Bridge)		North Richmond Bridge		Windsor (at Windsor Bridge)		Sackville		Wisemans Ferry (Webbs Creek Ferry site)	
% chance per year	1 in X chance per year	m AHD	m on gauge	m AHD	m on gauge	m AHD	m on gauge	m AHD	m on gauge	m AHD	m on gauge	m AHD	m on gauge
20%	1 in 5	34.8	8.2	19.6	5.4	11.4	11.4	9.9	9.7	6.3	6.3	2.8	3.0
10%	1 in 10	37.0	10.4	21.3	7.2	13.7	13.7	11.9	11.8	8.4	8.4	3.7	3.9
5%	1 in 20	39.3	12.7	23.3	9.2	15.4	15.4	13.7	13.6	10.1	10.1	4.8	5.0
2%	1 in 50	42.5	15.9	24.8	10.7	16.5	16.5	16.1	15.9	12.1	12.1	6.2	6.4
1%	1 in 100	44.6	18.0	25.8	11.6	17.6	17.6	17.3	17.2	13.2	13.2	7.2	7.4
0.5%	1 in 200	46.5	19.9	26.5	12.3	18.6	18.6	18.4	18.2	14.2	14.2	8.2	8.4
0.2%	1 in 500	48.9	22.3	27.1	13.0	19.8	19.8	19.6	19.5	15.6	15.6	9.5	9.7
0.1%	1 in 1000	50.7	24.1	27.5	13.4	20.7	20.7	20.6	20.4	16.7	16.7	10.5	10.7
0.05%	1 in 2000	54.2	27.6	28.4	14.2	21.9	21.9	21.7	21.6	18.0	18.0	11.4	11.6
0.02%	1 in 5000	58.3	31.7	29.4	15.3	22.8	22.8	22.6	22.5	19.2	19.2	12.8	13.0
PMF		66.3	39.7	32.8	18.6	26.8	26.8	26.4	26.6	23.6	23.6	14.5	14.7

Source: Hawkesbury-Nepean Valley Regional Flood Study: Final Report (July 2019) (15)

Note: For Wallacia Weir, higher flood levels for more frequent flood sizes are reported in the Upper Nepean River Flood Study (1995) (24). The 1% (1 in 100) AEP level is 45.6m AHD in the Upper Nepean River Flood Study. Further investigation of Wallacia flood levels is occurring through development of the Hawkesbury-Nepean River Flood Study (Infrastructure NSW) in 2020-21. This work may lead to changed flood level estimates for other locations too.

1.12 EXTREME FLOODING

For planning to be capable of being effective in all circumstances, it must take into account the worst floods that could occur. Information about the full range of possible flooding is obtained from scientific studies that have determined how bad the worst floods are likely to be. The greatest depth of rainfall possible over a given area in a nominated time period (e.g. 24hrs or 72hrs) is called the Probable Maximum Precipitation (PMP).

The highest possible flood level is called the Probable Maximum Flood (PMF). For the Hawkesbury-Nepean Valley it is when the PMP distributed over the whole catchment in a 72 hour period that the greatest depth of flooding results (i.e. the 72 hour PMF). The modelling for the 72 hour PMF in the Hawkesbury-Nepean Valley assumes the following conditions:

- Full storage at the Warragamba Dam;
- A fully saturated (wet) catchment.

The rainfall required is in the order of 770 millimetres across the Warragamba catchment in a 72 hour period (72 hour PMP) (15). Note that this requires an average of only about 11 millimetres/hour.

A PMP in the entire Hawkesbury-Nepean catchment and the resulting PMF is estimated to have 0.001% AEP (one chance in 100,000 each year) of occurring (15). This means they are very rare probability events.

Rainfall heavy enough to support the idea of PMP has been observed in various places around the world including Australia (Wollongong 1984 – 440 millimetres in 6 hours over a 100 square kilometre area). Flood records from around the world demonstrate that PMF events have occurred.

The PMP distributed over other time periods and the resulting floods that they would produce have also been modelled for the Hawkesbury-Nepean Valley and its sub-catchments. For instance, the 24 hour PMP for the Warragamba catchment results in the critical PMF for Warragamba Dam. The rapidly rising water results in the highest water level in Warragamba Dam (but not the downstream floodplain) and is therefore most critical for dam safety (25).

The 24 hour PMF for the Warragamba catchment would have an estimated peak inflow at Warragamba Dam of approximately 52,100 cubic metres of water each second and an outflow of approximately 42,200 cubic metres per second. It is estimated that this PMF would have a total flood volume of around 6,000 gigalitres (25).

By way of comparison, the November 1961 flood (the largest flood in living memory) had an estimated peak inflow at Warragamba Dam of 9,000 cubic metres per second and an outflow of 7,590 cubic metres per second. The November 1961 flood which reached 23.9m AHD at Penrith and 15.0m at Windsor has been estimated to have a 2.5% AEP (one in 40 chance of occurring in any one year) (25).

Floods much larger than those in living memory, and even larger than the flood of record can occur within the Hawkesbury-Nepean Valley.

Map 2 shows the predicted PMF Flood extent as well as the 1% AEP (1 in 100 year) flood extent for the Hawkesbury-Nepean Valley.

PART 2 EFFECTS OF FLOODING ON THE COMMUNITY

2.1 INFORMATION SOURCES

Data used in this plan has been sourced from the most current published reports. This information is currently being reviewed as part of the Hawkesbury-Nepean Valley Flood Review Stage 2 Taskforce. This plan will be updated accordingly as further information becomes available.

2.2 POPULATION

It is estimated that around 91,000 people are currently living in areas prone to flooding from the Hawkesbury-Nepean River. This estimate assumes that dwellings are occupied as they were on census night (2016), however these numbers are likely to vary with higher numbers expected during summer, on weekends and during holiday periods.

Sydney's population is expected to grow significantly into the future, with new development areas including part of the North West Growth Centre located within the Hawkesbury-Nepean floodplain (11). Within the Metropolitan West subregion of Sydney (most of which is located in the Hawkesbury-Nepean Valley) there is an expected increase of 89,000 people by 2031 (11).

2.3 SIGNIFICANCE OF AREA

The Western Sydney region is one of Australia's largest and most diverse economies with an annual gross regional product of over $104 billion in 2013-2014. Important industries include fresh fruit and vegetables, turf farms, horse studs, eggs and poultry, oyster farms, manufacturing and processing industries, water-ski parks and other forms of tourism.

The Hawkesbury-Nepean catchment is also significant due to its many natural values including the Blue Mountains World Heritage Area. It is the source of drinking water to over 5 million people in Sydney, the Illawarra and the Blue Mountains (26).

2.4 FLOOD EMERGENCY RESPONSE CLASSIFICATION OF COMMUNITIES

Communities can be affected by flooding either directly, or indirectly. Depending on their location in the landscape, and the roads and services available to them during a flood these communities can have differing needs for assistance during a flood such as information and warning provision, evacuation, resupply and/or rescue. Communities can be classified according to the impact that flooding has on them and the potential assistance they may require. The five classifications are outlined in the Flood Emergency Response Classification Guidelines and are described below (Refer to Figures 5 to 11):

- Flood Islands (High and Low);
- Areas with Overland Escape Routes;
- Areas with Rising Road Access;
- Trapped Perimeters (High and Low); and
- Indirectly affected areas.

Note: These definitions are described in terms of the impact of a PMF. However these classifications may be different at different levels of flooding (e.g. the same community may be isolated during a smaller flood event, but may be completely inundated during a larger event).

Flood Islands

These are inhabited areas of high ground within a floodplain linked to flood free areas by an access road. The access road can be cut by flood water, closing the only evacuation route and creating an island.

After closure of the road the only access to the area is by boat or by aircraft.

Flood islands are further classified according to what can happen after the evacuation route is cut into High Flood Islands and Low Flood Islands.

High Flood Island

The flood island is higher than the limit of flooding (i.e. above the PMF). The island is surrounded by flood water but there is still enough land available to provide a flood free space for people remaining in the area. This flood free space may not be enough to adequately sustain the population. Properties may or may not be flooded.

The area will require resupply by boat or air if not evacuated before the road is cut. Evacuation will have to take place before isolation occurs if it will not be possible to provide adequate support during the period of isolation, if essential services won't be available, or if houses will be flooded.

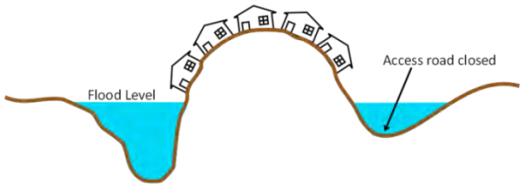


Figure 6: High Flood Island

Low Flood Island

The flood island is lower than the limit of flooding (i.e. below the PMF). If flood water continues to rise after it is isolated, the island will eventually be completely covered with all properties inundated. People left stranded on the island may drown unless rescued. Evacuation must be completed before roads are inundated.

Figure 7: Low Flood Island

Trapped Perimeters

These are similar to 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 unavailable during a flood event. In some cases normal access to the area is by boat but flood conditions may prevent usual boat access.

The ability to retreat to higher ground does not exist due to topography or impassable structures. Trapped perimeter areas are further classified according to what can happen after the evacuation route is cut as follows:

High Trapped Perimeters

These are inhabited areas above the PMF but the only access road/s is across flood prone land. Road access may be closed during a flood.

The area will require resupply by boat or air if not evacuated before the road is cut. Evacuation will have to take place before isolation occurs if it will not be possible to provide adequate support during the period of isolation, if essential services won't be available, or if houses will be flooded.

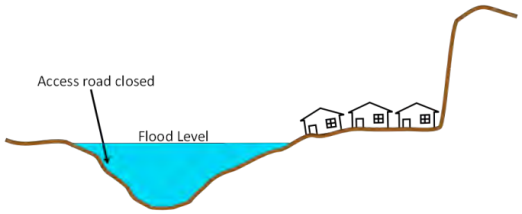


Figure 8: High Trapped Perimeter

Low Trapped Perimeters

The inhabited area is lower than the limit of flooding (i.e. 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. People left stranded may drown if not rescued. Evacuation must be completed before roads are inundated.

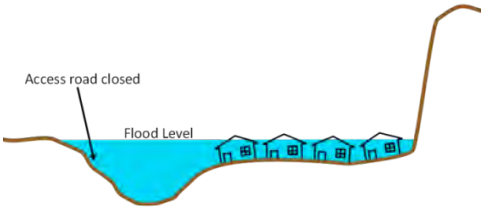


Figure 9: Low Trapped Perimeter

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 water will be possible by walking overland to higher ground. Anyone not able to walk out must be reached by using boats and aircraft. If people cannot get out before inundation, rescue will most likely be from rooftops. Pedestrian evacuation must never be relied upon as a primary evacuation strategy. It is only ever a back-up strategy if vehicular evacuation fails.

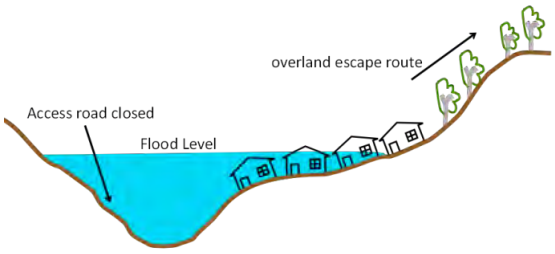


Figure 10: Area with Overland Escape Route

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. The community cannot be completely isolated before inundation reaches its maximum extent.

Evacuation can take place by vehicle or on foot along the road as flood waters advance. People should 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 will 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.

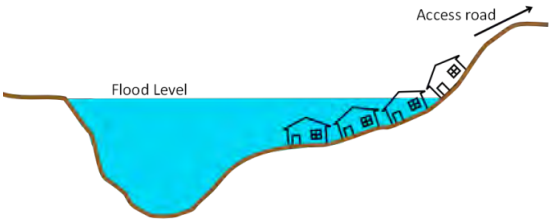


Figure 11: Area with Rising Road Access

Indirectly Affected Areas

There will be areas outside the limit of flooding which will not be inundated and will not lose road access. Never the less they may be indirectly affected as a result of flood damaged infrastructure such as due to the loss of transport links, electricity supply, water supply, sewage or telecommunications services. They may require resupply or in the worst case, evacuation.

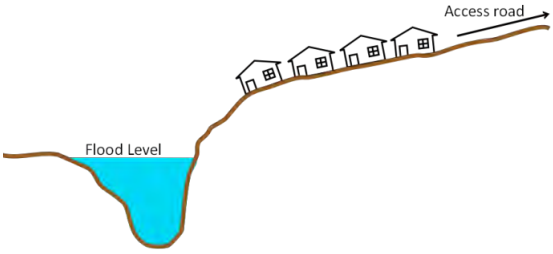


Figure 12: Indirectly affected area

2.5 HAWKESBURY-NEPEAN FLOOD EMERGENCY RESPONSE CLASSIFICATIONS

Within the Hawkesbury-Nepean Valley each area has been classified according to its flood emergency response classification. Some of the most critical areas including those that are classified as Low and High Flood Islands and Trapped Perimeters are shown in Table 3 and Table 4.

These are summarised by floodplain and according to the order that their evacuation routes are cut (See also Annex C, Tables 2 to 5 for a full list of Sectors, their Emergency Response Classification and heights at which roads are expected to be cut).

Table 3: The main Hawkesbury-Nepean flood risk areas and the heights at which they are expected to be flood affected in the Richmond Windsor Floodplain

Floodplain	Area (Sector / Sub-sector)	Flood Classification	Last Road Cut m AHD	Submersion Height m AHD	Comments
Richmond / Windsor / Wilberforce	Wilberforce / Grono's Point	High Flood Island	Around 6.5m to 6.75m (at Windsor gauge)	>PMF	Becomes isolated early during a flood at 5.1m AHD locally which is equivalent to around 6.5m to 6.75m at the Windsor gauge (27). Some small flood free area during a PMF (28) (29).
	Richmond Lowlands (RL203 road point ID)	Low Flood Island	10.86m AHD (30)		Properties begin to be flooded by 12.5m AHD at Richmond gauge (5) with most of the surrounding agricultural areas also flooded.
	McGraths Hill (MH1, MH1a, MH1b road point ID)	Low Flood Island	13.5m (31)	16.0 to 18m	Some properties are flooded in 5% AEP (13.7m at Windsor), with nearly all properties flooded in a 1% AEP (17.3m at Windsor) (5).
	Yarramundi	Trapped Perimeter	15.1 to 15.5m (5)	Not fully submerged	Becomes isolated in less than a 1% AEP event. Some properties flooded in a 2% AEP, with around 35 flooded in a PMF (5).
	Wilberforce / Ebenezer	High Flood Island	15.5m (5)	>PMF	Isolations begin from 9.6m AHD , with properties flooded from 11.1m AHD. During a PMF around 50% of properties would be flooded and 50% isolated (5).
	Pitt Town and Pitt Town Bottoms	Low Flood Island*	16m (30)	>PMF	*There is a very small area of land which remains flood free during a PMF. Some isolations begin from 6.2m (Windsor gauge) in Pitt Town Bottoms (32). A number of dwellings in Pitt Town would be flooded by 13.7m AHD (5).
	Windsor (Windsor 1 road point ID)	Low Flood Island	17.3m (33) (14m *)	26.0m	Some properties flooded from 11.1m AHD (5). *The Windsor North area also becomes a flood island at 14m AHD and is submerged at 22.3m (5).
	Bligh Park	Overland Escape (Low Flood Island)	18.5m (5) (17.2m*)	25.0m (>PMF)	There is some opportunity for overland escape into Windsor Downs Nature Reserve. *Internal road closures occur prior to 18.5m (5) from 17.2m AHD.
	Richmond RAAF	Low Flood Island	20.1m	20.4m	Flooding begins at around 16.4m at North Richmond gauge. 19.3m low point on Windsor St, Richmond affects late evacuations (5).

Floodplain	Area (Sector / Sub-sector)	Flood Classification	Last Road Cut m AHD	Submersion Height m AHD	Comments
Richmond / Windsor / Wilberforce	Richmond (RAO road point ID)	Low Flood Island	20.2m (5)	23.6m (5)	Some properties affected from 15.3m AHD at Richmond gauge, with most unaffected until above the 1% AEP event (17.5m at Richmond gauge).
	Windsor Downs	Flood Island (Parts Low parts High)	23.8m (16.7m - 19m internal roads cut) (5)	26.4m (PMF)	Some opportunity to escape by foot to the Windsor Downs Nature Reserve.

Note: Not all sectors are shown

Table 4: The main Hawkesbury-Nepean flood risk areas and the heights at which they are expected to be flood affected in other areas

Floodplain	Area (Sector / Sub-sector)	Flood Classification	Last Road Cut m AHD	Submersion Height m AHD	Comments
Lower Hawkesbury	Singletons Mill	Trapped Perimeter	Various locations from 1.2m (30)		Properties will become isolated during smaller flood events, but may be flooded during larger events.
	Gunderman	Trapped Perimeter	1.2 to 2m (30)		Wisemans Ferry Road becomes cut in a number of places between Wisemans Ferry and Spencer.
	Macdonald River	Trapped Perimeter	1.5m to 1.9m (30)		Cut at St Albans Rd (1.5m) and Settlers Rd (1.9m) causing isolations. Also isolated by Ferry Closures. Significant number of properties flooded in a 1% AEP event.
	Lower Reaches	Trapped Perimeter	1.5 to 4m (30)		River Road cut in a number of places from 1.5m AHD. Some caravan parks will become isolated and flood affected during 20% AEP events (5).
	Webbs Creek (ID 297 & 298 road point ID)	Trapped Perimeter	2.05m and 2.28m (30)		Webbs Creek Rd and Chaseling Roads are cut due to flooding (30) and Webbs Creek Ferry closes isolating properties and caravan parks.

Floodplain	Area (Sector / Sub-sector)	Flood Classification	Last Road Cut m AHD	Submersion Height m AHD	Comments
Emu Plains / Penrith / Castlereagh	Penrith / Peach Tree Creek West	Low Flood Island	22.1m at the Penrith gauge (28)		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 23.6m AHD.
	Penrith / North Penrith A	Low Flood Island	22.3m at the Penrith gauge (28)		This contains Industrial / Commercial areas.
	Penrith / Regentville (ID 56 road point ID)	Low Flood Island in parts	23.2m at the Penrith gauge (28)		Cut at Factory Road isolating a number of properties near the Nepean River which can be flooded in larger events (28).
	Emu Plains / Emu Heights	High Trapped Perimeter	23.8m at the Penrith gauge (28)	>PMF	Properties become isolated when Wedmore Road close to Alma Crescent is cut (28).
	Emu Plains / East	Low Flood Island	25.7m at the Penrith gauge (28)	28m	River Road is initially cut at Jamison Creek, then along its entire length.
	Emu Plains / Central West	Low Flood Island	25.7m at the Penrith gauge (28)	31m	This area becomes isolated around a 1% event (26m AHD or 11.9m at the Penrith gauge).
	Emu Plains / Leonay E, W, S, N and Central	Overland Escape	34.35m AHD locally (34)		Road evacuation route cut on Leonay Parade at Knapsack Creek culvert.
Wallacia	Wallacia / Bents Basin	Overland Escape	33.9m AHD locally (27)		Bents Basin Road is cut at Baines Ck early during flooding isolating the area. Properties may be flooded during larger flood events. Overland escape may be possible up the hills to the west.
	Wallacia / Sth Wallacia (WA1) (20) and (29) road point ID	High Flood Island	61.5m locally (39.8m main evac route cut)	>PMF	The Park Road Evacuation Route is cut at 39.8m AHD. The alternative route is through a private property on a dirt track. Many properties would be flood affected in a PMF.

Table 5: Estimated number of properties and people affected by flooding in the Hawkesbury-Nepean floodplain

	Properties			People		
Flood Size (1 in x chance per year)	Residential properties affected by flooding (Note 1) (Note 2)	Residential properties affected by flooding more than 2.1m deep at location of dwelling (Note 2)	Number of commercial and industrial buildings affected by flooding (Note 3)	Residents: Residential population in flooded areas	Employees: Employees who work in the floodplain but live outside the floodplain	TOTAL People who live or work in flooded areas
1 in 5	730	40	30	1,600	270	1,900
1 in 10	1,600	420	110	3,800	1,600	5,400
1 in 20	2,500	1,200	200	6,100	2,900	9,000
1 in 50	4,800	2,700	530	12,400	5,900	18,200
1 in 100	7,600	4,100	940	19,800	9,600	29,400
1 in 200	9,900	5,500	1,200	25,700	12,300	38,100
1 in 500	15,500	7,400	1,800	39,000	23,700	62,600
1 in 1,000	19,600	9,900	2,300	49,100	30,300	79,400
1 in 2,000	23,600	14,400	2,700	58,500	36,500	95,000
1 in 5,000	26,200	19,700	3,100	65,100	39,900	105,000
PMF	36,700	31,800	3,800	91,000	48,100	139,000

Source: HNV Strategy Database: January 2020

Values have been rounded

Note 1: Residential properties and population include manufactured homes (caravans, manufactured homes, temporary dwellings, cabins etc.) located within caravan parks

Note 2: The number of residential properties affected by flooding relates to the property level (2017 Lidar, 2011 Lidar downstream of Wisemans Ferry) at the location of the dwelling (not the centroid of the property). The number of properties does not relate to the floor level of the dwelling.

Note 3: The number of commercial and industrial buildings affected by flooding relates to the property level (2017 Lidar, 2011 Lidar downstream of Wisemans Ferry) at the centroid of the building (not the centroid of the property). The number of properties does not relate to the floor level of the building.

Table 6: Estimated number of residential properties flooded by Local Government Area

(from HNV Strategy Database, includes manufactured homes)

Flood Size (1 in x chance per year)	Residential properties affected by flooding by Local Government Area (Note 1) (Note 2)								TOTAL FLOOD PLAIN
	Liverpool City Council	Wollondilly Shire Council	Penrith City Council	Hawkesbury City Council	Blacktown City Council	The Hills Shire Council	Hornsby Shire Council	Central Coast Council	
1 in 5	0	0	0	240	<10	270	30	190	**730**
1 in 10	0	0	10	660	<10	690	40	220	**1,600**
1 in 20	0	<10	70	1,270	40	900	40	240	**2,500**
1 in 50	0	<10	270	2,990	260	990	50	260	**4,800**
1 in 100	<10	<10	1,740	4,200	370	1,020	60	290	**7,600**
1 in 200	<10	<10	2,610	5,400	520	1,050	70	310	**9,900**
1 in 500	<10	10	5,700	7,500	760	1,070	90	330	**15,500**
1 in 1,000	10	20	7,400	9,600	1,040	1,100	100	350	**19,600**
1 in 2,000	30	40	9,000	11,600	1,290	1,120	120	370	**23,600**
1 in 5,000	50	40	10,100	12,700	1,600	1,150	150	410	**26,200**
PMF	100	50	14,200	15,800	4,700	1,330	190	450	**36,700**

Source: HNV Strategy Database: January 2020

Values have been rounded

Note 1: Residential properties and population include manufactured homes (caravans, manufactured homes, temporary dwellings, cabins etc.) located within caravan parks.

Note 2: The number of residential properties affected by flooding relates to the property level (2017 Lidar, 2011 Lidar downstream of Wisemans Ferry) at the location of the dwelling (not the centroid of the property). The number of properties does not relate to the floor level of the dwelling.

2.6 RISK TO PROPERTY

There is a risk of above floor flooding of properties within the Hawkesbury-Nepean Valley from around a 5% AEP or 1 in 20 year event (13.55m at the Windsor gauge). The number of properties affected by flooding increases markedly with increasing flood size larger than a 1% AEP (1 in 100 chance per year flood) (Tables 5 and 6).

An estimated 36,700 dwellings could be flooded within the Hawkesbury-Nepean Valley during a PMF event.

Of the 36,700 properties flooded during a PMF, 31,800 or 87% of these would have flooding 2.1 metres deep and could be severely damaged (See tables 5 and 6).

2.7 EVACUATIONS

In flood events the people considered for evacuation includes residents and employees both in the flooded area and isolated by floodwaters (Figure 12). A PMF flood event would require the evacuation of around 139,000 people from the Hawkesbury-Nepean Valley.

During floods with a 5% chance of occurring each year (AEP) (i.e. 13.7m AHD at Windsor and 23.5m AHD at Penrith) around 9,000 people would require evacuation from flooded properties.

This number increases significantly to around 55,000 people requiring evacuation for floods above the 1% AEP (17.3m AHD at Windsor and 26.1m AHD at Penrith) as this is the default planning level at or above which residential floor levels have generally been set by Councils (11).

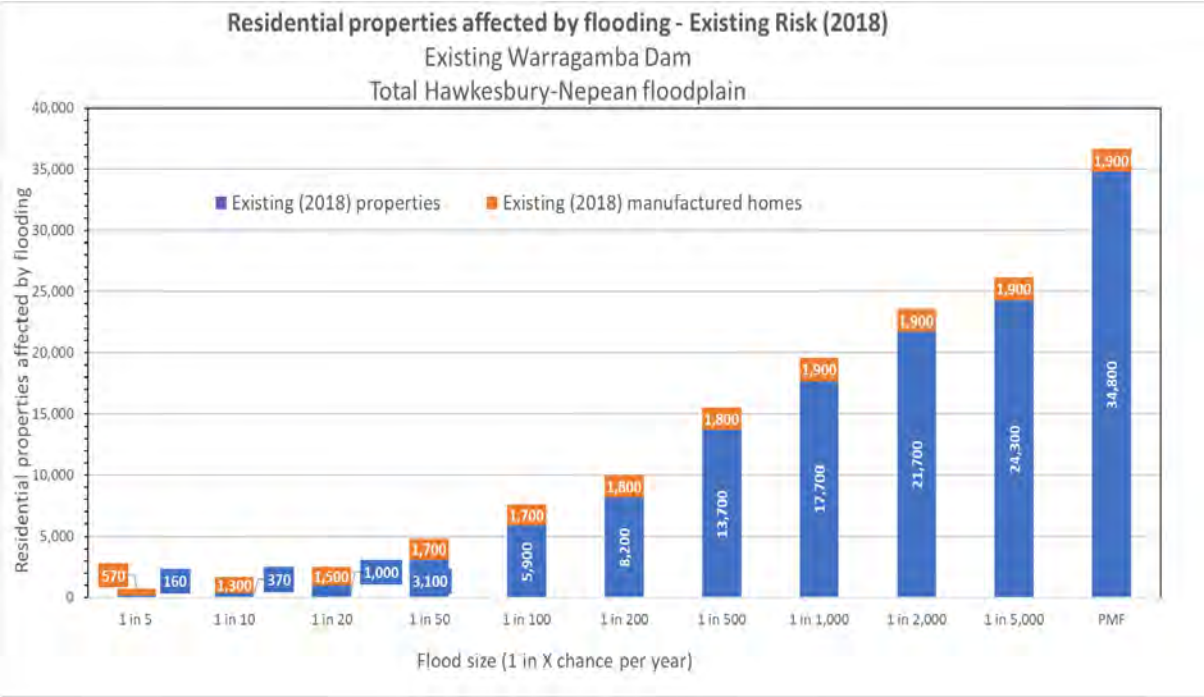


Figure 13: Estimates of the residential properties affected by flooding in the Hawkesbury-Nepean Valley dependant on flood size (Source: HNV Strategy Database, January 2020)

Risk to Life

During Hawkesbury-Nepean Valley floods there is a risk to life from drowning, electrocution and accidents which are mainly related to the depth and velocity of flood waters (35).

The decision point to call an evacuation of people from the Hawkesbury-Nepean Valley may need to be based only on uncertain rainfall predictions. This is due to the amount of time required to evacuate all vehicles, combined with rapid river rises. For example it is expected that the evacuation of Windsor could take more than 15 hours.

It means that evacuations may need to be called even before rain has started to fall and when river levels are still contained within the banks (11).

It is anticipated that it may be difficult to convince the community to leave without significant visual cues (35). Because of this people could potentially decide not to leave early enough and may become trapped on shrinking flood islands.

If people fail to evacuate in time there will be an expectation that mass rescues by either boat or helicopter will occur. The community and the government need to be aware that severe weather, resource limitations and the time required to complete such operations may mean that this is not possible and lives may be lost.

2.8 VULNERABLE FACILITIES, PEOPLE AND BUSINESSES

In addition to the evacuations required from residential areas, early evacuation of vulnerable facilities and assistance to other vulnerable people is required during Hawkesbury-Nepean flood events. There are also a number of important facilities located within the floodplain that require early notification of potential flooding.

Hospitals and Aged Care Facilities

There is one public hospital, three private hospitals, and 9 Residential Aged Care Facilities within the Hawkesbury-Nepean Valley (36).

Some facilities including the Hawkesbury Hospital will require evacuation when floods are predicted to reach around 16m AHD at the Windsor gauge and 12.9m (27m AHD) at the Penrith gauge (28).

Others may have to rely on emergency generator power, or consider evacuation if water supply and sewage were to be disrupted.

Other Vulnerable People

Particular assistance will also be required for the elderly, people living by themselves, those with health related issues, those with disabilities, those from culturally and linguistically diverse communities (CALD) and those who do not have access to their own vehicles.

Schools, Childcare Centres and other Educational Facilities

There are 37 schools and around 34 Childcare centres at risk of flooding within the Hawkesbury-Nepean Valley.

Western Sydney University, Richmond TAFE, Nirimba TAFE and Nepean TAFE are also located within areas that have the potential to be flood affected up to the PMF.

Businesses

There are a large number of businesses potentially affected by flooding within the Hawkesbury-Nepean Valley (35). This includes businesses in town centres and main shopping districts including Windsor, Richmond, Emu Plains and Penrith.

In addition to the main town centres, there are also a number of industrial and commercial precincts including Mulgrave, South Windsor, North Penrith, Peach Tree Creek (Penrith), Jamisontown and Emu Plains that are at risk of flooding.

Manufactured Home Estates and Caravan Parks

There are approximately 37 manufactured home estates and caravan parks located within flood prone areas of the Hawkesbury-Nepean Valley. The majority of these estates and parks are located along the banks of the Hawkesbury River downstream of Windsor with a mixture of long term, and short term caravan sites, manufactured homes and camping areas.

Many caravans are owned by people as holiday sites that can live some distance away. Some of these caravan parks are primarily accessed via the Windsor Bridge, and/or car ferries that are cut early during flood events. In the 1% AEP event several parks will be inundated by as much as 9m (5).

Many residents are retirees or other support, and may need assistance for evacuation.

Access can be lost early for most of these estates and parks therefore early notification of potential flooding is vital (5).

Correctional Facilities

There are two correctional facilities located within the Hawkesbury-Nepean Valley:

- The Emu Plains Correctional Centre is located on the floodplain at Emu Plains (37).
- The John Morony Correctional Complex incorporating the Dylwynia Correctional Centre (Womens) is located 5 km south of Windsor and is just on the edge of the PMF flood extent (37). Whilst it is not expected to be flooded its access and essential services may be affected.

RAAF Base Richmond

The RAAF base located at Richmond is the principal air transport facility for the Royal Australian Air Force. During the day there is expected to be up to 2350 people on the base, with around 800 people at night. However it can have up to 4610 people when at full capacity with Cadets (38). There is also a sewage treatment plant on site (5).

The RAAF base begins to have some flooding from above a 2% AEP (1 in 50 year) flood event (around 16.4m at the North Richmond gauge).

Most of the base would be flooded in a 0.2% AEP (1 in 500 year) flood event (at around 20.1 to 20.4m at the Nth Richmond gauge) (5).

2.9 HEALTH AND WELFARE

Direct contact with floodwaters can result in people becoming sick due to raw sewage and other contaminants being present in the water (35).

The trauma and stress arising from being evacuated, losing property, cleaning up and having to cope with severely disrupted living conditions. (35)

2.10 UTILITIES AND SERVICES

Flooding can impact on many utilities and services in both the flood affected and surrounding non-flooded areas (Refer to Table 7 and Table 8).

Electricity Supply

Electricity supply to Hawkesbury-Nepean Valley and surrounds is expected to be impacted by flooding due to damage to electricity network infrastructure as well as damage to the actual sub-stations. The amount of damage that is incurred will depend on the depth and velocity of floodwaters involved, as well as the amount of debris build up around them (35).

The first electricity outages to some rural customers are expected at moderate flood levels of around 8m to 10m AHD at Windsor and around 9.9m at Penrith (24m AHD) (35).

Above 14.5m at Windsor, electricity supplies are expected to be cut to the Northern side of the river.

Other electricity outages are expected to occur in both flooded and non-flooded areas as flood levels increase.

Following extreme floods some substations may need to be completely rebuilt, and electricity supplies may be disrupted for a number of months (35).

Communications

During flood events, land telephone systems are expected to be affected in some areas due to loss of electricity as well as inundation of telephone exchanges.

Telephone services will generally be able to be kept operational through the use of battery power for the first 6 hours, then the use of mobile generator power (35). However during major floods of above 22m at Windsor gauge and 13.9m (28m AHD) at Penrith land-line telephone services could potentially be disrupted for up to 2 to 4 weeks (35).

There is also likely to be a reduction of mobile telephone service availability within flooded areas, particularly above 18.6m AHD at the Windsor gauge and above 10.4m (24.5m AHD) at Penrith (35). However, mobile base stations could potentially be used to maintain some level of service if they are available.

Sewage

There are a number of sewage pumping stations within the floodplain which could potentially fail due to loss of power supply. This will result in raw untreated sewage being discharged into local waterways until power can be restored (35).

There are eight Sewage Treatment Plants (STPs) potentially affected by flooding in the Hawkesbury-Nepean Valley. Of these, the Penrith, St Marys, Nth Richmond, Richmond and McGraths Hill STPs are expected to be damaged to such an extent that they will need to be completely rebuilt when flood levels reach 31m AHD at Penrith and 20.1m AHD at Windsor. In these cases reconstruction is expected to take up to 12 months to become fully operational (35).

Water Supply

Water supply could potentially be disrupted by flooding due to damage to pumping stations, loss of electricity or damage to the actual pipelines.

Once the Windsor and North Richmond Bridges are closed, water supplies will be cut off as pipelines over these bridges are closed as a precaution to protect against damage to the pipes (39).

2.11 TRANSPORT INFRASTRUCTURE

Major road bridge and rail closures within the Hawkesbury-Nepean Valley are detailed in Annex H to this plan and within the relevant local flood plan.

Roads

Road closures including many road evacuation routes will occur throughout the floodplain at various flood levels as listed in Annex D. These road closures can isolate people in areas that may subsequently become inundated by flood waters.

Bridges

There are a number of bridges within the Hawkesbury-Nepean Valley that are inundated at various floods heights (refer to Annex H). These bridges will likely close prior to the listed heights dependant on debris and engineering assessments. They include (40):

- Blaxlands Crossing Bridge, Wallacia deck height 5.5m at Wallacia gauge (35.13m AHD);
- Yarramundi Bridge (Deck height 6.62m AHD (41));
- Windsor Bridge deck height 7.05m at Windsor gauge (7.2m AHD (41));
- North Richmond Bridge deck height 8.46m at North Richmond gauge (8.8m AHD (41));
- Victoria Bridge at Penrith deck height 15.7m at Penrith gauge (29.83m AHD (41)). However, damage to the Victoria bridge is expected at around 13.9m (28m AHD) at the Penrith gauge (35).
- Regentville Bridge over the M4 Motorway near Penrith deck height 32.79m AHD. Note, due to flood slope this bridge can be flooded during a PMF (41).

Whilst the Yarramundi, Windsor and North Richmond bridges have been designed to be submerged, the Victoria and Regentville Bridges (Penrith/ Emu Plains) have not.

Refer to Annex H for more detail.

Rail

There are two main rail lines within the Hawkesbury-Nepean Valley. The Western Rail Line and the Richmond Rail Line. These lines both convey passengers, with the Western Rail Line being important for transporting freight.

Both of these lines can be affected temporarily during minor flooding. The Richmond Rail Line will be closed due to Hawkesbury River flooding west of Schofields when river levels reach around 12.5m (at the Windsor gauge) (5).

If the Victoria Bridge over the Nepean River between Penrith and Emu Plains were to fail it would also take out the rail bridge and the main Western Rail Line affecting rail transport for around 6 months. This will have major implications for commuters as well as freight that are normally transported by rail (35).

The Western Rail Line can also be flooded where it crosses South Creek due to local catchment flooding at a height of 24.8m AHD (1). Refer to Annex H for further details.

Refer to Annex H for more detail.

Ferries

There are four vehicular ferries at Sackville, Lower Portland, Webbs Creek and Wisemans Ferry. The closure of these ferries result in the isolation of areas with potential difficulties for evacuation. This is particularly the case on the north western side of the river including the Macdonald Valley, Webbs Creek, Spencer and Gunderman areas.

Ferry closures are dependent on the amount of debris in the flood waters but generally occur when flood levels reach between 3m and 3.5m at the Windsor gauge (Refer to Annex H for further details).

2.12 AGRICULTURE

Much of the lowest lying land within the Hawkesbury-Nepean Valley is rural land used for agricultural purposes including orchards, turf farms, horses and cattle (35).

Direct impacts of flooding include inundation of farm plant and equipment, loss of livestock, damage to livestock fodder reserves and loss of crops in production (35).

There are also many indirect consequences including loss of production during the re-establishment of the business following flooding (35).

In smaller flood events livestock may be able to be moved to higher ground, however moderate and major flooding within the Hawkesbury-Nepean Valley will necessitate large scale movement and where possible evacuation of livestock.

Table 7: Summary of Utilities and Infrastructure Consequences Windsor / Wilberforce Floodplain

Category	Windsor Bridge Gauge	Transport	Power	Telecoms	Sewer	Water
Minor (<3 yr)	Up to 7m	Yarramundi Bridge and Ferries closed causing isolations.				
Moderate (Up to 1 in 3 yr)	Up 11m	Windsor & Richmond Bridges close	Some outages to rural areas			Loss of water to some areas due to pipes being shut off
Major (1 in 60 yr)	Up to 16m	Evacuation routes closed for Grono's Point, Lowlands, McGraths Hill, Mulgrave, Pitt Town, Yarramundi, Ebenezer and Wilberforce. Richmond train line closed.	Loss of Power to the north of the river for up to 2 days.	Telephone north of river reliant on battery or generator power. 6,500 properties lose services in evacuated areas.	McGrath Hill Sewage Treatment Plant (STP) damaged requiring up to 6 months to be fully operational. Pumping stations fail and raw sewage discharged	Loss of water to some areas. Pump stations flooded but water still available in other areas under water restrictions
Major (1 in 100 yr)	Up to 17.3m	Windsor evacuation route closed	2,400 non-flooded properties without power for up to 2 weeks		McGrath Hill STP damaged. Up to 6 months to be fully operational. Pumping stations fail and raw sewage discharged	
Major (1 in 1500 yr)	Up to 22m	Richmond and Bligh Park Evacuation Routes closed	No electricity to 20,800 non-flooded properties for >3 months	Loss of services for 2 weeks to some areas. Reduced mobile phone services. GRN reliant on alternate generator power	McGraths Hill STP severely damaged. North Richmond, South Windsor and St Marys STPs also damaged with up to 12 months to rebuild. Raw sewage discharged	
Extreme	Up to PMF 26.4m	Windsor Downs Evacuation Route closed	No electricity to 17,000 non-flooded properties > 3 months			

Table 8: Summary of Utility and Infrastructure Consequences Penrith / Castlereagh Floodplain

Category	Victoria Bridge Gauge, Penrith	Transport	Power	Telecoms	Sewer	Water
Minor (1 in 7)	Up to 21m AHD (Up to 6.9m at gauge)					Some pumping stations inundated but supplies maintained
Moderate (Up to 1 in 35)	Up to 24.5m AHD (Up to 10.4m at gauge)	Road closures isolating areas including Peach Tree Ck, Penrith North, Regentville and Emu Heights	Outages to 5,500 non-flooded properties for up to 2 days	Emu Plains reliant on temporary power. Reduced mobile services	Some pumping systems fail. Raw sewage discharged	
Moderate (Up to 1 in 100)	Up to 26m AHD (Up to 11.9m at gauge)	Road closures isolating additional areas (Emu Plains East and Central)	Outages to around 17,500 properties for between 2 and 14 days	Emu Plains and Penrith reliant on temporary power.	Penrith STP damaged. Shut for up to 1 week.	Some impacts water restrictions
Major (Up to 1 in 900)	Up to 28m AHD (Up to 13.9m at gauge)	Victoria Bridge and western rail line are damaged	Penrith sub-station damaged. Outages to non-flooded properties for up to 3 months	Possible reductions in service in and out of Sydney	Many impacts with raw sewage discharged. Around 6 months to repair.	Some damages. Supplies available, under restrictions
Extreme (Up to PMF)	Up to 32m AHD (Up to 17.9m at gauge)	Road closures isolating Leonay. No rail for up to 6 months	Penrith sub-station destroyed. Without power for 3 to 6 months	Telephone system fails for Penrith and Emu Plains	Many impacts with raw sewage discharged. Around 6 months to repair.	

Source: Adapted from Molino Stewart Pty Ltd 2012 (35)

2.13 ENVIRONMENT

Flooding is a natural process bringing with it many environmental benefits including flushing and deposition of rich fertile soils. However, there are numerous potential negative consequences of flooding in the Hawkesbury-Nepean Valley including:

- Significant amounts of debris being deposited within the floodplain including hazardous materials such as asbestos. This build-up of potentially contaminated debris is also expected to have significant waste disposal implications (35).
- Erosion and undermining of riverbanks, which may in turn threaten structures including houses, bridges, weirs, buried pipelines and roads (35).
- Reduced water quality due to sediments, dead livestock and other animals, raw sewage, chemicals and other pollutants from industrial premises and agricultural stores being washed into floodwaters from the catchment (35). If raw sewage continues to be discharged for extended periods of time secondary impacts could include algal blooms and aquatic weed growth.
- Flooding could potentially impact on the small patches of remaining remnant native vegetation on the floodplain by uprooting or undermining trees and other vegetation, introducing weeds and depleting native fauna populations (35).

2.14 TRANSITION TO RECOVERY

Because of the wide variation in flood behaviour between different flood events, it is difficult to predict how long homes might be inundated or areas isolated. However, an indication for some of the more severe events might be gained from the following:

- During a 1% AEP flood (17.3 metres AHD at Windsor), levels of flooding at Richmond and Windsor (above 10 metres AHD) could last for about 4 to 5 days;
- During a repeat of the 1867 flood (19.3 metres AHD at Windsor), river levels could remain above 25 metres AHD for a day at Penrith and above 16 metres AHD for about three days at Richmond and Windsor. Access to Windsor could be cut for an additional half day;
- During the PMF river levels could remain above 25 metres AHD for up to 3 days at Penrith and above 16 metres AHD for as long as 4 days at Richmond and Windsor. Access to Windsor could be cut for an additional half day.

Once floodwaters have receded, recovery operations and the restoration of services are expected to take some time. Depending on the size of the flood there will potentially be significant repairs that would be required of roads, bridges, utility services such as electricity transmission stations, water supply infrastructure and sewage treatments plants, some of which may need to be completely rebuilt.

In addition, hundreds to thousands of houses may have been significantly damaged or destroyed (See Tables 5 and 6).

This will mean that large numbers of people could require temporary accommodation whilst their properties are repaired or rebuilt.

- During a 1% AEP flood event around 19,800 people would require temporary accommodation, with 4,100 people from dwellings requiring significant repair (See Tables 5 and 6).
- Following a PMF, around 91,000 people are expected to require temporary accommodation, with up to 31,800 people from dwellings requiring significant repair (See Tables 5 and 6).

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