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# Agency Acronyms

## Australian Government

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<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ANZEMC</td>
<td>Australia-New Zealand Emergency Management Committee</td>
</tr>
<tr>
<td>BoM</td>
<td>Bureau of Meteorology</td>
</tr>
<tr>
<td>COAG</td>
<td>Council of Australian Governments</td>
</tr>
</tbody>
</table>

## New South Wales Government

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>DP&amp;I</td>
<td>Department of Planning and Infrastructure</td>
</tr>
<tr>
<td>OEH</td>
<td>Office of Environment and Heritage</td>
</tr>
<tr>
<td>LEMC</td>
<td>Local Emergency Management Committee</td>
</tr>
<tr>
<td>NOW</td>
<td>Office of Water</td>
</tr>
<tr>
<td>SCA</td>
<td>Sydney Catchment Authority</td>
</tr>
<tr>
<td>SEMC</td>
<td>State Emergency Management Committee</td>
</tr>
<tr>
<td>SES</td>
<td>State Emergency Service</td>
</tr>
</tbody>
</table>
## Glossary

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australian Height Datum (AHD)</td>
<td>A common national surface level datum corresponding approximately to mean sea level. It is used to measure height above sea level throughout Australia. It is also used to express the level or height of flooding associated with each chance per year flood.</td>
</tr>
<tr>
<td>Chance per year</td>
<td>Refers to the chance of a certain level of flooding occurring in any one year. The chance that a certain level of flooding occurs in any one year is not related to the timing of other floods. For example, a 1 in 100 chance per year flood refers to a level of flooding with a 1 in 100 (or 1 percent) chance of occurring in any one year, regardless of whether that level or other levels of flooding have occurred in that year.</td>
</tr>
<tr>
<td>Full supply level (FSL)</td>
<td>Refers to full supply level of Warragamba Dam.</td>
</tr>
<tr>
<td>Flood risk</td>
<td>Flood risk is a combination of the likelihood of occurrence of a flood event and the consequences of that event when it occurs.</td>
</tr>
<tr>
<td>Flood level</td>
<td>The level or height of flooding associated with each chance per year flood. This is often expressed in metres above mean sea level (AHD).</td>
</tr>
<tr>
<td>Flood planning level</td>
<td>Sets minimum floor levels and is determined by councils. In NSW the state-wide default flood planning level is based upon the level of flooding with a 1 in 100 chance per year of occurring.</td>
</tr>
<tr>
<td>Floodplain risk management process (NSW)</td>
<td>Process based on the NSW Floodplain Development Manual 2005 through which councils may conduct floodplain risk management studies and prepare floodplain risk management plans that detail how areas of flood prone land are to be used and managed.</td>
</tr>
<tr>
<td>Categories of flood risk developed for the purposes of this Review</td>
<td>In this review, minor, moderate, severe and extreme floods refer to the flood risk associated with the following flood levels:</td>
</tr>
<tr>
<td></td>
<td>Minor: 1 in 1 to 1 in 5 chance per year Moderate: 1 in 5 to 1 in 20 chance per year Major: 1 in 20 to 1 in 100 chance per year Severe: 1 in 100 to 1 in 1000 chance per year Extreme: 1 in 1000 to 1 in 110 000 (Probable Maximum Flood) chance per year</td>
</tr>
<tr>
<td>Term</td>
<td>Description</td>
</tr>
<tr>
<td>-------------------------------------------</td>
<td>-----------------------------------------------------------------------------</td>
</tr>
<tr>
<td>National Strategy for Disaster Resilience 2011 (NSDR)</td>
<td>Strategy developed by the Australia-New Zealand Emergency Management Committee of the Council of Australian Governments to provide high-level guidance on disaster management.</td>
</tr>
<tr>
<td>Natural Disaster Relief and Recovery Arrangements (NDRRA)</td>
<td>The Australian Government provides funding through these arrangements to States and Territories to help pay for natural disaster relief and recovery costs.</td>
</tr>
<tr>
<td>Probable Maximum Flood (PMF)</td>
<td>The worst flood that could conceivably occur at a particular location.</td>
</tr>
<tr>
<td>Review</td>
<td>The Hawkesbury-Nepean Valley Flood Management Review.</td>
</tr>
<tr>
<td>State Emergency Operations Controller (SEOCON)</td>
<td>A person appointed by the Governor, on the recommendation the Minister for Police and Emergency Services. The SEOCON is responsible for the overall direction, control and coordination of emergency response at State level where there is no combat agency or for coordinating support to a designated combat agency as requested, in accordance with the State Emergency and Rescue Management Act 1989.</td>
</tr>
<tr>
<td>State Emergency Recovery Controller (SERCON)</td>
<td>A person appointed by the Minister for Police and Emergency Services, who is responsible for controlling the recovery from an emergency in accordance with the State Emergency and Rescue Management Act 1989.</td>
</tr>
</tbody>
</table>
Executive summary

The Hawkesbury-Nepean Valley faces a serious and ongoing flood risk. The unique geographic characteristics of the valley can lead to a significant extent and depth of flooding over existing urban areas. Ongoing development within the floodplain, including infill development within established townships, has increased the population and infrastructure at risk from flooding.

The Hawkesbury-Nepean Valley Flood Management Review (the Review) began in early 2013, in response to the Government's adoption of The State Infrastructure Strategy 2012-2032 and ongoing community concerns about flood risk. This report presents the key findings of the first stage of the Review and proposed next steps.

The scope of the Review has been broad, as required by its terms of reference (Appendix One). Given the extensive work previously done within the Hawkesbury-Nepean Valley, it was important that Stage One of the Review identify current arrangements relating to flood mitigation, and assess their effectiveness and adequacy. This has required updating information for the valley on flood levels, development patterns and potential flood damages.

The Review adopted a holistic approach that explored all options with the potential to reduce flood risk to life and property. A framework was developed to ensure that recommendations arising from the Review addressed the key weaknesses or gaps in the existing approach to flood risk management in the Hawkesbury-Nepean Valley.

The overarching objective of the Review was to develop a package of management actions that would ensure the Hawkesbury-Nepean Valley is strategically managed so the community is more resilient to flood risk. This aligns with Goal 28 of the NSW 2021 Plan which aims to 'ensure NSW is ready to deal with major emergencies and natural disasters'.

Stage One of the Review has examined a broad range of potential enhancements to infrastructure, governance and other arrangements to reduce flood risk within the Hawkesbury-Nepean Valley. It has also identified those warranting more detailed investigation and cost benefit analysis in Stage Two of the Review, as anticipated in the terms of reference.

Flood emergency prevention, preparedness, response and recovery are currently the shared responsibility of a range of NSW Government agencies and councils within the valley. An Interagency Steering Committee was established to undertake Stage One of Review, comprising representatives of the Office of Water, Sydney Catchment Authority, Office of Environment and Heritage, Department of Finance and Services, NSW Treasury, the State Emergency Service, Department of Premier and Cabinet, the Department of Planning and Infrastructure and the Department of Trade and Investment. Representatives of these organisations have provided specialist input relating to flood mitigation, flood emergency planning and response, land use planning, flood modelling and monitoring and flood damages assessment.

The Review sought input on flood management issues and suggested solutions from the 23 councils in the Hawkesbury-Nepean catchment, particularly those most affected by flooding in the Hawkesbury-Nepean Valley (The Hills Shire Council and Penrith, Hawkesbury, Blacktown City Councils). Views were also sought from the Western Sydney Regional Organisation of Councils, the Hawkesbury-Nepean Local Government Advisory Group, Hawkesbury-Nepean Catchment Management Authority, Office of Penrith Lakes, Penrith Lakes Development Corporation, Infrastructure NSW and the Floodplain Management Association.
Albeit an infrequent event, a severe flood in the Hawkesbury-Nepean Valley would lead to economic, social and other impacts of State significance. If an event similar to the 1867 flood occurred today around 45,000 people would need to be evacuated, and there would be approximately four billion dollars in damage. This 1867 flood was the largest flood since European settlement and was previously estimated to be in the range of a 1 in 200 to 1 in 500 chance per year flood. Similarly, for the worst possible flood (1 in 110000 chance per year) around 73,000 people would need to be evacuated and over 20 thousand homes would be at risk of failure. Although such an event is extremely rare, community recovery from such a flood would be prolonged.

The NSW Government has spent $280 million on a range of actions in the Hawkesbury-Nepean Valley over the past 15 years including evacuation routes upgrades. There are parts of the current road network that could be further improved to enhance the evacuation capacity of the area. A community awareness campaign highlighting the risk of flooding in the valley should be implemented.

Detailed investigation is required to support a more integrated and coordinated approach to reduce overall flood risk in the valley. The Review has identified a need for enhanced community education on flood risk and response as well as improvements in incident response capacity and capability. A risk-based framework that considers the full range of potential flood events should be adopted. This framework should encompass planning systems, flood mitigation infrastructure, and emergency response. More consistent flood modelling, data and information is also required for use across the region.

There is no simple solution or single infrastructure option that can address all of the flood risk in the Hawkesbury-Nepean floodplain. Infrastructure options can reduce but not eliminate the risk to life and property. Effective evacuation is the only measure that can guarantee to reduce the risk to life.

The Review undertook a preliminary assessment of a range of infrastructure options to reduce flood risk. Raising the crest of the Warragamba Dam wall to create flood storage capacity was found to be the most effective infrastructure option for providing regional flood mitigation. However, like many other infrastructure options, it is expensive and would generally require a long lead time for implementation. It also has significant potential environmental costs. Raising the crest of the dam wall would significantly reduce but not eliminate the risk of significant flooding in the Hawkesbury-Nepean Valley.

Changing the operation of the existing Warragamba Dam to provide airspace to capture and store floodwaters through altered gate operation protocols or reducing full supply level, would reduce the impact of minor to moderate flood events only. Changing the operation of the dam can have significant costs and impacts on Sydney’s long term available water supply.

Significantly less cost-effective than raising the crest of Warragamba Dam wall are infrastructure options to enhance drainage of floodwater from the valley. This includes constructing flood channels, dredging of the river or building new dams elsewhere in the catchment.

It is proposed that the Review proceed to Stage Two to undertake a more detailed cost benefit analysis of specific flood mitigation infrastructure options as well as progress other actions identified in this Review Report to reduce flood risk in the short and longer term.
Introduction

In its ‘First Things First – The State Infrastructure Strategy 2012-2032’ report released in 2012, Infrastructure NSW (INSW) proposed a range of specific infrastructure investments and reforms over a 20-year period. INSW recommended the need for a review of flood mitigation options for the Hawkesbury-Nepean Valley as a high priority for NSW Government consideration.

At the same time, community awareness of flooding issues, and the potential role of dams in mitigating the effects of floods was heightened by significant flood events in south-east Queensland, Victoria as well as at various locations along the NSW coast.

Following its review of the INSW recommendations, the NSW Government released its State Infrastructure Strategy in December 2012 and identified the State’s infrastructure delivery and reform priorities over the next five years. One of the key projects in the strategy was a review of major flood mitigation options available in the Hawkesbury-Nepean Valley, including options for raising the crest of the Warragamba Dam wall and evacuation route upgrades. The Hawkesbury-Nepean Valley Flood Management Review (the Review) began in early 2013, and comprises three stages.

An Interagency Steering Group with representatives from relevant NSW Government agencies was formed to undertake the first stage of the Review. Five technical working groups were established to report on key elements of the Review. The governance arrangements for Stage One are shown in Figure 1.

The purpose of this stage was to report on the adequacy of the current flood information and management arrangements. It also identified options for improvement that could be actioned in the short term or considered for further assessment in a proposed Stage Two, including cost benefit analysis.

Stage Three is proposed to include public consultation on preferred improvement options.
The scope of the Review was defined by the terms of reference (Appendix One). The Interagency Steering Group was required to assess the adequacy and effectiveness of the current Hawkesbury-Nepean Valley flood management arrangements, in particular:

- current evacuation routes and whether upgrades are required
- the appropriateness of current urban planning policies
- current governance arrangements for flood planning and response and whether it is feasible that planning and response arrangements be overseen by a single agency
- whether changes to the operation and configuration of key pieces of water infrastructure, such as Warragamba Dam, are required

The study area for the Review was defined as the riverine floodplain of the Hawkesbury-Nepean River from Warragamba Dam to Brooklyn Bridge with consideration of the entire catchment for calculating flows that impact the floodplain.

The Review did not examine flooding upstream of Warragamba Dam and in the Nepean River upstream of Wallacia, nor did it examine localised flash flooding from smaller intense storm events. These are dealt with under council flood plans, and do not have the regional impacts of flooding on the Hawkesbury-Nepean floodplain.

This report presents the key findings and proposed next steps arising from Stage One of the Review for NSW Government consideration. Overall, the Review found that:

- there is no simple solution or single infrastructure option to deal with the complexity of the flood issues in the valley
- the risk of flooding in the valley cannot be eliminated
- it is possible to reduce and manage the risk to life and property through a combination of flood prevention, preparedness, response and recovery
The unique nature of the Hawkesbury-Nepean Valley floodplain

The natural characteristics of the Hawkesbury-Nepean Valley make it susceptible to significant flood risk. The combination of the large upstream catchments and narrow downstream sandstone gorges results in floodwaters backing up behind these natural ‘choke points’ and rising rapidly causing significant flooding (Figure 2). This ‘bathtub effect’ is different to other coastal floodplains and river valleys where the valley progressively widens as the river approaches the estuary.

![Figure 2: Area of inundation in Probable Maximum Flood (PMF) event due to ‘bathtub’ effect caused by natural choke points](image)

The worst flood that could conceivably occur is referred to as the Probable Maximum Flood (PMF). It is the PMF that defines the extent of the floodplain and the potential area to be evacuated. Management of risks from flooding, including danger to personal safety, needs to consider all floods up to the PMF although such an event is extremely rare.

Figure 3 shows the extent of the Hawkesbury-Nepean Valley floodplain and displays the extent of the 1 in 100 chance per year flood (typically used as the basis for the default flood planning level) together with the extent of the PMF. This highlights the significant scale of inundation around Richmond, Windsor, Bligh Park, Penrith, McGraths Hill and Marsden Park.
Figure 3: The extent of the 1 in 100 chance per year flood and the Probable Maximum Flood (PMF) in the Hawkesbury-Nepean Valley floodplain
In most NSW rivers, the difference in the flood depth between the 1 in 100 chance per year flood level (typically used as the basis for the default flood planning level) and the PMF is usually less than two metres. In the Richmond-Windsor region, the PMF is up to nine metres above the 1 in 100 chance per year flood level. The relatively large potential flood depth along with the short warning time greatly increases the risk to life and property. Figure 4 illustrates the flood depth differences in the Richmond-Windsor region and several other NSW townships on floodplains, with floor level at the default planning level (based on the 1 in 100 chance per year flood level).

Figure 4: Comparison of chance per year flood levels from 1 in 100 to Probable Maximum Flood (PMF) at three townships on three different NSW floodplains

Evacuation

Another critical feature of the Hawkesbury-Nepean Valley is that many evacuation routes have low points that flood and are cut off before the higher inhabited areas are inundated. This leads to isolated flood islands that can be totally inundated in extreme floods, potentially placing lives at risk. The townships of Richmond, Windsor, South Windsor, Bligh Park, Pitt Town and McGraths Hill can all become inundated flood islands during large floods. For example, McGraths Hill will be completely inundated in a one in 100 chance per year flood. Figure 5 identifies the flood evacuation routes within the Hawkesbury-Nepean Valley and the flood level (metres above mean sea level (AHD)) at which the routes are cut.
Figure 5: Hawkesbury-Nepean Valley floodplain evacuation routes and the flood level (metres above mean sea level (AHD)) at which the routes are cut
Large flood events in the Hawkesbury-Nepean Valley require the State Emergency Service (SES) to manage a complex sequence of evacuations. The growth in population and limited road capacity has created challenges for emergency management in the valley. Evacuation from the valley during large flood events may also be affected by evacuation from other areas of Sydney. The evacuation problem is compounded by low level of community awareness of flooding.

Windsor provides an illustration of the evacuation problem. The evacuation of Windsor needs to be completed before the Jim Anderson Bridge is cut, which will occur for 1 in 100 chance per year flood levels and higher. The SES estimates the time to complete an evacuation of Windsor to be 25 hours, a 67 percent increase from the evacuation time of 15 hours estimated when the Jim Anderson Bridge was completed in 2006. The time to complete this evacuation is determined by the time required to mobilise the SES, start the evacuation, and for traffic to drive across the single out lane on Jim Anderson Bridge and subsequent evacuation route.

As a result of the estimated time required to complete an evacuation of the current population of Windsor, the SES is forced to make the decision to evacuate based on forecast rainfall with uncertain accuracy. It is estimated that the decision would need to be made six hours ahead of rain actually falling and at a time when river levels are in bank or near normal river levels. The risks of this evacuation decision making context includes:

- an evacuation decision being made with forecast rainfall not eventuating, leading to a mass evacuation being found to be unnecessary with significant disruption to the community
- difficulty convincing the community to leave at the commencement of evacuation without significant visual clues due to river levels being in bank or near normal levels

Conversely if the forecast rainfall initially shows that the evacuation route is not forecast to be cut and the evacuation call is not made, the risk include:

- there being insufficient time to fully evacuate the area if forecast or actual rainfall increases and possibly cuts the evacuation route ahead of complete evacuation
- a large flood rescue problem for remaining trapped population

The long evacuation times and use of uncertain rain forecasts results in complicated and risky evacuation decisions. To overcome this problem across the valley, the capacity of evacuation routes needs to be increased.

The optimal evacuation strategy is a complex network and decision making problem which should also consider how broader evacuation from areas surrounding the floodplain in large floods may affect evacuation from the valley.

**Population**

The population of the Hawkesbury-Nepean Valley is larger than many other coastal catchments in NSW and is growing. Preliminary estimates are that 72,000 people are currently living in areas prone to flooding from the Hawkesbury-Nepean River. Over 13,000 of these people are living in homes that could be severely damaged due to flooding should a 1 in 200 chance per year flood, where floods two metres or more above the home’s floor level, occur (see Figure 6).
Figure 6: Preliminary estimates of current population living in houses at risk of severe damage in floods up to Probable Maximum Flood (PMF) in the Hawkesbury-Nepean Valley

The floodplain is also in the heart of the Western Sydney region, one of Australia’s largest and most diverse economies with an annual gross regional product of about $95.6 billion in 2010-11. Large flood events could impact the entire regional and NSW economy by affecting transportation routes and utilities outside the flooded area. Large flood events could impact the entire NSW economy by affecting transportation routes and utilities outside the flooded area.

The Metropolitan Strategy for Sydney, currently being finalised, will set out the framework for Sydney’s growth to 2031. The draft Strategy sets out a projected population increase in the Metropolitan West subregion (most of which is located in the Hawkesbury-Nepean Valley) of 89 thousand people by 2031, with a target of at least 39 thousand new homes and 37 thousand new jobs. Many of these are located in the floodplain, which encompasses large parts of the North West Growth Centre (Figure 7).

Most of the cost of flood damages arises from floods larger than the 1 in 100 chance per year flood. That is, the cost of flood damages arises in floods with levels at or above the default flood planning level which has shaped development patterns within the floodplain. Long term averaged costs of damages are mainly attributed to floods below the 1 in 500 chance per year flood level, as opposed to rarer higher flood levels.
Figure 7: Future Growth Centres in Hawkesbury-Nepean Valley
Historic flooding in the Hawkesbury-Nepean Valley

The Hawkesbury-Nepean Valley has a long history of flooding. The largest flood on record in the valley occurred in 1867 when the river level reached 19.7 metres above mean sea level (AHD) at Windsor (Figure 8). Recent work undertaken for this Review suggests that the flood may be closer to a 1 in 500 chance per year flood, noting that this work requires further verification.

Analysis of sediments within the Nepean gorge shows that prior to European settlement, but under current climatic conditions, at least one flood reached or exceeded the level of a flood with about a 1 in 1000 chance per year. Such a flood would reach around 20 metres above mean sea level (AHD) at Windsor. Table 1 shows flood levels and number of people needing evacuation from the Hawkesbury-Nepean Valley within each of the categories of flood risk developed for the purposes of this Review.

Each flood event is unique due to the timing of rainfall across the Hawkesbury-Nepean Valley catchment. The contribution of each subcatchment (shown in Figure 9) to flooding in the valley similarly varies for each flood event. Figure 10 illustrates how the subcatchment contributions have varied for recent floods at Windsor.

Minor to moderate flood events could occur in the Windsor-Richmond area from localised rainfall outside the Warragamba Dam catchment. However, the Warragamba Dam catchment is the largest contributor for major flood events on the Hawkesbury-Nepean floodplain. Analysis of available records for the 1867 flood suggests that the Warragamba River and possibly the Grose River were the principal sources of floodwater in that event, with relatively small contribution from the upper Nepean River.

Figure 8: A wood engraving of Ryan’s Punt, 27 July 1867

Source: State Library of Victoria
## Categories of flood risk developed for the purposes of this Review

### Minor (1 in 1 to 1 in 5 chance per year floods)

<table>
<thead>
<tr>
<th>Flood Size (Chance per year and date of historical flood)</th>
<th>Design Flood Levels (metres AHD)</th>
<th>Total number of people needing evacuation (2011)</th>
</tr>
</thead>
<tbody>
<tr>
<td>once per year</td>
<td>Penrith</td>
<td>Windsor</td>
</tr>
<tr>
<td>March 2012</td>
<td>15.4*</td>
<td>3.5*</td>
</tr>
<tr>
<td>1 in 2</td>
<td>18.4</td>
<td>6.0</td>
</tr>
<tr>
<td>November 1969</td>
<td>16.0*</td>
<td>7.4**</td>
</tr>
</tbody>
</table>

### Moderate (1 in 5 to 1 in 20 chance per year floods)

<table>
<thead>
<tr>
<th>Flood Size (Chance per year and date of historical flood)</th>
<th>Design Flood Levels (metres AHD)</th>
<th>Total number of people needing evacuation (2011)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 in 5</td>
<td>Penrith</td>
<td>Windsor</td>
</tr>
<tr>
<td>May 1974</td>
<td>19.3</td>
<td>10.4</td>
</tr>
<tr>
<td>July 1988</td>
<td>20.3</td>
<td>10.9</td>
</tr>
<tr>
<td>June 1975</td>
<td>21.5</td>
<td>11.2</td>
</tr>
<tr>
<td>August 1986</td>
<td>20.0</td>
<td>11.4</td>
</tr>
<tr>
<td>1 in 10</td>
<td>21.9</td>
<td>12.2</td>
</tr>
<tr>
<td>May 1988</td>
<td>22.6</td>
<td>12.8</td>
</tr>
<tr>
<td>August 1990</td>
<td>23.4</td>
<td>13.5</td>
</tr>
</tbody>
</table>

### Major (1 in 20 to 1 in 100 chance per year floods)

<table>
<thead>
<tr>
<th>Flood Size (Chance per year and date of historical flood)</th>
<th>Design Flood Levels (metres AHD)</th>
<th>Total number of people needing evacuation (2011)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 in 20</td>
<td>Penrith</td>
<td>Windsor</td>
</tr>
<tr>
<td>March 1978</td>
<td>23.5</td>
<td>13.7</td>
</tr>
<tr>
<td>June 1964</td>
<td>23.7</td>
<td>14.6</td>
</tr>
<tr>
<td>November 1961</td>
<td>23.9</td>
<td>15.0</td>
</tr>
<tr>
<td>1 in 50</td>
<td>24.8</td>
<td>15.8</td>
</tr>
</tbody>
</table>

### Severe (1 in 100 to in 1,000 chance per year floods)

<table>
<thead>
<tr>
<th>Flood Size (Chance per year and date of historical flood)</th>
<th>Design Flood Levels (metres AHD)</th>
<th>Total number of people needing evacuation (2011)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 in 100</td>
<td>Penrith</td>
<td>Windsor</td>
</tr>
<tr>
<td>1 in 200</td>
<td>25.9</td>
<td>17.3</td>
</tr>
<tr>
<td>June 1867**</td>
<td>26.5</td>
<td>18.3</td>
</tr>
<tr>
<td>1 in 500</td>
<td>27.1</td>
<td>19.6</td>
</tr>
</tbody>
</table>

### Extreme (1 in 1,000 chance year floods to Probable Maximum Flood)

<table>
<thead>
<tr>
<th>Flood Size (Chance per year and date of historical flood)</th>
<th>Design Flood Levels (metres AHD)</th>
<th>Total number of people needing evacuation (2011)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 in 1,000***</td>
<td>Penrith</td>
<td>Windsor</td>
</tr>
<tr>
<td>1 in 2,000</td>
<td>27.6</td>
<td>20.4</td>
</tr>
<tr>
<td>1 in 5,000</td>
<td>28.7</td>
<td>22.1</td>
</tr>
<tr>
<td>Probable Maximum Flood</td>
<td>30.3</td>
<td>23.8</td>
</tr>
<tr>
<td></td>
<td>31.5</td>
<td>26.2</td>
</tr>
</tbody>
</table>

* assumes drawdown of Warragamba Dam
** adjusted for Warragamba Dam
*** there is evidence that a flood of this size has occurred at least once before European settlement under current climate conditions

Table 1: Comparison of flood probabilities levels and number of people needing evacuation in the Hawkesbury-Nepean Valley
Figure 9: Sub-catchments of Hawkesbury-Nepean River
Recent flooding

New South Wales experienced broad scale and prolonged flooding between late 2011 and early 2012, with the State Emergency Service declaring approximately 80 percent of the state as flood affected. During this event the Hawkesbury-Nepean Valley experienced minor 1 in 3 chance per year flooding in March 2012, with Warragamba Dam spilling for the first time in 14 years. A minor flood of a similar size occurred in June 2013. These recent events, although relatively minor, caused considerable downstream disruption. Flood evacuation warnings were issued for low lying areas, including caravan parks along the Hawkesbury River from Windsor to Sackville. Yarramundi Bridge was closed, as were the Sackville, Lower Portland, Webbs Creek and Wisemans Ferry ferries.
Current management of floods in the Hawkesbury-Nepean Valley

Management of the flood risk in the Hawkesbury-Nepean Valley includes preventing or mitigating the impact of flood, planning and preparing for flooding as well as responding to and recovering from floods. This involves different NSW Government agencies and local government, with Australian Government support through funding programs for understanding and mitigating flood risk, response to and recovery from flooding as well as flood forecasting and warning. Australian government funding is also provided for developing and maintaining national databases. Figure 11 illustrates the current management arrangements for flood risk management in the Hawkesbury-Nepean Valley.

![Figure 11: Current flood management arrangements in the Hawkesbury-Nepean Valley](image)

The NSW Government uses its legislative powers to allocate responsibilities for flood risk management within the state. Responsibilities are identified in a range of specific legislation and in the NSW Flood Prone Land Policy and NSW Floodplain Development Manual 2005.

It is noted that the Sydney Catchment Authority (SCA) is a water supply authority that operates and maintains major dams in the Hawkesbury-Nepean catchment. These dams are operated for water supply purposes only and the SCA has no legislative requirement for flood mitigation, other than to operate the dams in accordance with dam safety requirements.
**Prevention** involves regulatory and physical measures to ensure that emergencies are prevented, or reduced in incidence or severity. Table 2 provides a summary of the distribution of responsibility and support for prevention activities within government in NSW.

<table>
<thead>
<tr>
<th>Activity</th>
<th>Primary Responsible</th>
<th>Support</th>
</tr>
</thead>
<tbody>
<tr>
<td>Investigations to understand flood behaviour</td>
<td>Local government</td>
<td>NSW Floodplain Development Manual 2005 and Guidance OEH specialist technical flood risk management expertise SES emergency risk management expertise NSW Floodplain Management Program</td>
</tr>
<tr>
<td>Flood mitigation works</td>
<td>Local government</td>
<td>OEH specialist technical flood risk management expertise State Floodplain Management Program</td>
</tr>
<tr>
<td>Floodplain management in rural areas of the Murray Darling Basin</td>
<td>NOW</td>
<td>OEH developing rural Flood Risk Management Plans and providing specialist flood risk management expertise to support NOW</td>
</tr>
<tr>
<td>State-wide flood warning systems</td>
<td>Existing, OEH, SCA, NOW, BoM, SES</td>
<td>NSW Flood Warning Consultative Committee OEH funding for Manly Hydraulics Lab</td>
</tr>
<tr>
<td>New gauges and local systems</td>
<td>Local government</td>
<td>NSW Floodplain Development Manual 2005 and Guidance OEH specialist technical flood risk management expertise BoM gauges NSW Floodplain Management Program</td>
</tr>
<tr>
<td>Regional strategic planning</td>
<td>DP&amp;I</td>
<td>Consult with other agencies including OEH, SES and NOW</td>
</tr>
<tr>
<td>Local strategic planning</td>
<td>Local government</td>
<td>DP&amp;I planning policies, directions and circulars, model clauses, planning advice, OEH/SES input into Local Environment Plans and development control plans</td>
</tr>
<tr>
<td>Major development planning</td>
<td>DP&amp;I</td>
<td>Consult with other agencies including OEH, SES and NOW</td>
</tr>
<tr>
<td>Local development scale planning</td>
<td>Local government , Private Certifiers</td>
<td>DP&amp;I planning policies directions and circulars</td>
</tr>
<tr>
<td>Informing the community</td>
<td>Local government</td>
<td></td>
</tr>
<tr>
<td>Informing insurers, infrastructure providers</td>
<td>Local government</td>
<td></td>
</tr>
<tr>
<td>Community education on risk</td>
<td>Local government</td>
<td>Floodplain risk management process provides information OEH some funding primarily for physical works</td>
</tr>
<tr>
<td>Community education on response to flood threats</td>
<td>SES</td>
<td>SES FloodSafe</td>
</tr>
</tbody>
</table>

Table 2: Prevention activities – prime responsibility and support generally available
Local government is primarily responsible for prevention activities through developing and implementing floodplain risk management plans and informing the community about flood risk. Local government’s role also includes land use planning to manage the growth in flood risk due to new development and flood mitigation works to reduce risk to existing development where warranted.

The NSW Government provides councils with technical support from flood risk management experts in the Office of Environment and Heritage (OEH) and financial assistance through the NSW Floodplain Management Program managed by the OEH.

The Office of Water (NOW), OEH, SCA and Sydney Water manage river level gauges that are essential to warning the community about a flood threat in the Hawkesbury-Nepean Valley. These agencies must report the gauge information to the Australian Bureau of Meteorology (BoM). While these agencies currently maintain these gauges, there is no regulatory requirement for them to do so for flood information purposes.

The Department of Planning and Infrastructure (DP&I) provides guidance on consideration of flood constraints in strategic planning instruments and leads regional and sub-regional planning processes. This includes the development of the Metropolitan Strategy which provides the framework for Sydney’s growth to 2031.

Councils and the State Emergency Service (SES) have roles in educating the community about flood risk and how to respond to a flood threat respectively.

**Preparedness** involves arrangements or plans to ensure the resources and services needed to cope with the effects of an emergency can be efficiently mobilised and deployed. The SES is responsible for emergency management planning for floods and for implementing these plans, including the Hawkesbury-Nepean Flood Emergency Sub Plan 2013 (HNFESP). These plans identify roles and responsibilities during a flood emergency. They are developed in conjunction with other relevant areas of NSW and local government and are approved by the State Emergency Management Committee. The HNFESP 2013 is the only state level sub plan to the NSW Emergency Management Plan (EMPLAN) developed due the unique flood risk in the Hawkesbury-Nepean Valley.

**Response** refers to actions taken in anticipation of, during, and immediately after an emergency. The actions aim to ensure that flood impacts are minimised and people affected are given immediate relief and support. The SES is also responsible for flood combat activities including coordinating support from functional areas (including welfare services) and local government for the welfare of affected communities. The State Emergency Operations Controller (SEOCON) works with the SES to coordinate response.

The SCA operates Warragamba Dam to protect the safety of the dam and Sydney’s water supply. The SCA also provides advice and information to the SES and BoM on the status of Warragamba Dam and the SCA flood gauges.

**Recovery** after major floods in the valley is addressed through the HNFESP 2013 which includes arrangements to form a Region Recovery Committee during or following a flood event. This Committee would develop a Recovery Action Plan and coordinate the activities of agencies responsible for delivering services and engaging affected communities to restore normal functioning.

For longer duration recovery from a flood with state-wide significance affecting multiple SES districts, the State Emergency Recovery Controller (SERCON) may invoke recovery arrangements under the NSW Recovery Plan 2010. These arrangements may include forming a State Recovery Committee and the appointment of a State or Regional Recovery Coordinator.
Reducing flood risk in the Hawkesbury-Nepean Valley

The Review adopted a holistic approach that explored all options with the potential for reducing flood risk to life and property in the Hawkesbury-Nepean Valley. A framework was used to ensure that recommendations arising from the Review address the key weaknesses or gaps in the existing approach to flood risk management. This framework is presented as Appendix Two.

The overall aim of the Review was to ensure:

\[
\text{The Hawkesbury-Nepean Valley is strategically managed so the community is more resilient to flood risk.}
\]

This is consistent with NSW 2012 Goal 28 - Ensure NSW is ready to deal with major emergencies and natural disasters.

The Review determined that the following three outcomes are required to support this aim:

- **Keeping the community safe** – the risk to life, property and infrastructure within existing development in the Hawkesbury-Nepean Valley is managed strategically
- **Community awareness** – an informed community that understands the benefits, costs and risks of living with floods in the Hawkesbury-Nepean Valley
- **Sustainable future growth** – future growth and development in the Hawkesbury-Nepean Valley is strategically managed considering the flood risk

Figure 12 illustrates the guiding principles and key inputs to the aims and desired outcomes of the Review. In particular, the ‘National Disaster Resilience Statement’ released by the Council of Australian Governments (COAG) in 2009, and the subsequent National Strategy for Disaster Resilience 2011 identified the important roles of government in helping communities to prepare for, respond to and recover from natural disasters such as severe floods. These roles were applied by the Review specifically in relation to flood risk management, as follows:

- **Preparing for extreme events** – supporting individuals and communities to prepare for extreme flood events
- **Emergency response** – ensuring the most effective, well-coordinated response from our emergency services and volunteers when disaster hits
- **Informing the community on flood response** – having clear and effective education systems so people understand what options are available and the best course of action in responding to a hazard as it approaches
- **Informing the community on flood hazard/risk** – having effective arrangements in place to inform people about how to assess risks and reduce their exposure and vulnerability to hazards
- **Land use planning** – developing and implementing effective, risk-based land management and planning arrangements
- **Recovery and learning** – working in a swift, compassionate and pragmatic way to help communities recover from devastation and to learn, innovate and adapt in the aftermath of disastrous events

The Review adopted these roles of government as guiding principles with which to assess the adequacy and effectiveness of existing flood management arrangements, as required by its terms of reference. The roles of government were also used to identify and evaluate specific enhancements to current approaches, including infrastructure, non-infrastructure and governance solutions to identified issues or problems. The Review aimed to ensure that the flood risk in areas of existing development and potential future growth was considered at each stage of the application of the framework.
OVERALL AIM OF THE REVIEW
The Hawkesbury-Nepean valley is strategically managed so the community is more resilient to flood risk.

DESIRED OUTCOMES OF THE REVIEW
Keeping the community safe - the risk to life, property and infrastructure within existing development in the Hawkesbury-Nepean valley is managed strategically.

Community awareness - an informed community understands the benefits, costs and risks of living with floods in the Hawkesbury-Nepean valley.

Sustainable future growth - future growth and development in the Hawkesbury-Nepean valley is strategically managed considering the flood risk.

NATIONAL STRATEGY FOR DISASTER RESILIENCE (2011) ROLES OF GOVERNMENT
1. Prepare for extreme events - supporting individuals and communities to prepare for extreme events
2. Recovery and learning - working in a swift, compassionate and pragmatic way to help communities recover from devastation and to learn, innovate and adapt in the aftermath of disastrous events
3. Emergency response - ensuring the most effective, well-coordinated response from our emergency services and volunteers when disaster hits
4. Informing the community on flood response - having clear and effective education systems so people understand what options are available and what the best course of action is in responding to a hazard as it approaches
5. Informing the community on flood hazards and flood risk - having effective arrangements in place to inform people about how to assess risks and reduce their exposure and vulnerability to hazards
6. Land use planning - developing and implementing effective, risk-based land management and planning arrangements and other mitigation activities.

MANAGING THE FLOODPLAIN A GUIDE TO BEST PRACTICE IN FLOOD RISK MANAGEMENT IN AUSTRALIA (2013)
Vision: Floodplains are strategically managed for the sustainable long-term benefit of the community and the environment, and to improve community resilience to floods.

Best practice requires the consideration and management of flood impacts to existing and future development within the community. It aims to improve community flood resilience using a broad risk management hierarchy of avoidance, minimisation and mitigation to:
- limit the health, social and financial costs of occupying the floodplain
- increase the sustainable benefits of using the floodplain
- improve or maintain floodplain ecosystems dependent on flood inundation.

Best practice promotes understanding flood behaviour so that the full range of flood risk to the community can be understood, effectively communicated and, where practical and justifiable, mitigated. It facilitates informed decisions on the management of this risk, and economic investment in development and infrastructure on the floodplain.

NSW GOVERNMENT FLOOD PRONE LAND POLICY
The primary objective is to reduce the impact of flooding and flood liability on individual owners and occupiers of flood prone property, and to reduce private and public losses resulting from floods.

The policy recognises the benefits flowing from the use, occupation and development of flood prone land. The policy promotes the use of a merit approach which balances social, economic, environmental and flood risk parameters to determine whether particular development or use of the floodplain is appropriate and sustainable.

In this way the policy avoids the unnecessary sterilisation of flood prone land. Equally it ensures that flood prone land is not the subject of uncontrolled development inconsistent with its exposure to flooding.

The policy highlights that primary responsibility for floodplain risk management rests with local councils, which are provided with financial and technical support by the State Government.

NSW 2021 - A PLAN TO MAKE NSW NUMBER ONE
NSW State Government’s 10-year Strategic Business Plan

Goal 28 - Ensure NSW is ready to deal with major emergencies and natural disasters.

Target 1: Ensure NSW has appropriate arrangements in place to respond to and recover from natural disasters.

Target 3: Increase the number of Floodplain Risk Management Plans available to support emergency management planning.

Figure 12: Guiding principles and key inputs to Review aims and desired outcomes
Specialist working groups were established to examine the major elements of flood management: flood emergency planning and response, flood mitigation, land use planning, flood damage assessment and flood modelling and monitoring. The roles of these working groups included:

- identifying, assessing and evaluating the adequacy and effectiveness of the current situation
- undertaking a gap analysis to identify the most important issues or problems requiring improvement
- auditing the extent to which recommendations of the 1997 Hawkesbury-Nepean Floodplain Management Strategy have been implemented

Together, these investigations identified the most critical gaps, problems or issues with current flood management arrangements, providing a sound basis for the Review's formulation of recommendations for future action. Twenty recommendations have been developed, which can be grouped into the following 10 Strategies.

**Infrastructure**

- Strategy A. Enhance flood mitigation infrastructure
- Strategy B. Enhance flood evacuation capacity of transport infrastructure

**Governance**

- Strategy C. Establish governance arrangements that support more integrated and effective management of flood risk
- Strategy D. Collection of post-event data and flood intelligence
- Strategy E. Improve flood recovery planning

**Non-infrastructure**

- Strategy F. Improve emergency management, planning and implementation
- Strategy G. Improve community education of flood risk and response
- Strategy H. Improve accessibility of flood risk information
- Strategy I. Improve flood modelling framework and tools
- Strategy J. Improve consideration of flood risk in land use planning

As required by its terms of reference, the Review particularly examined the potential for infrastructure measures to reduce flood risk in the Hawkesbury-Nepean Valley, including whether changes to the operation and configuration of key pieces of water infrastructure such as Warragamba Dam are needed. A detailed description of the Review’s consideration of flood mitigation infrastructure options is provided in the following section of this report.

A risk assessment was then undertaken to evaluate and prioritise the recommendations arising from the Review. This risk assessment was carried out in accordance with the National Emergency Management Committee’s *National Emergency Risk Assessment Guidelines 2010*, which provides a framework for evaluating risks from natural disasters in terms of:
• their mortality,
• their economic, social, infrastructure and environmental consequences, and
• the likelihood of such consequences in terms of their expected frequency of occurrence.

A listing of the 20 recommendations arising from this Review, together with their prioritisation from this risk assessment, is provided in Appendix Two. Detailed explanations of these recommendations, and the issues they seek to address, are provided in the following sections of this report.
Flood mitigation infrastructure assessment

Flood infrastructure can reduce risk to property by lowering the probability of a particular flood event and buy time to enable a more effective evacuation in large floods. It can reduce but not eliminate the risk of flooding due to the large flood depths associated with flood events in the Hawkesbury-Nepean Valley.

There is currently no significant flood-specific mitigation infrastructure in the valley. The presence of Warragamba Dam and the Upper Nepean dams provide some mitigation. However, the Upper Nepean dams do not have dam gates meaning that they cannot be operated as flood mitigation dams. Although Warragamba Dam has gates, these are operated for dam safety purposes and are not currently operated for flood mitigation.

The Review quickly identified that the most current knowledge on flood mitigation infrastructure in the valley was based on research from the late 1980s and early 1990s as part of process leading up to the proposed raising of Warragamba Dam in 1995. In light of the subsequent construction of an auxiliary spillway on Warragamba Dam to safely pass extreme floods along with developments in technology and flood modelling, the Review concluded there was a need to undertake updated investigations into extreme flood estimates, current and projected flood damages, and the design and cost of the most viable mitigation infrastructure options.

The following investigations were undertaken:

- An investigation of the extreme flood estimates of the current and shortlisted infrastructure options using updated estimation techniques was completed by the consultants WMAwater with support from the Sydney Catchment Authority.
- Engineering assessment of the design and costs of the shortlisted infrastructure options were undertaken by NSW Public Works.
- An updated assessment of the current and projected future potential damages from extreme floods for the current and proposed infrastructure options was undertaken by consultants with support from Infrastructure NSW.

The Review examined all flood mitigation infrastructure options previously considered in the Hawkesbury-Nepean Valley. No plausible new flood mitigation infrastructure options were identified for the valley through the Review’s consultation with key NSW Government agencies and councils. The Review selected a short-list of infrastructure options for further consideration based on their ability to reduce flood levels. Additional options strongly advocated by local communities and councils were also included. The short-listed infrastructure options were categorised into three groups, being those that:

- store or capture flood waters upstream of the valley
- drain or divert water away from the valley
- provide local protection up to a certain flood level within the valley

Water storage upstream of the valley

A number of options for storing water upstream of the valley were assessed. A previous review (1987-1995) considered a number of alternative sites for new flood mitigation dams, mostly located in National Parks. The Warragamba Dam site was found to have the greatest potential for cost-effective flood mitigation. Warragamba Dam has the largest storage capacity of the metropolitan water supply dams and its catchment represents over 40 percent of the total Hawkesbury-Nepean catchment area. The other flood storage or dam options were rejected by the earlier review due to their lower cost-effectiveness and significant environmental impacts.
These factors have not changed and there is no new information which necessitates any further consideration of new dam sites for flood mitigation.

A previous proposal to raise Warragamba Dam 23 metres, as detailed in a 1995 Environmental Impact Statement (EIS), was formulated primarily to ensure the dam could safely pass the Probable Maximum Flood (PMF), with flood mitigation as secondary objective. This crest raising proposal did not proceed, with construction of an auxiliary spillway to safely pass the PMF being completed in 2002.

This Review has found that the most effective option for storing floodwater upstream of the Hawkesbury-Nepean Valley and mitigating regional downstream flooding would be to raise the crest level of Warragamba Dam, (see Figure A4.1, Appendix Four for the current dam configuration). The timeframe and the scope for this Review only permitted a level of investigation corresponding to a pre-feasibility study. It was not possible to develop detailed concept designs for a large number of dam wall crest raising options in the time available.

Two dam crest raising options were selected to represent the indicative range of potential flood mitigation benefits and inform the feasibility of further investigations. Based on previous work and technical advice it was considered that a 15 metre dam wall crest raising could provide a reasonable lower boundary to assess flood mitigation potential (see Figure A4.2, Appendix Four for the possible design of the 15 metre crest raising). The 23 metre dam wall crest raising option was selected based on previous recommendations and its perception within the community as the level required.

Pre-feasibility assessments of both crest raising options were developed by NSW Public Works and peer reviewed by independent consultants SKM and their impact on the extent of downstream flooding was assessed by external experts. The pre-feasibility assessment estimated the direct costs for raising the dam were between a half and one billion dollars.

The Review found that raising the crest of the dam reduces peak flood levels but increases the duration and frequency of minor flood events. This is a result of the releases from the dam which must be made after flood events in order to maintain flood mitigation capacity (airspace).

The Review also assessed if the current operation of Warragamba Dam could be changed to provide flood mitigation, either as an interim or short to medium term measure. Dams can provide flood mitigation by having airspace available to store floodwaters, through:

- pre-releasing stored water ahead of a forecast flood inflow,
- lowering the full supply level (FSL), or
- surcharging the gates by raising them to follow the rising water level in the dam during a flood event (if it is a gated dam).

Pre-releasing relies on accurate rainfall and inflow forecasts, and the ability to release significant amounts of stored water without causing unacceptable downstream impacts. The Review found there was limited potential to pre-release from Warragamba Dam for flood mitigation as:

- weather forecasting is not yet sufficiently accurate or timely to allow for significant volumes of water to be released
- the downstream flooding could be exacerbated if floodwaters from the high rainfall Grose River catchment coincide with pre-releases from Warragamba Dam
- the water supply yield would be reduced if the forecast rainfall did not eventuate
In addition, the volume of water required to create sufficient airspace to provide flood mitigation in minor to moderate floods would lead to localised flooding impacts on a river-reliant community sensitive to small changes in river levels.

The Review assessed the impact of lowering the FSL of Warragamba Dam by two, five and 12 metres on downstream flood levels. Lowering FSL by 12 metres would reduce the storage available for water supply in the dam by 39 percent or 795 gigalitres. This is equivalent to one and half years water supply to Sydney. This significant impact on the current water supply yield of the dam and subsequent costs of alternative water supplies would need to be further investigated, and led to a decision not to pursue this option.

Lowering the FSL by five metres reduces the impact of minor to moderate floods (below 1 in 20 chance per year event), but has limited impact on the major to extreme flood events which pose the greatest threat to lives and property within the Hawkesbury-Nepean Valley.

Reducing the FSL by two metres has very limited benefits, due to the minimal airspace provided and the fact that the water level in the Dam is at least two metres below FSL under normal operation more than 85 percent of the time.

Given the timeline of this Review it has not been possible to model the impact of these options for reducing FSL. The five metre lowering was selected for more detailed examination, as it provides some flood mitigation in minor to moderate floods, with a moderate impact on water supply compared to the 12 metre option. Further work would be required to assess the suitability of the current gates on Warragamba Dam for implementing different operating rules.

State Water operates some of its dams for flood mitigation using the induced surcharge storage method of gate operations. This involves raising the gates in line with the rising water level in the dam during a flood event. This holds more floodwater behind the dam wall for longer. The Review has found that this method would result in minimal reductions in flood levels for minor to moderate floods, with an increase in flood levels for larger events. In addition, the downstream conditions, warning times and number of gates at the State Water dams are very different to Warragamba Dam. Further assessment of the safety of the gates and other operational arrangements would need to be undertaken prior to this option being considered further.

**Enhanced water drainage from the valley**

The Review assessed a number of options for enhancing the drainage of floodwaters from the valley by reducing the restriction of the Sackville gorge below Windsor. When flood waters reach Sackville the River is almost at sea level, with the 120 km section of meandering river confined by a sandstone gorge creating a natural choke point which restricts high flows leading to a backwater effect on the floodplain. There have been a number of downstream options proposed over recent years to remove a number of flow restrictions between Sackville and Brooklyn. However, only options that could eliminate the initial constrictions in the Sackville gorge would have significant flood mitigation benefits.

A broad range of flood drainage enhancements were considered, with the following options short-listed for more detailed assessment:

- **Currency Creek diversion** – a flood channel cut between Wilberforce and Currency Creek, which joins the Hawkesbury River near the Sackville Ferry
- **the Sackville cutoff** – a flood channel cut from upstream of the Sackville Ferry to the Cumberland Reach, located north of Sackville on the Hawkesbury River
- **the Sackville large diversion** – a flood channel cut from Sackville to Leets Vale
• **dredging the Hawkesbury River** – by 10 metres below the current bed level from Windsor to Wisemans Ferry

Figure A4.3, Appendix Four shows the locations of the Currency Creek diversion, Sackville cutoff and Sackville large diversion options assessed.

Figure A4.4, Appendix Four provides an indication of the area of dredging of the Hawkesbury River as assessed.

The Currency Creek diversion and Hawkesbury River dredging between Windsor and Wisemans Ferry have the same order of cost as raising the crest of the Warragamba Dam wall, have large environmental impacts, and provide less than half the flood mitigation benefits of raising the crest of the dam.

It should also be noted that these downstream flood mitigation options only increase the outflow from the valley during a flood event, so do not assist in flood evacuation operations. They have negligible reduction in flood levels at Penrith due to flow restriction at the Castlereagh gorge. In addition they would require ongoing maintenance and dredging to remain effective.

**Local protection**

The Review found there to be limited potential for localised flood mitigation using levees, due to the extreme depth of flooding in the valley, particularly in the Richmond-Windsor area. The Review assessed the three most promising of a long list of potential levees. The Review found that a flood levee on Peachtree Creek at Penrith may be viable. Levees in the Richmond and Windsor region would have to be very high to provide any significant flood mitigation, and their impact on local amenity is not likely to be acceptable.

Figure A4.5, Appendix Four presents an overview of the flood mitigation infrastructure options assessed at Penrith.

Figure A4.6, Appendix Four provides an overview of the flood mitigation infrastructure options assessed at Richmond-Windsor.

Figure A4.7, Appendix Four shows an aerial view of the possible designs of the Penrith levee options assessed.

Figure A4.8, Appendix Four presents an aerial view of the possible designs of the Pitt Town levee options assessed.

Figure A4.9, Appendix Four provides an aerial view of the possible designs of the McGraths Hill levee options assessed.
Issues, strategies and Review recommendations

The following section of this Report presents the issues, strategies and recommendations arising from Stage One of the Review. These have been grouped into three major categories:

- infrastructure that can be built to mitigate floods
- governance changes that can reduce the impact of floods through improved preparation and management
- non-infrastructure measures such as better flood response, planning, and modelling

As noted previously, the overall structure of the Review, which identifies gaps or weaknesses in current flood management arrangements, as well as the strategies and recommendations proposed to address these, is presented in Appendix Two. The infrastructure and non-infrastructure options considered by the Review are listed in Figure 13. All methodologies used to evaluate the issues, strategies and recommendations are presented in Appendix Three.
Figure 13: Infrastructure and non-infrastructure options for flood mitigation in the Hawkesbury-Nepean valley
Infrastructure

STRATEGY A - Enhance flood mitigation infrastructure

Flood risk in the Hawkesbury-Nepean Valley is driven by a combination of the ‘bathtub’ geography of the valley (which causes very high flood depths to build up between the large upstream catchment and the downstream narrow incised sandstone gorges) and population growth on the edge of Sydney.

Currently, there is no significant dedicated flood mitigation infrastructure in the valley. While the presence of Warragamba Dam and the Upper Nepean dams usually provides some mitigation they are not operated as flood mitigation dams.

Flood infrastructure can reduce risk to property by lowering the probability of a particular flood event. It can reduce but not eliminate the risk of flooding.

The Review examined the full range of upstream storage, downstream diversion and local protection infrastructure options and concluded that raising the crest of Warragamba Dam is the infrastructure option with the most potential for reducing the extreme flood risk in the Hawkesbury-Nepean Valley.

The catchment of Warragamba Dam makes up 80 percent of the Hawkesbury-Nepean River’s catchment at Penrith and 70 percent of the River’s catchment at Windsor. This means that spills from Warragamba Dam make the largest contribution to most floods above the current default flood planning level (based on the 1 in 100 chance per year flood level) in the Hawkesbury-Nepean Valley. Any potential flood mitigation dams on other creeks and rivers in the catchment would provide significantly less flood mitigation than raising the crest of Warragamba Dam wall and would generally be expensive to construct due to their location in wide river valleys.

Due to time constraints the Review only assessed the flood mitigation potential of raising of the Warragamba Dam wall crest by 15 and 23 metres. Pre-feasibility construction costs and reduction of flood levels have been calculated. However, economic, environmental and social costs and benefits have not been included at this stage.

Detailed cost benefit analysis would be required for any dam crest raising options in Stage Two. Although both dam wall crest raising options provided significant reductions in flood risk, the geography of the valley means that large floods would still occur, but with a significantly lower frequency. Raising the crest of the Warragamba Dam wall would also increase the time between the rain event and the flood peak at Penrith and Windsor, allowing for flood evacuation to occur in a more certain and orderly way. No Dam option eliminates the flood risk.

Given the time required to fully investigate, optimise, assess and possibly undertake the crest raising of Warragamba Dam, there is a need to more thoroughly examine the potential for some mitigation of floods in the short-medium term through changing the operation of Warragamba Dam. These minor to moderate flood events, with 1 in 1 to 1 in 20 chance of occurring in any one year, cut low-lying bridges and affect agricultural production. These smaller flood events are usually associated with Warragamba Dam spilling, but under certain localised weather conditions can also be caused by inflows from creeks and rivers downstream of the dam.
### RECOMMENDATION 1:

Determine the appropriateness and the steps required to allow the reduction of full supply level by up to five metres and/or the implementation of alternative gate operation at Warragamba Dam for the mitigation of minor to moderate flood events in the short-term.

Undertake investigations into

- the two methods for achieving flood mitigation through changes to the operation of the current Warragamba Dam worthy of further investigation:
  - lowering the full supply level and/or
  - operating the gates differently to allow temporary flood storage by surcharging the dam’s radial gates during flood events
- the safety risks of operating the radial gates with a flood surcharge and the costs of any modifications to the gates and associated control infrastructure to reduce these risks to an acceptable level
- potential environmental impacts of the additional temporary inundation of the Blue Mountains National Park from surcharging the radial gates
- the economic impacts of reducing the water supply yield by lowering the full supply level of Warragamba Dam
- potential flood mitigation achieved by lowering the full supply level, taking into account the difficulty in maintaining the lowered full supply level during wet years, and the current lowering of the dam level due to water consumption and potential environmental flow releases from Warragamba Dam
- acceptable flow rate for discharge of stored water from Warragamba Dam to recover the lowered full supply level, balancing the impacts of the prolonged high flows downstream and the need to quickly lower the storage to the lowered full supply level following inflow events to restore the dam’s flood mitigation storage

### RECOMMENDATION 2:

Optimise the configuration of a raised Warragamba Dam for flood mitigation of the full range of flood events and water supply, with due consideration of upstream impacts.

Further detailed investigation is required to optimise the configuration and height of a raised Warragamba Dam (likely to be between 15 and 23 metres investigated by this Review), and to determine and assess a range of engineering, economic, environmental and social impacts of such a major infrastructure proposal.
STRATEGY B - Enhance flood evacuation capacity of transport infrastructure

Large numbers of people need to be evacuated from the Hawkesbury-Nepean Valley during large flood events, particularly in the Richmond-Windsor floodplain. In addition, the undulating nature of the floodplain leads to roads being progressively cut, and the formation of isolated flood islands as flood levels rise. Many of these islands can be totally covered with floodwater if levels continue to rise, causing significant evacuation issues to anyone on those islands.

The adequacy of the road network was reviewed in the late 1990s and led to a number of improvements to evacuation routes including the construction of the Jim Anderson Bridge at a cost of $210 million. There are parts of the road network that could be further improved to enhance the evacuation capacity of the area.

Agent-based modelling considers the evacuation behaviour of each vehicle or person in a flood-affected area. Pilot agent-based evacuation modelling undertaken for the Windsor township has identified that a number of intersections on local roads may create previously unknown bottlenecks during flood evacuation. More comprehensive modelling of this type is required to determine the extent of this problem across the floodplain, and what opportunities exist to address such bottlenecks through cost effective modifications such as signage, local traffic lights, and merging lanes (see Recommendation 11).

There may also be potential for Transport for NSW to improve the ability of the Traffic Management Centre to coordinate major evacuation events through improved traffic controls in the region.

RECOMMENDATION 3:

Develop and implement a program of cost-effective road improvement works that can enhance flood evacuation capacity in the short-medium term.

The pilot of an agent-based vehicle evacuation model at Windsor has identified that intersections on local roads may create traffic bottlenecks during a flood evacuation. Opportunities to address these local bottlenecks should be identified and addressed as a matter of priority, through a process including:

- drawing on the findings of broader-scale agent-based evacuation modelling to identify critical traffic bottlenecks that may occurs during a flood evacuation
- identifying opportunities to mitigate these potential bottleneck, through cost-effective modifications of existing road infrastructure such as changes to signage, lane configurations, local intersections and associated traffic lights
- an assessment of the impact of these potential changes on the overall evacuation timeline

However, the overall evacuation timeframe is still determined by the capacity of the main evacuation routes from the valley, and the flood levels at which these routes get cut. As demonstrated by the Jim Anderson Bridge, increasing road capacity and raising low points on these roads can be expensive.
Raising the crest of the Warragamba Dam wall would reduce the likelihood and frequency of extreme flood events, and may increase the certainty of calling an evacuation, but would have limited impact in the total number of people that will need to be evacuated in extreme flood events.

While raising Warragamba Dam by 23 metres would reduce flood levels at Windsor from 26.2 metres in the largest possible flood event by around 3.8 metres to 22.5 metres, this depth covers a relatively small area at the edge of the floodplain and extensive evacuation would still be required because roads are cut at much lower levels of inundation (starting at 13.5 metres at McGraths Hill).

The interaction between the various options for raising the crest of Warragamba Dam and providing adequate flood evacuation capacity for the growing population in the valley is complex, and requires a more integrated approach to flood management and evacuation planning, as discussed in Recommendation 5.

**RECOMMENDATION 4:**

*Improve regional transport infrastructure to address current and projected flood evacuation capacity constraints and timelines.*

A process needs to be defined and implemented to identify specific road infrastructure options to provide necessary evacuation capacity throughout the Hawkesbury-Nepean floodplain.
Governance

STRATEGY C - Establish governance arrangements that support more integrated and effective management of flood risk.

Appropriate governance arrangements form an important basis for flood risk management, through the development and implementation of ‘best practice’ in flood planning, prevention, preparedness and response. Effective flood governance arrangements provide:

- clarity and awareness of the flood risk management roles, responsibilities and liabilities of all levels of government, the community, industry and non-government organisations
- linkages across flood prevention, preparedness and response in decision making, to manage the full range of flood risks to existing and future communities
- a proactive and cooperative approach to manage flood risk before events happen, through risk based land-use planning, mitigation works, building controls and emergency management planning, rather than focusing on emergency response and recovery
- community awareness of the support available to local communities, how to assess risks and reduce exposure and vulnerability to hazards, and options available to residents when responding to an approaching hazard
- monitoring, review and continuous improvement of the understanding and management of flood risk
- arrangements to ensure the most effective, well-coordinated responses from emergency services and volunteers when a disaster hits
- arrangements to ensure we learn, innovate and adapt in the aftermath of disastrous events

The Review has identified several opportunities to improve the existing governance framework for flood risk management. Some of these issues apply across NSW, or would be most effectively addressed through enhancements of broader, state-wide governance arrangements (see Recommendation 6), while others are specific to the Hawkesbury-Nepean Valley.

The management of flood risk in the Hawkesbury-Nepean Valley involves a number of agencies, councils and other stakeholders. Governance arrangements for flood planning, preparation and response need to encourage and facilitate effective coordination and cooperation between these organisations.

The 1997 Hawkesbury-Nepean Floodplain Management Strategy found that an ongoing advisory committee with dedicated technical support was required to meet this need. Such a committee is again needed today, with links to an appropriate high level cross-agency committee dealing with state-wide flood risk management issues with similar technical support.

Effective flood management requires an integrated approach to land use planning, flood mitigation, infrastructure and flood evacuation, which is linked to contemporary, catchment-scale flood information and modelling. While these issues are typically addressed through local floodplain risk management plans prepared by councils, the large number of councils within the Hawkesbury-Nepean floodplain has precluded a truly integrated approach.

A Regional Floodplain Risk Management Plan aimed at providing a strategic approach to reduce and manage risk from flooding from the main Hawkesbury-Nepean river system has not been developed, as recommended in the 1997 Hawkesbury-Nepean Floodplain Management Strategy.
The draft Sydney Metropolitan Strategy proposes a strategic policy framework for considering natural hazards, including flooding, to be planned for at an early stage, and for development and related infrastructure to avoid locations at risk from natural hazards unless the risks are demonstrated to be manageable. The draft Strategy also proposes that emergency management considerations be integrated with strategic land use planning decisions.

An integrated, regional governance framework is particularly important in ensuring evacuation planning. Whilst evacuation plans have been developed in the past, the capacity of evacuation routes has been exceeded over time, due to the:

- large number of councils and consent authorities in the Hawkesbury-Nepean Valley
- high levels of development, including infill within existing urban areas, which has exceeded levels assumed in evacuation route design
- failure to collect and maintain flood and development information
- absence of any mechanism to monitor development (greenfield and infill) to correlate against flood modelling and evacuation capacity planning to identify when evacuation capacity has or will be exceeded, and can be fed into planning of infrastructure upgrades
- absence of a regional approach or central coordinating body with responsibility to monitor and assess changes in the flood risk profile over time, as development proceeds throughout the valley

No mechanism exists to assess cumulative impact of development and associated changes to the risk profile of the valley on flood evacuation routes and capacity. Impacts of infill development within existing zonings are considered only on a case-by-case basis. Evacuation capacity should be a key consideration in the planning of land use, transport and other critical infrastructure. This can result in:

- loss of recent investment in additional evacuation capacity
- an ad hoc approach to investment in infrastructure and decisions on development
- increased flood risk to the community

Consent authorities need contemporary information and tools to increase awareness of problems relating to flood hazard and evacuation capacity. Evacuation capacity assessments need to inform decisions about zoning and growth targets in the floodplain.

Given the cumulative nature of evacuation issues in particular, consent authorities must satisfy themselves that evacuation capacity will not be exceeded with each development considered. Rezonings within the floodplain to allow for growth should not occur unless an evacuation capacity assessment is undertaken, potentially involving the SES where the assessment indicates a high risk to life.

To ensure they are considered in detail in statutory land use planning, catchment scale flood and evacuation modelling, mitigation strategies and evacuation plans need to be current and accessible. This would enable housing and employment targets in regional growth plans and subregional delivery plans to be informed by flood risk information, and allow flood mitigation funding mechanisms for large-scale development to be considered in growth infrastructure plans. Regional growth plans and subregional delivery plans will then directly inform local plans.

Improved governance arrangements are needed to undertake and maintain catchment-based flood modelling, mitigation and evacuation capacity studies and plans for a range of development scenarios and timeframes across the valley. These would ensure linkages between these elements of flood risk management, land use planning and development assessment. This
information should form part of a Regional Floodplain Risk Management Plan for the Hawkesbury-Nepean Valley.

The lack of a central body or other mechanism for undertaking catchment-scale flood and evacuation modelling and collating mitigation and evacuation capacity information has resulted in the lack of contemporary and accessible evidence to inform statutory land use planning.

In the past, regional plans have often only included general flood-related statements, rather than detailed consideration of the hazard and implications for growth. As a result these plans have not provided direction for LEP zonings to limit growth to the available evacuation capacity or prompted infrastructure upgrades to provide necessary evacuation capacity.

A more integrated and coordinated approach to land use planning, infrastructure, flood evacuation and flood modelling across the valley could most effectively be provided by establishing a new dedicated group or body within an appropriate agency to lead, undertake or integrate these activities. It would need appropriate linkages to other agencies and to any group dealing with broader state-wide flood risk management arrangements.

This body could also be responsible for tracking development across the valley, and cross-referencing this against flood modelling, flood mitigation strategies and evacuation capacity. It would need to consider cumulative impacts, and provide advice on the impacts of rezonings to consent authorities.

This evidence, and related databases and tools, would inform all levels of land use planning and decision making. It would also need to ensure that flood mitigation strategies do not negatively impact on the flood emergency management strategy for the affected area.
RECOMMENDATION 5:

Establish a dedicated group or body within an existing agency to provide a more integrated, coordinated and regional approach to land use, infrastructure and evacuation planning and flood modelling in the Hawkesbury-Nepean Valley.

Undertake further investigation of governance models/options to identify an optimal approach. One option may be a dedicated group or body whose roles could include:

- preparing and maintaining a regional Hawkesbury-Nepean Floodplain Risk Management Plan
- preparing and maintaining flood modelling, flood mitigation, evacuation capacity and infrastructure resilience studies and plans
- ensuring these studies and plans are taken into account in regional growth plans, subregional delivery plans, growth infrastructure plans and local plans
- feeding development data into updates of these studies and plans to monitor and assess cumulative impacts
- providing information and tools to feed into land use planning, development assessment, flood emergency response planning and recovery planning
- providing technical support and coordinating financial assistance for the flood risk management activities of councils
- developing a risk-based standard for flood evacuation capacity assessment to be used prior to rezoning for growth. Consideration may also be given to formalising the role of the SES in circumstances where the assessment indicates a high risk to life

As noted previously, the Review has identified opportunity for improvement in the existing governance framework for flood risk management. Governance issues of state-wide significance in NSW include:

- inconsistency in the legislative basis for flood risk management in NSW
- the lack of a legislative basis for a specialist technical role for NSW Government in flood risk management, or associated support for local government
- the absence of guidance on current administrative arrangements for flood risk management in NSW, which have changed since the development of the NSW Floodplain Development Manual in 2005
- flood prevention, preparedness and response falling across a number of agencies with no cross-agency group overseeing integration of these issues.
- a lack of coordination of technical efforts in flood risk prevention in NSW. The lack of a permanent inter-agency technical working group involving agency experts reduces the ability of government to deal quickly with issues as they arise in the most efficient and effective manner, and can inhibit coordination and strategic management of issues.
- ineffective tools to encourage councils to develop and implement flood risk management plans. Councils are encouraged to develop and implement such plans through the technical and financial assistance provided by the NSW Government, and the limited legal indemnity
provided by section 733 of the Local Government Act 1993. There is no ability for the NSW Government to direct councils to develop or implement a Flood Risk Management Plan or undertake associated studies.

These issues highlight the need for an improved governance framework for the management of flood risk at a state-wide scale in NSW.

**RECOMMENDATION 6:**

Review the NSW state-wide governance arrangements for flood risk management so that broader issues identified by this Review can be most effectively addressed.

These arrangements should consider:

- oversight of integrated delivery of flood risk management in NSW. This could be most effectively undertaken by a relevant cross-agency committee, similar to Metropolitan Water CEOs Committee or the State Emergency Management Committee. This group should include representatives of Department of Planning and Infrastructure, State Emergency Service, Office of Environment and Heritage, Office of Water and Minister of Police and Emergency Services

- establishment of a dedicated group with appropriate technical expertise within an appropriate agency to lead, undertake and/or integrate flood risk management activities in NSW. This group would address a range of gaps or inadequacies in current governance arrangements for flood risk management across NSW, through:
  - developing and maintaining an administrative guideline that outlines roles and responsibilities in flood risk management in NSW
  - developing and maintaining technical flood risk management guidelines to support policy delivery
  - monitoring the implementation of the NSW Flood Prone Land Policy across NSW
  - providing inter-agency input into projects such as development of the NSW flood database
  - coordinating advice on cross-agency issues such as flood insurance
  - providing specialist technical input into state planning policies and guidelines
  - providing linkages to other levels of government (Australian Government, local government) as appropriate
  - coordinating and supporting a State Flood Risk Management Technical Working Group to enable effective coordination at a technical level on flood risk management and associated issues
  - providing technical and financial assistance to local government for the development and implementation of flood risk management plans
  - other specific actions as identified by other Recommendations in this report

Effective flood response in the Hawkesbury-Nepean Valley, and across NSW, relies upon the availability of a quantitative flood warning service from the Bureau of Meteorology (BoM). Flood warnings rely on a total flood warning system, which includes instruments to collect data and the system to transfer the data to the BoM in real time to enable quantitative flood warnings.
In the Hawkesbury-Nepean Valley, this quantitative flood warning service relies upon a water level gauge network that is managed by a range of agencies, often installed for other purposes, and which is not funded for a flood warning purpose. The gauges are therefore vulnerable to removal or lack of maintenance as part of cost-savings by the funding organisation. They are also dependent upon telemetry systems and their supporting power supply. Without these gauges only a qualitative flood warning service would be available, severely hampering emergency response with significant impacts for community safety in the event of a flood threat.

The NSW State Flood Plan 2008 incorporates a list of locations where it is agreed that quantitative flood predictions are required. As part of the work of the Hawkesbury-Nepean flood monitoring group it was agreed to expand this annexure to document the key riverine flood gauges that enable this to occur in the Hawkesbury-Nepean Valley.

While flood warning systems have operated effectively in the Hawkesbury-Nepean Valley in the past, the potential for key gauges to be removed or inadequately maintained needs to be addressed to ensure they are available to fulfil their necessary function into the future. This is a broader issue across the state.

In addition, flood gauges are generally located on crown or private land. Site tenure can be tenuous relying on agreements with land owners which are becoming more expensive. Loss of access can inhibit continuity of service, and may require the relocation of instruments. There is a specific issue of gauge site ownership at Windsor, for example, that need to be addressed.

The following arrangements are proposed to ensure an effective flood gauging network in the Hawkesbury-Nepean Valley into the future. Together these proposals will ensure that key flood warning gauges will be maintained and upgraded as necessary to provide reliable information for flood warnings. Without implementation the pressures to remove or reduce maintenance on key flood warning gauges will continue.
RECOMMENDATION 7:
Ensure effective flood gauging arrangements in the Hawkesbury-Nepean Valley

Key aspects of this work will include:

- concluding the current process of identifying water level gauges necessary to support flood predictions at locations agreed under the NSW State Flood Plan 2008, in an annexure to that plan
- establishing an interim agreement with owners that no river water level warning gauges identified in the annexure to the NSW State Flood Plan 2008 be removed without appropriate consultation and alternative arrangements
- establishing a framework and long-term arrangements for gauge owners to ensure that critical river level gauges are maintained, including relevant standards
- developing standardised access arrangements for flood gauging sites
- identifying a funding source for river water level gauges identified in the NSW State Flood Plan 2008
- re-establishing the Flood Gauges Working Group previously convened by the State Emergency Management Committee to progress the above actions and report back to the Committee on any further action required
**STRATEGY D - Collection of post-event flood data and intelligence**

Lessons from rare flood events can provide critical insights to inform future response and management efforts.

Local government is responsible for post-event data collection and incorporating this information into its management decisions. The OEH has limited funding to help in this process, through the NSW Floodplain Management Program.

The OEH also undertakes post-event flood behaviour studies where flood behaviour is different to that expected. This is also funded through the NSW Floodplain Management Program.

The SES is responsible for updating and improving flood intelligence and emergency management planning. Post-event data collection is not eligible for Australian Government funding under Natural Disaster Relief and Recovery Arrangements (NDRRA).

There is no strategic, governance framework for coordinating data collection and related activities and, for continuous improvement through collection, access and provision of post-event data collection. To address this need, action is recommended to clarify roles, responsibilities, coordination arrangements and potential funding sources for post-event data collection.

Clarifying the governance arrangements for post-flood data collection would also provide a consistent framework to coordinate timely, quantitative inputs to flood plan reviews.

The benefits of improved collection and use of post-event data and intelligence are not limited to the Hawkesbury-Nepean Valley. A state-wide solution to this issue is preferable. Learning the lessons from large flood events would improve flood response and management in future, reducing risks to life and property.

**RECOMMENDATION 8:**

**Clarify roles, responsibilities and consider funding options for post-event collection of data and flood intelligence.**

Key issues to be addressed through this recommendation are:

- identifying and addressing any gaps and duplication in the roles of relevant agencies
- identifying funding options for this activity
- identifying other arrangements to ensure this activity provides appropriate quantitative inputs into flood plan and floodplain risk management plan reviews
STRATEGY E - Improve recovery planning

A severe flood in the Hawkesbury-Nepean Valley would lead to economic, social and other impacts of state-wide significance. Community recovery from such a flood would be prolonged and highly complex to coordinate.

Emergency response to major floods in this valley is addressed through the Hawkesbury-Nepean Flood Emergency Sub Plan 2013 (HNFESP). Arrangements exist within the HNFESP to form a Region Recovery Committee during or following a flood event, whose functions are to develop a Recovery Action Plan, coordinate the activities of agencies responsible for delivering services and engage with affected communities to restore normal functioning of the community.

For the longer-duration recovery from such a flood in the Hawkesbury-Nepean Valley that affects multiple districts and is of state-wide significance, the State Emergency Recovery Controller (SERCON) may invoke recovery arrangements under the NSW Recovery Plan 2010. These arrangements may include forming a State Recovery Committee and the appointment of a State or Regional Recovery Coordinator.

High-level principles for recovery planning are provided in the State Recovery Plan. However this plan does not provide the level of detail required for recovery activities in the Hawkesbury-Nepean Valley, such as critical ‘hotspot’ locations likely to require special attention.

The potential scale and duration of the flooding impacts within the Hawkesbury-Nepean Valley warrants the development of a specific Hawkesbury-Nepean Flood Recovery Sub Plan, incorporating strategies and arrangements for recovery from severe floods and providing the transitional support from response operations under the HNFESP to the full spectrum of recovery activities.

As a member of the State Emergency Management Committee, the SERCON would undertake the coordination of a Hawkesbury-Nepean Flood Recovery Sub Plan and the engagement of stakeholders in the plan development and testing phases.

RECOMMENDATION 9:

Develop a Hawkesbury-Nepean Flood Recovery Plan, which identifies strategies and arrangement for recovery from severe floods in the Hawkesbury-Nepean Valley.

The scope of the Hawkesbury-Nepean Flood Recovery Plan would include:

- roles and responsibilities of key stakeholders in the recovery activities
- organisational and command and control arrangements
- community consultation and engagement arrangements
- model arrangements for the delivery of services to enable the functioning of communities
- a funding framework in accordance with Natural Disaster Relief and Recovery Arrangements

The prompt restoration of utility service infrastructure, such as electricity and gas transmission systems, water and wastewater treatment and reticulation infrastructure and essential health and
other community infrastructure is clearly a critical aspect of planning the recovery from a major flood event in the Hawkesbury-Nepean Valley.

Utility service providers are regulated to include emergency management and business continuity arrangements in their network management and safety plans, and are networked on an industry-wide basis for business continuity planning.

Restoration of utility service infrastructure is coordinated through current NSW emergency management arrangements as required under section 16(2) of the State Emergency and Rescue Management Act 1989.

However, given the potential scale of impacts of a flood in the Hawkesbury-Nepean Valley, there may be considerable delays in establishing arrangements for the reconstruction of some infrastructure.

The Queensland Government found it necessary to establish new legislation and governance arrangements in the aftermath of the spate of natural disasters suffered in that state in 2010-11. Different arrangements are in place in NSW. Nonetheless, the scale of flooding in the Hawkesbury-Nepean Valley and potentially other floodplains will require a significant and coordinated reconstruction program following a major flood. With foresight, this warrants an investigation and assessment of the adequacy of current arrangements for the reconstruction of essential infrastructure following a major flood event in the valley.

The proposed review of the adequacy of current infrastructure reconstruction arrangements will provide the best possible basis for ensuring that infrastructure restoration efforts following a major flood event are supported by coordinated and effective governance, funding and planning frameworks. The costs and benefits of identified arrangements for infrastructure reconstruction, and their potential integration with Subregional Delivery Plans, should be evaluated in Stage Two of the Review.

**RECOMMENDATION 10:**

Review the adequacy of current arrangements for infrastructure reconstruction following a major flood event in the Hawkesbury-Nepean Valley.

The initial focus of the review should be to:

- consider the adequacy of current infrastructure reconstruction funding arrangements as part of a review currently being undertaken by NSW Treasury and the Emergency Management sector
- clarify options for obtaining funding for reconstruction of essential utility assets under the National Disaster Relief and Recovery Arrangements
Non-infrastructure solutions

STRATEGY F - Improve emergency management, planning and implementation

Evacuation capacity within sections of the Hawkesbury-Nepean floodplain is not optimal. This is a result of a range of factors, including greater development intensity within established urban areas and 'greenfield' expansion at the urban fringe. It is estimated that current evacuation capacities in some areas of the valley have declined and are now close to estimated 1997 evacuation capacities. This is despite the significant road infrastructure carried out through the Hawkesbury-Nepean Floodplain Management Strategy 1997 since that time.

Additional development within sections of Penrith and Hawkesbury local government areas has the potential to further compromise the flood evacuation capacity for communities in those areas. It will be important that further development in the region demonstrates that it will not compromise the work needed to rectify existing evacuation route inadequacies.

A pilot trial of agent-based modelling was undertaken to examine the evacuation timeline for the Windsor area. Preliminary results have indicated that congestion and queuing can occur on local roads before traffic gets onto the major evacuation routes during evacuation.

Further modelling of the road evacuation network and investigation of potential traffic congestion issues arising in a major to severe flood event is required. This model would provide a basis for a more integrated approach to urban development and evacuation planning at a regional and local scale. It would also provide better understanding of the dynamics of the road evacuation network and the interaction with sequencing of evacuations from the various operational sectors.

If these modelling and road infrastructure upgrade options are not undertaken then:

- SES Incident Controllers will have increasing difficulty in managing the sequencing of evacuations onto a complex road evacuation network that is very sensitive, even to normal day-to-day traffic conditions
- further development could adversely impact the road evacuation network.

RECOMMENDATION 11:

Develop a comprehensive road evacuation network model for floods in the Hawkesbury-Nepean floodplain to inform evacuation capacity assessments and strategic transport and land use planning, and to assist with the real-time operational management of evacuation during floods.

Development of a complete evacuation traffic model for the whole floodplain employing contemporary agent-based and network modelling would allow:

- a better understanding of how traffic congestion and queuing on local roads will affect the success of an evacuation operation
- investigation of evacuation traffic interaction on the Great Western Highway and the M4 Motorway involving traffic leaving Hawkesbury and Penrith LGAs
- analysis of vehicle flow rates through important intersections on regional and local evacuation routes
Overall evacuation times are predominantly determined by capacity of the main evacuation routes from the valley, and the flood levels at which these routes get cut. As demonstrated by the Jim Anderson Bridge, increasing the road capacity and raising low points is expensive.

Transport for NSW has a program of augmenting major roads from the Hawkesbury-Nepean Valley to meet the needs of the growing population in the area. As with other metropolitan regions, the focus is on reducing commuting times. However, the capacity of key major roads to provide a potentially life-saving evacuation route benefit during extreme flood events should also be considered in the planning and scheduling of main road upgrades in the valley. There is also potential for Transport for NSW to improve the ability of the Traffic Management Centre to coordinate major evacuation events through improved traffic controls in the region.

**RECOMMENDATION 12:**

Ensure future road infrastructure planning considers flood evacuation requirements throughout the Hawkesbury-Nepean floodplain.

Future regional road planning in the Hawkesbury-Nepean Valley must consider the current and projected evacuation requirements identified in the updated agent-based evacuation model.

The emergency response to a severe flood in the Hawkesbury-Nepean Valley is a resource intensive and complex operation. It is therefore critical that the State Emergency Service (SES) has the capacity to plan for, respond to and manage the full range of floods in the Hawkesbury-Nepean Valley.

There are three specific areas of risk with the potential to adversely impact on effectiveness of the flood emergency planning and response management arrangements. They are risks associated with:

1. the nature and timing of flood emergency evacuation decision making
2. community response to decisions to implement flood evacuation
3. the cumulative impact of population growth and the consequential demand on emergency services and evacuation infrastructure, beyond available capacity

Risks 2 and 3 cannot necessarily be addressed by altering specific emergency management arrangements, and are addressed elsewhere in this Review (see Recommendations 15 and 5 respectively). Addressing risks 2 and 3 is critical to ensure adequate flood emergency planning and response management arrangements.

To address risk 1 above it is recommended that the capacity of the SES to manage Hawkesbury-Nepean flood operations be enhanced.

Specifically, the key activities proposed for the SES to address the risk include:

- Review and further development of the Hawkesbury-Nepean Flood Emergency Sub-Plan 2013 (HNFESP) and Local Flood Plans:
- an ongoing plan review process, based on the best available information about the flood hazard and flood risk, to ensure the sustainability and quality of these Plans

- review the number and location of evacuation centres in light of emerging NSW emergency management policy

- regular review of Supporting Plans to the Hawkesbury-Nepean Flood Emergency Sub-Sub Plan 2013 (e.g. Health, Land Transport)

- review and refine inputs to the evacuation timeline analyses

- further detailed planning and spatial analysis for Hawkesbury-Nepean flood scenarios

- Continued development of SES capability through:
  - regular review (and improvement as necessary) of the SES’s capability and capacity to plan, exercise and respond to a flood threat in line with the scale and scope of the full range of flooding in the Hawkesbury-Nepean Valley
  - review of the adequacy of staff resources to maintain, exercise and review the HNFESP 2013 and Local Flood Plans, and to drive the necessary plan testing and exercises
  - continue training of SES Incident Controllers specifically in managing flood in the Hawkesbury-Nepean Valley
  - use of the SES’s capability development framework to ensure that it has the capacity to support implementation of the Hawkesbury-Nepean Flood Emergency Plan

- Exercises – internal and interagency:
  - implementation of a rigorous and persistent regime of operational decision-making exercises for SES Incident Controllers based on the development and interpretation of evacuation timeline modelling
  - continued training and exercising of SES Incident Controllers specifically on managing flood in the Hawkesbury-Nepean Valley. These exercises need to be coupled with regular familiarisation briefings about the flood risk and planned management arrangements in the valley
  - implementation of regular multi-agency exercises and briefings to ensure that all agencies with responsibilities under the NSW Emergency Management Plan (EMPLAN) and the HNFESP 2013 are aware of, and maintain capability to fulfil, their roles.
RECOMMENDATION 13:

Ensure the SES has the long-term capacity to plan and exercise for the full range of flood events in the Hawkesbury-Nepean Valley.

The key activities proposed include:

- review and further development of the Hawkesbury-Nepean Flood Emergency Plan and Local Flood Plans
- continued development of SES capability
- implementation of internal and interagency exercises by the SES
STRATEGY G - Improve community education on flood risk and response

The National Strategy for Disaster Resilience 2011 highlights the importance of having clear and effective education systems so people are aware of flood risks, and understand what options are available and what the best course of action is in responding to a hazard as it approaches.

Flood education was promoted in the Hawkesbury-Nepean Valley as part of the Hawkesbury-Nepean Floodplain Management Strategy 1997, which recommended ongoing delivery of community awareness programs. The results of community surveys in the Hawkesbury-Nepean Valley, most recently in 2008, indicate no significant success in improving the community’s understanding of flood risk. There is a need to raise community awareness using risk communication principles through direct community engagement.

The State Emergency Service and councils each have a role in community education. Councils provide information on flood risk and management to owners and purchasers. The SES educates the community (through its FloodSafe programs) on how to prepare for and respond to a flood threat, focussing on public safety and property protection.

Resourcing levels inhibit program delivery and the opportunities and benefits of joint efforts are not realised. Community attitudes and the effectiveness of flood education and awareness programs are not regularly measured.

Options to improve community awareness include:

1. continuation of councils’ individual flood education efforts. Consideration could be given to providing grant program funding for the developing suitable materials for this purpose, through the Natural Disaster Resilience Grants Scheme

2. initiation of an integrated, valley-wide flood education program by councils, linked to flood risk information as described in Strategy C

3. continuation and expansion of the SES’s FloodSafe program across the valley, potentially in combination with options 1 and 2 above

4. establishment of a coordinated and effective approach to flood education in the valley to improve understanding and preparedness for floods, and to maximise the efficiency and effectiveness of community education. This could build upon the SES’s FloodSafe program and be coordinated by the SES or the central body proposed in Strategy C

Given the urgency of this issue, an integrated, valley-wide flood awareness and education program is proposed, combining options 3 and 4 above. This program would involve:

- coordinating the flood education activities of councils across the Hawkesbury-Nepean Valley
- ongoing development and delivery of the SES’s FloodSafe programs, including those targeting business and agricultural industries in the valley
- periodic evaluation and revision of flood education programs, with incorporation of this information into flood emergency response planning, including a survey of community flood awareness in the near future, using a methodology comparable to the 2008 survey
RECOMMENDATION 14:

Undertake, coordinate and evaluate community education programs on flood risk and response.

This work would involve:

- coordinating the flood education activities of councils across the Hawkesbury-Nepean Valley
- ongoing development and delivery of the SES’s FloodSafe programs, including those targeting business and agricultural industries in the valley
- periodic evaluation and revision of flood education programs, with incorporation of this information into flood emergency response planning. This should include a survey of community flood awareness in the near future, using a methodology comparable to the 2008 survey

Community surveys carried out by the State Emergency Service (SES) of people living in the Hawkesbury-Nepean Valley suggest that between 20 and 30 percent of those living in flood prone areas do not believe it is necessary to evacuate when directed by the SES to do so. In the absence of other explanations, this belief suggests they apparently do not perceive or accept that there is a serious risk to their life in floods.

Community survey data specific to the Hawkesbury-Nepean Valley has been collected since 1999, with the most recent survey data being collected in 2008. The results of these surveys do not indicate any significant success in changing some fundamental indicators relating to flood risk understanding across the communities in the valley.

In particular, the results indicate the following about the Hawkesbury-Nepean Valley community:

- 20 percent of the population is unlikely to evacuate when directed to do so
- the perception of flood as a risk to life is rated as low
- less than 10 percent of the population have a plan for what to do in a flood
- only three percent of the population indicate a positive intent to seek flood risk information, with this indicator approximately halving from six percent measured in a 2006 survey
- only 50 percent of the population understand the components of the flood warning system

Given the depth of major floods in the Hawkesbury-Nepean Valley, flood evacuation is the only emergency response strategy that can guarantee to protect life for the size of the population at risk. It is therefore a serious concern that a consistent 20 percent of the population indicate that they would not be likely to evacuate if directed to do so. This response also suggests that this 20 percent of the community lacks a fundamental understanding of the level of risk that a severe to extreme flood can pose to their life. Alternatively, it might suggest that the community does not perceive the potential severity of floods in the valley.

Unfortunately, the surveys used in 2006 and 2008 were not designed to explore the responses to these important questions. Given the time lapse since 2008, it is essential that an update survey is conducted as soon as practicable to continue the longitudinal community profile.
To address this community response issue, the SES must apply an intensive and sustained community flood risk education program. This program must be informed by appropriate social research and best-practice approaches to behaviour change.

The Hawkesbury-Nepean Floodplain Management Strategy 1997 recommended an ongoing valley-wide flood education and awareness program. This led to the SES developing the award-winning FloodSafe program. With appropriate research, evaluation, resourcing and implementation, the FloodSafe program has the potential to positively address the issue of community response to flood emergencies.

Failure to properly research, resource implement and evaluate these programs will result in a community that is not primed to respond in a timely way to flood warnings with the result that evacuation may fail with a resultant rescue operation. Experience has shown that community awareness can, in the absence of a sustained community education program, decay rapidly between events.

**RECOMMENDATION 15:**

Monitor, investigate and address community response to flood warnings.

To ensure a positive community response to flood warnings, the SES will need to:

- review options for increasing the current limited funding for ongoing community engagement programs in the Hawkesbury-Nepean Valley including options to update the original surveys and continue to do this on a regular basis in order to effectively evaluate SES community engagement programs
- design a standard survey instrument to provide consistency in future surveys
STRATEGY H - Improve accessibility of flood risk information

The National Strategy for Disaster Resilience 2011 highlights the importance of having effective arrangements in place to inform people of flood risks so they can make informed decisions to reduce their exposure or vulnerability to flood hazard.

For the community to make informed decisions on investment, and in response to a flood threat, they need to understand that a flood risk exists and is relevant to them. This requires public access to information on flood risk in an understandable format.

Similarly, insurers and infrastructure providers need access to information to enable informed decisions. To be most effective in improving community resilience and decision making this information needs to be linked to community education activities.

The community has no single source of information on flood risk in the Hawkesbury-Nepean Valley. Local government has a key role in informing the community about flood risk. However, the availability and format of information available to the community varies within the valley, and across NSW and Australia. Data ownership and licensing issues can also inhibit the collection, availability and dissemination of flood information.

The need to improve accessibility and develop a standard for the provision and display of flood information has also been identified by:

- the Floodplain Management Association, a lead industry group with a significant number of local government members in NSW
- the NSW flood database project (NSWF), which is a priority action under the NSW 2021 Plan. This project provides a single pathway for flood information from local government to state government and a platform for sharing this data across government. However, the database is incomplete, relies on grant funding for development through the National Disaster Resilience Program, and has no recurrent funding to normalise its maintenance into day to day operations
- the National Flood Risk Information Project (NFRIP), part of the Commonwealth’s response to the Natural Disaster Insurance Review. This project aims to inform the community and insurers on flood risk. However, it relies upon the provision of data from the states and territories, potentially through projects such as NSWF. The Standing Council on Police and Emergency Managers has agreed to support the development of NFRIP
- the Insurance Council of Australia (ICA), which advises that residential flood insurance can be most accurately priced where detailed information on risk exists and is readily available. Insurance companies’ access to this information is currently via individual councils and the quality and format of this information varies. Financial recovery from major flood events is dependent on the uptake of flood insurance. The recent memorandum of understanding between the ICA and the Queensland Government to exchange flood modelling and insurance information may provide a model for future cooperation in NSW.

The development of an appropriate standard and mechanism to provide flood information to the community, insurers and government, with appropriate links to flood education, can enable improvements in understanding, managing and responding to the flood risk. This is partly through better informed investment decisions on the floodplain and pricing of flood insurance.

In addition, planning certificates issued for individual properties under section 149 of the Environmental Planning and Assessment Act 1979, can be misunderstood as advising if a flood
risk exists at a given location, rather than if a flood policy affects development of the property. Clarifying the role of these certificates would reduce the potential for this misunderstanding.

**RECOMMENDATION 16:**

Develop mechanisms and arrangements to promote and provide greater access to flood risk information.

A range of activities is proposed to improve access to information on flood risk, as follows:

- encouraging disclosure of flood risk information in planning guidance, grant conditions and through other mechanisms as appropriate
- establishing standards for the online display and accessibility of spatial flood risk information for the community, insurers and infrastructure providers
- developing and maintaining a mechanism for delivery of information on flood risk, ensuring consistent display, ready access for the community, insurance industry and infrastructure providers, and links to flood education resources
- liaising with the insurance industry and the National Flood Risk Information Project regarding access to and use of flood risk information
- investigating and resolving data licensing issues to improve the accessibility of flood information within government and to infrastructure providers, insurers and the community
- clarifying the role of planning certificates (section 149, *EP&A Act*) in communicating flood risk information, in the 'NSW Land Use Planning Guideline for Flood Prone Land' (proposed in Recommendation 18)
STRATEGY I - Improve flood modelling framework and tools.

Computer modelling of flood events provides an essential basis for many other aspects of flood management. The planning of land use, emergency response, flood evacuation and recovery all rely fundamentally on an ability to predict the levels and behaviour of floods of various magnitudes or frequencies.

A comprehensive and integrated regional flood model and flood modelling framework is required to support appropriate planning of land use, flood mitigation, emergency response and flood evacuation in the Hawkesbury-Nepean Valley. The regional flood model should comprise a valley-wide model for the main river, supported by a framework for all future flood modelling for the main river and its main tributaries, both upstream and downstream of Warragamba Dam.

A key component of the Environmental Impact Statement prepared for the proposed crest raising of Warragamba Dam in the early 1990s was the development of a detailed computer-based flood model for the Hawkesbury-Nepean Valley. This model was extensively peer reviewed by Australian and international experts who confirmed the validity of the work. This flood modelling (referred to as the 1995 RUBICON model) has formed the basis of nearly all flood modelling in the valley since that time and still forms the basis of most flood mapping, land use planning and emergency management decisions in the valley.

Councils, as the principal managers of flood prone land, have relied on and continue to rely on the results of the 1995 RUBICON model for their flood mapping and land use planning decisions. Using the results from the model, councils have developed separate local flood models in accordance with the NSW Government’s Floodplain Development Manual 2005. These local models are used to assess flooding from the main Hawkesbury-Nepean River channel and/or major tributaries, and to inform the zoning of land within each local government area on the basis of flood risk, in part through defining of default flood planning levels for urban development.

This work has typically been undertaken by specialist consultants, who maintain ownership and custodianship of the model, as clients do not generally have the technical expertise required to run the model. Funding is provided for flood modelling under the NSW Floodplain Management Program, with models typically being reviewed every 5–10 years in accordance with the NSW Floodplain Development Manual 2005.

Also using the 1995 RUBICON model as a basis, the Sydney Catchment Authority (SCA) has developed a flood model of the main Hawkesbury-Nepean River channel to assess the implications of dam failure, through the Warragamba Dambreak Study. As an in-house flood model, the SCA model has not been used for flood mapping, land use planning, the setting of flood planning levels or emergency management decisions by councils and other stakeholders.

A key component of Stage One of the Review has been a review of the SCA’s in-house flood model to assess the likely effectiveness of structural flood mitigation options on flood levels along the Hawkesbury-Nepean River, downstream of Warragamba Dam. This Review has determined that the SCA’s in-house flood model would provide an excellent basis for a new regional flood model of the main river between from Warragamba Dam to Broken Bay.

The SCA’s flood model could form the basis of a revised Hawkesbury-Nepean River Flood Study, the results of which could be used by councils and other stakeholders for flood mapping, flood hazard definition, strategic land use planning, setting of flood planning levels and emergency response management. Effective flood management and response requires a more comprehensive and integrated framework for flood modelling in the catchment, to ensure that:
- A single, appropriate flood model exists for the entire Hawkesbury-Nepean floodplain.
- The flood model has an owner or custodian with clearly defined roles and responsibilities, and adequate technical capabilities and resources to manage the model (i.e., to manage metadata, maintain data agreements and extract data for users).
- Councils, NSW Government agencies, and other stakeholders have reasonable access to information on flood behaviour along the Hawkesbury-Nepean floodplain.
- Appropriate data-sharing agreements exist between relevant stakeholders.
- Contemporary and consistent information is available from the model to provide inputs into site-specific and tributary flood models developed for councils, land developers or owners, or NSW Government agencies throughout the valley.
- Resources are committed to review and update the model over time, including the development of contemporary data inputs to the model (i.e., rainfall, bathymetry, etc.) and peer review of the model every 5-10 years.
- Councils within the valley are otherwise appropriately supported by the NSW Government in meeting their obligations under the NSW Floodplain Development Manual 2005.

A continuation of the current disaggregated approach to flood modelling in the valley will lead to further inconsistencies and inefficiencies in the planning of land use and flood management over the Hawkesbury-Nepean floodplain.

**RECOMMENDATION 17:**

Develop and maintain a comprehensive flood model and flood modelling framework for the Hawkesbury-Nepean Valley.

Key aspects of this work would include establishment of:

- A single, accessible flood model for the main river, either through the enhancement of the current SCA model to meet broader stakeholder needs, or the development of a new model.
- Appropriate governance, resourcing and other arrangements to ensure this model is accessible and uses contemporary data and techniques in flood prediction.
- A framework that facilitates flood modelling at various scales, and by different organisations, in a manner that supports appropriate planning of land use, flood mitigation, emergency response, and flood evacuation in the Hawkesbury-Nepean Valley.
STRATEGY J - Improve consideration of flood risk in land use planning.

Land use planning and development control are critical elements in minimising the impacts of floods on the community. Inappropriate location or design of urban development and associated infrastructure can incur large and recurrent costs on residents, businesses, and local and regional economies.

There is, however, no effective state-level policy for land use planning in relation to natural hazards, including flooding. This gap results in land use planning authorities applying:

- different principles in their flood-related functions
- different risk management approaches in land use planning
- different levels of response to flood management and risk assessment
- potentially different land use planning requirements and development assessment regimens

Similarly, there is no NSW land use planning guideline relating to flood prone land, resulting in a lack of clear principles to guide land use planning and development assessment in these areas.

These matters are particularly critical in the Hawkesbury-Nepean floodplain, where land use planning and development consent is the responsibility of six councils, with the Department of Planning and Infrastructure (DP&I) also having a role within the North-West and South-West Growth Centres. This can result in a range of different approaches to flood risk and land use planning, without a sound evidence and risk base to support such differences.

A further issue is that the ‘Guideline for Residential Development on Low Flood Risk Land’, released by the DP&I in 2007, restricts the application of controls for residential development to land at or below the 1 in 100 chance per year flood level (plus freeboard), unless ‘exceptional circumstances’ exist as defined in that guideline. No councils within the Hawkesbury-Nepean Valley have applied for ‘exceptional circumstances’, despite the risk of significant flood damages occurring in the Hawkesbury-Nepean Valley between the depth of the 1 in 100 chance per year flood level and the Probable Maximum Flood.

Additionally, the 2007 Guideline is often misunderstood as limiting councils in the application of a risk management approach to the whole floodplain. This guideline should therefore be reviewed as part of the development of a ‘NSW Planning Policy’ and ‘Land Use Planning Guideline for Flood Prone Land’.

A further issue is that Building, Land Use and Subdivision Guidelines prepared for the Hawkesbury-Nepean Flood Management Advisory Committee in 2006 were never officially endorsed by the NSW Government, which has resulted in under-use of these valuable resources by planning authorities.

The issues relating to the effectiveness and consistency in land use planning and development control would be most effectively addressed through the development of a ‘NSW Planning Policy’ relating to relevant natural hazards to be applied to all levels of land use planning in NSW, and a ‘NSW Land Use Planning Guideline for Flood Prone Land’ that will provide principles and guidance relating to strategic, statutory and development assessment matters relating to all flood prone land.

The White Paper for a New Planning System for NSW proposes that State Planning Policies will set the State’s planning objectives and priorities, rather than providing prescriptive controls. It is proposed that the above policy and guidance would be developed by the DP&I working closely
with relevant NSW Government agencies and councils, with community and stakeholder input and be underpinned by up-to-date evidence and research.

The development of this policy and associated guideline would provide for a more coordinated and consistent approach to land use planning and development assessment, from a flood perspective, across NSW. This would be particularly valuable in the Hawkesbury-Nepean Valley given the comparatively large number of land use planning authorities involved, and the potential for significant flood damages between the levels of the 1 in 100 chance per year flood level and the PMF.

Conversely, a continuation of the current framework would lead to ongoing planning of land use in a manner that fails to recognise the significance of flooding in a consistent and effective manner across the Hawkesbury-Nepean Valley.

**RECOMMENDATION 18:**

*Develop a NSW Planning Policy and Guideline to improve land use planning practices on flood prone land.*

Key aspects of this work will be development of:

- a ‘NSW Planning Policy’ relating to relevant natural hazards to be applied to all levels of land use planning in NSW
- a ‘NSW Land Use Planning Guideline for Flood Prone Land’
- a process for application of this policy in the Hawkesbury-Nepean Valley through strategic planning

The ‘Land Use Planning Guideline for Flood Prone Land’ should:

- include provisions to ensure all types of development including complying development adequately consider flood hazard, including evacuation capability
- adopt and promote risk-management principles and approaches
- reconsider the approach adopted in the 2007 ‘Guideline for Residential Development on Low Flood Risk Land’ relating to ‘exceptional circumstances’ to ensure the full range of flood risks are considered
- consider promotion of the Building, Land Use and Subdivision Guidelines prepared for the Hawkesbury-Nepean Flood Management Advisory Committee in 2006, as these documents provide guidance and assistance specifically for the Hawkesbury-Nepean Valley

Local environmental plans (LEPs) zone land within local government areas (LGAs) for specific uses. In 2006 the NSW Government standardised the definition of land use zones allowable for this purpose across NSW, through the Standard Instrument LEP Program. The Standard Instrument also provides a number of model local provisions, or overlays that can be used by councils within their LEP.

At present the Standard Instrument LEP provides no zones for land with high flood hazard or floodways. Additionally, there is only one flood overlay that can be used. A flood overlay does not limit land use but provides additional development controls relating to proposed development.
This results in a coarse system for managing flood hazard and flood function at the local land use planning level, and a process that relies on less enforceable development control plans (rather than LEPs) which councils often use to differentiate different areas of hazard and apply different controls.

The development of an additional zone that could be applied to high hazard land and floodways, combined with additional overlays and further information regarding flood hazard definitions, would provide an important mechanisms for improved local land use planning. This could be used in strategic planning to:

- guide development away from areas where it may exacerbate flooding of existing development
- avoid development where flood hazard is extreme and difficult to manage
- locate more vulnerable development away from areas most exposed to risk

Guidance on floodways, flood hazards and flood emergency response classification of communities is important to understanding the areas where flood function (flow) is important and to understand the degree and type of hazard (e.g. flow depth, velocity and difficulty in evacuation). Existing guidance is outdated and can be improved in light of recent research on flood hazard and technological advances in modelling.

It is recommended that a suite of improved planning tools be developed to improve the planning of land use in flood prone areas. This will assist councils in the Hawkesbury-Nepean Valley, as well as other areas, by providing improved statutory mechanisms for the control of flood hazard. It would allow the potential use of extreme hazard land to be known up-front, rather than subsequent to a development assessment process, thus creating greater certainty in the planning system.

In addition, providing greater definitional guidance helps ensure consistency between councils in the way that hazardous areas are identified.

Maintaining the current approach with a single overlay would not enable the effective breakdown of the floodplain considering flood hazard and function, or the effective consideration of this hazard in land use planning. This may result in future developments that are not compatible with the flood function or the degree or type of flood hazard present.
RECOMMENDATION 19:
Provide improved land use planning tools for managing flood prone land.

This would include:

- considering the development of a zone or other mechanisms that can be applied to land with extreme flood hazard to limit development potential in line with that hazard;
- reviewing the need for varied or additional flood overlays to distinguish between areas of differing flood hazard;
- providing additional guidance on defining floodways, flood hazards and flood emergency response classification of communities.

The draft Metropolitan Strategy for Sydney sets the framework for Sydney’s growth and prosperity to 2031. It includes objectives policies and actions to achieve five outcomes - balanced growth, a liveable city, productivity and prosperity, healthy and resilient environment, accessibility and connectivity. It sets out population projections, minimum housing and jobs targets and ‘city shaper’ priorities. The Strategy guides subregional planning by identifying the metropolitan priorities for each of the subregions across Sydney.

Regional and subregional land use planning provides critical opportunities for growth to be informed by flood risk and evacuation capacity considerations. Complex and unclear governance arrangements, combined with a lack of complete and easily accessible information about flood risks and evacuation modelling and constraints, can result in consideration of flood matters at the regional and subregional level in general terms only. This then means that detailed consideration of any implications or consequences of growth in flood prone areas occurs only at the local level. While detailed consideration of such matters must also occur at the local level, there are benefits from earlier consideration of flood risk in determining the constraints and costs associated with potential development.

Such an approach aligns with one the key transformative changes of the new planning system for NSW by providing a stronger focus on up-front strategic planning based on a detailed evidence base addressing all relevant issues to an area. The draft Metropolitan Strategy sets out for the first time an objective to ‘Build Resilience to Natural Hazards’. Although this objective focuses on matters broader than flooding; the risk associated with flooding in the Hawkesbury-Nepean Valley is recognised.

The resilience objective sets a strategic policy framework for natural hazards to be considered and planned for at an early stage. It also aims for development, particularly infrastructure, to be avoided in locations at risk from natural hazards unless the risks are demonstrated to be manageable. It also intends for emergency management considerations to be integrated with strategic land use planning decisions.

While further work is recommended by this Review in relation to governance arrangements, flood modelling and evacuation planning, regional and subregional planning continues in the Hawkesbury-Nepean Valley.
There is an immediate need to ensure that the best information currently available is considered for finalising the draft Metropolitan Strategy for Sydney and is capable of informing and being incorporated with subregional planning. This would ensure that consistent principles and objectives are used to guide the development of information relating to flood risk.

This approach will rely on existing or specifically requisitioned networks and groups within government to ensure that discussions between all relevant agencies are held early in planning process, and continue as planning processes proceed.

RECOMMENDATION 20:
Ensure appropriate consideration of flood risk in regional and subregional planning.

This approach will:

- ensure detailed consideration of flood risk and evacuation issues in regional and subregional planning processes undertaken in the valley in the near future
- rely on existing networks within government to ensure effective communication and sharing of information
- draw on existing information, or identify actions and guidance required to collect information to fill any data gaps
- provide a stronger focus on up-front, evidence-based strategic planning, in accordance with key changes introduced by the new planning system
Conclusion and next steps

The Review found that there is no simple or single solution that can completely address all of the flood risk in the Hawkesbury-Nepean Valley. The Review has identified that infrastructure options can reduce, but not eliminate, the flood risk in the Valley. Evacuation is the only mitigation measure that can guarantee to reduce risk to life, and detailed investigation is required to support an integrated approach to reduce overall flood risk in the valley.

The Review has developed ten strategies to improve flood risk management in the Hawkesbury-Nepean Valley, and has identified a suite of more detailed investigations and cost benefit analyses to be addressed in Stage Two of the Review.

The NSW Government will establish a dedicated Task Force, headed by an independent Chairperson, to lead the Review as it progresses to the next stage. The Task Force will include representatives from relevant Government agencies and will coordinate flood management and knowledge for the Hawkesbury-Nepean Valley.

The Task Force’s main responsibility will be to coordinate and oversee the implementation of Stage Two Review for improved flood management in the Hawkesbury-Nepean Valley and building better community preparedness and resilience to flood events.

The Task Force will undertake the following actions as a priority, with a focus on community awareness and emergency preparedness:

- review the Hawkesbury-Nepean Flood Emergency Sub Plan and other relevant emergency plans to ensure they include the most up-to-date information and data (from Strategy F)
- enhance community education programs and further investigating community attitudes and responses to flood risk (from Strategy G)
- develop an effective evacuation modelling tool to enable completion of an integrated traffic evacuation plan for the floodplain (from Strategy B)
- identify any minor road and intersection improvements that could assist in flood evacuation in the short term (from Strategy B)
- review key local and state government planning instruments and guidance to minimise the risks associated with ongoing infill and greenfield development (from Strategy J).
- investigate alternative gate operation procedures and reduction of the full supply level by up to five metres for Warragamba Dam. This could help reduce the frequency and impact of small floods. Water supply impacts would need to be fully considered (from Strategy A).

The next stage will also involve a detailed assessment of the infrastructure flood mitigation options identified by the review in relation to economic and social impacts, associated costs and time frames. These actions will focus on longer term planning and will include Warragamba Dam wall raising and regional road infrastructure upgrade considerations. They are:

- identifying major regional road and intersection improvements that would assist with evacuation and undertaking cost benefit analysis of the selected options (from Strategy B)
- revising the regional emergency management plan to include consideration of the implications of the scenario of more widespread flooding in the Greater Sydney region (from Strategy F)
- commencing development of a state-wide planning policy addressing floods and other natural hazards (from Strategy J)
• developing a flood recovery plan which includes consideration of reconstruction of essential infrastructure following a major flood (from Strategy E)
• undertaking detailed cost benefit analysis of optimising Warragamba Dam for flood mitigation and water supply, including consideration of upstream and downstream impacts (from Strategy A).
• seeking an agreed approach and consistent use of flood modelling and monitoring data for the region (from Strategy H and I).
• developing governance reforms to create an enduring and effective whole of government response to flood risks (from Strategies C and D).

The Task Force will consult with key stakeholders including local government, the insurance industry, water authorities, the Floodplain Management Association and the community as appropriate.
Appendix One: Terms of Reference of the Hawkesbury-Nepean Valley Flood Management Review

The terms of reference for Stage One of the Review were:

- Describe current management arrangements in relation to flood mitigation in the Hawkesbury-Nepean Valley and evaluate their adequacy and effectiveness. Flood mitigation includes flood emergency planning and response, land use planning and structural measures for Warragamba Dam and downstream of Warragamba Dam.

- Consider what factors have changed since the current management arrangements were put in place and, in particular, to consider the influence of the Sydney North West and South West Growth Centres on the changing risk profile within the valley.

- Collate current information and flood modelling to assist the Review, and scope any additional modelling required.

- Describe the management options that have previously been examined to further mitigating the impacts of flooding in the Valley, and review whether any of these options need re-assessment.

- Explore all options to improve flood mitigation strategies and processes in the Valley, including but not limited to:
  - assessment of current flood evacuation routes and whether upgrades are required
  - assessment of the appropriateness of current urban planning policies
  - consideration of current governance arrangements for flood planning and response
  - assessment of whether changes to the operation and configuration of key processes of water infrastructure, such as Warragamba Dam, are required.
### Appendix Two: Overall Structure of the Review and its strategies and recommendations

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<td>NSW 2021 - Go at 28</td>
<td>Ensure NSW is ready to deal with major emergencies and natural disasters</td>
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<td>Hawkesbury Nepean Valley Flood Management Review</td>
<td>The Hawkesbury-Nepean valley is strategically managed so the community is more resilient to flood risk.</td>
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<td>Community awareness</td>
<td>An informed community that understands the benefits, costs and risks of living with floods in the Hawkesbury-Nepean valley.</td>
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<td>Sustainable future growth</td>
<td>Future growth and development in the Hawkesbury-Nepean valley is strategically managed considering the flood risk.</td>
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<td>Land use planning</td>
<td>Developing and implementing effective, risk-based land management and planning arrangements and other mitigation activities.</td>
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<td>Strategy A:</td>
<td>Enhance flood mitigation infrastructure</td>
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<td>Strategy B:</td>
<td>Enhance flood evacuation capacity of transport infrastructure</td>
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<td>Strategy C:</td>
<td>Establish governance arrangements that support more integrated and effective management of flood risk</td>
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<td>Strategy D:</td>
<td>Collection of post-event flood data and intelligence</td>
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<td>Strategy E:</td>
<td>Improve recovery planning</td>
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<td>Strategy F:</td>
<td>Improve emergency management, planning and implementation</td>
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<td>Strategy G:</td>
<td>Improve community education on flood risk and response</td>
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<td>Strategy H:</td>
<td>Improve accessibility of flood risk information</td>
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<td>Strategy I:</td>
<td>Improve development and implementation of effective, risk-based land management and planning and arrangements in place to inform people about how to assess risks and reduce their exposure and vulnerability to hazards.</td>
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<td>Strategy J:</td>
<td>Improve consideration of flood risk in land use planning</td>
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**In-Infrastructure**

**Non-Infrastructure**

**Governance**
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<tr>
<th>Strategies</th>
<th>Recommendations</th>
<th>Risk</th>
<th>Risk Assessment - of inaction</th>
<th>Likelihood (of consequence)</th>
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<tr>
<td>Strategy A: Enhance flood mitigation infrastructure</td>
<td><strong>Recommendation 1.</strong> Determine the appropriateness and the stages required to allow the reduction of full supply level by up to five metres and/or the implementation of alternative gage operation at Warragamba Dam for the mitigation of minor flood events in the short term.</td>
<td>MEDIUM</td>
<td>MINOR - May prevent inundation of farm lands and closure of low lying bridges during small flood events.</td>
<td>LIKELY - Effective only for minor to moderate, frequent floods (up to 1 in 50 chance per year events).</td>
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<td><strong>Recommendation 2.</strong> Optimise the configuration of a raised Warragamba Dam for flood mitigation for the full range of flood events and water supply, with due consideration of upstream impacts.</td>
<td>HIGH</td>
<td>MAJOR - Initial assessment indicates providing temporary flood storage at Warragamba Dam is the most cost-effective means of reducing flood levels and associated impacts on the Hawkesbury-Nepean floodplain.</td>
<td>POSSIBLE - Would reduce impacts of full range of floods, including those in the range between 1 in 100 to 1 in 500 chance per year events.</td>
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<td><strong>Recommendation 3.</strong> Develop and implement a program of cost-effective road improvement works that can enhance flood evacuation capacity in the short to medium term.</td>
<td>HIGH</td>
<td>MAJOR - Flood evacuation may be compromised by inefficient use of existing road infrastructure, potentially leading to loss of life.</td>
<td>POSSIBLE - Constraints imposed by local road &quot;bottlenecks&quot; would only be evident in evacuations during rare flood events, including in range between 1 in 50 to 1 in 300 chance per year events.</td>
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<td><strong>Recommendation 4.</strong> Improve regional transport infrastructure to address current and projected flood evacuation capacity constraints and timelines.</td>
<td>HIGH</td>
<td>CATASTROPHIC - Traffic congestion on evacuation routes could directly threaten lives in a severe flood event.</td>
<td>POSSIBLE - Risk of congestion is (already) high, and of greatest concern in rare flood events (rater than 1 in 100 chance per year events).</td>
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<td>Strategy B: Enhance flood evacuation capacity of transport infrastructure</td>
<td><strong>Recommendation 5.</strong> Establish a dedicated group or body within an existing agency to provide a more integrated, coordinated and regional approach to land use, infrastructure and flood planning and modelling, in the Hawkesbury-Nepean valley.</td>
<td>HIGH</td>
<td>MAJOR - Continuation of a non-integrated approach to flood management poses risks to life due to capacity of evacuation infrastructure being exceeded by (infill and greenfield) development.</td>
<td>POSSIBLE - Consequences of continued poor integration of flood management would be most significant for rare flood events (rater than 1 in 100 chance per year events).</td>
</tr>
<tr>
<td></td>
<td><strong>Recommendation 6.</strong> Review the NSW state-wide governance arrangements for flood risk management so that broader issues identified in this Review can be most effectively addressed.</td>
<td>HIGH</td>
<td>MAJOR - Likely that continuation of current 'silo' approach to governance would directly threaten effectiveness of flood planning, leading to greater risk of loss of life and property from major floods.</td>
<td>POSSIBLE - Risk of development on flood hazardous land, sub-optimal evacuation etc. arising from poor integration and coordination.</td>
</tr>
<tr>
<td></td>
<td><strong>Recommendation 7.</strong> Ensure effective flood gauging arrangements in the Hawkesbury-Nepean valley.</td>
<td>MEDIUM</td>
<td>MODERATE - Compromised quantitative warning system may threaten evacuation.</td>
<td>POSSIBLE - Limited flood warning system would have significant consequences in rare flood events (rater than 1 in 100 chance per year events). Same action underway to address this, but unsure future.</td>
</tr>
<tr>
<td>Strategy C: Establish governance arrangements that support more integrated and effective management of flood risk</td>
<td><strong>Recommendation 8.</strong> Clarify roles, responsibilities and funding for post-event collection of data and flood intelligence.</td>
<td>MEDIUM</td>
<td>MODERATE - Some post-event information may reveal significant problems with established processes and understanding.</td>
<td>POSSIBLE - Post-event analysis may lead to significant (life-saving) improvements for rare flood events (rater than 1 in 100 chance per year events).</td>
</tr>
<tr>
<td></td>
<td><strong>Recommendation 9.</strong> Develop a Hawkesbury-Nepean Flood Recovery Plan, which identifies strategies and arrangements for recovery from severe floods in the Hawkesbury-Nepean valley.</td>
<td>HIGH</td>
<td>MAJOR - High social and economic costs associated with severe floods in the Hawkesbury-Nepean valley.</td>
<td>POSSIBLE - Recovery would occur in absence of Plan, but at greater social and economic cost, and over a longer time. Flood recovery most critical in rare flood events, including those in range between 1 in 50 to 1 in 300 chance per year events.</td>
</tr>
<tr>
<td></td>
<td><strong>Recommendation 10.</strong> Review the adequacy of current flood planning arrangements for infrastructure reconstruction following a major flood event in the Hawkesbury-Nepean valley.</td>
<td>HIGH</td>
<td>MAJOR - Mid-term failure of significant infrastructure and service delivery affecting large parts of the community.</td>
<td>POSSIBLE - Some arrangements exist, but possible that avoidable economic and social costs could be incurred due to inadequacies. Some critical infrastructure could be damaged in rare flood events, including a 1 in 300 chance per year event.</td>
</tr>
<tr>
<td></td>
<td><strong>Recommendation 11.</strong> Develop a comprehensive road evacuation network model for floods in the Hawkesbury-Nepean floodplain to inform evacuation capacity assessments and strategic transport planning, and to assist with the real-time operational management of the evacuation during floods.</td>
<td>HIGH</td>
<td>CATASTROPHIC - Traffic congestion could directly threaten lives in a severe flood event.</td>
<td>POSSIBLE - Risk of congestion is (already) high, and of greatest concern in rare flood events (rater than 1 in 100 chance per year events).</td>
</tr>
<tr>
<td></td>
<td><strong>Recommendation 12.</strong> Ensure future road infrastructure planning considers flood evacuation requirements throughout the Hawkesbury-Nepean floodplain.</td>
<td>HIGH</td>
<td>CATASTROPHIC - Traffic congestion could directly threaten lives in a severe flood event.</td>
<td>POSSIBLE - Risk of congestion is (already) high, and of greatest concern in rare flood events (rater than 1 in 100 chance per year events).</td>
</tr>
<tr>
<td></td>
<td><strong>Recommendation 13.</strong> Ensure the NSW State Emergency Service has the long-term capacity to plan and exercise for, and manage for the full range of flood events in the Hawkesbury-Nepean valley.</td>
<td>HIGH</td>
<td>CATASTROPHIC - Inadequate resourcing of SES would have direct impacts on survival rates.</td>
<td>POSSIBLE - Capacity of SES most critical in flood events in range of 1 in 50 to 1 in 300 chance per year events.</td>
</tr>
<tr>
<td></td>
<td><strong>Recommendation 14.</strong> Undertake, coordinate and evaluate community education programs on flood risk and response.</td>
<td>HIGH</td>
<td>CATASTROPHIC - Widespread loss of life possible due to low (reported) awareness of flood risk and/or low (reported) preparedness to evacuate when necessary.</td>
<td>POSSIBLE - Significant loss of life could result from floods in range of 1 in 100 to 1 in 300 chance per year events, given low flood awareness and preparedness to evacuate.</td>
</tr>
<tr>
<td></td>
<td><strong>Recommendation 15.</strong> Monitor, investigate and address community response to flood warnings.</td>
<td>HIGH</td>
<td>CATASTROPHIC - Widespread loss of life possible due to low (reported) preparedness to evacuate when required by emergency services.</td>
<td>POSSIBLE - Significant loss of life could result from floods in range of 1 in 100 to 1 in 300 chance per year events, given low flood awareness and preparedness to evacuate.</td>
</tr>
<tr>
<td>Strategy D: Collection of post-event flood data and intelligence.</td>
<td><strong>Recommendation 16.</strong> Develop mechanisms and arrangements to promote and provide greater access to flood risk information.</td>
<td>MEDIUM</td>
<td>MODERATE - Continued limited access to flood risk information contributes to inappropriate development in hazardous areas.</td>
<td>POSSIBLE - Possible inappropriate development on floodplain, including between 1 in 100 to 1 in 300 chance per year flood levels.</td>
</tr>
<tr>
<td></td>
<td><strong>Recommendation 17.</strong> Develop and maintain a comprehensive flood model and flood modelling framework for the Hawkesbury-Nepean valley.</td>
<td>HIGH</td>
<td>MODERATE - Land use, evacuation and infrastructure planning in the absence of a sound modelling framework could increase risks to life, property and infrastructure.</td>
<td>POSSIBLE - Possible inappropriate development or infrastructure planning on floodplain, including between 1 in 100 to 1 in 300 chance per year flood levels.</td>
</tr>
<tr>
<td></td>
<td><strong>Recommendation 18.</strong> Develop a NSW Planning Policy and Guideline to improve land use planning practices on flood prone land.</td>
<td>HIGH</td>
<td>MODERATE - Continued uncoordinated and inconsistent approach to land use planning and development control, and failure to recognise hazard between 1 in 100 chance per year events &amp; PMF, could lead to loss of life and property in such major flood events.</td>
<td>POSSIBLE - Possible inappropriate development on floodplain, including between 1 in 100 to 1 in 300 chance per year flood levels.</td>
</tr>
<tr>
<td></td>
<td><strong>Recommendation 19.</strong> Provide improved land use planning tools for managing flood prone land.</td>
<td>MEDIUM</td>
<td>MODERATE - Ineffective consideration of flood hazard and land use planning, leading to development not compatible with flood risk in land subject to flooding.</td>
<td>POSSIBLE - Possible inappropriate development on floodplain, including between 1 in 100 to 1 in 300 chance per year flood levels.</td>
</tr>
<tr>
<td></td>
<td><strong>Recommendation 20.</strong> Ensure appropriate consideration of flood risk in metropolitan, regional and suburban planning.</td>
<td>MEDIUM</td>
<td>MODERATE - Ineffective consideration of flood hazard and land use planning, leading to development not compatible with flood risk in land subject to flooding.</td>
<td>POSSIBLE - Possible inappropriate development on floodplain, including between 1 in 100 to 1 in 300 chance per year flood levels.</td>
</tr>
</tbody>
</table>
### Appendix Three: Methodologies used to evaluate issues, strategies and recommendations

<table>
<thead>
<tr>
<th>Possible Floodplain Risk Management Treatment Options</th>
<th>Methodologies used to evaluate issues, strategies and recommendations</th>
<th>Qualitative Methods</th>
<th>Quantitative Methods</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Aims and Desired Outcomes</td>
<td>Review of Best Practice</td>
<td>Previous Background Documents</td>
</tr>
<tr>
<td></td>
<td><strong>Qualitative Methods</strong></td>
<td><strong>Quantitative Methods</strong></td>
<td><strong>Qualitative Methods</strong></td>
</tr>
</tbody>
</table>

#### Infrastructure Measures

**Warragamba Dam Infrastructure Measures**

<table>
<thead>
<tr>
<th>Options Involving Operational Changes to Dam</th>
<th>Methodologies used to evaluate issues, strategies and recommendations</th>
<th><strong>Qualitative Methods</strong></th>
<th><strong>Quantitative Methods</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Alternative Gate Operation Protocols</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>Pre-release of water to create temporary flood mitigation airspace</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>Permanent lowering of full supply level to create flood mitigation ‘airspace’</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Options Involving Structural Changes to Dam</th>
<th>Methodologies used to evaluate issues, strategies and recommendations</th>
<th><strong>Qualitative Methods</strong></th>
<th><strong>Quantitative Methods</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Raise Dam wall by 15m to create flood mitigation storage airspace</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>Raise Dam wall by 23m to create flood mitigation storage airspace</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
</tr>
</tbody>
</table>

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<td></td>
<td>Aims and Desired Outcomes</td>
<td>Review of Best Practice</td>
</tr>
<tr>
<td></td>
<td>yes</td>
<td>yes</td>
</tr>
</tbody>
</table>

#### Non- Warragamba Dam Infrastructure Measures

- **Upstream Catchment Detention Dams**
  - yes
  - yes
  - yes
  - yes
  - yes

- **Downstream Channel Modification Works — Full list of Options**
  - yes
  - yes
  - yes
  - yes
  - yes

- **Downstream Channel Modification Works — Short list of Options**
  - yes
  - yes
  - yes
  - yes
  - yes

- **Downstream Local Levees — Full list of Options**
  - yes
  - yes
  - yes
  - yes

- **Downstream Local Levees — Short list of Options**
  - yes
  - yes
  - yes
  - yes

#### Non-Infrastructure Measures

- **Flood Data Management**
  - yes
  - yes

- **Flood Warning Network**
  - yes
  - yes

- **Flood Modelling**
  - yes
  - yes
### Possible Floodplain Risk Management Treatment Options

<table>
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<th>Quantitative Methods</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>Aims and Desired Outcomes</td>
<td>Review of Best Practice</td>
</tr>
<tr>
<td>Access to Flood Information</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>Post-flood data collection</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>Emergency Management and Response</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flood Planning, Response and Recovery Arrangements</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>Flood Evacuation Routes</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>Land Use Planning</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Land use planning policies, guidance and zoning mechanisms</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>Community Flood Awareness and Education</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Community Flood Awareness and Education programs</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>Resourcing of Community Awareness and Education programs</td>
<td>yes</td>
<td>yes</td>
</tr>
</tbody>
</table>
## Possible Floodplain Risk Management Treatment Options

<table>
<thead>
<tr>
<th>Aims and Desired Outcomes</th>
<th>Review of Best Practice</th>
<th>Previous Background Documents</th>
<th>Experience, Expertise Knowledge</th>
<th>Independent Peer Review</th>
<th>Short-listing Assessment</th>
<th>Pre-feasibility design &amp; Costings</th>
<th>Flood Modelling of Impacts &amp; Benefits</th>
<th>Flood Damages Saved</th>
<th>Broad Financial Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Community Perceptions and Response to Flood Risk and Flood Warning</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>Governance and Management</td>
<td></td>
<td></td>
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<td></td>
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<td></td>
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</tr>
<tr>
<td>State-wide governance arrangements</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Improved integration and coordination in Hawkesbury-Nepean Valley</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>
Appendix Four: Images of the flood mitigation infrastructure options considered by the Review

Figure A4.1: Current configuration of Warragamba Dam

Figure A4.2: Possible design of Warragamba Dam wall 15 metre crest raising

Figure A4.3: Locations of Currency Creek diversion, Sackville cutoff and Sackville large diversion channel options assessed

Figure A4.4: Representation of dredging the Hawkesbury River from Windsor to Wisemans Ferry option assessed

Figure A4.5: An overview of the flood mitigation infrastructure options assessed at Penrith

Figure A4.6: An overview of the flood mitigation infrastructure options assessed at Richmond-Windsor

Figure A4.7: An aerial view of the possible designs of the Penrith levee options assessed (illustrated in green)

Figure A4.8: An aerial view of the possible designs of the Pitt Town levee options assessed (illustrated in green)

Figure A4.9: An aerial view of the possible designs of the McGraths Hill levee options assessed
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